2021 United Nations Decade
2030 of Ocean Science
for Sustainable Development

UN environment programme

Impacts of Sand and Dust Storms on Oceans

A Scientific Environmental Assessment for Policy Makers

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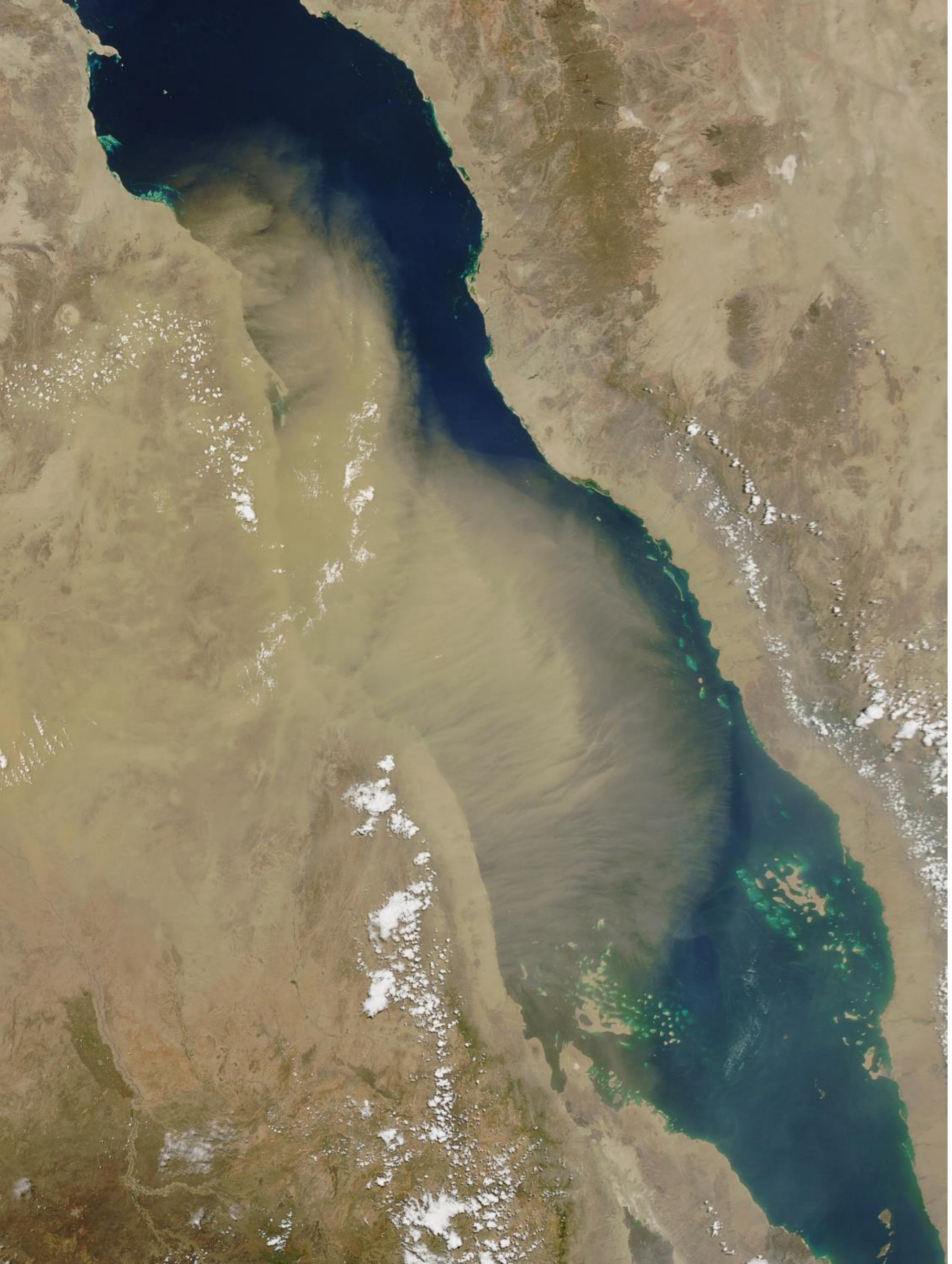
GESAMP
Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection

Global Partnership on Nutrient Management
GPNM

GPA Global Programme of Action for the Protection of the Marine Environment from Land-based Activities



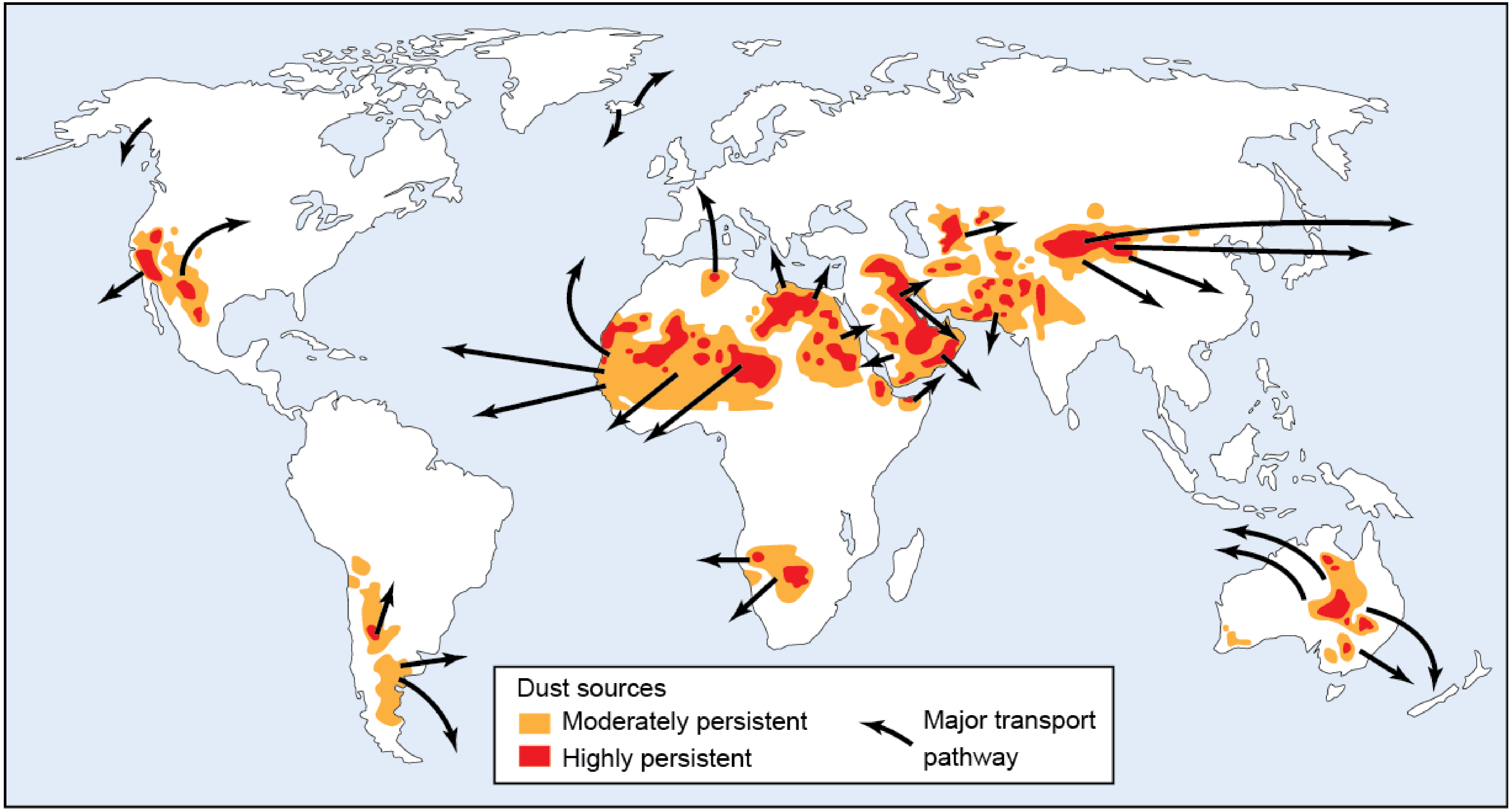
- Dust and biodiversity
  - Ocean primary production
  - Dust and algal blooms
  - Microbial pathogens
  - Dust and coral reef systems
- Dust and global climate
  - The carbon cycle: sequestration via the biological carbon pump
  - Dust in the Southern Ocean over glacial–interglacial cycles

