Some Thoughts on Future Directions

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with input from
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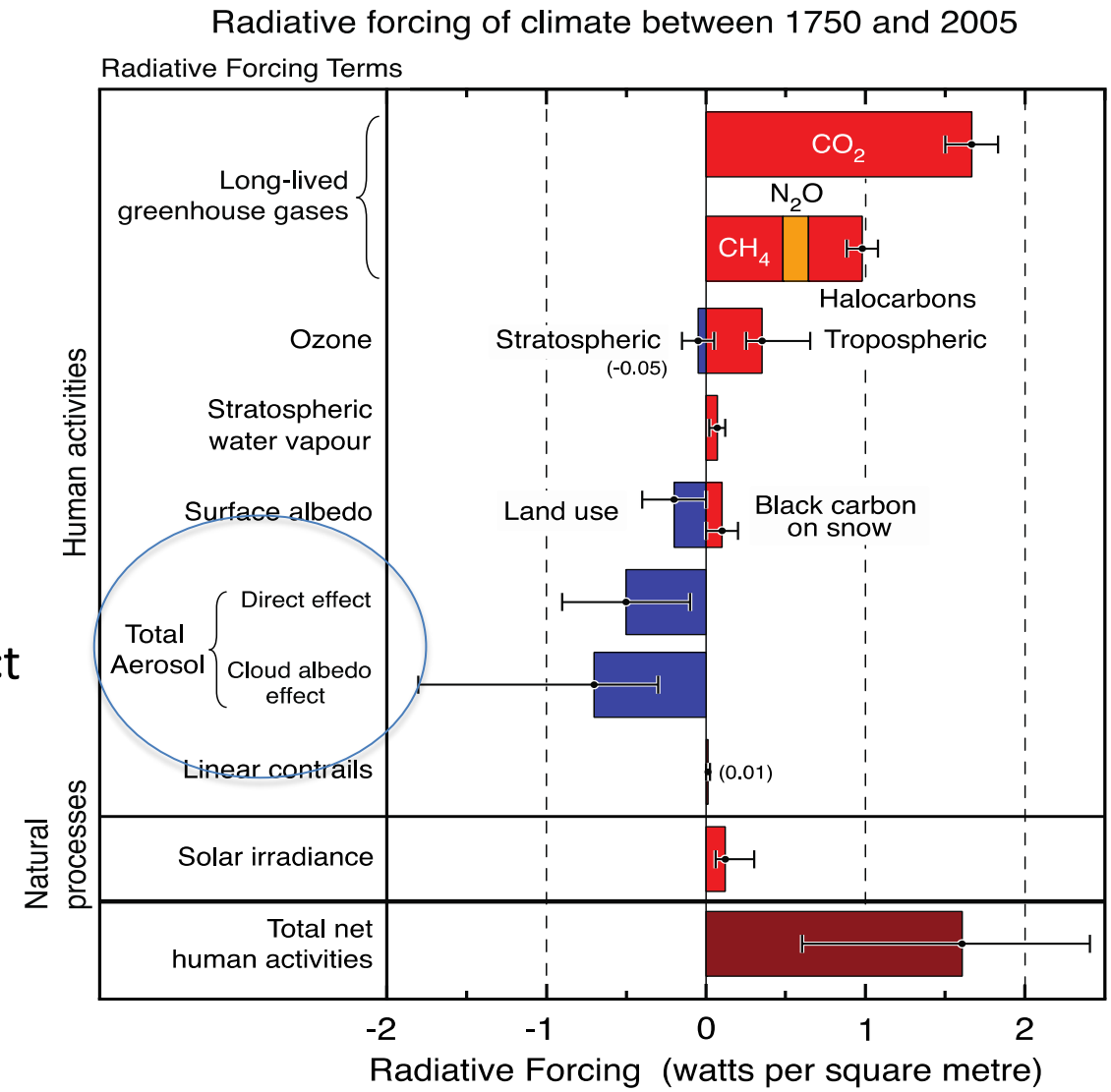
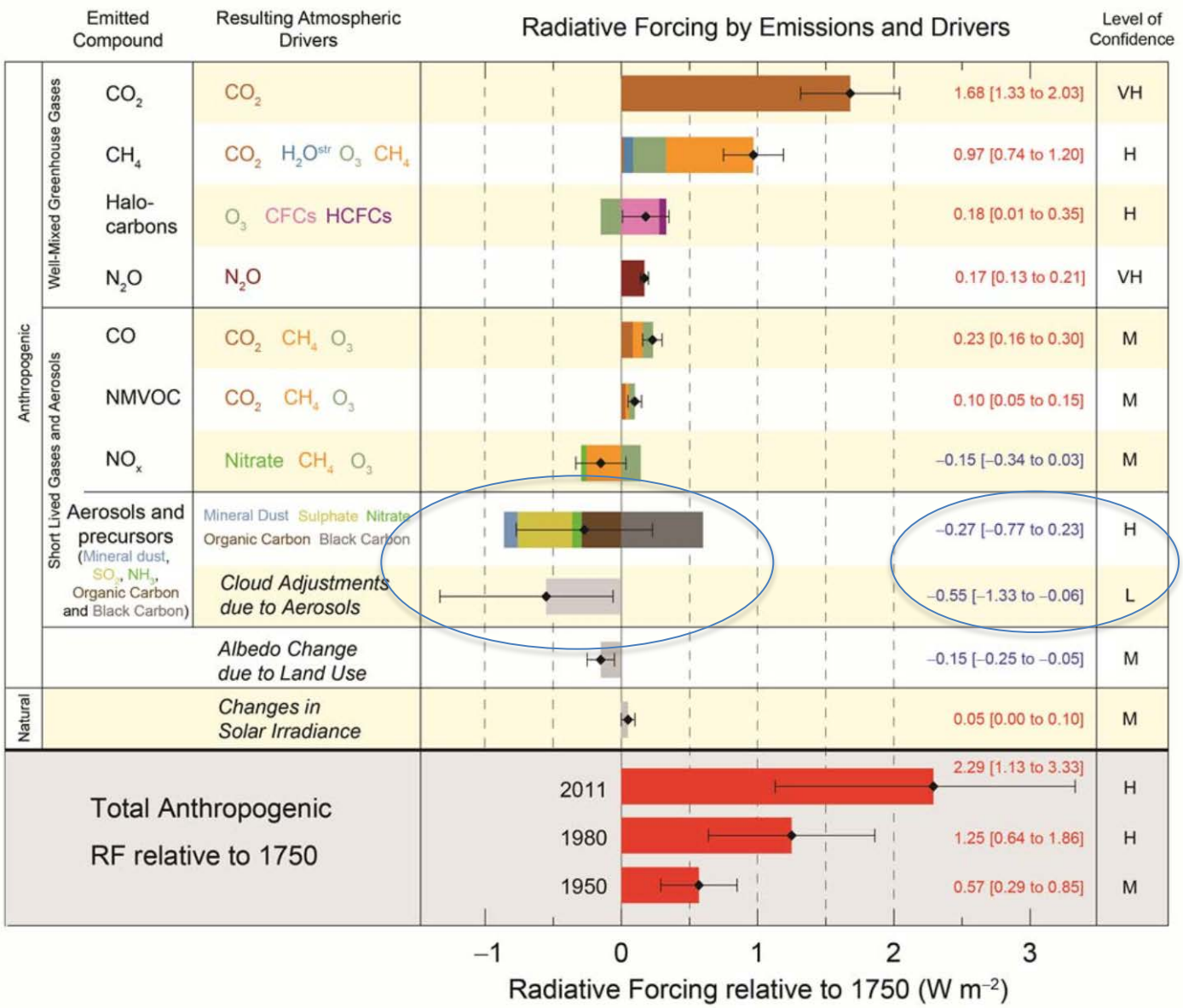
AR4

