The Iron Jigsaw:

Modeling the Impact of Deserts, Wildfires, and Climate Change on the Iron Deposition into the Oceans

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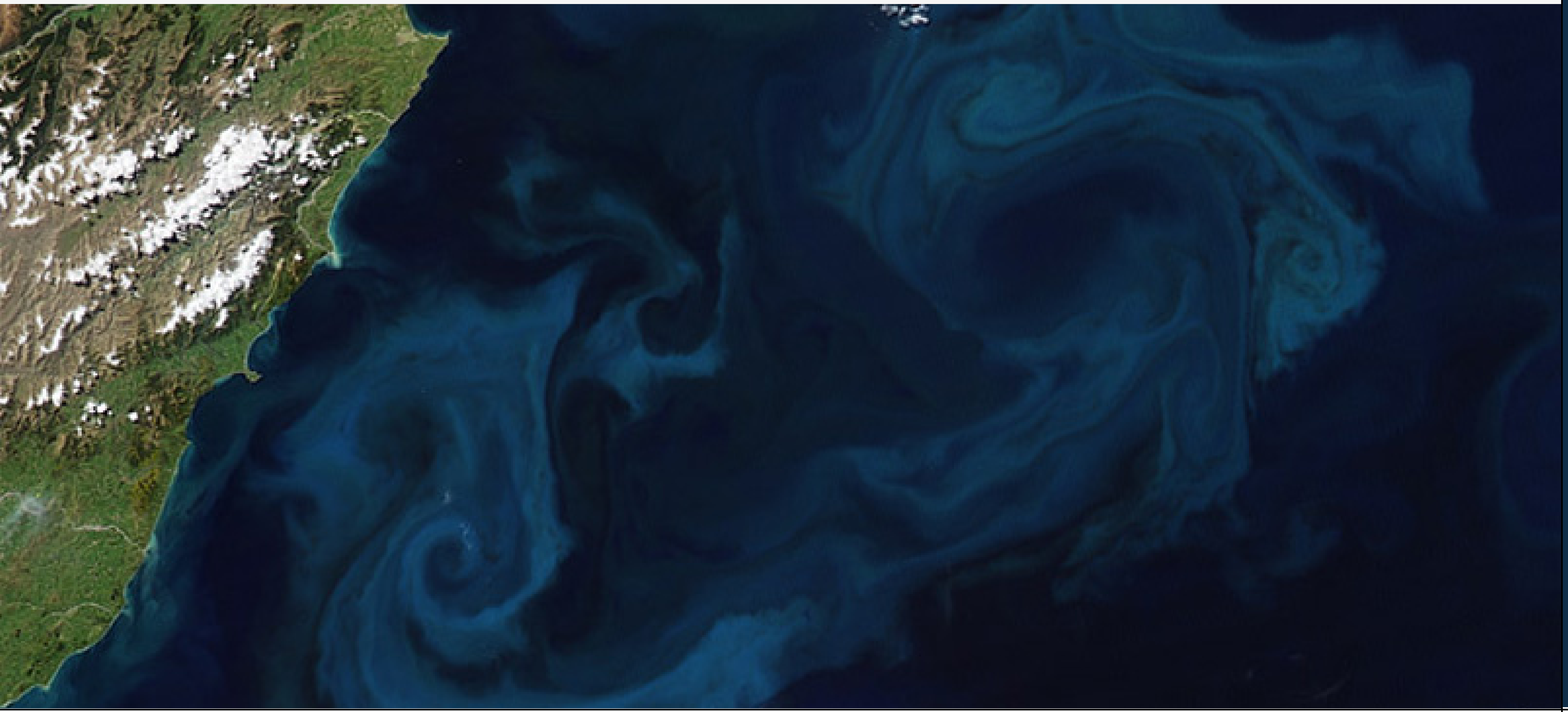
BARCELONATECH

SEVERO OCHOA RESEARCH SEMINAR

6TH JULY 2023

EXCELENCIA SEVERO OCHOA

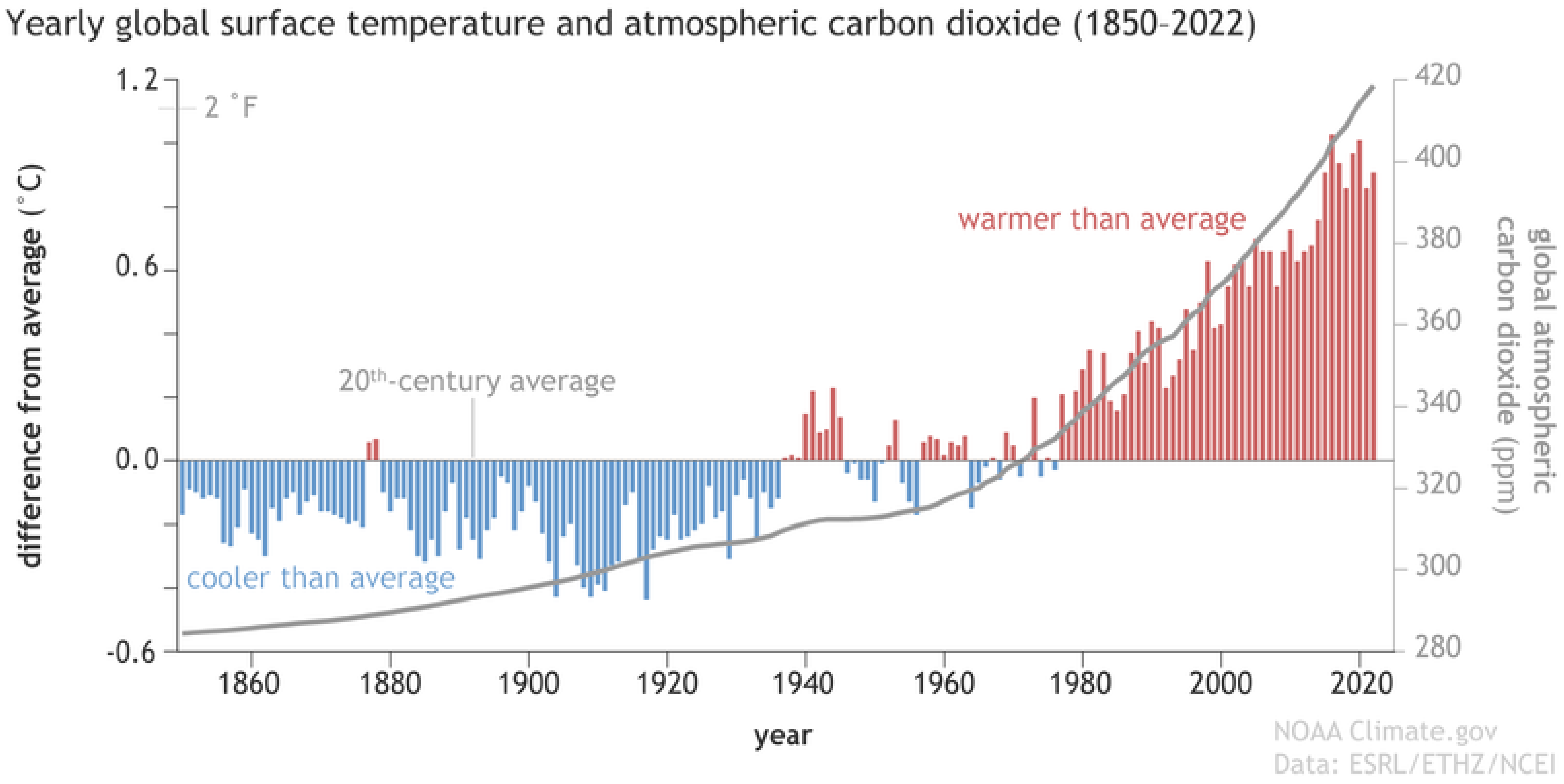
Outline



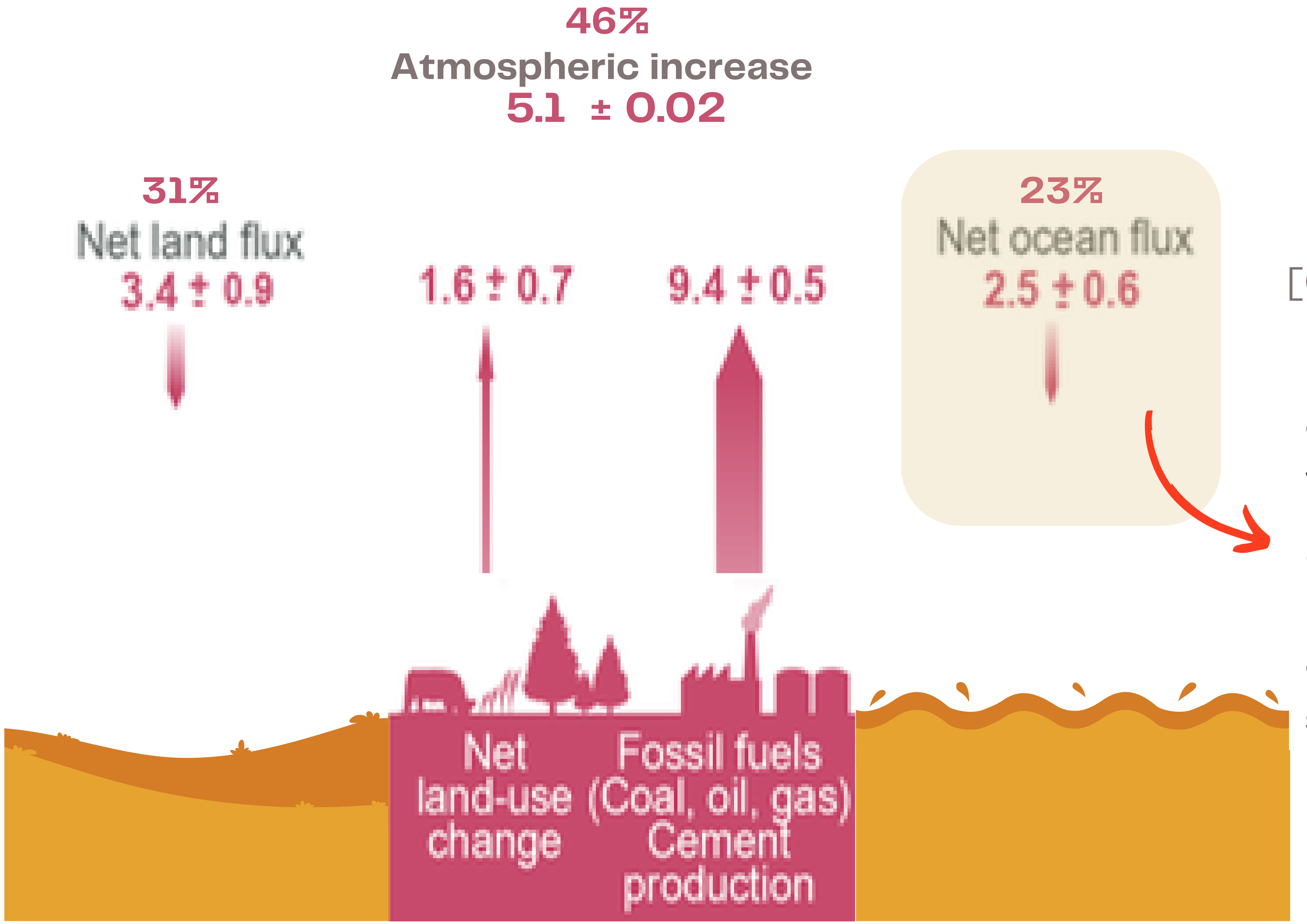
MAIN POINTS:

In a Global Warming Context

The atmospheric CO_2 growth rate has never been that high❗



Anthropogenic CO_2 cycle



[Gt CO_2/yr]

How does the ocean sink work ?

Can we increase the ocean carbon sink ?

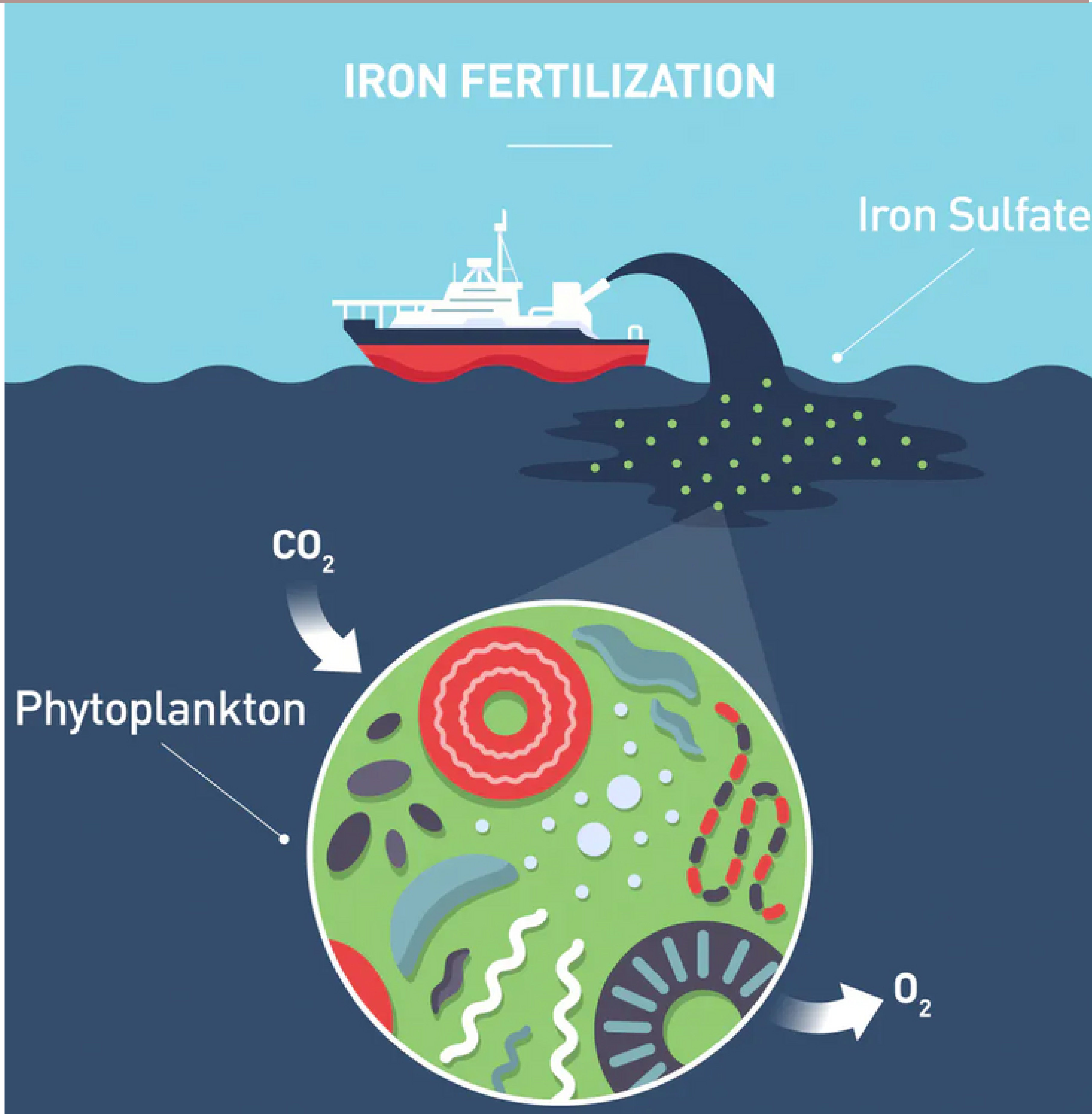
(modified based on Figure 5.3 in IPCC, 2021)

The Iron Hipothesis

"Give me half a tanker of iron, and I will give you an ice age."

