# Intraseasonal Temperature Variability in the UTLS from the GPS RO Measurements


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# Outline

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3. Analysis Methodology
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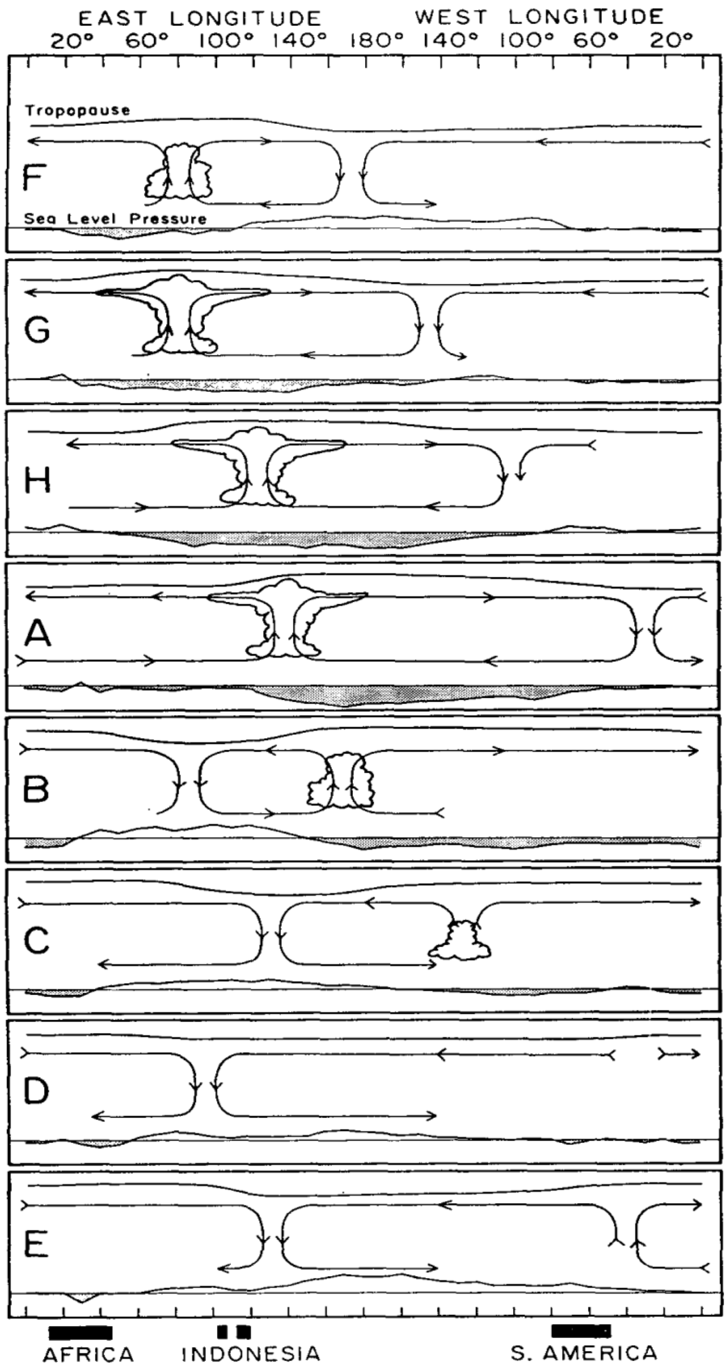
# Motivation

- The upper troposphere and lower stratosphere (UTLS) is a coupling or transition layer ±5 km around the tropopause that shares the properties of both troposphere and stratosphere. The UTLS is a topic of current active research [e.g., *Fueglistaler et al.*, 2009; *Gettelman et al.*, 2011].
- It has been long recognized that documenting and understanding the thermal structure of the UTLS is essential to understand the stratosphere-troposphere exchange, stratospheric dehydration and water vapor trends, and tropical thin cirrus cloud formation [e.g. *Holton et al.*, 1995; *Solomon et al.*, 2010; *SPARC*, 2000; *Virts and Wallace*, 2010].
- The time-mean thermal structure of the UTLS has well been studied based on the Global Positioning System (GPS) radio occultation (RO) observations [e.g., *Nishida et al*. 2000; *Randel et al.* 2003; *Kishore et al.*, 2006; *Schmidt et al.*, 2005; 2006; 2008; *Son et al*. 2011].
- However, very few studies have analyzed the intraseasonal variability of the UTLS thermal structure related to the Madden-Julian Oscillation (MJO) [*Madden and Julian*, 1971; 1972] using the GPS RO data.




# Madden-Julian Oscillation (MJO) or Intraseasonal Oscillation (ISO)

- ✓ The MJO is characterized by slow eastward-propagating oscillations in equatorial deep convection and large-scale circulation.
- ✓ It is the dominant form of intra-seasonal variability in the Tropics.
- ✓ It impacts a wide range of phenomena.
- ✓ It is predictable within 2-4 weeks.
- ✓ Our weather & climate models have a relatively poor representation.
- ✓ A comprehensive theory for the MJO is still lacking.

*Madden & Julian* [1971; 1972],
*Lau and Waliser* [2005; 2011], *Zhang* [2005]

# Motivation

- It has also been long recognized that the MJO can impact the UTLS thermal structure [e.g., *Madden and Julian* 1971; 1972; *Knutson and Weickmann* 1987; *Weickmann et al.* 1985; *Bantzer and Wallace* 1996; *Kiladis et al*. 2001; *Tian et al.* 2006; 2010; *Virts and Wallace* 2010].
- There are still many limitations for the above studies:
  - Sparse spatial sampling for radiosonde data.
  - Model-dependent errors and coarse vertical resolution for analysis/reanalysis data.
  - Coarse vertical resolution for previous satellite data (e.g., 5 km for MSU and 1-2 km for AIRS).
  - Potential scene-dependent sampling bias for previous satellite data (e.g., AIRS loses information when effective cloud amount is >70%).
  - Potential diurnal sampling bias for previous satellite data (e.g., two local time samples per day for AIRS).

# Advantages of GPS RO Temp Measurements in the UTLS

1. The GPS RO systems can measure the temperature profiles in the UTLS with a high accuracy (errors less than 1 K), a high vertical resolution (~200 m), under all-weather and all-cloud conditions, and with global coverage [*Anthes et al.*, 2008; *He et al.*, 2009].
2. The addition of COSMIC constellation [*Anthes et al.*, 2008] in 2006 provided much-needed spatial and temporal sampling (including the diurnal cycle) to study the intraseasonal temperature variability in the UTLS related to the MJO.

# Objectives

- To characterize and quantify the spatiotemporal patterns and vertical structure of the intraseasonal temperature variability in the UTLS related to the MJO using the temperature profiles from the recent GPS RO instruments.

- To compare the intraseasonal temperature variability in the UTLS related to the MJO between the GPS and AIRS measurements to highlight the new features of the GPS results and to evaluate the quality of the AIRS temperature profiles in the UTLS considering GPS temperature profiles in the UTLS as the benchmark.

# Data

- GPS RO temperature profiles in the UTLS produced by JPL:
  - 01/01/2006 − 12/31/2010
  - CHAMP, GRACE, SAC-C, and COSMIC
  - 10° lon x 5° lat spatial grids
  - 14 vertical pressure levels from 300 to 50 hPa with 25 hPa spacing below 100 hPa and 10 hPa spacing above 100 hPa
    → 7 vertical pressure levels: 300, 250, 200, 150, 100, 70, 50hPa
  - Lapse-rate tropopause height.

- Atmospheric Infrared Sounder (AIRS) V5 L3 temperature profiles in the UTLS:
  - 01/01/2006 − 12/31/2010
  - AIRS/AMSU combined retrievals
  - 1° lon x 1° lat spatial grids → 10° lon x 5° lat spatial grids
  - 7 vertical pressure levels: 300, 250, 200, 150, 100, 70, 50hPa

- TRMM 3B42 precipitation:
  - 0.25° x 0.25° spatial grids → 2.5° x 2.5° spatial grids
  - 3-hourly averaged to daily
  - 01/01/1998-03/31/2011.

# MJO Analysis Method

- ✧ Intraseasonal anomalies of daily data were obtained by removing the climatological seasonal cycle and data filtering through a 30–90-day band pass filter.

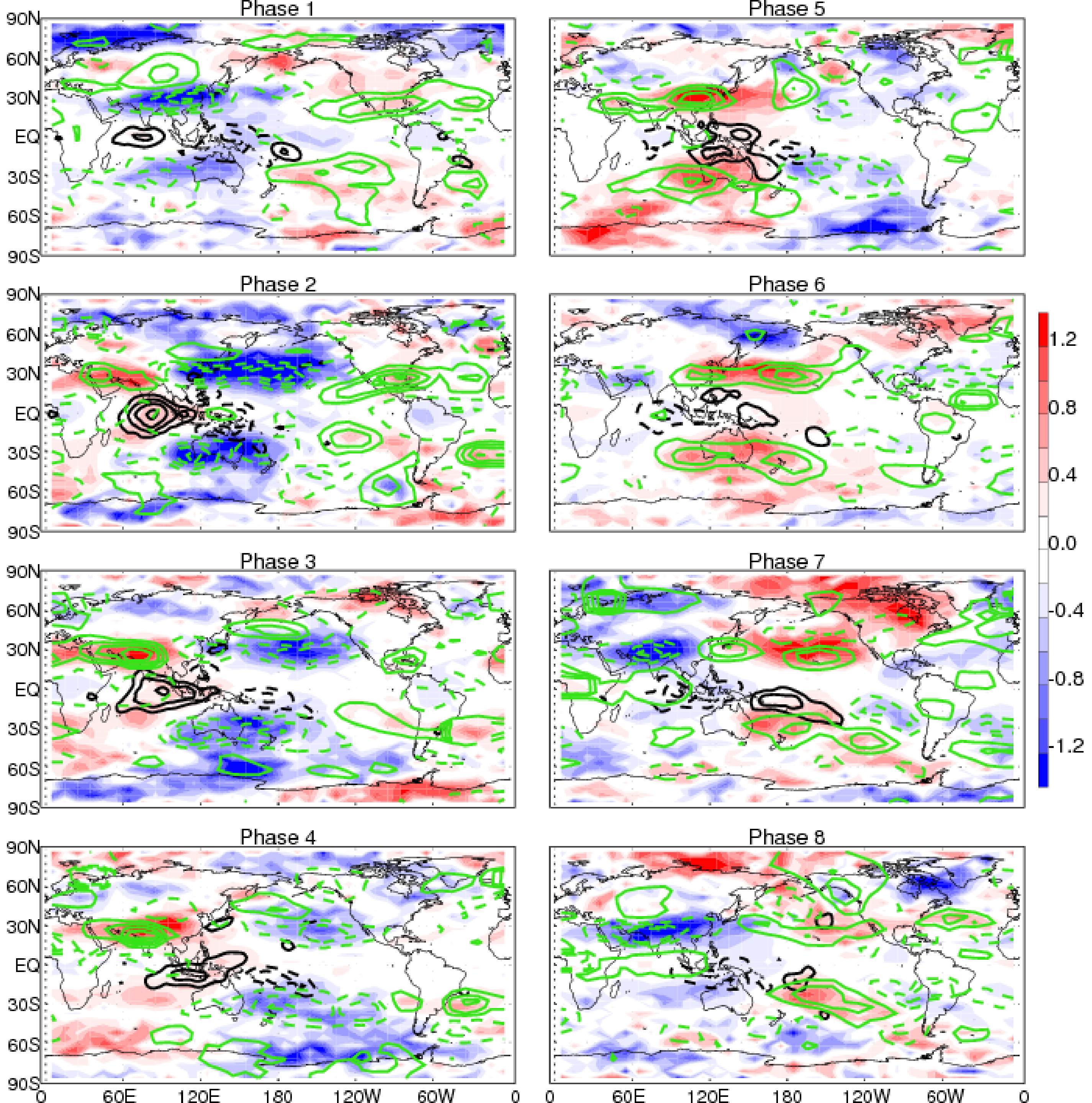
- ✧ The MJO phase for each day was determined by the Real-time Multivariate MJO (RMM) index, a pair of PC time series called RMM1 and RMM2 based on the leading pair of the multivariate EOFs of band-passed (30-90 day) NOAA OLR and NCEP/NCAR 850- and 200-hPa zonal winds.

