Evaluating Uncertainties in Marine Biogeochemical Models: The Case for Remote Aerosol Capability

OLU OGUNRO
CCSI, ORNL
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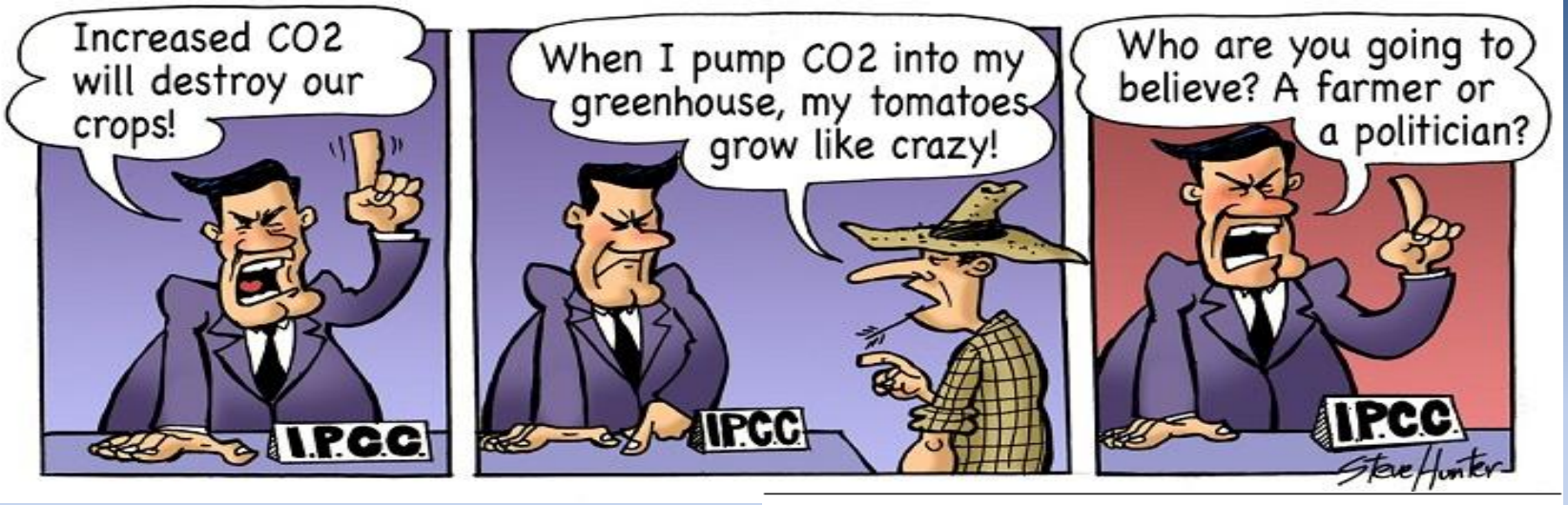
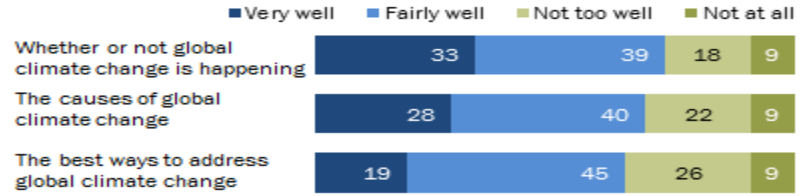


Minorities think climate scientists understand these aspects of global climate change very well

% of U.S. adults who say climate scientists understand ...



Note: Respondents who did not give an answer are not shown.
Source: Survey of U.S. adults conducted May 10-June 6, 2016.
"The Politics of Climate"

PEW RESEARCH CENTER

Motivation

❖Climate deniers have linked less than complete certainty with complete ignorance

❖Efforts to improve certainty has led to advanced subgrid parameterization and increased complexity and resolution

