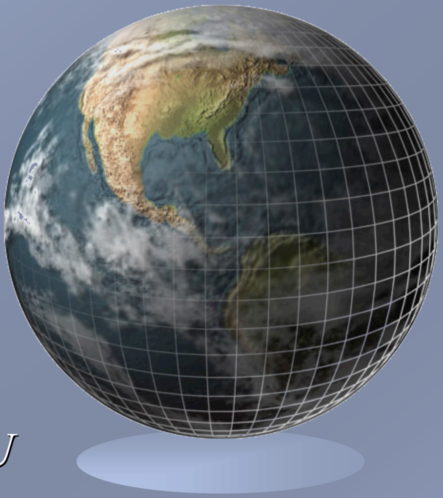
FROM CLOUD-ICE TO THE MJO: STUDIES AND PLANS FOR ADDRESSING THE TROPICAL CONVECTION PROBLEM

Duane Waliser/JPL
Frank Li/JPL
Baijun Tian/JPL
Steven Chan/JPL

AIRS. Fetzer/JPL
MLS/J. Jiang/JPL
GPS/C. Ao/JPL
CloudSat/D. Vane/JPL
CloudSat/G. Stephens/CSU

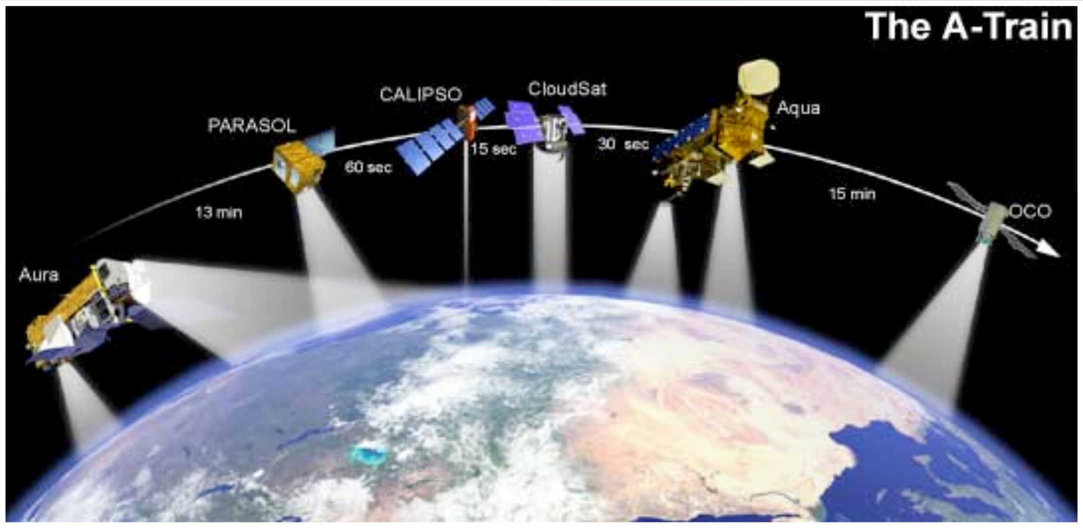
A. Tompkins/ECMWF
M. Kharitondov/CSU, Chern,Tao/GSFC,
Donner/GFDL, Bacmeister/GSFC, DelGenio/GISS



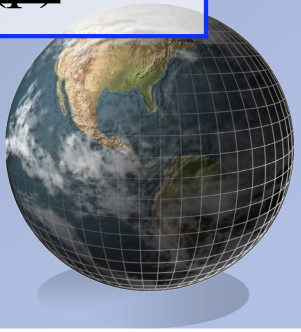
- *Emerging Data Sets for Characterizing Tropical Convection and the MJO*
- *US CLIVAR MJO Working Group*
- *Year of Tropical Convection*

2nd CMMAP Team
Meeting, Kuai, Hawaii,
February 20-22, 2007

Emerging Satellite Datasets for Characterizing Tropical Convection



- AIRS - High Quality Tropospheric Sounder => T(p), q(p)
- GPS - High Vertical Res. T or q Soundings => BL Height
- MLS - Upper Trop. Sounder => T(p), q(p), Cloud Ice (p)
  CloudSat - Cloud Radar => Cloud Ice (p)



Atmospheric InfraRed Sounder (AIRS)

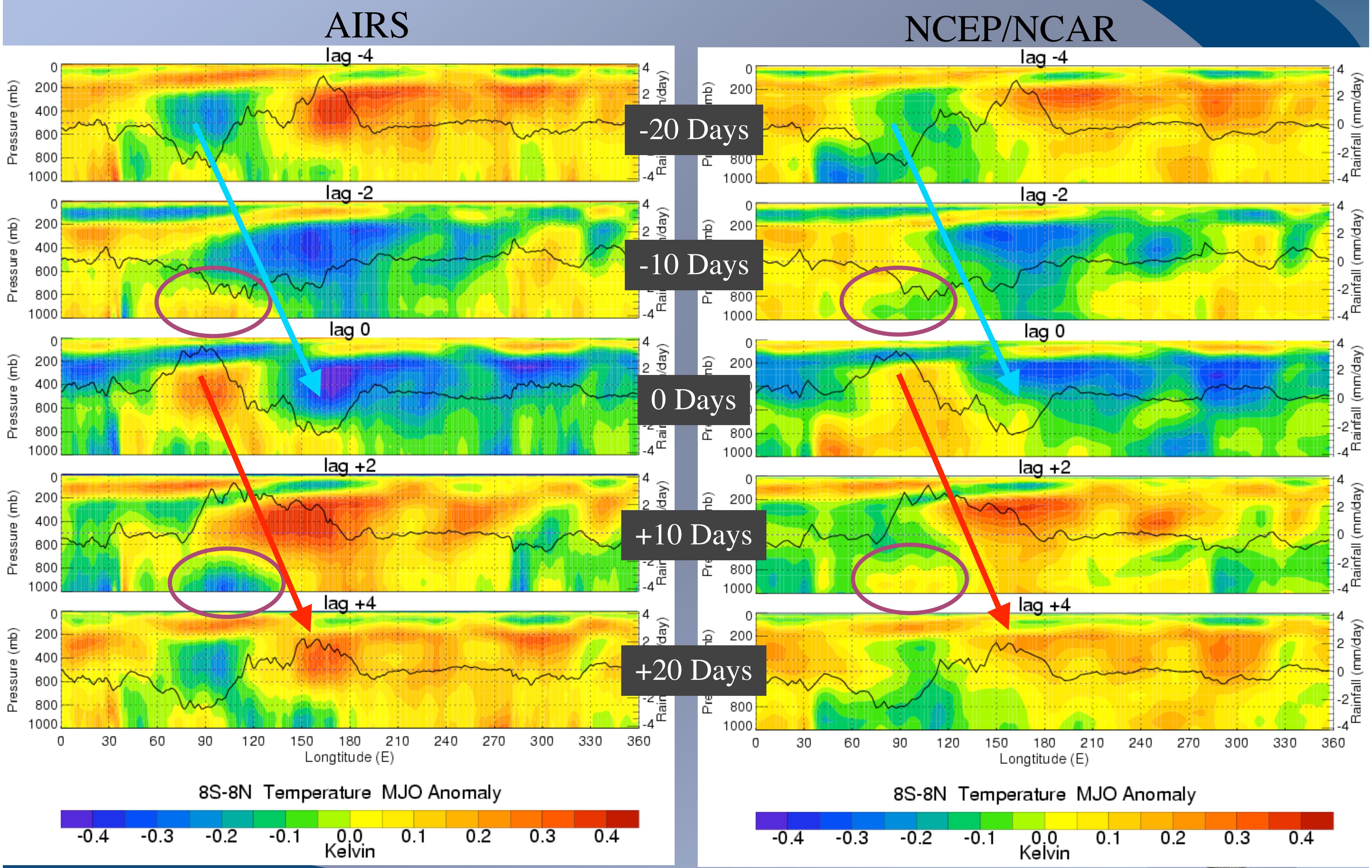
Characterization of the MJO

Tian et al. 2006

- AIRS is a temperature and humidity sounder on the Aqua EOS satellite flying within the A-Train satellite constellation.
- AIRS provides twice daily coverage with xy-resolution of ~45km and z-resolution of ~1-2km with T *(q)* data extending from the surface into the stratosphere *(to about ~200 hPa)*. 2378+ channels.
- Retrievals in areas up to 70% cloudy. Systematic biases over land due to emissivity challenges.
- The AIRS record now extends from Sept 2002, ~4.5 years.

Pressure-Longitude Diagrams of Temperature Anomaly Along Equator for the MJO

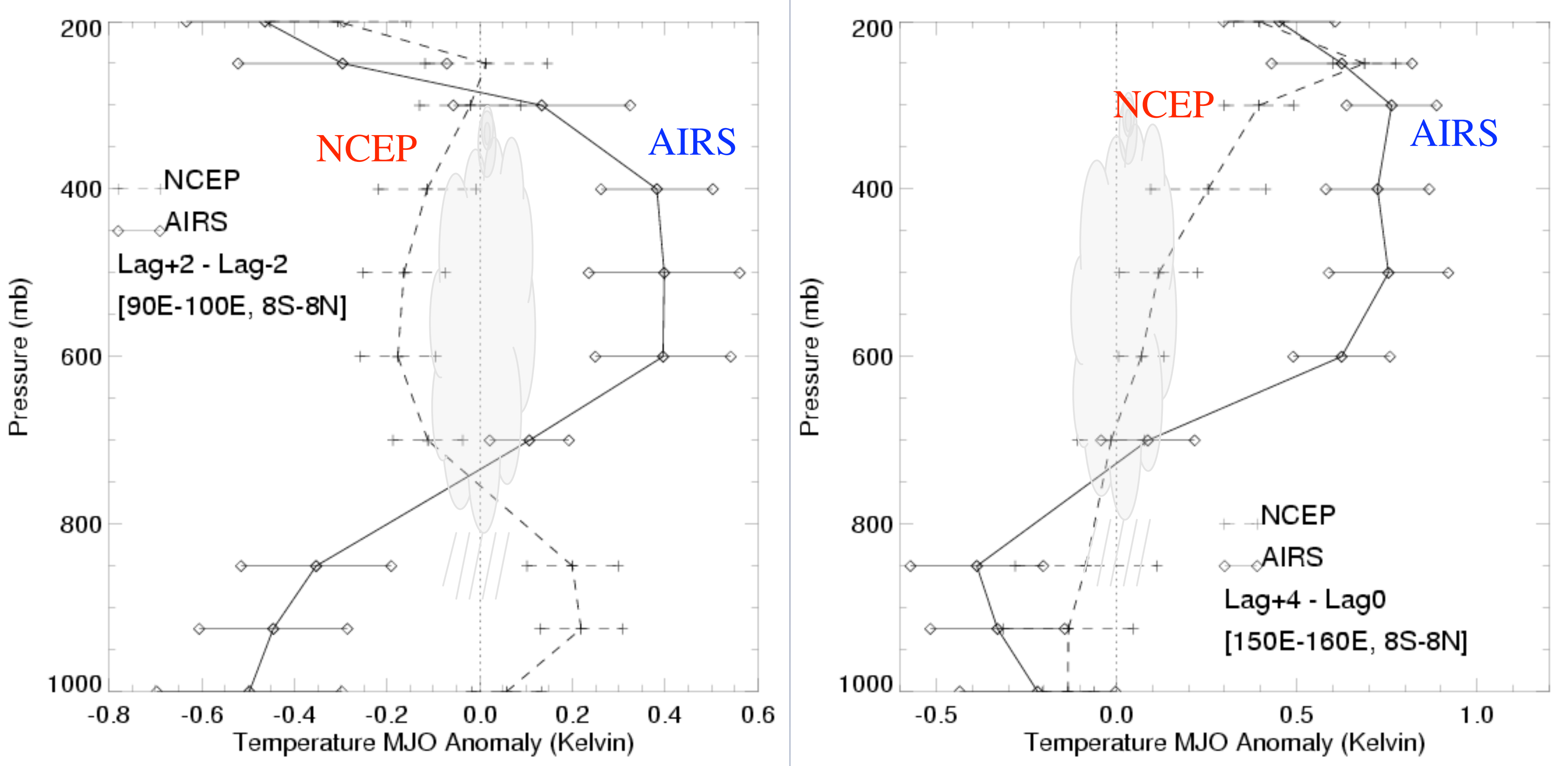
TRMM Rainfall Anomaly Shown as Line Plot (right axis); Panels Separated by 10 Days



Vertical Profiles of Temperature Anomaly In the Indian & W.Pacific Ocean for the MJO

Indian Ocean

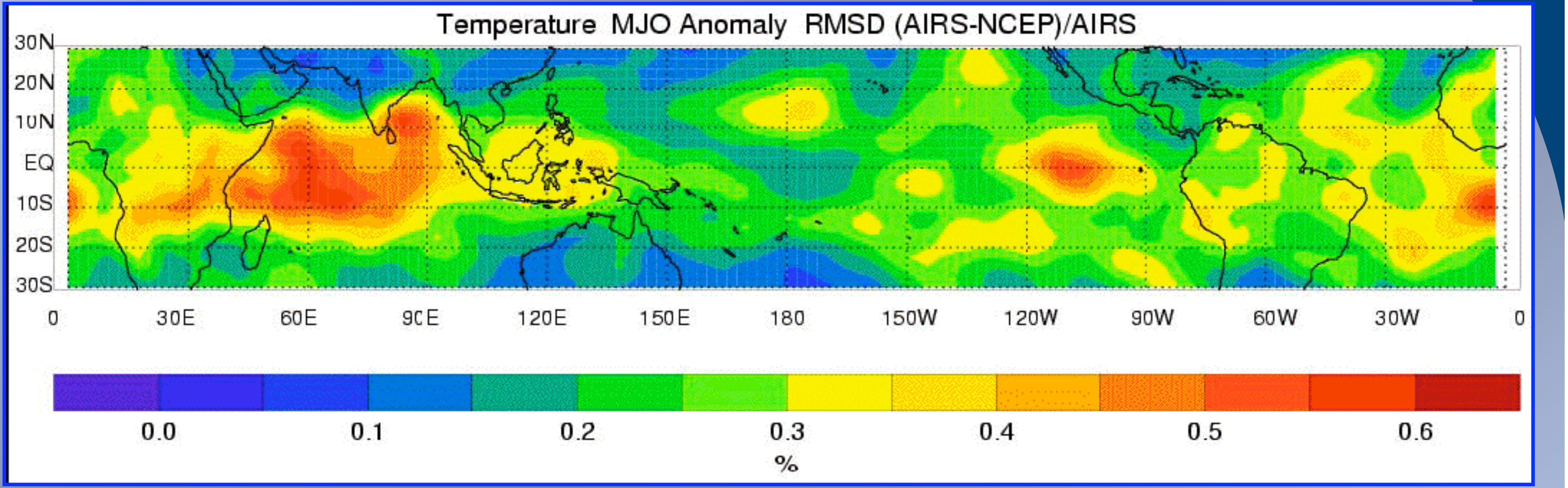
Western Pacific Ocean



The plot on the left shows the profiles over the Indian Ocean for Lag + 2 pentads (*disturbed*) minus Lag -2 pentads (*suppressed*). The plot on the right shows the profiles over the western Pacific Ocean for Lag +4 pentads (*disturbed*) - Lag 0 pentads (*suppressed*).

RMS DIFFERENCE BETWEEN AIRS & NCEP FOR MJO

AVERAGED OVER 200-1000 HPA

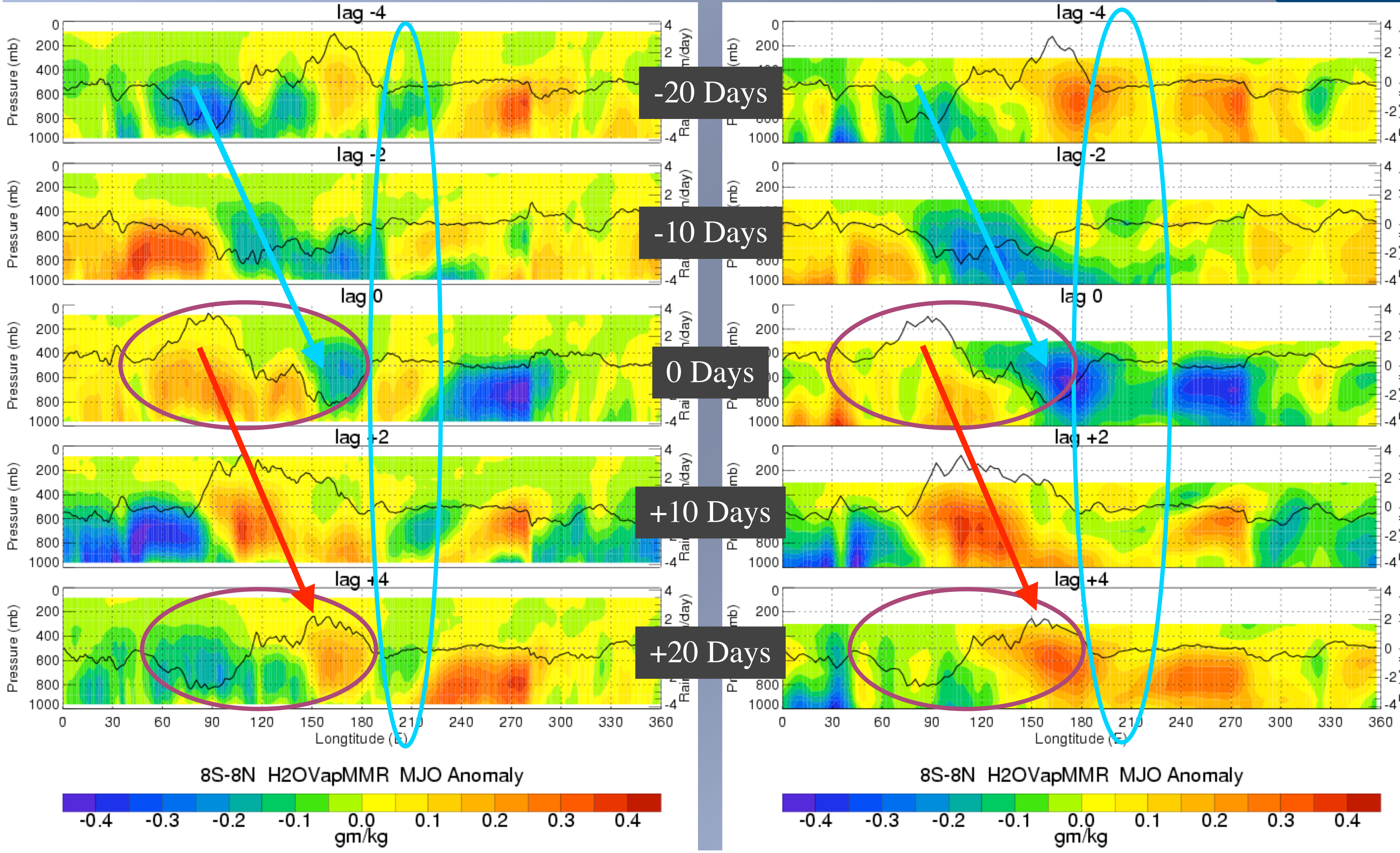


Pressure-Longitude Diagrams of Water Vapor Anomaly Along Equator for the MJO

TRMM Rainfall Anomaly Shown as Line Plot (right axis); Panels Separated by 10 Days

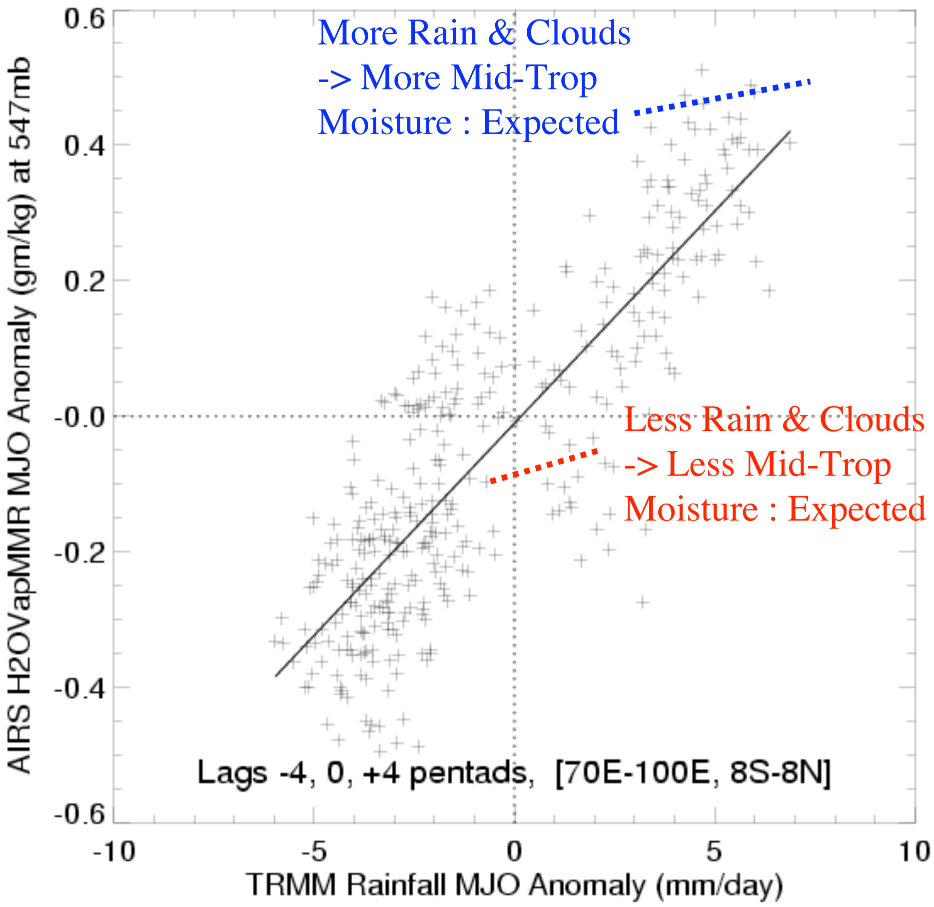
AIRS

NCEP/NCAR



Relation Between TRMM Rainfall and Mid-Troposphere Water Vapor Anomalies In the Indian Ocean for the MJO

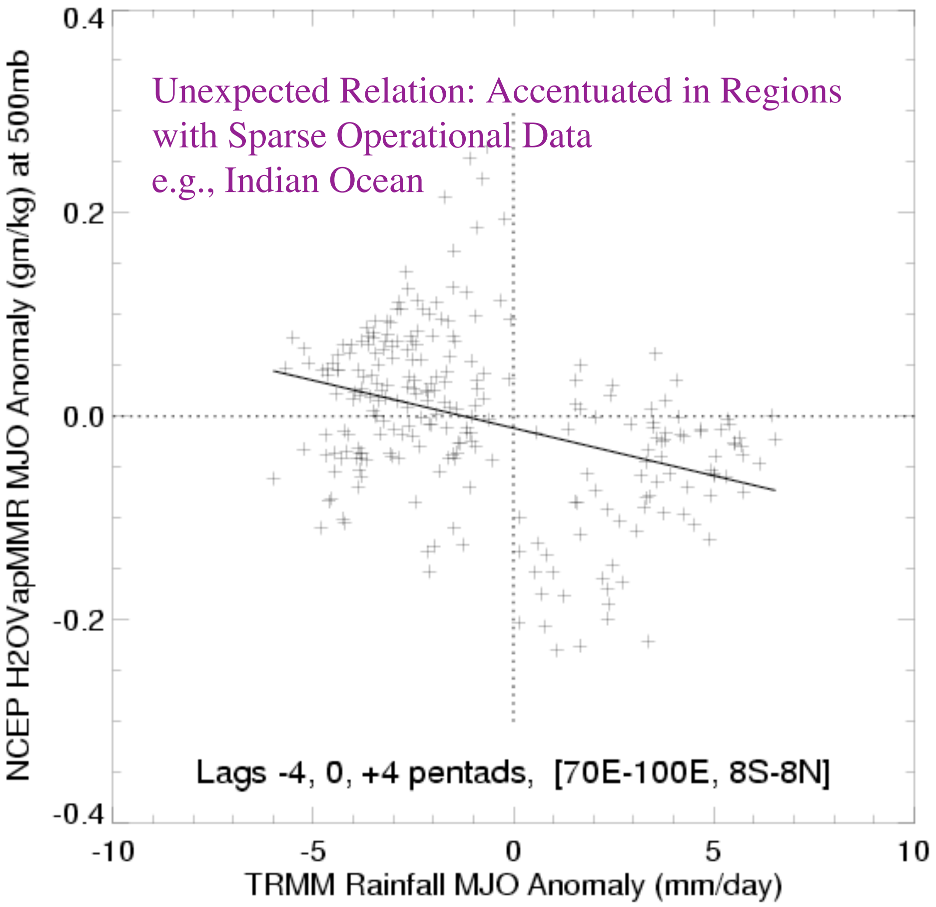
AIRS



More Rain & Clouds
-> More Mid-Trop
Moisture : Expected

Less Rain & Clouds
-> Less Mid-Trop
Moisture : Expected

NCEP/NCAR



Unexpected Relation: Accentuated in Regions
with Sparse Operational Data
e.g., Indian Ocean

The data points plotted are based on a combination of the strongly disturbed (Lag 0 pentads) and strongly suppressed (Lag -4 & +4 pentads) phases of the MJO *(i.e. data from Lags -2 & +2 pentads are not included)*.

GPS Occultation Profiles

- Active limb sounding, self-calibrating, with sub-km vertical resolution.
- Not affected by clouds or precipitation.
- ~ 250 soundings per day per antenna per LEO
- GPS/MET (1995-1997), CHAMP & SAC-C (2001-present), GRACE (2006-), COSMIC (2006-) [6 s/c constellation], METOP (2006?)

