

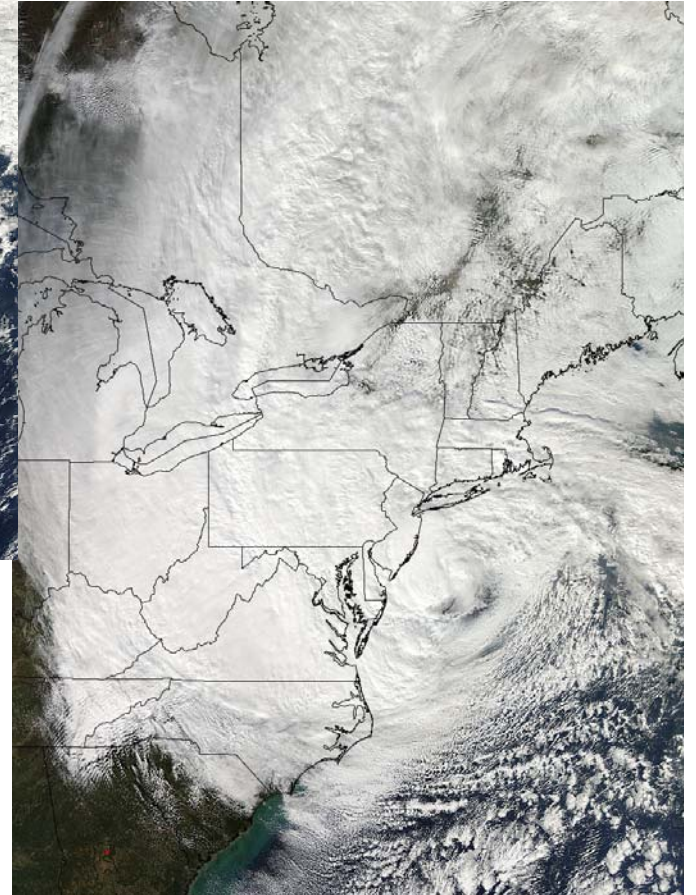
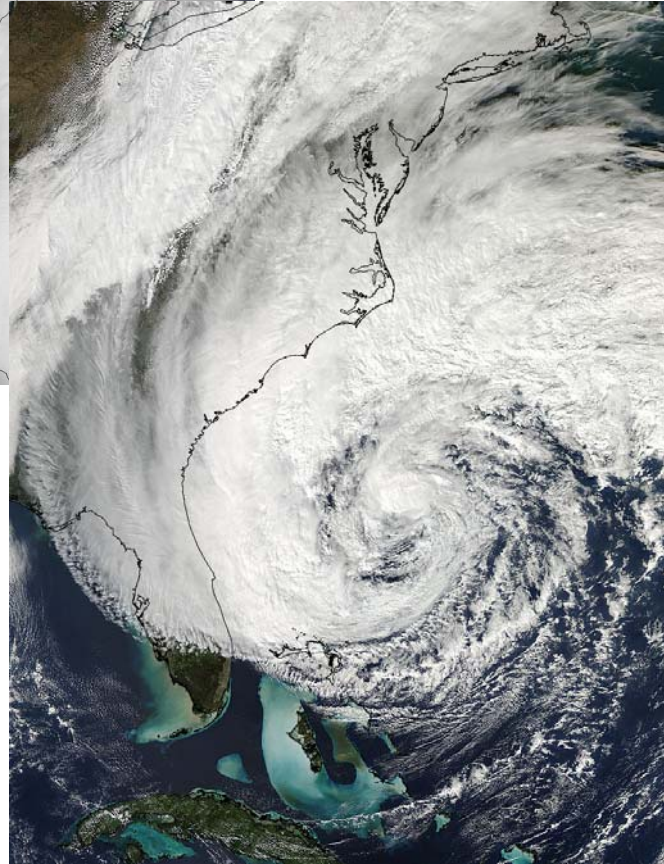
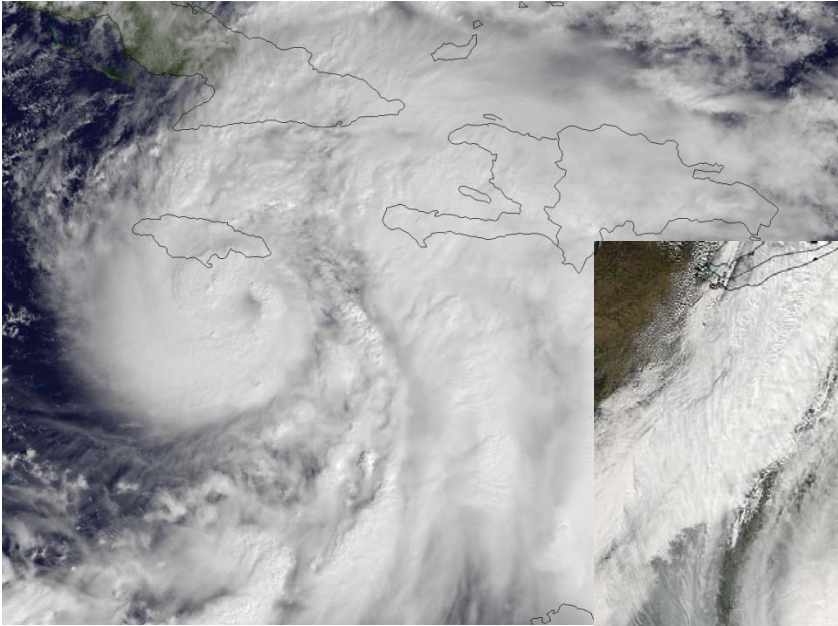


# Superstorm Sandy

**Joe Sienkiewicz**  
**NOAA**  
**Ocean Prediction Center**

**Thanks to:**  
**Dr. Louis Uccellini,**  
**NCEP Director**  
**Dr. David Novak,**  
**HPC**  
**Dr. Richard Knabb,**  
**NHC Director**

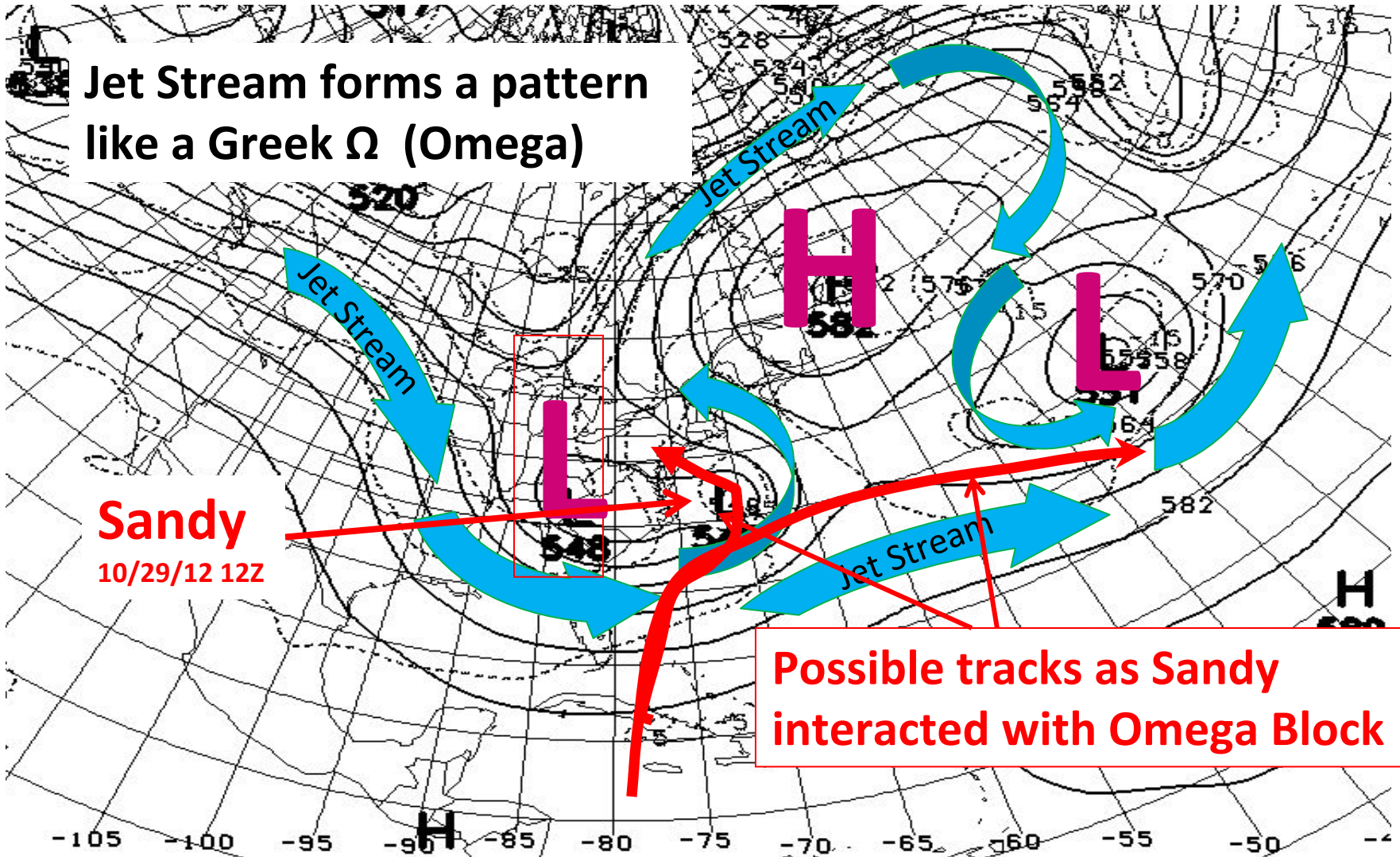
# Evolution

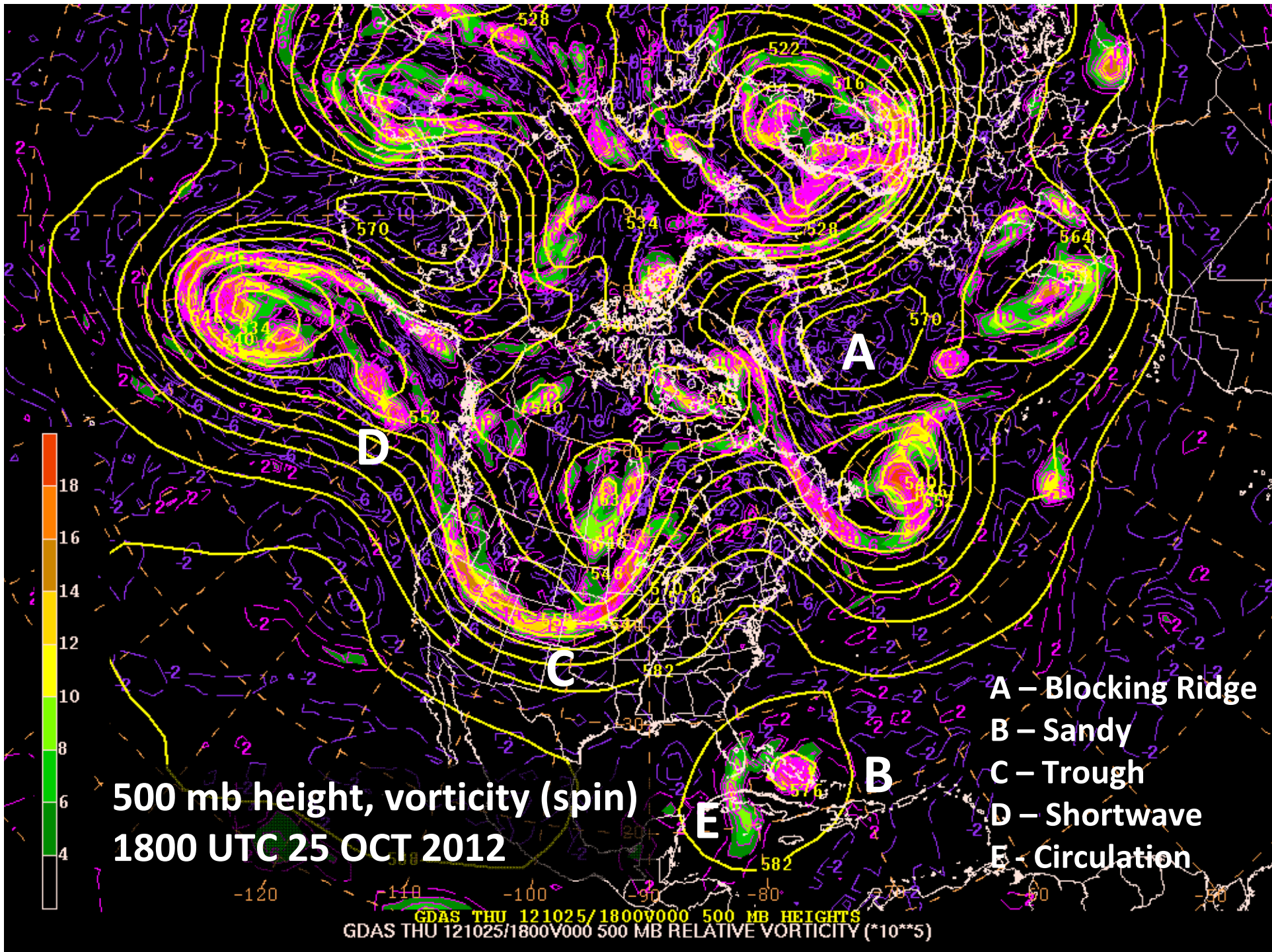




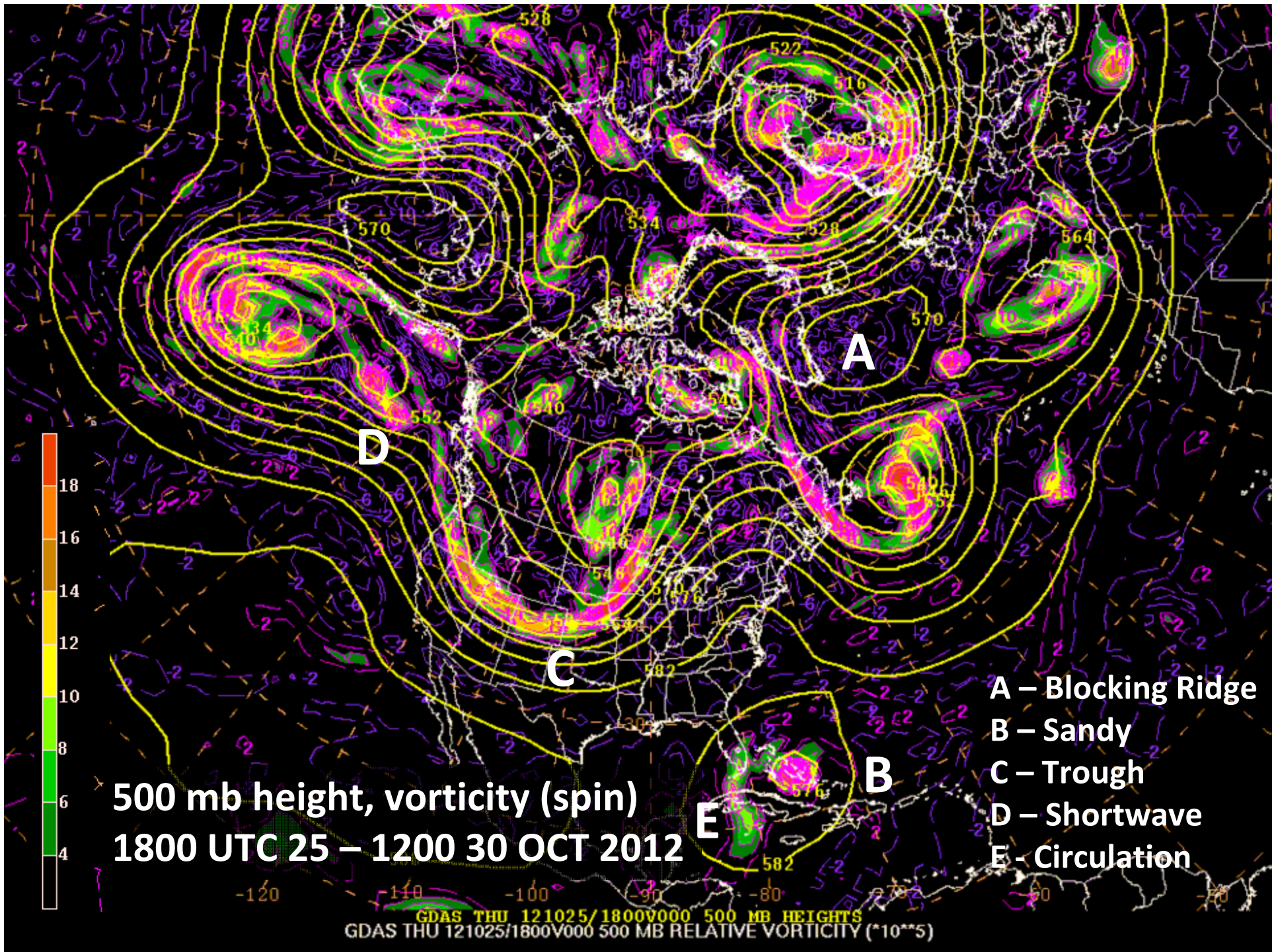
# Jet Stream 10/29/12 12Z (Blue)

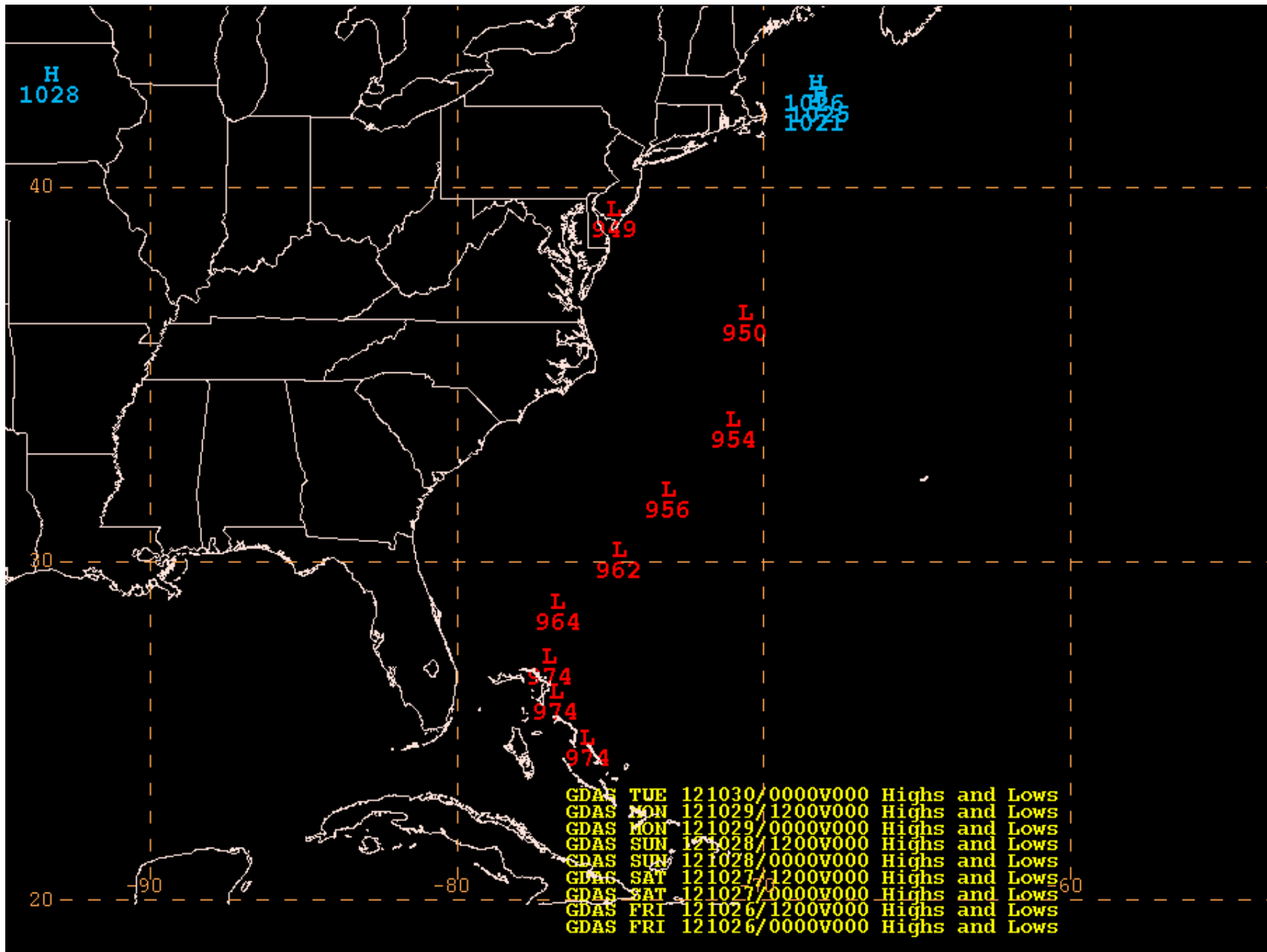
## Uncertainty in Sandy's track



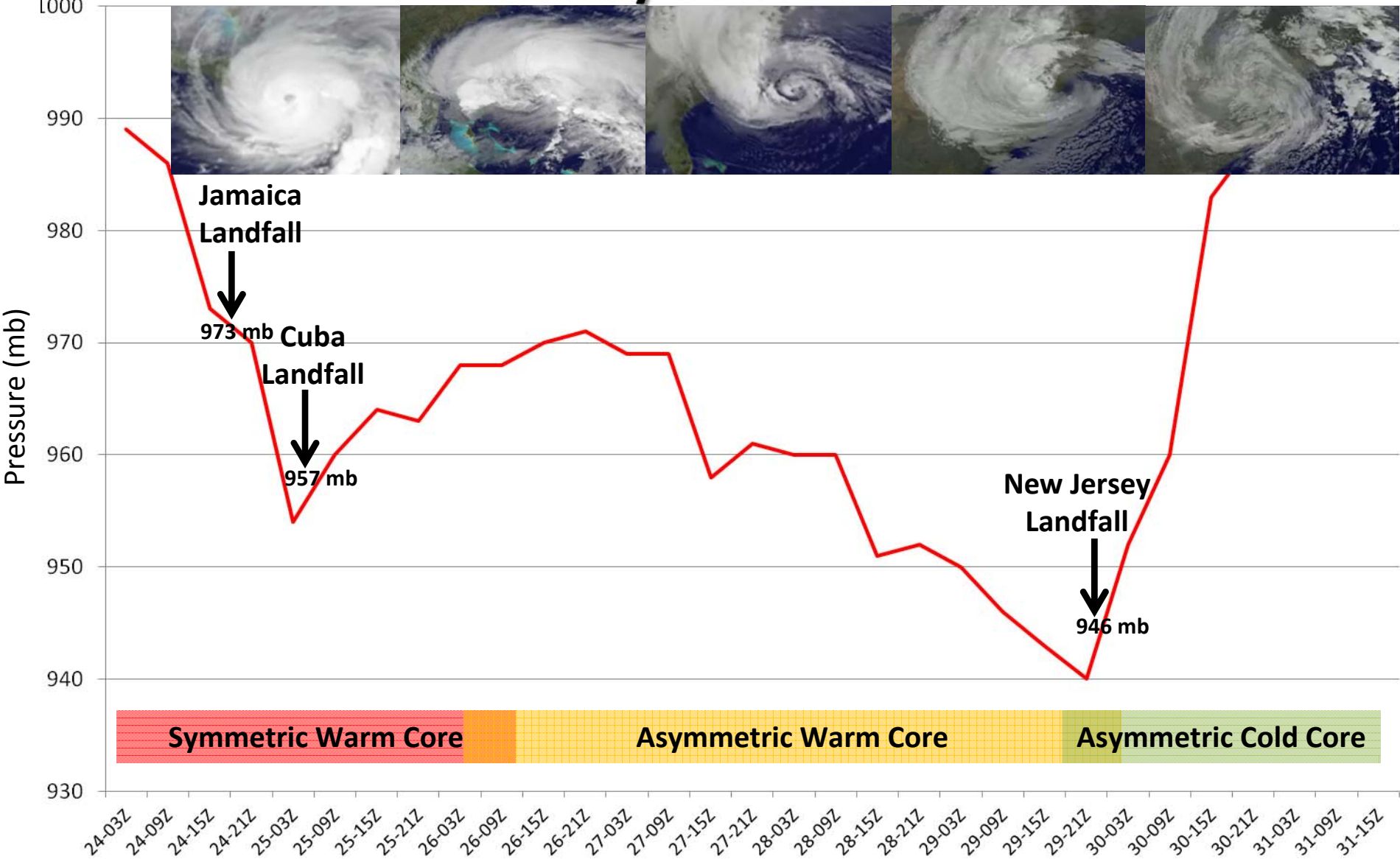






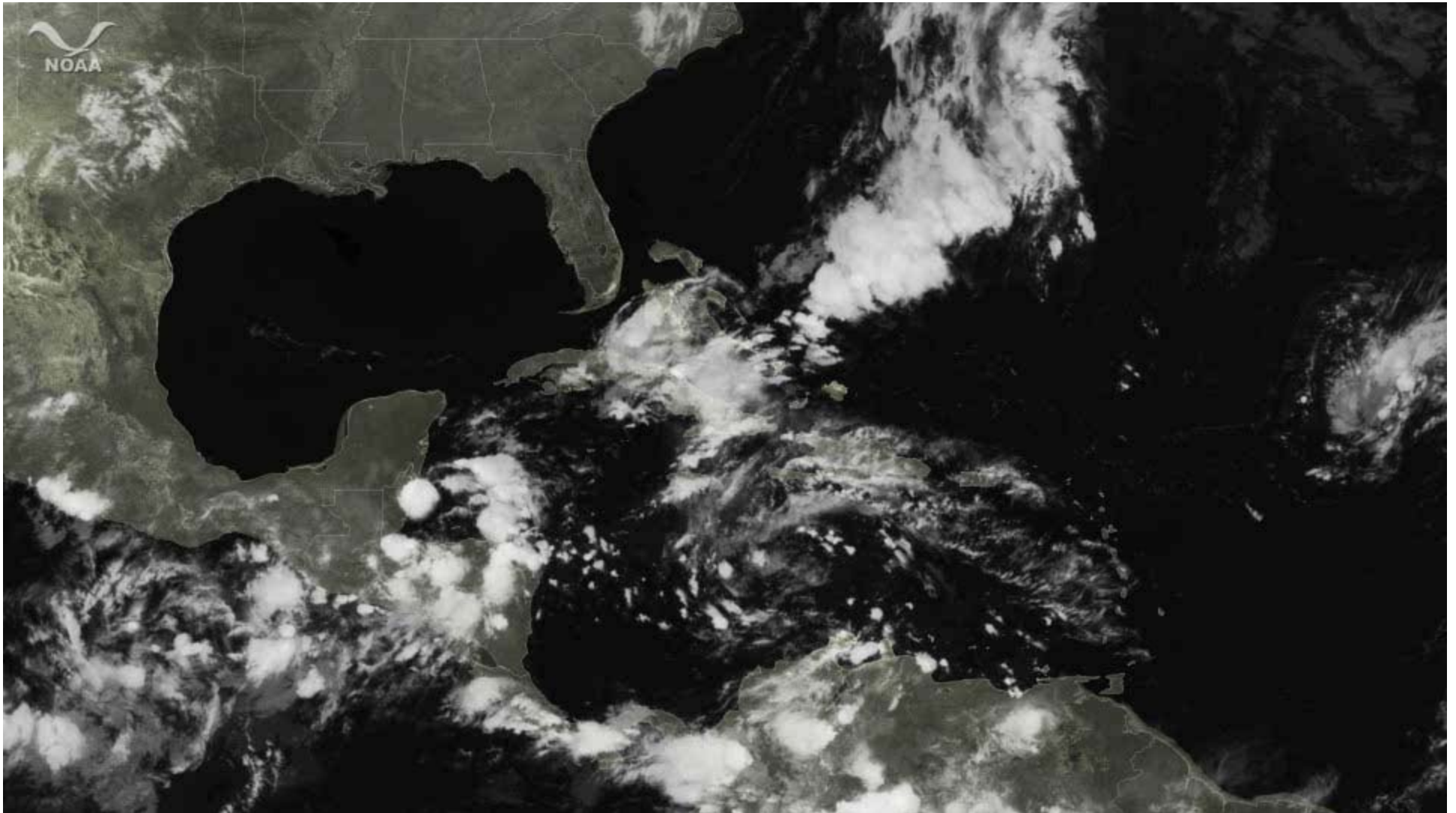


# Sandy's Evolution





Hurricane Sandy  
October 21, 2012 0345Z through October 31, 2012 1315Z



National Hurricane Center's 5 day forecast track issued at 11 a.m. EDT on Thursday, October 25





