Dust in the anthropocene

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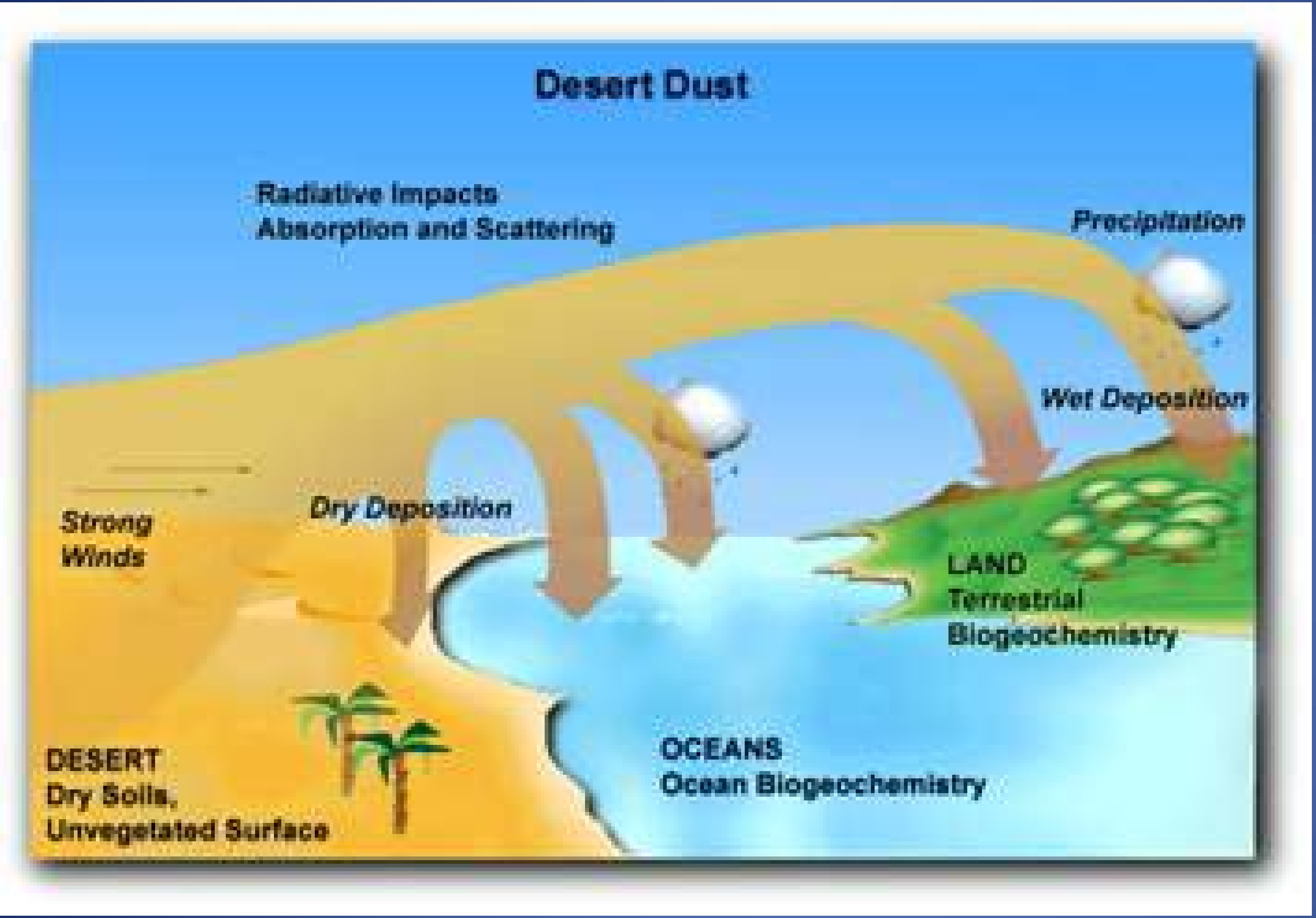
Desert dust has important interactions with climate and biogeochemistr



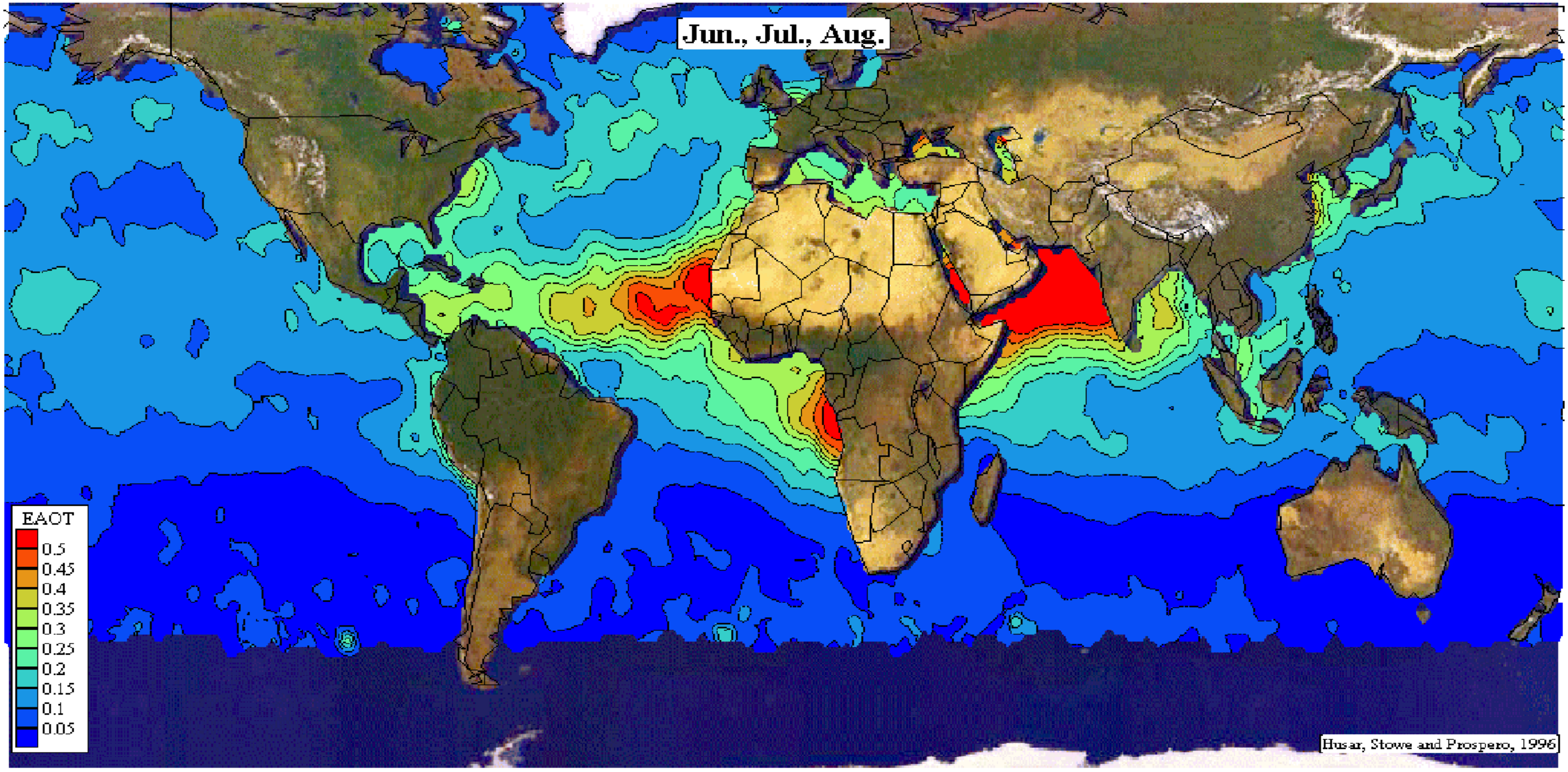
Dust impacts on climate:

1. Interacts directly with short and long wave
2. May change cloud properties

Dust impacts on biogeochemistry:

1. Iron in dust ‘fertilizes’ ocean
2. Phosphorus in dust may ‘fertilize’ tropical rain forests.

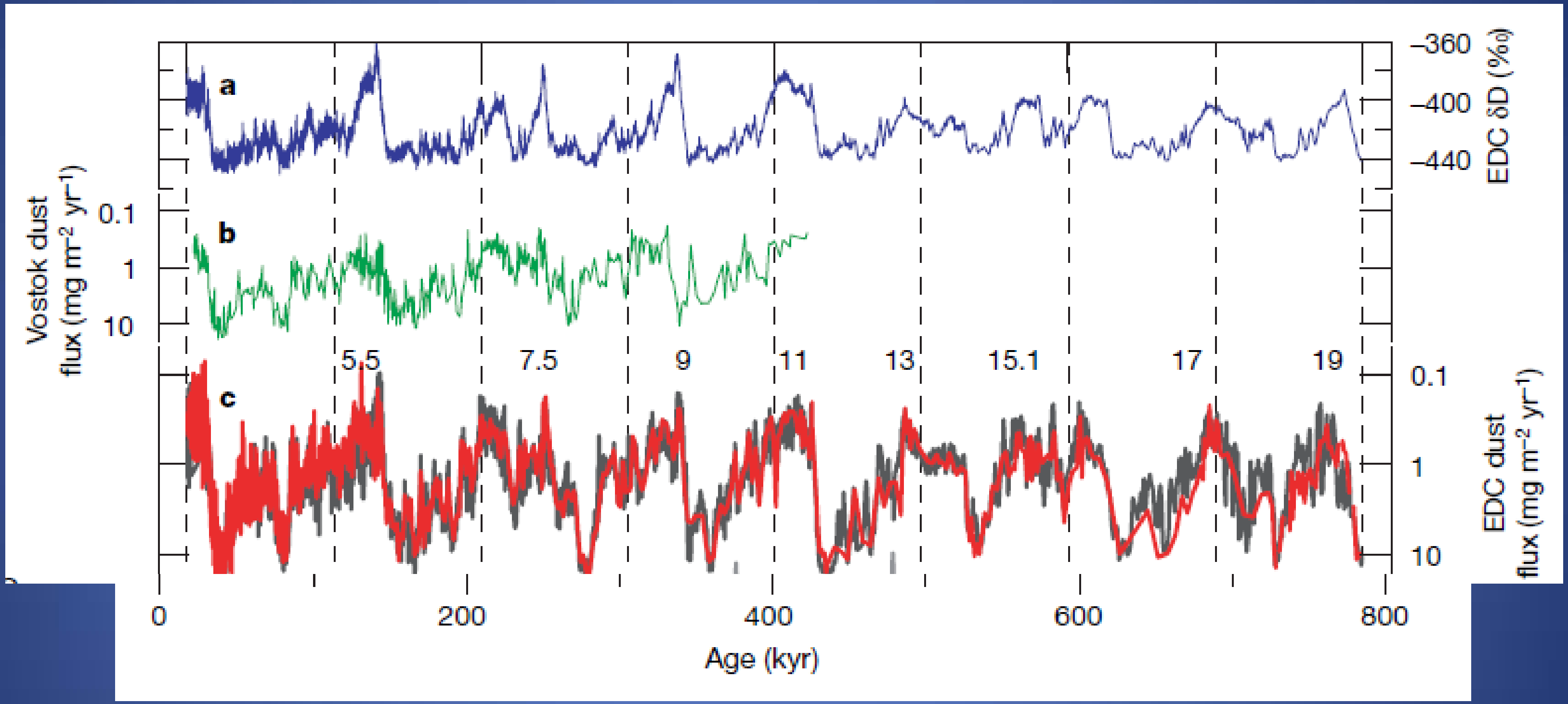
Desert dust/mineral aerosols represent an important aerosol for climate.



