

Daily Precipitation Statistics: An Intercomparison between NCEP Reanalyses and Observations

Vernon Kousky, Wayne Higgins &
Viviane Silva

14 April 2011

Motivation

- The Climate Prediction Center (CPC) is in the process of replacing the first generation reanalyses, used in support of operational monitoring and prediction activities, with the recently completed coupled Climate Forecast System (CFS) Reanalysis (1979-2010).
- As Part of this transition, a comprehensive intercomparison of the old and new products is being done.

NCEP Reanalyses

- NCEP/NCAR Reanalysis (R1) 1948-1995. Analyses continued forward in time to present, using the Climate Data Assimilation System (CDAS1). Resolution T62 (~2.5x2.5 degrees).
- NCEP-DOE Reanalysis (R2) 1979-1999. Analyses continued forward in time to present, using CDAS2. Resolution T62 (~2.5x2.5 degrees).
- Climate Forecast System Reanalysis (CFSR), a coupled land, ocean, atmosphere reanalysis 1979-2010. Resolution T382 (~0.3x0.3 degrees).

R1, R2, CFSR: Comparison to OI Station-based Precipitation Analyses

- The low-resolution reanalyses (R1 and R2) are compared to the CPC optimum interpolation [OI (T62)] gridded station-based daily precipitation analysis data set (1979-2006).
- The high-resolution reanalysis (CFSR) is compared to the OI(T382) version of the gridded daily precipitation analyses (1979-2006).

Statistics

- Various statistics are examined, including
 - Bias (R1-OI, R2-OI, CFSTR-OI)
 - Correlation (R1 vs OI, R2 vs OI, CFSTR vs OI)
 - Variance ratio (R1/OI, R2/OI, R2/R1, CFSTR/OI)
 - Precipitation Probabilities [ratios among R1, R2 and OI(T62); CFSTR and OI(T382)]

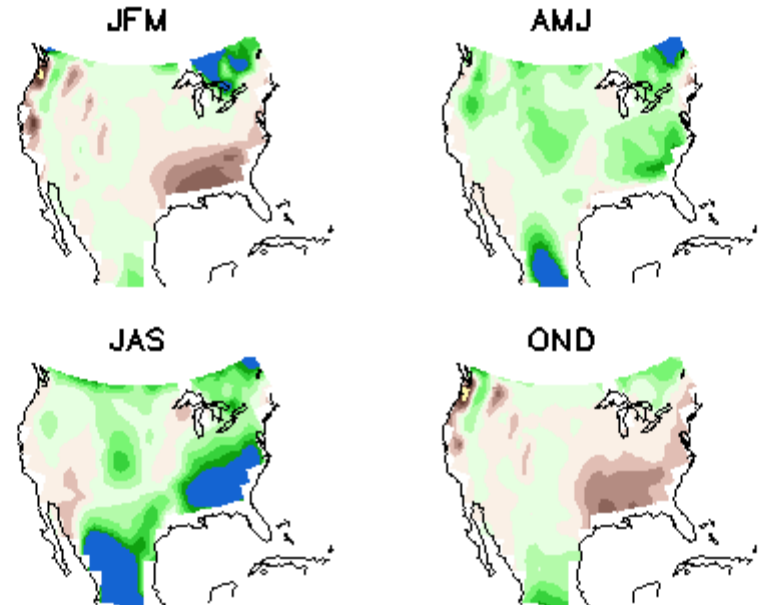
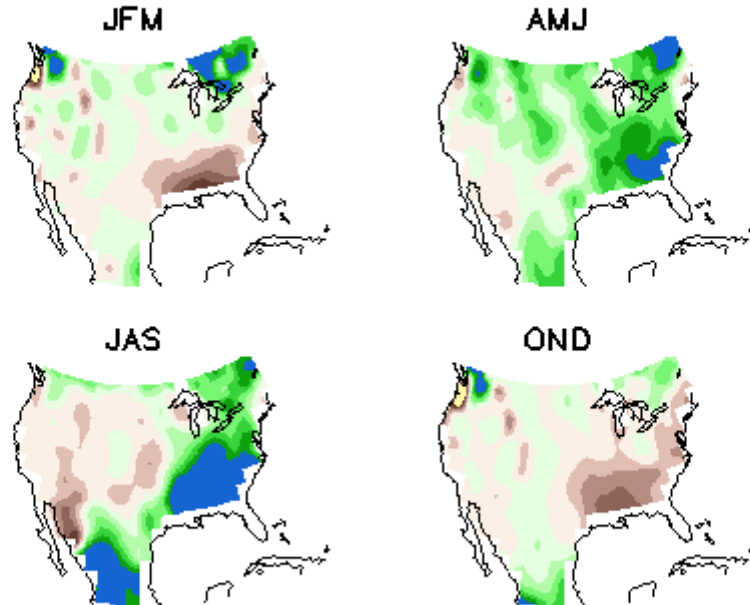
Mean Bias by Season

R1-OI(T62)

R2-OI(T62)

R1(12Z)-OI(T62) Mean Daily Precip. Diff. (mm)

R2(12Z)-OI(T62) Mean Daily Precip. Diff. (mm)



The bias patterns are generally similar for R1 and R2. Both show a dry bias in Gulf states during OND and JFM and a wet bias in the Southeast during AMJ and JAS.

There are some differences between R1 and R2: 1) the dry bias in JAS over the Southwest in R1 is greatly reduced in R2, and 2) the wet biases in AMJ over the northern U.S. and in AMJ and JAS in the Southeast in R1 are somewhat reduced in R2.

Mean Bias by Season

R1-OI(T62)

CFSR-OI(T382)

R1(12Z)-OI(T62) Mean Daily Precip. Diff. (mm)

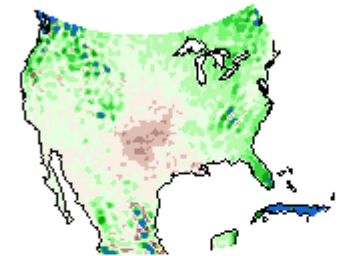
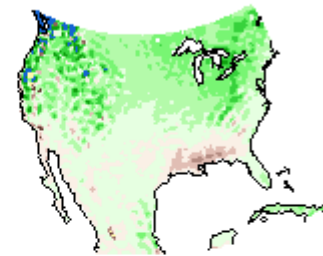
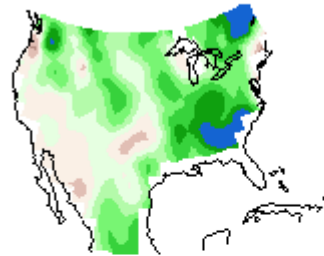
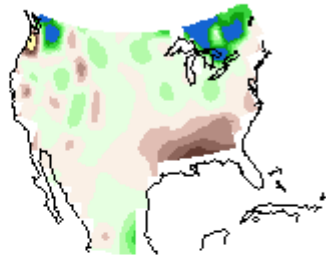
CFSR-OI(T382) Mean Daily Precip. Dif. (mm)

JFM

AMJ

JFM

AMJ

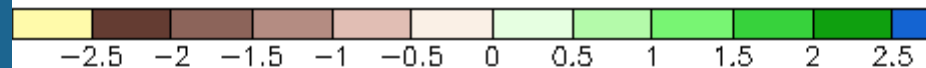
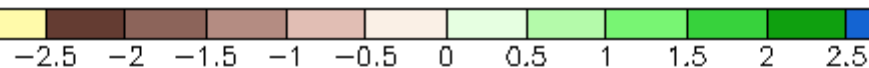
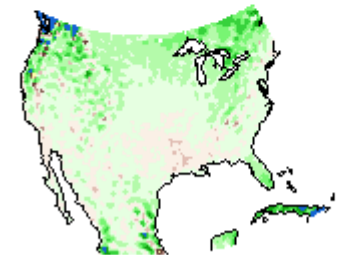
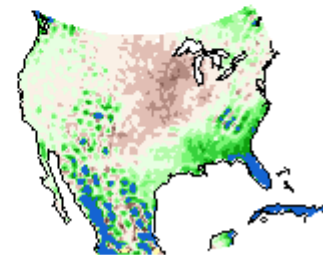
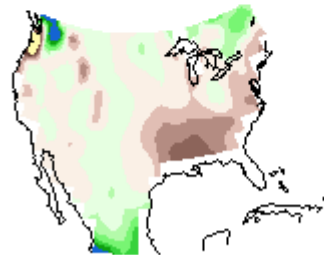
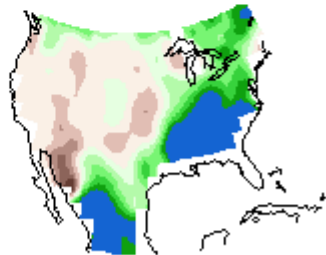


JAS

OND

JAS

OND



The differences between CFSR and OI(T382) are less than those between R1 and OI(T62) in many regions (e.g., Gulf Coast during the cool seasons, Southeast during the warm seasons, and Southwest during JAS).

However, CFSR has a wet bias across the northern states during OND and JFM, a feature not apparent in either R1 or R2.

Correlations of Daily Precipitation

R1-OI(T62)

R2-OI(T62)

R1-OI(T62) Daily Precip. Correlation ($\times 100$)

R2-OI(T62) Daily Precip. Correlation ($\times 100$)

JFM

AMJ

JFM

AMJ

JAS

OND

JAS

OND

10 20 30 40 50 60 70 80 90

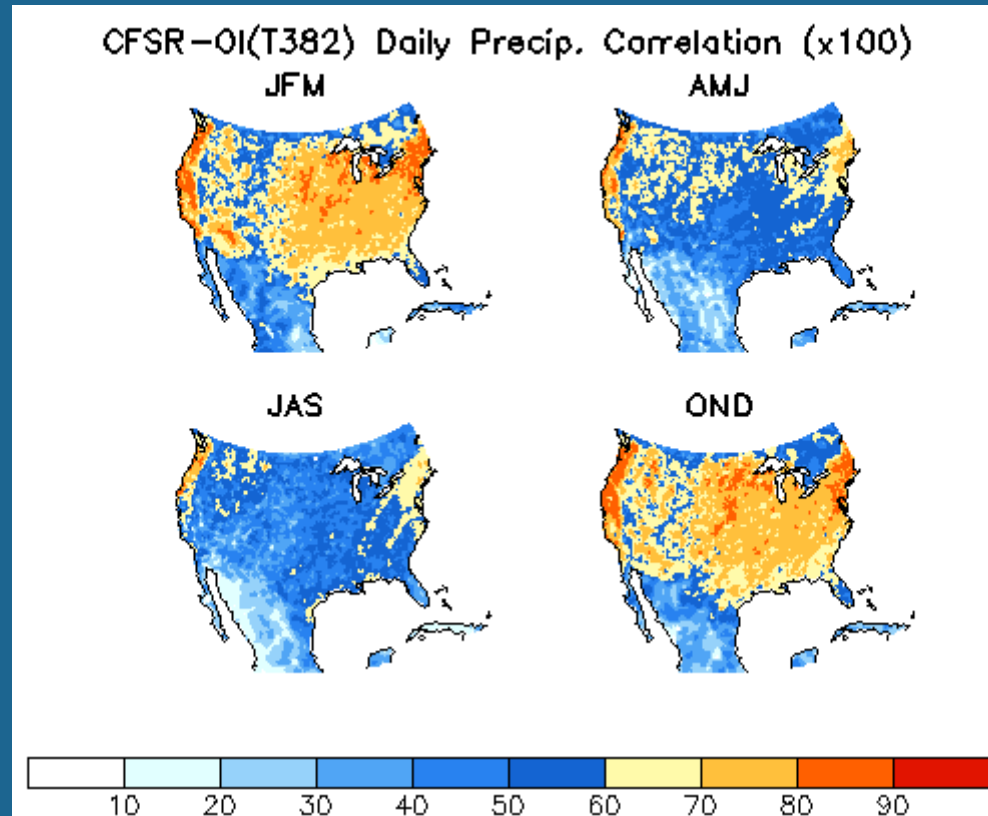
10 20 30 40 50 60 70 80 90

Correlations between R1/R2 and the OI(T62) gridded analyses are generally greatest during the cool seasons (JFM, OND) and least during the warm seasons (AMJ, JAS).

In other words, there is a better correspondence between the Reanalyses and observations during the time of the year when dynamics, rather than thermodynamics, plays a more important role in precipitation. During the warm seasons, when convective processes are more important, the correlations are generally weaker.

Correlations of Daily Precipitation

CFSR-OI(T382)



Correlations between CFSR and the OI(T382) gridded analysis are generally greatest during the cool seasons (JFM, OND) and least during the warm seasons (AMJ, JAS). These results are similar to those for R1/R2 and OI(T62) shown in the previous slide.

Variance Ratios

R1/OI(T62)

R2/OI(T62)

R1/OI(T62) Daily Precip. Variance Ratio

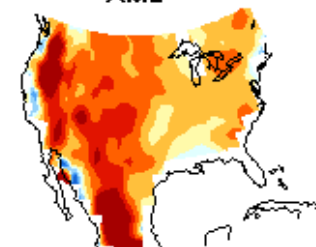
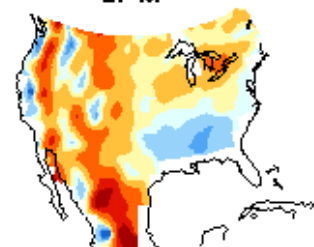
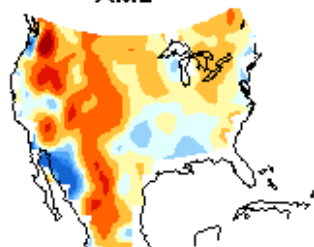
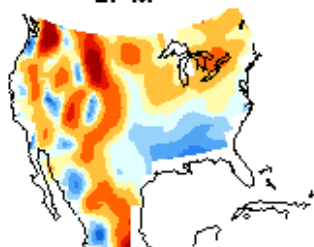
R2/OI(T62) Daily Precip. Variance Ratio

JFM

AMJ

JFM

AMJ

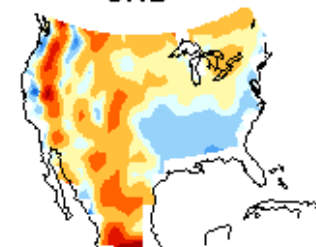
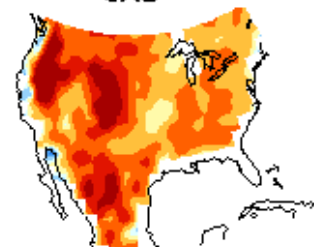
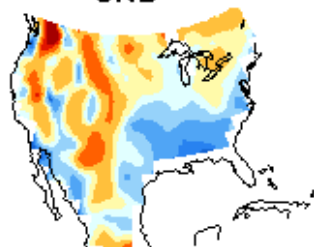
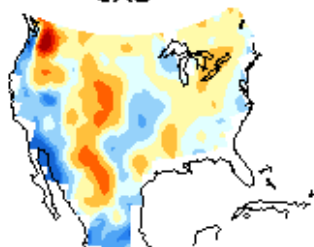


JAS

OND

JAS

OND



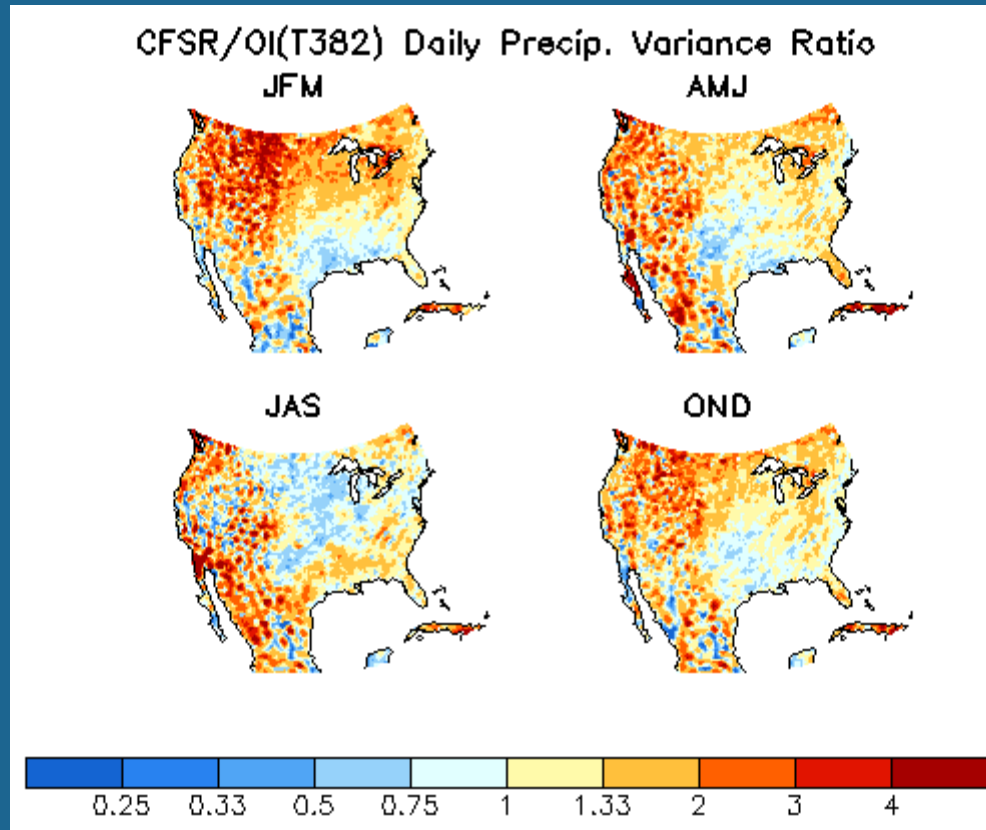
0.25 0.33 0.5 0.75 1 1.33 2 3 4

0.25 0.33 0.5 0.75 1 1.33 2 3 4

The variance in R1 and R2 generally exceeds the observed variance across the northern tier states and in the mountainous West during all seasons. R1 and R2 display less variance than observed over the south-central and southeastern U.S. during the cool seasons (JFM, OND).

Variance Ratios

CFSR-OI(T382)



As in R1 and R2, the variance in CFSR generally exceeds the observed variance across the northern tier states during OND, JFM and AMJ, and in the mountainous West during all seasons. CFSR displays less variance than observed over the south-central states during JFM, AMJ, and OND, and over the north-central states during JAS.