UN context

- SDS have significant implications for a number of SDGs, particularly SDG 14 on Life Below Water and SDG 15 on Life on Land, and demonstrates the interdependencies between the SDGs

- Report’s publication is timely: beginning of the United Nations Decade of Ocean Science for Sustainable Development (2021–2030) and the United Nations Decade on Ecosystem Restoration (2021–2030)

Global sources of desert dust and long-distant transport pathways (after Muhs et al. 2014)



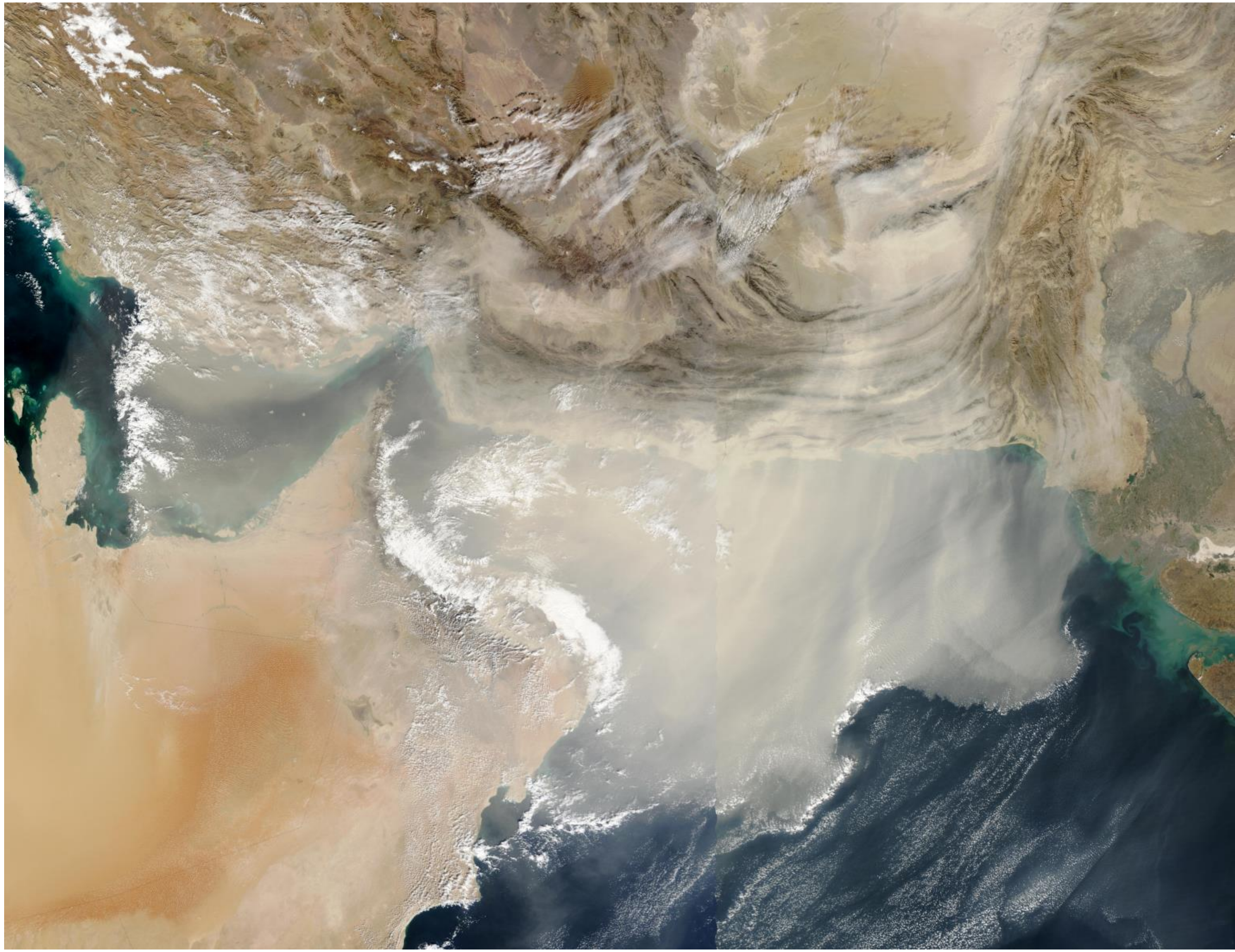
Desert dust deposition rates over the oceans (*Guieu et al., 2014*)