# Sandy

## Forecast Challenges

- Track
- Intensity
- tropical or non-tropical
  - warnings
  - responsibility
  - products
  - distribution

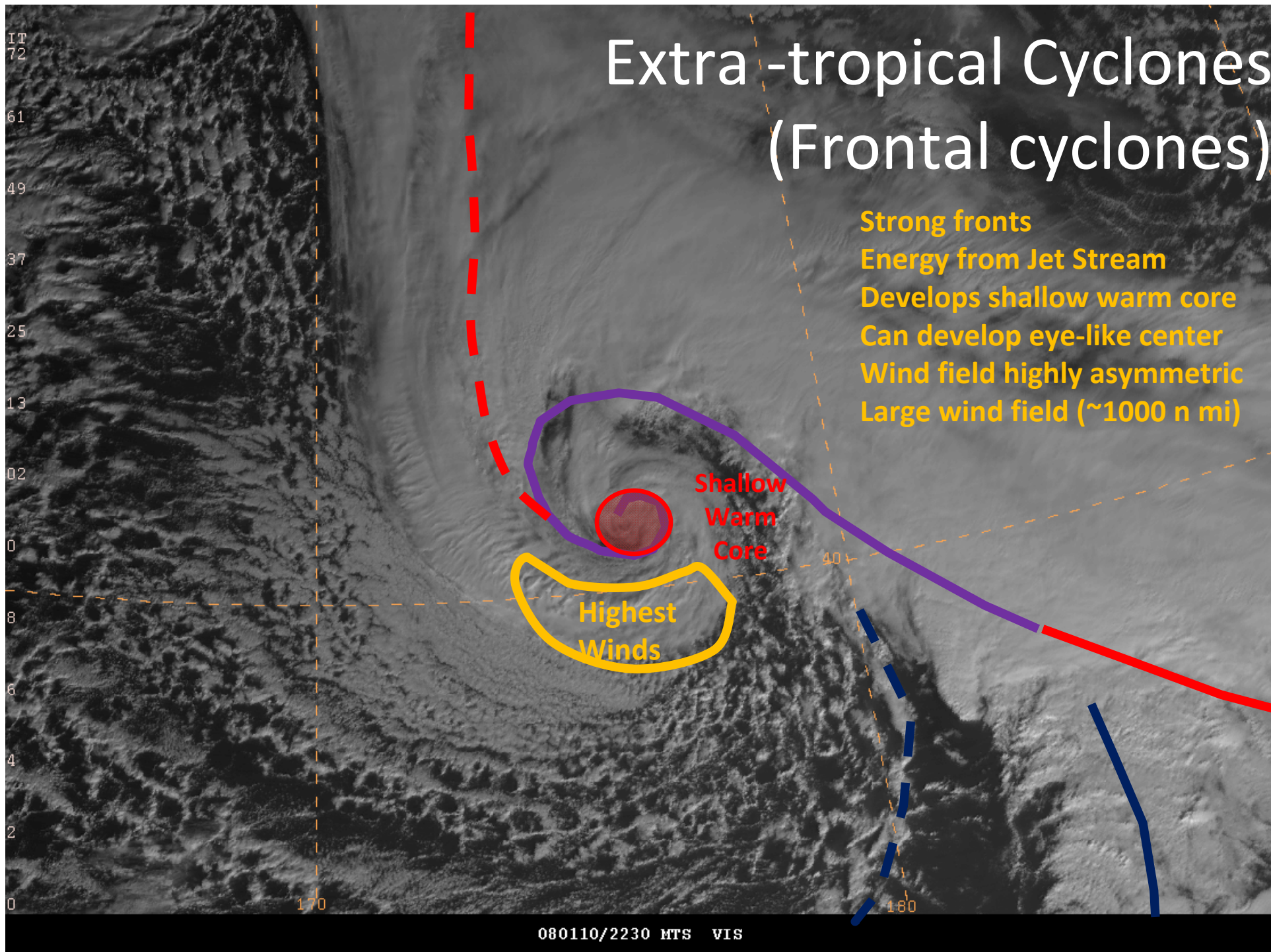


# Extra-tropical Cyclones (Frontal cyclones)

**Strong fronts**  
**Energy from Jet Stream**  
**Develops shallow warm core**  
**Can develop eye-like center**  
**Wind field highly asymmetric**  
**Large wind field (~1000 n mi)**

**Shallow  
Warm  
Core**

**Highest  
Winds**





Shapiro – Keyser Cyclone Model, 1990

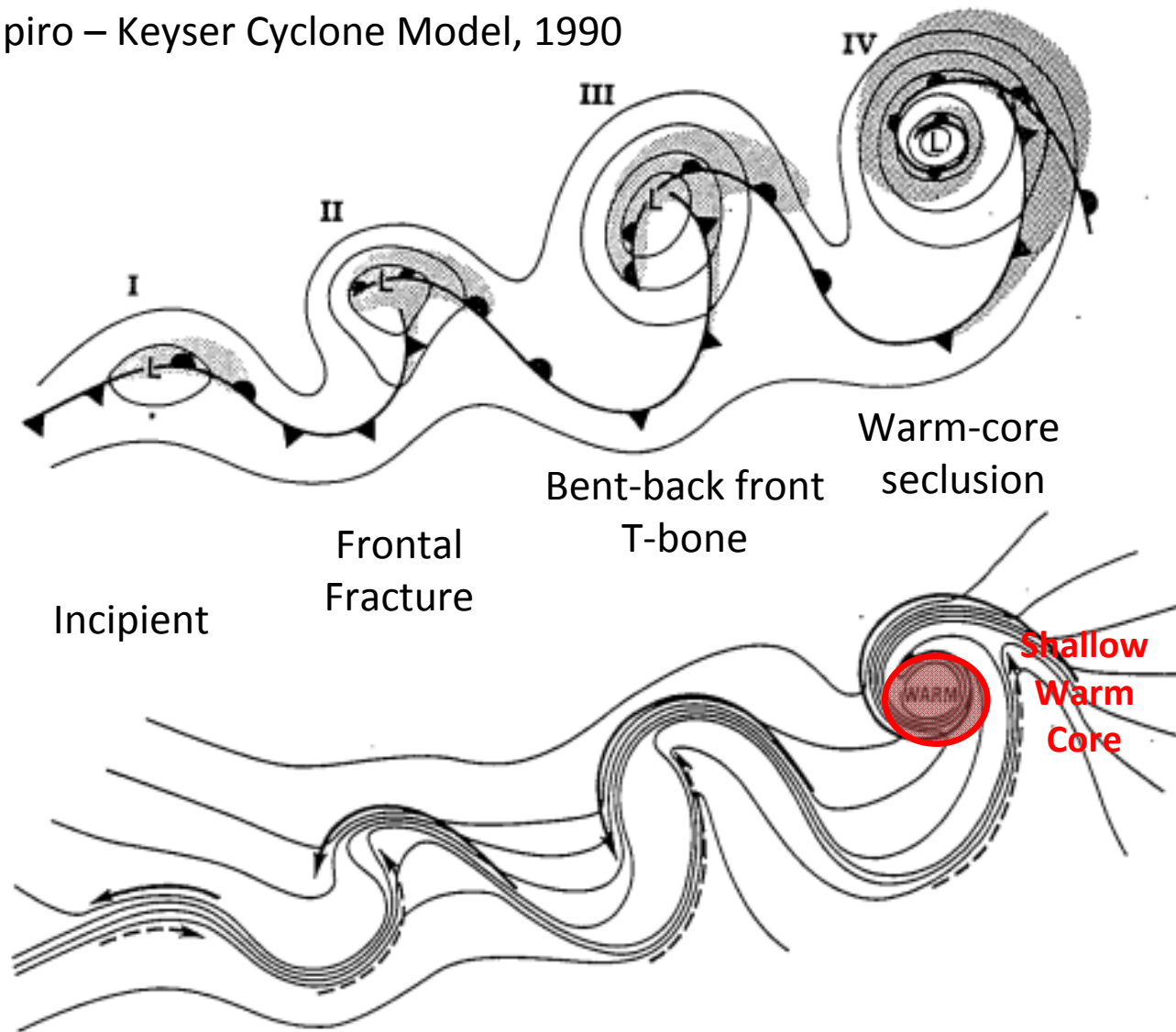


FIG. 10.27. The life cycle of the marine extratropical frontal cyclone: (I) incipient frontal cyclone; (II) frontal fracture; (III) bent-back warm front and frontal T-bone; (IV) warm-core frontal seclusion. Upper: sea-level pressure, solid lines; fronts, bold lines; and cloud signature, shaded. Lower: temperature, solid lines; cold and warm air currents, solid and dashed arrows, respectively.



# Tropical Cyclones (Non-Frontal)

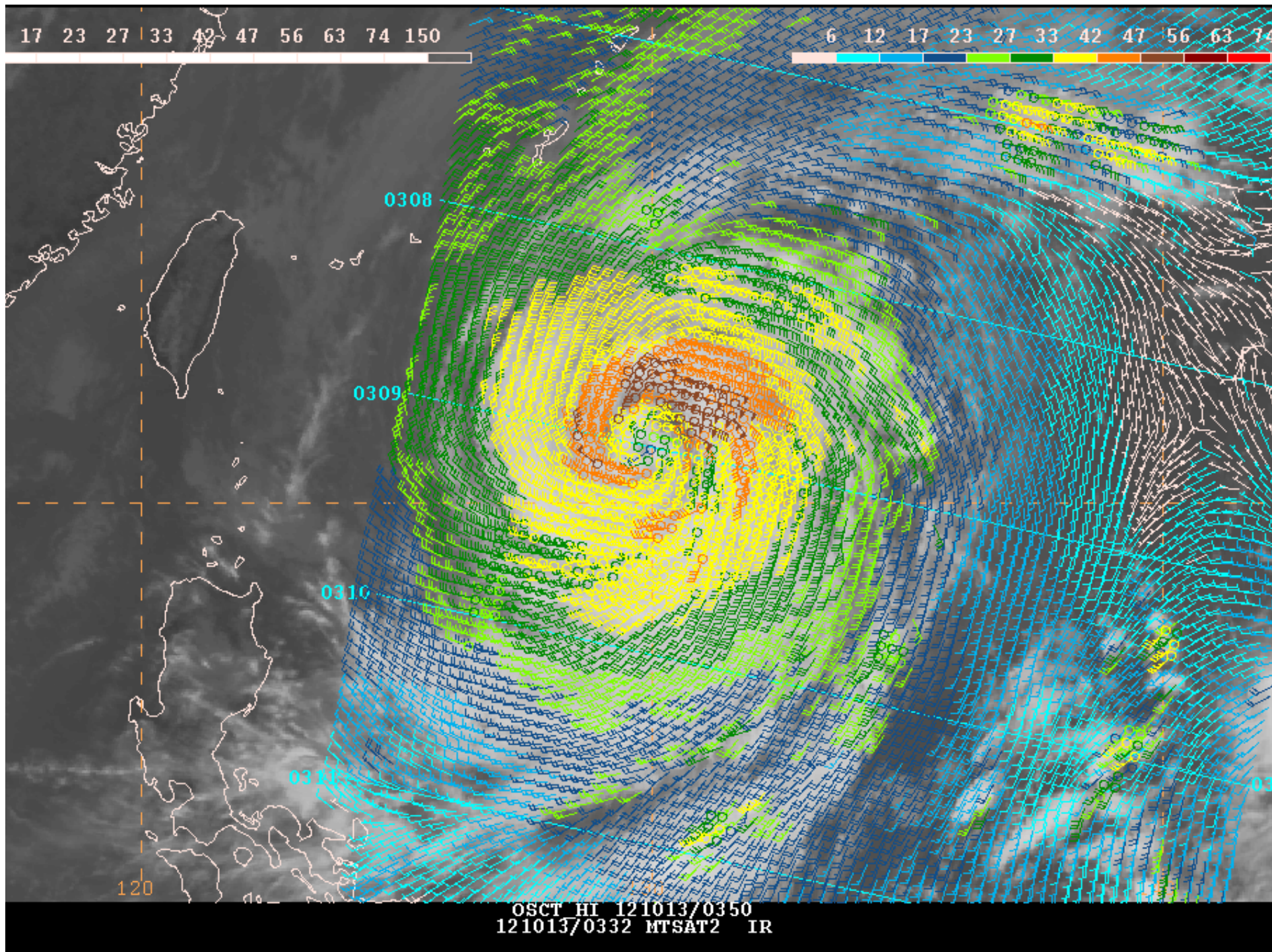
- No fronts
- Energy - ocean heat exchange
- Deep warm core
- Develops an eye
- Wind field highly symmetric
- Highest winds near eye wall
- Wind field diameter ~ 100s n mi

Hurricane  
"Danielle"

Tropical Storm  
"Earl"

Tropical Wave  
became T.S. Fiona  
Aug 30th

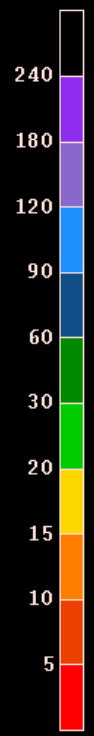
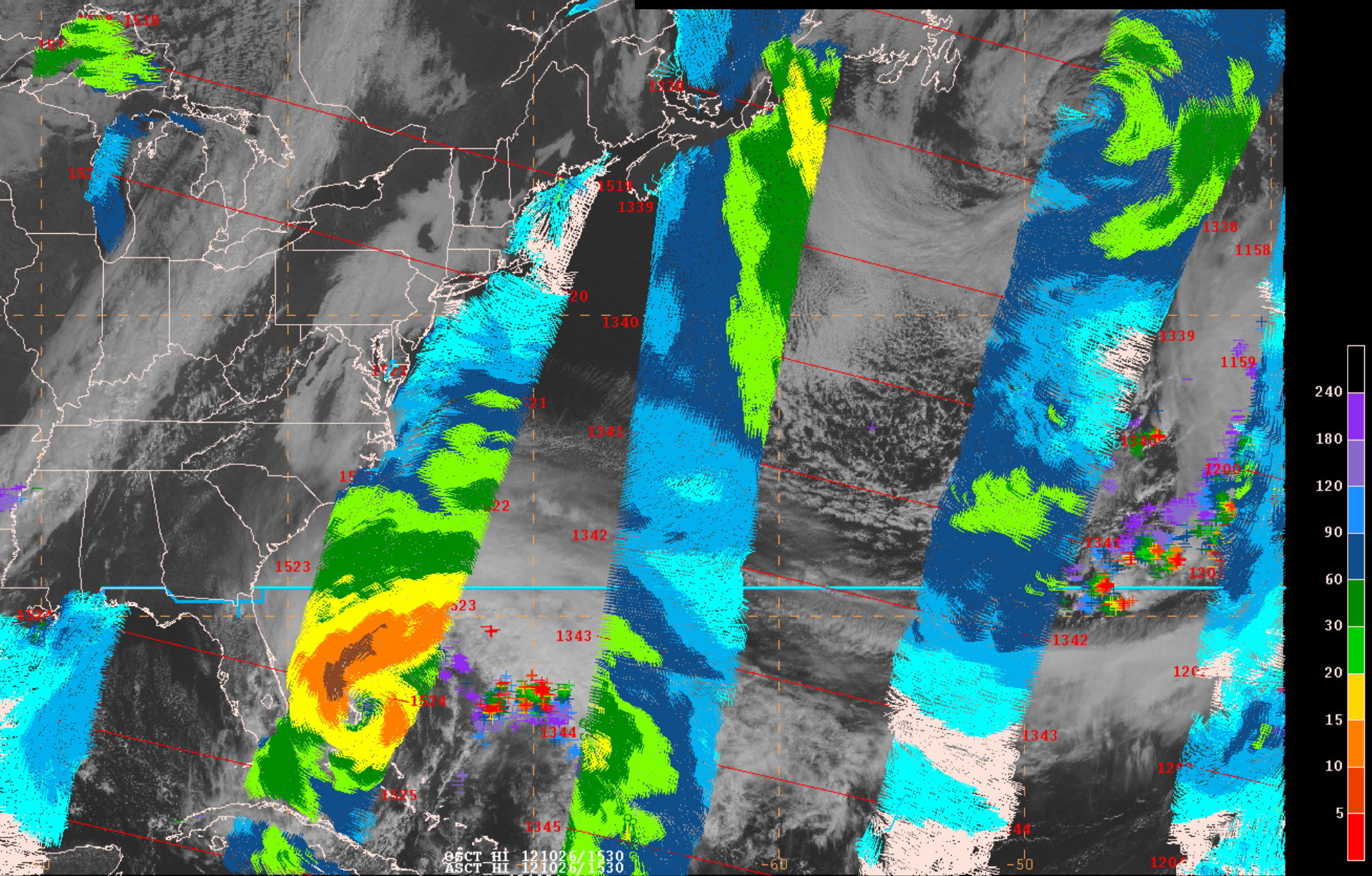








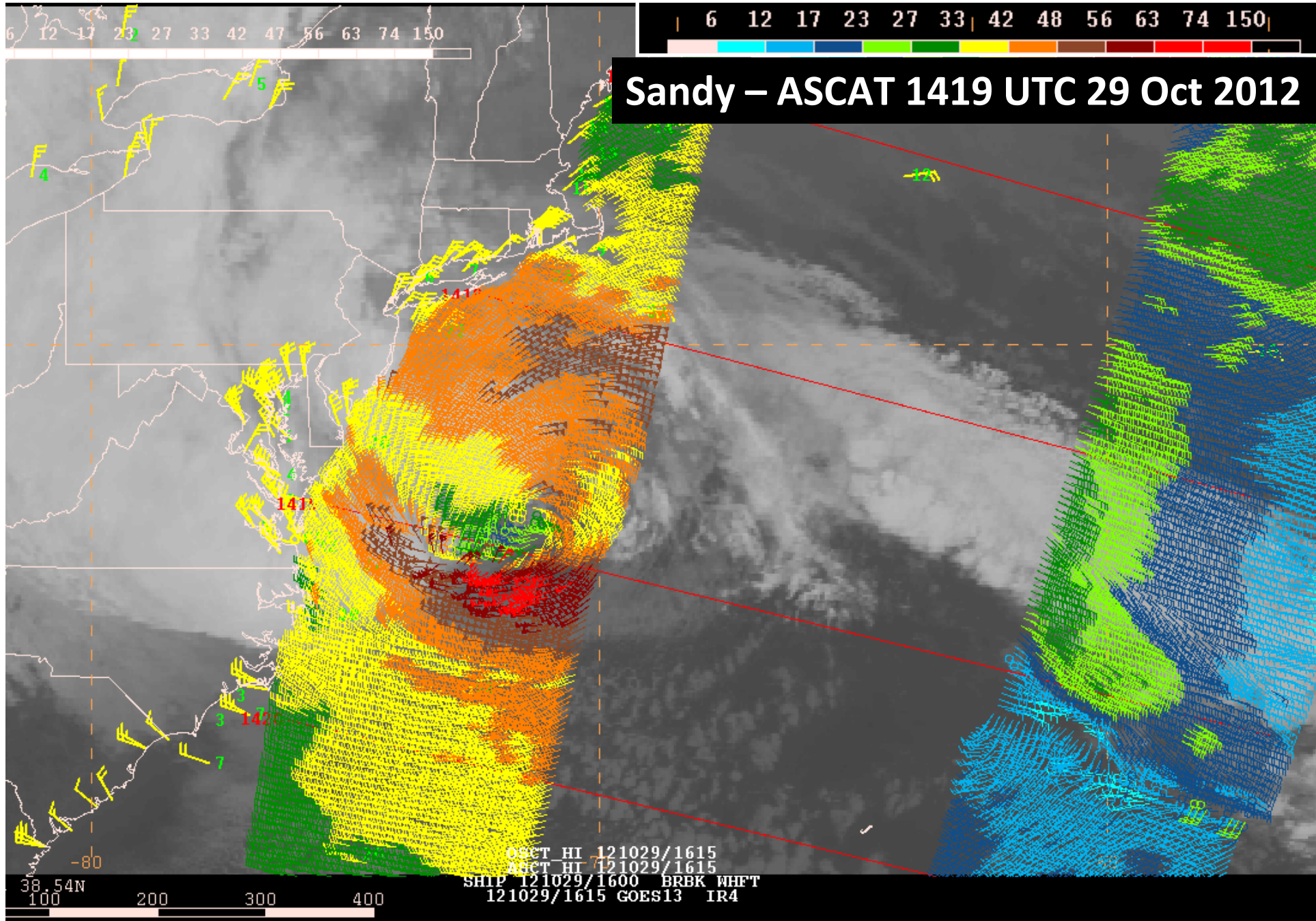
# Sandy – ASCAT 1524 UTC 26 Oct 2012



05 OCT HI 121026/1530  
ASCAT HI 121026/1530  
LTNG 121026/1530  
121026/1545 GOES13 VIS



# Sandy – ASCAT 1419 UTC 29 Oct 2012



OSCT HI 121029/1615  
ASCT HI 121029/1615  
SHIP 121029/1600 BRBK WHFT  
121029/1615 GOES13 IR4

# The Sandy **Warning** Dilemma

On Wednesday, five days before landfall, the NWS began internal coordination calls to anticipate and plan for a potentially unique forecast and warning situation. It identified that day:

## TWO INCOMPATIBLE CONSTRAINTS

(1) Emergency managers and public officials, including a State Governor, told the NWS of their strong preference that the **warning type (i.e., tropical or non-tropical) not change** once watches and warnings were initiated, because that would cause an unacceptable level of confusion and disruption during critical periods of preparation that included evacuations.

(2) The **forecast** from the **National Hurricane Center** called for **Sandy to change types (from tropical to non-tropical)** prior to the center making landfall, potentially a day before it was to come ashore.

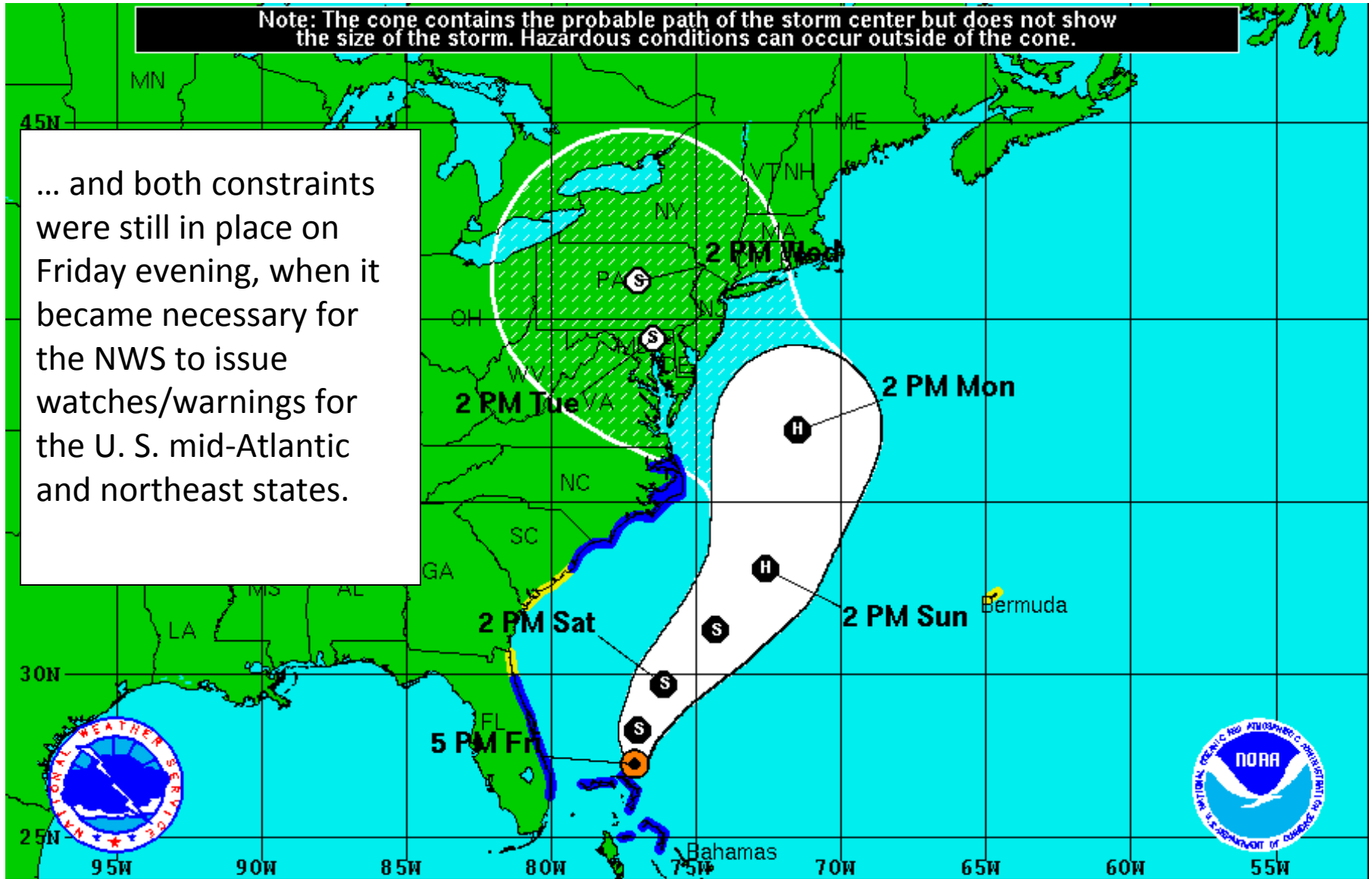


# Drawbacks to Issuing Hurricane Warning


- If hurricane watches/warnings had been issued 2-3 days before landfall, and if Sandy had become post-tropical well offshore, NWS would have faced three unacceptable options:
  1. **Drop it:** follow existing protocol, transfer forecast responsibility to other NWS offices, cancel hurricane warning, switch to local Weather Forecast Office warnings. NHC advisories would have ceased. **This would have caused widespread confusion, potentially impeded preparations and evacuations, and directly contradicted the desires and efforts of the emergency managers.**
  2. **Fake it:** continue to call Sandy a hurricane when it really wasn't one (potentially for a full day or longer) in order to maintain NHC advisories and the hurricane warning. **Intentionally misrepresenting Sandy as a hurricane would have severely damaged the credibility of the NWS and undermined its ability to serve the public for years to come.**
  3. **Wing it:** properly call Sandy post-tropical but continue to issue NHC advisories and leave up the hurricane warning. However, **a procedure for disseminating post-tropical advisories with tropical warnings had never been developed, tested, or publicized, and the NWS feared that hurriedly crafting and implementing untested procedures could easily break automated vendor software and disrupt the flow of information to users at a crucial moment.**



Note: The cone contains the probable path of the storm center but does not show the size of the storm. Hazardous conditions can occur outside of the cone.

