

Cloud Forcing of Surface Radiation

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Introduction

- Clouds are the major modulator of radiation budget at TOA and the surface.
- The effect of clouds on the surface SW diurnal cycle is not yet well understood.
- The diurnal cycle of clouds is coupled with the interaction of the surface and atmosphere.
- The NASA/GEWEX Surface Radiation Budget Data Set includes surface radiation fluxes for both all-sky and clear-sky which permits the computation of cloud forcing of these flux components.
- Examine both January and July to see seasonal effects.
- Skin temperature constant – but from two different sources in SRB.
- We neglect longwave up cloud forcing and concentrate on longwave down (LWD) and shortwave net (SWN) CF.

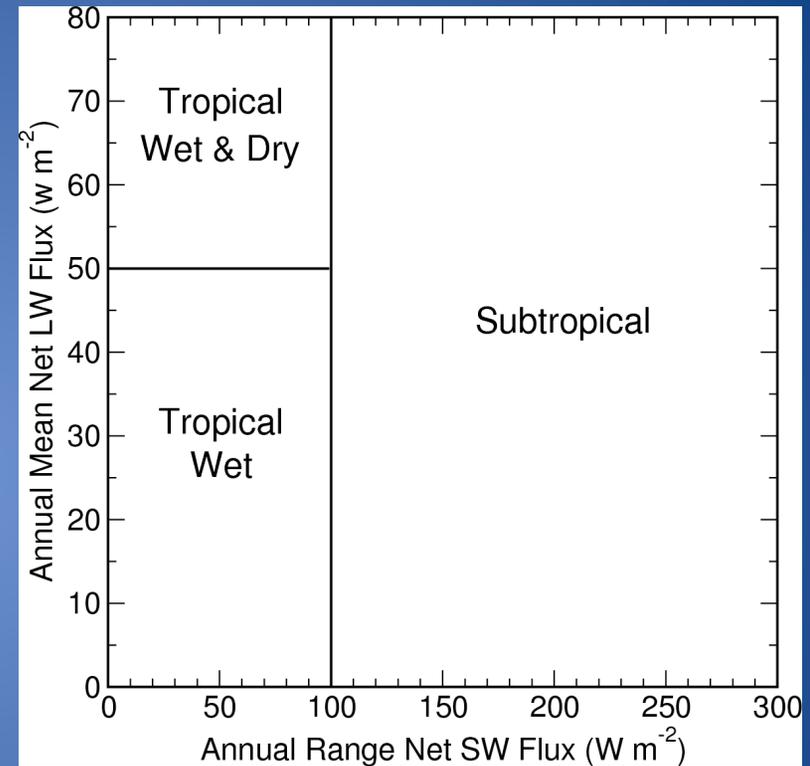
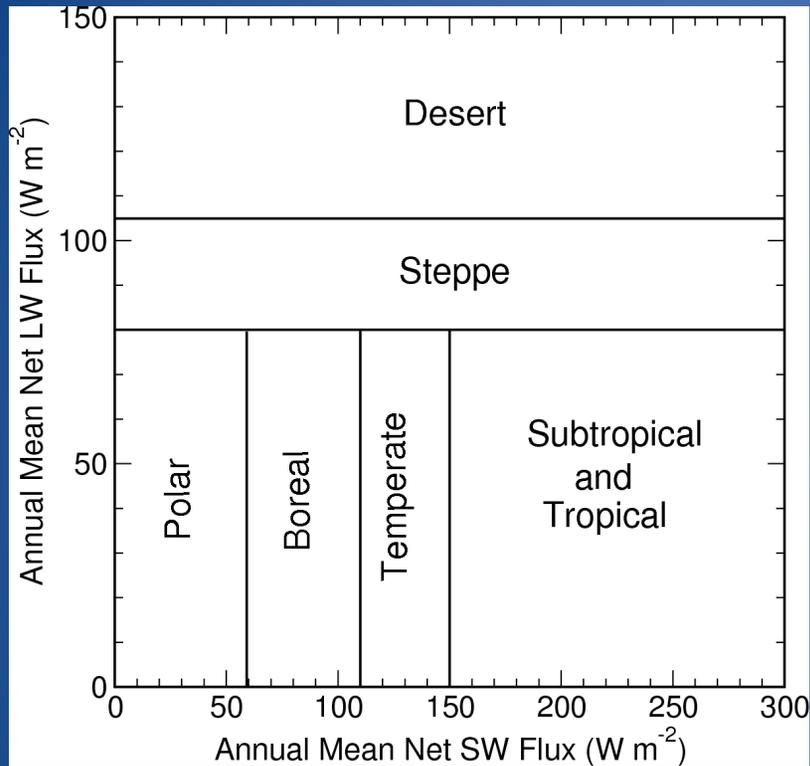


Data

- NASA/GEWEX Surface Radiation Budget Data Set Release 2.5/3.0
- 1° resolution in latitude and longitude
- 22 year set for LW: July 1983 – June 2005
- Use 3-hourly monthly means
- Both all-sky and clear-sky products available for upward and downward SW and LW