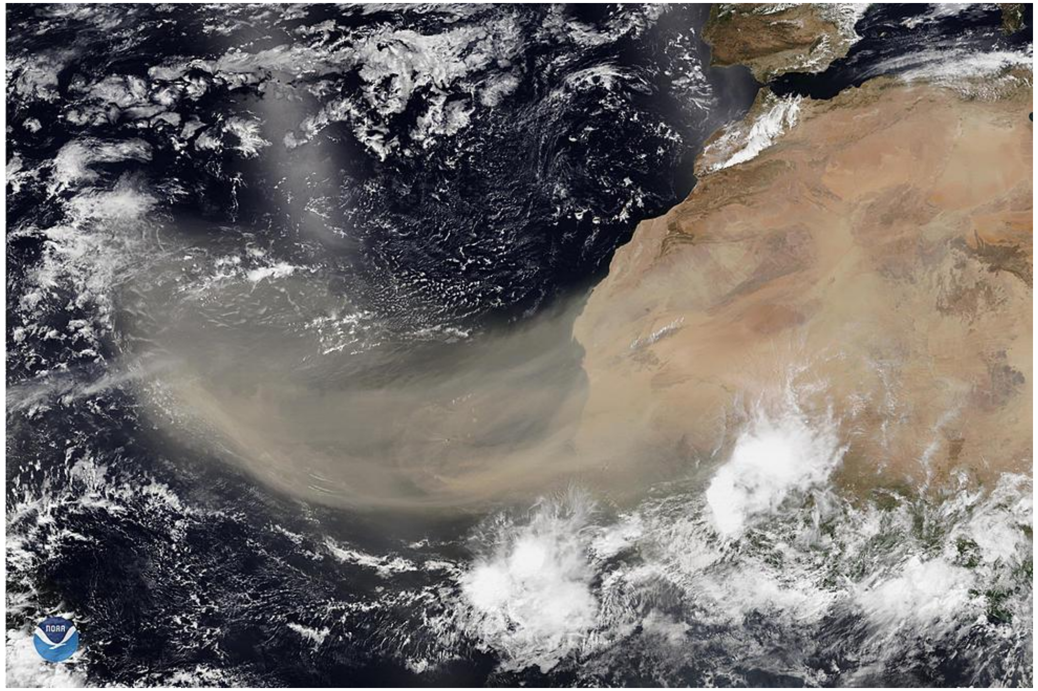
Ocean	Deposition ($Tg\ yr^{-1}$)	Reference
North Atlantic	202	Jickells et al. (2005)
Indian Ocean	118	Jickells et al. (2005)
North Pacific	72	Jickells et al. (2005)
Mediterranean Sea	40	Guerzoni et al. (1999)
South Pacific	29	Jickells et al. (2005)
South Atlantic	17	Jickells et al. (2005)
Arctic Ocean	6	Shevchenko and Lisitzin (2004)
All oceans	477	Mahowald et al. (2010)

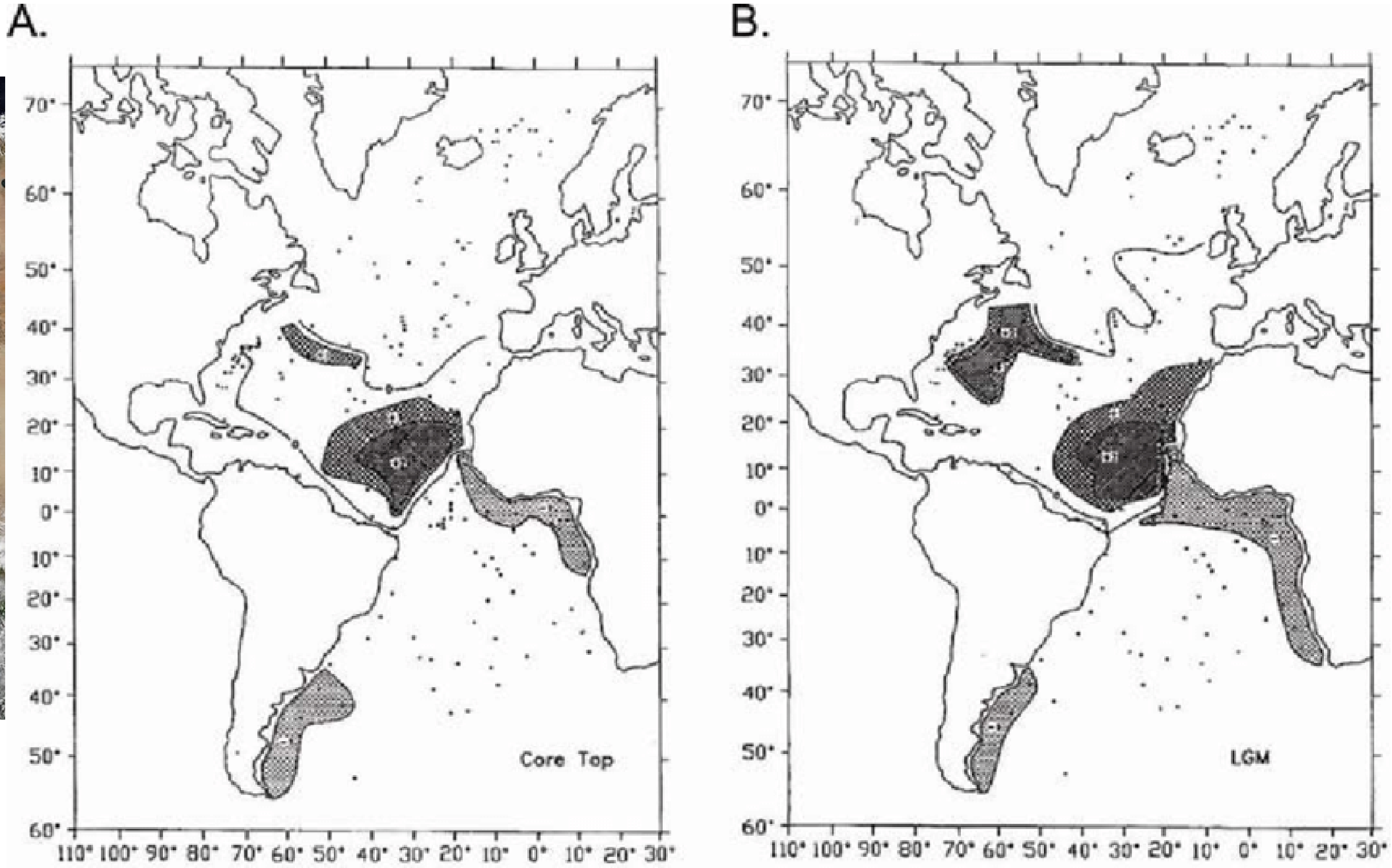
- Maximum dust deposition per unit area: N Atlantic and N Pacific
- Globally, dust input to oceans approx one tenth mass material delivered by rivers

But great regional variation:

- Dust flux > fluvial sediment flux from North Africa (x6) and Middle East (x2)
- Australia (c.=)
- Europe (negligible dust)
- NB atmospheric input over very large spatial scale, riverine input much more localized along coast