Direct effect
Cloud Albedo effect



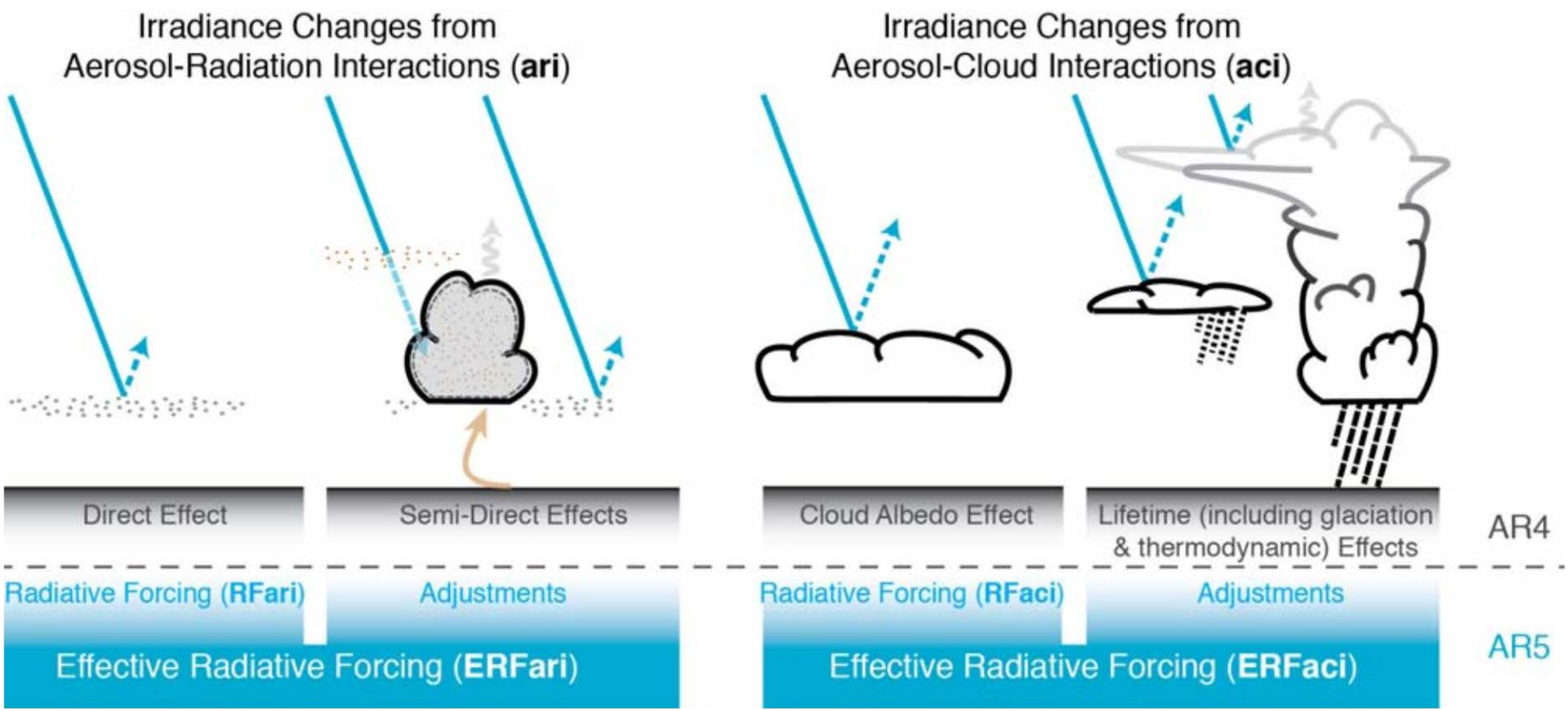
IPCC AR5 View



From SPM and Chapter 7

- Climate models now include more cloud and aerosol processes, and their interactions, than at the time of the AR4, but there remains *low confidence in the representation and quantification of these processes in models*
- [Aerosol and aerosol-cloud interactions] continue to contribute the largest uncertainty to the total RF estimate
- The effective radiative forcing due to aerosol-radiation interactions [“direct + semidirect”] is –0.45 W m^{-2} (–0.95 to +0.05) [Direct is -0.35 Wm^{-2}]
- The RF of the <u>total aerosol effect</u> in the atmosphere, which includes cloud adjustments due to aerosols, is –0.9 [–1.9 to −0.1] W m^{-2} (*medium confidence*)
- The net [cloud] radiative feedback is *likely* positive. Uncertainty in the sign and magnitude is due primarily to continuing uncertainty in the impact of warming on *low clouds*

