# Observing System Simulation Experiments: Methodology, Early results and plans for the future

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# OUTLINE

1. Introduction to OSSEs
2. Methodology
3. Summary of earlier results
4. Illustration of a rigorous OSSE and a Quick OSSE
5. Current work and plans for hurricane and ocean OSSEs.

# OBSERVING SYSTEM SIMULATION EXPERIMENTS

## OBJECTIVES:

1. To provide a QUANTITATIVE assessment of the potential impact of proposed observing systems on earth system science,data assimilation, and numerical weather prediction.

2. To evaluate new methodology for the processing and assimilation of remotely sensed data.

3. To evaluate tradeoffs in the design and configuration of proposed observing systems (e.g. coverage, resolution, accuracy and data redundancy).

4. Can also be used to determine the ability of existing observing system to detect climatic trends and to optimize the global observing system for climate monitoring and other applications.

# EARLY SIMULATION STUDIES

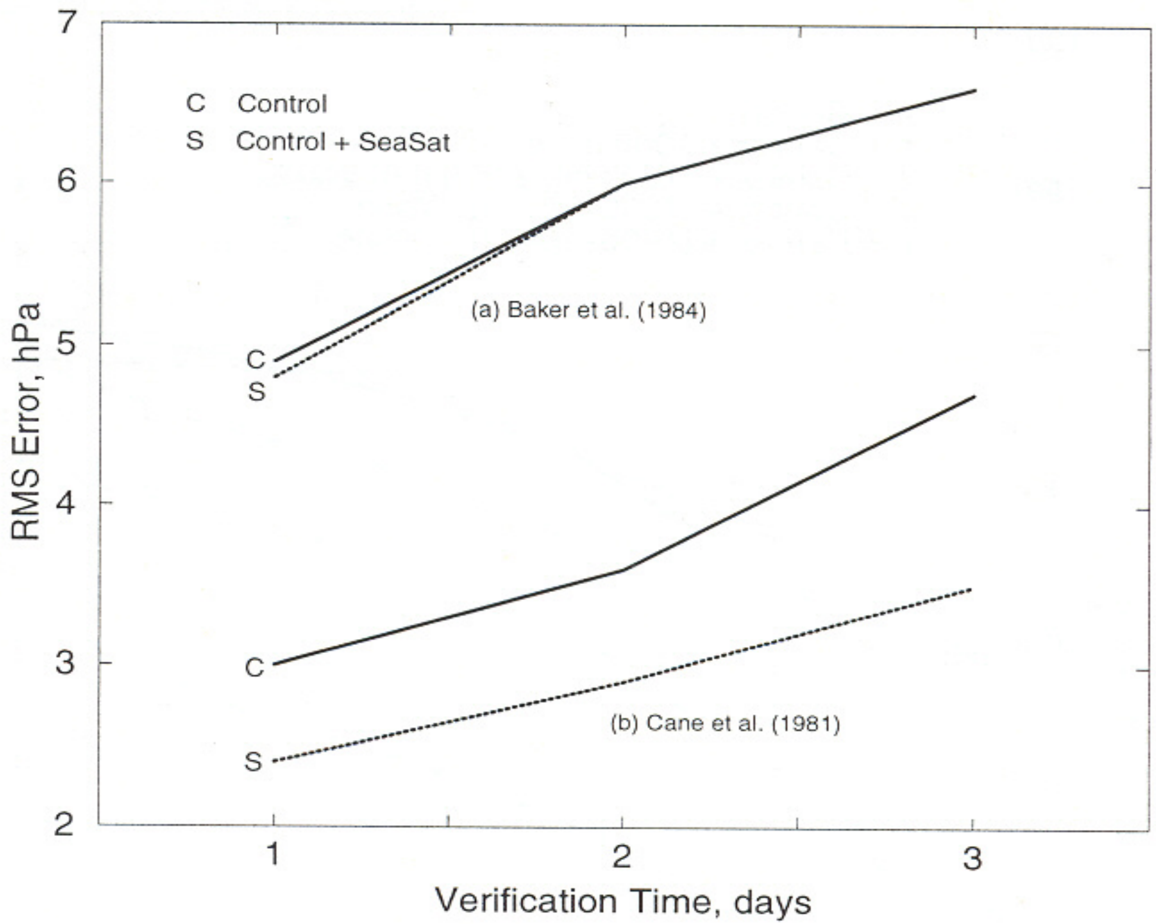
1. PROVIDED AN ANALYSIS OF
   - GARP DATA REQUIREMENTS
   - "USEFUL" RANGE OF PREDICTABILITY
   - NEED FOR REFERENCE LEVEL DATA
   - RELATIVE USEFULNESS OF ASYNOPTIC vs SYNOPTIC DATA ASSIMILATION

2. INDICATED THAT
   - ALL THREE OF THE PRIMARY VARIABLES (TEMPERATURE, MOISTURE, WIND) COULD BE DETERMINED IF A CONTINUOUS TIME HISTORY OF ANY ONE OF THESE VARIABLES WERE INSERTED INTO A GENERAL CIRCULATION MODEL. ("CHARNEY CONJECTURE")

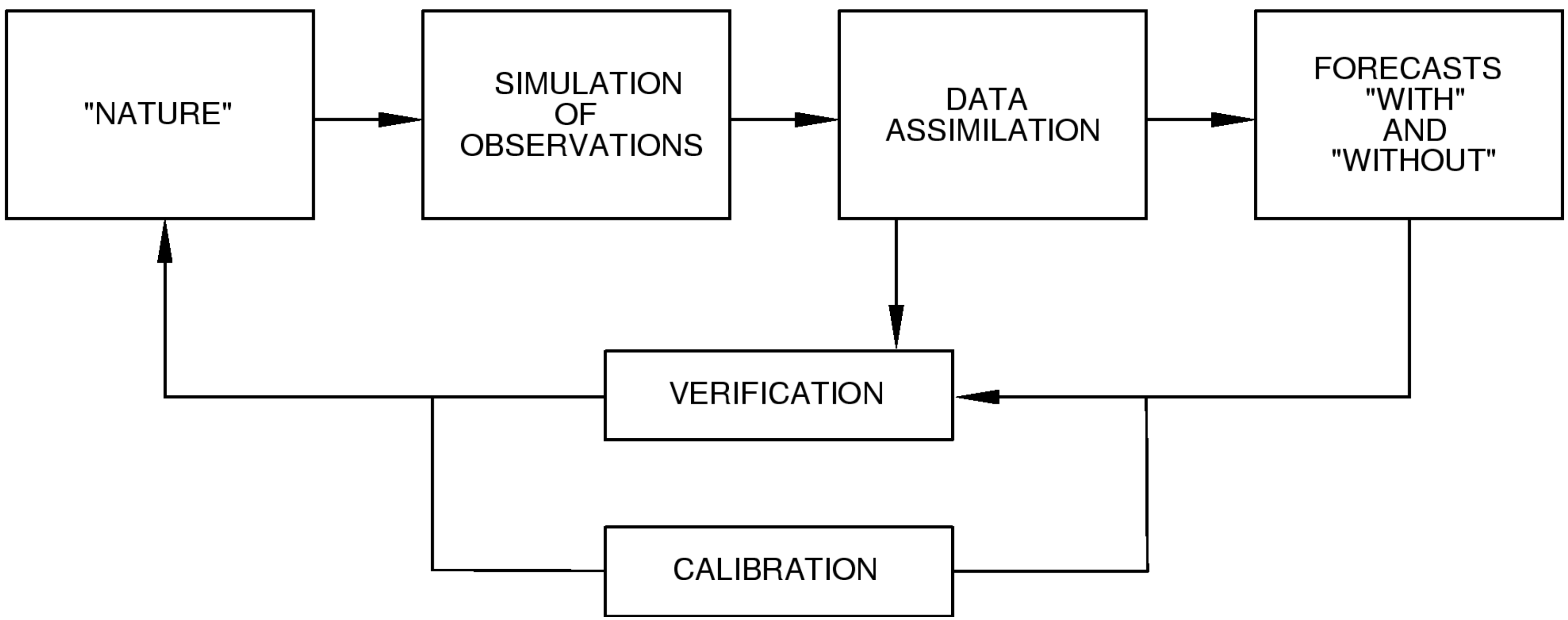
# LIMITATIONS OF PREVIOUS STUDIES

- MOST IMPORTANT IS THE USE OF THE SAME MODEL FOR NATURE AND ASSIMILATION / FORECASTING "IDENTICAL TWIN EXPERIMENTS"
- MODEL DEPENDENCE OF RESULTS
- TREATING OBSERVATIONAL ERRORS AS RANDOM AND UNCORRELATED

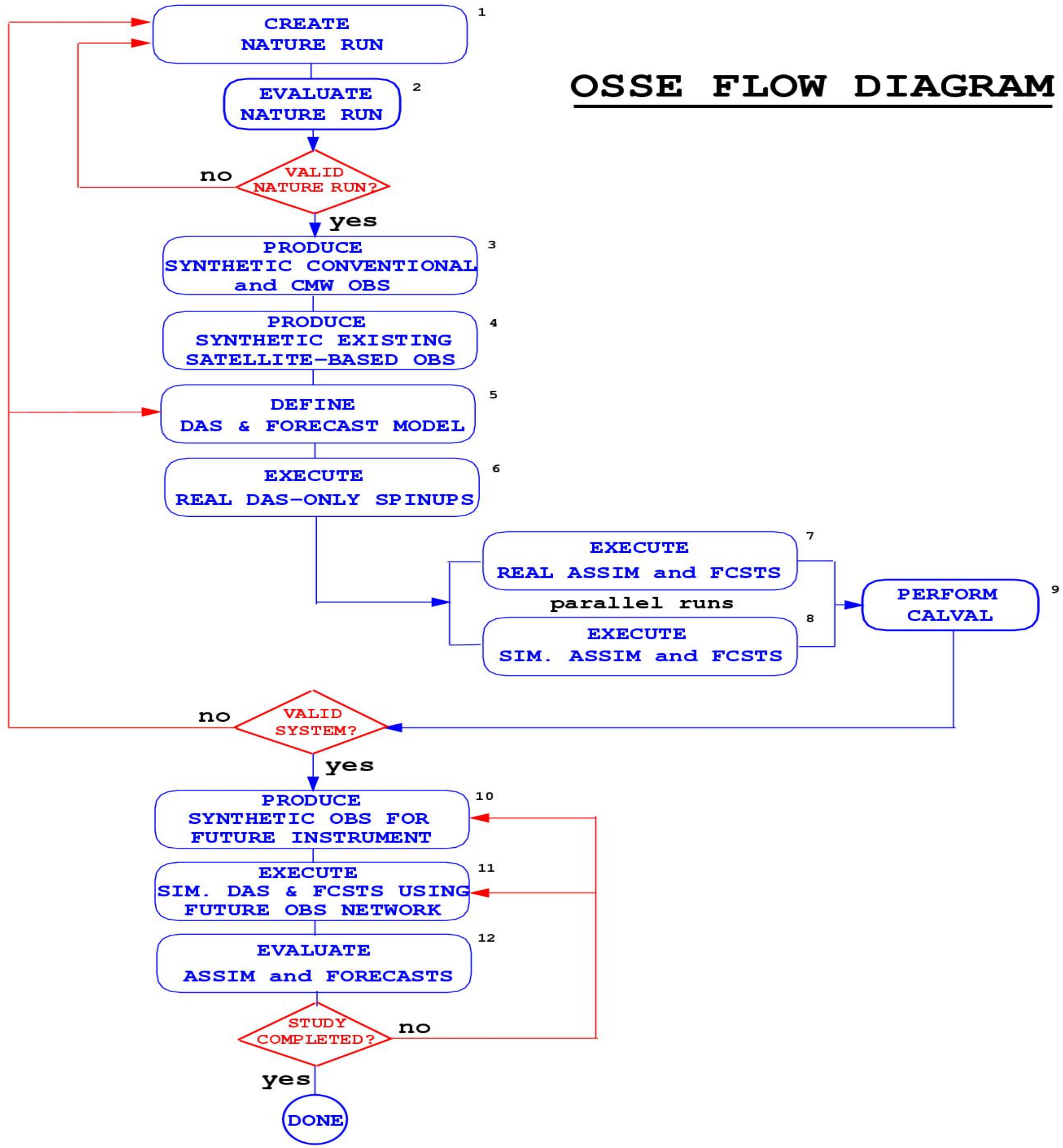
# Cane et al. (1981) OSSE for Seasat



## OBSERVING SYSTEMS SIMULATIONS



# OSSE FLOW DIAGRAM



# Previous OSSEs

1. **EVALUATED THE RELATIVE IMPACT OF TEMPERATURE, WIND AND MOISTURE DATA - These experiments showed wind data to be more effective than mass data in correcting analysis errors and indicated significant potential for space-based wind profile data to improve weather prediction.The impact on average statistical scores for the northern hemisphere was modest, but in approximately 10% of the cases a significant improvement in the prediction of weather systems over the United States was observed.**

2. **EVALUATED THE RELATIVE IMPORTANCE OF UPPER AND LOWER LEVEL WIND DATA.- These experiments showed that the wind profile data from 500hpa and higher provided most of the impact on numerical forecasting.**

3. **EVALUATED DIFFERENT ORBITAL CONFIGURATIONS AND THE EFFECT OF REDUCED POWER FOR A SPACE-BASED LASER WIND SOUNDER (LAWS).- These experiments showed the quantitative reduction in impact that would result from proposed degradation of the LAWS instrument.**

4. **DETERMINED DRAFT DATA REQUIREMENTS OF SPACE-BASED LIDAR WINDS.-These experiments evaluated different coverages, resolutions, and accuracies for lidar wind measurements to estimate both research and operational requirements for the Global Tropospheric Wind Sounder (GTWS) Mission.**

# Previous OSSEs (continued)

5. **DEVELOPED AND TESTED IMPROVED METHODOLOGY FOR ASSIMILATING SATELLITE SCATTEROMETER DATA.** - Applying this methodology resulted in the demonstration of the first significant positive impact of real scatterometer data in 1983.

6. **DEVELOPED AND TESTED DIFFERENT METHODS FOR ASSIMILATING SATELLITE SURFACE WIND SPEED DATA**.- This led to assimilation of SSM/I wind speed data to improve ocean surface wind analyses.

7. **EVALUATED THE QUANTITATIVE AND RELATIVE IMPACT OF ERS AND NSCAT YEARS PRIOR TO THEIR LAUNCH**.- These results were confirmed after the launch of both instruments.

8. **EVALUATED THE QUANTITATIVE IMPACT OF AIRS SOUNDING DATA AND THE IMPORTANCE OF CLOUD-CLEARING.** These results were also confirmed by later data impact experiments with real AIRS data.

# ILLUSTRATION OF AN OSSE

- **TO EVALUATE THE POTENTIAL FOR SPACE-BASED WIND PROFILE DATA TO IMPROVE ATMOSPHERIC ANALYSES AND NUMERICAL WEATHER FORECASTS.**

- **TO DETERMINE IF THE IMPACT OF SPACE-BASED WIND PROFILES WOULD BE SUBSTANTIALLY REDUCED IN THE PRESENCE OF ADVANCED SOUNDER OR WITH A MORE ACCURATE FORECAST MODEL**.

- **TO EVALUATE THE IMPACT OF SPACE-BASED WIND PROFILES ON THE ANALYSIS AND FORECASTING OF PHENOMENA NOT PREVIOUSLY STUDIED IN OSSEs. (eg. Hurricanes, jet streaks, and the hydrologic cycle.)**

# DESCRIPTION OF EXPERIMENT

- **The nature run was generated using the FVGCM at .5 deg resolution for the period from September 11 to December 31, 1999.**

- **A detailed evaluation of the nature run was performed.**

- **All conventional and satellite observations (that were assimilated at NASA at this time) were simulated with existing coverages and expected accuracies.**

# DESCRIPTION OF EXPERIMENT

- **Space-based wind profiles were simulated first in a very idealized way, with the same coverage as TOVS, 1m/s accuracy at all levels and no degradation due to cloud effects; in later experiments somewhat more realistic lidar winds with attenuation due to clouds, but still 1m/s accuracy were assimilated.**

- **The OSSE system was validated through comparison with real data impact experiments.**

- **The results of the OSSE were evaluated in terms of standard metrics (rms, anomaly correlation) and phenomena based metrics ( cyclones, jet streaks, hydrologic cycle).**

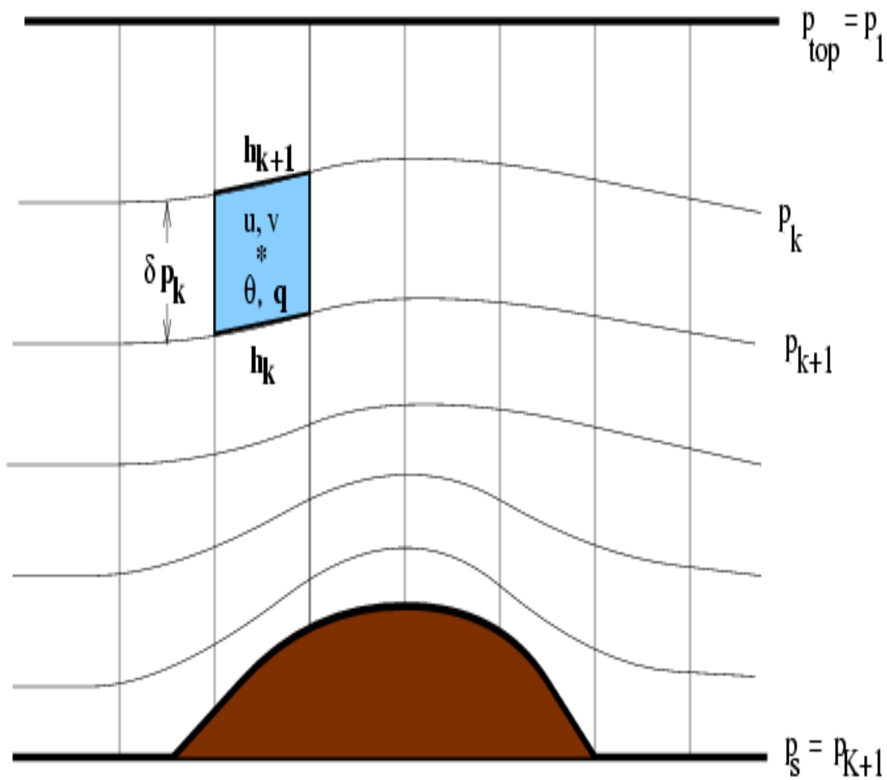
# The Finite-volume GCM

- The finite-volume GCM (fvGCM) was developed as a next generation modeling system based on a finite-volume dynamical core and the ***community built*** physical parameterizations and land surface model.

- Physical parameterizations are based on the NCAR CCM3.

- Partners in  developments of the fvGCM: NOAA/GFDL, ESRL and AOML, NASA, NCAR, DOE, and Universities.

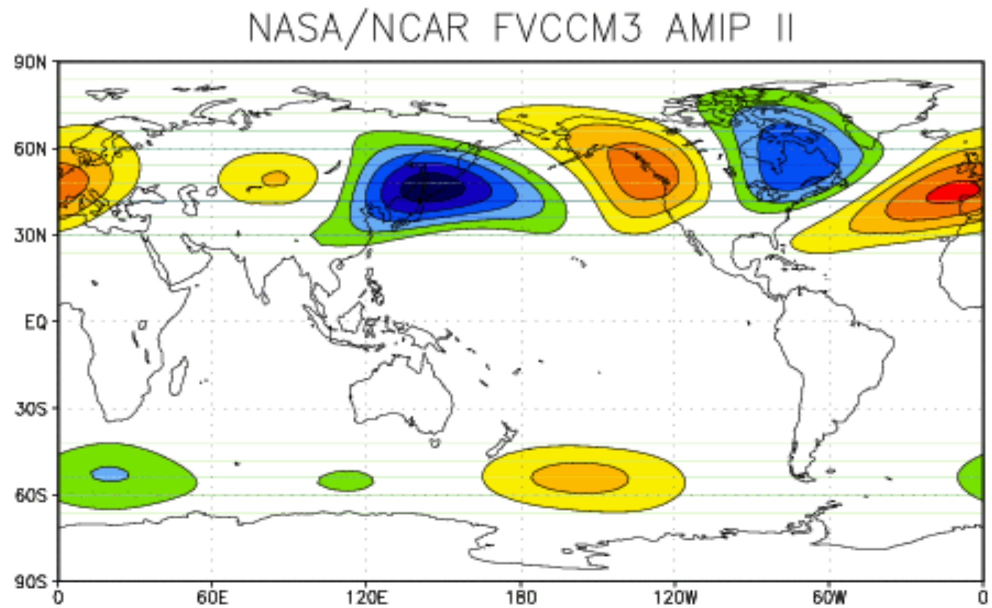
# The f-v Dynamical Core




- Terrain following Lagrangian control-volume vertical discretization of the basic conservation laws:
  - Mass
  - Momentum
  - Total energy
- 2D horizontal flux-form semi-Lagrangian discretization
  - Genuinely conservative
  - Gibbs oscillation free
  - Absolute vorticity consistently transported with mass dp within the Lagrangian layers.
- Computationally efficient

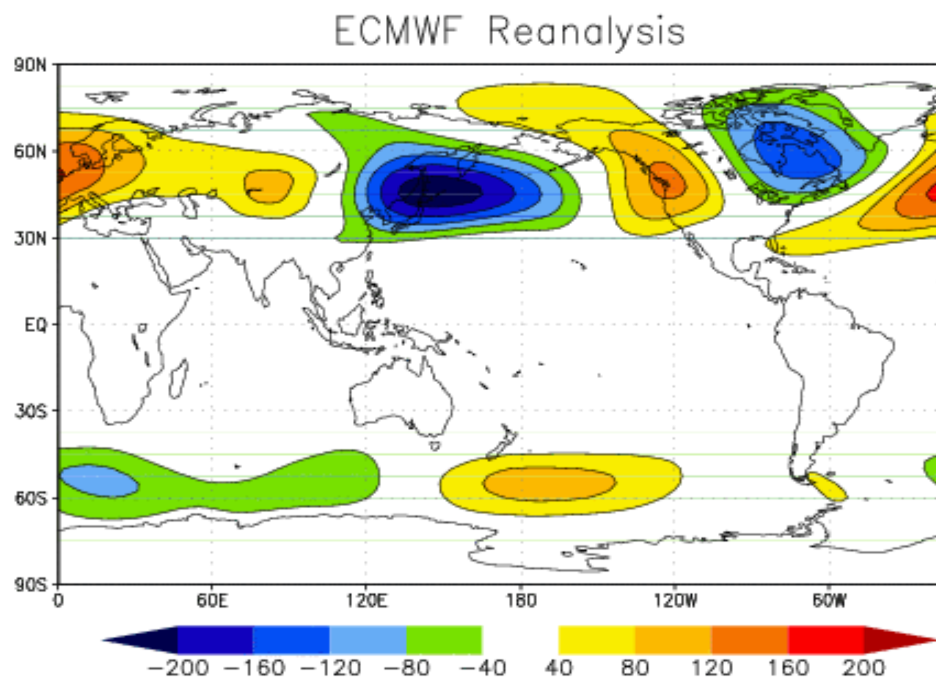
DJF 500-mb eddy height

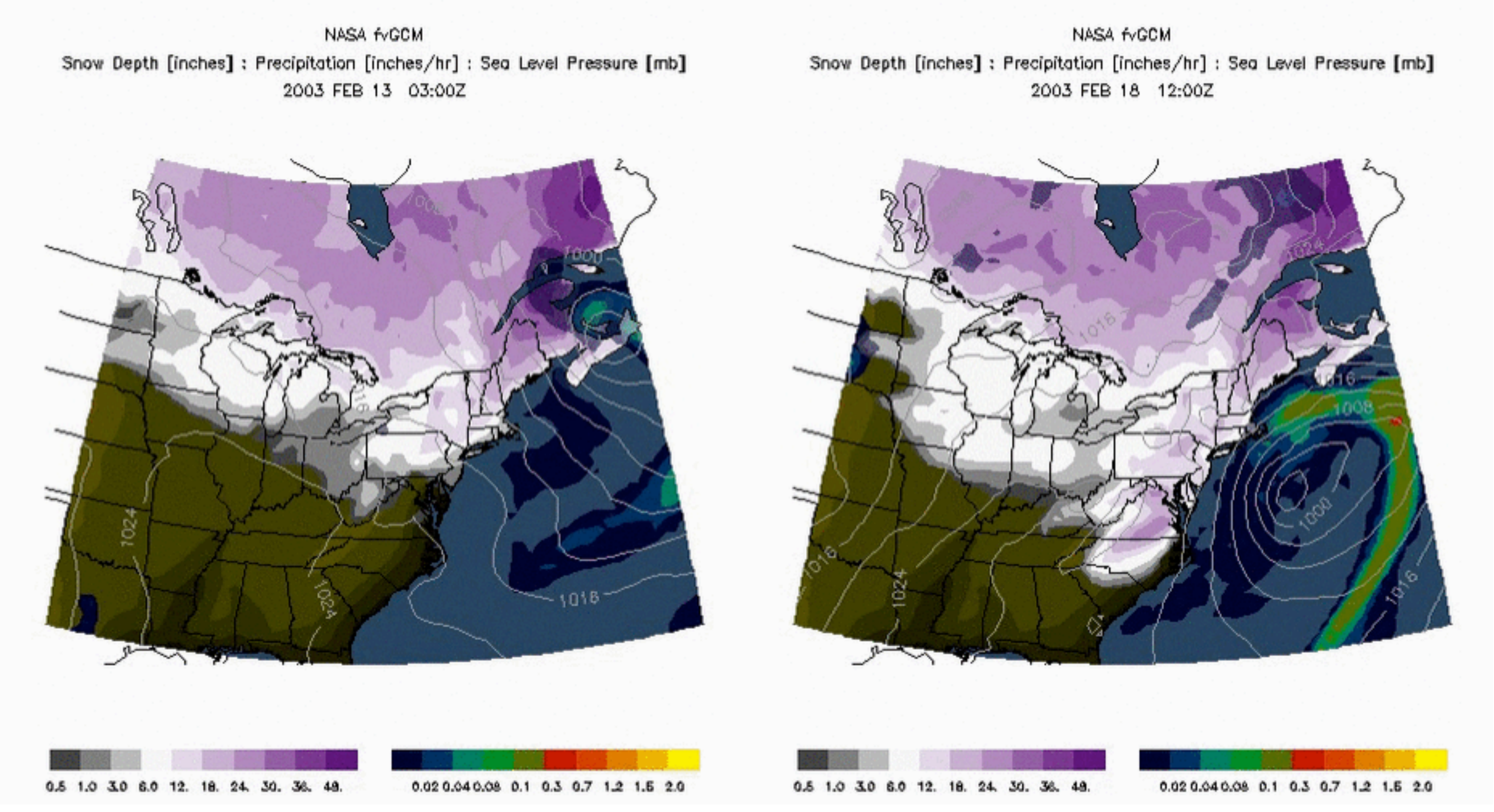
fvCCM (15-yr amip-2 run)




DJF 500-mb eddy height

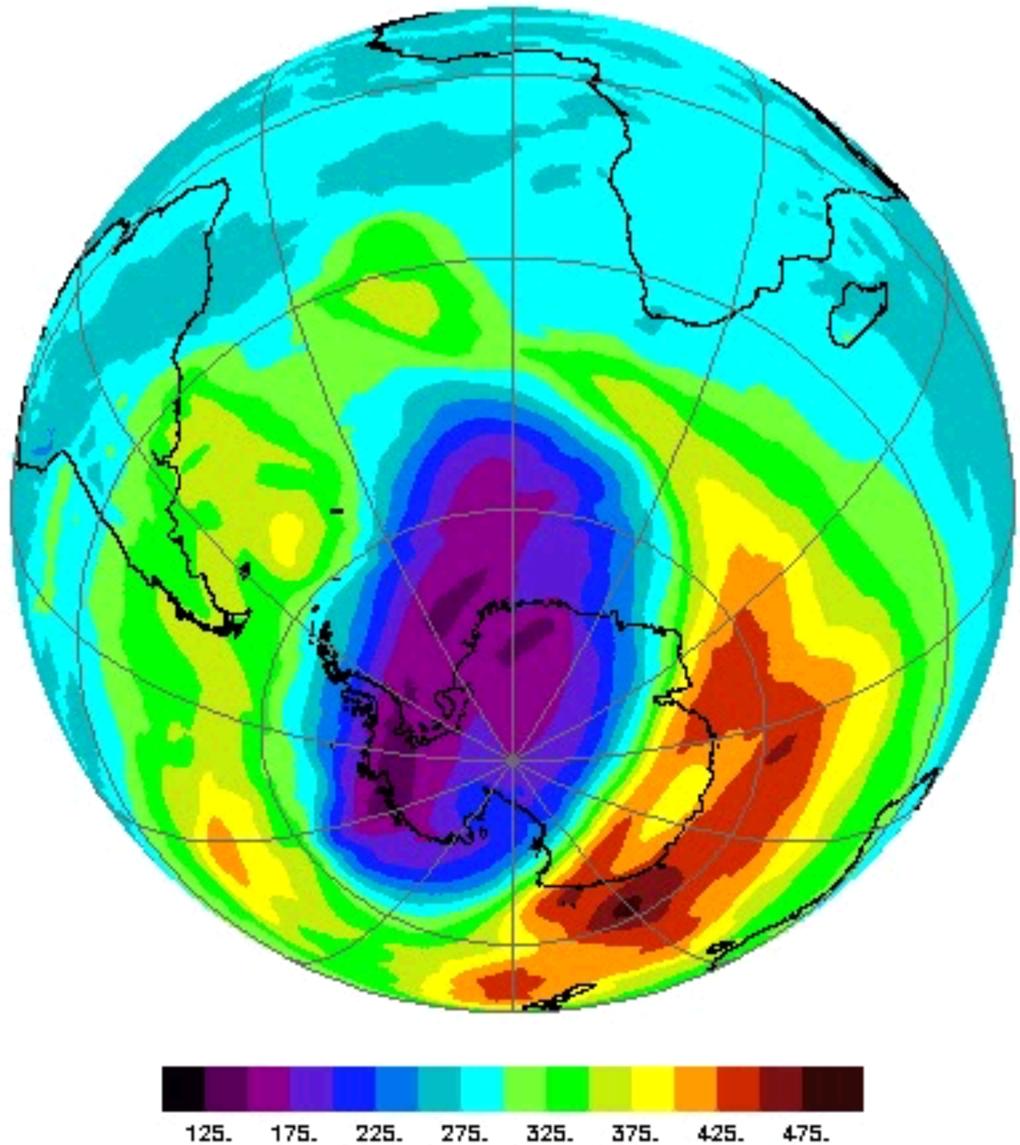
ECMWF analysis (15-yr)





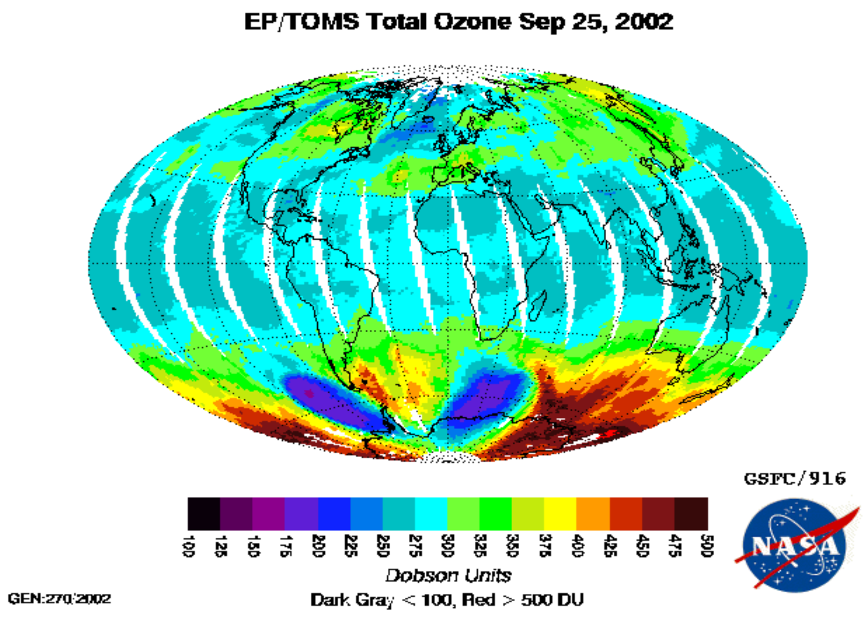

**NASA FVGCM forecast of severe winter storm**

fvGCM Total Column Ozone [Dobson Units]
2002 Sep 21 01Z

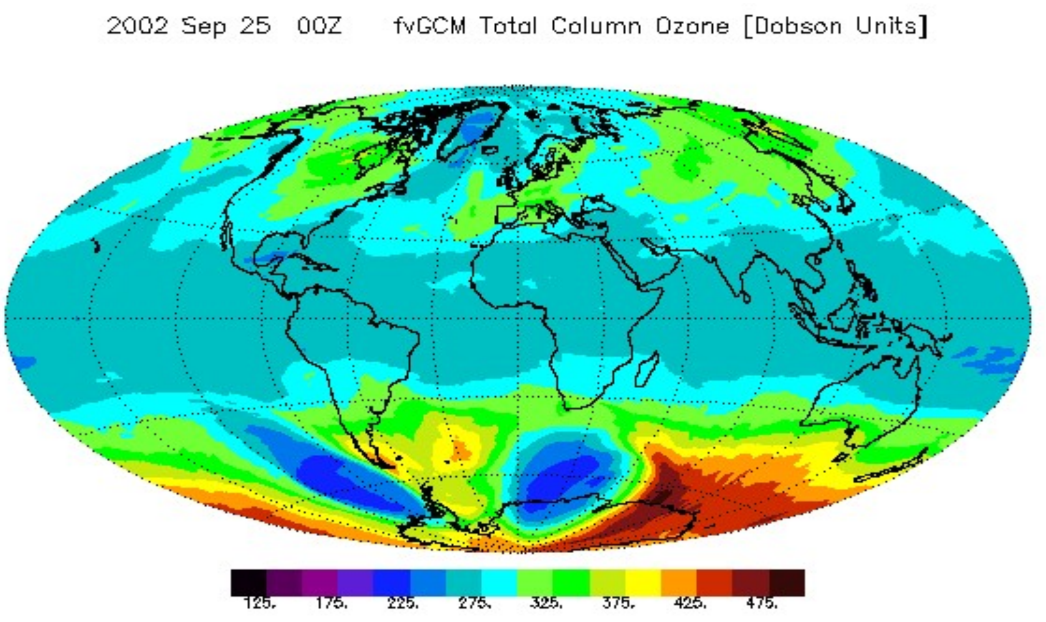


# *Validation of Ozone Prediction*

TOMS Ozone Satellite

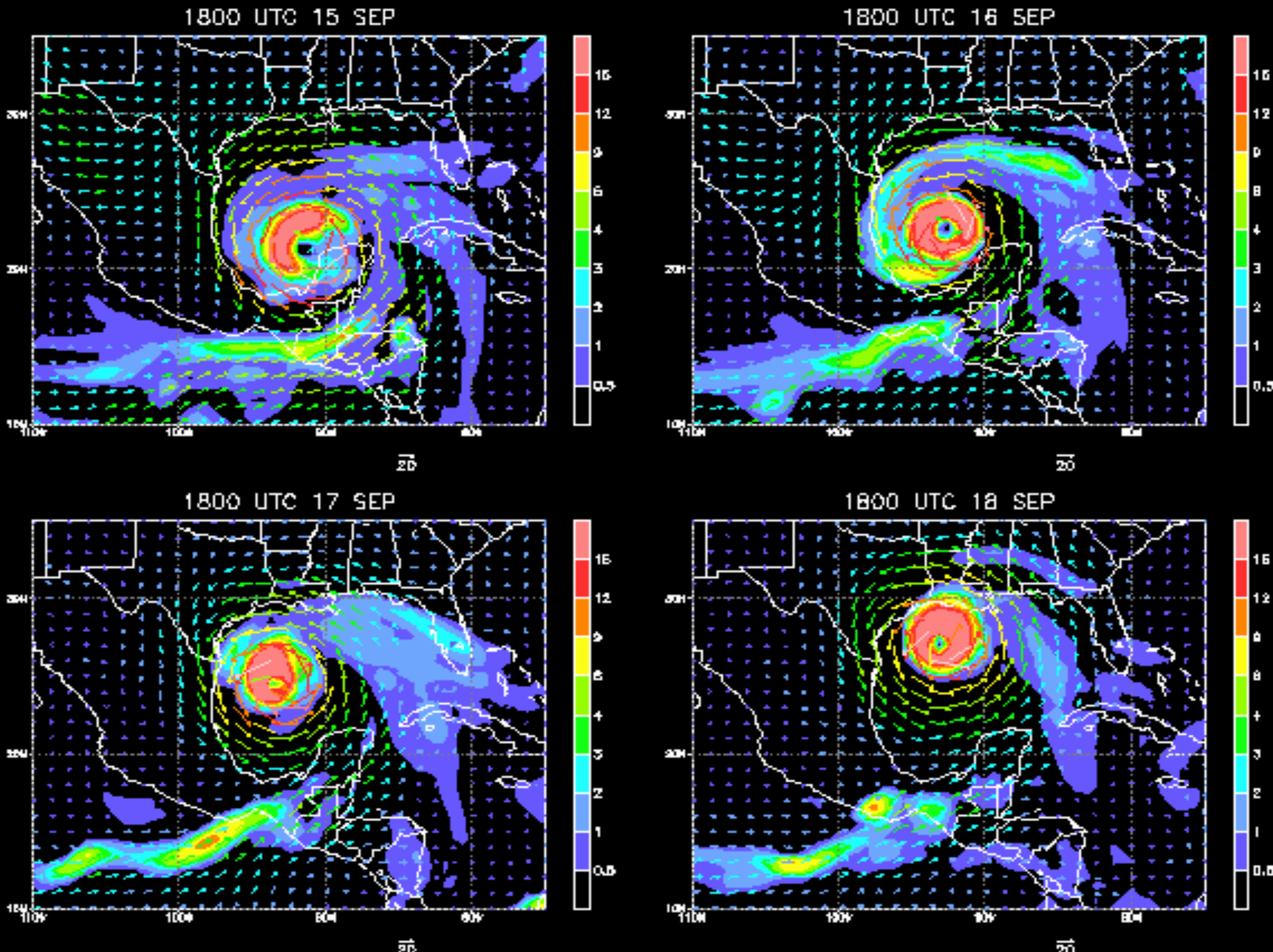



4-day prediction

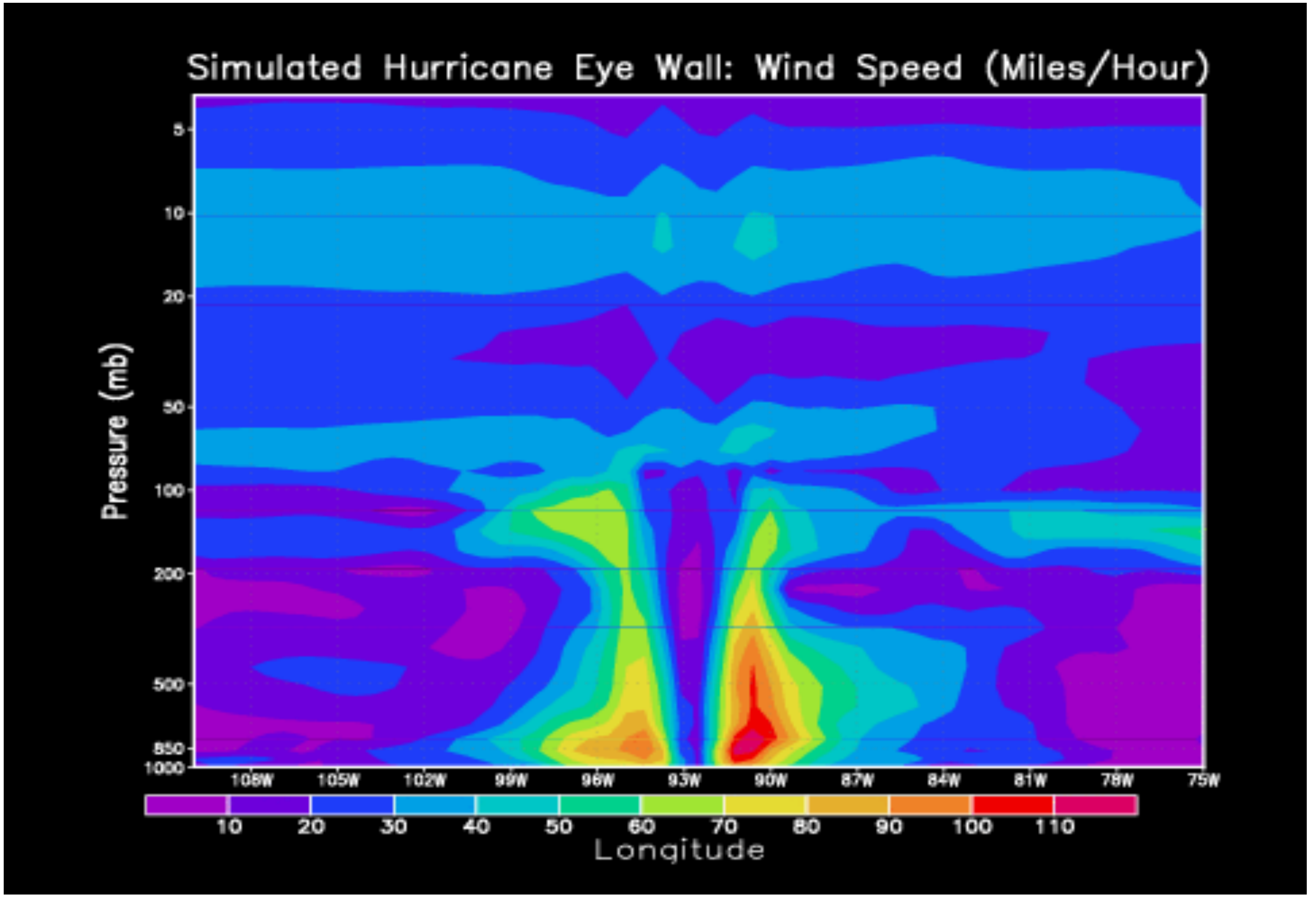


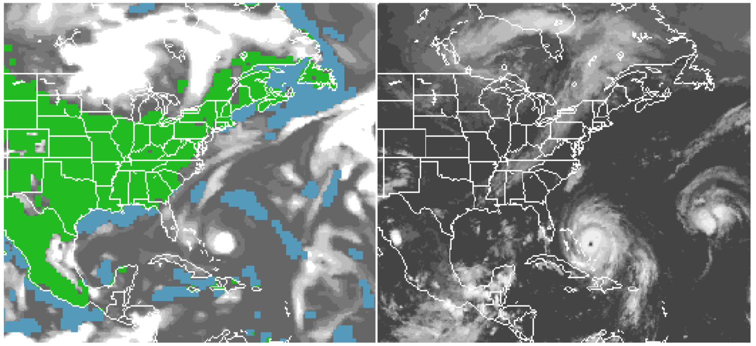
# Simulated Hurricane in NASA/NCAR 0.5x0.625 Model

