Atmospheric Physics

Presented by

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Advanced physics in high-resolution models

- As a central component of climate models, atmospheric physics is key to understanding climate variability and change (e.g., the atmosphere's thermal structure and hydrological cycle, radiative forcing, cloud processes).

  Affirmed by the *NOAA Next-generation Strategic Plan (NGSP)* and the *National Research Council (NRC) Report on Advancing Climate Modeling*.
- Relevant to NOAA's climate adaptation and mitigation goal;
- Possible research and development pathways were laid out in the *GFDL 5-10 Year Strategic Science Plan*;
- Striving for a healthy balance between resolution and complexity;

Main focus areas

1. **Aerosol modeling** [Ginoux and **Ming**]
2. **Cloud modeling** [Donner, Golaz, Guo and Zhao]
3. **Radiative transfer** [Freidenreich, Paynter and Schwarzkopf]
4. **Aerosol/cloud microphysics** [Sulia and Yun]
5. **Stratospheric processes** [P. Lin]

Red: Talks Blue: Posters

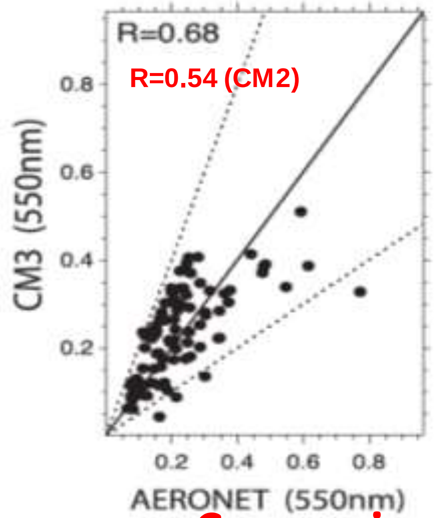
Physics improvements from CM2 to CM3

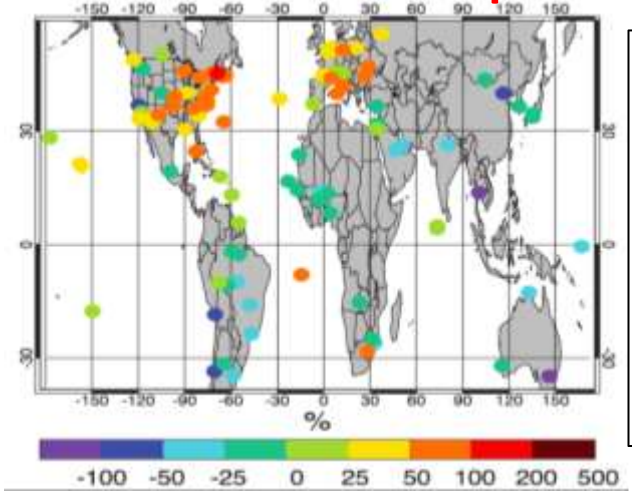
	CM2 (used for AR4)	CM3 (used for AR5)
Aerosol simulation	Offline (from a chemistry-transport model)	Emission-driven, interactive with model meteorology
Aerosol-radiation interactions	External mixing, pure scattering by organic carbon (OC)	Internal mixing between sulfate and black carbon (BC), mild absorption by OC
Aerosol-cloud interactions	None	Prognostic treatment of aerosol-liquid cloud interactions, with explicit droplet activation
Convection	Relaxed Arakawa-Schubert	Donner deep and UW shallow
Ozone	Offline	Online from interactive gas-phase chemistry

Note: The other model streams (i.e., CM2.X, ESM2-M or G, HiRAM) use the same aerosol/cloud scheme as CM2.

Simulation of aerosols and surface radiation

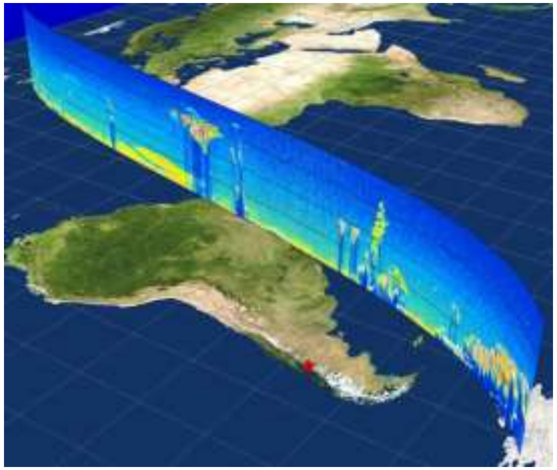
Comparison with AERONET aerosol optical depth (Donner et al., 2011)