Changes in Viewpoint



Terminology

- aci (aerosol-cloud interactions)
- ari (aerosol-radiation interactions)
- RFari (Radiative forcing associated with ari)

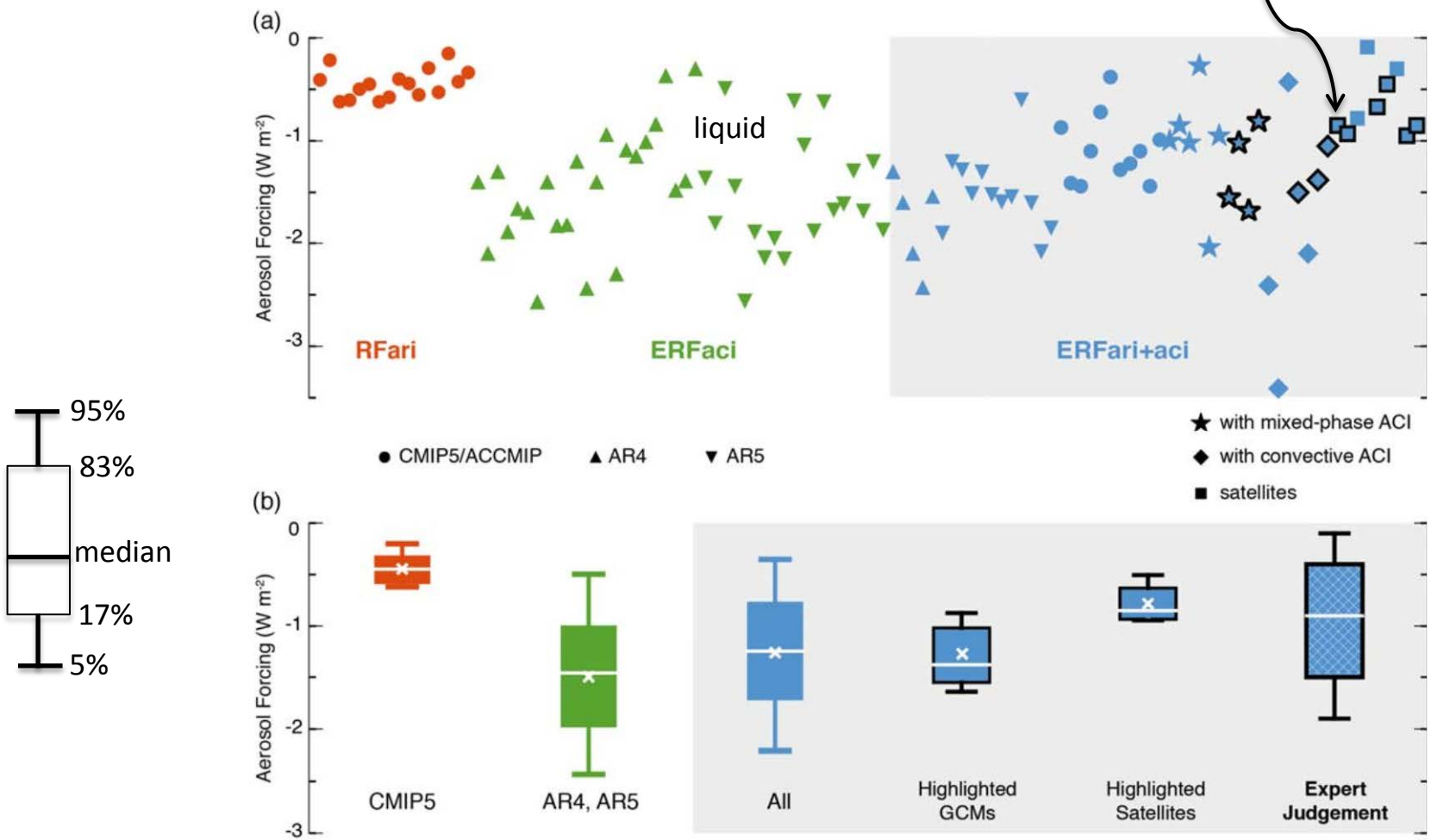
  direct effect
- ERFari (Effective radiative forcing associated with ari

  direct + semidirect
- RFaci (Radiative forcing associated with aci)