## Precip (mm/hr) and 850mb Wind



# *Simulated Eye Wall: wind speed*





# Synoptic Evaluation of the FVCCM Nature Run

*NASA Goddard Space Flight Center*
*Data Assimilation Office (DAO) Code 910.4*
*Greenbelt MD 20771*
*USA*

**R. Atlas, Shian-Jiann Lin, J. C. Jusem, G. Partyka**

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## Week 1: September 11-17, 1999

### Northern Hemispheric Overview

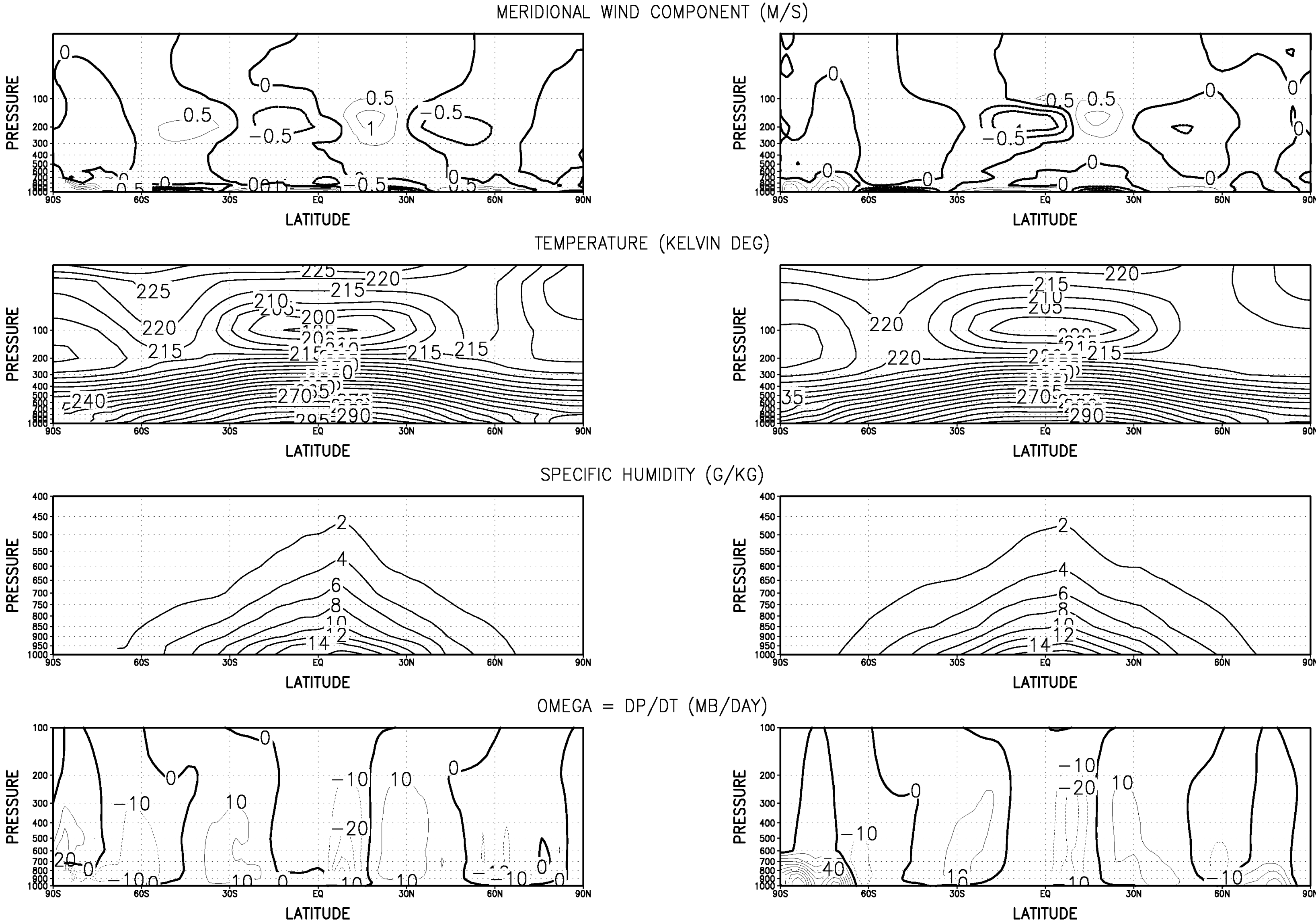
- deep Gulf of Alaska low days 1-2, redevelops days 4-5
- general Western US ridge, Eastern US trough pattern; main westerlies in Northern Canada
- deep Icelandic low days 1-2, cyclogenesis days 3-5 over Spain with a longwave trough over Europe through the period
- stationary omega high over central Europe with cut-off low to its east over Caspian Sea (figure 1n)
- very deep closed low develops over Northeastern China days 3-5 (figure 2n); propagates into the North Pacific days 6-7 and fills
- major hurricane in Caribbean Sea days 1-4 (figure 3n); recurves northward at day 5 affecting Southeastern US (figure 4n)
- other less intense Atlantic basin tropical cyclones days 1-4 mainly dissipate or become extratropical
- multiple tropical cyclones in Western Pacific under a large subtropical Pacific High

TIME_ZONAL AVERAGES, WHOLE RUN: 11SEP-31DEC 99

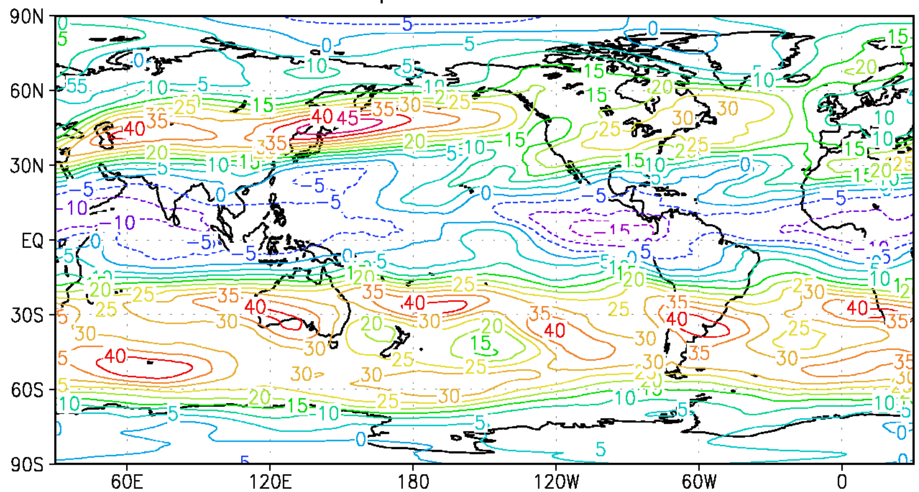
VERTICAL - MERIDIONAL CROSS SECTIONS

NATURE: RESOLUTION ADAPTED TO CLIMATOLOGY MODEL

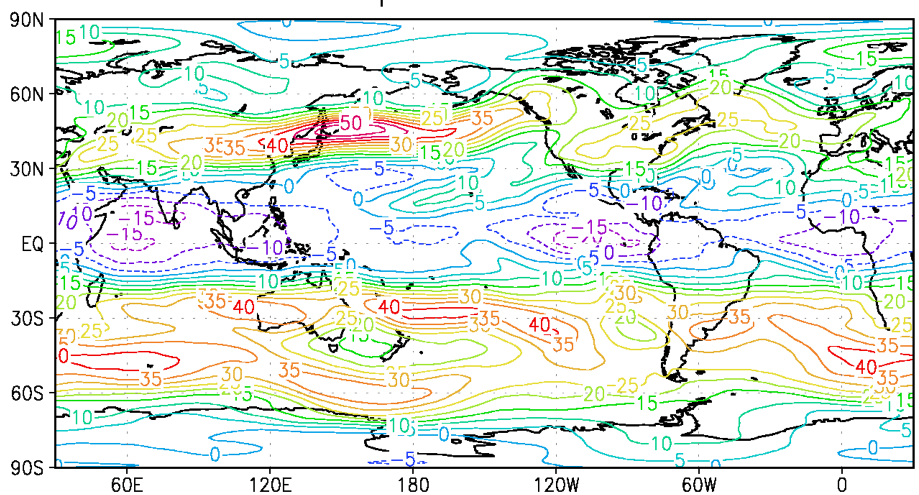
CLIMATOLOGY MODEL: NCEP: 2x2.5 18 LEVELS 1979-93



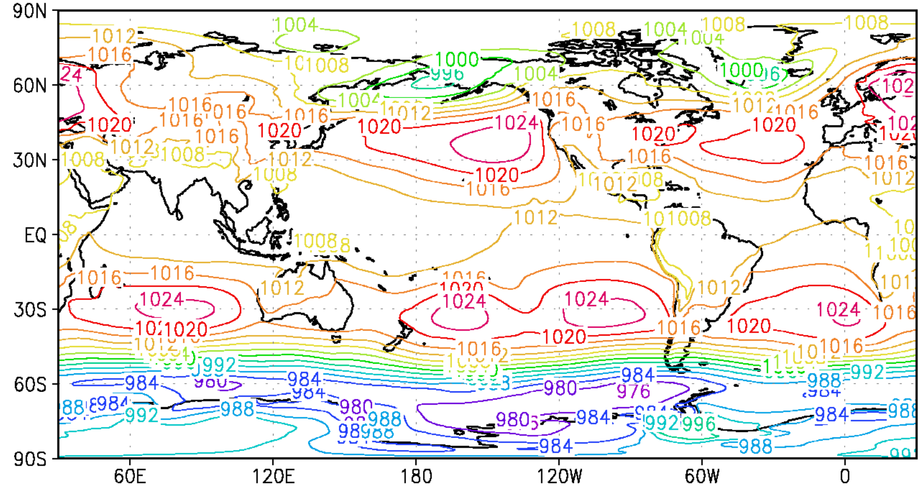
FV Nature 250 mb Zonal Wind (m/s)
11 Sep – 8 Oct 1999



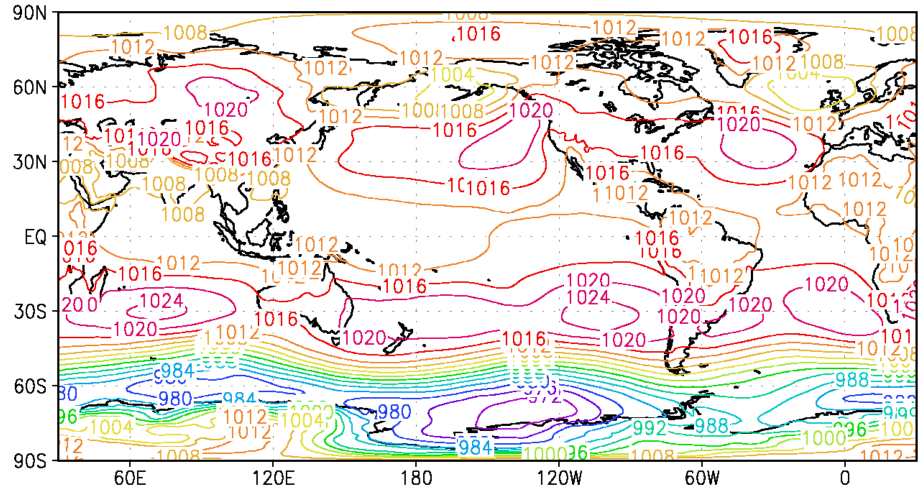

ECMWF Analysis 250 mb Zonal Wind (m/s)
11 Sep – 8 Oct 1999

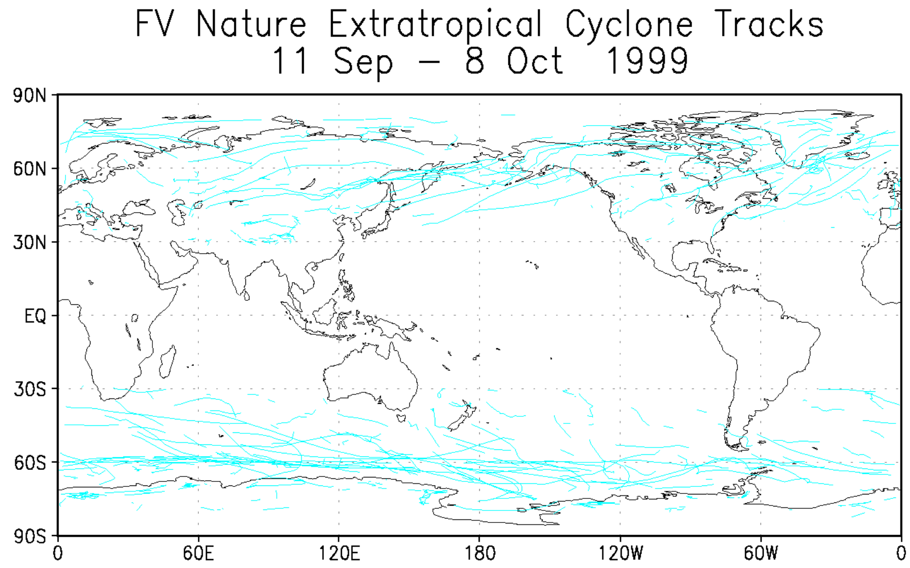


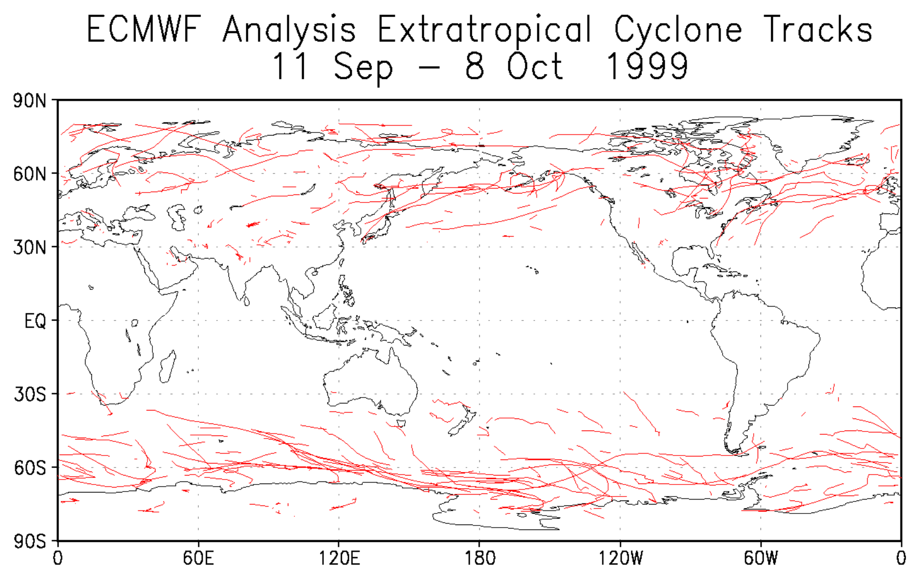
FV Nature Sea Level Pressure (hPa)
11 Sep – 8 Oct 1999




ECMWF Analysis Sea Level Pressure (hPa)
11 Sep – 8 Oct 1999

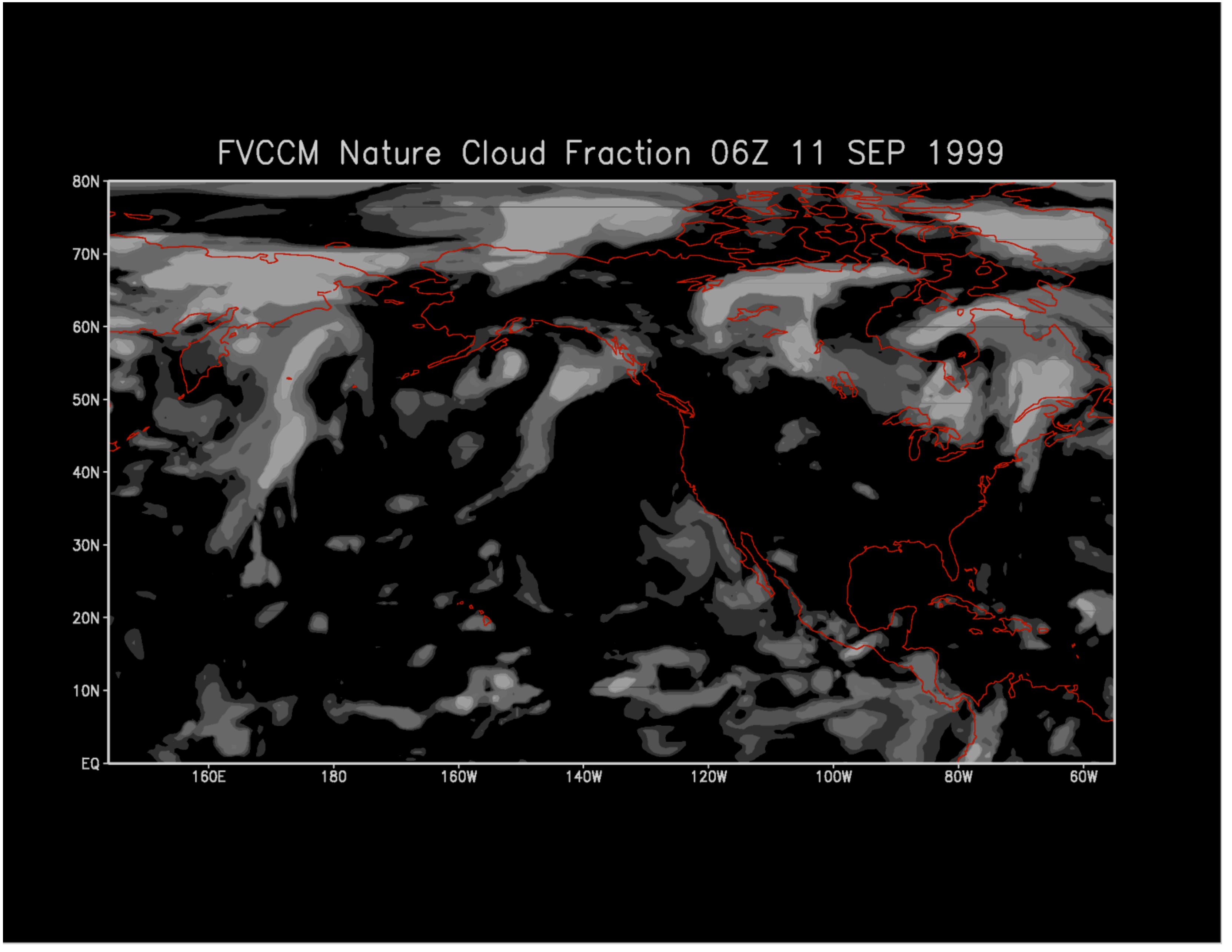



FV Nature Extratropical Cyclone Tracks
11 Sep – 8 Oct 1999
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0


ECMWF Analysis Extratropical Cyclone Tracks
11 Sep – 8 Oct 1999
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0

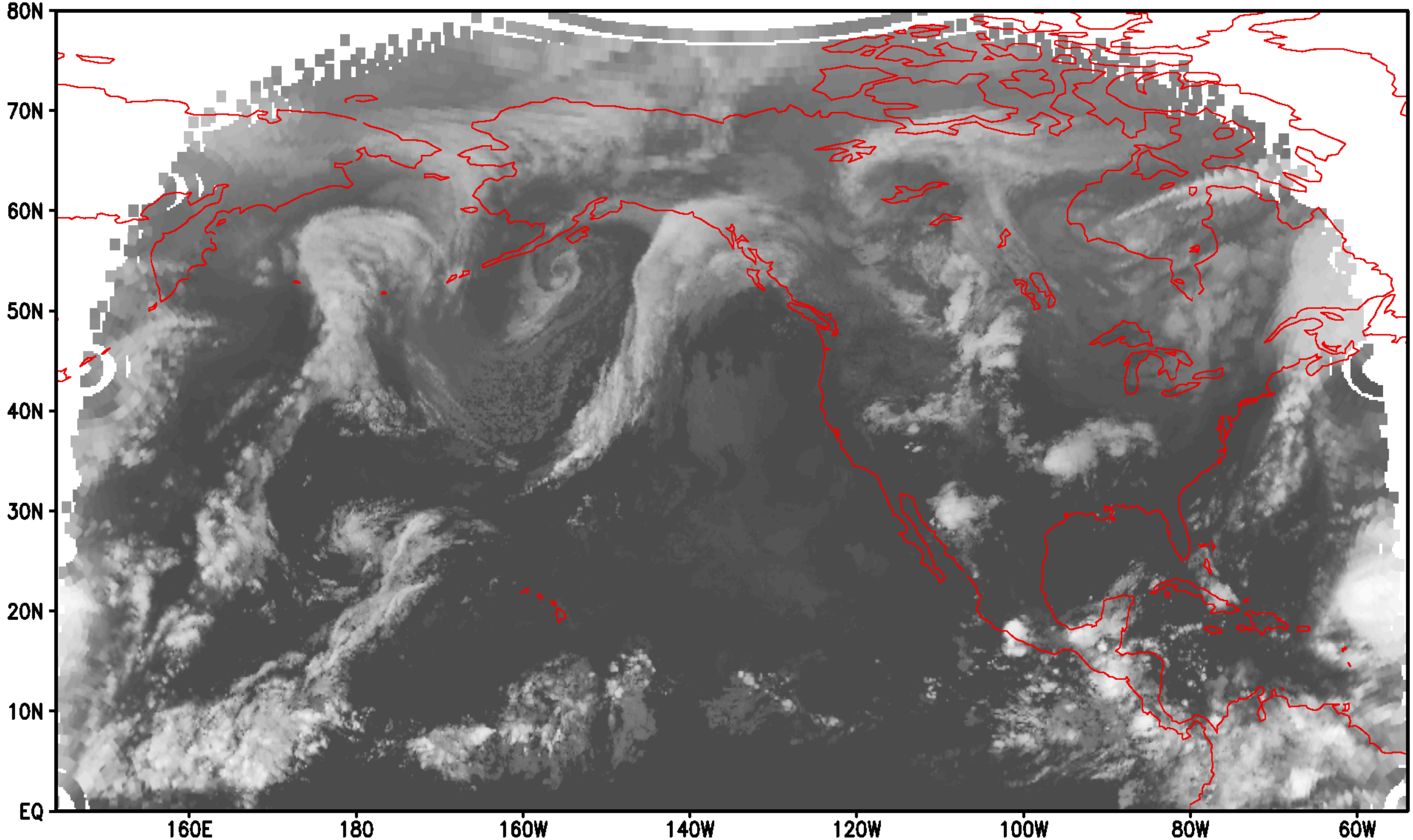
# Cyclone Verification for September through December 1999

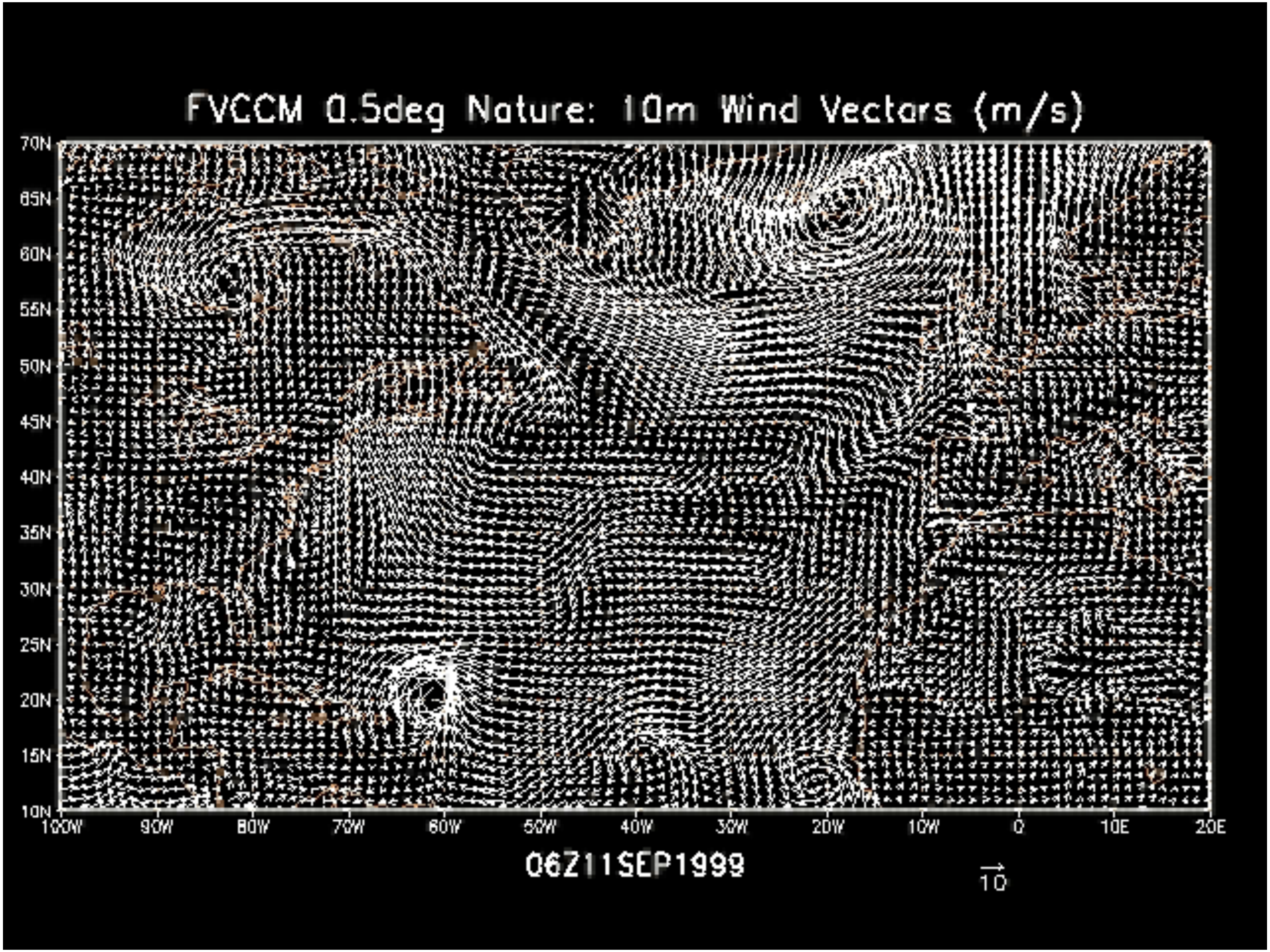
| | Global | | Southern Hemisphere Extratropics | | Northern Hemisphere Extratropics | |
|---|---|---|---|---|---|---|
| | ECMWF Analysis | FVCCM Nature Run | ECMWF Analysis | FVCCM Nature Run | ECMWF Analysis | FVCCM Nature Run |
| Avg number of cyclone centers per synoptic time | 24.3 | 28.8 | 10.7 | 13.6 | 12.9 | 14.5 |
| Avg number of genesis cases per synoptic time | 7.3 | 9.5 | 2.8 | 3.9 | 4.0 | 5.1 |
| Avg number of lysis cases per synoptic time | 7.2 | 9.5 | 2.8 | 3.9 | 4.0 | 5.0 |
| Mean central pressure (hPa) | 987.9 | 986.7 | 975.7 | 976.6 | 997.4 | 995.2 |
| Mean cyclone direction | $90^\circ$ | $90^\circ$ | $111^\circ$ | $110^\circ$ | $68^\circ$ | $69^\circ$ |
| Mean cyclone speed (km/h) | 36 | 35 | 37 | 35 | 35 | 36 |

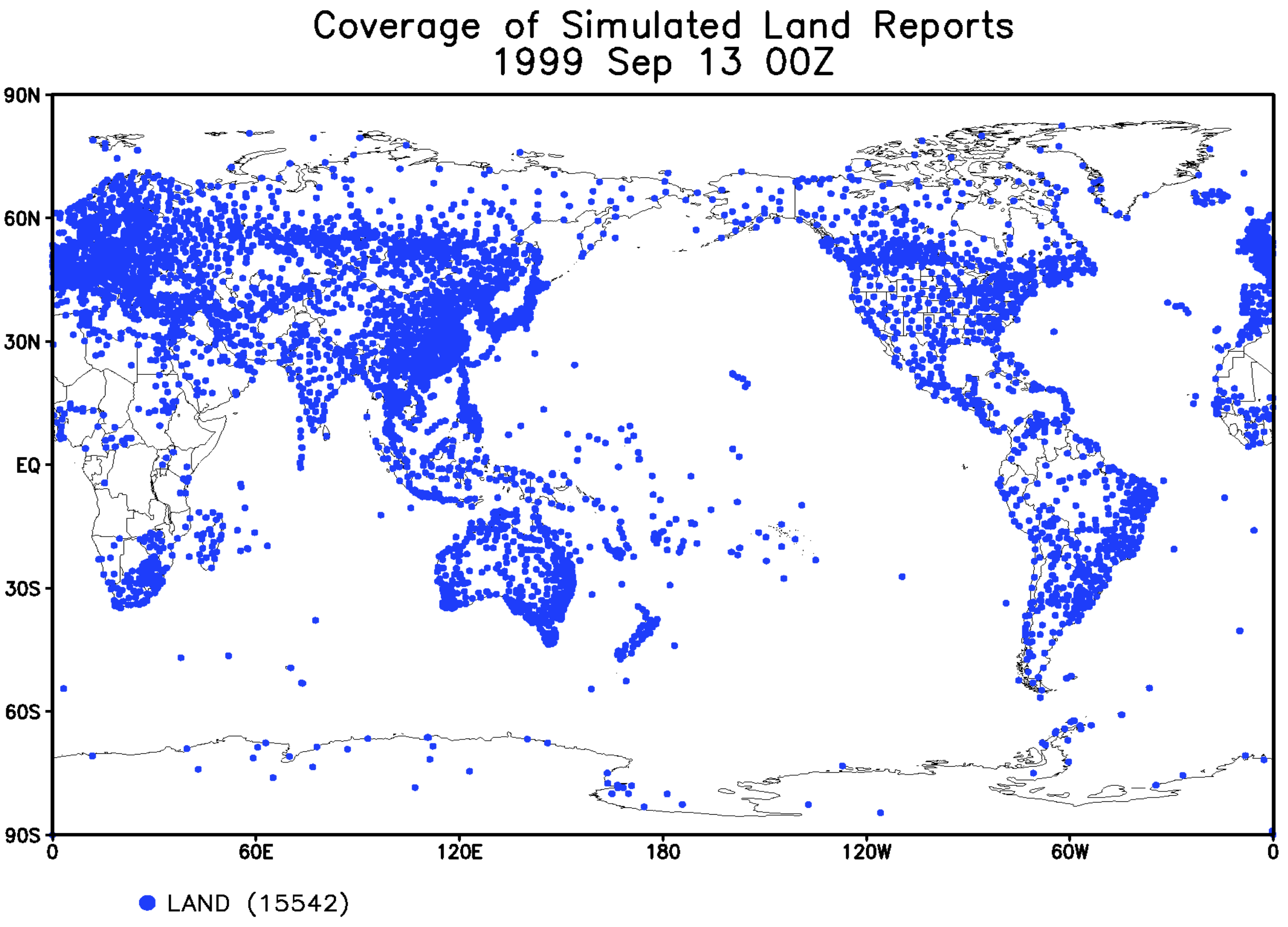


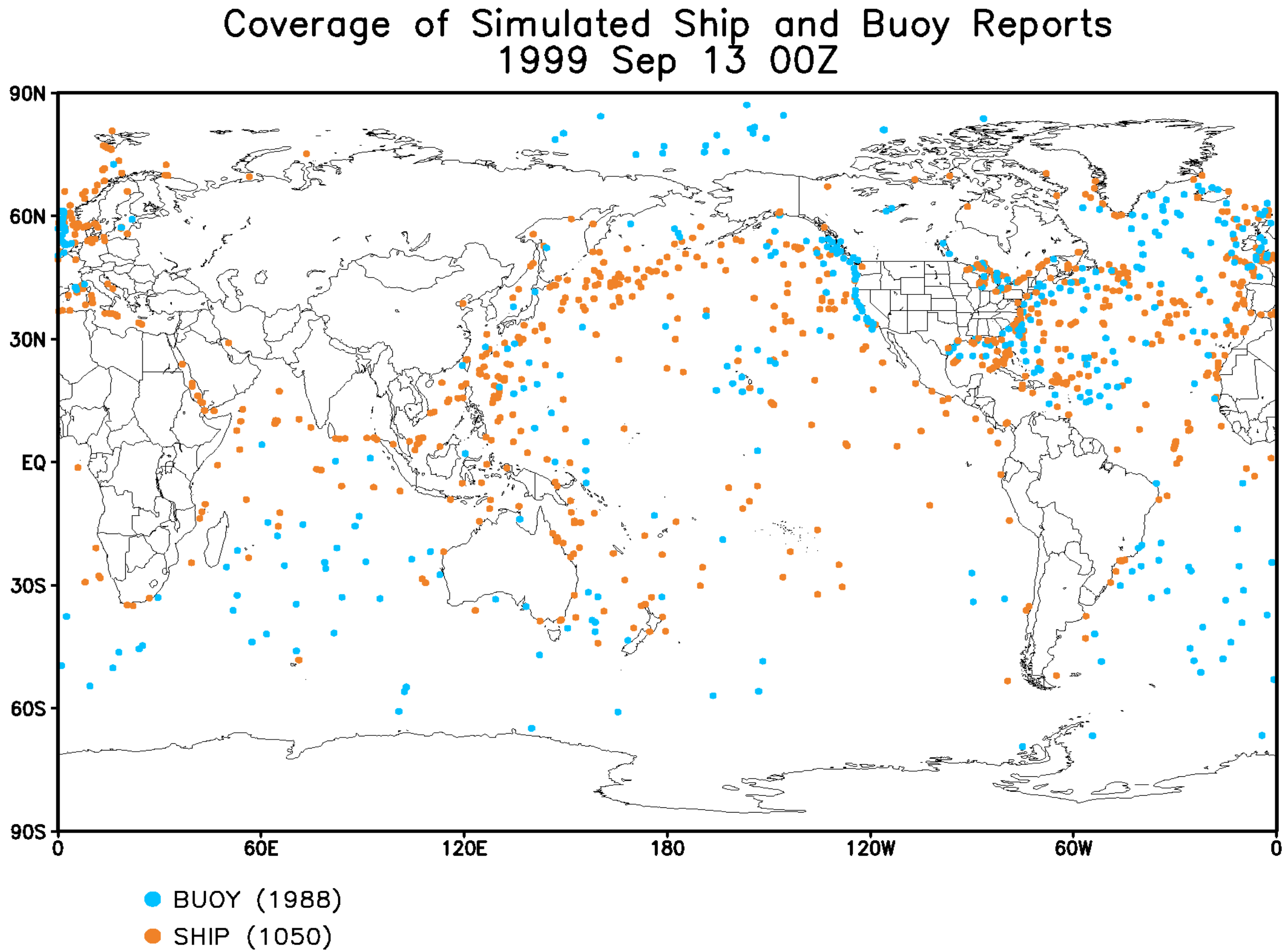
FVCCM Nature Cloud Fraction 06Z 11 SEP 1999
80N
70N
60N
50N
40N
30N
20N
10N
EQ
160E
180
160W
140W
120W
100W
80W
60W