Probability (Frequency of Occurrence) Ratios

- The ratio of probabilities (%) among R1, R2 and OI(T62), and CFSR and OI(T382) are shown for the following precipitation bands for the U.S. (1979-2006)

$P \geq 0.25$ mm, $P < 5$ mm

$P \geq 5$ mm, $P < 10$ mm

$P \geq 10$ mm, $P < 15$ mm

$P \geq 15$ mm, $P < 20$ mm

$P \geq 20$ mm, $P < 25$ mm

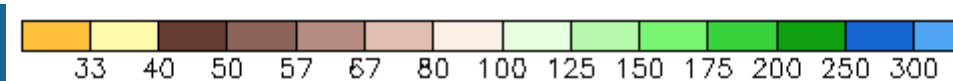
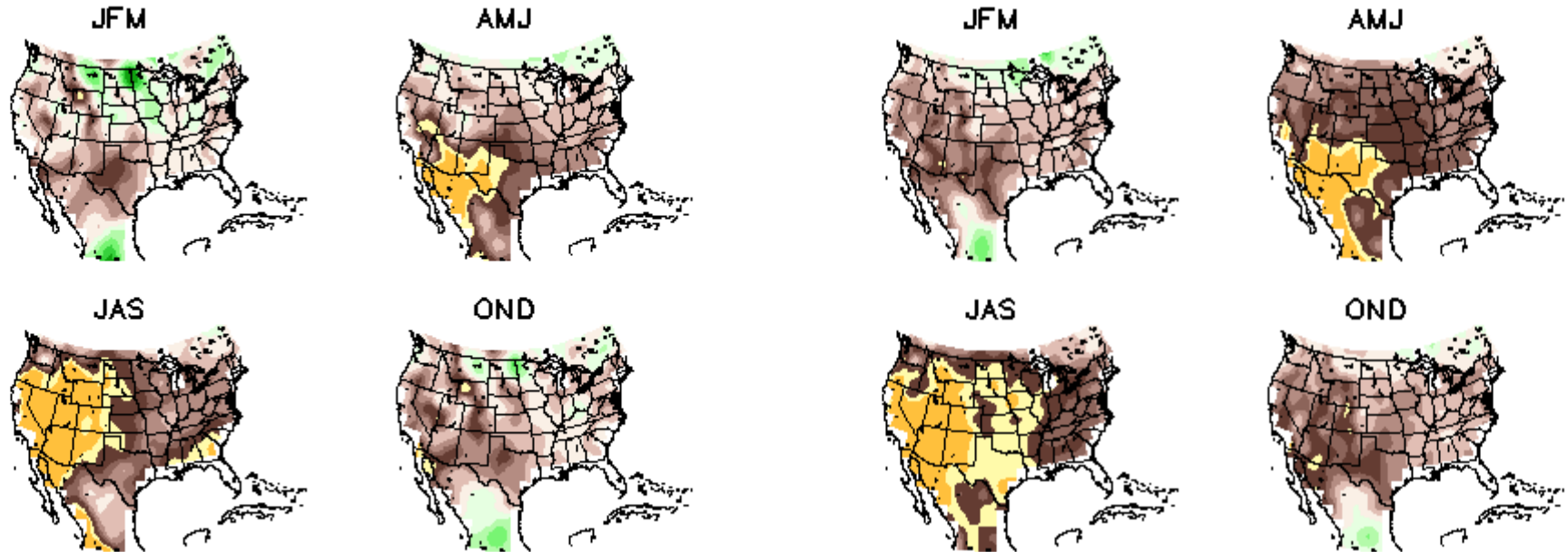
Probability Ratios (0.25 – 5 mm)

R1/OI(T62)

R2/OI(T62)

R1/OI(T62) Prob. Ratio (%) $P \geq 0.25\text{mm}$, $P < 5\text{mm}$

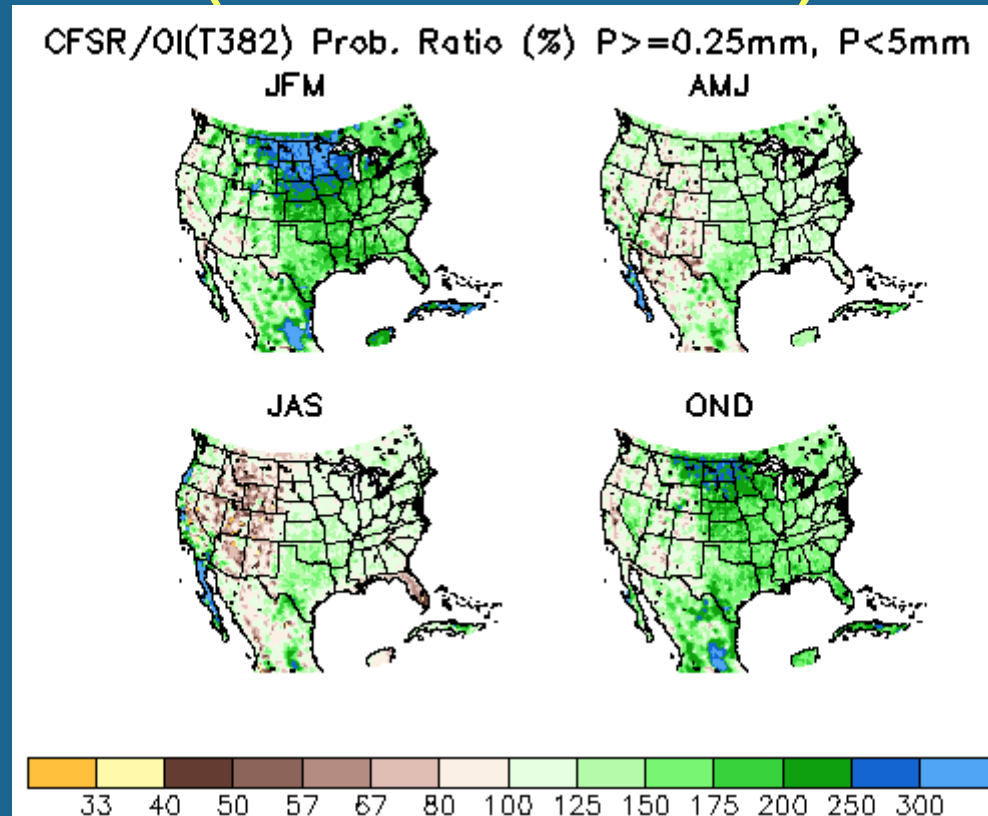
R2/OI(T62) Prob. Ratio (%) $P \geq 0.25\text{mm}$, $P < 5\text{mm}$



Both R1 and R2 have lower probabilities than observed in this band over nearly the entire contiguous U.S. throughout the year.

The probability ratios are lowest over the U.S. during the warm seasons (AMJ, JAS) and throughout the year in the West.

CFSR/OI(T382) Probability Ratios (0.25 – 5 mm)



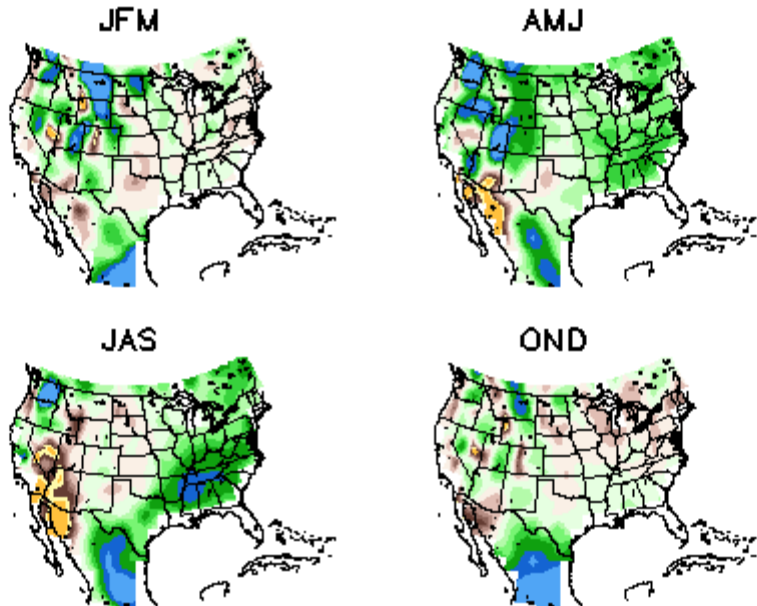
CFSR has higher probabilities than observed in this band.

The probability ratios are highest over the north-central U.S. during the cool seasons (OND, JFM). Probability ratios are lowest in the West during JAS.

Probability Ratios (5 – 10 mm)

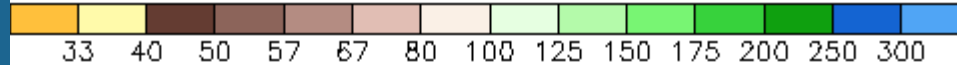
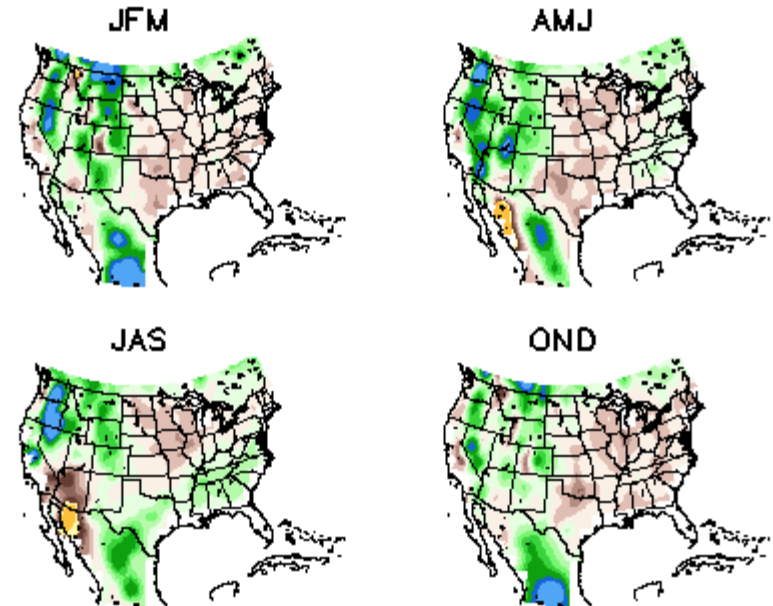
R1/OI(T62)

R1/OI(T62) Prob. Ratio (%) $P \geq 5\text{mm}$, $P < 10\text{mm}$



R2-OI(T62)

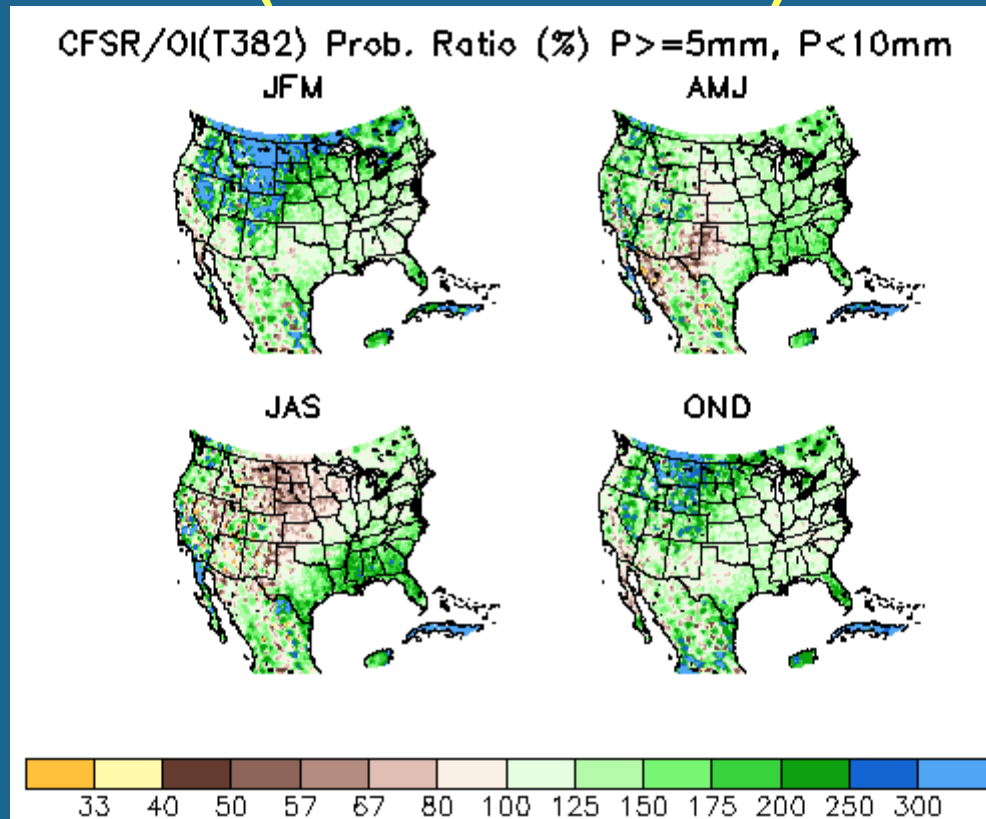
R2/OI(T62) Prob. Ratio (%) $P \geq 5\text{mm}$, $P < 10\text{mm}$



Over most of the western U. S. throughout the year both R1 and R2 exhibit greater probabilities than observed in this band.

R2 shows improvement, relative to R1, over the Southeast during the warm seasons (AMJ, JAS).

CFSR/OI(T382) Probability Ratios (5 – 10 mm)



CFSR displays larger probabilities than observed in this band throughout the year over most of the U.S.

The ratios are largest during OND and JFM over the northern and central High Plains. CFSR has smaller probabilities than observed over the north-central U.S. during JAS.

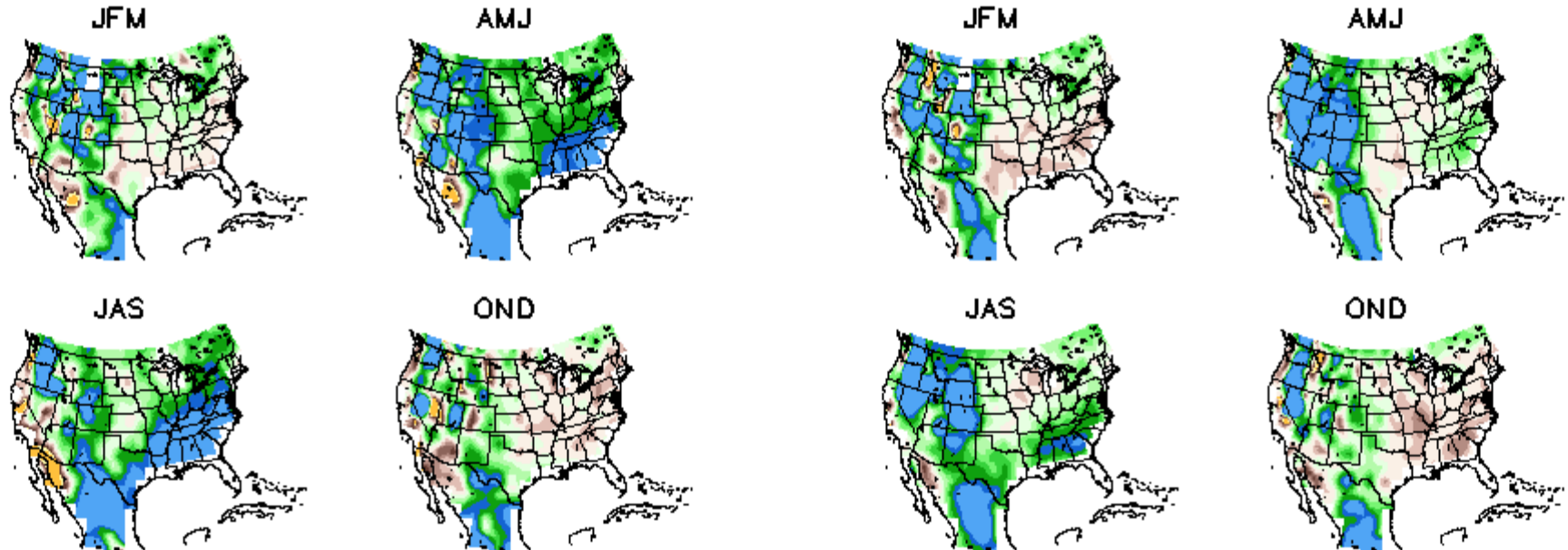
Probability Ratios (10 – 15 mm)

R1/OI(T62)

R2/OI(T62)

R1/OI(T62) Prob. Ratio (%) $P \geq 10\text{mm}$, $P < 15\text{mm}$

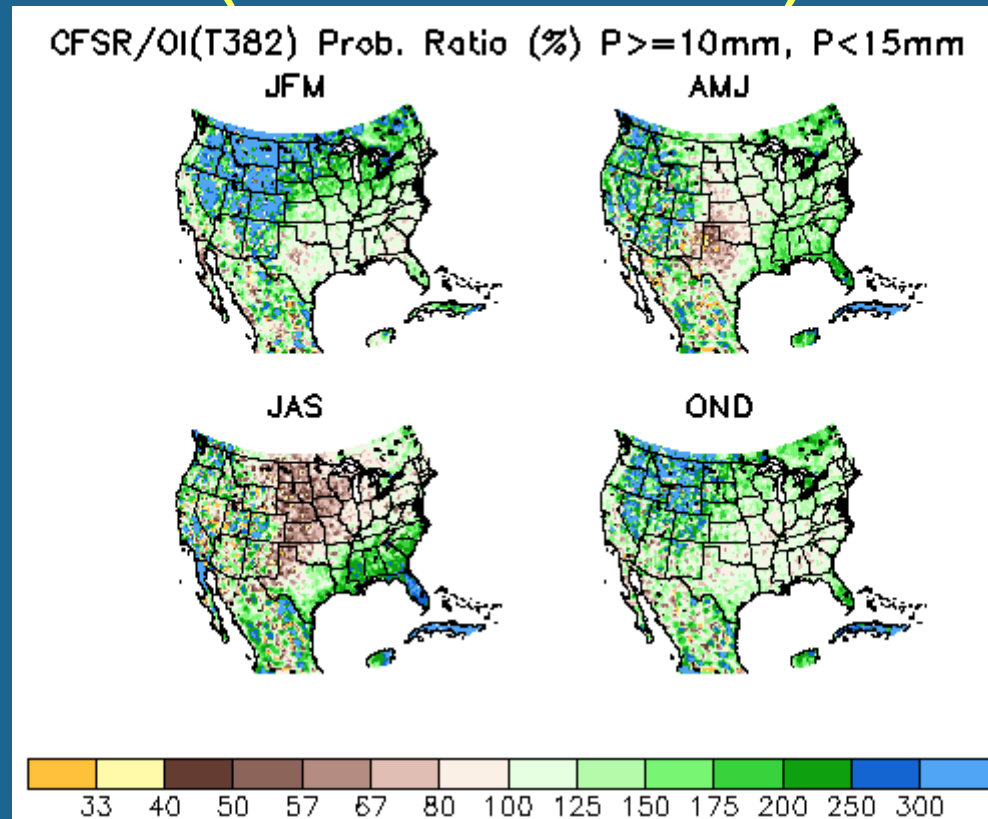
R2/OI(T62) Prob. Ratio (%) $P \geq 10\text{mm}$, $P < 15\text{mm}$



Over most of the western U. S. throughout the year both R1 and R2 exhibit greater probabilities than observed in this band.