  albedo effect
- ERFaci (effective radiative forcing associated with aci

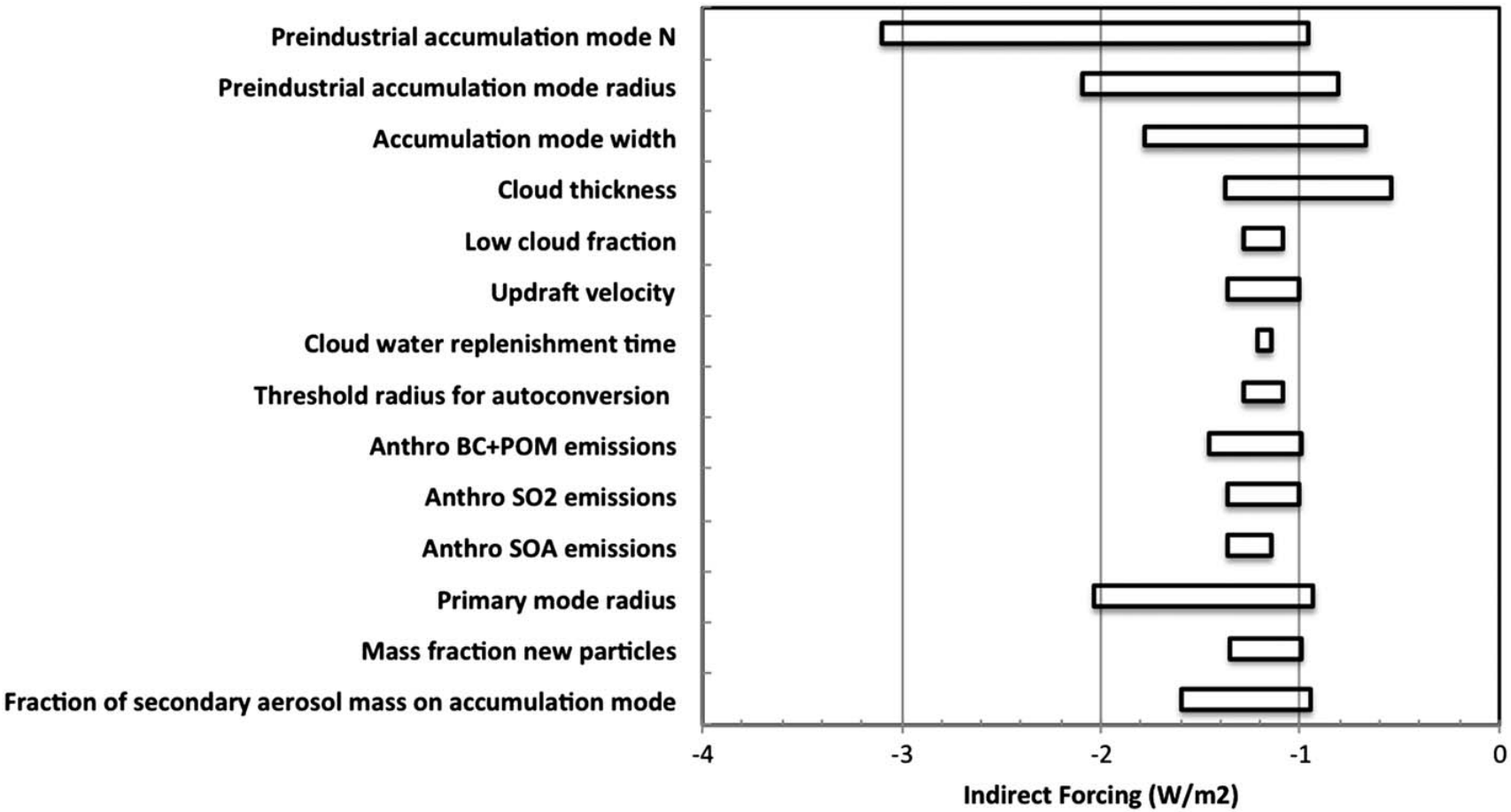
  albedo + lifetime effects

Highlighted symbols used for expert judgment



Note: No estimate of RFaci (formerly albedo effect)
Focus on *effective* (including adjustments) and *total* radiative forcing

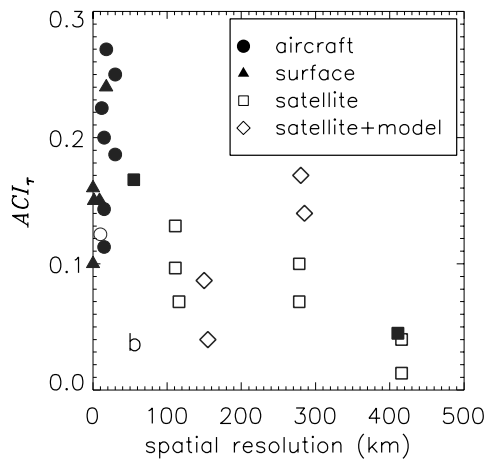
Sensitivities to Pre-Industrial Aerosol and other model specifications/assumptions



Ghan et al. 2013

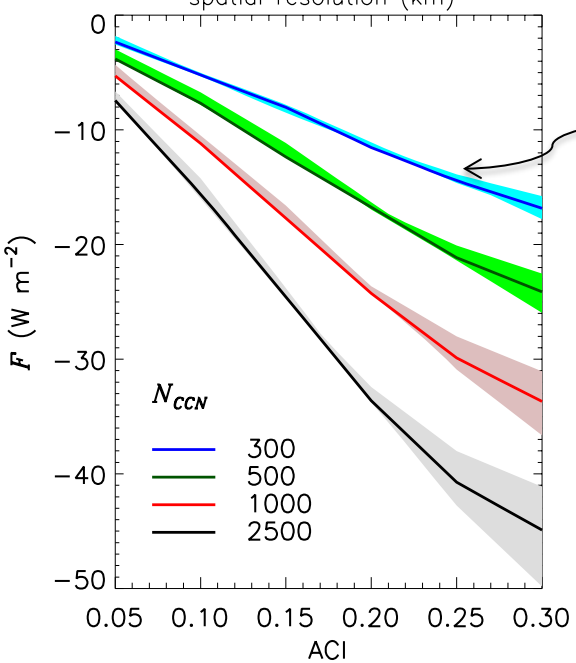
Can We Constrain Aerosol-Cloud Forcing Observationally?

