Review: Current Research on clouds and Precipitation in my Laboratory

T. N. Krishnamurti
Florida State University
Tallahassee, Florida, 32306

ECMWF-JCSDA Workshop on Assimilating Satellite Observations of Clouds and Precipitation into NWP models

15 – 17 June 2010

Collaborators : Anu Simon, Akhilesh Mishra, Lisa Bucci, Edward Bensman, A Thomas

MY MANY YEARS OF CONTACTS WITH ECMWF, THE LAST 31 YEARS STARTED WITH THE DAYS OF AKSEL WIIN NIELSON AND LENNART BENGTSSON

FSU VISITORS INCLUDED DAVID BURRIDGE (HE WAS IN OUR FACULTY) , BILL HECKLEY , TONY HOLLINGSWORTH AND A FEW OTHERS

THANKS TO PETER BAUER FOR THIS INVITATION

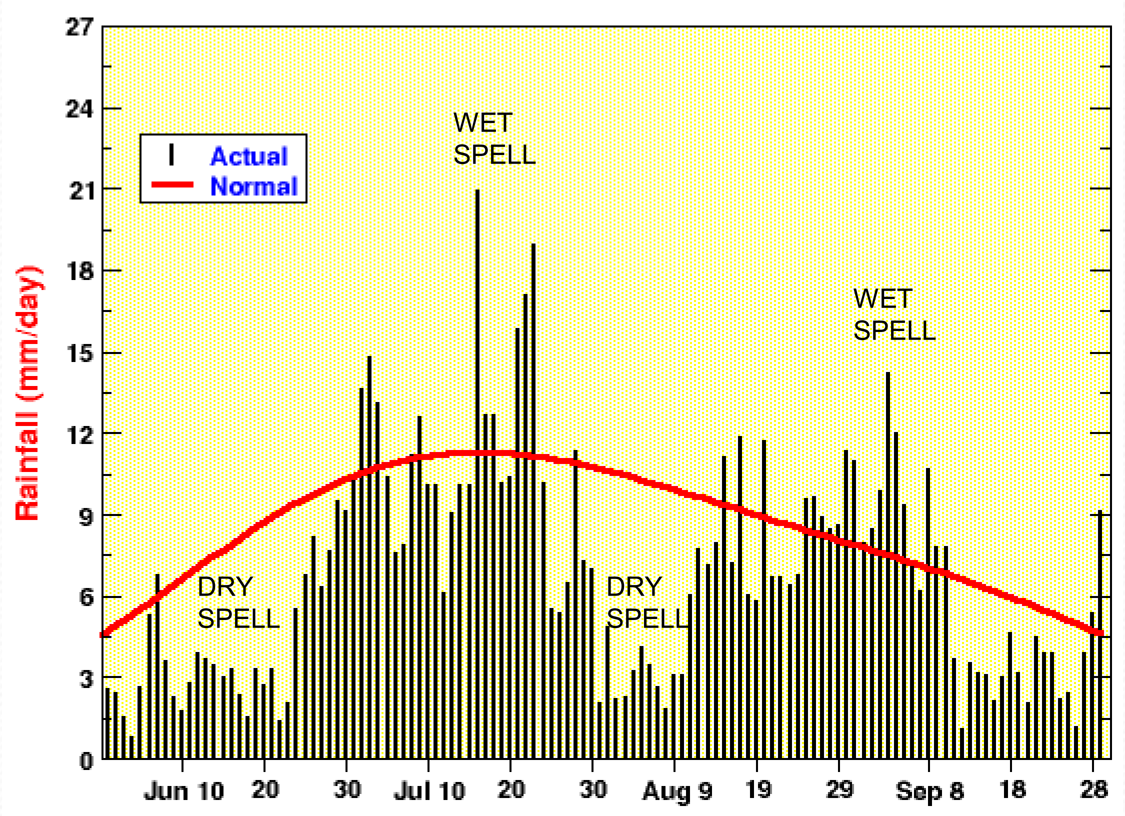
AND CANT RULE OUT MY SEVERAL MEETINGS WITH ADRIAN SIMMONS, TIM PALMER (my India Contact) ,MARTIN MILLER AND SO MANY OTHERS.

THANKS TO YOU ALL

Observational Aspects

Some important factors that relate to the dry spells of the Indian summer monsoon

2009 Summer Monsoon Rainfall



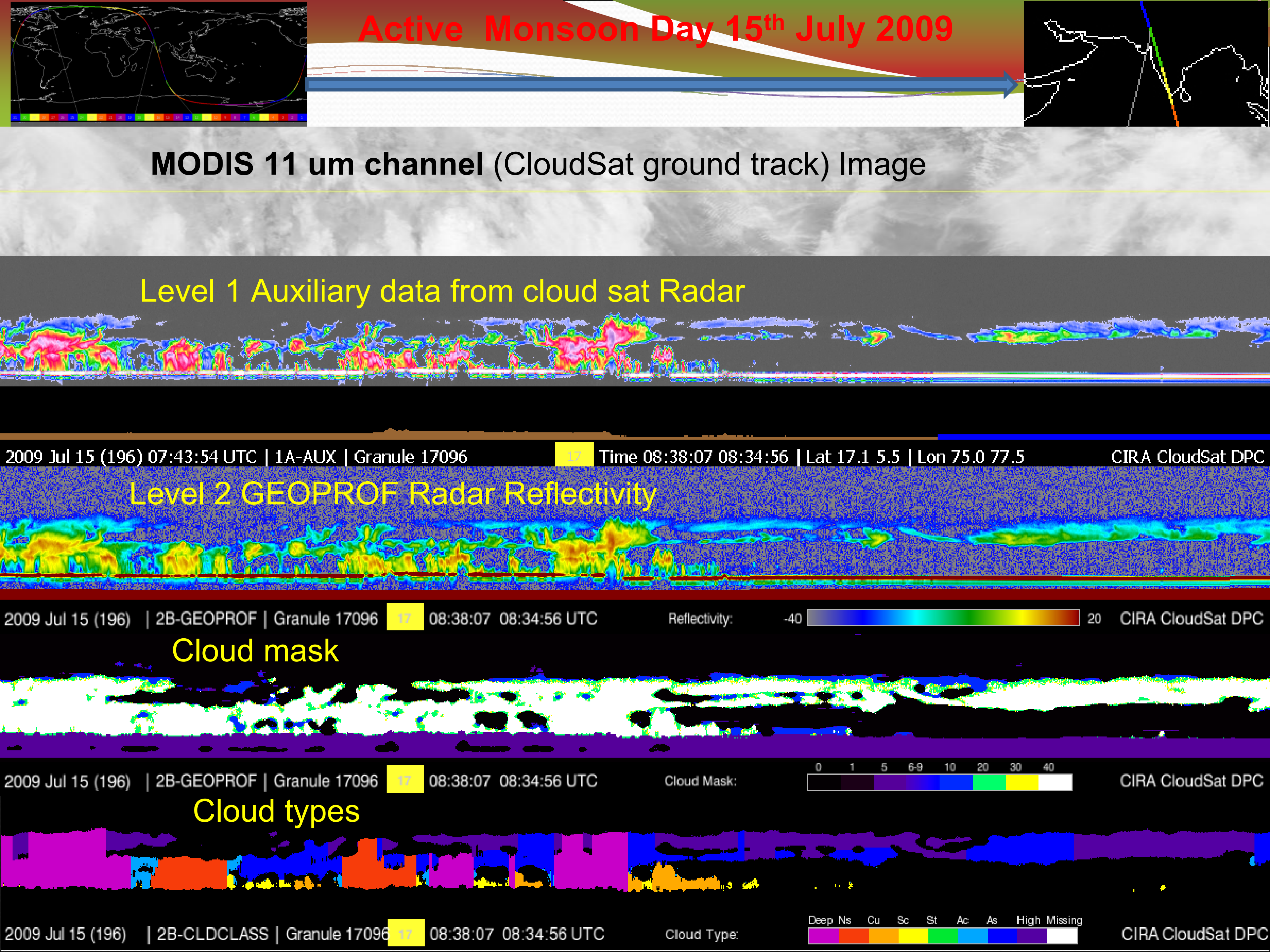
Dry and Wet Spells

Year	Break Days/Period	Active Days
2009	30th July-10th August	14th July -20th July
2008	14th- 19th July; 21st- 24th August	27th-29th July; 10th – 12th August
------	----	---

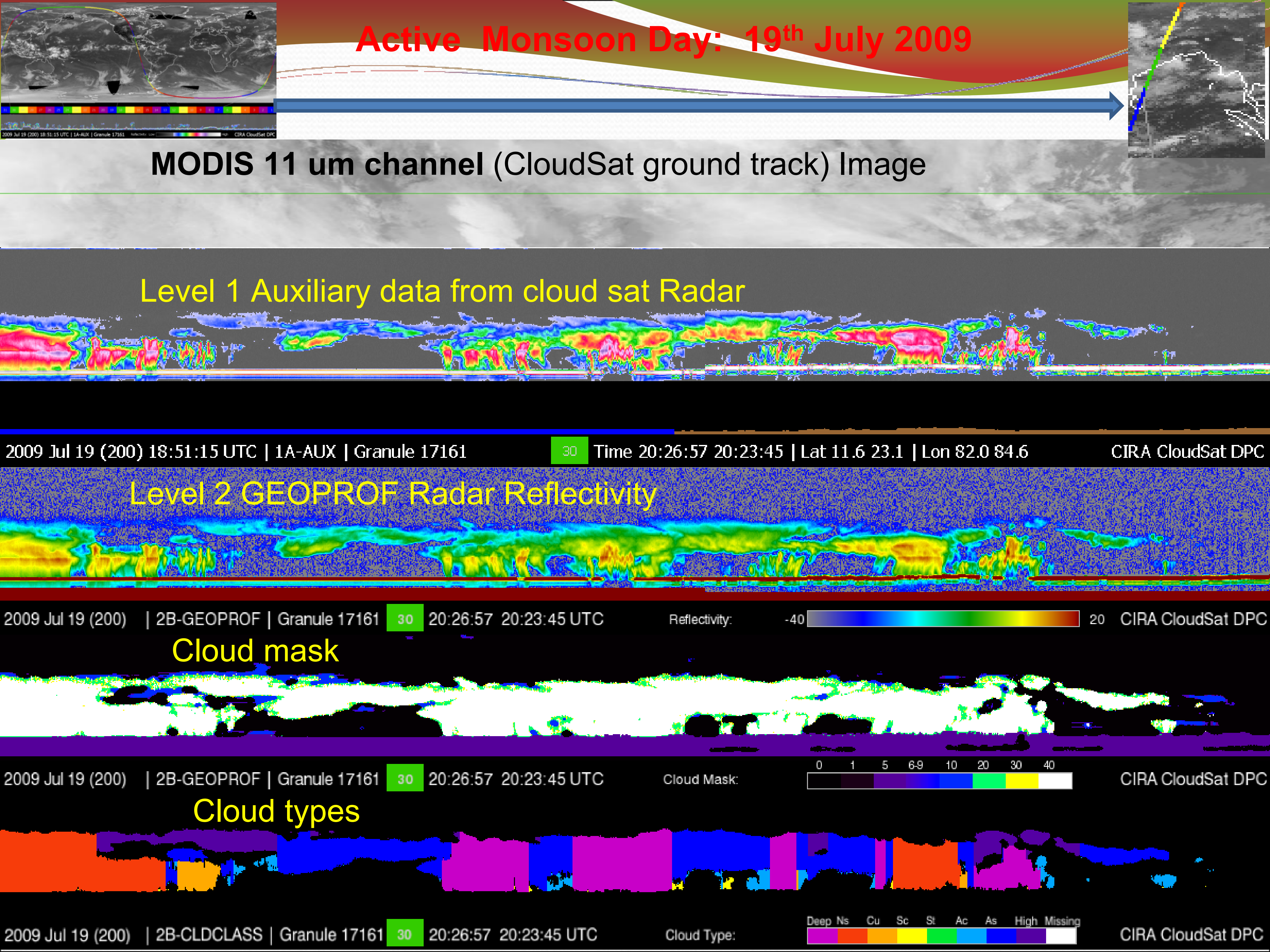
Wet Spell

Monsoon 2009

14th July -20th July


Active Monsoon Day 15th July 2009
MODIS 11 um channel (CloudSat ground track) Image
Level 1 Auxiliary data from cloud sat Radar
2009 Jul 15 (196) 07:43:54 UTC | 1A-AUX | Granule 17096
17
Time 08:38:07 08:34:56 | Lat 17.1 5.5 | Lon 75.0 77.5
CIRA CloudSat DPC
Level 2 GEOPROF Radar Reflectivity
2009 Jul 15 (196) | 2B-GEOPROF | Granule 17096
17
08:38:07 08:34:56 UTC
Reflectivity:
-40
20
CIRA CloudSat DPC
Cloud mask
2009 Jul 15 (196) | 2B-GEOPROF | Granule 17096
17
08:38:07 08:34:56 UTC
Cloud Mask:
0 1 5 6-9 10 20 30 40
CIRA CloudSat DPC
Cloud types
2009 Jul 15 (196) | 2B-CLDCLASS | Granule 17096
17
08:38:07 08:34:56 UTC
Cloud Type:
Deep Ns Cu Sc St Ac As High Missing
CIRA CloudSat DPC

