Interannual Variations of Surface Radiation Budget

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22nd Conference on Climate Variability and Change
Atlanta, GA – January 17-21, 2010

Objective

- To begin to quantify both temporally and spatially the interannual variations of surface radiation fluxes, namely shortwave net (SWN), longwave up (LWU), and longwave down (LWD) using principal component analysis with a global data set.
- To identify areas of interest (both in space and time) for further study.
- This is an exploratory study. We are not attempting to assign physical mechanisms to each mode.

Data Set

- NASA/GEWEX Surface Radiation Budget Data Set Releases 2.5/3.0
- 1° resolution in latitude and longitude
- 22 years: July 1983 – June 2005
- Monthly means of all-sky SWN, LWU, and LWD

Computation of Interannual Variations

- Compute climatological monthly means for the period July 1983 – June 2005.
- For any given region,
  Interannual variations =
  Flux values – Climatological monthly means
- Or another way to look at this:
  Flux = Climatological annual mean
  + Annual cycle
  + Interannual variations

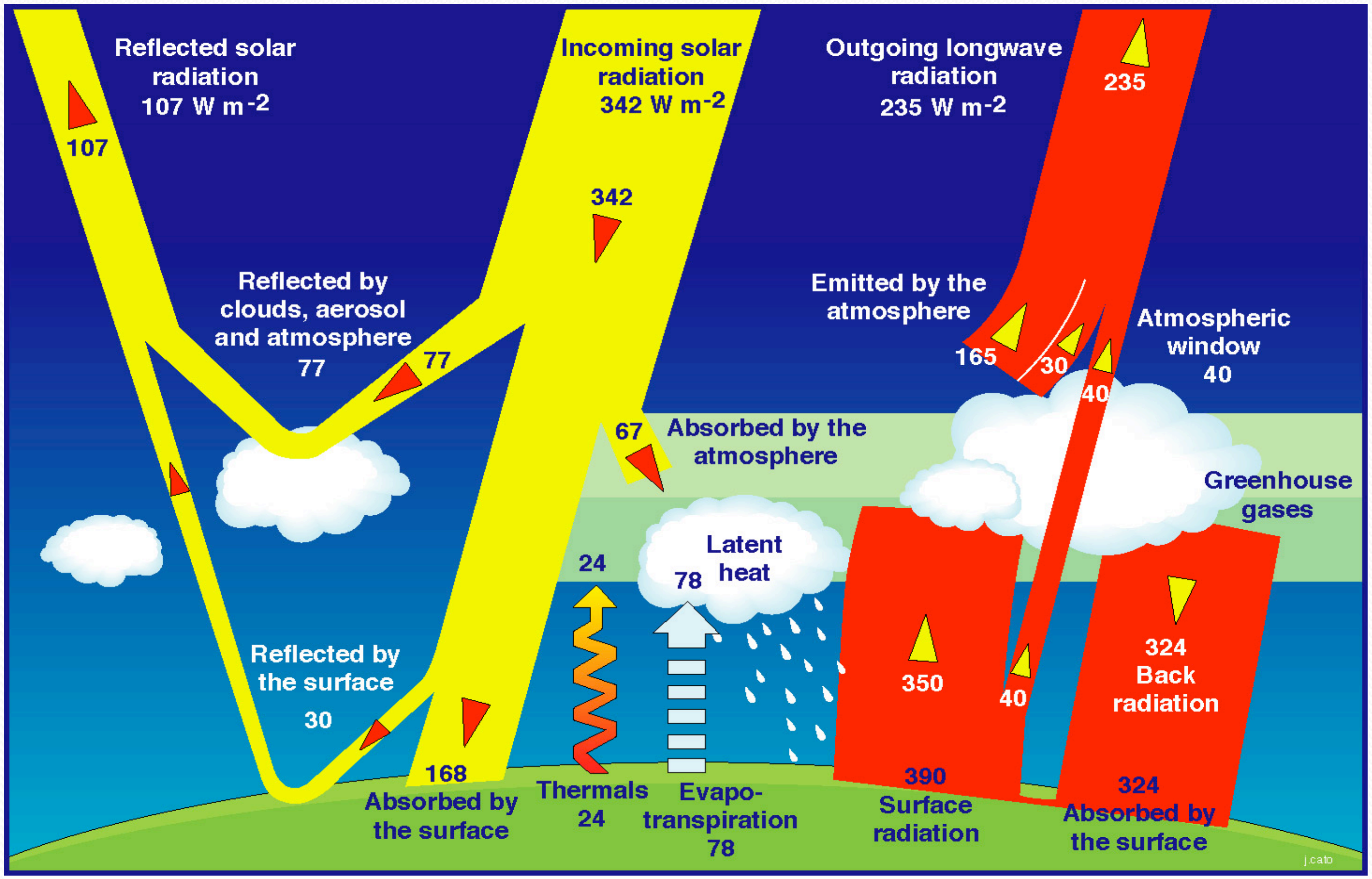
Analysis Method

- Use **principal component analysis** to compute variations as correlated in time for all 1° x 1° regions.
- The interannual variations at any given region may be represented by

$$y(x,t) = \sum_{i=1}^{264} PC_i(t) \times EOF_i(x)$$

- **Principal components (PC)** are the eigenvectors of the covariance matrix of variations. They represent the time series.
- The **eigenvalues** of the covariance matrix define the amount of variance explained by each PC.
- The PCs are projected onto the original data (variations) to obtain **EOF maps**, representing the geographical coefficients.