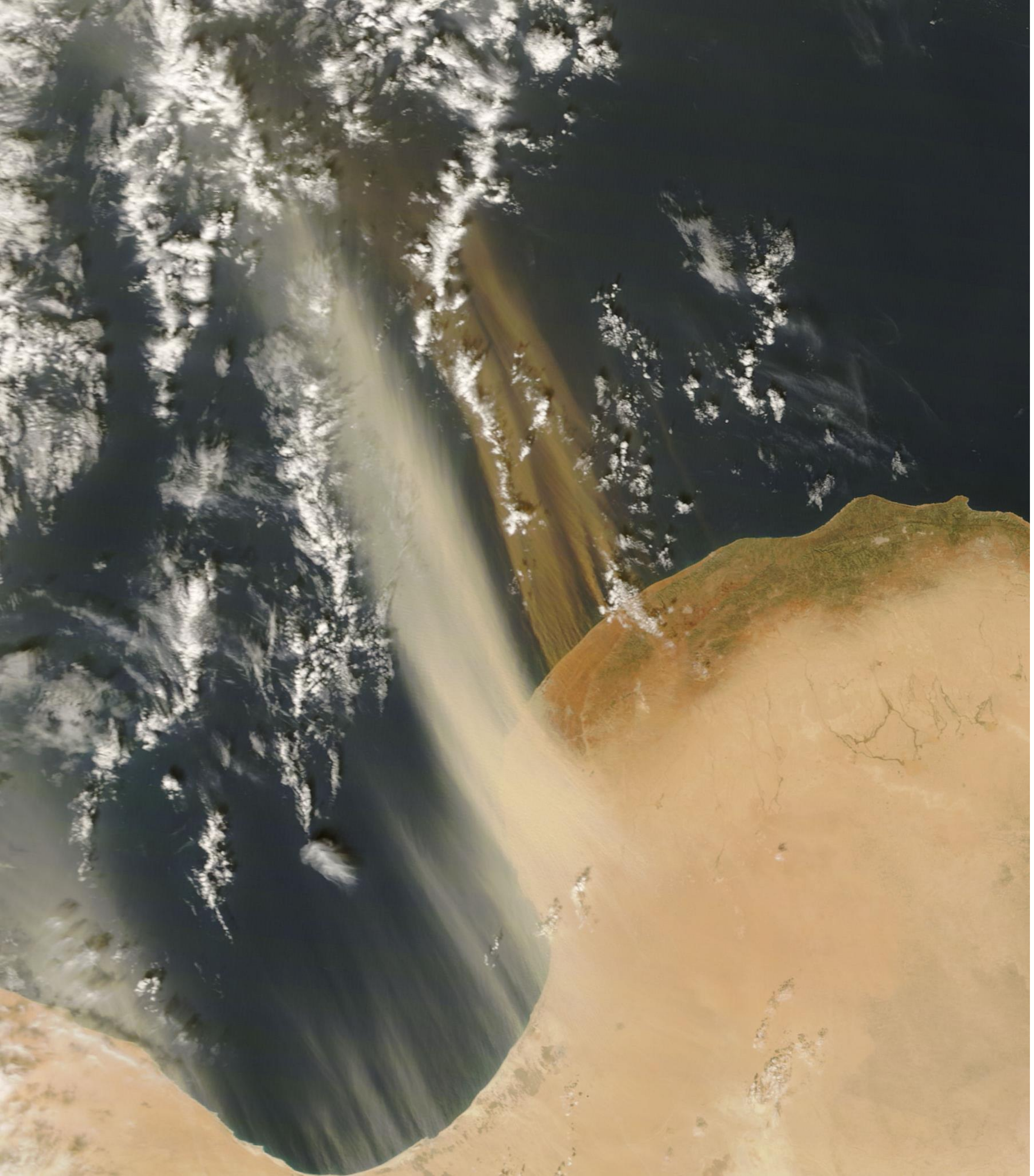
Large, lobe-shaped area of iron oxide-rich sediment on seabed off NW Africa indicates longevity of Saharan dust sources and trans-Atlantic transport pathway

Iron-rich sediments A modern, B Last Glacial Maximum (Balsam *et al.*, 1995)

Aerosol metal sources to the atmosphere (Gg yr^{-1})

Metal	Anthropo-genic	Dust	Fire	Biogenic	Sea spray	Volcanic	Total
Aluminium	3,000	80,000	2,000	200	1,000	5,000	90,000
Titanium	2	8,000	6				8,000
Manganese	10	900	20	30	2	40	1,000
Iron	700	50,000	1,000	200	200	9,000	60,000
Copper	30	20	20	3	10	9	100
Zinc	60	60	100	5	50	10	300
Cadmium	3	0	0	0.2	0	9	10
Lead	100	6	30	2	5	4	200
Sum	4,000	140,000	3,000	400	1,000	14,000	160,000

Source: Mahowald et al., 2018



Wind erosion sources dictate mineralogy of dust: two-toned dust plumes blowing northward off the Libyan coast 26 October 2007 (MODIS image)

Dust and biodiversity

Ocean primary production (phosphorus, nitrogen, iron)

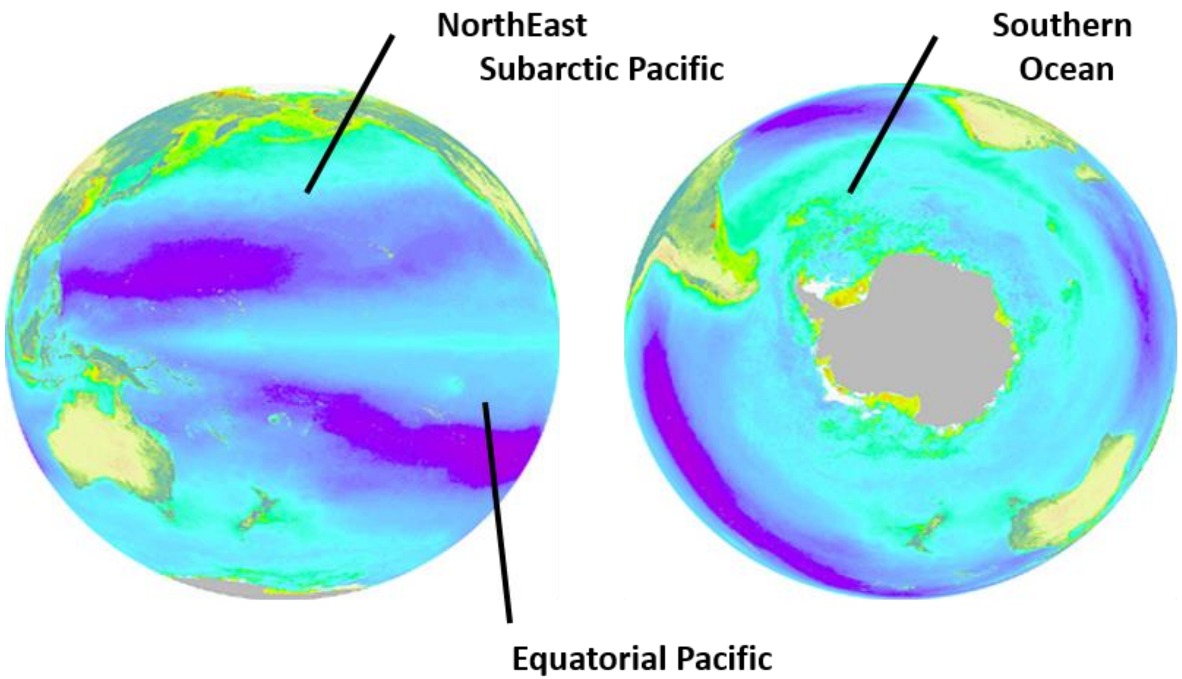
Field obs, experiments (lab and in situ) and numerical modelling establish links dust deposition and ocean chlorophyll concentrations

Two main ways in which deposition of nutrients available in desert dust can stimulate growth of phytoplankton in the oceans, if the receiving ecosystem is limited by an element present in the dust deposited:

- directly, by supplying P and/or Fe, alleviating limitation by these nutrients
- indirectly, when dust supplying P and/or Fe stimulates N fixation, alleviating N limitation

High Nutrient, Low Chlorophyll (HNLC) areas
c30% open ocean where Fe is main limiting factor

- Laboratory and in situ experiments show chlorophyll concentrations in surface waters increase proportionally to addition of Fe (Boyd et al., 2007)
- Debate on geographical patterns and importance of co-limitation by vitamins and micronutrients other than Fe (Moore *et al*., 2013; Hutchins and Boyd, 2016)



Regions of iron limitation (HNLC areas)

HNLC = High-macronutrient, low-chlorophyll (biomass)

Low Nutrient, Low Chlorophyll (LNLC) areas

c60% global ocean where dust-supplied P and/or Fe effect phytoplankton growth directly and indirectly

evidence from Mediterranean Sea (Guieu *et al*., 2014b), Caribbean Sea (Chien *et al*., 2016), Yellow Sea (Liu *et al*., 2013) and subtropical North Atlantic gyre (Neuer *et al*., 2004)

However, generalizations on links between dust-derived nutrient inputs and marine primary production are not necessarily universal

- Evidence **equivocal** for phytoplankton responses to dust deposition in Australian waters (Gabric *et al.*, 2010; Mackie *et al.*, 2008)
- **Time lags** of up to 16 days observed between Saharan dust storm events and enhanced chlorophyll-a concentrations off NW Africa and of 57 strong dust storms assessed 2000–2008 just 6 events clearly related to enhanced phytoplankton growth (Ohde and Siegel, 2010)
- Influence of dust on fertilization in equatorial Pacific **disputed** (Jacobel *et al.*, 2019)

MATTERS ARISING
https://doi.org/10.1038/s41561-019-0304-z
nature geoscie

No evidence for equatorial Pacific dust fertilization

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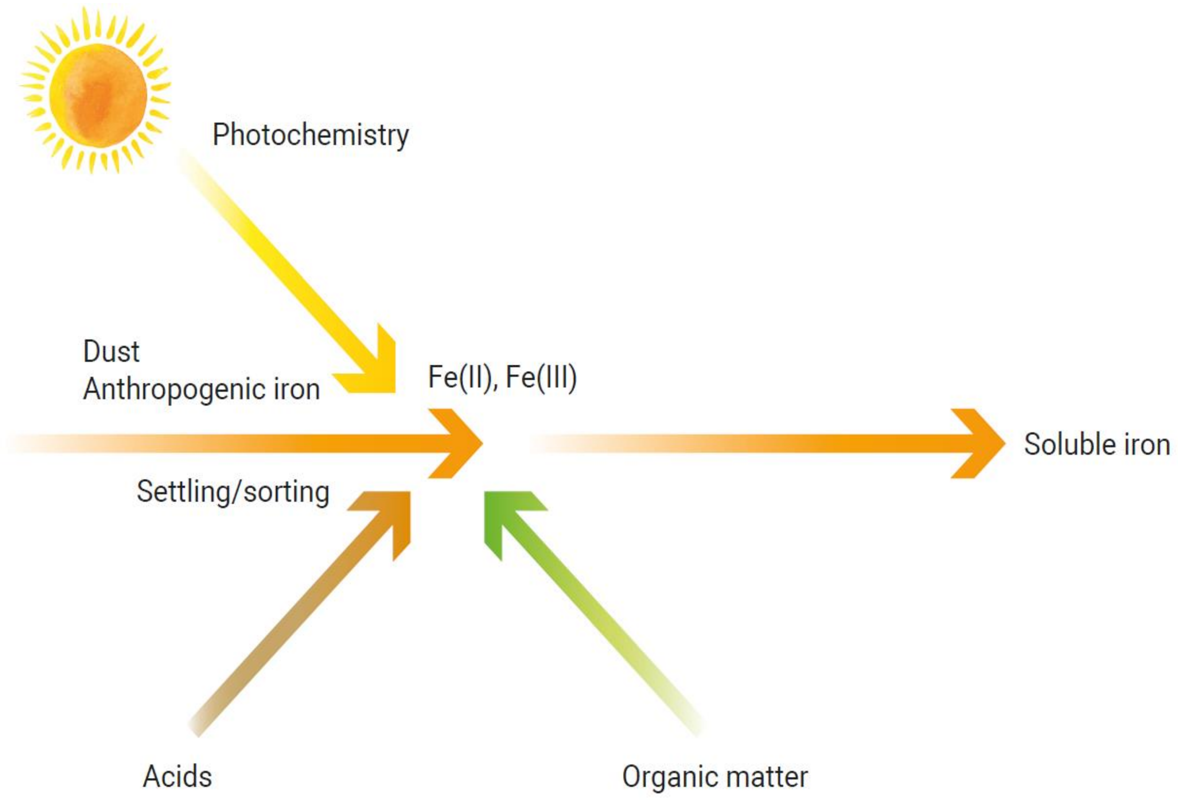
F. J. Pavia[1,2], E. M. Shoenfelt[1,2,5] and Y. Zhou[1,2]

