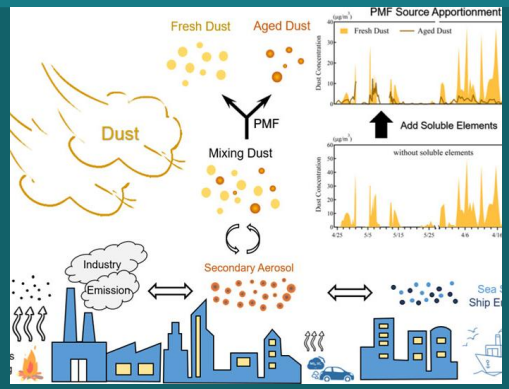
# My lectures

Desert Dust

9 April 2025

Persistent organic pollutants (POPs)

14 May 2025




source apportionment using positive matrix factorization (PMF)

15-29 May 2025

# Desert dust – a carrier of pollutants?

Dr. Kalliopi Violaki, research associate in EPFL/LAPI

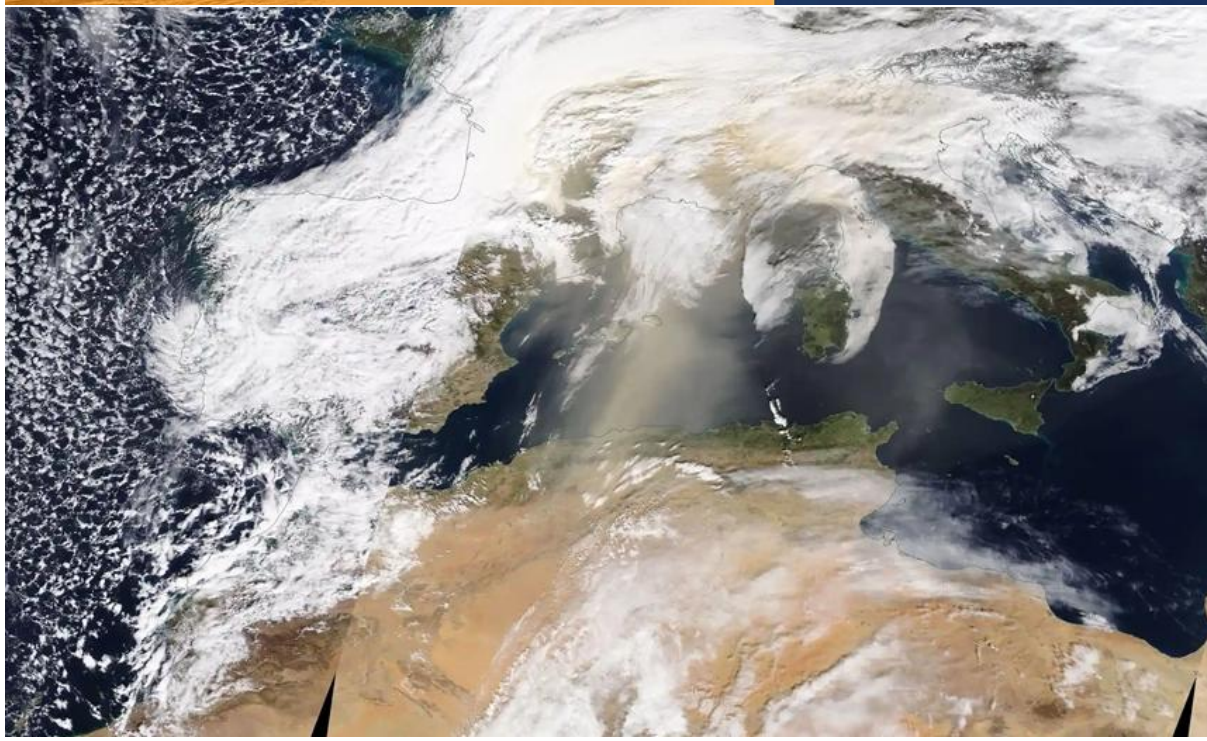
# Agenda

-What is dust aerosol?

-Chemical Composition

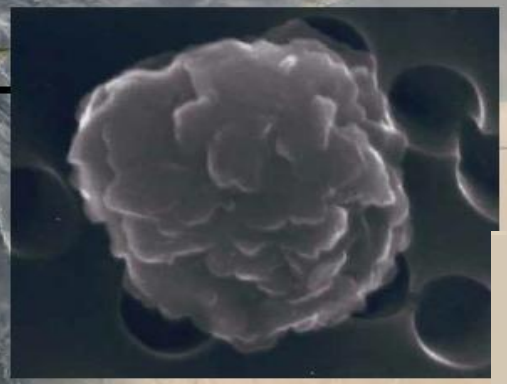
-Role to atmospheric Chemistry

-Impact to human health and Ecosystems

# A Dusty Planet

BY ROBERT A. DUCE



(background image) MODIS image of a large Sahara dust storm on March 4, 2004. *Image courtesy of Jeff Schmaltz, MODIS Rapid Response Team, NASA-GSFC.* (inset) A one micrometer kaolinite Sahara dust particle collected at 300 m elevation near St. Croix on July 22, 2011. *Image courtesy of James Anderson, Arizona State University*

1150 BCE

Darwin, 1846

We live on a dusty planet—and the mineral matter that we commonly call "dust" is critical in many components of our Earth system, including ... cal ... ge ... as ... rst mention of dust storms was in the ancient Chinese literature, referring to "dust rain," "dust fog," or "yellow fog," which usually occurred in the spring. The earliest known record of "dust rain" appears in 1150 BCE in the historical book *Zhu Shu Ji Nan* or *Chronicles Reported on Bamboo Slips*. Recent interest in dust in the marine environment focuses on associated iron content, which serves as a critical nutrient for marine primary productivity and nitrogen fixation in many ocean regions (see Grand et al., 2014, in this issue).

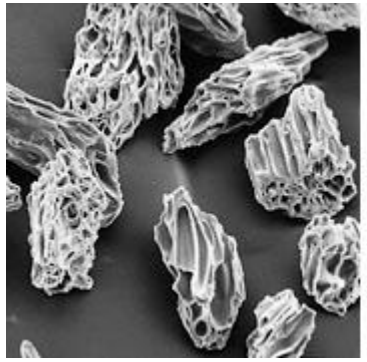
Charles Darwin noted the frequency of dust storms over the tropical Atlantic, writing: "Finally, I may remark that the circumstance of such quan-

Photograph by Katherine Mann.

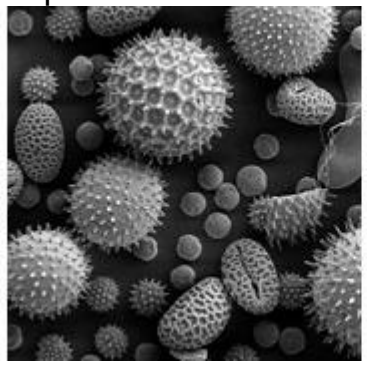
**The deserts on our planet are the second most important source of atmospheric particles globally (~2150 Mg yearly).**

**The first are the oceans (~3340 Mg yearly).**

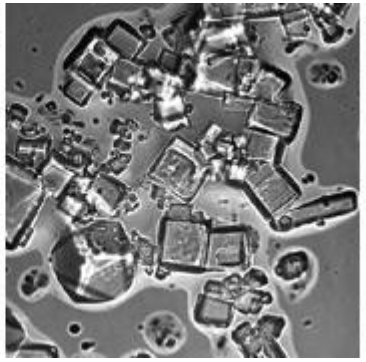
volcanic ash



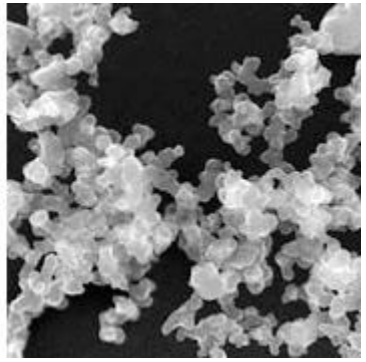
pollen



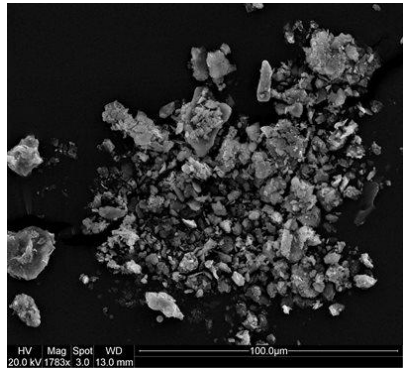
sea salt



soot



Dust



Source: https://earthobservatory.nasa.gov/features/Aerosols

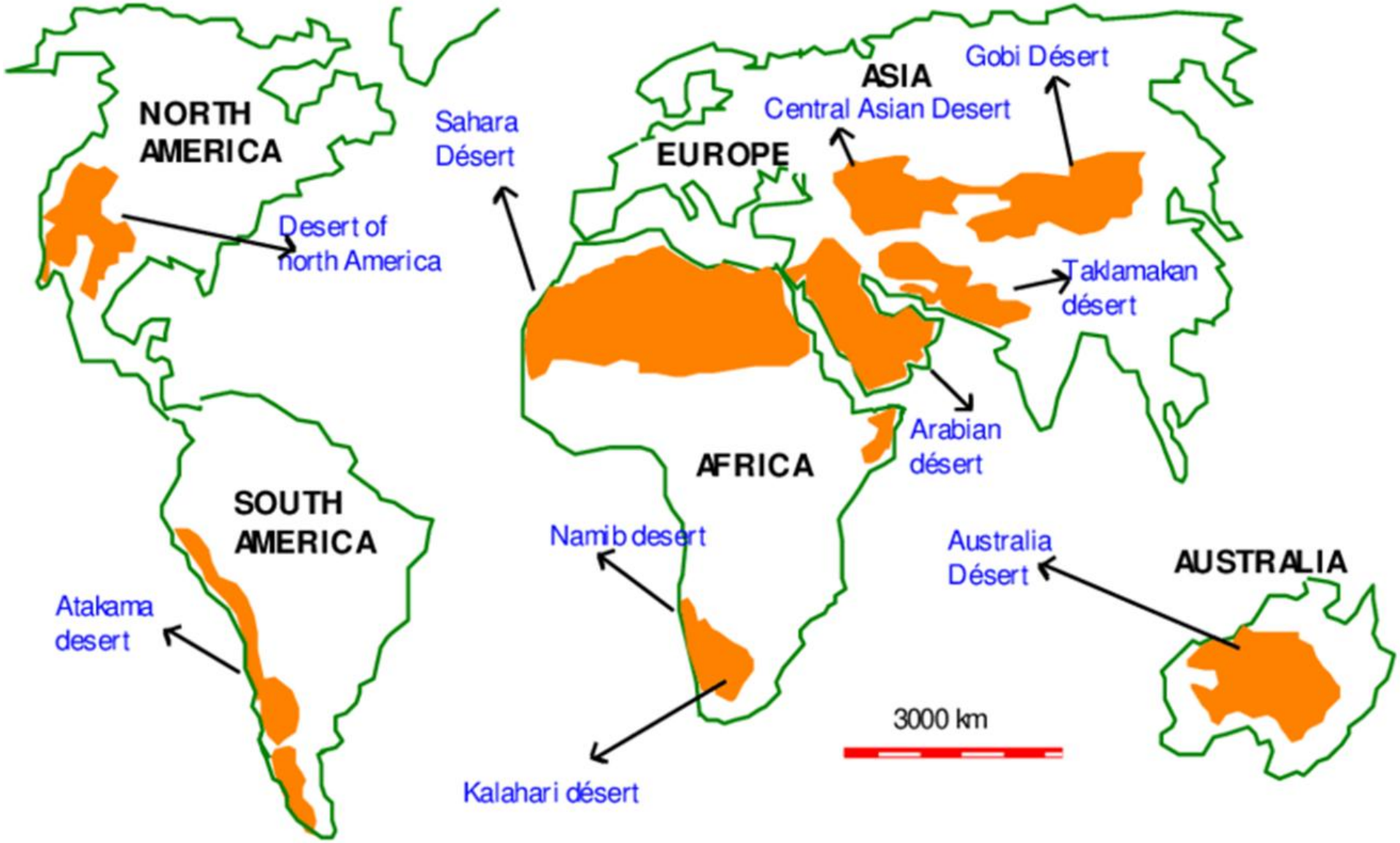
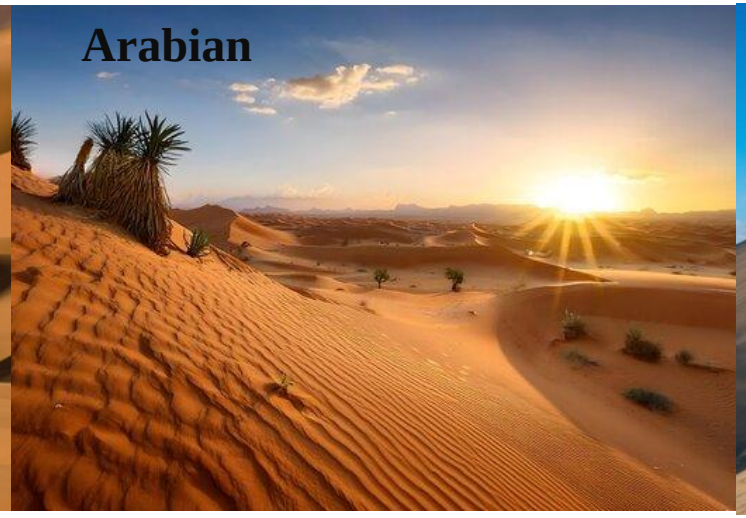



Diagram Remini, 2020


Sahara


Arabian

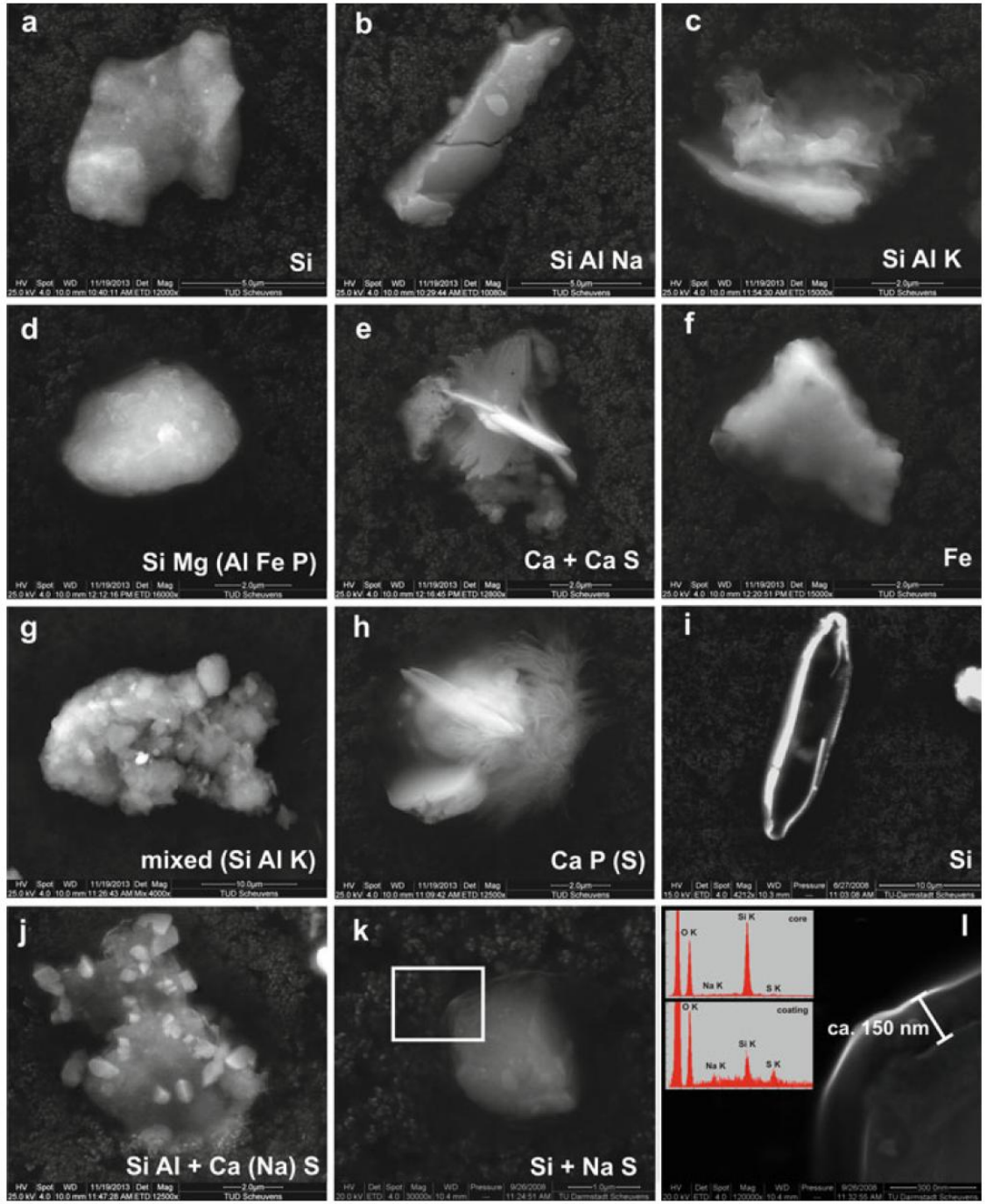

Gobi


Kalahari


Great Victoria


Patagonian

# SEM pictures from dust in Morocco




Dust particles are analyzed by energy-dispersive X-ray technique (EDX)