R2 shows improvement, relative to R1, over the Southeast during the warm seasons (AMJ, JAS). These results are similar to those shown for the 5-10 mm band.

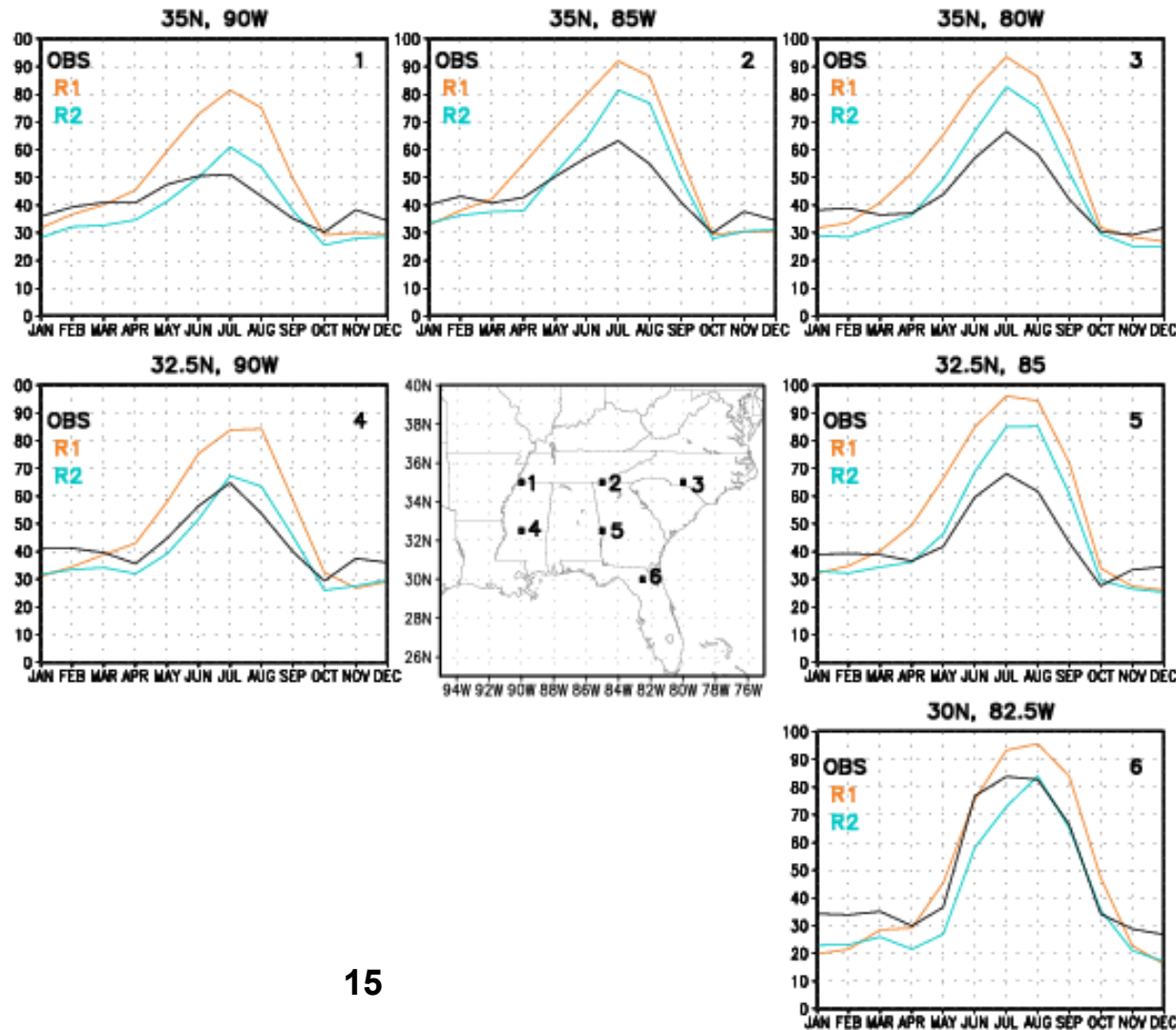
CFSR/OI(T382) Probability Ratios (10 – 15 mm)



CFSR displays larger probabilities than observed in this band throughout the year over most of the U.S. The ratios are largest during OND and JFM over the northern and central High Plains and western states. CFSR has smaller probabilities than observed over the north-central U.S. during JAS. These results are similar to those shown for the 5-10 mm band. Higher bands (15-20 mm and 20-25 mm) show similar patterns.

Annual cycle: Probability of daily precipitation ≥ 1 mm for locations in the Southeast

Probability $P \geq 1$ mm



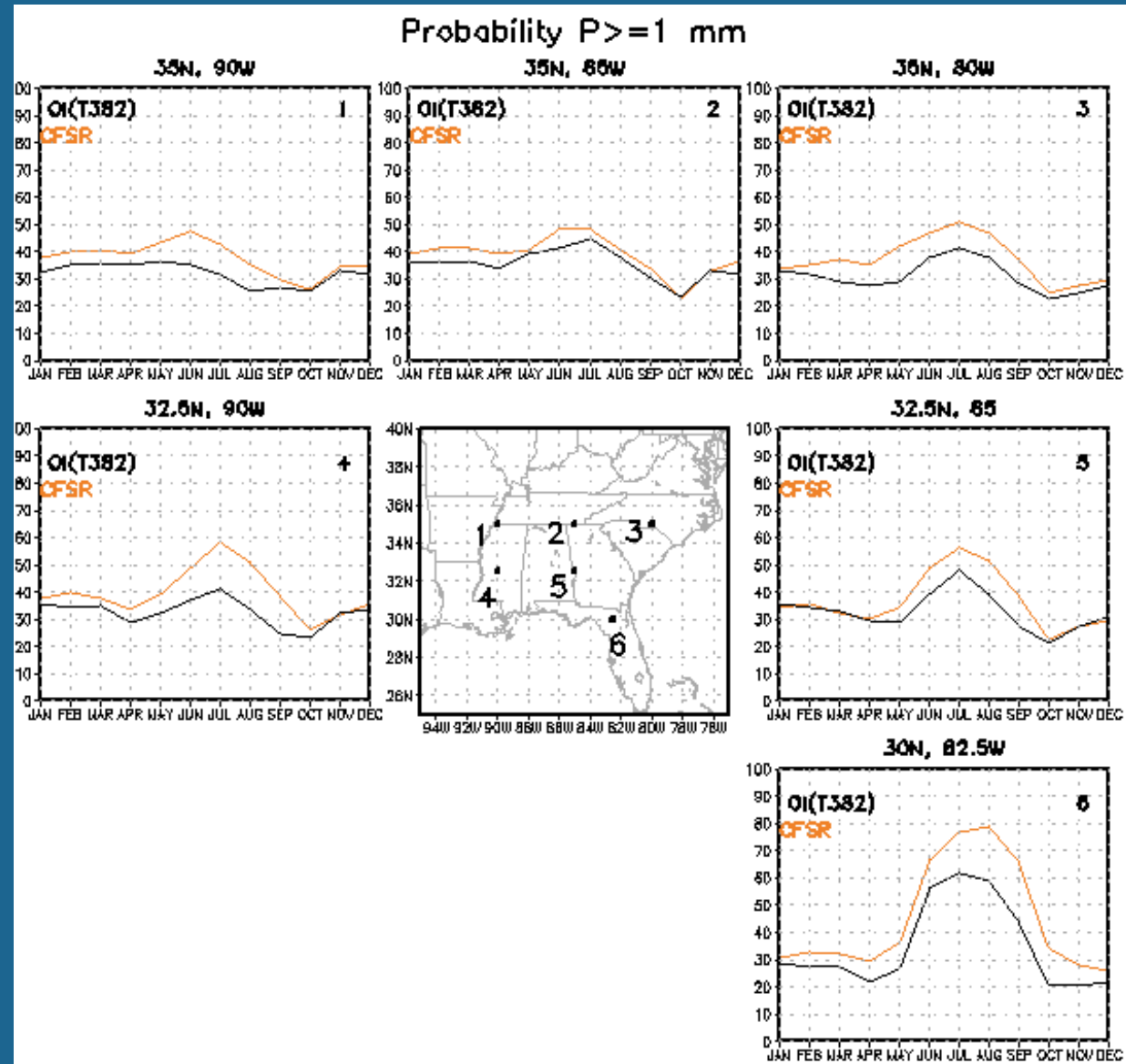
Additional Details:

- R1 and R2 probabilities are:
 1. greater than observed during the warm season (especially June to September), with greater biases in R1,
 2. and smaller than observed during the cold season (November to February), with greater biases in R2.
- The largest biases are during the warm season in R1 (and to a lesser extent in R2).

Annual Cycle: Probability ($P \geq 1\text{mm}$) at Selected Locations in the Southeast

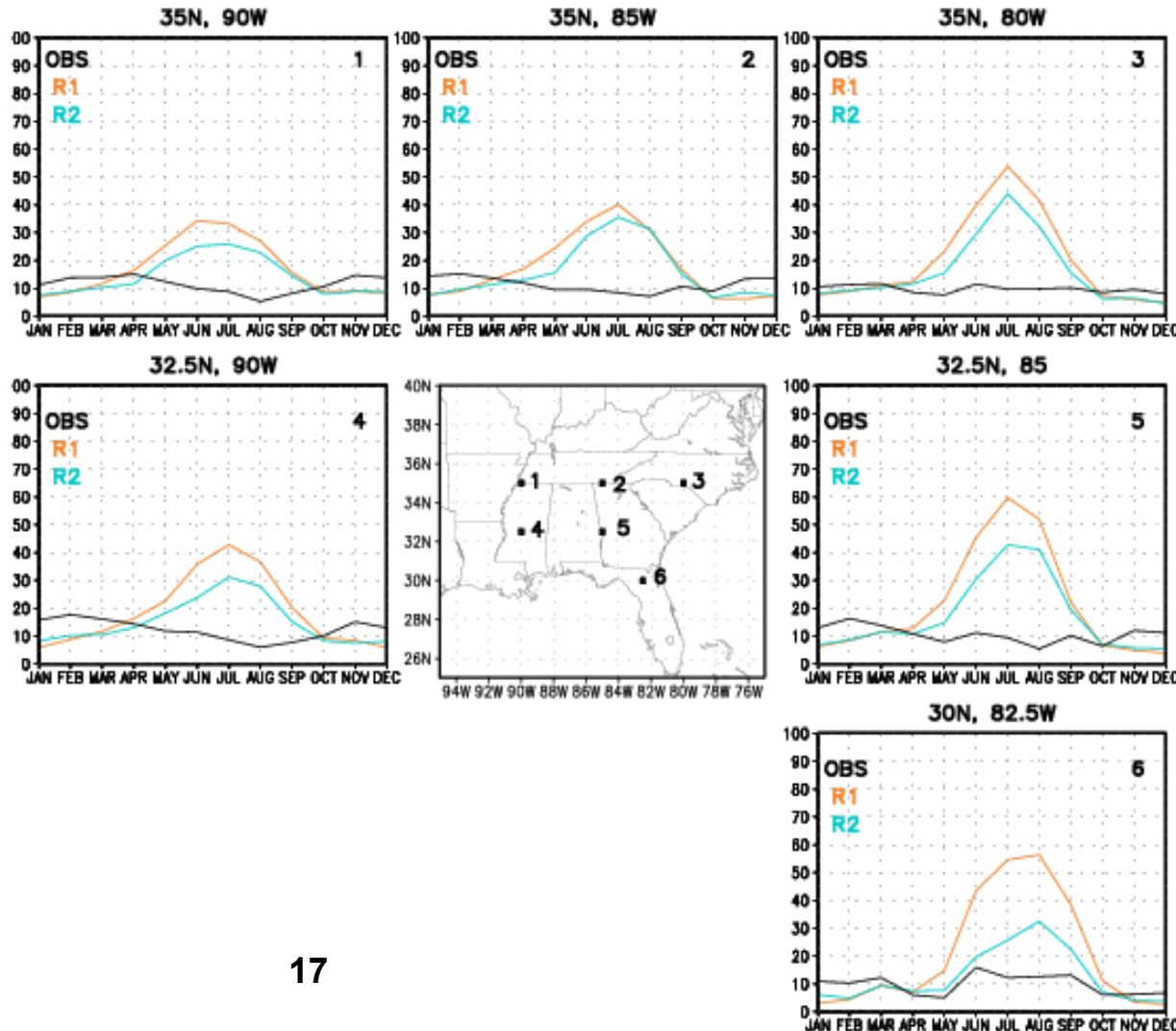
For the selected locations, the CFSR probabilities are greater than observed, especially during the warm season.

Note: These probabilities are less than those depicted for R1, R2 and OI (T62), which is related to the difference in resolution.



Annual cycle: probability of daily precipitation ≥ 10 mm for locations in the Southeast

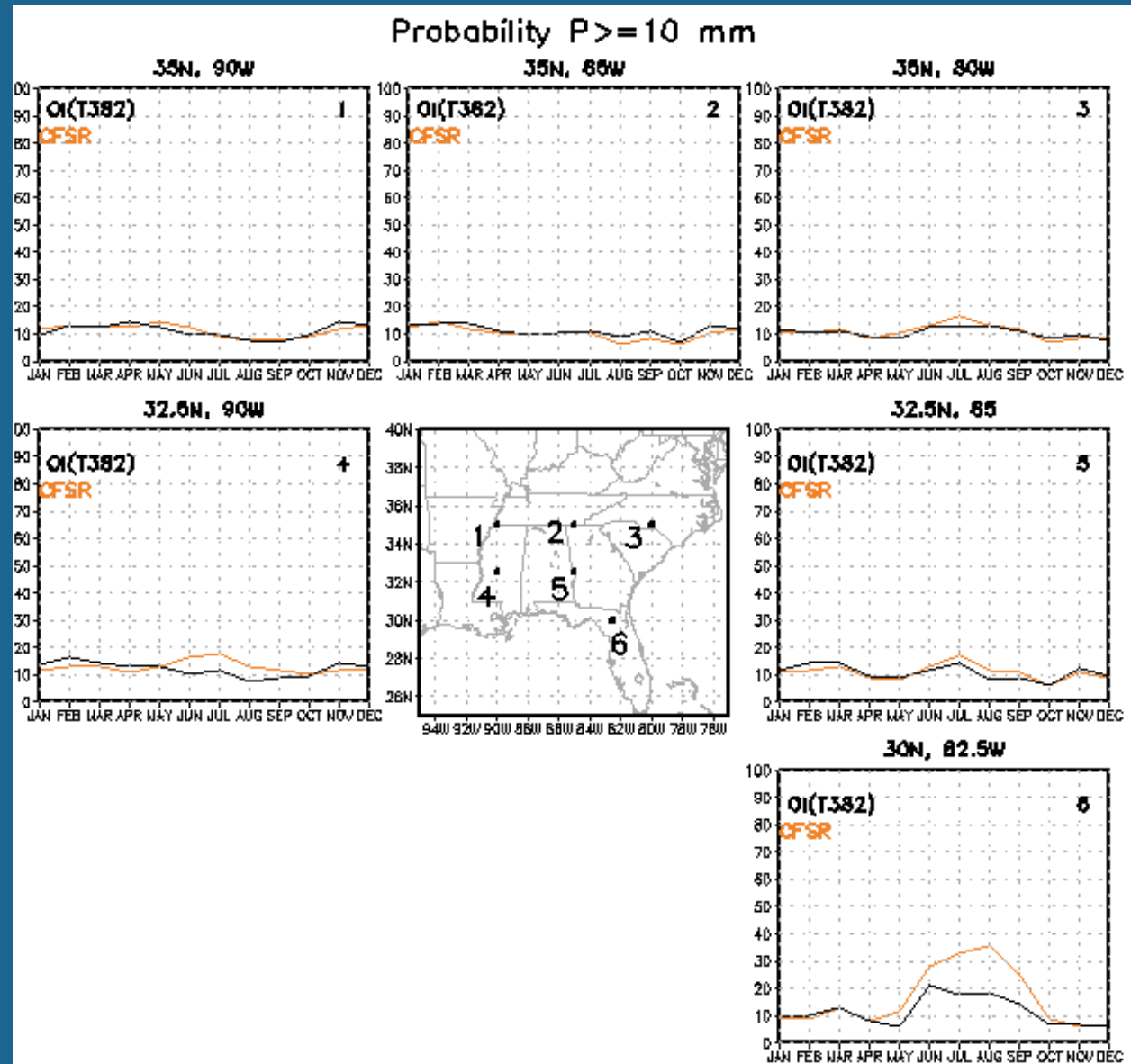
Probability $P \geq 10$ mm



- The **observed** probabilities remain relatively constant through the annual cycle (including the warm season).
- while the **reanalysis** probabilities show a distinct maximum during the warm season as they did for prob. > 1 mm.
- This is an indication that the overestimates of precipitation in R1 and R2 are mainly the result of too frequent relatively heavy (convective) precipitation events.