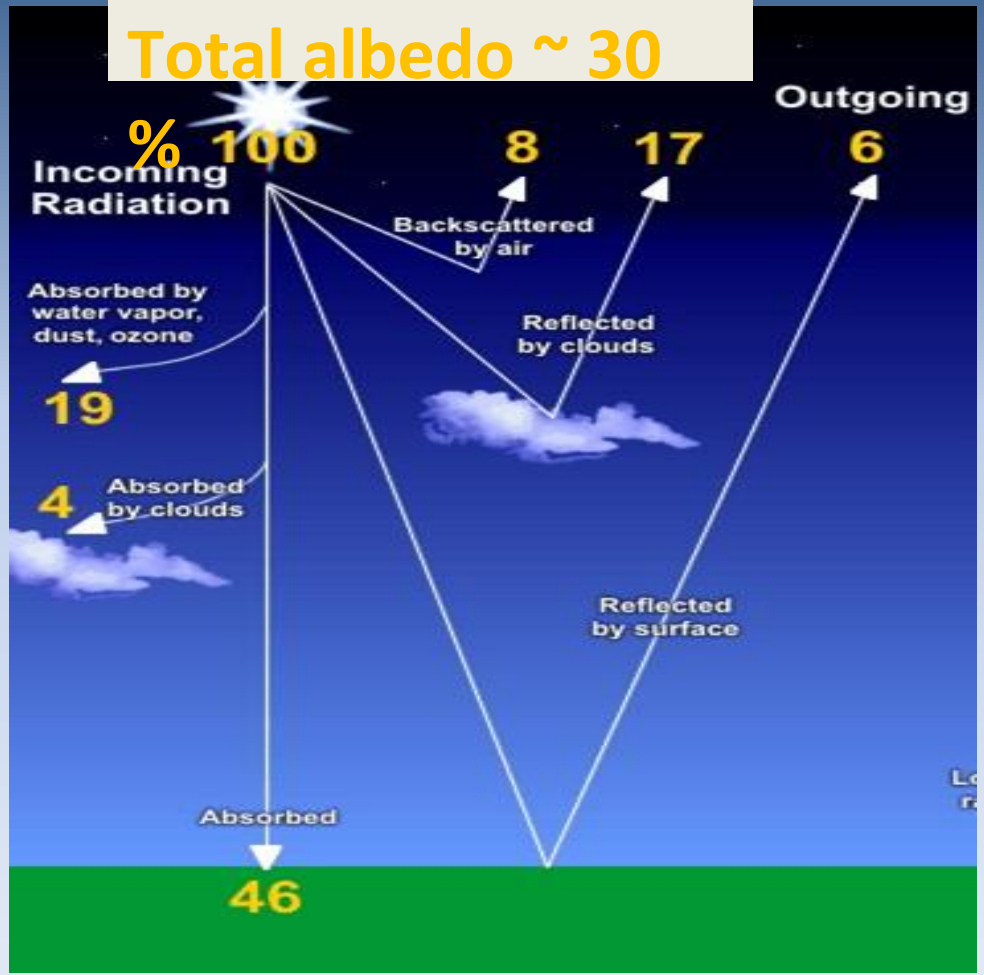
❖Increasing complexity of ESMs sometimes increases assumptions and uncertainty

❖To improve model development, there is an increasing need to benchmark contemporary model outputs with observational datasets and evaluate model projections

Two important areas introducing uncertainties to mBGC/Ocean models:

- Air-sea Interface and fluxes of mass and energy
- Ocean Biogeochemical control on atmospheric chemistry
    - What are the marine biogeochemical controls on the release of photochemically reactive gases into the atmosphere?
    - How will future changes in ocean biogeochemistry and anthropogenic emissions (NOX, VOCs) interact to influence tropospheric photochemistry and stratospheric ozone?

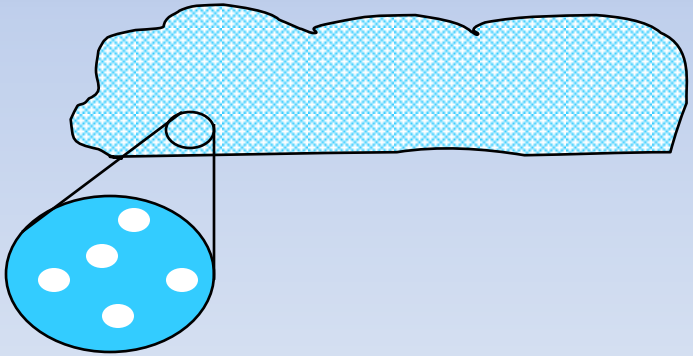
Earth's energy balance and albedo



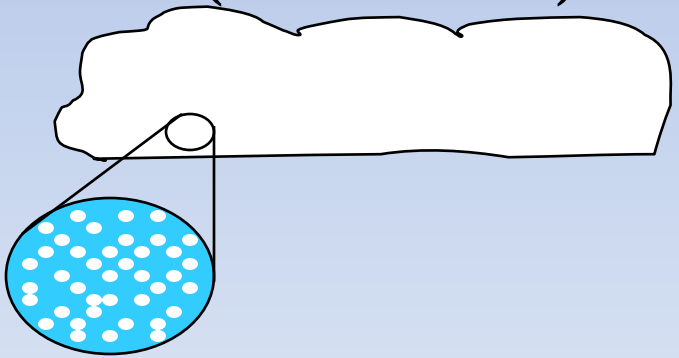
Indirect Aerosol Effect

"Twomey Effect" and Cloud Albedo

Few aerosols
Low droplet concentration
Less reflective cloud



More aerosols
High droplet concentration
More reflective cloud
(Cooler climate)



