Investigation of regional CF differences and their impact on TOA radiation budgets through an integrative analysis of CERES-MODIS, CloudSat/CALIPSO and NASA GISS AR5 results

Ryan Stanfield, Xiquan Dong, Baike Xi, Aaron Kennedy
University of North Dakota

Tony Del Genio, NASA GISS

Patrick Minnis, Dave Doelling, Norman Loeb
NASA Langley Research Center

Datasets and Simulations

CERES Results

- TOA radiation Budget: EBAF, temporally interpolated using geostationary observations to infer the diurnal variations among CERES measurements.
- Global Cloud Fraction: CERES-MODIS SYN1, Aqua and Terra observations were combined
- 1^ox1^o (Lat x Lon) resolution [03/2000 – 12/2005]

AR5 – NASA-GISS GCM

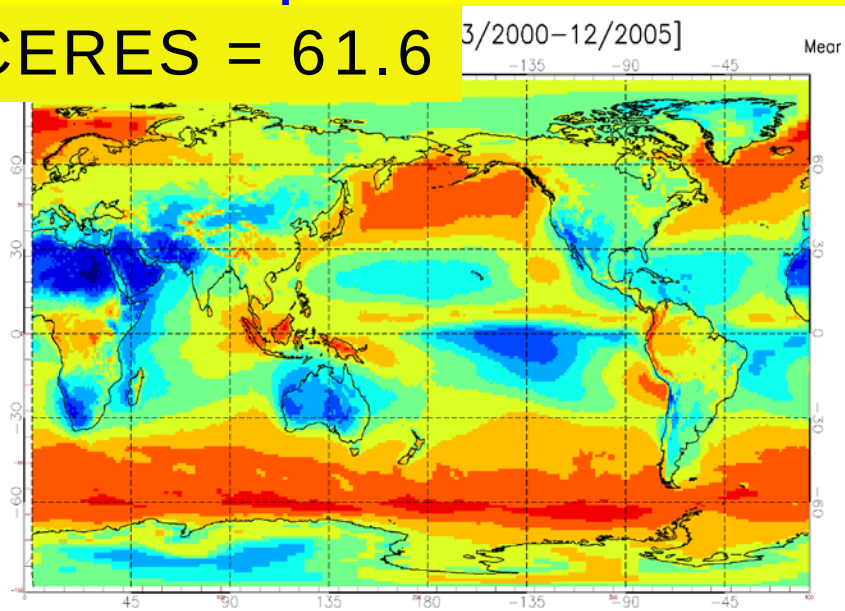
- 2^ox2.5^o (Lat x Lon) Resolution [03/2000 – 12/2005]
- This study uses the AMIP AR5 simulation downloaded from CMIP.

CloudSat/CALIPSO Results

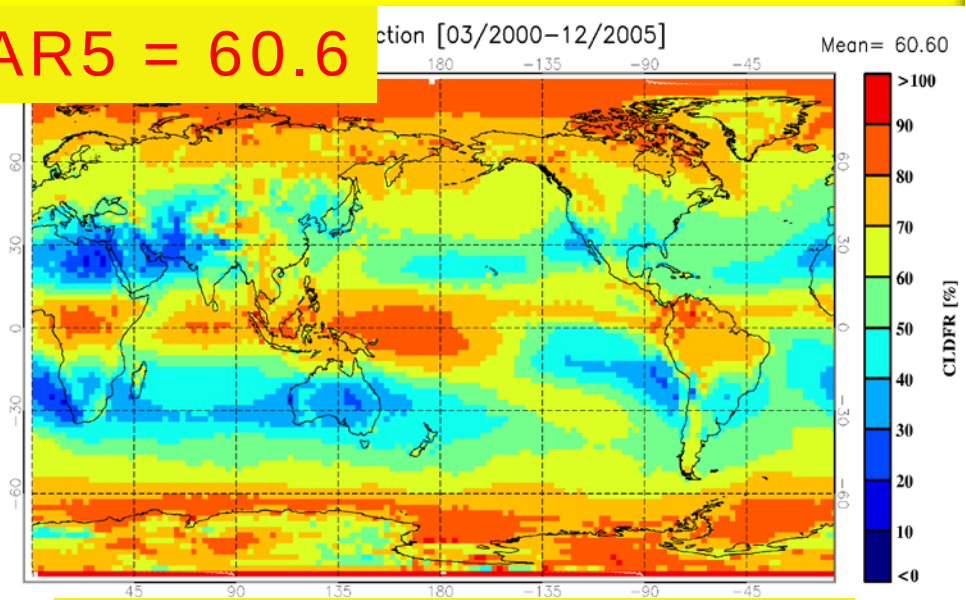
- Vertical distributions of Cloud fractions from the latest (RelB) data products (from Seiji Kato's CCCM), determined by both 94 GHz radar and LIDAR
- Time period: 2006-2010, different from CERES and AR5.

CF comparison between CERES and GISS AR5

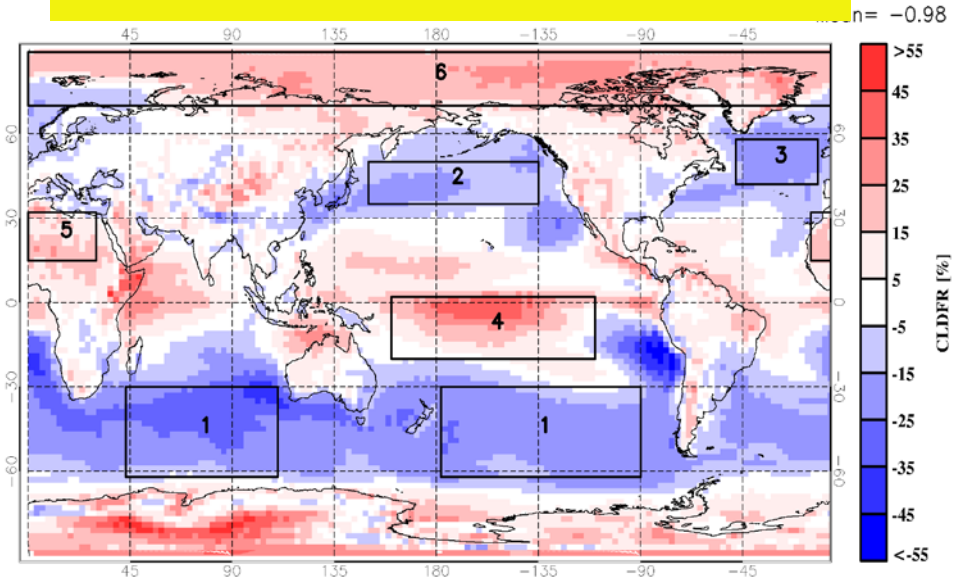
CERES = 61.6



AR5 = 60.6



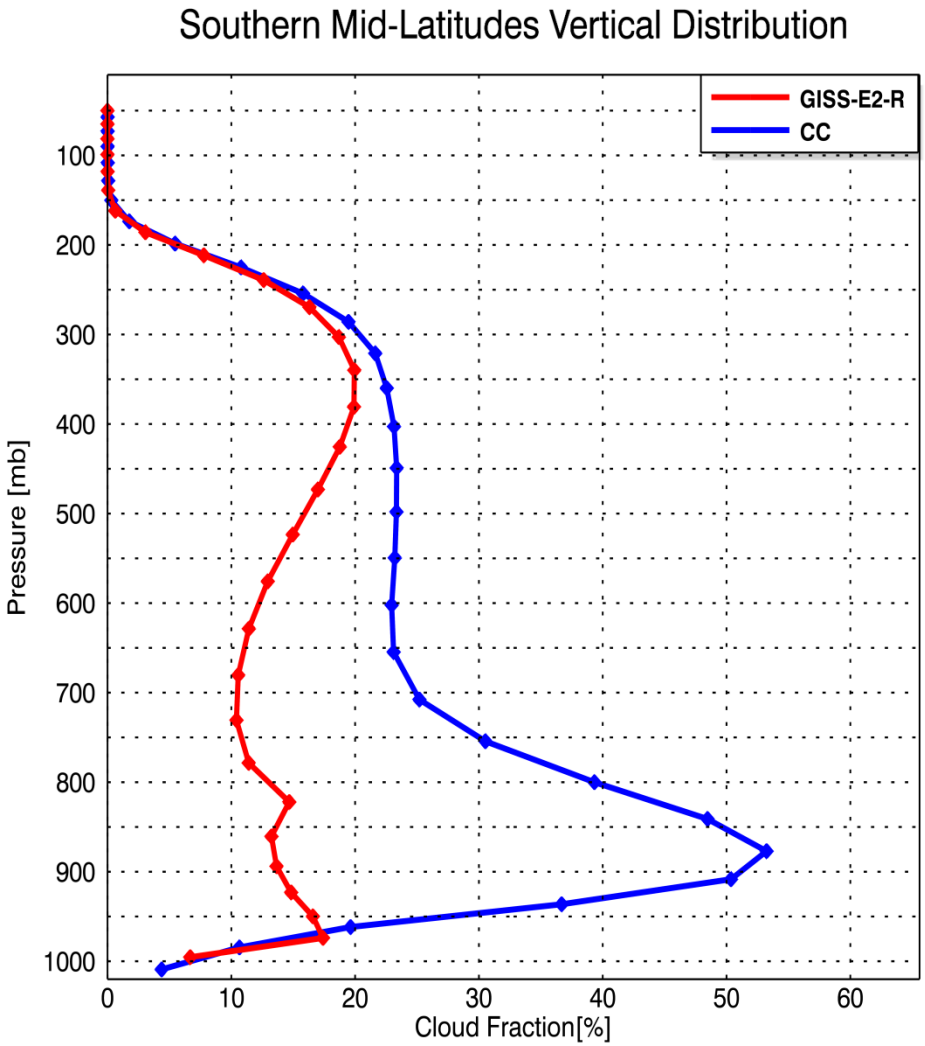
AR5 – CERES= -1.0



Although their global CF mean difference is within 1%, there are significant differences over some regions. For example, the model underestimates CFs in the South and North Mid-lat regions (1, 2, 3), and overestimates CFs over the Tropical, Sahara, and Polar regions (4, 5, 6).

Next, we want to investigate the causes leading to these CF discrepancies, and their impact on TOA radiation budgets.

CF comparison between CC and AR5 over Southern Midlat. (Region 1)



CC vertical distributions are grouped into AR5 levels using maximum overlap within a model layer.

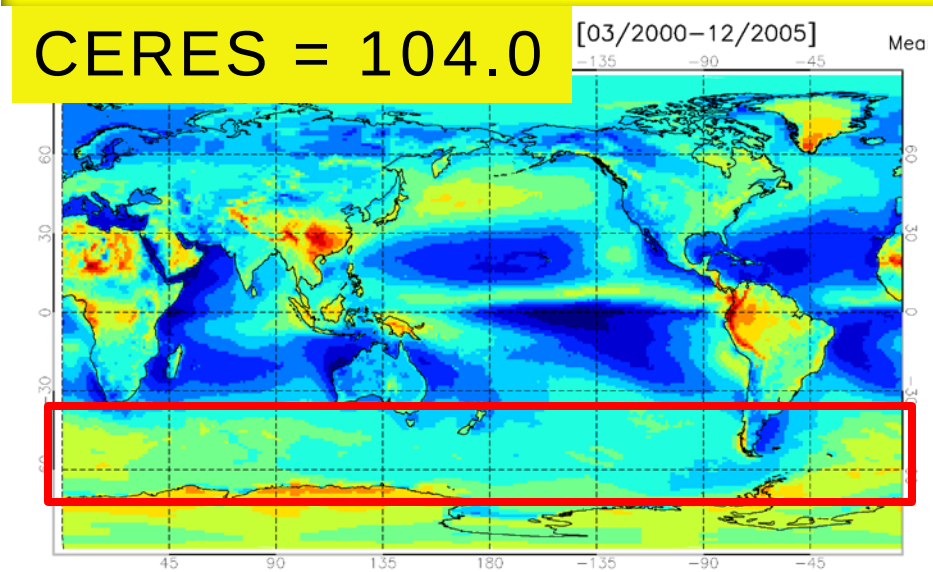
Compared to CC, AR5 underestimates low-level clouds, which may result in

1) lower SWup due to highly reflective low cloud

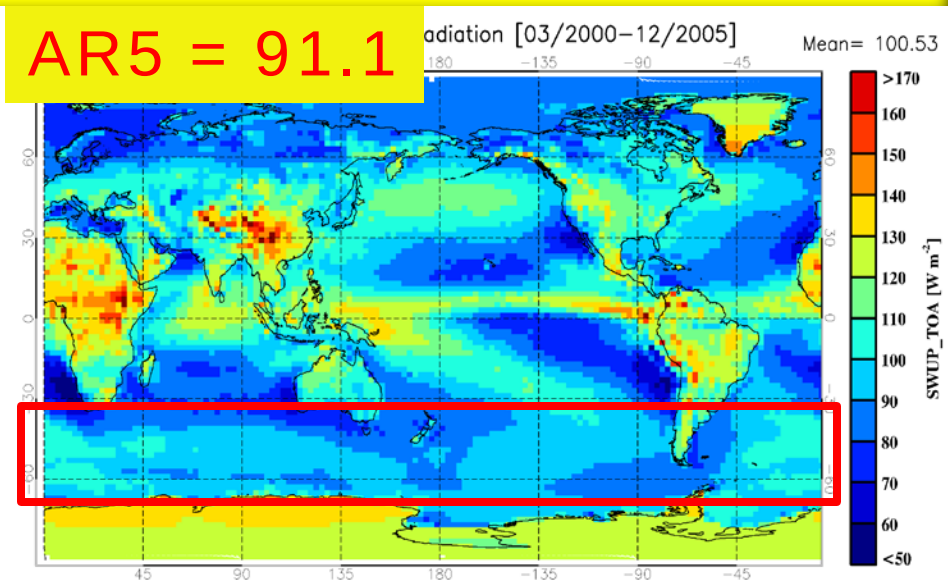
2) OLR differences should be small because cloud-top temperature is close to sea surface temperature.

SWup comparison between CERES and GISS AR5

CERES = 104.0

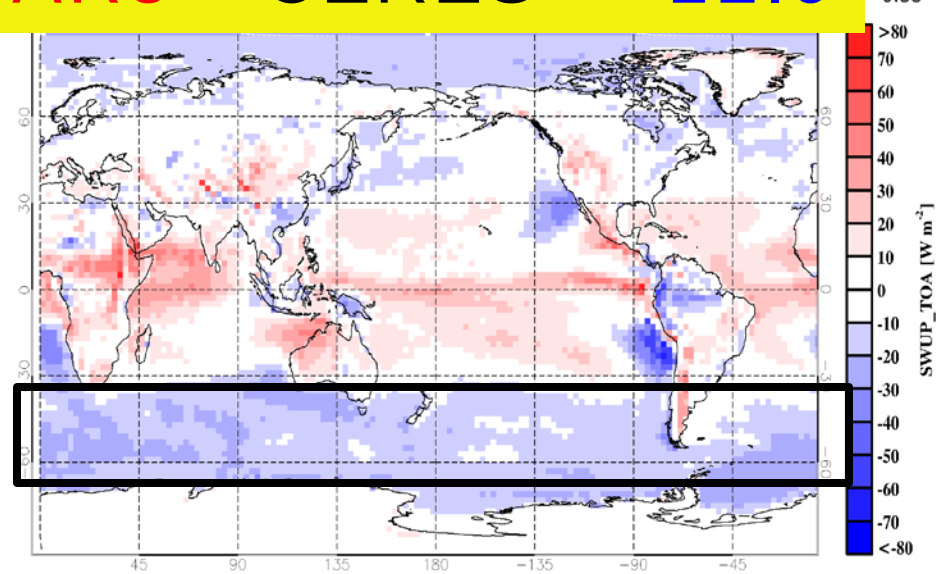


AR5 = 91.1



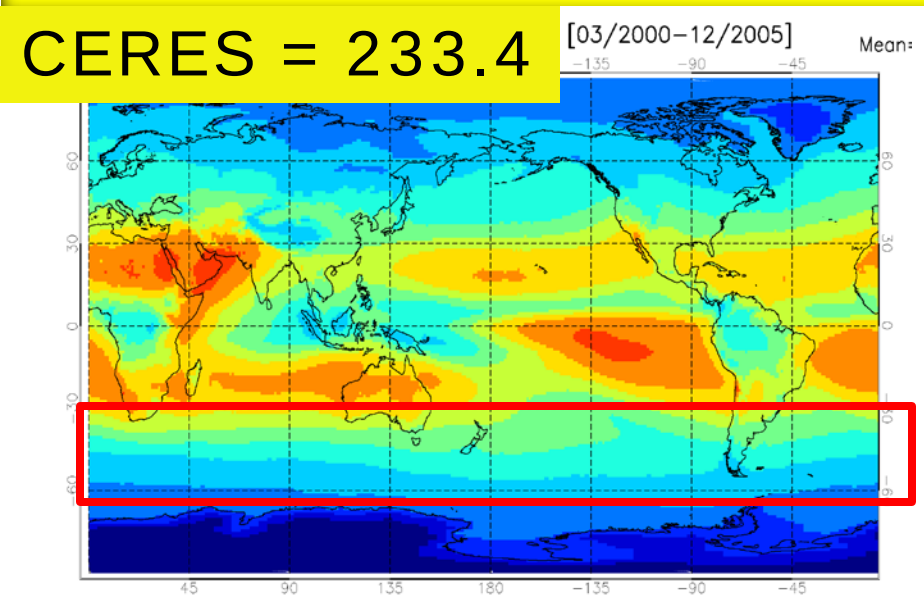
SWup comparison is similar to CF, meaning the global mean is similar (100 Wm^{-2}), but with large differences over some regions, such as modeled SWup is lower (ΔSW= -12.9 Wm^{-2}) in Southern Mid-latitudes due to less CF in AR5.

AR5 – CERES = -12.9

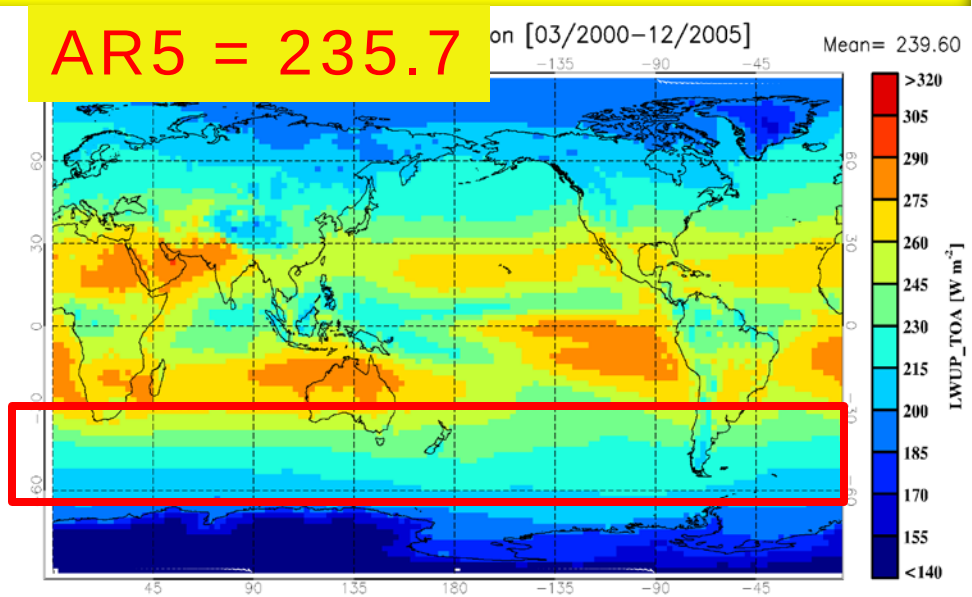


OLR comparison between CERES and GISS AR5

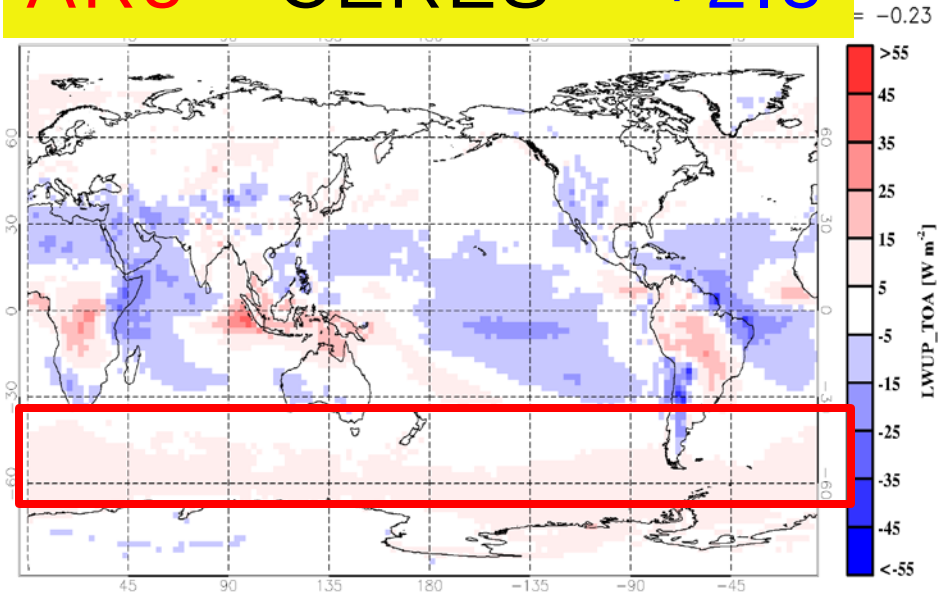
CERES = 233.4



AR5 = 235.7



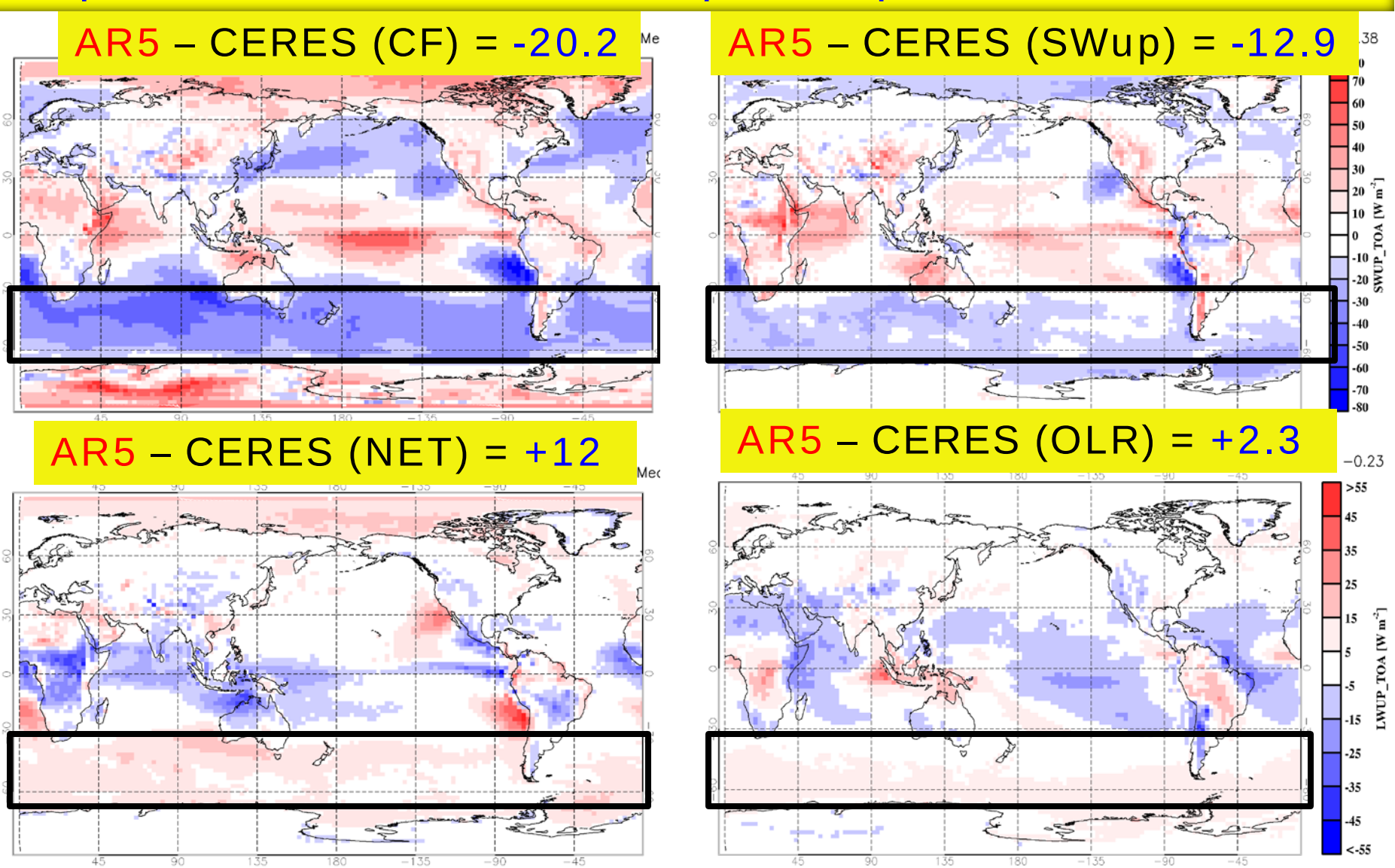
AR5 – CERES = +2.3



Opposite to SWup and CF comparisons.

