Comparison of Atmospheric Heating rates from Passive(Modis/Geo) Vs Active(C3M) Sensor Cloud Retrievals

Fred G. Rose[1], Seiji Kato[2], Seung-Hee Ham[1]

SSAI[1], Nasa LaRC[2]

September 11th 2018

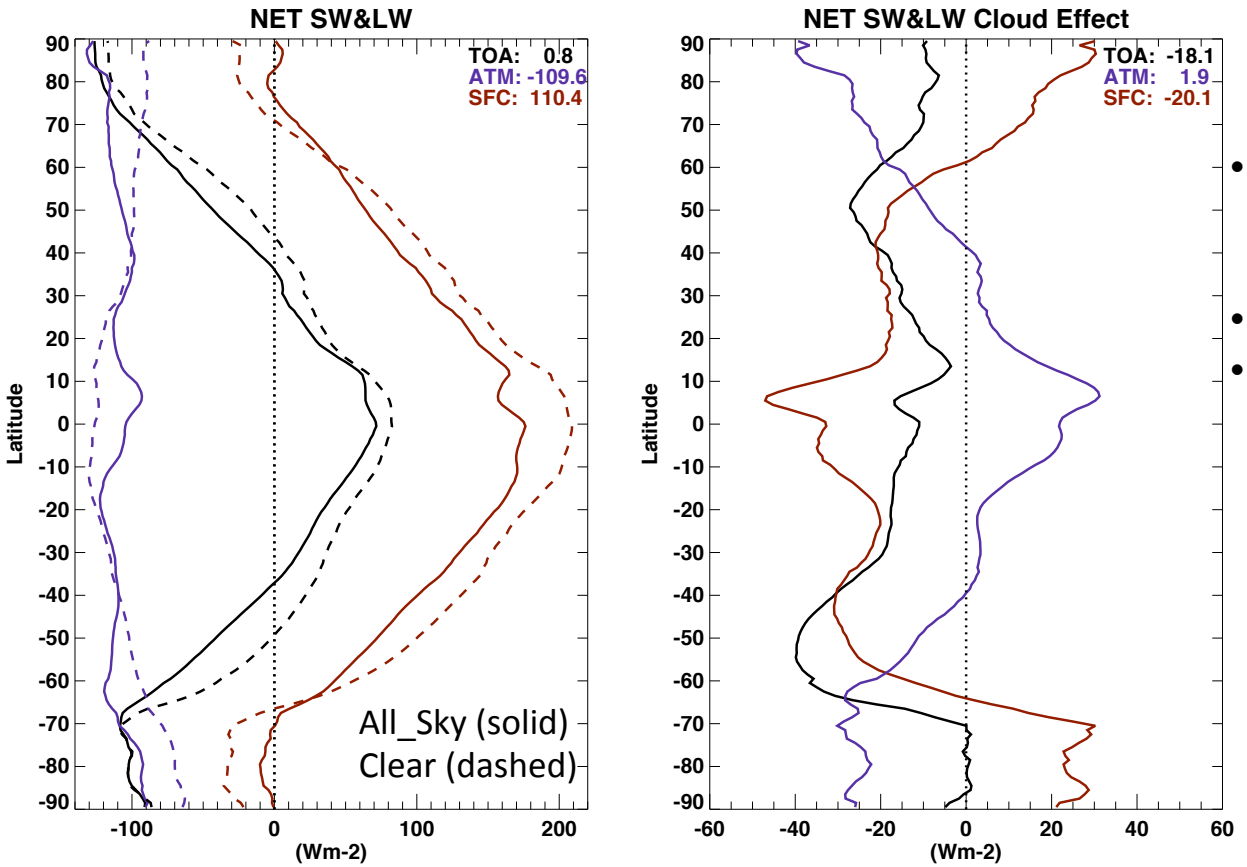
NCAR, Boulder CO.

Clouds and general circulation

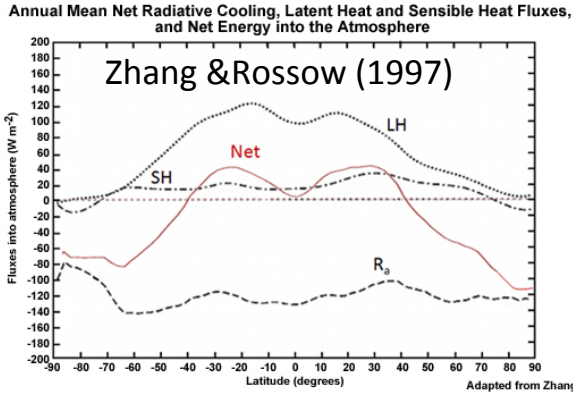
- Longwave cloud radiative effect warms the upper troposphere in the tropics, accelerates the subtropical jets, increases the precipitation maxima at low latitude, and strengthens the Hadley circulation (Slingo and Slingo, 1988).
- Clouds warm the tropical atmosphere below 7 km, cool near the tropopause, increase the height where the convection penetrates in the tropics, and suppress low-level convection by longwave radiation (Randall et al. 1989).

Zonal Atmosphere Net Radiation and Meridional Energy Transport

Ed4.0 Surface EBAF Atm. Net Mean (2000-2017)



- Cloud Effect on Atmosphere Net
  - Positive Tropics
  - Negative Poles
- Latent Heat (Tropics)
- Sensible Heat (Tropics , Mid-Lat)



Atmosphere Net Zonal profile is 'flattened' by Cloud Effect from it Clear sky values resulting in relatively zonally consistent value around -109 Wm^{-2}

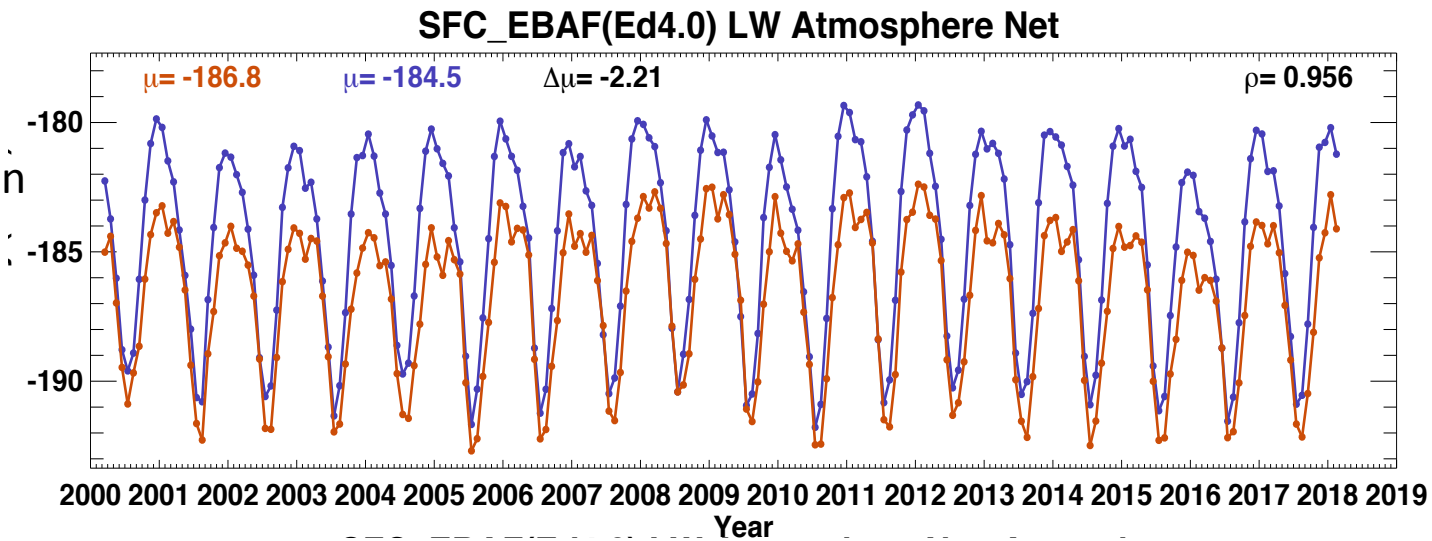
Outline

- Radiation Budget Basics from to CERES Ed4.0 EBAF
  - 18 year climatology of passive retrievals adjusted to CERES
  - Atmospheric Net and its variability
- Cloud Retrievals for Fu-Liou Radiative Transfer
  - Passive (Modis/Geo)
  - Active (Calipso/CldSat/ Modis)
    - Cloud Volume Comparisons
- Zonal-Height Heating rate comparisons

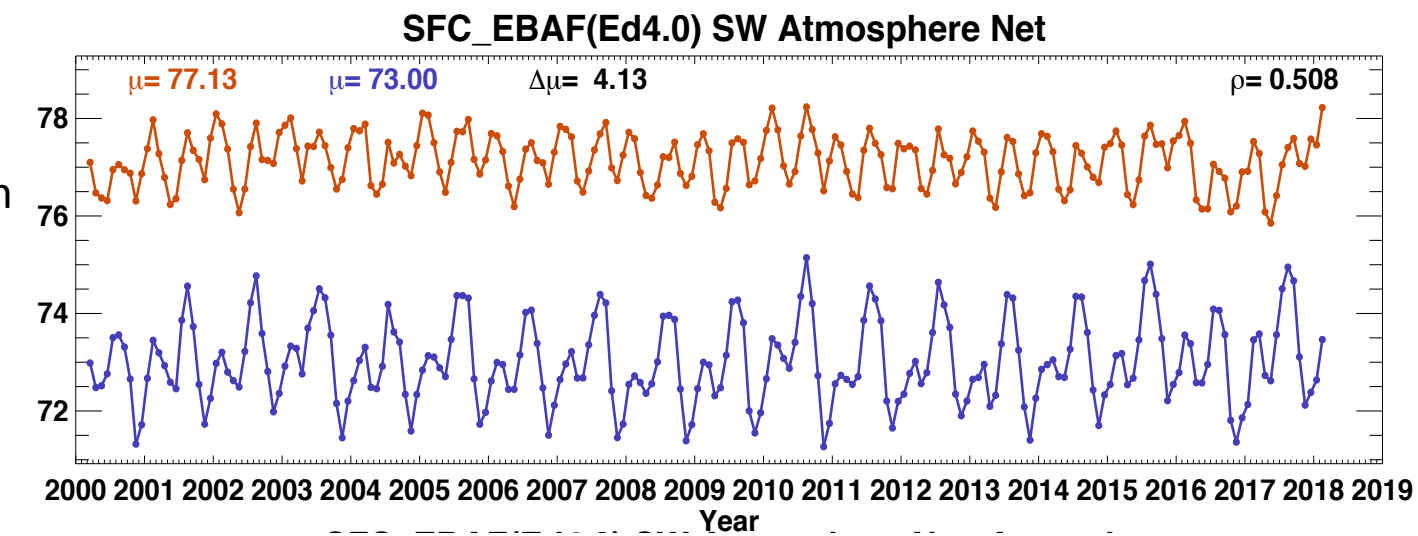
Global Monthly Mean Time Series 2000-2018
LW, SW Atmosphere Net Flux

