The NCEP Application of Ensemble Systems Across Multiple Scales and User Groups

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13th Workshop on Meteorological Operational Systems
European Center for Medium-Range Weather Forecasts
Reading, United Kingdom

October 31 – November 4, 2011

Where Americas Climate and Weather Services Begin

Outline

- **NCEP Background**
- **NCEP Operational Ensemble Systems**
  - GEFS
  - NAEFS
  - SREF
  - SSEO
- **Applications**
  - Convection and Severe Convective Storms
  - Winter Weather
  - Oceanic Prediction and Tropical Storms
  - Wildfires
  - Aviation
- **Summary**

National Centers for Environmental Prediction

"From Sun to Sea"

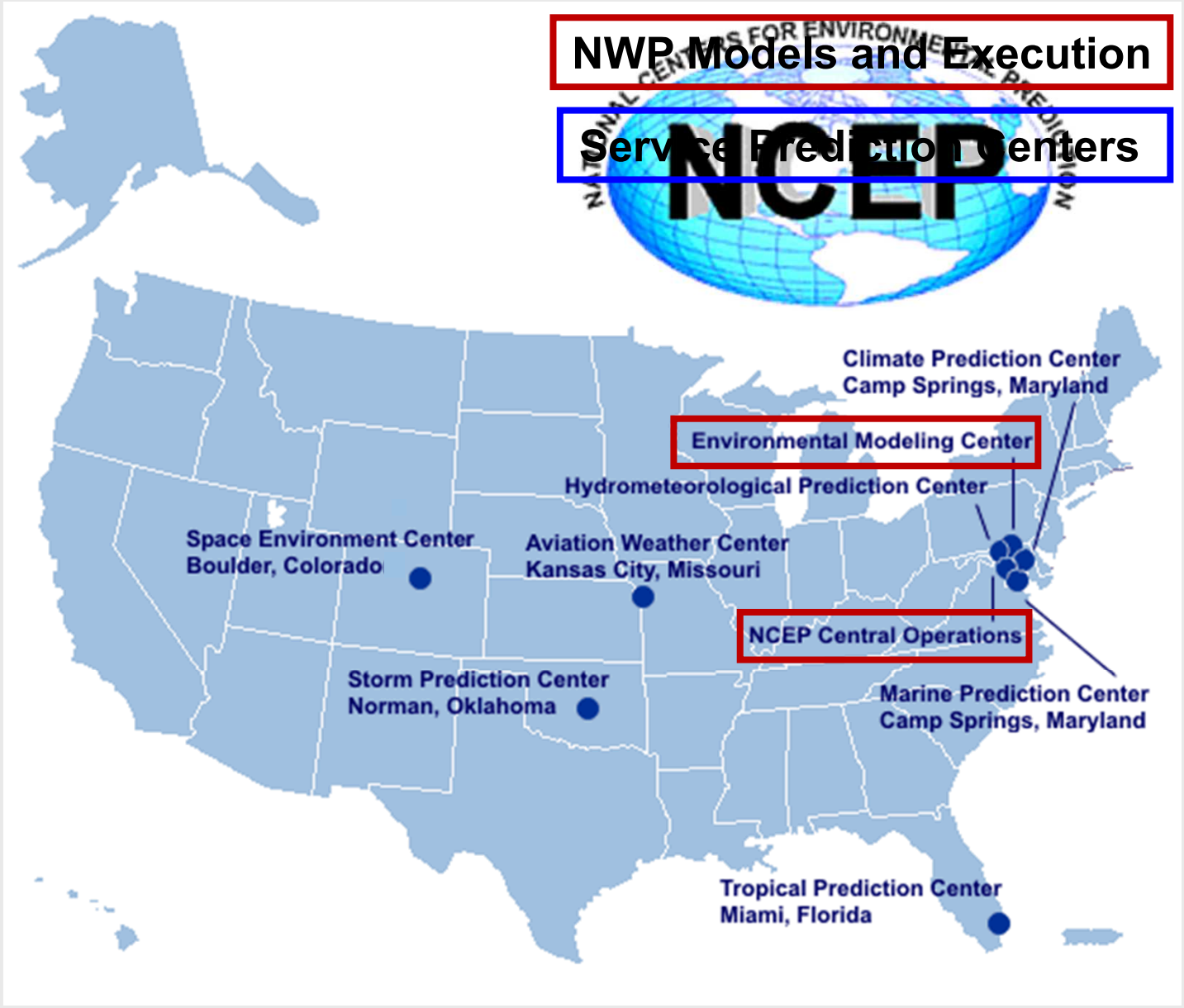







National Centers for Environmental Prediction

"From Sun to Sea"



AWC — Aviation Weather Center

SWPC — Space Weather Prediction Center

SPC — Storm Prediction Center

CPC — Climate Prediction Center

HPC — Hydrometeorological Prediction Center

OPC — Ocean Prediction Center

NHC — National Hurricane Center

National Centers for Environmental Prediction

Organization:

Central component of NOAA National Weather Service

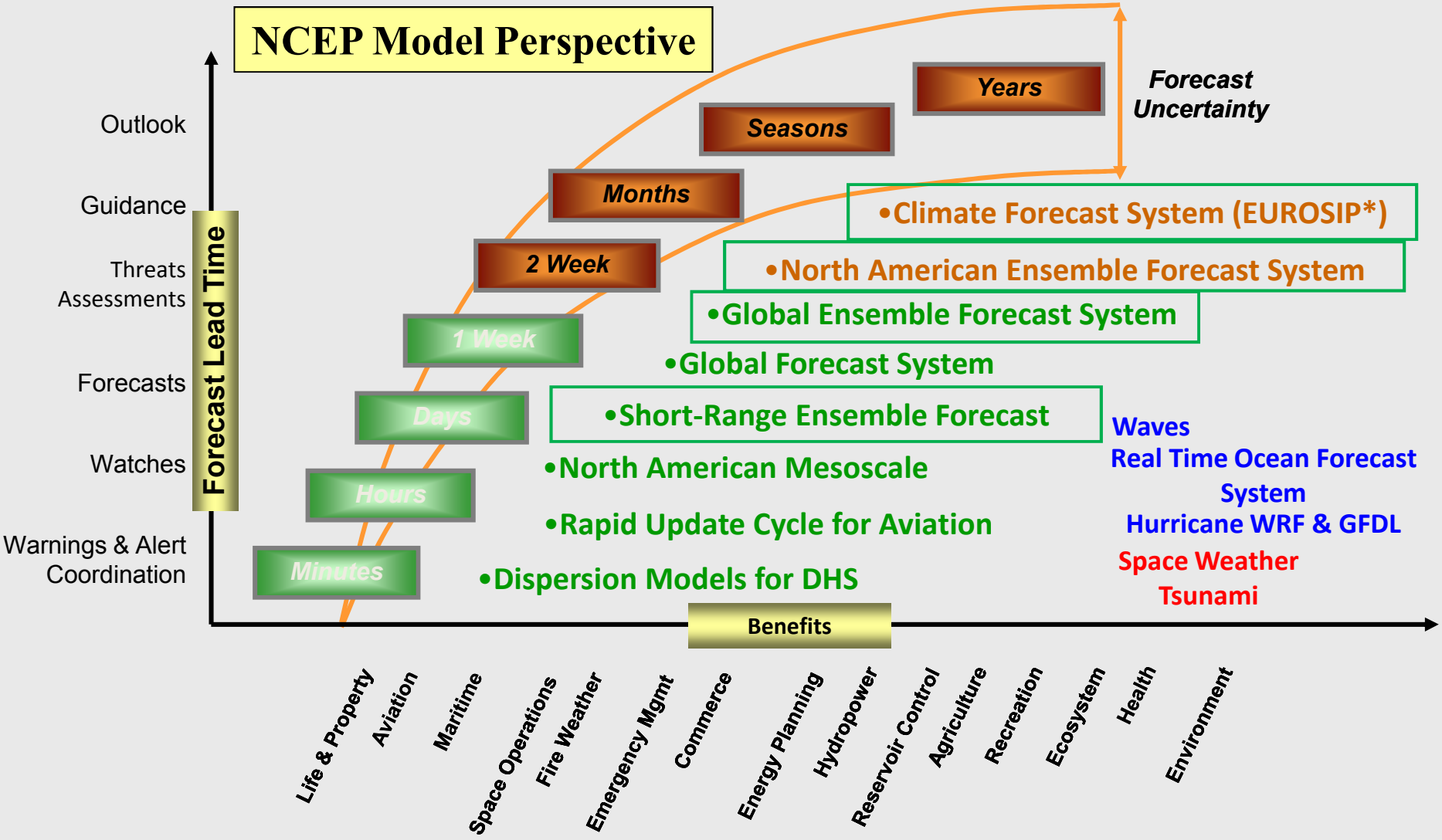
Mission:

NCEP delivers science-based environmental predictions to the nation and the global community. We collaborate with partners and customers to produce reliable, timely, and accurate analyses, guidance, forecasts, and warnings for the protection of life and property and the enhancement of the national economy.

Vision:

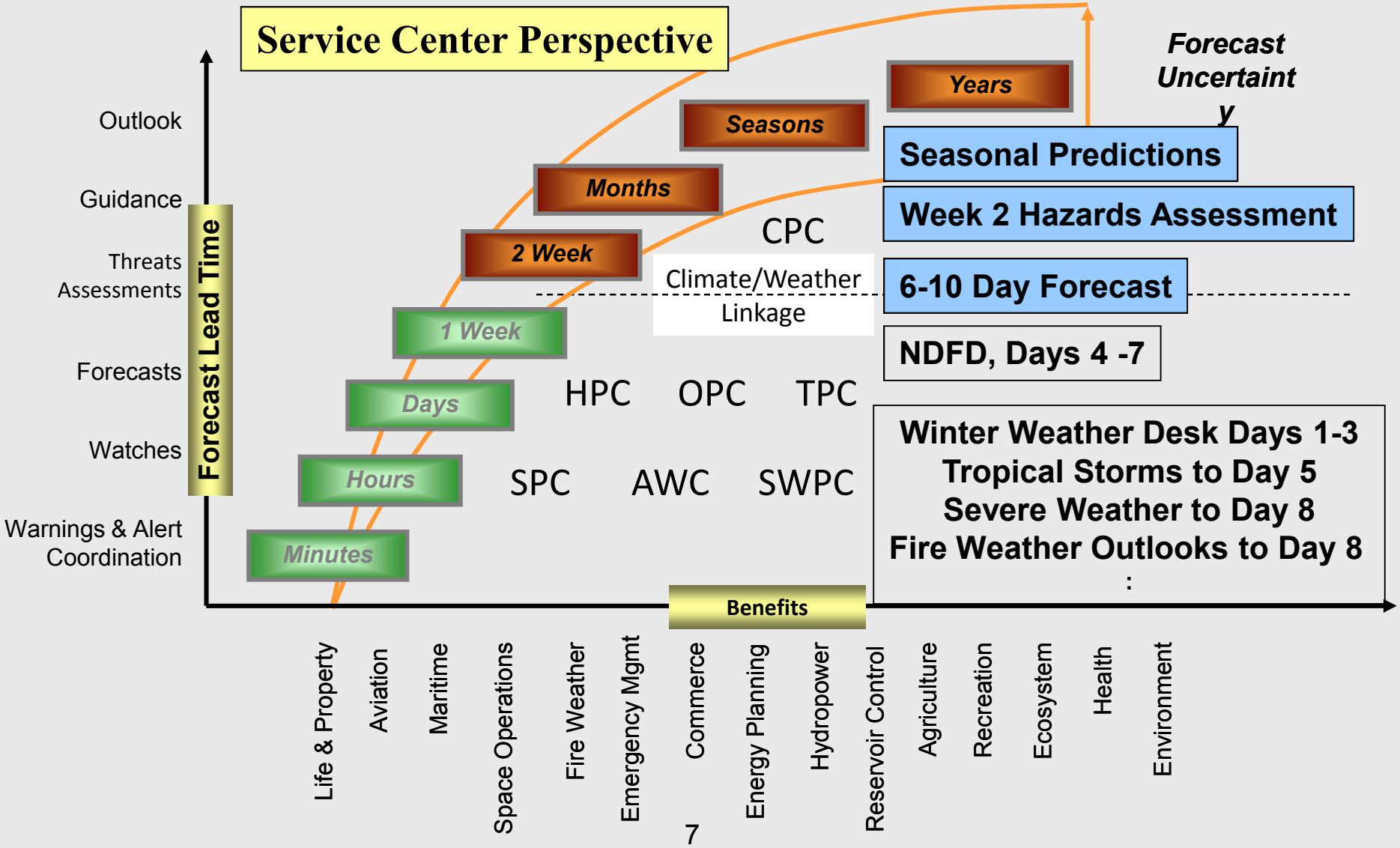
The Nation's trusted source, first alert, and preferred partner for environmental prediction services

NWS Seamless Suite of Forecast Products Spanning Weather and Climate



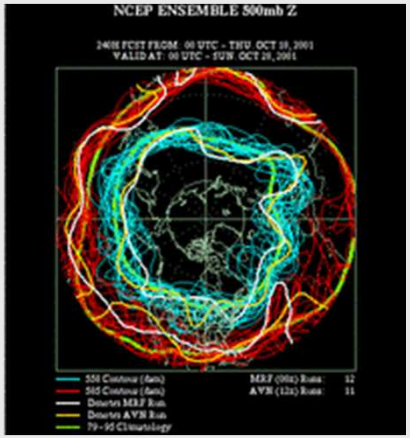
*To become available for NCEP operational seasonal prediction in Dec 2011

NOAA Seamless Suite of Forecast Products Spanning Climate and Weather



NCEP Ensemble Systems: GEFS

NWS/NCEP Global Ensemble Forecast System (GEFS)



Model	*Res*	*Levels*	*Mems*	*Cld Physics*	*Convection*
GFS	**T190* (~ 70 km)**	**28**	**20**	**GFS physics**	**Simple A-S**

- 20 statistically independent perturbations using Ensemble Transform with Rescaling (ETR) method (Wei et al. 2007)
- Integration through 16 days at 00, 06, 12, 18 UTC daily

NCEP Ensemble Systems: NAEFS

North American Ensemble Forecast System (NAEFS)



NAEFS was launched in 2004 as a joint experimental project between the U.S. National Weather Service, Meteorological Service of Canada, and the National Meteorological Service of Mexico.

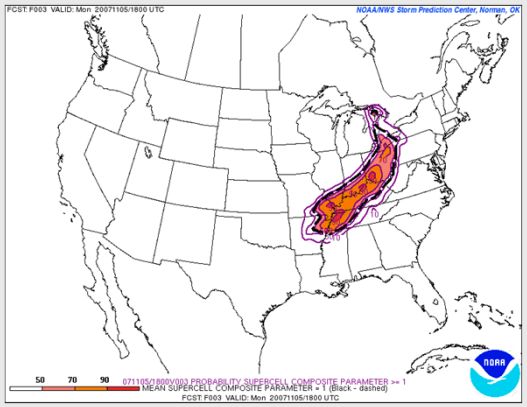
Advantages to combining two state-of-the-art ensemble systems:

- Increase spread through more members and inclusion of model uncertainty
- Provides seamless forecast guidance across national borders
- Allows for cost sharing of research, development, and maintenance costs

Model	*Res*	*Levels*	*Mems*	*Cld Physics*	*Convection*
GFS	T190 (~ 70 km)	28	20	GFS physics	Simple A-S
Model	*Res*	*Levels*	*Mems*	*Cld Physics*	*Convection*
GEM	0.6 deg	28	20	Sundqvist (mixed)	Mixed

384 hour forecasts at 00 & 12 UTC

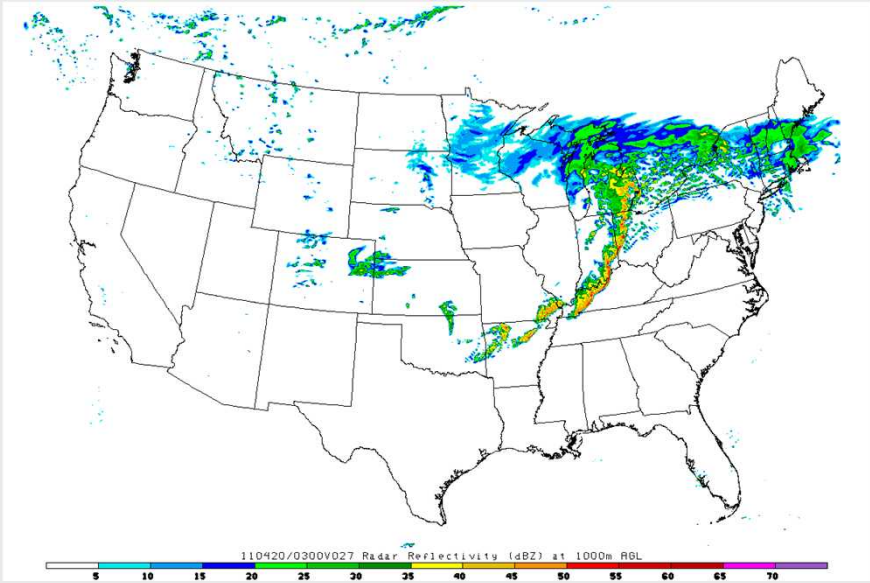
NCEP Ensemble Systems: SREF



NWS/NCEP Short Range Ensemble Forecast (SREF)

- EMC SREF system (21 members)
  - 87 hr forecasts four times daily (03, 09, 15, 21 UTC)
  - North American domain
  - Model grid lengths ~32 km
  - Multi-model: Eta, RSM, WRF-NMM, WRF-ARW
  - Multi-analysis: NAM, GFS initial and boundary conds.
  - IC perturbations and physics diversity
  - Output 1-hourly through F039 (for aviation and convection); 3-hourly thereafter

NCEP Ensemble Systems: SSEO



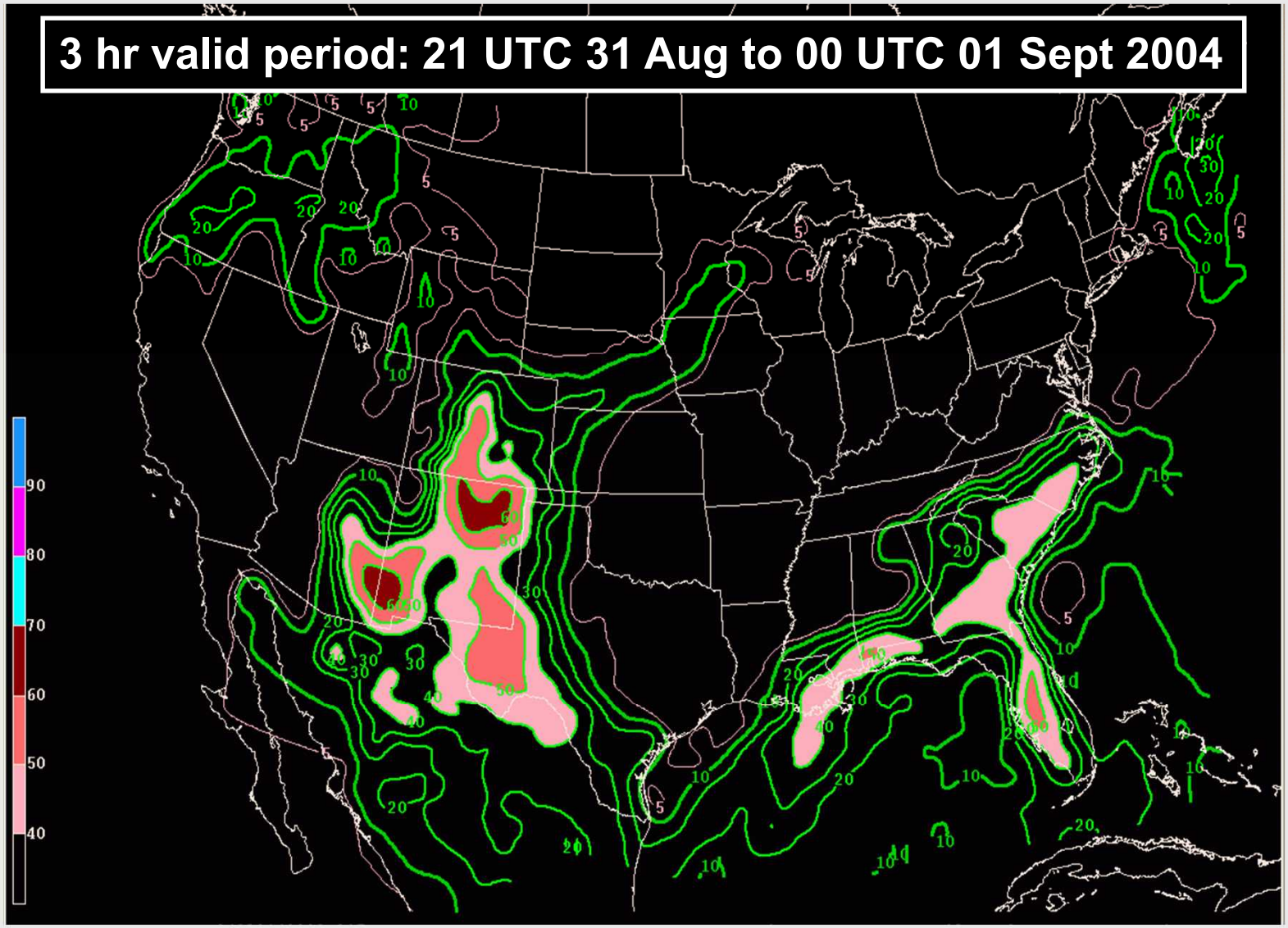
- Storm Scale Ensemble of Opportunity (SSEO). Initially developed by the SPC for HWT evaluation
- "Real-time experimental" seven member ensemble (~4 km grid space; covers eastern 3/4 of U.S.)
  - Post-process existing/operational convection-allowing deterministic models
    - NCEP: HiResWindow NMM and ARW; NAM NMMB nest; and two time-lagged members HiResWindow; 00Z SPC WRF;
    - NSSL: 00Z NSSL WRF-ARW
    - 7 storm scale "members of opportunity" (3 ARW; 1 NMMB; 3 NMM)
- Quasi-operational for high-resolution guidance
- Supports decision support and NCEP mission in all seasons