– J.Martin 1988

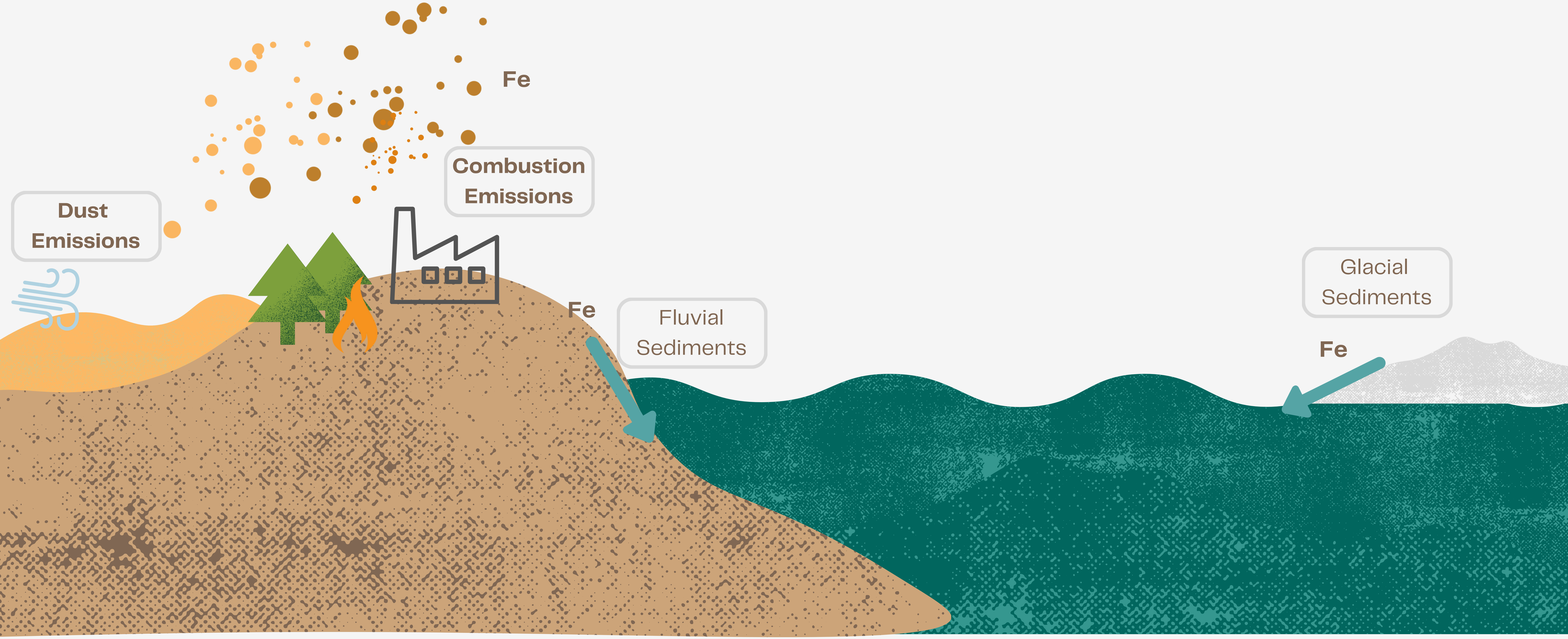
*ocean fertilization is currently prohibited by the London Protocol



Lou Patrick Mackay/Futurism

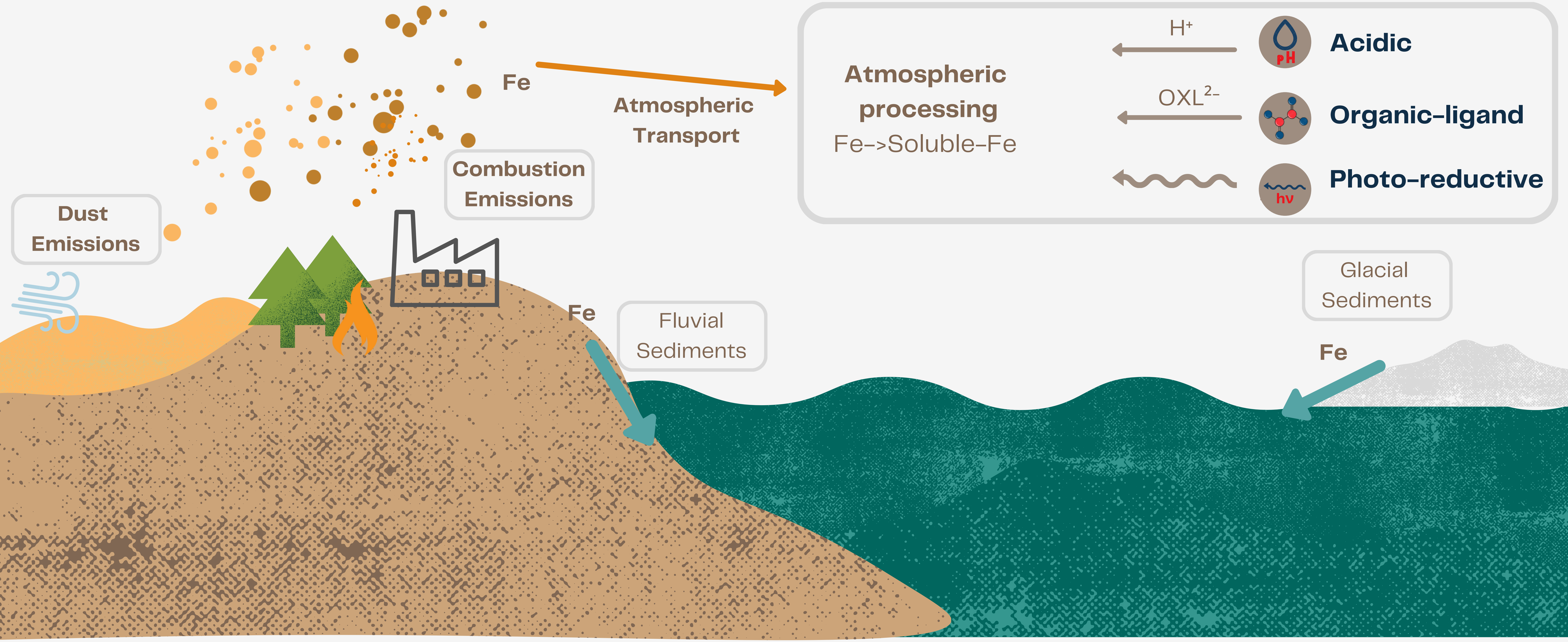
THE IRON CYCLE

1.EMISSIONS



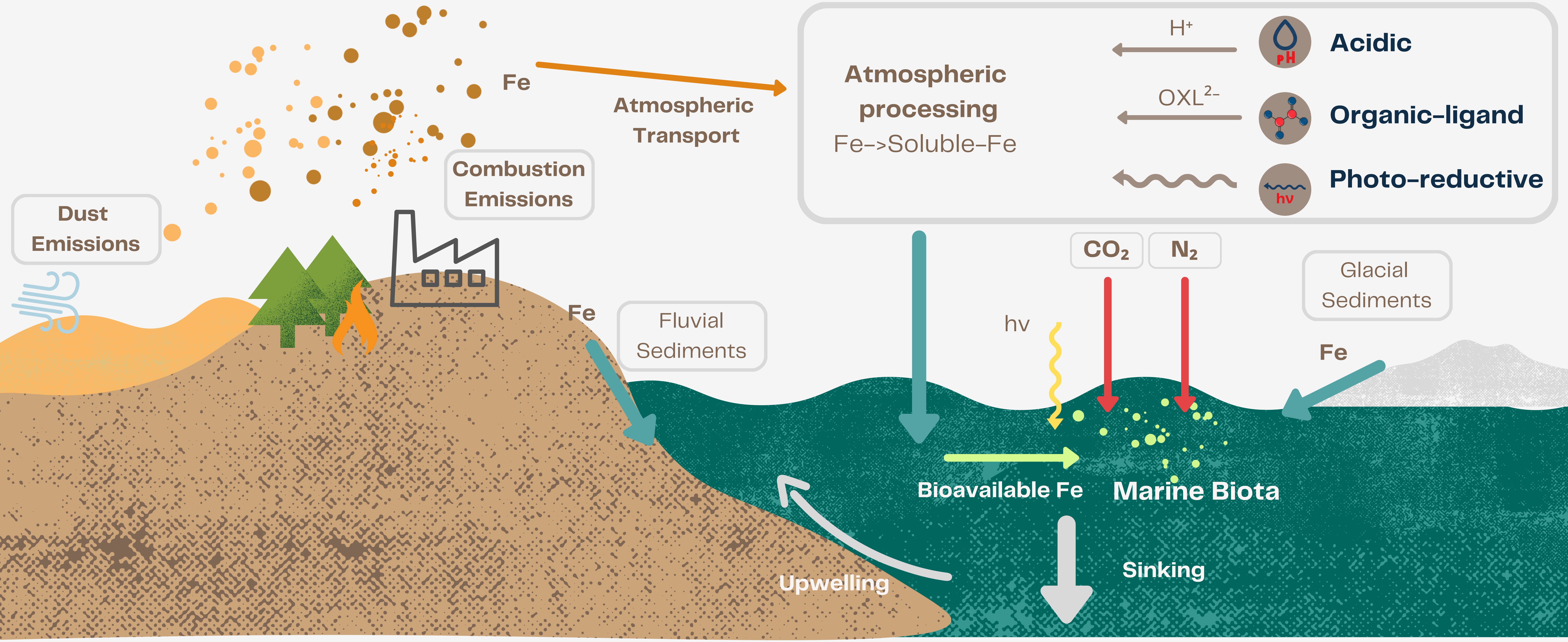
THE IRON CYCLE

2. ATMOSPHERIC PROCESSING



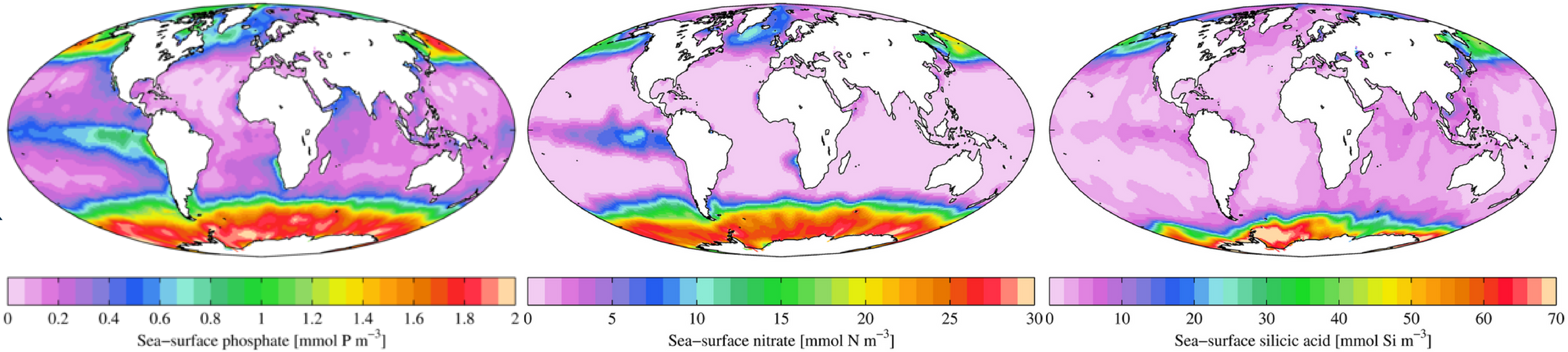
THE IRON CYCLE

3. DEPOSITION & OCEAN BIOGEOCHEMISTRY



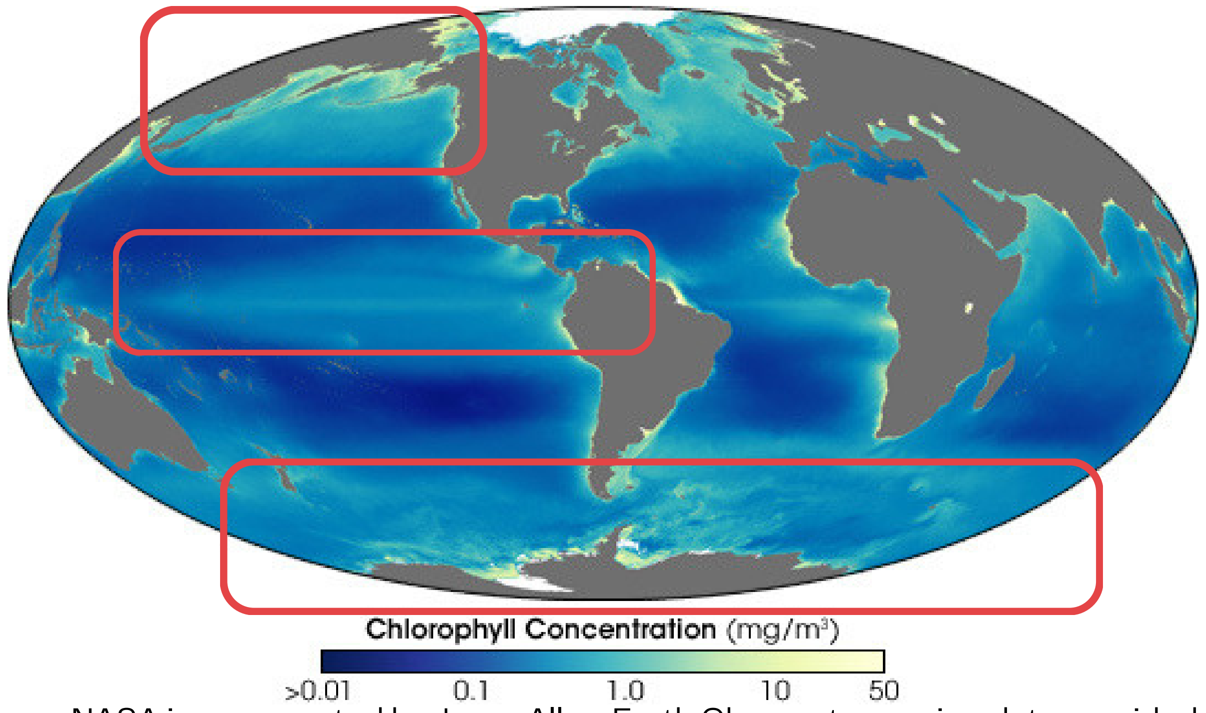
High Nutrient Low Chlorophyll Region

High Nutrient



Annual mean sea surface phosphate, nitrate and silicic acid from the World Ocean Atlas 2009, https://ca.wikipedia.org/wiki/Regions_HNLC

Low Chlorophyll



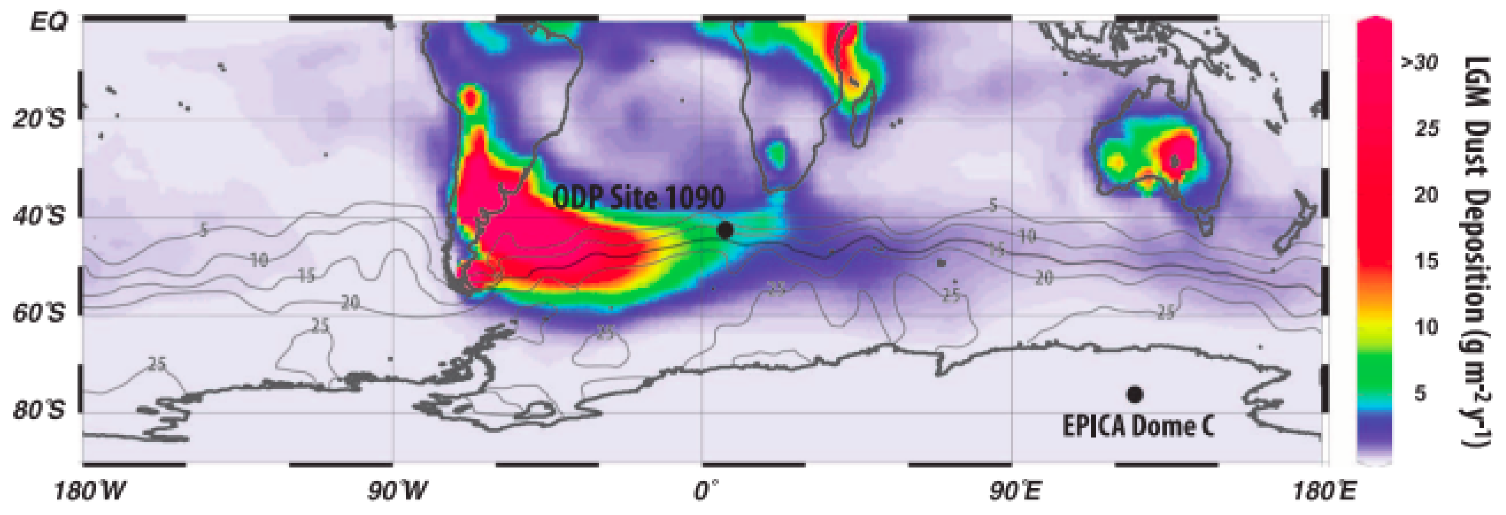
NASA image created by Jesse Allen, Earth Observatory, using data provided courtesy of the SeaWiFS Project, NASA/Goddard Space Flight Center, and ORBIMAGE.