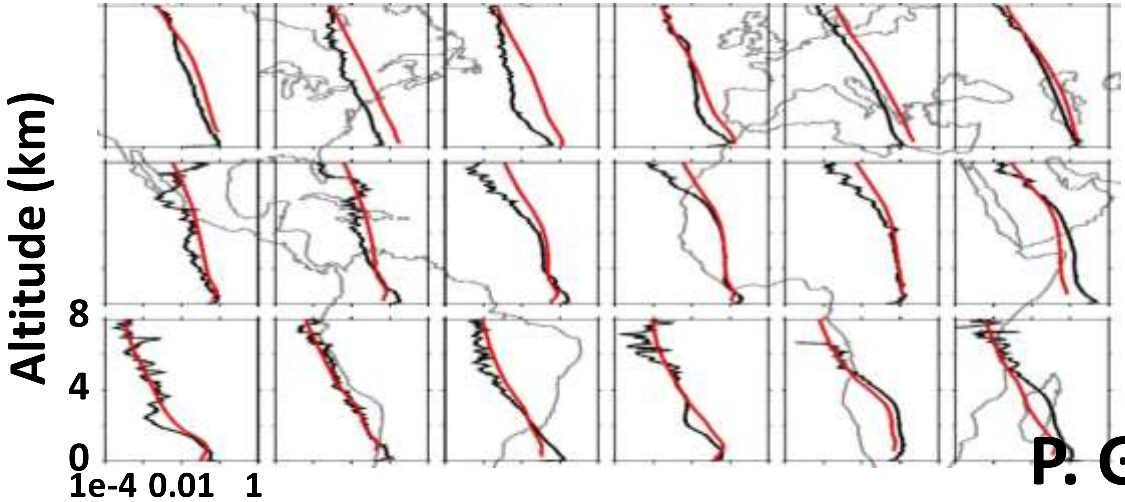




Among all CMIP5 models, CM3 performed best in capturing observed global dimming/brightening trends (Allen et al., 2012).

Comparison with CALIPSO aerosol extinction coefficient (km $^{-1}$)