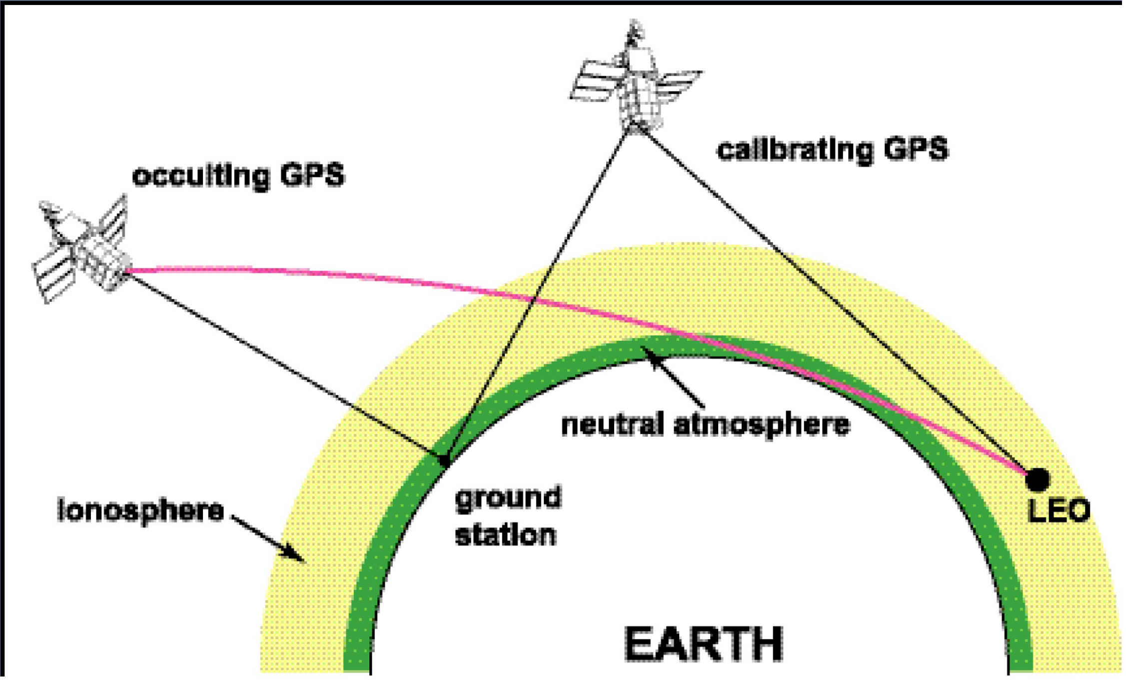
- Accuracy:

  T < 1 K at 8-25 km

  q < 0.2-0.5 g/kg above ~ 2 km

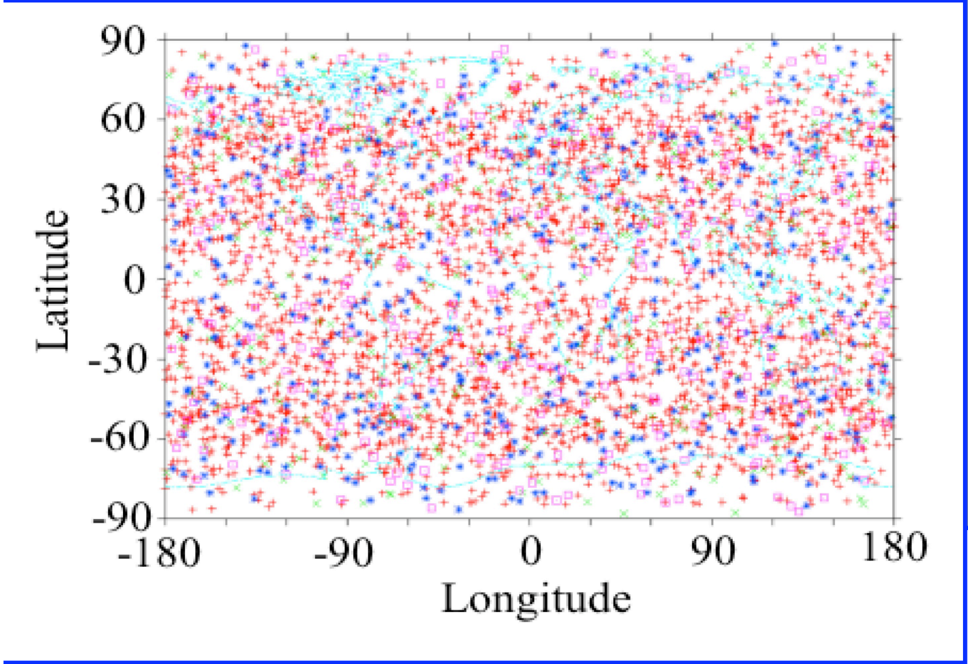
  < 1 g/kg below ~ 2 km
- Resolution:

  200 m vertical, 300 km horiz



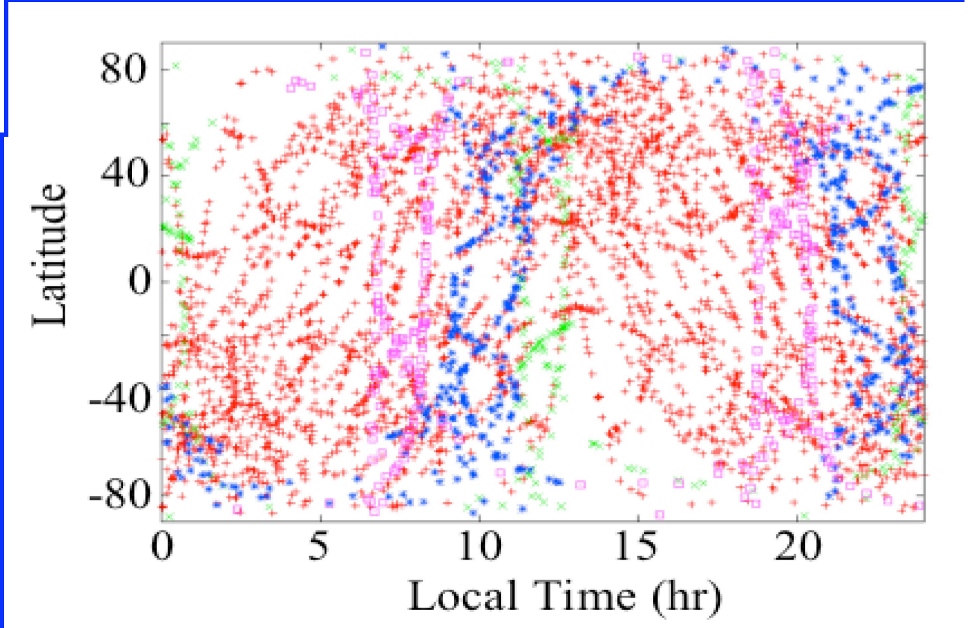
GPS Occultation Profiles

Spatial/Temporal Coverage (~3500/day)



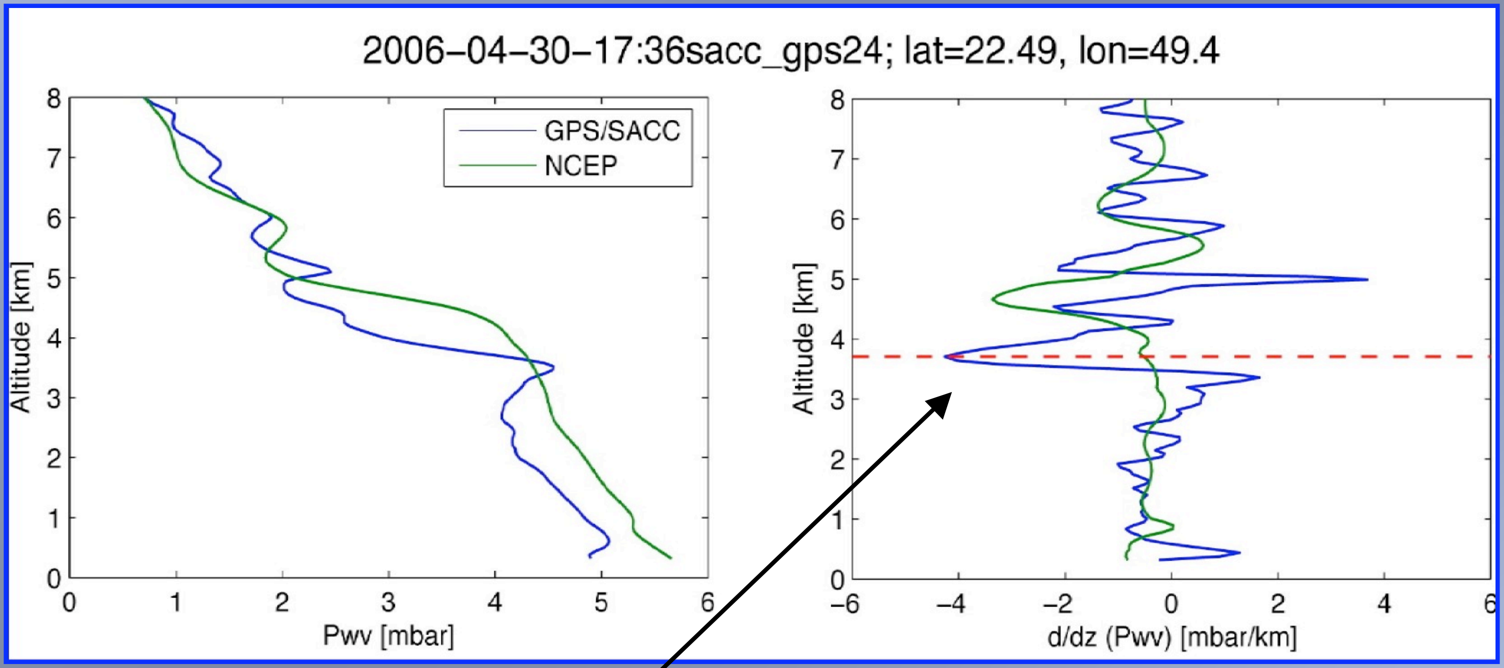
Daily coverage of
CHAMP (green) 2001-
SAC/C (blue) 2001-
GRACE (purple) 2006-
COSMIC (red) 2006-

Diurnal Coverage



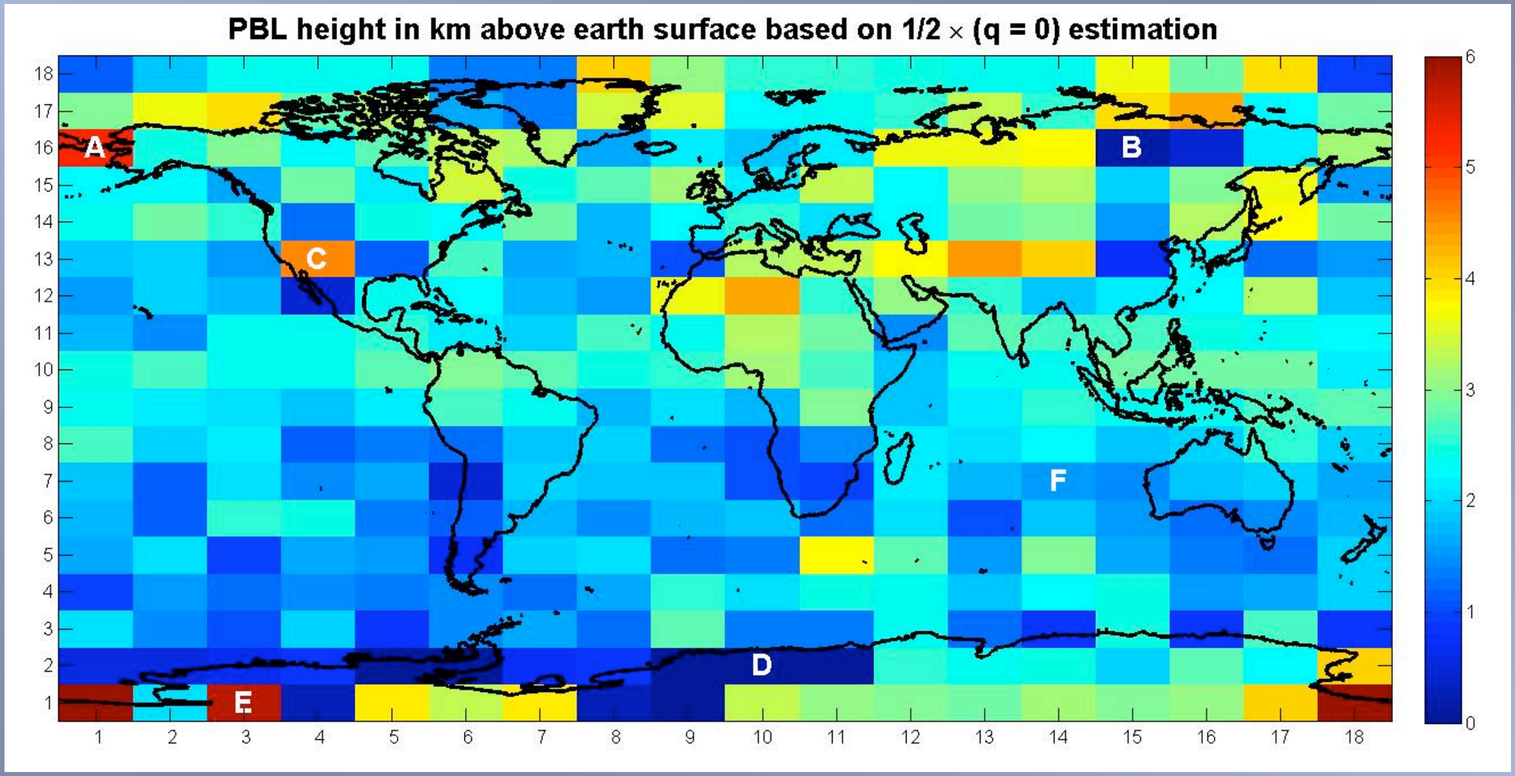
GPS OCCULTATION WATER VAPOR - PROFILES

EXAMPLE: GPS VS NCEP



Use Max Vertical Gradient To Derive Boundary Layer Depth

GPS OCCULTATION
WATER VAPOR PROFILES -> BLD

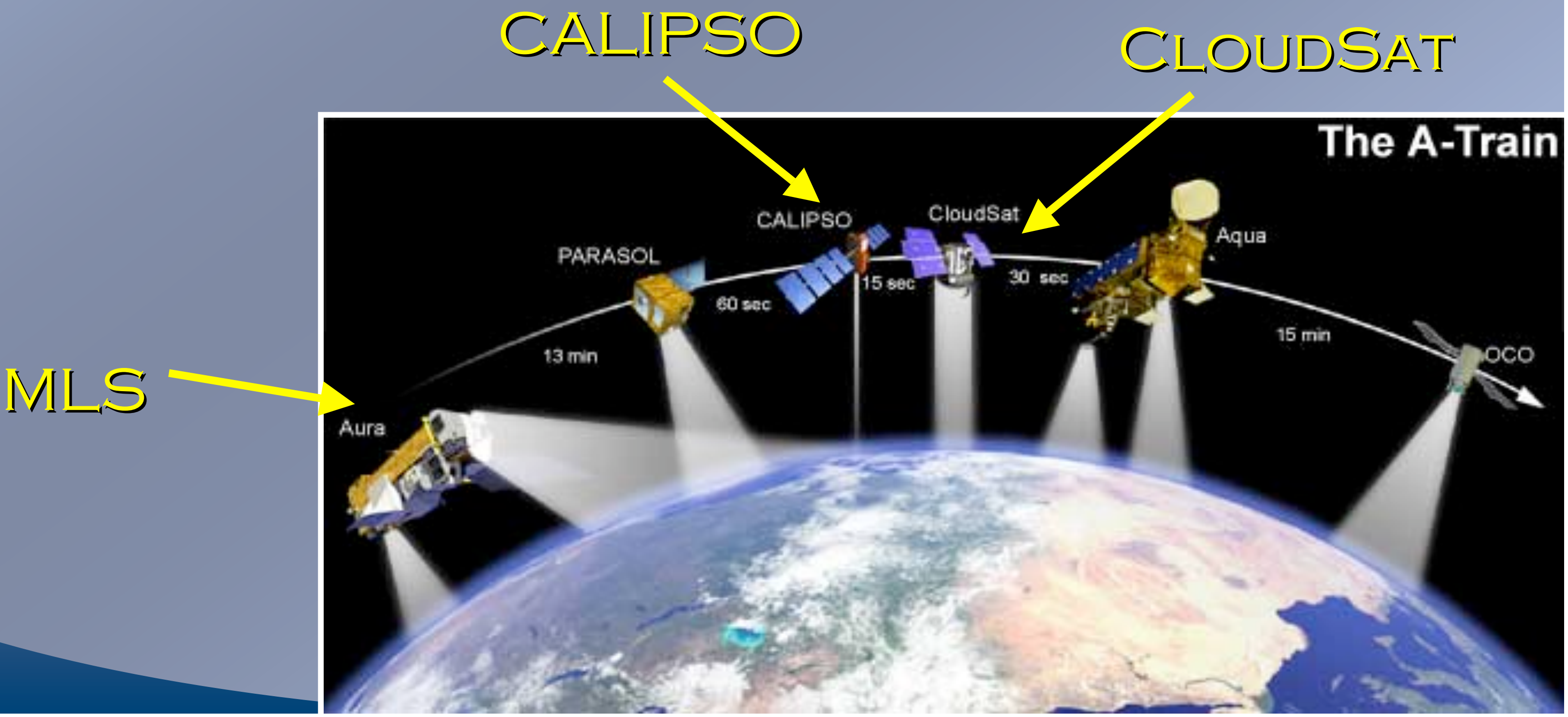


July/August 2006 Data -> BLD Climatology

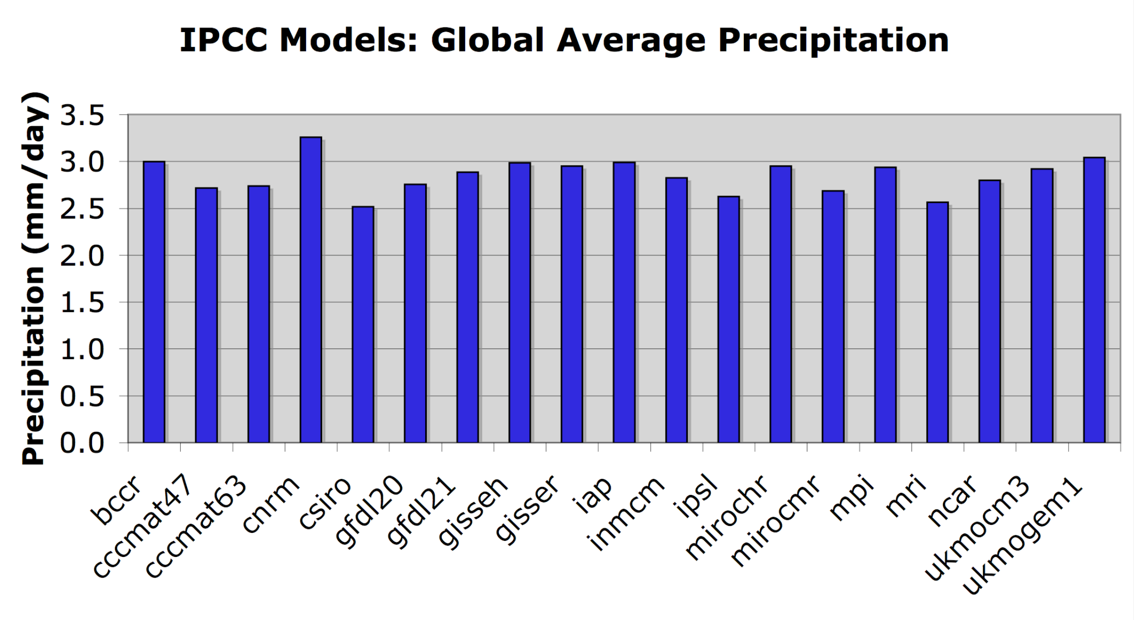
Experimental and Preliminary

Cloud Ice - a key attribute…

1) of clouds that arises from both large-scale and microphysical processes
2) of climate that connects the water and (latent & radiative) energy cycles in upper troposphere
3) of cloud modeling with significant uncertainties that impact the evolution and characteristics of the precipitation and radiation processes
4) that until recently had very few global observations.

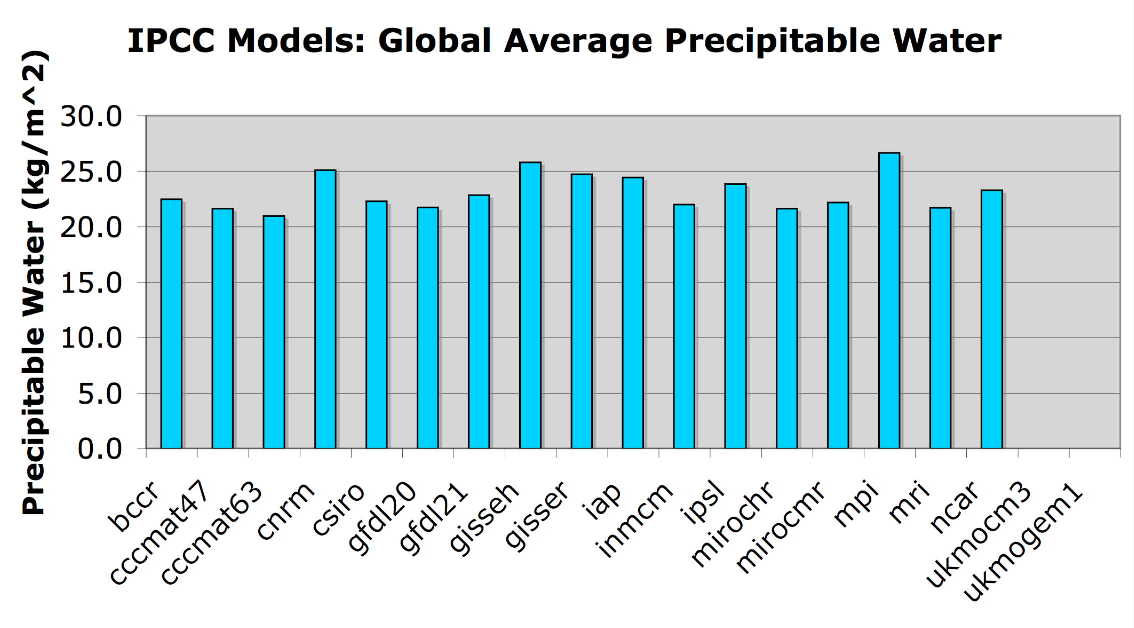


Modeling Implications: IPCC GCMs

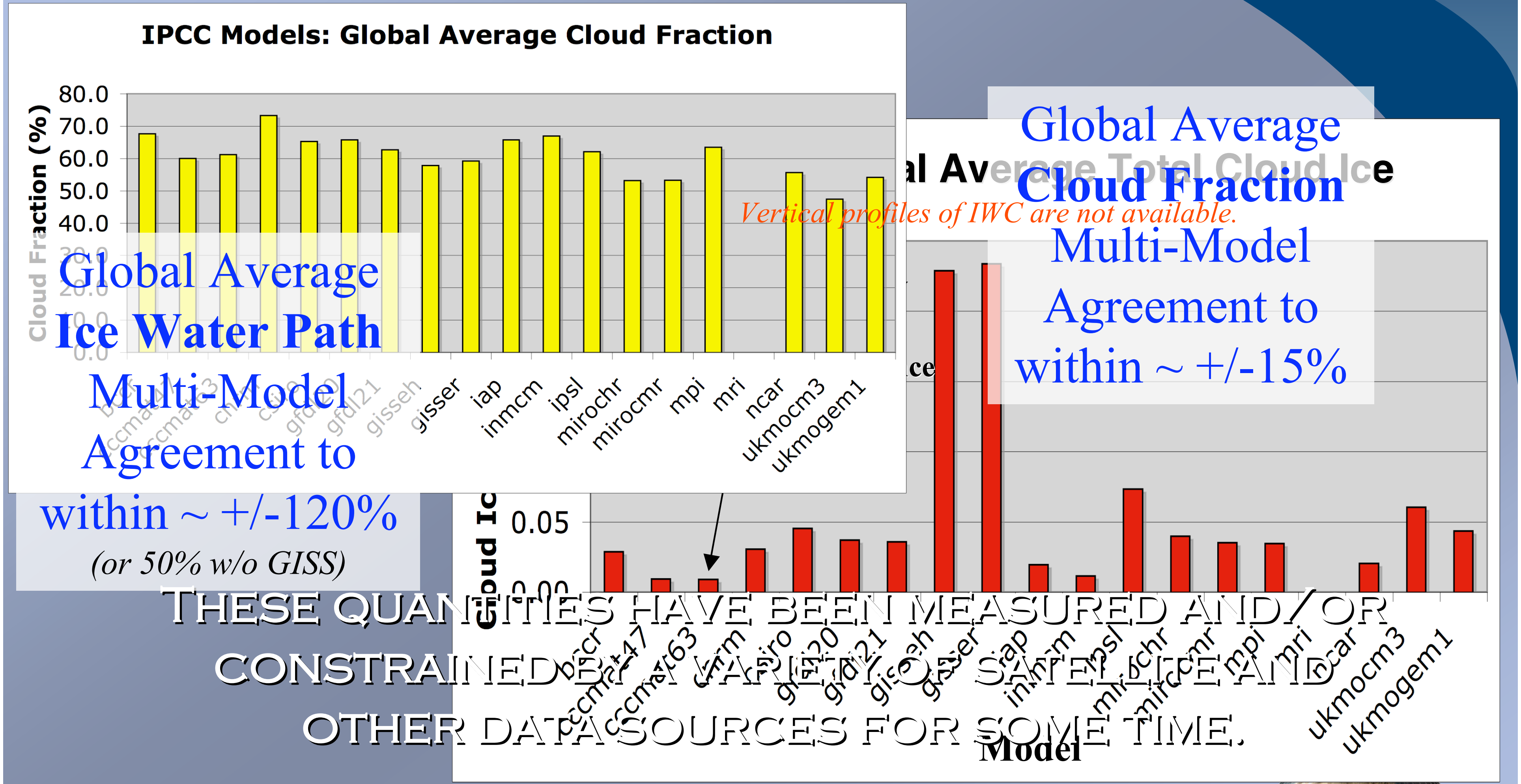


Global Average
Precipitation
Multi-Model
Agreement to
within ~ +/-10%

Global Average
Precipitable Water
Multi-Model
Agreement to
within ~ +/-10%



MODELING IMPLICATIONS: IPCC GCMS



Vertical profiles of IWC are not available.

Global Average
Ice Water Path
Multi-Model
Agreement to
within ~ +/-120%
(or 50% w/o GISS)

Global Average
Cloud Fraction
Multi-Model
Agreement to
within ~ +/-15%

THESE QUANTITIES HAVE BEEN MEASURED AND/OR CONSTRAINED BY A VARIETY OF SATELLITE AND OTHER DATA SOURCES FOR SOME TIME.

This disagreement needs to be reduced.
So, where have the observations been?