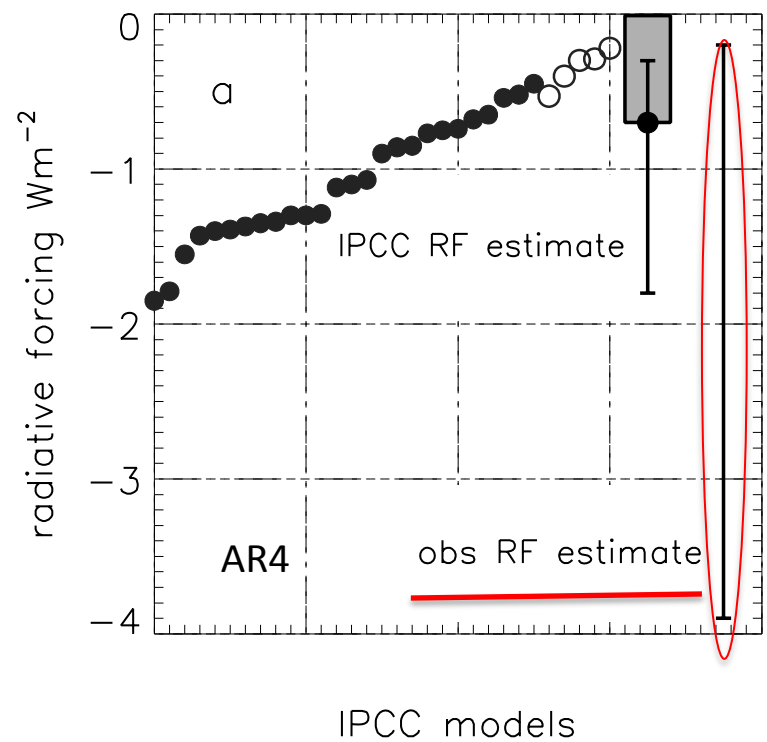
Stepping Back to AR4 and Albedo Effect



$$\mathrm{ACI}_\tau = \left.\frac{\partial \ln \tau_c}{\partial \ln \alpha}\right|_L$$

- *Uncertainty is huge*
- *Obs. are not an effective constraint*



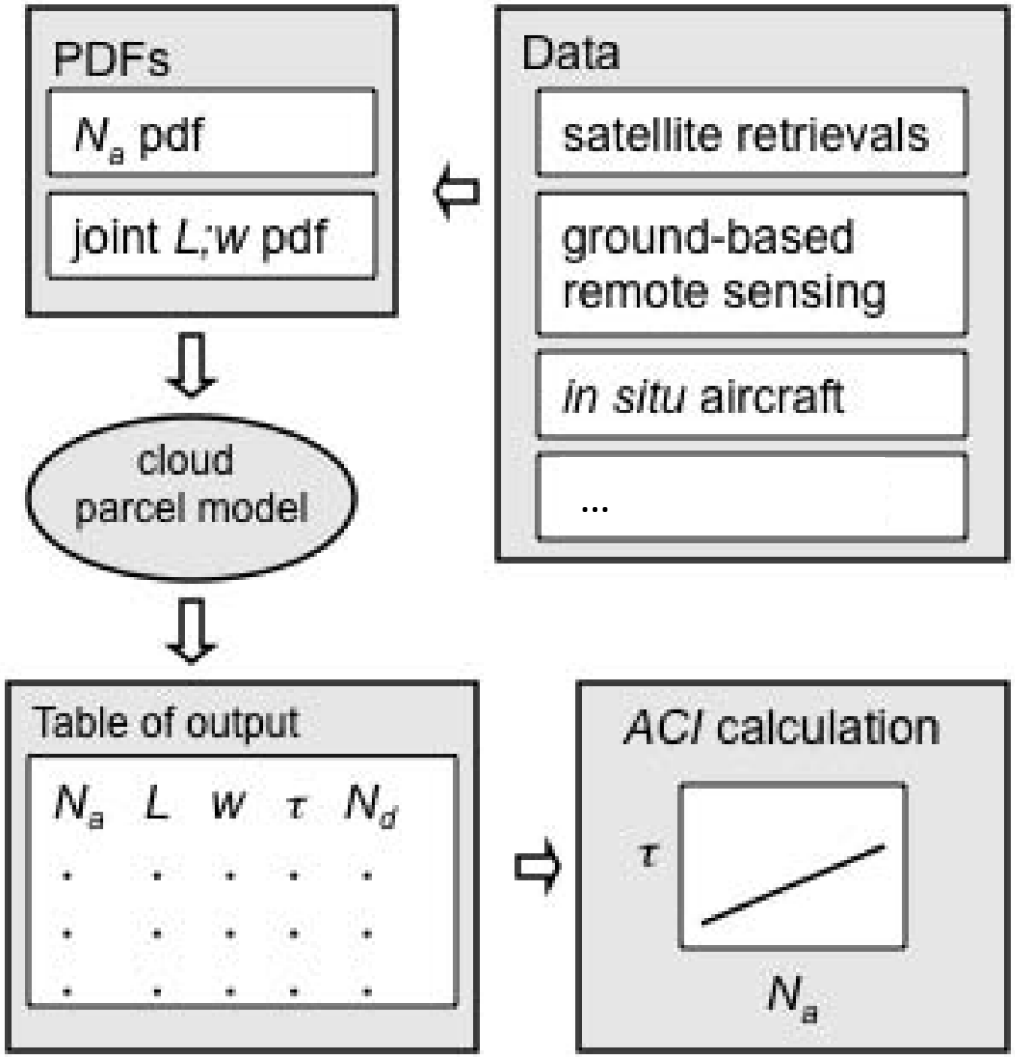


Obs RF estimate: assume a 3x increase in CCN (100 to 300 cm^{-3}) and a global average liquid water cloud cover of 25 % with mean LWP = 125 g m^{-2} (McComiskey and Feingold 2008)

McComiskey and Feingold 2012

Incremental Step:
ACI calculation based on PDF sampling

Use of physical model at the cloud scale



McComiskey and Feingold 2012

Beyond RFaci

- Tendency to equate ACI= - $dlnr_e/dlnN_a$ to an activation problem

- At satellite aggregation / GCM scales ACI represents *many* cloud physical processes (activation, collision-coalescence, scavenging, entrainment, etc.)