P. Ginoux

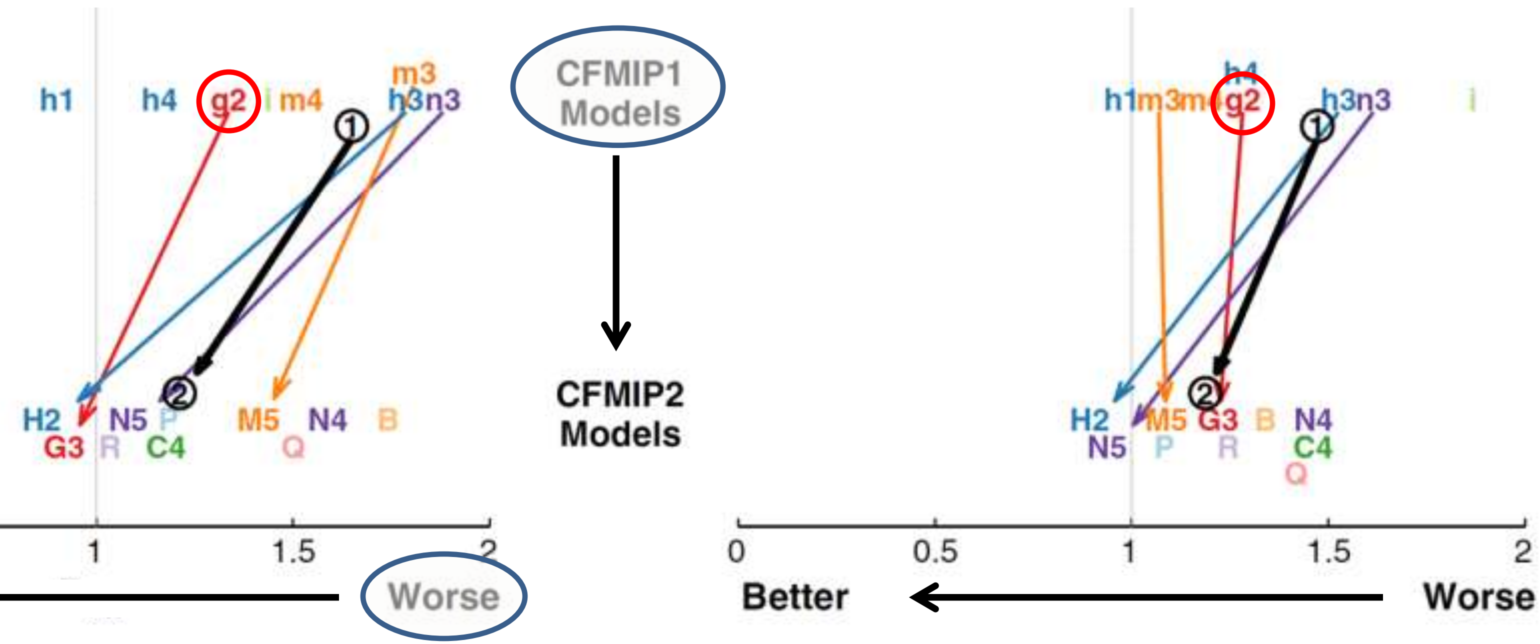
Simulation of cloud fields

Evaluation of CFMIP1 and CFMIP2 models (Klein et al. , 2013)
CFMIP: Cloud Feedback Model Intercomparison Project

Shortwave relevant cloud properties **Longwave relevant cloud properties**

g2: AM2
(GAMDT, 2004, *J. Climate*)

G3: AM3
(Donner et al., 2011, *J. Climate*)



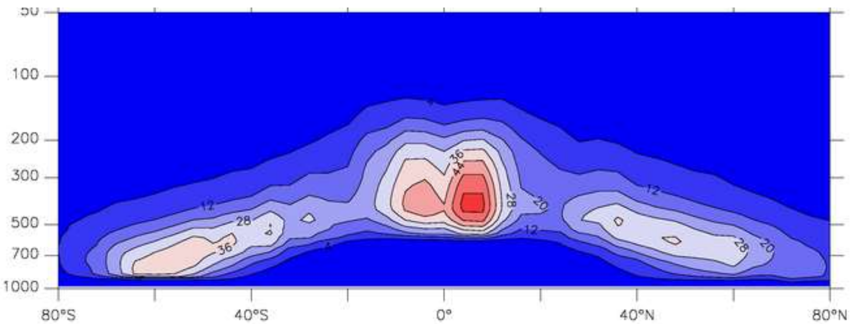
AM3/CM3 results are being widely analyzed; Donner et al. (2011) has been cited 153 times to date (Google Scholar).

L. Donner, C. Seman, L. Horowitz, and B. Hurlin

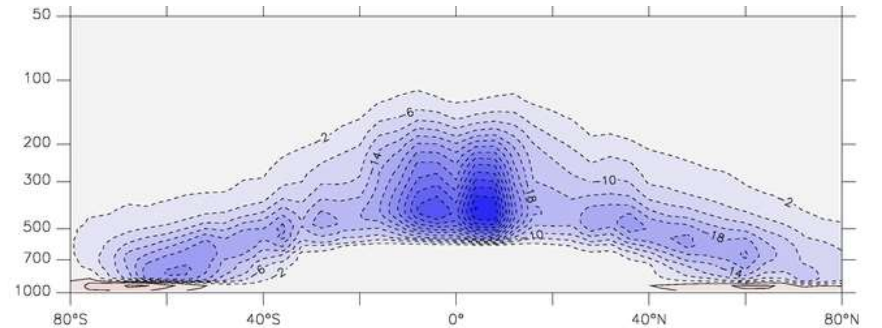
Cumulus parameterization

- Work is underway to improve various aspects of cumulus parameterization (e.g., sub-grid updraft, microphysics, interactions with aerosols, etc.);
- Satellite and field measurements provide important guidance for development.