We observe different morphology of the particles and chemical composition depending on the minerals type:

(a) Si-rich particle (quartz),
(b) (b) Na-bearing aluminosilicate (albite),
(c) (c) K-bearing aluminosilicate (illite),
(d) (d) Mg-dominated silicate (palygorskite),
(e) (e) Ca sulfate and Ca-dominated mineral (gypsum on calcite
(f) Fe-dominated mineral (iron oxide or iron hydroxide),
(g) complex internally mixed aluminosilicate with individual Fe-dominated phase (bright spot in center),
(h) Ca-P-S-bearing particle (biological?),
(i) Si-dominated particle (opaline diatom)
(j) aluminosilicate (kaolin group?) with Ca(Na) sulfate (gypsum, thenardite, glauberite?)
(k) Si-rich particle (quartz) with sulfate coating (overview)
(l) Detail of coating with EDX spectra for rim and core of the particle

SEM: Scanning electron microscope

# Desert dust contains biological material

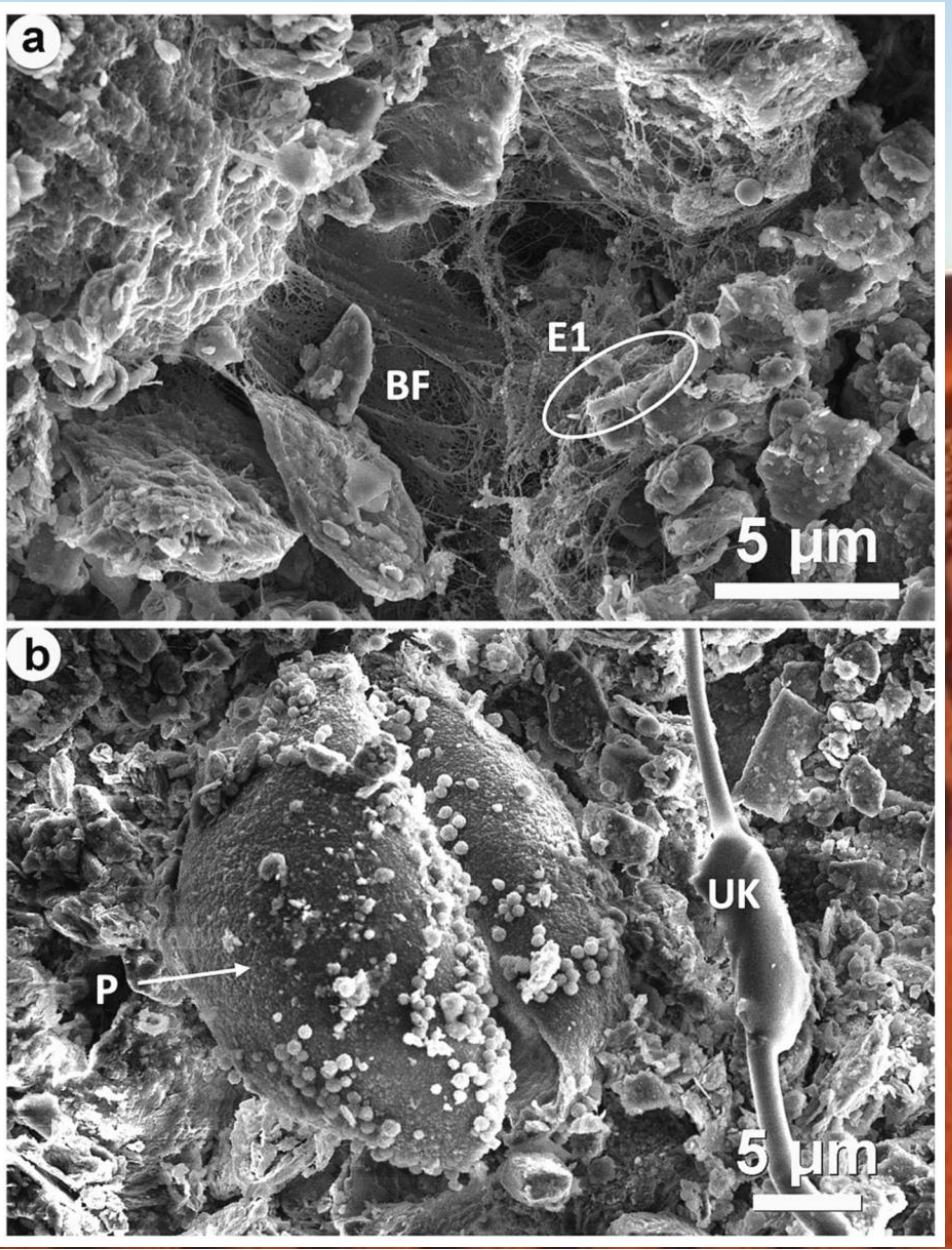



Fig. 1 (on the left). Evidence of biological material in red rains collected in S. Spain (Feb. 2017). a) BF: possible biofilm, and E1: bacterial cells. b) P: possible pollen grains 21.6 µm size. (UK): Unknown biological material of 26.8 µm

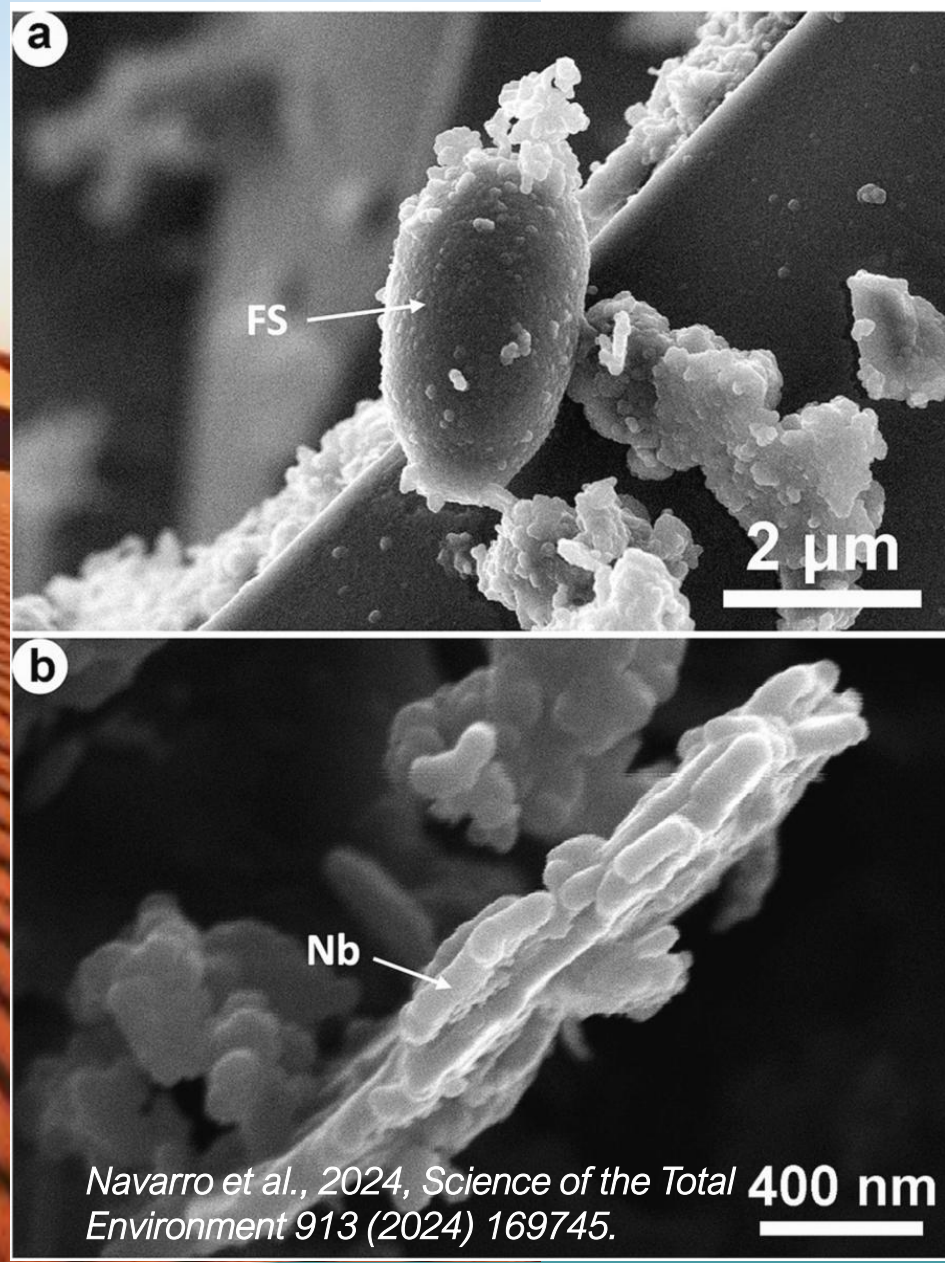



Fig. 2: Rain Dust collected on March 2022. New evidence of biological material in red rains. a) FS: Ellipsoidal-shaped fungal spore of 3.7 µm size. b) Nb: Bacillar-shaped nanobacteria with size ~0.25 µm , over mineral particles.

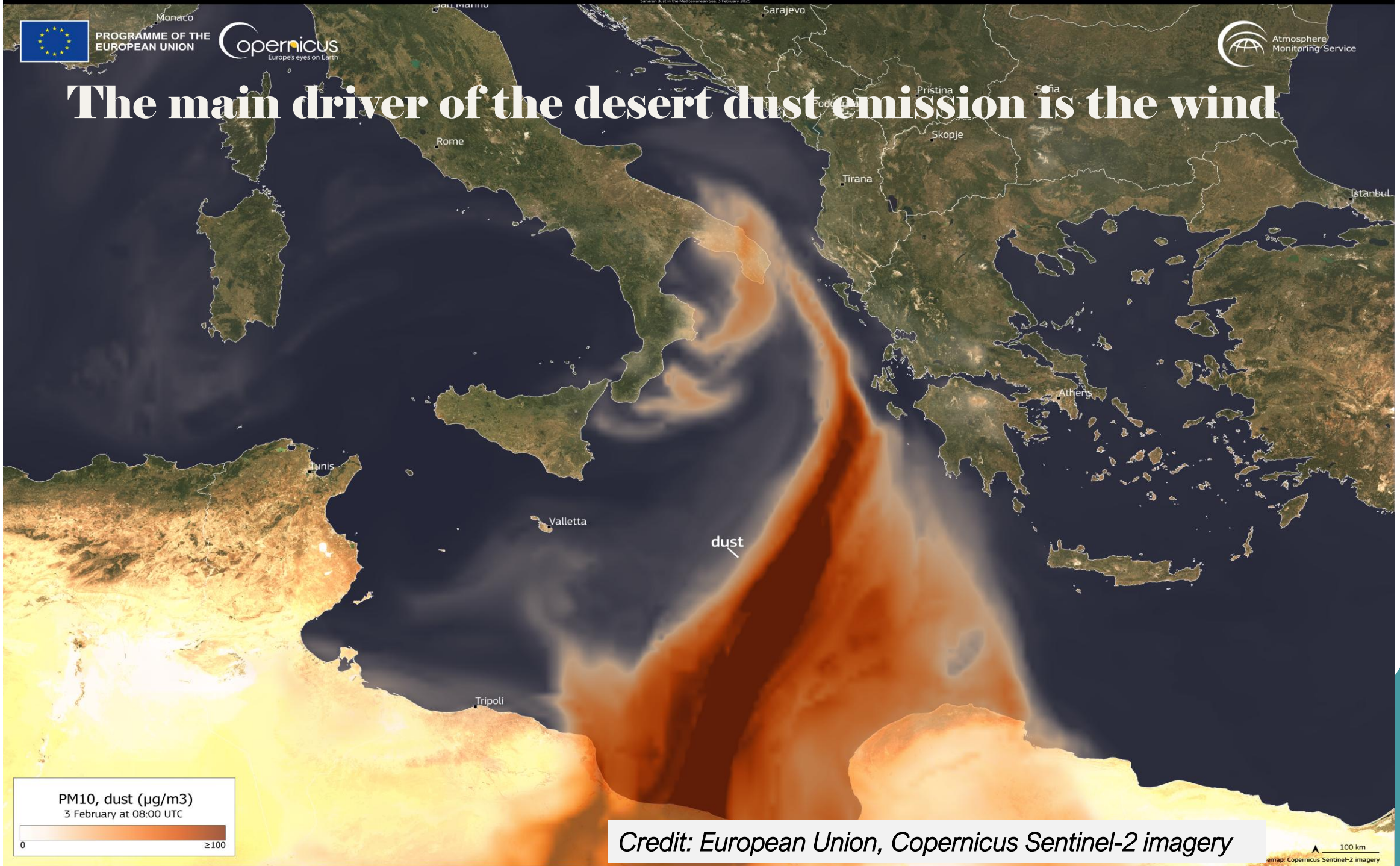
*Navarro et al., 2024, Science of the Total Environment 913 (2024) 169745.*

# What is desert dust aerosol

“Desert dust aerosols” are airborne particles found in the outflow of a mineral dust source, containing inorganic soil minerals mixed with additional material from other natural or anthropogenic sources.

The desert dust particles are mixed during their transportation across the polluted areas with toxic elements e.g. toxic metals (e.g. Pb, As, Cr) or toxic organic compounds e.g. PAHs.