AEROSOL EFFECTS

DIRECT EFFECT

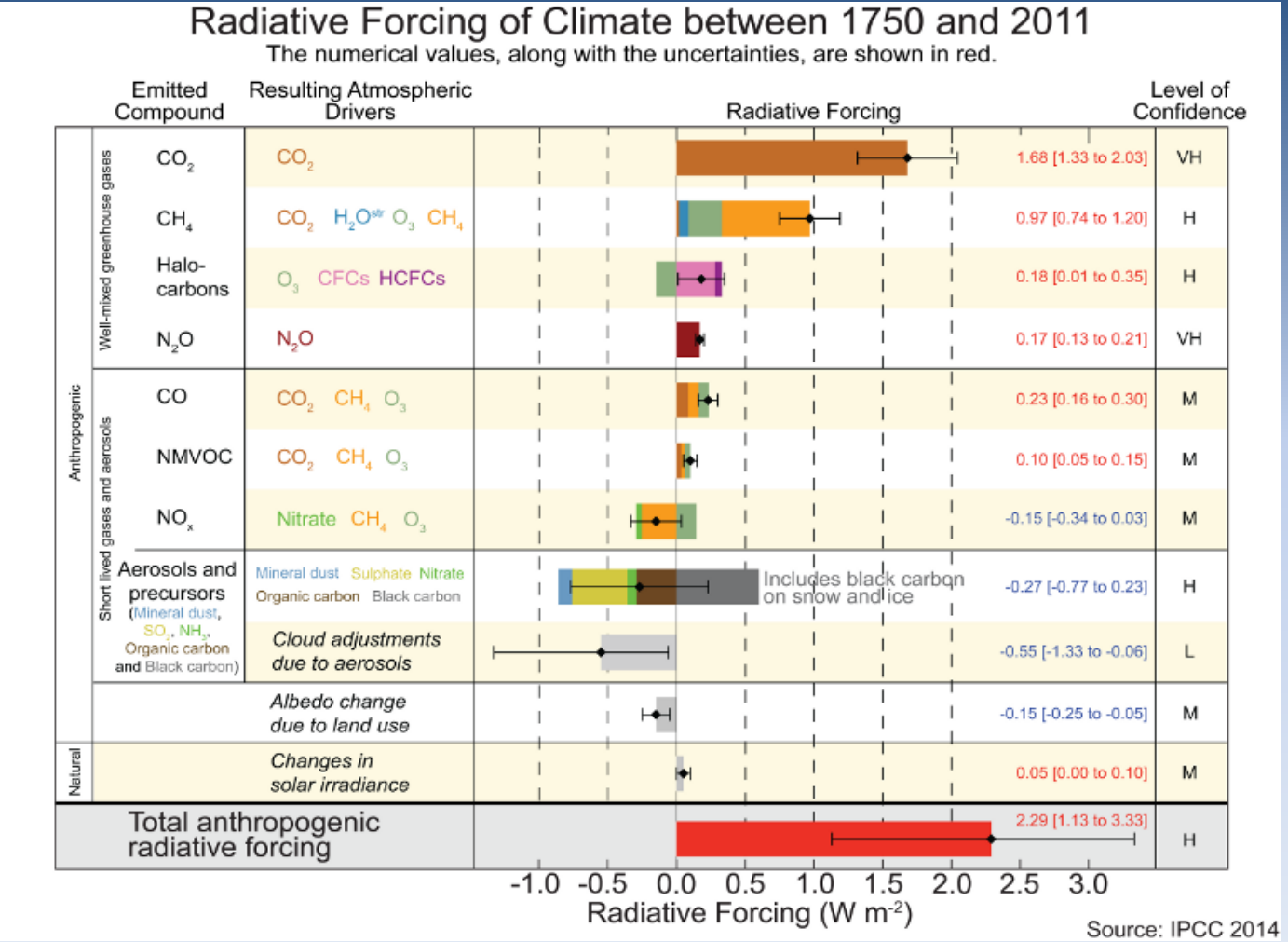
- Scattering of sunlight
- Absorb solar radiation
- Contributes to Earth's Albedo

INDIRECT EFFECT

Impact on cloud microphysical process

- Particles on which cloud droplets condense or ice nucleate
- Composition, size and supersaturation needed to form CCN and IN, leading to the formation of cloud droplets
- Cloud lifetime and cloud cover
- Contributes to Earth's albedo more than direct effect

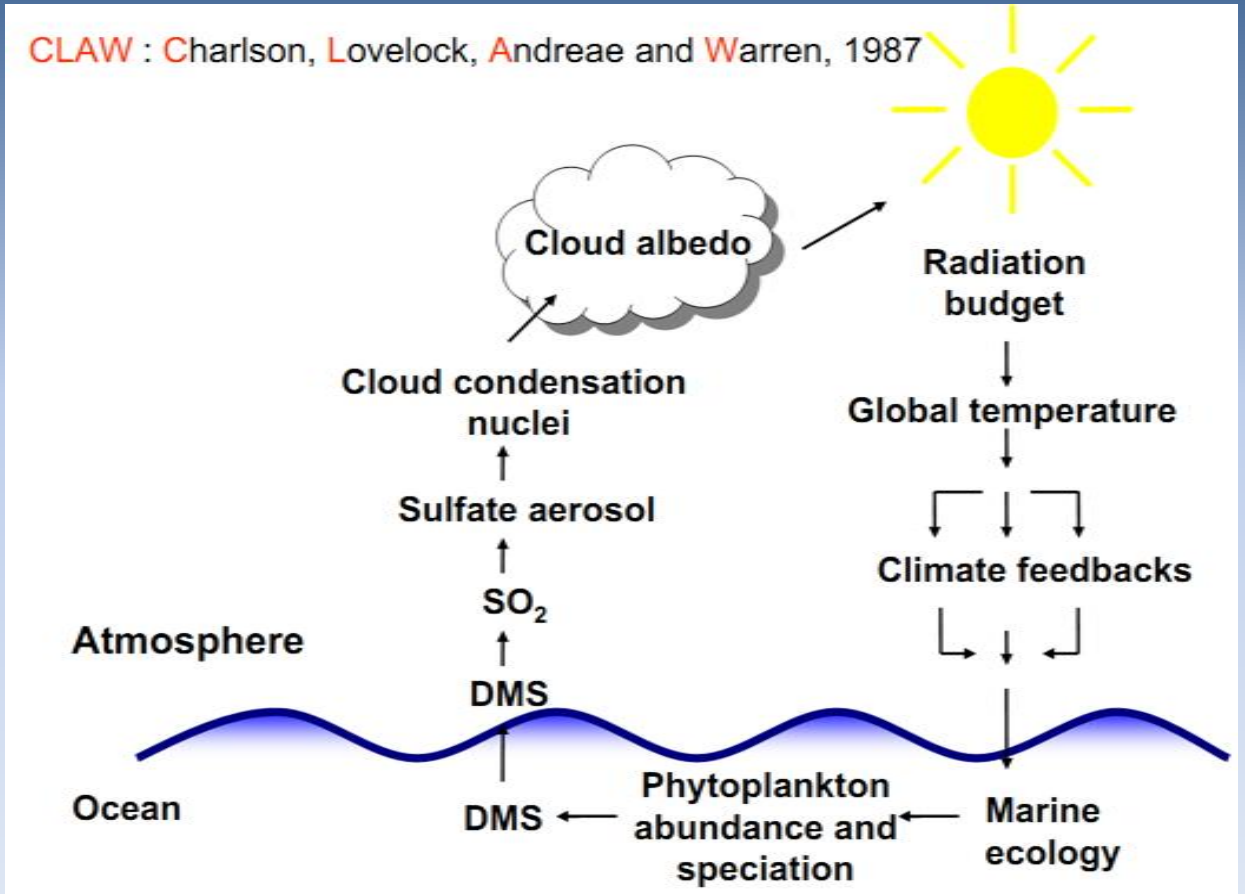
Aerosols have the largest uncertainty with respect to radiative forcing