- ✧ A composite MJO cycle (8 phases) was calculated by averaging band-passed daily anomalies of target quantity for each phase of the MJO cycle.

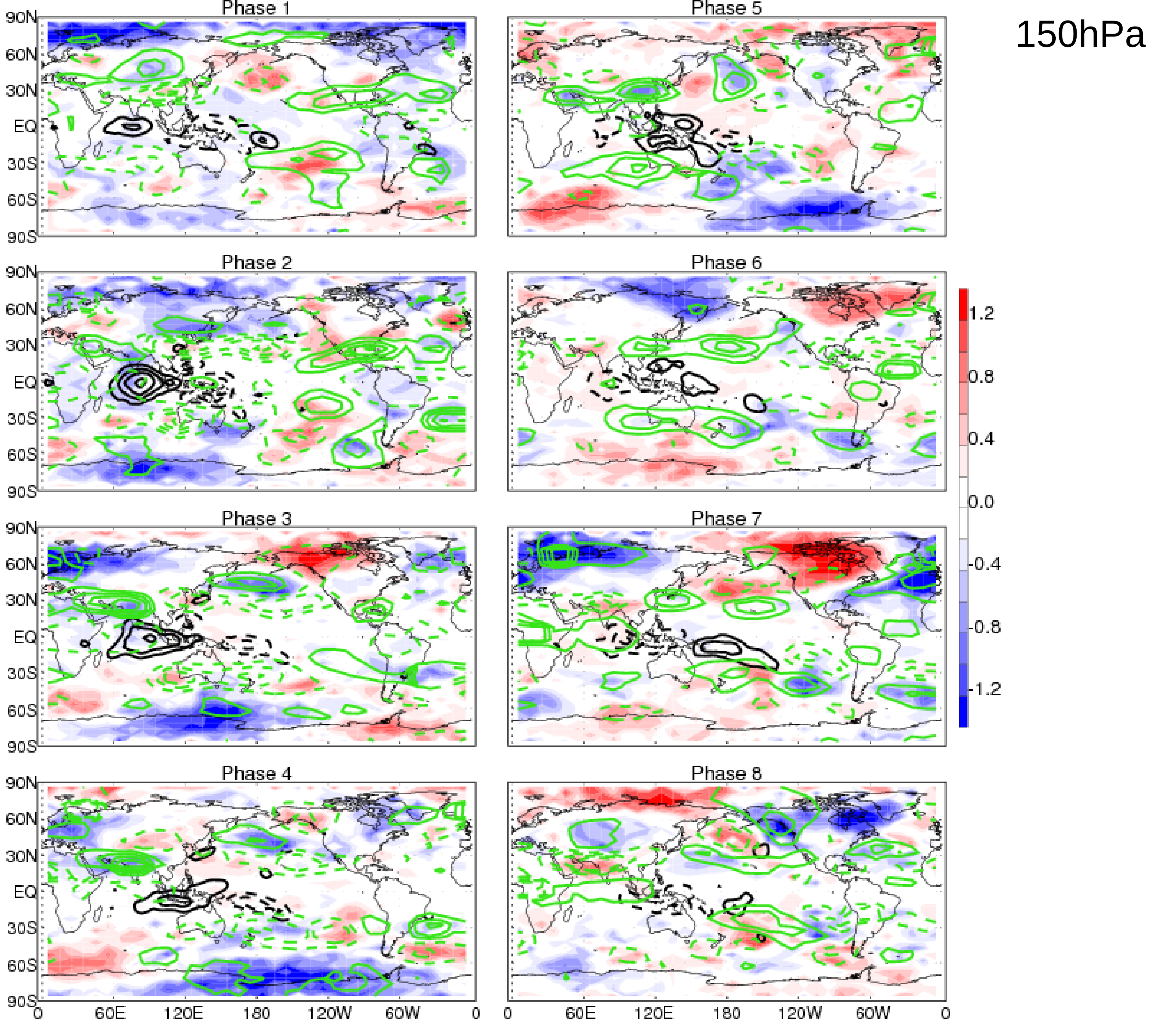
Wheeler and Hendon (2004), Tian et al. (2010; 2011), Li et al. (2010; 2012)

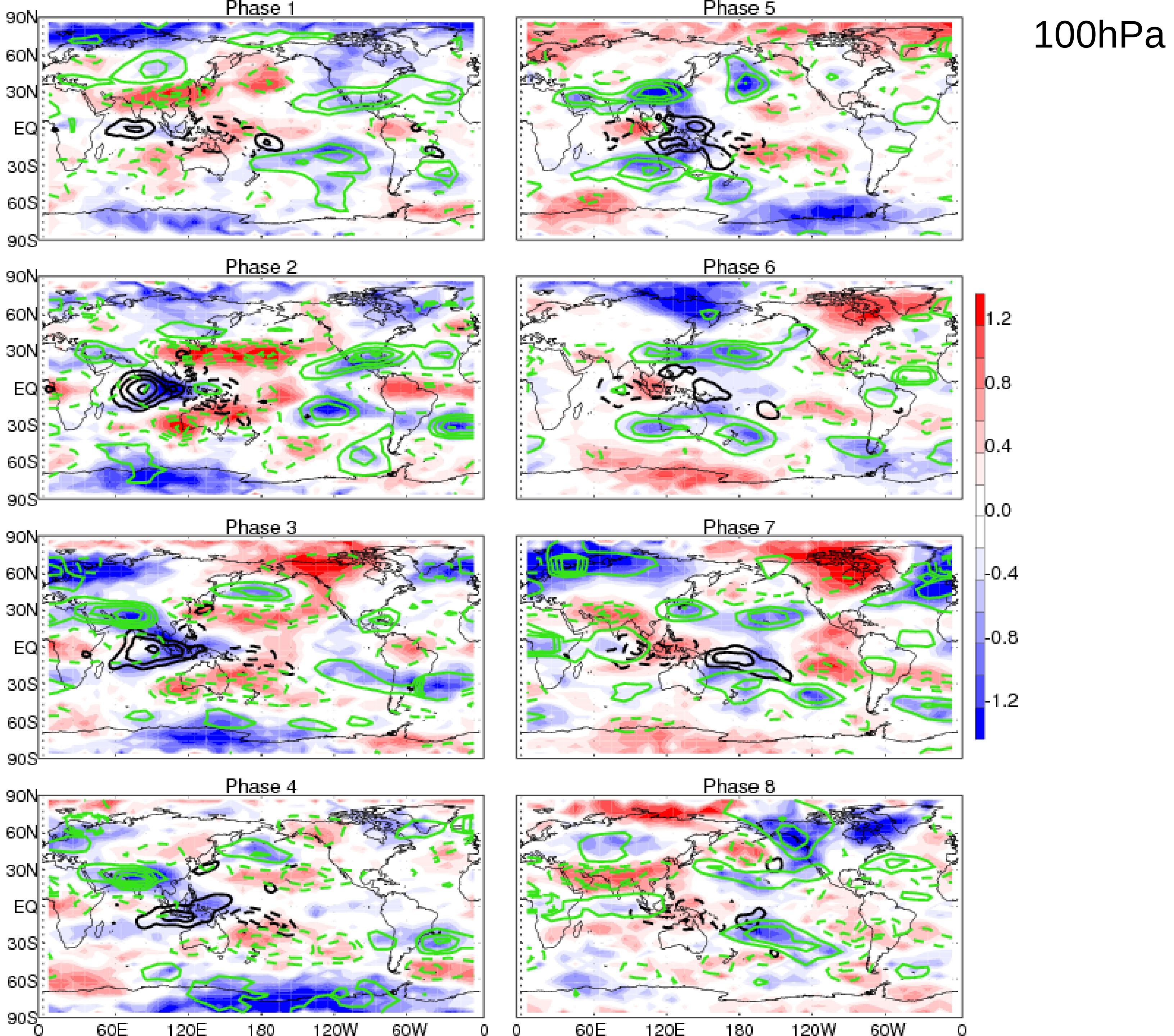
# GPS RO Results

250hPa



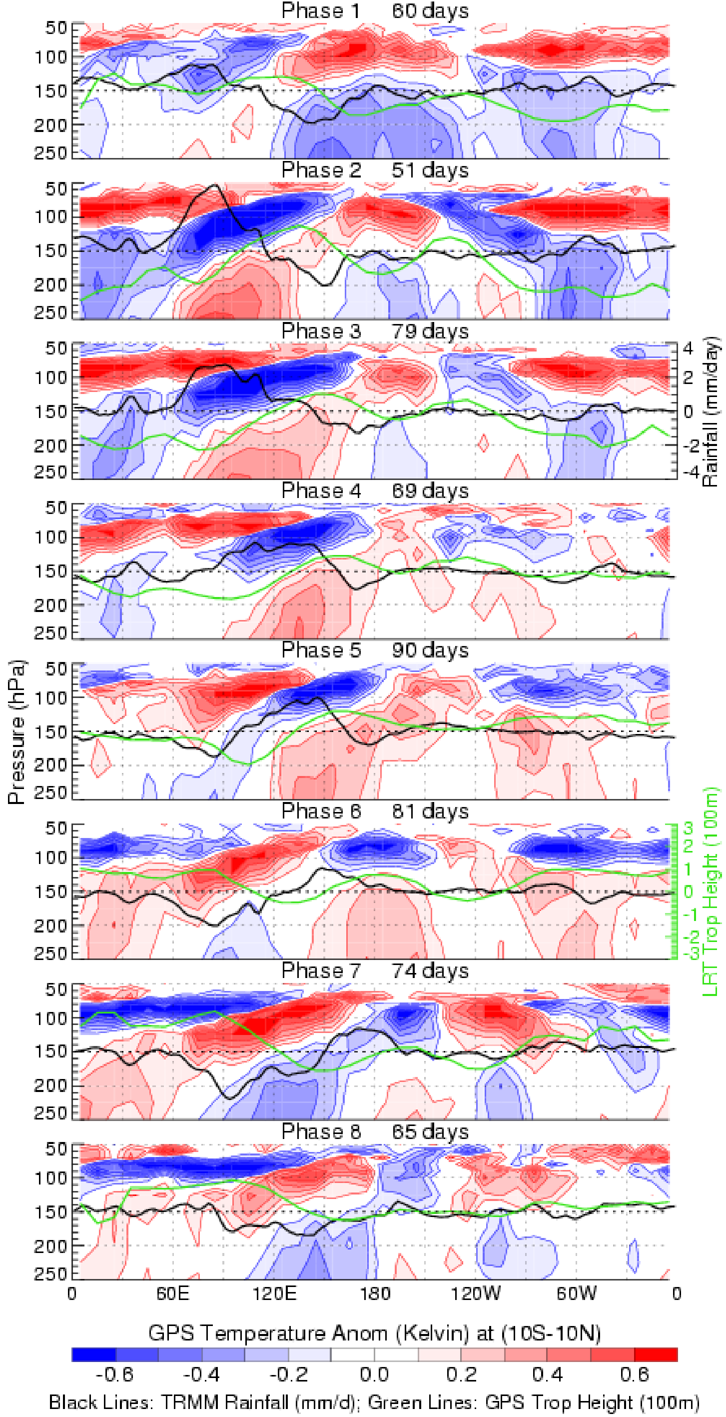
Phase 1
Phase 2
Phase 3
Phase 4
Phase 5
Phase 6
Phase 7
Phase 8
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
1.2
0.8
0.4
0.0
-0.4
-0.8
-1.2

