Earth System Modeling in CESM: Methane, Sulfur

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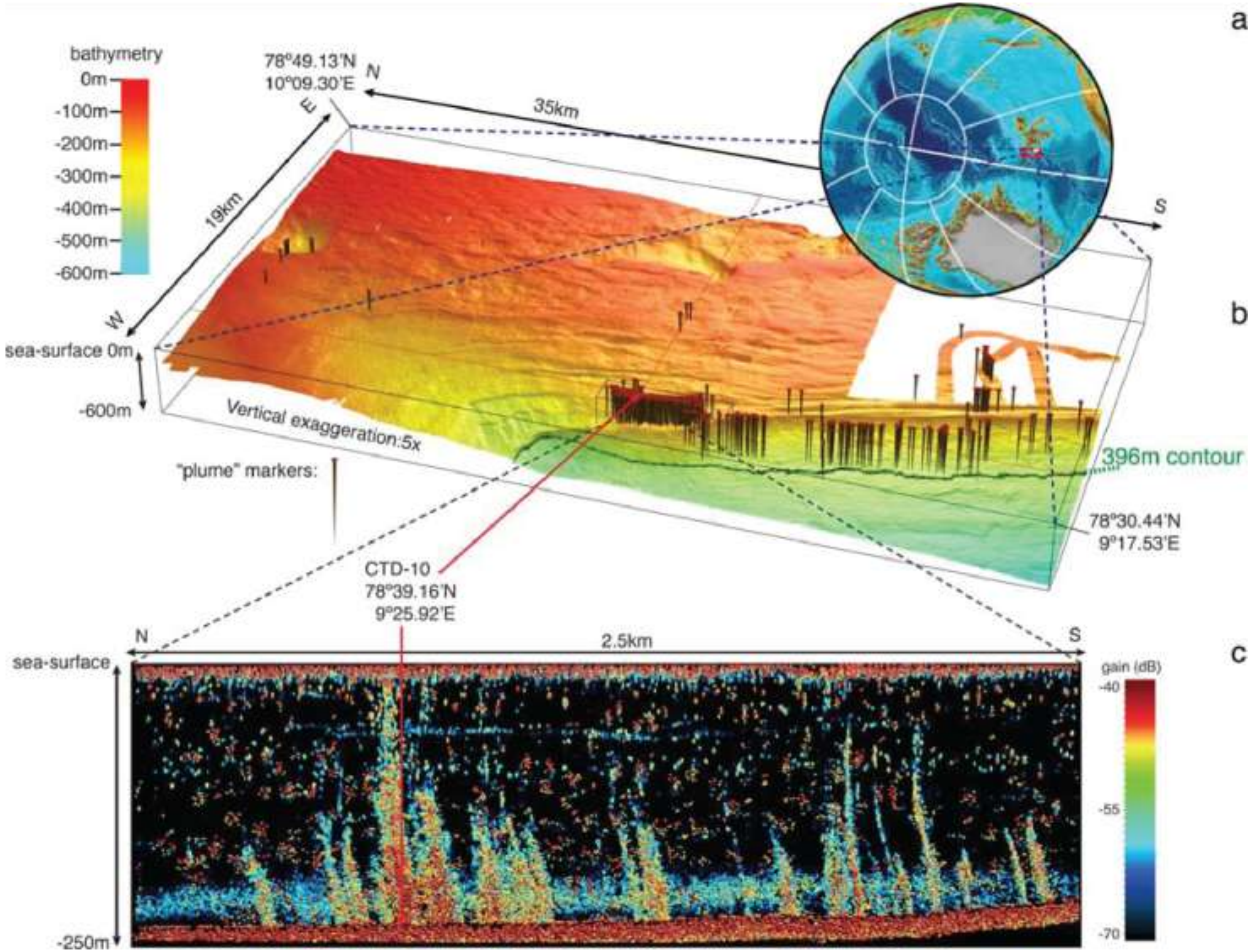
Acknowledgements: DOE IMPACTS Abrupt Change, Fossil Energy Gas Hydrates,

SciDAC Earth System Modeling, INCITE Climate End Station

OUTLINE

- Methane clathrates overview
- Methane in ocean.
- Methane in atmosphere
- Sulfur ESM
- Other (hi-res & aerosols)
- Conclusion

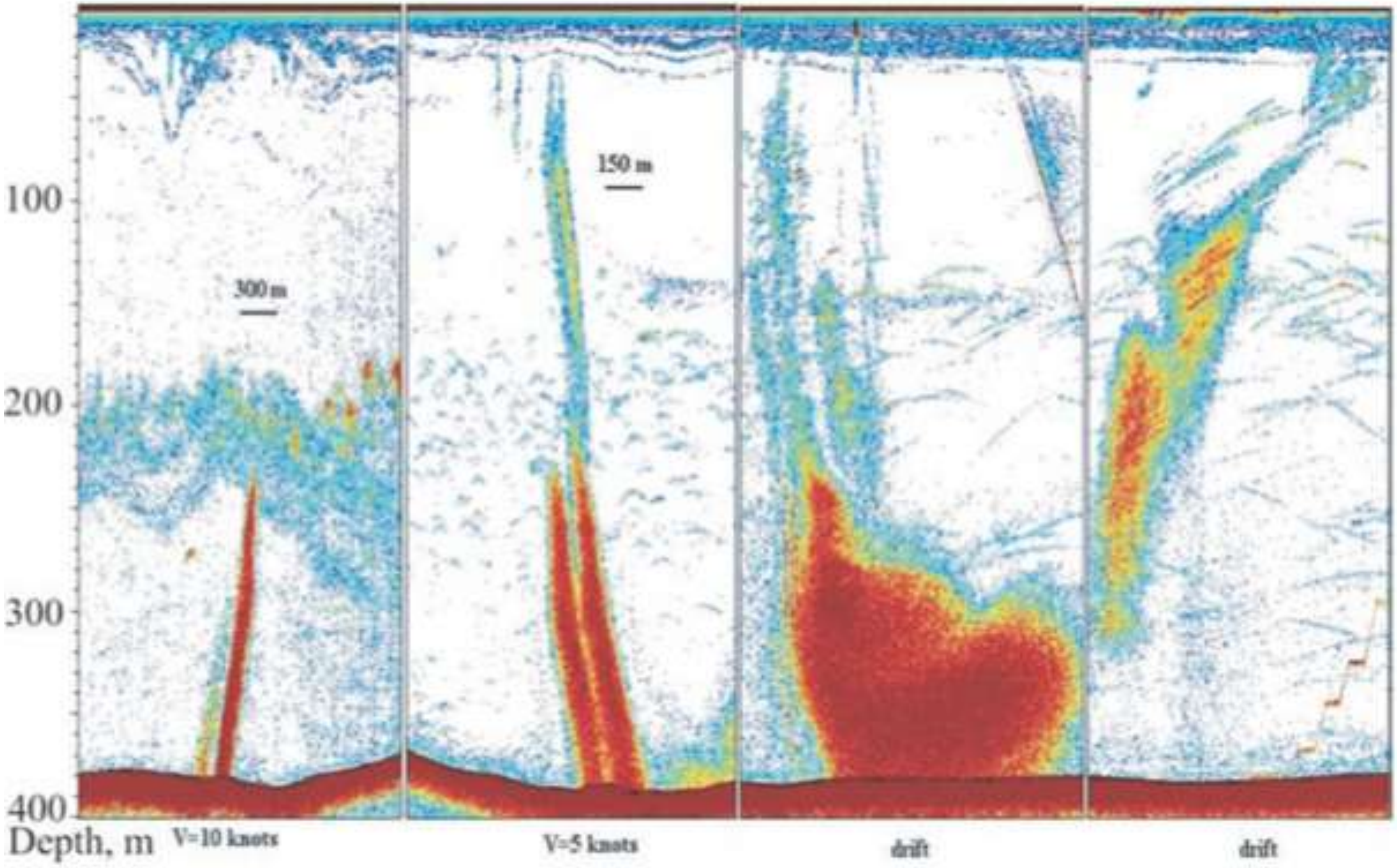
Methane plumes have been observed in the ocean at locations expected for clathrates.



Westbrook, et al., GRL, 2009.

