Towards more realistic LW coupling between surface and atmosphere in the E3SM: impact on simulated polar biases

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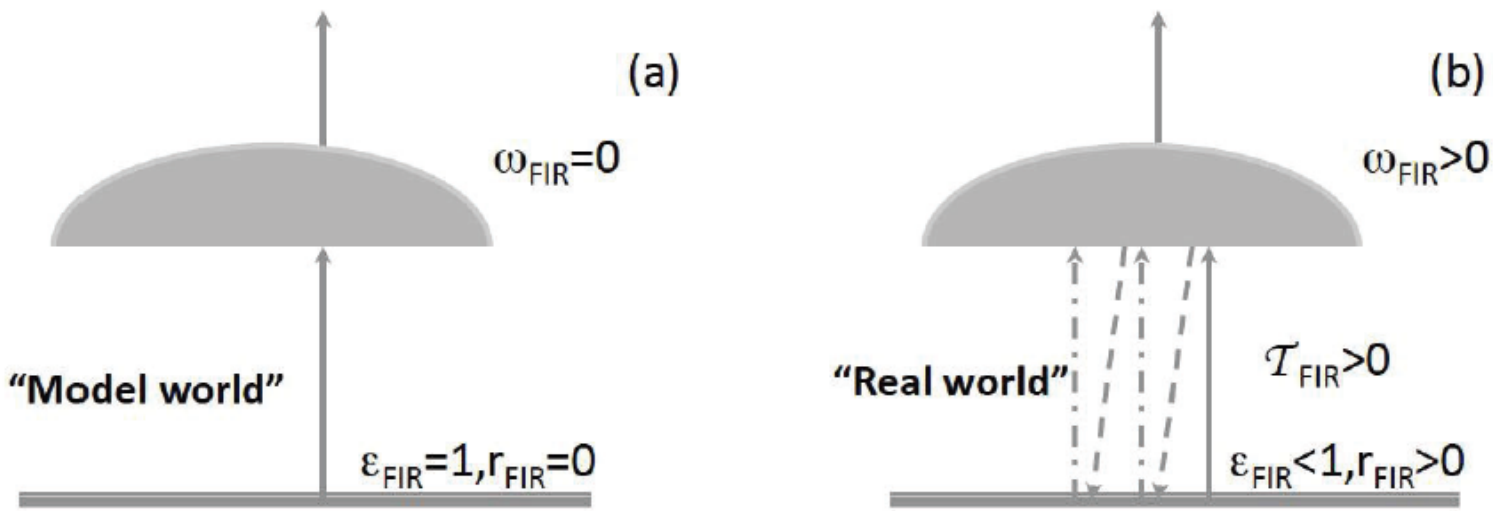
LW coupling: A missing physics in all GCMs/ESMs



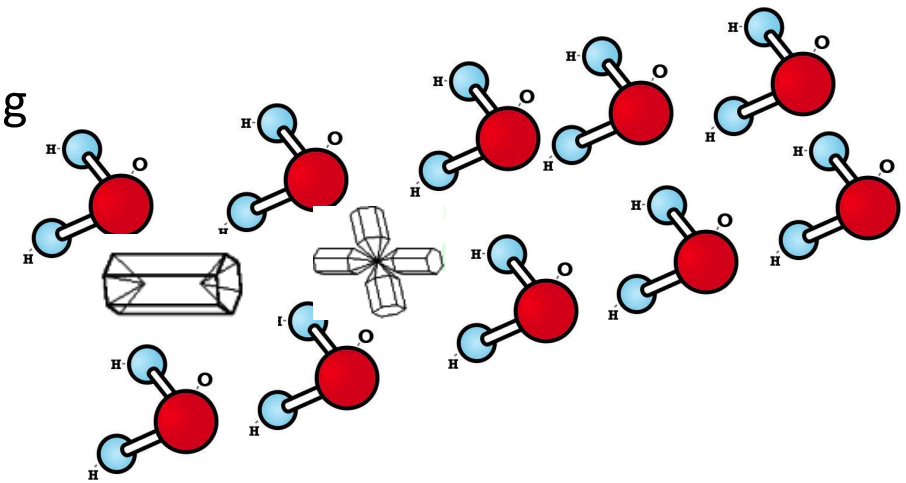
(Chen et al., 2014, GRL)

Premise: Reflective surface and scattering clouds➔IR photons scattered around➔more chance to be absorbed➔increased atmospheric absorption

To what extent does this matter?

It won't matter if

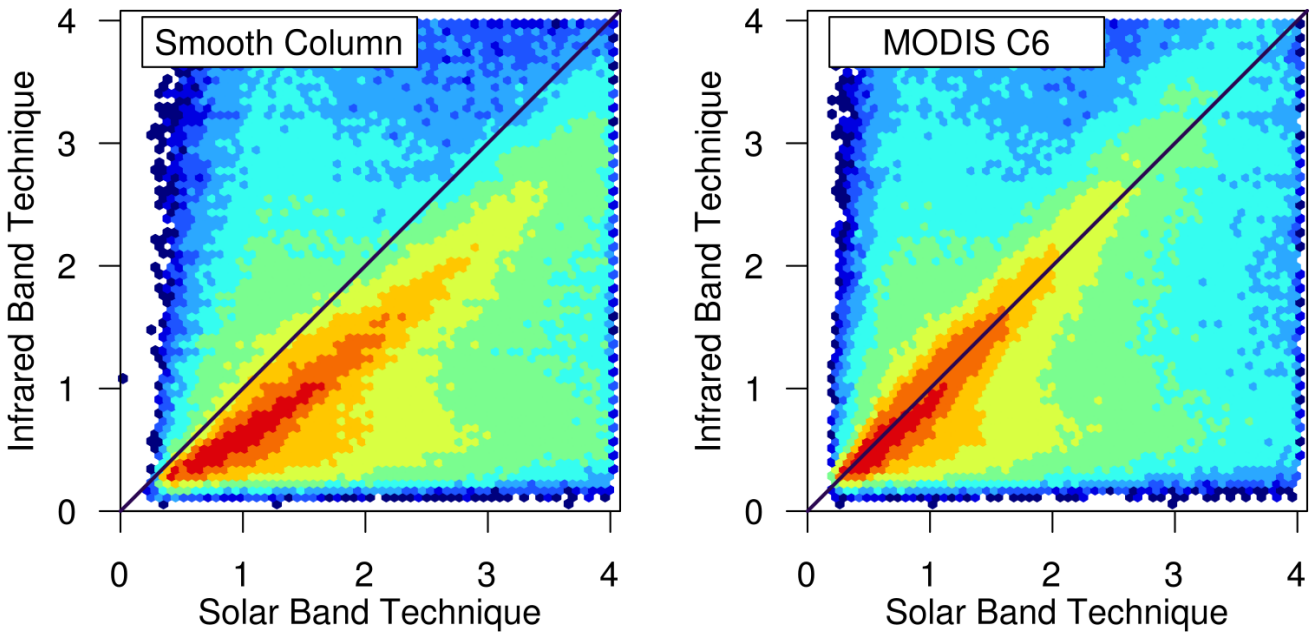
- Gaseous absorption is strong



- Ice scattering is not strong
  - But ice cloud scattering has a peak at the far-IR
  - Usually H_2O absorption is too strong to make this ice scattering a concern
  - But in polar region
    - TPW is small enough: weaker absorption from water vapor
    - Ice scattering starts to be important
  - CESM/E3SM cannot test this mechanism due to LW ice cloud scheme
    - Only parameterize cloud emissivity
    - Using different assumption from SW ice cloud scheme

New ice-cloud optics: MC6 ice model

- MC6: MODIS Collection 6 adopted the same model in their retrievals
- It achieves spectral consistency between retrievals based on solar bands and the counterparts based on thermal infrared bands
- Compare to current scheme in E3SM: smaller Q_{ext} in LW



What have we done so far

- Branch out from E3SM v1
- Put into MC6 ice cloud optics
- Modified RRTMG to have 2-stream solver for LW
- Put into surface emissivity, making it a prognostic variable for sea ice/snow/water
  - Prescribed over other land surfaces
- Initial assessment with fully-coupled run
  - AMIP run cannot reflect the LW atmosphere-surface coupling
  - Two runs to check against E3SM DECK v1
    - MC6 + non_scat
    - MC6 + scat