- *Little justification for pursuing quantification of RFaci (Twomey/albedo) as opposed to ERFaci (including system adjustments)*

- We need to engage in discussion of how to constrain ERFaci

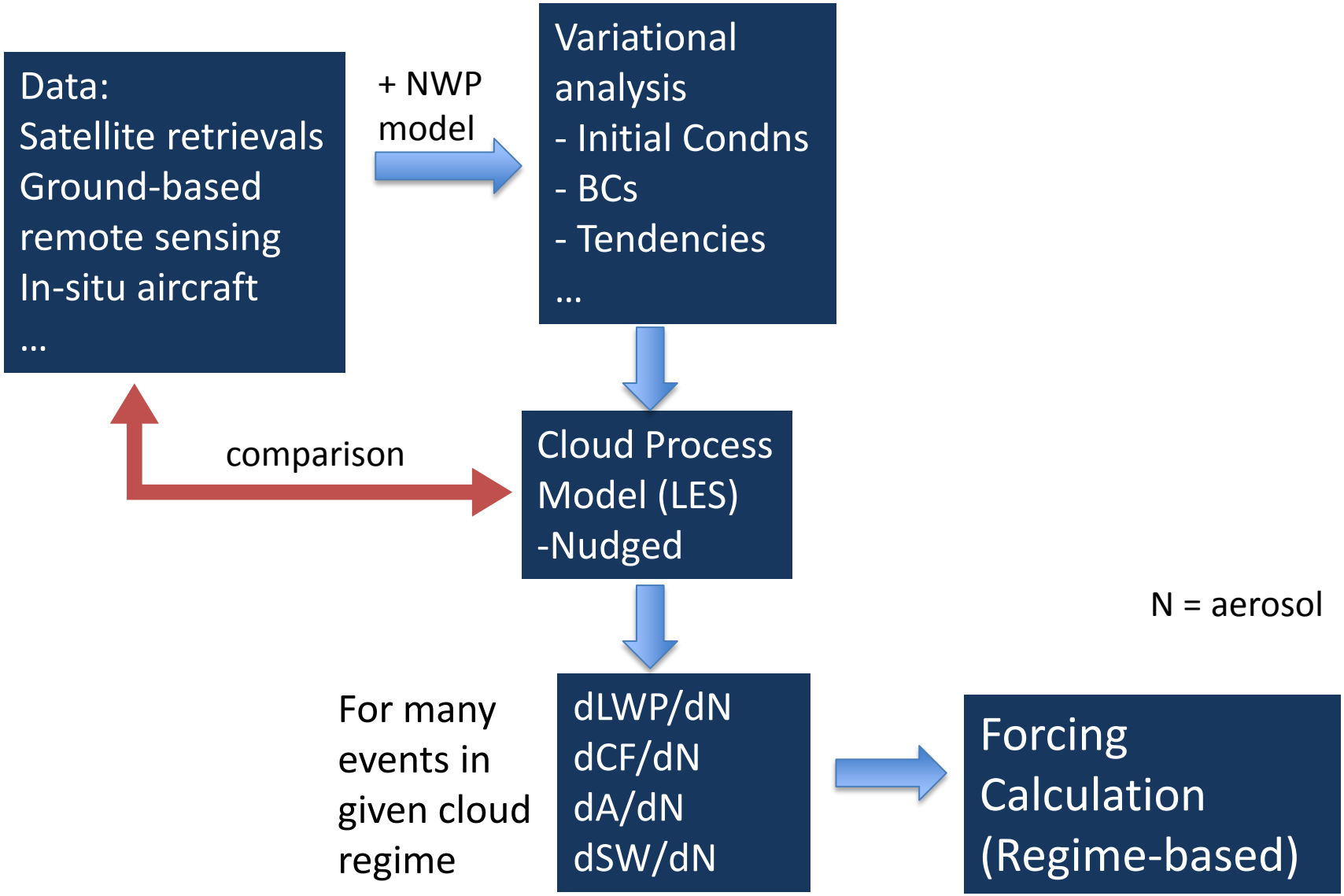
ERFaci

Some possible ingredients for *observationally-based* assessments:

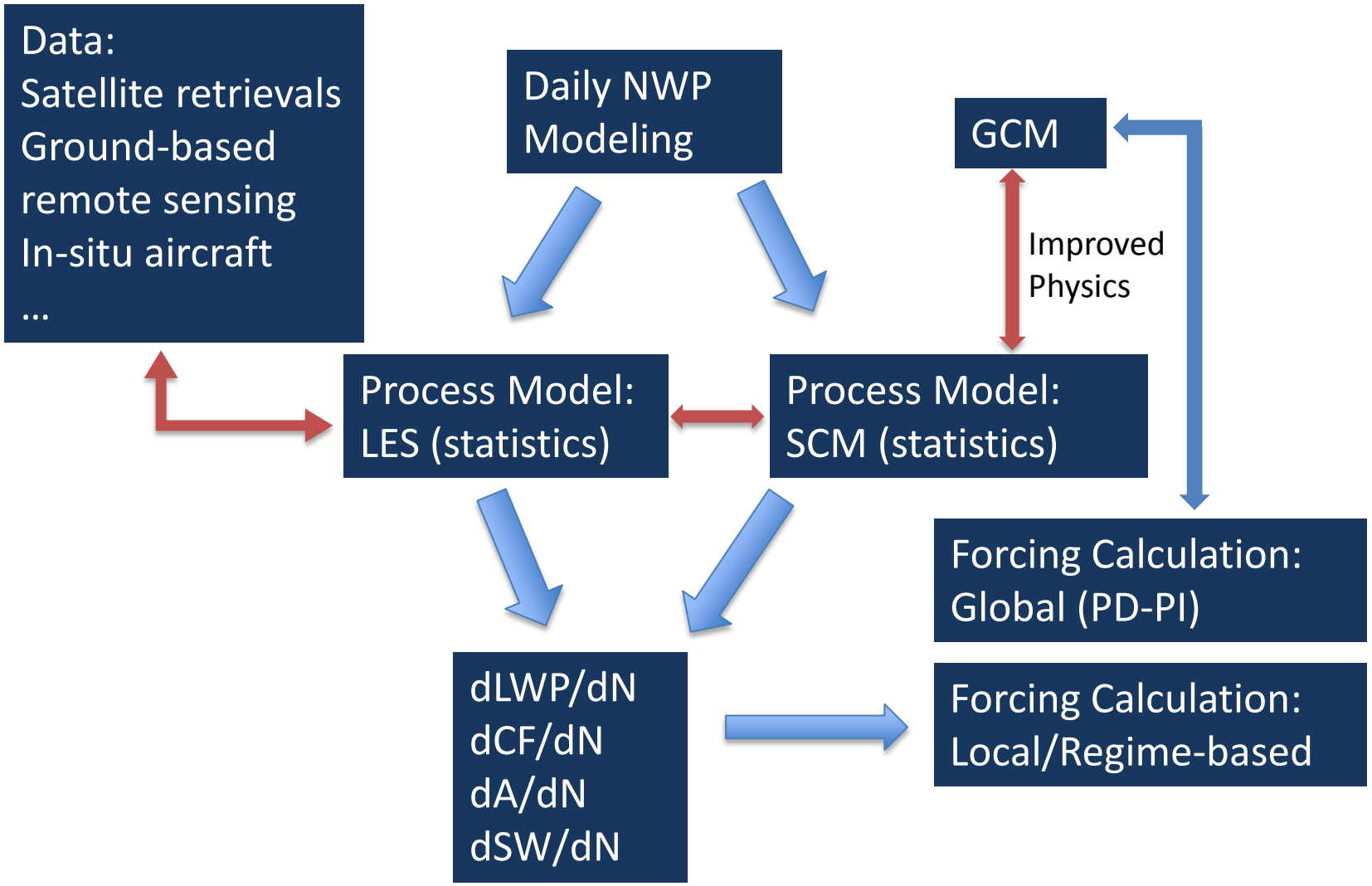
- Probabilistic approach
- Regime-based
- PDFs of LWP, updraft, aerosol, meteorological parameters

- *Use of process level models*
  - LES, CRM, SCM
  - Multimodel framework (MMF)
  - PDF approaches to representing subgrid turbulence [CLUBB, Larson and Golaz, 2005]

