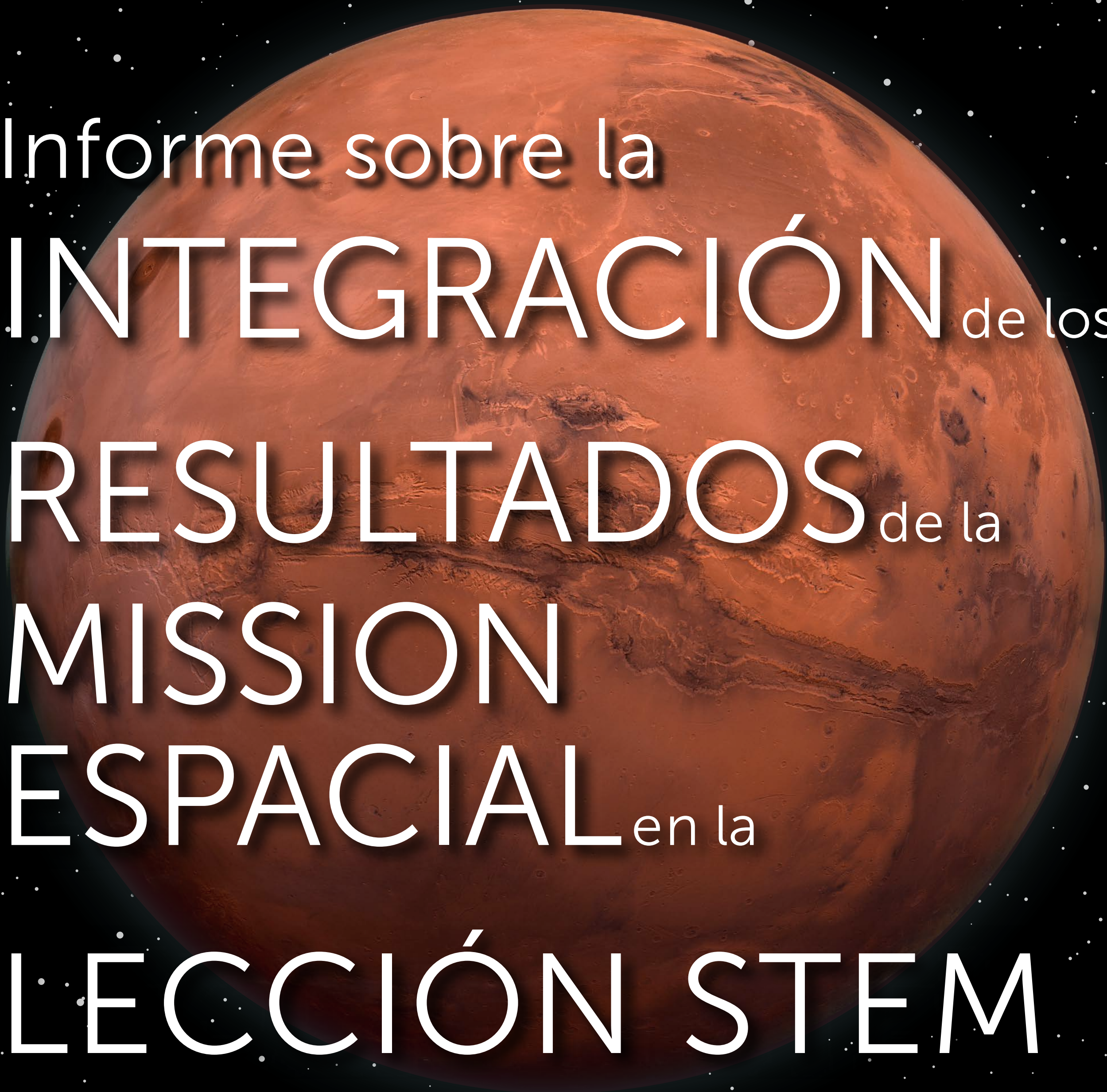

Informe sobre la INTEGRACIÓN de los RESULTADOS de la MISSION ESPACIAL en la LECCIÓN STEM

Acerca del proyecto Schools Tune Into Mars

El objetivo general del proyecto Schools Tune Into Mars (STIM) era proporcionar materiales didácticos para lecciones inspiradoras relacionadas con las Ciencias de la Tierra y del Espacio en general y con la planetología en particular. Los materiales del proyecto se basaron en los últimos avances en investigación y educación espacial, y satisfacen las necesidades de los profesores de oportunidades en el desarrollo profesional, haciendo uso de determinados conceptos científicos de la planetología y la sismología planetaria.

El proyecto Schools Tune Into Mars (STIM) reunió una red de escuelas y organizaciones con interés en la educación espacial y los estudios relacionados con el planeta Marte. Por lo tanto, STIM proporciona una orientación suficiente y adecuada para sustentar actividades innovadoras que se desarrollan como parte de un proceso de construcción conjunta entre investigadores y profesores.

Schools Tune Into Mars se inició como un proyecto de múltiples partes interesadas financiado por el Programa Erasmus+ y es una iniciativa conjunta del Liceo Internacional de Valbonne, Francia, European Schoolnet, Bélgica. Asociación Española para la Enseñanza de las Ciencias de la Tierra, España. y el Instituto Nacional de Física de la Tierra, Rumania.

Como parte del proyecto STIM se desarrollaron varias actividades complementarias, entre ellas:

- Un documento programático basado en los recursos STIM (por ejemplo, actividades prácticas, actividades basadas en datos registrados en Marte, experimentos webinars dedicados a los profesores) respaldado por un estudio destinado a evaluar la necesidad y oportunidad de los recursos de STIM para los profesores.
- Una guía didáctica para apoyar el uso de recursos de misiones espaciales en las aulas.
- Un Curso Masivo Abierto Online (MOOC), "Traer las misiones de Marte al aula", que proporciona formación en línea a los profesores con el fin de utilizar materiales didácticos innovadores relacionados con las misiones espaciales de Marte en las aulas.
- Recomendaciones para la creación de una red Mars-Edu para sentar las bases para una red colaborativa innovadora a largo plazo sobre educación espacial relacionada con las misiones a Marte.

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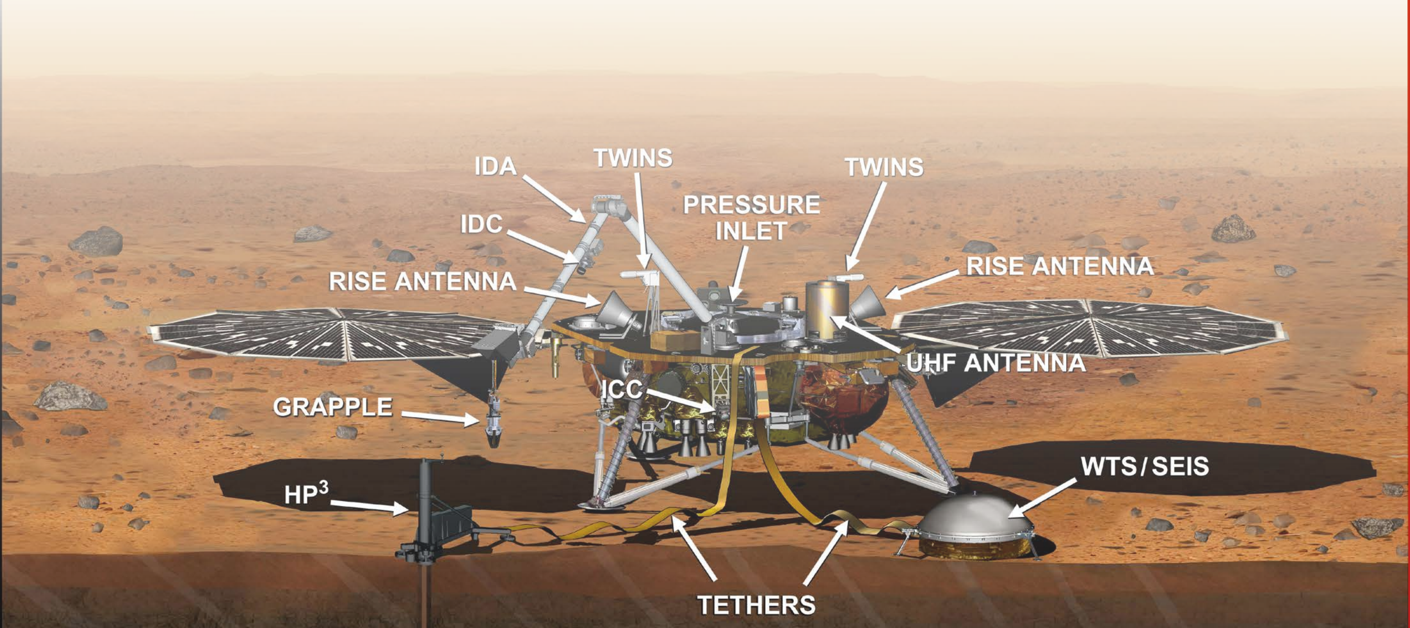
Resumen ejecutivo

Con el fin de apoyar a los profesores en el desarrollo de las altas habilidades STEM para los estudiantes que serán necesarias en un futuro próximo, el proyecto Schools Tune Into Mars (STIM) fue diseñado para mejorar la enseñanza efectiva y de calidad de las disciplinas STEM para la educación secundaria. También tiene como objetivo aumentar los conocimientos, las habilidades y el interés de los jóvenes europeos en la educación STEM proporcionando materiales didácticos relacionados con las asignaturas STEM y desarrollados tras un proceso coconstructivo entre investigadores y profesores dentro de temas como sismología planetaria, geología, geofísica, ciencias de la Tierra y del espacio. El objetivo principal de STIM es también involucrar a estudiantes y profesores con investigaciones científicas reales o auténticas.

Para lograr estos objetivos, las actividades STIM se construyen en torno a los resultados de la misión espacial InSight que tiene como objetivo "descubrir la estructura interna de Marte para comprender mejor el planeta Tierra", y que brindó una oportunidad única para desarrollar un programa científico específico que podría integrarse plenamente en las escuelas europeas y ampliarse aún más. InSight[1], abreviatura de "Exploración Interior usando Investigaciones Sísmicas, Geodesia y Transporte de Calor", es una misión del Programa de Exploración de la NASA para misiones de finalidad altamente científica que formulan preguntas críticas sobre la ciencia del sistema solar.

El uso de los resultados de la misión espacial en el aula, como los de InSight, promueve la implementación del "aprendizaje basado enproject", definido como "un modelo para la actividad en el aula que se aleja de las prácticas en el aula de lecciones cortas y aisladas centradas en el maestro y en su lugar hace hincapié en las actividades deaprendizaje que son a largo plazo, interdisciplinarias, centradas en el estudiante e integradas con problemas y prácticas del mundo real" (Holbrook, 2007)[2].

Esta publicación constituye el Resultado 1 del proyecto STIM y presenta un paquete de 23 actividades que incluyen actividades prácticas, actividades y experimentos por ordenador, así como seis seminarios web y tres EduTeasers (que son videos educativos cortos grabados con investigadores para introducir ciertas actividades) destinados a profesores de educación secundaria. Estas actividades fueron desarrolladas por los socios del proyecto, sobre la base de los últimos resultados publicados de las misiones de Marte, y en particular InSight, y teniendo en cuenta los resultados de una encuesta entre profesores sobre sus necesidades y expectativas para poder enseñar temas como el Tierra, el Universo y la Planetología, así como varios talleres realizados durante el primer año del proyecto. Los resultados de la encuesta y los talleres también se presentan en este informe. Todos estos recursos se desarrollaron tras un proceso coconstructivo entre los socios del proyecto, los investigadores y los profesores.



1 La misión InSight busca descubrir cómo se forma y evoluciona un cuerpo rocoso para convertirse en un planeta investigando la estructura interior y la composición de Marte. La misión también determinará la tasa de actividad tectónica marciana y los impactos de meteoritos.

2 Jack Holbrook & Miia Rannikmae (2007) The Nature of Science Education for Enhancing Scientific Literacy, International Journal of Science Education, 29:11, 1347-1362, DOI: 10.1080/09500690601007549

Tabla de contenidos

Tabla de Figuras

Introducción

FUNDAMENTO

Recientes resultados internacionales sobre Tendencias en el Estudio Internacional de Matemáticas y Ciencias (TIMSS, 2015) muestrans malos resultados de los estudiantes en disciplinas científicas en la mayoría de países de la Unión Europea. A nivel de secundaria, el progreso hacia los objetivos de menos del 15 % con bajo rendimiento, los resultados PISA muestran que la UE en su conjunto ha retrocedido en ciencias y matemáticas y ha dado un paso atrás en comparación con los resultados de PISA 2012. De 2003 a 2013, el número de personas empleadas en profesiones STEM (ciencia, tecnología, ingeniería y matemáticas) creció un 12% y para 2025, se espera que crezca un 13% más (EU Skills Panorama 2014)[1], a pesar de que la creciente demanda de estas profesiones no se corresponda con la contratación, detectando dificultades en la mayoría de los países de la UE. A medida que las tecnologías desempeñan un papel más importante en todas las áreas del trabajo y la vida, las competencias STEM y las habilidades STEM de alto nivel se están convirtiendo en la norma.

Con el fin de apoyar a los profesores en el desarrollo de las altas habilidades STEM para los estudiantes que serán necesarias en un futuro próximo, el proyecto Schools Tune Into Mars (STIM) fue diseñado para mejorar la enseñanza efectiva y de calidad de las disciplinas STEM para la educación secundaria. También tiene como objetivo aumentar los conocimientos, las habilidades y el interés de los jóvenes europeos en la educación STEM proporcionando materiales didácticos relacionados con las asignaturas STEM, desarrollados tras un proceso coconstructivo entre investigadores y profesores sobre de temas como sismología planetaria, geología, geofísica, ciencias de la Tierra y del espacio. El objetivo principal de STIM es también involucrar a estudiantes y profesores en investigaciones científicas reales o auténticas.

Para lograr estos objetivos, las actividades STIM se basaron en los resultados de la misión espacial InSight[2], de "Descubrir la estructura interna de Marte para entender mejor el planeta". Esto proporcionó una oportunidad única para desarrollar un programa científico específico que puede integrarse y ampliarse en las escuelas europeas.

El uso de los resultados de la misión en el aula promueve el "project-based learning", que se define como "un modelo para la actividad en el aula alejado de las prácticas en el aula de lecciones cortas y aisladas centradas en el docente y, en su lugar, hace hincapié en actividades de aprendizaje a largo plazo, interdisciplinarias, centradas en los alumnos e integradas con cuestiones y prácticas del mundo real" (Holbrook, 2007)[3].

Además, la enseñanza de misiones espaciales en el aula también permite a los estudiantes comprender el progreso tecnológico que se ha realizado en el campo de las ciencias de la Tierra. Comprender estas transformaciones es esencial para el proceso de toma de decisiones del estudiante.

De hecho, la geología es el estudio de la Tierra: cómo funciona y sus 4.500 millones de años de historia. Los geólogos estudian algunas cuestiones contemporáneas, como la energía, el agua y los recursos minerales, el medio ambiente, el cambio climático y los principales riesgos como deslizamientos de tierra, volcanes y terremotos. Estudiar la Tierra y Marte en un espíritu de "planetología comparativa" proporciona una mejor comprensión de cómo las leyes físicas y químicas universales han creado nuestro medio ambiente.

1 EU Skills Panorama (2014). STEM skills Analytical Highlight, prepared by ICF and Cedefop for the European Commission (https://skillspanorama.cedefop.europa.eu/sites/default/files/EUSP_AH_STEM_0.pdf)

2 La misión InSight busca descubrir cómo se forma y evoluciona un cuerpo rocoso para convertirse en un planeta investigando la estructura interior y la composición de Marte. La misión también determinará la tasa de actividad tectónica marciana y los impactos de meteoritos.

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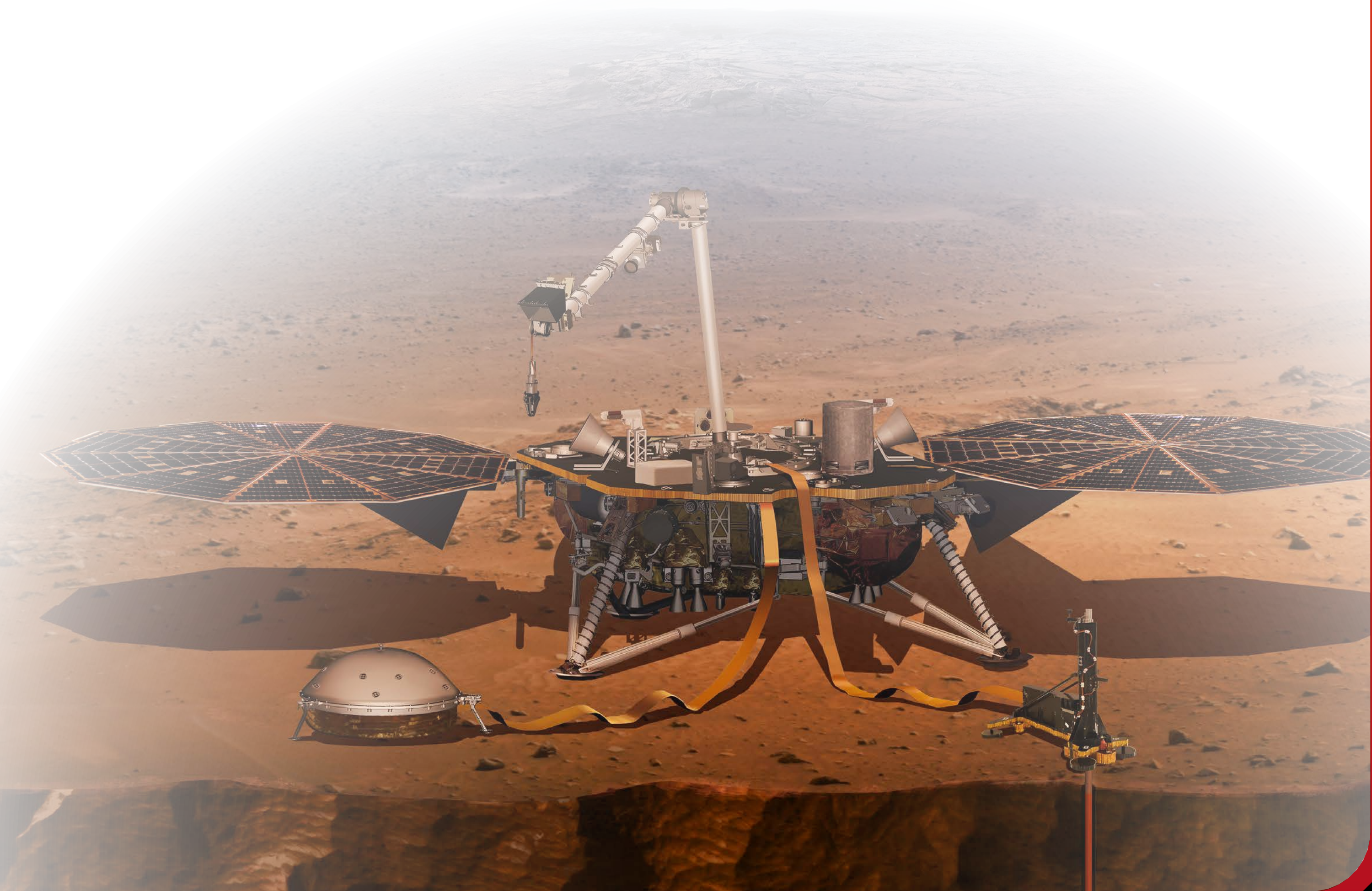
OBJETIVOS DEL INFORME

Esta publicación constituye el Resultado 1 del proyecto STIM y presenta un paquete de 23 actividades que incluyen actividades prácticas, actividades y experimentos basados en ordenadores, así como seis seminarios web y tres EduTeasers dedicados a profesores de educación secundaria. Los socios de STIM desarrollaron este conjunto de recursos STEM para profesores, en varios formatos (por ejemplo, actividades prácticas, actividades basadas en datos registrados en Marte, experimentos y seminarios web dedicados a profesores) para ser utilizados directamente en el aula. Estos recursos se desarrollaron tras una amplia encuesta difundida entre profesores de tres países europeos (Rumanía, Francia y España) y tras varios talleres que también se presentan en este informe. La encuesta en línea y los talleres realizados tenían como objetivo evaluar las necesidades y expectativas de los profesores en campos complejos como la educación de la Tierra, el Universo y la Planetología, ya que utilizan estos campos de especialización en varias disciplinas como geología, geofísica, química, etc. Estas disciplinas se integran en los planes de estudios de la mayoría de los países europeos y, por lo tanto, requieren una formación adecuada del profesorado para que éstos puedan transmitir las asignaturas antes mencionadas a los estudiantes.

Los resultados de la encuesta se presentan en la primera parte del informe, incluyendo información sobre los talleres realizados entre los profesores y que tenían como objetivo validar los resultados destacados por el estudio. La segunda parte se centra en el paquete de recursos que se desarrolló de acuerdo con los resultados de la encuesta y en un proceso coconstructivo dirigido entre investigadores y profesores utilizando nuevos datos recopilados de la misión espacial InSight. Los recursos educativos se complementaron con materiales de formación para los maestros, también presentados en este informe para apoyarlos cuando utilicen las actividades escolares relacionadas con InSight. Por ejemplo, se proporcionaron seminarios web para profesores y estudiantes para adquirir una buena comprensión de la sismología planetaria, la geología, la geofísica, y las ciencias de la Tierra y espaciales. Una serie de videos cortos también fue producida por investigadores sobre temas relacionados con la misión InSight y las acciones y resultados de STIM, explicando brevemente a los estudiantes temas de investigación de InSight y otros descubrimientos interesantes.



1. Evaluación de necesidades y mapa de expectativas de los beneficiarios

ANTECEDENTES Y ENFOQUE

El objetivo principal del proyecto era desarrollar recursos STEM que fomentaran el uso de datos de investigación, software y actividades prácticas como herramientas de aprendizaje. Por lo tanto, el propósito de la encuesta fue sacar a la luz las representaciones iniciales de los profesores y sus necesidades de desarrollo profesional sobre los temas propuestos (planetología y sismología planetaria). También tenía como objetivo determinar el lugar de estas enseñanzas en los programas oficiales y, por lo tanto, orientar mejor el desarrollo de todos los recursos STEM.

Para ello, se implementó el siguiente enfoque en dos pasos:

1. Desarrollo de una encuesta online
2. Organización de talleres con el fin de recibir feedback directo de los profesores

1.1 LA ENCUESTA ONLINE

La encuesta, realizada entre octubre y febrero de 2019, se dirigió al principal grupo objetivo de partes interesadas de la STIM (profesores de ciencias de la escuela secundaria) con diferentes perfiles:

- profesores que ya habían participado en otros proyectos/iniciativas STEM,
- profesores que nunca habían participado como usuarios en otros proyectos/iniciativas STEM.

192 profesores de Francia, Rumanía y España rellenaron un cuestionario en línea diseñado en colaboración con todos los socios del proyecto y teniendo en cuenta las características propias de los sistemas educativos nacionales (como los nombres de las disciplinas científicas, las limitaciones de los profesores, etc..). Los resultados aparecen en la Figura 1.

El cuestionario fue traducido a los idiomas nacionales todos los socios (francés, rumano y español) además del inglés y puesto a disposición utilizando la herramienta en línea SurveyMonkey. La encuesta se incluye como Anexo 1 de este informe.

Los resultados de la encuesta se dividen en tres secciones principales que se describen a continuación.

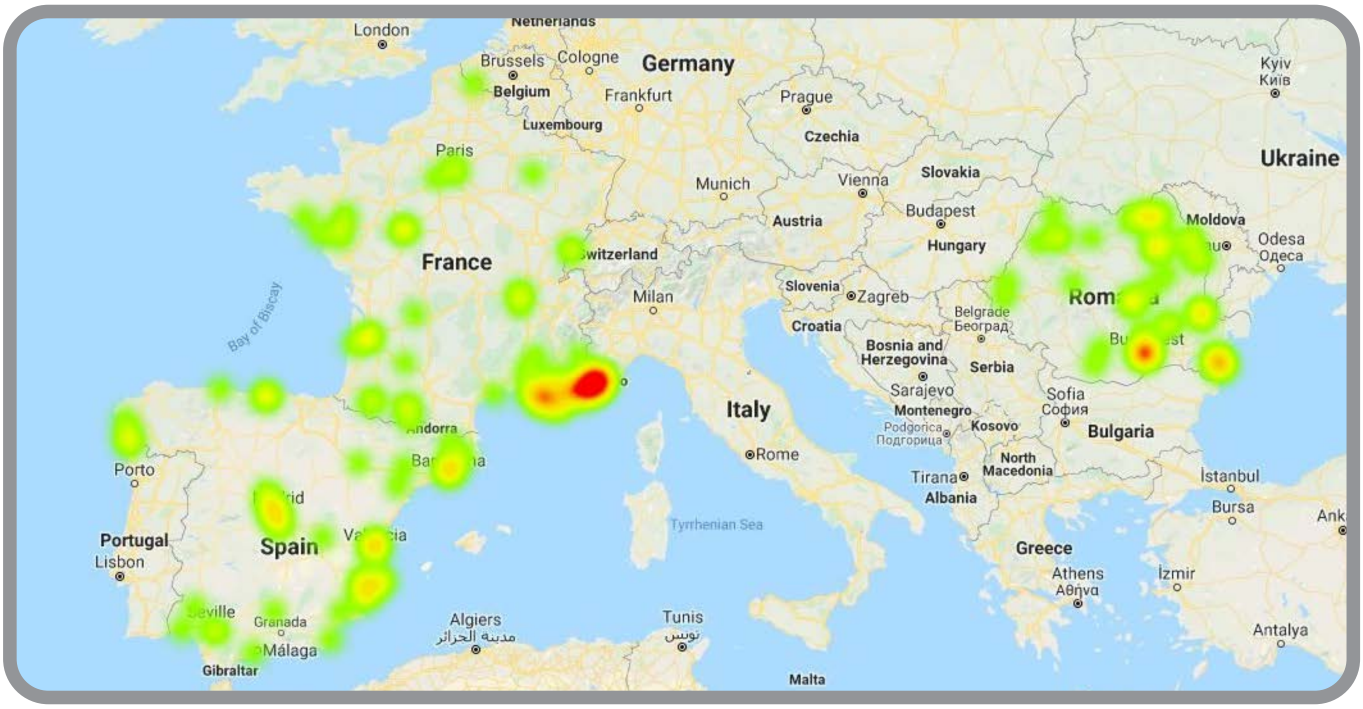


Figura 1: Origine de los participantes a la encuesta

a) Descripción de la muestra

En primer lugar, se pidió a los encuestados Figura 2 y perfil profesional (nivel educativo y disciplina enseñados, qué resultados se muestran en la figura 5 y 6). El objetivo era también encuestar a las personas de diferentes regiones de los países implicados para que los resultados pudieran ser geográficamente representativos. La experiencia docente obtenida osciló entre 12 meses y 25 años con un promedio de 10 años. Las principales tareas docentes de los profesores que respondieron a la encuesta fueron física, biología, ciencias, química y/o TIC. De los 192 profesores, el 41% eran hombres y el 59% mujeres. Los resultados del estudio indicaron que ninguno de los encuestados enumeró la geología como su principal asignatura de enseñanza. La mayoría de los docentes habían integrado las ciencias de la Tierra en la biología, la química o la física.

Los profesores de bachillerato (57% de los encuestados, con estudiantes de entre 15 y 18 años) fueron los más interesados en las asignaturas STIM. Esto era predecible ya que es en este nivel educativo donde las disciplinas comienzan a abordar temas relacionados con la planetología, el sistema solar, la estructura interna de los planetas, etc. Sin embargo, los profesores de secundaria obligatoria (30% de los encuestados, con estudiantes de entre 11 y 14 años) consideraron que materias como las abordadas en STIM pueden utilizarse si se adaptan a este nivel. En la mayoría de los casos, los conceptos/contenidos de las Ciencias del Sistema Terrestre (ESS) se integran dentro de los cursos generales de ciencias que comienzan en las escuelas intermedias.

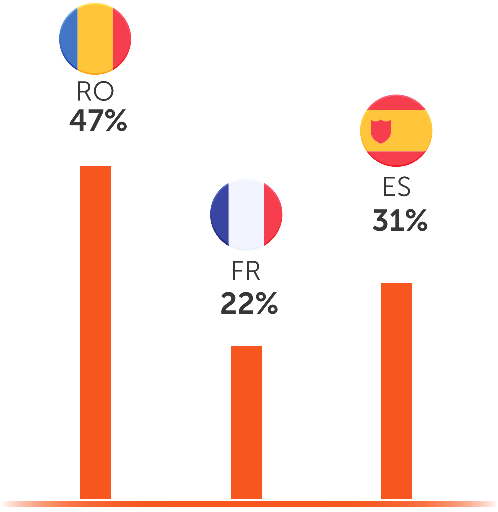


Figura 2: Descripción de la muestra: porcentaje de respuestas por país

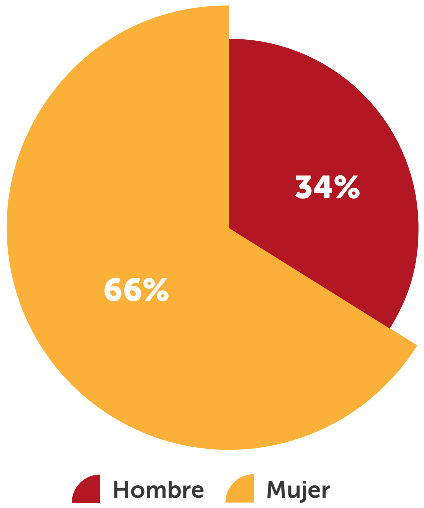


Figura 3: Descripción de la muestra: Género de los encuestados

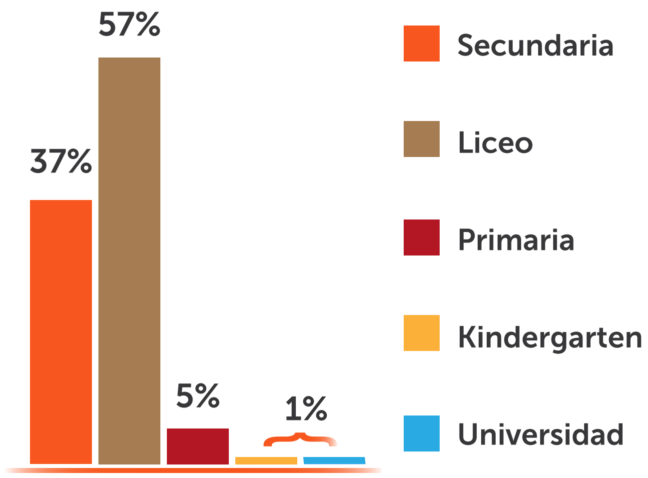


Figura 4: Descripción de la muestra. Niveles educativos

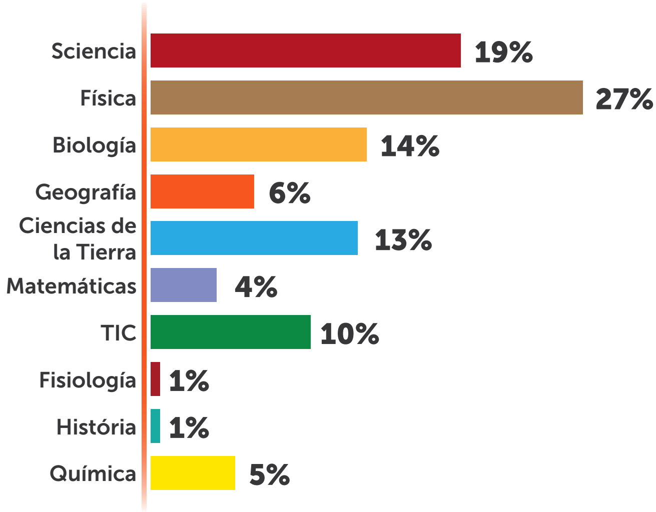


Figura 5: Descripción de la muestra: materias enseñadas por los encuestados

b) Evaluación de la relevancia de los temas STIM en el aula

Como se muestra en las Figuras siguientes Figura 6, Figura 7, Figura 8, Figura 9, Figura 10, Figura 11 y 12), los resultados de la encuesta destacaron que, en términos generales, aunque los profesores disponían de métodos científicos para enseñar conceptos de ciencias de la Tierra (61%), casi el 30% no se sentía cómodo transmitiendo conceptos más especializados como la planetología. Estos conceptos requieren un enfoque diferente más parecido al enfoque del investigador que cuestiona, utiliza el ensayo y error, modela y explota datos de investigación que hacen referencia cruzada a las contribuciones de diferentes disciplinas que inevitablemente debe dominar.

Por lo tanto, los resultados confirmaron que los profesores necesitaban una formación científica más profunda para consolidar sus conocimientos, pero también actividades clave que les ayudasen a transmitir estos conceptos relacionados con la planetología y la sismología planetaria a sus estudiantes.

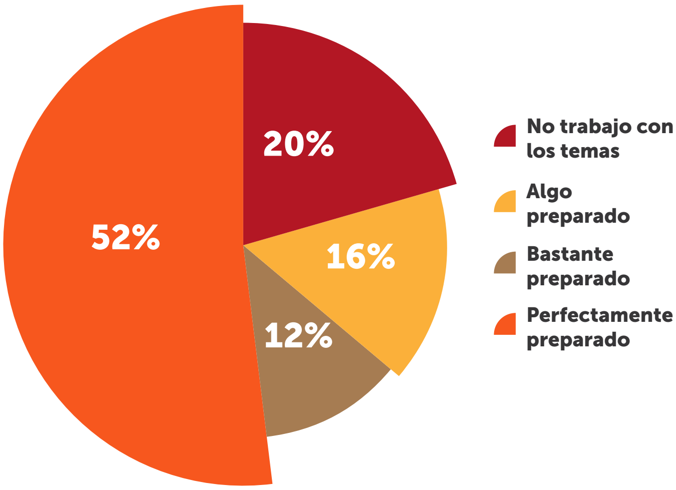


Figura 6: nivel de confianza de los encuestados respecto a la enseñanza de las características de la Tierra y sus procesos físicos

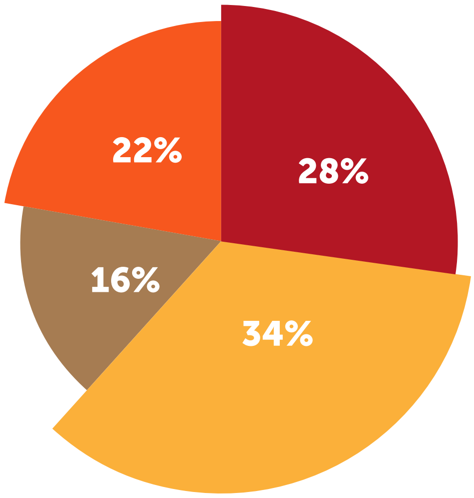


Figura 9: nivel de confianza de los encuestados respecto a la enseñanza de clasificación y estructura de la materia

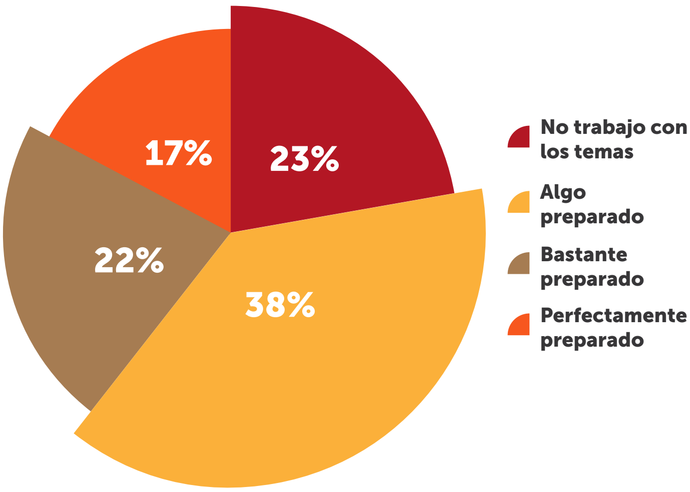


Figura 7: nivel de confianza de los encuestados respecto a la enseñanza de ciencia planetaria (planetología)

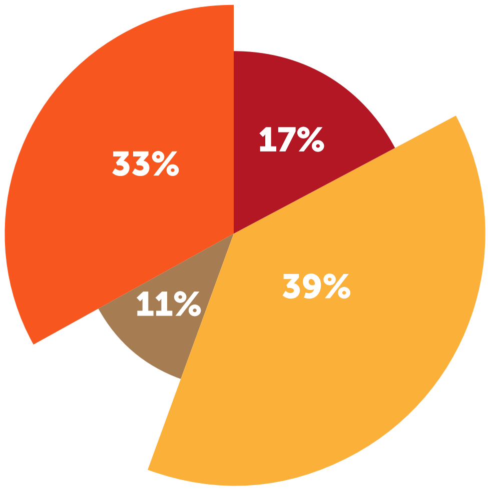


Figura 10: nivel de confianza de los encuestados respecto a la enseñanza de tipos de energía, fuentes de energía, conversión entre tipos de energía

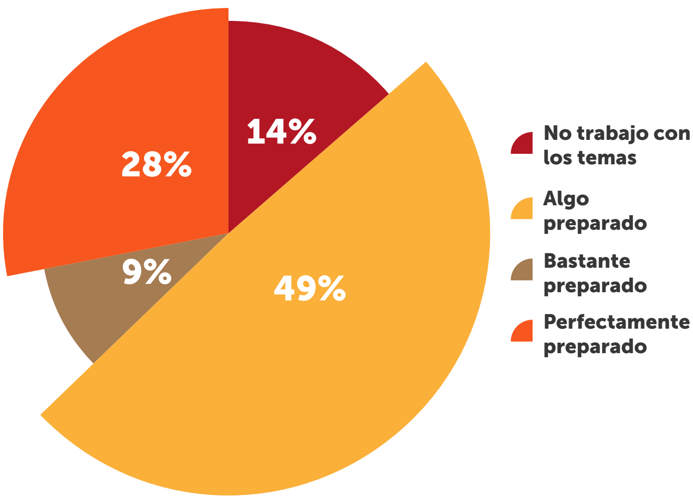


Figura 8: nivel de confianza de los encuestados respecto a la enseñanza del sistema solar y el universo

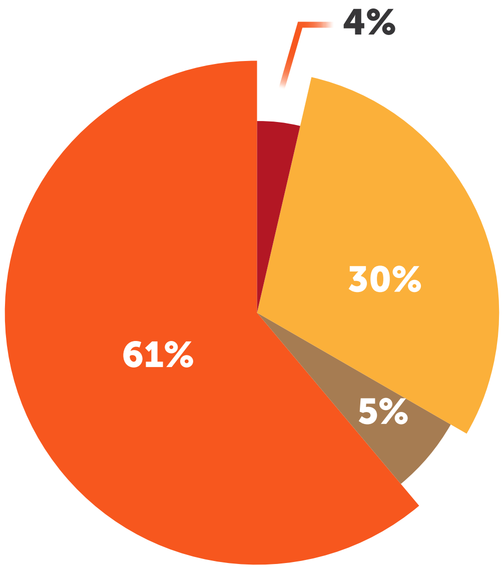


Figura 11: nivel de confianza de los encuestados respecto a la enseñanza de métodos científicos y habilidades de investigación

Figura 12: nivel de confianza de los encuestados respecto a la enseñanza de cuestiones ambientales y de recursos

Los resultados de la encuesta también confirmaron la necesidad de los profesores de formarse en materias que requieren conocimientos y habilidades para entender conceptos científicos difíciles (como la planetología y la sismología planetaria) utilizando un enfoque interdisciplinario (física, matemáticas, geociencias, tecnología, etc.). Los encuestados validaron las opciones previstas para las actividades del proyecto STIM: talleres (53%) y módulos en línea (por ejemplo, MOOCs – 30%) como se muestra Figura 13:

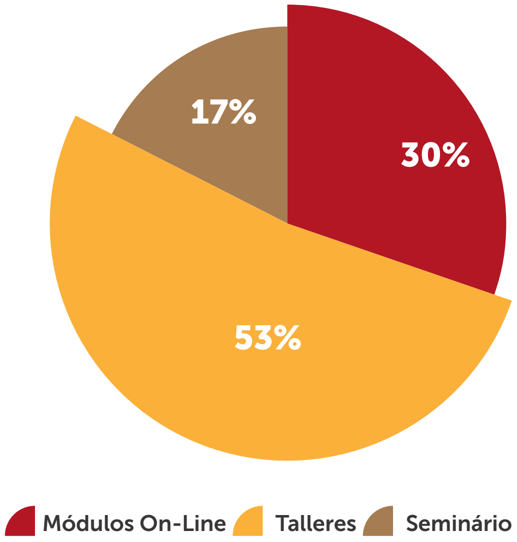


Figura 13: Método preferido de formación del profesorado

c) Factores de motivación para la formación colaborativa y la participación en STIM

Finalmente, el último conjunto de preguntas fue sobre los posibles factores que motivan a los docentes a unirse a proyectos o a implementar actividades STEM dentro y fuera del aula.

Como se Figura 14, con respecto a la motivación para implementar las actividades de STIM, el 30% de los encuestados mencionó promover el pensamiento crítico y el 21% mencionó motivar a los estudiantes a aprender, el 19% mencionó que las actividades STIM podrían ser utilizadas para diseñar o implementar un plan de estudios estimulante. Estos resultados confirman que los recursos de STIM satisfacen las expectativas de los planes de estudio oficiales tanto para la educación en ciencias de la Tierra como para la enseñanza de otras disciplinas, además de desarrollar habilidades transversales. De hecho, poder cruzar las miradas de diferentes disciplinas para resolver una cuestión compleja permitirá a los estudiantes entender la realidad compleja y sentirse más cómodos en el futuro en las carreras STEM.

Figura 14: factores de motivación para implementar las actividades STIM en el aula segun los encuestados

1.2 ORGANIZACIÓN DE TALLERES CON EL FIN DE RECOPILAR COMENTARIOS DIRECTOS DE LOS PROFESORES

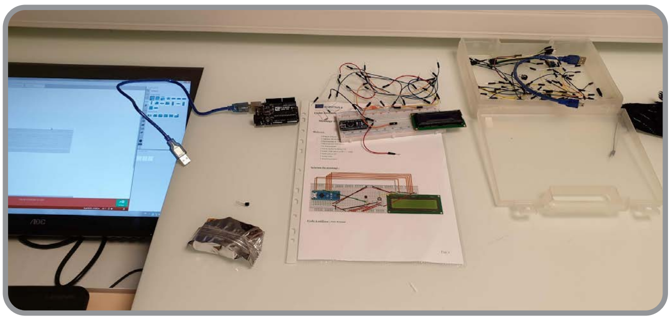
Cuatro eventos fueron organizados por los socios para profesores de secundaria, lo que brindó la oportunidad de consolidar los resultados de la encuesta en línea. Su objetivo era recopilar comentarios directos de los profesores sobre sus necesidades de mejorar el conocimiento y la comprensión de la planetología y la sismología planetaria, así como orientar aún más el desarrollo de todos los recursos del STIM.

Durante estos talleres, los formadores presentaron los temas principales del proyecto STIM (especialmente planetología y sismología planetaria) y los objetivos de las actividades y métodos innovadores propuestos. La retroalimentación solicitada era principalmente cualitativa, relacionada con la pertinencia de los temas propuestos en el contexto curricular y su adaptación al nivel educativo correspondiente.

Las conclusiones de los comentarios recogidos en los cuatro eventos en los que participaron 151 profesores en total, pueden resumirse de la siguiente manera:

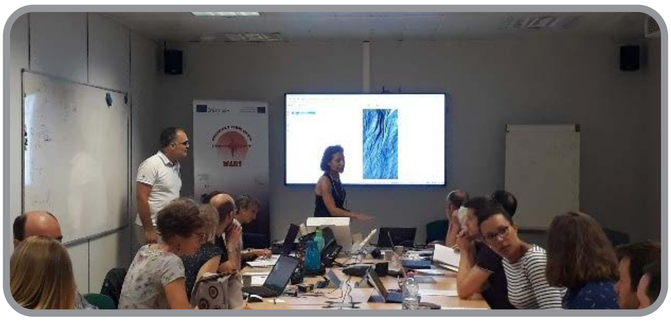
- los temas abordados en las actividades STIM tienen un fuerte carácter interdisciplinario que los hace útiles y capaces de integrarse en muchas formas, tanto en el contexto de la educación formal como informal,
- los métodos combinados utilizados están más cerca de lo que se define como educación futura, una mezcla de métodos experimentales, actividades interactivas e investigaciones,
- todas las actividades están diseñadas en torno a temas que son atractivos y relevantes para los estudiantes de secundaria y que se pueden utilizar para complementar el currículo escolar. Además, la mayoría de las actividades incitan a los alumnos a pensar y procesar información significativa,
- la mayoría de las actividades promueven la participación de los estudiantes a través del aprendizaje activo (enseñanza con tecnologías, discusión integrada en la conferencia, actividades prácticas y eventos de aprendizaje experiencial).

Los cuatro eventos que se organizaron se ilustran en las siguientes imágenes:



16-17 de enero de 2019, Sophia Antipolis, Francia – Taller de Educación IsSight / Scientix – algunas de las actividades de STIM fueron presentadas y probadas por 65 profesores participantes de Francia, España - Portugal - Haití – Grecia. Los temas abordados se referían a las características de los planetas rocosos.


12 -30 de agosto de 2019: Taller de profesores durante la Universidad de Ciencia y Tecnología de Verano, Rumania - Las actividades STIM fueron probadas por 25 profesores de ciencias participantes; los temas abordados se referían a las características de los planetas rocosos.

Los días 12 y 13 de junio de 2019, las actividades del STIM relacionadas con el medio ambiente de los planetas rocosos fueron presentadas y probadas por los 22 profesores en prácticas de la agencia espacial francesa, CNES, en Toulouse.


Los días 28 y 29 de septiembre de 2019, se celebró el seminario Calisph'air en el Liceo de la Mer en bassin d'Arcachon, Francia. Las actividades del STIM fueron probadas por 38 profesores de ciencias participantes, siendo los temas tratados la geodinámica interna de Marte frente a la Tierra.

A estos talleres asistieron profesores en prácticas de diferentes disciplinas, científicos e inspectores (que forman parte del consejo asesor del proyecto).

2. Paquete de recursos STIM

Los recursos de STIM pueden considerarse como un paquete de actividades STEM sobre temas relacionados con la misión InSight. Como cualquier otro plan de estudios STEM, implican la enseñanza interdisciplinaria y tienen como objetivo desarrollar las habilidades de investigación de los estudiantes y su capacidad para contextualizar conceptos científicos en situaciones reales. No se definen en términos de una ruptura contemas traditional, sino más bien un descanso con la enseñanza tradicional [Nistor,A., Gras-Velazquez, A., Billon, N. & Mihai, G. (2018). Ciencia,Tecnología, Ingeniería y Prácticas De Educación Matemática en Europa. Informe del Observatorio Scientix]

Los socios elaboraron un paquete de recursos STIM para fomentar el uso de los datos de investigación de InSight junto con software dedicado y actividades prácticas como entornos de aprendizaje.

Las actividades se propusieron teniendo en cuenta los temas tratados (sistema solar, planetas, estructura interna, sensores, monitoreo, parámetros atmosféricos, expediciones espaciales, etc.), las disciplinas para las que eran relevantes (e. g. ciencia, física, geografía, geología, astrofísica, tecnologías, etc.), su formaen (prácticas, experimentos, hojas de trabajo, etc.) y la experiencia de los socios (investigadores y profesores).

EL MÉTODO CIENTÍFICO DETRÁS DEL DESARROLLO DE LOS RECURSOS STIM

Todas las actividades fueron diseñadas integrando el enfoque científico para que los estudiantes pudieran ponerse en la piel de un investigador y adquirir este enfoque esencial para resolver problemas complejos. Este enfoque puede ser reactivado por el estudiante en otros contextos de la vida diaria.

