Recent developments with the NCEP and North American Ensemble Forecast Systems

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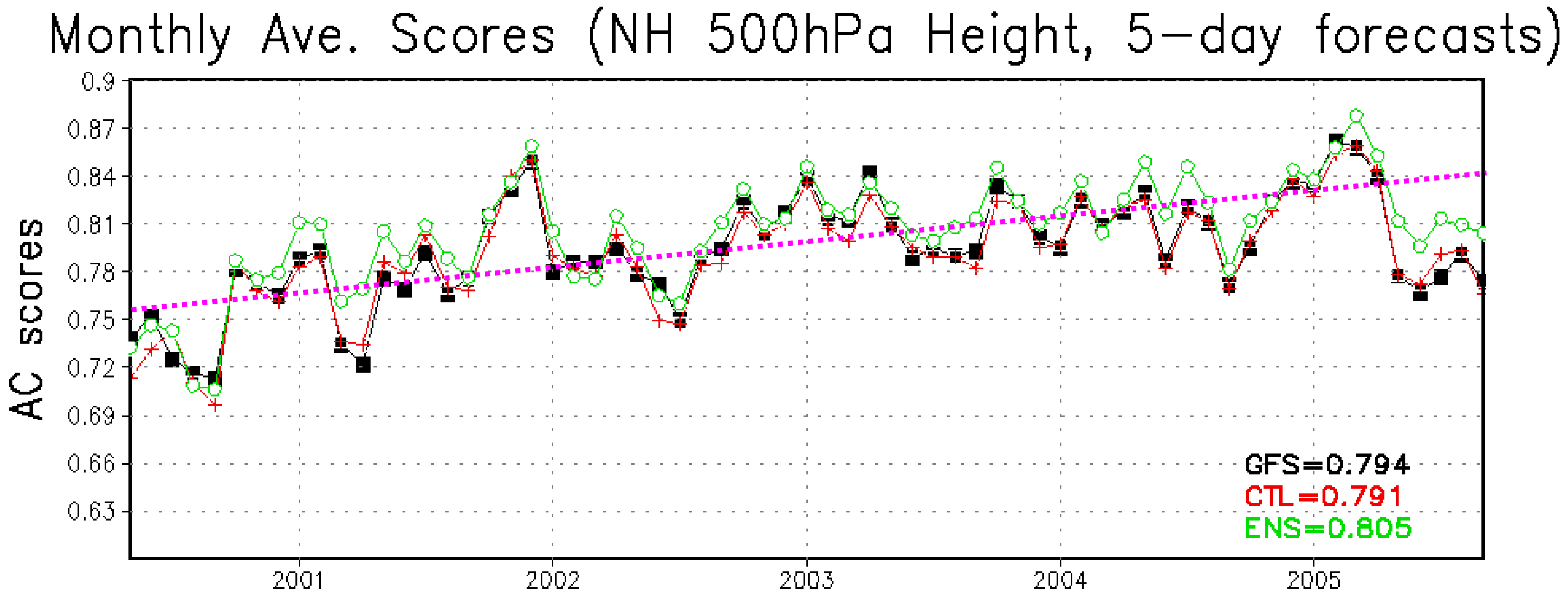
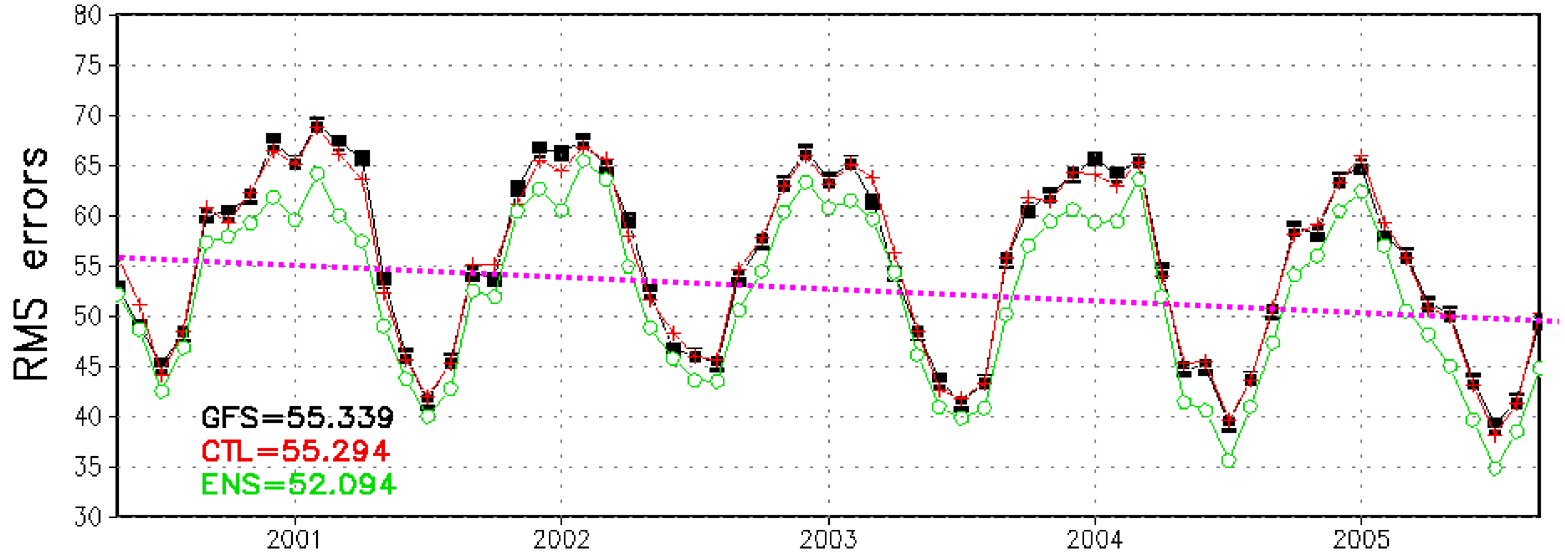
OUTLINE

