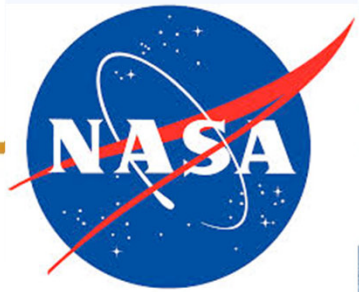
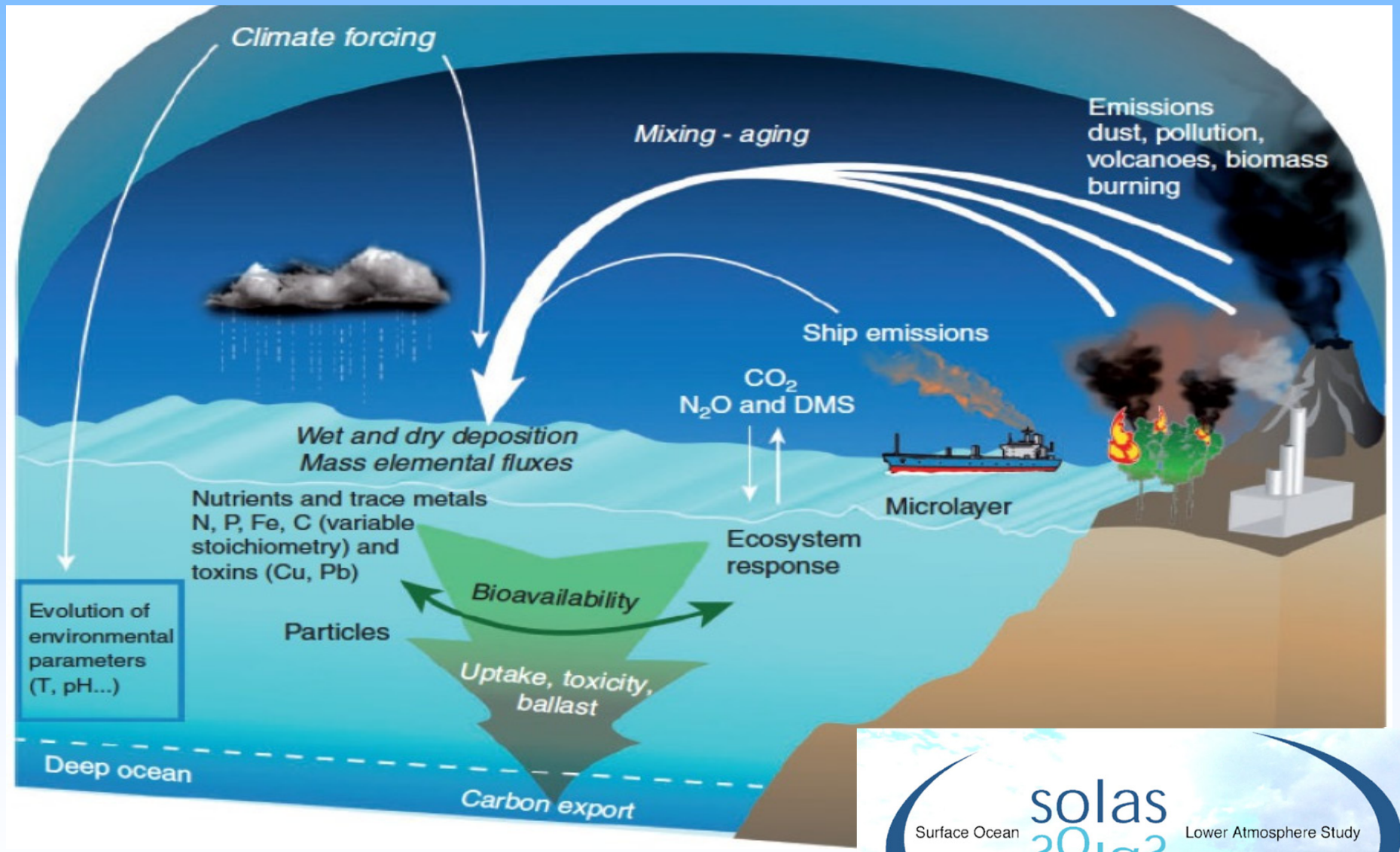
Overview of Nutrient Emissions, Sources & Scales of Impact

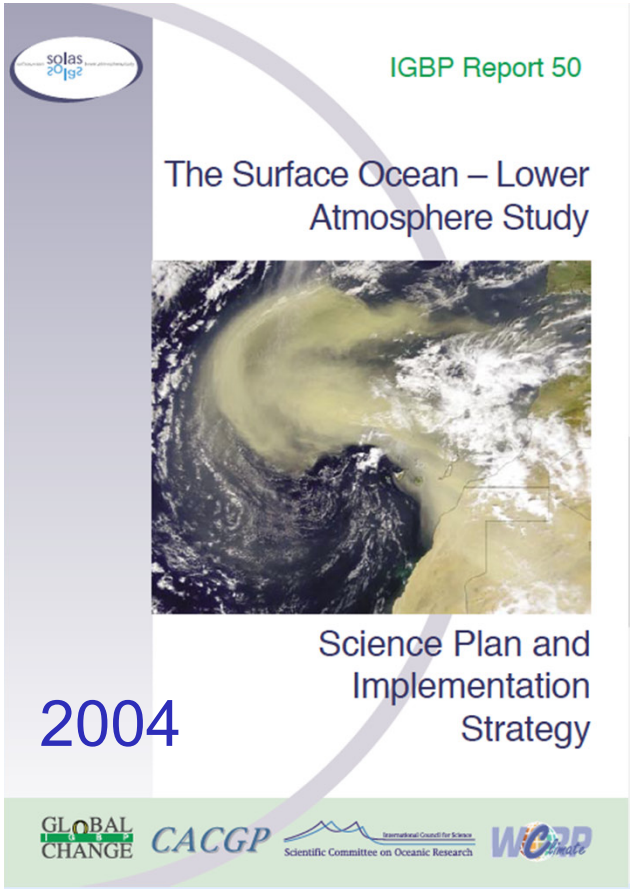
Scott Doney (WHOI) & Philip Boyd (Univ. Tasmania)

2015 OCB Summer Workshop Plenary Session:
Atmospheric Nutrient Deposition: Impacts on Marine Ecosystem & Biogeochemical Cycles



SOLAS—Surface Ocean–Lower Atmosphere Study

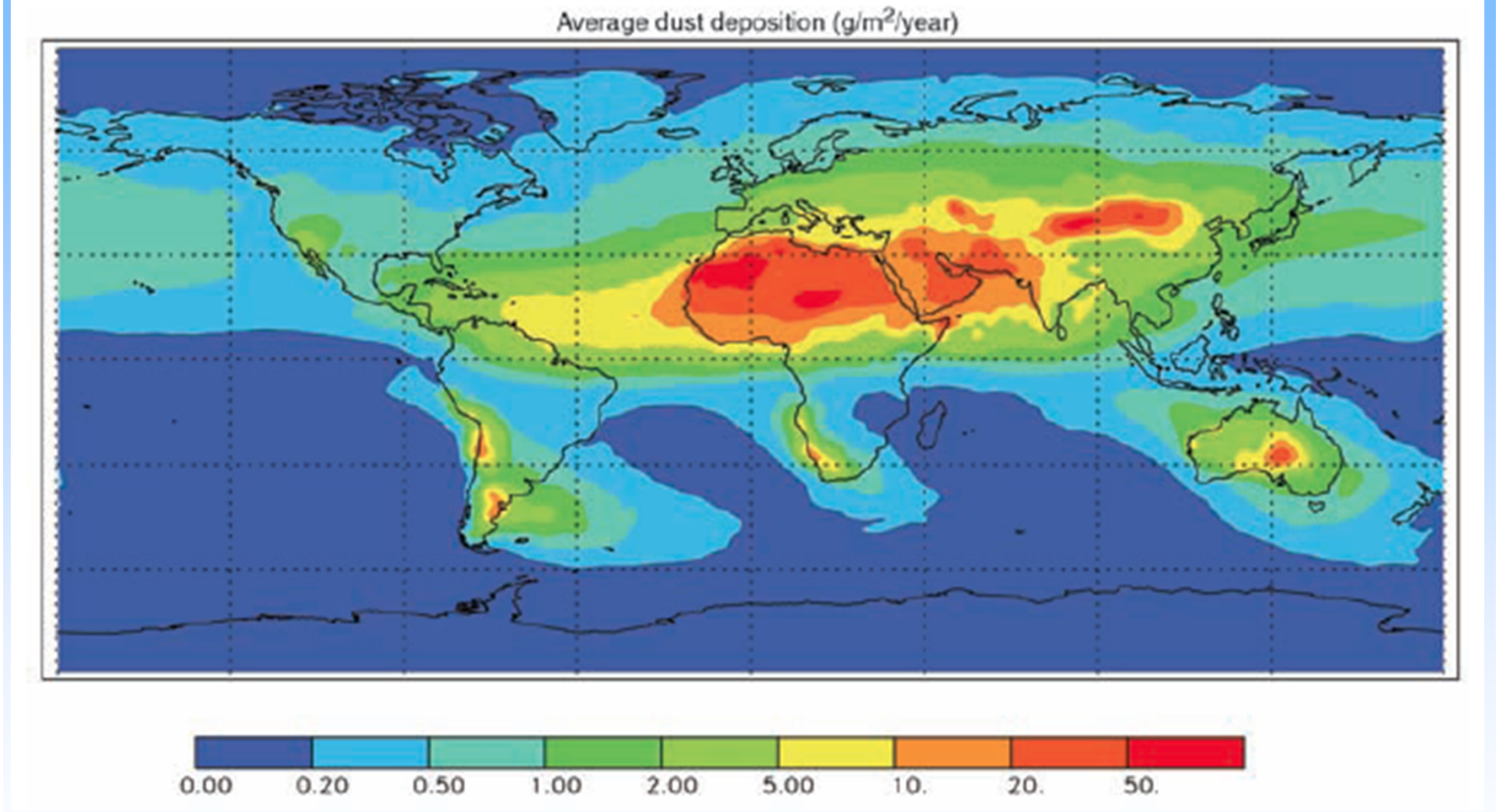




SOLAS Focus 1: Biogeochemical Interactions & Feedbacks Between Ocean and Atmosphere