# The main driver of the desert dust emission is the wind




*Credit: European Union, Copernicus Sentinel-2 imagery*

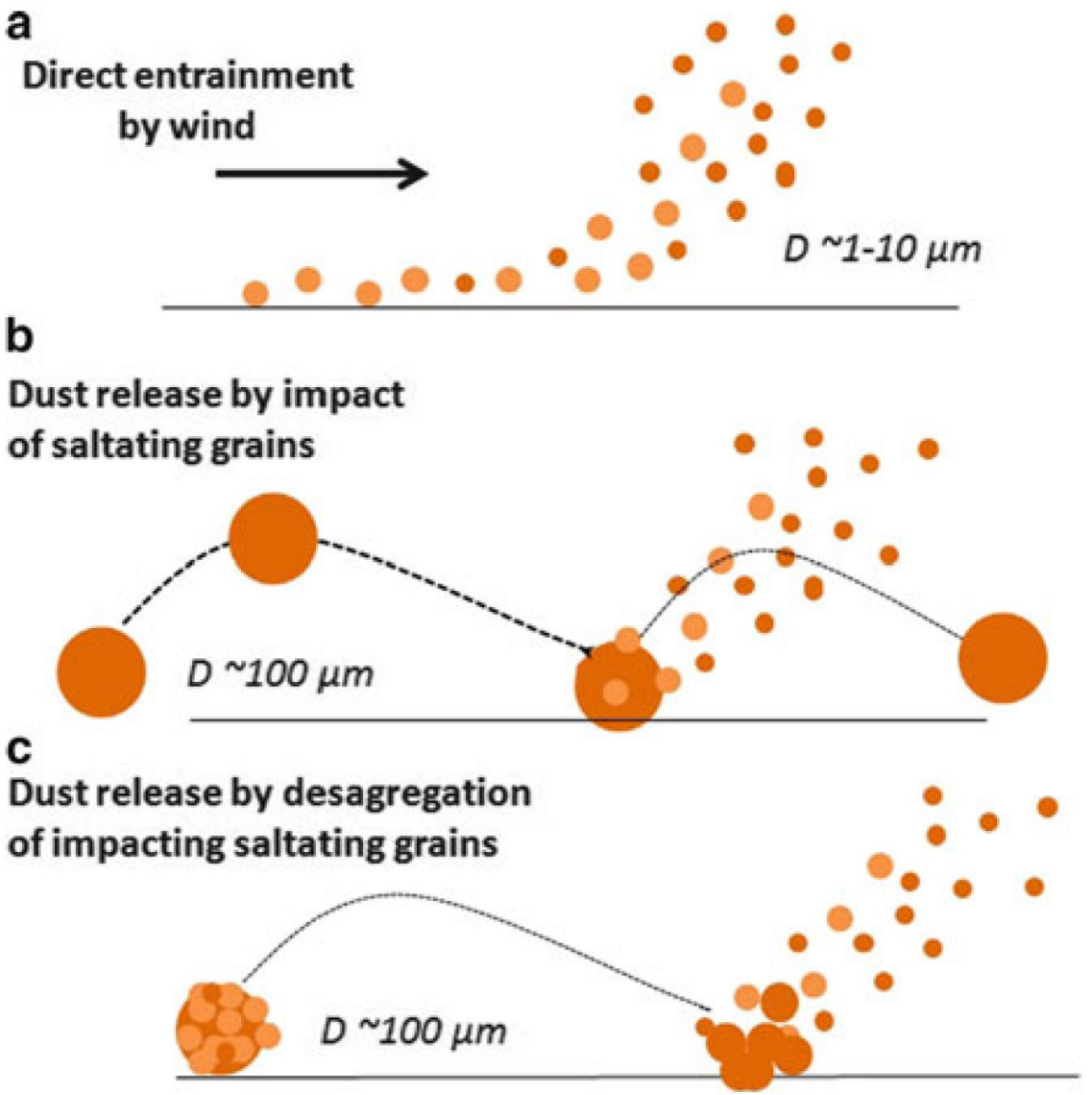
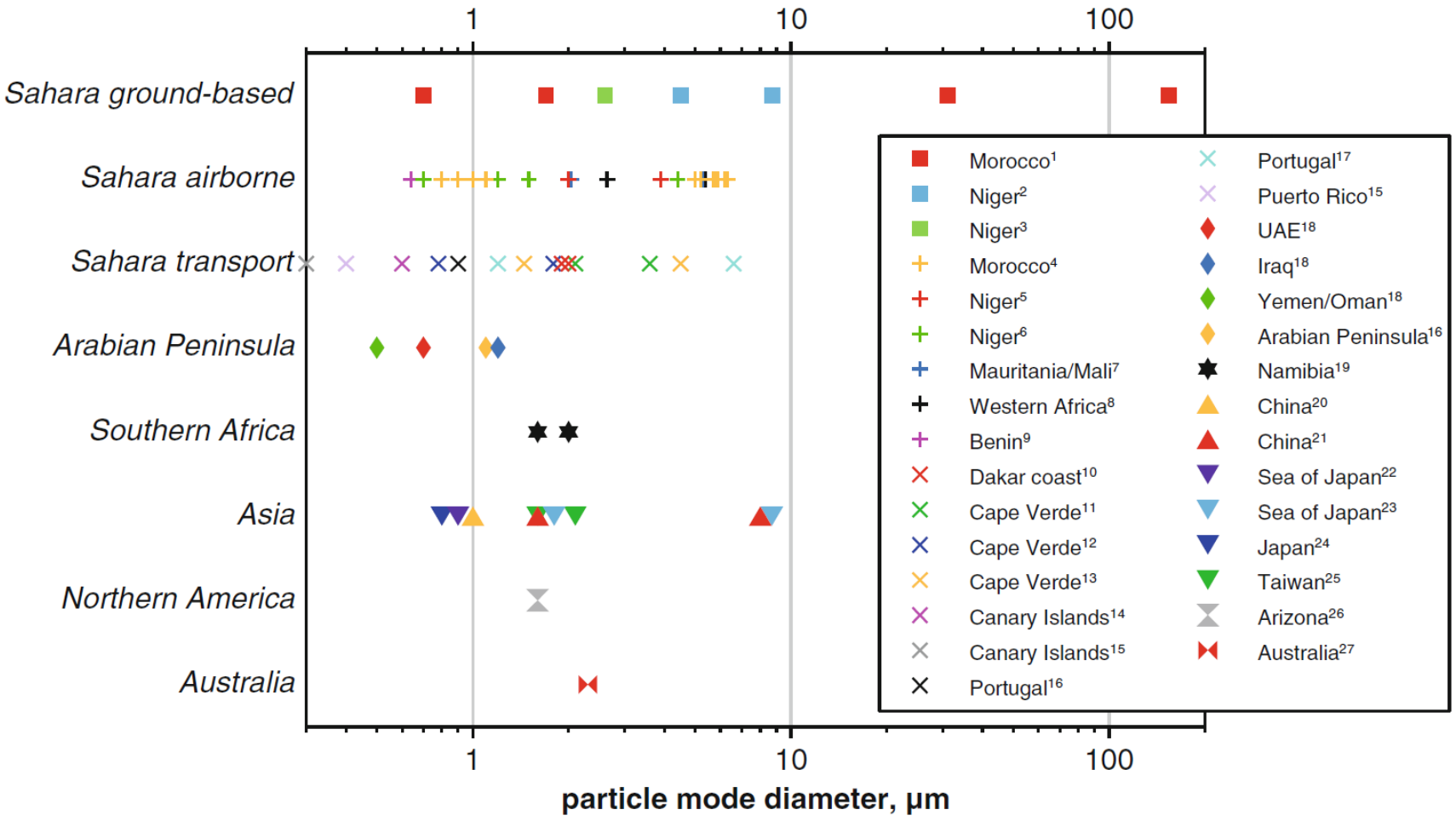


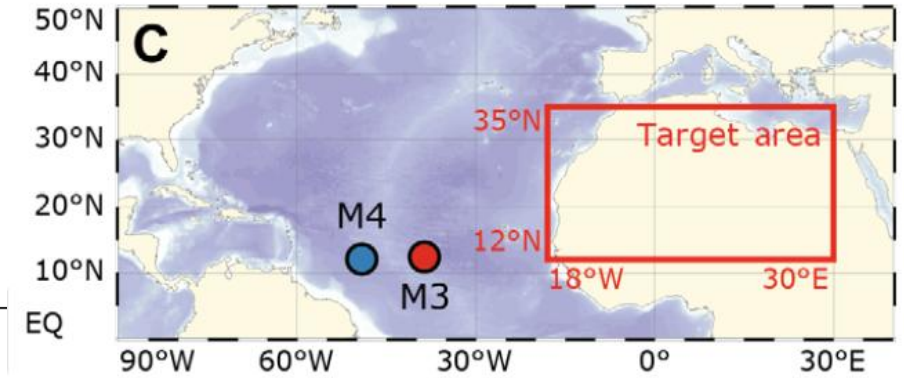

**Fig. 5.2** Mechanisms for dust emission. (**a**) Dust emission by aerodynamic lift, (**b**) by saltation bombardment and (**c**) through disaggregation (Adapted from Shao et al. 2011)

# Size distribution of Dust aerosols particles collected from different sites




**Dust particles have mostly 1<d<10 µm**

Evidence that giant mineral dust particles are transported through the atmosphere across the Atlantic Ocean, thousands of kilometers from their north African sources.




SCIENCE ADVANCES | RESEARCH ARTICLE

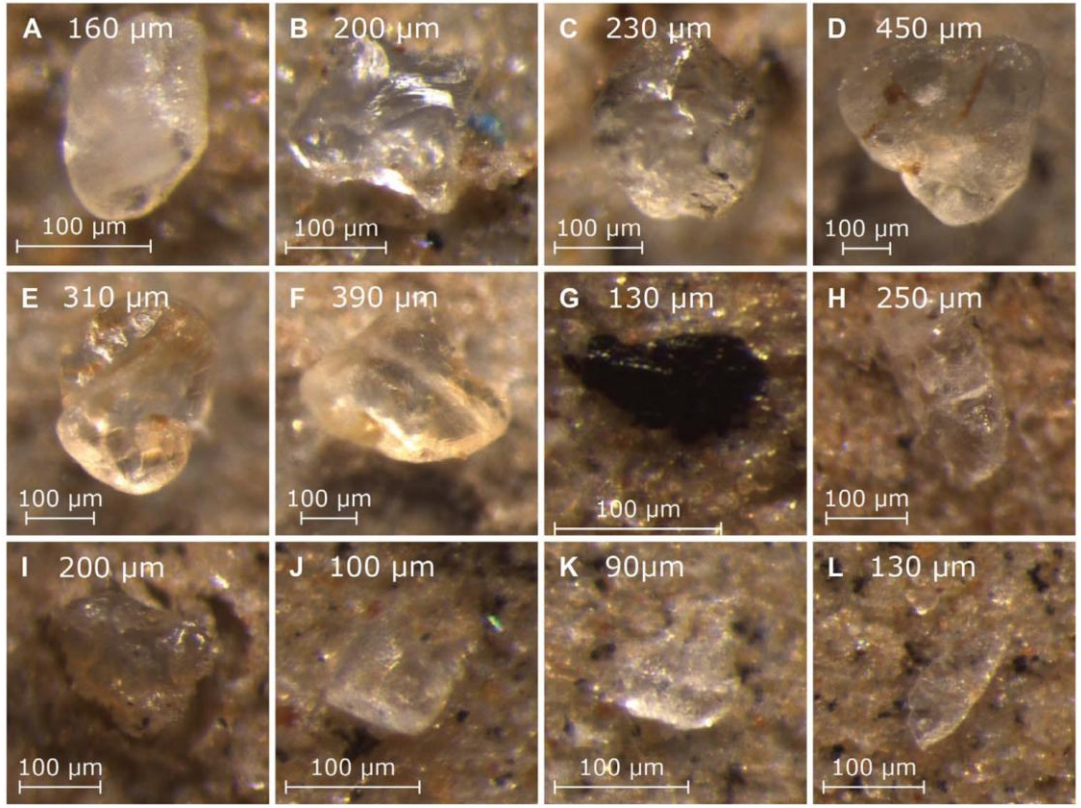
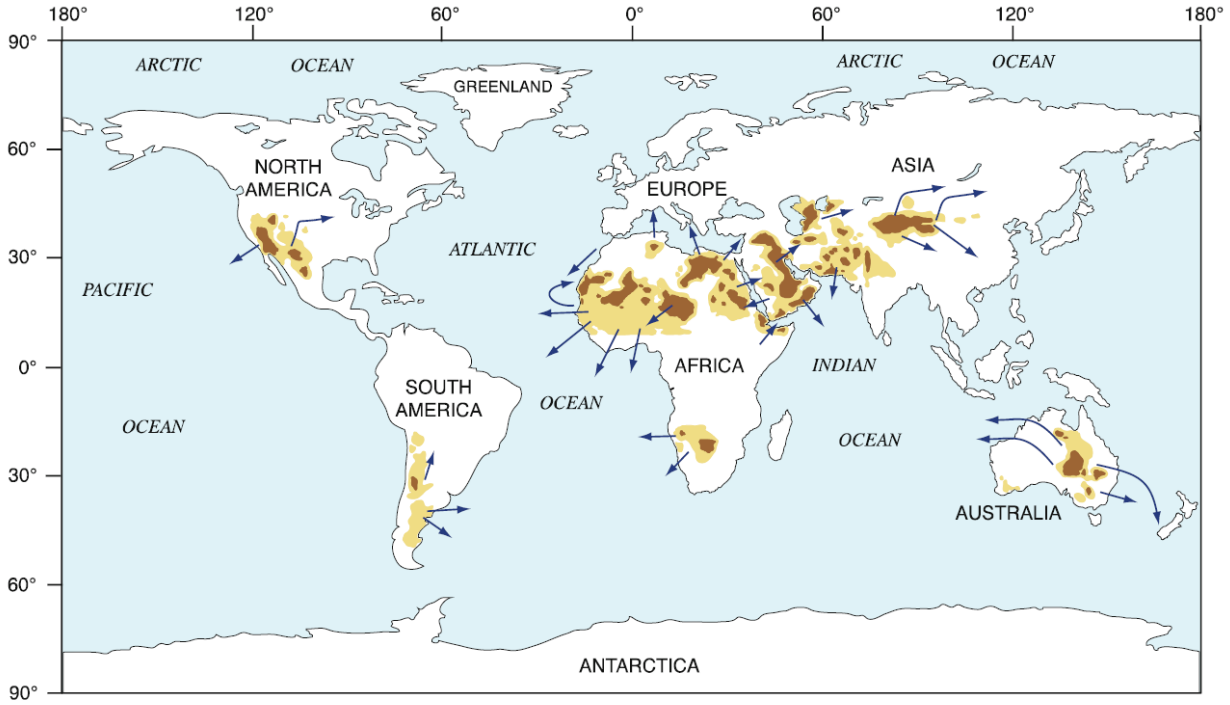


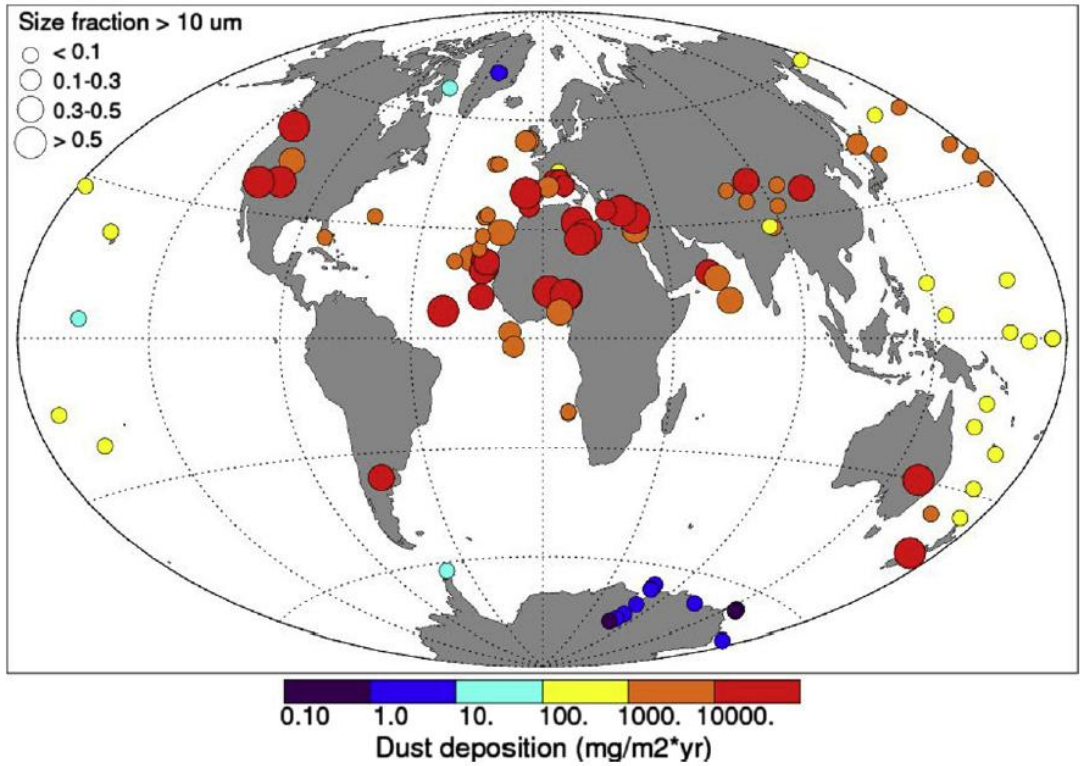

**Fig. 1. Giant mineral dust particles sampled by the MWAC samplers at M3 (12°N, 38°W) and M4 (12°N, 49°W) in 2014 and 2015, with their approximate diameters.** (**A** to **C**) 2014-M3; (**D** to **F**) 2014-M4; (**G** to **I**) 2015-M3; (**J** to **L**) 2015-M4.

The dust particles are transported over great distances within the turbulent Saharan Air Layer (SAL) in summer. This air layer is characterized by strong winds, and turbulence created in this layer in combination with high particle concentrations allows for triboelectrification of dust particles, compensating the particles' weight.

*Van der Does et al., Sci. Adv. 2018; 4 : eaau2768*

# The deserts globally

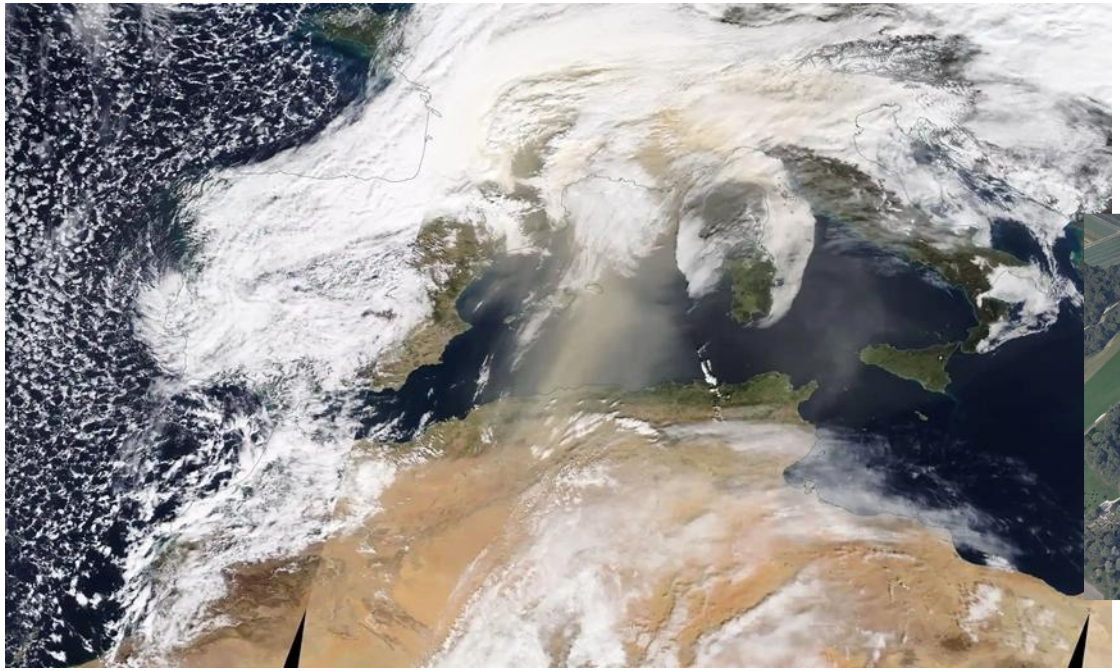


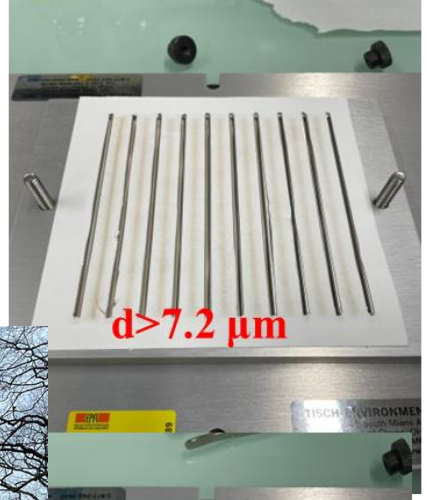



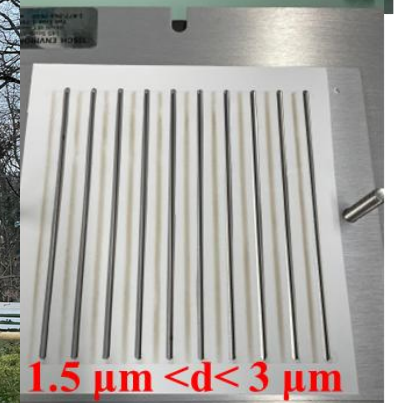

**-Fine particles travel long distances.**
**-Coarse particles travel shorter distances (there are exceptions for example in giant desert particles)**

