Using Models and Observations to Understand Climate Processes: Aerosols, Chemistry, Clouds and Radiation

Speakers: Yi Ming and Chris Golaz
Moderator: Leo Donner

Frontiers in Climate and Earth System Modeling: Advancing the Science

Geophysical Fluid Dynamics Laboratory

May 20, 2013

Physics and chemistry in high-resolution models

- Key to reducing model biases and uncertainties;

  Affirmed by the *2012 National Research Council (NRC) Report* on Advancing Climate Modeling and the *2010 NOAA Next-generation Strategic Plan* (NGSP).
- Relevant to NOAA's climate adaptation and mitigation goal;
- Striving for a healthy balance between resolution and complexity;
- New opportunities created by "marrying" more advanced physics and chemistry with finer spatial resolutions.

Recent research projects

Overarching theme: Understanding the complex roles of short-lived species and clouds in influencing climate and air quality.

1. Atmospheric Composition

- High resolution modeling of aerosol emissions and transport [Paul Ginoux];
- Influence of inter-continental transport and stratospheric intrusion on the western U.S. air quality [Meiyun Lin]

Recent research projects (2)

2. Radiation and climate forcing

- Parameterization of water vapor continuum [David Paynter];
- Validation of modeled surface radiative flux [Stuart Freidenreich];
- Surface radiative flux trends (global dimming) [Geeta Persad];
- Active participation in the Atmospheric Chemistry and Climate Model Intercomparsion Project (ACCMIP) [Vaishali Naik and Larry Horowitz];

3. Climate response

- Aerosol effects on South Asian monsoon [Massimo Bollasina];
- Non-local aerosol effects on the Atlantic Meridional Overturning Circulation (AMOC) [Dan Schwarzkopf];

Recent research projects (3)

4. Cloud Processes

- Large-scale clouds and aerosol-cloud interactions [Chris Golaz];
- Deep cumulus and satellite/process-level observations [Leo Donner];
- Shallow cumulus and climate sensitivity [Ming Zhao].

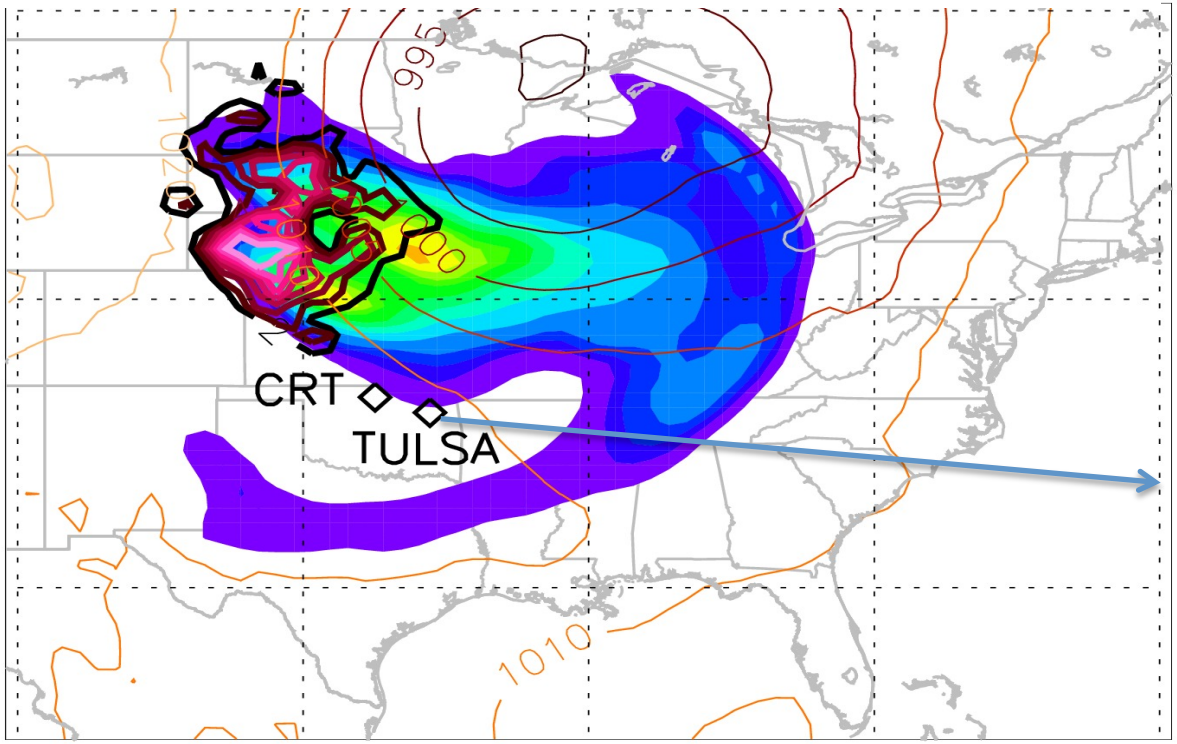
Outline of this talk

1. **Yi Ming**: overview, and the first three research fields (atmospheric composition, radiation and climate response);
2. **Chris Golaz**: cloud processes, and future research directions.

Continental dust plumes and land use

Nudged 50-km AM3 with land use dust sources (Ginoux et al., 2012)

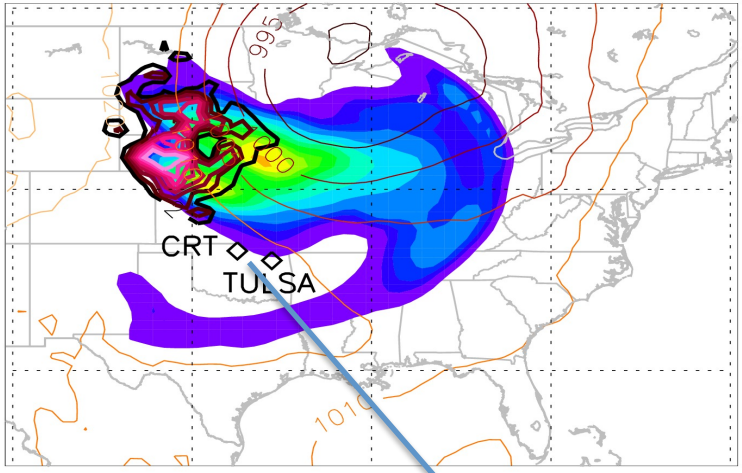
Dust Optical Depth and emission from agriculture (Oct 18, 2012)



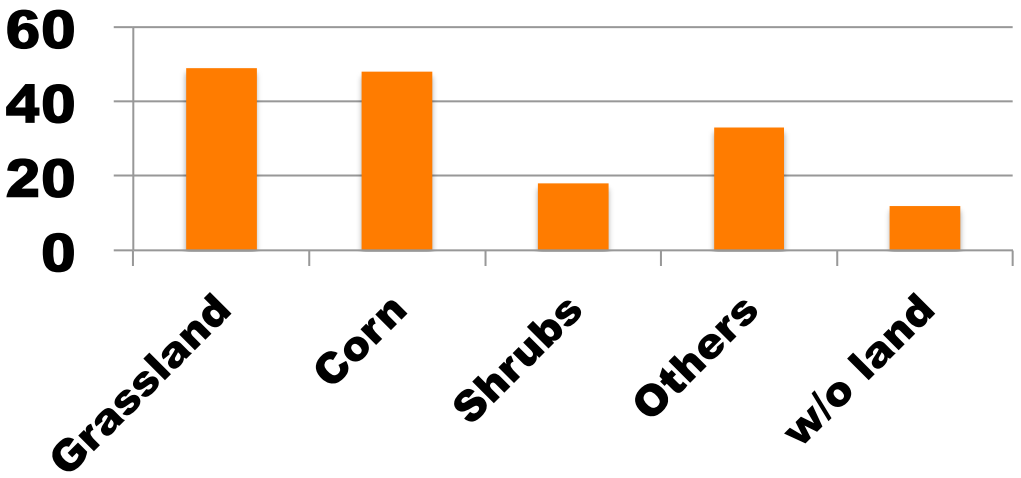
Accidents US I-60 near Tulsa (Oct 19, 2012)