PREVIOUS ESTIMATES OF IWC HAVE BEEN BASED ON:

In-Situ:

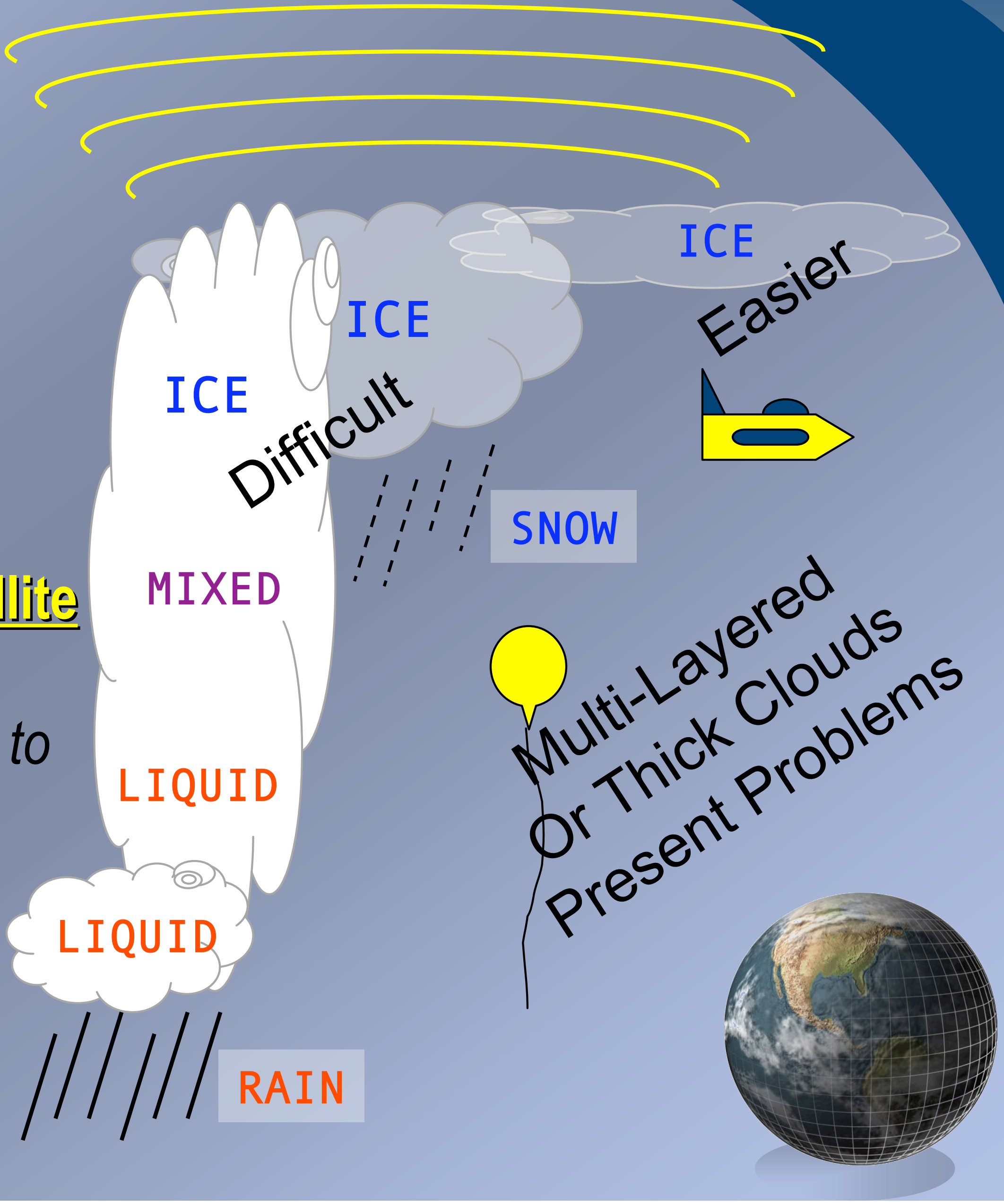
Sparse in Time & Space

e.g. McFarquhar et al. 1999; Heymsfield et al. 2005

Nadir-Viewing Passive Satellite Remote Sensing:

Path Estimate Only & Subject to Considerable Uncertainty

e.g., Rossow and Gardner 1993



DUE TO THE COMPLEX NATURE OF THE PROBLEM, WE NEED:

Radar:

Distinguishes particle type & size along vertical profile.

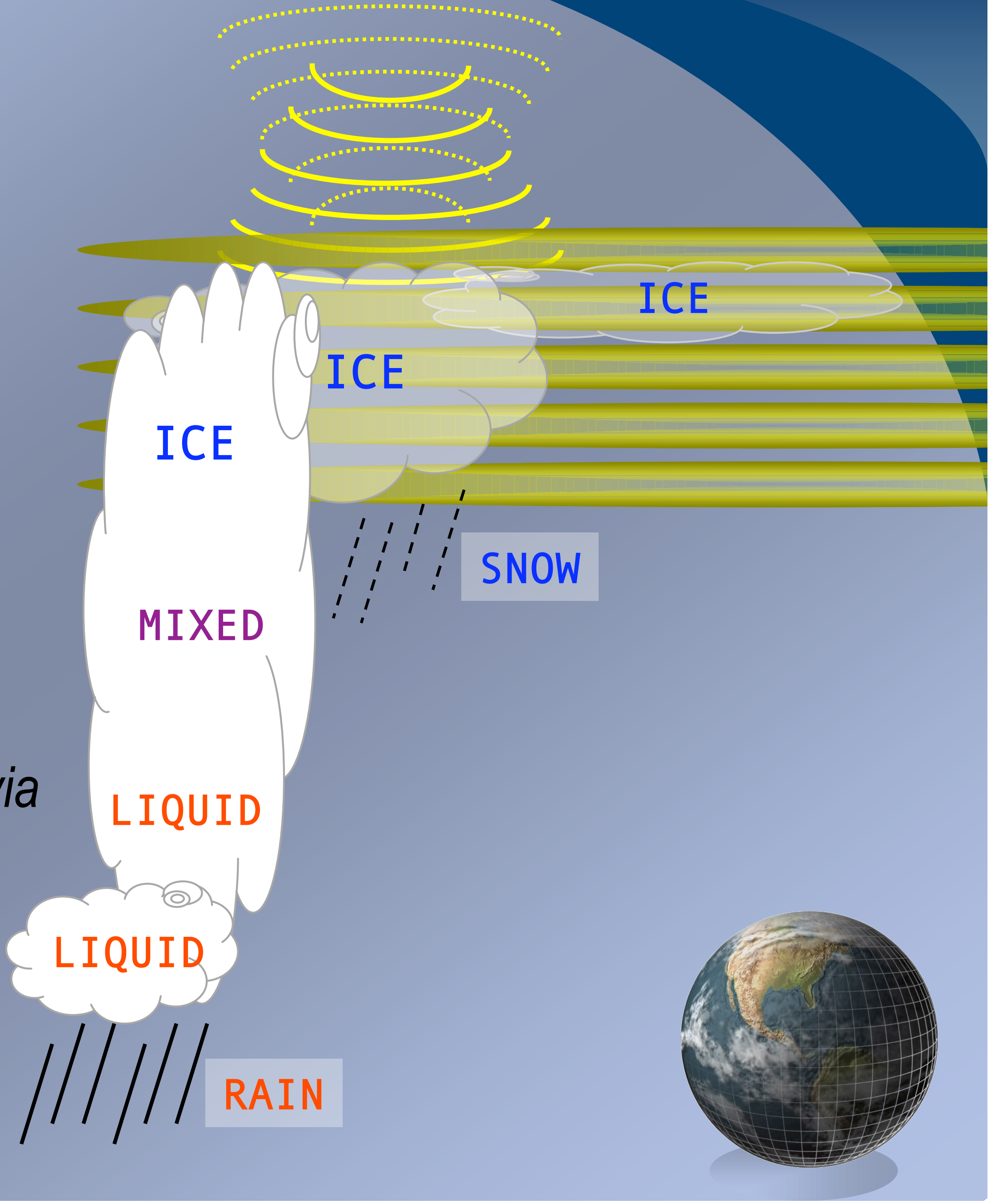
CloudSat: ~June 2006 ->

Limb Sounding:

Can achieve vertical profiles via passive techniques

MLS: August 2004 ->

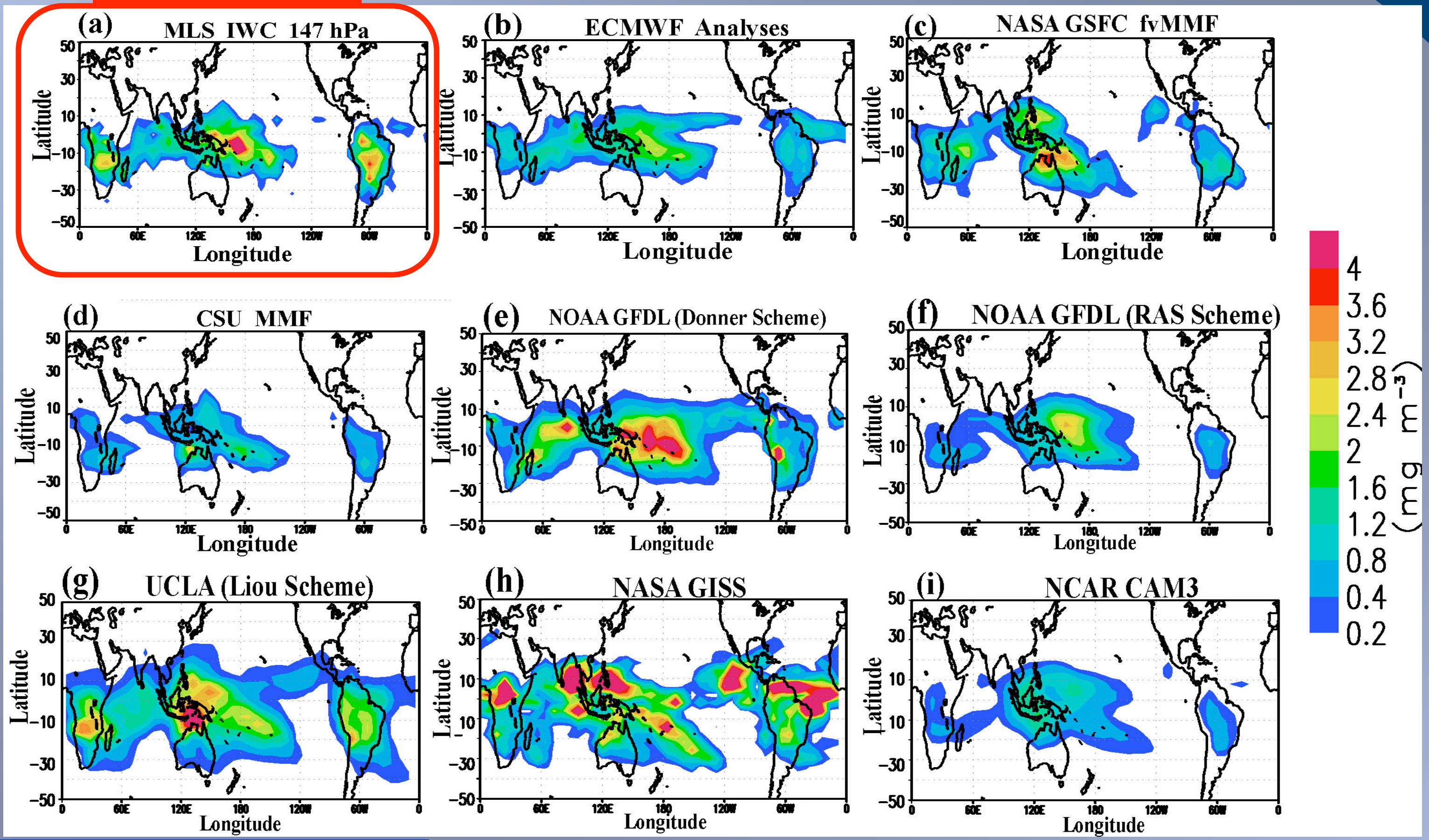
With T(p), q(p)

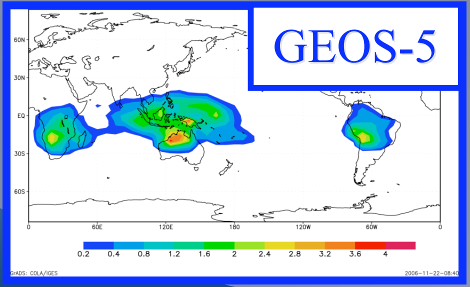


UPPER-TROPOSPHERIC CLOUD ICE: MLS vs MODELS

JANUARY 2005 OR CLIMATOLOGICAL JANUARY VALUES (LI ET AL. 2005)

MLS VALUES

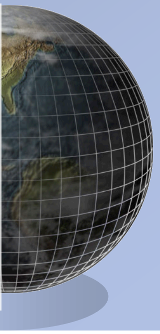




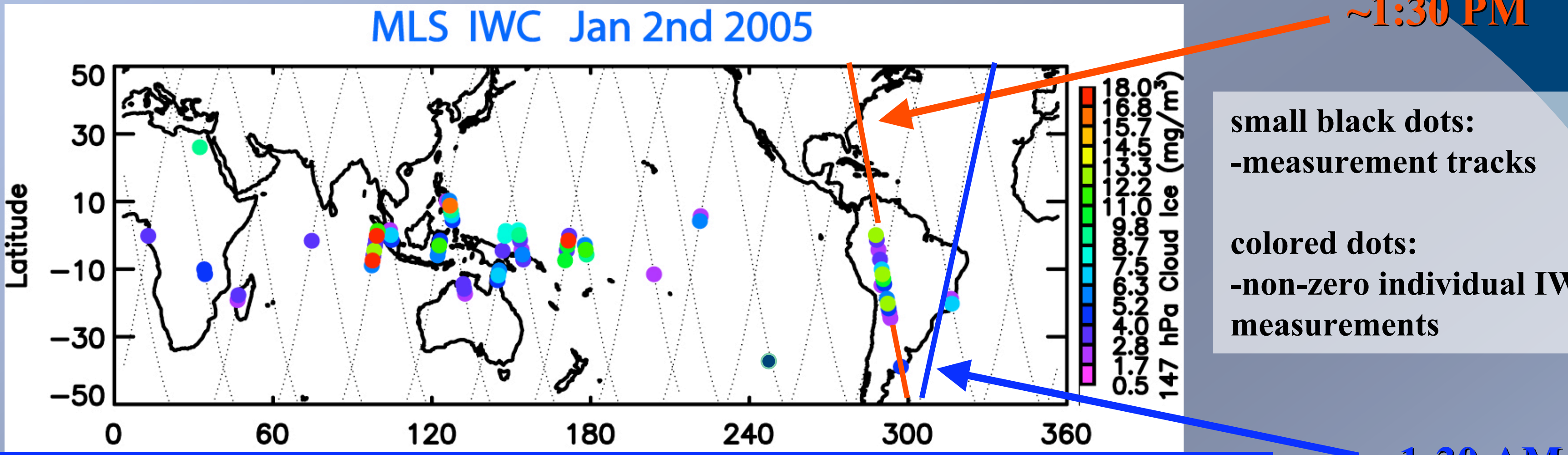
ABOVE MODELS DID NOT HAVE THE BENEFIT OF MLS/SATELLITE CLOUD ICE.

<--- GEOS-5 DEVELOPMENT DID.

HOWEVER, TO BE MORE QUANTITATIVE, A HOST OF SAMPLING CONDITIONS NEED TO BE CONSIDERED



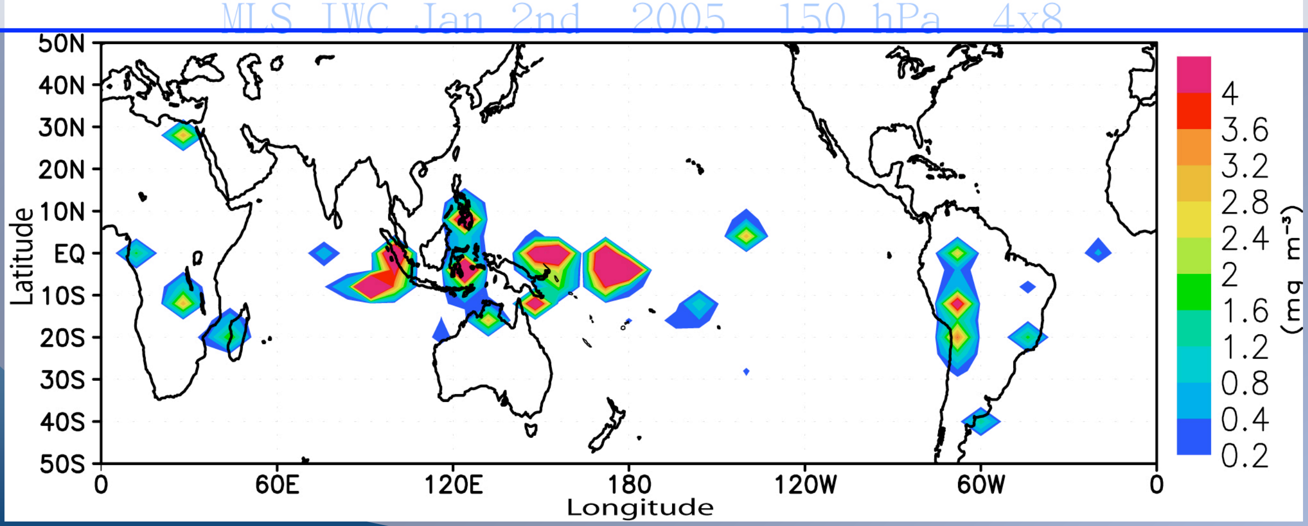
MLS IWC at 147 hPa for January 2nd 2005



small black dots:
-measurement tracks

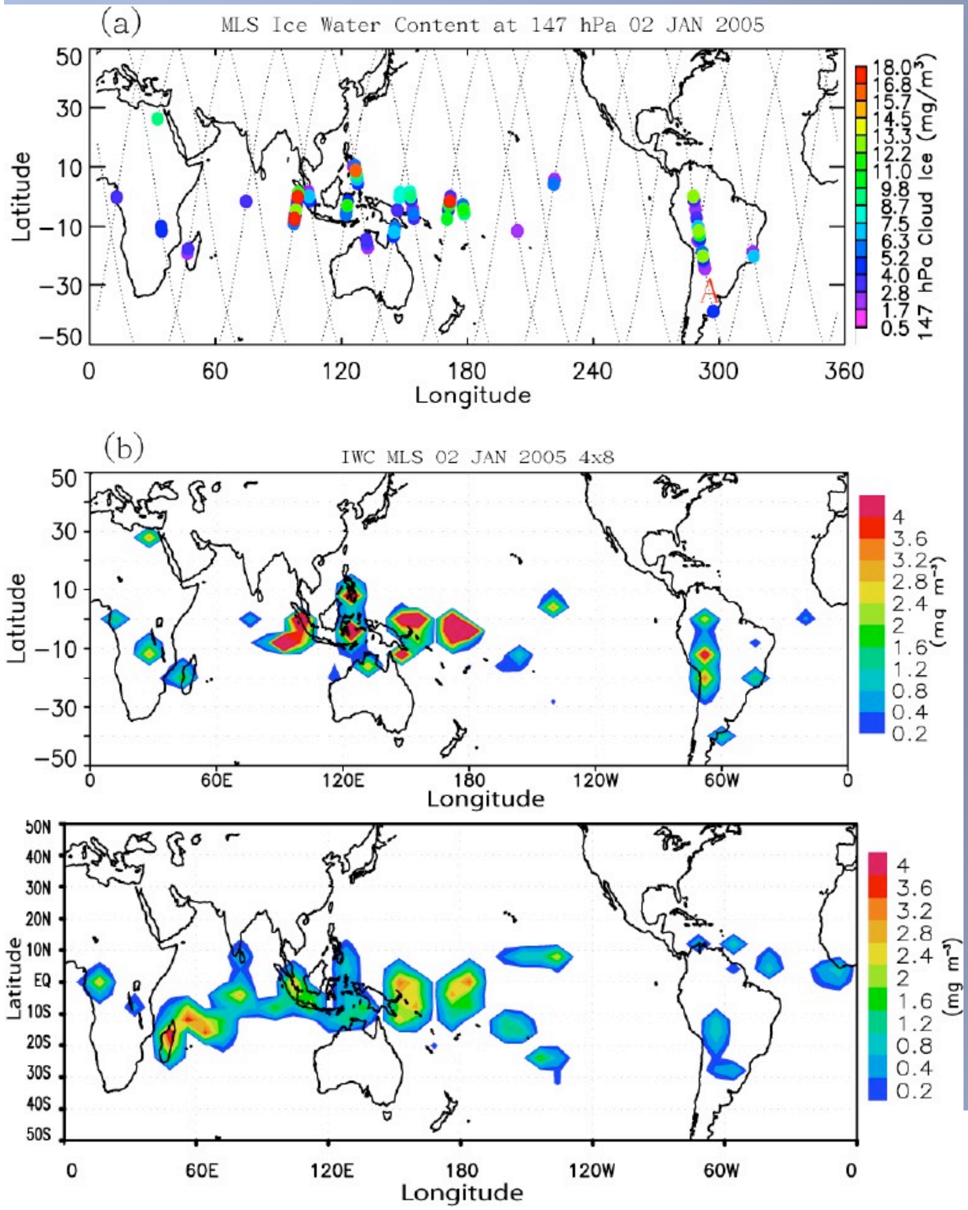
colored dots:
-non-zero individual IWC measurements

IWC amounts divided by the total number of measurements (including cloud free conditions) at each 4°× 8° lat-lon MLS grid.



CLOUD ICE: MLS vs ECMWF ANALYSES

147 hPa; Jan 2, 2005



MLS Orbits + Retrievals

MLS Averaged to 4x8 Grid

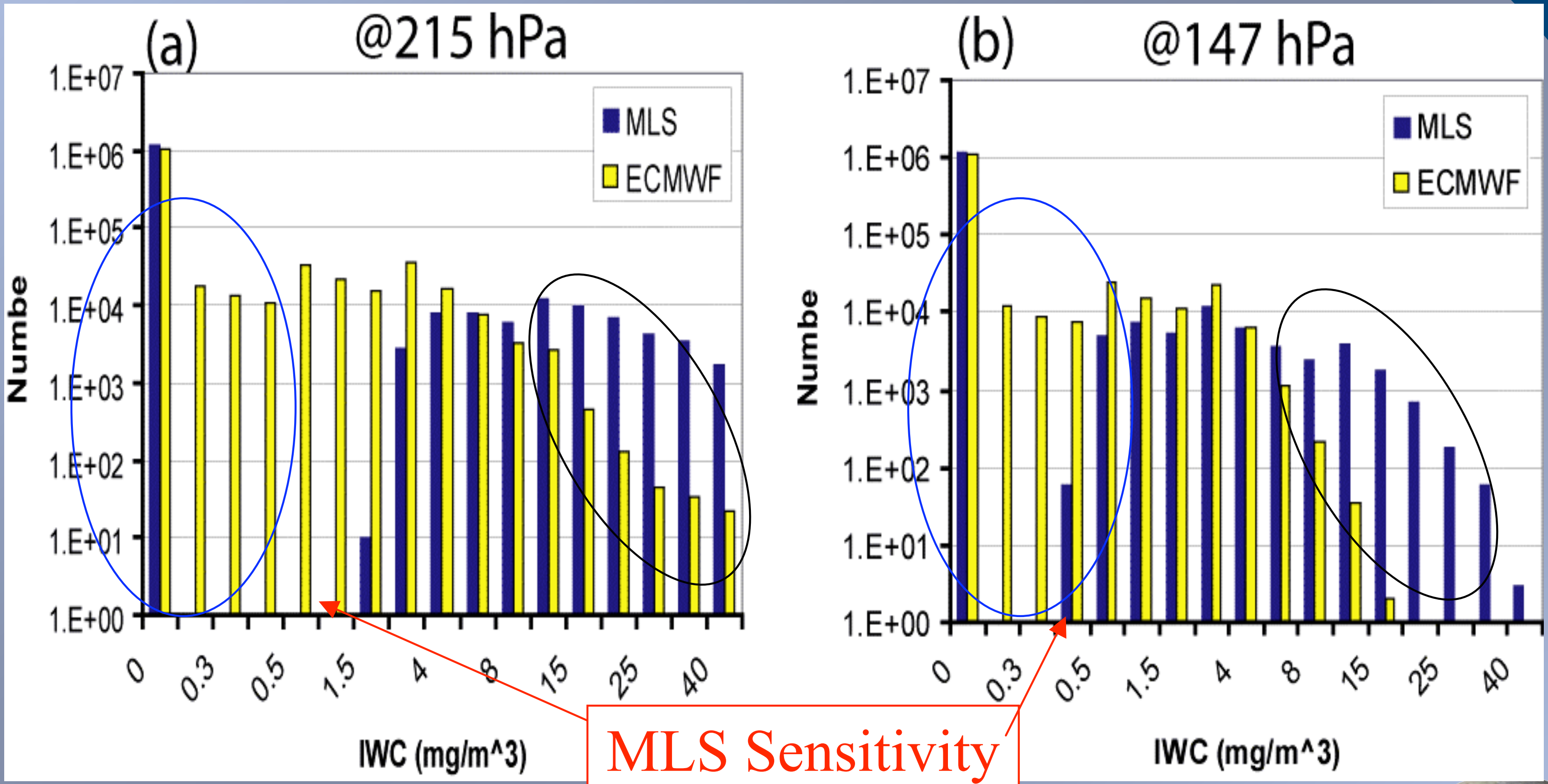
ECMWF Sampled Along Track

30R1

MLS vs SAMPLED ECMWF ANALYSES

30R1

Aug 2004 - Jul 2005; PDF of Instantaneous Values



MLS Sensitivity

ECMWF and MLS disagree at high values.