Obzhirov et al., Sea of Okhotsk off Sakhalin

Methane bubble flares

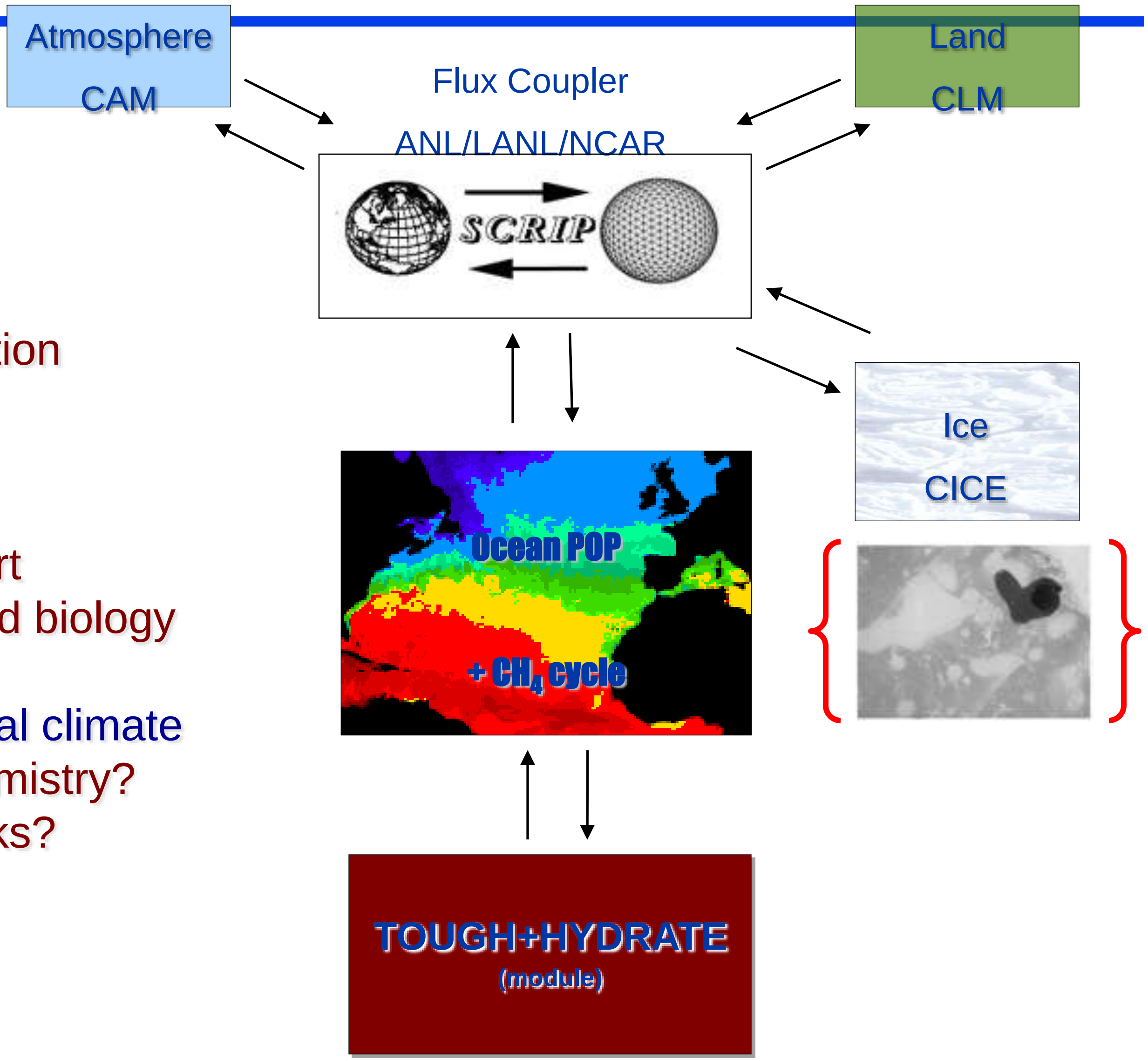


CESM: methane ESM

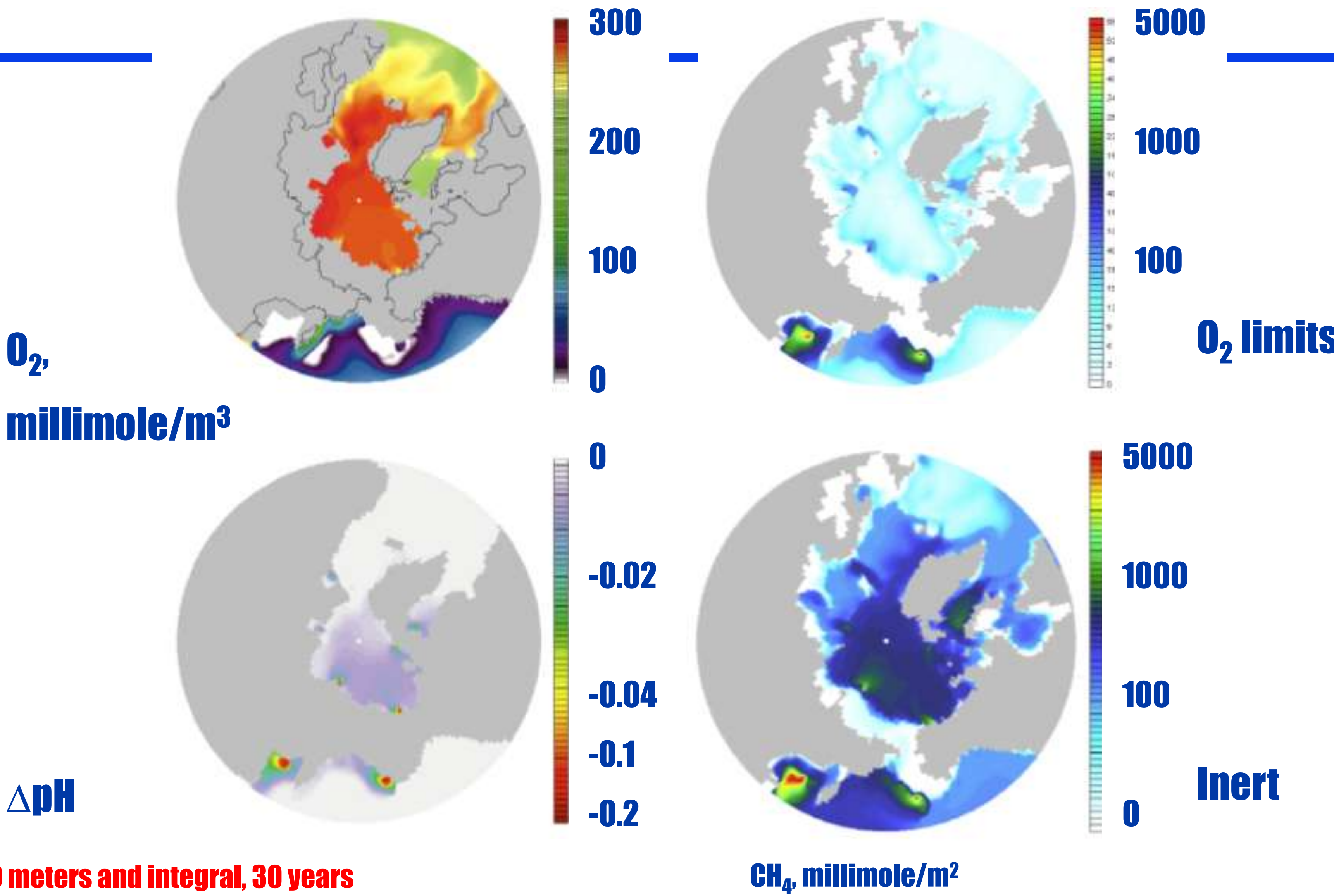
1) Sub-seafloor
   - Hydrate dissociation
   - Fluid transport

2) Ocean water column
   - Methane transport
   - Geochemistry and biology

3) Atmosphere and global climate
   - Atmospheric chemistry?
   - Positive feedbacks?