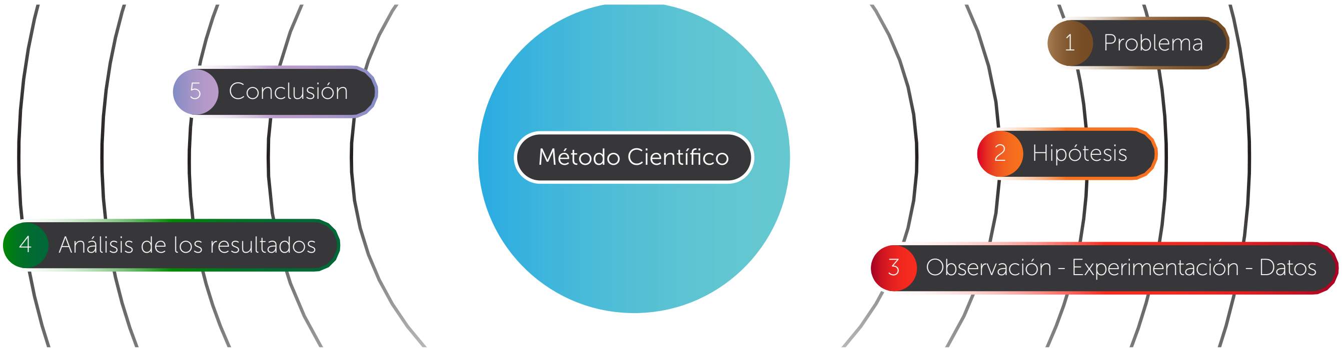


Figura 15: Método científico utilizado para el desarrollo de las actividades de la STIM

Estos recursos y enfoque científico STEM propuestos fueron una invitación a los profesores y sus estudiantes a participar en la aventura científica y tecnológica de la exploración de planetas rocosos como Marte y la Tierra, la búsqueda de sus orígenes y funcionamiento.

Cada recurso del STIM se describió utilizando una plantilla predefinida (hoja de trabajo), que ayudó a definir los principales atributos así como los materiales necesarios para llevar a cabo la actividad. Las actividades se detallaron paso a paso, la mayoría de ellas se complementaron con materiales de vídeo (seminarios web grabados, tutoriales y ejemplos de actividades) así como con enlaces a recursos adicionales, permitiendo a los profesores definir el nivel de implementación, desde el básico hasta el avanzado, desde la actividad independiente hasta la integrada.

CATEGORÍAS DE RECURSOS

Para estudiar la planetología, los temas se dividieron en cinco categorías, como se muestra en las páginas siguientes:

Tema	Descripción	Actividades
Características de los planetas rocosos **Tipos: experimentos**	Esta categoría comprende un conjunto de cuatro experimentos que explican principalmente las diferencias entre el interior de los planetas (rocosos), analizando cómo se enfrían (la velocidad a la que se disipa el calor), así como la influencia que la presencia o ausencia del campo magnético tiene en su formación y evolución. Los estudiantes usaron microcontroladores y sensores de temperatura para medir el flujo de calor. La quinta actividad se centró en las relaciones espaciales entre los diferentes planetas del sistema solar.	Actividad 1 - Modelo de enfriamiento para planetas rocosos Actividad 2 - Medición del flujo de calor Actividad 3 - Campo Magnético Actividad 4 - Movimiento de convección en el manto Actividad 5 - ¿Qué tan grande es nuestro Sistema Solar?
El medio ambiente de los planetas rocosos **Tipo: actividades de datos**	Este conjunto de actividades permitió a los alumnos descubrir el clima marciano que, al igual que la Tierra, tiene muchos tornados y fuertes vientos que transportan aerosoles durante varios kilómetros. Día tras día, los movimientos atmosféricos están modelando la superficie de Marte y la Tierra. Los estudiantes entendieron, a partir de modelos y datos, que el clima no es fijo y que estas fluctuaciones son inducidas por las variaciones orbitales en el planeta	Actividad 6 - Ruido sísmico atmosférico Actividad 7 - Aerosoles primarios e impacto climático en la Tierra Actividad 8 - Aerosoles primarios e impacto climático en Marte Actividad 9 - Variaciones diarias de temperatura en Marte Actividad 10 - SEIS, un sismómetro bien envuelto Actividad 11 - Instrumentos para medir la velocidad del viento marciano.
Geología externa de Marte vs. la Tierra	Utilizando los datos recogidos por todas las misiones marcianas, los científicos pueden ahora comparar la geodinámica externa de Marte y la Tierra. Estas actividades permitieron a los estudiantes sacar conclusiones sobre los factores responsables de su geomorfología. Los estudiantes usaron los datos de las imágenes satelitales y un experimento para confirmar sus hipótesis.	Actividad 12 - El agua salada - la fuente de los barrancos en Marte: ¿Información o engaño? Actividad 13 - Paisajes formados por tornados de polvo Actividad 14 - Los volcanes comparados: ¿Por qué un planeta más pequeño tiene un volcán más grande?
Geología interna de Marte vs. la Tierra	Los geofísicos tienen una poderosa técnica de investigación que les ha permitido durante varias décadas explorar el interior de la Tierra y comprender su estructura. Esta técnica se conoce como sismología. Las actividades en esta categoría incluyeron las especificidades de la sismología en	Actividad 15 - Cómo estimar la ubicación del epicentro con una sola estación sísmica en la Tierra Actividad 16 - Determinar la ubicación de un terremoto marciano desde un solo sismómetro Actividad 17 - Bolas de plastilina: ¿Cómo podemos explorar dentro de Marte?

Tema	Descripción	Actividades
Misión espacial a Marte	Marte y la Tierra utilizadas por los científicos y el uso de datos de investigación de la misión Mars InSight, pero también el estudio de los parámetros atmosféricos y su impacto en la sismología. .	Actividad 18 - Bolas de plastilina: comparando planetas Actividad 19 - El sismograma: una señal compleja Actividad 20 - Parámetros atmosféricos e impacto en los registros sísmicos
	En estas dos actividades los estudiantes aprendieron a diseñar una misión y a utilizar conceptos avanzados de álgebra para determinar la próxima oportunidad de lanzar una nave espacial para explorar el Planeta Rojo e imaginar un sistema de absorción de impactos para proteger a la nave espacial y a los astronautas cuando aterrizan.	Actividad 21 - La caída de los huevos Actividad 22 - Ir a Marte Actividad 23 - La energía solar, una fuente de energía sostenible

RECURSOS DE STIM PRODUCIDOS

FTras los resultados de la encuesta, se desarrollaron 23 actividades en inglés y se tradujeron a los tres idiomas de los socios (rumano, español y francés).

Además, los investigadores y formadores de planetología realizaron seis seminarios web (webinars) para explicar a los profesores las metodologías desarrolladas en las actividades y los complejos conceptos a dominar para poder enseñar estas actividades.

Los recursos se dividieron en las cinco categorías principales mencionadas anteriormente y están disponibles en el sitio web Insight.oca.eu como parte de un mapa de actividades ilustrado en la Figura 16 a continuación.

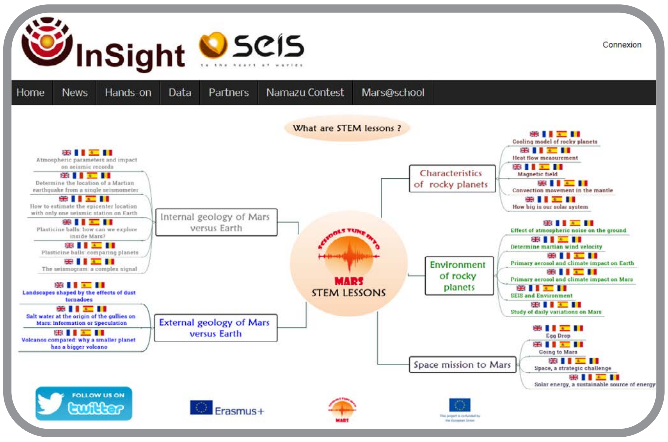
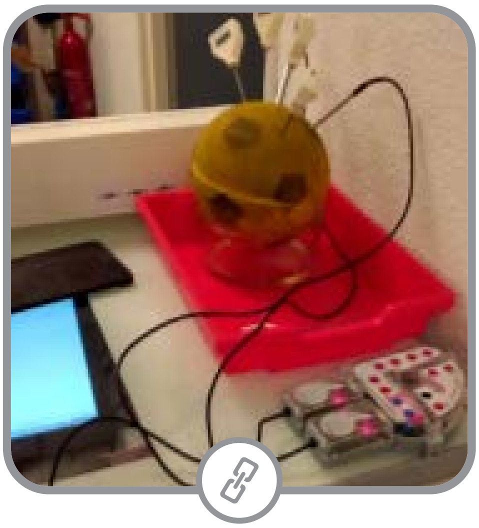


Figura 16: imagen del mapa de actividades publicado en el sitio web InSight.oca.eu

Las 23 actividades producidas se resumen a continuación:

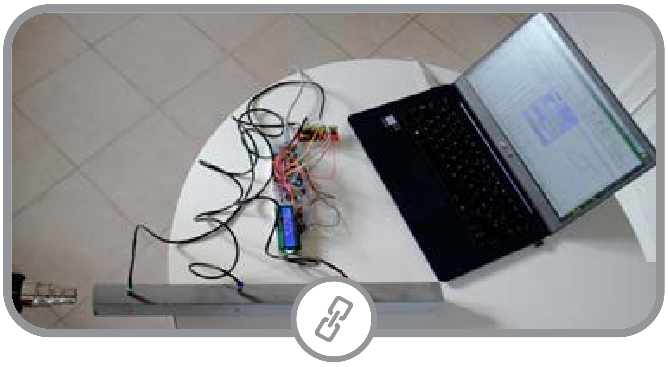
Características de los planetas rocosos

Actividad 1 - Modelo de enfriamiento para planetas rocosos | Actividades prácticas



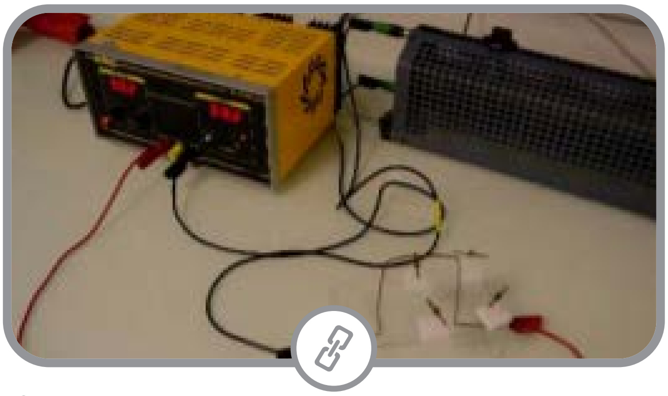
Cuando toda la energía de la fase de formación se ha convertido en calor, el planeta comienza a enfriarse disipando su calor interno hacia y a través de la superficie. Uno de los objetivos de InSight es determinar la cantidad de calor que continúa escapando de la superficie marciana (flujo de calor). utilizando una configuración de modelado experimental y la explotación matemática de los resultados, los estudiantes aprendieron sobre el flujo de calor, la disipación de calor y el gradiente geotérmico (más información en el Anexo 2).

Actividad 2 - Medición del flujo de calor | Actividades prácticas



¿Qué mecanismos causan la disipación de calor interno de Marte y la Tierra? En la Tierra, el gradiente de temperatura se obtiene midiendo directamente la temperatura a diferentes profundidades en pozos de sondeo o pozos de minas. Una vez que se conoce este gradiente y se determina la conductividad térmica de las rocas subyacentes, los científicos pueden estimar el flujo de calor en un punto de la superficie. Esto es lo que hará la misión InSight a Marte con su Paquete de Flujo de Calor y Propiedades Físicas, un instrumento conocido como HP3. En esta actividad, los estudiantes pudieron comprender el fenómeno de la conducción térmica midiendo la conductividad térmica de las rocas mediante tres sensores de temperatura, una fuente de calor y un dispositivo de registro de datos (más información en el Anexo 3).

Actividad 3 - Campo magnético | Actividades prácticas



¿Cuál es el mecanismo detrás de la rápida disipación del calor interno de Marte? La misión InSight ha volado con un magnetómetro InSight Fluxgate (IFG), que será el primer magnetómetro en registrar datos magnéticos directamente desde la superficie de Marte. La desaparición del campo magnético de Marte podría explicar la pérdida de calor mucho más rápida en comparación con el planeta Tierra. Los estudiantes pudieron descubrir cómo un campo eléctrico puede crear un campo magnético y cuál es el papel del campo magnético de un planeta rocoso (escudo terrestre). Los estudiantes generaron y modelaron un campo magnético usando una corriente eléctrica y observaron lo que sucede cuando colocan el alambre cerca de una pila de limaduras de hierro (más información en el Anexo 4).

Actividad 4 - Movimiento de convección en el manto Actividades prácticas

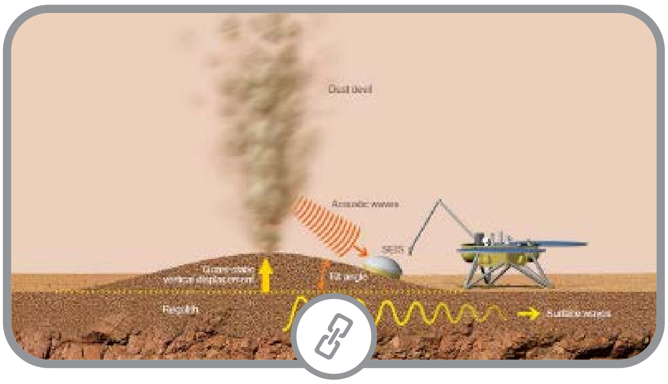
Si un cuerpo se enfría desde abajo y se calienta desde arriba, las áreas densas estarán en la parte inferior y las áreas menos densas en la parte superior. ¿Cuáles son los mecanismos que causan la disipación de calor interno de Marte y la Tierra? Este proceso se conoce como convección térmica y los estudiantes realizaron un experimento que explica los diferentes tipos de convección que causan la disipación de calor en un planeta rocoso (más información en el Anexo 5).

Activity 5 - ¿Qué tan grande es nuestro Sistema Solar? Actividades prácticas

Las distancias entre los diferentes planetas de nuestro sistema solar son tan enormes que para muchos estudiantes es muy difícil compararlas con las distancias de la vida diaria a las que están acostumbrados. Esta actividad tenía como objetivo mejorar la conciencia de los estudiantes sobre las relaciones espaciales entre los diferentes planetas del sistema solar, centrándose especialmente en Marte y la Tierra. Los estudiantes usaron objetos de la vida diaria para calcular las distancias relativas entre los planetas del sistema solar; esto les permitió hacer cálculos de razón (más información en el Anexo 6).

El medio ambiente de los planetas rocosos

Actividad 6 - Ruido sísmico atmosférico | Experimento



La fuente secundaria de ruido microsísmico atmosférico es producida por fuentes de ruido locales: el sitio de aterrizaje es afectado por ráfagas de viento o por la llegada de un torbellino de polvo cerca del módulo de aterrizaje. En ambos casos, el aire marciano ejerce una fuerza sobre el suelo: hacia arriba en caso de una caída de presión, hacia abajo en caso de sobrepresión. Los estudiantes determinaron si una simple caída de presión puede causar una deformación del suelo detectable por acelerómetros, aunque este tipo de deformación no es visible a simple vista (más información en el Anexo 7).

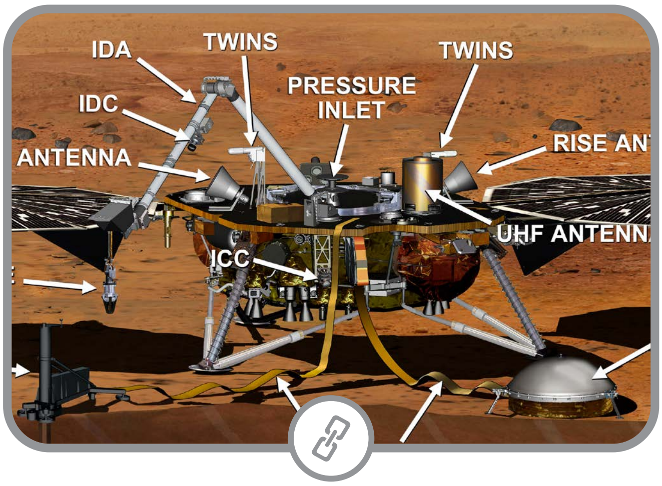
Actividad 7 - Aerosoles primarios e impacto climático en la Tierra | Experimento

Utilizando un hecho de la vida (lluvia fangosa) y el estudio de una muestra de prueba, los estudiantes descubrieron lo que es un aerosol primario y estudiaron su impacto en el clima, ya sea que esté suspendido en el aire o en la superficie de la Tierra. Los estudiantes determinaron el grosor óptico de las partículas de la muestra de ensayo extraída con un fotómetro para determinar su naturaleza y, por tanto, su impacto en el clima. Podrían entonces establecer si las dispersiones importantes de partículas tienen el potencial de influir significativamente en el clima de la Tierra (más información en el Anexo 8).

Actividad 8 - Aerosol primario e impacto climático en Marte | Experimento

Sabemos que incluso los aerosoles naturales pueden tener un impacto en el clima. Tanto en Marte como en la Tierra las partículas minerales están suspendidas. El impacto radiativo de un aerosol depende de la naturaleza de la superficie subyacente. ¿Podemos determinar si el transporte de polvo mineral marciano influye en el clima? (más información en el Anexo 9).

Actividad 9 - Variaciones diarias de temperatura | Datos

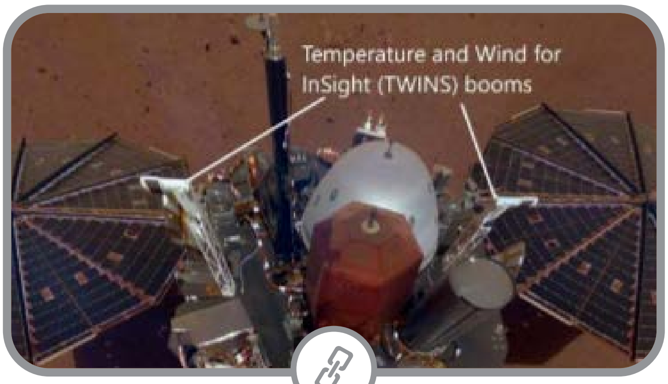


En la superficie de Marte, podemos encontrar tendencias estivales: 20°C, la brisa de los vientos alisios... Pero a partir del comienzo de la noche, los valores de temperatura descienden varias decenas de grados y las condiciones de congelación, que alcanzan los -100°C, prevalecen hasta la mañana siguiente. De hecho, el suelo marciano, que es seco y granular, puede almacenar muy poco calor. Su inercia térmica es muy pequeña comparada con la de la Tierra y sus océanos. El módulo de aterrizaje InSight está equipado con una estación meteorológica completa (APSS, Auxiliary Payload Sensor Suite). ¿Cómo puede el análisis de los datos meteorológicos ayudarnos a mejorar nuestro conocimiento de las perturbaciones meteorológicas en Marte, así como en la Tierra? Los estudiantes utilizaron un script de procesamiento de datos de Python, mostraron la información que podían recopilar sobre las perturbaciones meteorológicas y compararon e interpretaron los resultados obtenidos para la Tierra con los obtenidos para Marte (más información en el Anexo 10).

Actividad 10 - SEIS, un sismómetro bien empaquetado

La Tierra y Marte son planetas rocosos muy similares. Algunas personas incluso los llaman planetas "gemelos". Pero, ¿por qué los científicos insisten en cubrir el sismómetro con una cúpula protectora? El propósito de esta actividad fue determinar cómo la atmósfera y el ambiente de Marte difieren de los de la Tierra y por qué la construcción del módulo de aterrizaje necesitaba instrumentos realmente sólidos para ser probados repetidamente en condiciones extremas en la Tierra. Se pidió a los estudiantes que escribieran un artículo científico sobre los detalles de Marte y de la Tierra, en el que integraran los argumentos dados por los científicos para explicar el proceso responsable de la pérdida de gran parte de la atmósfera en Marte y dedujeran los argumentos que los científicos responsables de la misión InSight tuvieron en cuenta a la hora de desarrollar instrumentos de medición muy resistentes para resistir el medio ambiente marciano hostil (más información en el Anexo 11).

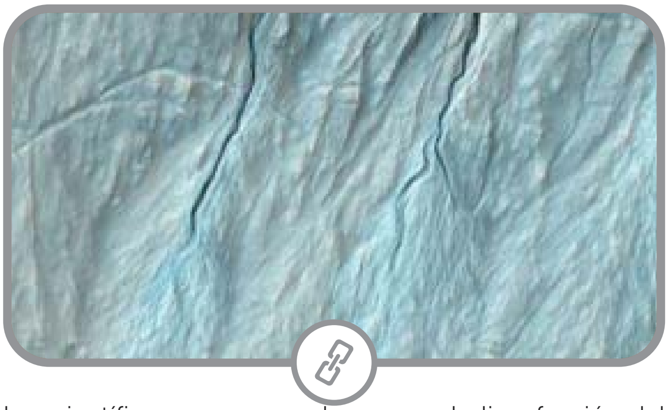
Actividad 11 - Instrumentos para medir la velocidad del viento Marciano | Experimento



En la Tierra, los sensores utilizados para medir la fuerza y dirección del viento son de dos tipos: sensores mecánicos con un anemómetro de copa y una veleta, o sensores ultrasónicos. ¿Cómo podemos determinar la velocidad del viento marciano a pesar de un ambiente hostil? Para InSight, los ingenieros eligieron TWINS (Sensores de temperatura y de viento para InSight) que registran la temperatura del aire, la velocidad y la dirección del viento dos veces por segundo. Los estudiantes utilizaron sensores similares para medir el viento y la temperatura y determinaron la dirección del viento y clasificaron los datos de viento (más información en el Anexo 12).

Geología externa de Marte contra la Tierra

Actividad 12 - El agua salada - la fuente de los barrancos en Marte: ¿Información o engaño? Actividades prácticas

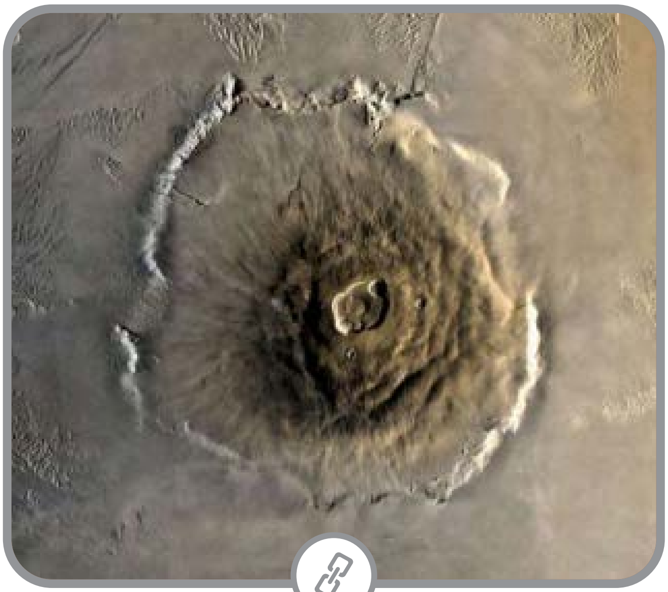


Los científicos creen que el proceso de licuefacción del suelo fue el responsable de la aparición de barrancos en Marte, es decir, un proceso mediante el cual las sales absorben el vapor de agua atmosférico cuando la temperatura y la humedad están elevadas al mismo tiempo. Parece que el proceso de formación de barrancos en Marte no se debe al goteo de "agua salada" sino a otra cosa. ¿Cómo se forman los barrancos en la Tierra y en Marte? ¿La erosión del suelo es la misma? Los estudiantes analizaron los documentos disponibles y el protocolo de modelización para el proceso de formación de barrancos en la Tierra (Erosión - Transporte - Deposición) y formularon una hipótesis plausible para la creación de barrancos en Marte (por ejemplo, variaciones estacionales en la presión superficial global) (más información en el Anexo 13).

Actividad 13 - Paisajes formados por tornados de polvo Experimento

El módulo de aterrizaje Mars InSight capturó un tornado de viento que limpió el polvo que se había estado acumulando en el panel solar del módulo de aterrizaje desde su llegada. Los estudiantes fueron guiados a entender las leyes físicas que gobiernan el movimiento de las masas de aire, es decir, la convección atmosférica, pero también el proceso subyacente a la formación de demonios de polvo para deducir aún más la causa de las huellas dejadas en el suelo que son tan representativas de Marte. ¿Existe tal fenómeno en la Tierra? Los estudiantes realizaron un experimento para enfatizar el movimiento de las masas de aire (más información en el Anexo 14).

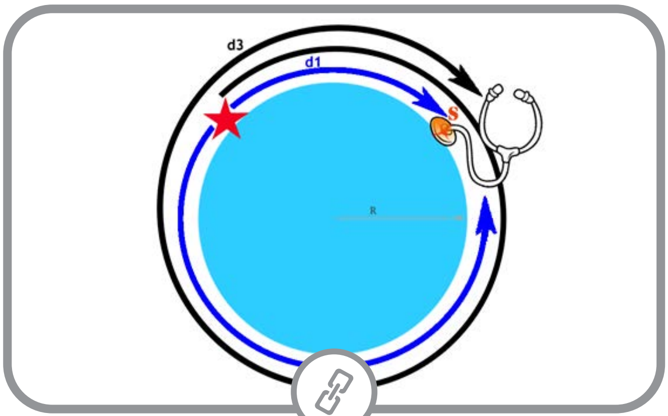
Actividad 14 - Los volcanes comparados: ¿Por qué un planeta más pequeño tiene un volcán más grande? Actividades prácticas



El tamaño y la forma de un cono volcánico en la Tierra permite a los vulcanólogos aprender muchas cosas sobre la historia del volcán, así como sobre la composición y otras propiedades físicas relacionadas del magma que lo formó, como su viscosidad. Muchos estudiantes saben que un volcán en el planeta Marte, el Olympus Mons, es la montaña más grande del sistema solar, o al menos, su volcán más alto. ¿Cómo podemos medir y comparar los tamaños de los volcanes más altos de ambos planetas, Mauna Kea en la Tierra y Olympus Mons en Marte? A través de una serie de cálculos simples, los estudiantes aprendieron sobre el tamaño de sus montañas más grandes. A partir de su volumen, composición y densidad, pueden calcular sus respectivos pesos. A continuación, elaboraron teorías para explicar las diferencias de tamaño y para comprender mejor la dinámica de un planeta con placas tectónicas que se mueven sobre una astenosfera plástica, en comparación con otro sin placas tectónicas activas en la actualidad (más información en el Anexo 15).

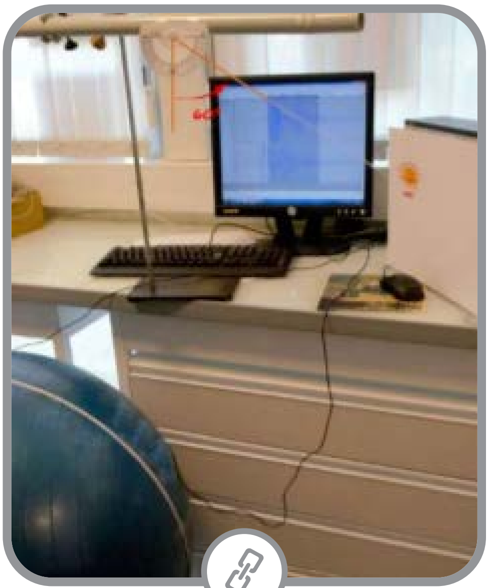
Geología interna de Marte contra la Tierra

Actividad 15 - Cómo estimar la ubicación del epicentro con una sola estación sísmica en la Tierra



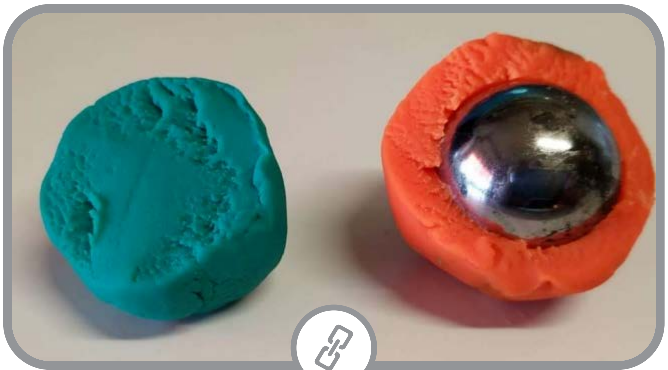
Con los registros de tres estaciones sísmicas, es posible estimar la ubicación del epicentro de un terremoto. En Marte, sólo hay un sensor para detectar y estimar la ubicación del epicentro de un terremoto. Es por eso que los estudiantes trataron de localizar un terremoto usando datos registrados en una sola estación sísmica. Aprendieron sobre las ondas de Rayleigh, estimaron el azimut posterior y analizaron los resultados utilizando un software dedicado (Seisgram) (más información en el Anexo 16).

Actividad 16 - Determinar la ubicación de un terremoto marciano desde un solo sismómetro | Datos y Experimento



La misión InSight tiene como objetivo localizar los maremotos usando un solo sismómetro. Teóricamente, Marte tiene un perímetro pequeño, los científicos esperan registrar varios trenes de ondas compensados en el tiempo que corresponden al mismo terremoto o impacto. Los estudiantes fueron guiados a entender cómo con un solo sismómetro es posible localizar el origen de las ondas sísmicas creadas por un impacto de un meteorito o un terremoto y experimentaron con un modelo para entender mejor la teoría (más información en el Anexo 17).

Actividad 17 - Bolas de plastilina: ¿Cómo podemos explorar dentro de Marte? | Actividades prácticas

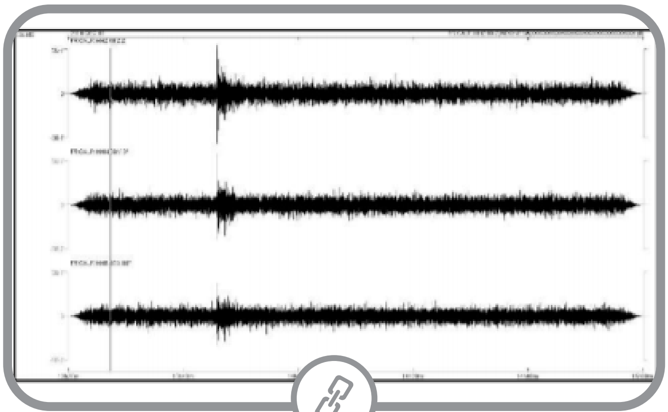


Durante los últimos siglos, muchos geocientíficos han estado trabajando para develar la estructura interna de la Tierra. Además de observar las rocas de la superficie de la Tierra y analizarlas y probarlas utilizando diferentes métodos, se ha desarrollado una amplia gama de herramientas para conocer mejor la estructura de la Tierra. Una vez que se demostró que los métodos directos como la perforación de la Tierra no podían proporcionar información sobre la estructura interna, los científicos se centraron en mejorar los métodos más indirectos. Los estudiantes tuvieron que enfrentarse a un problema y se les pidió que presentaran una hipótesis que pudiera ajustarse a los hechos (¿cómo pueden dos esferas que parecen iguales desde el exterior tener propiedades físicas muy diferentes en términos de masa y densidad?) (más información en el Anexo 18).

Actividad 18 - Bolas de plastilina: comparando planetas - Actividades prácticas

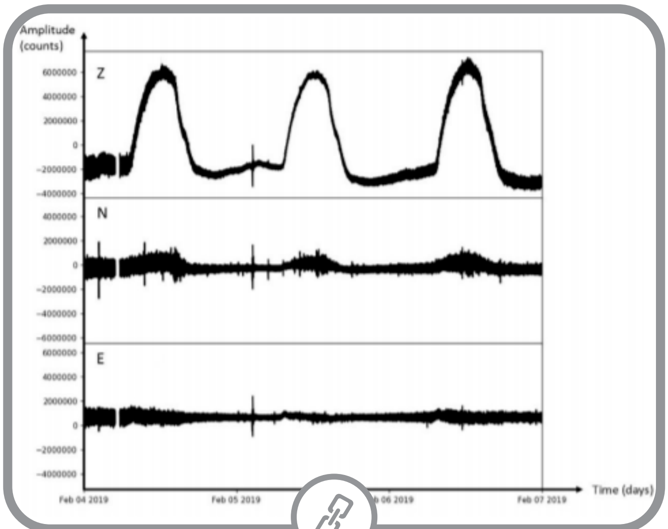
Esta actividad se realizará después de la actividad "Cómo podemos explorar dentro de Marte", en la que los alumnos aprendieron los diferentes métodos para estudiar la estructura interna de un planeta. A lo largo de esta actividad se desarrollaron dos aspectos del estudio de la estructura interna de un planeta: la distribución de las masas en su interior y la presencia o ausencia de un magnetismo general. Los estudiantes tuvieron que proponer una hipótesis y discutirla con el resto de los estudiantes, sugiriendo métodos para probar esta hipótesis, y entender cómo estas propiedades permiten o no hacer una distinción entre la Tierra y Marte, luego calcular la densidad de las diferentes bolas de arcilla y compararlas para decidir qué modelos de bolas son las mejores para la Tierra y Marte (más información en el Anexo 19).

Actividad 19 - El sismograma: una señal compleja | Datos



El movimiento del suelo es el resultado de la llegada de muchas ondas, cada una de las cuales tiene su propia frecuencia. Los sismómetros registran el movimiento del terreno continuamente y esta señal continua, sin la llegada de ondas sísmicas, se considera como el ruido sísmico ambiental. Cuando se registra un terremoto, las ondas sísmicas se identifican claramente en relación con el ruido sísmico de fondo. A veces, estas ondas habían sido registradas pero no eran perceptibles. Conociendo el rango de frecuencia de las ondas sísmicas, es posible encontrar un terremoto escondido en el ruido sísmico. Los estudiantes utilizaron el programa informático Seisgram para analizar los registros sísmicos, estimar una gama de frecuencias específica para los diferentes tipos de ondas sísmicas y utilizar filtros adecuados para identificar la señal útil (más información en el Anexo 20).

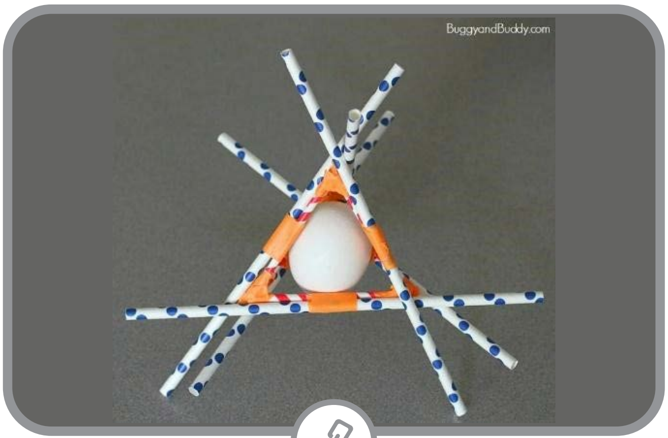
Actividad 20 - Parámetros atmosféricos e impacto en los registros sísmicos | Datos



Una estación sísmica está diseñada para detectar movimientos infinitesimales del suelo. Sus dispositivos electrónicos pueden ser impactados tanto por el movimiento del suelo como por los parámetros atmosféricos. Proponemos aquí sismogramas donde la señal continua no es plana: día tras día se observan grandes picos diarios. ¿Cómo podemos filtrar el ruido sísmico detectando las variaciones atmosféricas en la señal? Los estudiantes tuvieron que analizar y describir las señales continuas, encontrar un parámetro físico que puede inducir a la perturbación de la señal y encontrar un evento notable aparte de los picos diarios (más información en el Anexo 21).

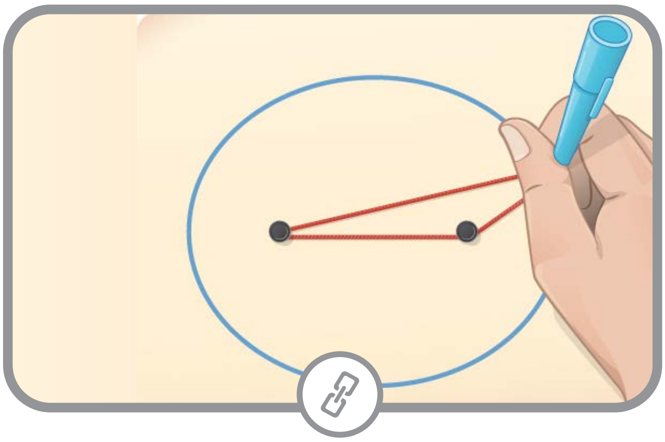
Misión espacial a Marte

Actividad 21 - Caída de huevos | Actividades prácticas



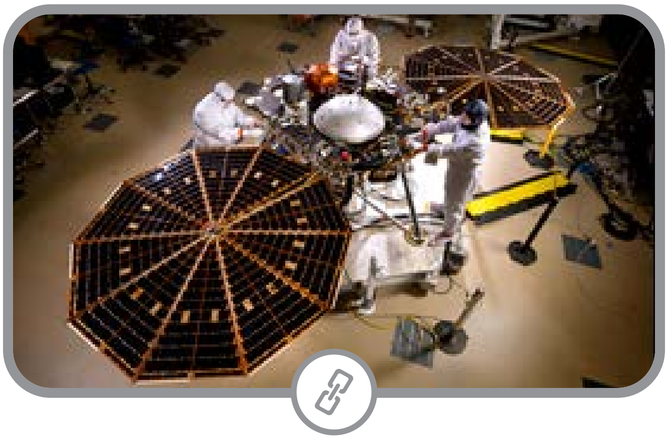
Las actividades de ingeniería dan a los niños la oportunidad de desarrollar habilidades de observación y resolución de problemas, de trabajar con herramientas y materiales interesantes y atractivos, y de aprender a trabajar como miembros de un equipo. Cuando se te cae algo, cae al suelo. Esto se debe a que es arrastrado por la gravedad de la Tierra. Algunas cosas caen más rápido que otras debido a la resistencia del aire. Los alumnos trataron de dejar caer un pedazo de papel y un ladrillo Lego para ver cuál es el que cae más rápido y también trabajaron con un huevo (más información en el Anexo 22).

Actividad 22 - Ir a Marte Actividades prácticas



Los estudiantes tuvieron que encontrar la posición relativa de la Tierra y Marte que corresponde al itinerario óptimo de la nave espacial en términos de consumo de energía utilizando datos de posición planetaria y conceptos algebraicos avanzados, todo para determinar la próxima oportunidad de lanzamiento a Marte (más información en el Anexo 23).

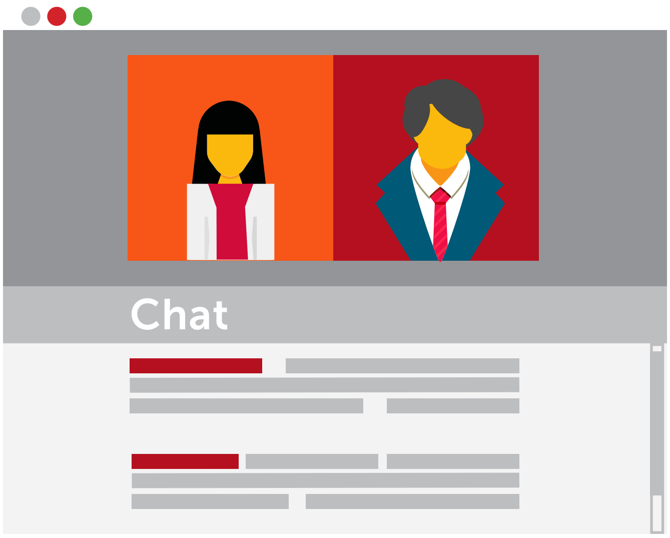
Actividad 23 - La energía solar, una fuente de energía sostenible



La NASA utiliza varias tecnologías diferentes para proporcionar la energía necesaria para la exploración espacial. Este aprendizaje basado en problemas de PBL exploró el uso de paneles solares como fuente de energía. En el proceso, los estudiantes aprendieron los conceptos básicos del aula relacionados con la energía, la transformación de la energía, la electricidad y los circuitos (más información en el Anexo 23).

SEMINARIOS WEB PARA PROFESORES

Se impartió una serie de seis seminarios web (webinar) a los profesores en el marco de la producción intelectual O1, que permitieron a los participantes adquirir una buena comprensión de los temas STIM relacionados con la planetología y la sismología planetaria. Los resúmenes de cada webinar se presentan a continuación y las grabaciones están disponibles en el sitio web Insight.oca.eu[4]:



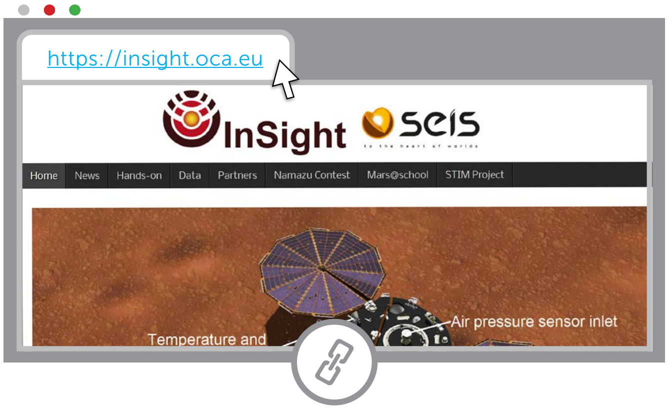
4 https://insight.oca.eu/fr/stim-resources

Tema	Resumen
Misión de InSight - pasado y presente	Webinar 1: En este webinar introductorio se presentaron los antecedentes científicos de las misiones espaciales a Marte y sus ramificaciones para nuestra sociedad. Se explicaron brevemente los principales experimentos que introducirán el tema a los estudiantes de educación secundaria para facilitar la comprensión de lo que es la misión de InSight y cómo puede ayudar a los profesores a mejorar sus prácticas en el aula.
Sismología y estructura de planetas telúricos	Webinar 2: La sismología es el estudio de los movimientos del terreno que contienen información sobre la ruptura sísmica, la propagación de ondas sísmicas y el comportamiento del suelo. Los movimientos del suelo difieren de un terremoto a otro, y su estudio específico proporciona información desde la superficie hasta las profundidades. Las ondas sísmicas pueden ser generadas por muchos fenómenos, como la ruptura tectónica y el impacto de los meteoritos. Estas son las principales fuentes esperadas de ondas sísmicas en Marte. Este webinar explicó cómo el estudio de la estructura interna de Marte podría ayudar a los investigadores a entender por qué Marte es hoy un planeta frío y desértico. Se propusieron sismómetros educativos y experimentos sencillos para ilustrar esta presentación.
La estructura interna de los planetas rocosos: una mirada a la Tierra	Webinar 3: El módulo de aterrizaje InSight finalmente ha hecho posible bajar el sismómetro SEIS a Marte. Los sismólogos exploran la sismología de otros planetas para entender mejor la Tierra. Pero, ¿cómo pueden los científicos de la misión determinar el epicentro de un terremoto o el impacto de un meteorito con un solo sismómetro en Marte? Este fue el tema de esta sesión.
Explorando más allá	Webinar 4: Utilizando los datos recogidos por las misiones marcianas, los científicos pueden ahora comparar la geodinámica externa de Marte y la Tierra. Este estudio permite extraer conclusiones sobre los factores responsables de su geomorfología. Los estudiantes usaron los datos de las imágenes satelitales y experimentaron para confirmar sus hipótesis.
Marte puede enseñarnos mucho sobre los escenarios pasados y futuros de nuestro propio planeta	Webinar 5: El módulo de aterrizaje InSight configuró la sonda HP3 que mide el flujo de calor de Marte. Los datos recolectados permitirán a los científicos estudiar la disipación del flujo de calor del núcleo marciano. En esta actividad, los estudiantes experimentaron con el funcionamiento de la sonda HP3 y recogieron los datos para utilizarla.
Crea tu propio escenario de aprendizaje	Webinar 6: En este webinar final planificamos juntos y presentamos diferentes escenarios de aprendizaje sobre cómo los profesores podrían llevar las misiones espaciales marcianas al aula

EDUTEASERS

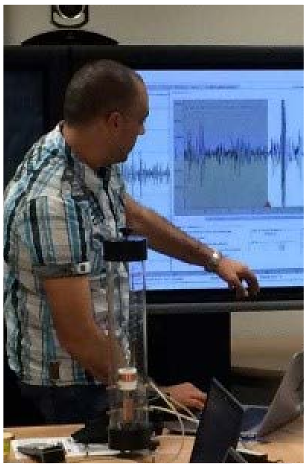
Además de los recursos mencionados anteriormente, se grabaron tres videos cortos con investigadores para introducir ciertas actividades y para aumentar la motivación de los estudiantes para participar en la misión de InSight.

Estos videos se publican en el sitio web Insight.oca.eu y se resumen a continuación.



Philippe Lognonné: Profesor de Geofísica y Ciencias Planetarias, Universidad de París Diderot - Investigador principal del instrumento SEIS sobre InSight (NASA), presenta la misión Mars insight y sus objetivos científicos. ¿Qué se esconde bajo la superficie de Marte? ¿Cómo se formó el rocoso Planeta Rojo? ¿Qué puede enseñarnos Marte sobre nuestro propio planeta Tierra? Las primeras respuestas están ahora disponibles gracias al módulo de aterrizaje en Marte, la Exploración Interior utilizando Investigaciones Sísmicas, Geodesia y Transporte de Calor, también llamado InSight. Con sus instrumentos de sismómetro y sonda de calor, InSight investiga la dinámica profunda de Marte, ayudando a los científicos a descubrir lo que se encuentra dentro de su núcleo y podemos aprender más sobre cómo se forman los cuerpos rocosos en todo el sistema solar.

Julien Balestra: Doctor en sismología, Ingeniero de Investigación del Proyecto IDEX "Observatorio EduMed" de la Universidad de Costa Azul (UCA) explica las actividades en el campo de la geodinámica interna, en particular relacionadas con el estudio de la sismología en la Tierra y en Marte. Los estudiantes descubrirán cómo los científicos explotan los datos sísmicos recibidos de Marte. Este Eduteaser introduce cómo el estudio de la estructura interna de Marte podría ayudar a los investigadores a entender por qué Marte es hoy un planeta frío y desértico.



Dragos Tataru:Sismólogo en el Instituto Nacional de Física de la Tierra, Rumania presenta en este Eduteaser el pasado, el presente y el futuro potencial de las misiones planetarias con un enfoque geofísico. Los detalles de la formación y la evolución temprana de la Tierra siguen siendo oscuros. Las investigaciones de las estructuras interiores de otros planetas en el sistema solar son, por lo tanto, de gran interés. ¿Cómo la sismología terrestre realmente ayudó a nuestra perspectiva de las Ciencias de la Tierra y lo que sabemos sobre la Tierra? Este breve video desencadena la discusión sobre algunas de las misiones planetarias, principalmente el sismómetro Insight and Insight y algunos otros instrumentos sísmicos potenciales en nuestro Sistema Solar.

Conclusiones

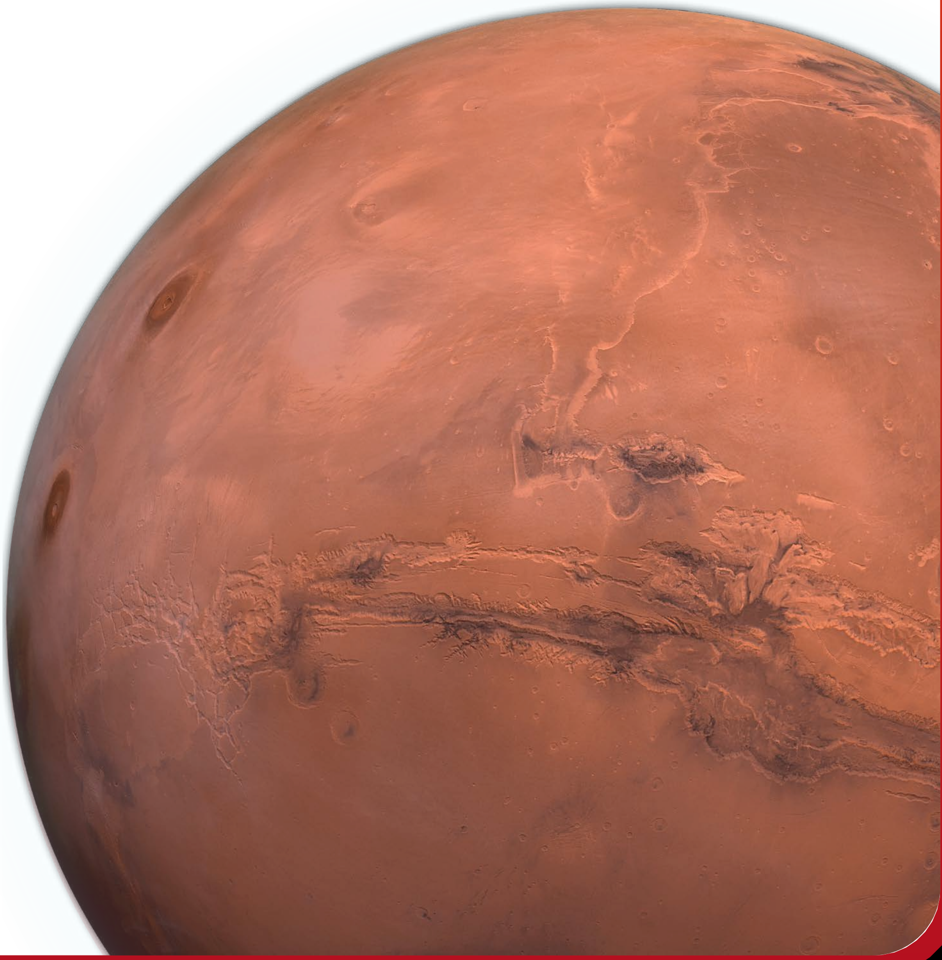
Los recursos de STIM contribuyen al desarrollo profesional de los profesores en materias como la Tierra, el Universo y la Planetología, pero también permiten implementar prácticas científicas auténticas en el aula.