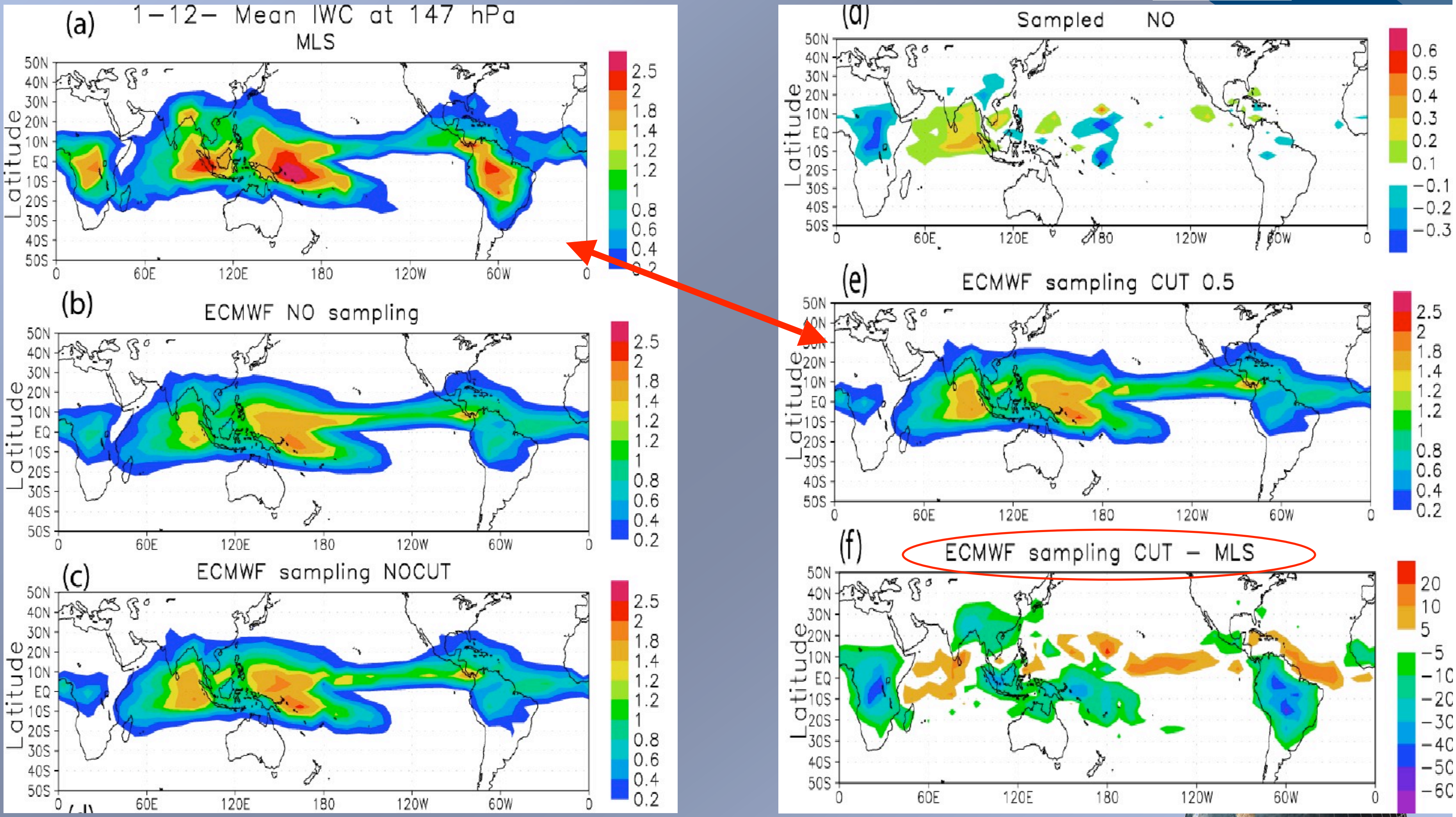
Low value representation needs to be accounted for.

CALIPSO & CloudSat will provide low+high value data

MLS vs sampled, Filtered ECMWF Analyses

Aug 2004 - Jul 2005; 147 hPa

30R1



Generally ECMWF < MLS
Evidence of Circulation Dependent Biass

Recent Updates to ECMWF Forecast System - motivated in part by MLS IWC comparisons

Moist Package Revisions

Operational Versions

- OLD : 30R1: up to Sep 12th 2006 (ECI).
- NEW : 31R1: starting operational on Sep 13th 2006.

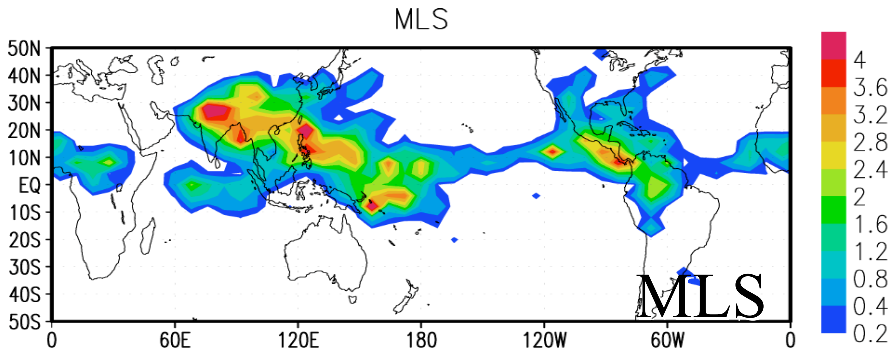
The changes in the moist processes are:

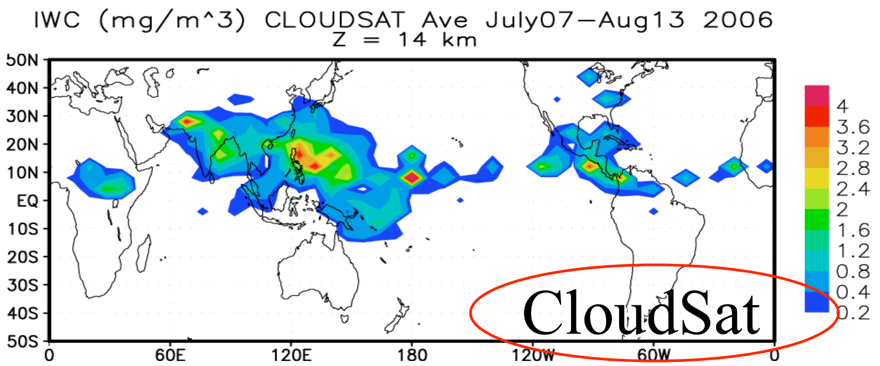
a) New parameterization to allow ice-phase supersaturation

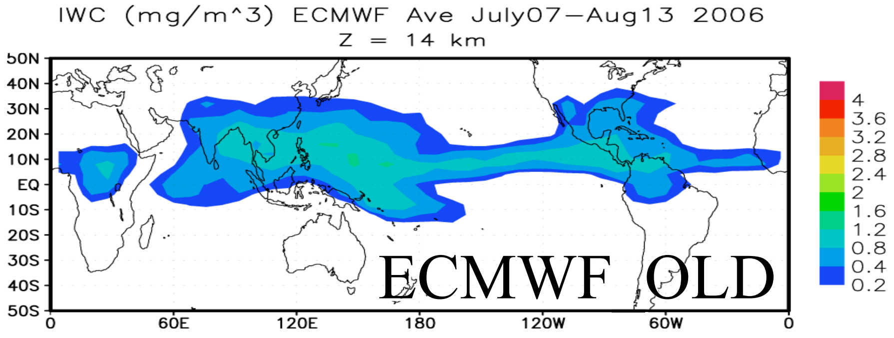
a) Revised ice crystal sedimentation and snow autoconversion

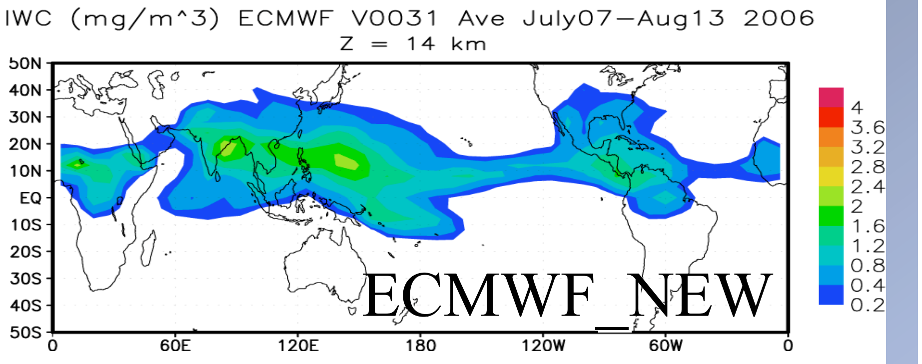
CLOUD ICE VALUES & IMPACT ON ECMWF INTEGRATED FORECASTING SYSTEM

Data are all from Jul07-Aug13, 2006 @ ~ 14km

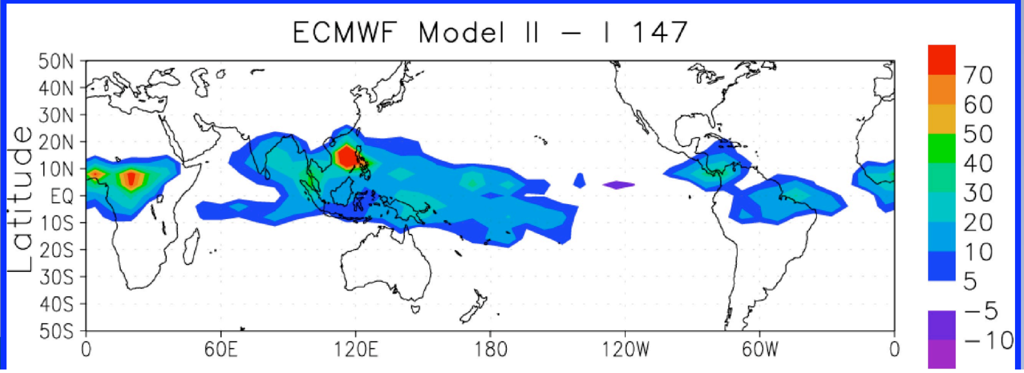

MLS


IWC (mg/m^3) CLOUDSAT Ave July07–Aug13 2006
Z = 14 km


IWC (mg/m^3) ECMWF Ave July07–Aug13 2006
Z = 14 km

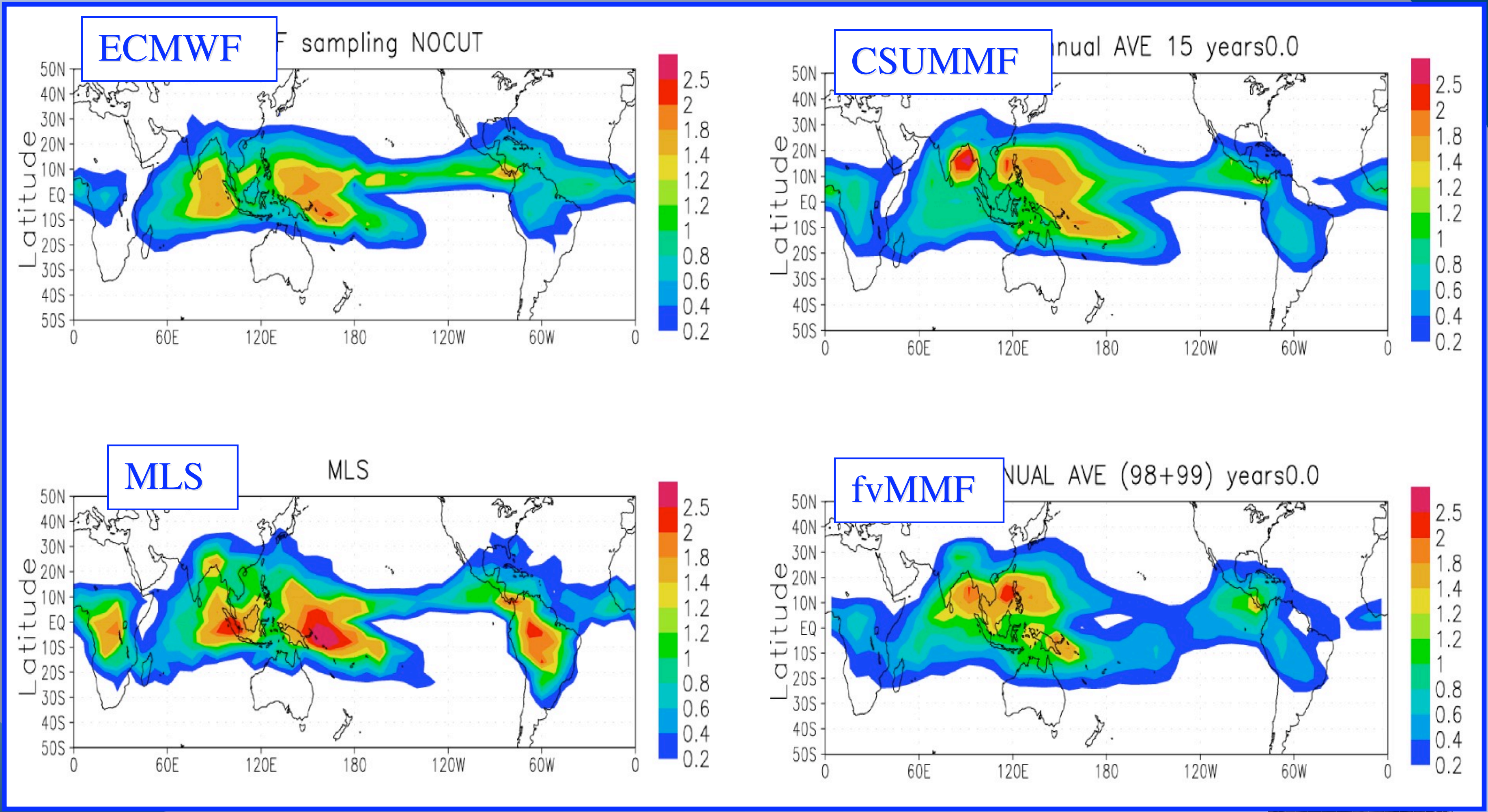

IWC (mg/m^3) ECMWF V0031 Ave July07–Aug13 2006
Z = 14 km

% change =>
In the Right Direction


ECMWF Model II – I 147

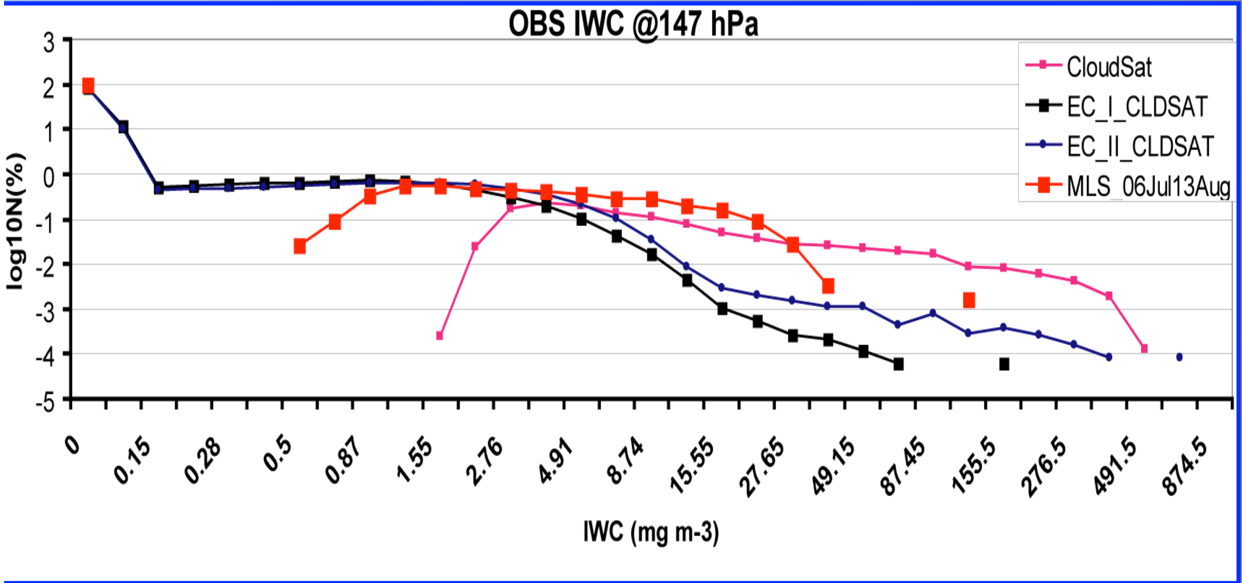
Cloud Ice Values & MMFs

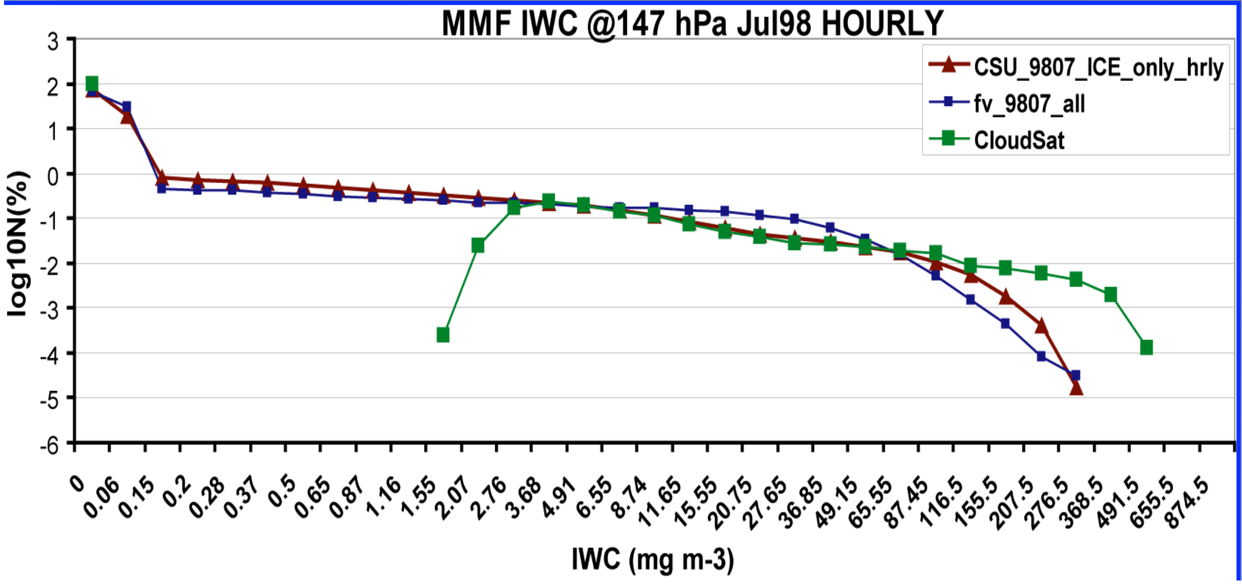
ANNUAL MEANS

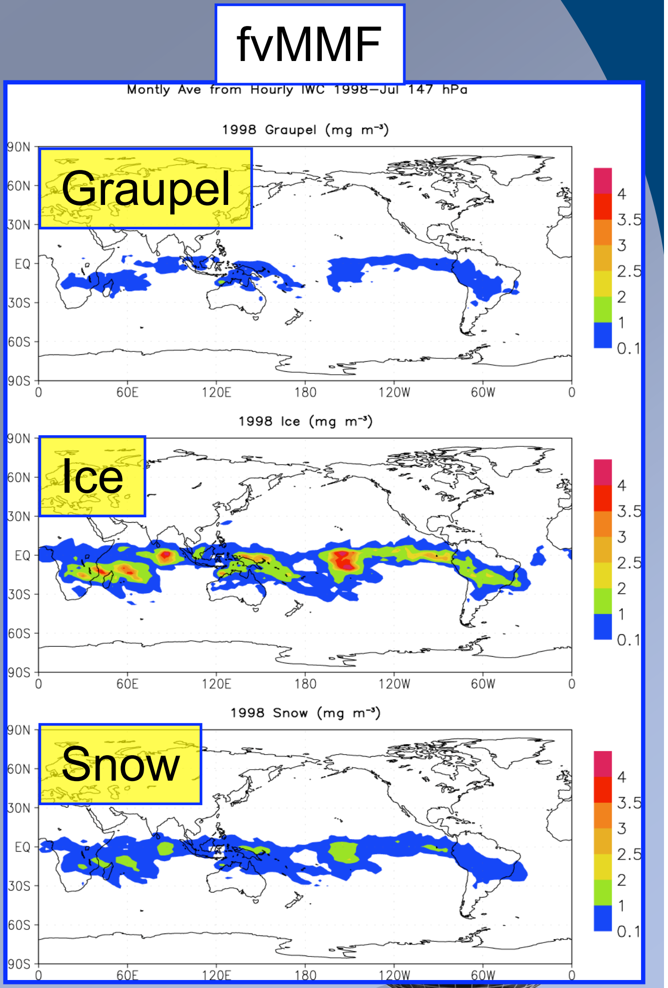


OBSERVATIONAL SENSITIVITY & MODEL REPRESENTATIONS

(FALLING AND/OR FLOATING - WHAT IS MEASURED/MODELED?)

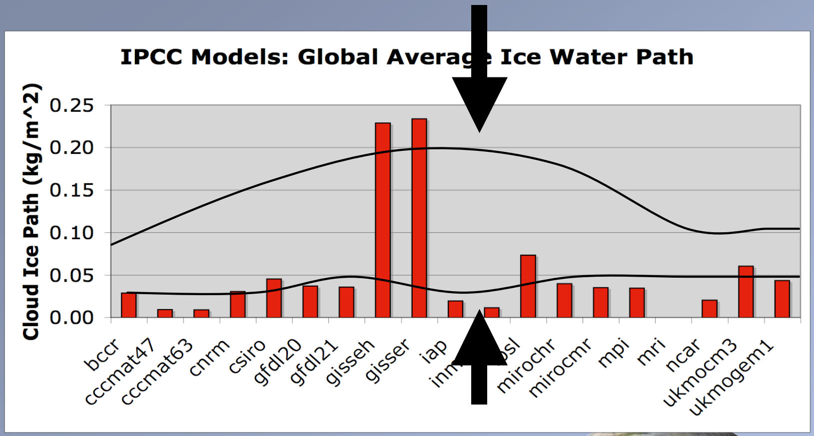

OBS IWC @147 hPa


MMF IWC @147 hPa Jul98 HOURLY


fvMMF
Montly Ave from Hourly IWC 1998–Jul 147 hPa

Data Summary:

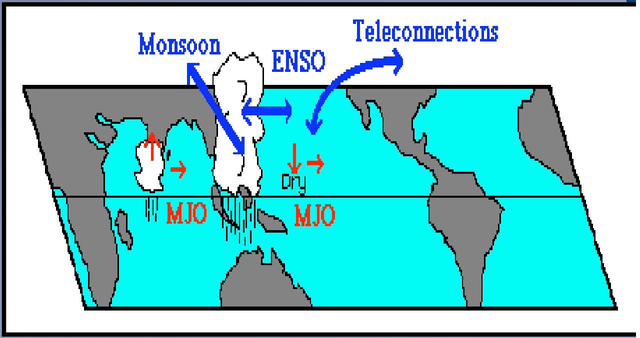
there are a number of new satellite datasets that offer altogether new opportunities for characterizing tropical convection/clouds, And Reducing Model Uncertainties.

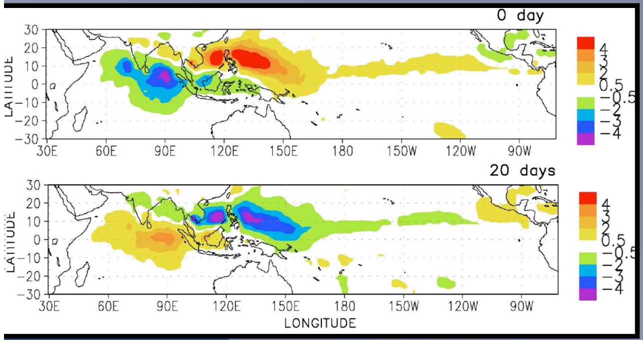


Switch Gears to MJO Working Group…Building a Framework to Utilize these Observations

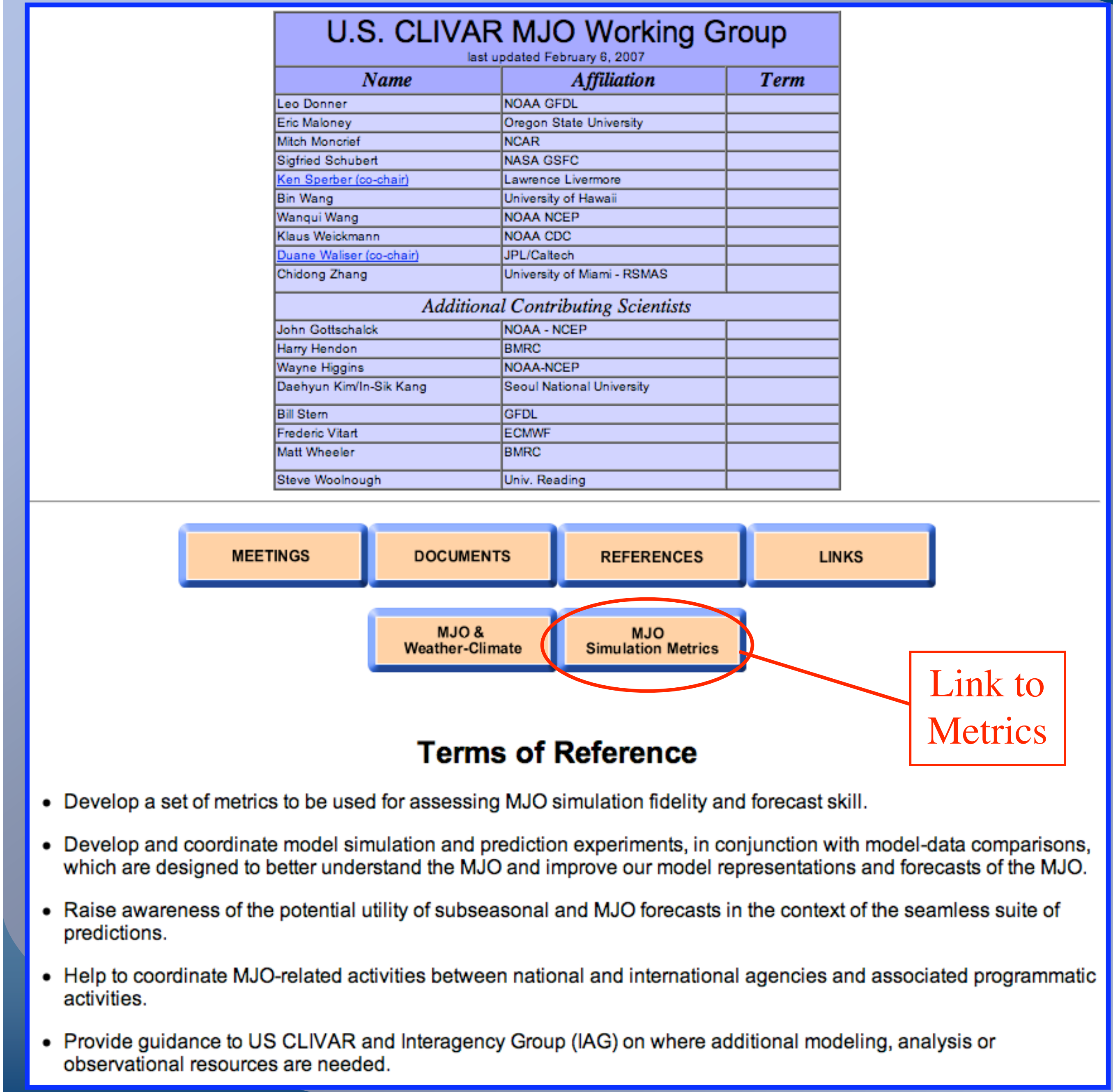
US CLIVAR MJO Working Group:
MJO Simulation Metrics

http://www.usclivar.org/Organization/MJO_WG.html





MEMBERSHIP & TERMS OF REFERENCE



U.S. CLIVAR MJO Working Group

last updated February 6, 2007

Name	*Affiliation*	*Term*
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Mitch Moncrief	NCAR	
Sigfried Schubert	NASA GSFC	
Ken Sperber (co-chair)	Lawrence Livermore	
Bin Wang	University of Hawaii	
Wanqui Wang	NOAA NCEP	
Klaus Weickmann	NOAA CDC	
Duane Waliser (co-chair)	JPL/Caltech	
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Harry Hendon	BMRC	
Wayne Higgins	NOAA-NCEP	
Daehyun Kim/In-Sik Kang	Seoul National University	
Bill Stern	GFDL	
Frederic Vitart	ECMWF	
Matt Wheeler	BMRC	
Steve Woolnough	Univ. Reading	

Link to Metrics

Terms of Reference

- Develop a set of metrics to be used for assessing MJO simulation fidelity and forecast skill.
- Develop and coordinate model simulation and prediction experiments, in conjunction with model-data comparisons, which are designed to better understand the MJO and improve our model representations and forecasts of the MJO.
- Raise awareness of the potential utility of subseasonal and MJO forecasts in the context of the seamless suite of predictions.
- Help to coordinate MJO-related activities between national and international agencies and associated programmatic activities.
- Provide guidance to US CLIVAR and Interagency Group (IAG) on where additional modeling, analysis or observational resources are needed.