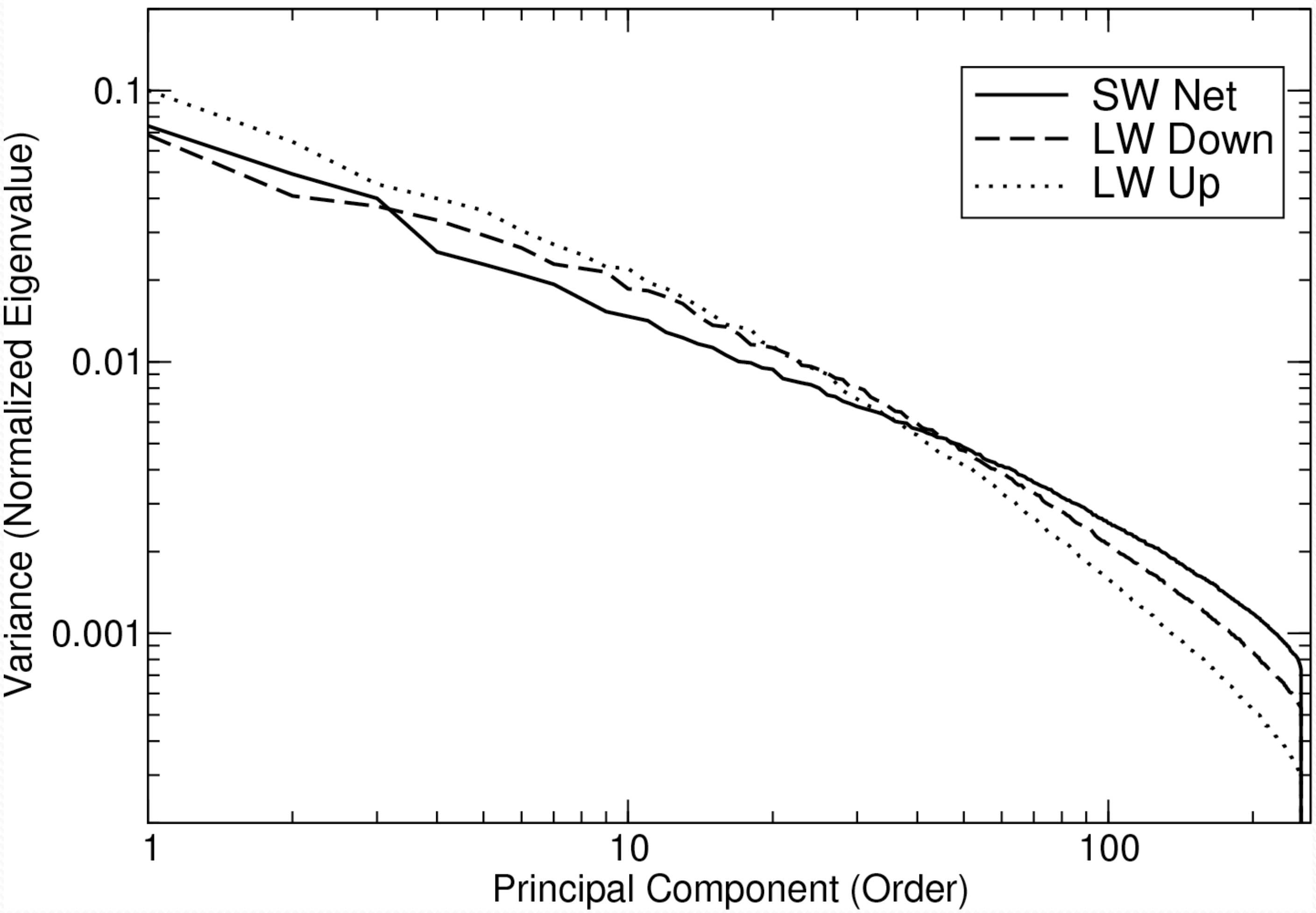
Global Annual Mean Energy Budget



RMS of Interannual Variations

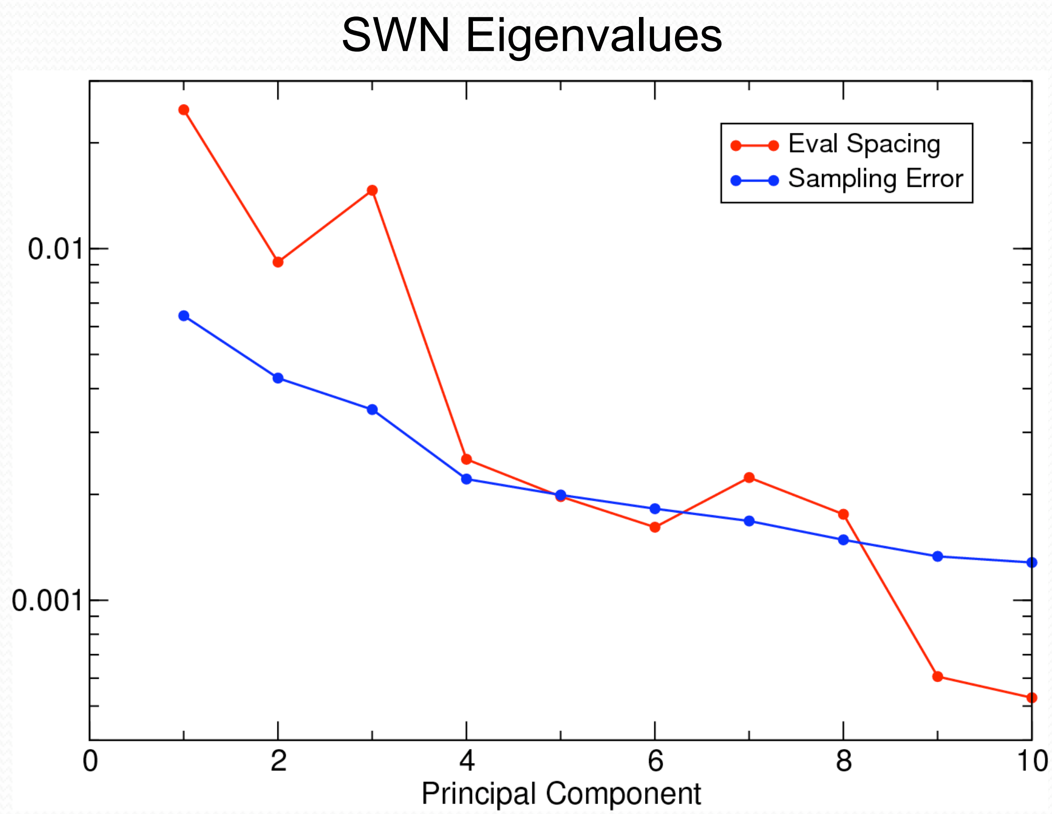
Parameter	SWN	LWD	LWU
Global Mean (W m^{-2})	168	324	390
RMS (W m^{-2})	14.4	7.3	6.8
RMS % of Global Mean	8.6	2.3	1.7
RMS(1) (W m^{-2})	3.91	1.92	2.16
λ_1 (normalized eigenvalue)	0.0740	0.0685	0.1001

Variances—or How Important Is Each PC



Validity of Principal Components

- How many PCs can we trust?
- Use North et al. (1982) criterion of comparing the eigenvalue sampling error to the distance between adjacent eigenvalues to determine where PCs/EOFs may be mixed.
- Where mixing is occurring, you don't have a unique solution.
- Even though the patterns may be mixed, the EOF maps will indicate active regions of interannual variability.



Satellite Coverage for ISCCP

- Cloud data inside SRB data set from ISCCP.
- Changes in satellites and coverage introduce artifacts into the data set.
- For interannual study, there is no time period where you don't have changes in spacecraft.
- We choose to work with the entire space and time domain of the SRB data set.

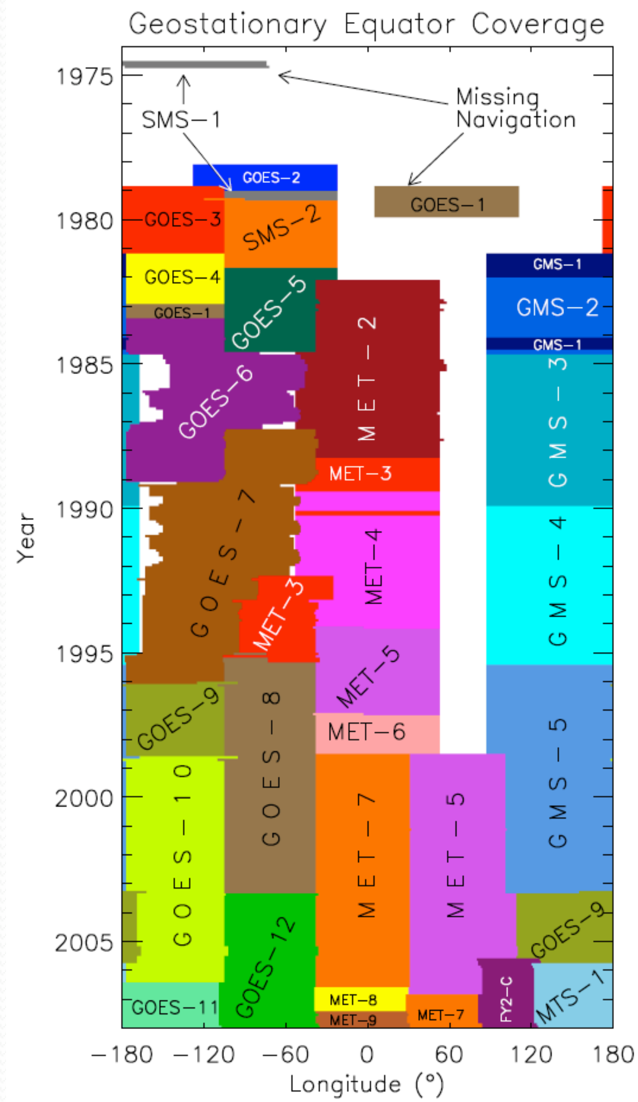


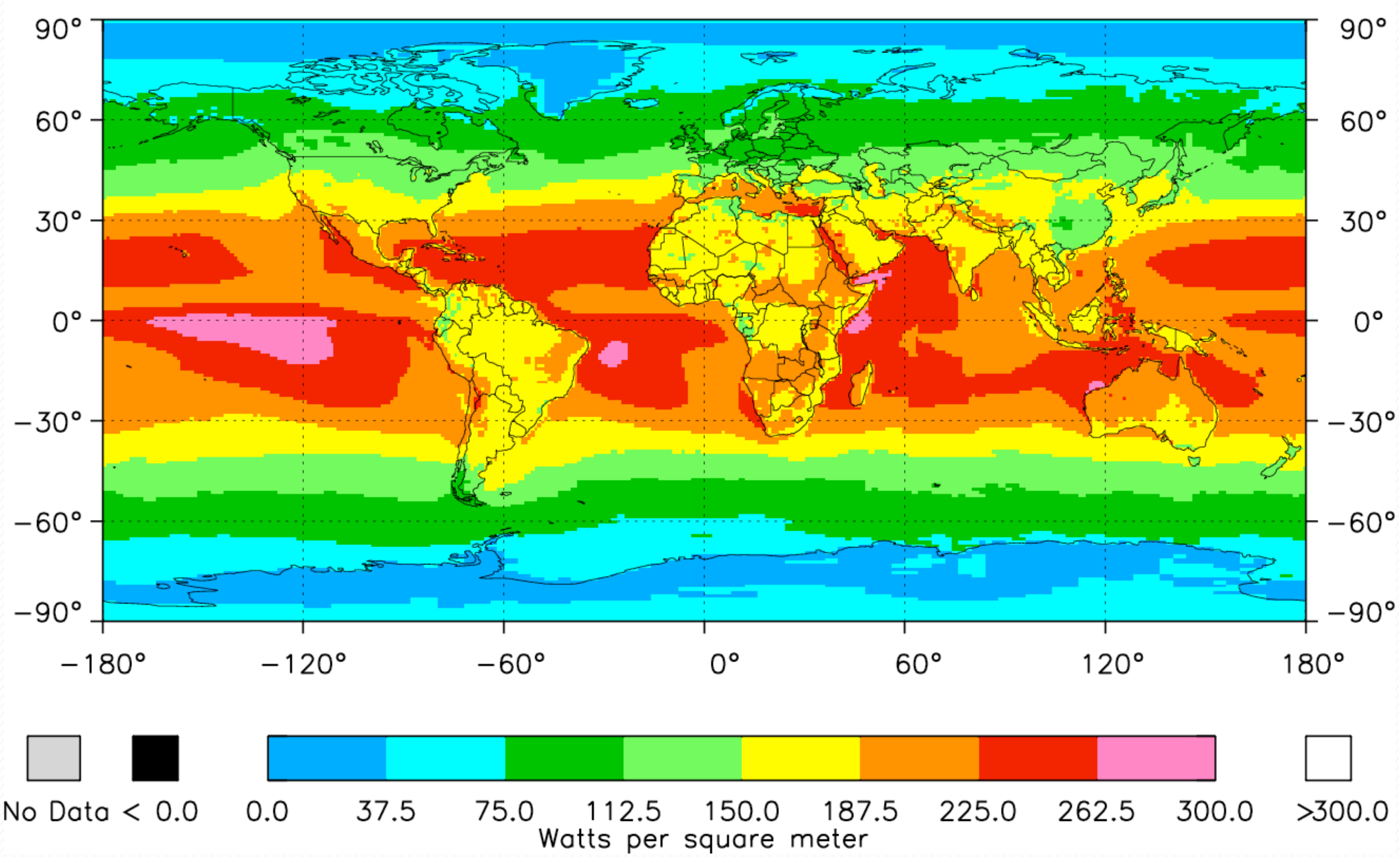
Fig. 1. Time series showing geostationary observations at the Equator.