Global Mean **Longwave** Atm Net Wm^{-2}

All Sky
Clear Sky



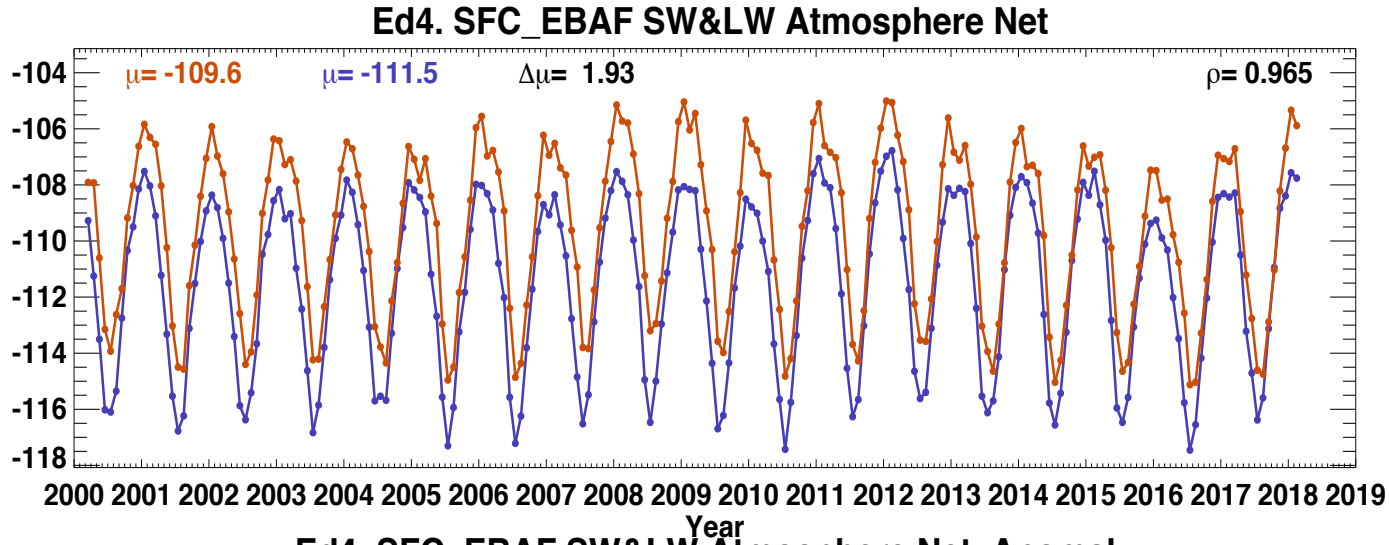
Global Mean **Shortwave** Atm Net Wm^{-2}



Global Monthly Mean
Time series of Atmosphere Net

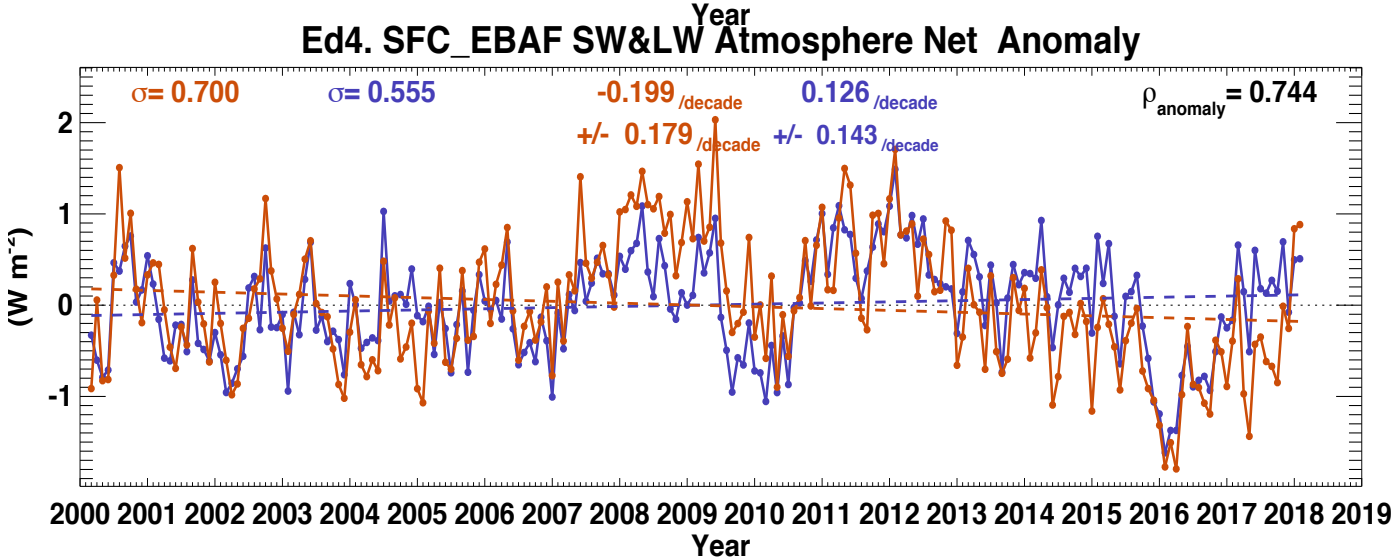
Cloud Effect Reduces Cooling

Longwave +Shortwave
Atm Net
Wm^{-2}

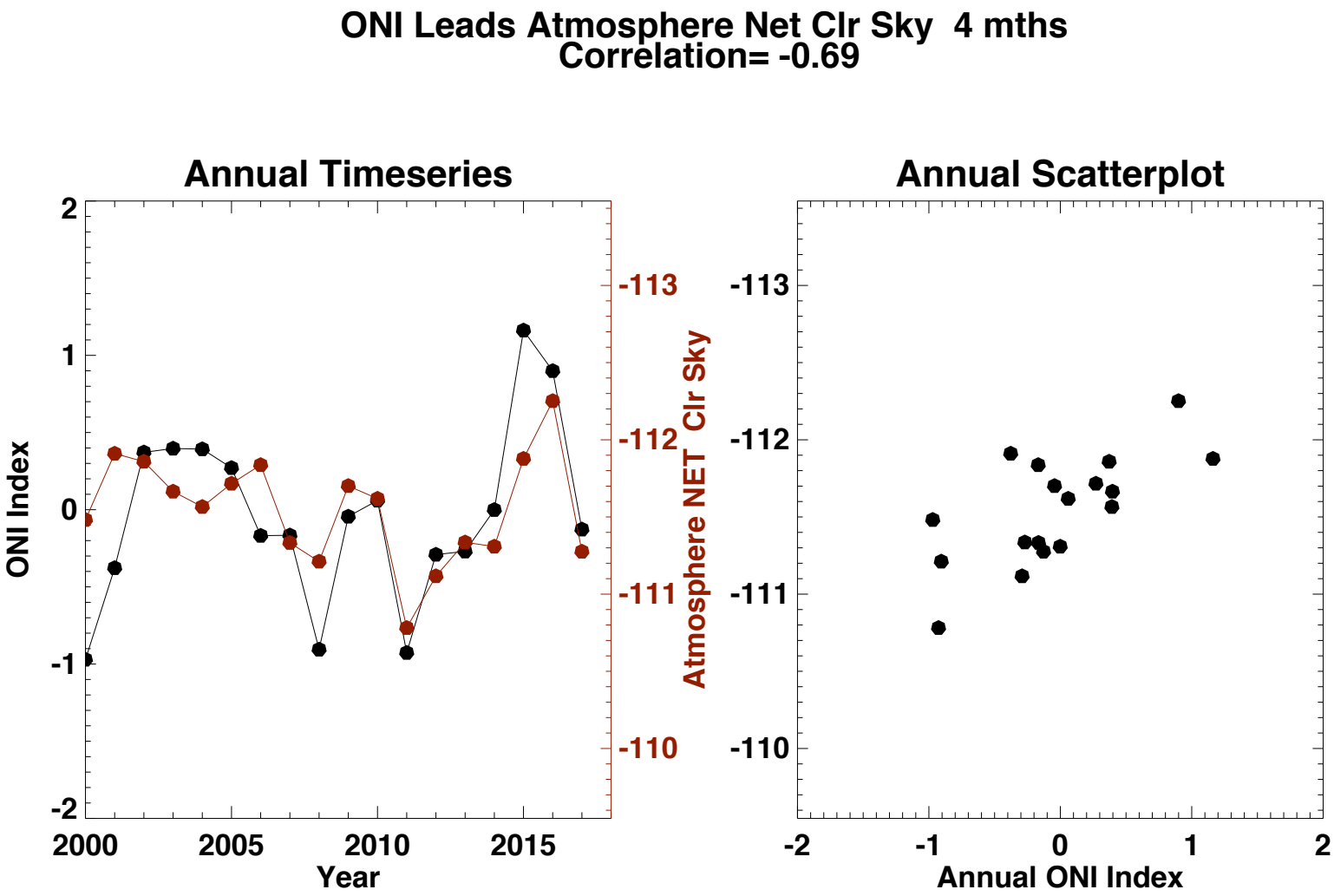


All Sky
Clear Sky

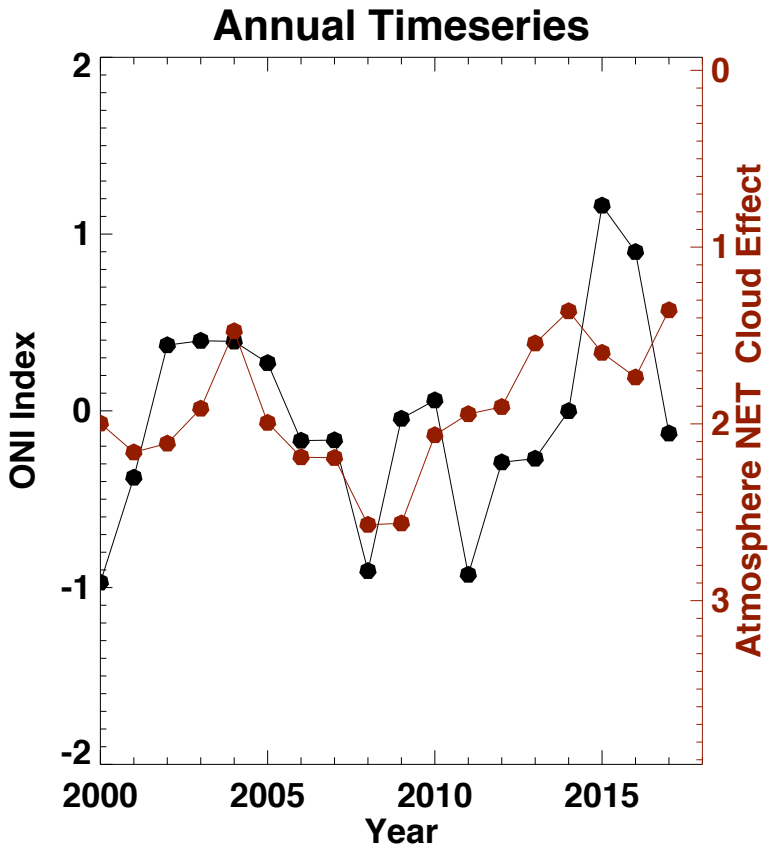
Anomaly Longwave +Shortwave
Atm Net
Wm^{-2}