Bioavailability of elements

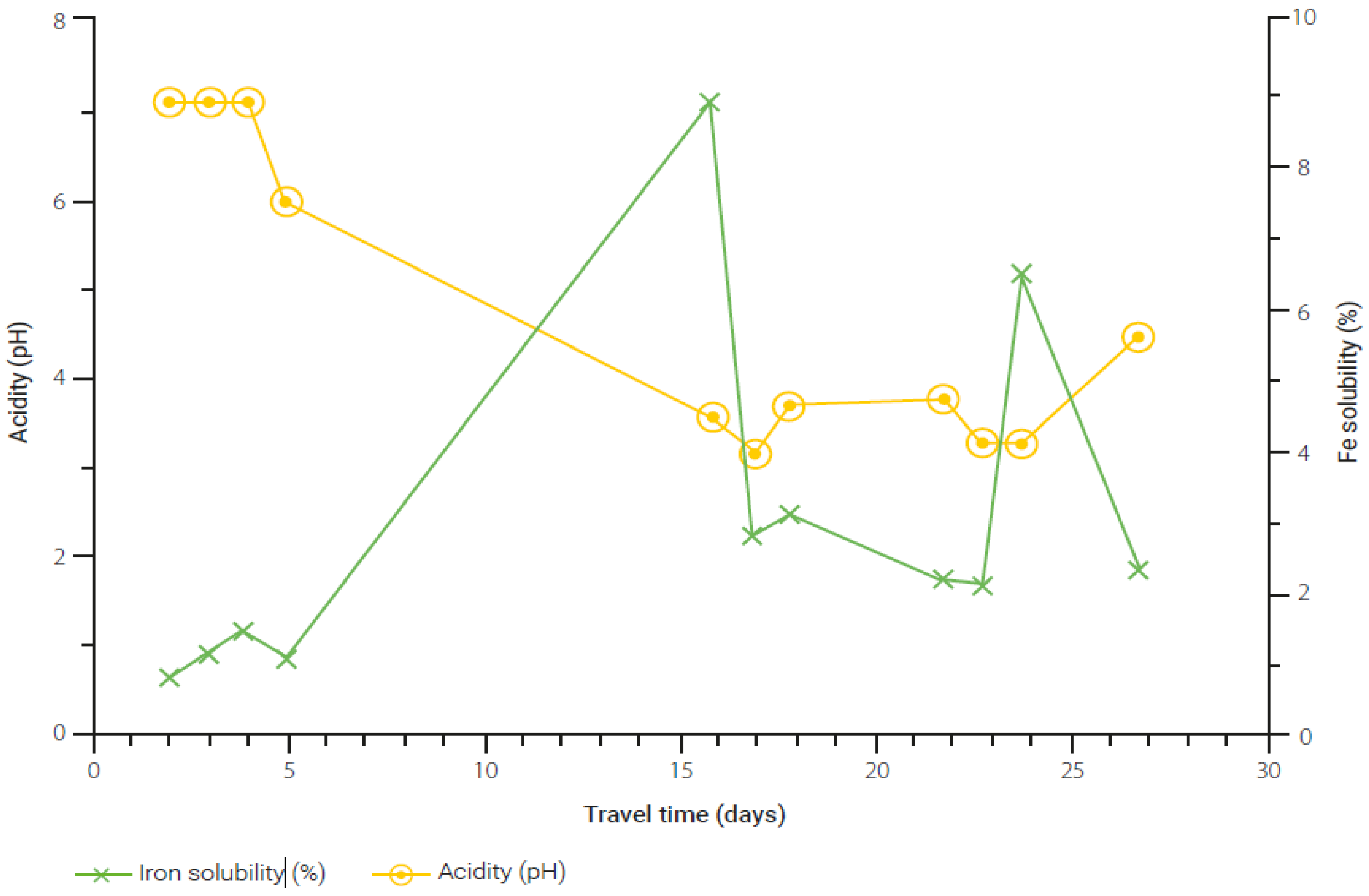
"one of the most poorly understood aspects of the entire global dust cycle" (Schulz *et al.*, 2012, p.10391)

Most of the phosphorus and iron in desert dust present as minerals that are not immediately soluble in water, and therefore are **not** bioavailable

Atmospheric processes that can modify the solubility of iron (both as oxidized iron, Fe(III), and the more soluble reduced Fe(II) form) from dust during transport through the atmosphere (after Jickells and Moore 2015)



Acidity and iron solubility for Saharan dust plumes (after Longo *et al*. 2016)



Dust and algal blooms

- dust-borne nutrients in ocean waters sometimes enhance growth of algal blooms (important food source for marine life, though some have detrimental effects on human health and economic activity - ‘red tides’ and harmful algal blooms or HABs)
- input of desert dust widely regarded as important regulator of many blooms—both harmful or otherwise—although nutrient pollution from anthropogenic sources also a critical factor in many nuisance cases
- unusually large blooms of floating *Sargassum* seaweed mats (Caribbean and Atlantic Ocean along W Africa and Brazil coastlines) - habitat for many open ocean species but near shore disrupt shipping, fishing and tourism
- enhanced nutrient loading—from coastal upwelling, land-based anthropogenic sources and/or from desert dust—and the effects of climate change and variability

Microbial pathogens

- Triggering effect of increased Fe supply in desert dust could apply to other organisms otherwise kept in check by nutrient limitations e.g. marine microbial pathogens
- Many species of *Vibrio* in the ocean, some pathogenic: cause disease in marine organisms and humans (e.g. cholera, shellfish-associated gastroenteritis)
- *Vibrio* rapid response to inputs of iron-rich Saharan dust in Caribbean (abundance increased c1% to c20% total microbial community in 24 hours) and open ocean of tropical mid-Atlantic (Westrich et al. 2016, 2018)
- Studies demonstrate pathogens in desert dust transported great distances in viable state (microorganisms in dryland soils highly resistant to desiccation, temperature extremes, high salinity, exposure to ultraviolet radiation)
- Estimated significant fraction (20–30%) of very diverse population of microorganisms in desert dust = species capable of causing disease in both marine and terrestrial organisms, though data on specific microbes lacking
- Dust-associated toxins of human origin may also impact health of downwind ecosystems through direct (toxin accumulation) or indirect (immunosuppression) means

Environmental Microbiology (2007) 9(12), 2911–2922 doi:10.1111/j.1462-2920.2007.01461.x

Life in Darwin's dust: intercontinental transport and survival of microbes in the nineteenth century