Summary

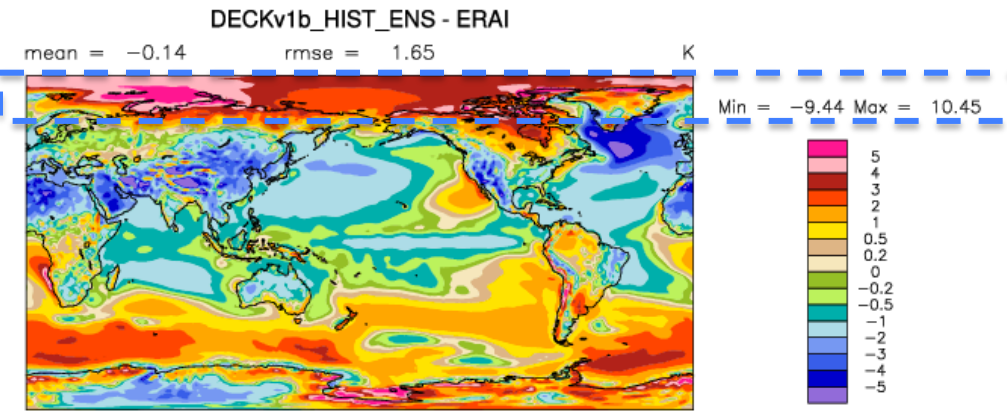
- Arctic
  - Cloud fraction biases are similar in DECKv1, noScat and Scat.
  - Scat reduces the warm bias in surface air temp in DECKv1, making it a small cold bias compared to OBS. This cold bias should be reduced when surface emissivity is included in the run.
- Antarctic
  - DECKv1, Scat, and noScat have similar biases in surface air temp, OLR, cloud fraction, etc.
- Tropics
  - DECKv1 has a positive bias in OLR over the ITCZ, which is likely due to underestimated cloud fraction. Either the inclusion of MC6 or scattering has little impact on cloud fraction thus little on the OLR bias too.

	DECKv1 - OBS	noScat - OBS	Scat - OBS	Scat - noScat
Arctic				
Surface air temp	++, esp DJF	--, esp DJF	-, ANN	+, esp DJF
Surf LW↓	+, esp JJA	-, DJF	=, + in JJA, - in DJF	+, esp DJF
Clrsky Surf LW↓	=	-, esp DJF	-, ANN	+, esp DJF
OLR	-, esp DJF	-, ANN	-, ANN	+, esp DJF
Clear-sky OLR	+, esp DJF	-, esp DJF	=	+, esp DJF
Cloud fraction	+ in low & high clouds, ANN	+ in low & high clouds, ANN	+ in low & high clouds, ANN	=
TOA LWCF	+, ANN	+ in JJA - in DJF	+, esp JJA	+, esp DJF

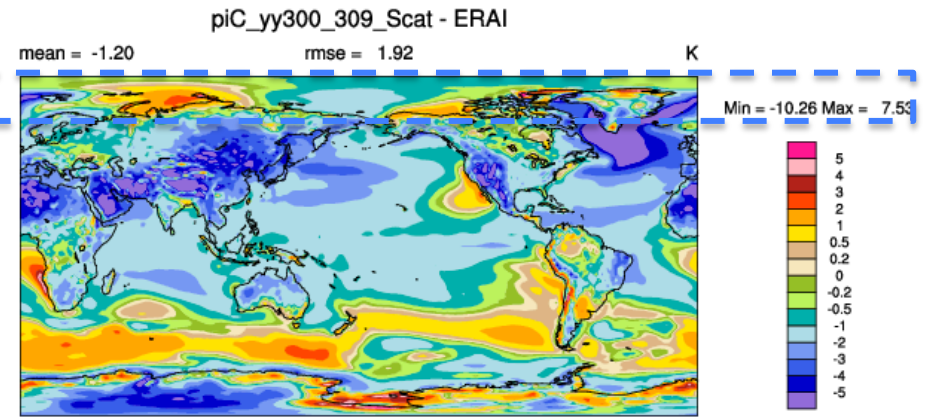
- DECKv1 has a negative bias in the OLR, which is probably due to too much high clouds. MC6 and scattering seem to have similar bias in cloud fraction.