Todos los estudiantes, independientemente de la carrera que elijan, deberían ser capaces de identificar y comprender los efectos de la ciencia en las sociedades y el medio ambiente. Las sociedades modernas están siendo profundamente transformadas por la ciencia y sus aplicaciones tecnológicas, como el control de los riesgos naturales y tecnológicos, la protección del medio ambiente y las comunicaciones (transporte, intercambio de información). Los estudiantes necesitan entender estas transformaciones para tomar decisiones informadas.

Los recursos del STIM desarrollados durante la primera fase del proyecto, que constituyen el núcleo del presente informe, fueron diseñados para ser el tipo de material didáctico que responda a las necesidades actuales de la enseñanza de las ciencias, creando experiencias de aprendizaje de alta calidad para los estudiantes. Se desarrollaron 23 actividades en total, agrupadas en cinco temas principales, junto con seis seminarios en línea y tres editores, que tratan de exponer a los estudiantes universitarios a los estudios planetarios a través de datos de teledetección procedentes de Marte y sus equivalentes en la Tierra.

La co-construcción entre profesores - investigadores - formadores condujo a la elaboración de una práctica realmente innovadora: un enfoque interdisciplinario para transmitir un concepto científico difícil "sismología planetaria" y facilitar la comprensión del complejo planeta por parte de los ciudadanos.

La segunda fase del proyecto se dedicará a la elaboración de una guía pedagógica que reúna todos los instrumentos, métodos y materiales necesarios para llevar a cabo las actividades de la enseñanza secundaria de la ciencia, la tecnología, la ingeniería y la ingeniería (STEM). También se elaborará un MOOC con cuatro módulos de formación en línea, en cada uno de los cuales se abordará la cuestión desde un ángulo diferente: ciencia, educación, experimentación e intercambio. Estos módulos se desarrollarán para proporcionar a los profesores los conocimientos y habilidades necesarios para enseñar los conceptos científicos difíciles que son la planetología y la sismología planetaria con el fin de hacerlos más accesibles a sus estudiantes



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Anexos

Annex 1

Erasmus+

SCHOOLS TUNE INTO MARS

This project is funded by the European Union

STIM needs assessment & opportunity mapping

This survey is part of a project Erasmus+ - School Tune into Mars (STIM) that aims to

- provide pedagogical materials with high-quality inspirational lessons related to STEM subjects
- provide adequate guidance and underpin innovative activities that are developed in a co-constructive process between researchers and teachers

The objective of the survey is to get the opinion of the science teachers in order to be better able to address their needs and interest and to improve the development of the projects.
The data collected will be deleted after 36 months

The survey is addressed to different profiles:

- IF YOU TEACH & PARTICIPATE AS A USER IN PROJECTS/INITIATIVES. First, we ask for some demographic variables. Secondly, we ask you about your participation in projects/initiatives. Finally, we ask you a sets of questions about your possible motivations: those that lead you to join projects or to implement activities

- IF YOU TEACH BUT YOU ARE NOT A USER IN PROJECTS/INITIATIVES. In addition to some demographic variables, we ask you - with the option of a free text - about the factors that motivate you

The last day of receipt of surveys is 28th of February
The estimated duration is about 10 minutes.
THANK YOU FOR YOUR TIME AND COLLABORATION

Data collection and processing

The data collected through this survey will be used strictly in line with the objectives defined above. This questionnaire is supported by Schools Tune Into Mars, a project financed by the Erasmus + programme and coordinated by the Lycée International de Valbonne (LIV) in collaboration with EUN Partnership AISBL, the Asociacion Espanola para la Ensenanza de las Ciencias de la Tierra (AEPECT) and the National Institute for

Earth Physics (NIEP). All anonymous data collected via this survey will be made freely available online (open access). If they wish, participants can provide their name and email at the beginning of the survey, only if they are interested in providing follow-up information which would lead to participating to a focus group and activities related to the project. The Lycée International de Valbonne (LIV) is the controller of this personal data. This information will not be shared outside the Lycée International de Valbonne (France) and partners of the project mentioned above (for example, your name and e-mail address will not be shared with external partners), and it will be used only according to the purposes declared and will be deleted at the end of 2020. If you have any questions regarding this survey, please contact Fatima Moujdi (Fatima.Moujdi@ac-nice.fr).

Email address:*

Last Name:*
First Name:

Gender:*

School (institution):*

Location (TOWN):*
Location (COUNTRY):

Section I - Academic and professional backgrounds

1. Educational level you teach (multiple choice)*
    a. Secondary
    b. Highschool
    c. Other
2. You are a..........teacher (multiple choice)*
    a. Science
    b. Physics
    c. Chemistry
    d. Biology
    e. Geography
    f. Geology
    g. Earth Science
    h. Other

3. What is the highest level of formal education you have completed (single choice)?
   a. Bachelor's degree or equivalent
   b. Master's degree or PhD
   c. Other

4. By the end of this school year, how many years will you have been teaching altogether (short answer - number format validation)?

Section II - Motivation for participation

1. How well prepared do you feel you are to teach…(multiple choices one per line)*

	I do not teach these topics	Not well prepared	Somewhat prepared	Well prepared
earth science – earth's features and physical processes?				
earth science – the solar system and the universe?				
Planetary science (planetology)				
chemistry – classification and structure of matter?				
physics – types of energy, sources of energy, conversion between energy types?				
environmental and resource issues?				
scientific methods and inquiry skills?				
…..				

2. Preferred Method of Professional Development Training (multiple choices)*
   a. On-Line Modules
   b. Workshops
   c. Webinars

4. Which would be the main motivation to implement STIM activities in class (multiple choices)*
   a. Motivate students to learn
   b. Assess students' current skills and knowledge
   c. Design or implement a challenging curriculum

   d. Including problem solving techniques
   e. Design appropriate out-of-class assignments and activities
   f. Translate subject matter content into standards-based activities
   g. Promote critical thinking
   h. Other
3. Have you ever implement activities starting from topics presented in STIM project (for more details about STIM project and topics please access the links published at the end of the questionnaire)*
   a. Yes
   b. No
   c. Other

5. Would you be willing to implement activities / use resources developed in the STIM project in class? If yes, in what form?* (multiple choice question)

a. No
b. YES/in extra-curricular activities
c. YES/in activities complementary to compulsory courses
d. YES/in In a dedicated science class
e. YES/in Optional school curriculum
f. YES/in Other

....

LINKS
https://twitter.com/STIMerasmus
http://www.scientix.eu/projects/project-detail?articleId=777418

The personal data collect will be used only for:

- assessing the needs and opportunity of implementing STIM activities
- better configure the intellectual outputs of the project
- contacting to share the results and propose further involvements in the project activities

Consent By consenting to this privacy notice you are given us the permission to process your personal data specifically for the purposes identified.

Disclosure Project partner institutions will not pass on your personal data to third parties without first obtaining your consent.

Disclaimer
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Erasmus+

SCHOOLS TUNE INTO MARS

This project is co-funded by the European Union

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Cooling model for rocky planets

1. Introduction & Problem

The internal heat of a rocky planet comes first of all from the energy accumulated during the accretion phase, then from the formation of the iron core and finally from the radioactivity of the uranium, thorium and potassium present in the mantle.
When all the energy from the formation phase has been converted into heat, the planet begins to cool down.
Pb: What happens to the heat from the formation phase of a rocky planet?

2. Age of students

15 -17 years

3. Objectives

Show that the planet cools down by dissipating its internal heat up to and through the surface.
Experimental modelling and mathematical exploitation of results

4. Primary subjects

Mathematics – Physics – Earth Sciences.

5. Additional subjects

Geography – Computer Science

6. Time required

2hrs

7. Key terms

Geothermal gradient, heat flow, heat dissipation.

8. Background

Excel spreadsheet - Python

9. Materials

- 'Pétanque' ball
- Saucepan of boiling water
- Foam football
- 4 temperature sensors
- Computer with software
- Excel

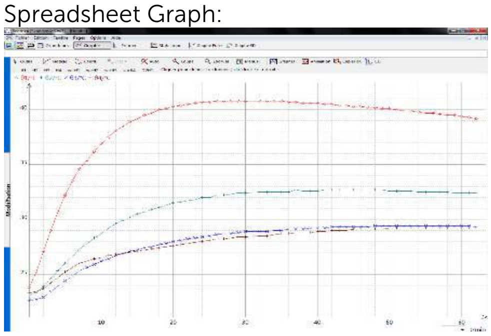
10. Procedures

- Modelling internal heat dissipation (heat flow):
One of InSight's missions is to determine the amount of heat that continues to escape from its surface (heat flow).

- Push 4 temperature sensors through the surface of a foam football and make sure they are at depths of
- 1 cm, 2 cm, 3 cm and 4 cm.
  - Dip a pétanque ball in boiling water then place it inside the football.
- Close the foam football tightly (to limit the loss of heat).
  - Note the temperature reading on the screen every minute for one hour.

Modelling:

Temperature change profile versus depth using a Spreadsheet Graph:



- Mathematical evaluation of measured heat flow data

We are looking for a possible relationship between time t and temperature T.
When the relationship is “affine”, it means T = a + bt, so we talk about a linear regression.
Even if there is a relationship, the data measured do not usually match this relationship perfectly.

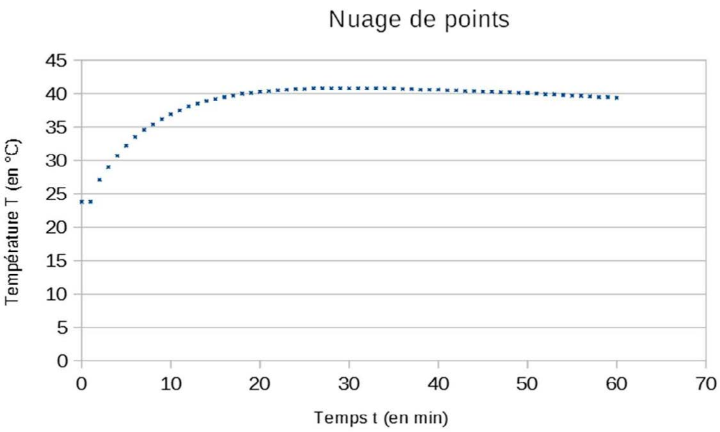
First study: Using a spreadsheet to determine a relationship between time t and temperature T

We are going to study the thermal probe database for a specific depth.
In this example, the thermal probe depth is 5 cm.

1) Open the file Insight_Mars_Hp3.ods or Insight_Mars_Hp3.xlsx containing the measurement data.

2) Copy the database time *t* and *corresponding* temperatures *T* to a spreadsheet.

Represent this database with a point cloud graph.

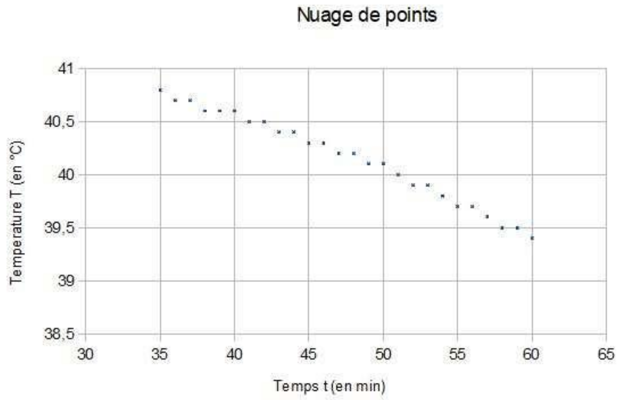


	A	B	C
1	temps	Prof 5 cm	
2	En min	en °C	
3			
4	0	23,8	
5	1	23,8	
6	2	27,1	
7	3	29	
8	4	30,7	
9	5	32,2	
10	6	33,5	
11	7	34,6	
12	8	35,4	
13	9	36,2	
14	10	36,9	
15	11	37,5	
16	12	38,1	
17	13	38,5	
18	14	38,9	
19	15	39,2	
20	16	39,5	
21	17	39,7	
22	18	40	
23	19	40,1	
24	20	40,3	
25	21	40,4	
26	22	40,5	

The second part of the curve, which reflects the cooling process (like on Earth and Mars) appears to be expressed as a straight line.
We will study how to determine this straight line and whether our data fits it.

3) In this example, measurements start at time t=35’.

Represent the database $\{(t_i, T_i), i = 35, \ldots, 60\}$ with a spreadsheet.



Looking for an affine relationship between two variables t and T means looking for a straight line which best fits this scatter graph.

The least squares method is used to find the line of best fit through an equation:

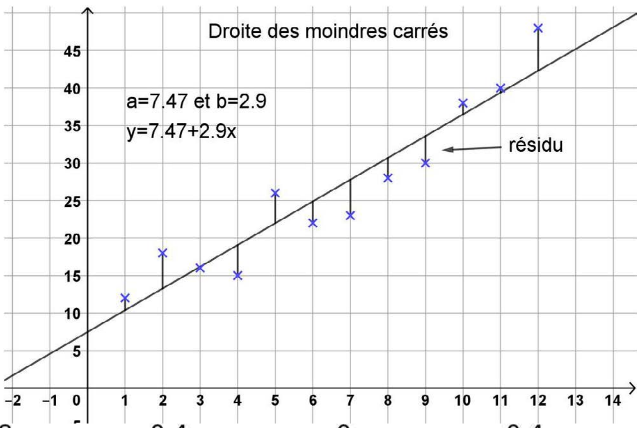
y=a+bt *with a* and *b* which minimise the sum of squares:

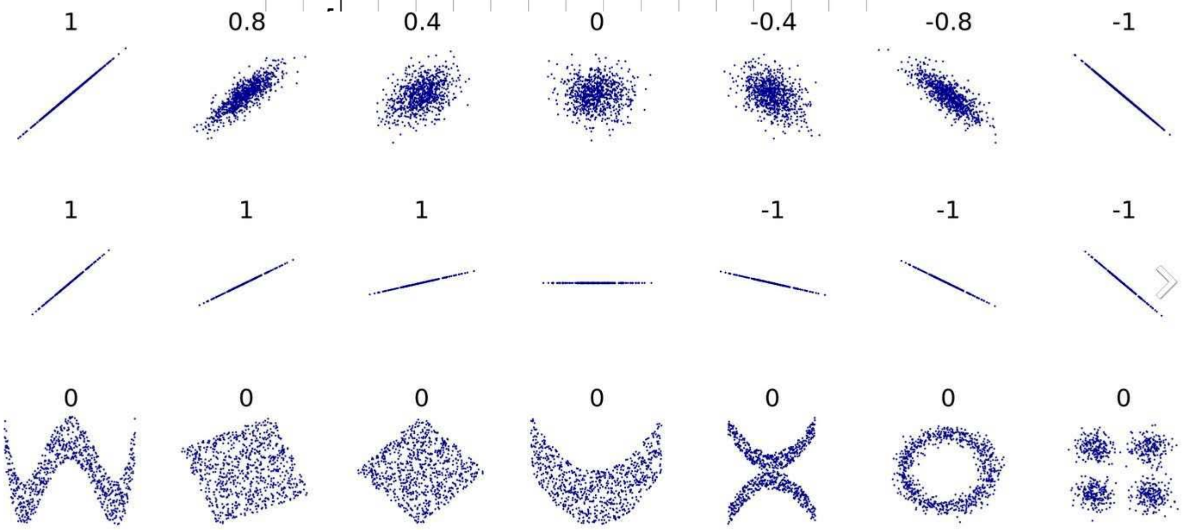
$$\sum_{i=1}^{n}\left(y_i-(a+bt_i)\right)^2$$

This straight line, which is considered to be the only one like it, is called the least squares regression line.

The idea is to determine a straight line which minimises the summed measurement of a range between the points of the scatter graph and the points with the same abscissa on this line.

The smaller the measurement, the closer to all the points of the scatter graph will be the straight line and the better the fit.





Source : hhttps://en.wikipedia.org/wiki/Pearson_product-moment_correlation_coefficient

We do not intend to study the minimisation of the range in this activity.

We call real number r the "linear correlation coefficient", defined by: $r = \frac{\sigma_{t,y}}{\sigma_t \sigma_y}$

With $\sigma_{t,y} = \frac{1}{n}\sum_{i=1}^{n}(t_i - \bar{t})(y_i - \bar{y})$, $\sigma_t = \sqrt{\left(\frac{1}{n}\sum_{i=1}^{n}(t_i - \bar{t})^2\right)}$

$$\sigma_y = \sqrt{\left(\frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2\right)}$$

$\bar{t}$ and $\bar{y}$ represent the average of t_i and y_i , $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} t_i$ And $\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$

The coefficient will reveal whether the fit is relevant or not, and give information on the scatter graph according to the value of r:

We will use the following numerical criteria using r^2:

- if $0{,}75 \leqslant r^2 \leqslant 1$ then there is a good linear correlation between Y and t
- if $0{,}25 \leqslant r^2 \leqslant 0{,}75$ then there is a weak linear correlation between Y and t
- if $0 \leqslant r^2 \leqslant 0{,}25$ then there is a poor linear correlation between Y and t

4) Calculate coefficient r with the data temperature at a depth of 5cm.

(Caution: the Y coordinates correspond to the temperature values, T)

We are going to see whether such a straight line exists during the cooling process, which in our case took between 35 min and 60 min.

Complete the spreadsheet in order to determine the value of r and r^2:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	temps	Prof 5 cm			$t_i - \bar{t}$	$T_i - \bar{T}$	$(t_i - \bar{t})^2$	$(T_i - \bar{T})^2$	$(t_i - \bar{t})(T_i - \bar{T})$	σ(t,T)	σ(t)	σ(T)	Coefficient de corrélation r	Valeur de r^2
2	En min	en °C												
3			Calcul de la moyenne $\bar{t}$ des temps t											
4	0	23,8												
5	1	23,8												
6	2	27,1	Calcul de la moyenne $\bar{T}$ des températures T											
7	3	29												

If the fit is relevant, we continue...

5) If the fit is relevant, the linear regression line $y = a + bt$ can be found by calculating numbers a and b with the formula:

$$b = \frac{\sigma_{t,y}}{\sigma_t^{\,2}} \qquad \text{and} \qquad a = \bar{y} - b\bar{t}$$

Calculate the numbers a and b and the equation of the linear regression line fitting this scatter graph.

The existence of such a relationship between time t and temperature T at each point in time reveals the existence of thermal conductivity proper to its environment, here the foam football.

<u>Continuation:</u>

Let us pool the results found by each group in charge of the study for a particular depth.

We will highlight a relationship between time and heat exchange between two heat sensors.

Second study: Using Python software to determine a relationship between time t and temperature T.

We are going to study the thermal probe database for a depth of 5 cm.

We are looking for a possible relationship between time t and temperature T with the Python software and we will limit ourselves to studying linear fit.

1) Run the Pyzo software and copy files Temps.csv and Temperature.csv to the directory where the Python program is saved.

2) The following code is used to transform the csv file into a list under Python.

```
import csv

    # Les fichiers csv doivent être stockés dans le même repertoire que les fichiers python sauvegardés

    # Code pour convertir le fichier Temps.csv en fichier utilisable par Python à fournir aux élèves

with open("Temps.csv") as f:
    Temps = list(csv.reader(f))
var_list = []
list_tot = []
for i in range(0,len(Temps)):
    var_list = Temps[i]
    var_list = list(map(int,var_list))
    list_tot = list_tot + var_list
Temps = list_tot

    # Code pour convertir le fichier Temperature.csv en fichier utilisable par Python à fournir aux élèves

with open("Temperature.csv") as f:
    Temperature = list(csv.reader(f))
var_list = []
list_tot = []
for i in range(0,len(Temperature)):
    var_list = Temperature[i]
    var_list = list(map(float, var_list))
    list_tot = list_tot + var_list
Temperature = list_tot

from math import sqrt
```

The study of Python functions Map and Open is not the subject of this activity.

The time database is stored in the list "Temps" (Time).

The temperature database is stored in the list "Temperature".

We want to edit a program giving:

- correlation coefficient r for the range of time starting at n min and ending at 60 min (n corresponds to the time the cooling regime is reached)
- coefficients a and b of the regression line being sought if the fit is relevant

To do this, we have to determine all the elements necessary for these calculations.

(The calculation formulas are recalled on the last page)

After copying the previous code into the program, proceed as follows:

```
def equation_moindre_carre(n):
```

3) a) Complete this program to calculate the average:

- of time $\bar{t}$ noted "moyenne_t "

- of temperature $\overline{T}$ noted "moyenne_T"

b) Complete this program to obtain a list giving values $t_i - \bar{t}$ noted "ecart_t"

c) Complete this program to obtain a list giving values $T_i - \overline{T}$ noted "ecart_T"

d) Complete this program to obtain a list giving values $(t_i - \bar{t})^2$ noted "carre_ecart_t"

e) Complete this program to obtain a list giving values $(T_i - \overline{T})^2$ noted "carre_ecart_T"

f) Complete this program to calculate $\sigma_{t,T}$ noted "Sigma_t_T"

g) Complete this program to calculate σ_t noted "Sigma_t"

h) Complete this program to calculate σ_T noted "Sigma_T"

i) Complete this program to calculate the value of r when n=41.

Is the fit relevant?

4) Determination of the equation for the least squares regression line:

a) Complete this program to calculate value a.

b) Complete this program to calculate value b.

c) Complete your program so that it displays the equation for this line.

Formula:

$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} t_i$ $\overline{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$ $\sigma_t = \sqrt{\left(\frac{1}{n}\sum_{i=1}^{n}(t_i - \bar{t})^2\right)}$ $\sigma_y = \sqrt{\left(\frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2\right)}$

$\sigma_{t,y} = \frac{1}{n}\sum_{i=1}^{n}(t_i - \bar{t})(y_i - \bar{y})$ $r = \frac{\sigma_{t,y}}{\sigma_t \sigma_y}$

The equation of the linear regression line is: $y = a + bt$ with: $b = \frac{\sigma_{t,y}}{{\sigma_t}^2}$ and $a = \bar{y} - b\bar{t}$

The following numerical criteria will be used using r^2 :

- if $0{,}75 \leqslant r^2 \leqslant 1$ then there is a good linear correlation between Y and t
- if $0{,}25 \leqslant r^2 \leqslant 0{,}75$ then there is a weak linear correlation between Y and t
- if $0 \leqslant r^2 \leqslant 0{,}25$ then there is a poor linear correlation between Y and t

11. Discussion of the results and conclusions

We have just shown that rocky planets dissipate their internal heat up to and through the surface, which leads to their cooling.

Scientists have proposed models showing how Earth's internal heat can be dissipated by convection, thermal conduction, volcanism, plate tectonics, etc. On Mars, heat dissipation is due largely to significant volcanism and probably more gradually by "convection".

We will explore these processes in the following activities (2, 3 and 4).

Erasmus+

SCHOOLS TUNE INTO MARS

This project is co-funded by the European Union

Heat flow measurement

1. Problem : What mechanisms cause the internal heat dissipation of Mars and Earth?

Hypothesis: It is hypothesised that for a solid and rigid planet, heat is transferred to the surface by thermal conduction.

2. Age of students: 14 -17 years

3. Objective:

To Understand the phenomenon of thermal conduction.

4. Primary subjects:

Mathematics – Physics – Earth Sciences.

5. Additional subjects:

Computer Science (Arduino)

6. Time required : 2hrs

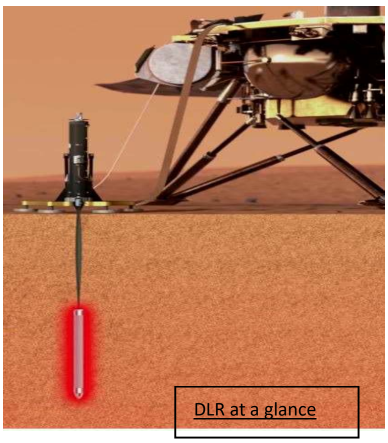
7. Key terms :

Geothermal gradient, heat flow, heat dissipation, conductivity.

8. Background :

On Earth, the temperature gradient is obtained by directly measuring the temperature at different depths in boreholes or mine shafts. This is what the InSight mission to Mars will do with its Heat flow and Physical Properties Package, an instrument known as HP3.
Once this gradient is known and the thermal conductivity of the underlying rocks is determined, scientists can deduce the heat flow at a point on the surface.
To determine the thermal conductivity of rocks, they are sampled in wells and measured in the laboratory.

On Mars, the heat flow will be measured by HP3, also known as the "mole":



DLR at a glance

Every 50 cm, the probe emits a hot pulse and its sensors monitor changes in this thermal pulse over time.

If the crust material is a good heat conductor, such as metal, the pulse will quickly disappear.

If it is a bad conductor, like glass, the pulse will cool down slowly. This tells scientists how quickly the temperature increases with depth and how heat circulates inside Mars.

The heat wave emanating from the mole's heating sheath will spread through the Martian soil, allowing scientists to determine the thermal conductivity of the regolith. Measurements should be accurate, even if the soil is not very conductive. The daily attenuation of the daytime temperature wave will provide HP3 with another way to characterise the ground's thermal conductivity.

9. Materials :

Modelling the thermal conductivity of a rock:	Modelling with temperature sensors like HP3:
- Basalt rock sample - Paraffin pellet - Flat heater	- 2 bars of rock (basalt - granite) - Heat gun. - T° Sensors - Arduino and PC

10. Procedures :

Modelling the thermal conductivity of a rock :

- Attach a sample of rock to the support (basalt, granite...)

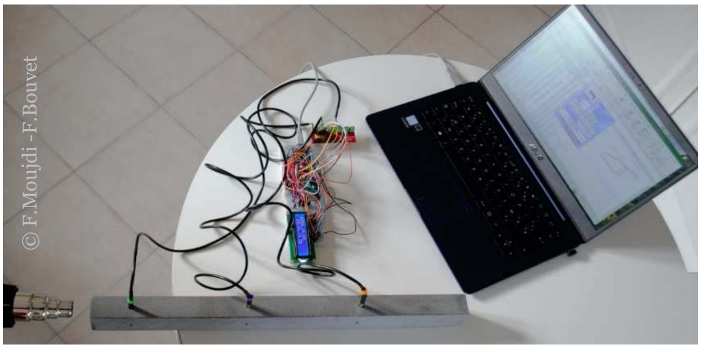
- Place paraffin pellets (3 to 5 depending on the length of the rock sample) on the rock, spacing them about 1.5 cm apart

- Light the candle and adjust the height so that the free end of the rock is over the flame.

- Observe.

Result:
The pellet just above the candle melts first and then the other pellets melt successively.

Modelling with temperature sensors like HP3:



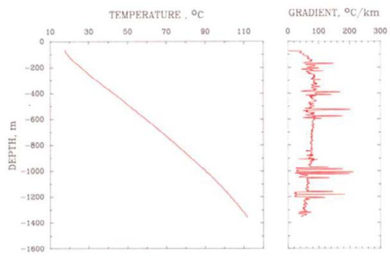
On the screen, we can follow the temperature increase for each sensor and see the heat propagate from one side of the rock to the other without moving any material.

We observe heat propagation from one side to another without any displacement of material.
This heat transfer depends on the thermal conductivity of the material passed through.

Type of material	Thermal conductivity (W/m/K)
Basalt	2.5
Granite	2.7
Peridotite	4.2 to 5.8
Limestone	1.7 to 3.3
Silver	420
Water	6

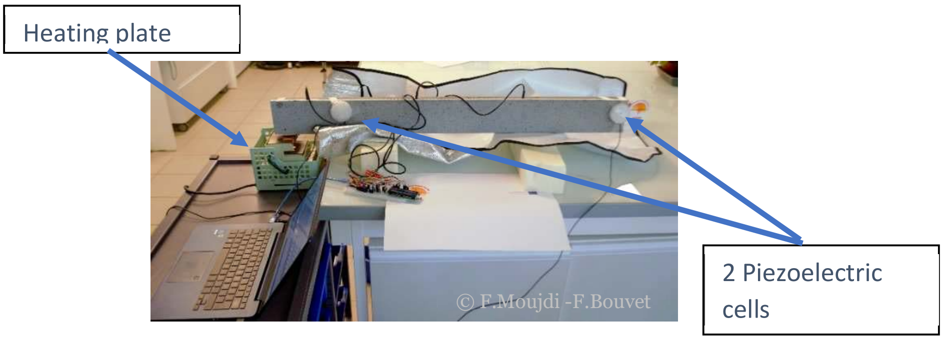
Fourier's law:

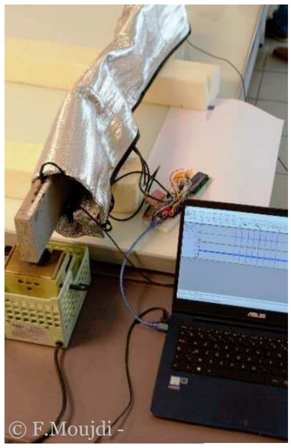
$$q = -K\frac{dT}{dz}$$



We know the conductivity of rocks studied in the laboratory.
Once the thermal gradient measured on Mars is known, geophysicists will be able to deduce the heat flow, i.e. the amount of (thermal) energy that passes through a unit of surface per unit of time (unit = $J/s/m^2$ or W/m^2). Fourier's law explains that heat flow is the opposite of the product of the thermal conductivity of rocks by the temperature gradient.

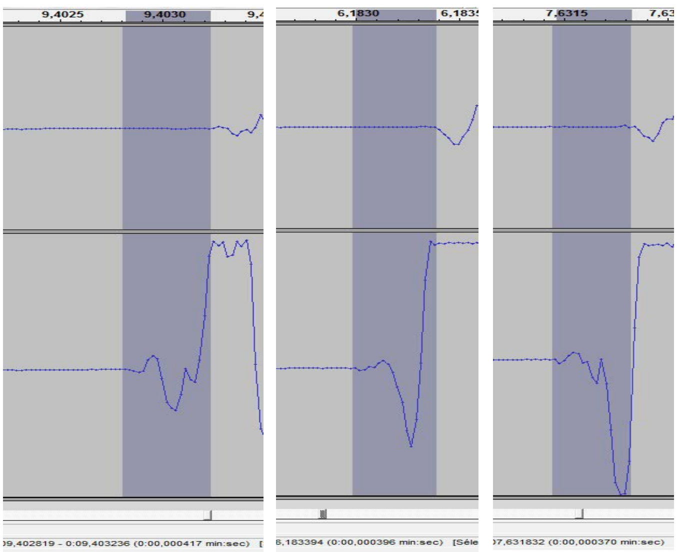
Modelling with temperature sensors such and 2 piezoelectric cells :

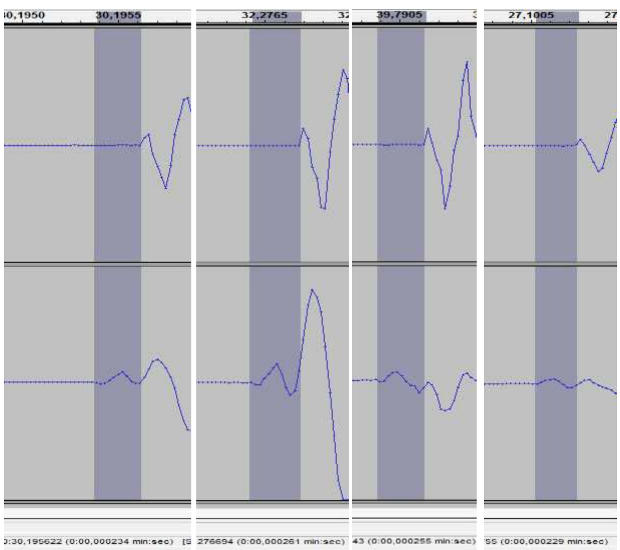




Ambient temperature in the rock : 18,5°C

T1= 63,13 °C, T2 = 22.81°C, et T3= 20,38°C





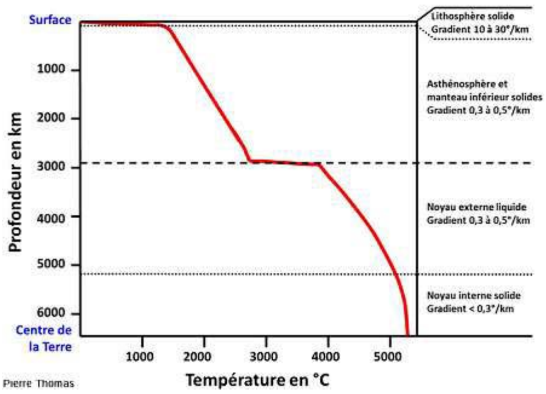
The propagation velocity of the seismic waves can be calculated in these two assemblies. The influence of temperature on wave propagation and the characteristics of the rock traversed can be determined.

11. Discussion of the results and conclusions

On Earth, internal heat is evacuated by conduction near the surface. But deeper down, another process known as convection explains heat transfer.

Using seismological data, combined with contributions from laboratory studies on the physical characteristics of terrestrial minerals subjected to high pressure and high temperature (diamond anvil cell studies), scientists have modelled the evolution of temperature versus depth.

Evolution of the Earth's internal temperature as a function of depth:



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This is what the scientists of the InSight mission are trying to do.

13. Follow-up activities

Note the temperature data from the HP3 instrument and compare it with terrestrial data to determine the type of rock that constitutes the depths of Mars.

14. Explore More (additional resources for teachers)

- https://www.seis-insight.eu/fr/?option=com_content&view=article&id=175:les-autres-instruments&catid=54:la-mission-insight&lang=fr-FR

- http://planet-terre.ens-lyon.fr/article/chaleur-Terre-geothermie.xml

- The Red Planet: "*Histoire d'un autre monde*" Belin – François Forget, François Costard, Philippe Lognonné

Erasmus+

SCHOOLS TUNE INTO MARS

This project is co-funded by the European Union

Magnetic Field

1. Problem:
   What is the mechanism behind the rapid dissipation of Mars' internal heat from the Earth ?

Hypothesis: the disappearance of Mars' magnetic field could explain its much faster heat loss than that of the planet Earth.

2. Age of students: 15 -17 years

3. Objective:

Show how an electric field can create a magnetic field and power it. and Show the role of the magnetic field of a rocky planet (earth shield).

4. Primary subjects:

Mathematics – Physics – Earth Sciences.

5. Additional subjects:

Computer science: satellite image processing with the free QGis software

6. Time required:_2hrs

7. Key terms:

Magnetic field – Electric field.

8. Background:

The magnetic field of a telluric planet is created by movements in its iron core, which is both fluid and a good conductor of electricity. Scientists hypothesise that convection within the liquid core generates an electric current which, in turn, produces a magnetic field: this is known as the "dynamo" effect.

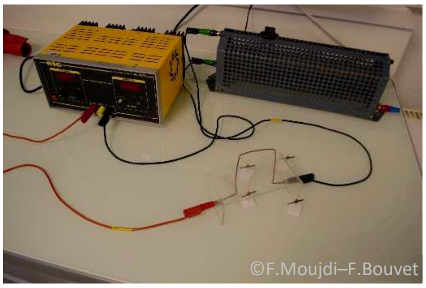
9. Materials:

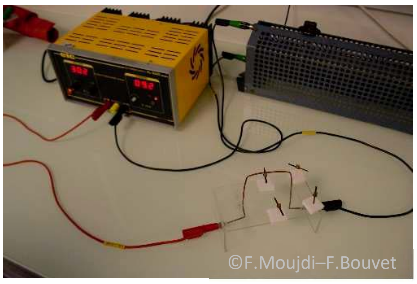
Magnetic field modelling:	Remanent magnetic field modeling:
- A power supply - Copper wire - A piece of plexiglass (about 10 cm × 10 cm) - 4 small compasses - Iron filings	- Basalt sample - Compass - 1 small compass

10. Procedures:

Magnetic field modelling:

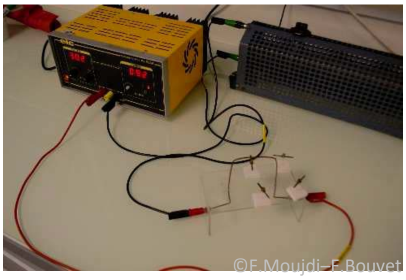
No electric current; the compass needles are aligned with the Earth's magnetic field.

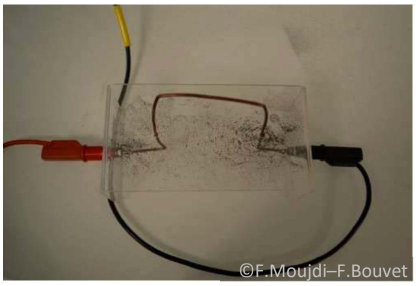




The electric current creates a magnetic field around the wire.

When the direction of the current is reversed, the magnetic field changes direction.





When the operation is repeated with the iron filings, they form a pattern of concentric circles around the wire.

On Mars, just after accretion (4.45 billion years ago), the planet had a liquid core hot enough for convection movements to generate a magnetic field like on Earth.
Mars Global Surveyor has detected the remains of an old magnetic field. Like the Earth, Mars has a magnetic crust producing strong magnetic anomalies.

<table>
<tr><th>Earth</th><th>Mars</th></tr>
<tr>
<td>
The magnetic field's strength varies from 20 μT at the magnetic equator to 70 μT at the magnetic poles (Langlais et al.[2010]).
This magnetic field has been present since 4.5 Ma. It is variable over time and is known to have undergone polarity reversals.

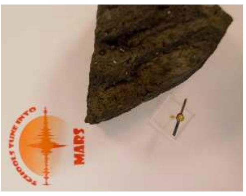
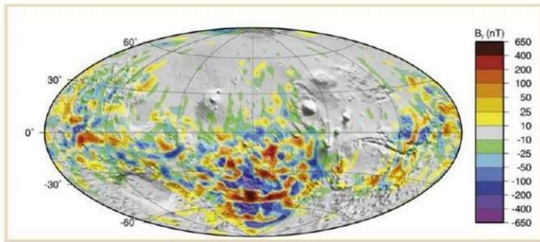

On Earth, lava magnets in the opposite direction to the current magnetic field have been discovered, indicating that the Earth's magnetic field has already undergone several polarity inversions in the past.
</td>
<td>
The MGS spacecraft identified traces of remanent magnetization at the surface and up to 400 km above and an equatorial surface field ranging from 20 to 65 nT (Langlais et al.[2010]). It produced the first complete map of the global crustal magnetic field of Mars.


FIGURE 1.11 – Composante radiale du champ magnétique crustal de Mars (Langlais et al. [2004]).
These traces of magnetization indicate the presence of a magnetic field. In addition, the orientation of these magnets shows that the magnetic field has lasted long enough to have undergone an inversion of the magnetic poles.
The most magnetized regions are concentrated in the former southern highlands, indicating that the magnetic field was present for about 500 million years (Stevenson[2001]).
</td>
</tr>
</table>

11. Discussion of the results and conclusions

These results allow us to understand the genesis of a telluric planet's magnetic field. Scientists assume that convection movements within the liquid core (the heat from the iron core rises until it reaches the boundary with the mantle, cools on contact with it, drops back into the core and heats up, etc.) generate an electric current which in turn produces a magnetic field: this is the dynamo effect.

Accidentally created magnetic microfields in the environment produce the electric current which, in turn, produces a global magnetic field.

The absence of a magnetic field maintained by an internal dynamo that has not worked for a long time and the absence of a thick atmosphere have made our neighbour a cold and arid world whose surface is subjected to the harmful bombardment of cosmic rays.

13. Follow-up activities

The InSight mission has embarked an InSight Fluxgate magnetometer (IFG), which will be the first magnetometer to record magnetic data directly from the Martian surface. It is sensitive to 0.1 nano-Tesla. Once the data have been received, we may observe the remnants of a former magnetic field on Mars and compare them to the data from other missions.

14. Explore More (additional resources for teachers)

- "*Terre à cœur ouvert*" *Pour la Science* No. 67 April – June 2010

- Mars "*Histoire d'un autre monde*" Belin – François Forget, François Costard, Philippe Lognonné

Erasmus+

SCHOOLS TUNE INTO MARS

This project is co-funded by the European Union

Convection movement in the mantle

1. Problem :

What are the mechanisms that cause the internal heat dissipation of Mars and Earth?

Hypothesis: It is assumed that the transport and evacuation of heat is carried out by convection.

2. Age of students 14 -17 years

3. Objectives:

Explain the different types of convection that cause heat dissipation in a rocky planet

4. Primary subjects

Mathematics – Physics – Earth Sciences.

5. Additional subjects

Computer science: Arduino code

6. Time required _2hrs

7. Key terms:

Convection

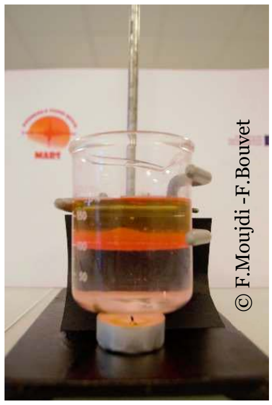
8. Background:

If a body is cooled from below and heated from above, the dense areas will be at the bottom and the less dense areas at the top. This is a stable situation that will not generate any movement. If, on the other hand, a body is heated from below and cooled from above, the dense areas will be at the top, and the less dense areas at the bottom. The cold material at the top will tend to sink and the warm, slightly less dense material at the bottom will tend to rise. This process is known as thermal convection.

9. Materials

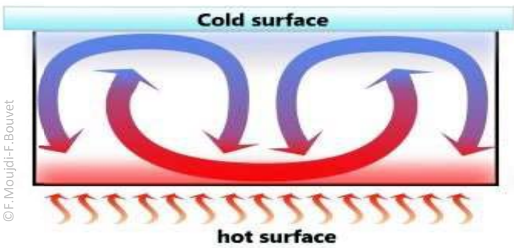
Single-layer convection modelling	Two-layer convection modelling
- Beaker - Oil - Chalk - Colouring agent	- Beaker - Oil - Coloured water

10. Procedures

Single-layer convection modelling	Two-layer convection modelling
The bottom of the heated container is hotter than the oil. The heat is transmitted to the oil, which gradually heats up. As soon as it is a little warmer and less dense than the material above, it starts to rise. As it rises, it no longer receives heat, so its temperature remains almost constant. When it reaches the top, it loses some of its heat, and sinks to the bottom without cooling down during the descent.  	If two immiscible fluids are put in a container (water at the bottom, and oil above), and heated from below, the water is subject to convection, heating the oil from below. The oil then also enters the convection process. This is referred to as "two-stage convection". 

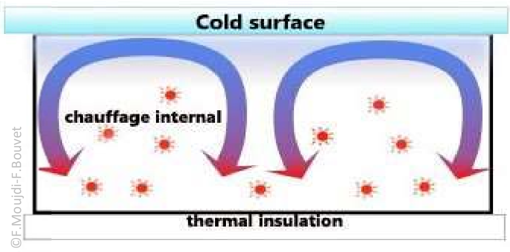
11. Discussion of the results and conclusions

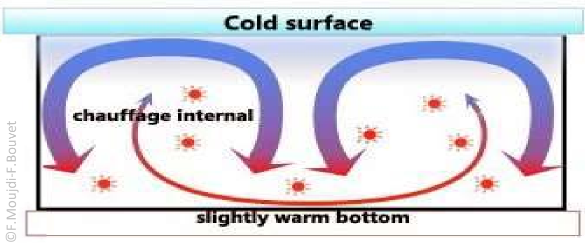
<u>Convection can take place in three possible cases:</u>



The dense, cold layer at the top sinks while the warmer layer rises. Between the two moving layers, the material moves little and keeps a constant

Red hot spots are produced in the material. Only the cold layer dives because it is denser.





This case models the mantle where the surface is slightly heated. The core releases little heat compared to the mantle's radioactivity, which releases more heat

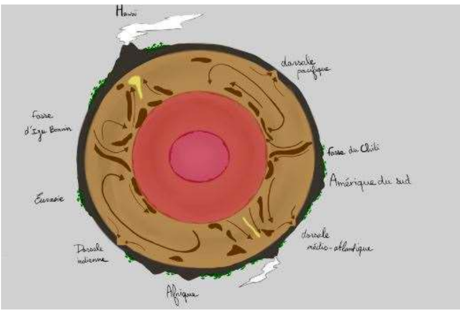
For the first 2 billion years, there was major convection in the Martian mantle, as evidenced by the planet's giant volcanoes.

Gradually, however, the most radioactive elements disappeared from the mantle, either by disintegration or because they rose into the crust with the lava.

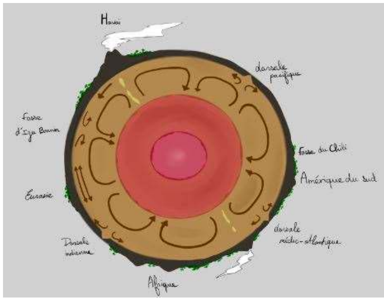
The convection didn't stop completely, though. The crust that trapped the radioactive elements now acts as a blanket heating up the mantle. By surrounding itself with an increasingly thick shell, Mars has confined its mantle under a layer of rigid, insulating materials known as the lithosphere. Mars probably still has a very hot mantle and a liquid core. The InSight mission will provide us with more information about the structure of Mars.

On Earth, nearly 40% of heat production has been concentrated in the continental crust. Scientists are divided between two models of convection:

<u>1 convection layer :</u>



<u>2 convection layers :</u>



Convection in the mantle (Silver, Carlson, Nicolas) La planète Terre Ophrys

12. Explore More (additional resources for teachers)

- "*Terre à cœur ouvert*" *Pour la Science* No. 67 April – June 2010

- Mars "*Histoire d'un autre monde*" Belin – François Forget, François Costard, Philippe Lognonné

Annex 6

Erasmus+

SCHOOLS TUNE INTO MARS

This project is co-funded by the European Union

How big is our Solar System

1. Introduction & Pb

The distances among the different planets of our Solar System are so enormous that for many students it's very difficult to compare them with the daily life distances they are used to. This activity is intended to improve the awareness of the students about the spatial relationships among the different planets in the Solar System, focusing especially in Mars and the Earth. Students will use daily life objects; this allows them to make ratio calculations. Before starting the activity, it could be useful if the students have already done the activity "Take a selfie with Mars". So, they can use the planets they have created themselves according to a fixed scale.

2. Age of students 12 - 16 years

3. Objectives

Students can:

- calculate de relative distances among the planets of the Solar System
- understand how big these distances are
- calculate distances in relation to the scale of the planets
- develop communication abilities
- (optional) use TIC to produce a semiautomatic method to calculate the distances between the model of the planets

4. Primary subjects

Earth Science

Mathematics

5. Additional subjects

Physics

6. Time required

"45 minutes + 15 minutes preparing the models"

7. Key terms.

Earth, Mars, Jupiter, planet distances, scale measurements

8. Materials

- Measuring tape (40 - 200m aprox.)
- Computer with the Google Earth™ software or similar that allows to measure distances

- Cardboards or (alternatively) balloons
- Scissors, ruler, pencil
- (optional): computer with a spreadsheet software

9. Background

Using models is a good strategy to improve the ability of students to be aware of absolute and relative distances among planets. Relating models made of daily materials (balloons) with the real world (the planets) is a bridging activity.

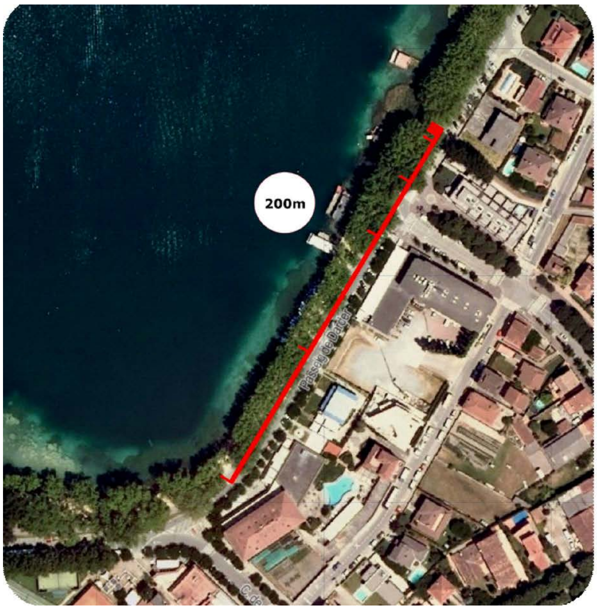
The table below shows the measurements to scale that the students may need to complete the activity:

	average orbit distance (km)	equatorial circumference (km)
Mercury	57909227	15329
Venus	108209475	38024
Earth	149598262	40030,2
Mars	227943824	21296,9
Jupiter	778340821	439263,8
Saturn	1426666422	365882,4
Uranus	2870658186	159354,1
Neptune	4498396441	154704,6
Sun		4370005,6

Data from https://solarsystem.nasa.gov/

10. Procedures

NOTE: The distances between planets are very big, take it into account to make a model in real scale.



