Topic II Environment of rocky planets

- Effect of atmospheric noise on the ground
- Determine martian wind velocity
- Primary aerosol and climate impact on Earth
- Study of daily variations on Mars
- SEIS and Environment
- Primary aerosol and climate impact on Mars

Atmospheric seismic noise

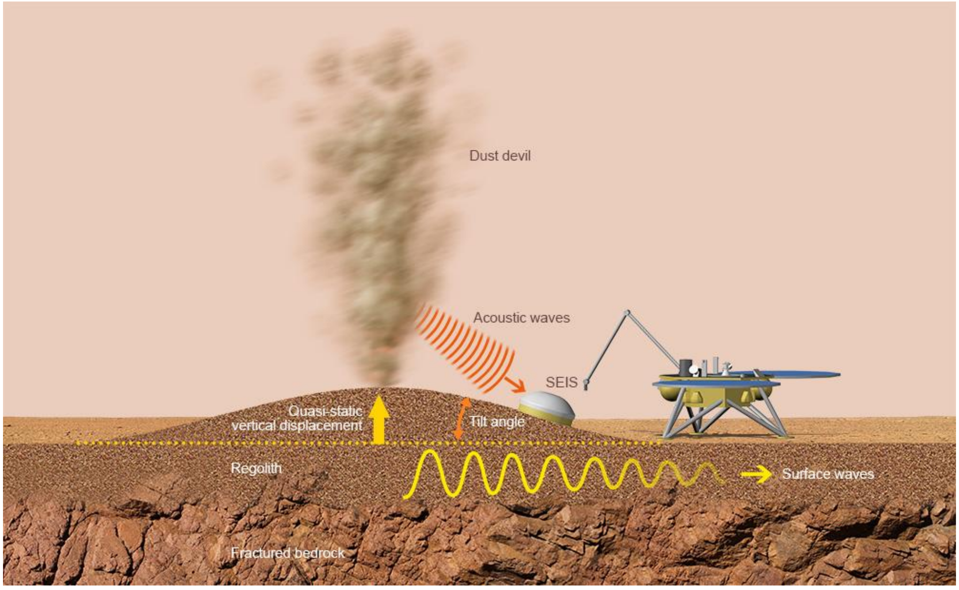
1. Introduction & Pb

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

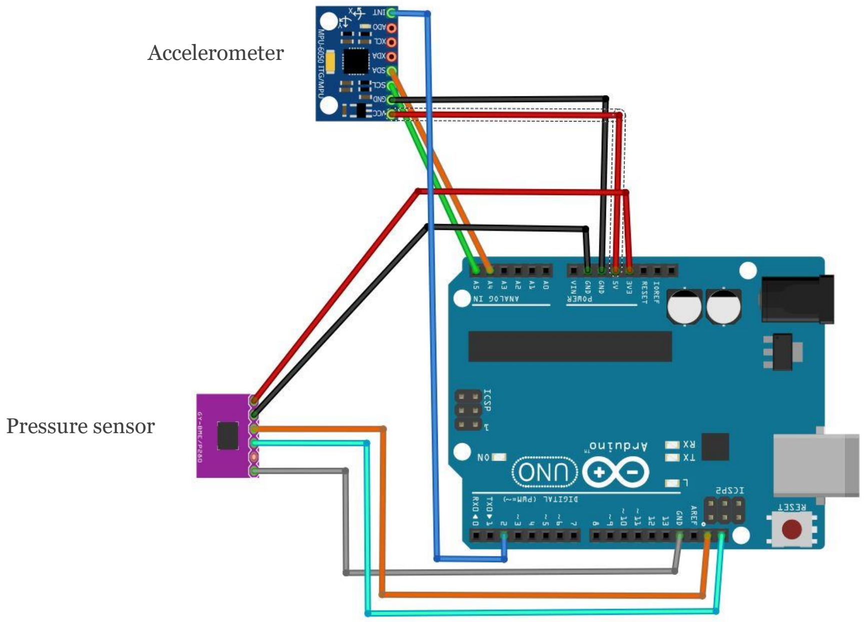
A 1600W hair dryer

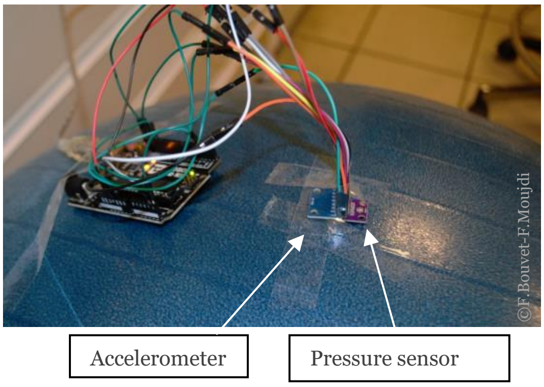
10. Procedures

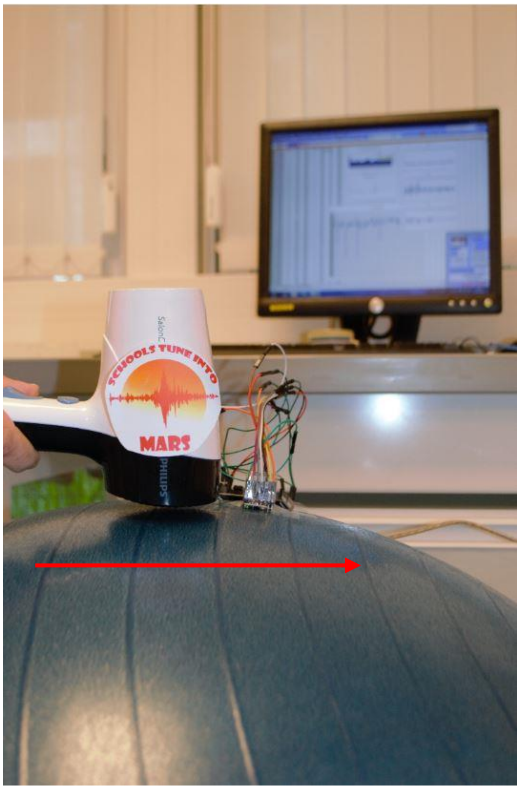
Place the fitness ball on the polystyrene bars in order to avoid any kind of contact with the soil

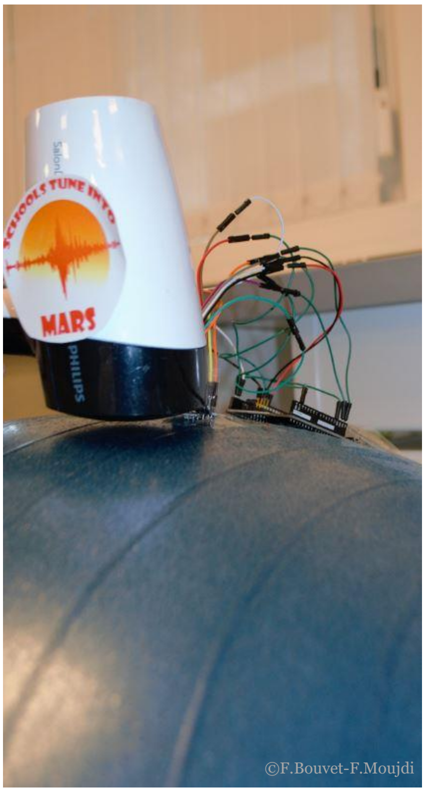
Firmly attach the accelerometer and the pression sensor using adhesive tape

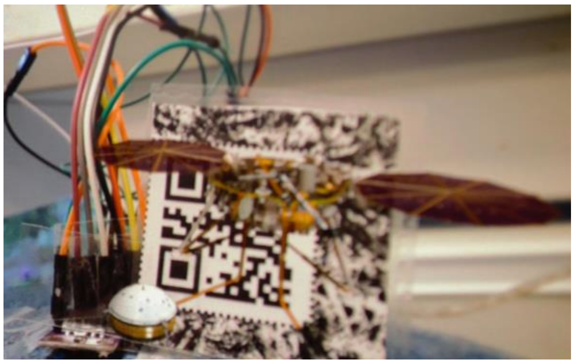
Hold the hair dryer's air outlet in a vertical position towards the fitness ball and blowing upwards without touching it.