Knapp, K. R., 2008: Scientific data stewardship of International Satellite Cloud Climatology Project B1 global geostationary observations, *J. Appl. Remote Sens.* **2**, 023548.

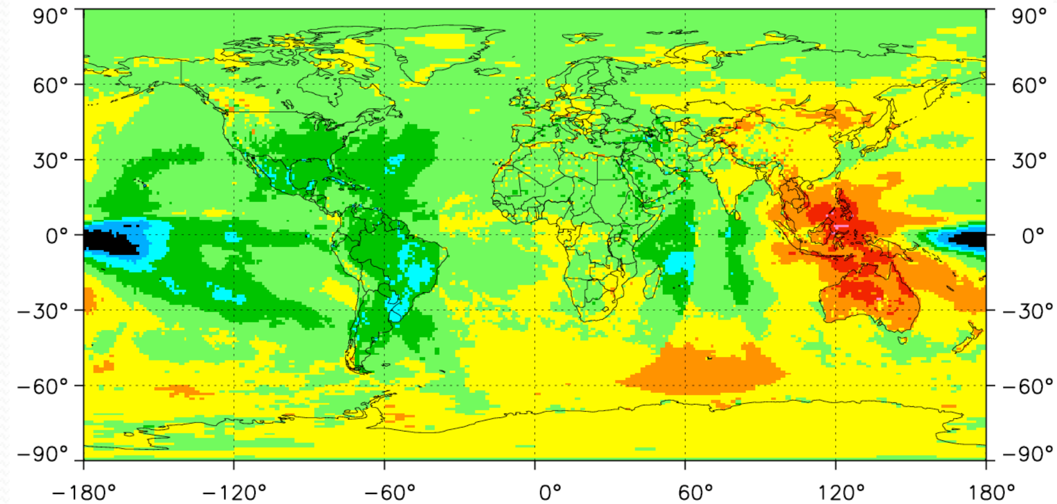
Global Results

- Shortwave Net
  - Annual Mean (climatological)
  - Principal Components and EOF Maps
- Longwave Upward
  - Annual Mean (climatological)
  - Principal Components and EOF Maps
- Longwave Downward
  - Annual Mean (climatological)
  - Principal Components and EOF Maps