Climate Reforecast for CFS Version 2

- A coupled prediction system for extended-range and seasonal predictions; Implemented March 2011,
  - Atmospheric model-resolution T126, 64 vertical levels
  - Ocean model (MOM4) horizontal resolution: 1/2 Deg. in zonal direction; 1/4 Deg between 10S-10N gradually increasing to 1/2 Deg poleward of 30S and 30N, Vertical Resolution: 40 layers; with 27-layers in upper 400m, and a bottom at approximately at 4.5 km in the ocean
- Atmosphere/Ocean/Land/Sea Ice Initial conditions from the CFS Reanalysis
- Reforecasts for calibration
  - Seasonal (9-month): 1981 – 2010 (4 runs every five days)
  - Extended-range (45-day) – 1999-2010 (4 runs every day)
  - Over 10,000 years of reforecasts
- Data availability from the NCDC

Convection and Severe Convective Storms

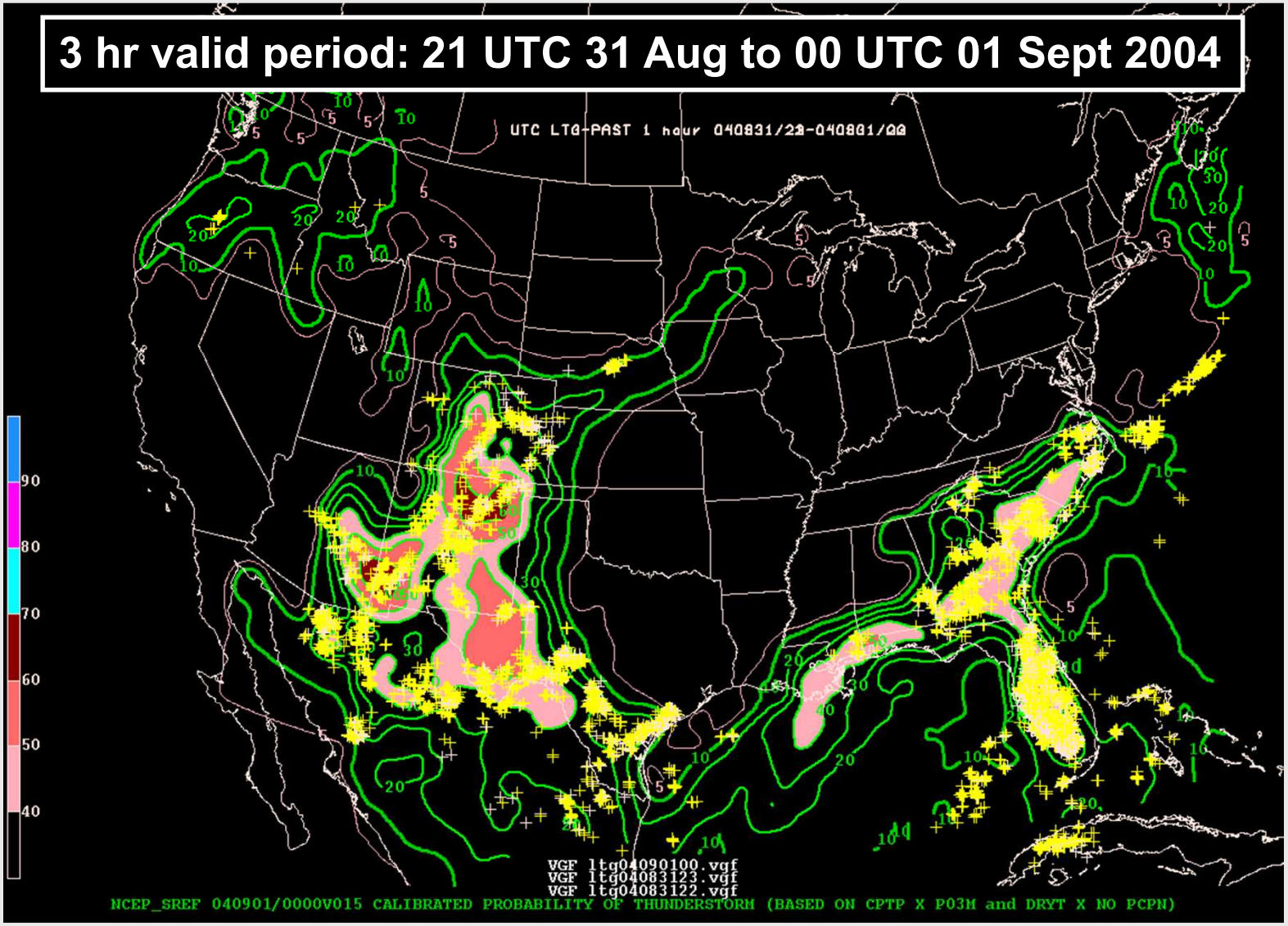
Calibrated Probability of a Thunderstorm



15h Forecast Ending: 00 UTC 01 Sept 2004

Calibrated probability: Solid/Filled

Calibrated Probability of a Thunderstorm



NATIONAL CENTERS FOR ENVIRONMENTAL PREDICTION
NCEP

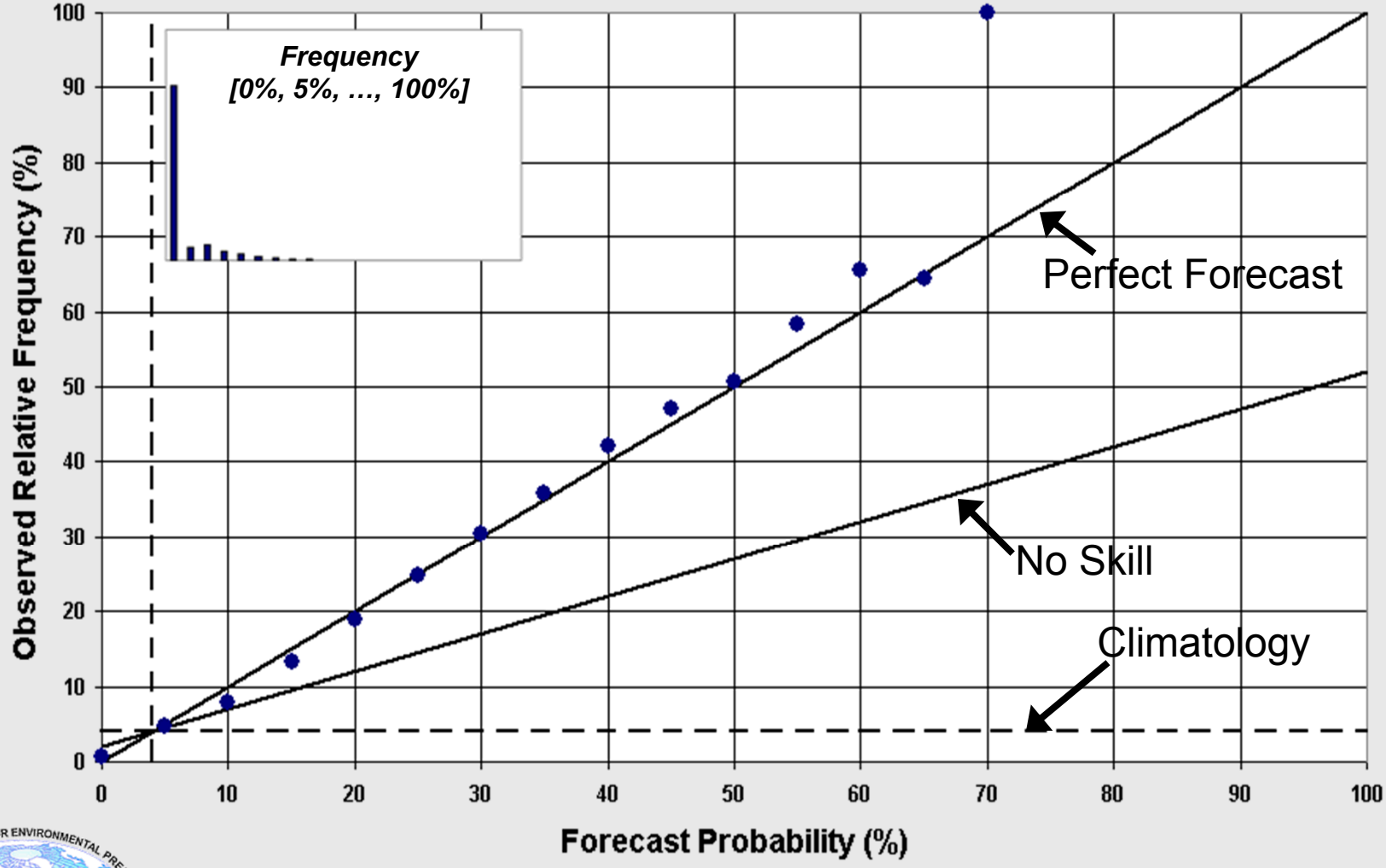
15h Forecast Ending: 00 UTC 01 Sept 2004

Calibrated probability: Solid/Filled; NLDN CG Strikes (Yellow +)

Calibrated Reliability

(5 Aug to 5 Nov 2004)

Attributes Diagram (3h forecasts, F03-F63)



NCEP

Calibrated Thunder Probability

SREF Probability of STP Ingredients: Time Trends

48 hr *SREF Forecast Valid 21 UTC 7 April 2006*

Prob (MLCAPE $\geq$ 1000 Jkg^{-1})

X

Prob (6 km Shear $\geq$ 40 kt)

X

Prob (0-1 km SRH $\geq$ 100 m^2s^{-2})

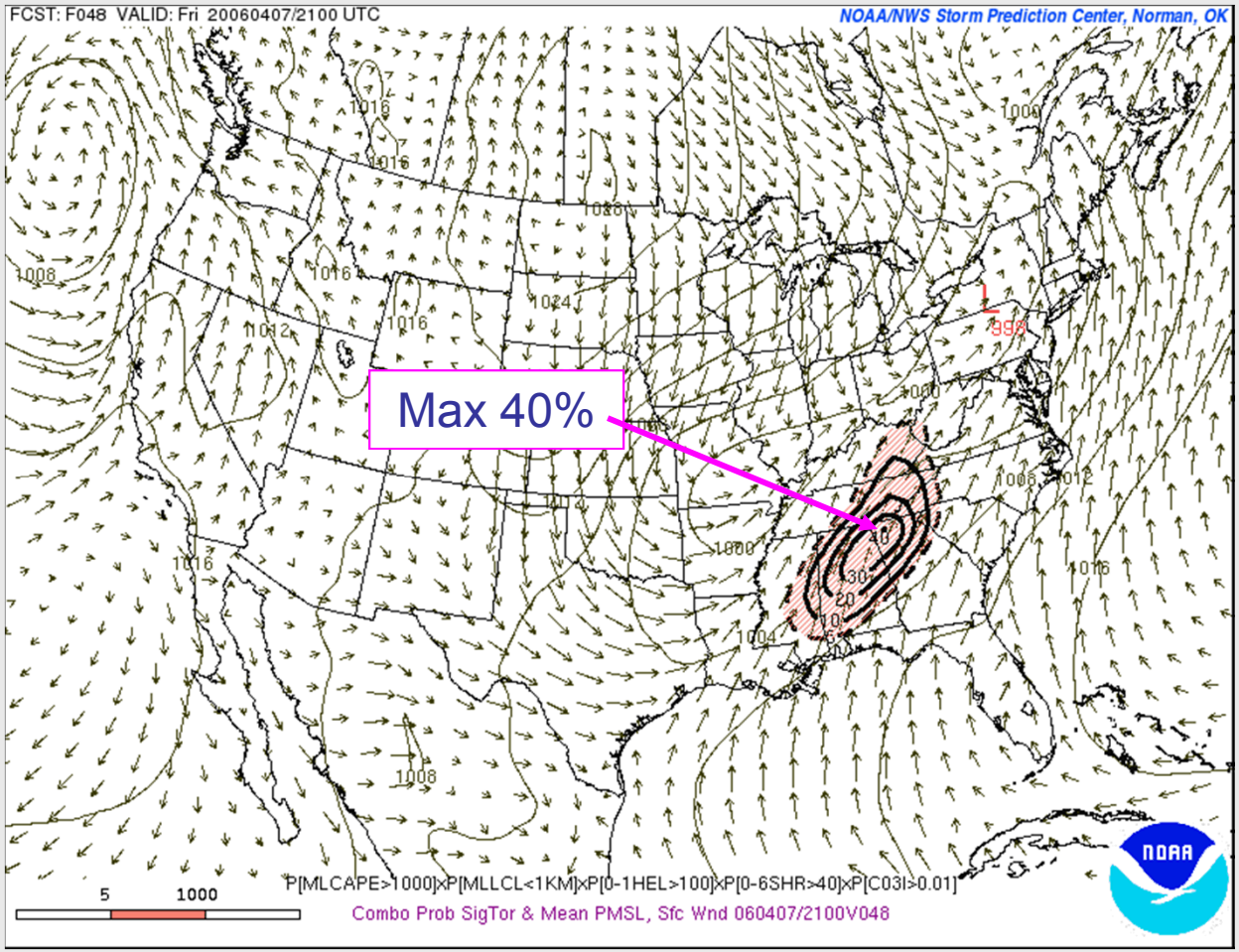
X

Prob (MLLCL $\leq$ 1000 m)

X

Prob (3h conv. Pcpn $\geq$ 0.01 in)

Shaded Area Prob $\geq$ 5%



SREF Probability of STP Ingredients: Time Trends

36 hr *SREF Forecast Valid 21 UTC 7 April 2006*

Prob (MLCAPE ≥ 1000 Jkg^{-1})

X

Prob (6 km Shear ≥ 40 kt)

X

Prob (0-1 km SRH ≥ 100 m^2s^{-2})

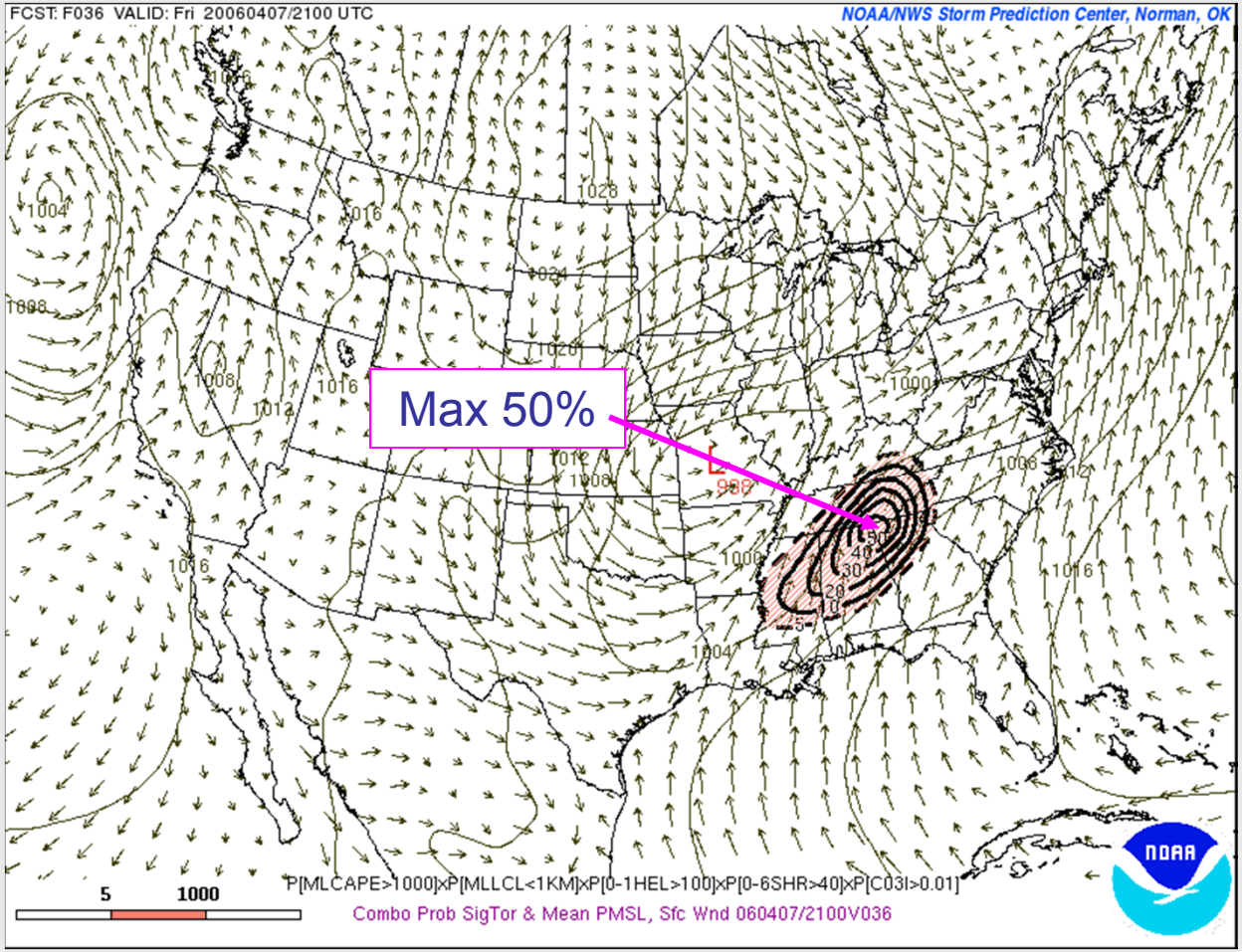
X

Prob (MLLCL ≤ 1000 m)

X

Prob (3h conv. Pcpn ≥ 0.01 in)

Shaded Area Prob ≥ 5%



SREF Probability of STP Ingredients: Time Trends

24 hr *SREF Forecast Valid 21 UTC 7 April 2006*

Prob (MLCAPE $\geq$ 1000 Jkg^{-1})

X

Prob (6 km Shear $\geq$ 40 kt)

X

Prob (0-1 km SRH $\geq$ 100 m^2s^{-2})