Fe is the limiting factor for marine productivity in HNLC regions

"anemic ocean regions"

Evidences of High Iron Deposition in the Last Glacial Maximum

Peak glacial times are characterized by **increases in dust flux, productivity, and the degree of nitrate consumption**; this combination is consistent with Subantarctic iron fertilization.

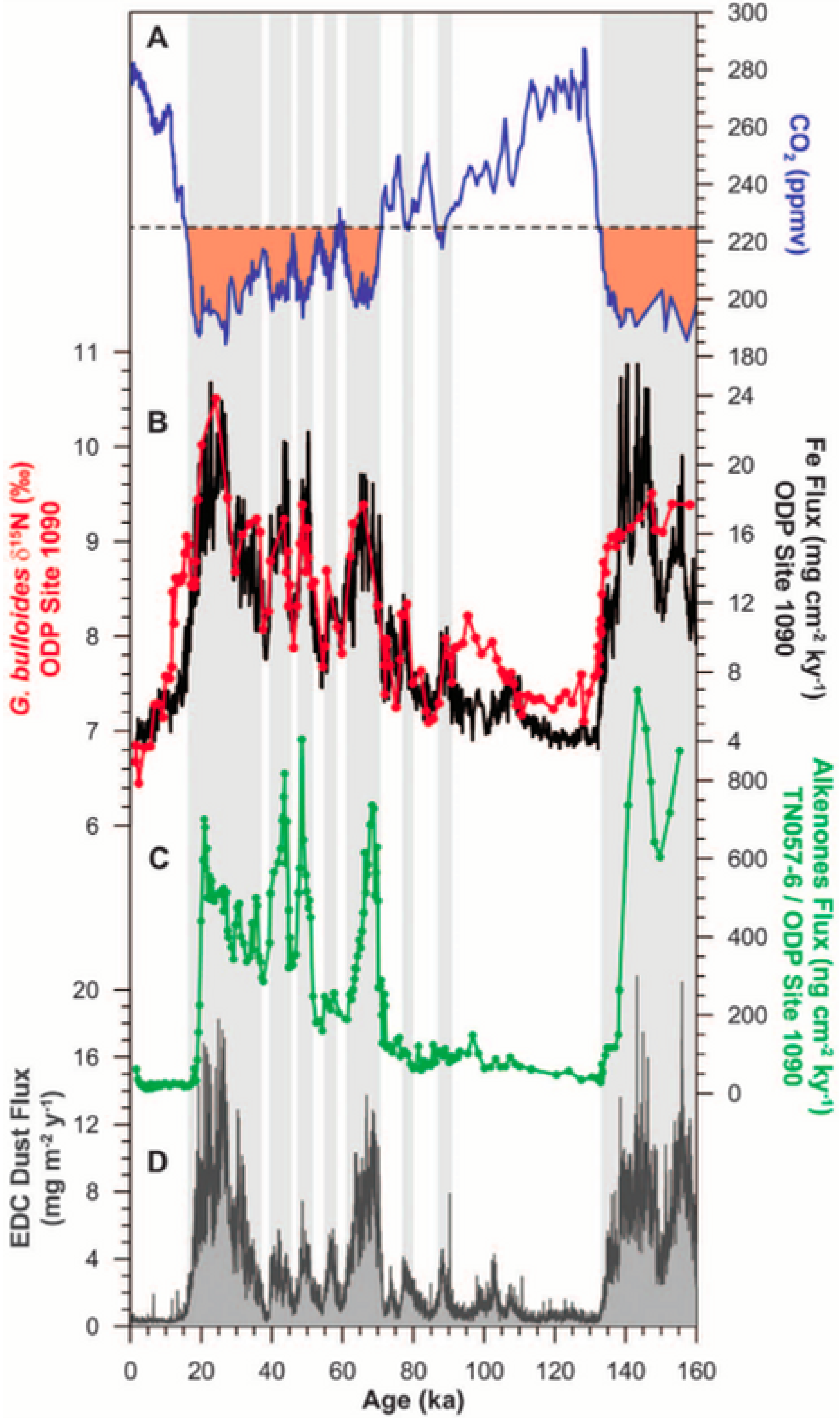


Atmospheric CO_2 concentrations measured in Antarctic ice cores

Iron flux from ODP Site 1090

Alkenone flux, proxy for **ocean productivity** at ODP Site 1090

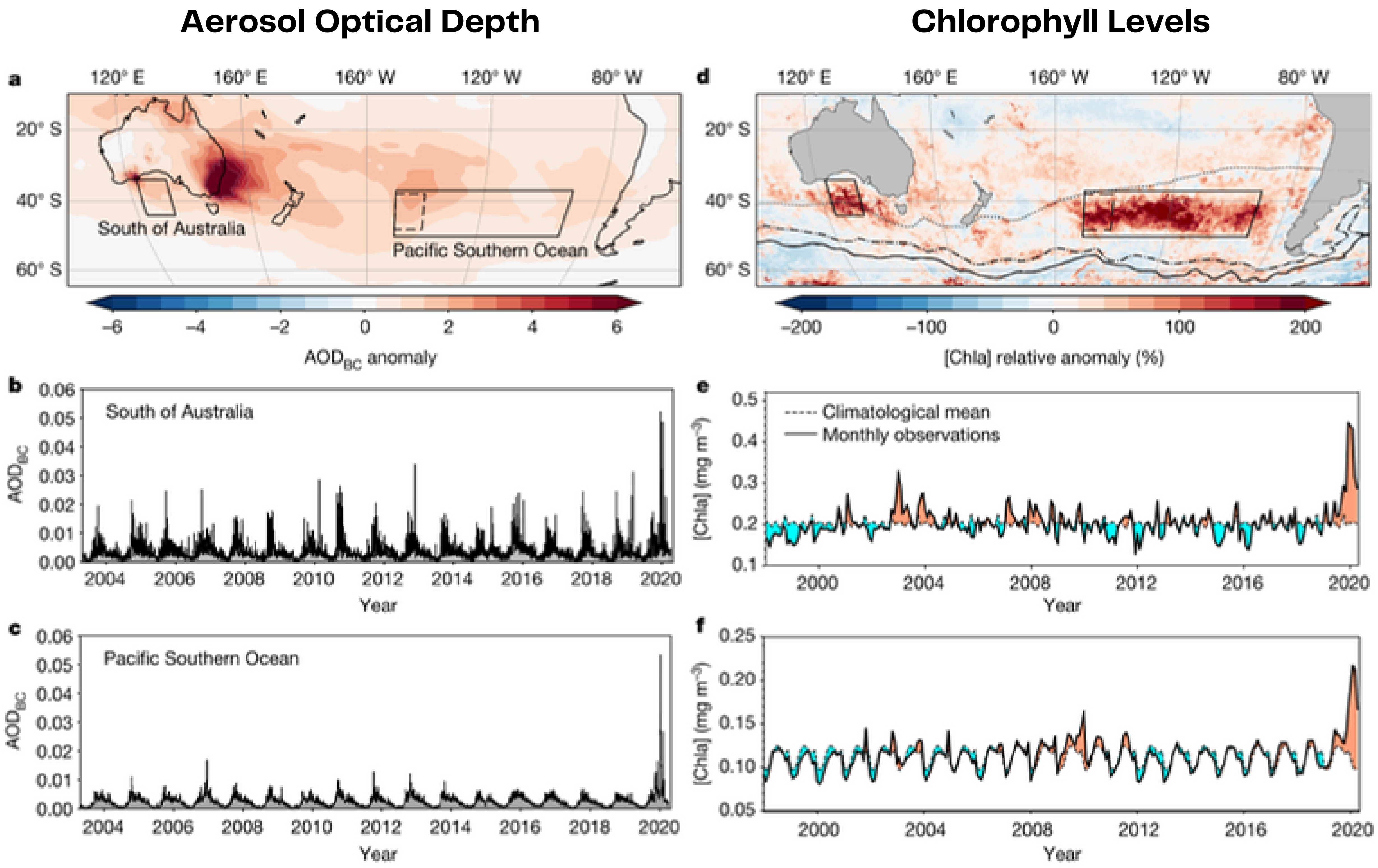
Dust flux at Antarctic ice core EPICA Dome C



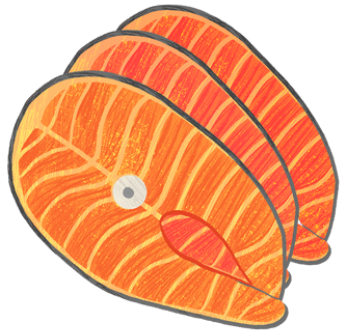
(Martínez-García A et al., 2014)

Importance of Biomass-Burning Iron

- Widespread **phytoplankton blooms triggered by 2019–2020 Australian wildfires** (Tang et al 2021)



Other Implications of Iron Fertilization



To Increase Salmon Populations, Company Dumped 110 Tons of Iron Into the Pacific Ocean

Adding iron to the ocean can make life bloom, but scientists are uneasy about the potential unknown consequences

Far-field effects like "**nutrient robbing**":
enhanced macronutrient uptake by phytoplankton due to iron addition in one region may deprive another region downstream of nutrients and thereby reduce productivity

Increase in the surface water concentrations of a range of climate-relevant gases associated with phytoplankton growth.

- dimethylsulphide (DMS) emissions → cloud formation.

...

Our Scientific Questions

The overarching goal of this work is to **improve our understanding and quantify the atmospheric supply of bioavailable iron (Fe) to the ocean and its climate impacts.**

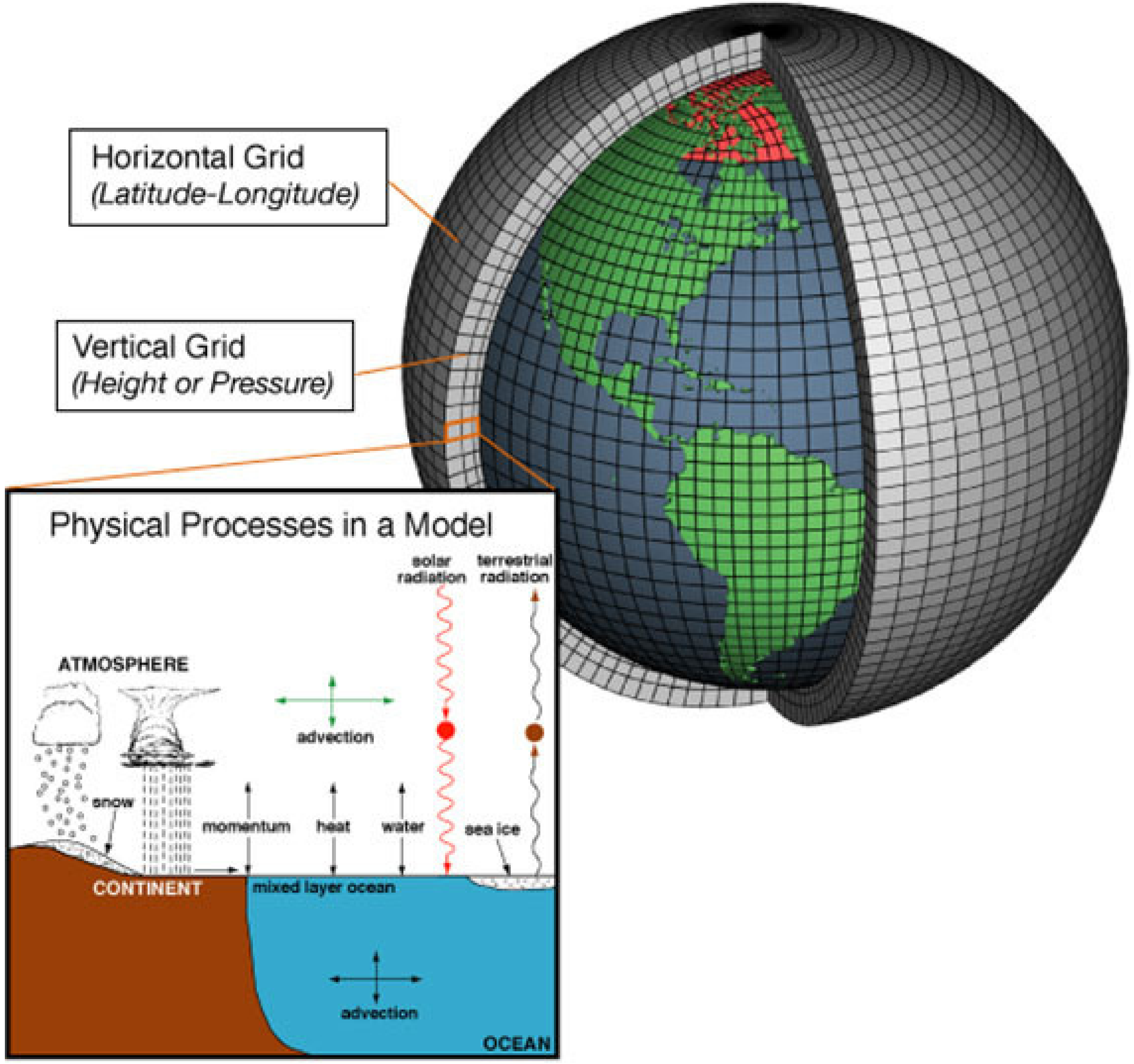
- **relative role of the natural vs anthropogenic sources**
- **different contribution of atmospheric dissolution mechanisms**

changes in past, present-day, and future in the soluble Fe deposition to the ocean

