Dust – Climate Interactions

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TROPOS
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Dust Impacts

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- Direct and indirect climate forcing
- Regional impacts on temperature and hydrological cycle
- Dust as micro-nutrient fertilises marine and terrestrial ecosystems
- Neutralisation of ‘acid rain’, atmospheric chemistry
- Transport medium for bacteria, fungi, and pesticides
  - ‘Coral bleaching’
- Human health
- Economy
  - Reduced visibility (aviation, ground transport, solar energy, ...)
  - Limited reliability of electronic devices

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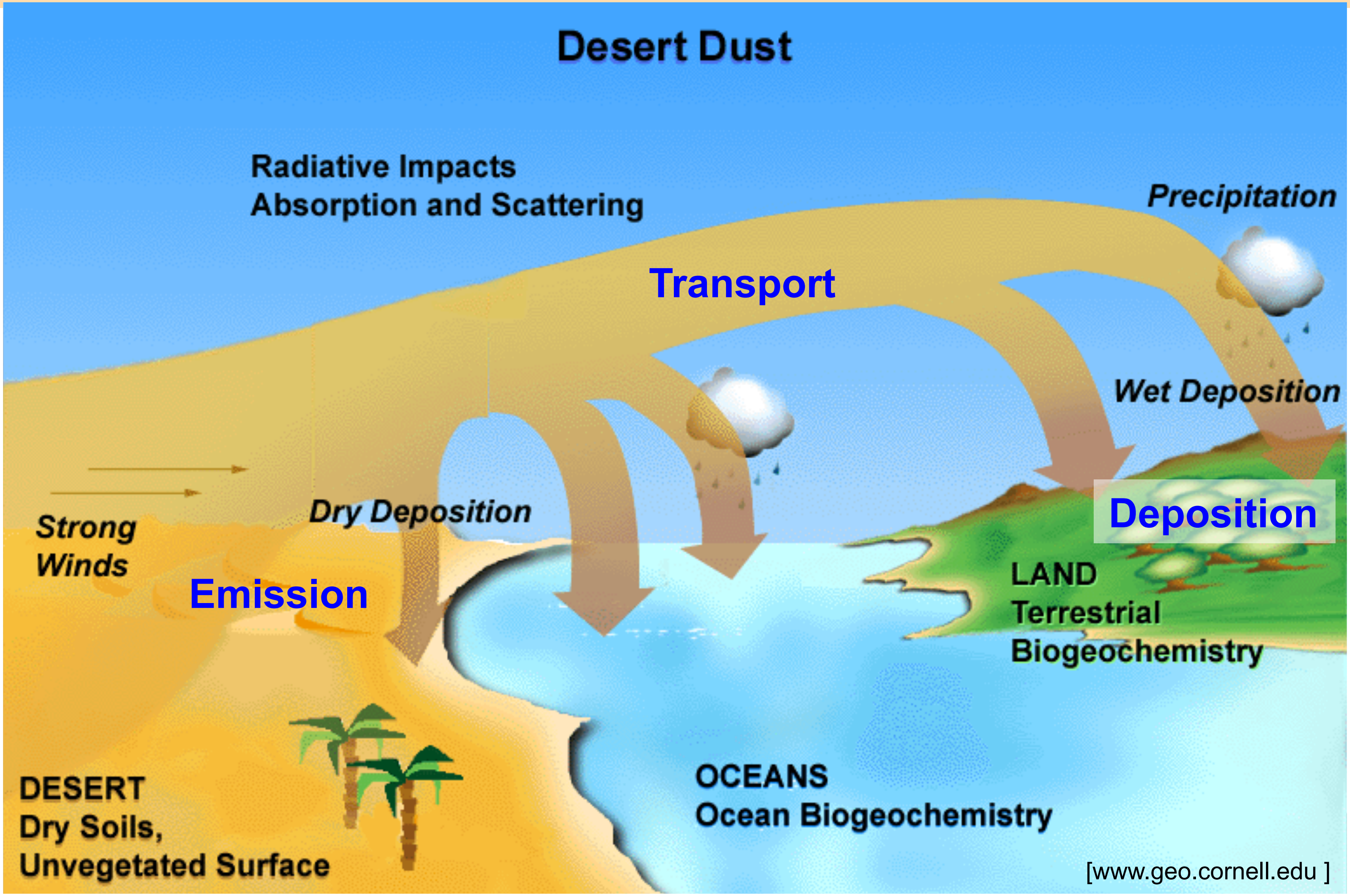
Atmospheric Dust Cycle



Dust Mobilisation

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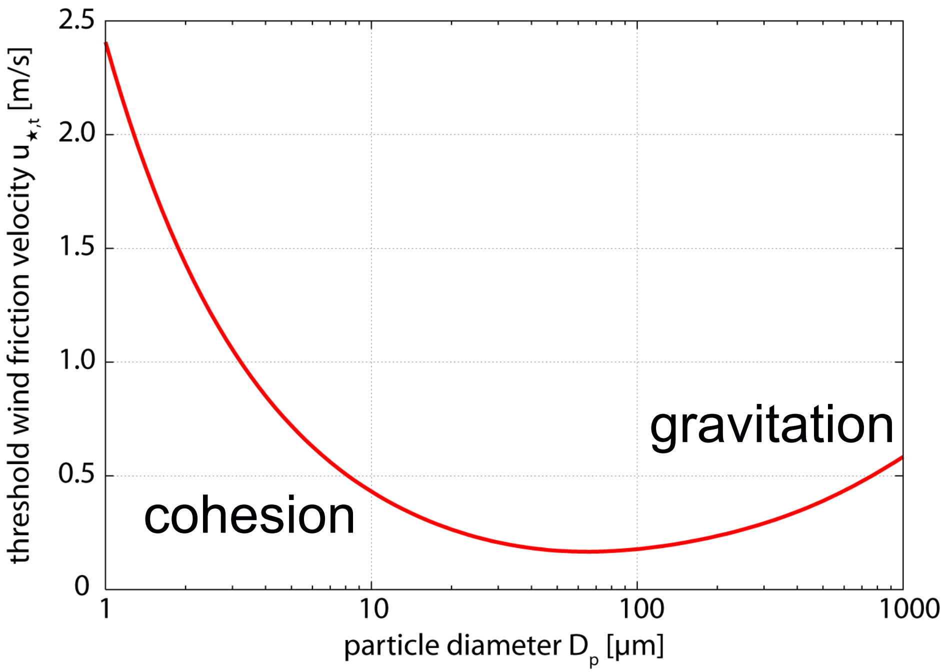
- **Transport of momentum** from the atmosphere to soil surface
- Soil moisture, vegetation, and surface texture affect **aeolian errosion** (threshold problem)

- Size distribution of mobilized dust particles depend on **cohesion and gravitation**
- Mobilisation of small particles for long-range transport by **saltation**



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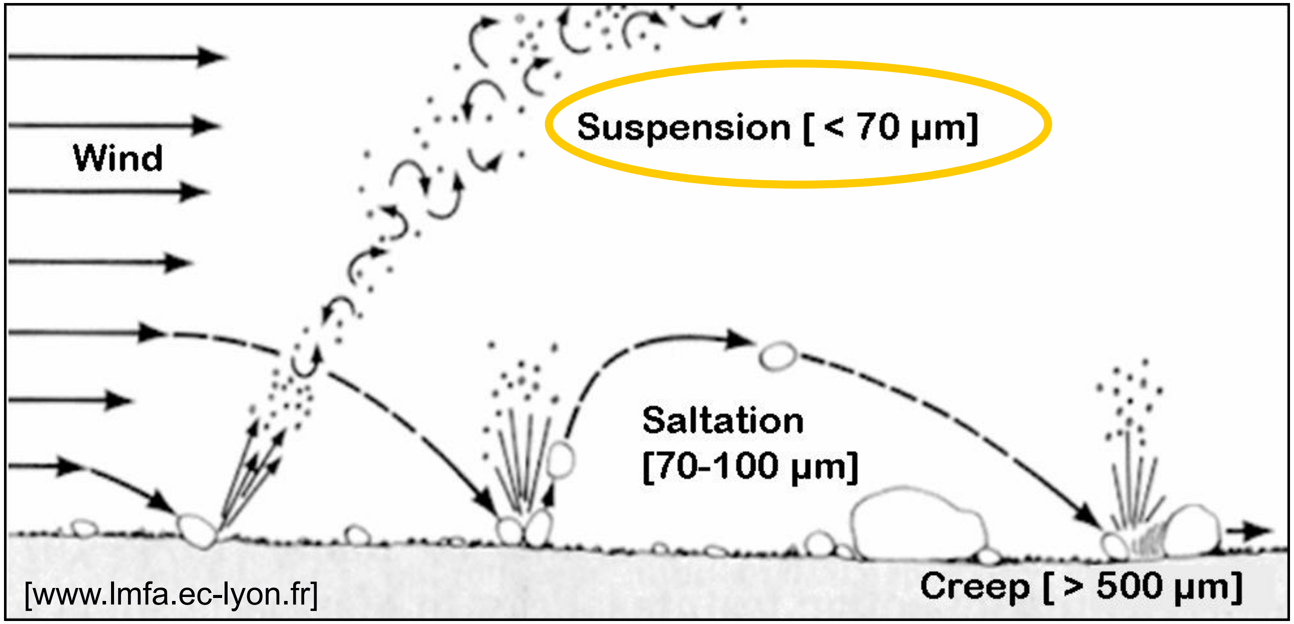
Dust in suspension,
Mauritania

Dust Emission



Dust – Climate Interactions

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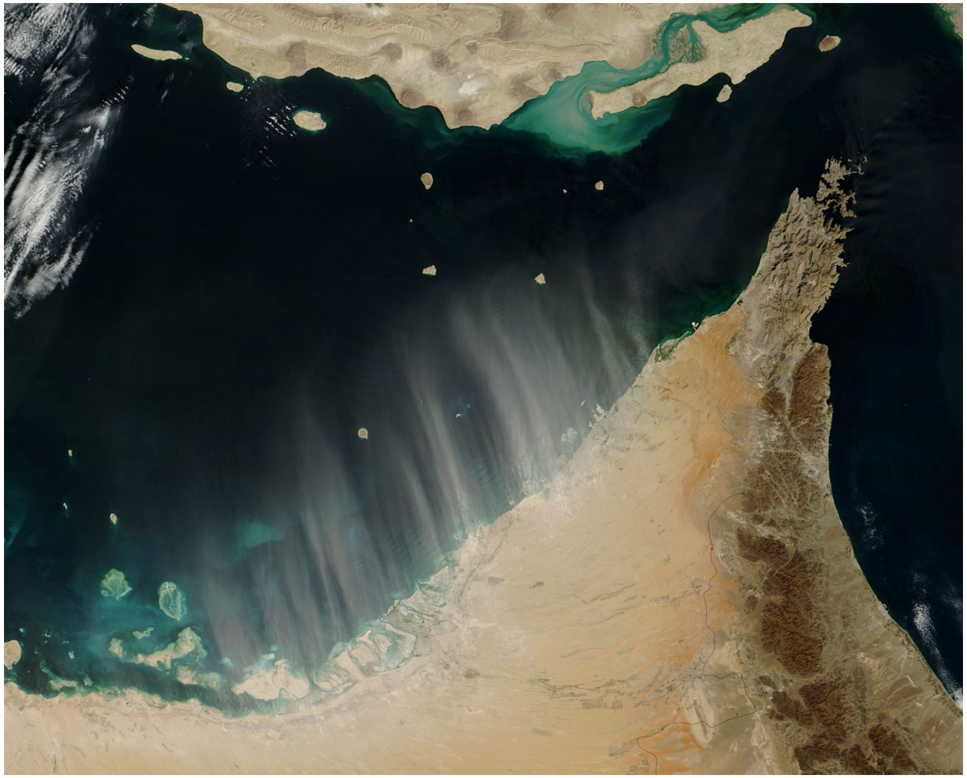
Airborne Dust

dust uplift

Dust Emission



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Airborne Dust

dust uplift

settlement

Dust Emission

Dust Deposition

Dust – Climate Interactions

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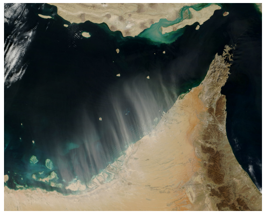
Airborne Dust