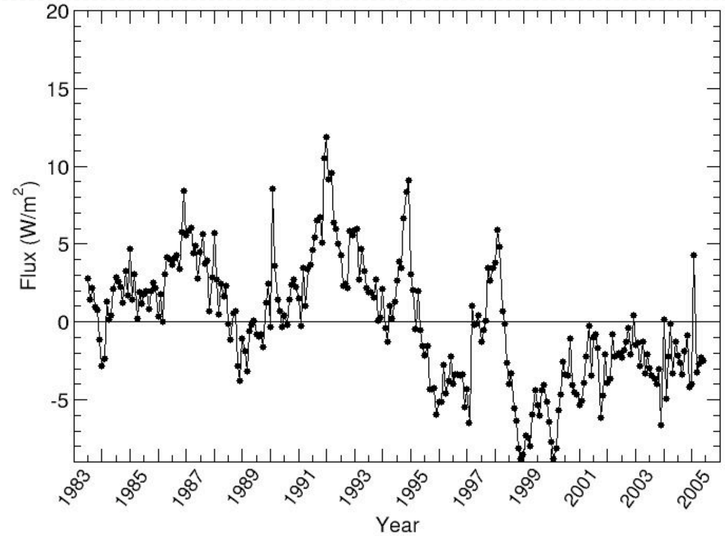
SWN Annual Mean



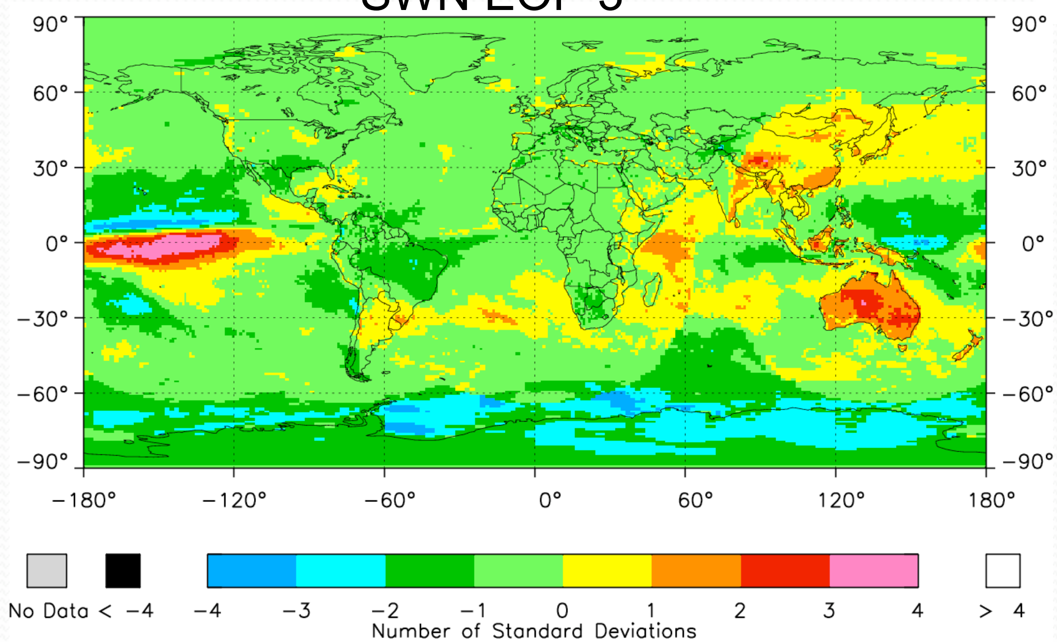
SWN EOF-1



SWN PC-1

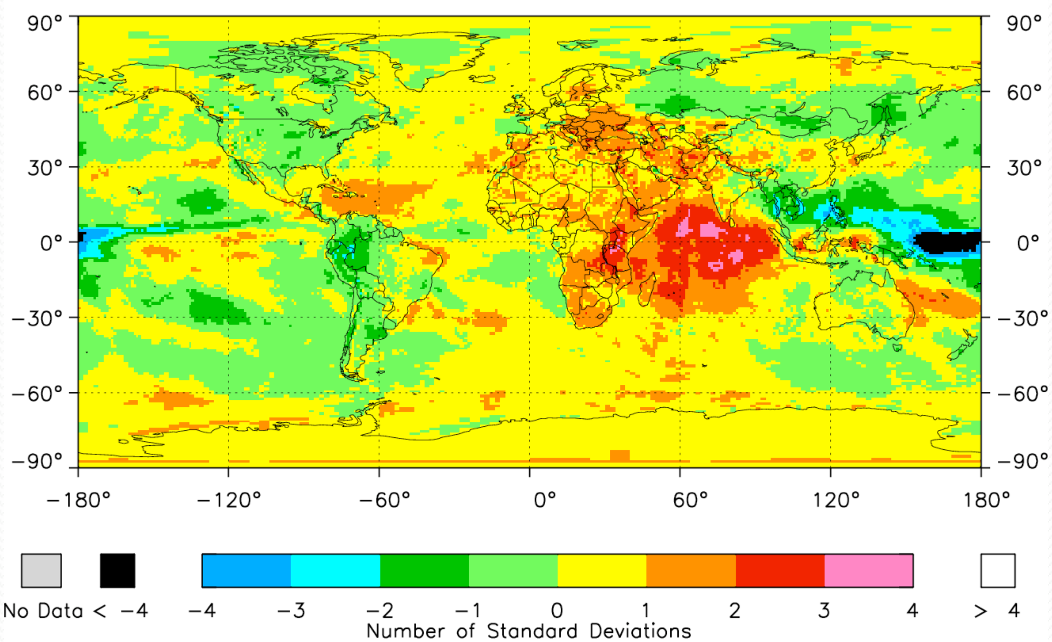


SWN EOF-3

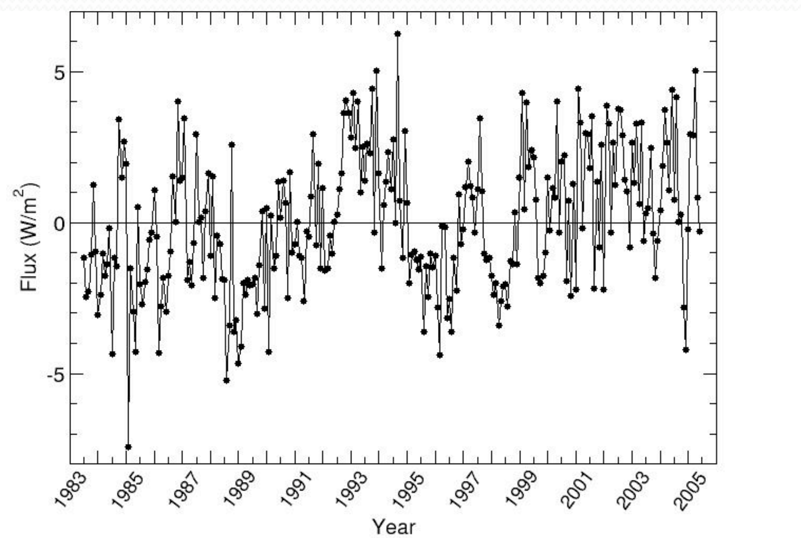


- EOF-1 describes ENSOs but also shows artifacts.
- EOF-3 describes north-south variations of ENSOs.
- Since the PC carries the units, it shows the magnitude of the interannual variations.

SWN EOF-4



PC-4

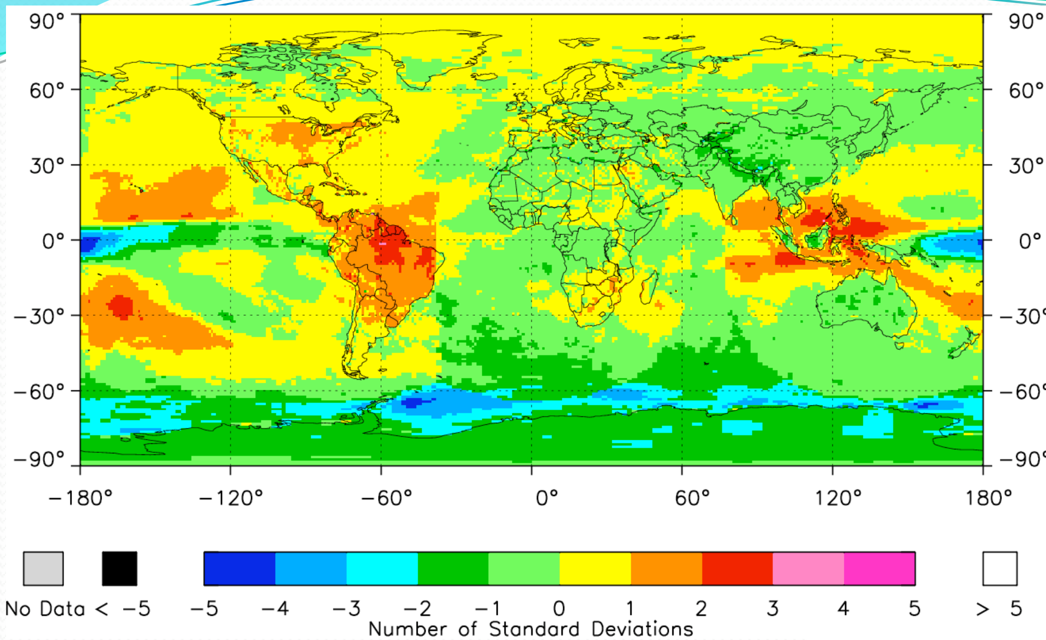


- EOF-4 shows a pattern of Indian Ocean activity plus variations over the equatorial Pacific.
- PC-4 is typical of many of the PC plots—noisy, but useful for seeing the magnitude of the cycle.

Indian Ocean Activity

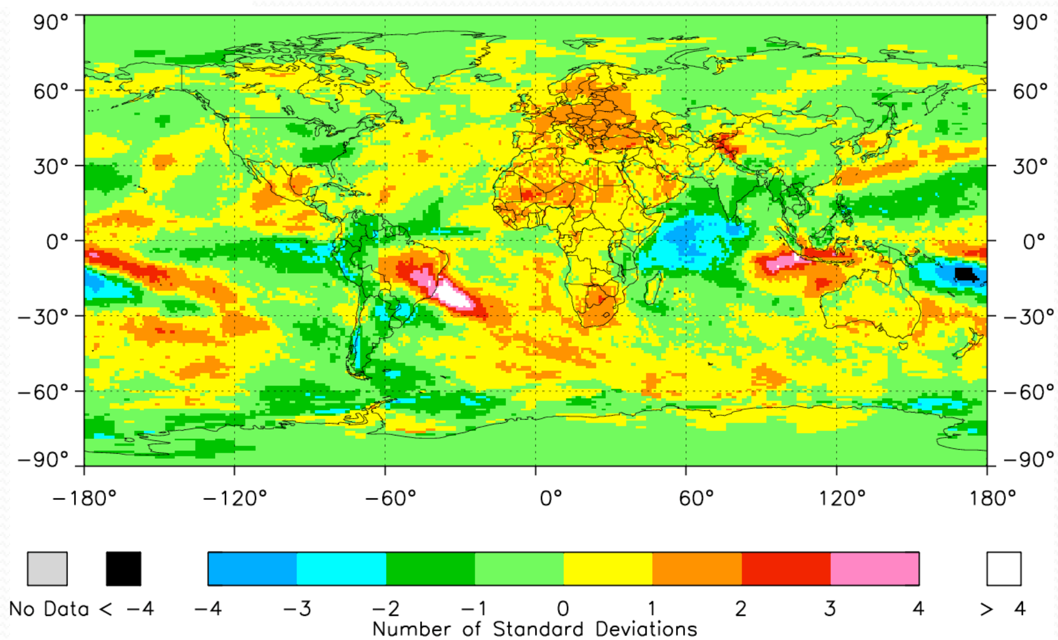
- EOFs 4 – 9 show patterns of SWN interannual variability over the Indian Ocean.
- What might we be seeing there?
  - The Madden-Julian Oscillation with periods of 40-60 days can alias into the monthly means. MJO initiates in this region with deep convective activity.
  - Variability of the Indian monsoons.
  - Indian Ocean dipole.
  - Artifacts due to spacecraft.

SWN EOF-2



- EOF-2 shows artifacts due to the lack of satellite coverage over the Indian Ocean as well as the boundary between GOES-East and Meteosat.
- Temporal sampling issues at high southern latitudes.