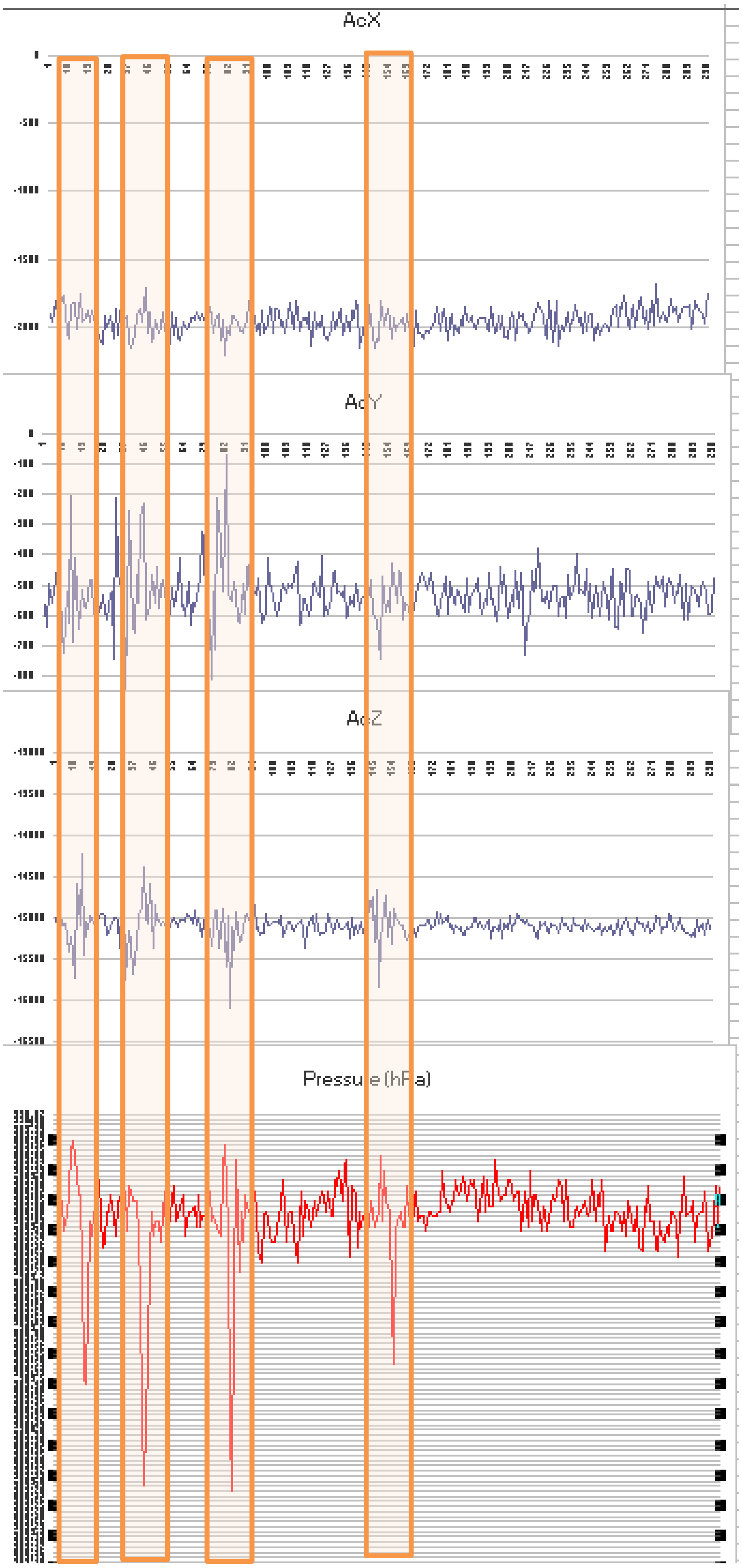






Move around the hair dryer without touching the fitness ball, but keep it close while maintaining a constant distance.

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.

Instruments to measure the speed of the Martian wind

1. Introduction & Pb

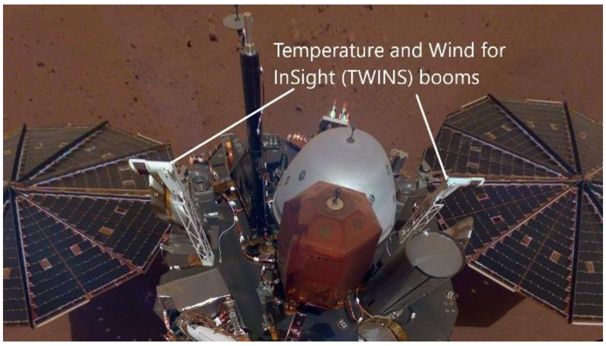
On Earth, the sensors used in the Météo-France network to measure wind force and direction are two types: mechanical sensors with a cup anemometer and a weather vane, and ultrasonic sensors.

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

<u>Pb :</u> **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

V_{TEMP} is the tension measured at the sensor's TEMP output

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

8. Background

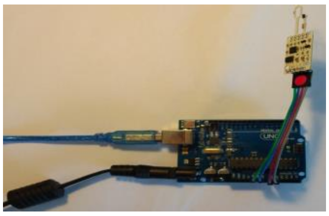
Assembling a sensor and simple programming Arduino.

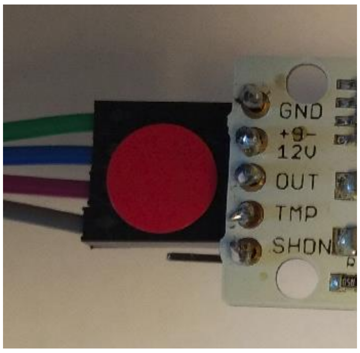
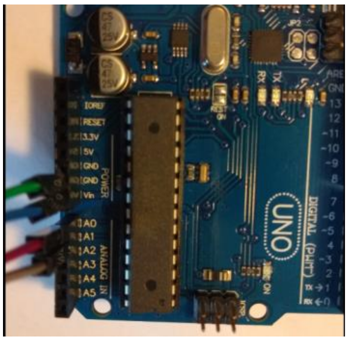
9. Procedures

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



	Sensor	Wire color in the image	Arduino	
	GND		GND	
	+12 V		Vin	
	OUT		A0	
	TEMP		A1	

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. Setting up the second sensor:

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. Determining the direction

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
}
```

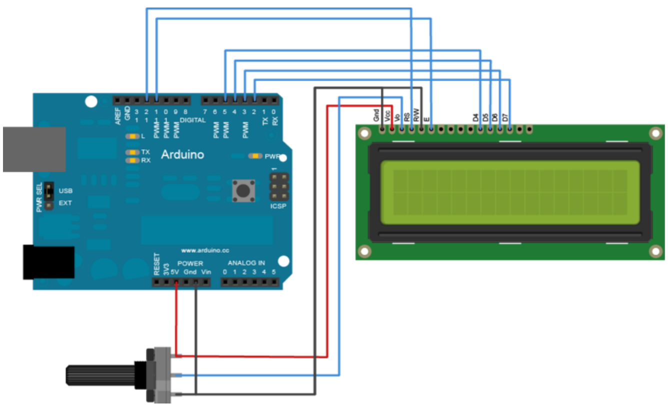
10. Discussion of the results and conclusion

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

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

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

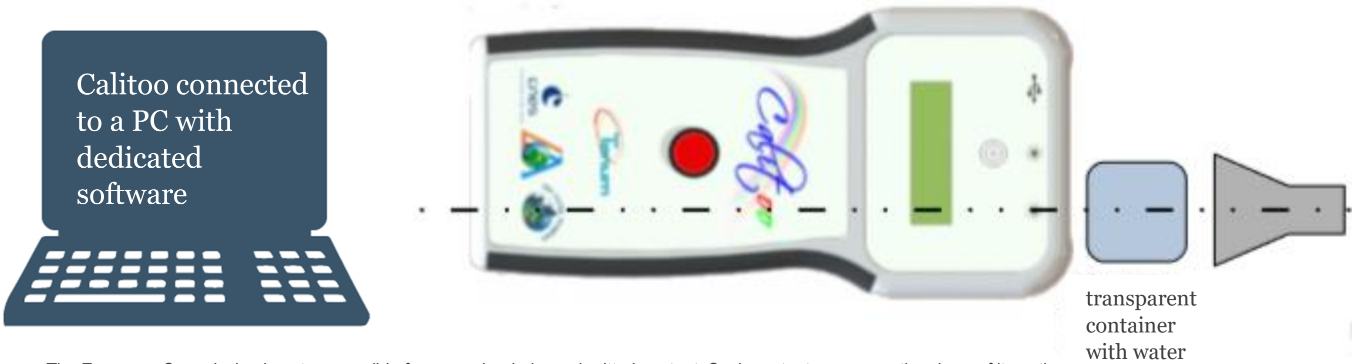
- A sample of damp dustfall, for this example particles in suspension collected from the orange snow in the Southern Alps.
- A digital light meter
- Two transparent containers
- A 12 V lamp placed in a holder

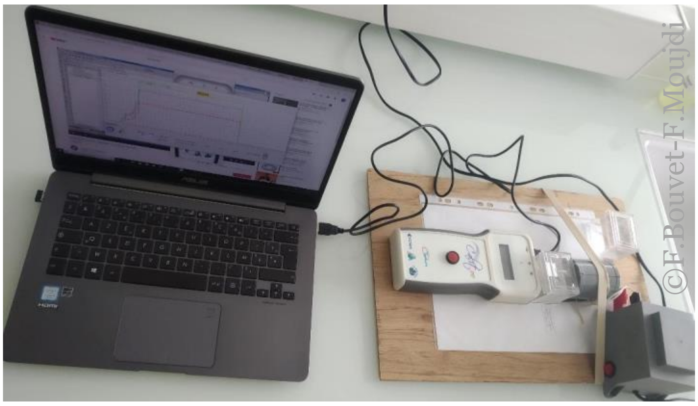
9. Background

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:

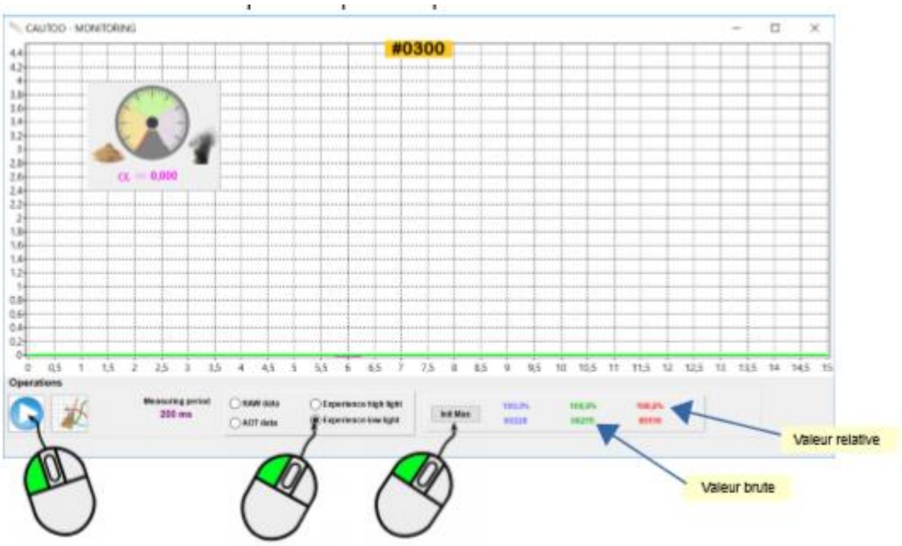




- Initialising the measurement functions

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 on 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.

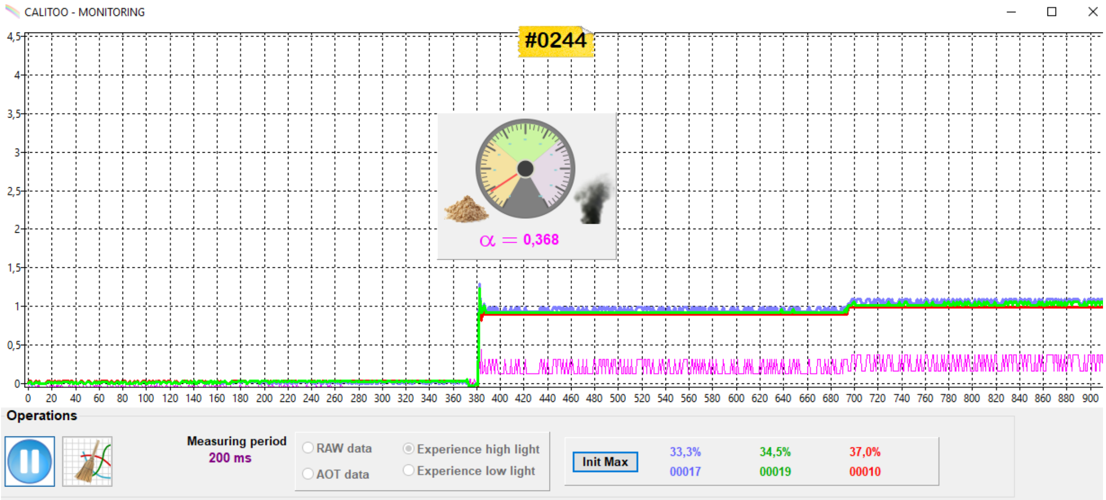
  Replace the pure water container by a container carrying the particles in suspension.

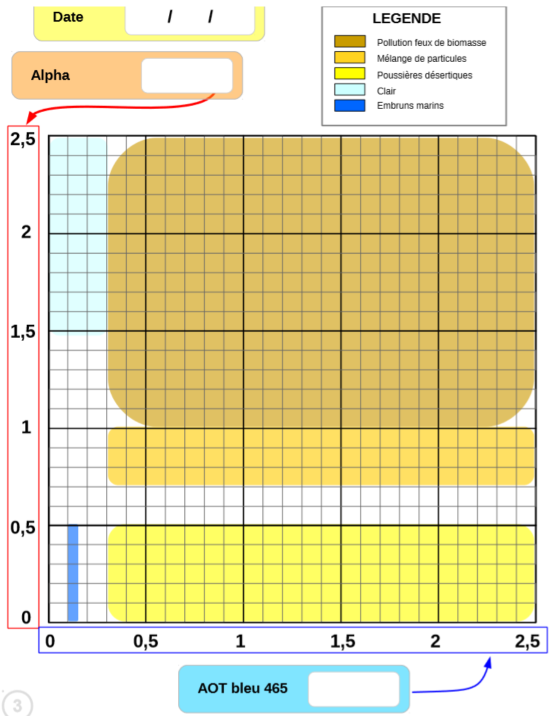
Outcome :

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.

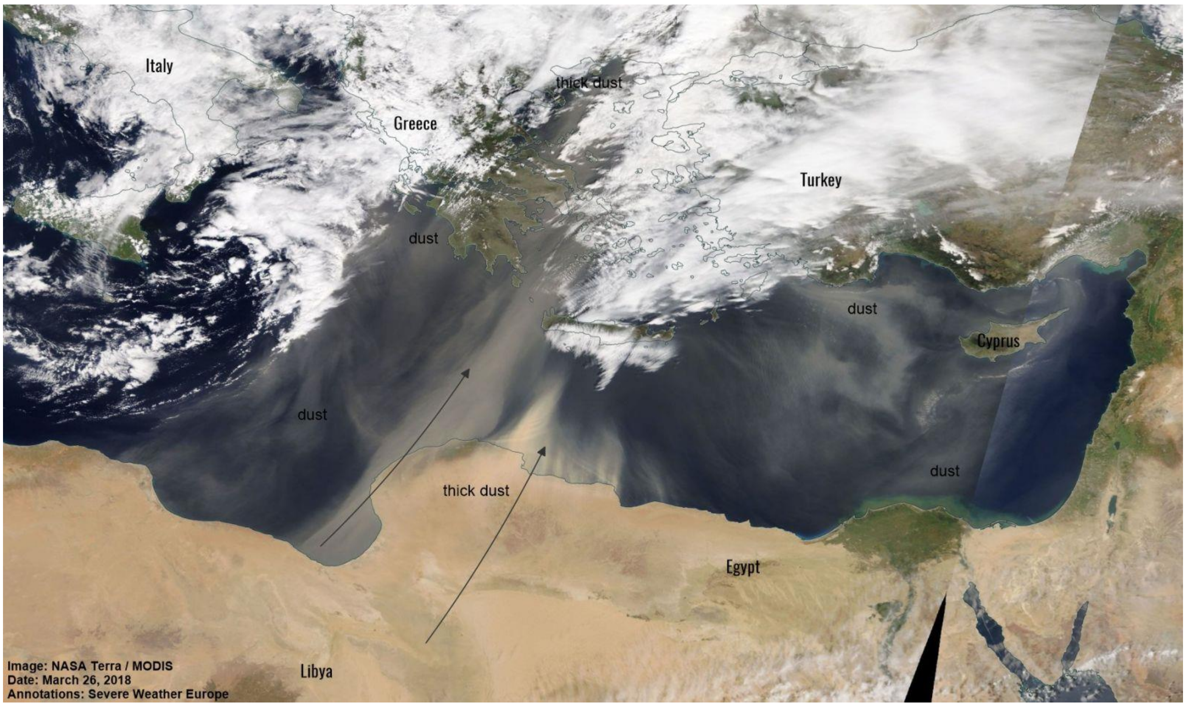




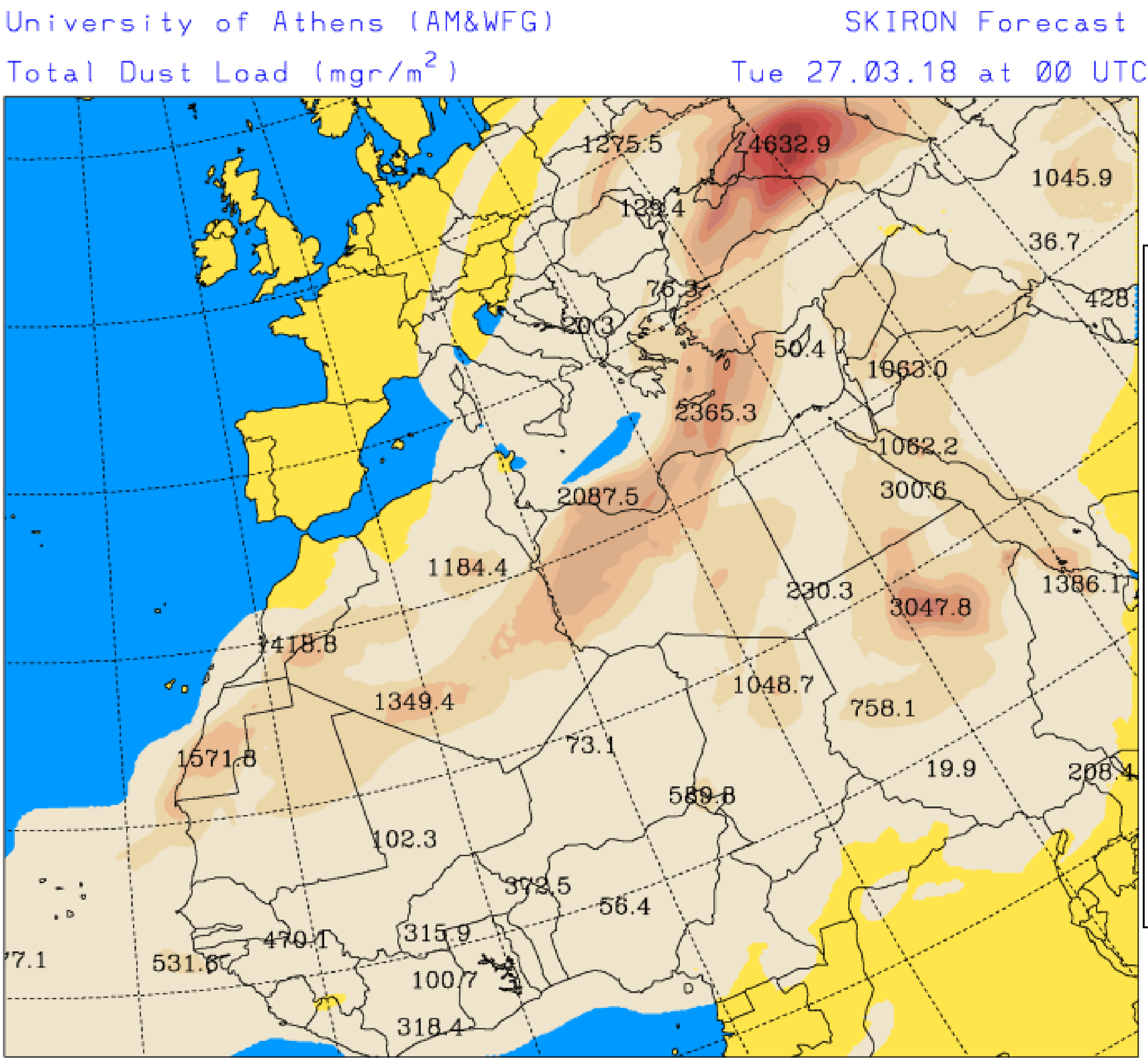
We therefore suppose that these particles are particles of sand but our hypothesis must overlap with weather data.

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

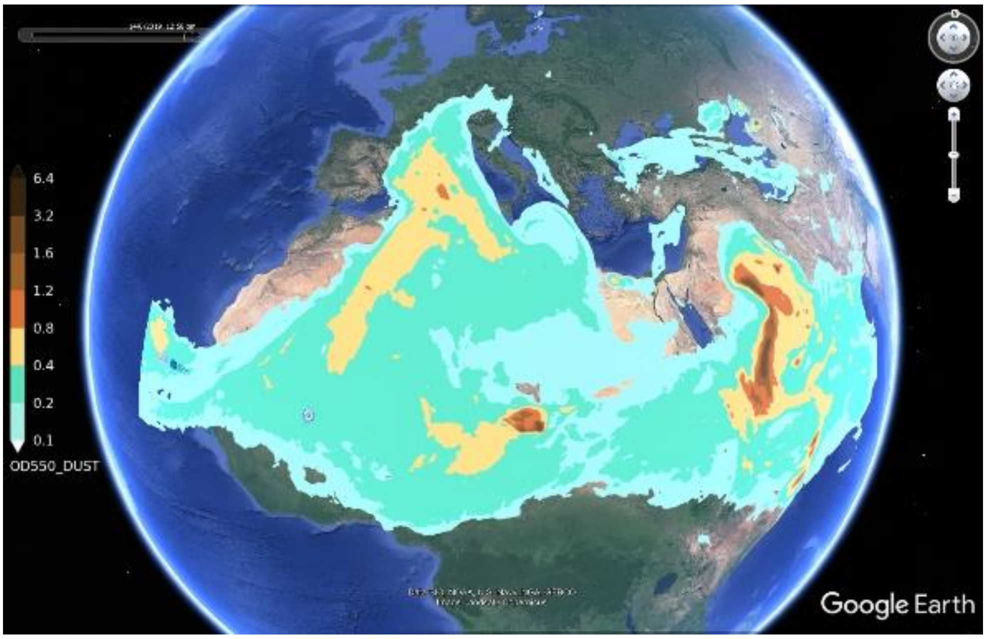
A weather map study and sattellite images from 26 and 27/08/2018 data corresponding to snowfalls in Sotchi validate the hypothesis.



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



University of Athens SKIRON model forecast for March 27



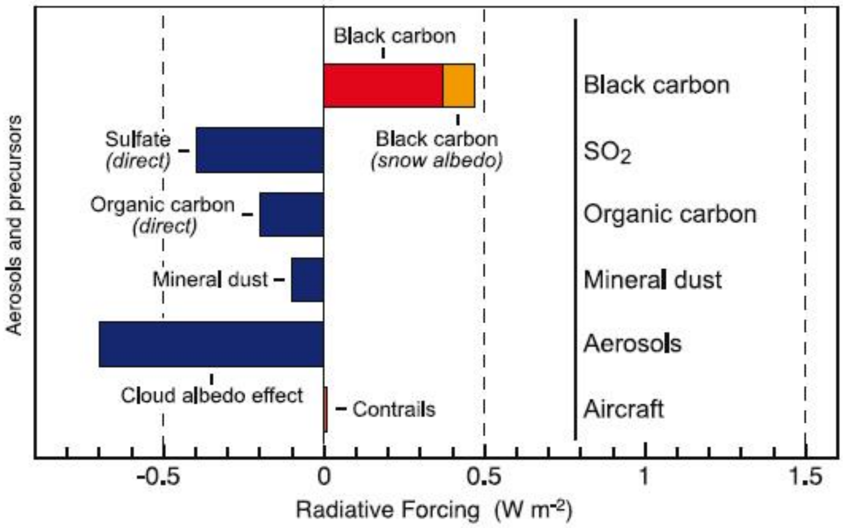
We can also observe that the South of France is frequently affected by desert dust outbreaks