INTERNATIONAL PARTICIPATION IS FACILITATED/ SUPPORTED BY INTERNATIONAL CLIVAR

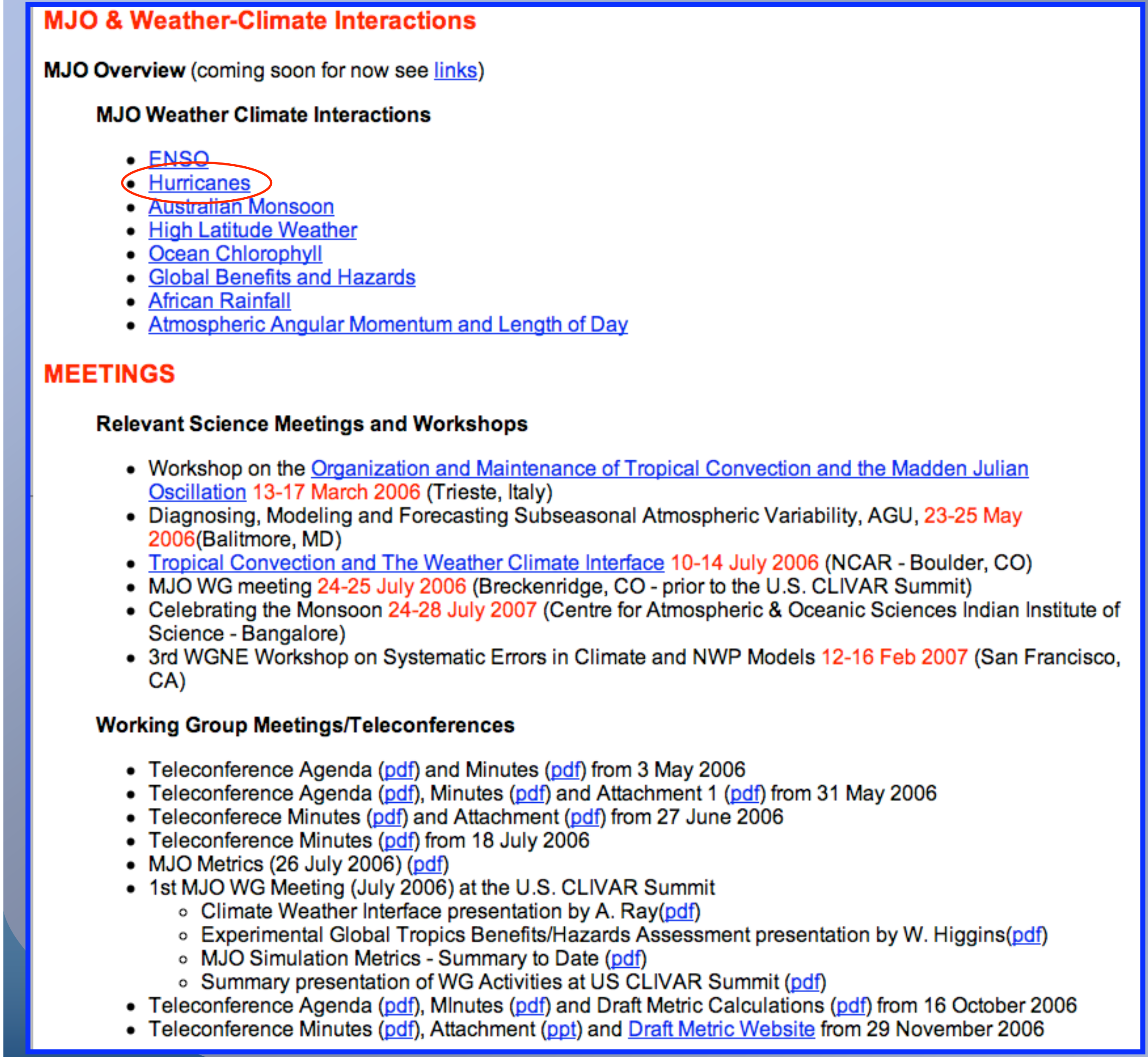
US CLIVAR: MJO WORKING GROUP

Near-Term Goals

1) Develop MJO WG Web Site. DONE
2) Metrics for Assessing/Diagnosing Model Simulations of the MJO. NEARLY DONE
3) Prediction Targets and Metrics for MJO Forecasts. STARTED
4) Using the Above, Develop an Experimental/ Diagnostics Theme for Modeling/Predicting the MJO in Conjunction With a Workshop. HORIZON

Web Site Resources

Theme Pages
&
WG Activities



MJO & Weather-Climate Interactions

MJO Overview (coming soon for now see links)

MJO Weather Climate Interactions

- ENSO
- Hurricanes
- Australian Monsoon
- High Latitude Weather
- Ocean Chlorophyll
- Global Benefits and Hazards
- African Rainfall
- Atmospheric Angular Momentum and Length of Day

MEETINGS

Relevant Science Meetings and Workshops

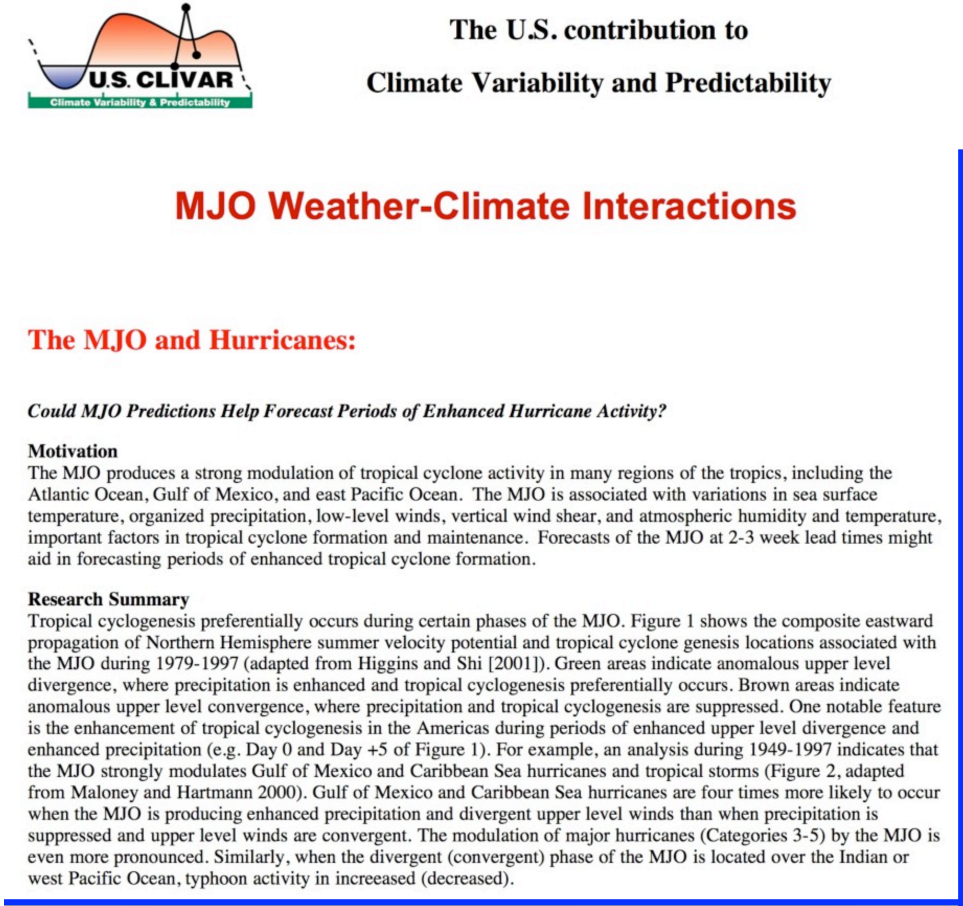
- Workshop on the Organization and Maintenance of Tropical Convection and the Madden Julian Oscillation 13-17 March 2006 (Trieste, Italy)
- Diagnosing, Modeling and Forecasting Subseasonal Atmospheric Variability, AGU, 23-25 May 2006(Balitmore, MD)
- Tropical Convection and The Weather Climate Interface 10-14 July 2006 (NCAR - Boulder, CO)
- MJO WG meeting 24-25 July 2006 (Breckenridge, CO - prior to the U.S. CLIVAR Summit)
- Celebrating the Monsoon 24-28 July 2007 (Centre for Atmospheric & Oceanic Sciences Indian Institute of Science - Bangalore)
- 3rd WGNE Workshop on Systematic Errors in Climate and NWP Models 12-16 Feb 2007 (San Francisco, CA)

Working Group Meetings/Teleconferences

- Teleconference Agenda (pdf) and Minutes (pdf) from 3 May 2006
- Teleconference Agenda (pdf), Minutes (pdf) and Attachment 1 (pdf) from 31 May 2006
- Teleconferece Minutes (pdf) and Attachment (pdf) from 27 June 2006
- Teleconference Minutes (pdf) from 18 July 2006
- MJO Metrics (26 July 2006) (pdf)
- 1st MJO WG Meeting (July 2006) at the U.S. CLIVAR Summit
  - Climate Weather Interface presentation by A. Ray(pdf)
  - Experimental Global Tropics Benefits/Hazards Assessment presentation by W. Higgins(pdf)
  - MJO Simulation Metrics - Summary to Date (pdf)
  - Summary presentation of WG Activities at US CLIVAR Summit (pdf)
- Teleconference Agenda (pdf), MInutes (pdf) and Draft Metric Calculations (pdf) from 16 October 2006
- Teleconference Minutes (pdf), Attachment (ppt) and Draft Metric Website from 29 November 2006

MJO Weather-Climate Theme Pages

Example: MJO & Hurricanes
by Eric Maloney



The U.S. contribution to

Climate Variability and Predictability

MJO Weather-Climate Interactions

The MJO and Hurricanes:

Could MJO Predictions Help Forecast Periods of Enhanced Hurricane Activity?

Motivation
The MJO produces a strong modulation of tropical cyclone activity in many regions of the tropics, including the Atlantic Ocean, Gulf of Mexico, and east Pacific Ocean. The MJO is associated with variations in sea surface temperature, organized precipitation, low-level winds, vertical wind shear, and atmospheric humidity and temperature, important factors in tropical cyclone formation and maintenance. Forecasts of the MJO at 2-3 week lead times might aid in forecasting periods of enhanced tropical cyclone formation.

Research Summary
Tropical cyclogenesis preferentially occurs during certain phases of the MJO. Figure 1 shows the composite eastward propagation of Northern Hemisphere summer velocity potential and tropical cyclone genesis locations associated with the MJO during 1979-1997 (adapted from Higgins and Shi [2001]). Green areas indicate anomalous upper level divergence, where precipitation is enhanced and tropical cyclogenesis preferentially occurs. Brown areas indicate anomalous upper level convergence, where precipitation and tropical cyclogenesis are suppressed. One notable feature is the enhancement of tropical cyclogenesis in the Americas during periods of enhanced upper level divergence and enhanced precipitation (e.g. Day 0 and Day +5 of Figure 1). For example, an analysis during 1949-1997 indicates that the MJO strongly modulates Gulf of Mexico and Caribbean Sea hurricanes and tropical storms (Figure 2, adapted from Maloney and Hartmann 2000). Gulf of Mexico and Caribbean Sea hurricanes are four times more likely to occur when the MJO is producing enhanced precipitation and divergent upper level winds than when precipitation is suppressed and upper level winds are convergent. The modulation of major hurricanes (Categories 3-5) by the MJO is even more pronounced. Similarly, when the divergent (convergent) phase of the MJO is located over the Indian or west Pacific Ocean, typhoon activity in increased (decreased).

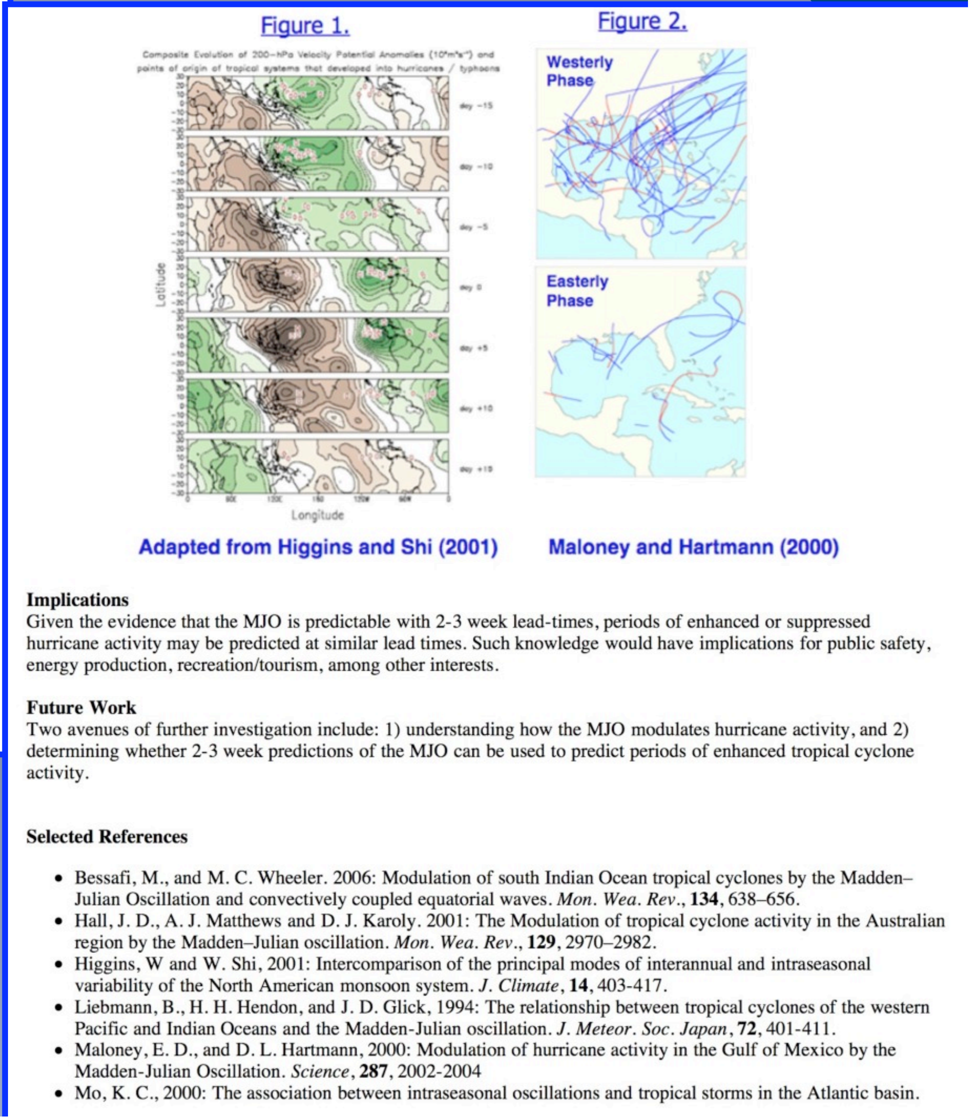


Figure 1.

Adapted from Higgins and Shi (2001)

Figure 2.

Maloney and Hartmann (2000)

Implications
Given the evidence that the MJO is predictable with 2-3 week lead-times, periods of enhanced or suppressed hurricane activity may be predicted at similar lead times. Such knowledge would have implications for public safety, energy production, recreation/tourism, among other interests.

Future Work
Two avenues of further investigation include: 1) understanding how the MJO modulates hurricane activity, and 2) determining whether 2-3 week predictions of the MJO can be used to predict periods of enhanced tropical cyclone activity.

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- Hall, J. D., A. J. Matthews and D. J. Karoly. 2001: The Modulation of tropical cyclone activity in the Australian region by the Madden–Julian oscillation. *Mon. Wea. Rev.*, **129**, 2970–2982.
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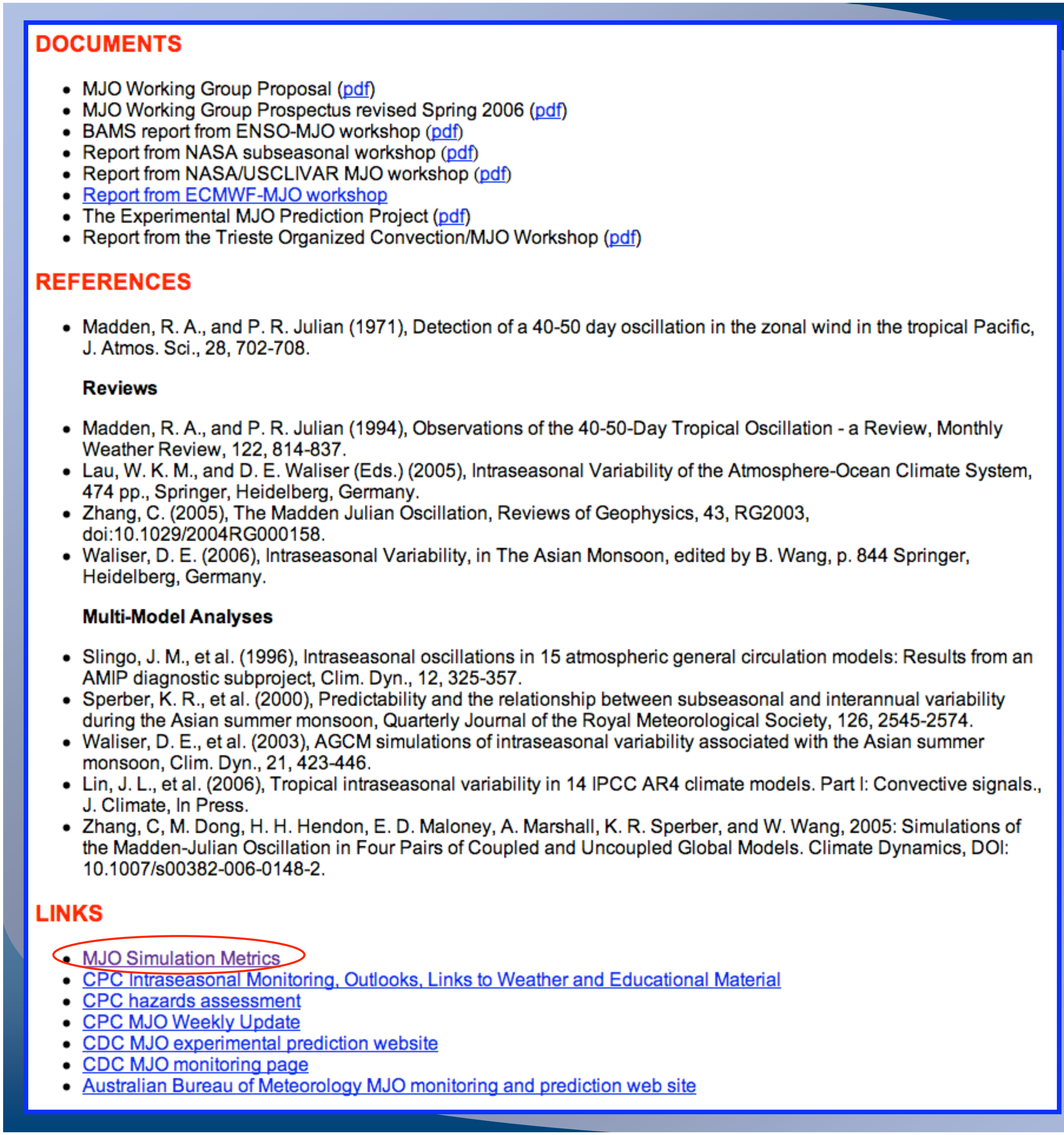
- Maloney, E. D., and D. L. Hartmann, 2000: Modulation of hurricane activity in the Gulf of Mexico by the Madden-Julian Oscillation. *Science*, **287**, 2002-2004
- Mo, K. C., 2000: The association between intraseasonal oscillations and tropical storms in the Atlantic basin.

WEB SITE RESOURCES

PAST REPORTS
REFERENCES
LINKS



DOCUMENTS

- MJO Working Group Proposal (pdf)
- MJO Working Group Prospectus revised Spring 2006 (pdf)
- BAMS report from ENSO-MJO workshop (pdf)
- Report from NASA subseasonal workshop (pdf)
- Report from NASA/USCLIVAR MJO workshop (pdf)
- Report from ECMWF-MJO workshop
- The Experimental MJO Prediction Project (pdf)
- Report from the Trieste Organized Convection/MJO Workshop (pdf)

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- Madden, R. A., and P. R. Julian (1994), Observations of the 40-50-Day Tropical Oscillation - a Review, Monthly Weather Review, 122, 814-837.
- Lau, W. K. M., and D. E. Waliser (Eds.) (2005), Intraseasonal Variability of the Atmosphere-Ocean Climate System, 474 pp., Springer, Heidelberg, Germany.
- Zhang, C. (2005), The Madden Julian Oscillation, Reviews of Geophysics, 43, RG2003, doi:10.1029/2004RG000158.
- Waliser, D. E. (2006), Intraseasonal Variability, in The Asian Monsoon, edited by B. Wang, p. 844 Springer, Heidelberg, Germany.

Multi-Model Analyses

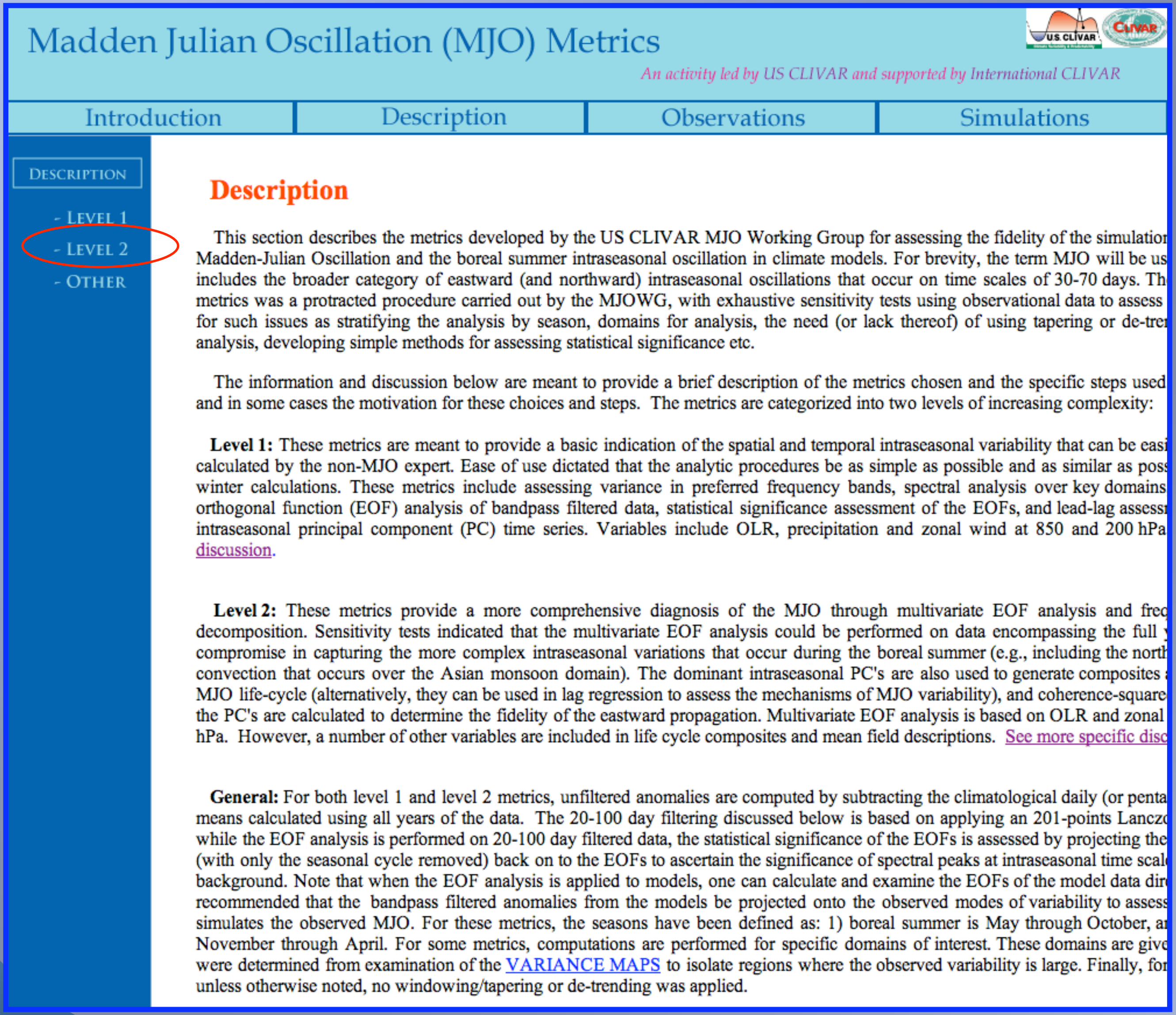
- Slingo, J. M., et al. (1996), Intraseasonal oscillations in 15 atmospheric general circulation models: Results from an AMIP diagnostic subproject, Clim. Dyn., 12, 325-357.
- Sperber, K. R., et al. (2000), Predictability and the relationship between subseasonal and interannual variability during the Asian summer monsoon, Quarterly Journal of the Royal Meteorological Society, 126, 2545-2574.
- Waliser, D. E., et al. (2003), AGCM simulations of intraseasonal variability associated with the Asian summer monsoon, Clim. Dyn., 21, 423-446.
- Lin, J. L., et al. (2006), Tropical intraseasonal variability in 14 IPCC AR4 climate models. Part I: Convective signals., J. Climate, In Press.
- Zhang, C, M. Dong, H. H. Hendon, E. D. Maloney, A. Marshall, K. R. Sperber, and W. Wang, 2005: Simulations of the Madden-Julian Oscillation in Four Pairs of Coupled and Uncoupled Global Models. Climate Dynamics, DOI: 10.1007/s00382-006-0148-2.

