Earth System Modeling in CESM: Sulfur, Methane

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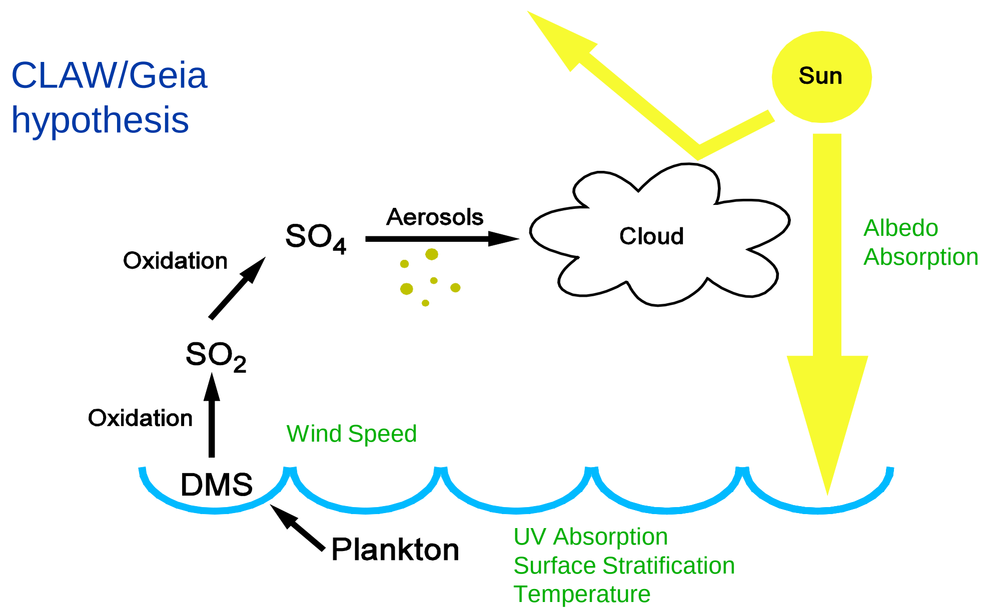
Acknowledgements to DOE: SciDAC Earth System Modeling, INCITE (Climate End Station), IMPACTS Abrupt Change, Fossil Energy Gas Hydrates,

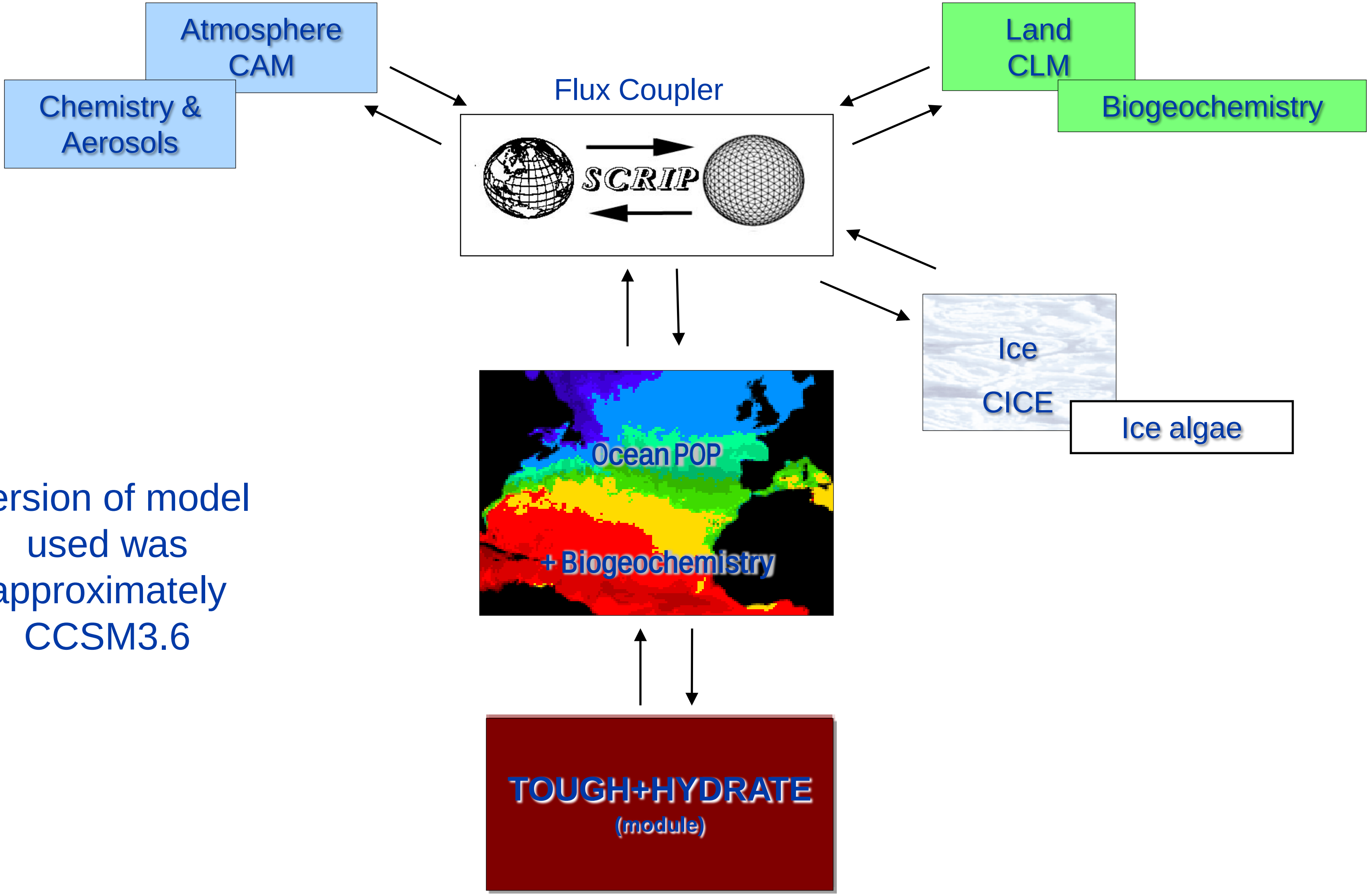
LLNL-PRES-489140

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

- The biosphere and atmospheric chemistry interact to affect climate.
- End goal is to
  a. Quantify the climate feedback.
  b. Test the CLAW/Gaia climate stabilization hypothesis.