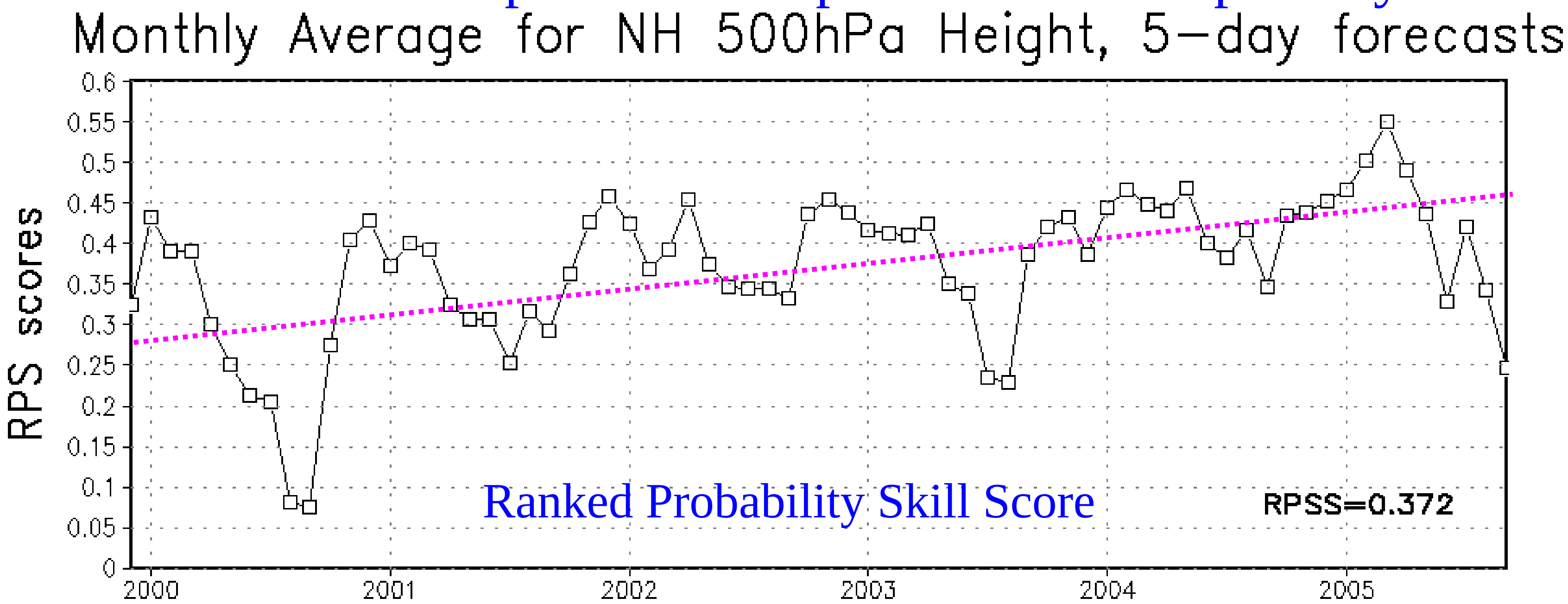
- Long-term performance stats for NCEP GEFS
- Recent implementation
  - Improvements in
    - Short-range statistics
    - Tropical Storm forecasts
    - Extended-range forecasting
- Planned implementation for NAEFS
- NAEFS & THORPEX (TIGGE)