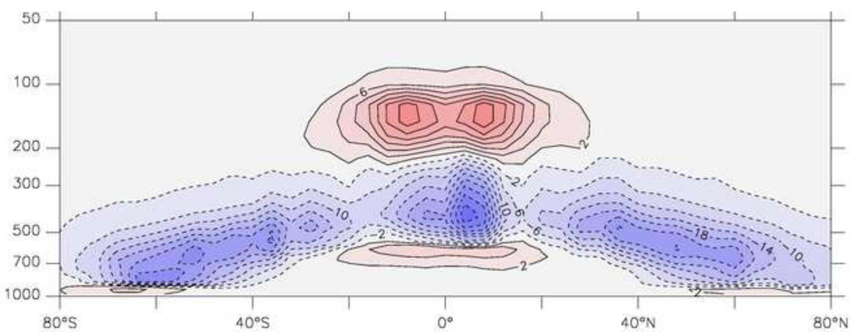
NASA JPL CloudSat Ice Water Content (mg kg^{-1})



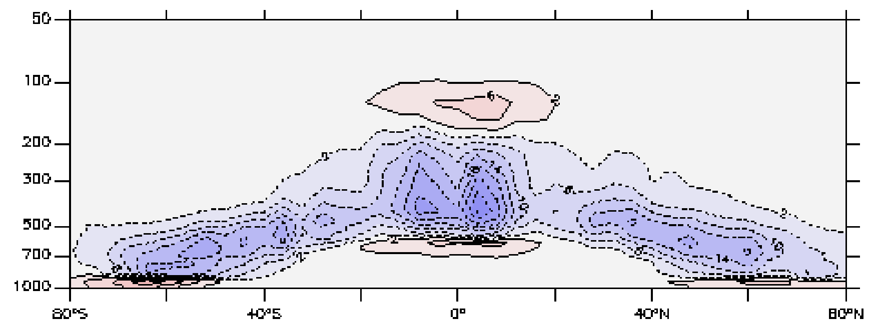
ESM2M minus OBS



AM3 minus OBS

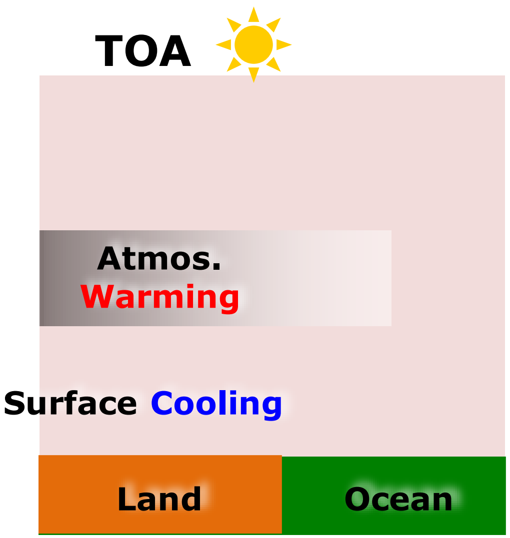


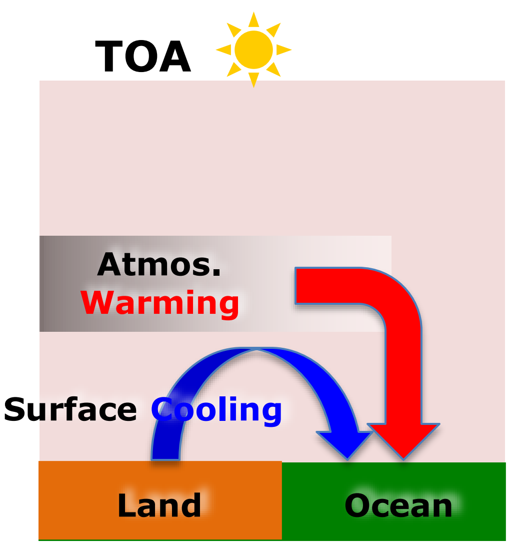
AM3 w/ diff. closure and trigger (Benedict et al., 2013) minus OBS