O_2, CO_2 and Plume Expansion

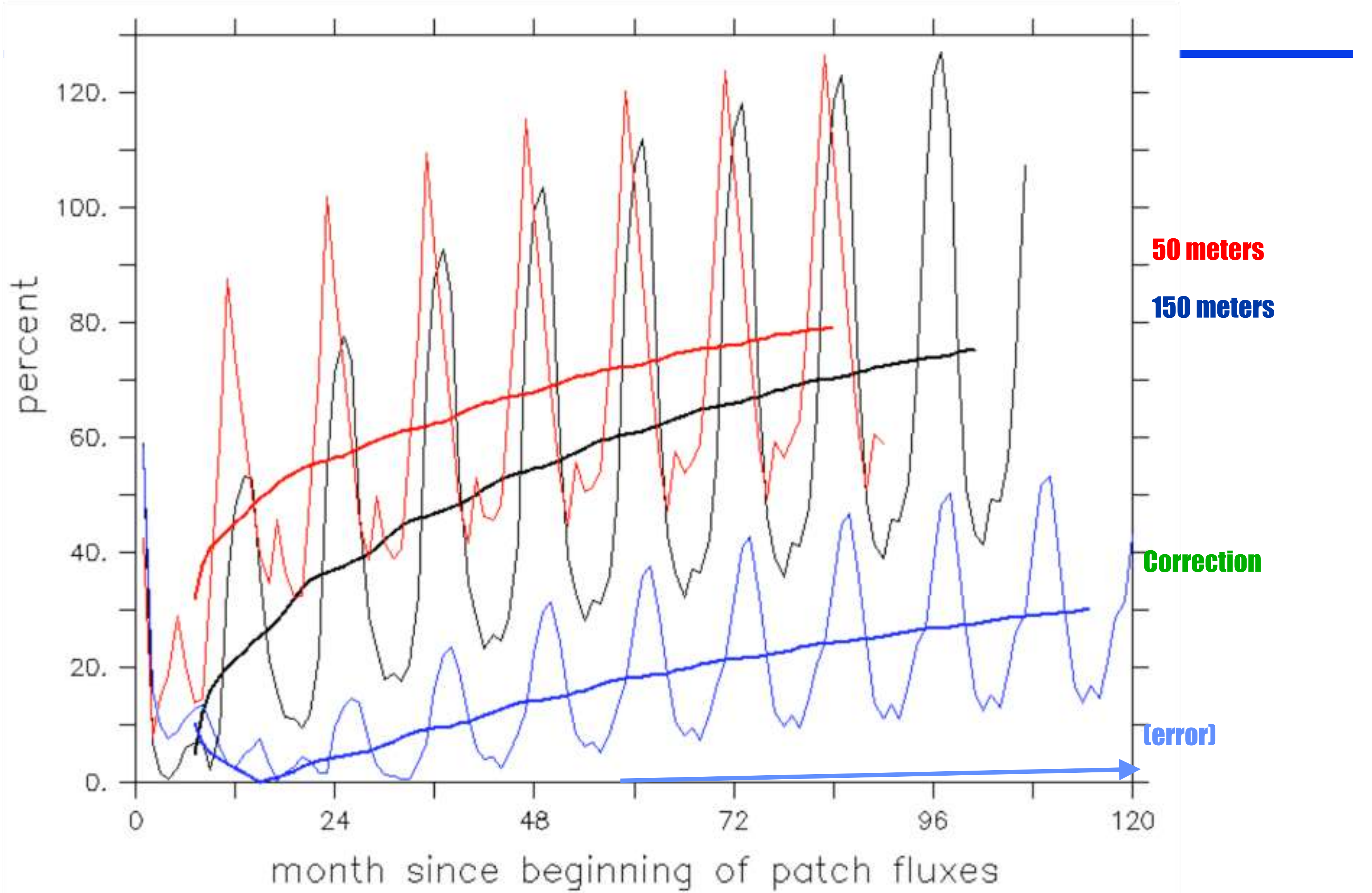


300 meters and integral, 30 years

Originally reported leakage % level

Integrated escape to Arctic atmosphere from JGR patches

Ten years, sea floor then injections, z = 150 and 50 meters



Impact of Abrupt Methane Release

P. Cameron-Smith, D. Bergmann, S. Bhattacharyya, & collaborators*

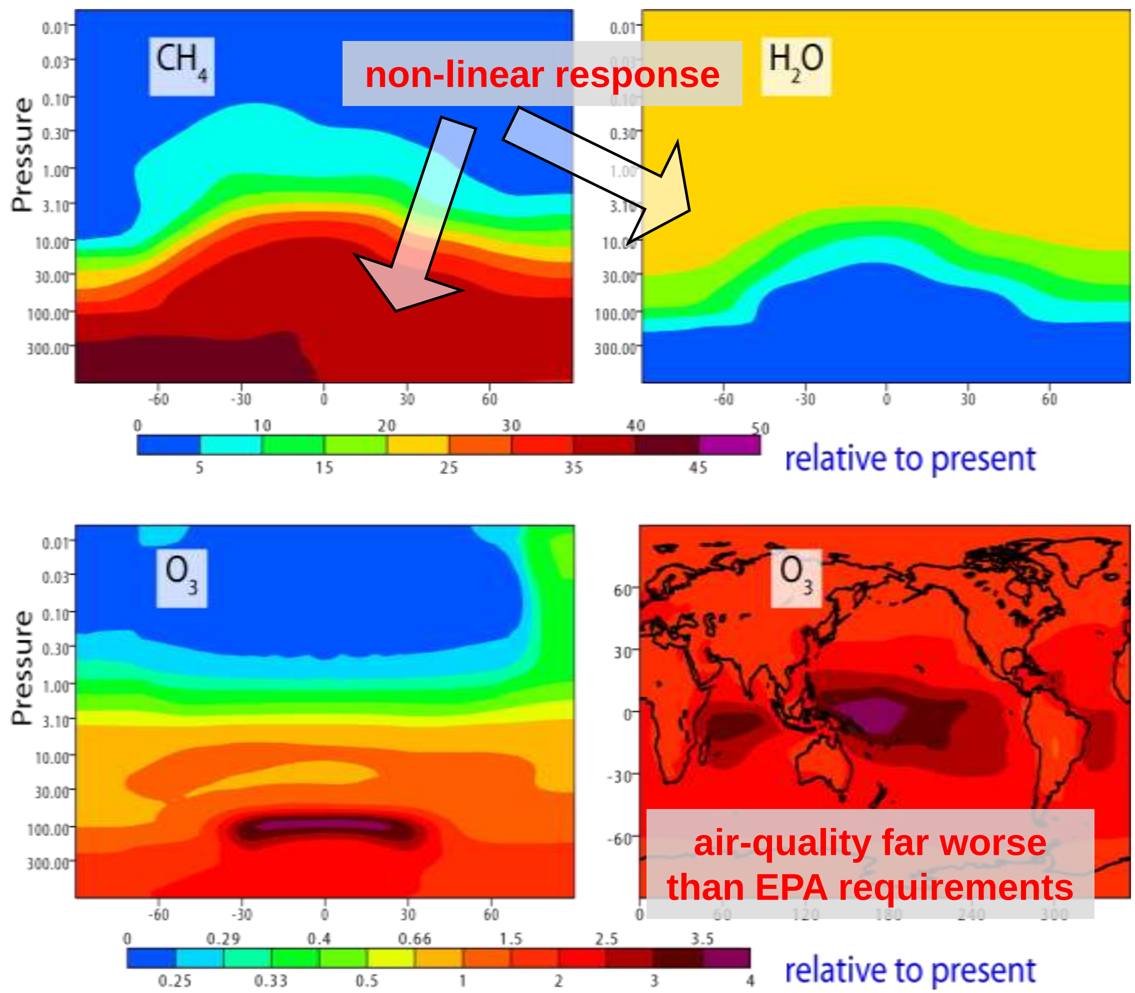
Lawrence Livermore National Laboratory

More carbon is frozen in ocean clathrates than all other fossil fuels combined.

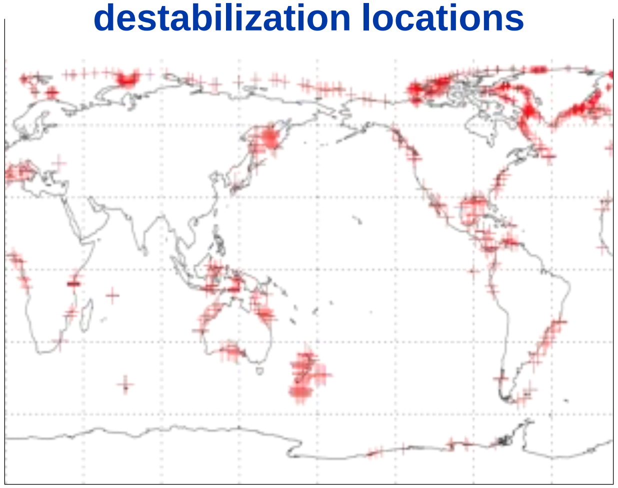
Rapid clathrate destabilization due to climate warming would significantly increase methane release, causing:

- Strong greenhouse heating,
- Ocean dead-zones (hypoxia),
- Poor air-quality,
- Reduced stratospheric ozone layer,
- Intensification of the Arctic ozone hole.

Large changes in GHGs due to ten fold methane emissions



Predicted Clathrate destabilization locations



*Collaborating with LANL, LBNL.

Atmospheric Impact of Methane Releases

P. Cameron-Smith, D. Bergmann, S. Bhattacharyya

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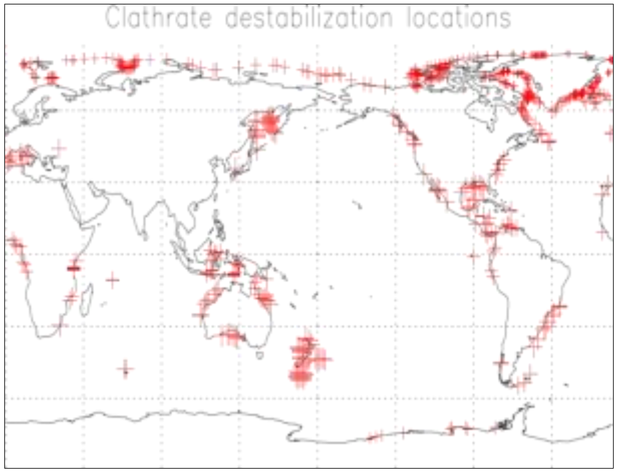
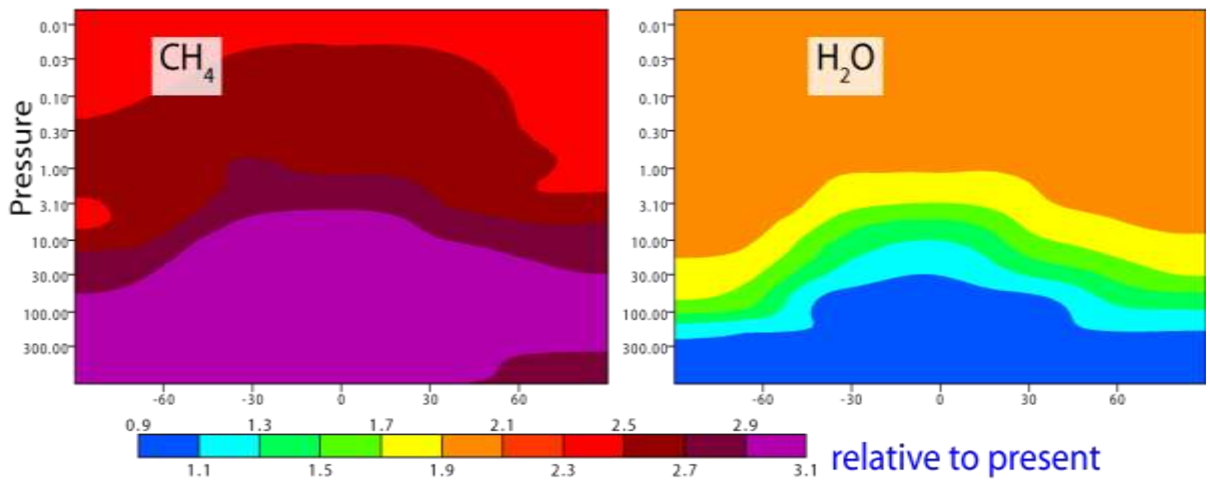
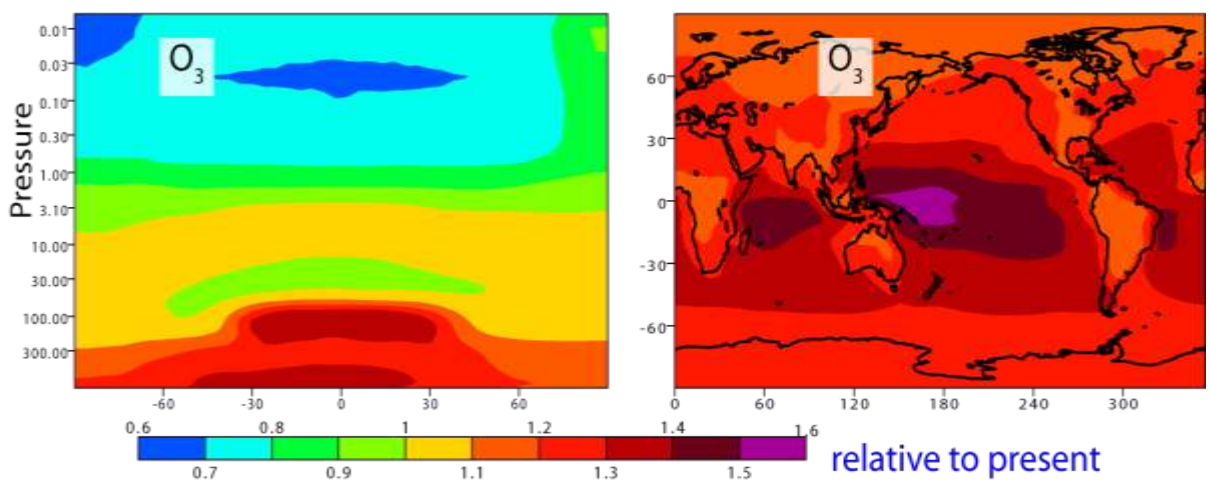
Clathrate destabilization locations