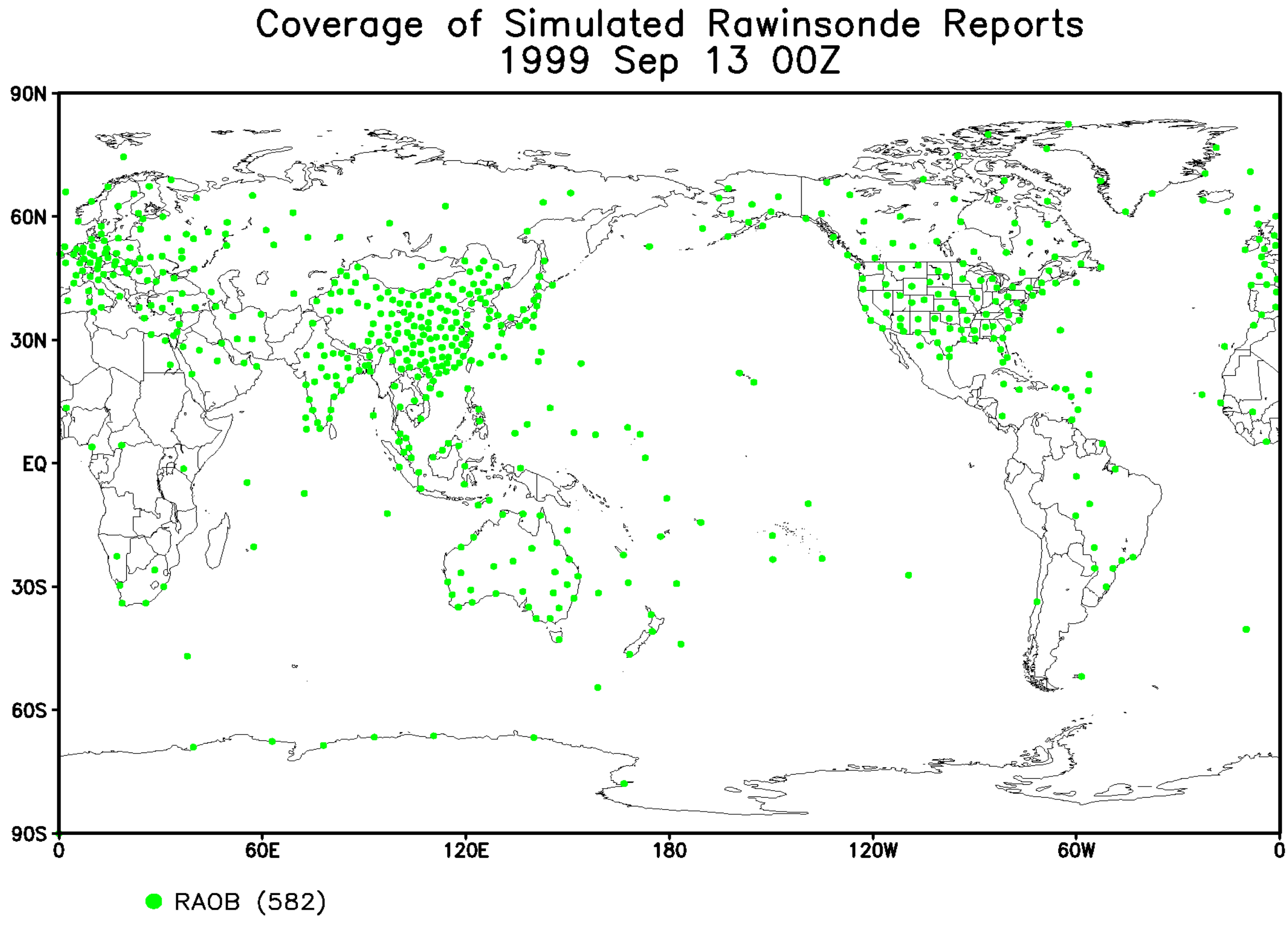
GOES-10 IR 06Z 11 SEP 1999

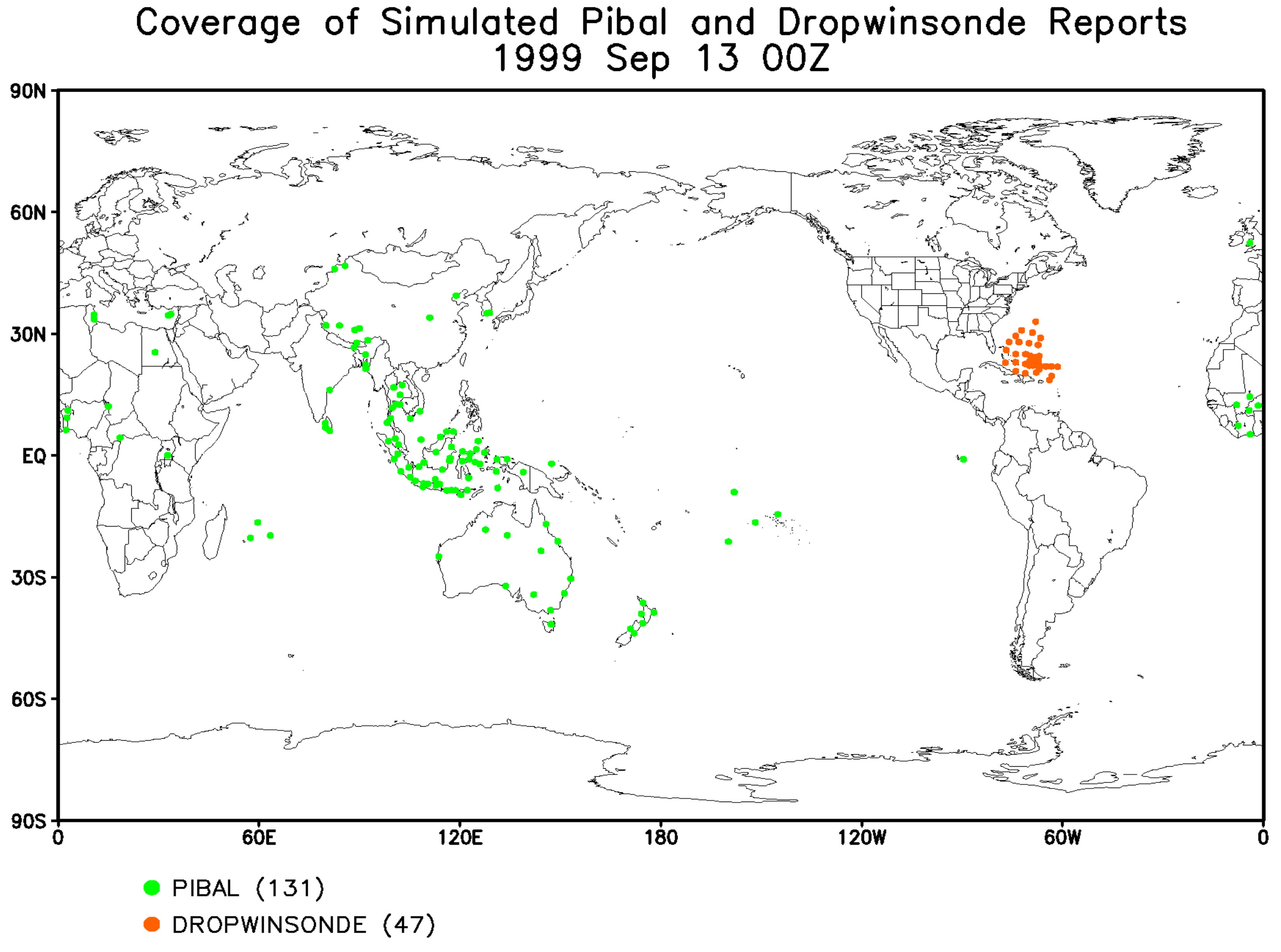


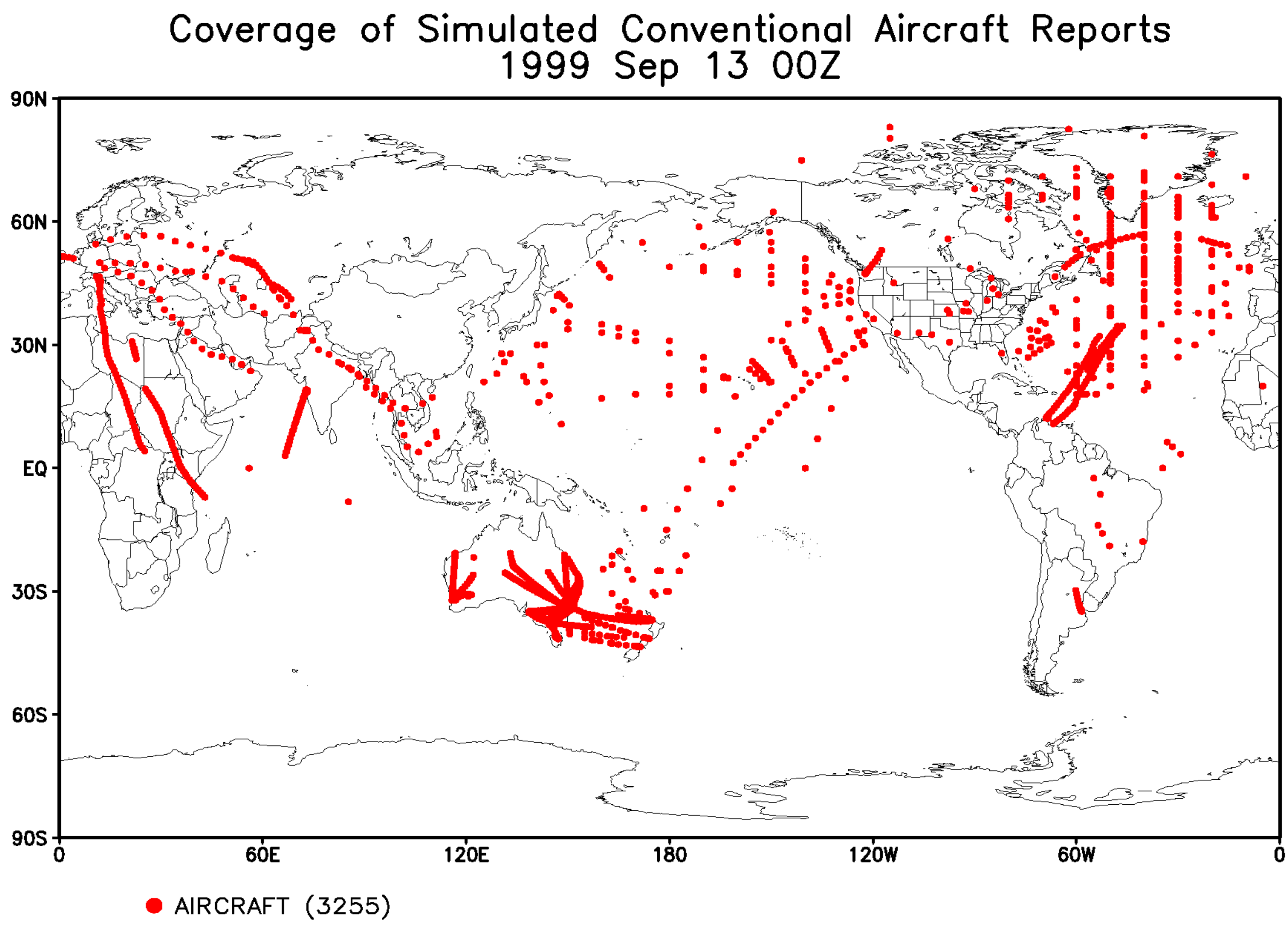

FVCCM 0.5deg Nature: 10m Wind Vectors (m/s)
70N
65N
60N
55N
50N
45N
40N
35N
30N
25N
20N
15N
10N
100W
90W
80W
70W
60W
50W
40W
30W
20W
10W
0
10E
20E
06Z11SEP1999
10


Coverage of Simulated Land Reports
1999 Sep 13 00Z
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
LAND (15542)

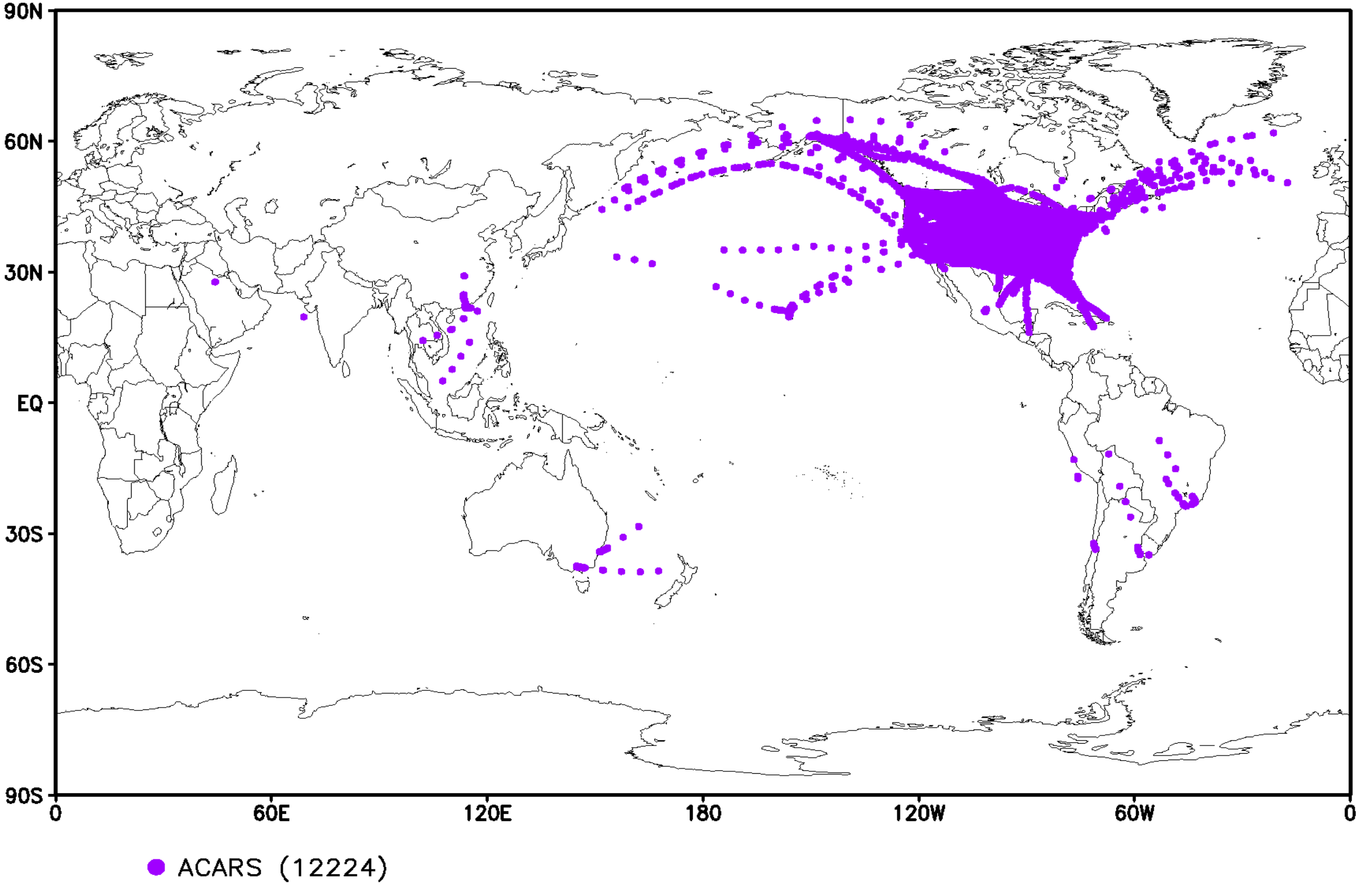

Coverage of Simulated Ship and Buoy Reports
1999 Sep 13 00Z
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
BUOY (1988)
SHIP (1050)


Coverage of Simulated Rawinsonde Reports
1999 Sep 13 00Z
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
RAOB (582)

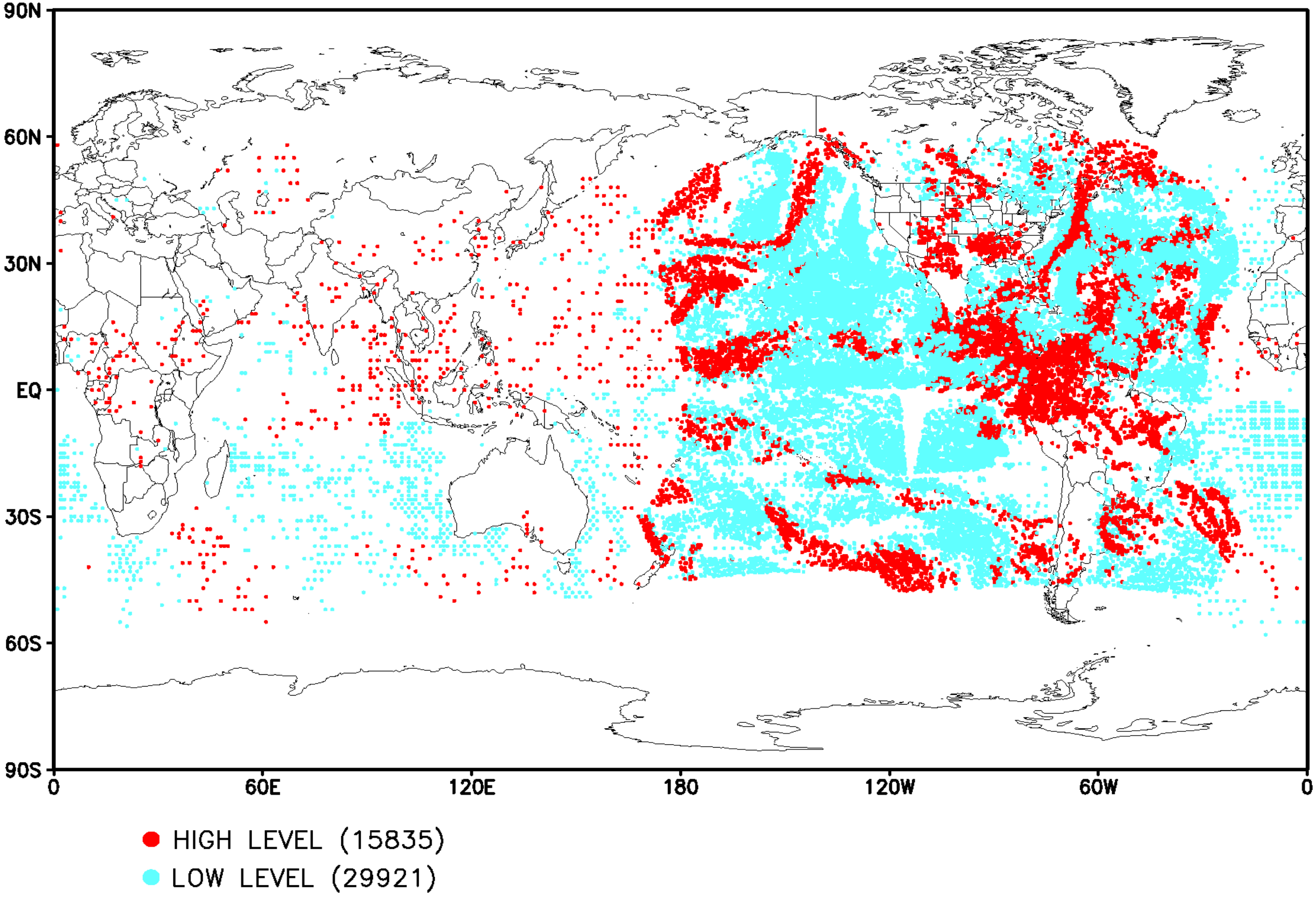

Coverage of Simulated Pibal and Dropwinsonde Reports
1999 Sep 13 00Z
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
PIBAL (131)
DROPWINSONDE (47)

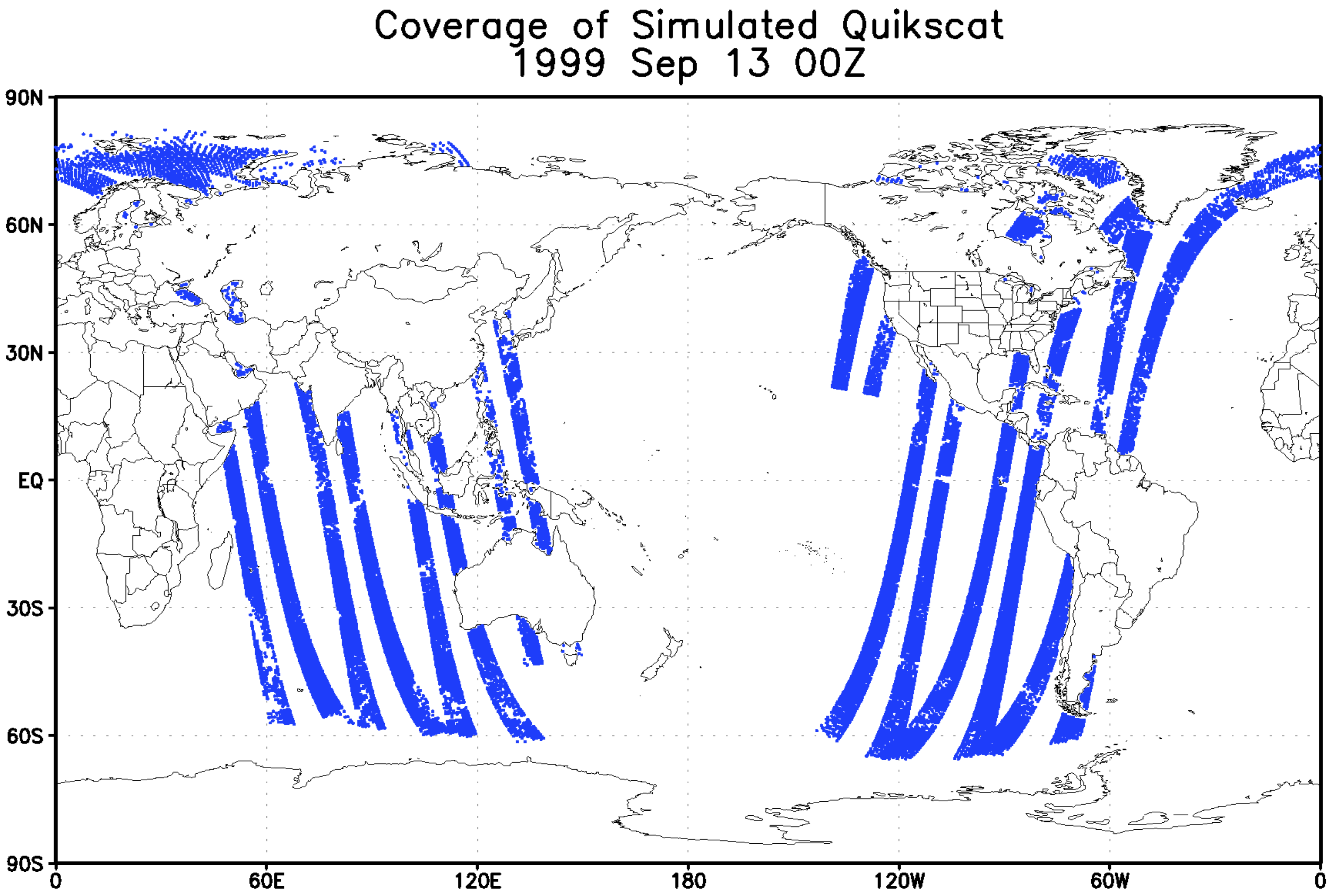

Coverage of Simulated Conventional Aircraft Reports
1999 Sep 13 00Z
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
AIRCRAFT (3255)

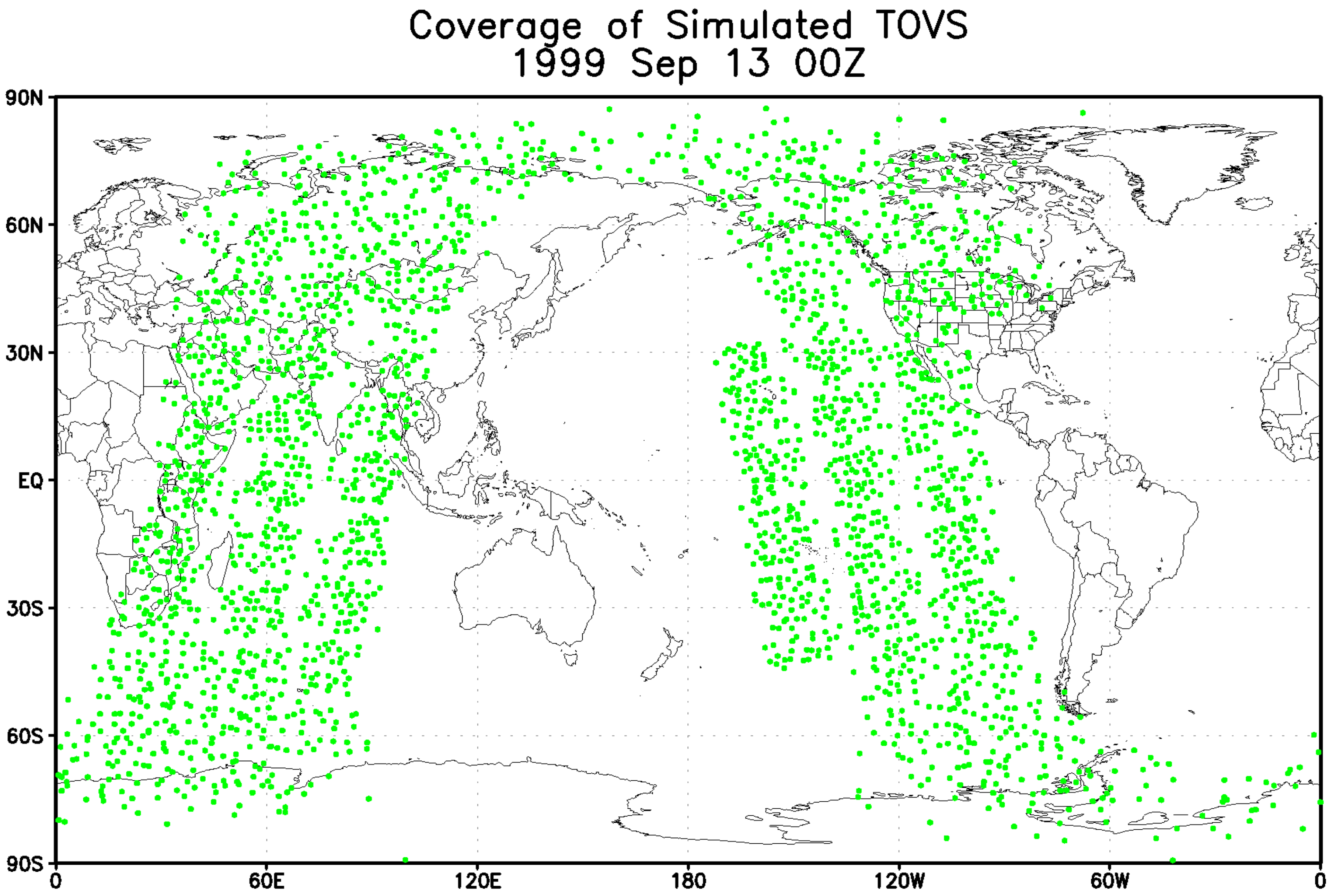
# Coverage of Simulated ACARS Reports
## 1999 Sep 13 00Z

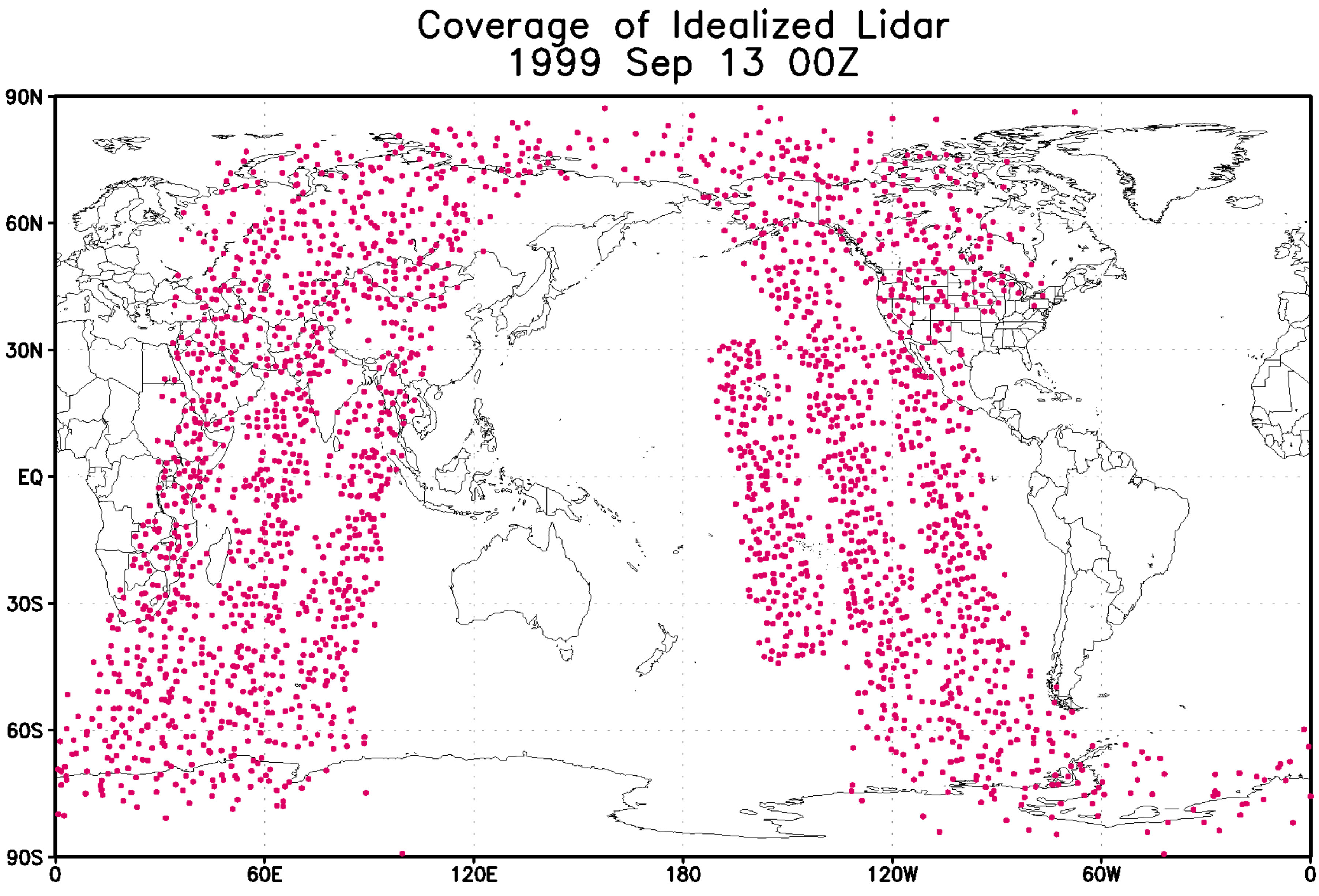


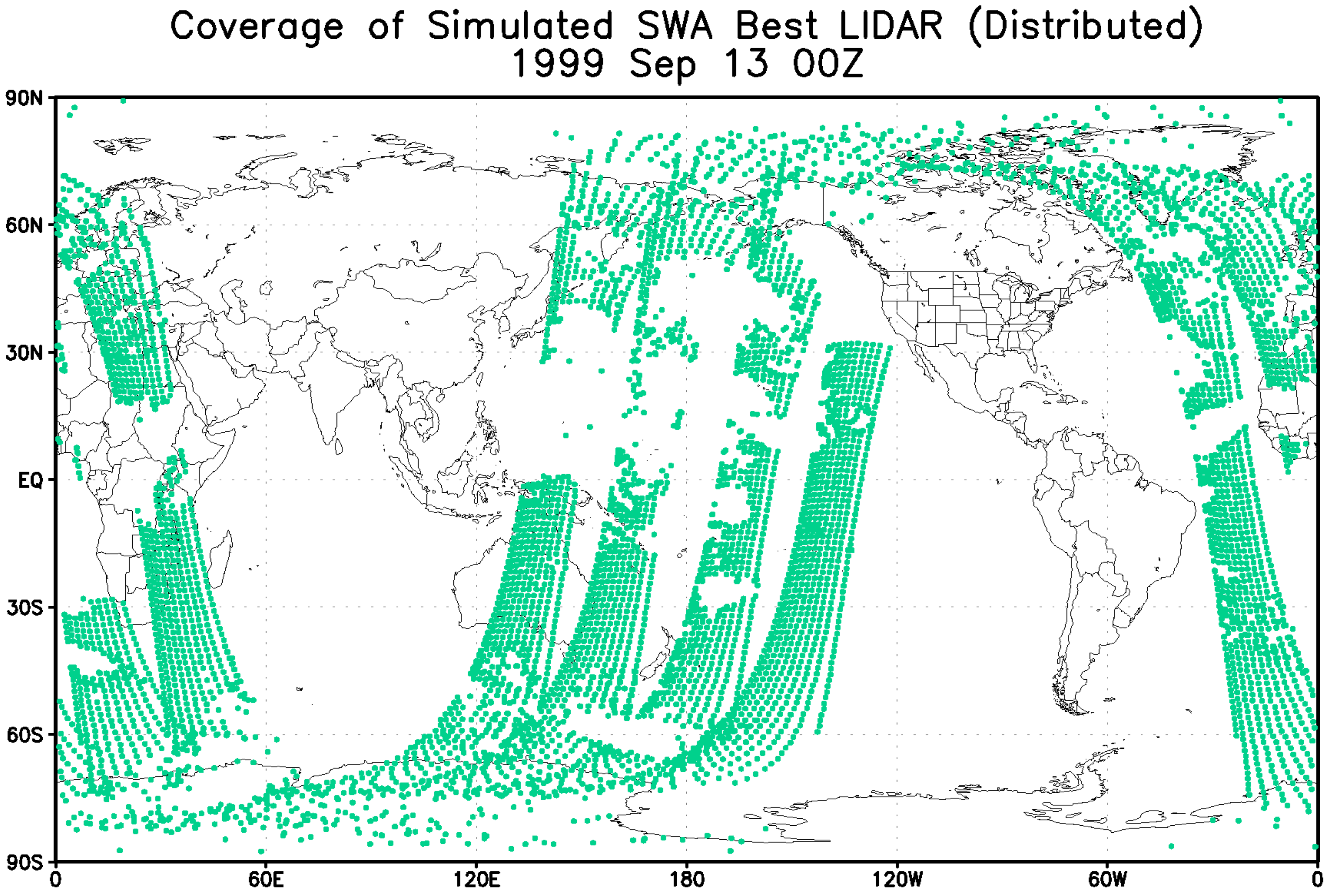
## Coverage of Simulated Cloud Motion Wind Reports

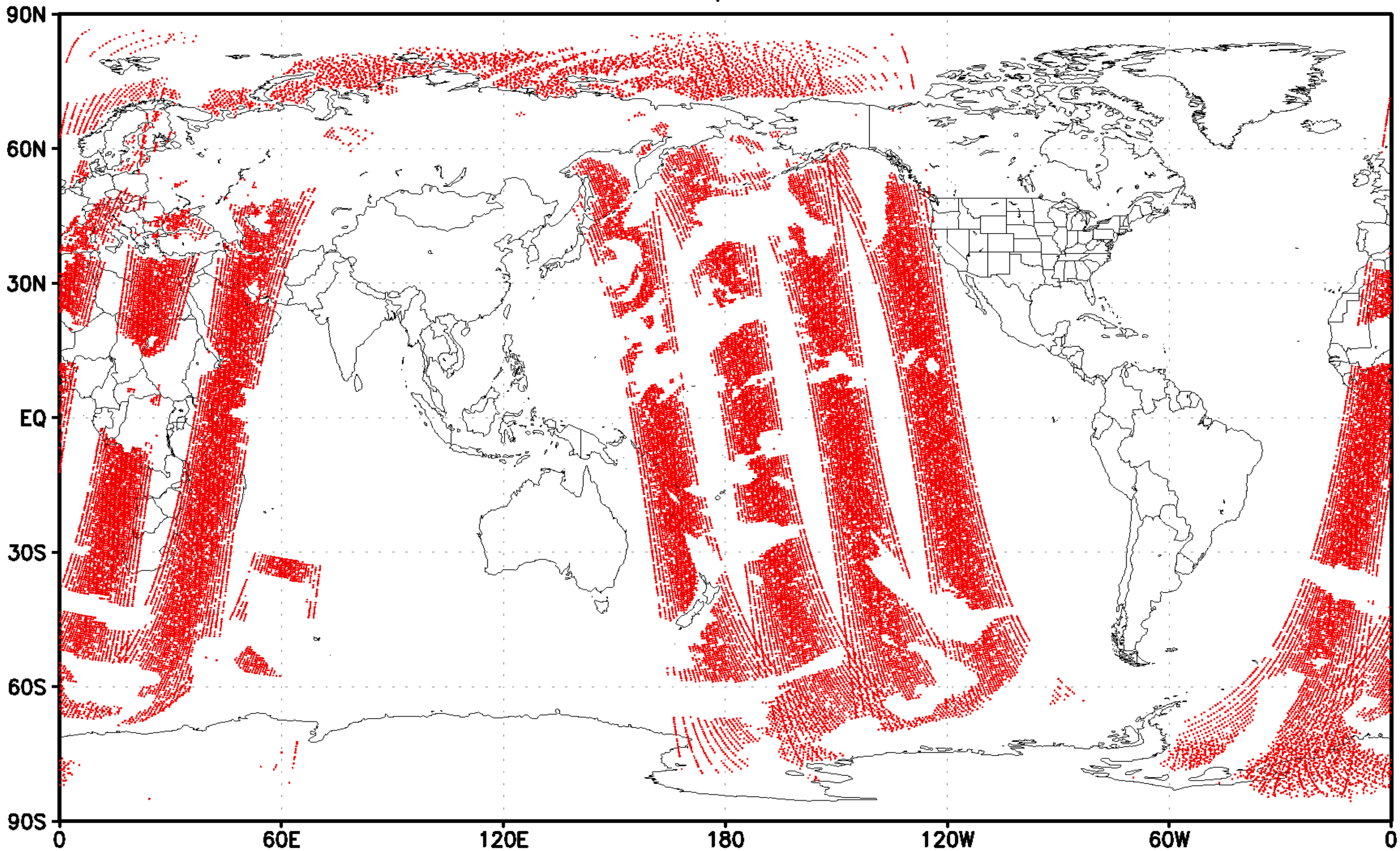



Coverage of Simulated Quikscat
1999 Sep 13 00Z
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0


Coverage of Simulated TOVS
1999 Sep 13 00Z
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0


Coverage of Idealized Lidar
1999 Sep 13 00Z
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0


Coverage of Simulated SWA Best LIDAR (Distributed)
1999 Sep 13 00Z
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0



90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0

# Description of Experiments

NATURE RUN:

FVGCM at .5 deg resolution for the period from September 11 to December 31, 1999.