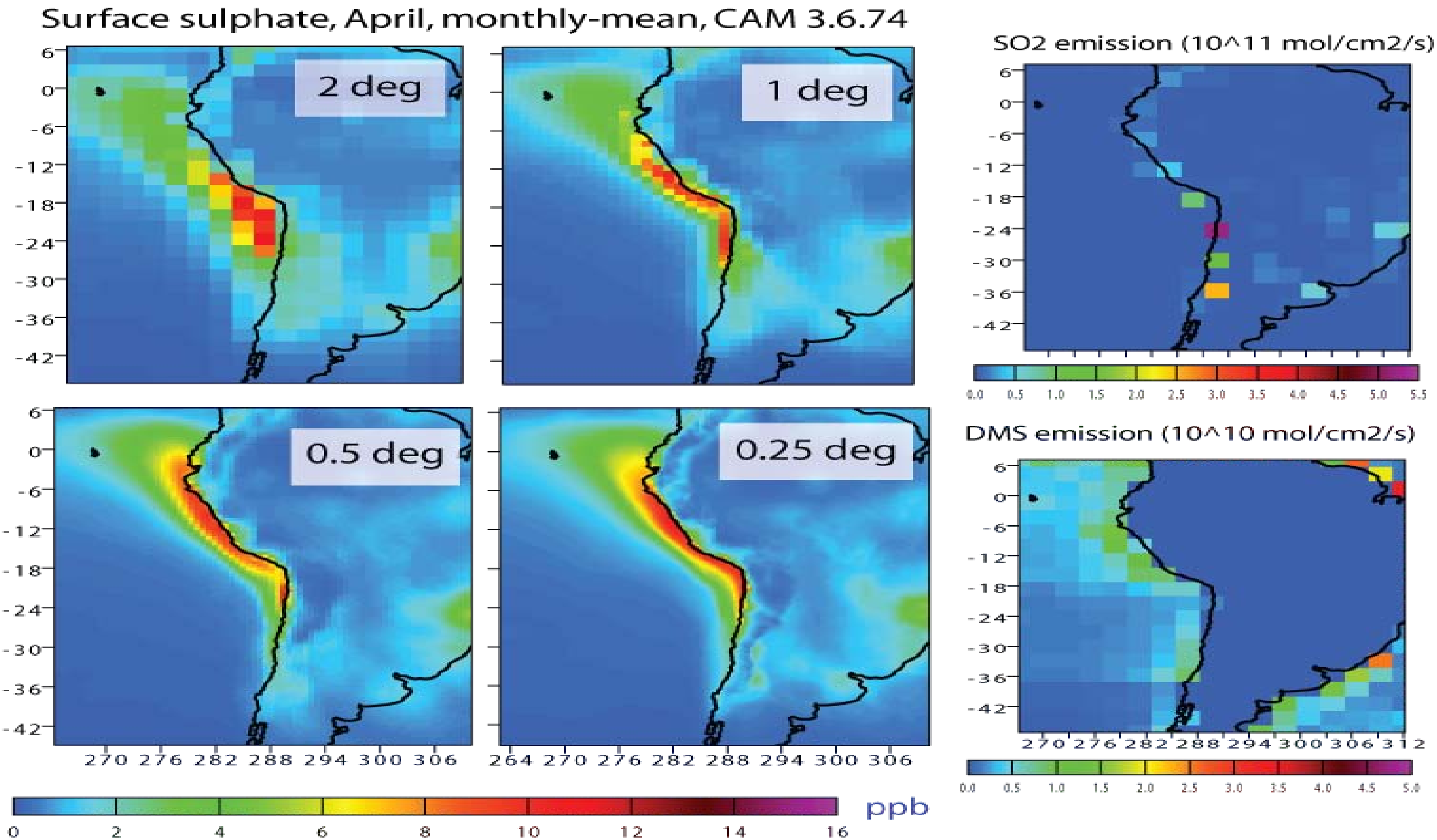


Sulfur & Methane ESMs

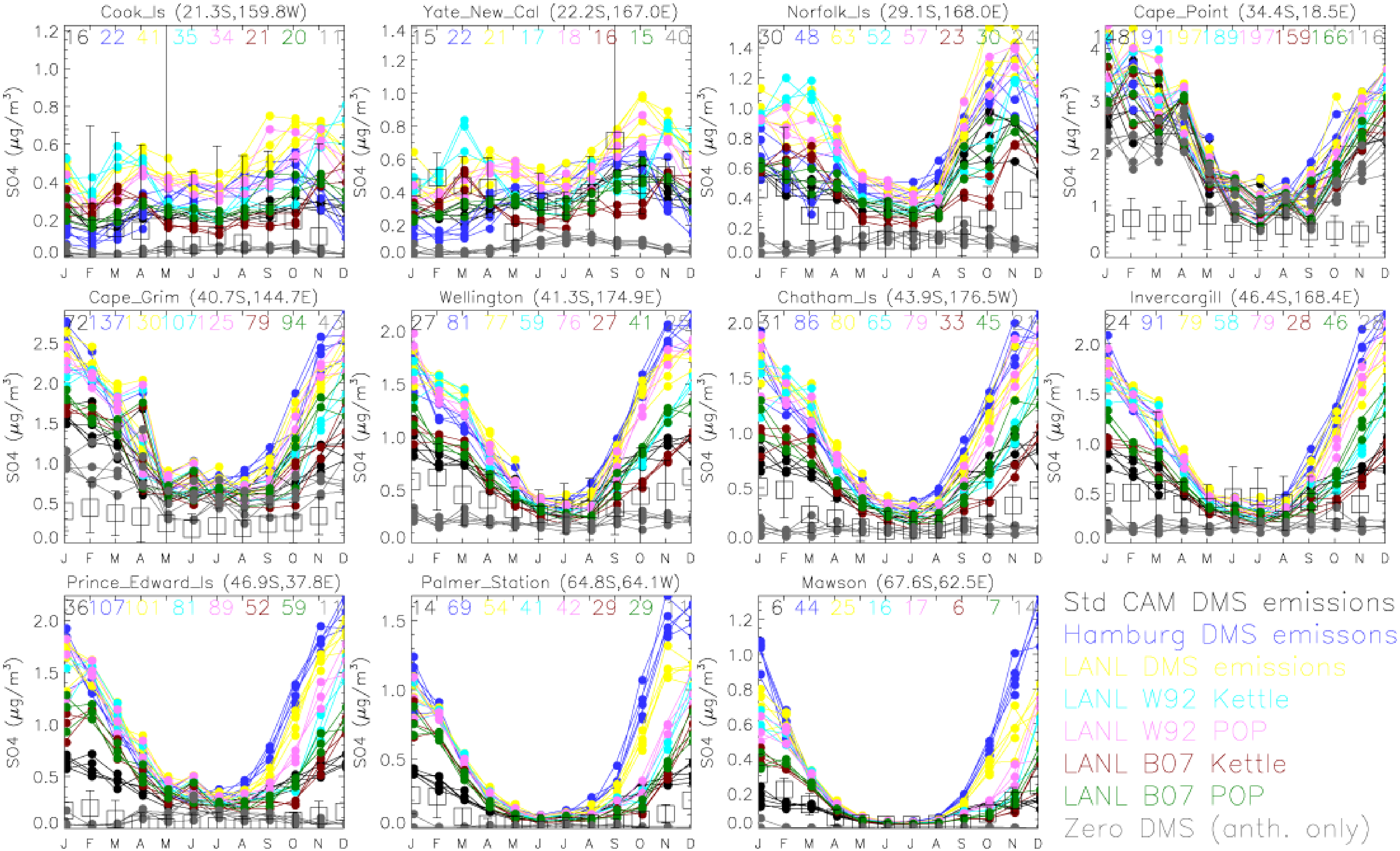


Version of model used was approximately CCSM3.6

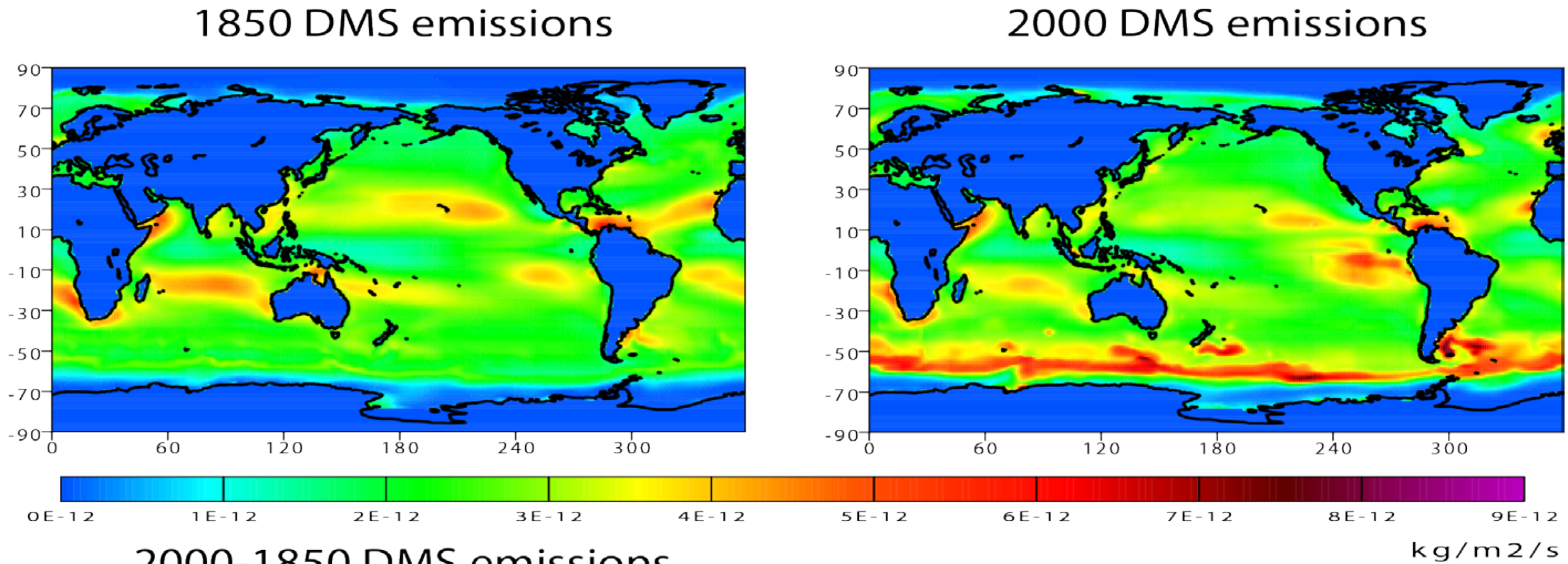
Hi-res chemistry shows narrower sulfate band off South America.

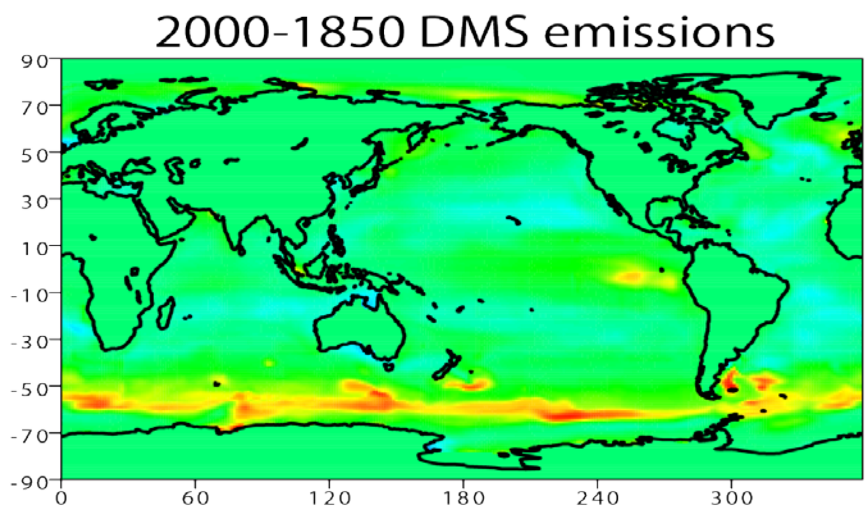


Sulfate aerosols validate well against surface observations.



DMS flux changes dramatically from 1850 to 2000, especially in Southern ocean





Globally averaged increase in DMS emission is 10%

Change in net SW radiation from *direct* DMS sulfate of 0.1 W/m^2

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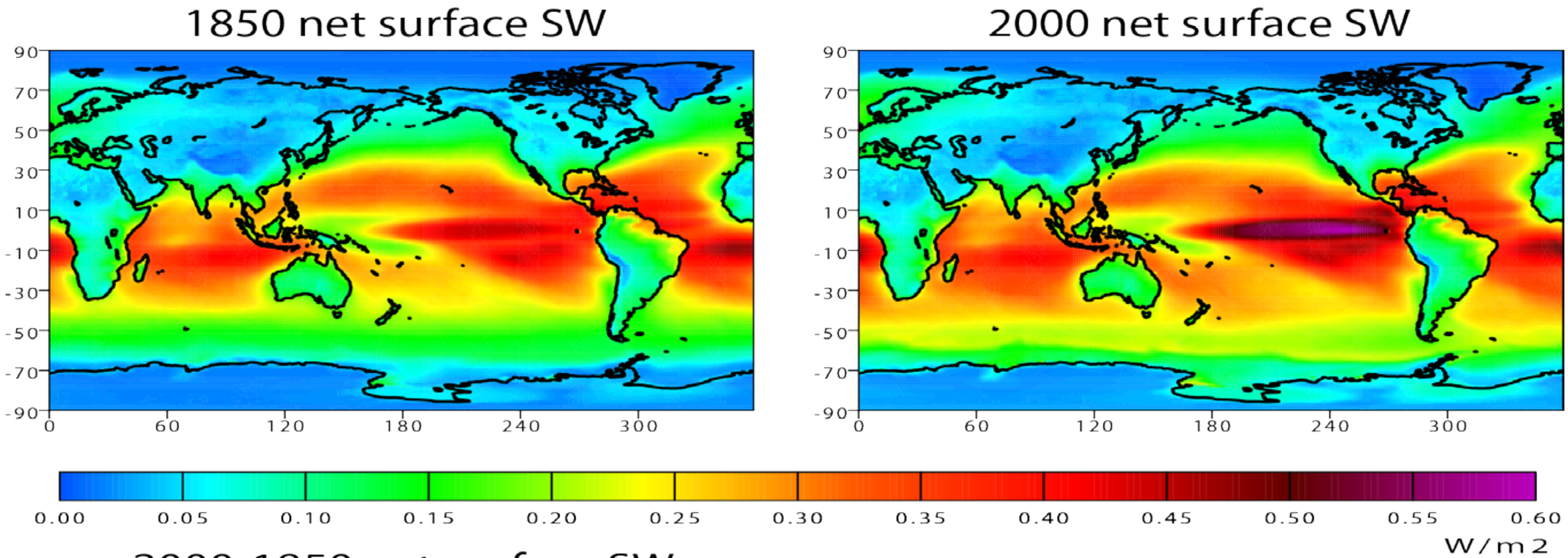
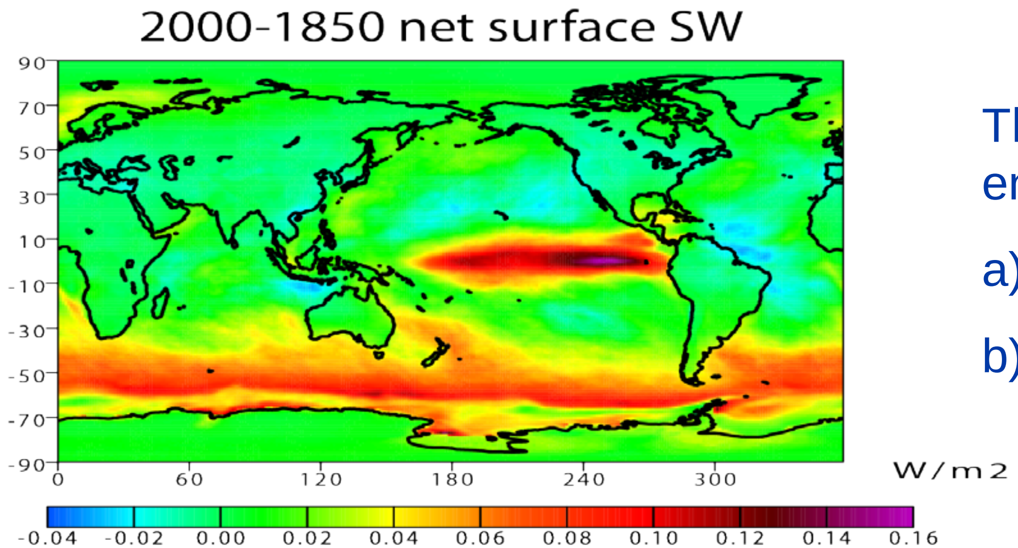