dust uplift

settlement

Dust Emission

Dust Deposition

Dust – Climate Interactions

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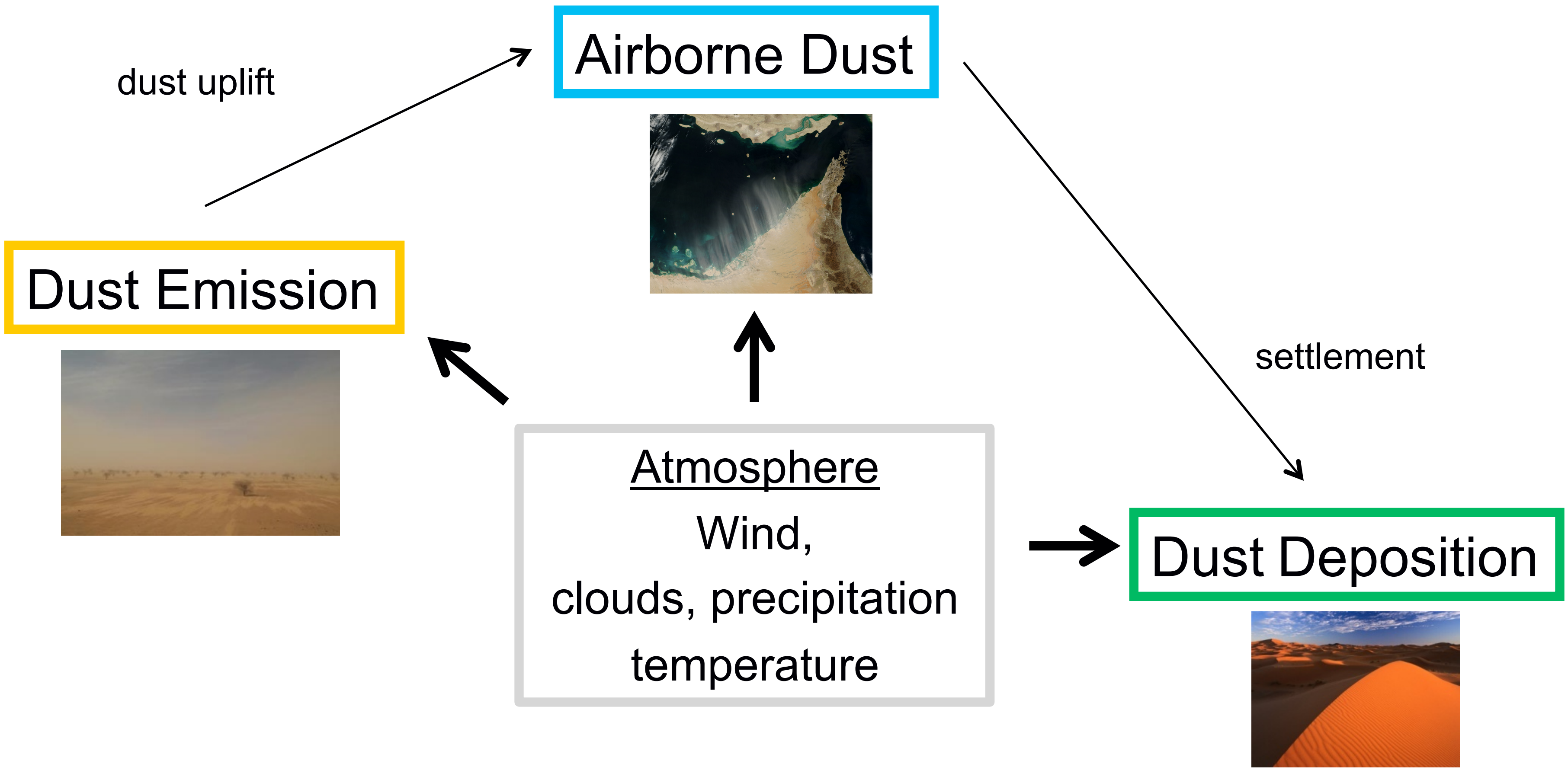

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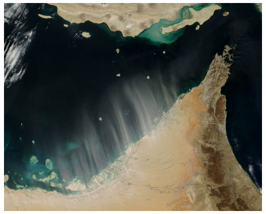
Airborne Dust