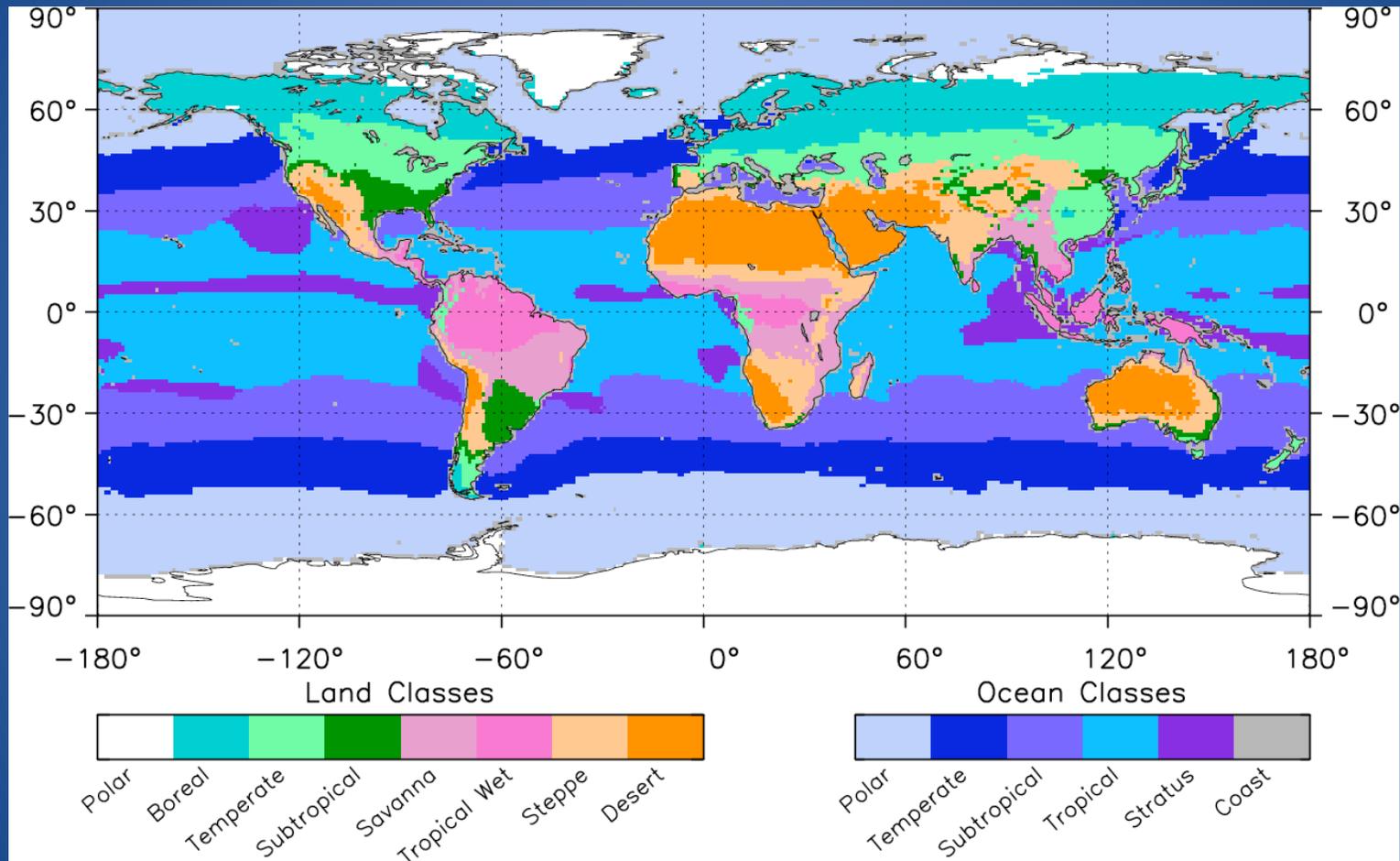
SRB and Climate Class



- An approximation to climate classification using only SRB.
- Based on Smith et al., 2002: Surface radiation budget and climate classification, *J. Climate*, **15**, 1175-1188.
- They used 8-year $2.5^\circ \times 2.5^\circ$ SRB data set.
- We tweaked the criteria to obtain a satisfactory climate class map with latest version of SRB.



Climate Class Map



Computation of Diurnal Cycle

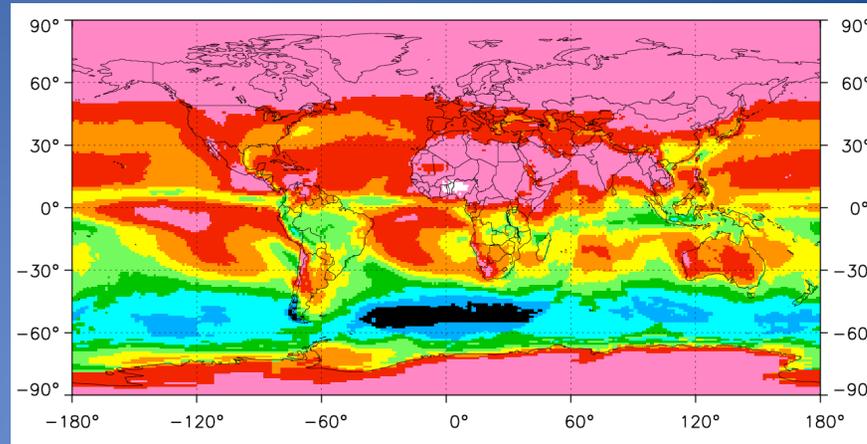
- Average 3-hourly monthly means across all Januarys or Julys – 22-year average.
- Interpolate to get hourly values on LST from 3-hourly values on GMT.
- Cloud forcing = All-sky – Clear-sky
- Compute daily mean value at each region.
- Subtract from every hour to obtain mean diurnal cycle.



