Are clouds improving in CMIP models? Evaluation with ISCCP simulator output

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Outline

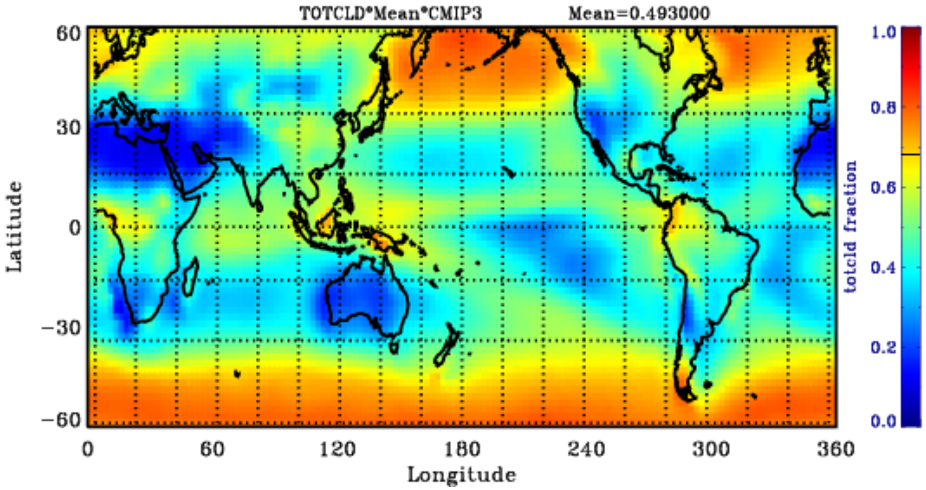
- Details of our analysis
- Analysis of total cloud fraction
- Analysis of cloud properties
  - Cloud-top pressure p_{ct} and cloud optical depth τ
- Radiative impact of model errors
- Conclusions

Details of our analysis

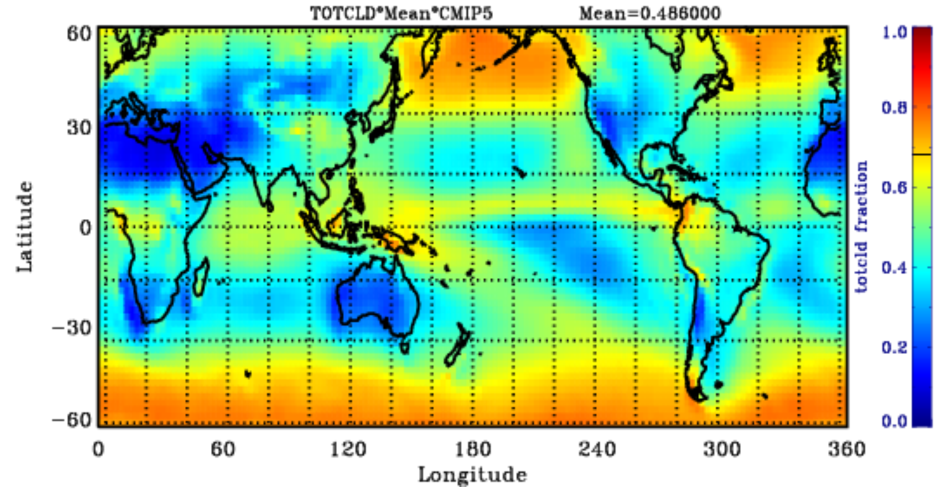
- We use 9 CMIP3/CFMIP1 and 8 CMIP5/CFMIP2 models
- Experiments:
  - CMIP3: Slab-ocean models (controls) (duration ~20 years)
  - CMIP5: AMIP integrations (duration ~30 years)
- ISCCP simulator is not quite identical, but close enough
- Climatological annual cycles formed of model output – comparison to equivalent composites of ISCCP (1983-2008) and MODIS (2001-2010) observations
- We analyze data only for 60 N – 60 S
- We examine individual models and multi-model means formed for CMIP3 and CMIP5
  - We also examine behavior of model families

Total cloud fraction ($\tau > 0.3$)