GLOBAL DATA ASSIMILATION SYSTEM USED:

GEOS-3, 1 X 1 deg horizontal resolution

GEOS-4, 1 X 1.25 deg horizontal resolution

SPINUP: 35 days

PERIOD OF ASSIMILATION: Sept. 11 - Oct. 31, 1999

CALIBRATION EXPERIMENTS (REAL and SIMULATED):

CTRL (Conventional Data + TOVS + CTW + QSCAT)

CTRL-ALL SAT (Conventional Data only)

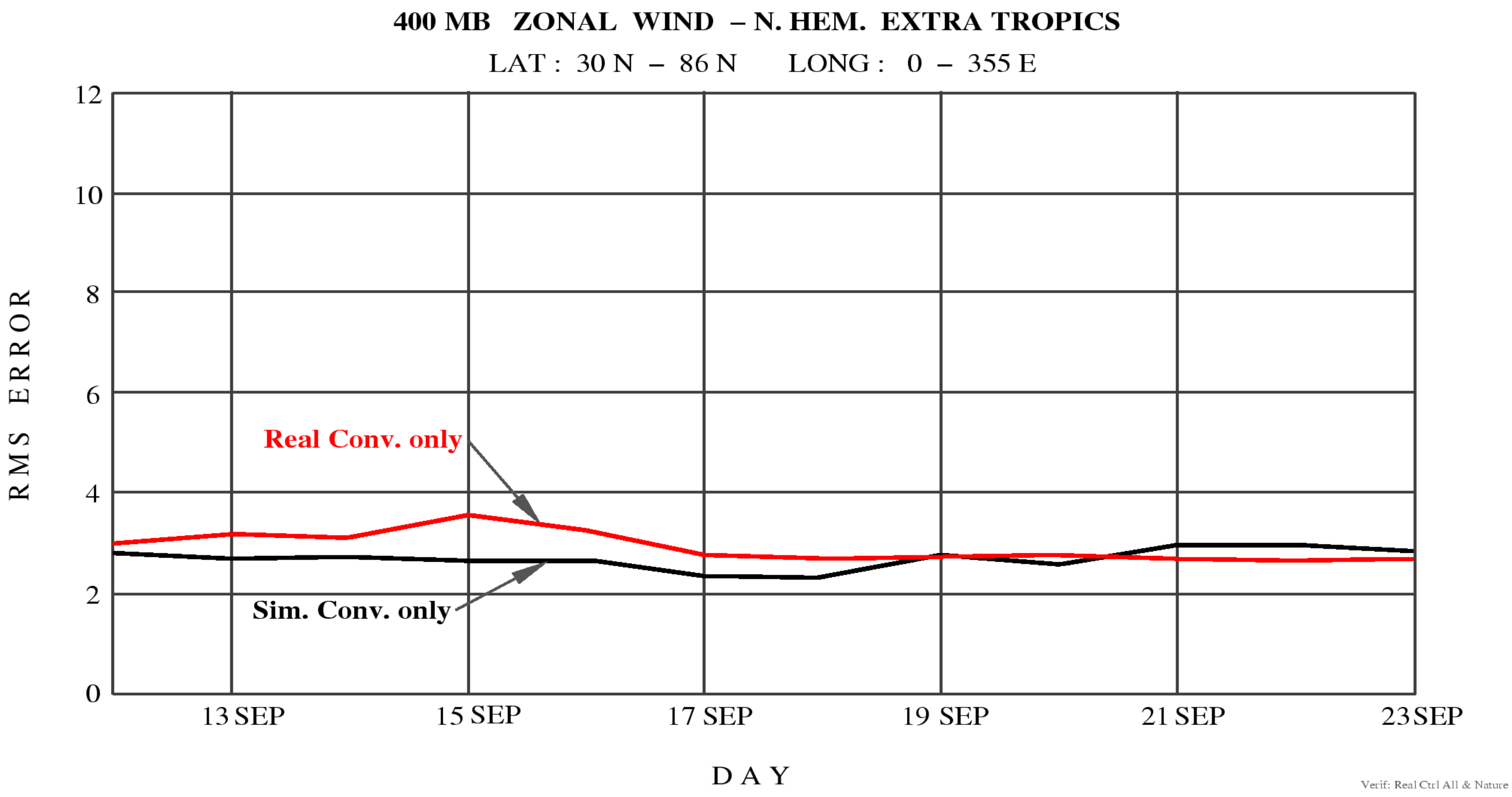
CTRL-SAT TEMP (Conventional Data + CTW + QSCAT)

CTRL-QSCAT (Conventional Data + TOVS + CTW)

SIMULATED DATA EXPERIMENTS:

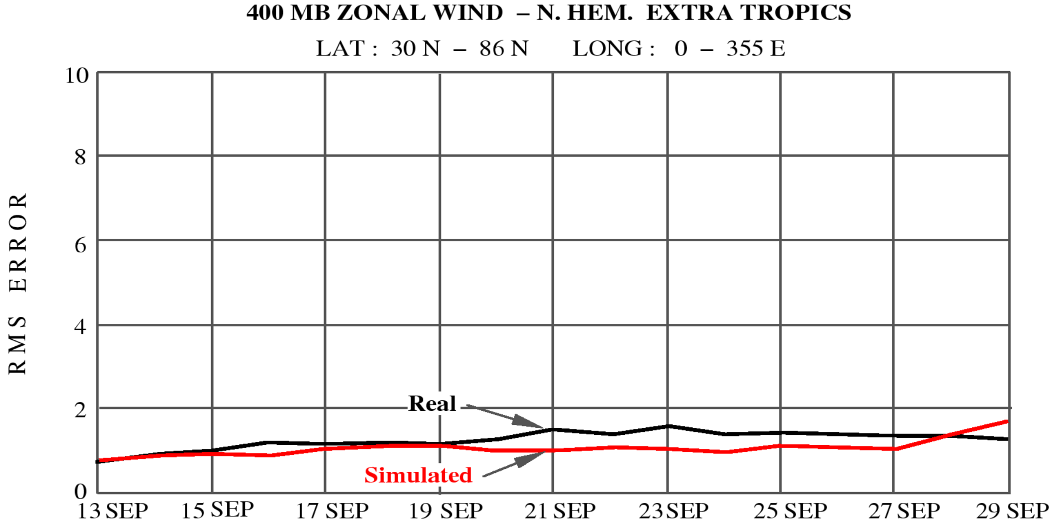
CTRL + Lidar Winds (with varying coverage)

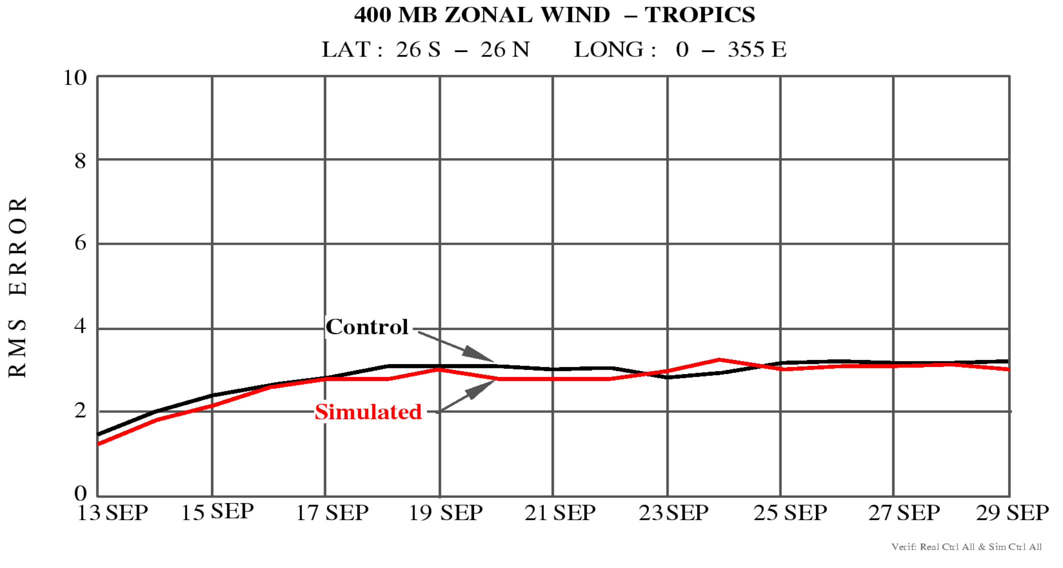
## Comparison of Real and Simulated Analysis Accuracy for Conventional Data Only Assimilations



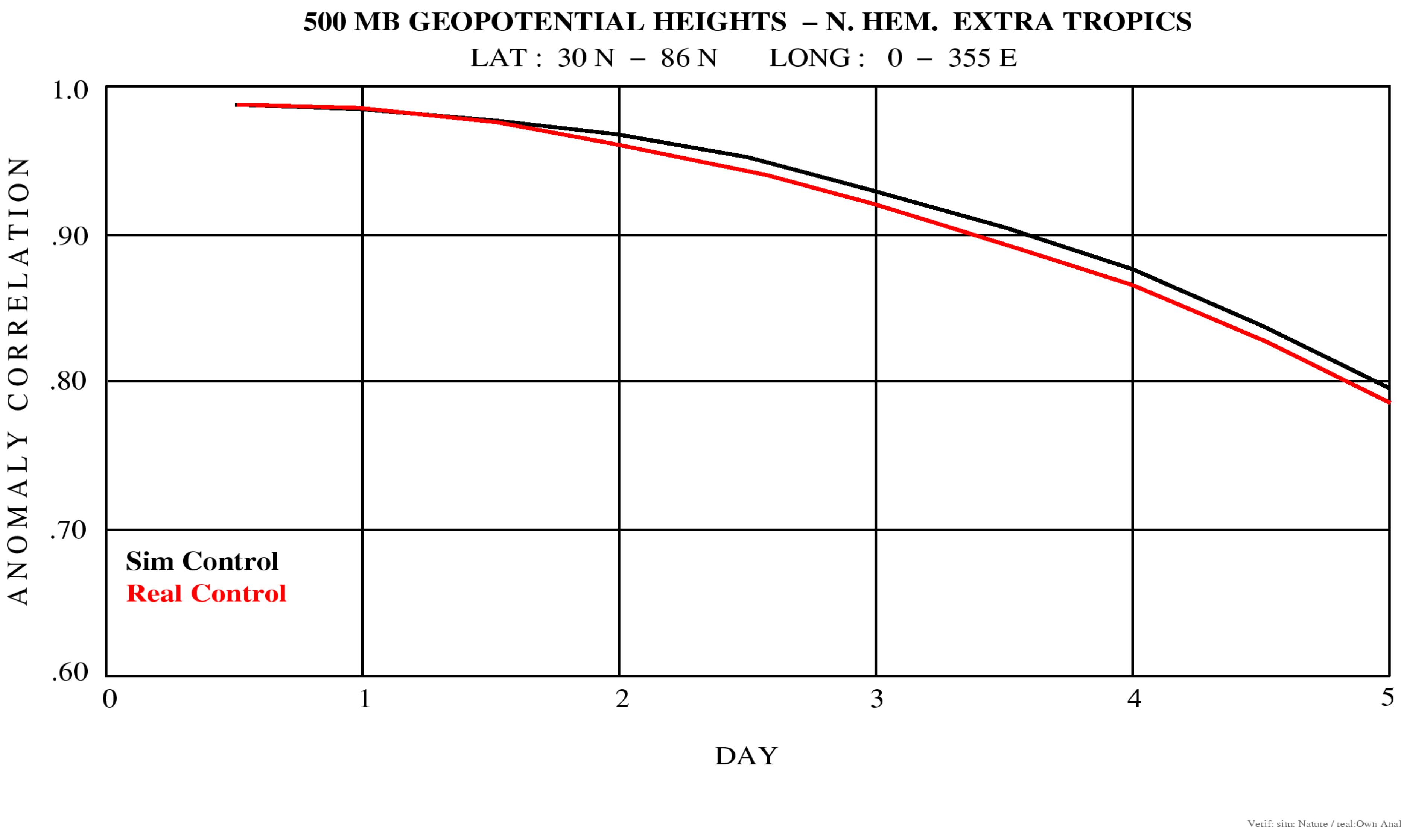
# Impact of Satellite Data

(RMS difference between analyses with and without QSCAT data)

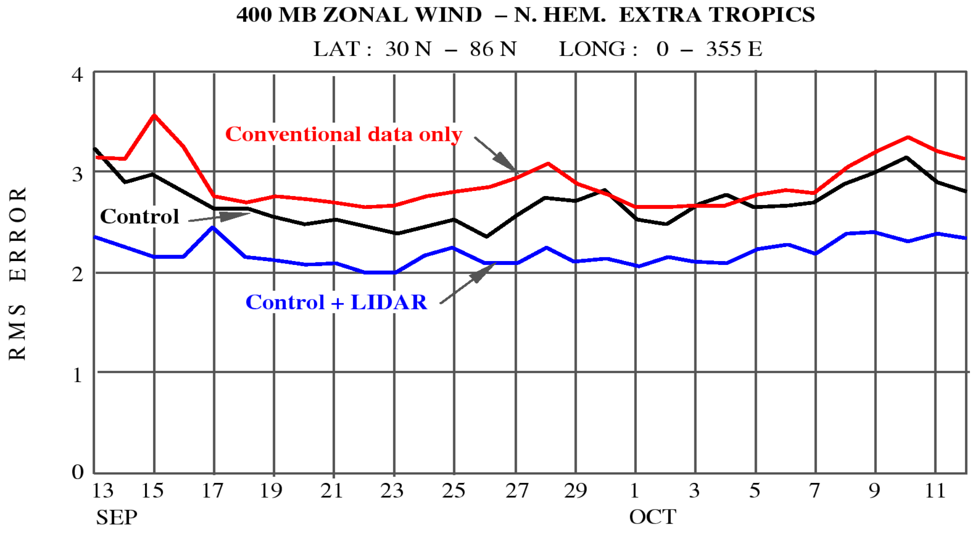


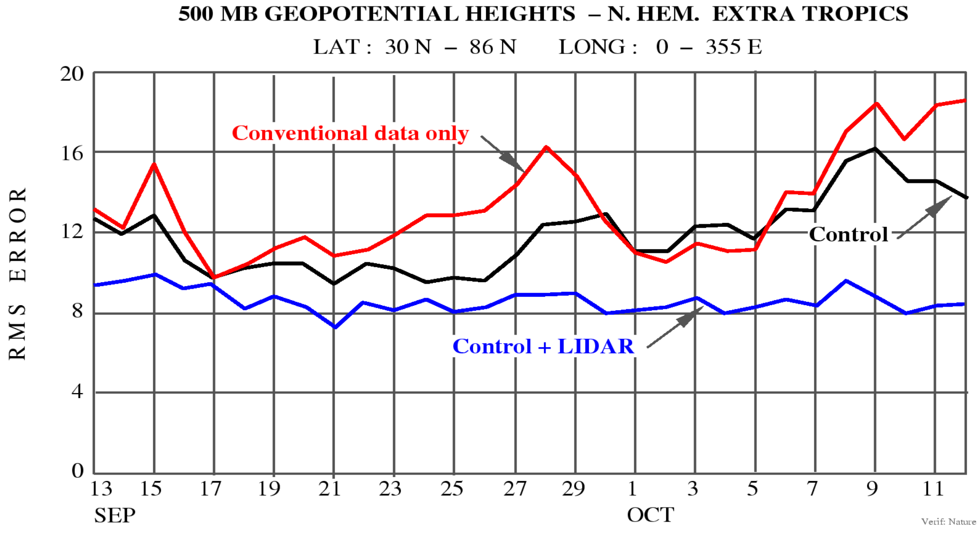



# Comparison of Real and Simulated Forecast Accuracy



# Impact of Simulated LIDAR Winds on GEOS–3 Analyses



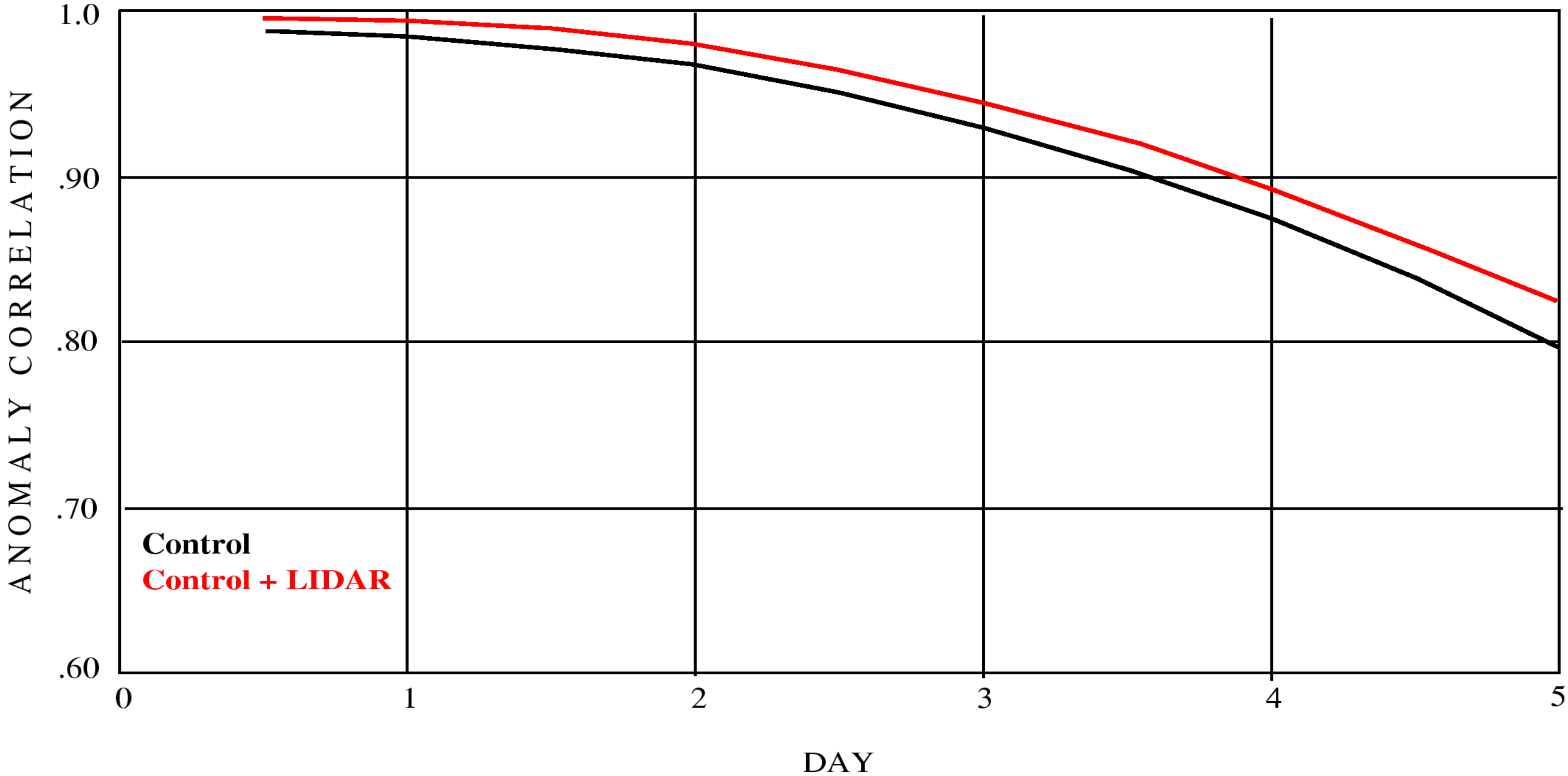



# Impact of LIDAR Winds on GEOS–3 Forecasts

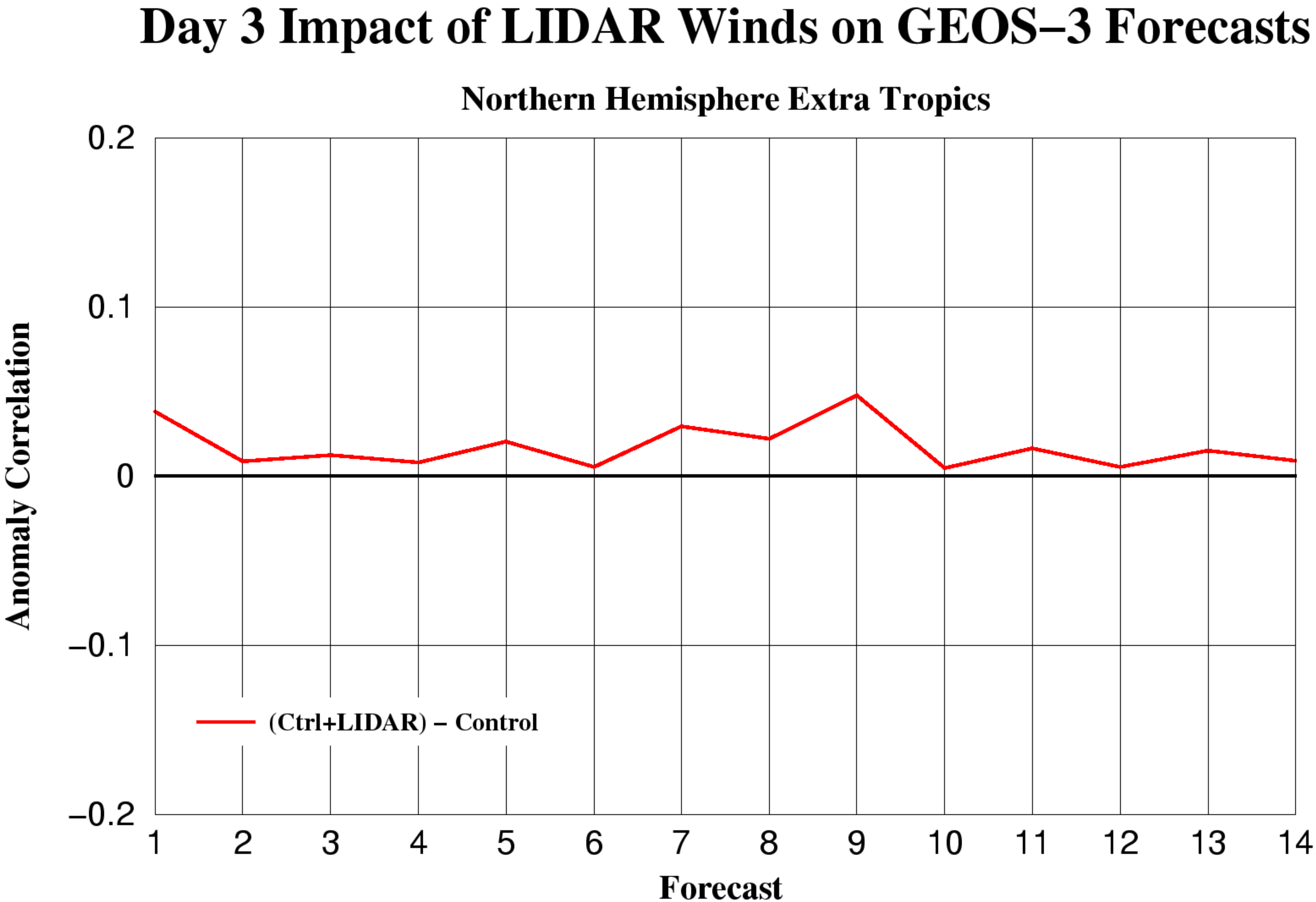
Average of 14 Five–Day Forecasts

**500 MB GEOPOTENTIAL HEIGHTS – N. HEM. EXTRA TROPICS**

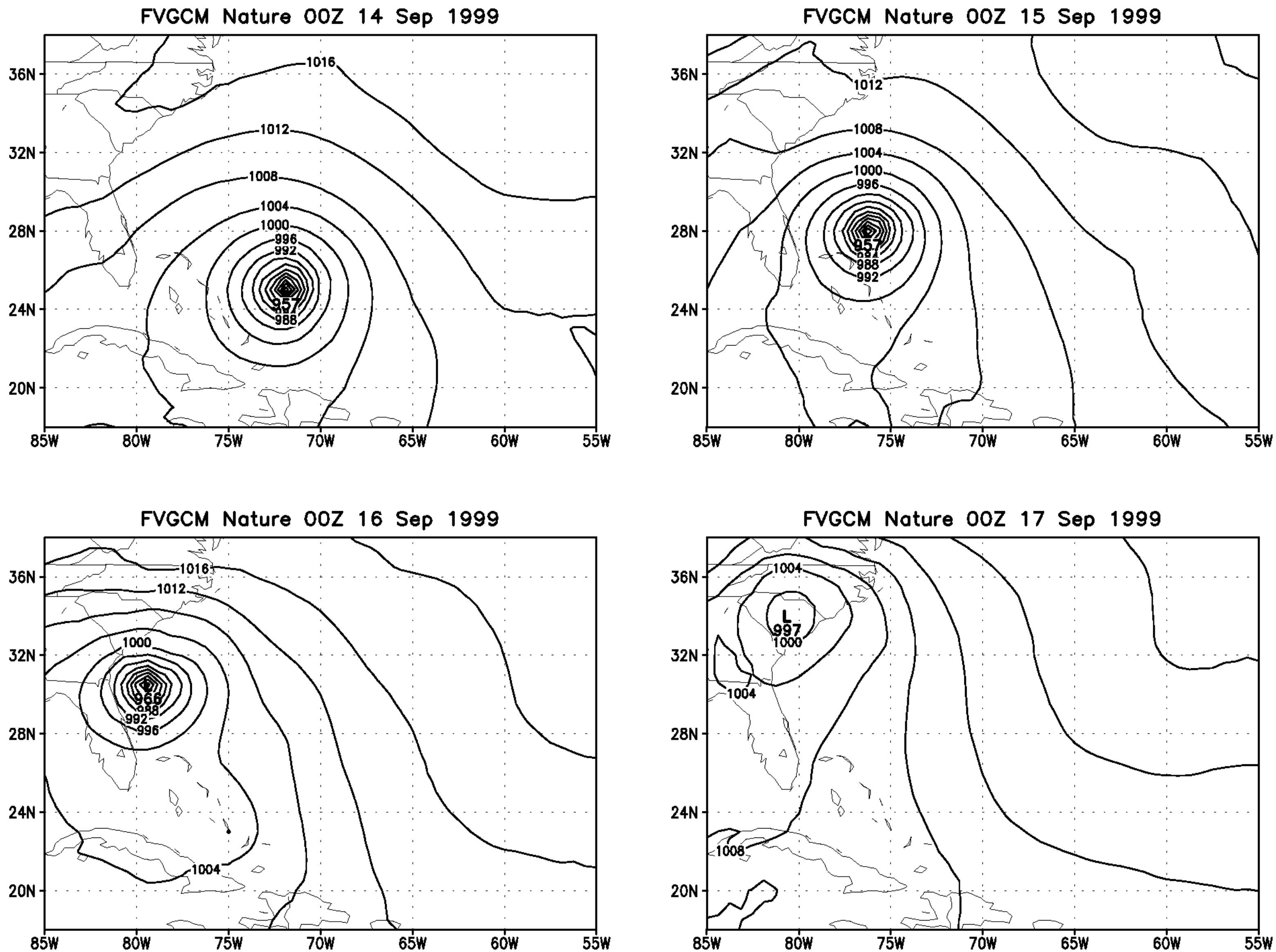
LAT : 30 N – 86 N LONG : 0 – 355 E

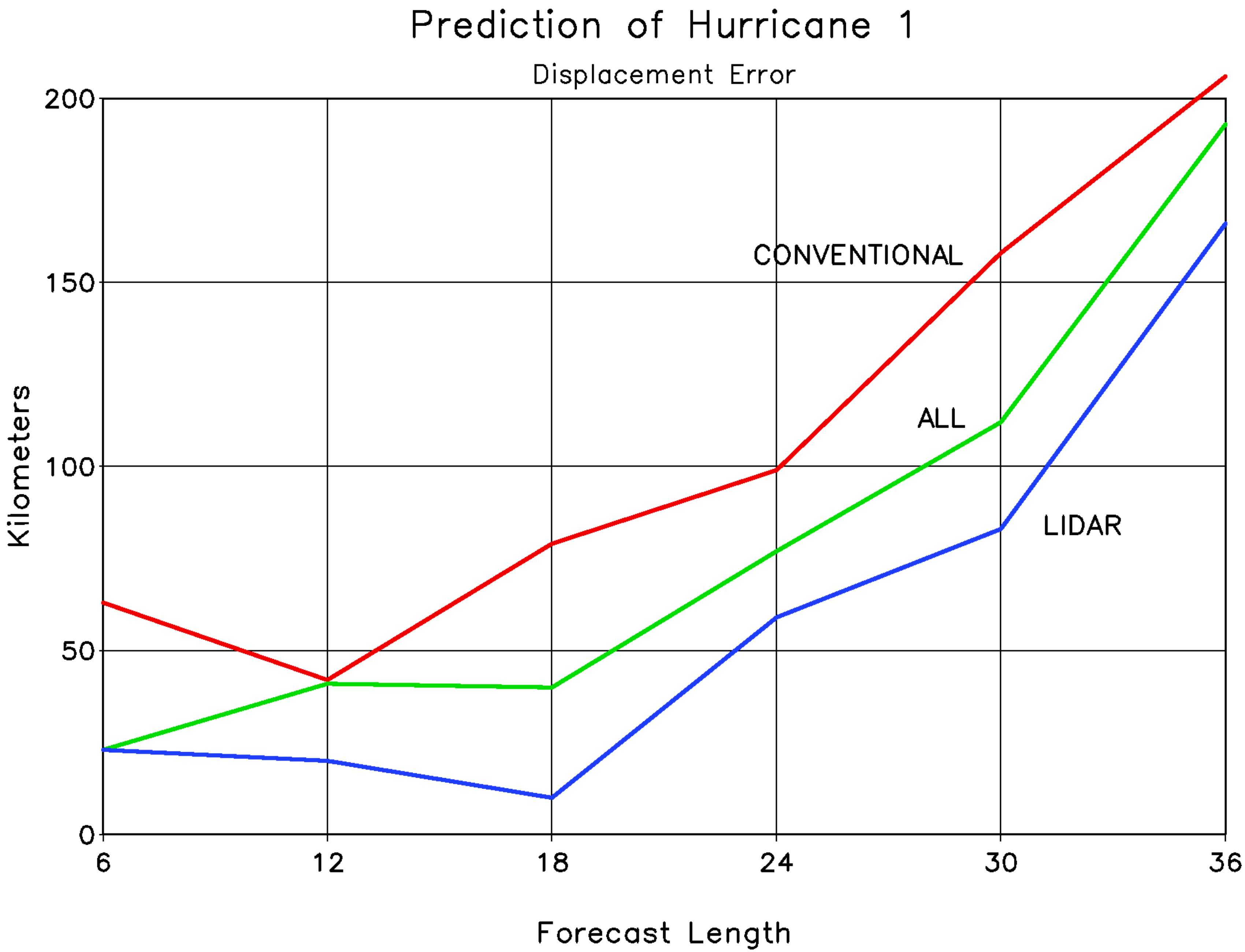



Verif: Nature


Day 3 Impact of LIDAR Winds on GEOS−3 Forecasts
Northern Hemisphere Extra Tropics
0.2
0.1
0
−0.1
−0.2
Anomaly Correlation
(Ctrl+LIDAR) − Control
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Forecast

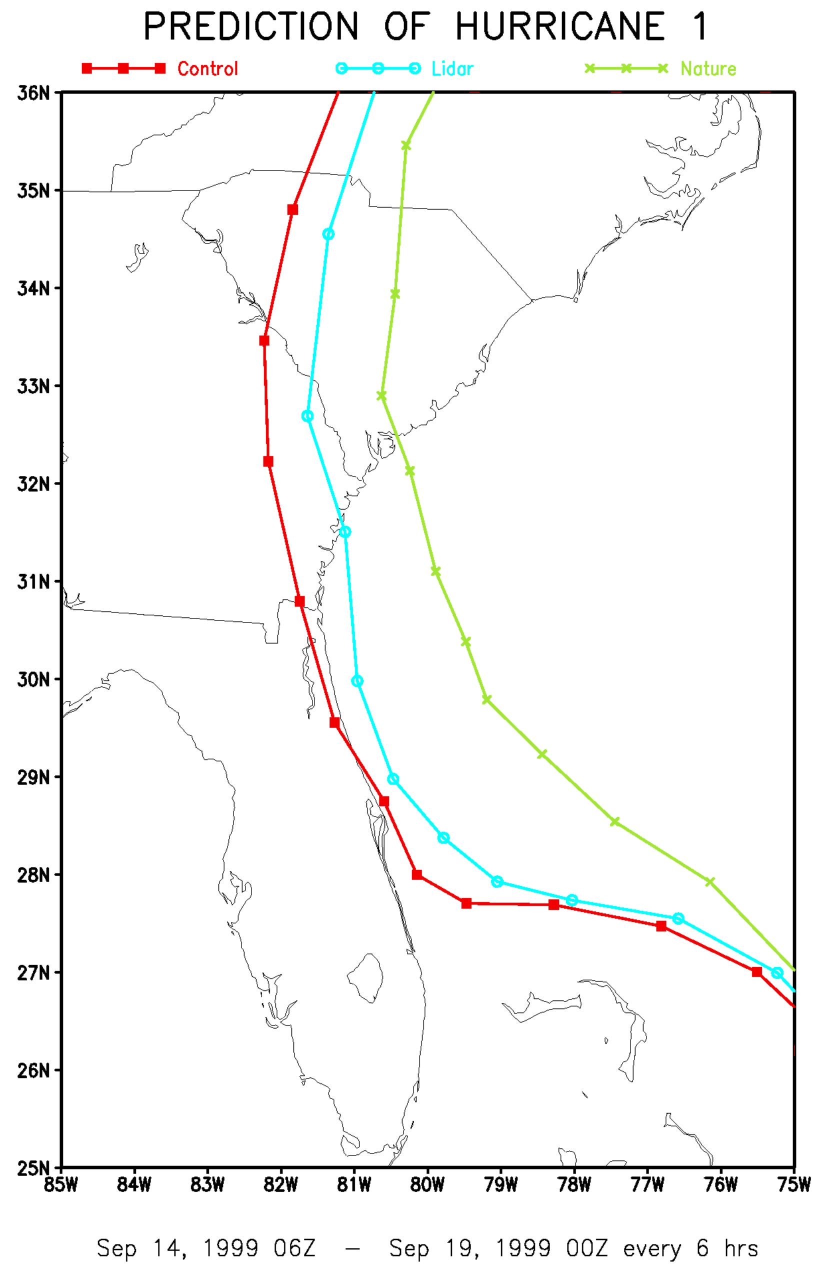
# Evolution of Hurricane 1




Prediction of Hurricane 1
Displacement Error
Kilometers
200
150
100
50
0
6
12
18
24
30
36
Forecast Length
CONVENTIONAL
ALL
LIDAR

# Potential Impact of new space-based observations on a Hurricane Track Prediction

- Tracks
  - Green: actual track
  - Red: forecast beginning 63 hours before landfall with current data
  - Blue: improved forecast for same time period with simulated wind lidar

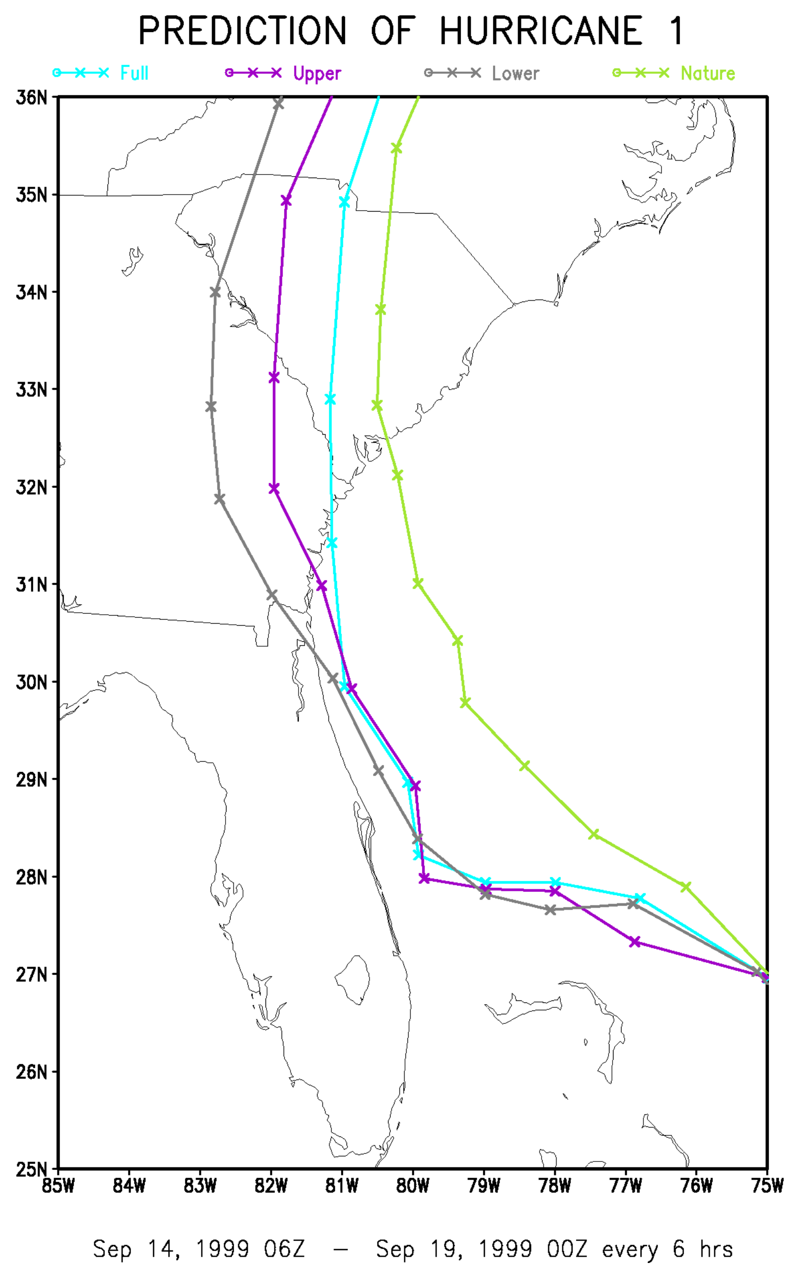


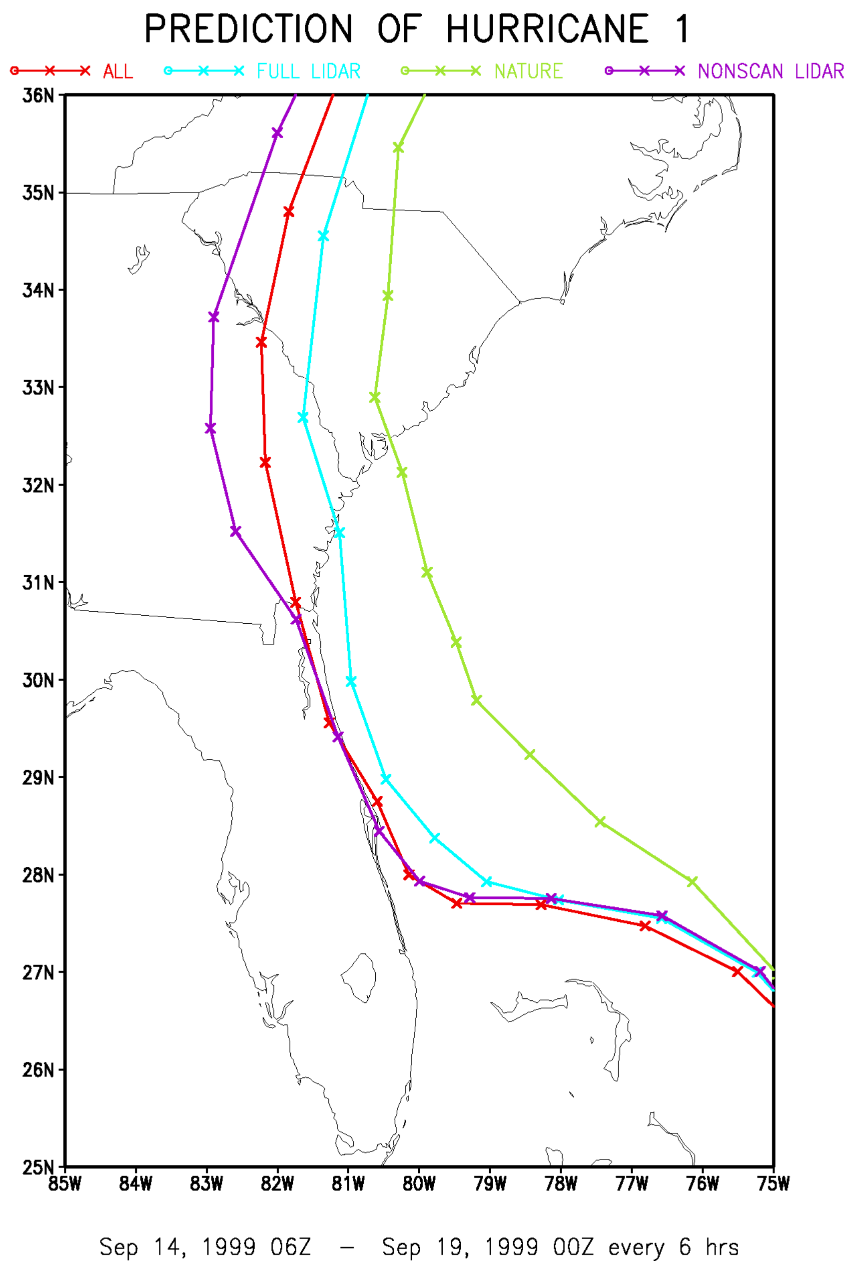
# SUMMARY OF LIDAR WIND EXPERIMENTS USED IN THE HURRICANE 1 CASE STUDY

PERIOD OF ASSIMILATION: Sept. 11 - Sept. 14, 1999
FIVE DAY FORECASTS: From Sept. 14, 1999

LIDAR WIND EXPERIMENTS:

CTRL + Full Lidar (complete profile and + / - 1100 km swath)
CTRL + Full Lidar (no data after Sept. 13, 1999, 0.0z)
CTRL + Full Lidar (no data before Sept. 13, 1999, 0.0z)
CTRL + Upper Lidar (500mb and above)
CTRL + Lower Lidar (1000 - 700mb)
CTRL + Full non-scanning Lidar


PREDICTION OF HURRICANE 1
Full
Upper
Lower
Nature
36N
35N
34N
33N
32N
31N
30N
29N
28N
27N
26N
25N
85W
84W
83W
82W
81W
80W
79W
78W
77W
76W
75W
Sep 14, 1999 06Z – Sep 19, 1999 00Z every 6 hrs


PREDICTION OF HURRICANE 1
ALL
FULL LIDAR
NATURE
NONSCAN LIDAR
36N
35N
34N
33N
32N
31N
30N
29N
28N
27N
26N
25N
85W
84W
83W
82W
81W
80W
79W
78W
77W
76W
75W
Sep 14, 1999 06Z – Sep 19, 1999 00Z every 6 hrs

# Preliminary Adaptive Targeting Experiment

## Purpose of Experiments

To assess a lidar adaptive targeting method on hurricane forecasting

## Experiments

Control: Conventional + cloud motion winds + TOVS + Quikscat observations

Center Orbit: Control + Lidar observations centered over hurricane

West Orbit: Control + Lidar observations over west portion of hurricane

East Orbit: Control + Lidar observations over east portion of hurricane

## Assimilations

NASA FVSSI hybrid DAS (T62) Sep 12 00Z to Sep 17 18Z 1999

## Forecasts

24 FVGCM forecasts at 1.25 deg resolution

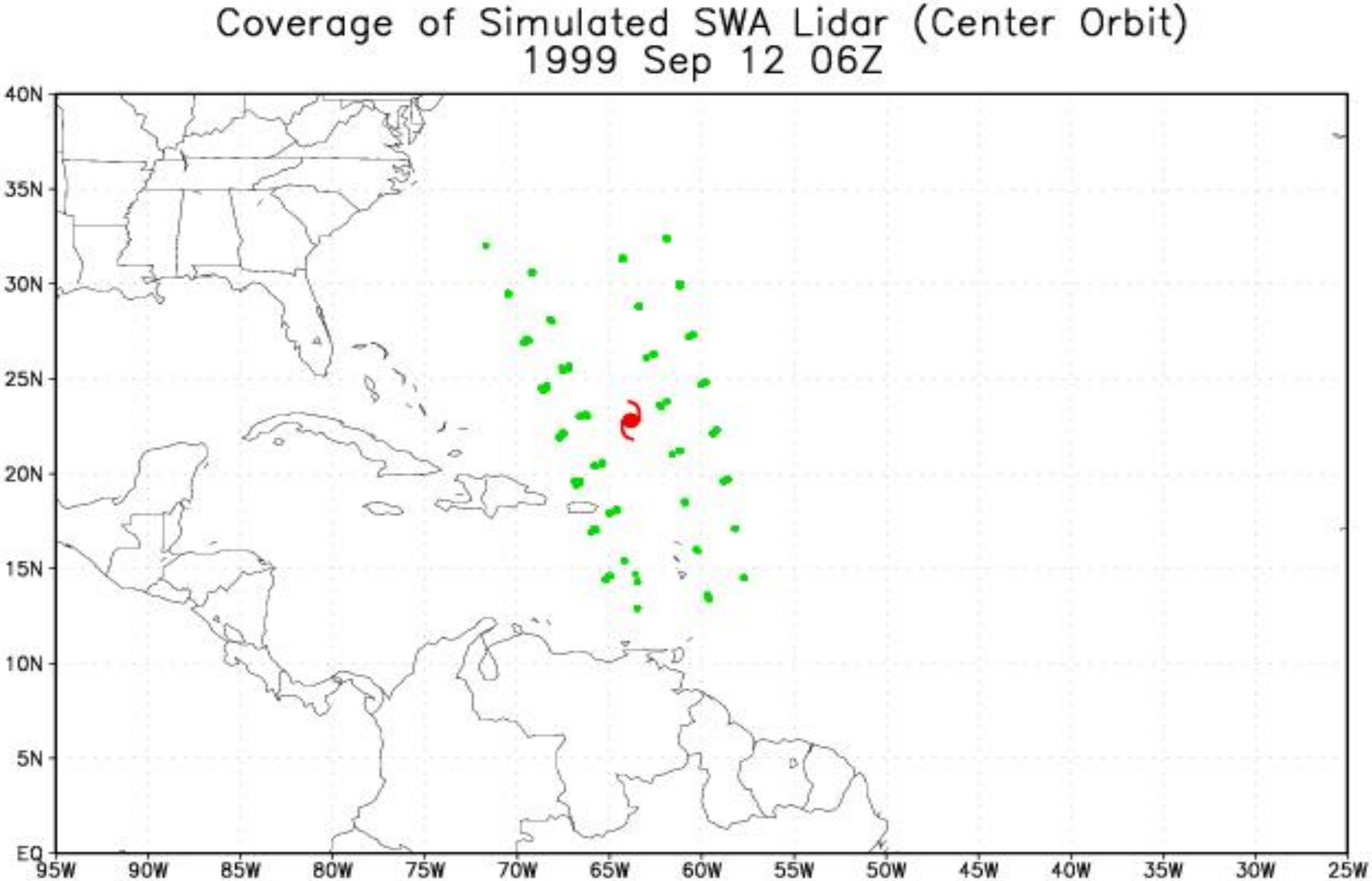
Initial conditions from Sep 12 00Z to Sep 17 18Z 1999 every 6 hours

## Adaptive Observing System

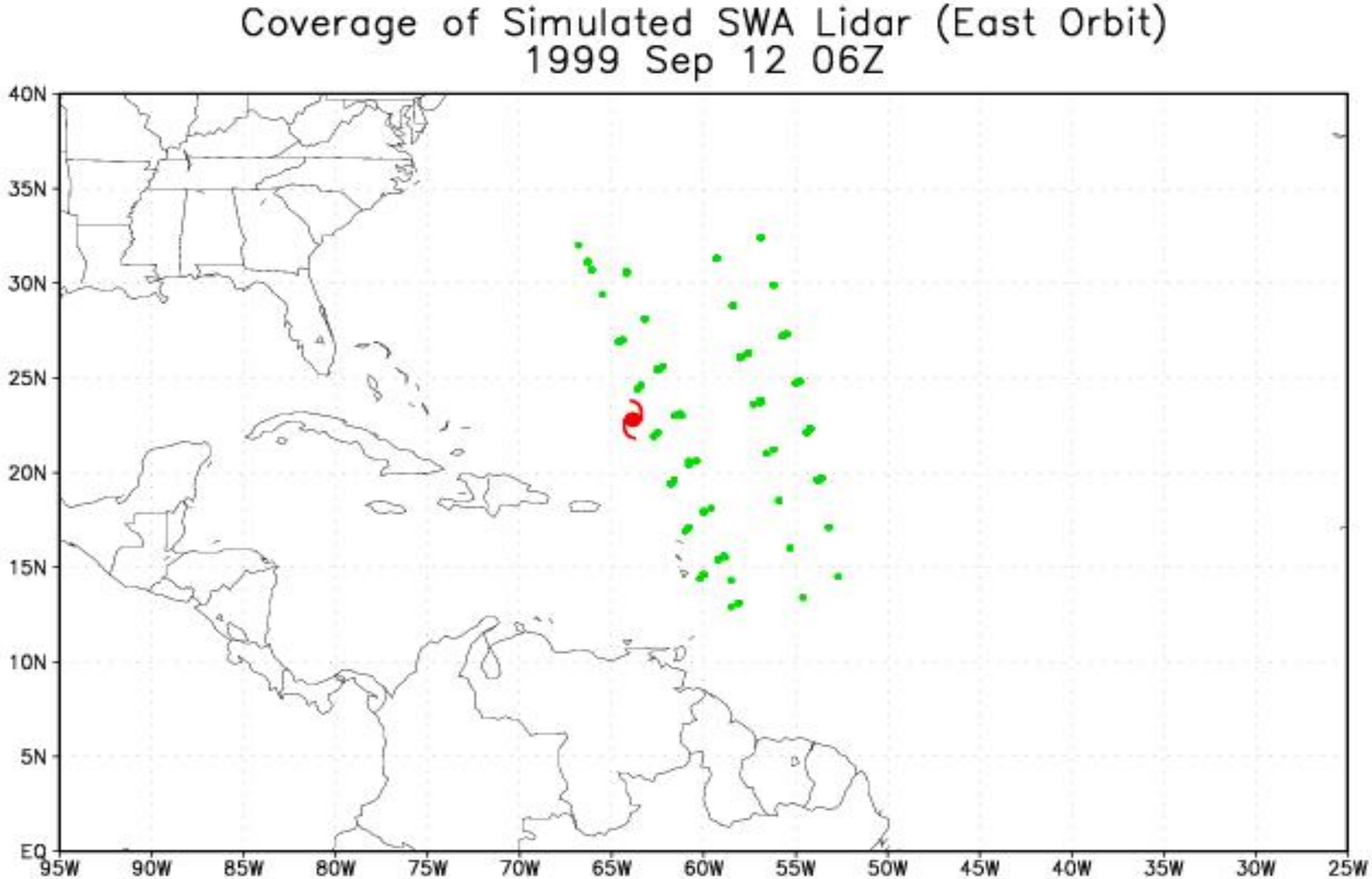
Coherent lidar with step-stare scanning.