dust uplift

Dust Emission

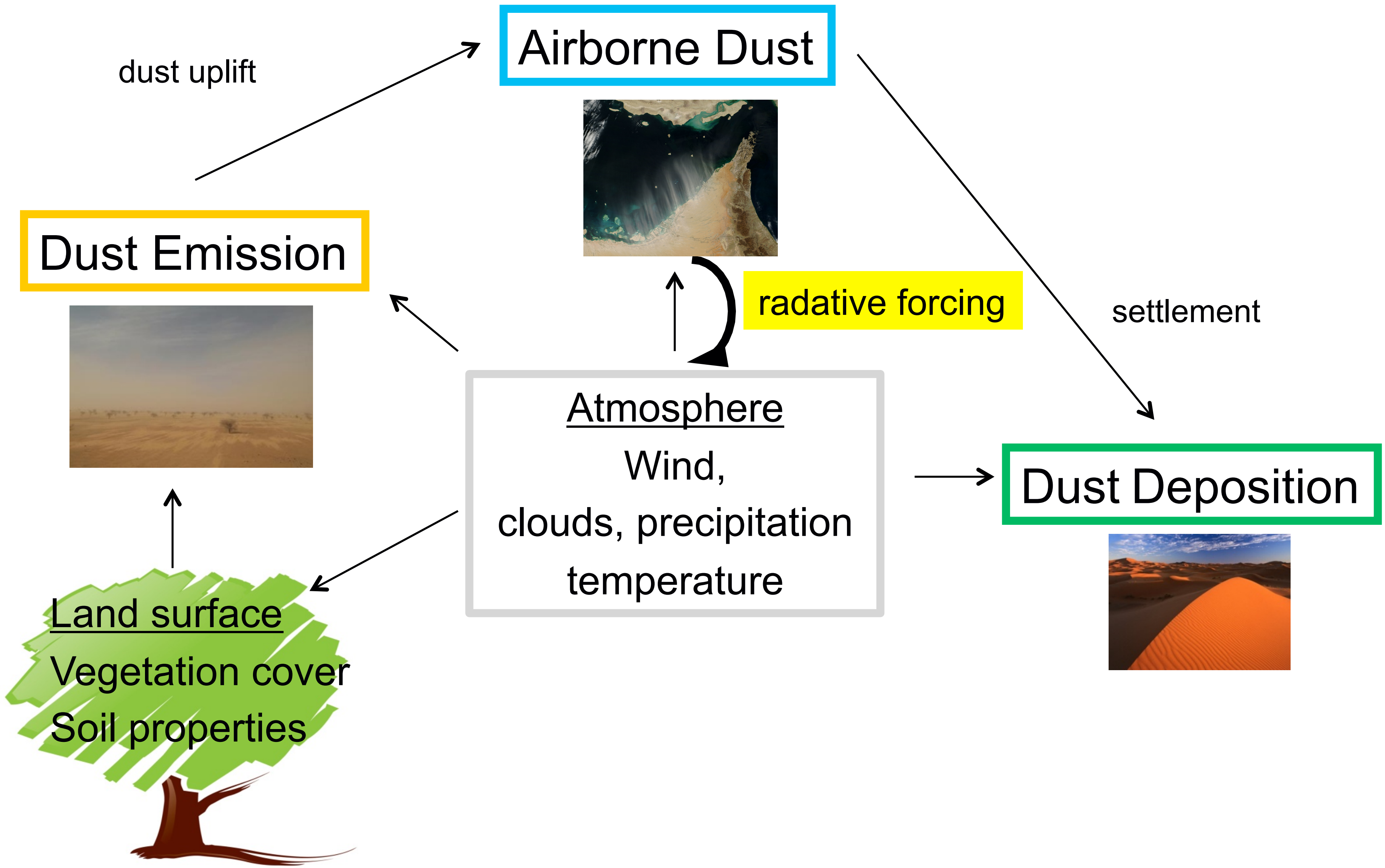
settlement

Atmosphere
Wind,
clouds, precipitation
temperature

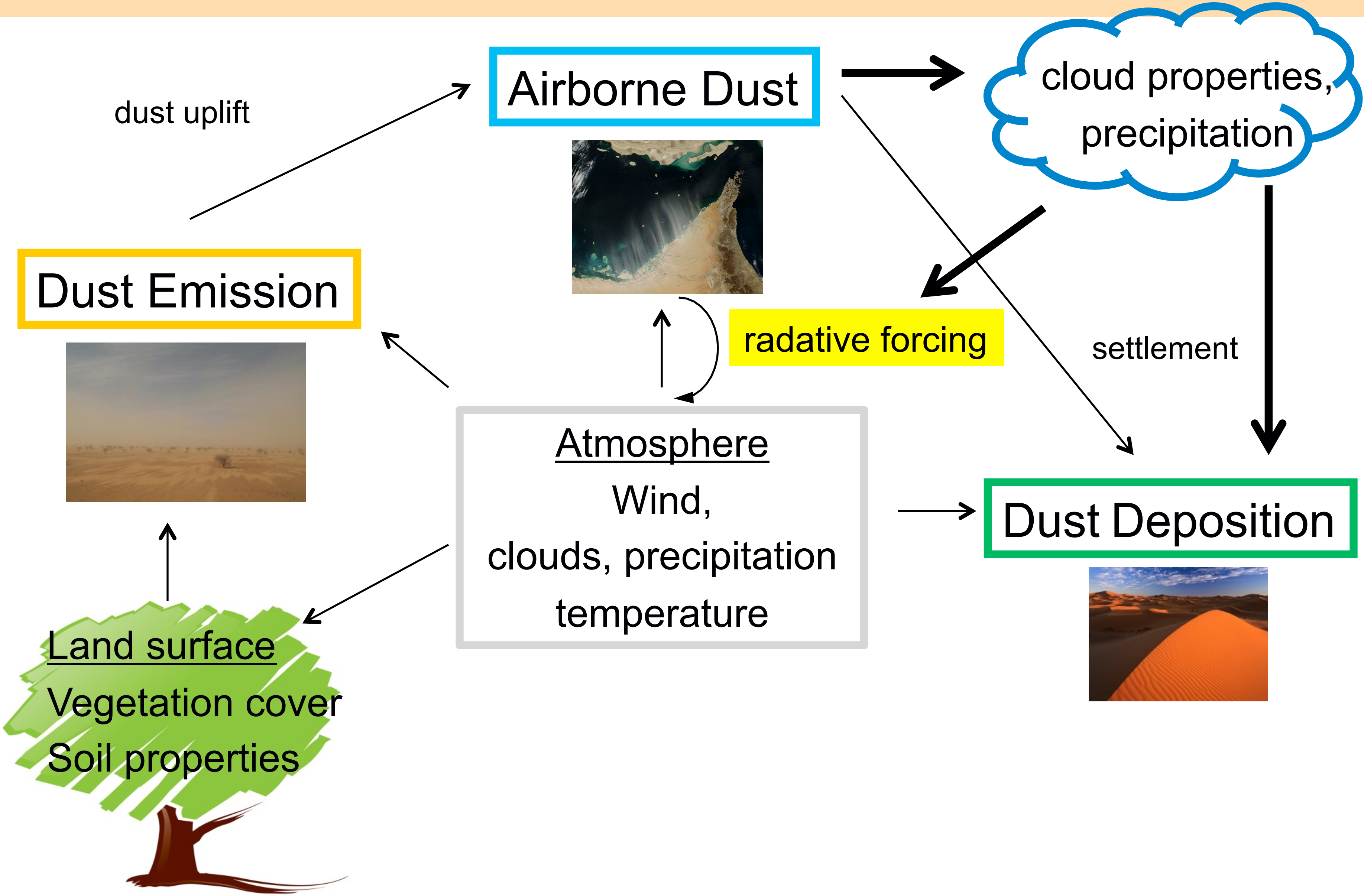
Dust Deposition

Land surface
Vegetation cover
Soil properties

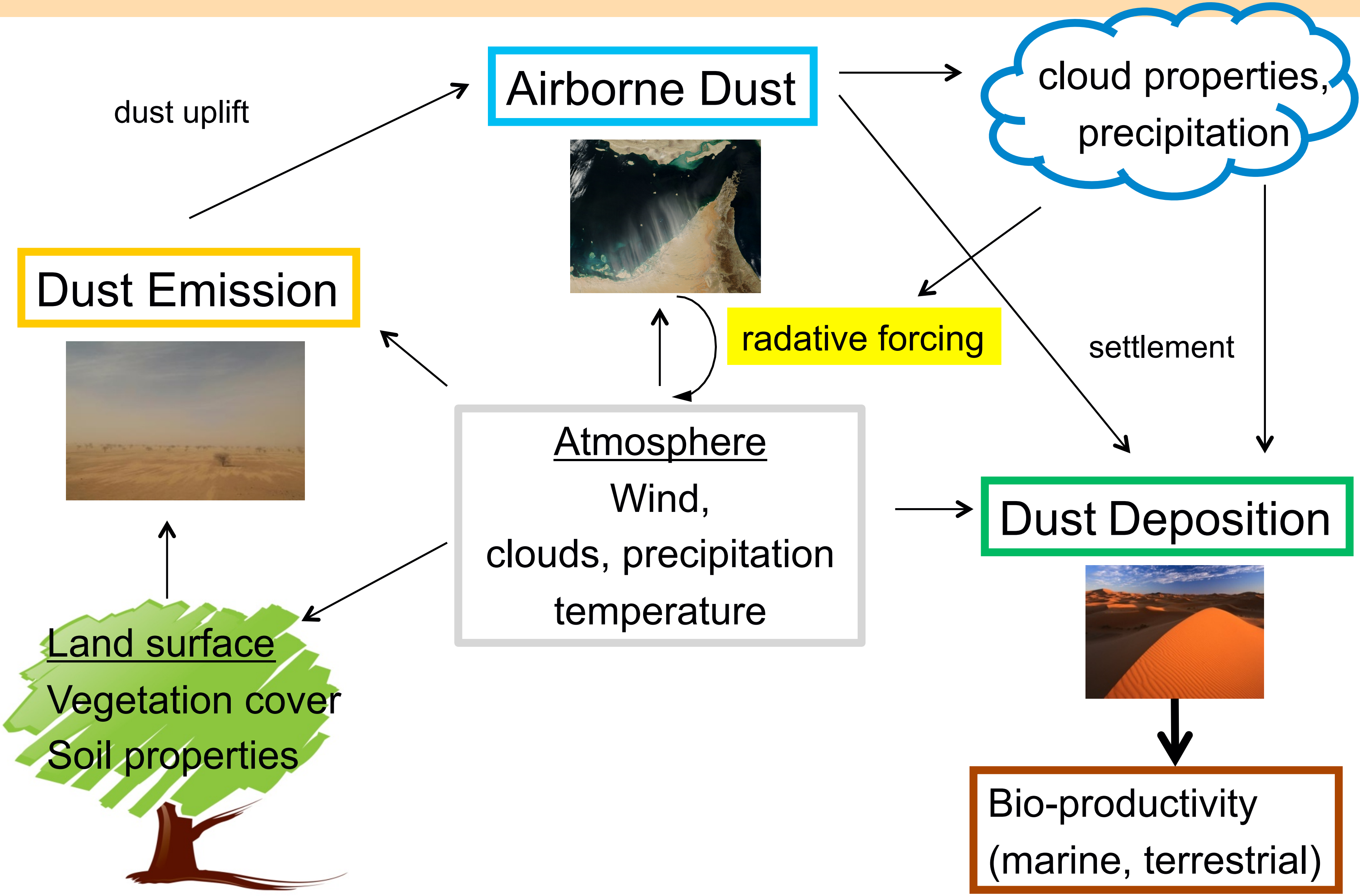
Dust – Climate Interactions



Dust – Climate Interactions



Dust – Climate Interactions



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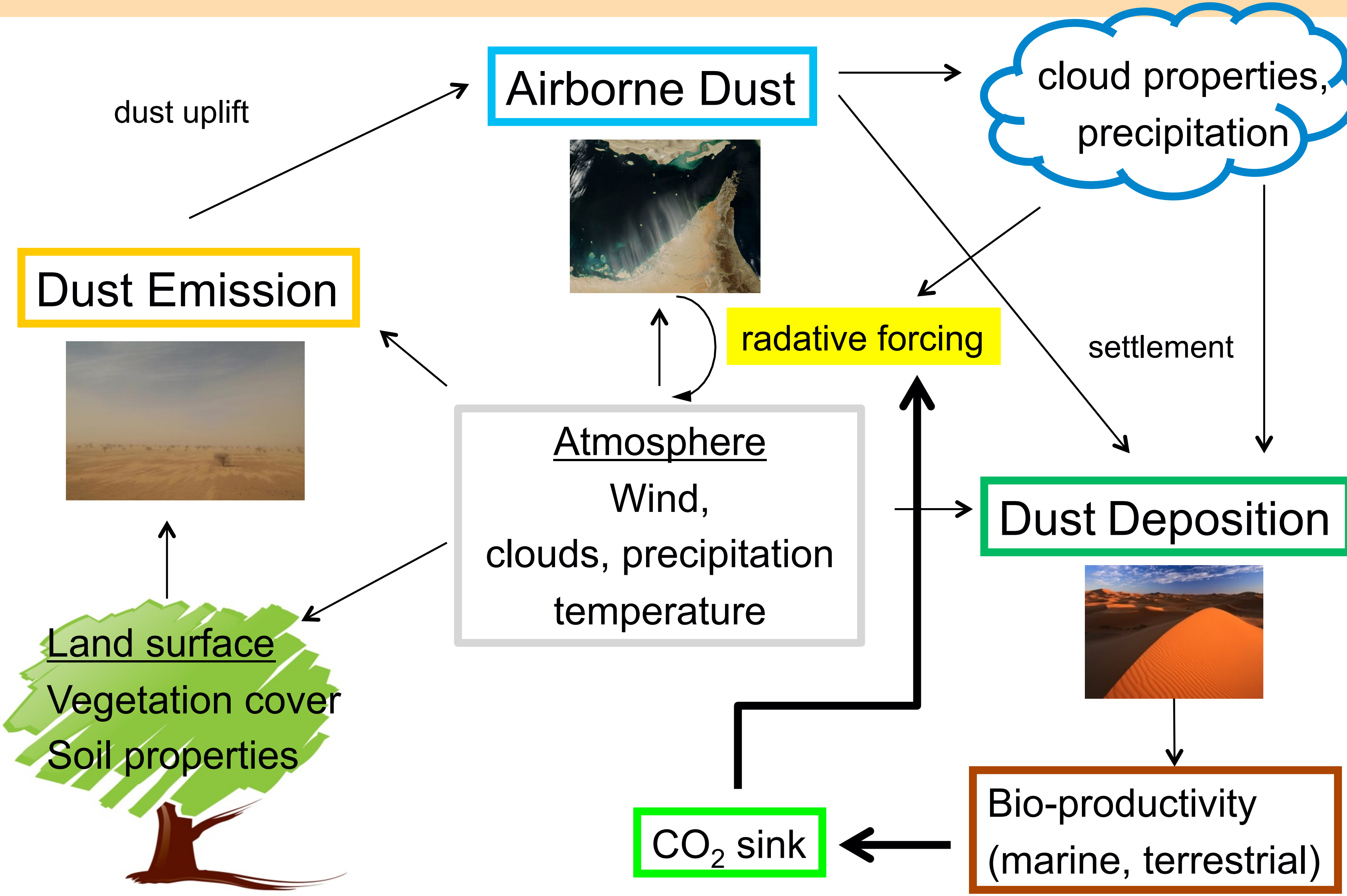

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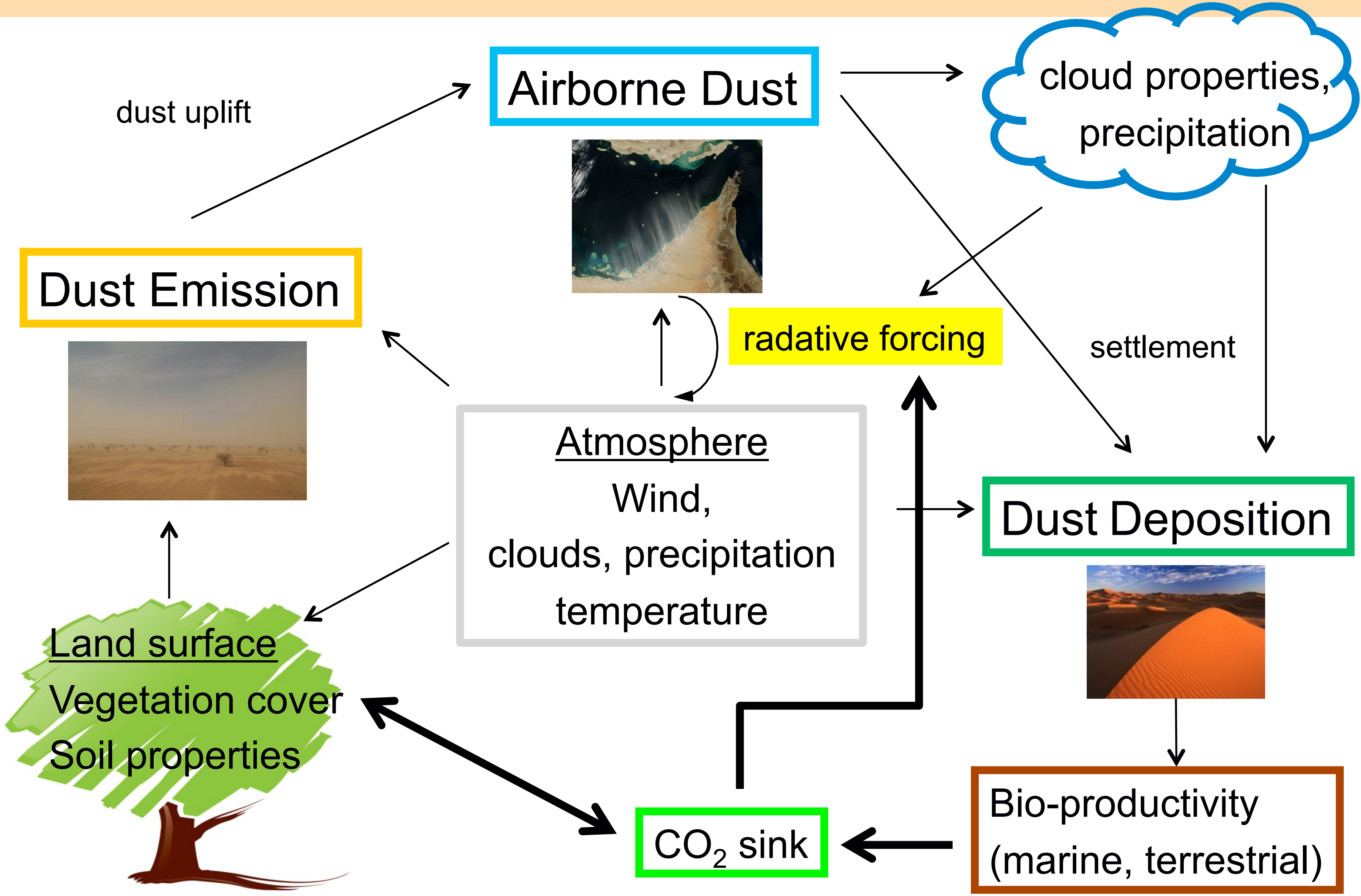

Towards understanding the Role of Dust in Climate Change

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- Describe the amounts and geographic distribution of mineral dust fluxes (models/remote sensing).
- Quantify the direct radiative forcing effects of a realistic dust field and the resulting impacts on climate.
- Assess the impact of increased dust input on marine productivity.