... and both constraints were still in place on Friday evening, when it became necessary for the NWS to issue watches/warnings for the U. S. mid-Atlantic and northeast states.



**Hurricane Sandy**  
 Friday October 26, 2012  
 5 PM EDT Advisory 18  
 NWS National Hurricane Center

**Current Information:**   
 Center Location 27.3 N 77.1 W  
 Max Sustained Wind 75 mph  
 Movement N at 7 mph

**Forecast Positions:**  
 Tropical Cyclone  Post-Tropical  
 Sustained Winds: D < 39 mph  
 S 39-73 mph H 74-110 mph M > 110mph

**Potential Track Area:**  
 Day 1-3  Day 4-5

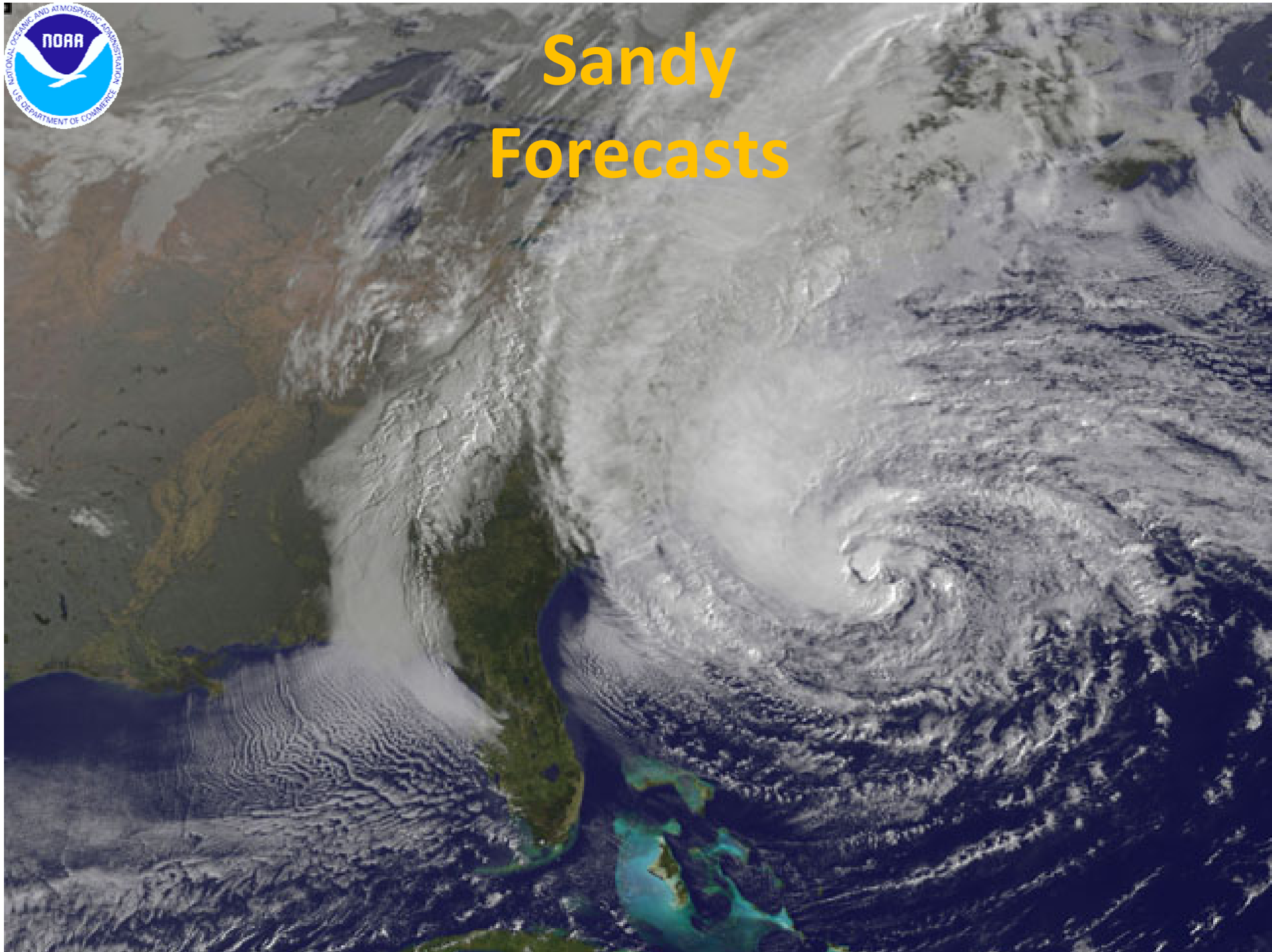
**Watches:**  
 Hurricane  Trop.Storm

**Warnings:**  
 Hurricane  Trop.Storm



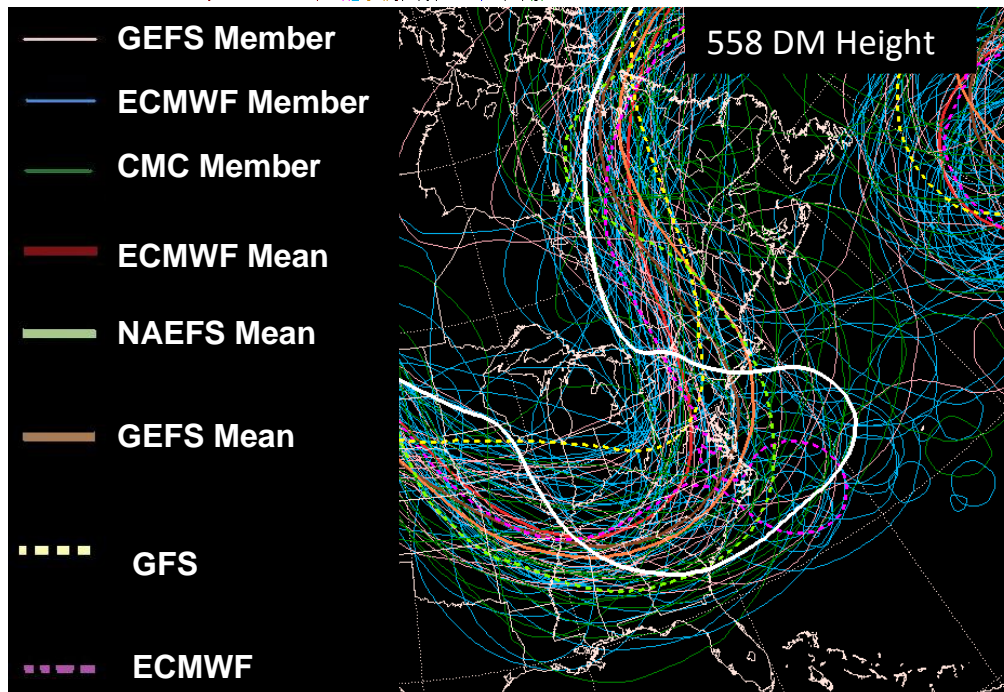
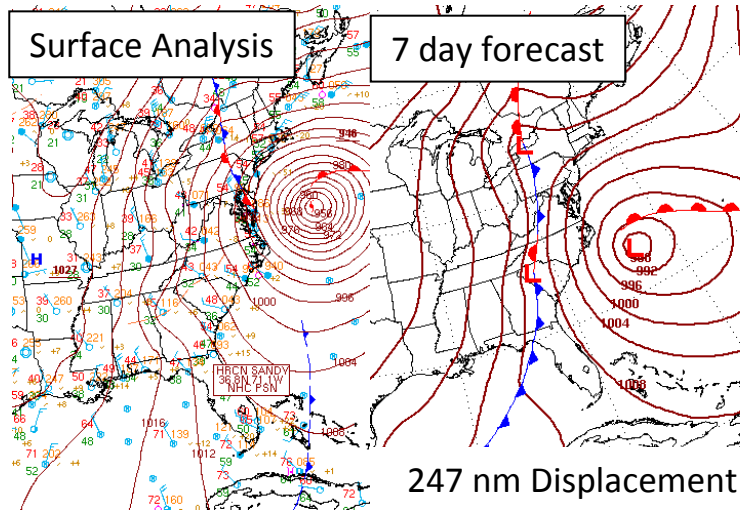


# Sandy Forecasts



# A Success for Ensembles and Forecasters

## Charts Valid 12Z October 29, 2012



FOR NOW, HAVE KEPT THE INCREASINGLY HYBRID CYCLONE OFF THE EAST COAST, THOUGH NOT AS FAR OUT TO SEA AS THE GFS AND GEFS MEMBERS.

CONSIDERING THE WILDLY DIVERSE DETERMINISTIC SOLUTIONS AND ENSEMBLE MEMBERS...THAT SEEMS TO HAVE BEEN A SAFE BET.

**Day 7 Forecast**  
**Mon 22 Oct 2012**

CISCO



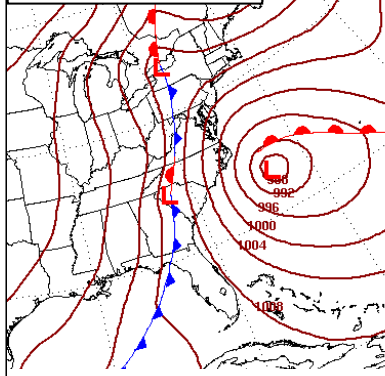
# A Success for Ensembles and Forecasters

## Charts Valid 12Z October 29, 2012

Surface Analysis

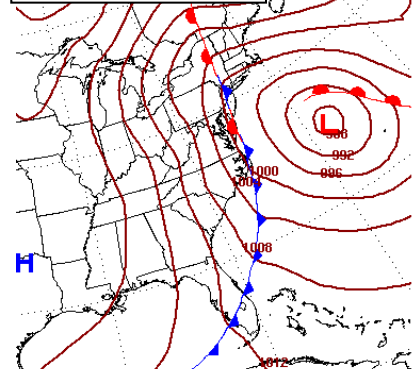


7 day forecast



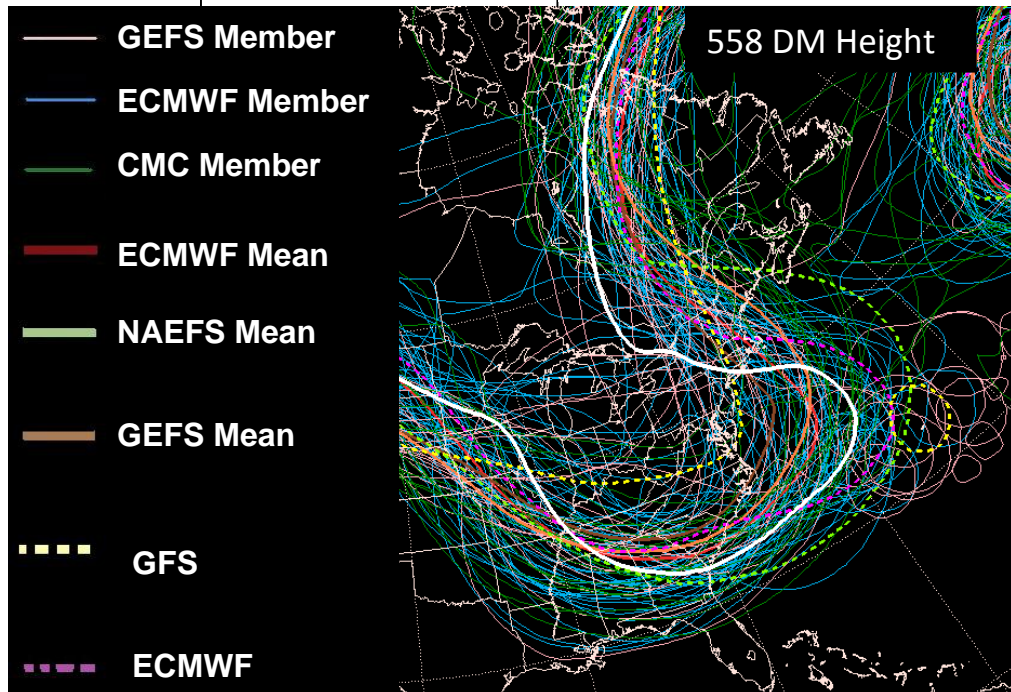
247 nm Displacement

6 day forecast



186 nm Displacement

Day 6 Forecast  
23 Oct 2012



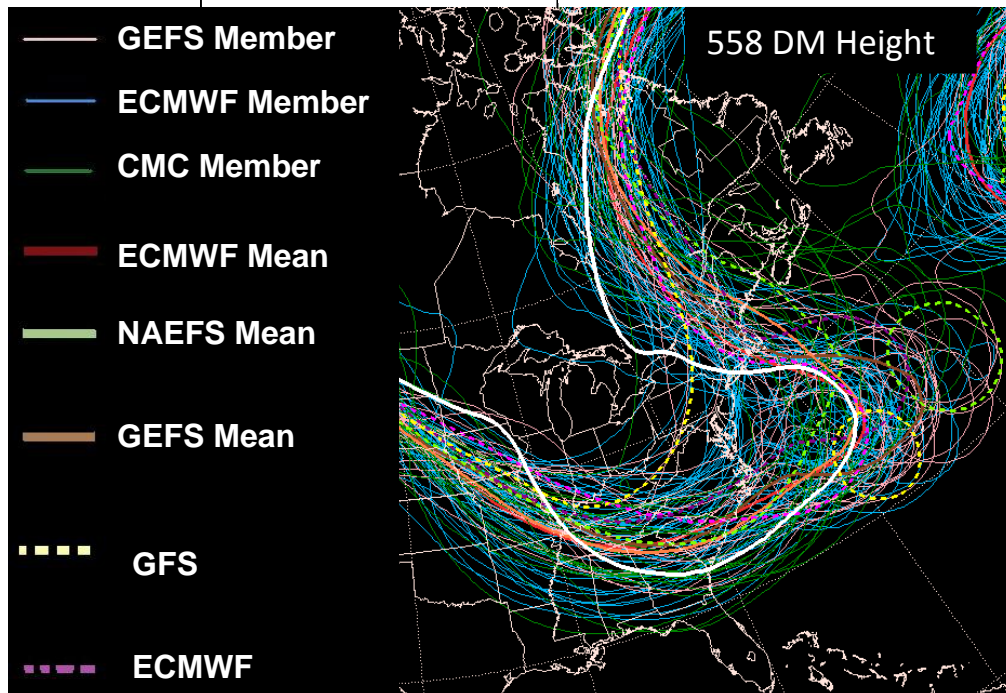
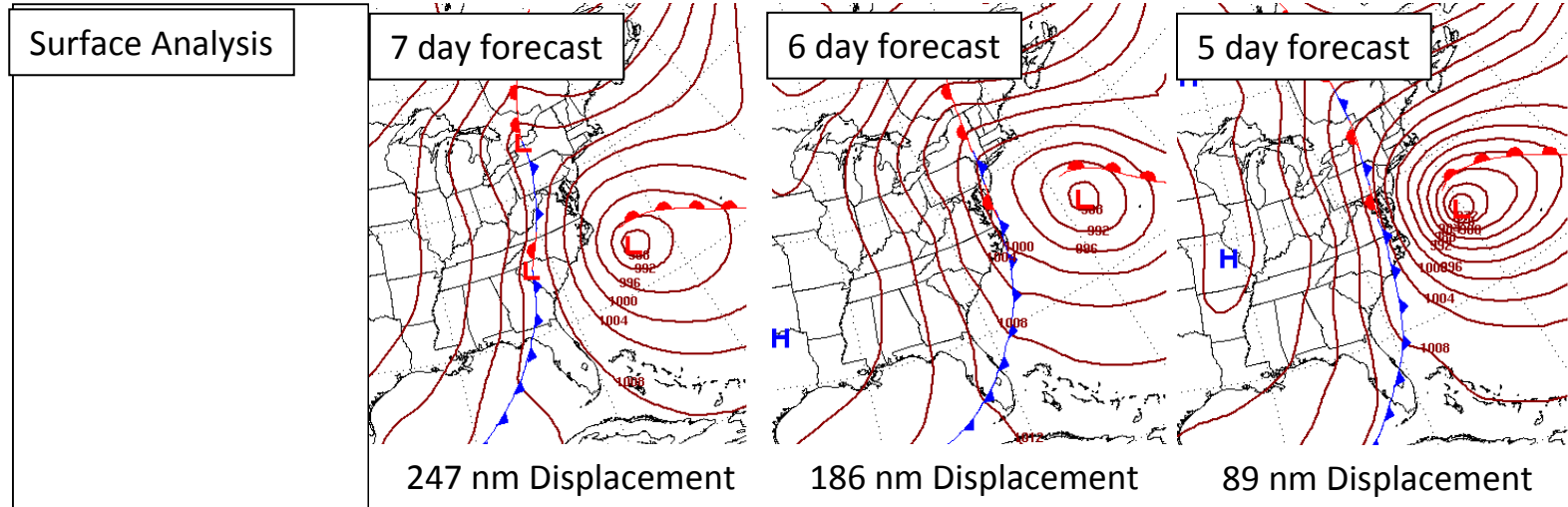
THERE HAVE BEEN GFS ENSEMBLE MEMBERS QUITE SIMILAR TO THE ECMWF/GEM CAMP FOR THE LAST FEW DAYS OF MODEL CYCLES, PUTTING THE DETERMINISTIC GFS SOLUTIONS IN A BROADER FRAMEWORK...

CISCO

Day 6 Forecast  
Tue 23 Oct 2012

# A Success for Ensembles and Forecasters

## Charts Valid 12Z October 29, 2012



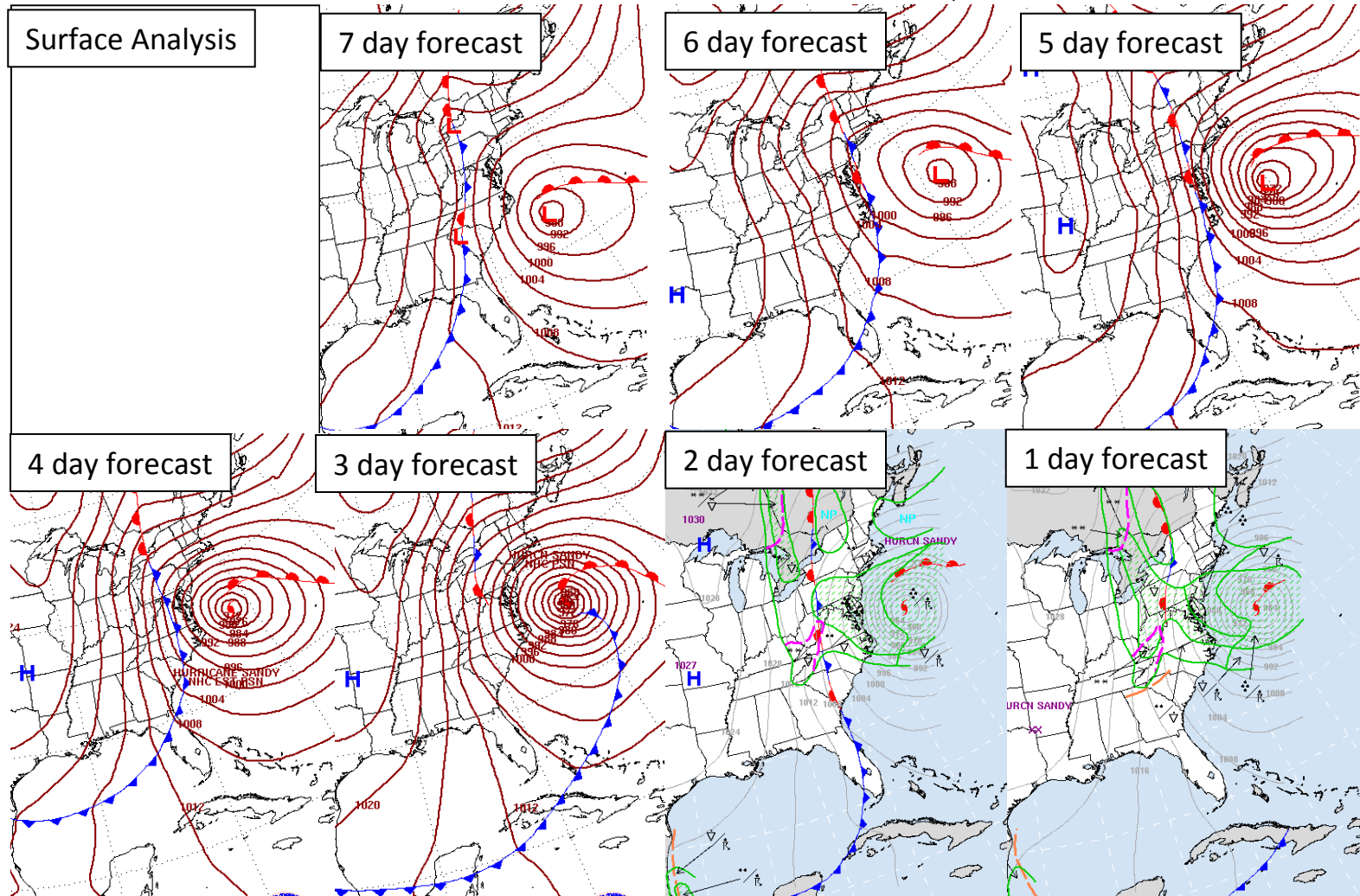
THE DETERMINISTIC SOLUTIONS... ARE OUTLIERS TO THE MAJORITY OF THEIR ENSEMBLE BROTHERS AND SISTERS, WITH THE LION'S SHARE OF THE ENSEMBLE GUIDANCE INDICATING A WHOLESALE INCORPORATION OF SANDY'S POST-TROPICAL CIRCULATION INTO THE UPPER VORTEX...

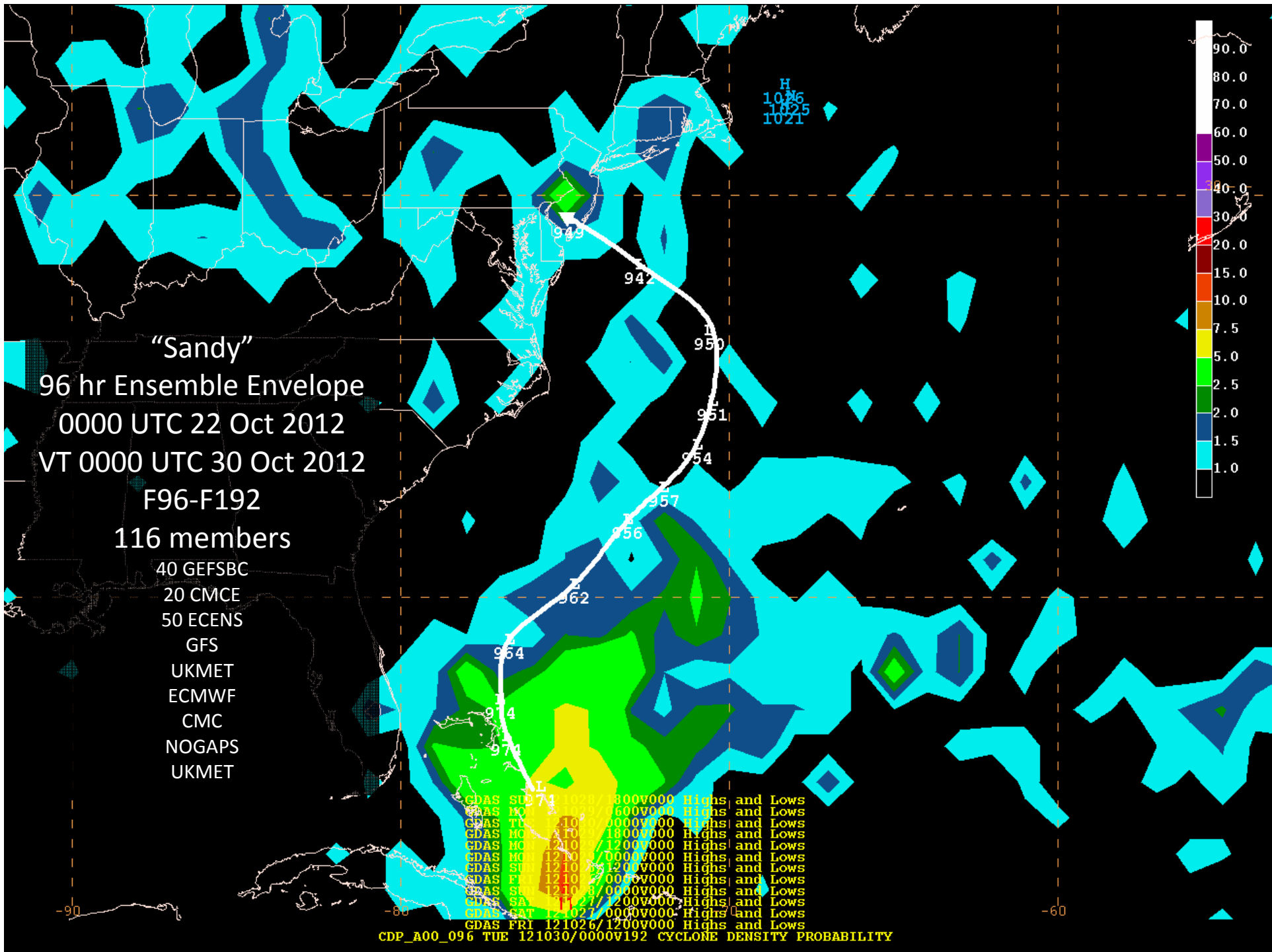
Day 5 Forecast  
Wed 24 Oct 2012



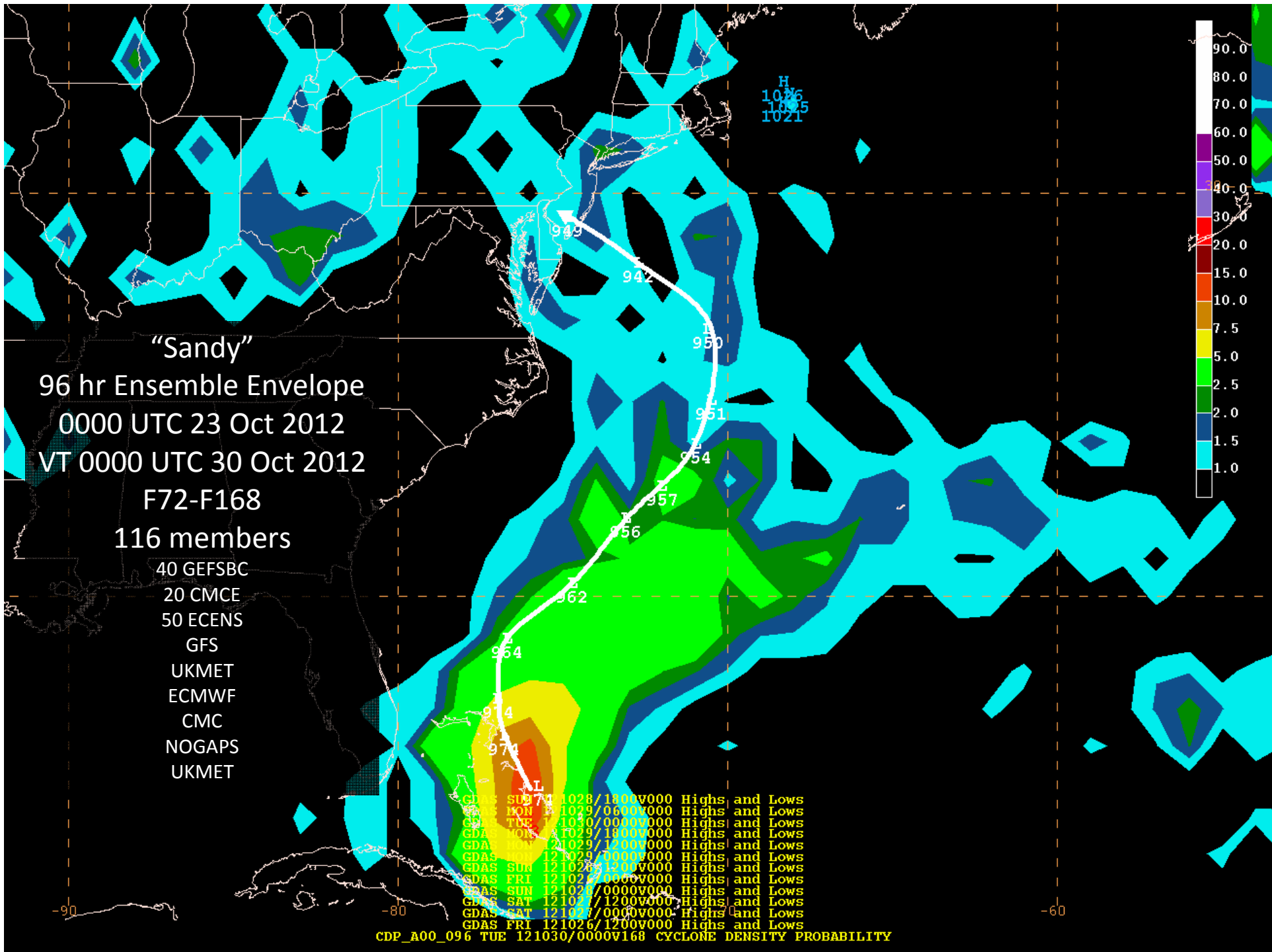
# A Success for Ensembles and Forecasters