Annual Cycle: Probability ($P \geq 10$ mm) at Selected Locations in the Southeast

There is good agreement between CFSR and OBS (OI-T382) everywhere, except over northern FL during May-Sep.



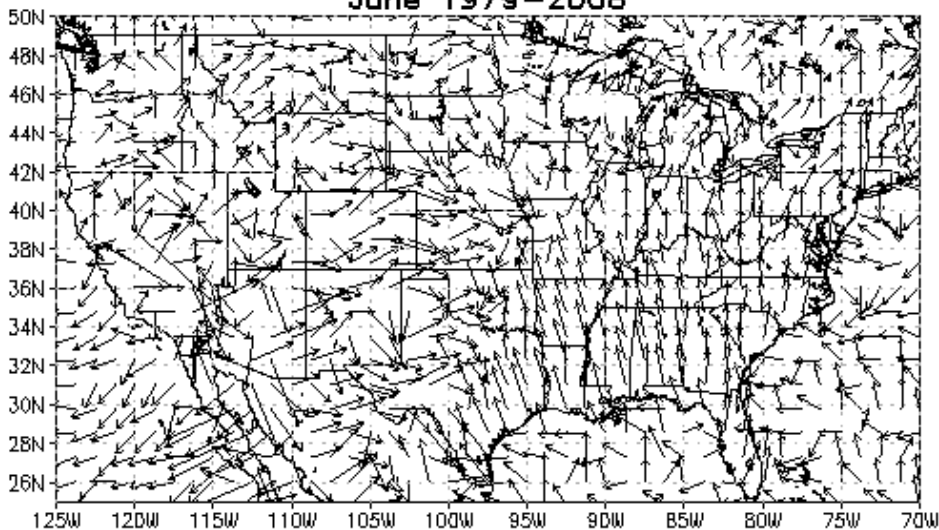
Possible Causes for Bias in the Southeast

- Wet bias and higher probabilities of light rainfall events during the warm season suggests that the convective parameterization scheme and diurnal cycle in the model might be responsible.
- The following slides show some preliminary diagnostic results related to the CFSR diurnal cycle.

CFSR/HPD Comparison: June

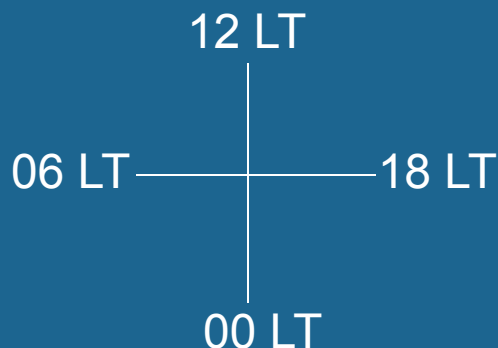
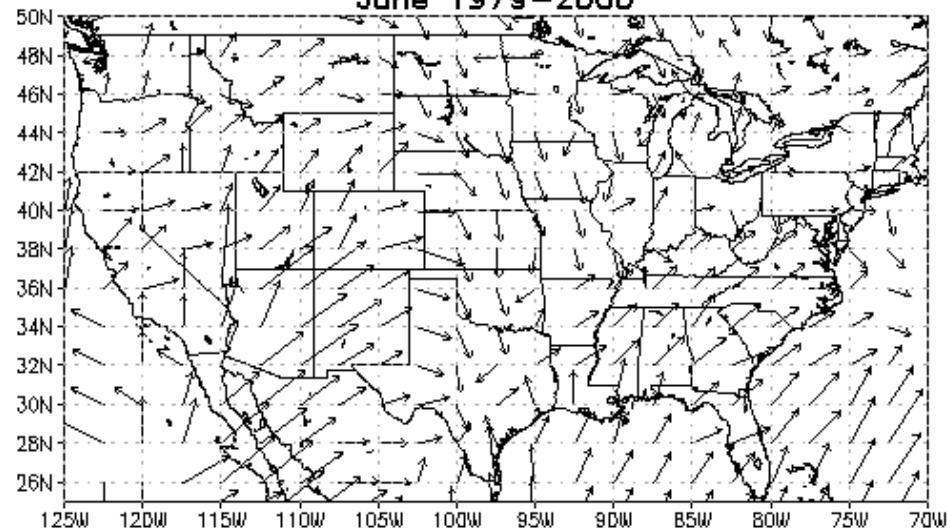
CFSR

Amplitude and Phase of the Diurnal Cycle of Precip.
June 1979–2008



Hourly Precipitation Dataset Analysis

HPD Amp. and Phase of the Diurnal Cycle of Precip.
June 1979–2000

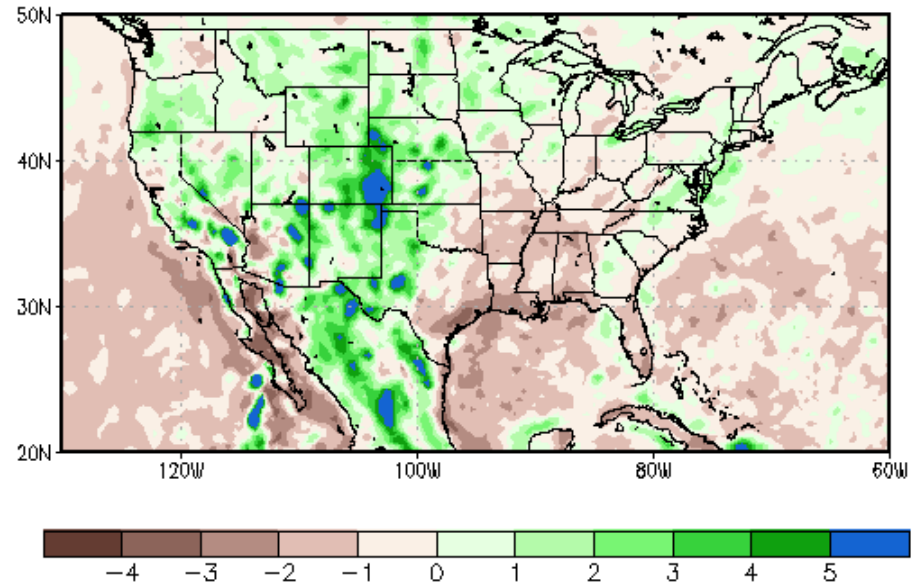


The amplitude and phase in CFSR and HPD are similar over most of western U.S.

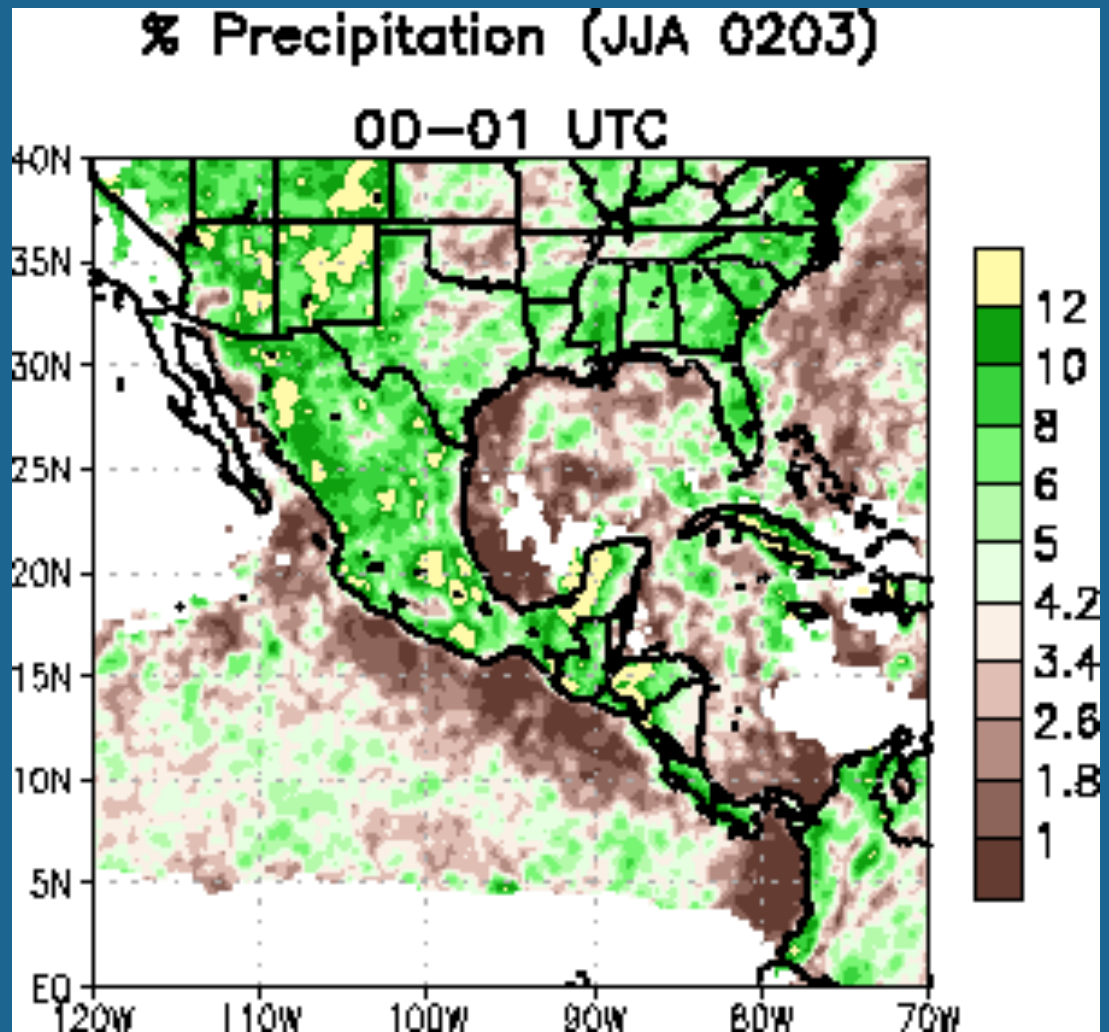
However, there is a distinct phase shift between the two analyses over the Southeast (CFSR ~ 3-4 hours too early).

CFSR Diurnal Cycle

CFSR Precip. Depart. (%) June 1979–2008
01Z



CMORPH Diurnal Cycle



Summary

- In general, the daily precipitation statistics in CFSR are improved over those in R1 and R2 over the conterminous United States.
- Though the CFSR has similar bias patterns to those in R1 and R2, in many cases the biases are reduced.
- Notably, comparisons of the probability of precipitation for various intensity bands shows that CFSR is better than R1 and R2 in reproducing the observed frequency and intensity of daily precipitation.
- Moreover, an examination of the annual cycle of the probability of wet events (wet days, $P \geq 1$ mm; $P \geq 10$ mm) at selected locations in the Southeast showed better agreement between the high-resolution analyses (CFSR and OI (T382)) than between the low-resolution ones (R1, R2 and OI (T62)).
- These results illustrate that future upgrades of CFS should focus on the issue of model bias, in particular by improving the model physics (at the same resolution, i.e. T382). This would provide a better basis for evaluating improvements, at least for relatively unconstrained variables like precipitation.

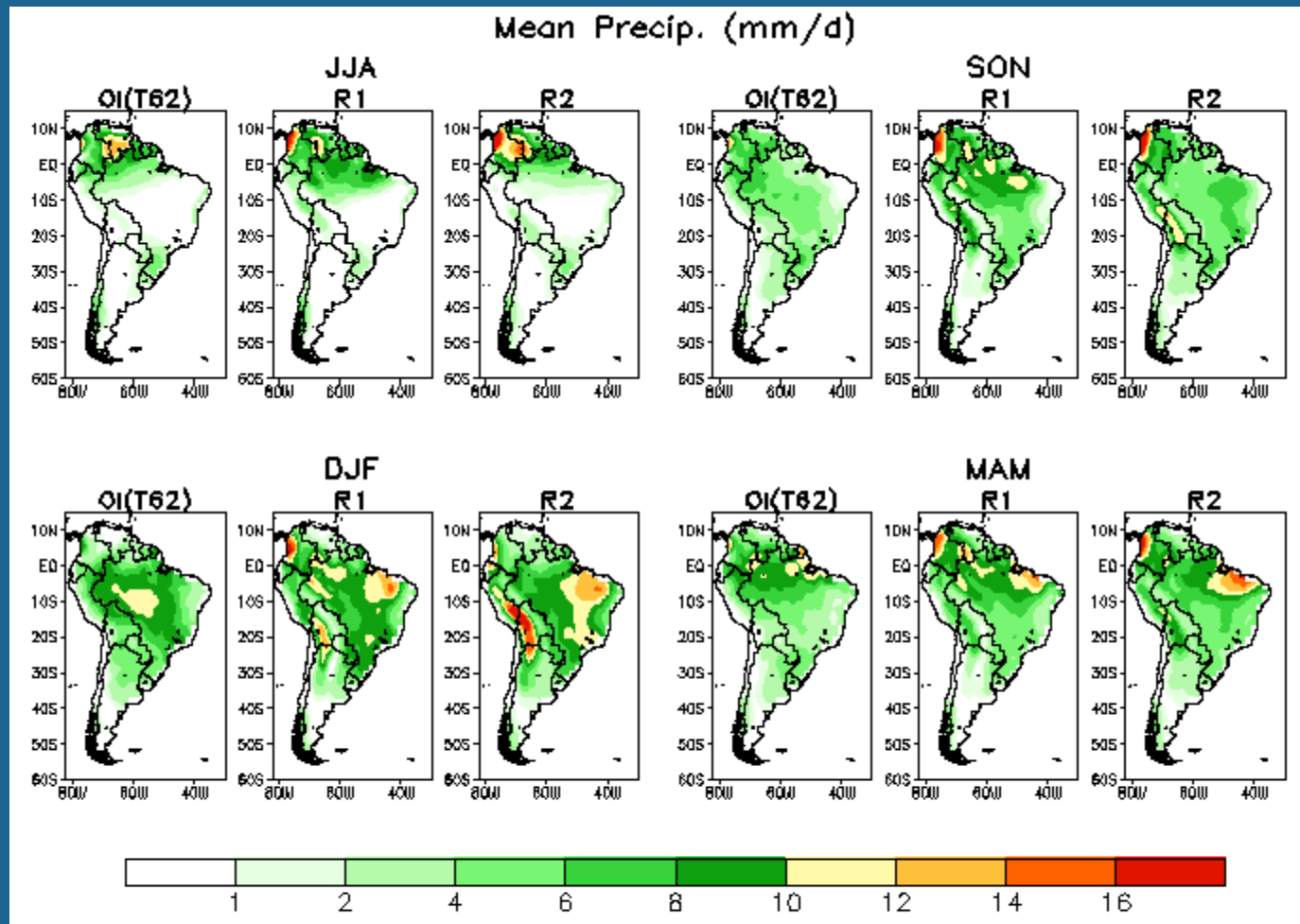
Precipitation Statistics:

South America

Mean Daily Precipitation

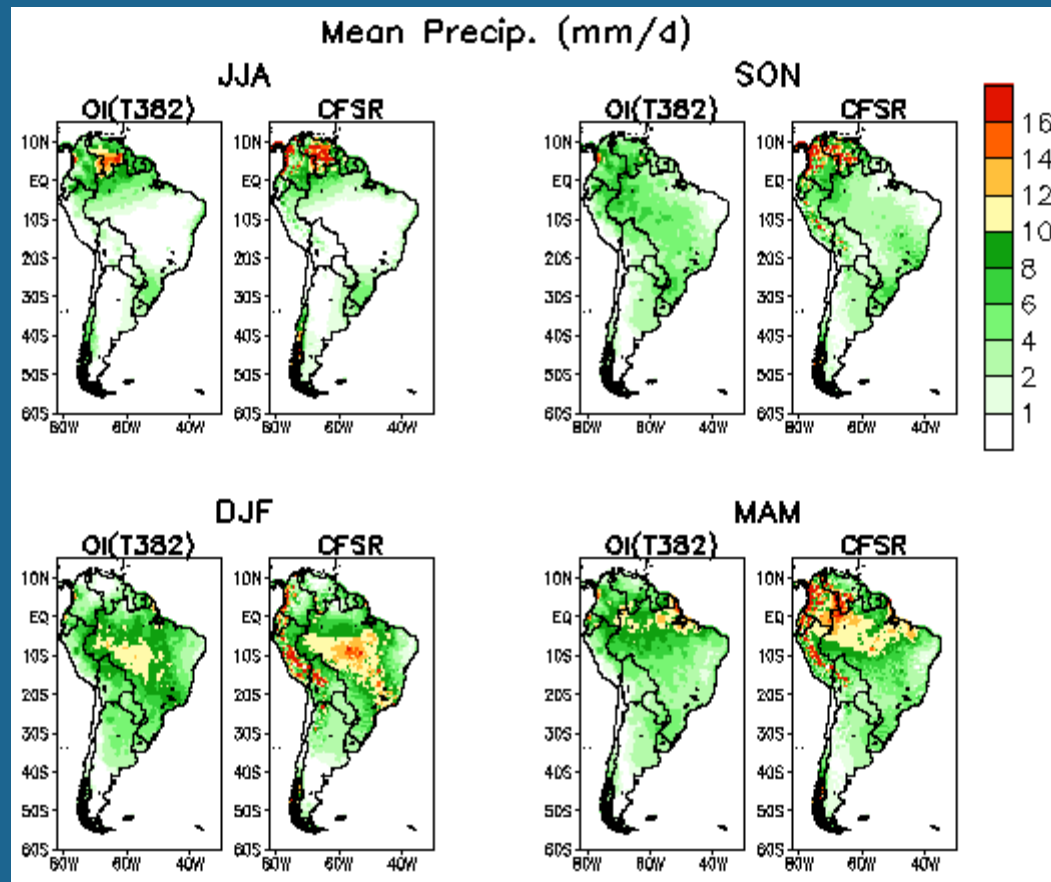
- Seasonal patterns
- Seasonal differences (biases)
 - R1 minus OI(T62)
 - R2 minus OI(T62)
 - CFSR minus OI(T382)

Mean Daily Precipitation



R1 and R2 show similar patterns throughout the year, which are quite different from the OI analyses, especially during DJF (maximum in precipitation over Brazil is too far east and too intense in R1 and R2).