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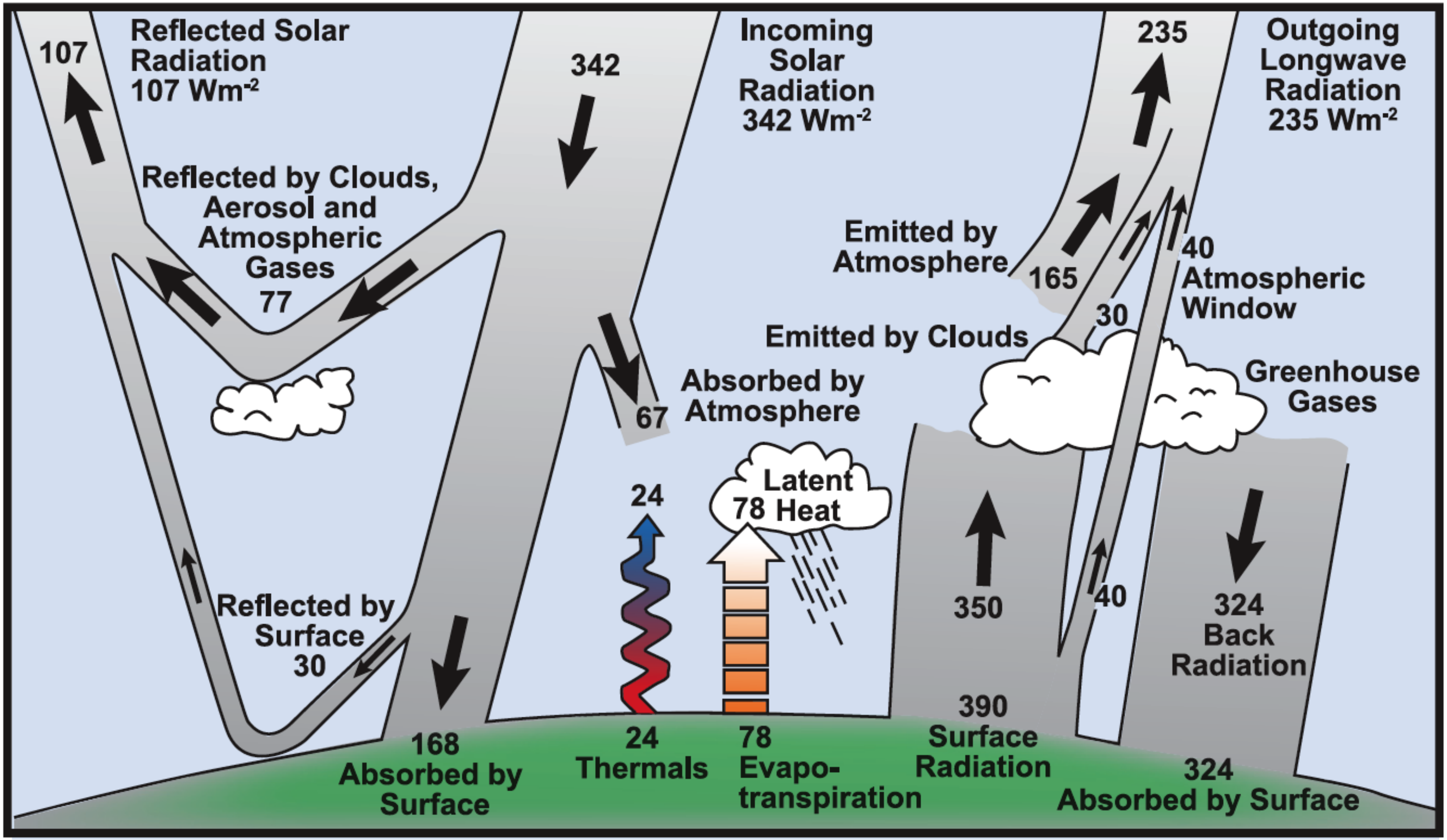
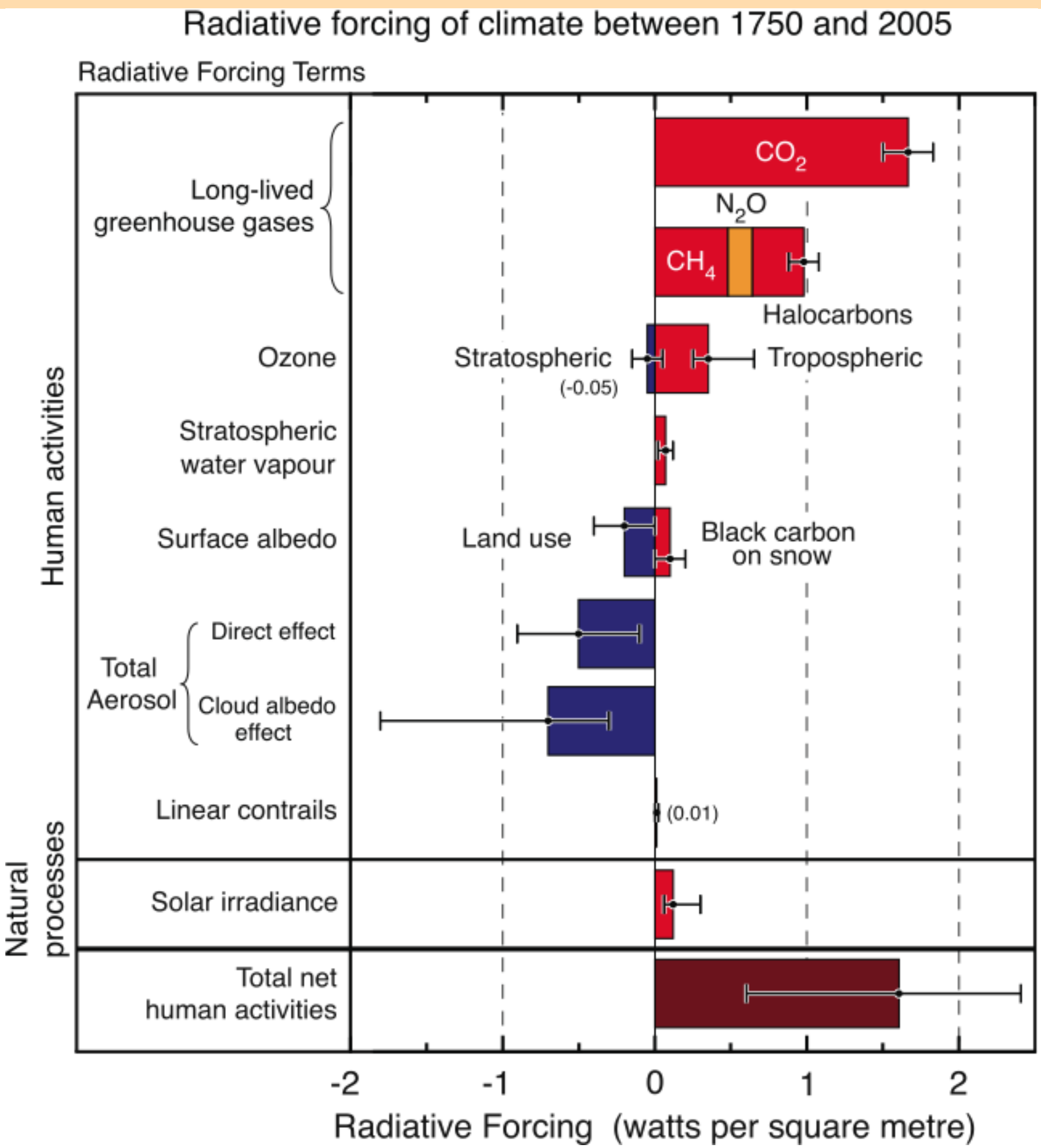
Energy Balance



IPCC report, 2007

Radiative Forcing

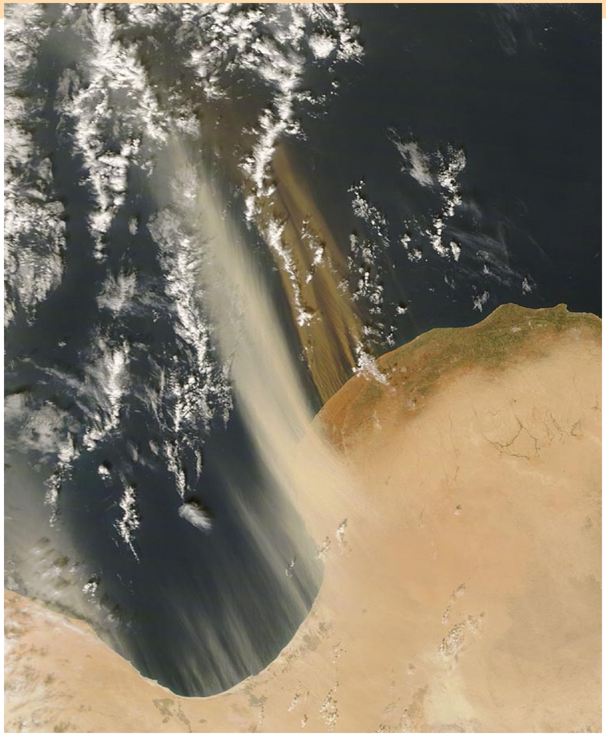


- 'Greenhouse gases' as carbon dioxide warm the atmosphere by efficiently absorbing thermal infrared radiation emitted by the Earth's surface
- Backscattering of incoming sunlight by aerosol particles partly offsets this warming
- Soil dust aerosol is a major part of the atmospheric aerosol load

IPCC report, 2007

Dust Radiative Forcing

- Extinction efficiency
  - ⇨ Light absorption and scattering per particle
- Single scattering albedo
  - ⇨ Ratio of light scattering to light extinction
- Asymmetry parameter
  - ⇨ Fraction of forward scattered light



Parameters depend on **particle size**, **mineralogical composition**, and **particle shape** !

Direct Radiative Forcing

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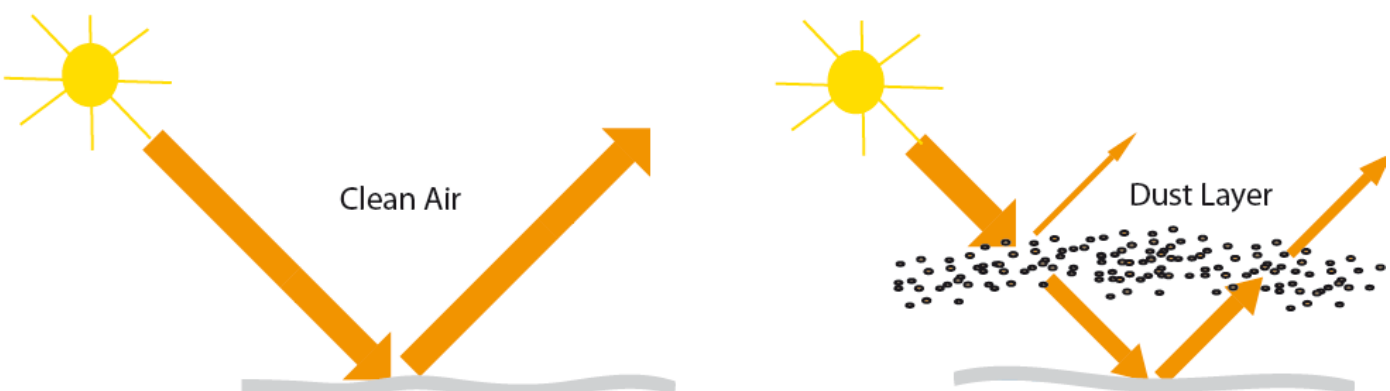
Dust causes increased reflection of sunlight