SWN EOF-8

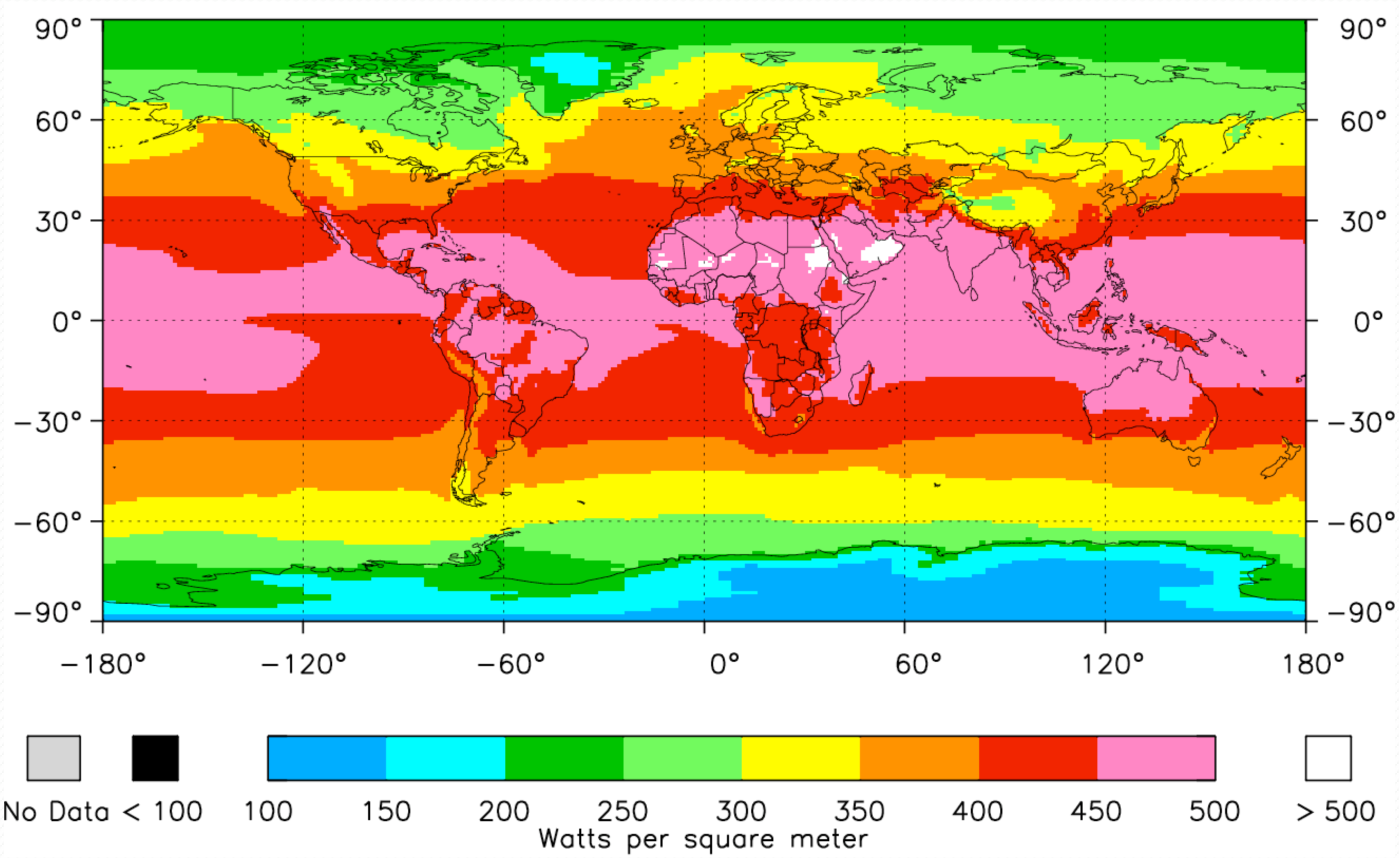


- Based on the North criterion, EOF-8 is a mix of patterns.
- But it shows an interesting feature in the SWN variations in the region of the South Atlantic Convergence Zone which we will look at separately.

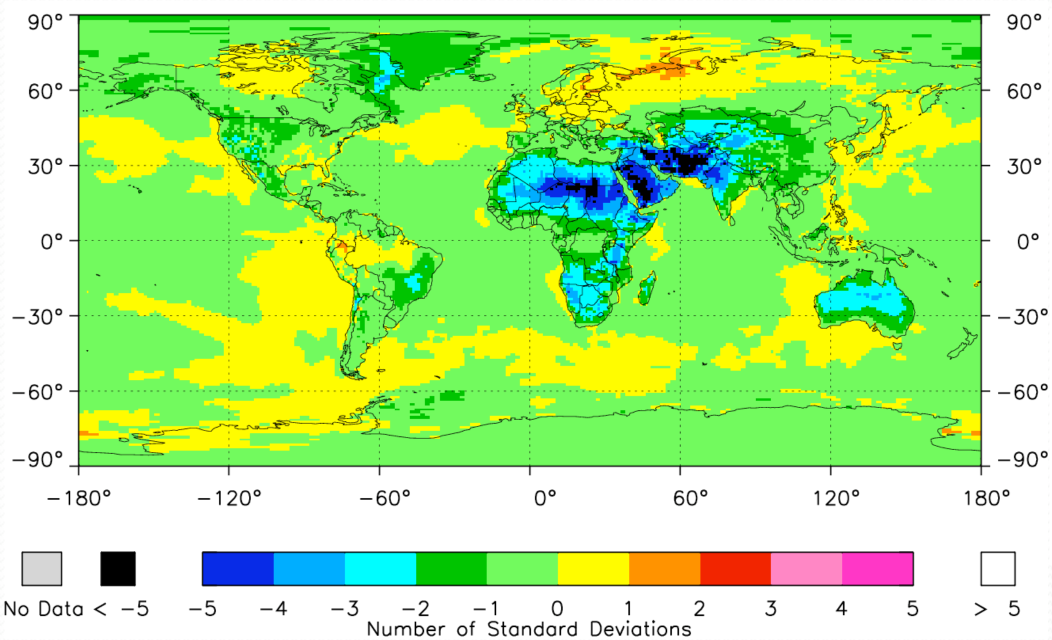
Tropics vs. Extratropics

- Many studies of interannual variability have focused on changes in pressure heights, which is suitable for extratropical regions.
- One advantage of looking at the SWN record is that near the Equator lack of Coriolis force results in small variations of pressure heights, so that in the tropics, variations in SWN are more sensitive to processes than are the pressures.

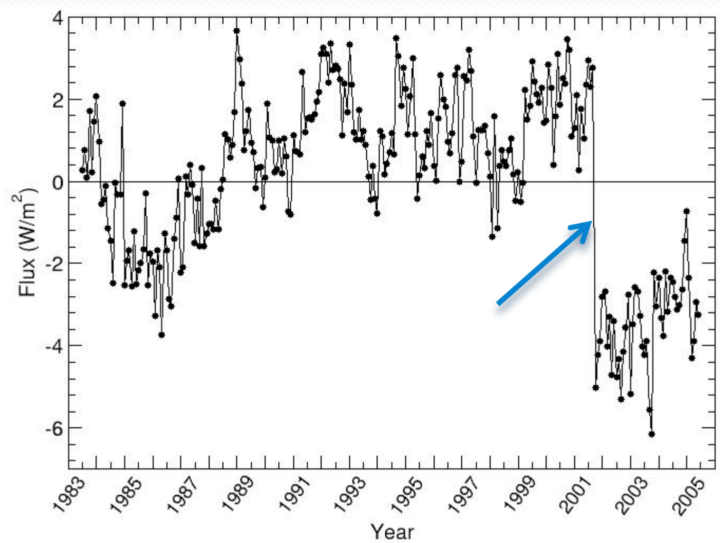
LWU Annual Mean



LWU EOF-1



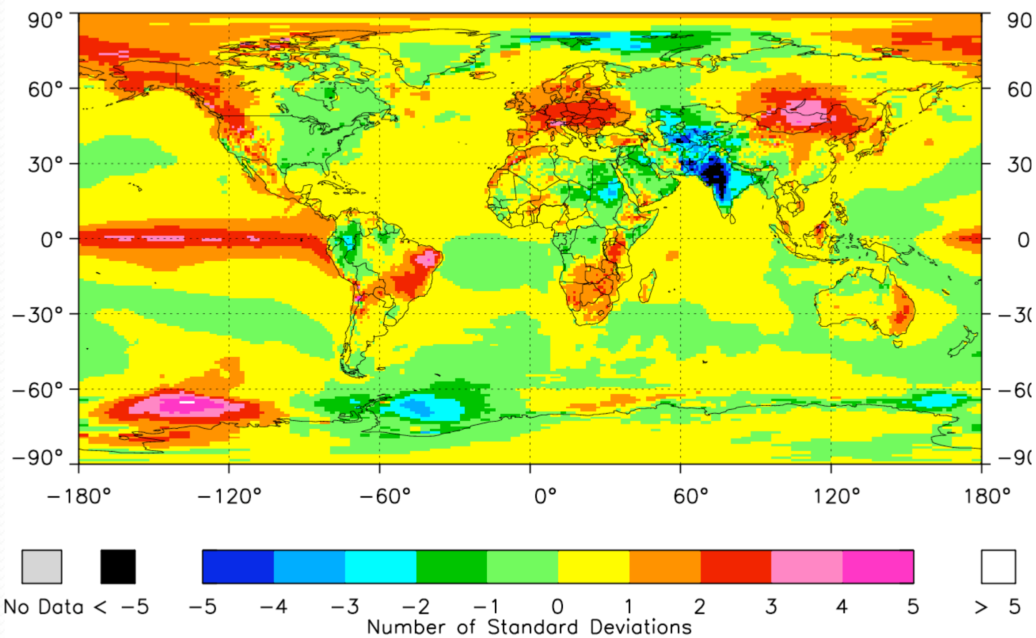
LWU PC-1



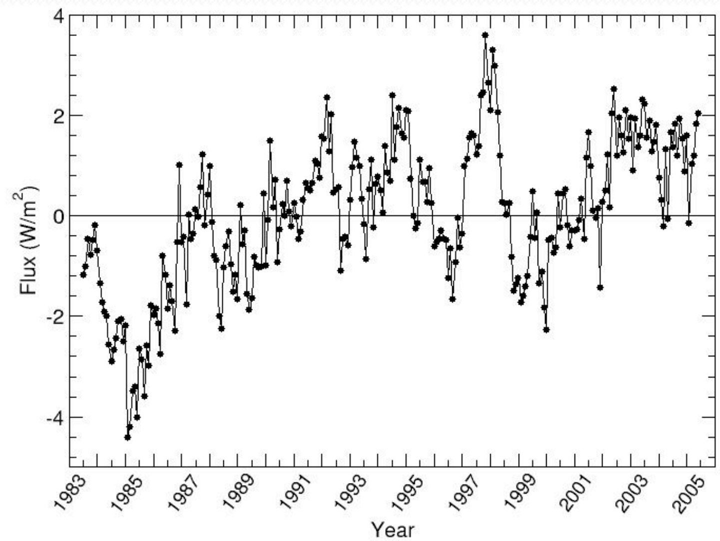
- EOF-1 shows strong signal over North Africa, Middle East and SW Asia, but it is flat everywhere else.