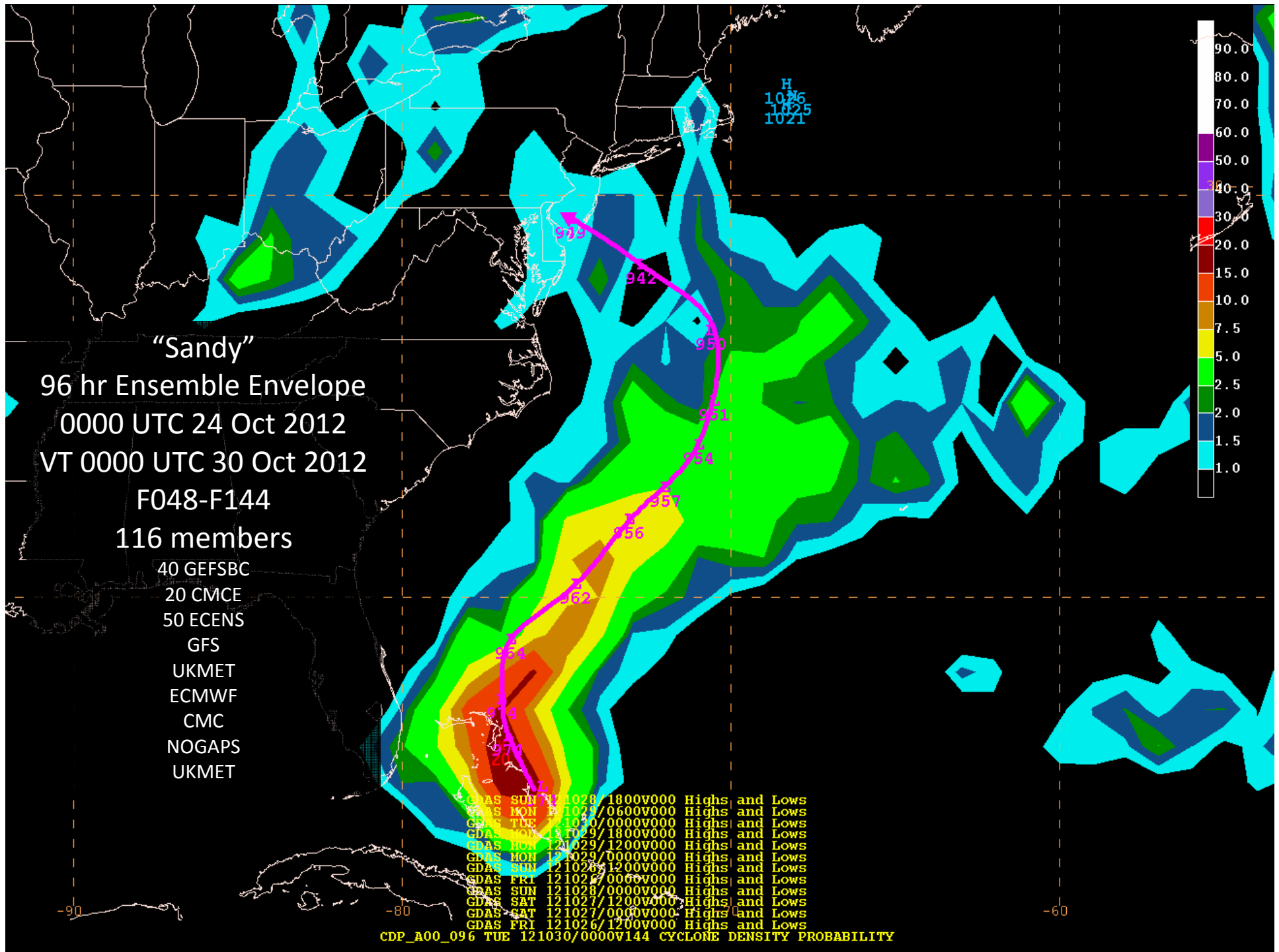
## Charts Valid 12Z October 29, 2012



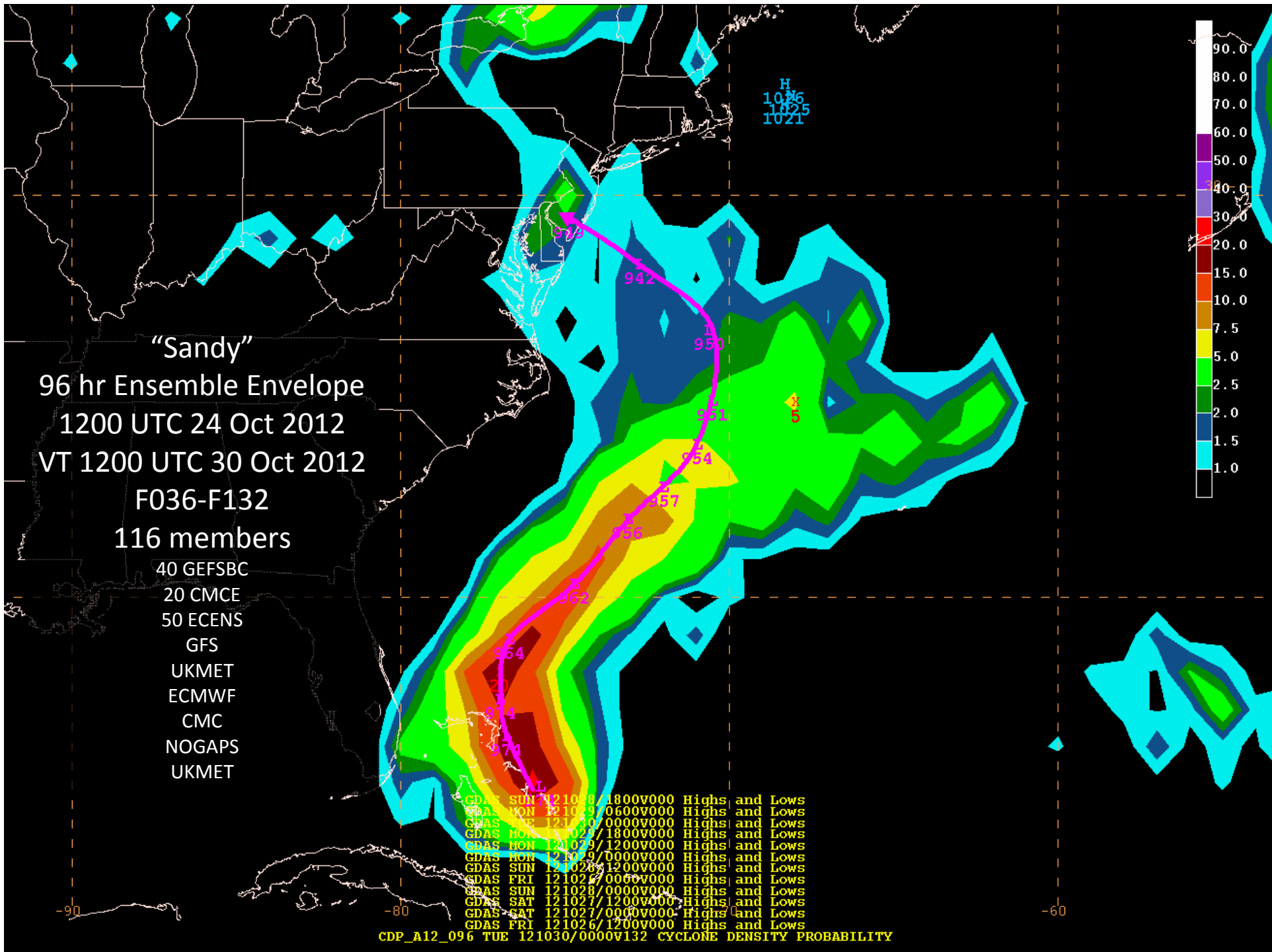


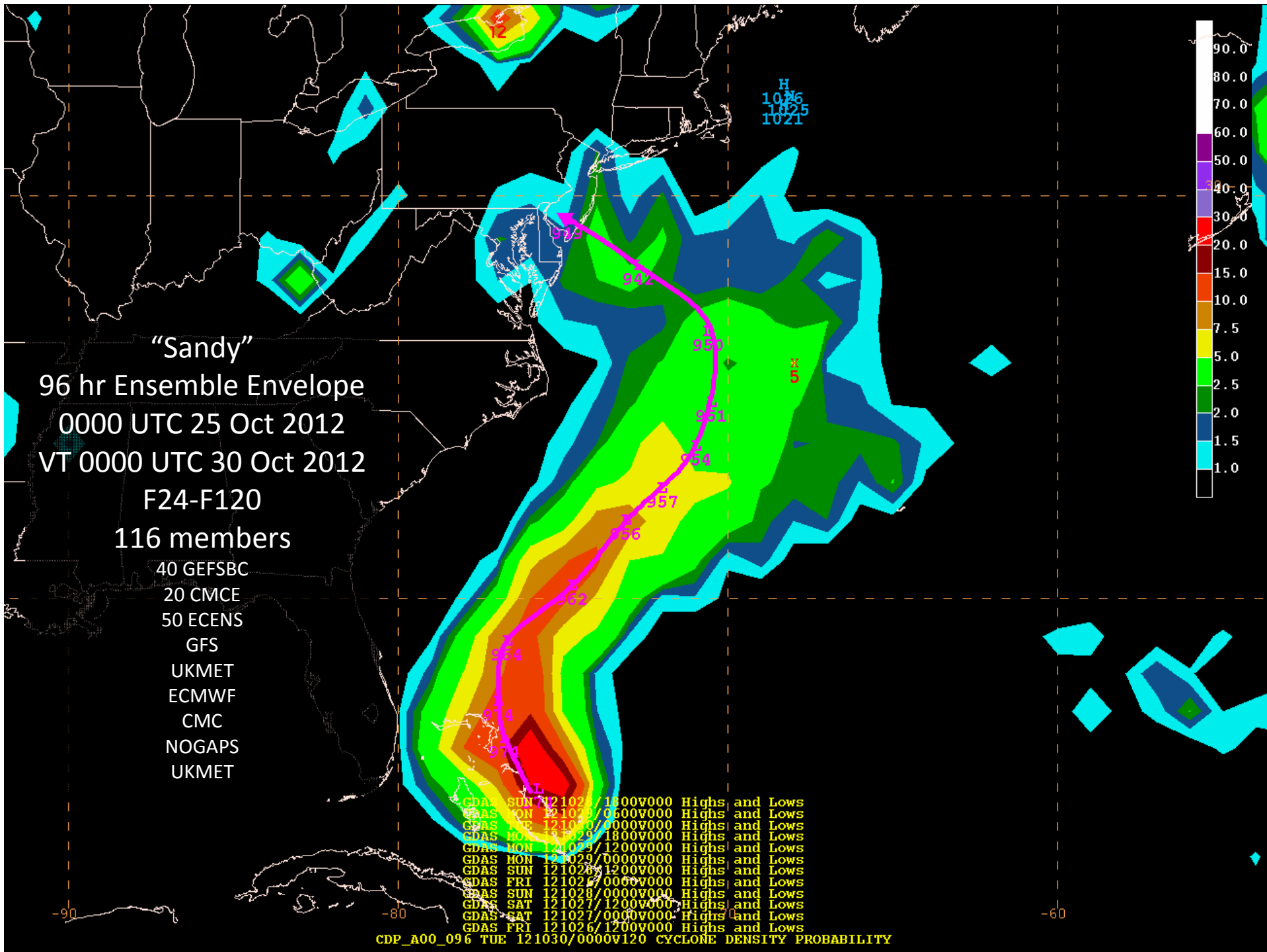




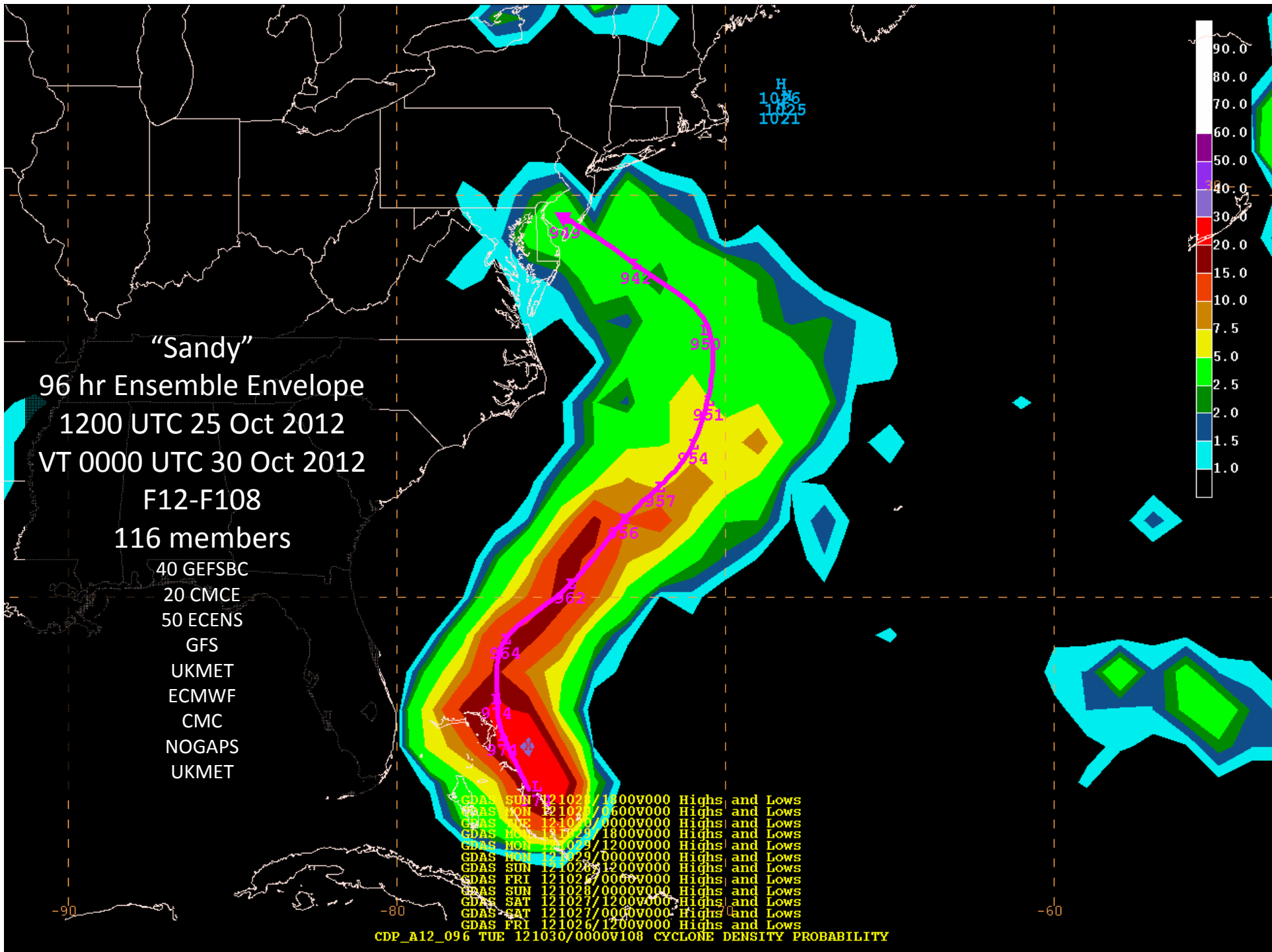


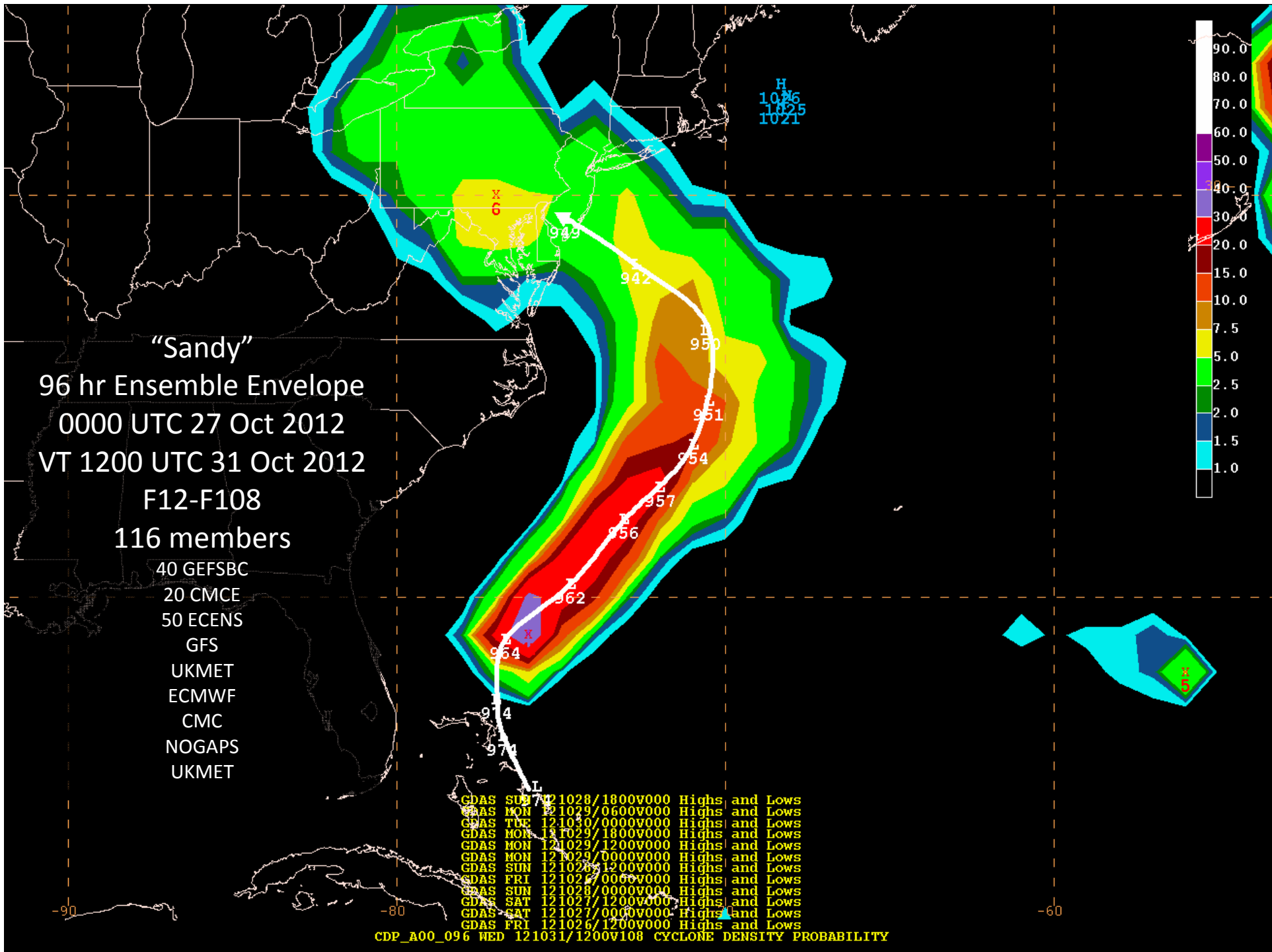






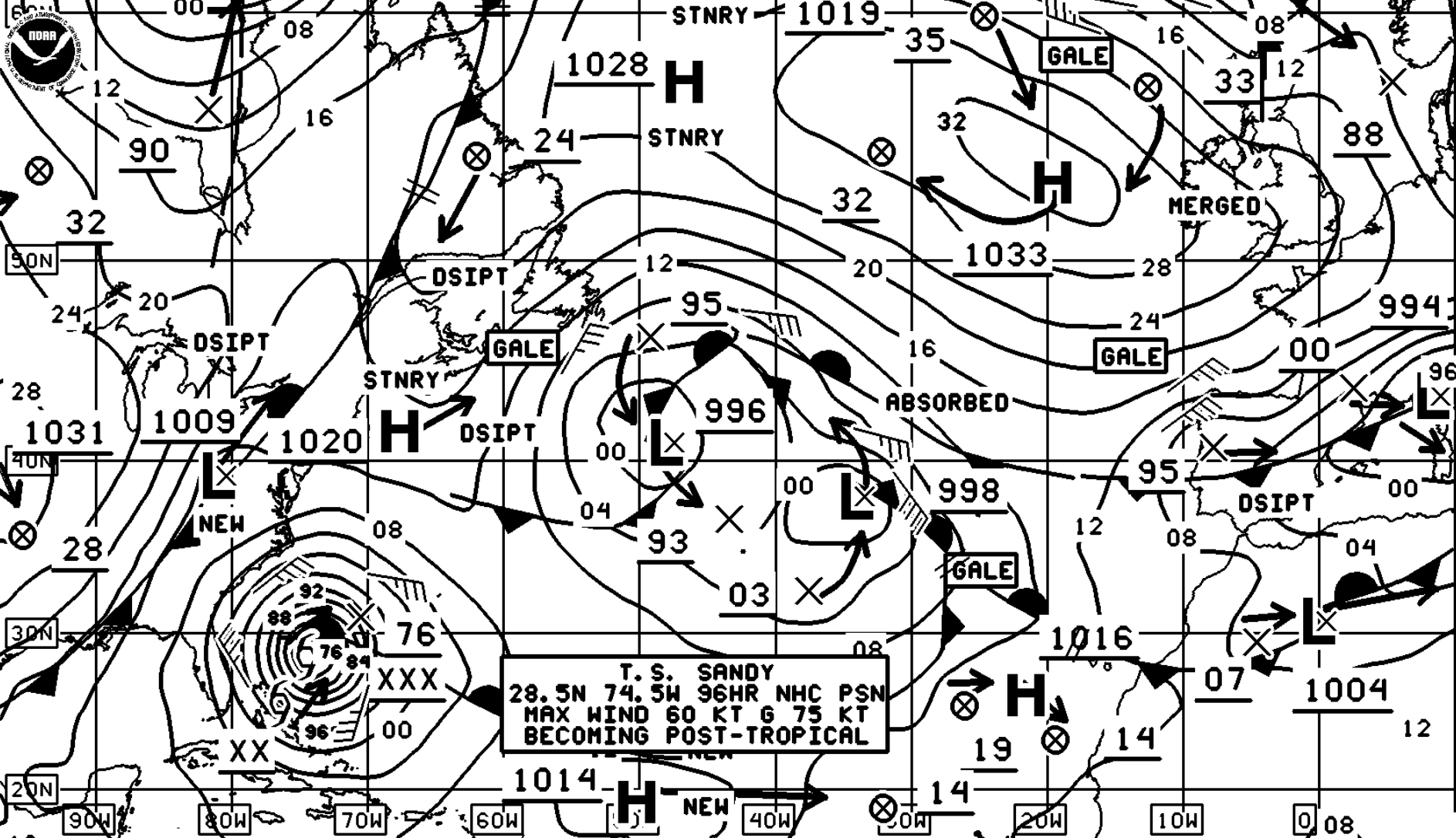








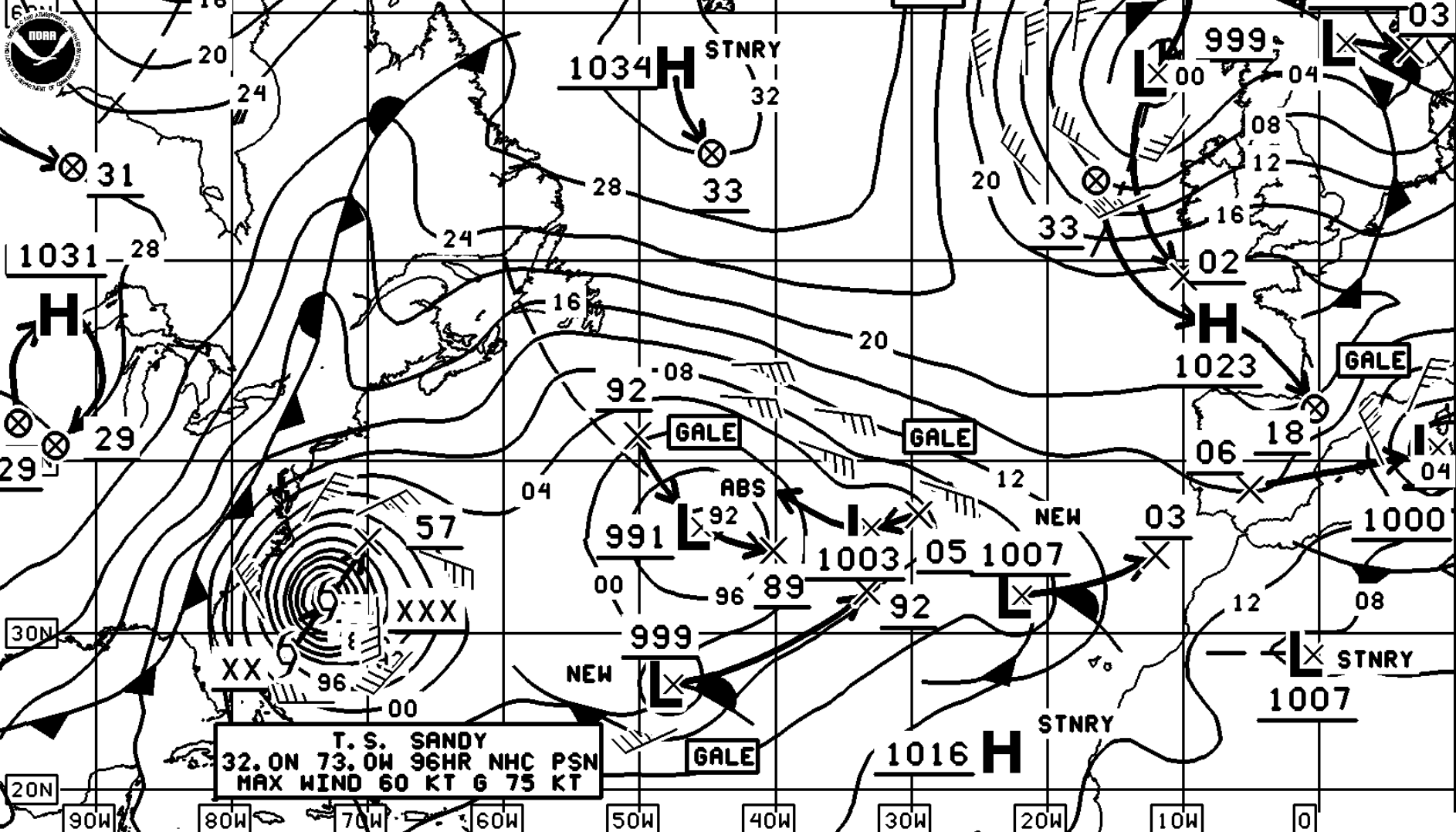
96-HOUR SURFACE FORECAST  
 ISSUED: 18:18 UTC 23 OCT 2012  
 VALID: 12:00 UTC 27 OCT 2012  
 FCSTR: BANCROFT