Active Monsoon Day: 19th July 2009

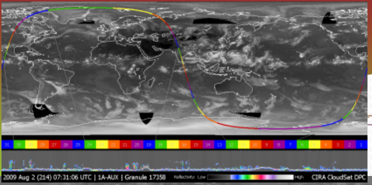


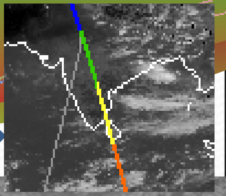
Dry Spell

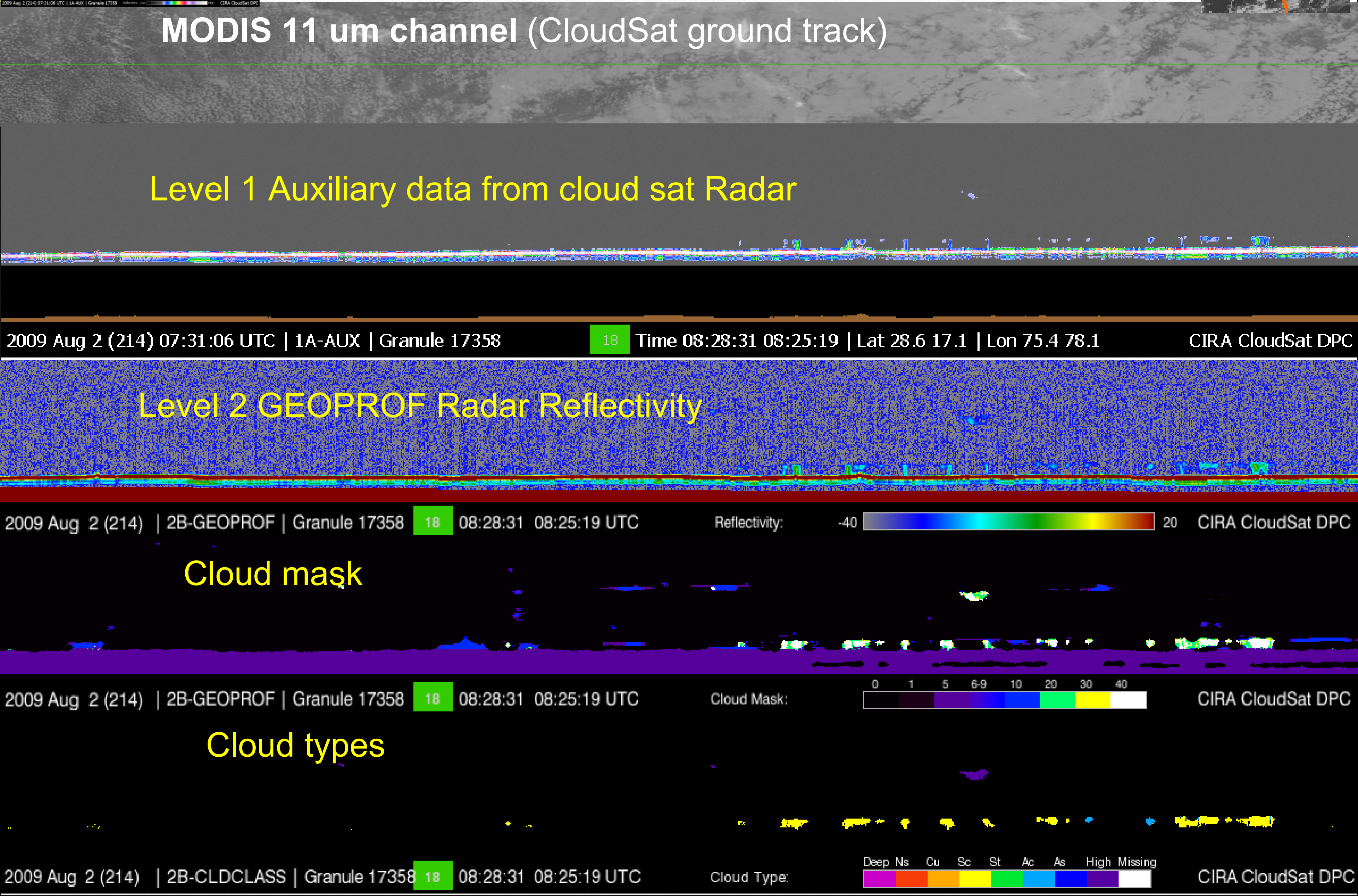
Monsoon 2009

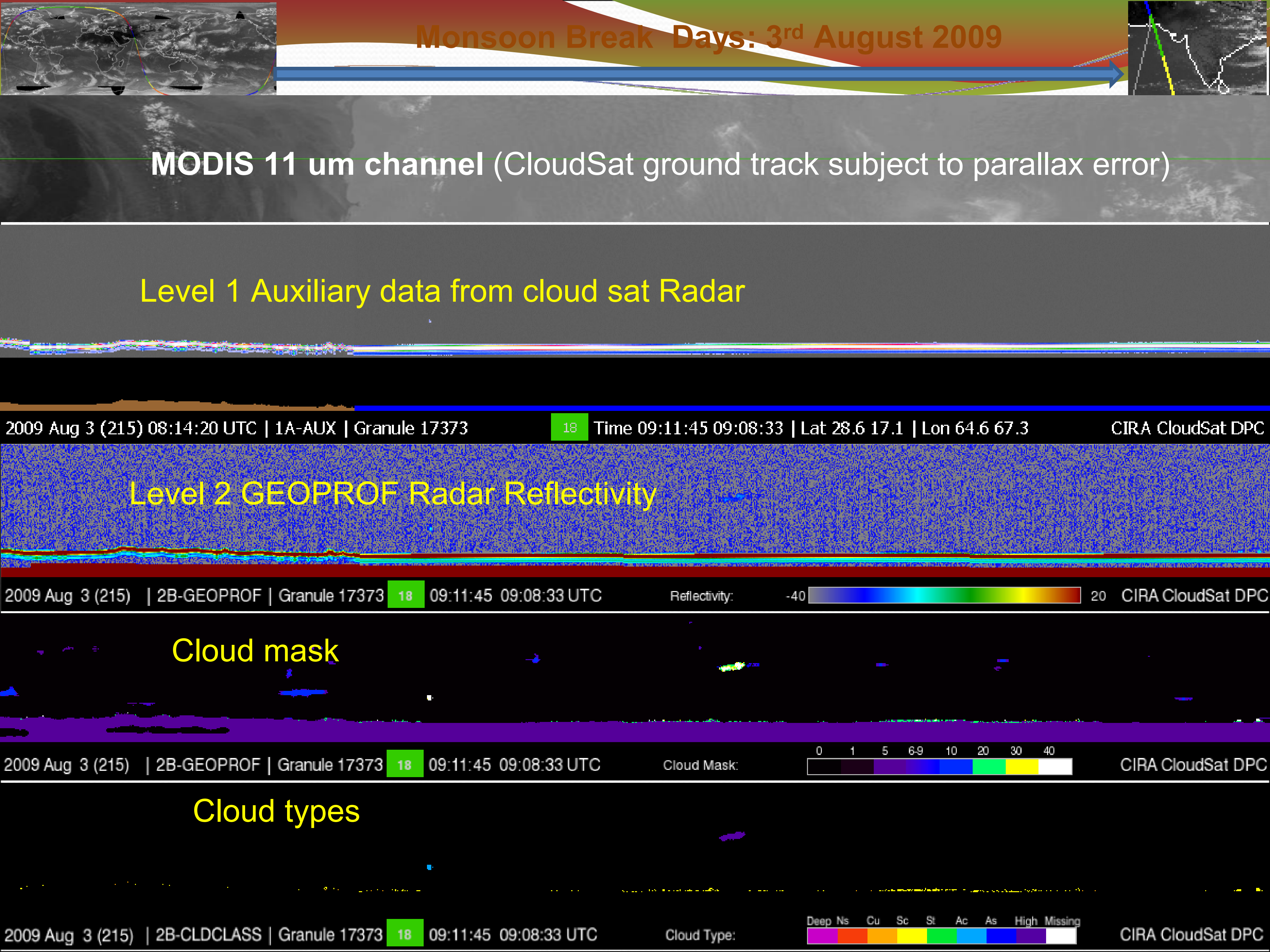
30th July-10th August

Monsoon Break Days: 2^{nd} August 2009

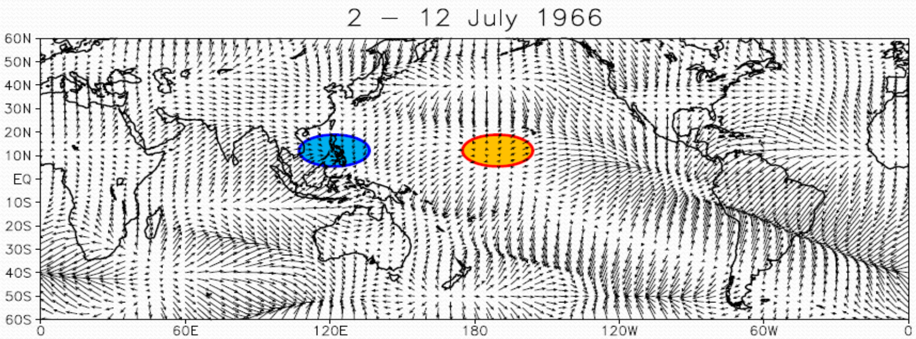


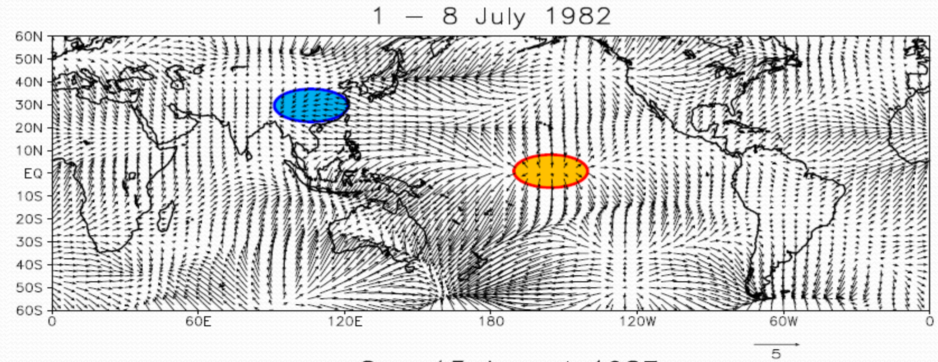


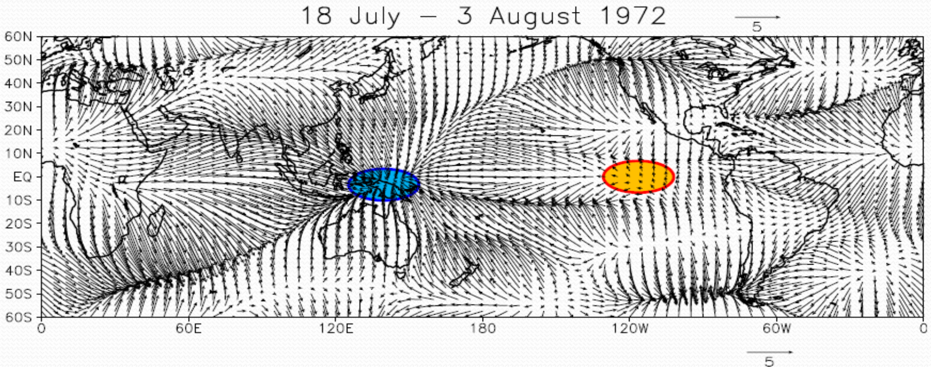


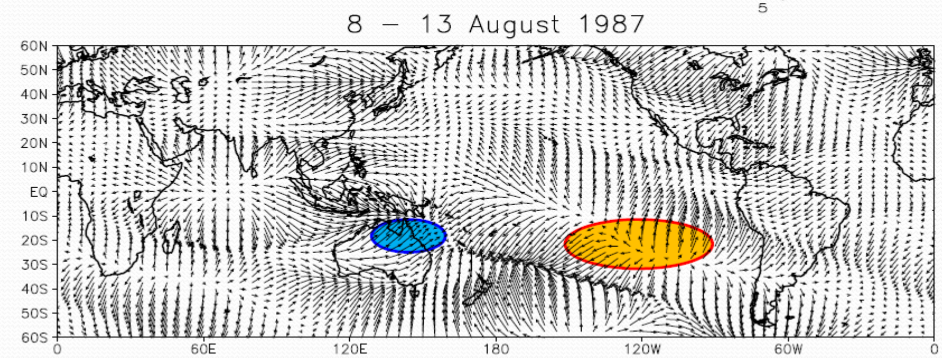

Monsoon Break Days: 3rd August 2009
MODIS 11 um channel (CloudSat ground track subject to parallax error)
Level 1 Auxiliary data from cloud sat Radar
2009 Aug 3 (215) 08:14:20 UTC | 1A-AUX | Granule 17373
18
Time 09:11:45 09:08:33 | Lat 28.6 17.1 | Lon 64.6 67.3
CIRA CloudSat DPC
Level 2 GEOPROF Radar Reflectivity
2009 Aug 3 (215) | 2B-GEOPROF | Granule 17373
18
09:11:45 09:08:33 UTC
Reflectivity:
-40
20
CIRA CloudSat DPC
Cloud mask
2009 Aug 3 (215) | 2B-GEOPROF | Granule 17373
18
09:11:45 09:08:33 UTC
Cloud Mask:
0 1 5 6-9 10 20 30 40
CIRA CloudSat DPC
Cloud types
2009 Aug 3 (215) | 2B-CLDCLASS | Granule 17373
18
09:11:45 09:08:33 UTC
Cloud Type:
Deep Ns Cu Sc St Ac As High Missing
CIRA CloudSat DPC

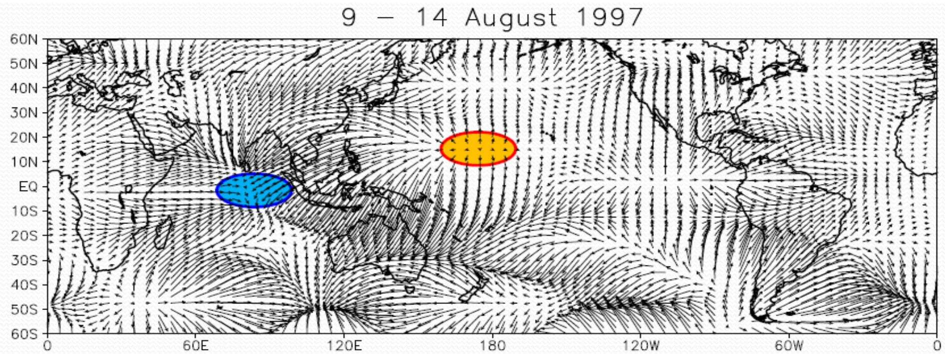
The El-Nino Factor

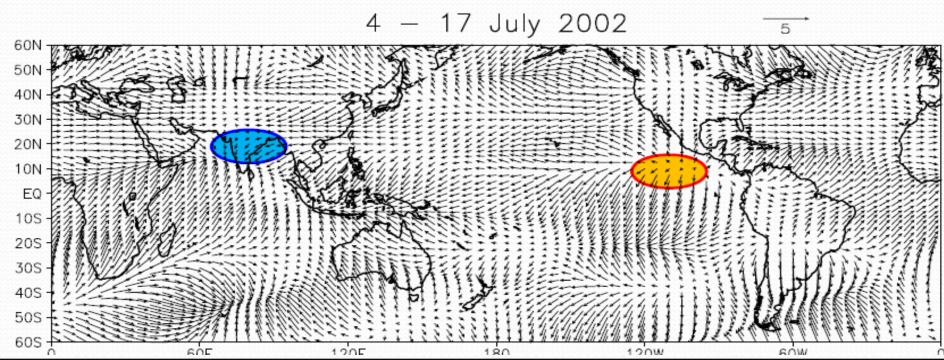






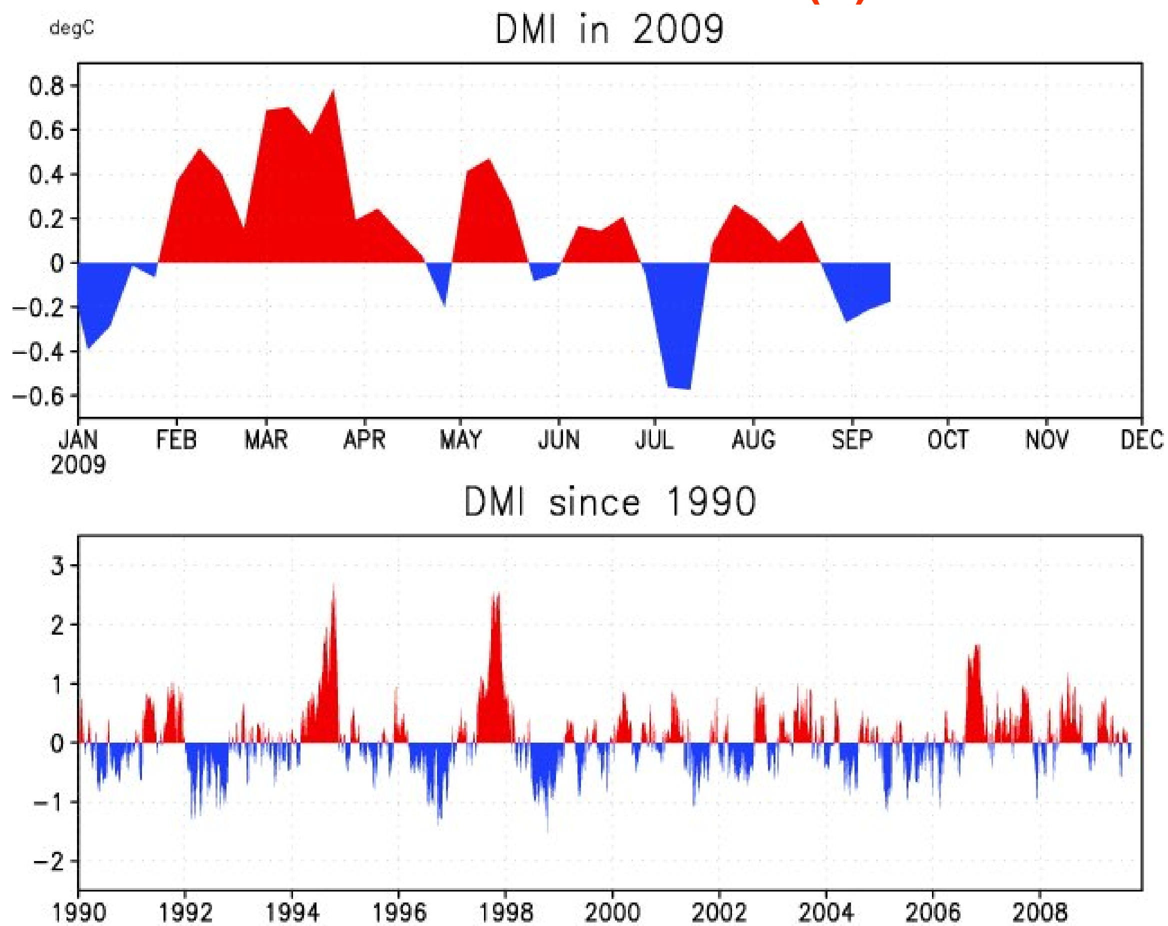






While the ascending lobe Seems to reside close to El-Nino warm SST anomaly, the descending lobe menders from one El-Nino to the next

Indian Ocean Dipole Mode Index (DMI) from Reynolds OIv2, (a) for 2009 and (b) 1990-2008



In Krishnamurti et al (2009) we have examined the relationship of the all India Summer Monsoon Rainfall (AISMR) over India with respect to the Indian Ocean Dipole Index , Saji et al (1999). This relationship was made using the Rajeevan et al (2006) precipitation data sets over India and the SST data sets of Reynolds, Reynolds (1994). The correlation among the IOD index and the AISMR was noted close to be around 0.2. This lack of correlation suggests that the descending lobe of the divergent circulation, related to the IOD convection is not a fixed entity. That descent meanders a lot and impacts different parts of the land and the Indian ocean basins during different years of the positive IOD Index and is not a robust parameter for the behavior of the summer monsoon rains.

The correlation of AISMR and ION index is 0.1.

Other factors:

1.EQUINO

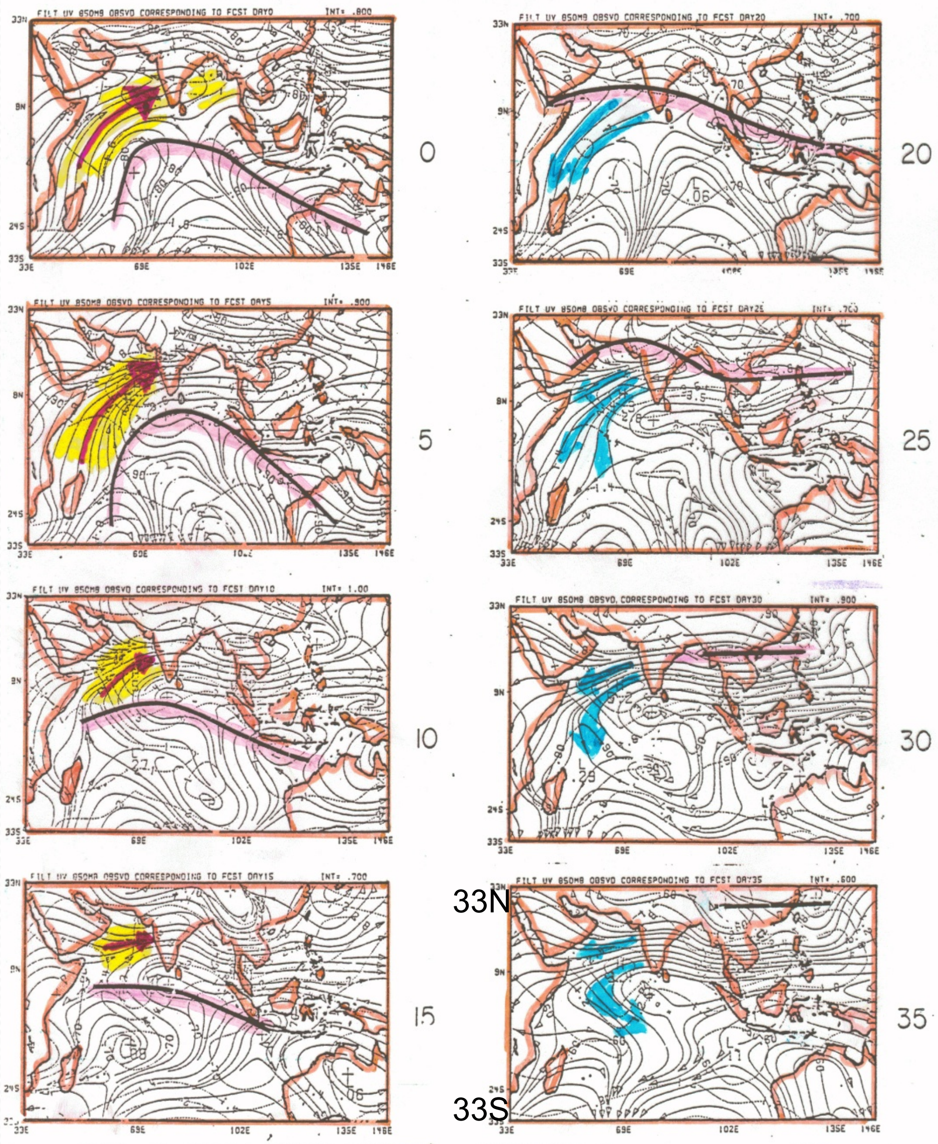
2.Eurasian Snow Cover

3.Himalayan Ice Cover

Passage of Intraseasonal Waves

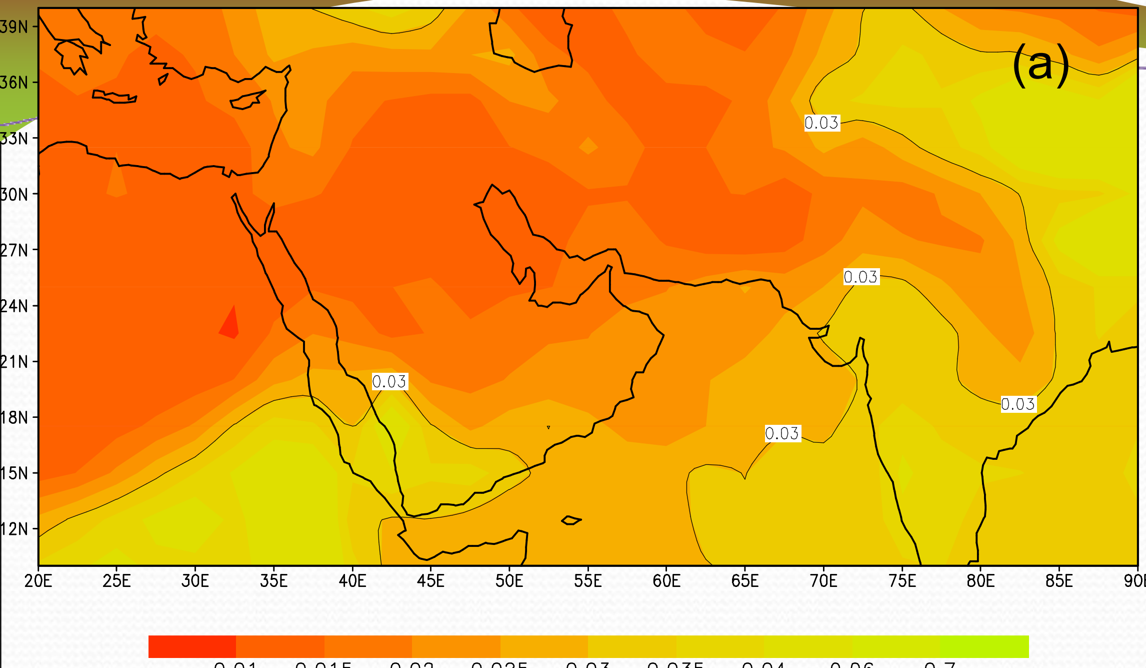
ISO and the Summer Monsoon

850 hPa time filtered winds in 5 day intervals



- ISOs are a major influence to the monsoon over the Arabian Sea
- Strengthen when the flow is parallel
- Weaken when flow is antiparallel (opposite each other)
- The amplitude and phase are not a very robust indicator of WET and DRY spells

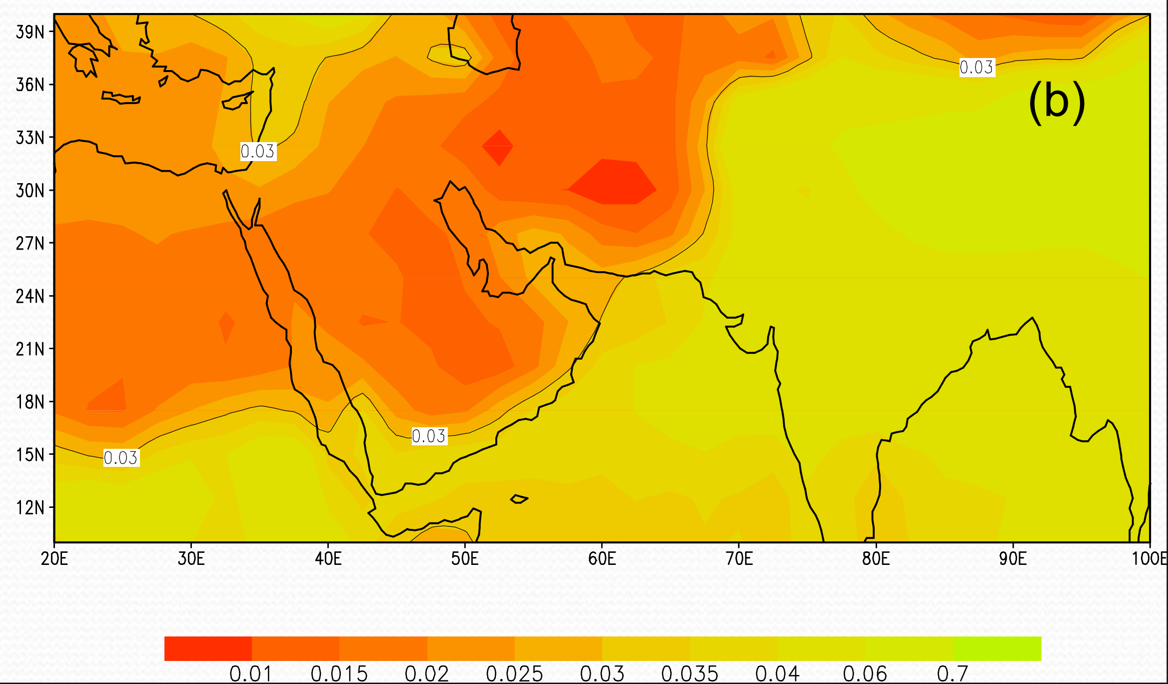
DRY AIR INCURSIONS
OBSERVATIONAL ASPECTS



The vertically integrated lower tropospheric (950 to 700 hPa levels) specific humidity (kg/kg) for dry and wet spells of monsoon rains over central India.

