Ensemble Forecasting and Its Application

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Outlines

- Ensemble Forecasting
  - Responsibility of ensemble development team
  - Concept of seamless forecast
  - NCEP all ensemble systems
- Data Distribution and Product Generation
  - Data access through all available resource
  - Digital probabilistic products
  - Web-based products
- Applications
  - NCEP service centers
  - NWS WFO
  - Private sectors
- Values and Benefits
  - Probabilistic, not deterministic
- Future Expectation and Plan
  - Improve ensemble system

Ensemble Forecasting

Responsibilities of Ensemble Development
- *Assess, model, communicate uncertainty in numerical forecasts*

- Present uncertainty in numerical forecasting
  - Tasks
    - Design, implement, maintain, and continuously improve ensemble systems
  - Sciences
    - Initial value related uncertainty
    - Model related forecast uncertainty
  - Ensemble systems
    - Global – GEFS / NAEFS / NUOPC
    - Regional – SREF / HREF / NARRE-TL / HWAF ensemble
    - Climate – Contributions to future coupling CFS configuration
    - NAEFS/GEFS downscaled
    - Ocean wave ensemble (MMA/EMC)
- Statistical correction of ensemble forecasts
  - Current tasks
    - Correct for systematic errors on model grid, correct ensemble spread.
    - Downscale information to fine resolution grid (NDFD)
    - Combine all forecast info into single ensemble/probabilistic guidance
- Probabilistic product generation / user applications
  - Contribute to design of probabilistic products
  - Support use of ensembles by
    - Internal users (NCEP Service Center, WFOs, OHD/RFC forecasters and et al.)
    - External users (research, development, and applications)

4

NWS Seamless Suite of Forecast Products Spanning Weather and Climate

5
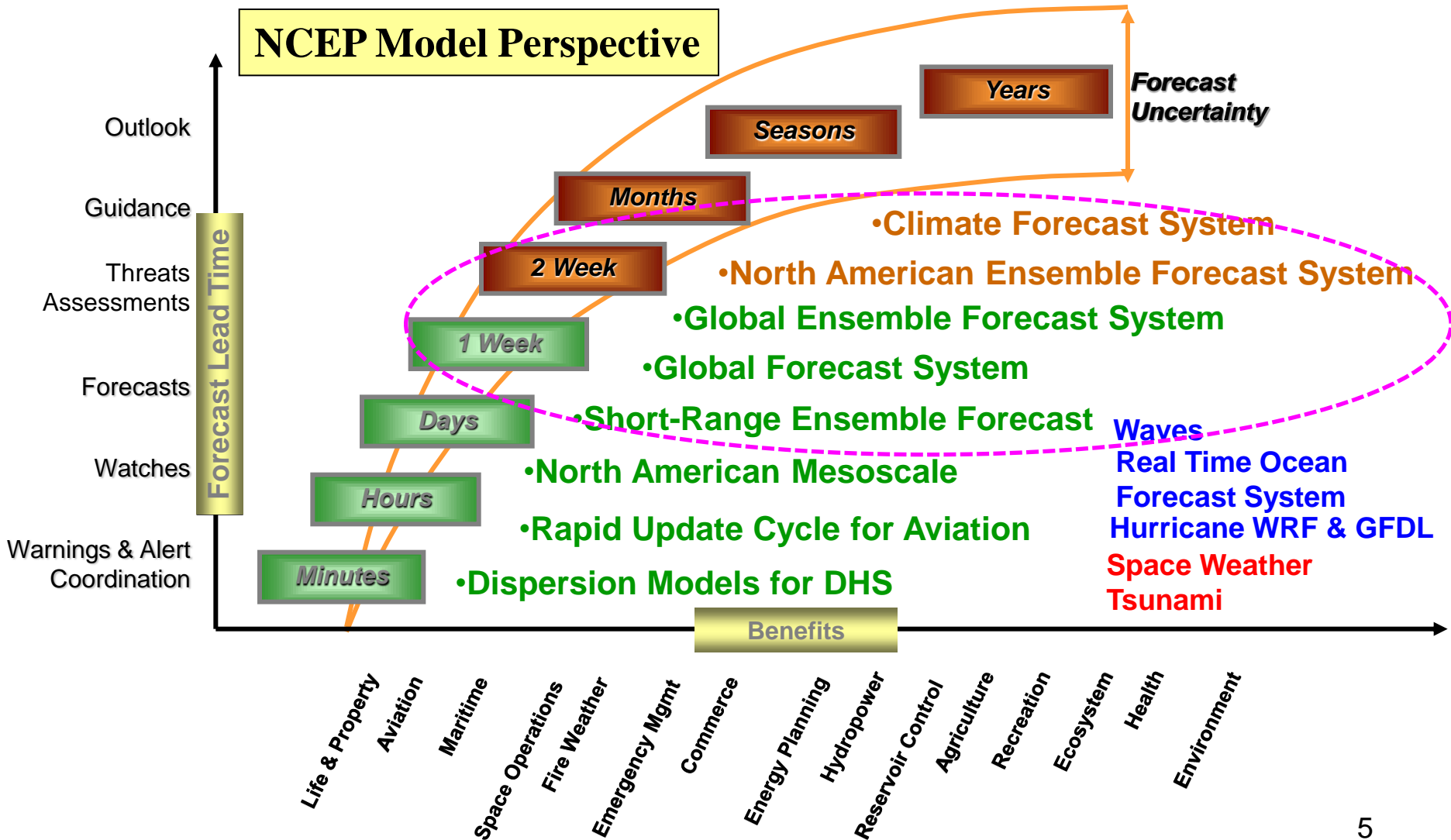
Evolution of NCEP GEFS configuration

	Initial uncertainty	TS relocation	Model uncertainty	Resolution	Forecast length	Ensemble members	Daily frequency
1992.12	BV	None	None	T62L18	12	2	00UTC
1994.3				T62L18	16	10(00UTC) 4(12UTC)	00,12UTC
2000.6				T126L28(0-2.5) T62L28(2.5-16)		10	
2001.1				T126(0-3.5) T62L28(3.5-16)			
2004.3				T126L28(0-7.5) T62L28(7.5-16)			00,06,12,18UTC
2005.8		TSR		T126L28			
2006.5	ETR					14	
2007.3						20	
2010.2			STTP	T190L28			
2012.2				T254L42(0-8) T190L42(8-16)			

Evolution of NCEP SREF configuration

	IC uncertainty	Physics uncertainty	Model resolution	Forecast length	Ensemble members	Daily frequency
2001	BV	Multi-model (MM, Eta and RSM)	48km	63hr	10	09, 21z
2003		Multi-model + Multi-physics (MMMP, add ETA_kf)			15	
2004		MMMP (add more diverse physics schemes to Eta)	40km	87hr		
2005		MMMP (add NMM and ARW)			21	
2006						03,09,15,21z
2009	BV + downscaled ETR	MMMP (less Eta and more WRF, add more physics scheme to RSM)	32km	87hr	21	03,09,15,21Z
2012	BV + Downscaled ETR	NEMS-NMMB WRF-NMM WRF-ARW	22km	87hrs	21	03,09,16,21Z

NAEFS Current Configuration

Updated: February 14th 2012

	NCEP	CMC	NAEFS
Model	GFS	GEM	NCEP+CMC
Initial uncertainty	ETR	EnKF	ETR + EnKF
Model uncertainty/Stochastic	Yes (Stochastic Pert)	Yes (multi-physics)	Yes
Tropical storm	Relocation	None	
Daily frequency	00,06,12 and 18UTC	00 and 12UTC	00 and 12UTC
Resolution	T254L42 (d0-d8)~55km T190L42 (d8-16)~70km	(d0-d16) ~ 66km	1*1 degree
Control	Yes	Yes	Yes (2)
Ensemble members	20 for each cycle	20 for each cycle	40 for each cycle
Forecast length	16 days (384 hours)	16 days (384 hours)	16 days
Post-process	Bias correction (same bias for all members)	Bias correction for each member	Yes
Last implementation	February 14th 2012	August 17th 2011	

Data Distribution and Product Generation

NAEFS Products Distribution

System	Current available products
Config.	1.deg 0-384h, every 6 hours, 20 members (NCEP) and 20 members (CMC), ens. control (NCEP and CMC)
Format	GRIB1 (and GRIB2, GIF images for web display)
CCS	NCEP: pgrba, pgrbb, pgrba_bc, pgrba_an, pgrba_wt, ensstat, ndgd CMC: pgrba, pgrba_bc, pgrba_an, pgrba_wt, ensstat NAEFS: ndgd, pgrba_an, pgrba_bc
NCEP FTPPRD	ftp://ftpprd.ncep.noaa.gov/pub/data/nccf/com/gens/prod cd gefs.${yyyymmdd} for NCEP ensemble 1. pgrb2a (00, 06, 12 and 18UTC) (1.0 degree, all lead times, 1(c) + 20 (p)) 2. pgrb2alr (00, 06, 12 and 18UTC (2.5 degree, all lead times, 1(c) +20 (p)) 2. pgrb2b (00, 06, 12 and 18UTC) (1.0 degree, all lead times, 1(c) + 20 (p)) 4. pgrb2blr (00 and 12UTC) (2.5 degree, all lead times, 1(c) + 20 (p)) 5. ensstat (00UTC) (prcp_bc, pqpf and pqpf_bc files) 6. wafs (00 and 12UTC) 7. ndgd_gb2 (00, 06, 12, 18UTC) (CONUS-5km, all lead times and all probability forecasts) ftp://ftpprd.ncep.noaa.gov/pub/data/nccf/com/gens/prod cd cmce.${yyyymmdd} for CMC ensemble 1. pgrba (00 and 12UTC) (1.0 degree, all lead times,1 control + 20 members) ftp://ftpprd.ncep.noaa.gov/pub/data/nccf/com/gens/prod cd naefs.${yyyymmdd} for NAEFS products 1. pgrb2a_an (00, 12UTC) (1.0 degree, all lead times, anomaly for ensemble mean) 2. pgrb2a_bc (00,12UTC) (1.0 degree, all lead times, probabilistic forecasts) 3. ndgd_gb2 (00,12UTC) (CONUS-5km, all lead times, probabilistic forecasts)
TOC	ftp://tgftp.nws.noaa.gov/SL.us008001/ST.opnl/ cd MT.ensg_CY.${cyc}/RD.${yyyymmdd} for NCEP only 1. PT.grid_DF.gr1_RE.high (00 and 12UTC) (Pgrba: 1.0 and 2.5 degree, 0-384 hrs, c + 10 (p)) 2. PT.grid_DF.gr1_RE.low (00 and 12UTC) (Pgrbb: 1.0 degree, 0-84 hrs, 2.5 d, 90-384 hrs, c + 10 (p)) 3. PT_grid_DF.bb
NOMADS	NOAA main data service for public: currently, most data are available for three ensembles from NOMADS http://nomad5.ncep.noaa.gov/ncep_data/ for ftp: combined pgrba and pgrbb at 1 degree resolution, for all ensemble members (c+20(p)) and all lead time (0-384 hours) http://nomad5.ncep.noaa.gov/pub/gens/archive/ for http: combined pgrba and pgrbb at 1 degree resolution

Web-based Probabilistic Products

- NCEP web-site
  - NCO supported all ensemble probabilistic products (main page)
  - EMC (experimental) developed probabilistic products
    - PQPF for various thresholds (include precipitation types)
    - RMOP for 500hPa height
    - Tropical storm track forecast
    - Extra-tropical storm track forecast (global tracking)
- NAEFS web-site
  - CPC developed extended probabilistic forecast
    - Temperature, 500hPa height and precipitation
  - NCO supported NAEFS products
    - Spaghetti,
  - EMC (experimental) NAEFS products
    - PQPF for various thresholds
    - Anomaly forecast
  - CMC supported NAEFS products
    - Metagrams for NA major cities (example)
- NUOPC web-site
  - EMC (experimental) NUOPC products
    - PQPF for various thresholds (include precipitation types)
    - TS track forecast for multi-model ensembles
  - FNMOC's NUE probabilistic products (example)