Over Southern Mid-lat, AR5 OLR is slightly larger (ΔLW=+2.3 Wm^{-2}) than CERES results because model underestimated CF, and SST is slightly higher than low-level cloud-top temp

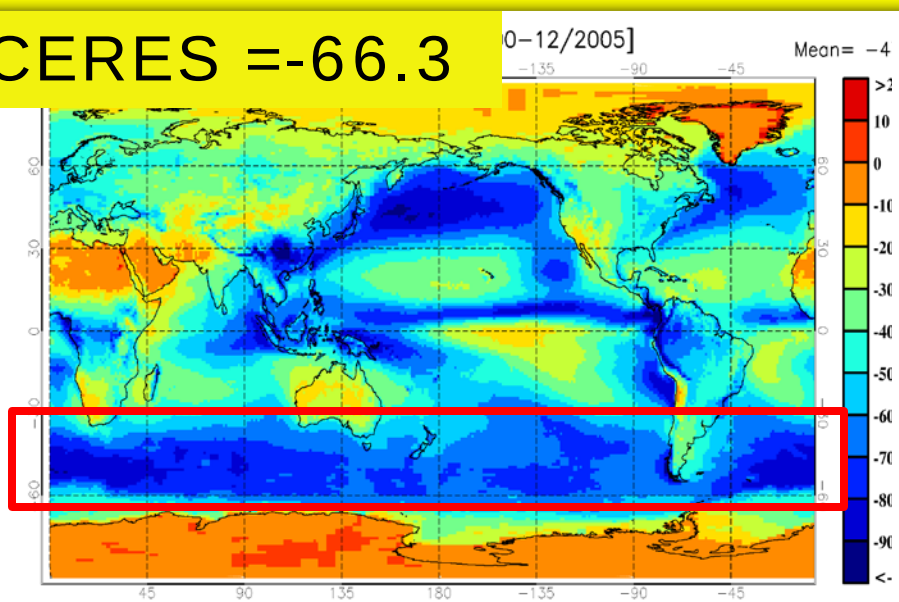
Impacts of Clouds on SWup, LWup, and NET fluxes



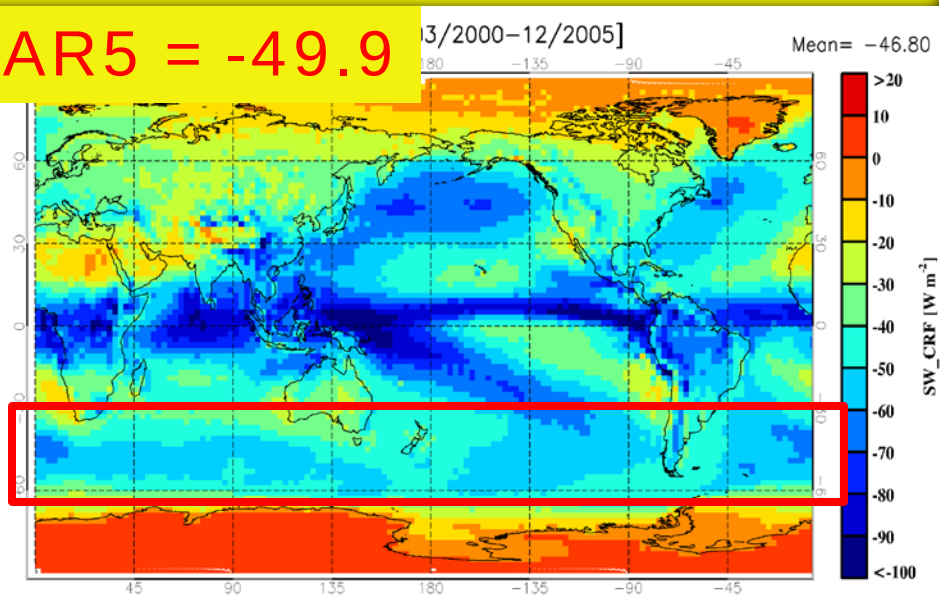
Over Southern Mid-lat, when modeled CF is lower than data, its SWup is lower and OLR is slightly higher (less low-level clouds). Finally modeled NET flux is slightly higher. NET flux=(SWdown – SWup) – OLR

Comparison of SW CRE between CERES and AR5

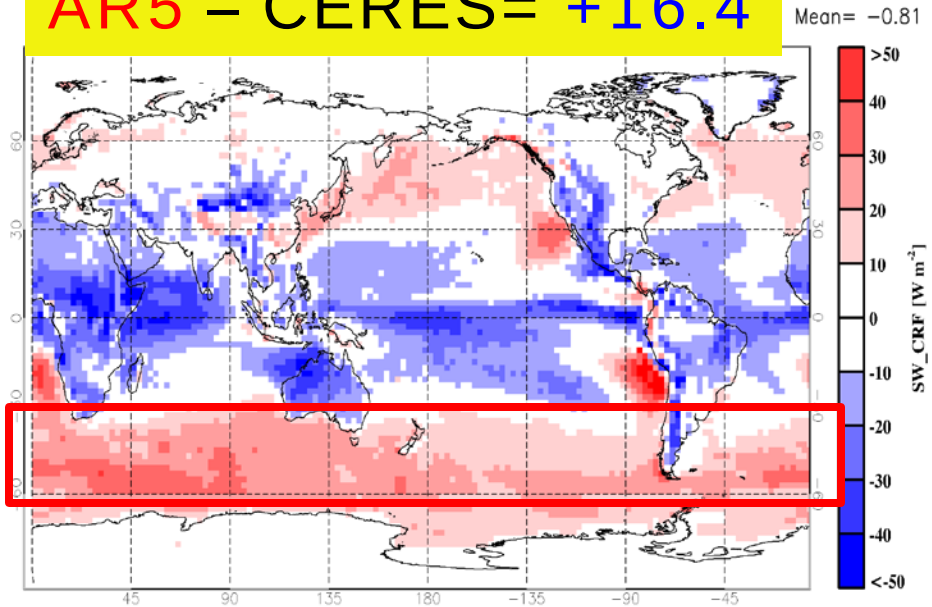
CERES =-66.3



AR5 = -49.9



AR5 – CERES= +16.4



Remember:

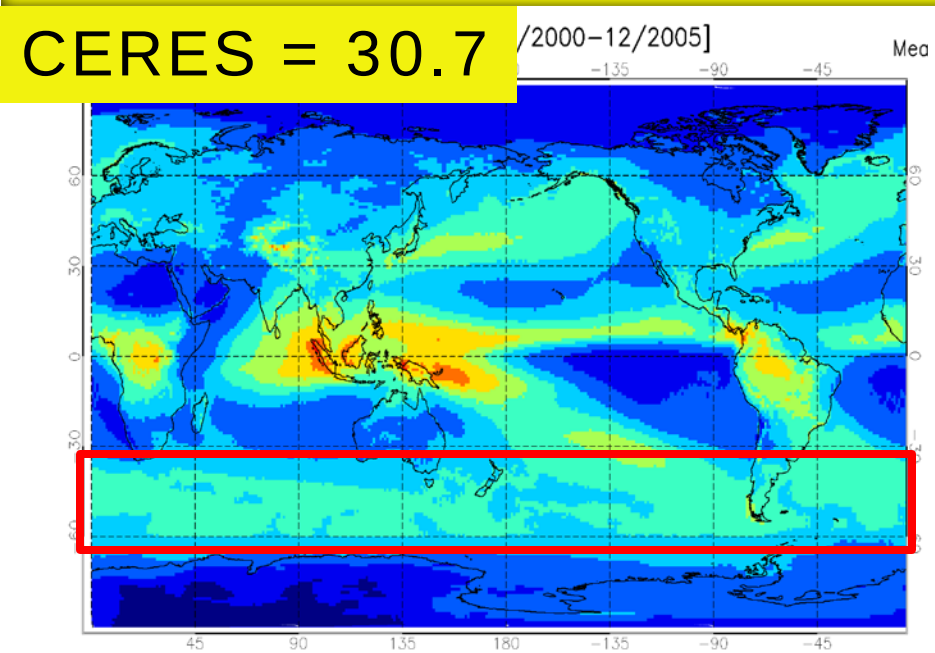
SW CRE= $SW_{clear}\uparrow$ - $SW_{all}\uparrow$

CERES SW CRE over southern mid-latitudes are much more negative than AR5 simulations because CERES $SW_{all}\uparrow$ is higher than AR5 over that region.

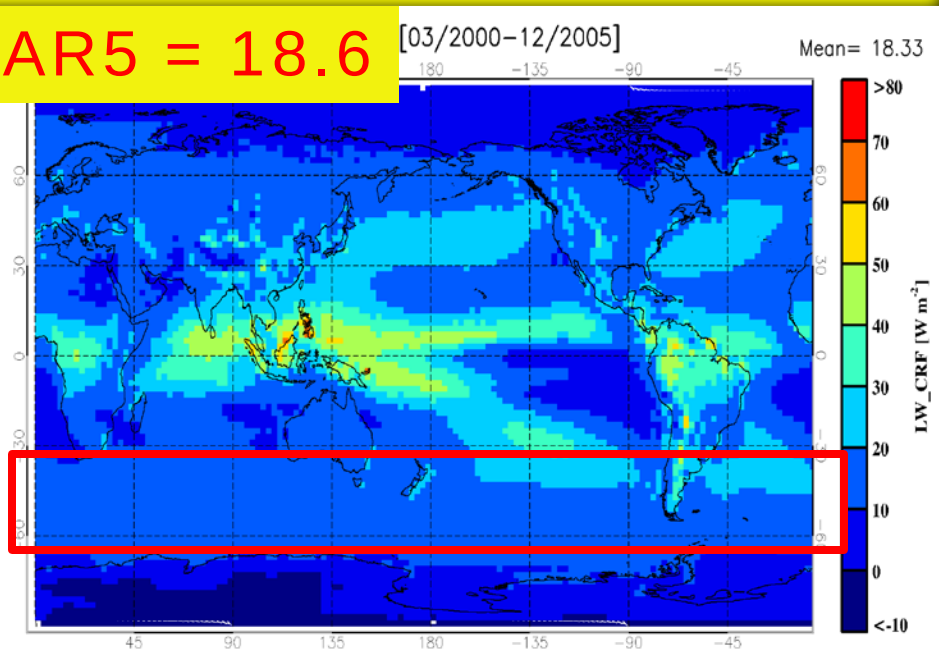
Higher low-level CF➔ larger $SW_{all}\uparrow >> SW_{clear}\uparrow$

Comparison of LW CRE between CERES and AR5

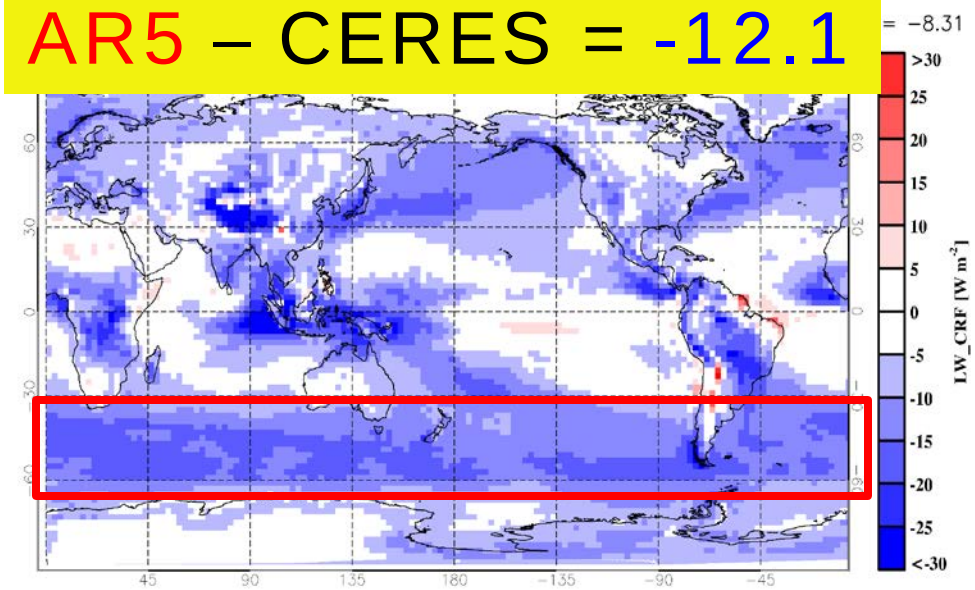
CERES = 30.7



AR5 = 18.6



AR5 – CERES = -12.1

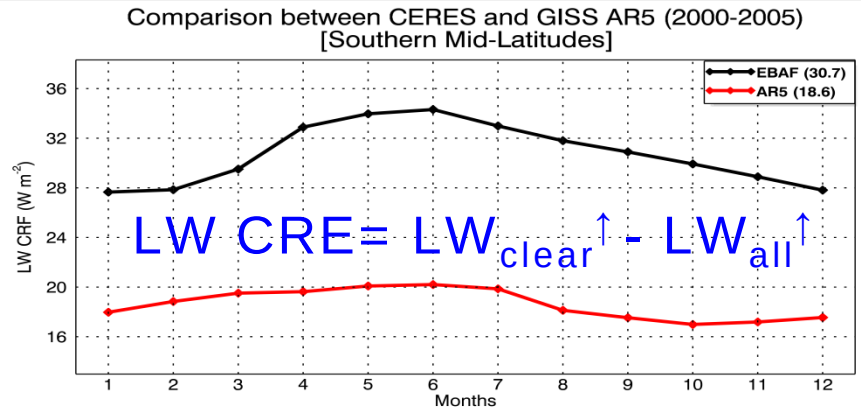


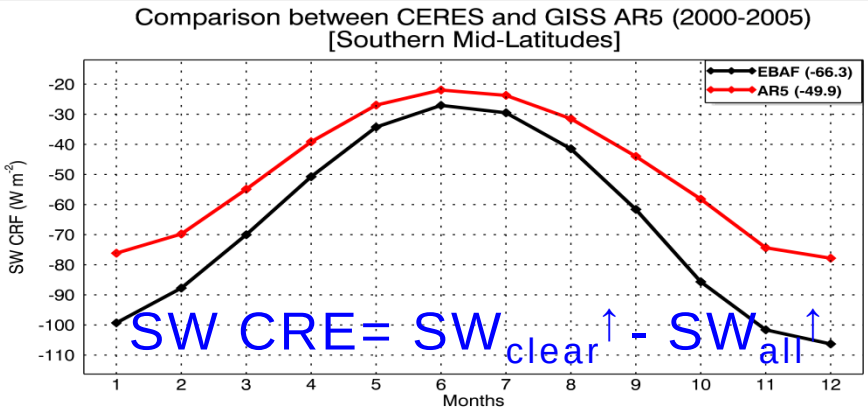
Remember:

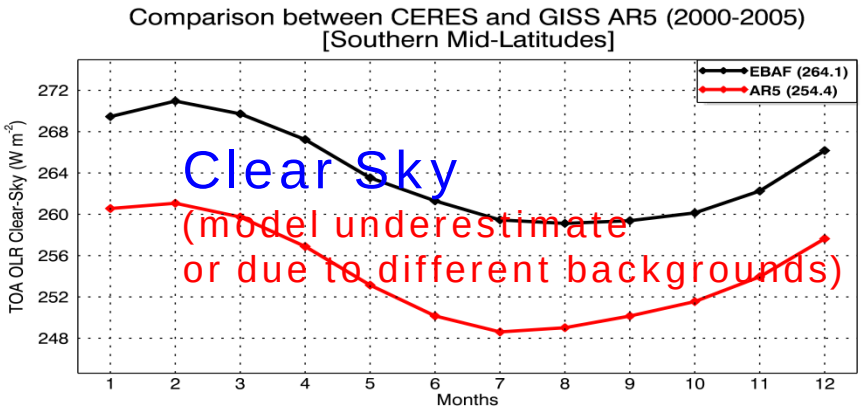
LW CRE= $LW_{clear}\uparrow$ - $LW_{all}\uparrow$

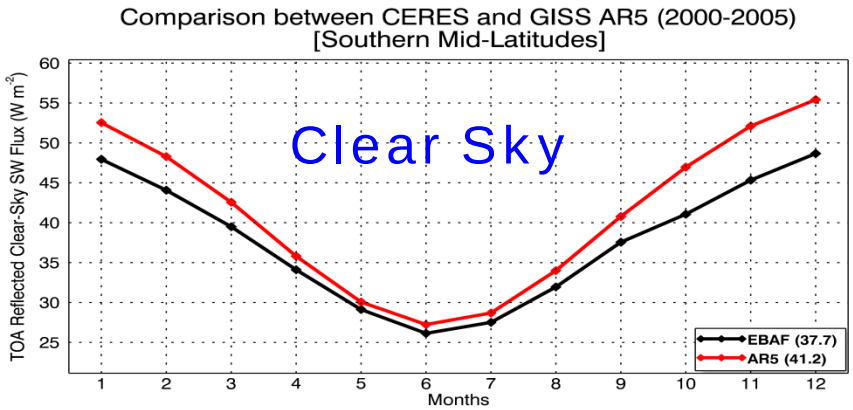
CERES observed and AR5 simulated all-sky SWup $LW_{all}\uparrow$ over Southern mid-latitudes are close to each other. So LW CRE difference must come from clear-sky LWup flux difference.

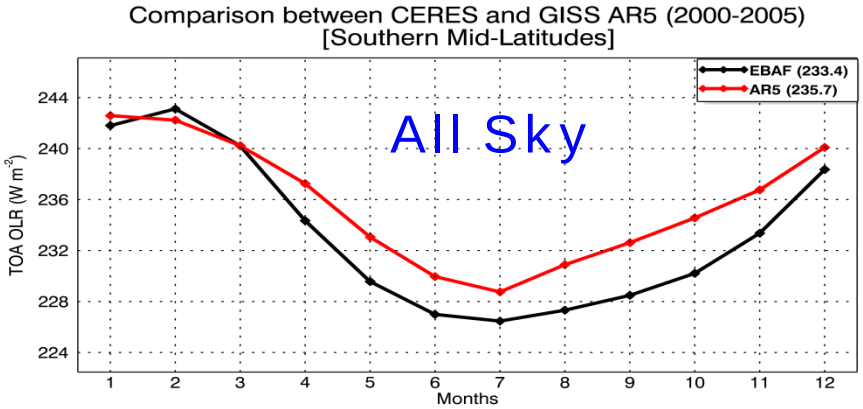
Comparison of Clear-sky, All-sky and CREs