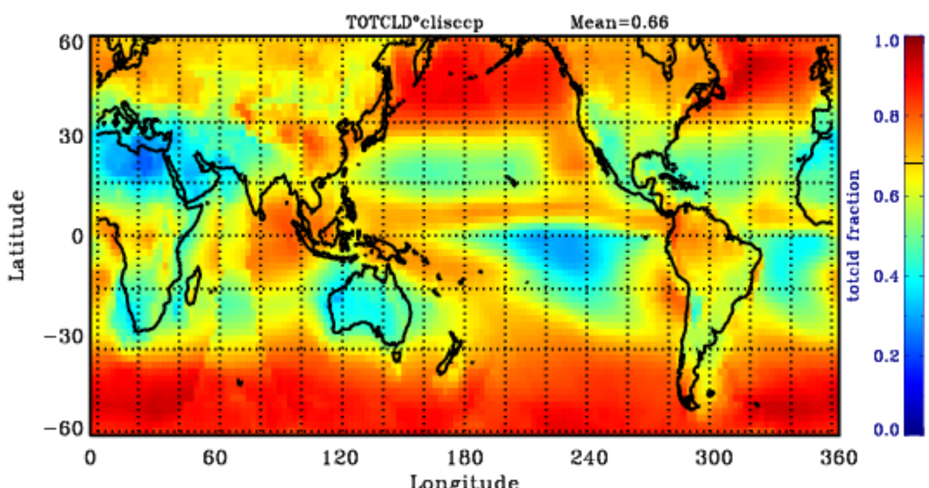
Mean CMIP3 Model



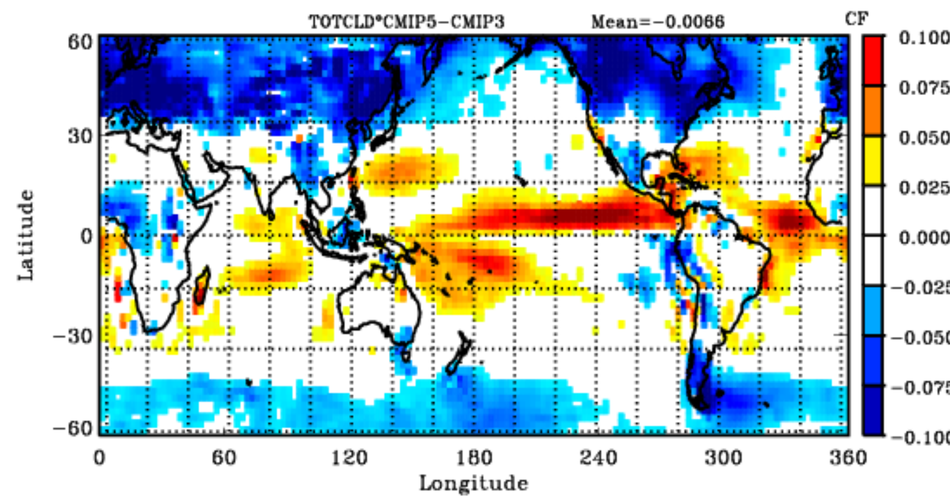
Mean CMIP5 Model



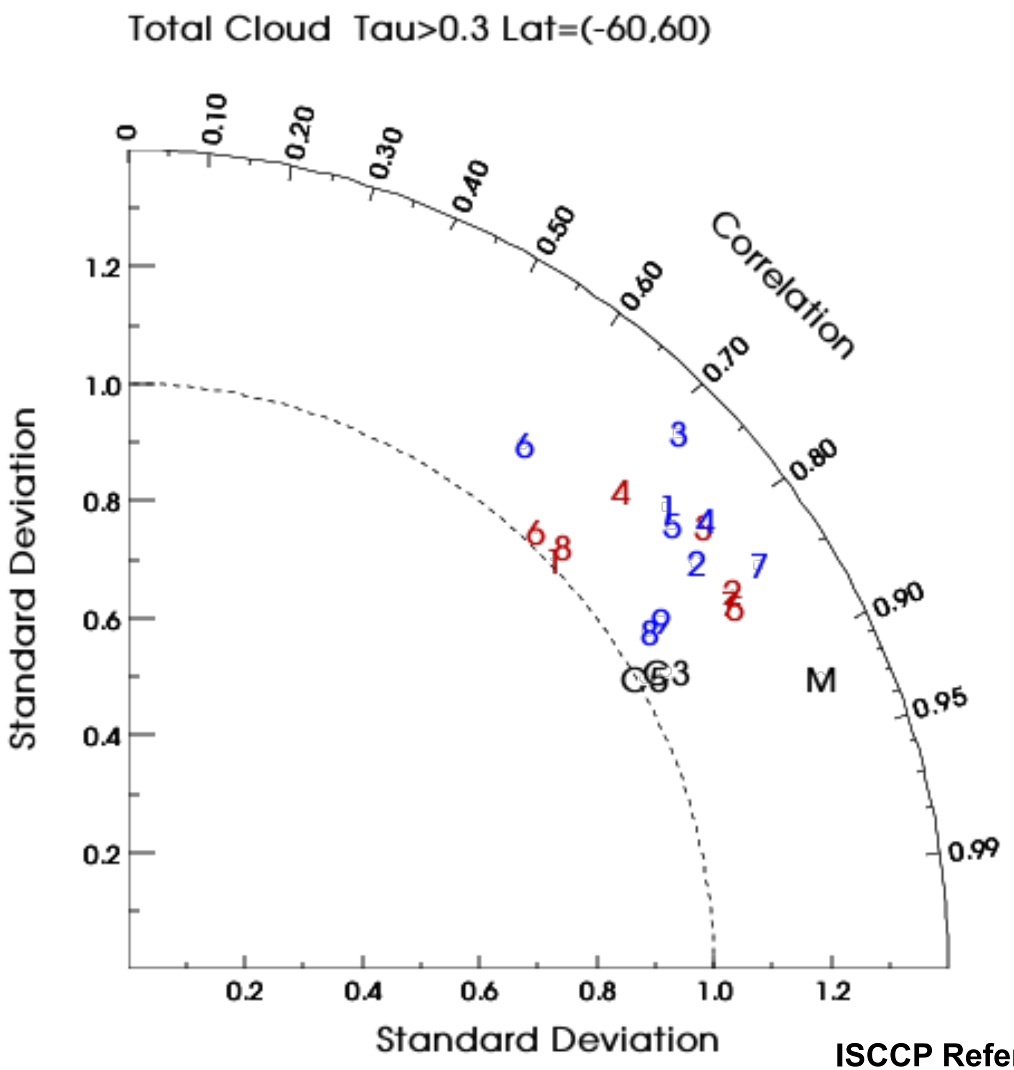
ISCCP Observations



CMIP5 – CMIP3



Total cloud fraction Taylor diagram



- *No marked difference in statistics between model ensembles*
- *Some models improve; some change little*
- *Statistics of multi-model mean superior to individual models*

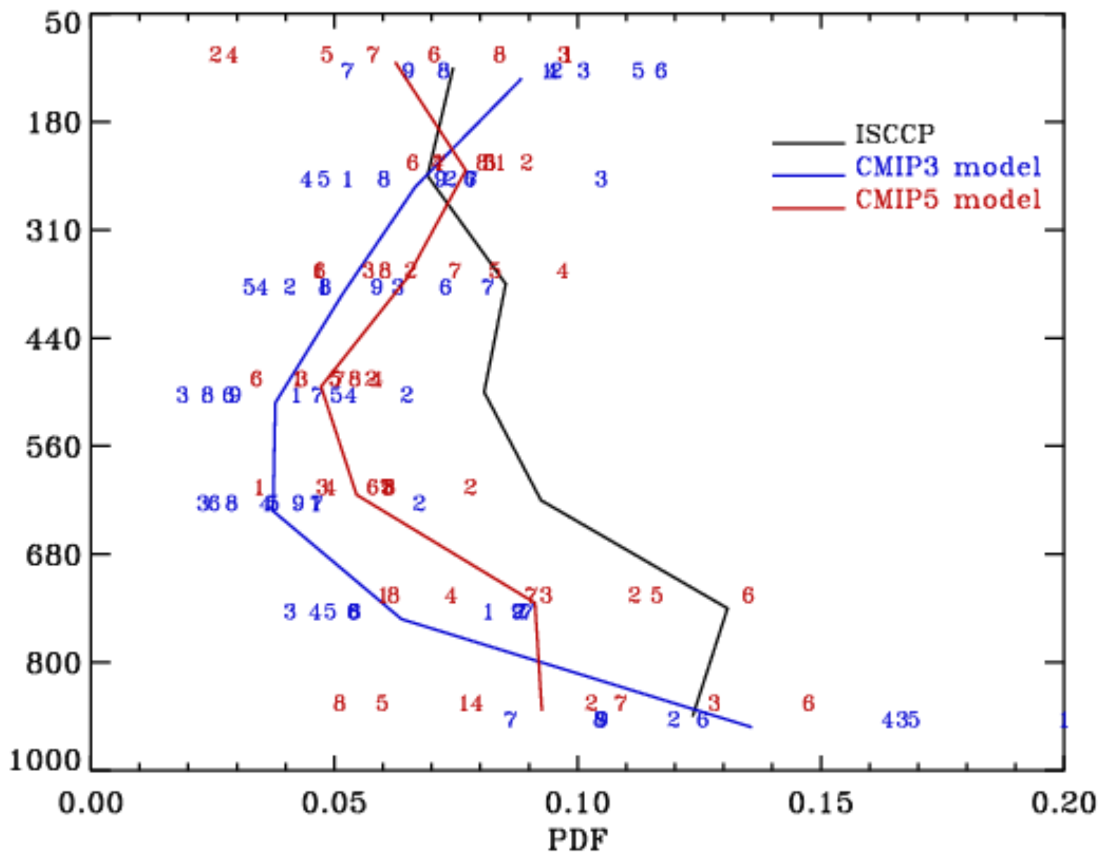
ISCCP Reference
M – MODIS
C3 - Mean_CMIP3
C5 - Mean_CMIP5

CMIP3 models
1 - cccma_agcm4_0
2 - gfdl_mlm2_1
3 - ipsl_cm4
4 - miroc_hisens
5 - miroc_losens
6 - ncar_ccsm3_0
7 - ukmo_hadgsm1
8 - ukmo_hadsm3
9 - ukmo_hadsm4

CMIP5 Models
1 - CAM4_amip
2 - CAM5_amip
3 - CanAM4_amip
4 - CNRM-CM5_amip
5 - HadGEM2-A_amip
6 - MIROC5_amip
7 - MPI-ESM-LR
8 – MRI-CGCM3