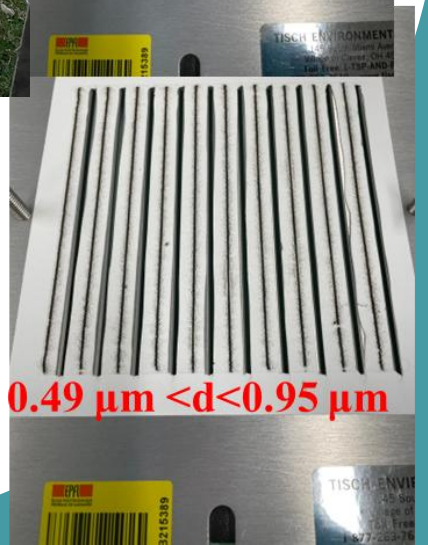
*Mahowald et al., Aeolian Research, Vol 15, p53-71, 2014.*

# Dust event over Switzerland on 6th Feb 2021






NASA's Earth Observing System Data and Information System (EOSDIS) image showing the drift of Saharan dust across the Mediterranean Sea into Europe on 6th February 2021
Photograph: NASA Worldview

In the dust particles, there are hidden polluted particles

# Chemical Composition

Exposed filter

**Digestion with $HNO_3$ or other acid mixtures (e.g HF and $HNO_3$)**

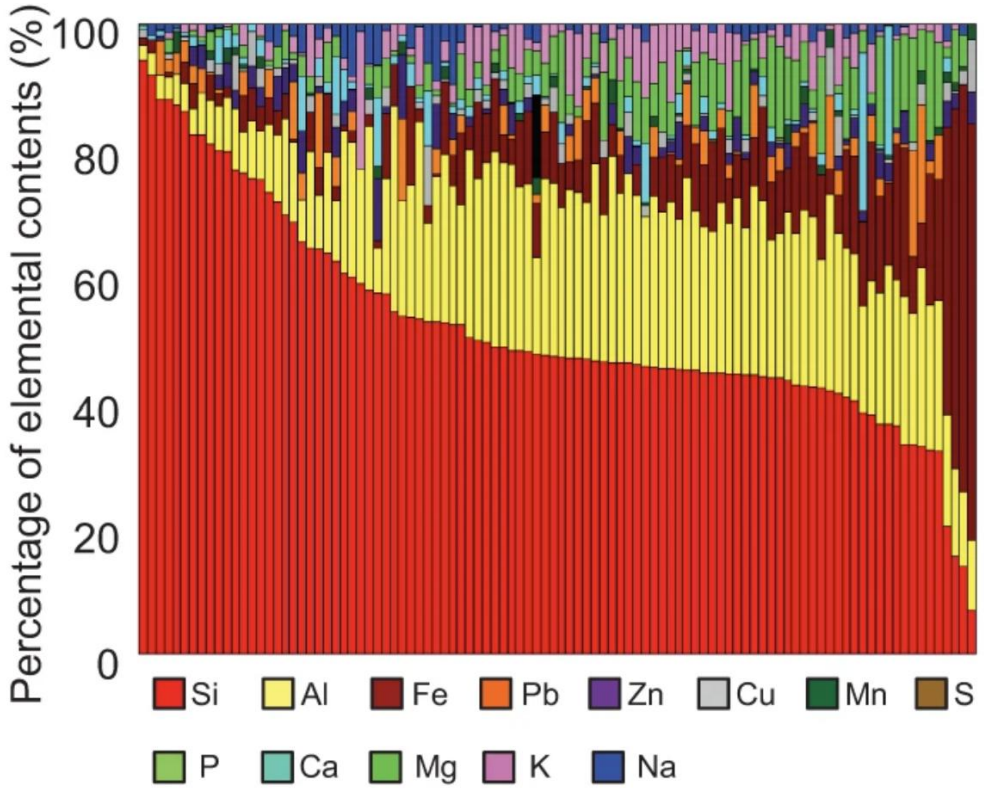
| Element | Elemental Abundance (ppm by mass) | |
|---|---|---|
| | Soil | Crustal Rock |
| Si | 330,000 | 311,000 |
| Al | 71,300 | 77,400 |
| Fe | 38,000 | 34,300 |
| Ca | 13,700 | 25,700 |
| Mg | 6,300 | 33,000 |
| Na | 6,300 | 31,900 |
| K | 13,600 | 29,500 |
| Ti | 4,600 | 4,400 |
| Mn | 850 | 670 |
| Cr | 200 | 48 |
| V | 100 | 98 |
| Co | 8 | 12 |

*Source:* Warneck (1988).

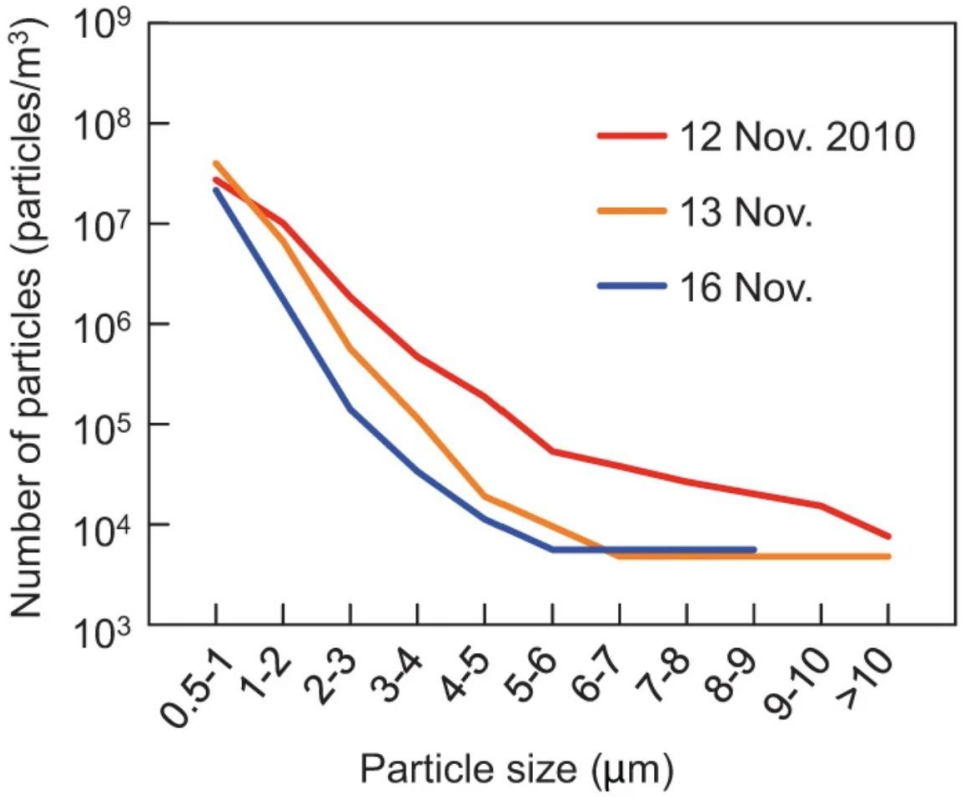
**Common tracers for Dust aerosols**

# Chemical Speciation & Size distribution of Asian Dust Particles

a)




b)




**Each bar represents one of the 100 sample of dust particles**

Metals with anthropogenic origin (here Pb, Cu and Zn)

*Yamaguchi, N., et al. (2012) Sci. Rep. 2, 525; DOI:10.1038/srep00525.*

# Role of dust in atmospheric Chemistry

-The **size** of long-range transported dust is generally considered to be 1–3 μm, but there are reports of giant particles (>75 μm) ***being transported many thousands of kilometres away from sources.***

-The transport of mineral dust particles through the atmosphere results in a number of processes that ***alter its physicochemical properties***, which affects the direct and indirect impacts of dust on climate.

- ***Heterogeneous chemistry (depends on chemical composition)*** on dust surfaces leads to uptake and release of several atmospherically important trace gas species, as well as the formation or alteration of secondary coatings on mineral particles.

*Arimoto, et al., (1997), J. Geophys. Res., 102( D13), 15867– 15874, doi:10.1029/97JD00796.*

# Processing and Ageing in the Atmosphere

Mineral dust aerosol contains a variety of semiconductor metal oxides, such as $TiO_2$, ZnO and $Fe_2O_3$. With solar radiation are released e- responsible for the reductions.

$$\mathrm{Dust(TiO_2)} + h\nu \rightarrow h^+_{vb} + e^-_{cb} \quad (1)$$

$$NO_3^- + h^+_{vb} \rightarrow NO_3 \quad (2)$$

During the transportation of dust in the atmosphere :

$$NO_3 + h\nu \rightarrow NO + O_2 \quad (3)$$

**1) Nitric Acid and Nitrogen Oxides**

Nitric acid reacts with mineral dust resulting in formation of surface nitrate and gas-phase species including NO, $NO_2$ and $N_2O$ (Rubasinghege & Grassian 2009). NOx leads to the formation of tropospheric $O_3$.

$$NO_3 + h\nu \rightarrow NO_2 + O \quad (4)$$

$$O + O_2 \rightarrow O_3$$

*Rubasinghege G, Grassian VH (2009) J Phys Chem A 113:7818–7825*

# OZON ($O_3$)

Trace amounts of $TiO_2$ (semiconductor) may be responsible for ozone loss in the troposphere.

Heterogeneous photochemistry of $O_3$ depends on the surface properties of oxides. For example, ***$Fe_2O_3$ shows high uptake capacity and catalytic decomposition towards $O_3$***

**Proposed Ozone Uptake Mechanism by Nicolas et al. (2009):**

The formation of electrons on irradiated $TiO_2$ does activate catalytic chain reactions with possibly nonlinear effects on the uptake kinetics. ***They are produced OH· and the end product is the $O_2$.***

$$TiO_2 + h\nu \rightarrow TiO_2(e^- + h^+) \quad (1)$$

$$O_3 + e^- \rightarrow O_3^{\bullet -} \quad (2)$$

$$O_3^{\bullet -} + H^+ \rightarrow HO_3^{\bullet} \quad (3)$$

$$HO_3^{\bullet} \rightarrow O_2 + HO^{\bullet} \quad (4)$$

$$HO^{\bullet} + O_3 \rightarrow O_2 + HO_2^{\bullet} \quad (5)$$

$$O_2 + e^- \rightarrow O_2^{\bullet -} \quad (6)$$

$$O_2^{\bullet -} + O_3 \rightarrow O_3^{\bullet -} + O_2 \quad (7)$$

*Nicolas M, Ndour M, Ka O, D'Anna B, George C (2009) Environ Sci Technol 43:7437–7442*

# Processing and Ageing in the Atmosphere

During the transportation of dust in the atmosphere :

**2) $SO_2$ reacts on mineral dust particles**

Atmospheric $SO_2$ can be oxidized to sulphate or sulphuric acid on dust surfaces (Wu et al. 2011).

***Both $HNO_3$ and $H_2SO_4$ reduced the pH on dust particles (Acidification of dust).***

In the acidified dust it is observed potentially an increase in the solubility of nutrients, such as iron (Fe) and phosphorus (P).

**Solubility ↔ Bioavailability for the marine and terrestrial ecosystems.**

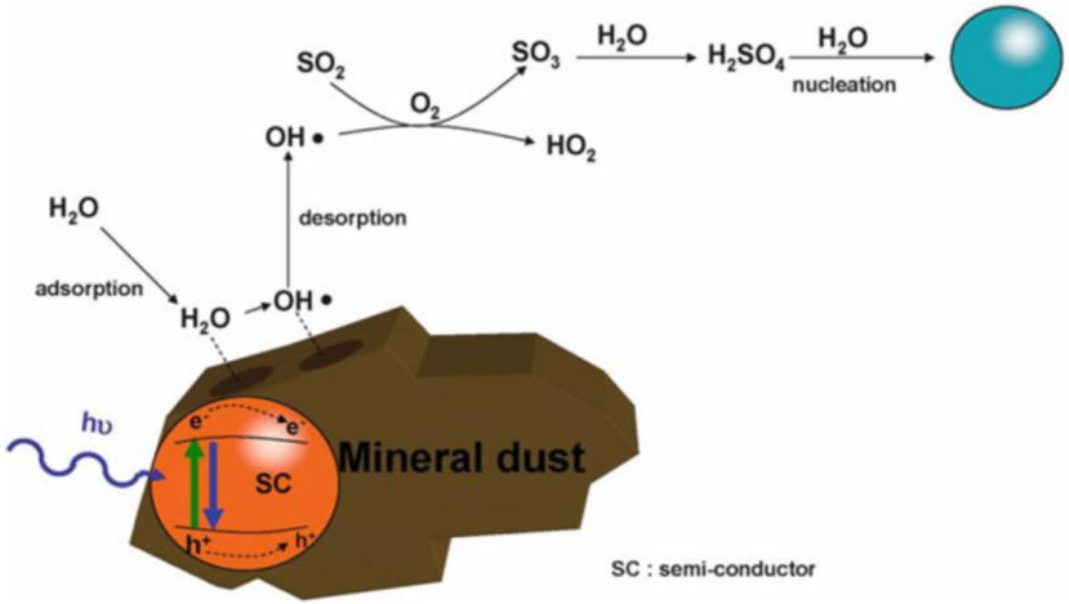



**Fig. 4.6** The semiconductor (SC) components of dust under UV irradiation are producing OH radicals that can desorb and oxidise $SO_2$. The produced sulphuric acid may then initiate nucleation events (Reprinted with permission from Dupart et al. (2012). Copyright (2012) National Academy of Sciences, USA)

*Wu LY, Tong SR,WangWG, Ge MF (2011). Atmos Chem Phys 11:6593–6605*

# Processing and Ageing in the Atmosphere

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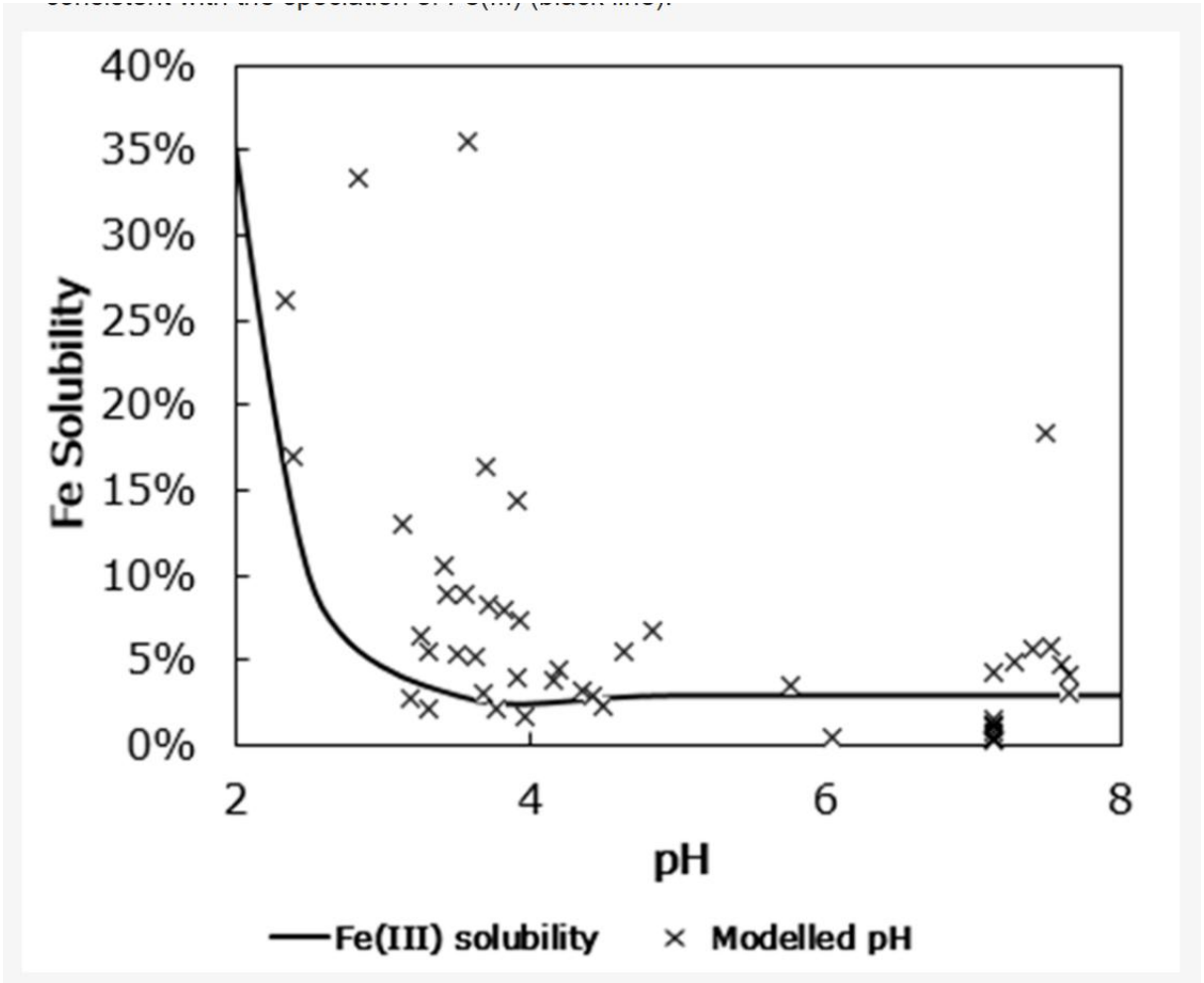



*Ingall, E.D.; Feng, Y.; Longo, A.F.; Lai, B.; Shelley, R.U.; Landing, W.M.; Morton, P.L.; Nenes, A.; Mihalopoulos, N.; Violaki, K.; et al. Enhanced Iron Solubility at Low pH in Global Aerosols. Atmosphere 2018, 9, 201. https://doi.org/10.3390/atmos9050201*

# Impact of desert Dust to human health

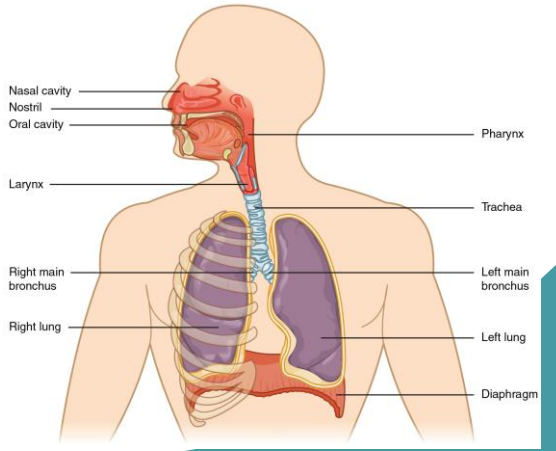
1. **Increase to particulate mass (PM) concentration more than 10 times or in extreme events more than 100 times.**

Acceptable daily average limit is 50 ug/$m^3$ but during a dust event the PM mass could reach up 6000 ug /$m^3$ as it happens in Greece!