1.3 DMS & Climate
1.4 Iron & Productivity
1.4 Ocean-Atmosphere N Cycling

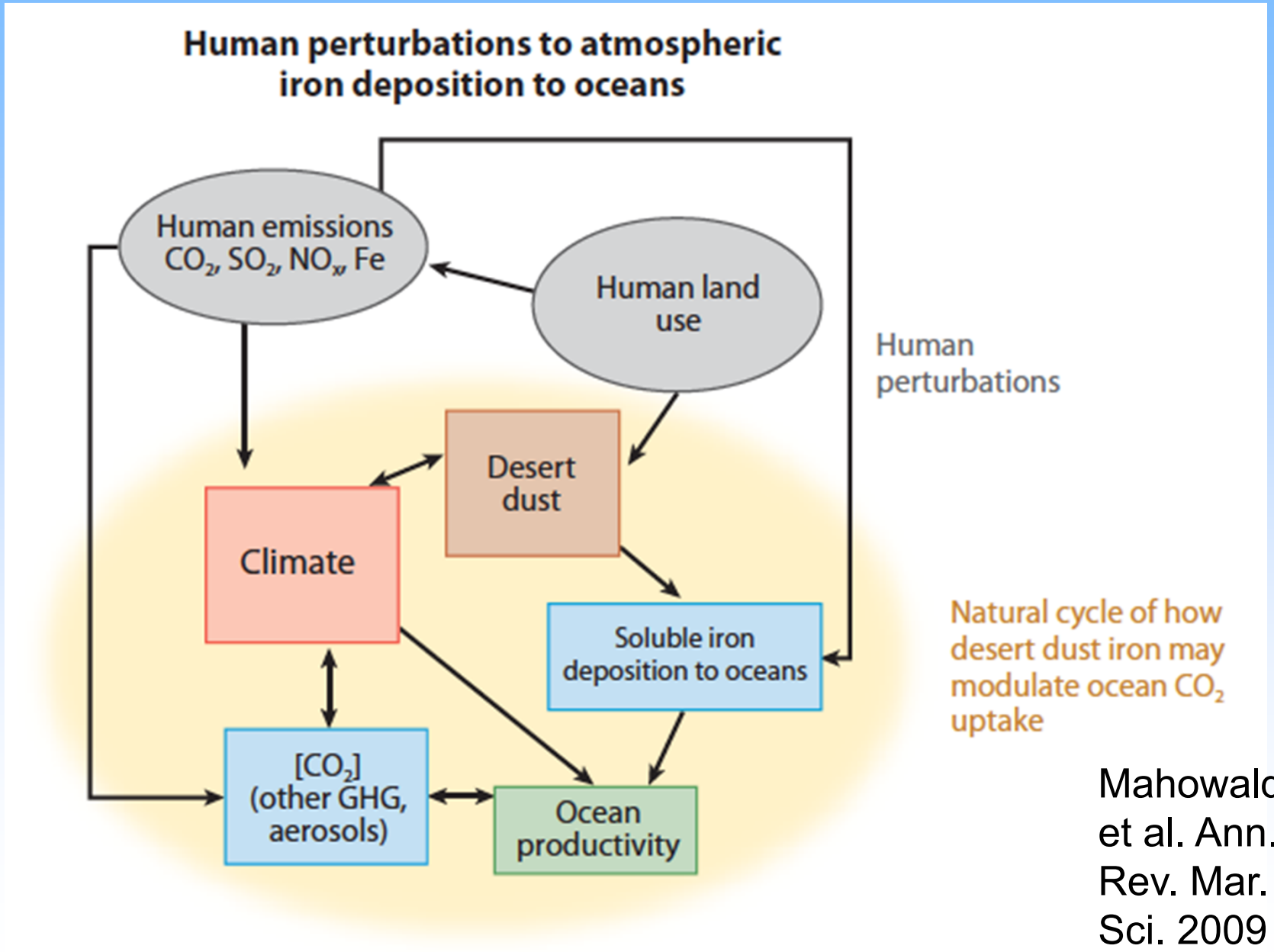
Atmospheric Dust Deposition



Jickells et al. Science 2005

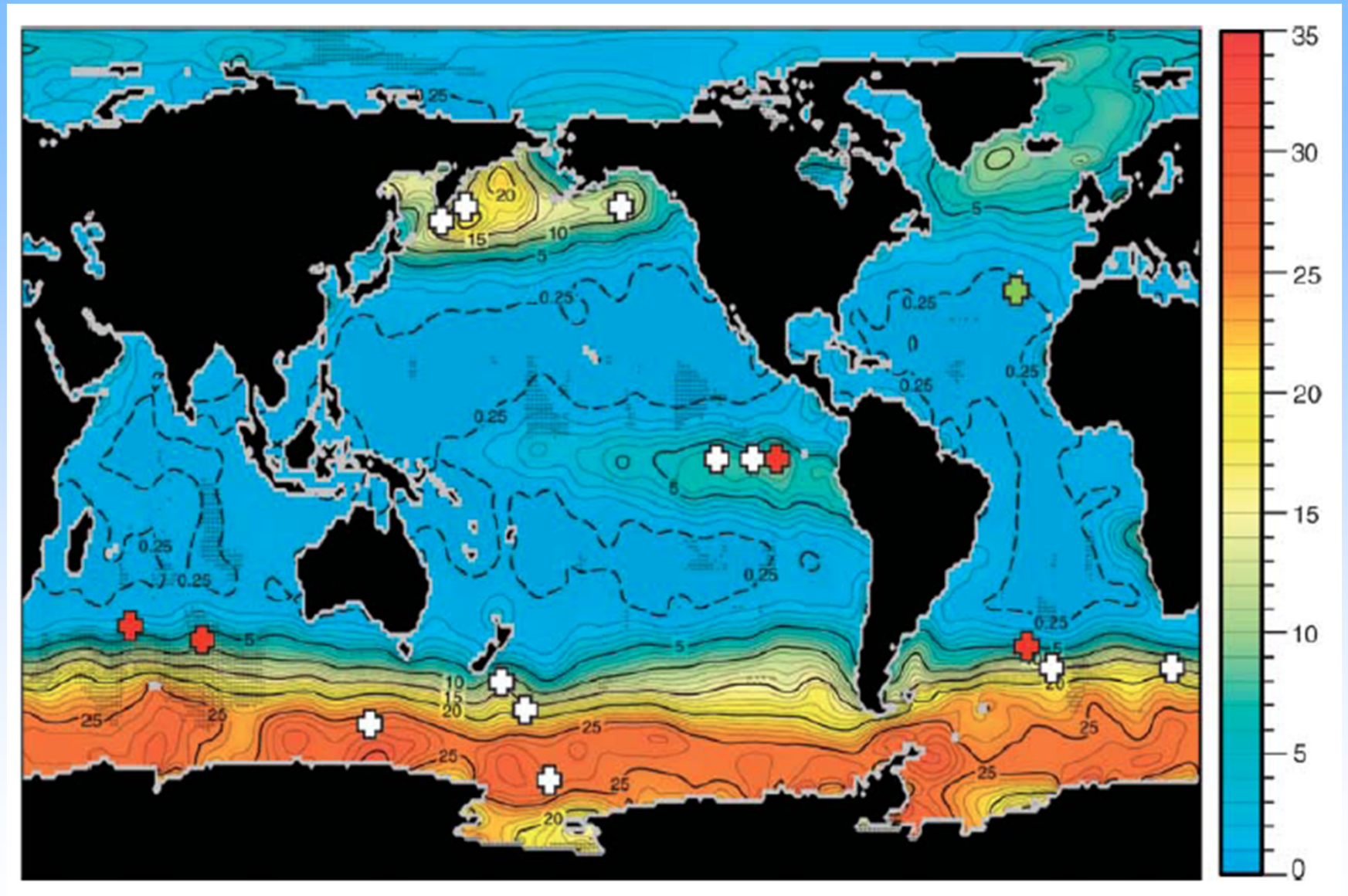
See also Mahowald et al. Ann. Rev. Mar. Sci. 2009

Dust - Iron - Climate Interactions



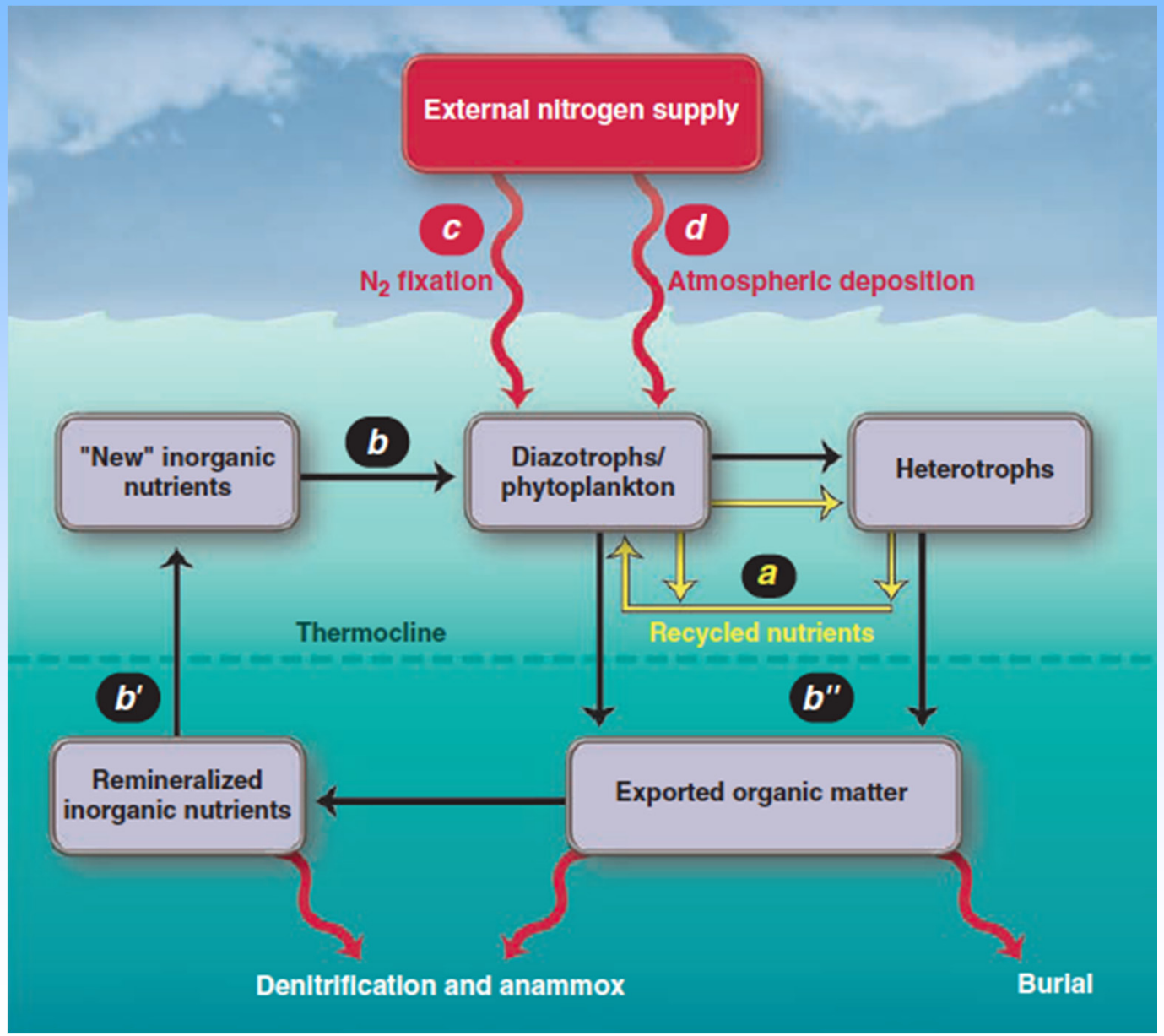
Mahowald et al. Ann. Rev. Mar. Sci. 2009

Iron Enrichment Studies



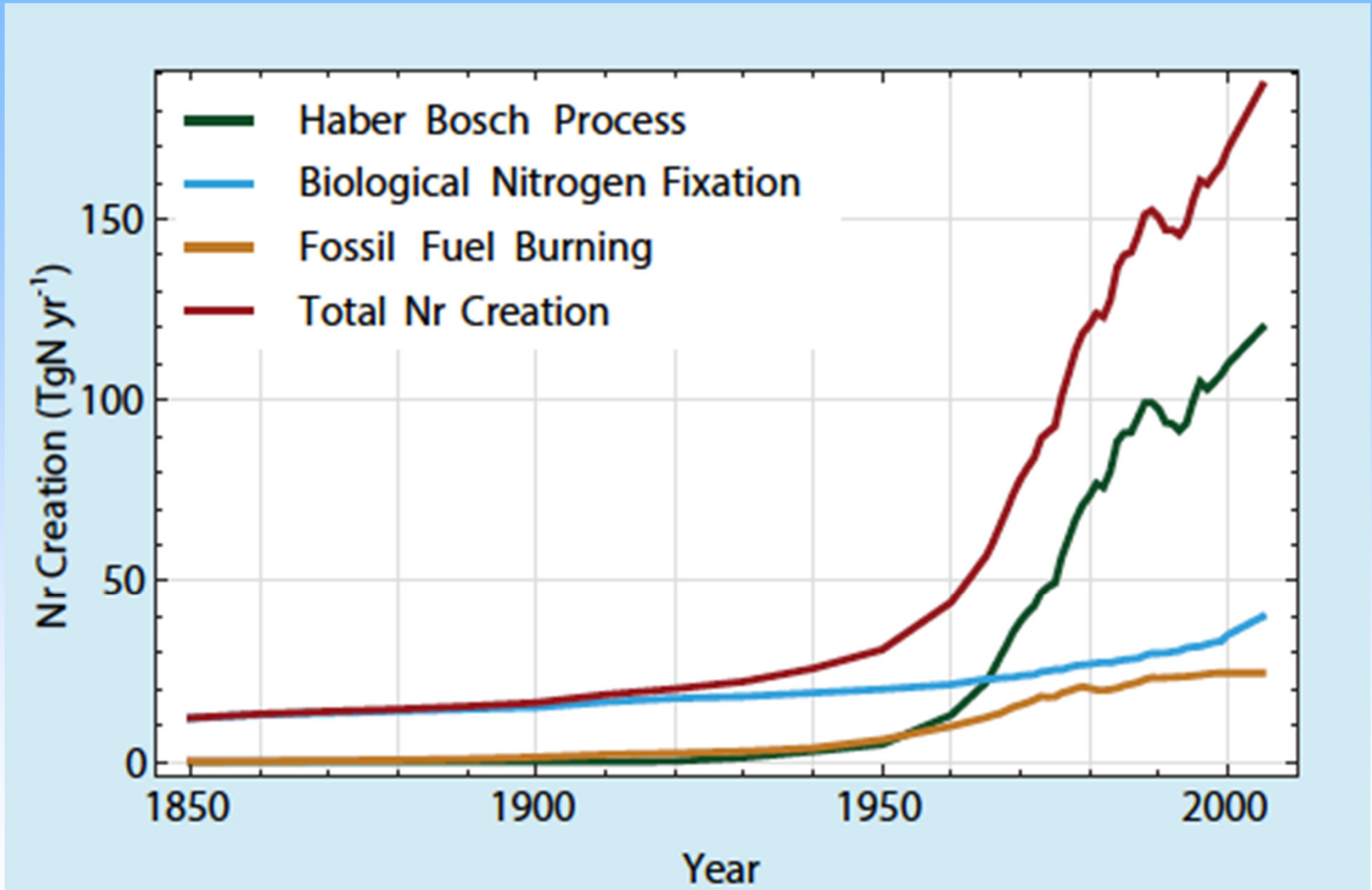
Boyd et al. Science 2007

Atmospheric Nitrogen Deposition



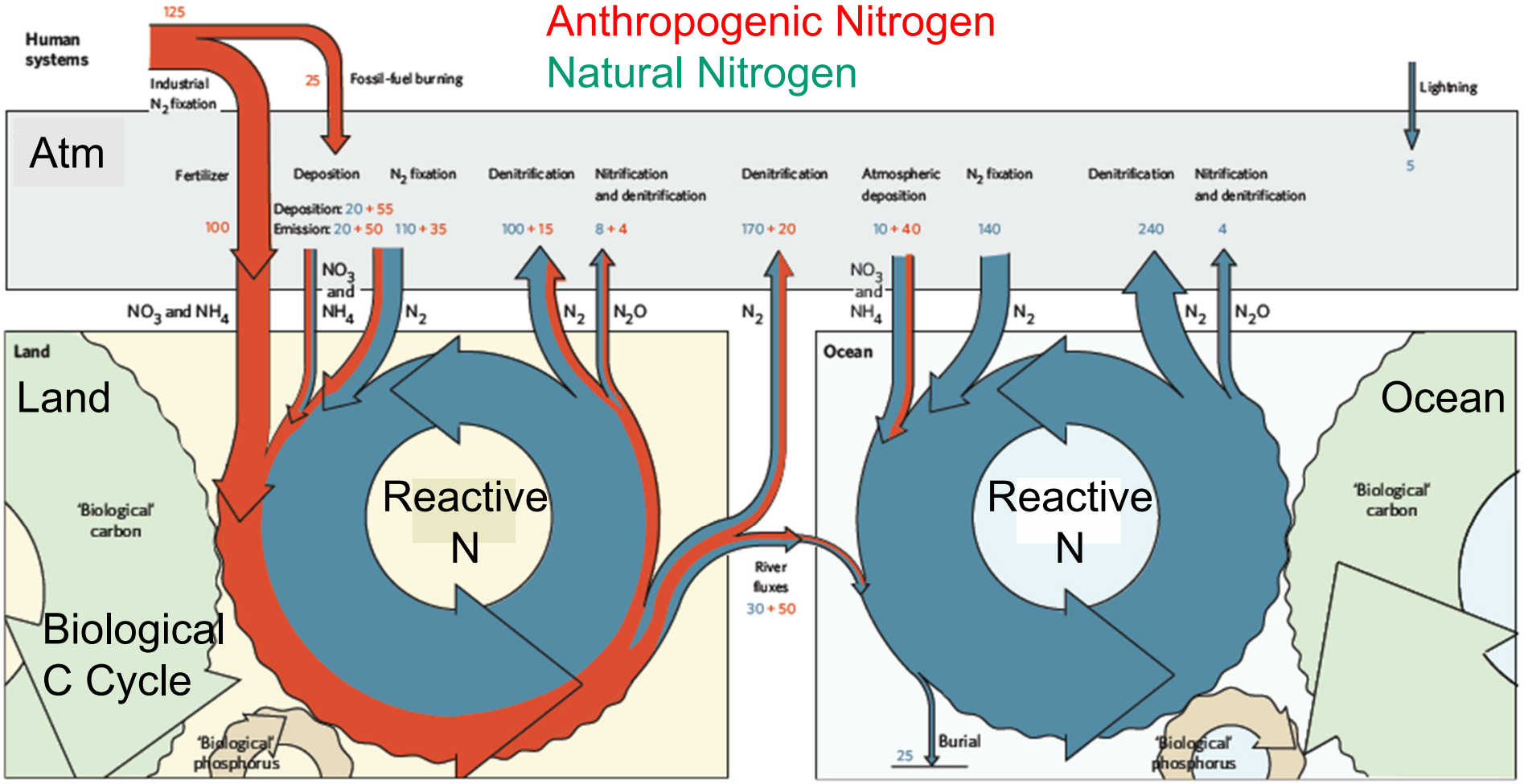
Duce et al.
Science
2008

Human Perturbations to the Global Nitrogen Cycle



IPCC 2013

Contemporary Land & Ocean Nitrogen Cycles



Biological P Cycle

Gruber & Galloway Nature 2008

Evolving Questions on Atmospheric Inputs

Overlay of natural variability on anthropogenic trends

Composition, bioavailability & stoichiometry (Fe, P, N, etc.)