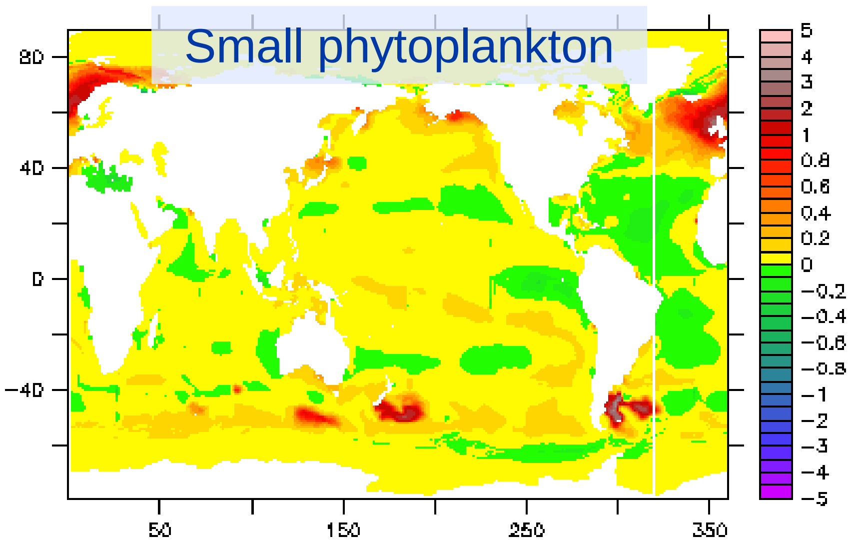


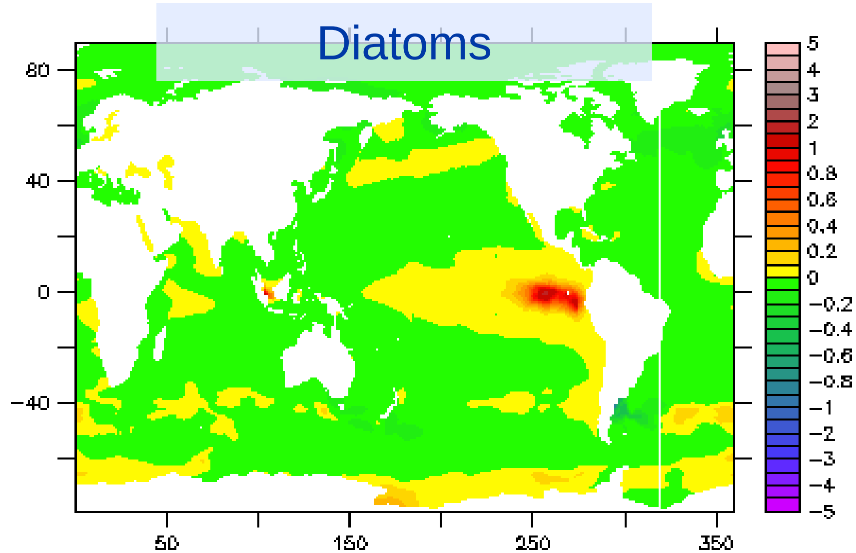
The effect of sulfate from DMS is enhanced in tropics because of

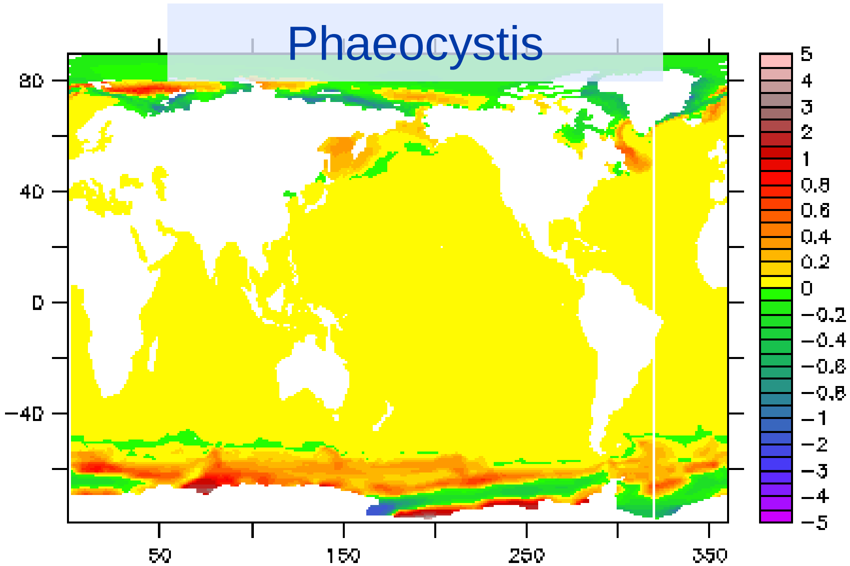
a) higher solar radiation,

b) faster oxidation of SO2 to SO4.

Changes in DMS are strongly affected by changes in ecosystem structure.







Change in DMS concentration (in sea-water) contributed by different phytoplankton types.

Units are normalized DMS concentrations, and are comparable across panels.

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

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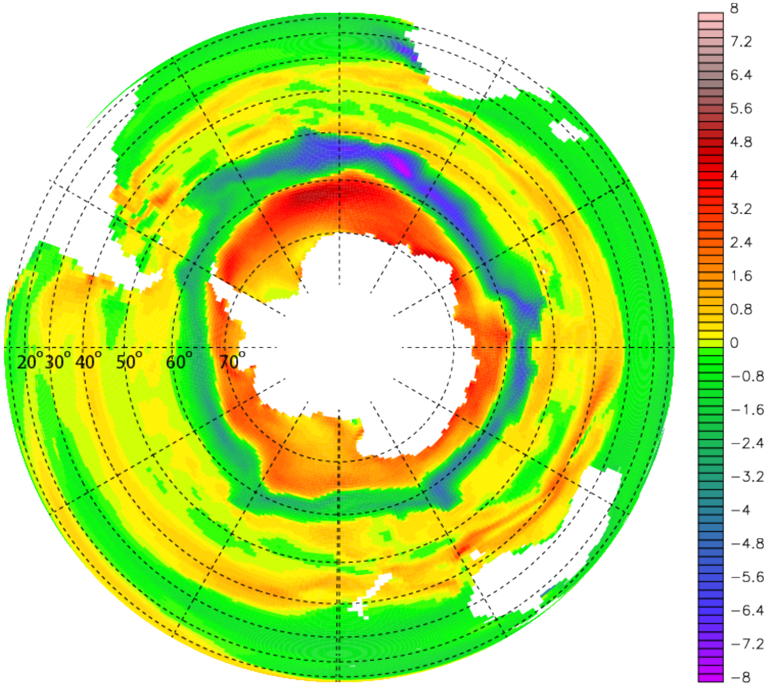
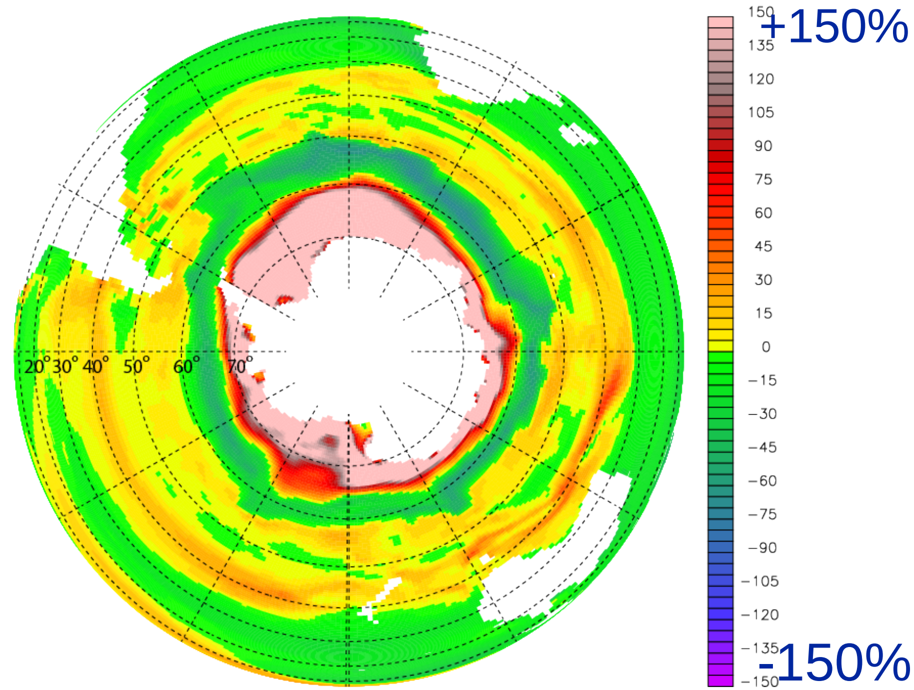
Change in DMS emissions to the atmosphere over 21st century



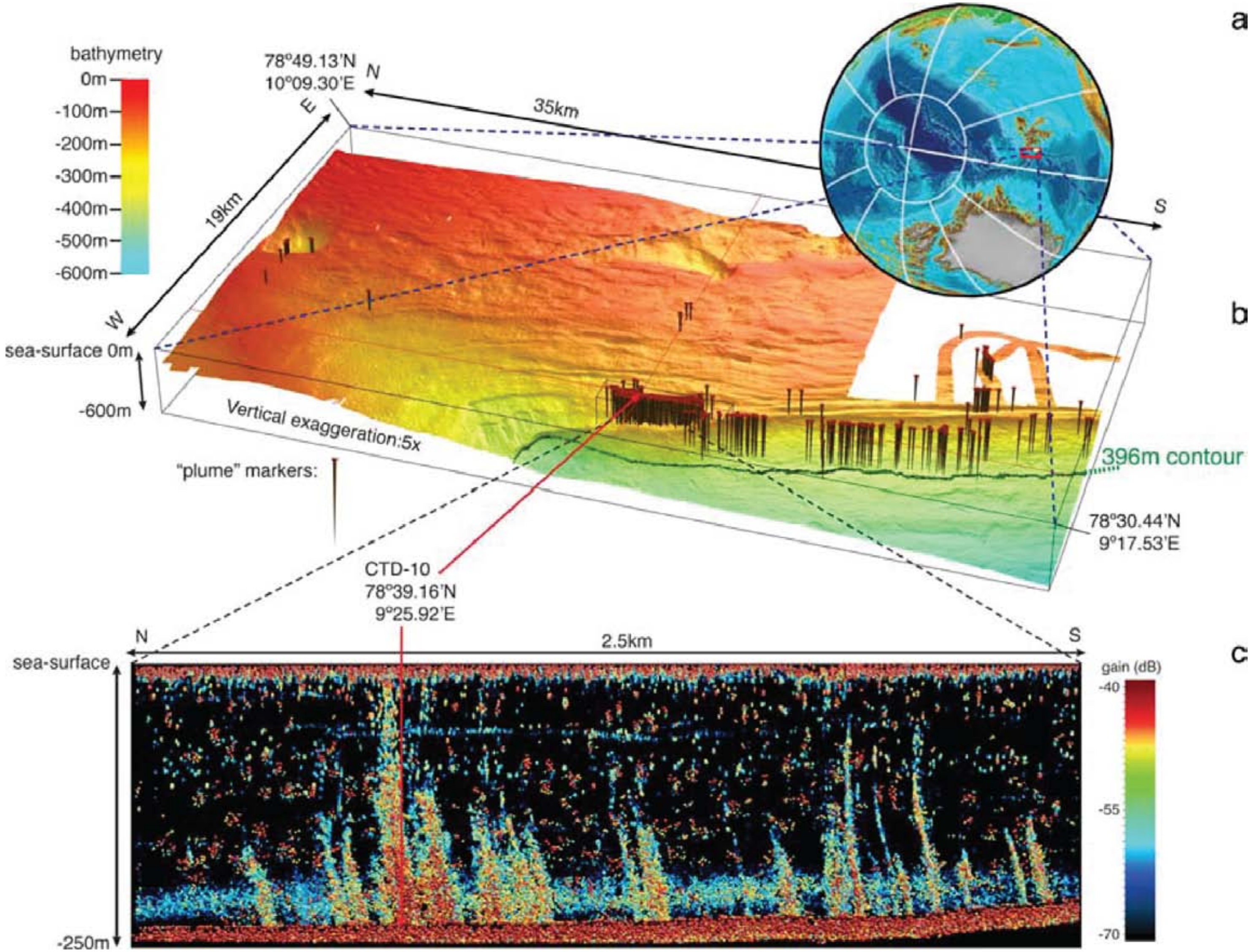


Raw difference nmoles/m^2/s **% difference**

P. Cameron-Smith, S. Elliott, M. Maltrud, D. Erickson, O. Wingenter, *Geophys. Res. Let*., **38**, L07704, 5 pp., doi:10.1029/2011GL047069, 2011.