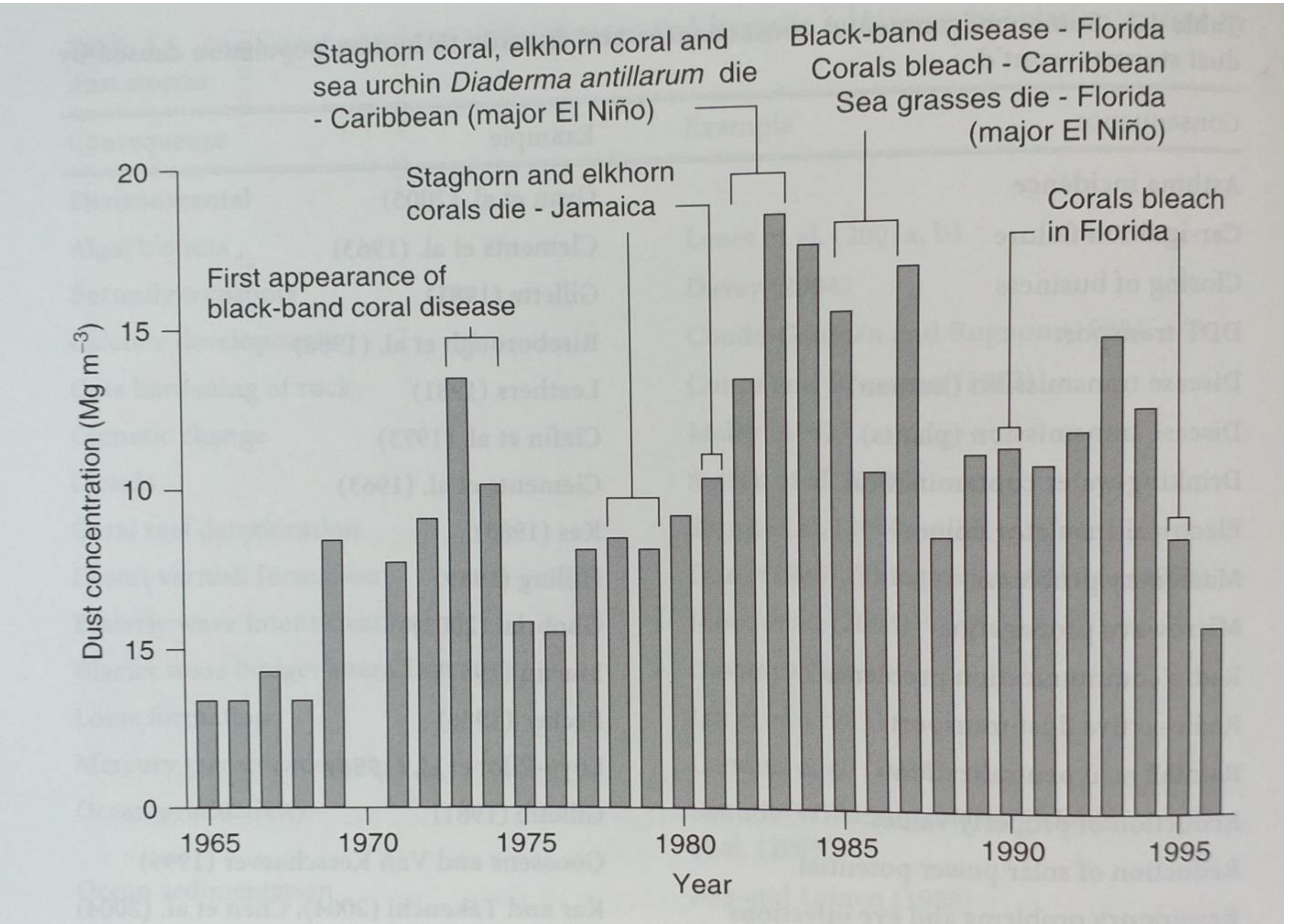
Dust and coral reef systems

Microorganisms in desert dust implicated as causal agents of diseases affecting coral:

- Aspergillosis (aka sea fan disease): fungus *Aspergillus sydowii* widely found in soils, salt-tolerant and capable of growing in the sea
- Black band disease: relationship + desert dust depends on iron content of dust, which facilitates pathogenicity
- White plague (aks white syndrome): also suspected link to iron-rich dust
- White pox: link to desert dust less definitive, possibly introduced to coral reefs via river discharge

A sea fan coral (*Gorgonia ventalina*) infected with *Aspergillus sydowii* - purple lesions are indicative of infection (*Source: Ernesto Weil)*

Dust and coral reef systems



- Still limited understanding of diseases that affect coral, their causative agents and pathogenesis
- Dust deposition – combined with nutrient enrichment, SST anomalies, anthropogenic pollutants – may undermine resilience of coral reefs to disturbances such as disease

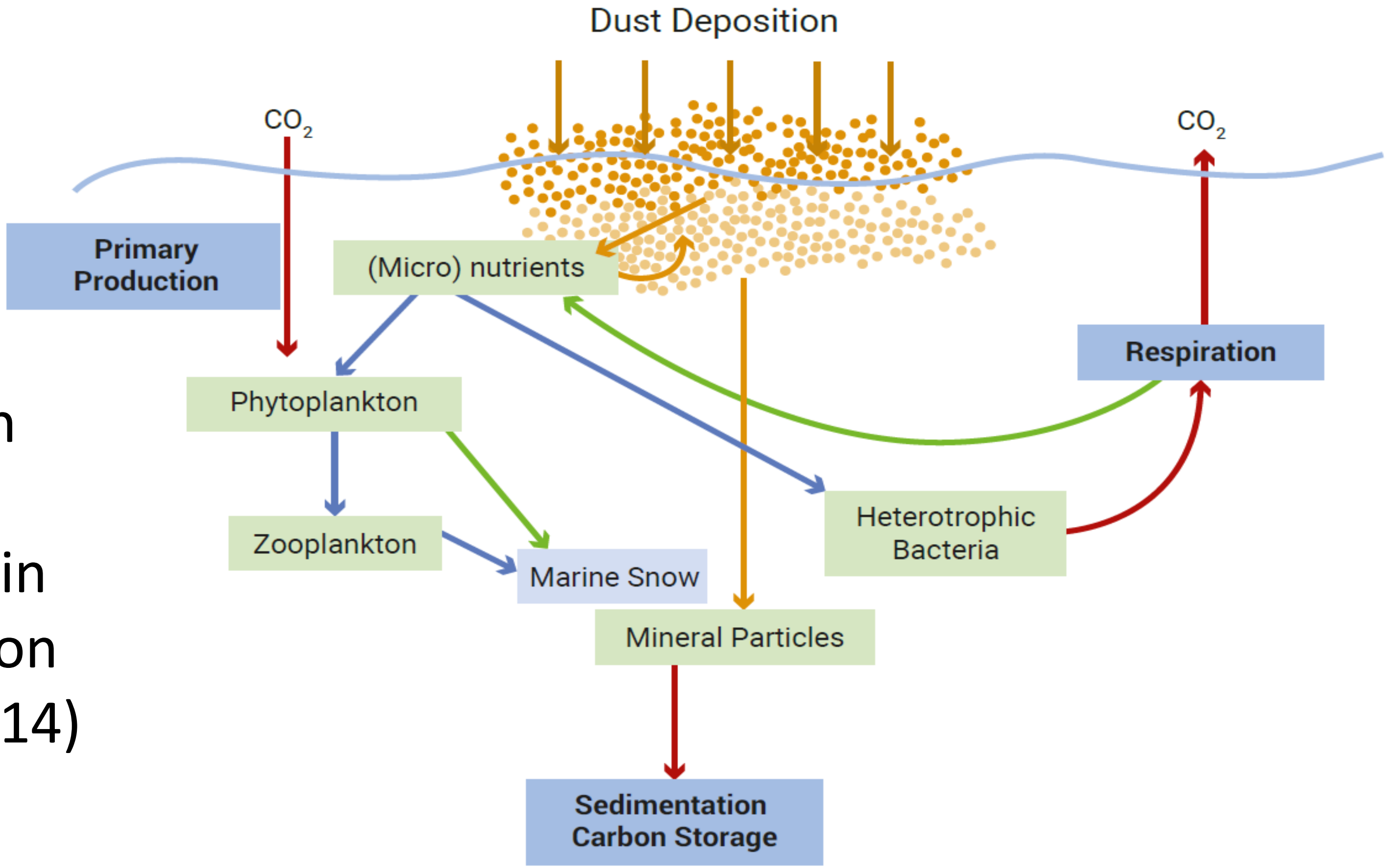
Peak years for dust at Barbados were 1983 and 1987, also years of extensive damage to Caribbean coral reefs (After Shinn et al 2000)