OPTION A : (a combination with Take a selfie with Mars)

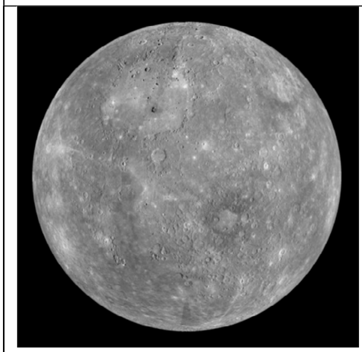
If the students have pairs of planets in real scale which they have done with balloons. Let them to calculate the real distance between the pair of planets that they have made during the activity. If the distances and spaces in the school allow you to make previous made planets in the real distance, do it.

It is easy to work with internal planets. This is so because the distances between them are shorter than for external planets. For example: if the students take a 9cm of circumference as planet Earth and a 5cm of circumference as Mars, the real distance between them is 170m. On the other hand, if they use similar size external planets, the distance between them would have to be much higher. For example: with a 7cm of circumference as Uranus, and a 6,8 cm of circumference as Neptune, they would have to place them 700m apart one from the other.

OPTION B:

Using a school corridor of which you know its length (for example 40m) the sizes of the planets would be extremely small. In this case, you couldn't use the balloons model because of tis extremely small size, You should use cards with a design of the planet to scale, Students should calculate it by handb or using an excel table. Students could make cards with the scale planet and some information about it. After this process, cards can be fixed on the corridor walls.

Students can work in groups to make the planet cards and explain their planet characteristics to other students.

<table>
<tr><th colspan="2">Mercury</th></tr>
<tr><td>Planet Profile</td><td>Facts About the Planet</td></tr>
<tr><td>Diameter: 4,879 km
Mass: 3.29 x 10^23 kg
(0.06 Earths)
Moons: None
Orbit Distance: 57,909,227 km
(0.39 AU)
Orbit Period: 88 days
Surface Tº: -173 to 427°C
First Record: 14th century BC</td><td>Mercury does not have any moons or rings.
Mercury is the smallest planet.
Mercury is the closest planet to the Sun.
Your weight on Mercury would be 38% of your weight on Earth.
A day on the surface of Mercury lasts 176 Earth days.
A year on Mercury takes 88 Earth days.
It's not known who discovered Mercury.</td></tr>
<tr><td>
Source: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington</td><td>Size of the planet in real scale of this solar system:

Scaled diameter: X,XXmm</td></tr>
</table>

11. Discussion of the results and conclusions

Students understand the relative distances of the planets in the solar system. This gives them a better understanding of the solar system as a whole.

Cooperation and teamwork are also encouraged.

12. Follow up activities

If you want to try the option A of the procedures, you should do "Take a selfie with Mars" activity before. Nevertheless, these tow activities are independent from each other

13. Explore More (additional resources for teachers)

https://solarsystem.nasa.gov/planets/overview/

https://space-facts.com/planets/

This project is co-funded by the European Union

Atmospheric seismic noise

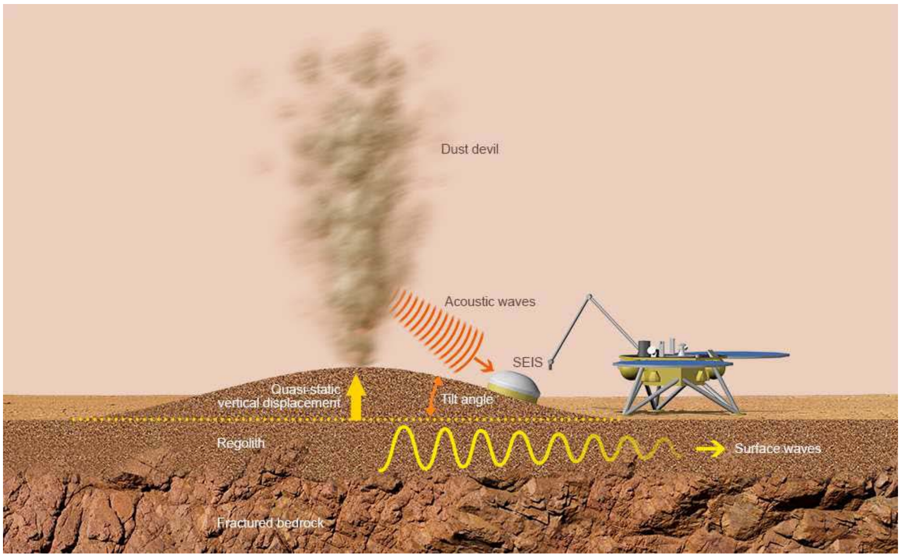
1. Introduction & Pb

The secondary source of atmospheric micro seismic noise is produced by local noise sources: the landing site is affected by gusts of wind or the oncoming of a dust whirlwind near the lander.

In both cases, Martian air exerts a force on the soil: upwards in case of a drop-in pressure, downwards in case of overpressure.

A 10 m dust whirlwind thus causes a drop in the pression on soil of the same proportion as that of a small car blown off the surface

Static deformation of the surface of the planet will have an impact on the seismometer and particularly on the pendulums that measure horizontal and vertical movement. Although soil has a downward movement, the dominant effect is that of lateral movement, that can be detected by SEIS sensors.



Simulation of ground deformation around the InSight lander (© IPGP/David Ducros)

2. Age of students 15 - 17 years old

3. Objectives

Let's determine if a simple drop in pressure can cause a soil deformation effect detectable by accelerometers, although this type of deformation isn't visible to the naked eye.

4. Primary subjects

Earth Science- physic

5. Additional subjects

Arduino

6. Time required 2H

7. Key terms.

Accelerometer - Seismogram - Propagation waves - Atmospheric movements.

8. Background

The Martian air, by constantly moving around the Martian globe, is able to excite the planet, and make it vibrate like a bell, at very specific frequencies.
Geophysicists call this phenomenon the "hum" of the planet, a kind of persistent hum, which only long-period sensitive seismometers like SEIS can hear.
Despite the fact that this haunting murmur can be considered as a parasitic background noise, it is of particular interest to geophysicists. Thanks to it, it will be possible to probe the surface layers of the Martian soil, at depths ranging from several tens of metres to several hundred kilometres (access to the mantle), even in the absence of earthquakes.

9. Materials

A soft elastic ball, such as a fitness ball of 250 cm in diameter

An Arduino type UNO

A MPU5060 accelerometer, a BME280 pression sensor, connected to a predefined UNO

A PC with the PLX-DAQ-v2.11 file available

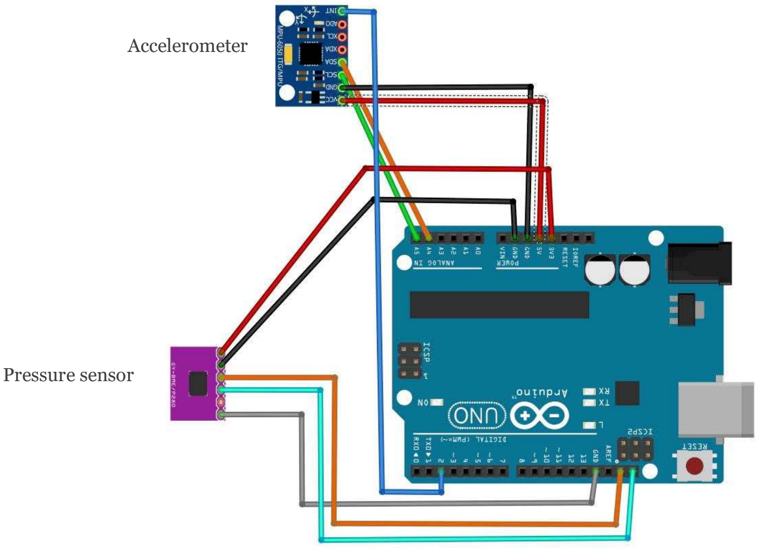
A 1600W hair dryer

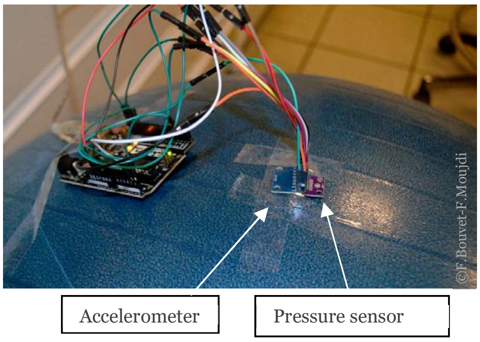
10. Procedures

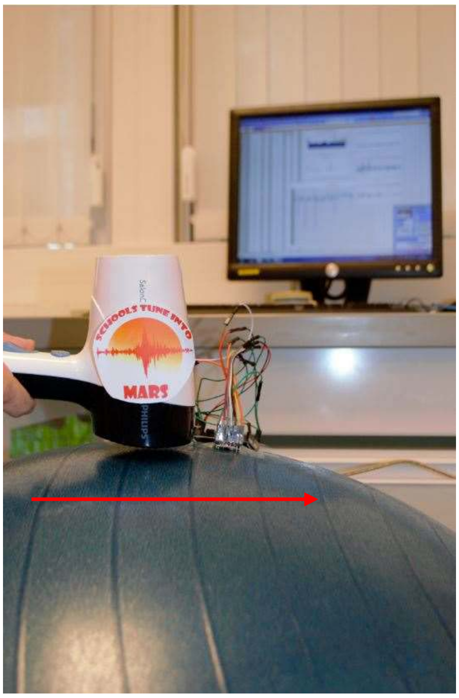
Place the fitness ball on the polystyrene bars in order to avoid any kind of contact with the soil

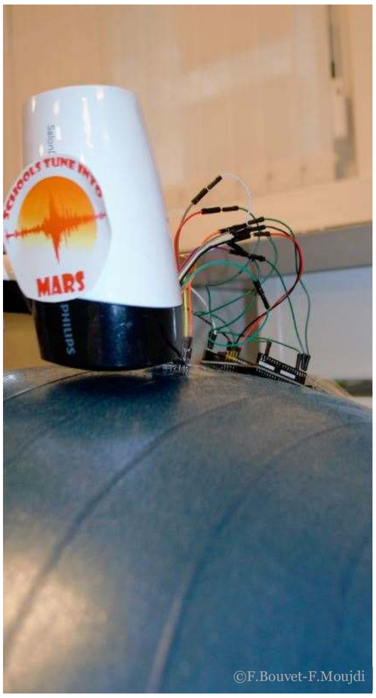
Firmly attach the accelerometer and the pression sensor using adhesive tape

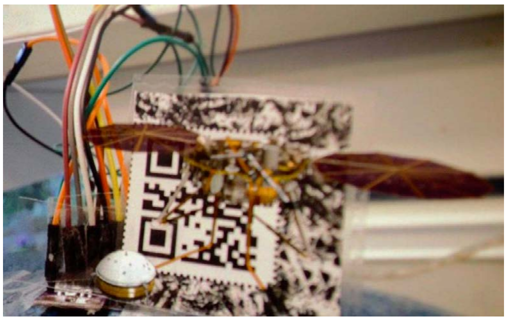
Hold the hair dryer’s air outlet in a vertical position towards the fitness ball and blowing upwards without touching it.





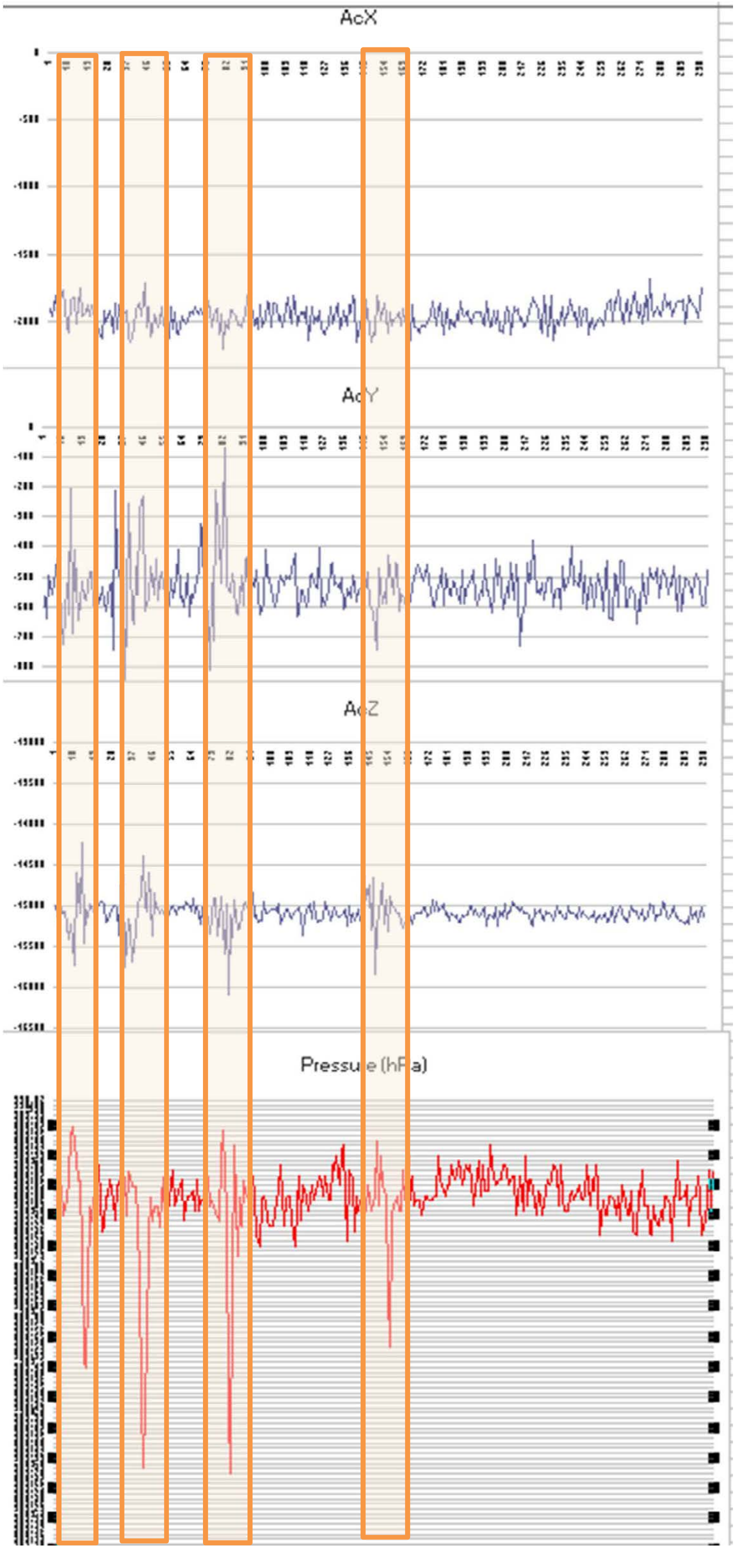






Move around the hair dryer without touching the fitness ball, but keep it close while maintaining a constant distance.

Obtained results:



Enclosed in boxes are the recordings of the successive passages of the hair dryer above the sensors.

We can observe a movement throughout the surface at low pressure.

Erasmus+ — SCHOOLS TUNE INTO MARS — This project is co-funded by the European Union

Primary aerosols and climatic impact on Earth

1. Introduction & Pb

In March 2018 a strange phenomenon takes place in Russia and on the whole Eastern Europe : Orange snow covers the ski slopes.

We can frequently see coloured snow layers in the French Alps during winter and so-called muddy rains to the delight of car wash workers.

In Marseille, the road, cars and buses are covered in sand. – Maxppp
https://www.francebleu.fr/infos/climat-environnement/la-provence-touchee-par-des-pluies-de-sable-1459761392

A skier in Sotchi, Russia.
https://www.parismatch.com/Actu/Environnement/Pourquoi-il-est-tombe-de-la-neige-orange-en-Russie-1486670

Let's try to explain the phenomena.

2. Age of students 15 – 17 years

3. Objectives

Using a fact of life and the study of a test sample, we will discover what a primary aerosol is and study its impact on the climate whether it is suspended in air or back on the Earth's surface.

First, we will try to determine the optical thickness of the particles in the test sample extracted with a photometer in order to determine their nature and therefore their impact on the climate.

We can then establish if major dispersals of particles have the potential to significantly influence Earth's climate.

4. Primary subjects

Physics – Earth Science – technology

5. Additional subjects Programming Arduino

6. Time required 2hrs

7. Key terms.

Aerosols, albedo, absorbance.

8. Materials

- Step 1

- A sample of damp dustfall, for this example particles in suspension collected from the orange snow in the Southern Alps.
- A Calitoo
- Two transparent containers
- A 12 V lamp placed in a holder
- A PC with Calitoo software installed

- Step 2

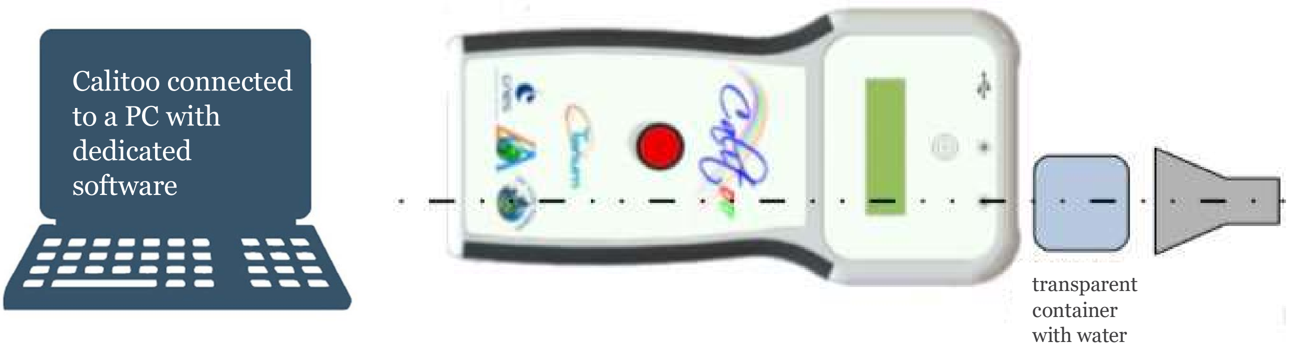
- A sample of damp dustfall, for this example particles in suspension collected from the orange snow in the Southern Alps.
- A digital light meter
- Two transparent containers
- A 12 V lamp placed in a holder

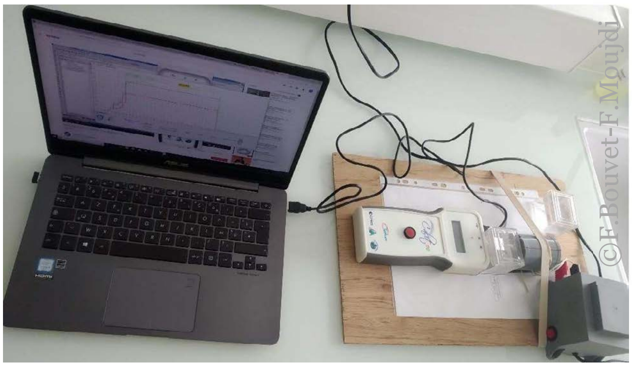
9. Background

The Calitoo is a photometer that determines the level of aerosols present in the atmosphere and characterizes their size distribution (smoke, polluting gases, ice crystals, dust).
The Calitoo measures the optical thickness of the atmosphere at different wavelengths: blue (465nm), green (540nm) and red (615nm).
Scientists define an aerosol as a suspension of particles in the atmosphere. These particles are made up of solid and/or liquid substances. Mineral or organic, composed of living matter (pollens...) or not, large or fine, suspended particles constitute an extremely heterogeneous set of pollutants whose size varies from a few tenths of nanometers to a hundred micrometers.
The albedo of the Earth-atmosphere system is the fraction of solar energy that is reflected back to space. Its value is between 0 and 1, and the more reflective a surface is, the higher its albedo. The elements that contribute most to the Earth's albedo are clouds, snow and ice surfaces and aerosols. For example, the albedo of fresh snow is 0.87, which means that 87% of the energy is reflected by this type of snow.

10. Procedures

- Setting up the Calitoo arrangement:

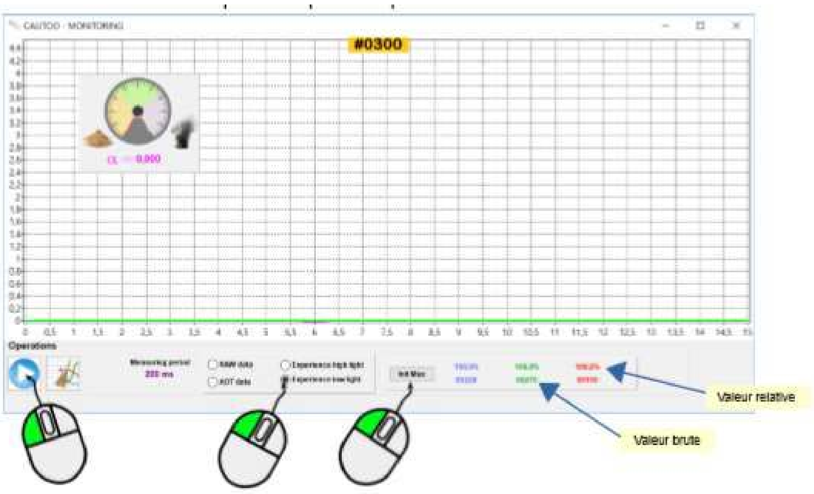




- Initialising the measurement functions

The initial step of the simulation is setting the base level. That is the equivalent of an aerosol-free atmosphere and hence we need to measure the luminous flux through a container filled with pure water.

In the monitoring module, select
◦ Low light experiment, then in order to start the measurements, click or the blue round icon in the bottom left corner.
Place the container filled with pure water and turn on the light.
Click on [Init Max] button to start the program and set the base level.



- Experiment using our sample of particles collected from orange snow.

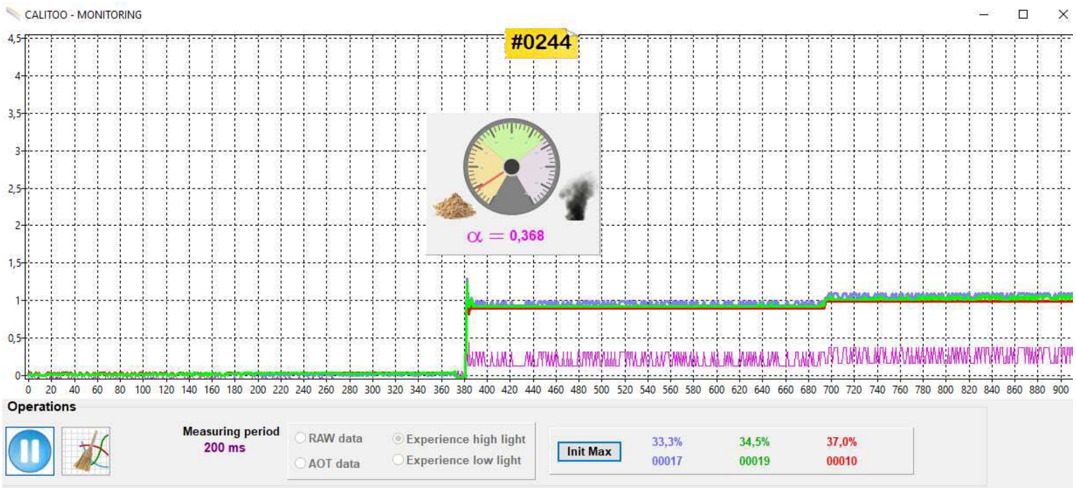
  Replace the pure water container by a container carrying the particles in suspension.

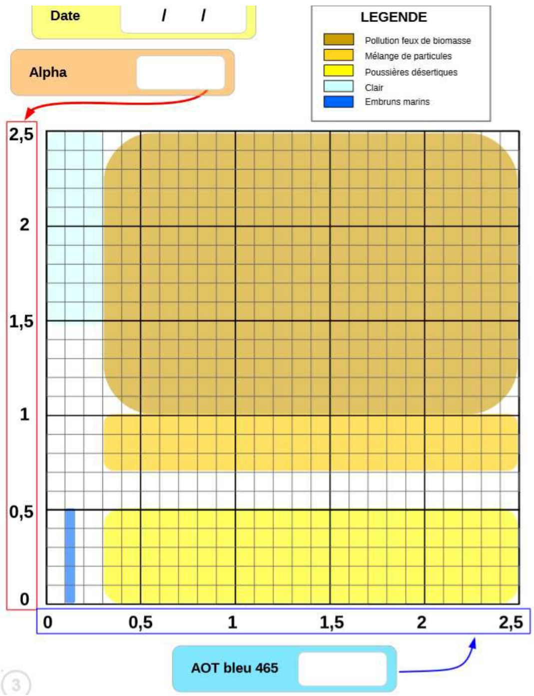
Outcome :

The blue, green and red curves are visually close.

- The particle gauge indicator points to the mass of sand which shows detection of large particles.

- The Angström exponent (Alpha) is feeble, a clear sign of a preponderence of large particles.

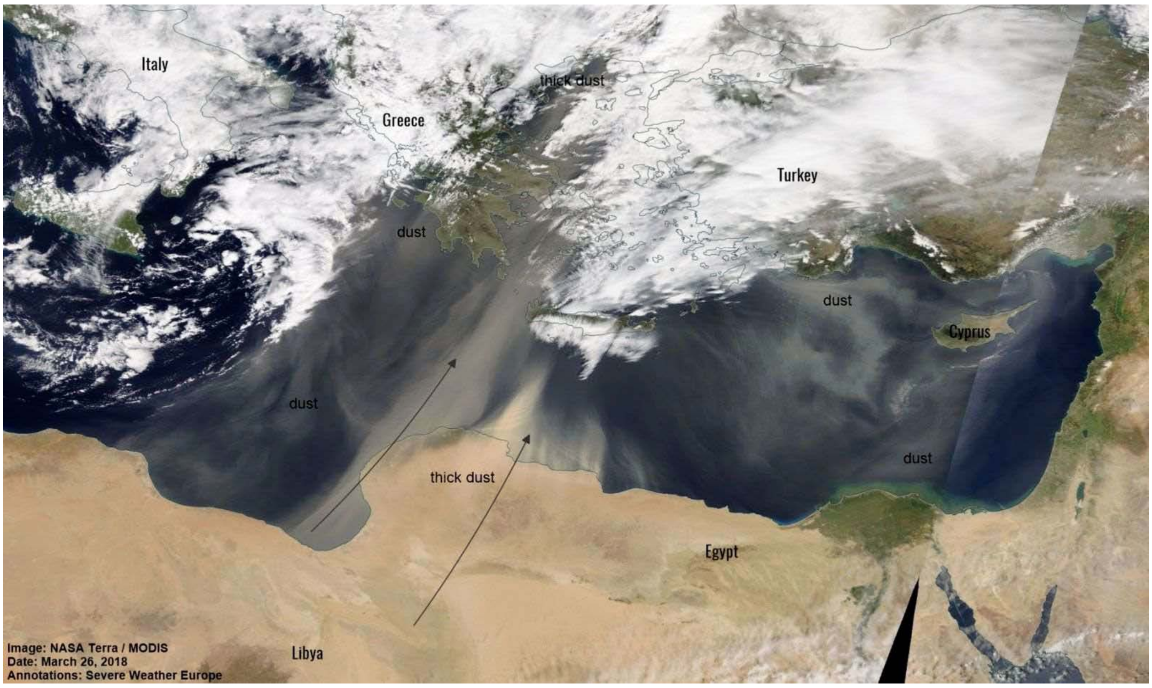




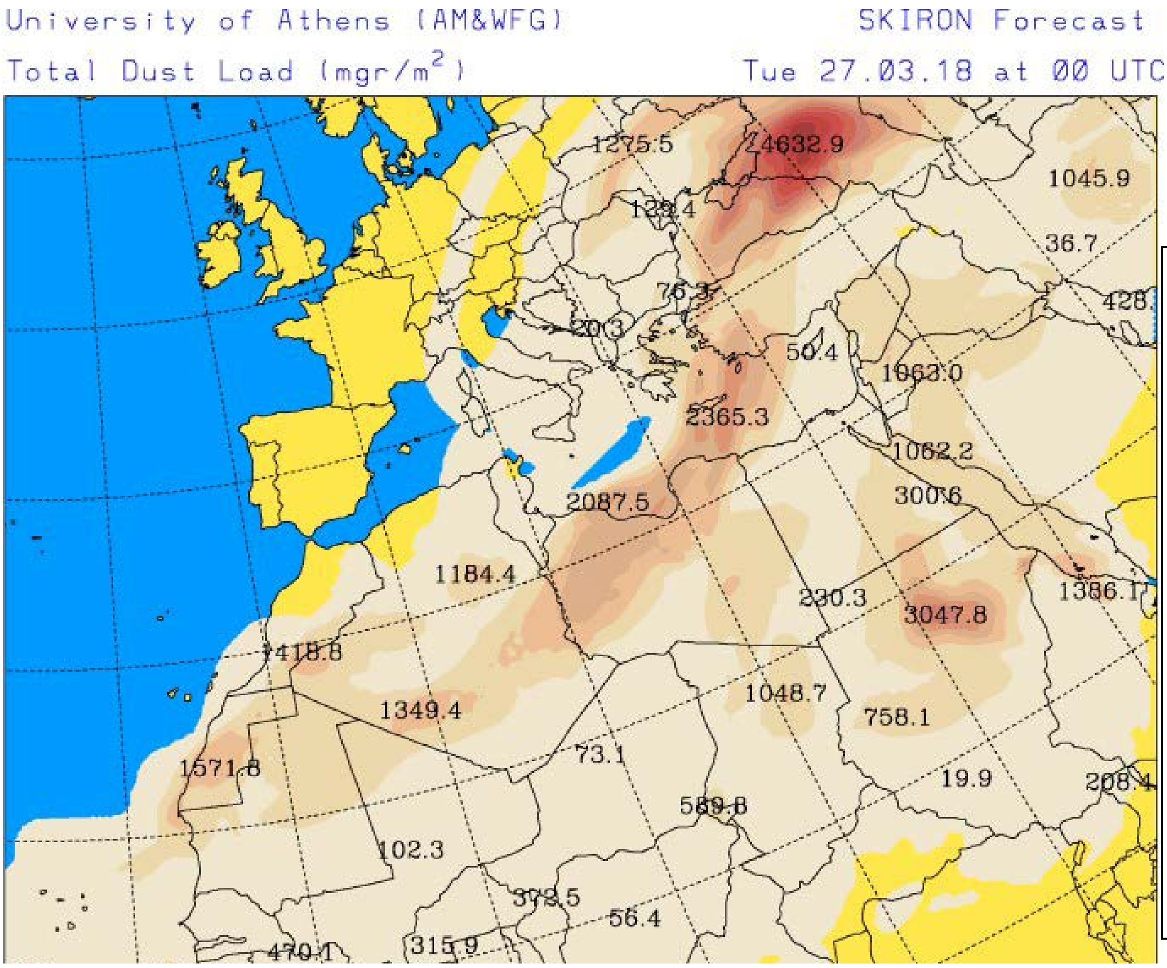
We therefore suppose that these particles are particles of sand but our hypothesis must overlap with weather data.

http://www.calitoo.fr/uploads/documents/fr/usermanual_fr.pdf

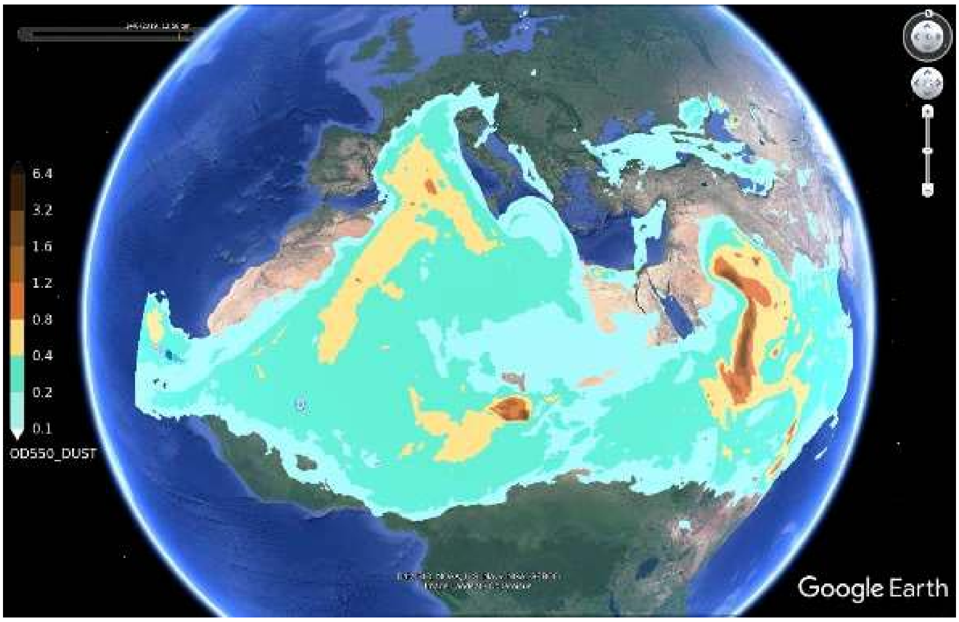
A weather map study and sattellite images from 26 and 27/08/2018 data corresponding to snowfalls in Sotchi validate the hypothesis.



Nasa Terra / MODIS satellite image of the Mediterranean, March 26. Credit: Severe-weather.eu.



University of Athens SKIRON model forecast for March 27



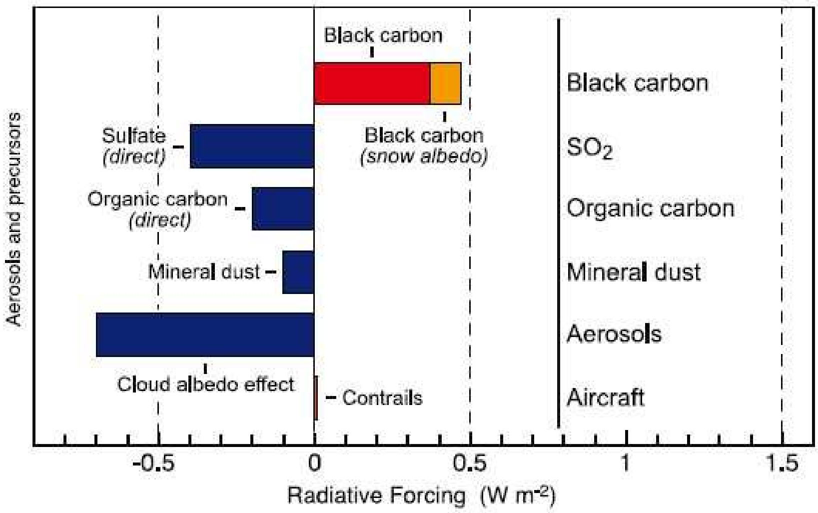
We can also observe that the South of France is frequently affected by desert dust outbreaks

https://dust.aemet.es/forecast

- What are the effects of these mineral particles on the climate ?

  When the particles in the air are aerosols

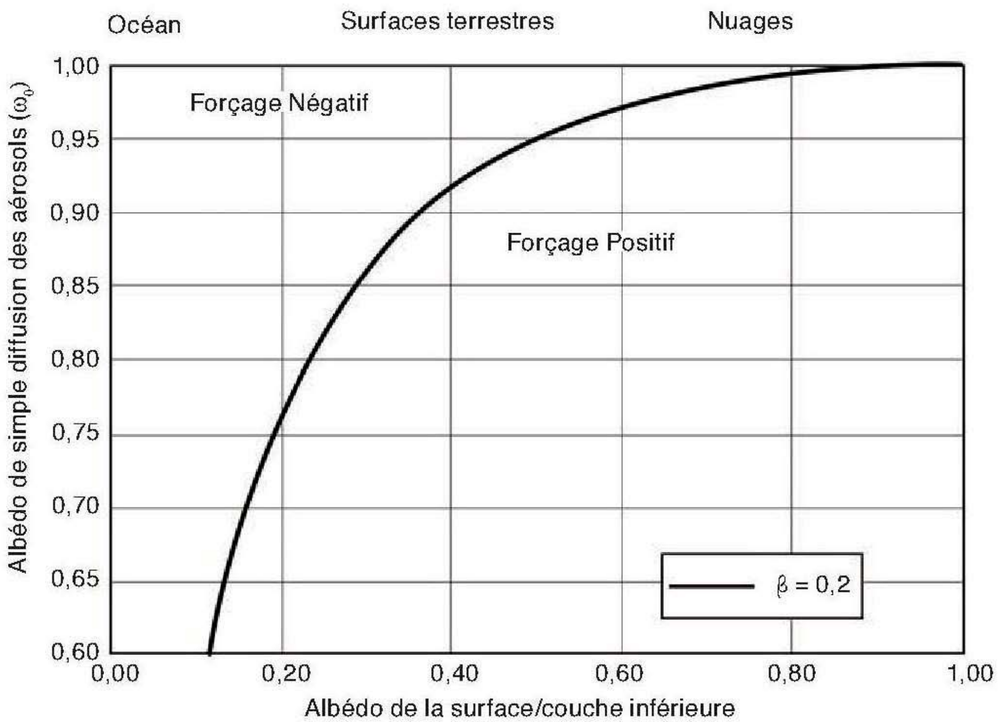
  The assessment of the global impact of aerosols as a whole is easier and provides more consistent values than if we think of particles individually. Scientists try however to quantify the radiative forcing of each type of aerosols. For example, we have the following estimations for the mean radiative forcing of different aerosols classes :



Radiative forcing by different aerosol classes (source : GIEC, 4ième rapport, chp. 2, 2007).

It is indeed extremely difficult to establish a radiative impact of mineral dust particles as it was shown that a great deal of factors has an influence, such as cloud formation and also the altitude of the cloud ceiling and the altitude of the dust layer, the size of dust particles and their optical depth.
Radiative forcing by mineral dust aerosols: Sensitivity to key variables H. Liao J. H. Seinfeld

Moreover, the radiative impact of an aerosol depends on the nature of the underlying surface, for example "above dark surfaces such as the ocean, the aerosols whether absorbant or not will always cause an increase in the albedo and thus a negative forcing (cooling effect). For surfaces that are more reflective, like desert surfaces (ρs = 0,5), the aerosol's effect will be very significant for its absorptive capacity : a ω0 albedo lower than 0,95 will suffice for creating an warming effect on the climate."

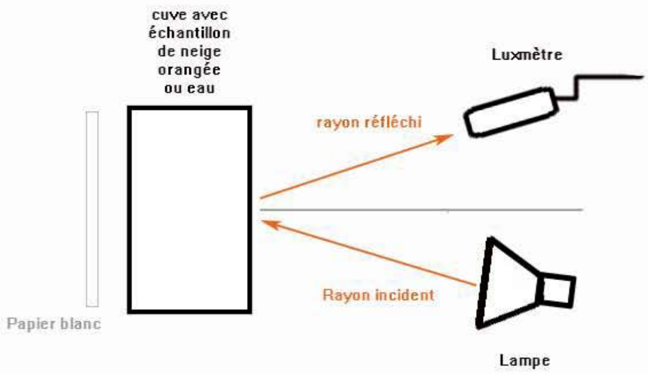


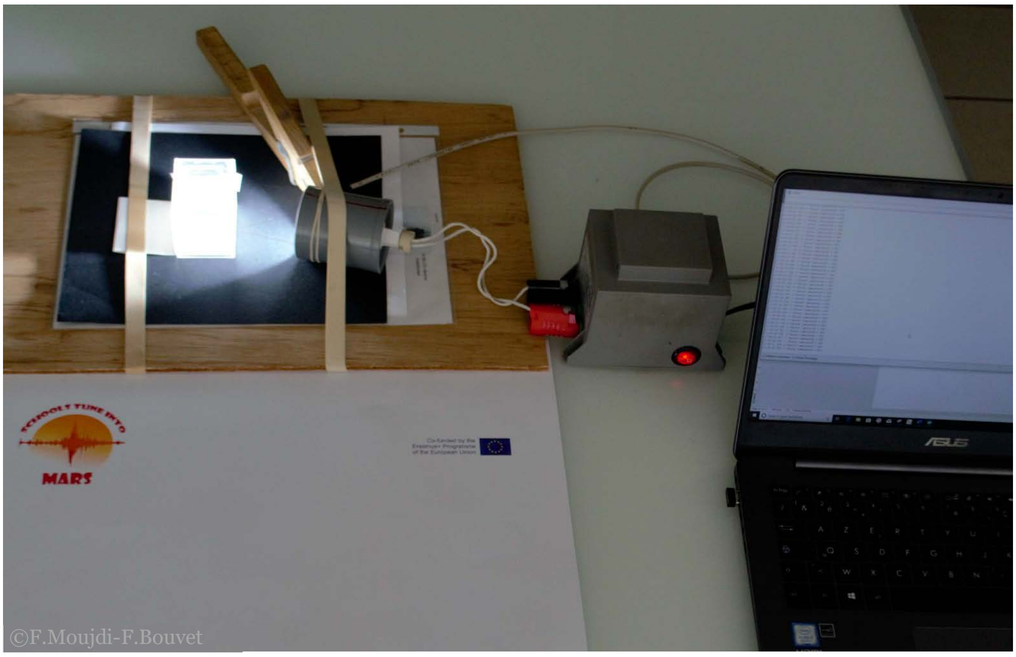
Didier Tanré, Physicist, Research director at CNRS, LOA, Villeneuve d'Ascq. https://books.openedition.org/editionscnrs/11354

- Let's see of our desert dust particles extracted from orange snow can modify the surface albedo locally.

The albedo of the Earth-atmosphere system is a fraction of the solar radiation reflected back into space.

We will hence measure the luminous intensity reflected by a white surface and then the luminous intensity reflected by a white surface covered by sand particles.





©F.Moujdi-F.Bouvet

Outcome :

Be careful: As a luxmeter we used here a photoresistance mounted on an Arduino board, the measured value has no unit! This is a purely indicative value.

No sand particles: `10:51:13.092 -> Valeur luminosité = 916`

With sand particles: `10:52:41.037 -> Valeur luminosité = 897`

The amount of reflected light decreases with desert dust

The colour of the snow therefore reduces its albedo and temporarily promotes an increase in ground temperature and accelerates snowmelt.

Erasmus+

SCHOOLS TUNE INTO MARS

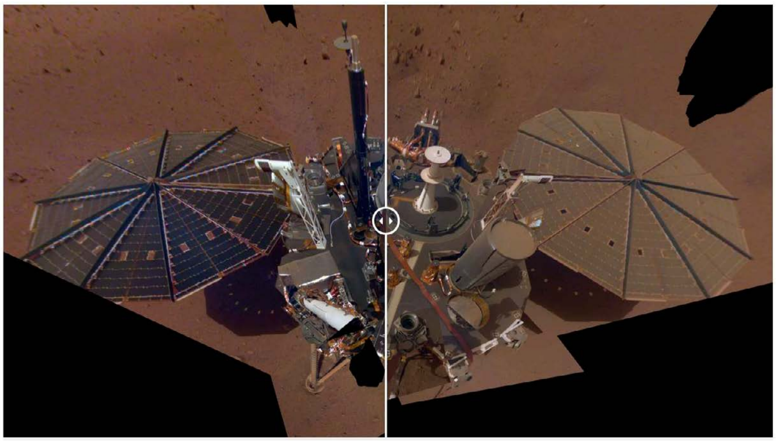
This project is co-funded by the European Union

Primary aerosol and climatic impact on Mars

1. Introduction & Pb

We know that even natural aerosols can have an impact on the climate.

On Mars as on Earth mineral particles are suspended as shown by the selfies of insight.



We can see on these insight selfies that mineral dust has settled on the Lander. This can also be set in motion again by atmospheric turbulences such as dust devil as evidenced by sudden variations in the efficiency of solar panels.

Selfie d'Insight fait Dec. 6, 2018
NASA/JPL-Caltech

Selfie d'Insight fait May. 6, 2019

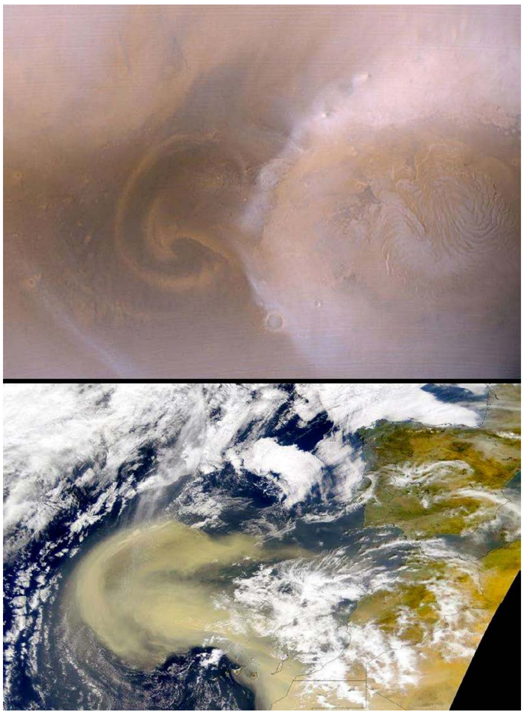
In the same way, satellite images confirm that there are large-scale phenomena in March involving the suspension of mineral particles in the atmosphere.

Pb: How can the transport of aerosols impact the climate of a planet?

In this picture, we compare a recent dust storm on Mars with a storm that occurred earlier this year on Earth.

The top image shows a dust storm from the North Martian Pole observed on August 29, 2000. The storm moves like a front, outward from a central "jet", and marginal "eddies" can be observed. In this image, it extends about 900 km from the seasonal ice cap of the North Pole. The area on the right side of the image of Mars includes the North Pole. The bottom image shows a ground dust storm on February 26, 2000. This storm extends about 1800 km (1100 mi) off the coast of northwestern Africa, near the Earth's equator.

Both images are displayed at the same scale; 4 km (2.5 mi) per pixel



https://www.jpl.nasa.gov/spaceimages/details.php?id=PIA02807

2. Age of students: 15 – 17 years

3. Objectives

Determine whether the transport of Martian mineral dust has an influence on the climate

4. Primary subjects

Physics – Earth Science

5. Additional subjects

6. Time required: 2h

7. Key terms.

Aerosols, albedo.

8. Materials

- Mesurim
- A luxmeter
- Two transparent polystyrene containers
- A 12 V lamp placed in a sleeve

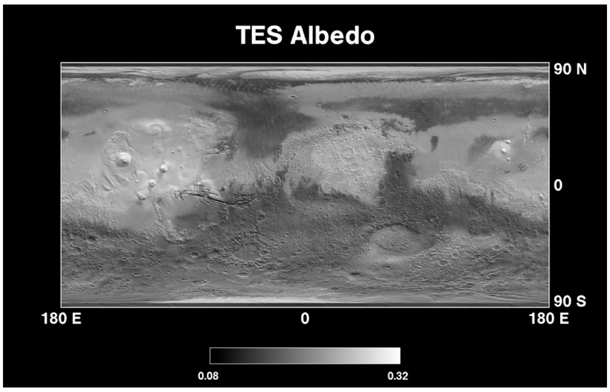
9. Background

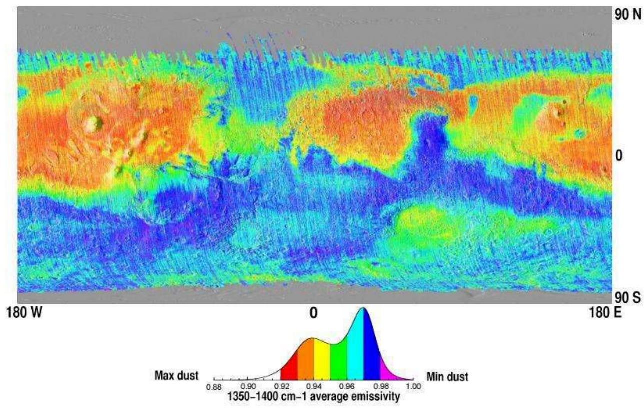
Scientists define an aerosol as a suspension of particles in the atmosphere. These particles are made up of solid and/or liquid substances. Mineral or organic, composed of living matter (pollens...) or not, large or fine, suspended particles constitute an extremely heterogeneous set of pollutants whose size varies from a few tenths of nanometers to a hundred micrometers.
The radiative impact of an aerosol will depend on the nature of the underlying surface.