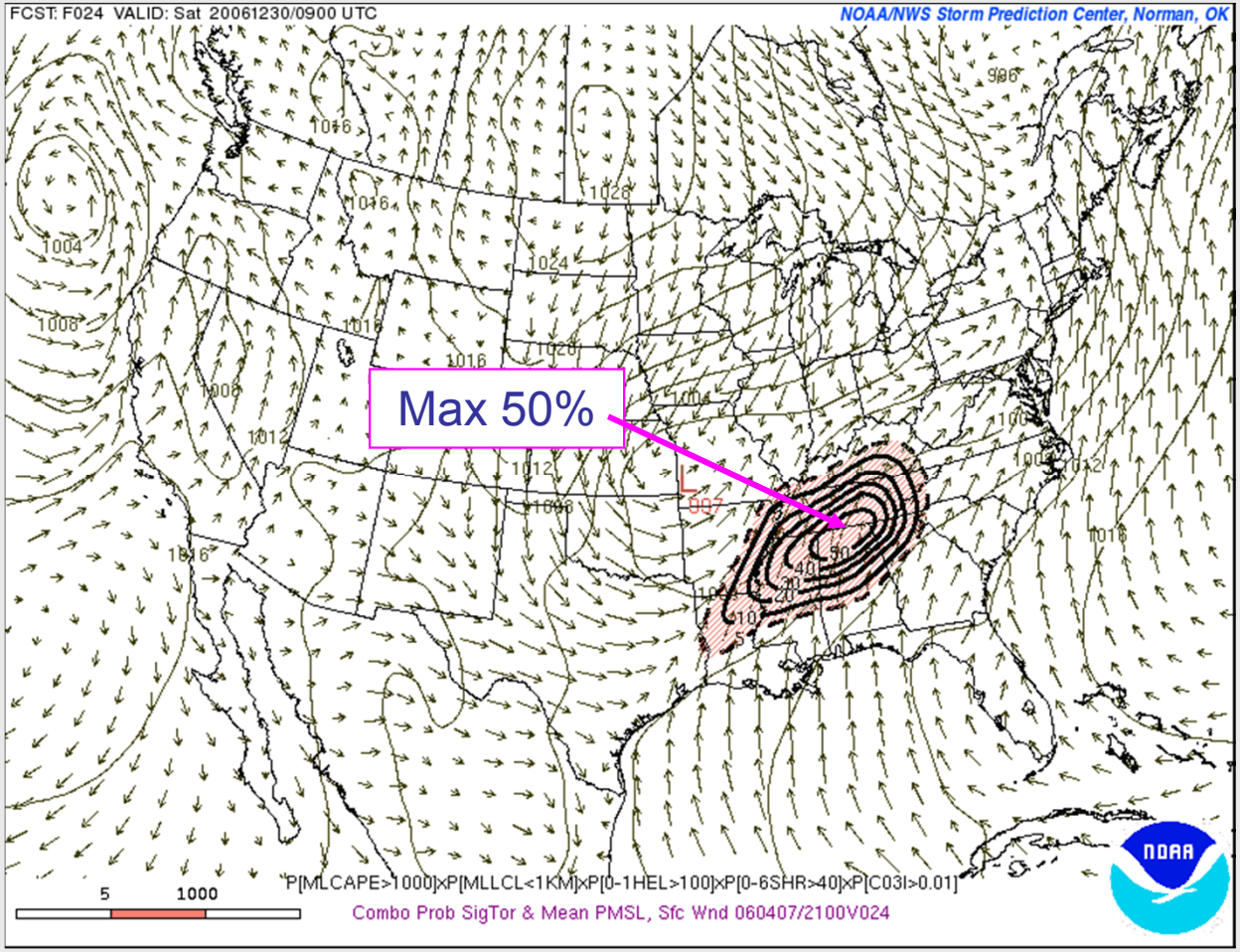
X

Prob (MLLCL $\leq$ 1000 m)

X

Prob (3h conv. Pcpn $\geq$ 0.01 in)

Shaded Area Prob $\geq$ 5%



SREF Probability of STP Ingredients: Time Trends

12 hr *SREF Forecast Valid 21 UTC 7 April 2006*

Prob (MLCAPE ≥ 1000 Jkg^{-1})

X

Prob (6 km Shear ≥ 40 kt)

X

Prob (0-1 km SRH ≥ 100 m^2s^{-2})

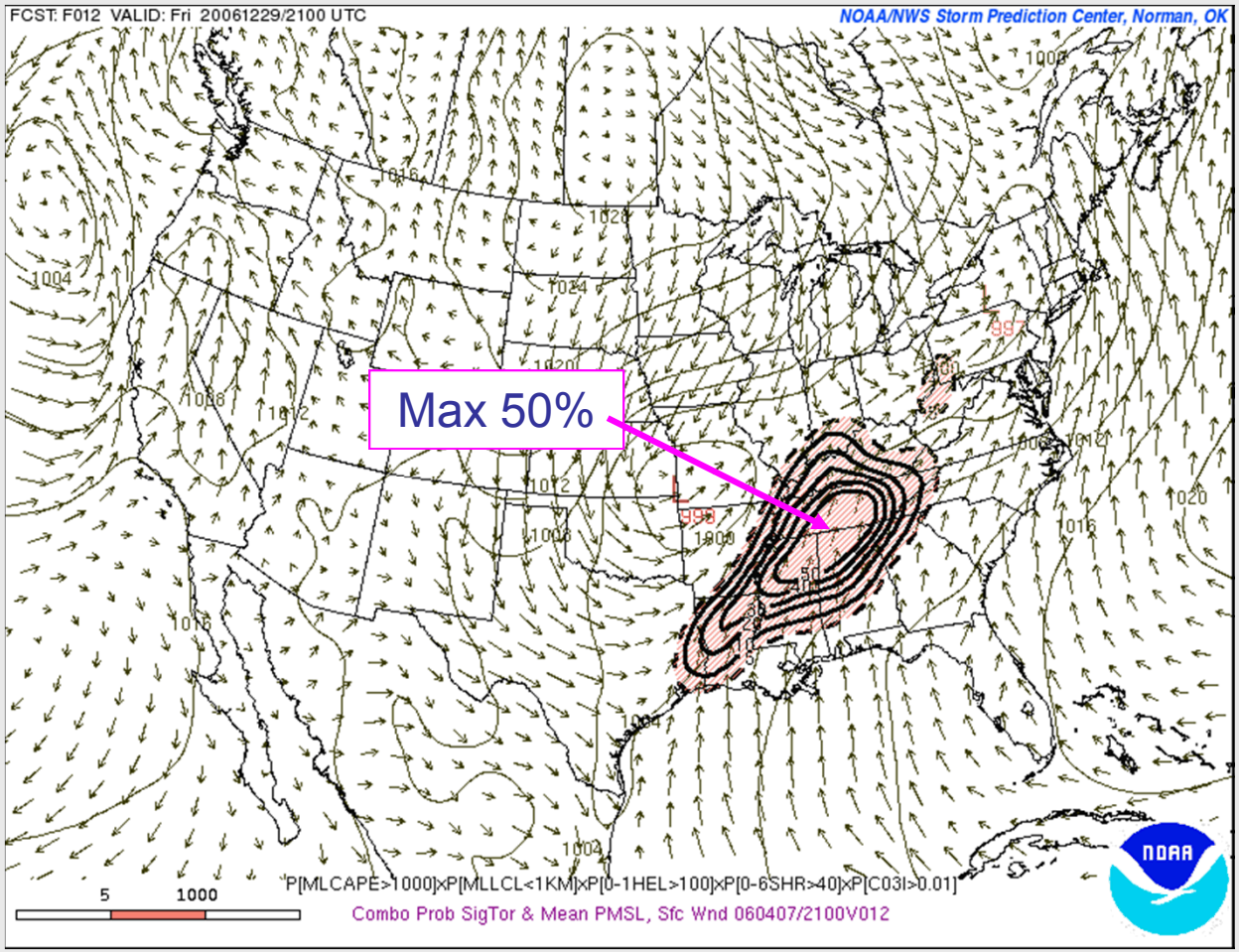
X

Prob (MLLCL ≤ 1000 m)

X

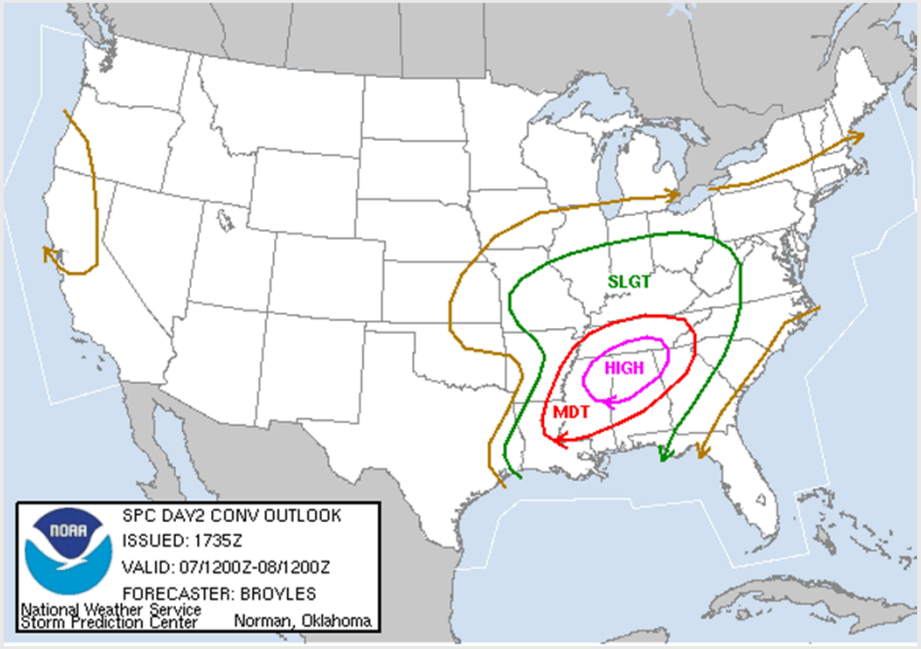
Prob (3h conv. Pcpn ≥ 0.01 in)

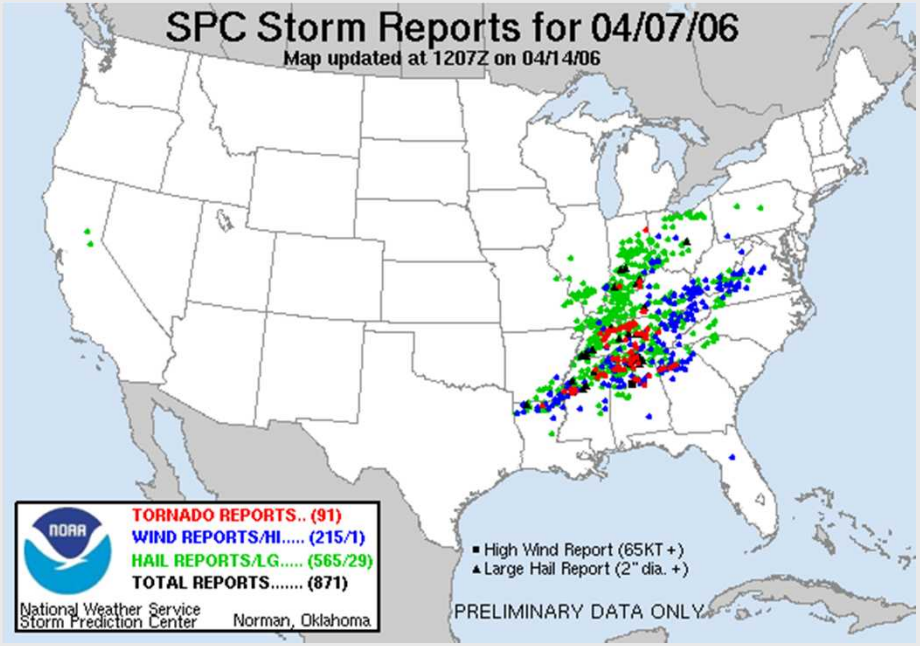
Shaded Area Prob ≥ 5%



Severe Event of April 7, 2006

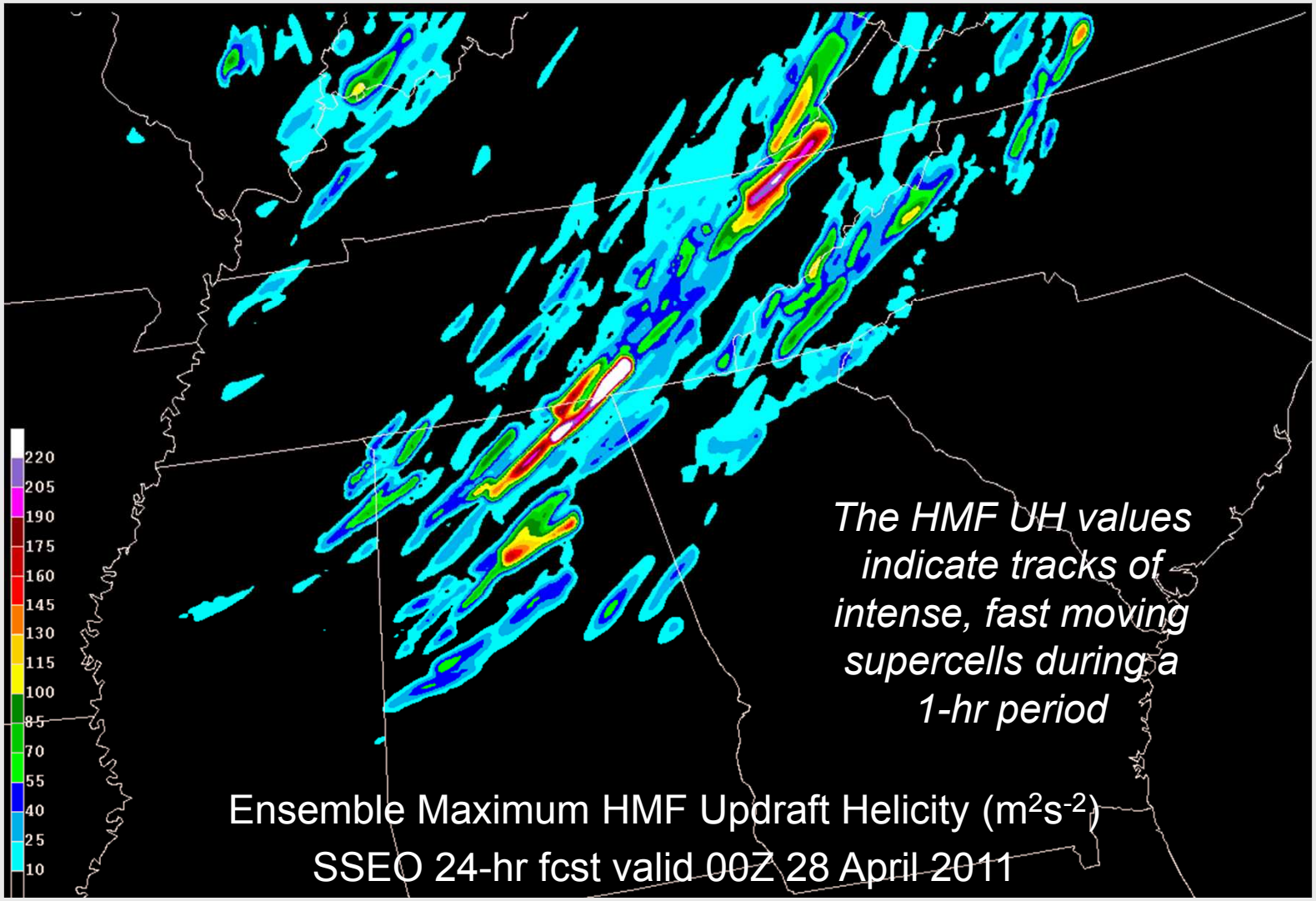
- **First ever** Day 2 outlook High Risk issued by SPC
- More than 800 total severe reports
  - 3 killer tornadoes and 10 deaths
- SREF severe weather fields aided forecaster confidence