- source variations (e.g., soils, combustion, agriculture)
- atmospheric chemistry
- other trace elements
- organic compounds & ligands

Relative balance of atmospheric & other sources

- rivers, sediments, volcanoes & hydrothermal
- internal ocean recycling & physical transport

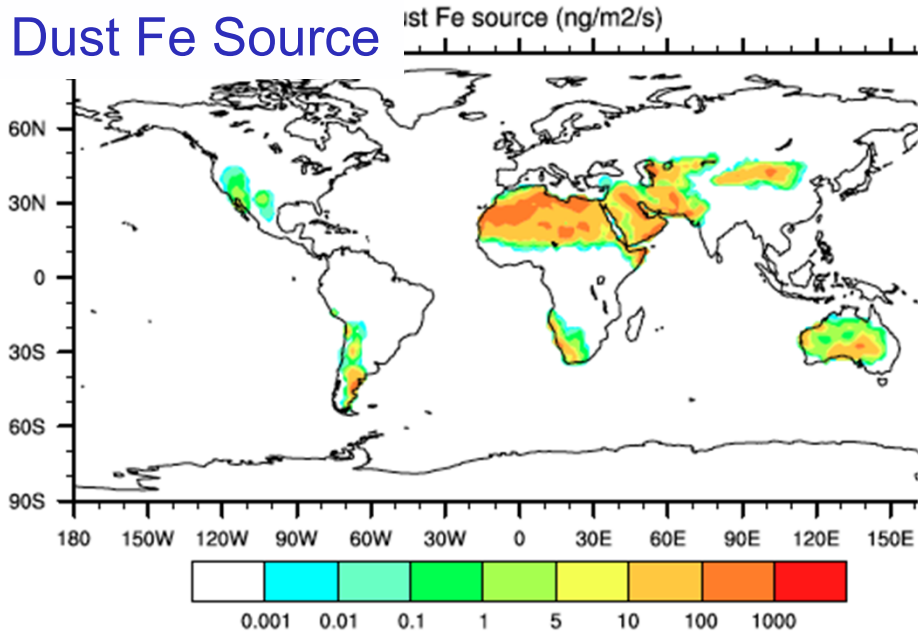
Sensitivity of HNLC versus LNLC ocean regions

Metrics beyond chlorophyll and primary production

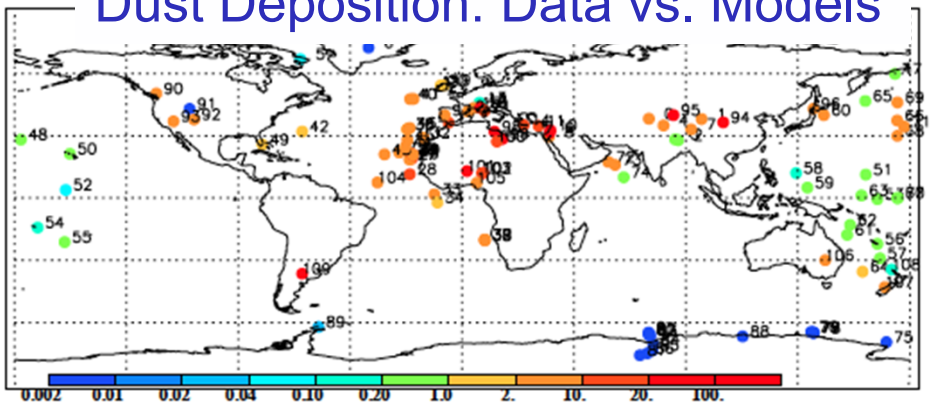
- N fixation, community composition, export magnitude & quality, trace gases, acidification, etc.

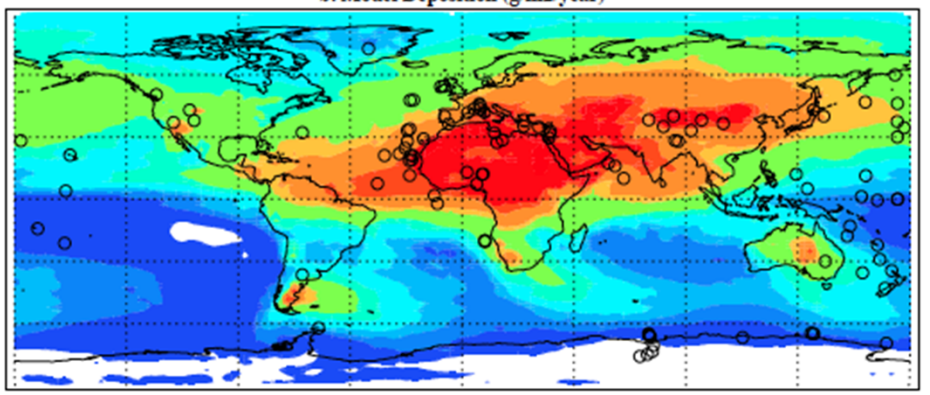
Desert Dust, Iron Sources & Deposition

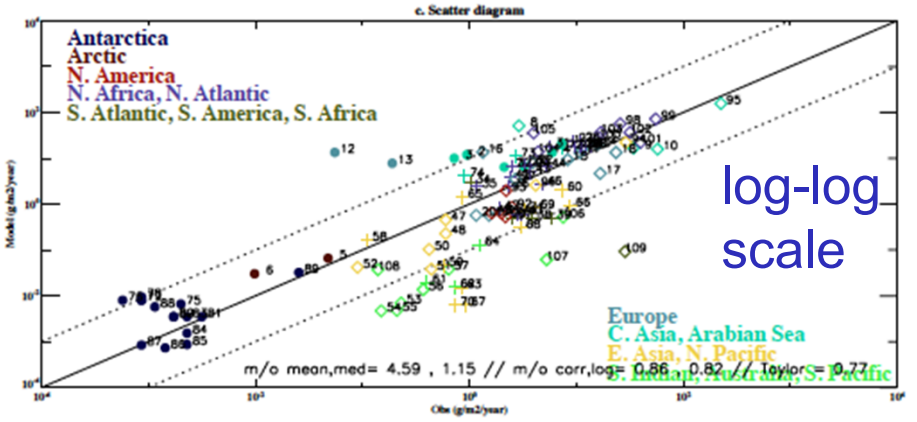
Dust Fe Source



Dust Deposition: Data vs. Models



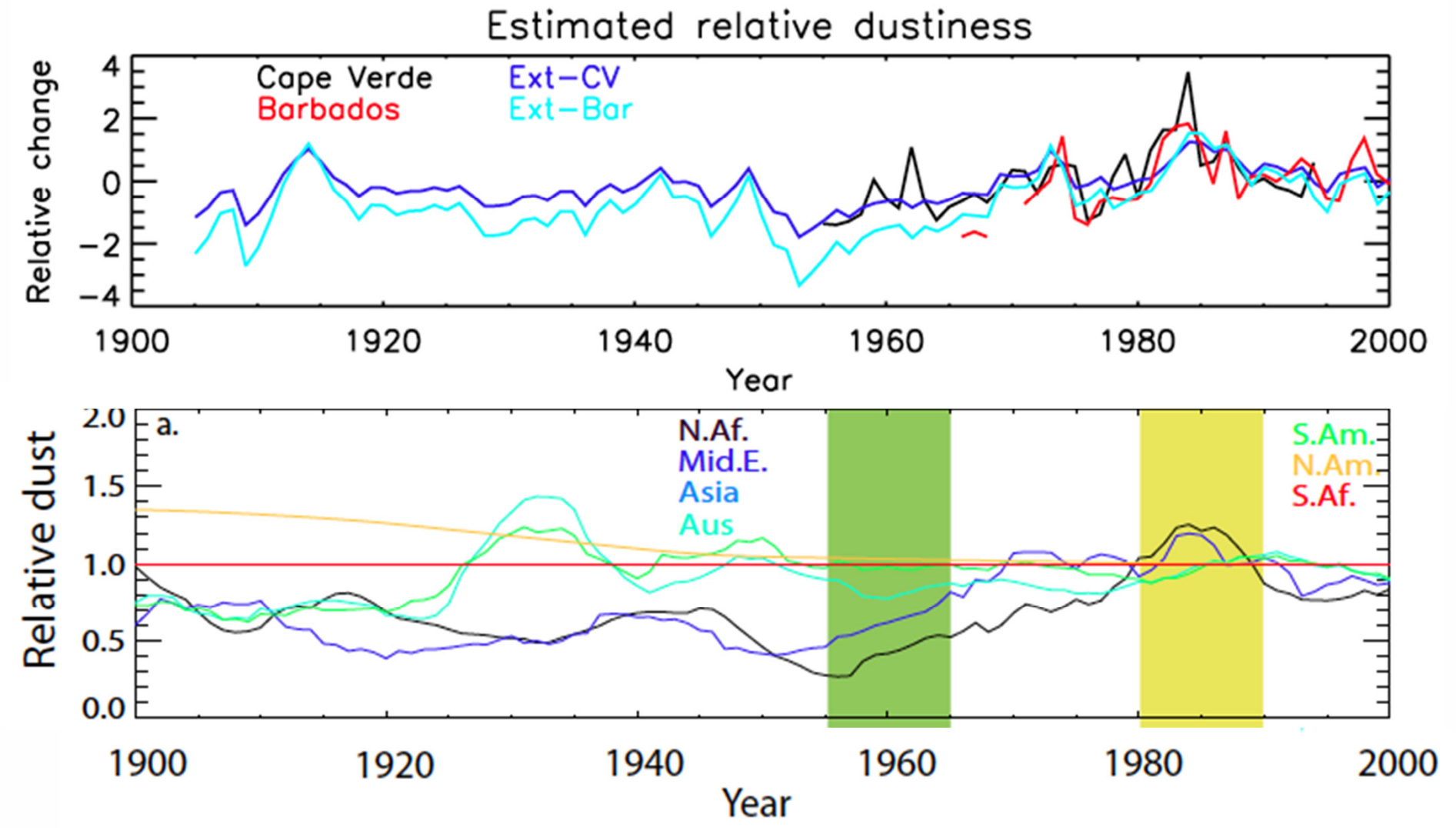




Luo et al.
Global Biogeochemical Cycles
2008

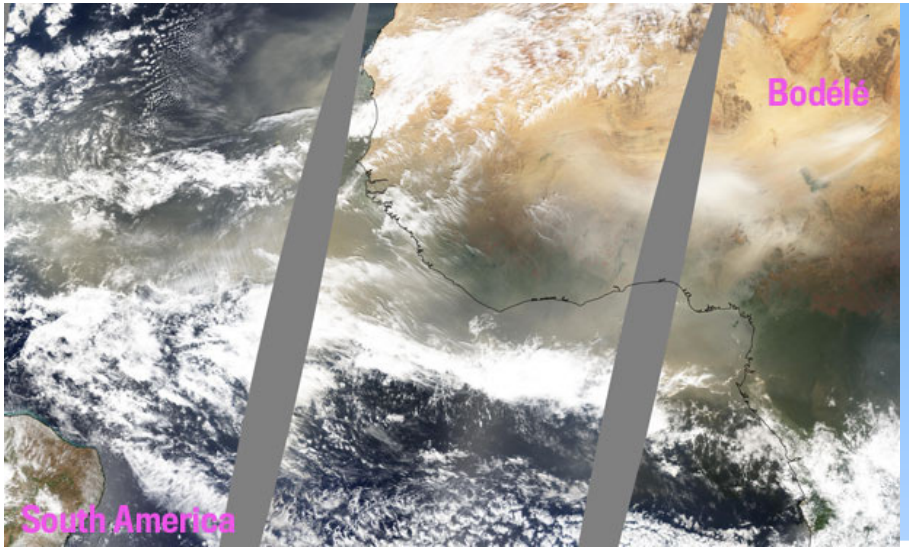
Zhang, Mahowald, et al.
Biogeosciences
Discussions 2014