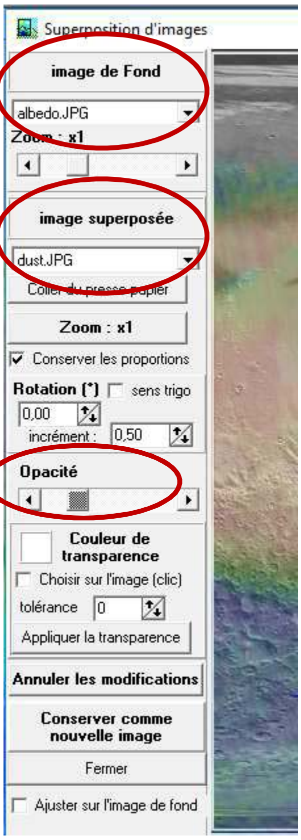
10. Procedures

- We will first try to find out if the albedo differences can be explained by a difference in the composition of the Martian ground.

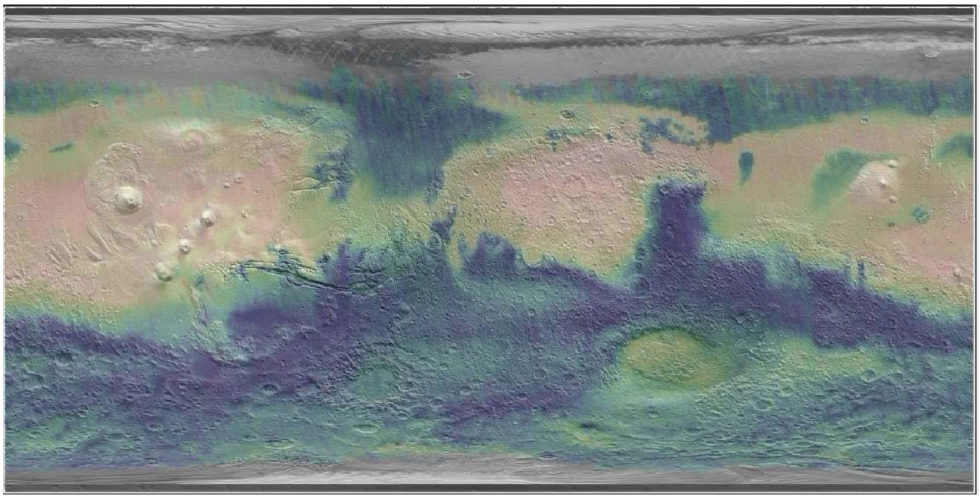
We will compare a map of the global albedo of March and the distribution of sand. To do this we will use mesurim and the overlay function.





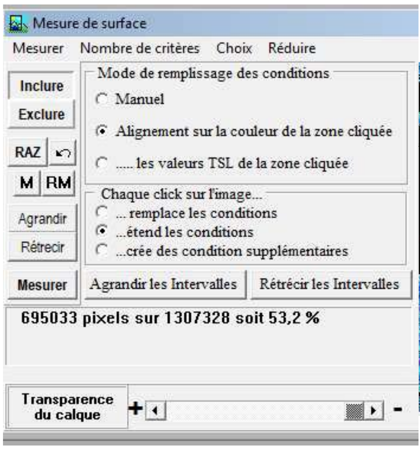


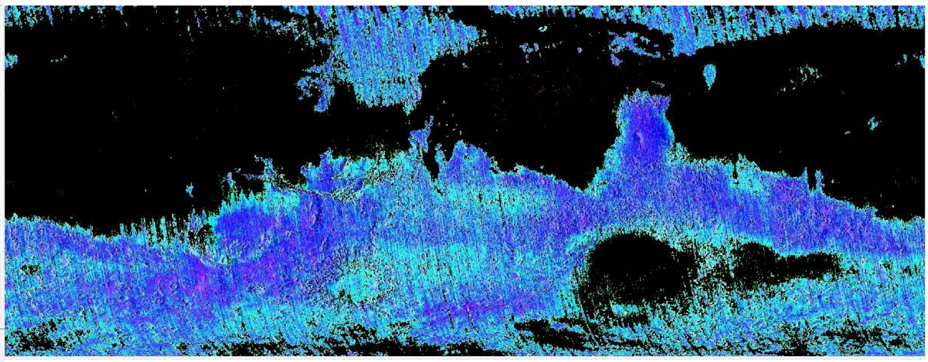
Open "albedo.jpeg" and "dust.jpeg" in mesurim.
Then in Image choose to overlay image as shown opposite
Adjust the opacity to make it easier to read.



We immediately see a correlation between albedo and the presence of sand.

If we evaluate, with Mesurim, the surface of the ground covered by sand on the Martian planisphere we can see that it occupies about 50% of the total surface for which we have data.

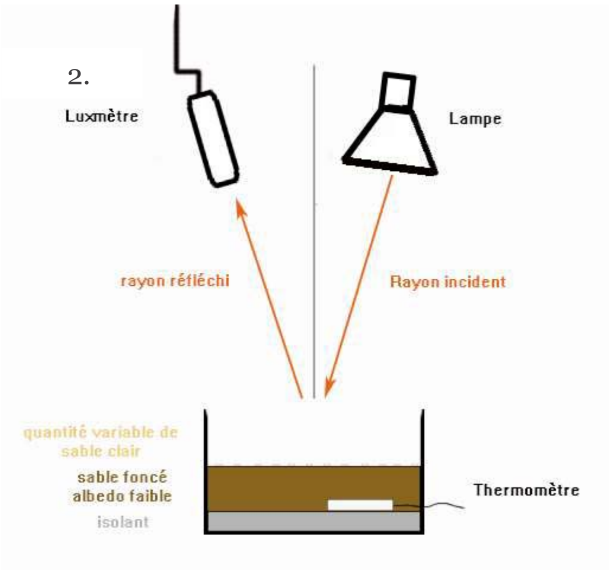


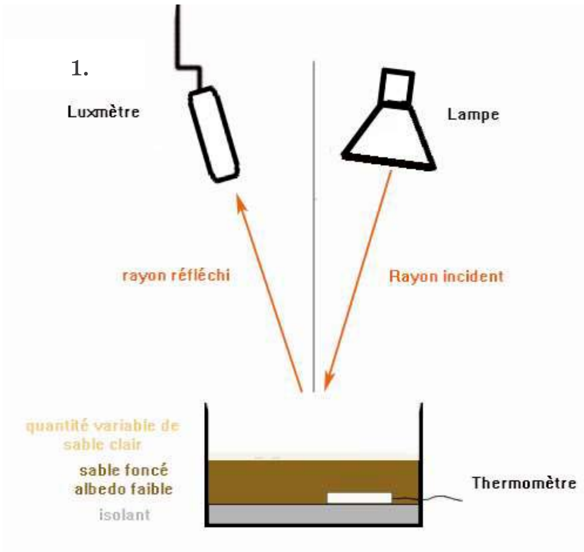


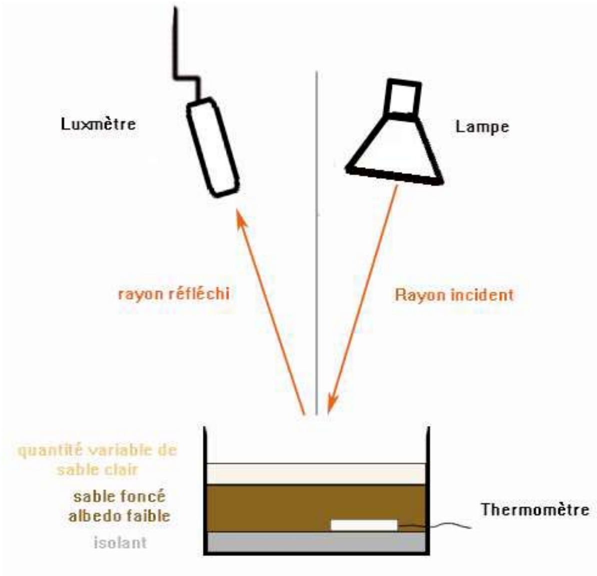
Dust transport could have an impact on the thermal inertia of areas with a lower albedo that represent a large surface area of the planet.

- Let's try to model the deposition coating of mineral particles with a high albedo from ground to lower albedo.

Compare the temperature evolution of the following three assemblies over an equivalent time period:
Attention the total quantity of dust must be equivalent for each experiment





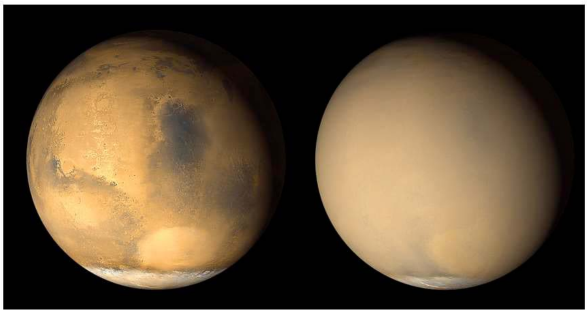


11. Discussion of the results and conclusions

There is a decrease in the heat absorbed by the ground but only if the quantity of light sand completely covers the dark ground and over a large thickness (Figure 3.) a simple under-powdering (Figure 2.) is not sufficient to have an effect on the temperature even if there is an increase in reflected light.

So only an accumulation of a large quantity of mineral matter could have an influence on albedo and therefore the inertia of the of the planet.

Source : http://www.mars.asu.edu/~ruff/DCI/2001JE001580.pdf



However, it has been observed that Global Sandstorms could occur on Mars, following which variations in albedo can be observed for one year following this storm.

Two images taken in 2001 by NASA's Mars Global Surveyor orbiter camera show a dramatic change in the appearance of the planet as the dust cloud raised by the storm in the south spread around the world. The images were taken about a month apart.

https://www.researchgate.net/publication/263856153_Mars_surface_albedo_and_changes

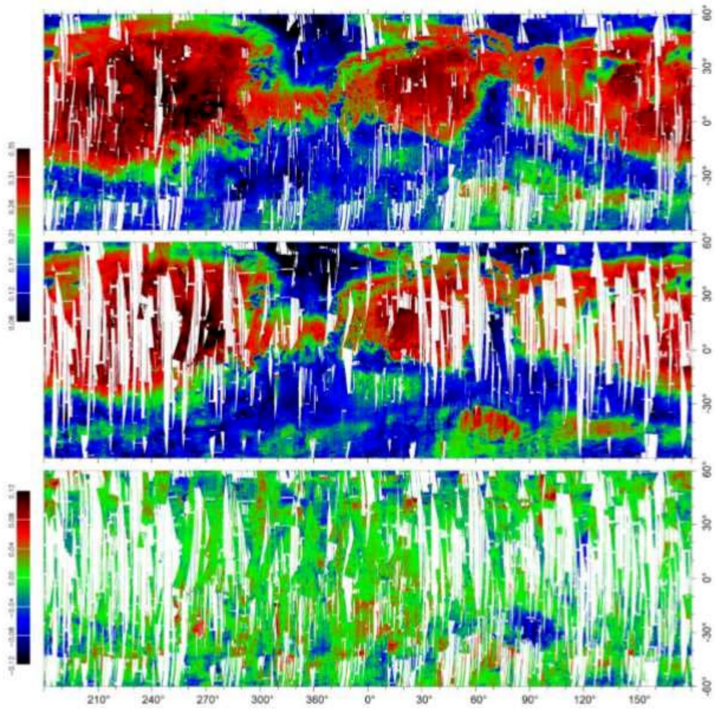


Figure 9: (top) albedo map prior to the MY28 GDS (orbits ≤ 4463: data from MY26 LS 330° to MY 28 L_s 265°: 86% coverage). (middle) albedo map after the MY GDS (orbits ≥ 4758: data from MY 28 L_s 315° to MY 30 L_s 135°: 74% coverage). (bottom) difference albedo map (middle – top: 63% coverage). Quality level # 1 (Table 1) is used. Bright areas or brightening ≥ 0.04 are in red, dark areas or darkening ≤ -0.04 are in blue. Intermediate albedo and stable areas are in green.

12. Explore More (additional resources for teachers)

- https://www.researchgate.net/publication/263856153_Mars_surface_albedo_and_changes

- Arduino

Erasmus+

SCHOOLS TUNE INTO MARS

This project is co-funded by the European Union

Daily temperature variations on Mars

1. Introduction & Pb

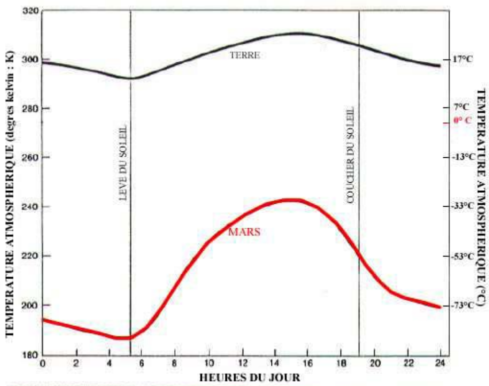
On Mars' surface, we can find summer trends: 20 °C, the breeze of trade winds… But starting with the onset of night, temperature values plummet by several tens of degrees and freezing conditions reaching – 100 °C will prevail until the morning after. In fact, Martian soil, dry and granular, can store only very little heat. Its thermal inertia is very small compared to that of the Earth and its oceans. The atmosphere being thin, temperature variations are more significant.

On Earth, daily temperature variations are less pregnant than those on Mars.

Chart of day-night temperatures of telluric planets:

Planet	T day (°C)	T night (°C)
Mercury	430	-170
Venus	460	450
Terra	15	5
Mars	-23	-93

Comparison between the daily variations of the atmospheric temperature on Viking 1 site and those of a terrestrial desert site (China Lake, California) :



DAILY VARIATIONS IN ATMOSPHERIC TEMPERATURE at the *Viking 1* landing site (*color*) are qualitatively similar to those at China Lake, Calif., a desert site (*black*). In both cases the temperature touches a minimum around sunrise and reaches a peak about 10 hours later. The daily range, however, is about three times greater on Mars than it is on the earth. At Viking site range is 55 degrees, from about 187 to 242 degrees Kelvin (–86 to –31 degrees Celsius). At China Lake range is 18 degrees, from 292 to 310 degrees K. (19 to 37 degrees C.).

Case 2 shows a minimal temperature at sunrise.

Daily thermal fluctuations are 3 times stronger on Mars than On Earth.

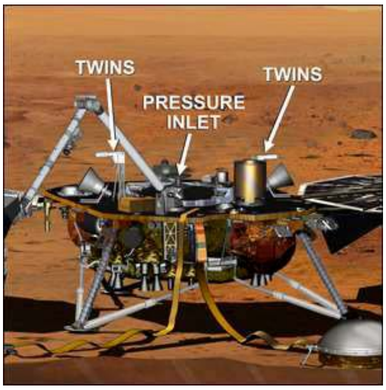
Source: Reserved rights - © 1979 According to Ryan et Henry, JGR

The InSight lander is equiped with a comprehensive weather station (APSS, Auxiliary Payload Sensor Suite).

The various sensors on this station (temperature, weather vane, anemometer, barometer and magnetometer) play a crucial role in the interpretation of data provided by InSight's seismometer SEIS, but also in enhancing the knowledge about Martian weather and its current climate. The knowledge acquired will help us to get a better grasp of weather perturbations on our planet Earth.

The ultrasensitive air-inlet pressure sensor of the APSS weather station installed on the deck of InSight (© NASA/JPL-Caltech/IPGP/Philippe Labrot).

This pressure sensor is ultrasensitive, meaning it is capable to react to variations of pressure at an order of dozen microPascals (i.e. 10-7 mbars). It's installed on the lander's deck, underneath the Wind and Thermal Shield (WTS).



NASA/JPL-Caltech - http://photojournal.jpl.nasa.gov/figures/PIA17358_fig1.jpg

TWINS sensors (Temperature and Wind Sensors for InSight) are thermal anemometers. There are two of them on the deck. The data is recorded at a maximum rate of one per second.

At a rate of 2 times per second, they record air temperature and also wind speed and direction, all this during the entire duration of the mission, that is a Martian year, equivalent to two terrestrial years.

The data that scientists obtain on a regular basis will allow us to better understand the phenomena linked to weather on Mars.

Pb : How can the analysis of meteorological data help us enhance our knowledge on weather perturbations on Mars, as well as on Earth ?

2. Age of students 15 – 17 ans

3. Objectives

Using a Python data processing script, show the information we can collect from the weather perturbations such as the diurnal cycle, the passing of a Dust Devil...

4. Primary subjects

Mathematics – Physics – Python Programming

5. Additional subjects

Earth Science

6. Time required 3hrs

7. Key terms

Geothermal gradient, heat flow, heat dissipation.

8. Materials

- Computer with software
- Excel – Python

9. Background

Thermal inertia of the soil, the rotational period and the atmosphere are the main parameters that control the day-night temperature disparity of a planet.

The **moving average** is a type of statistical average value used to analyse arrays of data, most frequently temporary arrays by removing the temporary fluctuations so that we can highlight longer term trends. This average value is called *moving average* because it is continuously recalculated, using for each rendition a subset of elements in which the newest element replaces the oldest one or is added to the subset.

This type of average value is generally used as a data processing method.

10. Procedures

- On Earth :

You have at your disposal, in « csv » format, the data corresponding to 9/7/2019 (cf csv data sheet) downloaded from the meteo website « WillyWeather » on China Lake Acres site (environment similar to that of Mars).

1. You will have to represent the Temperature, Pressure and Wind Speed plots provided to you in Python script.

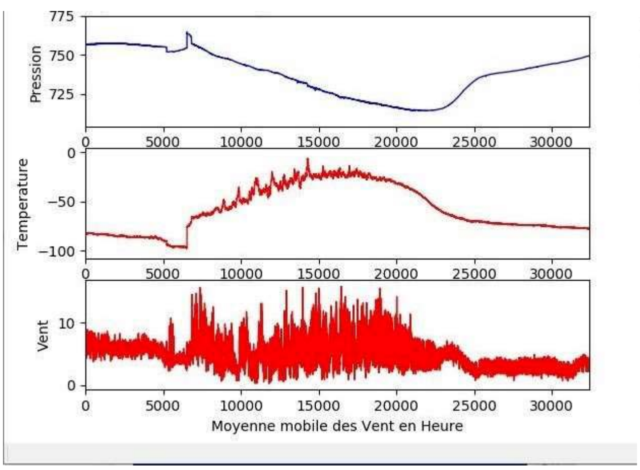
- On Mars :

You have at your disposal, in « csv » format, the meteorological data corresponding to the 15th day of the InSight mission (cf csv data sheet).

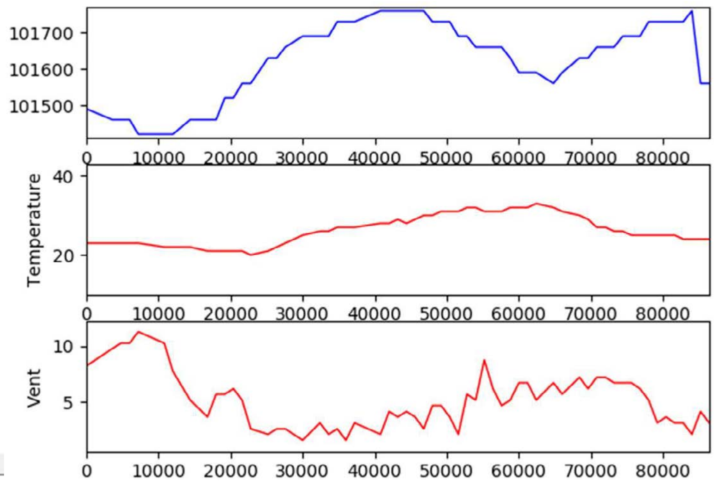
2. You will be asked to represent the plots for the parameters provided to you in Python language.

Expected Results :

On Mars



On Earth



Time : second – Temperature : K – Wind Speed : m/s – Pressure : Pa

3. Compare and interpret the results obtained for Earth with those obtained for Mars.

We can distinguish significant temperature fluctuations on Mars, growing from – 83°C (at night) to 13°C (during day) that correspond to the diurnal cycle of Mars. In contrast, fluctuations in day-night temperatures on Earth are less significant (from 23°C to 32°C). The same goes for pressure.

In order to conduct a sharper study from the data, scientists need to take measurements less « polluted » by irregular values that re-enforce these exceptional phenomena such as dust devils and so on.

We will therefore use particular statistically obtained mean values that allow us to interpret the values with the purpose of excluding the so-called ***aberrant*** values (values distant from other observations made on the same phenomenon). These statistical mean values represent the «moving average or rolling/running average ».

Simple moving averages on 3 values, for a series of 9 measurements.

Mesures	2	3	5	8	8	7	8	5	2
Moyenne glissante	néant	(2 + 3 + 5)/3 3,3333	(3 + 5 + 8)/3 5,3333	(5 + 8 + 8)/3 7	(8 + 8 + 7)/3 7,6666	(8 +7 + 8)/3 7,6666	(7 + 8 + 5)/3 6,6666	(8 + 5 + 2)/3 5	néant

Source : https://fr.wikipedia.org/wiki/Moyenne_mobile

In our particular case, the values being related to the atmospheric domain, we will use a « moving average on 6 hours, 8 hours and 12 hours » for Temperature and Pressure values, the same as computing the average values from 0h00 to 8h00, from 1h00 to 9h00, from 2h to 10h00 and so forth...

As our data recordings cover 3 days, we will thus be able to measure the maximum and minimum value of the rolling average to get an idea on the thermic amplitude for a Martian day, etc...

The purpose of using a rolling average is to interpret the potential accidental deviations (twist devil, ...).

Operating mode for plotting the moving averages :

- Lists and operations made on the lists
- Curve plots

1) a) Write the **average** function (List_of_numbers) that allows you to obtain the mean value of a list of numbers.

Bonus) Write the **modified_average(List_of_numbers)** function that allows you to compute the mean value without the need for the **sum** function available in Python.

2) Write the **List_extract(p, n, List_of__nbrs)** that allows you to extract a list of a given **n** size starting from a given rank **p**.

3) a) Write the **Compute_Moving_Average (n, List)** function that allows you to obtain the list of moving averages
on a n range of values of a given list.

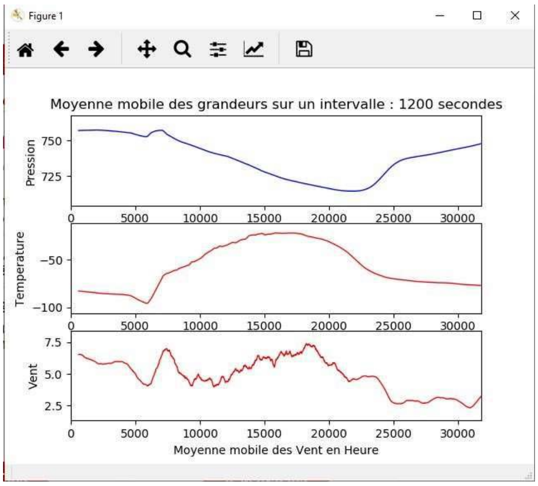
b) Provide the list of moving averages on a range of 8 values on the data recorded:
i) time values ii) temperature values iii) pressure values iv) winds

4) a) Write the **Moving_Average(n, List1, List2, List3,List4)** function that will display the temperature, pressure and wind speed mean values depending on the average time, on a range of 8 time values.
(We take into account the following correlations List1=Time List2=Temperature List3=Pressure List4=Wind)

b) Modify the **least_square_regression(n)** function code to assess the possible correlation between the two averaged physical quantities, Temperature and Pressure.

Colour code of graphs isn't required and will be provided in the student file

Plot obtained with a moving average for 20' of Martian data values:

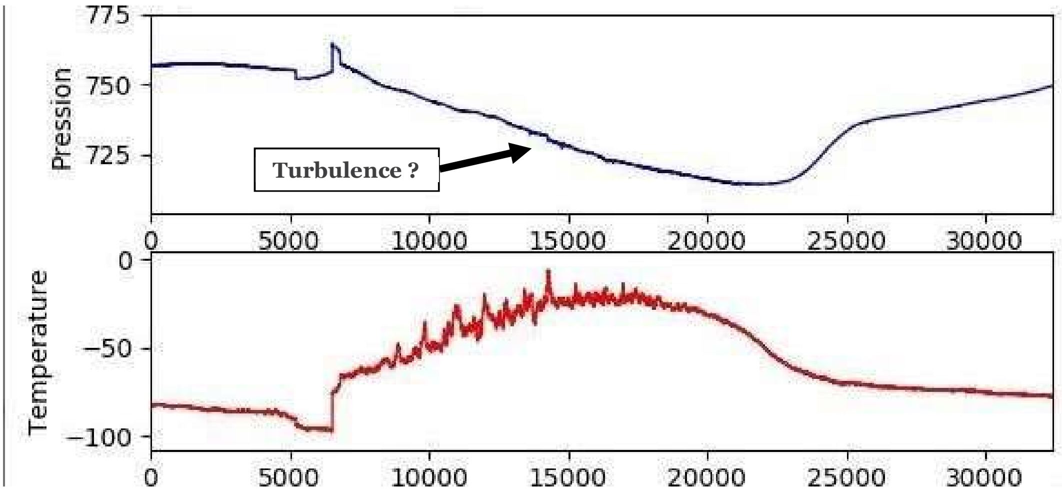


We can observe on the 'Pressure on Mars' plot large scale waves known as « thermal tides ».

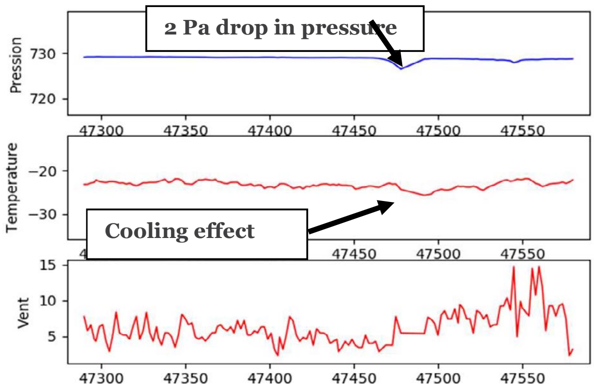
Basically, thermal tides are global-scale waves generated by fluctuations in the regular day-night cycle in the Sun's heating of atmosphere (insolation). These waves are displayed on wind components and they evolve with local solar time.

We observe a significantly marked diurnal cycle and violent winds up until sunrise. They are due to the cooling T° close to the ground during the night.

We observe on the Martian data plot (below) two perturbations that could be local «dust devil » whirlwinds, but we should carry out a more precise sampling in order to make sure of their presence:



Sampling on 250 seconds of Martian data isolating the Dust-related data we observed in the previous plots:

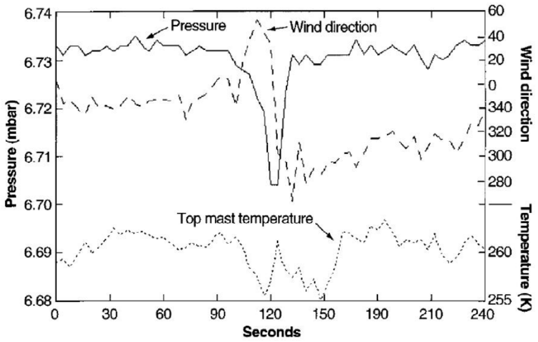


Comparison of the results obtained with data downloaded from Pathfinder website defining a Dust on Mars :

The thermal tides in the atmosphere of the planet Mars have a much higher amplitude than that of the Earth because thermal forcing is very strong due to the infrared absorption of atmospheric CO_2, the absorbtion of infrared radiation emitted by the surface and the fact that the atmosphere on Mars is thinner.

The effect that atmospheric tides have on zonal and meridian average flow is therefore of great significance in the Martian atmosphere.

Pressure (hPa), wind (m/s) et temperature (K) measurements available on the Pathfinder site:



The data sampling rate is 4s. A dust devil passing through at cyclostrophic balance above the lander is reflected in a 2.5 Pa dew point depression and a decrease in temperature of approximately 5K. Wind's characteristic circulation was also recorded by the anemometers on Pathfinder, however the calibration issues didn't make possible to have an accurate measurement of the fluctuating wind amplitude. Image by Schofield et al. [1997].

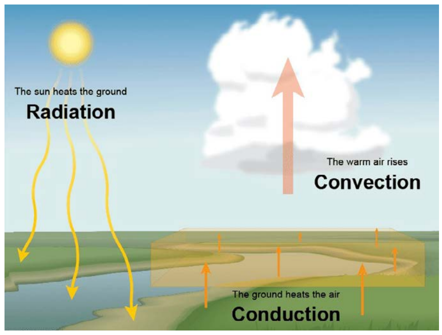
Source : Thesis by M. Aymeric Spiga « Mesoscale dynamic model of the Martian atmosphere: defining a meteorological model and analyse of observations made by OMEG/Mars Express »

Modelling the physical phenomena at the root of local whirlwind formation:

In an arid area, air close to soil surface is heated in a different manner. The heat will be transfered vertically by the radiation to a layer of colder dry air and will undergo an upward thrust according to Achimedes' principle and reach convection.

The arrival of a horizontal transport of air mass will generate a rotation in the air which will then confine all the dust in its proximity.

The altitude and diameter of a a whilwind depends on the air's instability and dryness.



Source : https://www.thoughtco.com/what-is-convection-4041318

Plan three simple experiments to get a model for each heat transfer method: Convection – Conduction – Radiation. You can only use the materials provided for you.

convection

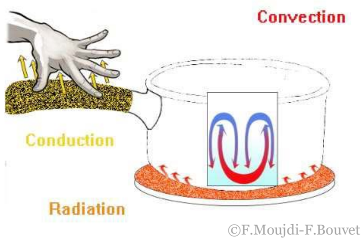
the movement caused within a fluid by the tendency of hotter and therefore less dense material to rise, and colder, denser material to sink under the influence of gravity, which consequently results in transfer of heat.

Conduction

the process by which heat or electricity is directly transmitted through a substance when there is a difference of temperature or of electrical potential between adjoining regions, without movement of the material.

Radiation

the emission of energy as electromagnetic waves or as moving subatomic particles, especially high-energy particles that cause ionization.



11. Discussion of the results and conclusions

Martian weather resembles that of Earth in many ways. It is basically abundant in storms, tornadoes, dust…

And yet, Mars sets itself apart from planet Earth. Martian atmosphere is in fact not so thick, the phenomenon of diurnal wind variation, of so little significance on Earth, is identified by the great fluctuations in the day-night cycle.

The analysis of meteorological data allowed us to discover weak signals in the large-scale cosmic structure (thermal tides) and fast signals in the local scale (whirlwinds and convective turbulence).

En effet, les oscillations diurnes de la température et du vent à la surface excitent indirectement toutes les autres couches de l'atmosphère. Ce qui entraîne la vibration de la couche atmosphérique martienne ou plus exactement propage des ondes de de fréquence diurne (une oscillation par jour) appelée « onde de marée thermique ». Ces oscillations diurnes vont interagir avec les autres vents et influencer la circulation atmosphérique qui sera enregistrée inévitablement par le sismomètre SEIS.

In fact, diurnal variations of temperature and wind values found at the horizon indirectly stimulate other layers of the atmosphere. Which therefore stimulates the vibration of the Martian atmosphere or more precisely propagates waves of diurnal frequency (one amplitude per day) called « atmospheric thermal tides». These diurnal oscillations will interact with other winds and have an effect on atmospheric circulation inevitably captured by SEIS.

Once the data is continuously collected, meteorologists responsible for this mission will have to separate the thermal tides from the data provided by InSight's seismometer SEIS.

12. Explore More (additional resources for teachers)

- "Planet Mars" : Edition Belin – François Forget, François Costard – Philippe Lognonné

- M. Aymeric Spiga's Thesis « Mesoscale dynamic model of the Martian atmosphere: defining a meteorological model and analyse of observations made by OMEG/Mars Express »

Annex 11

Erasmus+

SCHOOLS TUNE INTO MARS

This project is co-funded by the European Union

SEIS, a securely-packed seismometer

1. Introduction & Pb

In 2018, NASA sent a new lander on Mars to explore for the first time the « depths » of the planet. To successfully carry out the mission that plans to record the seismic activity, meteorite impacts and thus determine the planet's internal structure: the robot is equipped with an ultrasensitive, but impervious seismometer called SEIS, constructed by CNES (The National Centre for Space Studies from Toulouse in partnership with IPG (Paris Global Institute).

In order to shield the seismometers from the environment, seismologists placed them in basements on Earth.

But to ensure SEIS' protection from the Martian environment, scientists designed a double protection: a Wind and Thermal Shield (WTS). To check its thermal resistance, the equipment was put in ovens and tested in high temperature conditions (up to 60 °C), before being placed in compounds that had glacial temperatures, down to -75°C.

Philippe Laudet, SEIS project manager at CNES

The Earth and Mars are greatly similar rocky planets. Certain people even call them « twin » planets.

Pb: Yet why do scientists insisted to cover the seismometer with a protection dome?

2. Age of students: 14 – 16 years

3. Objectives

The purpose of this activity is to determine how Mars' atmosphere and environment differ from those of the Earth and why the lander's construction needed really solid instruments to be tested repeatedly in extreme conditions on Earth?

4. Primary subjects

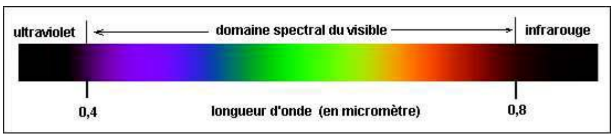
Chemistry – Earth Sciences

5. Additional subjects

6. Time required 1h30

7. Key terms

Atmosphere – Gas – Carbon cycle – Radiation balance – Solar radiation – Infrared.



8. Materials:

Atmospheric composition of the planets in the Solar System	Modelling of the Radiation balance of a planet	Modelling of the effect of variations in solar radiation on a planet	Modelling of the movement of air masses
- « Solar System» software : https://www.pedagogie.ac-nice.fr/svt/productions/systeme-solaire/	- Lab plate - Insulator - Thermometer - Glass	- Lamp - Planisphere - Plate pierced by holes	- Incense burner - Cold plate - Support stand - Black sheet of paper

9. Background

Solar radiation has a spectral range of ultraviolet radiation with wavelength below 0.4 mm and a range of infrared with wavelength greater than 0.8 mm.
Greenhouse gases (water vapour, carbonic acid gas, methane...) are basically transparent in the solar beams (visible light spectrum) and opaque in the infrared light emitted by the Earth.
Heating is thus averted.

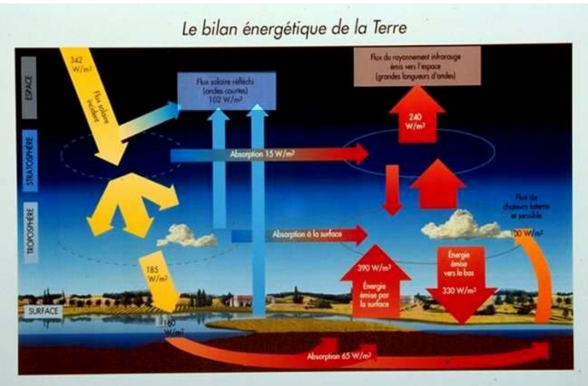
10. Procedures

You will have to write a scientific paper on the specifics of Mars and of the Earth, in which you will integrate the arguments given by scientists to explain the process responsible for the loss of a great part of the atmosphere on Mars which would partly explain its hostile environment.
Lastly, you will deduct the arguments that scientists responsible for the InSight Mars mission took into consideration when developing very resistant measuring instruments to withstand the hostile environment of Mars.

I. The atmosphere of rocky planets in the solar system:

1. Fill in the following table using « The solar system » software.

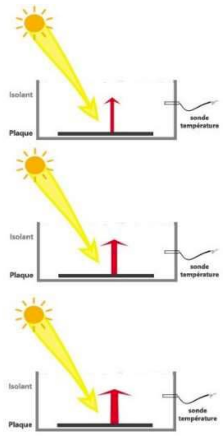
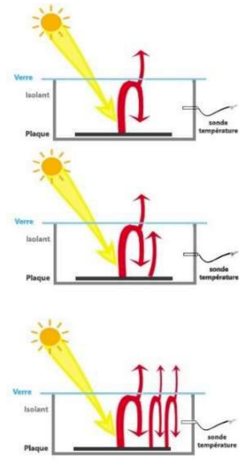
	Thickness	Main components of the atmosphere	Water's states of matter	Presence of Ozone
Earth				
Mars				



Mars has only half of the isolation on Earth.
The atmosphere's composition (95% CO_2) makes is transparent in the visible light.
The atmosphere is therefore heated by the incident visible light and cooled down by the thermal infrared emission.
The radiation flux emitted by the surface in infrared light is partly absorbed by the atmosphere. The greenhouse effect has a very low amplitude on Mars: 5K due to low pressure and narrowness of the absorbtion/emission of CO_2.

Image source: (CNES, scarab site): http://scarab.cnes.fr:8020/

2. <u>Modelling of the Radiation balance of a planet with and without the greenhouse effect:</u>

Temperature in case of no greenhouse effect	Temperature in case of greenhouse gases
	
T° =	T°=

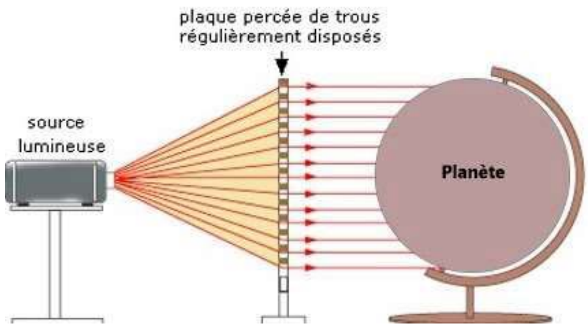
The plate that is exposed to the sun heats up. It receives energy from the Sun, therefore its T° increases. It will thus emit more radiation and will lose more energy in return.
The surface of glass allows the solar radiation to go through and absorbs all the infrared radiation. Glass therefore absorbs all the infrared radiation emitted by the plate and warms up. While it's warming up, the surface itself emits more infrared radiation and its temperature will increase up until the surface will lose as much energy as it receives.
The radiation that is emitted upwards by the glass is lost and the radiation emitted downwards is absorbed by the plate. The plate now receives more radiation than it loses, hence it's temperature will increase until the loss of energy will be equal to the amount of energy received by the plate.
We reach a balance, in which the temperature of the plate is higher than in the no-glass setup: that is the greenhouse effect.

II. <u>Circulation of wind on Earth and on Mars:</u>

Atmospheric circulation on Earth and on Mars is governed by the same laws.
Thermal contrasts in the atmosphere are interpreted as a large amplitude oscillation of pressure with altitude. Air masses from high pressure areas (warm regions) are drawn to areas of low pressure (cold areas).
They are set in motion and generate winds. We will plot the factors responsible for wind formation.

1. <u>Thermal contrasts:</u>

Solar radiation generates atmospheric circulation by creating contrasts in temperature. For the same pressure value on the surface we will find more air at higher altitudes because warm air masses take up more volume.

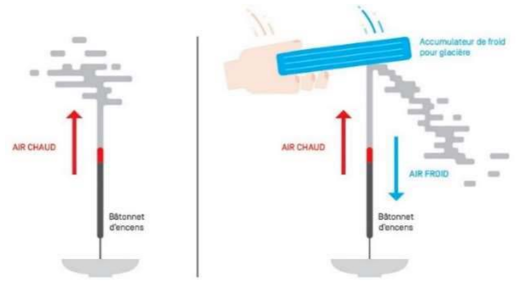


Tropical regions receive a greater amount of solar irradiation per unit area than polar regions.

On Earth, the average gap between two areas remains constant over time, there is thus a transfer of energy from the equator to the poles. This transfer is maintained by the two types of circulation of fluids of the planet, that is the atmosphere and the oceans.
The thermal contrast on Earth therefore takes place at low atmospheric pressure warmer in the sub-tropics than to the poles.

Whereas on Mars, the thermal contrast happens between the warm spring/summer hemisphere and cold autumn/winter hemisphere. Except during the equinox when the two poles, North and South, are cold.

- Meridional circulation:



We observe a meriodional flow circulation driven by the diferences in temperature and thus in the density of air (warm air dilates and goes up). Oscillations of atmospheric pressure are caused by this type of circulation.

Collective work "SVT, Cycle 4" 'Réseau Canopé', 2017

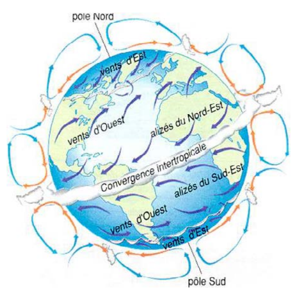
This flow transports hot air in the direction of the poles at high altitude and the cold air masses are transported towards the equator at low altitude levels on Earth: we mention Hadley Cells named after the English physicist (1735). This movement of warm and cold air masses generates winds.

On Mars, there is a single Hadley cell that joins the hemispheres together by transiting the equator.

2. Planetary rotation:

Air masses movement is also affected by the planetary rotation.
The rotation speeds of Mars and of the Earth as well as seasonal variations of insolation are identical, hence the similar meteorology.
As a matter of fact, we discover « jet stream » that meander round the planet from west to east in the southern and northern middle latitudes; the trade winds between the Tropics…

Earth



Source: eduscol.education.fr

11. Discussion of the results and conclusions

Earth's atmosphere is very different from the atmosphere of Mars: in terms of composition, thickness, radiation balance…
Earth absorbs a greater amount of energy that it reflects back in the atmosphere, the system pulls energy. Or, in the case of Mars, the radiation balance is negative and the planet losses energy. Thermal contrast is more significant on Mars than on Earth. The environmental conditions on Mars are: significant thermal gaps and violent winds.

Scientists had to design the SEIS seismometer both ultrasensitive and especially ultra-resilient to withstand the hostile environment of Mars characterised by extreme temperature oscillations, but also violent winds, atmospheric perturbations…

12. Explore More (additional resources for teachers)

- https://planet-terre.ens-lyon.fr/article/td-cycle-du-carbone2.xml
- “Planet Mars”, Françoic Forget – François Costard – Philippe Lognonné, Belin Edition

- Paper in ‘Sciences and Avenir’ « Solar flares : why would they be devastating for our planet », by Erwan Lecomte on 25.07.2014

- Collective work « SVT, Cycle 4 » Canopé Edition Agir, 2017

Annex 12

Erasmus+

This project is co-funded by the European Union

Instruments to measure the speed of the Martian wind

1. Introduction & Pb

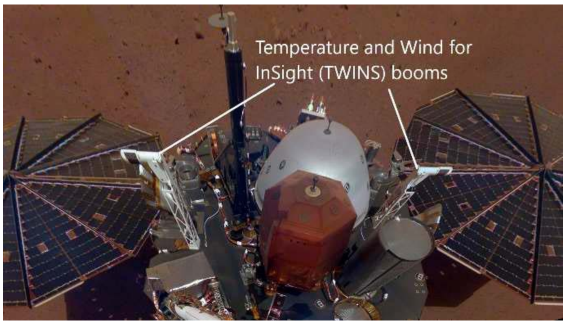
On Earth, the sensors used in the Météo-France network to measure wind force and direction are two types: mechanical sensors with a cup anemometer and a weather vane, and ultrasonic sensors.

Mechanical sensor Déolia 96

Ultrasonic sensor

For the Insight sensor, engineers chose TWINS (Temperature and Wind Sensors for InSight) sensors, very similar to the REMS (Rover Environmental Monitoring Station) sensors used for the Curiosity Rover, which has been operating since 2012 inside the Gale impact crater

TWINS sensors from the InSight weather station (© NASA)



NASA/JPL-Caltech

Insight has two sensors called « Twins ». They register air temperature, windspeed and wind direction 2 times per second. These data are recorded throughout all the mission, which will take one Martian year, equal to two terrestrial years

Pb : How can we determine the speed of the Martian wind despite a hostile environment?

2. Age of students 13-15 years

3. Objectives

The objective is to determine how the Twins sensors of the Insight probe work and why scientists need to know precisely the wind direction and the continuous temperature.

4. Primary subjects

Earth Sciences - Physics - Computer Science

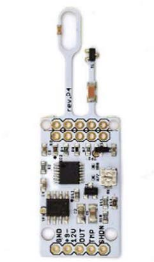
5. Time required 2hrs

6. Key terms

Anémomètre - Météorologie

7. Materials

- Hot wire anemometer sensor



The sensor's analog output OUT provides a tension value that we can correlate with windspeed as follows :

$$Vent_{ms} = 0{,}44704 \times \left(\frac{\frac{(V_{OUT} - V_{sansVent})}{(3{,}038517 \times (temp_C)^{0{,}115157})}}{0{,}0087288}\right)^{3{,}009364}$$

In case of a room temperature of 25°C, the website indicates a value $V_{no\ wind}$ = 1,3692 V. We can compare this value with that of our set up

TEMP sensor's output measures the ambient temperature.

$$Tmp = \frac{(V_{TEMP} - 0.400)}{0.0195}$$

V_{OUT} is the tension measured in volts at the OUT output of the sensor

$V_{no\ wind}$ is the tension measured in volts when the sensor is sheltered from the wind (for example, by a bell)

$Temp_C$ is the temperature of the room measured in °C

$Vwind_{ms}$ est is the wind unit measured in m/s

To follow windspeed evolution, we will connect the sensor with an Arduino

8. Background

Assembling a sensor and simple programming Arduino.

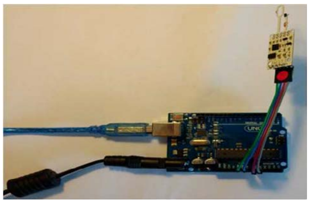
9. Procedures

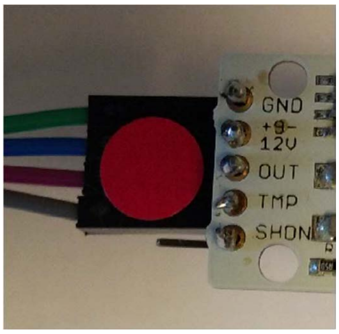
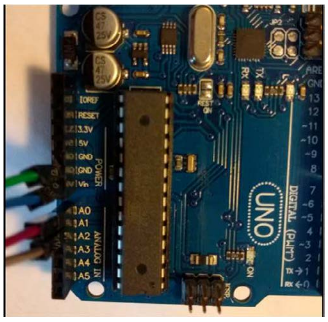
The Lander Insight is equipped with anemometers without mechanical parts to avoid wear problems (due to temperature differences, among other things).
We will use similar sensors for wind measurement and temperature measurement.
It is a hot wire anemometer: a resistance is heated by a 12V power supply, the higher the temperature of the wire the higher its electrical resistance. The wind will cool the resistance, it is this drop in temperature that makes it possible to know the wind speed.

To follow the evolution of the wind speed and temperature we will connect the sensor to an arduino

1. <u>Setting up the first sensor</u>

The cable connection for one cable is depicted in the picture below



<table>
<tr><td rowspan="5"></td><td>Sensor</td><td>Wire color in the image</td><td>Arduino</td><td rowspan="5"></td></tr>
<tr><td>GND</td><td>(green)</td><td>GND</td></tr>
<tr><td>+12 V</td><td>(blue)</td><td>Vin</td></tr>
<tr><td>OUT</td><td>(purple)</td><td>A0</td></tr>
<tr><td>TEMP</td><td>(olive)</td><td>A1</td></tr>
</table>

Below is the software that obtains the windspeed and temperature values in a Serial Monitor.

```
TP1
const int OutPin  = A0; // La sortie OUT du capteur sur la sortie analogique A0
const int TempPin = A1; // La sortie TEMP du capteur sur la sortie analogique A1
const int VSV = 284; // Valeur de la tension OUT en absence de vent
int OUT1;
int TMP1;
int ventms1; // valeur du vent en m/s
int temp1; // valeur de la température en °C

void setup() {
  Serial.begin(9600);
}

void loop() {
  // lecture des variables issues du capteur
  OUT1 = analogRead(OutPin);
  TMP1 = analogRead(TempPin);

  //Utilsation des formules pour donner les mesures en m/s et °C
  ventms1 = int(pow((((float)OUT1 - VSV) / 85.6814), 3.36814) / 0.44704); //conversion de la valeur du capteur en m/s
  temp1 = int (((((float)analogRead(TMP1) * 5.0) / 1024.0) - 0.400) / .0195);

  //affichage dans le moniteur des valeurs
  Serial.print(" Le vent est de ");
  Serial.print(ventms1);
  Serial.print(" m/s et la température est de ");
  Serial.print(temp1);
  Serial.println(" °C");
```

We then obtain

```
19:18:29.042 -> Le vent est de 0 m/s et la température est de 25 °C
19:18:29.108 -> Le vent est de 0 m/s et la température est de 25 °C
19:18:29.174 -> Le vent est de 0 m/s et la température est de 25 °C
19:18:29.241 -> Le vent est de 0 m/s et la température est de 25 °C
19:18:29.307 -> Le vent est de 0 m/s et la température est de 25 °C
```

2. <u>Setting up the second sensor:</u>

The set-up of the second sensor is similar to the first example.
Presented below is the assembly diagram and the corresponding set up.