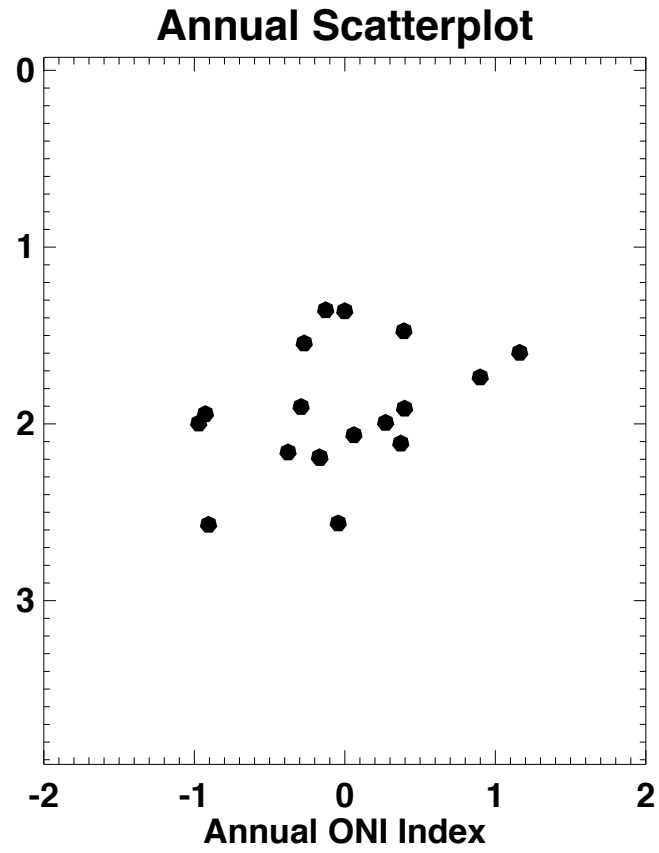


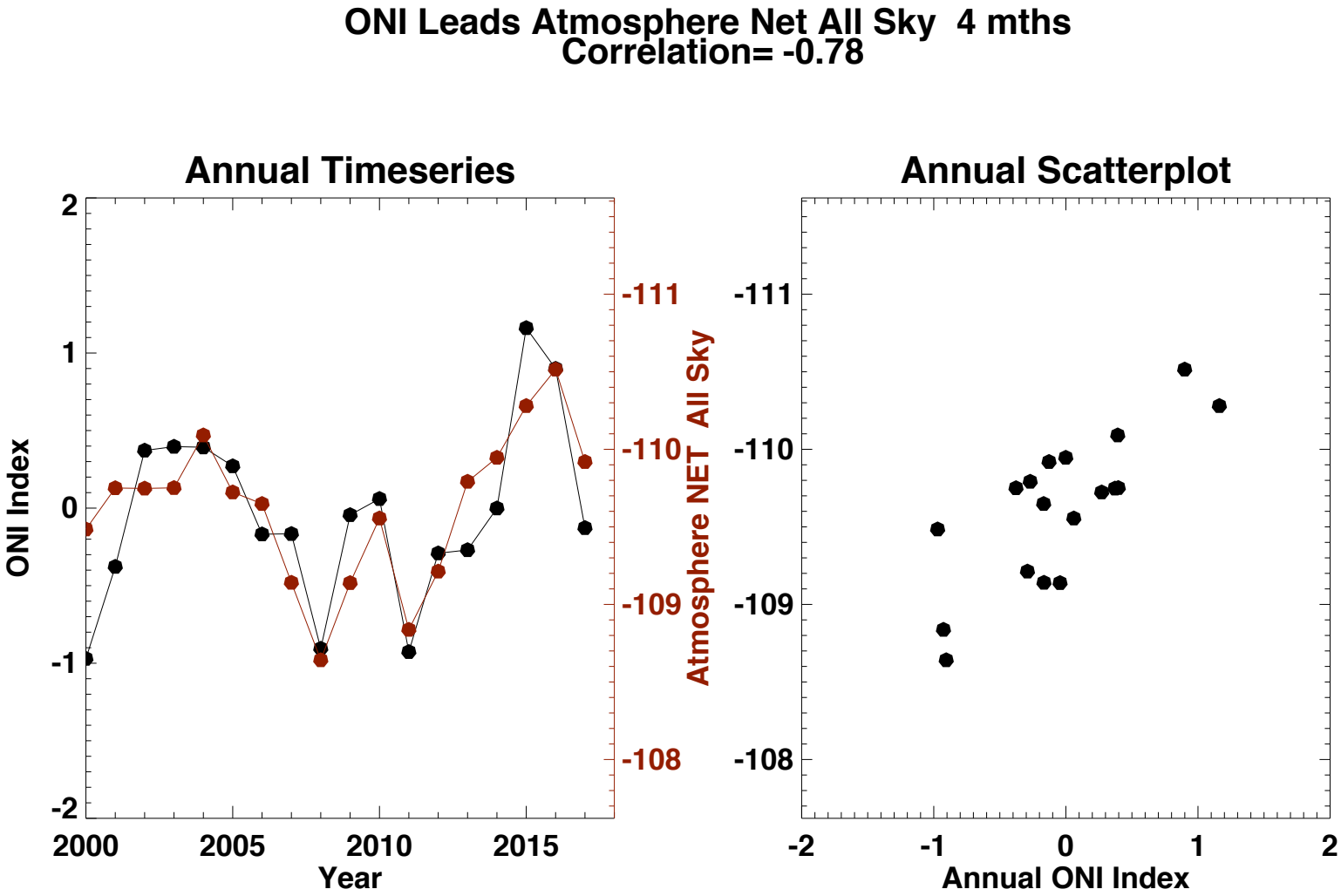
All and Clear Sky anomalies are correlated, Variability ENSO related


ONI Leads Atmosphere Net Clr Sky 4 mths
Correlation= -0.69
Annual Timeseries
ONI Index
Year
Atmosphere NET Clr Sky
Annual Scatterplot
Annual ONI Index

ONI Leads Atmosphere Net Cloud Effect 4 mths
Correlation= -0.38






ONI Leads Atmosphere Net All Sky 4 mths
Correlation= -0.78
Annual Timeseries
ONI Index
Year
Atmosphere NET All Sky
2
1
0
-1
-2
2000
2005
2010
2015
-111
-110
-109
-108
Annual Scatterplot
Annual ONI Index
-2
-1
0
1
2
-111
-110
-109
-108

“MODIS/GEO” (Passive Cloud Retrievals) Grid Scale Hourly Sampling

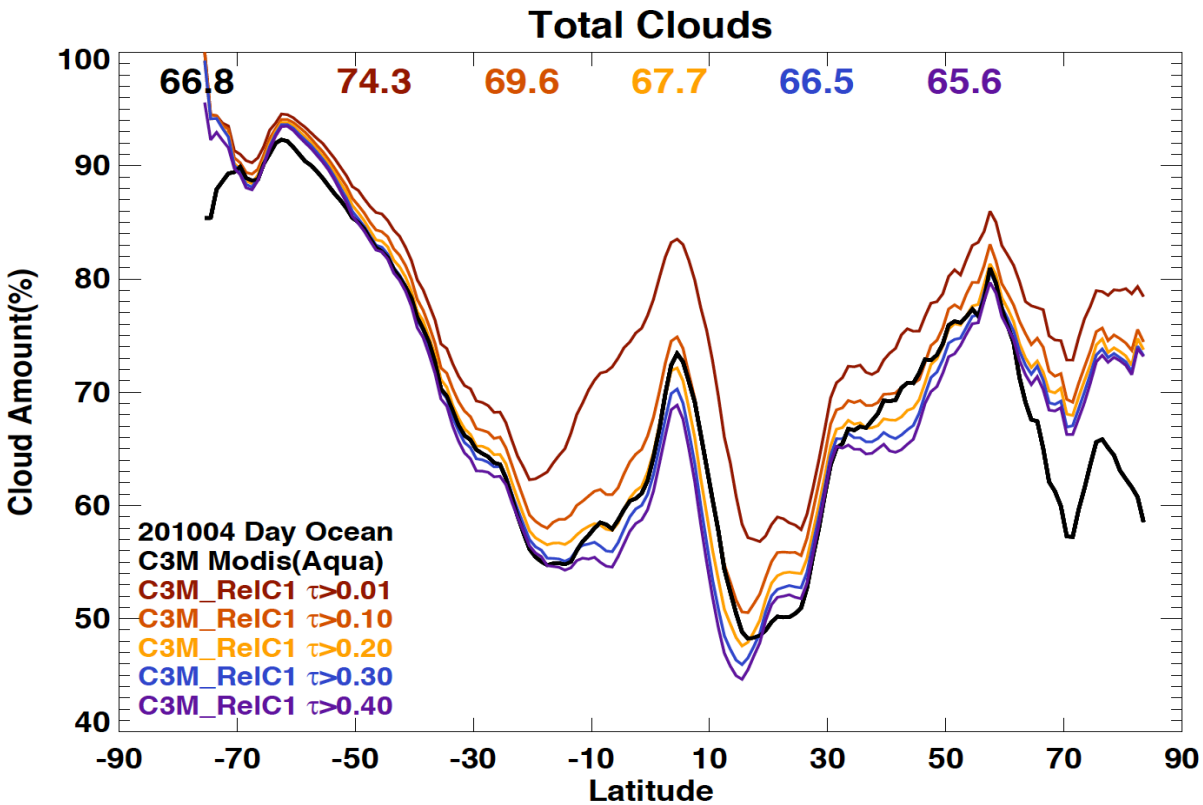
- Modis (Terra / Aqua)
  - Multi-channel (0.65, 2.1, 3.7 , 6.7 ,8.6,10.8 ,12) um
  - Fraction , Tau , Phase , Particle size Re/De , Top , Base
  - Twice a day swath sampling
- Multiple GEOs
  - Mix of 1st,2nd and 3rd Generation Satellites
    - Cloud retrieval accuracy
  - Discontinuities at Satellite boundaries
    - Large View angles
  - Hourly sampling
- Clouds retrievals vertically averaged into 4 height bins (Hourly ,1x1deg)
- Fu-Liou SW and LW Radiative transfer with GMAO Geos 5.4.1 Temperature, Humidity, Match Aerosols
    - RT at 35 vertical levels
    - CERES Syn1deg_Month (Flux output at 5 vertical levels)
    - Special internal run (Fluxes output at 25 vertical levels)

“C3M” (Active Cloud Retrieval) with Near Nadir Sampling

- Aqua (A-Train) 2:30 PM Equator Crossing Time
  - Calipso (Lidar)
    - Cloud top and base of *thin* clouds
    - Extinction profiles
  - Cloud Sat (Radar)
    - Cloud top and base of *thick* clouds
    - LWP/IWP profiles
  - Modis
    - Cloud Optical Depth
    - Merged C3M Calipso/CloudSat/Modis/Ceres FOV and sub-FOV scale clouds.
  - Fu-Liou Radiative Transfer using GMAO Geos4 & Geos5.2
    - Fluxes computed at ‘Cloud group’ sub-FOV resolution , RT effectively at Calipso/Cldsat scale
    - 135 Vertical levels

What is Passively Retrieved Cloud Detecting?

Calipso cloud detection is very sensitive.
Applying different Cloud Tau thresholds to Calipso gives different cloud fraction results.
This method results in a good match of Calipso to Modis passive retrievals at about **Tau > ~0.3**



This comparison is at near nadir.

Passive retrieval are more sensitive at larger view angles.

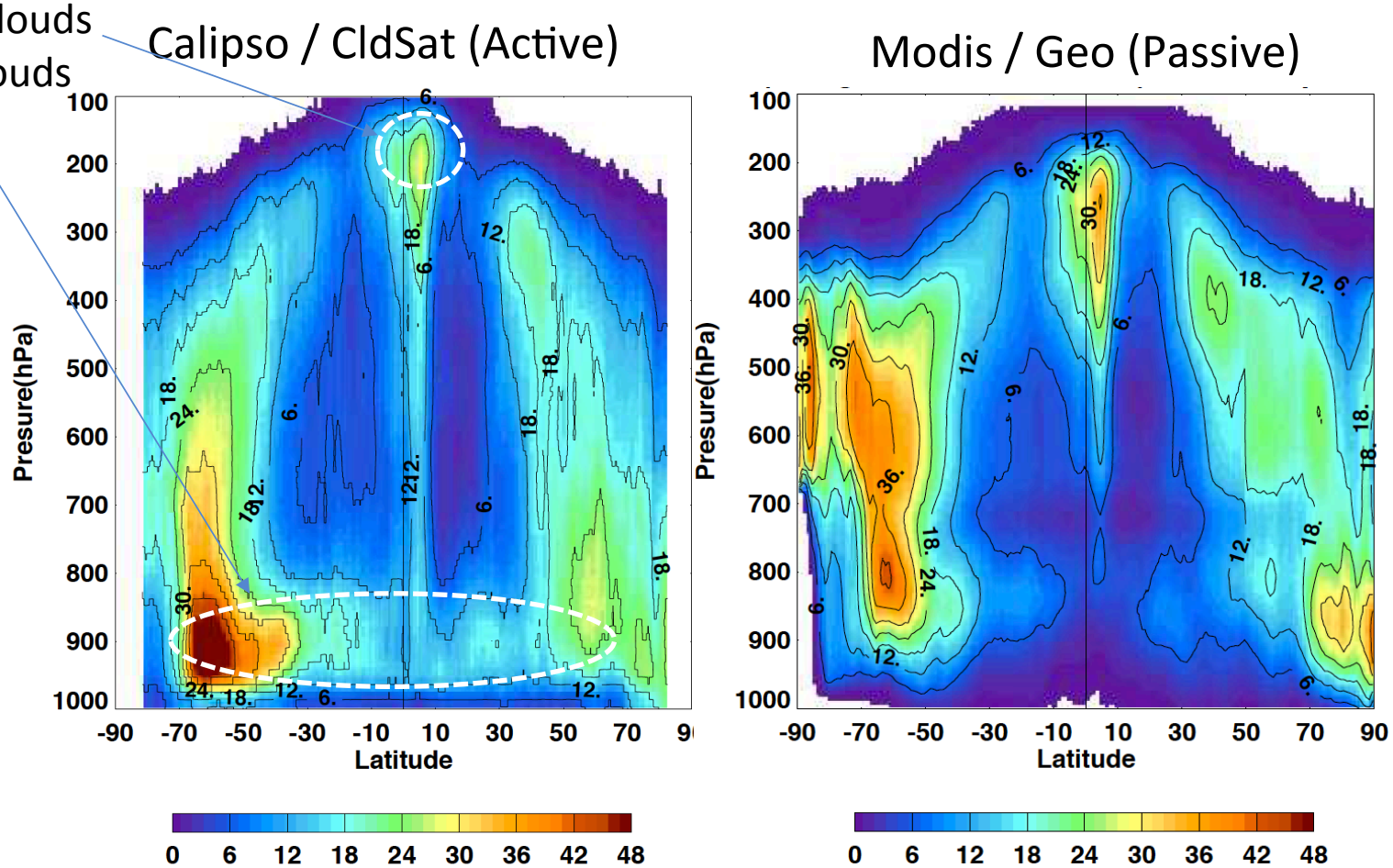
Cloud volume fraction

- the volume cloud fraction is the number of cloud occurrence in a layer in the atmosphere divided by the number of vertical profiles sampled over a specific time period (one month) and region (one degree zone).