Mean Daily Precipitation



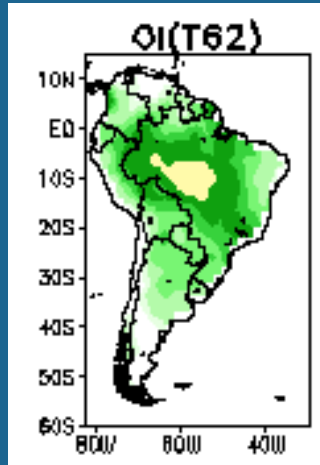
CFSR and OI(T382) have similar patterns throughout the year. The rainfall rates are too large in CFSR during DJF and MAM in the monsoon core region (southern Amazon Basin and central Brazil) and along the Andes Mountains (Peru and Bolivia). The rainfall rates in CFSR are too small during SON over the western Amazon Basin.

Pattern correlations of mean daily precipitation for the South American Monsoon System (SAMS) core region (0°-35°S, 35°-65°W).

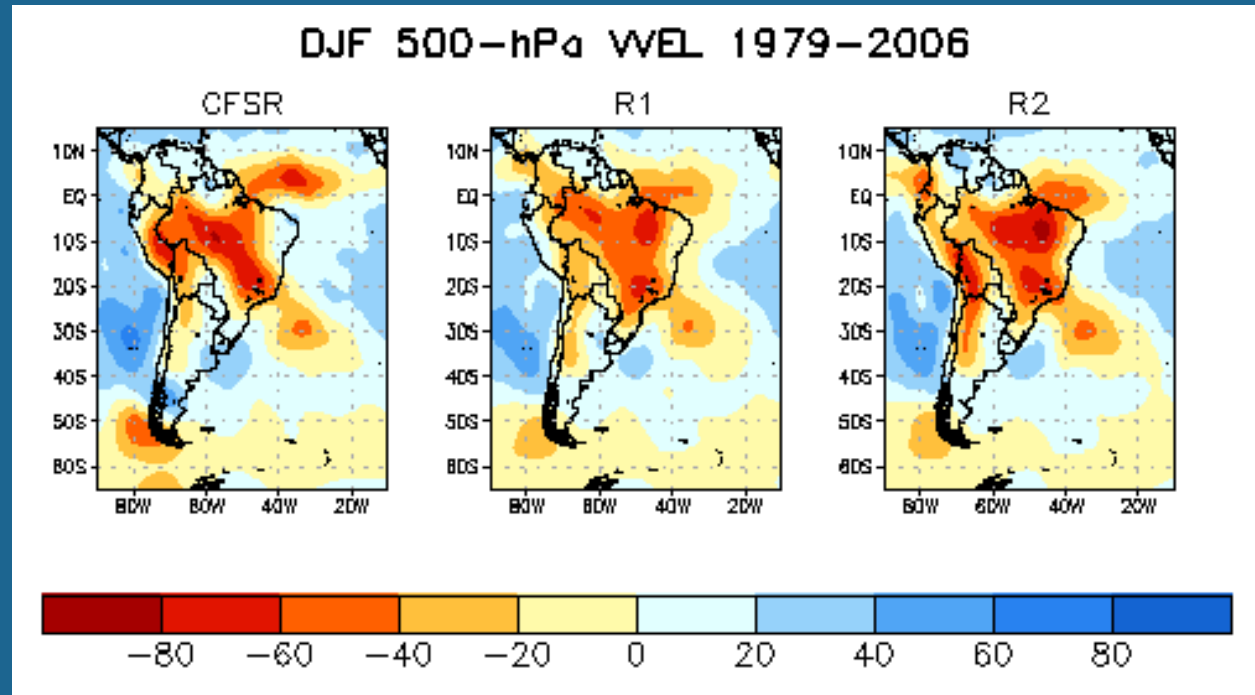
Season	R1 vs OI(T62)	R2 vs OI(T62)	CFSR vs OI(T382)
DJF	0.46	0.47	0.85
MAM	0.80	0.67	0.86
JJA	0.72	0.88	0.86
SON	0.43	0.30	0.61

CFSR has substantially higher pattern correlations than either R1 or R2 during the wet season (SON, DJF, and MAM).

Mean Daily Precip.



500-hPa Vertical Motion (Omega)

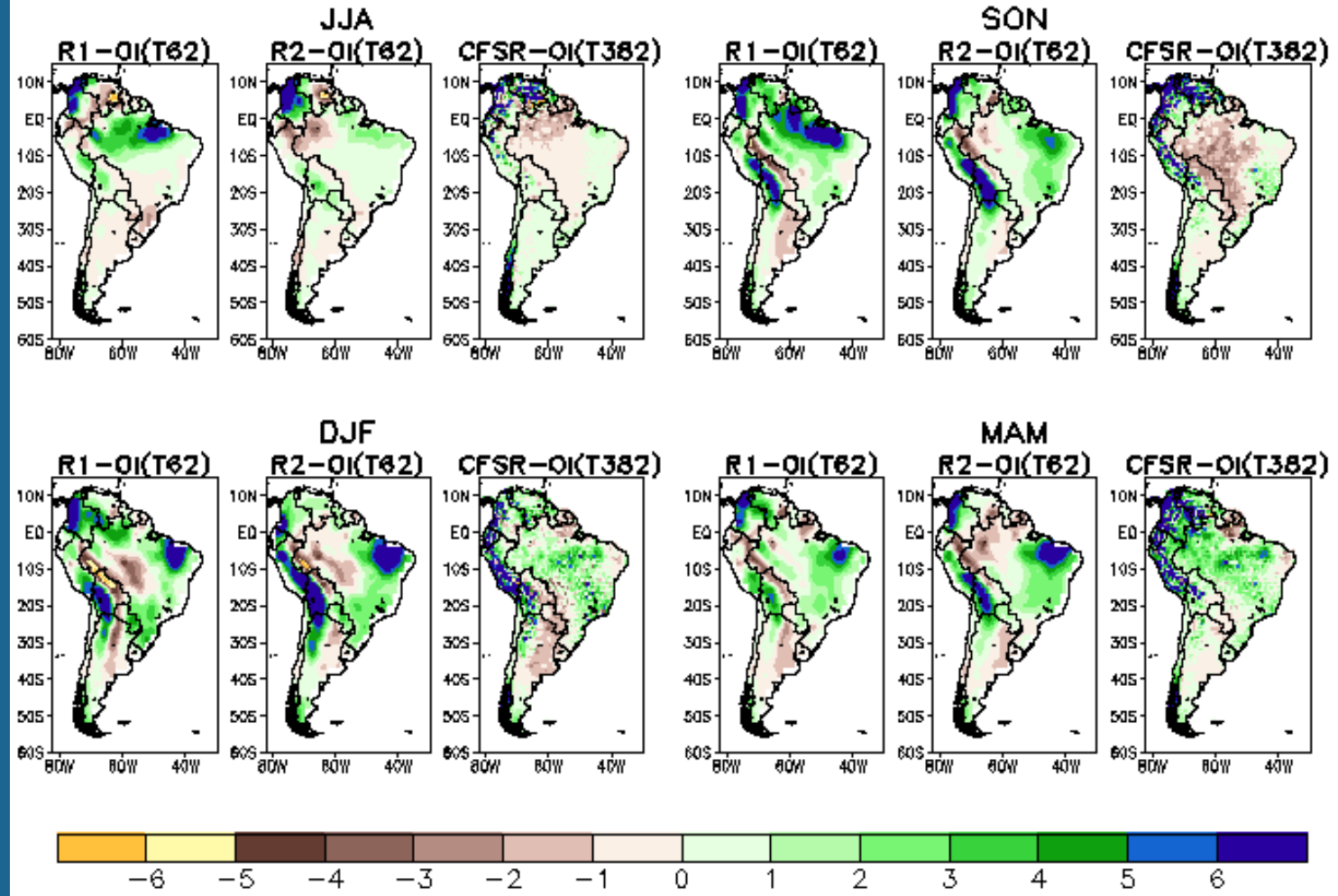


The pattern correlations between the 500-hPa vertical motion (omega) and observed precipitation fields at 2.5 deg lat/lon resolution for R1, R2 and CFSR in DJF over the SAMS core region (0°-35°S, 35°-65°W) are:

a) -0.72 for R1, b) -0.60 for R2, and c) -0.87 for CFSR.

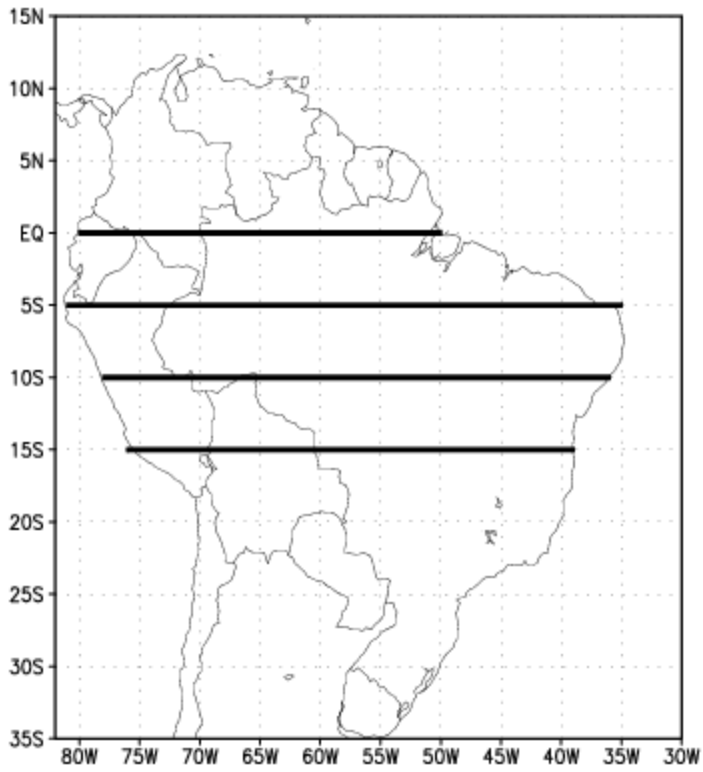
The DJF CFSR 500-hPa omega pattern agrees much better with the observed mean daily precipitation pattern than does either R1 or R2.

Mean Daily Precipitation Difference

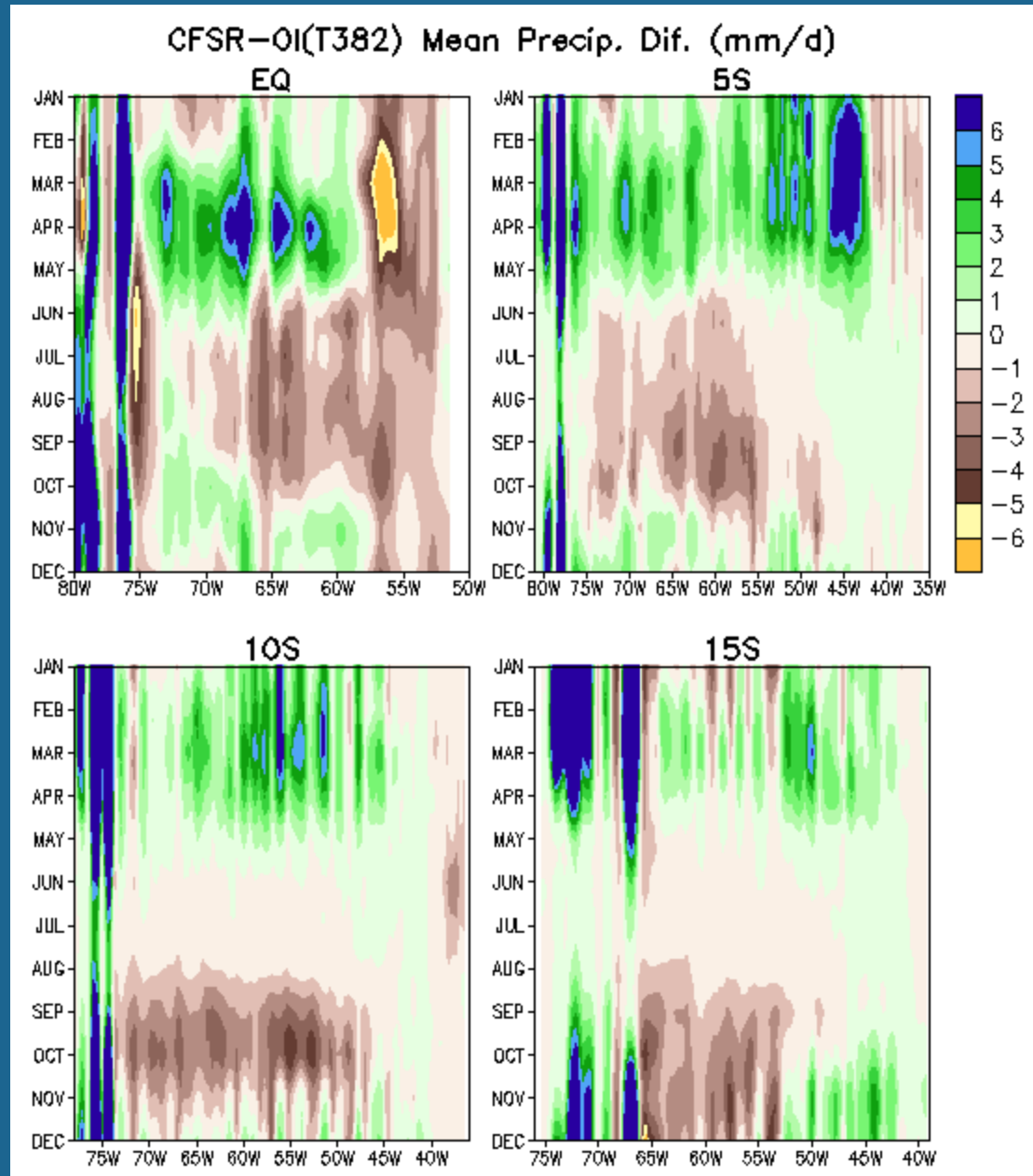


The CFSR biases are less than those in R1 and R2 in the vicinity of the Andes, probably due to the increase in CFS resolution (all seasons). The CFSR biases are less than R1 and R2 over portions of northeastern Brazil (SON, DJF and MAM). The CFSR dry bias over west-central Brazil (SON) is more extensive than in either R1 or R2.

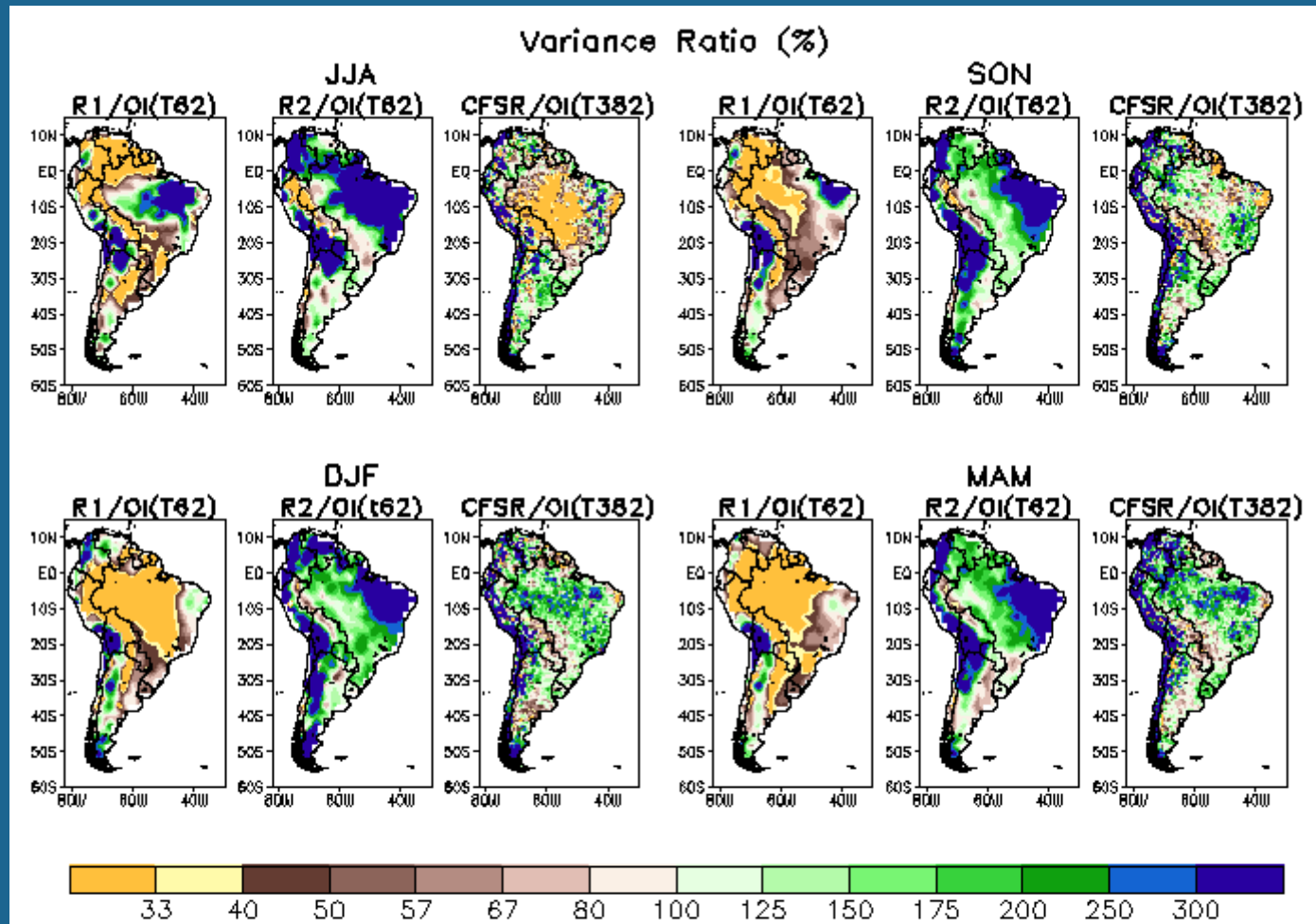
Time-Longitude Sections: CFSR – OI(T382)



The annual cycle of the CFSR-OI differences shows a dry bias during the onset phase (Aug-Oct) of the SA wet season and a wet bias during the peak and decay phases (Feb-Apr) of the wet season.