https://dust.aemet.es/forecast

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

When the particles in the air are aerosols

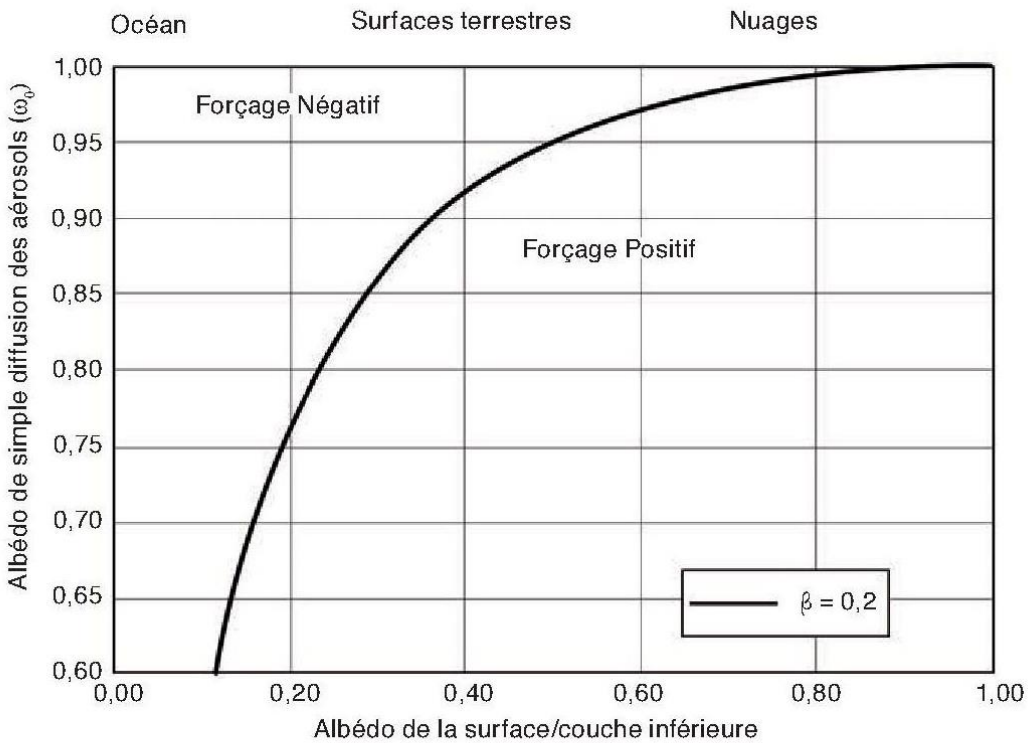
The assessment of the global impact of aerosols as a whole is easier and provides more consistent values than if we think of particles individually. Scientists try however to quantify the radiative forcing of each type of aerosols. For example, we have the following estimations for the mean radiative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

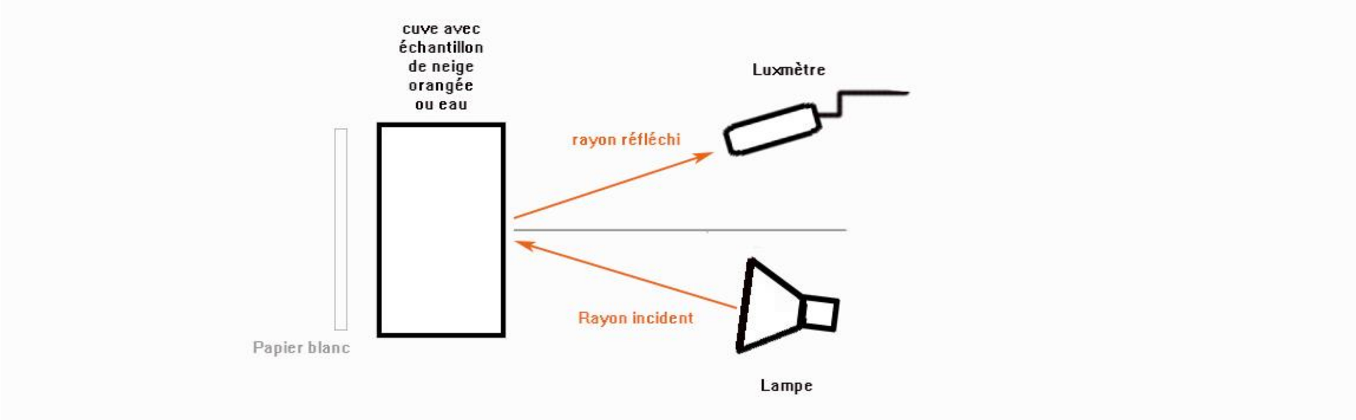


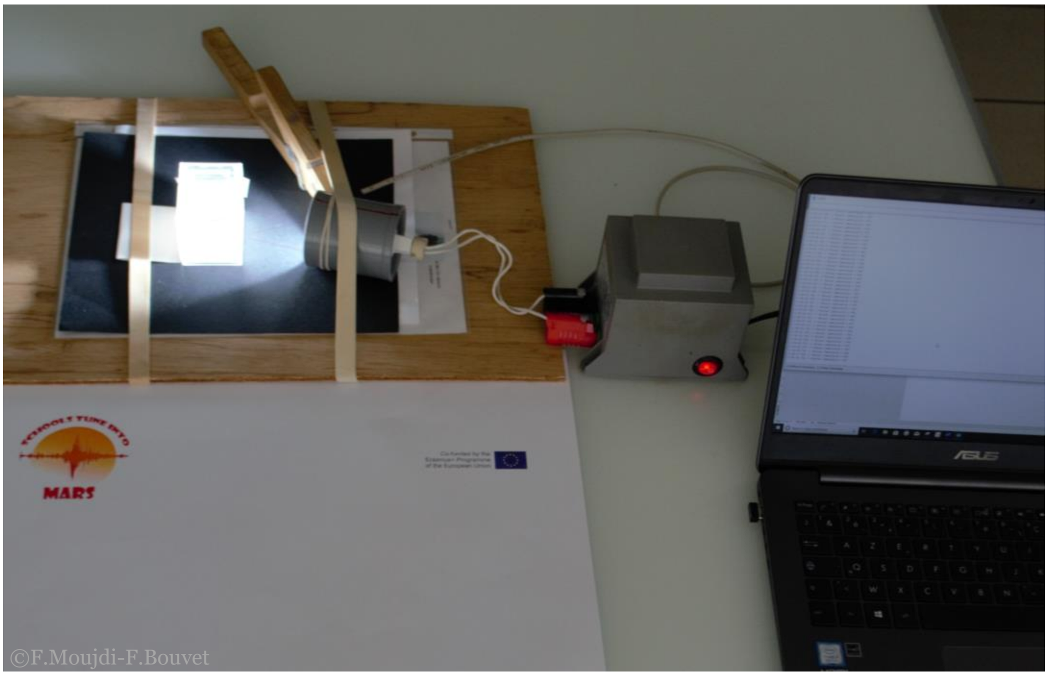
Didier Tanré, Physicist, Research director at CNRS, LOA, Villeneuve d'Ascq.
https://books.openedition.org/editionscnrs/11354

- 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.





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

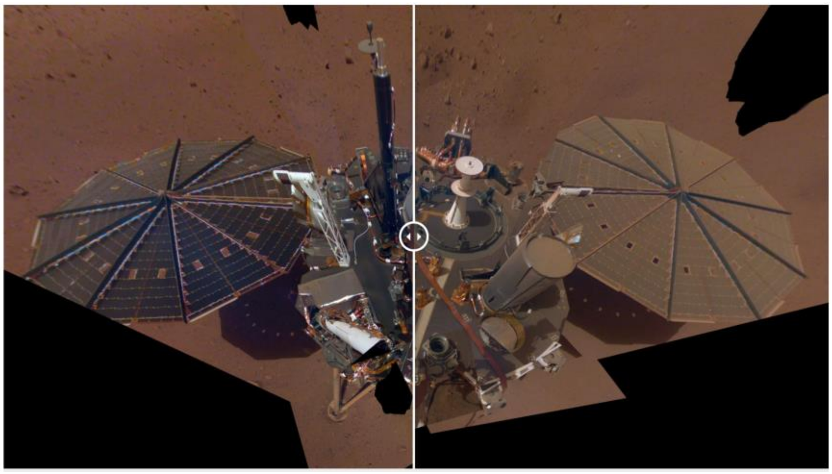
The colour of the snow therefore reduces its albedo and temporarily promotes an increase in ground temperature and accelerates snowmelt.

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.



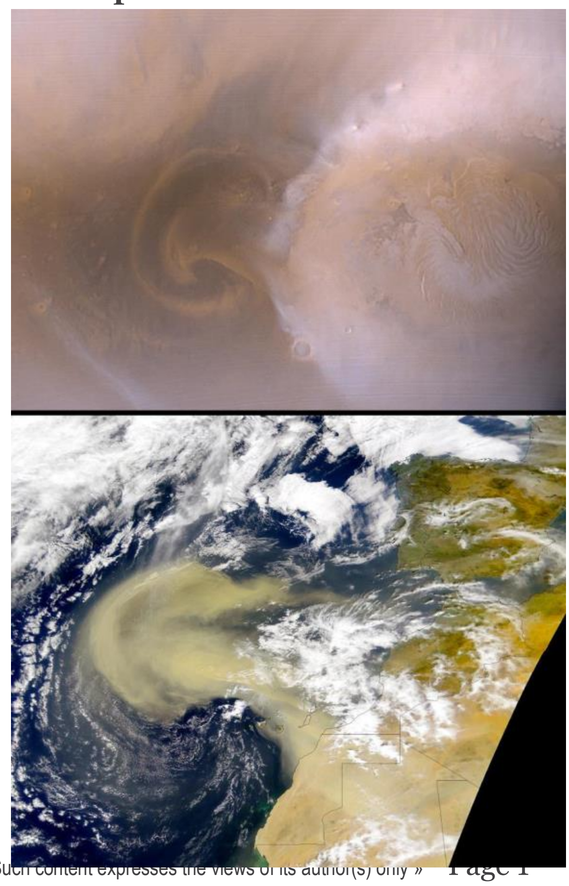
We can see on these insight selfies that mineral dust has settled on the Lander. This can also be set in motion again by atmospheric turbulences such as dust devil as evidenced by sudden variations in the efficiency of solar panels.

Selfie d'Insight fait Dec. 6, 2018   *Selfie d'Insight fait May. 6, 2019*

NASA/JPL-Caltech

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

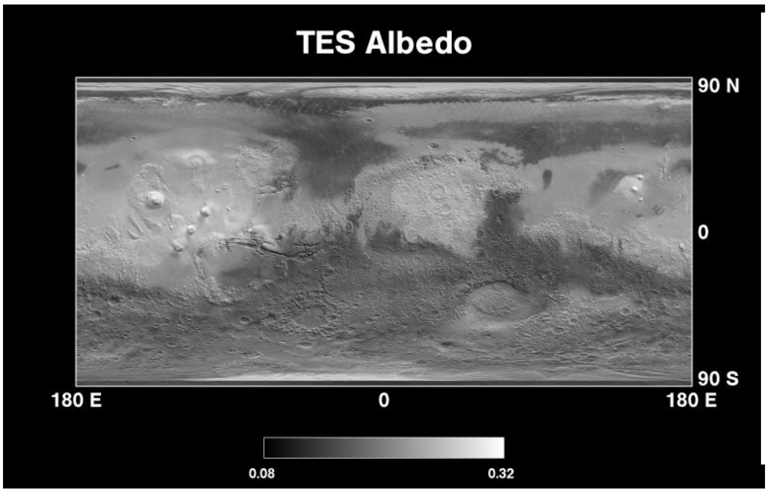
9. Background

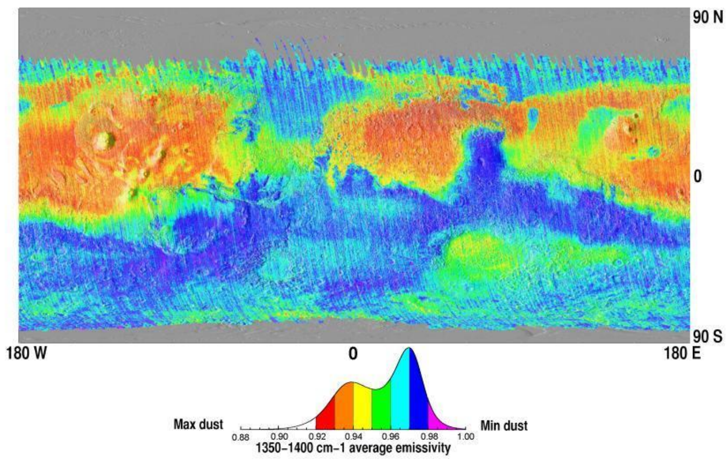
Scientists define an aerosol as a suspension of particles in the atmosphere. These particles are made up of solid and/or liquid substances. Mineral or organic, composed of living matter (pollens...) or not, large or fine, suspended particles constitute an extremely heterogeneous set of pollutants whose 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.