L. Donner and C. Seman

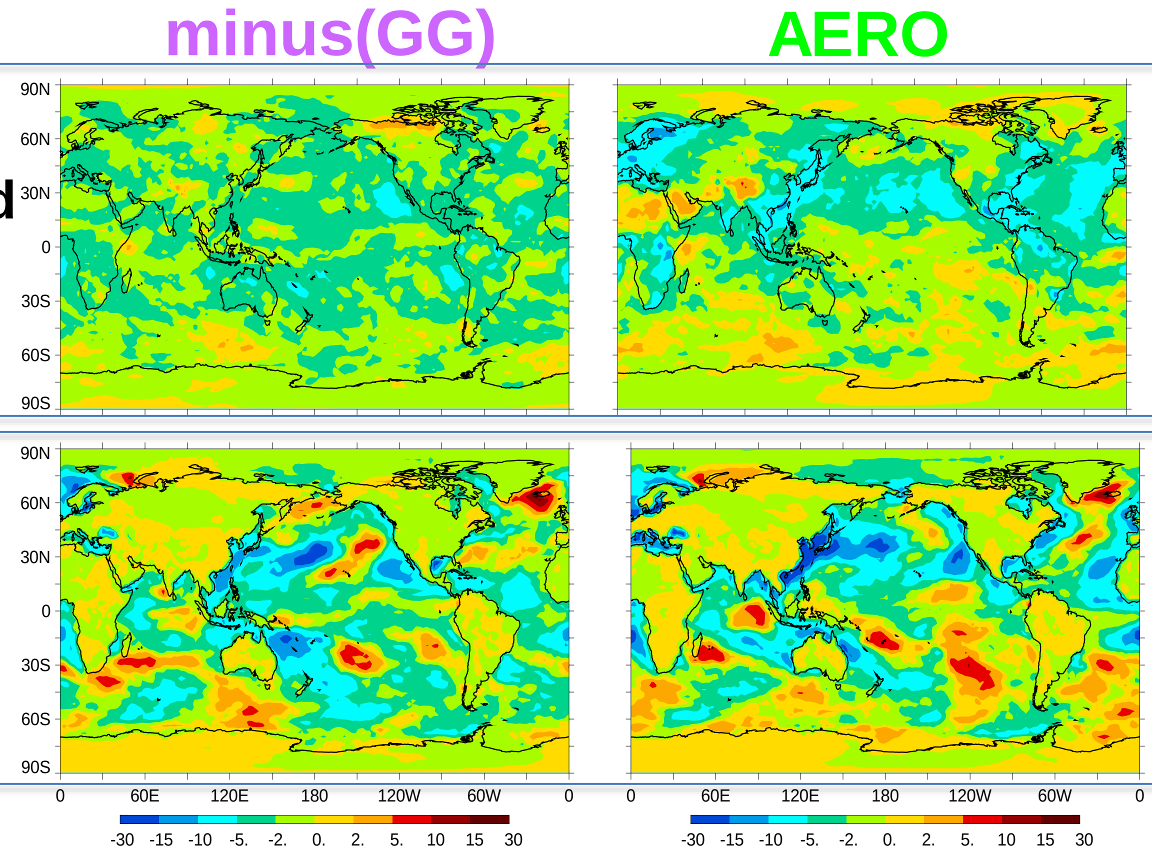
Similar surface forcing patterns of GHG and aerosols





TOA adjusted forcing
R=0.48

Surface forcing
R=0.59

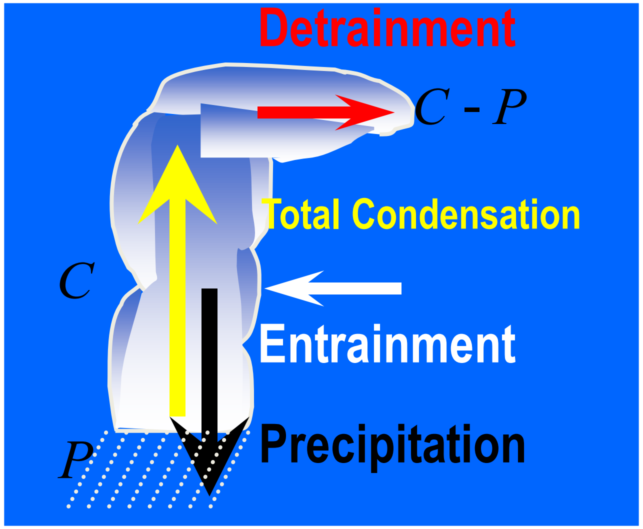


Surface forcing: change in the total surface energy flux after atmosphere/land adjustment