Cloud Volume Fraction Mean April 2010

Active cloud retrievals

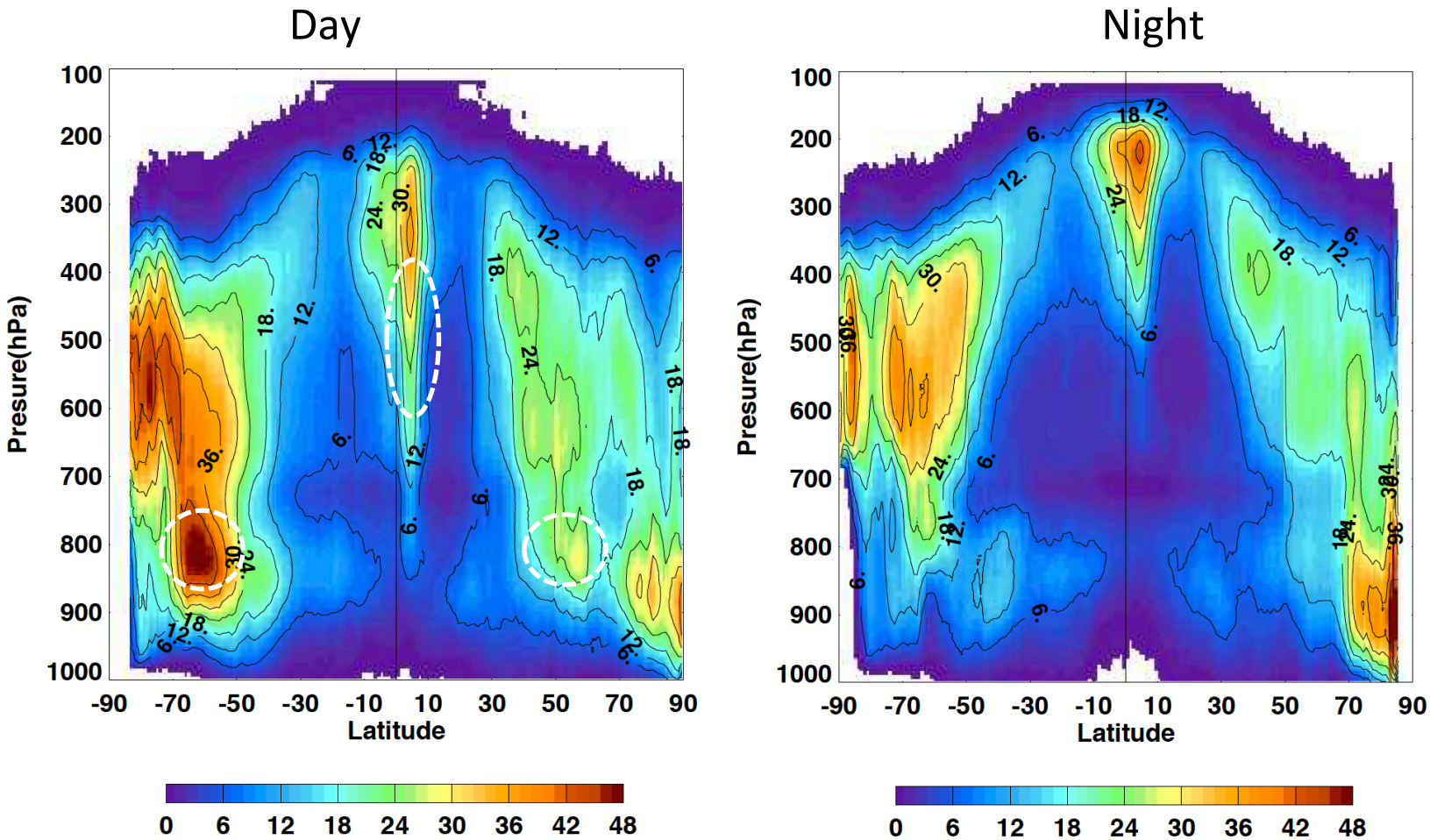
- Higher high clouds
- Lower low clouds



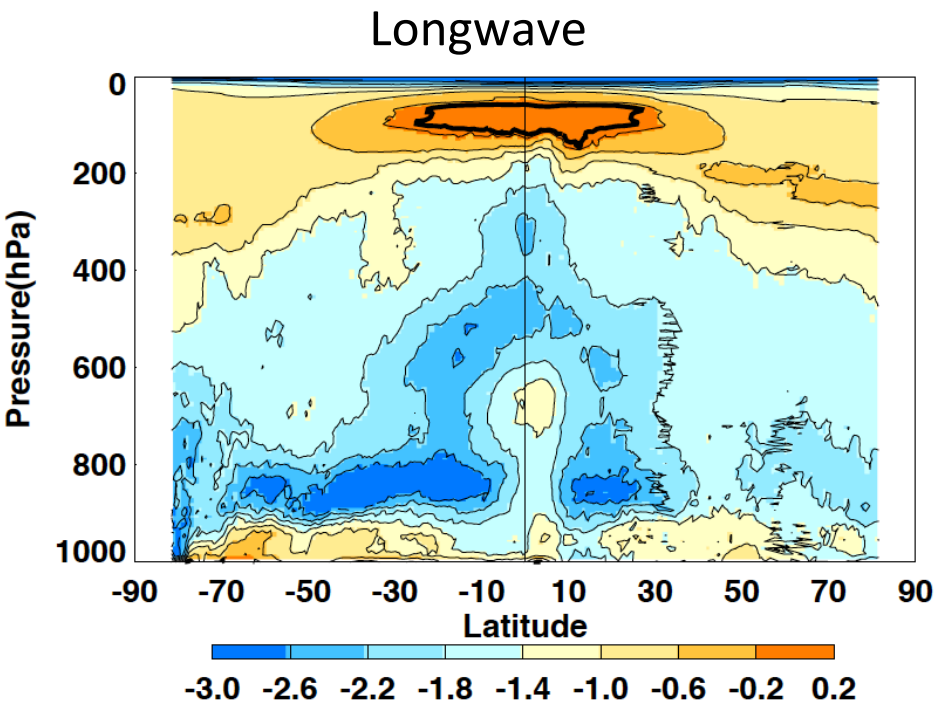
Mean fraction and frequency of occurrence between cloud tops and bases

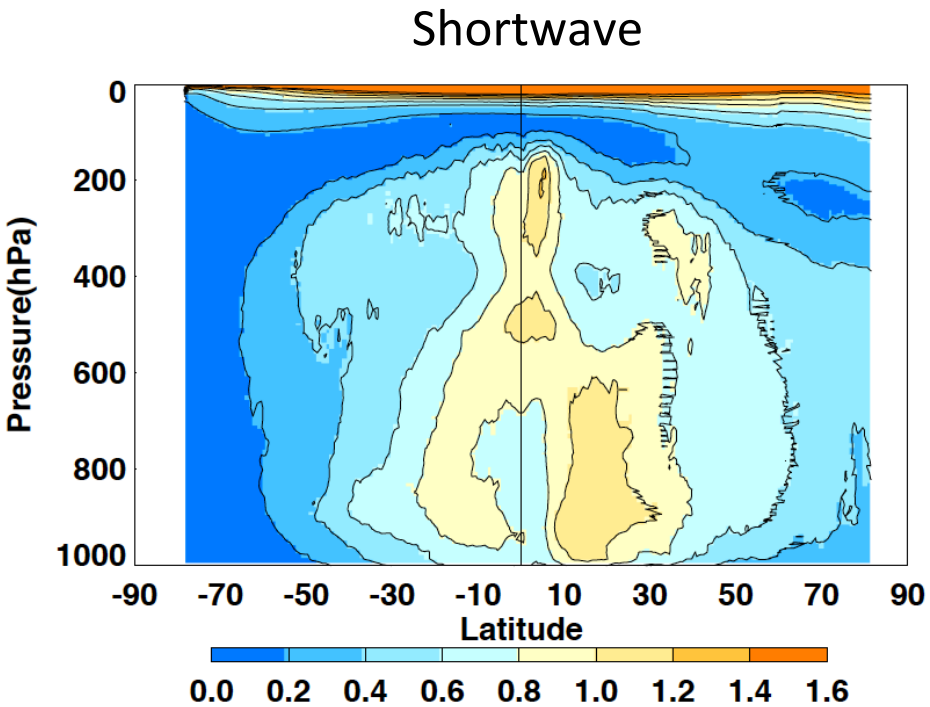
Modis/Geo Cloud Volume Fraction April 2010

Passively retrieved clouds use algorithm based on cloud tau to estimate cloud base
Cloud tau at night saturates at lower value resulting in higher cloud bases

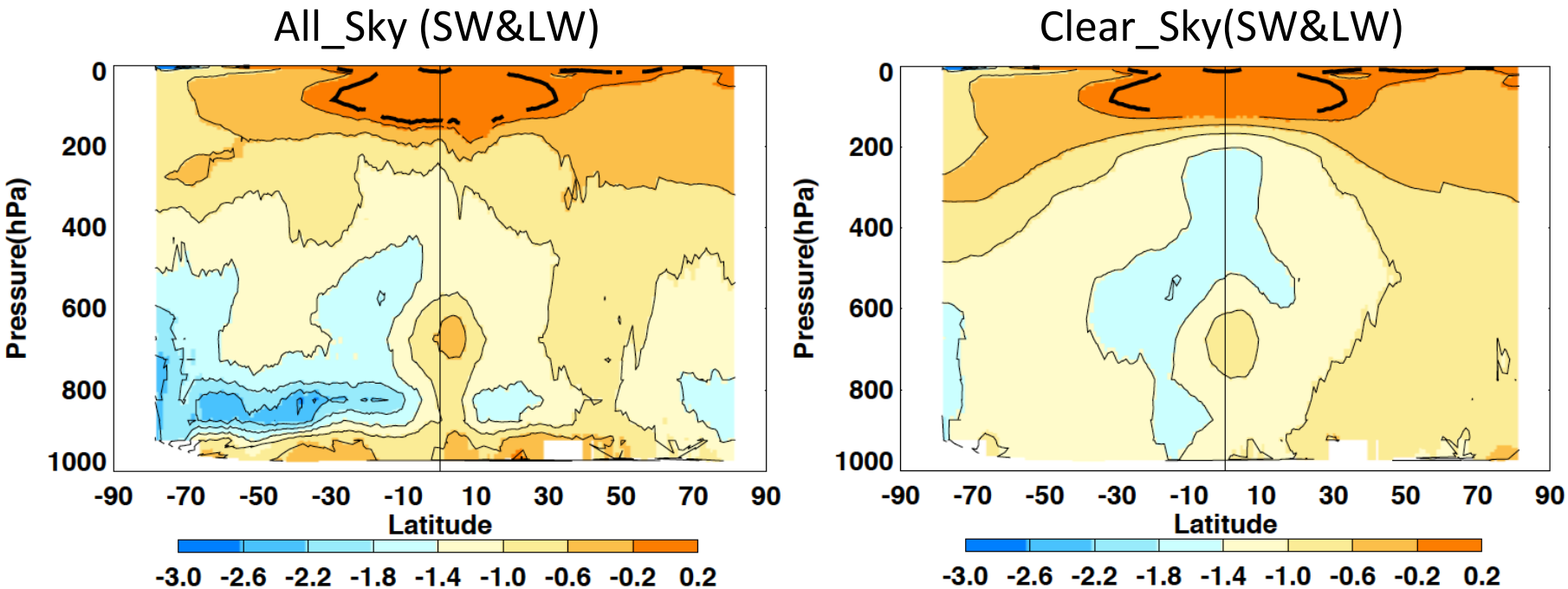


Active(C3M) April 2010 Zonal /Height Mean Atmosphere Heating Rates (K/day)