Credit: P. Ginoux

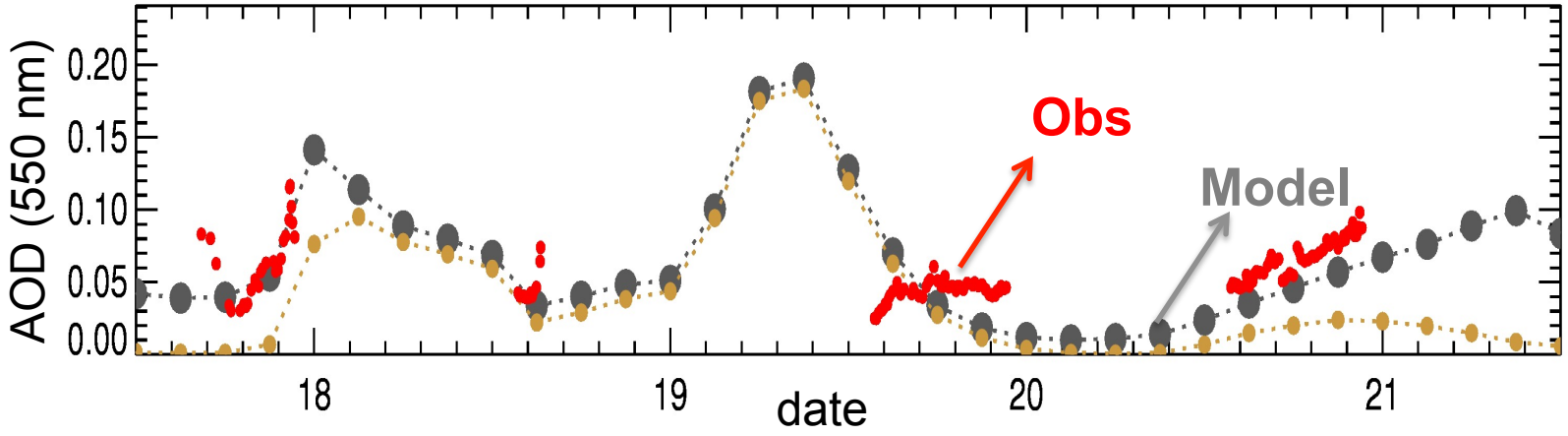
Continental dust plumes and land use (2)