R=0.73 for equilibrium surface temp. changes

Y. Ming (in prep.)

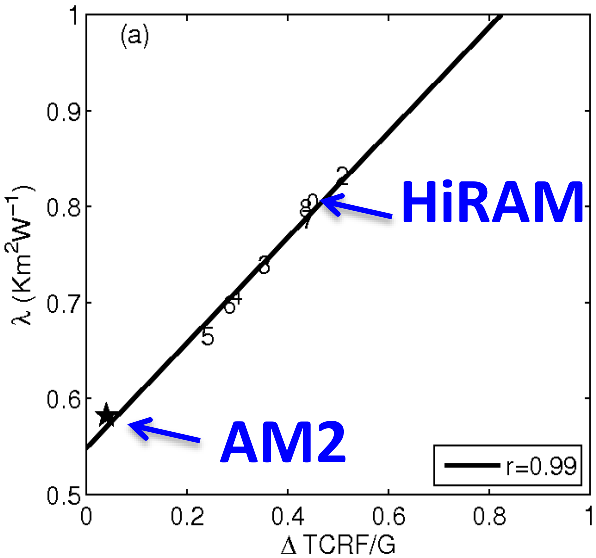
Cloud feedback and climate sensitivity

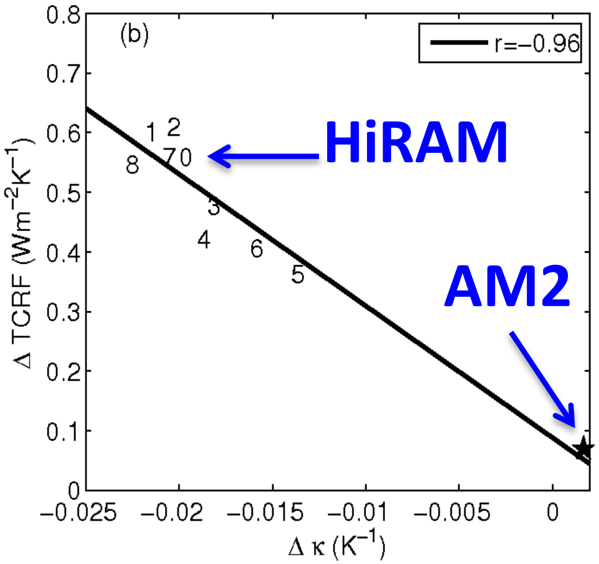


Cloud detrainment efficiency

$$k = \frac{C - P}{P}$$

A suite of HiRAM configurations are then created by varying lateral mixing or microphysics.





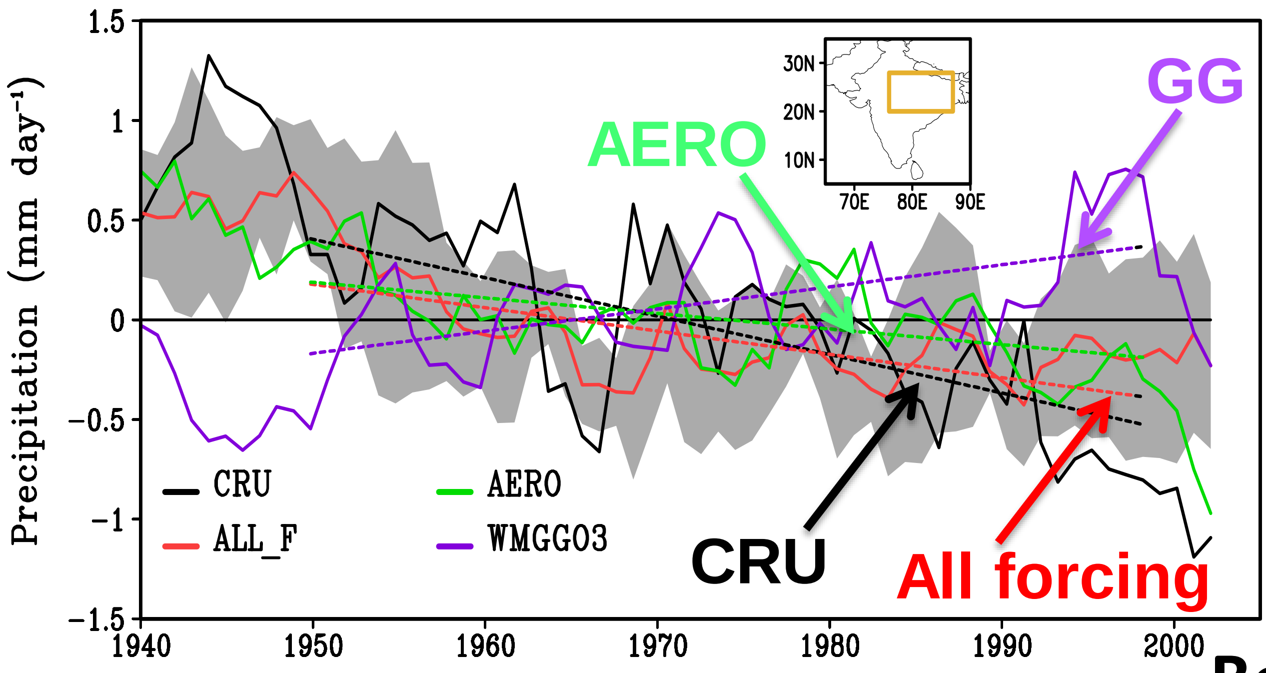
λ: climate sensitivity parameter
TCRF: total cloud radiative forcing
Δ: warming minus control
G: change in net TOA radiative flux
N: net TOA radiation flux, Ts: SST