There is large glacial-Interglacial variability in dust

T proxy

Dust

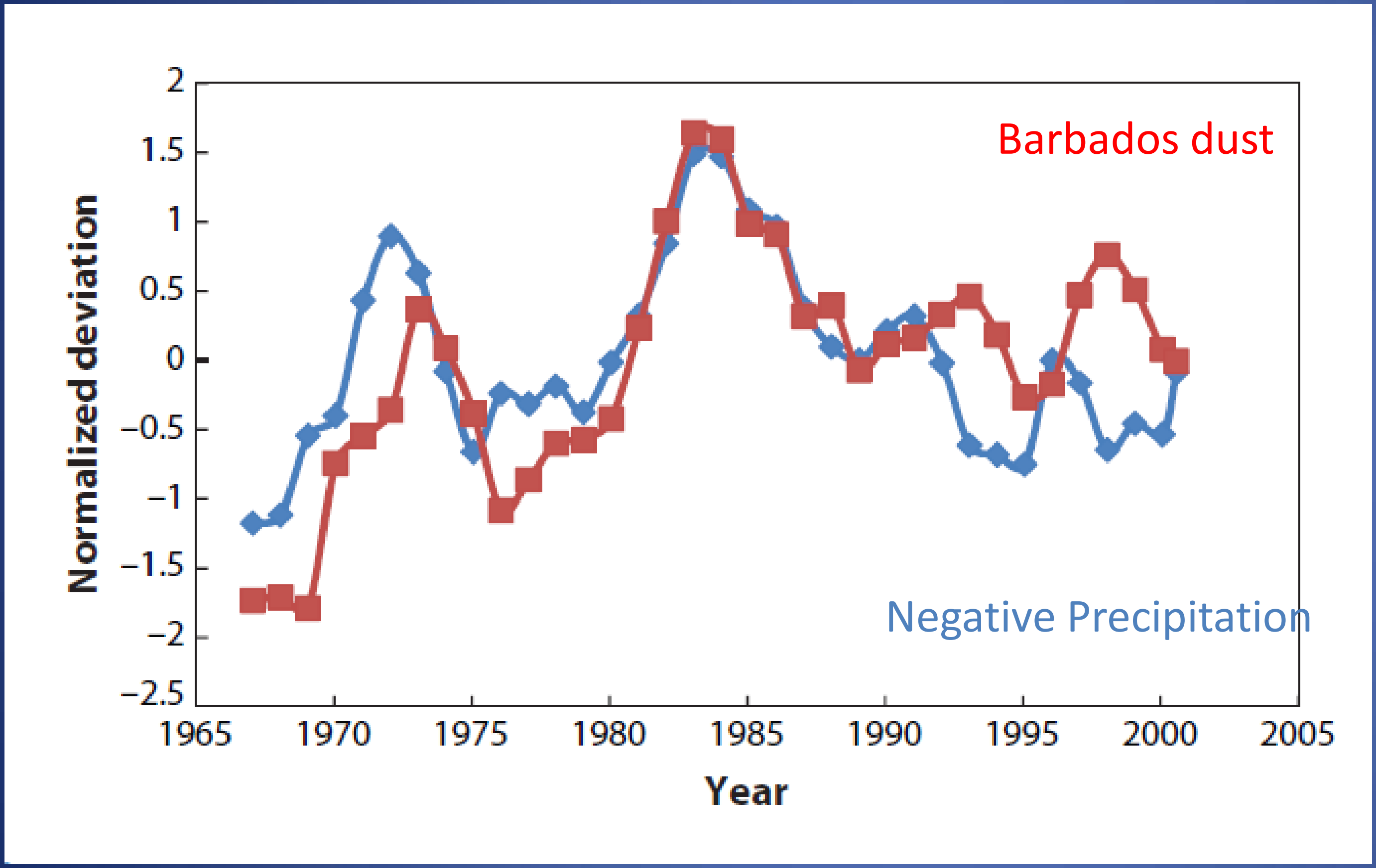


Time (before present) →

Antarctic ice cores (Lambert et al., 2006): Vostock and EPICA DOME C ice cores

Dust changes: factor of 20 dustier in glacial periods than interaglacial at EDC, globally 2-4 fold dustier in glacial periods (Rea, 1995; Mahowald et al., 1999)

North African dust varies by 4x

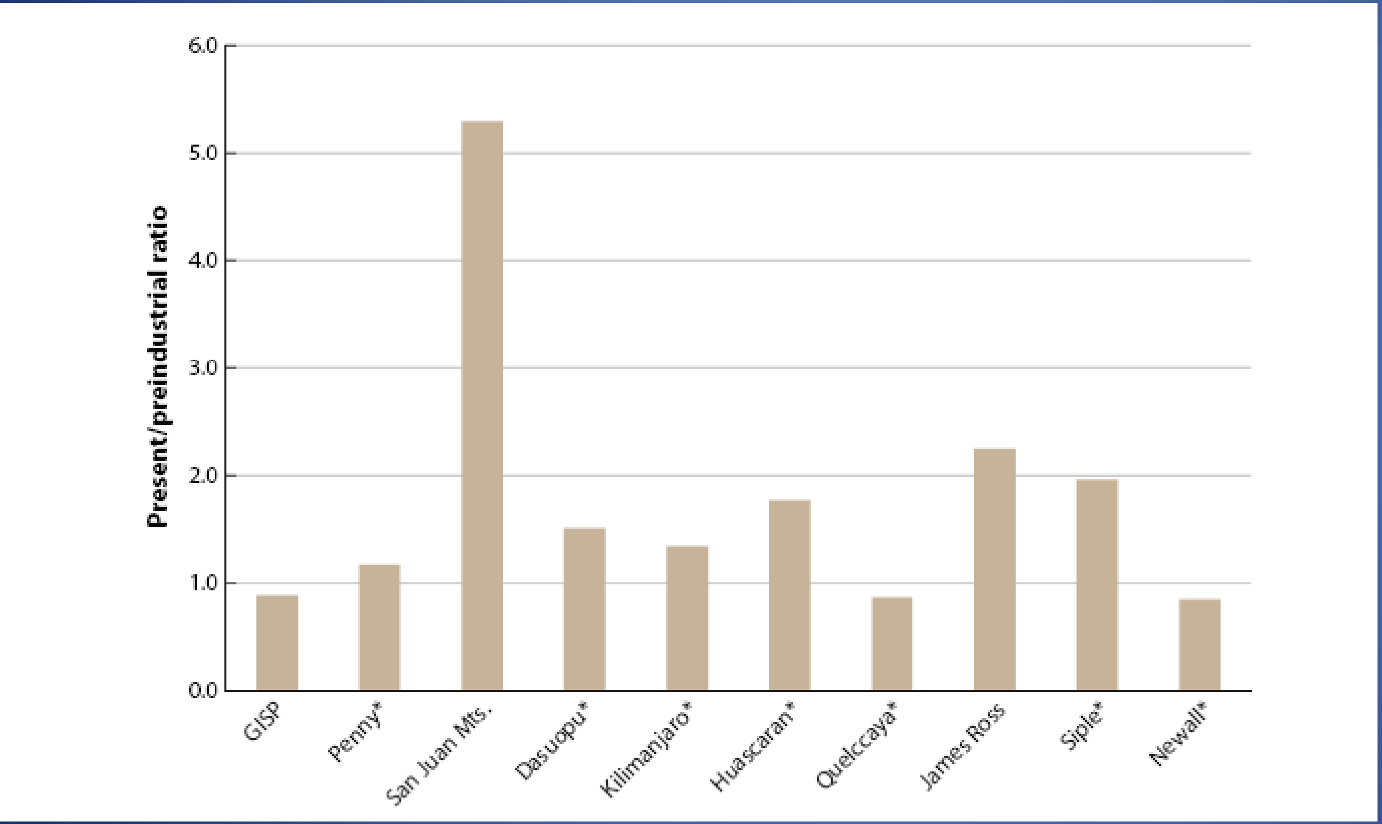


Correlates well with negative Sahel precipitation

(more rain, less dust)

Mahowald et al., 2009:
data from Prospero and Nees, 1986; Prospero and Lamb, 2004; Chen et al., 2002

What is happening over anthropocene?