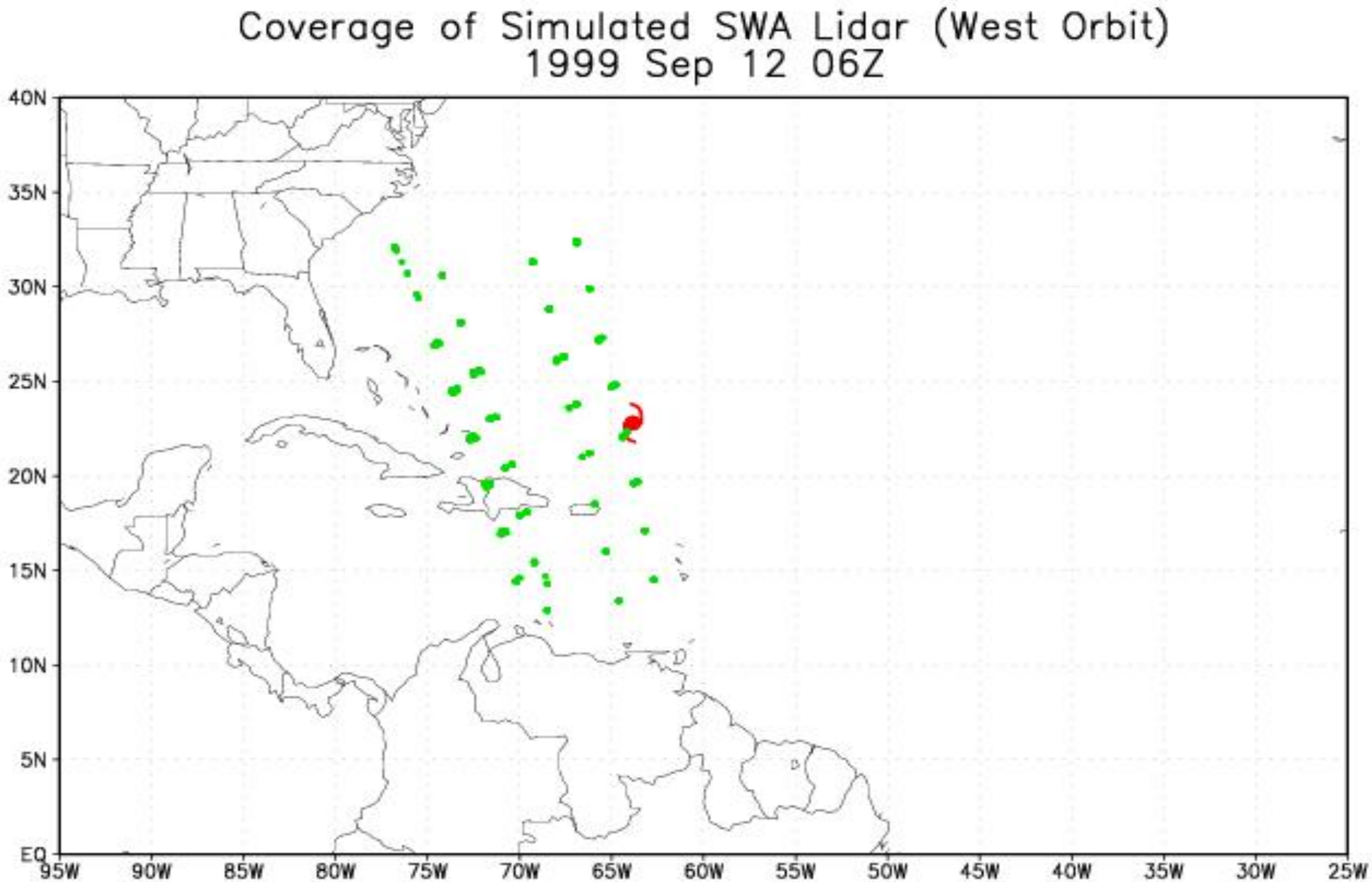
A lidar pass over hurricane occurs every 06Z and 18Z.

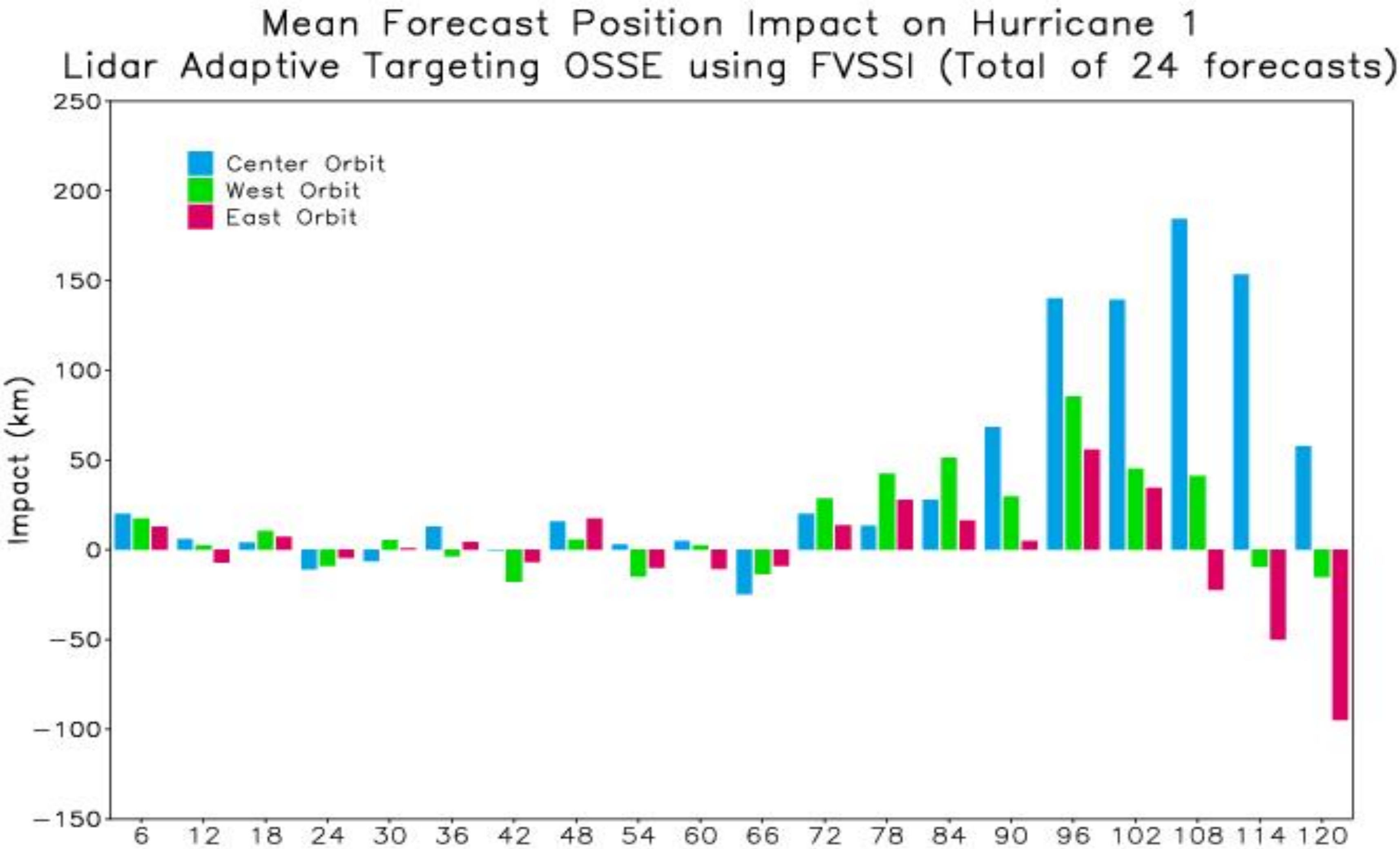
Lidar wind information introduced to DAS as line-of-sight winds.



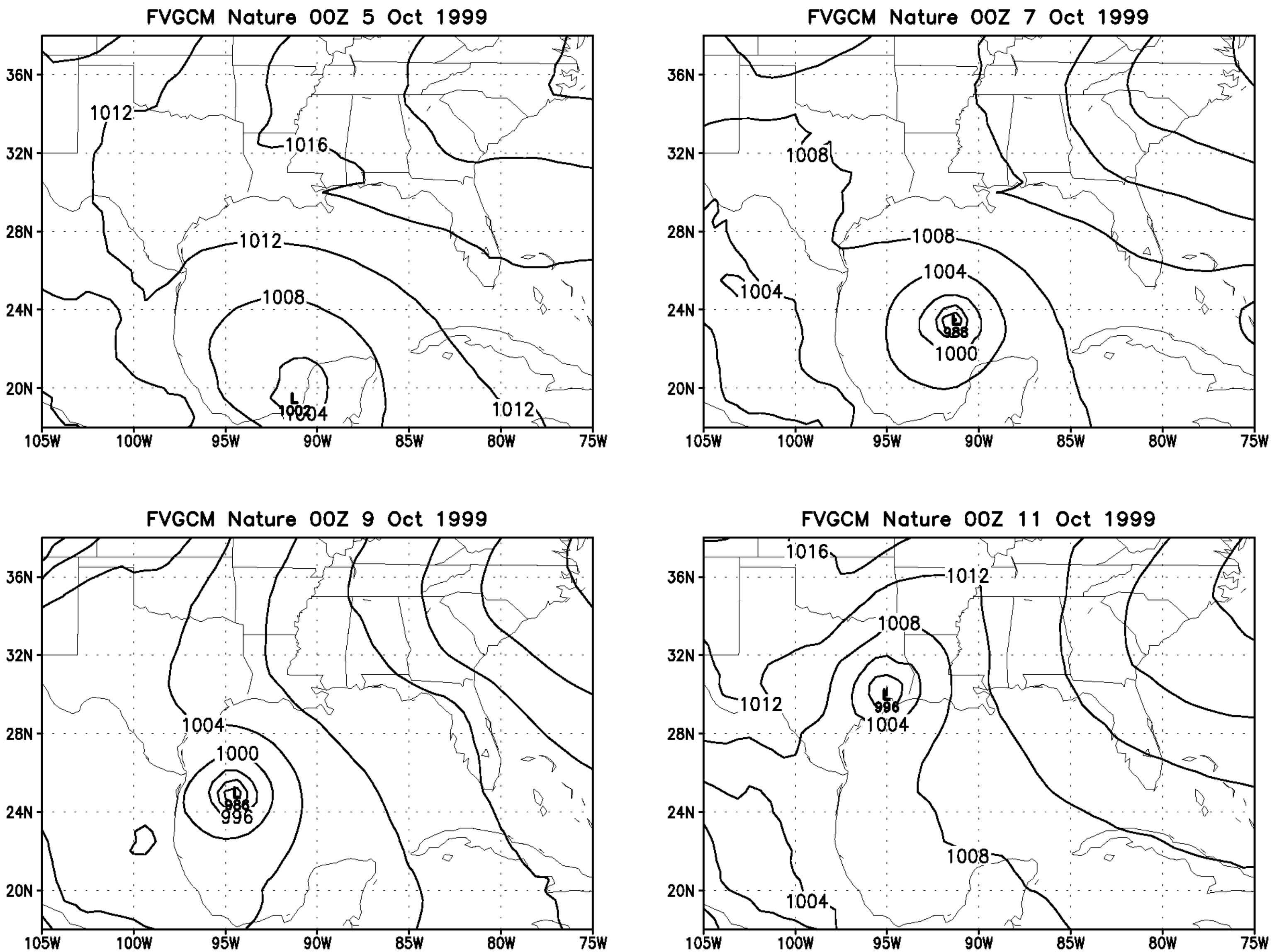
Coverage of Simulated SWA Lidar (Center Orbit)
1999 Sep 12 06Z
40N
35N
30N
25N
20N
15N
10N
5N
EQ
95W
90W
85W
80W
75W
70W
65W
60W
55W
50W
45W
40W
35W
30W
25W

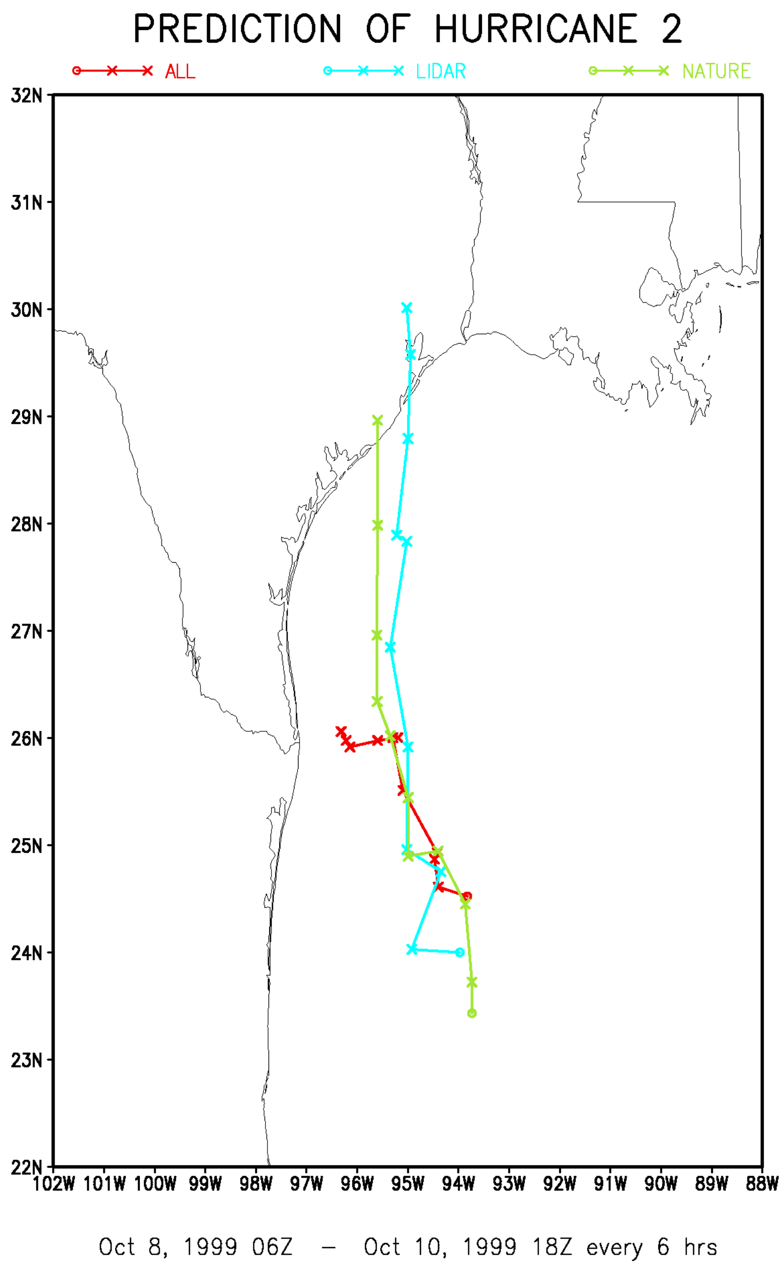

Coverage of Simulated SWA Lidar (East Orbit)
1999 Sep 12 06Z
40N
35N
30N
25N
20N
15N
10N
5N
EQ
95W
90W
85W
80W
75W
70W
65W
60W
55W
50W
45W
40W
35W
30W
25W

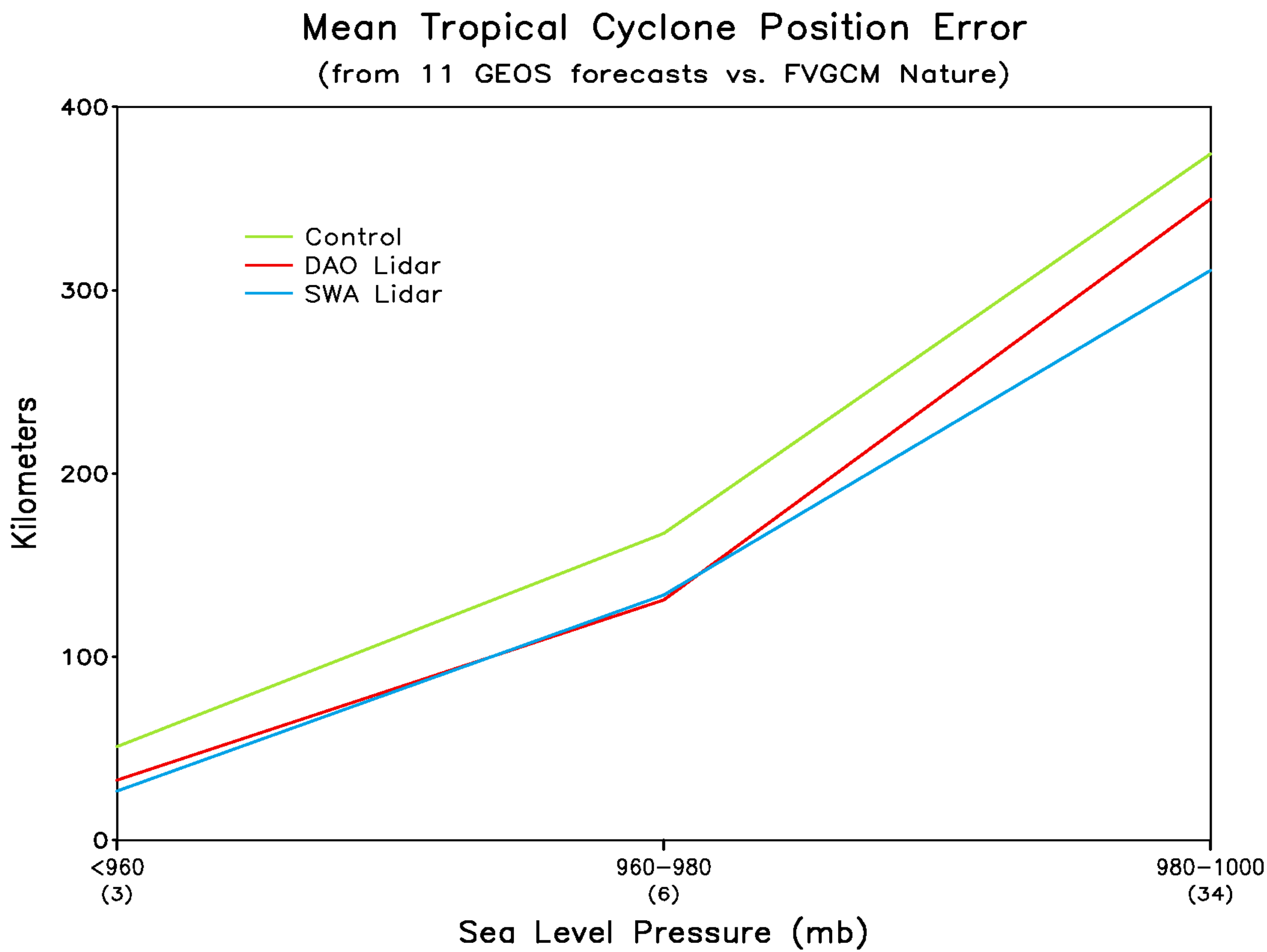

Coverage of Simulated SWA Lidar (West Orbit)
1999 Sep 12 06Z
40N
35N
30N
25N
20N
15N
10N
5N
EQ
95W
90W
85W
80W
75W
70W
65W
60W
55W
50W
45W
40W
35W
30W
25W

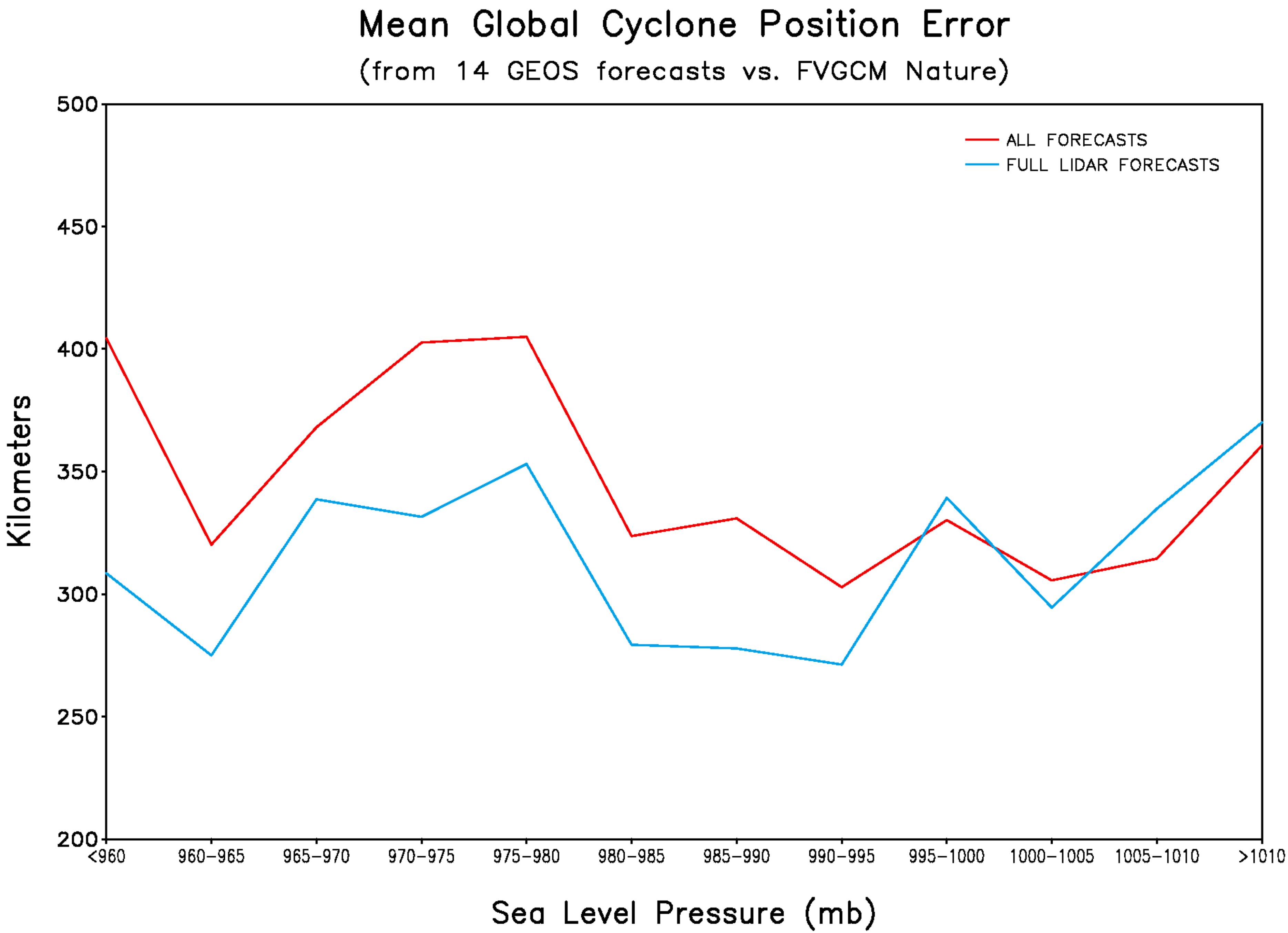

Mean Forecast Position Impact on Hurricane 1
Lidar Adaptive Targeting OSSE using FVSSI (Total of 24 forecasts)
Center Orbit
West Orbit
East Orbit
Impact (km)
250
200
150
100
50
0
−50
−100
−150
6
12
18
24
30
36
42
48
54
60
66
72
78
84
90
96
102
108
114
120

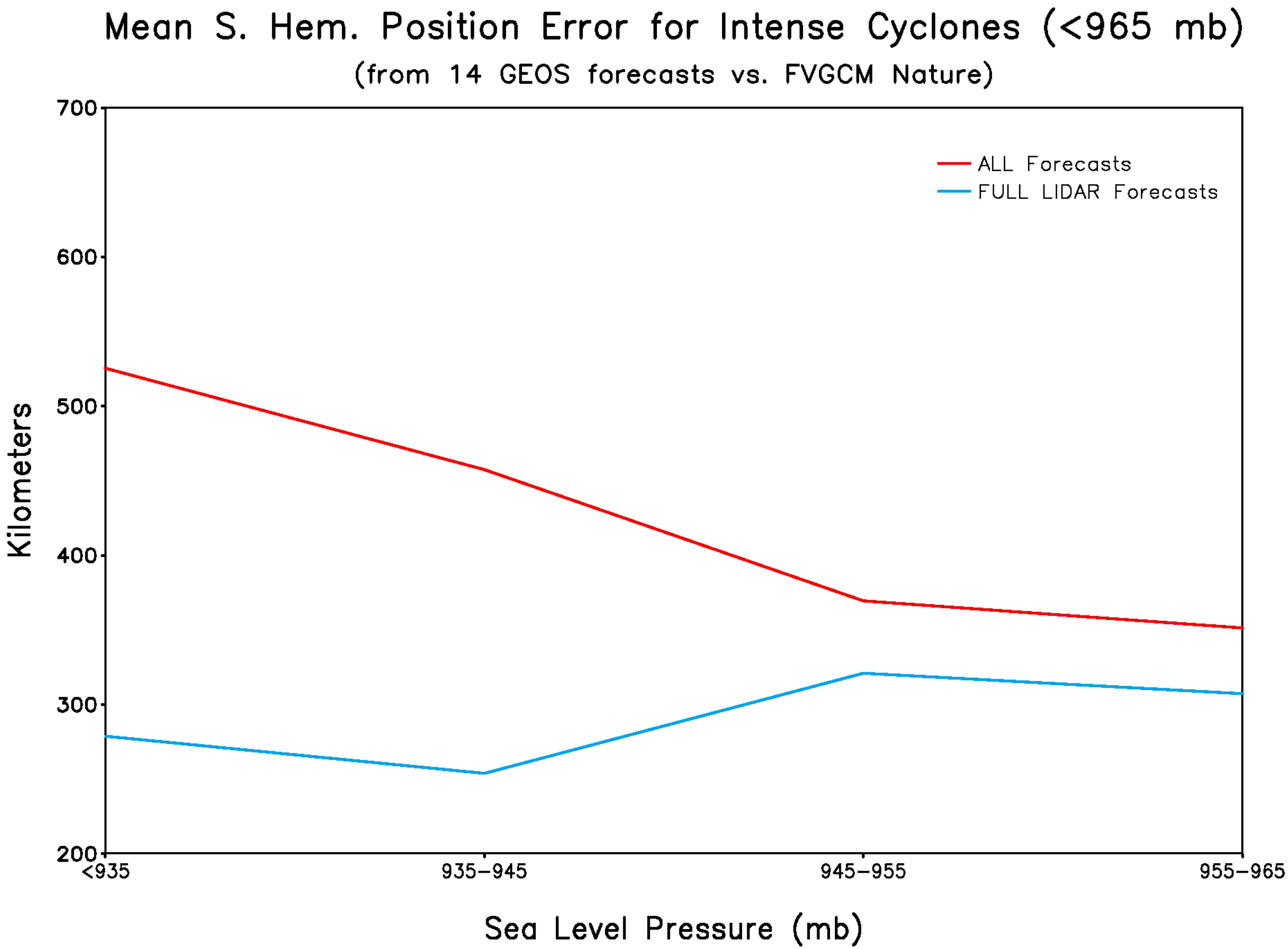
# Evolution of Hurricane 2




PREDICTION OF HURRICANE 2
ALL
LIDAR
NATURE
32N
31N
30N
29N
28N
27N
26N
25N
24N
23N
22N
102W 101W 100W 99W 98W 97W 96W 95W 94W 93W 92W 91W 90W 89W 88W
Oct 8, 1999 06Z – Oct 10, 1999 18Z every 6 hrs


Mean Tropical Cyclone Position Error
(from 11 GEOS forecasts vs. FVGCM Nature)
400
300
200
100
0
Kilometers
Control
DAO Lidar
SWA Lidar
<960
(3)
960–980
(6)
980–1000
(34)
Sea Level Pressure (mb)


Mean Global Cyclone Position Error
(from 14 GEOS forecasts vs. FVGCM Nature)
ALL FORECASTS
FULL LIDAR FORECASTS
Kilometers
500
450
400
350
300
250
200
<960
960-965
965-970
970-975
975-980
980-985
985-990
990-995
995-1000
1000-1005
1005-1010
>1010
Sea Level Pressure (mb)



Mean S. Hem. Position Error for Intense Cyclones (<965 mb)
(from 14 GEOS forecasts vs. FVGCM Nature)
ALL Forecasts
FULL LIDAR Forecasts
Kilometers
700
600
500
400
300
200
<935
935–945
945–955
955–965
Sea Level Pressure (mb)

# IMPACT OF LIDAR WINDS ON CYCLONE PREDICTION

## 5-day Average Reduction in Position Error

| | |
|---|---|
| Global: | 35 km (10% improvement) |
| N. America: | 48 km (11% improvement) |

## 10-day Average Reduction in Position Error

| | |
|---|---|
| Global; | 66 km (17% improvement) |
| N.H.X.T: | 17 km (5% improvement) |
| S.H.X.T: | 48 km (24% improvement) |

## Reduction in Hurricane Landfall Position Error

For United States: 239 km (66% improvement) at 63h

# Determining Experimental Impact on Jet Maxima

## 1. Local Scan

Perform 3–dimensional search for wind speed maxima in nature run (850 to 150 hPa).

Look for wind speeds that radially increase toward a jet center in a continuous manner.

## 2. Regional Scan

Isolate the dominant center in a jet region to remove ambiquity of multiple local centers.

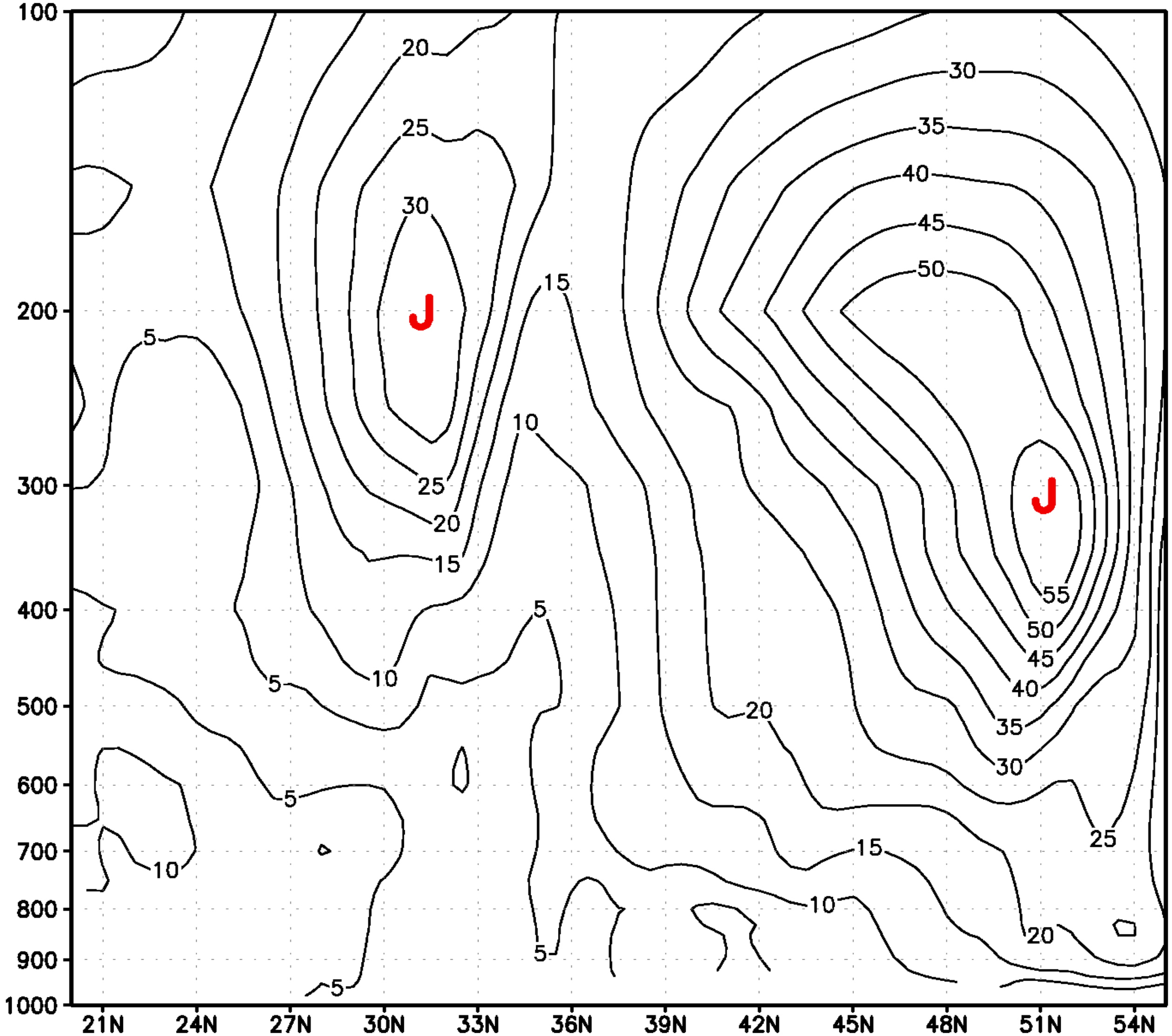
## 3. Impact

At the nature jet locations, for all jet maxima, compute wind speed RMS error between nature run and each experiment.