Next

http://mag.ncep.noaa.gov/NCOMAGWEB/appcontroller

Map of PQPF and Precipitation Types: every 6 hours, 4 different thresholds

Ensemble Based Probabilistic Quantitative Precipitation Type Forecast
Ini:2012022800 Valid:2012022800−2012022806 Amount>=1.000mm/6hrs

back
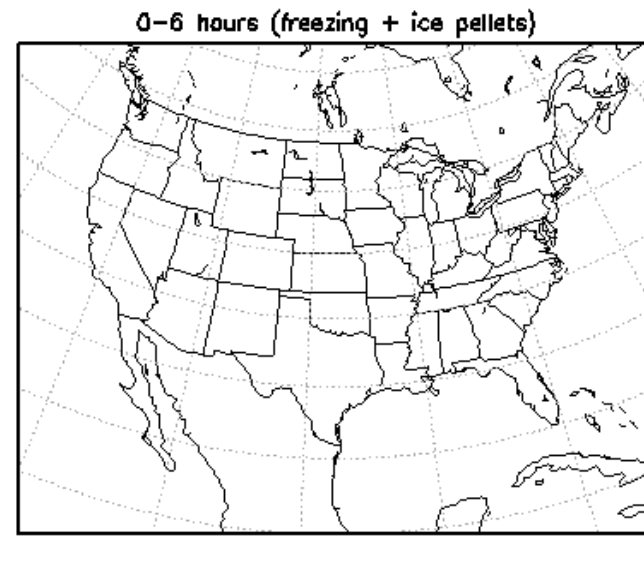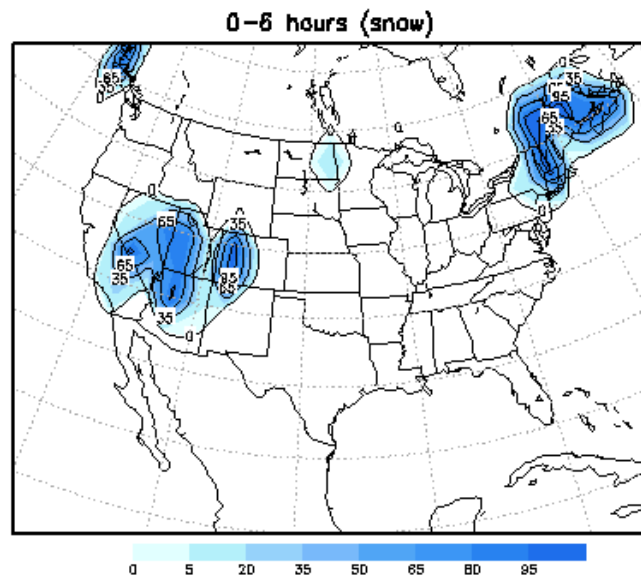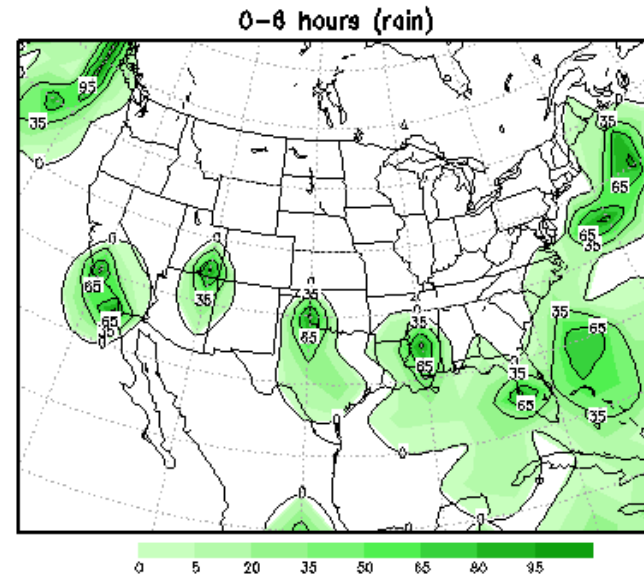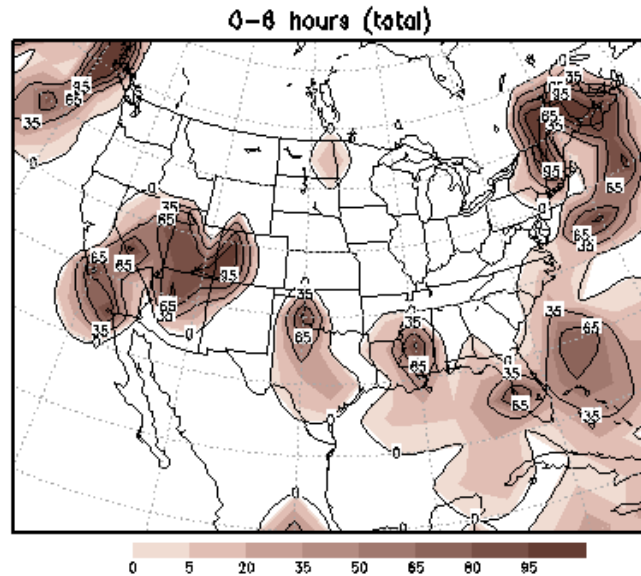
Example: The tracker puts out 4 time a day for all cyclones (Northern Hemisphere)

NCEP Ensemble Perturbation Forecast Storm Tracks
For forecast with initial time = 2011113000
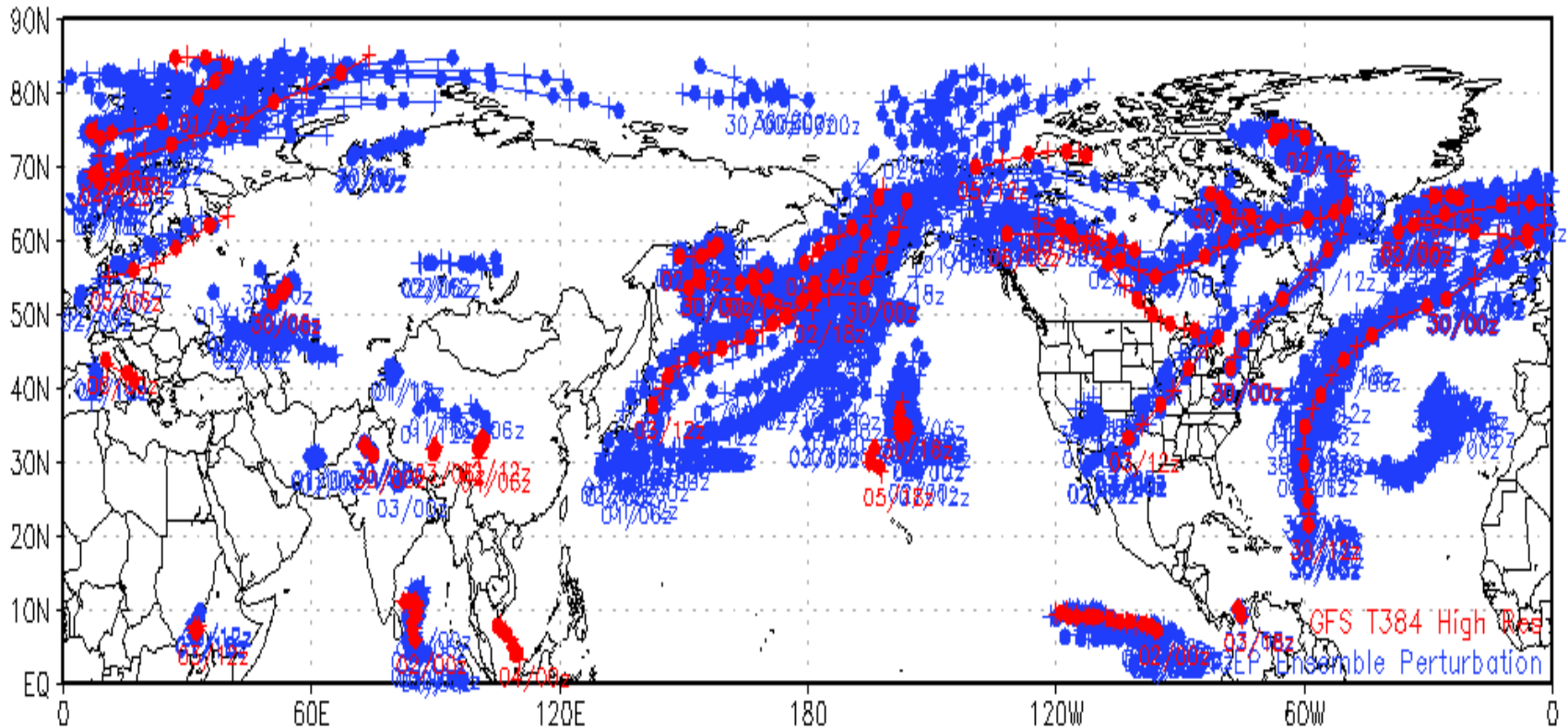
● — Indicates a position at 00 or 12 UTC
+ — Indicates a position at 06 or 18 UTC
Date (dd/hhz) is first time storm was able to be tracked in model

Example of temperature forecast

Upper tercile

Lower tercile

back

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NAEFS products – Metagram (examples)

NUOPC probabilistic products from FNMOC
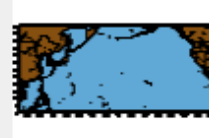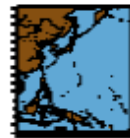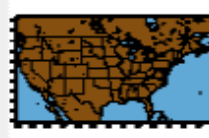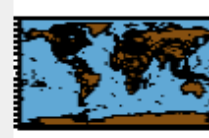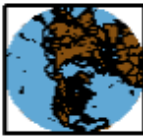
User Applications

SPC - Day 3-8 Fire Weather Outlook Issued on Mar 3, 2012

This product provides a daily probabilistic forecast of critical fire weather conditions for dry thunderstorms and/or strong winds combined with low relative humidity across the continental U.S. during the Day 3-8 period.

Strong Winds

SPC DAY 3-8 EXP PROB STRONG WIND FW
ISSUED: 2143Z 03/03/2012
VALID: 05/1200Z-11/1200Z
FORECASTER: JIRAK
NOAA/NWS Storm Prediction Center, Norman, Oklahoma

Day 3-8 Fire Weather Legend:
D3 | D4 | D5 | D6 | D7 | D8
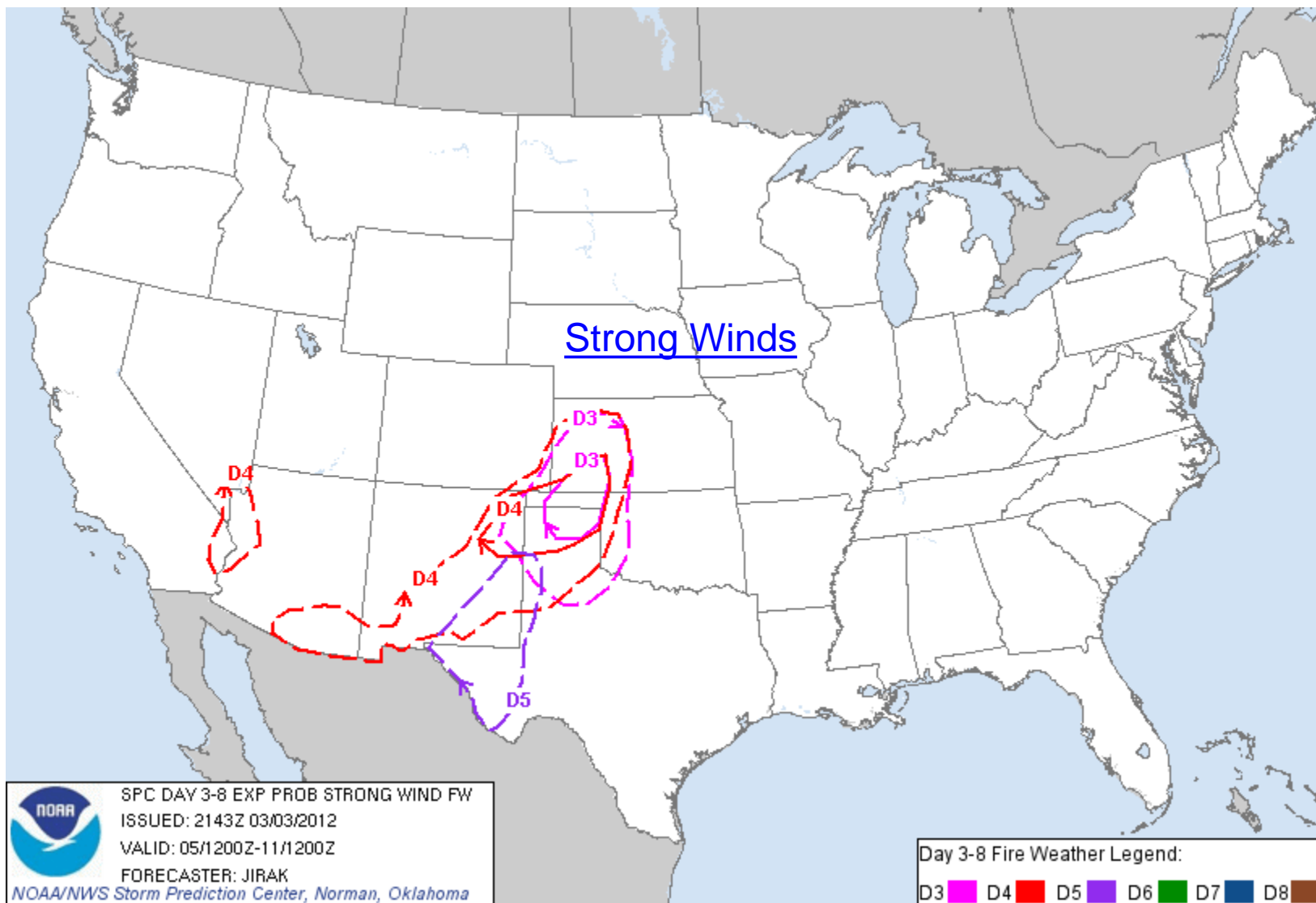
Example of Ensemble Joint Probability

24 hours 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^{2}s^{-2})

X

Prob (MLLCL $\leq$ 1000 m)

X

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

Shaded Area Prob $\geq$ 5%

FCST: F024 VALID: Sat 20061230/0900 UTC

NOAA/NWS Storm Prediction Center, Norman, OK

Max 50%

"P[MLCAPE>1000]xP[MLLCL<1KM]xP[0-1HEL>100]xP[0-6SHR>40]xP[C03I>0.01]"