**T. S. SANDY**  
 28.5N 74.5W 96HR NHC PSN  
 MAX WIND 60 KT G 75 KT  
 BECOMING POST-TROPICAL

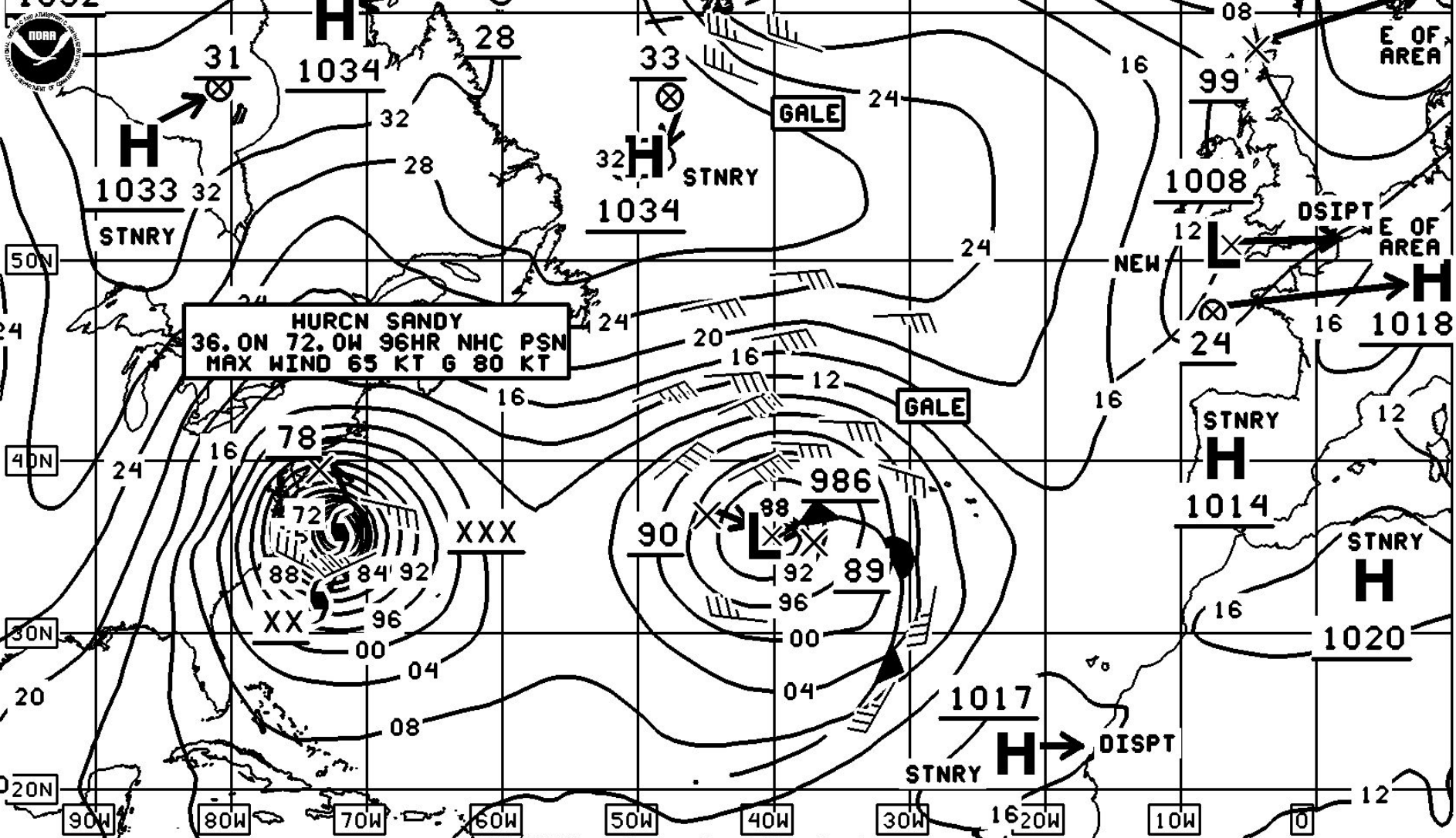
NWS/NCEP - Ocean Prediction Center  
[www.opc.ncep.noaa.gov](http://www.opc.ncep.noaa.gov)

96-HOUR SURFACE FORECAST  
 ISSUED: 17:36 UTC 24 OCT 2012  
 VALID: 12:00 UTC 28 OCT 2012  
 FCSTR: SCOVIL



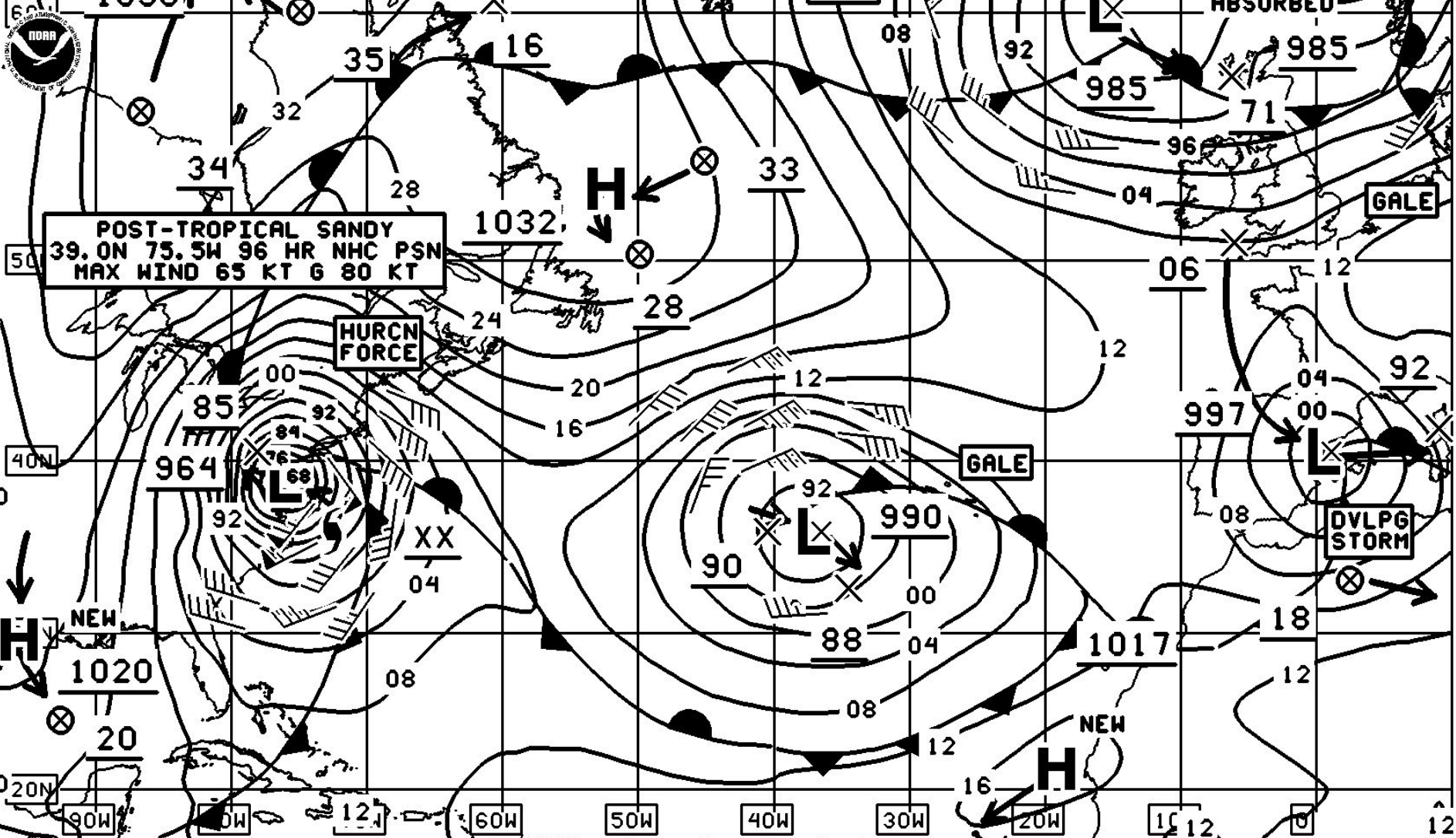
T. S. SANDY  
 32.0N 73.0W 96HR NHC PSN  
 MAX WIND 60 KT G 75 KT

96-HOUR SURFACE FORECAST  
 ISSUED: 20:46 UTC 25 OCT 2012  
 VALID: 12:00 UTC 29 OCT 2012  
 FCSTR: MCRANDAL





96-HOUR SURFACE FORECAST  
 ISSUED: 18:39 UTC 26 OCT 2012  
 VALID: 12:00 UTC 30 OCT 2012  
 FCSTR: BANCROFT



POST-TROPICAL SANDY  
 39.0N 75.5W 96 HR NHC PSN  
 MAX WIND 65 KT G 80 KT

HURCN  
 FORCE

GALE

DVLPG  
 STORM



# Storm Surge





BULLETIN

HURRICANE SANDY ADVISORY NUMBER 21

NWS NATIONAL HURRICANE CENTER MIAMI FL

AL182012

1100 AM EDT SAT OCT 27 2012

STORM SURGE...THE COMBINATION OF A DANGEROUS STORM SURGE AND THE TIDE WILL CAUSE NORMALLY DRY AREAS NEAR THE COAST TO BE FLOODED BY RISING WATERS. THE WATER COULD REACH THE FOLLOWING DEPTHS ABOVE GROUND IF THE PEAK SURGE OCCURS AT THE TIME OF HIGH TIDE...

FL EAST COAST NORTH OF CAPE CANAVERAL...1 TO 2 FT

NC SOUTH OF SURF CITY...1 TO 3 FT

NC NORTH OF SURF CITY INCLUDING PAMLICO/ALBERMARLE SNDS...3 TO 5 FT

SE VA AND DELMARVA INCLUDING LOWER CHESAPEAKE BAY...2 TO 4 FT

UPPER CHESAPEAKE BAY...1 TO 2 FT

OCEAN CITY MD TO THE CT/RI BORDER...4 TO 8 FT

LONG ISLAND SOUND...RARITAN BAY...AND DELAWARE BAY...4 TO 8 FT

SURGE-RELATED FLOODING DEPENDS ON THE RELATIVE TIMING OF THE SURGE AND THE TIDAL CYCLE...AND CAN VARY GREATLY OVER SHORT DISTANCES. GIVEN THE LARGE WIND FIELD ASSOCIATED WITH SANDY...ELEVATED WATER LEVELS COULD SPAN MULTIPLE TIDE CYCLES RESULTING IN REPEATED AND EXTENDED PERIODS OF COASTAL AND BAYSIDE FLOODING. IN ADDITION...ELEVATED WATERS COULD OCCUR FAR REMOVED FROM THE CENTER OF SANDY. FURTHERMORE...THESE CONDITIONS WILL OCCUR REGARDLESS OF WHETHER SANDY IS A TROPICAL OR POST-TROPICAL CYCLONE. FOR INFORMATION SPECIFIC TO YOUR AREA...PLEASE SEE PRODUCTS ISSUED BY YOUR LOCAL NATIONAL WEATHER SERVICE OFFICE.





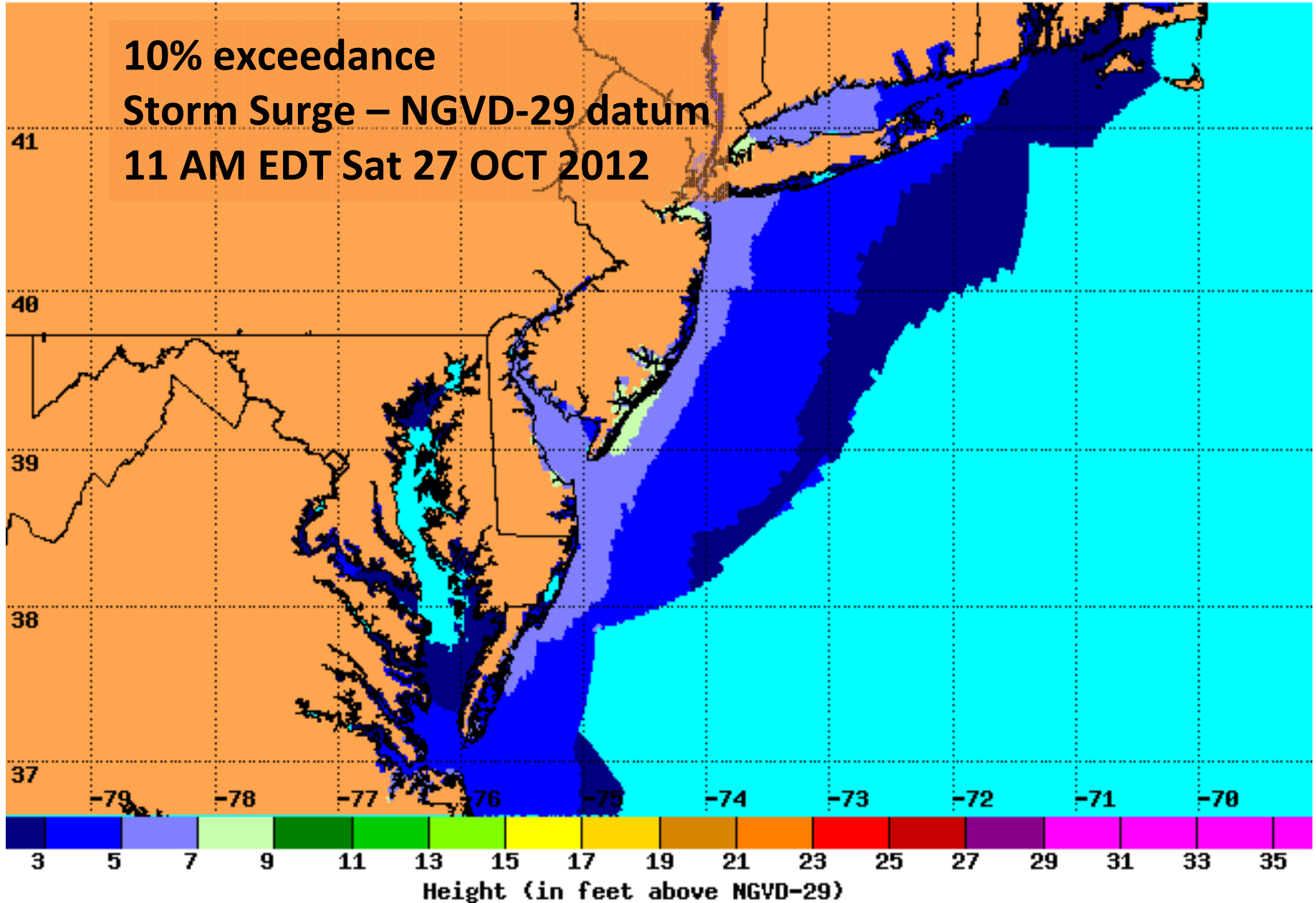
Tropical Cyclone Storm Surge Heights (NGVD-29)  
That Have a 1 in 10 Chance of Being Exceeded

Hurricane Sandy (2012) Advisory 21

Valid from 11 AM EDT Sat Oct 27 to 04 PM EDT Tue Oct 30



10% exceedance  
Storm Surge – NGVD-29 datum  
11 AM EDT Sat 27 OCT 2012

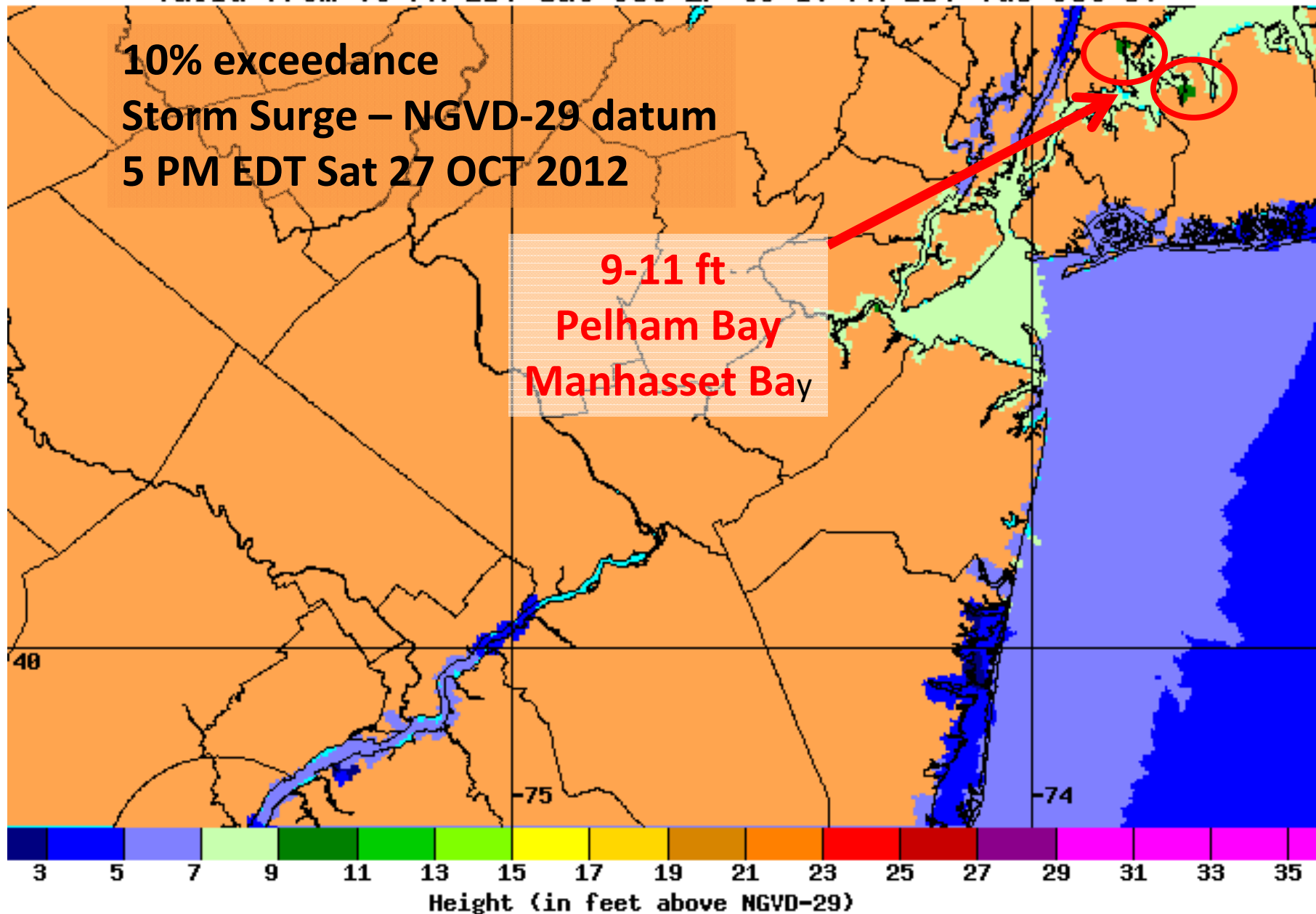




Tropical Cyclone Storm Surge Heights (NGVD-29)  
That Have a 1 in 10 Chance of Being Exceeded

Hurricane Sandy (2012) Advisory 22

Valid from 05 PM EDT Sat Oct 27 to 10 PM EDT Tue Oct 30



BULLETIN

HURRICANE SANDY INTERMEDIATE ADVISORY NUMBER 23A  
NWS NATIONAL HURRICANE CENTER MIAMI FL AL182012  
200 AM EDT SUN OCT 28 2012

...SANDY CONTINUES TO MOVE PARALLEL TO THE SOUTHEAST U.S. COAST...  
...EXPECTED TO BRING STRONG WINDS AND A SIGNIFICANT STORM SURGE TO  
THE MID-ATLANTIC STATES AND SOUTHERN NEW ENGLAND...

NC SOUTH OF SURF CITY...1 TO 3 FT  
NC NORTH OF SURF CITY INCLUDING PAMLICO/ALBEMARLE SNDS...4 TO 6 FT  
SE VA AND DELMARVA INCLUDING LOWER CHESAPEAKE BAY...2 TO 4 FT  
UPPER AND MIDDLE CHESAPEAKE BAY...1 TO 2 FT  
LONG ISLAND SOUND AND RARITAN BAY...5 TO 10 FT  
ELSEWHERE FROM OCEAN CITY MD TO THE CT/RI BORDER...4 TO 8 FT

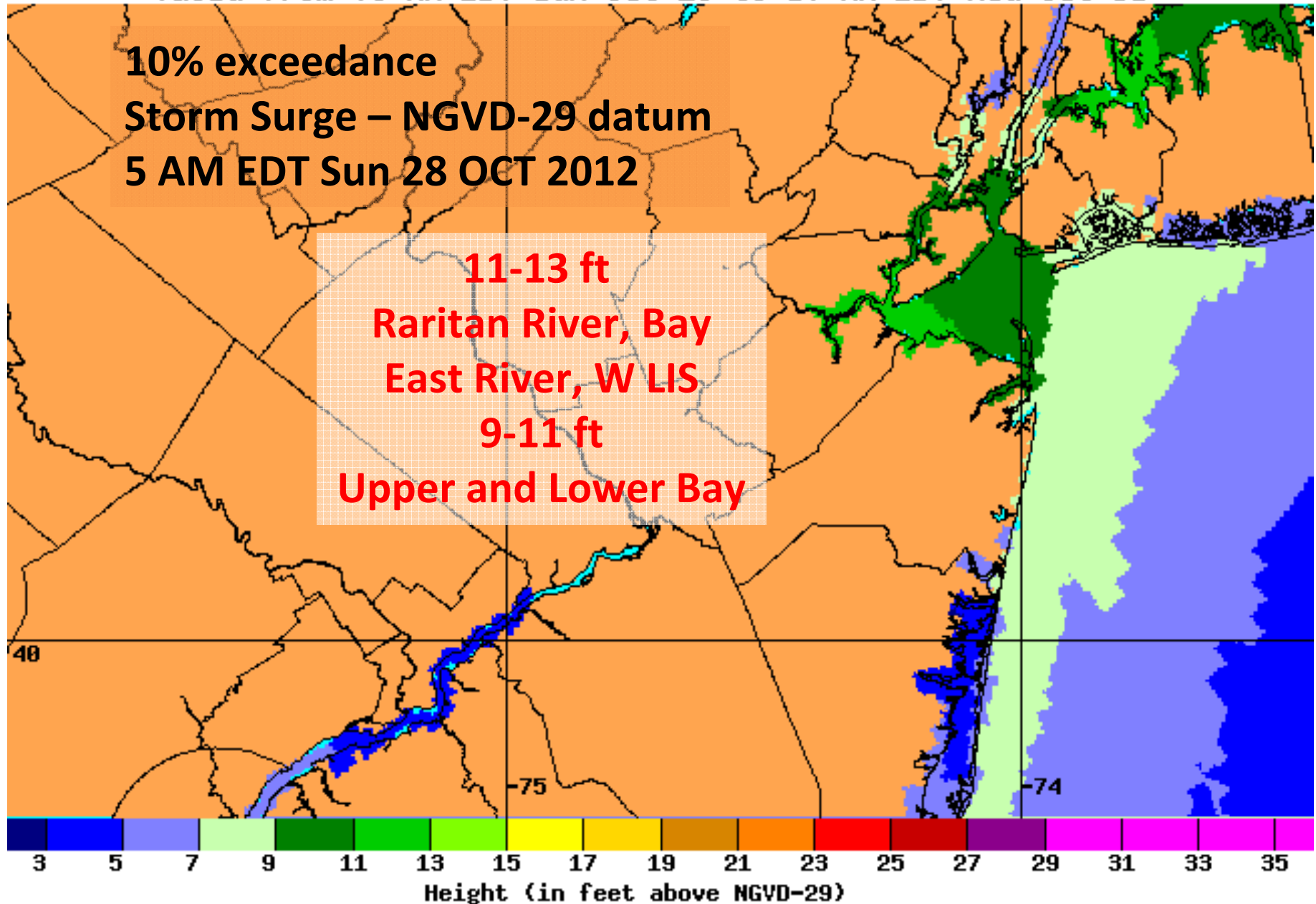




Tropical Cyclone Storm Surge Heights (NGVD-29)  
That Have a 1 in 10 Chance of Being Exceeded