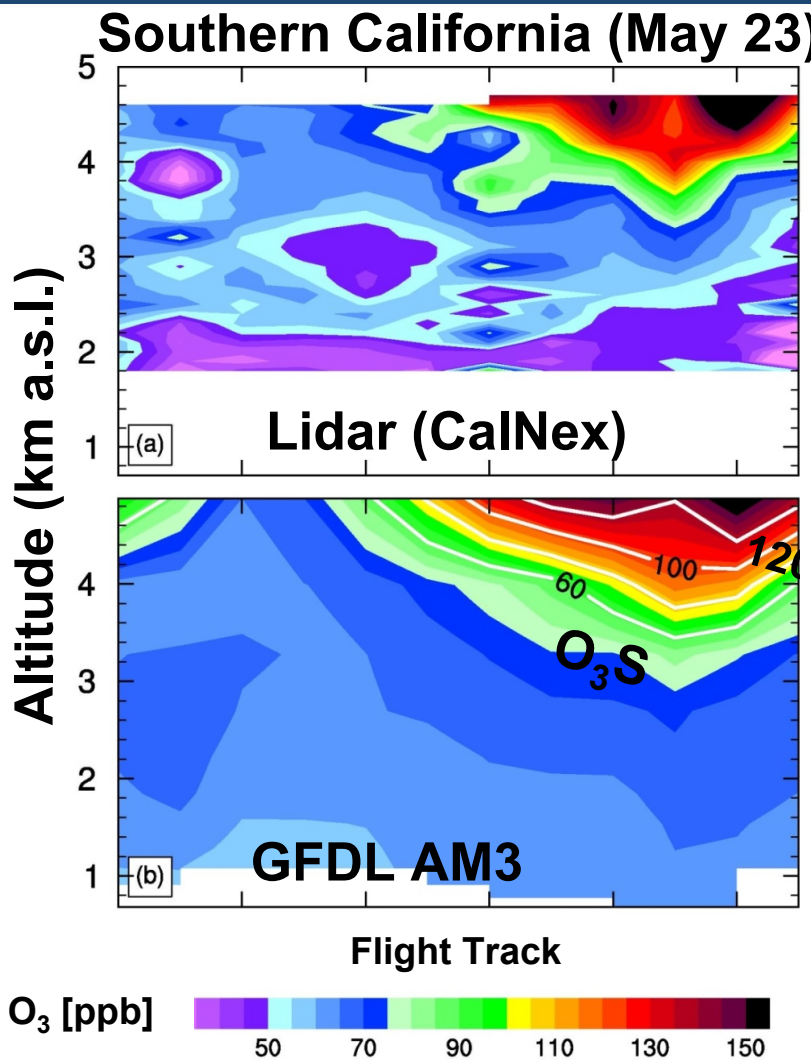
Emission (mg/m2/day) by land use type

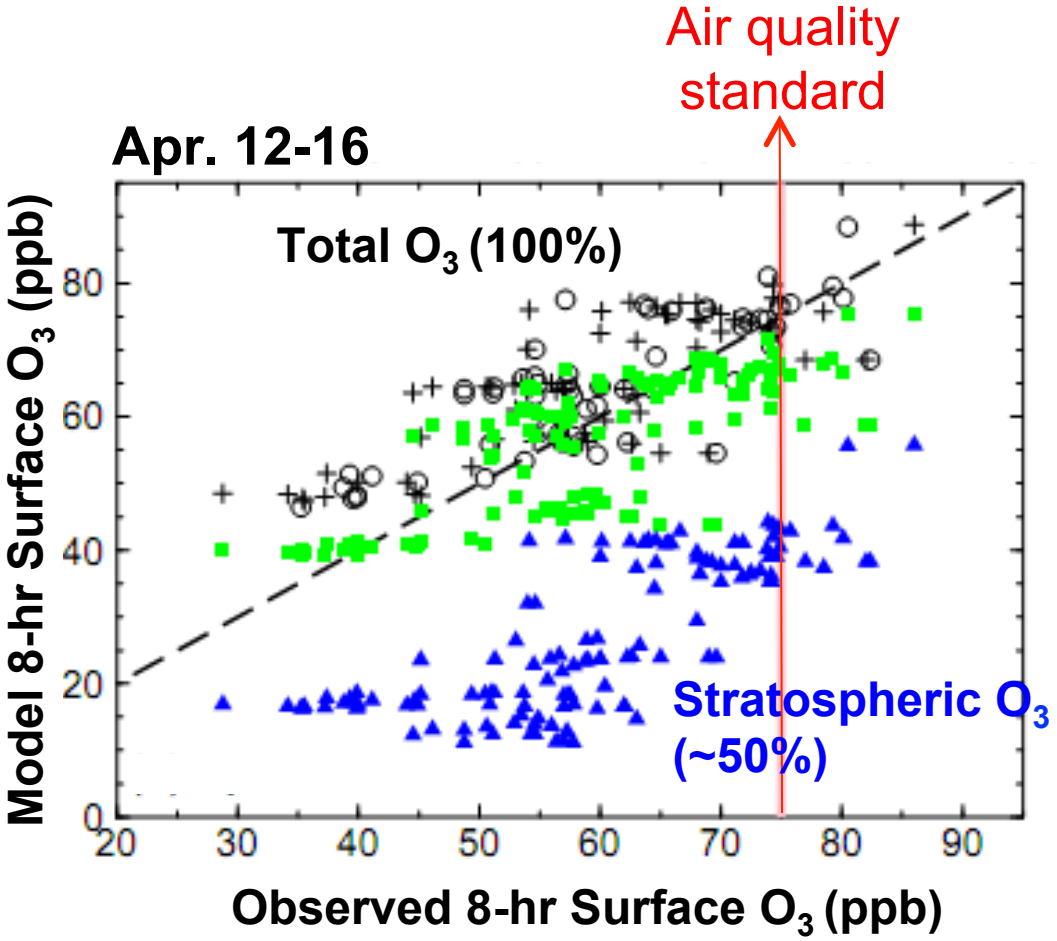


Sunphotometer @ CRT



Stratospheric influence on western U.S. surface ozone

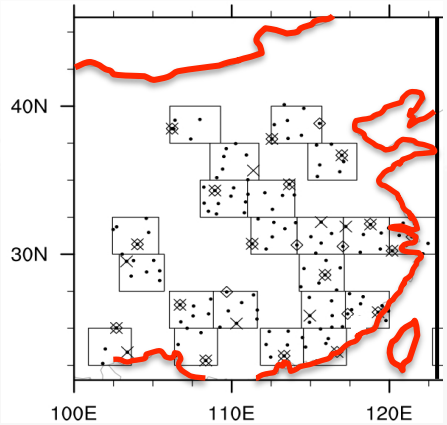




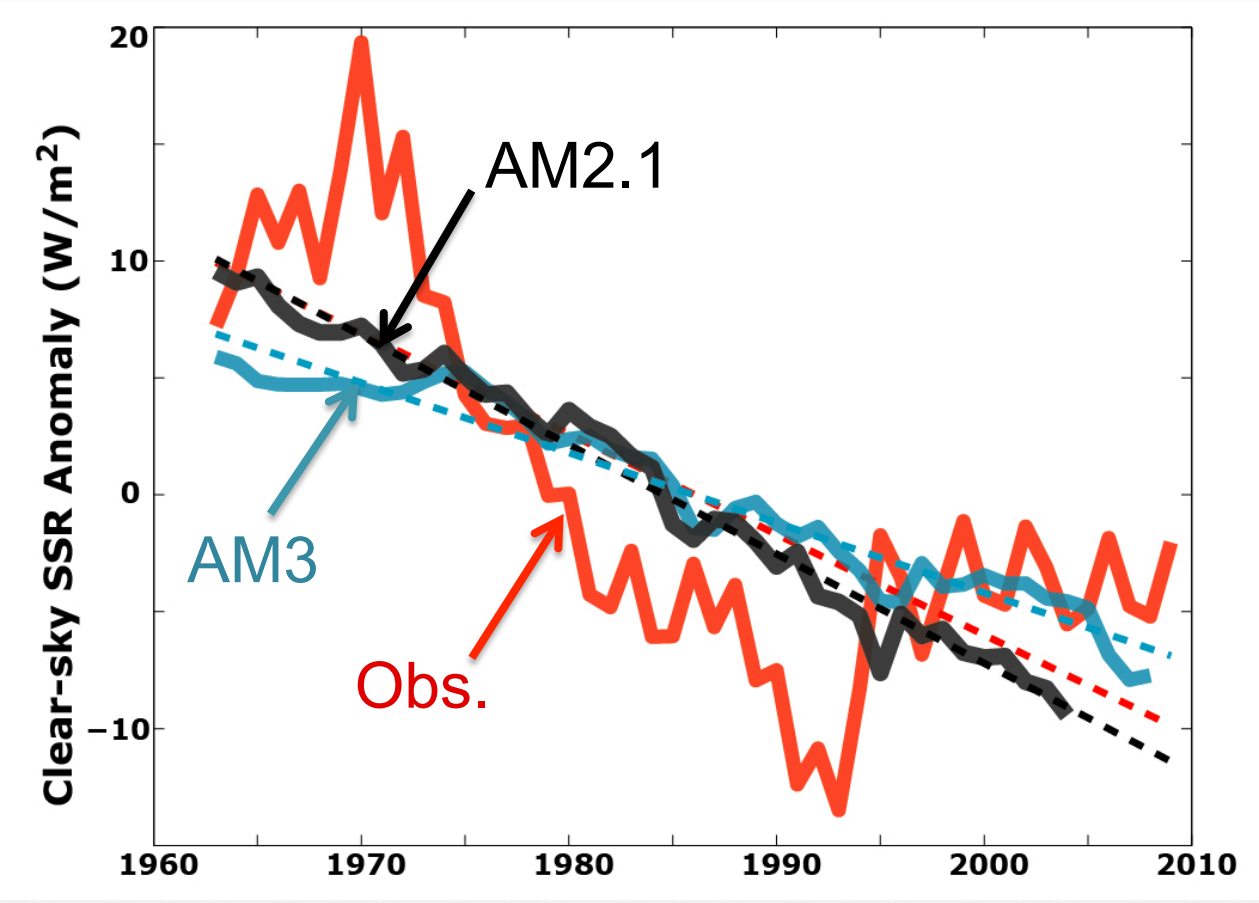
Lin et al. (2012)

Credit: M. Lin

Surface shortwave radiative (SSR) flux trend



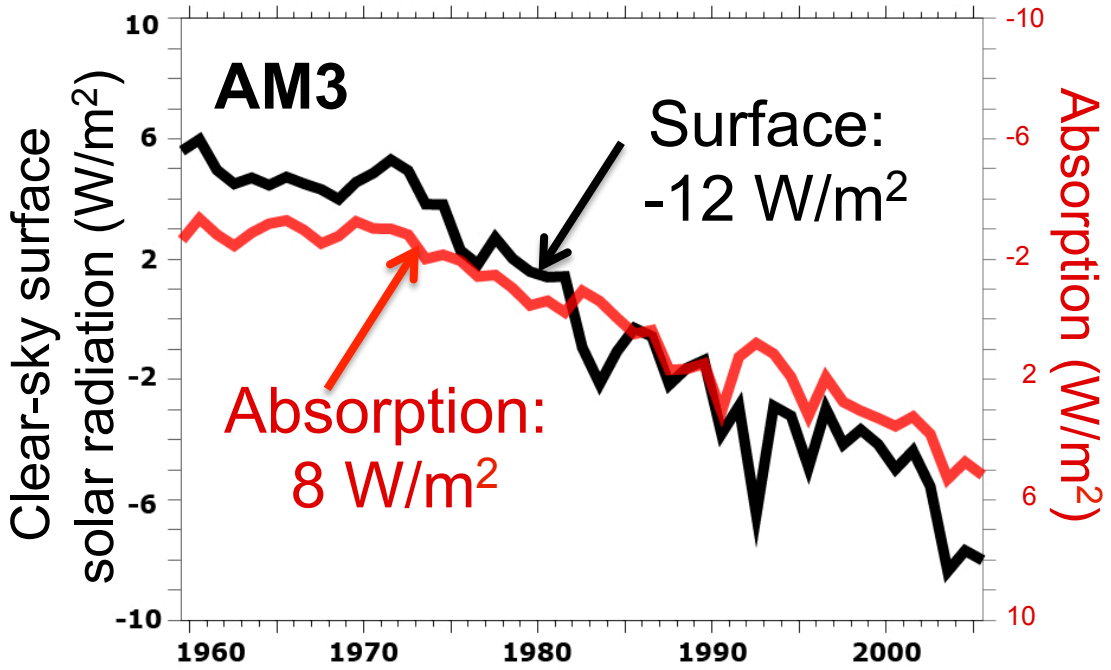
Global Energy Balance Archive (GEBA) stations used in Norris and Wild (2009)