Combo Prob SigTor & Mean PMSL, Sfc Wnd 060407/2100V024
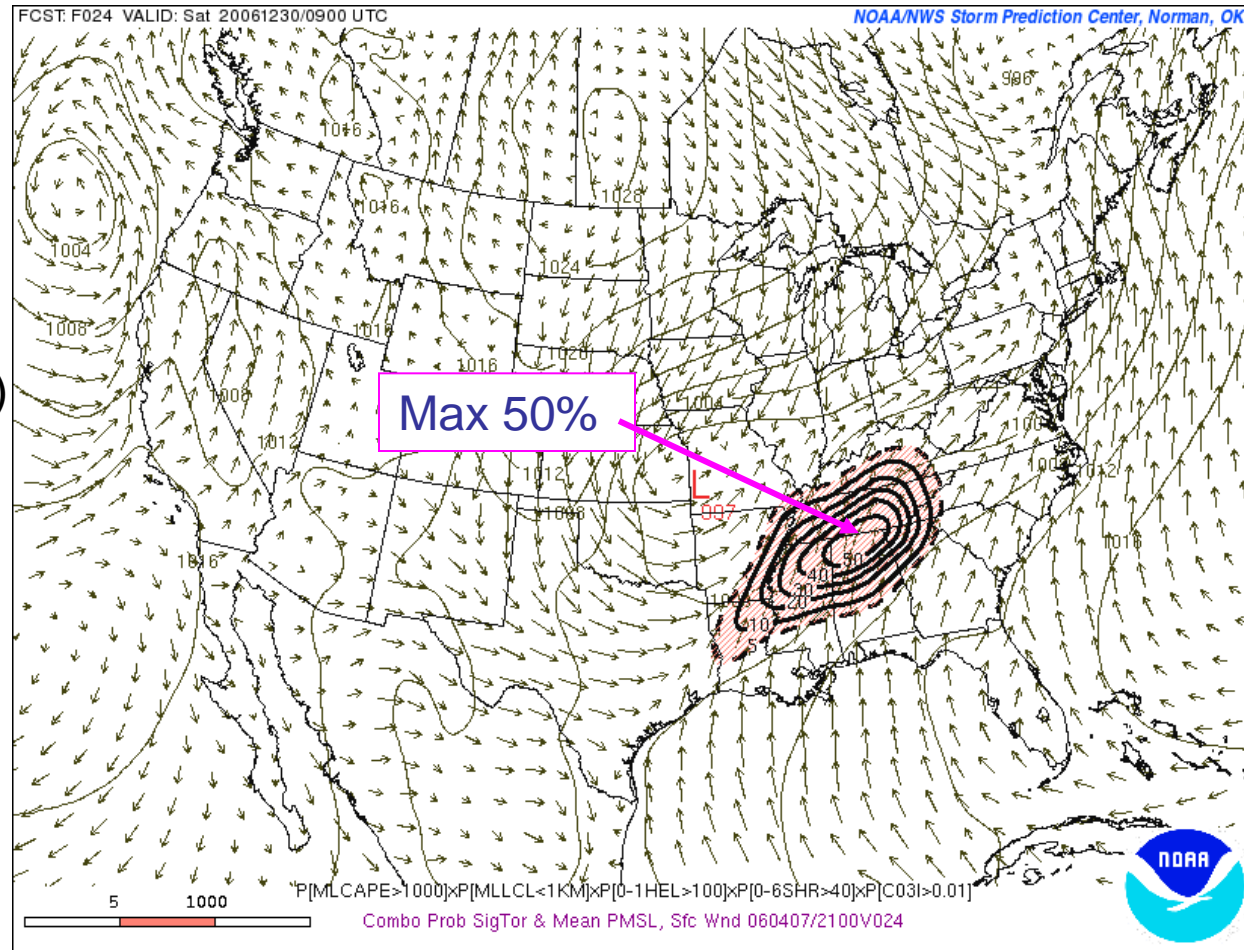
OPC - Surface Wind Prob. from 90 members
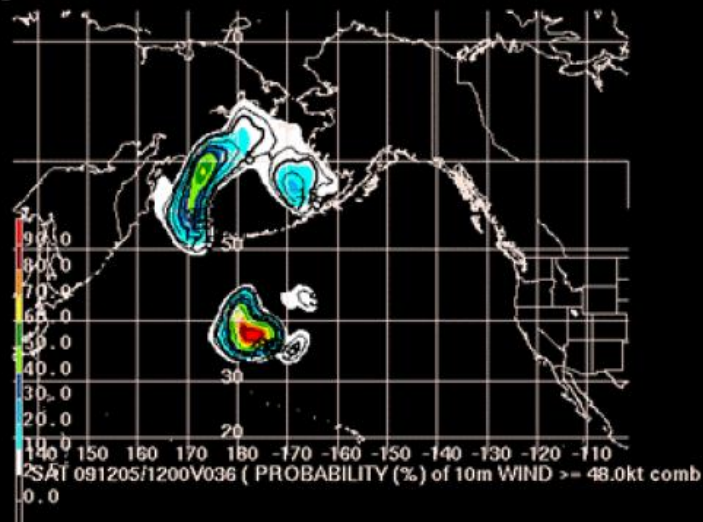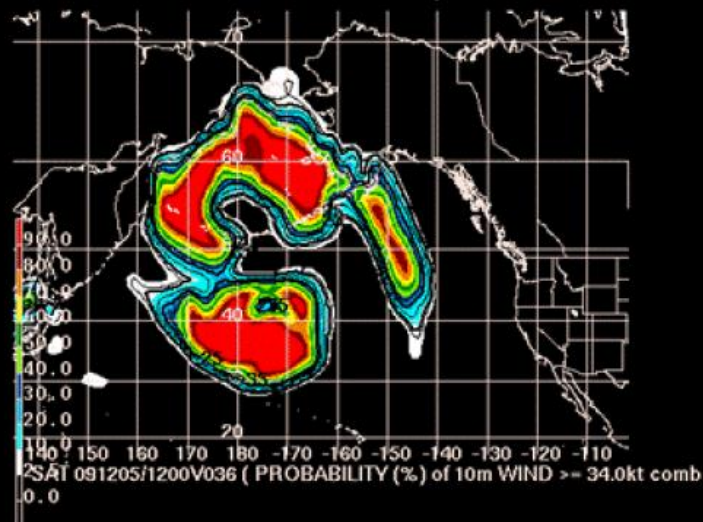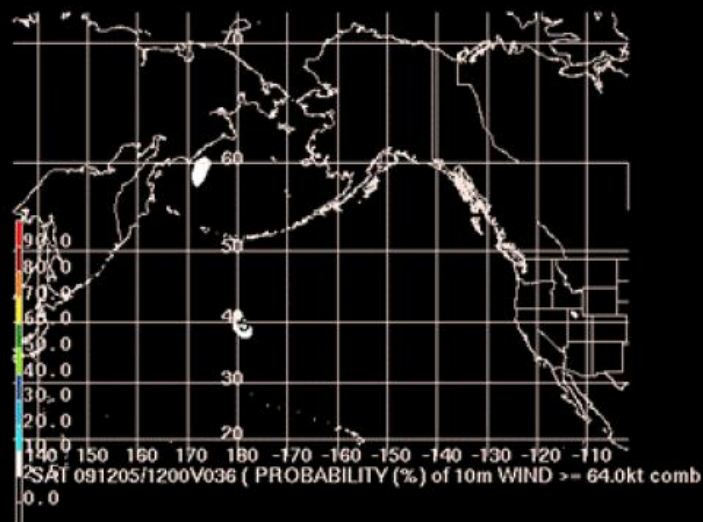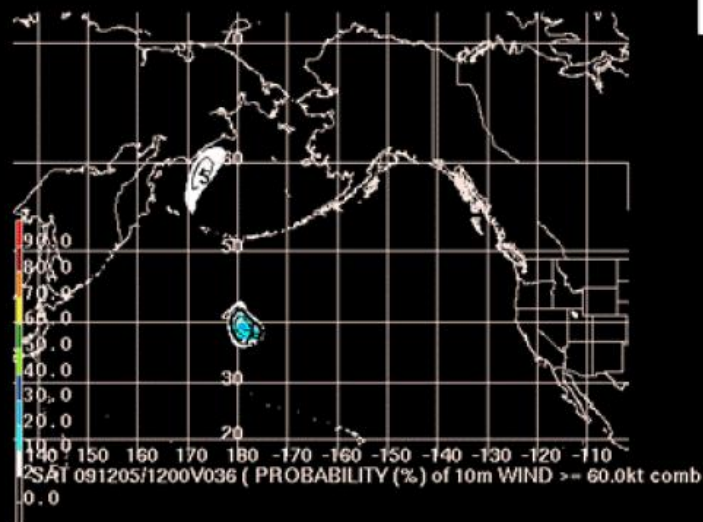
HPC - Subjective Use of Ensembles (1)

Spaghetti

QPF isohyets

Low Clusters
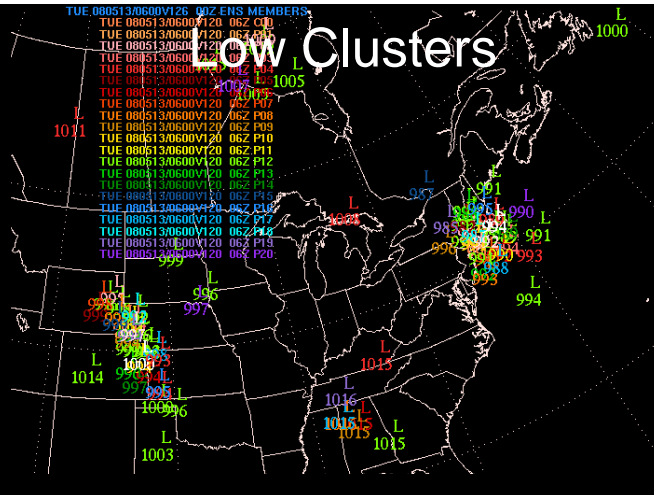
Mean/Spread
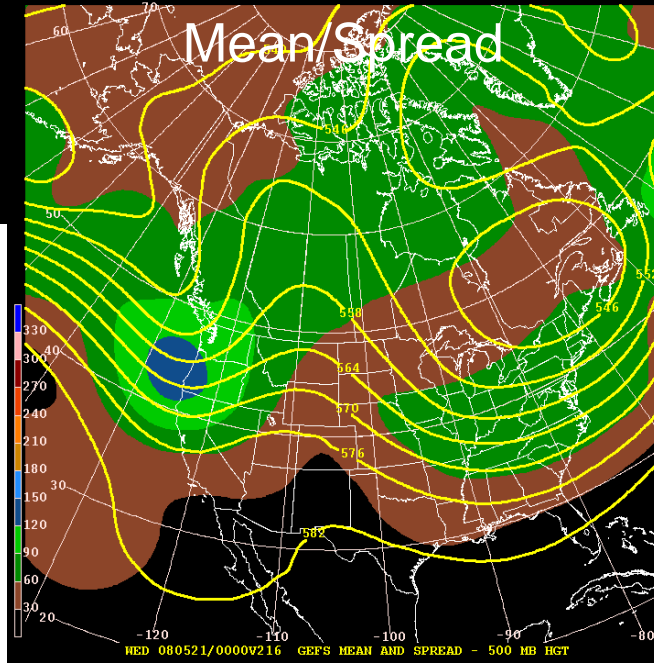
- *Assess predictability*
- *Establish forecaster confidence*
- *Identify outliers and clusters*
- *Identify preferred solutions*

HPC - Subjective Use of Ensembles (2)

Identify preferred solutions

Used as inputs to model blends (weights) selected by forecasters for first-guess forec

HPC - Subjective Use of Ensembles (3)

Uncertainty information communicated via forecasts, discussions and user-interactions

PROBABILITY LEGEND
SLGT: AT LEAST 10% PROB
MDT: AT LEAST 40% PROB
HIGH: AT LEAST 70% PROB

NWS NCEP HPC SNOW ACCUMULATION
DAY 3 PROBABILITY OF AT LEAST 4 INCHES
VALID 12Z TUE APR 19 2011
THRU 12Z WED APR 20 2011
ISSUED: 07:45Z SUN APR 17 2011
FORECASTER: VOJTESAK

SNOW IS DEPICTED FOR ELEVATIONS LESS THAN 7500 FT
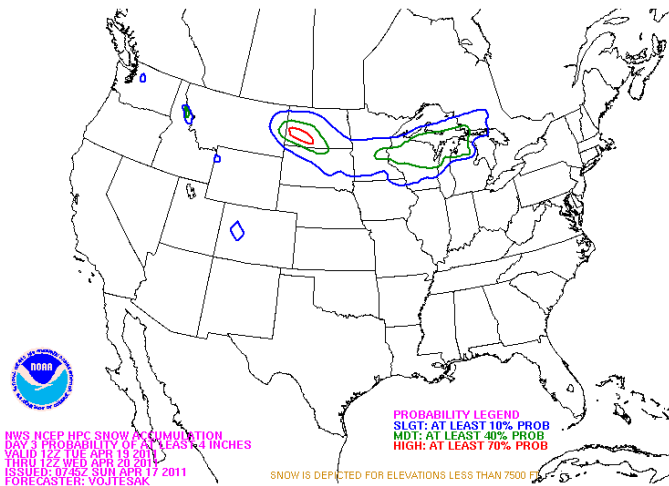
PRELIMINARY EXTENDED FORECAST DISCUSSION
NWS HYDROMETEOROLOGICAL PREDICTION CENTER
959 AM EDT SUN APR 17 2011