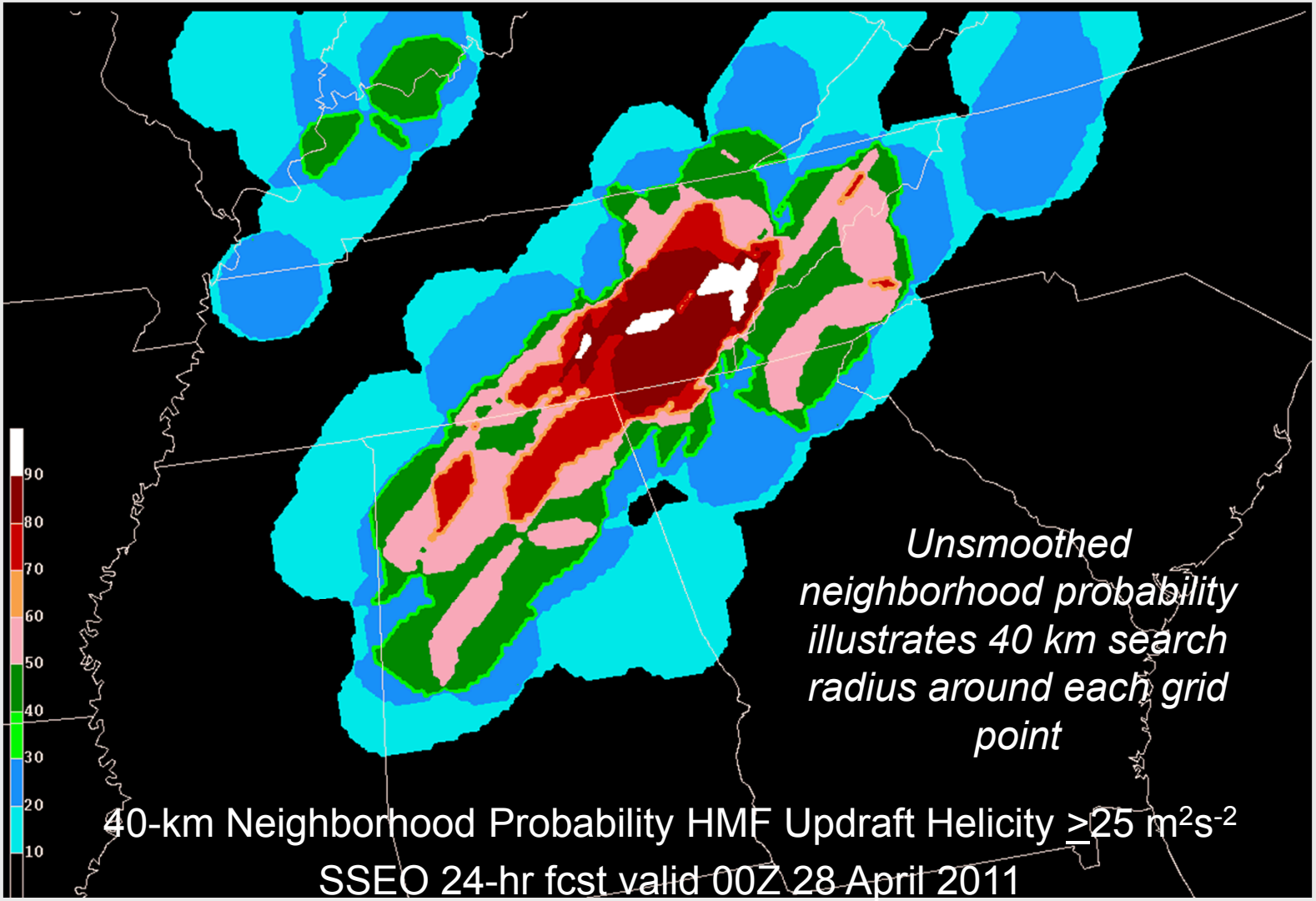
SSEO Ensemble Applications

Storm-Scale Guidance: SSEO Maximum Example



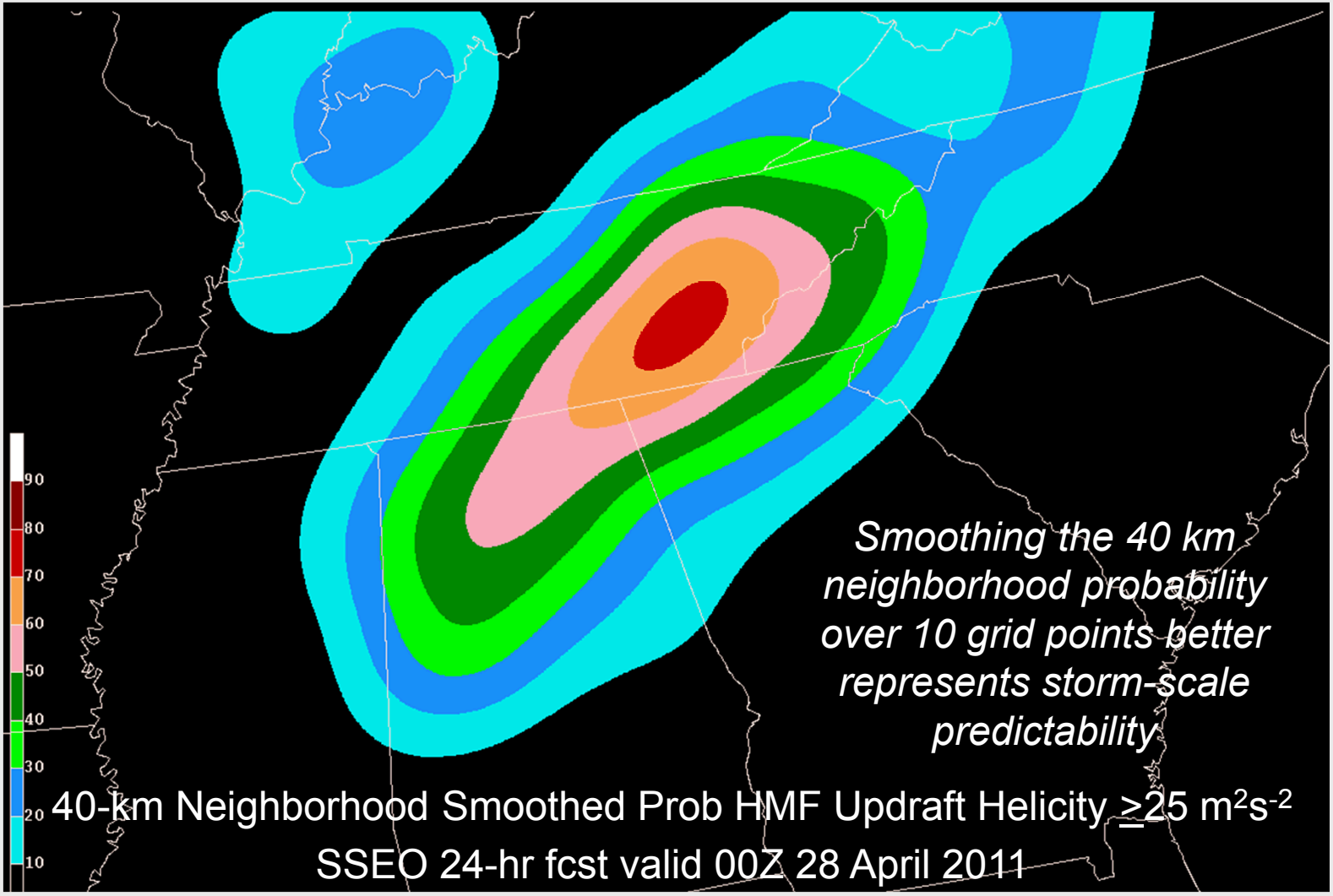
SSEO Ensemble Applications

Storm-Scale Guidance: SSEO Probability Example



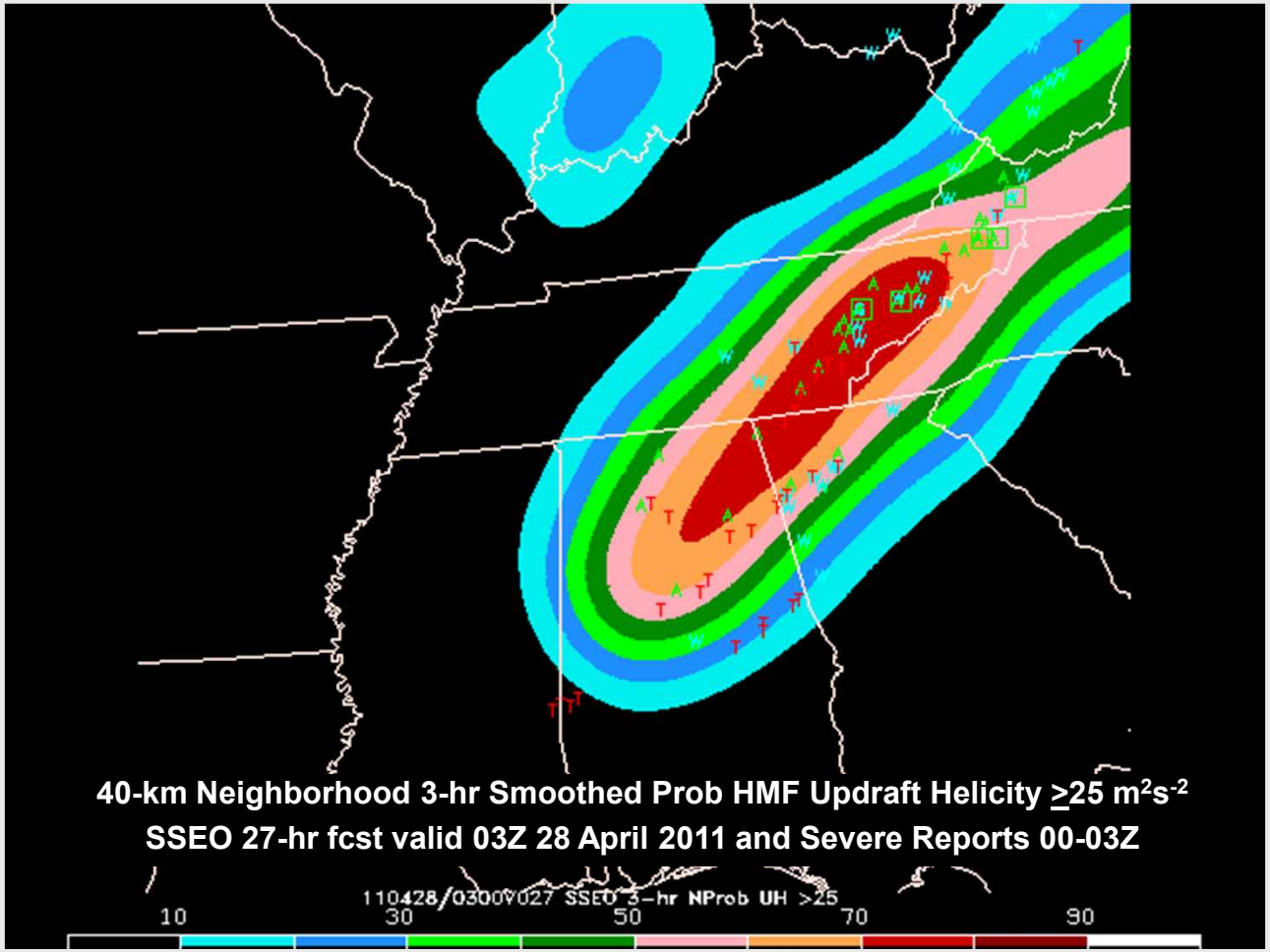
SSEO Ensemble Applications

Storm-Scale Guidance: SSEO Probability Example



SSEO Ensemble Applications

Storm-Scale Guidance: SSEO Probability Example



40-km Neighborhood 3-hr Smoothed Prob HMF Updraft Helicity ≥25 m^2s^{-2}

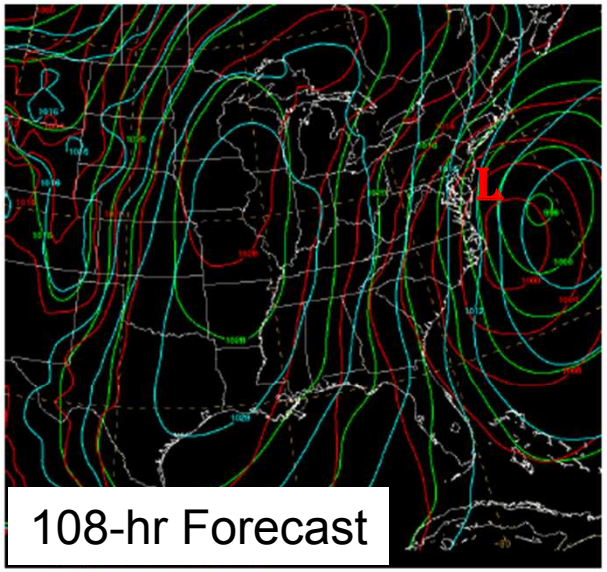
SSEO 27-hr fcst valid 03Z 28 April 2011 and Severe Reports 00-03Z

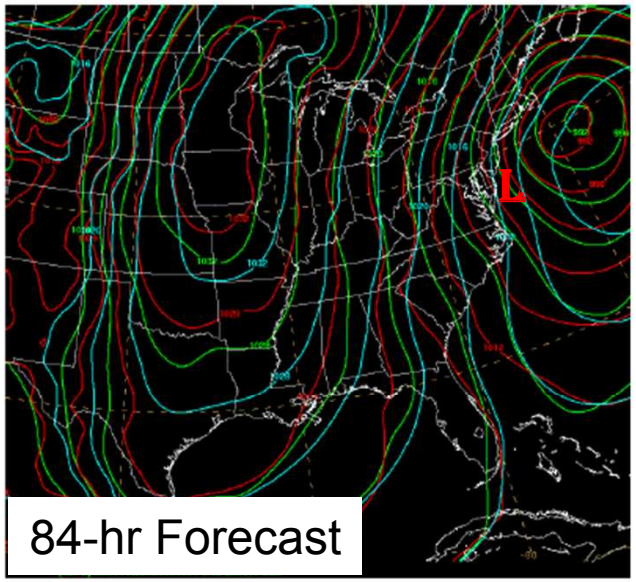
Winter Weather

The Blizzard of 25-27 December, 2010

Ensemble Mean: PMSL

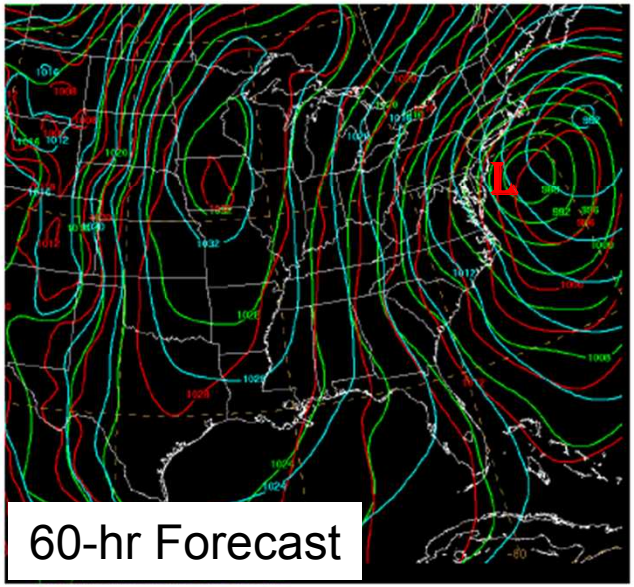
Valid Time: 00 UTC 27 Dec 2010





Blue: Canadian
Red: ECMWF
Green: GFS

L = Obs



NATIONAL WEATHER SERVICE
AWC
AVIATION WEATHER CENTER

NATIONAL WEATHER SERVICE
HPC
Hydrometeorological Prediction Center

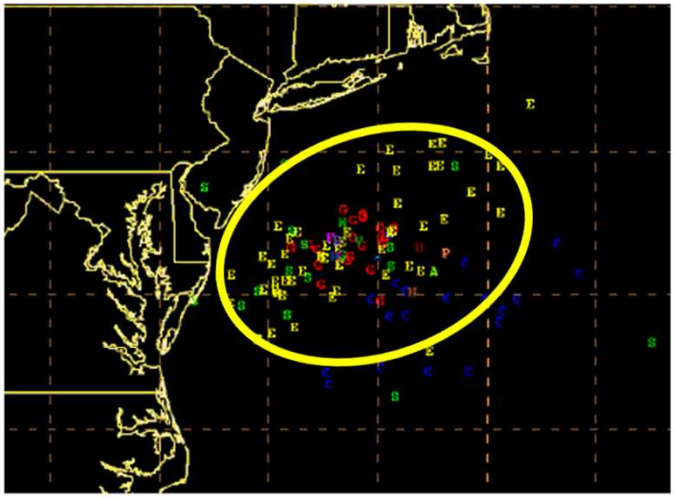
NATIONAL WEATHER SERVICE
SPC
STORM PREDICTION CENTER

Ensemble Members: Sfc Low Centers

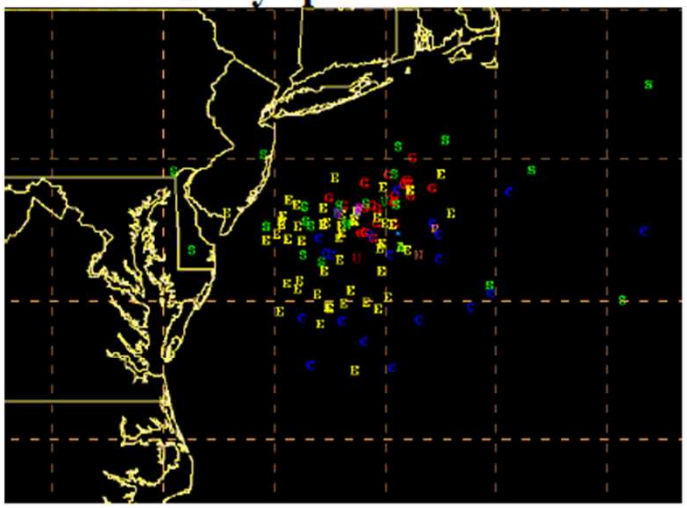
Valid Time: 00 UTC 27 Dec 2010

C: Canadian
E: ECMWF
G: GFS
S: SREF

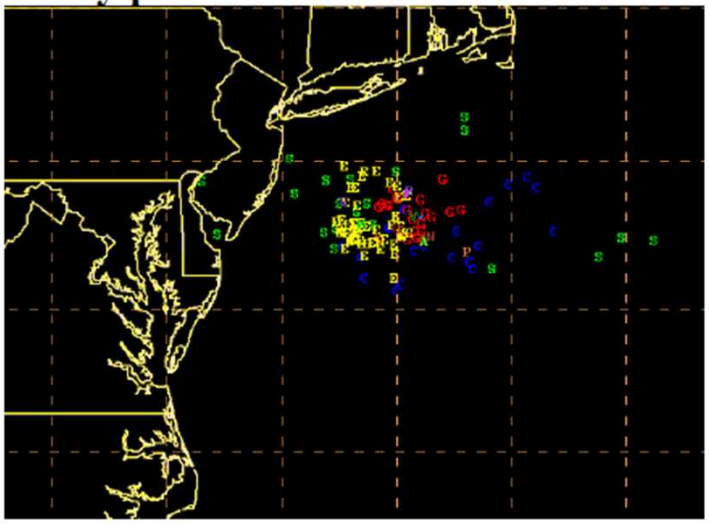
2 days prior: 48-h fcst vt 00z 12/27/10



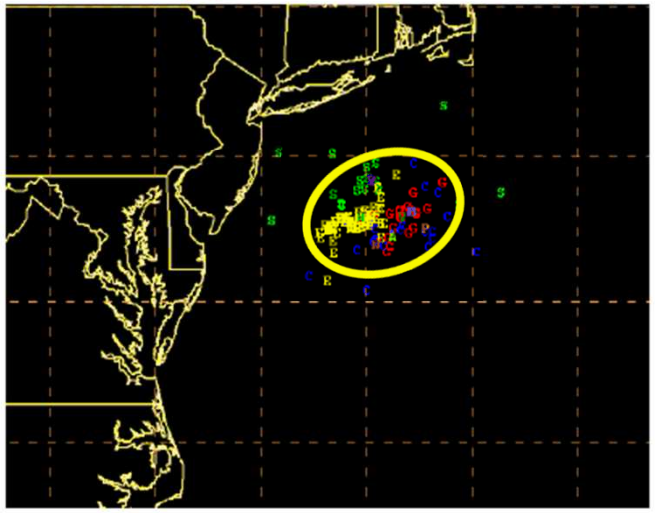
1 ½ days prior: 36-h fcst vt 00z 12/27/10