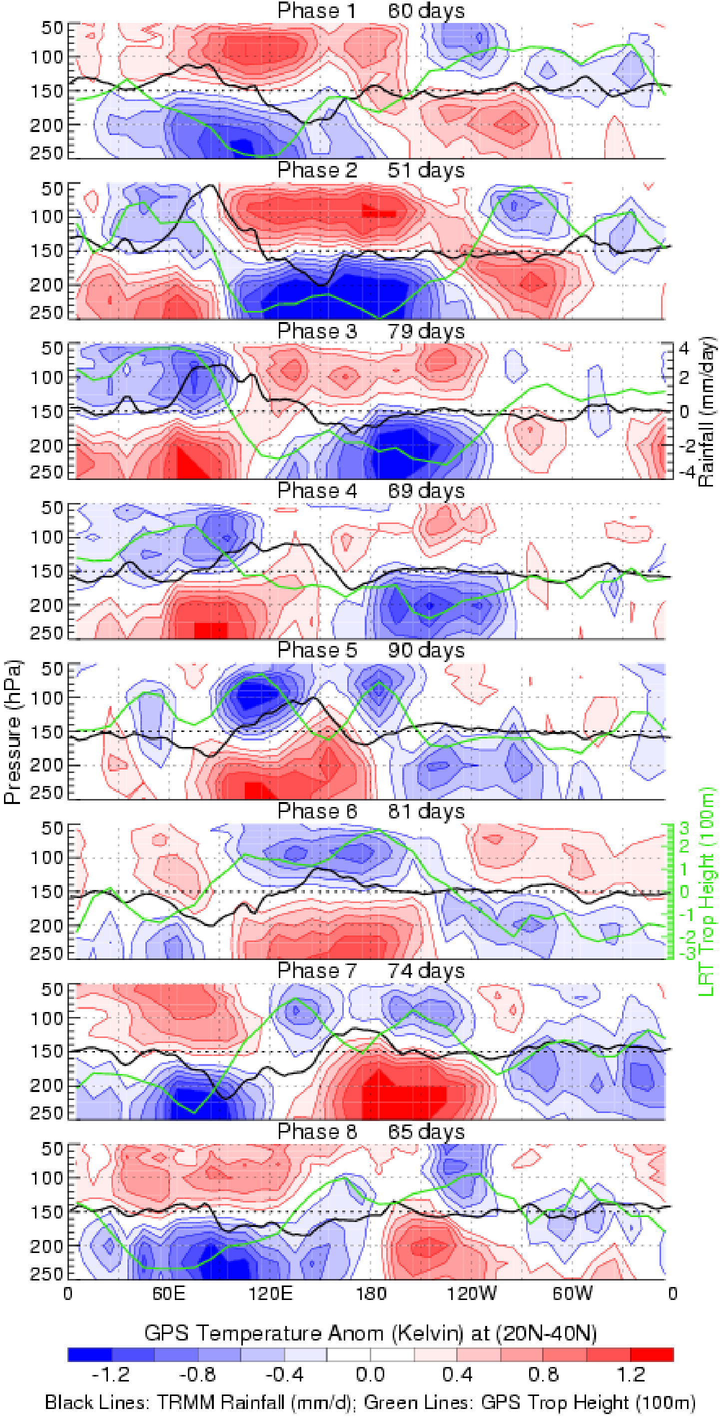

150hPa
Phase 1
Phase 2
Phase 3
Phase 4
Phase 5
Phase 6
Phase 7
Phase 8
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
1.2
0.8
0.4
0.0
-0.4
-0.8
-1.2



100hPa
Phase 1
Phase 2
Phase 3
Phase 4
Phase 5
Phase 6
Phase 7
Phase 8
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
1.2
0.8
0.4
0.0
-0.4
-0.8
-1.2