VALID 12Z THU APR 21 2011 - 12Z SUN APR 24 2011
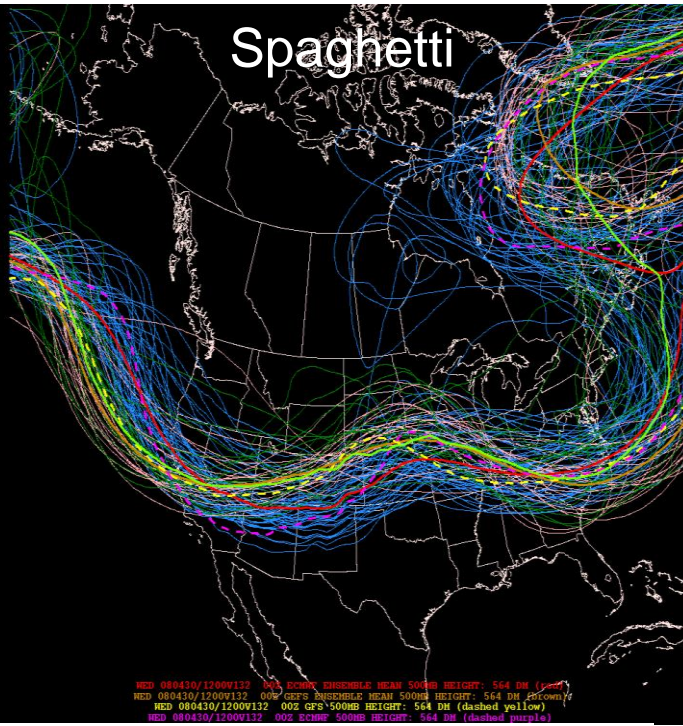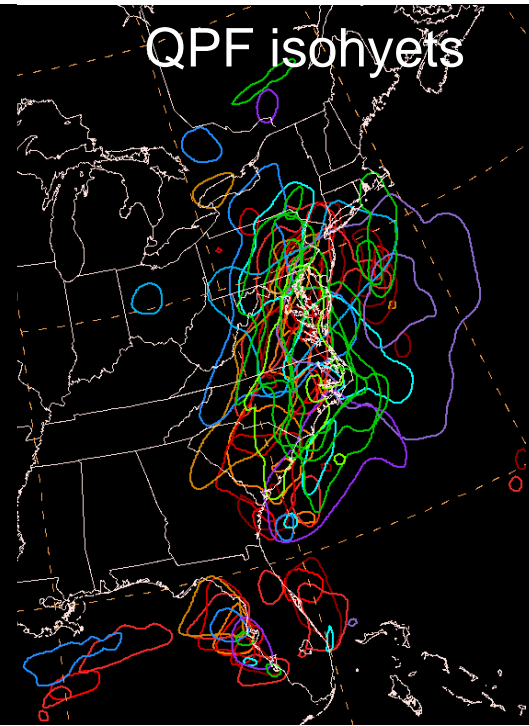
MODELS AND ENSEMBLES SHOW PROGRESSIVE FLOW OVER THE LOWER 48 WITH
VARIED TIMING AND AMPLITUDE OF A SERIES OF EMBEDDED SYSTEMS AT
SHORT AND MEDIUM RANGE TIME SCALES. THIS FLOW PATTERN SCREAMS
USAGE OF ENSEMBLE MEANS TO SMOOTH LESS PREDICTABLE FORECAST
COMPONENTS AS INDIVIDUAL GUIDANCE RUNS SHOW MORE RUN TO RUN
CONTINUITY ISSUES. UPDATED HPC PRELIM MEDIUM RANGE PROGS HAVE
BEEN PRIMARILY DERIVED FROM A COMPROMISE 50-50 BLEND OF QUITE
COMPATIBLE 00 UTC GFS ENSEMBLE MEAN AND 00 UTC ECMWF ENSEMBLE MEAN
WITH A RESULTANT SOLUTION NEAR THE MIDDLE OF THE FULL ENVELOPE OF
SOLUTIONS. HOWEVER...MANUAL ADJUSTMENTS TO THIS BLEND WERE
APPLIED TO MAINTAIN SLIGHTLY BETTER EMBEDDED SURFACE LOW/FRONTAL
ORGANIZATION CONSIDERING RECENT HISTORY IN THIS FLOW WITH SOME
DYNAMIC SYSTEMS.

HPC - Objective Use of Ensembles (4)

Role of the Forecaster

Combine manual deterministic forecast with ensemble distribution and spread to generate probabilities
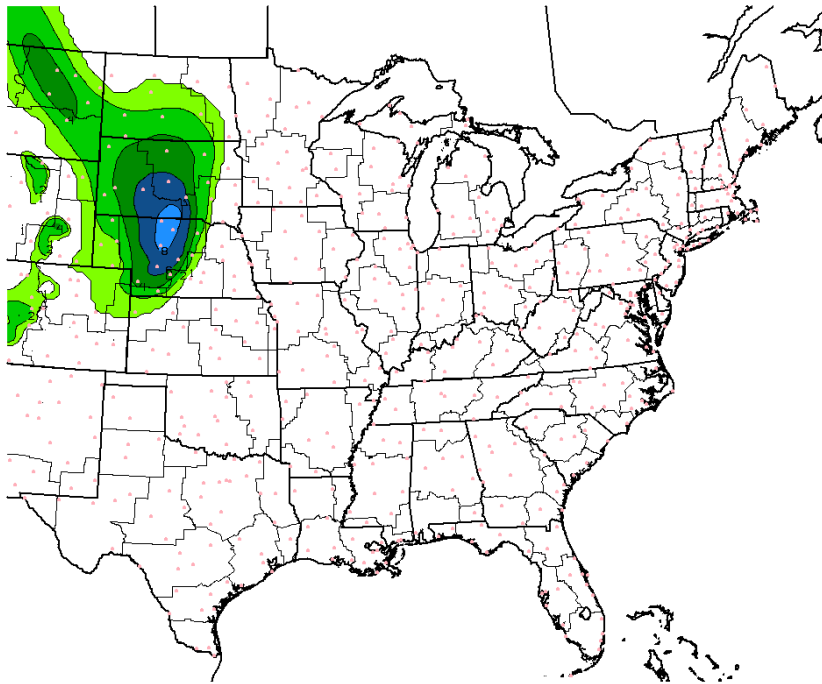
Deterministic Snow
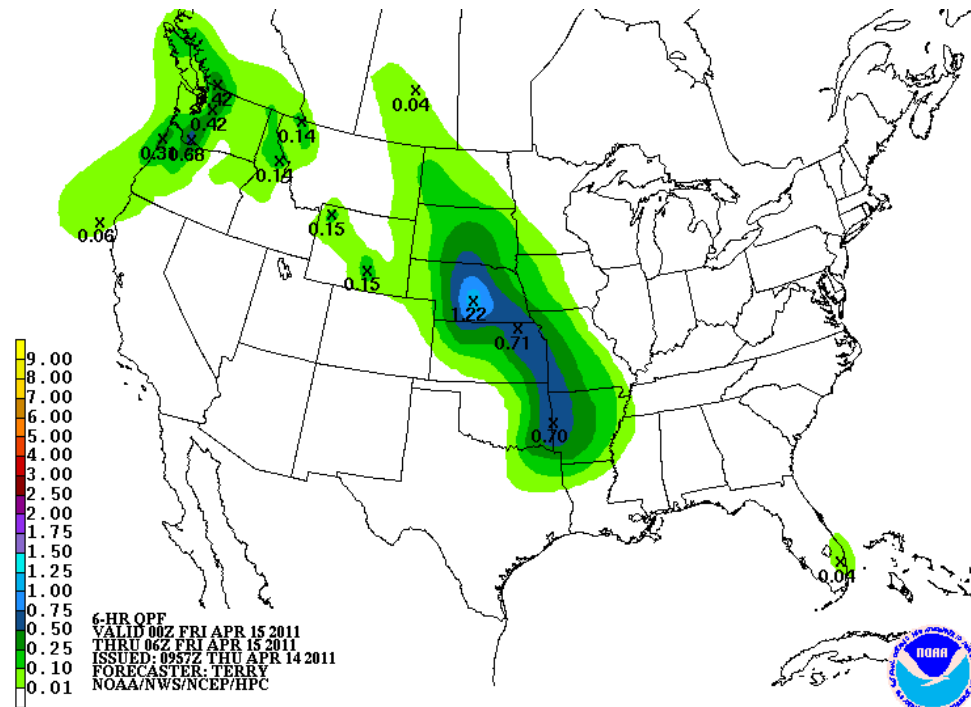
Deterministic QPF

HPC - Objective Use of Ensembles (5)

Role of the Forecaster

Combine manual deterministic forecast with ensemble distribution and spread to generate probabilities
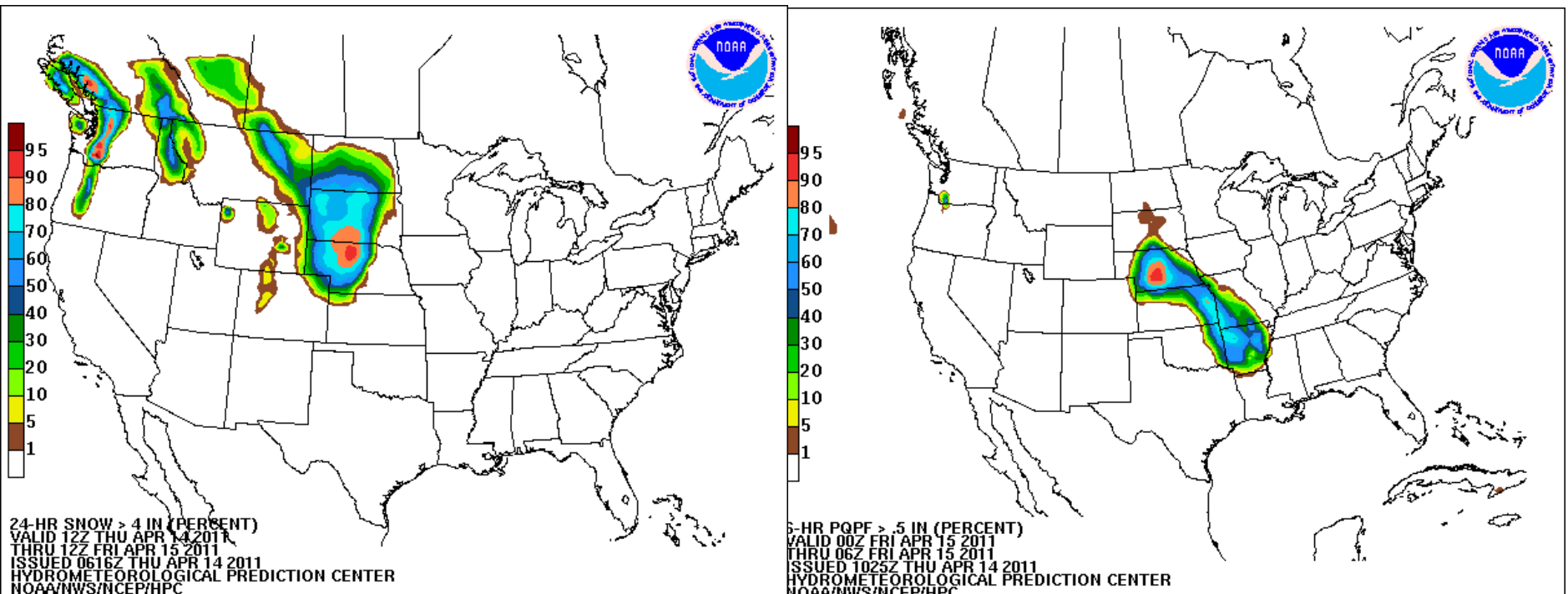
Probability > 4" Snow