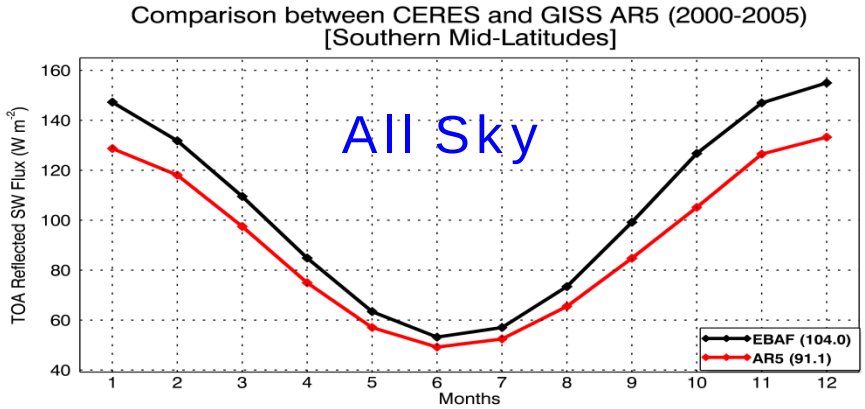






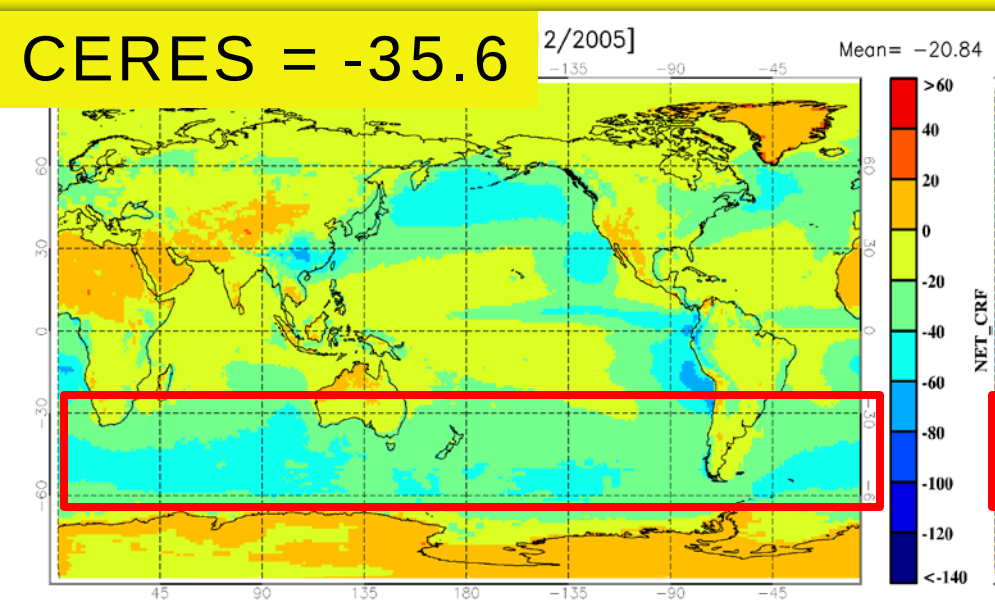




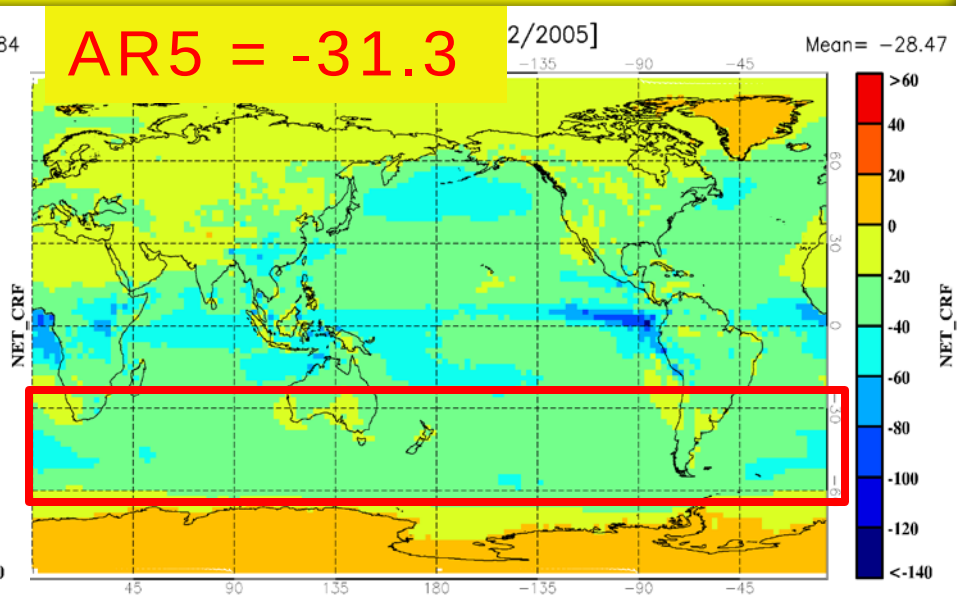


Comparison of NET CRE between CERES and AR5

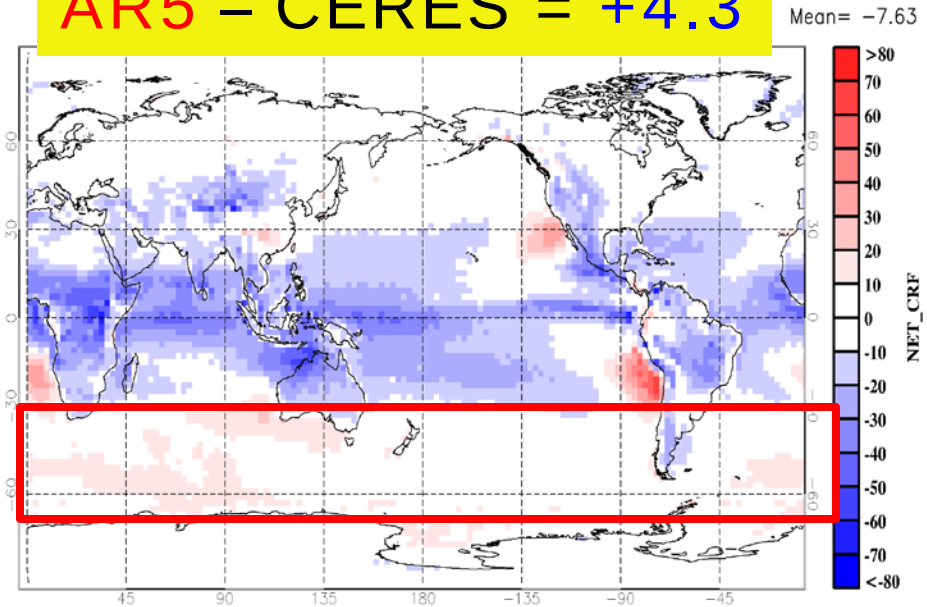
CERES = -35.6



AR5 = -31.3



AR5 – CERES = +4.3

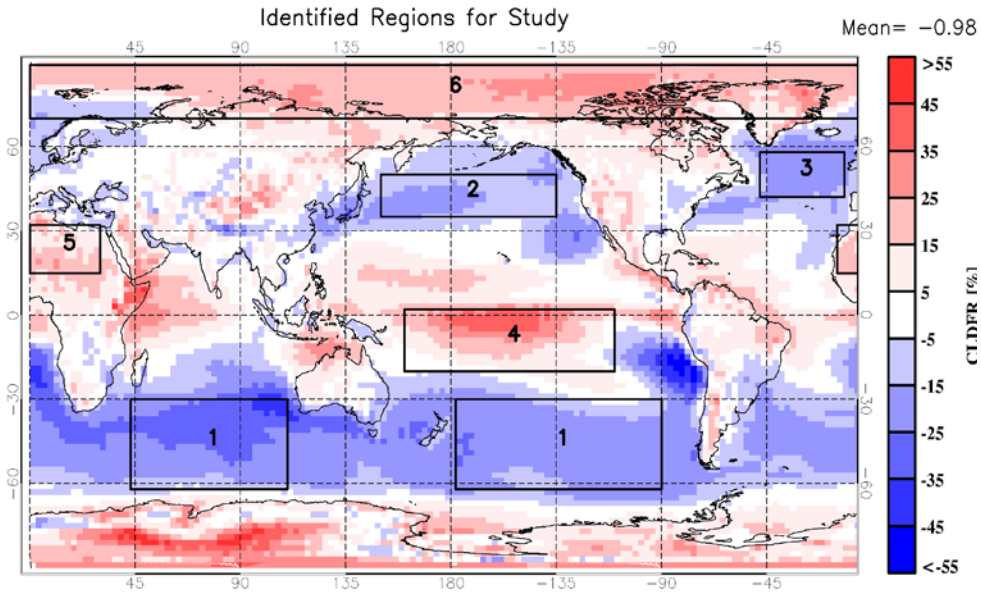


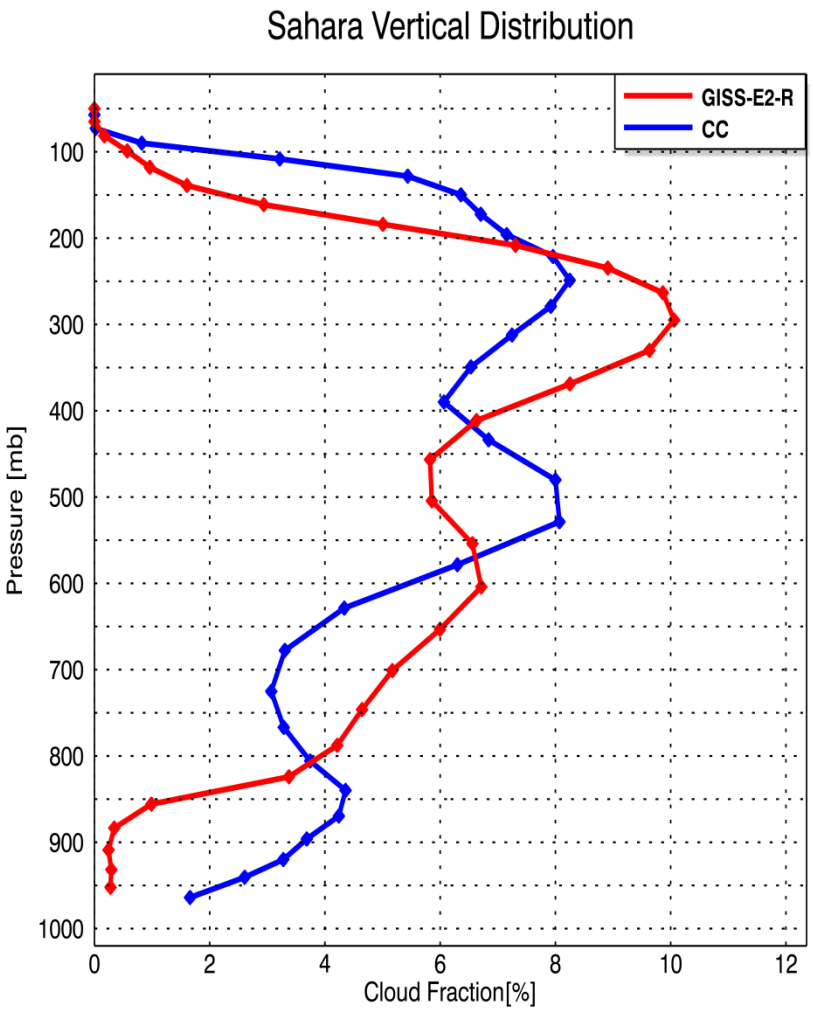
NET CREs over S. Mid-lat.

EBAF:
NET CRE=SW CRE+LW CRE
= -66.3 + 30.7= -35.6

AR5:
NET CRE=SW CRE+LW CRE
= -49.9 + 18.6= -31.3

CF comparison over Zone 5 – Sahara Desert





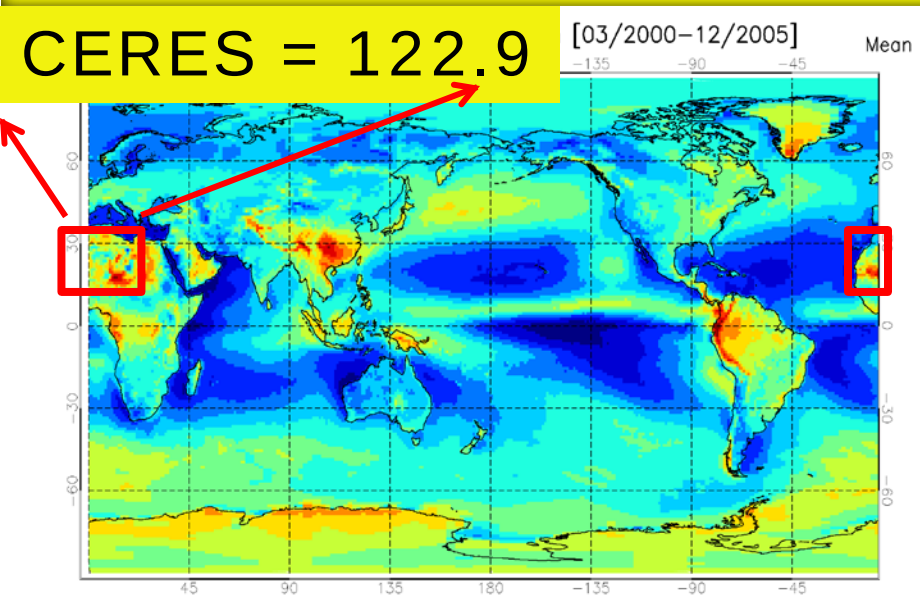
AR5 slightly overestimates CF over Sahara Desert region, particularly for high-level clouds.

This may result in:

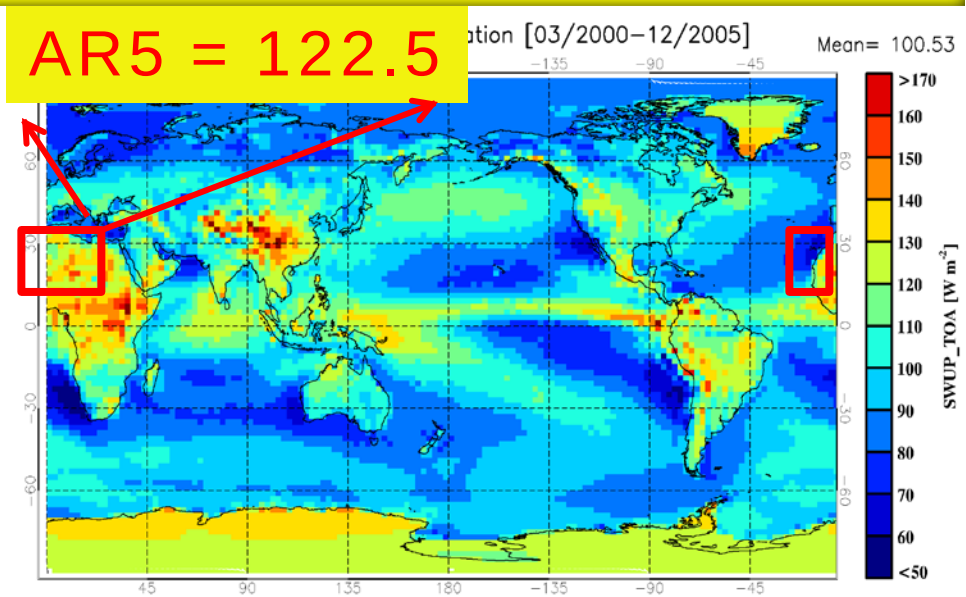
1) a small difference in reflected SW (SWup)
2) Underestimation in OLR

All-sky SWup comparison between CERES and AR5

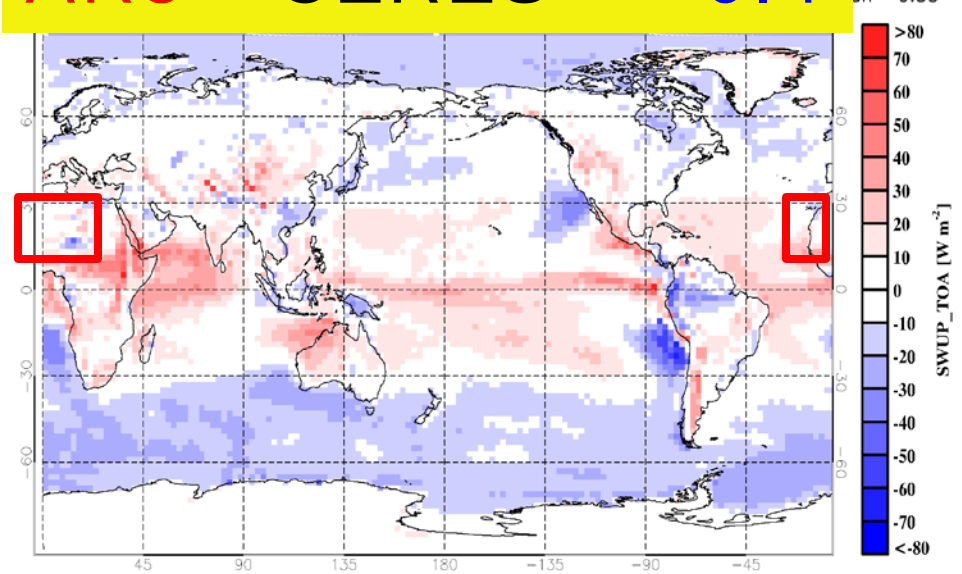
CERES = 122.9



AR5 = 122.5



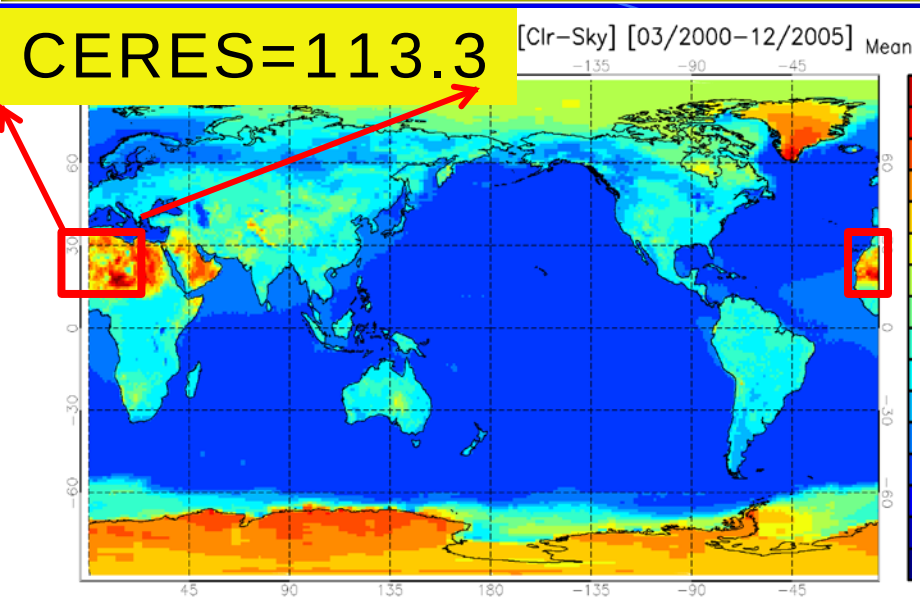
AR5 – CERES = +0.4



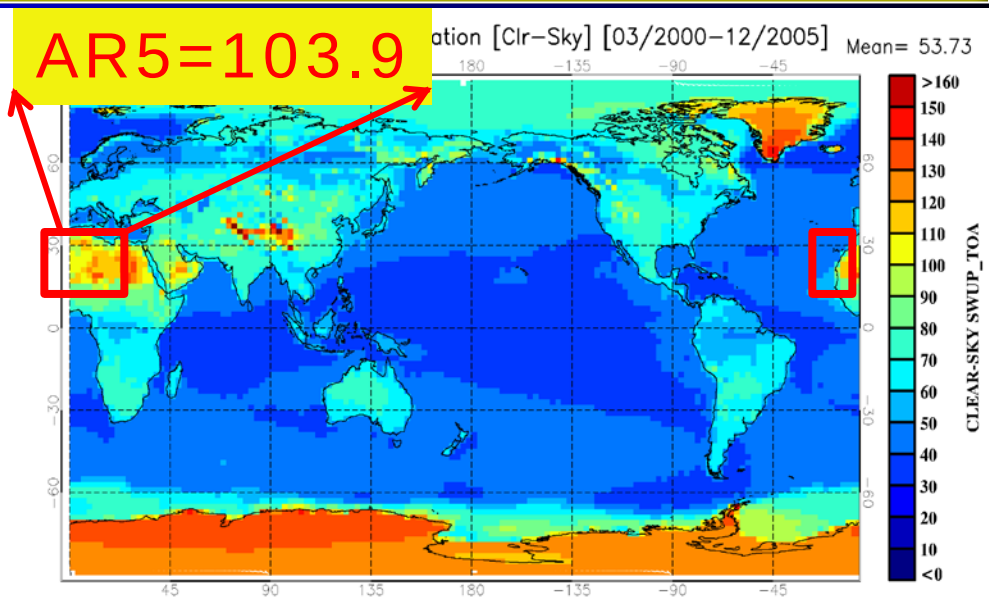
With the combination of high-level clouds and small cloud fractions, comparisons over the Sahara show only a small overestimation of $SW_{all}\uparrow$ by the model ($\Delta SW = +0.4\ Wm^{-2}$)

Clear-sky SWup comparison between CERES and AR5

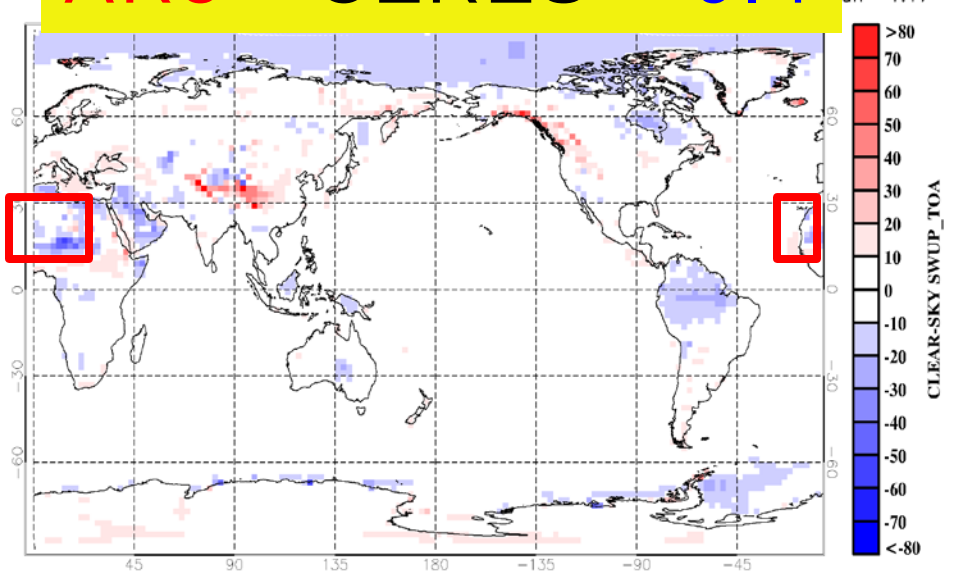
CERES=113.3



AR5=103.9



AR5 – CERES= -9.4

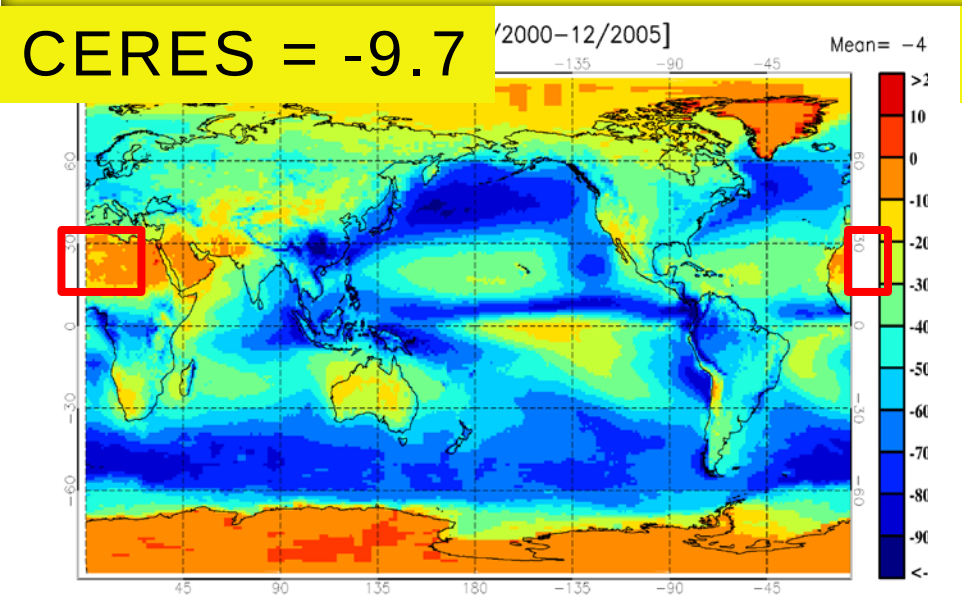


Over most regions, Clear-Sky SWup has a minimal difference. This is however not the case over the Sahara, where the model underestimates clear-sky reflected SW.

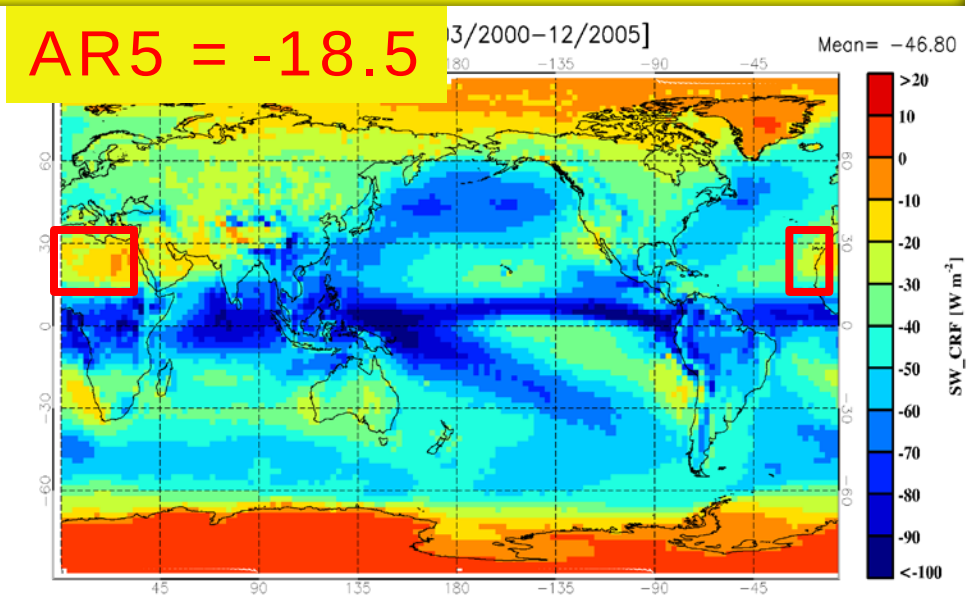
(ΔC-SW= -9.4 Wm^{-2})

Comparison of SW CRE between CERES and AR5

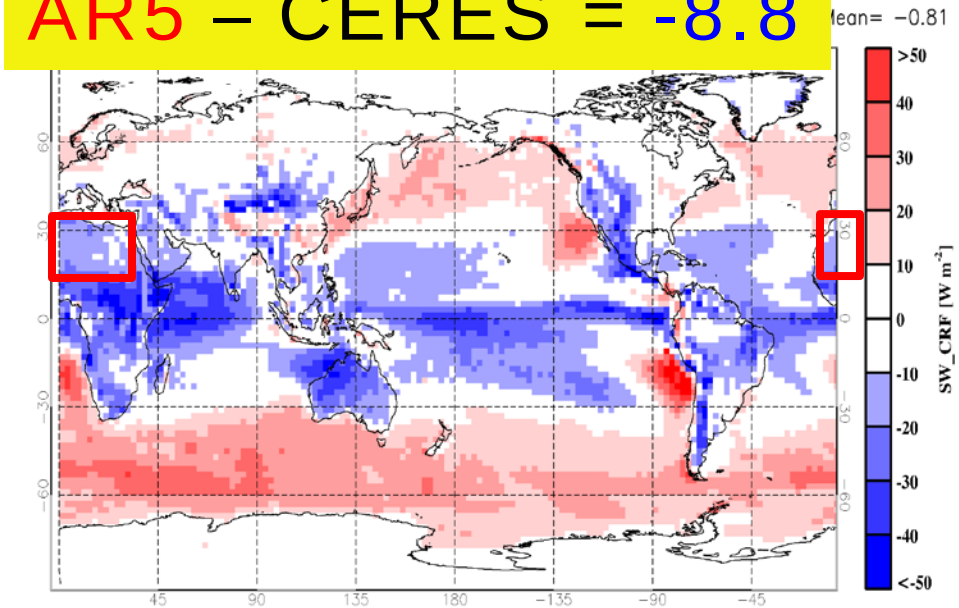
CERES = -9.7



AR5 = -18.5



AR5 – CERES = -8.8



Remember:

SW CRE= $SW_{clear}\uparrow$ - $SW_{all}\uparrow$

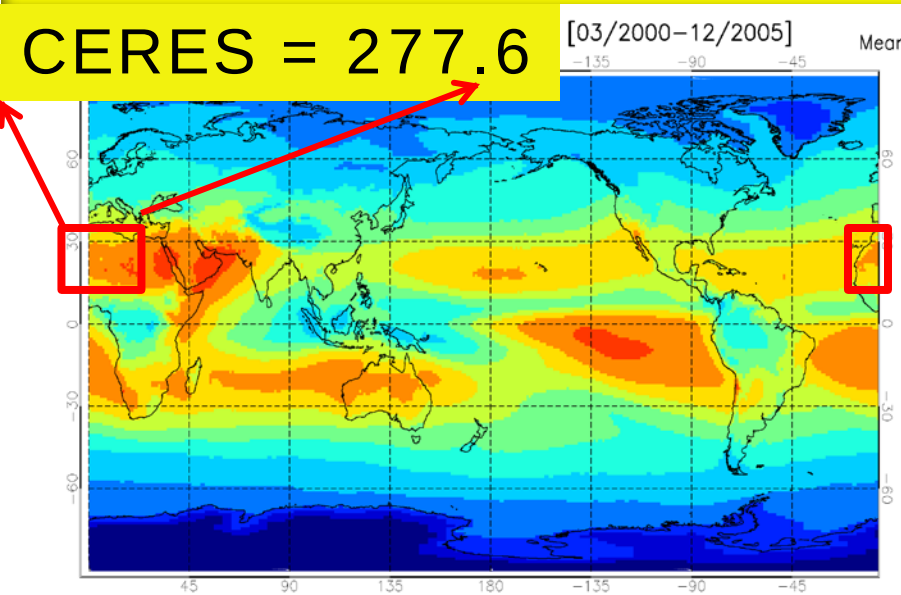
CERES SW CRE over the Sahara is much higher than AR5 simualtions because CERES $SW_{all}\uparrow$ is lower and $SW_{clear}\uparrow$ is higher than AR5 over that region.