Hurricane Sandy (2012) Advisory 24

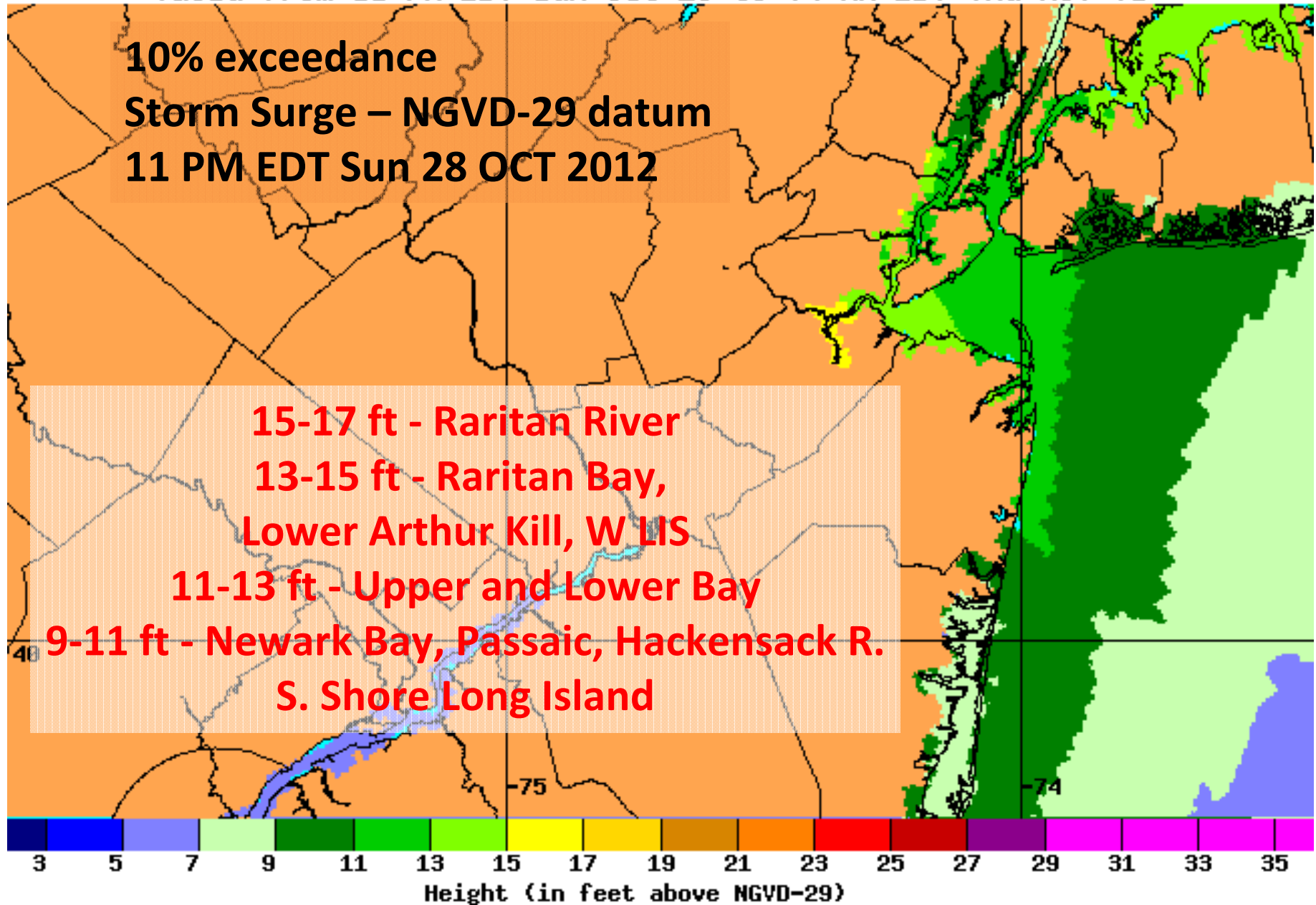
Valid from 05 AM EDT Sun Oct 28 to 10 AM EDT Wed Oct 31





Tropical Cyclone Storm Surge Heights (NGVD-29)  
That Have a 1 in 10 Chance of Being Exceeded

Hurricane Sandy (2012) Advisory 27  
Valid from 11 PM EDT Sun Oct 28 to 04 AM EDT Thu Nov 01



BULLETIN

HURRICANE SANDY INTERMEDIATE ADVISORY NUMBER 24A...CORRECTED  
NWS NATIONAL HURRICANE CENTER MIAMI FL AL182012  
800 AM EDT SUN OCT 28 2012

...SANDY EXPECTED TO BRING LIFE-THREATENING STORM SURGE FLOODING TO  
THE MID-ATLANTIC COAST...INCLUDING LONG ISLAND SOUND AND NEW YORK  
HARBOR...

...WINDS EXPECTED TO BE NEAR HURRICANE FORCE AT LANDFALL...

NC SOUTH OF SURF CITY...1 TO 3 FT

NC NORTH OF SURF CITY INCLUDING PAMLICO/ALBEMARLE SOUNDS...4 TO 6 FT

SE VA AND DELMARVA INCLUDING LOWER CHESAPEAKE BAY...2 TO 4 FT

UPPER AND MIDDLE CHESAPEAKE BAY...1 TO 2 FT

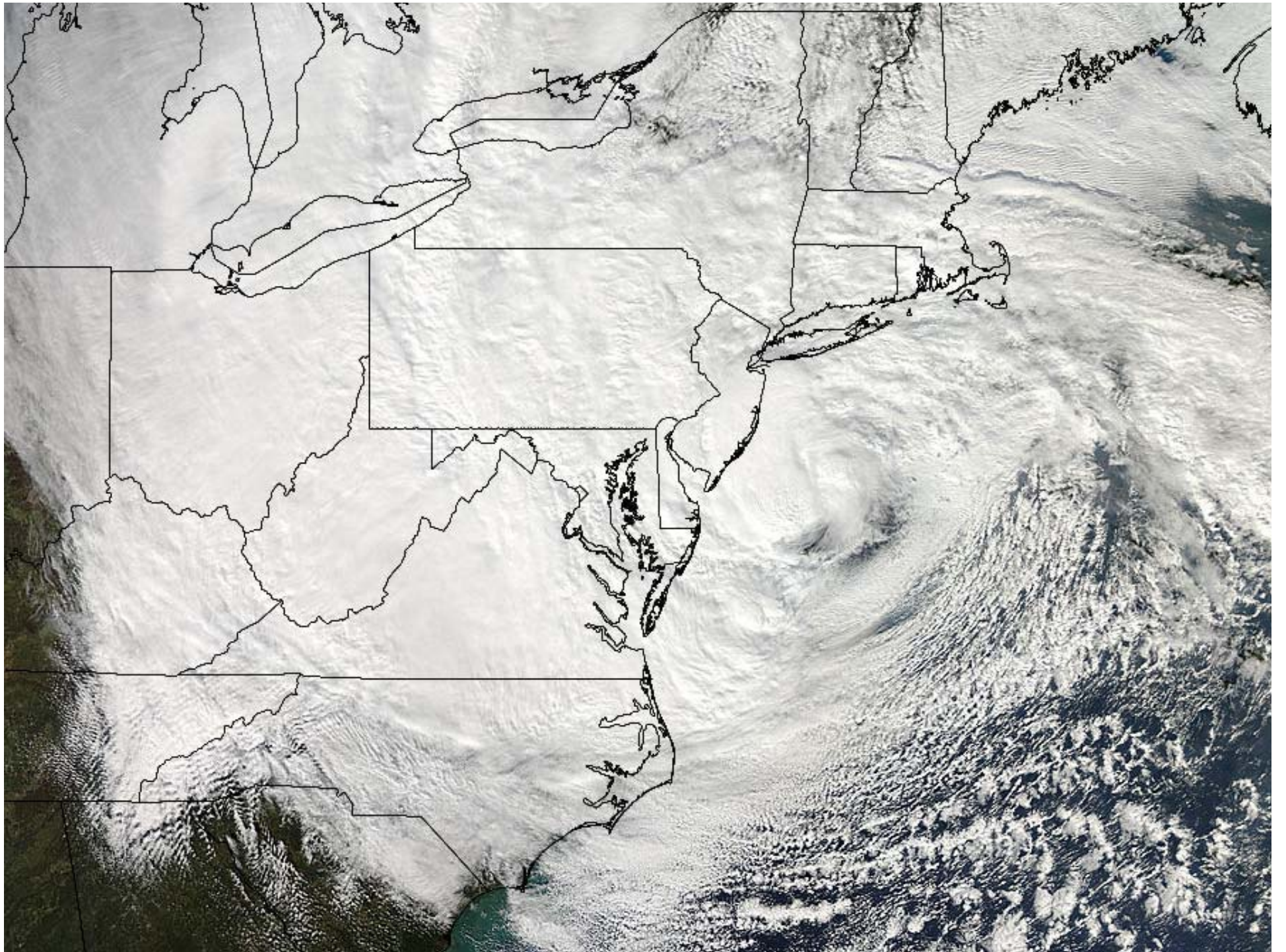
LONG ISLAND SOUND AND RARITAN BAY INCLUDING NEW YORK HARBOR...6 TO

11 FT

ELSEWHERE FROM OCEAN CITY MD TO THE CT/RI BORDER...4 TO 8 FT

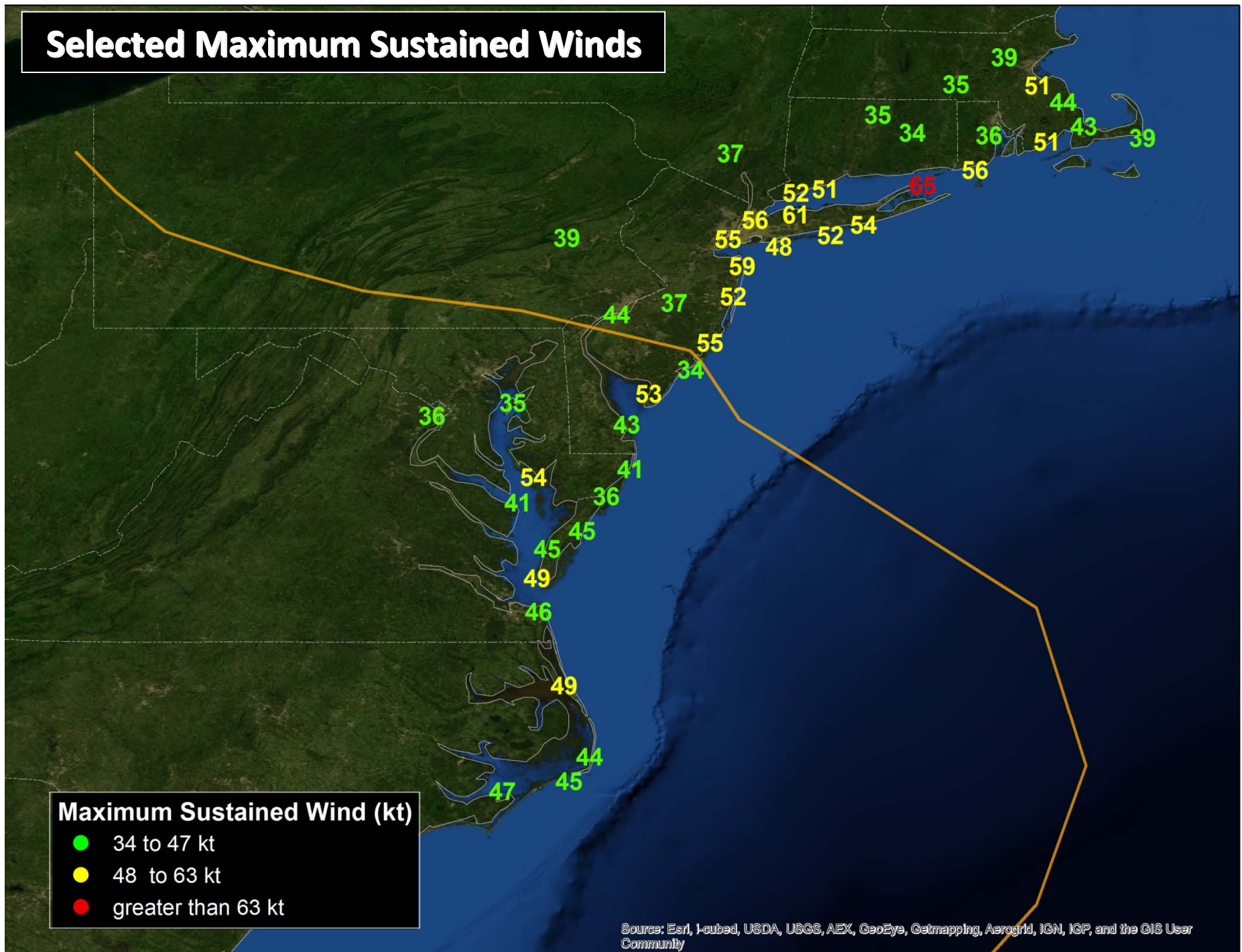
CT/RI BORDER TO THE SOUTH SHORE OF CAPE COD INCLUDING BUZZARDS  
BAY...3 TO 5 FT







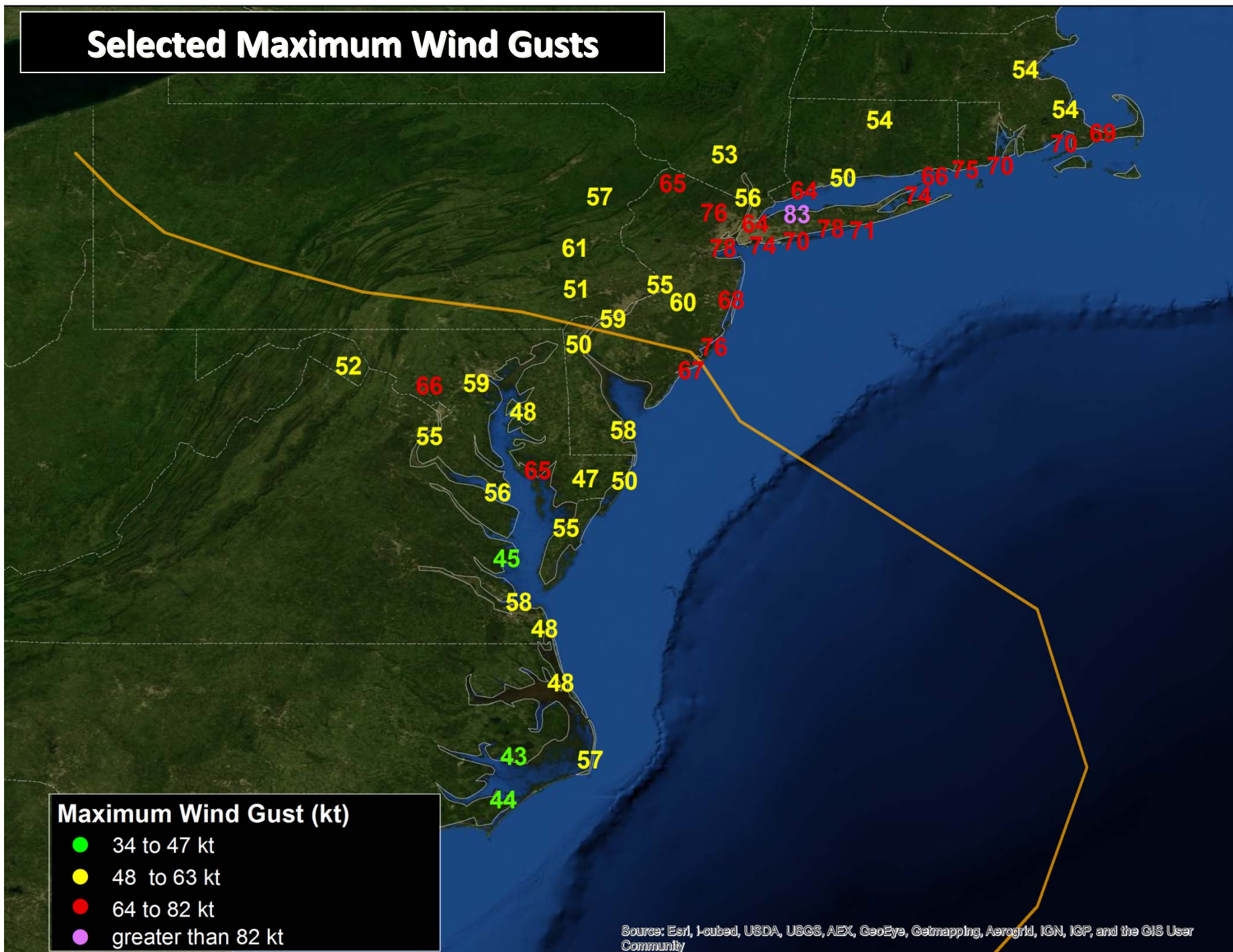
# Selected Maximum Sustained Winds



- Maximum Sustained Wind (kt)**
- 34 to 47 kt
  - 48 to 63 kt
  - greater than 63 kt

Source: Esri, I-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

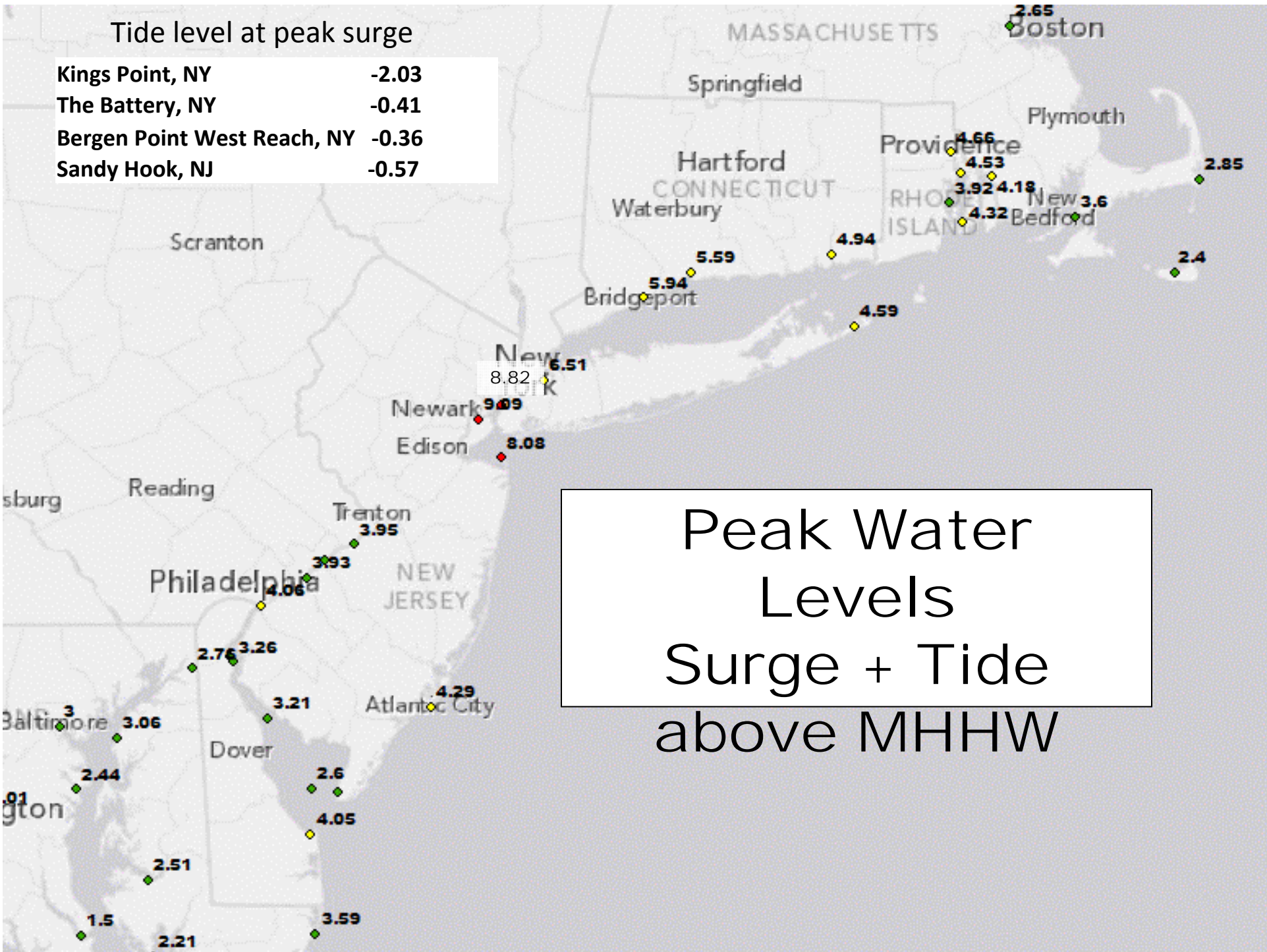
# Selected Maximum Wind Gusts





Tide level at peak surge

Kings Point, NY	-2.03
The Battery, NY	-0.41
Bergen Point West Reach, NY	-0.36
Sandy Hook, NJ	-0.57



Peak Water Levels  
Surge + Tide  
above MHHW

# Sandy

## Summary

- **Historic event**
  - Unusual track
  - Rare, complex evolution
  - Destructive potential
  - Widespread and varied impacts
- **Forecasts**
  - Heavy reliance on ensemble datasets
  - A large team effort with extensive collaboration
- **A coordinated message**
  - Weather enterprise





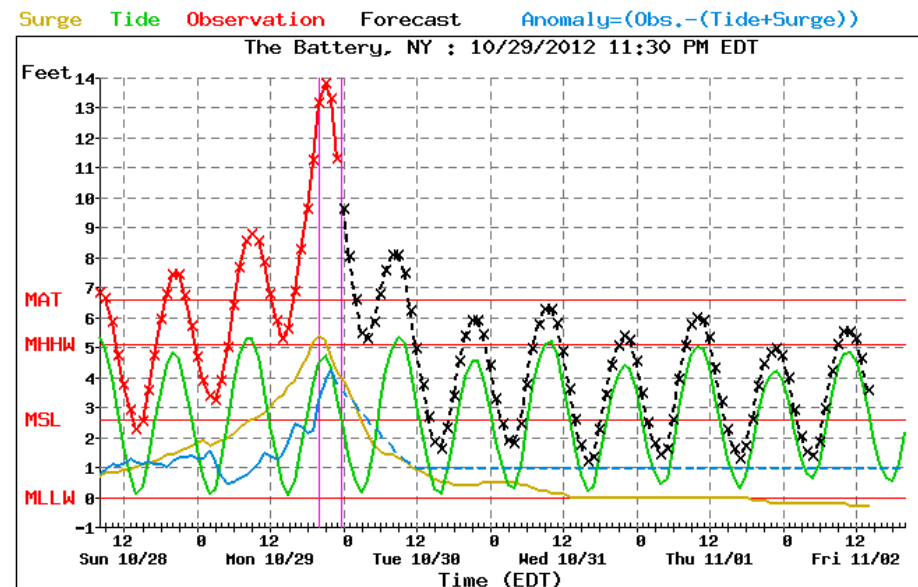
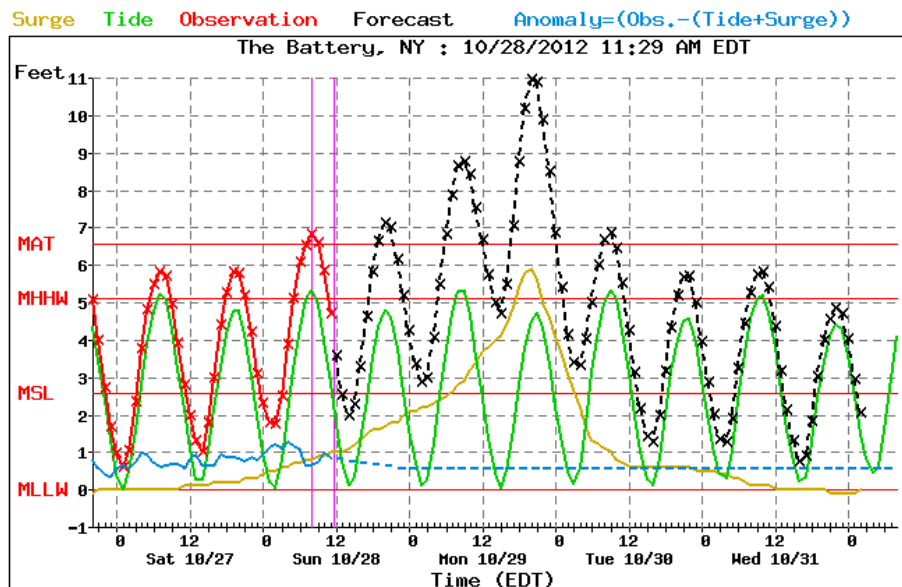
# Additional Slides





# Hurricane Sandy: Collaborative Forecast Process

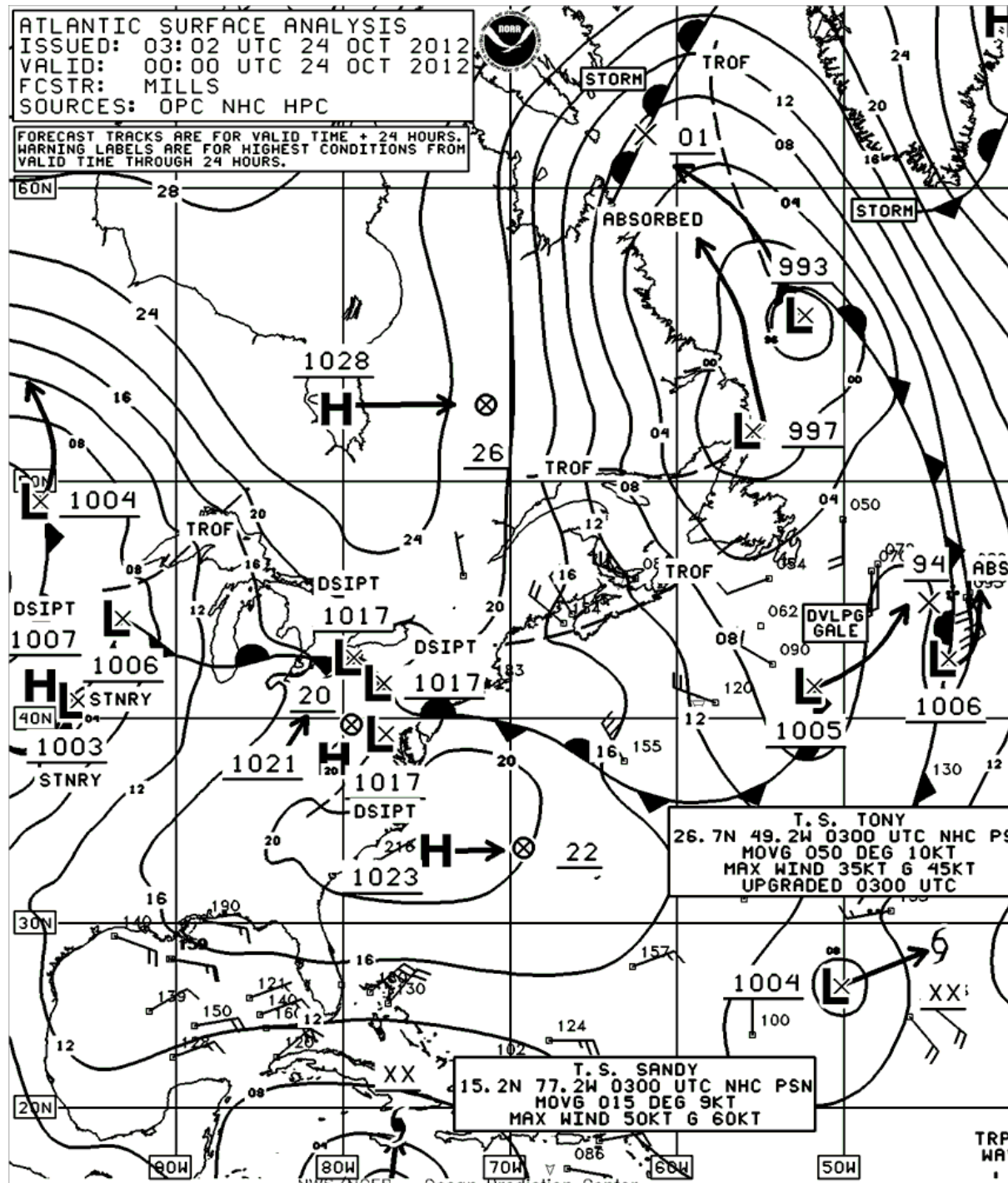
MDL NWS Surge Guidance and Verification:  
Forecasts were coordinated among NHC, OPC, local WFOs