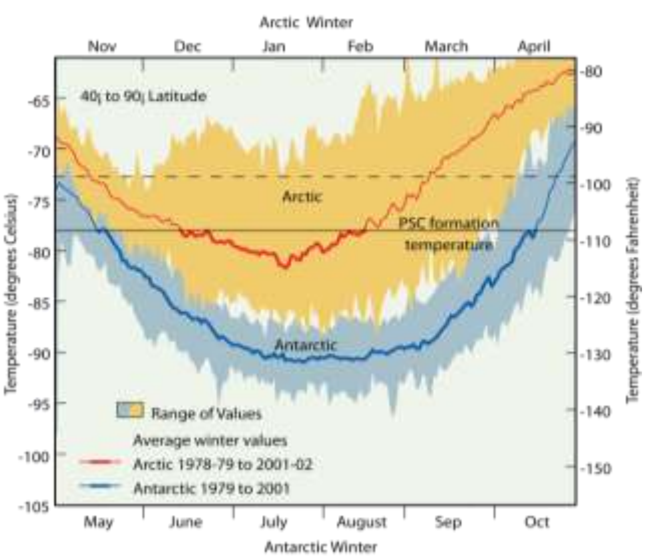


Substantial changes in key tracers due to 2x CH_4 emissions





Ozone hole in Arctic?

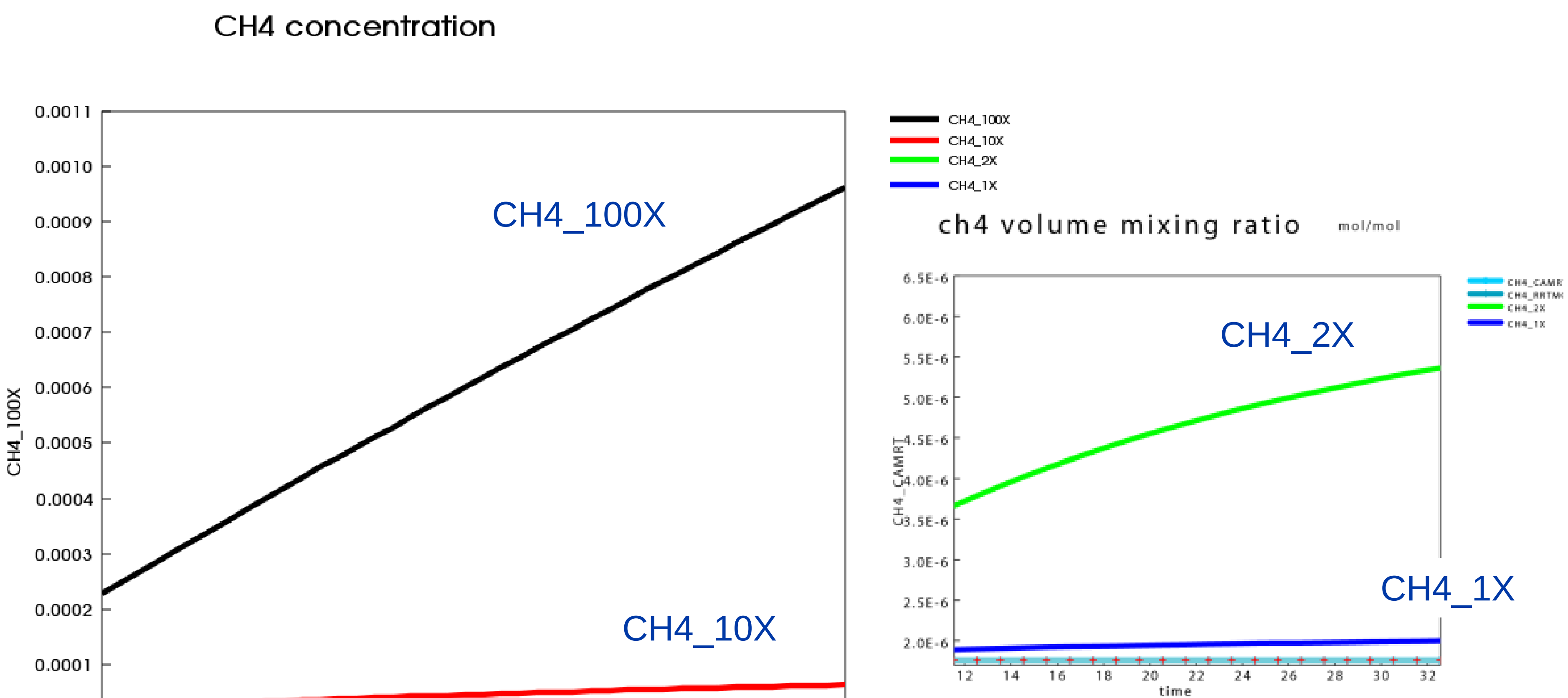


Atmospheric Study Cases:

- RRTMG (nochem): CAM4 physics, RRTMG Radiation package with no chemistry
- CAMRT (nochem): CAM4 physics, CAMRT package with no chemistry
- CH4_1X: CAM4 physics, Fast Chemistry, RRTMG Radiation Package with present day emission estimates
- CH4_2X, CH4_10X, CH4_100X: CAM4 physics, Fast Chemistry, RRTMG Package with 2x, 10x, 100x CH4 emissions distributed over oceans.