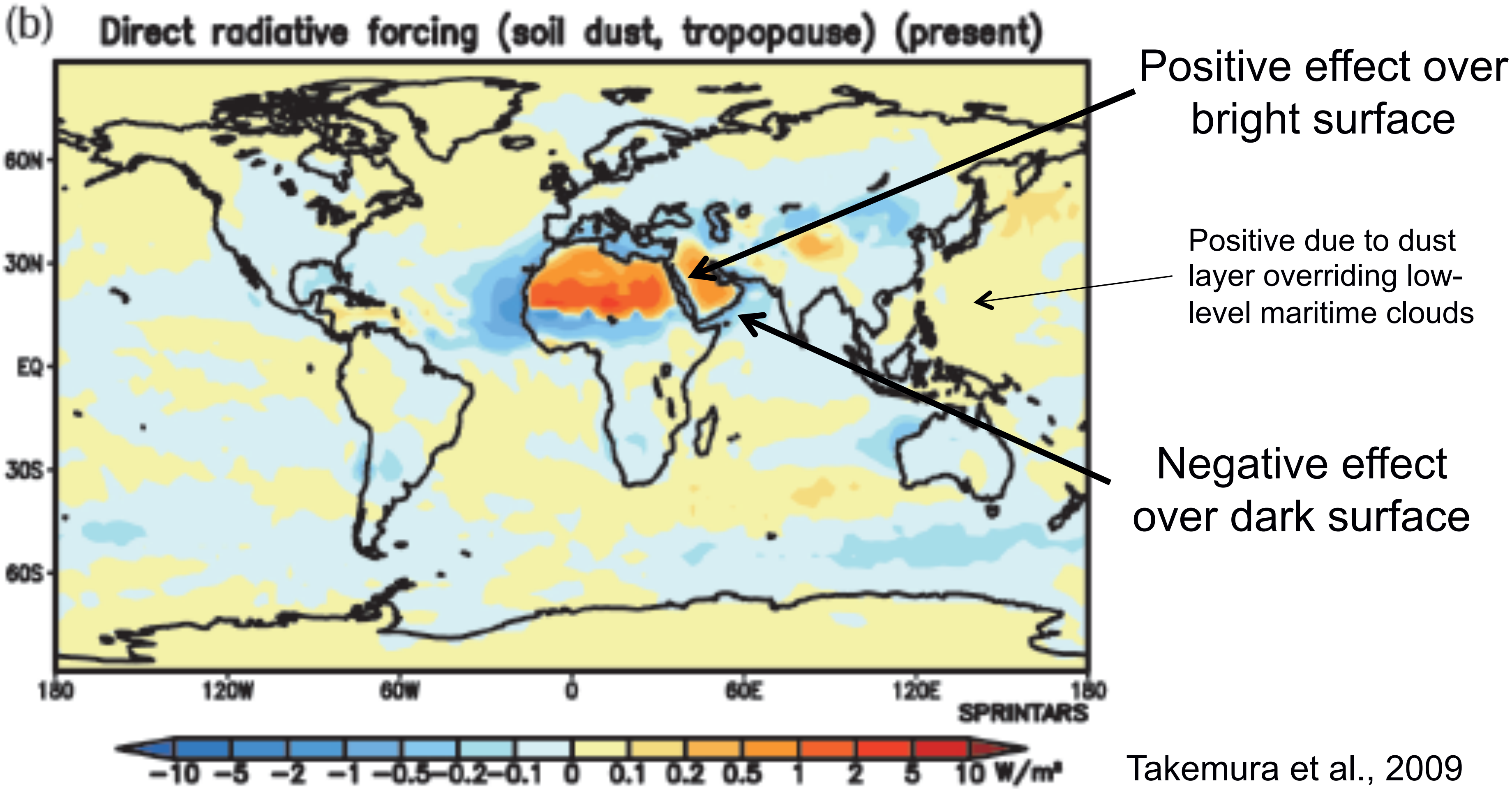
Dark Surface (e.g. Ocean)

Dust causes decreased reflection of sunlight



Bright Surface (e.g. Desert)

Direct Radiative Forcing



Takemura et al., 2009

Direct radiative forcing: difference in radiative budget between including and excluding dust aerosol within the same simulation

Direct Radiative Forcing

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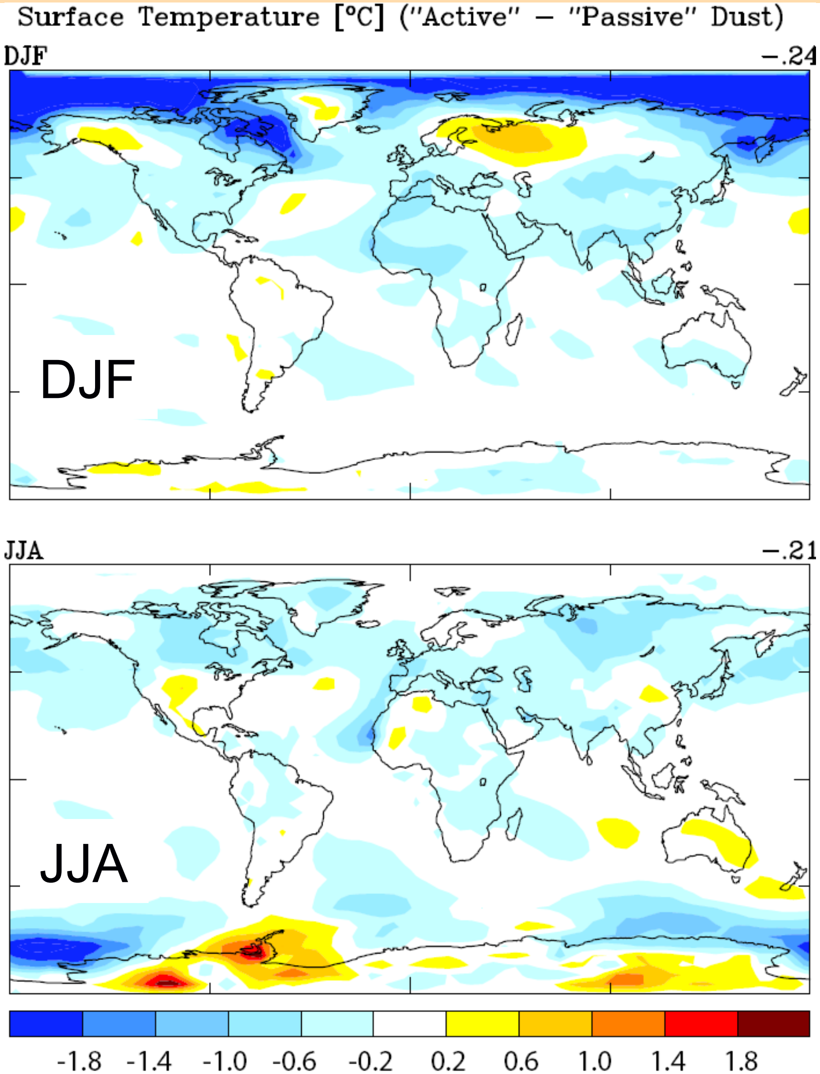


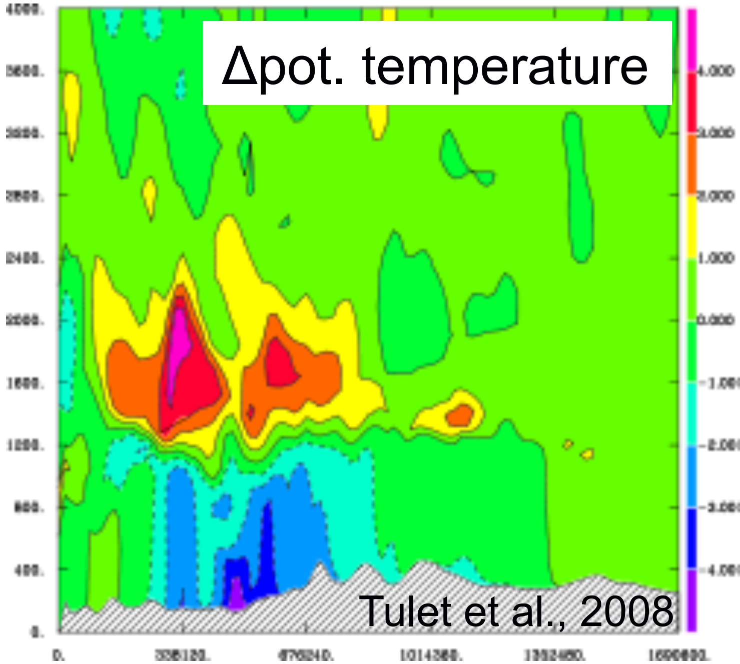
GISS model simulation, I. Tegen

- Change in temperature due to dust
- Negative feedback
  - reduced surface winds
  - enhanced atmospheric stability
  - reduced dust emission
- Replicates dust radiative forcing patterns
- Indicates complex interactions

Dust Radiative Forcing

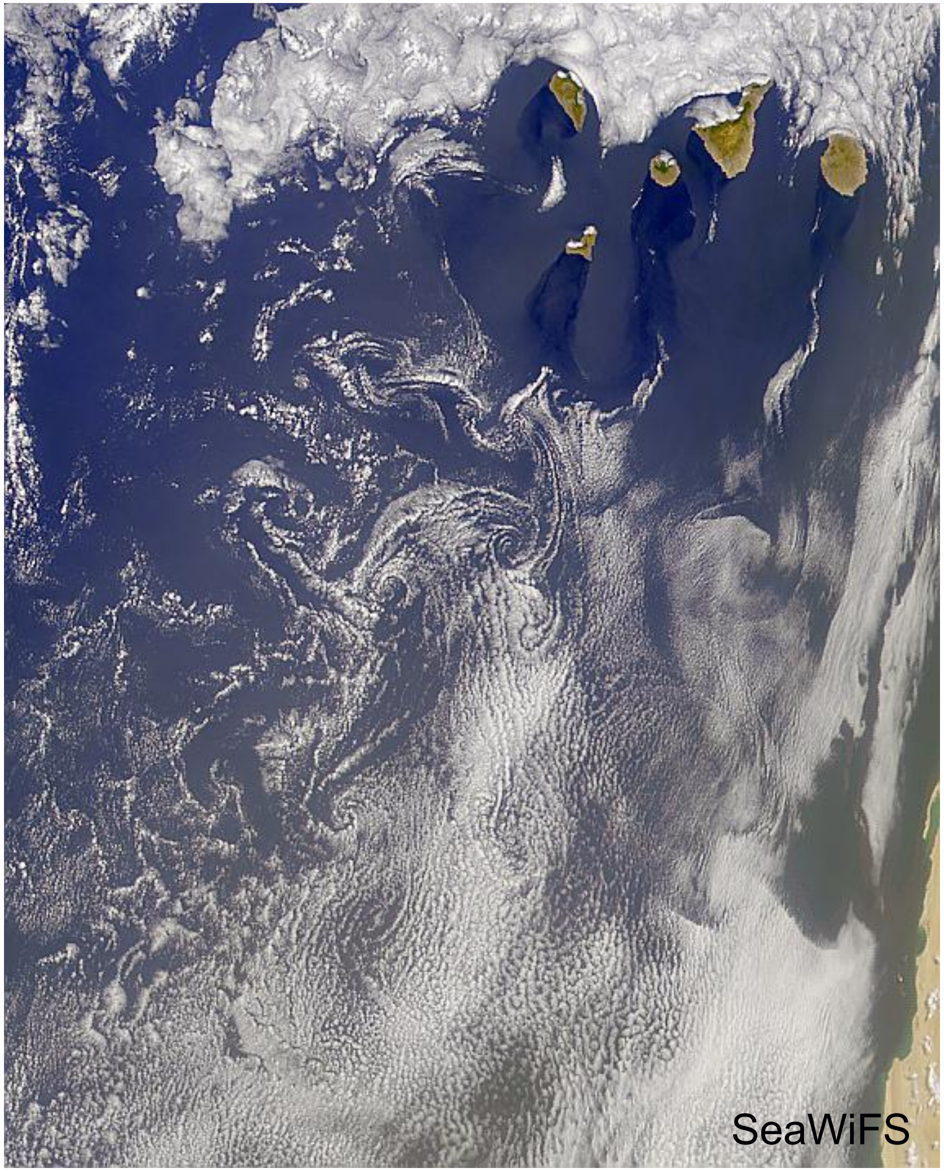
For individual cases:

- Reduction in surface temperature much stronger
  - “Disturbed” diurnal cycle for surface temperature
- Strengthening of Saudi Arabian heat low
  - Dust protects the heat low from its destruction due to cold, northwesterly winds
- Enhanced atmospheric stability
  - “Dust layer as second heat source”
  - Cooling below dust layer
  - Effect on intensity of Somali jet
  - Effect on diurnal cycle of sea breeze