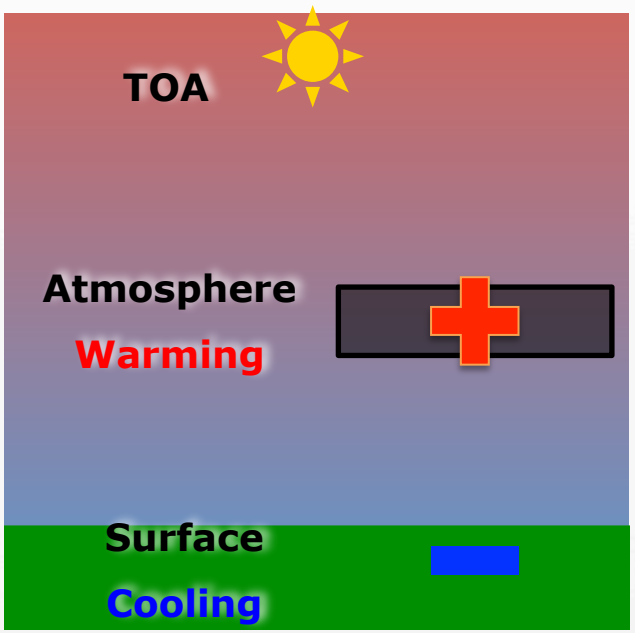


The GFDL AM3/CM3 model has the best representation of the dimming trends among all CMIP5 model (Allen et al., 2012).

Credit: G. Persad

Surface shortwave radiative flux (SSR) trend (2)





AM2.1 → AM3

Ext.→Int. Mixing		More → Less Aerosol
More absorption	+	Less absorption
More dimming		Less dimming

→ **Similar trends**

Anthropogenic aerosols and South Asian monsoon

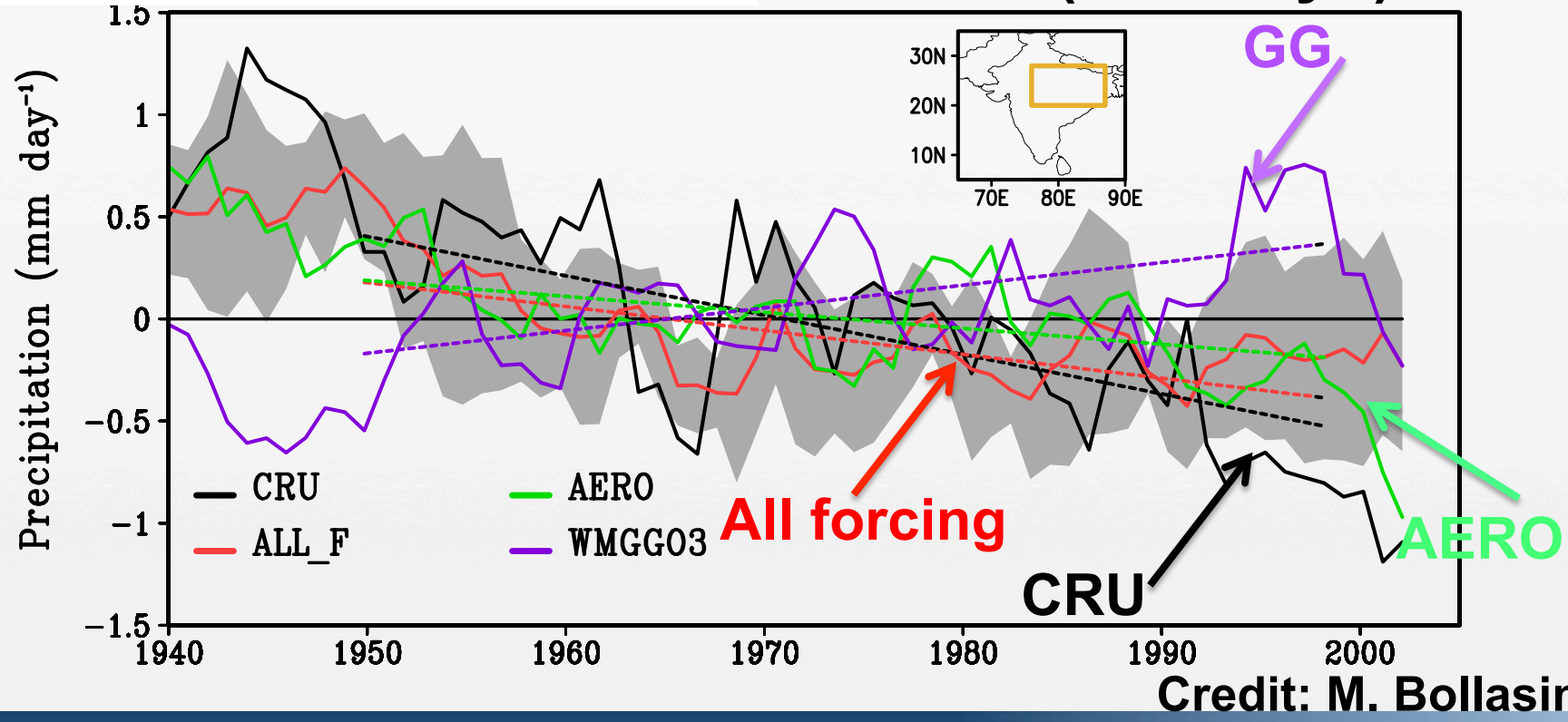
REPORTS

Science
AAAS

Anthropogenic Aerosols and the Weakening of the South Asian Summer Monsoon

Massimo A. Bollasina,[1] Yi Ming,[2]* V. Ramaswamy[2]

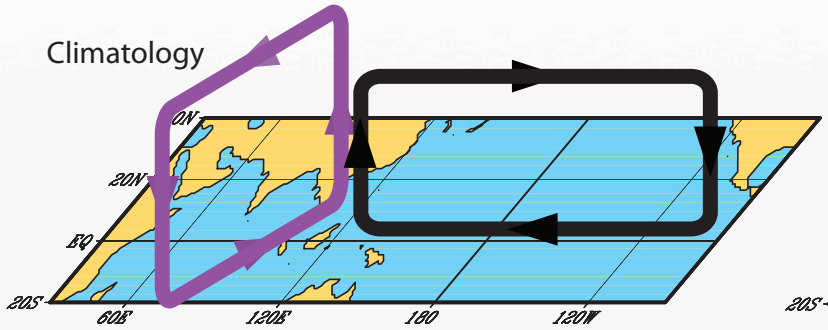
Linear trends of average JJAS rainfall over central-northern Indian (mm day^{-1})