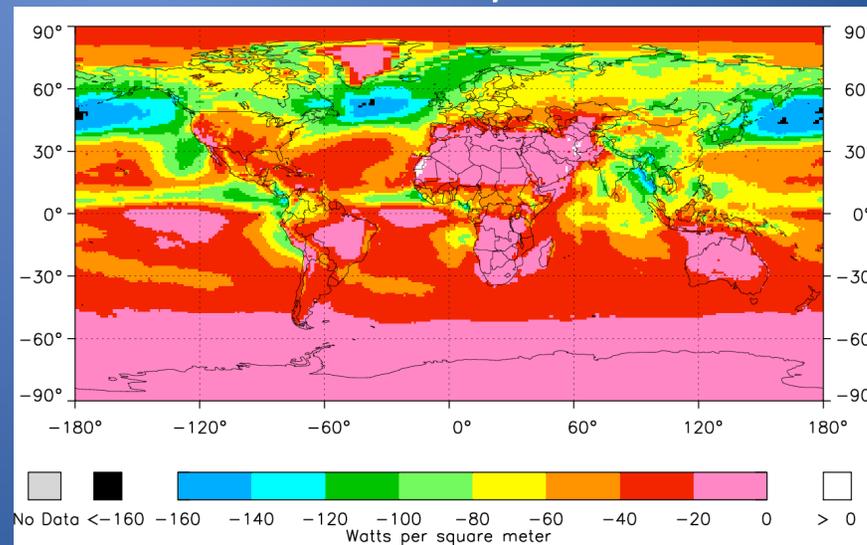
Mean SWN Cloud Forcing

- Clouds reflect and absorb solar radiation, cutting back on SWN at the surface; hence we see negative values for SWN CF.
- Desert and subsidence regions lack clouds; small SWN CF.
- In ITCZ, larger SWN CF.
- Clouds diminish SWN at high latitudes over ocean in both summer hemispheres, especially near 60°S in January, where clouds are strongly reducing SWN over the whole zone.
- Monsoon region over Bay of Bengal and Myanmar.

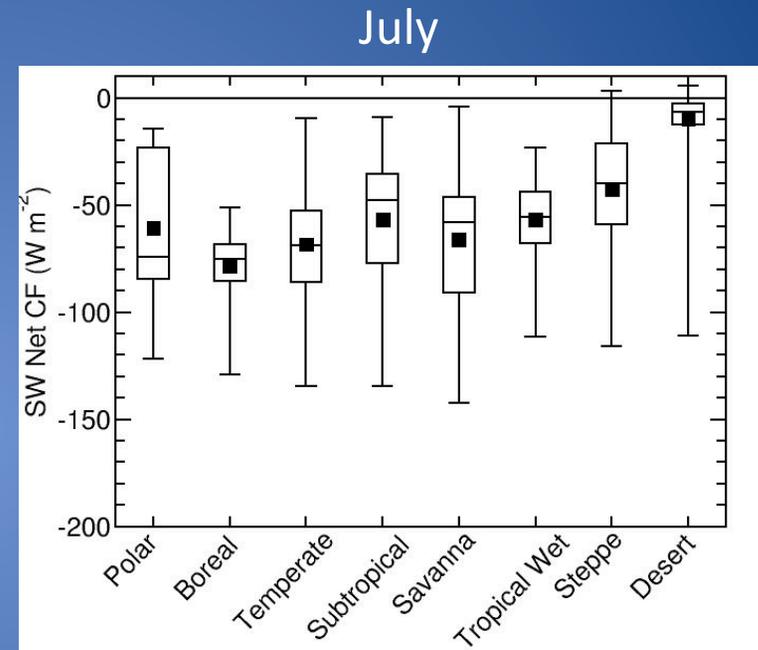
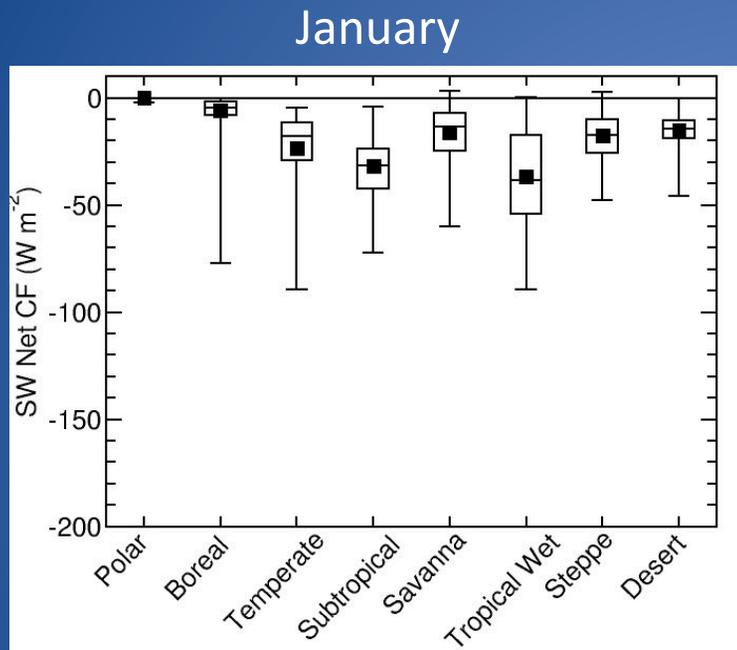
January



July



Mean SWN Cloud Forcing over Land in Northern Hemisphere



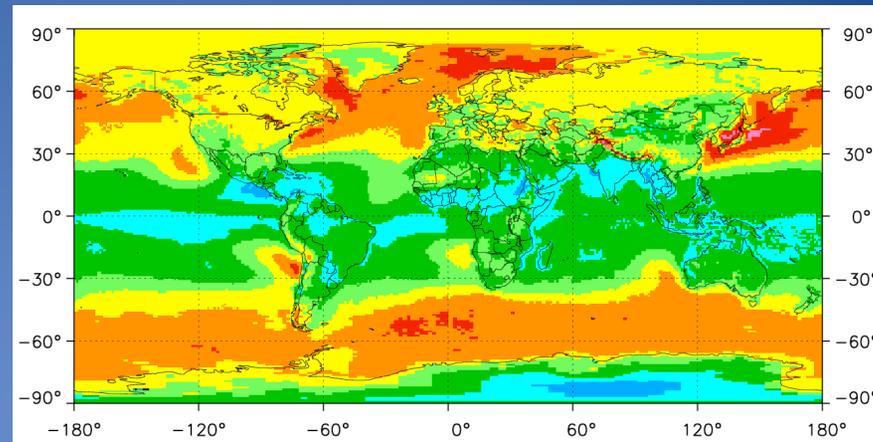
- In January you see a slight progression of SWN CF increasing from pole through subtropical zones. The rains are gone from the savanna, and so those areas act like steppe and desert.
- In July, these regions from pole through savanna have a mean SWN CF in same range. The rains are back in the savanna, and those areas act like tropical wet regions.