**Health effect: Inhaled particles from the nose are trapped (d<2.5 μm) in the lungs while particles inhaled by mouth (d>10 μm) are deposited mainly in the digestion system. Particles that are deposited in the different parts of the respiratory system can react chemically with the fluids and tissues causing oxidative stress and systemic inflammation.**

Given that an intense dust event was characterized by surface concentrations exceeding of 1000 ug/$m^3$ and the one male adult breath 20 $m^3$ daily means that **20 mg of dust was inhaled during daily exposure**.

**Hospitals in Barcelona:** It was observed that daily mortality increased by 8.4 % during Saharan dust days in Barcelona (Perez et al. 2007).

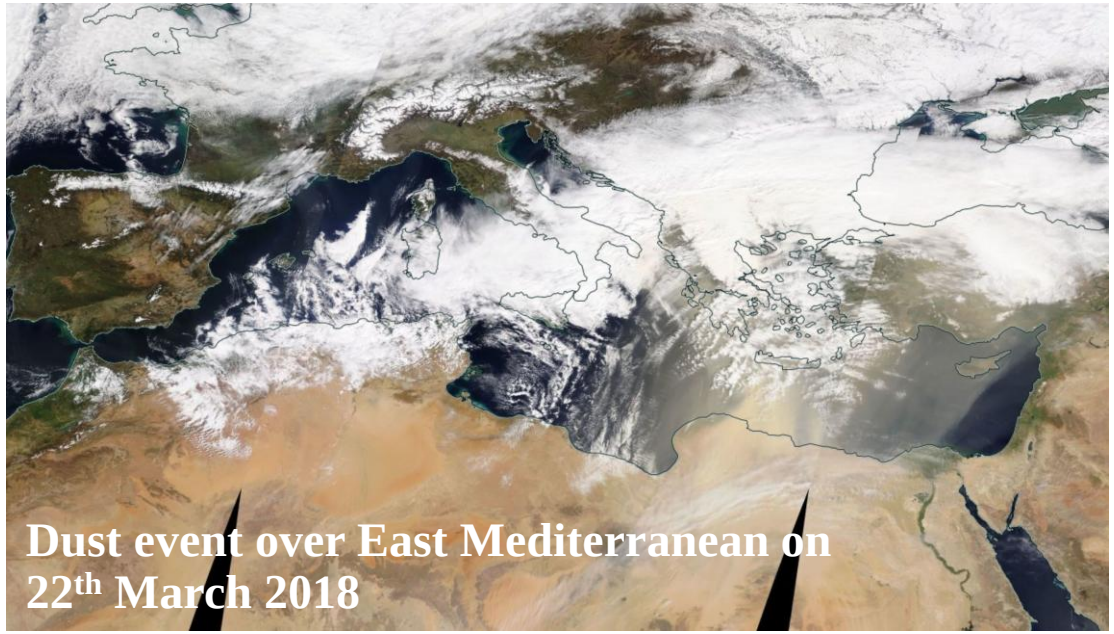



*Perez L, et al (2007) Epidemiology 19:800–807*
*Plumlee GS, Ziegler TL (2007) vol 9, Chapter 7. Elsevier, pp 1–61.*

# 2. Dust contains Toxic Metals

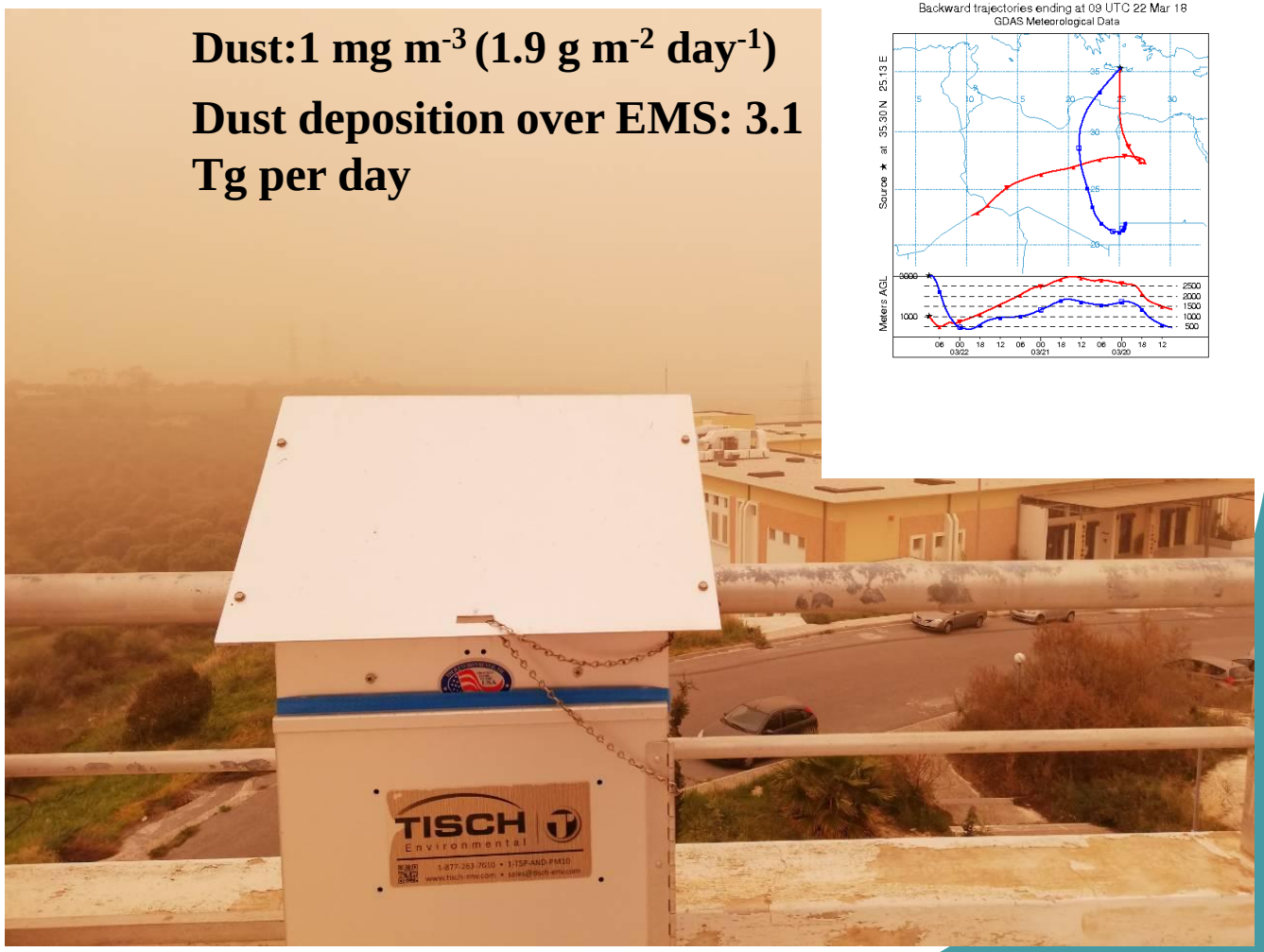
The concertation of toxic metals in desert dust is increased during its transportation above urban and industrialized areas

Toxic Metals are: Pb, As, Cr, Cu, Fe, Cd, V and Ni



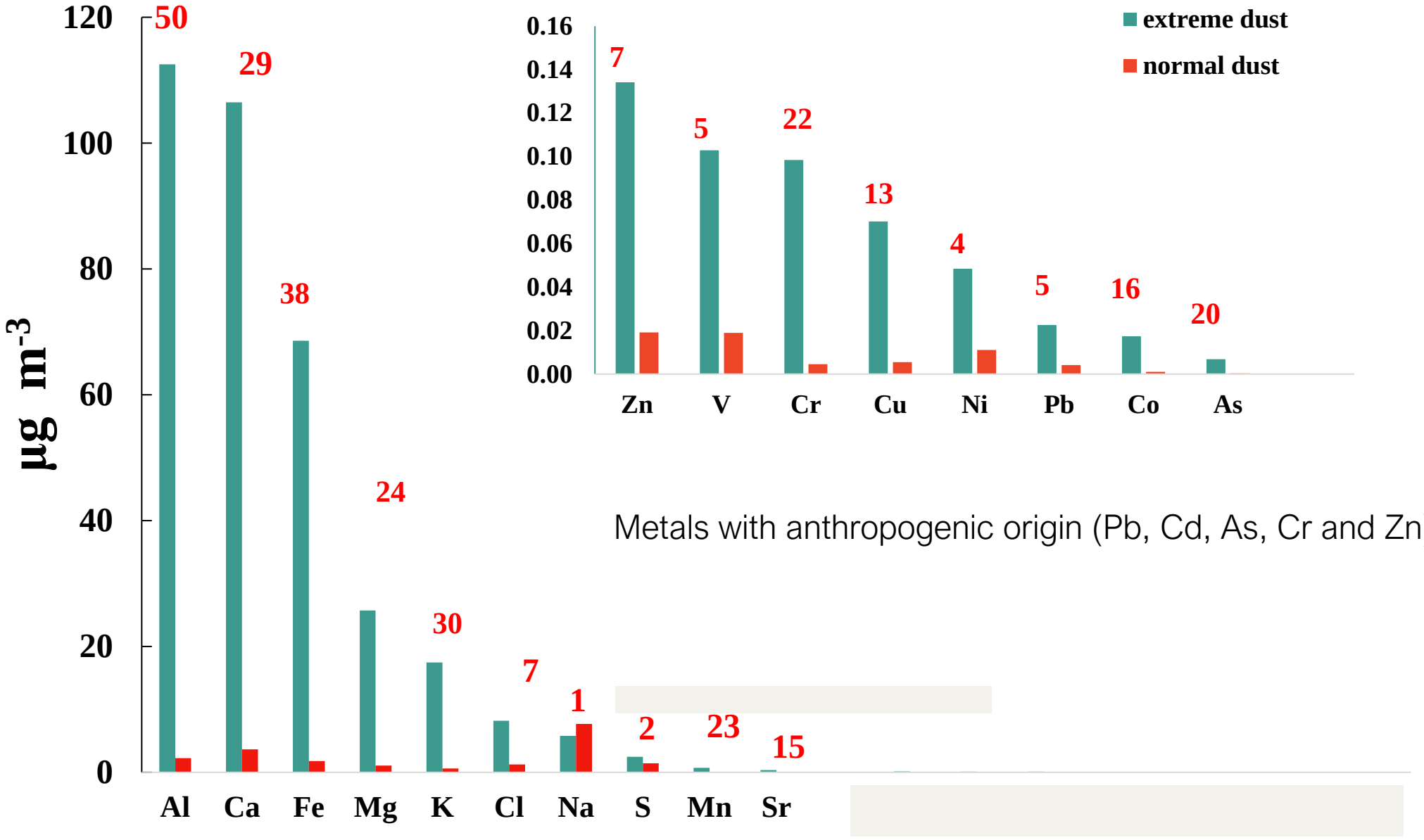
**Dust event over East Mediterranean on 22th March 2018**

The event was characterized by surface concentrations exceeding 1000 μg $m^{-3}$ for a period of 4–7 h, reaching record values higher than 6000 μg $m^{-3}$ at the background station in Crete (Solomos et al., 2018).




*Solomos et al., 2018. Atmosphere, 9(7), 240; https://doi.org/10.3390/atmos9070240*

# Comparing….




Metals with anthropogenic origin (Pb, Cd, As, Cr and Zn)

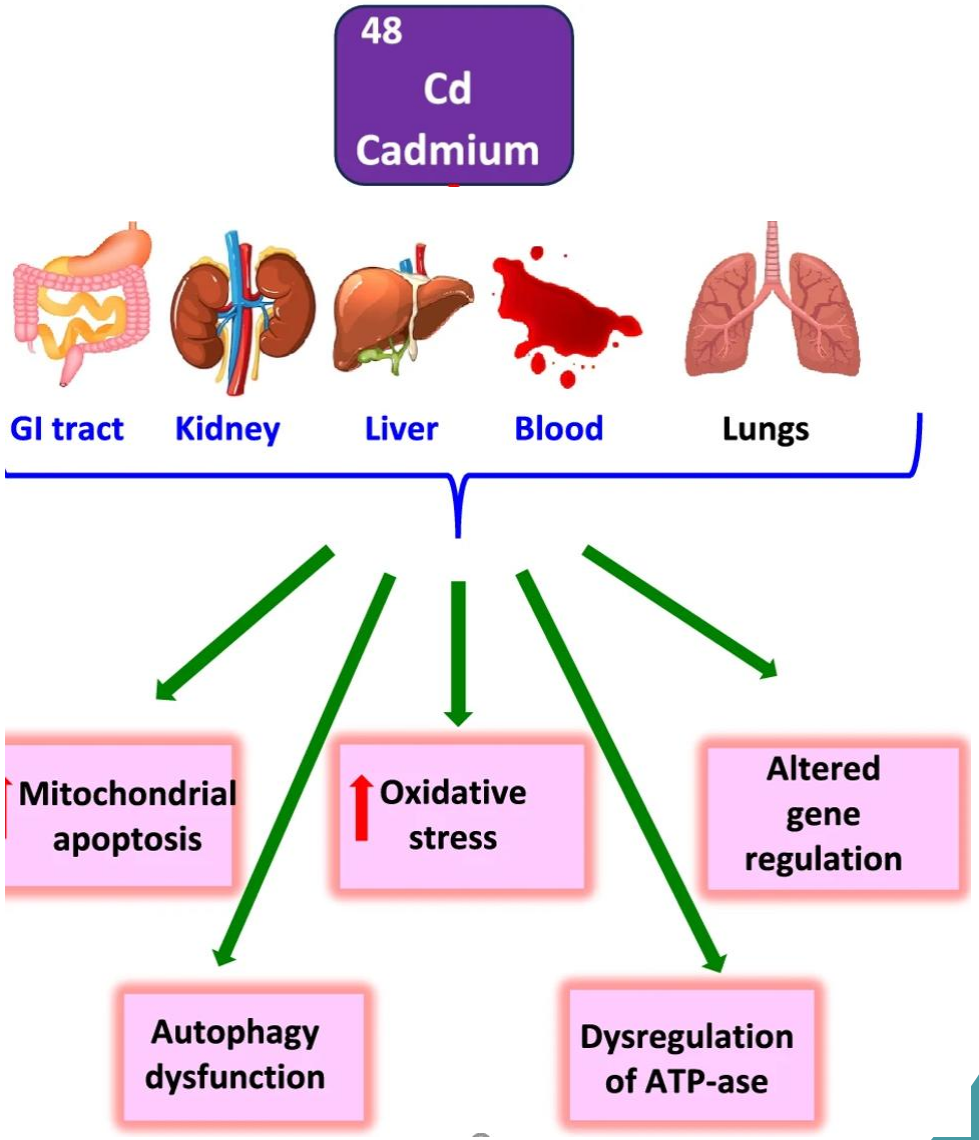
*Violaki et al., unpublished data*

## 2. Dust contains Toxic Metals

### Health effects:

Bioaccumulation of toxic metals leads to a diversity of toxic effects on a variety of body tissues and organs.