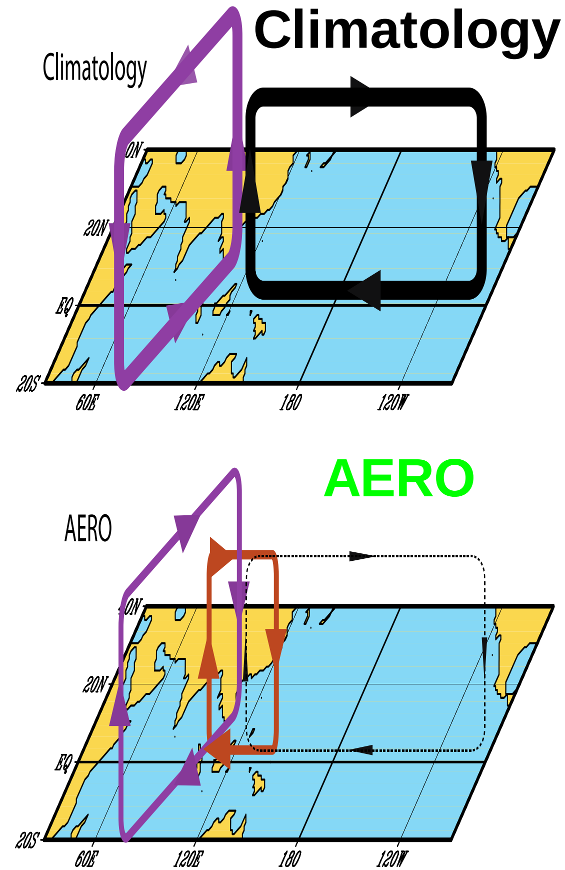
Zhao (2014)

Anthropogenic aerosols and monsoon

Use CM3 historical simulations, forced with forcing combinations, to attribute observed long-term climate trends.

Linear trends of average JJAS rainfall over central-northern Indian (mm day^{-1})



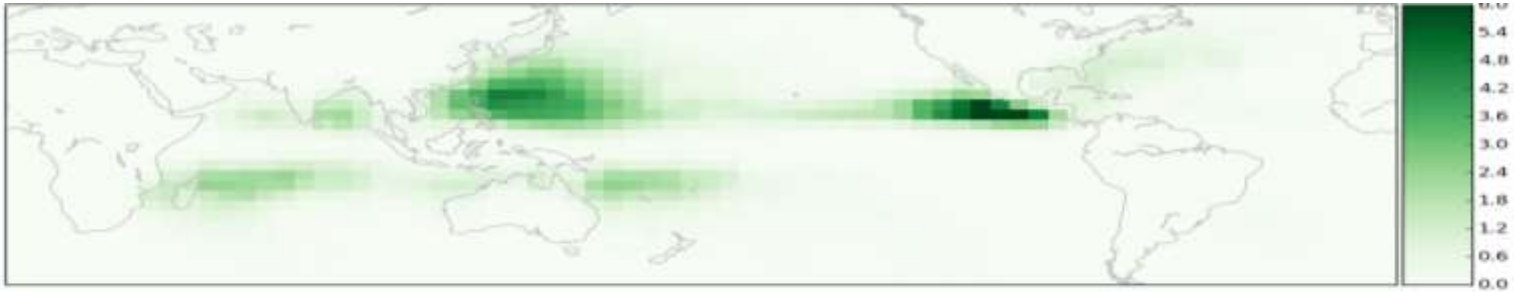


Bollasina et al. (2011)

Aerosol impacts on tropical cyclones (TC)