The Impact is the difference in the experimental RMS errors:

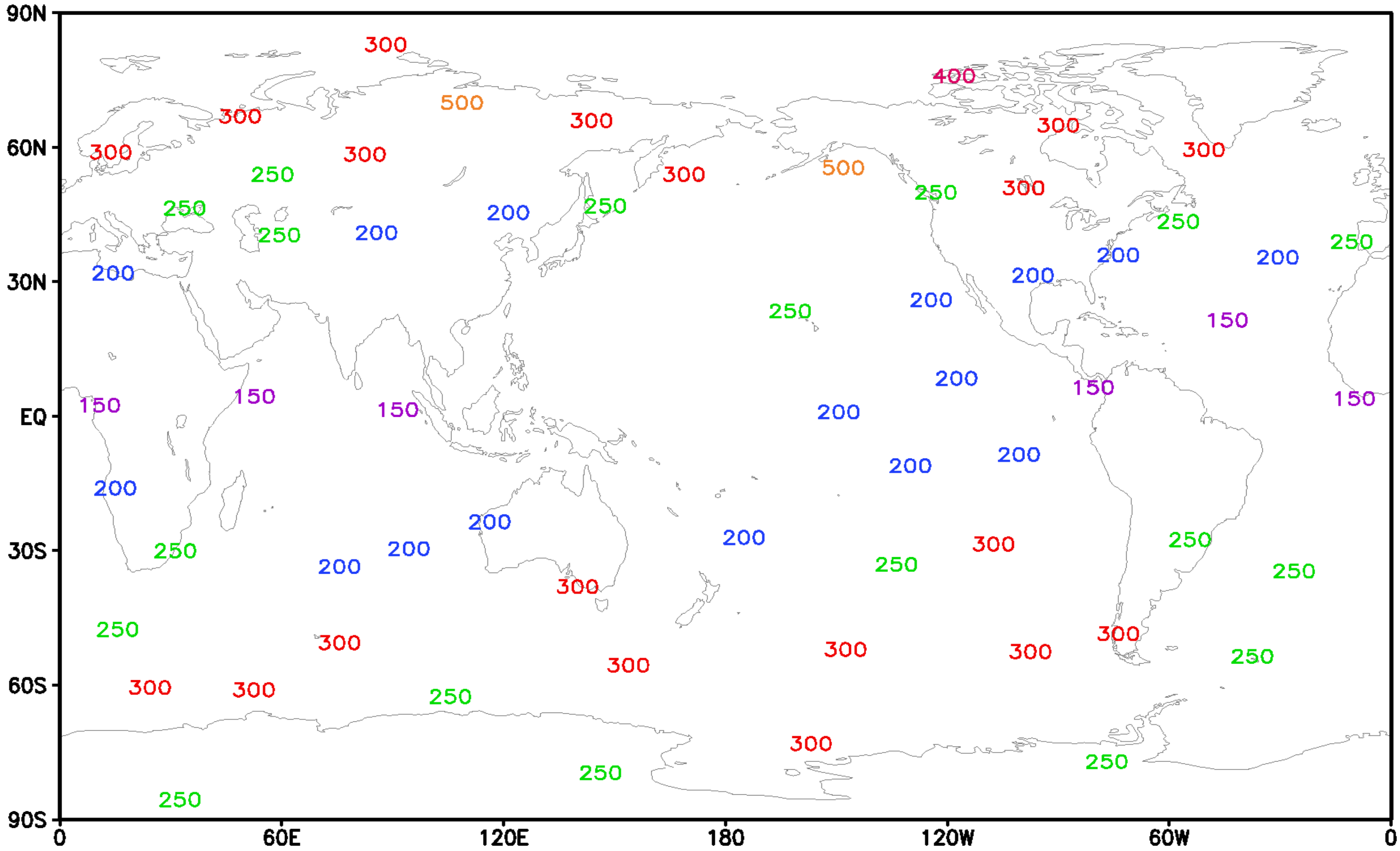
$$\text{Impact} = [\text{RMS Error}]_{exp1} - [\text{RMS Error}]_{exp2}$$

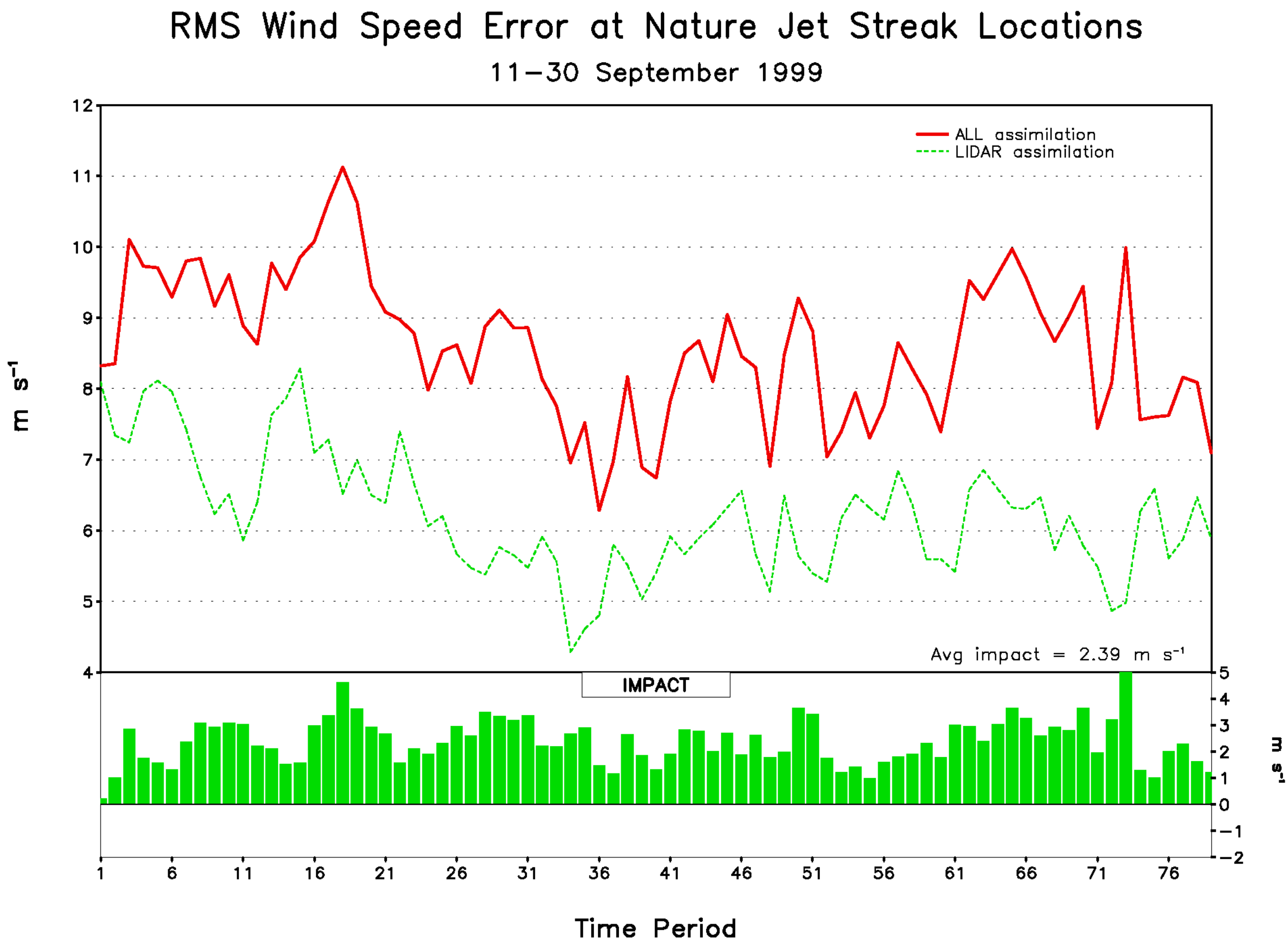
Vertical Cross Section of Nature Run Jet Maxima
2 Oct 1999 00 UTC

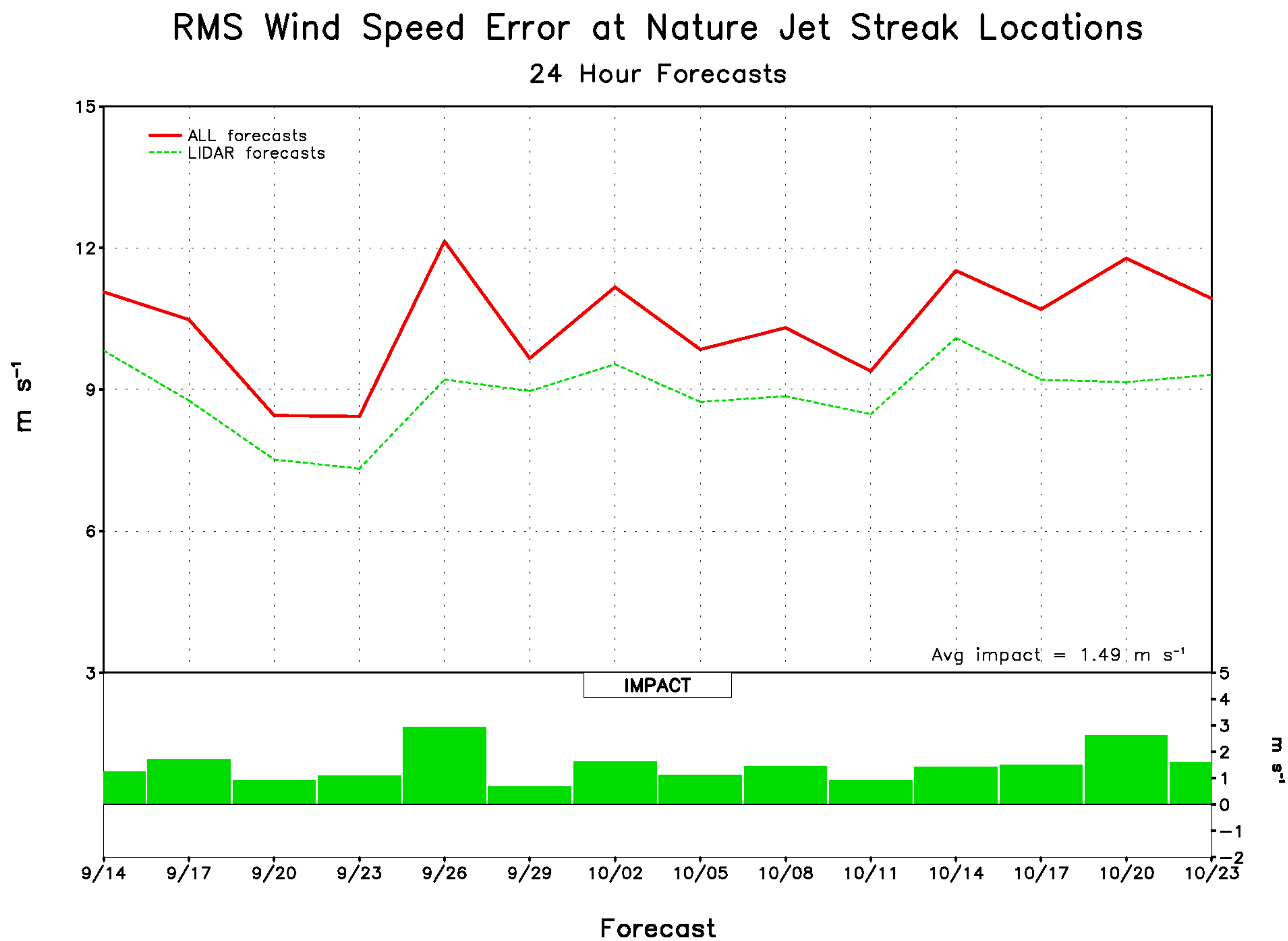


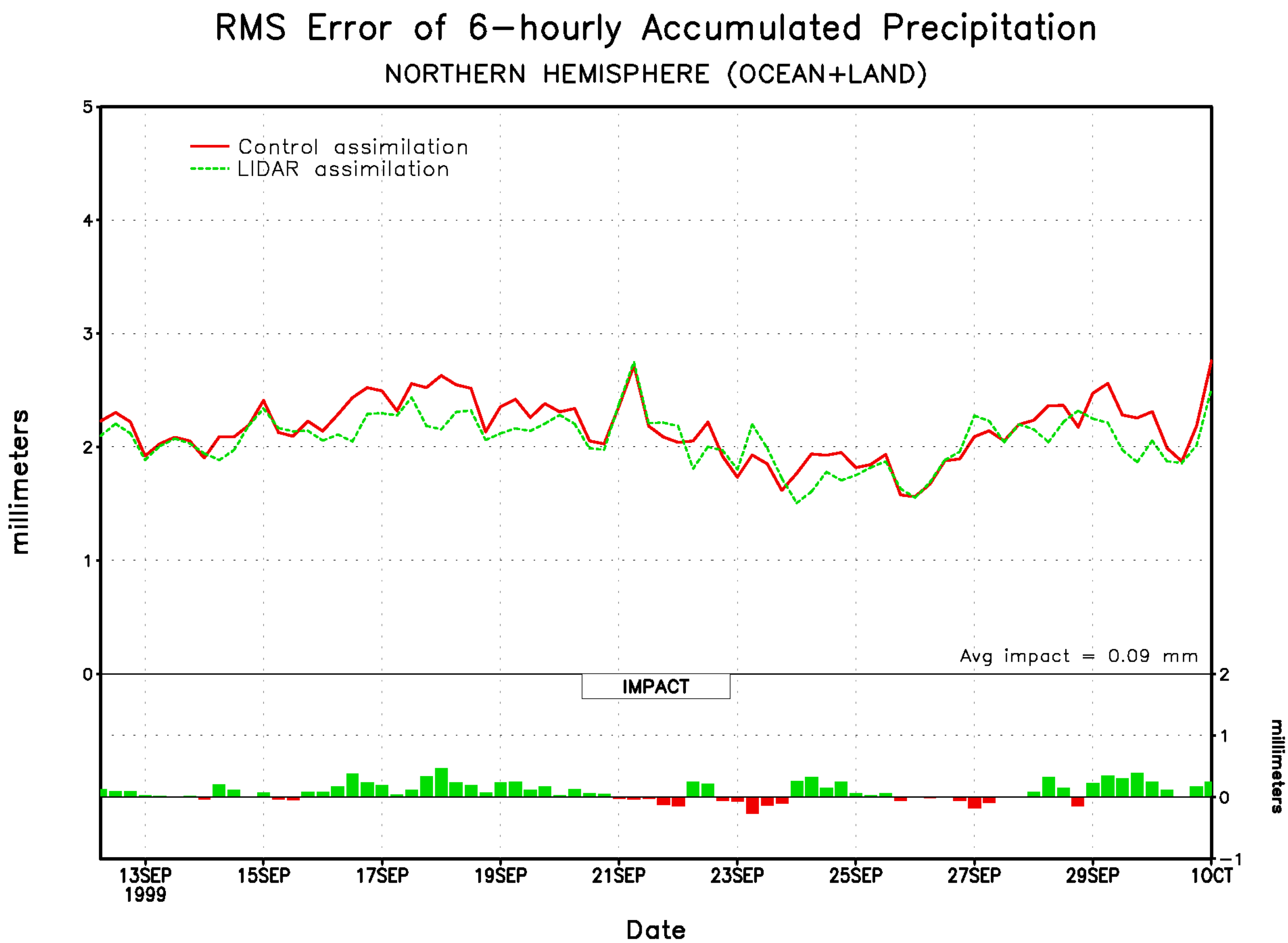
# Locations and Levels of Wind Speed Maxima in FV Nature

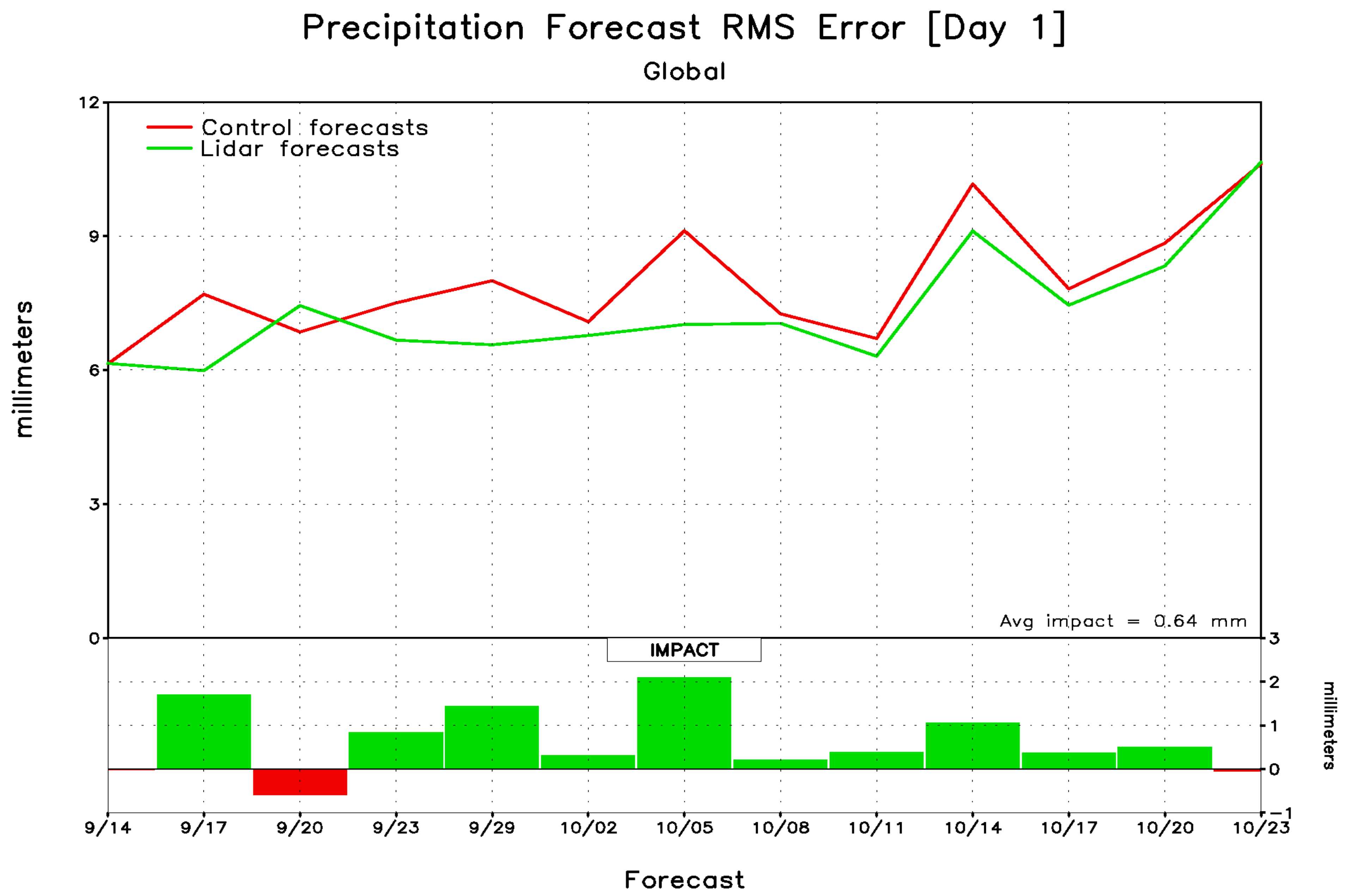
2 Oct 1999 00 UTC



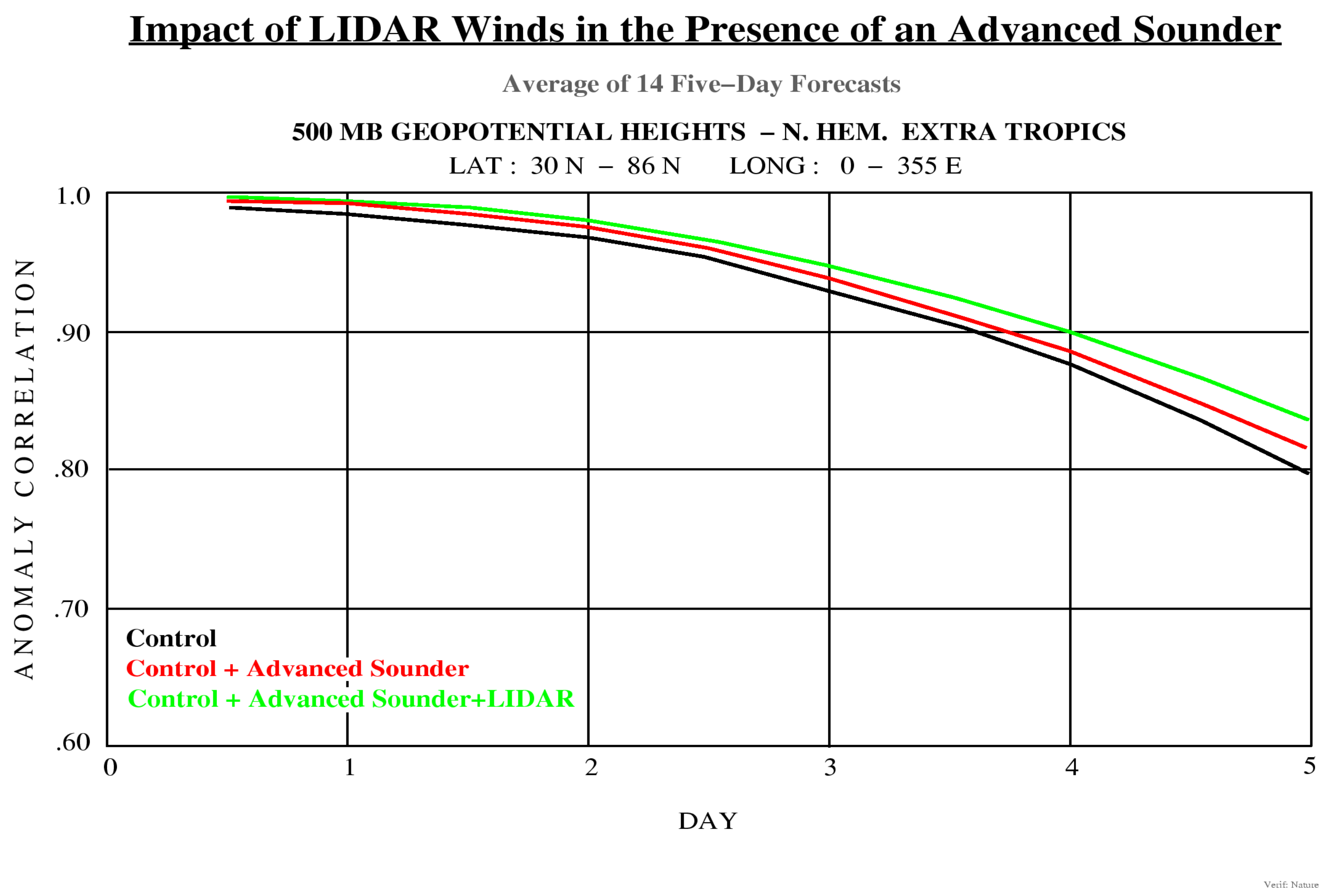

RMS Wind Speed Error at Nature Jet Streak Locations
11–30 September 1999
ALL assimilation
LIDAR assimilation
Avg impact = 2.39 m s⁻¹
IMPACT
m s⁻¹
Time Period


RMS Wind Speed Error at Nature Jet Streak Locations
24 Hour Forecasts
ALL forecasts
LIDAR forecasts
m s-1
15
12
9
6
3
Avg impact = 1.49 m s-1
IMPACT
5
4
3
2
1
0
−1
−2
m s-1
9/14
9/17
9/20
9/23
9/26
9/29
10/02
10/05
10/08
10/11
10/14
10/17
10/20
10/23
Forecast


RMS Error of 6-hourly Accumulated Precipitation
NORTHERN HEMISPHERE (OCEAN+LAND)
Control assimilation
LIDAR assimilation
Avg impact = 0.09 mm
IMPACT
millimeters
millimeters
0
1
2
3
4
5
2
1
0
-1
13SEP
1999
15SEP
17SEP
19SEP
21SEP
23SEP
25SEP
27SEP
29SEP
1OCT
Date



Precipitation Forecast RMS Error [Day 1]
Global
Control forecasts
Lidar forecasts
millimeters
12
9
6
3
0
Avg impact = 0.64 mm
IMPACT
3
2
1
0
−1
millimeters
9/14
9/17
9/20
9/23
9/29
10/02
10/05
10/08
10/11
10/14
10/17
10/20
10/23
Forecast

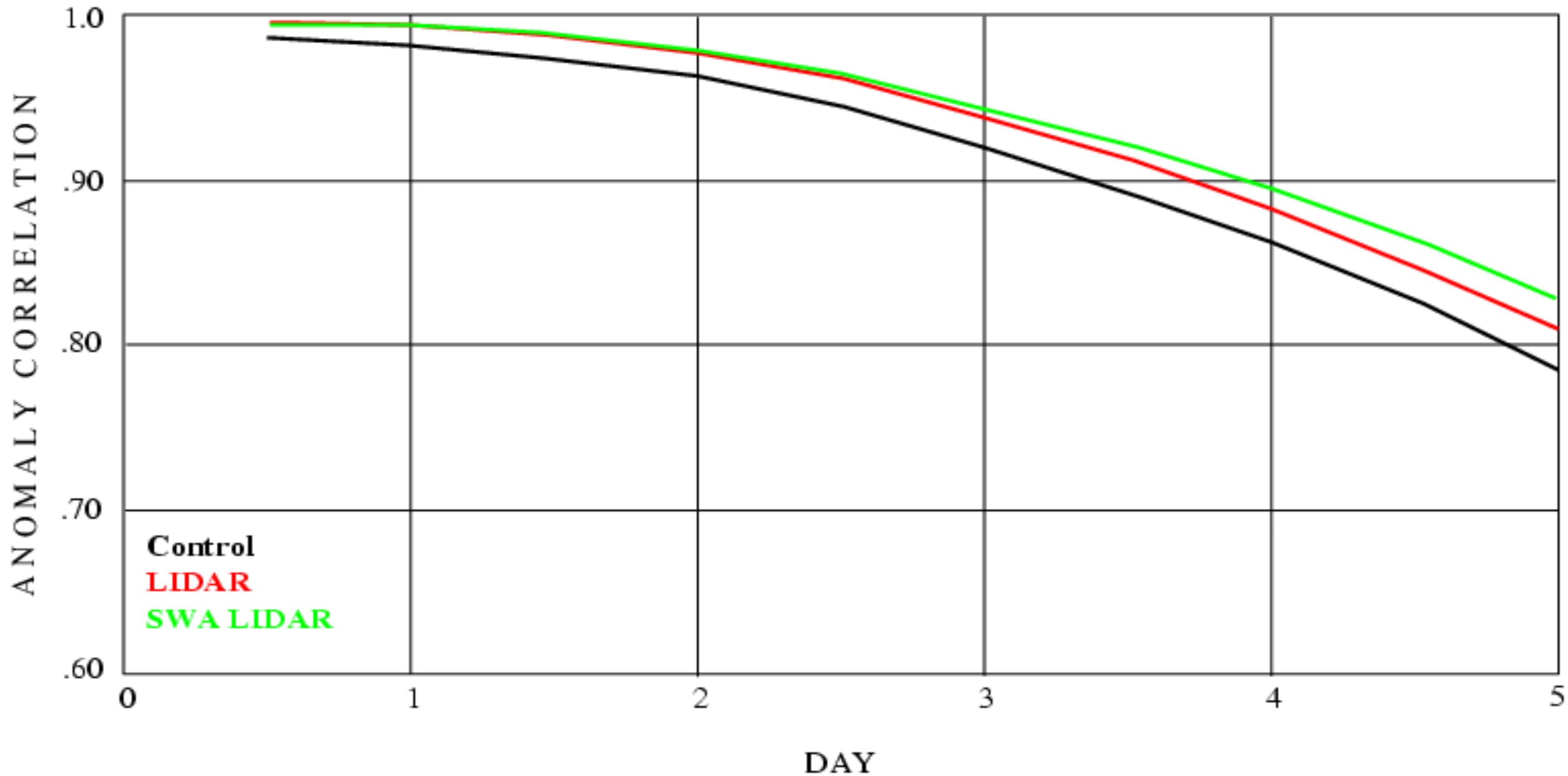

Impact of LIDAR Winds in the Presence of an Advanced Sounder
Average of 14 Five–Day Forecasts
500 MB GEOPOTENTIAL HEIGHTS – N. HEM. EXTRA TROPICS
LAT : 30 N – 86 N LONG : 0 – 355 E
ANOMALY CORRELATION
1.0
.90
.80
.70
.60
0
1
2
3
4
5
DAY
Control
Control + Advanced Sounder
Control + Advanced Sounder+LIDAR
Verif: Nature

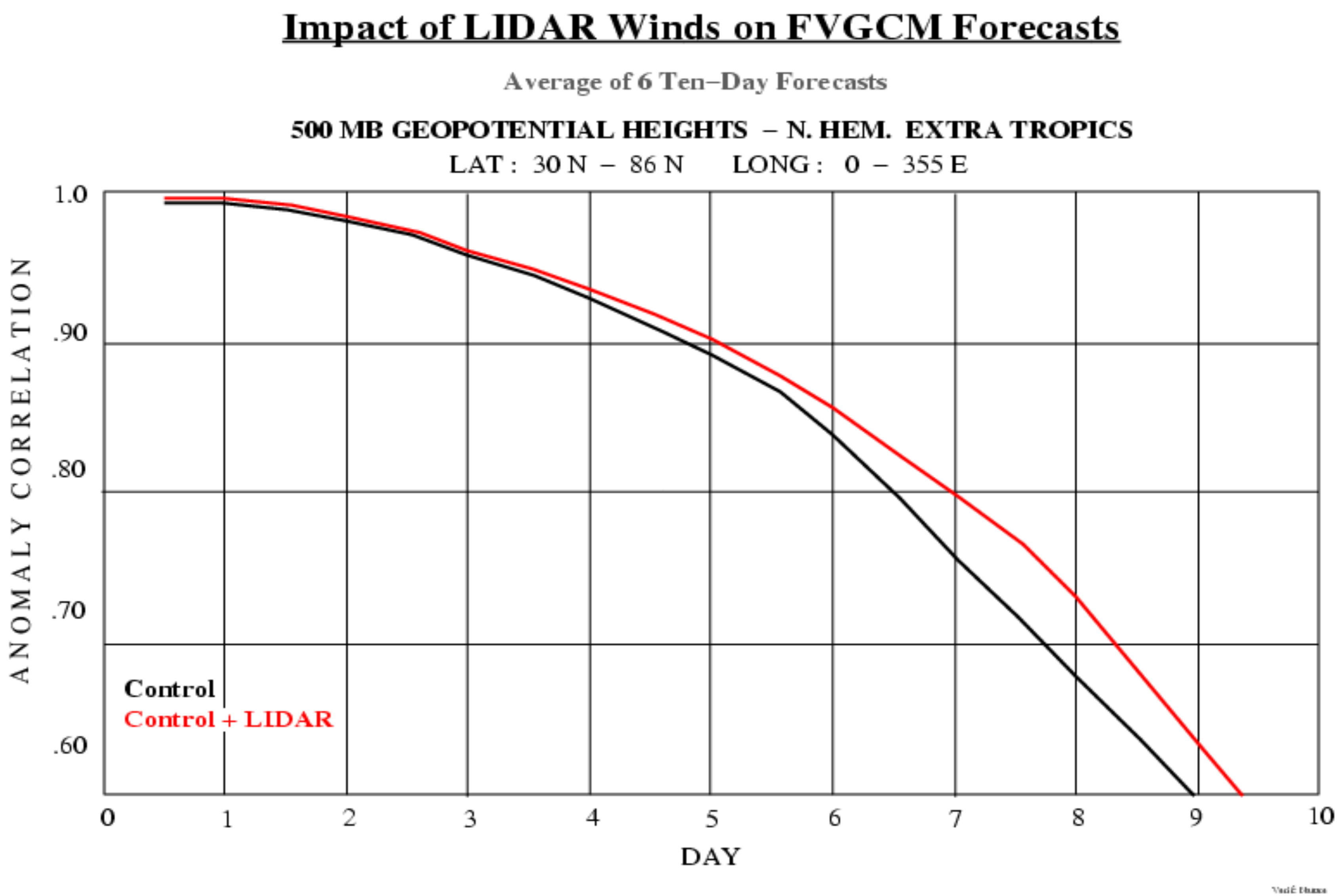
# Impact of SWA Best LIDAR on GEOS–3 Forecasts

Average of 11 Five–Day Forecasts

**500 MB GEOPOTENTIAL HEIGHTS – N. HEM. EXTRA TROPICS**

LAT : 30 N – 86 N LONG : 0 – 355 E



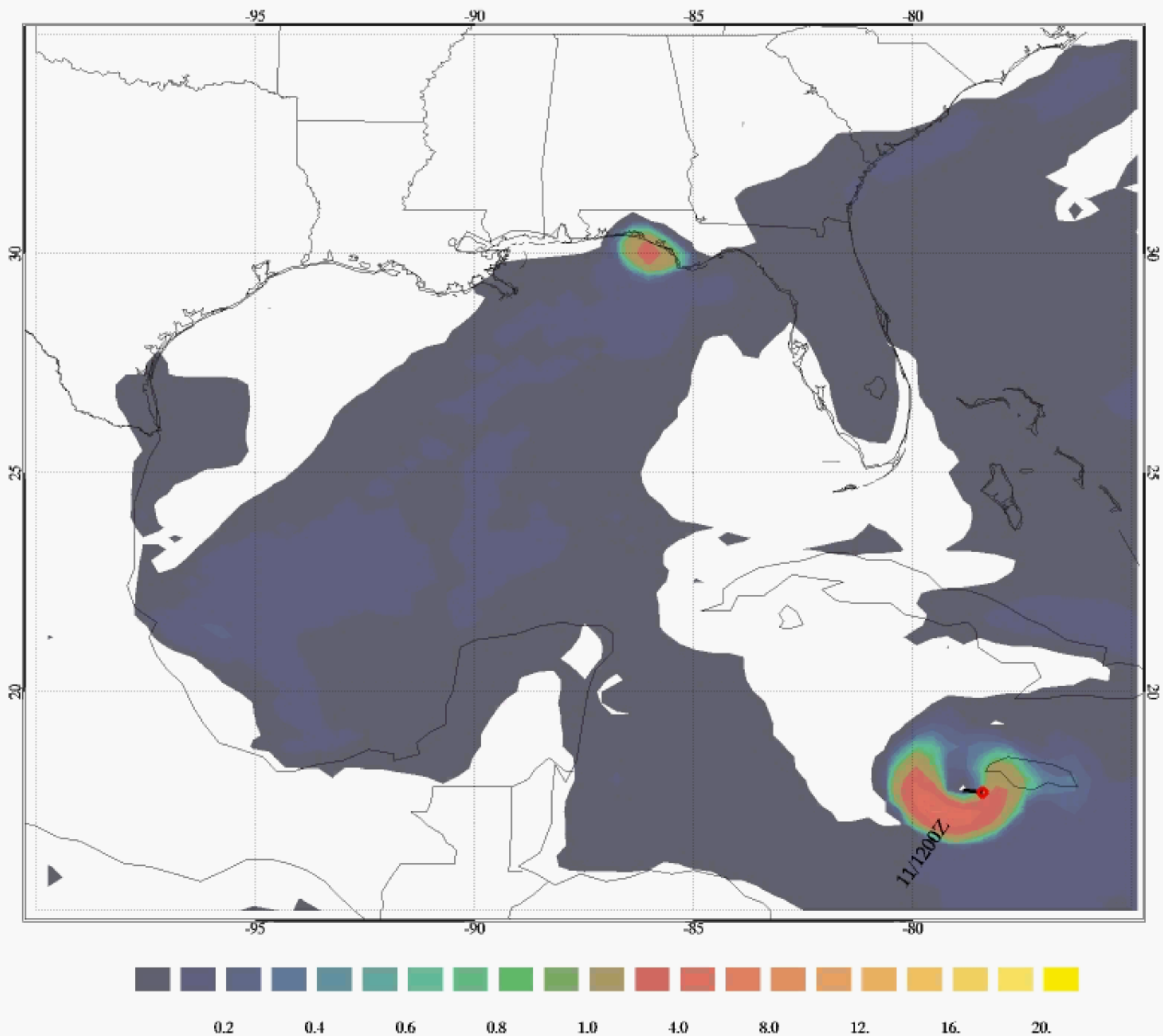


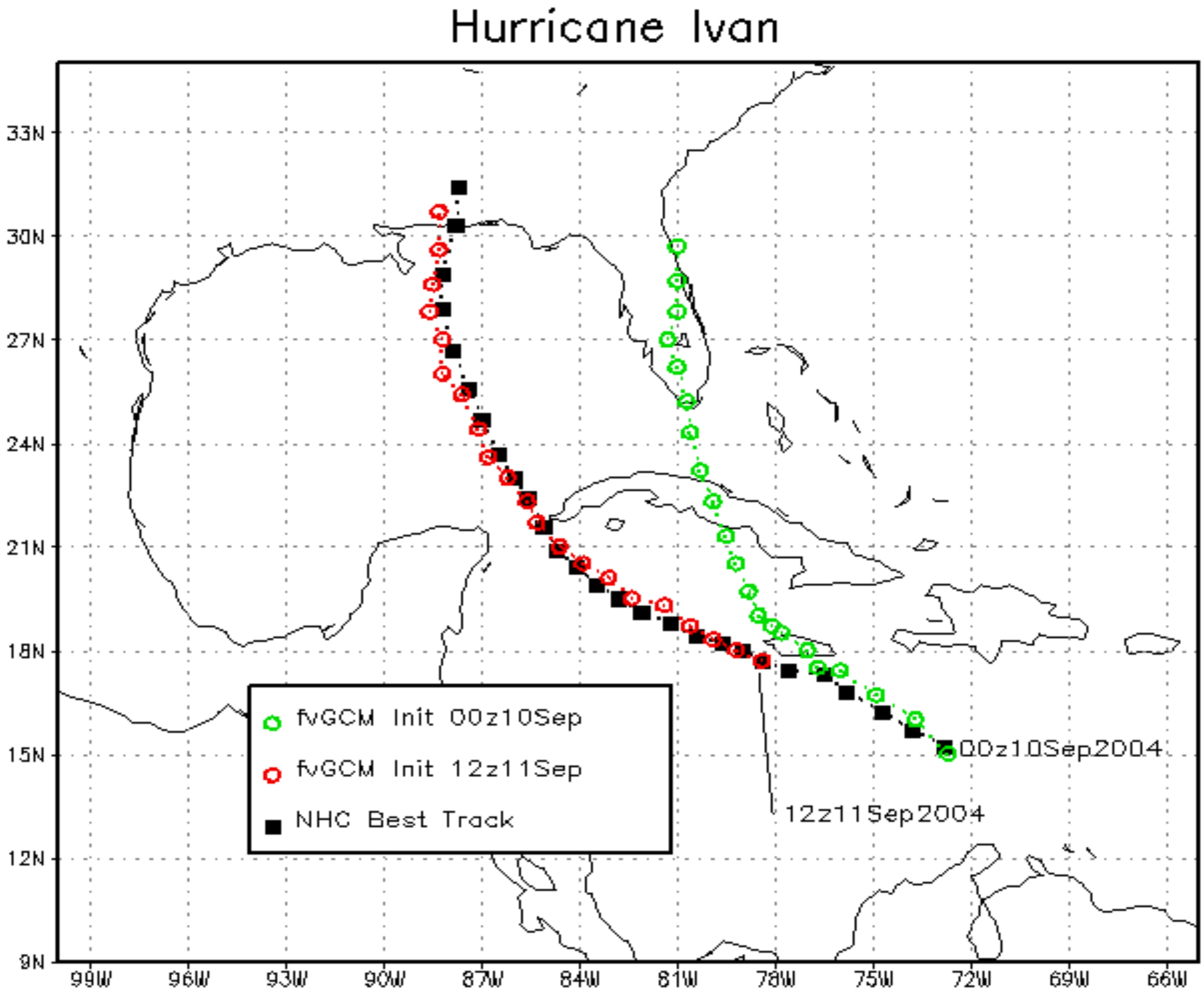

Potential Impact of Lidar Winds in the presence of a more advanced forecast model

NASA fvGCM Hurricane Ivan Forecast Track [Black] and NHC Observed [Blue]

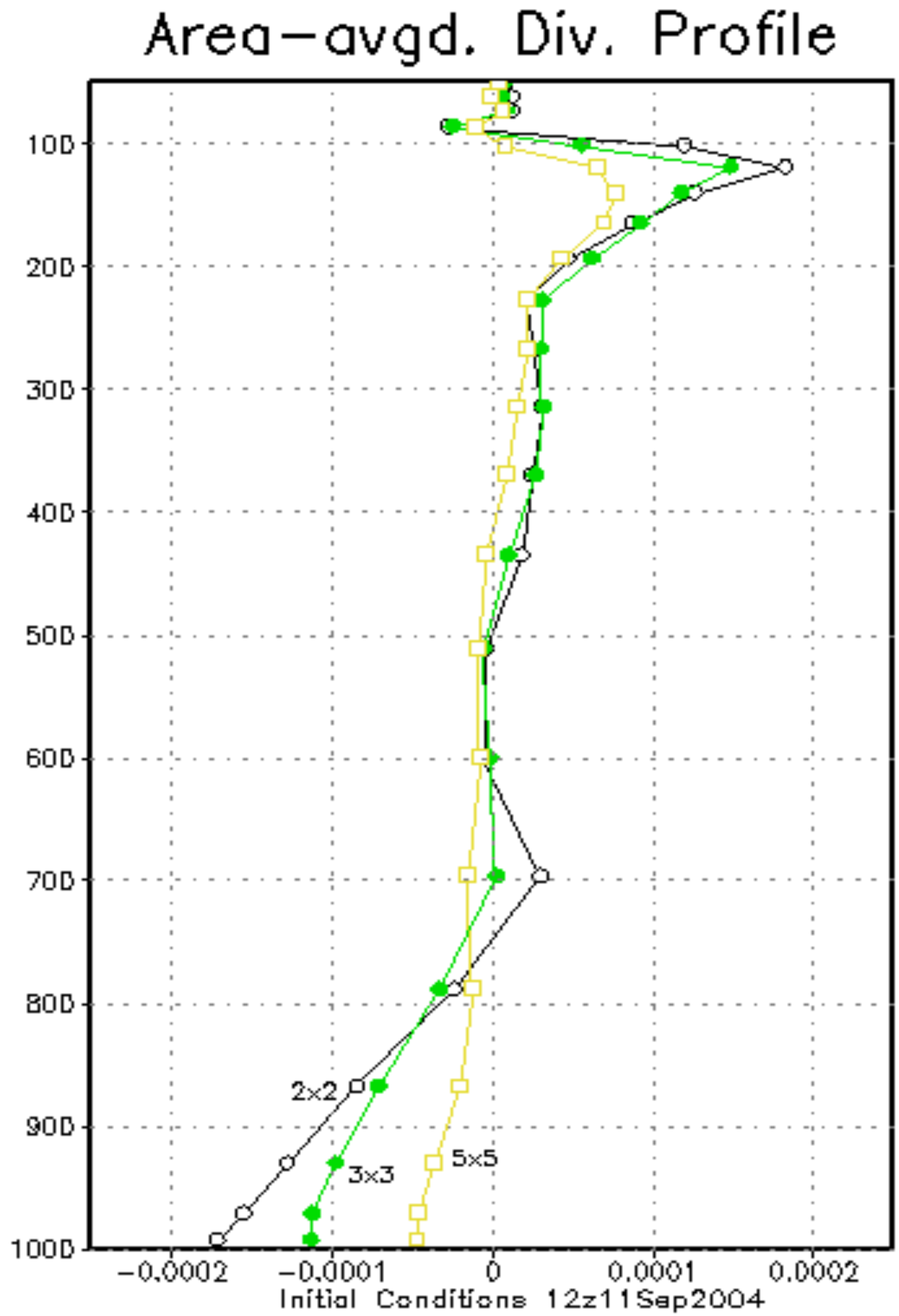
Accumulated Precipitation [inches]