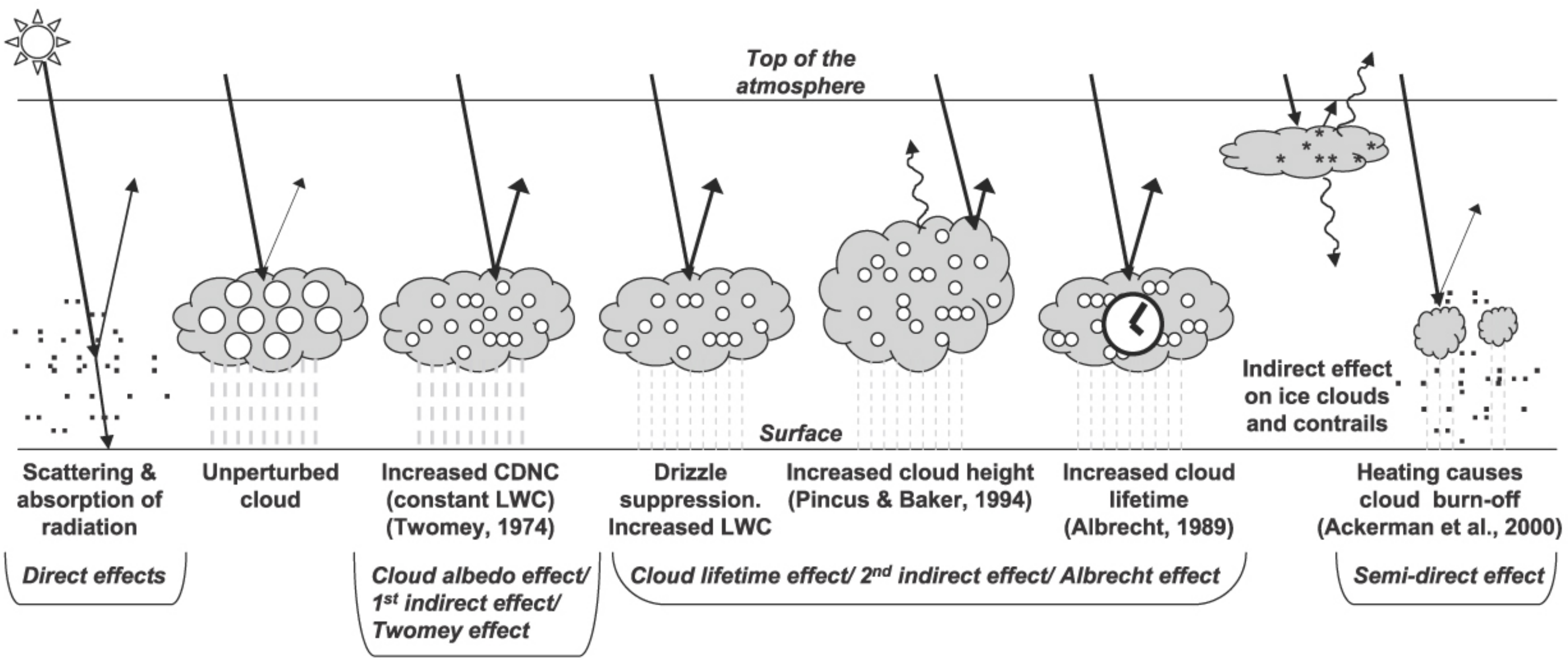
Indirect Dust Effect

- Dust, and aerosol particles at all, can interact with clouds – modify their properties and ultimately their radiative effect
- “polluted” clouds tend to show higher ice-phase particle concentration



Aerosol – Cloud Interactions

Indirect effect: aerosol-cloud effect



IPCC report, 2007

Aerosol Invigoration Effect

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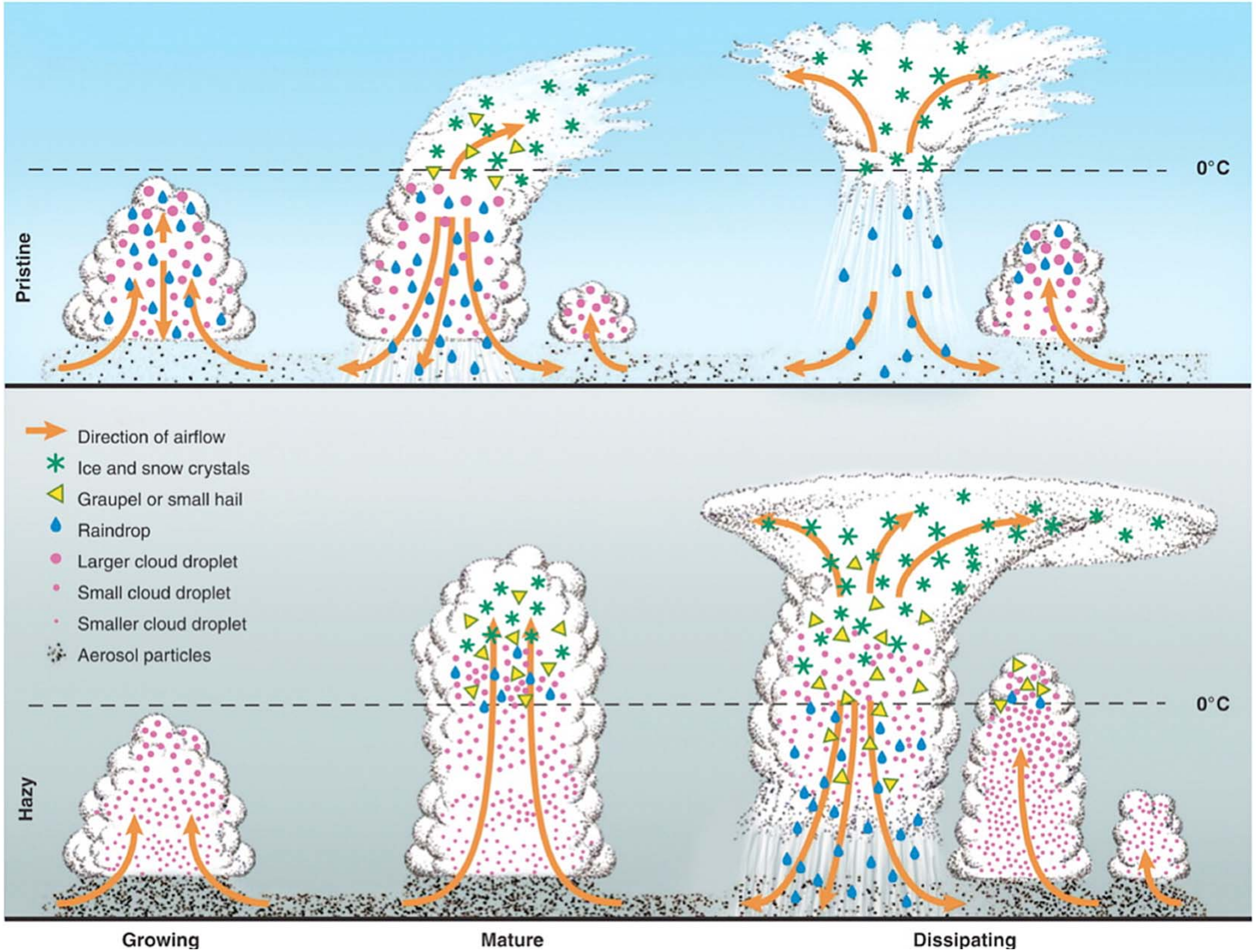
Clean air