# Equatorial Region (10S – 10N)

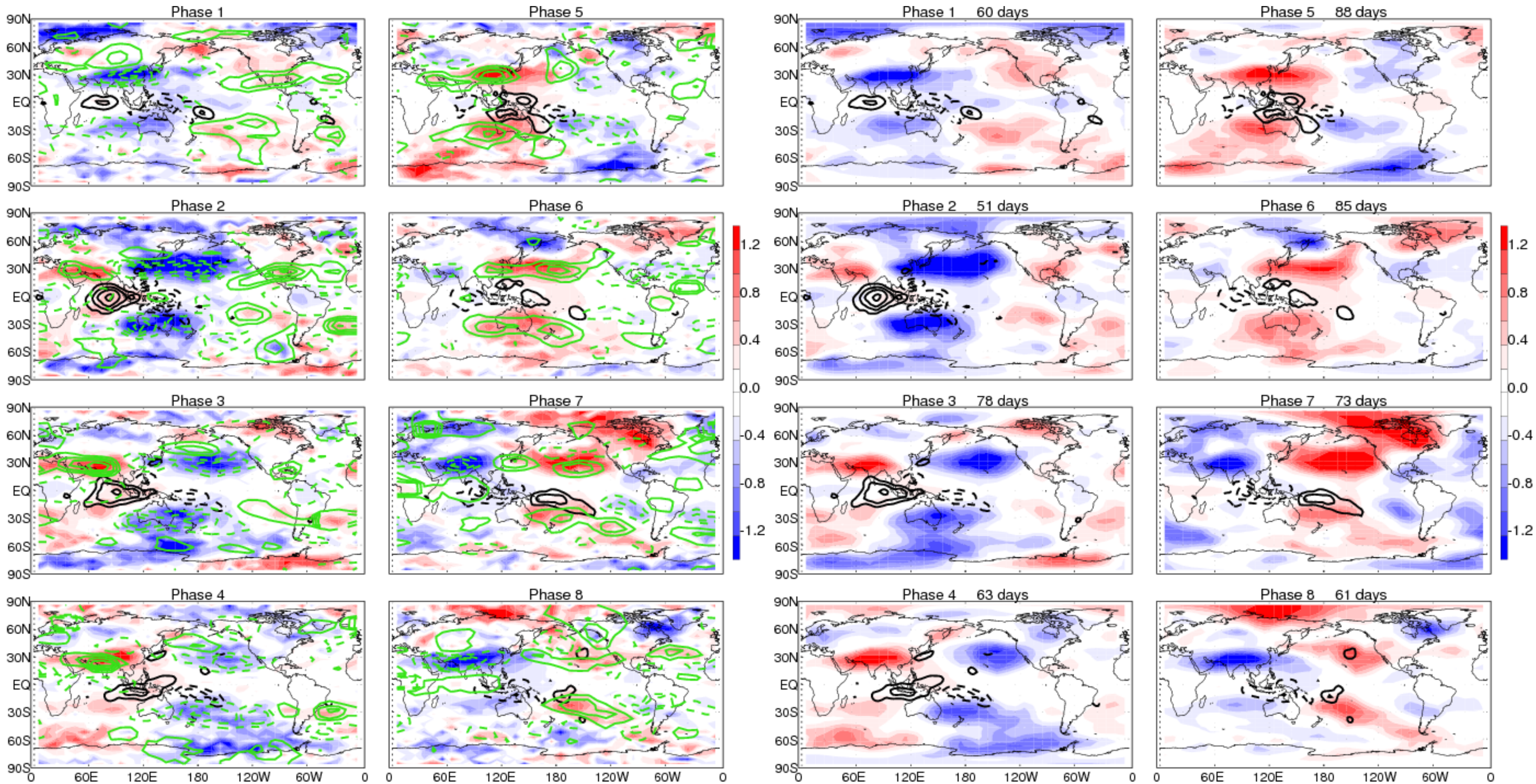




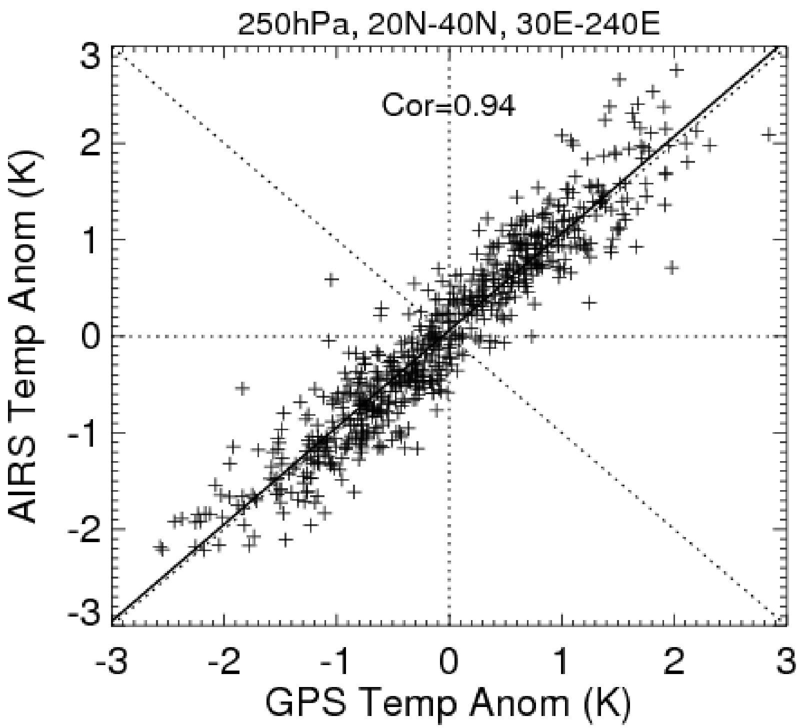

# Northern Subtropics (20N – 40N)

# Comparison between GPS and AIRS

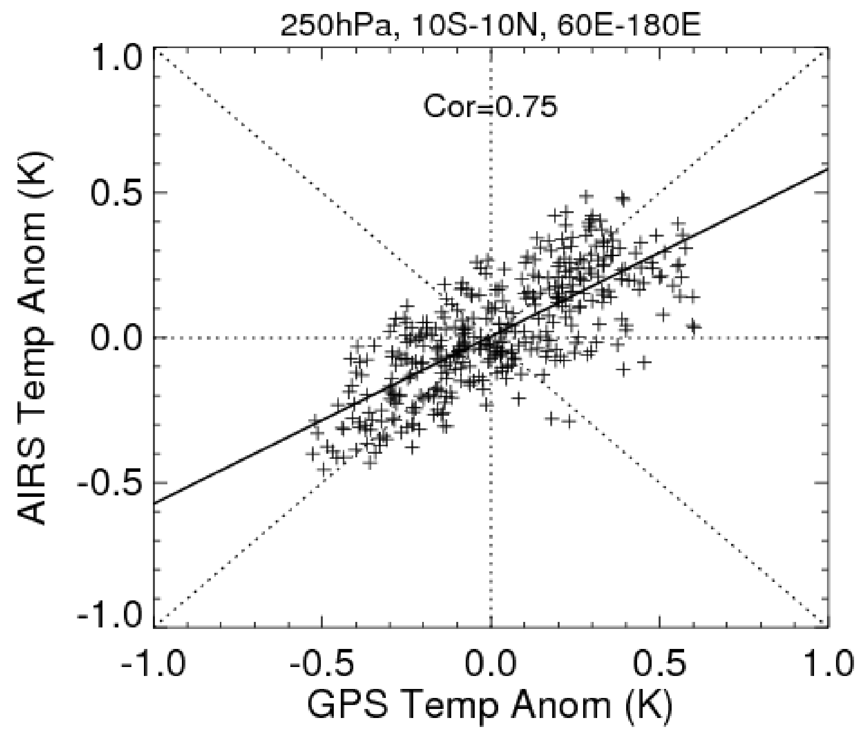
GPS AIRS 250hPa



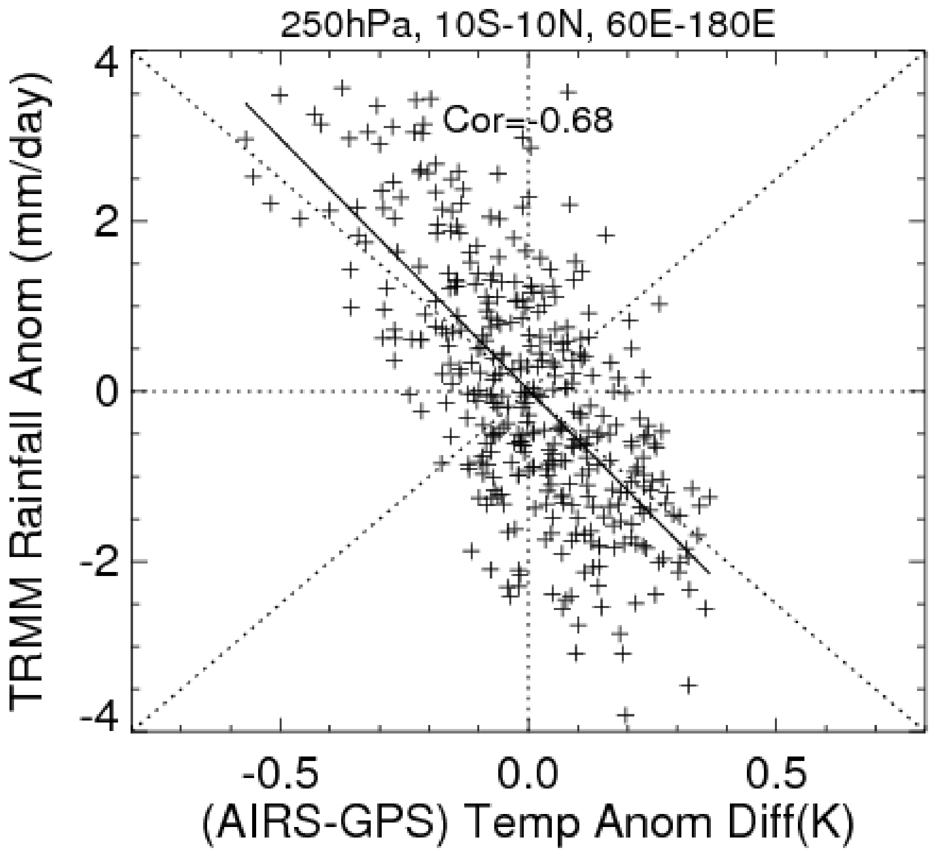
# 250hPa

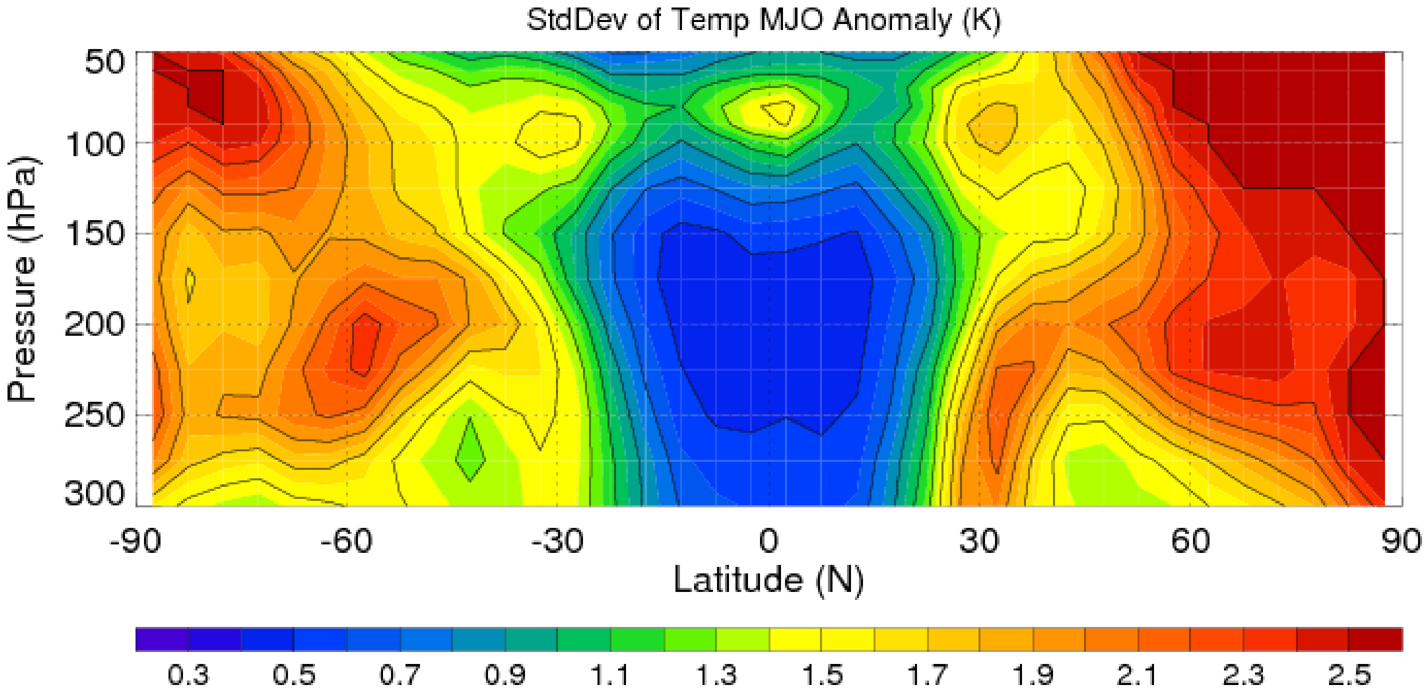


250hPa, 20N-40N, 30E-240E
Cor=0.94
AIRS Temp Anom (K)
GPS Temp Anom (K)
3
2
1
0
-1
-2
-3

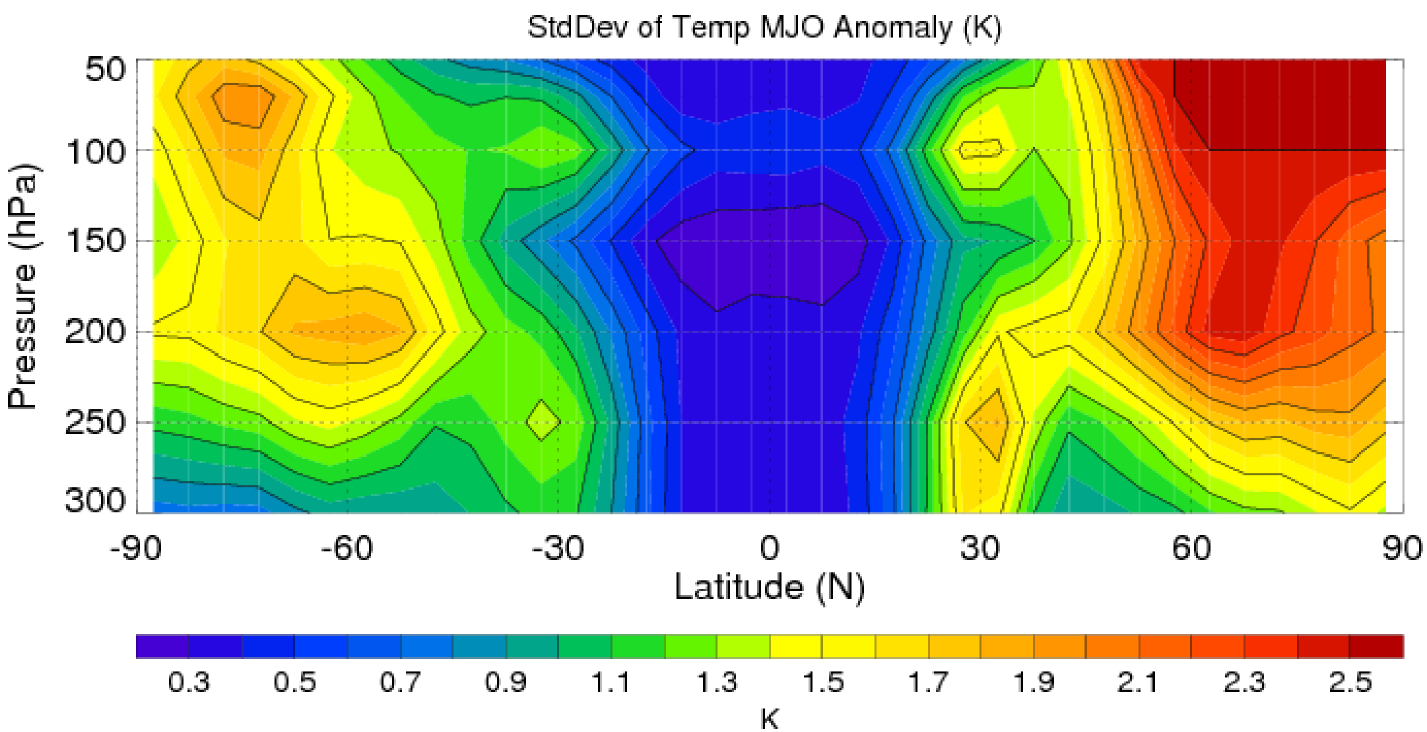



250hPa, 10S-10N, 60E-180E
Cor=0.75
AIRS Temp Anom (K)
GPS Temp Anom (K)
1.0
0.5
0.0
-0.5
-1.0


250hPa, 10S-10N, 60E-180E
Cor=-0.68
TRMM Rainfall Anom (mm/day)
4
2
0
-2
-4
-0.5
0.0
0.5
(AIRS-GPS) Temp Anom Diff(K)