LINKS

- MJO Simulation Metrics
- CPC Intraseasonal Monitoring, Outlooks, Links to Weather and Educational Material
- CPC hazards assessment
- CPC MJO Weekly Update
- CDC MJO experimental prediction website
- CDC MJO monitoring page
- Australian Bureau of Meteorology MJO monitoring and prediction web site

WEB SITE METRICS

GENERAL STRATEGY & DESCRIPTION



Description

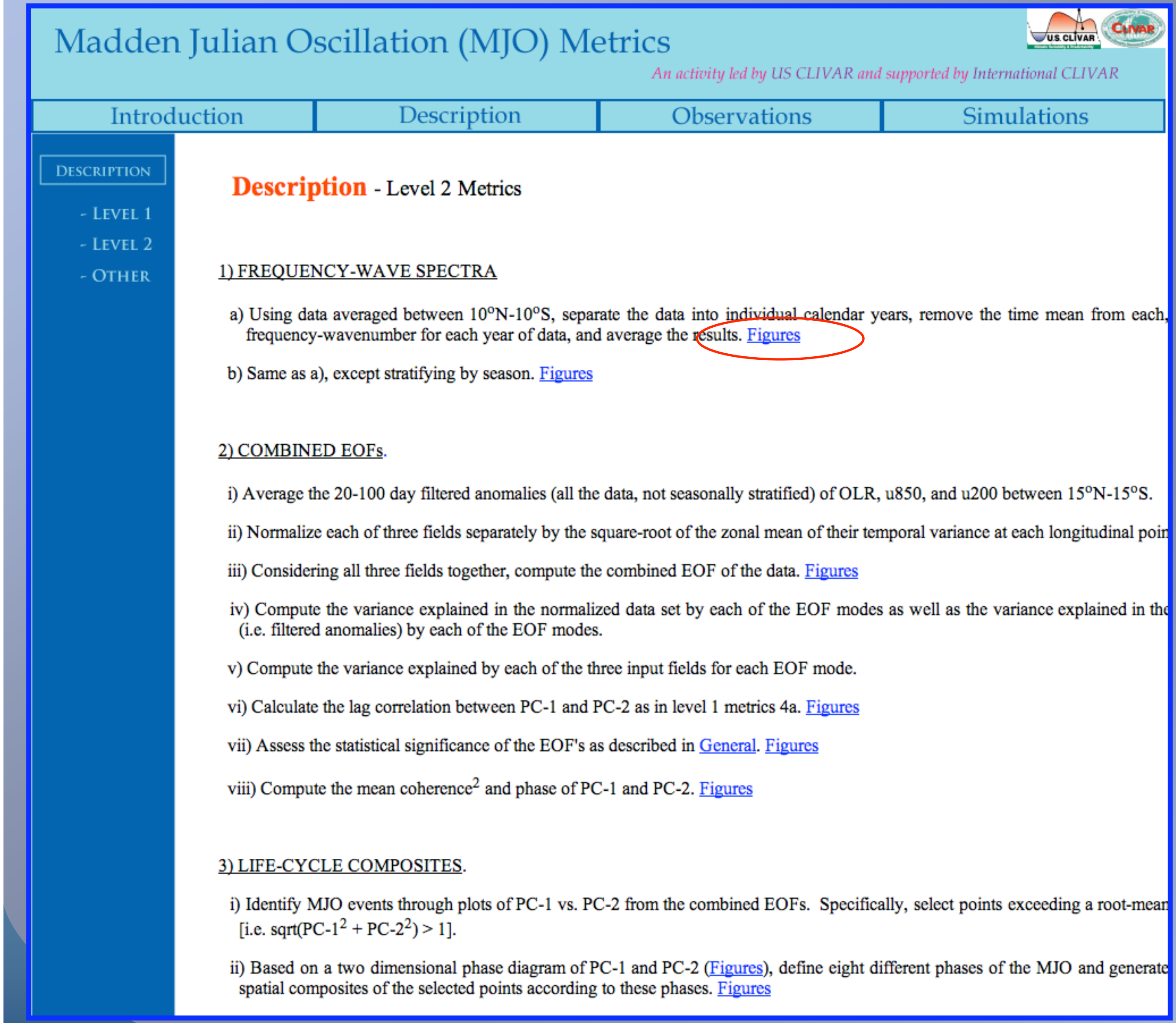
This section describes the metrics developed by the US CLIVAR MJO Working Group for assessing the fidelity of the simulatio Madden-Julian Oscillation and the boreal summer intraseasonal oscillation in climate models. For brevity, the term MJO will be us includes the broader category of eastward (and northward) intraseasonal oscillations that occur on time scales of 30-70 days. Th metrics was a protracted procedure carried out by the MJOWG, with exhaustive sensitivity tests using observational data to assess for such issues as stratifying the analysis by season, domains for analysis, the need (or lack thereof) of using tapering or de-tre analysis, developing simple methods for assessing statistical significance etc.

The information and discussion below are meant to provide a brief description of the metrics chosen and the specific steps used and in some cases the motivation for these choices and steps. The metrics are categorized into two levels of increasing complexity:

Level 1: These metrics are meant to provide a basic indication of the spatial and temporal intraseasonal variability that can be easi calculated by the non-MJO expert. Ease of use dictated that the analytic procedures be as simple as possible and as similar as poss winter calculations. These metrics include assessing variance in preferred frequency bands, spectral analysis over key domains orthogonal function (EOF) analysis of bandpass filtered data, statistical significance assessment of the EOFs, and lead-lag assess intraseasonal principal component (PC) time series. Variables include OLR, precipitation and zonal wind at 850 and 200 hPa discussion.

Level 2: These metrics provide a more comprehensive diagnosis of the MJO through multivariate EOF analysis and fre decomposition. Sensitivity tests indicated that the multivariate EOF analysis could be performed on data encompassing the full compromise in capturing the more complex intraseasonal variations that occur during the boreal summer (e.g., including the nort convection that occurs over the Asian monsoon domain). The dominant intraseasonal PC's are also used to generate composites MJO life-cycle (alternatively, they can be used in lag regression to assess the mechanisms of MJO variability), and coherence-square the PC's are calculated to determine the fidelity of the eastward propagation. Multivariate EOF analysis is based on OLR and zonal hPa. However, a number of other variables are included in life cycle composites and mean field descriptions. See more specific disc

General: For both level 1 and level 2 metrics, unfiltered anomalies are computed by subtracting the climatological daily (or penta means calculated using all years of the data. The 20-100 day filtering discussed below is based on applying an 201-points Lancz while the EOF analysis is performed on 20-100 day filtered data, the statistical significance of the EOFs is assessed by projecting the (with only the seasonal cycle removed) back on to the EOFs to ascertain the significance of spectral peaks at intraseasonal time scal background. Note that when the EOF analysis is applied to models, one can calculate and examine the EOFs of the model data dir recommended that the bandpass filtered anomalies from the models be projected onto the observed modes of variability to assess simulates the observed MJO. For these metrics, the seasons have been defined as: 1) boreal summer is May through October, a November through April. For some metrics, computations are performed for specific domains of interest. These domains are give were determined from examination of the VARIANCE MAPS to isolate regions where the observed variability is large. Finally, fo unless otherwise noted, no windowing/tapering or de-trending was applied.



Madden Julian Oscillation (MJO) Metrics

An activity led by US CLIVAR and supported by International CLIVAR

Description - Level 2 Metrics

1) FREQUENCY-WAVE SPECTRA

a) Using data averaged between 10°N-10°S, separate the data into individual calendar years, remove the time mean from each, frequency-wavenumber for each year of data, and average the results. Figures

b) Same as a), except stratifying by season. Figures

2) COMBINED EOFs.

i) Average the 20-100 day filtered anomalies (all the data, not seasonally stratified) of OLR, u850, and u200 between 15°N-15°S.

ii) Normalize each of three fields separately by the square-root of the zonal mean of their temporal variance at each longitudinal poin

iii) Considering all three fields together, compute the combined EOF of the data. Figures

iv) Compute the variance explained in the normalized data set by each of the EOF modes as well as the variance explained in the (i.e. filtered anomalies) by each of the EOF modes.

v) Compute the variance explained by each of the three input fields for each EOF mode.

vi) Calculate the lag correlation between PC-1 and PC-2 as in level 1 metrics 4a. Figures

vii) Assess the statistical significance of the EOF's as described in General. Figures

viii) Compute the mean coherence^2 and phase of PC-1 and PC-2. Figures

3) LIFE-CYCLE COMPOSITES.

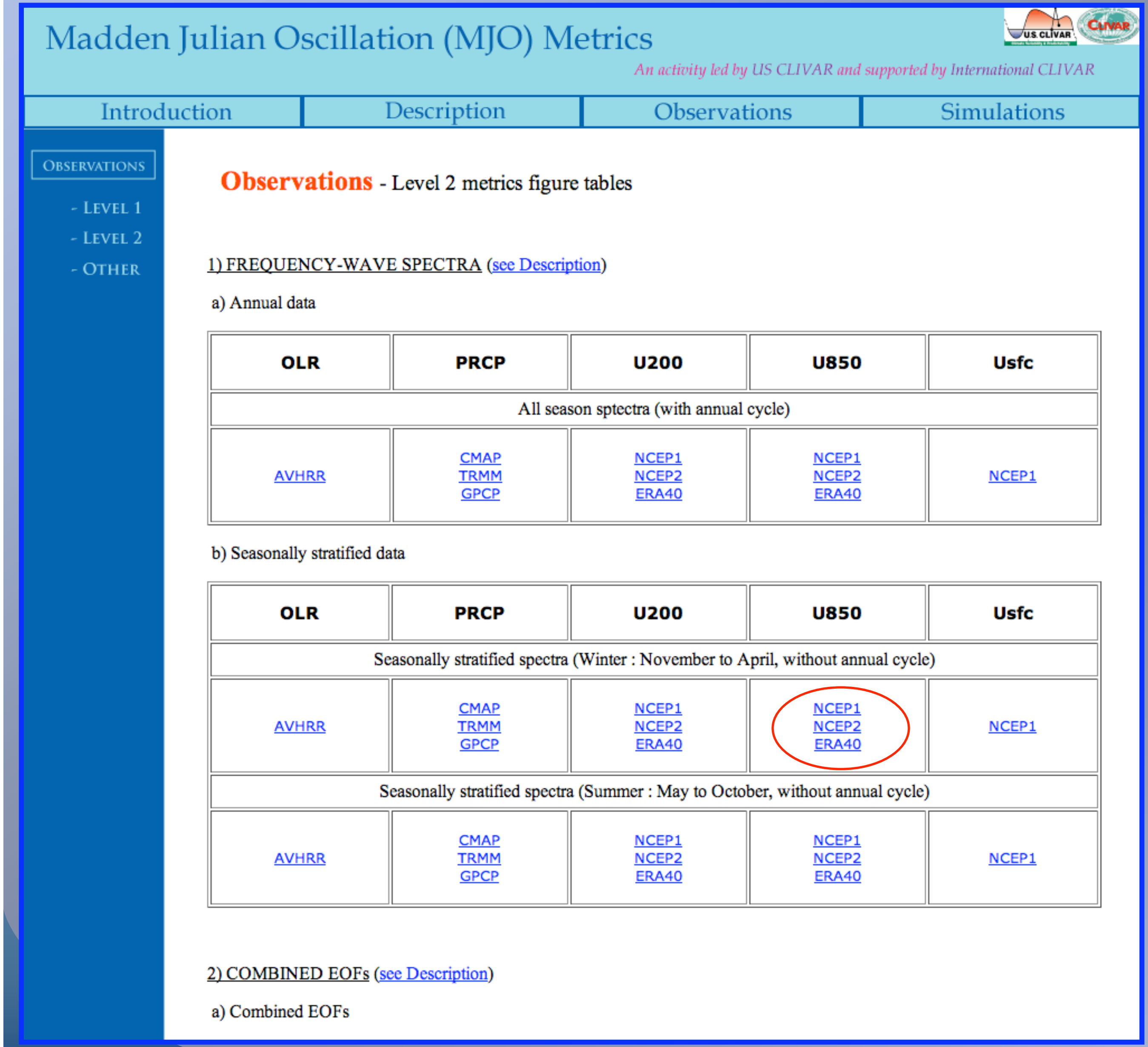
i) Identify MJO events through plots of PC-1 vs. PC-2 from the combined EOFs. Specifically, select points exceeding a root-mean [i.e. $\mathrm{sqrt}(PC\text{-}1^2 + PC\text{-}2^2) > 1$].

ii) Based on a two dimensional phase diagram of PC-1 and PC-2 (Figures), define eight different phases of the MJO and generate spatial composites of the selected points according to these phases. Figures

Web Site Metrics

Recipe for Calculating Metrics

Plan To Make Calculation Codes Available



Madden Julian Oscillation (MJO) Metrics

An activity led by US CLIVAR and supported by International CLIVAR

Observations - Level 2 metrics figure tables

1) FREQUENCY-WAVE SPECTRA (see Description)

a) Annual data

OLR	PRCP	U200	U850	Usfc
All season sptectra (with annual cycle)				
AVHRR	CMAP TRMM GPCP	NCEP1 NCEP2 ERA40	NCEP1 NCEP2 ERA40	NCEP1

b) Seasonally stratified data

OLR	PRCP	U200	U850	Usfc
Seasonally stratified spectra (Winter : November to April, without annual cycle)				
AVHRR	CMAP TRMM GPCP	NCEP1 NCEP2 ERA40	NCEP1 NCEP2 ERA40	NCEP1
Seasonally stratified spectra (Summer : May to October, without annual cycle)				
AVHRR	CMAP TRMM GPCP	NCEP1 NCEP2 ERA40	NCEP1 NCEP2 ERA40	NCEP1

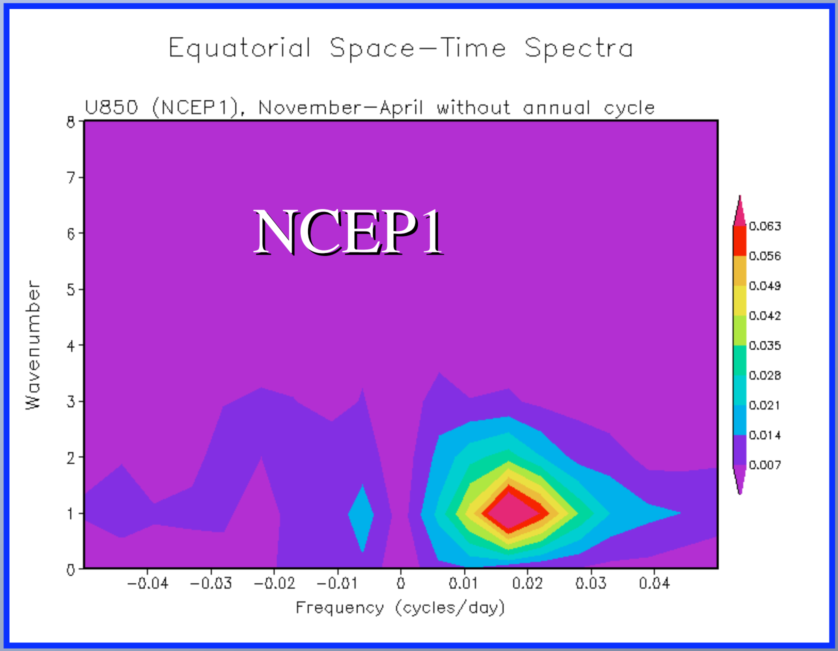
2) COMBINED EOFs (see Description)

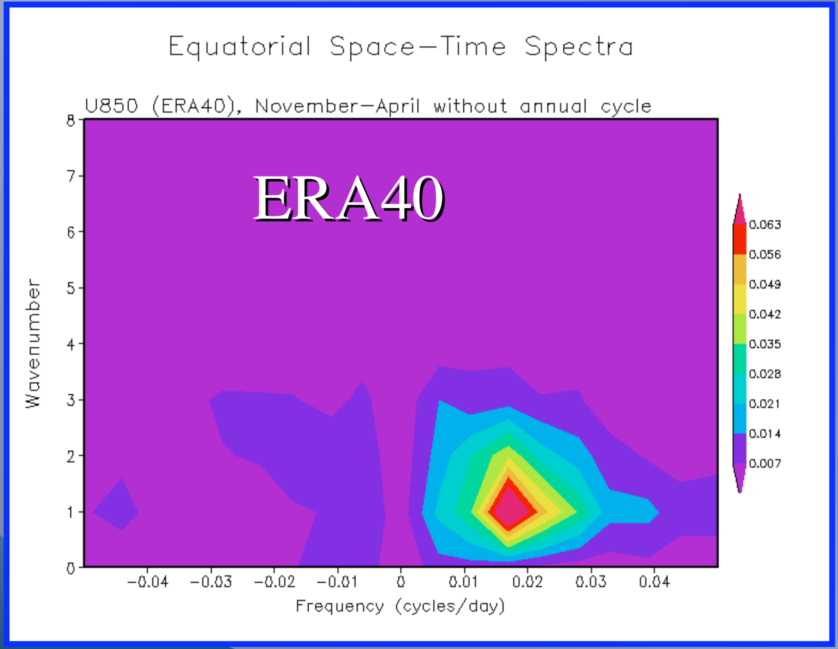
a) Combined EOFs

WEB SITE METRICS

PLAN TO MAKE THE ACTUAL MAP/PLOT DATA AVAILABLE

SUMMARIZE RESULTS IN A JOURNAL ARTICLE





WEB SITE METRICS

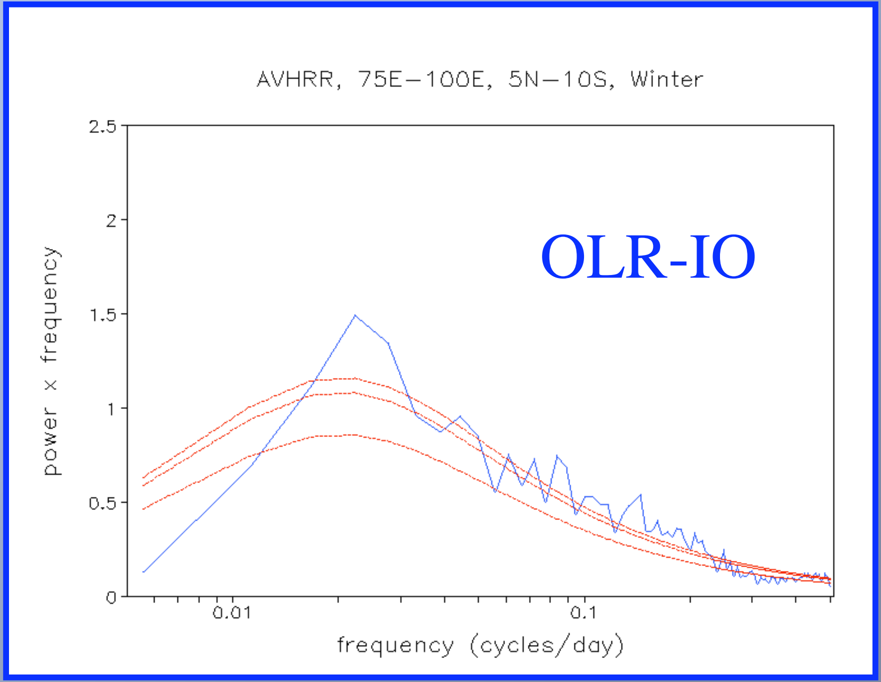
EQUATORIAL SPACE-TIME SPECTRA U, RAIN, OLR

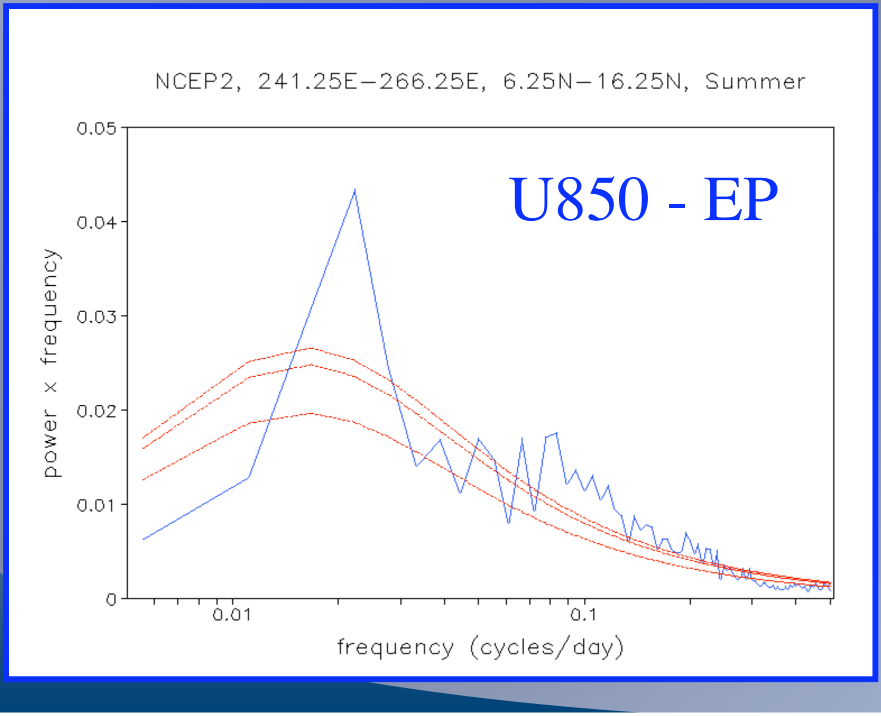
NCEP1,
NCEP2,
& ERA40

WEB SITE METRICS

TIME SERIES SPECTRA
U, RAIN, OLR

DOMAINS OF INTEREST





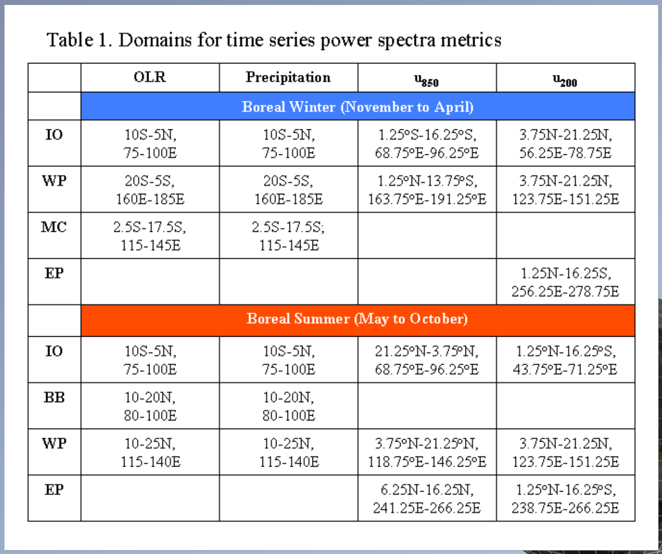
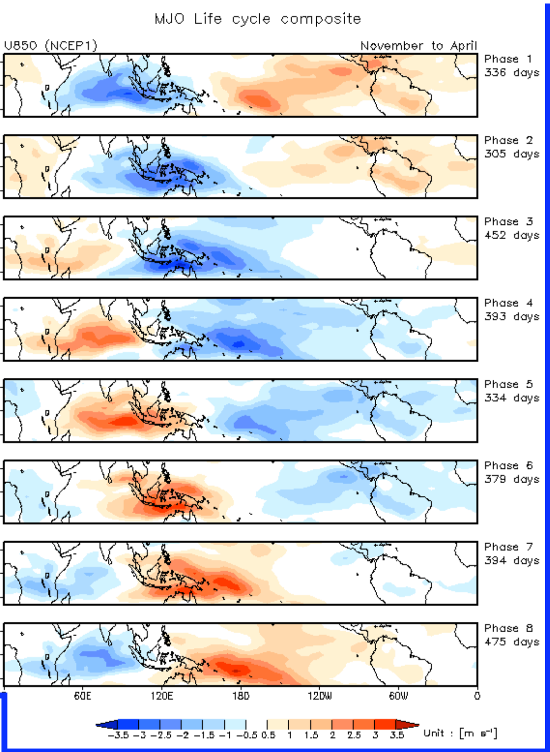


Table 1. Domains for time series power spectra metrics

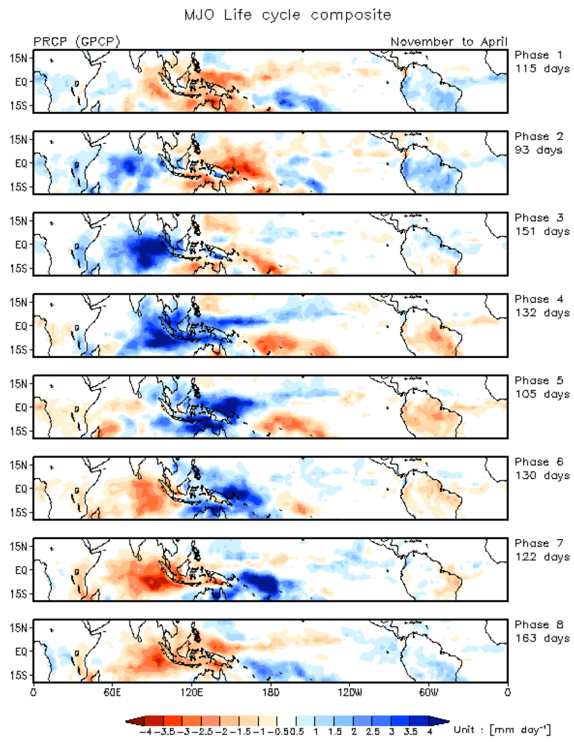
	OLR	Precipitation	u_{850}	u_{200}
	Boreal Winter (November to April)			
IO	10S-5N, 75-100E	10S-5N, 75-100E	1.25°S-16.25°S, 68.75°E-96.25°E	3.75N-21.25N, 56.25E-78.75E
WP	20S-5S, 160E-185E	20S-5S, 160E-185E	1.25°N-13.75°S, 163.75°E-191.25°E	3.75N-21.25N, 123.75E-151.25E
MC	2.5S-17.5S, 115-145E	2.5S-17.5S; 115-145E		
EP				1.25N-16.25S, 256.25E-278.75E
	Boreal Summer (May to October)			
IO	10S-5N, 75-100E	10S-5N, 75-100E	21.25°N-3.75°N, 68.75°E-96.25°E	1.25°N-16.25°S, 43.75°E-71.25°E
BB	10-20N, 80-100E	10-20N, 80-100E		
WP	10-25N, 115-140E	10-25N, 115-140E	3.75°N-21.25°N, 118.75°E-146.25°E	3.75N-21.25N, 123.75E-151.25E
EP			6.25N-16.25N, 241.25E-266.25E	1.25°N-16.25°S, 238.75E-266.25E