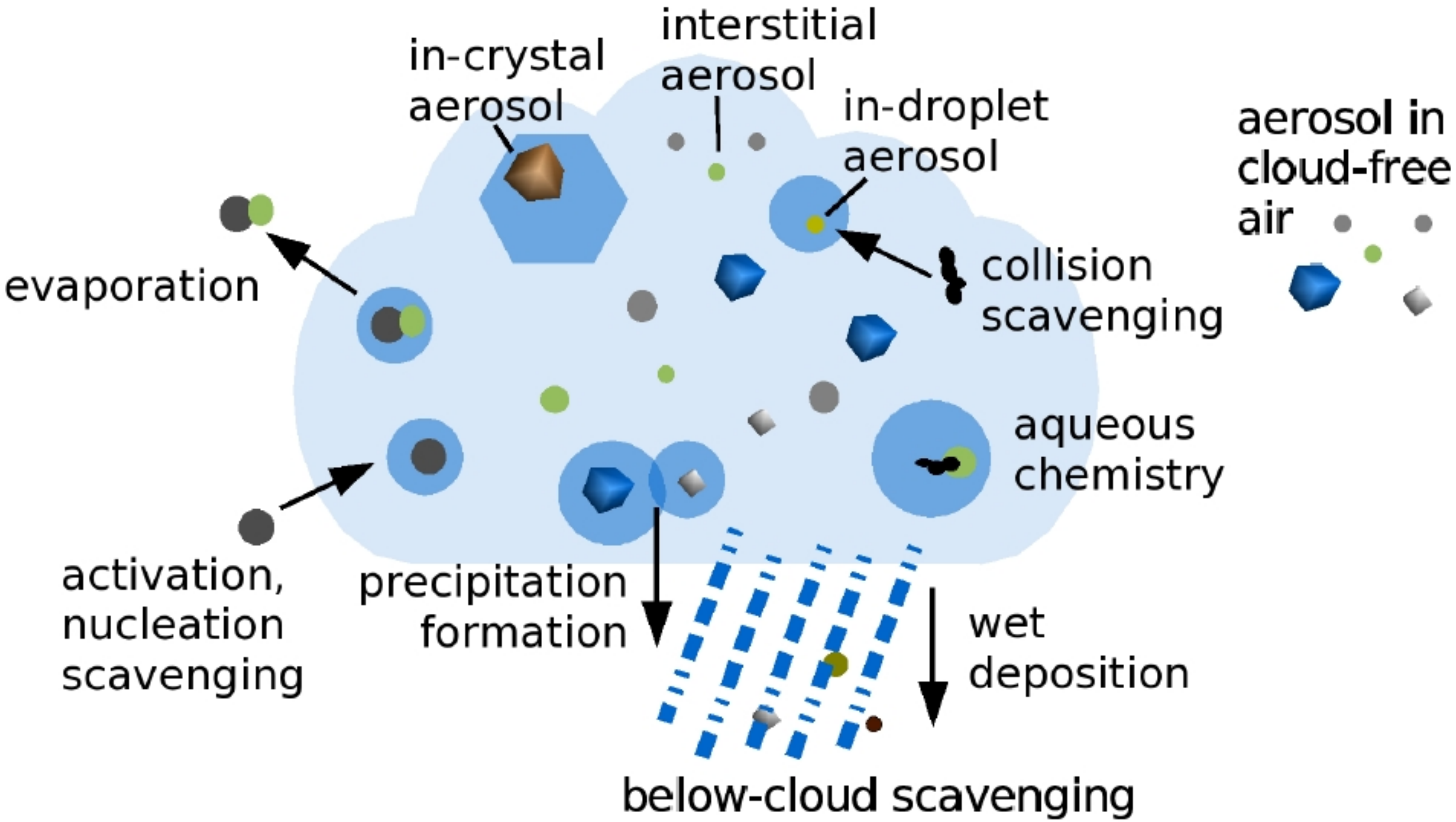
Polluted air



Tao et al., 2012

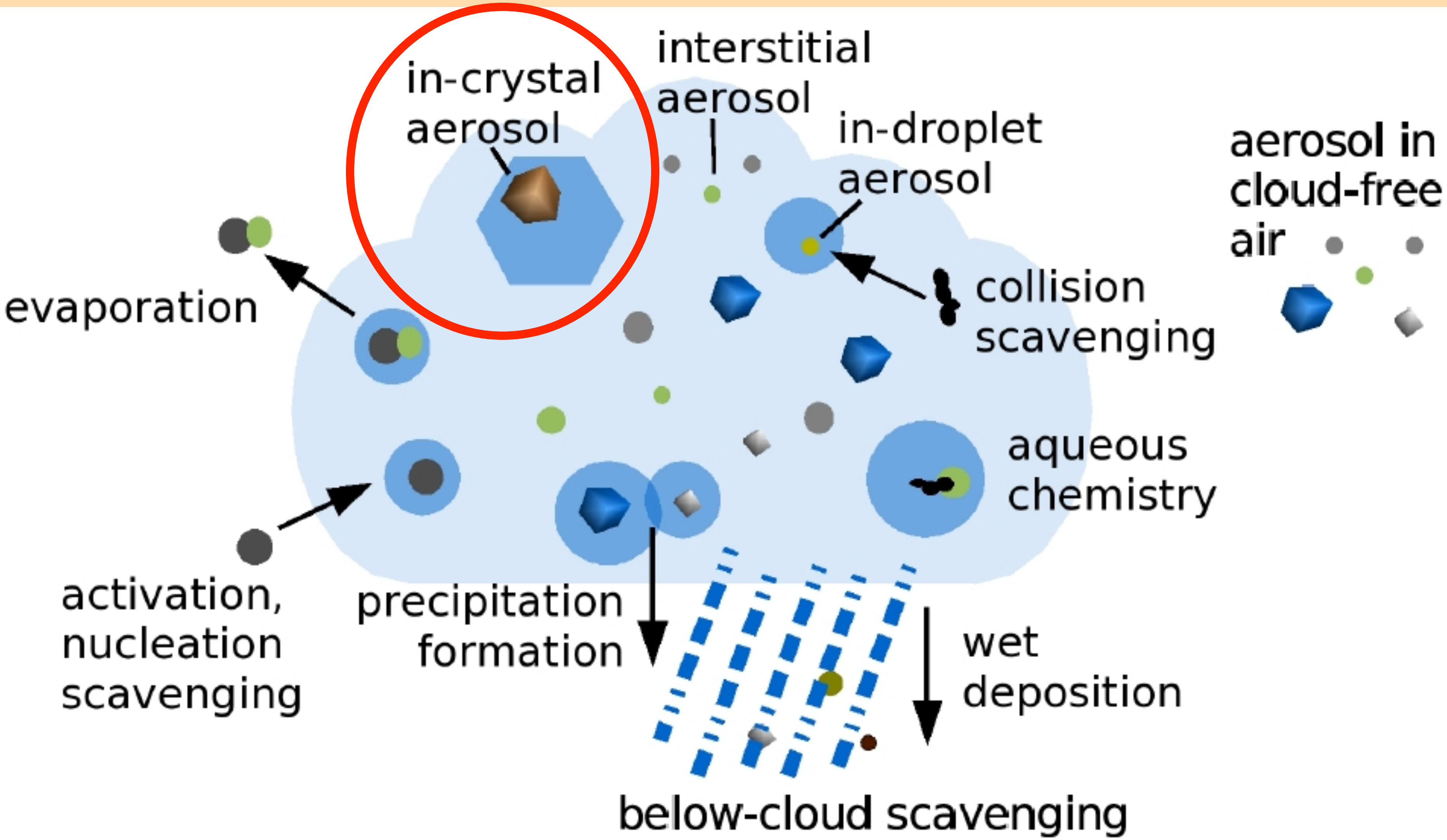
Clouds in polluted atmosphere tend to grow higher and become stronger thunderstorms than it would under pristine conditions.

Aerosol – Cloud Interactions



Hoose et al., 2008

Aerosol – Cloud Interactions



Hoose et al., 2008

Dust triggering Droplet Freezing

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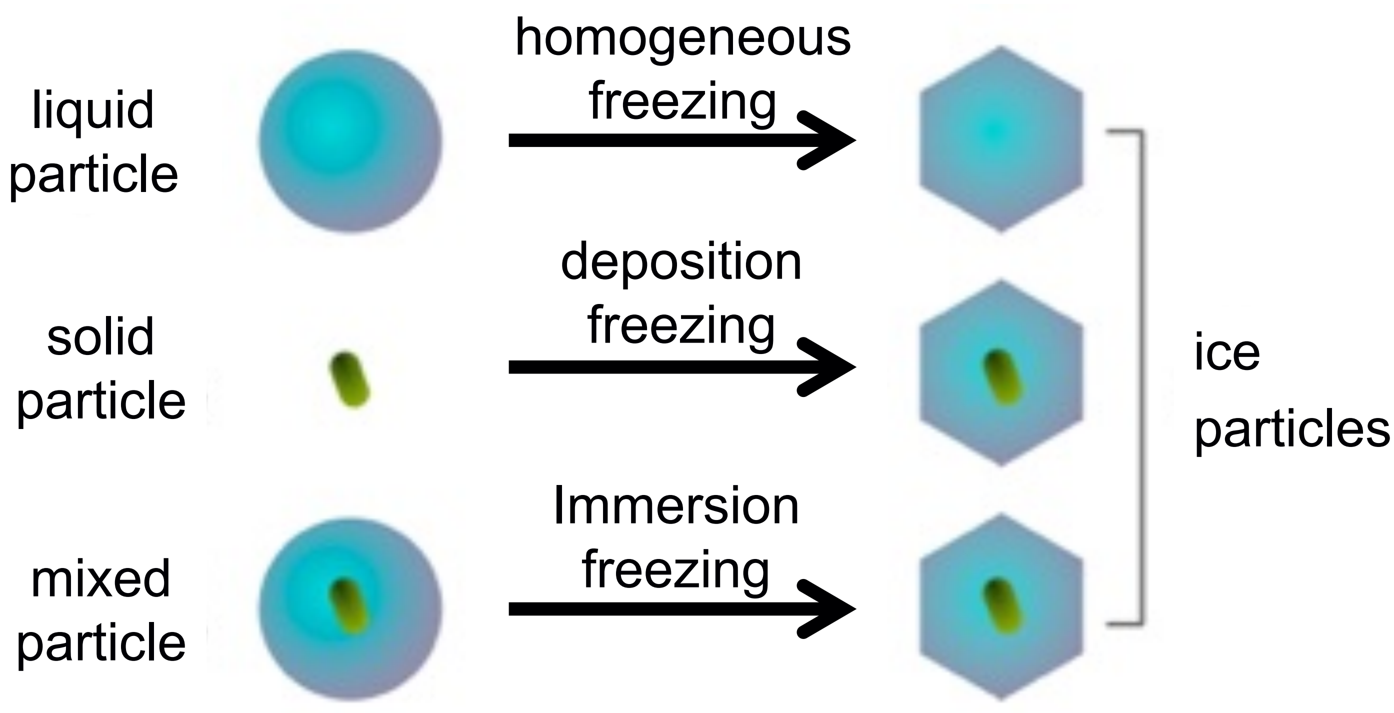
- Droplet freezing at -38°C < T < 0°C
- Main mechanism:



- Importance of indirect dust-cloud effect is still unclear!

image: http://www2.chem.ubc.ca

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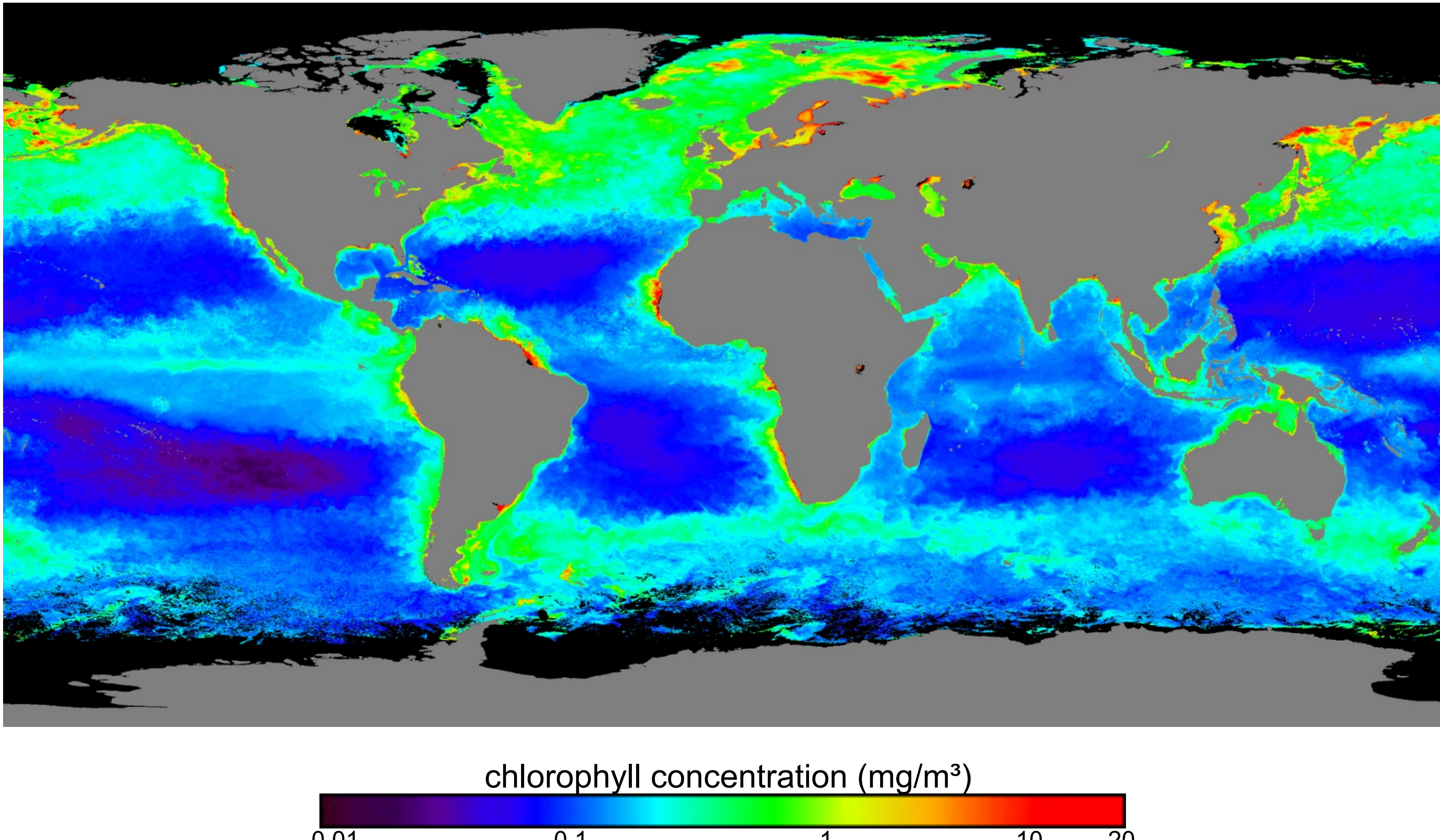
Marine Bio-Productivity: Chlorophyll