CERES $SW_{clear}\uparrow$ > AR5 $SW_{clear}\uparrow$

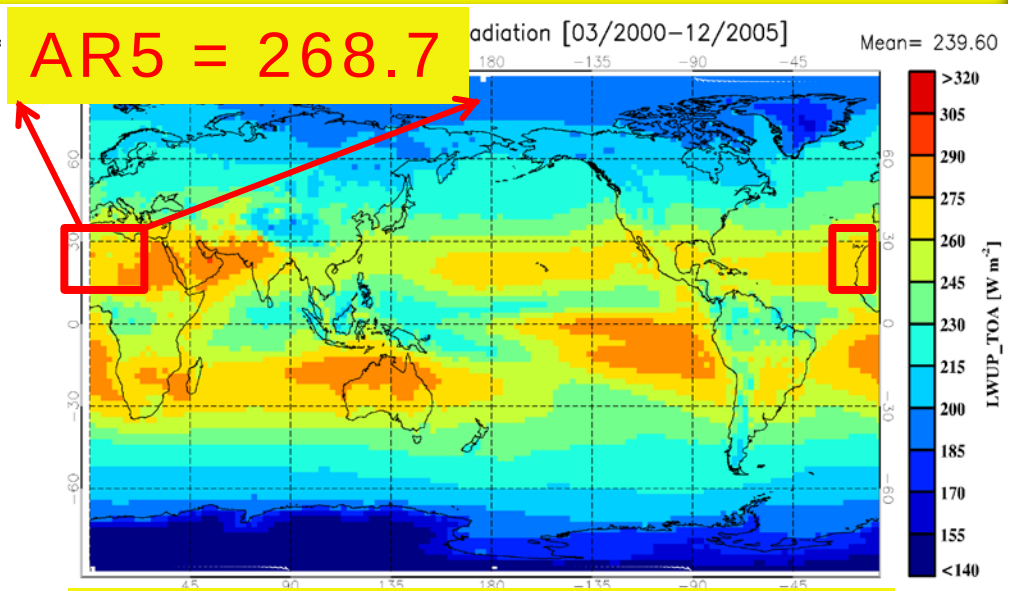
CERES $SW_{all}\uparrow$ < AR5 $SW_{all}\uparrow$

OLR comparison between CERES and GISS AR5

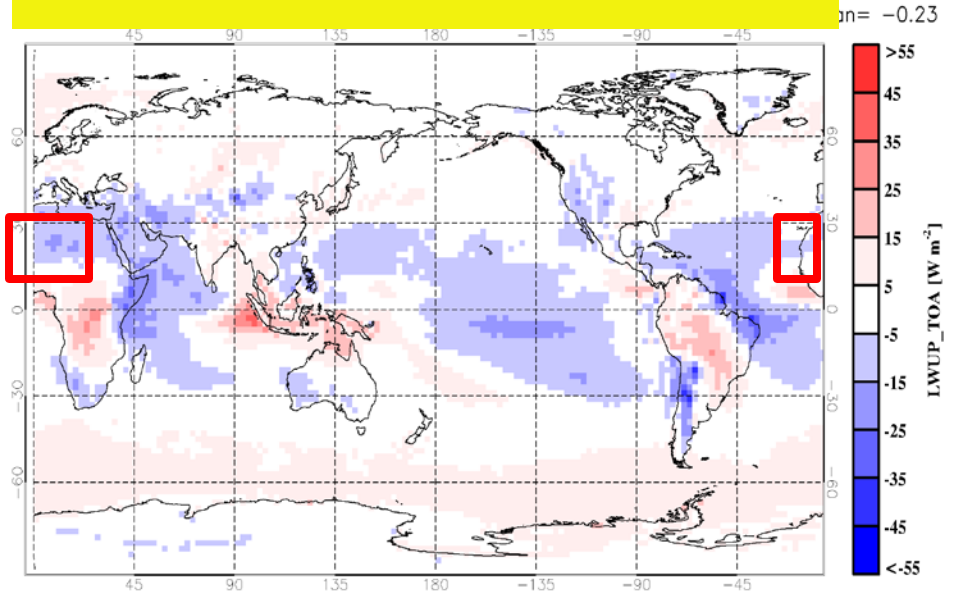
CERES = 277.6



AR5 = 268.7



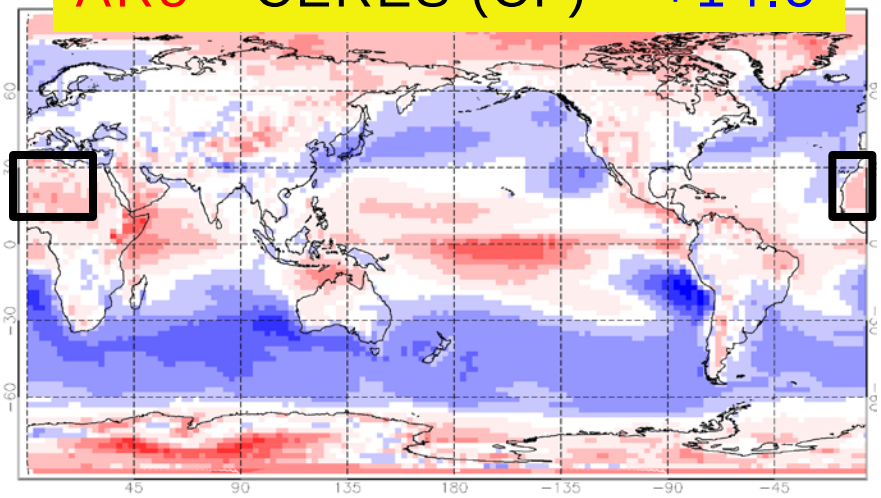
AR5 – CERES = -8.9



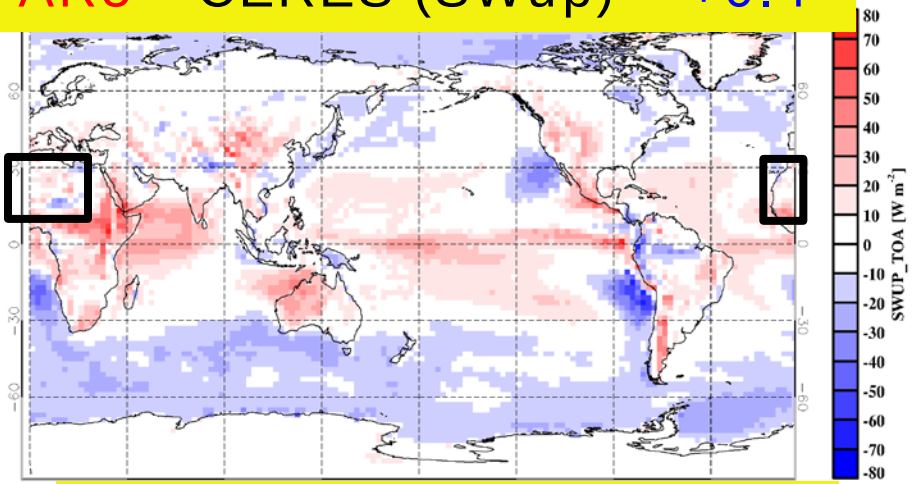
As we expected, the AR5 modeled OLR is lower (ΔLW=-8.9 Wm^{-2}) than CERES result due to model overestimation of high CFs, and high-level cloud-top temp is much lower than desert surface temperature.

Impacts of Clouds on SWup, LWup, and NET fluxes

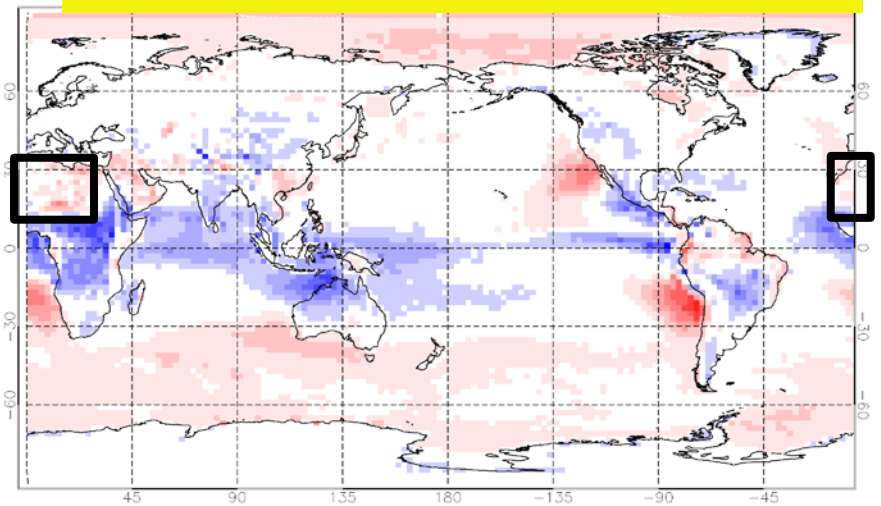
AR5 – CERES (CF) = +14.5



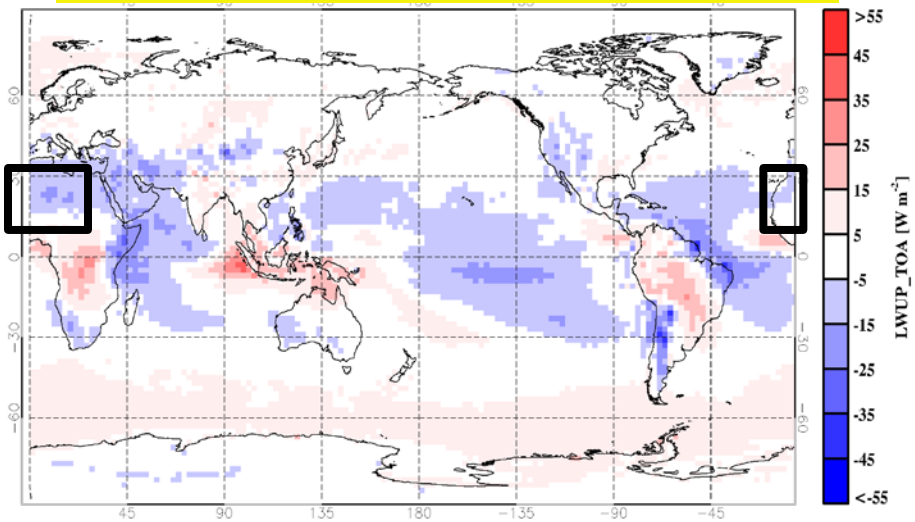
AR5 – CERES (SWup) = +0.4



AR5 – CERES (NET) = +12

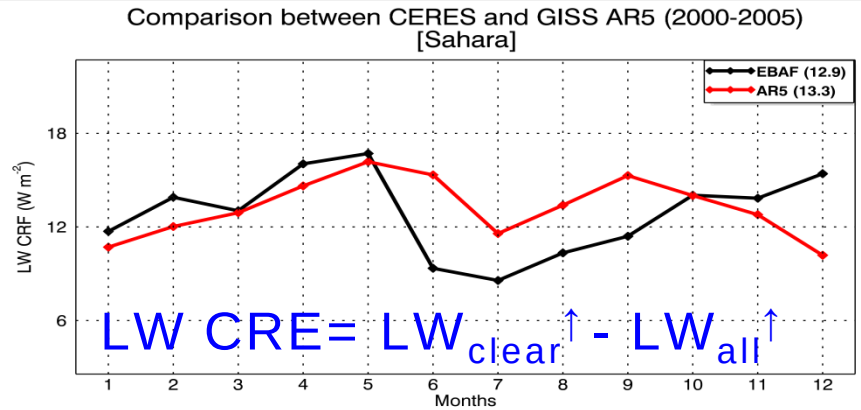


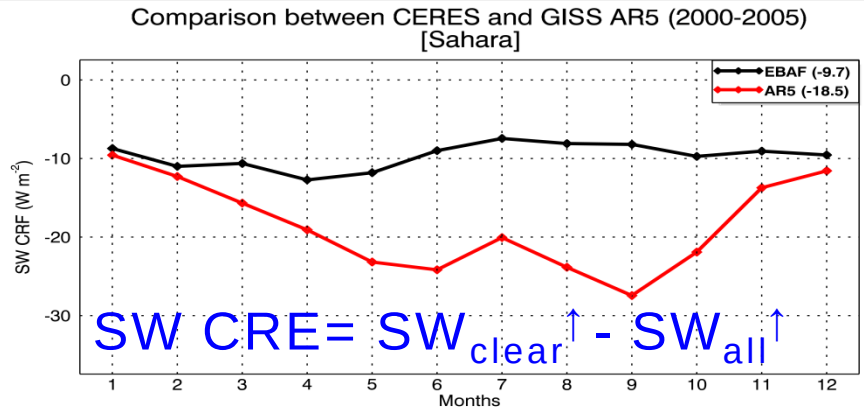
AR5 – CERES (OLR) = -8.9

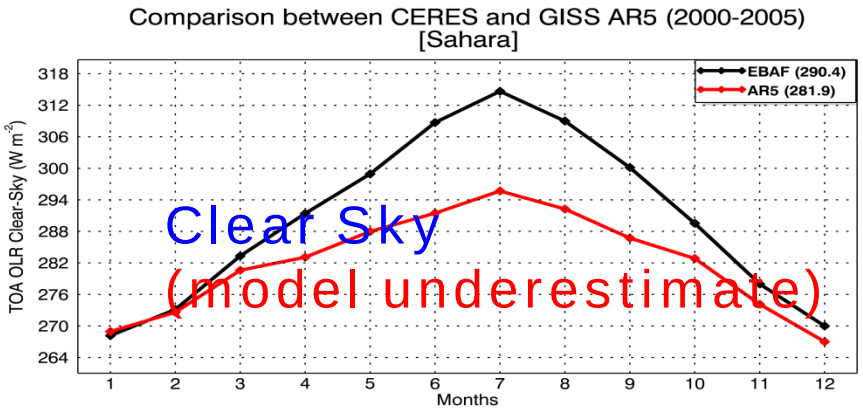


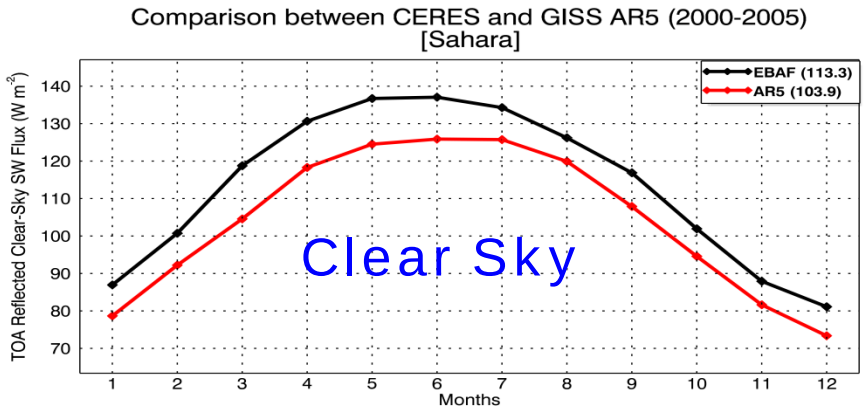
Over the Sahara, modeled SWup is slightly higher while modeled OLR is lower (due to overestimated high clouds). The decrease in OLR outweighs the increase in SWup, leading to a higher modeled NET flux. NET flux=(SWdown – SWup) – OLR

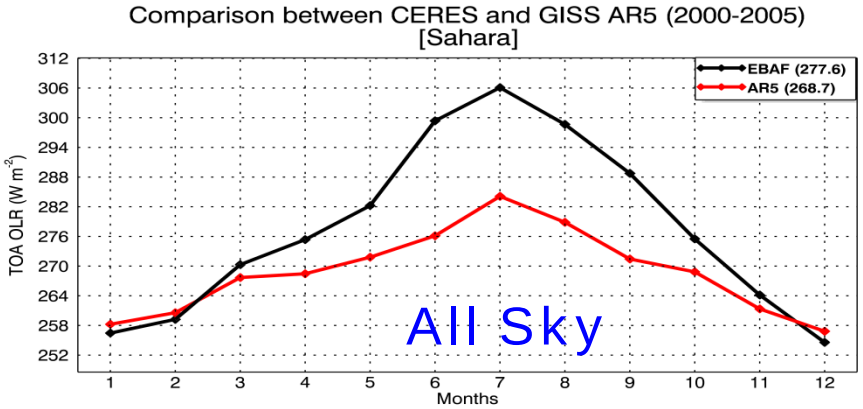
Comparison of Clear-sky, All-sky and CREs

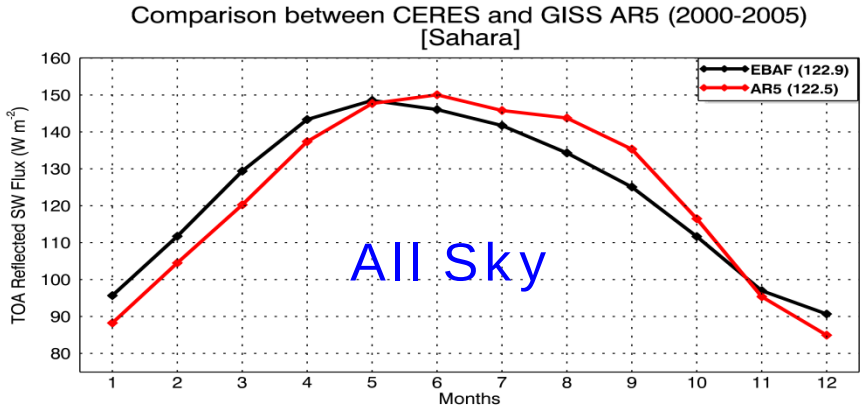






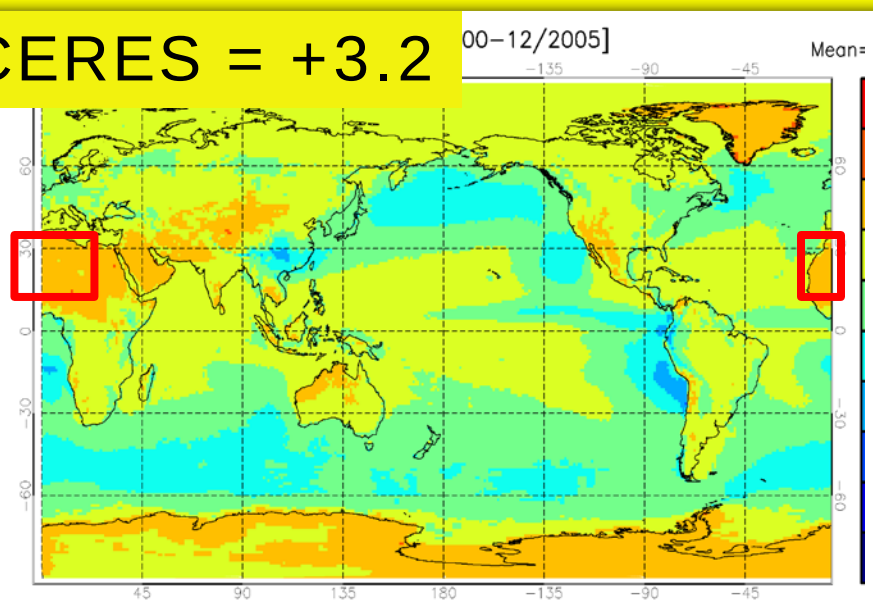




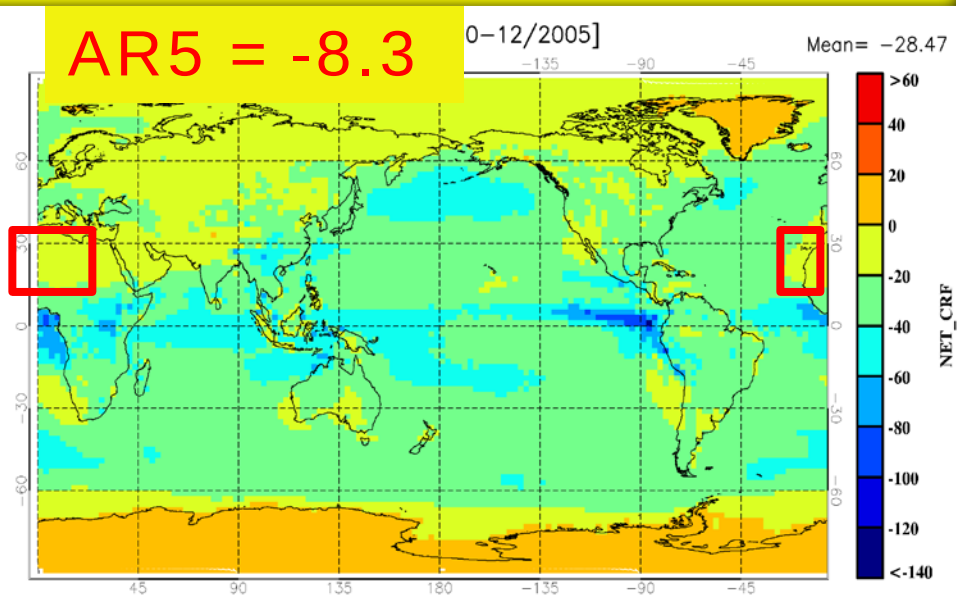


Comparison of NET CRE between CERES and AR5

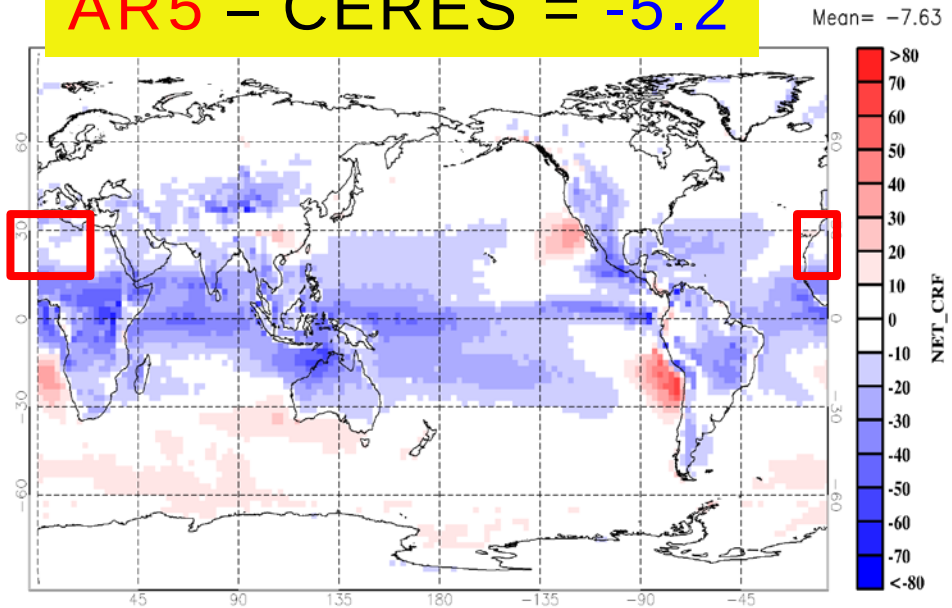
CERES = +3.2



AR5 = -8.3



AR5 – CERES = -5.2



NET CREs over Sahara

CERES:
NET CRE=SW CRE+LW CRE
= -9.7+ 12.9= 3.2

AR5:
NET CRE=SW CRE+LW CRE
= -18.5+ 13.3= -5.2

Summary and Conclusions

- Although their global mean CF difference is within 1%, there are significant differences over some regions, which have significant impacts on the regional TOA radiation budgets.

  In this study, we have selected two regions: Southern Mid-lat and Sahara Desert.

Southern Mid-Latitudes

➔Model underestimates low-level clouds, which leads to larger underestimation of SWup (**Δ**SW= -12.9 Wm^{-2}) and small overestimation of OLR (**Δ**LW=+2.3 Wm^{-2}).