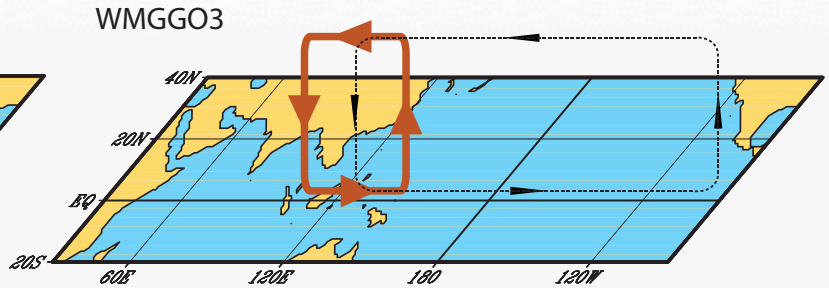
Credit: M. Bollasina

Anthropogenic influences on tropical circulation change

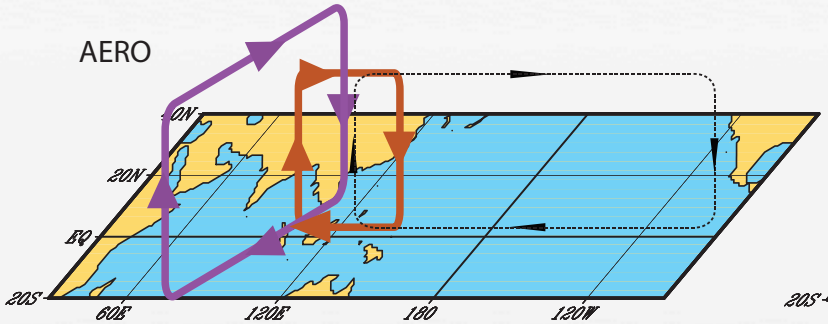
Climatology



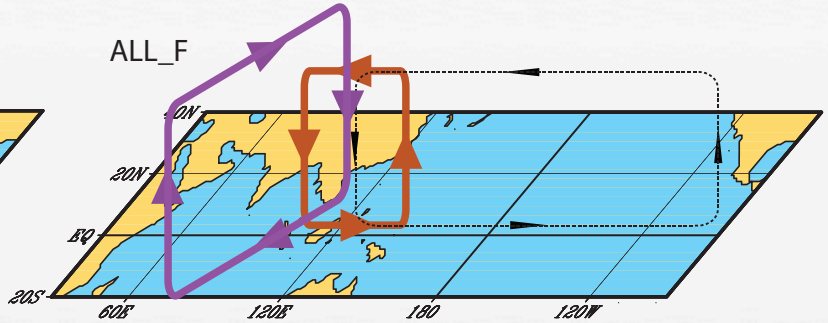
GG



AERO

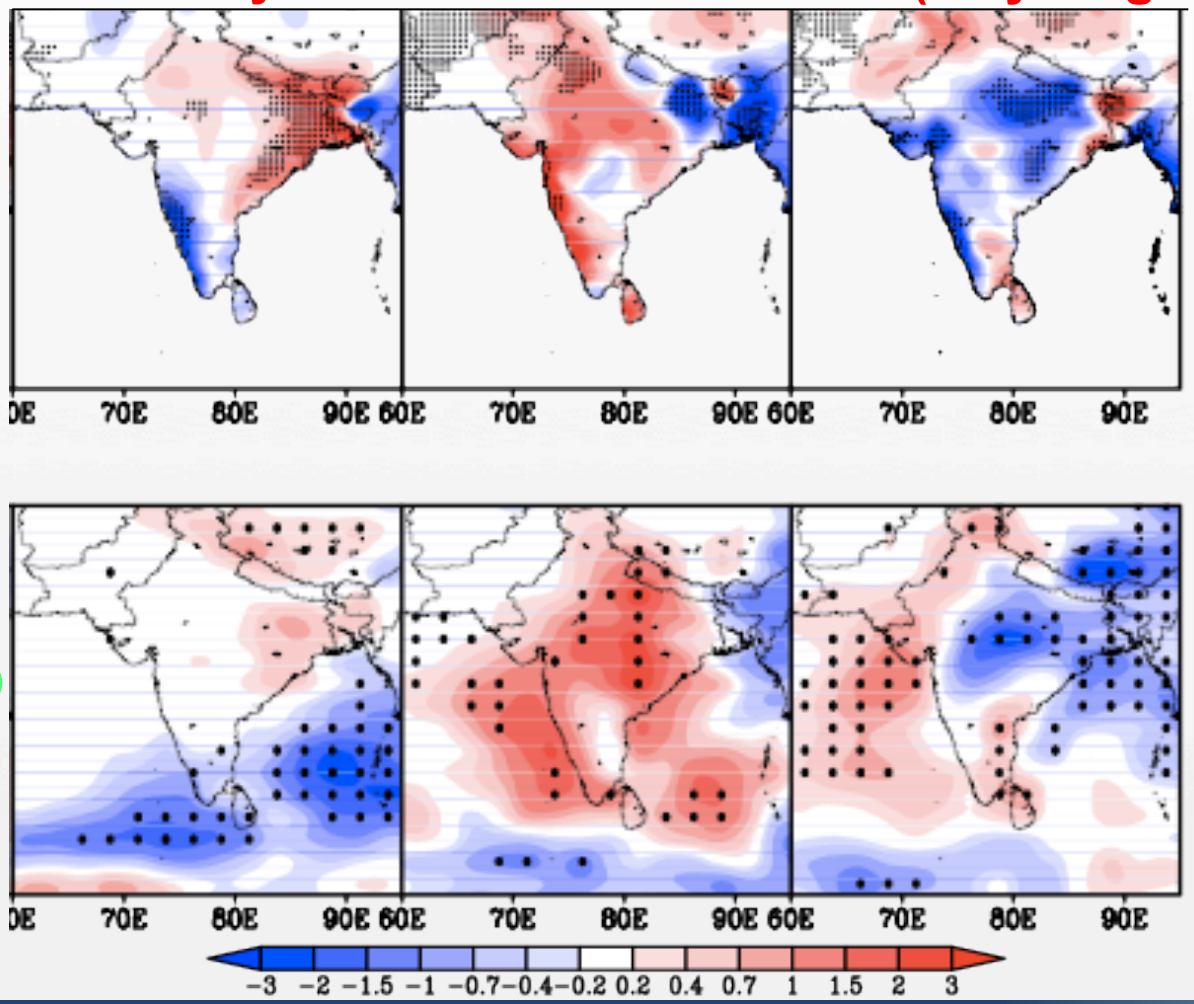


All forcing



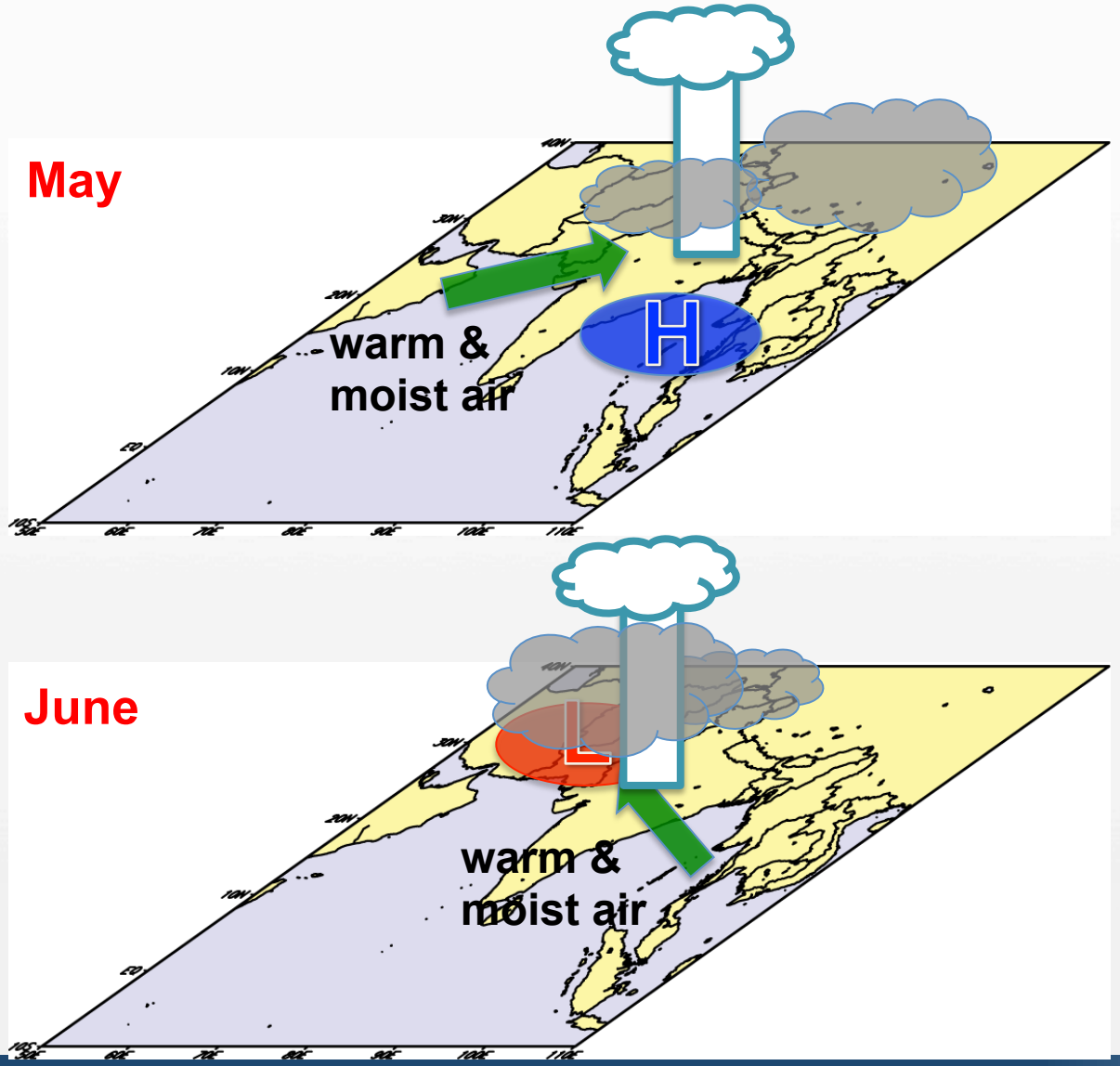
Aerosol impact on monsoon onset

Linear trends of precipitation [mm day^{-1} 50 yr^{-1}]



- **Aerosols tend to increase rainfall in May and June, while suppressing it in JAS;**
- **An earlier monsoon onset;**
- **Consistent with observations.**

Aerosol impact on monsoon onset (2)