- Metal toxicity can have acute or chronic health impact.
- Upon inhalation they influence the nervous system and trigger allergens especially for children.
- Heavy metals disrupt cellular functions including growth, proliferation, differentiation, damage-repairing processes, and apoptosis.
- Promote epigenetic alterations (DNA damage) which can influence gene expression.
- Induce toxicity including ROS generation, weakening of the antioxidant defense, enzyme inactivation, and oxidative stress.




*Front. Pharmacol. , 13 April 2021, Sec. Predictive Toxicology, Volume 12 - 2021* | https://doi.org/10.3389/fphar.2021.643972
Jomova, K., Alomar, S.Y., Nepovimova, E. et al. Heavy metals: toxicity and human health effects. Arch Toxicol 99, 153–209 (2025). https://doi.org/10.1007/s00204-024-03903-2

# Impact to human health

**3. Dust contains toxic organic compounds such PAHs, polychlorinated biphenyls (PCBs), Pesticides.**

Garrison et al. (2006) found that dusts from Mali, Africa, and downwind sites in the Caribbean contained pesticides, polycyclic aromatic hydrocarbons, and polychlorinated biphenyls from various anthropogenic sources

**Health effect: Toxic organic compounds cause cancer, effects on the immune system, reproductive system, nervous system, endocrine system.**

**4. Dust contains allergens**

The dust events are occurred mainly in Spring and Autumn.

Pollen and plant debris are transported by dust.

**Health effect: Allergies to pollen are more intense during dust events, especially for individuals with respiratory diseases e.g. asthma.**

*Garrison et al (2006) Rev Biol Trop 54(Suppl 3):9–21*
*Kirkhorn SR, Garry VF (2000) Environ Health Perspect 108(S4):705–712*

**5. Dust contains millions of bacteria, fungi and virus.**

Biological components such as virus, bacteria, endotoxins, and fungi are transported in long distances with dust.

**Health effect: Some microorganisms (potentially pathogens) are acknowledged as precursors of disease (e.g., meningitis). Others, such as endotoxins, may contribute to asthma-related symptoms and inflammation.**

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## Origin-Dependent Variations in the Atmospheric Microbiome Community in Eastern Mediterranean Dust Storms

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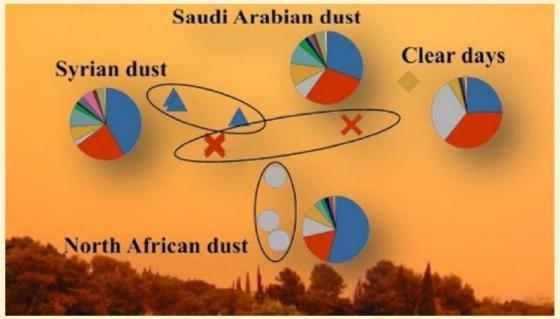
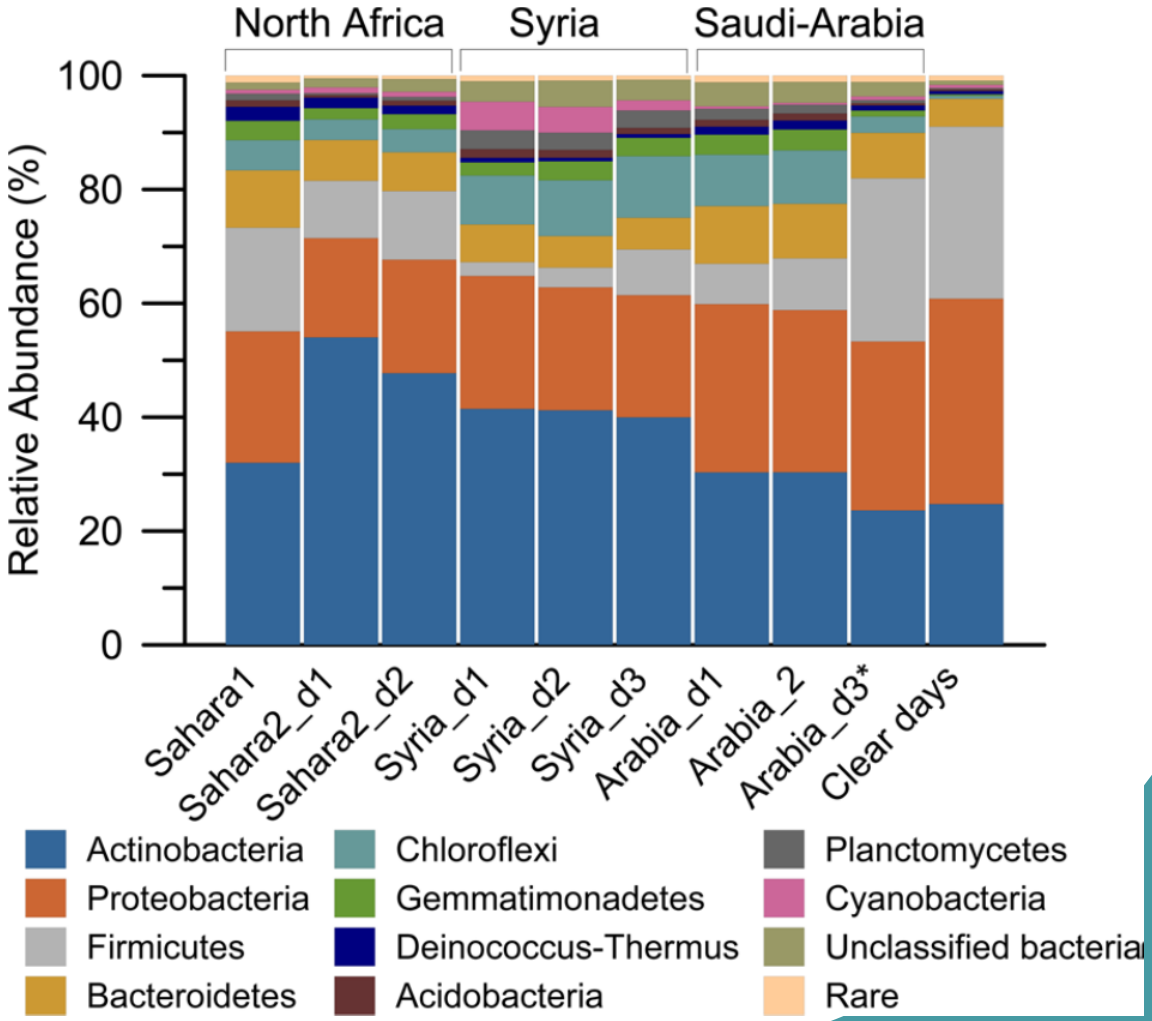
Supporting Information

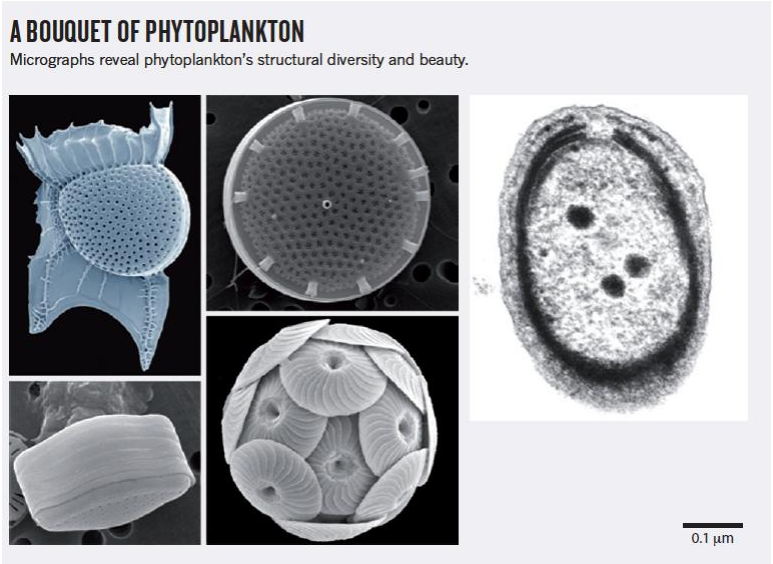
**ABSTRACT:** Microorganisms carried by dust storms are transported through the atmosphere and may affect human health and the functionality of microbial communities in various environments. Characterizing the dust-borne microbiome in dust storms of different origins or that followed different trajectories provides valuable data to improve our understanding of global health and environmental impacts. We present a comparative study on the diversity of dust-borne bacterial communities in dust storms from three distinct origins (North Africa, Syria and Saudi Arabia) and compare them with local bacterial communities sampled on clear days, all collected at a single location: Rehovot, Israel. Storms from different dust origins exhibited distinct bacterial communities, with signature bacterial taxa. Dust storms were characterized by a lower abundance of selected antibiotic resistance genes (ARGs) compared with ambient dust, asserting that the origin of these genes is local and possibly anthropogenic. With the progression of the storm, the storm-borne bacterial community showed increasing resemblance to ambient dust, suggesting mixing with local dust. These results show, for the first time, that dust storms from different sources display distinct bacterial communities, suggesting possible diverse effects on the environment and public health.



# Impact of Desert Dust to ecosystems

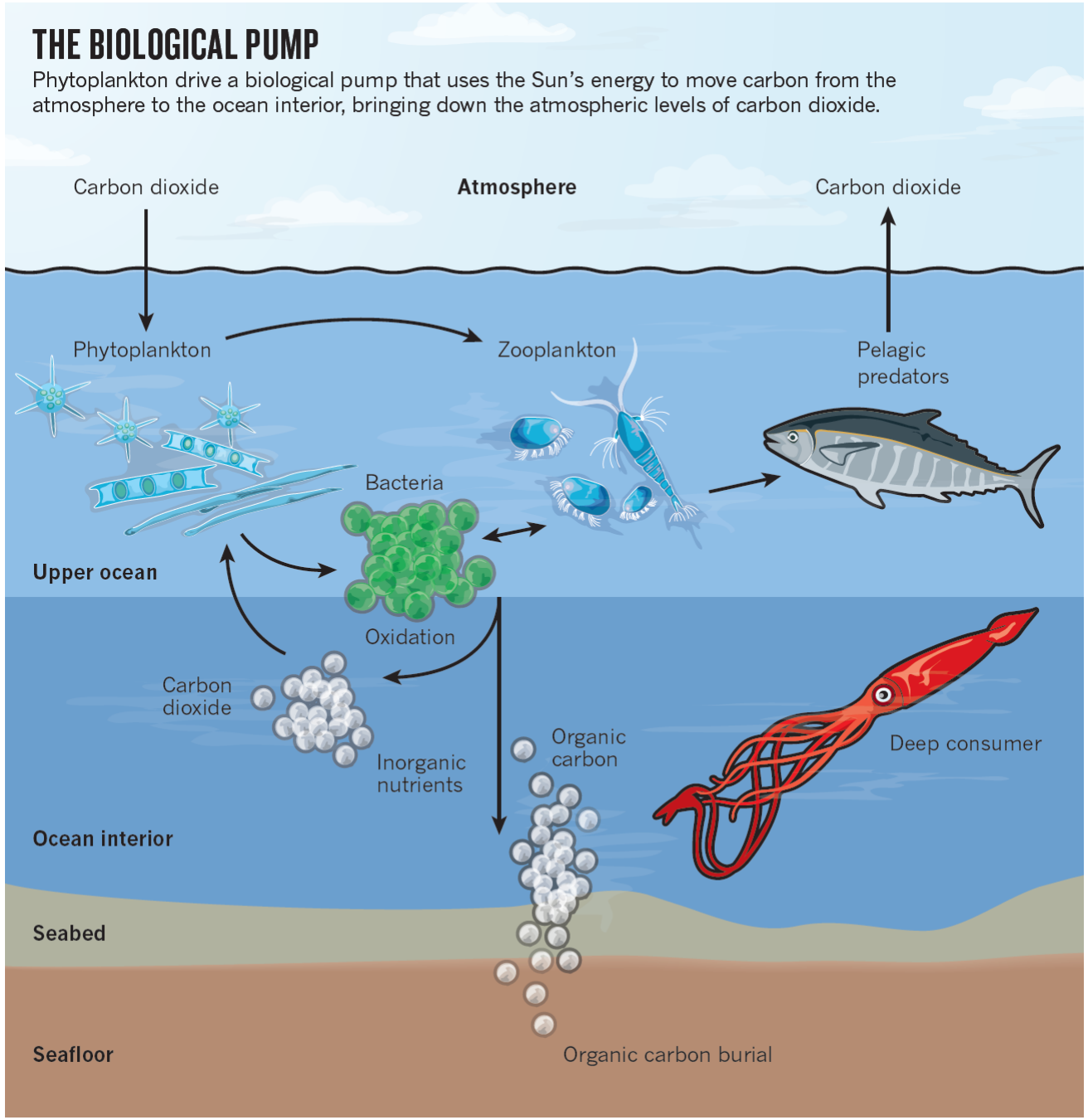
## What are phytoplankton?




Phytoplankton, are microscopic marine algae. They are similar to terrestrial plants in that they contain *chlorophyll* and require ***sunlight*** in order to live and grow. Most phytoplankton are buoyant and float in the upper part of the ocean, where sunlight penetrates the water. Phytoplankton also *require inorganic nutrients such as nitrates, phosphates, and sulfur which they convert into proteins, fats, and carbohydrates.*

The two main classes of phytoplankton are *dinoflagellates and diatoms*. Dinoflagellates use a whip-like tail, or flagella, to move through the water and their bodies are covered with complex shells. Diatoms also have shells, but they are made of a different substance and their structure is rigid and made of interlocking parts. Diatoms do not rely on flagella to move through the water and instead rely on ocean currents to travel through the water.

*https://oceanservice.noaa.gov/facts/phyto.html*




- In a balanced ecosystem, phytoplankton provide food for a wide range of sea creatures including shrimp, snails, and jellyfish.
- When too many nutrients are available, phytoplankton may grow out of control and form harmful algal blooms (HABs). These blooms can produce extremely toxic compounds that have harmful effects on fish, shellfish, mammals, birds, and even people. This called *"Eutrophication"* of marine ecosystems.
- *"Oligotrophic"* ecosystems is commonly used to describe terrestrial and aquatic environments with very low concentrations of nutrients e.g., nitrates, iron, phosphates, and carbon sources.
- Redfield ratio

# Redfield ratio

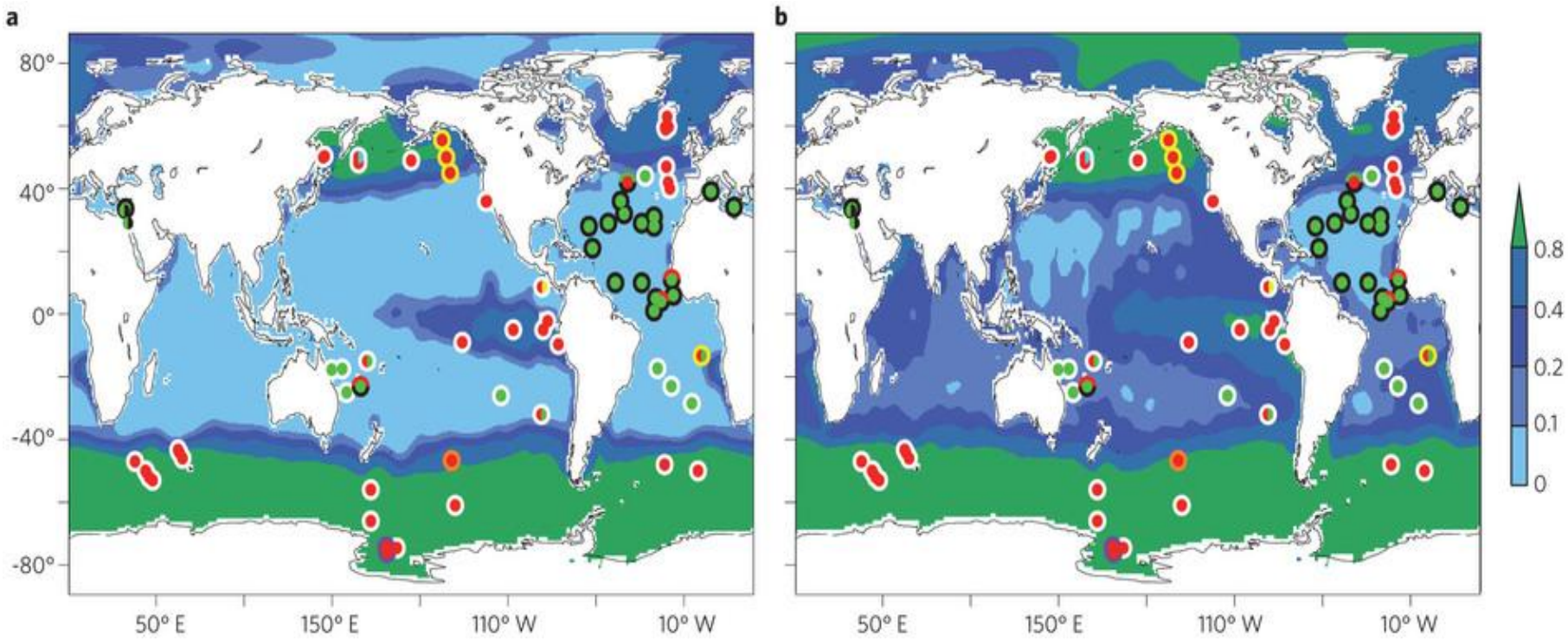
$$106CO_2 + 16NO_3^- + HPO_4^{2-} + 122H_2O \rightarrow (CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 138O_2$$

This equation represent

- The synthesis of phytoplankton biomass from inorganic nutrients.
- The **ratio C:N:P = 106:16:1** describes the molar composition of this organic matter.
- Describe the nutrient limitation and remineralization processes in the ocean.

| N:P Ratio | Interpretation | Eutrophication Implication |
|---|---|---|
| N:P > 16:1 | Phosphorus-limited system | Excess nitrogen input (e.g., fertilizers); eutrophication risk if P increases |
| N:P < 16:1 | Nitrogen-limited system | Often seen in estuaries or tropical waters; denitrification may be occurring |
| N:P ≈ 16:1 but both N and P are high | Balanced but excessive nutrients | High nutrient load overall; strong risk of algal blooms and oxygen depletion |

# Nutrient status in oceans around the globe




Backgrounds indicate annual average surface concentrations of nitrate (a) and phosphate (b) in μmol $kg^{-1}$. Symbols indicate the primary (central circles) and secondary (outer circles) limiting nutrients as inferred from chlorophyll and/or primary productivity increases following artificial amendment of: **N (green)**, **P (black)**, **Fe (red),** **Si (orange),** **Co (yellow),** **Zn(cyan)** and vitamin **B12(purple).** Divided circles indicate potentially co-limiting elements. White outer circles indicate that no secondary limiting nutrient was identified, which in many cases will be because of the lack of a test.