➔The NET flux is highly dependent of SWup flux difference

➔ Underestimation of LW CRE is due to dry bias

Sahara

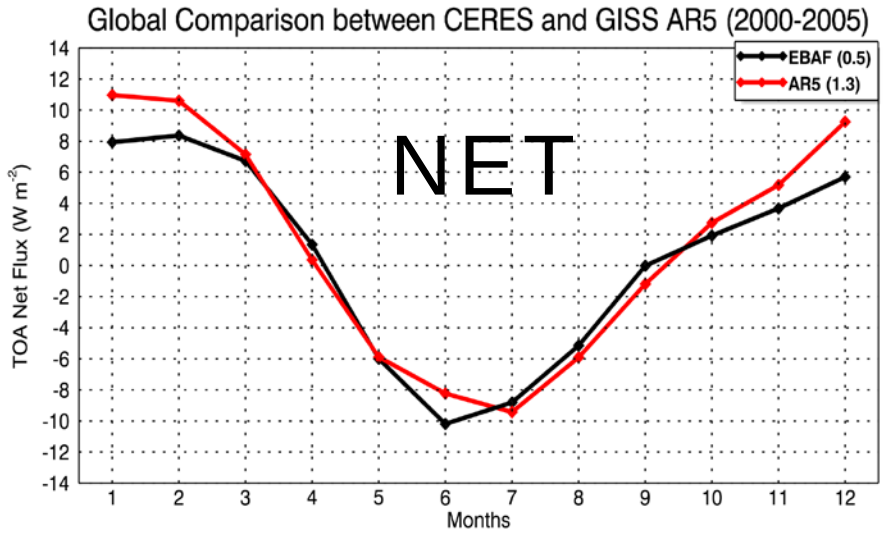
➔Model overestimates high-level clouds.

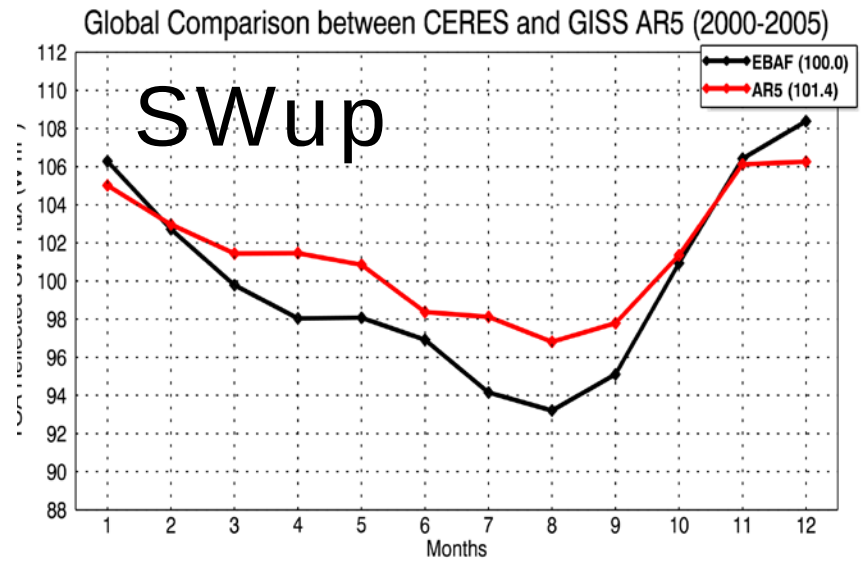
➔Modeled SWup is slightly higher (ΔSW= +0.4 Wm^{-2}) while modeled OLR is much lower (**Δ**LW=-8.9 Wm^{-2}) than CERES results, leading to a higher modeled NET flux.

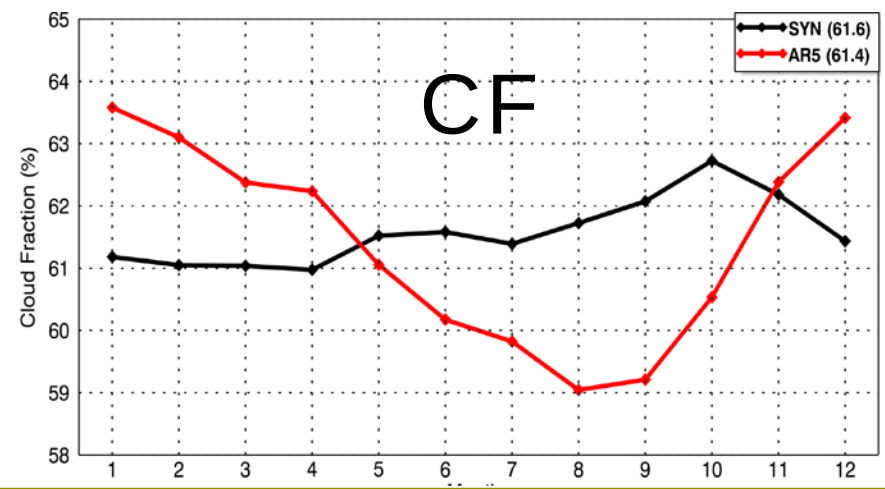
➔Modeled clear-sky SWup is much lower (ΔC-SW= -9.4 Wm^{-2}), leading to large difference in SW CRE.

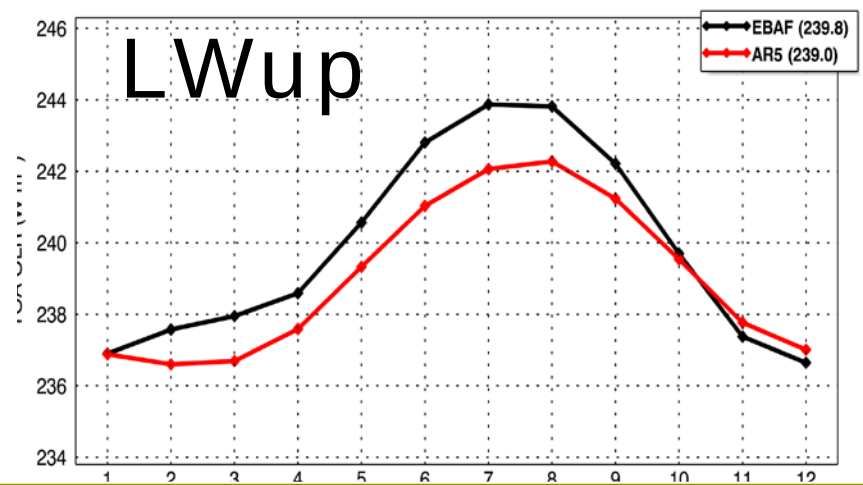
Reference Slides

Monthly mean Comparisons



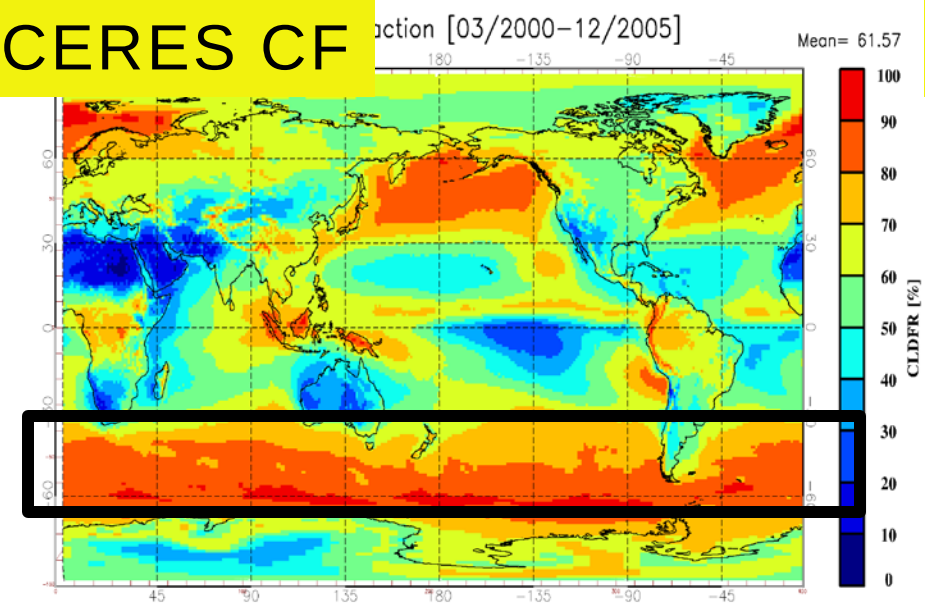




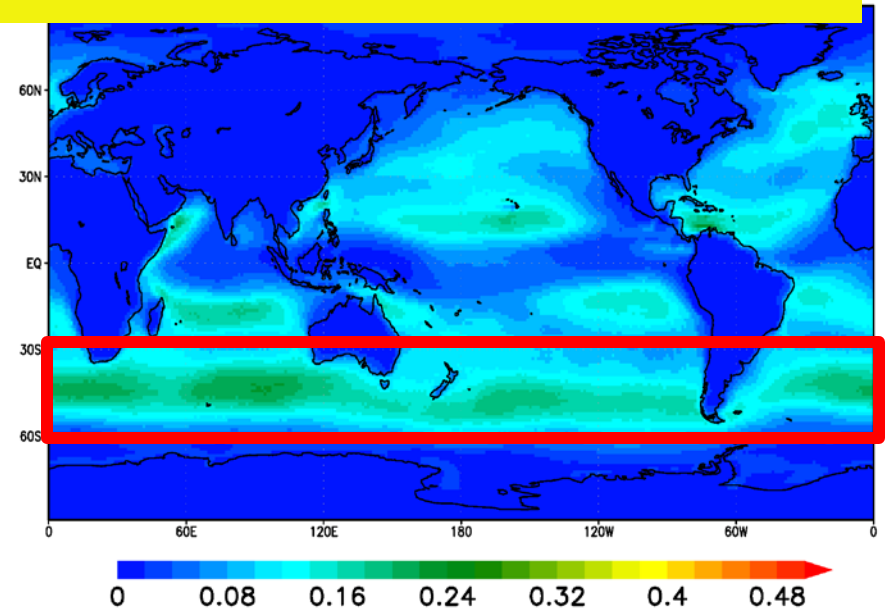


Excellent agreement in NET flux, compensated from SWup and LWup flux differences. However, they are NOT associated with CF➔This is the reason we need do regional studies.

CERES CF

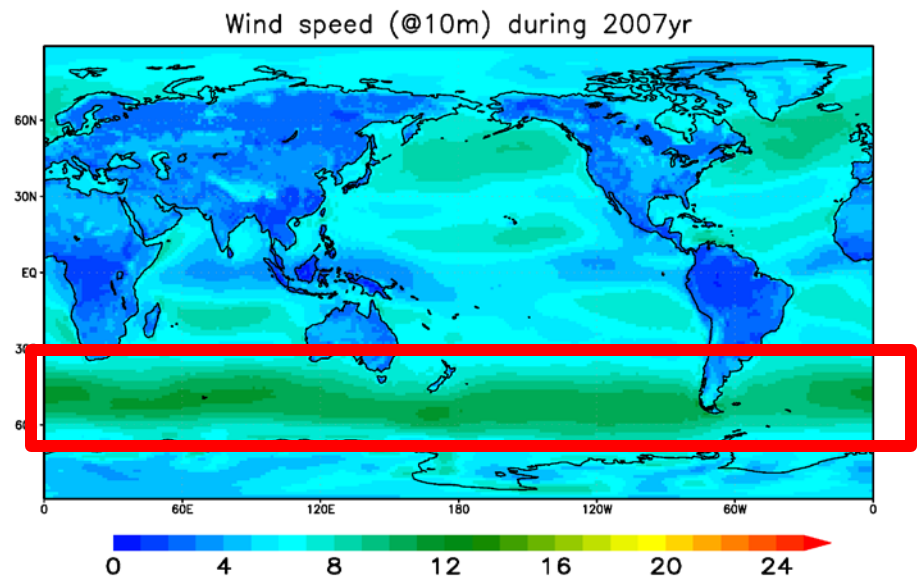


Simulated Sea Salt AOT

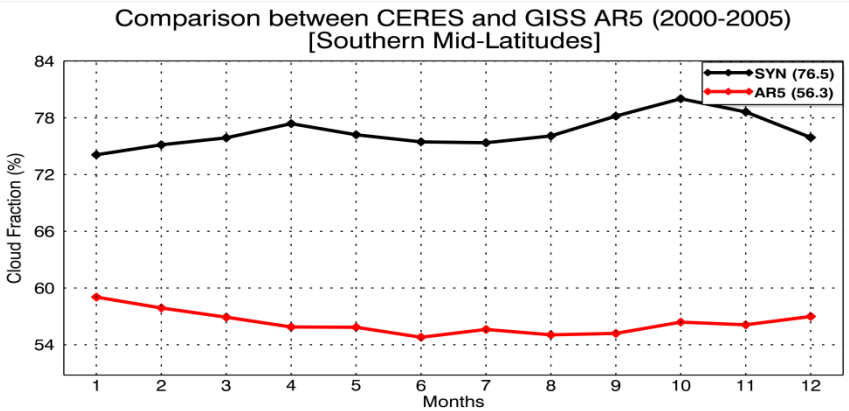


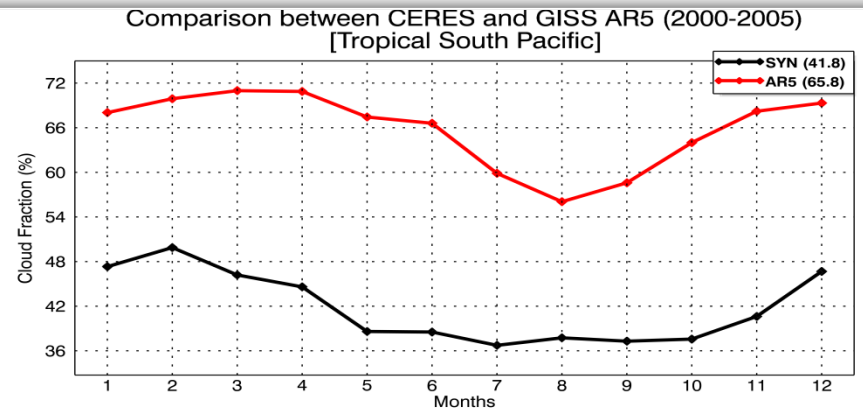
More Low-level clouds over Southern Mid-latitudes are strongly related to higher Sea-salt AOT and surface wind Speed.

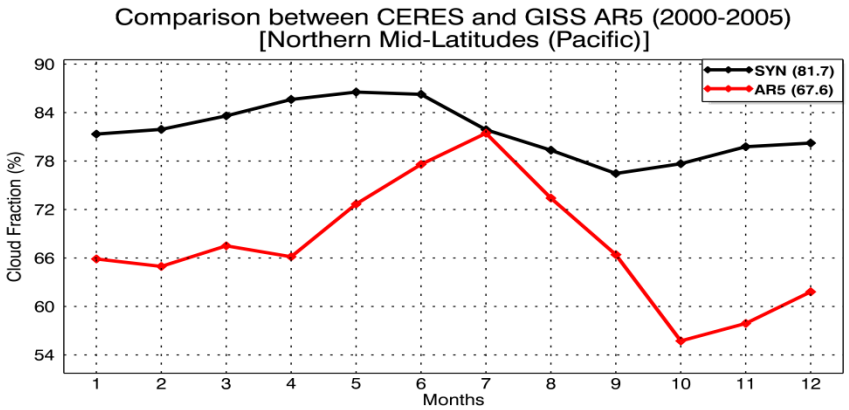
Surface Wind Speed

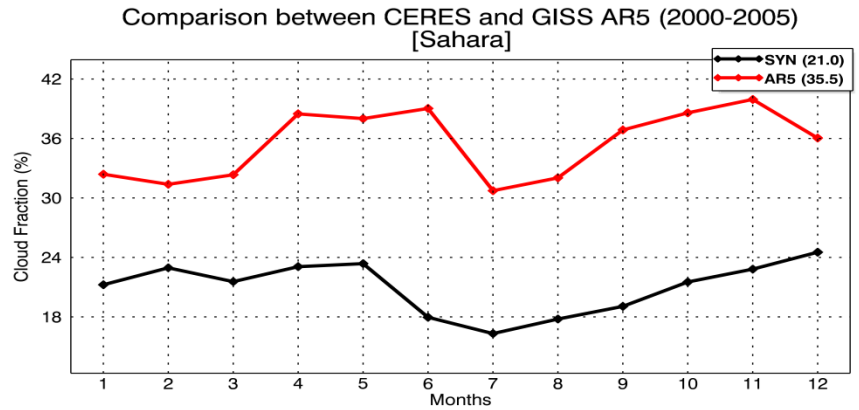


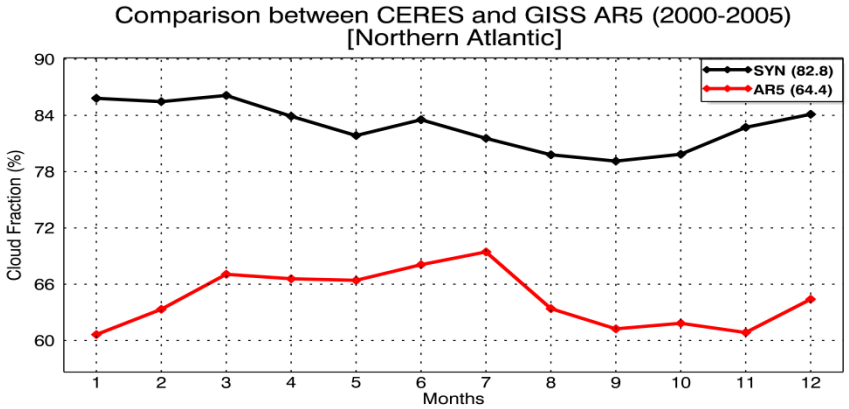
Comparison of CF

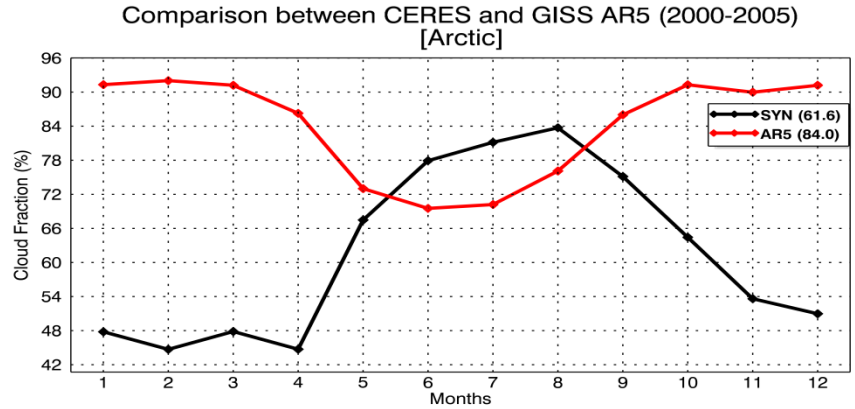




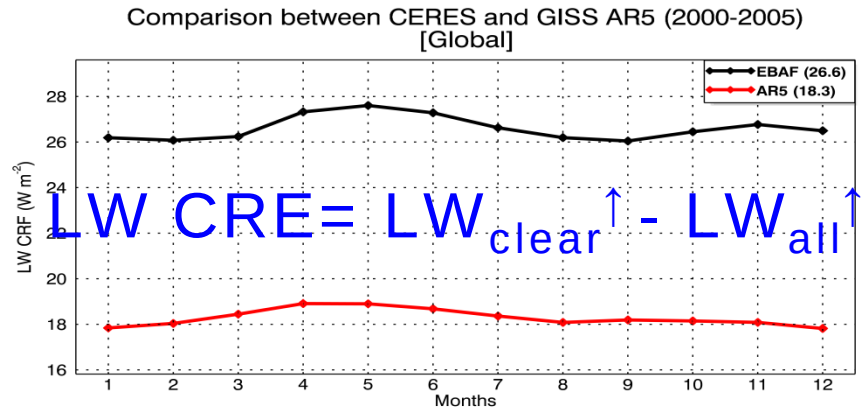


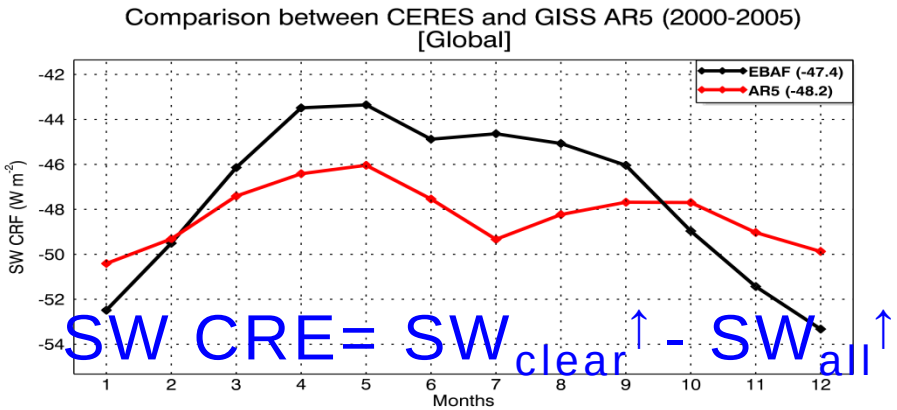


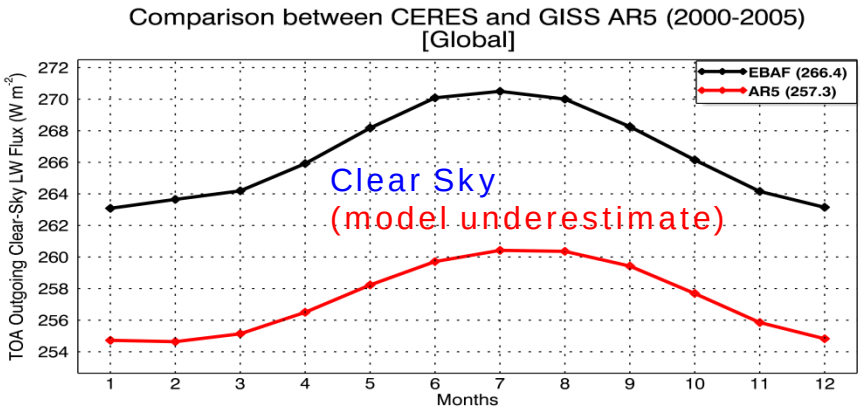


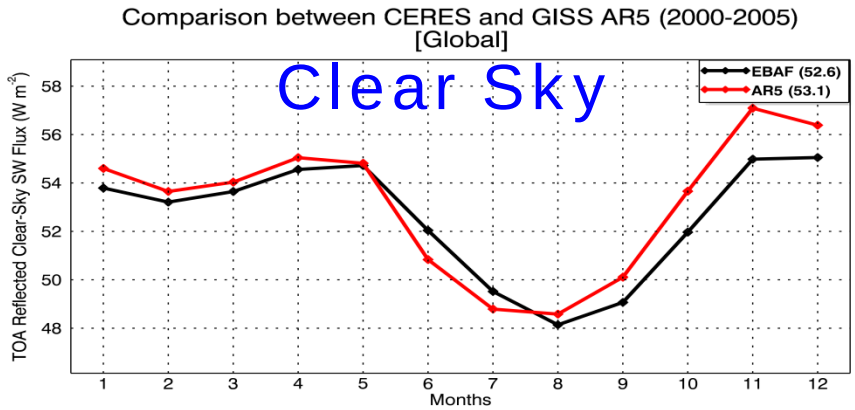


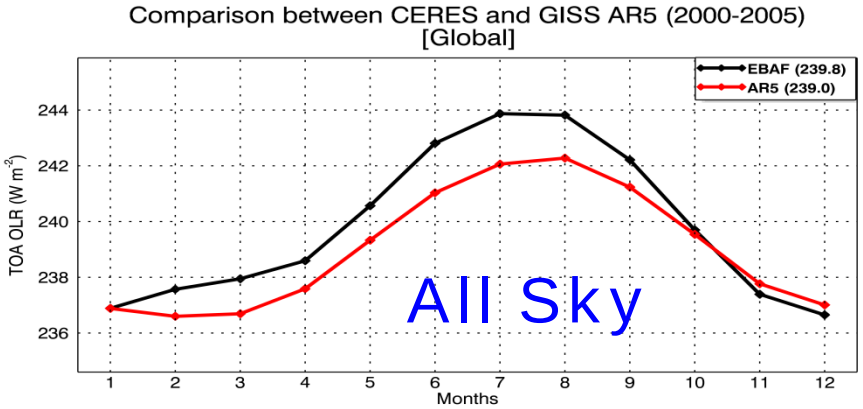
Comparison of Clear-sky, All-sky and CREs