(a) June 10 to 19, 2009 for the dry spell and;

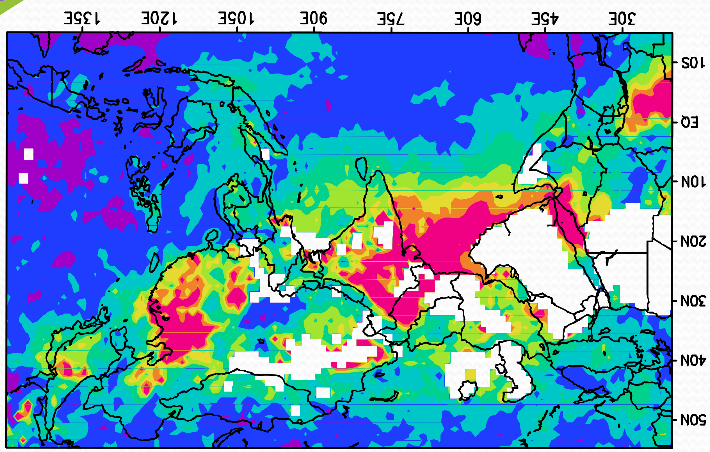
(b) July 14 to 20, 2009 for a wet spell.



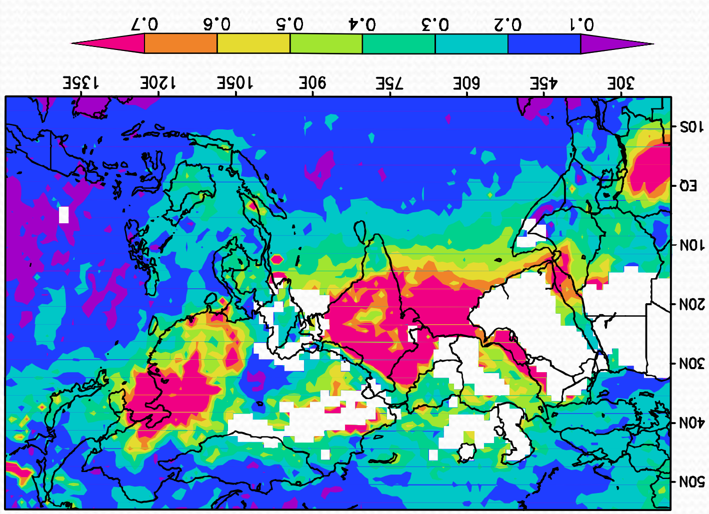
AOD Composited for Break days (2002-2009) from MODIS (Terra/Aqua)

- Aerosol Optical Depth at 550 nm from http://daac.gsfc.nasa.gov/

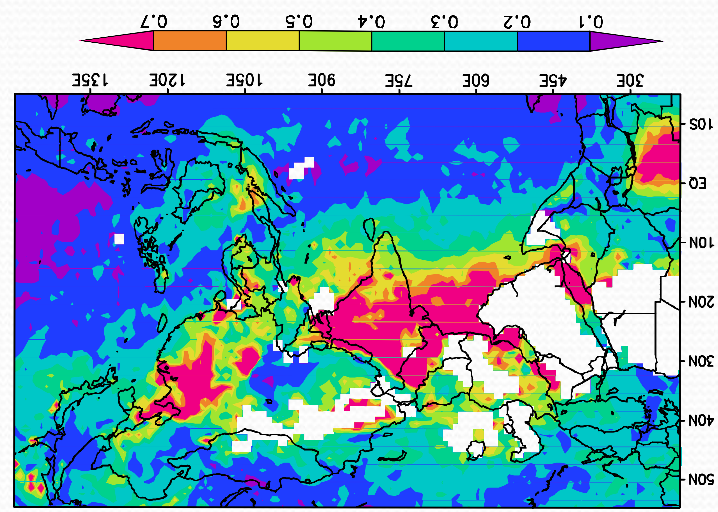
* 550nm wavelenth being in visible, MODIS is not able to capture AOD at Deserts (Albedo is very high).



3-day prior

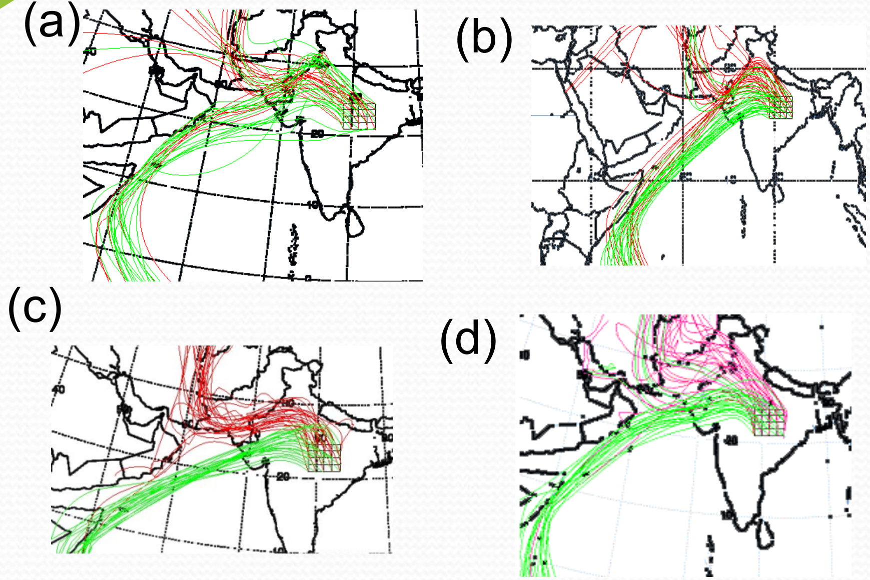


0-day

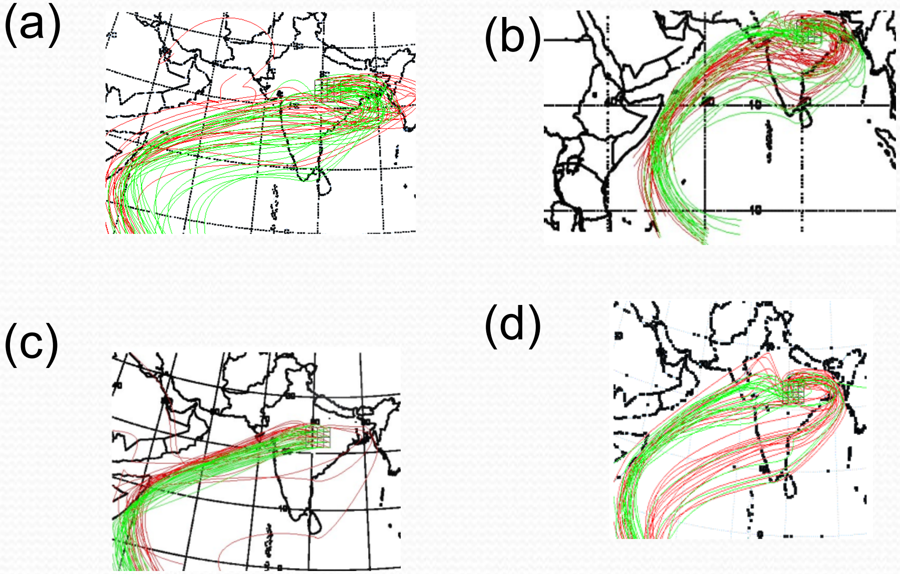


3-day after

Trajectories during the Dry Spells



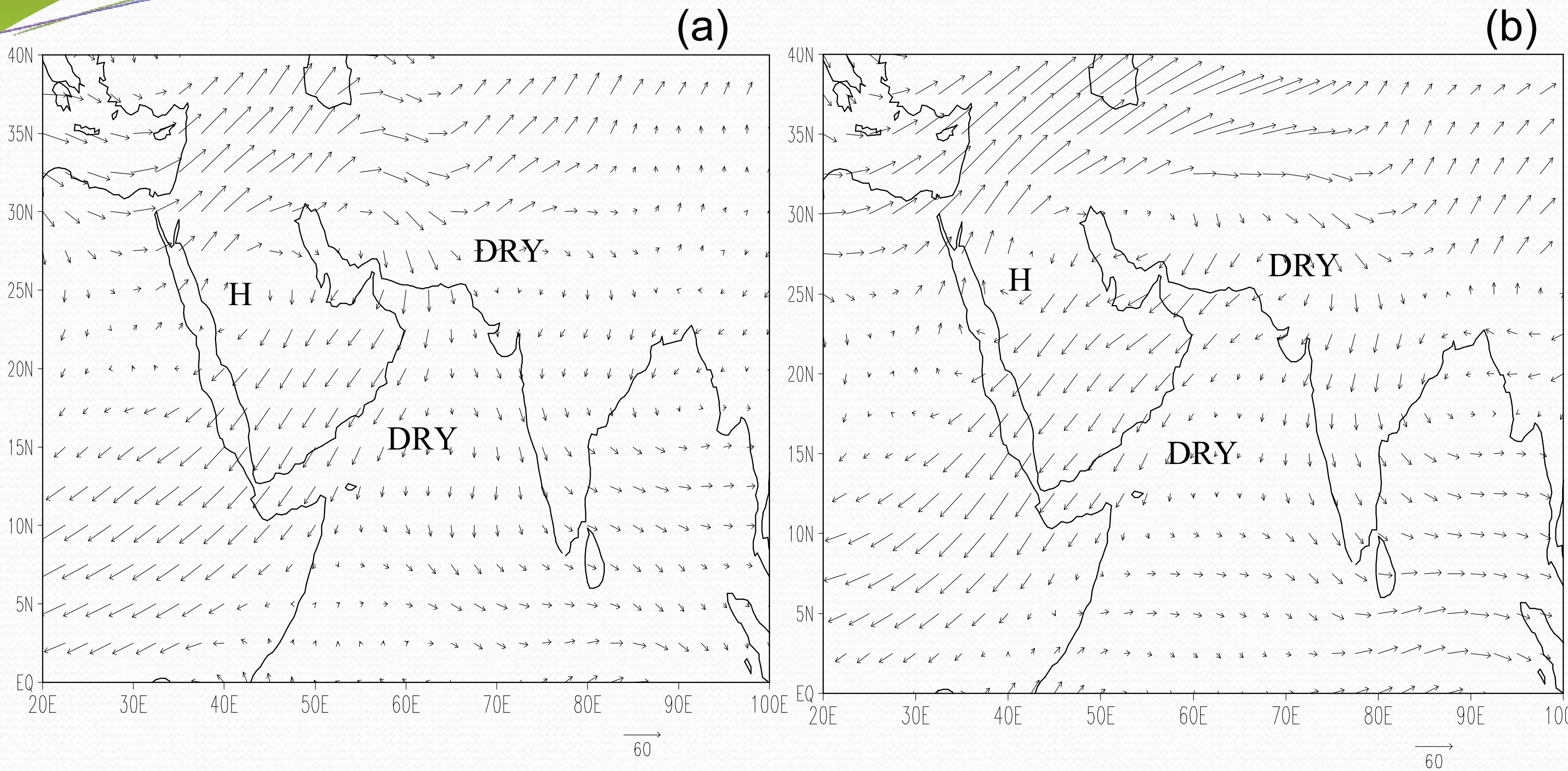
Trajectories during the Wet Spells



10 day back trajectories from Central India terminating at the 850 (green) and 700 (red), for the dry spells of the Indian summer monsoon. (a) 18 June 2009; (b) 14 August 2005; (c) 16 July 2002; (d) 30 August 2001;

10 day back trajectories from Central India terminating at the 850 (green) and 700 (red), for the wet spells of the Indian summer monsoon. (a) 14 July 2009; (b) 01 August 2005; (c) 31 August 2002; (d) 12 July 2001

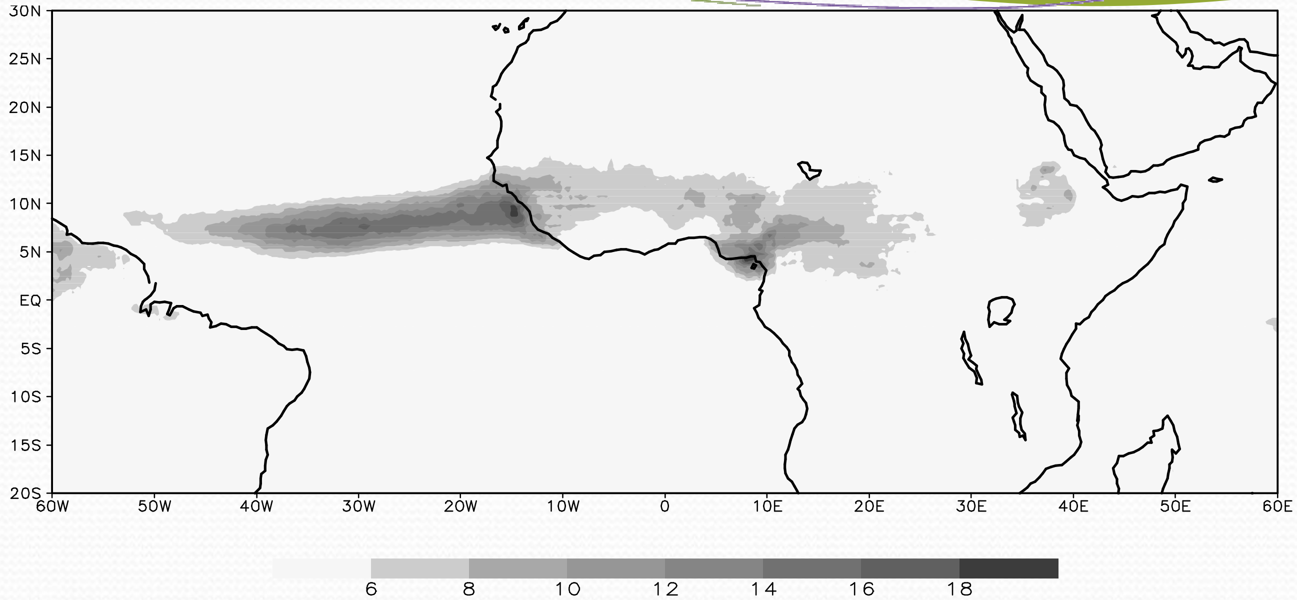
Deep BLOCKING HIGH between 700 and 300 hPa over Arabia



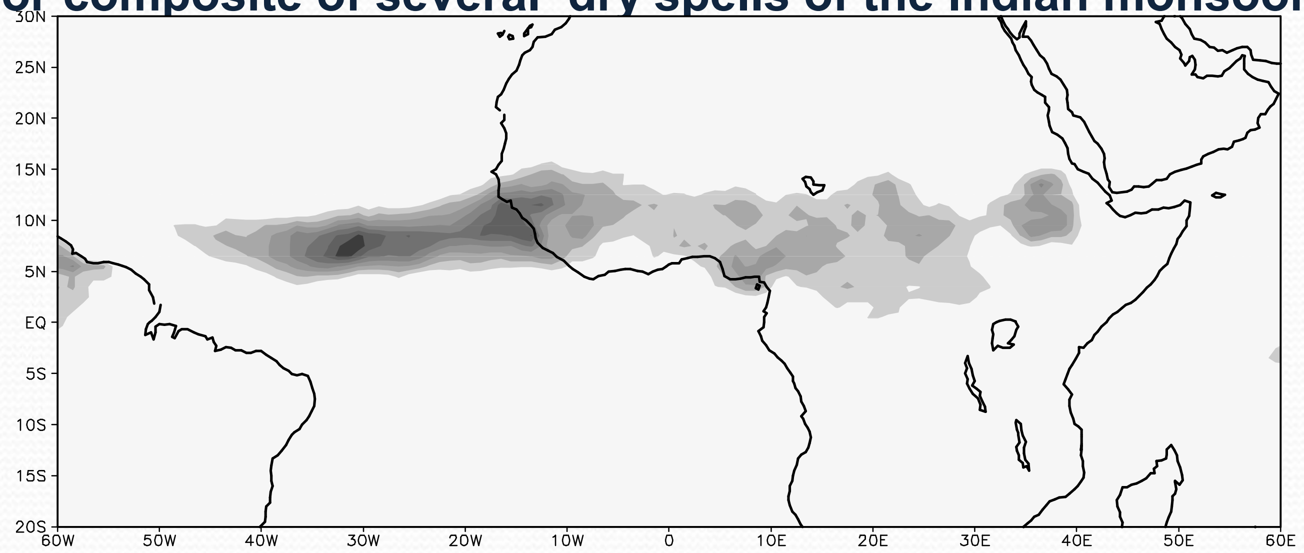
The blocking high of west Asia for different dry spells of the Indian summer monsoon. These are based on vertically integrated horizontal winds from the 700 to the 300 hPa levels. The lengths of the arrows are defined by the bottom inset in units of ms^{-1}. (a) 4 to 17 July 2002 ; **(b)** 26 to 30 August 2001

Antecedents of the West Asian Blocking High

The climatological mean (June, July and August) of Intertropical Convergence Zone (ITCZ) (mm/day)