Challenges leading to aerosol uncertainties

- Aerosols can exist with either single or multiple components, organic, inorganic, biogenic and/or anthropogenic
- The ability of an aerosol to form CCN or IN is also a function of its composition
- Formation of CCN through inorganic material is well understood, but organic materials are much more complex
- Understanding the mechanism of CCN and IN formation with organic components is necessary to reduce the uncertainty associated with aerosol and improve climate change prediction

CLAW Hypothesis



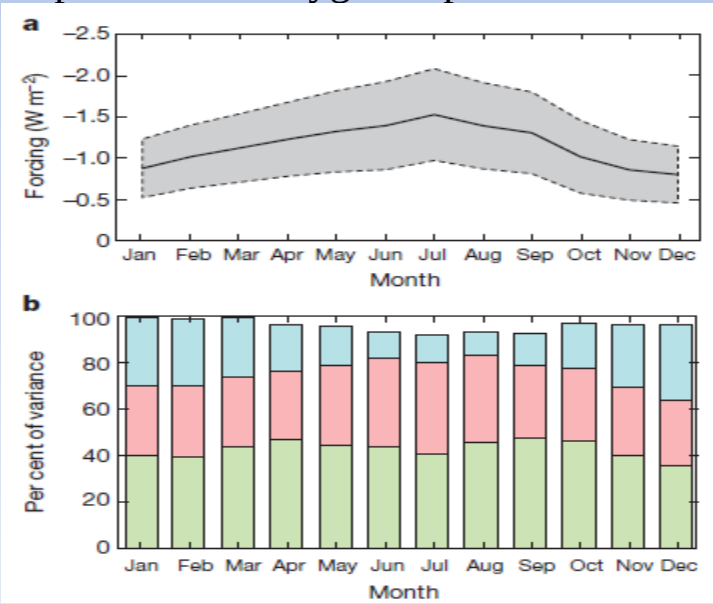
Kloster et al. 2007

Uncertainty in Ocean Contribution to the Marine Boundary Layer Aerosol Budget

❖45 per cent of the variance of aerosol forcing since about 1750 arises from uncertainties in natural emissions

❖Accurate representation of natural background aerosols is critical for improved assessment of direct and indirect anthropogenic aerosol forcing

❖ Reduction of the uncertainties over the representation of natural aerosols in climate models requires improved quantification of number, size distribution, chemical composition, and hygroscopic properties of aerosol in the marine boundary layer (MBL)



Magnitude and sources of uncertainty in global mean aerosol indirect forcing (a) Global mean forcing (b) Global monthly mean forcing variance (green, Nat; pink, anthr; blue, aerosol processes); Carslaw et al. 2013

Approach to DMS flux simple empirical model

EQUATIONS:

- Flux parameterization using Nightingale *et al*. [2000]
- Schmidt equation derived from Saltzman and King [1993]

INPUTS:

- Climatology DMS data from Lana *et al*. [2011]
- Climatology SST data from WOA (2013v2)
- Climatology wind data from NCEP/NCAR reanalysis database

Calculating Sea-Air Flux of DMS

- $F = k (C_w - C_a)$

Where F = Flux (mol/sec/m^2)
k = Piston velocity (m/s)
C_w = DMS concentration on the ocean surface (mol/m^3)
C_a = DMS concentration in air (mol/m^3)