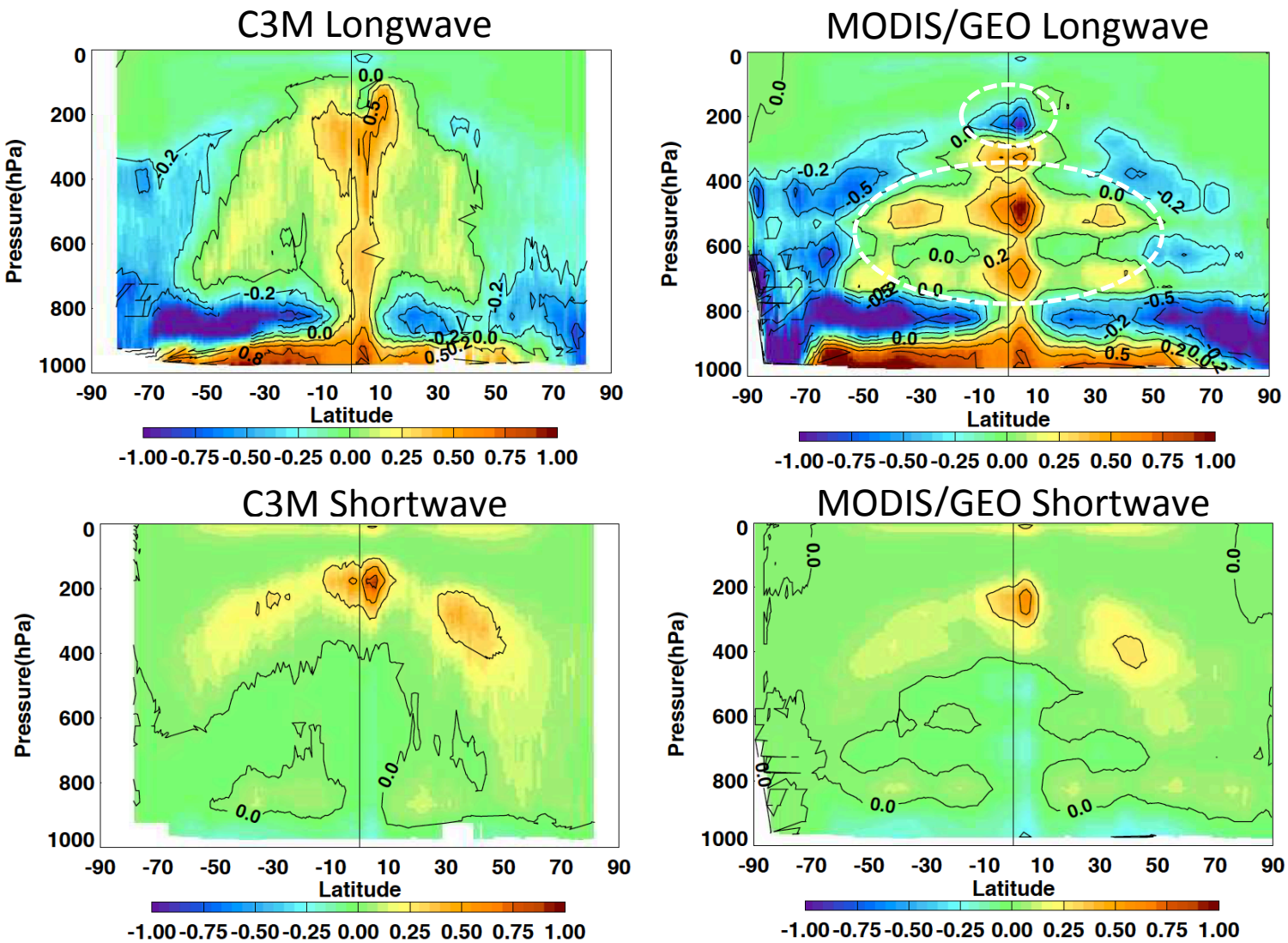


C3M April 2010 Zonal /Height Mean SW&LW Atmosphere Heating Rates (K/day)



All-sky heating (cooling) rate in troposphere is largely caused by longwave
Cloud radiative effect = all sky – clear sky

Cloud Effect on Heating Rates (K/day) Apr 2010

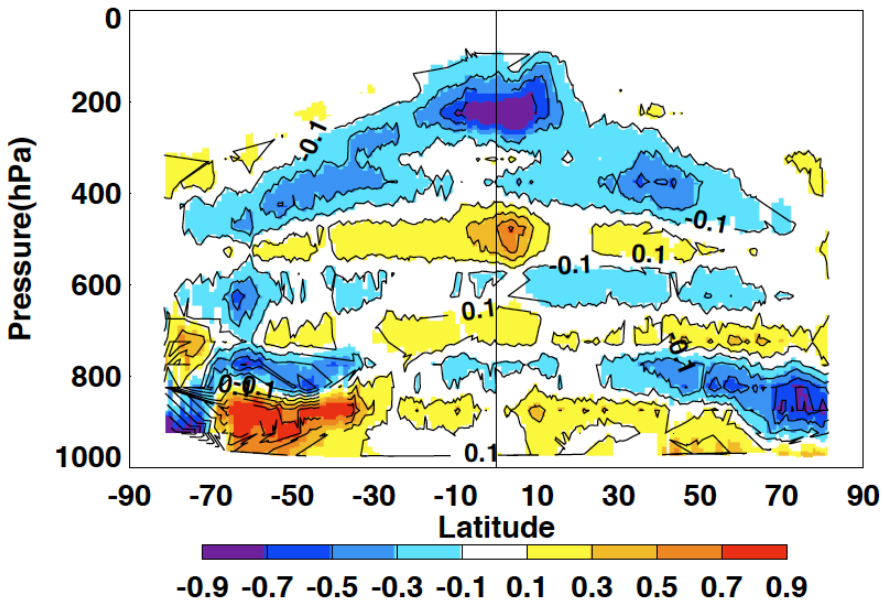


Clouds are thicker and lower in upper Troposphere in Modis/Geo Resulting in more cooling

Layer discretization evident In Modis/Geo LW Cloud Effect

Difference (Passive – Active) of Heating Rate Cloud Radiative Effect April 2010

Longwave



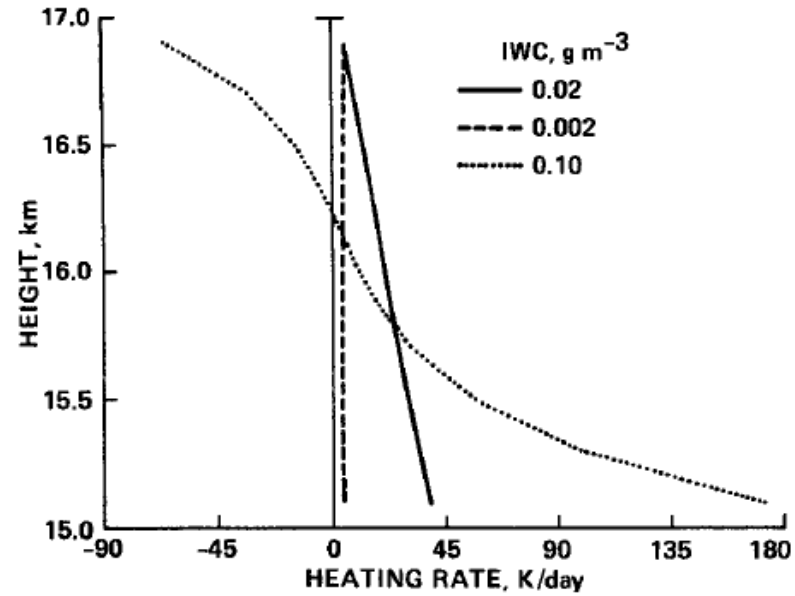


FIG. 6. In-cloud heating rates as a function of height for three constant ice water contents: 0.02 g m^{-3} (solid curve), 0.002 g m^{-3} (dashed), and 0.10 g m^{-3} (dotted). (Note the horizontal scale of this figure is substantially compressed relative to other figures.)

Summary

- CALIPSO retrieves higher high cloud and lower low cloud than passive Modis/Geo
- Therefor active(C3M) retrievals have :
  - Less cooling in the tropical upper troposphere (high cloud is higher)
  - More cooling in the mid-latitude lower troposphere (low clouds is lower)
- Binning and and averaging of the passive (Modis/Geo) cloud into four vertical layers before flux computations results in an artificial vertical striping of heating rates.
  - Overlapping clouds but retrieved as single layer contribute increasing extinction coefficients
- Paper Submitted to JGR-Atmospheres

Kato, S., F. G. Rose, S.-H., D. A. Rutan, A. Radkevich, T. E. Caldwell, S. Sun-Mack, W. F. Miller, and Y. Chen, 2018: Radiative heating rate computed with clouds derived from satellite based passive and active sensors and their effects on generation of available potential energy, submitted to *JGR-Atmosphere*.

BACKUP Slides

Atmosphere Net Radiation (Wm^{-2})

Ed4 Sfc_Ebaf (2000-2018) Atm Net.

SW : 340- 99 -187*+23 = 77*

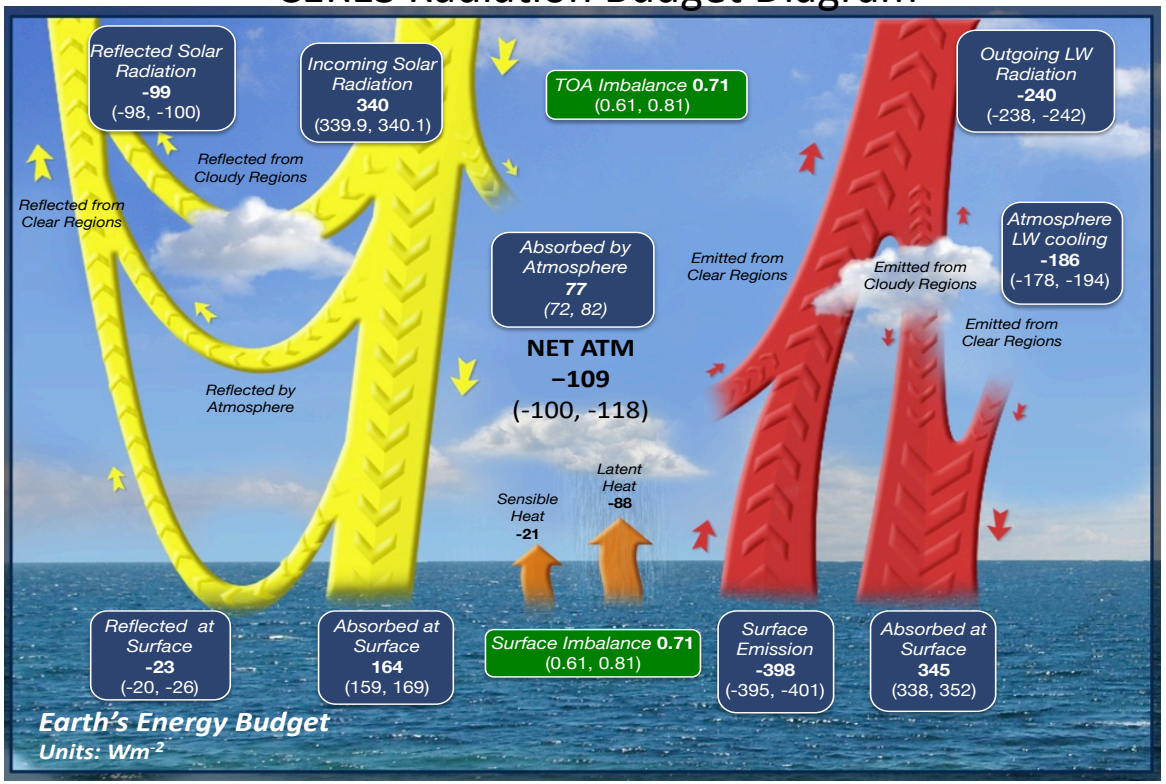
LW : 0-240 -345+398 = -187

SW&LW = -110

*Computation of Ed4 surface shortwave down relies on Collection 5.0 Modis AOT which have been found to be too small compared to Modis Collection 6.1