ITCZ for composite of several dry spells of the Indian monsoon

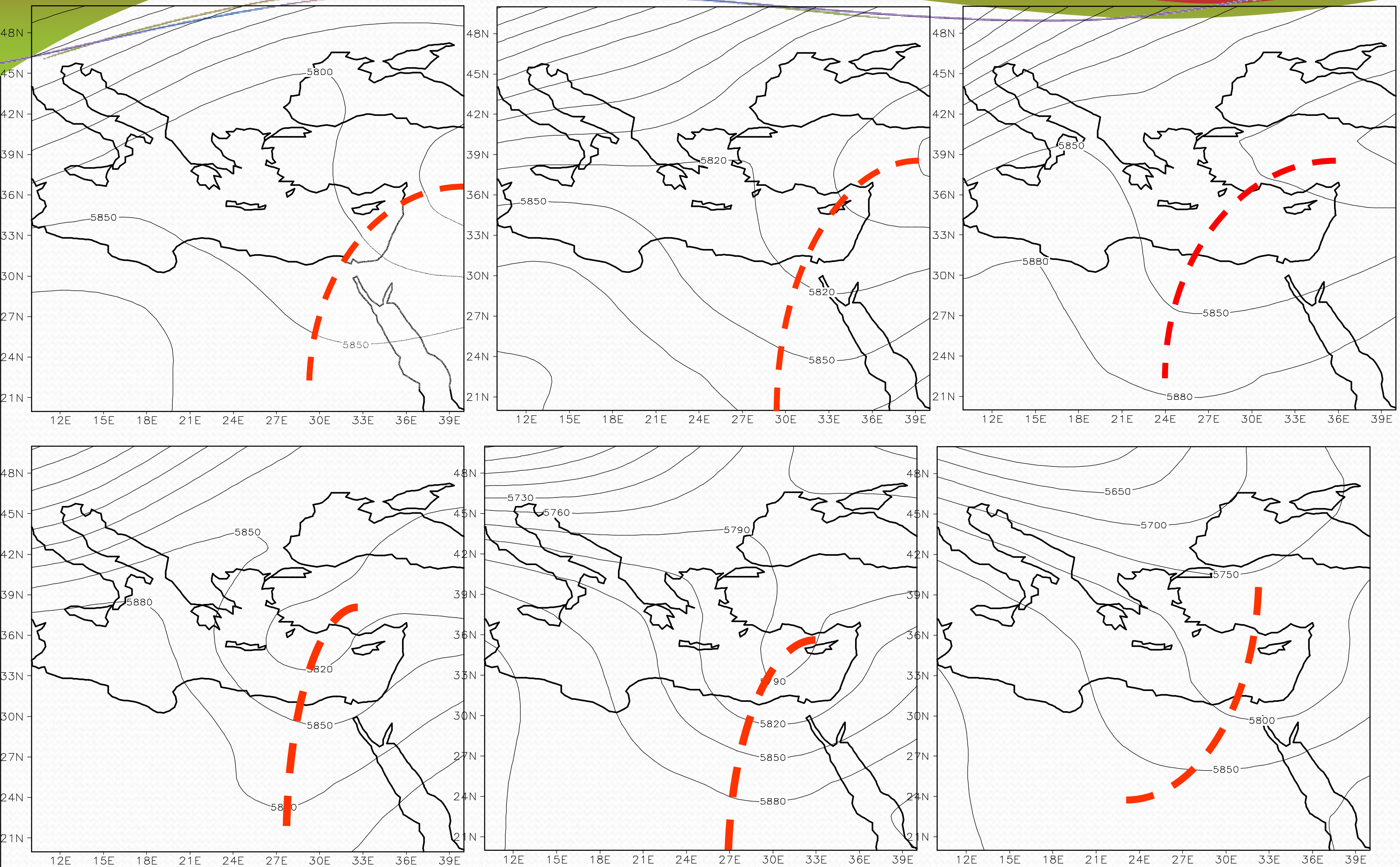


Frequent Occurences of Supergradient Winds at 200hPa

The dates, locations, observed winds (V), geostrophic winds (Vg) and their ratio

Date	Latitude (N)	V(m/s)	Vg(m/s)	V/Vg(m/s)
10-Jun-09	27.5	4	1.01	3.97
12-Jun-09	27.5	7	1.46	4.80
17-Jun-09	27.5	31	12.55	2.47
18-Jun-09	27.5	24	10.95	2.19
20-Jun-09	27.5	14	5.71	2.45
15-Jun-09	27.2	15.9	5.39	2.95
16-Jun-09	27.2	18	5.45	3.30
17-Jun-09	27.2	15.4	6.26	2.46
18-Jun-09	27.2	16	3.92	4.09
19-Jun-09	27.2	12	2.35	5.11
20-Jun-09	27.2	12.3	1.46	8.41
10-Jun-09	27.6	4	1.01	3.97
11-Jun-09	27.6	11.2	5.19	2.16
17-Jun-09	27.6	30.9	12.55	2.46
18-Jun-09	27.6	23.7	10.95	2.17
20-Jun-09	27.6	13.9	5.71	2.43
2-Jun-09	22.8	30	14.98	2.00
17-Jun-09	22.8	14	6.55	2.14
18-Jun-09	22.8	20	8.84	2.26
19-Jun-09	22.8	19	5.43	3.50

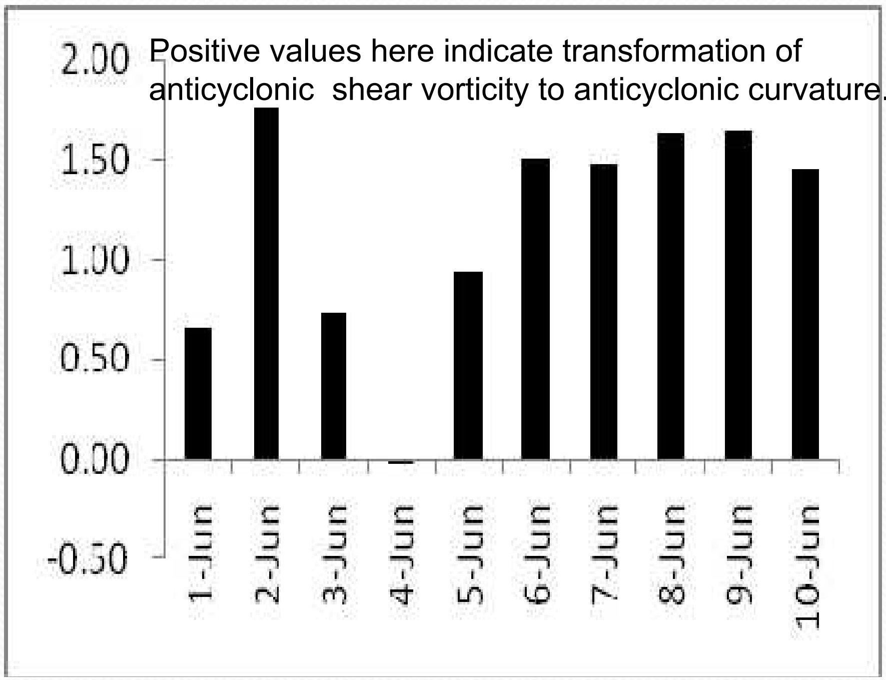
Middle Latitude Mid-Tropospheric Tilted Waves



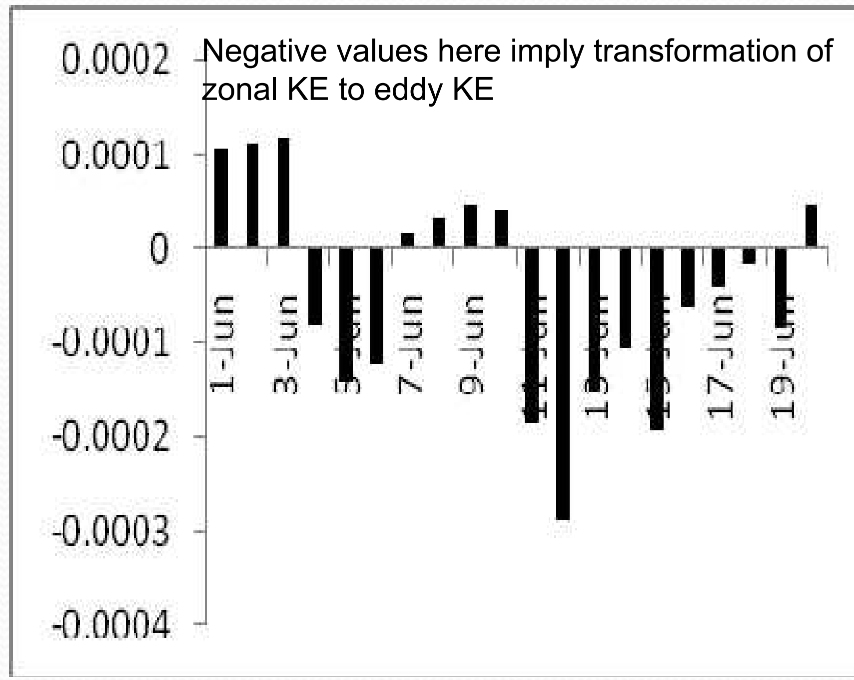
A sequence of 500 hPa charts of the geopotential heights (m) when a Blocking High was present over west Asia. The dashed line denotes a south west to north east tilted trough. Dates are 7 June 2009 to 12 June 2009.

Conversion of Anticyclonic Shear to Anticyclonic Curvature & energy exchange from Eddy Kinetic Energy to the Zonal Kinetic Energy

(a)



(b)



(a) Conversion of shear vorticity into curvature vorticity (along ordinate) in units 10^{-10}sec^{-2} (b) The energy exchange from Eddy Kinetic Energy to the Zonal Kinetic Energy (Units m^{2} sec^{-1}) .

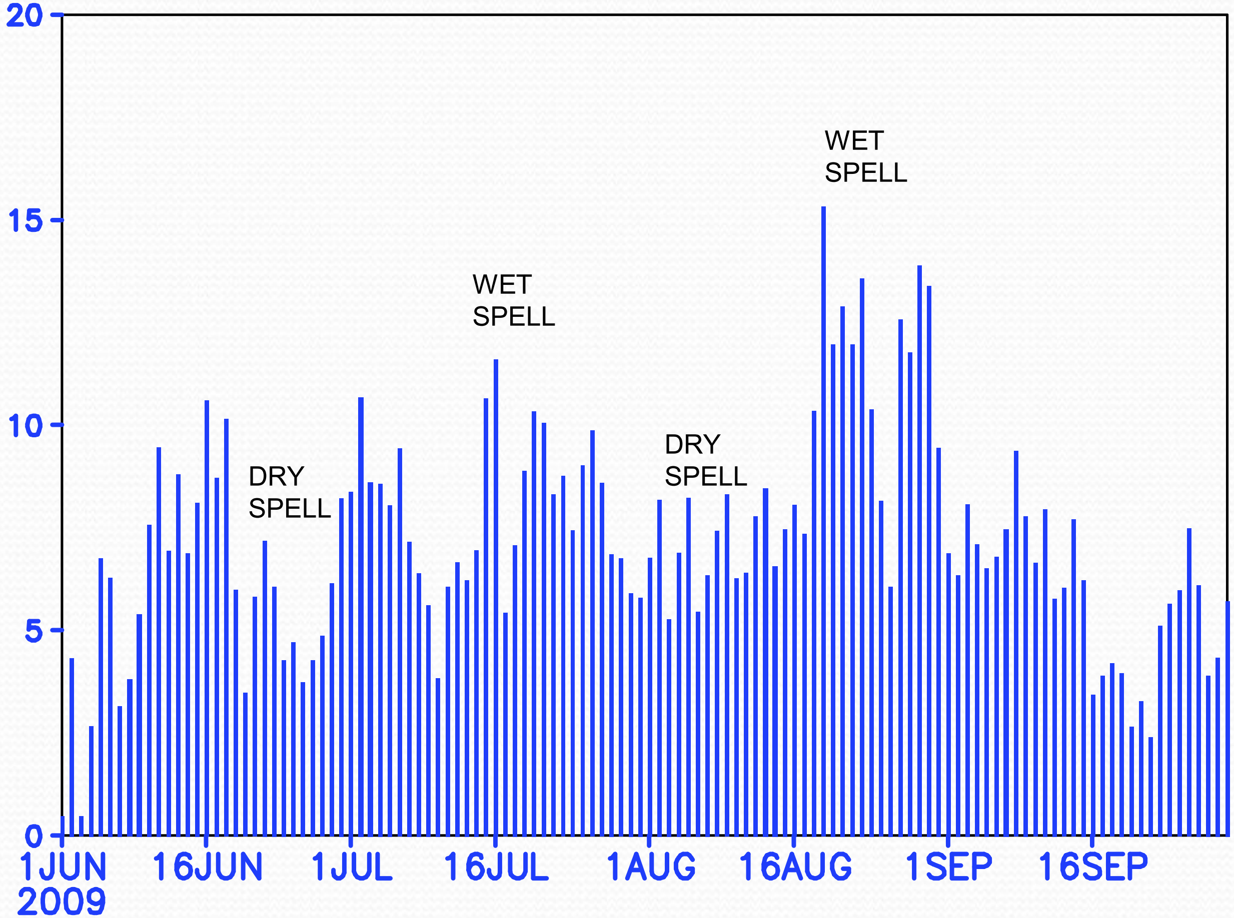
Modeling Results

Table 2. Salient features of the 4 FSU coupled atmosphere–ocean general circulation models used in this study.

Name (Source)	Atmospheric component			Oceanic component		
	Model	**Resolution**	**Initial Condition**	**Model**	**Resolution**	**Initial Condition**
ANR (FSU)	FSUGSM with Arakawa–Schubert convection and new radiation (band model)	T63L14	ECMWF with physical initialization	HOPE global	5° longitude, 0.5°–5° latitude, 17 levels	Coupled assimilation relaxed to observed SST
AOR (FSU)	FSUGSM with Arakawa–Schubert convection and old radiation (emissivity–absorptivity based)	T63L14	ECMWF with physical initialization	HOPE global	5° longitude, 0.5°–5° latitude, 17 levels	Coupled assimilation relaxed to observed SST
KNR (FSU)	FSUGSM with Kuo convection and new radiation (band model)	T63L14	ECMWF with physical initialization	HOPE global	5° longitude, 0.5°–5° latitude, 17 levels	Coupled assimilation relaxed to observed SST
KOR (FSU)	FSUGSM with Kuo convection and old radiation (emissivity–absorptivity based)	T63L14	ECMWF with physical initialization	HOPE global	5° longitude, 0.5°–5° latitude, 17 levels	Coupled assimilation relaxed to observed SST

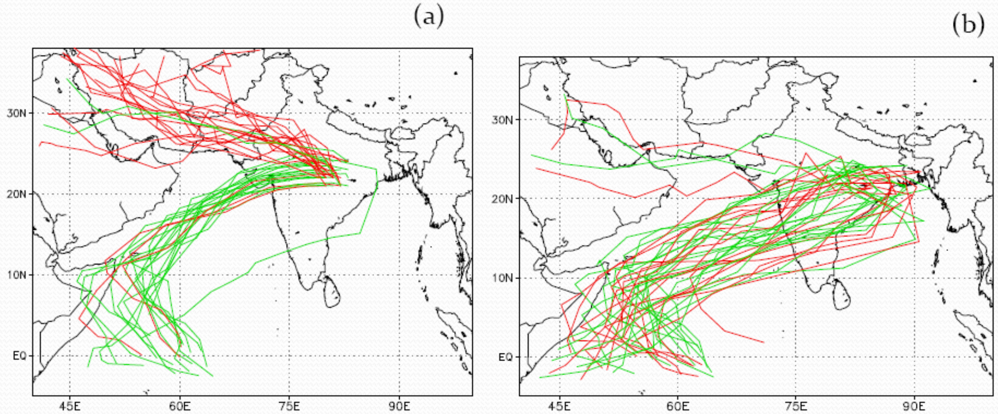
Period of the experiment was covered 1987-2009, twice per-month

MODEL BASED DAY BY DAY RAINS OVER CENTRAL INDIA



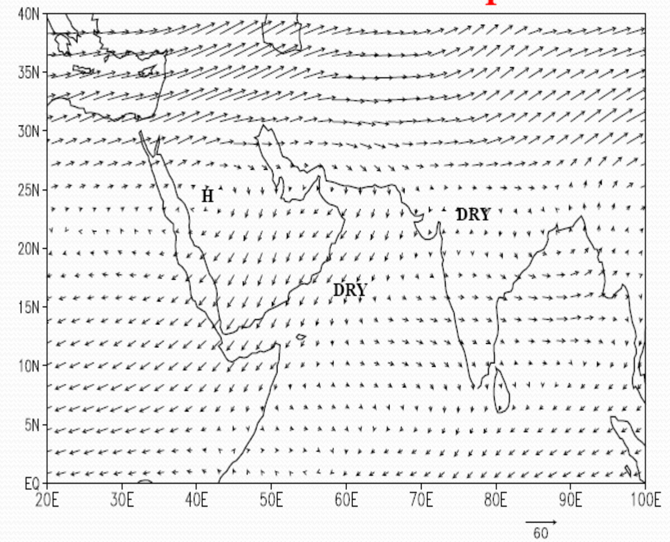
Daily rainfall (mm/day) from the model output for 2009

MODEL BASED TRAJECTORIES



10-day back trajectories from central India from model output for trajectories terminating at the 850 (green) and 700 (red), for (a) the dry spell, 20 June 2009 and (b) the wet spell, 14 August 2009.

Blocking High over West Asia from the Model Output



The Blocking High of west Asia from the model output for the dry spell during 8 to 27 June 2009. These are based on vertically integrated horizontal winds from the 700 to the 300 hPa levels. The lengths of the arrows are defined by the bottom inset in units of ms^{-1}.

Conversion of Anticyclonic Shear to Anticyclonic Curvature & energy exchange from Eddy Kinetic Energy to the Zonal Kinetic Energy

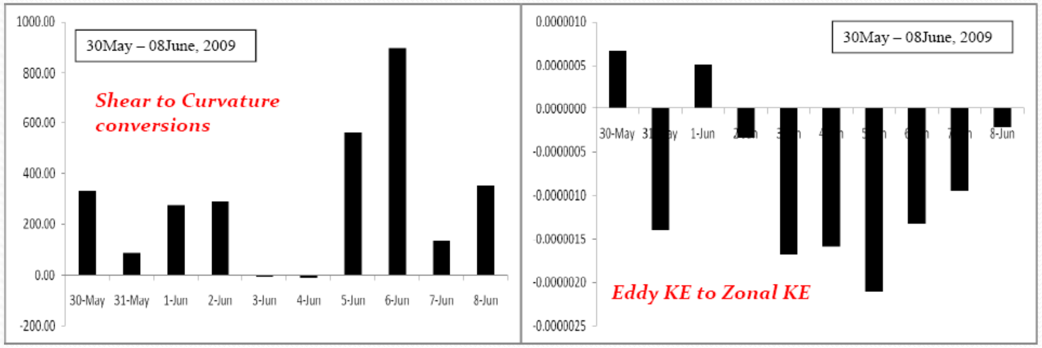
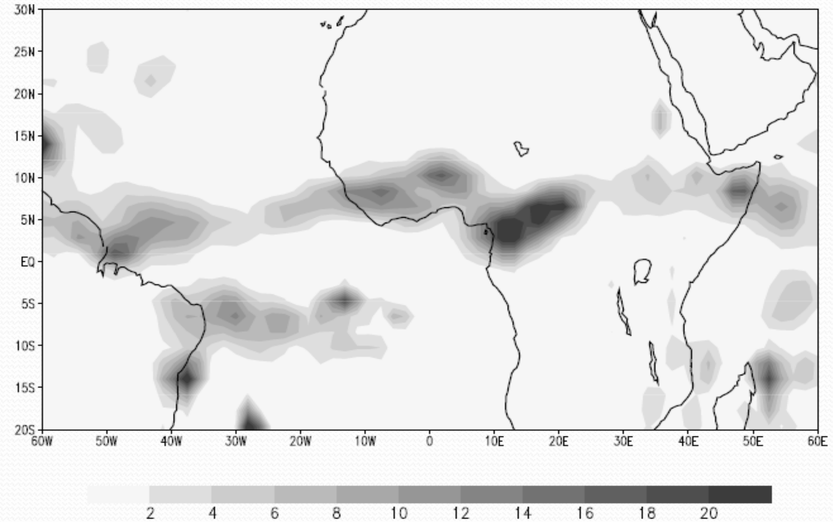


Figure 16: (a) Conversion of shear vorticity into curvature vorticity (along ordinate) in units $10^{-10}sec^{-2}$; from model output for dry spell during 2009; (b) The energy exchange from Eddy Kinetic Energy to the Zonal Kinetic Energy from model output for dry spell during 2009 (Units $m^2\ sec^{-1}$)

ITCZ from the model output for the dry spell during June 8 through 27 (mm/day)



CLOUD BURSTS AND RAPID INTENSIFICATION OF HURRICANES

ARW Model Description

The real-time ARW forecasts in 2005 used a two-way nested configuration (Michalakes et al. 2005), that featured a 12-km outer fixed domain with a movable nest of 4/1.33-km grid spacing.

The nest was centered on the location of the minimum 500-hPa geopotential height within a prescribed search radius from the previous position of the vortex center (or within a radius of the first guess, when first starting).

Nest repositioning was calculated every 15 simulation minutes and the width of the search radius was based on the maximum distance the vortex could move at 40 m s^{-1}.

On the 12-km domain, the Kain–Fritsch cumulus parameterization was used, but domains with finer resolution had no parameterization.

All domains used the WRF single-moment 3-class (WSM3) microphysics scheme (Hong et al. 2004) that predicted only one cloud variable (water for $T > 0°C$ and ice for $T < 0°C$) and one hydrometeor variable, either rainwater or snow (again thresholded on 0°C).

Both domains also used the Yonsei University (YSU) scheme for the planetary boundary layer (Noh et al. 2003).

This is a first-order closure scheme that is similar in concept to the scheme of Hong and Pan (1996), but appears less biased toward excessive vertical mixing as reported by Braun and Tao (2000).

The drag formulation follows Charnock (1955) and is described more in section 5. The surface exchange coefficient for water vapor follows Carlson and Boland (1978), and the heat flux uses a similarity relationship (Skamarock et al. 2005).

The forecasts were integrated from 0000 UTC and occasionally 1200 UTC during the time when a hurricane threatened landfall within 72 h.

Forecasts were initialized using the Geophysical Fluid Dynamics Laboratory (GFDL) model, with data on a ⅙° latitude–longitude grid. The Global Forecast Model (GFS) from the National Centers for Environmental Prediction (NCEP), obtained on a 1° grid, was used only when the GFDL was unavailable.