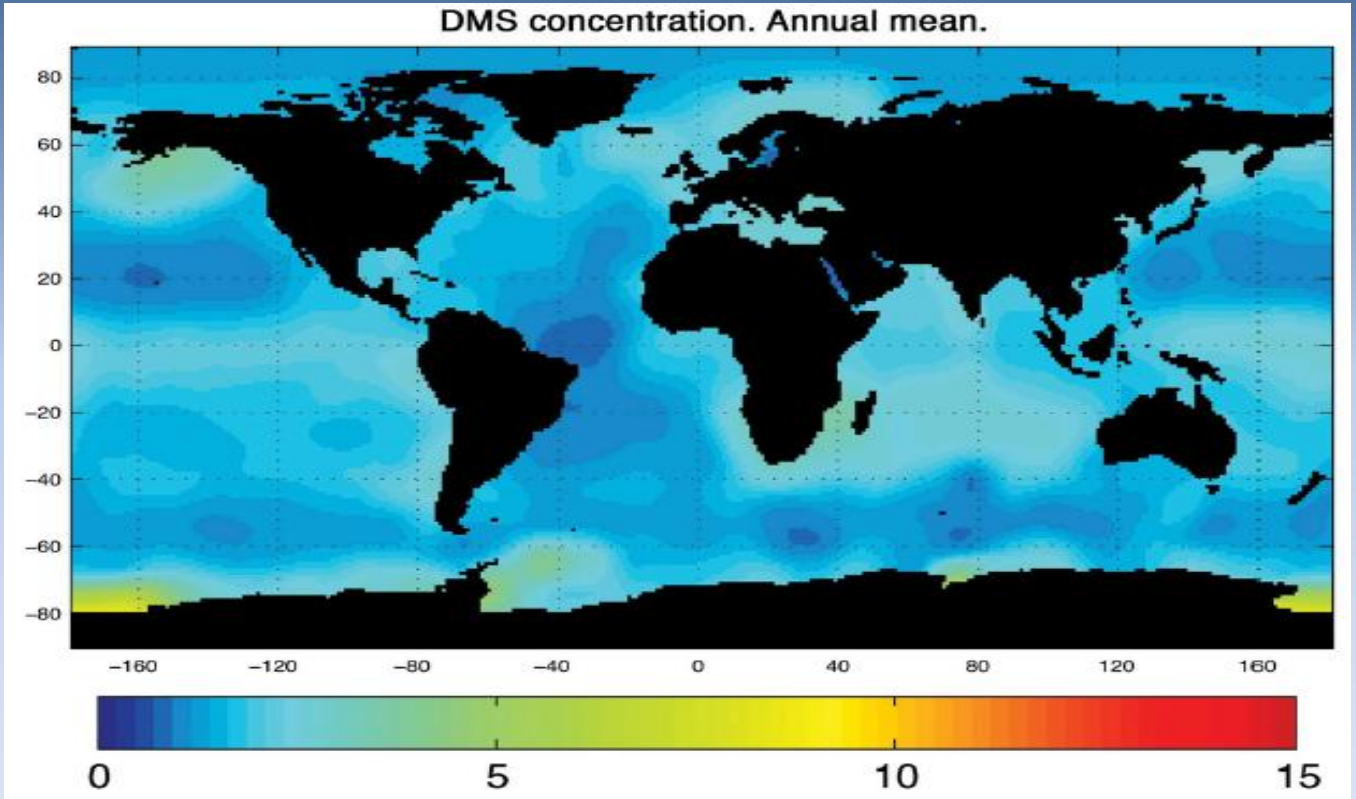
- $k = (0.333U_{10} + 0.222(U_{10})^2)\ (600/Sc)^{1/2}$

Where U_{10} = Wind speed at 10 meters above sea surface
S_c = Schmidt value for diffusivity of DMS in sea water

- $S_c = 2674.0 - 147.12T + 3.726T^2 - 0.038T^3$

Where T = Temperature

Nightingale et al. 2000 and Saltzman and King 1993



Annual global mean climatology of DMS concentrations (nM), Extract from Lana et al., 2011

Dataset	Temporal Coverage	Spatial Coverage	Variables	Reference
WOA	Monthly Climatology	Globally Gridded and Layered	no3, po4, si, o2, sos, tos	[57,58]
SeaWIFS	Monthly Climatology	Globally Gridded	chl	[59]
NCEP Reanalysis	Monthly Climatology	Globally Gridded	sfcWind	[60]
Boyer Montegut	Monthly Climatology	Globally Gridded	omlmax	[61]
OSU	Monthly Climatology	Globally Gridded	intpp	[62]
Lana	Monthly Climatology	Globally Gridded	dms	[14]

Table 1: Observational Dataset incorporated into IOMB to benchmark various model outputs.
All ocean data were encoded in the 4-dimensional CF compliant format. All variable naming and abbreviation follows CMIP5 convention.