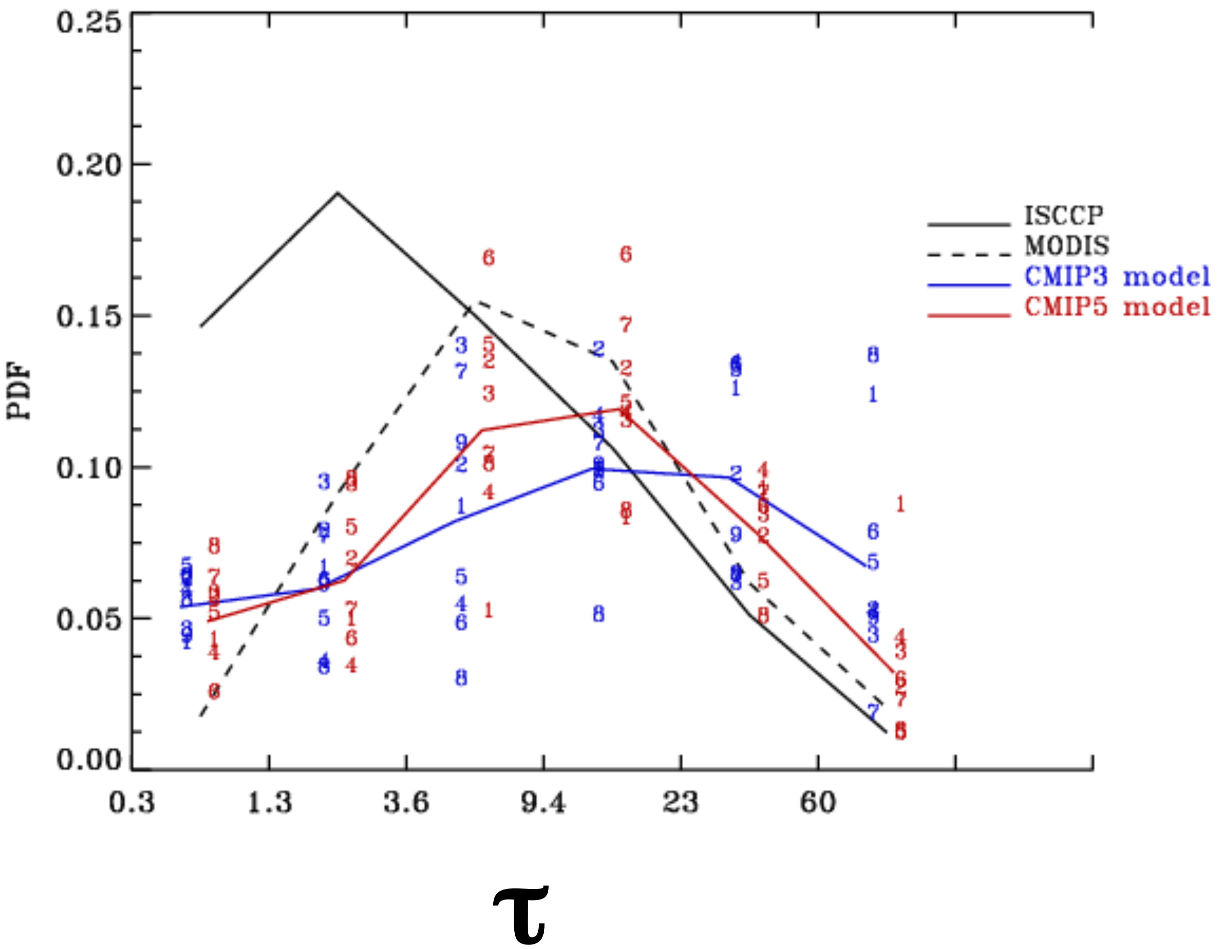
PDF of cloud-top pressure p_{ct}

P_{CT}
(hPa)



- *Models still have too few middle- and low-level clouds*
- *Improvement in the relative amount of the lowest two height bins may be result of ISCCP simulator change – as opposed to a real model change*

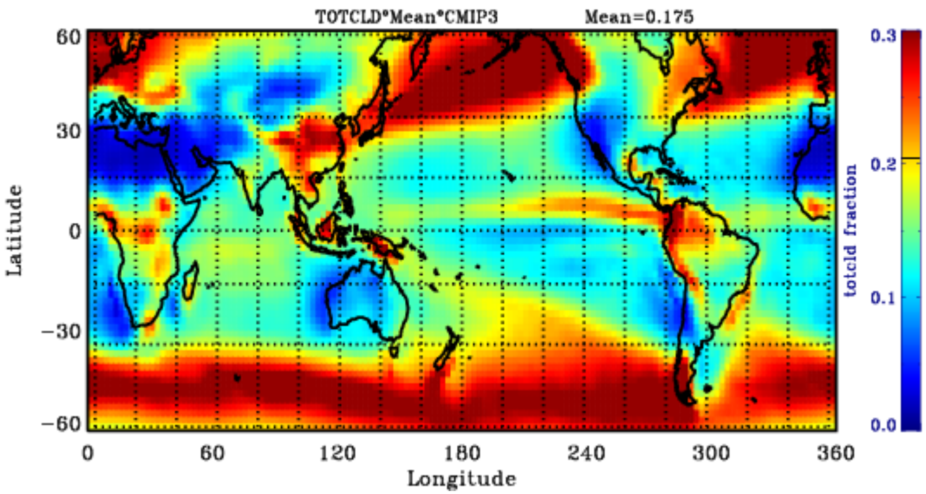
PDF of cloud optical depth τ



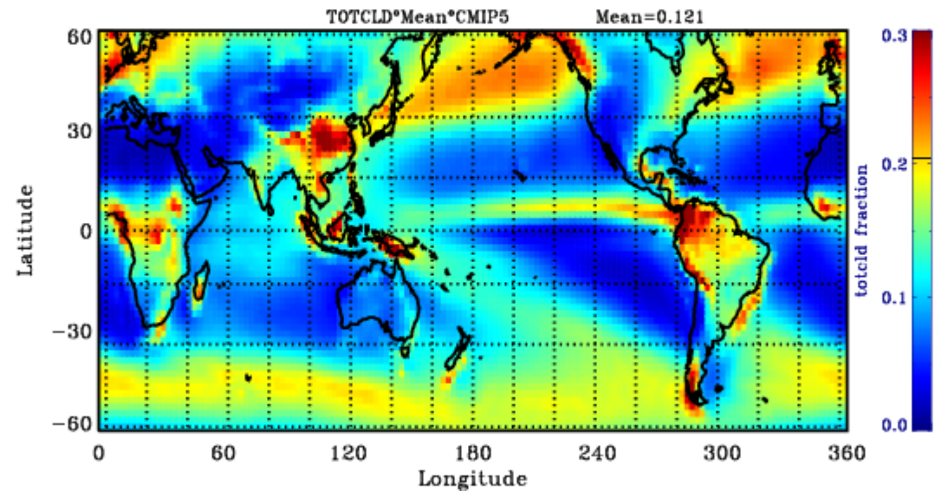
- *Marked improvement in optical thickness distribution with very significant reduction in the amount of clouds with τ > 23!*

Total cloud fraction (τ > 23)