Dust and global climate

Carbon cycle: sequestration via the biological carbon pump

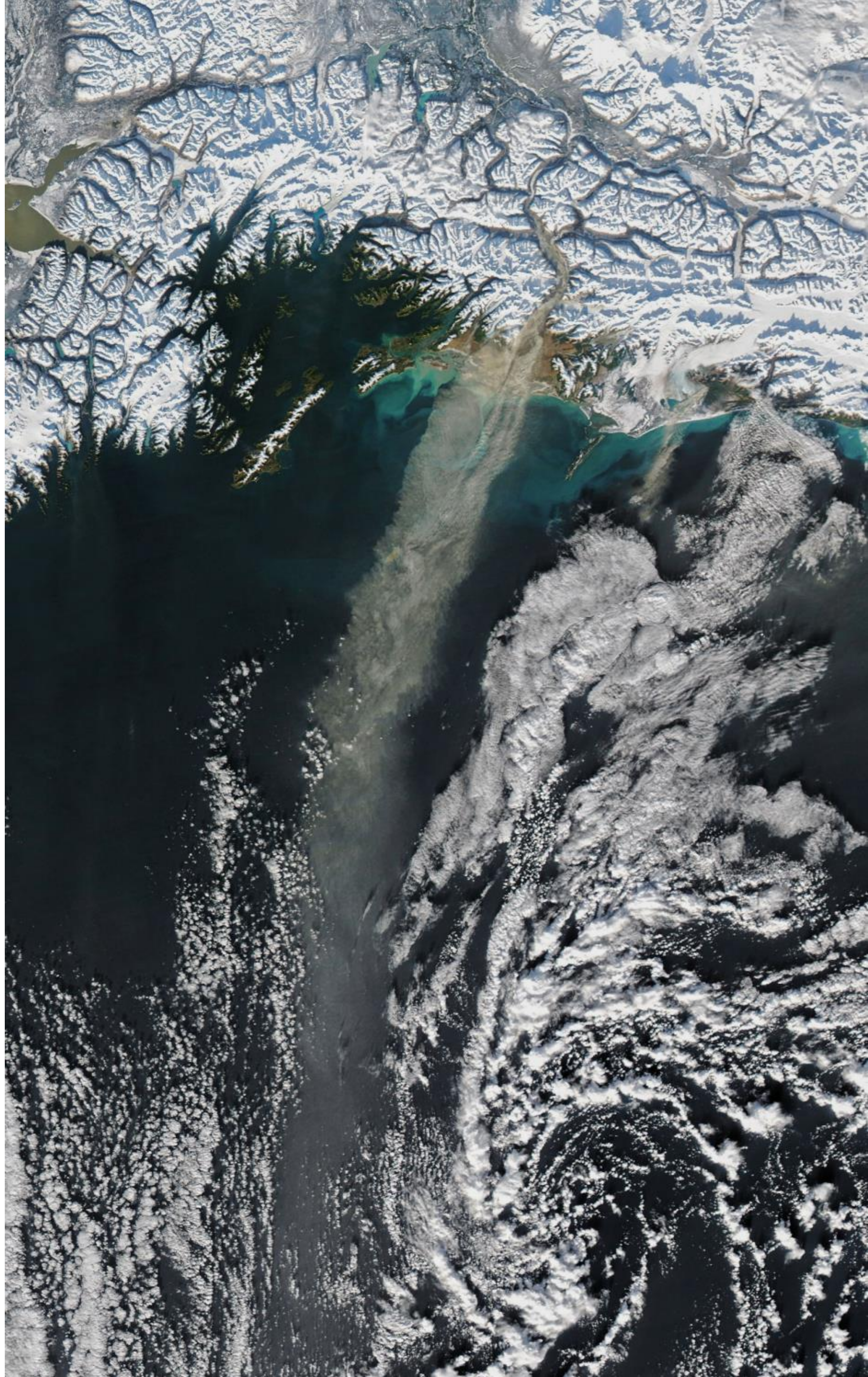
Polarstern 2004 experiment fertilized part of Southern Ocean with Fe (Photo: Mario Hoppmann/Alfred-Wegener-Institut)

Biological carbon pump: dust deposition affects stocks (green boxes) and fluxes (blue boxes) which result in overall sequestration of carbon in deep ocean sedimentation (after de Leeuw *et al*. 2014)



Dust in the Southern Ocean over glacial–interglacial cycles

- **Biological carbon pump** ? more efficient during glacial periods
- Hypothesis (ice core and marine sediment core evidence) that high atmospheric concentrations of Fe-rich dust deposited in oceans during glacials enhanced phytoplankton growth, thus lowering atmospheric CO2 in those periods by 10−20 ppm (Martin, 1990). Effect ? most pronounced in HNLC areas, particularly **Southern Ocean**, where productivity limited by Fe deficiency
- Dominance Southern Ocean in large-scale atmospheric CO2 drawdown **debatable**:
- Southern hemisphere does **not** have major continental dust sources in present day
- But glacials marked by **increased dust deposition** to oceans ? x25 from South American dust sources (Lambert *et al*., 2008)
- And dust from high-latitude glacial sources have **elevated levels** of bioavailable Fe (Shoenfelt *et al*., 2017)



Recommendations

1. Encourage further research on SDS sources and emissions (N.B. natural vs anthropogenic sources)
2. Promote establishment of network of different ocean study sites for long-term measurements in marine atmospheric boundary layer
3. Encourage further development of dust cycle models (global and regional scales, emission, transport and deposition simulation)
4. Promote ecosystem restoration projects that can help mitigate SDS sources (e.g. Africa’s Great Green Wall).
5. Encourage research into interactions natural desert dust constituents and dust-associated toxins of human origin
6. Encourage research into interactions desert dust deposited in oceans and indirect impacts on human health
7. Encourage research into processes affecting bioavailability of P and Fe in desert dust and assess combined effects of different stressors (warming, pH, ultraviolet radiation, etc.) on ecosystems response to dust deposition
8. Promote implementation of coordinated field experiments involving both atmospheric and marine measurements to address processes and role of dust, iron and phosphorus fertilization on marine biogeochemistry and climate
9. Promote assessments of economic value of SDS damage to enhance policy development and mitigation
10. Enhance science–policy interface on SDS to support implementation of relevant resolutions and decisions taken Conferences of the Parties of UNCCD, UN Environment Assembly and other relevant MEAs, in particular to address SDG 14 on Life Below Water and SDG 15 on Life on Land, including target 15.3 on LDN

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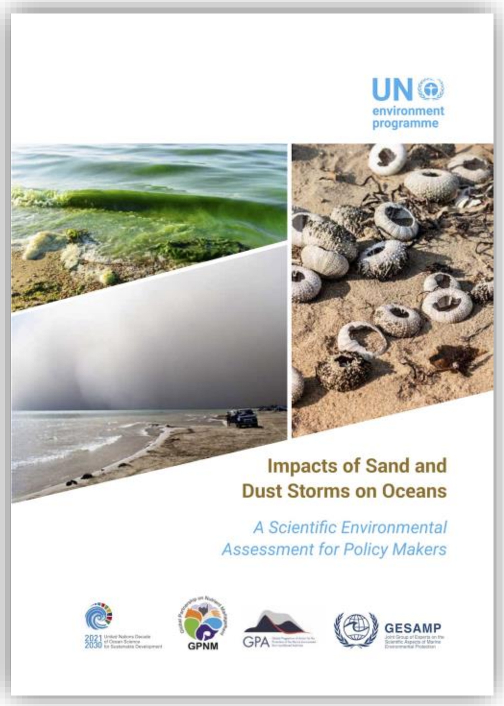

download:

www.unep.org/resources/report/impacts-sand-and-dust-storms-oceans

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