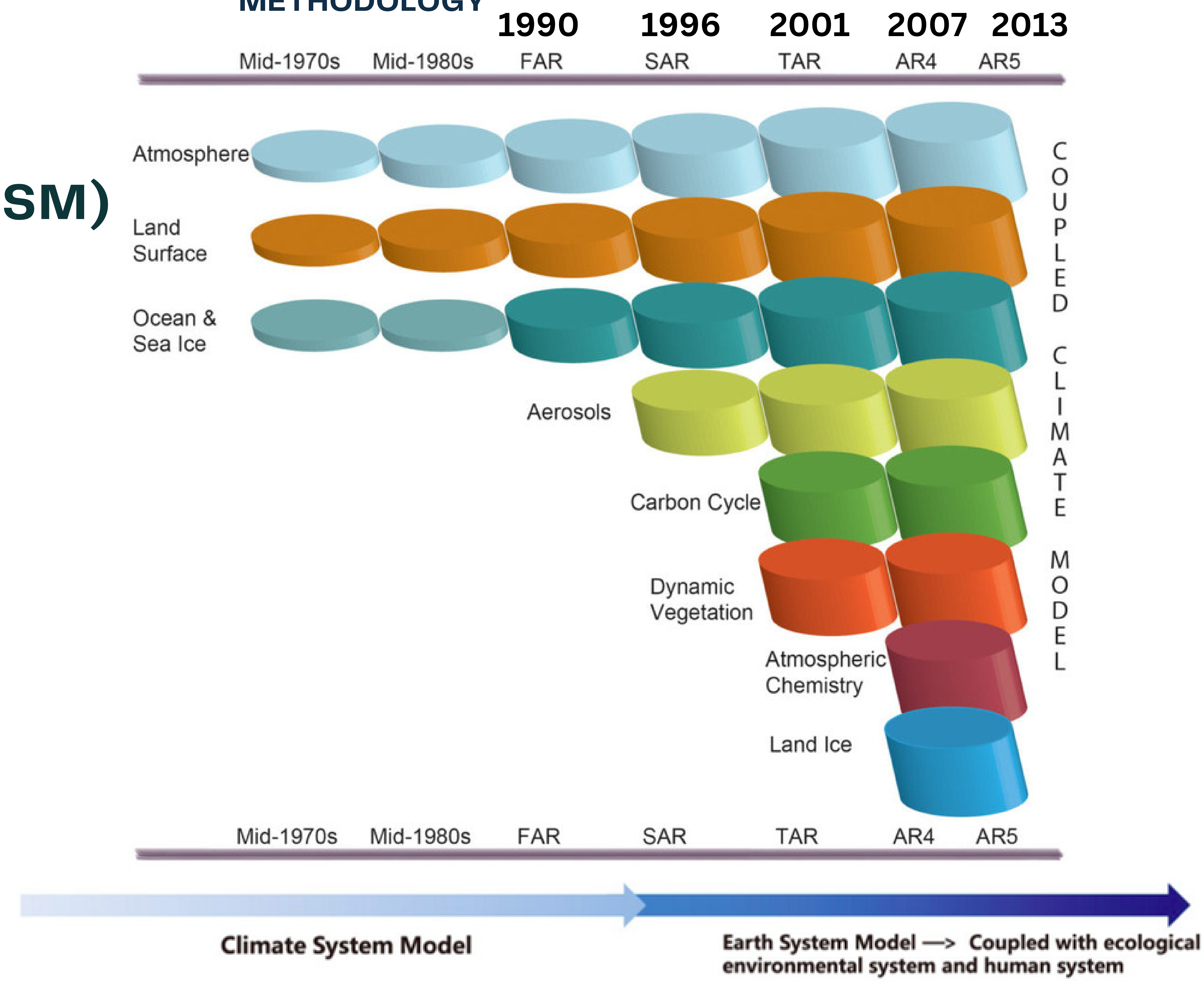
Alteration of global biogeochemical cycles due to changes in soluble iron deposition

Methodology

Climate System Model



Earth System Model (ESM)



(modified based on Figure 1.13 of IPCC AR5)

Lines of codes …

& super-computers


```
!*
!          1.     OPTICAL PARAMETERS FOR AEROSOLS AND RAYLEIGH
                  ------------------------------------------
! N.B.: COMPUTED IN *UVRADI*
!
     -----------------------------------------------------
!*
!          2.     TOTAL EFFECTIVE CLOU
                  ---------
DO JK = 1
```

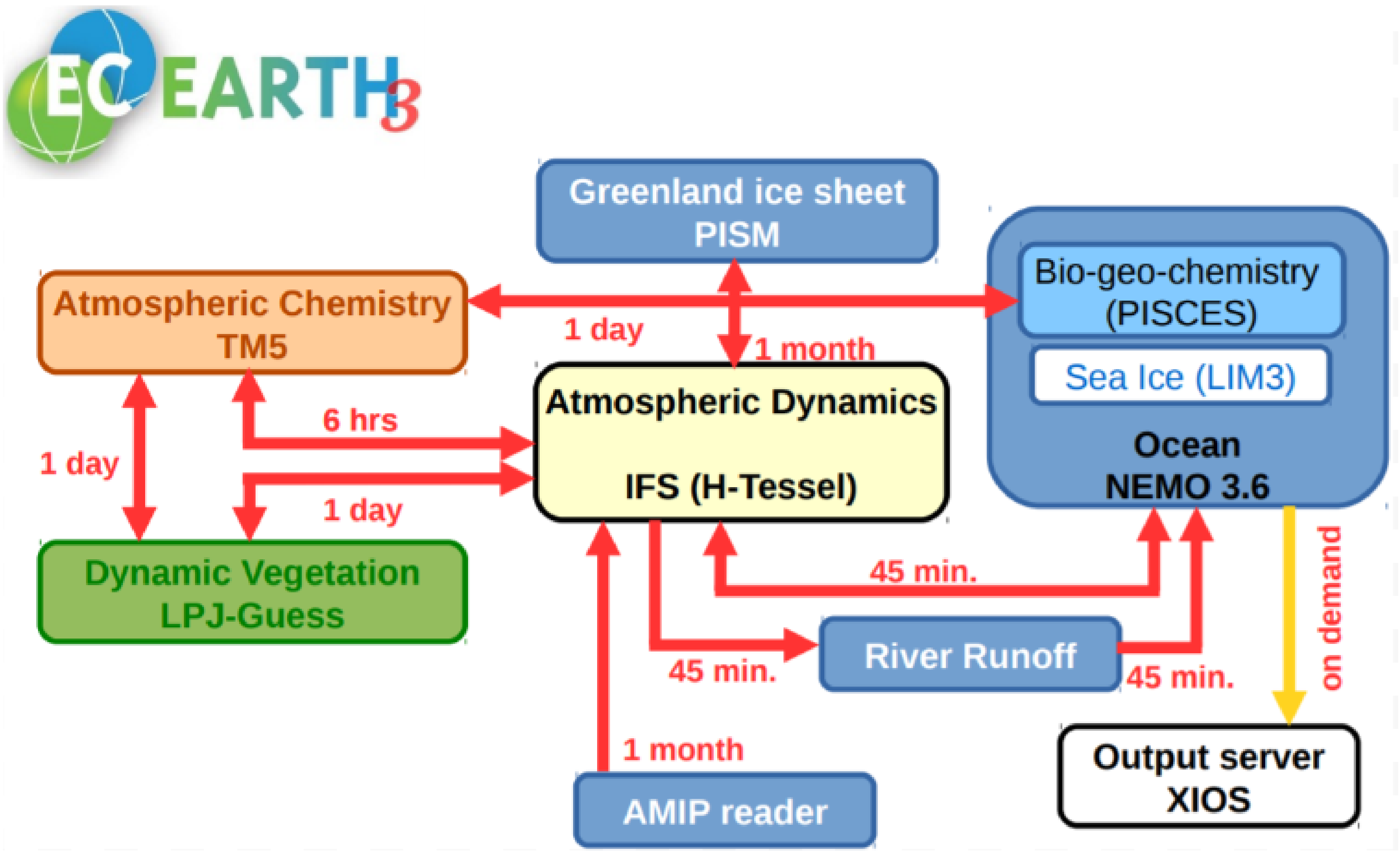
```
      END IF    ! if idust=1
               print *, 'lai_eff=1 everywhere'
      !
      !-----------------------------------------------------------------
      !     Lowering the threshold friction velocity depending on the presence of cultivations
      !-----------------------------------------------------------------
      !     Factors according to dsf increase seen in data **
      !-----------------------------------------------------------------
      umin2(i,j) = umin
      !
      !-----------------------------------------------------------------
      IF( cult(i,j) <= 0.5 .AND. cult(i,j) > 0.08 ) THEN
        IF( desert(i,j) > 0. .OR. tv_dat(iglbsfc,16)%data(i,j,1) > 50 .OR. tv_dat(iglbsfc,17)%data(i,j,1) > 50 ) &
           umin2(i,j) = umin * 0.93
        !
        !-----------------------------------------------------------------
        IF( tv_dat(iglbsfc,2)%data(i,j,1) > 50 .OR. tv_dat(iglbsfc,7)%data(i,j,1) > 50 ) &
           umin2(i,j) = umin * 0.99
      END IF !cult=2

      !
      !-----------------------------------------------------------------
      IF( cult(i,j) > 0.5 ) THEN
        IF( ( desert(i,j) > 0 ) .OR. ( tv_dat(iglbsfc,16)%data(i,j,1) > 50 ) .OR. ( tv_dat(iglbsfc,17)%data(i,j,1) > 50 ) ) &
           umin2(i,j) = umin * 0.73
      END IF !cult=1

      !-----------------------------------------------------------------
      !      Daily z0 and efficient fraction feff
      !-----------------------------------------------------------------

      i_s1 = INT( soil_type(i,j) )          ! soil type index for the calcl. of horiz. dust flux
      IF( i_s1 == 0 ) i_s1 = 9              ! set it the same as ice if the soil type is not defined

      ! Roughness length [cm] of the surface without obstacles, i.e. of the smooth surface:
      Z0S  = 0.001 !! en cm, these Marticorena p.85     ! optimum value for the calculation of energy loss
```



Schematics of the EC-Earth version 3 components and the coupling frequency between them..

Döscher et al., 2022

Challenges when Modelling the Iron Cycle

- Spatial distribution and time evolution of Fe sources
  - Dust is a non-homogeneous entity
  - Fe speciation in combustion emissions
  - Past and future of dust emissions
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- High complexity of atmospheric chemistry involved
- Few Fe-related observations

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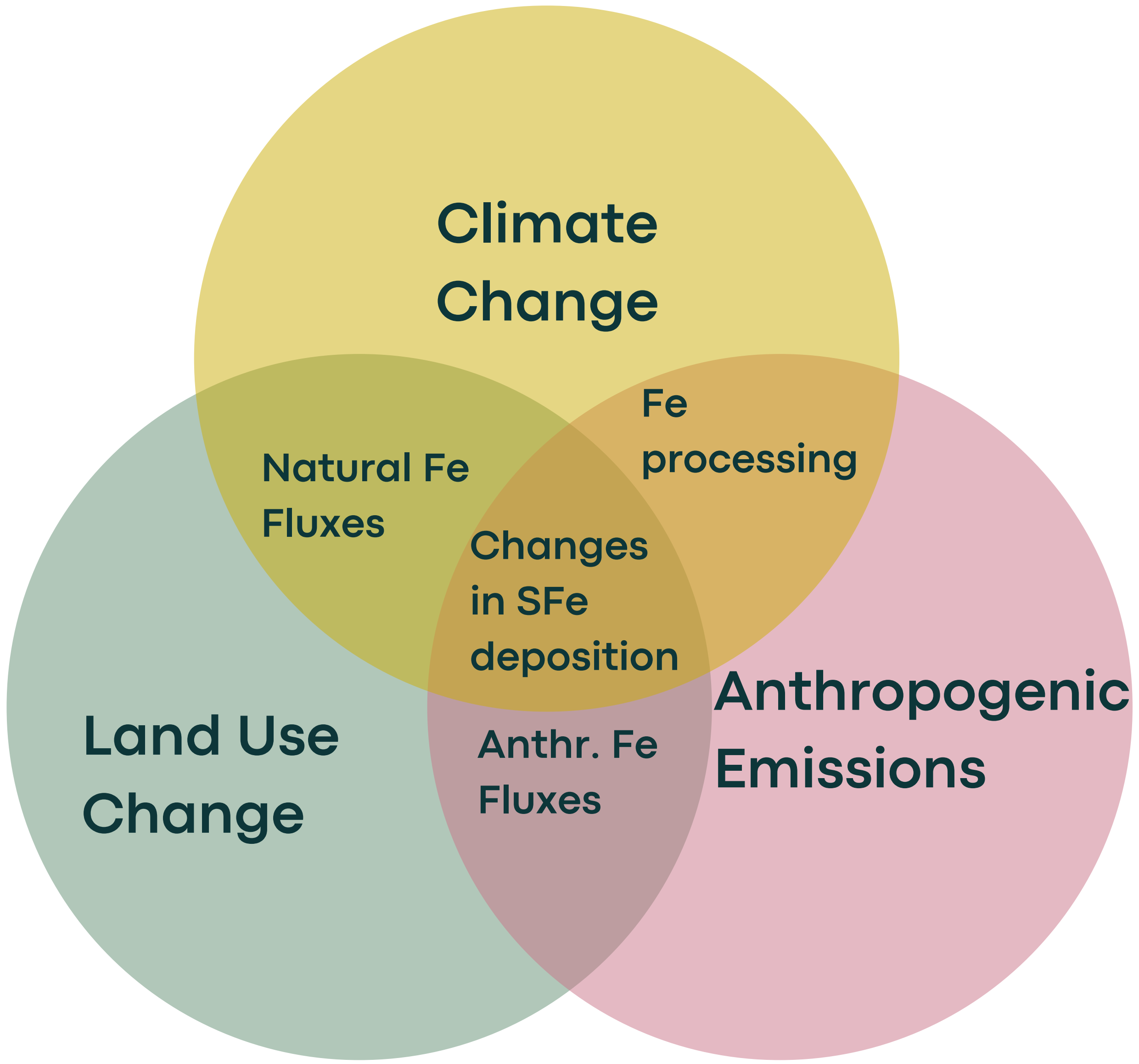

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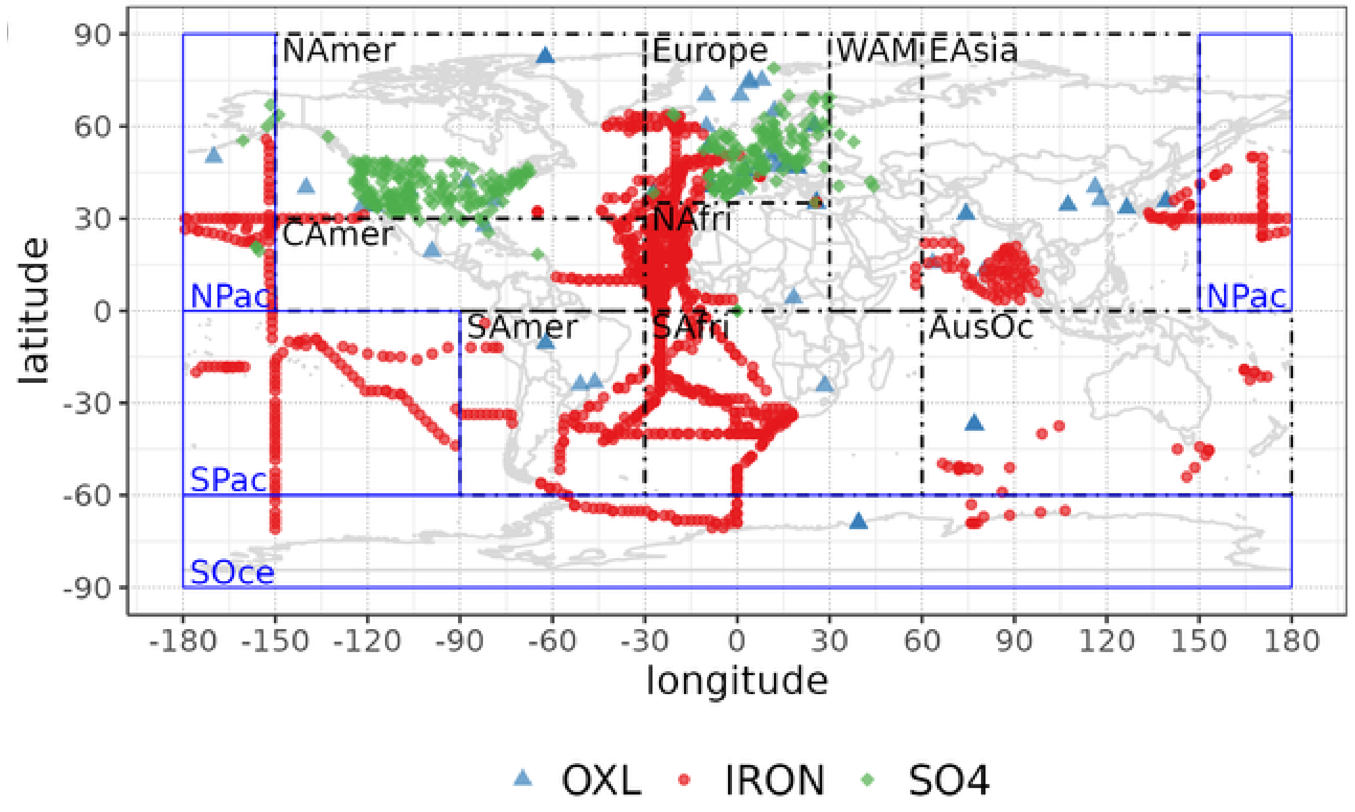