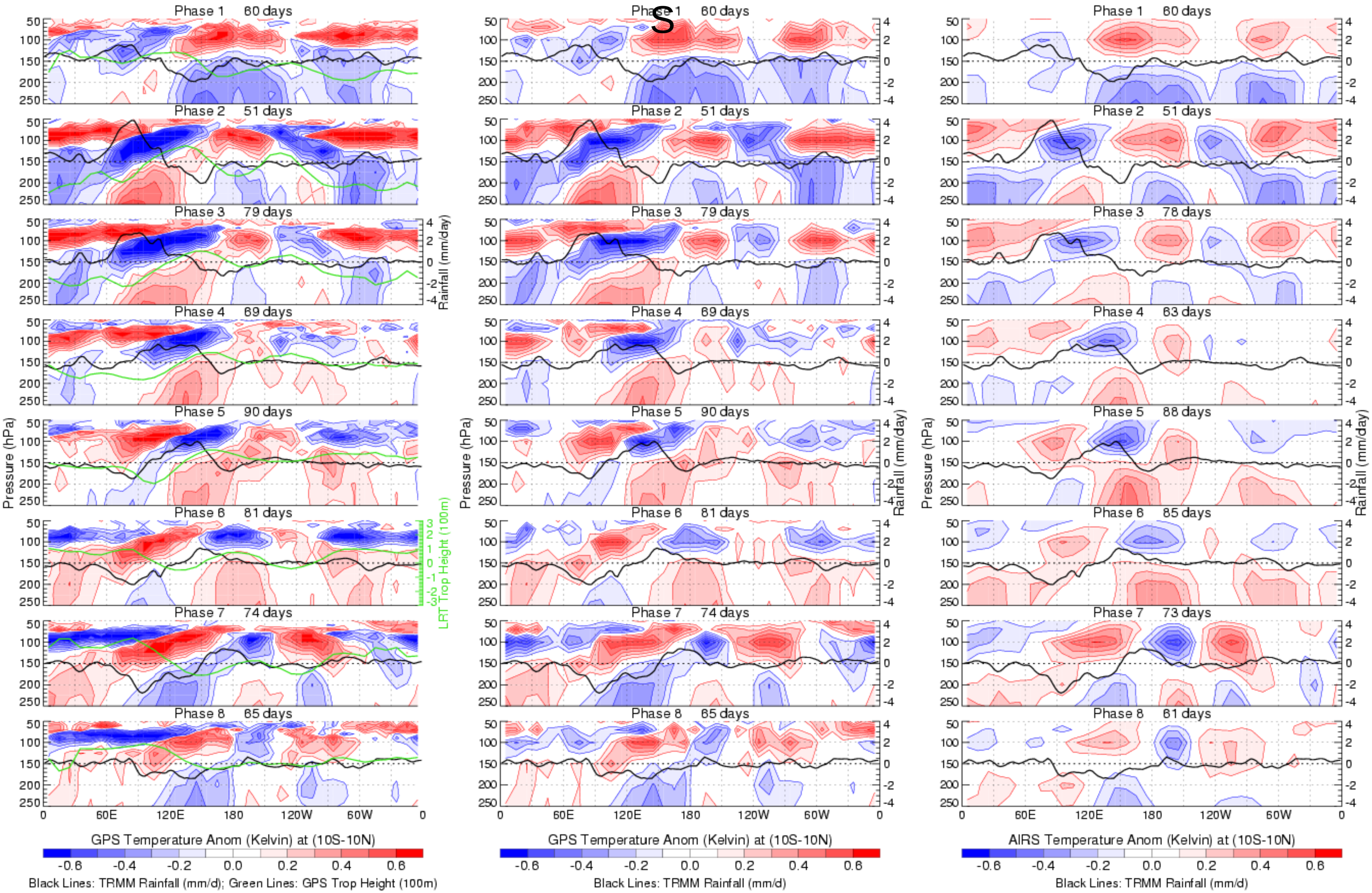

StdDev of Temp MJO Anomaly (K)
Pressure (hPa)
50
100
150
200
250
300
-90
-60
-30
0
30
60
90
Latitude (N)
0.3
0.5
0.7
0.9
1.1
1.3
1.5
1.7
1.9
2.1
2.3
2.5

GPS


StdDev of Temp MJO Anomaly (K)
Pressure (hPa)
50
100
150
200
250
300
-90
-60
-30
0
30
60
90
Latitude (N)
0.3
0.5
0.7
0.9
1.1
1.3
1.5
1.7
1.9
2.1
2.3
2.5
K

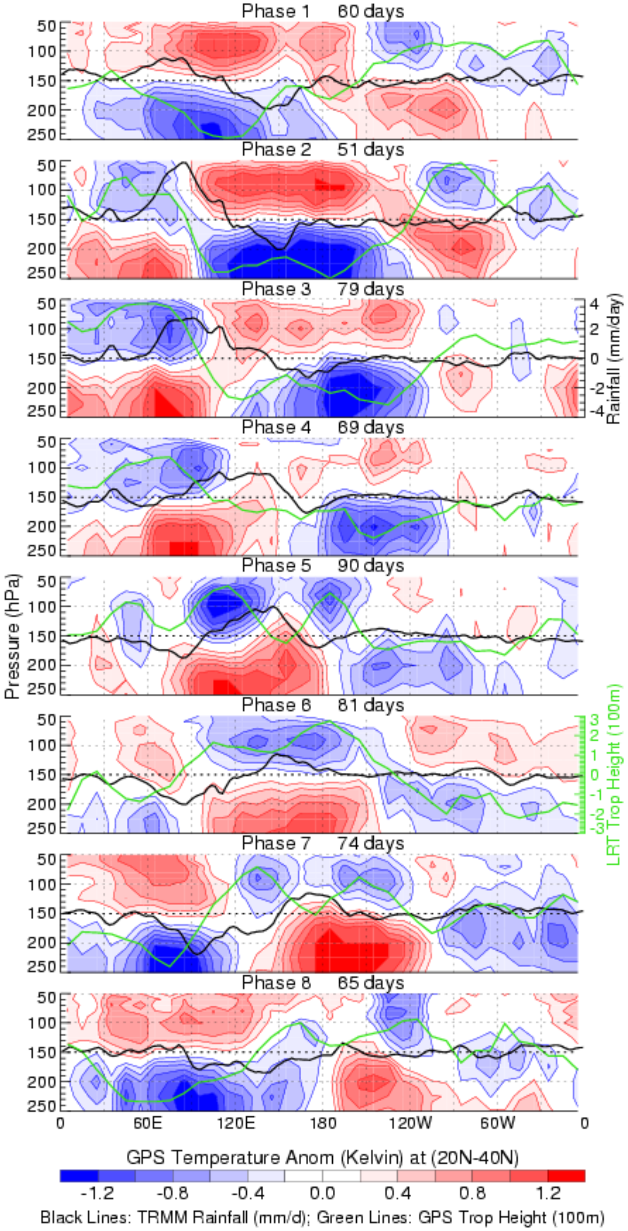
AIRS

GPS GP S EQ (10S-10N) AIRS




14 pressure levels 7 pressure levels 7 pressure levels

GPS

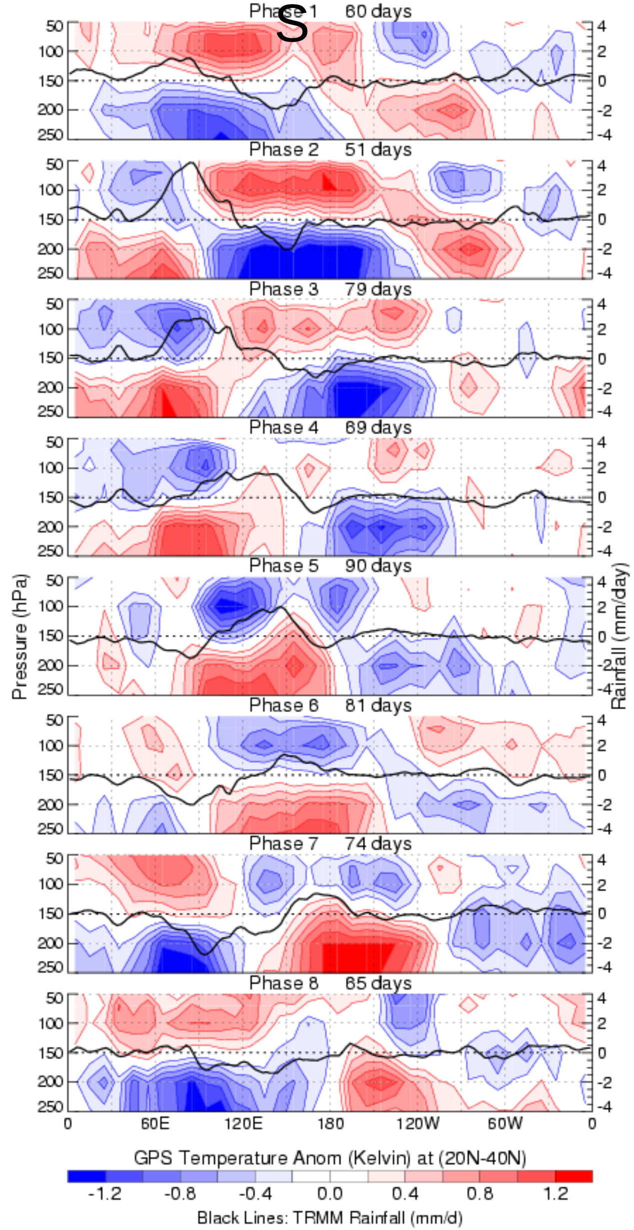



14 pressure levels

GP

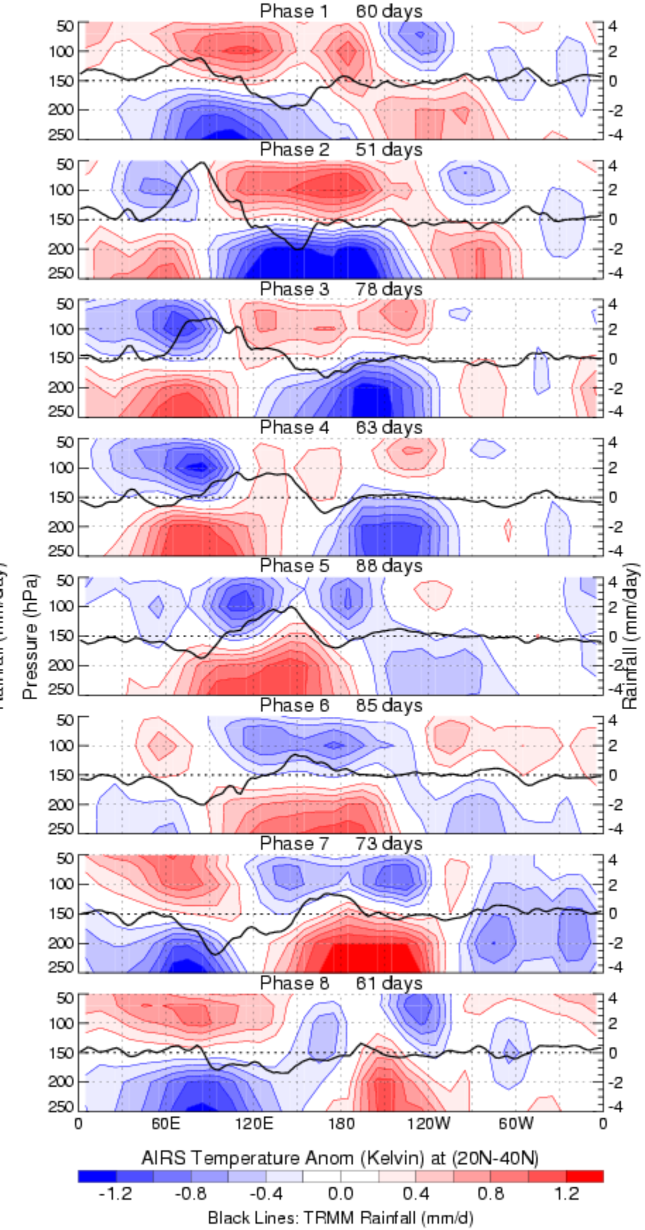
S

ST (20N-40N)




7 pressure levels

AIRS




7 pressure levels

# Summary

- We have studied the intraseasonal temperature variability in the UTLS related to the MJO using the recent GPS RO temperature measurements.