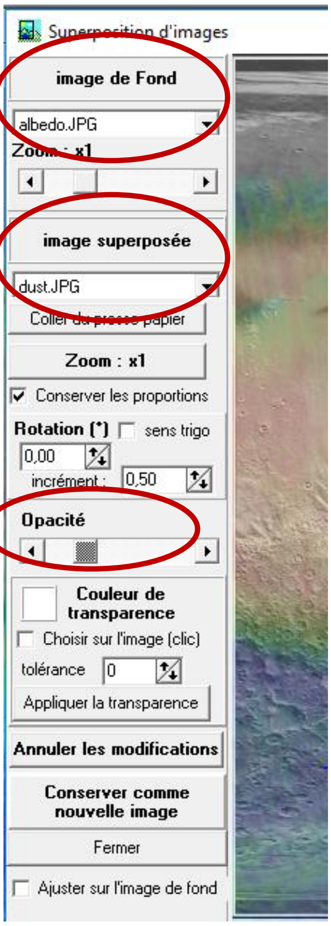
10. Procedures

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

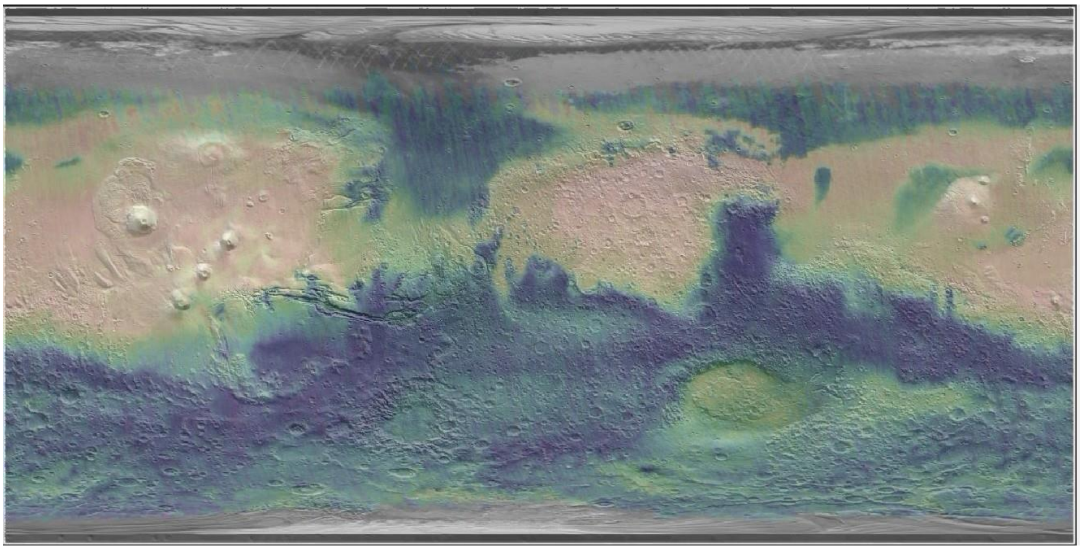
We will compare a map of the global albedo of March and the distribution of sand. To do this we will use mesurim and the overlay function.





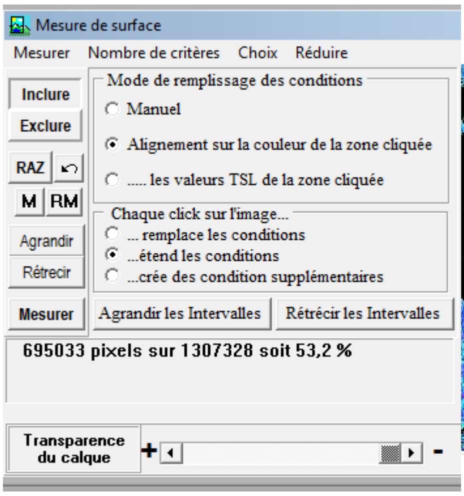


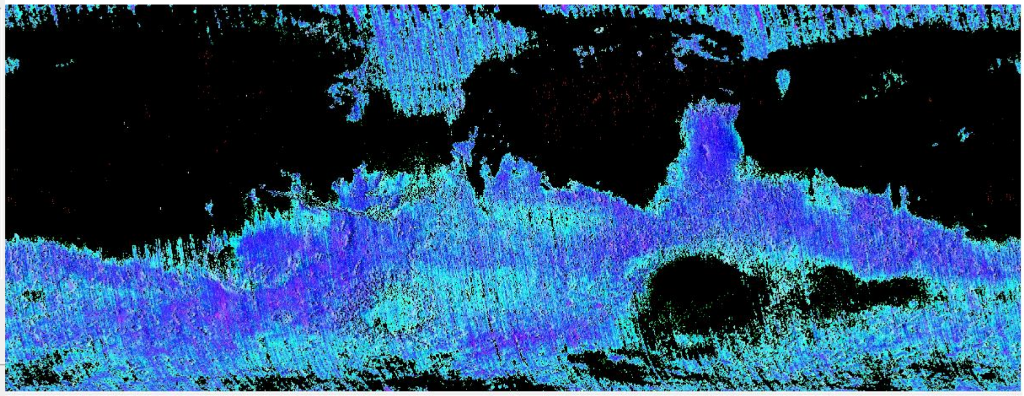
Open "albedo.jpeg" and "dust.jpeg" in mesurim.
Then in Image choose to overlay image as shown opposite
Adjust the opacity to make it easier to read.



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.

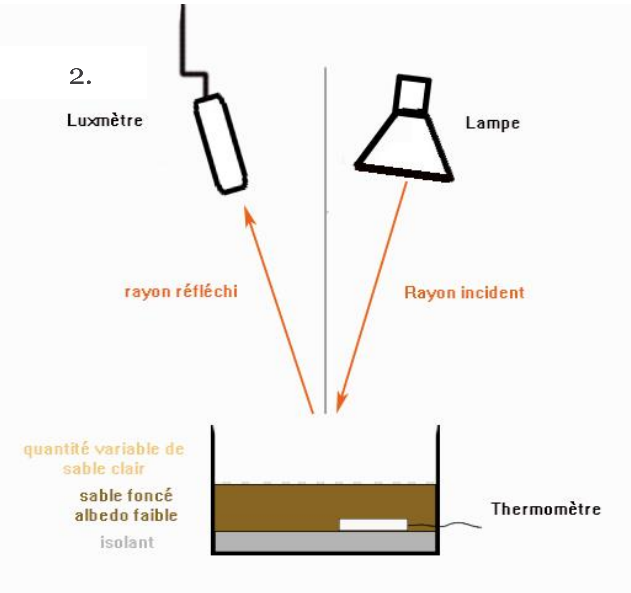


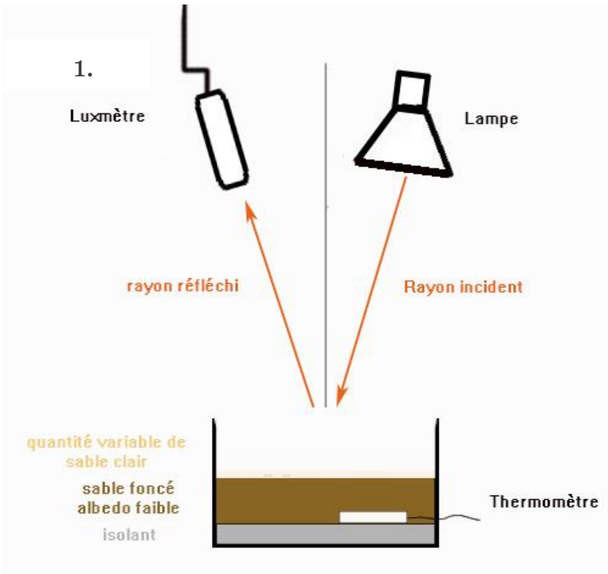


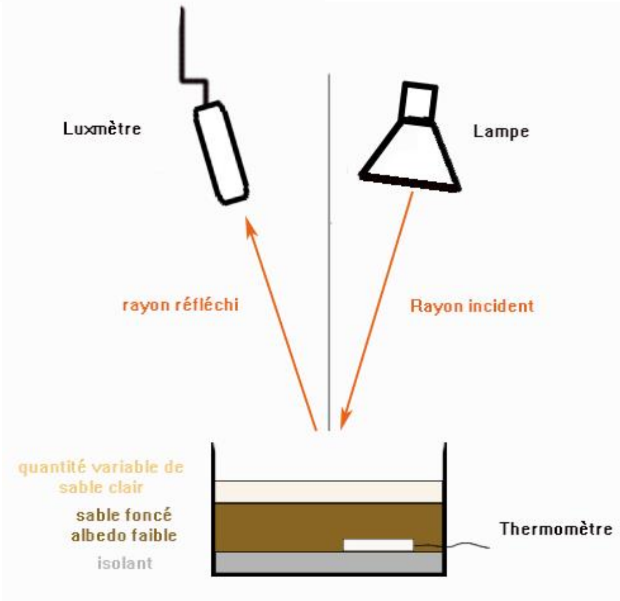
Dust transport could have an impact on the thermal inertia of areas with a lower albedo that represent a large surface area of the planet.

- 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





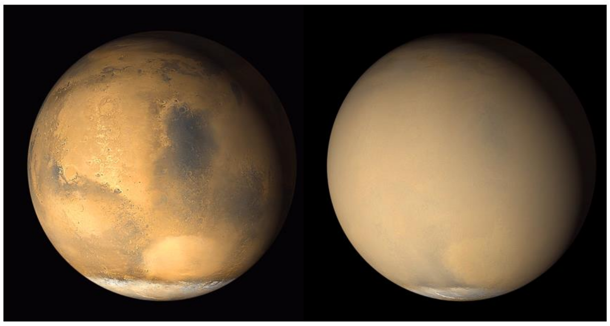


11. Discussion of the results and conclusions

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

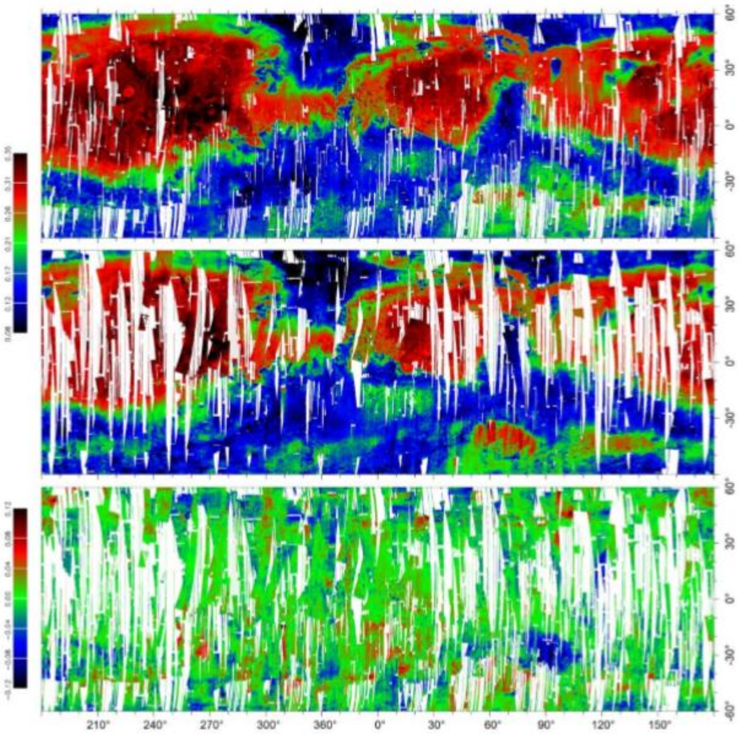


Figure 9: (top) albedo map prior to the MY28 GDS (orbits ≤ 4463: data from MY26 LS 330° to MY 28 L_s 265°: 86% coverage). (middle) albedo map after the MY GDS (orbits ≥ 4758: data from MY 28 L_s 315° to MY 30 L_s 135°: 74% coverage). (bottom) difference albedo map (middle – top: 63% coverage). Quality 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

Daily temperature variations on Mars

1. Introduction & Pb

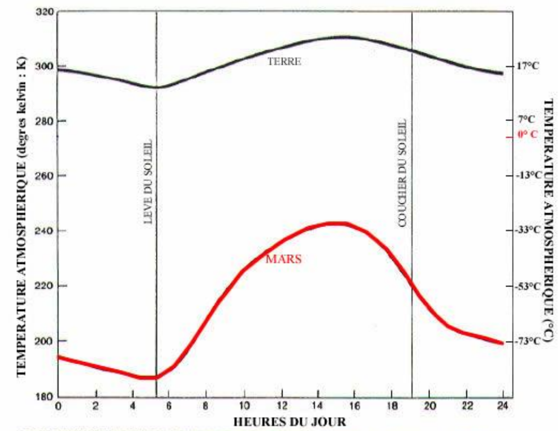
On Mars' surface, we can find summer trends: 20 °C, the breeze of trade winds… But starting with the onset of night, temperature values plummet by several tens of degrees and freezing conditions reaching – 100 °C will prevail until the morning after. In fact, Martian soil, dry and granular, can store 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.