*Moore et al., Nature Geoscience 6, 701–710 (2013)*

# Fe and P minerals in the Dust

| Species or mineral | Chemical forms |
|---|---|
| Ferrihydrite | $Fe(OH)_3$ |
| Goethite | $FeOOH$ |
| Hematite | $Fe_2O_3$ |
| Magnetite | $Fe_3O_4$ |
| Fluoroapatite | $Ca_{10}(PO_4)6F_2$ |
| crandallite | $CaAl_3(PO4)_2(OH)_5{\cdot}H_2O$ |

-1-5% of Dust is Fe (in most atmospheric models is assumed to be 3.5%).
-The soluble fraction ranges from 0.1 to 80%.
-Fe(II) is in general more soluble than Fe(III).
-Dissolved Fe(II) in the dust, once dissolved in sea water, may be oxidized rapidly to Fe(III) or complexed with organics, which are at least partially bioavailable.
-Acidity of dust particles increase the solubility of Fe & P.

Recent findings support the idea that the microorganisms containing on the dust particles could be potentially nutrients for the ecosystems (Violaki et al., 2025).

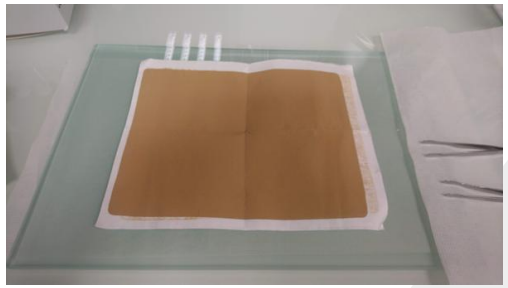
# Evidence from solid-state $^{31}$P NMR


The amount of analyzed Saharan dust (N=5) was ~ 25 mg

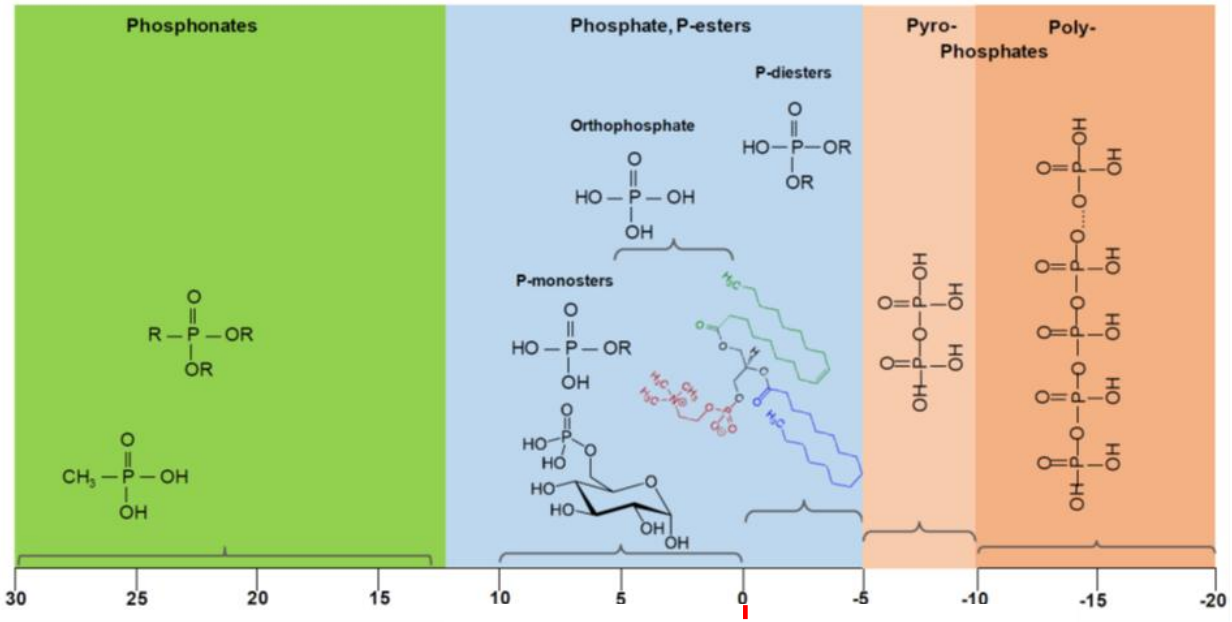
The dusts were analyzed using magic angle spinning (MAS) solid-state $^{31}$P-NMR technique at the EPFL/ISIC/NMR facilities.

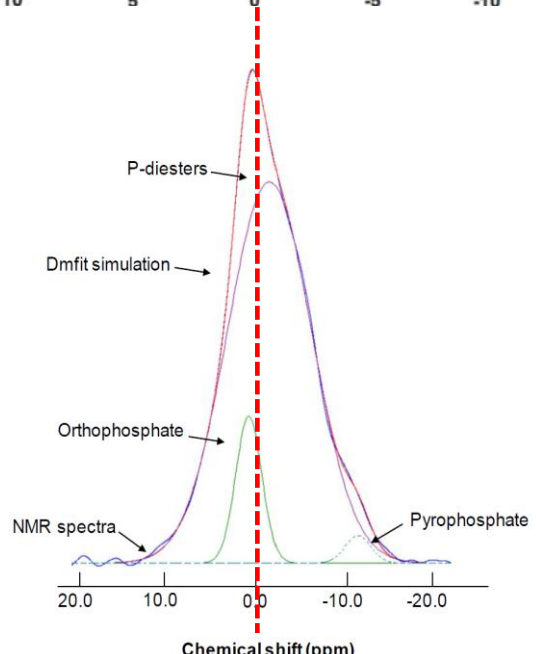
Sample spin rate at 20 KHz and 15000-55000 scans permit acquisition of a decent spectrum (3 days and 3 nights running).

*Solid-state NMR spectrometer*



# P-diesters are the main atmospheric P species in Saharan dust



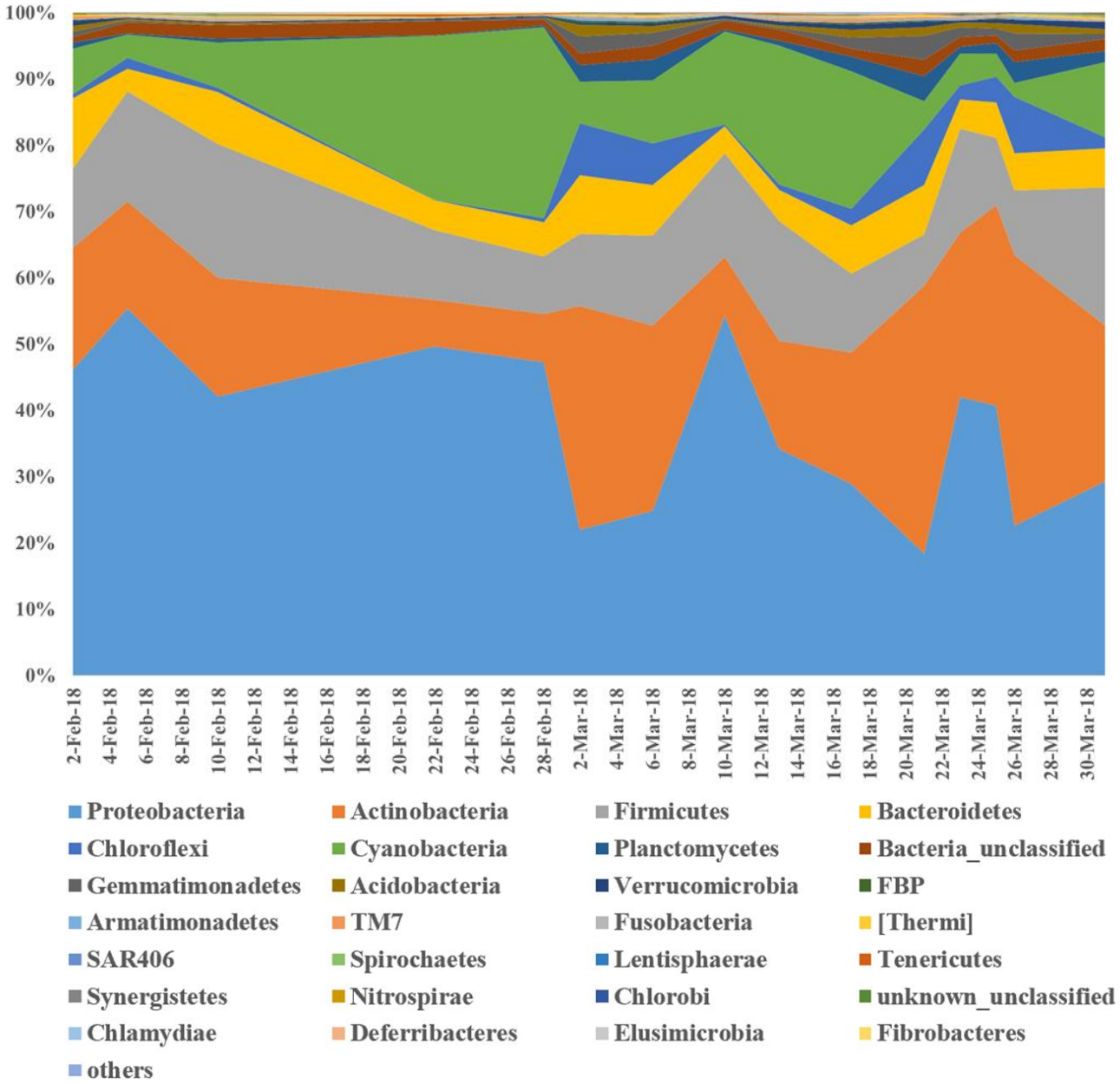

The typical functional groups in P speciation, are:

- Orthophosphate and monophosphate esters (AMP, glucose 6-P) which sharing the same chemical shift.
- P-diesters ($R_1R_2$ $HPO_4$) are mainly found in nucleotides and their derivatives (e.g., DNA, RNA) and phospholipids.
- Pyrophosphate ($H_4P_2O_7$).
- No phosphonates were detected (C-P bond).

| N=5 | $PO4^{3-}$ | P-diesters | Pyro-P | TP |
|---|---|---|---|---|
| nmol P $m^{-3}$ | 1.6±2.0 | 7.7±7.9 | 0.3±0.3 | 9.6±10.2 |
| % | 13 | 83 | 3 | |

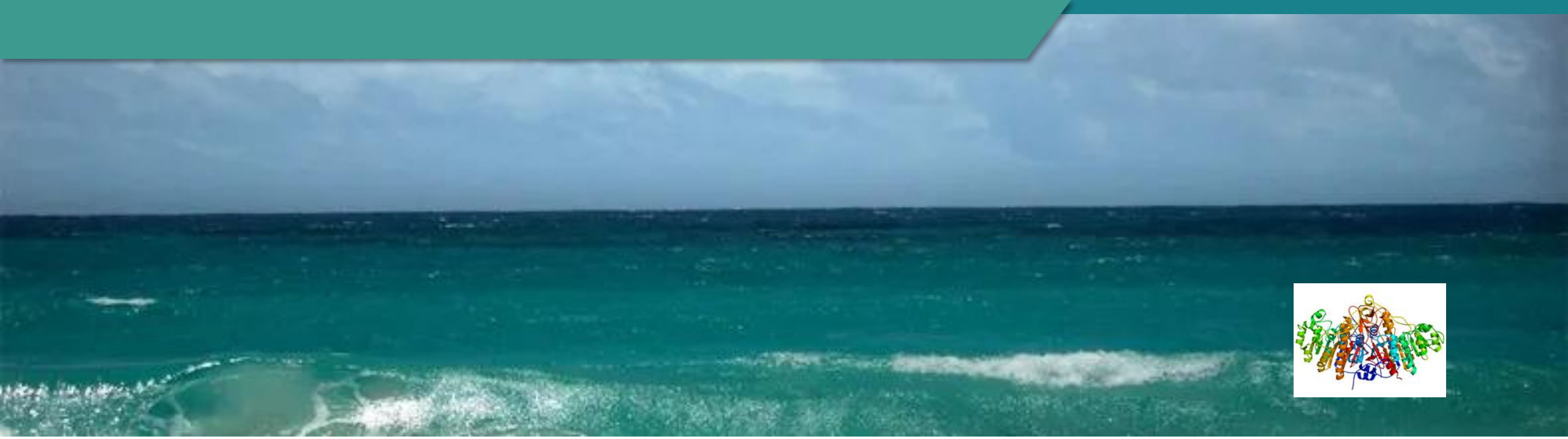
*Violaki, K., et al. Commun Earth Environ 6, 225 (2025). https://doi.org/10.1038/s43247-025-02164-w*

# Relative abundance of bacterial phyla in the dust samples

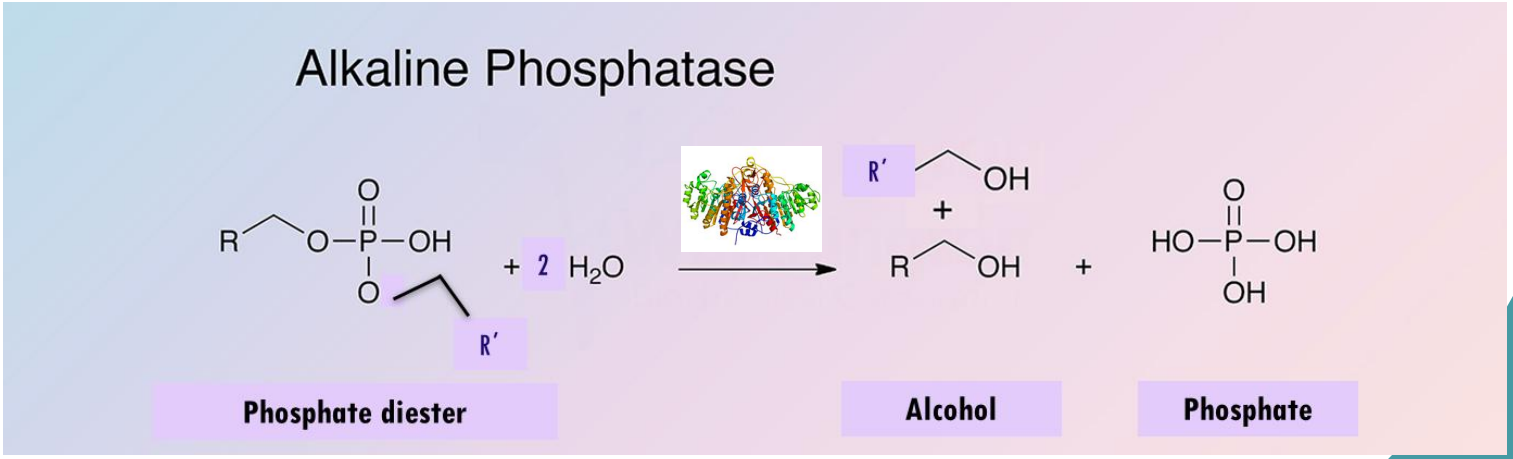



- ✓ The majority (90%, n=15) of bacteria communities found in all samples, were Proteobacteria (37 ± 12 %), Actinobacteria (22 ± 11 %), Firmicutes (13 ± 4 %), Cyanobacteria (11 ± 9 %).
- ✓ Identical bacteria communities were found in the Sahara Desert soil (Belov et al., 2018).
- ✓ Cyanobacteria are emitted mainly from aquatic environments (Romano et al., 2019, Mescioglu et al., 2019).