Surface air temperature

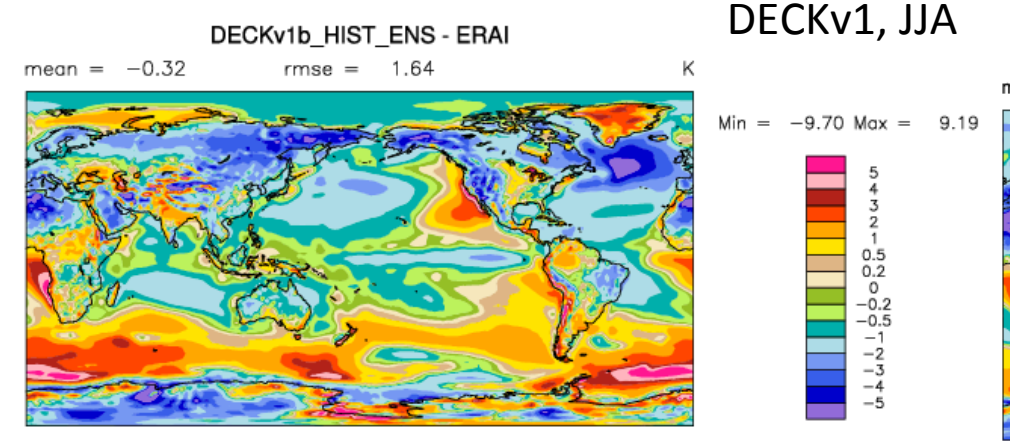
DECKv1, ANN



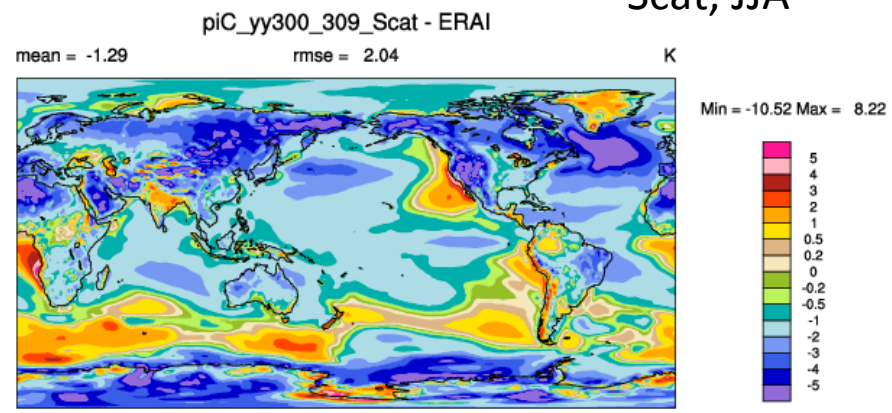
Scat, ANN



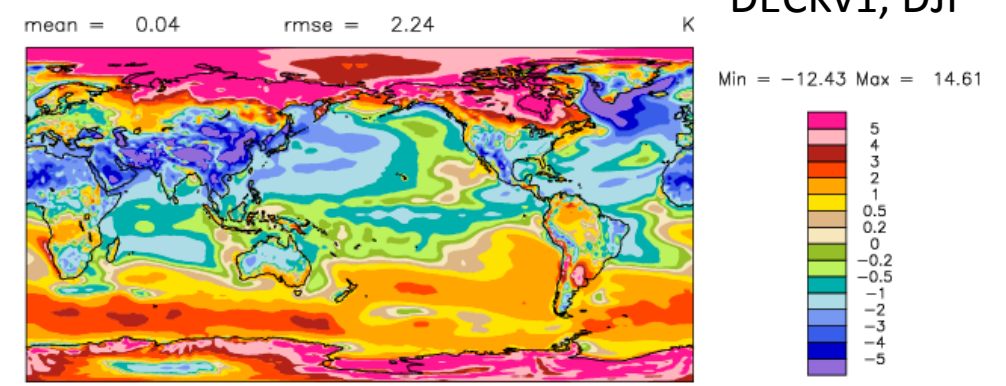
DECKv1, JJA



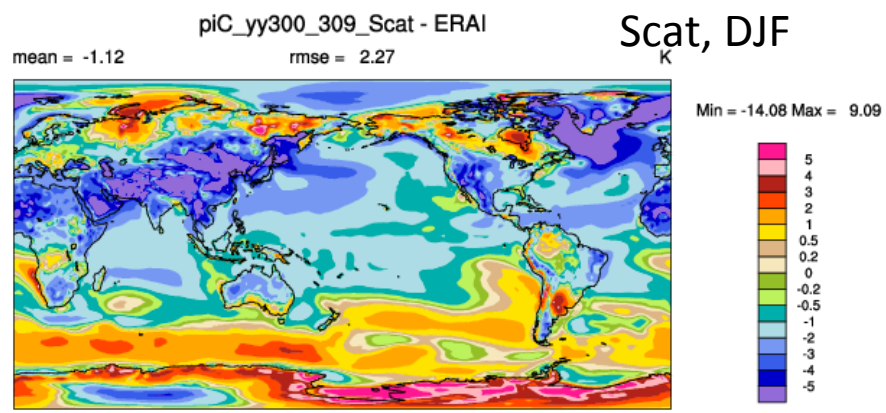
Scat, JJA



DECKv1, DJF



Scat, DJF

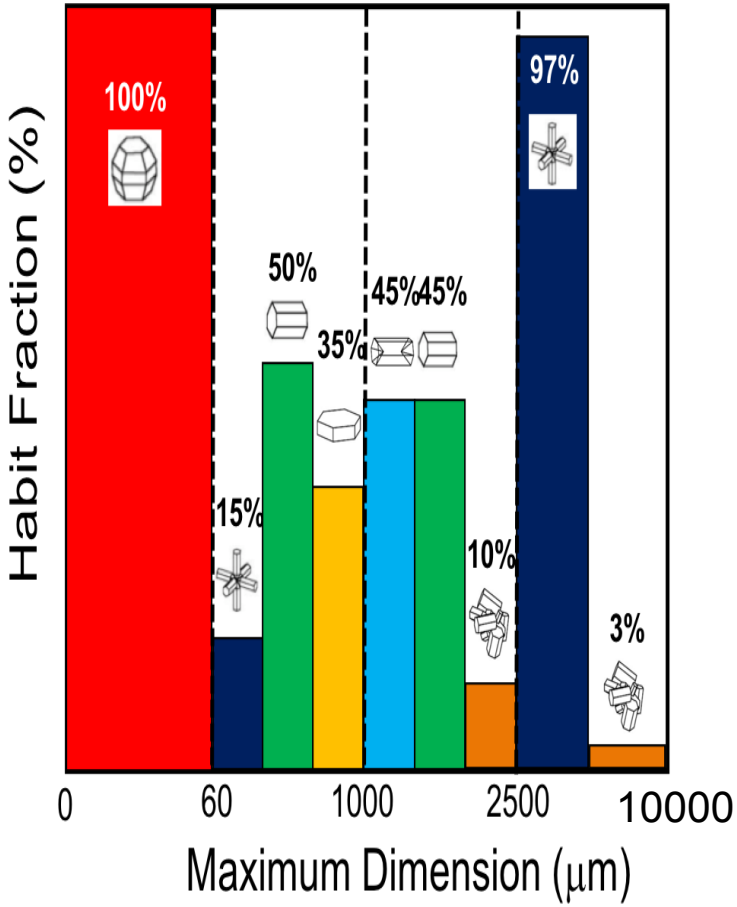


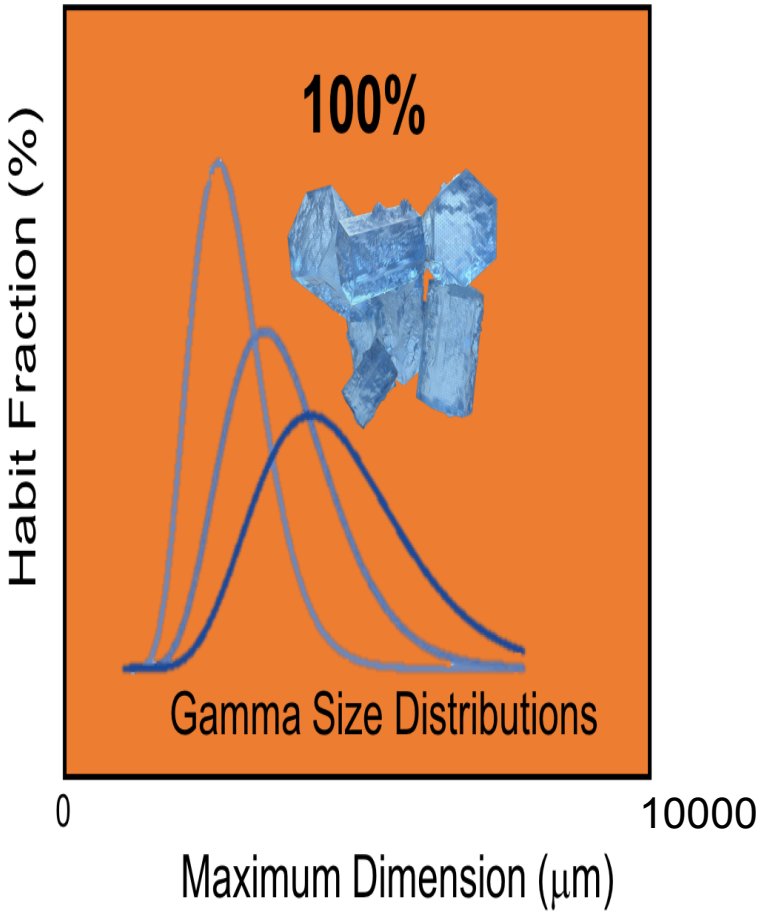
	DECKv1 - OBS	noScat - OBS	Scat - OBS	Scat - noScat
Antarctic				
Surface air temp	-, JJA +, DJF	-, JJA +, DJF	-, JJA +, DJF	+, ANN
Surf LW↓	-, esp JJA	-, esp JJA	-, esp JJA	+, esp DJF
Clrsky Surf LW↓	-, in JJA	-, esp JJA	-, esp JJA	+, esp DJF
OLR	=	=	=	=
Clear-sky OLR	- in JJA + in DJF	- in JJA + in DJF	- in JJA + in DJF	+, esp DJF
Cloud fraction	+ in middle & high clouds, ANN	+ in middle clouds, ANN	+ in middle & high clouds, ANN	=
TOA LWCF	- in JJA + in DJF	- in JJA + in DJF	- in JJA + in DJF	=

- E3SM DECKv1, noScat, and Scat have similar biases in surface air temp, Surf LW↓, cloud fraction, etc.

Backup slides

MODIS Ice Particle Models (Collections 5 & 6)