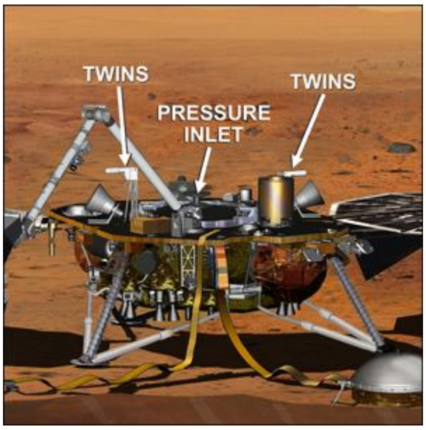
Source: Reserved rights - © 1979 According to Ryan et Henry, JGR

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.**

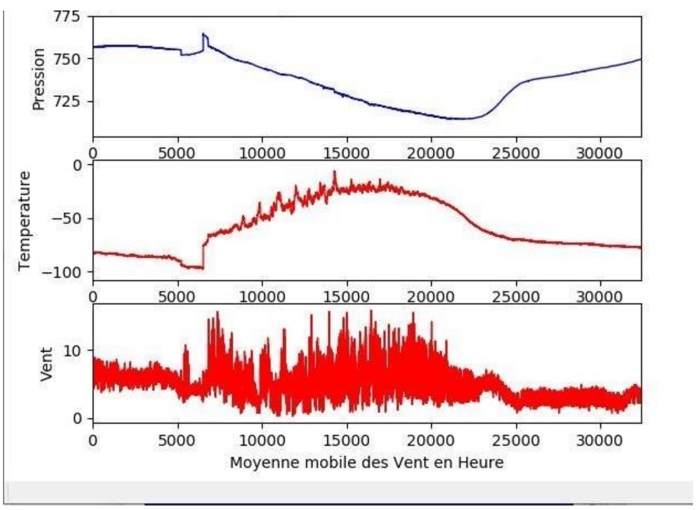
- On Mars :

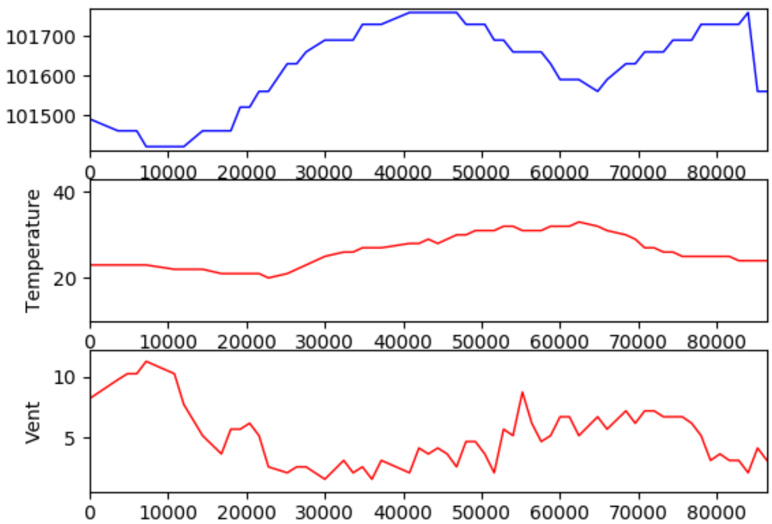
You have at your disposal, in « csv » format, the meteorological data corresponding to the 15th day of the InSight mission (cf csv data sheet).

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

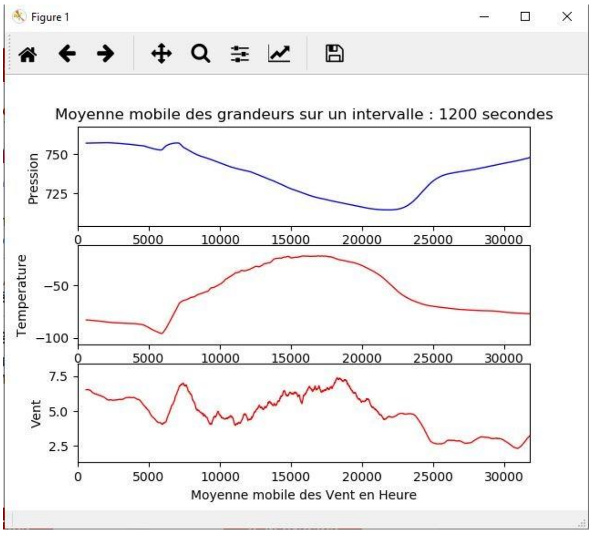
4) a) Write the **Moving_Average(n, List1, List2, List3,List4)** function that will display the temperature, pressure and wind speed mean values depending on the average time, on a range of 8 time values.

(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:

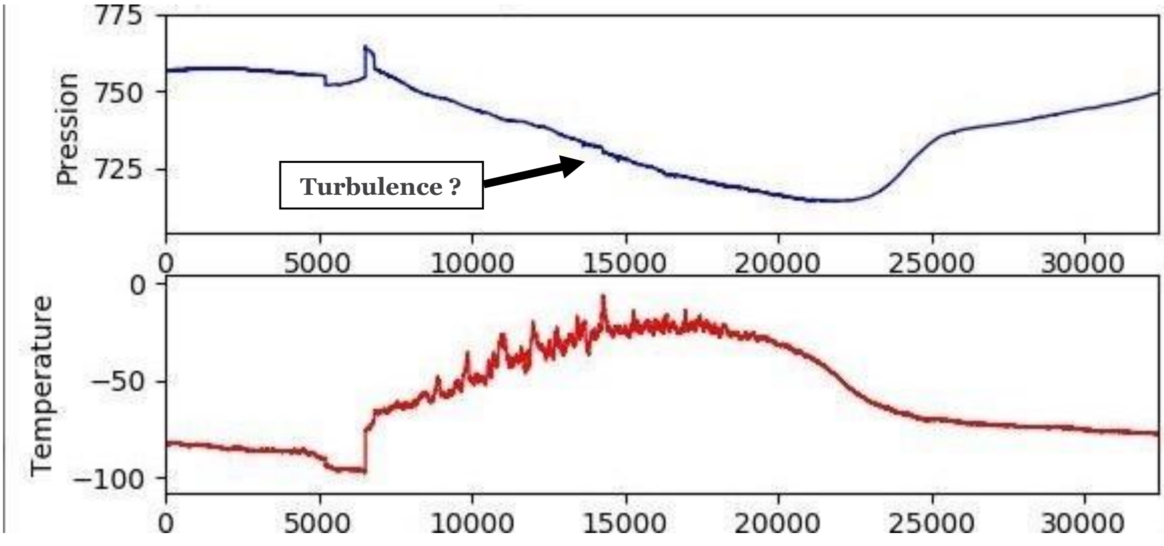


We can observe on the 'Pressure on Mars' plot large scale waves known as « thermal tides ».

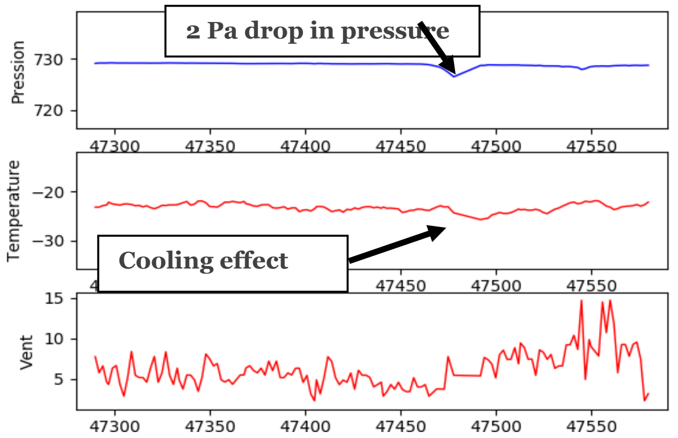
Basically, thermal tides are global-scale waves generated by fluctuations in the regular day-night cycle in the Sun's heating of atmosphere (insolation). These waves are displayed on wind components and they evolve with local solar time.

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:

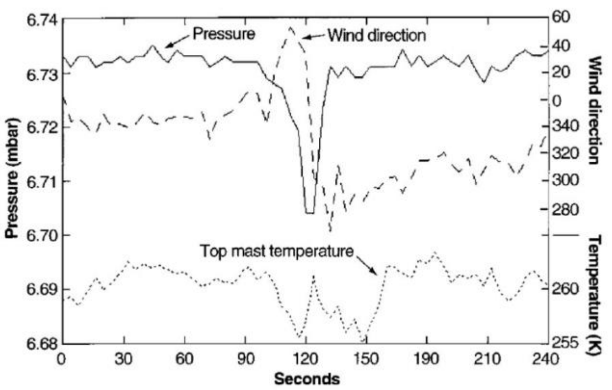


The thermal tides in the atmosphere of the planet Mars have a much higher amplitude than that of the Earth because thermal forcing is very strong due to the infrared absorption of atmospheric CO2, the absorbtion of infrared radiation emitted by the surface and the fact that the atmosphere on Mars is thinner.

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

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

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].

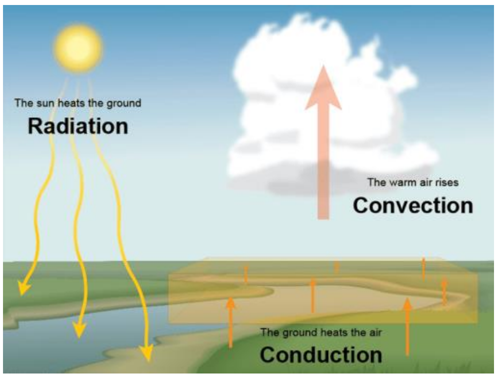