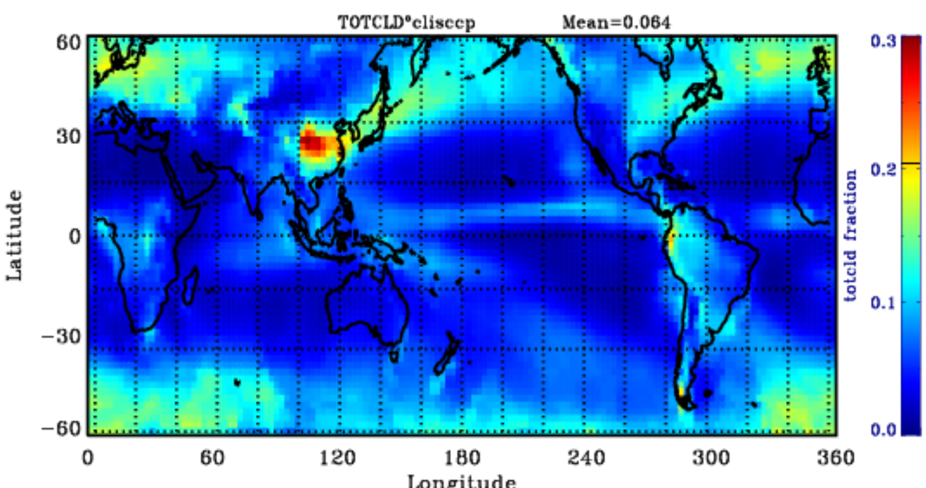
Mean CMIP3 Model



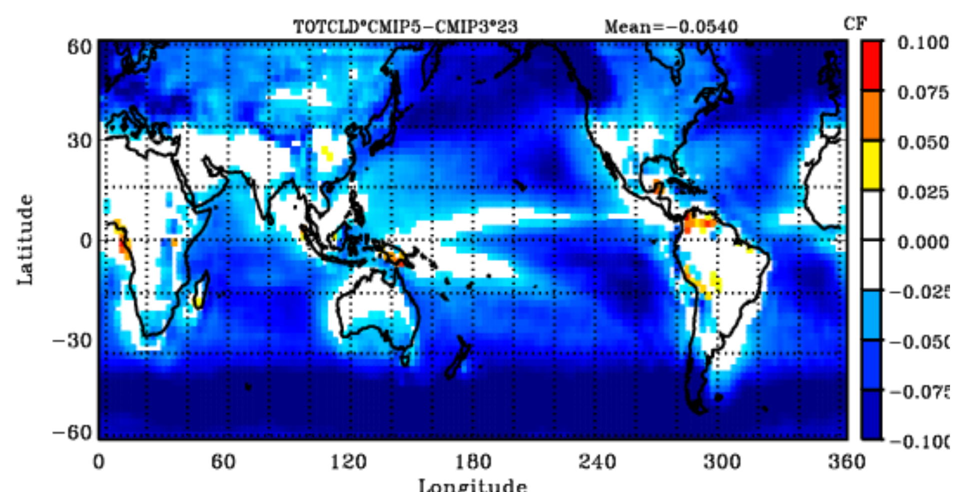
Mean CMIP5 Model



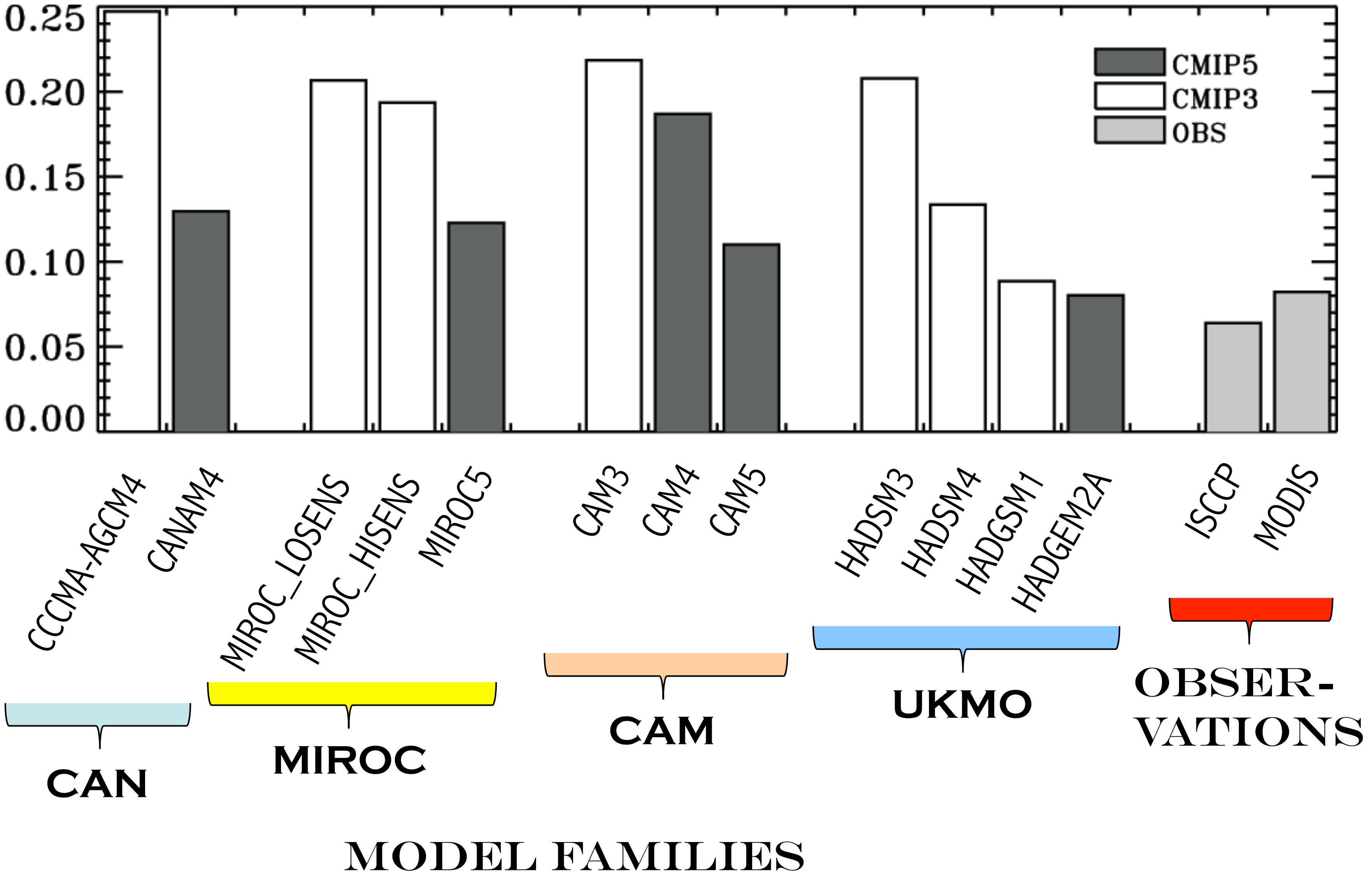
ISCCP Observations



CMIP5 – CMIP3



Area covered by clouds with τ > 23



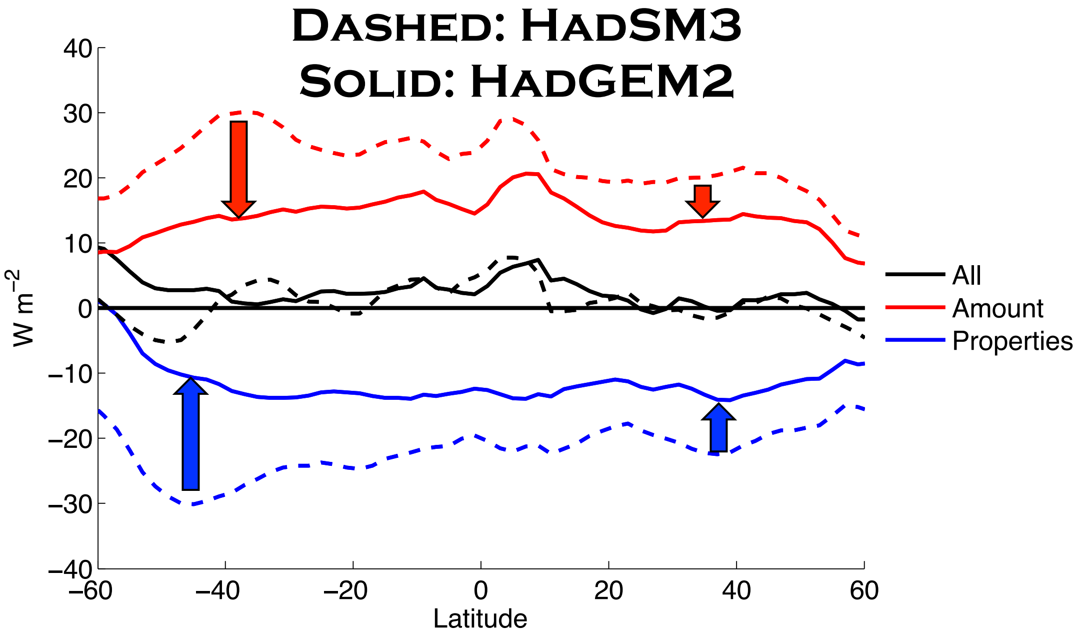
Radiative impact of cloud errors

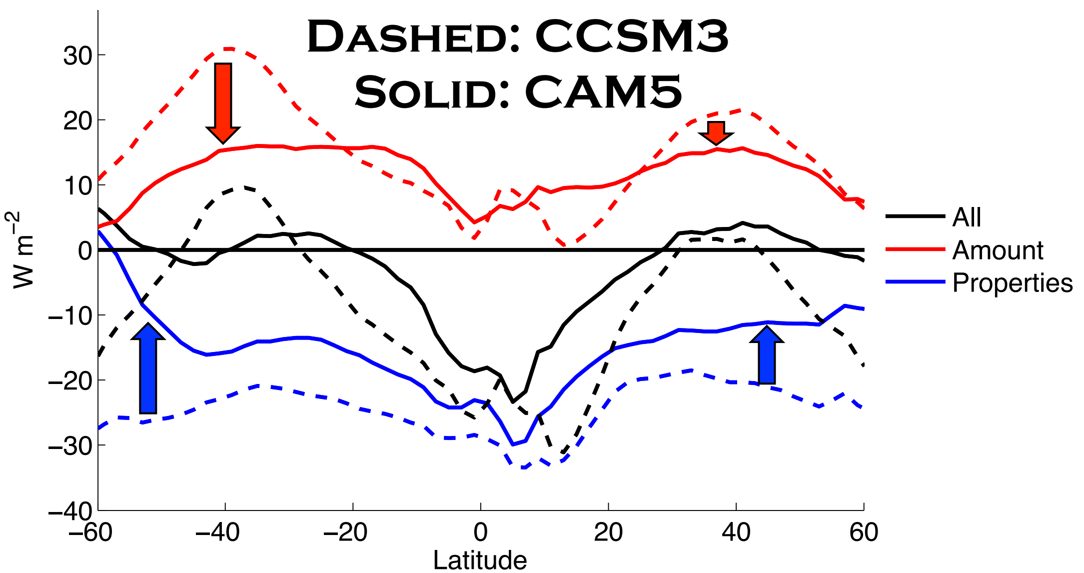
- Can we quantify the radiative impact of compensating errors in cloud amount and cloud properties (i.e., the "too-few / too-bright" problem)? *Yes!*
- Using cloud kernels *(Zelinka et al. 2012, in press)*, we quantify cloud amount and cloud property errors as:

Cloud amount error: The radiative impact of errors due models incorrectly simulating the total amount of clouds assuming that the model perfectly reproduces the observed relative distribution of cloud properties (τ & p_{ct})