- **Use a global 25-km hurricane seasonal forecast model (Chen and Lin, 2011, 2013) with a diagnostic treatment of aerosol-cloud interactions;**
- **Anthropogenic aerosols alone increase global TC by 6% [significant at the 90% confidence level] (comparable to GHG-only effect, Held and Zhao, 2011), and Atlantic TC by 11%.**

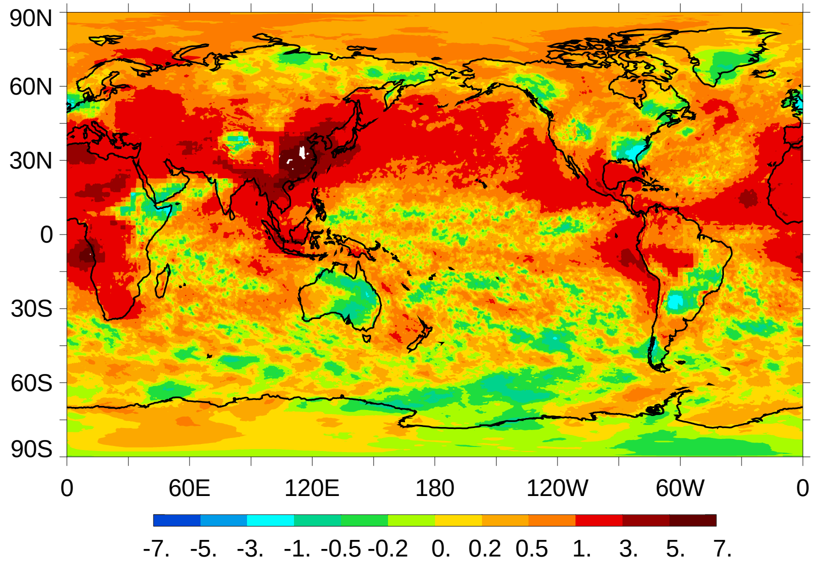
Distribution of simulated TC



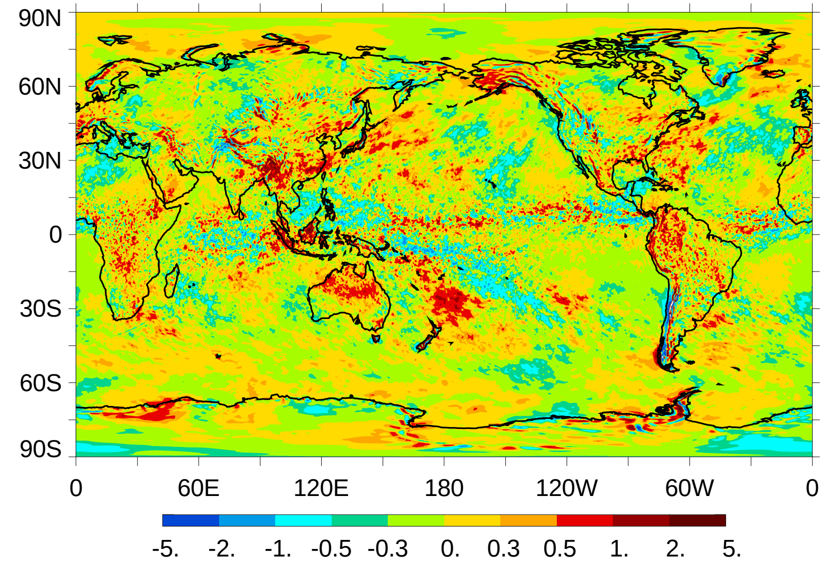
Differences due to aerosols(PD minus PI)

Enhanced absorption and ascent

Aerosol absorption (W m^{-2})



$\Delta\omega$ (10^{-2} Pa s^{-1})



- **The bottom-heavy aerosol absorption destabilizes the atmosphere, and increases large-scale ascent, thus favoring TC genesis (Held and Zhao, 2011).**
- **Other factors: land-sea contrast, aerosol indirect effects, …**

Y. Ming, S. Lin, J. Chen and L. Harris (in prep.)

Summary

- **In the last five years, we developed successfully GFDL's CM3 model with interactive aerosols and aerosol-cloud interactions;**
- **The advanced physics package improved the quality of many aspects of the climate simulation;**
- **CM3 allowed us to address some of the leading questions in climate science (such as the regional climate impacts of short-lived climate forcers);**
- **By exploring various physics options in the high-resolution setting, we were able to identify new research avenues and set up the stage for developing GFDL's next-generation trunk model CM4.**