Atmospheric Dust Variations

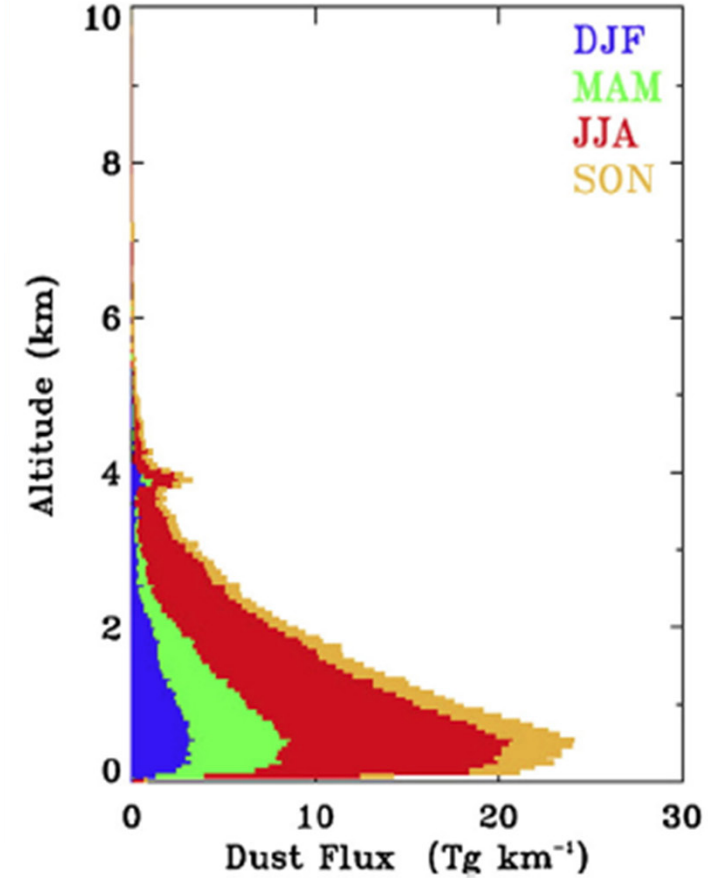


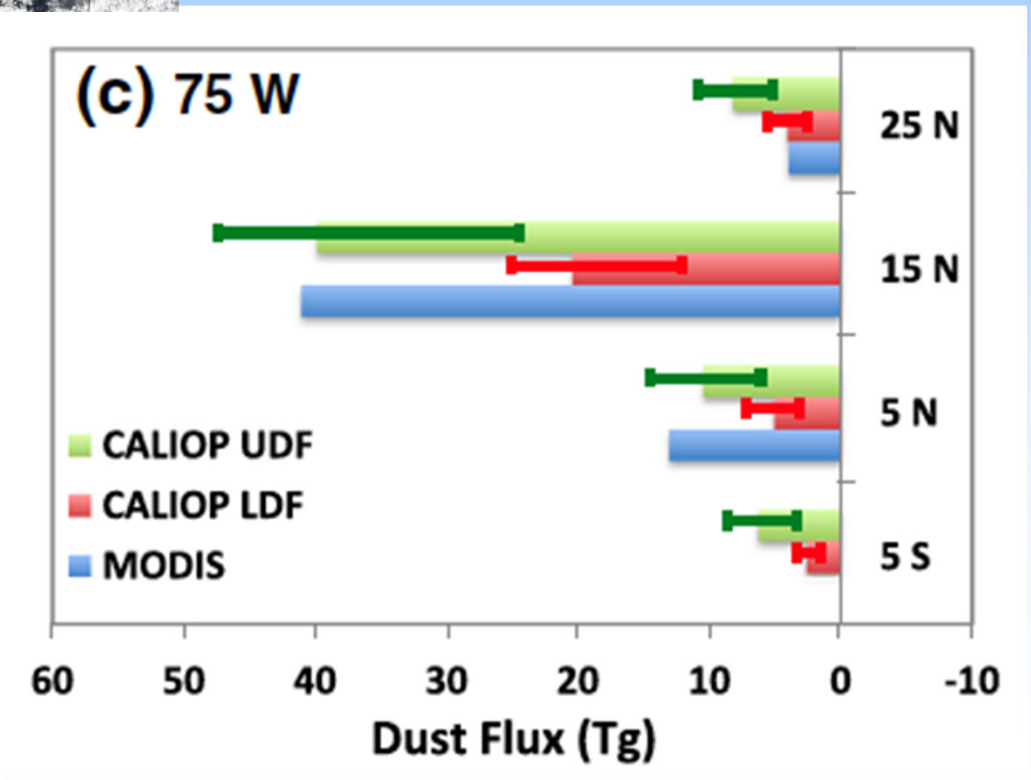
Mahowald et al. Atmos. Chem. Physics 2010

Satellite Aerosol Measurements



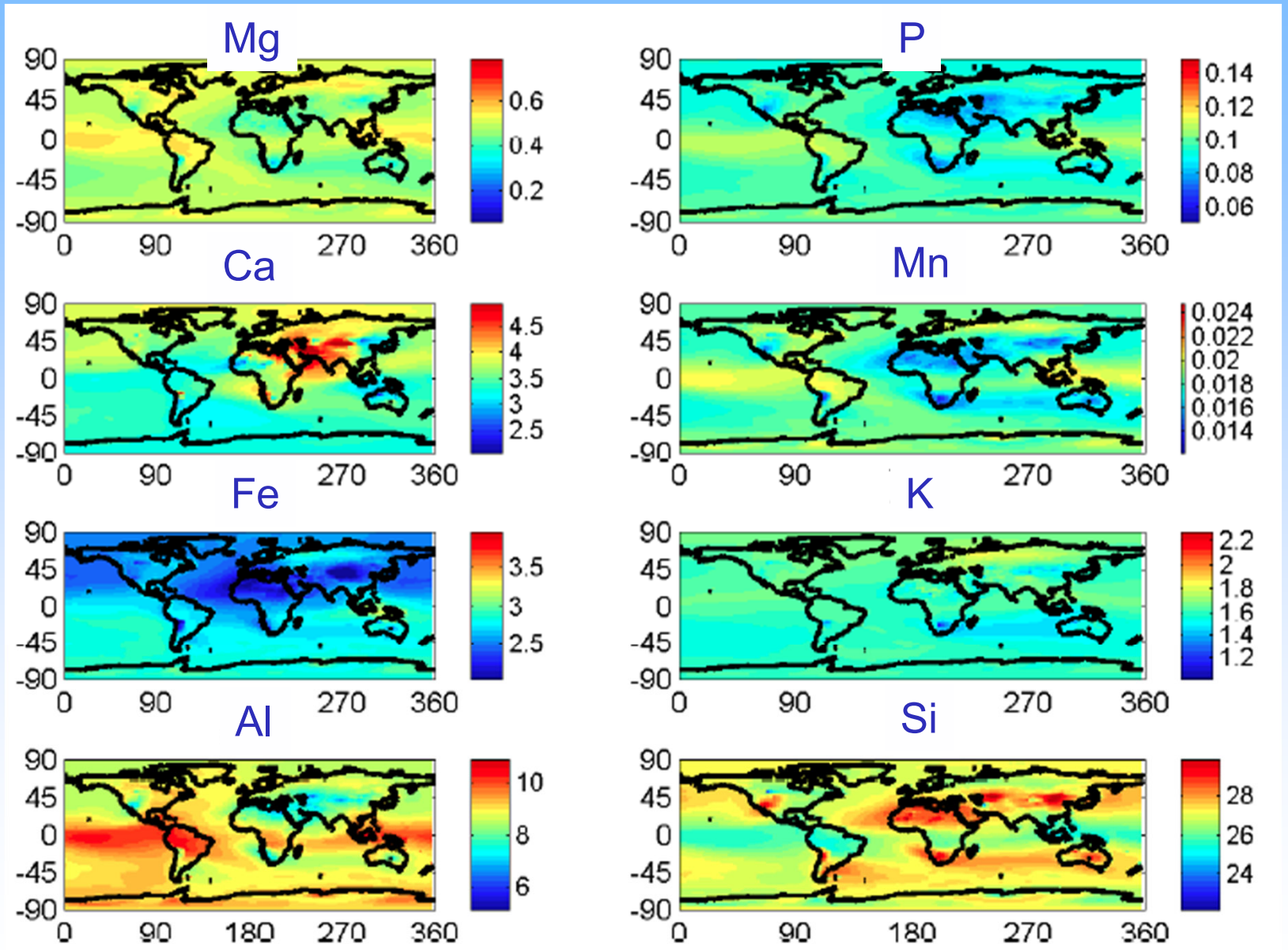
Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP)





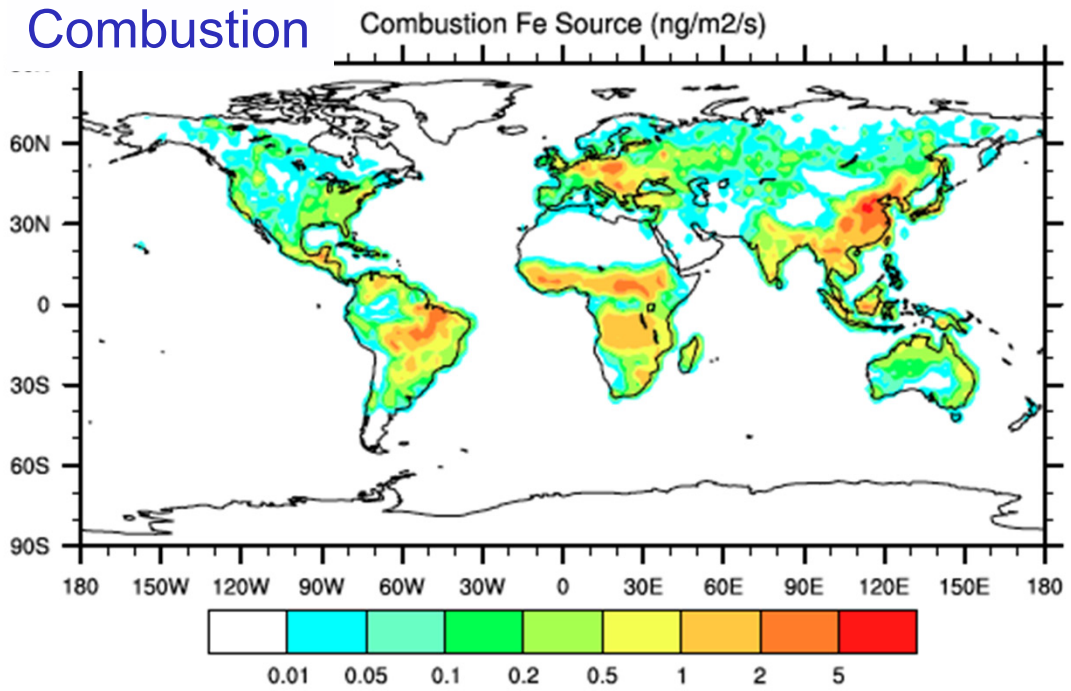
Yu et al. Remote Sensing Environment 2015

Variations in Dust Composition

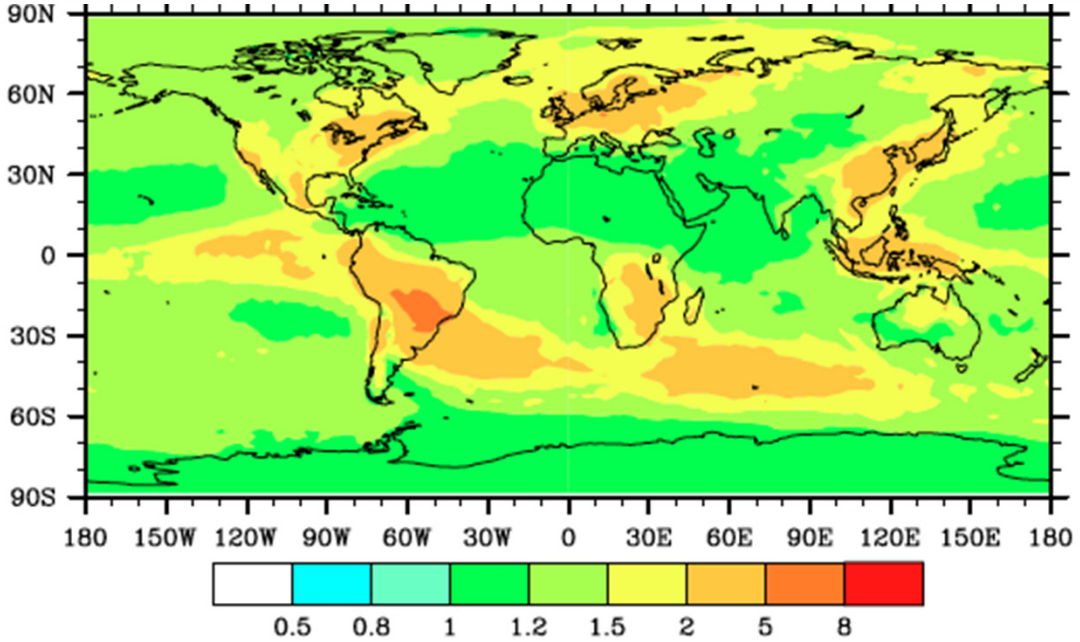


Zhang, Mahowald, et al. Biogeosciences Discussions 2014

Combustion



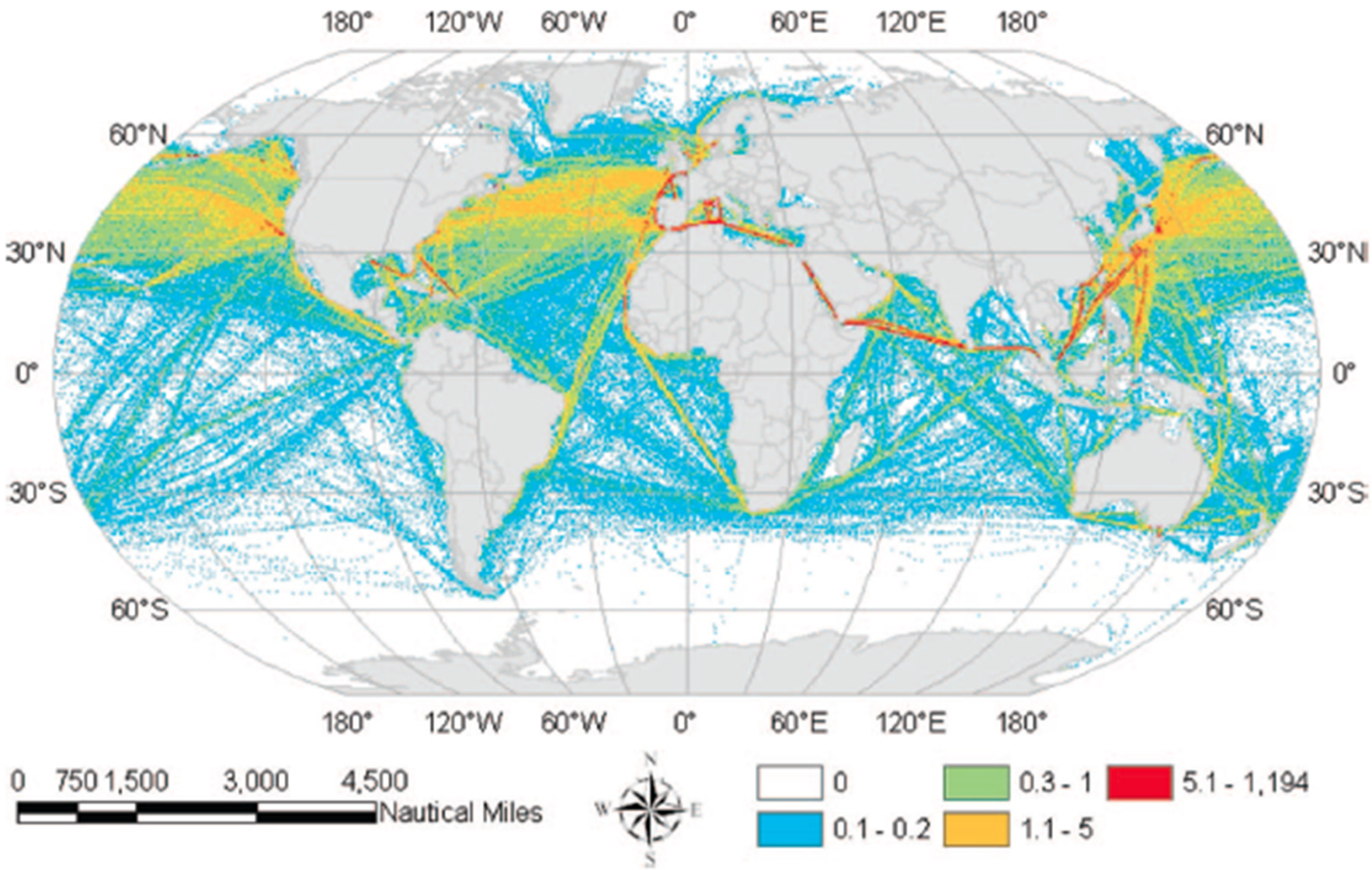
Ratio of Current to Preindustrial Soluble Iron