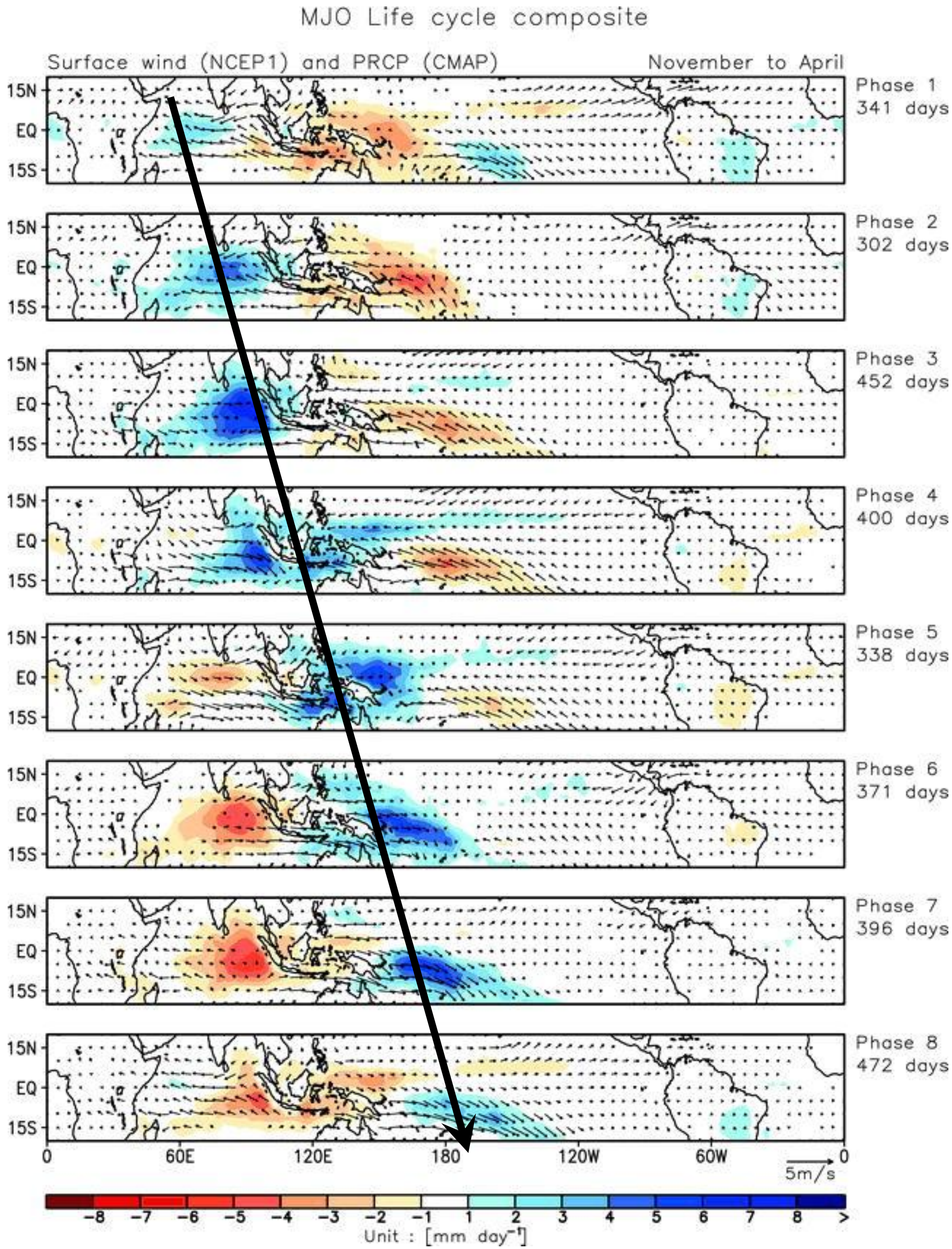
- The MJO-related temperature anomalies in the UTLS are small near the equator (<0.6 K) but large over the subtropics and extratropics (>1.2 K).

- We have also compared the intraseasonal temperature variability in the UTLS between the GPS and AIRS.

- Both AIRS and GPS have a very consistent vertical structure in the subtropical UTLS with a high correlation coefficient 0.92 and similar magnitudes.

- Both AIRS and GPS also show a generally consistent vertical structure of the intraseasonal temperature anomalies in the equatorial UTLS. However, GPS reveals many detailed fine-scale vertical structures of the equatorial temperature anomalies that are not well captured by AIRS. Furthermore, the equatorial temperature anomalies are about 40% underestimated in AIRS in comparison to GPS.

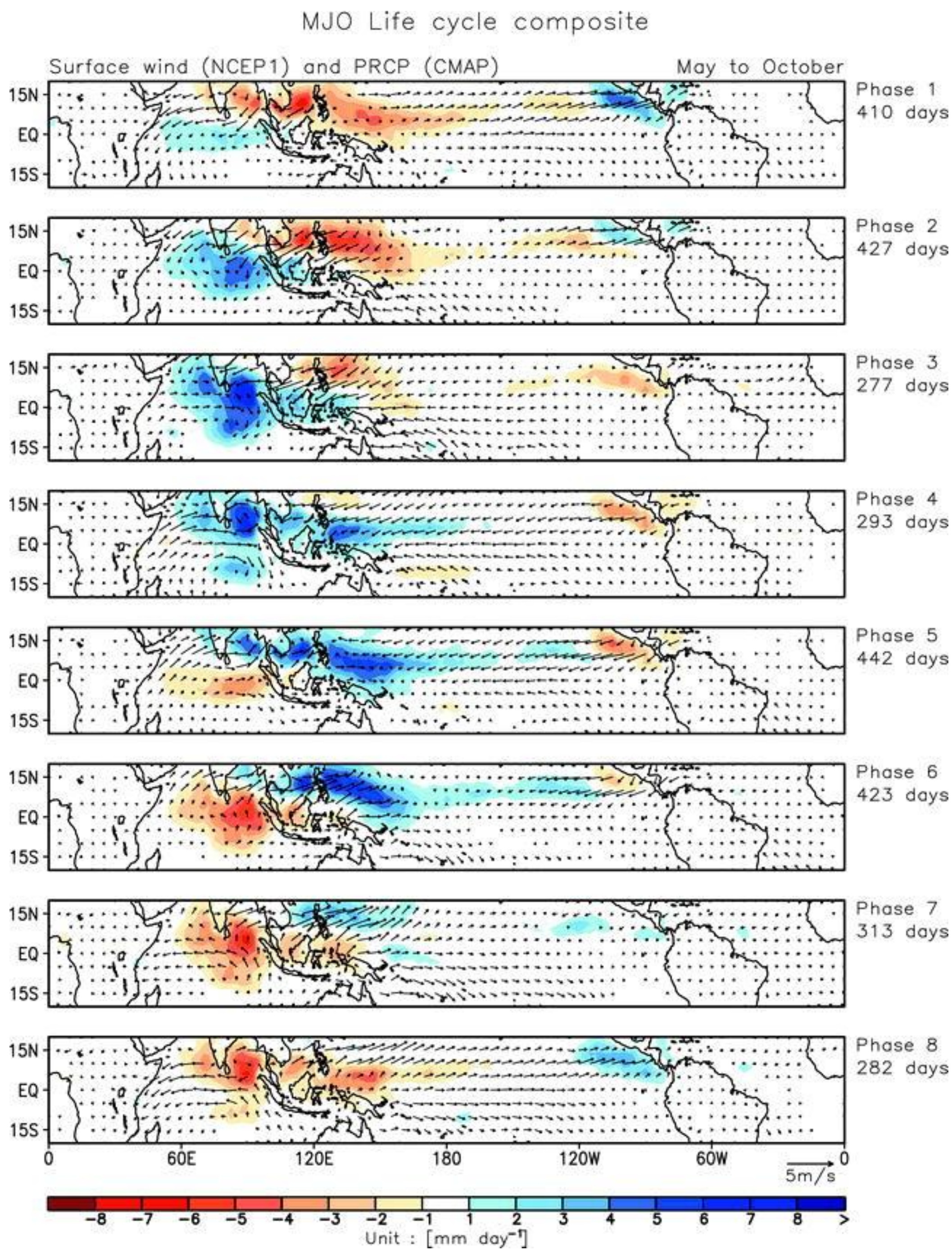
Thank You




# A Composite MJO Cycle in N.H. Winter (Nov-Apr)

- Rainfall (convection) anomalies propagate ***eastward*** and mainly affect the tropical eastern hemisphere.
- Surface wind anomalies also propagate ***eastward*** and can affect the global tropics.

Fig. 12 of *Waliser et al.* [2009]