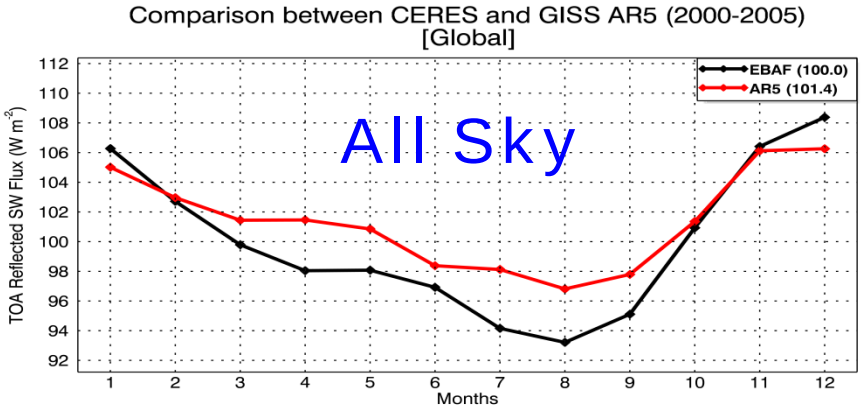




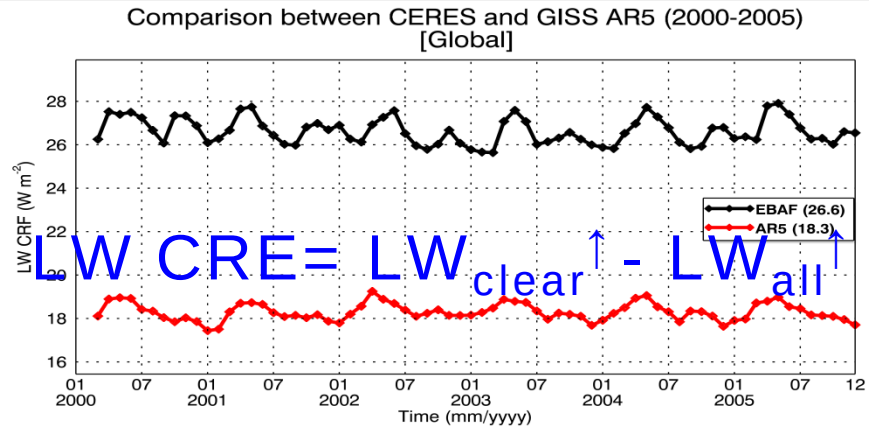




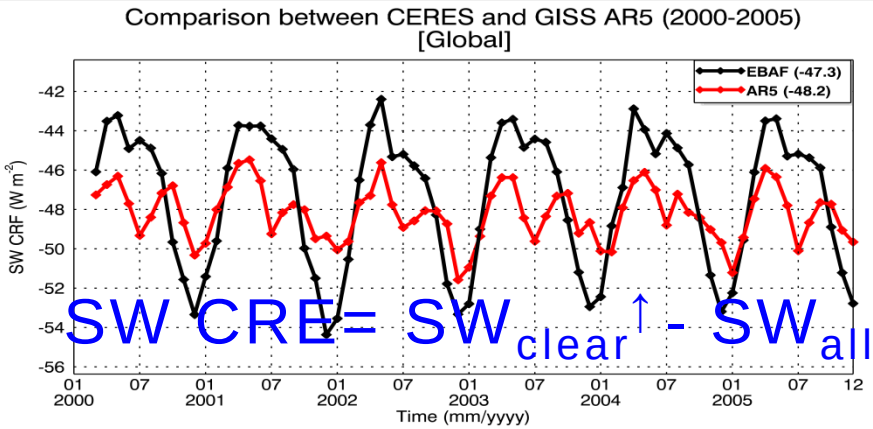




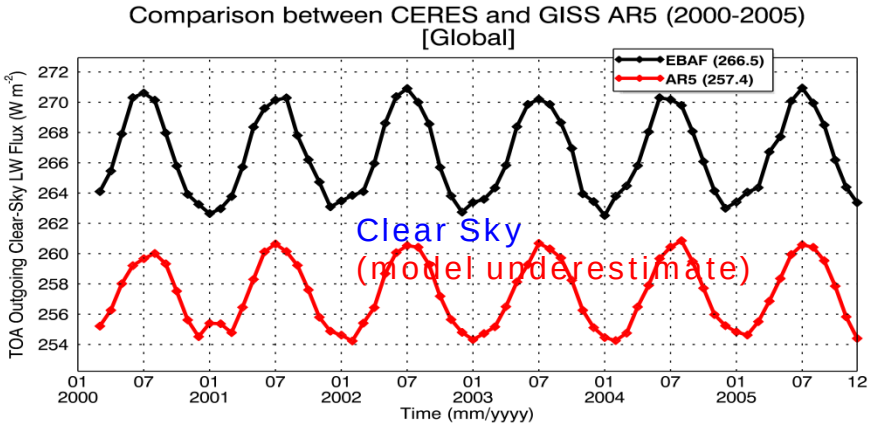
Comparison of Clear-sky, all-sky and CREs

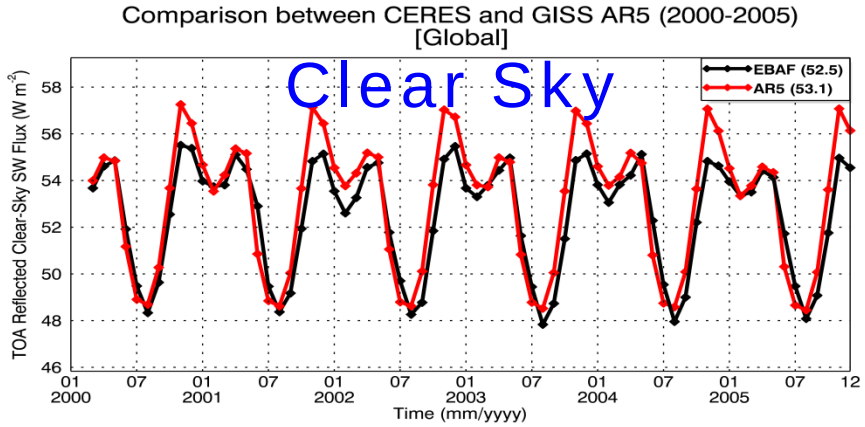


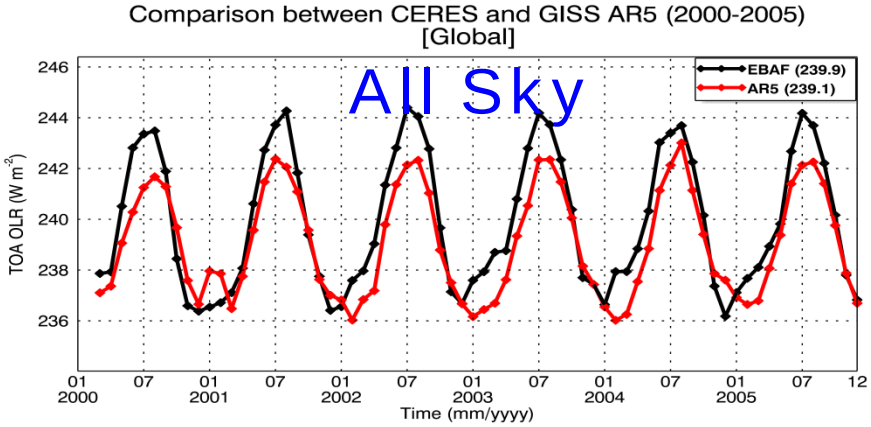
$$LW\ CRE = LW_{clear}\uparrow - LW_{all}\uparrow$$

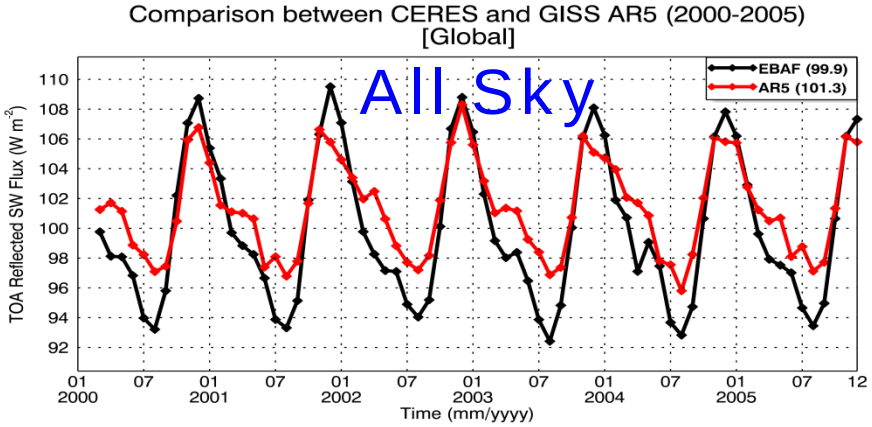


$$SW\ CRE = SW_{clear}\uparrow - SW_{all}\uparrow$$

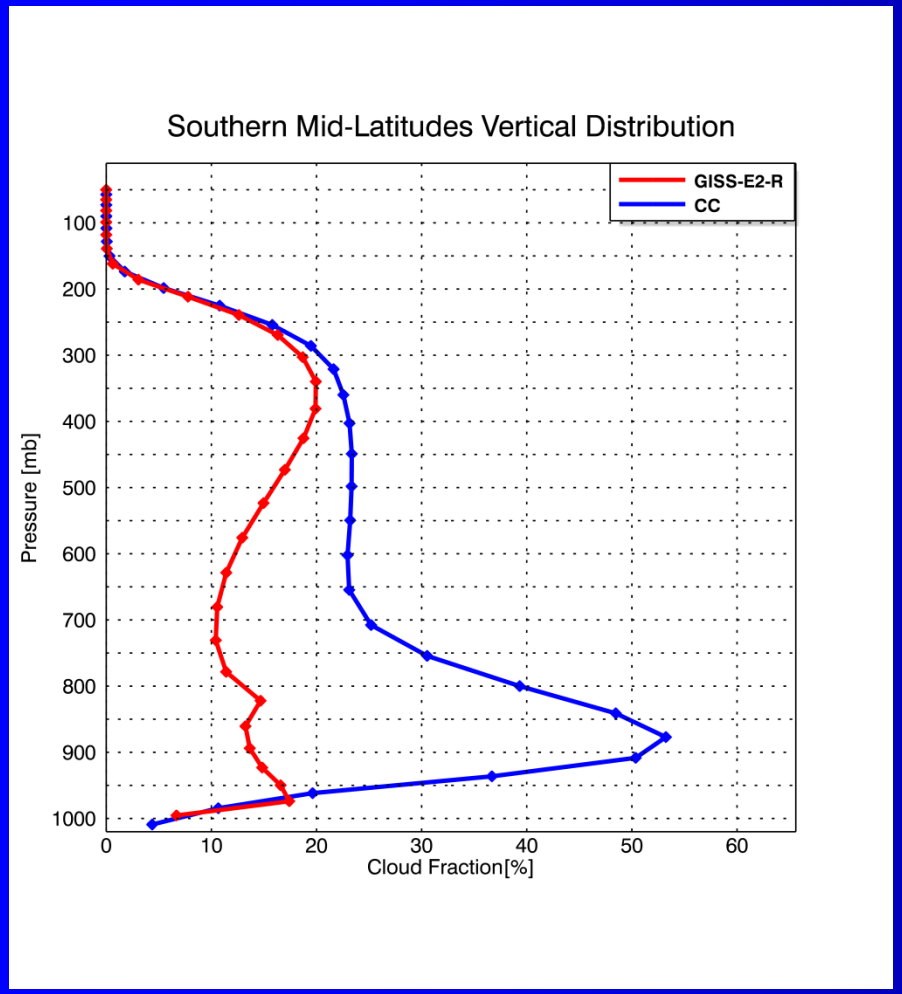


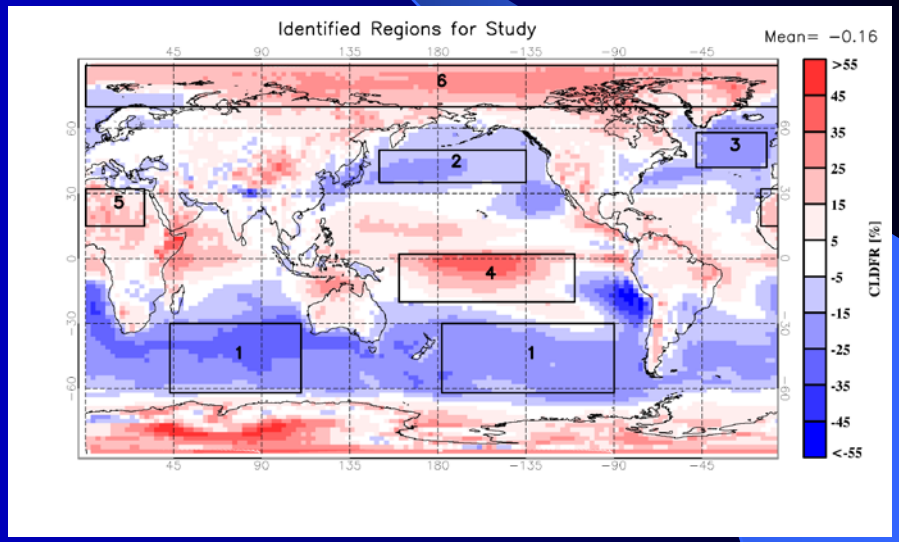




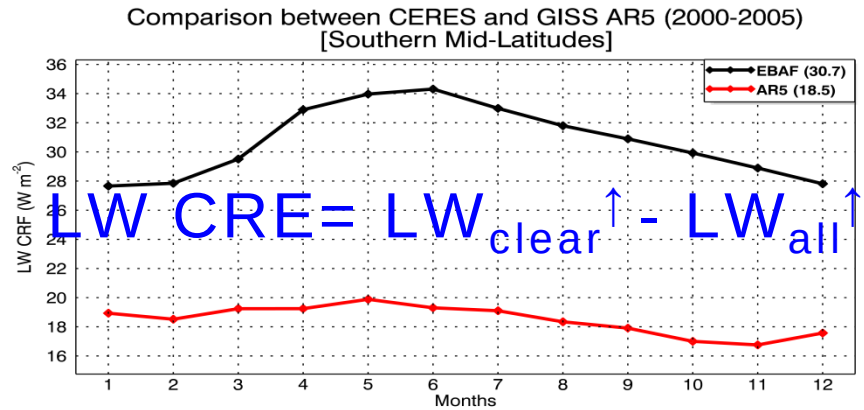


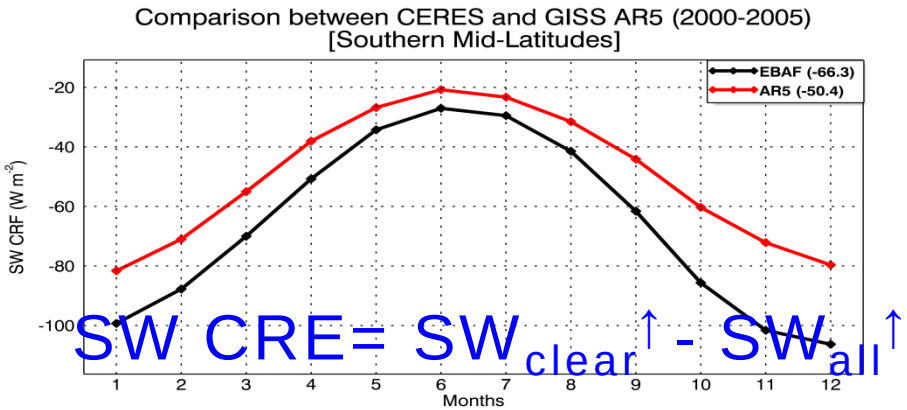
Zone 1 – Southern Mid-Latitudes

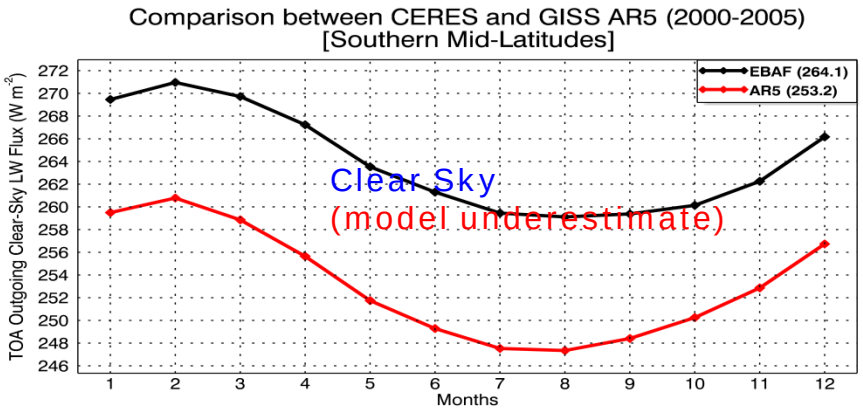


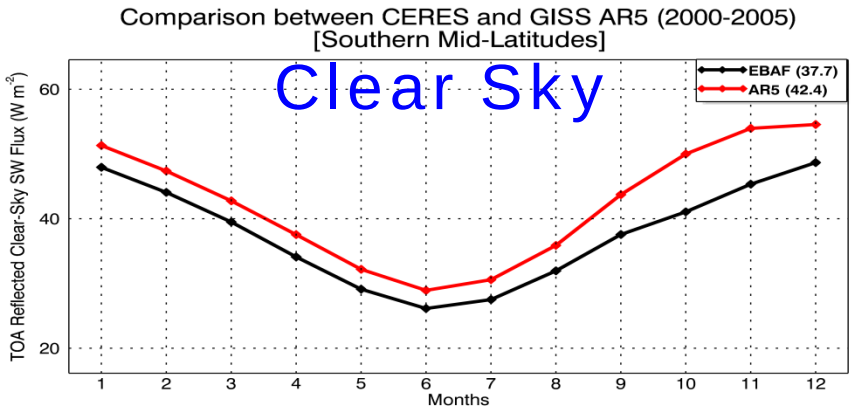


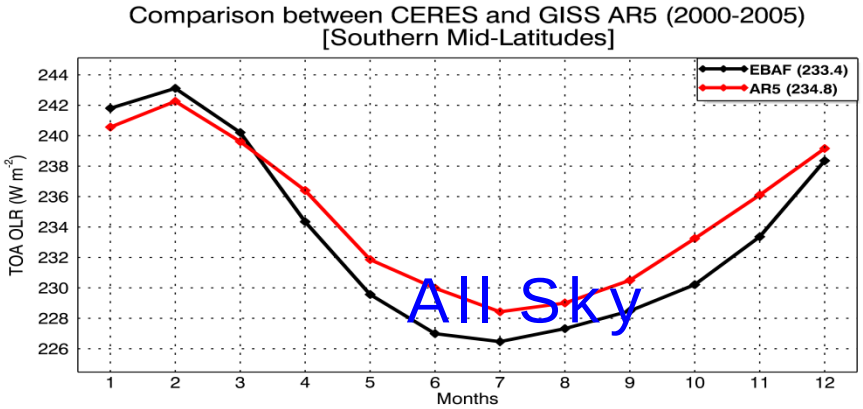
Comparison of Clear-sky, All-sky and CREs

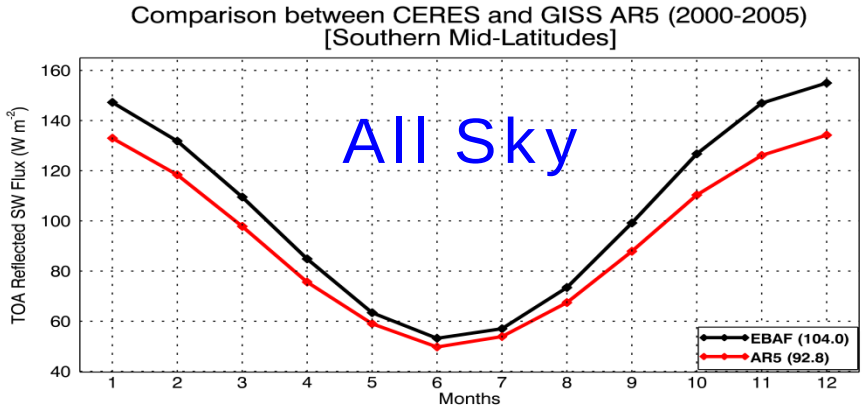




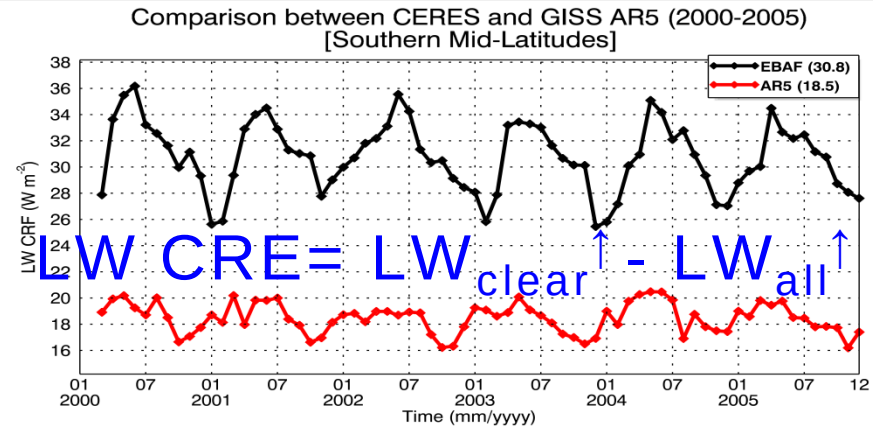


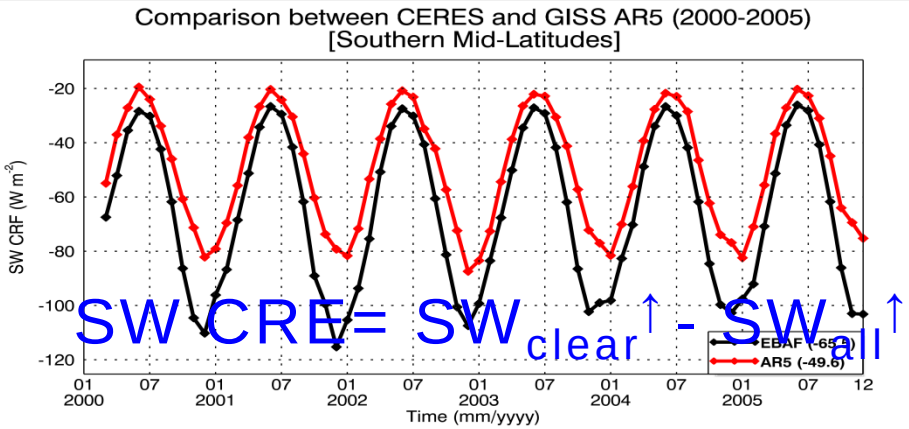


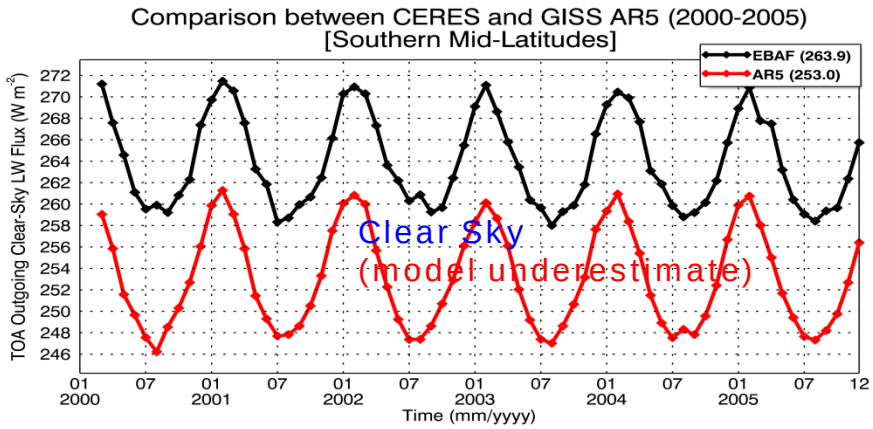


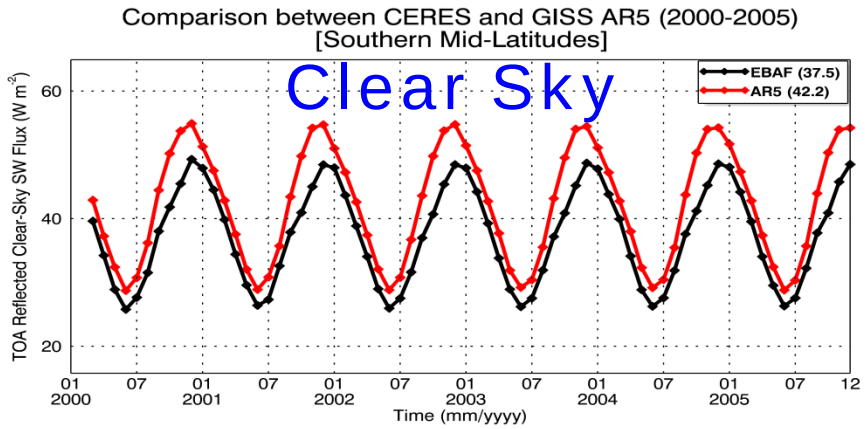


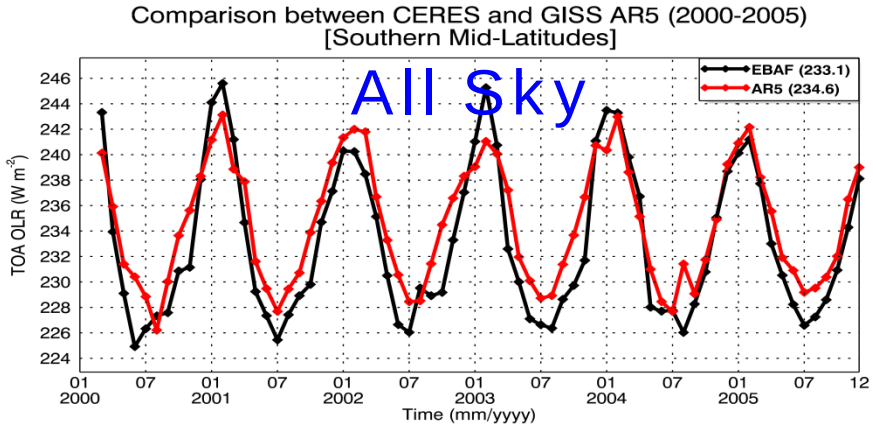
Comparison of Clear-sky, all-sky and CREs