1 day prior: 24-h fcst vt 00z 12/27/10

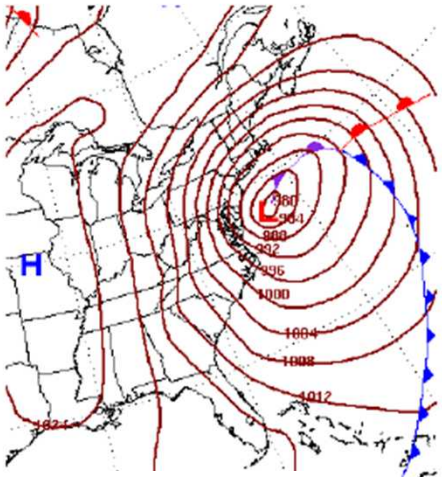


½ day prior: 12-h fact vt 00z 12/27/10

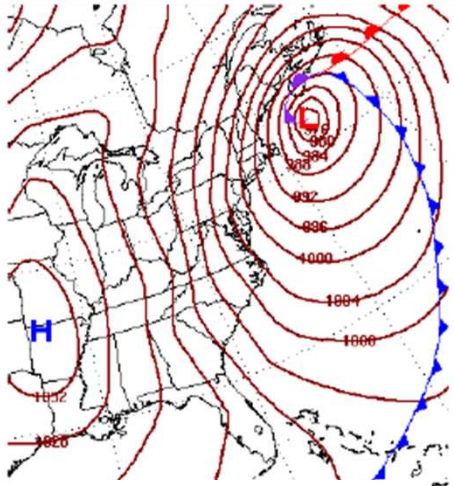


HPC Surface Forecast

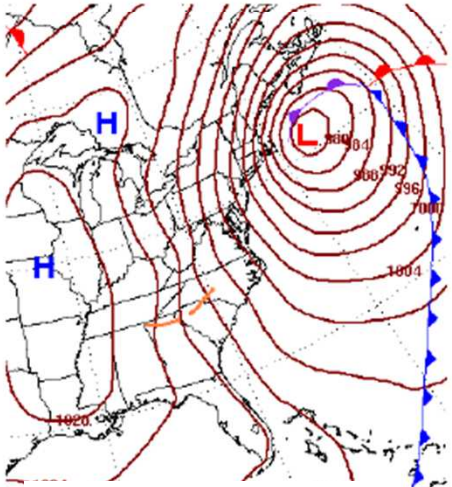
Valid Time: 12 UTC 27 Dec 2010



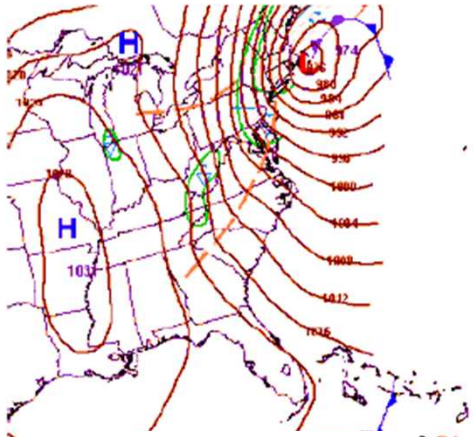
5-Day Forecast



4-Day Forecast



3-Day Forecast



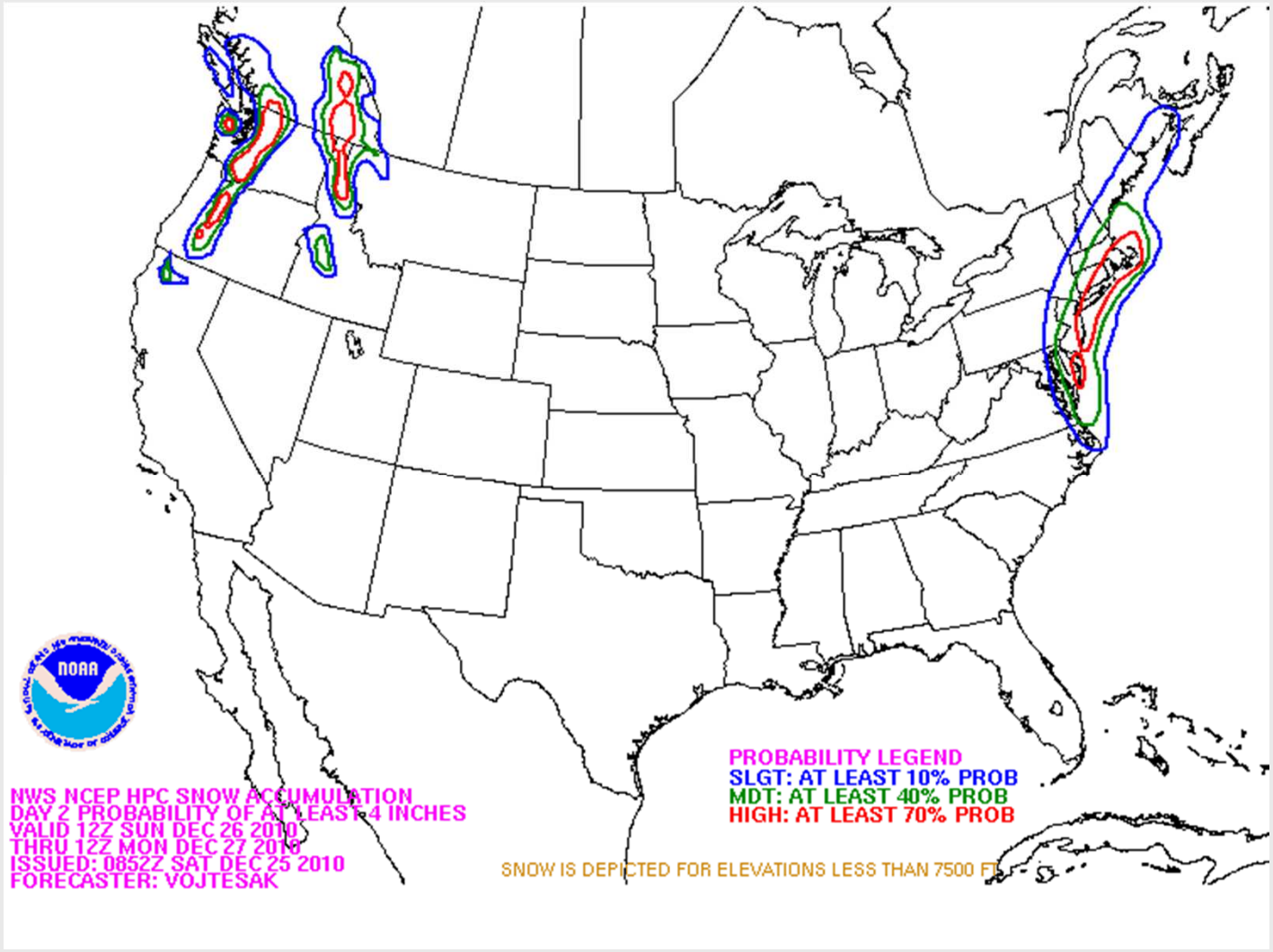
2-Day Forecast

NATIONAL WEATHER SERVICE
HPC
Hydrometeorological Prediction Center

HPC Probability of >4 Inches

Valid: 24 hours ending 12Z 27 Dec 2010

Issued: 0852 UTC 25 Dec 2010

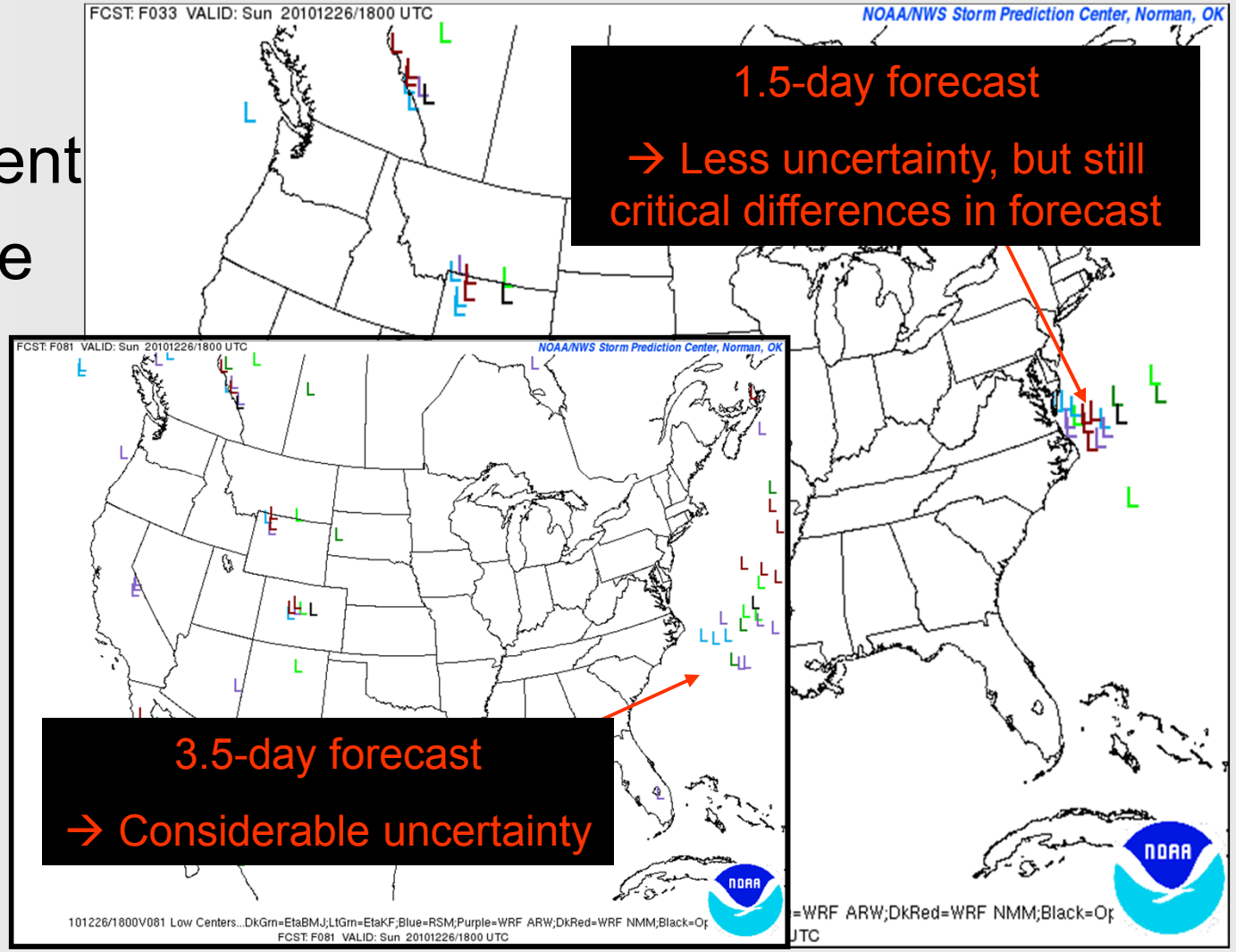


NATIONAL WEATHER SERVICE
HPC
Hydrometeorological Prediction Center

Aviation Impacts Briefing

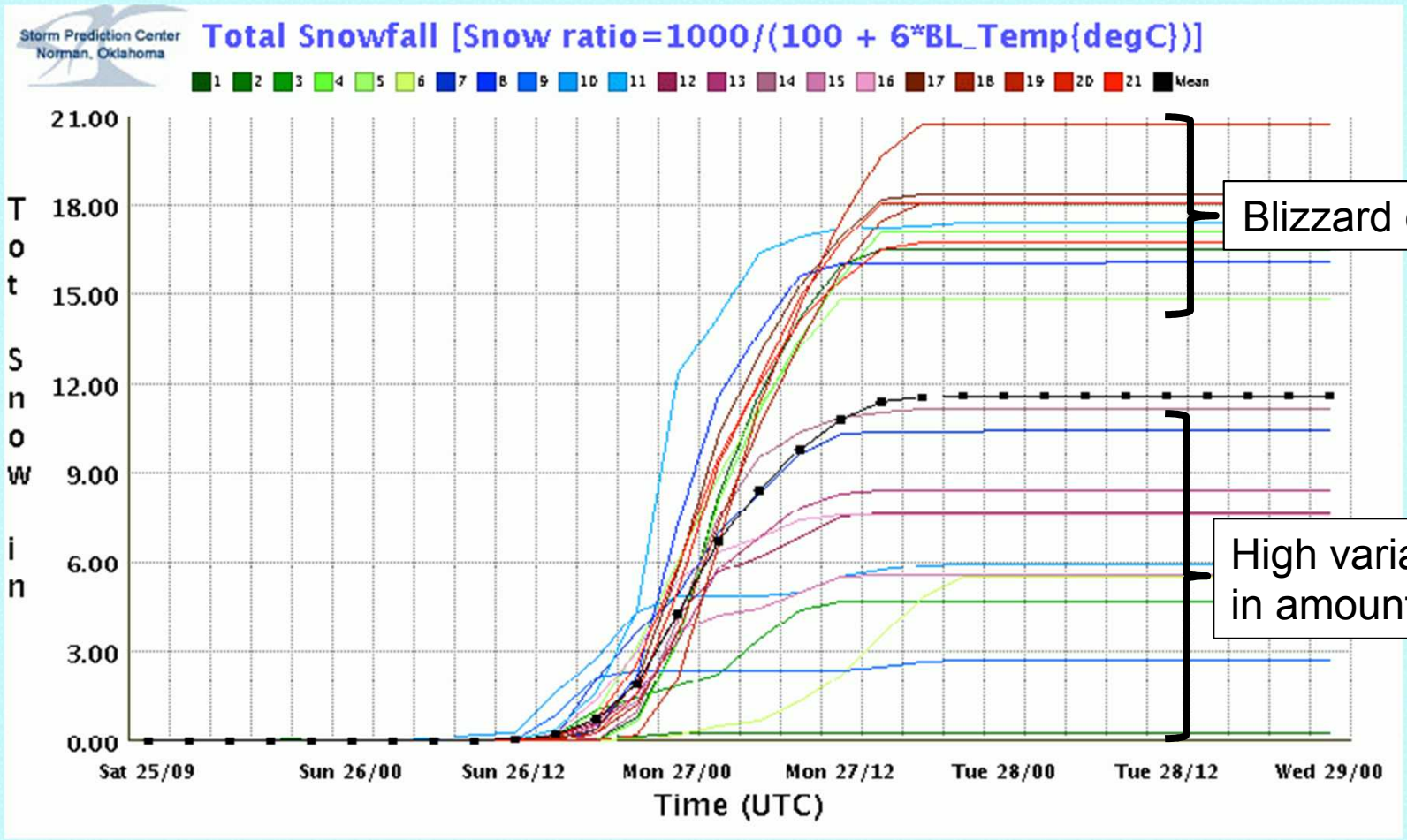
Occurred: 17 UTC 25 Dec 2010

"Much greater model agreement on low pressure system center position on Sunday."



SREF Snowfall at JFK

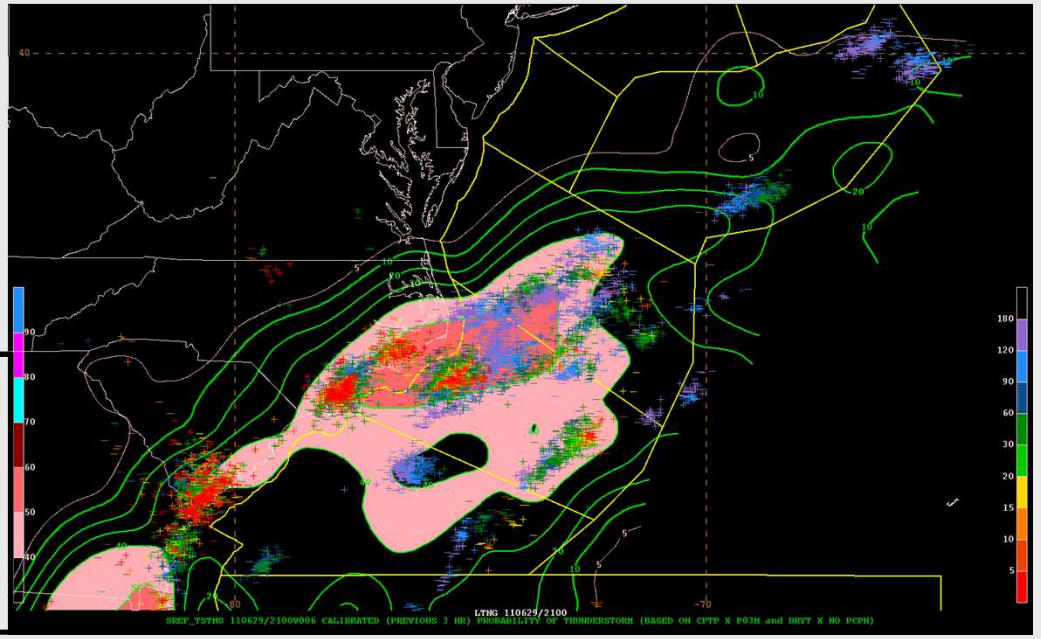
runtime= 20101225_09; field= sxxm; type=plume;
value(s)=1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,Mean; location= 40.65, -73.78;
Latitude= 40.65 Longitude= -73.78

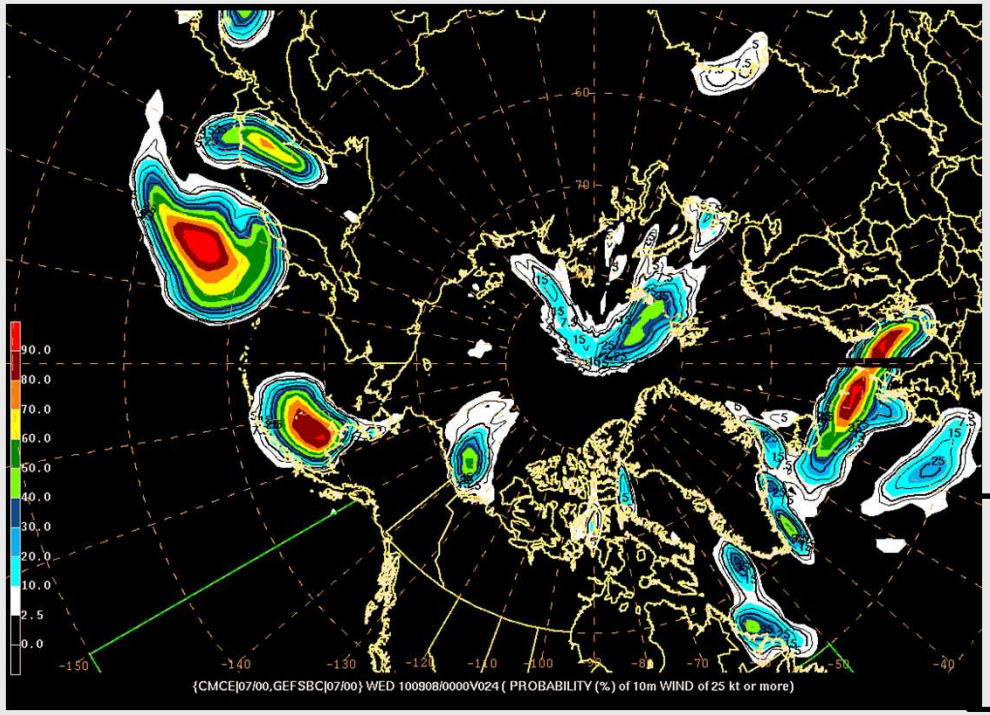


Ocean Prediction and Tropical Storms

NATIONAL WEATHER SERVICE
OPC
Ocean Prediction Center

SREF SPC probabilistic calibrated thunderstorm extended to offshore marine areas.





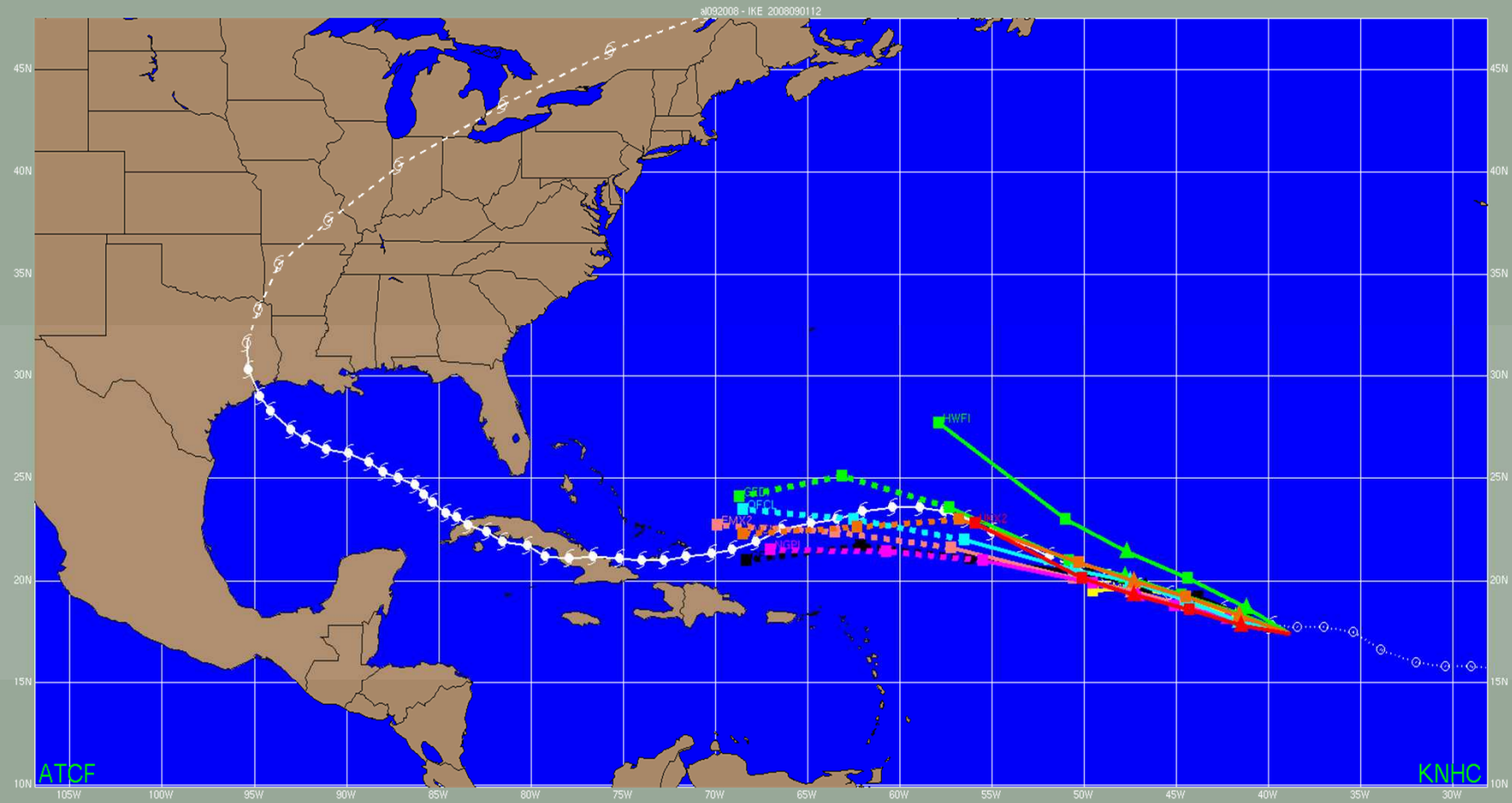
GEFS surface wind exceedance probabilities used for Atlantic and Pacific shipping forecasts.

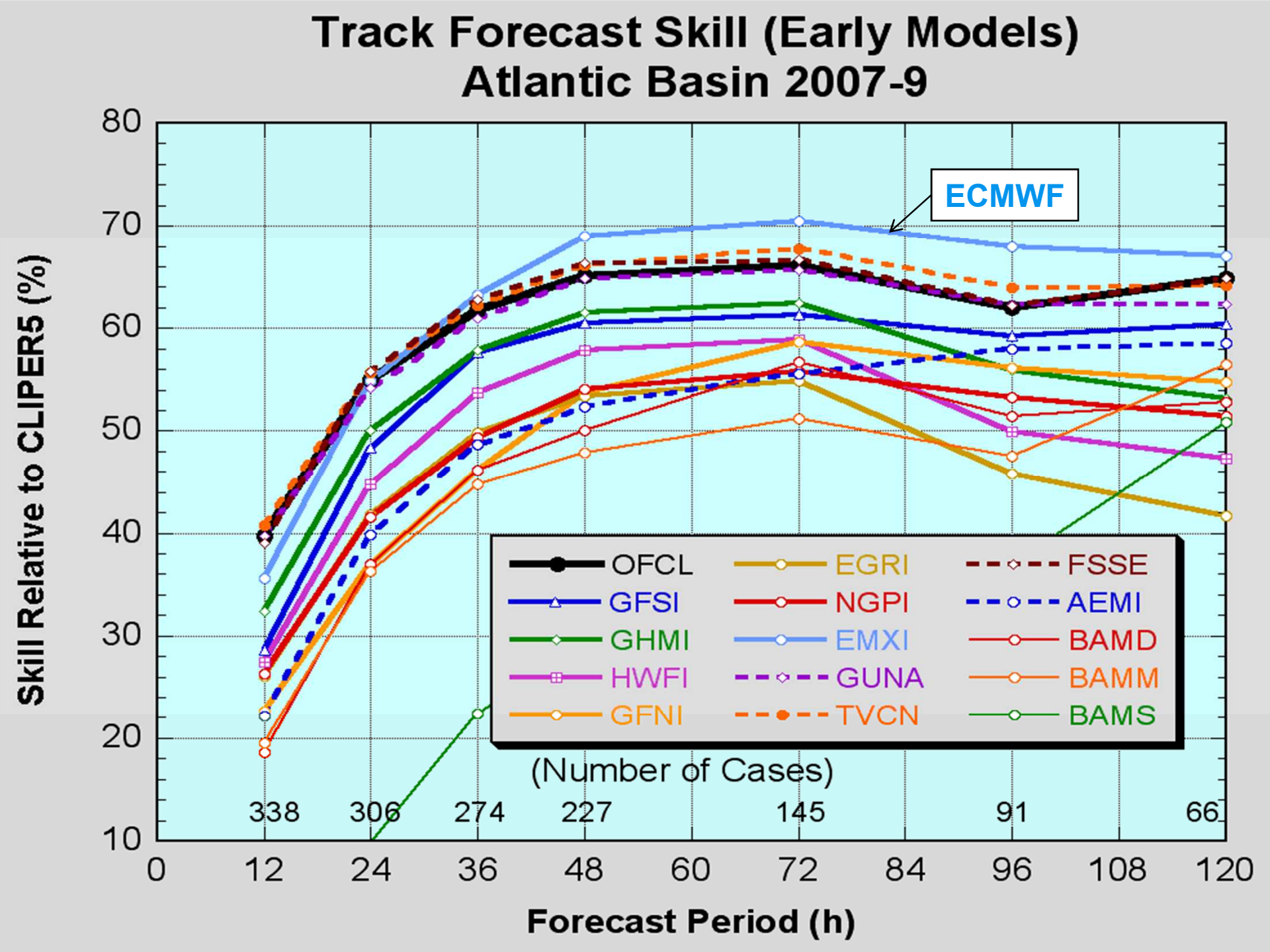
NHC: Operational Probabilistic Products

- Tropical Storm Genesis *
- Forecast Track “Cone”
- Probabilistic Wind Speed Forecasts
- Intensity Probabilities *
- Storm Surge Probabilities *