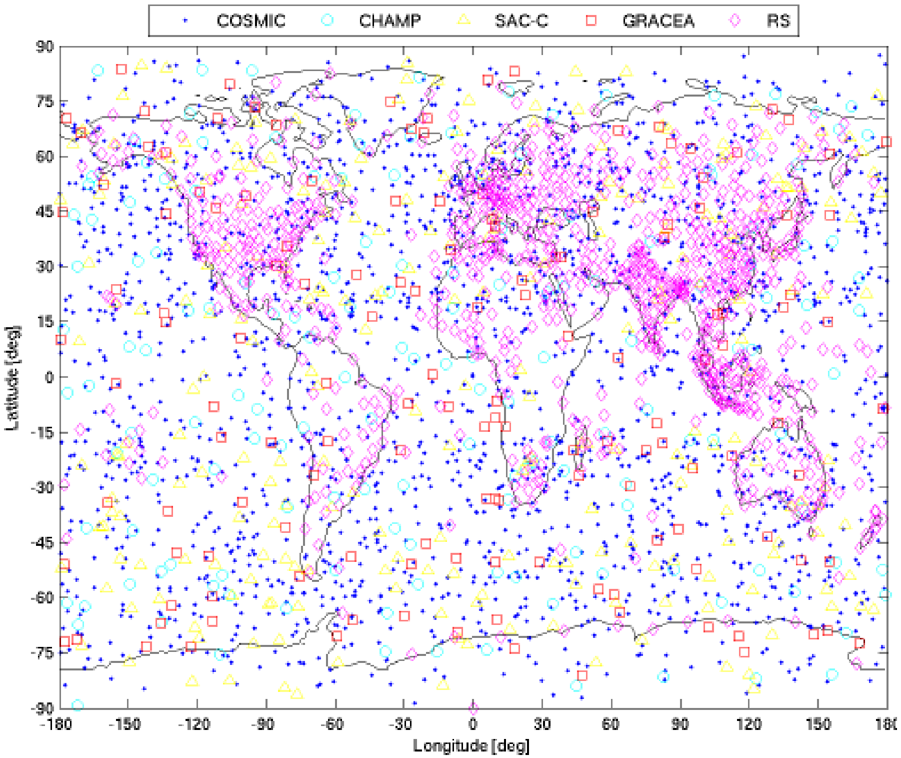


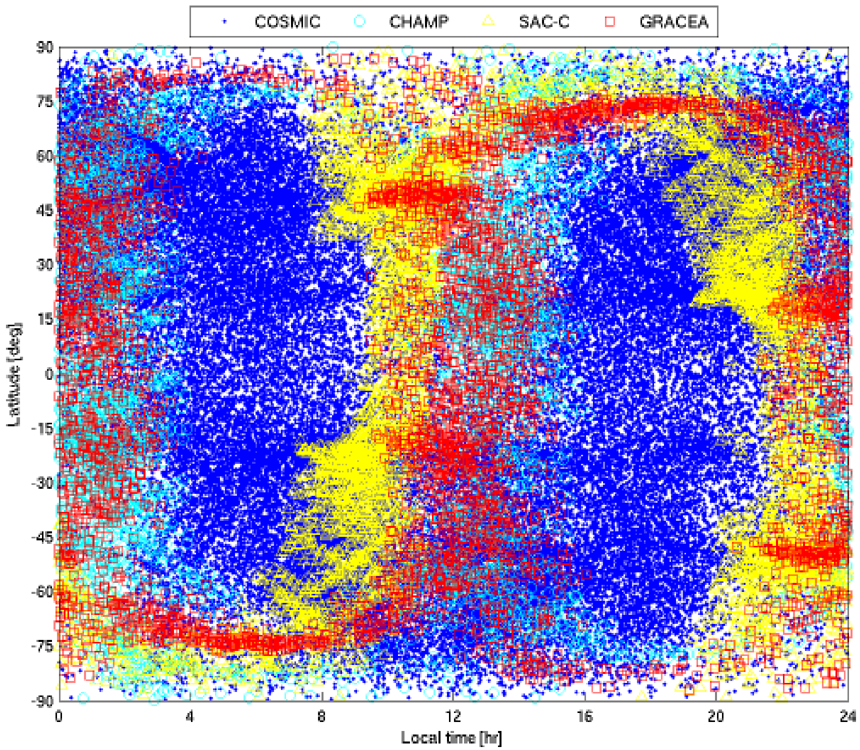

# A Composite MJO Cycle in N.H. Summer (May-Oct)

- Rainfall (convection) anomalies propagate ***northeastward*** and mainly affect the tropical eastern hemisphere.
- Surface wind anomalies can affect the global tropics.

Fig. 11 of *Waliser et al.* [2009]

# Spatial and Diurnal Samplings of GPS RO Measurements



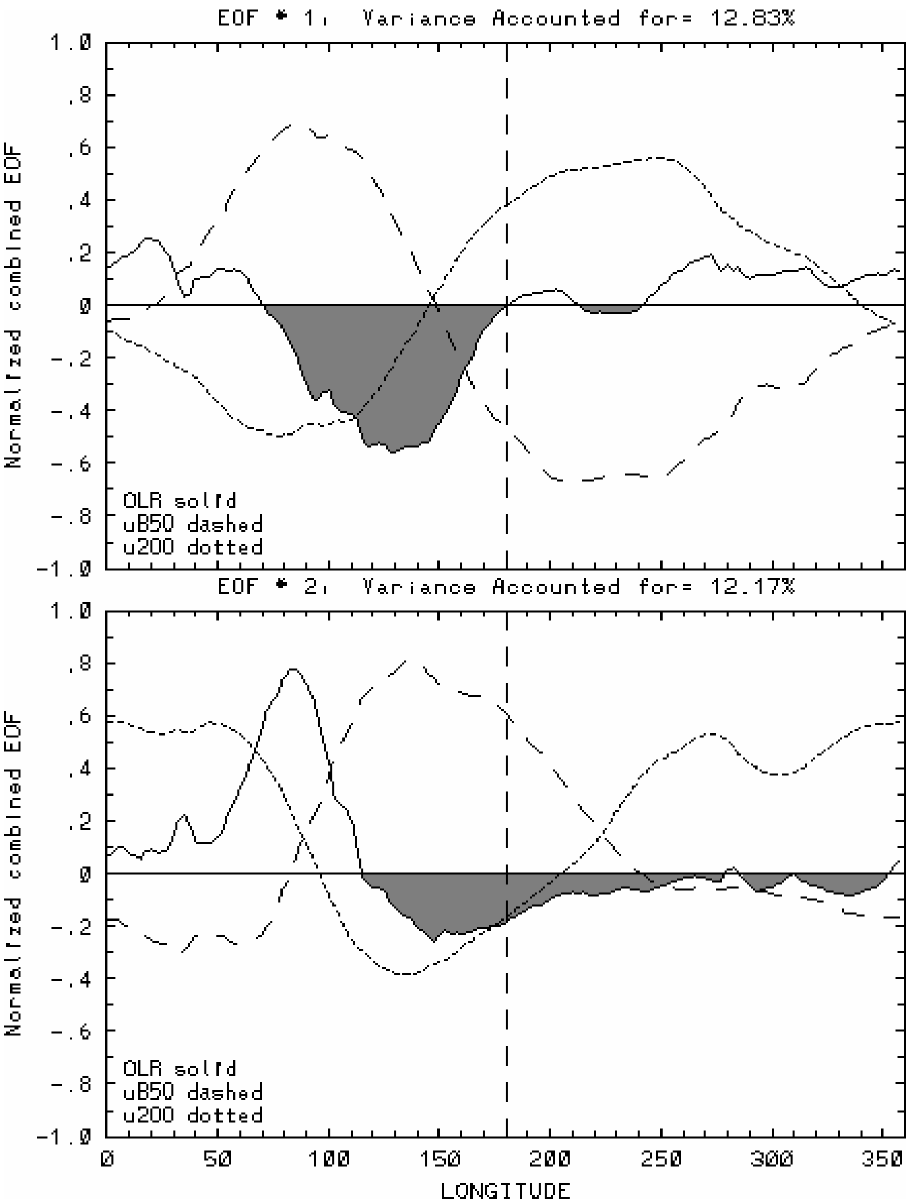

(Left) Spatial sampling from COSMIC and other low-earth orbiters with GPS RO receivers in a typical day.

(Right) Local time sampling in a typical month showing coverage of the full diurnal cycle.

# The RMM Index

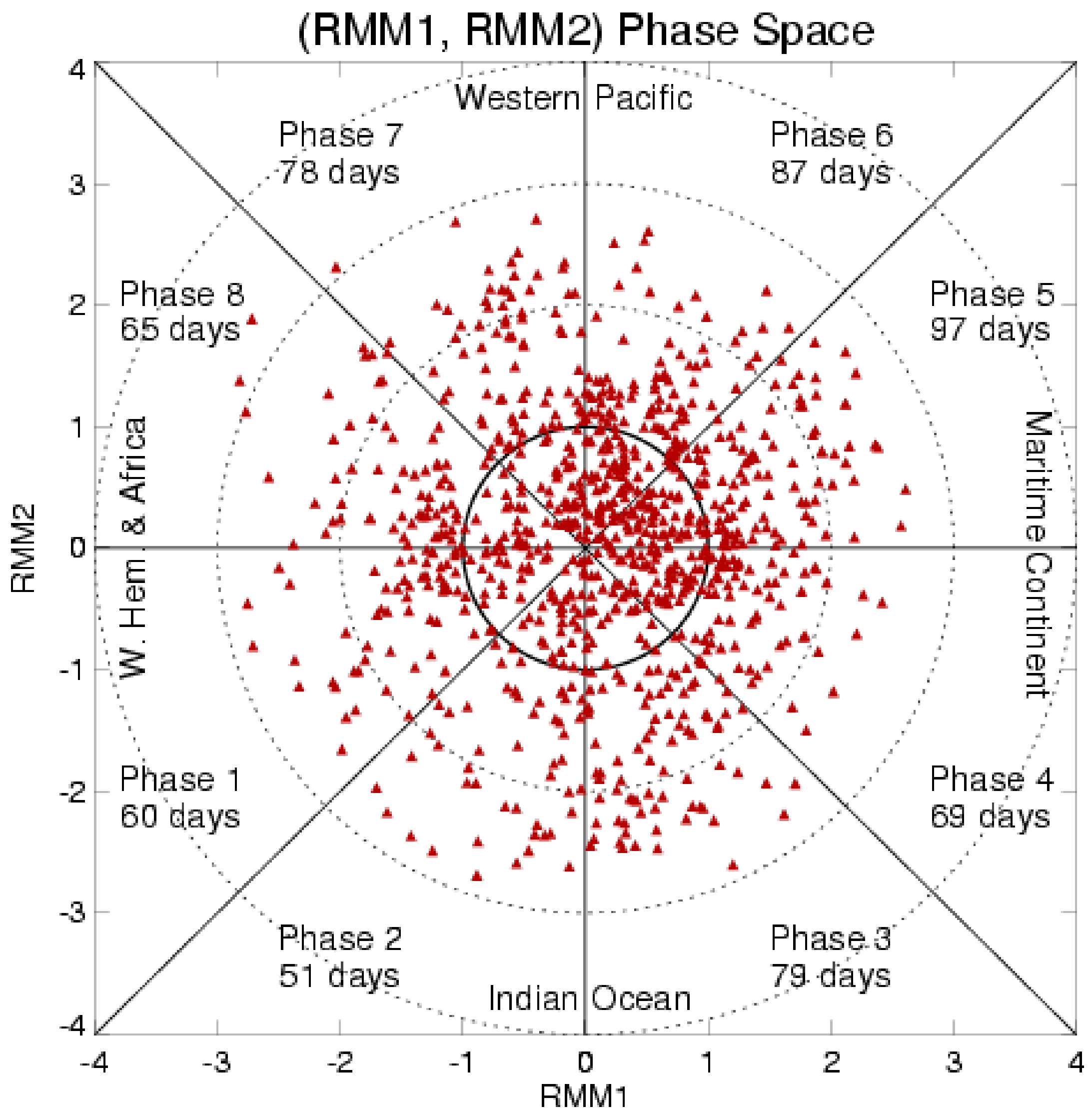
The Real-time Multivariate MJO (RMM) index is the projection of the daily observed NOAA outgoing longwave radiation (OLR) and NCEP/NCAR reanalysis and/or Australian Bureau of Meteorology Research Center Global Analysis and Prediction (GASP) analysis 850- and 200-hPa zonal winds, with the annual cycle and components of interannual variability removed, on a pair of multiple-variable empirical orthogonal functions (EOFs). Two such EOFs are the leading pair of EOFs of the combined daily intraseasonal filtered fields of near-equatorially averaged (15° S-15° N) NOAA OLR and NCEP/NCAR 850- and 200-hPa zonal winds for all seasons from 1979 to 2001 (23 years).