Combustion Iron Sources

Luo et al.
Global Biogeochemical Cycles
2008

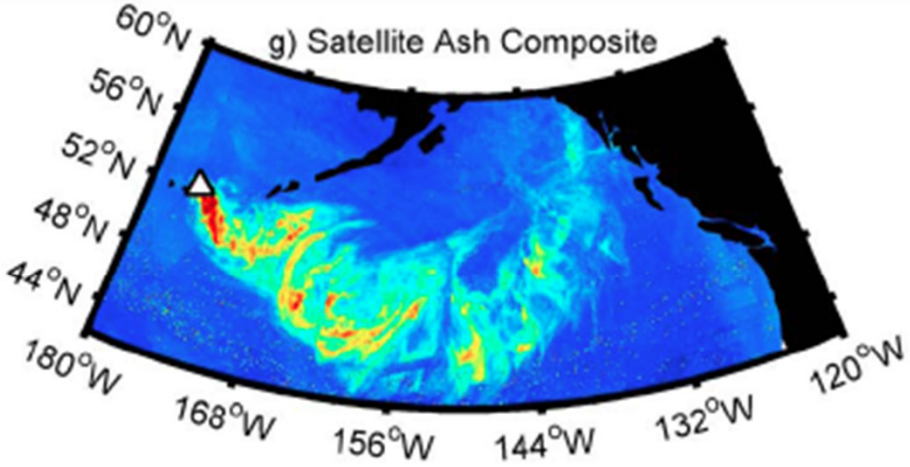
Ship Emissions

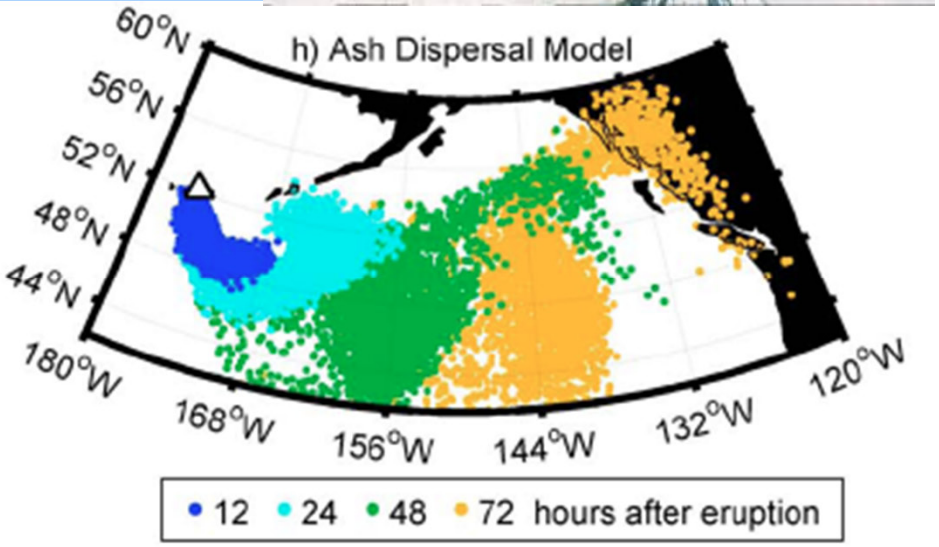


Wang et al. Environ. Sci. Technol. 2008.

Iron From Volcanic Ash

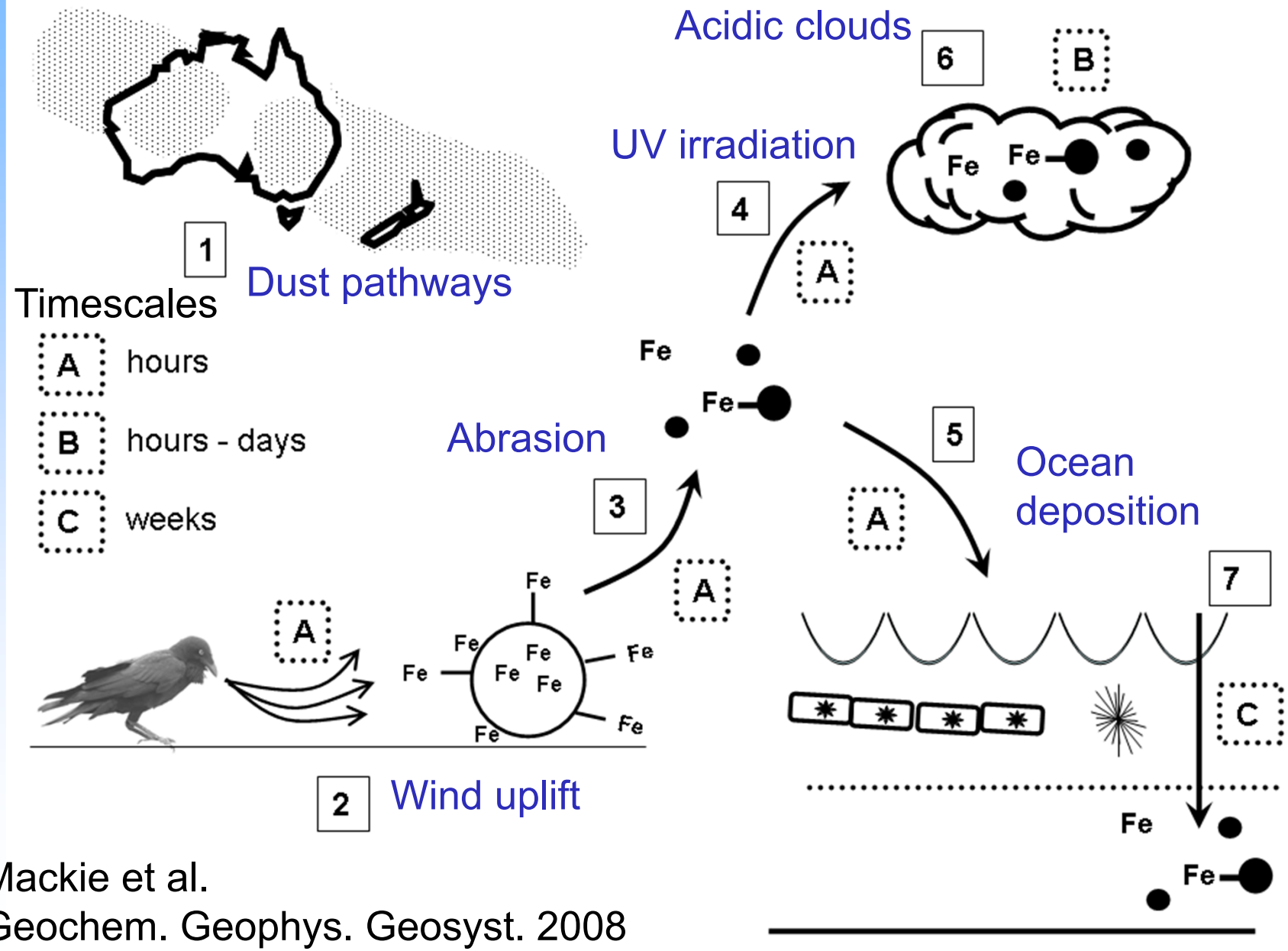
Kasatochi August 2008 eruption





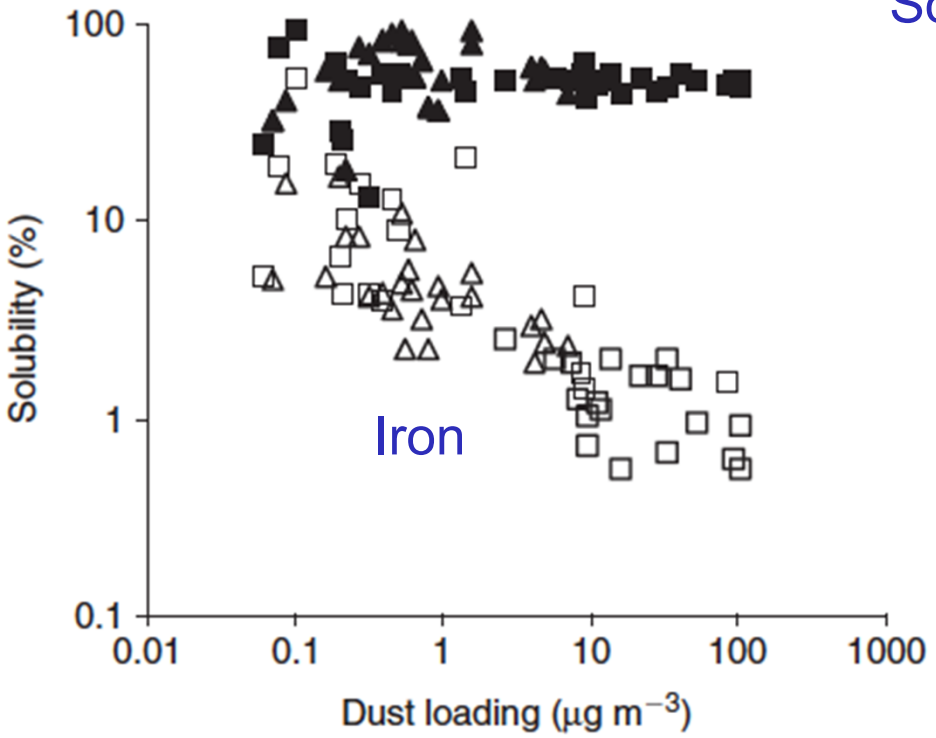
Hamme et al. Geophysical Research Letters 2010

Dust, Iron & Atmospheric Transformations

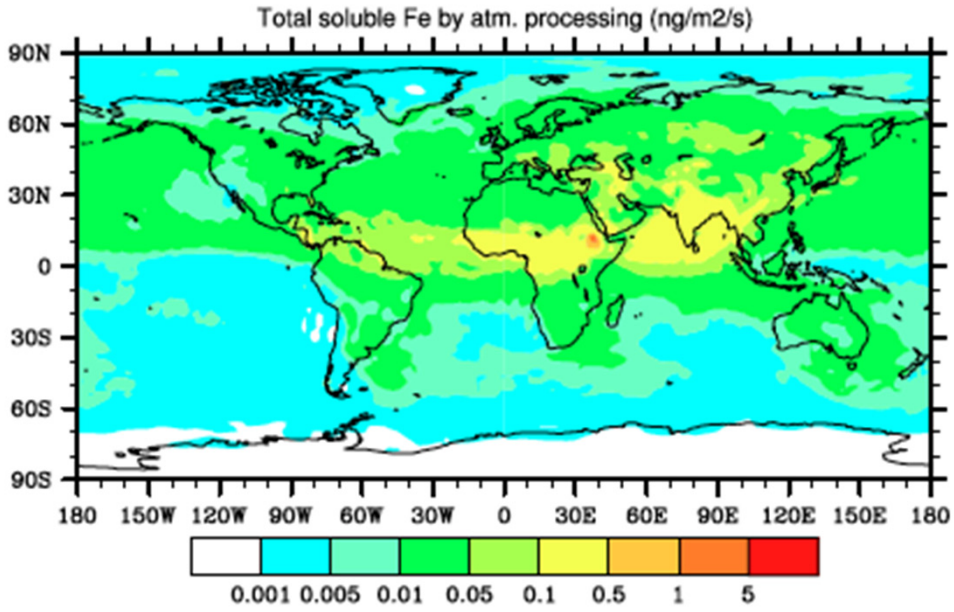


Mackie et al.
Geochem. Geophys. Geosyst. 2008

Dust Solubility & Atmospheric Processing



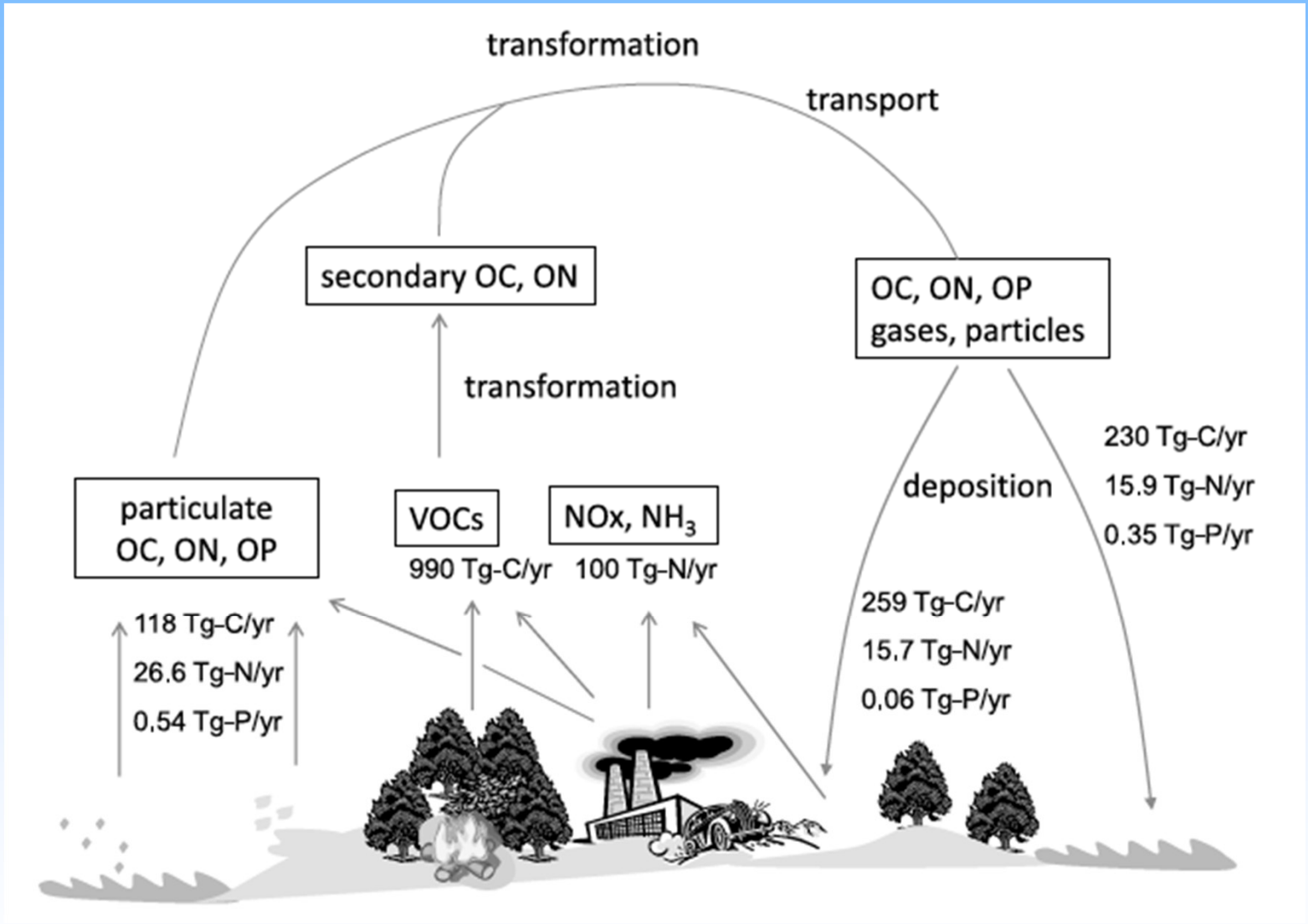
Soluble iron from atmospheric processing