Aerosols

Higher SLP

Lower SLP

Surface wind

Precipitation

Why do clouds matter? Sensitivity and forcing

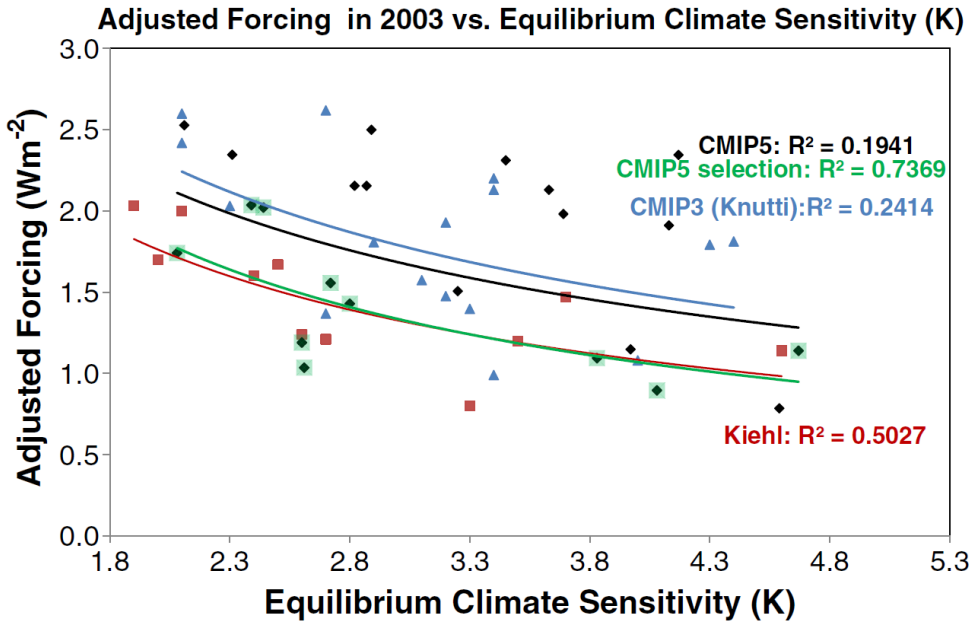
Sensitivity and **forcing** are key climate properties. At equilibrium:

$$\Delta T = \lambda F$$

F **(adjusted) forcing**: radiative perturbation (GHGs, aerosols, clouds, land-use, …)

λ **sensitivity**: temperature response per unit of forcing.

- **Clouds impact both.**



Forster et al. (2013); Kiehl (2007).

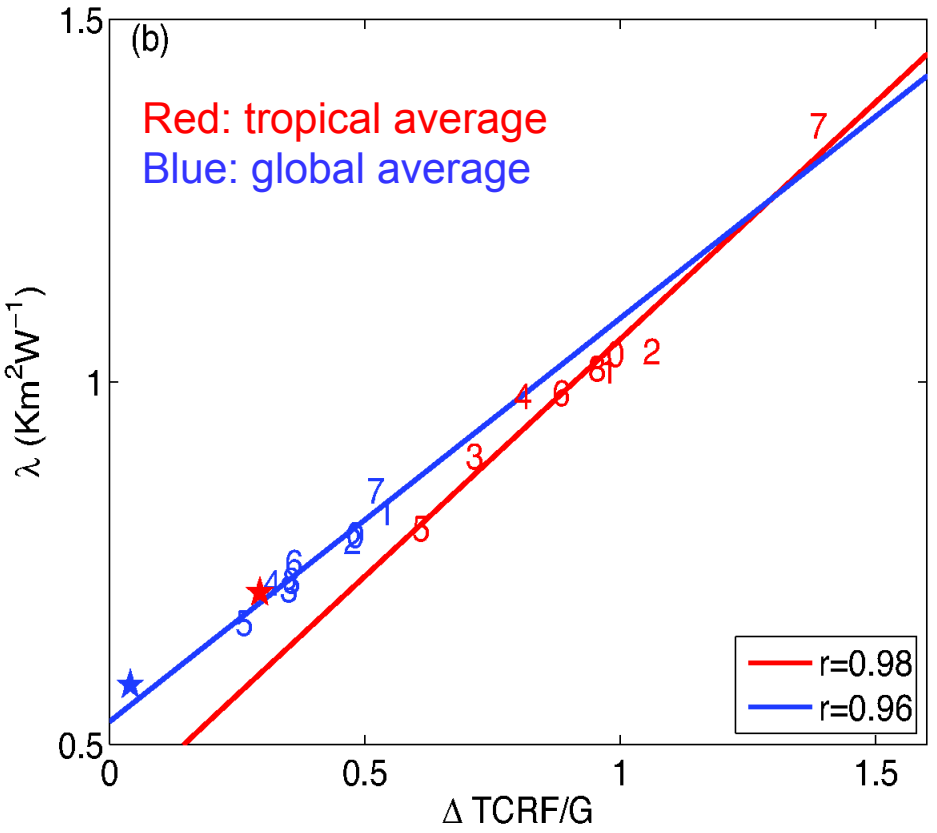
Anti-correlation between sensitivity and forcing among models that reproduce observed warming.