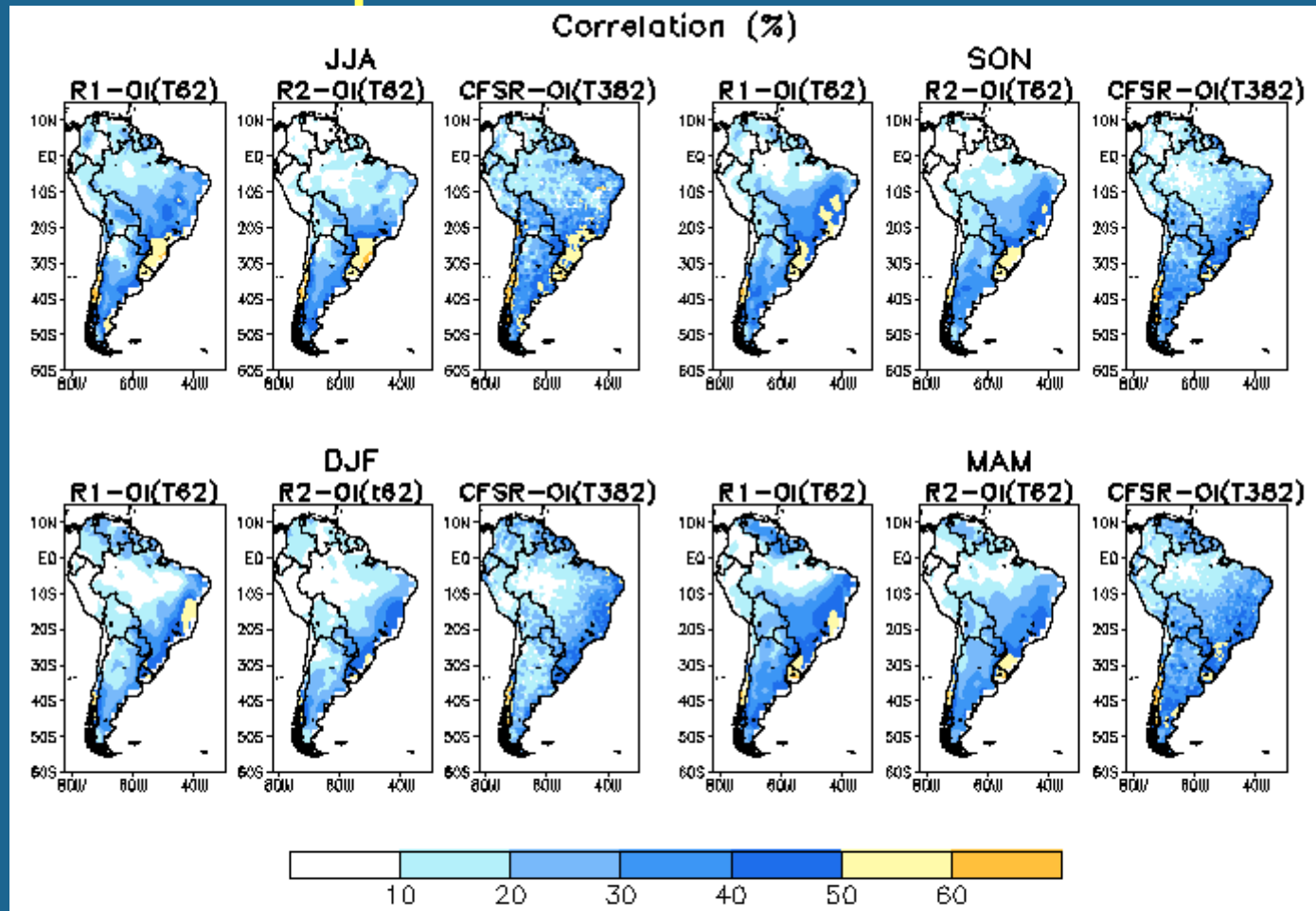


Variance Ratios



R1 has less variance than observations over most of South America in all seasons. R2 has more variance than observations over most of South America in all seasons. The magnitude of the variance bias in CFSR is less than in R1 and R2. The CFSR Variance is greater than observed in most areas during DJF and MAM.

Temporal Correlations



The temporal correlations between the daily reanalysis precipitation and the observed precipitation is highest over mid-latitudes and along the east coast of South America.

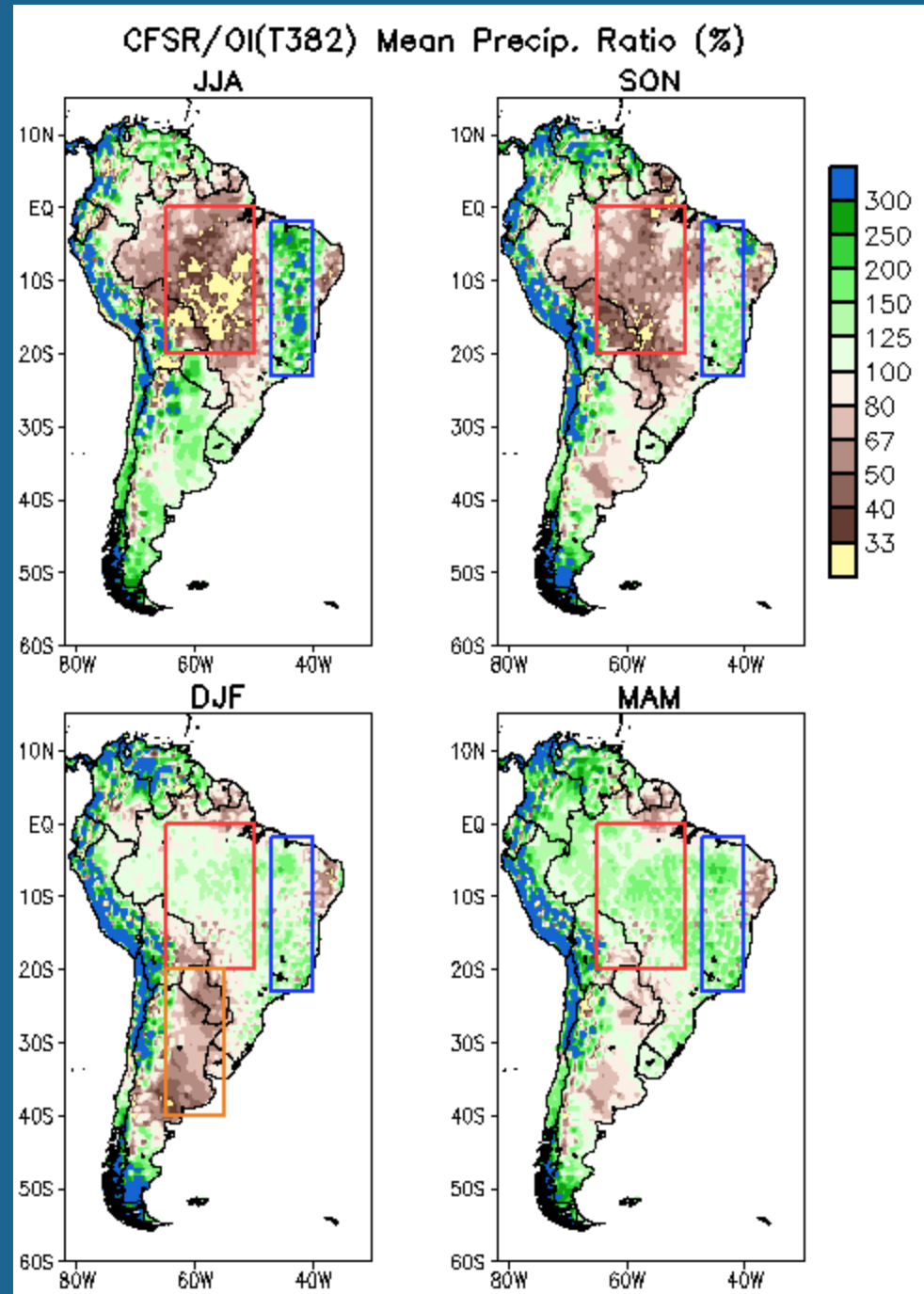
In those regions synoptic disturbances (e.g., frontal systems and upper-level waves) tend to organize convection. Over tropical latitudes, where convection tends to be less spatially organized on the large scale, correlations are very low.

CFSR/OI(T382) Ratio of Mean Daily Precipitation

Over the Amazon Basin (red rectangles) the CFSR is too dry during the dry season and onset phase of the SAMS wet season (SON), and too wet during the peak (DJF) and decay (MAM) phases of the SAMS wet season.

CFSR is too dry over Paraguay and the northern two thirds of Argentina (orange rectangle) during DJF, and too wet over portions of eastern Brazil in all seasons (blue rectangles).

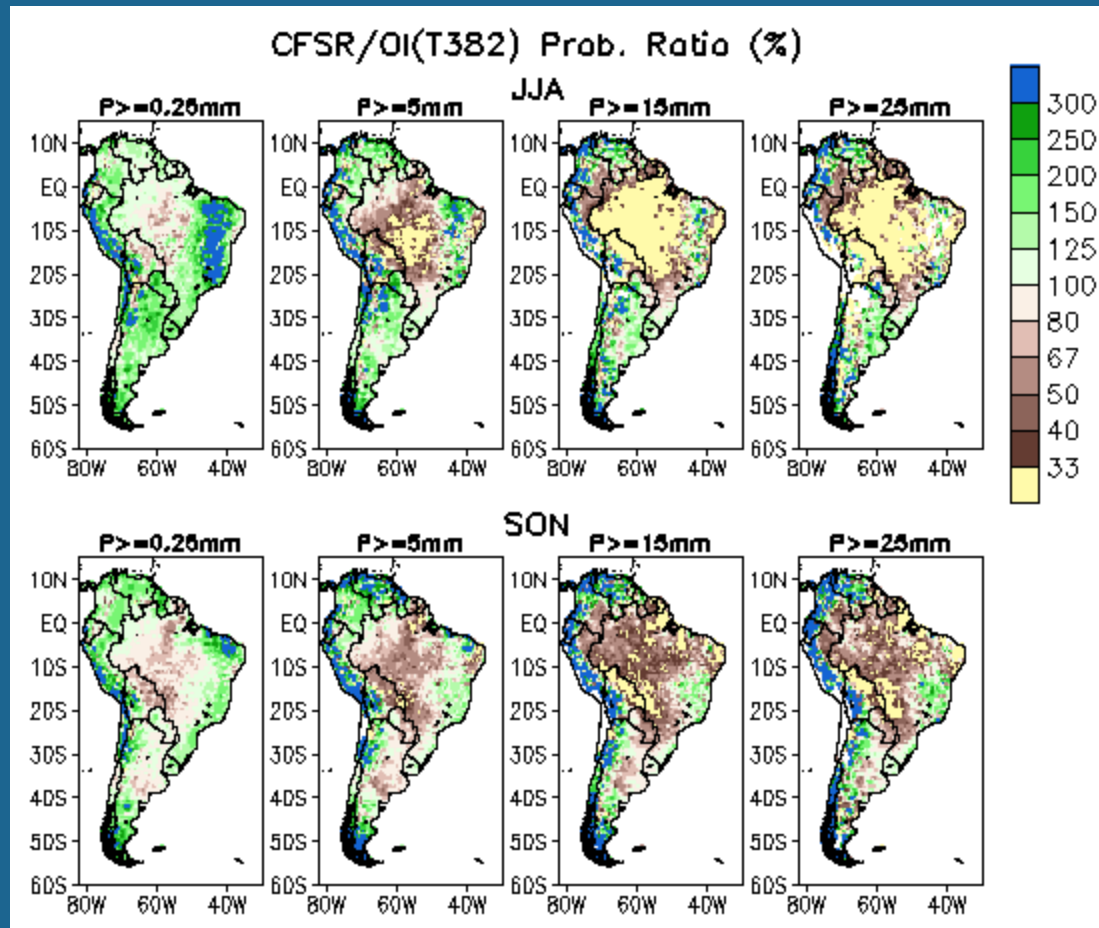
CFSR is too dry along the east coast of Northeast Brazil in all seasons.



Speculation

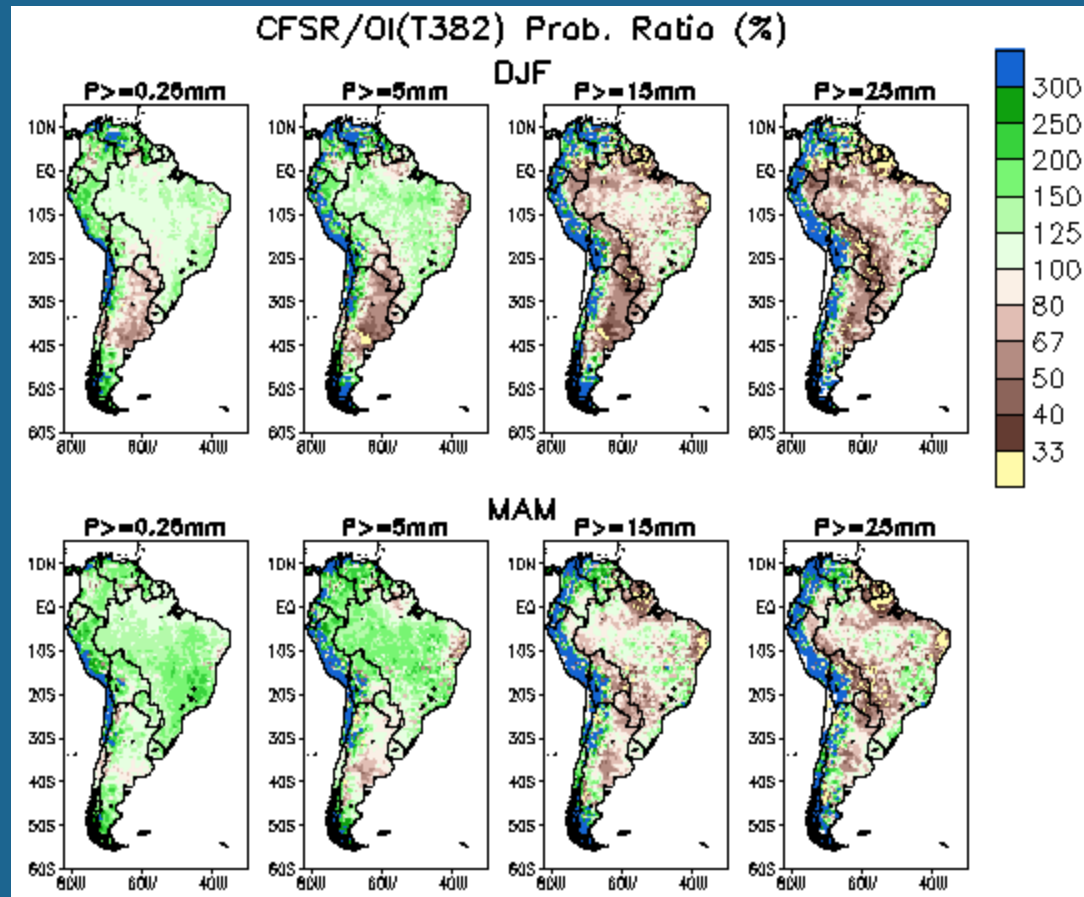
- The dry bias in the CFSR during the onset phase of the SAMS wet season and wet bias during the peak and decay phases of the SAMS wet season may be related to model biases in soil moisture and/or evapotranspiration, and the effects that those have on initiating precipitation in the model.
- During December-May, when soil moisture and evapotranspiration are high, the CFSR is too wet. During July-October, when soil moisture and evapotranspiration are lower, the CFSR is too dry.
- Further diagnostic research is necessary to determine the causes for the annual cycle in daily precipitation biases.

Probability Ratio: CFSR/OI(T382)



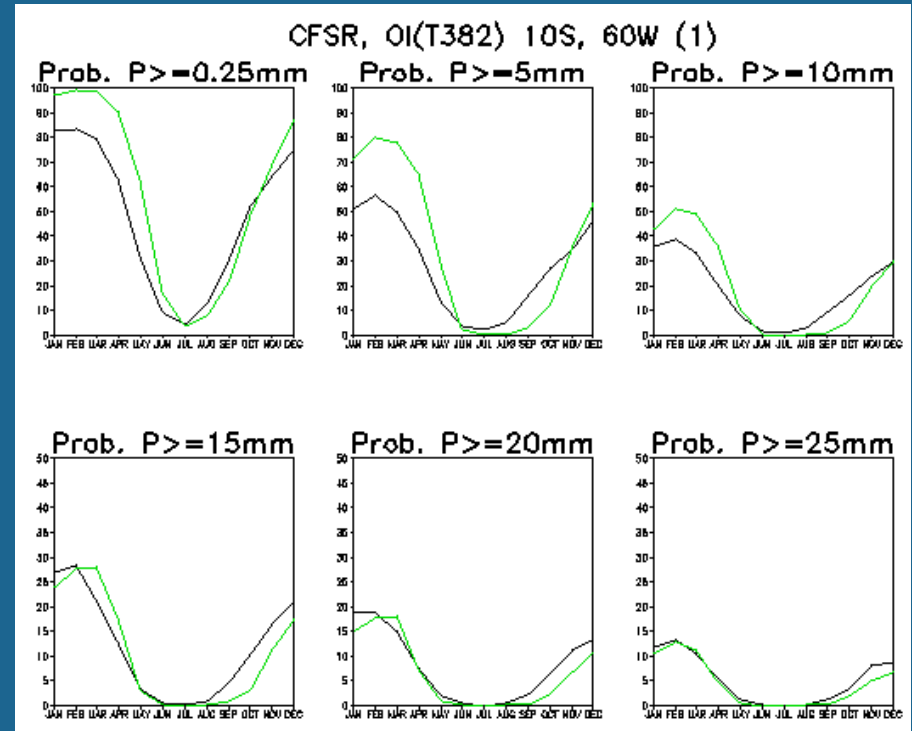
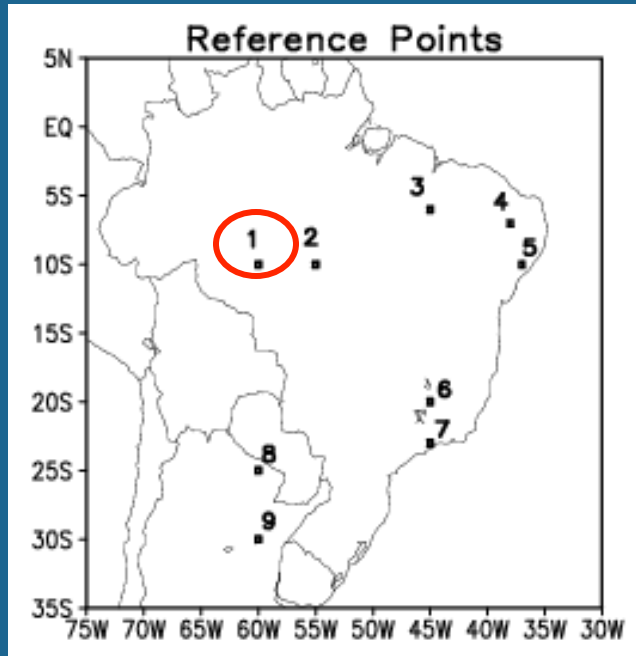
Over tropical South America (core monsoon region) the CFSR probabilities are generally less than the observed probabilities during JJA and SON for the three highest thresholds (5, 15 and 25 mm).