Highlighted in "If Gaia could talk", Maurice Levasseur, Nature Geoscience, **4**, pp 351–352, doi:10.1038/ngeo1175, May 2011.

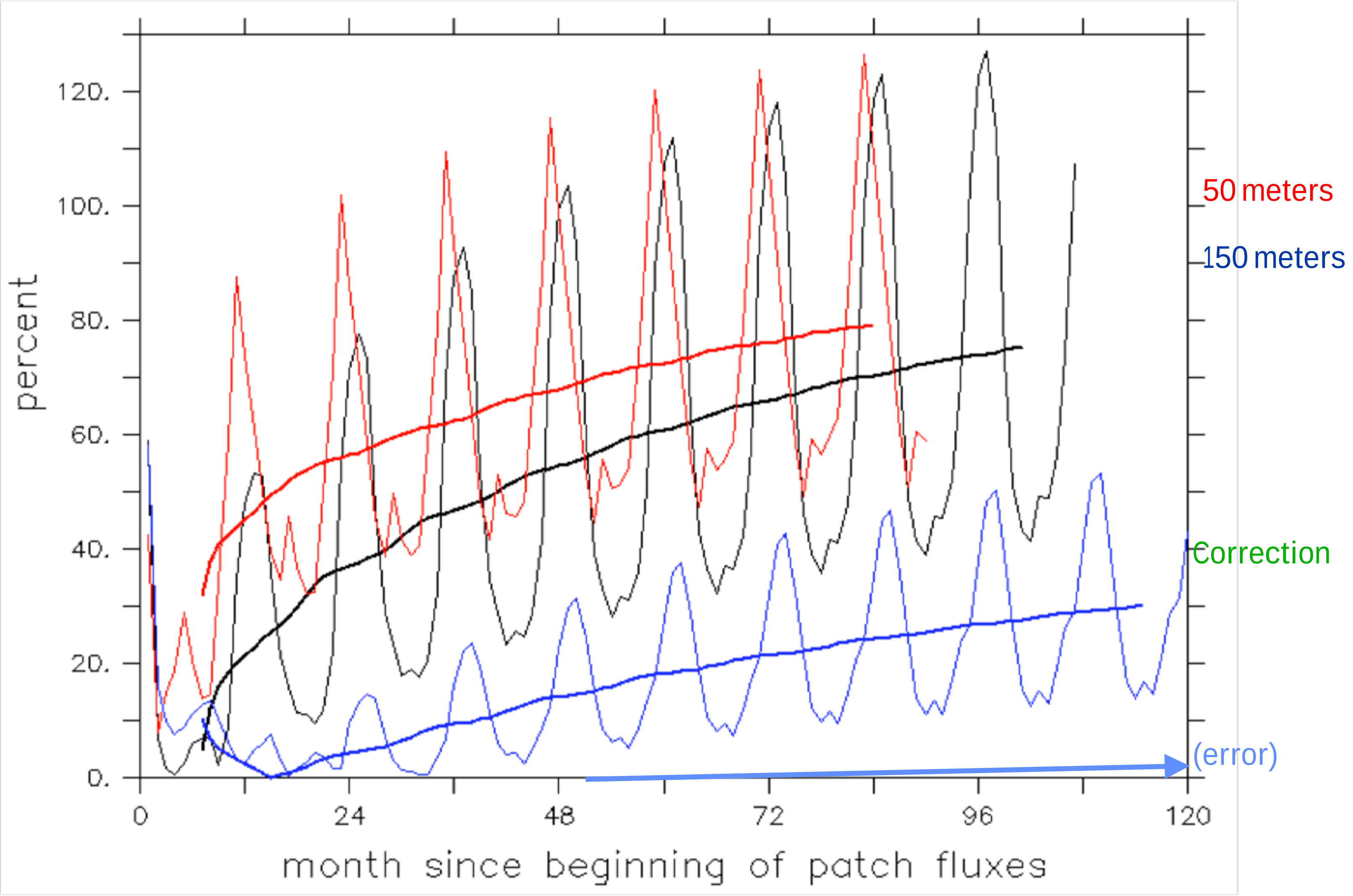
Methane plumes have been observed in the ocean at locations expected for clathrates.



Westbrook, et al., GRL, 2009.

Integrated escape to Arctic atmosphere from JGR patches

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



Atmospheric Impact of Methane Releases

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

Lawrence Livermore National Laboratory

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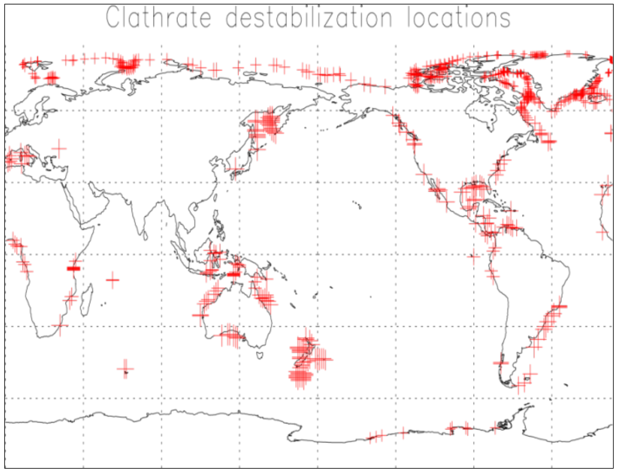
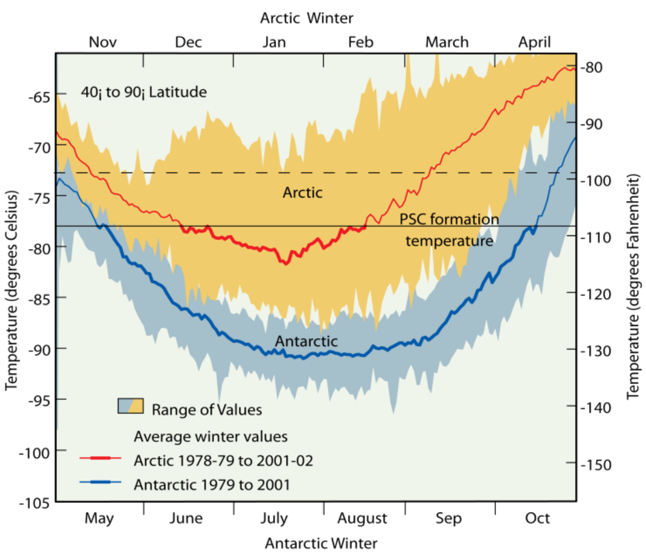
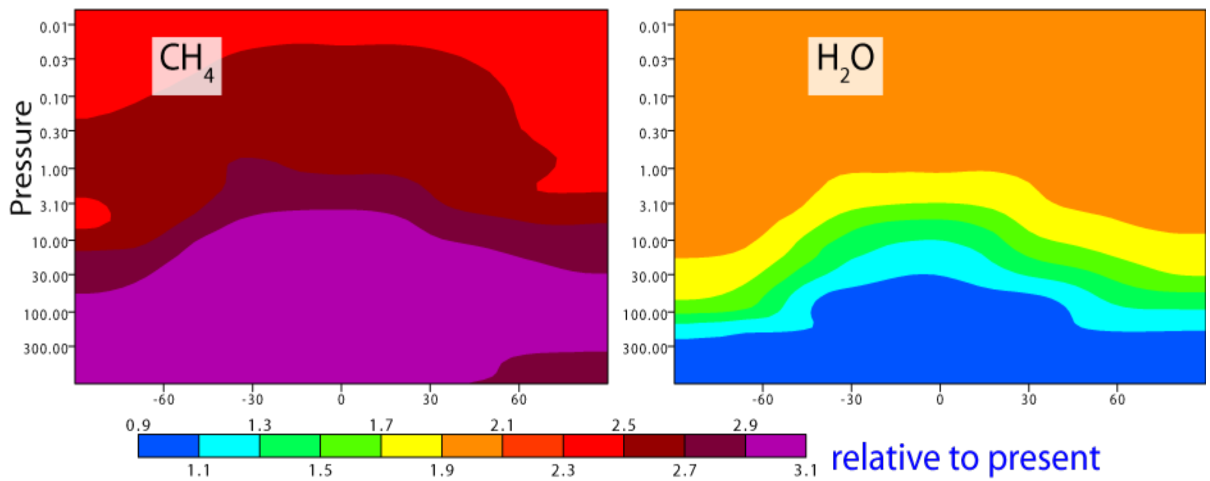
Clathrate destabilization locations

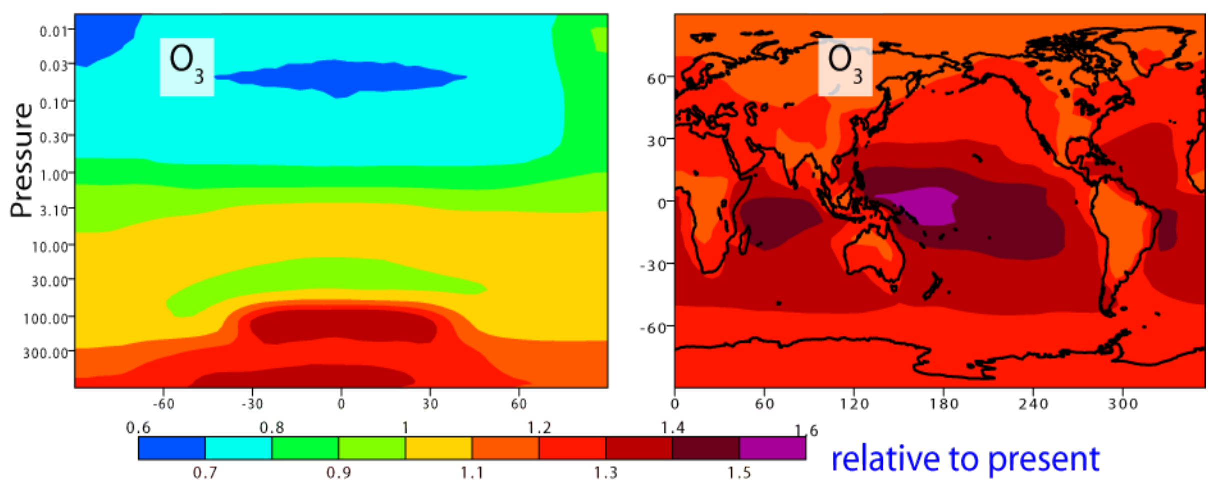


Ozone hole in Arctic?



Substantial changes in key tracers due to 2x CH_4 emissions





Conclusions.

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Sulfur

- 3x increase in DMS in southern ocean (2000-1850).
- Local *direct* forcing of 0.1 W/m^2 (2000-1850).
  - Indirect forcing should be larger still.
- Dramatic shifts in DMS over 21st century.
  - Importance of DMS also likely to increase as anthropogenic SO_2 is expected to decrease (pollution control).

Methane

- CH_4 may be released from Arctic ocean because of nutrient limitation and bubble rise.
- Atmospheric impact of CH4 emissions is large (temperature and chemical).