Davis, C., W. Wang, S.S. Chen, Y. Chen, K. Corbosiero, M. DeMaria, J. Dudhia, G. Holland, J. Klemp, J. Michalakes, H. Reeves, R. Rotunno, C. Snyder, and Q. Xiao, 2008: Prediction of Landfalling Hurricanes with the Advanced Hurricane WRF Model. *Mon. Wea. Rev.*, 136, 1990–2005.

Departures from balance laws

The full divergence equation can be written in the form (from Fankhauser 1974):

$$-\nabla^2\phi = -f\left(\frac{\partial u}{\partial y}-\frac{\partial v}{\partial x}\right)-2\left(\frac{\partial v}{\partial x}\frac{\partial u}{\partial y}-\frac{\partial u}{\partial x}\frac{\partial v}{\partial y}\right)+\beta u+\left(\frac{\partial \omega}{\partial x}\frac{\partial u}{\partial p}+\frac{\partial \omega}{\partial y}\frac{\partial v}{\partial p}\right)+D^2+$$

$$\left(\frac{\partial D}{\partial t}+u\frac{\partial D}{\partial x}+v\frac{\partial D}{\partial y}+\omega\frac{\partial D}{\partial p}\right)+\left(\frac{\partial F_u}{\partial x}+\frac{\partial F_v}{\partial y}\right)$$

Red lines represent the balance equation (Haltiner and Williams 1980). The blue underlined terms denote the non linear balance which is also expressed as .

$$\nabla^2\phi = f\nabla^2\psi + 2J\left(\frac{\partial \psi}{\partial x},\frac{\partial \psi}{\partial y}\right)$$

Implication of gradient wind departures on hurricane intensity

In local cyclindrical storm centered coordinate we can write the complete radical equation of motion in the form:

$$\frac{\partial V_r}{\partial t}+V_\theta\frac{\partial V_r}{r\partial\theta}+V_r\frac{\partial V_r}{\partial r}+\omega\frac{\partial V_r}{\partial p}-\frac{V_\theta^2}{r}-fV_\theta=-g\frac{\partial z}{\partial r}+F_r \text{ or}$$

$\frac{V_\theta^2}{r}+fV_\theta-g\frac{\partial z}{\partial r}+GWD=0$ where GWD denotes the gradient wind departure.

Where $GWD=-\frac{\partial V_r}{\partial t}-V_\theta\frac{\partial V_r}{r\partial\theta}-V_r\frac{\partial V_r}{\partial r}-\omega\frac{\partial V_r}{\partial p}-F_r$

V_θ can be expressed by the relation, $V_\theta=\dfrac{-f\pm\sqrt{f^2-\frac{4}{r}\left(GWD-g\frac{\partial z}{\partial r}\right)}}{\frac{2}{r}}$.

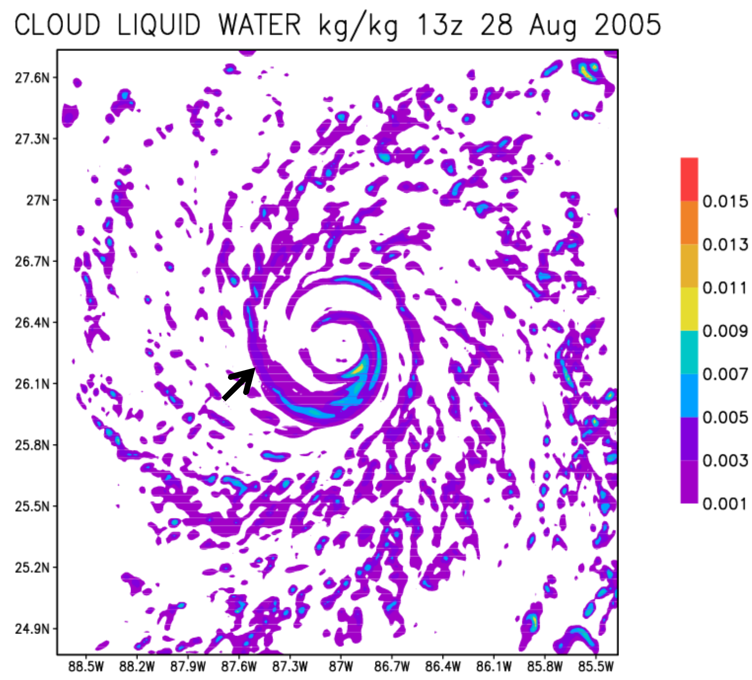
We shall next illustrate several examples of the following scenario:

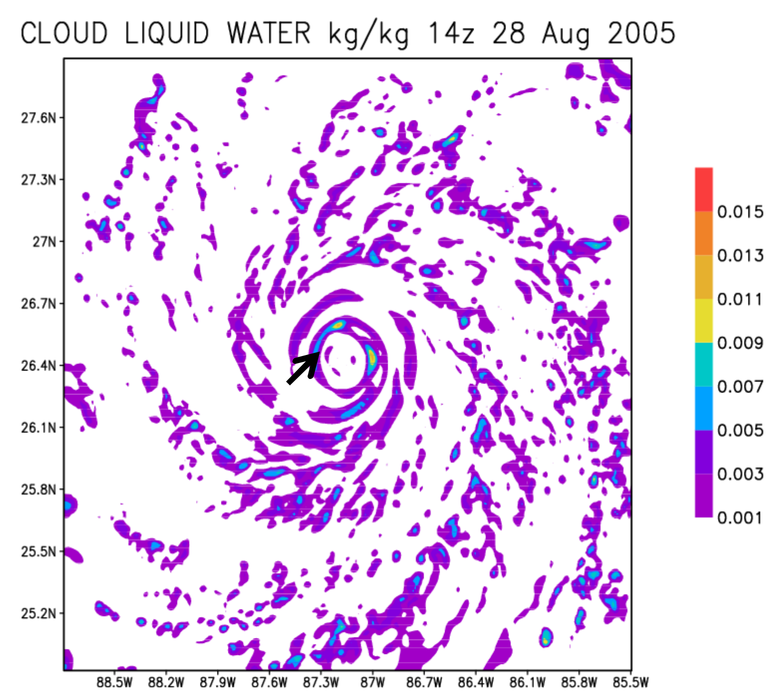
1. Deep convection flares up near the eye wall, as seen from the local growth of rain water mixing ratio, liquid water mixing ratio or radar reflectivity as implied from model hydrometeors.
2. Divergence flares up
3. Departures from balance laws flare up 10^{-5}
4. Solution of complete radial equation shows rapid growth of hurricane intensity.

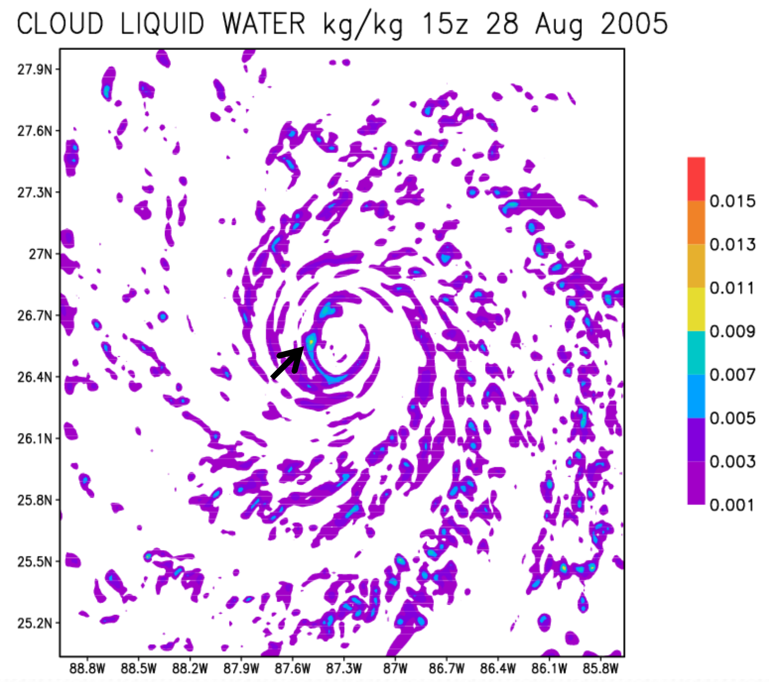
REFERENCE

Paper to be published in JAS.

Initial time: 10z 28 August 2005

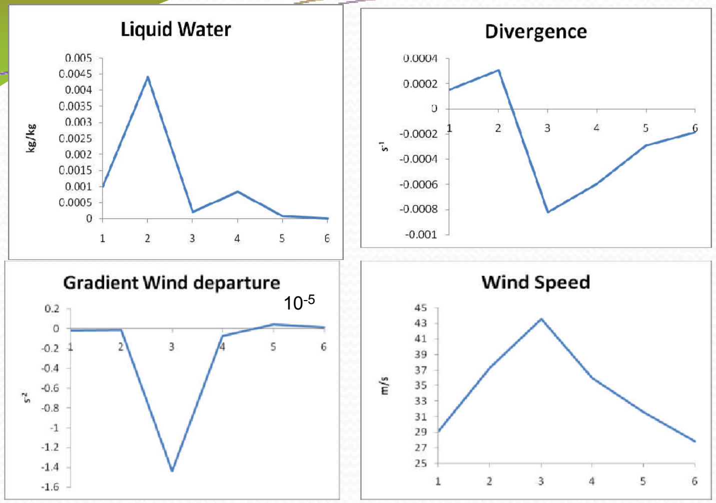




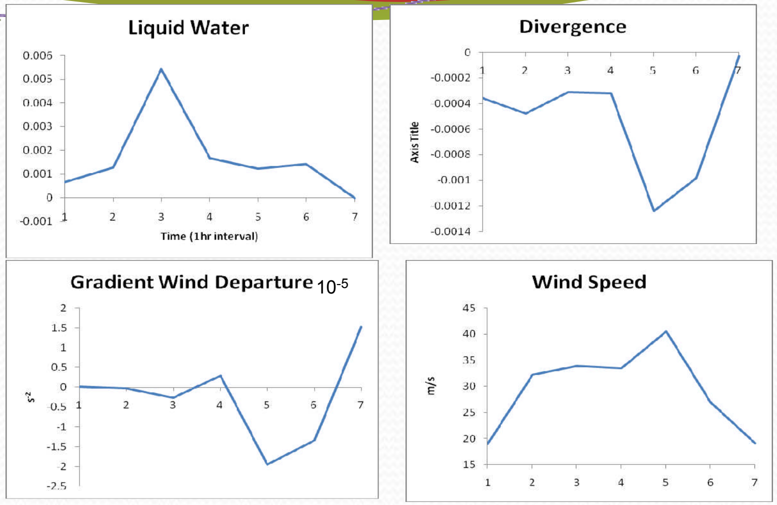


CLOUD LIQUID WATER

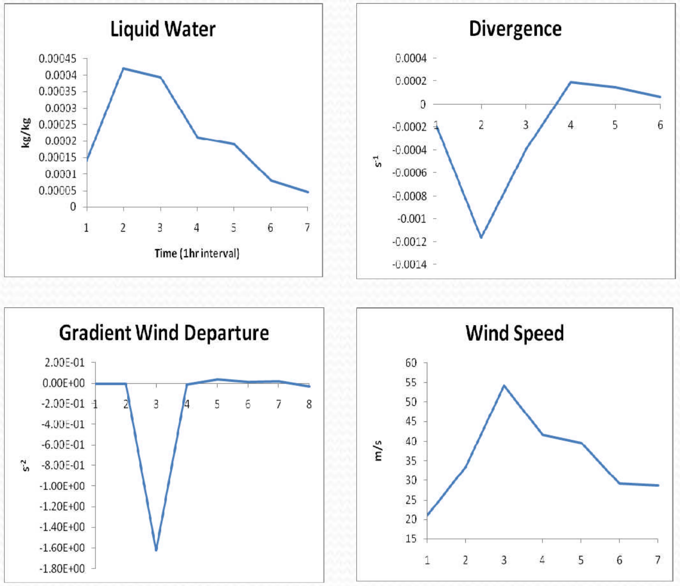
Hourly plots



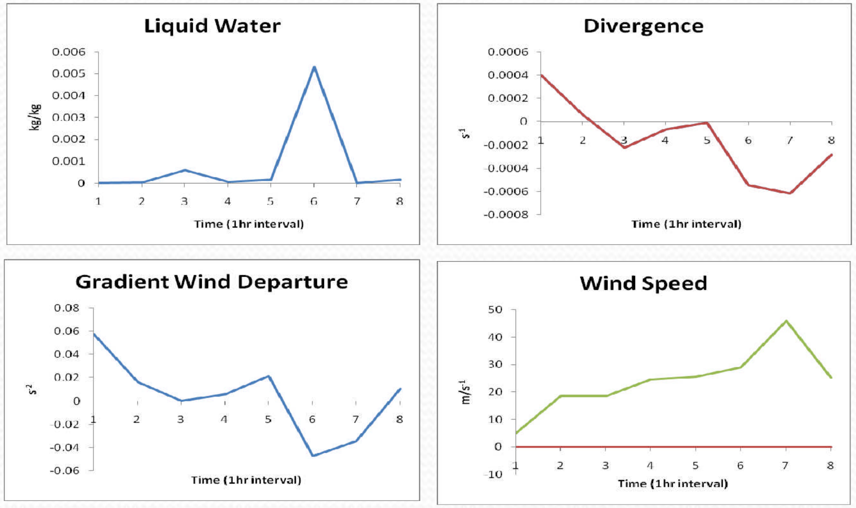
Initial time: 10z 28 August 2005



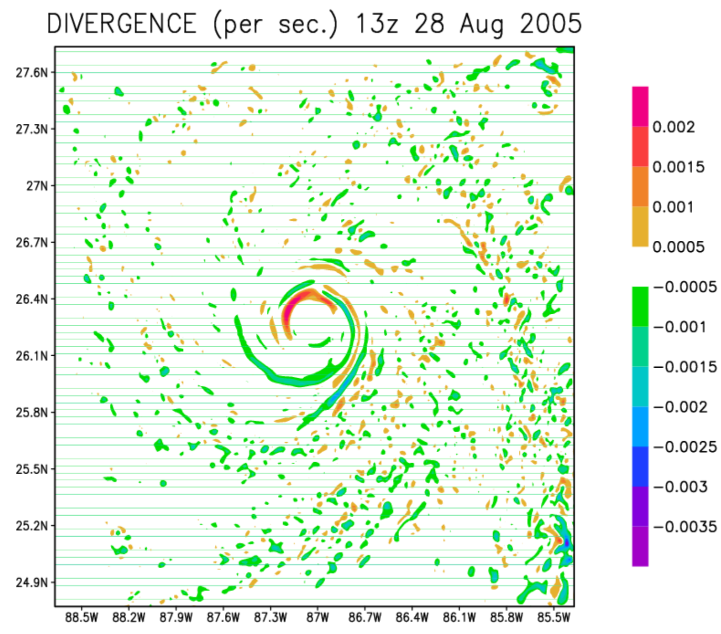
Initial time: 09z 28 August 2005



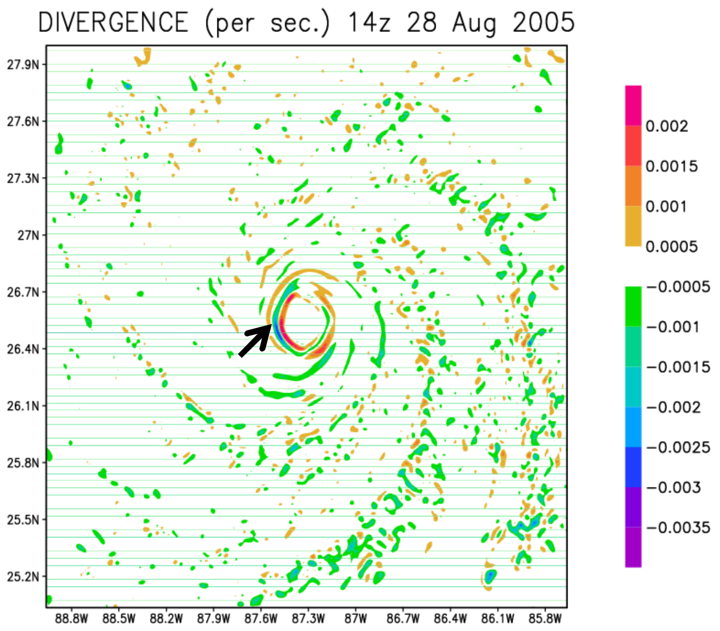
Initial time: 09z 28 August 2005



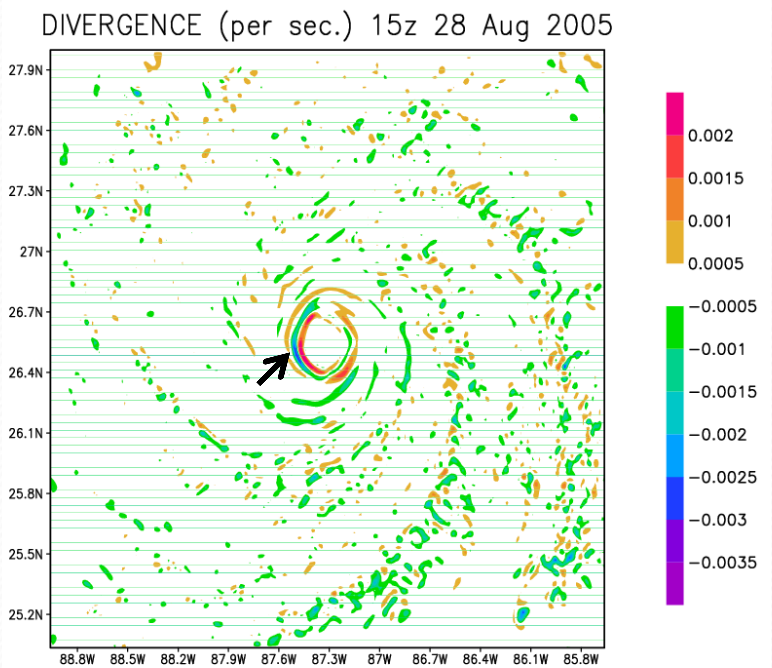
Initial time: 09z 28 August 2005



DIVERGENCE (per sec.) 13z 28 Aug 2005
27.6N
27.3N
27N
26.7N
26.4N
26.1N
25.8N
25.5N
25.2N
24.9N
88.5W 88.2W 87.9W 87.6W 87.3W 87W 86.7W 86.4W 86.1W 85.8W 85.5W
0.002
0.0015
0.001
0.0005
−0.0005
−0.001
−0.0015
−0.002
−0.0025
−0.003
−0.0035