(Myriokefalitakis et al., 2022)

EC EARTH3-Iron *(Myriokefalitakis et al. 2022)*

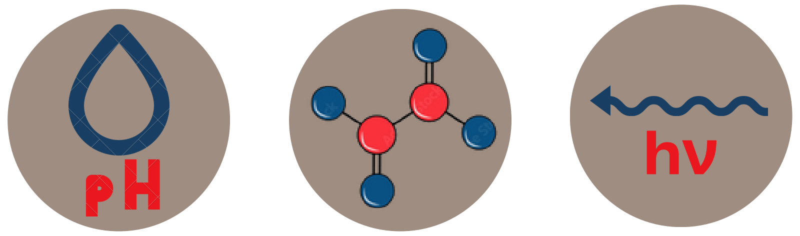
1 **New Fe tracers for the different sources (accumulation/coarse soluble/insoluble):**

- Fe-dust (soil mineralogical composition information)
- Fe-biomass burning
- Fe-anthropogenic combustion

2 **Acidity calculations** for water contained in fine and coarse aerosols, as well as, for cloud droplets

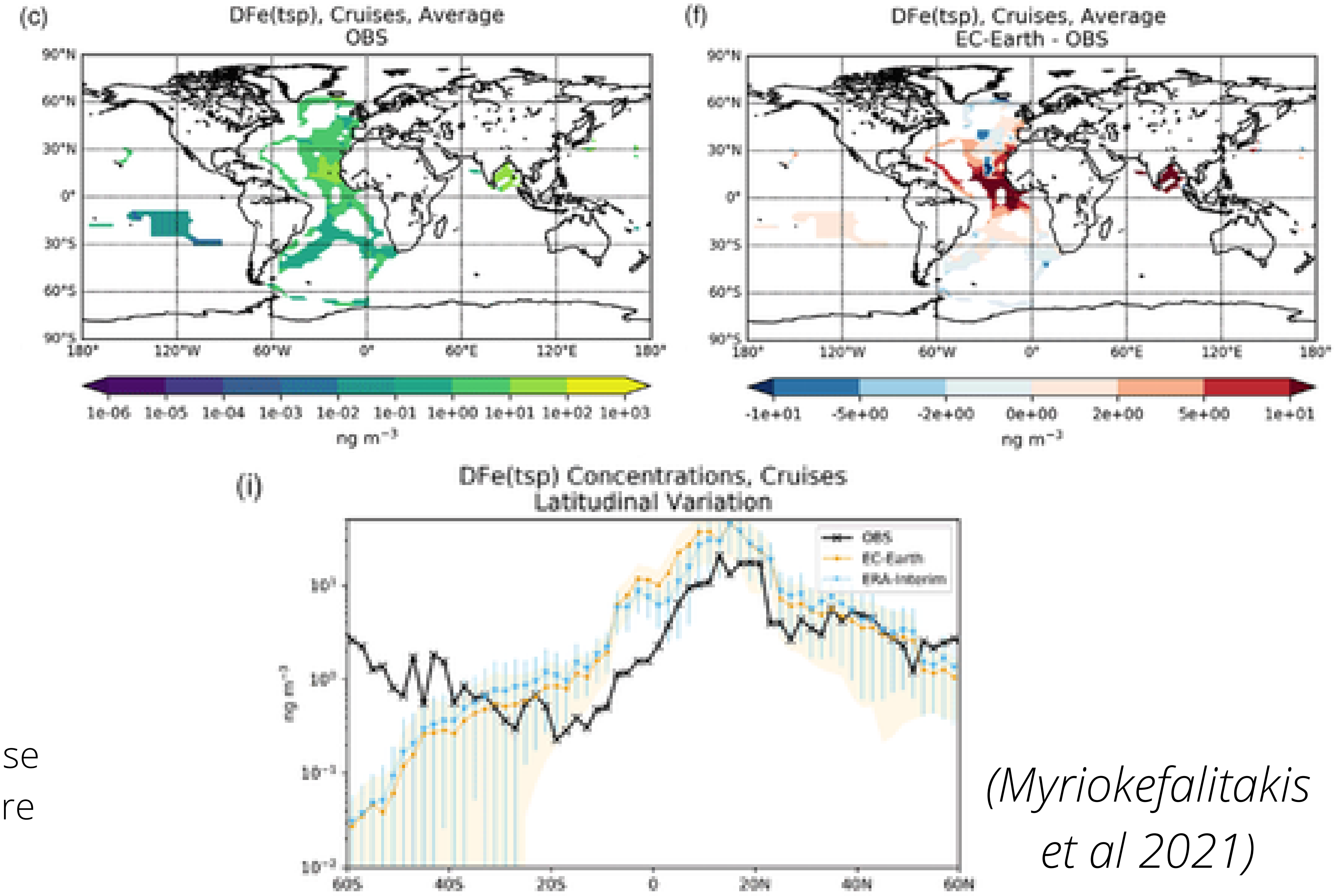
3 A **comprehensive aqueous phase chemistry scheme** in cloud droplets and aerosol water

4 An **explicit description of the Fe-containing aerosol dissolution processes**



Soluble Fe Deposition Evaluation with EC-EARTH3-Iron

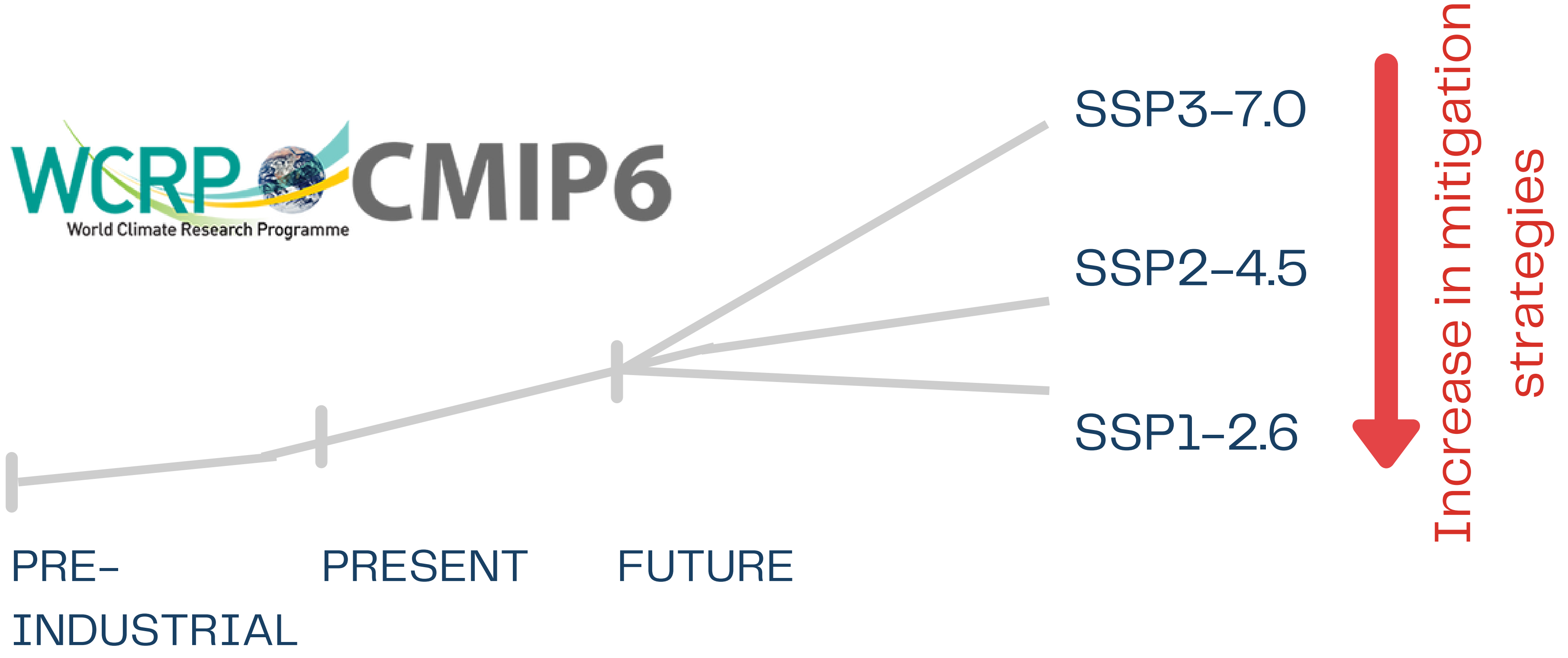
- Overestimation downwind main dusty regions
- Underestimation in south hemisphere high latitudes
- Observations are low and use different technics to measure soluble iron

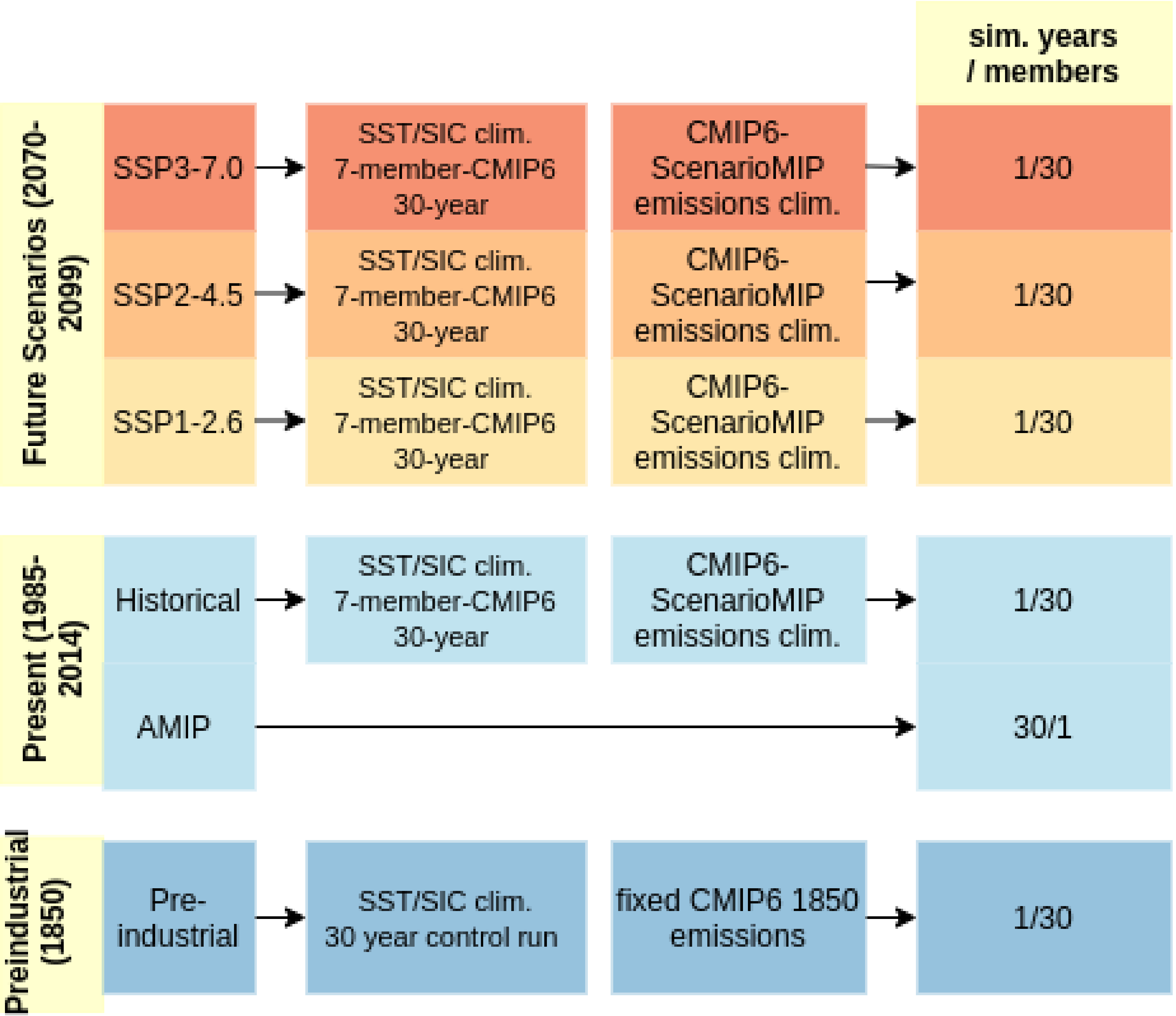


(Myriokefalitakis et al 2021)