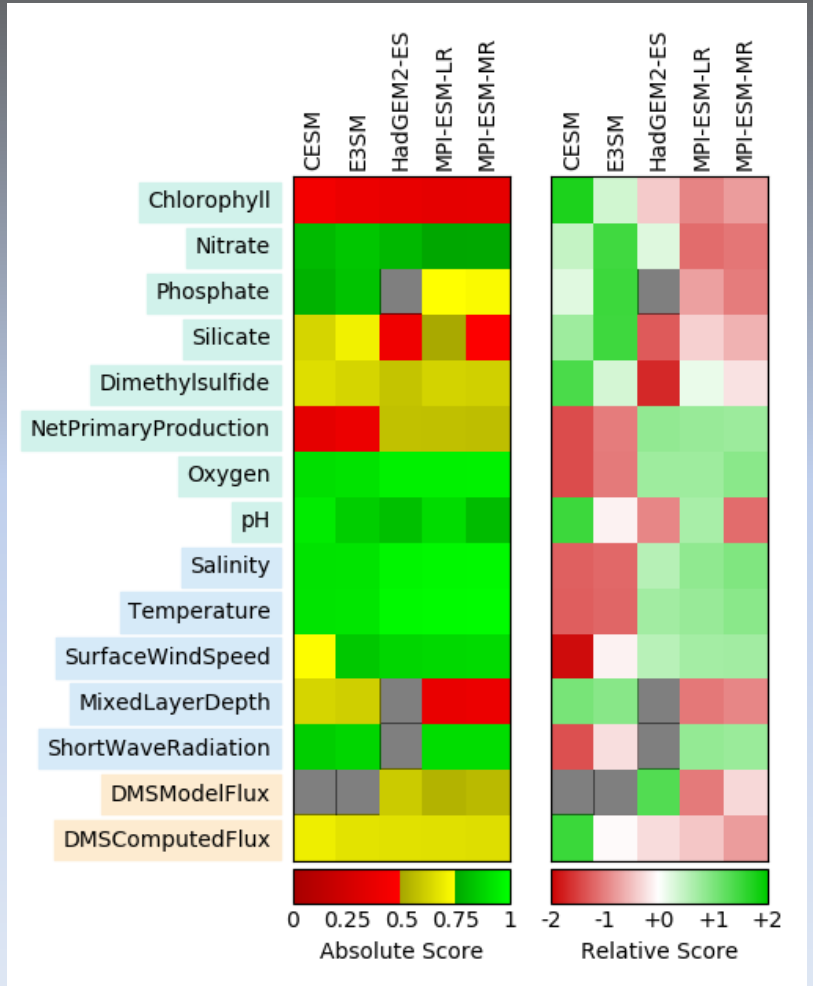


Figure 1: Benchmarking results showing absolute and relative scores, computed between five ESMs

❖CMIP5 models with mBGC give reasonable performance with respect to a benchmark global temporal mean of MLD - results are within 10*m* of observational data.

❖Nutrient concentrations in the High Nutrient Low Chlorophyll (HNLC) region of the eastern tropical Pacific are lower in CMIP5 models when compared with WOA datasets.

❖Global average emission of 28.1 (17.6 - 34.4) Tg of S yr^{-1} was estimated by Lana et al. 2011

❖Using IOMB, we estimate a total value of 30.6 Tg of Sulfur transferred from the ocean into the MBL annually in the form of DMS gas.

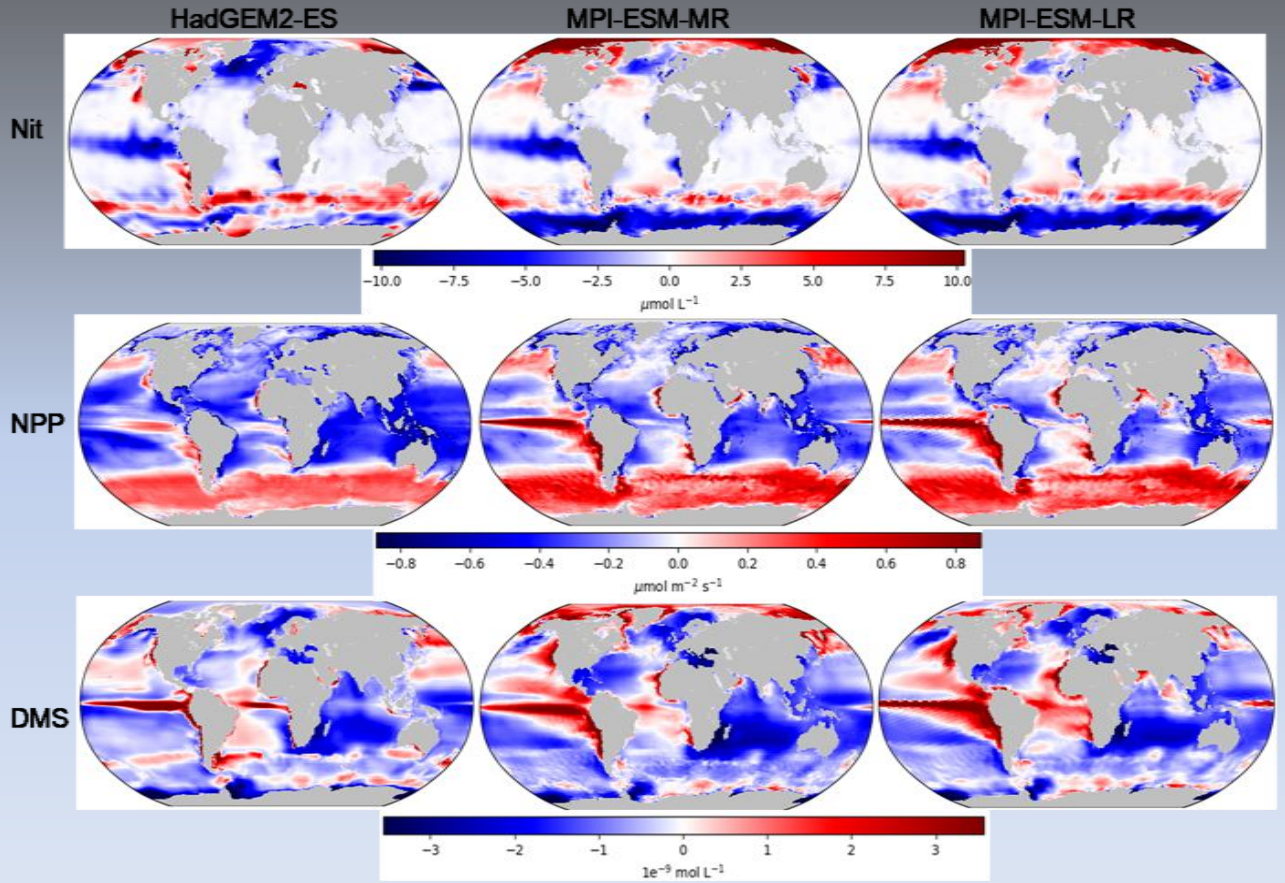


Figure 2: Nitrate (Nit), Net Primary Production (NPP) and Dimethylsulfide (DMS) surface mean bias . Three ESMs with DMS concentrations were considered: HadGEM2-ES, MPI-ESM-MR and MPI-ESM-LR.