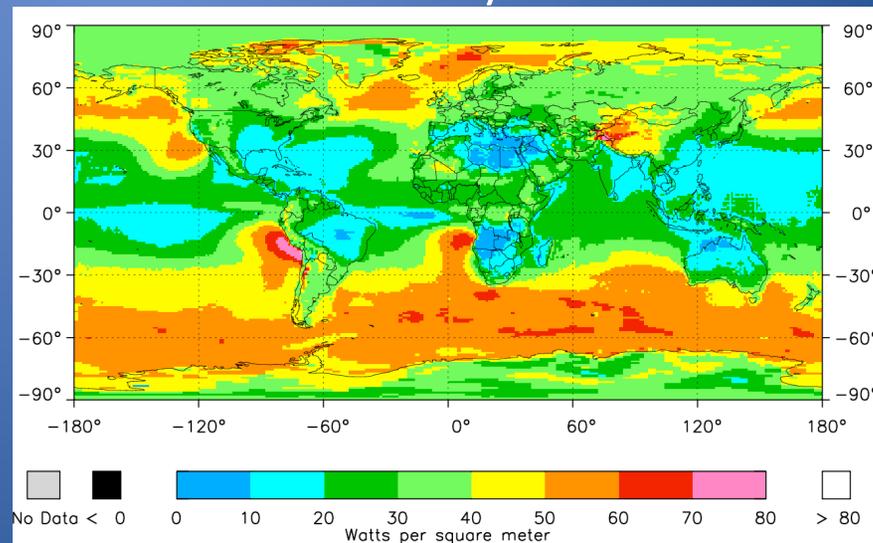
Mean LWD Cloud Forcing

- Clouds increase LWD at the surface, depending on cloud fraction and cloud base height; hence we see positive values for LWD CF.
- From 40° to 70° in each hemisphere, the daily mean LWD CF is between 40 and 60 $W m^{-2}$ in both winter and summer.
- LWD CF is small along equator, but ITCZ is visible on either side. Values are small primarily due to moist boundary layers. Presence of large cirrus anvils may obscure some low clouds.
- Note areas of stratocumulus stand out with large values of LWD CF because the clouds are low and thick.
- In July, subsidence regions over the North Atlantic and Pacific have small LWD CF. We don't see this in the Southern Ocean in January.

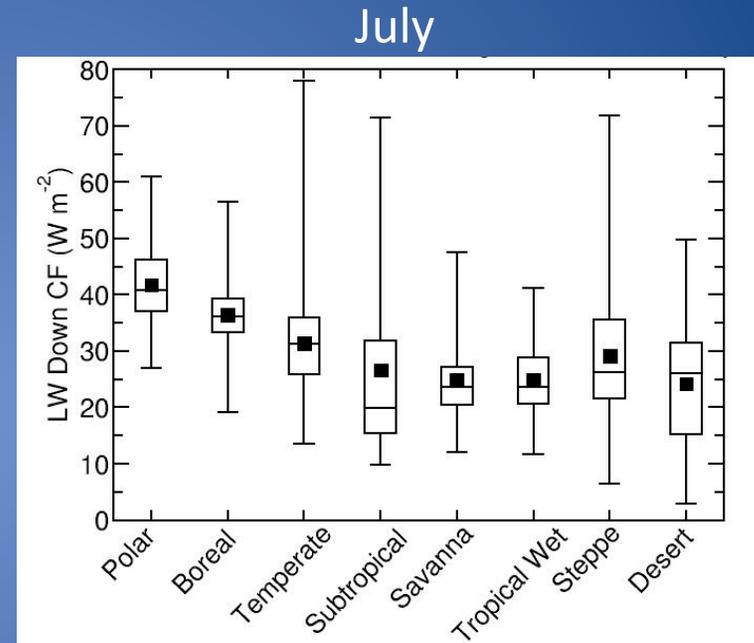
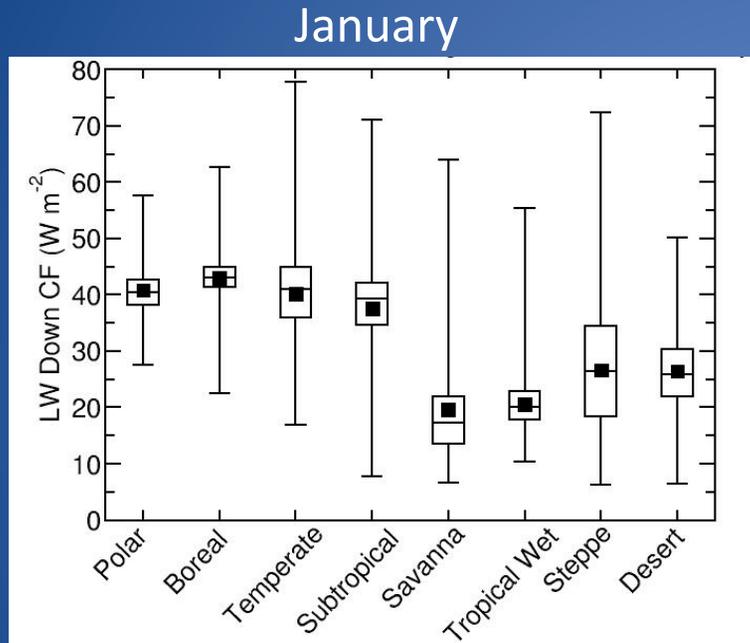
January



July



Mean LWD Cloud Forcing over Land in Northern Hemisphere



- In winter, the mean from pole through subtropical is fairly uniform. Stratiform clouds are dominant now.
- In summer, the mean LWD CF decreases with progression to lower latitudes. More convective clouds as you move south from boreal through subtropical.
- The tropical regimes are consistently low, with mean values changing by only 5 W m⁻² between seasons.