- PC-1 indicates jumps from positive to negative in 2001.
- When negative PC-1 values are multiplied by negative EOF-1 coefficients, an increase in LWU occurs.
- TOVS algorithm change--increased surface temperatures and therefore increased LWU.

LWU EOF-3

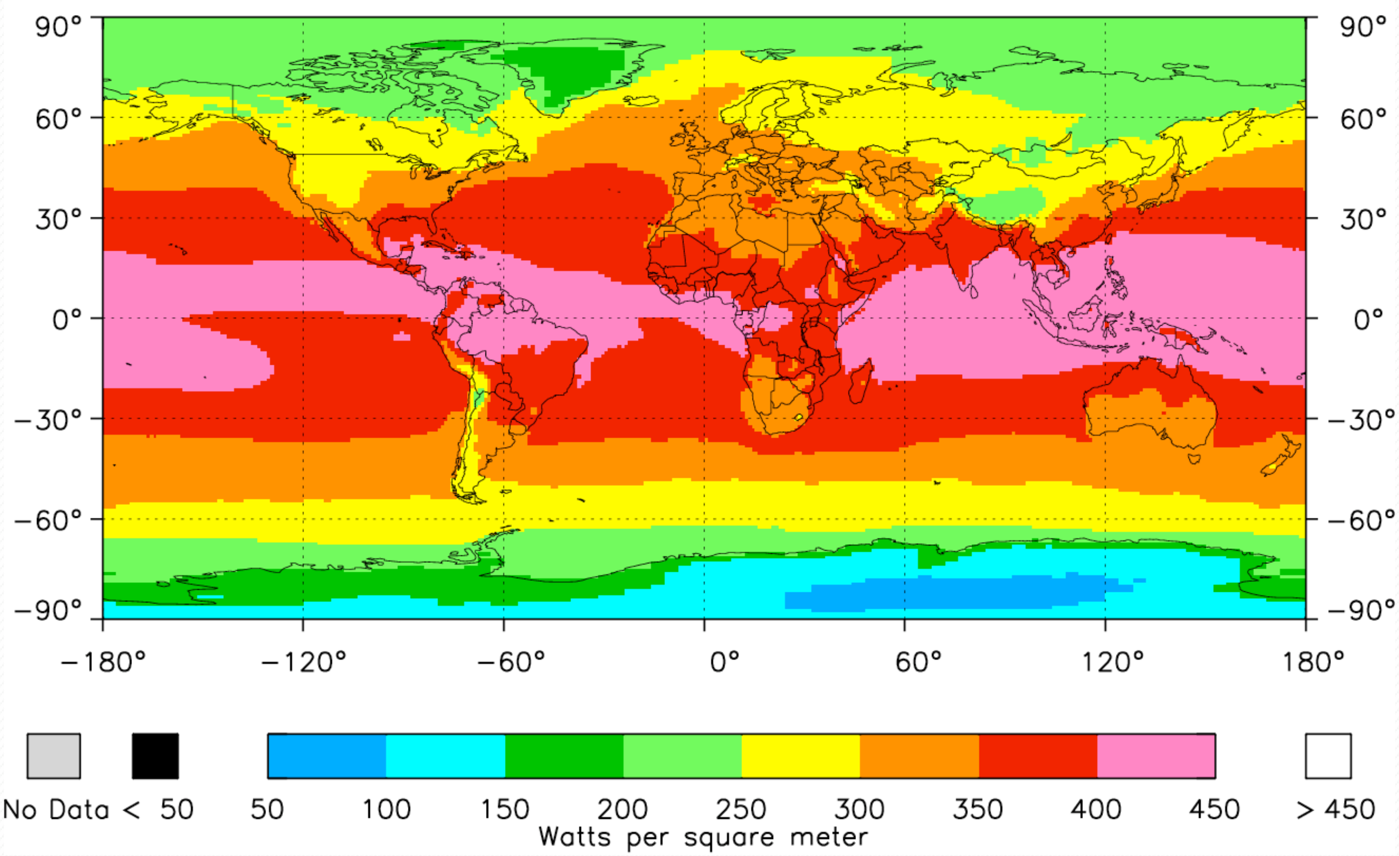


LWU PC-3

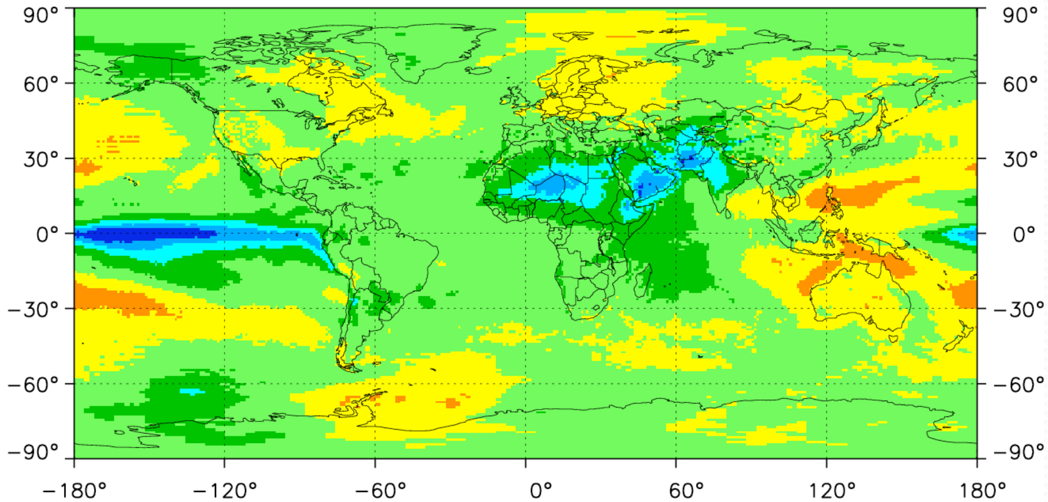


- EOF-3 describes ENSO signal.
- Note strong signature in PC-3 during 1997-98 event.