Probability > 0.50" QPF

Experimental maps to support CSTAR program for winter season
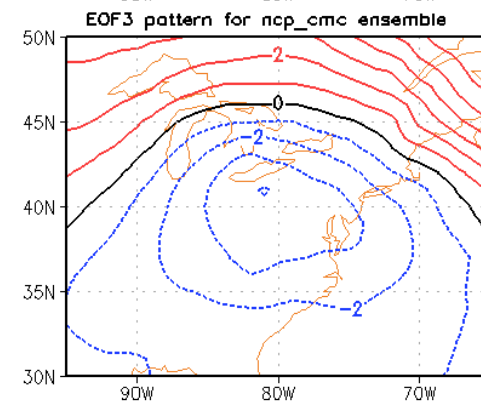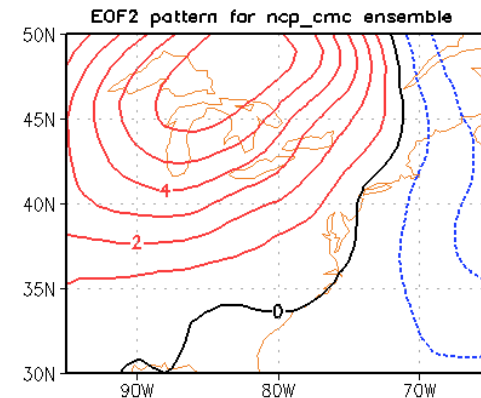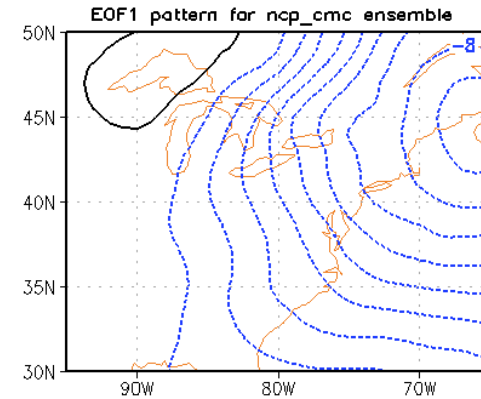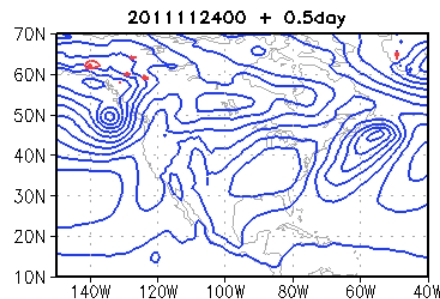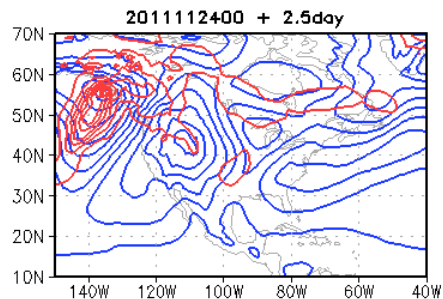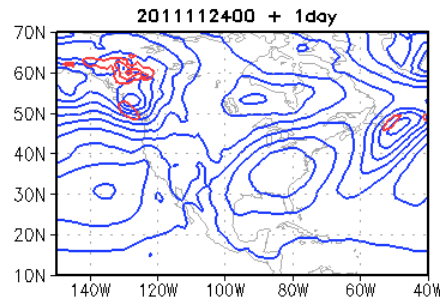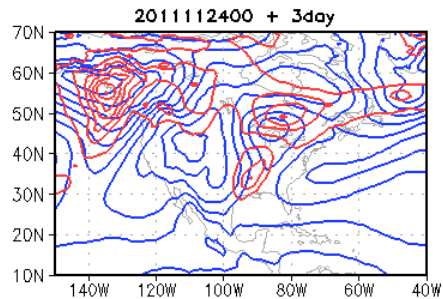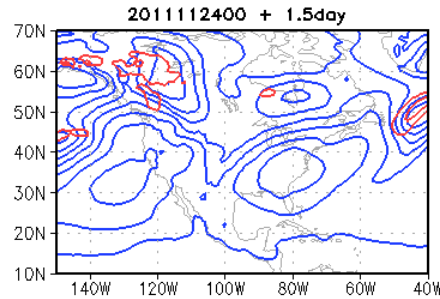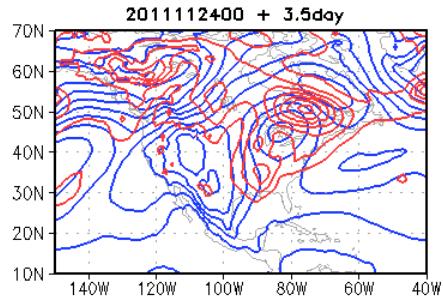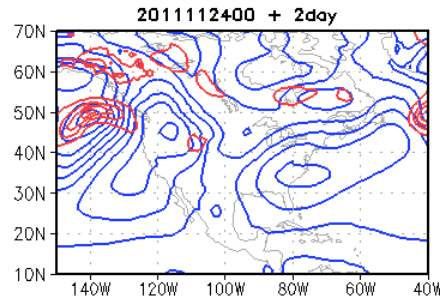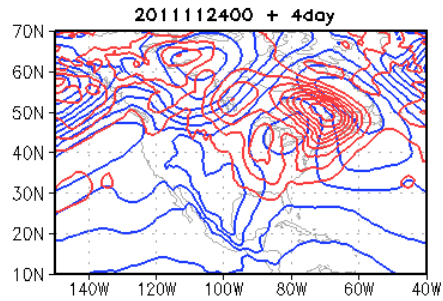
red contours: variance of MSLP at different fcst time; unit(mb²); contour interval: 15mb²
blue contours: ensemble mean of MSLP at different fcst time; unit(mb); contour interval: 5mb
ncp_cmc ensemble initialized at 2011112400; LON: from 150W to 40W; LAT: from 10N to 70N

first three EOF space patterns for MSLP; unit(mb); valid time: 2011113000
is computed for default area; LON: from 95W to 65W; LAT: from 3N to 50N

2 Meter Temperature Forecast
Ini: 2008042300 (solid line: 50% shaded: 10-90%)
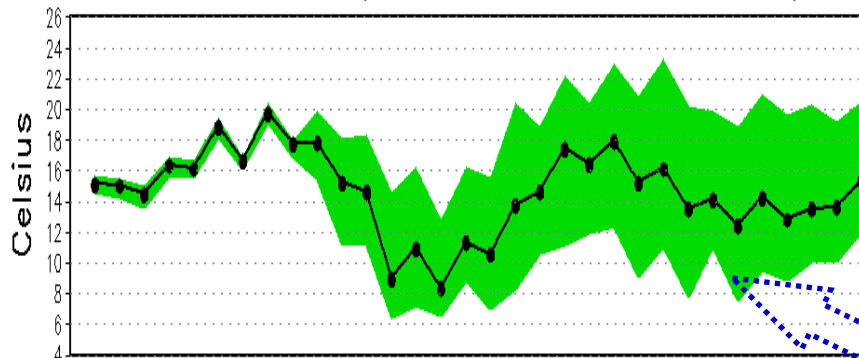
Surface Pressure Forecast
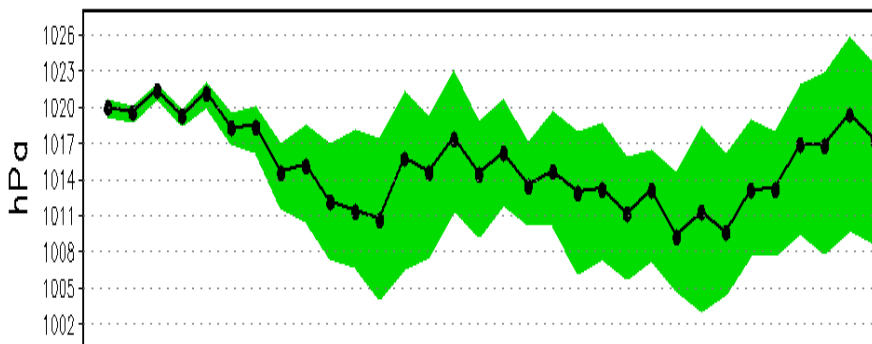
500hPa Geopotential Height Forecast
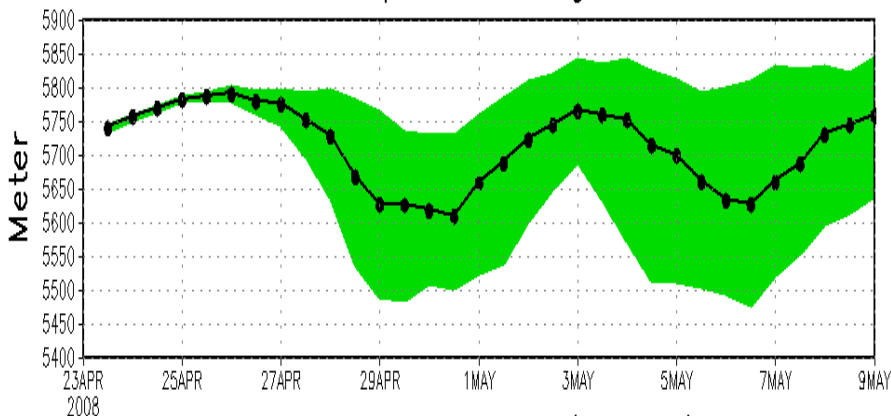
Location: Washington DC (37N 77W)

2-m temp 10/90 probability forecast verification Northern Hem, period of Dec. 2007 – Feb. 2008

Legend:
- P10-expect
- P10-ncepraw
- P10-naefs
- P90-expect
- P90-ncepraw
- P90-naefs

90%

10%

3-month verifications

Probabilities (percent)

Lead time (hours)
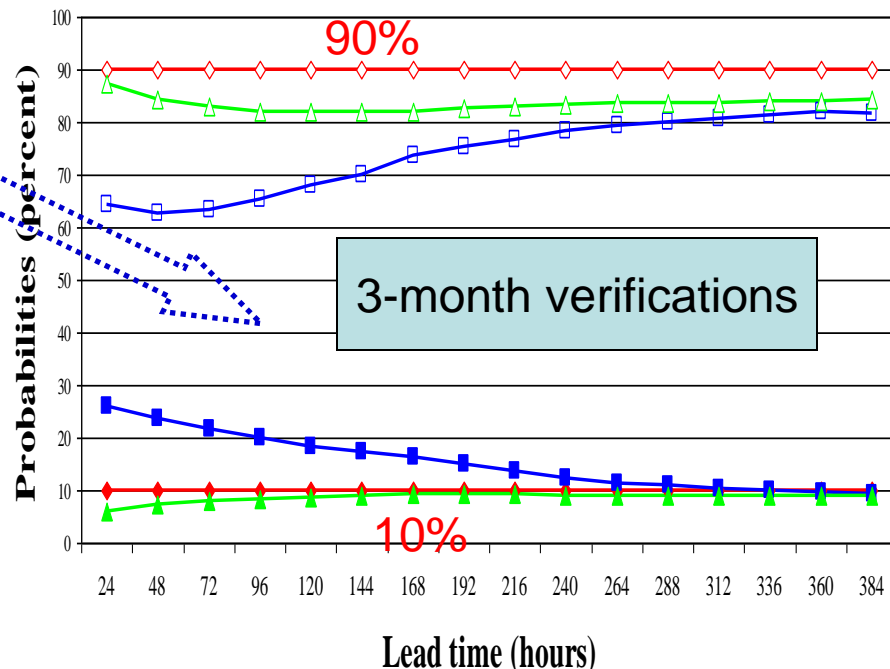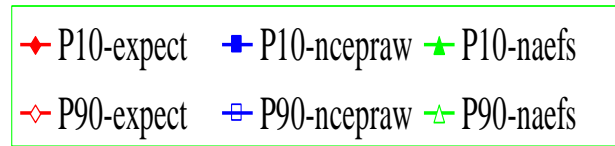
Top: 2-m temperature probabilistic
forecast (10% and 90%) verification
red: perfect, blue: raw, green: NAEFS

Left: example of probabilistic forecasts
(meteogram) for Washington DC, every
6-hr out to 16 days from 2008042300

Strike Probability (NHC)

NATIONAL WEATHER SERVICE/NATIONAL HURRICANE CENTER ADVISORY NUMBER 21
PROBABILITY THAT CENTER OF CHARLEY WILL PASS WITHIN 75 STATUTE MILES
DURING THE 72 HOURS STARTING AT 2:00 AM EDT SAT AUG 14 2004
■ 10-19%   ■ 20-49%   ■ 50-99%   ■ 100%
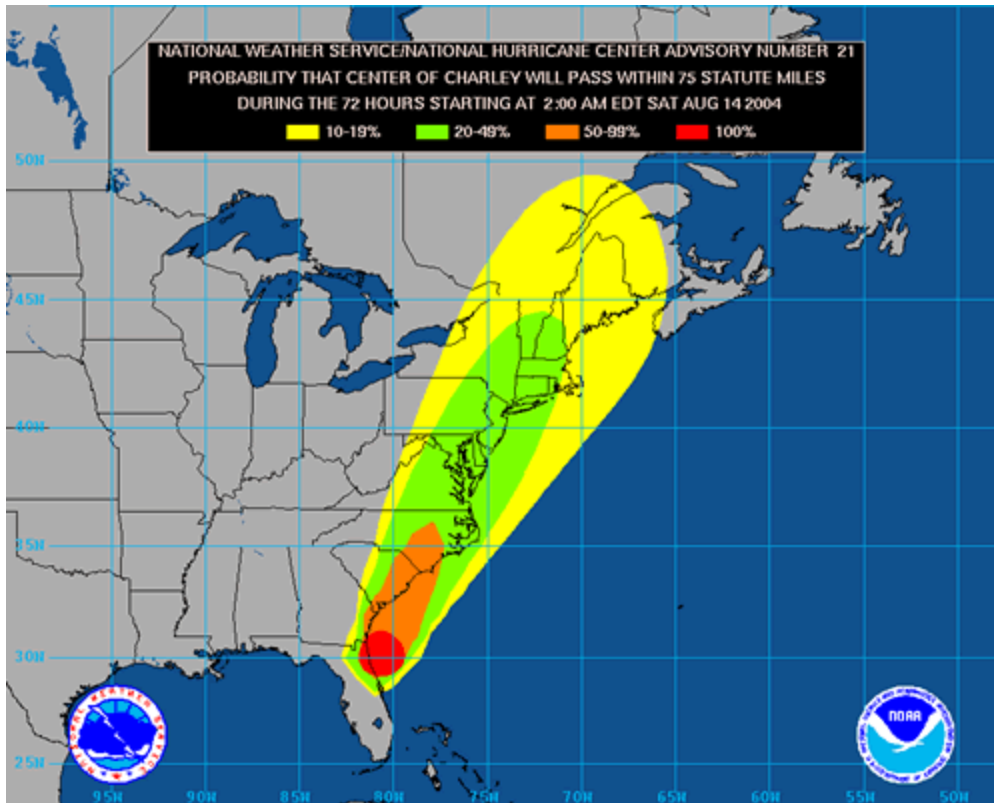
NHC started to calculate strike probability forecast products since 2004. It has been phased out since they introduced wind speed probability.

NHC's method of calculation is based on single deterministic and uncertainties (cone) from historic analysis and forecast

The map above is a hurricane strike probability map for Hurricane Charley from August, 2004. It maps the probability, in percent, that the center of the storm will pass within 75 statute miles of a location during a 72 hour time interval. Contour levels shown are 10% (yellow), 20% (green), 50% (orange) and 100% (red).