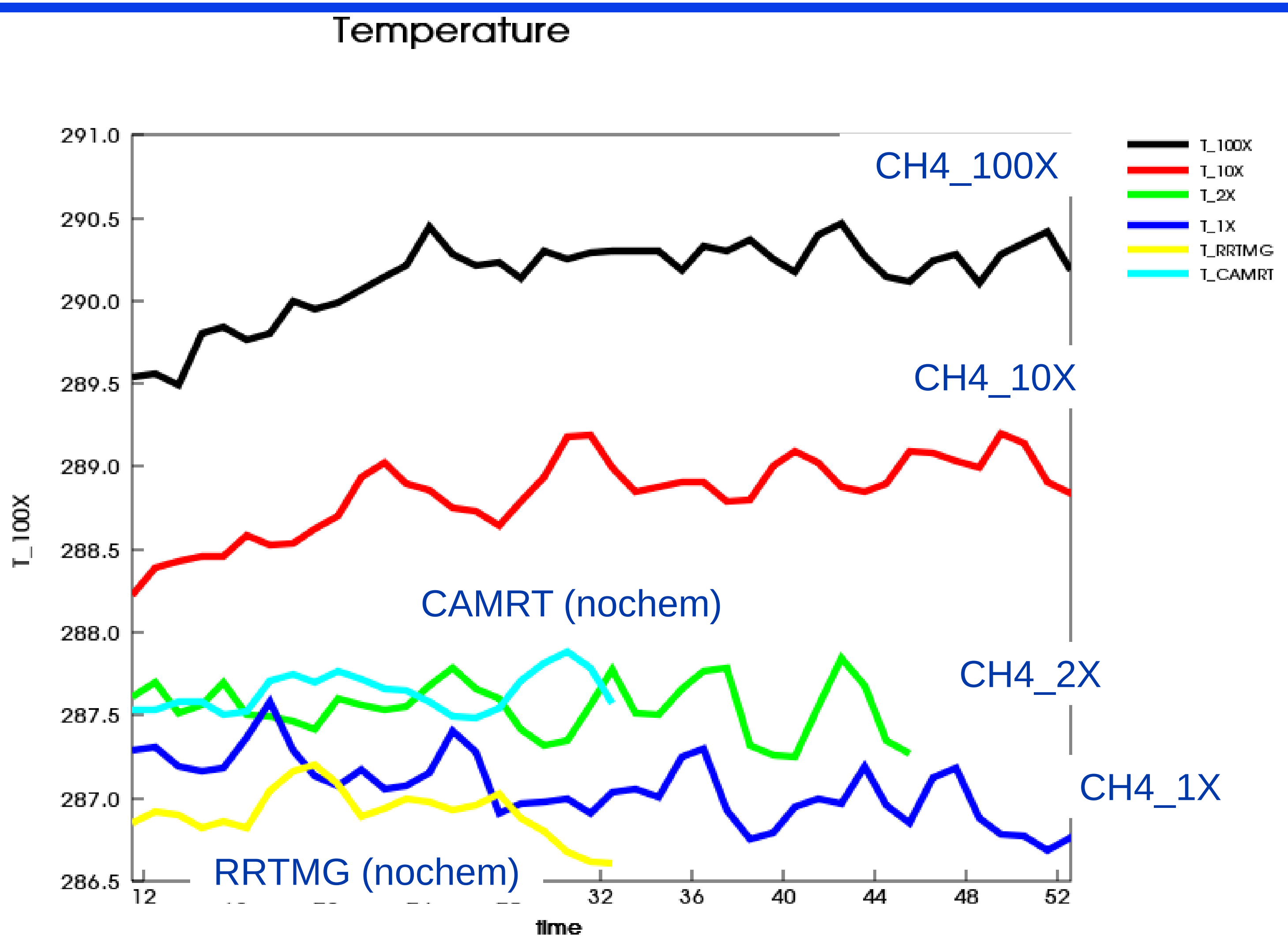
Version Used: CESM1_0_beta14

Annual Average of CH4 volume mixing ratio for 40 years after 11-years of spin-up



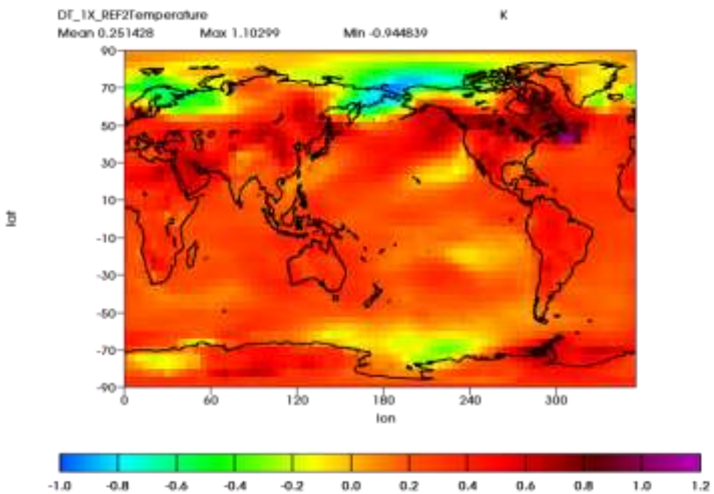
CAMRT & RRTMG (nochem)

Annual mean surface air temperature for 40 years after 11 years of spin-up (at 4x5 res)

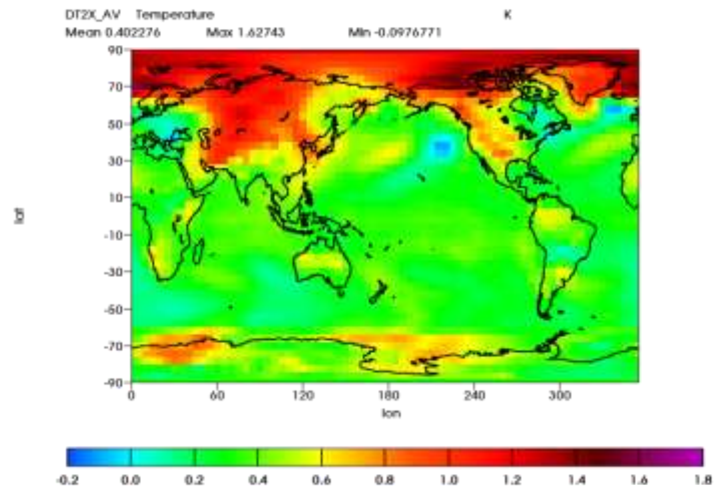


Annual Mean Temperature Differences in Fully coupled model

CH4_1X and RRTMG (nochem)

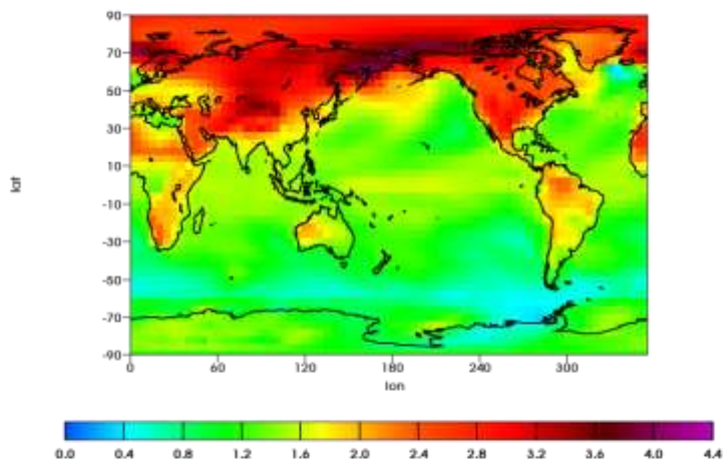


CH4_2X and CH4_1X



Max = 1.6 W/m2

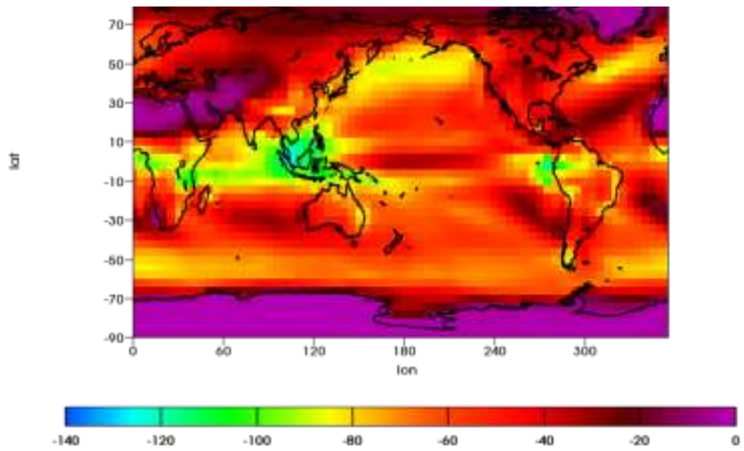
CH4_10X and CH4_1X



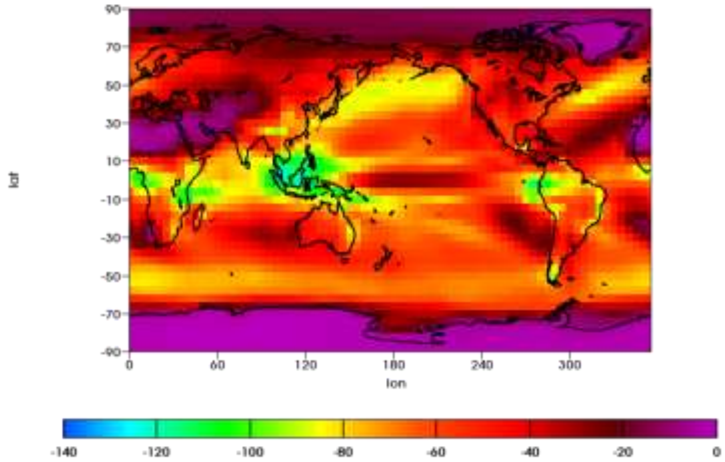
Max = 4 W/m2

Short Wave Cloud Forcing: no big changes seen

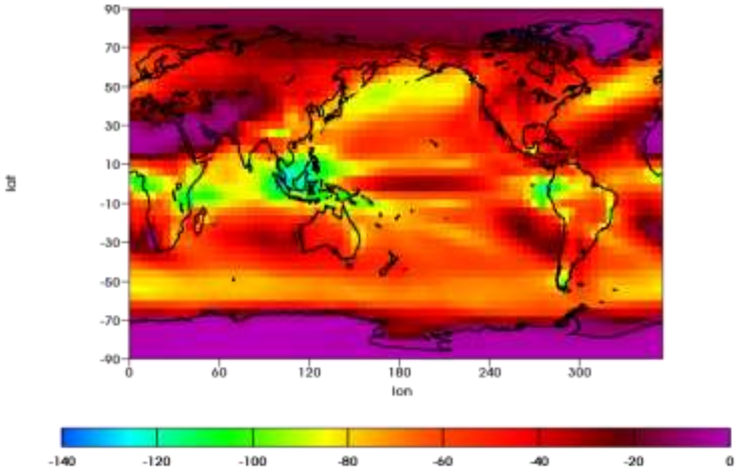
CAMRT (nochem)



RRTMG (nochem)



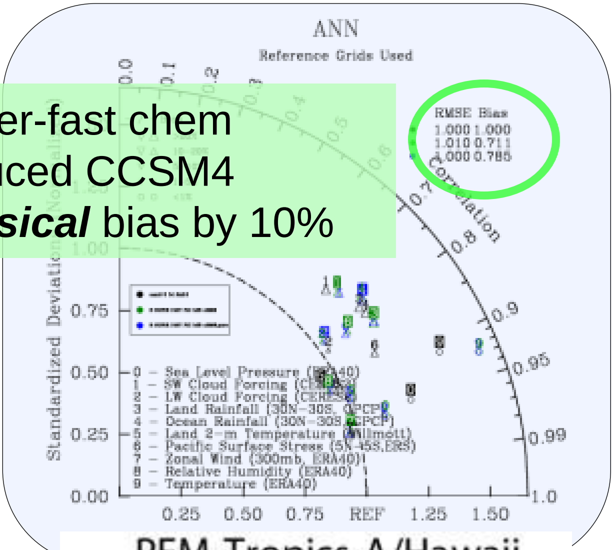
CH4_1X



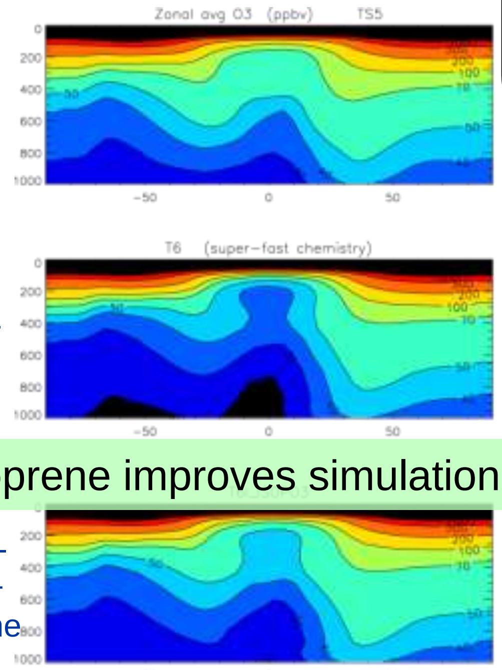
Super-fast chemistry included in CCSM4 & IPCC simulations

Cameron-Smith, Bergmann, Mirin, Chuang & collaborators*

- Our fast mechanisms validate well for mean-state and sensitivities, and provide:
  - Consistent GHG and aerosol fields,
  - chem-aerosol-climate feedbacks,
  - Interaction with biosphere (land & ocean),
  - Reduced climate bias.
- Fast enough (+25%) for inclusion in IPCC simulations.
- Part of ESM
  - Coupled to land & ocean ecosystems.