Global average emission of 28.1 (17.6 - 34.4) Tg of S yr^{-1}

CMIP5 Models

HadGEM-ES = 34.3

MPI-ESM-MR = 39.2

MPI-ESM-LR = 42.3

Estimate from CMIP5 Models wind and SST

HadGEM-ES = 21.1

MPI-ESM-MR = 22.3

MPI-ESM-LR = 23.8

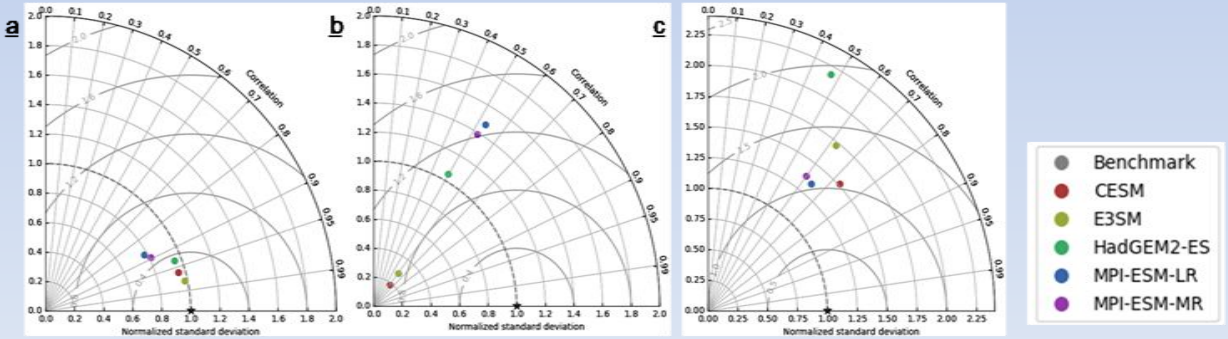


Figure 3: (a) Nitrate (b) Net Primary Production and (c) Dimethylsulfide (DMS) spatial Taylor diagrams.