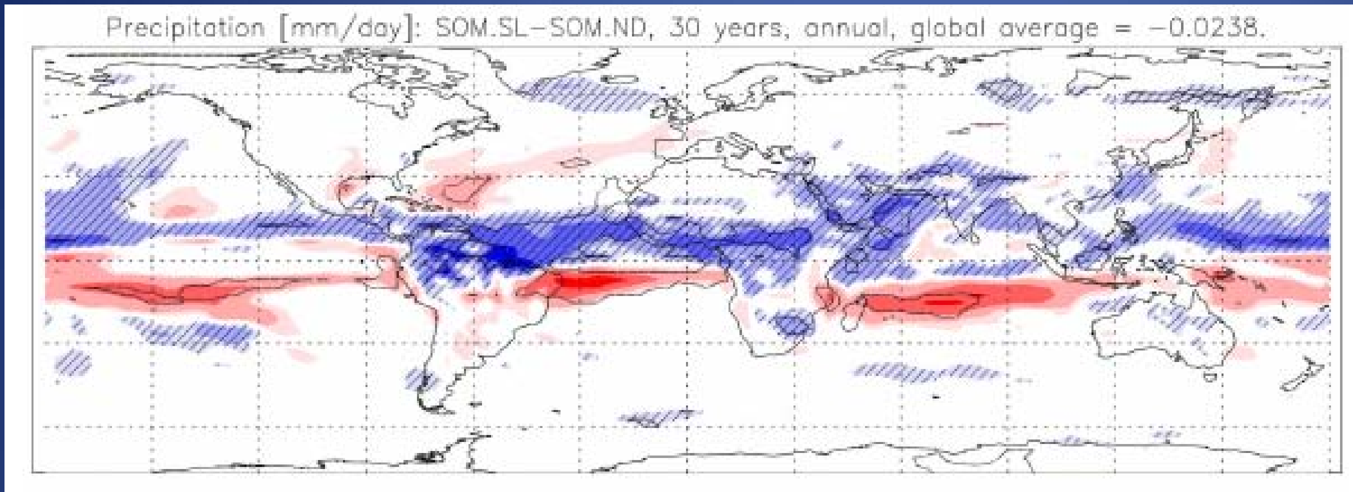


Very few data points for preindusrial to current: signal not clear

Mahowald et al., 2009

How do changes in dust impact climate and biogeochemistry?

Impacts of dust onto climate/precipitation



Dust cools atmosphere and shifts precipitations into Southern Hemisphere

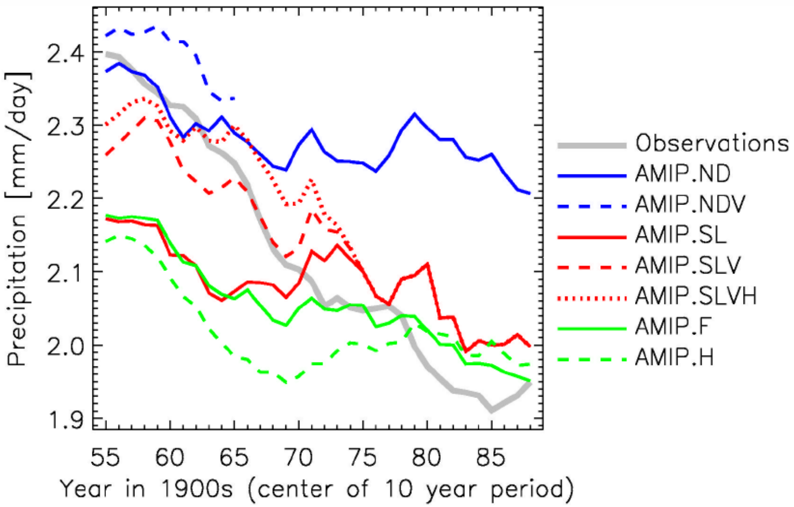


Figure 8. Rainfall trend in the Sahel (10°N–20°N, 18°W–20°E) in observations (gray solid), AMIP.ND (blue solid), AMIP.NDV (blue dashed), AMIP.SL (red solid), AMIP.SLV (red dashed), AMIP.SLVH (red dotted), AMIP.F (green solid), and AMIP.H (green dashed) simulations.
(Precipitation values are 10-year running means. For example, the abscissa value of 55 represents the period from 1951 to 1960.)

Dust impacts on Sahel precip.
- SSTs ~50% of observed precip change
- Vegetation changes Not significant
- Model can't capture dust changes observed, but observed dust changes (when forced onto model) cause ~30% change in observed precip in Sahel

- Dust could be important feedback on Sahel precip

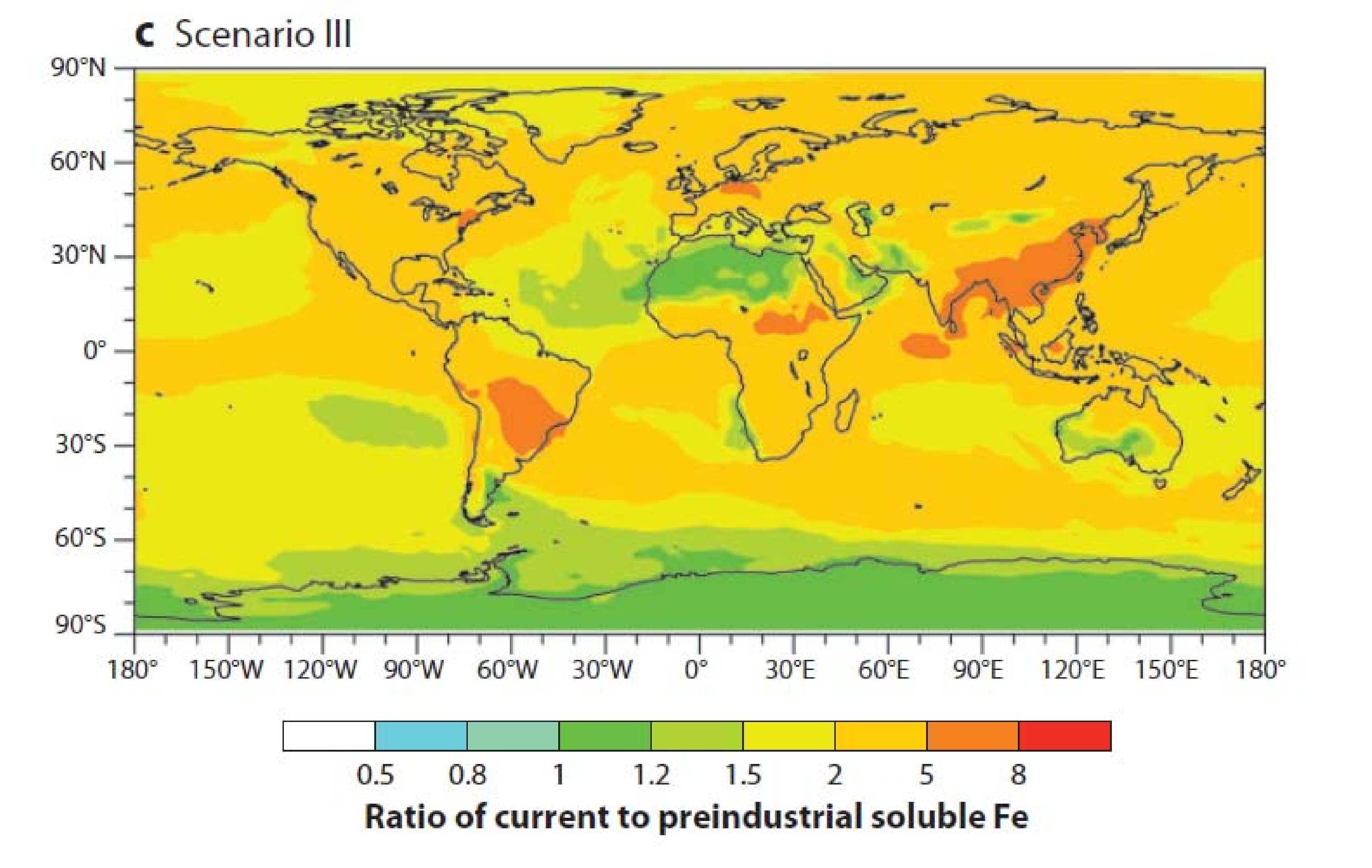
Yoshioka et al., 2007

Iron in oceans

- Iron is a micronutrient (required in small quantities)
- ~3.5 % of crustal material (soils) is iron
- Atmospheric deposition of iron is important source in open ocean
  - High nutrient low chlorophyll regions in the oceans are related to iron limitation (e.g. Martin et al., 1990)
  - LGM was dustier: might be responsible for some of the CO_2 drawdown in the ocean (e.g. Martin et al., 1991)