Super-fast chem reduced CCSM4 ***physical*** bias by 10%

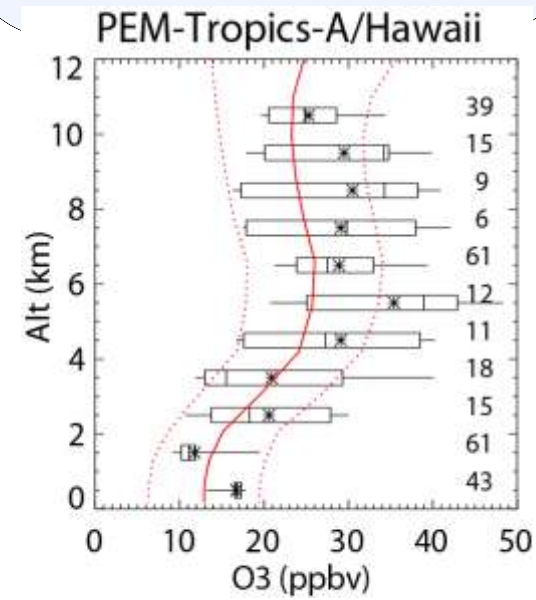


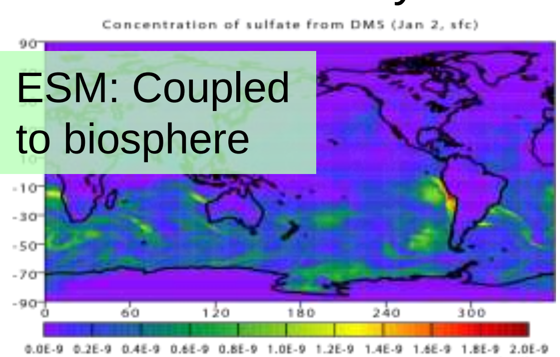
Full

Super-Fast

Isoprene improves simulation

Super-Fast + Isoprene



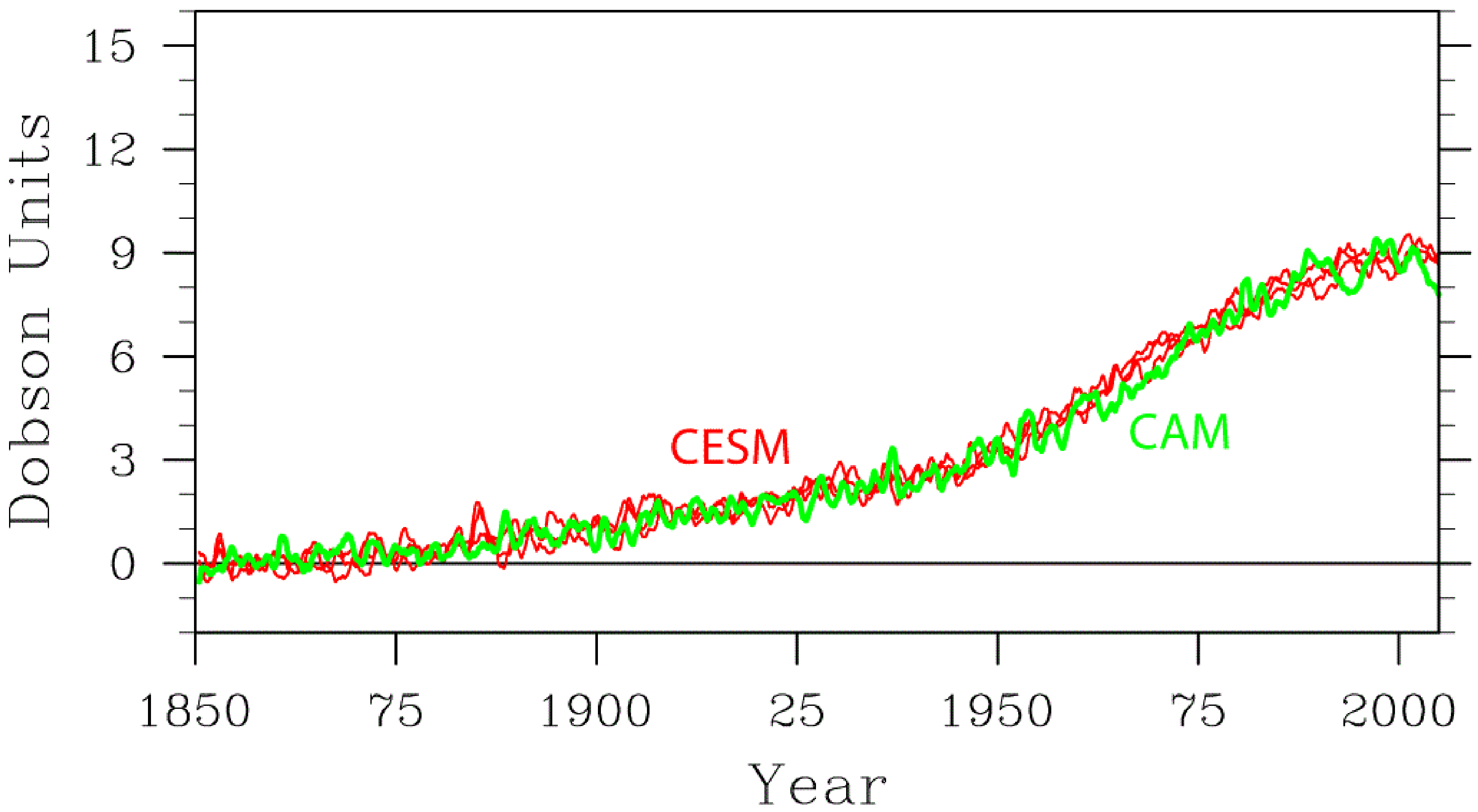


ESM: Coupled to biosphere

*Collaborating with LANL, NCAR, PNNL, ORNL, ANL, UC Irvine.

Hot off the press: Our IPCC ensemble simulations show internal variability.

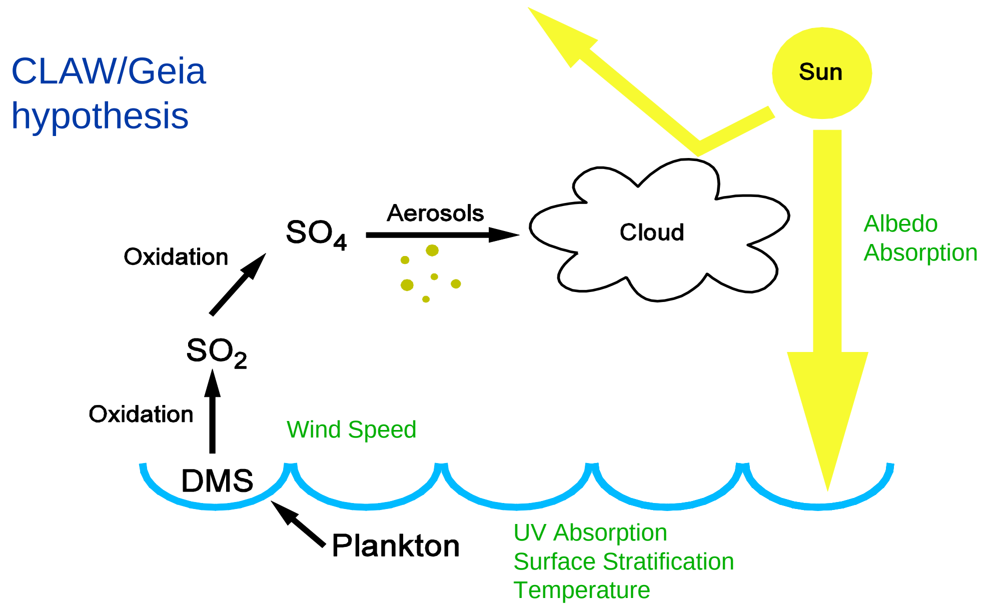
Change in global mean tropospheric ozone column