Source : Thesis by M. Aymeric Spiga « Mesoscale dynamic model of the Martian atmosphere: defining a meteorological model and analyse of observations made by OMEG/Mars Express »

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.

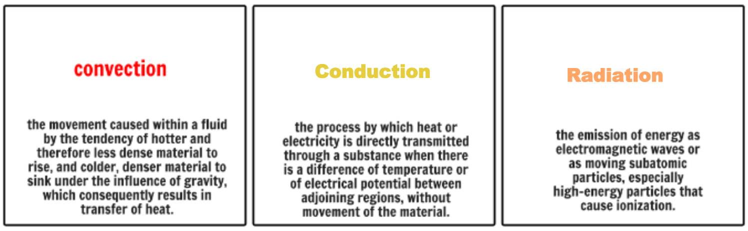
The arrival of a horizontal transport of air mass will generate a rotation in the air which will then confine all the dust in its proximity.

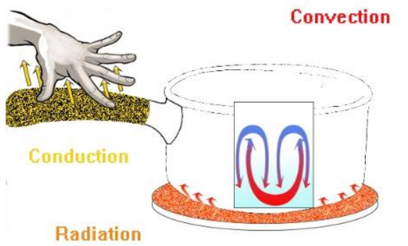
The altitude and diameter of a a whilwind depends on the air's instability and dryness.



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

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





©F.Moujdi-F.Bouvet

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 »

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

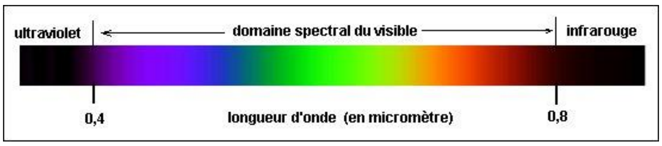
Chemistry – Earth Sciences

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

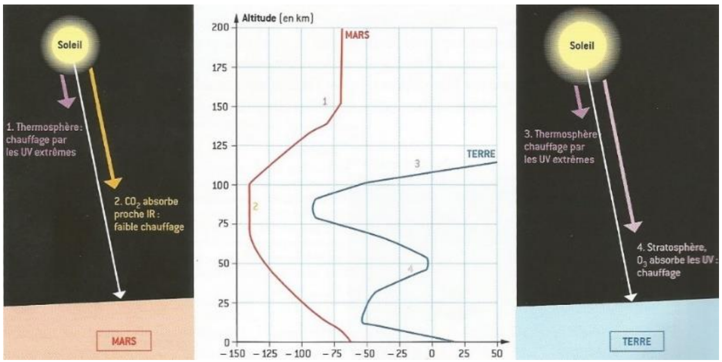
You will have to write a scientific paper on the specifics of Mars and of the Earth, in which you will integrate the arguments given by scientists to explain the process responsible for the loss of a great part of the atmosphere on Mars which would partly explain its hostile environment.
Lastly, you 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. <u>The atmosphere of rocky planets in the solar system:</u>

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				

Medium temperature profile on Earth and on Mars:



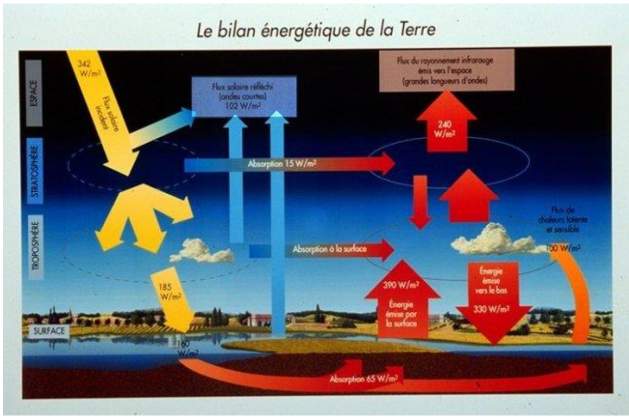
On both planets, the most of the atmsphere is confined in the first kilometers above the surface. The thermal structure of the atmosphere is defined by a thick layer of ozone heated by the process of absorbtion of ultraviolet radiation.

There's no such thing on Mars, where the ozone layer is insignificant.

Planet Mars, Belin – 'Pour la Science' – Forger, Costard et Lognonné