Cloud property error: The radiative impact of errors due to models incorrectly simulating the cloud properties under the assumption that the model perfectly reproduces the observed total amount of clouds

Cloud-induced shortwave errors





- *For UKMO, the compensation between cloud amount and cloud property errors was reduced by 40-50%*
- *For CAM, the compensation reduction is concentrated in the middle-latitudes with reductions of 20-40%*

Conclusions

- Broadly speaking, the quality of cloud amount simulations in CMIP models is unchanged
  - Individual models may behave differently!
- However, there is a significant reduction of the overestimate of optically thick clouds, particularly for middle-latitude & subtropical low-level clouds.
  - Some models exhibit significantly less compensation of shortwave radiation errors resulting from errors in cloud amount and τ
- The reduction in τ may be the reason why optical depth feedbacks are more negative in CMIP5

Conclusions

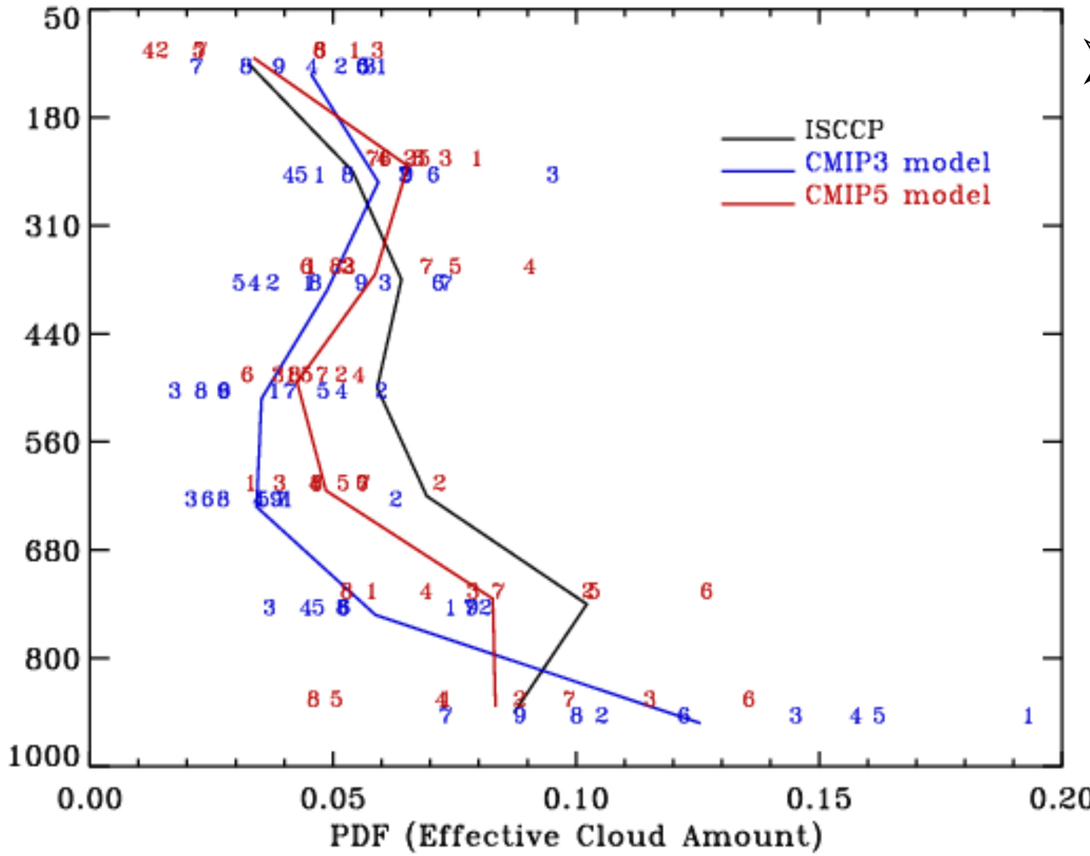
- Why is there improvement in the simulation of middle-latitude & subtropical (low-level) τ?
  - Better vertical / horizontal resolution?
  - Better microphysics?
  - Use of ISCCP simulator during model-development?
- Why not more progress?
  - Other priorities, such as aerosol-cloud interactions or carbon cycle
  - Limited number of people working on cloud parameterizations relative to problem difficulty
  - Climatological means not the only way to measure model progress

Thank you!

Extra slides

PDF of cloud-top pressure p_{ct} for emissivity-weighted cloud amount

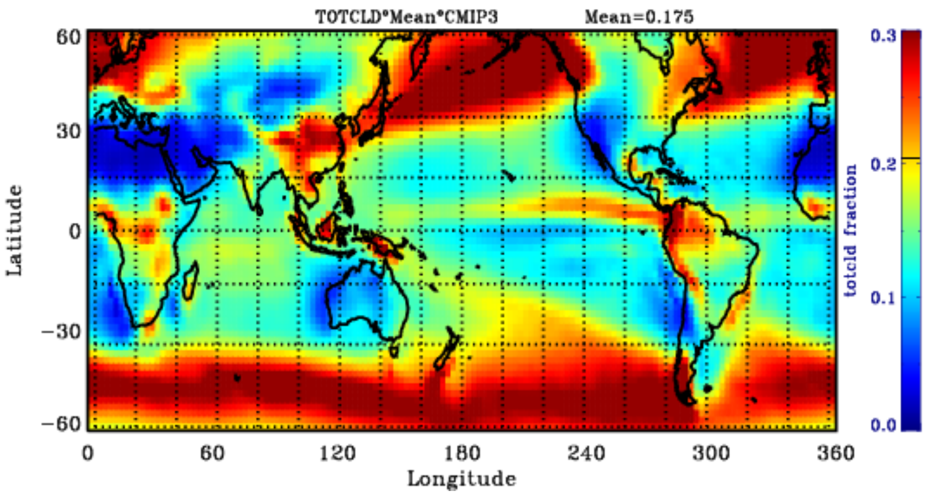
P_{CT} (hPa)



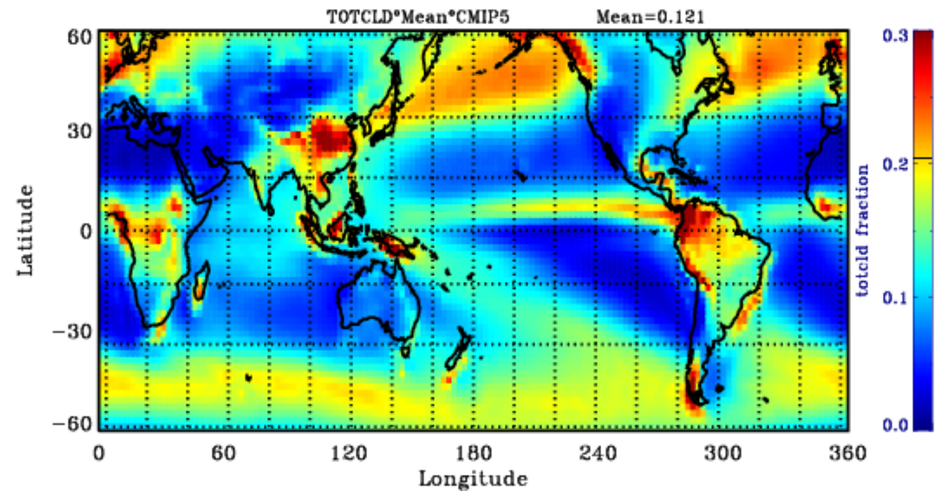
- *No sensitivity of conclusions regarding cloud-top pressure to whether you consider only LW radiatively active clouds*

Total cloud fraction ($\tau > 23$)