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Example of Hurricane Katrina

Tropical Storm Force Wind Speed Probabilities
For the 120 hours (5 days) from 2 PM EDT Fri Aug 26 to 2 PM EDT Wed Aug

Probabilities of sustained tropical storm force surface winds (1
◇ indicates HURRICANE KATRINA center locatio

5% 10%   20%   30%   40%
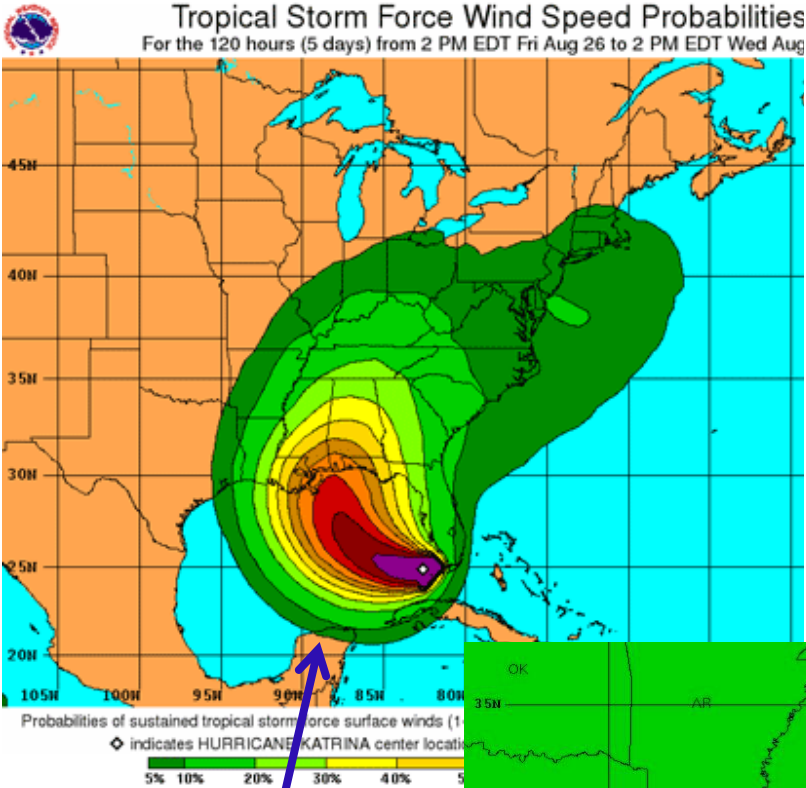
20050826 12 UTC
Probability that KATRINA will pass within 120km radius during the next 120 hours
tracks: black=OPER, green=CTRL, blue=EPS numbers: observed positions at t+..h

0-120 hours
120km radius

Hurricane Katrina
August 26, 2005
5 PM EDT Friday
NWS TPC/National Hurricane Center
Advisory 14
Current Center Location 24.8 N 82.9 W
Max Sustained Wind 100 mph
Current Movement WSW at 8 mph

- Current Center Location
- Forecast Center Positions
  H Sustained wind > 73 mph
  Potential Day 1-3 Track Area
- Tropical Storm Warning

True at 30.00N
SM   125   250   375   500
Approx. Distance Scale (Statute Miles)

Early prediction:
Friday – August 26
NHC's prediction

ECMWF ensemble
forecast: Strike
probability from
Friday – August 26

AL07(Earl) 2010082812 Strike-P D<65nm T<120hr
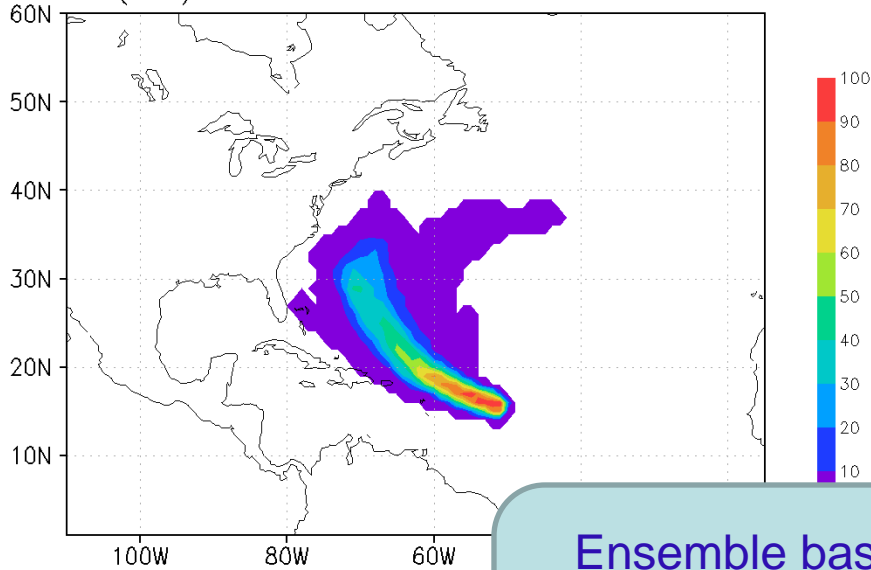
AL11(Igor) 2010091312 Strike-P D<65nm T<120hr

EP04(Celia) 2010062012 Strike-

Strike-P D<65nm T<120hr
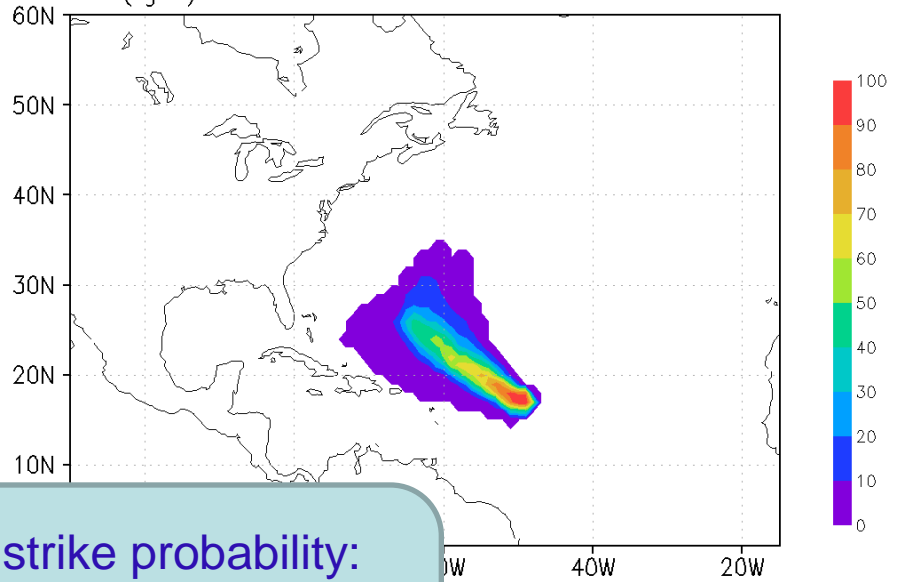
Ensemble based strike probability: Accumulated probability of 0-120 hours at 65 nautical miles radius of tropical storm forecast tracks.

Courtesy of Jiayi Peng
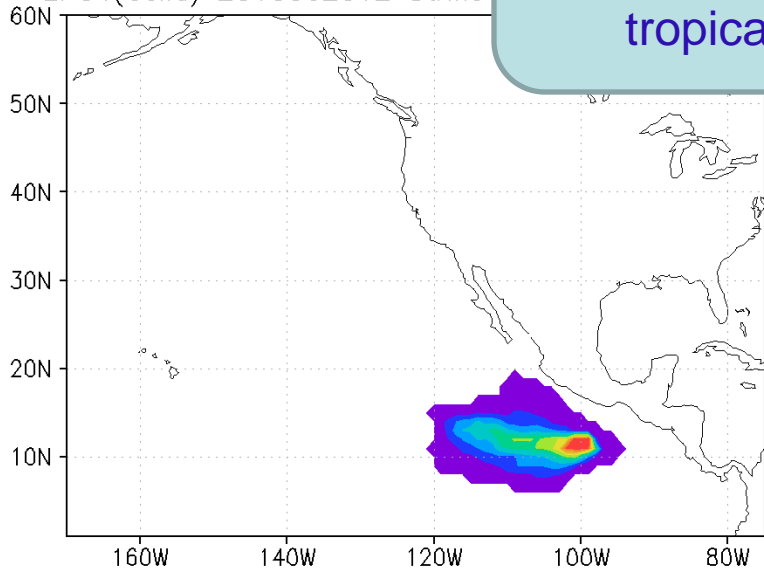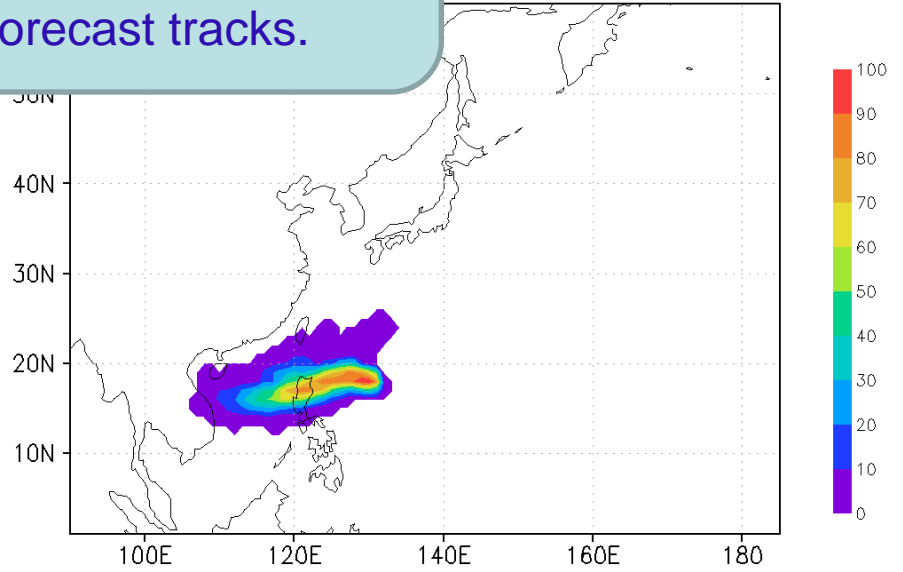
An experimental multi-model product

Dot area is proportional to the weighting applied to that member

• = ens. mean position* = observed position
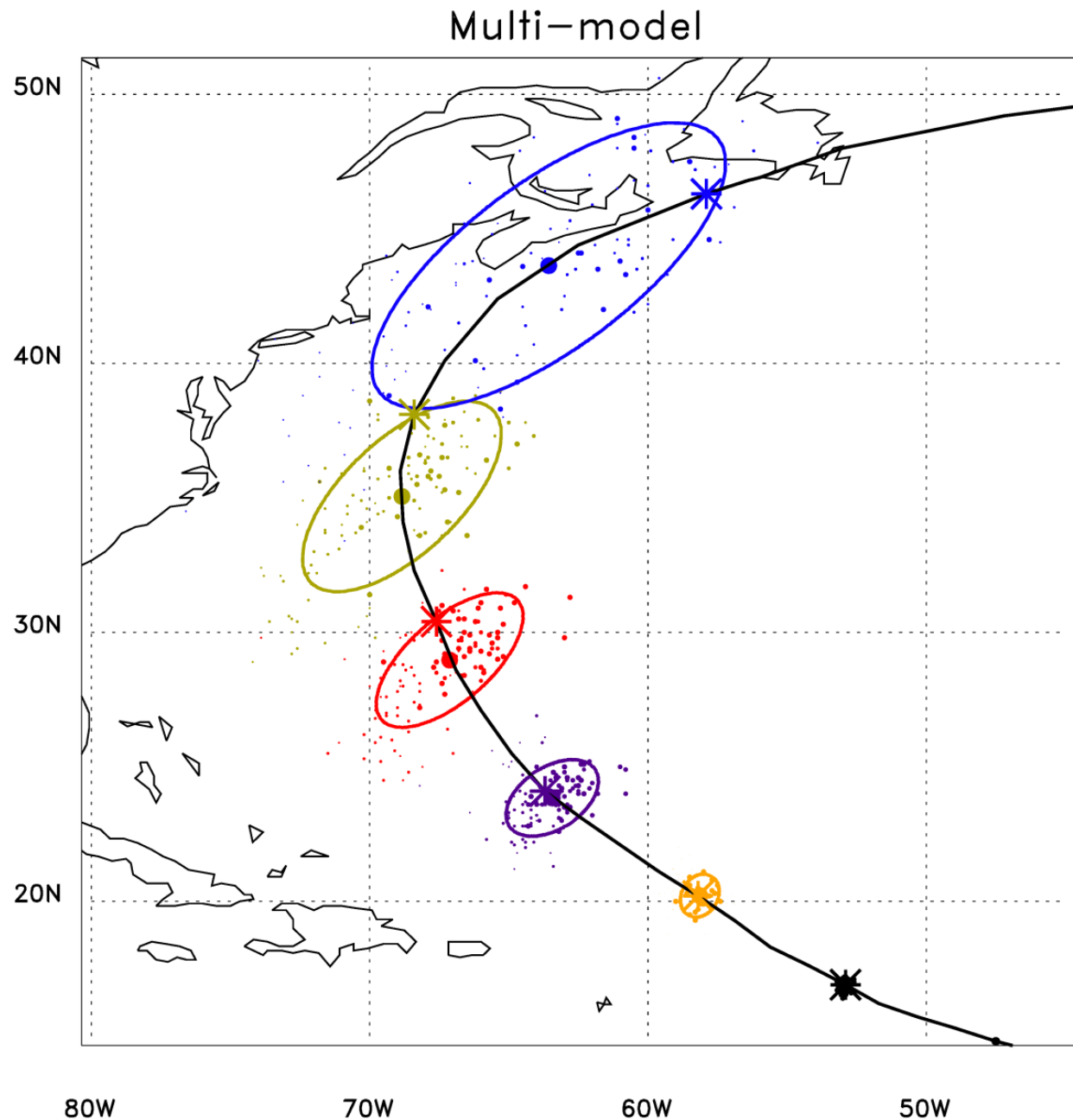
Values and Benefits