“Life Threatening” statements issued Sunday morning by NHC and called into NYC Emergency Operations Center; NYC initiates evacuations and shut down of public transportation shortly thereafter

ATLANTIC SURFACE ANALYSIS  
 ISSUED: 03:02 UTC 24 OCT 2012  
 VALID: 00:00 UTC 24 OCT 2012  
 FCSTR: MILLS  
 SOURCES: OPC NHC HPC

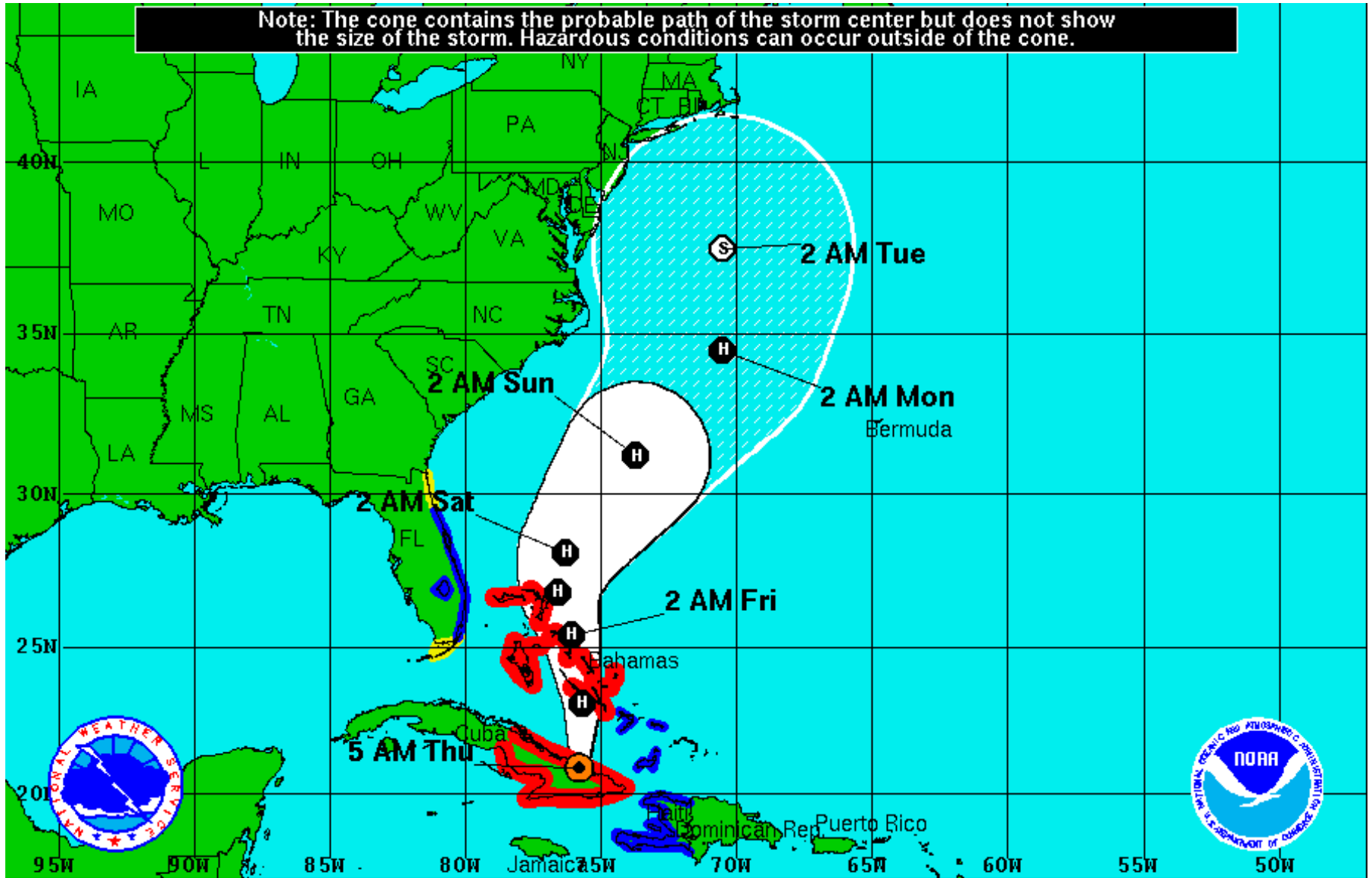
FORECAST TRACKS ARE FOR VALID TIME + 24 HOURS.  
 WARNING LABELS ARE FOR HIGHEST CONDITIONS FROM  
 VALID TIME THROUGH 24 HOURS.




T. S. TONY  
 26.7N 49.2W 0300 UTC NHC PS  
 MOVG 050 DEG 10KT  
 MAX WIND 35KT G 45KT  
 UPGRADED 0300 UTC



T. S. SANDY  
 15.2N 77.2W 0300 UTC NHC PSN  
 MOVG 015 DEG 9KT  
 MAX WIND 50KT G 60KT

Note: The cone contains the probable path of the storm center but does not show the size of the storm. Hazardous conditions can occur outside of the cone.



**Hurricane Sandy**  
 Thursday October 25, 2012  
 5 AM EDT Advisory 12  
 NWS National Hurricane Center

**Current Information:**   
 Center Location 20.9 N 75.8 W  
 Max Sustained Wind 105 mph  
 Movement N at 18 mph

**Forecast Positions:**  
 Tropical Cyclone  Post-Tropical  
 Sustained Winds: D < 39 mph  
 S 39-73 mph H 74-110 mph M > 110mph

**Potential Track Area:**  
 Day 1-3  Day 4-5

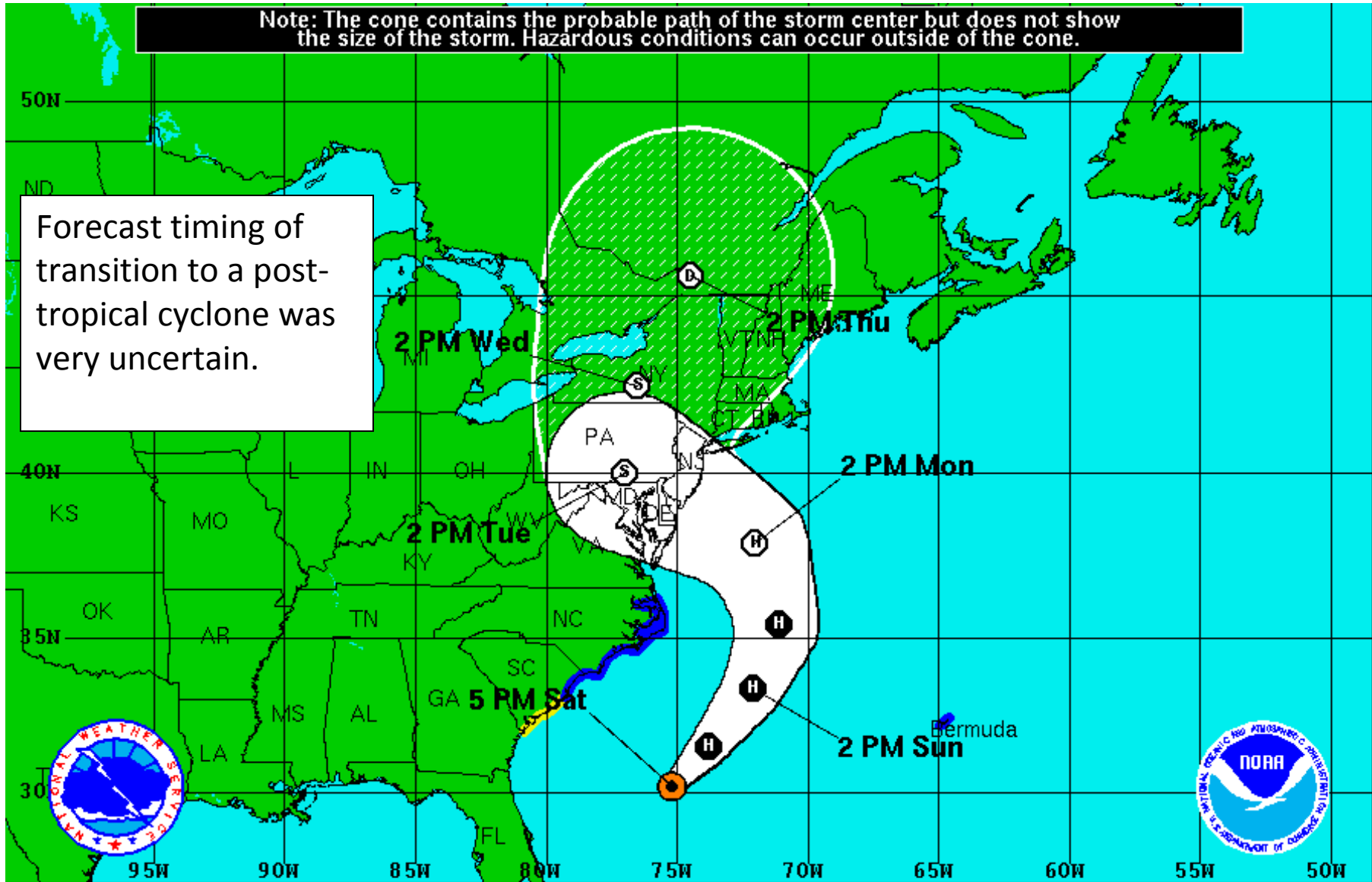
**Watches:**  
 Hurricane  Trop.Storm

**Warnings:**  
 Hurricane  Trop.Storm



Note: The cone contains the probable path of the storm center but does not show the size of the storm. Hazardous conditions can occur outside of the cone.

Forecast timing of transition to a post-tropical cyclone was very uncertain.



**Hurricane Sandy**  
 Saturday October 27, 2012  
 5 PM EDT Advisory 22  
 NWS National Hurricane Center

**Current Information:** ●  
 Center Location 30.2 N 75.2 W  
 Max Sustained Wind 75 mph  
 Movement NE at 13 mph

**Forecast Positions:**  
 ● Tropical Cyclone ○ Post-Tropical  
 Sustained Winds: D < 39 mph  
 S 39-73 mph H 74-110 mph M > 110mph

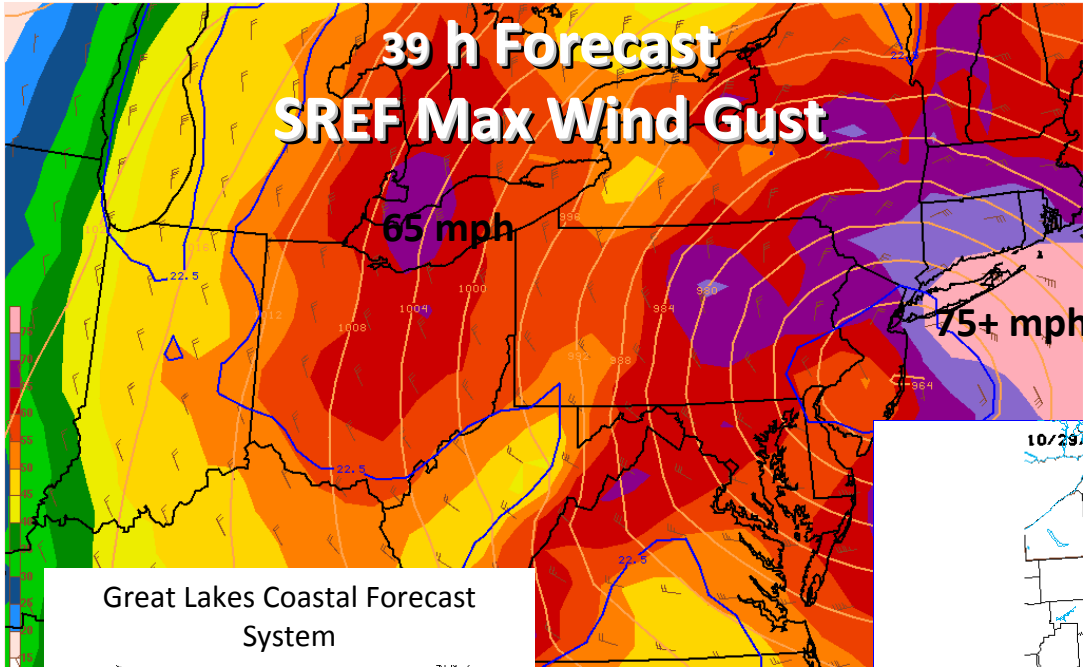
**Potential Track Area:**  
 ▽ Day 1-3 ▽ Day 4-5

**Watches:**  
 ■ Hurricane ■ Trop.Storm

**Warnings:**  
 ■ Hurricane ■ Trop.Storm

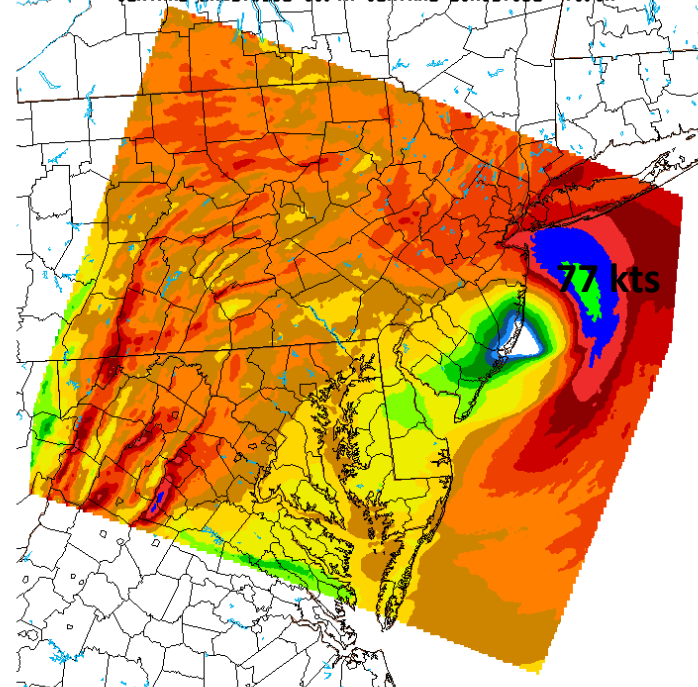


# Wind and Wave Forecasts

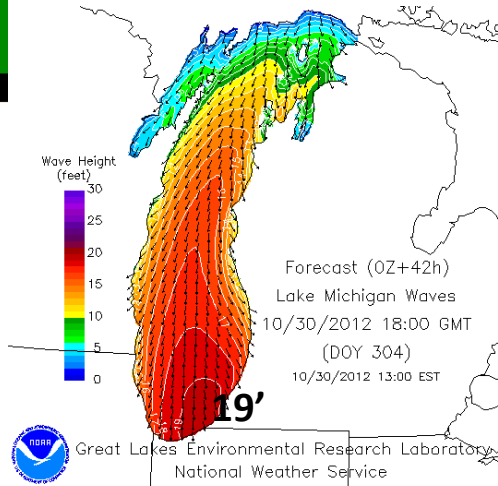


18 h Forecast  
1.33 km NAM  
Wind Gust

10/29/2012 06UTC-018HR FCST VALID TUE 10/30/2012 00UTC NCEP/NWS/NO  
CENTRAL LATITUDE=39.7N CENTRAL LONGITUDE=-76.0W

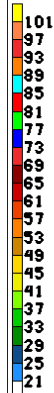


Great Lakes Coastal Forecast  
System



Issued Sunday Morn

Courtesy Peter Manouse



Issued Saturday Evening, Oct 27

Issued Monday Morning, Oct 28

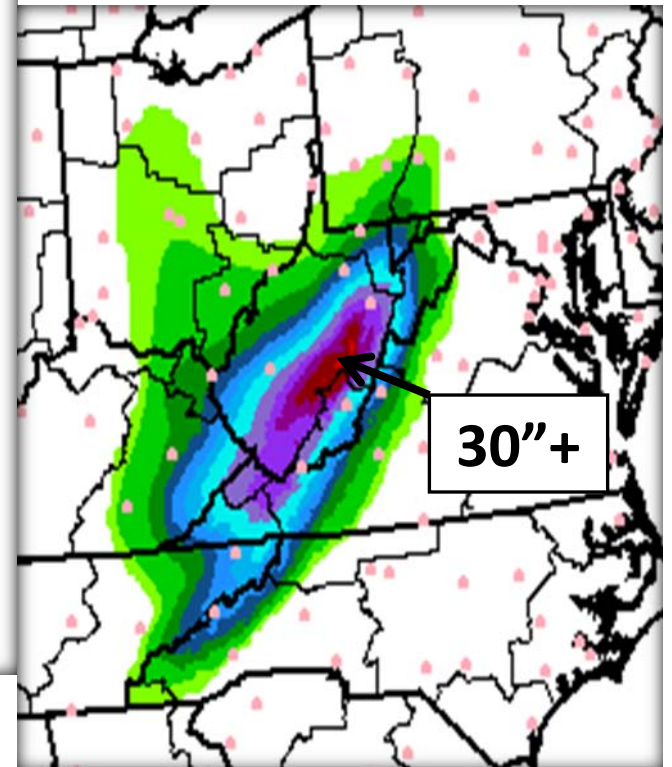
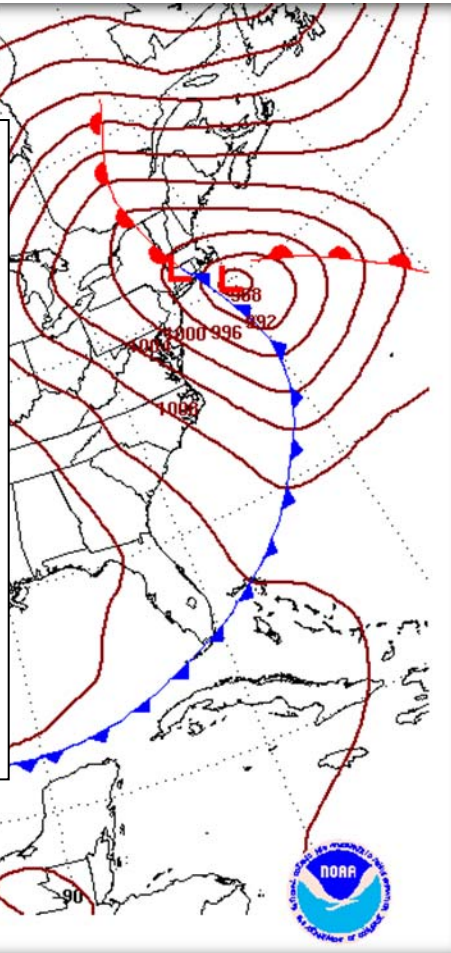
# Snowfall

**7 Days Prior to Landfall:**

**"...BESIDES THE WIND, THE OTHER SENSIBLE WEATHER THREAT IS HEAVY RAINS, WITH HEAVY SNOWS POSSIBLE ON THE SOUTHWEST SIDE OF THE HYBRID CIRCULATION..."**

CISCO

HPC DAY 7 SFC PROG  
ISSUED: 1847Z TUE OCT 23 2012  
VALID: 12Z TUE OCT 30 2012  
FCSTR: CISCO  
DOC/NOAA/NWS/NCEP/HPC

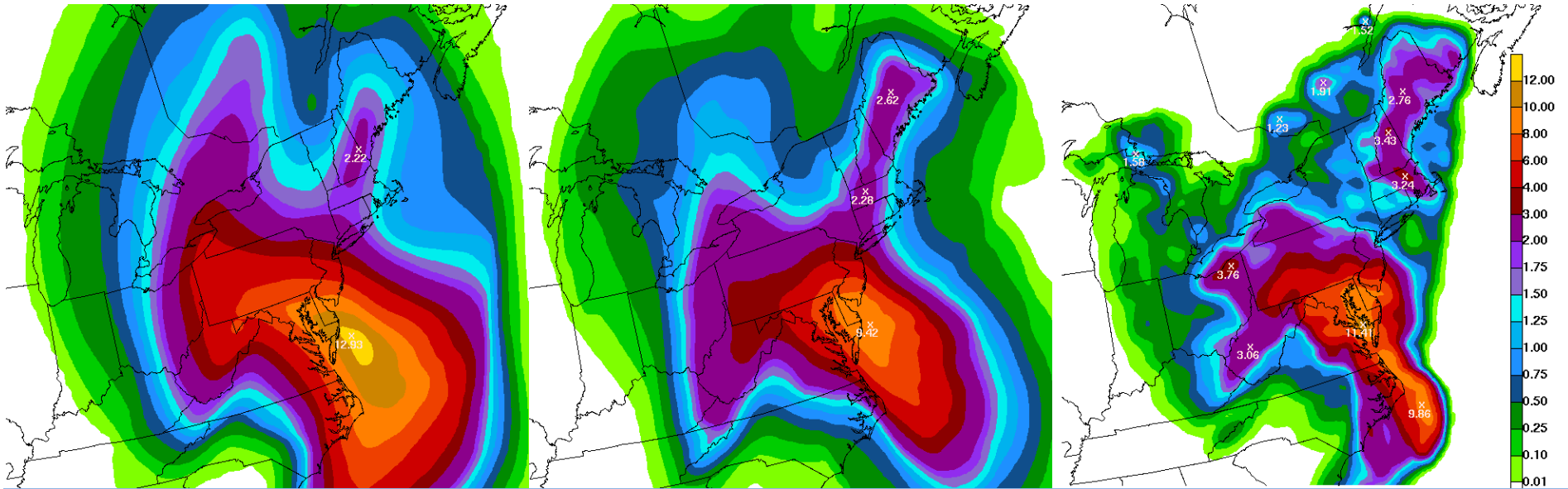


3 day Snow Total:  
Issued Sunday morning, Oct 28



# Rainfall

## Very accurate rainfall forecasts



5 Day Precipitation Forecast:  
Issued Friday morning, Oct 26

3 Day Precipitation Forecast:  
Issued Sunday morning, Oct 28

Observed Rainfall

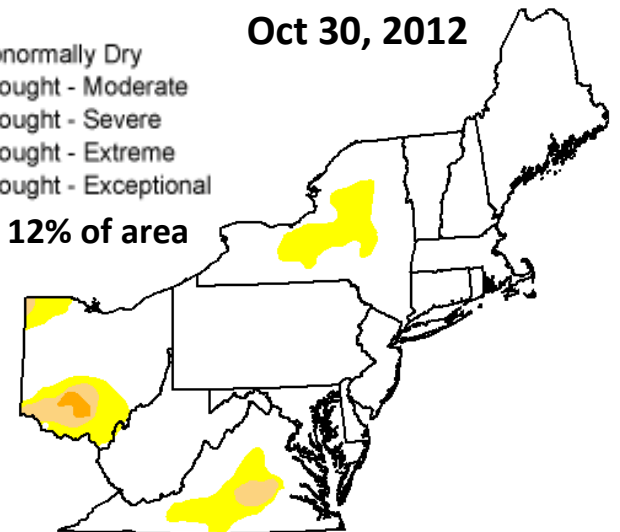
## Rainfall alleviated drought

### Intensity:

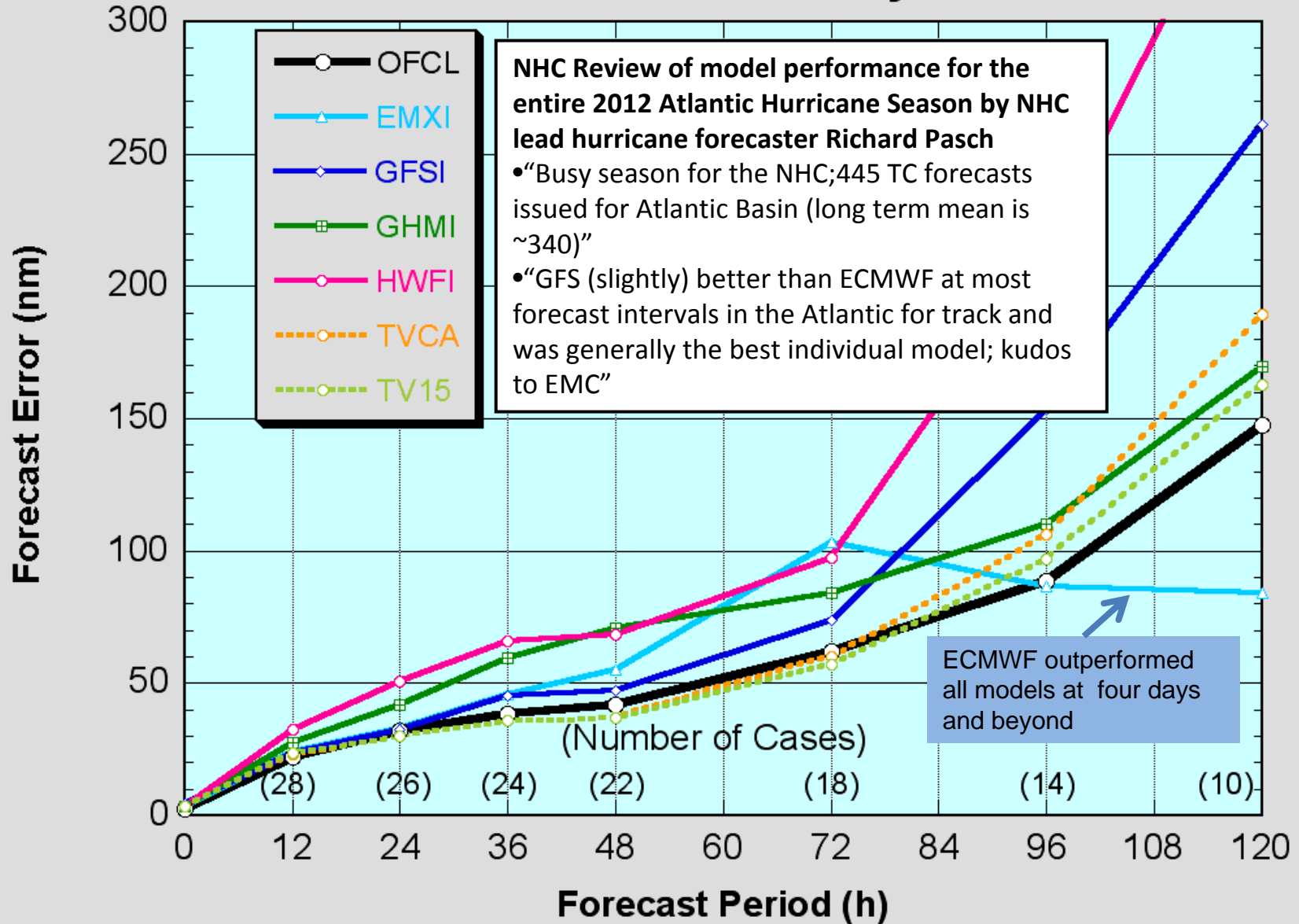
- D0 Abnormally Dry
- D1 Drought - Moderate
- D2 Drought - Severe
- D3 Drought - Extreme
- D4 Drought - Exceptional