To obtain information from the second sensor, 2 new OUT2 et TMP2 variables need to be created which will further be integrated in the same way as in the previous software.
The layout in the serial monitor is similar to the previous example:

```
//affichage dans le moniteur série des valeurs
Serial.print(" Vent mesuré par capteur 1 : ");
Serial.print(ventms1);
Serial.print(" m/s et Vent mesuré par capteur 2 : ");
Serial.print(ventms2);
Serial.println(" m/s");
delay(1000);//pause d'une seconde
Serial.print(" température du capteur 1 : ");
Serial.print(temp1);
Serial.print(" ° c et celle du capteur 2 : ");
Serial.print(temp2);
Serial.println(" °C");
delay(1000);//pause d'une seconde
```

In no-wind conditions we obtain from the serial monitor the following :

```
18:09:19.514 -> température du capteur 1 : 24 ° c et celle du capteur 2 : 24 °C
18:09:20.507 -> Vent mesuré par capteur 1 : 0 m/s et Vent mesuré par capteur 2 : 0 m/s
18:09:21.534 -> température du capteur 1 : 24 ° c et celle du capteur 2 : 24 °C
18:09:22.527 -> Vent mesuré par capteur 1 : 0 m/s et Vent mesuré par capteur 2 : 0 m/s
18:09:23.554 -> température du capteur 1 : 24 ° c et celle du capteur 2 : 24 °C
18:09:24.548 -> Vent mesuré par capteur 1 : 0 m/s et Vent mesuré par capteur 2 : 0 m/s
```

3. <u>Determining the direction</u>

Now that the 2 sensors are set up, it's interesting to compare the windspeed values and find out the direction of the wind.

To do this, we will consider that the sensor 1 is placed to the left on the station and the sensor 2 to the right.

We will make a simple comparison between the sensor 1 output and the sensor 2 output.
Below is the part of the software that compares the values and displays the dominant windspeed.

```
// comparaison des sorties OUT des 2 capteurs
if (OUT2 > OUT1) {
  Serial.print("Le vent vient de la droite et il vaut : ");
  ventms2 = int(pow((((float)OUT2 - VSV) / 85.6814), 3.36814) / 0.44704); //conversion de la valeur du capteur en m/s
  Serial.print(ventms2);
  Serial.println(" m/s");
} else {
  Serial.print("Le vent vient de la gauche et il vaut : ");
  ventms1 = int(pow((((float)OUT2 - VSV) / 85.6814), 3.36814) / 0.44704); //conversion de la valeur du capteur en m/s
  Serial.print(ventms1);
  Serial.println(" m/s");
}
delay(1000);//pause d'une seconde
```

<u>We will then determine the direction of wind and categorize wind data into 3 groups</u>:

- Strong wind,
- Medium wind
- Feeble wind

In order to do this, we will obtain the maximum of windspeed achievable with our set up. This value will be memorized as a MaxWind constant and will help compare values.

- If the wind measured is lower than 33 % of MaxWind, we will then display "the wind is feeble"
- If the wind measured is lower than 66 % of MaxWind, we will then display "the wind is medium"
- If the wind measured is higher than 66 % of MaxWind, we will then display "the wind is strong"

Here is an exemple :

```
void loop() {
  // lecture des variables issues du capteur
  OUT1 = analogRead(OutPin1);
  OUT2 = analogRead(OutPin2);

  // comparaison des sorties OUT des 2 capteurs pour déterminer le vent dominant
  if (OUT2 > OUT1) {
    VentDom = OUT2;
    Serial.print("Le vent vient de la droite.");
  } else {
    VentDom = OUT1;
    Serial.print("Le vent vient de la gauche.");
  }

  // comparaison du vent dominant avec ventMax
  if (VentDom < 0.33 * ventMax) {
    Serial.print("Le vent est faible");
  } else if (VentDom < 0.66 * ventMax) {
    Serial.print("Le vent est moyen");
  } else {
    Serial.print("Le vent est fort");
  }
  delay(1000);//pause d'une seconde
}
```

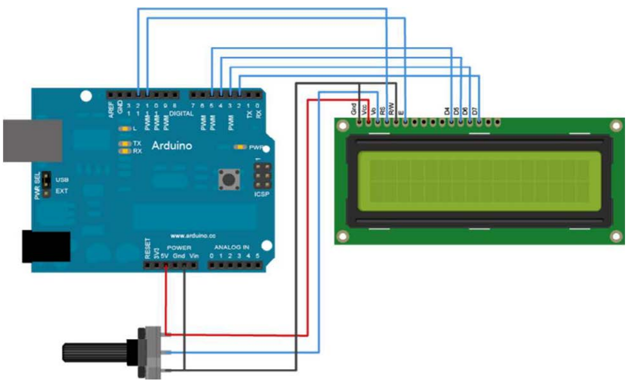
10. Discussion of the results and conclusion

The determination of wind speed on Earth as well as on Mars is a determining factor in meteorology. This measurement can be made using different instruments depending on the accuracy of the measurement, the environment...
Seismologists on land do not need to equip seismic stations with meteorological stations because seismometers are stored in cellars protected from atmospheric disturbances.
On the other hand, the interaction of the Martian atmosphere with the ground leaves its mark on seismic recordings.
That's why the engineers designed and placed a weather station on the Lander Insight and placed the SEIS seismometer under a wind protection shield, the WTS, which effectively blocks most wind effects, but cannot completely cancel them out. We will therefore be able to record these gusts of wind and by combining the data from the WTS station and the SEIS recordings learn more about the Martian environment.

11. To follow up activities

Using an LCD display
If we use a computer to visualize wind speed, we can have the messages obtained on an LCD display rather than have them on the Arduino serial monitor. This can be easily obtained, as in the picture below, with an Arduino development environment. The example is available if we open the suggested software in File>examples>LiquidCrystal>Display.

Set up with an LCD:



After having « HelloWorld » displayed, we can use the screen layout connected to our software.

The difference is in the displayed sequence, instead of Serial.print () we use lcd.print()

```
void loop() {
  // lecture des variables issues du capteur
  OUT1 = analogRead(OutPin1);
  OUT2 = analogRead(OutPin2);
  //On va d'abord effacer tout les caractères sur l'écran:
  lcd.clear();
  lcd.setCursor(0, 0); //ici, on se positionne en haut à gauche de l'écran

  // comparaison des sorties OUT des 2 capteurs pour déterminer le vent dominant
  if (OUT2 > OUT1) {
    VentDom = OUT2;
    lcd.print("Vent de droite");
  } else {
    VentDom = OUT1;
    lcd.print("Vent de gauche");
  }

  lcd.setCursor(0, 1); //On se place sur la deuxième ligne
  // comparaison du vent dominant avec ventMax
  if (VentDom < 0.33 * ventMax) {
    lcd.print("vent faible");
  } else if (VentDom < 0.66 * ventMax) {
    lcd.print("vent moyen");
  } else {
    lcd.print("vent fort");
  }
  delay(1000);//pause d'une seconde
}
```

12. Follow up activities (additional resources for teachers)

- Météo France : http://www.meteofrance.fr/prevoir-le-temps/observer-le-temps/moyens/les-stations-au-sol
- Météo à l'école : https://www.infoclimat.fr/pedagogie/
- Site Arduino

Annex 13

Erasmus+

SCHOOLS TUNE INTO MARS

This project is co-funded by the European Union

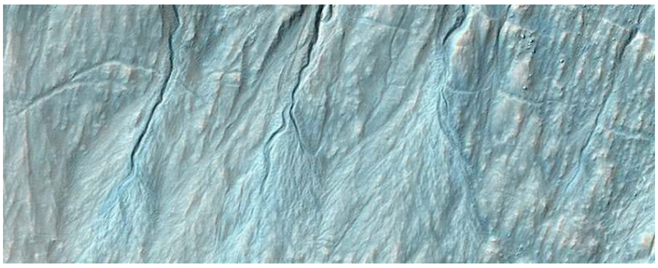
Saltwater - the source of ravines on Mars : Info or Hoax?

1. Introduction & Problem

Scientists believed that the process of soil liquefaction was responsable for the occurrence of ravines on Mars. That is, a process throughout which salts absorb atmospheric water-vapours when both temperature and humidity are elevated at the same time.
Such surface activity is also detected in the Antarctic, where similar water remnants are formed by trickling down brines on a shallow depth. But the night is a lot more cold on Mars than in the Antarctic and the active layer of ground that isn't freezing is a lot more shallow. This process, combined with the rarefied Martian air, can result in solely unnoticeable water quantities, certainly not enough for forming currents along the escarpment.

It seems that the process allowing ravines to be formed on Mars isn't due to the trickling of «saltwater » , but to another aspect.

Mars



A New Gully Channel in Terra Sirenum
Source: *NASA/JPL/University of Arizona*

Earth

Gully erosion in mudstones, PACA region
Source: www.lithotheque.ac-aix-eille.fr/Affleurements_PACA

How are ravines formed on Earth and on Mars ? Is soil erodibility the same ?

2. Age of students 13 - 15

3. Objectives

Explain ravine shaping on Earth and Mars and determine the soil erodibility factor (also known as the k-factor) and explain the sediment transport and deposition process.

4. Primary subjects

Physics –Geoscience - Chemistry

5. Additional subjects

6. Time required: 2h

7. Key terms

Ravine – Erosion – Soil erodibility factor– Sediment transport and deposition

8. Materials

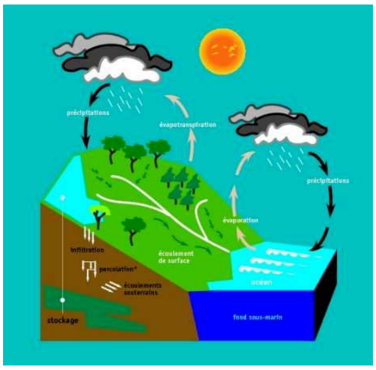
Ravine creation on Earth	Franklin Flask	Image processing
- Laboratory basin sink - Water - Wedge - Sand	- One Franklin flask (laboratory vessel) - Water - Arduino Temperature Sensor - Hot plate - Laboratory stopper - Support stand	- Qgis software - Satellite Images obtained from Hirise

9. Background

The fundamentals of the hydrologic cycle and CO2 cycle on Earth.

10. Procedures

<u>On Earth :</u>

<table>
<tr><th>Hydrologic Cycle</th><th><u>Ravines on Earth simulation:</u></th></tr>
<tr><td>


</td><td>
- Simulation protocol, in A. Prost, The Earth, 50 experiments to discover our planet, Belin, 1999.

1 – Equally spread the sand in the basin sink (0,2 mm) and level the surface.

2 – Give the bowl a slight slope by placing a wedge on one side.

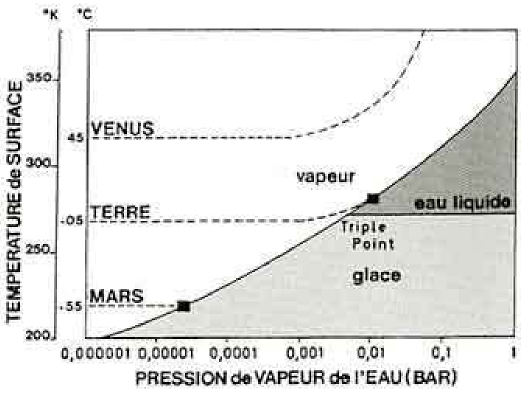
3 –Place the hose at the highest point of the bowl.

4 – Gently turn on the tap and lead the water jet to the bottom of the basin (downstream) : the trickle of water infiltrates in the sand.
Increase water flow until water stays on the surface.
</td></tr>
<tr><td><u>Source :</u> Water Cycle on Earth (© DocSciences – P. Veyret)</td><td><u>Author :</u> (Van Vliet-Lanoë, 2005)</td></tr>
</table>

1. Use the available documents and the modeling protocol for the process of ravine formation on Earth (Erosion – Transport - Deposition)

<u>On Mars :</u>

Pressure-Temperature phase diagram for water and the position of planets:



<u>Author :</u> (Van Vliet-Lanoë, 2005)

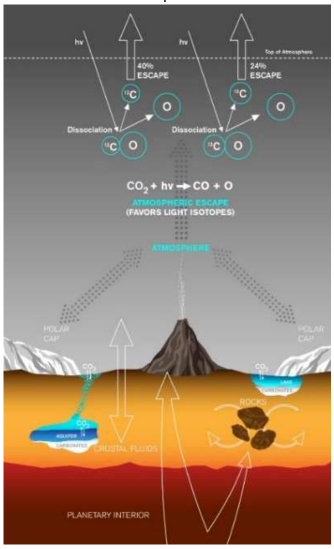
Tens of thousands of such ravine formations, having at times the length of many kilometers, cross slopes situated at Mars' mid-lattitudes. Their formation involved great quantities of liquid, which are very hard to explain. But the planet's atmospheric pressure is so low that any pure surface water inevitably freezes, evaporates or quickly boils. In fact, temperature and pressure conditions (see phase P° and T° diagram for water) are really close to pure water's critical point.

Isn't actually water that digs ravines on Mars ? What is in fact the factor responsible for this process ?

Martian atmosphere composition and Earth's atmosphere composition:

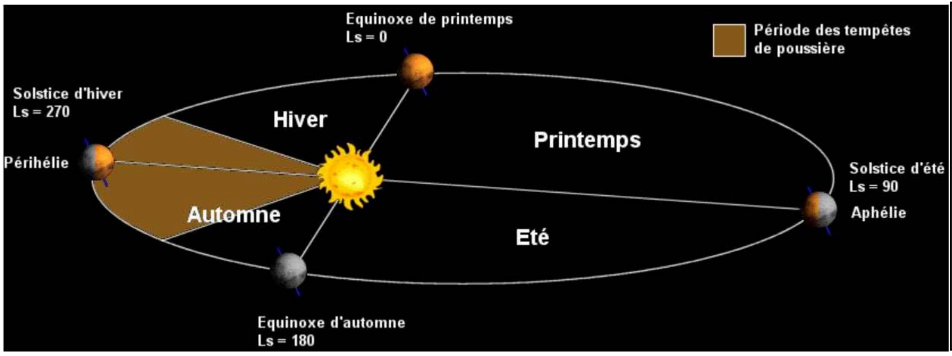
Gas	Mars (%)	Earth (%)
CO2	95,97 %	0,035 %
Ar	2 %	0,93 %
N2	1,89 %	78 %
O2	0,146 %	20,6 %
CO	557 ppmv	0,2 ppmv
H2O (varying)	0,021 %	0,4 %
O3 (varying)	0,01 – 5 Dobs	300 Dobs

CO2 cycle on Mars :
Source : doc. Lance Hayashida/Caltech



2. Formulate a plausible hypothesis:

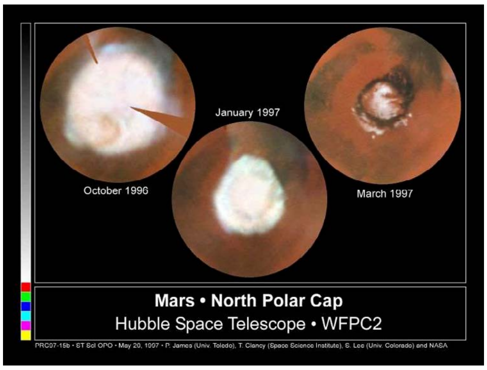
Hypothesis : CO2 could be responsible for ravine creation on Mars.
Distribution of seasons during a Martian year:



Sl : means Solar Longitude, measured using angles. One Martian year equals 360 degrees, i.e. one complete rotation around the Sun.

One degree in solar longitude matches the angle between the planet and the Sun on the day of Boreal spring equinox.

Photo Credit: © Philippe Labrot, according to the Dynamic Meteorology Laboratory diagram. Little by little by Calvin J. Hamilton

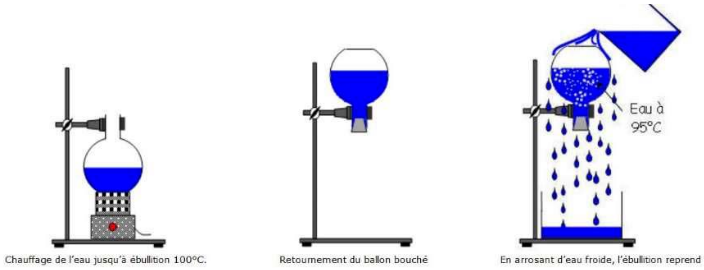
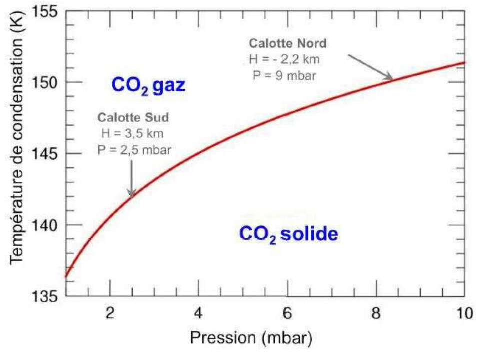


These white polar caps fluctuate in size depending on seasons. Towards the end of summer, only the so called **permanent** or **residual** polar caps remain, formed of "eternal ice fields". The surfaces of white polar caps grow in autumn and winter as they restore and surround by a layer of frost, frost that undergoes condensation in autumn and winter and then sublimation in spring and summer. We thus refer to them as **temporary or seasonal caps.**

Droits réservés - © 1996-1997 Phil James (Univ. Toledo), Todd Clancy (Space Science Inst., Boulder, CO), Steve Lee (Univ. Colorado), NASA

There is also the seasonal variation of global surface pression. Whenever there is a large residual cap to the north or to the south (winter and summer solstices), the pression is 75 Pa times weaker than the anual mean value. In absence of residual nothern or southern polar caps (spring and autumn equinoxes), the global pressure is 75 Pa times stronger than the mean value. This variation of 150 Pa between the equinox and solstice (25% of the average pression) shows that 25% of atmospheric CO_2 undergoes condensation and transforms into dry ice during winter and sublimes back the following spring. This transfer of 25% atmosphere between the north and the south that takes place 2 times during a martian year could be the cause of peculiar and generalized storms.

CO2 behaves differently on Mars because of T° and P° values.

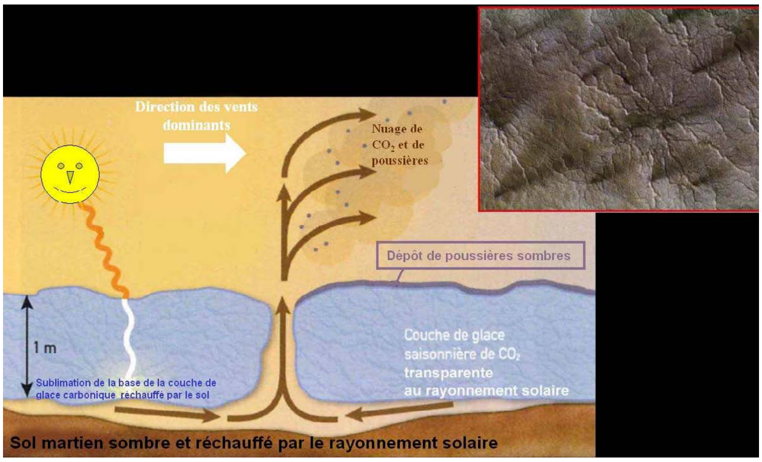
Franklin Flask Experiment	Phase diagram for CO2
We will experiment with changes in the status of a chemical species, in this case water, to show students the effect of T° and P° on these changes.  Source : https://applilocale.ac-besancon.fr/geogebra/labo/films/franklin/bouillant.htm	 H : average elevation of the surface P : equilibrium surface pressure *Source : Thesis « Seasonal condensates on Mars » Florence Grisolle.* Frost occurs when the temperature of air falls below -125°C, temperature at which CO_2 changes its state of matter in this range of pressure.

Temporary caps, thin layers of frost, seem mainly formed of dry ice (carbon dioxide ice). But what do those dry ice caps become and what do they transport?

In winter, a layer of carbonic frost forms on the martian regolith. During spring, this layer that is translucent to solar rays is heated from its base.

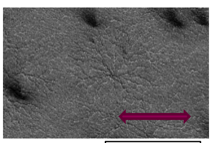
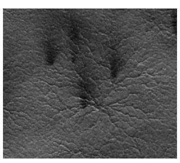
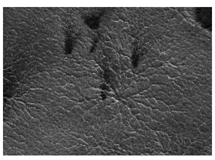
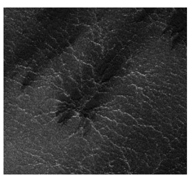
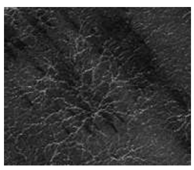
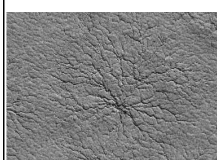
The ice sublimes: i.e. transitions directly to the gas phase. Gaseous CO_2, trapped underneath the ice layer, is dispersed into regolith pores where the pression increases. The pression can then generate the fracturing of the top ice layer and the swift decompression of the regolith made of broken rock and dust drifted CO_2 thus allowing the drainage of a part of soil by digging a network of channels more or less convergent (woven meshes).

Dust brought to the surface will be deposited in the surrounding area, shaped by the dominant winds. (les éventails).
Source : https://planet-terre.ens-lyon.fr



Rights reserved - © 2003 Piqueux et al. ;NASA/JPL/University of Arizona

<u>To exemplify the phenomenon :</u> Present the sequence of images using Qgis software
You can open these image from a Qgis rendered file and thus overlay the layers to see the evolution of woven webs.

End of Winter	Start of Spring	Middle of Spring	End of Spring	Start of Summer	Summer
 100 m					

This sequence is a part of a December 2007 AGU presentation : "Spring at the South Pole of Mars". The sequence of events is studied in a series of images taken during spring and summer in the southern hemisphere and depicts the sublimation of a specific woven web.

End of Winter: We zoom on a single "web". There is a bunch of channels radially organized on the surface, covered by a slab of seasonal translucent carbon dioxide ice (dry ice).

The "date" is Ls = 181.1 (Ls being the unit of time on Mars : at Ls = 180, the Sun crosses the Equator to the south ; at Ls = 270, the Sun reaches its southernmost latitude and Summer begins.)

Start of Spring: obtained at Ls = 195,4. Four dust winds escaped from the woven channels. Translucent ice is warmed from the ground up and evaporated under the seasonal frost layer. Gas finds a weak spot and escapes to the top of the frost layer, transporting the surface dust across the ice. Dust is then swept away by the dominant wind.

Middle of Spring: calculated at Ls = 199,6. The dust is stuck in the channels.

End of Spring: obtained at Ls = 226 shows that the winds' direction changed, that the existing "fan system" is now elongated and an increasing number of new dust winds (éventails) originate from the channels as the frost layer gets thinner.

Start of Summer: established at Ls = 233,1, when a great part of surface frost disappears. The channels are translucent because the Sun shines more directly on their walls. A slim layer of darker dust can be seen on the bottom of the largest channels.

Middle of Summer: calculated at Ls = 325,4, in the middle of austral summer. All seasonal ice disappeared. It's obvious that the channels were dug in the surface and not into the seasonal frost layer. The dust storms eventeils disappeared, meaning that they no longer contrast with the surface material from which they originated. The surface material is dirt solidified by iced water covered by a layer of approximately 5 cm of dried out silt, whici is redistributed every season within this process of éventail creation and transport.

Written by: Candy Hansen (12 December 2007) – Source : NASA/JPL/University of Arizona

11. Discussion of the results and conclusions

Water is the factor of erosion in the case of ravine creation on Earth; on Mars, that factor is CO2.
This activity allows students to understand that the action of chemical species depend on Temperature and Pression values.
It is important that students develop a sense of critical thinking so that they remain unbiased and inquiring with every paper published in the scientific field.
Science is not a fixed discipline, it rather evolves depending on technological and scientific progresses.

12. Follow up activities

Show the effect of erosion by CO2-enriched water: Karst landforms

Source : http://www.lithotheque.ac-aix marseille.fr/Affleurements_PACA/13_allauch/carte_geologique_allauch250.htm

—Massive coherent, non-porous carbonate rocks form rocky slopes in the geological landscape. Vertical limestone walls and talus slopes of marly limestone are displayed in an alternate matter. These rocks are deeply eroded by the water flow and form the so called Pepino hills or Lapiaz: grooves with a circular shape formed on tilted slopes. The dissolution process is also the starting process for rock shelter formation or glacial potholes carved into the rocky bed of a watercourse. The erosion is caused by rock blocks transported by temporary water flows.

— Limestone erosion helps enlarge vertical or tilted joints that affect limestone bedding plane. The phenomenon causes rock blocks to detach from cliffs and collapse at the bottom of bedding planes.
—The karst erosion depicted here formed under a vegetation cover, as water rich in carbon dioxide percolates the soil and slowly dissolves the chalk to give it the characteristic shaping of calcareous massifs. Nowadays, this chemical erosion has little to no effect on the rock outcrops.

13. Explore More (additional resources for teachers)

- https://www.uahirise.org/
- https://applilocale.ac-besancon.fr/geogebra/labo/films/franklin/bouillant.htm
- http://www.lithotheque.ac-aix-marseille.fr
- A. Prost, *La Terre, 50 expériences pour découvrir notre planète*, Belin, 1999.
- https://planet-terre.ens-lyon.fr/

Annex 14

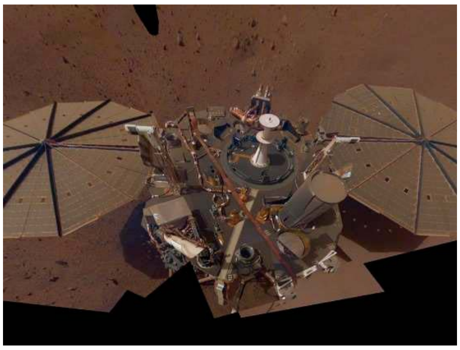
Erasmus+

This project is co-funded by the European Union

Landscapes shaped by dust tornadoes

1. Introduction & Pb

Mars InSight lander captured a wind tornado that cleared the dust that has been piled on the lander's solar panels since its arrival.



« On the 1st of February 2019, two solar panels of the InSight lander that investigate the geology of planet Mars regained their previous power. This event was associated to a wind tornado which lifted a part of the dust particles covering the panels. It isn't an isolated event on Mars, but it is the first time this has been studied having complete meteorological parameters. »

Source : *Sciences and the future « A Martian passing dust wind swept over the pannels of InSight's solar pannels »*

Source : NASA/JPL-Caltech

The meteorological station APSS (Auxiliary Payload Sensor Suite) recorded a maximum wind speed of 45km/h. As the same time as the dust devil, there was a 13% drop of in atmospheric pression. According to the scientists in charge of the sensor, those conditions are consistent with the passing of a so-called "dust devil".

These tornadoes leave highly visible traces of their crossing on the Martian landscape and thus contribute to the particular geomorphology of the planet Mars, which is not the case on Earth.

Traces left by Dust Devils in the Richardson crater :

The dunes in the image are situated 72° to the south; on Earth, they would have been beyond the Antarctic circle. Due to their position being too close to the pole, enormous temperature variations appear throughout the Martian year. The image on the left was captured at the vernal equinox in the Southern Hemisphere which marks the end of summer and the beginning of fall.

There are still many visible **whirlwind traces**, displayed as subtle intersecting lines, but they will gradually be covered anew by the dry ice layer as austral winter settles in.

NASA/JPL/University of Arizona

Pb : How do these Dust Devil form on Mars ? Is there such a phenomenon on Earth?

2. Age of students: 13 – 15 years

3. Objectives

Understanding the physical laws that govern the movement of Air Masses, i.e. atmospheric convection. But also the process underlining Dust Devils' formation to further deduct the causes of traces left on the soil so representative of the planet Mars.

4. Primary subjects

Physics –Earth Sciences

5. Additional subjects

6. Time required: 2h

7. Key terms.

Dew point depression – Atmospheric convection –

8. Materials

Dust vortex modeling
- Incense
- Plexiglass sheet
- Candle
- Ice cube tray

Pressure sensor (see: Arduino Technical Data Sheet)

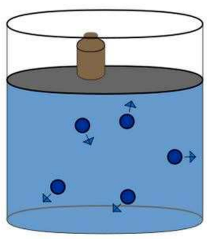
9. Background

<u>Displacement of stable air masses by atmospheric convection :</u>

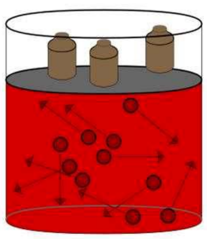
The ratio between pressure values and temperature values (Gay-Lussac's Law) underlying the atmospheric convection principle:

French chemist and physicist Louis Joseph Gay-Lussac (1778-1850) proved that there is a connection between the pression and temperature values of a gas. For a constant volume and a given quantity of a gas, he observed that pressure of a given gas increases directly with the absolute pressure of the gas and vice versa. The mathematical relationship he deducted from his experiments is called Gay-Lussac's law.

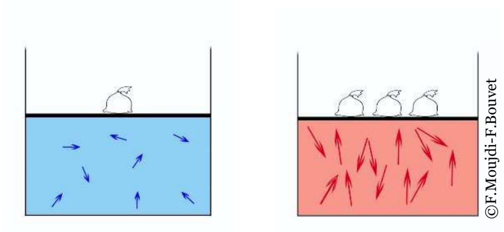
« Gay-Lussac's law describes the relation between the pression and the temperature of a gas. It stipulates that, for a constant volume, pressure of a given quantity of gas is directly proportional to the absolute temperature of the gas. »



Temperature T



Temperature 3T



According to this kinetic-molecular theory of gases, an increase in temperature should cause an increase in the kinetic energy of particles.

The molecular collision risk is higher, which causes a change in pression. If volume of the gas remains constant, its pressure will increase.

10. Procedures

Same as on Earth, winds on Mars are powered by solar thermal energy. Observations made by the Viking landers show that atmospheric dust particles on both Mars and Earth can be lifted by dust storms. These phenomena can reach significant dimensions. A tornado draws in the surrounding air masses and concentrates them in its core.

Amazonis Planitia

A large dust whirl projects a serpentine shadow on the Martian soil.
The photo covers an 644m wide area. The North is facing upwards. The dust wind reaches 800m altitude and 30m in diameter.
A westerly breeze half as high as the dust whirl produced a slight curve in the middle. The photo was taken when the planet is at its aphelion (farthest point from the Sun).

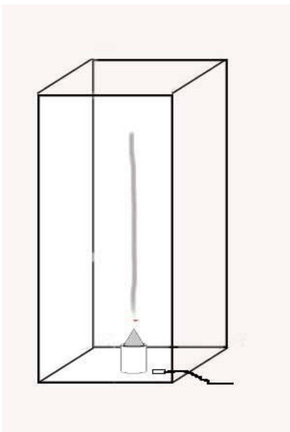
Satellite: Mars Reconnaissance Orbiter
Copyright: NASA/JPL-Caltech/University of Arizona

The same phenomenon happens on Earth, generally during summer. A dust devil is formed from the soil up when certain criteria is met. Dust tornadoes are whirlwinds of air masses entraining dust particles.

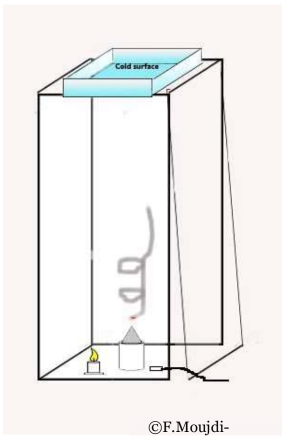
Air masses dynamics model :
Conduct the following experiment to emphasize the movement of air masses.

P° sensor on the inside and on the outside :

Without external disturbing factor



With external disturbing factor



1. <u>Write down the results :</u>

	Experiment 1		Experiment 2	
	T=0	T=3'	T=0	T=3'
Pression inside the tube				
Pression outside the tube				
Interpretation of laboratory results				

2. Using the obtained results, **explain** the phenomenon that took place during the experiment and what exactly allowed the movement of warm air masses.

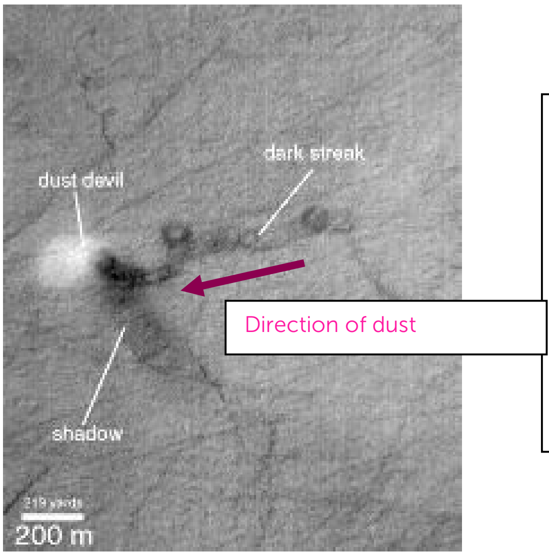
I. Tornado in action :

We have just shown that the ascent of hot air is the trigger of a tornado. This updraft also allows horizontal rotations to become vertical because of the tangential shear of vertical winds.

Afterwards, when the tornado is produced, air rises to its core, generating the violent suction of surrounding air and sustains the dew point depression.

When a dust devil travels on the surface of Mars, it can gather and disrupt the detached dust layers, leaving behind darker trails.

<u>Dust in action, photographed on orbit by MGS on 11/12/1999 :</u>



- <u>Dark streak:</u> The trace left by the passing of dust (70m wide) that swept the thin layer of clear dust particles covering the soil. Its sinuous form and dark color make the trace highly visible.

- <u>Dust devil:</u> Dust cloud

- <u>Shadow:</u> The shadow of the tornado on the soil.

Reserved rights- © 2004 NASA/JPL/Malin Space Science Systems

11. Discussion of the results and conclusions

Dust devils on Mars are created in the same way they occur on Earth. The soil gets warmer during the day and heats the air just above the surface (through radiation). The mass of hot air rises and the colder mass of air above falls, thus creating vertical convection cells. A horizontal burst of wind will swirl the convection cells, which will then create a dust whirlwind.
Tornadoes that bring dust with them will contribute to the shaping of Martian landscape, leaving traces behind.
But these traces will gradually be covered once again by dry ice during austral winter. Mars' appearance changes depending on the season.

12. Follow up activities

- https://visionscarto.net/once-upon-a-thirst

13. Explore More (additional resources for teachers)

- https://planet-terre.ens-lyon.fr/article/mars-2005-04-13.xml

- https://www.nirgal.net/mars_science_atm.html

-

Annex 15

Erasmus+

SCHOOLS TUNE INTO MARS

This project is co-funded by the European Union

Volcanos compared: why a smaller planet has a bigger volcano?

1. Introduction & Pb

The size and shape of a volcanic cone on the Earth allows the volcanologists to learn many things of the

history of the volcano as well as to know about the composition and other related physical properties of the magma that originated it, as for instance, its viscosity.

Many students know that a volcano on the planet Mars, Olympus Mons, is the biggest mountain in the Solar System, or at least, its highest volcano. It size (almost 22,000 m high) more than doubles the highest mountain on the Earth: another volcano located in Hawaii (Mauna Kea, 10,000m high).

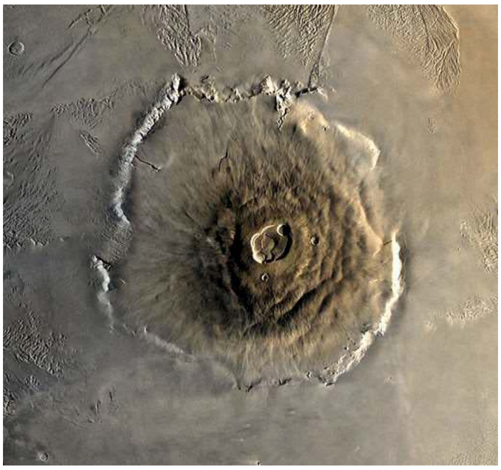


Figure 1: Olympus Mons
© NASA

2. Age of students 16 to 18 years old.

3. Objectives

Through this activity, students can:

- compare the sizes of the two planets (Earth and Mars);
- compare the sizes of the highest volcanoes on both planets, Mauna Kea on Earth and Olympus Mons on Mars;
- be aware that Olympus Mons is not only the biggest volcano in the Solar System, but also its biggest mountain;
- make calculations to calculate the volume, mass, density and weight of the two volcanoes;
- compare the eruptions of both volcanoes and to understand that both are shield volcanoes formed by lavas with a basaltic composition.

4. Primary subjects

General science, Geology, Maths, Physics, Geometry

5. Additional subjects

Arts (drawing)

6. Time required 30 minutes plus 30 minutes more for the "Follow up activities"

7. Key terms

Volcanoes, basalt, shield volcanoes, volume, density, gravity, weight, scale, equivalence of units, asthenosphere, deformation

8. Materials

- graph paper,
- ruler,
- compass,
- pencil

9. Background

Figure 2: Olympus Mons compared to France. Published under Creative Commons Attribution-Share Alike 4.0 International

Many students find difficult to compare the dimensions of the different planets in the Solar System, as well as the relative size of the volcanos of both planets.

Through a series of simple calculations, they learn about the size of its biggest mountains. From its volume, composition and density, they can calculate their respective weights.

They can produce, then, theories to explain the differences in size as well as to better understand the dynamics of a planet with tectonic plates moving upon a plastic asthenosphere compared to another one with no active tectonic plates in the present.

10. Procedures

Before starting the activity, ask the students to use an engine search (i.e. Google™) in order to find out which are the biggest mountains on Earth and Mars as well as its dimensions (height and maximum diameter.

Their results should be:

PLANET	MOUNTAIN	TYPE	HEIGHT	DIAMETER
Earth	Mauna Kea (Hawaii)	Volcano	about 9,100m*	about 180km*
Mars	Olympus Mons	Volcano	about 25,000m*	about 600km*

*Results may differ from one source to another because of the *reference surface* to calculate the height as well as the shape of the basis that is not circular and therefore the measure of the diameter approximates the *mean diameter*.

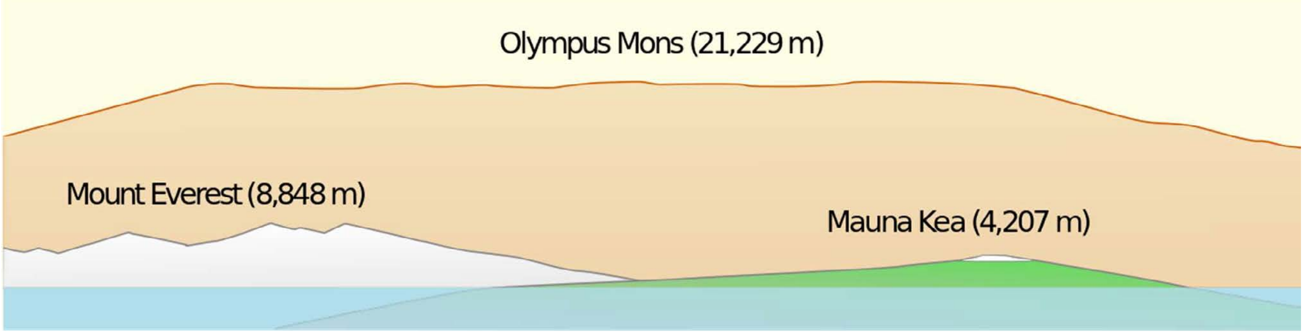


Figure 3: Olympus Mons compared to Mount Everest and Mauna Kea.
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Now give them a graph paper and ask them to represent a cross section of both volcanoes.

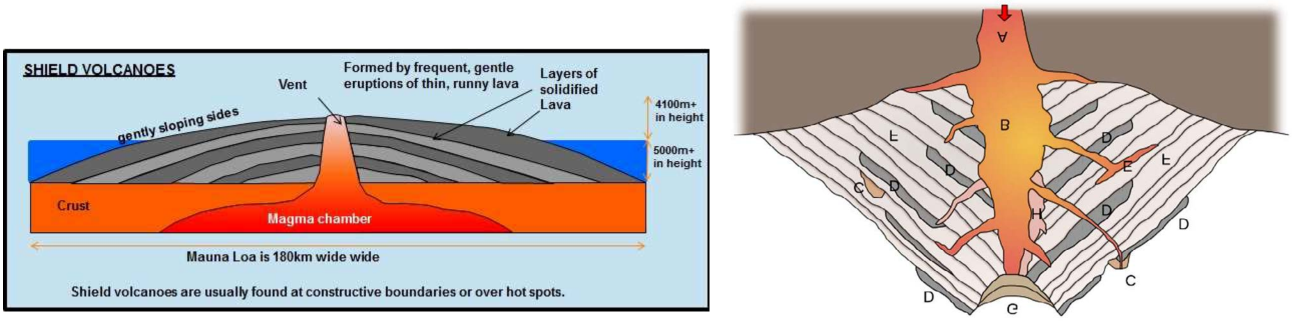
Scales suggested are: - horizontal: 1:2,500,000;

- vertical: 1:1,000,000.

Then, ask the students to calculate the tangent of the slopes of both volcanoes using the following formula:

Tangent = height / radius

It is expected both results to be quite similar. As the Mauna Kea is a typical shield volcano formed by runny, basaltic high temperature lavas, with low angle slopes, we can find out that Olympus Mons is a Martian shield volcano also formed by basalt type lavas. The samples analysed in Mars confirm this theory.



Shield volcano (Wikimedia commons)

Stratovolcano (Wikimedia commons)

Figure 5: A shield volcanoes compared to a stratovolcano.

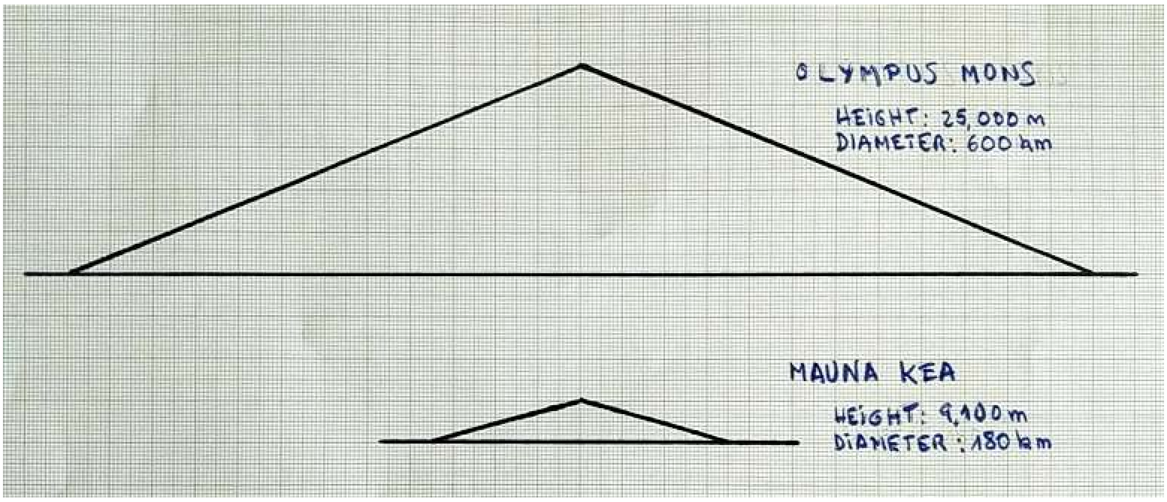


Figure 6: The two volcanoes plotted on a graph paper. Scales: horizontal 1:2,500,000; vertical: 1:1,000,0
Drawing: Xavier Juan

11. Discussion of the results and conclusions

A final discussion about the results should lead to the question: why Mars (a smaller planet than the Earth) has such an enormous volcano compared to the Earth volcanoes?

Possible answers are:

- *In Hawaii, the movement of the Pacific plate upon a unmoving plume causes the formation and extinction of successive volcanos that d0n't have time enough to grow very high.*
- *In Mars an unmoving plume feeding the volcano for a long time causes a higher volcanic building.*
- *A lower gravity in Mars seems to favour a higher volcanic activity.*

12. Follow up activities

Calculating the volume of the two volcanoes:

Accepting that the approximate shapes of the two volcanoes is a cone, and knowing its height and radius, students could calculate both volumes by using the formula:

$$V = 1/3\ \pi r^2 h$$

Where r is the radius of the base an h, the height of the cone.

Calculating the mass of the two volcanoes:

Now, knowing the volume of both volcanoes and the average density of basalt (about 3,000 kg/m^3), the students should be able to calculate the mass of the two volcanoes by using the following formula:

$$\rho = m / V$$

where ρ is the density, m the mass and V the volume.

Calculating the weight of the two volcanoes:

Now, provided that the average gravity is for the Earth and Mars (9.8m/s^2 and 3.7 m/s^2, respectively), pupils should be able to calculate the weight of both volcanoes:

$$W = mg$$

Where W is weight, m the mass and g the acceleration of gravity.

Discussing the results:

Knowing the weight of Mauna Kea upon the Earth crust and Olympus Mons upon Mars, ask the students to propose explanations for the fact that the Earth's crust is depressed around Mauna Kea because of its weight and that there's no evidence of such a sinking of Mars surface around Olympus Mons.

Possible answers are:

- The pressure (= weight (force) / surface) is less on Mars than on the Earth.
- As the outer layer of the Earth (lithosphere) is broken in several tectonic plates, the Pacific plate behaves apart from the rest of plates to the pressure caused by Mauna Kea.
- Mauna Kea is not a single volcano in the Hawaii area, but one of a complex of volcanoes with a resulting weight bigger than the one that they have calculated.
- In the Earth, the existence of a plastic layer below the lithosphere (asthenosphere) allows the Pacific plate deformation because of the weight of
  the Hawaii volcanoes. This is not the case for Mars where it seems that there's not a plastic layer like in the Earth.

All the possible answers could be true but, probably, the most significant is the absence of asthenosphere in Mars

13. Explore More (additional resources for teachers)

NASA Mars Exploration Program: https://mars.nasa.gov/

A flight simulation over Olympus Mons : https://www.youtube.com/watch?v=OTazRNGXSC8

Olympus Mons *(largest volcano in the solar system!)*: https://mars.jpl.nasa.gov/gallery/atlas/olympus-mons.html

Annex 16

Erasmus+

SCHOOLS TUNE INTO MARS

This project is co-funded by the European Union

How to estimate epicenter location with only one seismic station on Earth

1. Introduction & Pb

Usually, students work on epicenter location by using origin time of the earthquake and arrival time of seismic waves. With records from three seismic stations, it is possible to estimate the epicenter location.

On Mars, there is only one sensor to detect and to estimate the epicenter location. We propose here to invite students to estimate the epicenter of the Mw 9.0 Tohoku-Oki earthquake (Mars 11, 2011, Japan), with only one seismic station.

2. Age of students 15 – 17 years

3. Objectives

Use an approach similar to that used by researchers working on the mission insight to estimate the epicenter location of an earthquake with only one record from a three-components seismic station.

4. Primary subjects

Physics – Earth Science

5. Additional subjects

6. Time required: 2h

7. Key terms

Rayleigh waves, Epicentral distance, azimut

8. Materials

Supports used :

- Data from RESIF network
- SeisGram2K80_ECOLE© : To download free of charge from the Edumed website: http://edumed.unice.fr/fr/tools-lab

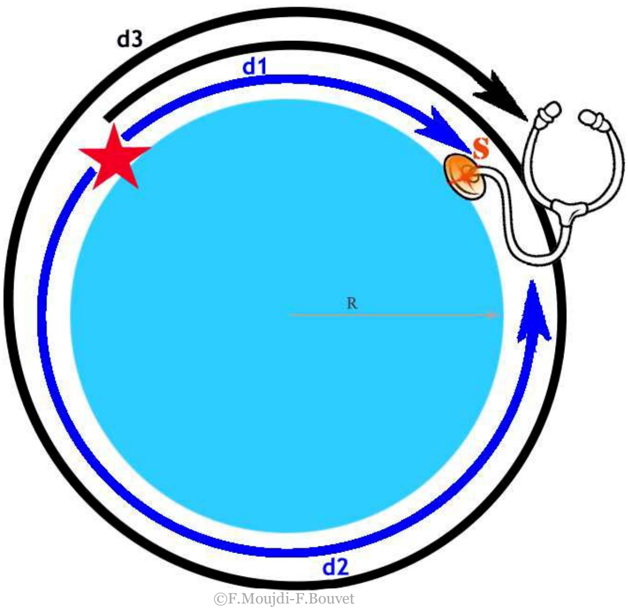
Data :

- The Mw 9.0 Mars 11, 2011 Tohoku-Oki earthquake (Japan), recorded at the station CALF (Observatoire de la Côte d'Azur, Calern, France).