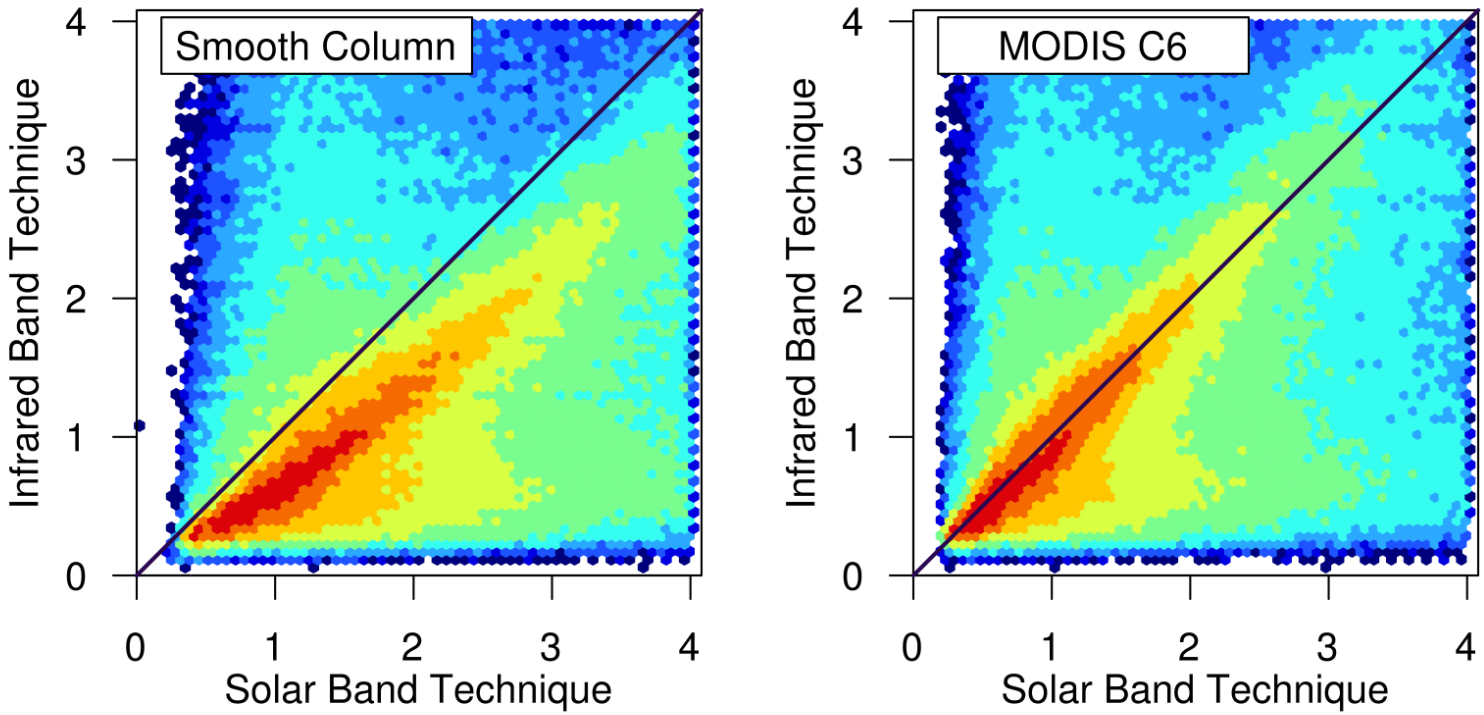




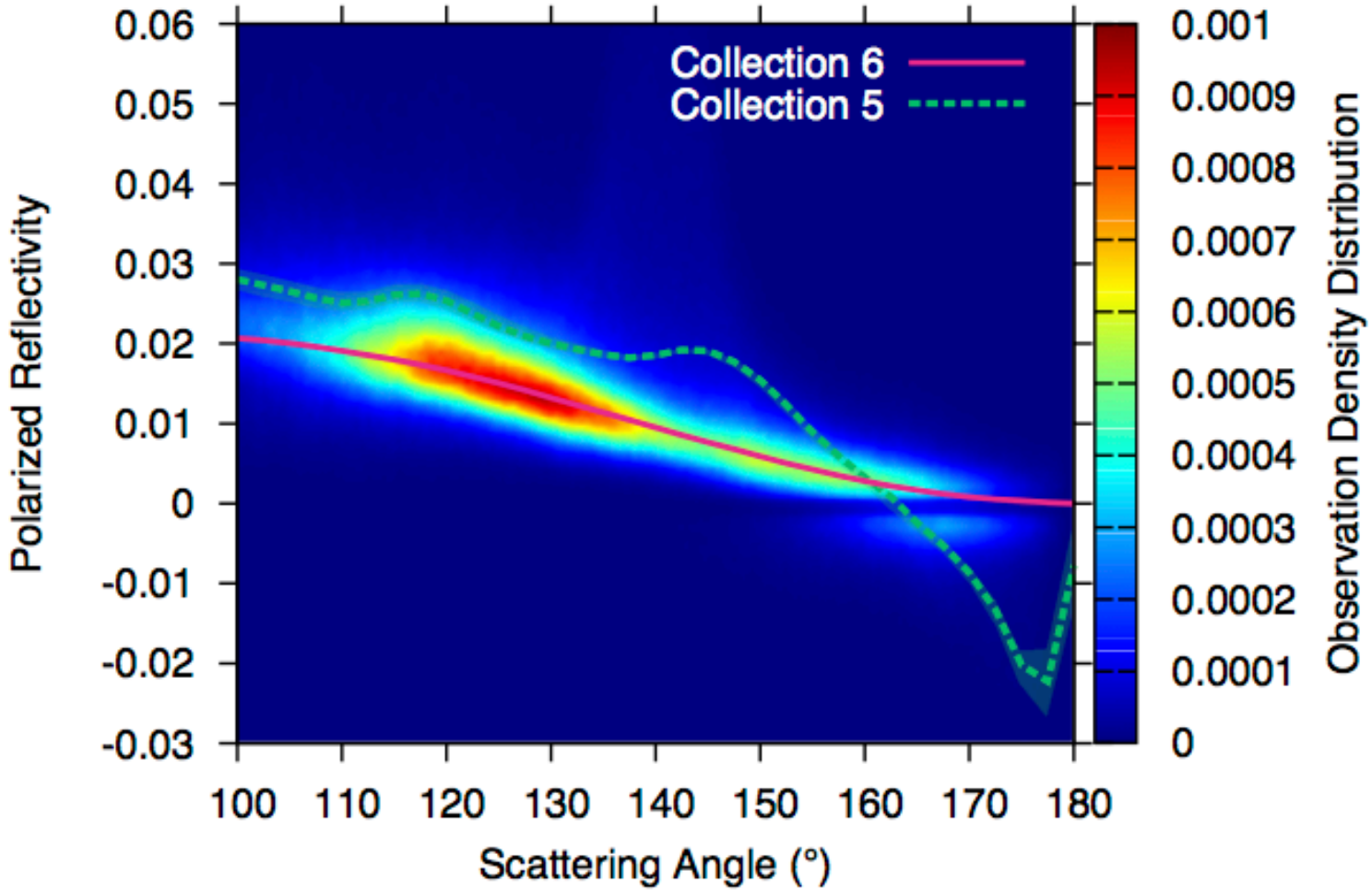
MODIS C6 model achieves spectral consistency between retrievals based on solar bands and the counterparts based on thermal infrared bands

Left panel: a smooth ice crystal model

Right panel: MODIS C6 model



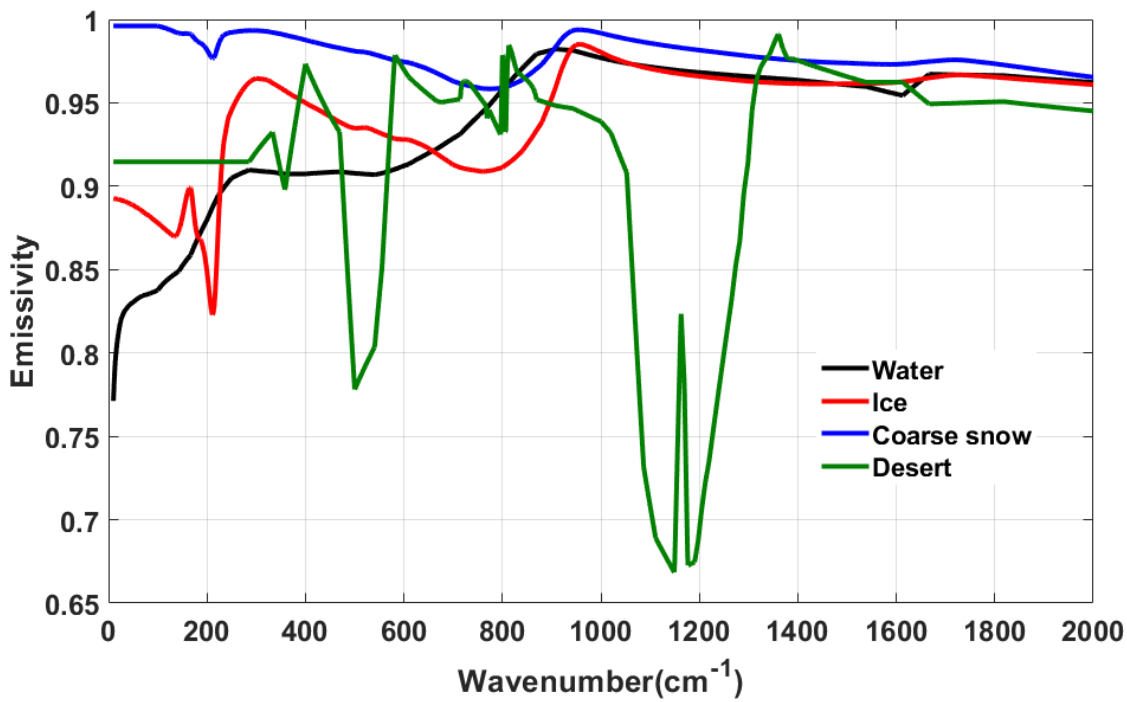
MODIS C6 Ice Model leads to polarization consistency with observation