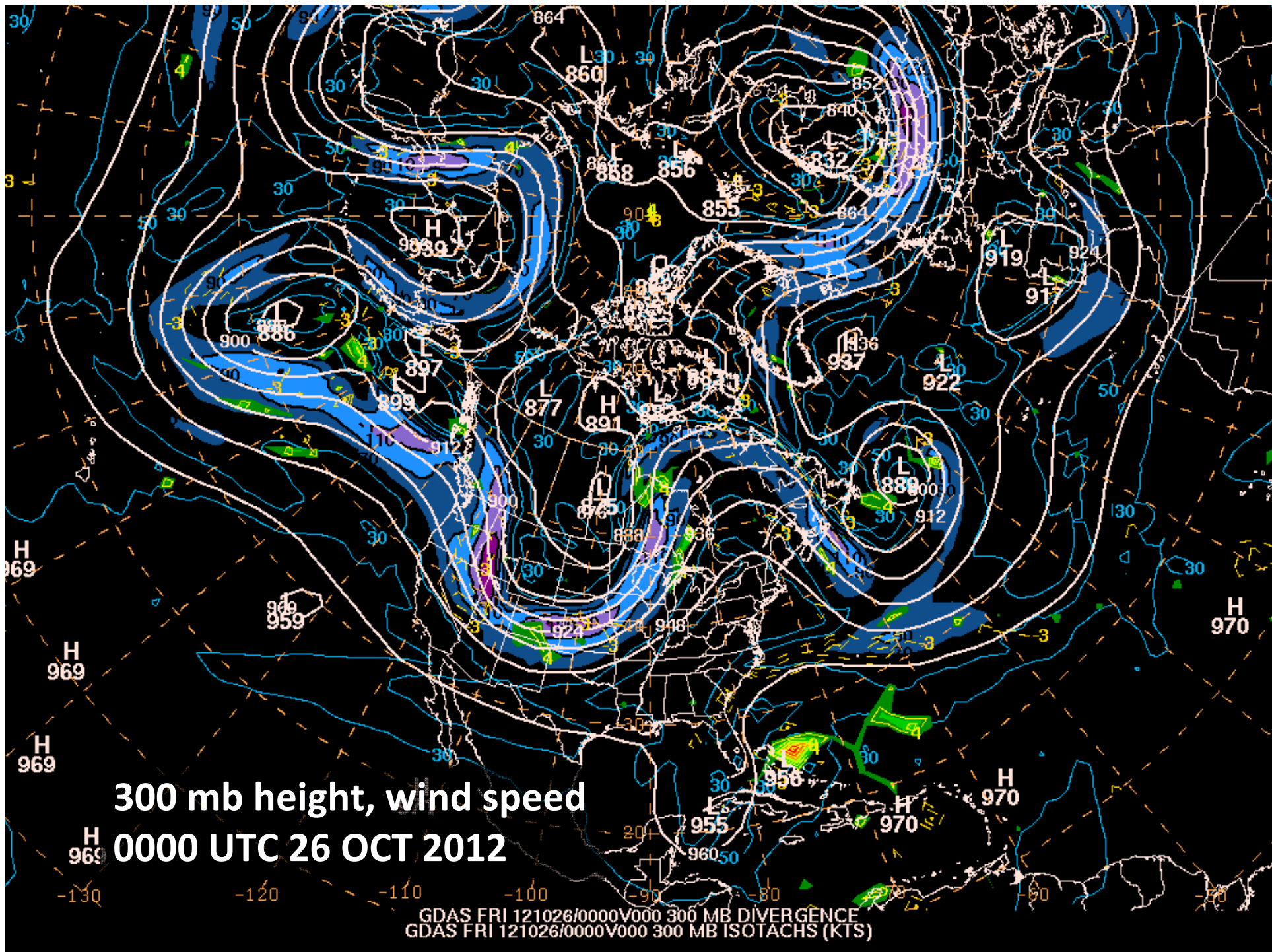
**D0-D4: 12% of area**

**Oct 30, 2012**

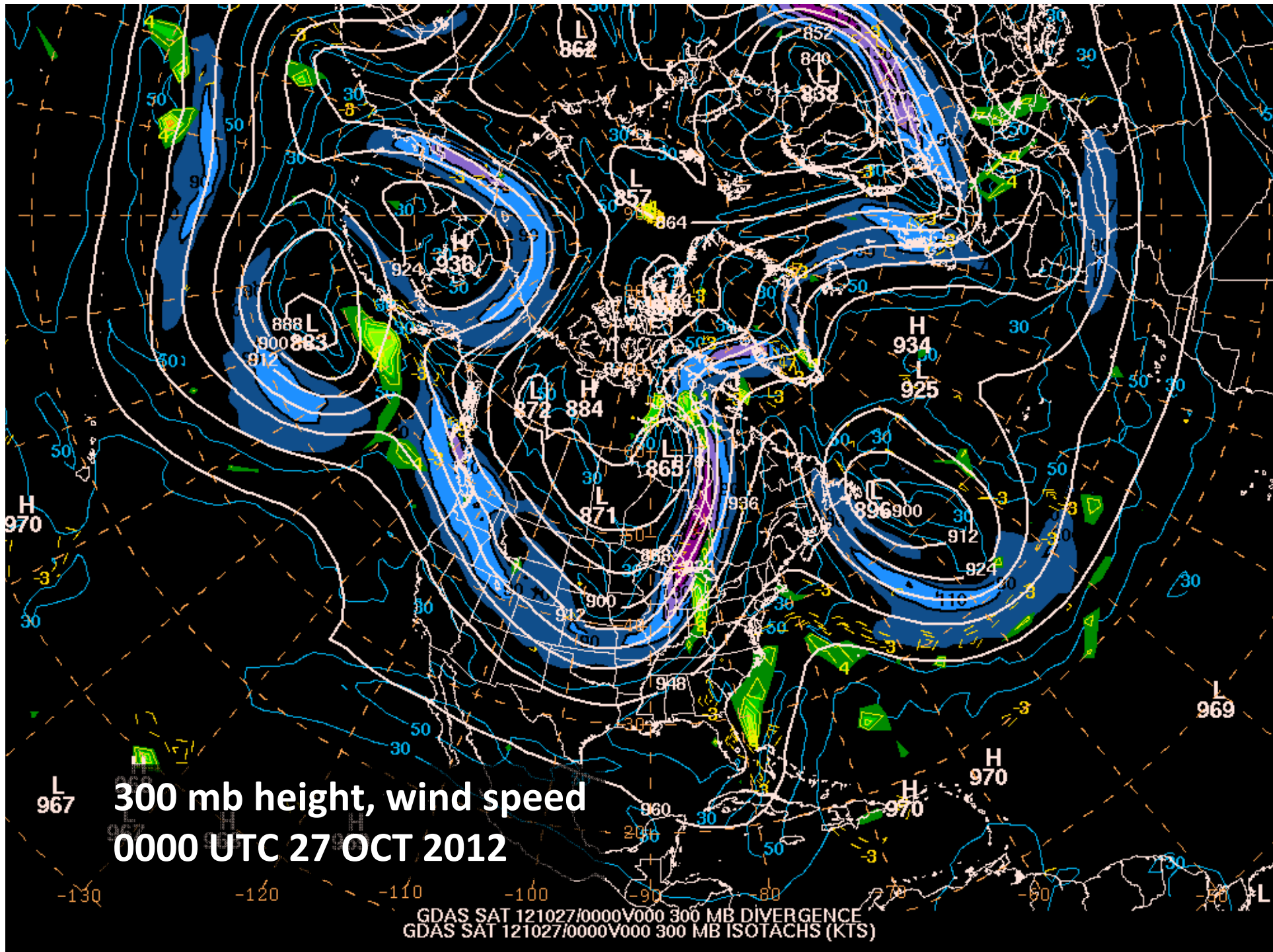


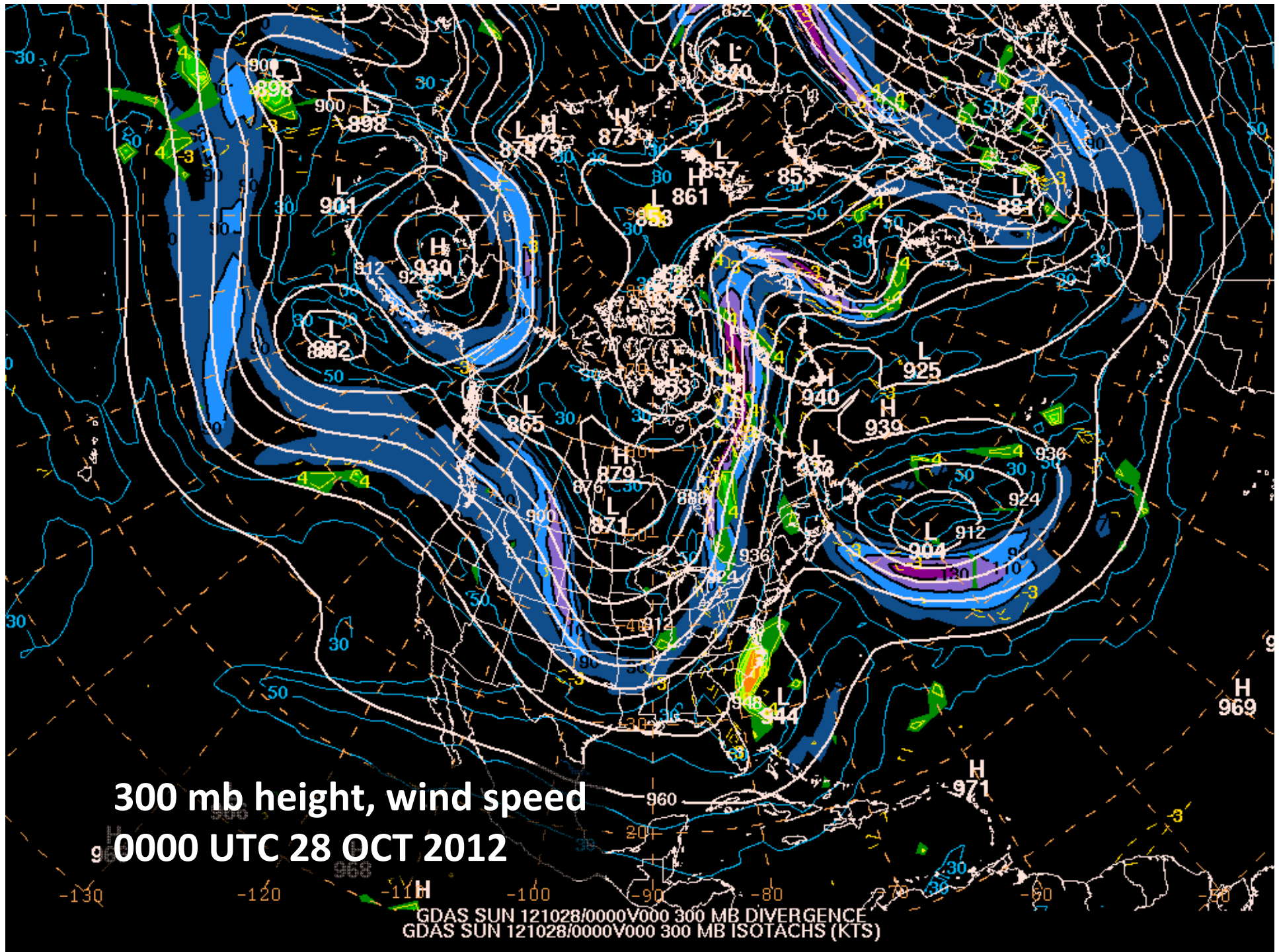
# Preliminary Average Track Errors Hurricane Sandy



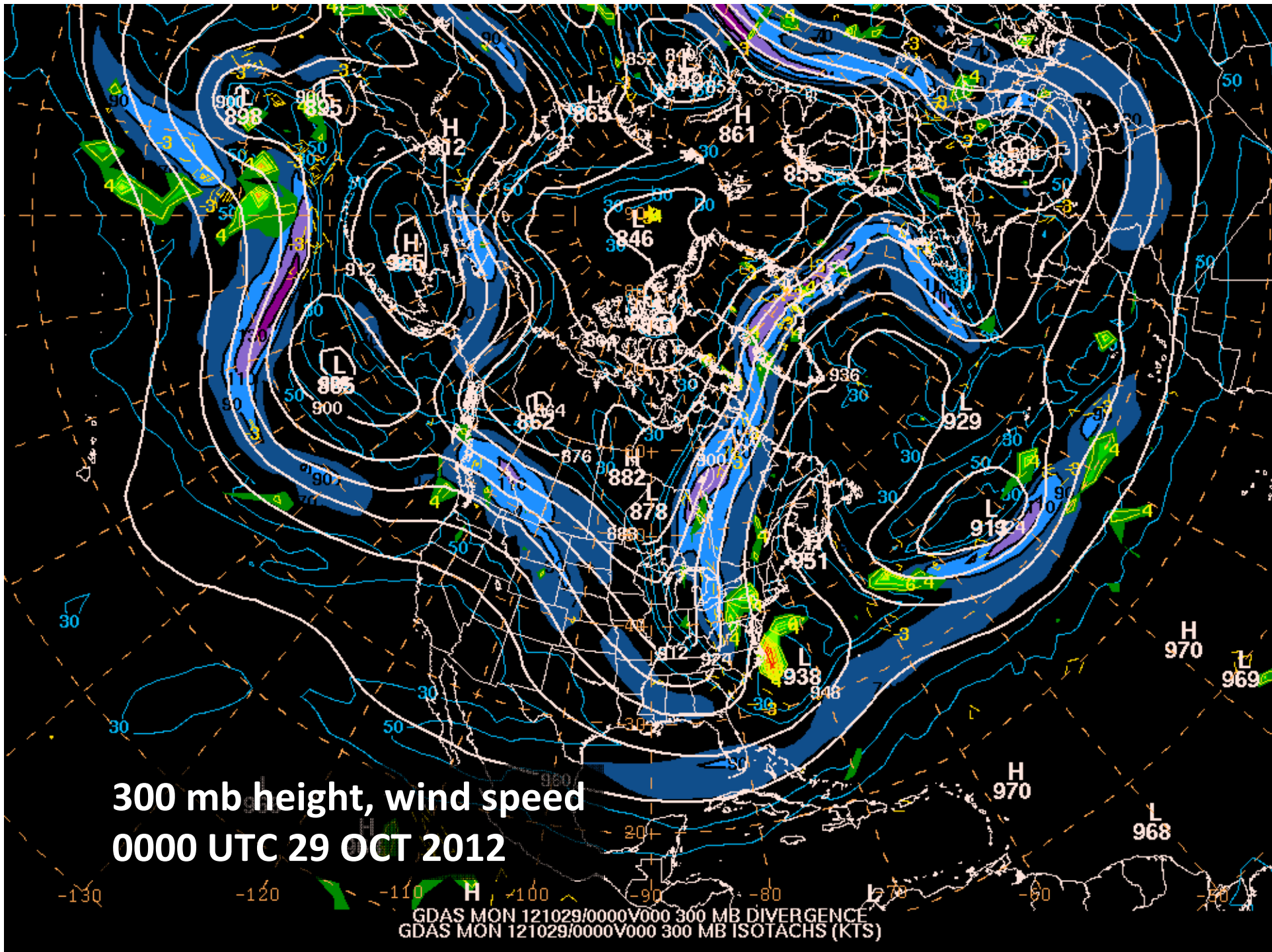




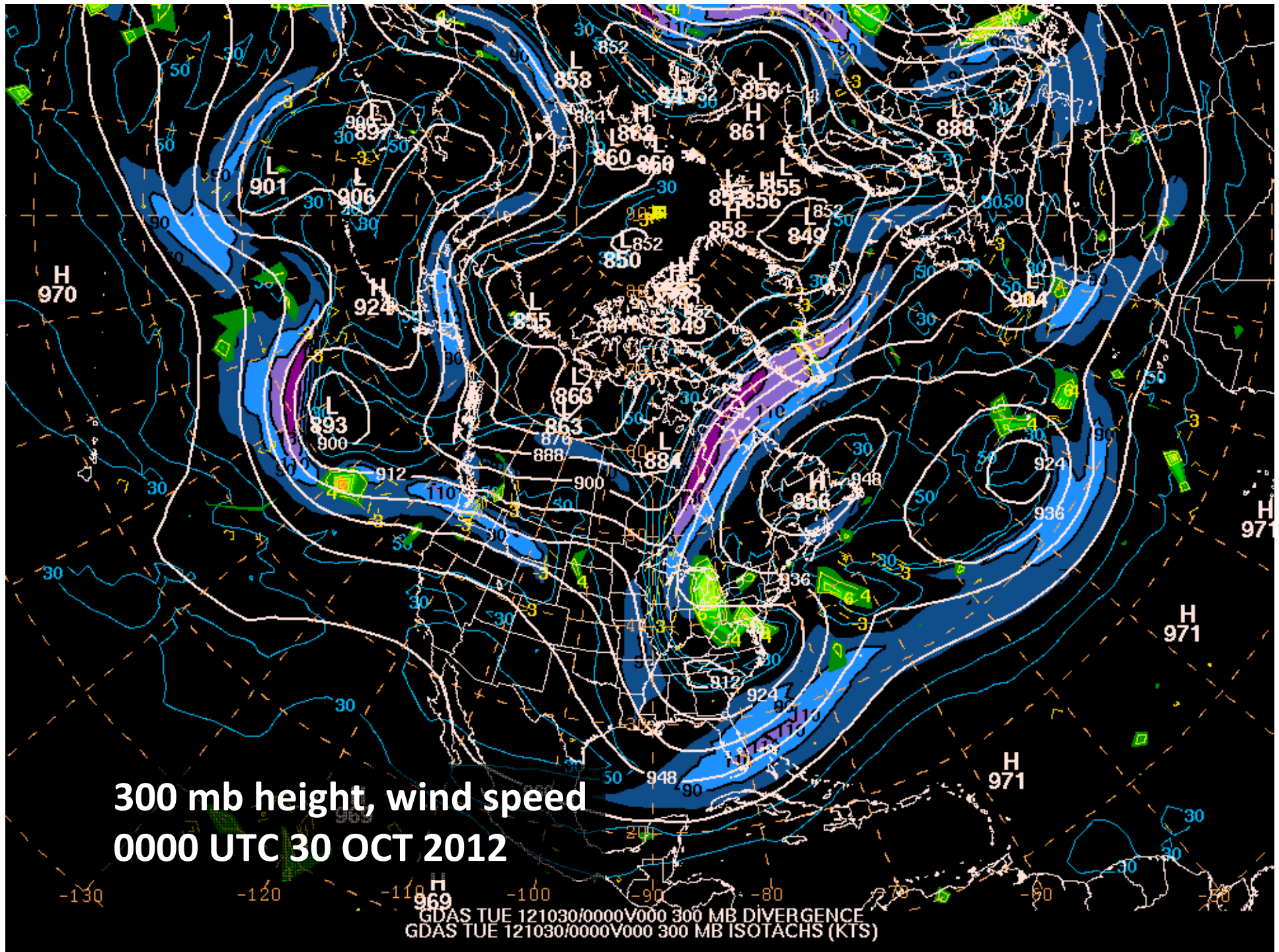


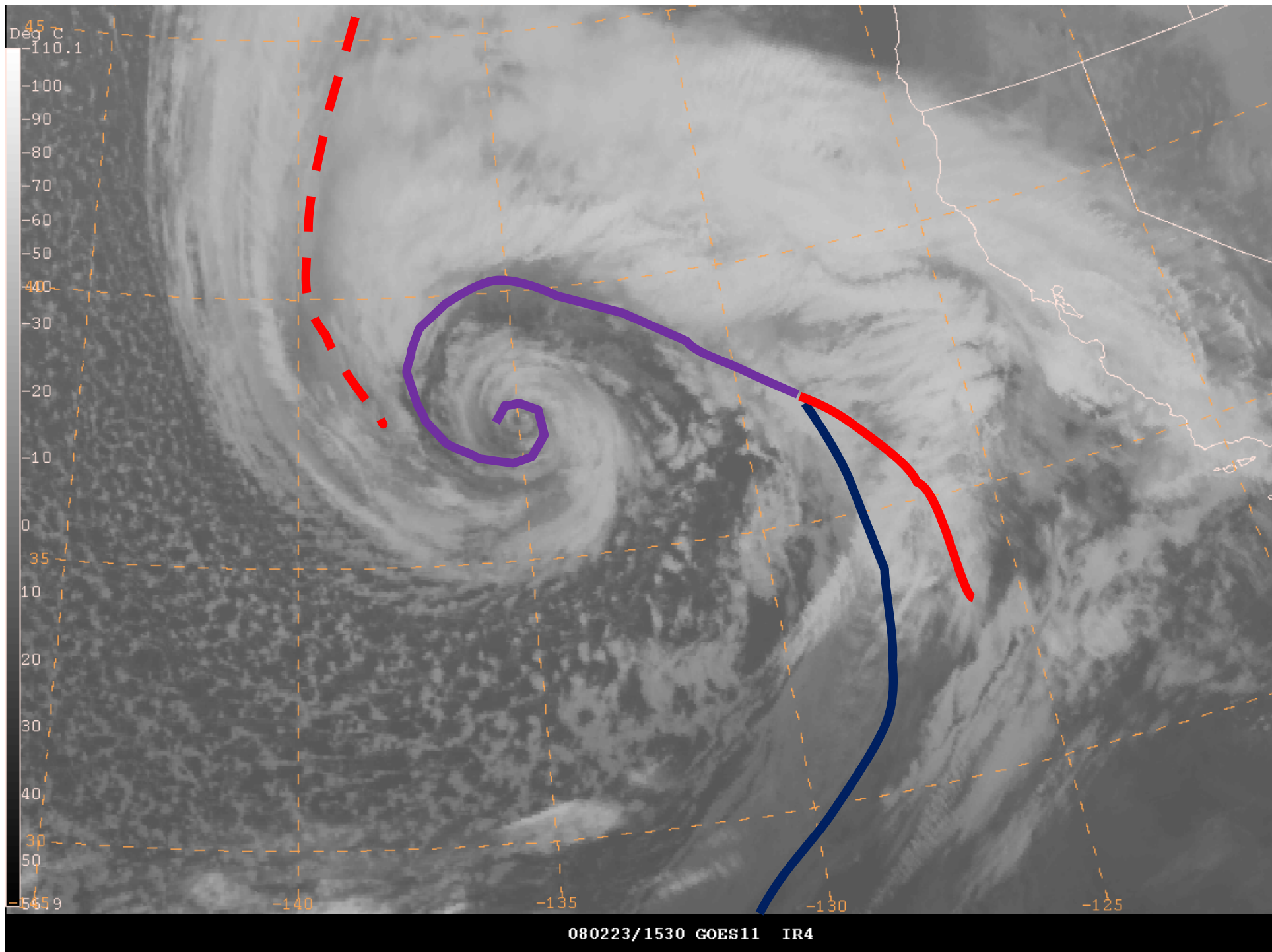




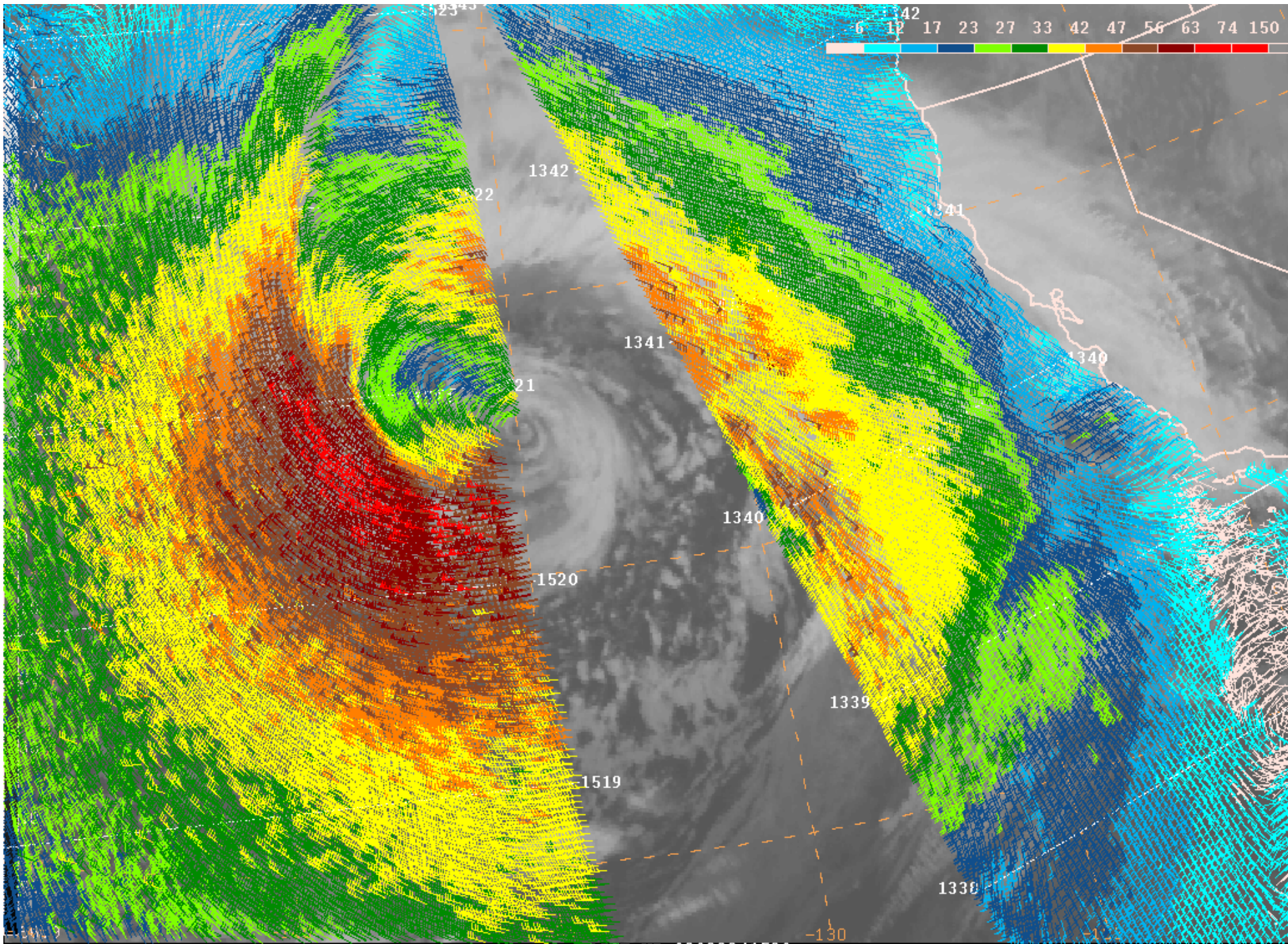












OSCT HI 080223/1530  
080223/1530 GOES11 IR4



# Extra-tropical Cyclones (Frontal cyclones)