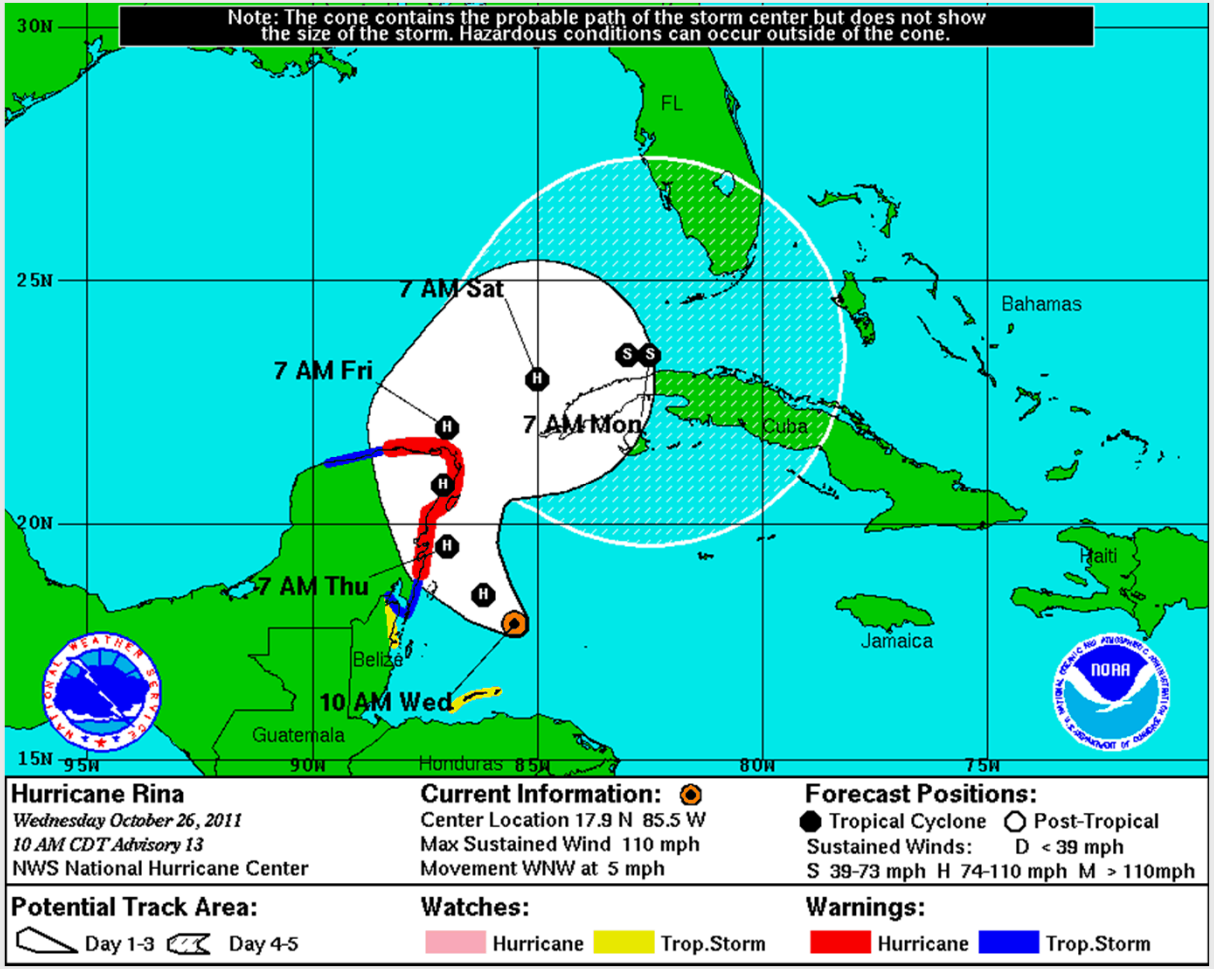
* ***Not discussed today***

Hurricane Ike Track models



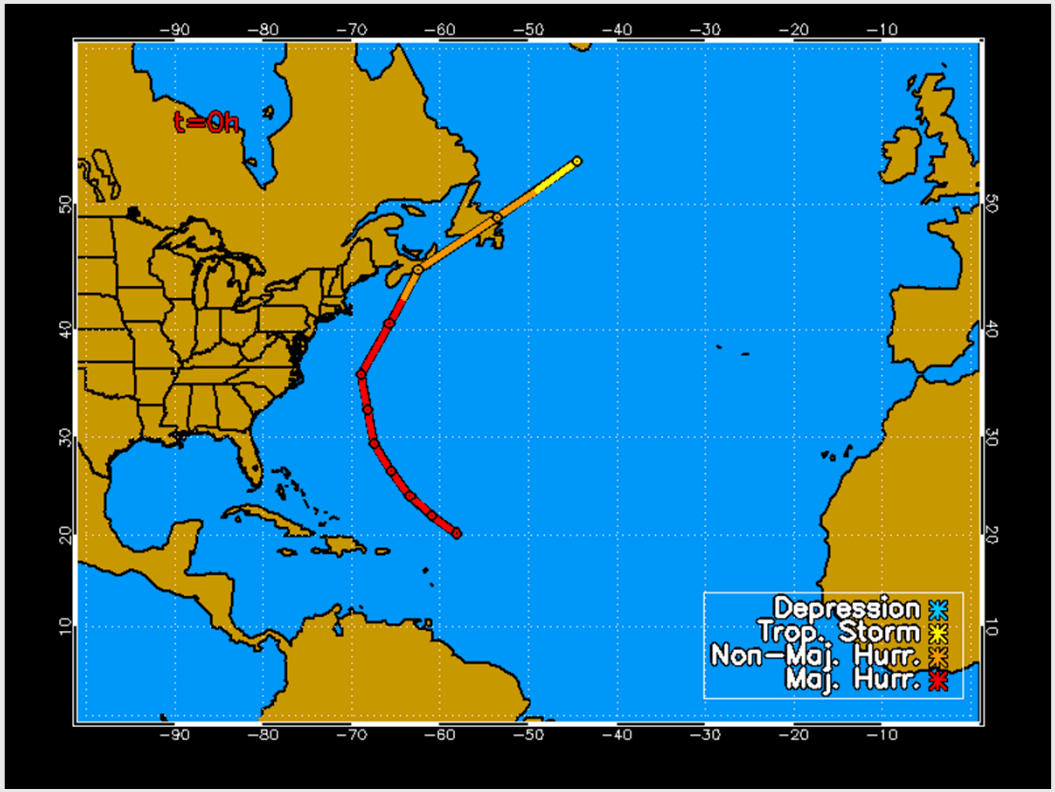

Track Forecast Skill (Early Models)
Atlantic Basin 2007-9
Skill Relative to CLIPER5 (%)
80
70
60
50
40
30
20
10
0
12
24
36
48
60
72
84
96
108
120
Forecast Period (h)
ECMWF
OFCL
GFSI
GHMI
HWFI
GFNI
EGRI
NGPI
EMXI
GUNA
TVCN
FSSE
AEMI
BAMD
BAMM
BAMS
(Number of Cases)
338
306
274
227
145
91
66

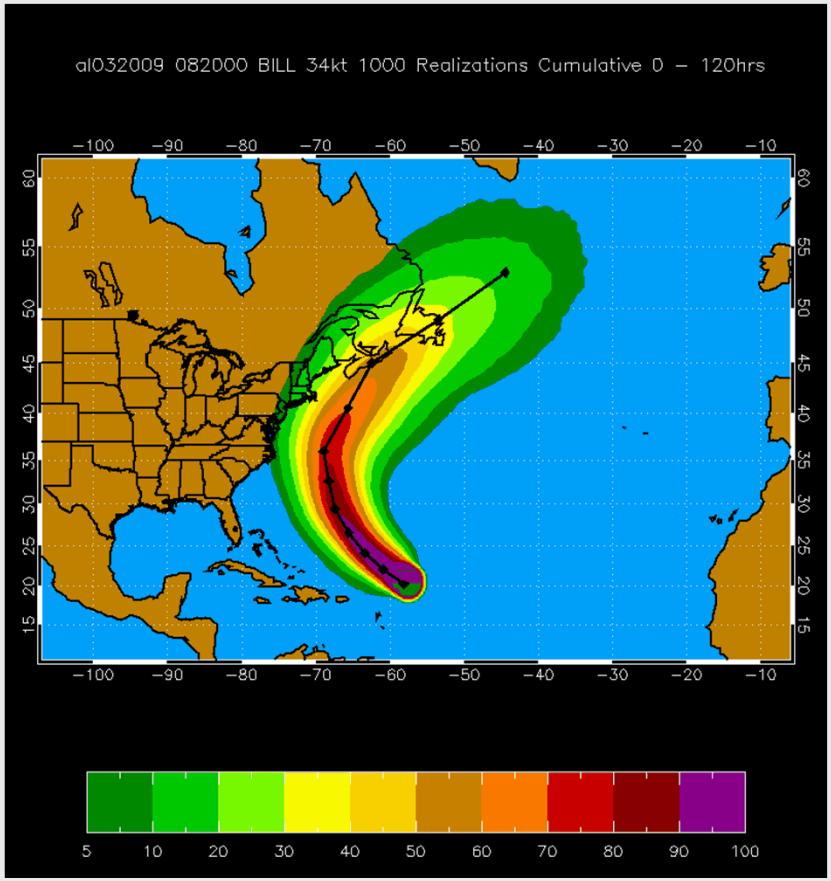
NHC Forecast Cone



- Probabilistic track of the center of the tropical cyclone.
- The size of the cone represents tropical cyclone position 67% of the time.

Probabilistic Wind Speed Example
Hurricane Bill 20 Aug 2009 00 UTC

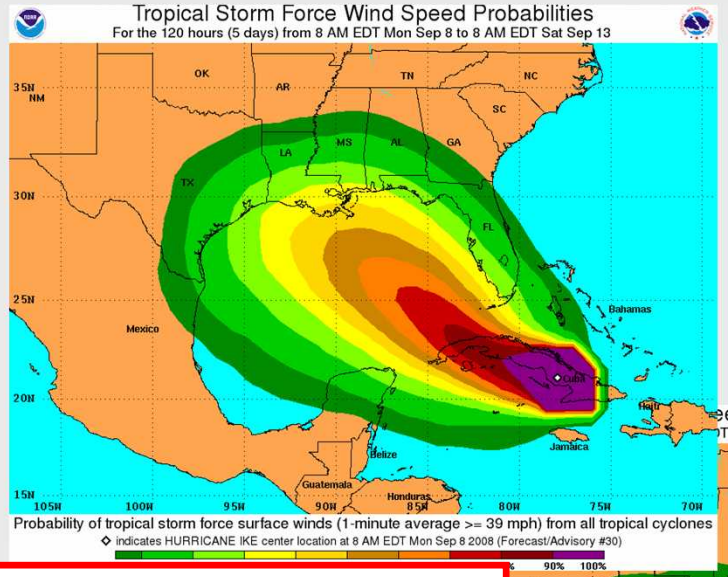


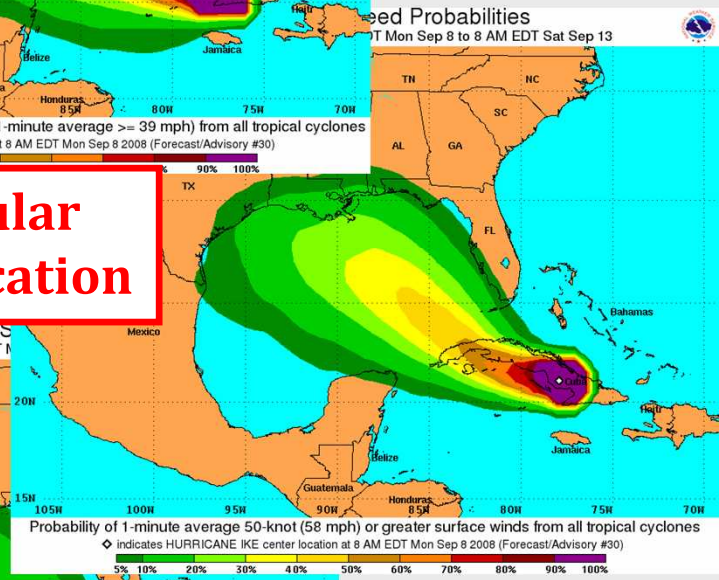


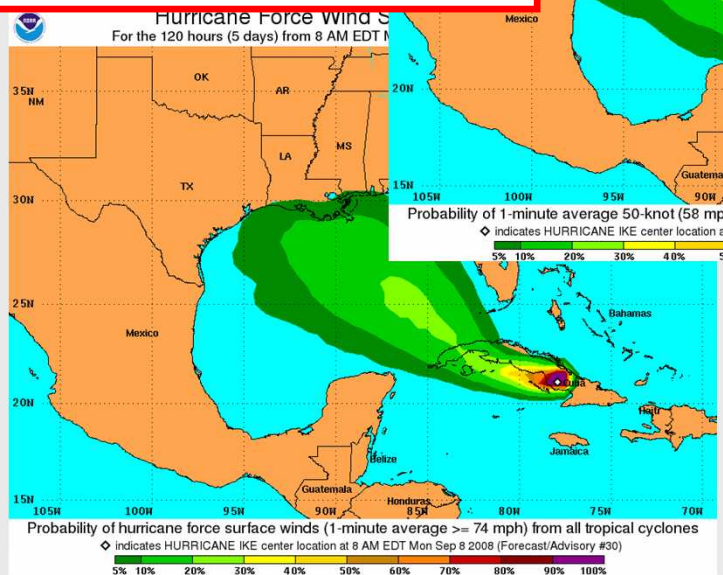
- Monte Carlo bootstrap: 1000 track realizations
- Conditional on spread of 5-member ensemble
- Output: Text and Graphical

Wind Speed Probabilities

```
ZCZC MIAPWSAT4 ALL
TTAA00 KNHC DDHHMM
HURRICANE WILMA PROBABILITIES NUMBER  20
NWS TPC/NATIONAL HURRICANE CENTER MIAMI FL
0900Z THU OCT 20 2005

...THIS IS AN EXPERIMENTAL PRODUCT FOR 2005...

AT 0900Z THE CENTER OF HURRICANE
WILMA WAS LOCATED NEAR LATITUDE 18.3 NORTH...
LONGITUDE  85.0 WEST WITH
MAXIMUM SUSTAINED WINDS NEAR 130 KTS...150 MPH...240 KM/HR.

CHANCES OF EXPERIENCING WIND SPEEDS OF AT LEAST
   ...34 KT (39 MPH... 63 KPH)...
   ...50 KT (58 MPH... 93 KPH)...
   ...64 KT (74 MPH...119 KPH)...
FOR LOCATIONS AND TIME PERIODS DURING THE NEXT 5 DAYS

PROBABILITIES FOR LOCATIONS ARE GIVEN AS IP(CP) WHERE
    IP  IS THE PROBABILITY OF THE EVENT BEGINNING DURING
        AN INDIVIDUAL TIME PERIOD (INDIVIDUAL PROBABILITY)
   (CP) IS THE PROBABILITY OF THE EVENT OCCURRING BETWEEN
        06Z THU AND THE FORECAST HOUR (CUMULATIVE PROBABILITY)

PROBABILITIES ARE GIVEN IN PERCENT
X INDICATES PROBABILITIES LESS THA
LOCATIONS SHOWN WHEN THEIR TOTAL C
   PROBABILITY IS AT LEAST 2.5 PER

Z INDICATES UNIVERSAL COORDINATED


  - - - - WIND SPEED PROBABILITIES FOR SELECTED LOCATIONS - - - -

                FROM    FROM    FROM    FROM    FROM    FROM    FROM
  TIME        06Z THU 18Z THU 06Z FRI 18Z FRI 06Z SAT 06Z SUN 06Z MON
PERIODS         TO      TO      TO      TO      TO      TO      TO
              18Z THU 06Z FRI 18Z FRI 06Z SAT 06Z SUN 06Z MON 06Z TUE

FORECAST HOUR    (12)    (24)    (36)    (48)    (72)    (96)    (120)
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
LOCATION       KT

MIAMI FL       34  X   X( X)   X( X)   2( 2)  16(18)  23(41)   5(46)
MIAMI FL       50  X   X( X)   X( X)   X( X)   6( 6)  11(17)   3(20)
MIAMI FL       64  X   X( X)   X( X)   X( X)   2( 2)   5( 7)   1( 8)

KEY WEST FL    34  X   X( X)   2( 2)   7( 9)  26(35)  18(53)   3(56)
KEY WEST FL    50  X   X( X)   X( X)   1( 1)  14(15)  11(26)   1(27)
KEY WEST FL    64  X   X( X)   X( X)   X( X)   8( 8)   5(13)   1(14)

MARCO ISLAND   34  X   X( X)   X( X)   5( 5)  20(25)  23(48)   4(52)
MARCO ISLAND   50  X   X( X)   X( X)   1( 1)  10(11)  12(23)   2(25)
MARCO ISLAND   64  X   X( X)   X( X)   X( X)   5( 5)   6(11)   X(11)
```