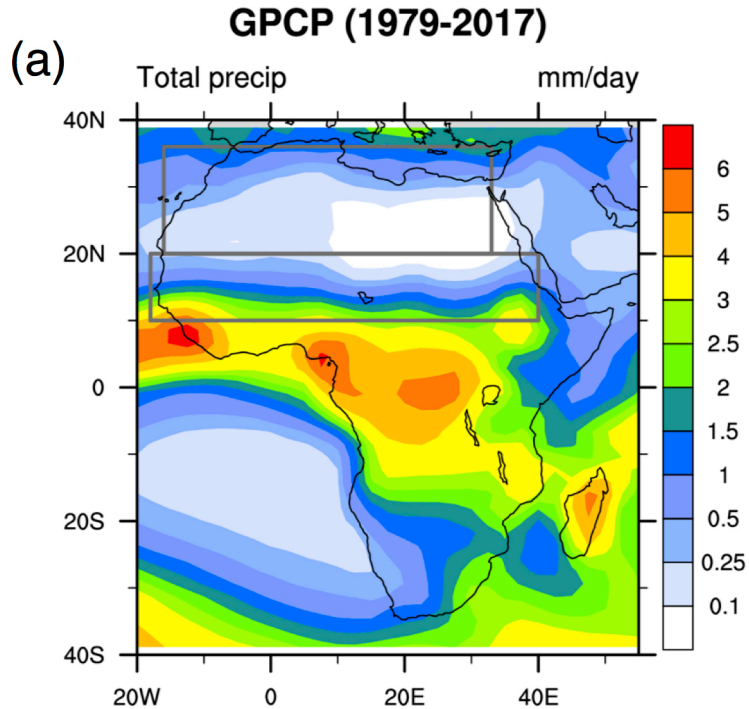


Observation density distribution of polarized reflectivity from the POLDER sensor and the theoretical prediction (MODIS Collections 5 and 6). Data are collected from cold ice clouds over Western Pacific in September 2005 ($BT_{31} < 208$ K).

It won't matter if

- Surface emissivity is close to one
  - *Having broadband surface emissivity is not enough because atmospheric R.T. is spectrally dependent*

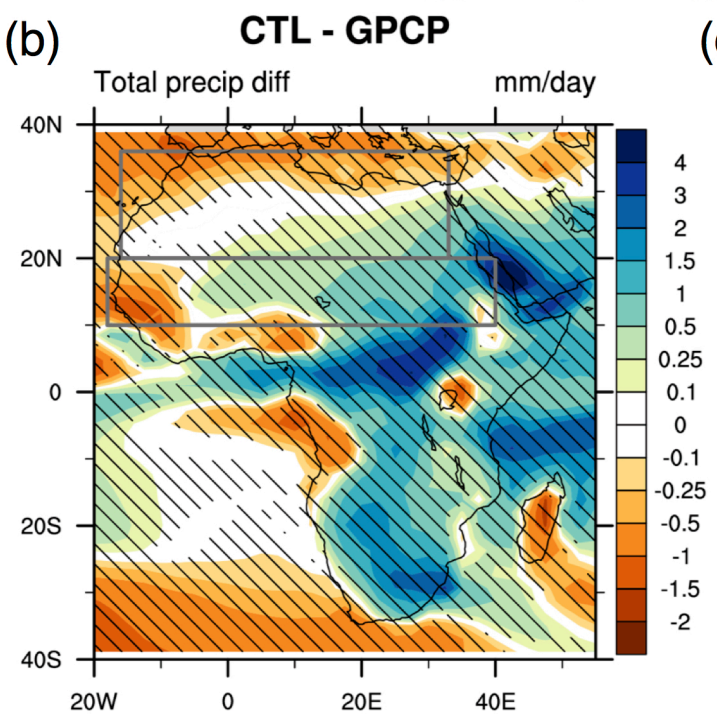


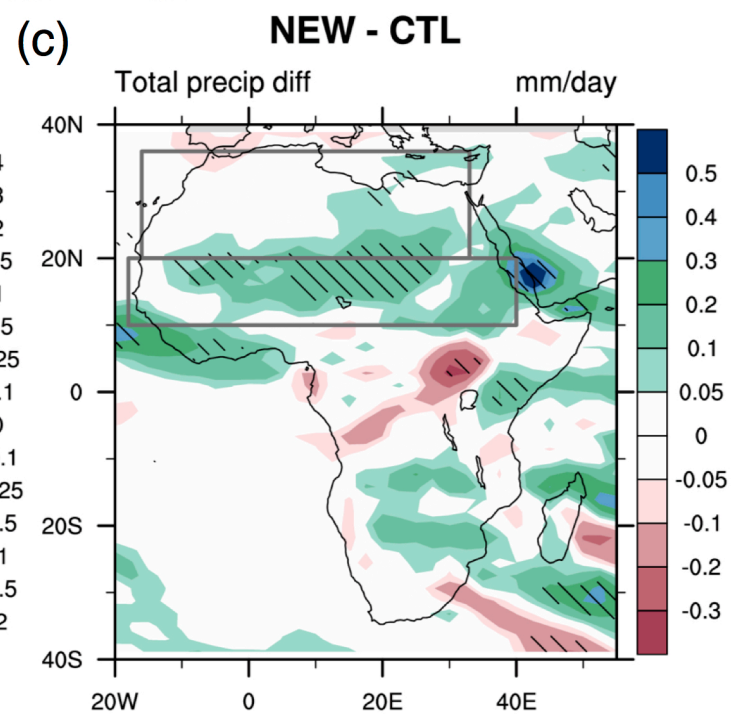


Changing emissivity alone can affect precipitation by

- Increase local evaporation
- Affect moisture convergence

Results based on the CESM 1.1

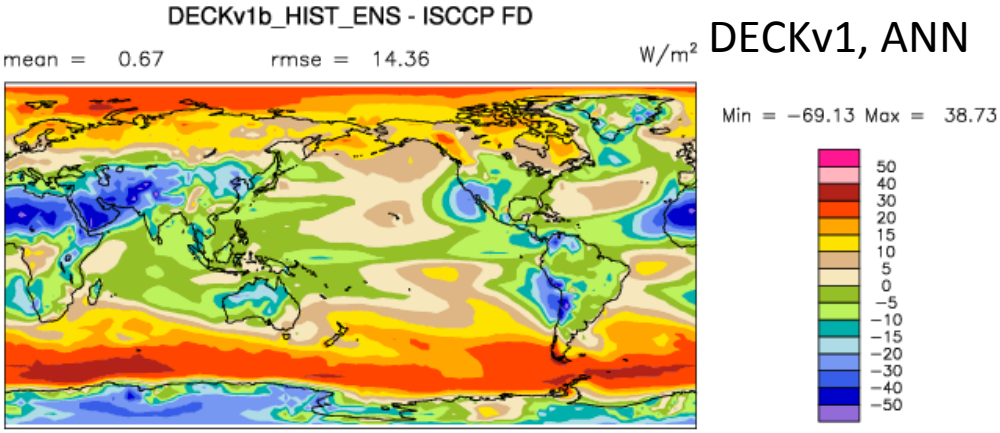




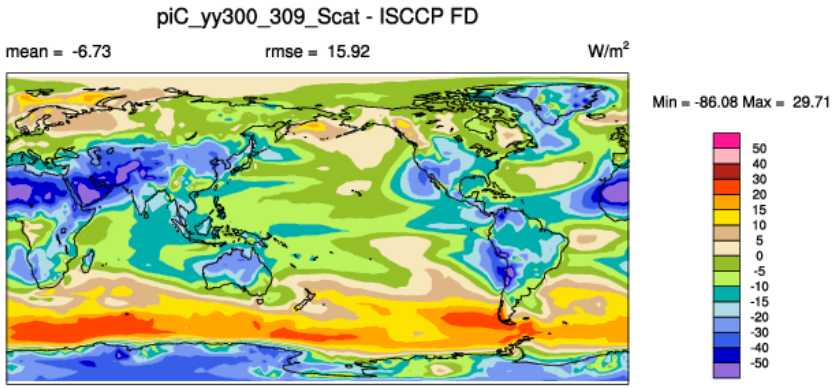
(Chen et al., under revision)