PC Analysis

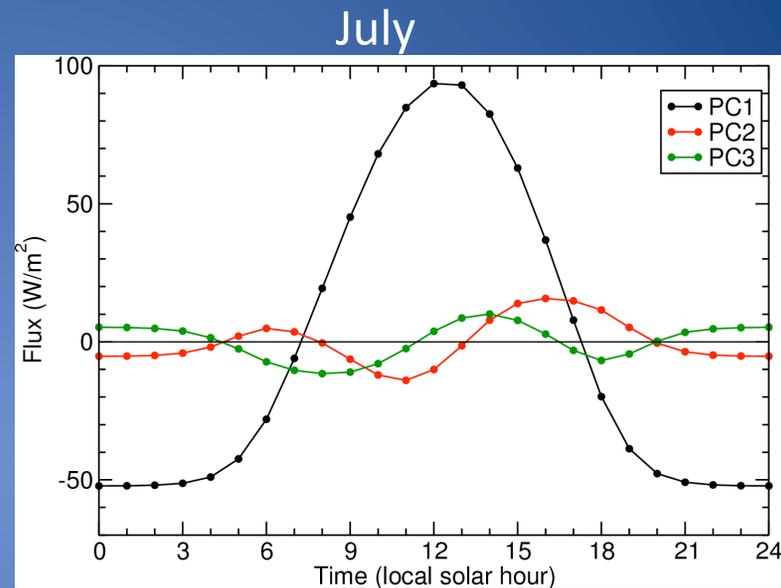
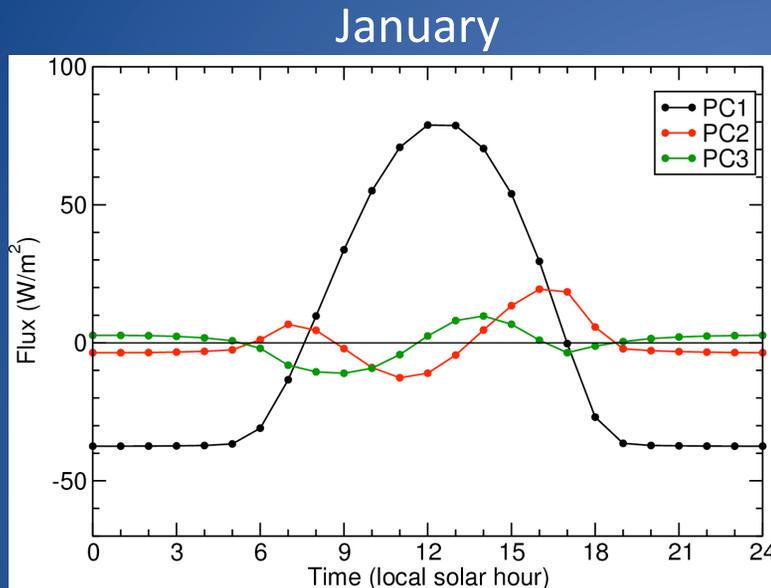
- Use principal component (PC) analysis to look at all regions, separating into land or ocean.
- The diurnal cycle at any given region may be represented by

$$D(x,t) = \sum PC_n(t) EOF_n(x)$$

- PC is the time history of the diurnal cycle.
- EOF is the spatial coefficient.



Principal Components of SWN CF over Land



- The time history of SWN CF.
- The peak of PC-1 is not directly at noon.

Order	Eigenvalues		Physical Mechanism
	January	July	
1	95.03	96.06	Insolation change during day
2	3.04	2.09	Length of day change with latitude & AM/PM cloud change
3	1.36	1.31	

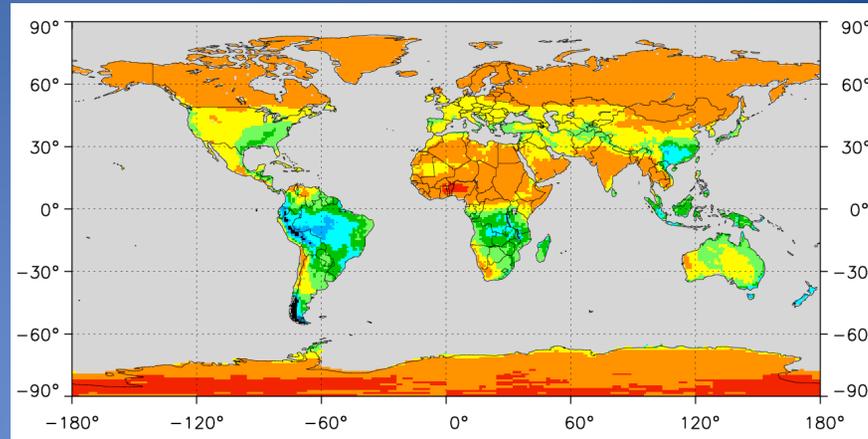
PC-2 and PC-3 do not separate out nicely.