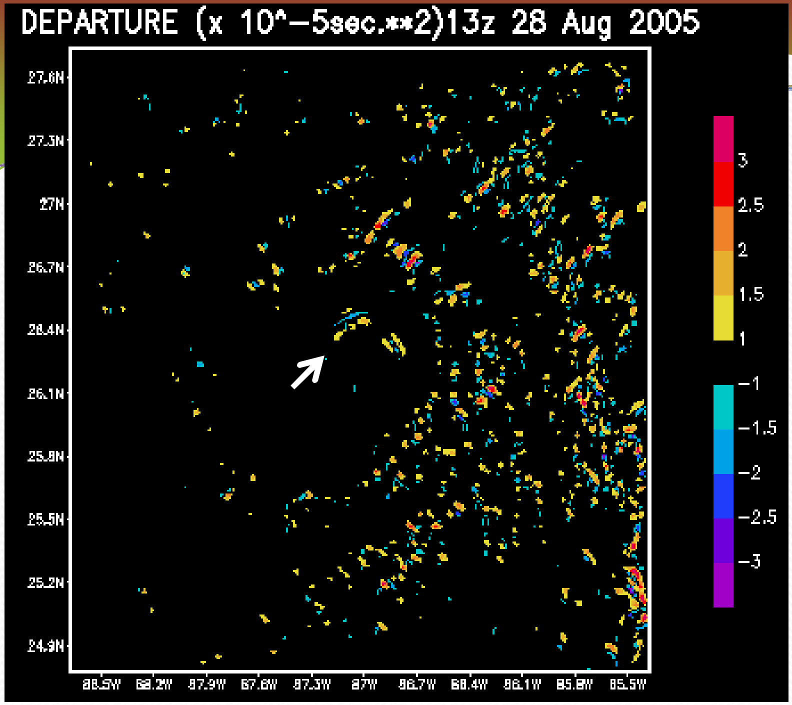


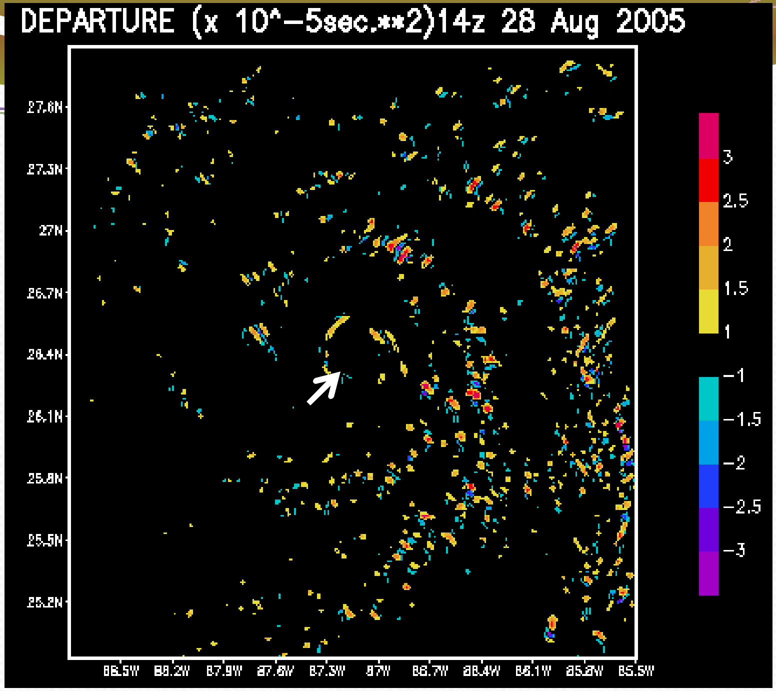
DIVERGENCE (per sec.) 14z 28 Aug 2005
27.9N
27.6N
27.3N
27N
26.7N
26.4N
26.1N
25.8N
25.5N
25.2N
88.8W 88.5W 88.2W 87.9W 87.6W 87.3W 87W 86.7W 86.4W 86.1W 85.8W
0.002
0.0015
0.001
0.0005
−0.0005
−0.001
−0.0015
−0.002
−0.0025
−0.003
−0.0035

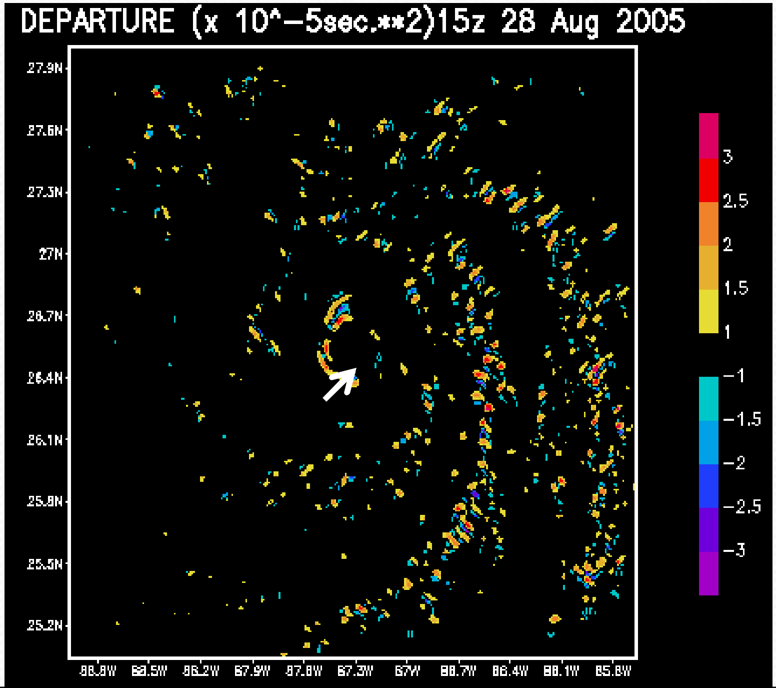


DIVERGENCE (per sec.) 15z 28 Aug 2005
27.9N
27.6N
27.3N
27N
26.7N
26.4N
26.1N
25.8N
25.5N
25.2N
88.8W 88.5W 88.2W 87.9W 87.6W 87.3W 87W 86.7W 86.4W 86.1W 85.8W
0.002
0.0015
0.001
0.0005
−0.0005
−0.001
−0.0015
−0.002
−0.0025
−0.003
−0.0035

DIVERGENCE

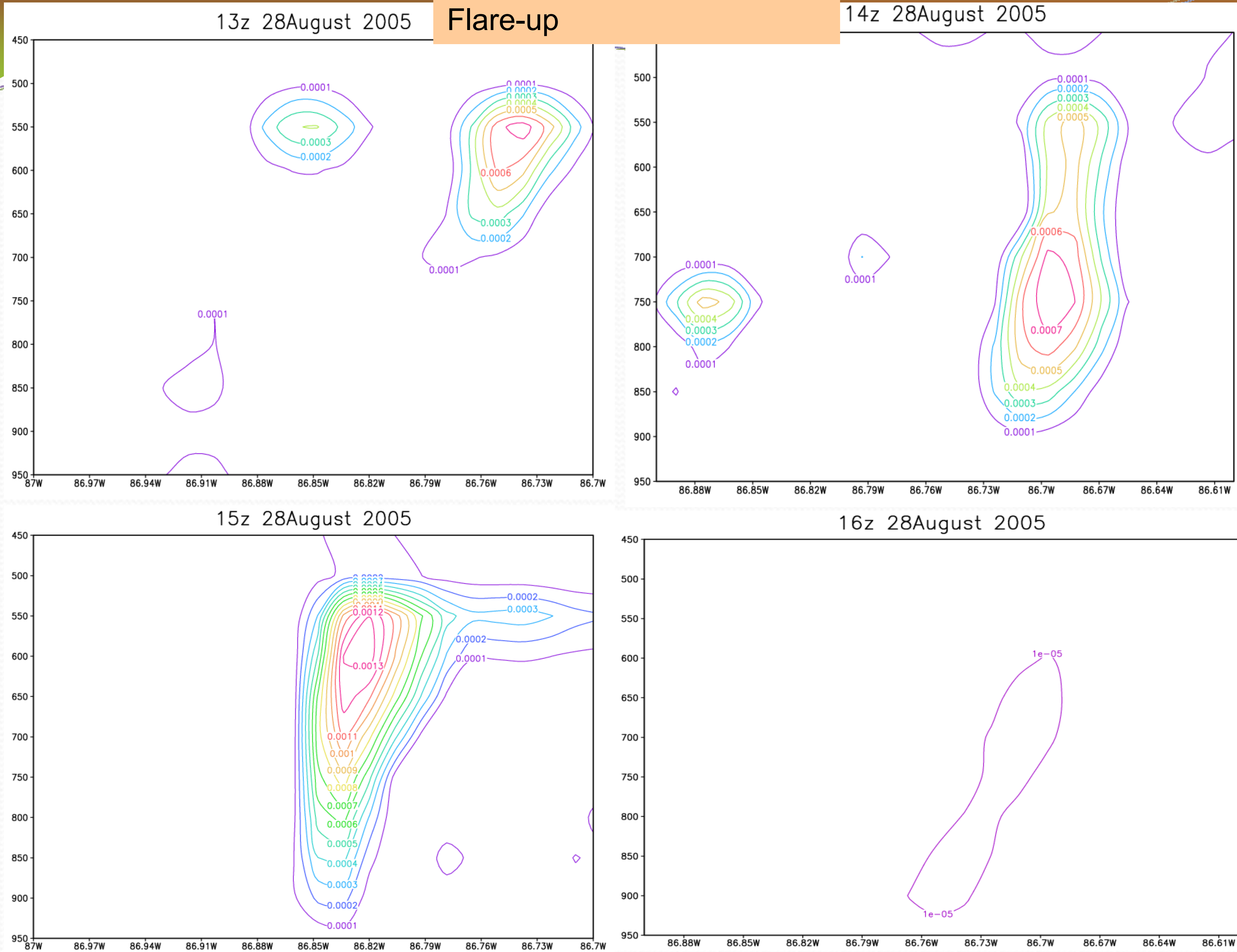




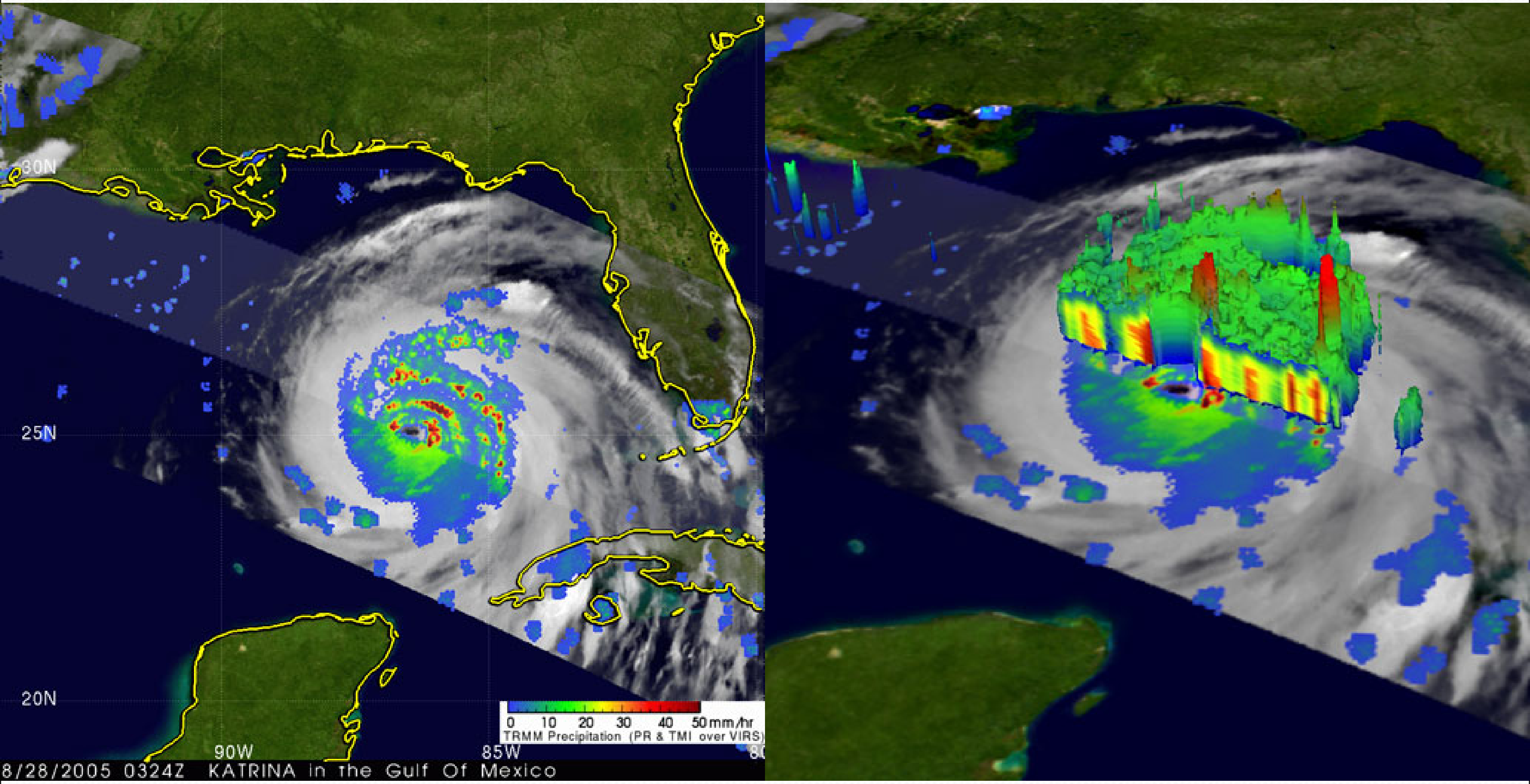


Gradient Wind Departure

Model Prediction of a Cloud Flare-up



TRMM looking at the rapid intensification stage of Katrina 2005



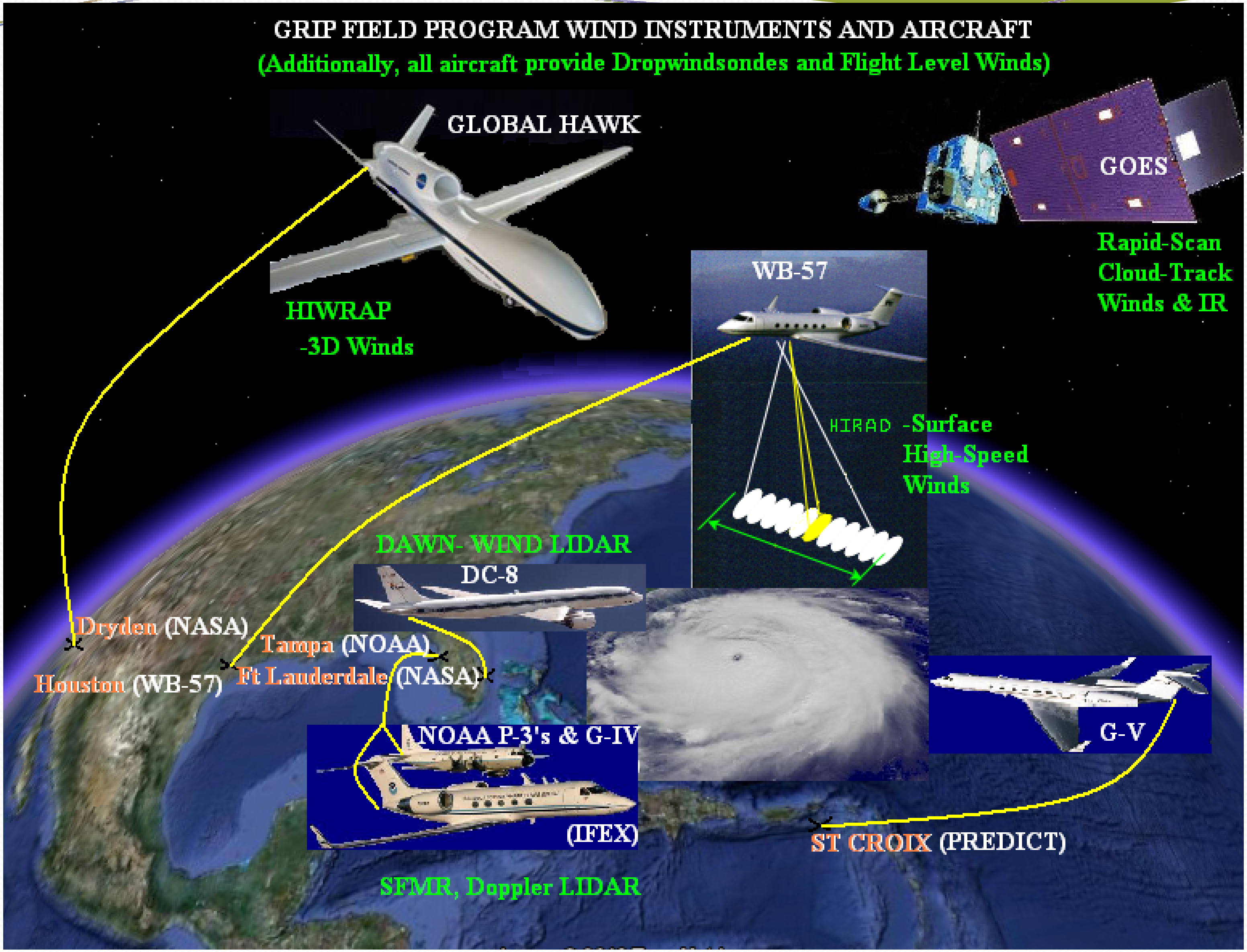
At the time of this image, Katrina was at Category 5 intensity with maximum sustained winds measured at 140 knots (161 mph) by NHC. Katrina initially made landfall at 6:10 am CDT south of Buras, Lousiana along the Mississippi delta as a strong Category 4 storm. The eye eventually crossed the coastline again along the Mississippi- Louisiana border with the most dangerous part of the storm, the eastern eyewall hitting along the same part of the Mississippi coastline that was wiped out by Hurricane Camille back in 1969

IN PRACTICE HERE IS WHAT IS NEEDED:

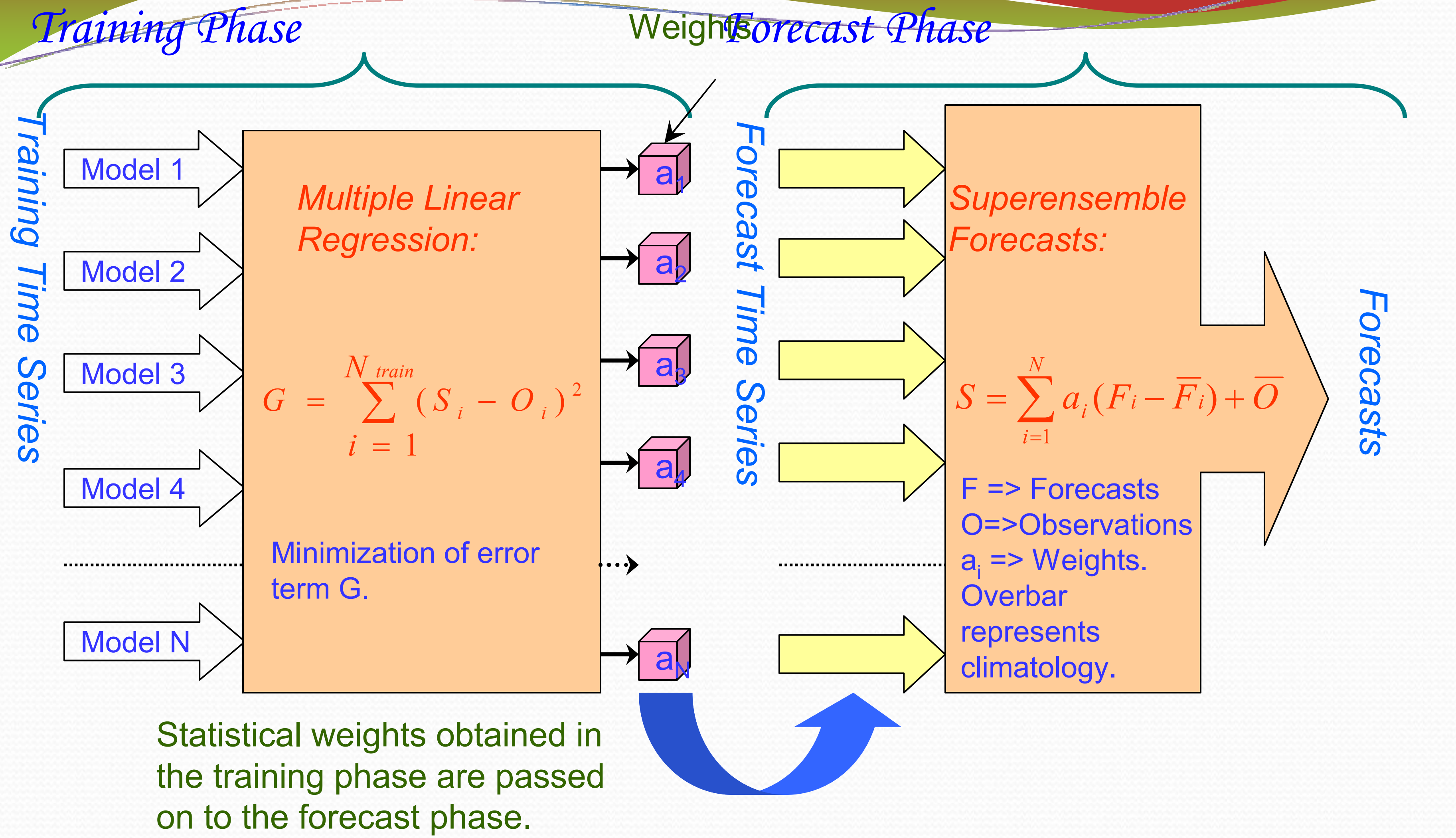
- WE NEED RAPID SCAN IMAGERY TO IDENTIFY CLOUD FLARE UPS ALONG THE INNER EYE WALL

- WE NEED AN ONGOING HOURLY HIGH RESOLUTION (1KM) DATA ASSIMILATION .