- Not all iron is bioavailable
  - ~2% iron is bioavailable (e.g. Jickells and Spokes, 2001)
  - Atmospheric processing (e.g. by acids like sulfate) may create more bioavailable iron (e.g. Zhu et al.,1992)
  - Combustion iron is potentially more bioavailable than dust iron (Chuang et al., 2005; Guieu et al., 2005; Sedwick et al., 2006)

Humans may have caused large increase in bioavailable iron deposition



- Model estimate in current to preindustrial soluble iron due to increased atmospheric acidity (sulfate) and combustion iron sources (from Mahowald et al., 2009)
- Assumes no change in dust deposition amounts

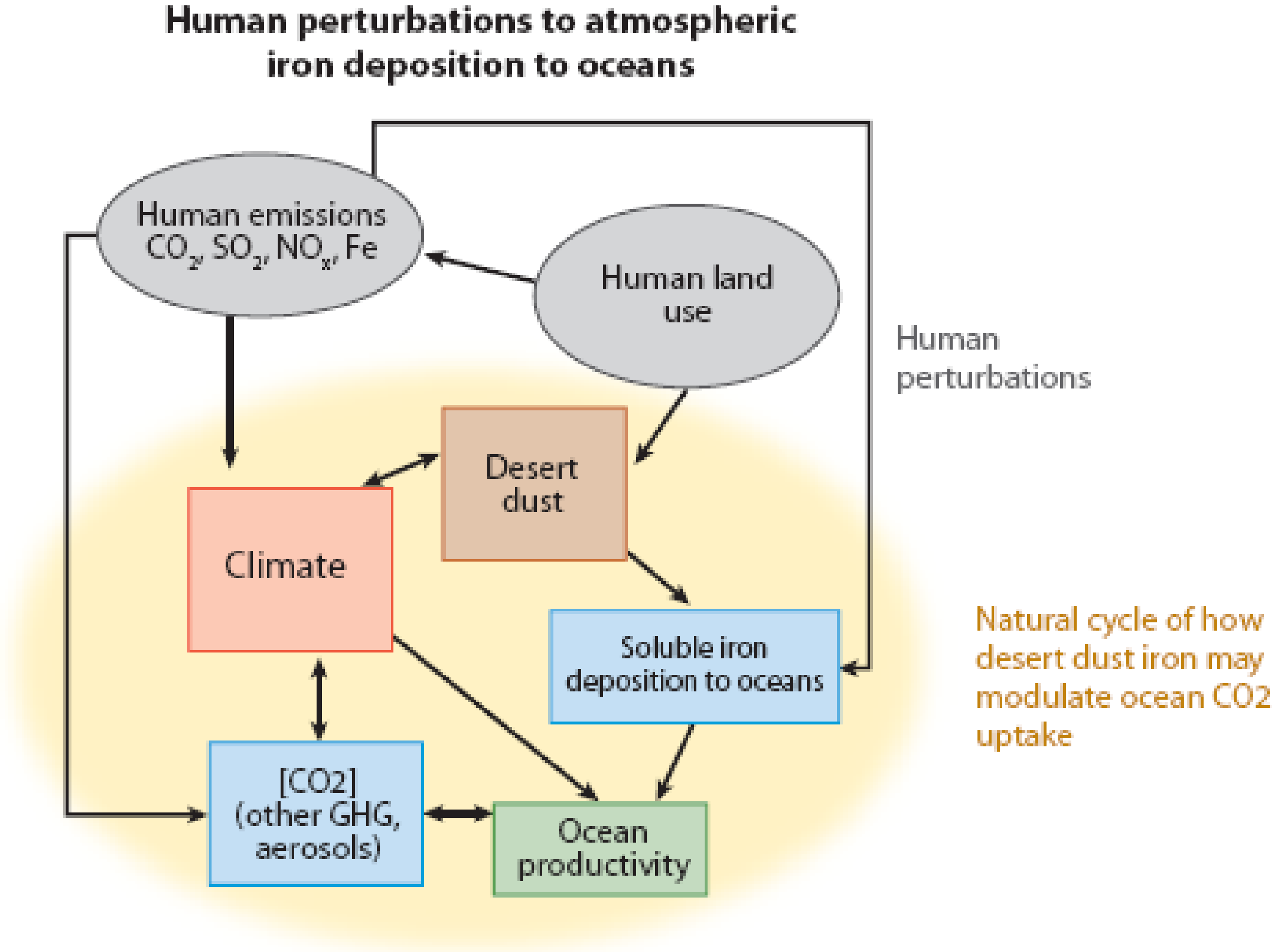
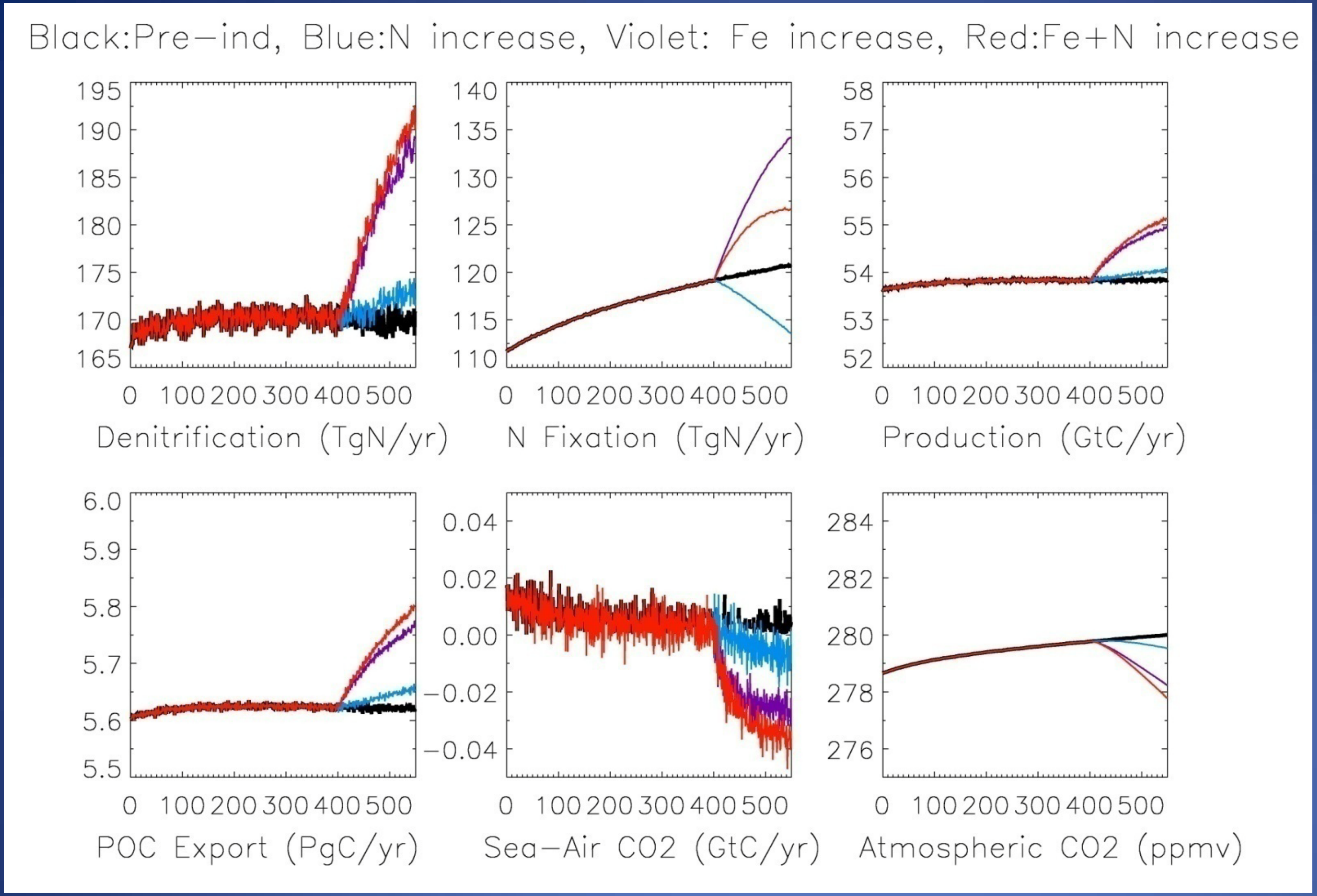