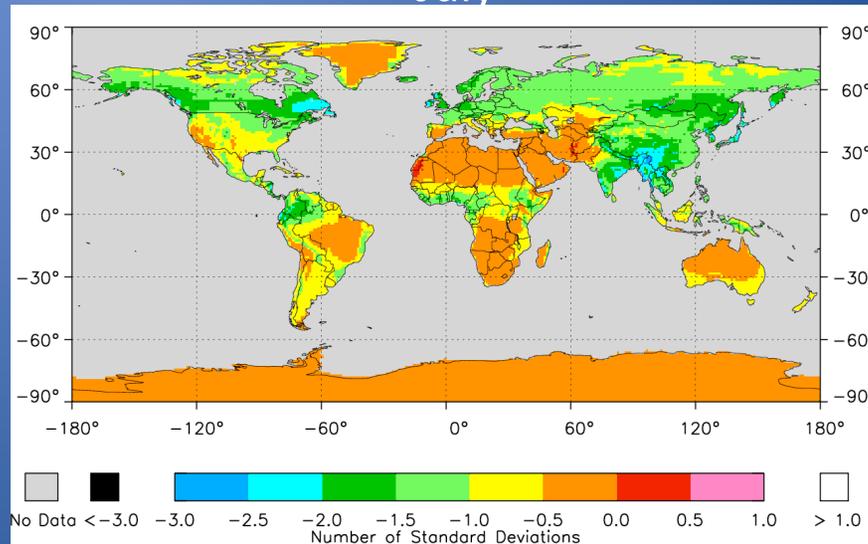
SWN Cloud Forcing EOF-1

- Geographical coefficient of PC-1.
- Negative values of EOF-1 mean negative SWN CF during the day.
- Primary effect is diurnal cycle of TOA insolation.
- Diurnal cycle of SWN CF near noon will also appear here.
- In January deep convection over Amazon and Congo produces strong EOF-1.
- In January low insolation results in small CF north of 50° N.
- Larger SWN CF over ITCZ and monsoon regions.
- Deserts have small CF.

January



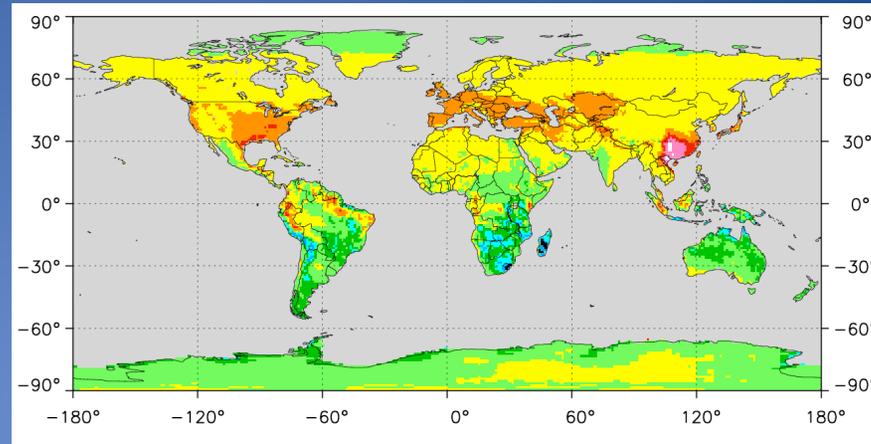
July



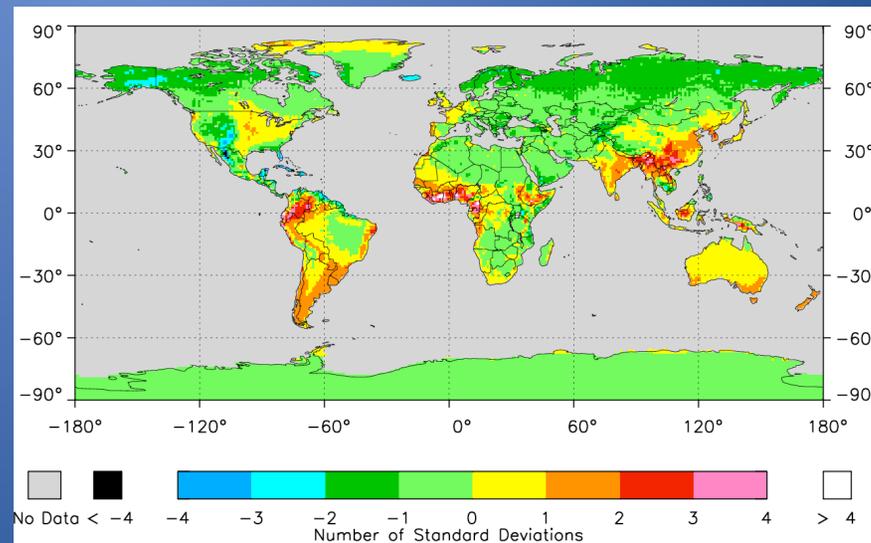
SWN Cloud Forcing EOF-2

- EOF-2 shows effects of both the change in length of day with latitude and morning/afternoon cloudiness.
- In North America in July, afternoon cloudiness, or convection, is apparent.
- Monsoon cloudiness over south coast of North Africa and Myanmar.