Probability Ratio: CFSR/OI(T382)



Over tropical South America (core monsoon region) the CFSR probabilities are generally greater than the observed probabilities during DJF and MAM for the two lightest thresholds (0.25 and 5 mm), and near the observed probabilities for the two highest thresholds (15 and 25 mm). CFSR has a wet bias resulting from more frequent than observed light precipitation events.

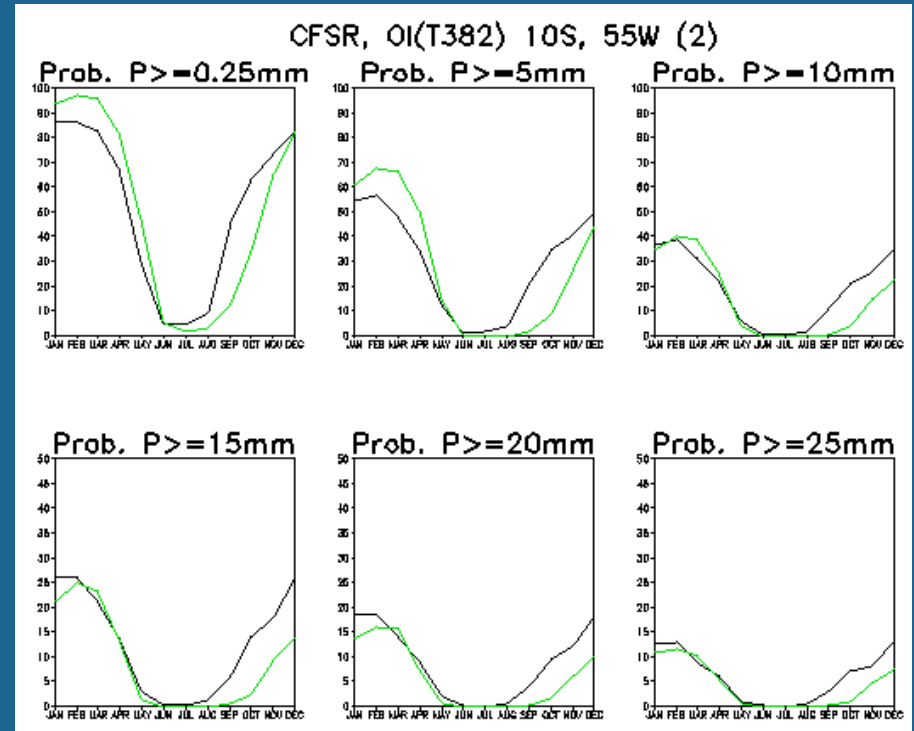
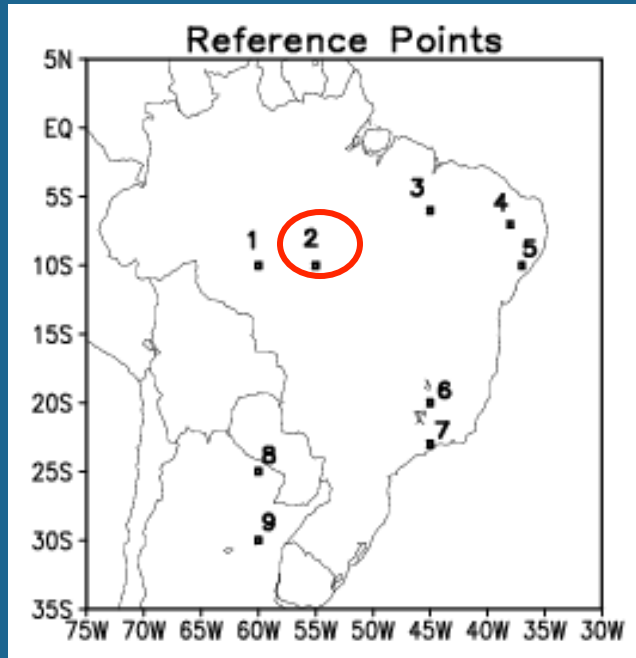
Probabilities of Precipitation Exceeding Selected Thresholds: Annual Cycle Amazon Basin



The CFSR probabilities generally exceed the observed probabilities during Jan-May for the three lightest thresholds (0.25, 5 and 10mm). During Jan-May, there is good agreement between CFSR and OBS for the two highest thresholds.

The CFSR probabilities are generally less than observed for all thresholds during the period Jul-Dec.

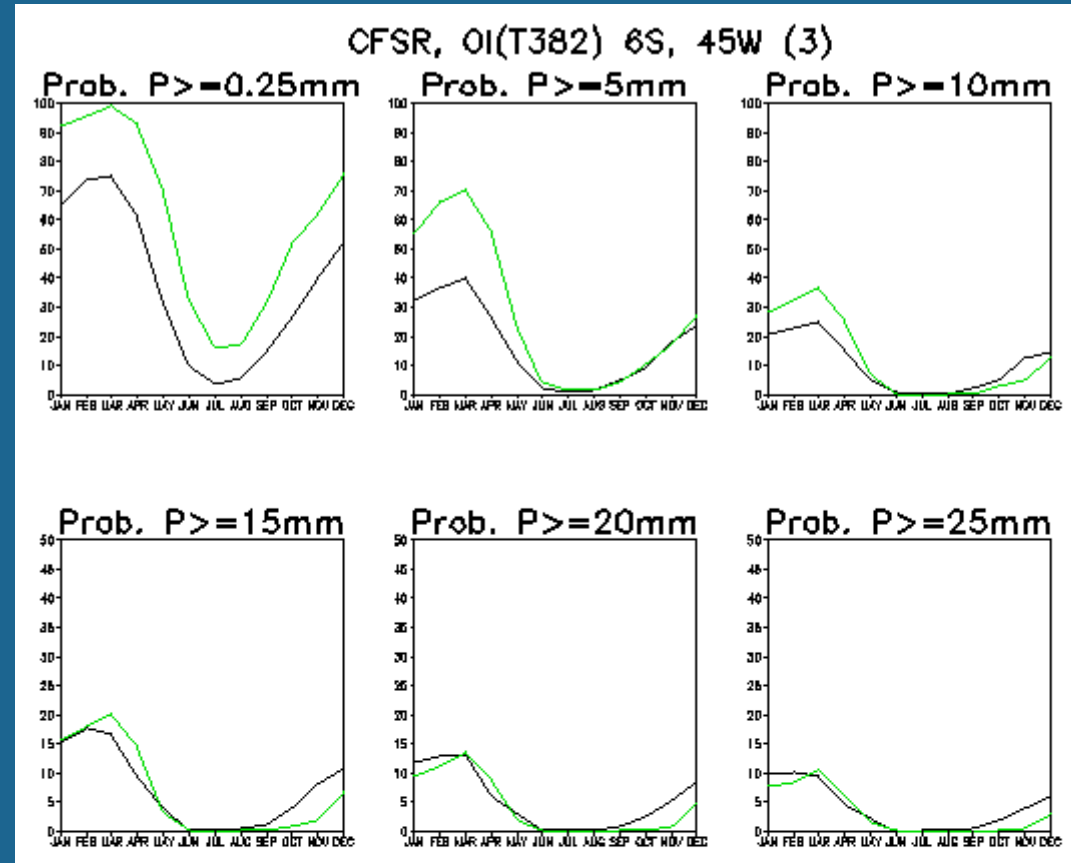
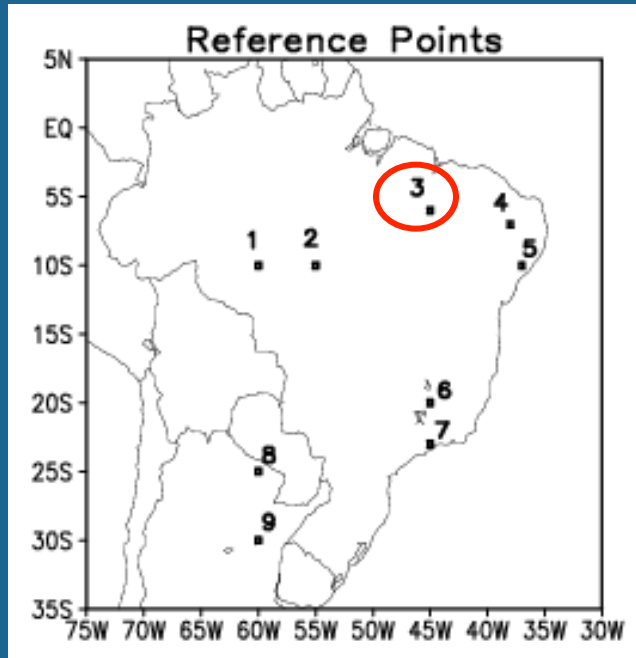
Probabilities of Precipitation Exceeding Selected Thresholds: Annual Cycle Amazon Basin



The CFSR probabilities generally exceed the observed probabilities during Jan-May for the two lightest thresholds (0.25 and 5 mm). During Jan-May there is good agreement between CFSR and OBS for the four highest thresholds.

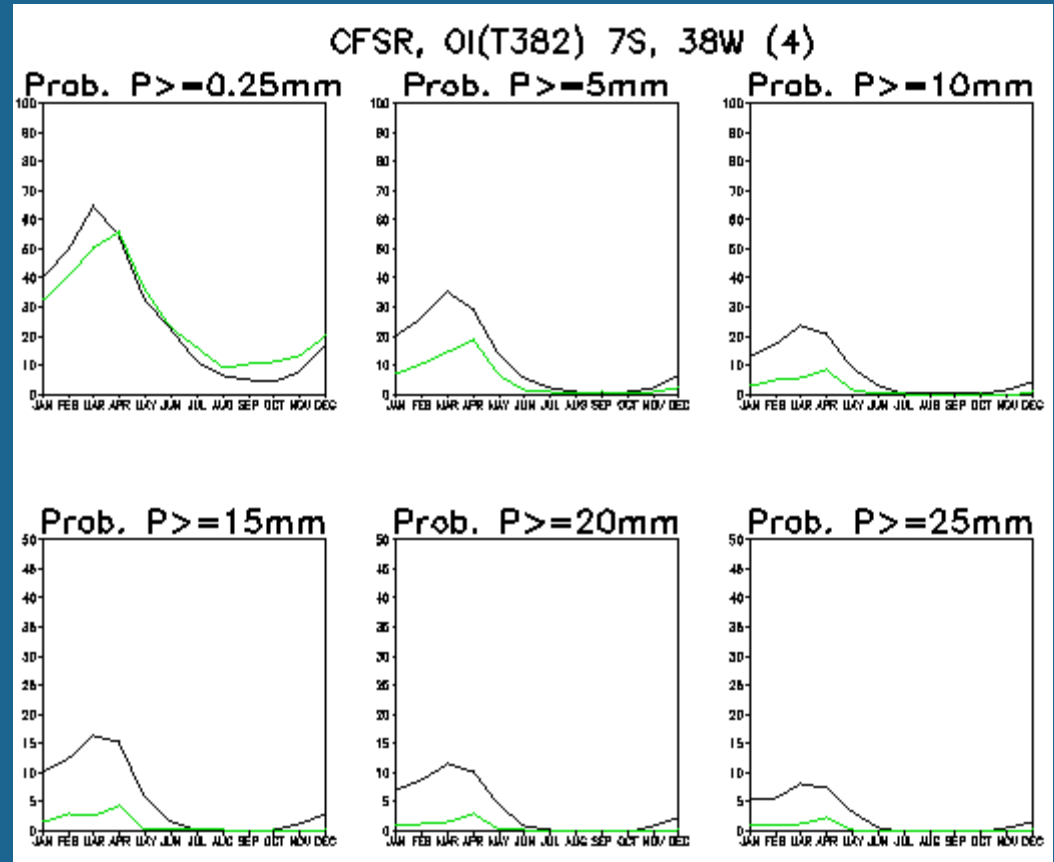
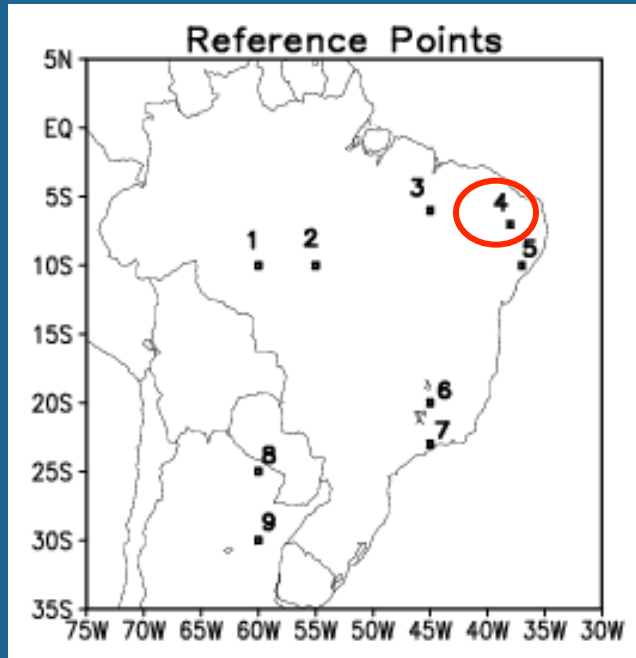
The CFSR probabilities are generally less than observed for all thresholds during the period Jul-Dec.

Probabilities of Precipitation Exceeding Selected Thresholds: Annual Cycle Northeast Brazil



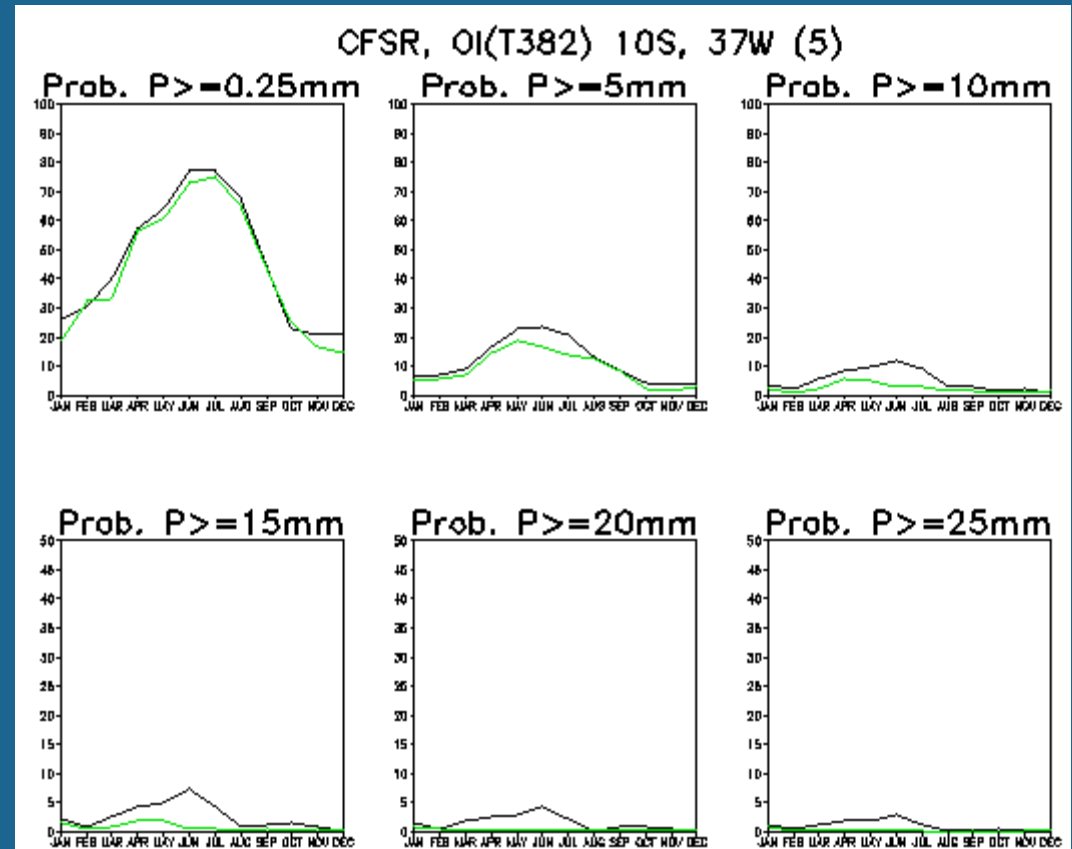
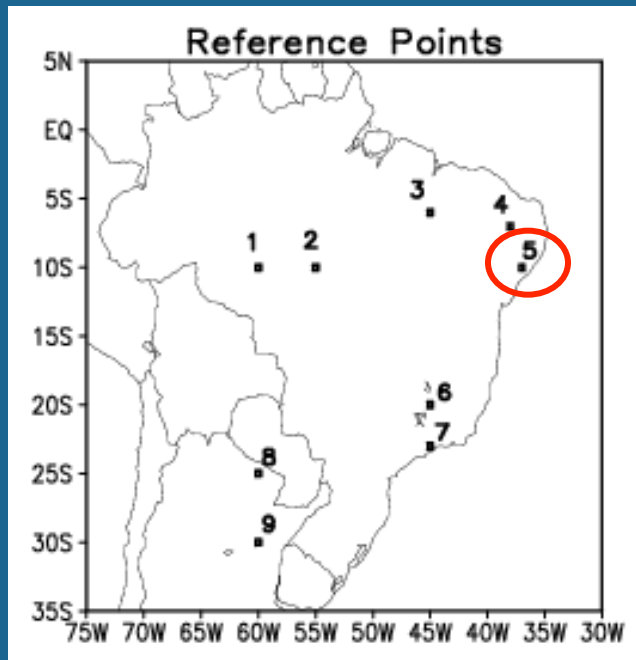
The CFSR probabilities are generally greater than OBS for the lightest three categories during Jan-May. The CFSR probabilities are less than OBS for the highest four categories during Oct-Dec.