Figure 17

Schematic representing feedbacks between the natural ocean carbon cycle, carbon dioxide concentrations, and iron inputs; also shows how humans could be perturbing the iron deposition to the oceans.

Mahowald et al., 2009



Changes in key biogeochemical fluxes over the period of 550 year simulations. The N and Fe deposition increase after year 400 as a linear increase between preindustrial values and current

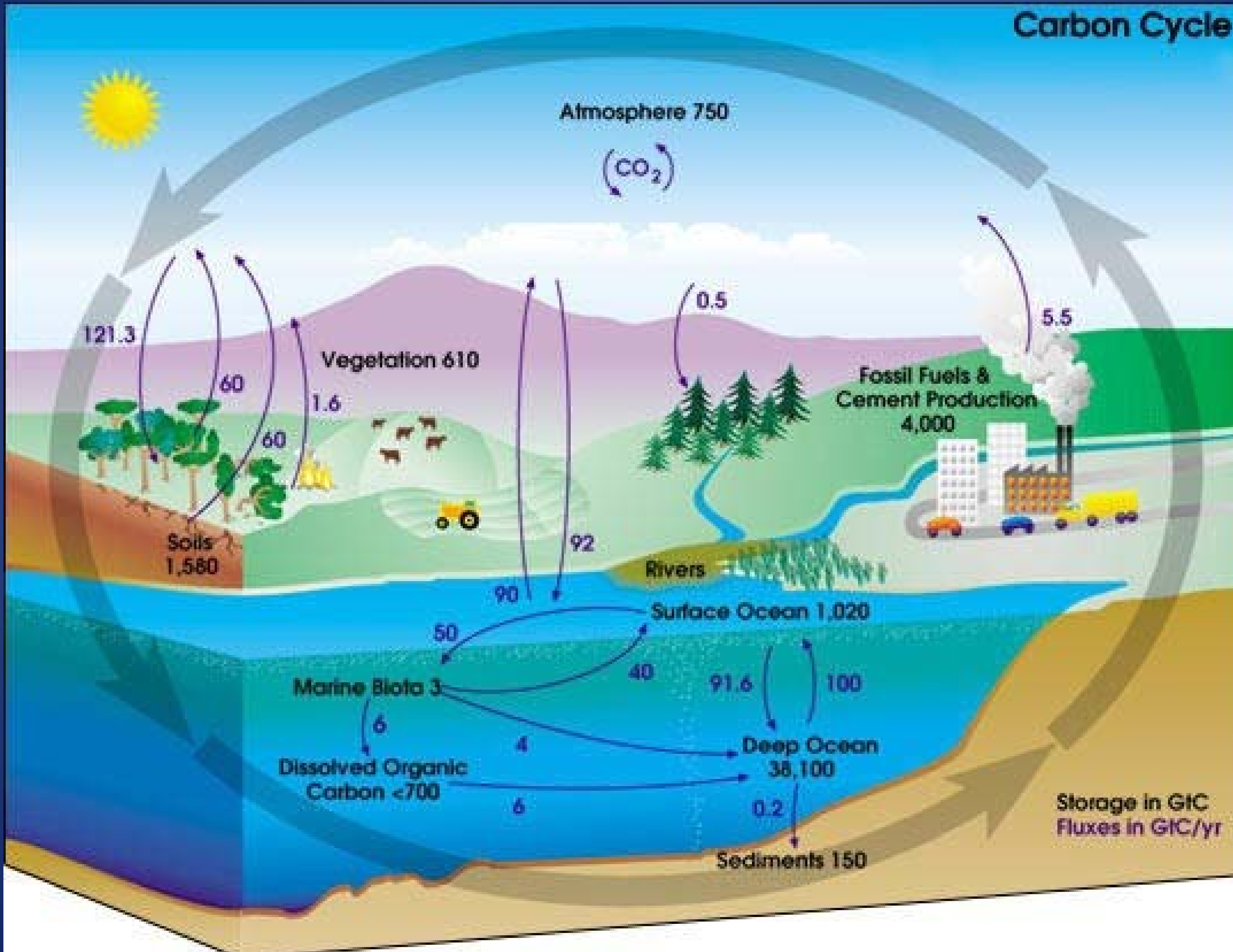
From Krishnamurty et al., 2010

Doubling of soluble iron deposition to the oceans (in a model) increases ocean N-fixation: substantially changes N budget.