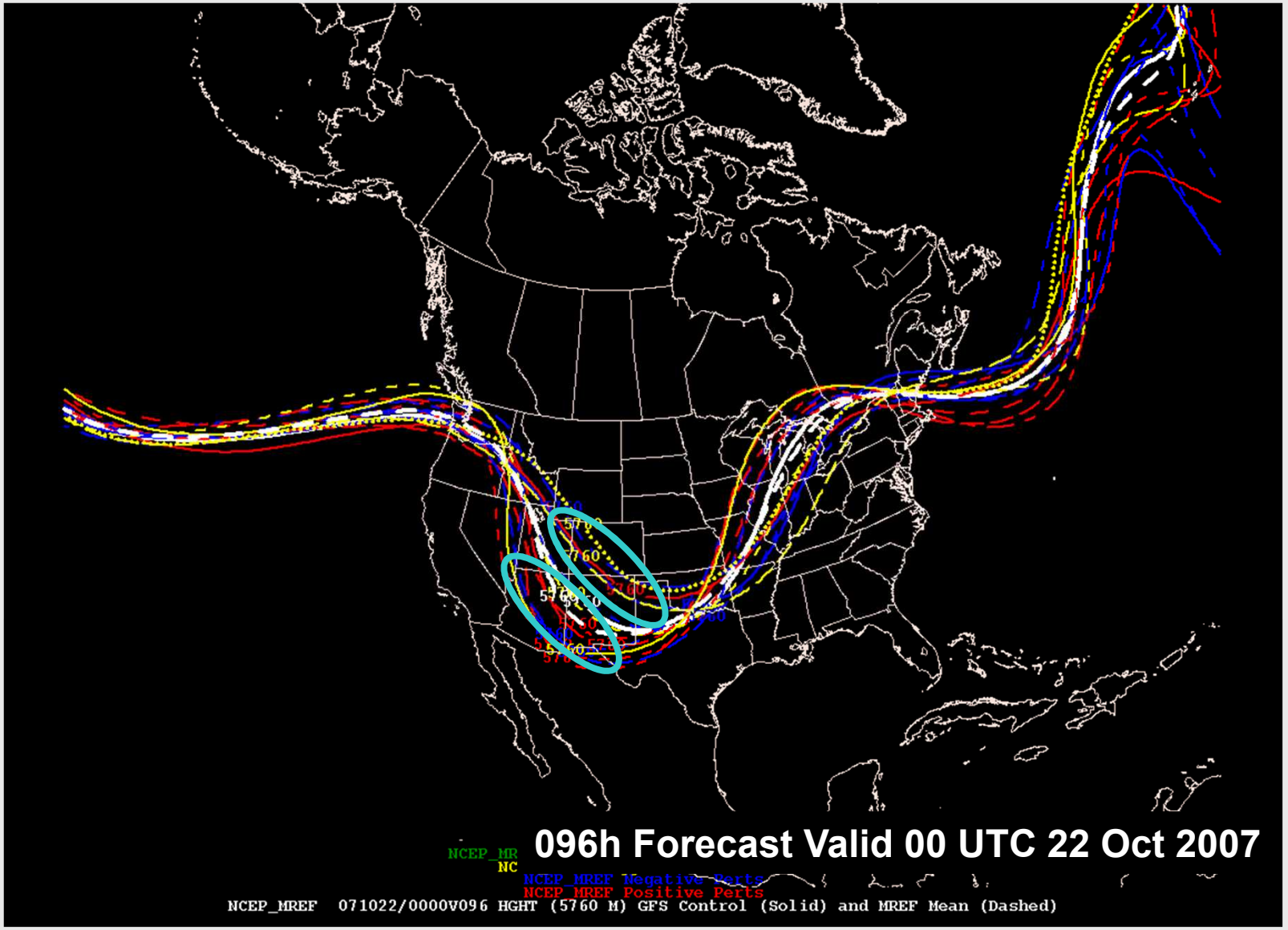






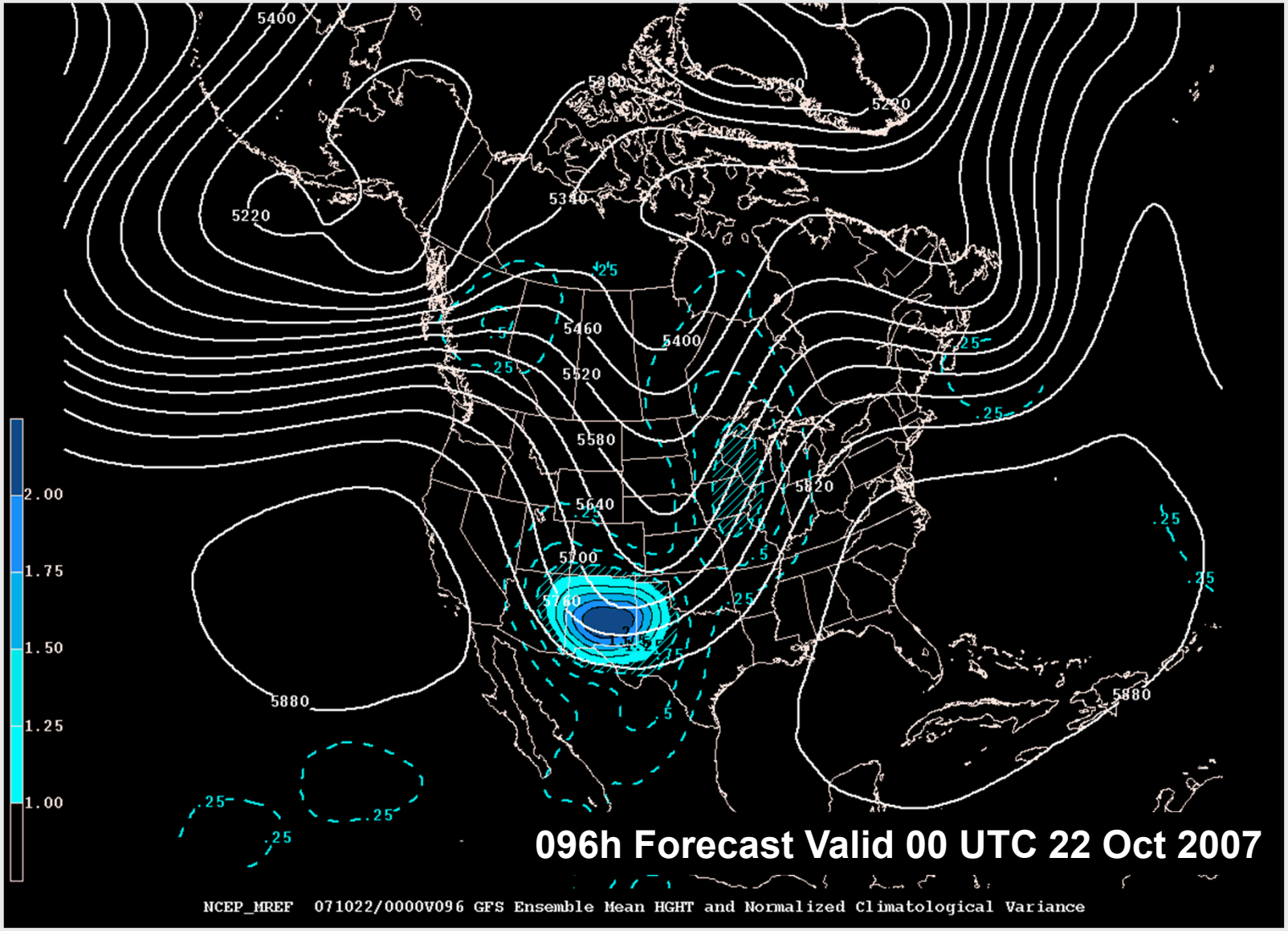
Shows the chance of a particular event occurring at a specific location

Wildfires



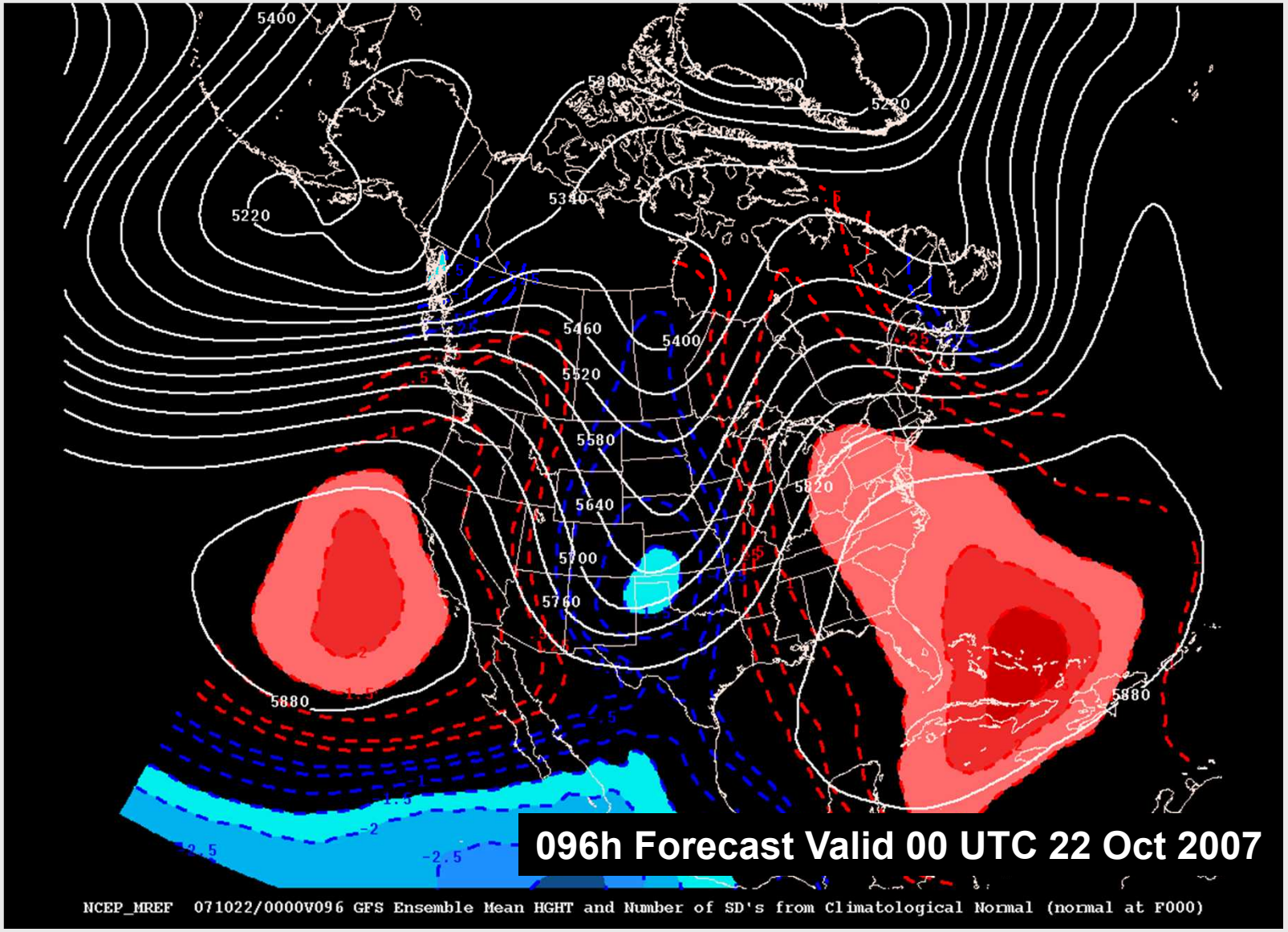
GEFS Ensemble Spaghetti: 500 mb Height (Single contour at 5760 m)

$$\text{Normalized Spread} = \frac{\text{Ensemble Spread}}{\text{Climate Spread}}$$

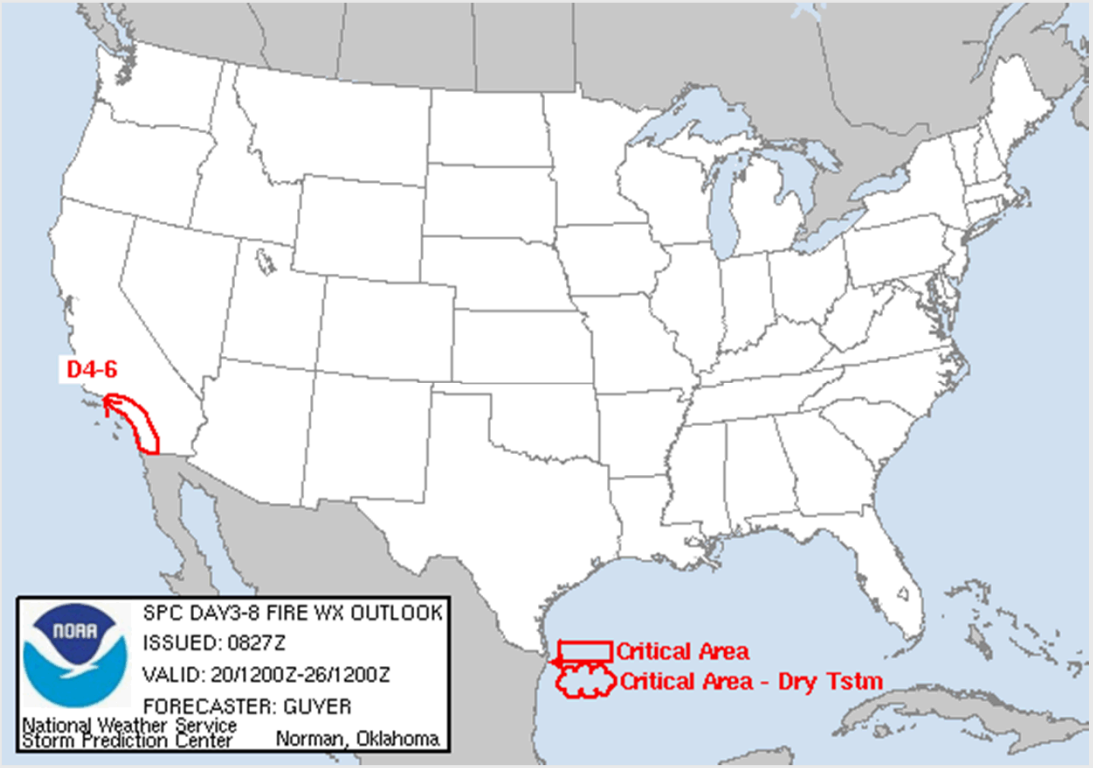


GEFS Ensemble: Mean 500 mb Height (m) and its climatologically normalized SD

Hart and Grumm 2001; Stuart and Grumm 2006;



GEFS Ensemble: Mean 500 mb Height and its Departure from Normal (# of SD)



...DISCUSSION...

LATEST MEDIUM RANGE DETERMINISTIC MODELS/ENSEMBLES SUGGEST THE NEXT IN A SERIES OF UPPER TROUGHS WILL LIKELY CROSS THE WESTERN STATES THIS WEEKEND. CONSIDERABLE MODEL DISCREPANCY EXISTS IN REGARDS TO THE PROGRESSION OF THIS SYSTEM...WITH THE 00Z EUROPEAN SUGGESTING THE TROUGH COULD BECOME CUT-OFF OVER THE SOUTHERN ROCKIES.

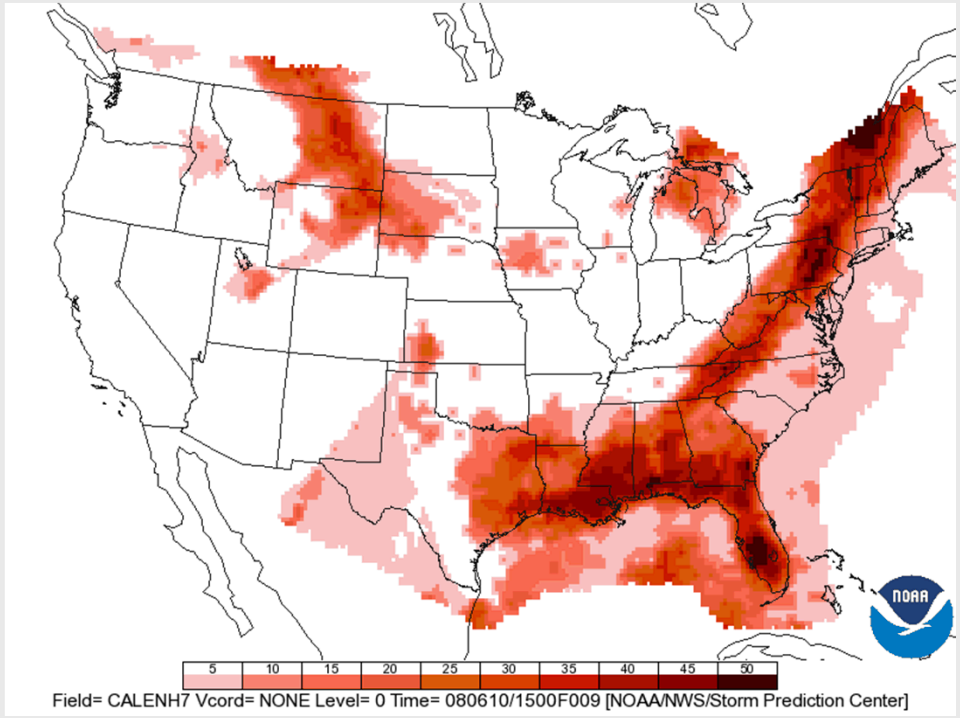
INITIALLY ON DAY 3/SATURDAY...STRONG GUSTY WINDS ASSOCIATED WITH THE UPPER TROUGH/STRONG JET COULD YIELD AT LEAST NEAR-CRITICAL CONDITIONS ACROSS THE SOUTH CENTRAL HIGH PLAINS. THEREAFTER...IN THE WAKE OF THE UPPER TROUGH...CONFIDENCE CONTINUES TO INCREASE THAT A MODERATE-STRONG OFFSHORE/SANTA ANA WIND EVENT MAY BECOME ESTABLISHED ACROSS SOUTHERN CA BY LATE DAY 3/SATURDAY AND DAY 4/SUNDAY THROUGH DAY 6/TUESDAY. AS SUCH...THE POTENTIAL WOULD EXIST FOR NOCTURNALLY-ENHANCED GUSTY WINDS ACROSS SOUTHERN CA...ALONG WITH WARMER TEMPERATURES AND LOWER RH VALUES INTO EARLY NEXT WEEK.

Aviation Weather

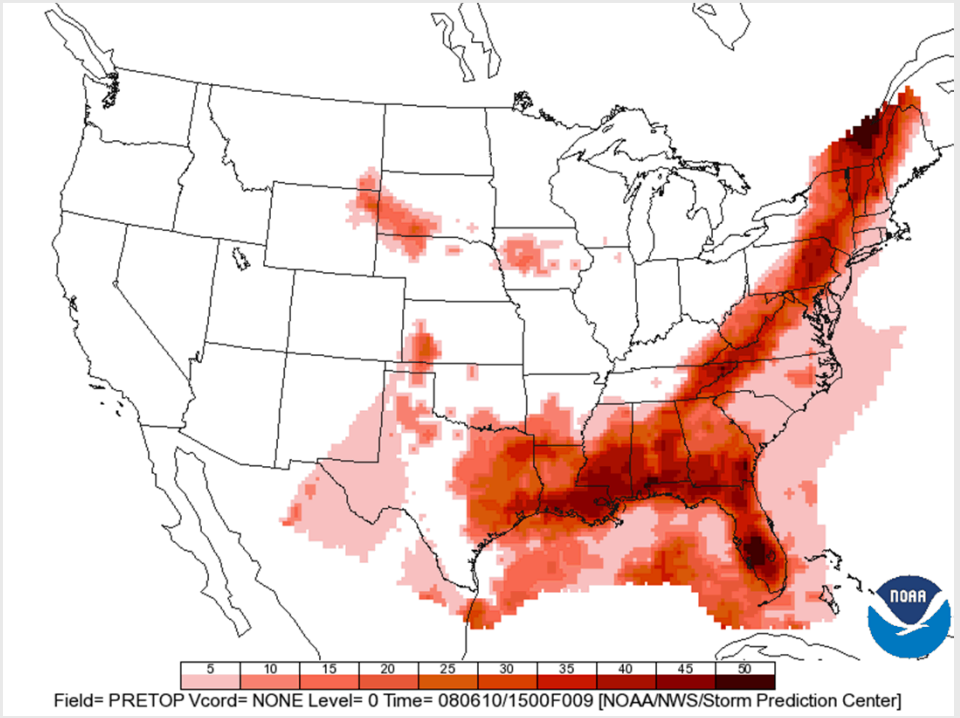
SREF Guidance 15 UTC 10 June 2008

F009 valid at 00 UTC 11 June 2008

Calibrated Probability of a T-Storm



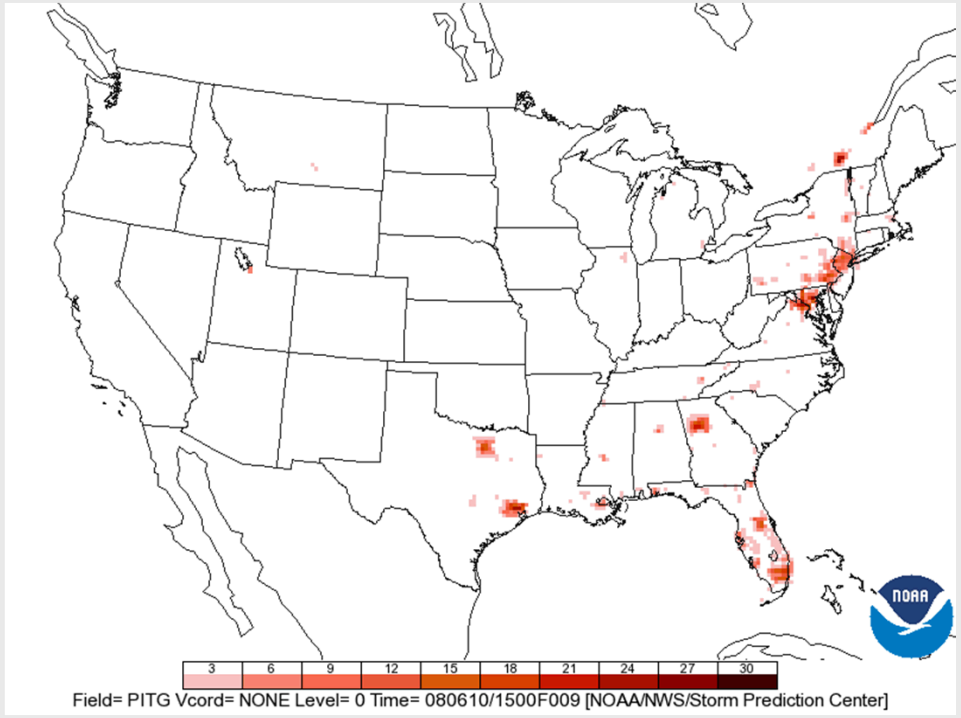
Probability of Tops ≥ 37,000 Feet



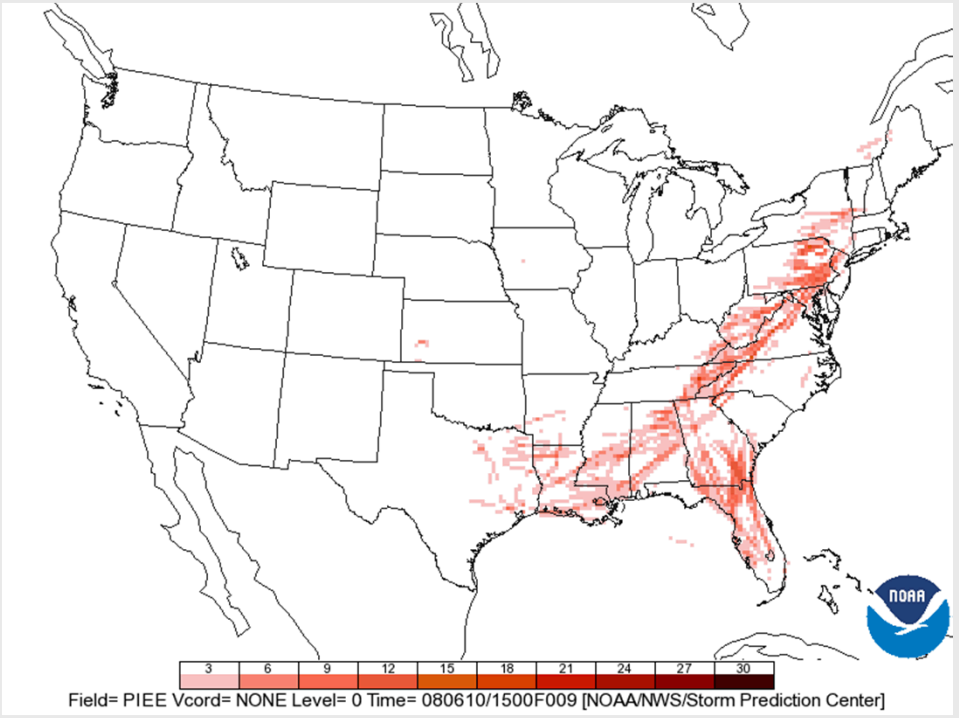
SREF Impact Guidance 15 UTC 10 June 2008