January



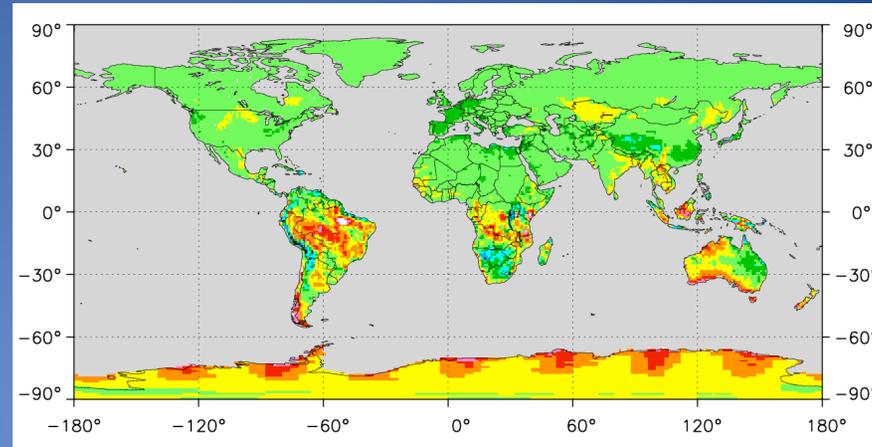
July



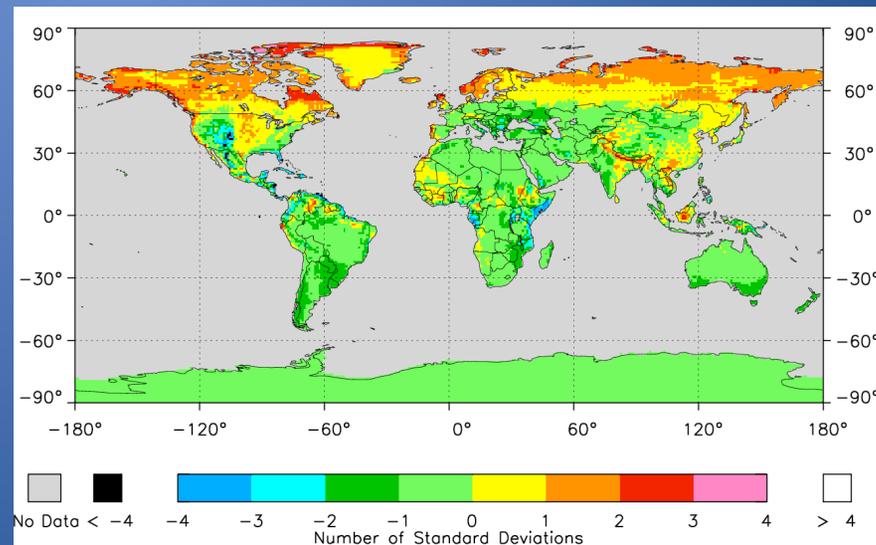
SWN Cloud Forcing EOF-3

- EOF-3 also shows effects of both the change in length of day with latitude and morning/afternoon cloudiness.
- The change in length of day is most obvious in this July map.
- Over Antarctica you can see the artifacts from AVHRR in ISCCP.
- Afternoon convection in western US.
- With EOF-2 and EOF-3, you can pull out regional features, but you cannot make global generalizations.

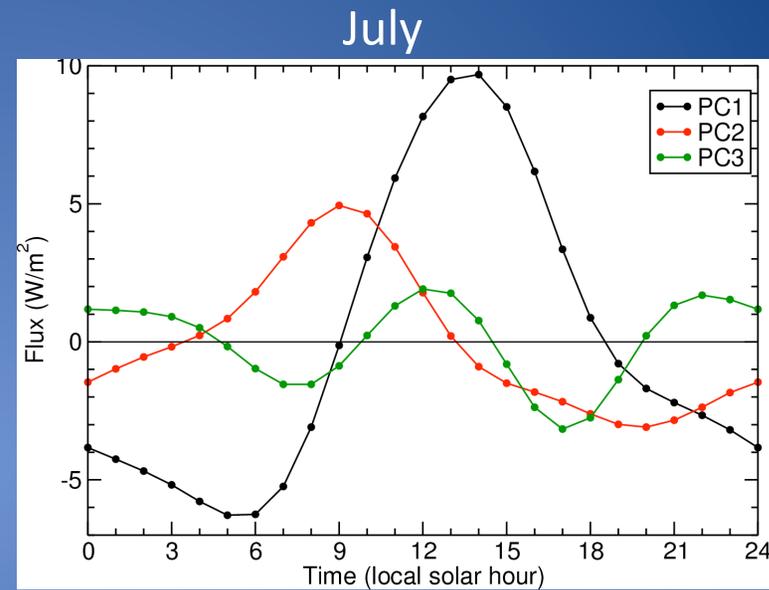
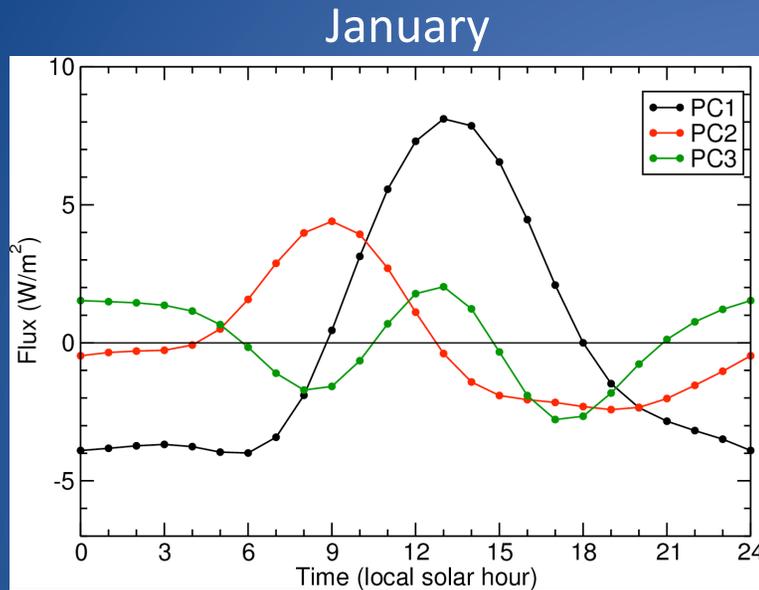
January



July



Principal Components of LWD CF over Land



- The time history of LWD CF.
- Lags behind SWN CF PC-1.

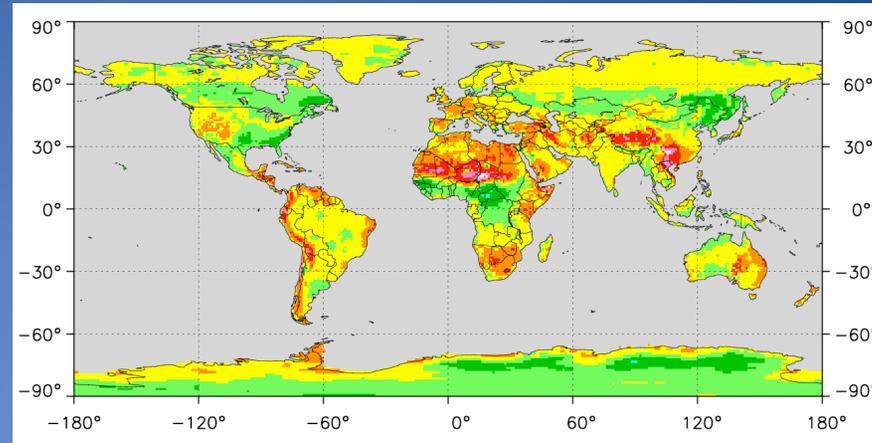
Order	Eigenvalues		Physical Mechanism
	January	July	
1	65.94	70.20	Heating of atmosphere
2	16.23	15.62	AM/PM cloud change
3	7.57	5.54	Length of day change with latitude & AM/PM cloud change