Surface downward LW flux

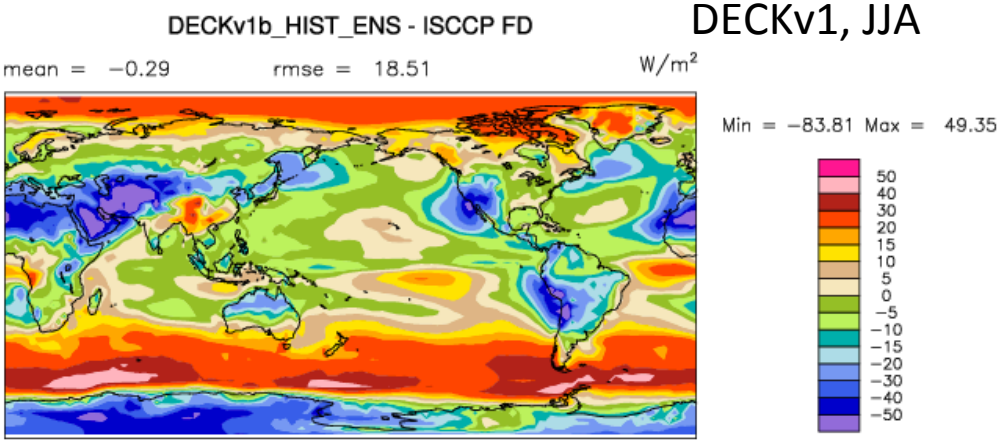
DECKv1, ANN



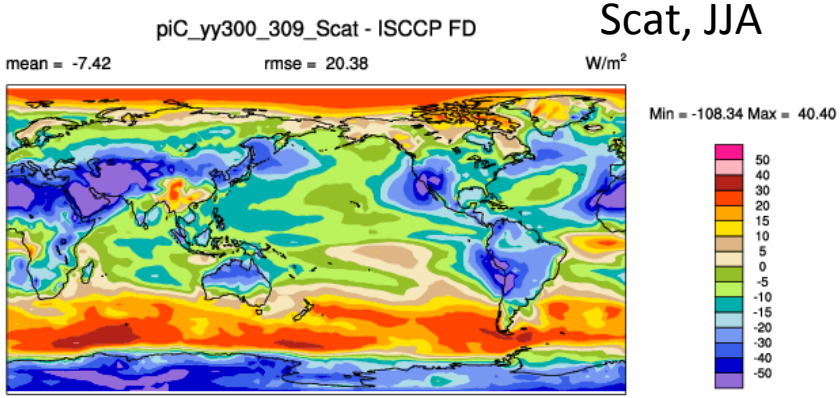
Scat, ANN



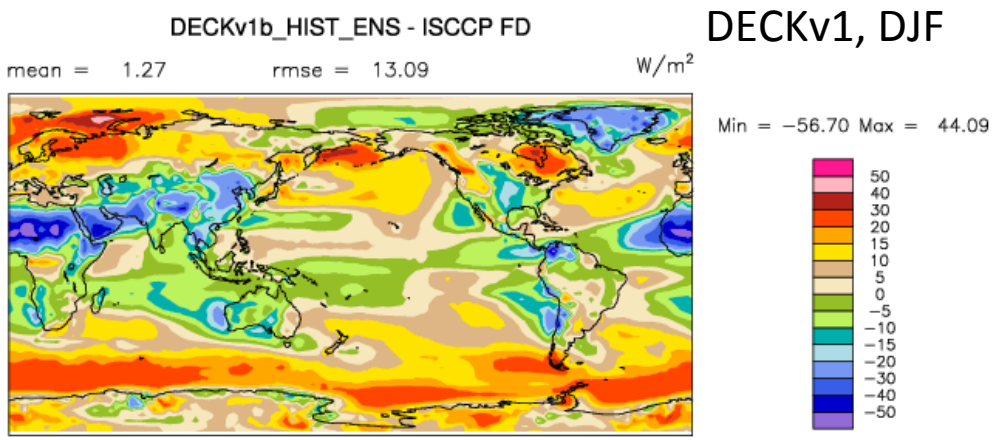
DECKv1, JJA



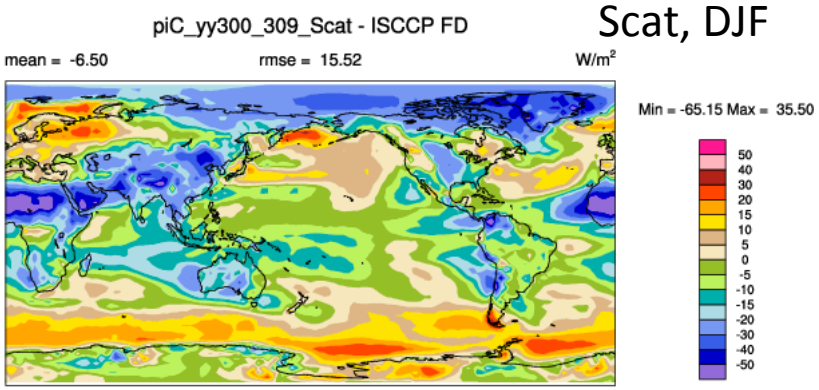
Scat, JJA



DECKv1, DJF

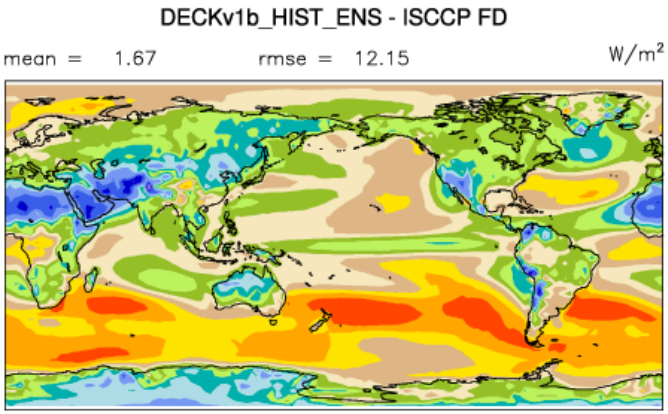


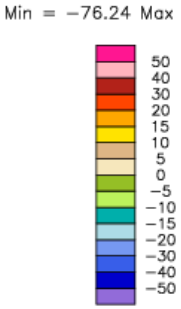
Scat, DJF



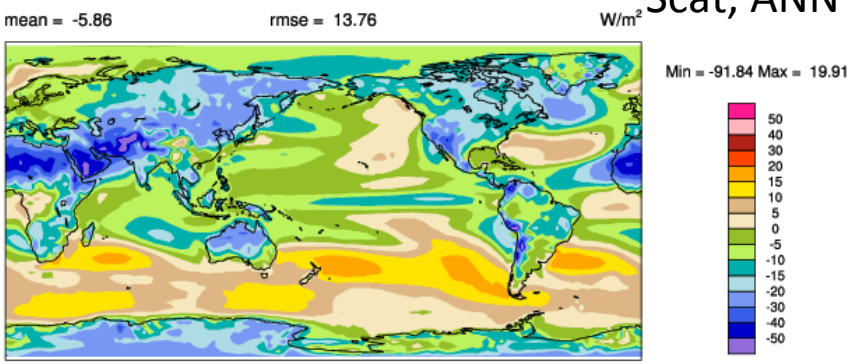
Clear-sky Surface downward LW flux

DECKv1, ANN