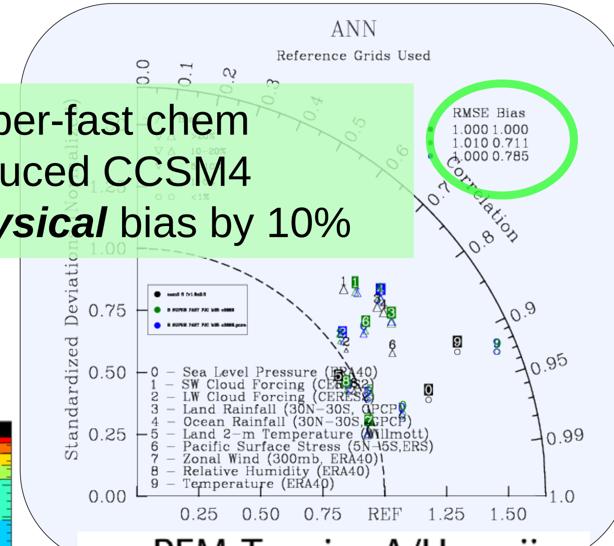
The End

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.

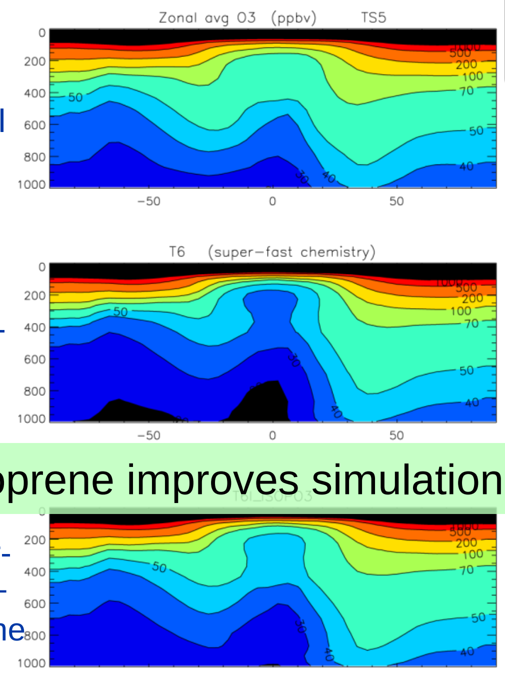
Super-fast chem reduced CCSM4 ***physical*** bias by 10%



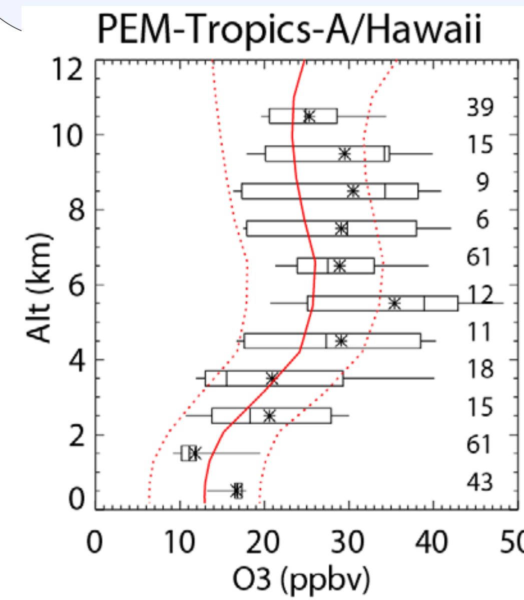
Full

Super-Fast

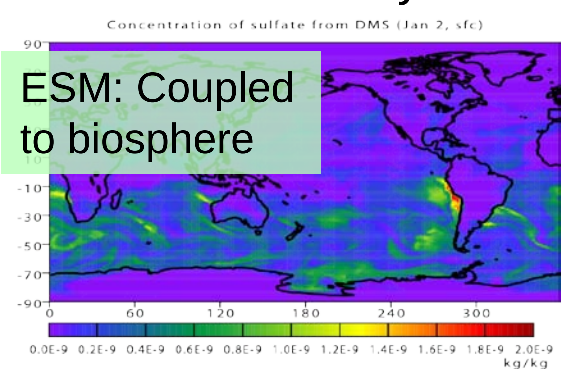
Super-Fast + Isoprene



Isoprene improves simulation



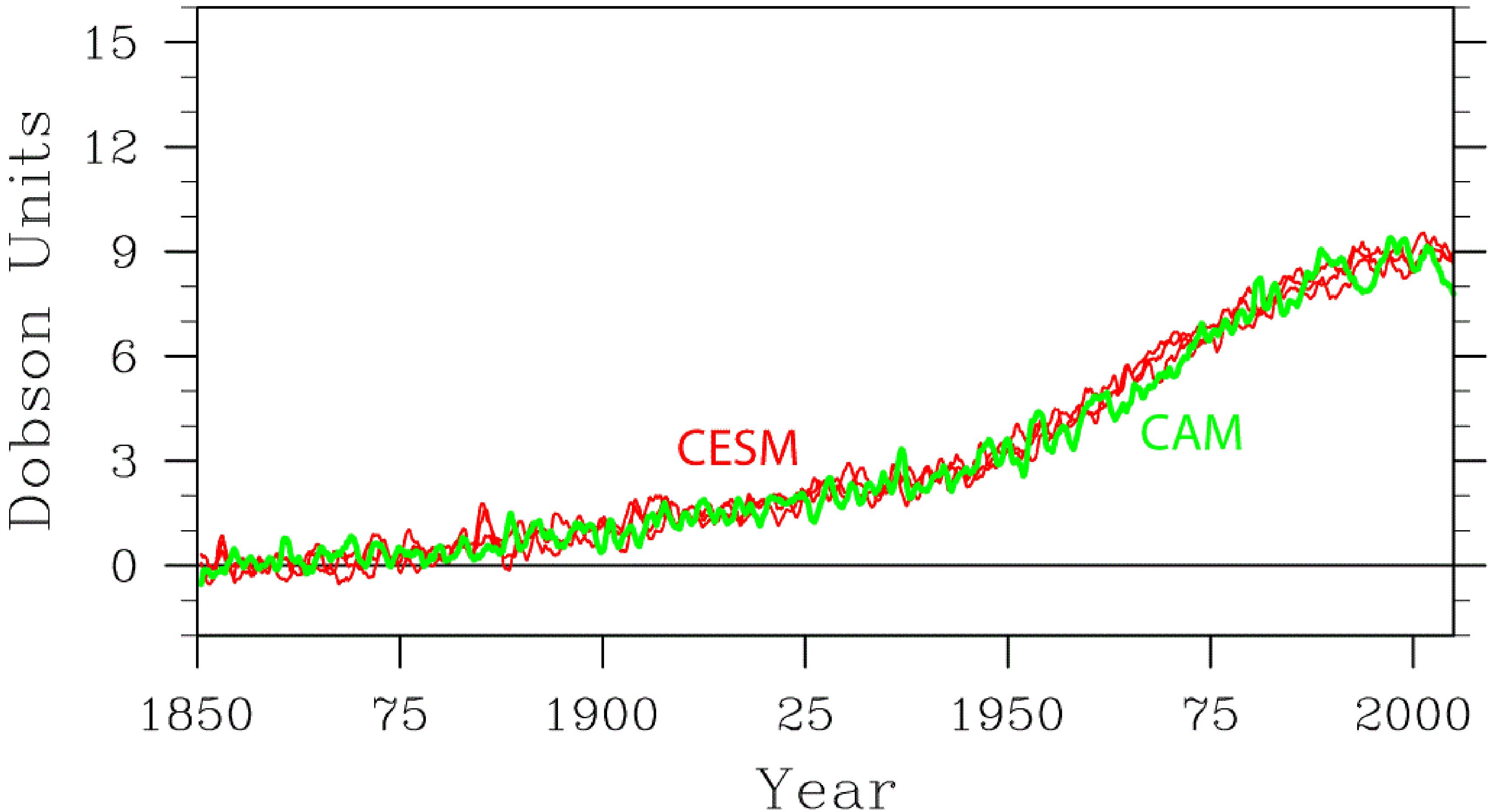
ESM: Coupled to biosphere



*Collaborating with LANL, NCAR, PNNL, ORNL, ANL, USC

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

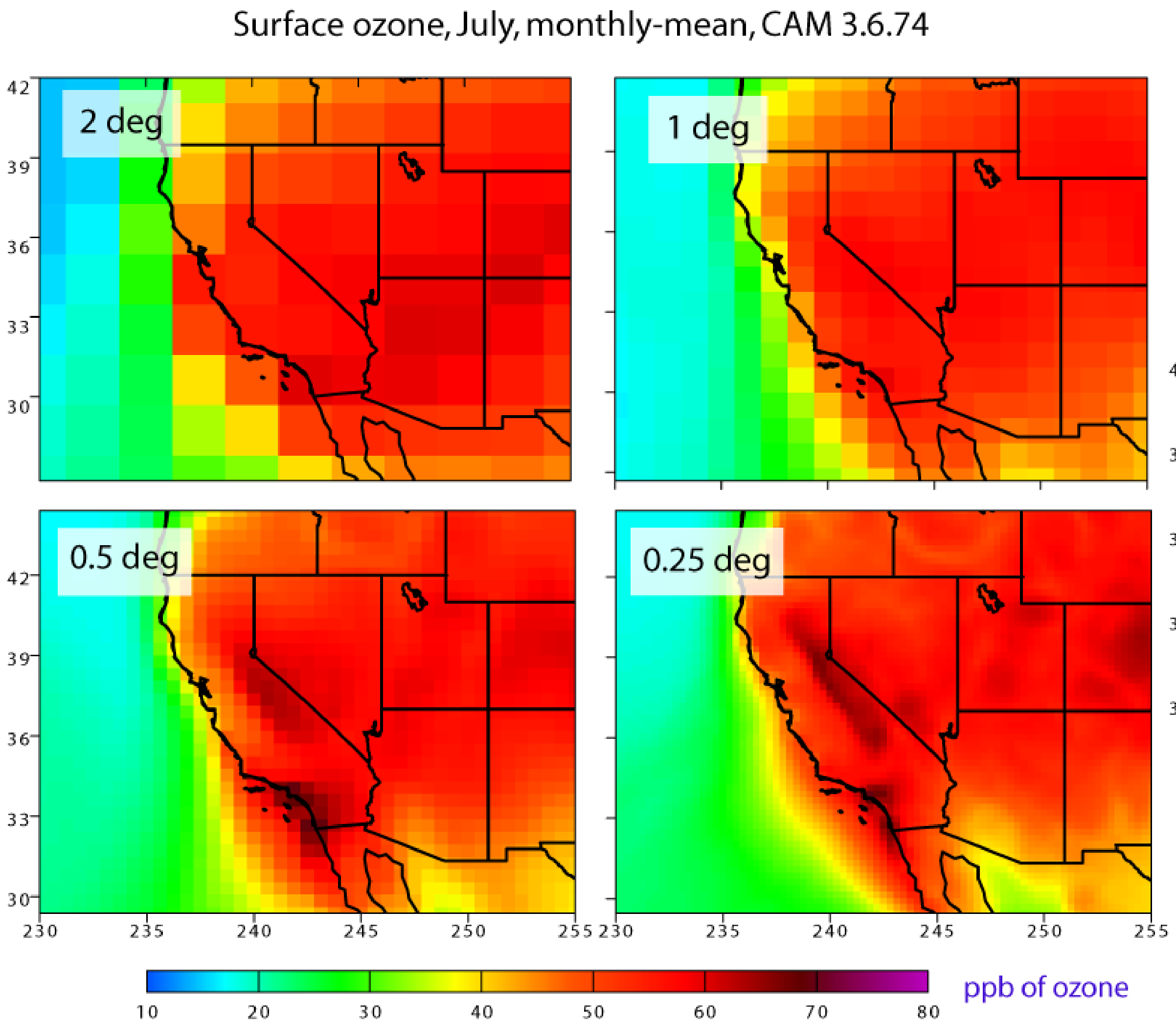
Change in global mean tropospheric ozone column

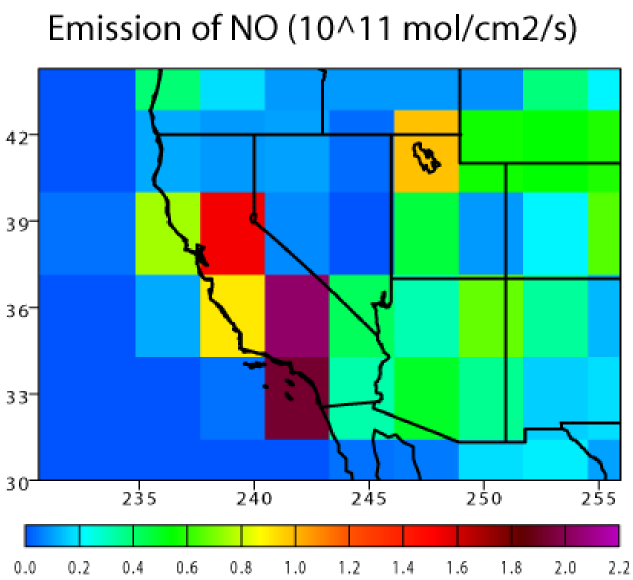


Hi-res chemistry shows smog over Los Angeles due to orographic enhancement.