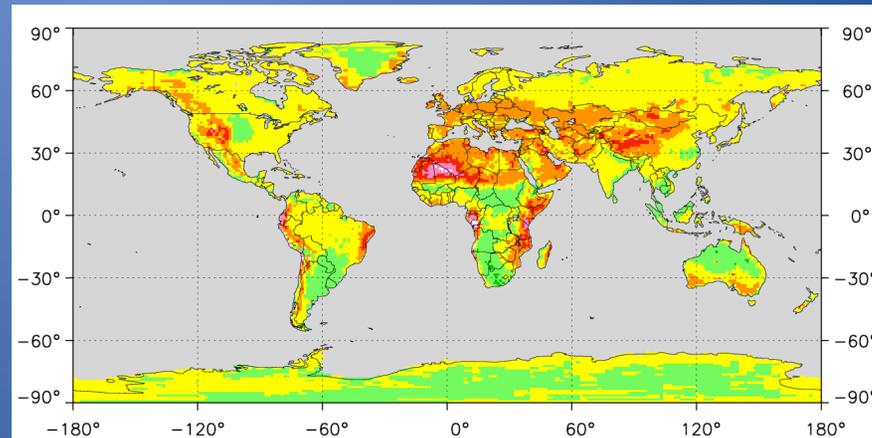
LWD Cloud Forcing EOF-1

- A negative EOF-1 value means nighttime cloudiness because it changes the sign of PC-1.
- In January, there is more LWD CF over North America and Asia than during July.
- Otherwise, no striking changes between seasons.
- Since this first PC and EOF explain only 65 – 70% of the diurnal cycle, you need to look at the next few PCs/EOFs to get an overall picture of the diurnal cycle of LWD CF about the mean.

January



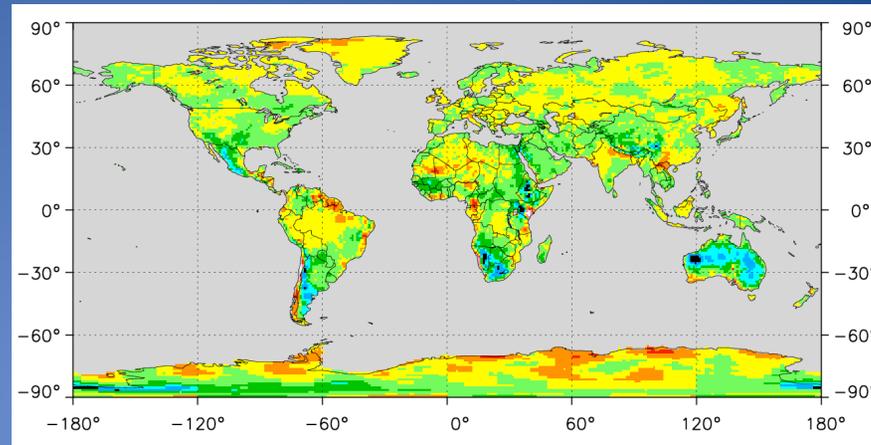
July



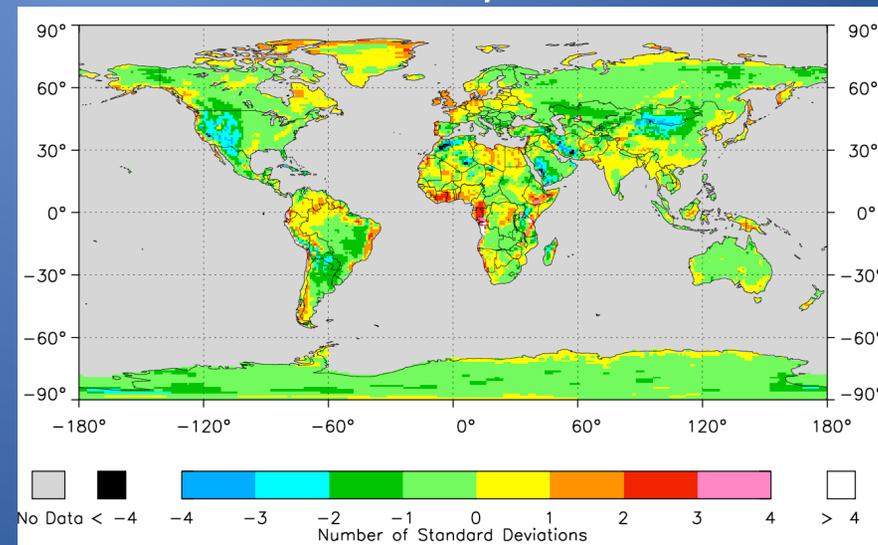
LWD Cloud Forcing EOF-2

- A negative EOF-2 value means afternoon cloudiness.
- In July, you can see afternoon convection in western US and east of mountain regions in the Sahara.
- In July, the monsoon region of the south coast of North Africa has morning cloudiness.

January



July



Conclusions

- For January and July, we have defined the daily mean of cloud forcing of both SWN, which drives the system, and LWD.
- The daily mean of LWD CF is between 25 and 40 W m⁻² over land in the Northern Hemisphere, regardless of season.
- We used PC analysis to help quantify globally the magnitude of the diurnal cycle of SWN CF and LWD CF.
- We used climate class as a tool to help understand the physical mechanisms behind the diurnal cycle of cloud forcing.



Possible Future Work

- Look at individual regions to better understand their behavior, especially in terms of LWD CF.
- Use Fu-Liou radiative transfer code to calculate LWD CF with respect to different cloud amounts, cloud base heights, atmospheres.
- Compare with CERES hourly surface fluxes to see if we are consistent.
- Compare with model output.