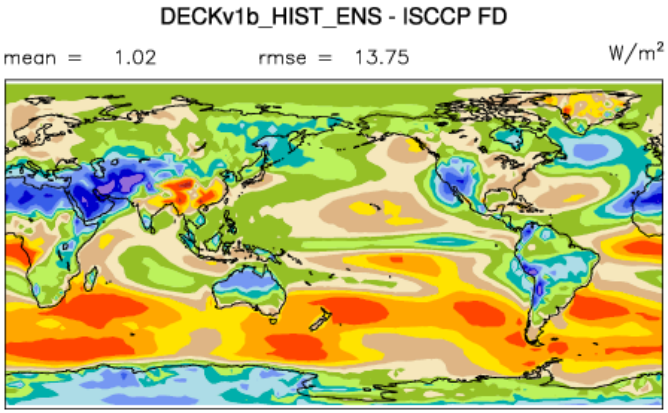


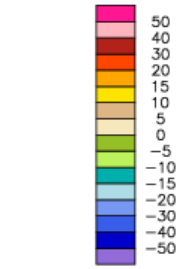


Scat, ANN

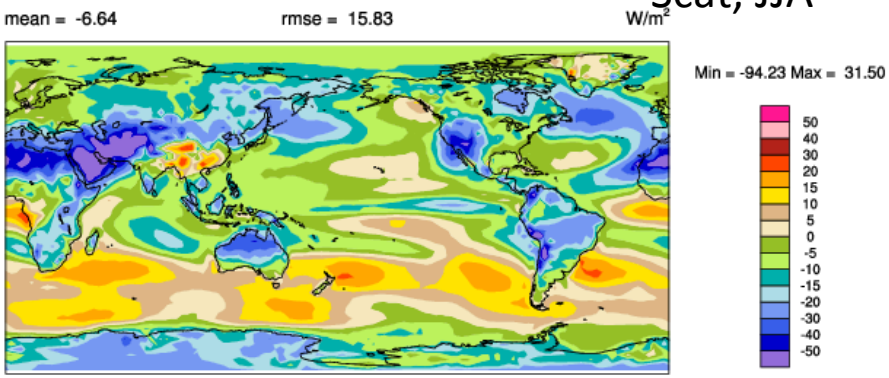


DECKv1, JJA

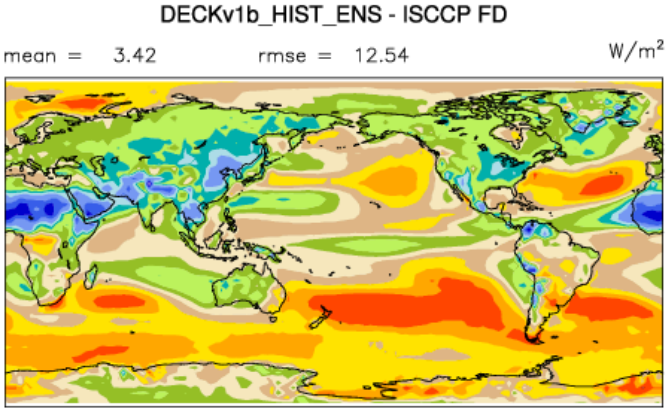


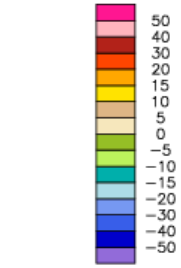


Scat, JJA



DECKv1, DJF





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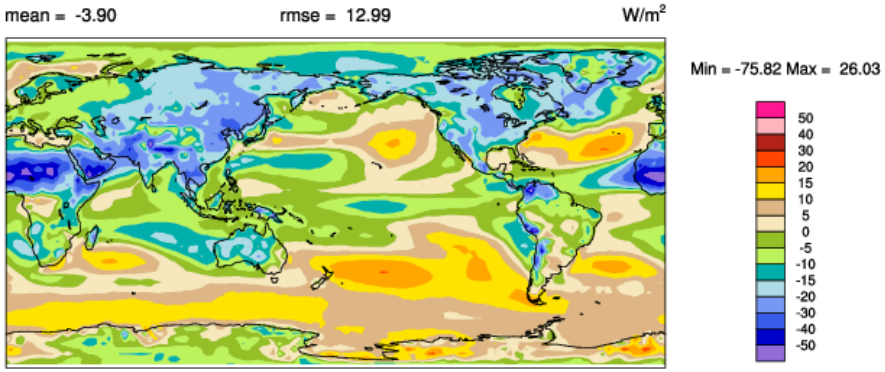
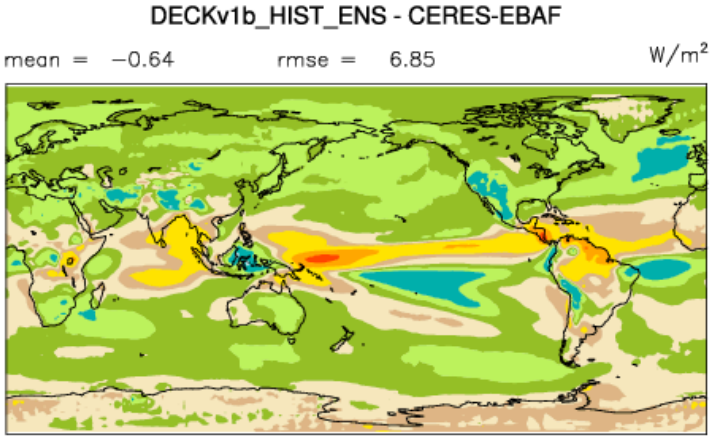
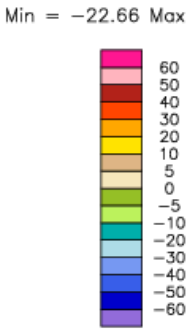