F009 valid at 00 UTC 11 June 2008

Joint Probability:
TRW & Aircraft ≤ 10 kft



Joint Probability:
TRW Tops & Aircraft ≥ 25 kft

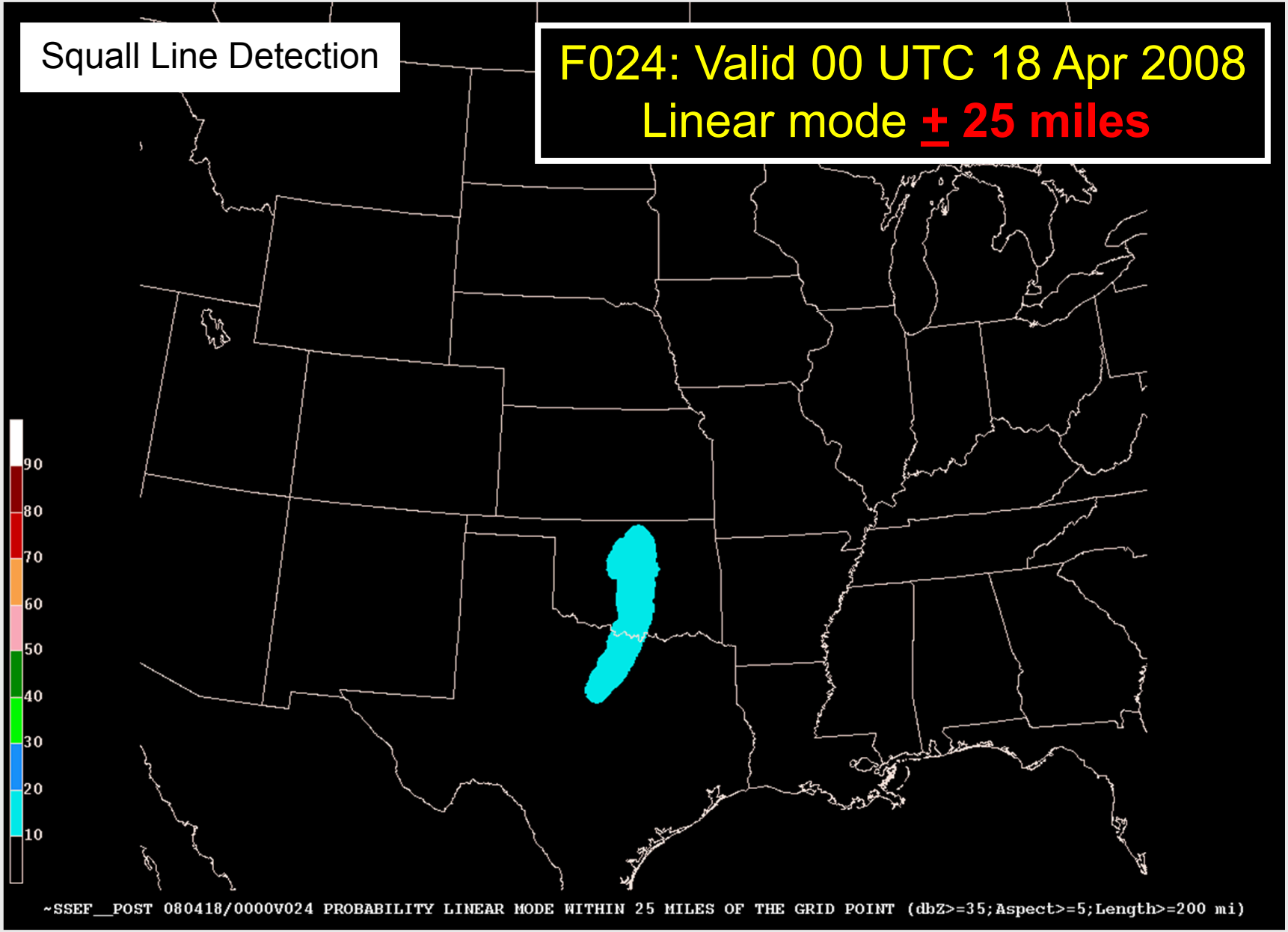


Joint probabilities estimated from 5-year historical archive of aircraft position

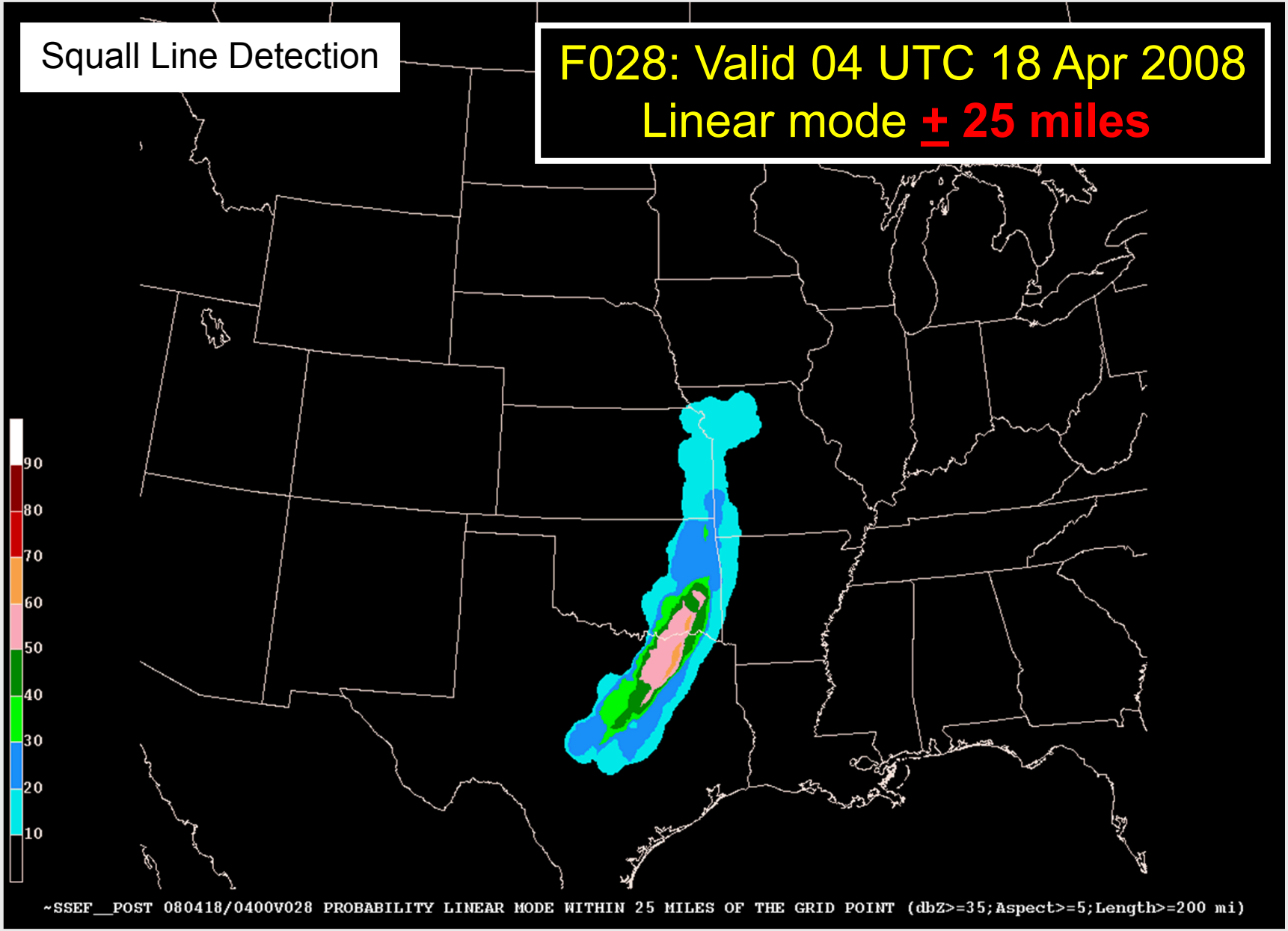
Convective Mode: Linear Detection

- Determine contiguous areas exceeding 35 dbZ
- Estimate mean length-to-width ratio of the contiguous area; search for ratios ≥ 5:1
- Flag grid point if the length exceeds:
  - 200 miles

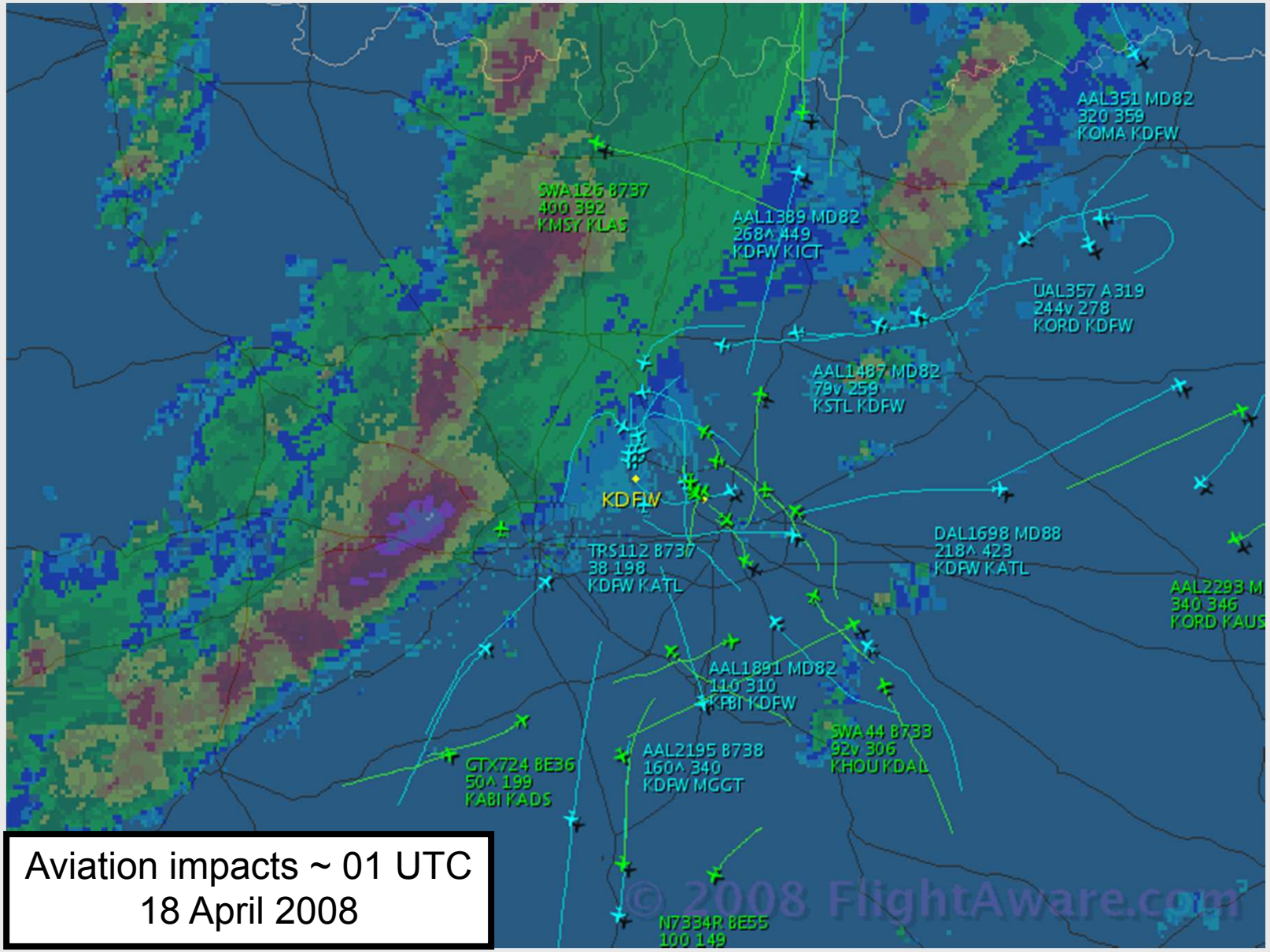
Probability Linear Mode Exceeding 200 miles



Probability Linear Mode Exceeding 200 miles



Linear Convective Mode: Impacts



Aviation impacts ~ 01 UTC
18 April 2008

Image provided by Jon Racy

Summary

- NCEP's multi-scale mission to deliver reliable, timely, and accurate analyses, guidance, forecasts, and warnings largely depends on ensemble systems.

- Multi-model ensembles and emerging "ensembles of opportunity" help to quantify the threat and aid high-impact decision support services.

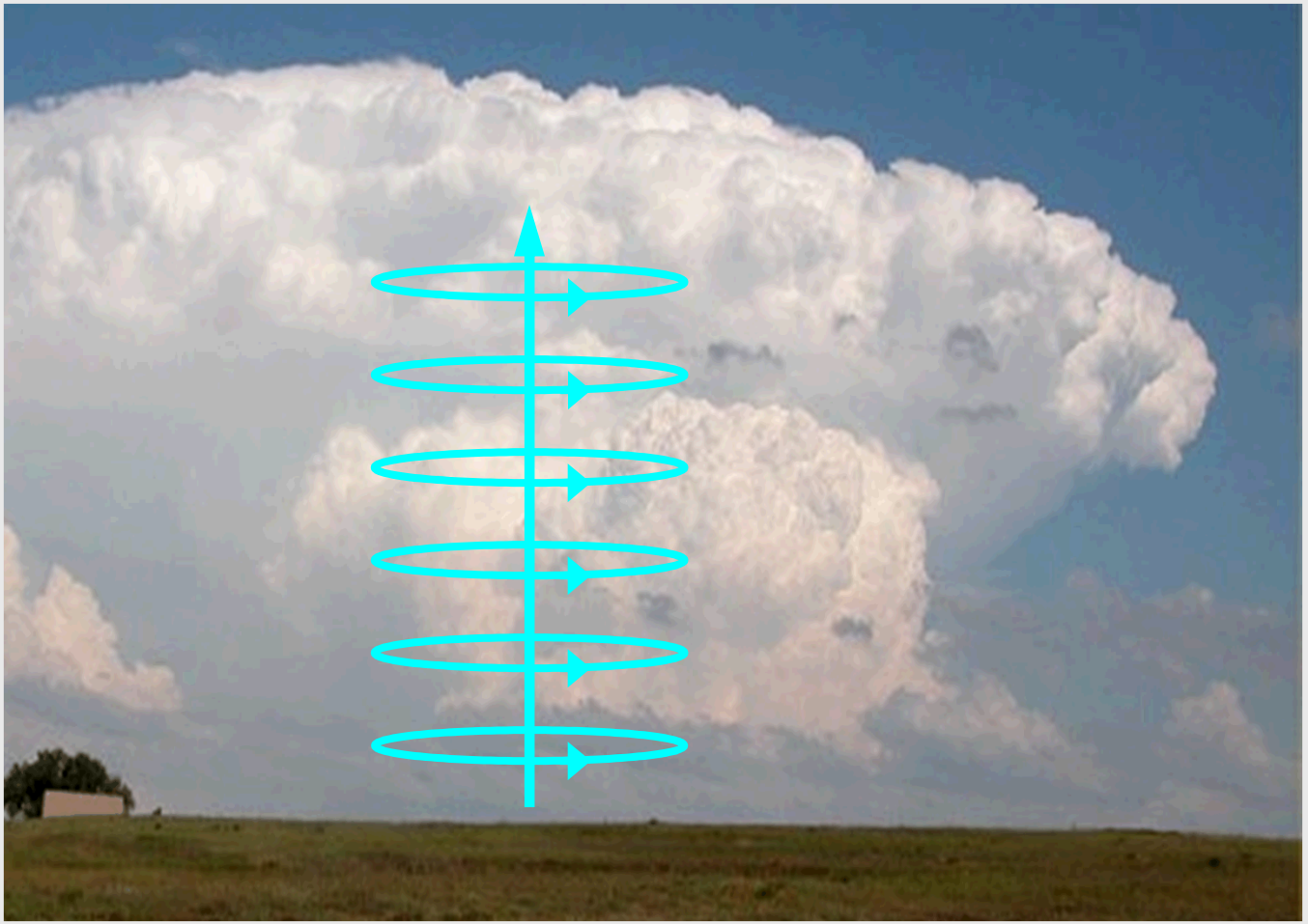
- David Novak will present on emerging guidance, Testbeds, and opportunities using ensemble data.

NATIONAL CENTERS FOR ENVIRONMENTAL PREDICTION
NCEP

Where Americas Climate and Weather Services Begin

Convective Mode: Supercell Detection

Besides simulated reflectivity, need a quantitative tool for supercell detection and strength in deterministic and ensemble forecasts



Convective Mode: Supercell Detection (Updraft Helicity)

General definition of helicity:

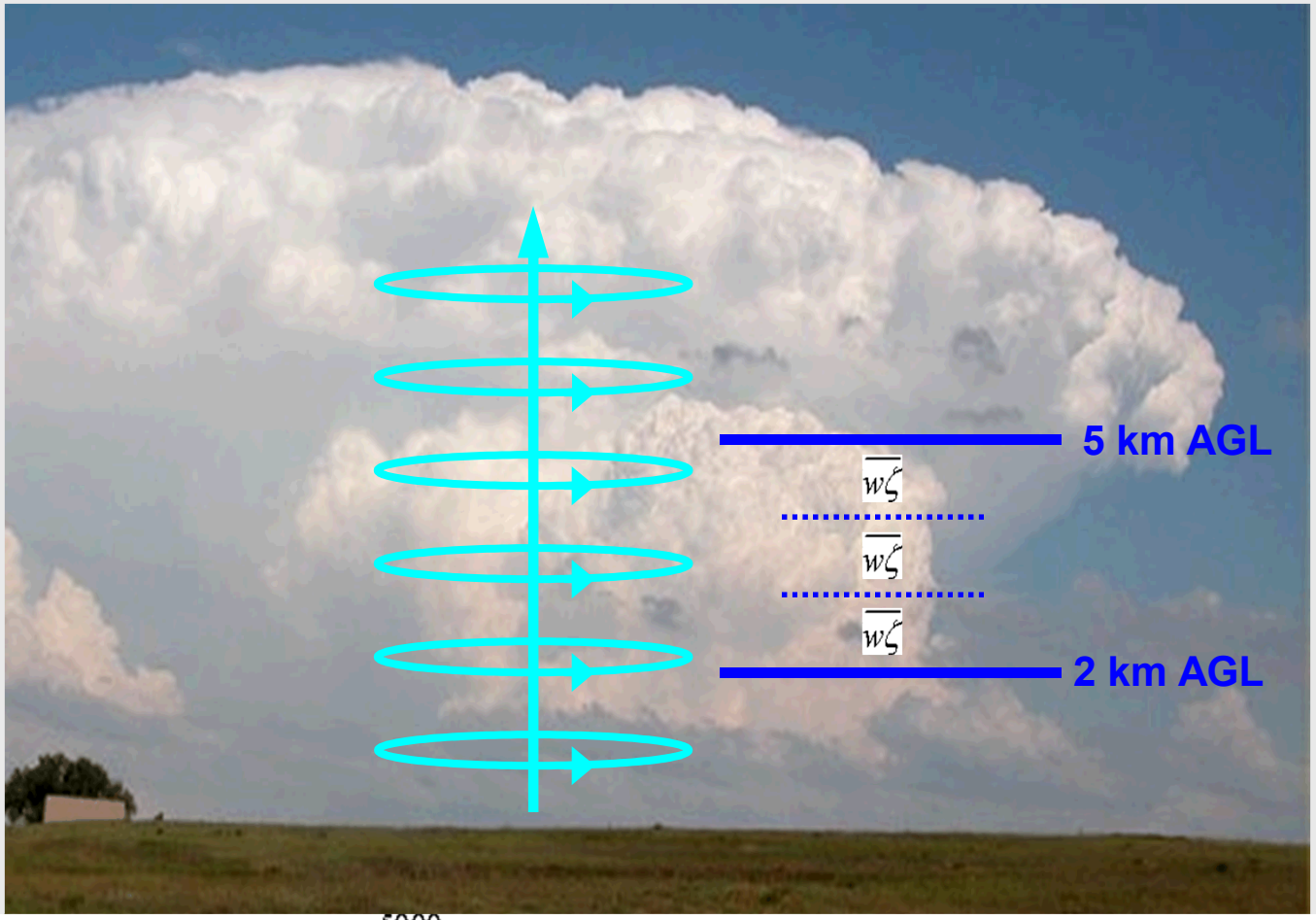
$$H = \vec{V} \bullet \nabla \times \vec{V}$$

In component form:

$$H = u\left(\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}\right) + v\left(\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}\right) + w\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)$$

Convective Mode: Supercell Detection

Besides simulated reflectivity, need a quantitative tool for supercell detection and strength in deterministic and ensemble forecasts



$$U_H = \int_{z_o}^{z} [w\zeta]dz \approx \sum_{z=2000\,m}^{z=5000\,m} (\overline{w\zeta}\Delta Z) = (\overline{w\zeta}_{2,3} + \overline{w\zeta}_{3,4} + \overline{w\zeta}_{4,5}) \times 1000$$