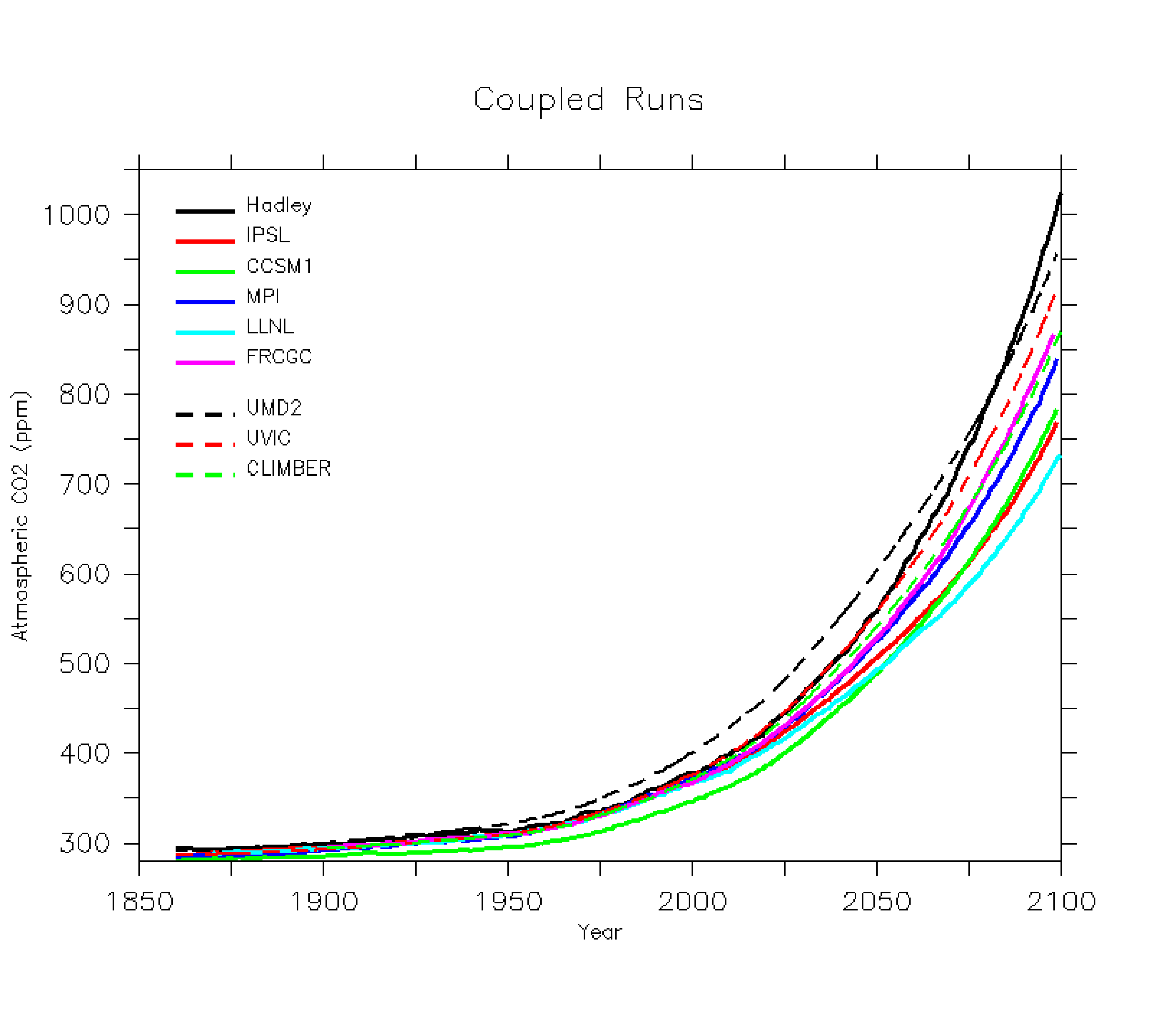
Increases uptake of carbon slightly (~2ppm over 130 years, compared to 100ppm increase from humans).
Note that this is smaller than previous estimates from the same model, because of increases in our estimates of sedimentary iron sources

Dust in earth system models

- Earth system models predict not just physical climate but carbon dioxide as well
  - ½ of anthropogenic carbon dioxide is taken up by land or oceans now
  - Will that continue in future?
- Depends on
  - Land: precipitation, temperature controls on vegetation and soil respiration
  - Ocean: nutrient availability: mixed layer overturning and changes in iron, potentially
- Dust may interact with both parts of the system to change carbon dioxide and temperature feedbacks


Carbon Cycle
Atmosphere 750
CO2
121.3
60
60
1.6
Vegetation 610
90
92
0.5
5.5
Fossil Fuels &
Cement Production
4,000
Soils
1,580
Rivers
Surface Ocean 1,020
50
40
Marine Biota 3
91.6
100
6
4
Deep Ocean
38,100
Dissolved Organic
Carbon <700
6
0.2
Sediments 150
Storage in GtC
Fluxes in GtC/yr

Intergovernmental Panel on Climate Change (IPCC) AR4 includes multiple models which predict CO2—from the Coupled Carbon Cycle Climate Model Intercomparison Project (C4MIP)