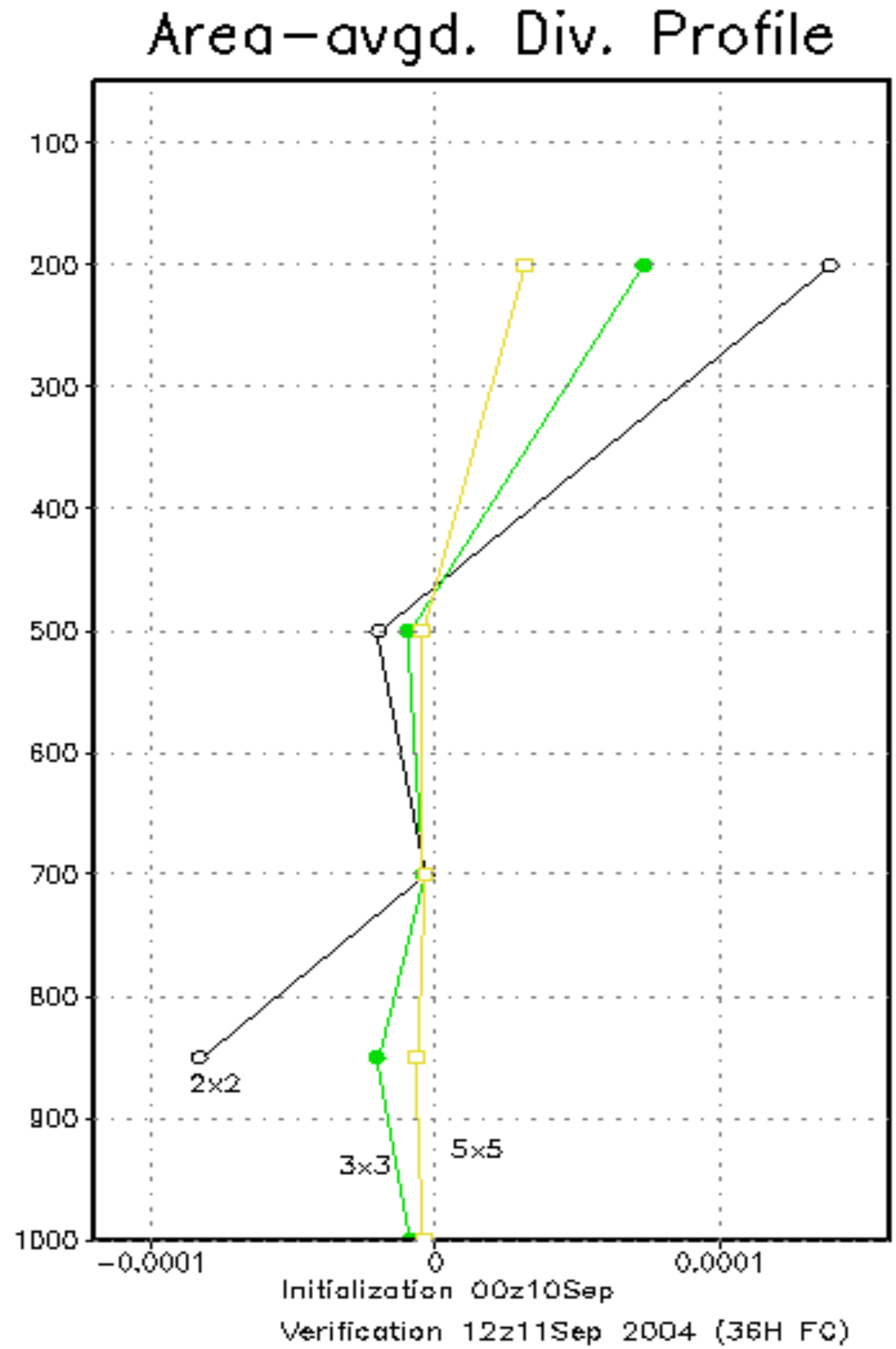
Initialized 2004 SEP 11 12Z : Valid 2004 SEP 11 15:00Z





Hurricane Ivan
33N
30N
27N
24N
21N
18N
15N
12N
9N
99W
96W
93W
90W
87W
84W
81W
78W
75W
72W
69W
66W
fvGCM Init 00z10Sep
fvGCM Init 12z11Sep
NHC Best Track
00z10Sep2004
12z11Sep2004


Area-avgd. Div. Profile
100
200
300
400
500
600
700
800
900
1000
-0.0002
-0.0001
0
0.0001
0.0002
Initial Conditions 12z11Sep2004
2x2
3x3
5x5


Area-avgd. Div. Profile
100
200
300
400
500
600
700
800
900
1000
-0.0001
0
0.0001
Initialization 00z10Sep
Verification 12z11Sep 2004 (36H FC)
2x2
3x3
5x5

# Description of Quick OSSE Experiments

Nature Run : fvGCM .25 x .36 deg horizontal resolution,
start on Sep. 11, 2004 at 12z

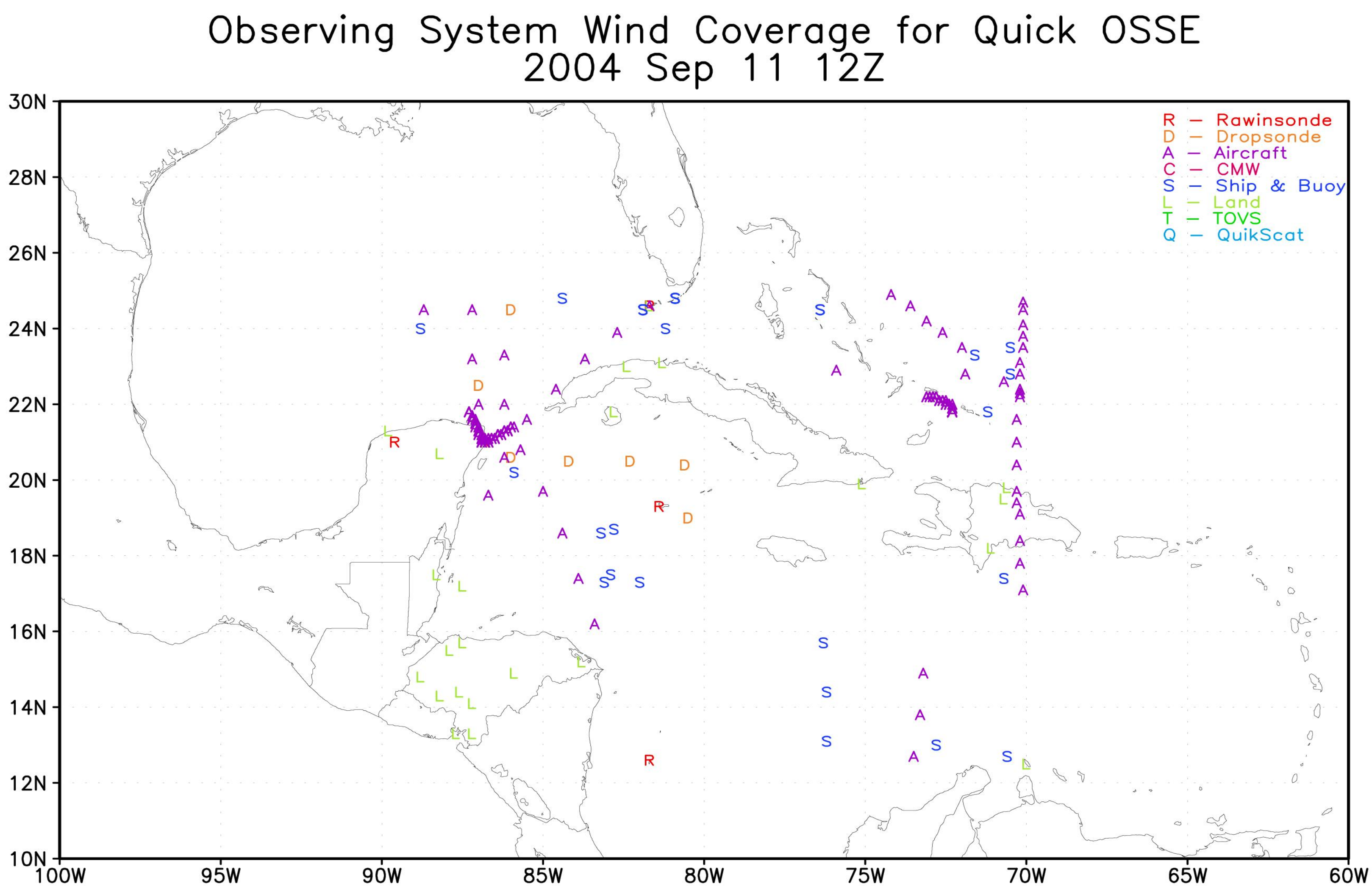
Observations : simulated from the Nature Run
for Sep. 11, 12z – Sep.12, 12z, 2004.

Data Assimilation Experiments : fvSSI , 1 x 1.25 deg resolution,
ran Sep. 11, 00z – Sep.12, 12z, 2004.

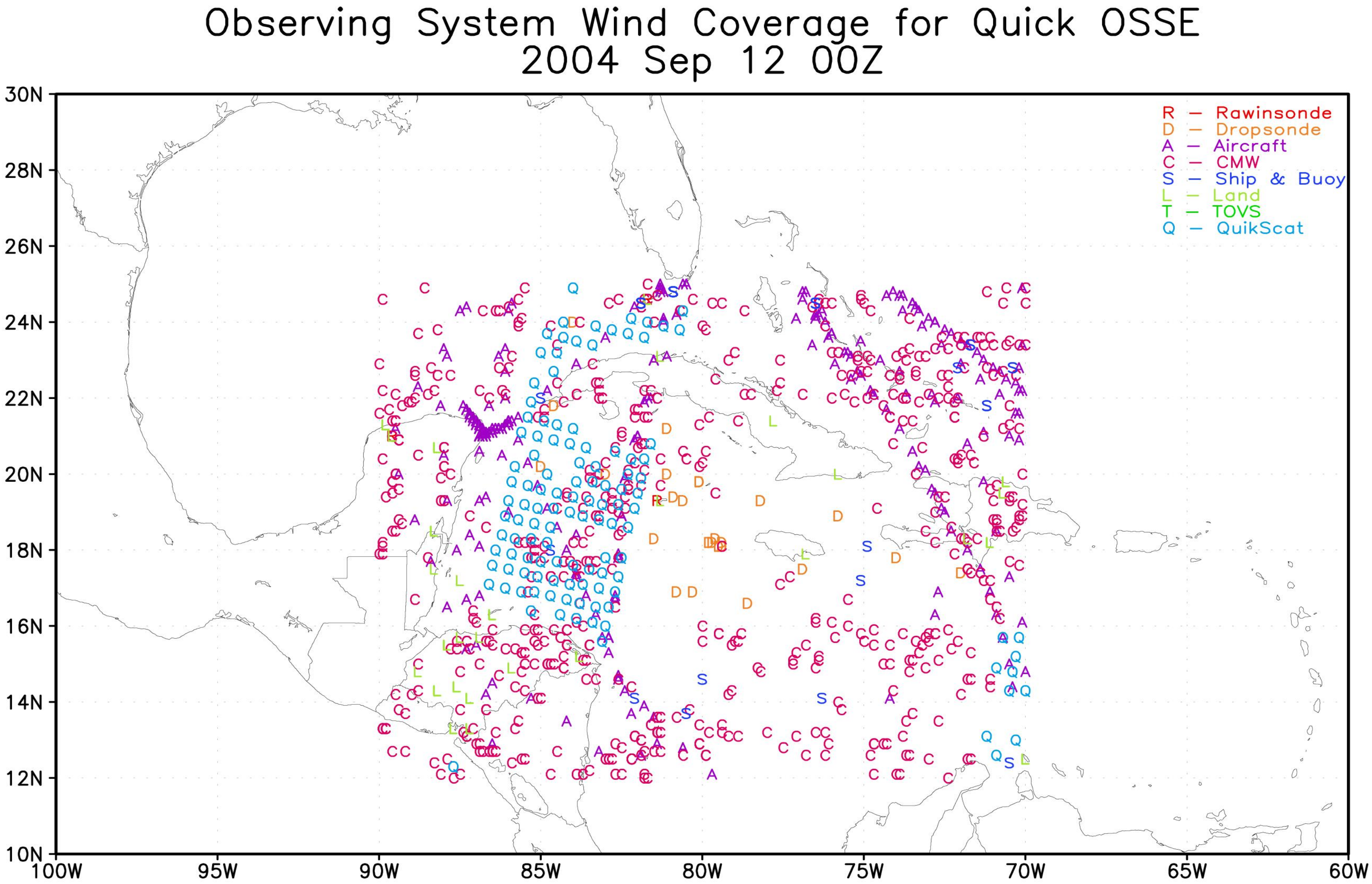
Control - compliment of operationally globally observed data,
including satellite temperature profiles

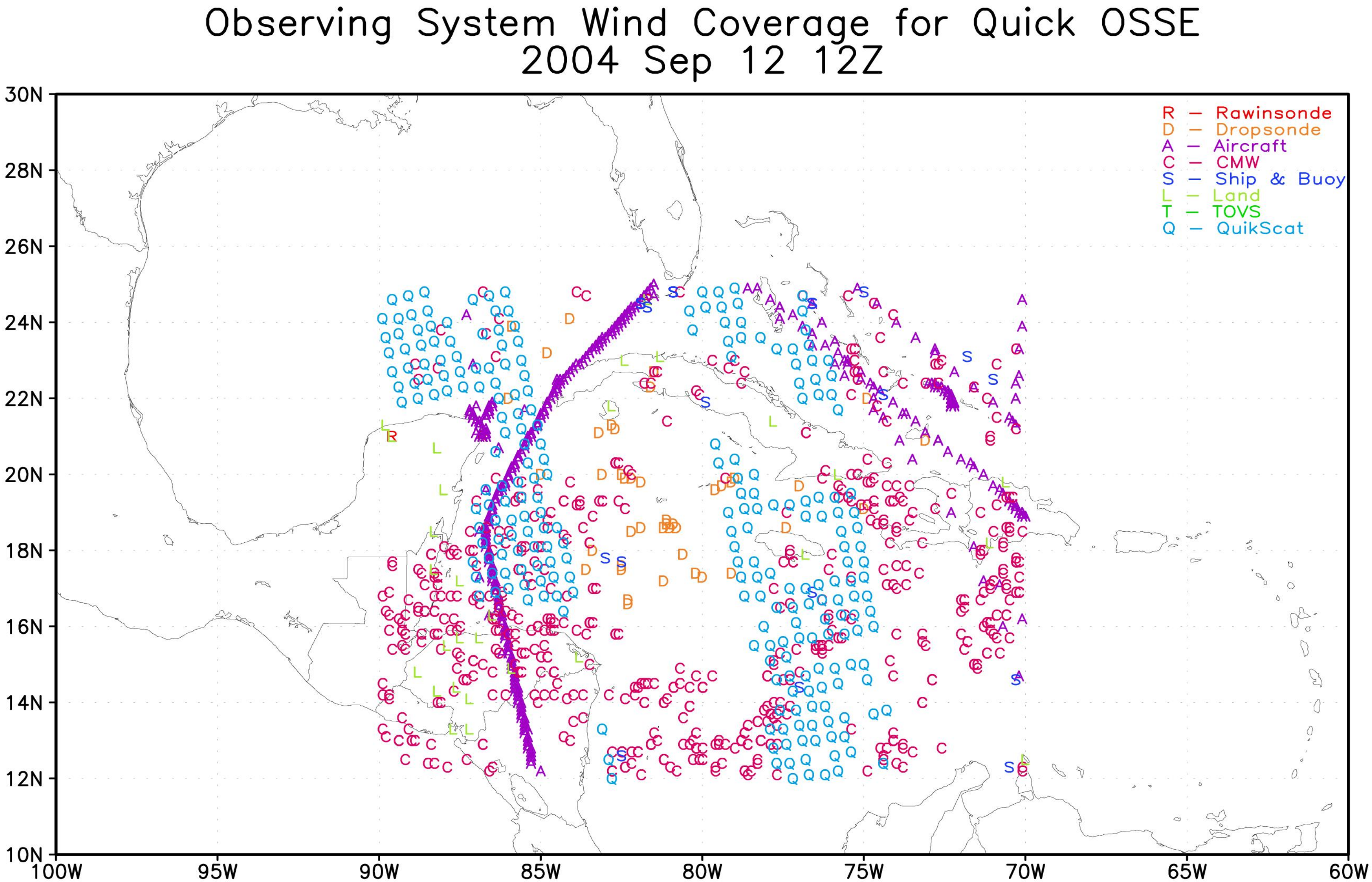
Lidar - Idealized wind profiles added in the vicinity of the hurricane

5 Day Forecasts : Started on Sep.11, 12z, Sep.12, 00z and 12z
ran at both 1 x 1.25 deg and .25 x .36 deg horizontal resolution



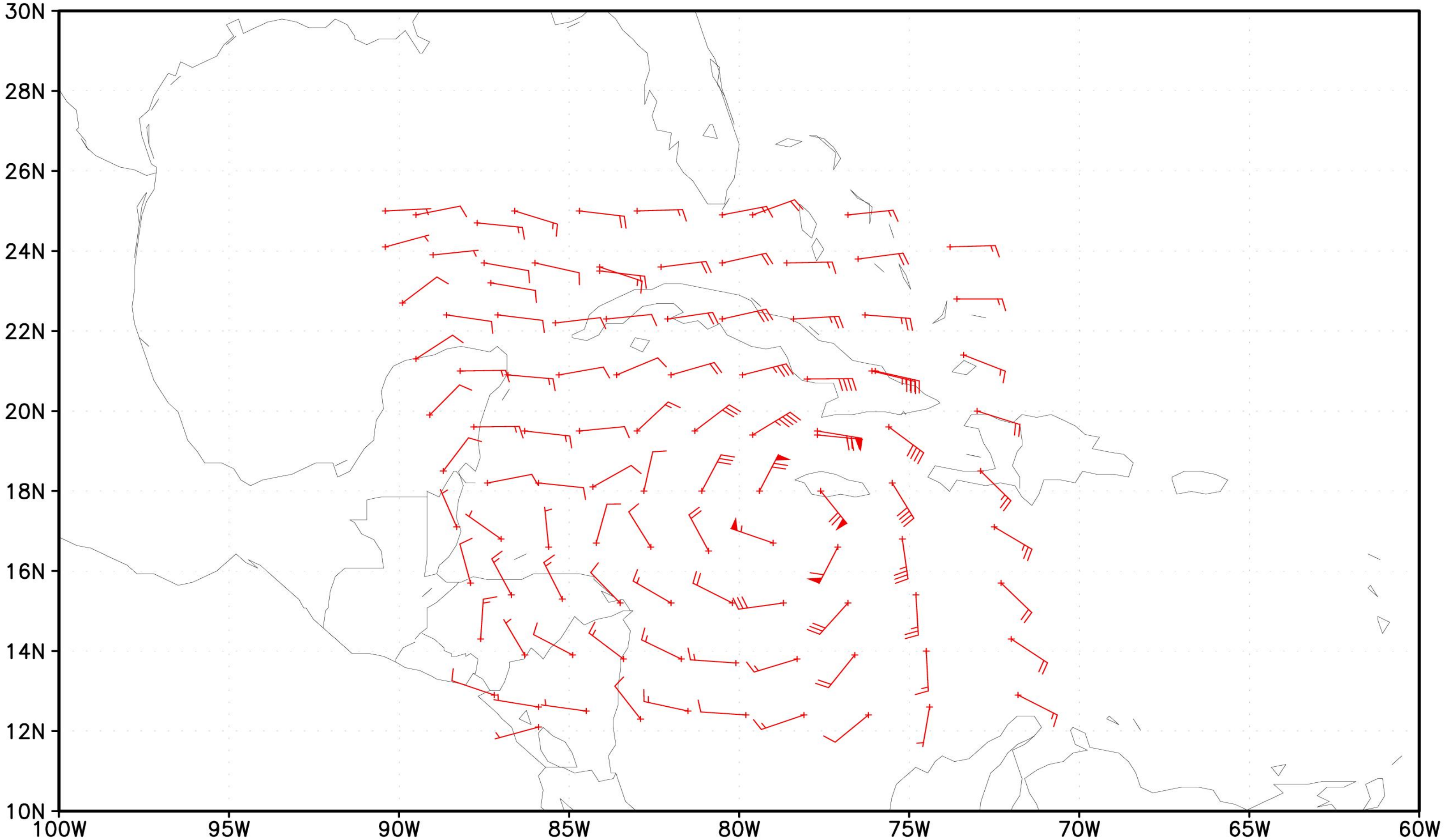
Observing System Wind Coverage for Quick OSSE
2004 Sep 11 12Z
R – Rawinsonde
D – Dropsonde
A – Aircraft
C – CMW
S – Ship & Buoy
L – Land
T – TOVS
Q – QuikScat
30N
28N
26N
24N
22N
20N
18N
16N
14N
12N
10N
100W
95W
90W
85W
80W
75W
70W
65W
60W


Observing System Wind Coverage for Quick OSSE
2004 Sep 12 00Z
R – Rawinsonde
D – Dropsonde
A – Aircraft
C – CMW
S – Ship & Buoy
L – Land
T – TOVS
Q – QuikScat
30N
28N
26N
24N
22N
20N
18N
16N
14N
12N
10N
100W
95W
90W
85W
80W
75W
70W
65W
60W

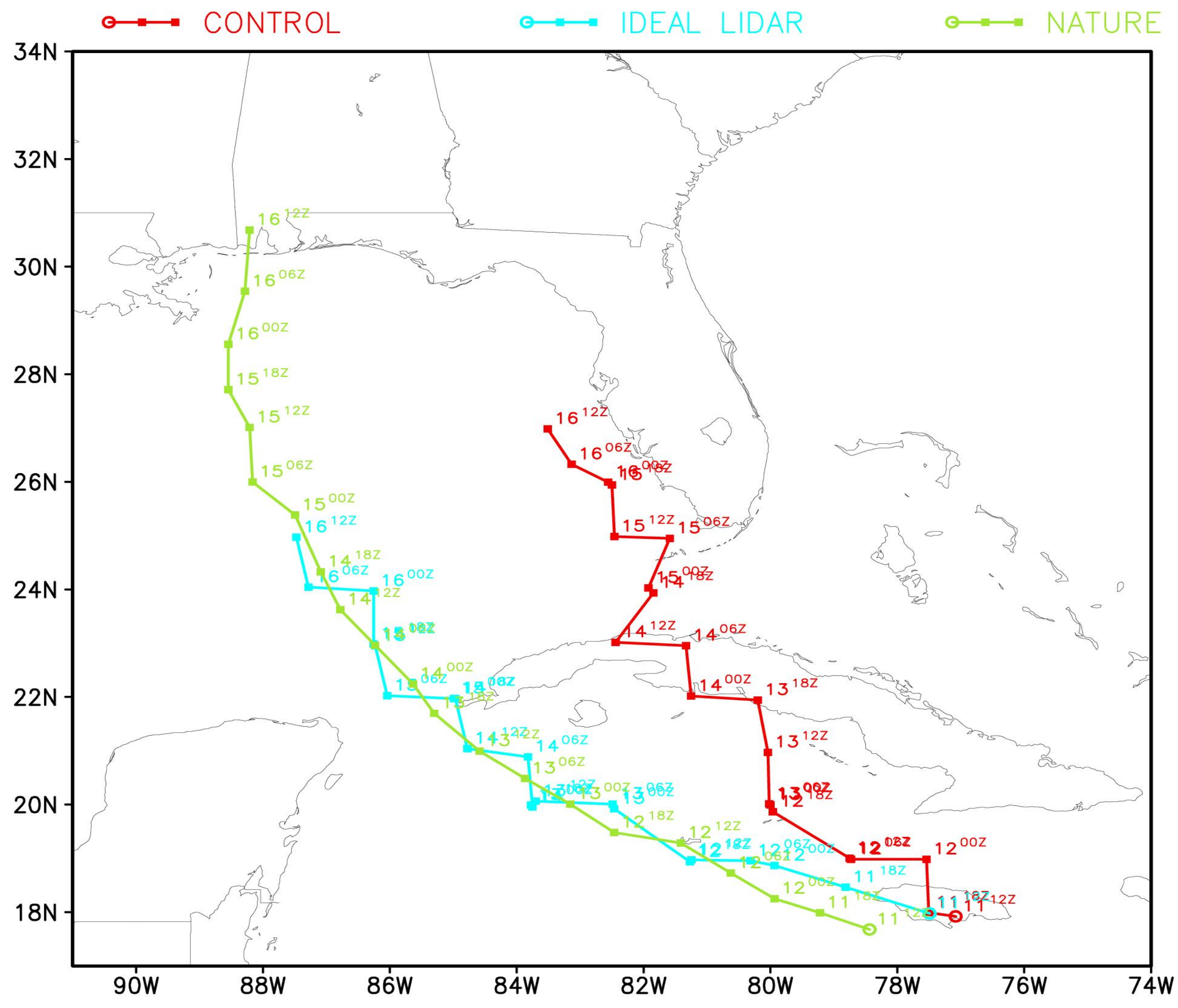


Observing System Wind Coverage for Quick OSSE
2004 Sep 12 12Z
30N
28N
26N
24N
22N
20N
18N
16N
14N
12N
10N
100W
95W
90W
85W
80W
75W
70W
65W
60W
R – Rawinsonde
D – Dropsonde
A – Aircraft
C – CMW
S – Ship & Buoy
L – Land
T – TOVS
Q – QuikScat

# Simulated 850 hPa Idealized Lidar Winds with Errors
## 2004 Sep 11 12Z



Prediction of Ivan (1° FvGCM Forecasts)




Sep 11, 2004 12Z — Sep 16, 2004 12Z every 6 hrs

# Current and planned OSSEs for hurricanes

- OSSEs to determine potential impact of UAS and to optimize sampling strategies. (ESRL, AOML,RSMAS, JCSDA)
- Sensor Web OSSEs (NASA GSFC, SWA, AOML, RSMAS)
- OSSEs in support of HFIP to evaluate sampling strategies for hurricane reconnaissance, new observing systems, modeling and data assimilation and predictability. (NOAA, Academia)

Current work aimed at developing rigorous regional OSSE system for USWRP OSSE Testbed. (AOML, ESRL, SWA, RSMAS)

# An Observing System Simulation Experiment for the use of Unmanned Aircraft Systems in improving tropical cyclone forecasts

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A41B-0071

## What is an OSSE?

An Observing System Simulation Experiment (OSSE) is a modeling experiment used to evaluate the potential improvement to numerical weather forecasts when a new type of observation is introduced (Atlas, 1997). OSSEs have many uses including:

- providing guidance for instrument development
- determining the best way to implement new observations in operational numerical weather prediction
- estimating cost-benefit analysis of potential future observing systems
- evaluating data assimilation systems

This project is part of a Joint OSSE collaboration involving more than a dozen agencies around the world. This OSSE is supported by the NOAA UAS program in order to provide guidance for the use of UAS for improving weather forecasts.

## OSSE Setup: Nature Run

The Nature Run is used in the OSSE as a representation of the real world; usually, the Nature Run consists of a long, free forecast from an operational forecasting model. All observations used in the OSSE are derived from the Nature Run fields, and the Nature Run is used for forecast verification. The Nature Run must have sufficiently realistic representation of the atmospheric phenomena which are the subject of the OSSE investigations.

The Nature Run used here is a 13-month integration of the ECMWF operational model version c31r1 at T511/91L from 1 May 2005 to 21 May 2006 (Andersson and Masutani, 2010). Evaluation of the Nature Run has shown it to have reasonable representation of tropical cyclones (Reale, et al. 2007), although the model does not resolve detailed structure of the storms.

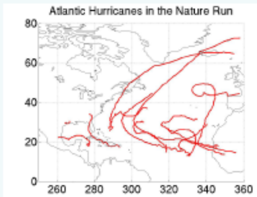



Figure 1. Tracks of Atlantic basin hurricanes in the Nature Run.

## OSSE Setup: Forecast Model

The forecast model used in an OSSE should be different from the model used to generate the Nature Run to prevent fraternal or identical twin problems. In this OSSE, the National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) model is used, along with the Gridpoint Statistical Interpolation (GSI) data assimilation package. Experiments are performed with the GSI/GFS at T382/64L resolution.

## OSSE Setup: Synthetic Observations

The observations assimilated into the GSI/GFS are generated by interpolating the Nature Run fields at the same locations and times as archived observations during the Nature Run period.

Conventional observation types were generated by NCEP, along with GOES radiance and OSBUV ozone data. AIRS, AMSU-A, AMSU-B, HIRS2, HIRS3, and MSU radiance observations were generated by the NASA Global Modeling and Assimilation Office (GMAO). Brightness temperatures were calculated along vertical profiles using the Community Radiative Transfer Model (CRTM) version 1.2 (Errico et al., 2010).

Observation errors were added to the synthetic observations, using random errors drawn from a normal distribution with mean of zero and standard deviation which varies with observation type. Vertically correlated errors were added to conventional sounding data, and horizontally correlated errors were added to most satellite observations. These errors are intended to encompass representativeness errors and instrumentation errors to increase realism of the OSSE.

## Unmanned Aircraft Systems

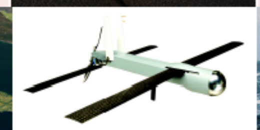
Unmanned Aircraft Systems (UAS) are exciting new platforms for atmospheric observations. Each UAS consists of an aircraft, a communications system, and an operator who controls the aircraft remotely. There is a wide range of aircraft capabilities, including small expendable platforms and large platforms which can carry heavy payloads for more than 24 hours on a single flight. These aircraft offer the possibility of observing remote and dangerous data-poor regions.

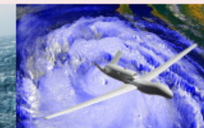
The National Oceanic and Atmospheric Administration (NOAA) UAS Program is investigating the use of these platforms to improve observations over the Arctic and oceans. The technology involved with UAS is rapidly developing, and the best way to use UAS for atmospheric and oceanic observations is not yet known.

## Observing Hurricanes with UAS

UAS have great potential for improving observations in tropical cyclones. Small expendable UAS can be launched into a hurricane where they would sample conditions near the air-sea boundary without risking lives. Large, high-altitude UAS can observe cyclogenesis in the remote ocean, and can loiter in the vicinity of the storm and return continuous observations for long periods.

Several UAS field missions have recently been performed to observe tropical cyclones. The low-altitude, long-endurance Aerosonde platform was flown into Tropical Storm Ophelia in 2005 and into Hurricane Noel in 2007, in a joint mission between NOAA and the National Aeronautics and Space Administration (NASA). In September 2010, a NASA Global Hawk high-altitude, long-endurance UAS was flown over Hurricane Earl as part of the Genesis and Rapid Intensification Processes (GRIP) experiment.





## OSSE Setup: Calibration

The OSSE should be calibrated to verify that the behavior of the OSSE system is similar to that seen in the real world. The UAS OSSE was calibrated through a series of data denial experiments conducted both with archived real data and with the synthetic observations. The conventional data were calibrated by adjusting the observation error added to the perfect observations so that the analysis impact of each observation type matched the real data impact as closely as possible. Figure 2 shows the successful calibration of wind analysis impact for RAOB observations. The synthetic radiance observations could not be adjusted in this fashion.

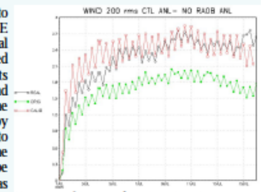



Figure 2. Calibration of synthetic RAOB observations for horizontal wind at 200 mb. Analysis impact (m/s) from real data shown in black, uncalibrated OSSE analysis impact in green, and calibrated OSSE analysis impact in red.

Extended data denial tests were performed following calibration of all conventional data types. Seven-week integrations were generated for data denial of AIRS, RAOB, Aircraft, AMSU-A, and GOES radiance. The agreement between the OSSE system data impact and real data impact is satisfactory in general, as shown in Figure 3, although there are some regional discrepancies and issues near the surface. Future advances in methods for generating synthetic observations may improve the performance of the OSSE system.

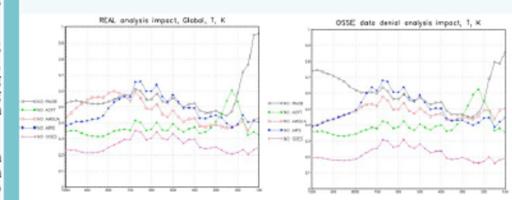



Figure 3. Data denial experiment comparisons for real data (left) and calibrated OSSE data (right). Global mean analysis impact for temperature, K.

## OSSE Experiments: UAS Flight Paths and Sampling

The impact of dropsondes released from a high-altitude UAS on hurricane track forecasts is investigated in a series of case studies. Control forecasts which include the 'standard' observational data set are performed for the first Atlantic tropical cyclone, AL01. The 5 August 12Z forecast is selected for further study due to the relatively large forecast track error.

Several UAS flight paths were investivated (Figure 4); greatest improvement in track forecasts is seen for circumnavigational flights with larger radii. Sampling of the storm environment leads to slower poleward translation of the hurricane (Figure 5).

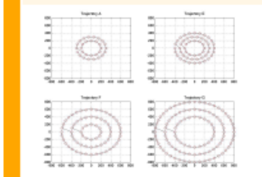


Figure 4. Experimental UAS flight paths, red circles indicate location of dropsonde releases.

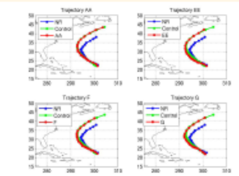


Figure 5. Storm track forecasts for AL01, 5 August 12Z. Blue line indicates the Nature Run best track.

The impact of sampling frequency on track forecast improvement is studied by testing two UAS flight scenarios. A 'thinned' sampling strategy is developed as illustrated in Figure 6. Reducing the dropsonde release frequency has only a minor impact on the hurricane track forecast improvement, as seen in Table 1.

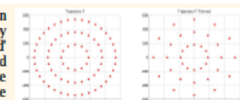


Figure 6. UAS flight paths for sampling strategy experiments.

Table 1. AL01 forecast hurricane track errors improvement compared with control, km. Forecast cycles from 1 Aug to 5 Aug. Left, Trajectory F; right, thinned trajectory.

| Traj. F | Anl | 24 hr | 48 hr | 72 hr | 120 hr |
|---|---|---|---|---|---|
| 1 Aug 12Z | 5 | 112 | 91 | 100 | 190 |
| 2 Aug 12Z | 37 | 34 | 98 | 198 | -188 |
| 3 Aug 12Z | 43 | 150 | 210 | 290 | 123 |
| 4 Aug 12Z | 117 | 122 | 105 | 51 | -222 |
| 5 Aug 12Z | 64 | 75 | 49 | 53 | -157 |

| Traj. F Thin | Anl | 24 hr | 48 hr | 72 hr | 120 hr |
|---|---|---|---|---|---|
| 1 Aug 12Z | -5 | 117 | 105 | 97 | 186 |
| 2 Aug 12Z | 37 | 40 | 83 | 107 | -158 |
| 3 Aug 12Z | 39 | 137 | 198 | 265 | 81 |
| 4 Aug 12Z | 139 | 122 | 103 | 67 | 16 |
| 5 Aug 12Z | 93 | 95 | 51 | 65 | 132 |

## OSSE Experiments: Idealized Observations

OSSEs may also be used for theoretical studies. The addition of UAS observations generally results in improved hurricane track forecasts, but some track error still remains. How much of the track forecast error is due to model error rather than initial condition error? A 'net' of perfect sounding observations (Figure 7) is added to the standard observational data set for several cycles prior to the forecast of interest to investigate this question.

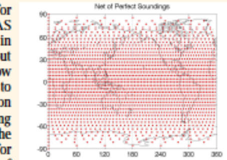



Figure 7. 'Net' of perfect soundings added to observational suite.

Cross-track error during the first 72 hours of the forecast on 5 August 12Z is greatly reduced when the additional soundings are included (Figure 8), indicating that this error in the control forecast is related to the initial conditions. However, the storm moves poleward too rapidly late in the forecast, which may be due to model error. At least 36 hours of cycling with the addition soundings are needed in order to achieve the best improvement in track forecasts, as shown in Table 2. This type of experiment helps to quantify the best forecast improvement possible through the addition of new observations, and illustrates some of the advantages of using an OSSE framework.

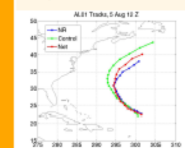



Figure 8. AL01 forecast track for 5 Aug 12Z with net of perfect soundings cycling from 1 Aug 00Z.

Table 2. AL01 forecast hurricane track errors, km, initial time 5 Aug 12Z. Ingestion of 'net' of perfect sounding observations starting at various cycles.

| Init. Cycle | Anl | 24 hr | 48 hr | 72 hr | 96 hr | 120 hr |
|---|---|---|---|---|---|---|
| 1 Aug 00Z | 24 | 24 | 35 | 35 | 162 | 530 |
| 4 Aug 00Z | 24 | 15 | 39 | 19 | 119 | 375 |
| 4 Aug 12Z | 35 | 57 | 73 | 62 | 166 | 420 |
| 5 Aug 00Z | 46 | 84 | 104 | 53 | 193 | 440 |

## OSSE Experiments: Future Work

Preliminary experiments have indicated that UAS observations may have a positive impact on hurricane track forecasts. Future investigations anticipated for this OSSE setup include:

- Analysis of the impact of UAS observations on additional tropical cyclones from the Nature Run
- Evaluation of additional flight path and sampling scenarios
- Examination of the use of different UAS platforms and instruments, such as low-altitude UAS and remote sensing payloads
- Exploration of the potential impact of UAS observations on other atmospheric phenomena, such as atmospheric rivers
- Comparison and evaluation of data assimilation systems

OSSEs can be powerful tools that both support the development of new observing systems and extend our understanding of how observations are ingested into data assimilation systems.

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Atlas, R. "Atmospheric observations and experiments to assess their usefulness in data assimilation." *J. Met. Soc. Japan.*, 75, 111-130, 1997.

Errico, R., R. Yang, M. Sienkiewicz, R. Todling, and H-C. Liu. "Validation of version one of the Observing System Simulation Experiments at the Global Modeling and Assimilation Office." *Quart. Jour. Royal Met. Soc.*, submitted.

Reale, O., J. Terry, M. Masutani, E. Andersson, L.P. Riishojgaard, and J.C. Jusem. "Preliminary Evaluation of the European Centre for Medium-range Weather Forecasts nature run over the tropical Atlantic and African monsoon region." *Geo. Res. Let.*, 34, doi:10.1029/2007GL031640.

# Hurricane Observation Capability of Future Hurricane Imaging Radiometer (HIRAD)


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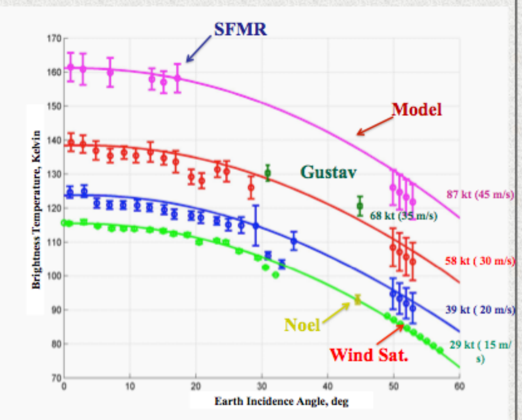
University of Central Florida

Christopher S. Ruf
Space Physics Research Laboratory,
AOSS Dept., University of Michigan


## HIRAD Radiometric Model

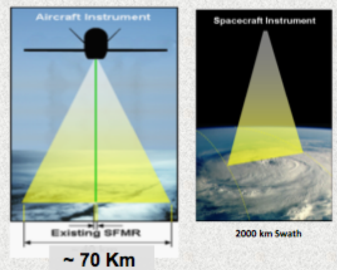



HIRAD extends SFMR capability to wide swath

## Hurricane Imaging Radiometer (HIRAD)

HIRAD utilizes NASA Instrument Incubator Technology:

- Provides unique observations of sea surface wind, temp and rain
- Advances understanding / predictability of hurricane intensity
- Expands Stepped Frequency Microwave Radiometer capabilities
- Uses synthetic thinned array and RFI mitigation technology of Lightweight Rain Radiometer

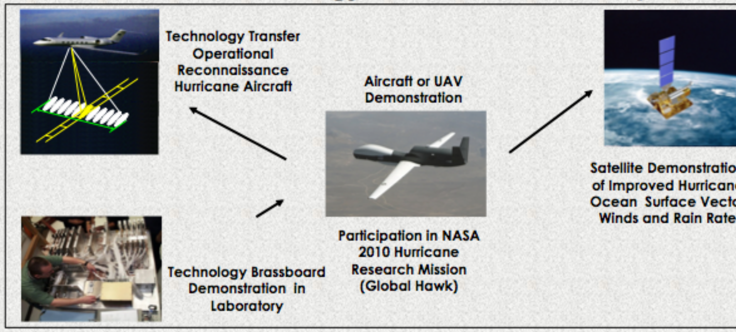



Passive Microwave C-Band Radiometer withFreq: 4, 5, 6 & 6.7 GHz:
•*Version 1:* H-pol for ocean wind speed,
•*Version 2:* dual-pol for ocean wind vectors
•20 km Aircraft Altitude

Performance Characteristics:
•Earth Incidence angle: 0°- 60°,
•Spatial Resolution: 2-5 km,
•Swath: ~70 km

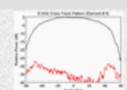
Observational Goals:
WS 10 - >85 m/s RR 0 - > 100 mm/hr


## HIRAD Technology Investment Roadmap

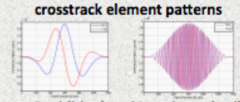



## HIRAD Instrument Development

Brassboard Successfully Demonstrated in Chamber

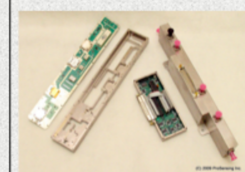


Co-pol (black) and X-pol (red) crosstrack element patterns



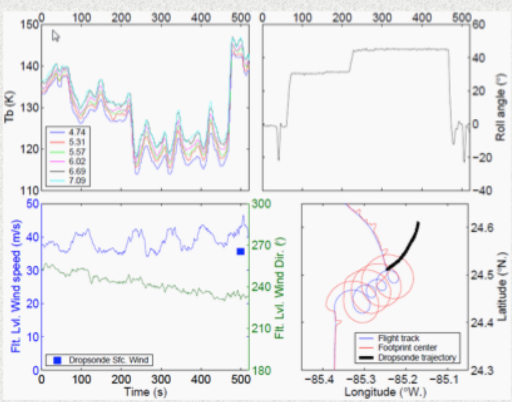
Real (blue) and Imaginary (red) interference patterns for minimum (left) and maximum (right) baselines

HIRAD Flight Receiver

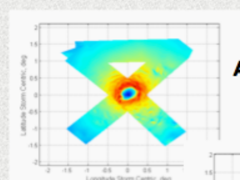


## SFMR at non-zero nadir angle

SFMR turns (Gustav, 2008)

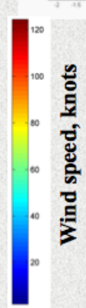


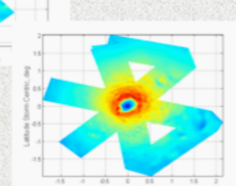

## Simulated HIRAD Surveillance Flights



Alpha

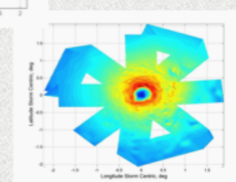
Peak winds are captured in a single Alpha or Butterfly pattern (from 20 km altitude).