- NEED TO HAVE AN OBSERVATIONAL DOCUMENTATION OF THE SCENARIO AND MODELLING, i.e.
  DIVERGENCE FLARE UPS
  GRADIENT WIND DEPARTURE FLARE UPS,
  GENERATION OF SUPERGRADIENT WINDS &
  COMPUTE SUPERGRADIENT WIND


GRIP FIELD PROGRAM WIND INSTRUMENTS AND AIRCRAFT
(Additionally, all aircraft provide Dropwindsondes and Flight Level Winds)
GLOBAL HAWK
HIWRAP
-3D Winds
GOES
Rapid-Scan
Cloud-Track
Winds & IR
WB-57
HIRAD -Surface
High-Speed
Winds
DAWN- WIND LIDAR
DC-8
Dryden (NASA)
Tampa (NOAA)
Houston (WB-57)
Ft Lauderdale (NASA)
NOAA P-3's & G-IV
(IFEX)
G-V
ST CROIX (PREDICT)
SFMR, Doppler LIDAR

SUPERENSEMBLE BASED FORECASTS OF CLOUDS AND MESOSCALE PRECIPITATION


Training Phase
Weights
Forecast Phase
Training Time Series
Model 1
Model 2
Model 3
Model 4
Model N
Multiple Linear Regression:
$G = \sum_{i=1}^{N_{train}} (S_i - O_i)^2$
Minimization of error term G.
a_1
a_2
a_3
a_4
a_N
Forecast Time Series
Superensemble Forecasts:
$S = \sum_{i=1}^{N} a_i (F_i - \overline{F}_i) + \overline{O}$
F => Forecasts
O=>Observations
a_i => Weights.
Overbar represents climatology.
Forecasts
Statistical weights obtained in the training phase are passed on to the forecast phase.

ISCCP Data

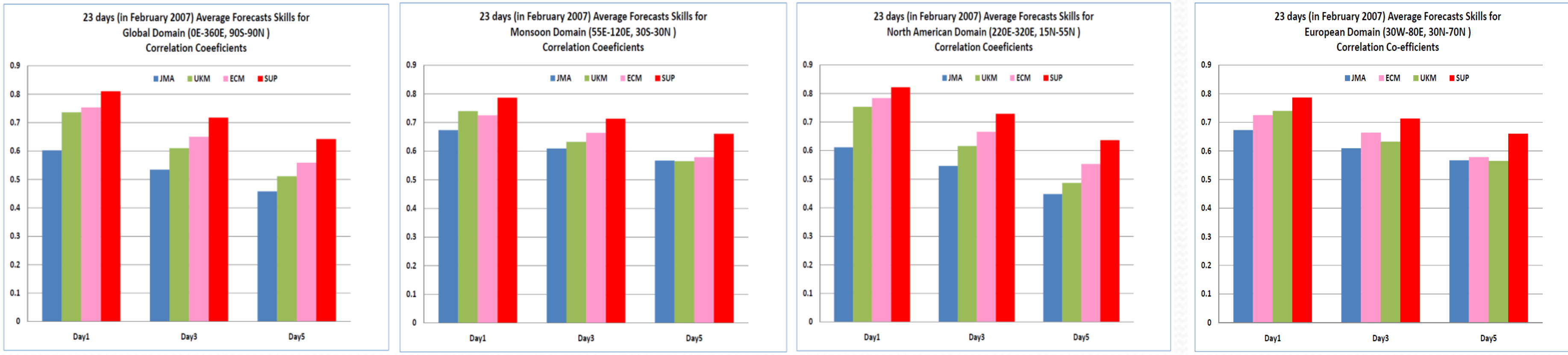
- International Satellite Cloud Climatology Project
- Six geostationary and two polar orbiting satellites
  - Regridded to a 30 km spatial resolution (pixels)
  - 3 hour temporal resolution
- Pixel flag indicating cloudiness
- Cloud top pressure was also included and used to determine cloud altitude.

TIGGE Data

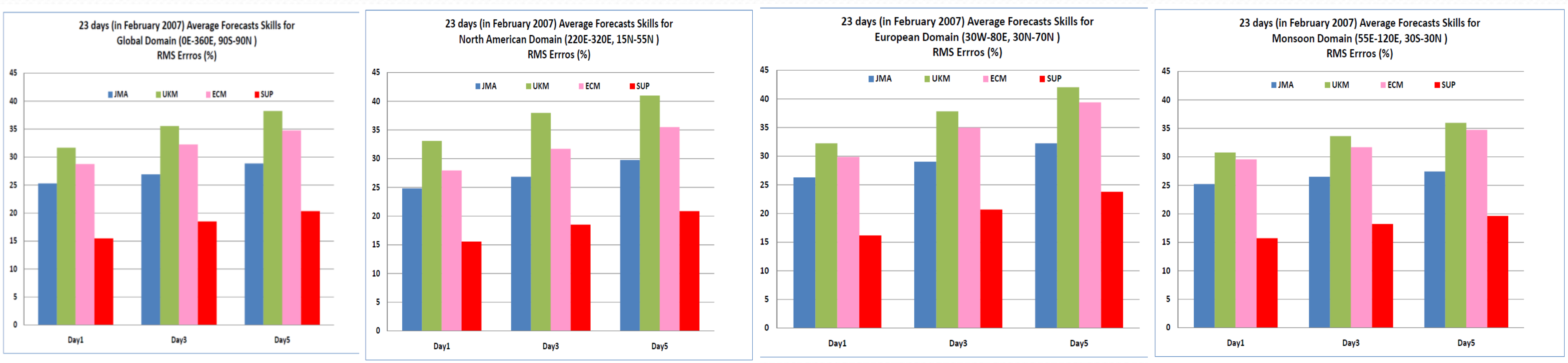
- Archives of ensemble model forecast data is available from many international meteorology centers.
- Records began in October 2006 with ECMWF, JMA, UKMet
- Spatial resolution varied from model to model.
- Total cloud forecasts are available for 6 hourly intervals.
- Specific humidity and temperature at seven standard pressure levels were used to create layer cloud cover datasets.

Methodology- Total Cloud Forecasts

- Spatial resolution of 1° latitude by 1° longitude between 60°S and 60°N.
- Temporal resolution of 24 hours out to a 168 hour forecast (7 days)
- Model input from ECMWF, JMA, GFS and UKMet
- Training periods varied from 20 days to 120 days using increments of 20 days.
- Sensitivity tested by removing best model.
- Two regions were examined: Global tropics (30°S to 30°N) and North America (10°N to 70°N and 140°W to 60°W).



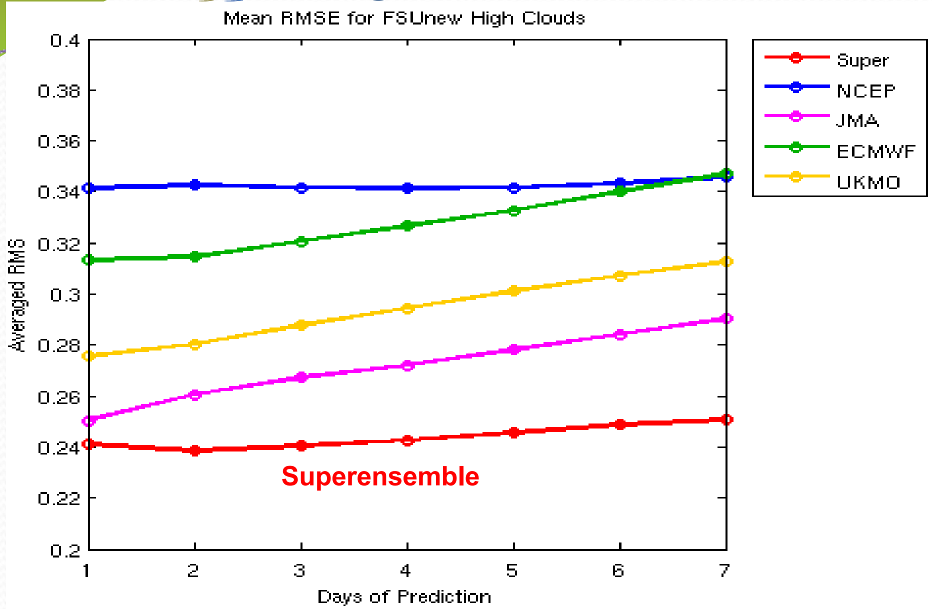
Shows the spatial correlations of Total Cloud Cover , based on 23 days of forecasts, for days 1, 3 and 5 of forecasts. The four panel of diagrams show results for whole Global Tropics, Monsoon Domain, North American Domain and a European Domain. The four vertical bars from left to right carry the spatial correlations for the models JMA, UK Met, ECMWF and the Multimodel Superensemble.

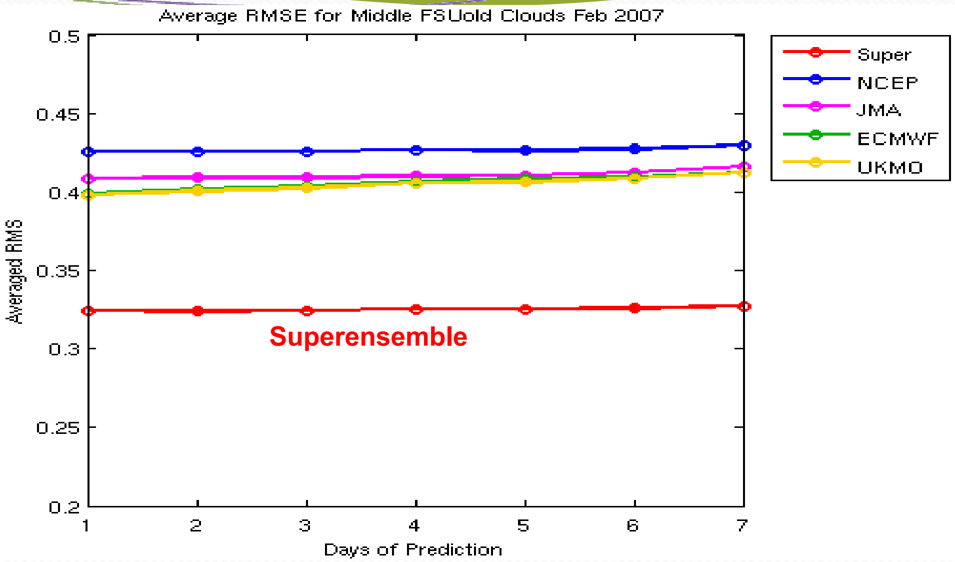


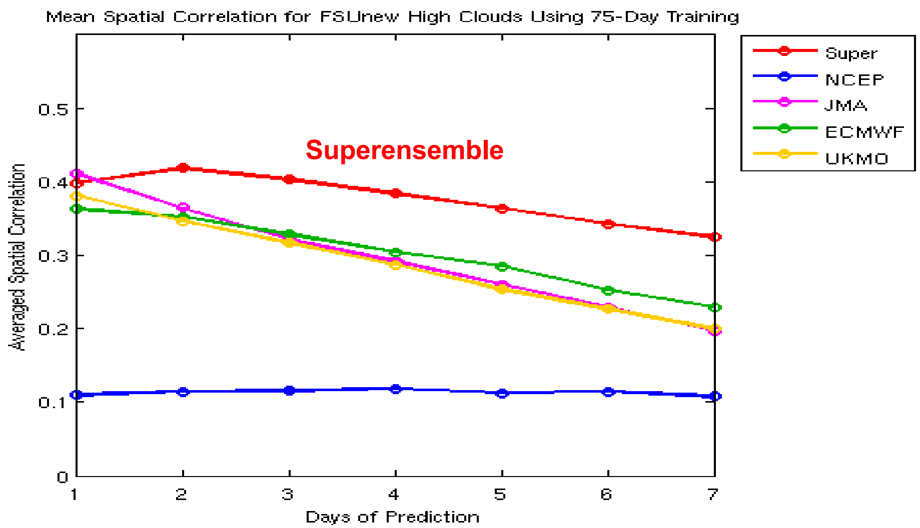
Shows the RMS Errors of Total Cloud Cover , based on 23 days of forecasts, for days 1, 3 and 5 of forecasts. The four panel of diagrams show results for whole Global Tropics, Monsoon Domain, North American Domain and a European Domain. The four vertical bars from left to right carry the RMS Errors for the models JMA, UK Met, ECMWF and the Multimodel Superensemble.

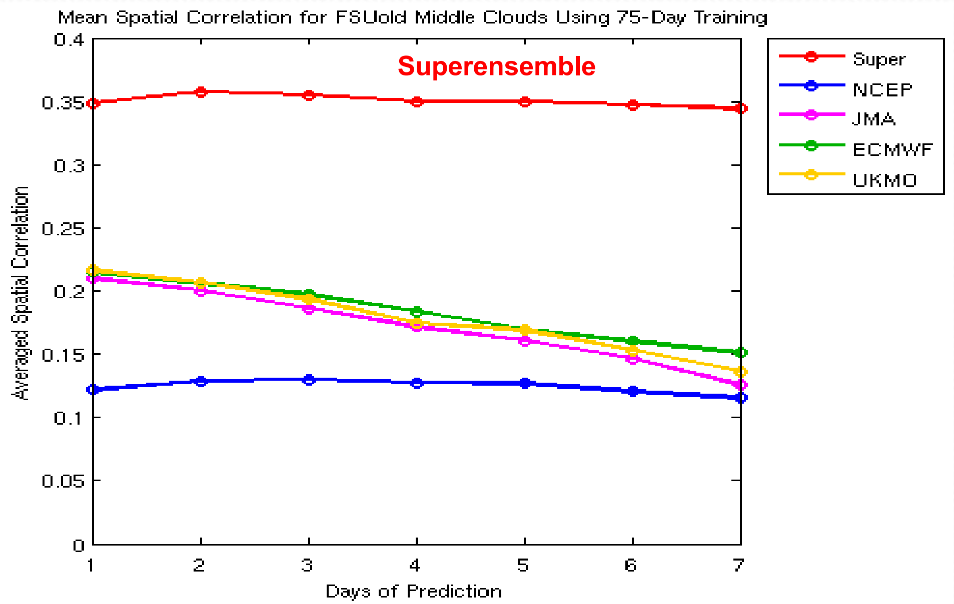
Results- High Clouds

Results- Middle Clouds

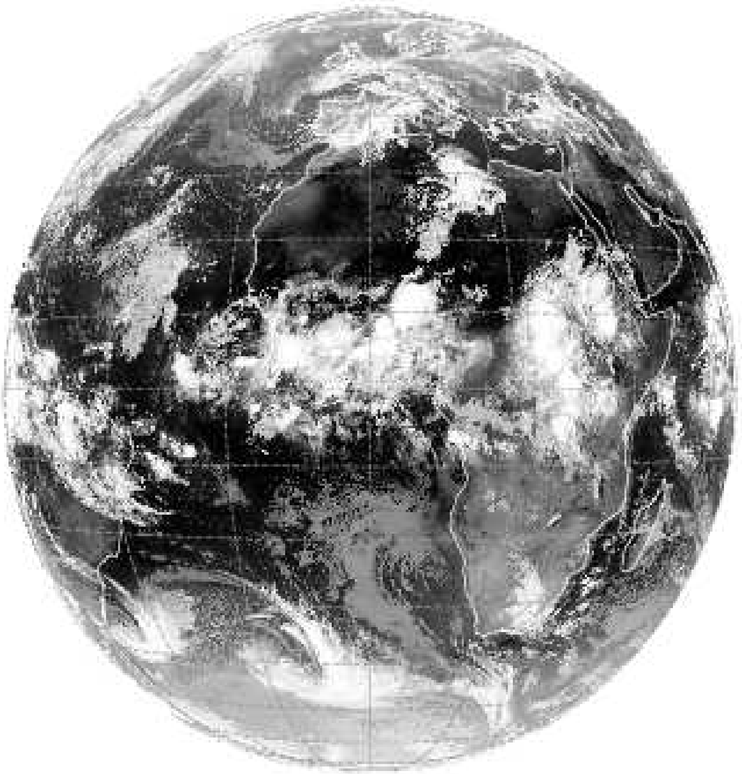


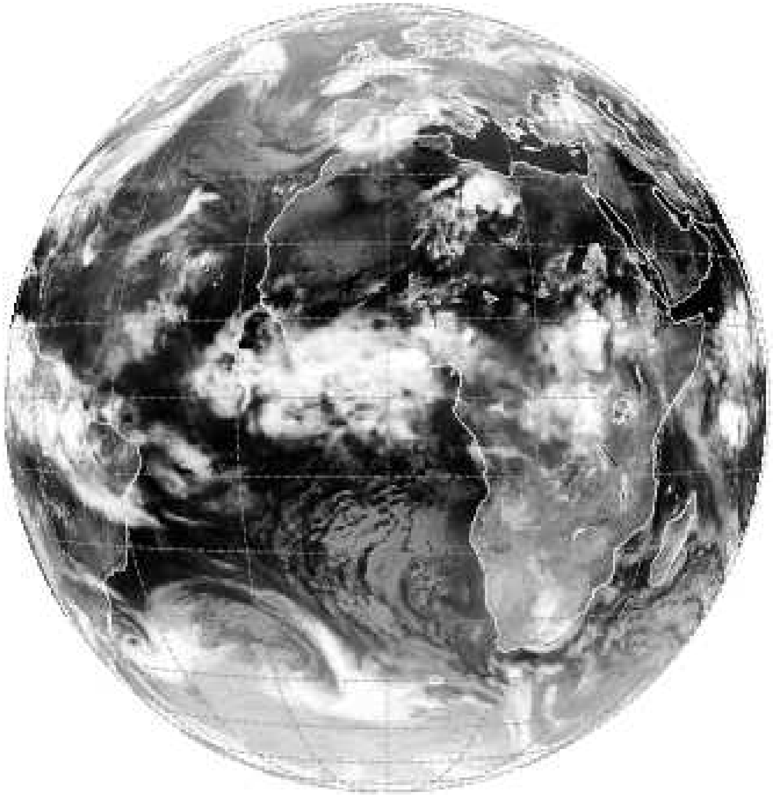






Background- Cloud Forecasts

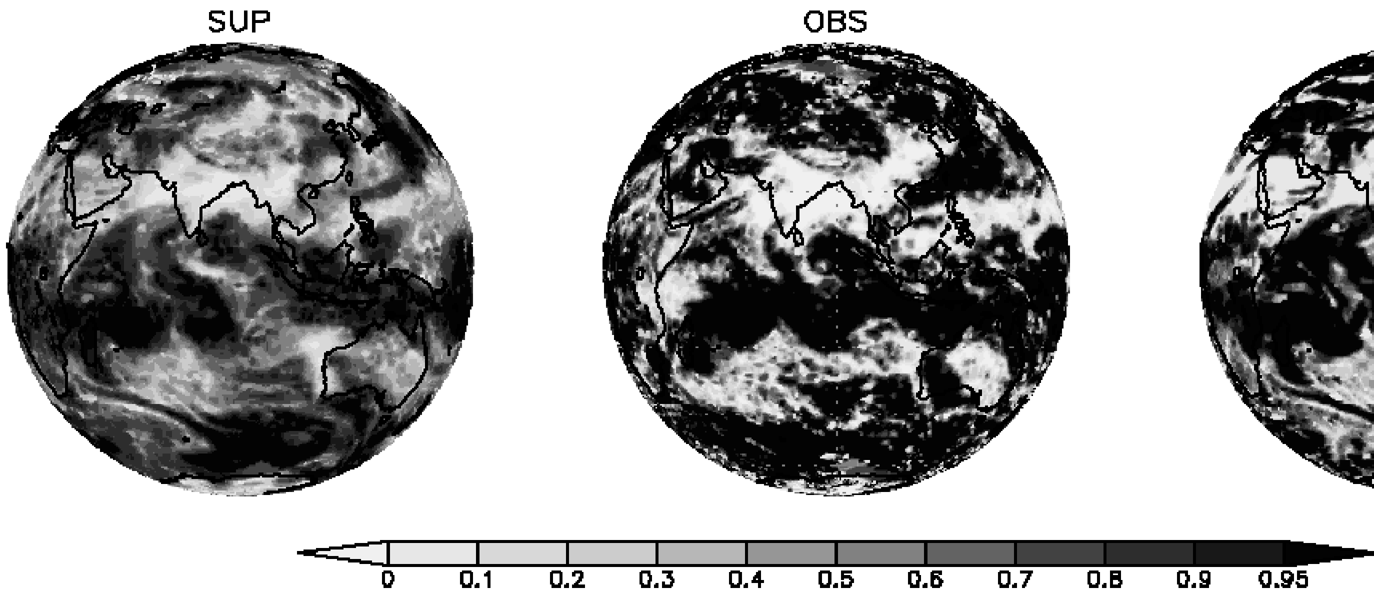


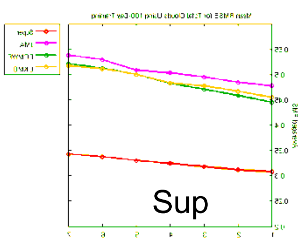


HATS OFF TO ECMWF

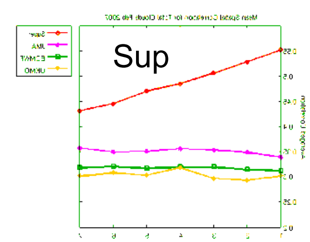
2007 Vintage TIGGE Data based forecasts, 1 degree lat-lon resoultion