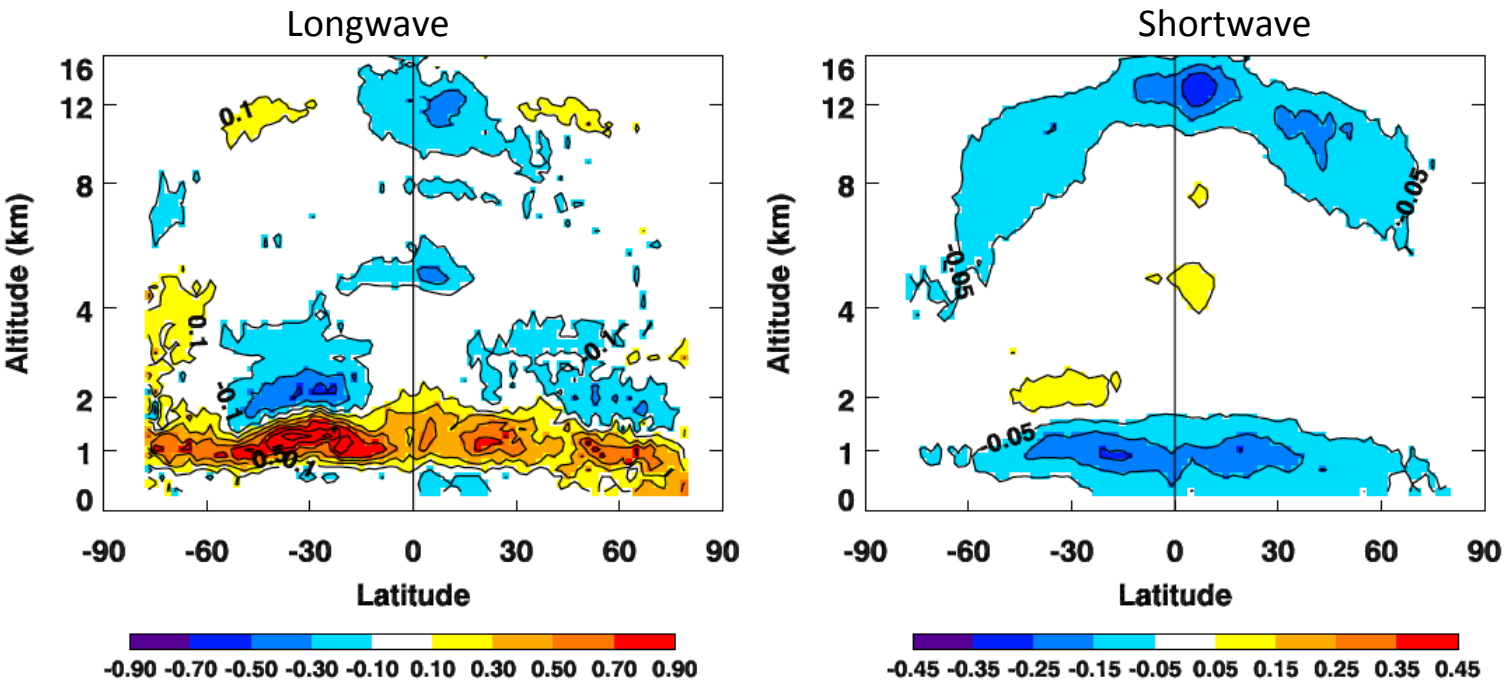
Increasing AOT would primarily reduce shortwave surface down, and reduce surface SW net.

CERES Radiation Budget Diagram



More recent estimates
Latent 83 Wm^{-2}
Sensible 26 Wm^{-2}

Active Retrieval Inter-Product Differences

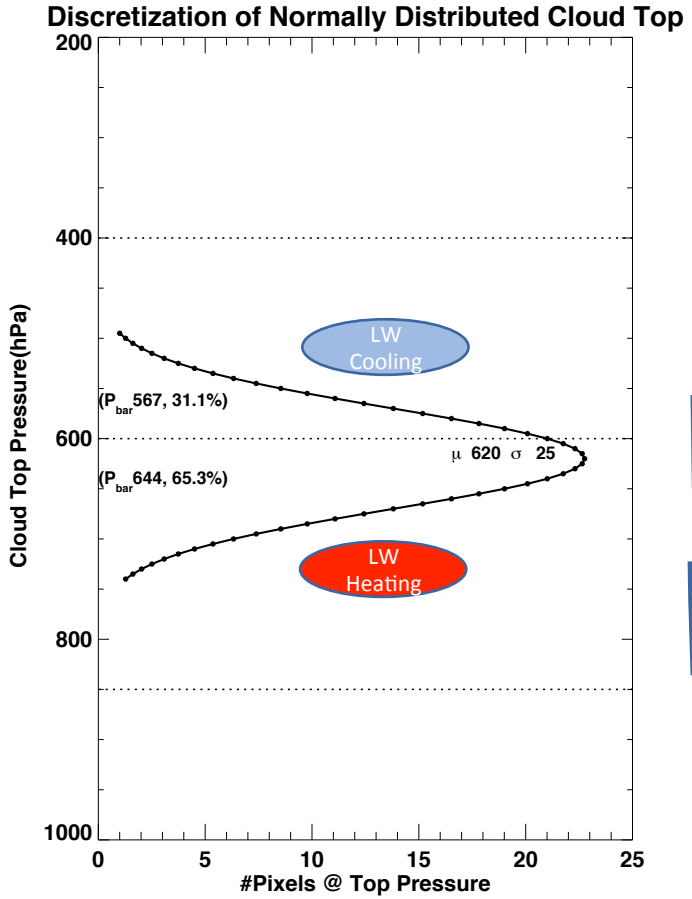


Heating rate difference derived from two data products that use active and passive sensors to derive cloud properties. The left plot is for longwave and right plot is for shortwave. Daytime only from February, April, July and October 2010 are used for the plot (after Ham et al. 2017). The increment of contour lines is 0.2 for longwave and 0.1 for shortwave.

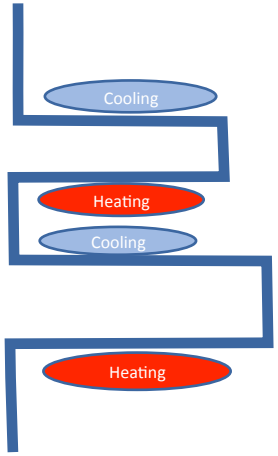
Introduction of artificial cloud tops and bases due to averaging to *four* height bins for each 1x1 deg hour box

In this example a normal distribution of cloud tops with a mean @ 620hpa and std.dev of 25 results in two cloud layers in the radiative transfer.

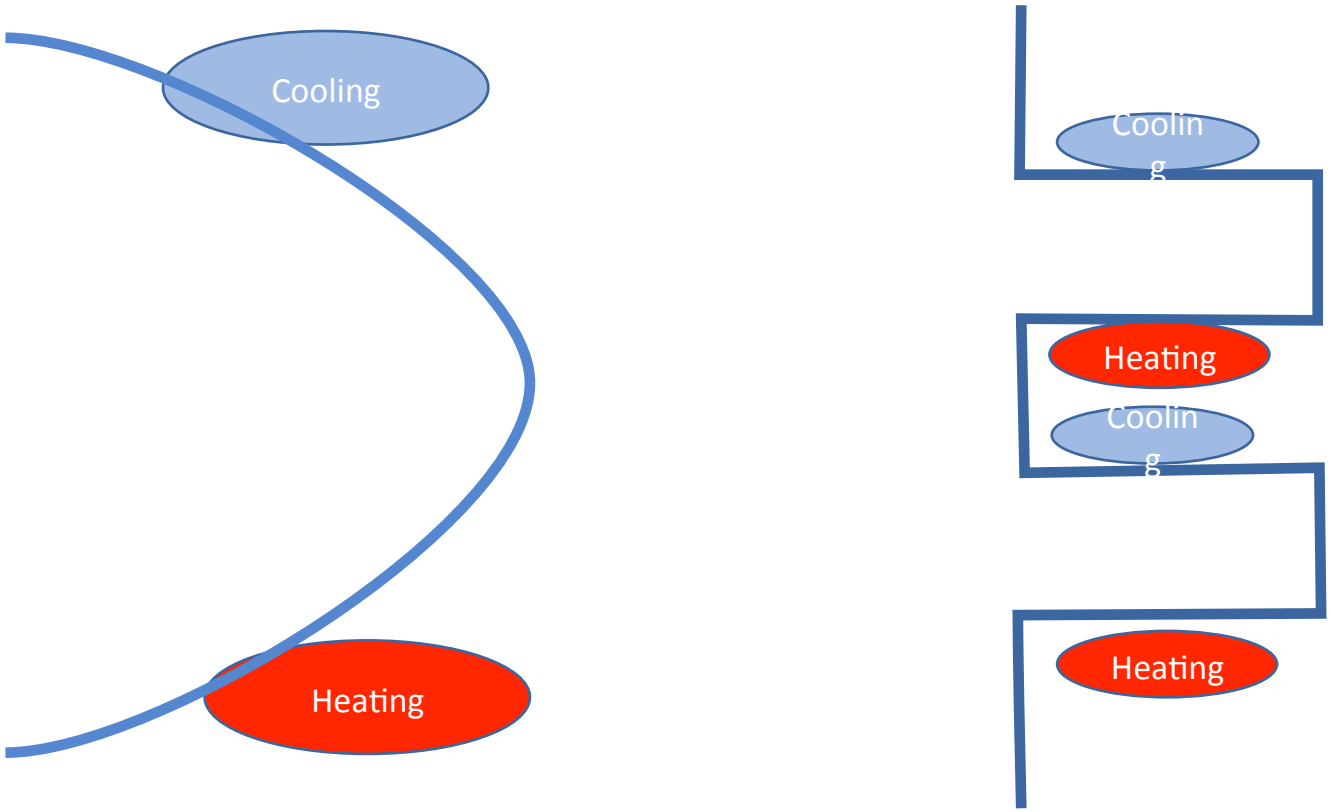
This results in additional locations of longwave cooling at cloud top(s) and heating at below cloud base(s)



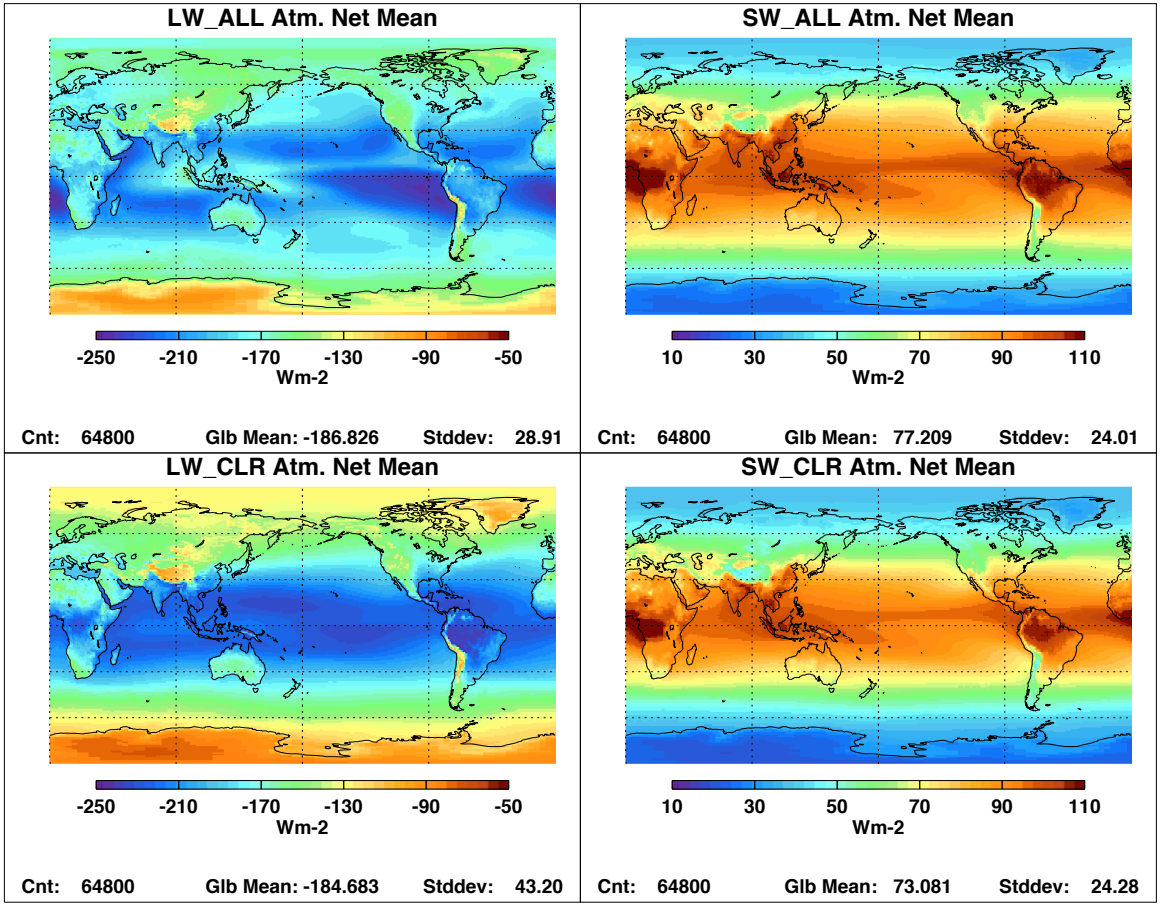
Schematic Illustrating effect on LW Heating rate due to Vertical Discretization