Waeles et al.
Environmental Chemistry
2007

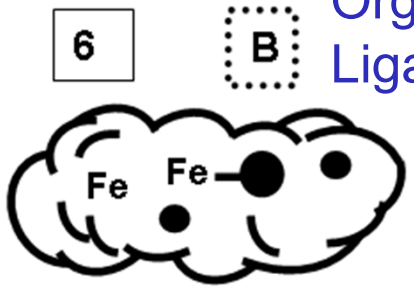
Luo et al.
Global Biogeochemical Cycles
2008

Organic & Inorganic C, N & P emissions



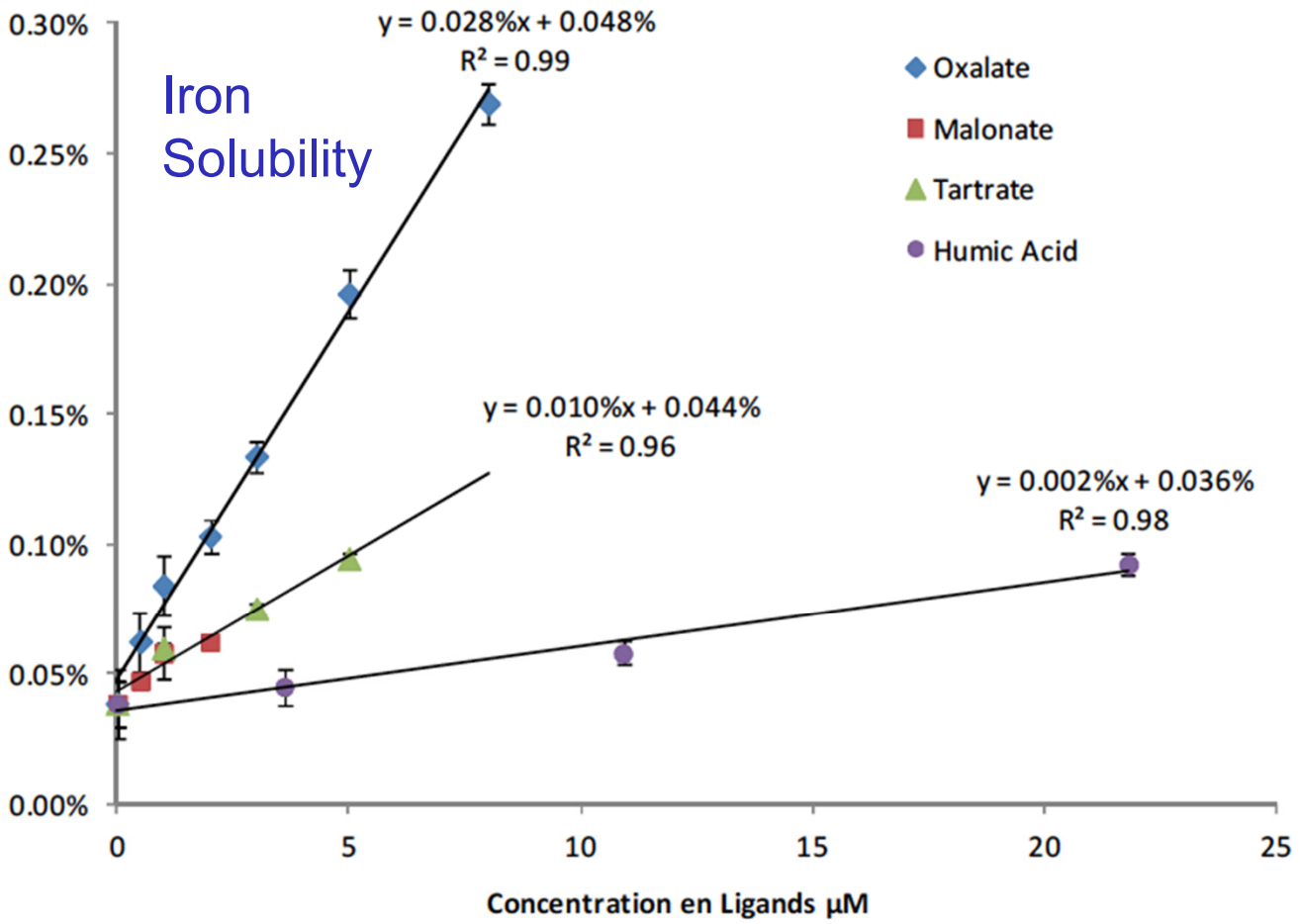
Kanakidou Global Biogeochemical Cycles 2012