Livermore Computing

Grand Challenge 2009-2011





Surface air temperature change from 1850 to 2000 (all forcings)

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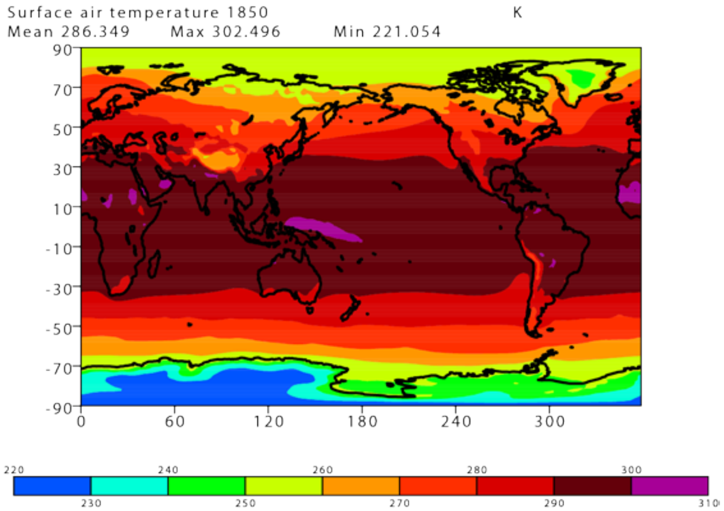
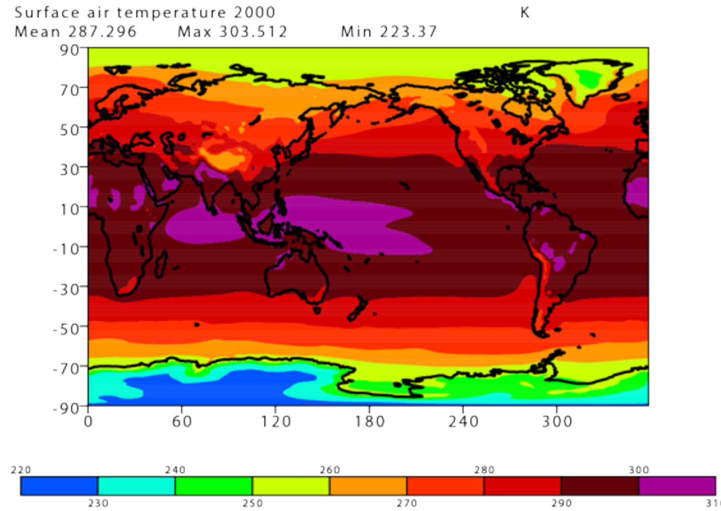
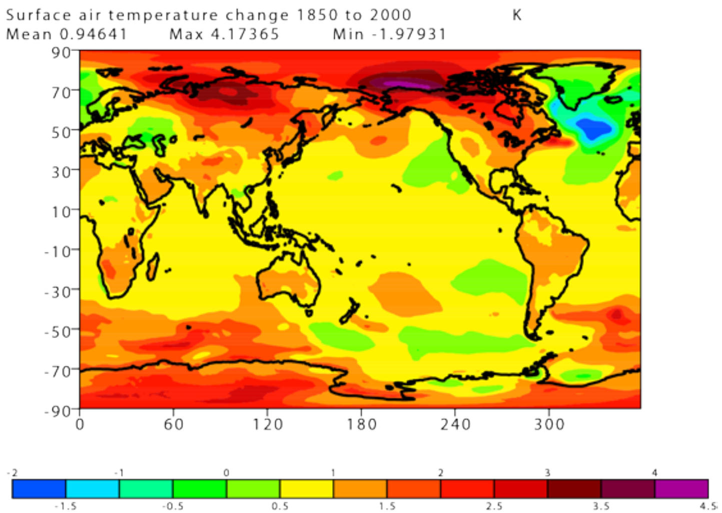




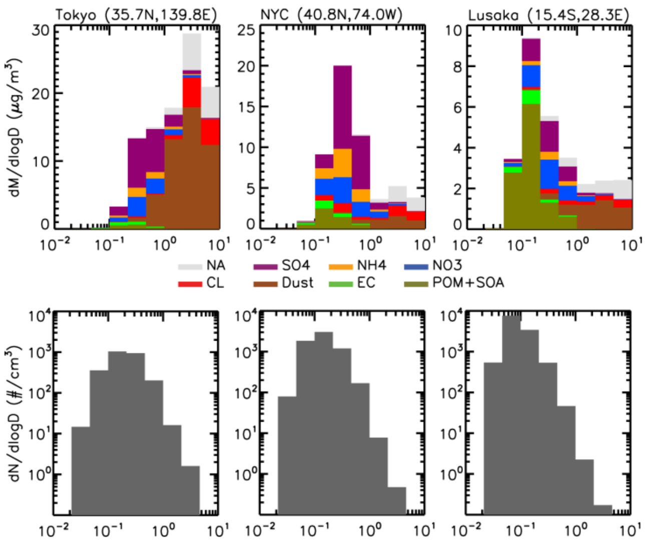


LLNL is adding sectional aerosol scheme to CAM, including SOAs.

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.



Impact of Abrupt Methane Release

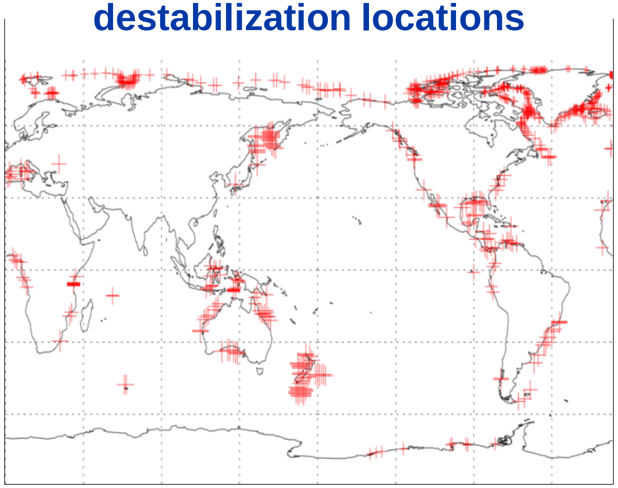
P. Cameron-Smith, D. Bergmann, S. Bhattacharyya, & collaborators*

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

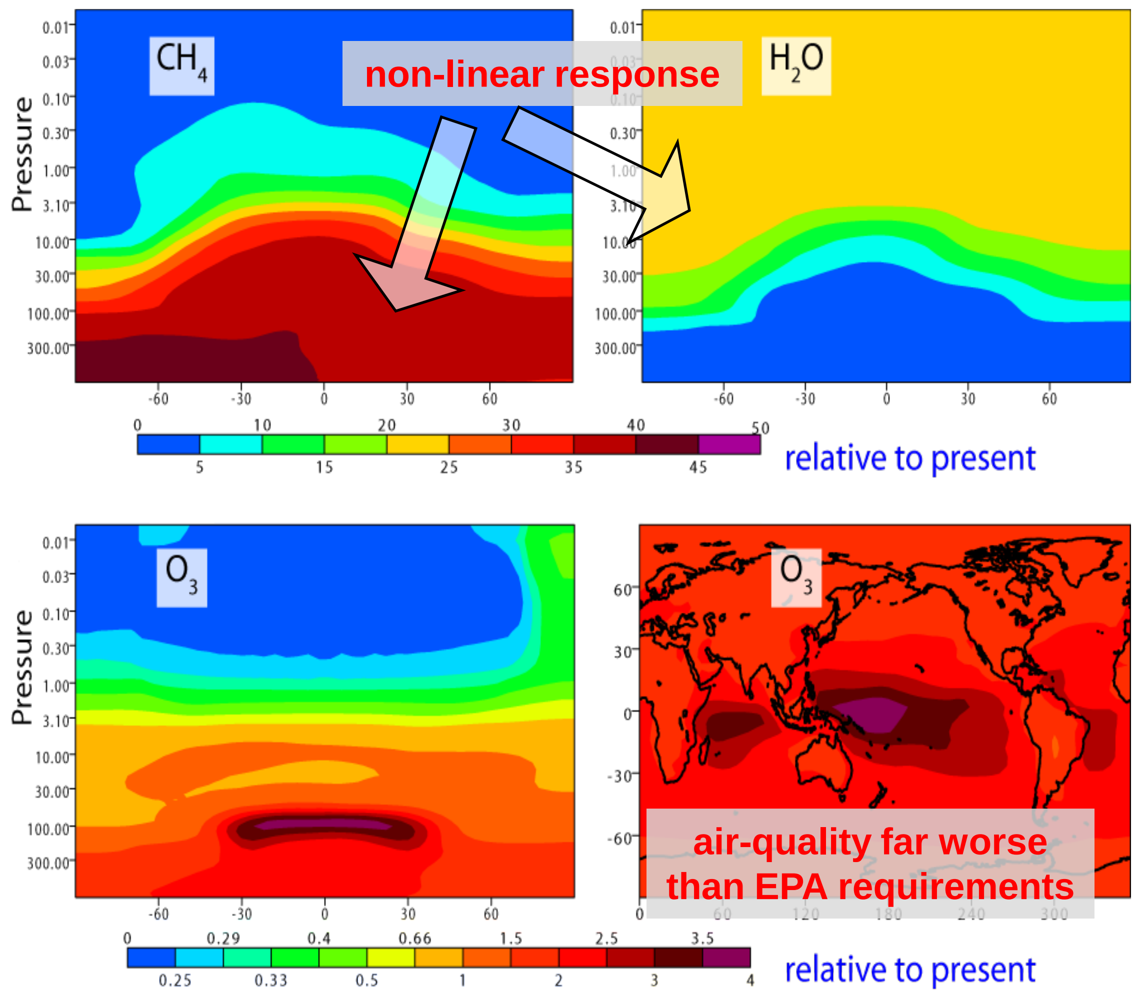
Rapid clathrate destabilization due to climate warming would significantly increase methane release, causing:

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

Predicted Clathrate destabilization locations

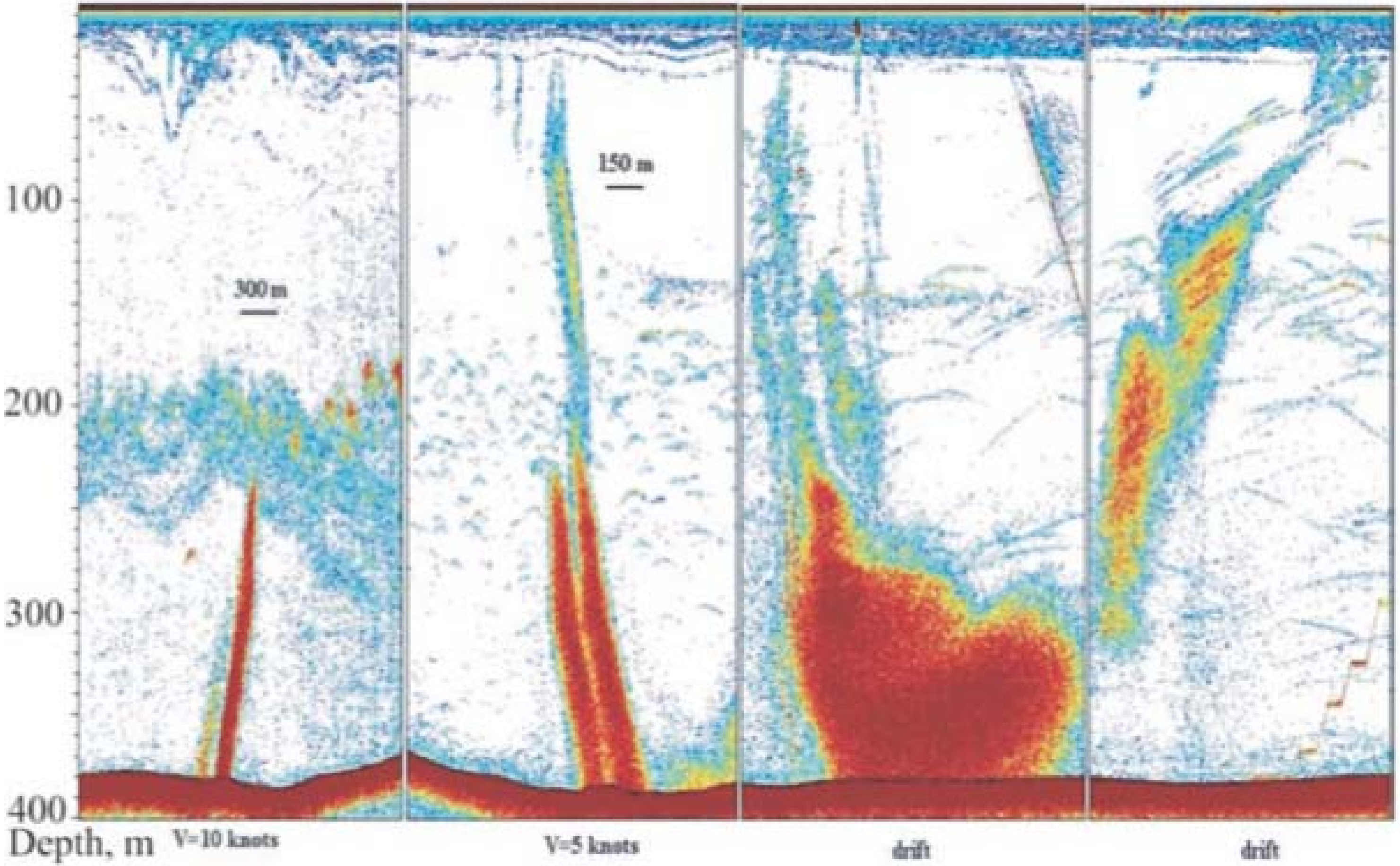


Large changes in GHGs due to ten fold methane emissions



Obzhirov et al., Sea of Okhotsk off Sakhalin

Methane bubble flares

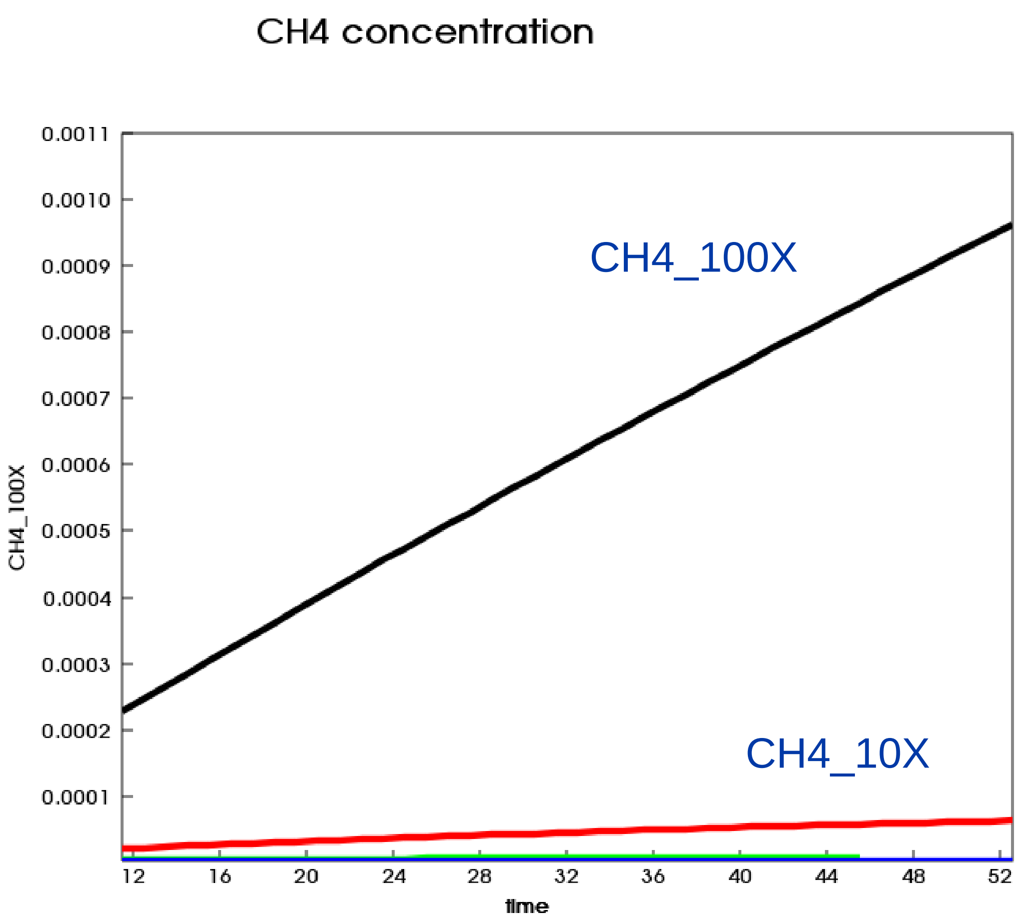


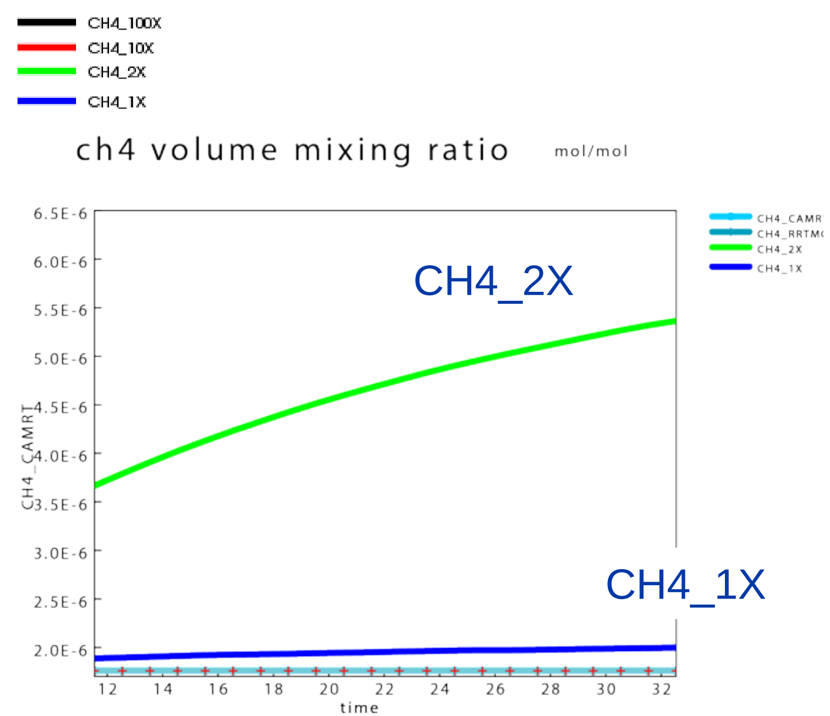
Atmospheric Study Cases:

- 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)

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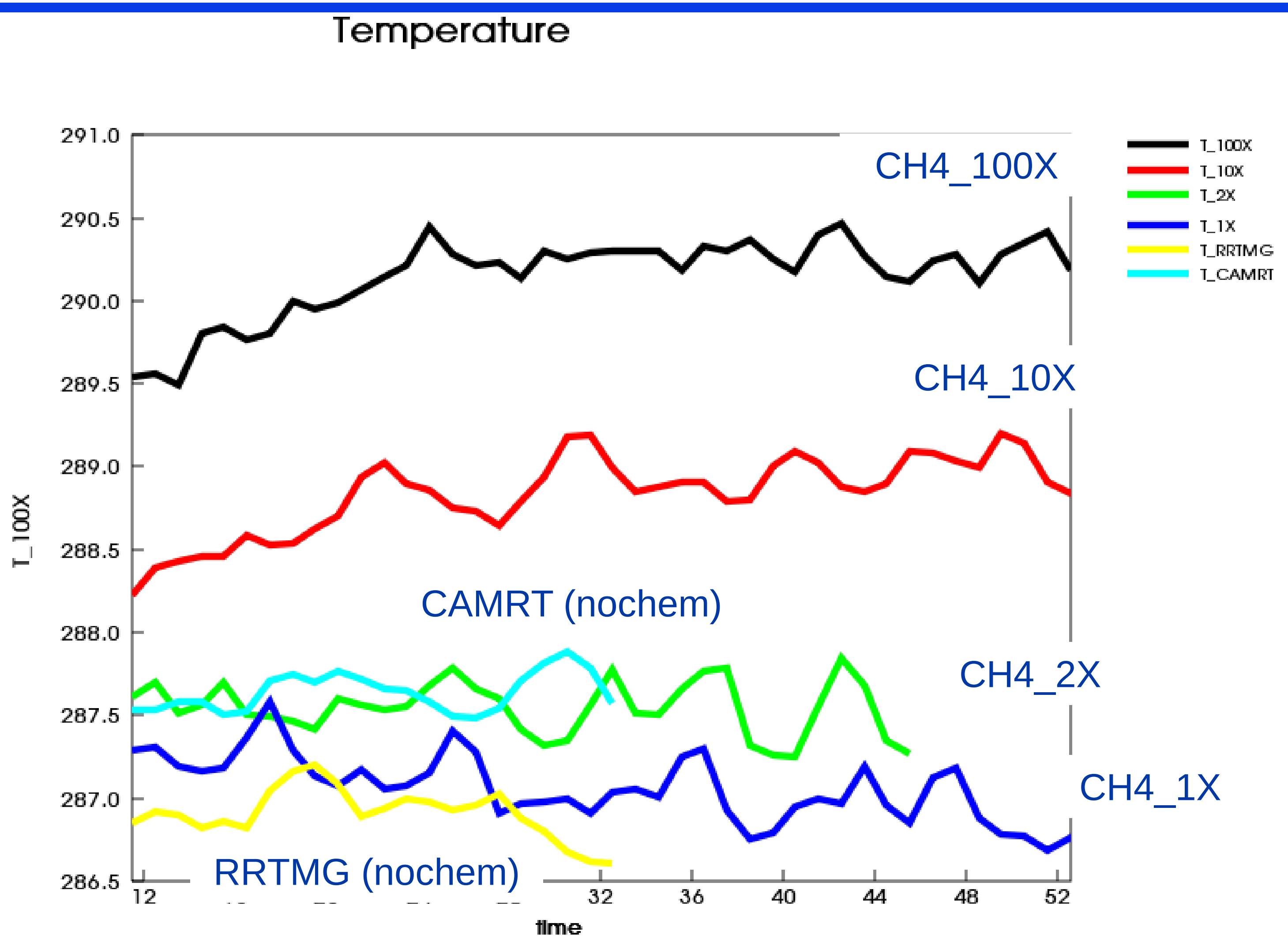