Data driving Process Models

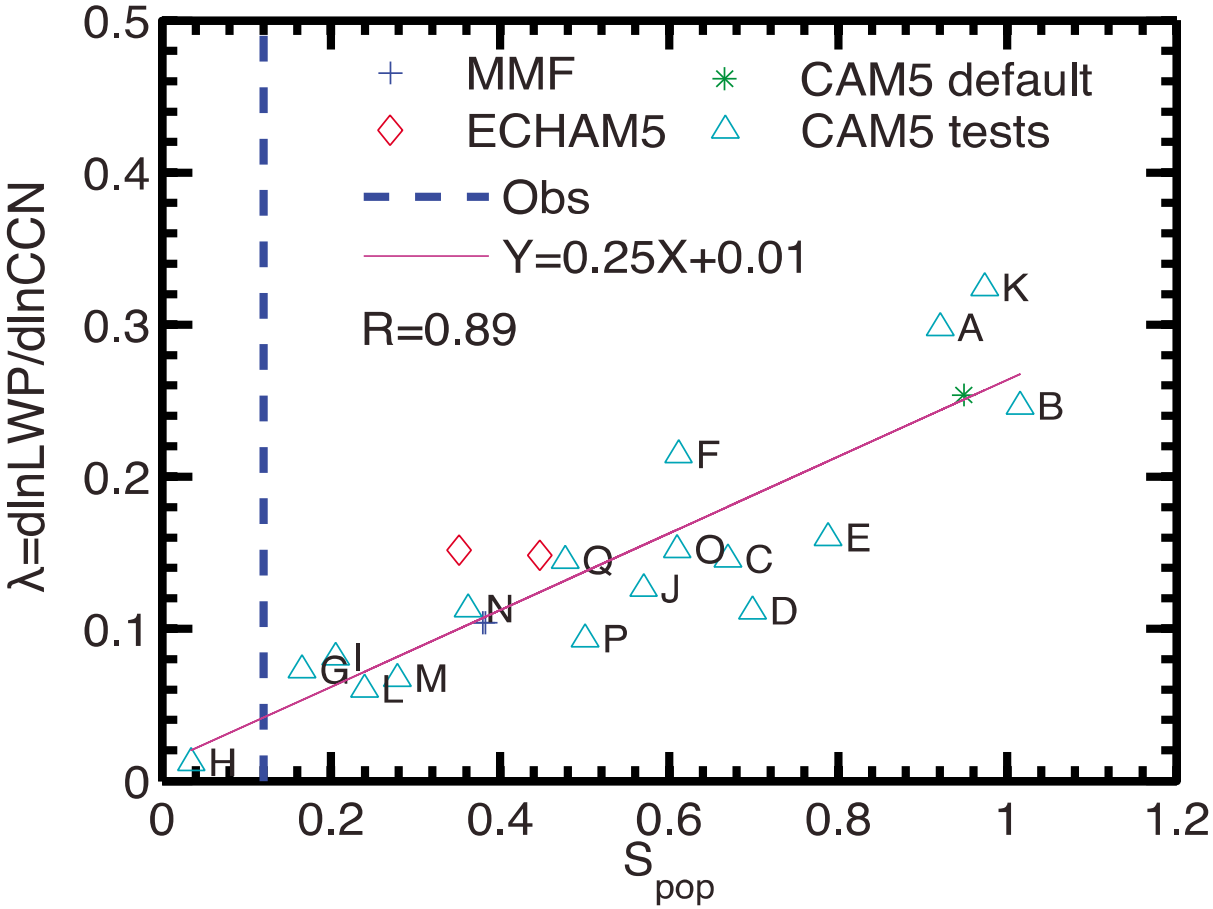


Test Bed Approach



N = aerosol

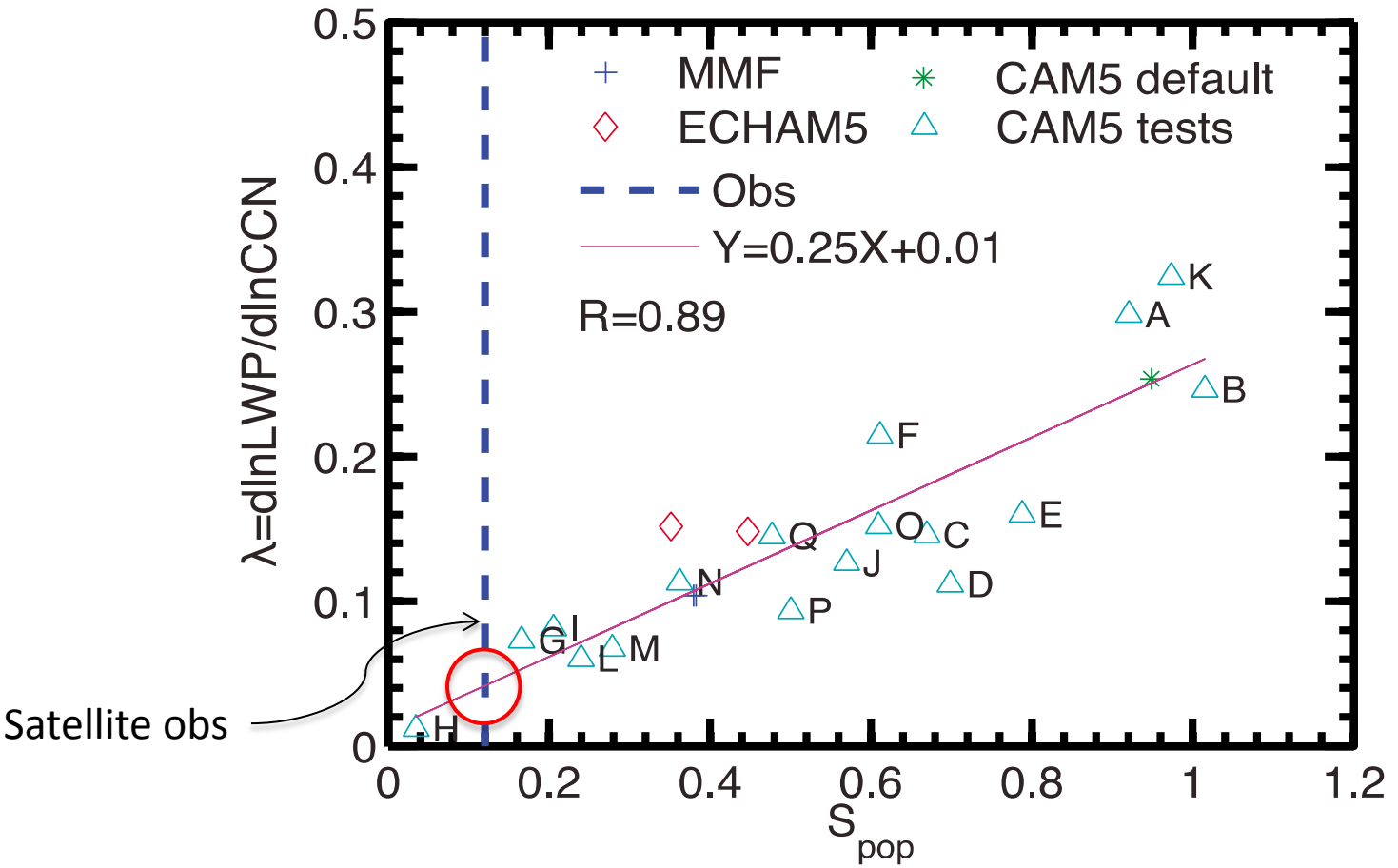
Precipitation Susceptibility and ERFaci: Observational Constraints on Models



Susceptibility in Terms of Probability of Precipitation

Minghuai Wang et al. 2012

Precip Susceptibility and ERFaci: Observational Constraints on Models



Susceptibility in Terms of Probability of Precipitation

Minghuai Wang et al. 2012

Analysis of individual trade cumuli generated by LES

$dlnR/dlnr_e$

S_o

Influence of lifecycle of cloud

- S_o changes as cloud lifecycle progresses

- R response to r_e captures the essence of S_o (both in terms of qualitative shape and lifecycle dependence)

Duong, Sorooshian, Feingold 2011

Feingold, McComiskey, Rosenfeld, Sorooshian, 2013

Analysis of individual trade cumuli generated by LES

- Quantifying S_o is difficult
- Some of these issues might be resolved by S_{pop}
  - Others may not: e.g., scale, aggregation

$dlnR/dlnr_e$

S_o

Influence of averaging

Duong, Sorooshian, Feingold 2011

Summary

- Presentation of IPCC AR5 view of ACI
  - New thinking reflected in new terminology
  - Direct, Indirect (albedo effect and lifetime effect) terminology is out *but underlying physics is not!*
  - Effective radiative forcing due to aerosol-radiation interactions (ERFari)
  - Effective radiative forcing due to aerosol-cloud interactions (ERFaci)
  - “Effective” = adjustments of the system to pertrbation

- Examples of how to observationally constrain ERFaci
  - Use of process models
  - Scaling of GCMs with satellite-based measurements (Spop)