***Violaki, K., et al. Commun Earth Environ 6, 225 (2025). https://doi.org/10.1038/s43247-025-02164-w***



Upon Deposition In The Marine Environment The Organic P-diesters Are Enzymatically Hydrolyzed to Phosphate Ions



# Nutrient Exchange with the Biosphere: Iron and Phosphorus

Mineral dust represents a major source of iron and other micronutrients which are essential for marine primary productivity.

**In marine ecosystems, the most important external source of iron is dust.**

Iron is the limiting nutrient for over 25% of the surface ocean.

Changes in the atmospheric dust cycle could play a role in climate dynamics by altering the ocean-atmosphere carbon cycle and thus atmospheric carbon dioxide concentrations, although evidence for the importance of such a dust-ocean-climate feedback process is still limited (Mahowald et al., 2010) .

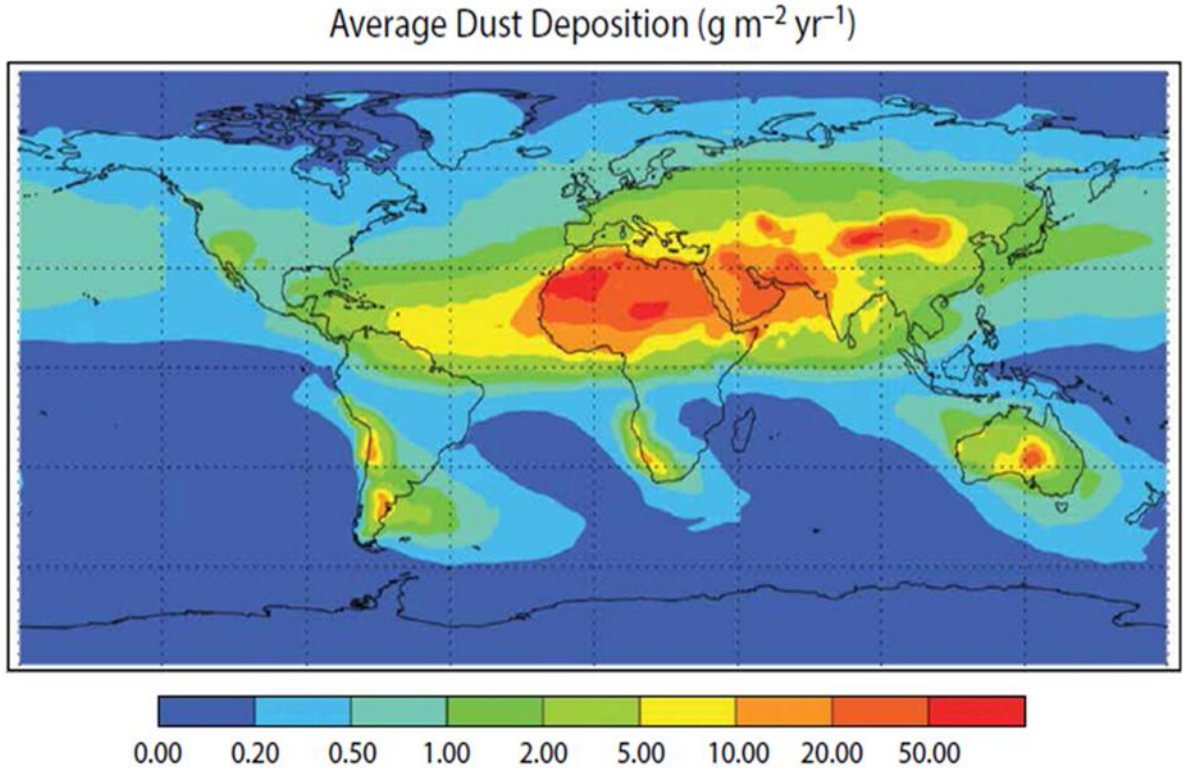



Figure 2. Atmospheric dust deposition to Earth's surface, in g m$^{-2}$ yr$^{-1}$. *From Jickells et al. (2005), reprinted with permission from AAAS*

| Ocean basin | Dust deposition Mt ($10^{12}$ g) year$^{-1}$ |
|---|---|
| North Pacific | 72 |
| South Pacific | 29 |
| North Atlantic | 202 |
| South Atlantic | 17 |
| Indian Ocean | 118 |
| Global emissions | 1,790 |

Mahowald et al. (2005b)

*Mahowald et al (2005a) Global Biogeochem Cycles 19. doi:10.1029/2005GB002541*
*Mahowald et al (2010), Atmos Chem Phys 10:10875–10893*

# P deposition over terrestrial ecosystems

P limitation is relatively widespread in the tropical forest e.g. Amazon and savannah regions. In Europe is co-limited with N(NP co-limited).

Globally, about 20 % of terrestrial ecosystems are P limited.

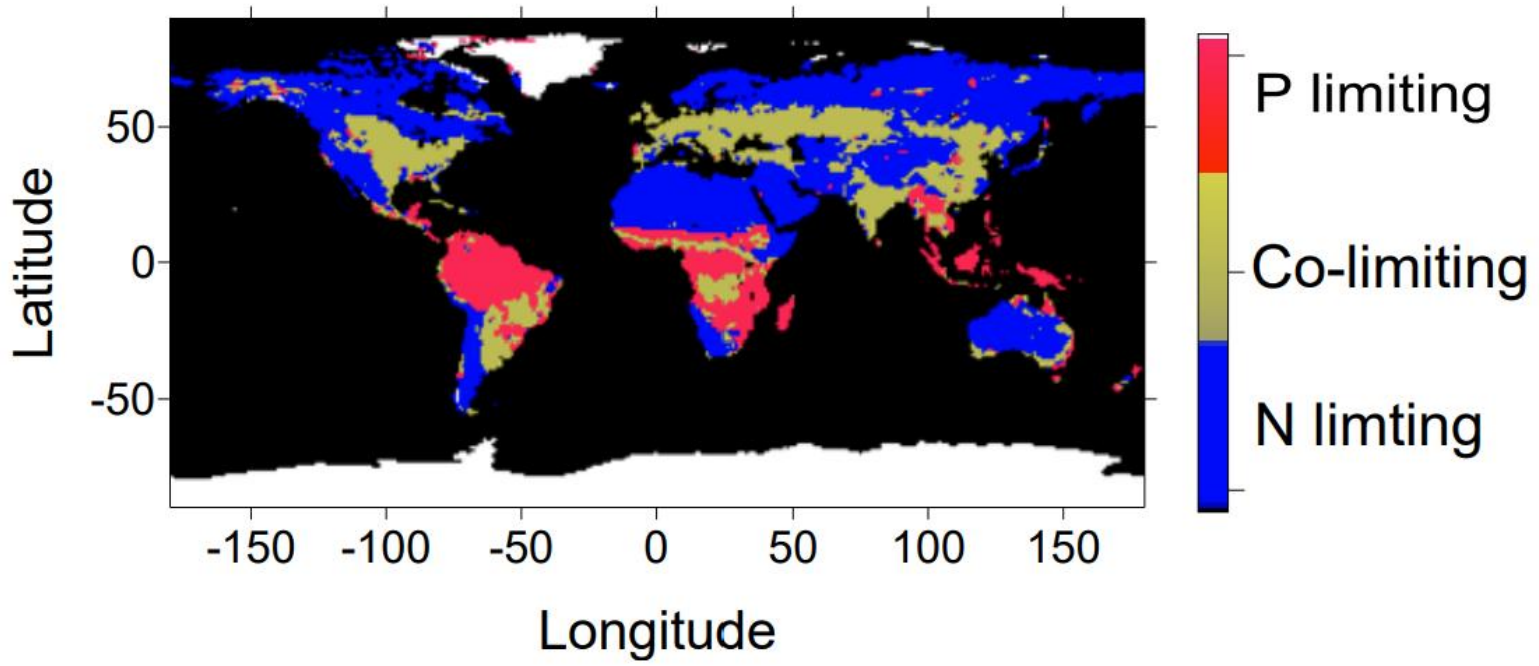
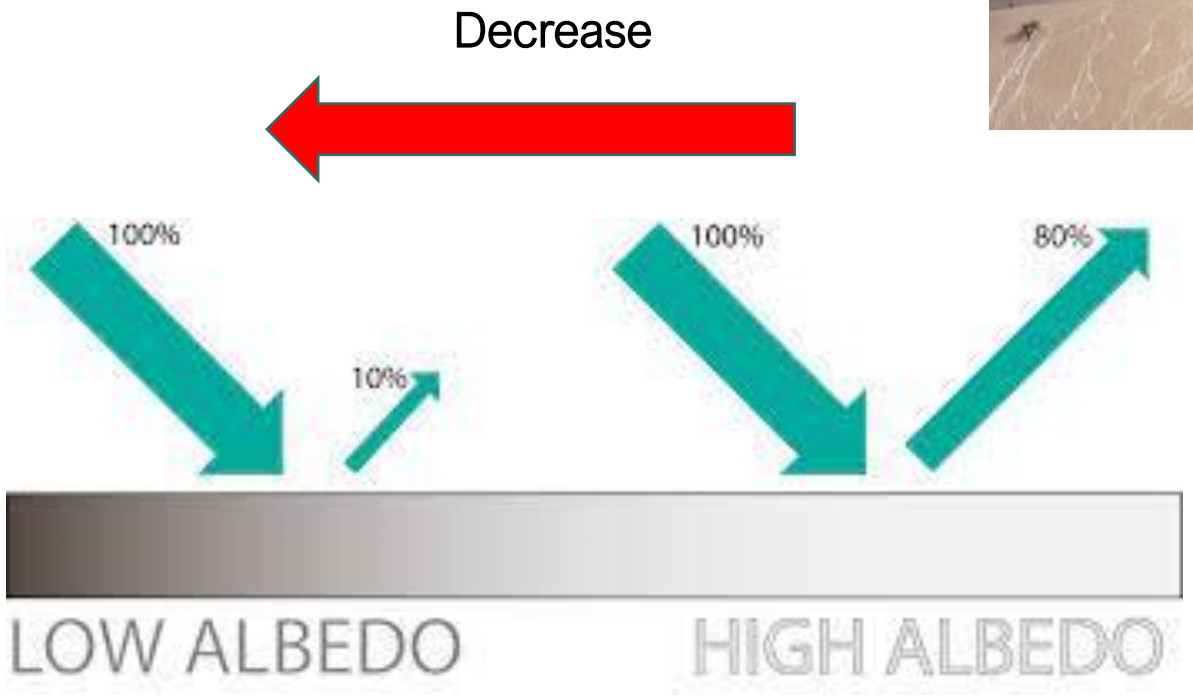



**Fig. 14.4** Estimates of the terrestrial regions where net primary productivity is N limited, P limited or N and P co-limited (Wang et al. 2010)

*Wang et al., (2010) Biogeosciences 7:2261–2282*

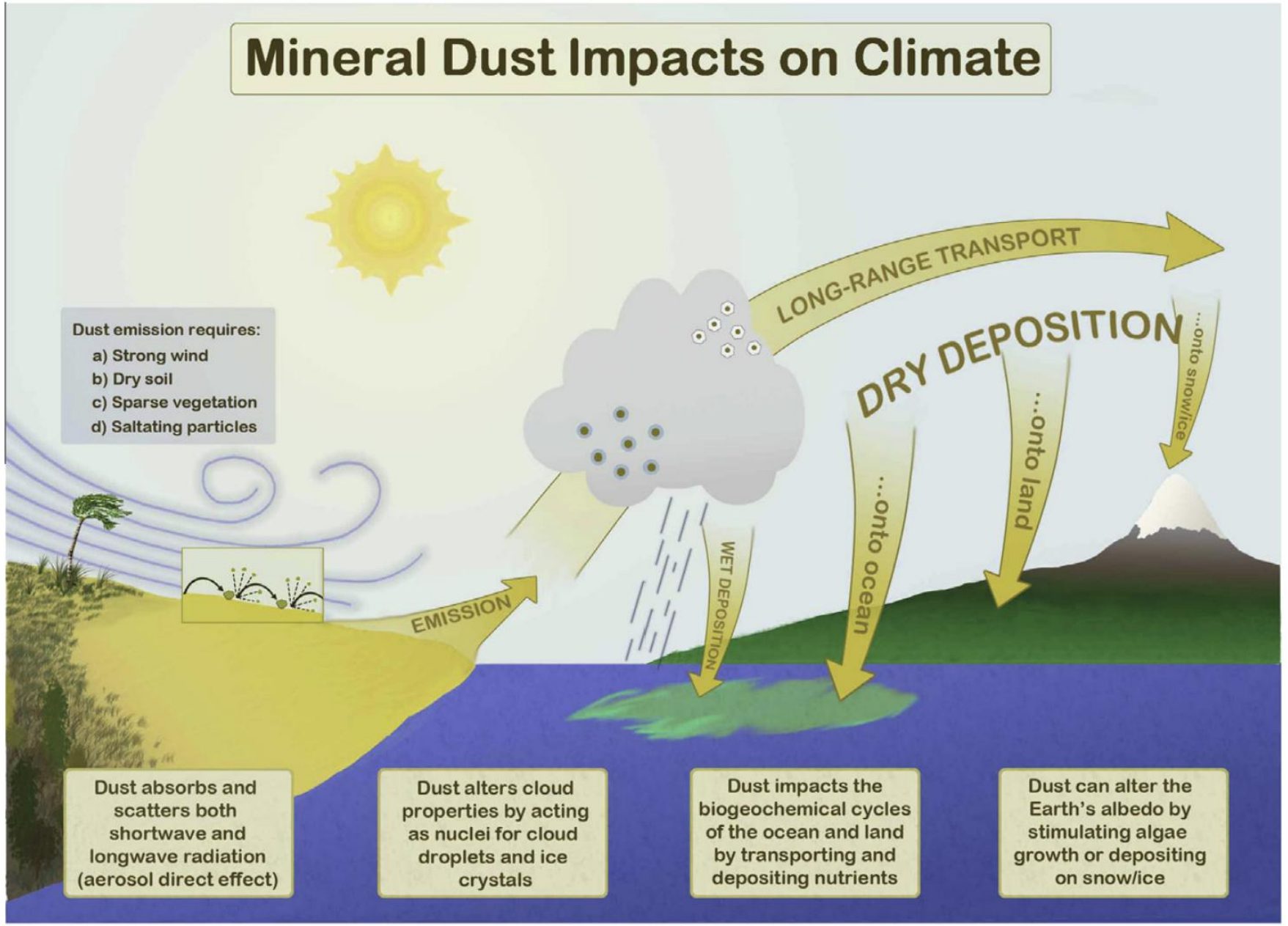
# Impact to Climate

**The ability of ice to reflect the light (albedo) is decreasing remarkably when is covered by dust, affecting the Earth's albedo.**



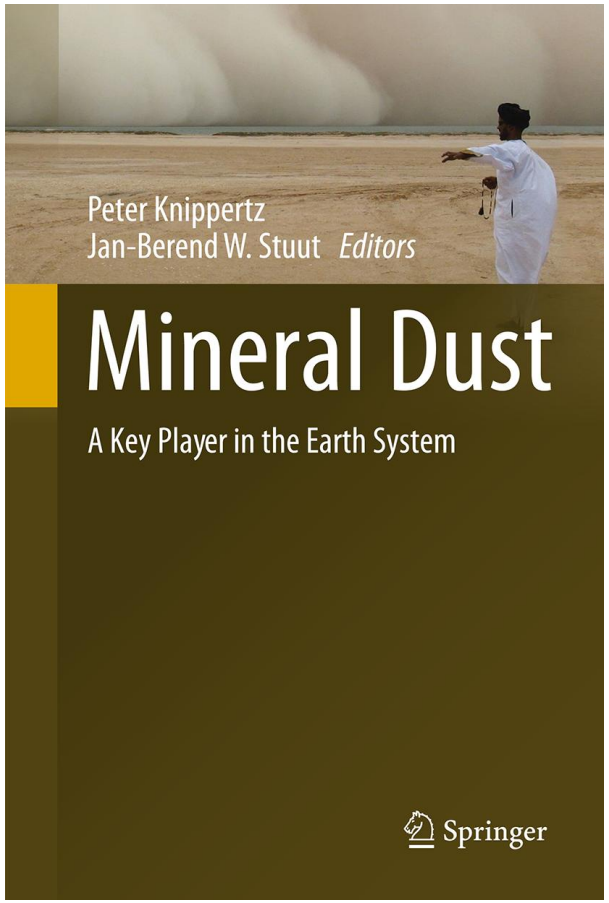
# Summary

- **The transport of mineral dust particles through the atmosphere results in several processes that alter its physicochemical properties, affecting the direct and indirect impacts of dust on climate.**
- **Influence the atmospheric chemistry (NOx, $SO_2$, $O_3$).**
- **Influence negatively the human health (e.g., toxic metals, toxic organic compounds, pathogen microorganisms).**
- **Significant nutrient source for marine (Fe) and terrestrial ecosystems (P).**
- **Deposition measurements suggest that the global mass of dust aerosols doubled during the twentieth century (Mahowald et al. 2010). Models predict that the dust events will be more often and more intense in the future.**
- **The research is on going…..**




*Mahowald et al., Aeolian Research, Vol 15, p53-71, 2014.*

# Source:

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# Thank You

Questions?

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# NASA Satellite Reveals How Much Saharan Dust Feeds Amazon's Plants

https://www.nasa.gov/content/goddard/nasa-satellite-reveals-how-much-saharan-dust-feeds-amazon-s-plants