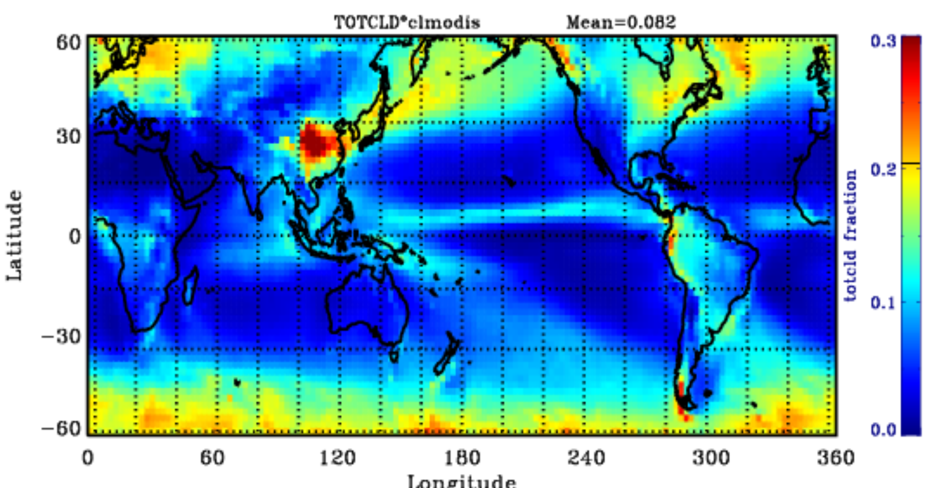
Mean CMIP3 Model



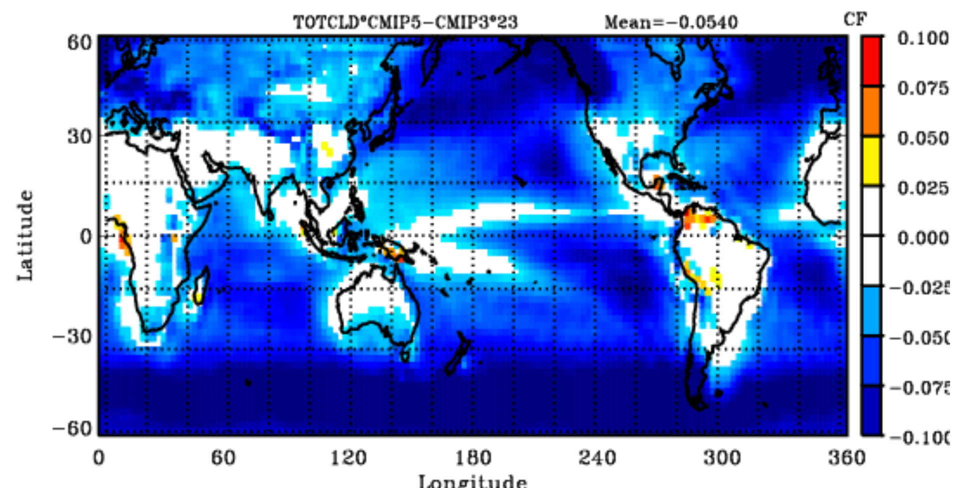
Mean CMIP5 Model



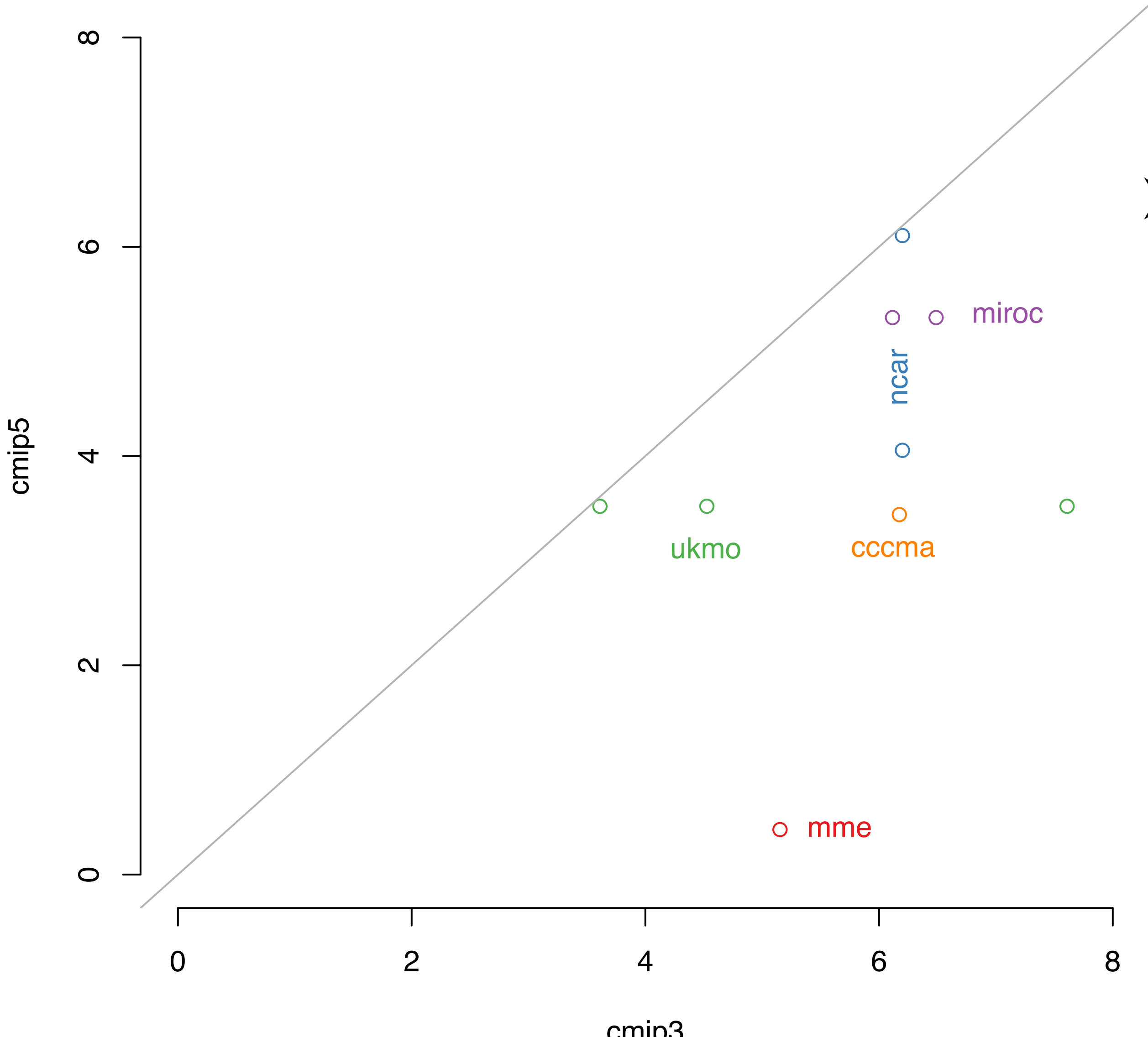
MODIS Observations



CMIP5 – CMIP3



Improvement in PDF of optical depth



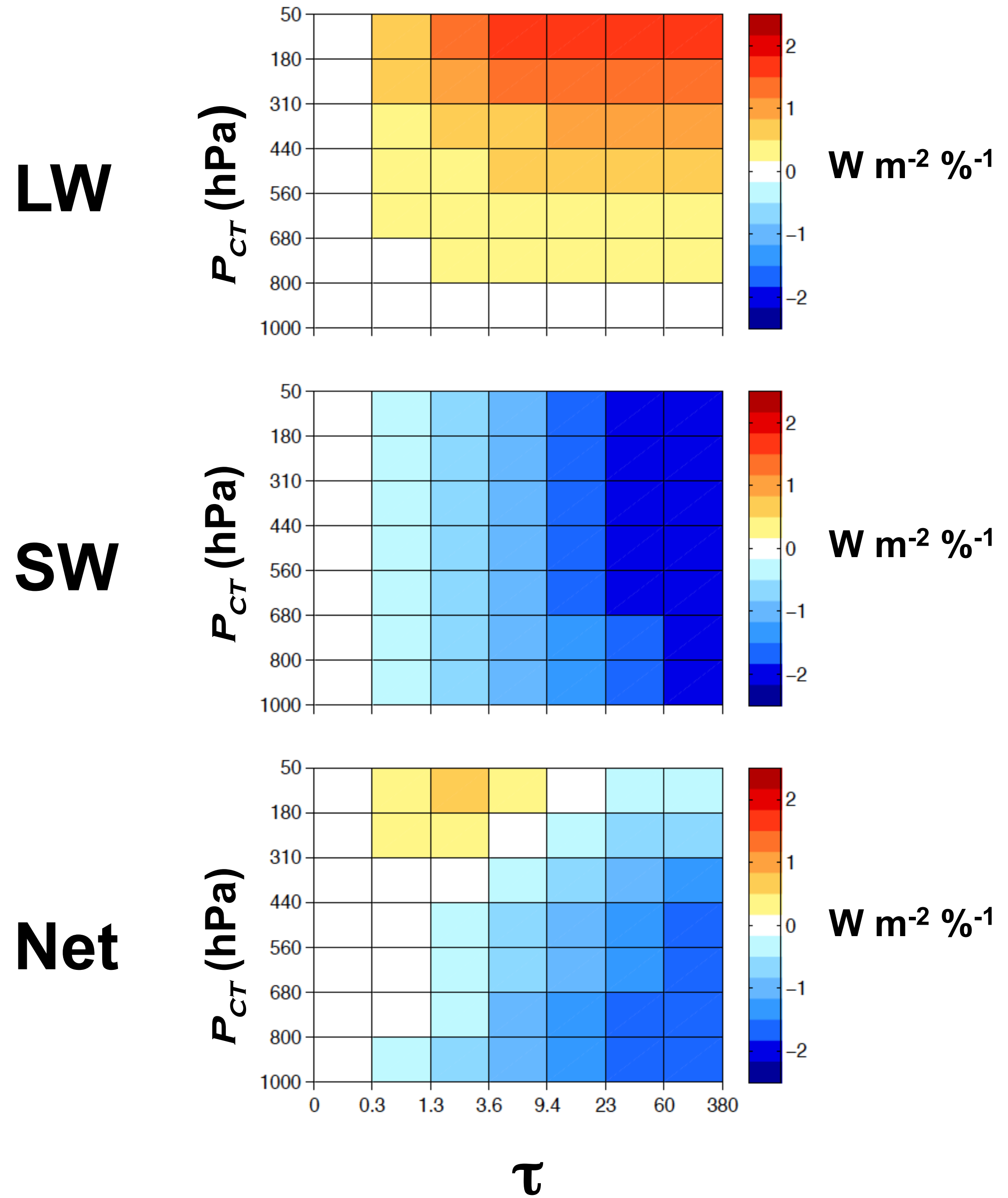
- *PDF error is computed as the root mean square difference in the 60N-60S area-averaged annual mean τ PDF for $\tau > 1.3$.*