WEB SITE METRICS

LIFE-CYCLE COMPOSITES
U, RAIN, OLR, SLP, SF



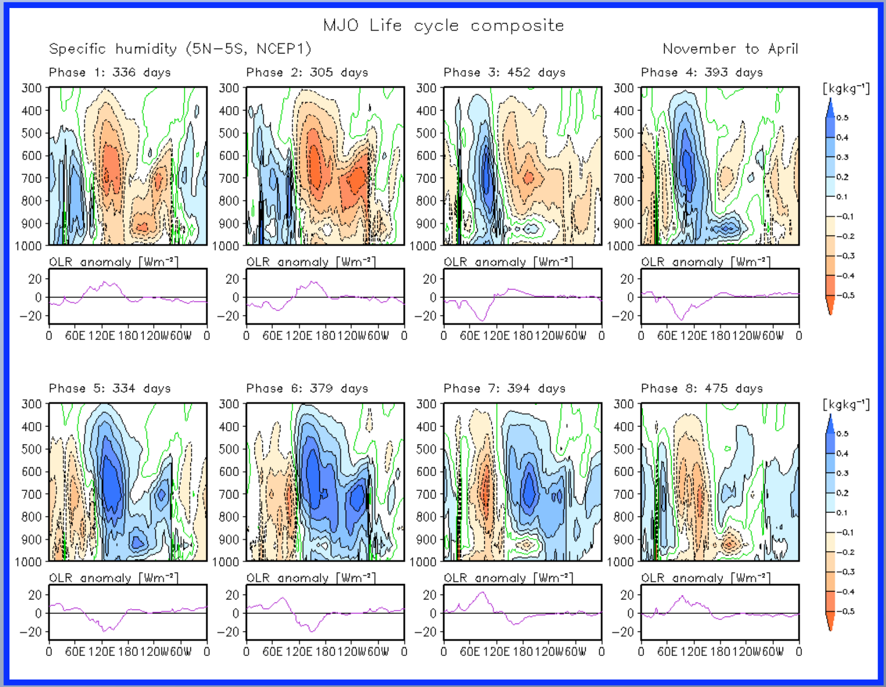
U850



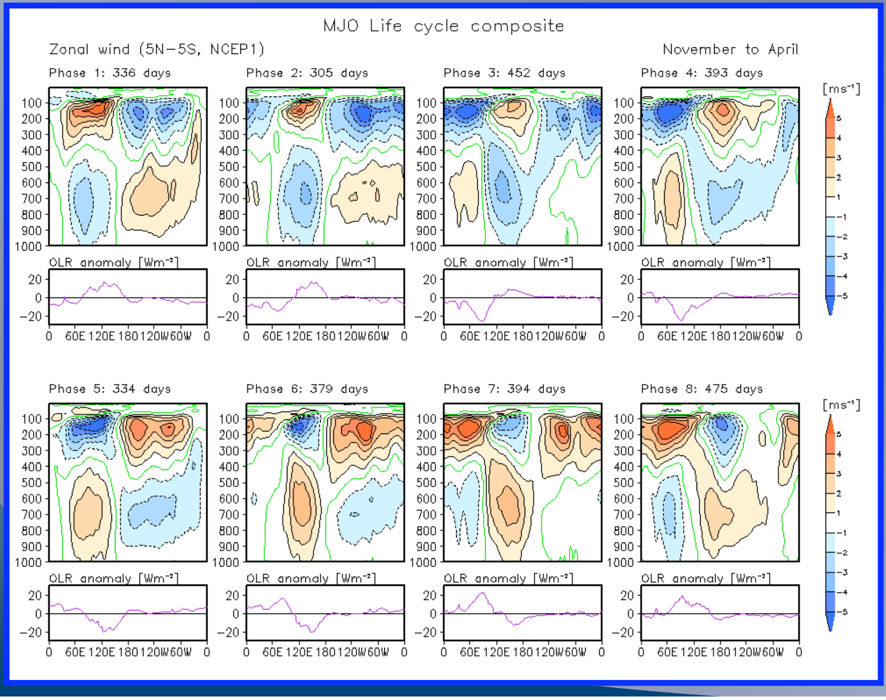
Rainfall

<u>SATELLITE RAIN/CLOUD</u>: AVHRR, GPCP, TRMM
<u>ANALYSIS DATA:</u> NCEP1,NCEP2

WEB SITE METRICS



Specific Humidity (x,p)



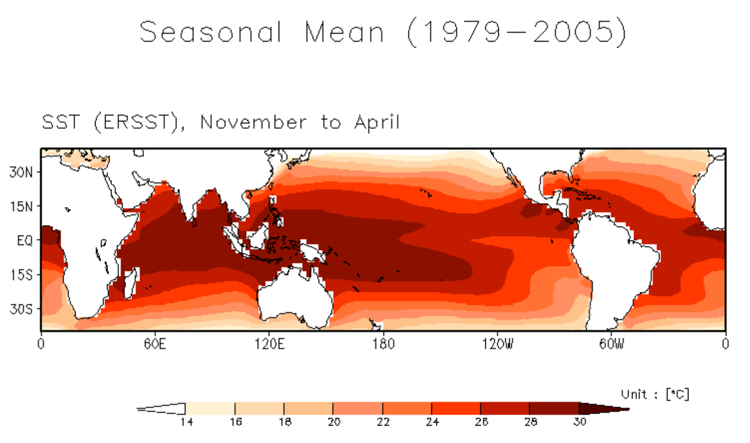
Zonal Wind (x,p)

LIFE-CYCLE
3D COMPOSITES
T, Q, U, W

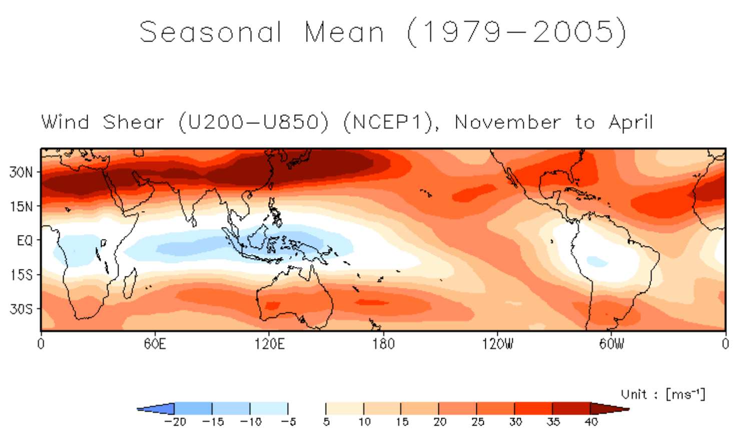
Web Site Metrics

Important Mean State Quantities

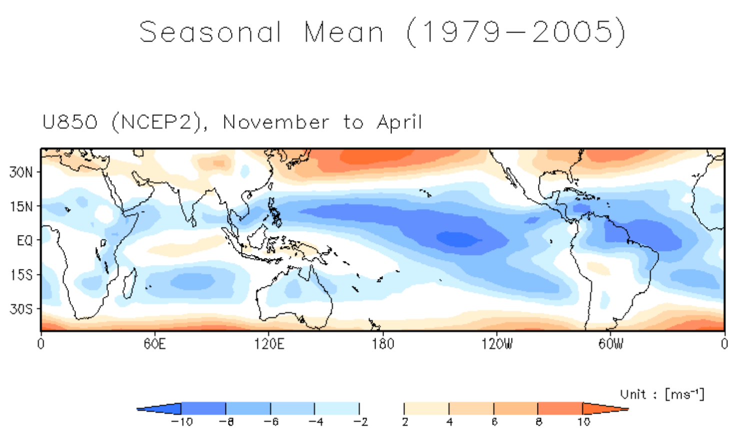
Mean SST

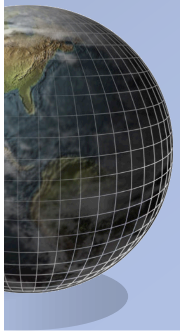


Mean Zonal Wind Shear



Mean 850 hPa Zonal Wind





MJO FORECAST METRICS

Metrics to Assess in Common Terms MJO Forecast Skill/Predictability and Prediction Targets Focused on Users and Applications

- Similar Considerations as with Simulations Metrics
- Connect to the Simulation Metrics As Much as Possible
- Real-time Constraints Introduce Challenges in Identifying the MJO
- Less Groundwork to Rely On - Will Need to Entrain Operational Weather and Seasonal Forecast Expertise.
- Dissemination - Similar to Simulation Metrics

Hope to be here by Summer

PROPOSED WORKSHOP THEME

New Thinking, Tools & Resources for Assessing & Improving simulations and forecasts of the MJO

-> CMMAP INPUT WELCOME

- **New Thinking**:
  Multi-scale structure, Emphasis on Vertical Structure Analysis, Utility of Forecast Framework, A Bridge Between Weather-Climate

- **New Tools & Resources:**
  New Era of Satellite Observations, GOOS/IO Array, Multi-Scale Modeling.

- **Principle Focus Areas:**
  ----> Metrics Application & Vertical Structure ->
  -> Experimental Framework for Multi-Scale Models --->
  -> Experimental Framework for Forecast Experiments --->

http://www.usclivar.org/Organization/MJO_WG.html

And now for a Broader Context

A Joint WCRP/THORPEX Proposed Activity

Year of coordinated Observing, modeling and Forecasting:

Addressing the Challenge of Organized Tropical Convection

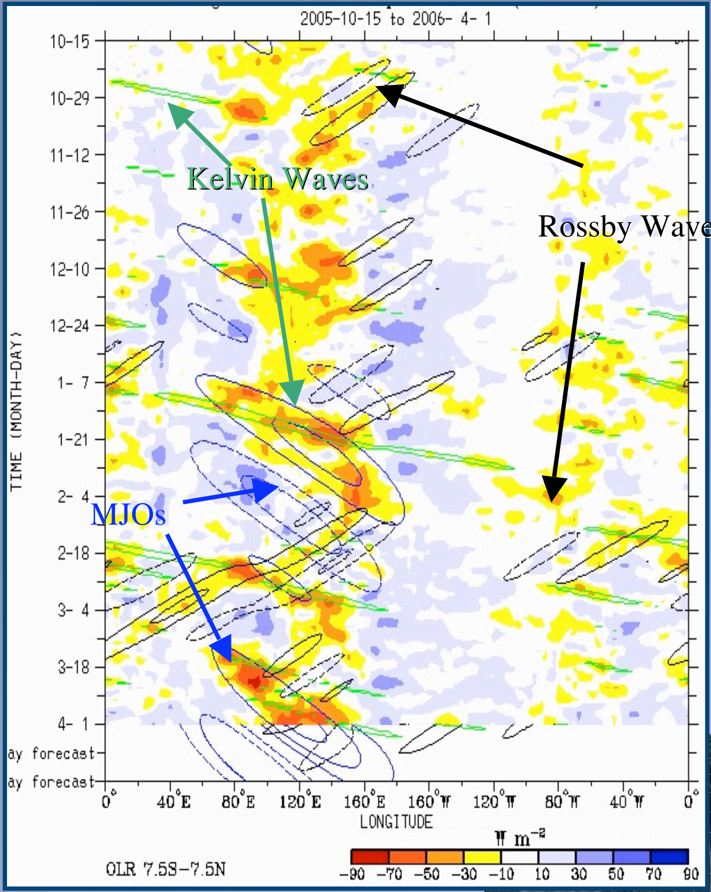
AKA : Year of Tropical Convection (YOTC)

A recommendation from the THORPEX/WCRP/ICTP Workshop on Organization and Maintenance of Tropical Convection and the MJO, in Trieste, March 2006. If implemented in 2008/9, this would be a WCRP/THORPEX contribution to the UN Year of Planet Earth.

Our shortcomings in tropical convection severely limit the representation of key physics in weather & climate models

- Diurnal cycle - strongest "forced" signal in the climate system.
- Synoptic waves and **easterly waves**, including development & evolution of **hurricanes and Tropical cyclones**
- **Madden-Julian Oscillation** (**MJO**) and other large-scale convectively-coupled waves
- **monsoon** variability, including onset and break activity.
- Tropical mean state, including ITCZ and distributions of rainfall over oceans & continents

Winter 2005-6

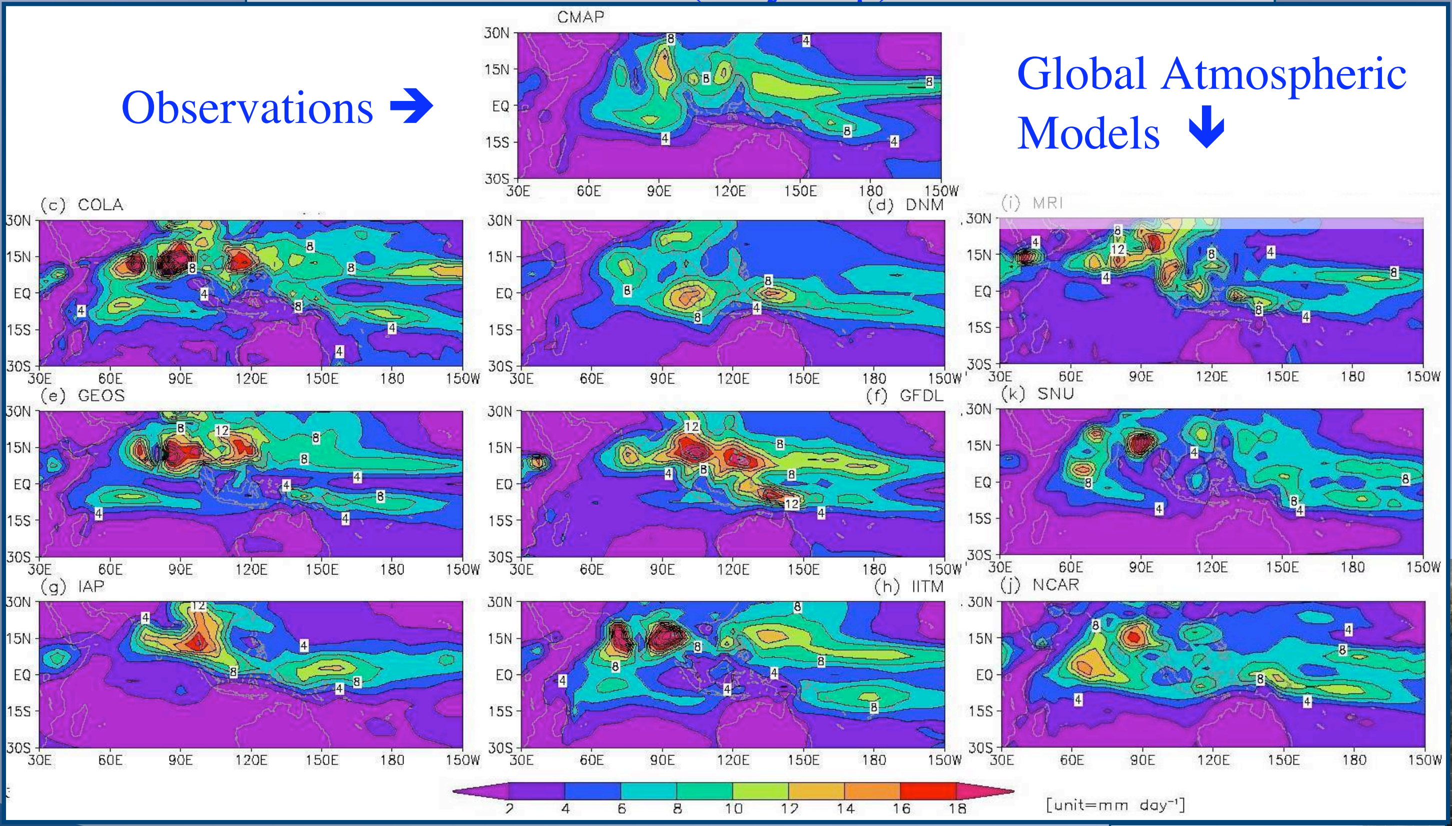


Dominant Convectively-Coupled Tropical Waves Projected onto OLR Anomalies. Wheeler and Weickmann, 2001

New and/or consolidated approaches are needed, approaches that are able to coordinate and focus the vast new resources developed in recent years . Past attempts included programs such as GATE, FGGE & TOGA COARE.

Our new approaches should combine the strengths of such efforts with our vastly expanding observational infrastructure & the tremendous gains seen in computational power.

Mean Asian Summer (May-Sep) Monsoon Rainfall


Observations ➔

Global Atmospheric Models ⬇

Waliser et al., 2003

SIGNIFICANT ADVANCES IN RESOURCES

THE PAST 10-15 YEARS HAVE MARKED EXTRAORDINARY GAINS IN OBSERVATIONS, MODELING AND TECHNOLOGICAL INFRASTRUCTURE. IN PARTICULAR:

- SUBSTANTIAL PROGRESS TOWARDS GOOS
- ESTABLISHED ENHANCED IN-SITU OBSERVATIONAL SITES
- ARRIVAL OF EOS-ERA OF SATELLITE OBSERVATIONS

THE TROPICAL ATMOS-OCEAN-LAND SYSTEM HAS NEVER BEEN SO WELL OBSERVED.

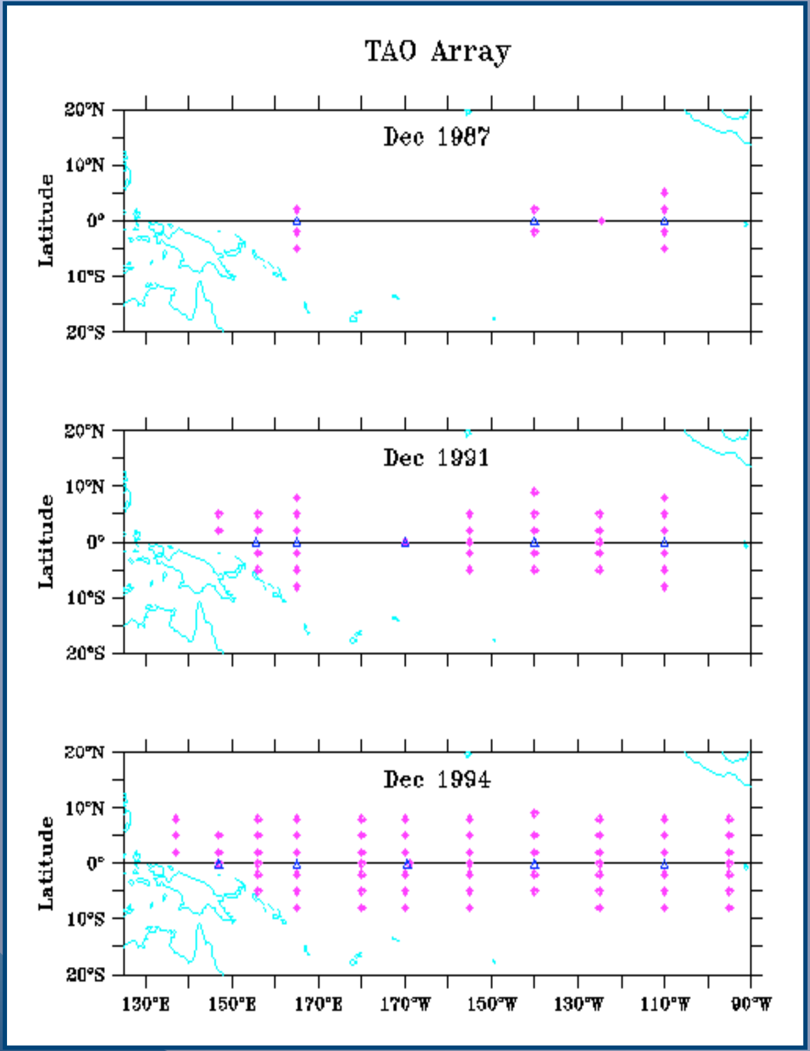
- ARRIVAL OF GLOBAL CLOUD-SYSTEM "RESOLVING" MODELS

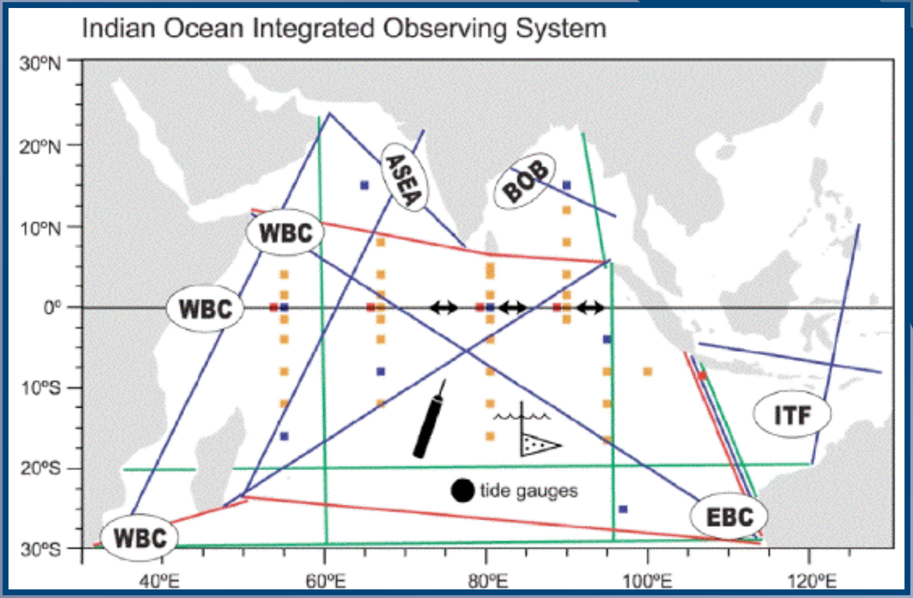
WE HAVE COME TO APPRECIATE IN MANY CASES:

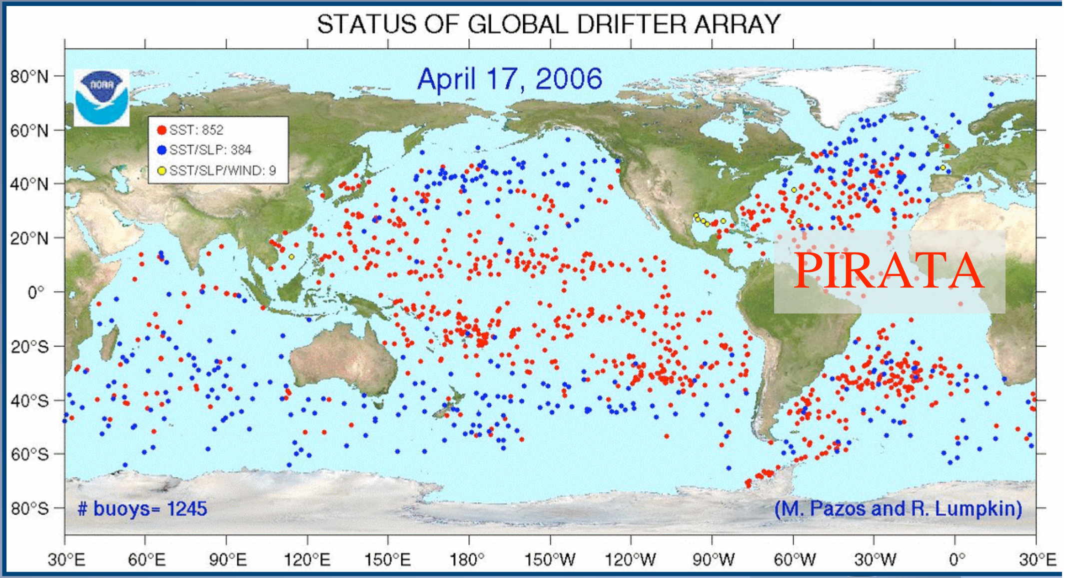
- SHORT-TERM WEATHER ERRORS <-> LONG-TERM CLIMATE BIASES

THESE ADVANCES IN RESOURCES, TECHNOLOGY AND THINKING NEED TO BE, WOVEN TOGETHER TO MAXIMIZE RETURN ON INVESTMENT.