Total Cloud Cover (%), obs and 22FEB2007 Day-1 forecasts





RMS



Correlation

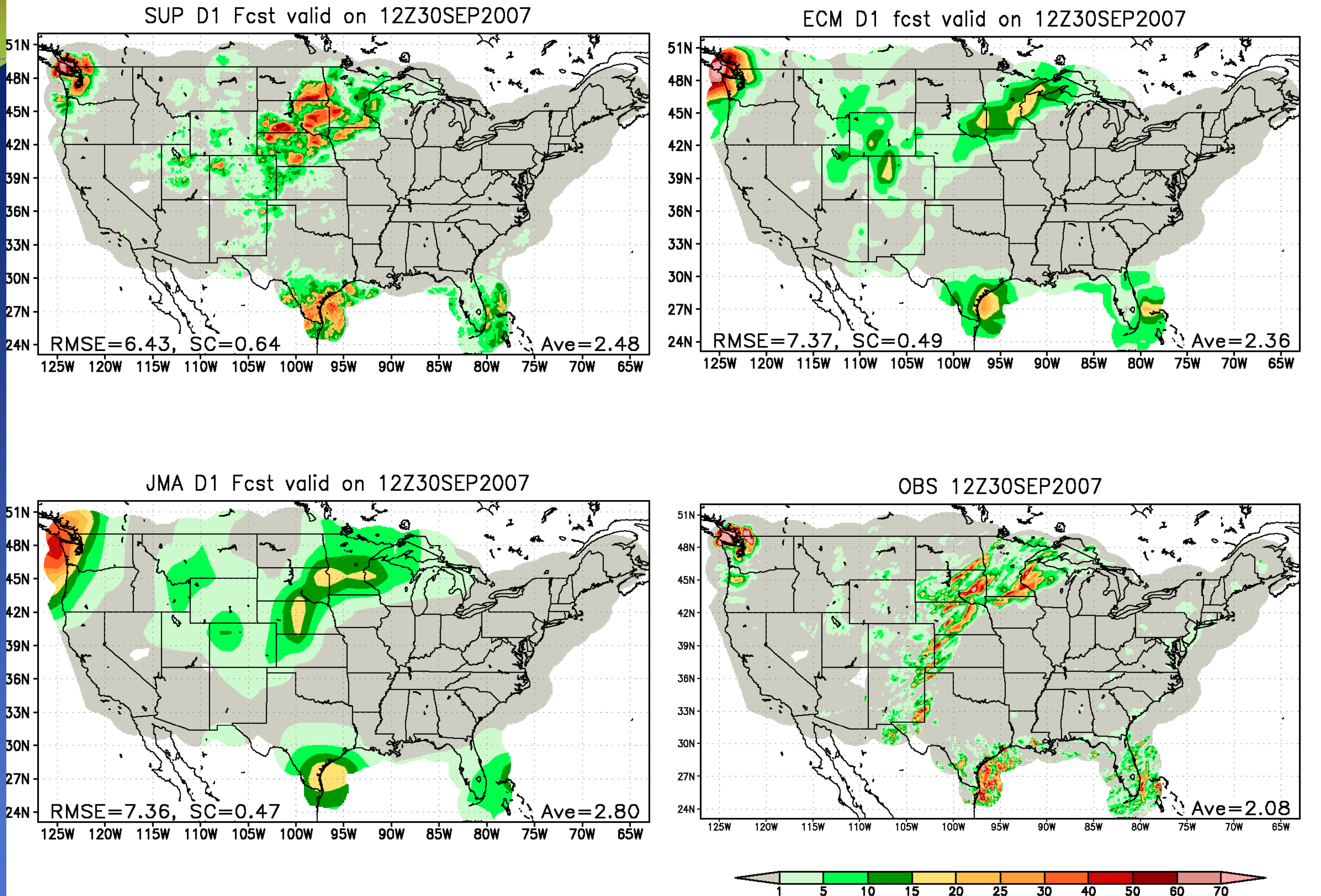
GrADS: COLA/IGES

2010-04-26-16:53

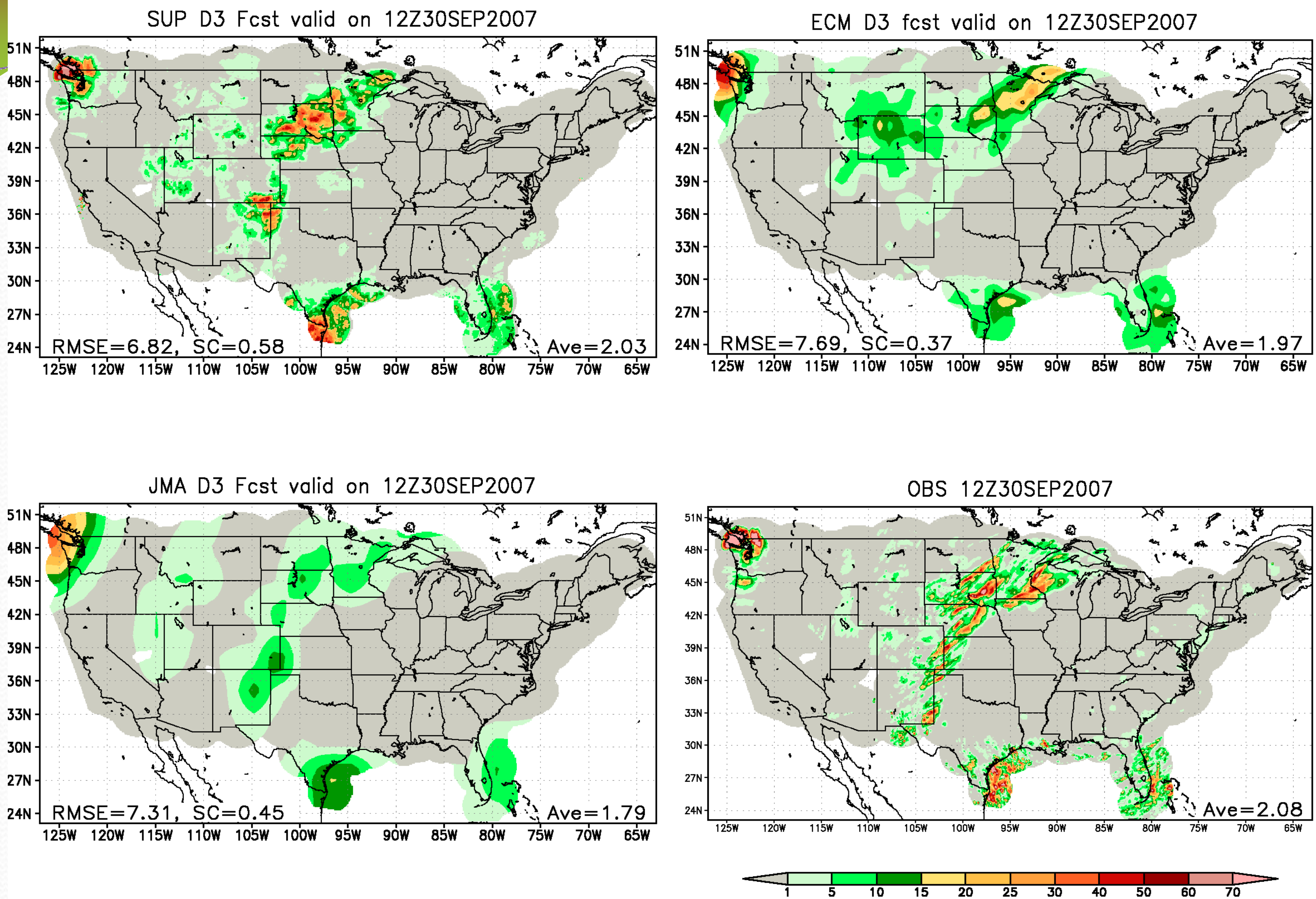
Five day prediction of US rainfall at a 4 km resolution using 4 Km WSR-88/ Raingauge Stage IV downscaling, TIGGE models and multimodel superensemble.

Last section

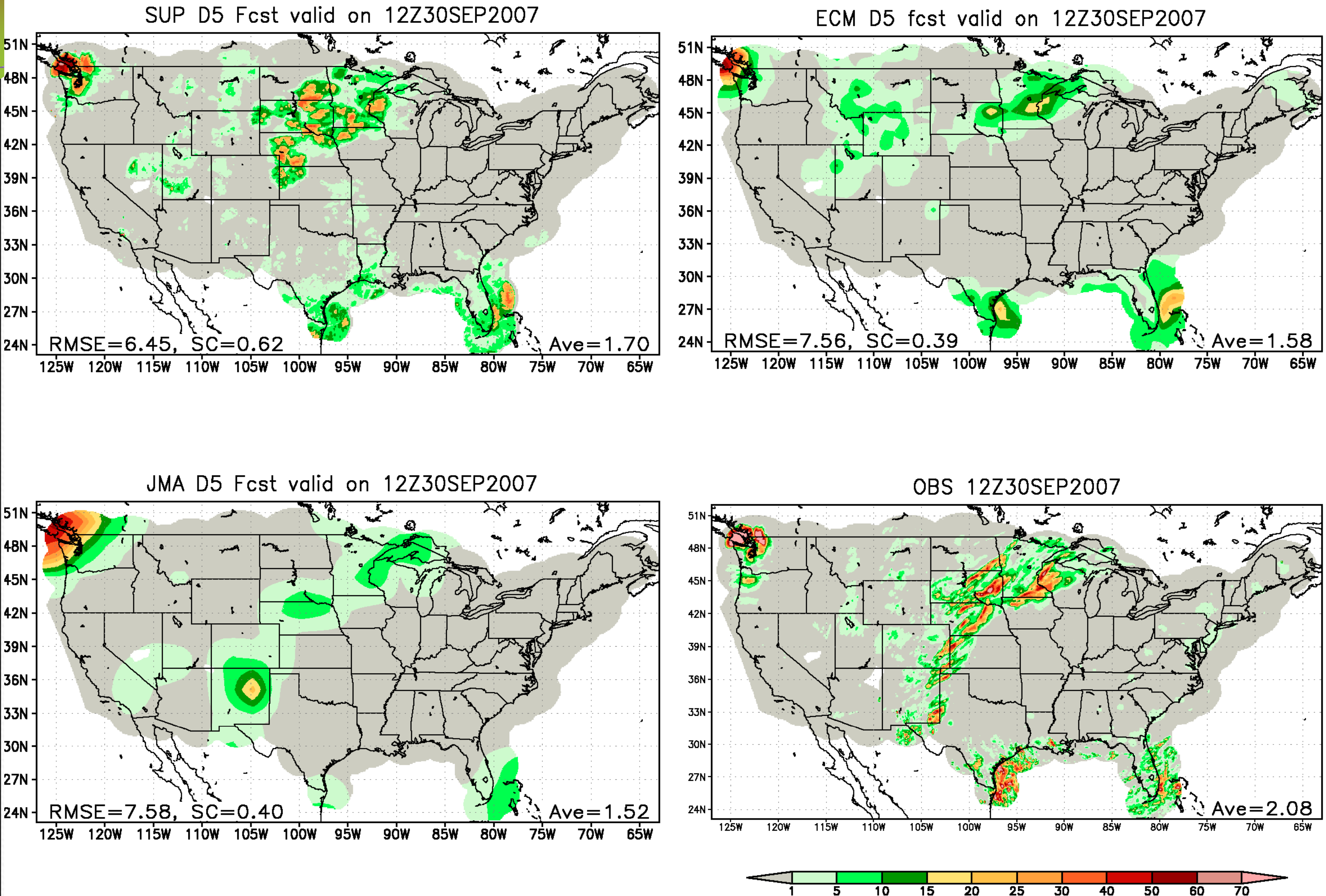
24 Hour Forecast



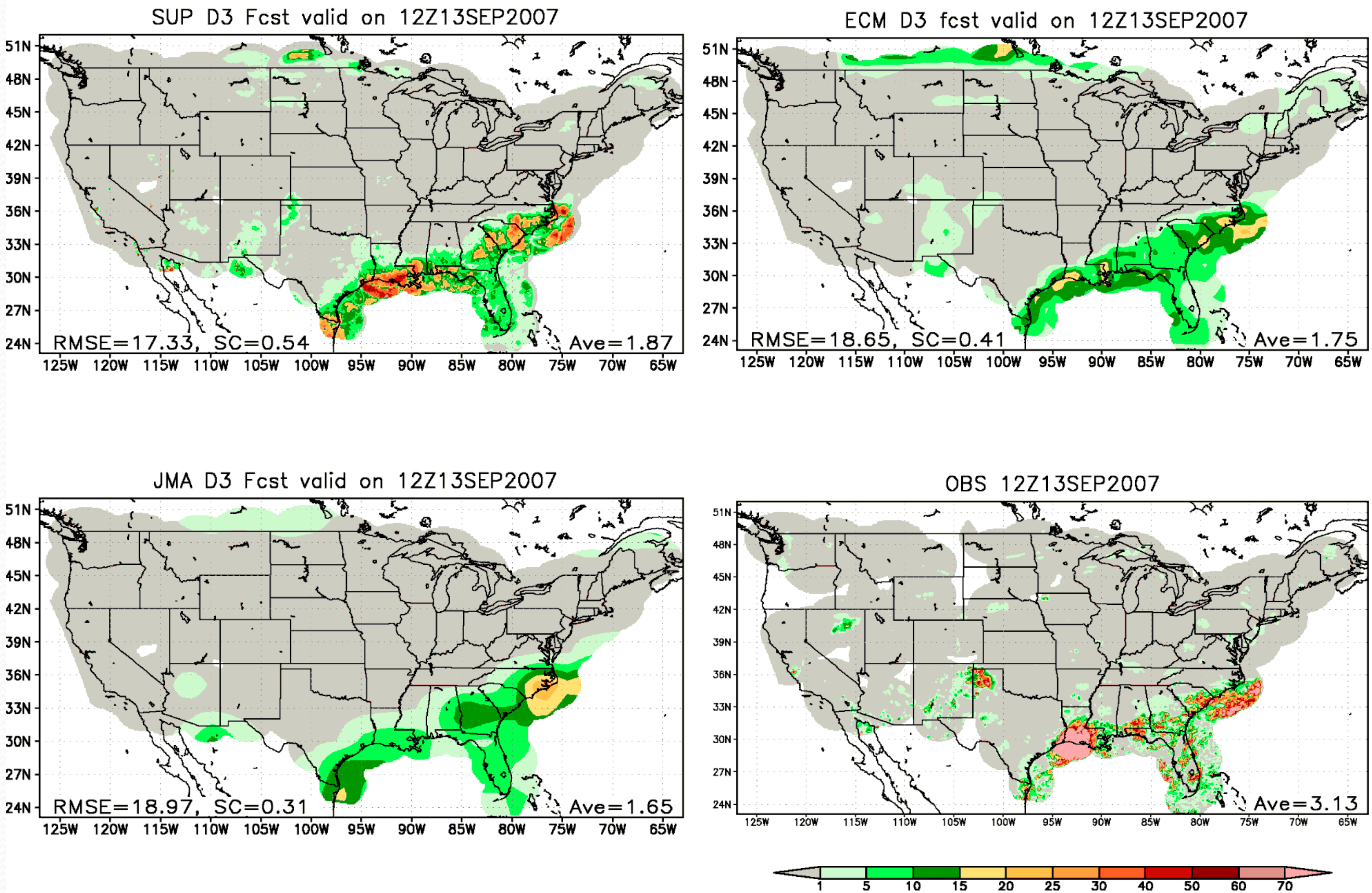
72 Hour Forecast



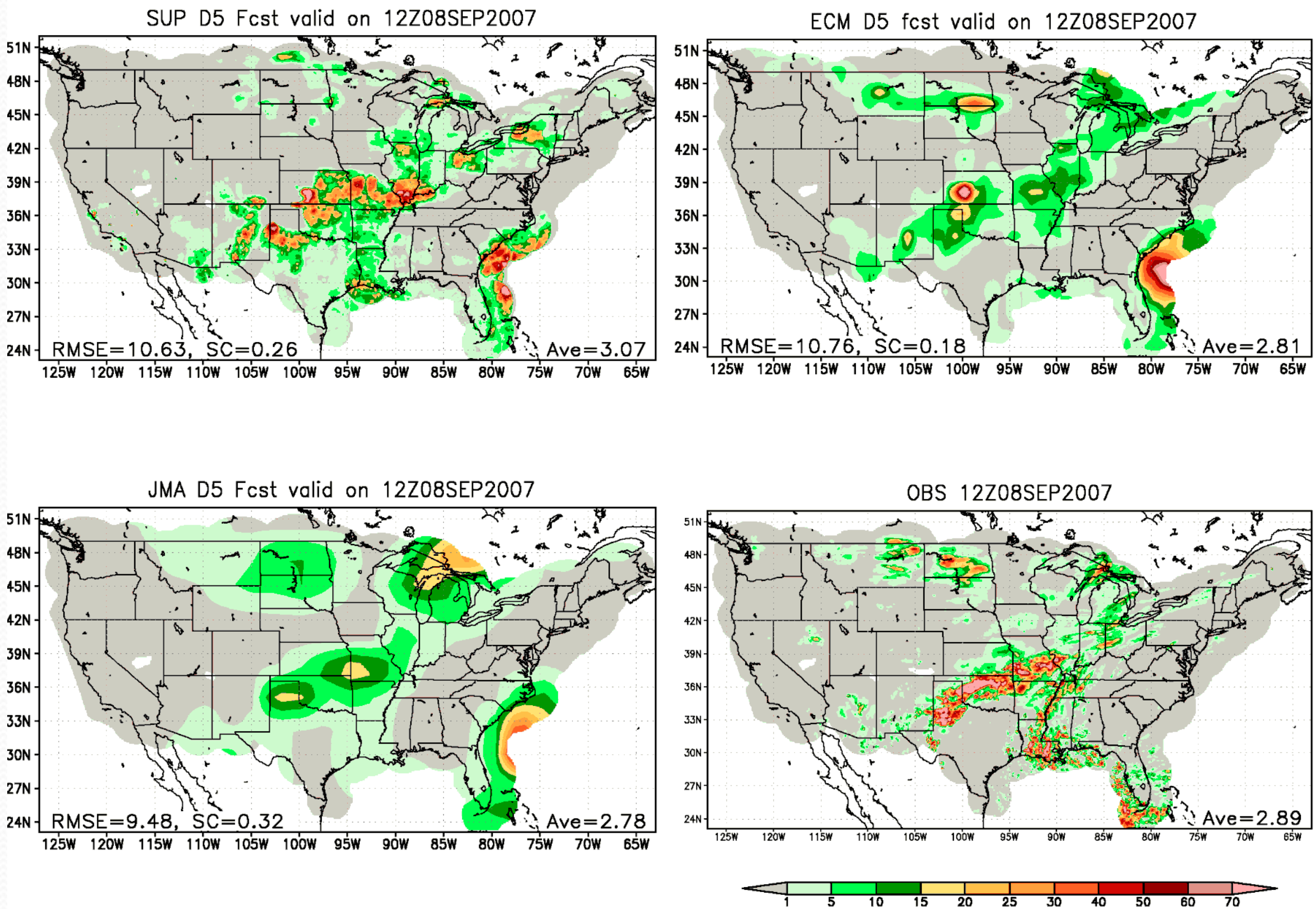
120 Hour Forecast



Day 3 Forecast valid on September 13th 2007



Day 5 Forecast valid on September 8th 2007



Summary

This is a short review on current research in my laboratory on clouds and precipitation. This review provides a short summary on our work on the transition monsoon from a wet to a dry spell. A hurricane scenario relates cloud burst in the inner eye wall of a hurricane to growth of convergence, to the rapid increase of departures from balance laws leading to a consequent rapid intensification of super-gradient winds.

This summary also alludes to the multimodel superensemble with some skillful forecasts for global clouds and precipitation over the US at a 4 km resolution

thanks ECMWF for this opportunity,

THANK YOU