Solube Iron Deposition Scenarios

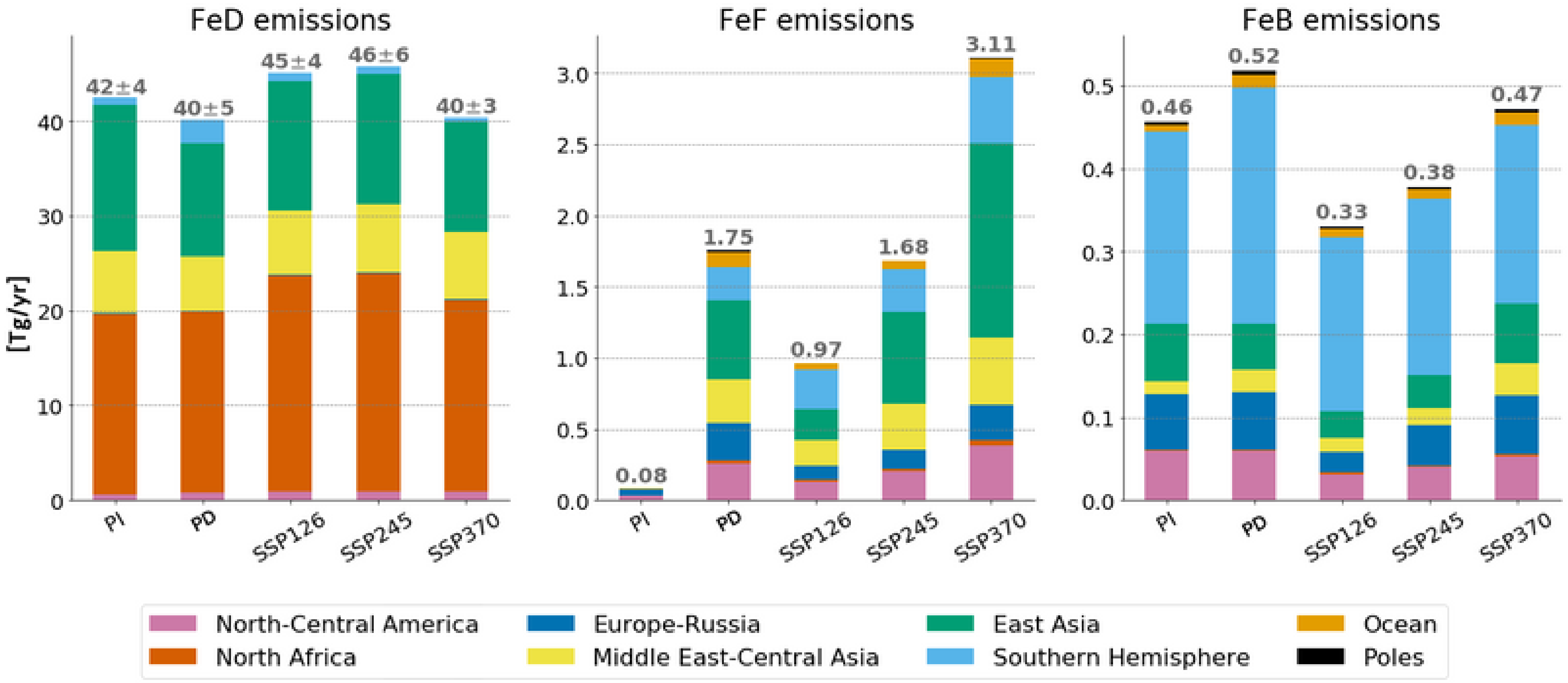
Scenarios Considered





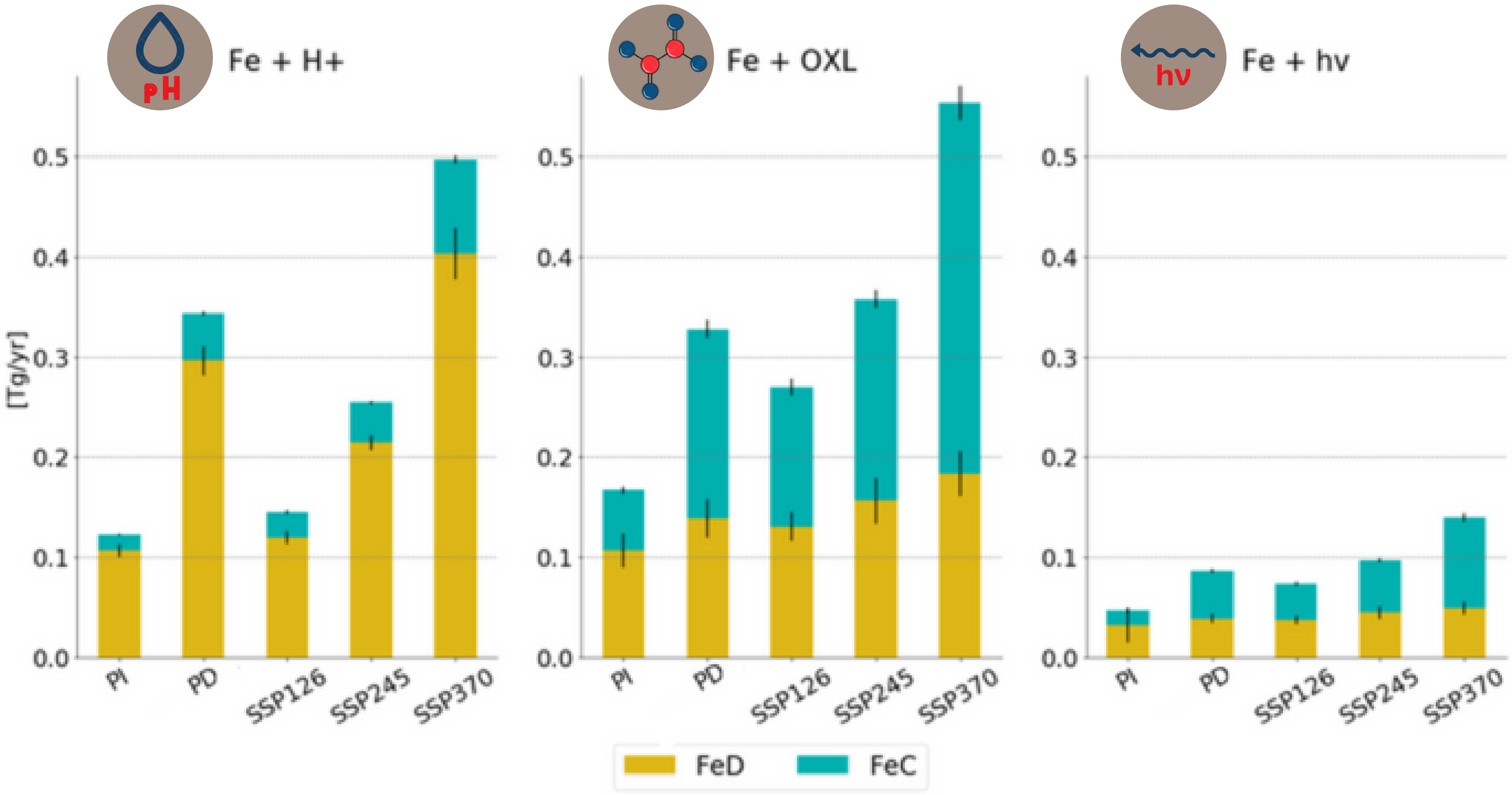
Global annual Fe emission budgets

- Fe-dust (FeD) emissions are dominant (and low variability) among all sources and scenarios
- Sharp increase in Fe-fossil fuels combustion (FeF) for SSP370 (x1.8 higher than for PD)
- Decrease in Fe-biomass urning (FeB) emissions in all three future scenarios



Global annual mean Fe solubilization budgets

- Main dissolution process for FeD is acidic dissolution
- Main dissolution pathway for FeC is OXL promoted dissolution for all scenarios
- Solubilization gets boosted for SSP370
- Photoreductive dissolution has a limited impact



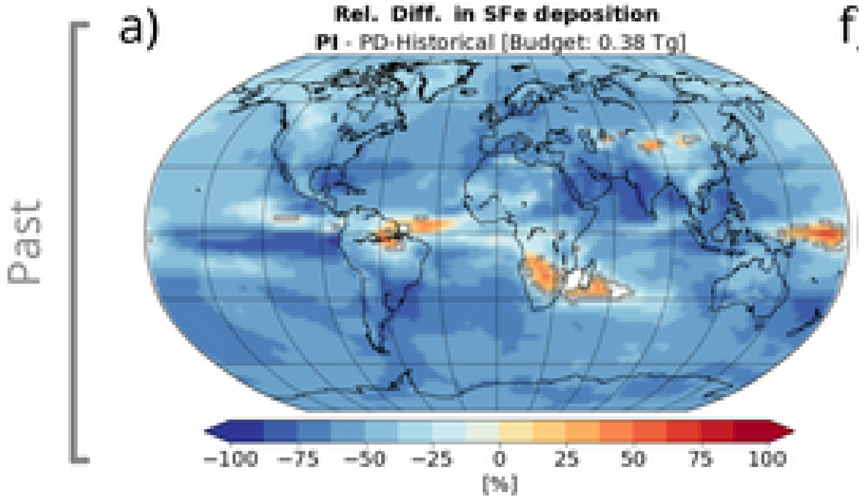
Global annual mean Soluble Fe (SFe) deposition

- SFe deposition has doubled since PI
- SFe deposition decreses for SSP126 and SSP245 with respect to PD (-35% and -10% respectively)
- SFe deposition has relative increse of 40% for SSP370 with respect to PD

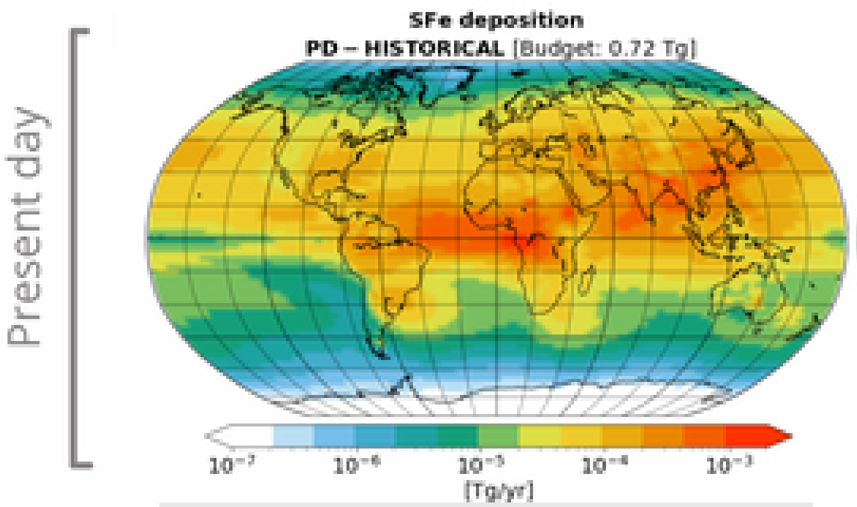
0.38 Tg/yr

x2

0.72 Tg/yr



Rel. Diff. in SFe deposition [%]

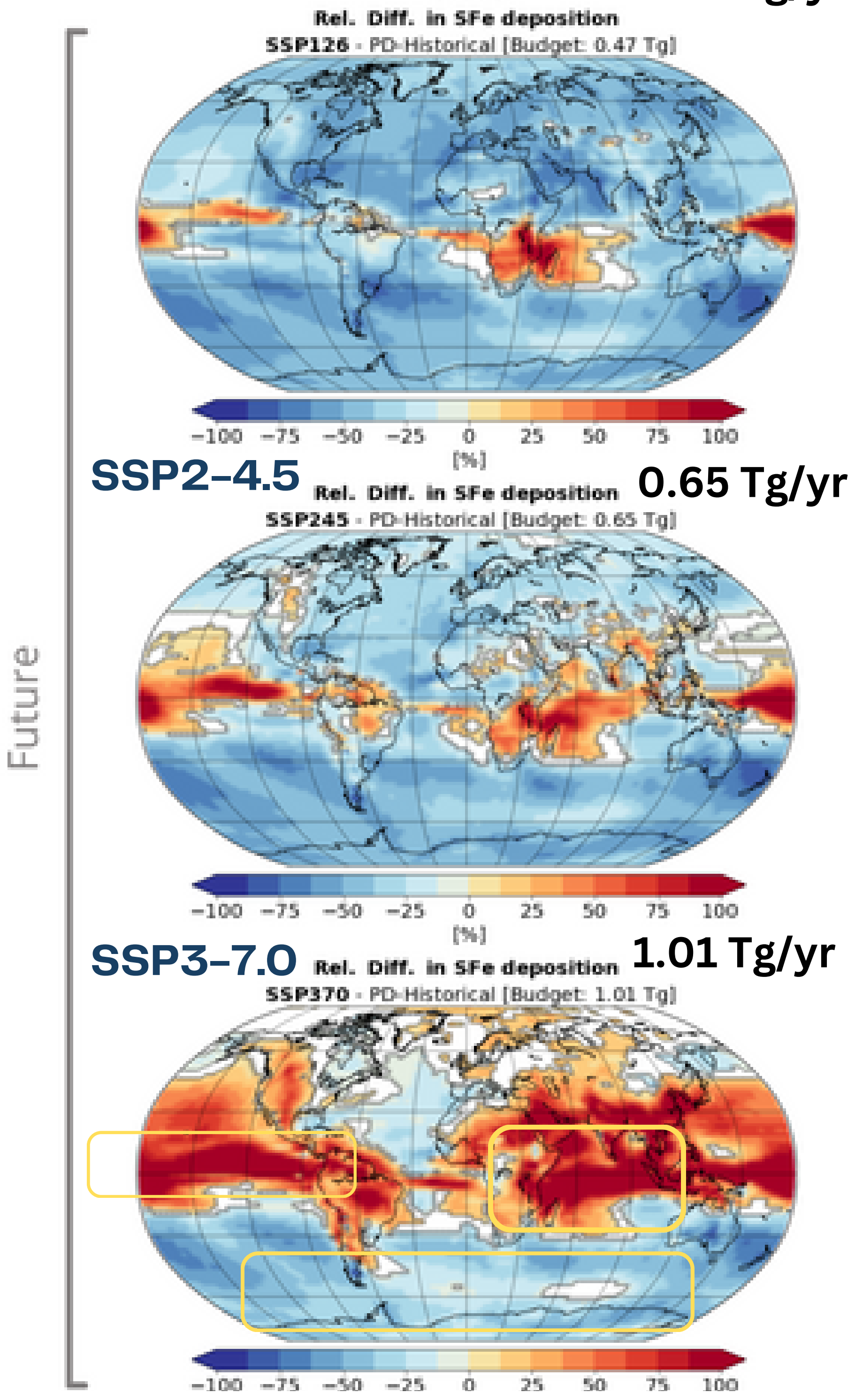


SFe deposition [Tg/yr]

SSP1-2.6 0.47 Tg/yr

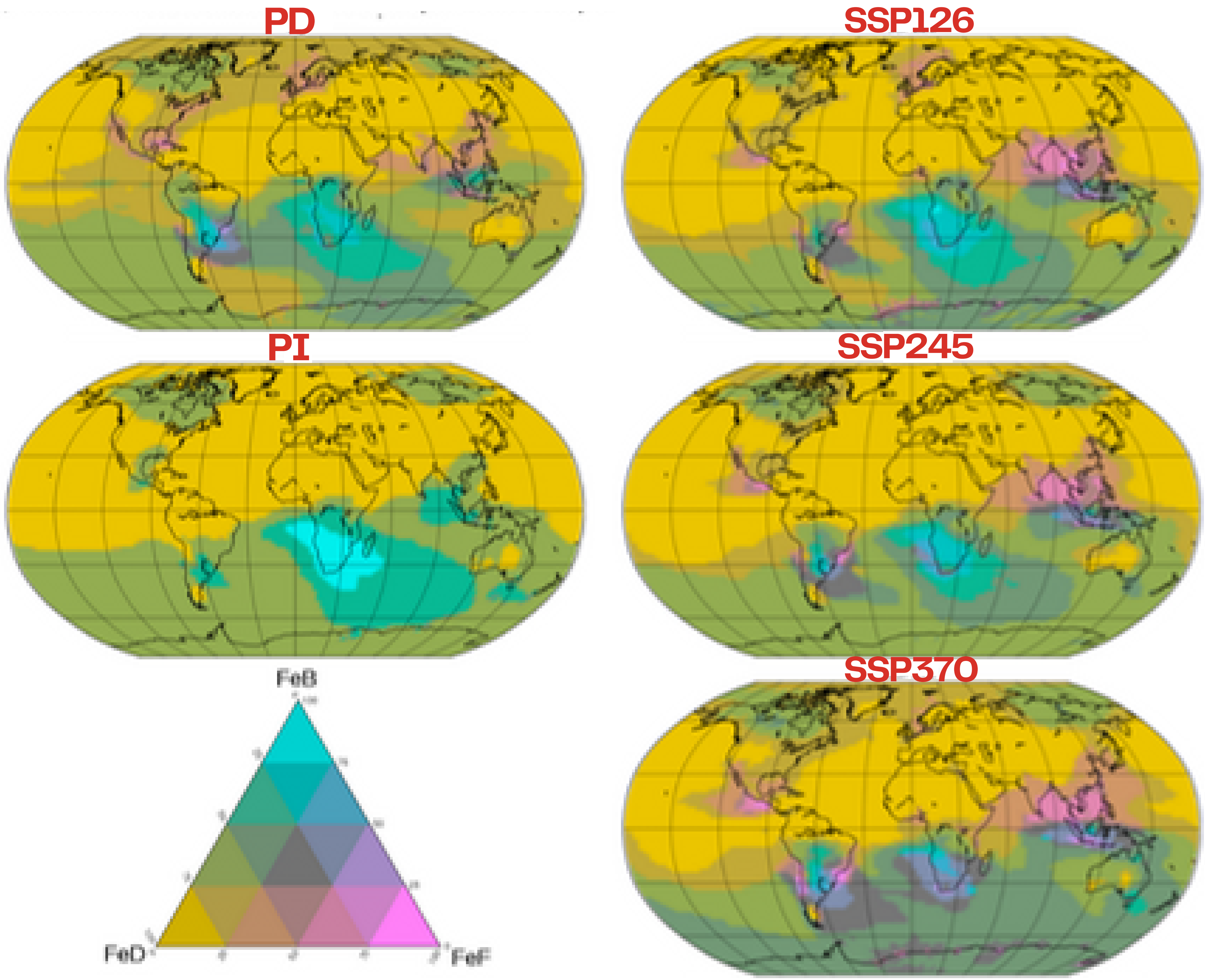
SSP2-4.5 0.65 Tg/yr

SSP3-7.0 1.01 Tg/yr



Rel. Diff. in SFe deposition [%]

Source contribution to soluble-Fe deposition



Results Conclusions

Changes in climate and emissions can substantially modify atmospheric aerosol acidity, OXL production, and the strength and distribution of SFe deposition.