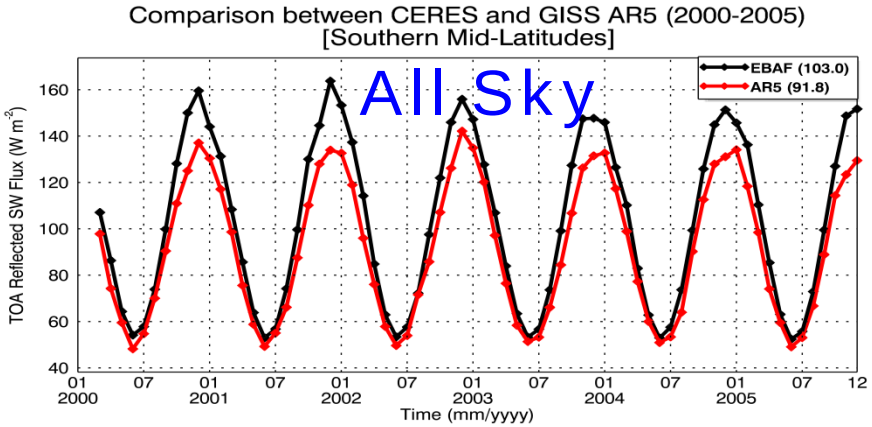




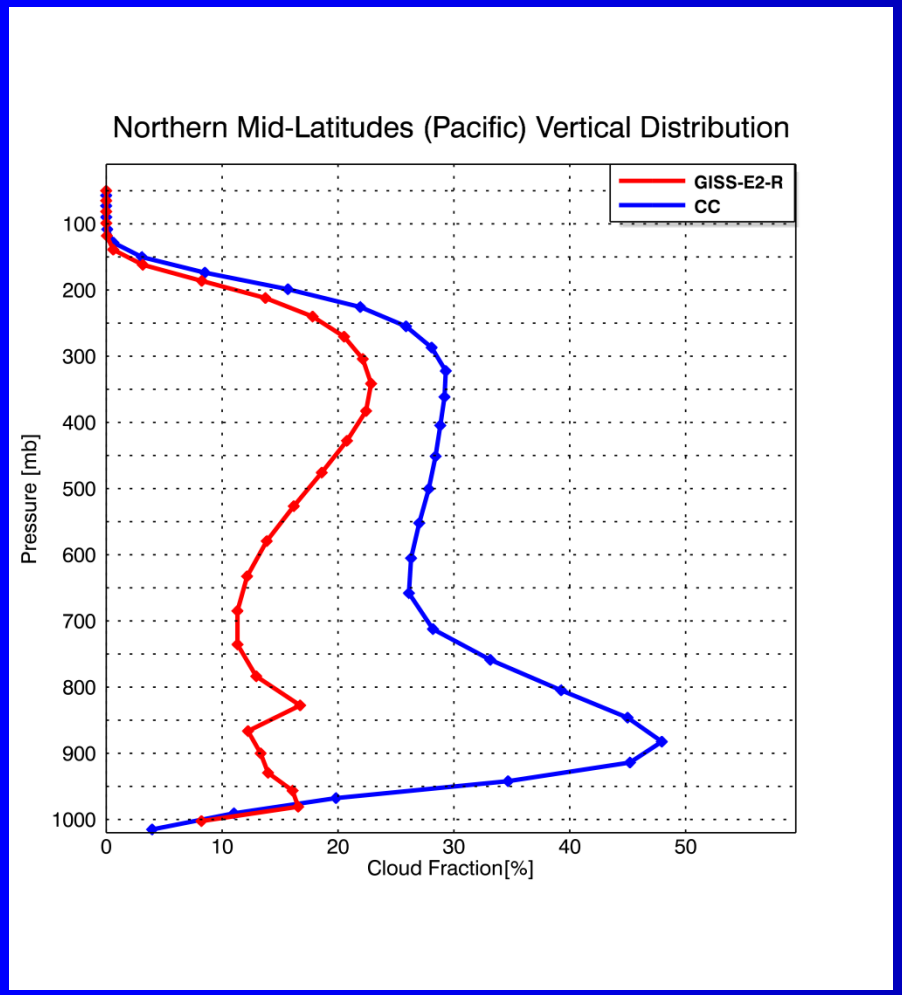


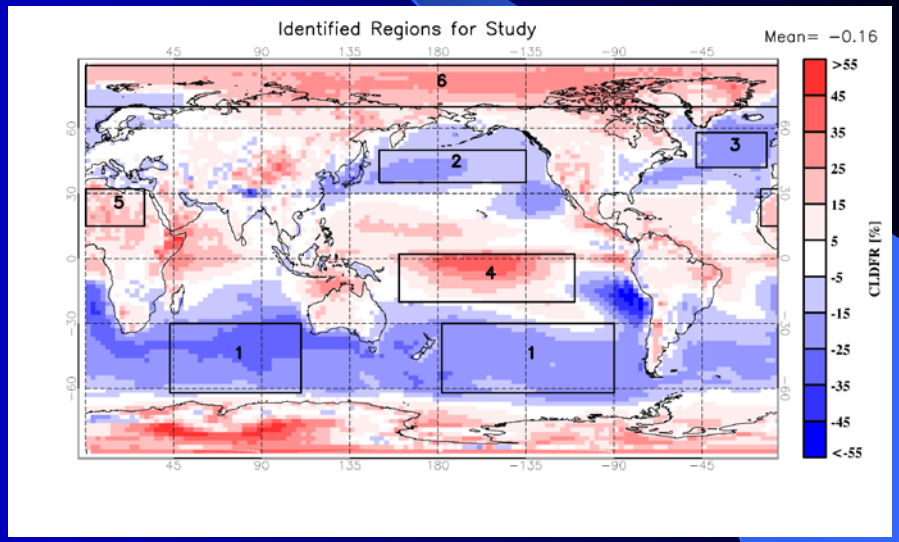




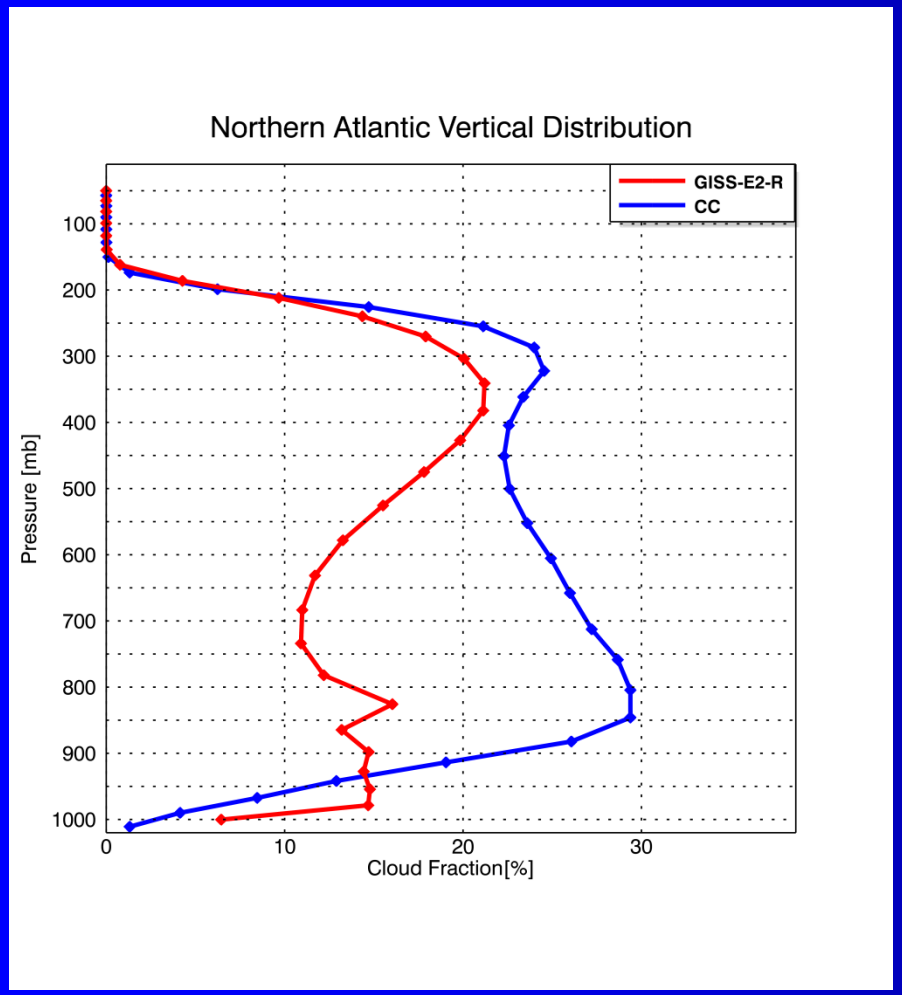


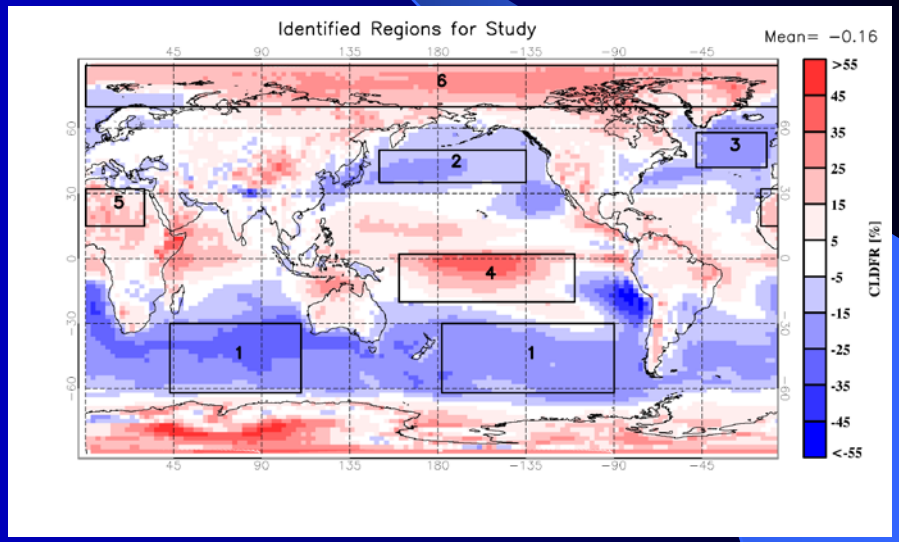
Zone 2 – Northern Mid-Latitudes



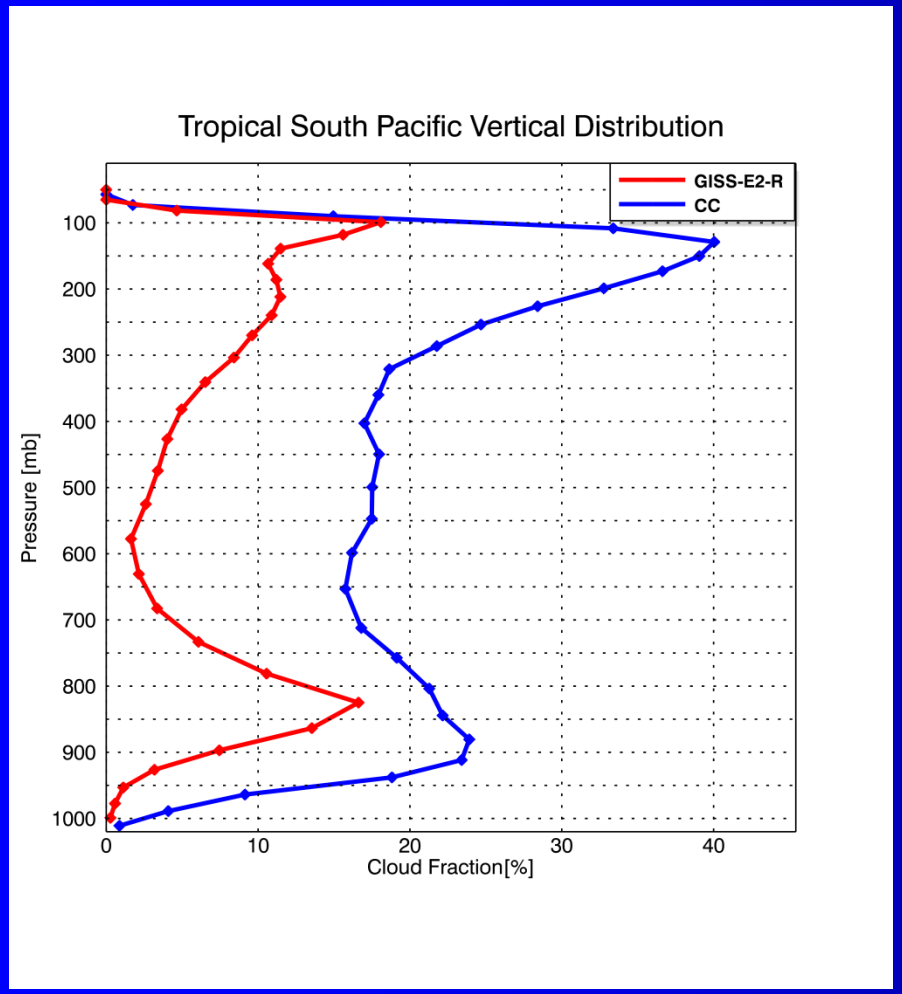


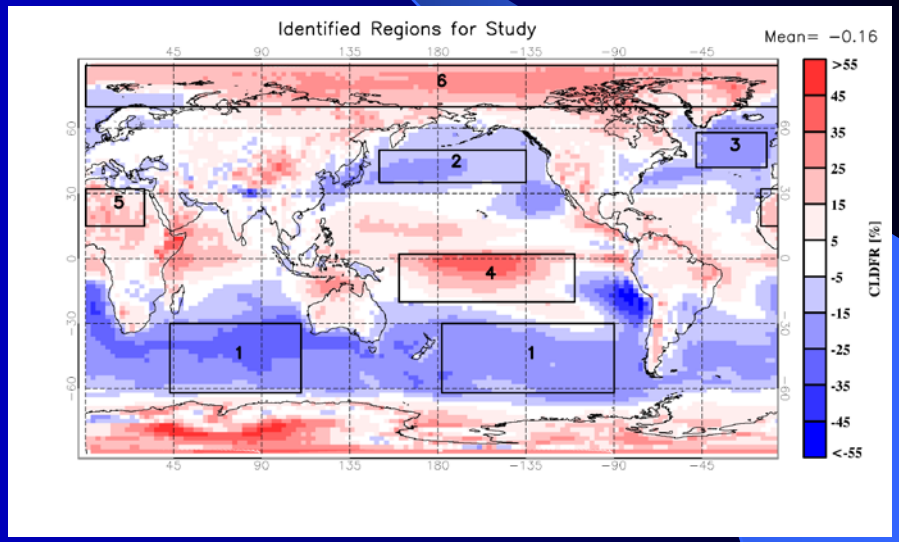
Zone 3 – Northern Atlantic



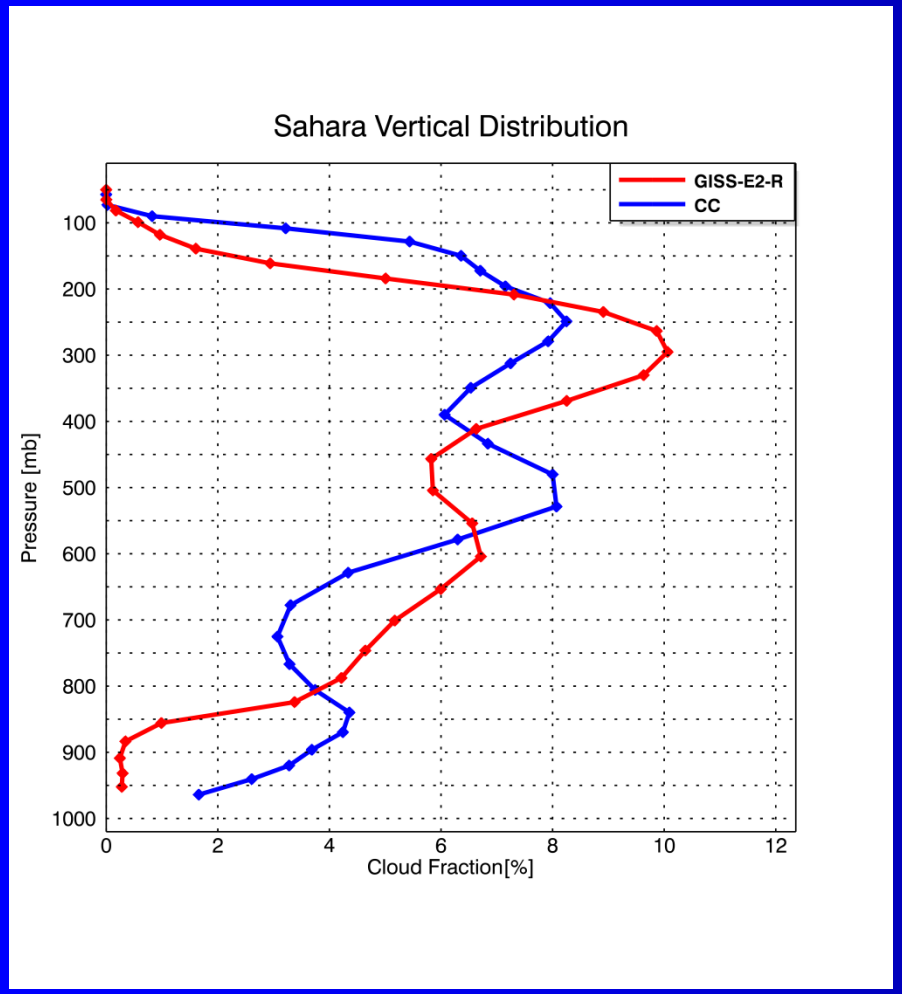


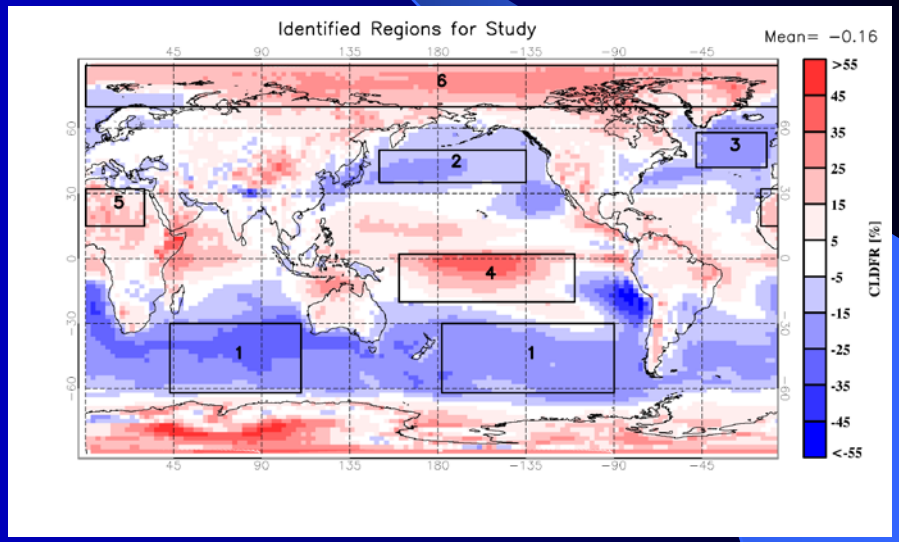
Zone 4 – Tropical South Pacific



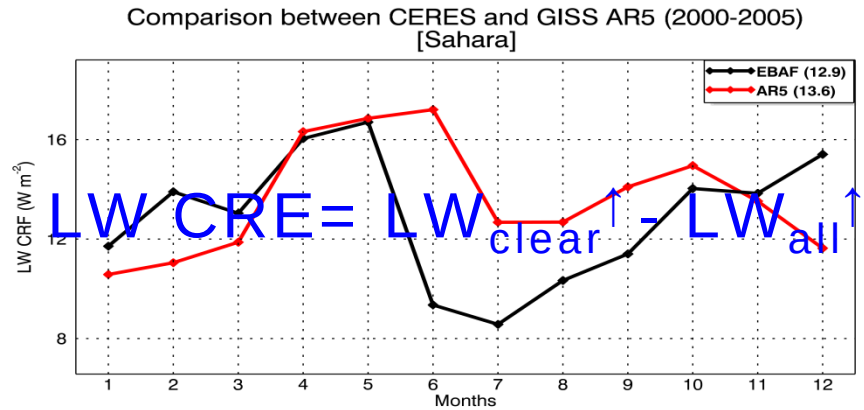


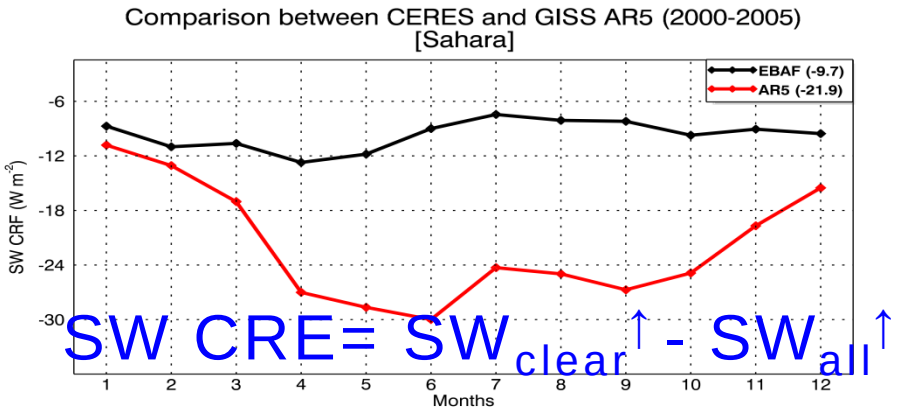
Zone 5 – Sahara

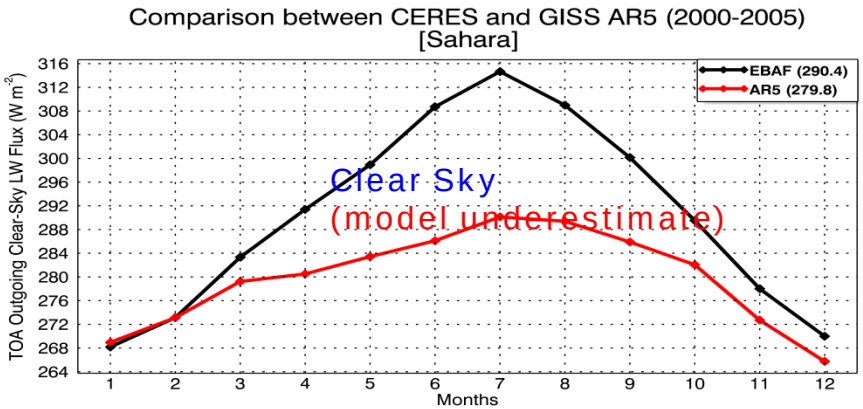


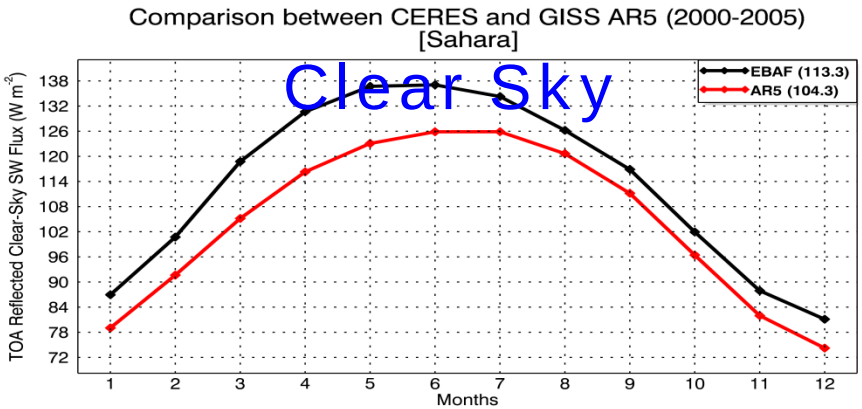


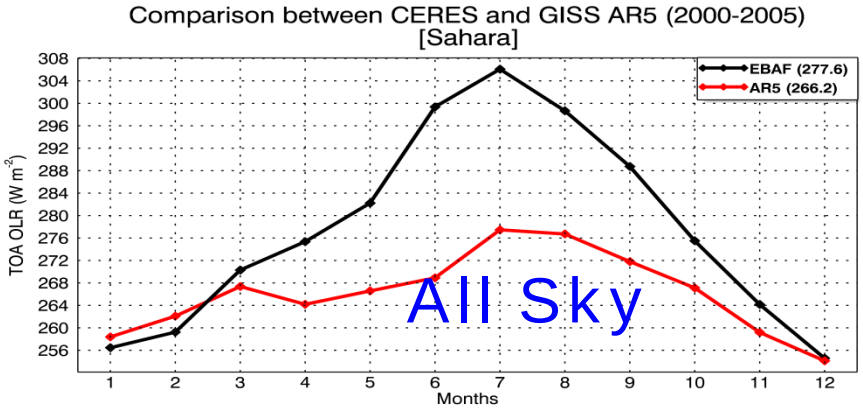
Comparison of Clear-sky, All-sky and CREs