# Spatial Structures of EOF 1 & 2

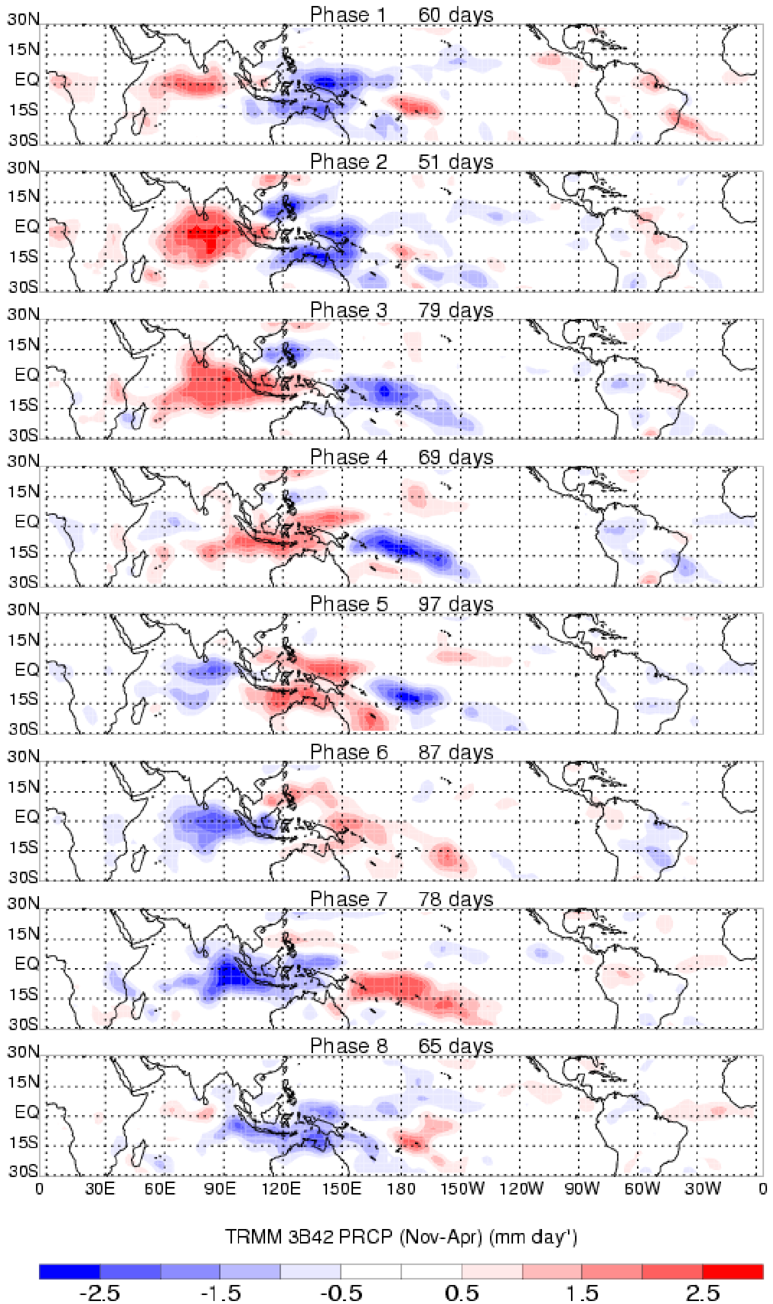


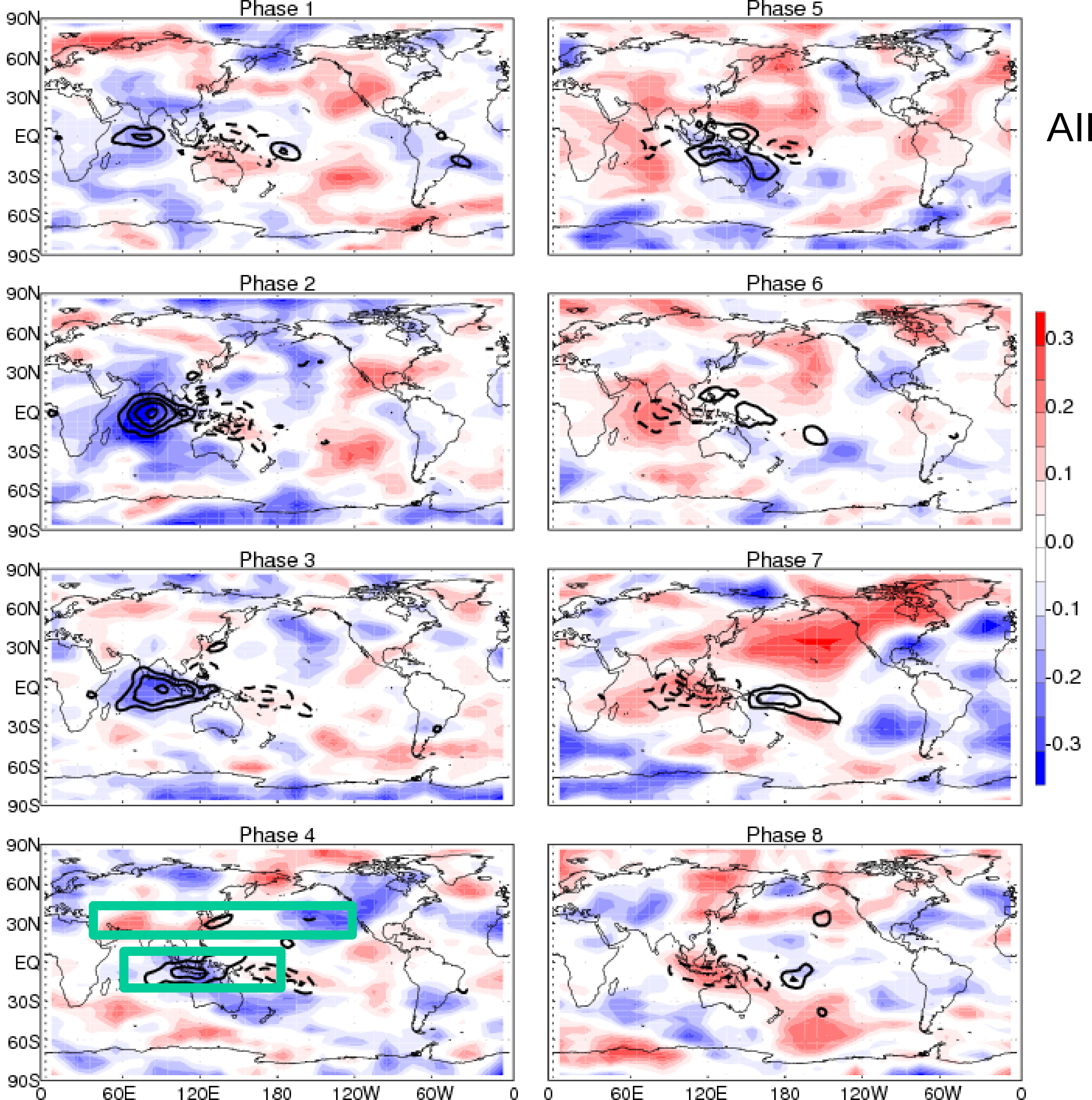

EOF1 describes the situation when the MJO produces enhanced convection (negative OLR anomalies) at the Maritime Continent (MC): low-level westerly wind anomalies extend through-out the Indian Ocean (IO) and MC, and low-level easterlies exist across the Pacific, while upper-level wind anomalies are in the opposite direction to those below. EOF2 has enhanced convection over the Pacific Ocean and wind patterns that are in close quadrature to those of EOF1. Together, they describe the key features of the MJO, such as eastward propagation of convection anomalies in the Eastern Hemisphere; out-of-phase relationship between lower and upper-tropospheric wind anomalies; the predominance of lower-tropospheric westerly anomalies near and to the west of enhanced convection.

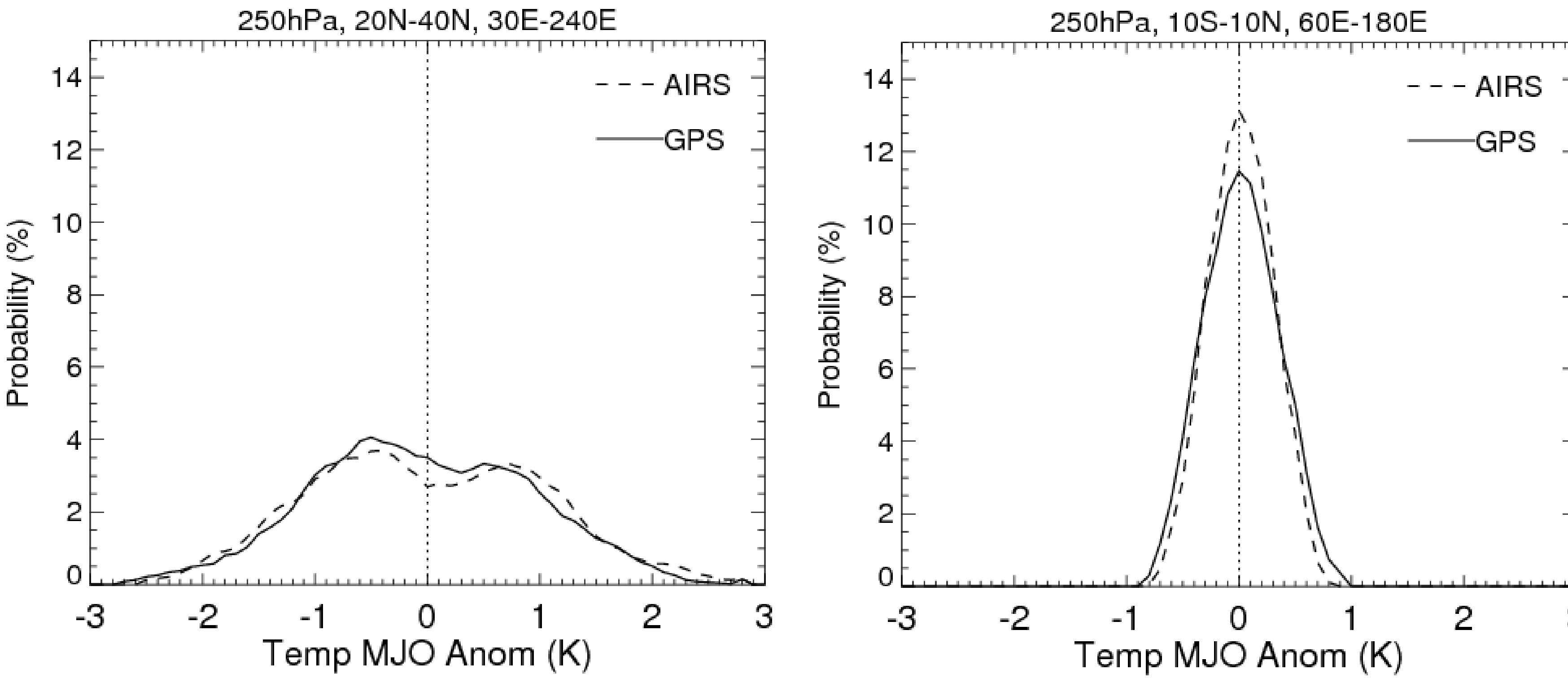
# MJO Phase Space from 1/1/2006 to 12/31/2010



# Composite TRMM Rainfall Anomalies




250hPa
AIRS–GPS
Phase 1
Phase 2
Phase 3
Phase 4
Phase 5
Phase 6
Phase 7
Phase 8
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3


250hPa, 20N-40N, 30E-240E
AIRS
GPS
Probability (%)
Temp MJO Anom (K)
250hPa, 10S-10N, 60E-180E
AIRS
GPS
Probability (%)
Temp MJO Anom (K)