Anthropogenic Emissions → ***Atmospheric acidity and Oxalate concentrations*** → ***Soluble-Fe Deposition***

- Global soluble iron deposition will increase (decrease) by 40% (35%) with weak (strong) climate mitigation policies
- Aerosol acidity controls the dissolution of iron from dust sources and oxalate from combustion sources in the past, present and future

Future observational and modeling **studies should focus** on better characterizing the **evolution of fire and dust emissions and its interaction with other Earth System components** to ultimately better represent the Fe cycle.

EXCELENCIA SEVERO OCHOA

Doctoral stage

NC STATE UNIVERSITY

Douglas Hamilton

Reassessment of Future Fires and implications for the iron cycle

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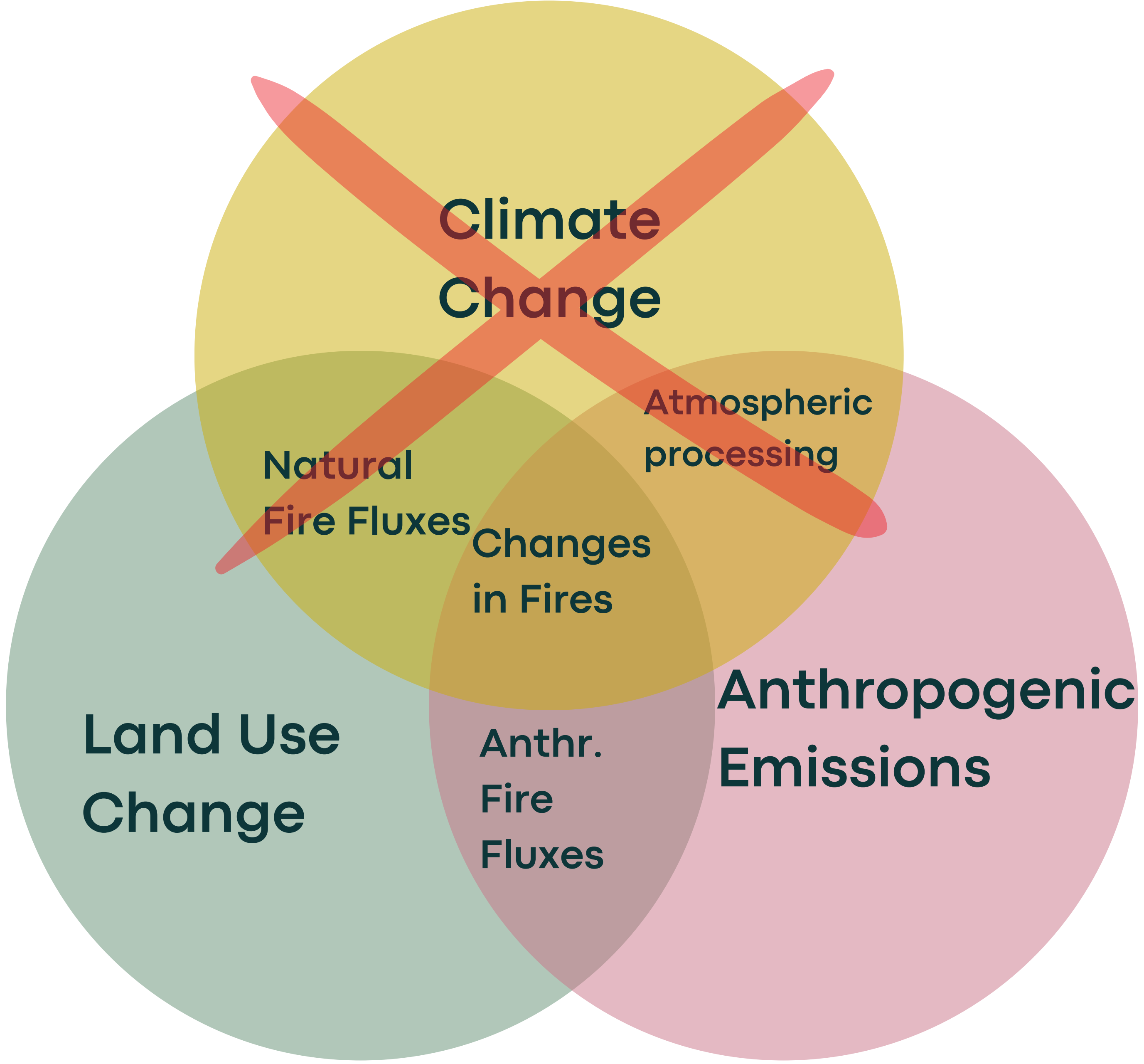
CMIP6 underestimates fire emissions for the future

- CMIP6 SSP fire emission scenarios **neglect the impact of climate change** on natural fire activity, this results in **unrealistic reductions in emissions across all scenarios and all regions** of the world, even in scenarios with a large global warming.



Future Fire Emissions Reassesment

ENSAMBLE MEAN CMIP6 MODELS WITH INTERACTIVE FIRES

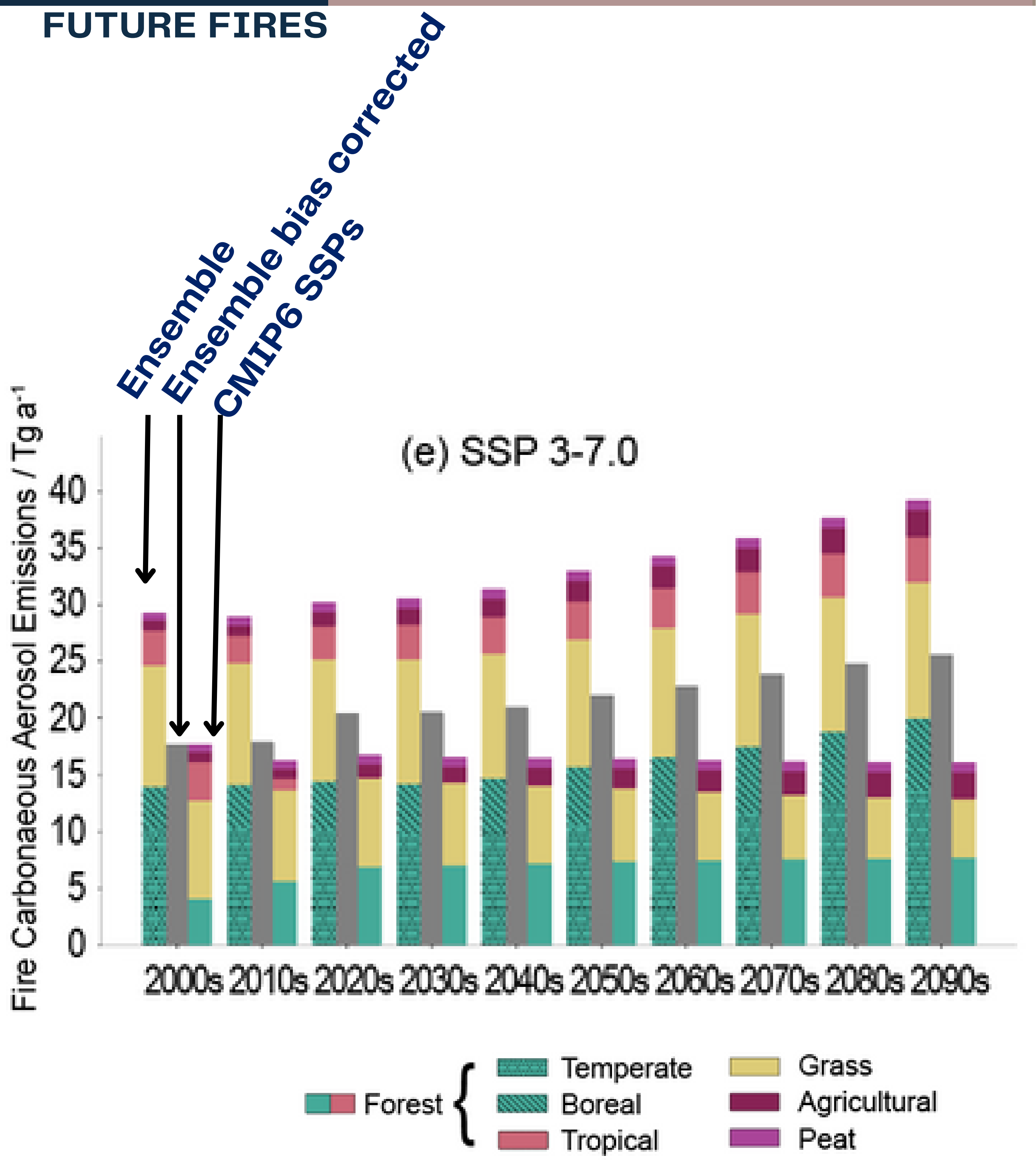
Climate Change impacts

+

SSP CMIP6 EMISSION DATASET

Anthropogenic changes impacts

Bias Corrected to present day observations (GFED4s)



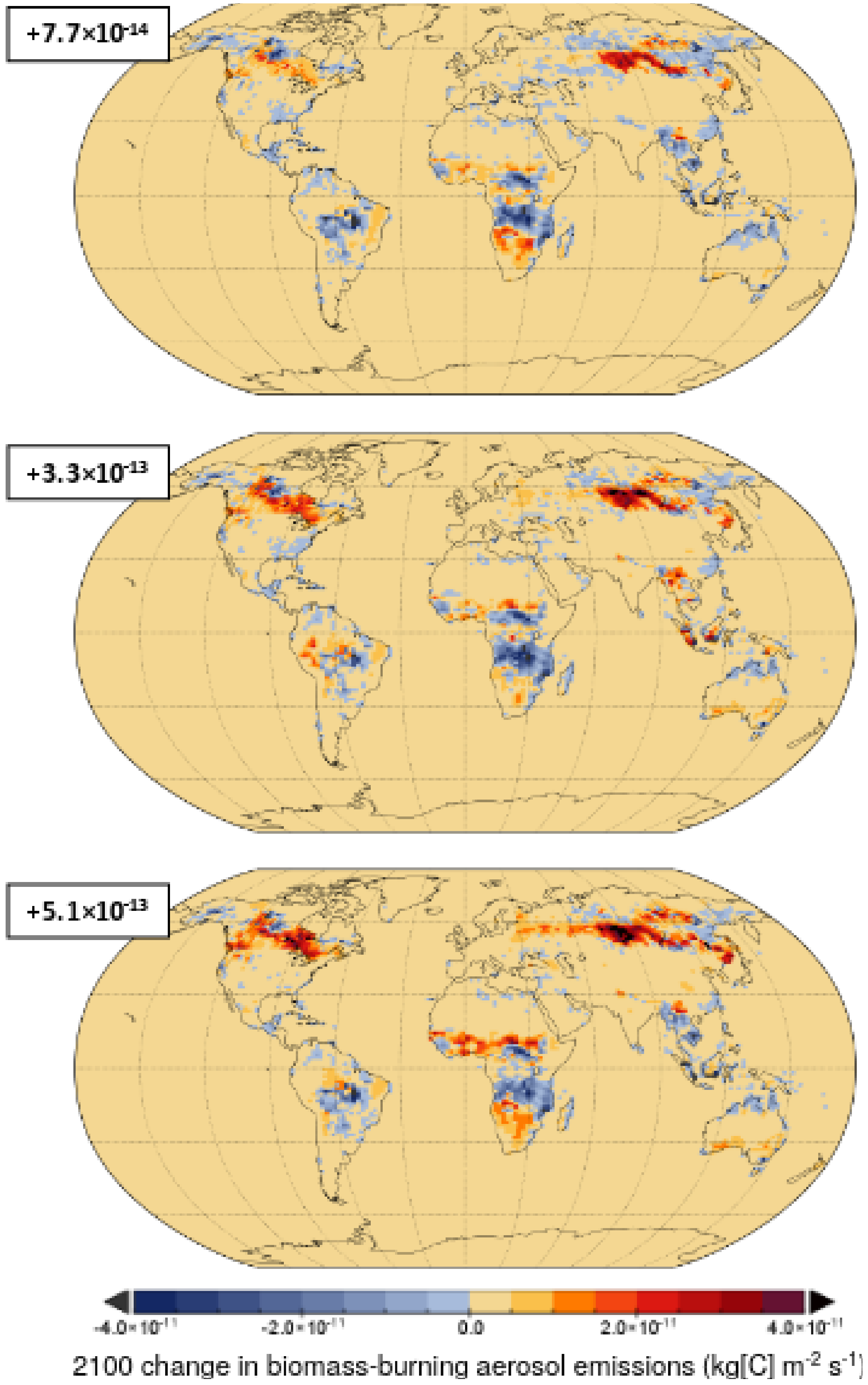
(Hamilton et al, in production)

Future Fire Emissions Reassesment

SSP1-2.6*

SSP3-7.0*

SSP5-8.5*

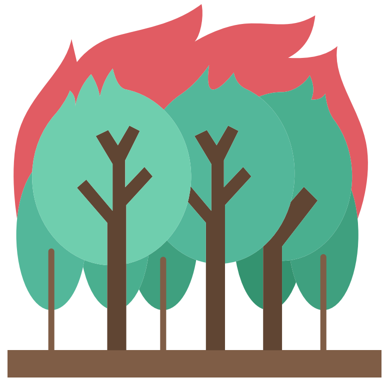


extra-tropical fire emissions

(Hamilton et al, in production)

EC-EARTH3-Iron & MIMI (CAM6)