NH Anomaly Correlation for 500hPa Height
Period: January 1st – December 31st 2010
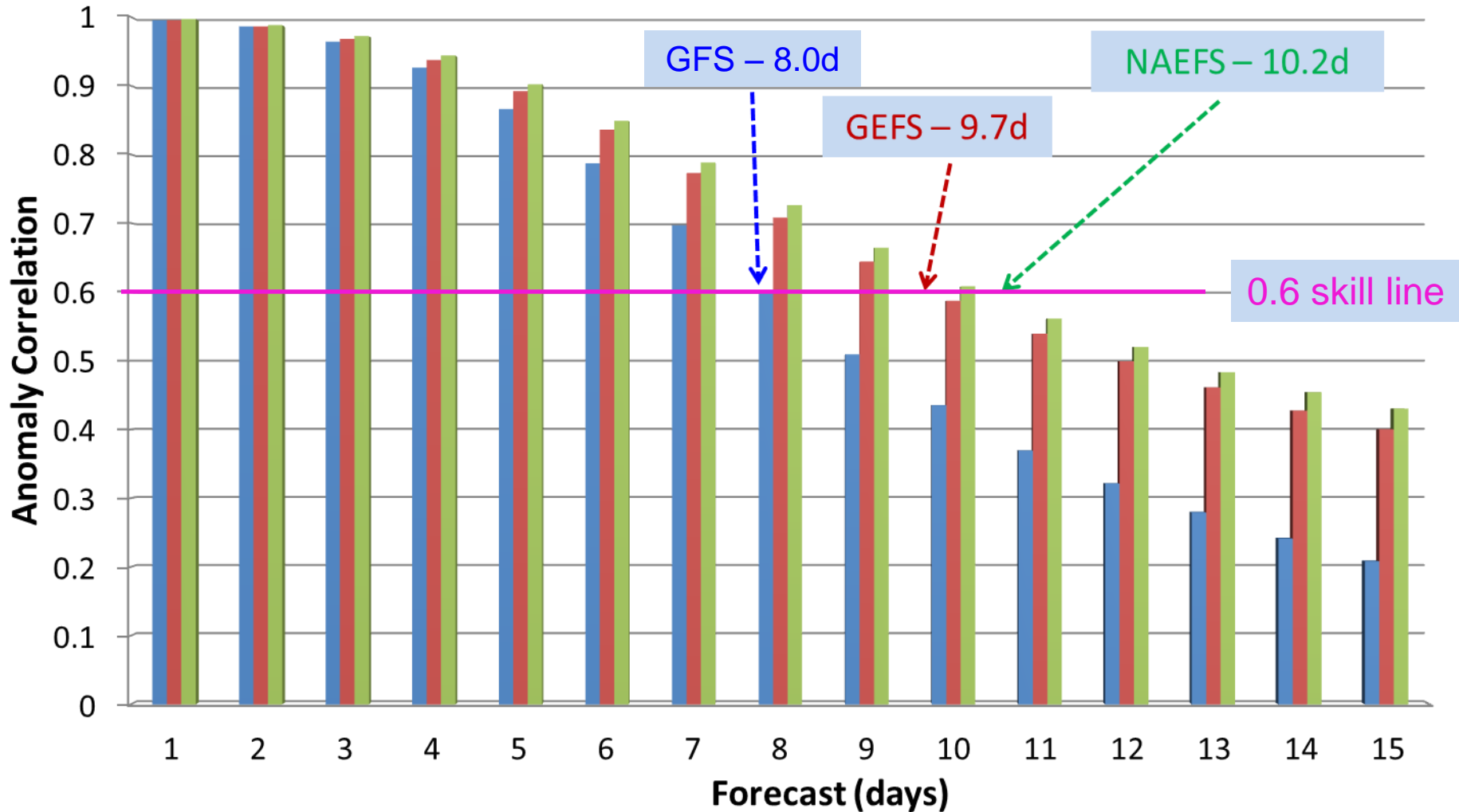
Day at which forecast loses useful skill (AC=0.6)
N. Hemisphere 500hPa height calendar year means
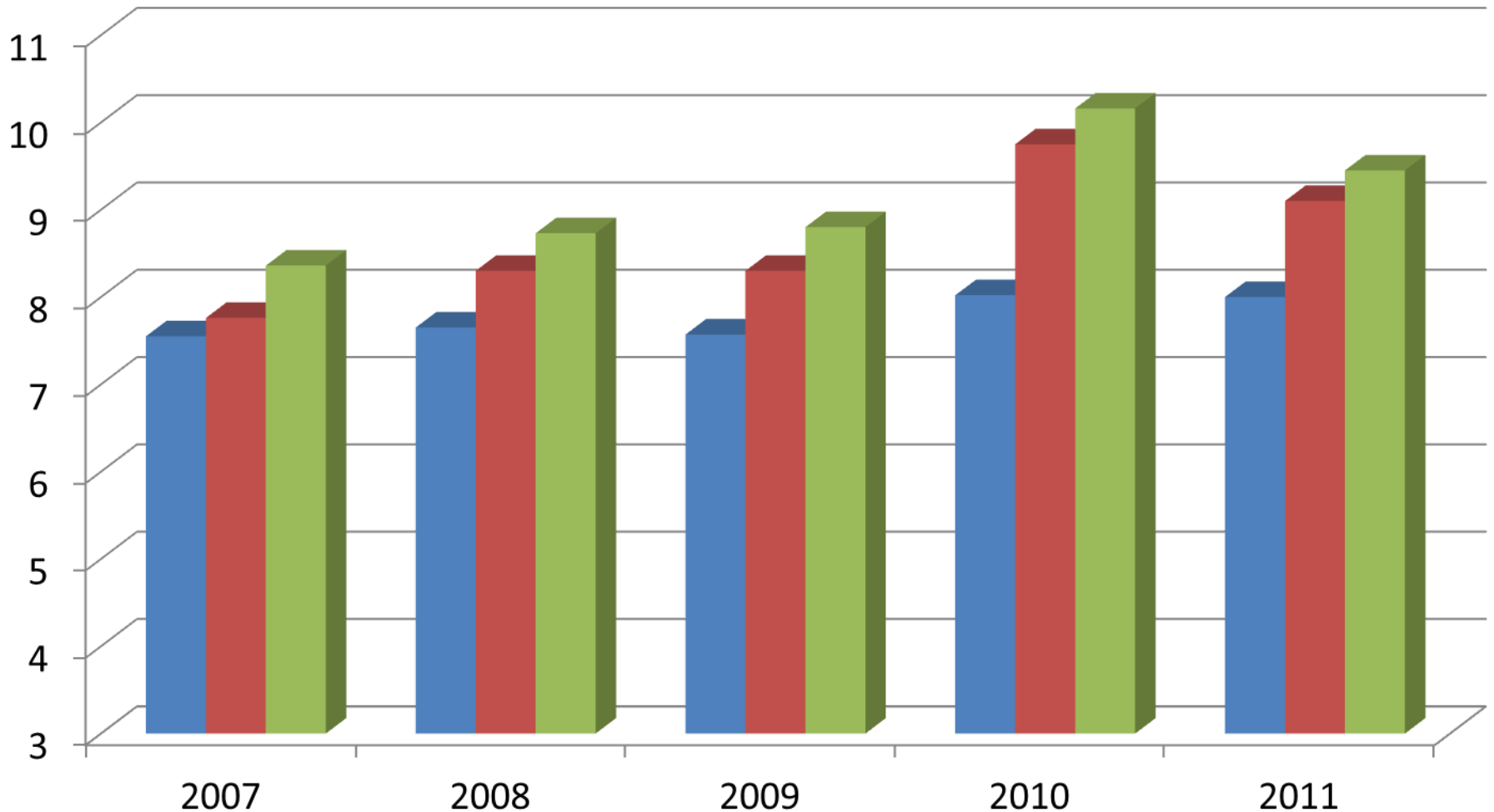
Atlantic, AL01~19 (06/01~11/30/2011)
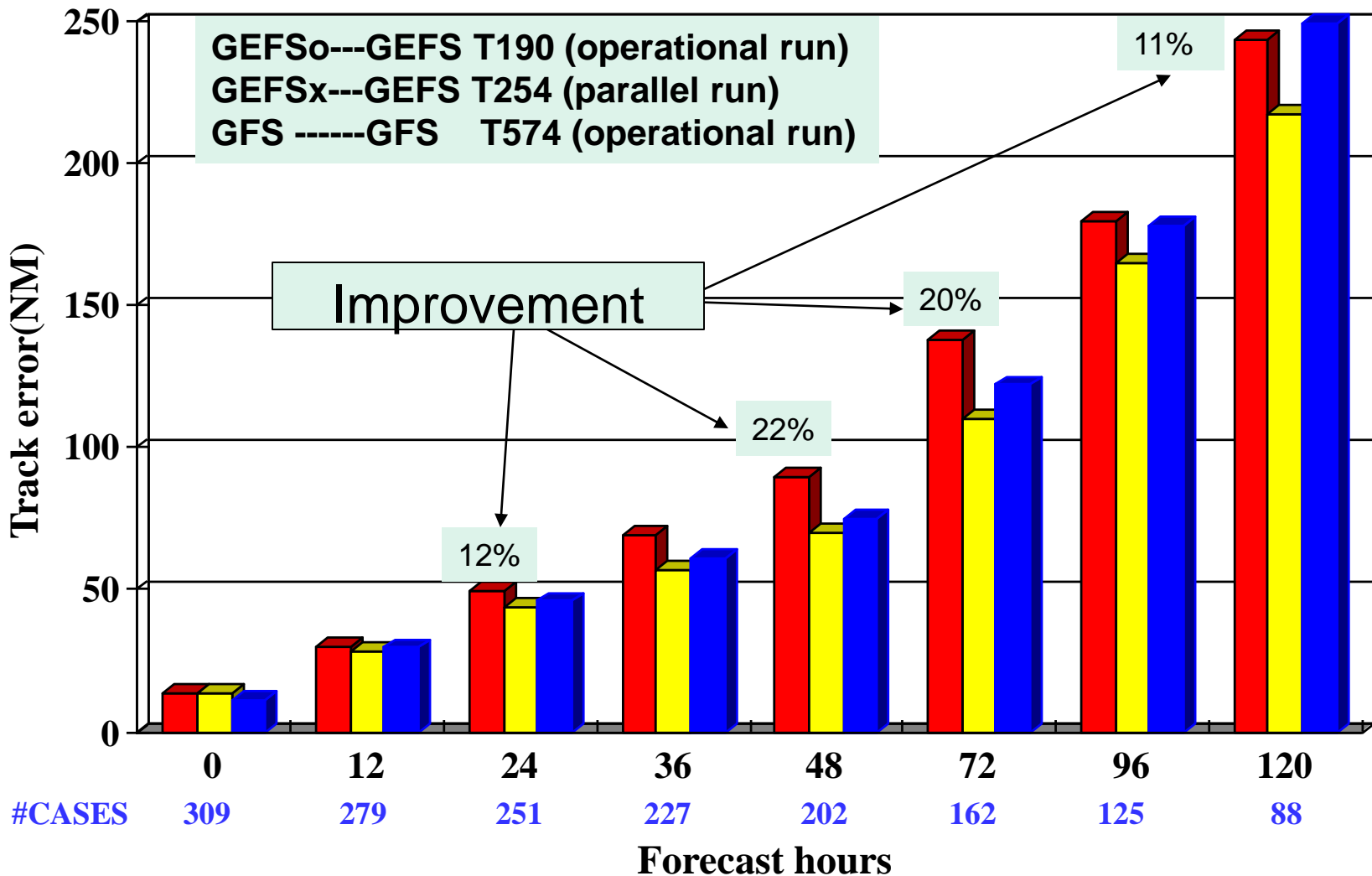
RTMA Region 2m Temperature
Averaged From 2007090100 to 2007093000

NCEP/GEFS raw forecast

4+ days gain from NAEFS

NAEFS final products

From   Bias correction (NCEP, CMC)
        Dual-resolution (NCEP only)
        Down-scaling (NCEP, CMC)
        Combination of NCEP and CMC

Legend:
- NAEFS
- NCEP_raw
- NCEP_drbcds
- CMC_bcds

X-axis: Lead Time (Days)
Y-axis: Mean Absolute Error (C)