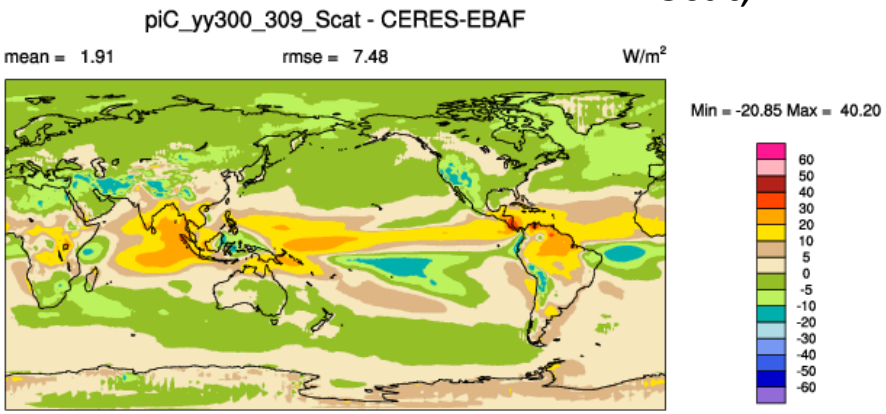
Outgoing LW radiation

DECKv1, ANN

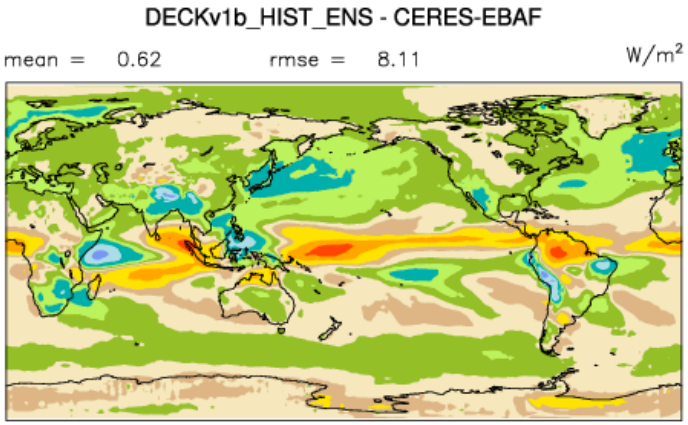


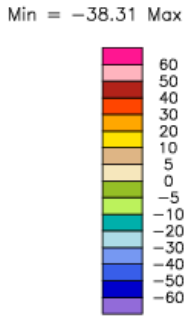


Scat, ANN

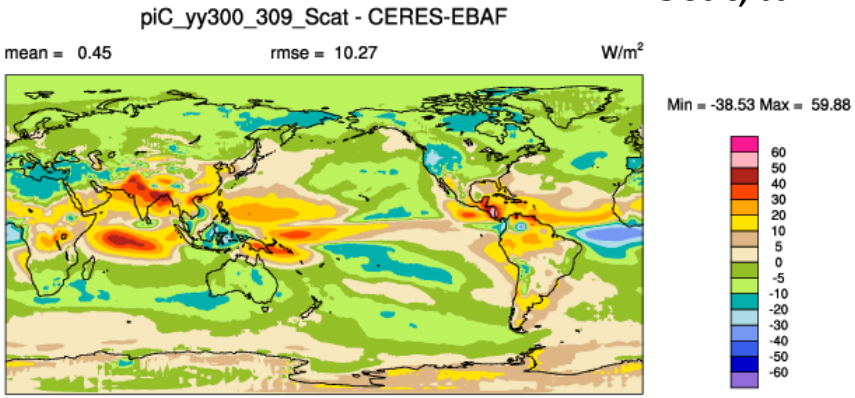


DECKv1, JJA

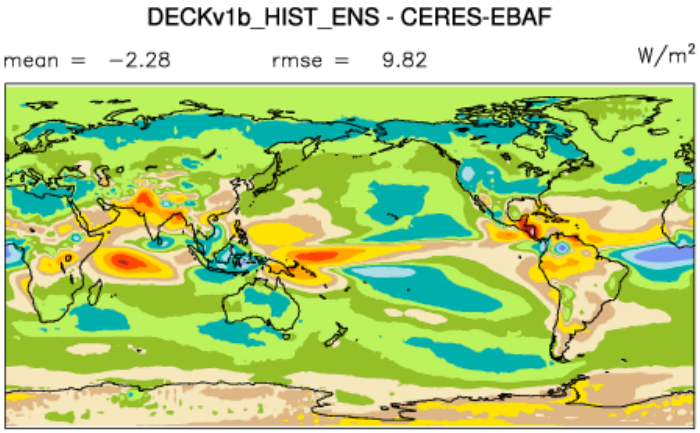


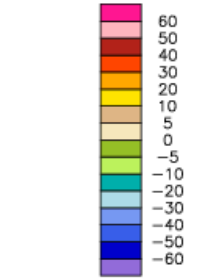


Scat, JJA

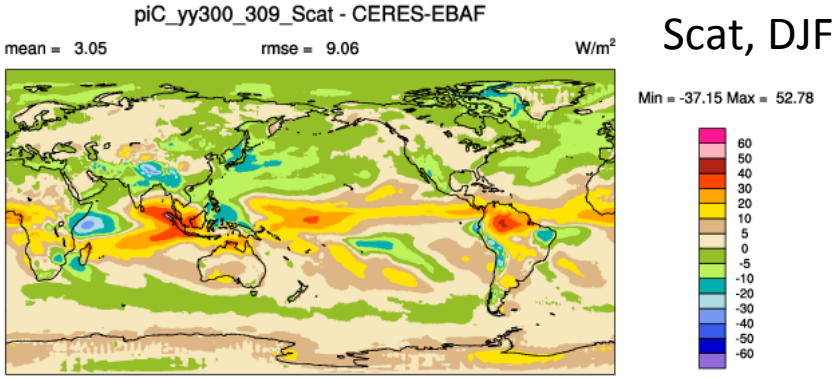


DECKv1, DJF



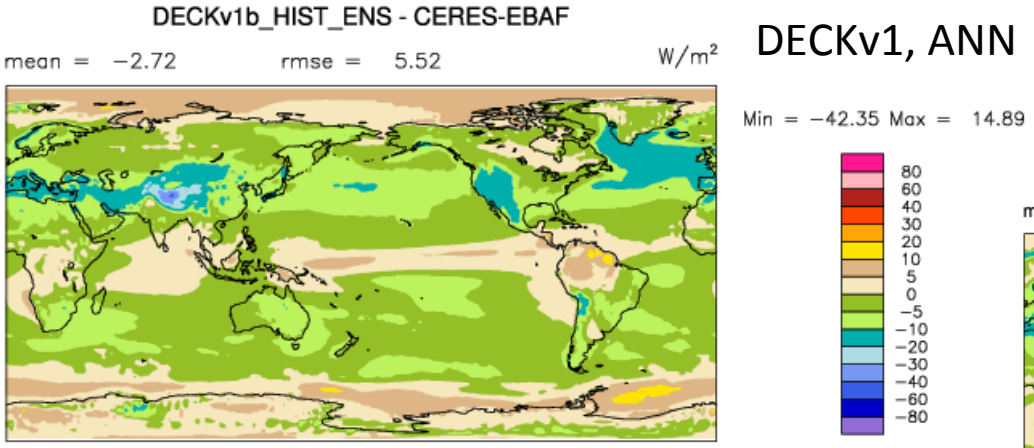


Scat, DJF

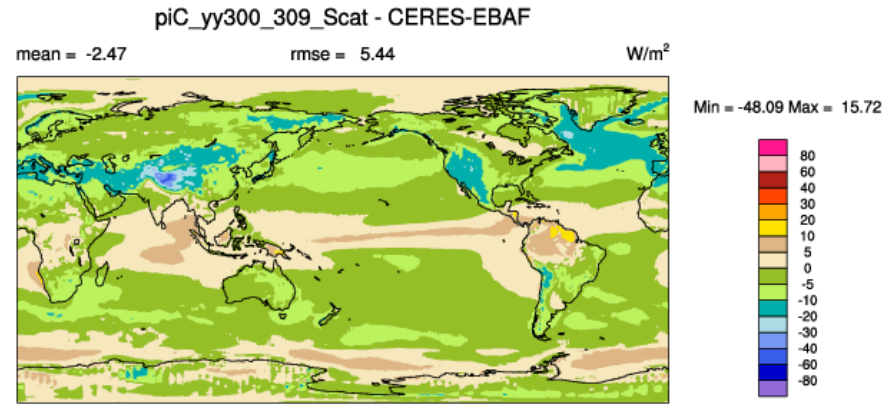


Clear-sky Outgoing LW radiation

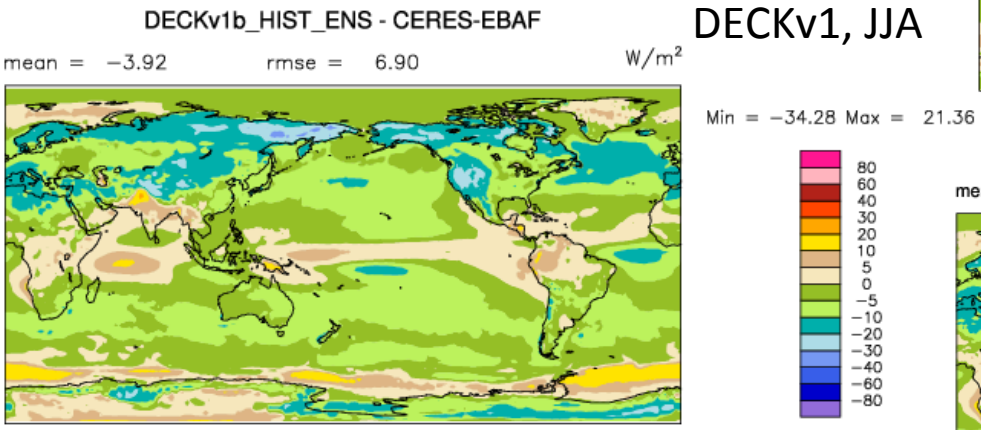
DECKv1, ANN



Scat, ANN



DECKv1, JJA



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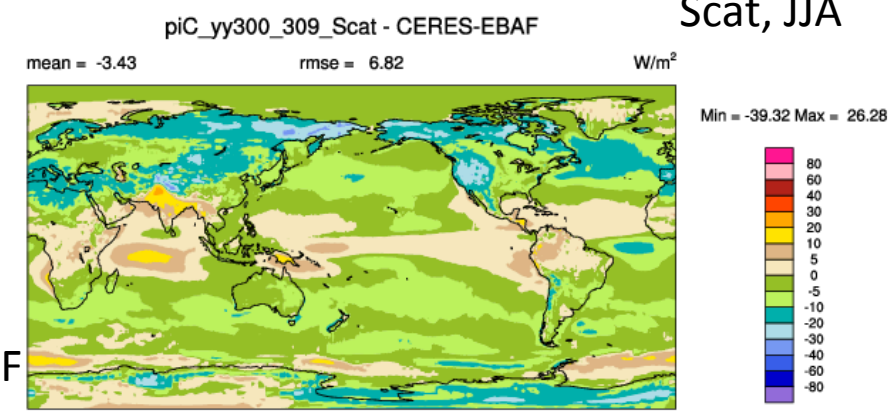
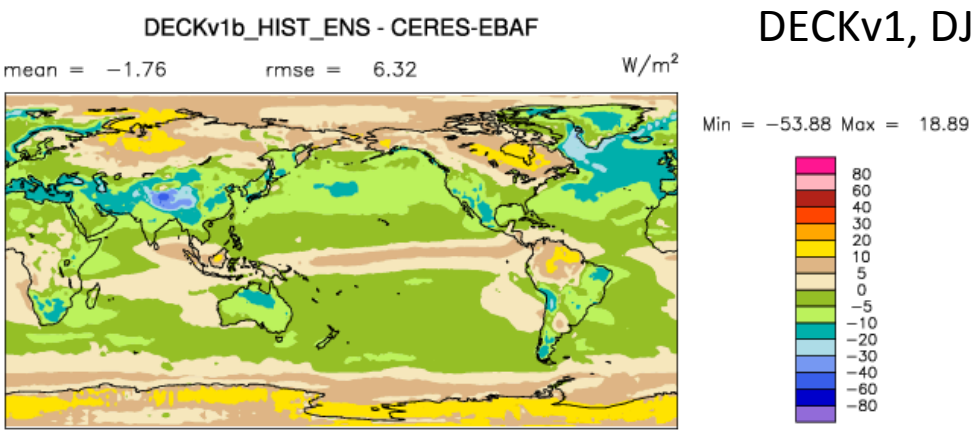


DECKv1, DJF



Scat, DJF