Myriokefalitakis et al., 2022 ***Hamilton et al., 2019***

\+ 

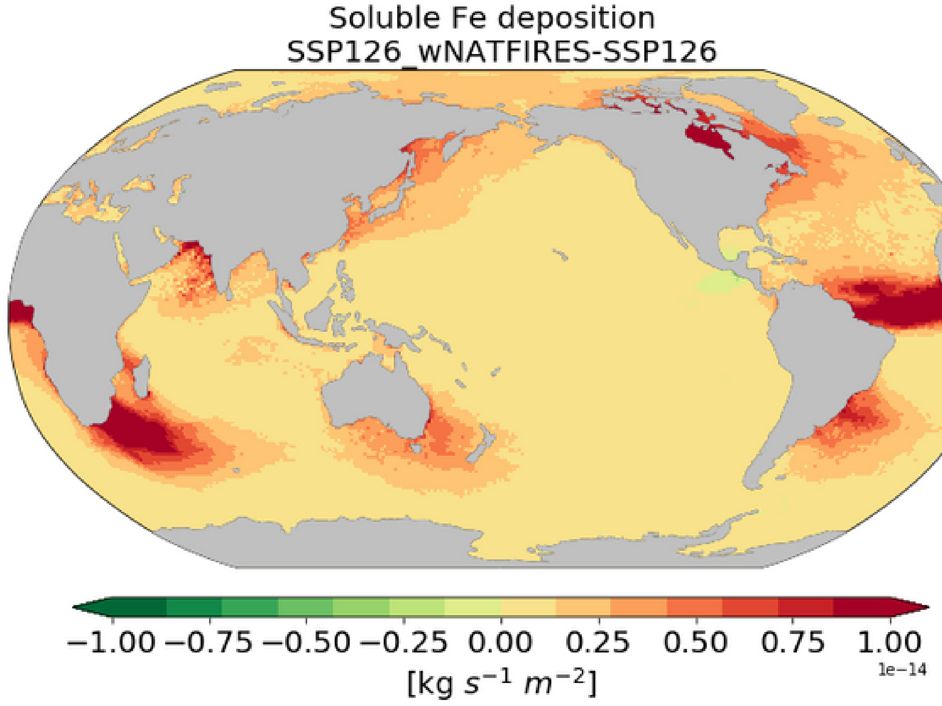
New CMIP6 fire emission scenarios

New soluble Fe deposition fields for the future

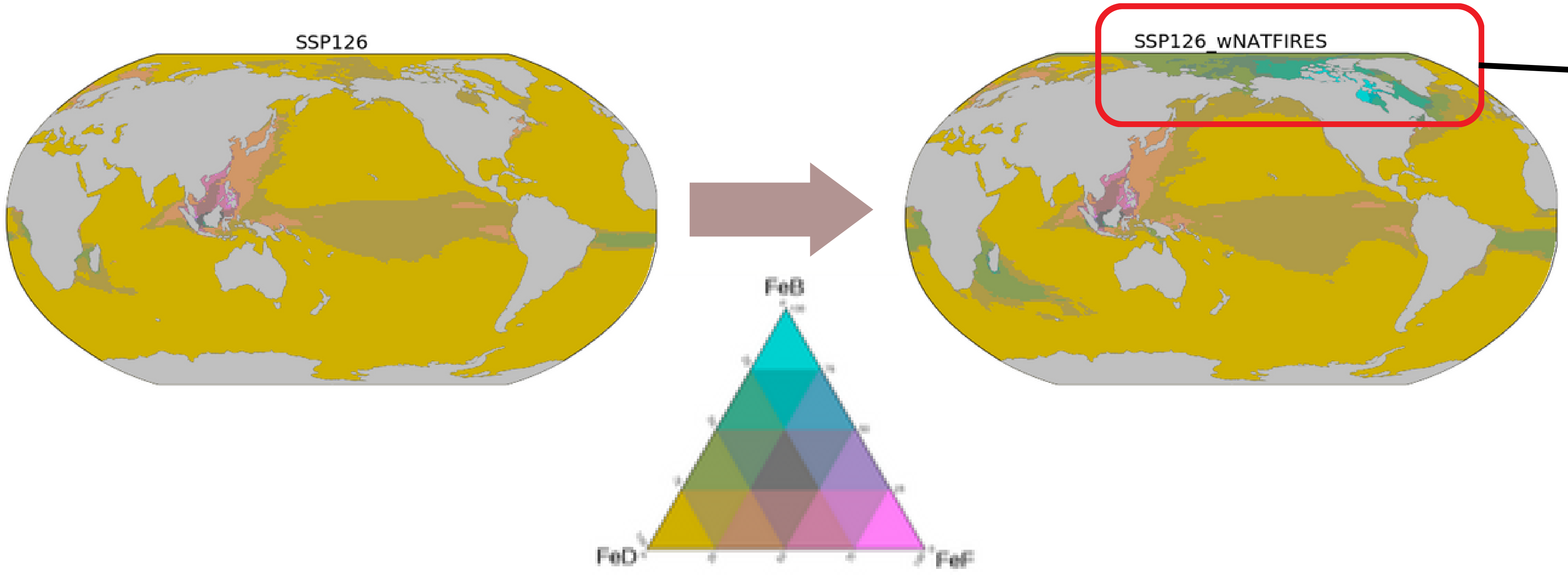
Hypothesis:

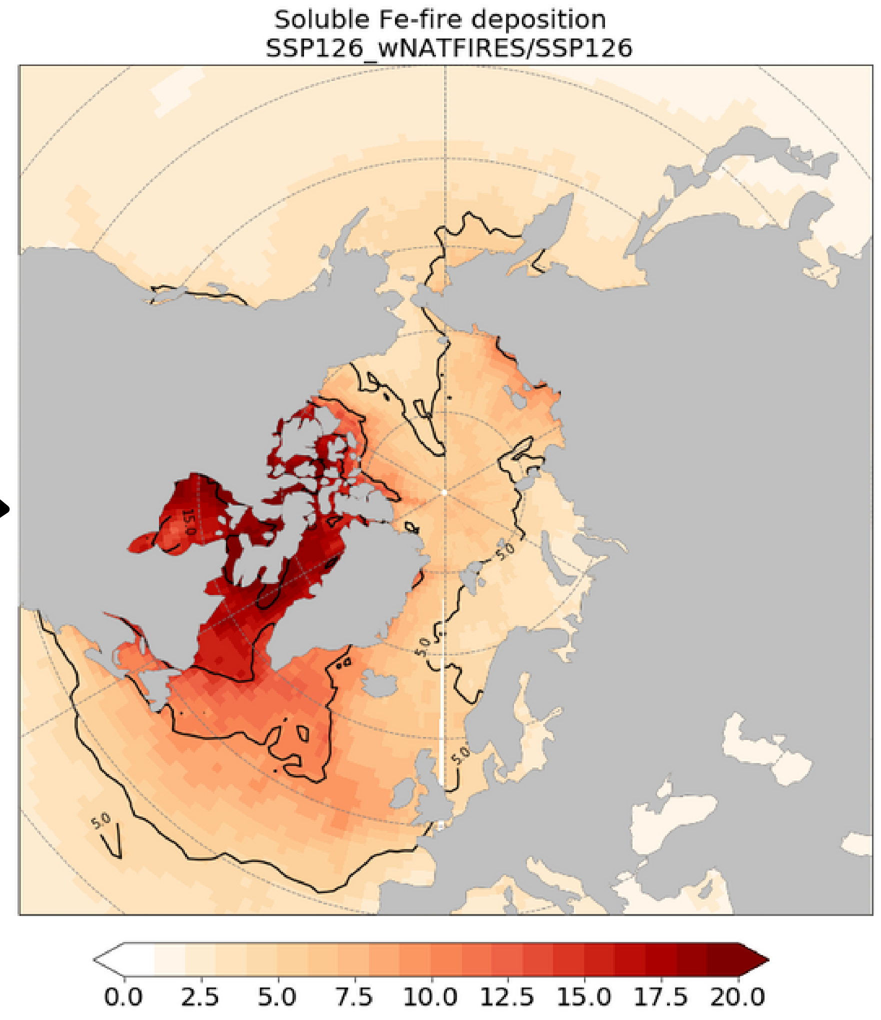
- Increase in Soluble Fe deposition over HNLC regions such as the SO & North Pacific
- The change in fire emissions will also affect the burden of precursors of OXL and therfore Fe dissolution will be boosted.

Preliminary Results
MIMI (CAM6)



- **In some arctic regions the flux from fires is x20 bigger with the reassesment**





Conclusions

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Conclusions

We have set a promising model baseline for EC-Earthv3 accounting for an explicit representation of the atmospheric iron cycle that allows us the quantification of soluble iron deposition under a range of scenarios.

- We have seen that different future socio-economic pathways lead to important changes in soluble iron deposition
- We have worked on reducing uncertainties such as the estimates of future fires and its impact on the iron cycle, where we already see high differences in some regions
- We can now compare EC-Earth-iron with other models, like MIMI, which have lower complexity in their chemistry parametrizations.
- **Considering both Fe atmospheric processing and deposition over oceans should be used in ESMs for the assessment of the impact of nutrient-containing aerosol deposition on marine productivity.**

Future Work

Impacts on Ocean Biogeochemistry of the new Iron Deposition Estimates

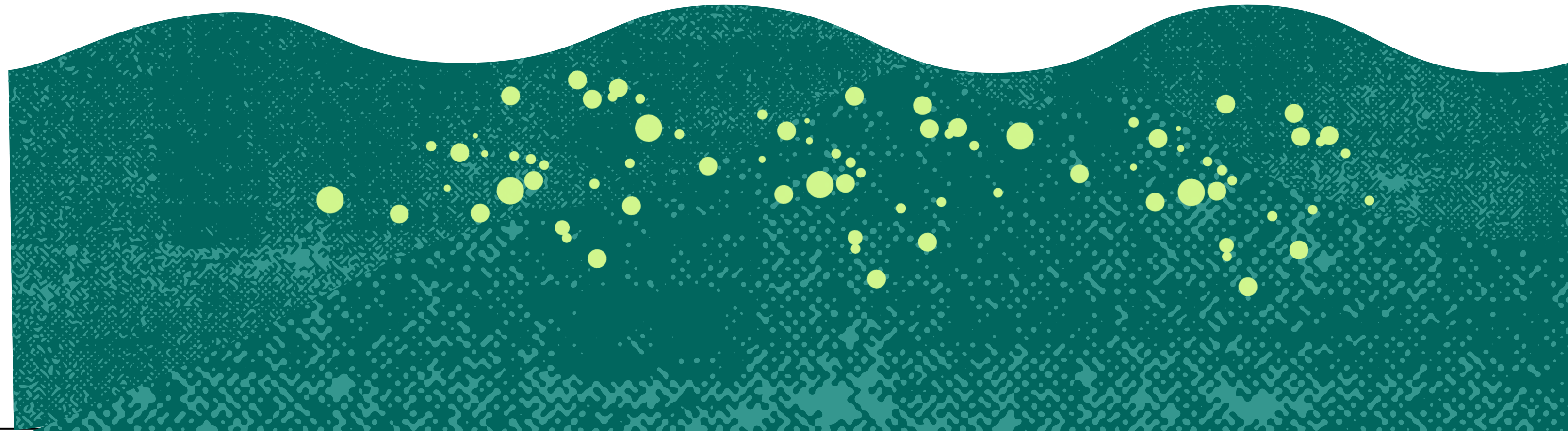
With all the work carried out so far, we can estimate the impact of iron deposition on global oceanic productivity under different climates.

Now in PISCES

~~Fe-Dust deposition ctt monthly fields, no yearly changes~~

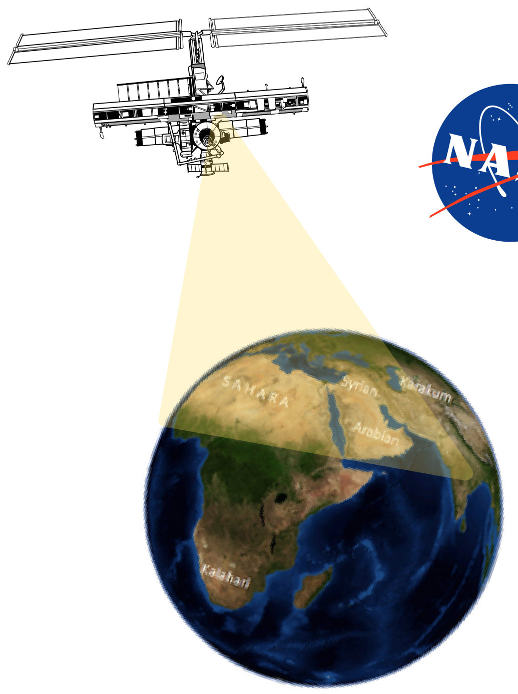
Our Planned Work

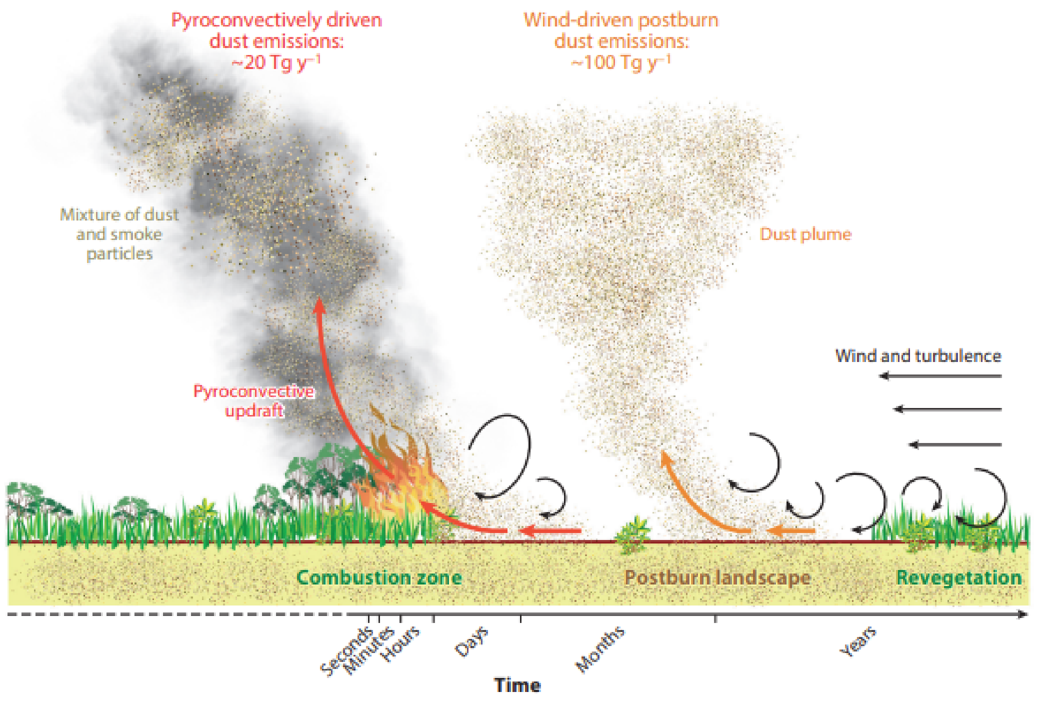
FeD, FeBB, FeF deposition PI, PD, FU monthly (or daily) fields with yearly changes



Other uncertainties we could tackle as future work:

- Better Representation of Soil Mineralogy
- Anthropogenic Dust-Iron Emissions
- Enhanced dust emission following large wildfires due to vegetation disturbance
- Underestimation of future shipping emissions in the Arctic Ocean
- ...





Projects

This work contributes to several projects:

NUTRIENT: quantifying the present and future atmospheric delivery of bioavailable iron to the ocean

FRAGMENT: quantifying the effects of dust mineralogy on climate

FORCES: reducing the uncertainty in anthropogenic aerosol radiative forcing

DOMOS: The Dust-Ocean Modelling & Observing Study (DOMOS) will advance the understanding of dust and ocean interactions in a changing climate through an innovative use of model and observations.

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Thanks for your attention

.

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