Radiation balance and the greenhouse effect:

Earth

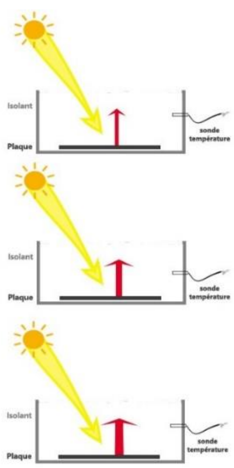
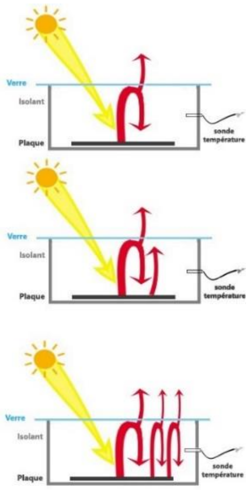


Mars

Mars has only half of the isolation on Earth. The atmosphere's composition (95% CO2) 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 CO2.

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

2. Modelling of the Radiation balance of a planet with and without the greenhouse effect:

Temperature in case of no greenhouse effect	Temperature in case of greenhouse gases
	

T° =	T°=

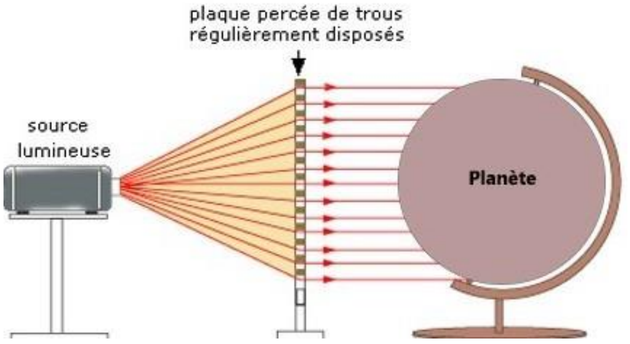
The plate that is exposed to the sun heats up. It receives energy from the Sun, therefore its T° increases. It will thus emit more radiation and will lose more energy in return.
The surface of glass allows the solar radiation to go through and absorbs all the infrared radiation. Glass therefore absorbs 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. Circulation of wind on Earth and on Mars:

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. Thermal contrasts:

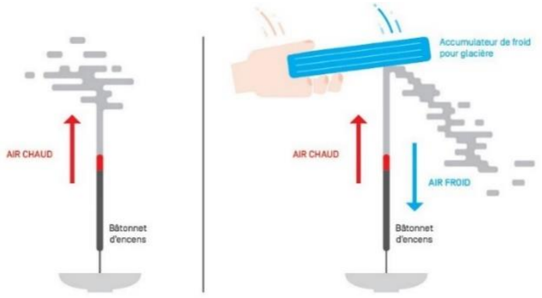
Solar radiation generates atmospheric circulation by creating contrasts in temperature. For the same pressure value on the surface we will find more air at higher altitudes because warm air masses take up more volume.



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.

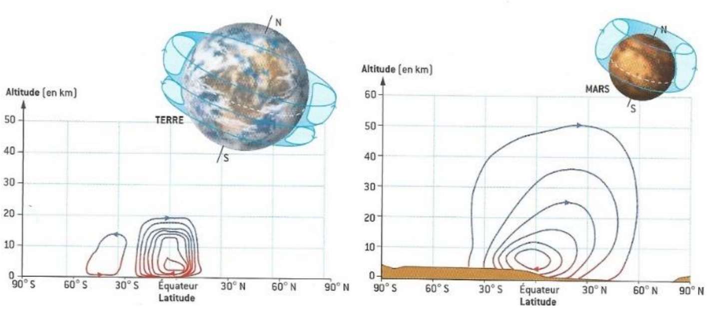
- **Meridional circulation:**



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.

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.

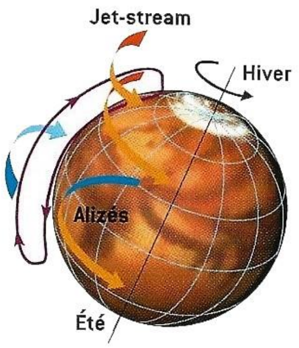


La planète Mars, Belin – Pour la Science – Forger, Costard et Lognonné

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…

Mars



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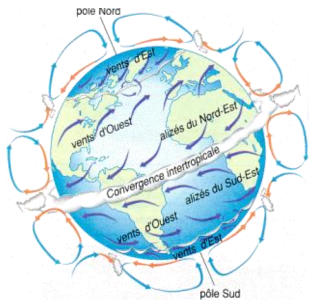
Earth



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