Ever-Crowded Chemical Skies



Organics
Ligands

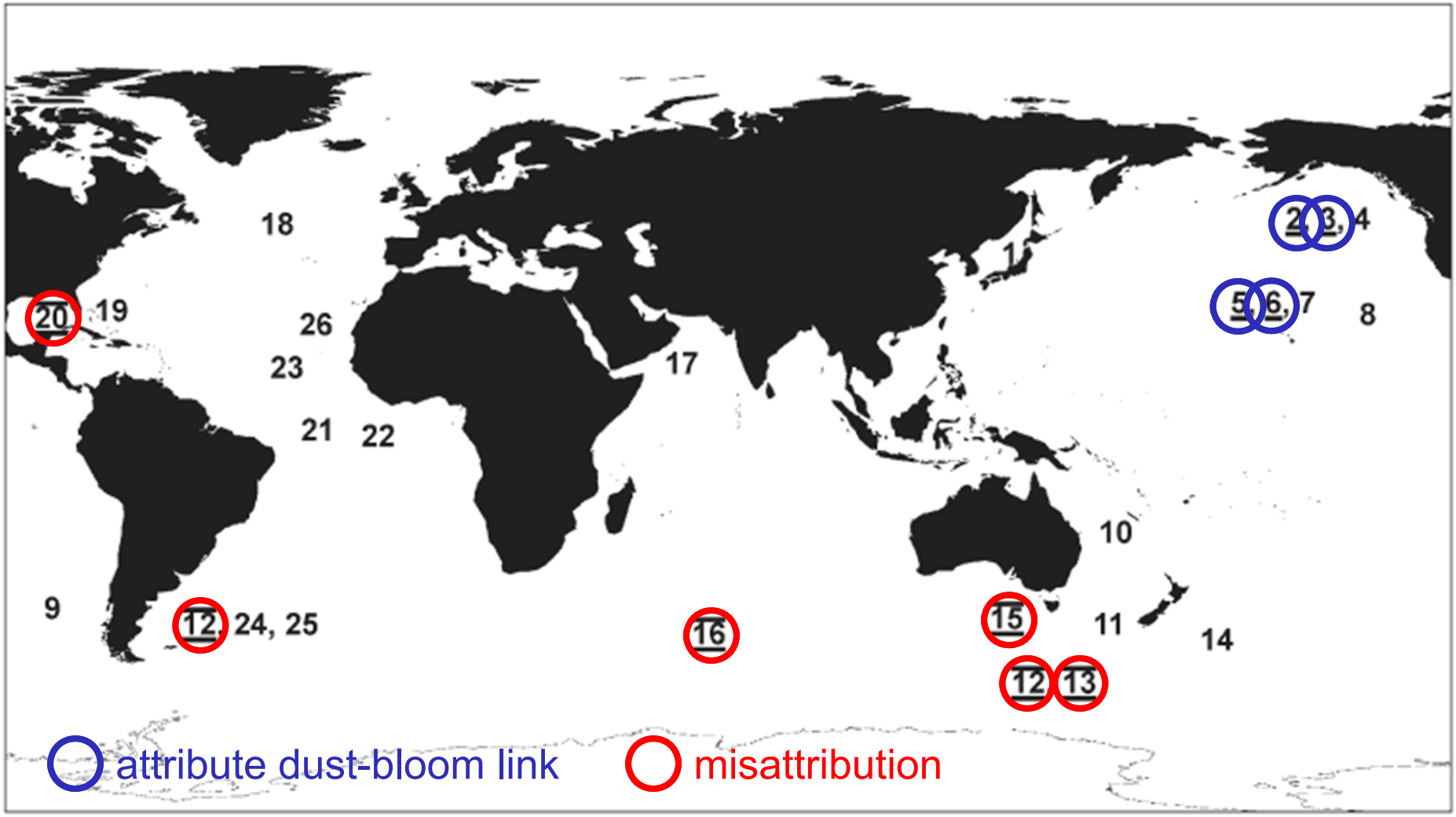
Anthro N, Cu, V, Zn …



Ligand Concentration

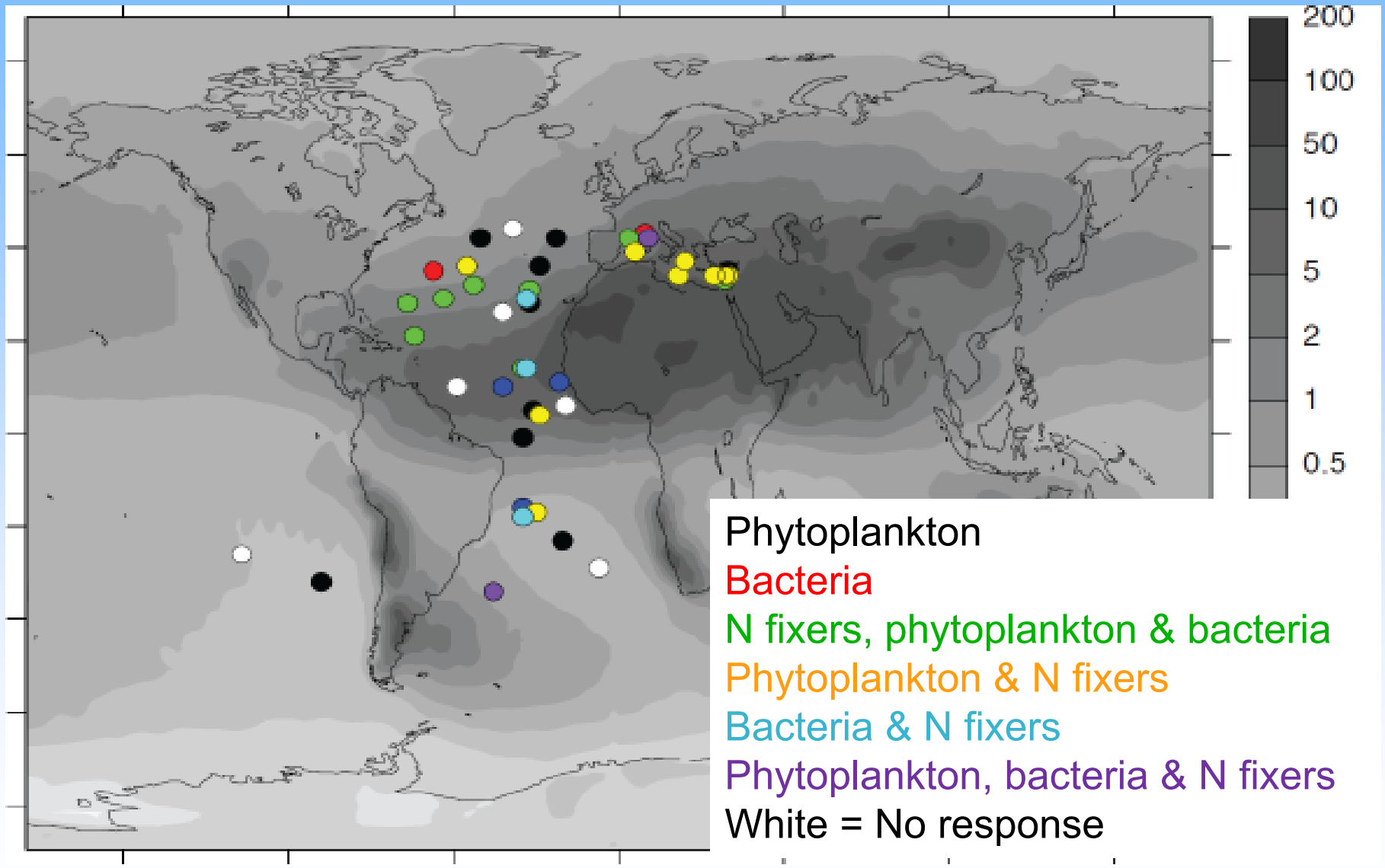
Paris Desboeufs
Atmos. Chem. Phys. 2013

Re-evaluating Dust-Iron-Phytoplankton Bloom Links



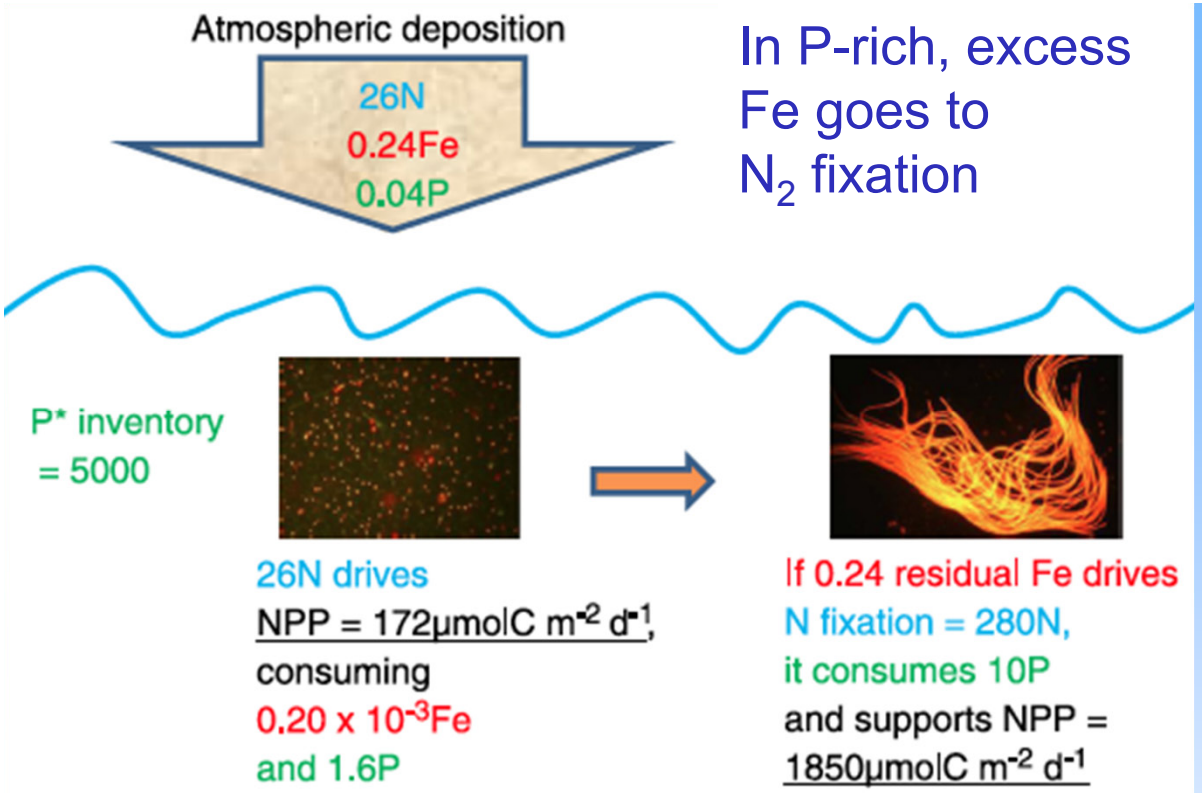
Boyd et al. Marine Chemistry 2010

In Situ Microbial Responses to Dust Additions



Moore et al. Nature Geosciences 2012

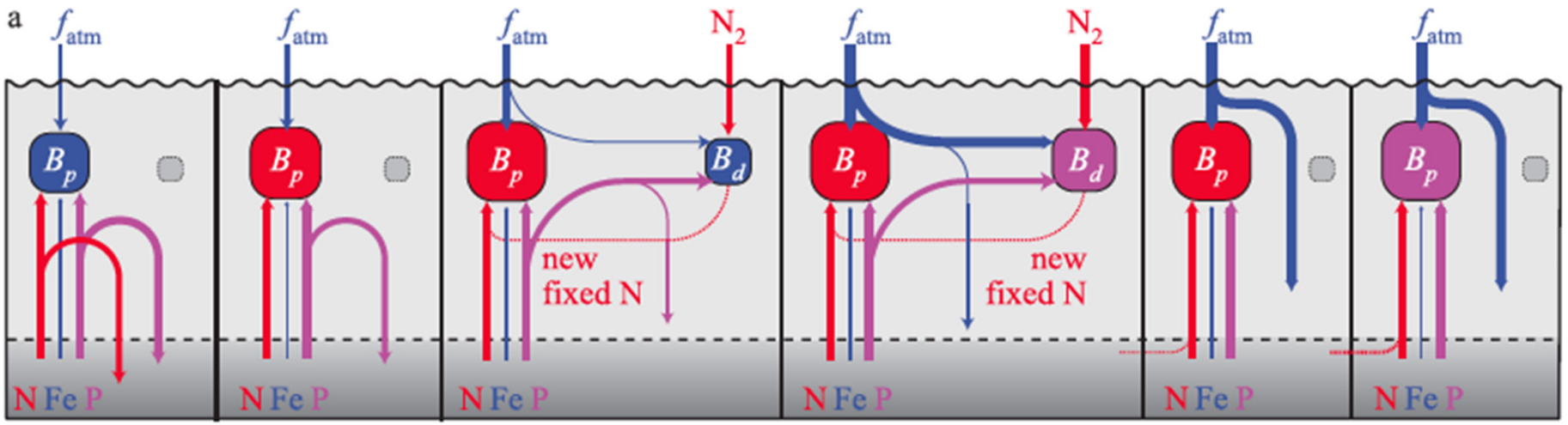
Impact of Atmospheric Elemental Stoichiometry



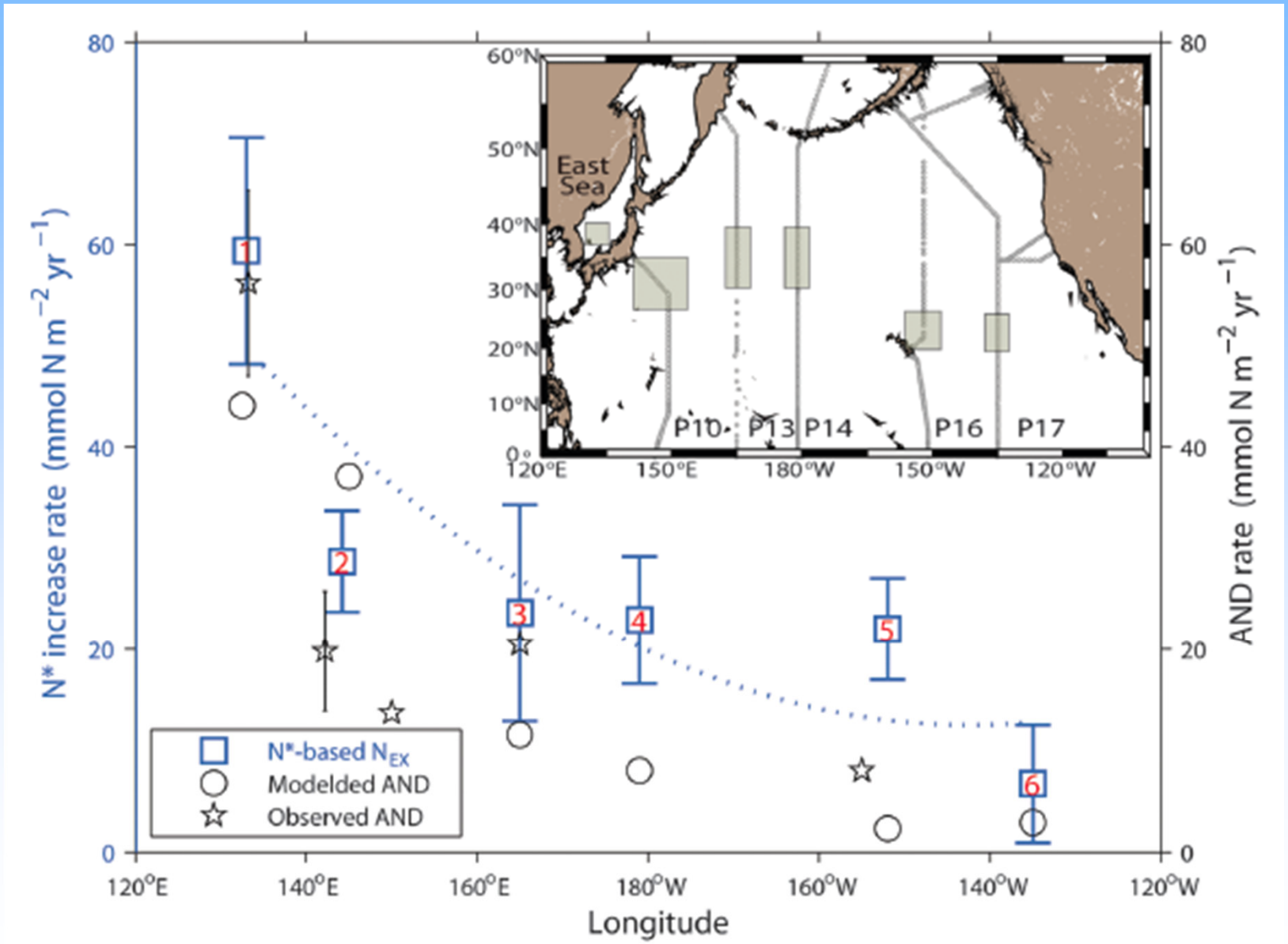
Martino et al. Global Biogeochemical Cycles 2014

Ward et al. Limnology & Oceanogr. 2013

Increasing Fe:N supply ratio → Decreasing P:N supply ratio →



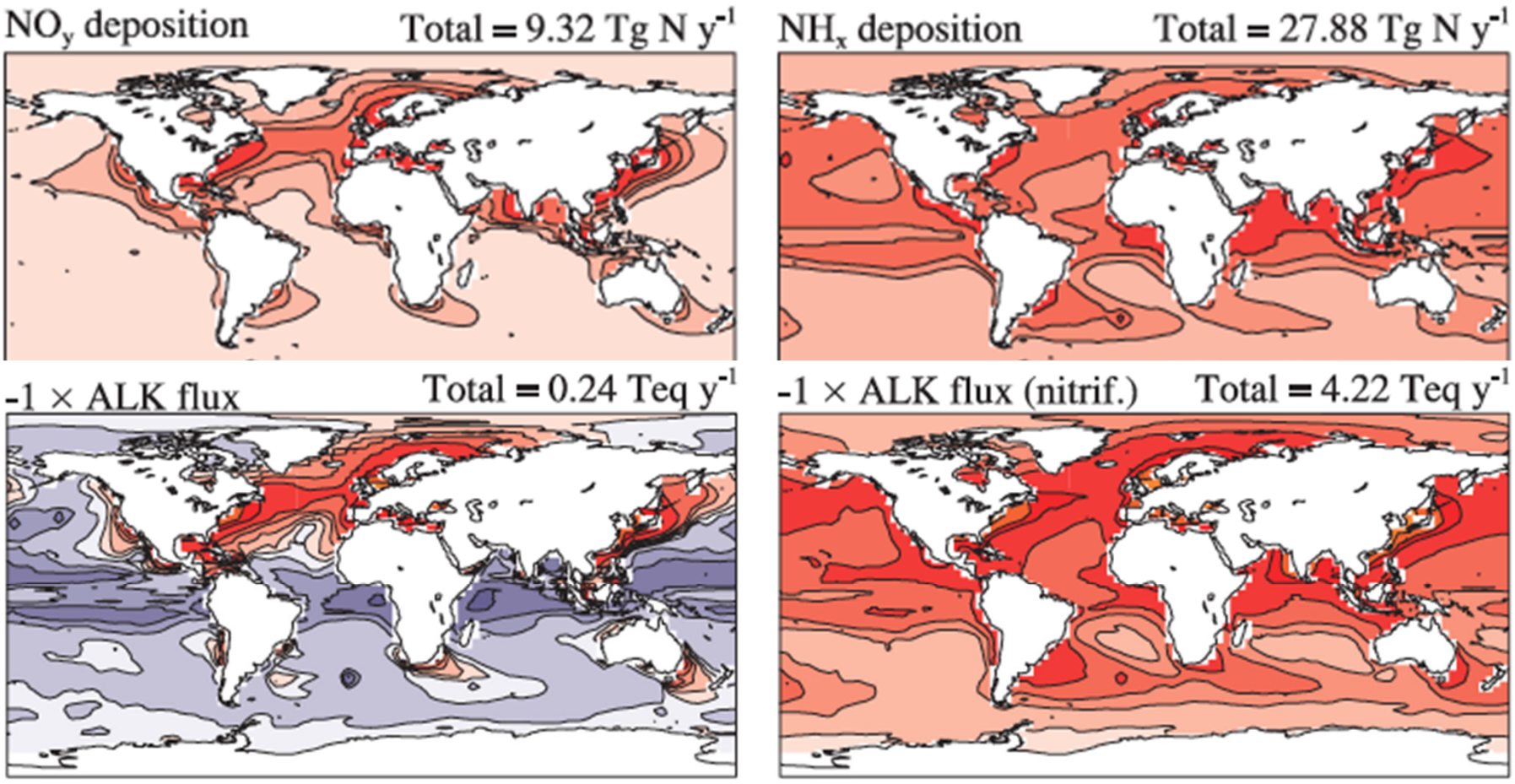
Atmospheric N Deposition & N* Trend



Kim et al. Science 2014

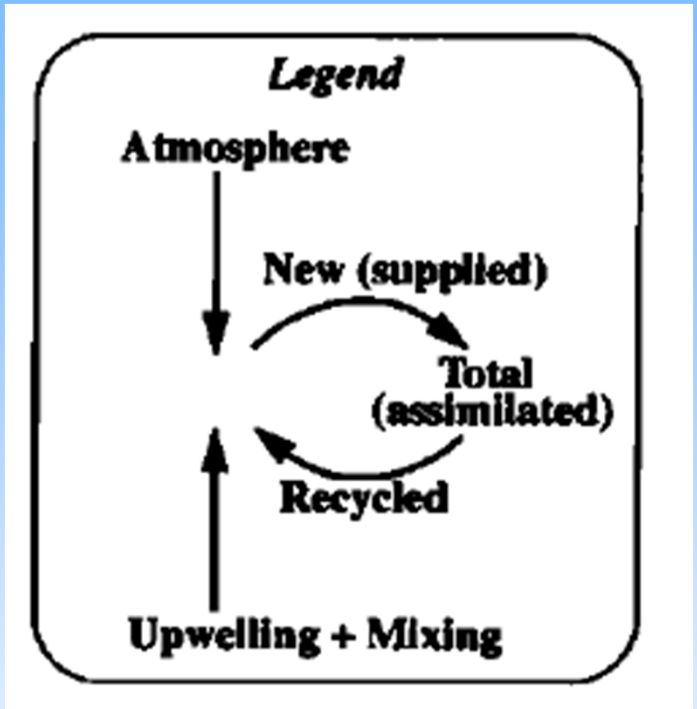
Anthropogenic Nitrogen Fluxes & Acidification