Probabilities of Precipitation Exceeding Selected Thresholds: Annual Cycle Northeast Brazil



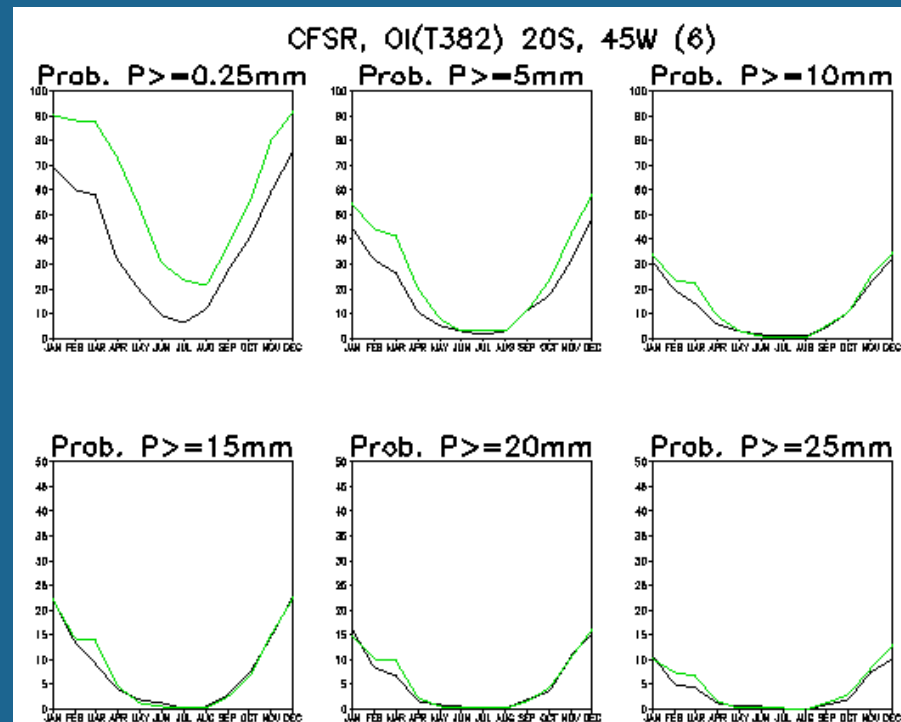
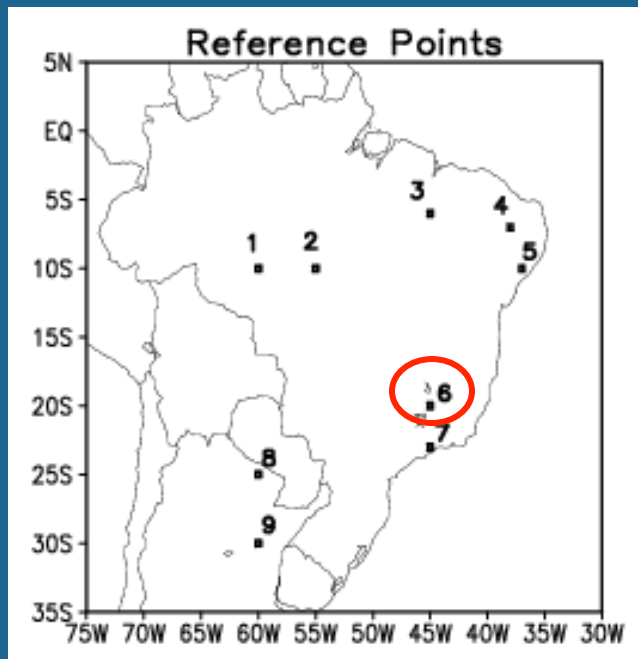
The CFSR probabilities are generally less than OBS for all categories during the wet season (Jan-May).

Probabilities of Precipitation Exceeding Selected Thresholds: Annual Cycle Northeast Brazil (east coast)



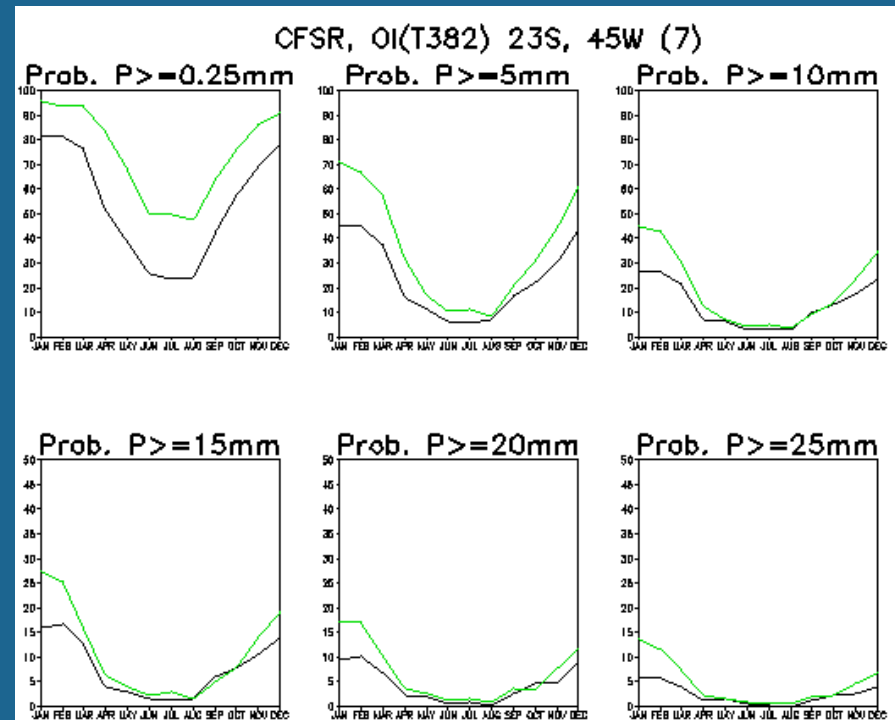
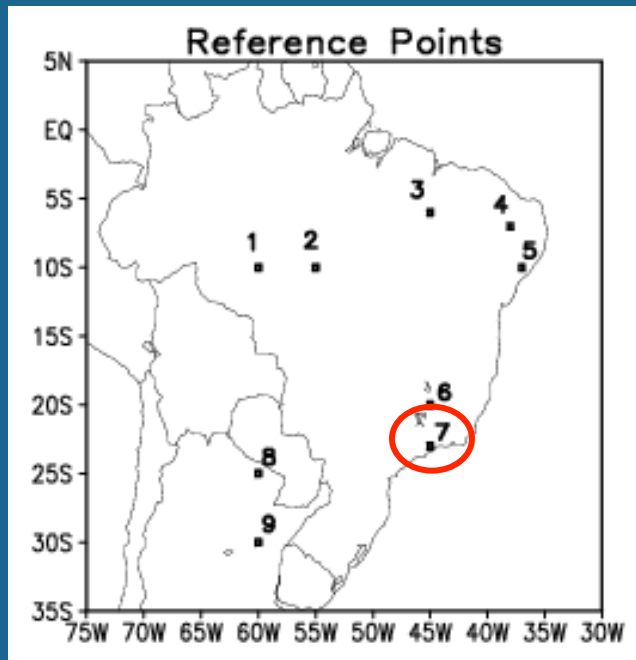
The CFSR probabilities agree quite well with the observed probabilities for wet days ($P \geq 0.25$ mm). The CFSR probabilities are less than OBS for the four highest categories during the wet season (Apr-Jul).

Probabilities of Precipitation Exceeding Selected Thresholds: Annual Cycle Southeast Brazil



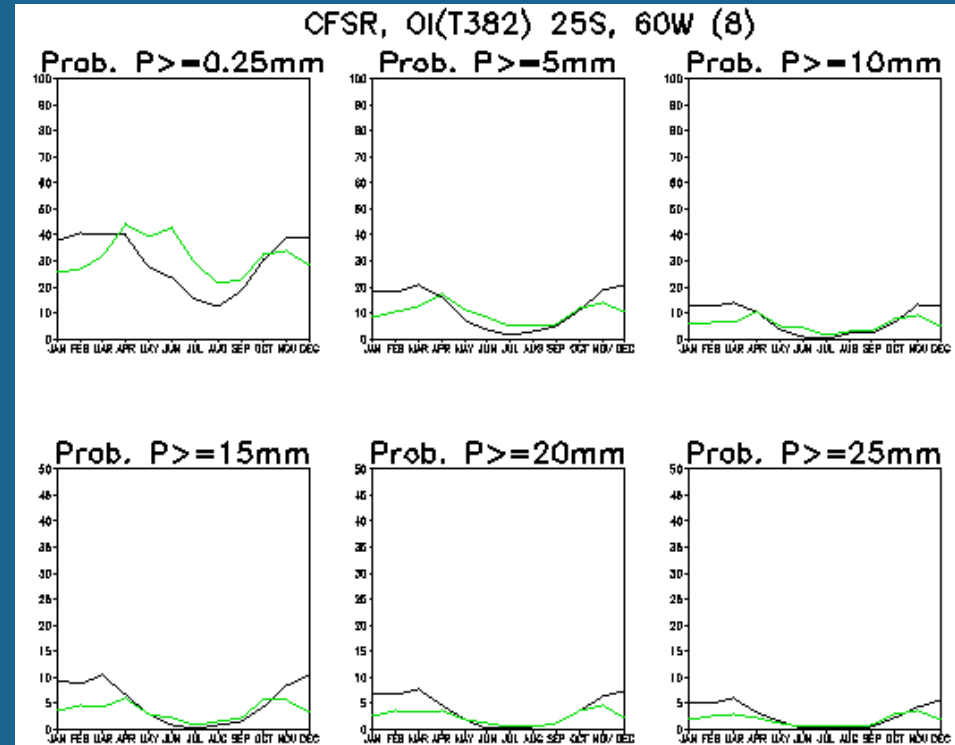
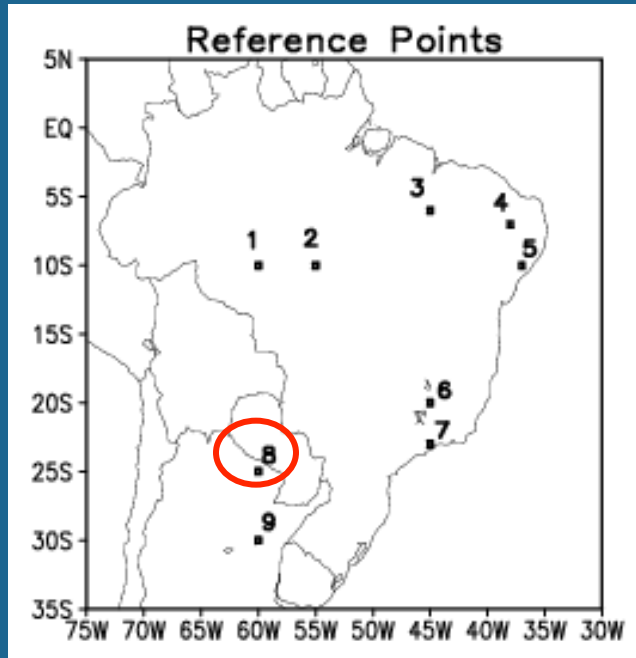
The CFSR probabilities generally exceed the observed probabilities throughout the year for the two lightest categories (0.25 and 5mm). There is good agreement between CFSR and OBS for the four highest amounts.

Probabilities of Precipitation Exceeding Selected Thresholds: Annual Cycle Southeast Brazil



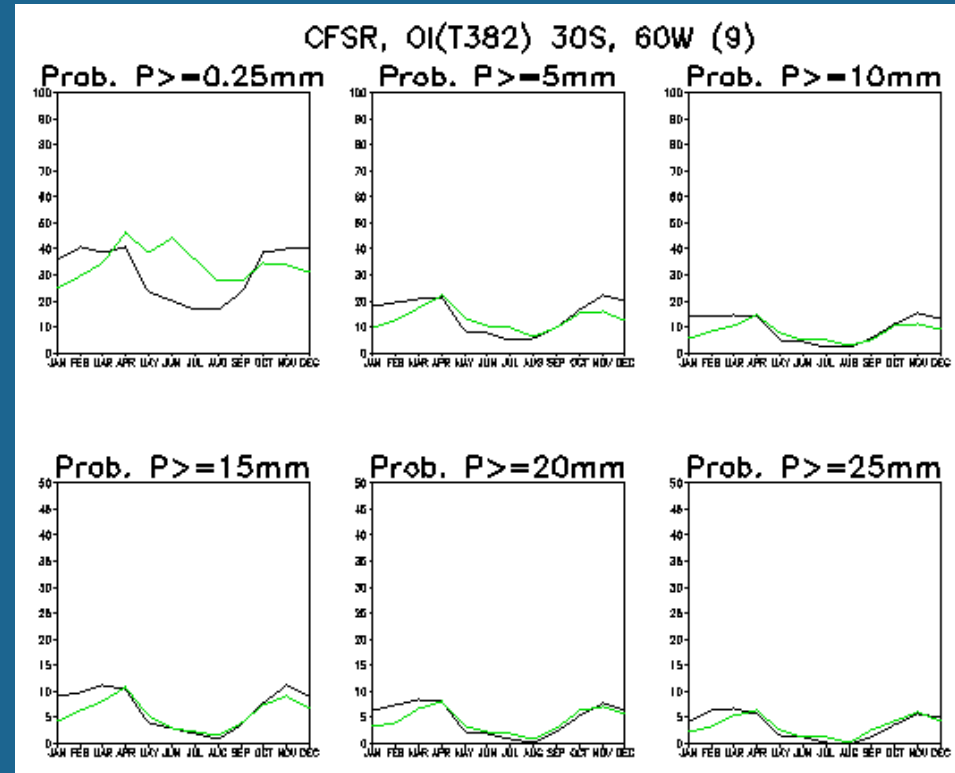
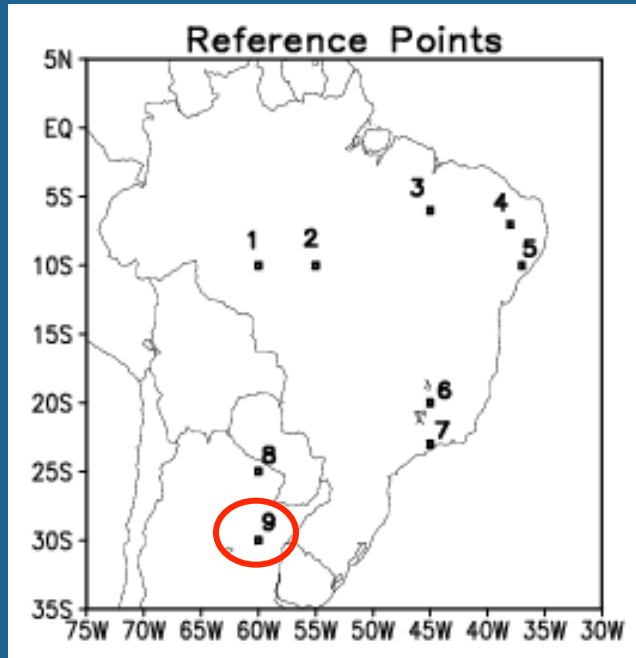
The CFSR probabilities generally exceed the observed probabilities throughout the year for the three lightest amounts (0.25, 5 and 10 mm). The CFSR probabilities exceed OBS during the wet season (Nov-Apr) for all thresholds.

Probabilities of Precipitation Exceeding Selected Thresholds: Annual Cycle Central South America



The CFSR probabilities are less than observed probabilities for all thresholds during Dec-Mar (wet season), and exceed observed probabilities during May-Aug (dry season) for the two lightest thresholds.

Probabilities of Precipitation Exceeding Selected Thresholds: Annual Cycle Central South America



The CFSR probabilities are less than observed probabilities for all thresholds during Jan-Mar (wet season), and exceed observed probabilities during Apr-Aug (dry season) for the lightest threshold.

Summary

- The CFSR shows notable improvements in the large-scale precipitation patterns compared with the previous reanalyses (R1 and R2).
- These improvements are reflected in the mean mid-tropospheric (500-hPa) vertical motion (omega) patterns, especially during December-February.

Summary (cont.)

- In spite of these improvements in the CFSR patterns of precipitation, substantial biases in intensity and frequency of occurrence of rainfall events exist in the CFSR.
- The dry bias in the CFSR during the onset phase of the SAMS wet season and wet bias during the peak and decay phases of the SAMS wet season may be related to model biases in soil moisture and/or evapotranspiration.
 - There is a need for more research to determine the causes for this seasonal variation in mean daily precipitation biases.

Summary (cont.)

- There is a dry bias in the CFSR in coastal areas near the mouth of the Amazon and along the east coast of Northeast Brazil.
 - This may indicate that the CFSR is not capturing the intensity and/or frequency of land-sea-breeze induced rainfall that is observed in this region. Type of precipitation (warm cloud vs cold cloud) may also be a contributing factor. More research is necessary.
- The higher-than-observed probabilities of light rainfall events and less-than-observed probabilities of heavy rainfall events in the CFSR for many areas in Brazil during DJF and MAM suggest that the CFS may be too quick to initiate diurnal convective rainfall, resulting in weaker events.
 - This hypothesis needs to be explored in a detailed evaluation of the model diurnal cycle of precipitation and related variables.

Conclusion

- The CFSR shows notable improvements in the precipitation biases over the southern U.S. and the precipitation pattern over South America.
- However, wet biases remain or appear in several areas (e.g., SE U.S., Andes and central Brazil, and northern U.S. in winter).
- Future reanalysis efforts should emphasize model bias reduction.