Cloud Kernel Approach

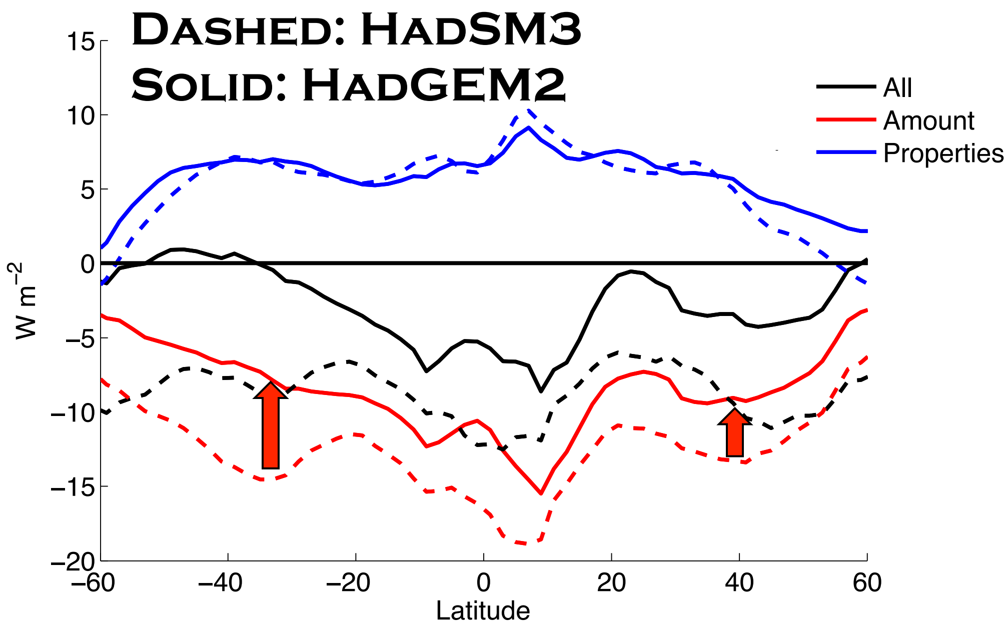
- Use an offline radiative transfer model to calculate the impact on TOA fluxes for each of the ISCCP 49 cloud types as a function of month, latitude, longitude, and surface albedo

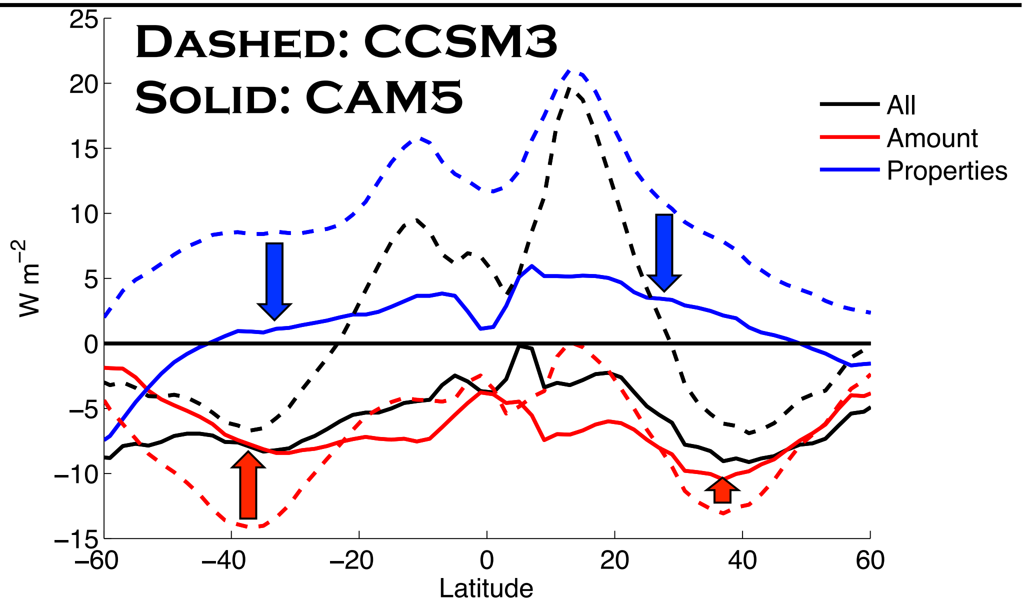
- These kernels $K(\tau, P_{CT}, LAT, LON, MONTH, \alpha_S)$ can be multiplied by monthly mean ISCCP simulator output to give you the radiative impact on each cloud type change