9. Background

- Rayleigh waves detection:
    - They are low periods waves, the associated arks are longer than arks from body waves. They're also higher in amplitude.
    - If the earthquake has sufficient energy, the surface wave can pass several times at the station: packs of longer period signal can appear in the signal.

es (Fig. 1)



$$distance_{(source/station)} = \frac{t3 - t2}{2} \cdot \frac{2\pi R}{t3 - t1}$$

Figure 1. Theorical approach to estimate an epicentral distance from Rayleigh waves. White start seismic source. Black inverted triangle: Seismic station. d1: shortest distance between the source and the station. d2: longest distance between the source and the station. d3: travel along the d1 distance plus a complete rotation around the planet. t1: arrival time of Raleigh waves after the propagation along d1. d2: arrival time of Raleigh waves after the propagation along d2. T3: arrival time of Raleigh waves after the propagation along d3. R: radius of the planet.

10. Procedures

Students are then invited to pick Rayleigh waves from the Tohoku-Oki earthquake, recorded at the station CALF.

- pick of the three arrival times, and compute of the epicentral distance.

Here, the automatic tool provided by SeisGram2k is not used. Students read arrival times and compute manually the distance to the epicenter from the formula in Figure 1.

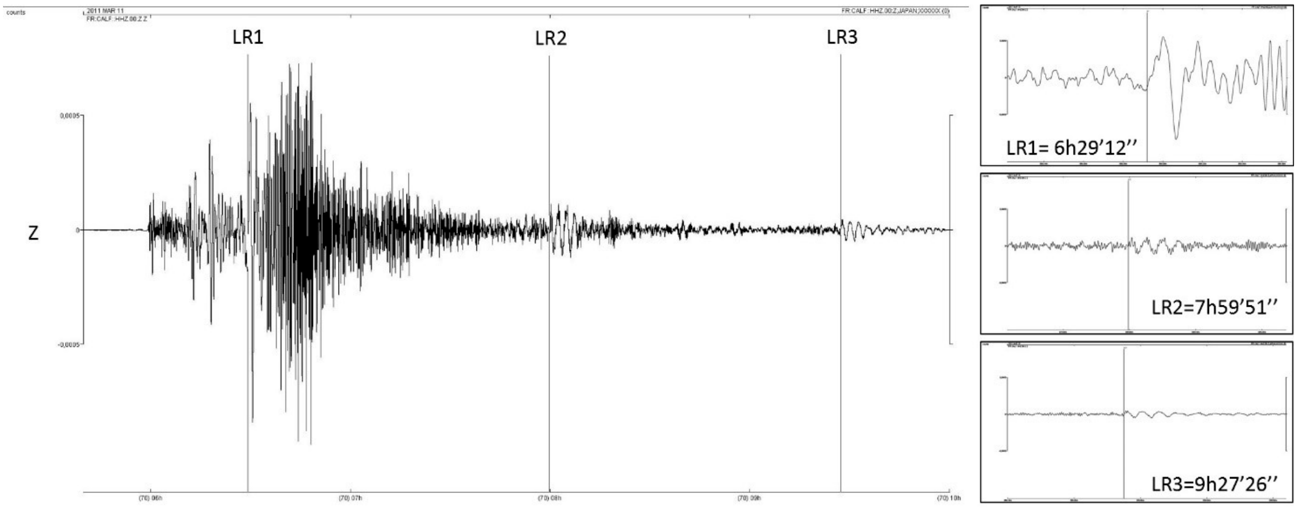


Figure 2. Pick of the three passage of Rayleigh waves (Tohoku-Oki earthquake) at the station CALF. Right column: zoom of each pick, with the observed arrival times (UTC).

10. Discussion of the results and conclusions

In this case, the epicentral distance computed is equals to 9841 km.

- Estimate the backazimuth.

The epicentral distance computed previously indicate that the epicenter is on a circle, which the radius is equals to 9841 km. Two parameters are required to find the correct position on this circle: the azimuth, and the backazimut. The azimuth gives the direction of the first ground motion in the horizontal plane at the station, positive clockwise. The backazimut gives the sense where the epicenter is. The polarity of the P wave from the vertical component is required: i) if the polarity is positive, the first motion is upwards, the backazimuth is equals to the azimuth plus 180°; ii) if the polarity is negative the first motion is downwards, the backazimuth is equals to the azimuth.

SeisGram2k allows to determine the azimut value, with the rotation tool. It's possible to virtually rotate the geographical frame and to compute amplitudes in the new frame. By rotating the frame, amplitude of the P wave vary between two maxima, passing by a null value, on each component. The rotation value which allows to cancel the P wave on the East component give the azimuth: the motion is only in the North direction of the new geographical frame.

a. Detect the first P waves on each horizontal components.

Use zoom tool of seismogram to select a time windows adapted to highlight the first P wave. The increase/decrease amplitude tool could be used.

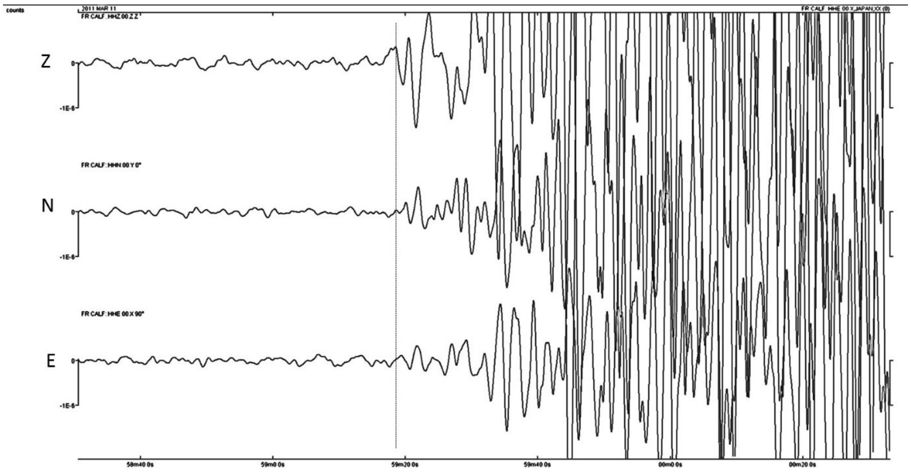


Figure 3. Records of the Tohoku-Oki earthquake. Vertical black dashed line: pick of the P wave. E: East component. N: north component. Z: vertical component.

b. Rotate horizontal component (clockwise) to cancel the P wave on the East component

In this case, a rotation equals to +30° allows to cancel the P wave amplitude on the East component. The first motion is in a direction equals to +30° (clockwise) from the North in the real geographic frame: it's the value of the azimuth.

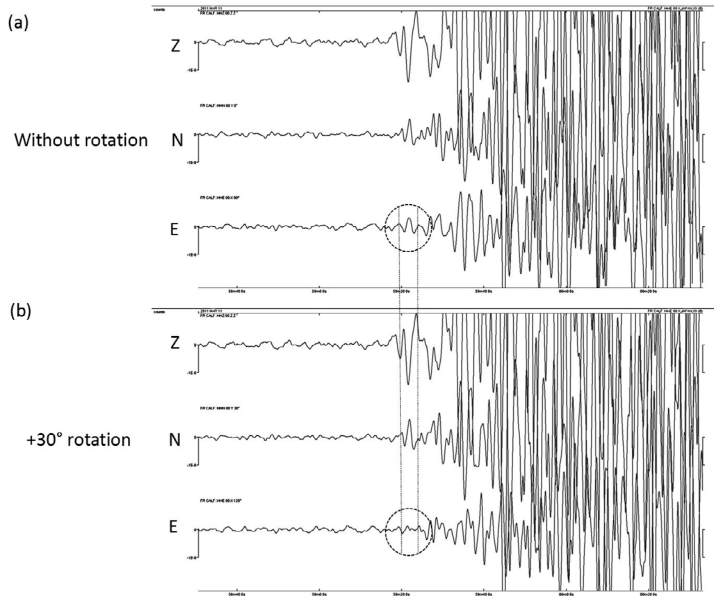


Figure 4. Records of the Tohoku-Oki earthquake. (a) Raw seismograms. Black dashed ellipse: identification of the P wave from the east component. (b) Seismograms after a rotation equals to +30°: the P wave amplitude is canceled. E: East component. N: north component. Z: vertical component.

c. Estimate the backazimut value from the P wave polarity on the vertical component

In this case, the P wave is downwards on the vertical component (Fig. 3): the backazimut is equals to the azimuth.

Information file in SeisGram2K indicate an azimuth equals to 329.5°. This azimuth is corresponding to the direction at the epicenter from the geographic North to the station: it is equals to the angle between the geographical north minus the backazimuth (counter-clockwise).

Annex 17

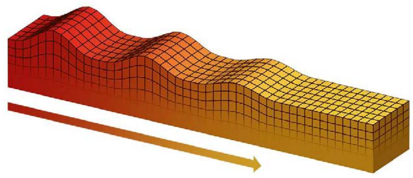
This project is co-funded by the European Union

Determine the location of a Martian earthquake from a single seismometer

1. Introduction & Pb

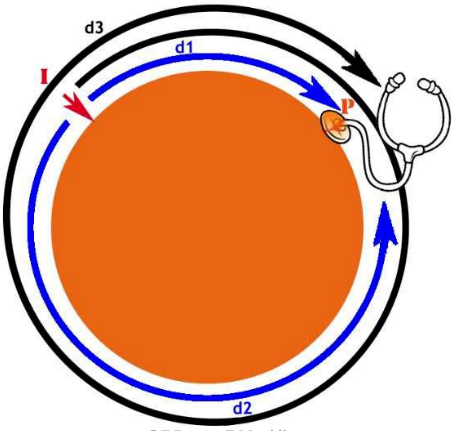
Let's try to understand how with a single seismometer it will be possible to locate the origin of seismic waves created by a meteorite impact or an earthquake.

Theoretically, Mars having a small perimeter, scientists hope to record several wave trains, shifted in time corresponding to the same earthquake or impact.



Principe de déplacement d'une onde de surface (© IPGP/David Ducros).

The waves that can circle the planet several times are the Rayleigh surface waves.



©F.Bouvet-F.Moujdi

I: point of impact, origin of the seismic wave.

P: seismometer

T1: the time taken by seismic waves to travel the distance **d1**

T2: the time taken by seismic waves to travel the distance **d2**

T3: the time taken by seismic waves to travel the distance **d2+2d1** or **d3**

2. Age of students 15 – 17 years

3. Objectives

The Insight mission aims to locate an earthquake on Mars using a single seismometer.
In this activity, students will use experimentation to better understand the scientific approach used by researchers to estimate the location of an epicentre of an earthquake with the recording of a single seismometer.
In our experiment we will use a piezo cell to simulate the work of the SEIS instrument.

4. Primary subjects

Physics – Earth Science – Mathematics

5. Additional subjects

6. Time required: 2h

7. Key terms.

Epicenter, surface waves, frequency, seismogram

8. Materials

- A pilates balloon, perimeter 250 cm
- Audacity 1.2.6
- 1 piezo cell
- 2 polystyrene bars
- 1 tape measure
- 1 ball of 11,5g and 1,4cm suspended from a 1m wire fixed to a protractor

9. Background

The notions of seismic wave propagation, the origins of an earthquake.

10. Procedures

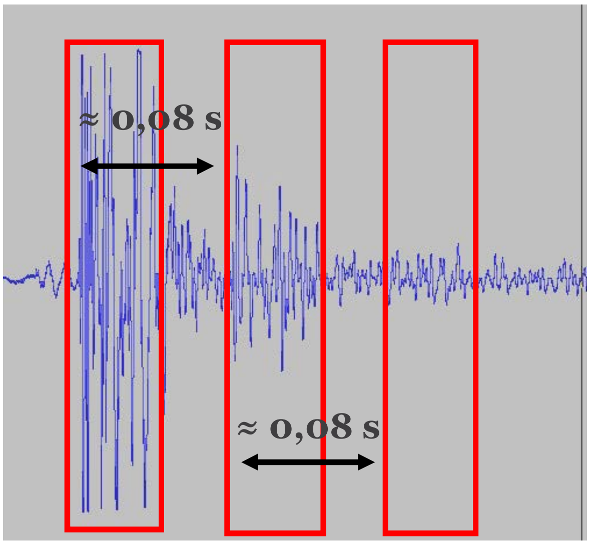
Place the balloon on the polystyrene bars to avoid any contact with the ground
Tape a piezo cell onto the balloon
Determine a striking zone 93cm from the piezo cell
Hang the protractor so that the ball is level with the hitting area.

Let's experiment with a model to better understand the theory
Detail of the experimental device

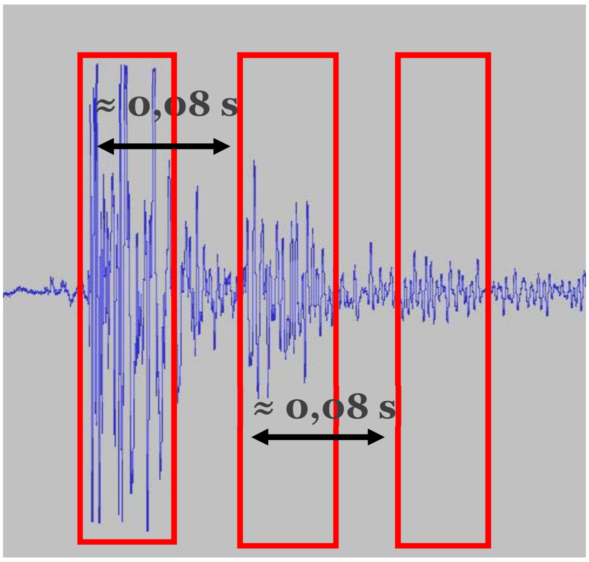
Make several successive recordings with impacts of constant intensity. To do this, move the ball so that the wire faces an angle of 50° with the vertical.

<u>Let's analyze the results obtained:</u>
Several wave trains are observed as predicted by the scientists' simulations. Let's determine the time elapsed between the different wave trains.

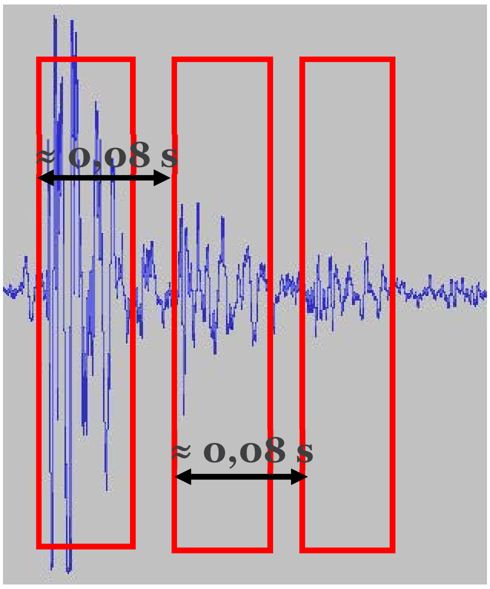
Record 1



Record 2



Record 3



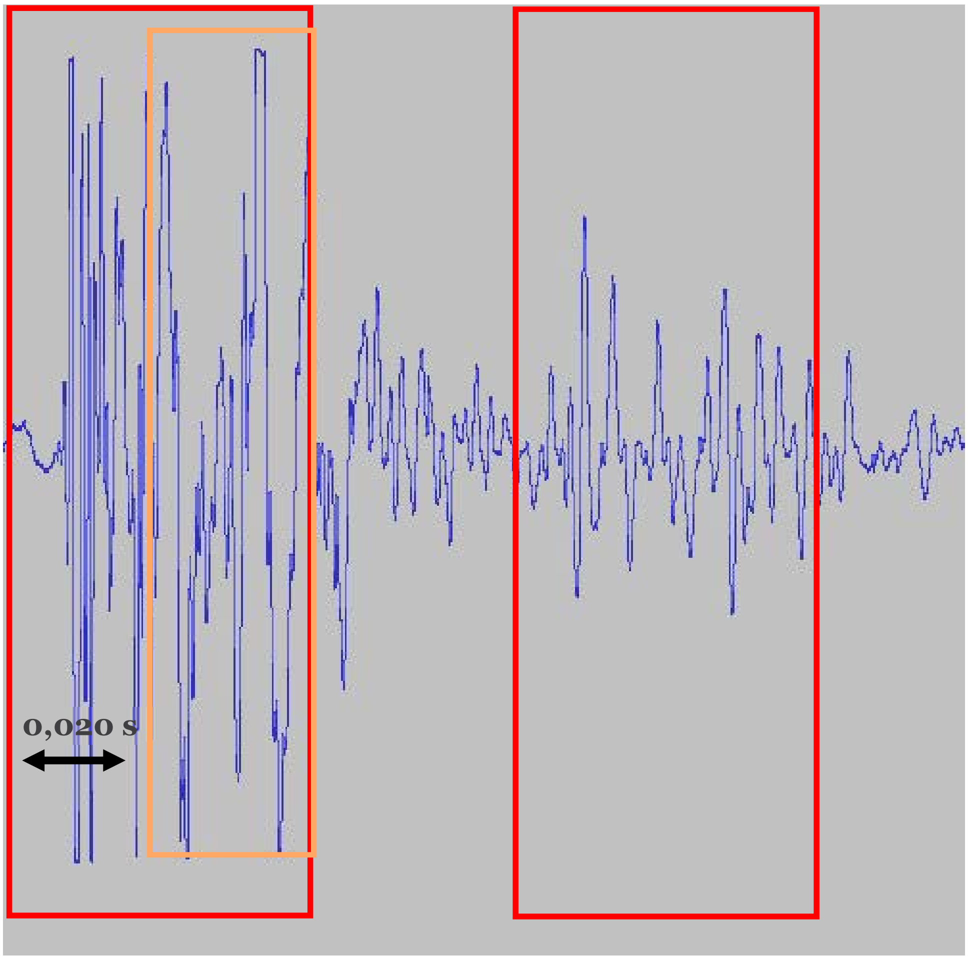
From the obtained results, let us assume that the time elapsed between each wave train corresponds to the time taken by the latter to complete a complete balloon revolution d2+d1

We can therefore determine an approximation for the speed of wave propagation on the surface of the balloon.

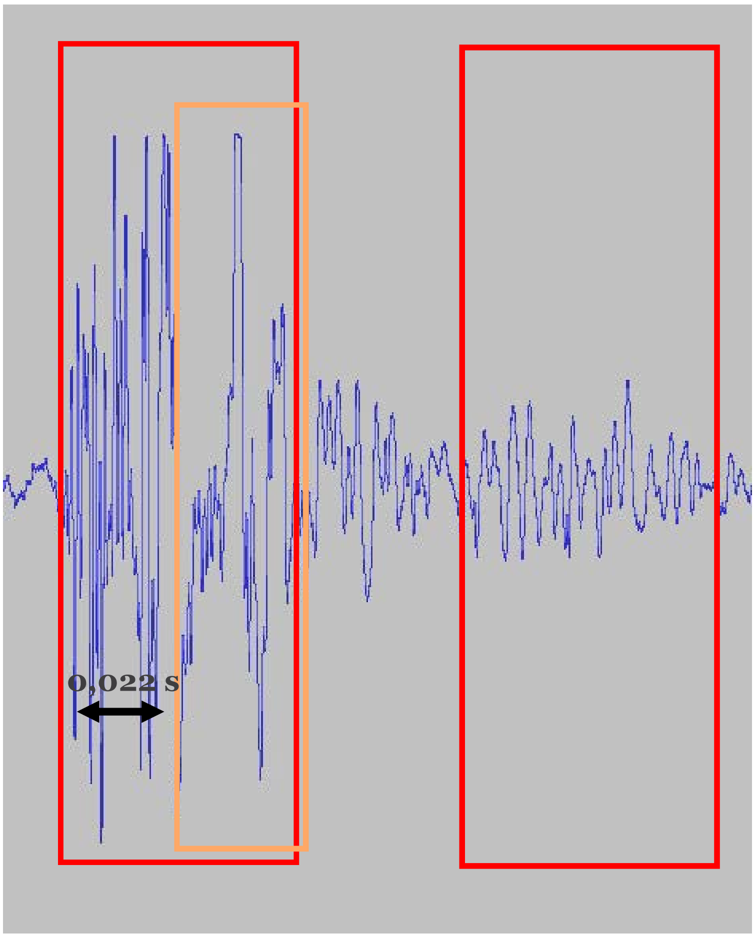
$V = d / t = (d1+d2) / t$
$= 250 / 0{,}08 = 3125\ cm.s^{-1}$

Let's take a closer look at the first. We are trying to find out if the waves that travelled the distance d2 were detected by the piezo.

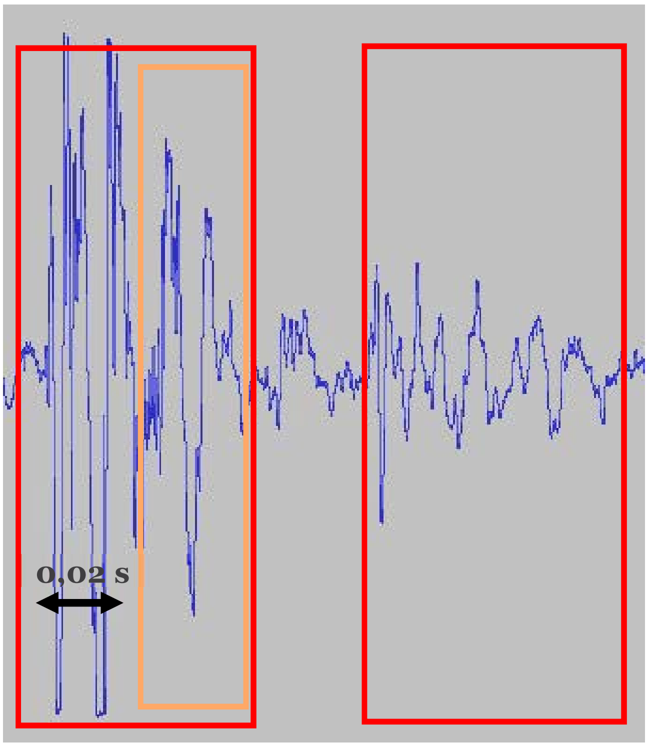
Record 1



Record 2



Record 3



Let us suppose that this signal corresponds to the waves that travelled the distance d2.

We can estimate an impact area.

d2-d1 = $\Delta t \times V$

d2-d1 = 0,02 x 3125 = 62,5 cm

d1 =(250 -62,5)/2 = 93 ,75 cm

11. Discussion of the results and conclusions

The distance between the seismometer and the earthquake source, the time of the earthquake, and the average speed at which waves travel over the planet's surface can be estimated by combining the arrival times of waves R1, R2 and R3. Earthquakes of magnitude 4.5 or greater are relatively rare events on Mars, but geophysicists estimate that over the duration of the mission (one Martian year, or two terrestrial years), it should be possible to observe between about 3 and 5.

It is important to note that the effectiveness of the techniques that will be implemented for the InSight mission has been validated on Earth with data from unique stations. (cf: activity on the study of earthquakes on Earth from a single seismometer). These have led to the discovery of one of the Earth's internal structure models commonly used by geophysicists (PREM) with acceptable error bars.

However, there are unknowns, and the validity of the technique summarized above cannot be confirmed until scientists receive and analyze records from Mars.

12. Follow up activities

On the Moon geophysicists were astonished to discover that the lunar crust caused enormous diffraction of the seismic waves, preventing the existence of surface waves. Since the Martian crust, just like the lunar crust, was exposed to a massive bombardment of asteroids early on in the formation of the solar system, its pulverised nature and numerous craters, especially in the planet’s southern hemisphere, could also cause seismic waves to be diffracted; seriously complicating analysis.

13. Explore More (additional resources for teachers)

- https://www.seis-insight.eu/en/public-2/martian-science/seismic-activity
- The geology of Mars, edited by Mary Chapman

Erasmus+
Schools Tune into MARS
This project is co-funded by the European Union

Plasticine balls: how can we explore inside Mars?

1. Introduction & Pb

During the latest centuries, many geoscientists have been working to unveil the internal structure of the Earth. Apart from observing the rocks on the Earth surface and analysing and testing them using different methods, a wide range of tools to find out how it is the structure of the Earth have been developed.

In 1970, the Kola Superdeep Borehole failed to reach the depth it had been designed for: to drill a hole 15 km deep in the Kola Peninsula (ancient USSR). This deepest hole drilled in the Earth reached a depth of 12,262 metres. So, the geoscientists don't have direct access to any rock below this depth.

Once proven that direct methods like drilling the Earth could not provide information about the internal structure of the whole Earth (its radius being of about 6,400 km), the scientists focused on improving even more the indirect methods that had already being developed since the 19th Century. Refining these techniques and making them more precise has been a major contribution to our current knowledge of the internal structure of the Earth as well as the dynamic processes that take place deep in our planet.

These methods include:

- Calculating the average density of the Earth by knowing its mass and volume.
- Studying the seismic waves that travel through its layers every time an earthquake takes place anywhere on the Earth.
- Studying and analysing the meteorites falling on the Earth surface.
- Studying the general Earth's magnetic field and what causes it.
- Studying how the Earth spins (its rotational inertia).

2. Age of students

14 to 18 years old

3. Objectives

Students can:

- propose hypothesis and discuss them with the rest of students
- suggest methods for testing these hypothesis
- suggest which of these could be useful to probe the Earth
- suggest which of these could be used to probe Mars with the available technology

4. Primary subjects

- Earth science
- Physics
- Maths

5. Additional subjects

Technology

6. Time required 30 minutes

7. Key terms

Internal structure, Earth, Mars, scientific hypothesis, testing, probing, density, seismic waves, magnetism, spheres, meteorites.

8. Materials

- plasticine^{TM} of two colours
- small bar bearings
- several toothpicks
- a Magnaprobe^{TM}
- scale (optional)
- slide gauge (optional)

9. Background

Students have to face a problem when they are given two clay ball of the same size but different weight. They are asked to provide hypothesis that could fit with the fact that two spheres that look externally the same (apart from their colour) have a very different physical propertes (mass and, therefore their density).

Then they are asked to suggest methods to test what is the internal structure of both balls and to decide which of those could be useful when studying the internal structure of a planet like the Earth or Mars.

10. Procedures

Give to every group of three students two plasticine balls of different colours but the same size and ask them if they feel any difference between the two balls. They easily realize that the weight, and therefore, the density is different.

Figure 1: Two balls: the same size, different weight. Green lighter, red heavier

Ask them to suggest hypothesis that could explain the difference between the two balls. They can provide five different solutions:

- the two balls are made of two types of plasticine with different densities
- one of the balls has something heavier inside
- one of the balls has something lighter inside
- the density of one of the balls increases gradually as you go deeper in it
- the density of one of the balls decreases gradually as you go deeper in it

(The right answer is the that the heavier one contains a bar bearing inside)

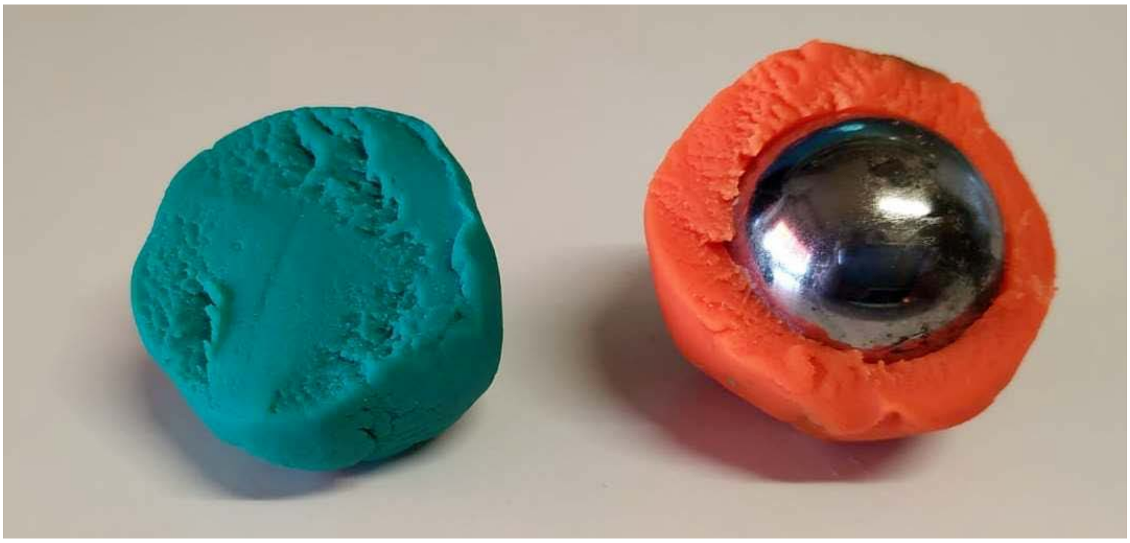


Figure 2: The two balls cut to show their internal structure: green, pure Plasticine^{TM}; red ball bearing inside.

Now ask them how, with all the apparatus and technologies available in the Earth, could they test which is the difference between the two balls.

Possible answers:

- weighting the two balls (with a scale) and calculating their density
- drilling them (with toothpicks, for example)
- testing its magnetism (with a small compass)
- using X-rays
- ultrasounds (like the one used to see embryos inside the uterus)
- electromagnetic resonance (EMR) like the ones used in many hospitals
- ionising radiation (alpha, beta or gamma radiation)
- how the Earth spins

Then, ask the students which of these methods are suitable for studying the internal structure of the Earth.

Possible answers:

- weighting the two balls (with a scale) and calculating their density. *Yes, astronomical calculations allow scientists to know the mass of the Earth and, knowing the Earth radius, its possible to calculate the volume, and therefore, the density of the Earth*.

- drilling them (with toothpicks, for example). *Not much, as we have not been able to drill more than 13 km deep*.
- testing its magnetism (with a small compass). *Yes, there's a general magnetic field in the Earth, related with its outer (liquid) and inner (liquid) iron core. It can be detected with a compass*.
- using X-rays. *No, they can't penetrate the Earth*.
- ultrasounds (like the one used to see embryos inside the uterus). *No, they can't penetrate the Earth. However, infrasounds or seismic waves can penetrate the Earth and provide a very useful information about its layers as well as their physical state (solid or fluid).*
- electromagnetic resonance (EMR) like the ones used in many hospitals. *No, they can't penetrate the Earth*
- ionising radiation (alpha, beta or gamma radiation). *No, only gamma radiation can penetrate a few meters into concrete*.
- How the Earth spins. *Yes, the way the Earth spins suggest a denser core inside it*.

Now provide the students with two more clay balls of different colours: one lighter than the lighter they already have (with a ball of expanded polystyrene, EPS, inside) and another one the same weight as the heavier they already have (with a magnet bar inside).

Ask them to order them by increasing density; the results should be:

1. EPS core
2. Plasticine™ core
3. Ball bearing and magnet cores (approximately the same density)

Now, ask them which of these four should be the less suitable to model the internal structure of a planet. (Answer: 1 and 2, as usually, gravity pushes the heaviest materials to "sink" deep in the core of the planets).

Provide them with a small compass and ask them wich of the balls 3 or 4 fits better with the internal structure of the Earth and which fits better with Mars. (*Answer: the one with the magnet inside fits better with the model of the Earth as our planet has a general magnetic field related to a liquid iron outer core, while Mars seems to have an iron core but completely solid and, therefore it has no general magnetic field*)

11. Discussion of the results and conclusions

Students can compare the physical properties both of Earth and Mars, discuss which methods are the best to study them, which are available in each planet and compare the degree of knowledge about the internal structure of the Earth and Mars.

12. Follow up activities

Students can use an Internet search engine to research for the equipment of the probe Insight landed on Mars. From this information they can discuss which of the methods suggested for studying the internal structure of the Earth could apply in Mars according with this equipment.

They can also, using a scale and a slide gauge, calculate the density of the four spheres knowing that the formula to calculate the volume of a sphere is:

$$V = \frac{4}{3} \cdot \pi \cdot r^3$$

... and that de density (D) is:

$$\rho = \frac{m}{V}$$

13. Explore More (additional resources for teachers)

- This activity has been developed from the Earthlearningidea "From clay balls to the structure of the Earth" in www.earthlearningidea.com.
- https://www.nasa.gov/. Official website of the National and Aeronautics Space Administration (NASA)
- All the relevant information about InSight Mission in https://www.nasa.gov/feature/jpl/for-insight-dust-cleanings-will-yield-new-science .

Annex 19

This project is co-funded by the European Union

Plasticine balls: comparing planets

1. Introduction & Pb

This activity is intended to be carried out after "Activity 4A. How can we explore inside Mars" in which pupils have learned about the different methods for studying the internal structure of a planet. Nevertheless, this activity can be carried out individually and completely apart of the other one.

Two aspects of the study of the internal structure of a planet have been developed along this activity: the distribution of masses inside it and the presence or absence of a general magnetism.

2. Age of students

14 to 18 years old

3. Objectives

Students can:

- propose hypothesis and discuss them with the rest of students
- suggest methods for testing these hypothesis
- understand how these properties allow or not to distinguish between the Earth and Mars
- calculate the density of different clay balls and compare them
- decide which ball models better the Earth and Mars

4. Primary subjects

- Earth science
- Physics
- Maths

5. Additional subjects

Technology

6. Time required

20 minutes

7. Key terms.

Internal structure, Earth, Mars, scientific hypothesis, testing, probing, density, magnetism, spheres, meteorites.

8. Materials

- plasticine™ of different colours
- small bar bearings
- magnets
- small balls of Expanded Polystyrene (EPS)
- a Magnaprobe™
- scale

9. Background

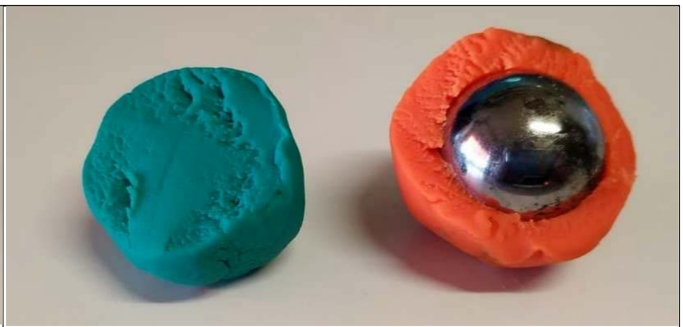
Students are given four plasticine balls of different colours and they are informed about the composition of the four balls.

They have to decide which of the four balls models better the features (distribution of masses and magnetism) of the two planets, Mars and the Earth.

10. Procedures

Provide your students with the four balls but without telling them which colour each sphere is. The four spheres are approximately the same size and their respective composition is:

- *sphere 1*: all of it is made of pure Plasticine™
- *sphere 2*: the Plasticine™ ball contains a ball of Expanded Polystirene (EPS) inside
- *sphere 3*: contains a ball bearing inside it
- *sphere 4* contains a magnet weighting about the same as the ball bearing of sphere 3

Balls 1 and 3 (green and red) as used in the Activity 3

Ball 3 showing the EPS ball inside

Ball 3 showing the magnet inside

Now, ask them which of the four balls fit better with what is expected about the distribution of layers in any planet and which of the four fit better with the internal structure of the Earth and of Mars respectively.

(The right answer is the that the heavier one contains a bar bearing inside)

Now ask them how, all the apparatus and technologies available in the Earth, could they test which is the difference between the two balls.

Possible answers:

- weighting the two balls (with a scale) and calculating their density
- drilling them (with toothpicks, for example)
- testing its magnetism (with a small compass)
- using X-rays
- ultrasounds (like the one used to see embryos inside the uterus)
- electromagnetic resonance (EMR) like the ones used in many hospitals
- ionising radiation (alpha, beta or gamma radiation)
- How the Earth spins

Then, ask the students which of these methods are suitable for studying the internal structure of the Earth.

Possible answers:

- weighting the two balls (with a scale) and calculating their density. *Yes, astronomical calculations allow scientist to know the mass of the Earth and, knowing the Earth radius, its possible to calculate the volume, and therefore, the density of the Earth*.
- drilling them (with toothpicks, for example). *Not much, as we have not been able to drill more than 13 km deep*.
- testing its magnetism (with a small compass). *Yes, there's a general magnetic field in the Earth, related with its outer (liquid) and inner (liquid) iron core. It can be detected with a compass*.
- using X-rays. *No, they can't penetrate the Earth*.
- ultrasounds (like the one used to see embryos inside the uterus). *No, they can't penetrate the Earth. However, infrasounds or seismic waves can penetrate the Earth and provide a very useful information about its layers as well as their physical state (solid or fluid).*
- electromagnetic resonance (EMR) like the ones used in many hospitals. *No, they can't penetrate the Earth*
- ionising radiation (alpha, beta or gamma radiation). *No, only gamma radiation can penetrate a few meters into concrete*.
- How the Earth spins. *Yes, the way the Earth spins suggest a denser core inside it*.

Now provide the students with two more clay balls of different colours: one lighter than the lighter they already have (with a ball of expanded polystyrene, EPS, inside) and another one the same weight as the heavier they already have (with a magnet bar inside).

Ask them to order them by increasing density; the results should be:

1. EPS core
2. Plasticine^{TM} core
3. Ball bearing and magnet cores (approximately the same density)

Now, ask them which of these four should be the less suitable to model the internal structure of a planet. (*Answer: 1 and 2, as usually, gravity pushes the heaviest material to "sink" deep in the core of the planets*).

Provide them with a small compass and ask them with of the balls 3 and 4 fits better with the internal structure of the Earth and which fits better with Mars. (*Answer: the one with the magnet inside fits better with the model of the Earth as our planet has a general magnetic field related to a liquid iron outer core, while Mars seems to have an iron core but completely solid and, therefore it has no general magnetic field*)

11. Discussion of the results and conclusions

Students can compare other physical properties both of Earth and Mars, discuss which methods are the best to study them, which are available in each planet and compare the degree of knowledge about the internal structure of the Earth and Mars.

12. Follow up activities

Students can, also, using a scale and a slide gauge, calculate the density of the four spheres knowing that the formula to calculate the volume of a sphere is:

$$V = \frac{4}{3} \cdot \pi \cdot r^3$$

... and that de density (D) is: $\rho = \frac{m}{V}$

13. Explore More (additional resources for teachers)

- This activity has been developed from the Earthlearningidea "From clay balls to the structure of the Earth" in www.earthlearningidea.com.
- https://www.nasa.gov/. Official website of the National and Aeronautics Space Administration (NASA)
- All the relevant information about InSight Mission in https://www.nasa.gov/feature/jpl/for-insight-dust-cleanings-will-yield-new-science .

Erasmus+

SCHOOLS TUNE INTO MARS

This project is co-funded by the European Union

The seismogram: a complex signal

1. Introduction & Pb

The ground motion is the result of arrivals of many waves, which have their own frequency. Seismometers record ground motion continually and this continue signal, without arrival of seismic waves, is considered as the ambient seismic noise.

When an earthquake is well recorded, seismic waves are clearly identified relative to the continue seismic noise. But sometimes, these waves had been recorded, but they are not perceptible. Knowing frequencies ranges of seismic waves, it is possible to find an hidden earthquake in the seismic noise.

2. Age of students 15 – 17 years

3. Objective

Filtering a seismogram with adapted bandwidth to observe seismic waves.

4. Primary subjects

Earth science - Physics

5. Additional subjects

Informatics: Audacity software

6. Time required 2hrs

7. Key terms

Wave – Frequency - Seismograms

8. Materials

Supports used:

- Data from RESIF network
- SeisGram2K80_ECOLE© : To download free of charge from the Edumed website: http://edumed.unice.fr/fr/tools-lab

Data:

- The Mw 4.8 January 1, 2019 earthquake (Greece), recorded at the station CALF (Observatoire de la Côte d'Azur, Calern, France).
- The Mw 6.3 December First, 2018 earthquake (Indonesia), recorded at the station CALF.

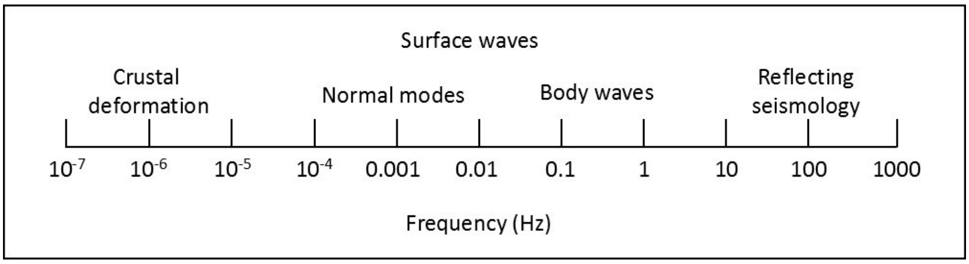
9. Background Seismogram2K -

10. Procedures

Step one: processing of the Greek earthquake to display P waves

The raw seismograms are extractions of continuous seismic signal where seismic waves should be perceptible. On each component, no seismic waves are observable. Related to the magnitude (Mw 4.8) and the epicentral distance (15.87°). By considering an average P wave velocity of 8 km/s (related to the epicentral distance), first P wave should arrive on 11:45:43 a.m.

By providing the following frequencies scale to students, they can estimate a specific frequencies range for body waves.

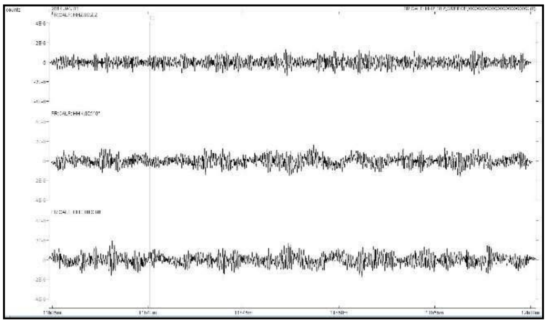


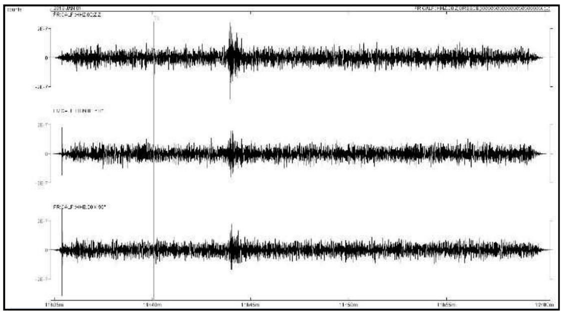
This scale (from Stein and Wysession, 2013) is an indicative scale. Student can observe that the body waves frequencies spread out from values lower than 0.01 Hz and upper than 1 Hz.

Exercise: test different bounding values for a bandpass filtering in order to highlight seismic waves.

In this case, the lower value for a bandpass filtering must be greater than or equal to 1 Hz. The greater value has no influence on the emergence of seismic waves.

<u>Results:</u>





<u>Step two:</u> processing of the Indonesian earthquake to display P waves

As previously, no seismic waves are observable in raw data.

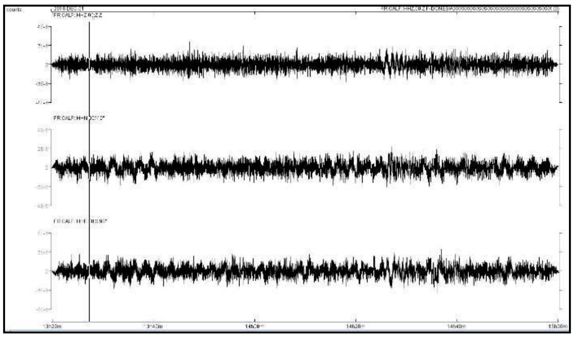
Exercise: students are again asked to found adapted values for bandpass filtering which allow highlighting seismic waves.

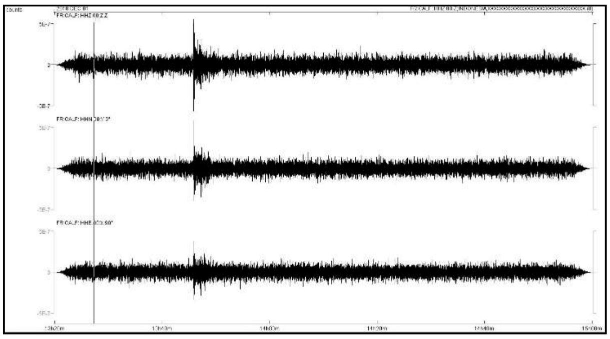
In this case, the lower value for bandpass filtering to display P wave can be greater than or equal to 0.5 Hz.

First conclusion: although seismic waves are not observable in seismograms, they can be highlighted with an adapted processing. These two steps show that P waves are easly observable in frequencies range greater than 1 Hz.

But what about S waves and surface waves ?

Results:

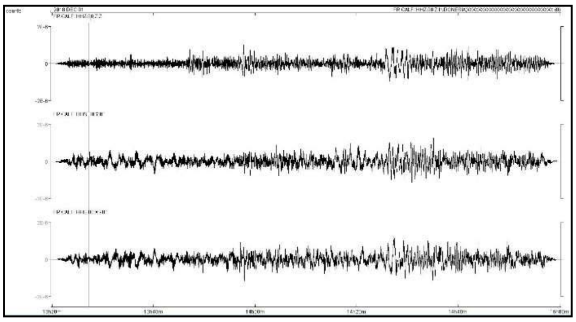


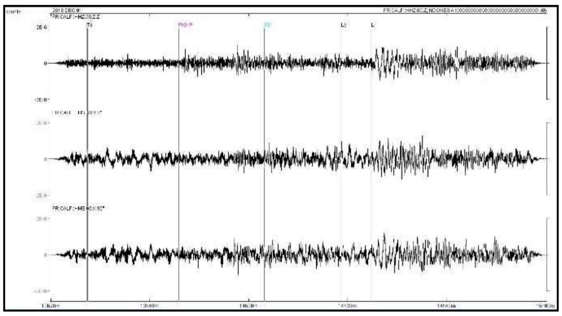


Step three: processing of the Indonesian earthquake to display P, S and surface waves

Exercise: students are asked to find adapted values in order to highlight P, S, and surface waves.

In this case, range values between 0.01 and 0.1 Hz allows displaying body and surface waves. Pick of theorical arrival times with SeisGram2K allows to easy identifying the different waves packs. For this teleseismic event P waves are in fact PKIKP waves, and S waves are SS waves. Rayleigh waves are well display and easly identifying.





11. Discussion of the results and conclusions

Seismograms contain a large frequency content, and seismic waves could be hidden in the seismic noise, on Earth as on Mars. Scientists will have to process future data with accuracy in order to detect waves from future impacts and marsquakes.

Main conclusion:

Seismograms contain a large frequency content, and seismic waves could be hidden in the seismic noise, on Earth as on Mars. Scientists will have to process future data with accuracy in order to detect waves from future impacts and marsquakes.

Annex 21

Erasmus+

This project is co-funded by the European Union

Atmospheric parameters and impact on seismic records

1. Introduction & Pb

A seismic station is designed to detect infinitesimal ground motions. Its electronic devices can be impacted by ground motions, and also by atmospheric parameters. We proposed here seismograms where the continuous signal is not flat: day after day big daily arks are observed.

2. Age of students 15 – 17 years

3. Objective

Filter seismic noise by detecting atmospheric variations in the signal

4. Primary subjects

Earth science - Physics

5. Additional subjects

Informatics: SeisGram2K80_ECOLE©

6. Time required 2hrs

7. Key terms

Seismograms – Frequency - Waves

8. Materials

Supports used:

- Data from RESIF network
- SeisGram2K80_ECOLE© : To download free of charge from the Edumed website: http://edumed.unice.fr/fr/tools-lab

Data:

- Continuous seismic signal from February 3 to February 7, 2019, recorded at the station MYLF (Forcalquier, Alpes de Haute Provence, Observatoire de la Côte d'Azur).

9. Background

Using the SeisGram2K80_ECOLE© software

10. Procedures

Step one: Analysis of the continuous signal.

Students have to describe continuous signals from the picture in Figure 1.

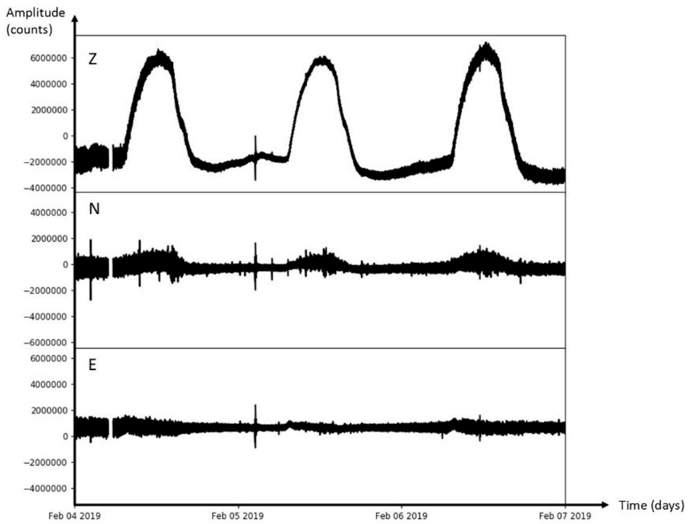


Figure 1. Records from the station MLYF (from February 4 to February 7, 2019). E: East component. N: North component. Z: vertical component.