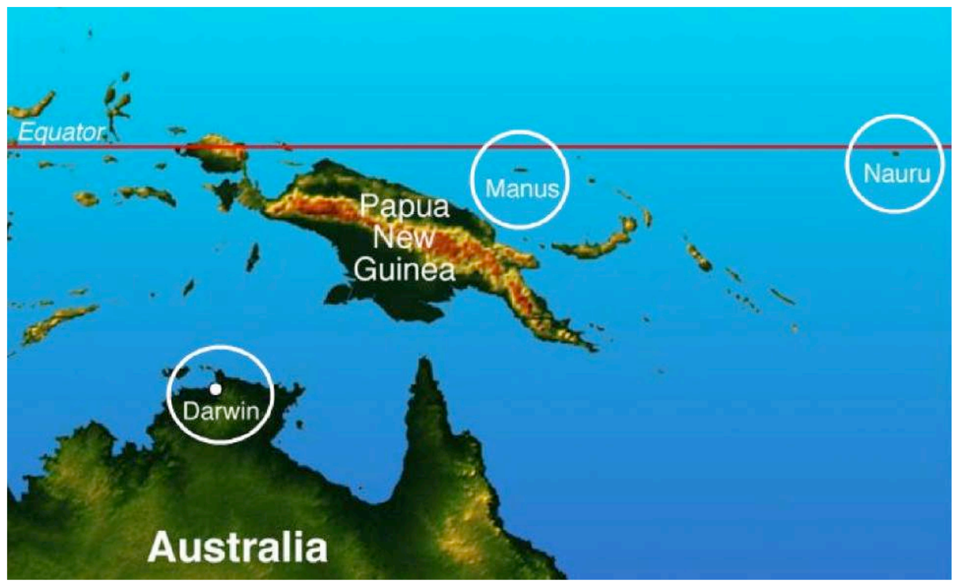
PROGRESS TOWARDS GOOS


TAO Array


Indian Ocean Integrated Observing System

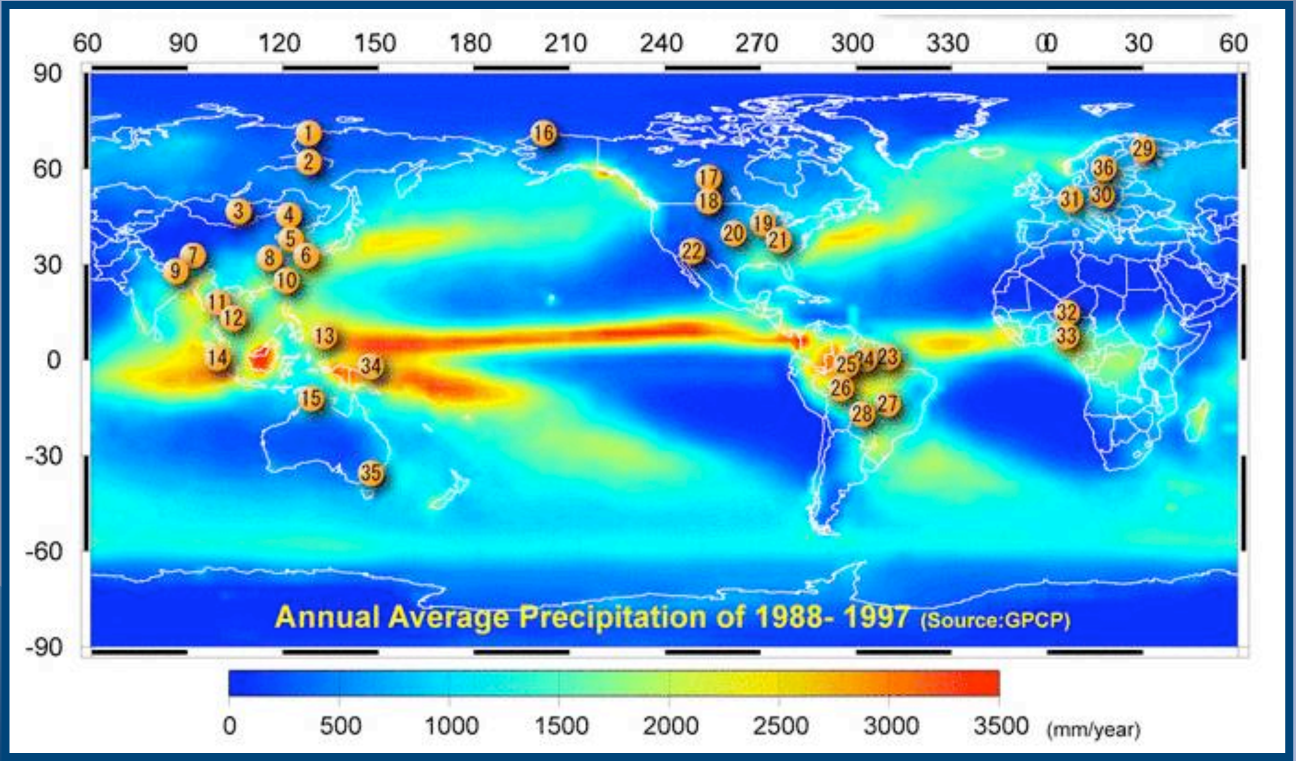

STATUS OF GLOBAL DRIFTER ARRAY
April 17, 2006

ENHANCED IN-SITU OBSERVATION PROGRAMS



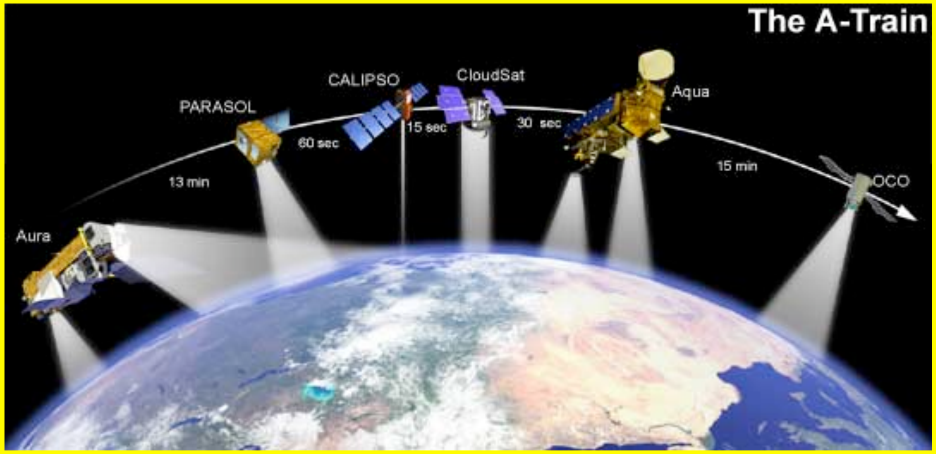
ARM TWP

GEWEX/CEOP



Annual Average Precipitation of 1988- 1997 (Source:GPCP)

Arrival of the EOS-era of Satellite Observations



Merely a sample, consider where we were 10-15 years ago…

TOPEX: sea surface height
QuickScat: ocean surface winds
TRMM: precipitation
TMI: sea surface temperature w/clouds
AIRS: temperature and water vapor profiles
CloudSat: cloud profiles
Calipso: aerosol/thin-cloud profiles
AMSRE: ocean precip, water vapor, liquid water
MLS: upper tropospheric water vapor, cloud ice, temperature
CERES: TOA and surface radiative fluxes
MODIS: cloud characteristics, ocean color, land characteristics
AURA platform: atmospheric composition/chemistry
MISR: aerosol and cloud structure

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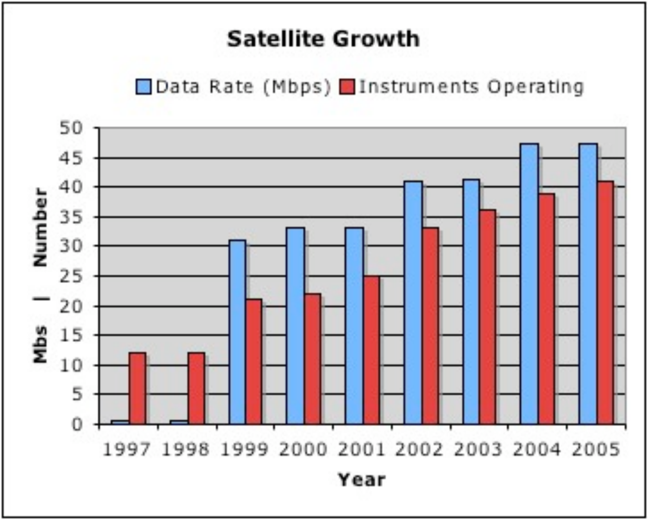
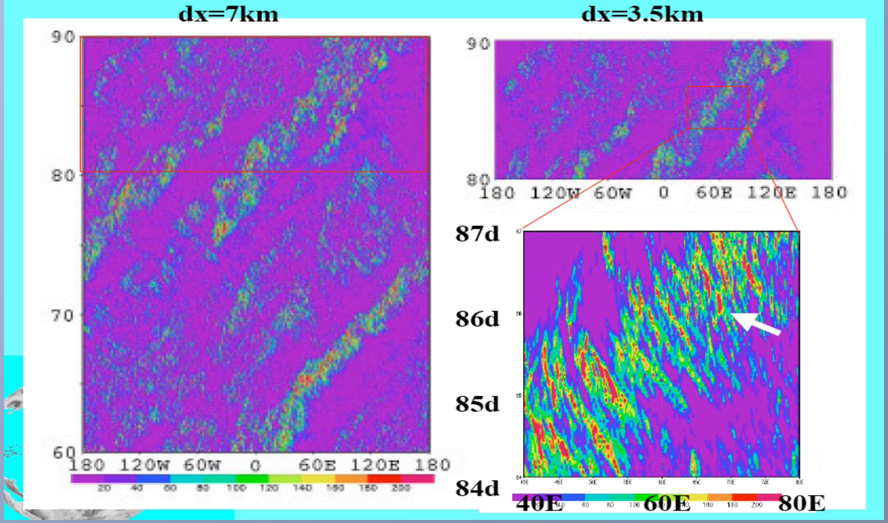
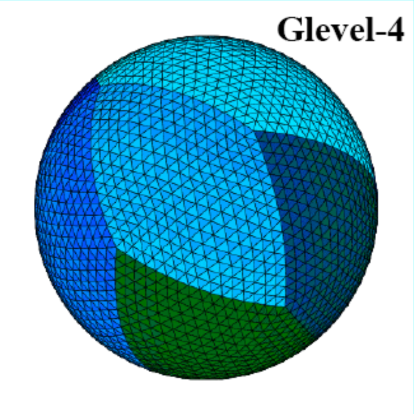


GLOBAL CLOUD-SYSTEM RESOLVING MODELS

Far from a single enterprise anymore…

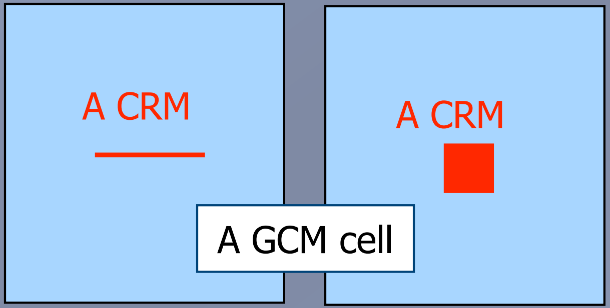


Courtesy Satoh Frontier Research Center for Global Change



Glevel-9: Δx=14km
Glevel-10: Δx=7km
Glevel-11: Δx=3.5km

MMF; "superparameterization"



A CRM

A CRM

A GCM cell

@ CSU, LLNL, GSFC & PNNL

NCAR
CHANNEL
Model"

DARE

Rossby radius
~100km

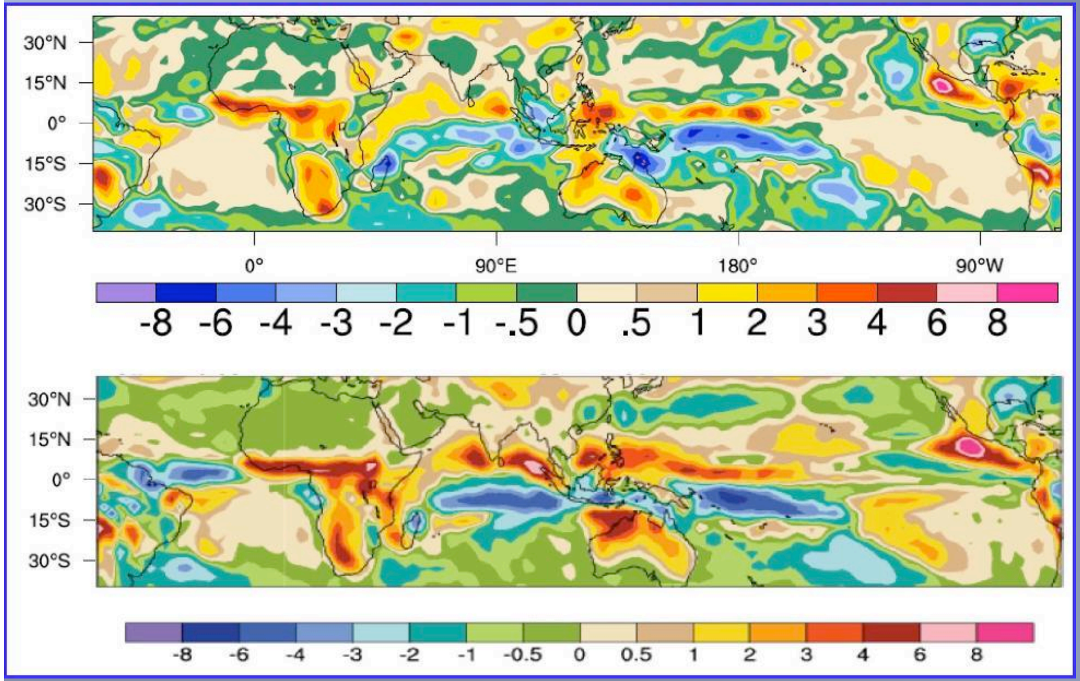
4km

Courtesy Kuang

Short-term weather errors <-> Long-term climate biases

CAPT Project runs climate models in weather forecast mode*

Perfectly suited to a "focus year" Approach



NCAR Day 3 Precipitation Error
for DJF 1992-93

NCAR Precipitation Error
for DJF Climatology

**The CAPT project is a joint project at LLNL of the DOE CCPP and ARM Programs*

Courtesy S. Klein

YEAR OF COORDINATED OBSERVING, MODELING AND FORECASTING OF TROPICAL CONVECTION

Motivation

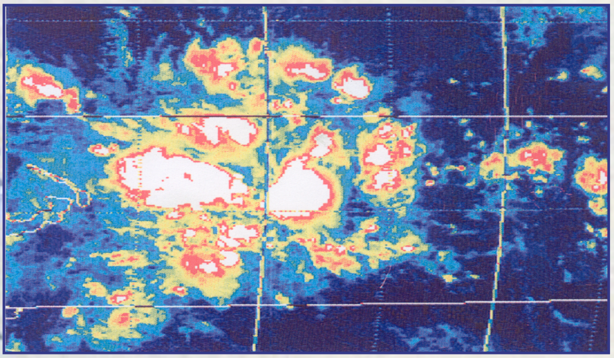
Leveraging the vast new observational datasets and computational resources in conjunction with new / high-resolution modeling frameworks to better characterize, understand, model and forecast multi-scale convective processes / dynamical interactions.

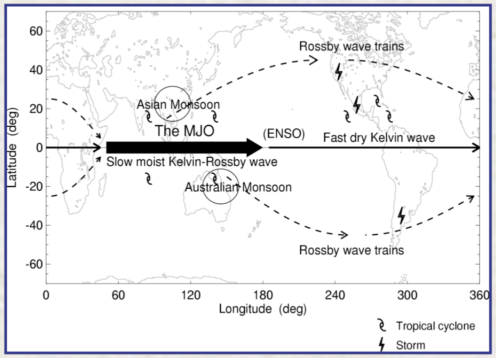
Proposal: Focus Year of Observation, Modeling & Prediction.
Timeframe: ~2008 for ~ 1 Year
Region: ~ 40N - 40S : tropical-extratropical interests may warrant extending this.
Time Scales: Diurnal to Seasonal.
Case Study with Detailed Analyses**,** Modeling & Forecasting.
Central Repositories of in-situ, satellite & model data to store/disseminate data.
Leverage/Coordinate existing resources.

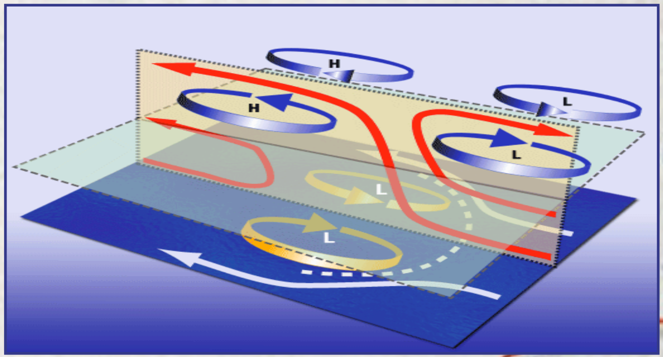
Year of Coordinated Observing, Modeling and Forecasting Of Tropical Convection

Fundamental Science Questions

- What are the most crucial elements of the large-scale circulation that influence the development, organization and maintenance of tropical convection?
- Under what circumstances and with what mechanisms is energy and momentum transferred between the convective, mesoscale, synoptic scale, and the large/planetary scale?
- How does organized tropical convection interact with the extra-tropical circulation?







YEAR OF COORDINATED OBSERVING, MODELING AND FORECASTING OF TROPICAL CONVECTION

Potential Target Phenomena

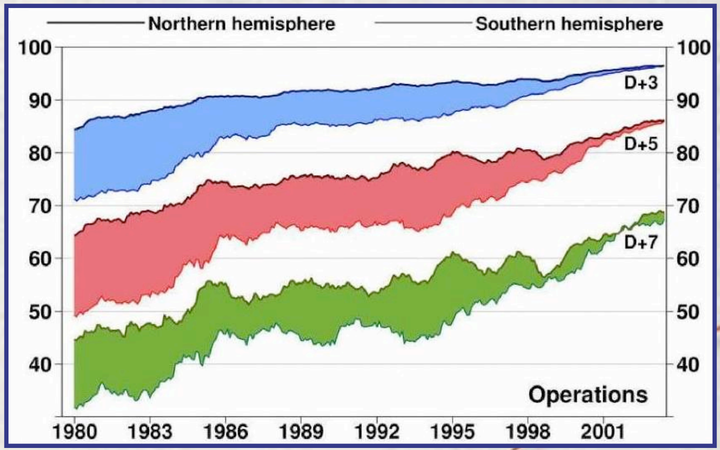
- **Madden-Julian Oscillation (MJO)**-Advances in our modeling capabilities in the MJO are expected to lead to significant untapped predictability in both tropical weather forecasts, monsoon onsets and breaks, extra-tropical weather, and provide a bridge between weather and climate predictions.
- **Convectively Coupled Waves (CCWs)** - Considered to be important building blocks of tropical convective variability and its organization (including the MJO), it is essential that such fundamental modes of variability be properly represented in our weather and climate models.
- **Easterly Waves** - An important triggering mechanisms for tropical storms and cyclones, this organizing mechanism is crucial for properly forecasting high impact events as well as simulating an important land-atmosphere-ocean interaction and its impact on mean state features (e.g., ITCZ).
- **Diurnal Cycle -** Our shortcomings in representing arguably the most basic and strongest forced mode of variability demands attention. Moreover, studies indicate that the diurnal scale can rectify onto longer time scale processes.
- **Monsoons -**These are complex multi-scale processes and within the proposed activity could be considered as the ultimate challenge or integrating theme as their variability is strongly influenced by the diurnal cycle, CCWs, the MJO, and land-atmosphere-ocean interaction.

YEAR OF COORDINATED OBSERVING, MODELING AND FORECASTING OF TROPICAL CONVECTION

Overarching Goals

Through better understanding, improved data assimilation techniques/resources, and modeling capabilities, **achieve significant gains in forecast skill** by 2010 in:

- **Medium-range tropical weather forecasts, particularly disturbed conditions associated with organized convection.**
- **Extended-range/subseasonal forecasts of the MJO.**
- **Medium-to-extended range extratropical forecasts derived from improved tropical weather/climate and tropical-extratropical interactions.**



Courtesy A. Simmons & M. Miller

YEAR OF COORDINATED OBSERVING, MODELING AND FORECASTING OF THE TROPICS

Resources / Implementation

Research Agenda

- A set of “Target Phenomena” working groups and a series of international workshops designed to identify the most pressing and tractable problems from the Focus Year, design and coordinate activities, share modeling strategies and successes, report results, and iterate on additional problems or future Years.

Observations

- Traditional aspects of the operational in-situ and satellite network.
- The wide array of new, research-oriented satellite missions.
- Time-scale relevant aspects of the GOOS (e.g., buoy arrays, drifters, floats),
- Enhanced in-situ measurement programs (e.g., ARM, GEWEX/CEOP)
- IOPs of opportunity (e.g., AMMA, VOCALS, TACE, T-PARC)

YEAR OF COORDINATED OBSERVING, MODELING AND FORECASTING OF THE TROPICS

Resources / Implementation, Continued

Modeling & Forecasts

- THORPEX Interactive Grand Global Ensemble (TIGGE). *Examine forecast error growth to investigate model parameterization shortcomings as well as initial condition errors, with special emphasis on identified cases/events.*
- A variety of research-oriented multi-scale simulation/hindcast modeling components (e.g., global and regional CRM, MMFs, channel models, AGCMs, CGCMs). *Improving understanding and modeling of multi-scale organized convection, and transitioning knowledge into improved parameterizations and forecasting capability.*

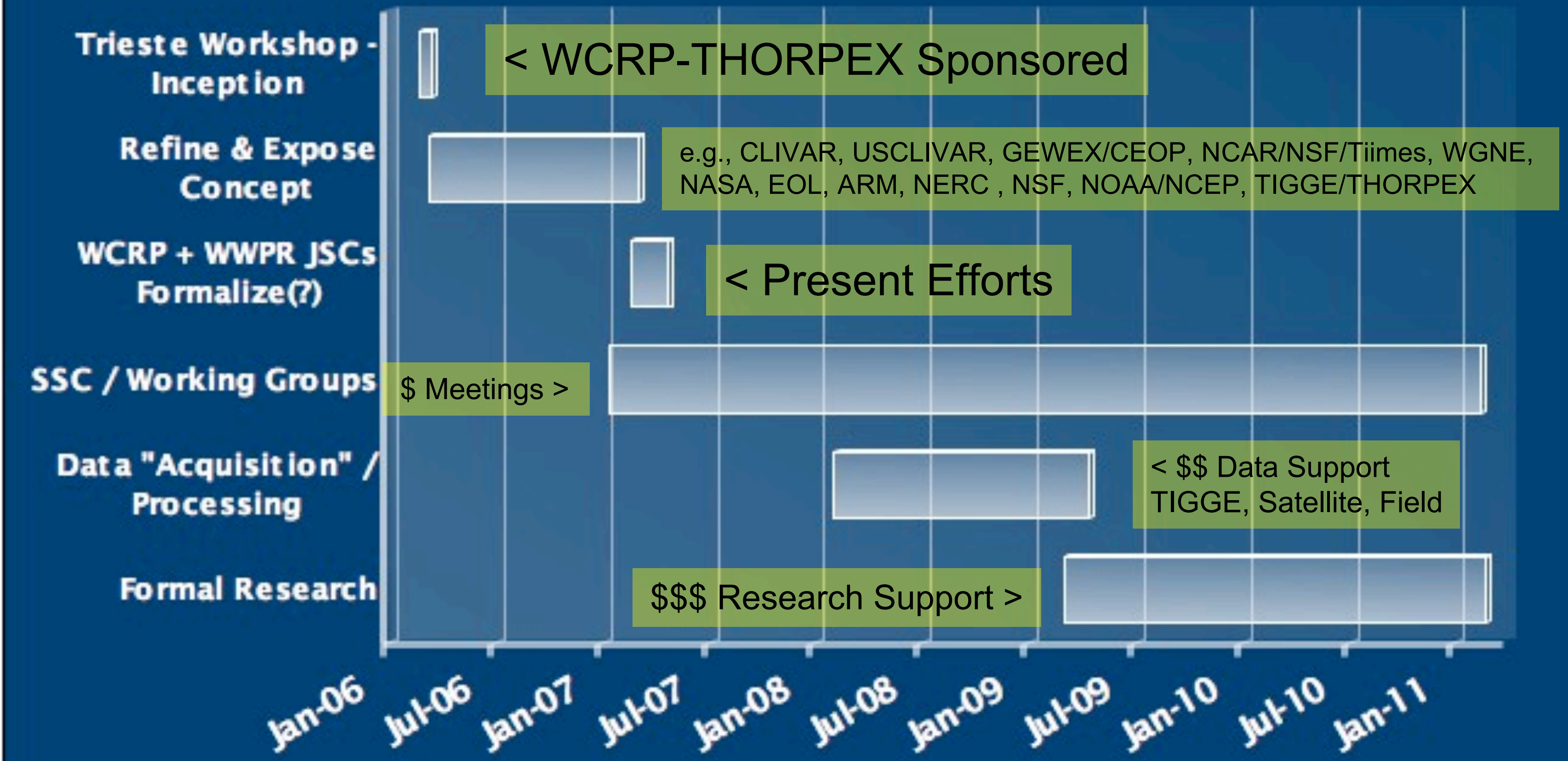
Potential/Additional Data Archiving/Dissemination Resources

- Multi-Component: WIS - WMO Information System
- Field Programs: NCAR/EOL - formerly JOSS
- Satellite: NASA GES DISC (e.g., Giovanni, ATDD)
- Analyses & Forecasts: TIGGE Archive Centers - ECMWF, CMA, NCAR

YEAR OF TROPICAL CONVECTION

Development & Tentative TimeLine

Stems from WCRP-THORPEX Joint Efforts/Discussions on Tropical Convection



< WCRP-THORPEX Sponsored

e.g., CLIVAR, USCLIVAR, GEWEX/CEOP, NCAR/NSF/Tiimes, WGNE, NASA, EOL, ARM, NERC , NSF, NOAA/NCEP, TIGGE/THORPEX

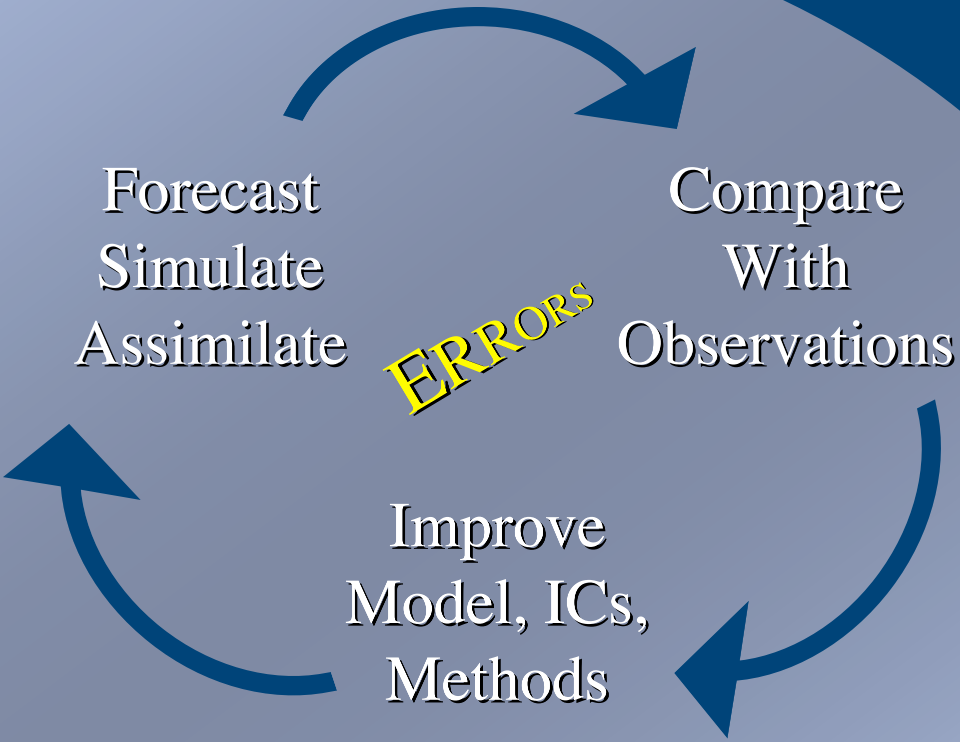
< Present Efforts

$ Meetings >

< $$ Data Support
TIGGE, Satellite, Field

$$$ Research Support >

Year of Coordinated Observing, Modeling and Forecasting Of Tropical Convection



Forecast
Simulate
Assimilate

Compare
With
Observations

Errors

Improve
Model, ICs,
Methods

2007 2008 2009 2010

diurnal cycle, synoptic systems,
intraseasonal, seasonal,
mesoscale-to-planetary-scale organization