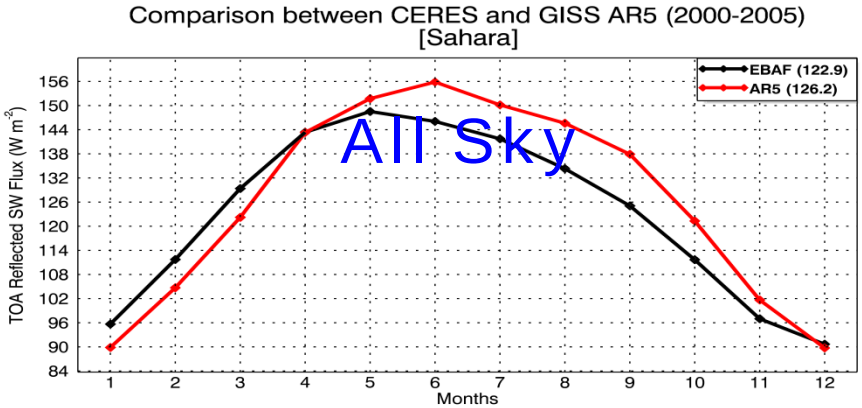




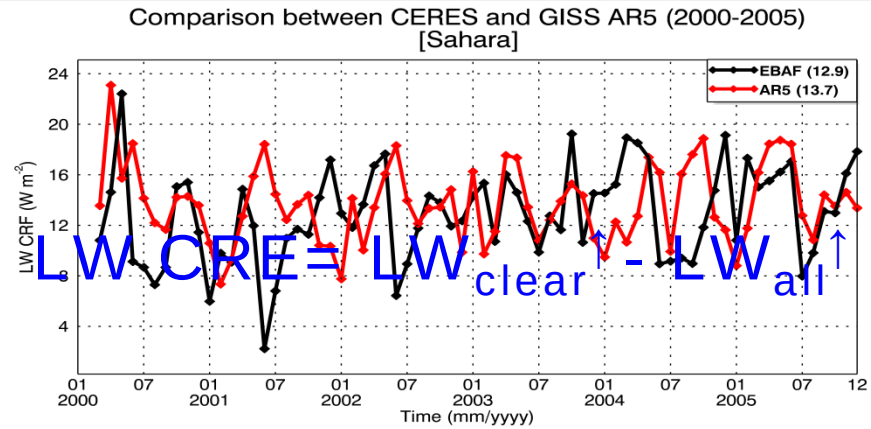


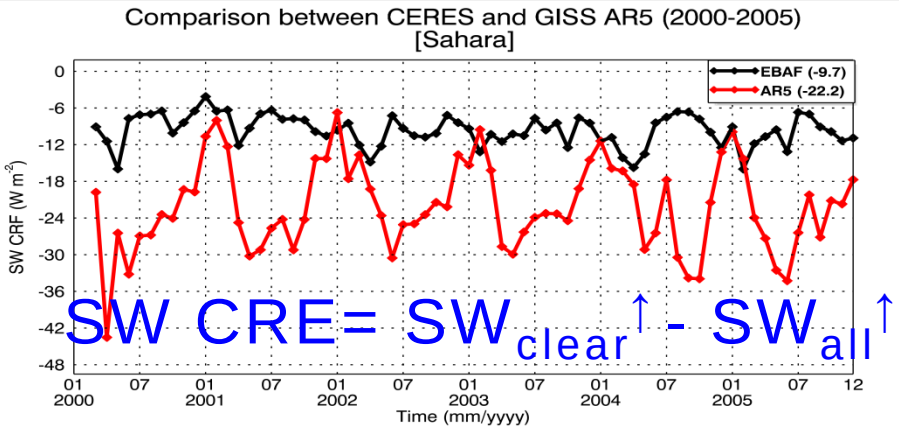


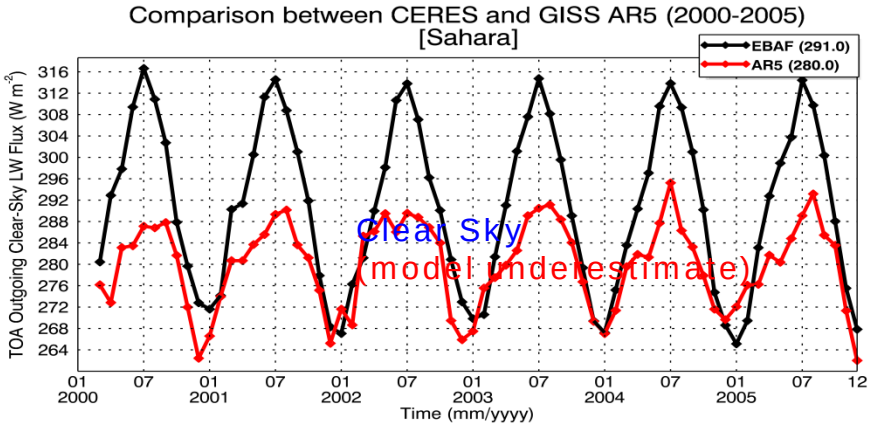


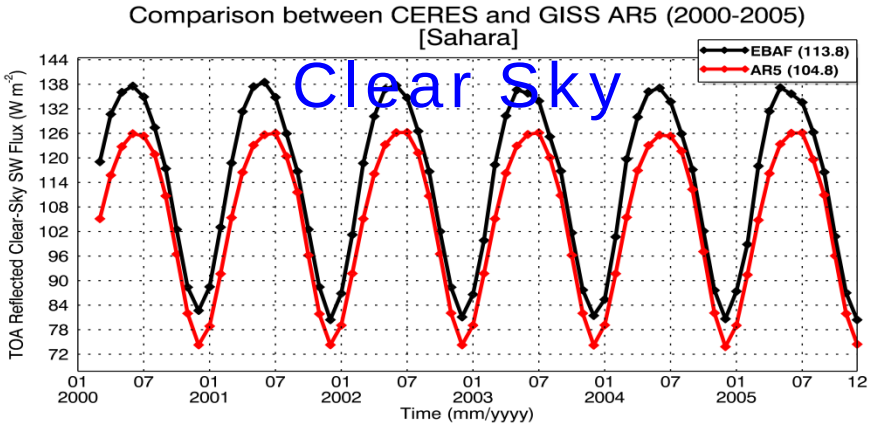


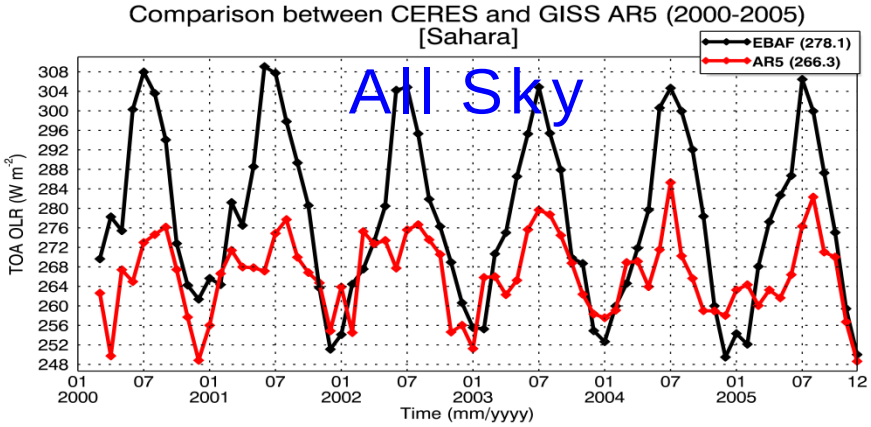
Comparison of Clear-sky, all-sky and CREs

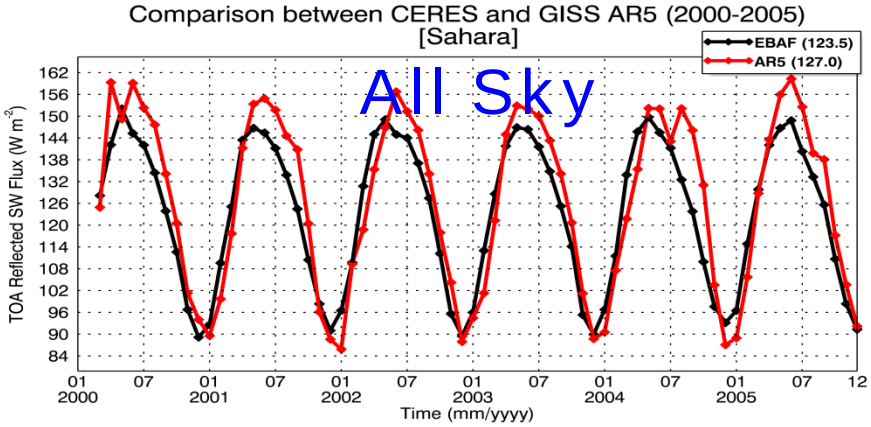




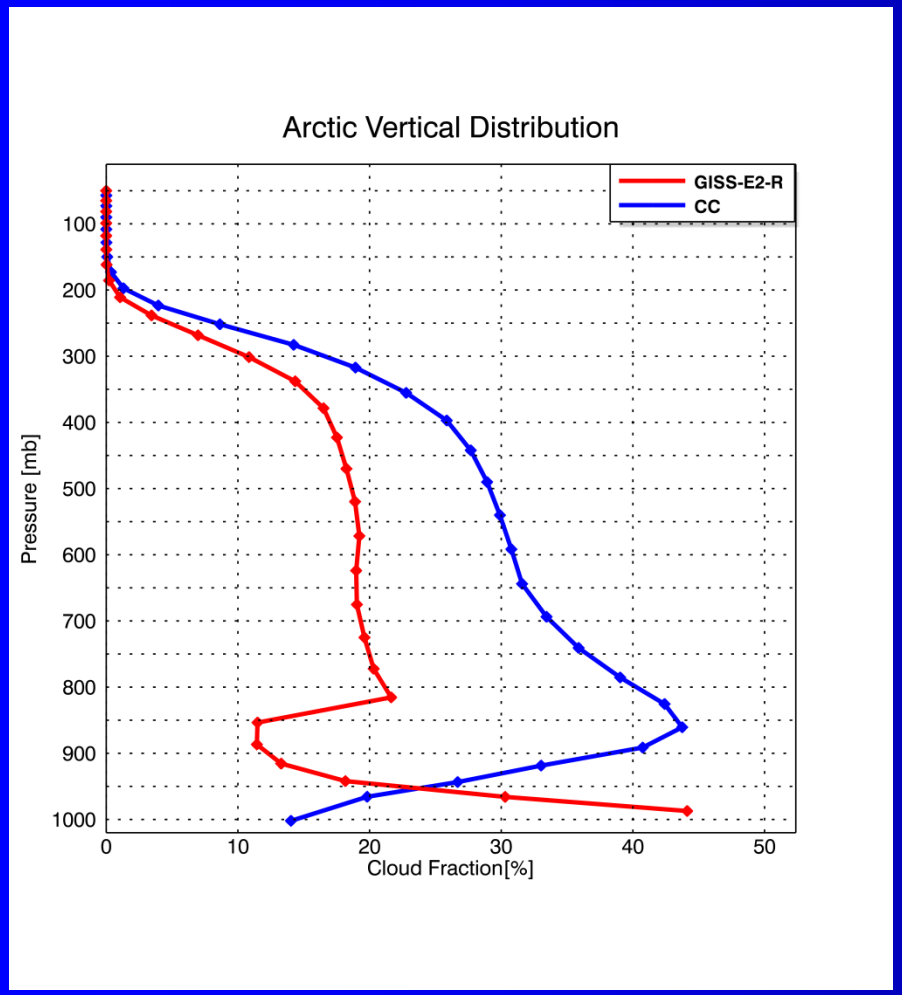


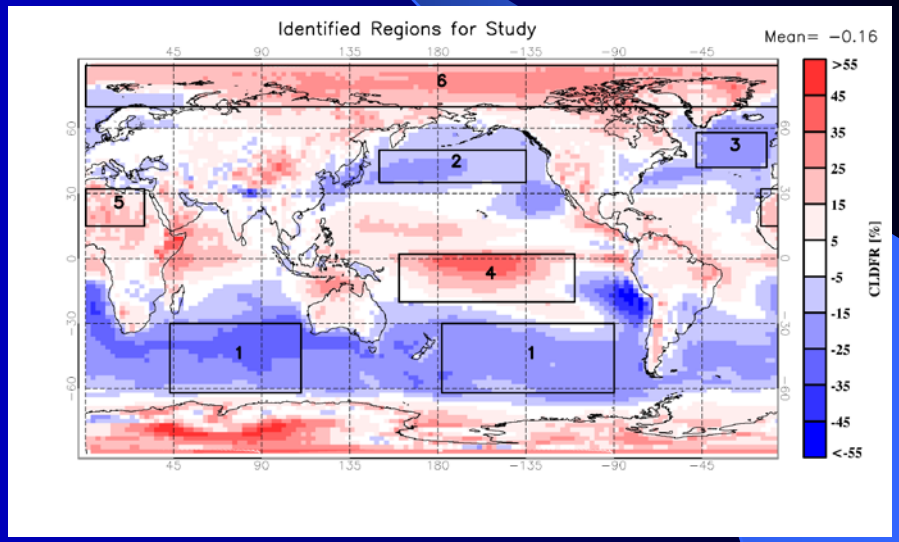




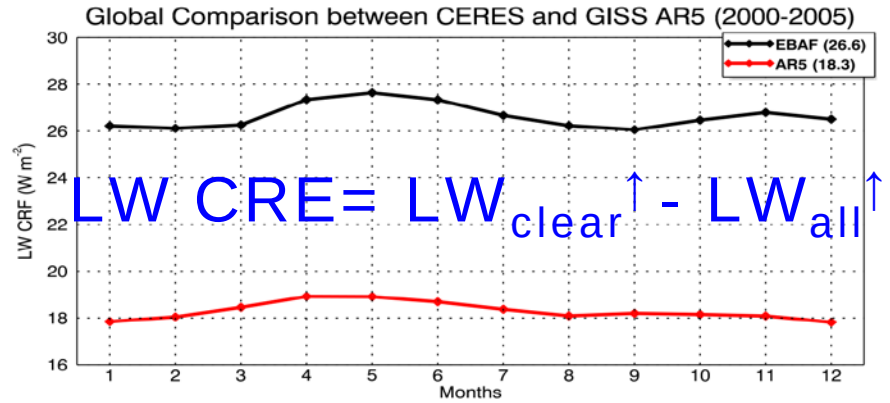


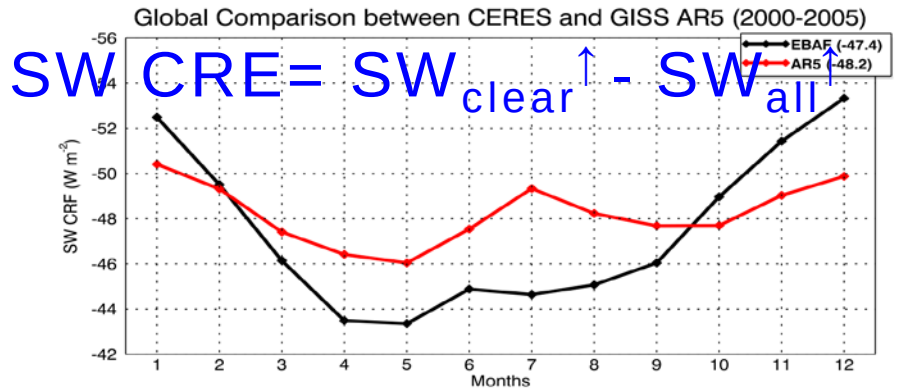
Zone 6 – Arctic

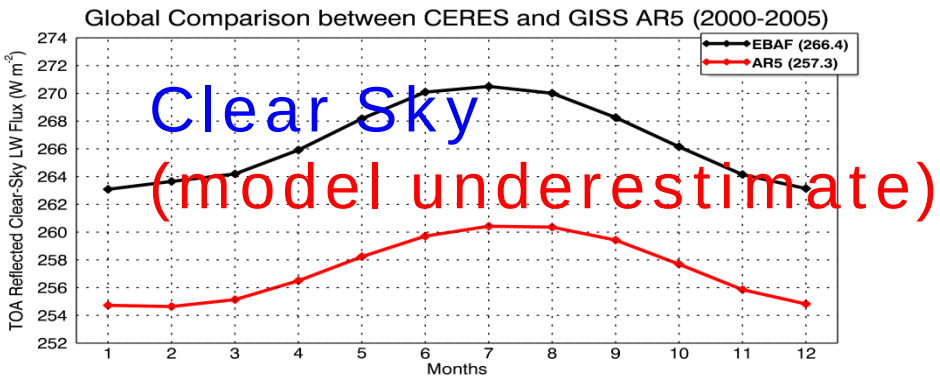


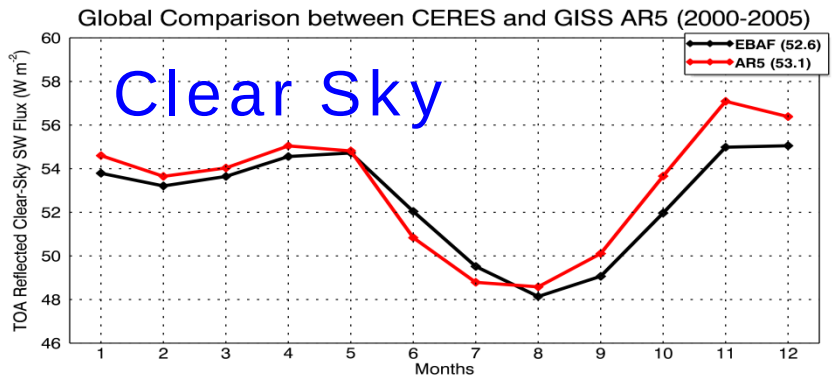


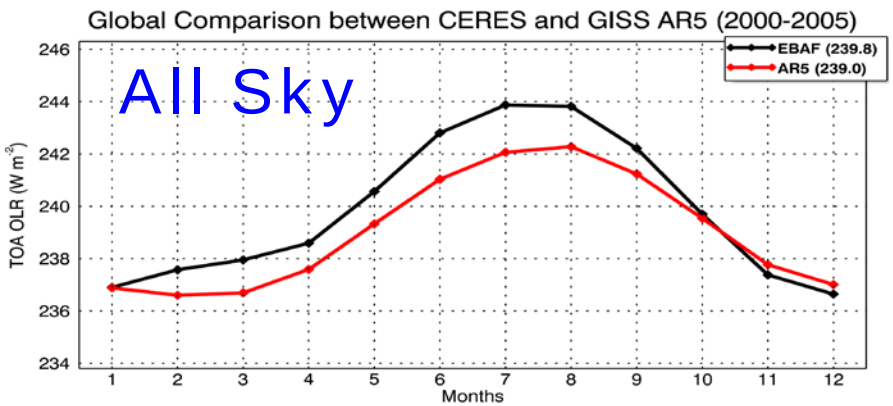
Comparison of Clear-sky, all-sky and CREs

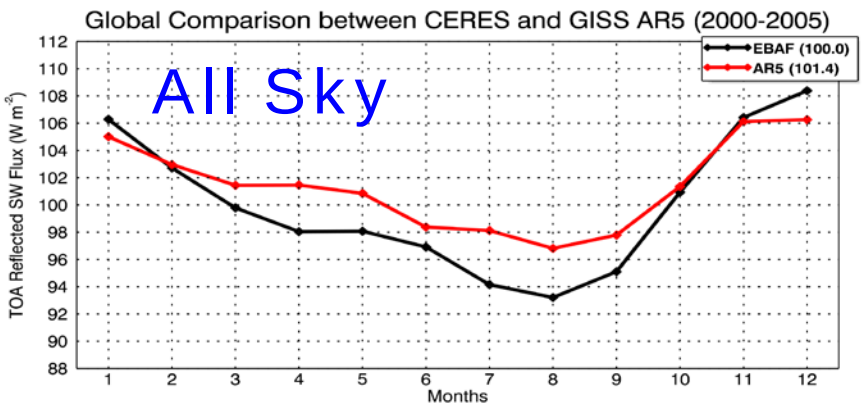


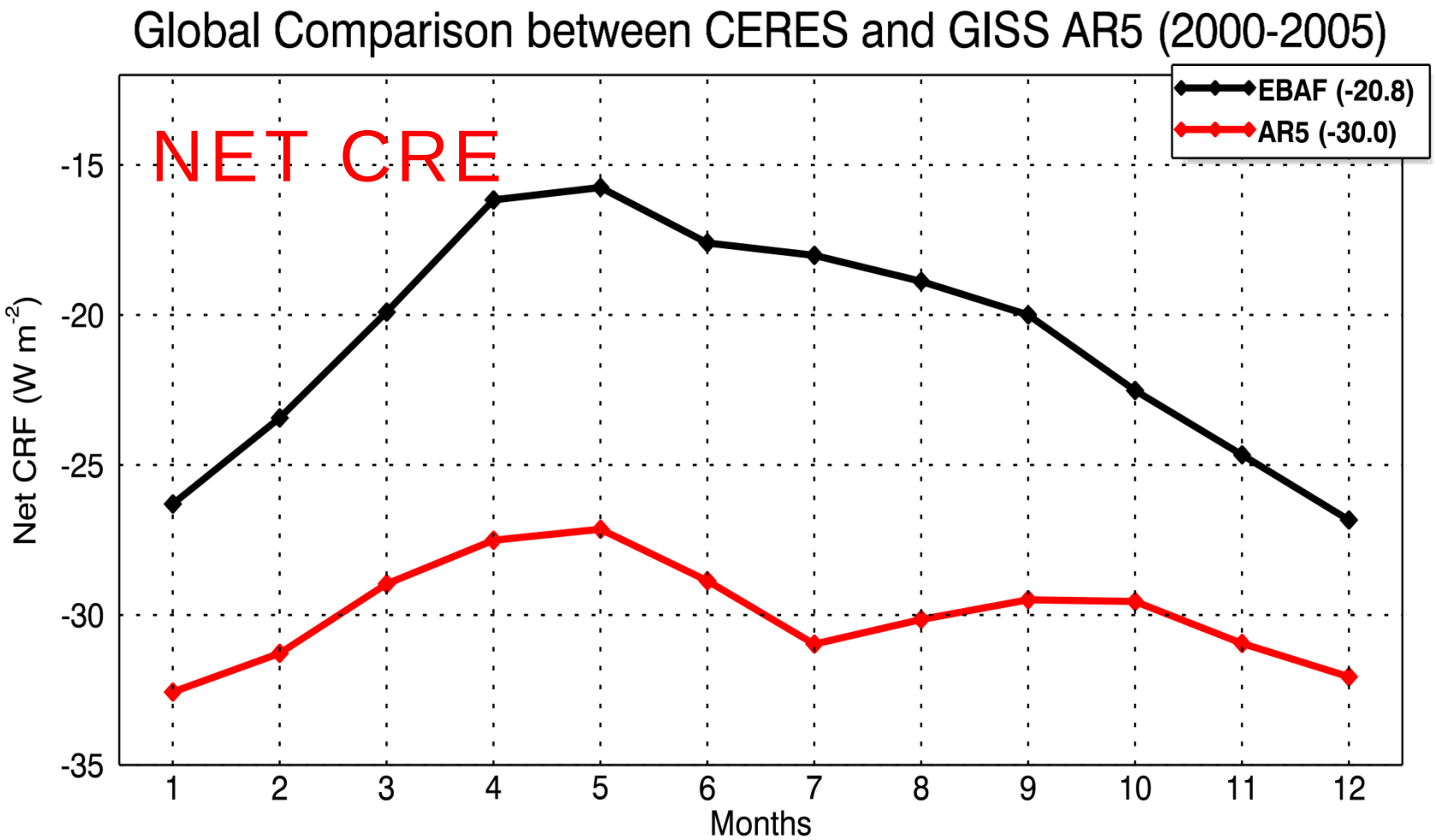












Clouds generate -20.8 Wm^{-2} cooling effect from CERES data, while AR5 is -30 Wm^{-2} mainly from clear-sky LW flux difference.