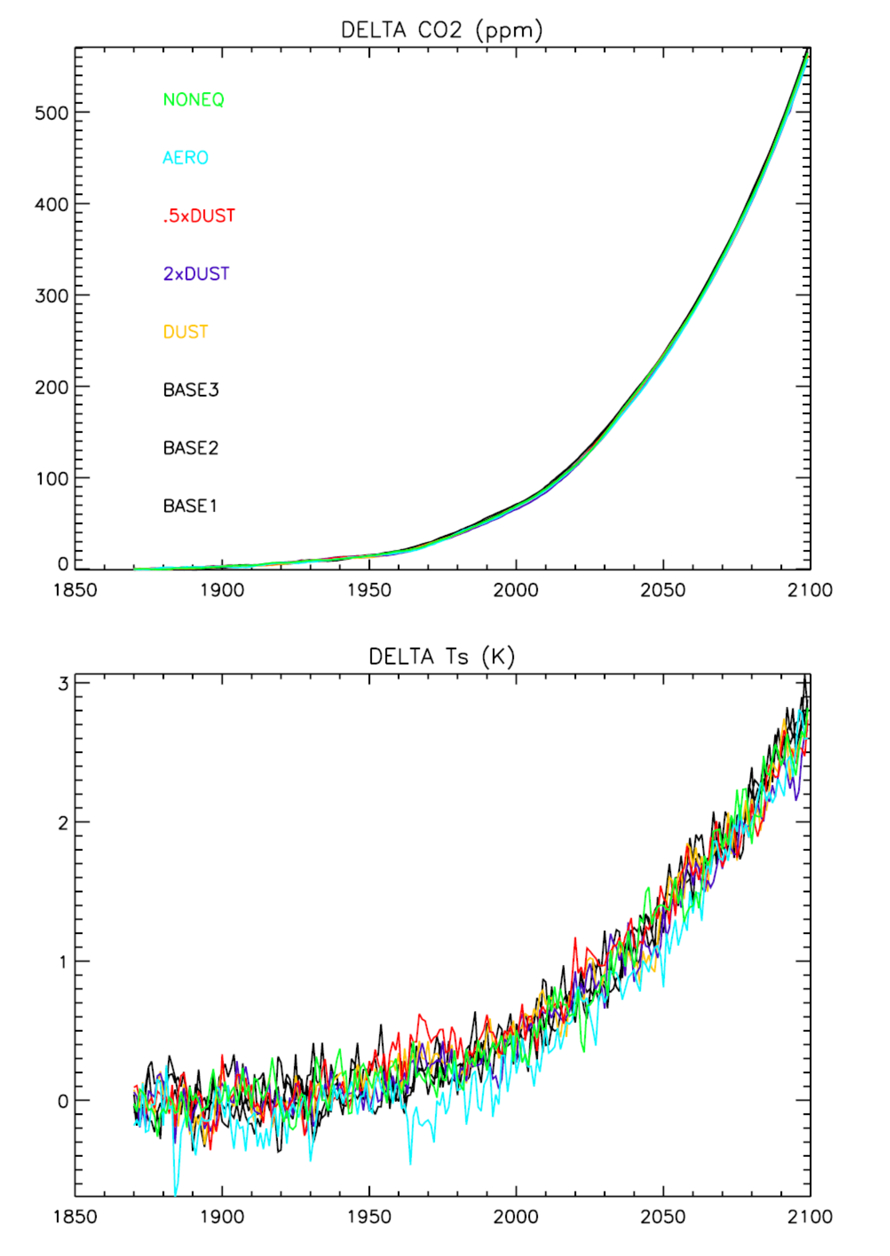


Models:

- Range from full to intermediate in complexity
- Include land and ocean biogeochemistry
- Different strengths
- Very different physical response and biases

- Very different CO2 levels!

Friedlingstein et al., 2006



CCSM3.1 simulations (Thornton et al., 2009; Mahowald et al., in prep):

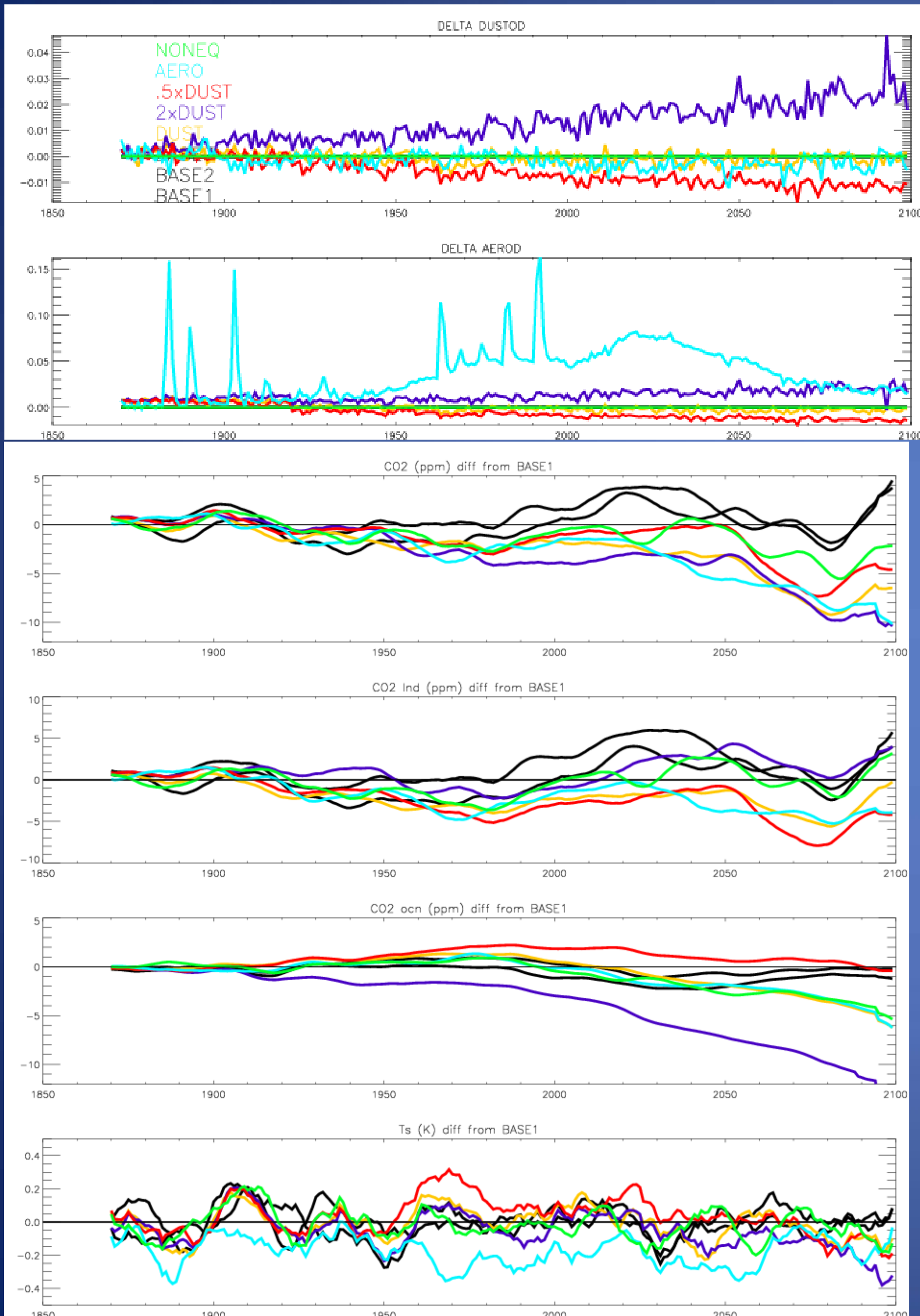
- Include colimitation on land by N
- Get a lot of CO_2 staying in the atmosphere (without loss of Amazon, as in Cox et al., 2000)

- Here we show results with a wide variety of cases, including dust and other aerosols:
- Aerosol interactions do not make a difference to 0^{th} order (different than Jones et al., 2006)
- Our model has very small negative carbon feedback from climate

But statistical significant changes to global Ts, regional climate, and where the carbon goes do occur.

Mahowald et al., in prep

How does the evolution of the system change with aerosols?



Dust AOD

AOD

Total CO2

Land CO2 tracer (atmos co2 from land)

Ocean CO2 tracer (atmos co2 from land)

Ts(K)

Differences in the difference between transient and preindustrial for this case, versus BASE1.

1. Dust does not respond to climate much in these runs (need to hit source hard to get changes in dust)
2. CO2 differences at 2100 are <10ppm
3. Ocean and land CO2 respond oppositely
4. our model is less sensitive to the inclusion of aerosols than Jones et al., 2003

Mahowald et al., in prep

Dust in the anthropocene

- Desert dust is a driver and archiver of climate
- Desert dust usually is important at the 0-30% level: not the dominant forcer, but 2nd order.
- Desert dust significantly changes regional climate and biogeochemistry
- Understanding past and future regional changes requires inclusion of desert dust impacts