Climate sensitivity and cloud feedback

- **Increased climate sensitivity in HiRAM (and AM3) compared to AM2.**
- **Sensitivity highly correlated with cloud feedback (change in cloud radiative effect).**

Cloud feedback

- ➢ **impacted by details of convective parameterization,**
- ➢ **linked to convective precipitation efficiency.**



Sensitivity

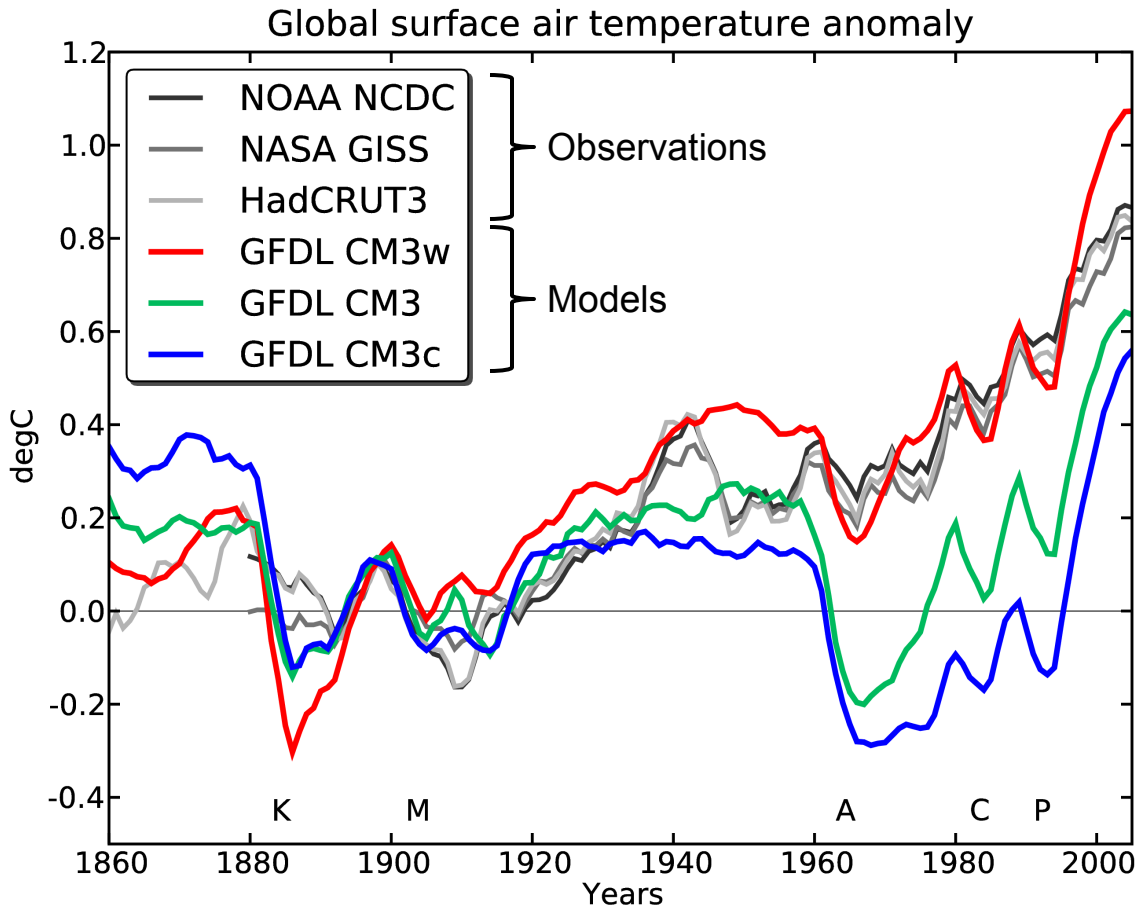
Cloud feedback parameter

★	AM2
0	c48 HiRAM
1-4	perturbed cumulus mixing
5-8	perturbed cumulus microphysics

Zhao (2013 , *J. Climate,* submitted)

Credit: M. Zhao

Clouds and forcing: indirect effect



Golaz et al. (2013, *GRL*)

Models

CM3: official GFDL CMIP5 model.

CM3w,c: configurations with alternate but plausible parameter choices.

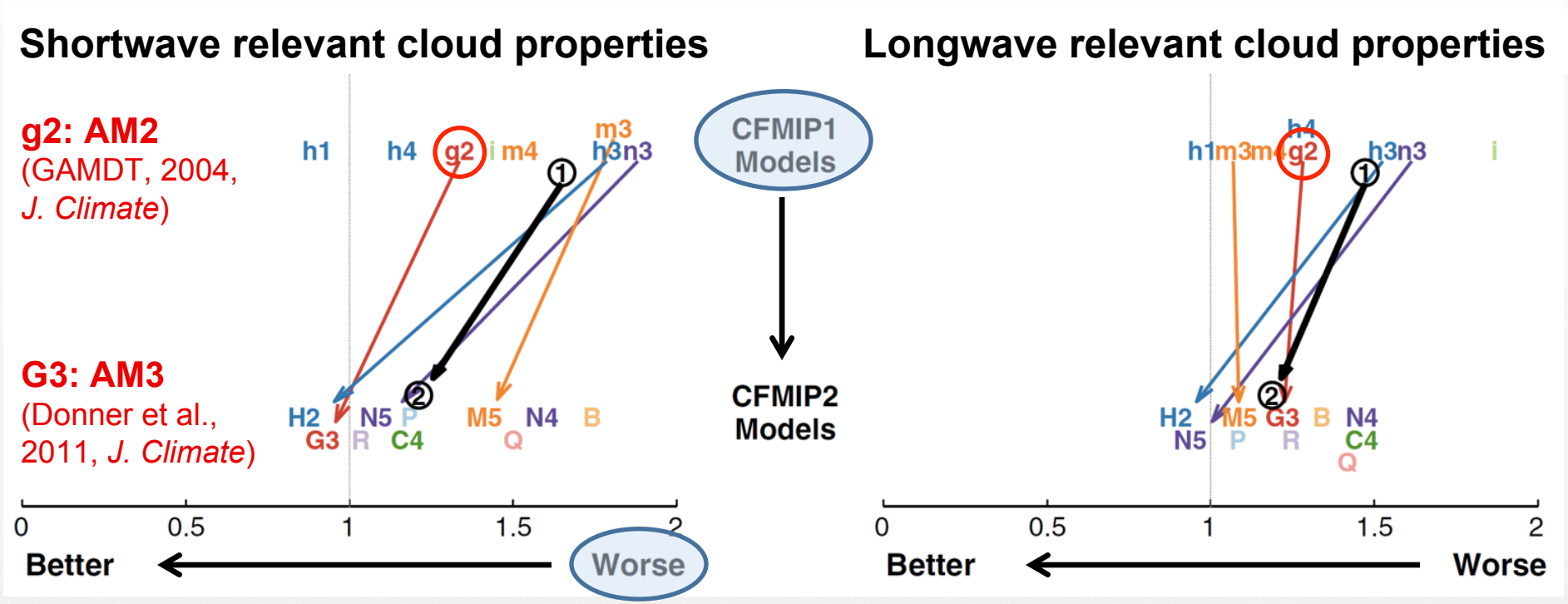
Net warming

NOAA NCDC	0.59 ºC
NASA GISS	0.53 ºC
HadCRUT3	0.56 ºC
CM3w	0.57 ºC
CM3	0.22 ºC
CM3c	-0.01 ºC

Credit: C. Golaz

Clouds: have we made progress?