Annual Mean Temperature Differences in Fully coupled model

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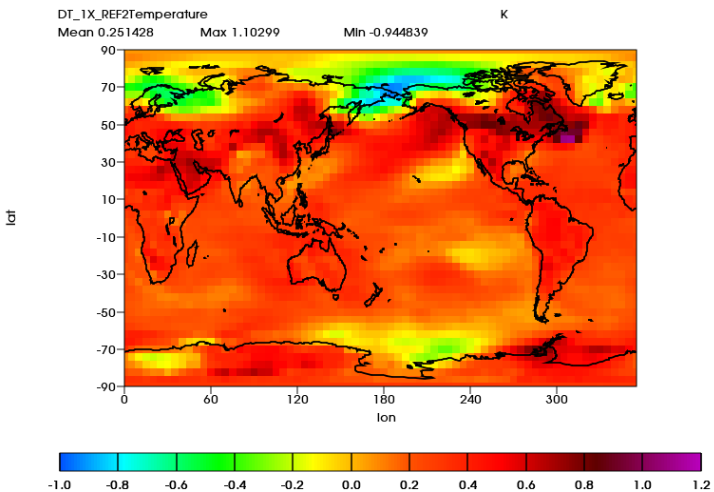
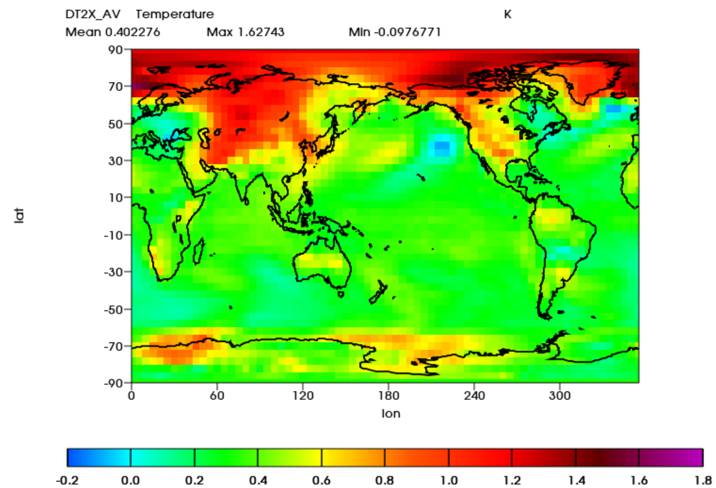
CH4_1X and RRTMG (nochem)

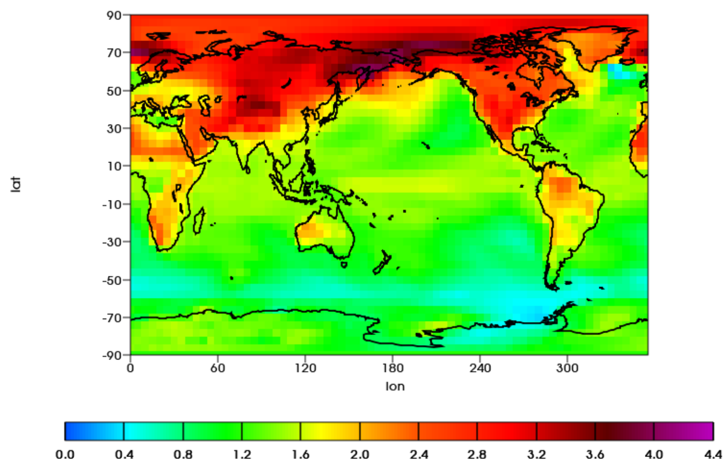


CH4_2X and CH4_1X



Max = 1.6 W/m2

CH4_10X and CH4_1X



Max = 4 W/m2

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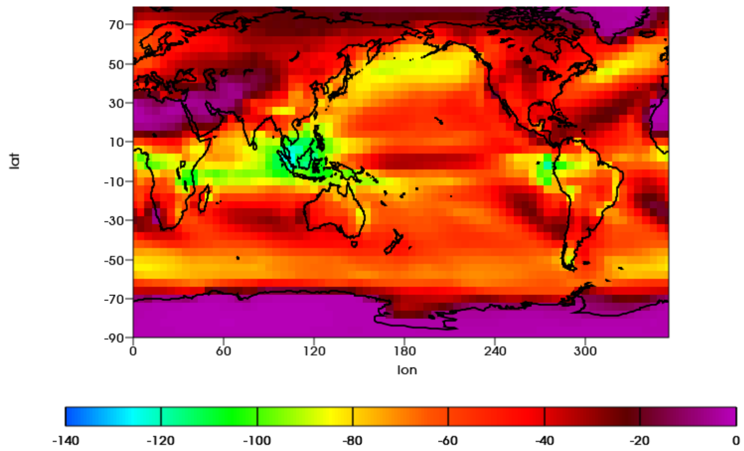
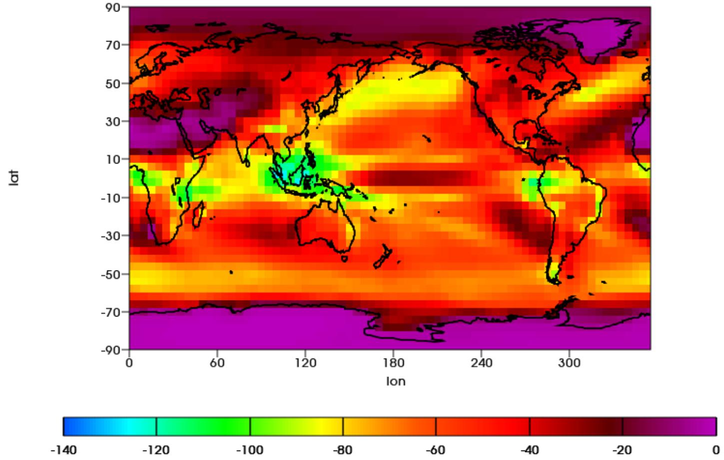
Short Wave Cloud Forcing: no big changes seen

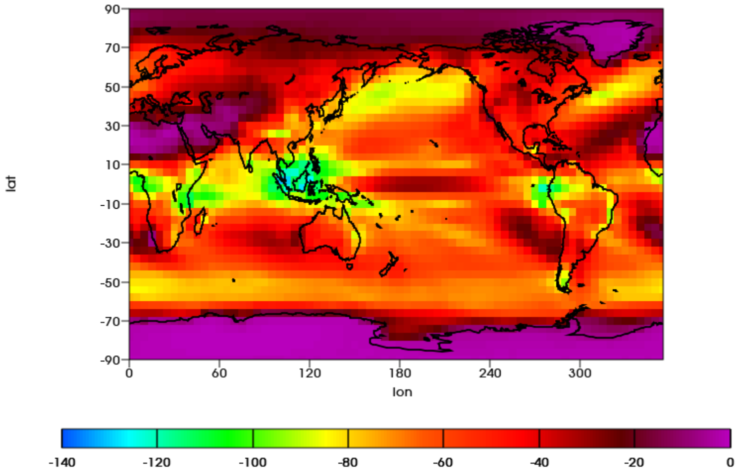
CAMRT (nochem)



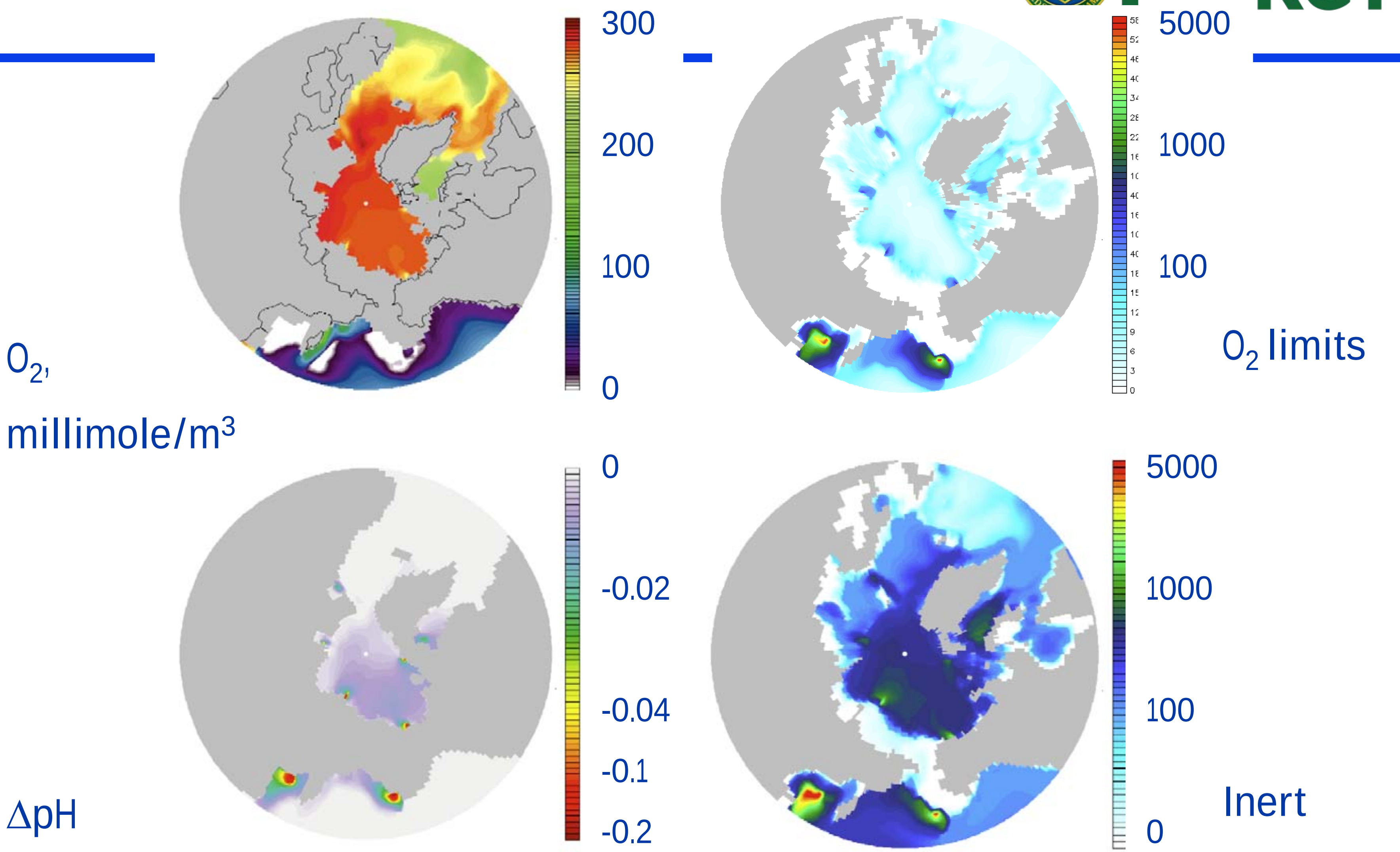
RRTMG (nochem)



CH4_1X



O_2, CO_2 and Plume Expansion



300 meters and integral, 30 years

CH_4, millimole/m^2

Originally reported leakage % level