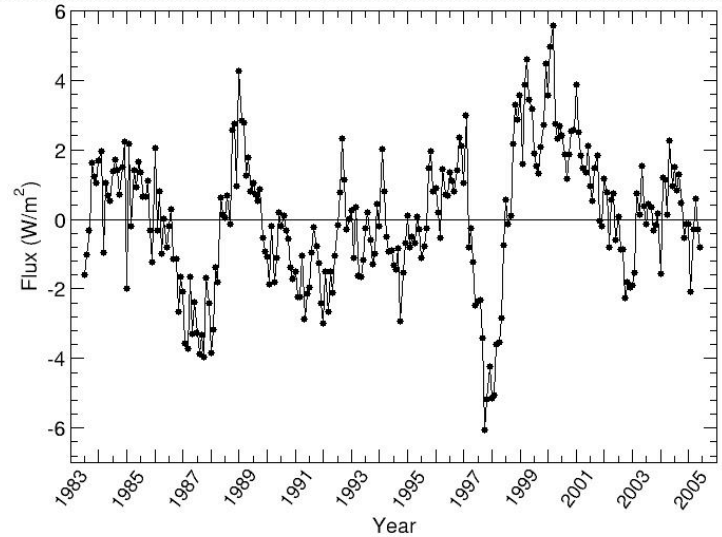
LWD Annual Mean



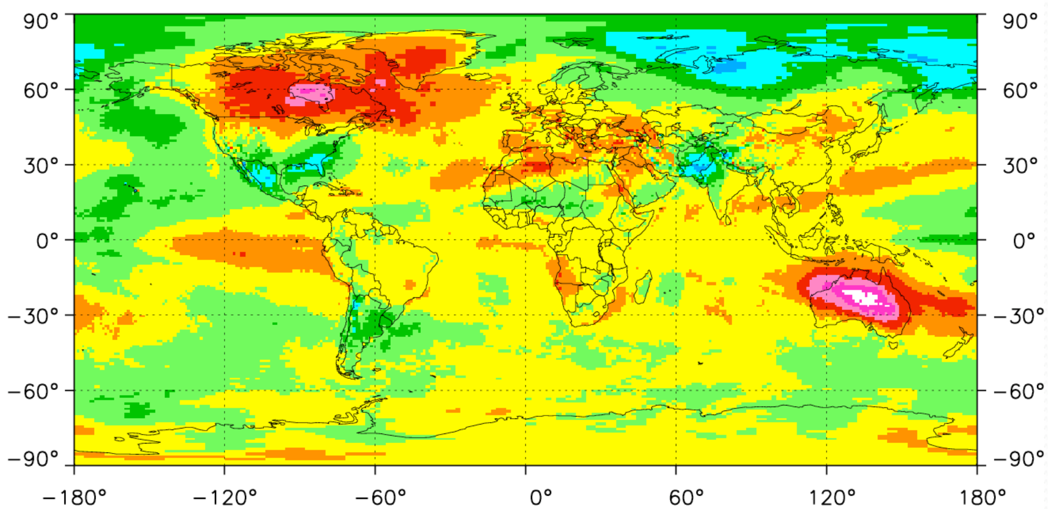
LWD EOF-1



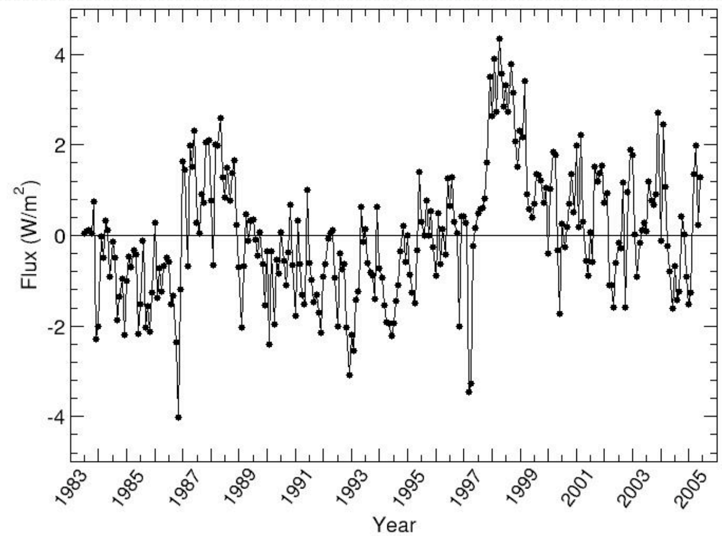
LWD PC-1

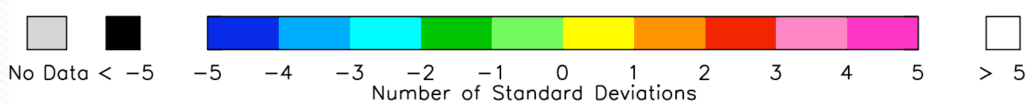


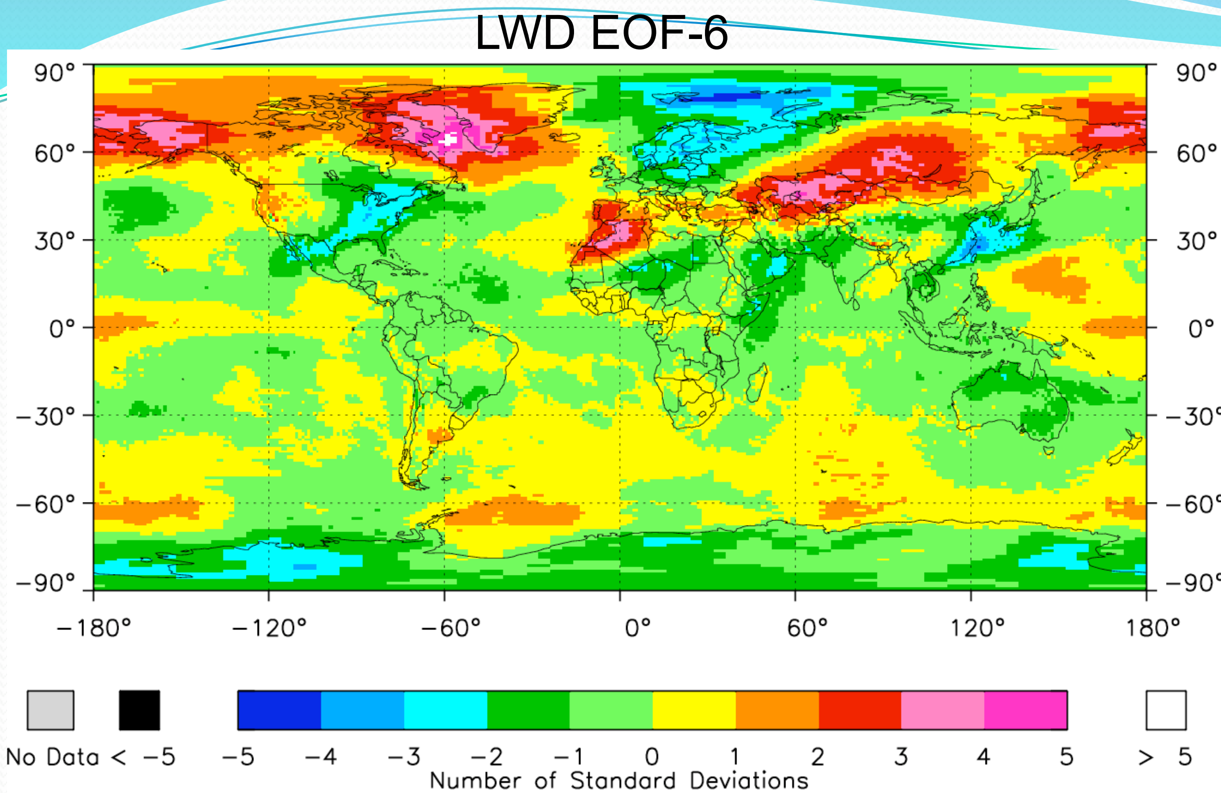
LWD EOF-3



LWD PC-3





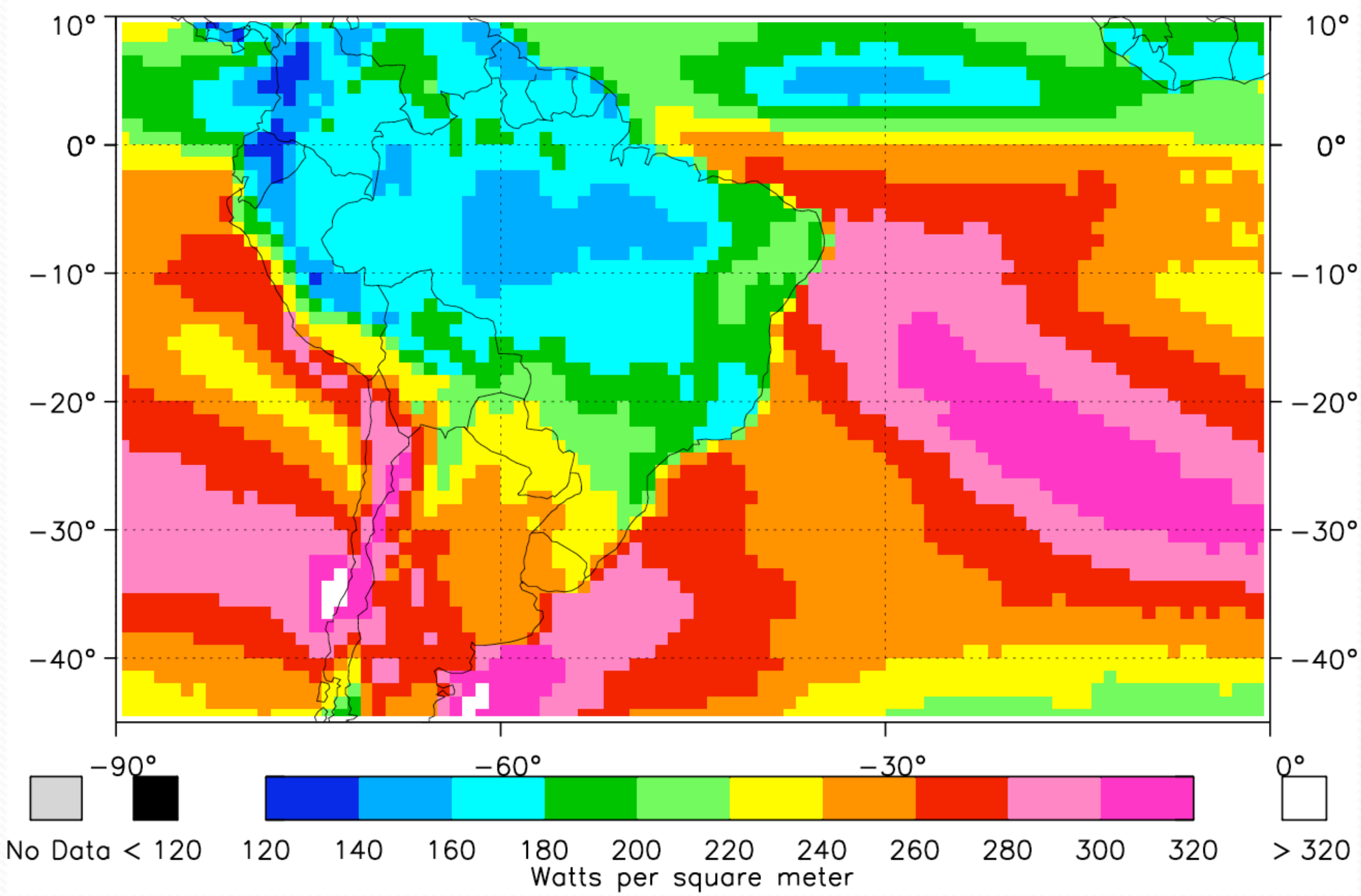


- Variations are more prominent at high latitudes.
- What might we be seeing there?
  - At low latitudes, high humidity in the boundary layer may mitigate variations.
  - At higher latitudes, stratiform clouds may increase variations in LWD.