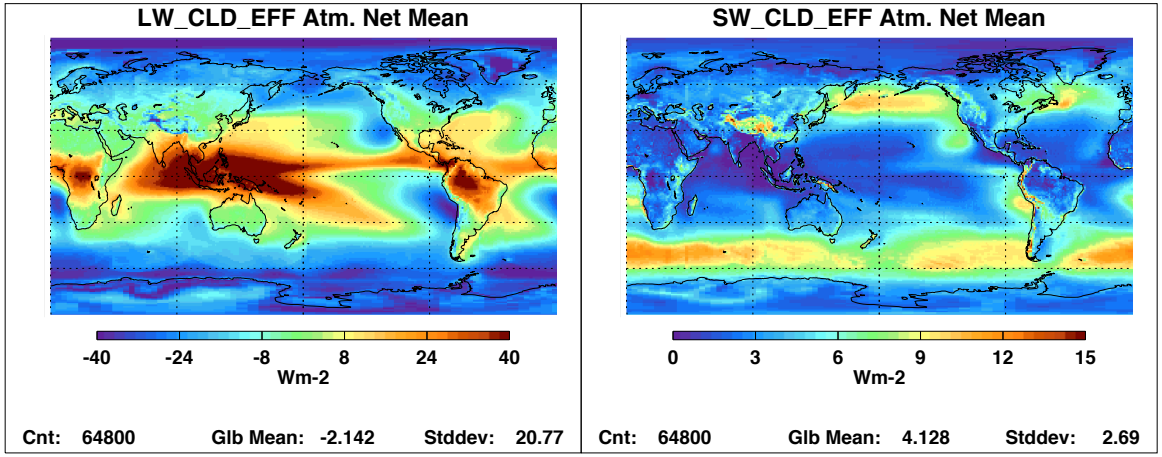


Schematic Illustrating effect on LW Heating rate due to Vertical Discretization

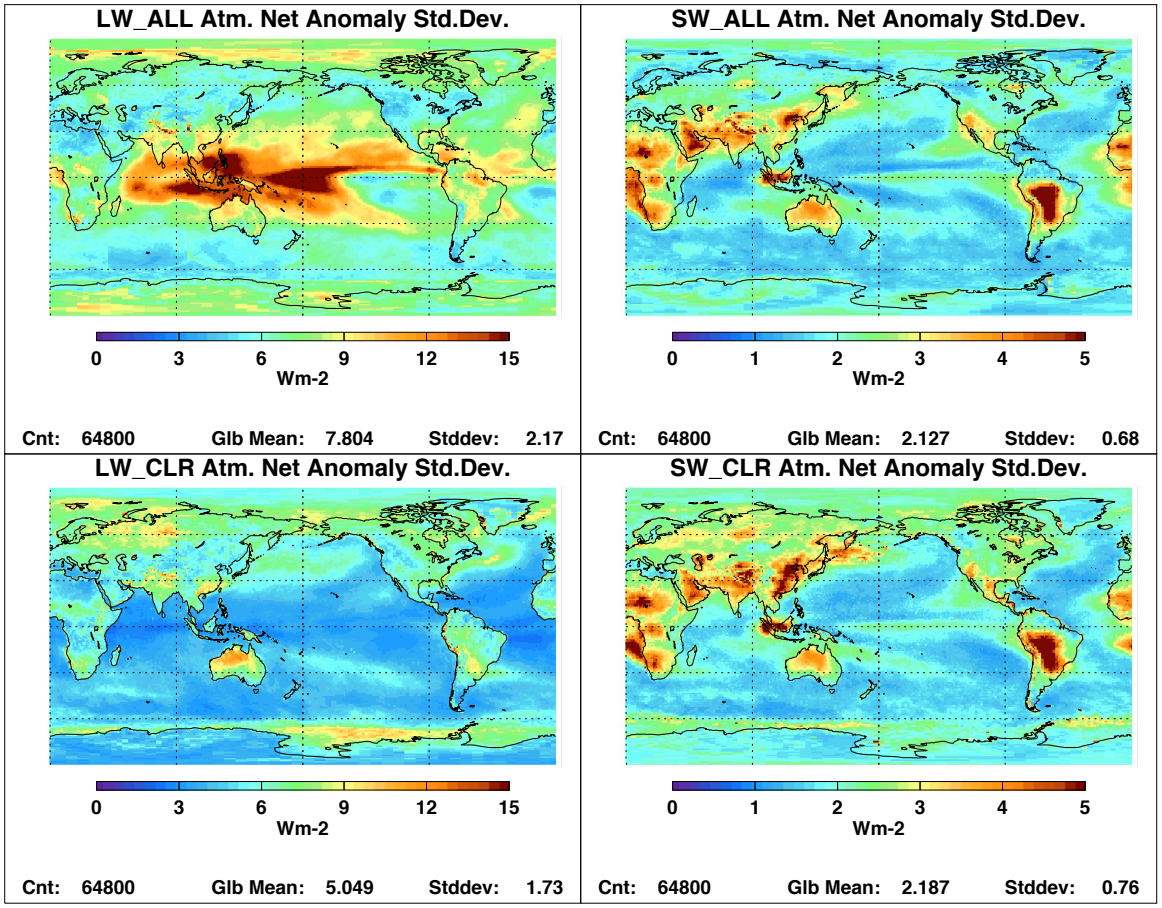


Atmosphere Net Radiation (10 year mean) Ed4 SFC_EBAF 2000-2017

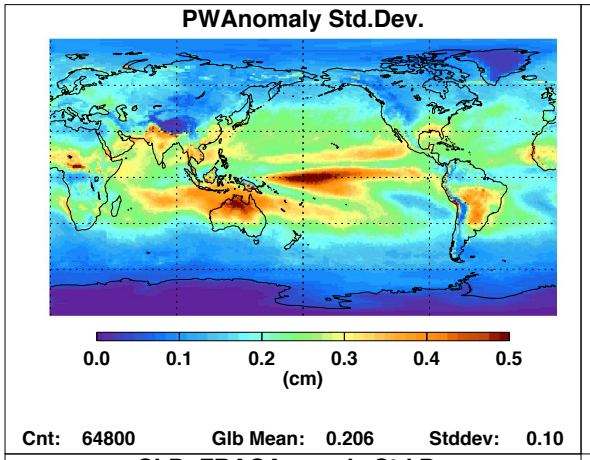


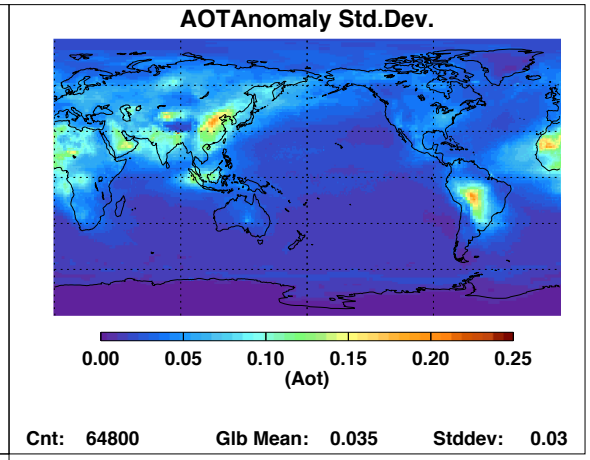

LW_CLD_EFF Atm. Net Mean
-40
-24
-8
8
24
40
Wm-2
Cnt: 64800
Glb Mean: -2.142
Stddev: 20.77
SW_CLD_EFF Atm. Net Mean
0
3
6
9
12
15
Wm-2
Cnt: 64800
Glb Mean: 4.128
Stddev: 2.69

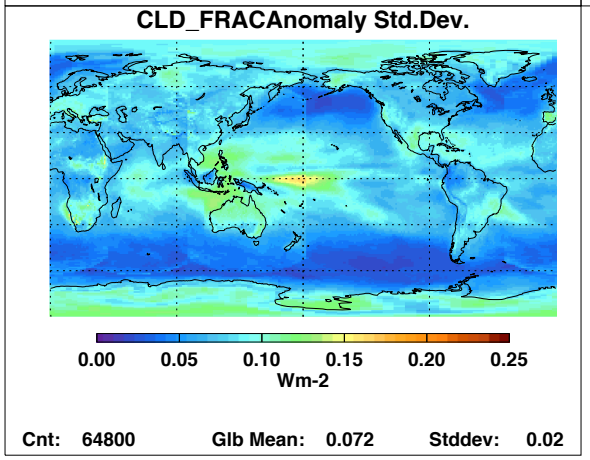
Atmosphere Net Radiation (Monthly Anomaly Standard Deviation) Ed4 SFC_EBAF 2000-2017



(Monthly Anomaly Standard Deviation) 2000-2017



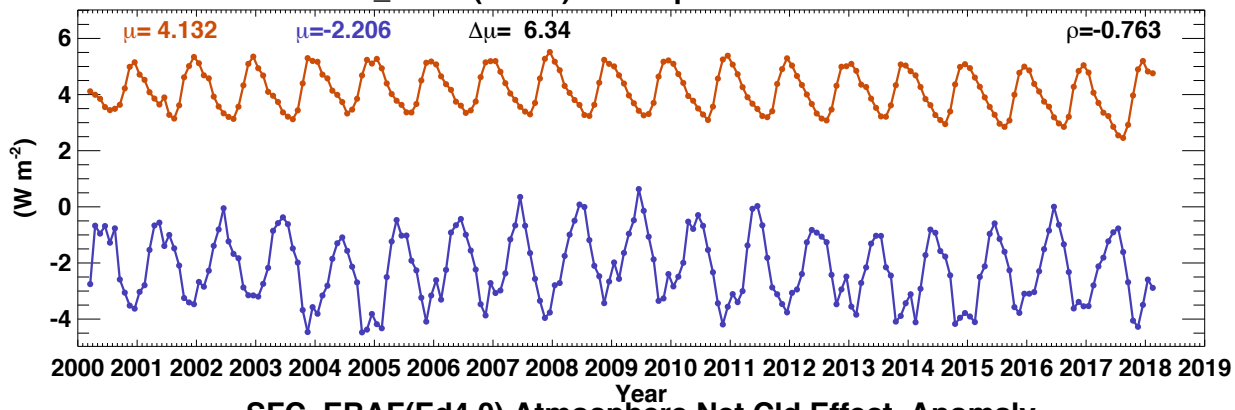




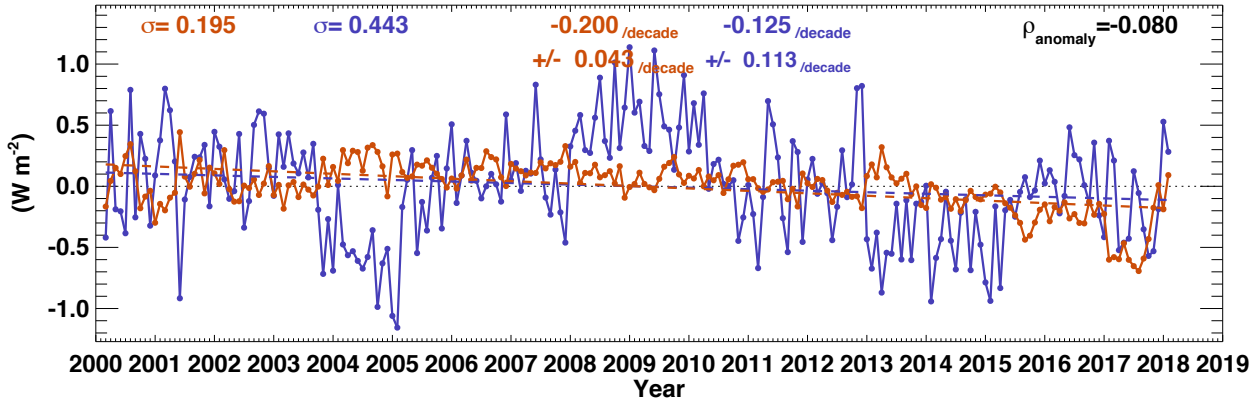
- Geos 5.4.1
- Match C5.0
- CERES Modis Clouds