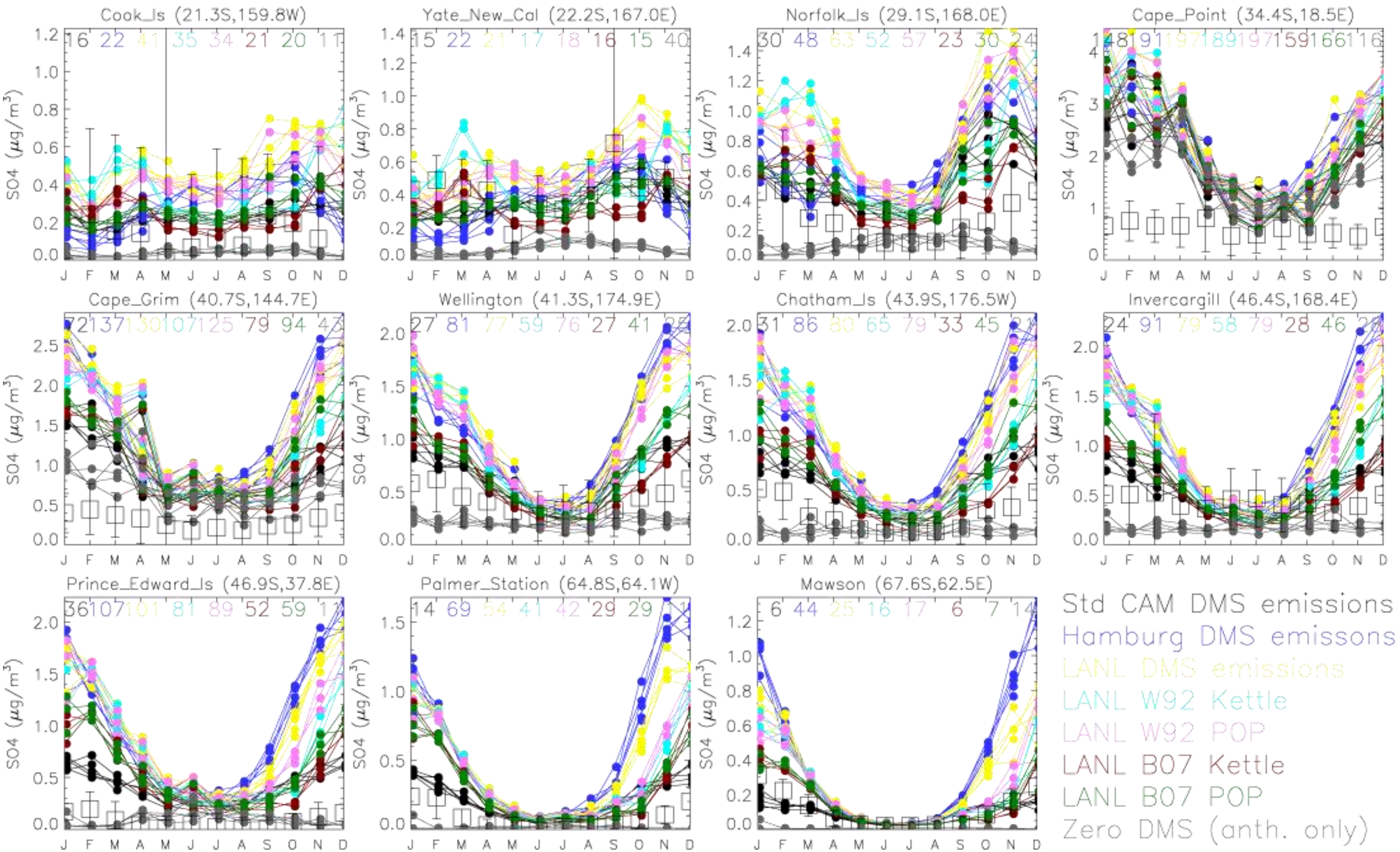
We are developing an Earth System Model (ESM): biosphere-atmosphere-chemistry coupling in CCSM.

P. Cameron-Smith, S. Elliott, M. Maltrud, R. Jacob, D. Bergmann, D. Erickson, M. Ham.

- The biosphere and atmospheric chemistry interact to affect climate.
- We are combining our atmospheric chemistry with the state-of-the-art ocean sulfur cycle from LANL in CCSM.
- End goal is to test the CLAW/Gaia climate stabilization hypothesis.

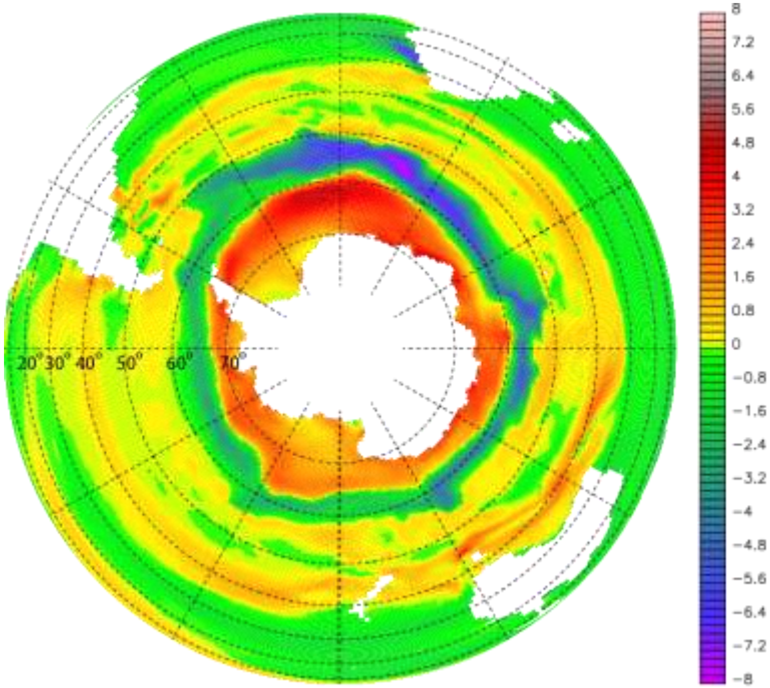


Sulfate aerosols validate well against surface observations.



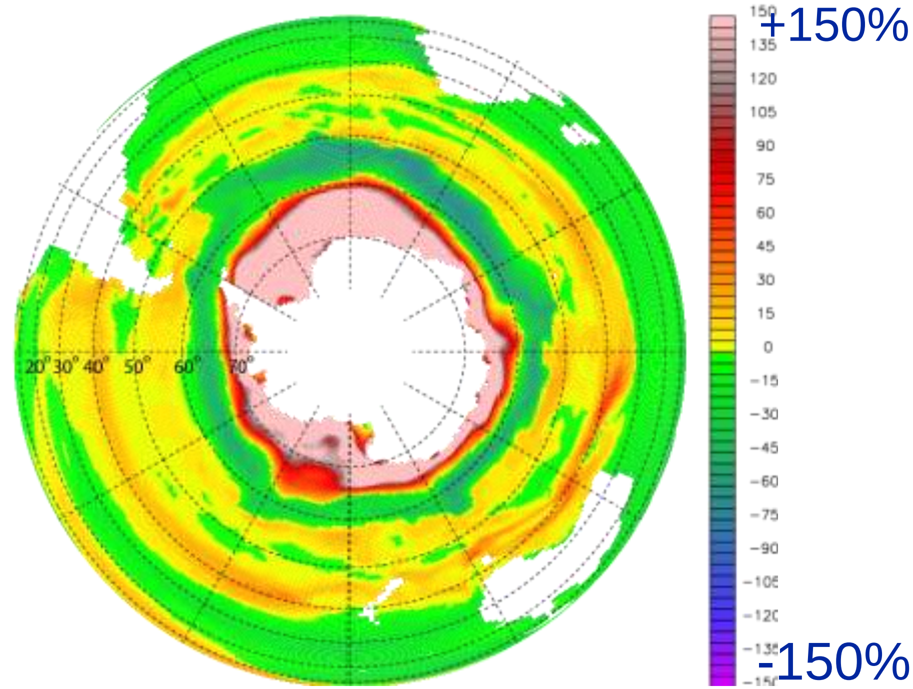
DMS emissions shifts over 21st century could be larger then previously thought around Antarctica.