Global Annual Mean Cloud Kernels



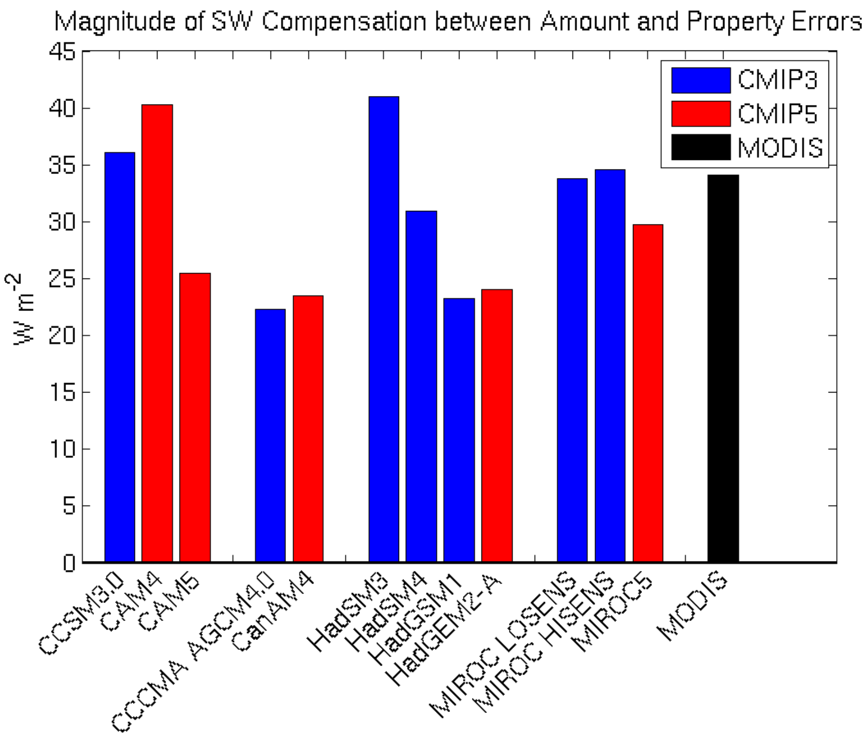
Cloud-induced longwave errors

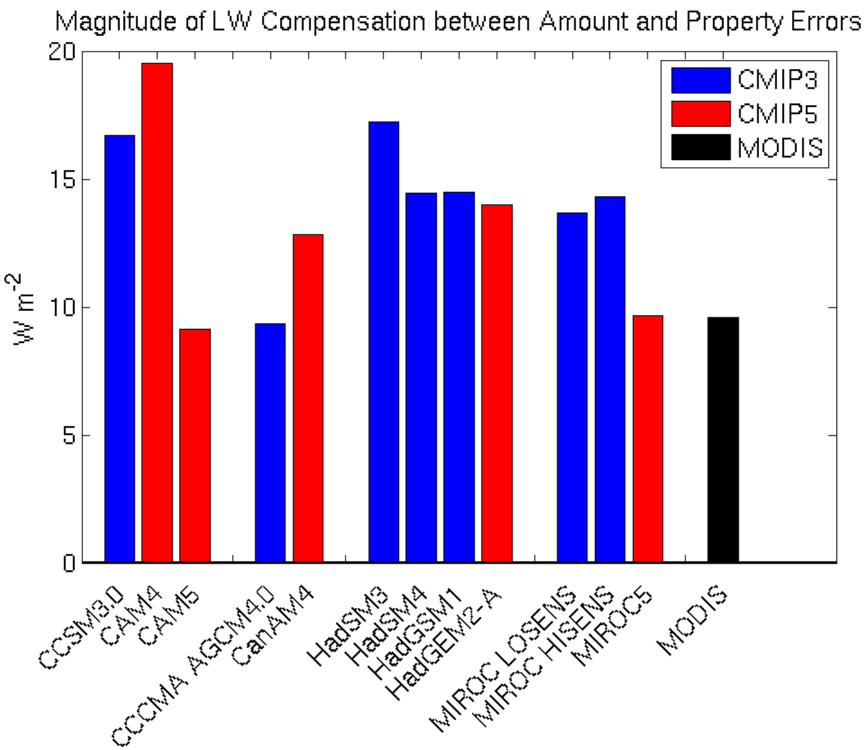




- For UKMO, only cloud amount errors were reduced
- For CAM, the compensation reduction is largest at middle-latitudes with bigger reductions of cloud property errors (at all latitudes)

Compensating errors in model families





- *Errors are calculated as the absolute value of the difference between the cloud amount and cloud optical property errors*

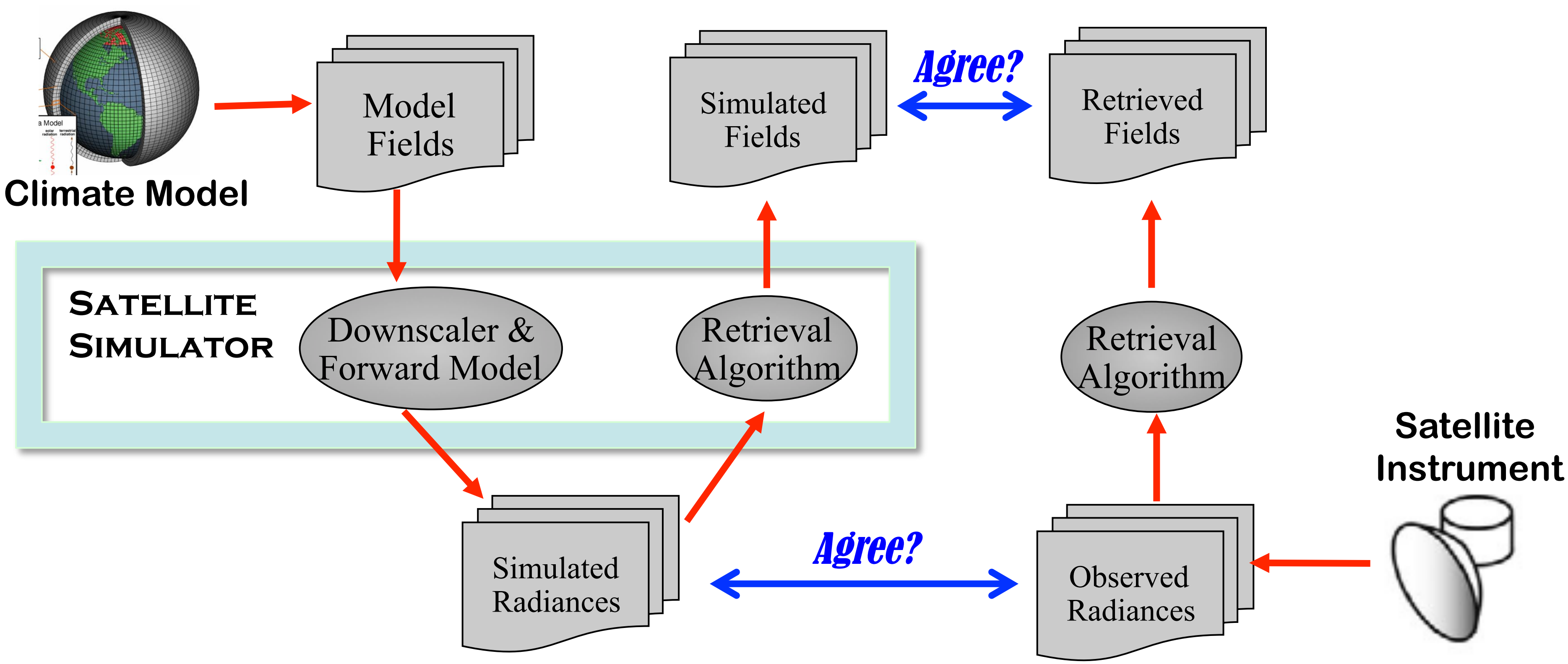
Why "satellite simulators" for clouds?

- Diagnosing cloud processes in climate models with observations is difficult and fraught with issues
  - Correspondence of model quantities to available observations
  - Limitations of satellite observations
  - Scale of model grids (~100 km) vs. satellite pixels (~1 km)

- Simulators reduce the effects of these issues in order that comparisons between models and observations more likely are an evaluation of the model

- The simulator is a piece of diagnostic code that mimics the observational process by converting model variables into pseudo-satellite observations
  - *What would a satellite see if the atmosphere had the clouds of a climate model?*

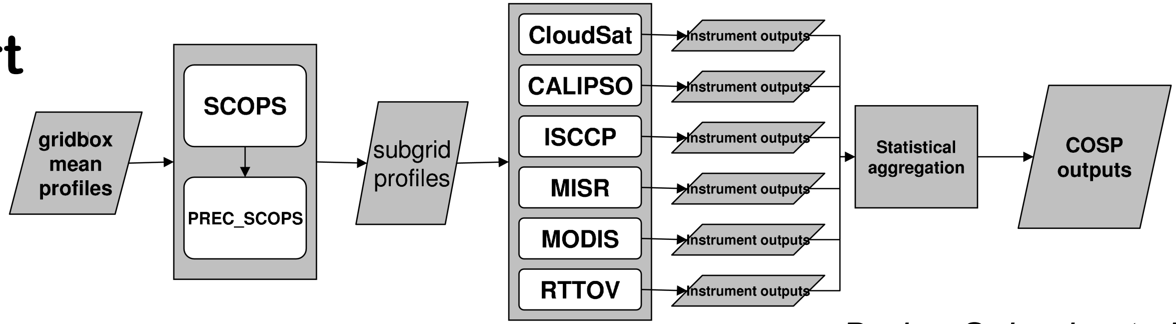
Simulator conceptual diagram



- A simulator addresses issues of
  - Cloud overlap (column-integrated τ and cloud-top pressure p_{ct} of the high cloud in the column)
  - Detection thresholds (τ >= 0.3, dBZ > -25, SR > 5)
  - Retrieval characteristics (different ways to calculate p_{ct})

CFMIP Observation Simulator Package

COSP Flow Chart



Bodas-Salcedo et al. (2011)

- About 5 years ago, the CFMIP community came together to form a community software package of simulators
- COSP has simulators for 5 satellite cloud products
  - ISCCP, MISR, MODIS, CloudSat, Calipso
- All major climate models use COSP
  - Also used in global models with very-high resolution (~10 km)
  - Most have put the code in-line to their model
- A matching set of observations for each simulator has been specially prepared in ESG compatible format