$$fAlk = 2fCa^{2+} - 2fSO_2 - 2fSO_4^{2-} - fNO_3^- + fNH_3 + fNH_4^+$$



Doney et al. PNAS 2007

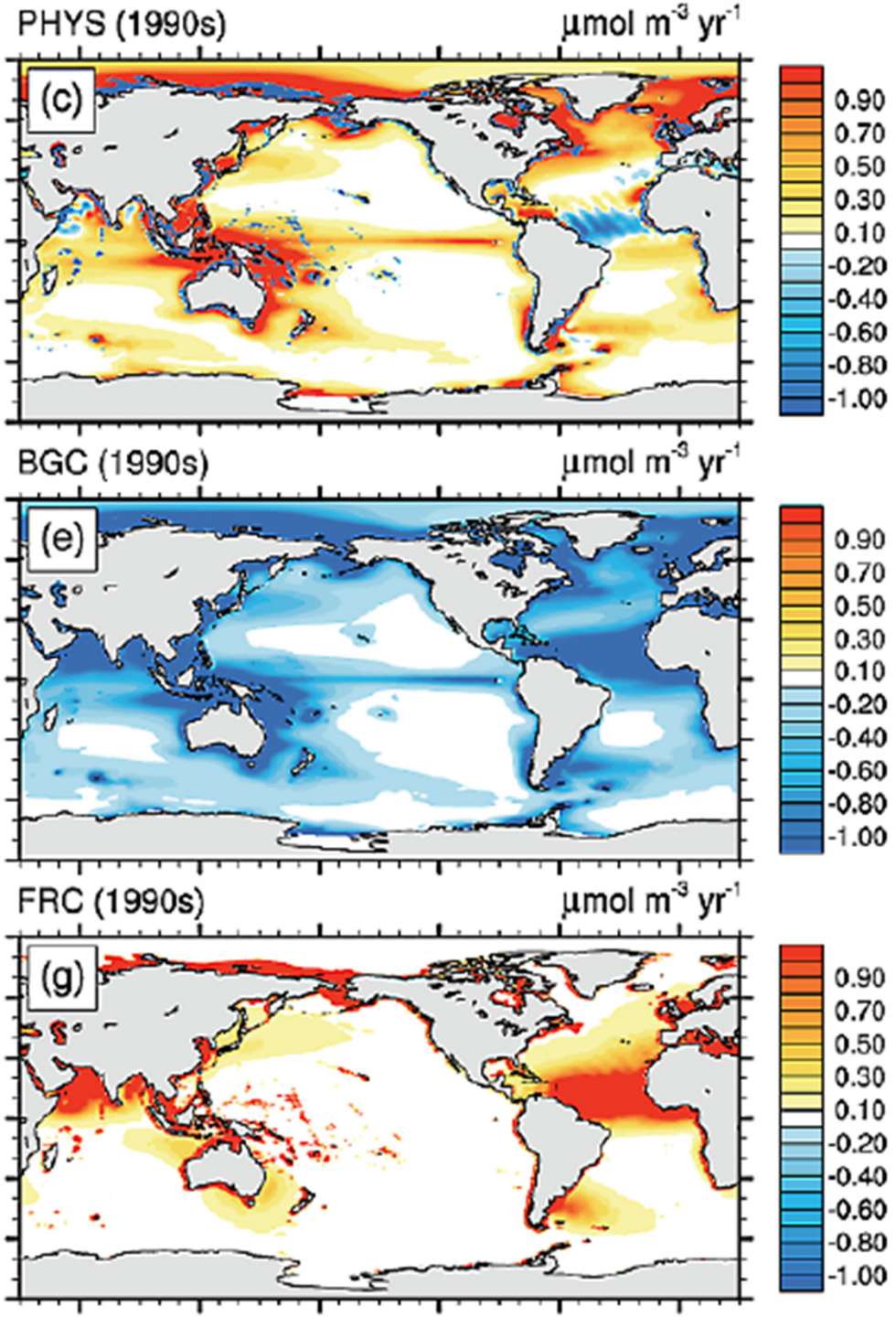
Ocean Inputs



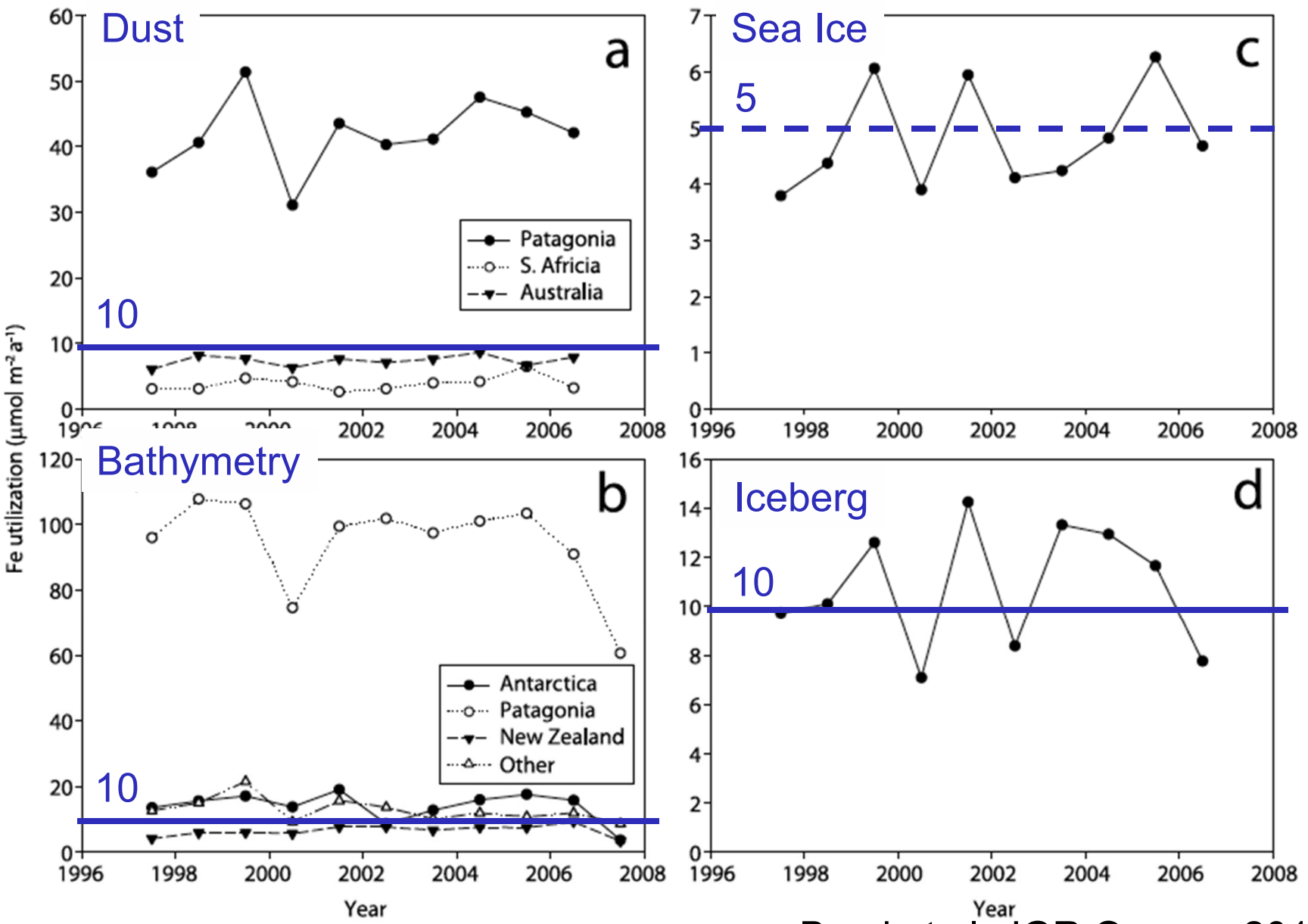
Fung et al.
Global Biogeochemical Cycles
2000

See also Boyd et al.
J. Geophys. Res. 2012

Misumi et al.
Biogeosciences
2014

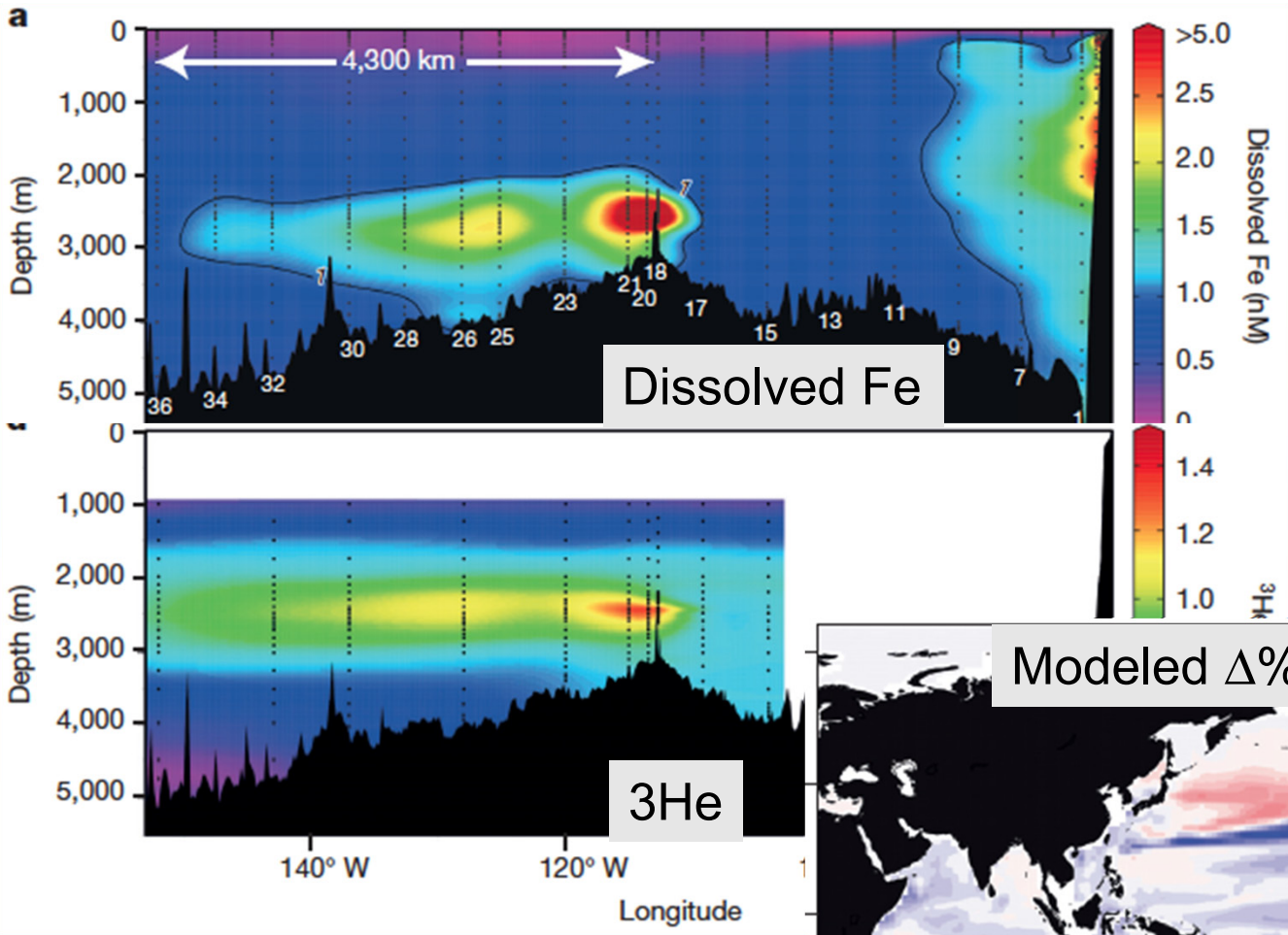


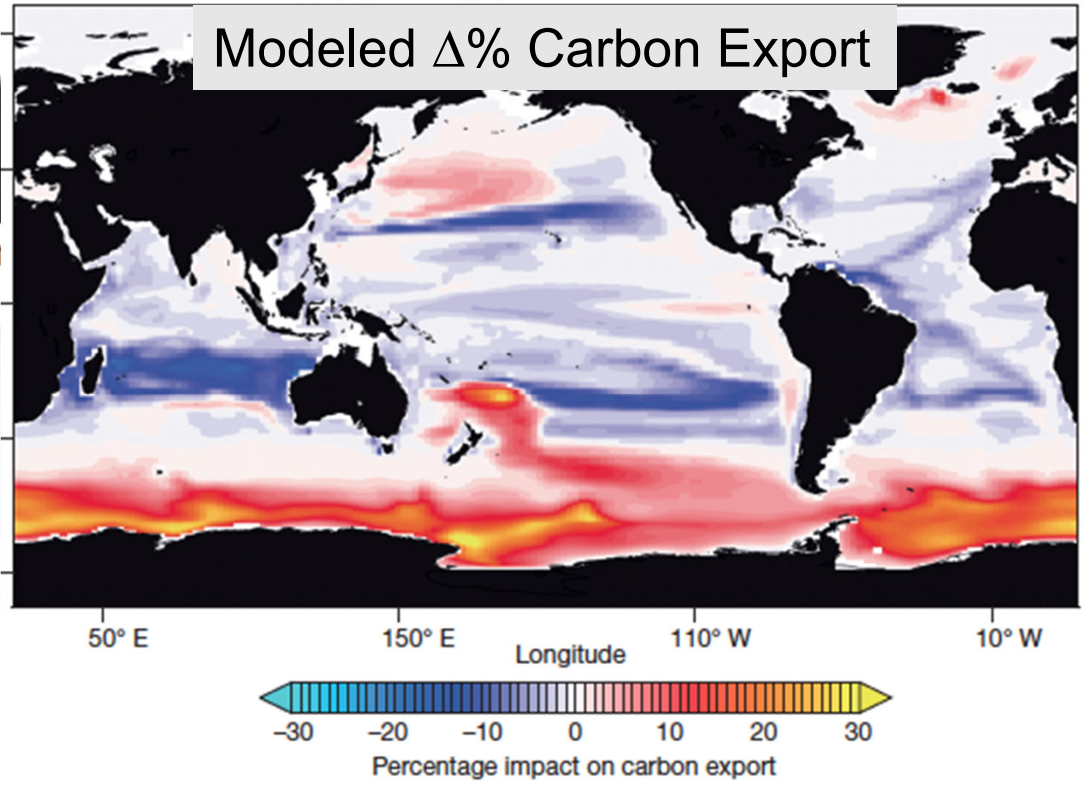
Southern Ocean Iron Sources



Boyd et al. JGR Oceans 2013

Hydrothermal Iron Source & Impacts on Export Production





Resing et al. Nature 2015

See also
Saito et al.
Nature Geosci. 2013

Evolving Questions on Atmospheric Inputs

Overlay of natural variability on anthropogenic trends

Composition, bioavailability & stoichiometry (Fe, P, N, etc.)

- source variations (e.g., soils, combustion, agriculture)
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Atmospheric Nutrient Deposition: Impacts on Marine Ecosystem & Biogeochemical Cycles

Fabien Paulot: Global oceanic emission of ammonia: Constraints from seawater and atmospheric observations

Meredith Hastings: Stable isotopes as tracers of anthropogenic nitrogen sources, deposition, and impacts

Ray Najjar: Deposition of Atmospheric Nitrogen to Coastal Ecosystems (DANCE): a study in seasonally oligotrophic waters off the eastern U.S.

J. Keith Moore: Impacts of atmospheric nutrient deposition (N, P, Fe) on marine productivity and the CO_2 system

Alex Baker: Atmospheric and marine controls on aerosol iron solubility and bioavailability in seawater

Adina Paytan: Aerosols and trace metal toxicity

Discussion on potential SOLAS-OCB partnering opportunities

SOLAS Mid-Term White papers

Atmospheric control of nutrient cycling and production in the surface ocean

Dust in Earth System context
(Jickells et al. Science 2005)

Synthesis of mesoscale iron enrichments
(Boyd et al. Science 2007)

Anthropogenic atmospheric N–impact on ocean
(Duce et al. Science 2008)