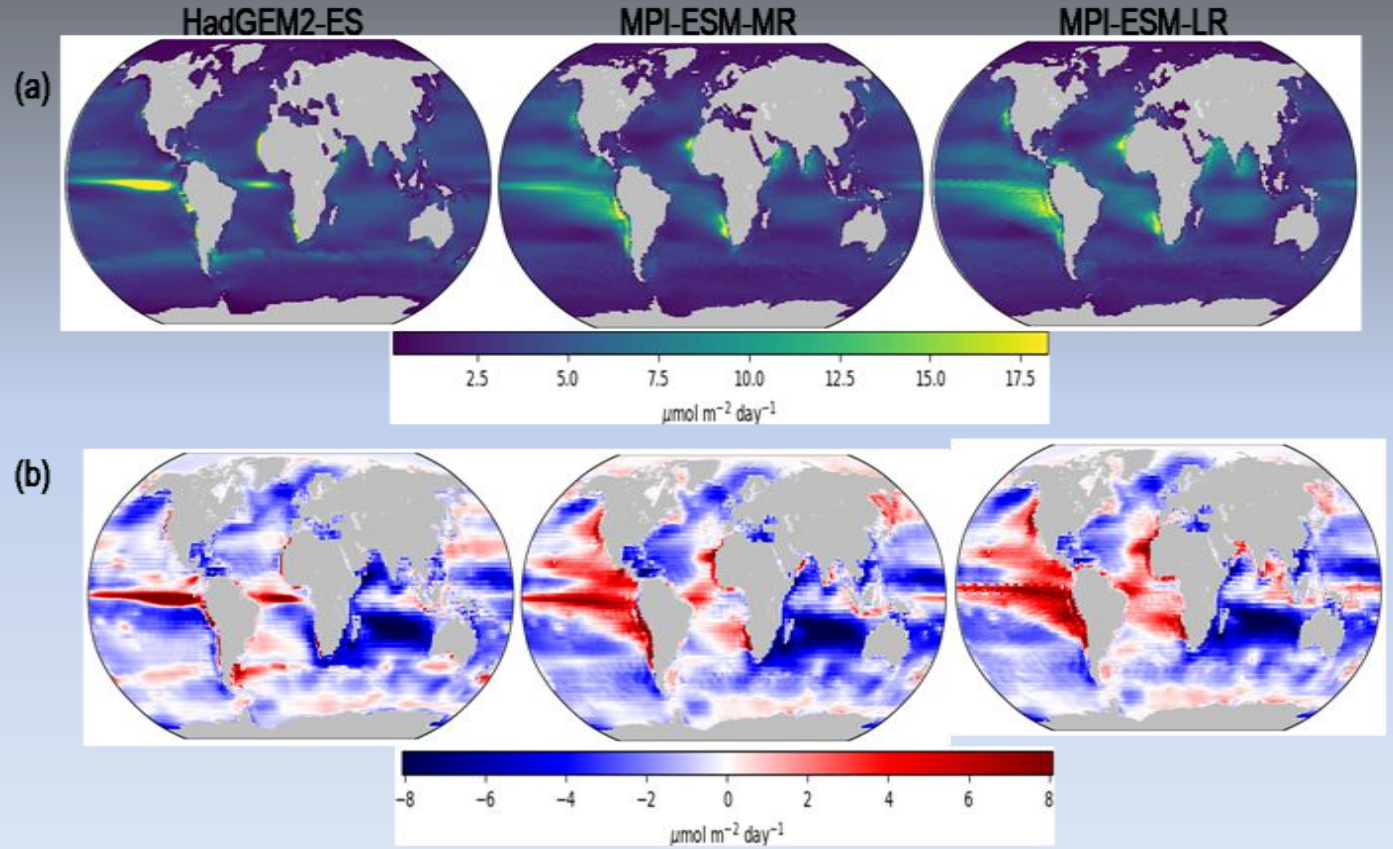


Figure 4: (a) Temporally integrated period mean and (b) Bias of DMS Model Flux (DMF) for HadGEM2-ES, MPI-ESM-MR and MPI-ESM-LR between 1978 to 2008

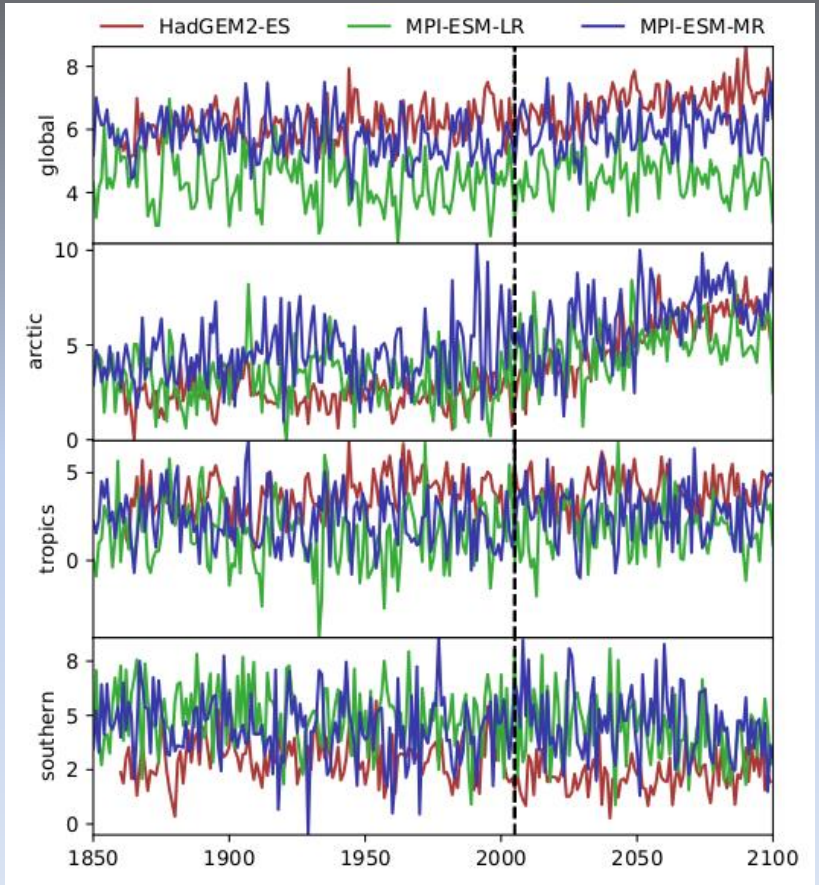


Figure 5: Global and regional trends of sea-air DMS flux (µmol m^{-2} day^{-1}) in CMIP5 models from 1850 to 2100. HadGEM2-ES outputs started in 1860. There is a transition from historical simulation results to RCP 8.5 in year 2005.

More work to be done …

❖To what degree does the bias in DMS flux projection influence the aerosol distribution?

❖Influence of increasing sulfate aerosol in the Arctic on tropospheric photochemistry

❖Improve measurements and field experiments is necessary to obtain more benchmarking datasets

❖Answers to questions on size distribution, chemical composition, and hygroscopic properties of aerosol in the marine boundary layer (MBL) will undoubtedly be instrumental in future climate change policy

Summary

❖Most CMIP5 models do not have a dynamic representation of dimethylsulfide

❖Models tend to over-predict DMS surface concentrations in the productive region of eastern tropical Pacific by almost a factor of two and the sea-air fluxes by a factor of three

❖Using IOMB, our estimate of natural sulfur emission is close to value obtained in Lana et al. 2011

Conclusions

❖There is need for quality time- and space-resolved estimates of DMS concentrations and fluxes

❖Dynamic representation of surface ocean concentrations and fluxes of marine VOCs should be extended to more coupled ocean/mBGC models

❖A benchmarking tool for marine biogeochemical results, such as IOMB, is indispensable as we continue to improve ESM process representations and understand the dynamics of climate – carbon cycle feedbacks from the ocean.

❖This verification and validation system will be employed to analyze outputs from ocean models, including those contributing results to the sixth phase of Coupled Model Intercomparison Project (CMIP6)

QUESTIONS?