BO CUI, GCWMB/EMC/NCEP/NOAA
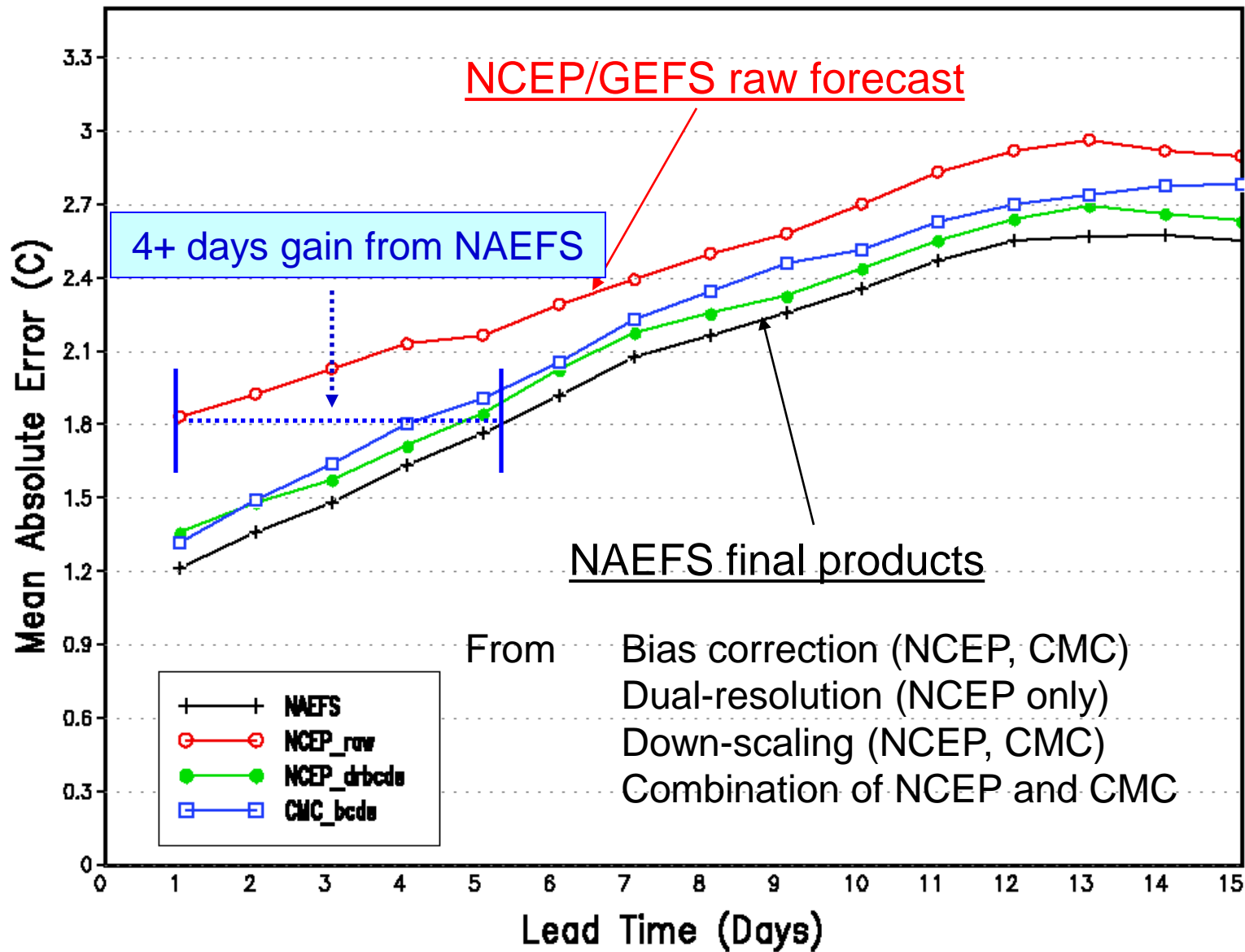
NAEFS NDGD Probabilistic 2m Temperature
Forecast Verification For 2007090100 – 2007093000
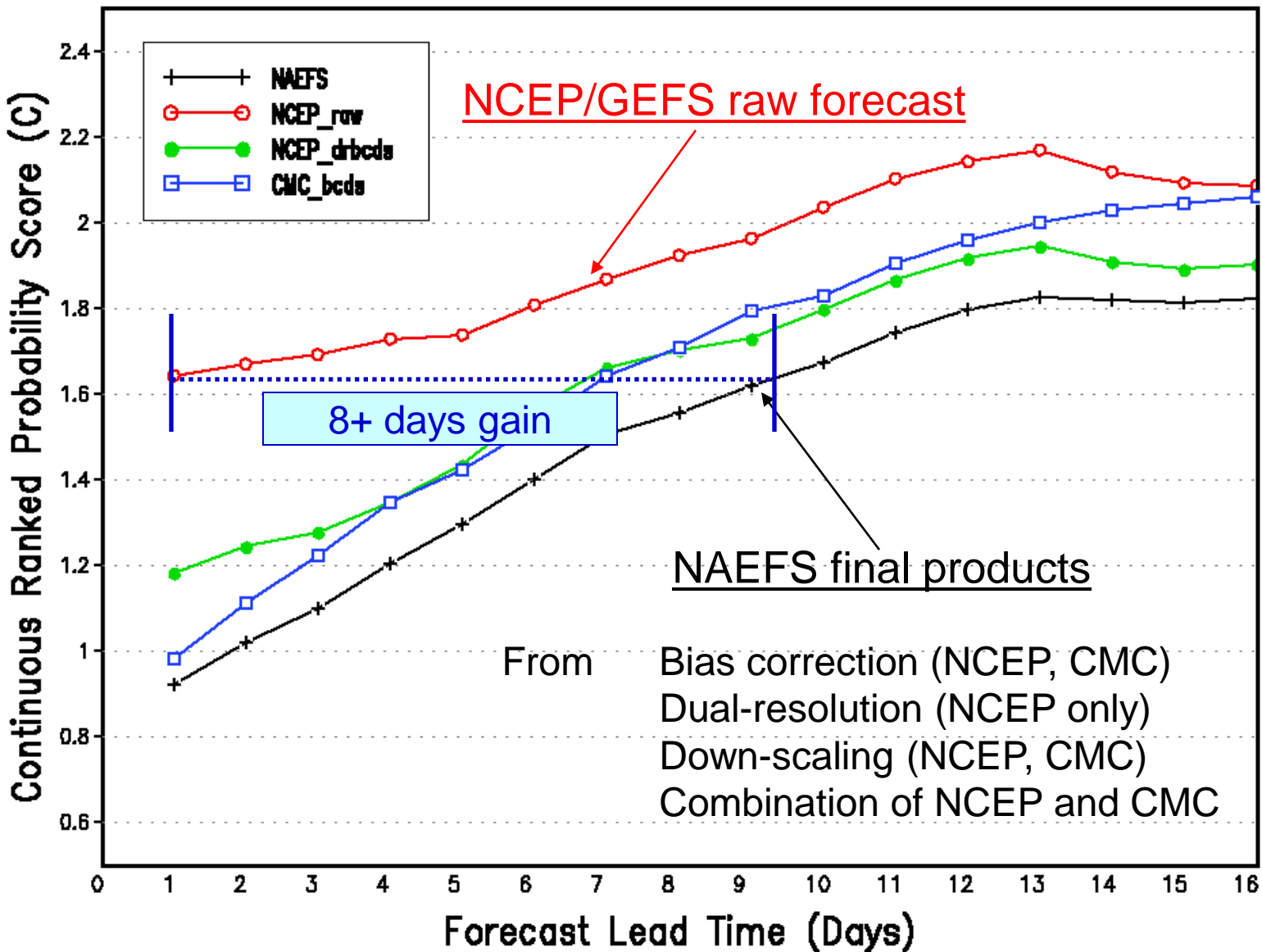
Overall temperature forecasts: Average over past 30 days: (20080929-20081028)

		MAE	Bias	>10 err	<3 err	off. rank	Best G.		2nd G.		Worst G.	
1	12-hr	2.44	0.7	0.1%	67.3%	1 out of 7	NAM40	65.4%	NAM12	60.1%	NGM80	44.4%
2	24-hr	2.84	1.0	0.3%	59.1%	2 out of 7	NAM40	60.3%	NAM12	56.9%	SREF	47.0%
3	36-hr	2.94	0.8	0.3%	57.8%	1 out of 7	NAM40	55.9%	NAM12	52.6%	NGM80	44.0%
4	48-hr	3.36	1.6	2.1%	52.8%	1 out of 7	MOSGd	48.9%	NAM40	48.3%	NGM80	12.9%
5	60-hr	3.26	1.0	1.7%	54.8%	1 out of 6	MOSGd	50.1%	NAM12	48.8%	NAM40	6.2%
6	72-hr	3.35	1.3	2.1%	53.1%	1 out of 5	MOSGd	49.9%	NAM12	49.5%	SREF	44.0%
7	84-hr	3.80	0.6	4.7%	49.0%	1 out of 5	NAEFS	48.6%	SREF	44.5%	NAM12	2.6%
8	96-hr	3.96	0.7	4.0%	44.4%	2 out of 4	NAEFS	46.2%	HPCGd	42.6%	MOSGd	40.6%
9	108-hr	4.43	0.9	5.5%	38.5%	2 out of 3	NAEFS	41.7%	MOSGd	37.7%	MOSGd	37.7%
10	120-hr	4.57	1.0	5.9%	36.6%	2 out of 4	NAEFS	40.9%	HPCGd	36.5%	MOSGd	36.3%
11	132-hr	4.83	0.7	7.8%	34.7%	1 out of 3	NAEFS	34.5%	MOSGd	34.4%	MOSGd	34.4%
12	144-hr	4.83	0.5	7.4%	34.7%	3 out of 4	HPCGd	36.4%	NAEFS	35.5%	MOSGd	33.3%
13	156-hr	5.43	0.1	11.9%	30.3%	3 out of 3	NAEFS	32.1%	MOSGd	30.8%	MOSGd	30.8%
14	168-hr	5.74	0.3	14.4%	27.7%	2 out of 4	HPCGd	27.7%	MOSGd	26.9%	NAEFS	26.1

Minimum temperature forecast: Average over past 30 days: (20080929-20081028)

		MAE	Bias	>10 err	<3 err	off. rank	Best G.		2nd G.		Worst G.	
1	12-hr	3.17	-1.2	1.0%	53.4%	3 out of 7	NAEFS	59.7%	SREF	57.1%	NGM80	21.8%
2	24-hr	3.03	-0.9	0.6%	55.5%	2 out of 7	SREF	57.2%	NAEFS	54.2%	NGM80	24.9%
3	36-hr	3.25	-0.8	0.9%	51.6%	3 out of 7	NAEFS	54.2%	SREF	53.9%	NGM80	23.2%
4	48-hr	3.94	-1.1	2.9%	43.2%	3 out of 7	NAEFS	51.9%	SREF	45.8%	NGM80	6.2%
5	60-hr	4.30	-0.4	4.4%	39.1%	4 out of 6	NAEFS	49.2%	SREF	43.0%	NAM40	8.9%
6	72-hr	4.76	0.1	6.4%	33.7%	5 out of 5	NAEFS	42.9%	SREF	40.1%	NAM12	35.2%
7	84-hr	4.85	0.3	7.5%	34.7%	2 out of 6	NAEFS	40.0%	MOSGd	33.4%	NAM12	8.9%
8	96-hr	5.24	0.4	13.0%	33.1%	1 out of 3	NAEFS	32.7%	MOSGd	29.9%	MOSGd	29.9%
9	108-hr	5.11	0.8	12.8%	35.4%	1 out of 4	HPCGd	34.5%	NAEFS	32.1%	MOSGd	30.5%
10	120-hr	5.31	0.7	12.0%	31.9%	1 out of 3	MOSGd	31.6%	NAEFS	24.8%	NAEFS	24.8%
11	132-hr	4.97	0.7	9.9%	35.1%	2 out of 4	HPCGd	38.0%	MOSGd	30.9%	NAEFS	27.2%
12	144-hr	5.42	0.6	15.0%	35.0%	1 out of 3	MOSGd	31.3%	NAEFS	29.0%	NAEFS	29.0%
13	156-hr	5.40	0.5	14.9%	35.7%	1 out of 4	HPCGd	32.9%	MOSGd	32.7%	NAEFS	23.4%
14	168-hr	5.46	1.1	17.7%	38.1%	1 out of 3	MOSGd	35.6%	NAEFS	28.4%	NAEFS	28.4%

Official Guidance: NGM80, NAM40, SREF, NAM12, MOSGd, HPCGd, NAEFS

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Contributed by Richard Grumm (WFO)

Decision Theory Example

Critical Event: sfc winds > 50kt

Cost (of protecting): $150K

Loss (if damage): $1M

Forecast?

		YES	NO
Observed?	YES	*Hit* $150K	*Miss* **$1000K**
	NO	*False Alarm* $150K	*Correct Rejection* $0K

Case	Deterministic Forecast (kt)	Observation (kt)	Cost ($K)	Probabilistic Forecast	Cost ($K) by Threshold for Protective Action					
					0%	20%	40%	60%	80%	100%
1	65	**54**	150	42%	150	150	150	**1000**	**1000**	**1000**
2	58	**63**	150	71%	150	150	150	150	**1000**	**1000**
3	73	**57**	150	95%	150	150	150	150	150	**1000**
4	55	37	150	13%	150	0	0	0	0	0
5	39	31	0	3%	150	0	0	0	0	0
6	31	**55**	**1000**	36%	150	150	**1000**	**1000**	**1000**	**1000**
7	62	**71**	150	85%	150	150	150	150	150	**1000**
8	53	42	150	22%	150	150	0	0	0	0
9	21	27	0	51%	150	150	150	0	0	0
10	52	39	150	77%	150	150	150	150	0	0
		Total Cost:	$ 2,050		$1,500	$1,200	$1,900	$2,600	$3,300	$5,000

Optimal Threshold = 15%

Future plans

- **Ensemble systems**
  - Increasing model resolutions
  - Improving DA and forecast model
  - Multi-model, multi-physics – advance of NAEFS (and/or NUOPC)
  - NAEFS - LAM
  - Extend ensemble forecast (beyond week-2 to 45 days, for coupling A-O models)
- **Ensemble productions**
  - Enhance post process
    - Optimum using joint samples and reforecasts
    - 2nd moment adjustment
  - Enhance collaborations
- **Ensemble applications**
  - Considering user requests
  - Expand anomaly forecast
  - Maximum using probabilistic information???

BACKGROUND