SW
LW

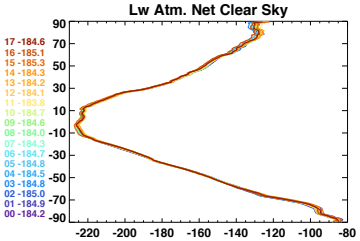
SFC_EBAF(Ed4.0) Atmosphere Net Cld Effect

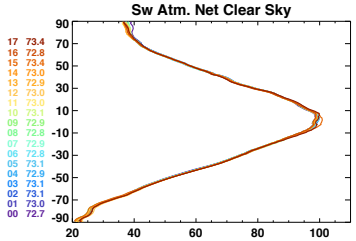


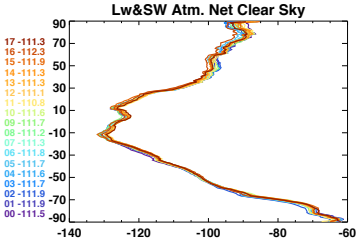
SFC_EBAF(Ed4.0) Atmosphere Net Cld Effect Anomaly

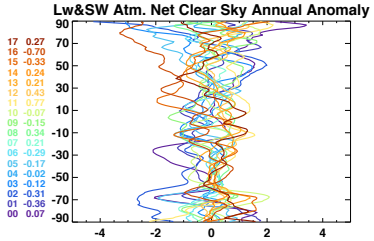


Annual Mean Clear Sky Atmosphere Net

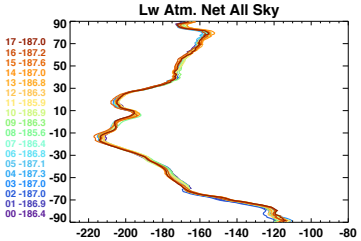


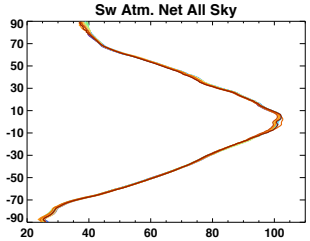


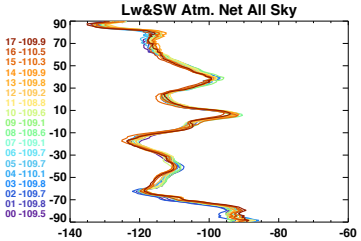


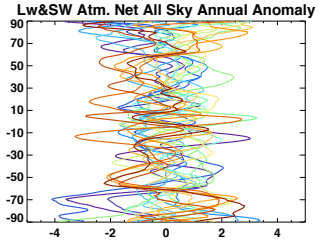


Annual Mean All Sky Atmosphere Net

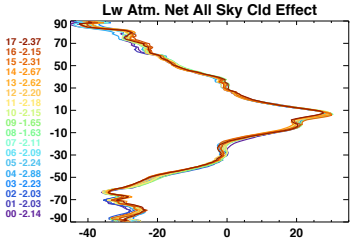


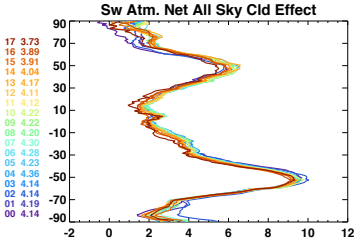


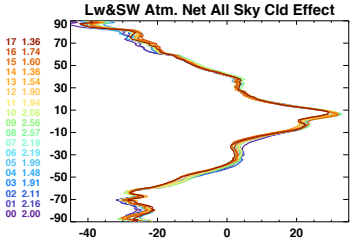


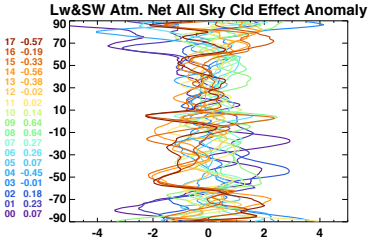


Annual Mean Cloud Effect Atmosphere Net









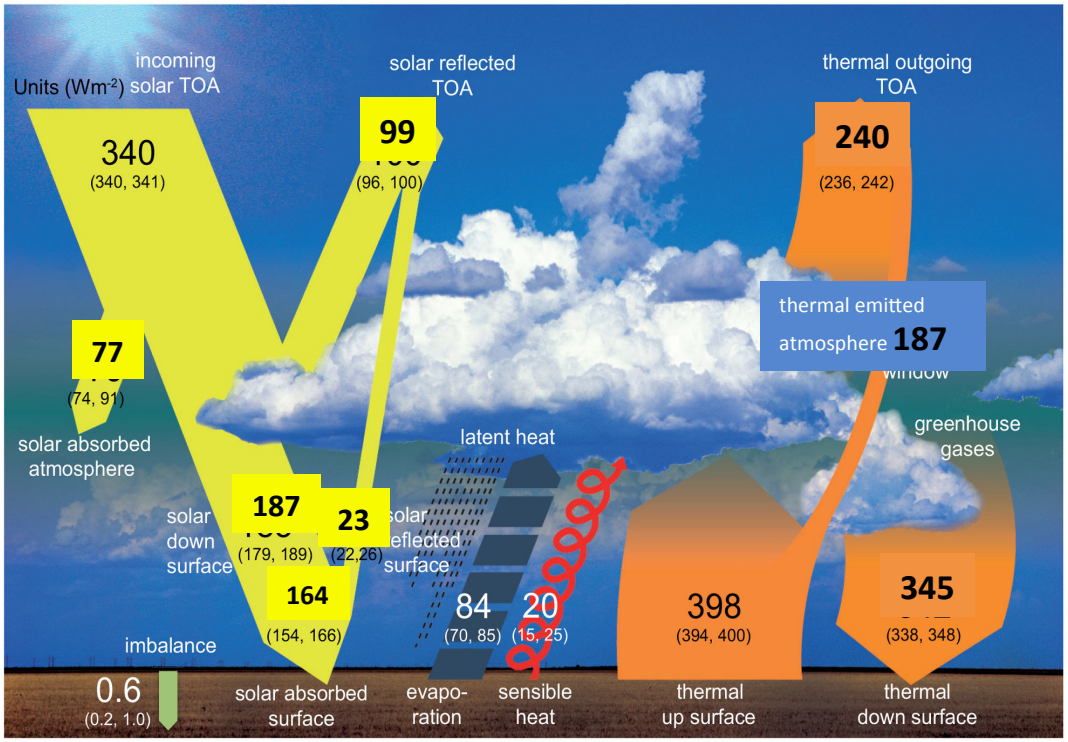
Atmosphere Net Radiation (Wm^{-2})

Ed4 Sfc_Ebaf (2000-2018)

SW : 340- 99 -187*+23 = 77*

LW : 0-240 -345+398 = -187

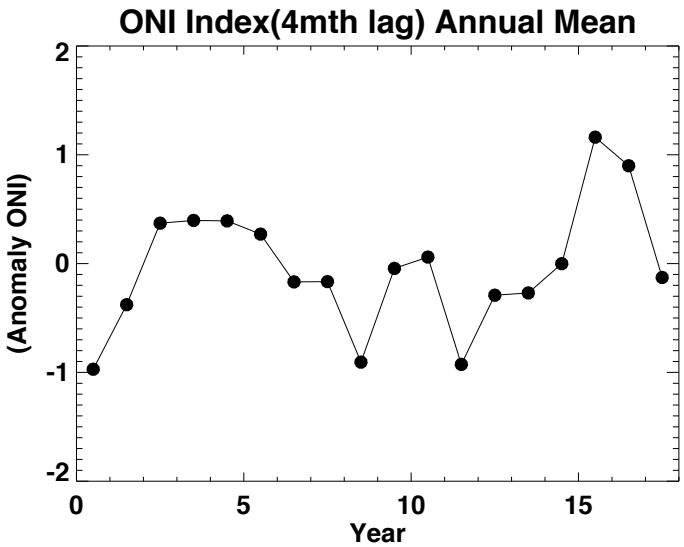
SW&LW = -110

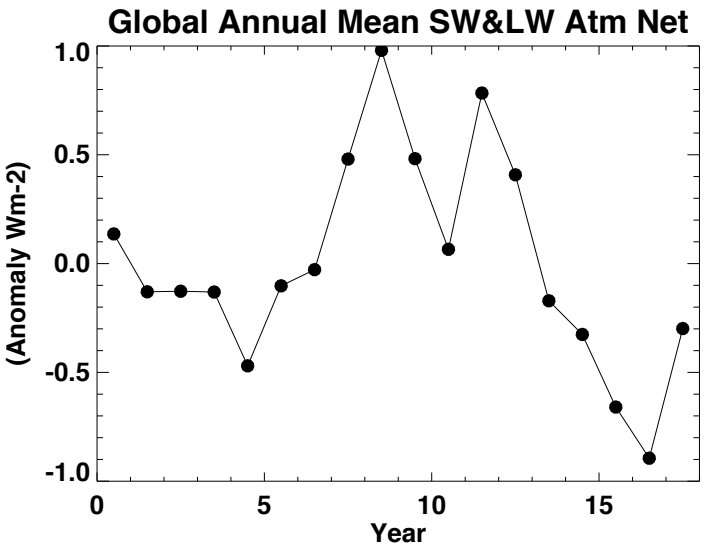


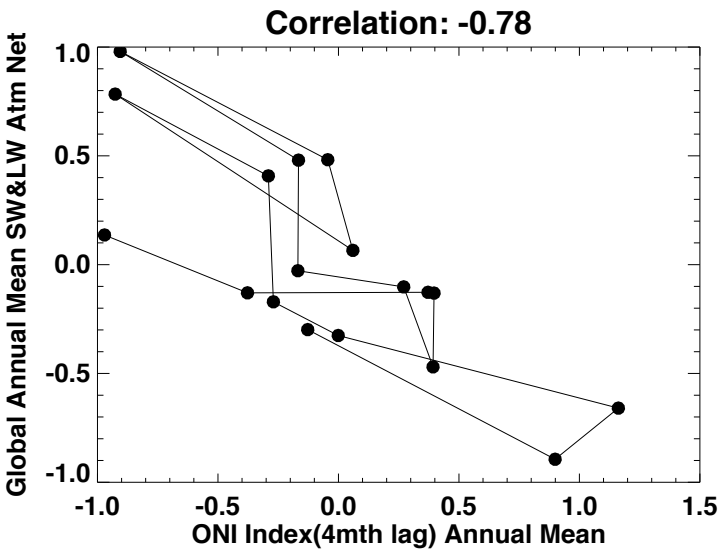
*Computation of Ed4 Surface shortwave down relies on Collection 5.0 Modis AOT which have been found to be too small compared to Modis Collection 6.1

In the Surface EBAF process, which forces consistency with observed CERES Shortwave TOA , Increasing AOT would primarily reduce shortwave surface down, and likely slightly increase surface up over land, the combined effects would act to decrease surface SW net.

Oceanic Nino Index (ONI) and Atmosphere Net







ENSO Result in Enhanced/Reduced Atmospheric Radiative Cooling with a lag of about 3 to 4 Months