Change in DMS emissions to the atmosphere over 21st century



nmoles/m2/s

Absolute difference

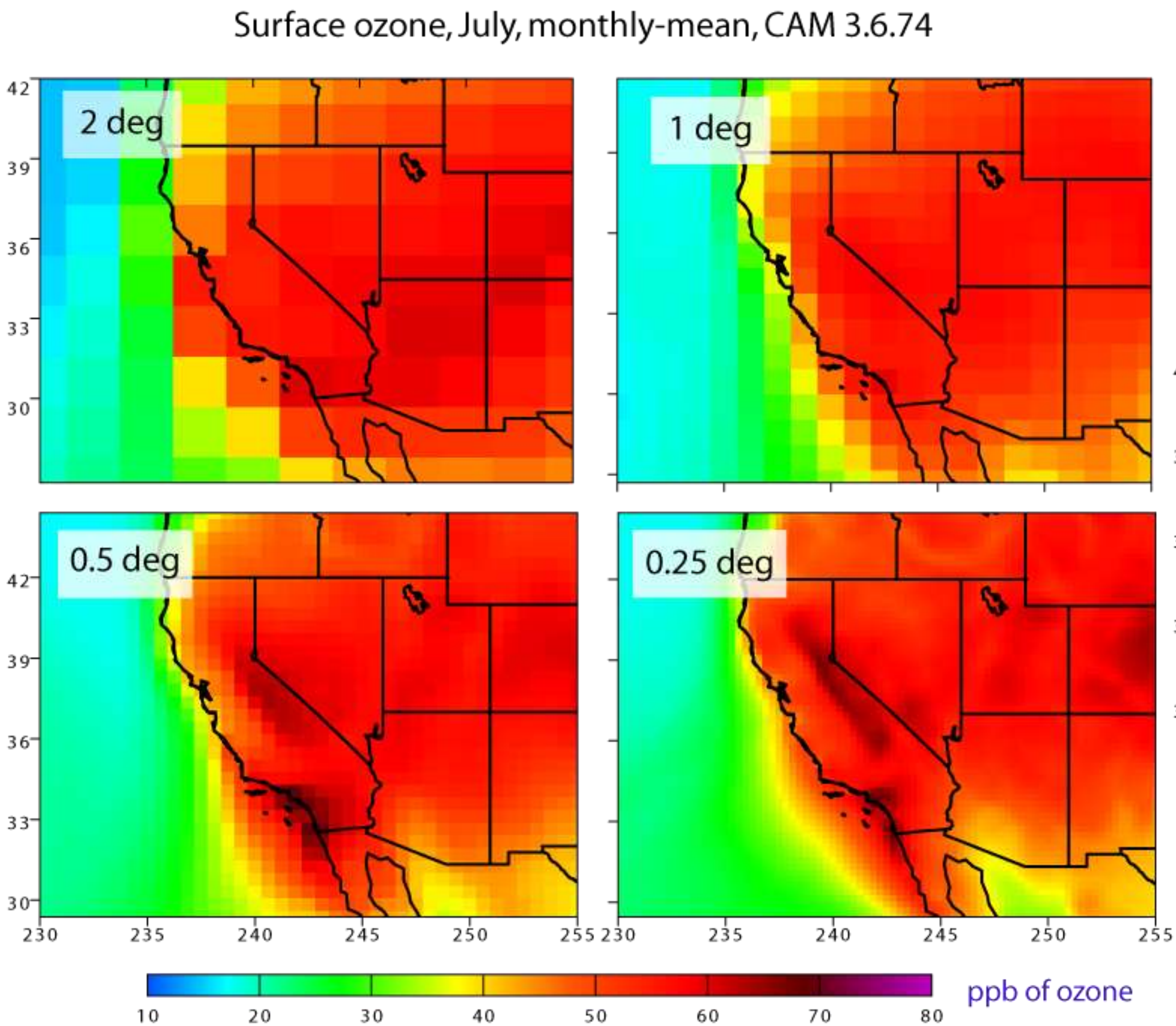


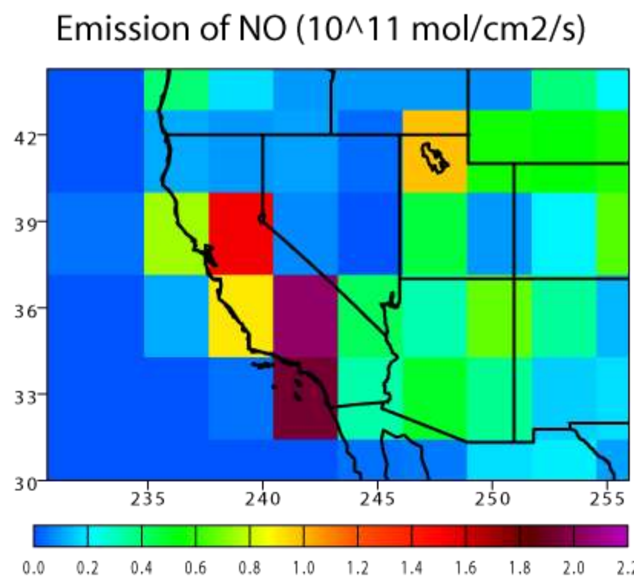
% difference

Hi-res chemistry shows smog over Los Angeles due to orographic enhancement.

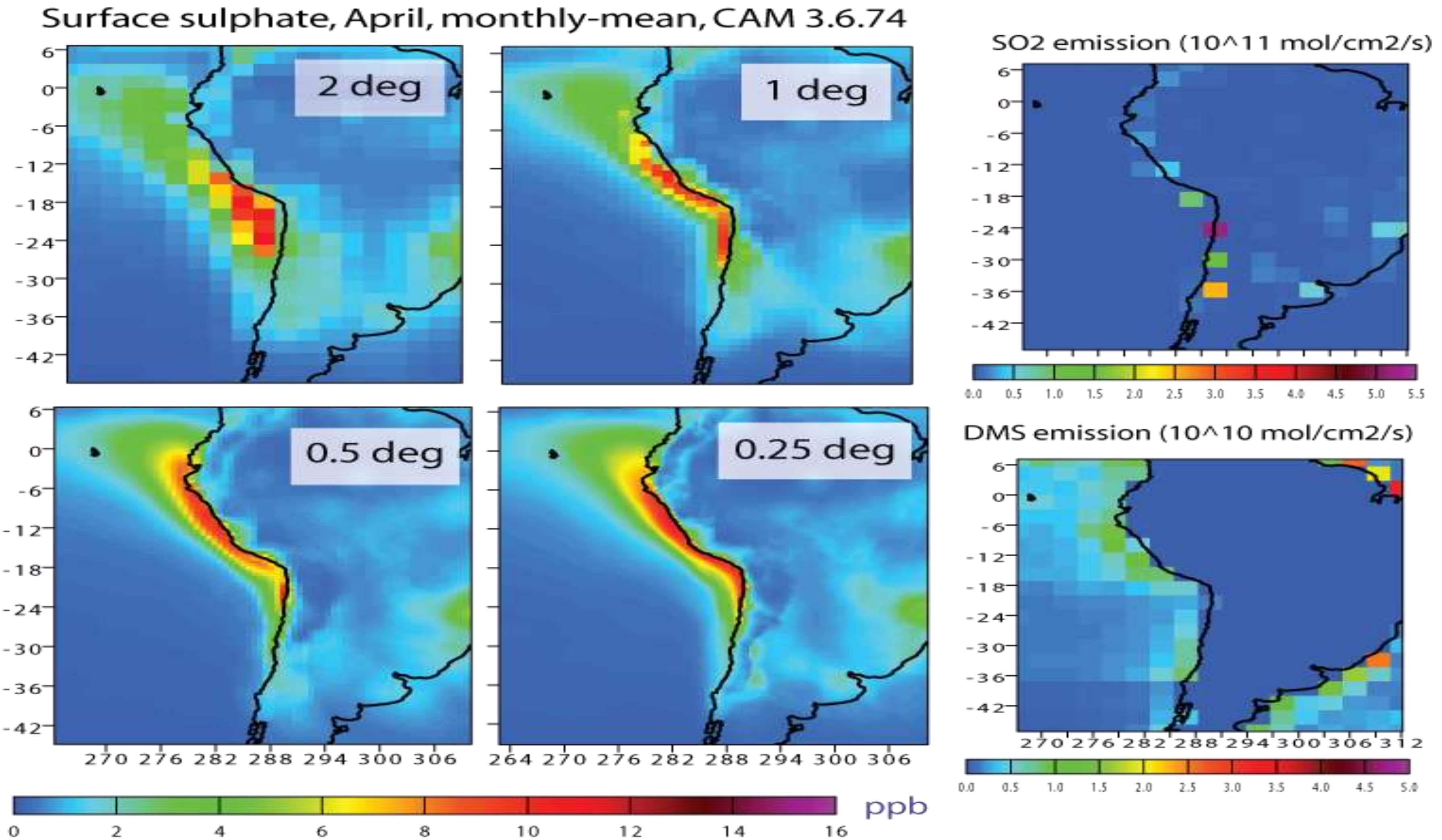
Livermore Computing

Grand Challenge 2009-2011





Hi-res chemistry shows narrower sulfate band off South America. The reason is unclear.

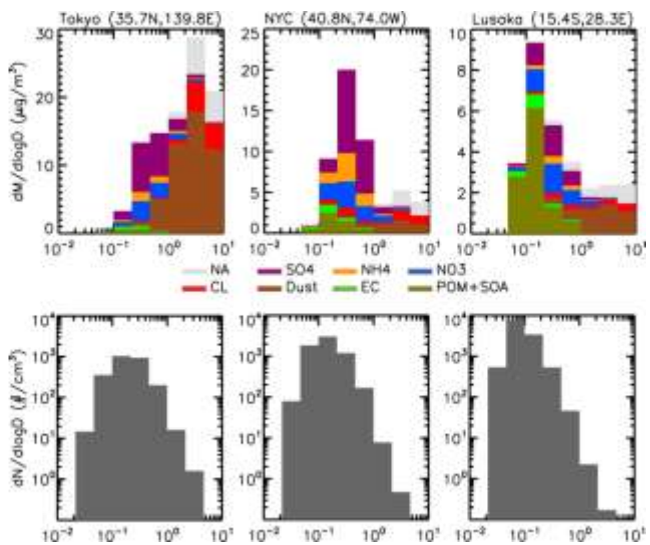


LLNL is adding sectional aerosol scheme to CAM, including SOAs.

Chuang, Bergmann, Cameron-Smith.

- Implement an aerosol microphysics model (MADRID) and an online biogenic emission system (MEGAN) into LLNL IMPACT model
  - MADRID predicts the chemical compositions, *number, and mass* size distributions of *inorganic* and *organic* aerosol components.
  - MEGAN calculates the hourly emissions of 20 compound classes, representing 138 compounds, which can be grouped into various chemical mechanism.
- Perform our first global simulation of size-resolved aerosol concentrations and mixing, including the secondary organic aerosols (SOAs)
  - Compare the simulated PM1 to measurements from Aerosol Mass Spectrometer in 37 field campaigns.
  - Assess the predictions of aerosol concentrations with IMPROVE network at 156 national parks.
- Incorporate the SOA chemistry and MADRID into the NCAR Community Climate System Model
  - Chemistry mechanism installed in CAM with 8 size bins for aerosols and > 300 total species
  - Land model (CLM) modified to accommodate a more detailed version of MEGAN
  - Installation of MADRID in progress

Simulated aerosol mass and number distributions in regions of Tokyo, New York City, and Lusaka.



Conclusions.

Methane

- Significant CH_4 may be released from Arctic ocean, depending on ecosystem nutrient limitation and bubble rise.
- Atmospheric impact of increased CH_4 emissions is significant (temperature and chemical).
- Next step is to couple sediment, ocean, and atmosphere.

Sulfur

- Have sulfur ESM.
- See significant shifts in DMS over 21^{st} century.

The End