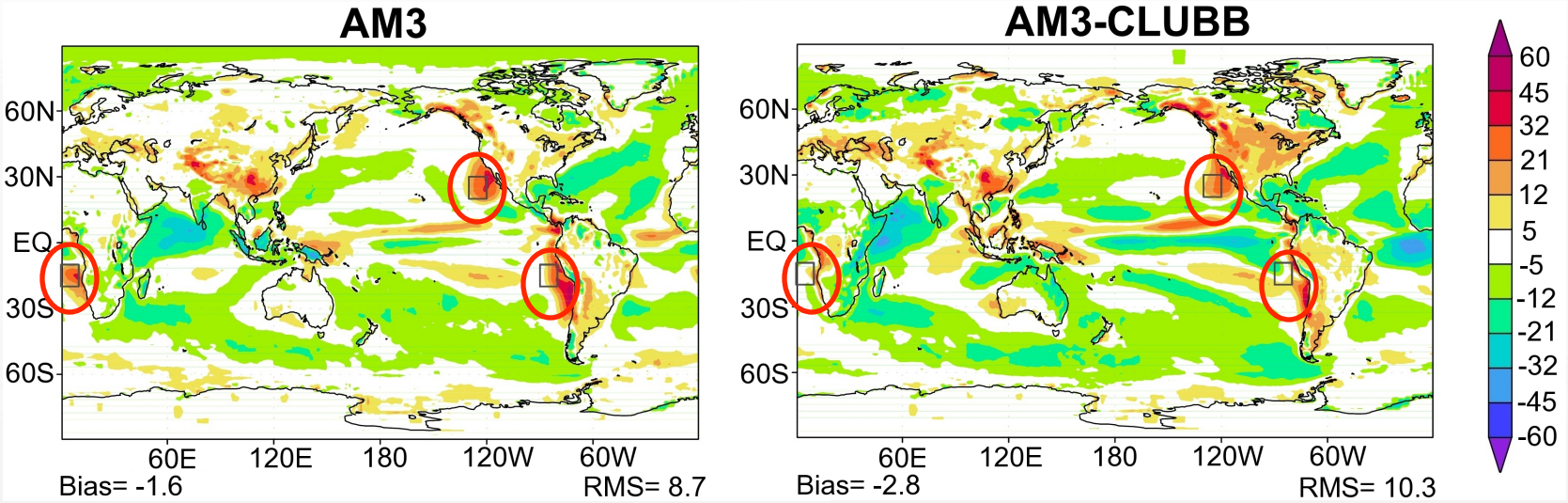
Evaluation of CFMIP1 and CFMIP2 models
Klein et al. (2013, JGR)



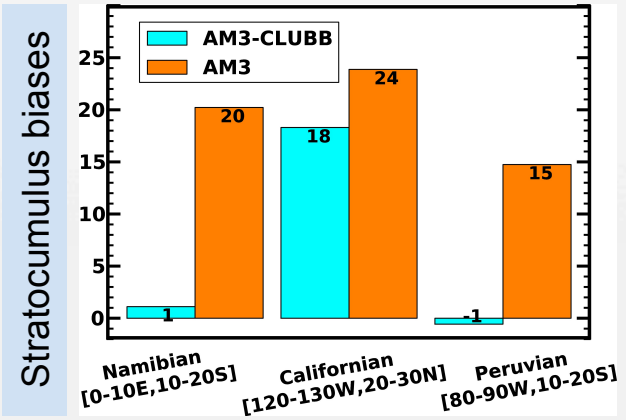
AM3/CM3 results are being widely analyzed (53 citations to date).
GFDL CFMIP credit: L. Donner, C. Seman, L. Horowitz, B. Hurlin

New cloud and turbulence parameterization

CLUBB* (NOAA/NSF Climate Process Team)
Short-wave cloud forcing error [W m^{-2}]



- **Long-standing stratocumulus biases are reduced in AM3-CLUBB.**
- **Overall performance slightly lags AM3.**



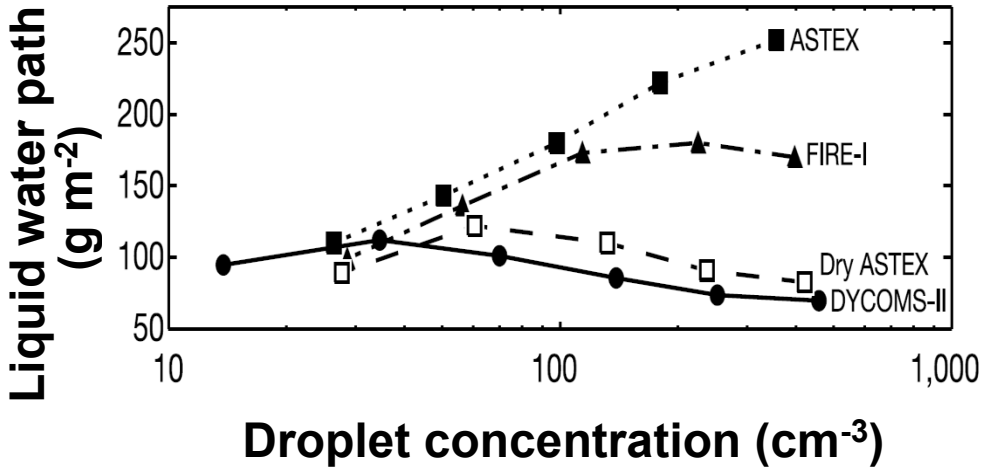
*Cloud Layers Unified by Bi-Normals

Credit: H. Guo

New cloud and turbulence parameterization

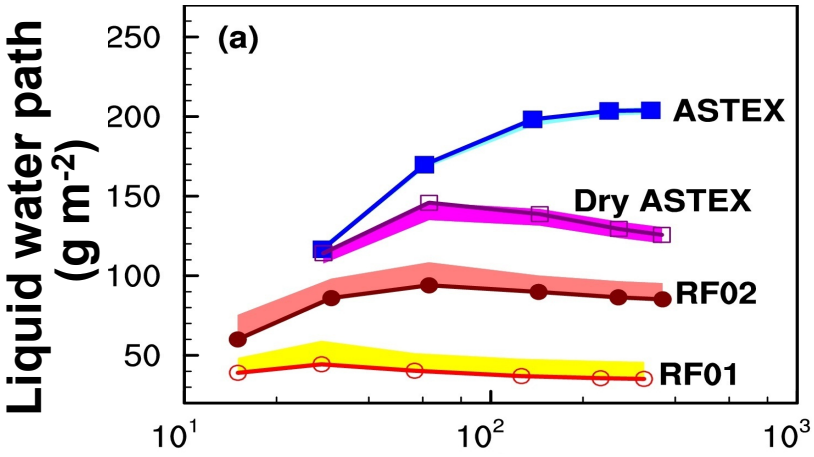
CLUBB* (NOAA/NSF Climate Process Team)
Indirect effect for different stratocumulus cases

Large eddy simulations



Ackerman et al. (*Nature*, 2004)

CLUBB



Guo et al. (*GRL*, 2011)

- **Full liquid water path response to aerosols could potentially decrease magnitude of indirect effect.**

***Cloud Layers Unified by Bi-Normals**

Credit: H. Guo

Future research directions

Improved understanding and new modeling capabilities:

- Aerosol-ice cloud interactions (e.g., black carbon as ice nuclei);
- Double-moment aerosol/cloud microphysics;
- Aerosols (e.g., black carbon and dust) on snow;
- Aerosol-vegetation-biogeochemistry coupling (e.g., dust and wild fires);
- Chemistry-climate interactions (e.g., methane lifetime);
- Improvement of radiative transfer parameterization (e.g., water continuum);
- More unified and physically sound cloud and convective parameterizations (e.g., CLUBB coupled with double-moment cloud microphysics).

Relevance to the NOAA's NGSP goals

- Our process-oriented research generates
  1) mechanistic understanding of existing model biases and uncertainties,
  2) new modeling capabilities that enhance the realism of regional climate and Earth System simulation.
- Both aspects are crucial for developing the next-generation GFDL Earth System Model, an essential tool for advancing NOAA's climate adaptation and mitigation goal.