In this case, students must highlight that the signal from the Z component is clearly daily disturbed: each day, the signal form an ark which increase till midday, and decrease after. This phenomenon is also observed in signal from the north component. The East component seems less impacted.

Step two: Find a physical parameter which can induce this drift of the continuous signal.

The seismogram from the vertical component can be used to ease analyse the continuous signal.

Step three: Find remarkable event except the daily arks.

In this case, an earthquake is recorded on 02h29m06s.

But in this continuous signal four others earthquakes are recorded (Fig. 2).

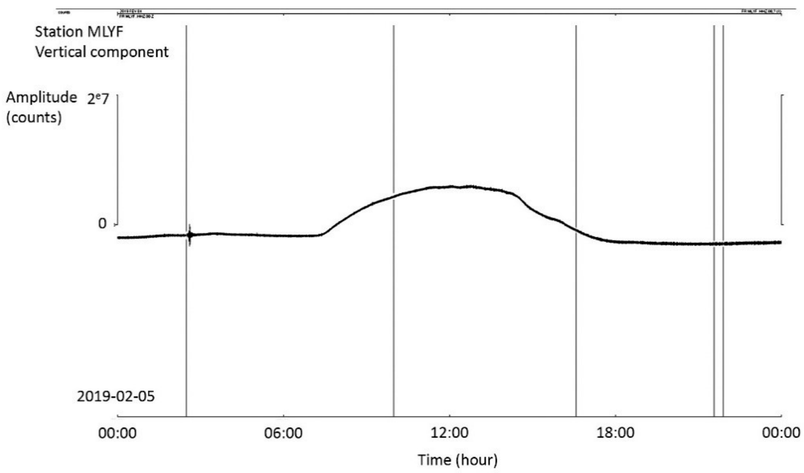


Figure 2. Continuous signal from the station MLYF (February 5, 2019). Vertical black lines: pick of earthquakes recorded this day.

Step four: Observation of these earthquakes

With SeisGram2K and the zoom and scroll tools, try to identify seismic waves recorded at each pick marker on Figure 2, and find the corresponding earthquake in Table 1.

time	Latitude (deg)	Longitude (deg)	Depth (km)	Magnitude
02/05/2019 02:23:20	44.623	6.999	5.22619	1.10
02/05/2019 02:59:21	44.620	6.996	5.90243	0.98
02/05/2019 03:14:54	44.627	6.995	3.97904	1.05
02/05/2019 03:24:12	44.632	6.994	4.50887	0.67
02/05/2019 03:30:24	44.622	7.002	5.23938	0.78
02/05/2019 03:46:13	44.631	7.004	5.74260	0.99
02/05/2019 06:40:26	44.321	7.203	2.69562	0.89
02/05/2019 11:08:10	43.431	6.337	3.15283	1.66
02/05/2019 16:33:52	43.600	5.367	0.00	2.20
05/02/2019 02:19:15	44.510	10.100	22.00	2.3
05/02/2019 06:54:58	43.420	12.470	9.00	2.1
05/02/2019 08:30:59	45.860	7.050	2.00	3.1
05/02/2019 08:31:00	45.850	7.080	10.00	3.1
05/02/2019 09:02:50	45.840	7.030	5.00	2.4
05/02/2019 09:52:45	45.970	6.970	8.00	3.0
05/02/2019 09:55:54	45.880	7.040	8.00	1.5
05/02/2019 11:47:51	44.440	12.190	32.00	2.2
05/02/2019 21:32:59	46.030	5.600	5.00	3.4
05/02/2019 21:52:57	45.980	5.580	10.00	3.2

Table 1. Catalog of seismicity on February 5, 2019 (From the catalog of European Mediterranean Seismology Center and the catalog of the laboratory Géoazur). The covered area is centered on the Region PACA, and North Italy.

11. Discussion of the results and conclusions

Meteorological parameters can have an influence if the sensors is not well isolated from its close environment. On Mars, the seismometer SEIS is protected by a dome against atmospheric activity as daily variation of the temperature and the wind. This dome could withstand squalls of 216 km/h and should even be able to survive winds of 360 km/h (https://www.seis-insight.eu/en/public-2/seis-instrument/wts).

Annex 22

Egg drop

1. Introduction & Pb

The landing phase of a probe is one of the most critical phases of a mission. This is why scientists model these phases in the laboratory before launching. We will take the case of the Insight mission that landed on Mars a few months ago.

To survive the intense friction forces that characterize entry into the atmosphere, the InSight probe is protected by a large diameter heat shield. The latter is covered with tiles made of a special material, which will absorb the impressive amount of energy due to the resistance of the atmosphere to the passage of InSight.

After atmospheric entry, the second stage of InSight's landing consists of a parachute descent. The latter will be deployed at an altitude of about 9 kilometres.

Finally, at an altitude of about 1.3 kilometres, while still flying at a speed of 224 kilometres per hour, InSight separated from its parachute, and found itself in free flight, falling like a rock towards the rusty surface of Mars and quickly moving away from the rear shield it had left behind (and to which the parachute had remained attached).

But very quickly, half a second after this event, the landing gear turns on its retrorockets, to brake and stabilize.

Drawing showing the InSight probe during the final (propelled) stage of landing on the equatorial plain of Elysium.

(© IPGP/Manchu/Bureau 21).

Engineering activities give kids a chance to develop problem solving and observations skills, to work with interesting and engaging tools and materials, and to learn how to work as a member of a team. When you drop something, it falls to the ground. This is because it is pulled by the gravity of the Earth. You'll notice that some things drop faster than others, this is because of air resistance. Try dropping a piece of paper and a lego brick. Which drops the fastest?

2. Age of students

6-17 years

3. Objectives

- Describe and define material properties.
- Identify the forces of gravity, drag, and the term air resistance
- Design and build a system that will protect an egg from a 1-meter drop.

4. Primary subjects

Physics

5. Additional subjects

6. Time required

1 hour

7. Key terms.

design process, landing, egg drop competition

8. Materials

eggs
big zip bags
cotton-wool
pencils/paper or computer
any construction materials from students' homes

9. Background

When you drop something, it falls to the ground. This is because it is pulled by the gravity of the Earth. You'll notice that some things drop faster than others, this is because of air resistance. Try dropping a piece of paper and a lego brick. Which drops the fastest?

If you tried dropping paper and a lego brick or similar, the paper should have dropped to the floor more slowly than the brick, this is because the paper has a larger surface area, so has to push against more air as it drops, which means the air resistance is greater and it drops more slowly.

You need to create something that can absorb the energy the egg gathers as it accelerates towards the ground. A hard surface will crack the egg so you have to think carefully about how you can protect it. Something that will cushion the egg at the end of its fall is a good place to start, you want the egg to decelerate slowly so it doesn't crack or smash all over the ground. You'll need to run a few trials so have some eggs.

10. Procedures

The idea is to wrap the egg in a layer of cotton-wool that will protect it from landing. Put the egg wrapped in cotton-wool in a zippered bag and allow it to fall from about 1 m high. If the cotton layer is thin the egg will crack.

11. Discussion of the results and conclusions

After the experiment, analyze your data. In an egg drop project, you will determine how well your design performed. If the egg broke after the first drop, you know that revisions need to be made. However, this does not mean the experiment was a bad one. In science, all results are good results, because all results offer an opportunity to learn. When something goes wrong or does not work the way it is expected, it provides a chance to find out why and correct it. If an egg breaks, look at the data, assess the performance of your design and use it to figure how it can be made better.

12. Follow up activities

13. Explore More (additional resources for teachers)

STEM activities websites

- https://www.seis-insight.eu/fr/public/la-mission-insight/atterrissage
- "Mars in a minute" du Jet Propulsion Laboratory (© JPL-Caltech/IPGP).

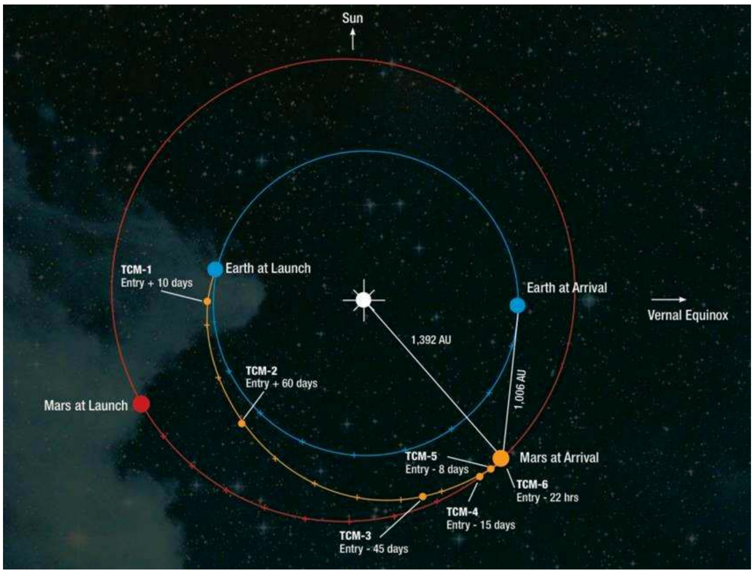
Annex 23

This project is co-funded by the European Union

Going to Mars

1. Introduction & Pb

Finding the relative position of Earth and Mars which correspond to the optimal spacecraft travel path in terms of energy consumption, using planetary position data and advance algebra concept, all in order to determine the next launch opportunity to Mars.



Orbit followed by the InSight probe between Earth and Mars (© NASA)

2. Age of students 15-17 years

3. Objectives

The objective is to determine the next launch window to Mars from the relative position of Earth and Mars that corresponds to the optimal trajectory of the spacecraft in terms of energy consumption and using planetary position data and the concept of advanced algebra.

4. Primary subjects

Mathematics - Physics – Earth and Space Science

5. Additional subjects

6. Time required

30 min – 1 hour

7. Key terms.

Orbits, Earth, Mars, space missions, launch windows, graph

8. Materials

Calculator, push-pins, graph paper, quadrille ruled, planetary heliocentric longitudes data sheet

9. Background

To get a spacecraft from Earth to any planet, you need to consider the curved travel path resulted as a combination of spacecraft velocity and planet gravitational pull. To get the most from this scenario scientists need to "work" with these forces and travel as much as possible with engines off, so lowering the cost of the mission.

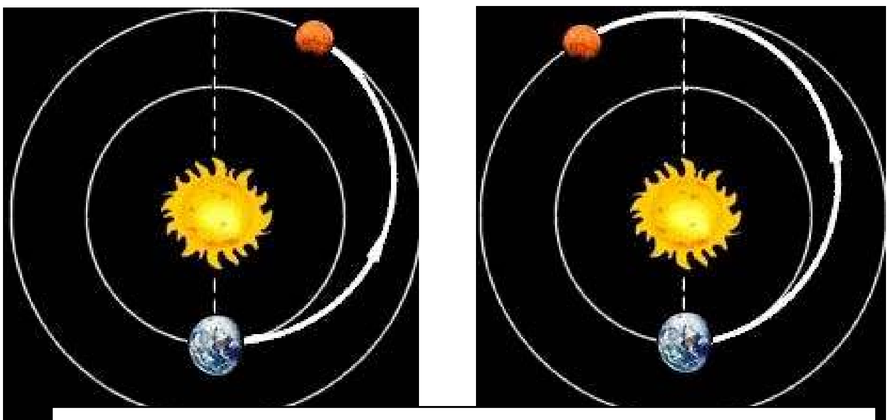
As in many similar scenarios (e.g: passing a ball to a running football teammate) what essentially need to be considered is the initial impulse given to the spacecraft (the launch equivalent to the ball throw) the position of the targeted planet in any moment (described by its orbit) and then the gravitational pull.

Even if the spacecraft could take a variety of curved paths from the launching point to the landing planet, one is considered to be the most efficient in terms of energy consumption - Hohmann transfer orbit.

In the case of Earth to Mars travel path, the Hohmann transfer is an elliptical orbit with the sun at one focus of the ellipse that intersects the orbit of the target planet. Launch occurs when Earth is at Hohmann perihelion (the point of the Hohmann orbit that is closest to the sun). Arrival occurs when Mars is at Hohmann aphelion (the point of the Hohmann orbit that is farthest from the sun).

This is a simple explanation for a far more complex scenario where scientists need to take into account a variety of parameters that are more or less constant. What need to be clearly understood is that a specific launching time window have to be calculated and validated through multiple simulation way before the launching. This will allow a proper launch window, so the spacecraft will arrive in the planet's orbit just as the planet arrive at the same place.

A B



In A, the respective positions of Mars and Earth at the time of launch. In B, the respective positions of Mars and Earth during landing (Crédit photo : © Philippe Labrot).

10. Procedures

Students will be explained that a space station must have an elliptical trajectory around the sun to reach the same point at the same time as the planet Mars. What they should do next is to figure out what the launch time should be so that this intersection will take place.

Students will be explained that the most efficient orbit from the point of view of energy consumption needed for the trip must be calculated, called the Hohmann transfer, in which the spacecraft will travel half of one orbit about the sun, leaving Earth at the orbit's perihelion and arriving at Mars (or any outer planet) at the orbit's aphelion.

Bring into discussion the Kepler's Second Law also tells us that planets travel at different rates of speed in their elliptical orbits, moving faster when they are closer to the sun and slower when they are farther from the sun.

To make possible the complex mathematical task of launching a spacecraft while considering he orbital dynamics of the planets, mention to students three assumptions, actually some unrealistic simplifications but that will allow us a sufficiently accurate calculation of the launch window

The orbits of Earth and Mars are circular and centered on the sun. (Earth's orbit is more circular than Mars' orbit, but they are both slightly elliptical.)

Earth and Mars travel at constant speeds. (They do not. See Kepler's Second Law).

The orbits of Earth and Mars are in the same plane. (They are close but slightly out of plane with one another).

Explain to students the concept of heliocentric longitude. Just as longitudes on Earth measure position with respect to a fixed point (the prime meridian), heliocentric longitudes measure position in space along the ecliptic with respect to the vernal equinox.

Knowing that Earth is, on average, 1 astronomical unit (AU) from the sun and Mars is, on average, 1.52 AUs from the sun have students find the length of the semi-major axis of the transfer orbit in astronomical units (AU).

Using the string and pushpins have students draw the assumed-circular orbits of Earth and Mars about the sun, and the approximation of the Hohmann transfer orbit on graph paper

Determine the period of the Hohmann transfer orbit and then the travel time to Mars along this orbit using Kepler's Third Law (Law of Harmony)

Kepler's Third Law states that the square of the period of any planet is proportional to the cube of the semi-major axis of its orbit. An equation can represent this relationship:

$P^2=ka^3$ with k being the constant of proportionality

Using Earth as an example, we can measure P in years and a in astronomical units so P = 1 year and a = 1 AU. Thus, $P^2=ka^3 \rightarrow k=1 \Rightarrow P^2=a^3$

$P^2= (1.26\ AU)^3 \Rightarrow P \sim 1.41$ years ~ 517 days

The full period of this Hohmann transfer orbit is 517 days. Travel to Mars encompasses half of one orbit, so approximately 259 days.

Considering the daily motions of Earth and Mars, compute the ideal relative position of both planets during the launch.

1 Mars revolution = 687 days => 0.524 degrees/day => 136 degree/259 days

To calculate the position of Mars at the time of launch, subtract the amount of its motion during the spacecraft's travel time (136 degrees) from its point of arrival (180 degrees). 180 degrees – 136 degrees = 44 degrees.

Using the planetary heliocentric longitudes, approximately when is the next opportunity for a launch to Mars?

11. Discussion of the results and conclusions

What happens if the estimation of the launching window is shorter or longer that it should be? Can we estimate an average length?

Do you know how these launching windows have been calculated in the early times of space missions?

12. Follow up activities

Make a short phyton script that will subtract heliocentric longitudes for Earth and Mars to simplify launch window calculations.

13. Explore More (additional resources for teachers)

Stomp Rockets Activity

https://www.jpl.nasa.gov/edu/teach/activity/stomp-rockets/

When Computers Were Human https://www.jpl.nasa.gov/edu/news/2016/10/31/when-computers-were-human/

Mars in a Minute Video Series https://www.jpl.nasa.gov/edu/teach/activity/mars-in-a-minute/

Acknowledge This activity was inspired from the JPL Education Program

Erasmus+
SCHOOLS TUNE INTO MARS
This project is funded by the European Union

Solar energy, a sustainable source of energy

1. Introduction & Pb

NASA uses several different technologies for providing energy for space exploration. Each technology meets the requirements for different types of exploration. For space exploration close to the Sun (near the inner planets—Mercury, Venus, Earth, and Mars), solar power with battery backup is often an optimal option. This problem-based learning PBL will explore the use of solar panels as a power source. In the process, students will learn core classroom concepts related to energy, energy transformation, electricity, and circuits.

Solar cell technology is improving rapidly. The solar cells used on the ISS are about 12 percent efficient. Those developed for the Mars Rovers are about 26 percent efficient. Current solar cells have higher efficiency. The students will have to do some research to determine the efficiency. When NASA engineers plan a mission, they have to know all the specifications for all of the components, and the components have to be space tested. Sizes, electrical characteristics, masses, and connections must be known at the beginning of the planning. Since a mission might take 10 years to plan and construct, equipment might be 10 or more years "outdated." Your students will have to work with the same restrictions. They will be required to use solar cells that are currently available. They will have to research current technology.

NASA's InSight lander, which touched down on Mars Nov. 26 and successfully extended its large solar arrays hours later, is already setting records. During its full first day on the Red Planet, the solar-powered lander generated more electrical power in one day than any previous Mars vehicle has, mission team members said. "It is great to get our first 'off-world record' on our very first full day on Mars," Tom Hoffman, InSight project manager at NASA's Jet Propulsion Laboratory (JPL) in California, said in a statement. "But even better than the achievement of generating more electricity than any mission before us is what it represents for performing our upcoming engineering tasks," Hoffman added. "The 4,588 watt-hours we produced during sol 1 means we currently have more than enough juice to perform these tasks and move forward with our science mission." The 4,588 watt-hours InSight generated on its first sol, or Martian day, from solar power is well over the 2,806 watt-hours generated in a day by NASA's Curiosity rover, which runs on a nuclear system called a radioisotope thermoelectric generator. Coming in third was the solar-powered Phoenix lander, which generated around 1,800 watt-hours in a day, according to NASA officials.

2. Age of students

15-17 years

3. Objectives

1. Given solar cells or panels, students list variables that affect the operation of solar panels and explain how these variables affect the power production of solar panels.

2. Through computer simulations or laboratory investigations with electricity, students create parallel and series circuits, calculate power, and apply this knowledge to solve a theoretical problem.

3. By analyzing the power requirements of their own homes, students design a solar system that could supply the power to their home.

4. Using their own models, students propose and defend a design to provide power for a Martian research habitat for six explorers.

4. Primary subjects

Mathematics - Physics – Earth and Space Science

5. Additional subjects

Computer Science

6. Time required

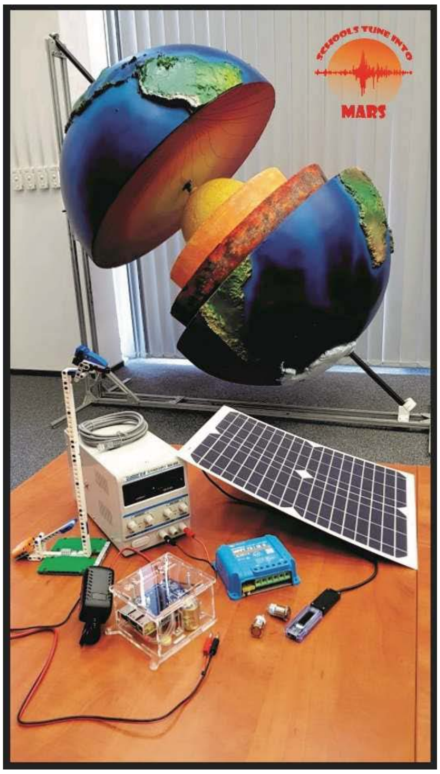
1 hour – 2 hours

7. Key terms

Solar panels, Solar energy, Earth, Mars, space missions

8. Materials

Solar panel. Solar charger (optional). Voltmeter. Calculator. Red, Green, and Blue transparency film. Electrical wire to connect solar cell and the electric devices. Notebooks and pencils. 12v bulb and battery (optional).



9. Background

A number of variables affect solar cell operation. Students will brainstorm, predict, and test variables in Activity 1: Investigating Solar Cells. The critical variables that affect solar cell performance—other than the efficiency of the cell itself—affect the intensity of light on the solar cell.

There are several factors that affect intensity:

Blocking - Natural conditions can block solar radiation from reaching the solar cells. Earth's atmosphere can partially block incoming solar radiation. The amount of light reaching Earth above the atmosphere is about 1366 Watts per square meter. When the Sun is directly overhead at the Equator, the intensity of solar radiation reaching Earth's surface is between 800 and 1,000 Watts per square meter. On the Moon and on Mars, solar panels can be blocked by dust. It was expected that the solar panels on the NASA Mars Rovers would become covered with dust and cease to provide energy for the systems. A chance dust devil swept the panels clean. Dust devils occur frequently enough on Mars that Rover panels are kept relatively clean.

Angle - The angle between the Sun and the solar panel is critical. The intensity of light is measured in Watts (power) per square meter. You can experimentally quantify how the angle changes the intensity. Hold a flashlight directly above a sheet of graph paper. The light source is at 90° to the paper. Count the number of squares illuminated. Keep the flashlight at the same distance from the paper, but tilt the flashlight so that it is at an angle to the paper. This represents a lower Sun angle. Count the squares illuminated again. More squares will be illuminated at the lower angle. The power of the light stays the same, but the area lit increases as the angle gets lower. When the same amount of power is spread over a larger area, the intensity decreases. The 23.5° tilt of the Earth's axis determines the angle of sunlight. The Sun is overhead in June in the Northern Hemisphere at the Tropic of Cancer at 23.5° N. latitude. The Sun is overhead in January in the Southern Hemisphere at the Tropic of Capricorn at 23.5° S. The GEMS (Great Explorations in Math and Science) Guide, The Real Reasons for the Seasons, could be used during this lesson to help students understand how the tilt of the Earth's axis affects the light intensity and the seasons. The axis of Mars is tilted at 25°, so very similar conditions prevail on Mars except the year is longer and each season is longer than Earth's. During the winter on Mars, the Rovers are parked on the slope of a hill to point the solar panels more directly at the Sun. As the International Space Station orbits Earth, the solar panels can be rotated to point more directly at the Sun. At times, the entire space station is pointed in a different direction to improve the angle between the panels and the Sun. For more information see:

What are ISS Attitudes? http://spaceflight.nasa.gov/station/flash/iss_attitude.html.

Distance from the Sun - As you know, the further you are from a light source, the dimmer (less intense) the light is. Students can confirm this experimentally and discover that the intensity (I) of light is inversely proportional to the square of the distance (r) from the light source ($I \propto 1/r2$). You will need a light bulb, a meter tape measure, and a light intensity probe. In a dark room, measure the intensity of light at 10 cm, 20 cm, 40 cm, and 80 cm from the light. Plot Intensity versus distance. If you plot this curve on a graphing calculator, you can also obtain the equation for the curve. The intensity decreases because the light spreads out farther away from the source. The Sun emits light energy in all directions. The light of the Sun is spread out over the surface of an imaginary (hollow) sphere with its center at the Sun. The farther the sphere is from the Sun, the bigger the sphere is and the more surface it has (surface area of a sphere = $4\pi r2$). So, the power (energy per second) emitted by the Sun as light spreads over the surface of this imaginary sphere. Close to the Sun, the sphere is small. There is a lot of power per square meter (Intensity). Farther away, the sphere is big. There is less power per square meter. There is an equation that lets us calculate the intensity of light at a distance from a light source.

The equation is: Intensity = Power/(4πr2) But how can you measure the power of the Sun at its source? You can't. However, scientists have measured the intensity of light at Earth and we know the distance from the Sun to Earth. The intensity of sunlight outside the Earth's atmosphere is 1366 Watts/m2 (It varies slightly with solar output). The distance (r) from the Sun to Earth is 150,000,000 km (kilometers). If you substitute these values into the equation above and solve for Power, the value for the power of light from the Sun is 384.6 x 1024 Watts (Joules/second). Now we can use this value for Power in the equation above and calculate the intensity of light at Mars. The average distance from the Sun to Mars is 227,900,000 km. You can calculate that the intensity of light at Mars is 589.2 W/m2. That is less than half of the intensity at Earth!

But wait! The orbit of Mars is less circular than Earth's orbit. It is more elliptical. At perihelion (closest to the Sun), Mars is 206,600,000 km away from the Sun, and the intensity is calculated to be 717.1 W/m2. At aphelion (farthest from the Sun), Mars is 249,200,000 km away from the Sun, and the intensity drops to 492.9 W/m2.

These differences could be significant to the design of a solar energy system.

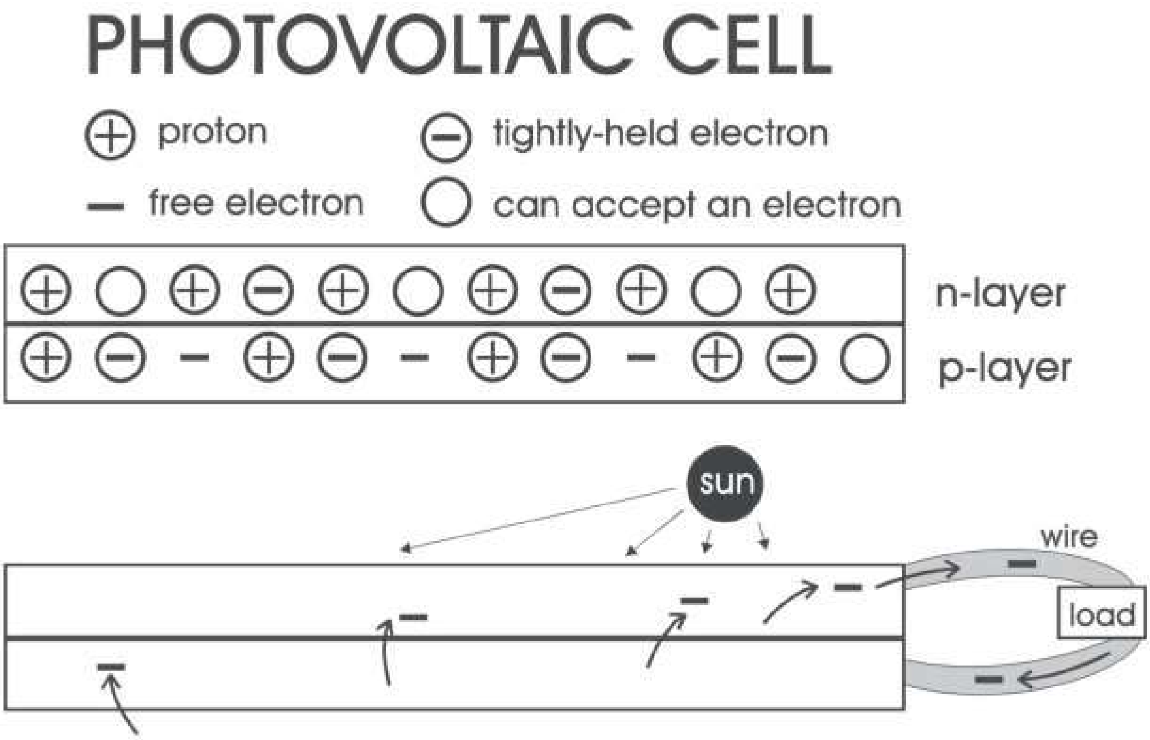
You will have to judge whether your students will be able to understand the math involved.

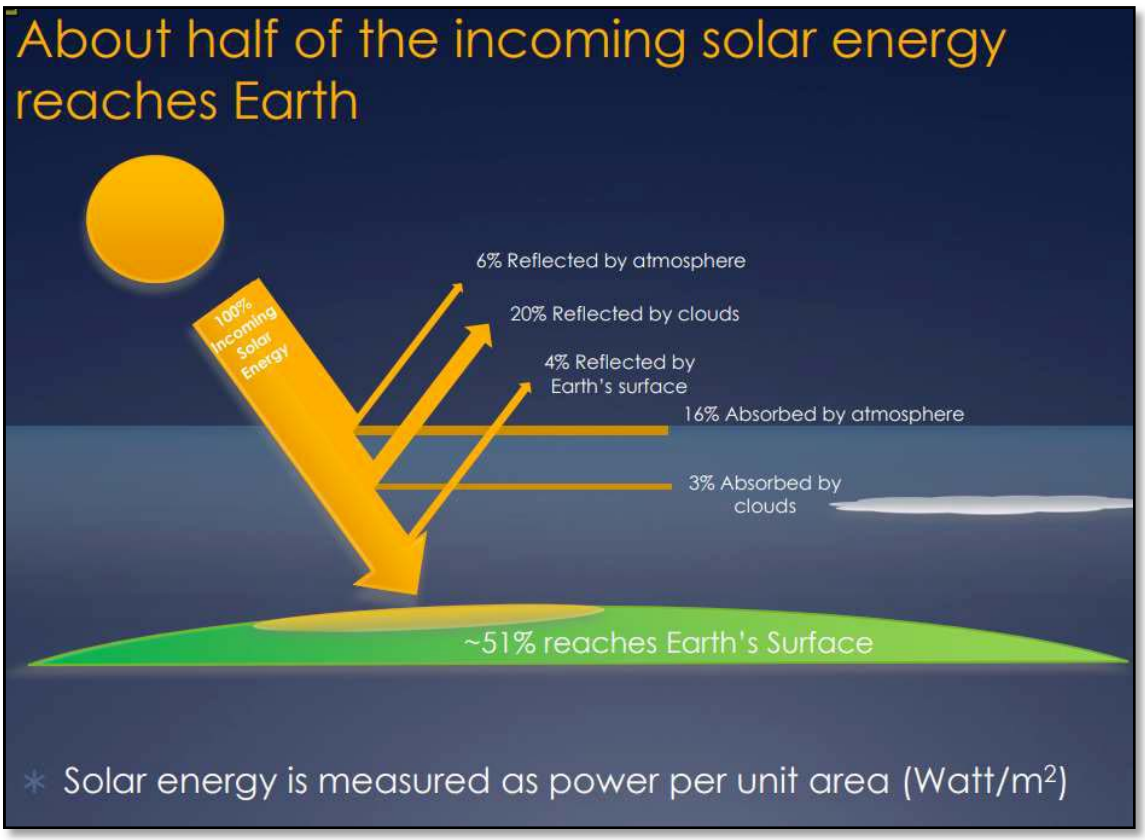
Crédit : Lockheed Martin

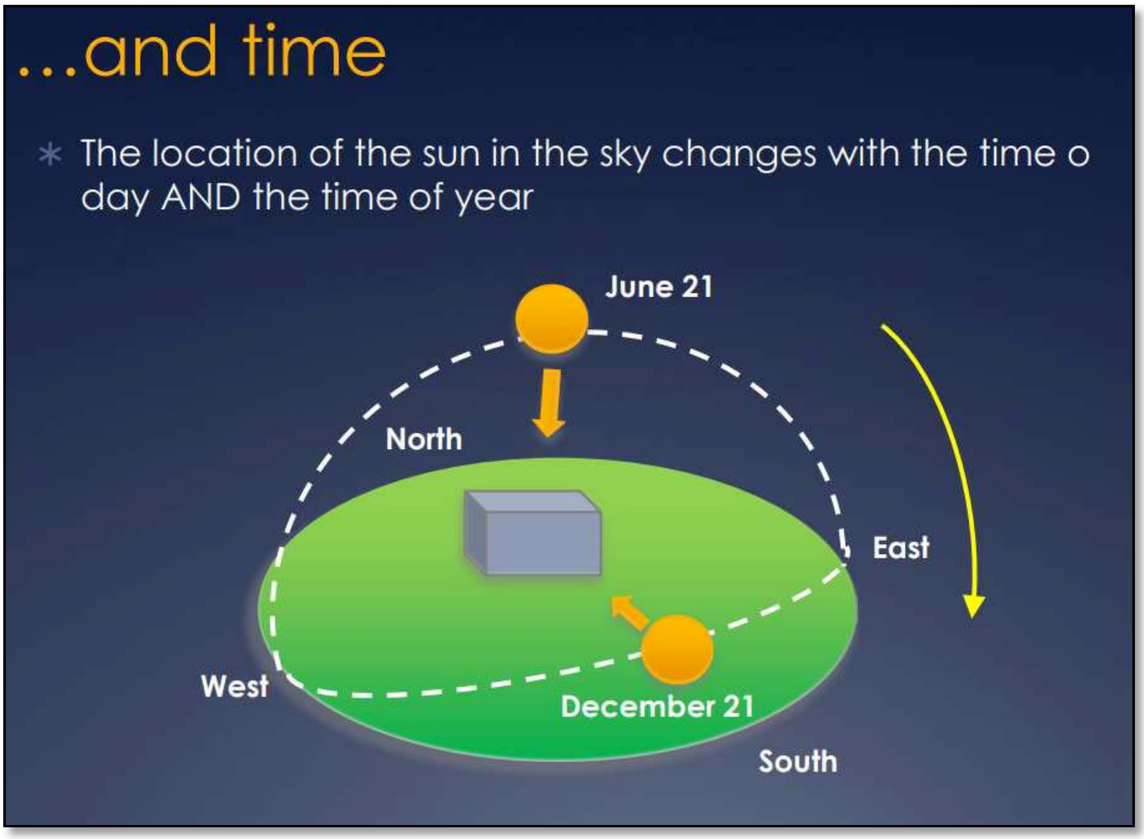
NASA/JPL-Caltech/Lockheed Martin

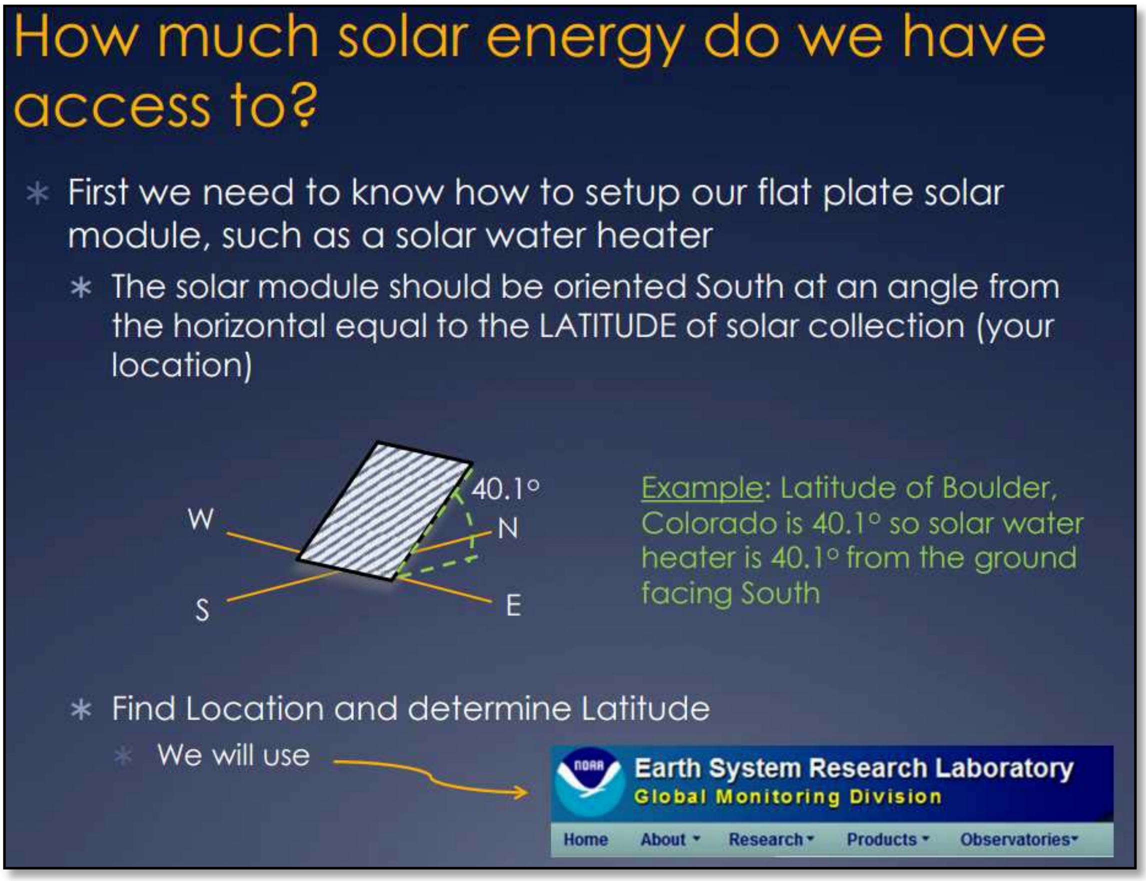
Activity 2: Solar Panels on Earth.

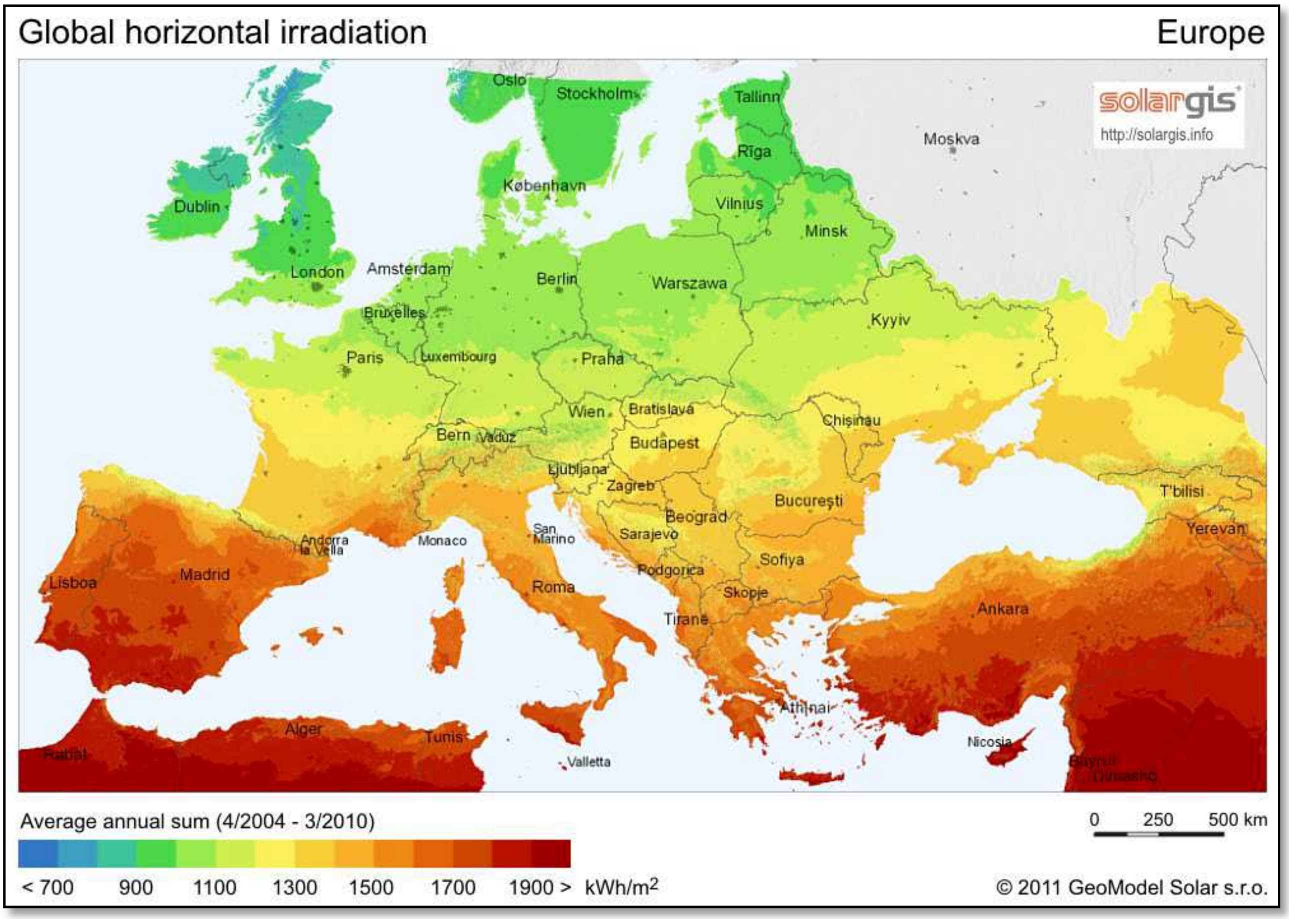
SOLAR ELECTRICITY Solar energy can also be used to produce electricity. Two ways to make electricity from solar energy are photovoltaics and solar thermal systems. The word photovoltaic comes from the words photo meaning light and volt, a measurement of electricity. Photovoltaic cells are also called PV cells or solar cells for short. You are probably familiar with photovoltaic cells. Solar-powered toys, calculators, and roadside telephone call boxes all use solar cells to convert sunlight into electricity. Solar cells are made of two thin pieces of silicon, the substance that makes up sand and the second most common substance on earth. One piece of silicon has a small amount of boron added to it, which gives it a tendency to attract electrons. It is called the p-layer because of its positive tendency. The other piece of silicon has a small amount of phosphorous added to it, giving it an excess of free electrons. This is called the n-layer because it has a tendency to give up electrons, a negative tendency. When the two pieces of silicon are placed together, some electrons from the n-layer flow to the p-layer and an electric field forms between the layers. The p-layer now has a negative charge and the n-layer has a positive charge. When the PV cell is placed in the sun, the radiant energy energizes the free electrons. If a circuit is made connecting the layers, electrons flow from the n-layer through the wire to the p-layer. The PV cell is producing electricity--the flow of electrons. If a load such as a lightbulb is placed along the wire, the electricity will do work as it flows. The conversion of sunlight into electricity takes place silently and instantly. There are no mechanical parts to wear out. Compared to other ways of producing electricity, PV systems are expensive. It costs 10-20 cents a kilowatt-hour to produce electricity from solar cells. On average, people pay about eight cents a kilowatt-hour for electricity from a power company using fuels like coal, uranium or hydropower. Today, PV systems are mainly used to generate electricity in areas that are a long way from electric power lines.


PHOTOVOLTAIC CELL
proton
tightly-held electron
free electron
can accept an electron
n-layer
p-layer
sun
wire
load


About half of the incoming solar energy reaches Earth
100% Incoming Solar Energy
6% Reflected by atmosphere
20% Reflected by clouds
4% Reflected by Earth's surface
16% Absorbed by atmosphere
3% Absorbed by clouds
~51% reaches Earth's Surface
Solar energy is measured as power per unit area (Watt/m²)

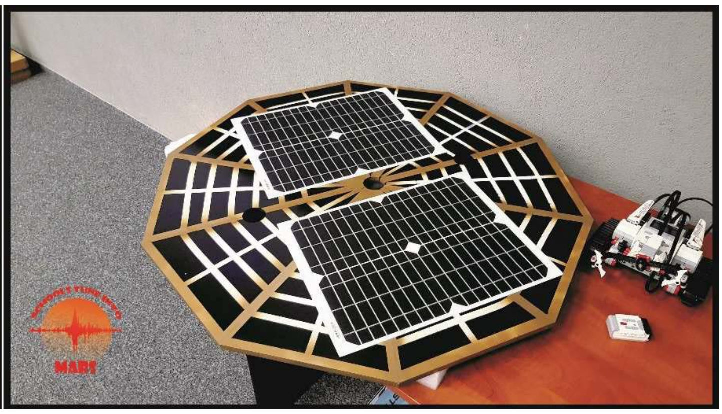

...and time
The location of the sun in the sky changes with the time o day AND the time of year
June 21
North
East
West
December 21
South


How much solar energy do we have access to?
First we need to know how to setup our flat plate solar module, such as a solar water heater
The solar module should be oriented South at an angle from the horizontal equal to the LATITUDE of solar collection (your location)
40.1°
W
N
S
E
Example: Latitude of Boulder, Colorado is 40.1° so solar water heater is 40.1° from the ground facing South
Find Location and determine Latitude
We will use
Earth System Research Laboratory
Global Monitoring Division
Home
About
Research
Products
Observatories



10. Procedures

Activity 1: Investigating Solar Cells.

Questions (students will answer these questions after doing the investigation)

1. What happened when you covered part of the solar cell with black paper? Why?

....

....

....

2. What is the relationship between the amount of solar cell that is covered and the functioning of the powered electrical devices? Explain.

....
....
....

3. How did the colored transparencies affect the solar cells ability to function?

....
....
....

4. What happens when you connect in series multiple solar panels compared with the initial specifications of one solar panel? What about connecting them in parallel?

....
....
....

Activity 2: Solar Panels on Earth.

- On the map find your location and determine what color your area corresponds to. Use the Legend to find out the energy range in "kWh/m^2/Day" from the "average annual sum kWh/m^2 ". Once you have the range, you will average the highest and lowest values on the range to get your energy estimate. For example, in France, the range is 2.7 – 4.4 kWh/m^2/Day, the average value is 3.55 kWh/m2/Day.

  Energy range for your location:________ _____ kWh/m^2/Day

  Average energy:_________________ kWh/m^2/Day

- Next, find the amount of solar energy available per unit area of your solar module (for example, a solar water heater), which depends on the time you expose your module to the sun. If you want to test your solar water heater for 1 hour, your duration of sun exposure is '1 hour' (this can be less than one if you test for less than an hour → 45 minutes = 0.75 hours). If you do not already have these values for a solar module, just use the following example values.

  Duration of sun exposure:___________ hours (example: 1 hour)

  Now you will need to find the energy in units of Watt-hours/m^2, referred to as '**insolation**':

  (kWh/m^2/day) x (1 day/24 hours) x (duration of sun exposure [hours]) x (1000 Wh/1 kWh) =

  (__ kWh/m^2/day) x (1 day/24 hours) x (__ hours) x (1000 Wh/1 kWh) =

  _______ Watt-hours/m^2

- To find the solar energy used by your solar module you will also need its surface area (m^2). Say you have a solar water heater that is 1 meter by 1.5 meters, the surface area would be 1.5 m^2 (you may need to convert feet to meters).

  Solar module surface area:___________________ m^2 (example: 1.5 m^2)

  Next, you need to use your surface area and **insolation** value to find out how much energy enters your solar module. This incoming energy is called **heat energy (Q_{in})** and is in units of Watt-hours:

  Q_{in} = [Insolation (Watt-hours/m^2)] x [Surface Area (m^2)]

  Q_{in} = (______ Watt-hours/m^2) x (_______m^2)

  Q_{in} = _________ Watt-hours

- What would be the '**tilt angle**' of your solar module? Why do you want your solar module to face south?

  ....
  ....
  ....

- How do you think the amount of solar energy available in Arizona for the same month would compare to the value for your location? (Hint: check out the maps, you don't need to calculate anything https://www.nrel.gov/gis/images/solar/solar_ghi_2018_usa_scale_01.jpg) What about the solar energy available in Alaska? In which location (Arizona or Alaska) would it be easier for engineers to use the solar energy available for heating or electricity?

  ....
  ....
  ....

11. Discussion of the results and conclusions

How does dust affect solar panels on Mars?

How are the scientists dealing with this challenge?

What really happened on Mars with the Insight Lander's solar panels?

What can and can't be done for future space missions in this matter?

12. Follow up activities

Challenge: Solar Energy for Moon and Mars. Working in small groups, students will choose either the Moon or Mars as the location for a NASA research habitat. Each group will estimate the requirements for the research habitat using what is known about home power requirements and the power requirements for the ISS. Then, each group will propose a design for a solar energy system to meet the energy requirements. This activity could be used as an assessment.

13. Explore More (additional resources for teachers)

Solar Maps

These solar maps provide average daily total solar resource information on grid cells.

https://www.nrel.gov/gis/solar.html

https://earsc-portal.eu/pages/viewpage.action?pageId=16548947

TeachEngineering is a digital library comprised of standards-based engineering curricula for K-12 educators to make applied science and math come alive through engineering design.

https://www.teachengineering.org/

https://www.nasa.gov/

Acknowledge This activity was inspired from the JPL Education Program & TeachEngineering

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