Butterfly

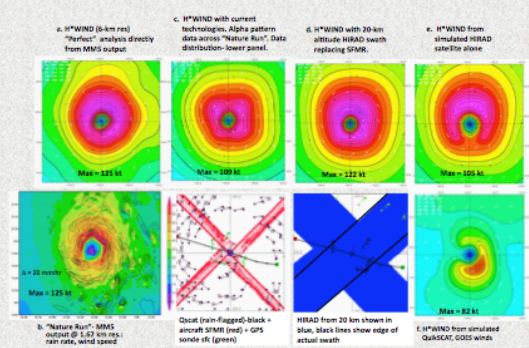
Rotated Alpha



## Observing System Simulation Experiments (OSSE's)

"Quick OSSE" Technique:

1. Create nature run with numerical model (MM5 @ 1.67 km inner-most grid resolution - U. Miami).
2. Create simulated observations from the model fields, modeling full instrument characteristics including errors and limitations.
3. Use selected "observations" in the hurricane H*WIND analysis scheme to demonstrate value of the various measurement platforms and instruments.



# Hurricane Observation Capability of Future Hurricane Imaging Radiometer (HIRAD)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From Science to Solutions

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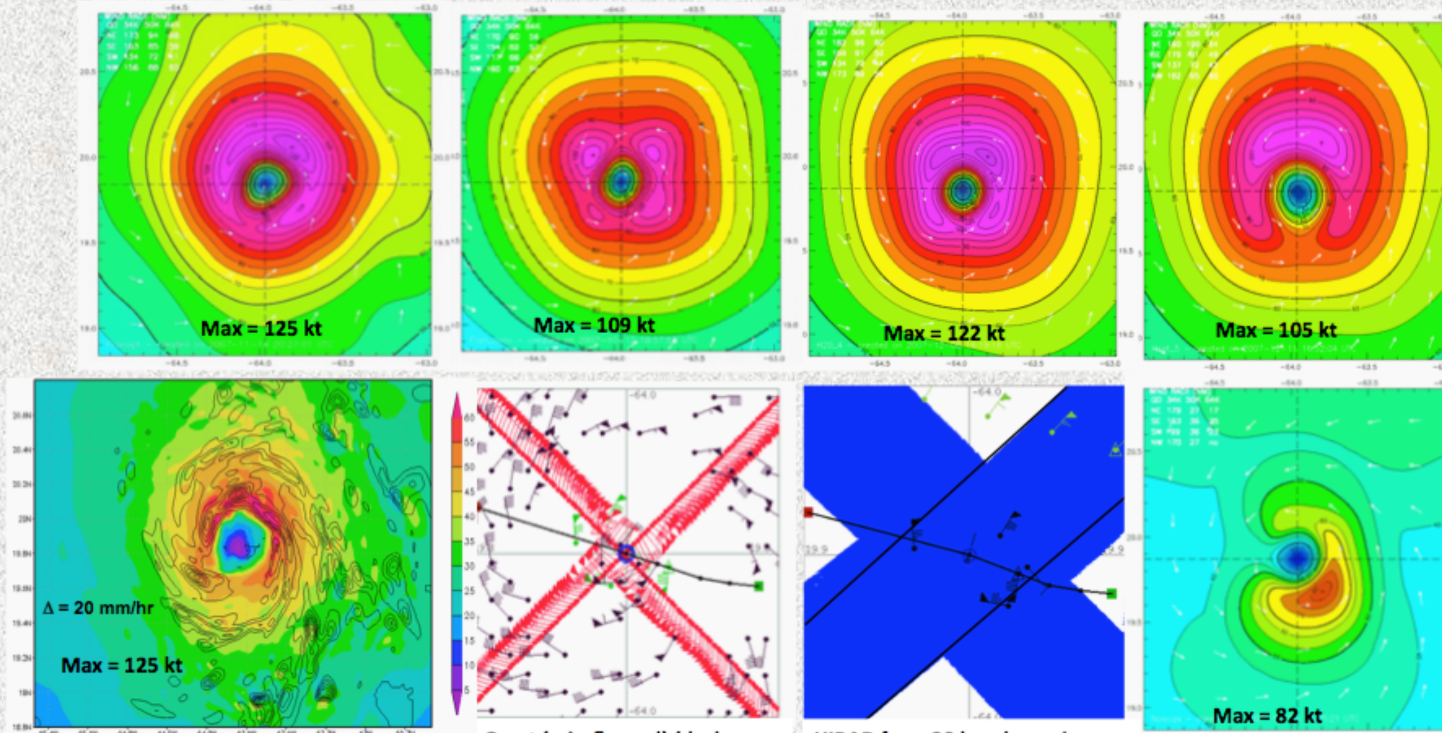
a. H*WIND (6-km res) "Perfect" analysis directly from MM5 output

c. H*WIND with current technologies. Alpha pattern data across "Nature Run". Data distribution- lower panel.

d. H*WIND with 20-km altitude HIRAD swath replacing SFMR.

e. H*WIND from simulated HIRAD satellite alone




b. "Nature Run"- MM5 output @ 1.67 km res.: rain rate, wind speed

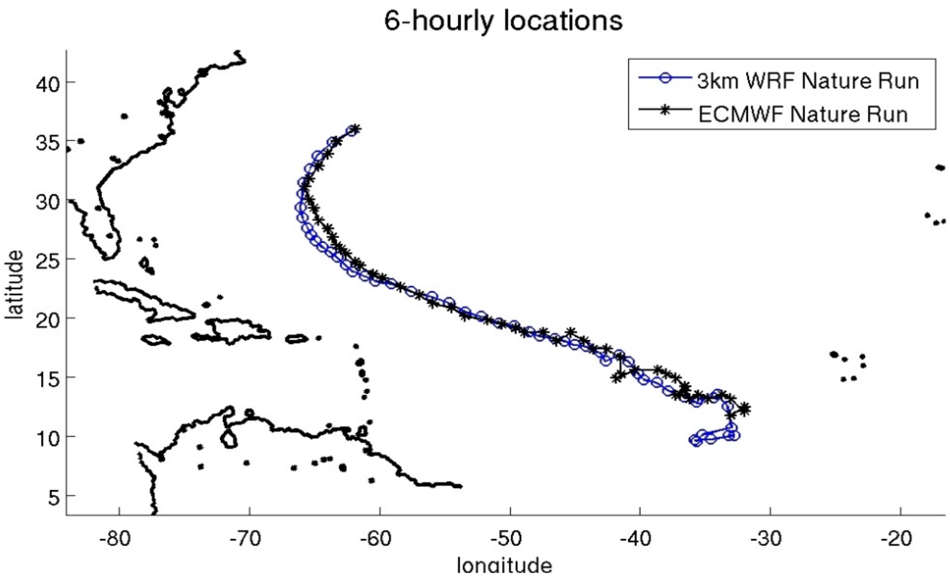
Qscat (rain-flagged)-black + aircraft SFMR (red) + GPS sonde sfc (green)

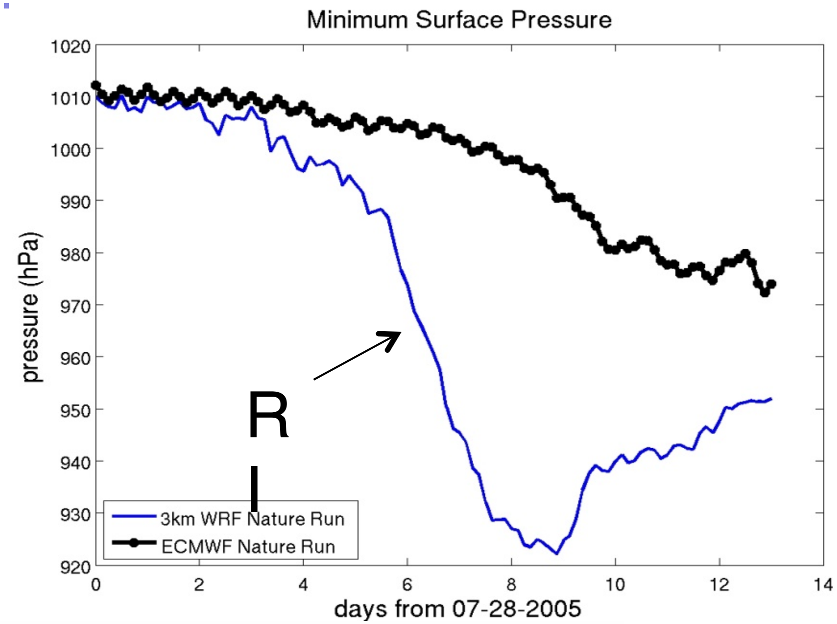
HIRAD from 20 km shown in blue, black lines show edge of actual swath

f. H*WIND from simulated QuikSCAT, GOES winds

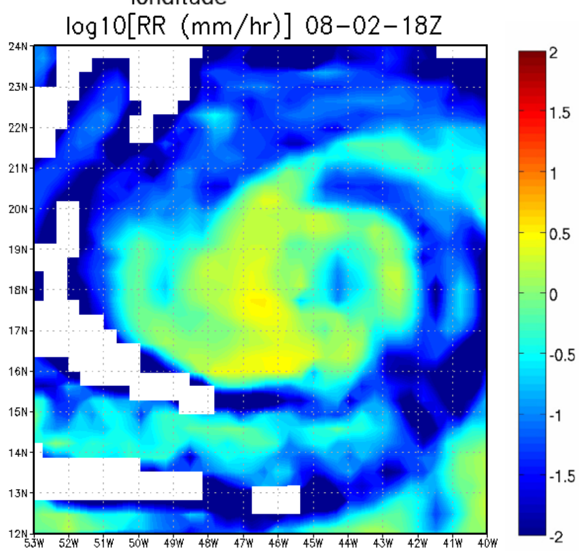
# High Resolution Hurricane Nature Run: WRF Simulation Embedded Inside the ECMWF Nature Run

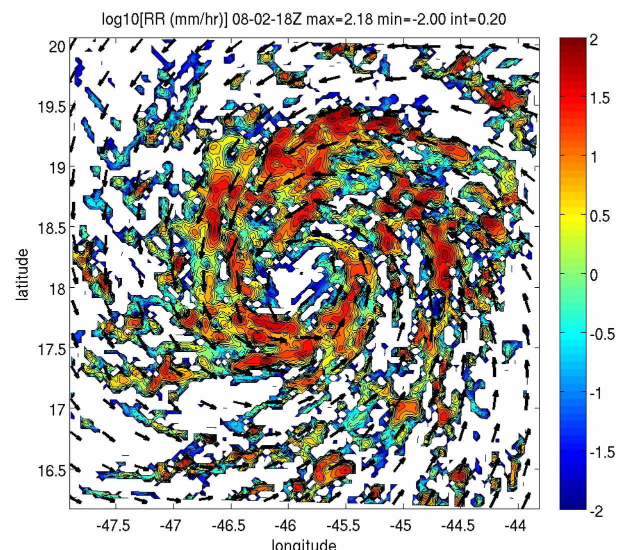
60 levels; 3km resolution; double-moment microphysics; advanced radiation schemes.




ECMWF T511 Nature Run

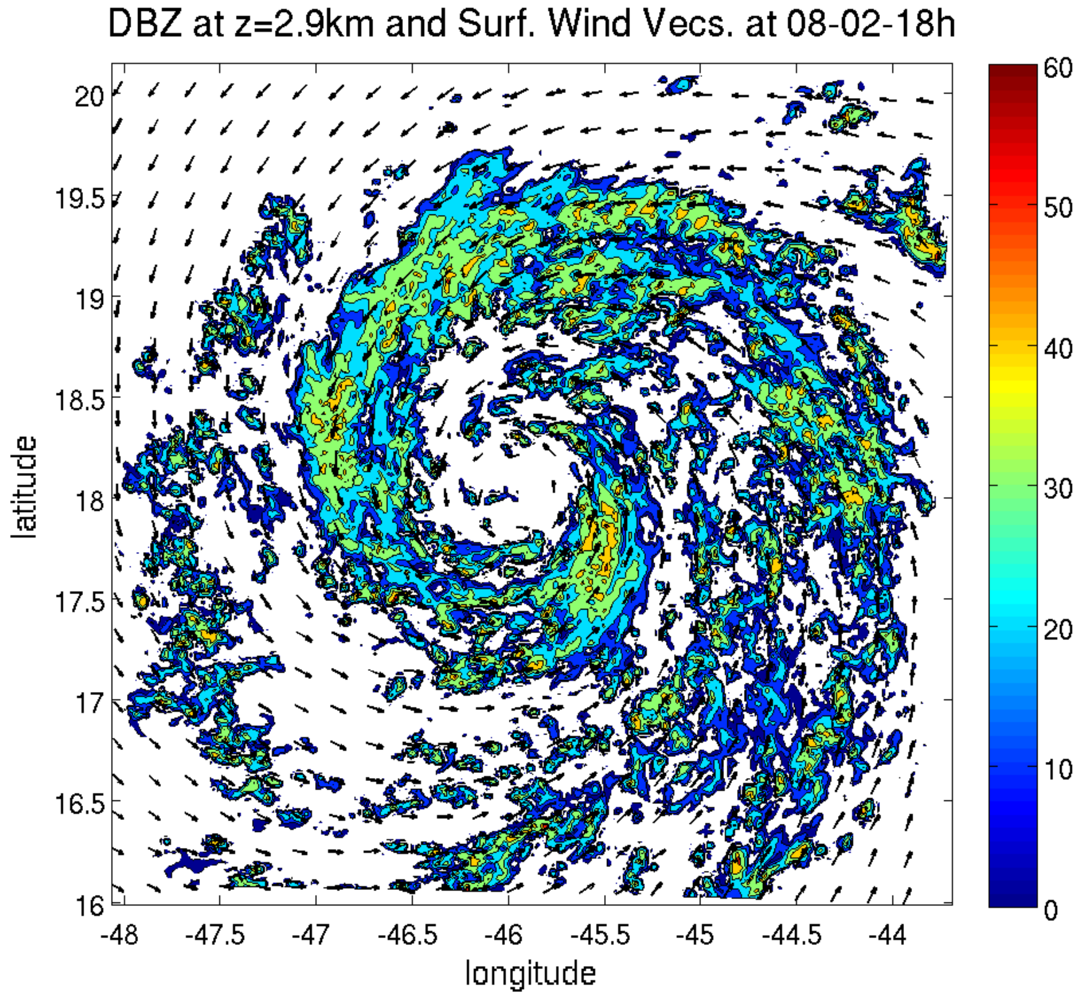



3 km WRF-ARW Nature Run

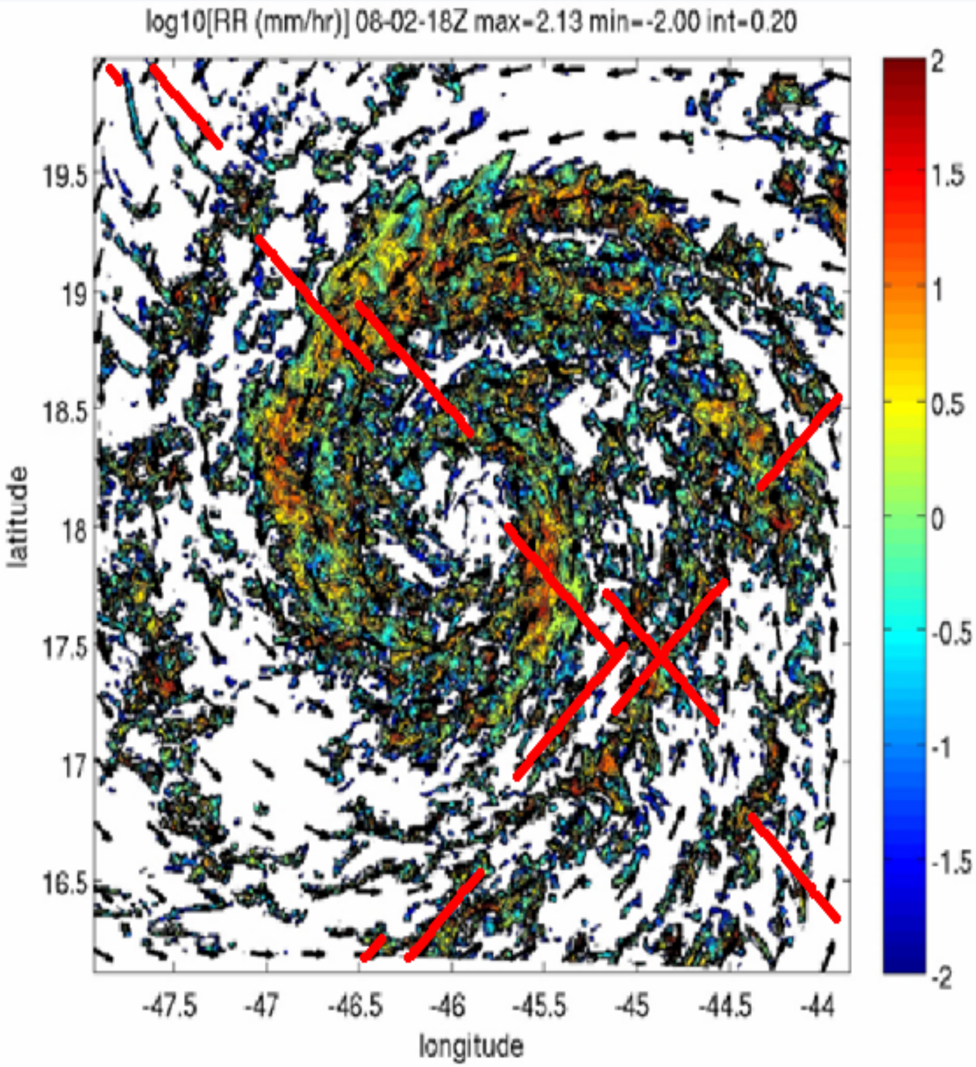
# Further improvements expected from 1 km resolution:

3km simulation nested to 1km for 18 hours

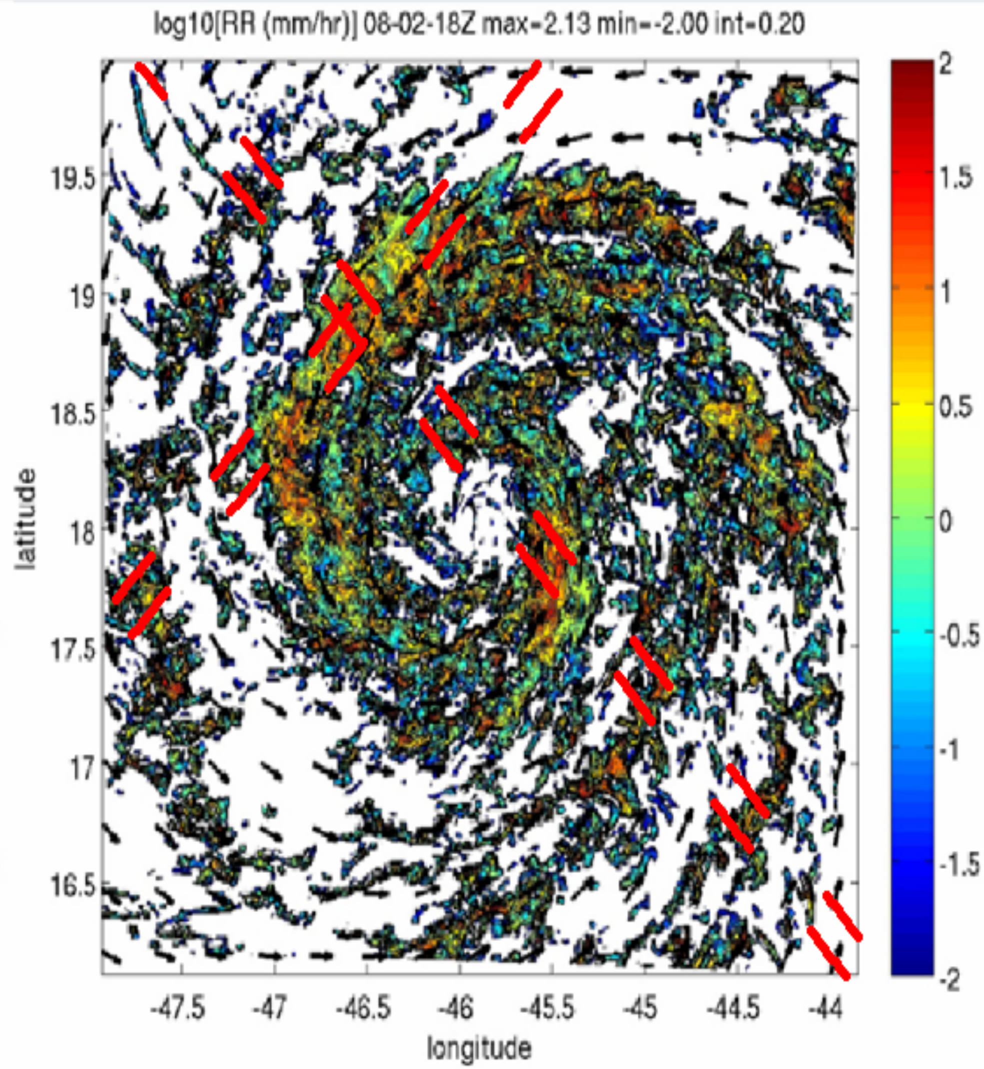



- More realistic distribution of precipitation
- 20 grid points between each arrow shown above

# Coverage of Coherent DWL on ISS over WRF-AFW Nature Run Hurricane *




Coherent DWL at 12 sec Dwells




Coherent DWL at 4 sec Dwells

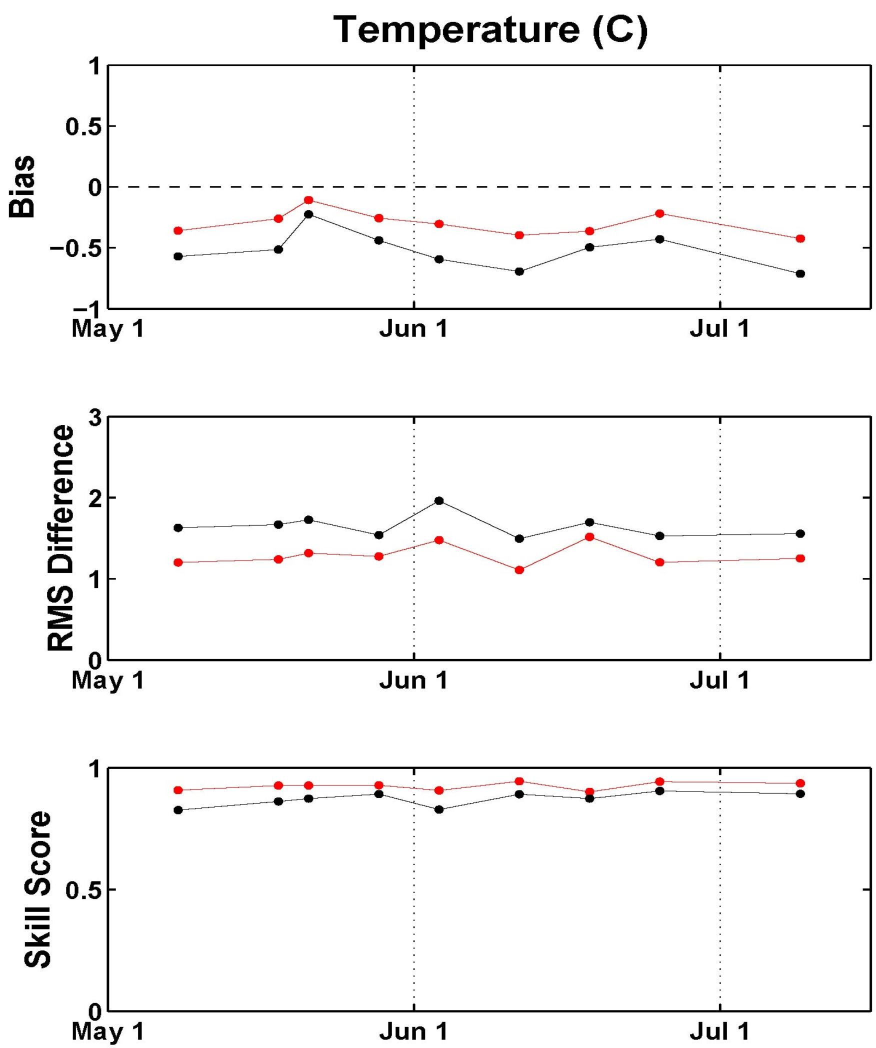
* - R. Atlas (AOML) and L. Bucci (SAIC), 2011

Simpson Weather Associates, Inc., 2011

# Initial Ocean OSE/OSSE Activities at AOML

# Observing System Experiments

- **Evaluate impact of WP-3D profiles on ocean analyses during the DWH oil spill**




Twin data-assimilative HYCOM experiments, one denying the P-3 observations, demonstrate reduction in both bias and RMS error in temperature over the upper 360 m (left) between the ocean analyses and observations

Future work will study impact of data assimilation procedure, update cycle, etc. on these results.

RED: With P-3 assimilation
BLACK: No P-3 assimilation

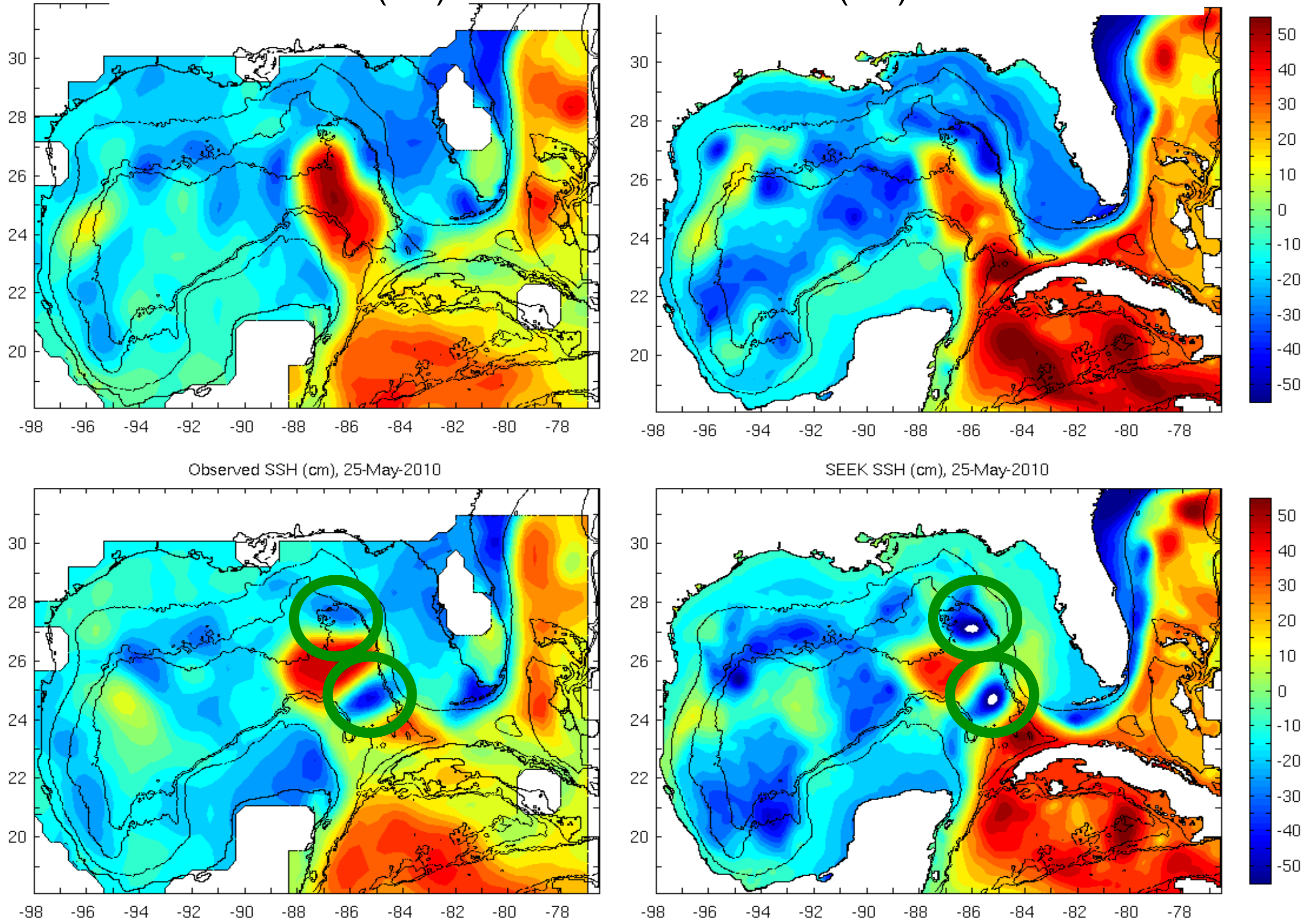
# Observing System Simulation Experiments (1)

- **Status of OSSE System Development:**
  - **Implement multiple data assimilation schemes in HYCOM**
    - **SEEK filter already implemented**
    - **Three other schemes being evaluated**
      - **Ensemble Kalman filter**
      - **MVOI**
      - **ROIF filter**
  - **Develop and test OSSE software toolbox**
    - **Generation of synthetic observations from nature run**
      - **Altimetry, ship and satellite SST, ship profiles, ARGO floats already implemented**
      - **Realistic errors are added to the synthetic observations**
    - **Post-processing software to quantify evolution of analysis and forecast errors with respect to the "true" ocean (nature run)**

# Observing System Simulation Experiments (2)

- **OSSEs in the Gulf of Mexico**
  - **Improve ocean model analyses for regional climate studies**
  - **Improve initialization for ocean forecasting (e.g. oil spill, hurricanes)**
  - **New very-high-resolution (~1.8 km) GoM HYCOM available for nature run**
    - **Tests of SEEK filter data assimilation in this model are shown below**

Observed SSH (cm) SEEK SSH (cm) – DA: SSH+SST




May 1

Location of Loop Current and surrounding eddies corrected by SSH and SST assimilation.

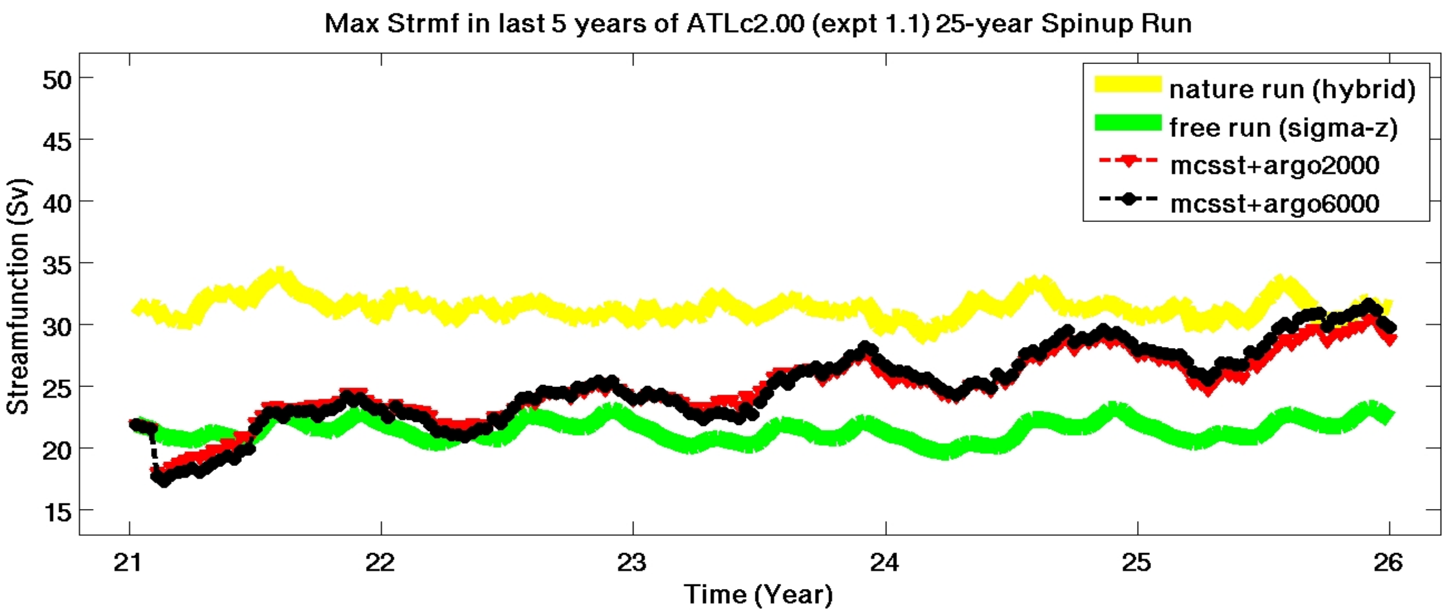
May 25

# Observing System Simulation Experiments (3)

- **OSSEs to design global ocean climate observing strategies**
  - **Initial tests of HYCOM-based OSSE software toolbox performed in low-resolution (2°) Atlantic domain (not intended to be a rigorous OSSE)**

Objectives: 1. Test and evaluate HYCOM DA system and OSSE software toolbox
2. Demonstrate feasibility of HYCOM fraternal twin approach

Approach: 1. Run two multi-decadal runs using two HYCOM configurations
2. Demonstrate that these runs differ significantly in representation of the AMOC
3. Sample synthetic obs. from one runs (nature run model ) and assimilate into the model with the alternate configuration (operational model)
4. Test below illustrates impact of assimilating ARGO float profiles on AMOC transport with a gradual correction of transport magnitude in the operational model




Four Model Runs

Nature Run Model

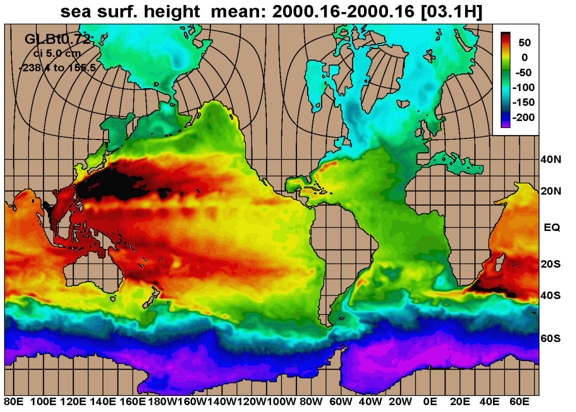
Operational model, no DA

Assimilate synthetic ARGO profiles to 2000 m

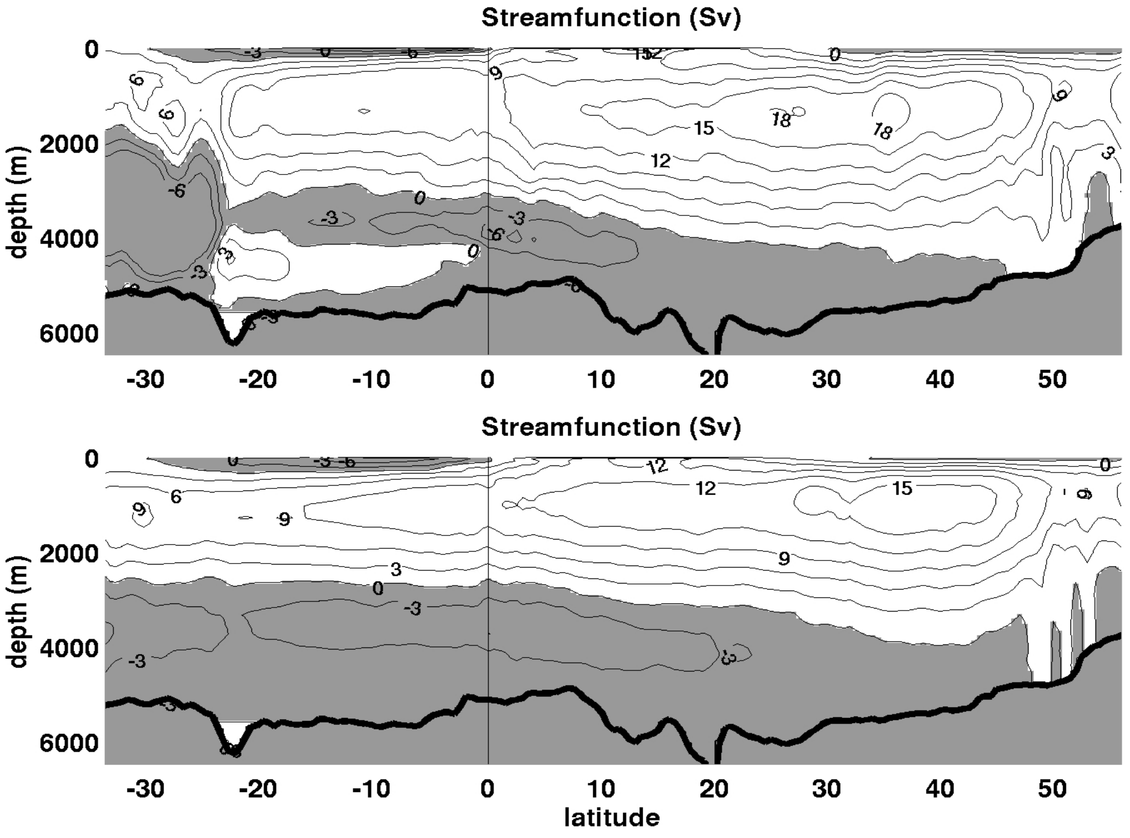
Assimilate synthetic ARGO profiles to 6000 m

# Observing System Simulation Experiments (4)

- **Initial rigorous ocean climate OSSE**
  - **Fraternal twin experiments to be performed using 0.72° global HYCOM (right) as nature run, lower-resolution Atlantic HYCOM (with different configuration as the operational model**
  - **Global model run 1948-2010 using two configurations**
  - **AMOC transport streamfunction for 2000 shown below for two configurations – structures and magnitudes are realistic but differ substantially**
  - **Next step: perform OSSE to evaluate impact of extending ARGO profiles into the deep ocean**




Sea Surface Height




Stream function of the Atlantic Meridional Overturning Circulation as reproduced by the two versions of the model. The MOC transport at 26.5°N in the upper panel is 18 Sv in agreement with the observations.

# Near-Term Plans

- We are ready to perform a large suite of ocean OSSE studies
  - GoM OSSEs
    - Evaluate the impact of current and new observing systems
      - Gliders
      - Coastal high-frequency radar
      - Targeted airborne observations to improve ocean forecasts
  - Global Ocean Climate OSSEs
    - Perform observing system design studies for monitoring changes in the Atlantic and Global Overturning Circulation
    - Expand these studies to other critical ocean climate problems (e.g. tropical Atlantic variability)
- Develop the capability at AOML to perform OSSEs for a broad range of oceanographic problems on relatively short notice
  - Develop a library of regional and global validated nature runs
  - Develop capability to set up relocatable regional domains on short notice

# Conclusions

1. Observing System Simulation Experiments (OSSEs) provide an effective means to:
   - Evaluate the potential impact of proposed observing systems
   - Determine tradeoffs in their design
   - Evaluate new data assimilation methodology

2. Great care must be taken to ensure the realism of the OSSE's and in the interpretation of OSSE results.

3. Previous OSSE's conducted with 4 different data assimilation systems (from 1985-1999) all showed significant potential for space-based lidar wind profiles to improve atmospheric analyses and weather predictions.

4. OSSEs are currently being conducted to assess the potential impact of of many new observing systems in current data assimilation systems.

5. Rigorous OSSE methodology is being extended to severe storm, ocean and climate applications.