South Atlantic Convergence Zone

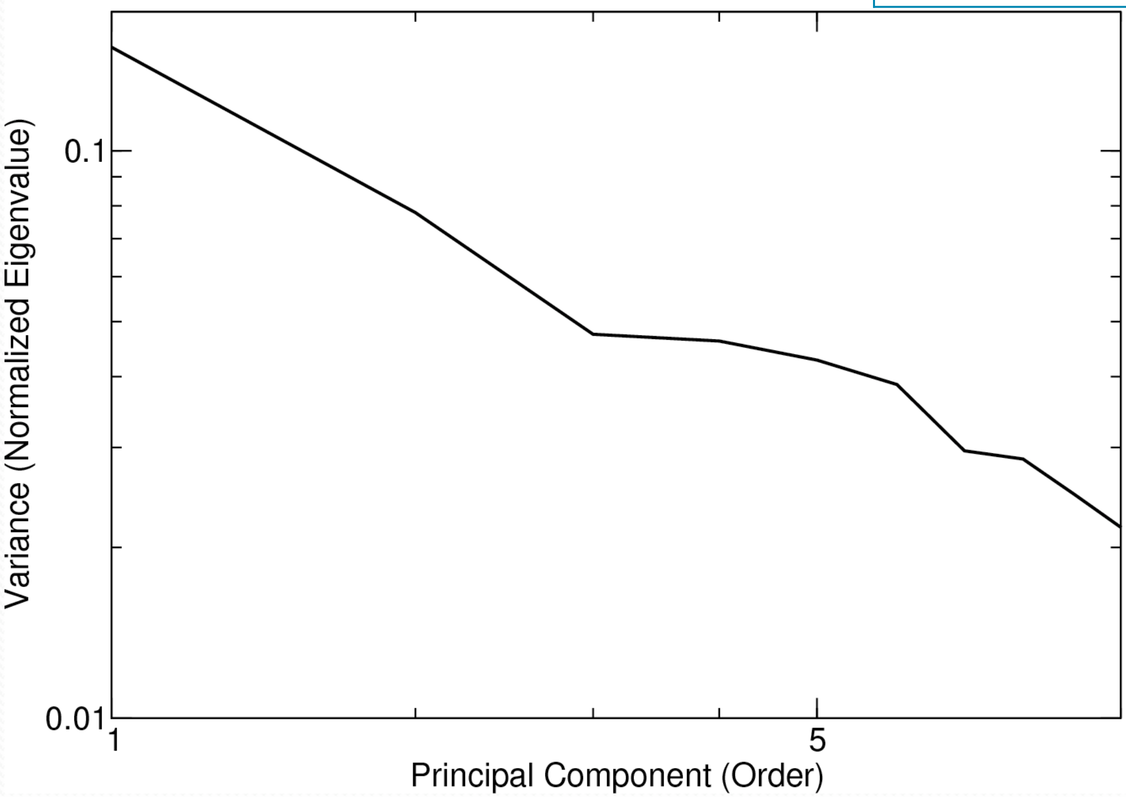
- The higher order SWN EOFs show variability in this region, even though there is mixing of solutions.
- We perform PCA on this restricted region.

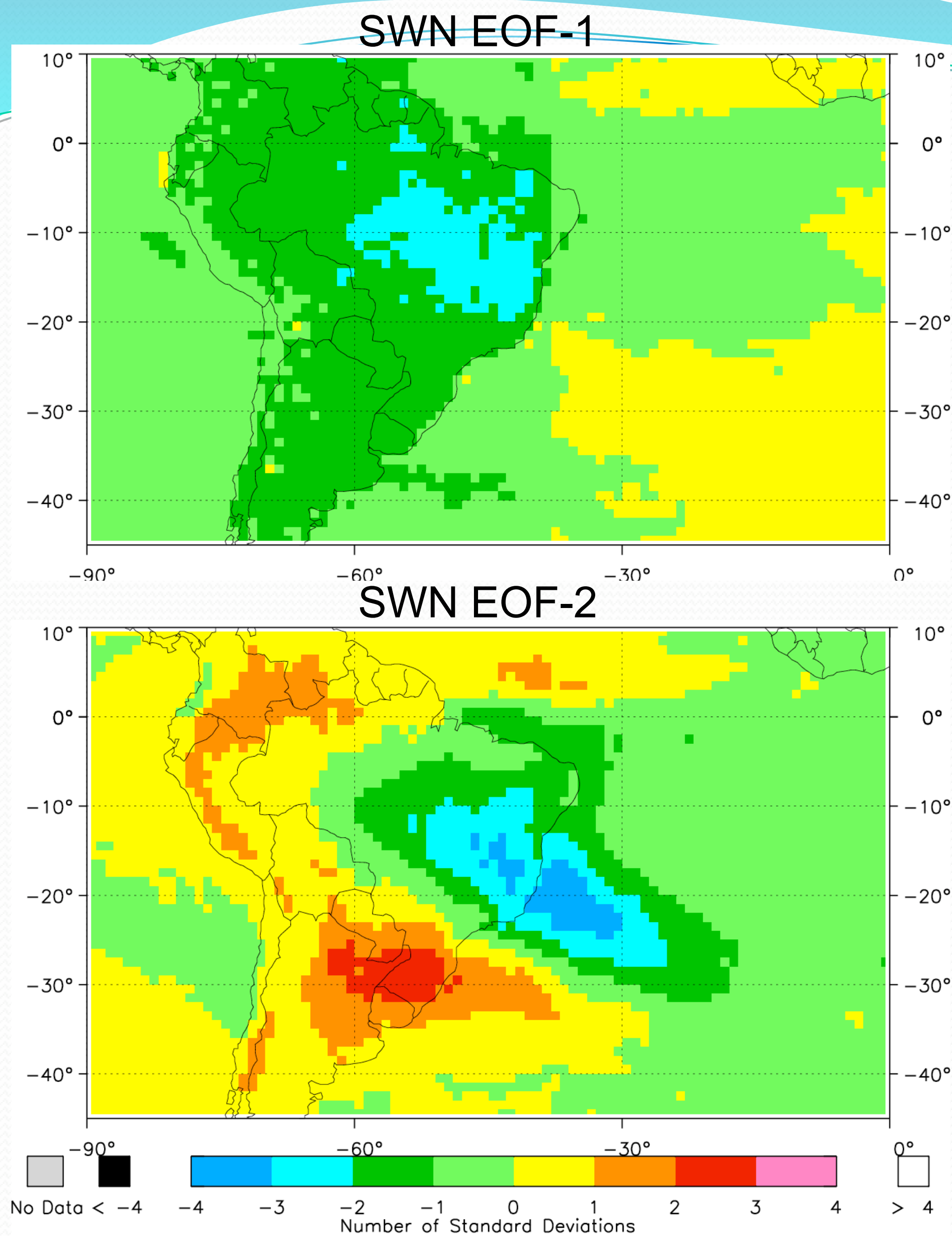
SWN Mean for December



Variance of SWN PCs over SACZ

Order	SWN Normalized Eigenvalue
1	0.1523
2	0.0778
RMS (total) W m^{-2}	14.6





- EOF-1 shows the variation from year to year of convective activity over the continent.
- EOF-1 also shows the boundary between GOES-East and Meteosat.
- EOF-2 shows the variation in the position of the outflow of clouds from the convective region.

Summary and Conclusions

Shortwave Net Areas of Interest

PC	Major Effect
1	ENSO
2	Artifact due to spacecraft
3	ENSO North-South variation
4	Indian Ocean Activity
5	Indian Ocean Activity
6	Indian Ocean Activity
7	Equatorial and Subtropical Pacific
8	SACZ

Longwave Down Areas of Interest

PC	Major Effect
1	ENSO and North Africa
2	North Africa, Eastern Russia, Eq. Pacific
3	Canada and Australia
4	North America and Eurasia
5	High Latitudes North and South
6	High Latitudes North
7	High Latitudes North and N. Africa
8	Canada and Australia

Conclusions

- There are about 4 variations discernable in SWN, LWU and LWD.
- For SWD, EOF-1 and -3 describe ENSOs.
- Artifacts are clearly shown, especially those due to satellite availability.
- Indian Ocean activity is strong in SW.
- We have identified some regions for future study of the interannual variability.
- SWD EOF-8 shows variations of clouds in the SACZ.

Questions

- Why are SW variations large at low latitudes?
- Why are LW variations more prominent at higher latitudes?
- How valid are these results? Do errors in the PC analysis outweigh any physical mechanisms behind the variations?

Future Research

- Examine areas of interest with rotated EOF analysis.
- Evaluate effects of TOVS operational sounding algorithm changes and ISCCP skin temperature retrievals.
- Evaluate effects of observing system changes.
- Need to relate radiation changes to other climate parameters/indices.

Thank You