http://earthobservatory.nasa.gov

Dust Effect on Marine Ecosystem

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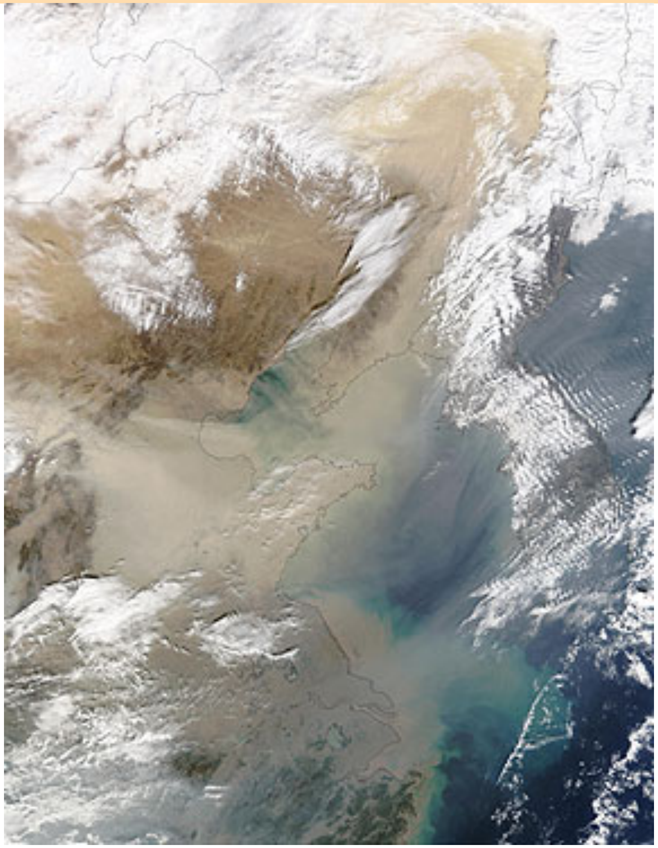
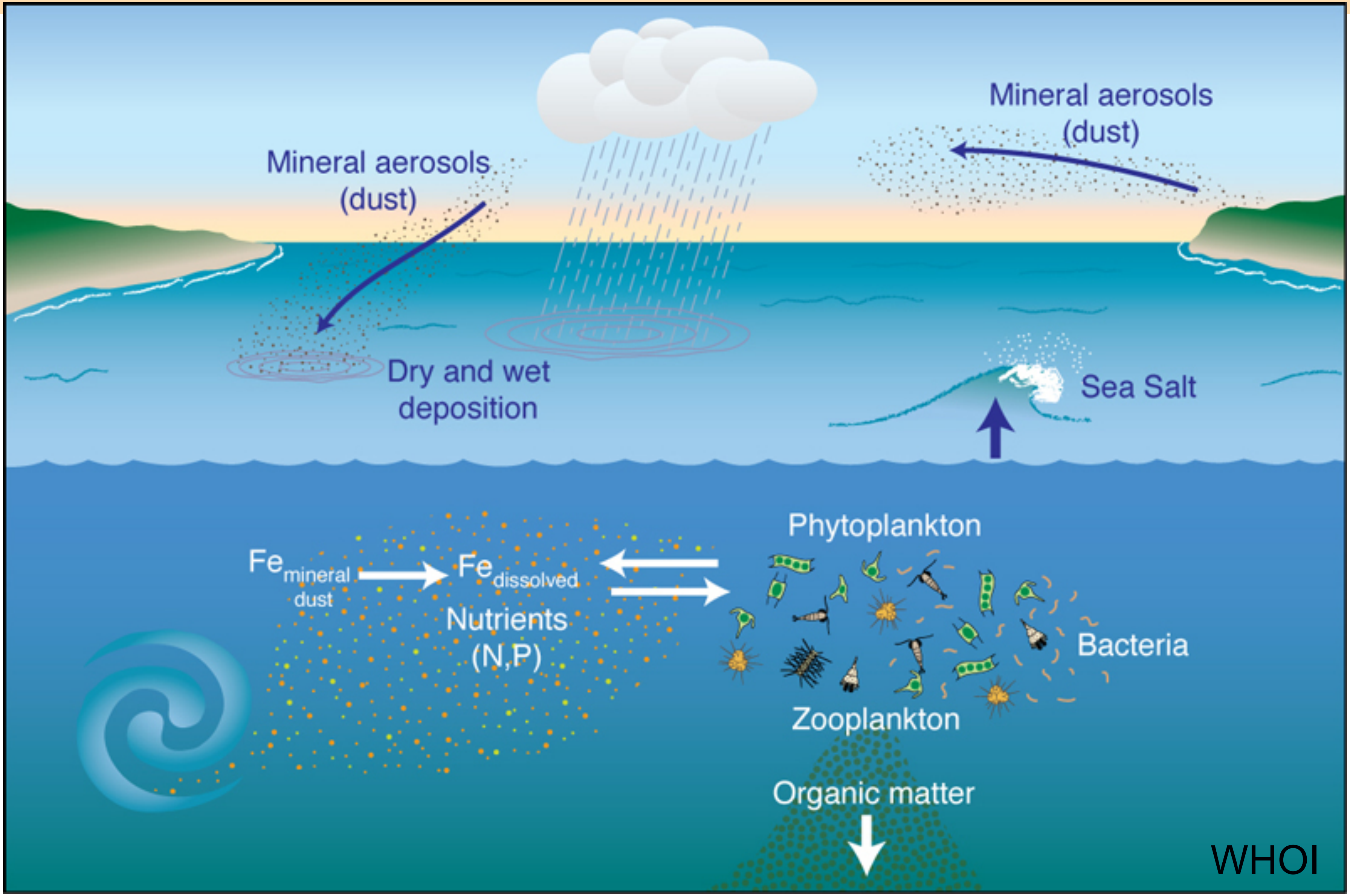
"Iron Hypothesis"

- Even at high levels of nutrients (e.g. Nitrate, phosphate) certain ocean areas show less bio-productivity, i.e. Phytoplankton growth [Martin et al., 1988]
- Iron can be a controlling factor for marine live in high-nutrient low chlorophyll (HNLC) regions
- Iron contained in desert dust blown over ocean regions can contribute to iron supply in such regions, increasing bio-productivity and ultimately Co_2 uptake



NASA

Dust Effect on Marine Ecosystem



Marine Ecology:
Iron Fertilization Experiment

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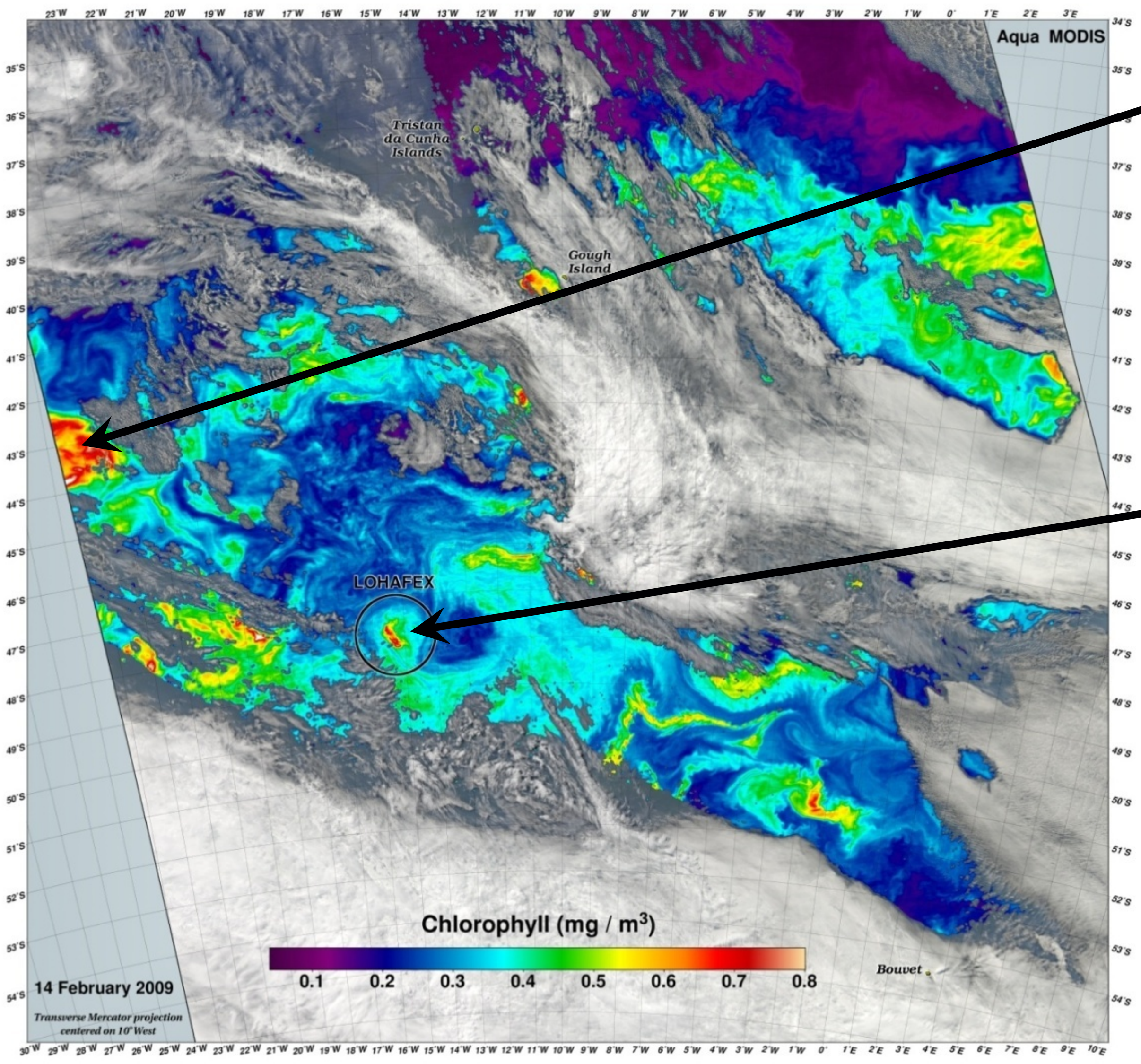

Natural plankton bloom

Plankton bloom after artificial addition of iron (LOHAFEX experiment)

Coral Bleaching

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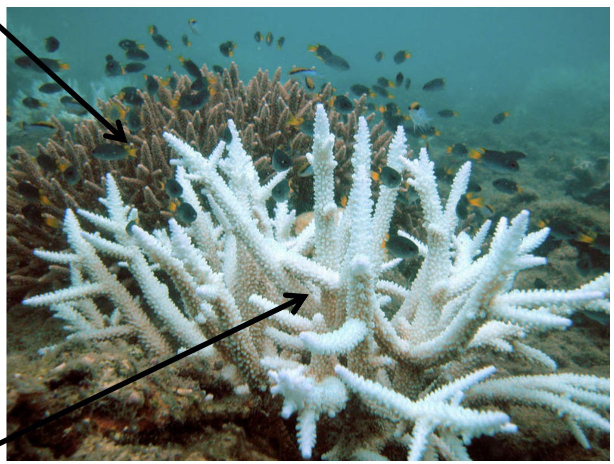
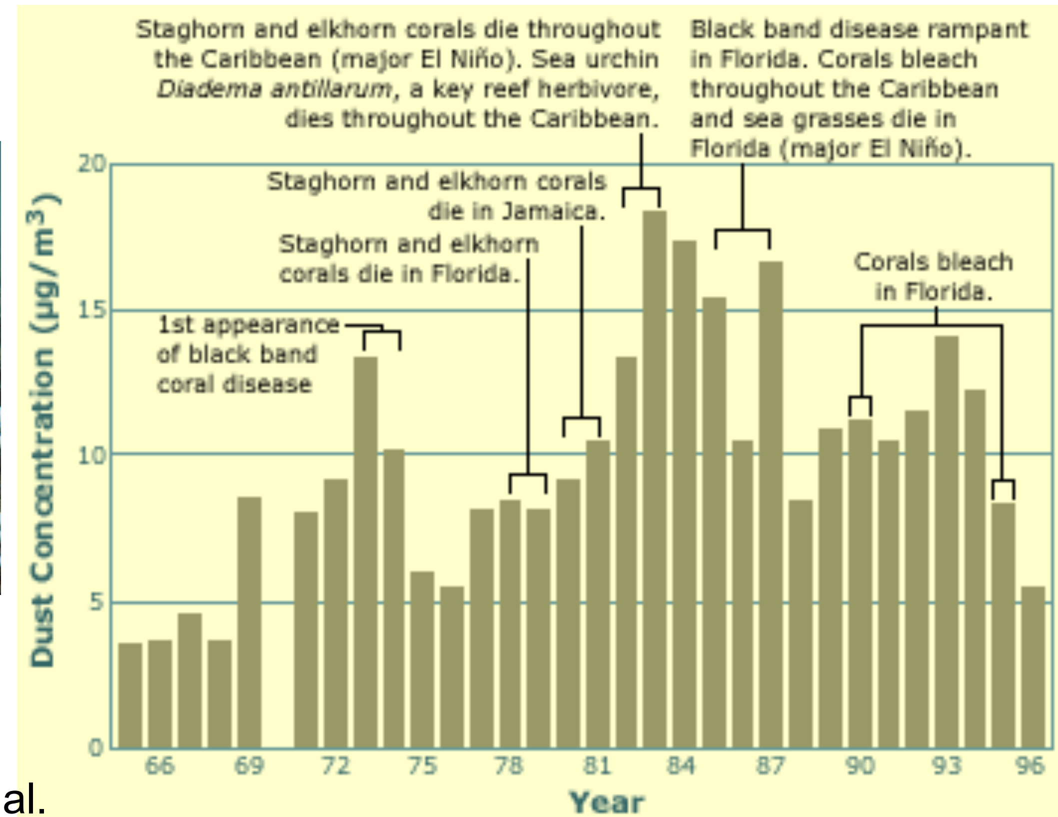
Coral Bleaching: ”loss of intracellular endosymbionts due to expulsion or loss of algal population” [wikipedia]

- Related to pathogens transported on dust [Shinn et al., 2000]

normal branch



bleached branch



http://earthobservatory.nasa.gov, Shinn et al.

Summary

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- Distribution of airborne dust particles depends on atmospheric parameters, such as surface winds, vertical mixing, precipitation, vegetation cover

- Dust, however, impacts on climate in various ways
  - **Direct radiative forcing** by dust leading to surface cooling is its best understood climate effect
  - **Indirect dust effects** on cloud properties or the marine ecosystem are suspected to be important, but remain unquantified so far.