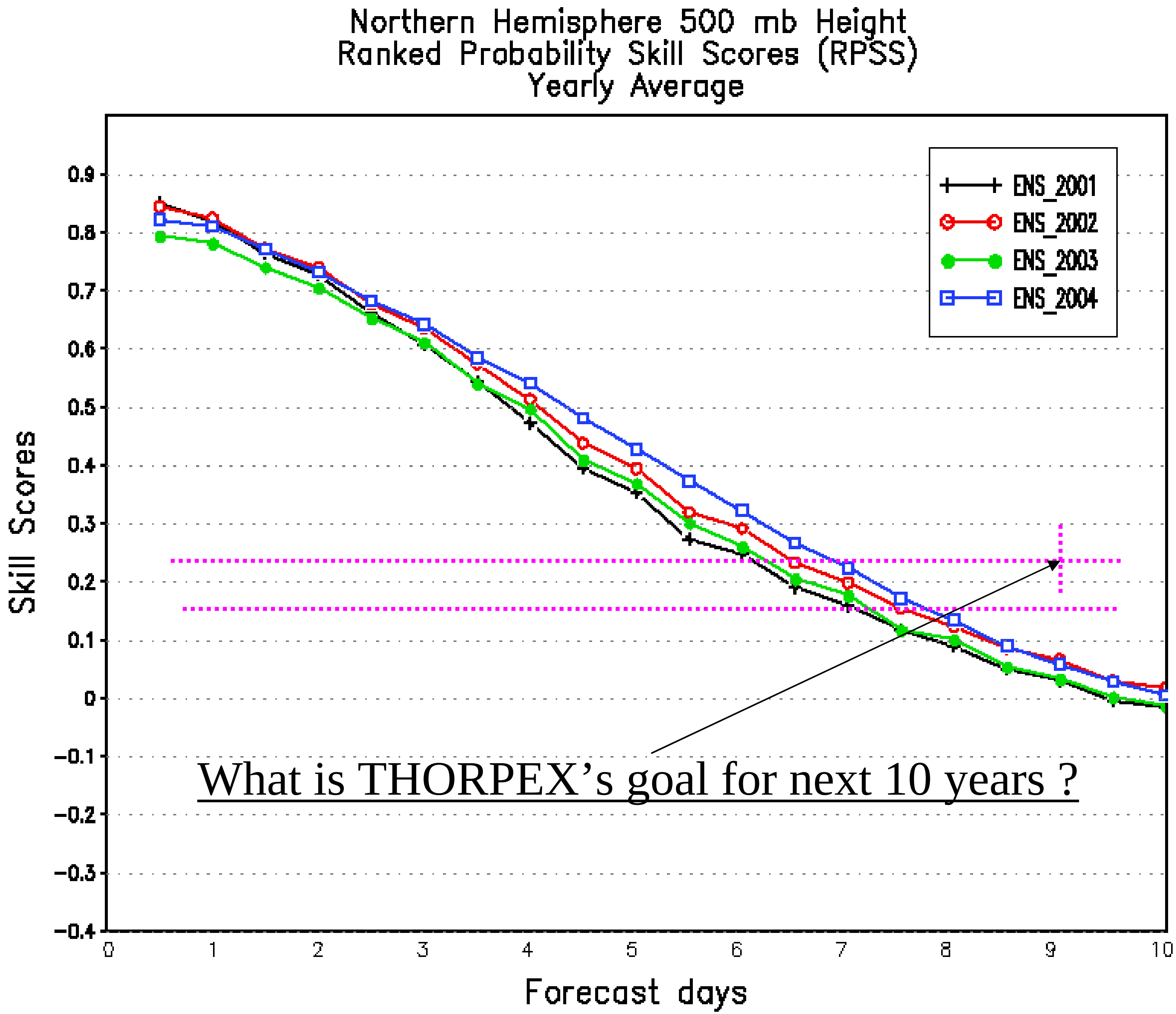


NCEP ensemble mean performance for past 6-year



NCEP ensemble probabilistic performance for past 6-year





Northern Hemisphere 500 mb Height
Ranked Probability Skill Scores (RPSS)
Yearly Average
ENS_2001
ENS_2002
ENS_2003
ENS_2004
Skill Scores
Forecast days
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
0
1
2
3
4
5
6
7
8
9
10
What is THORPEX's goal for next 10 years ?

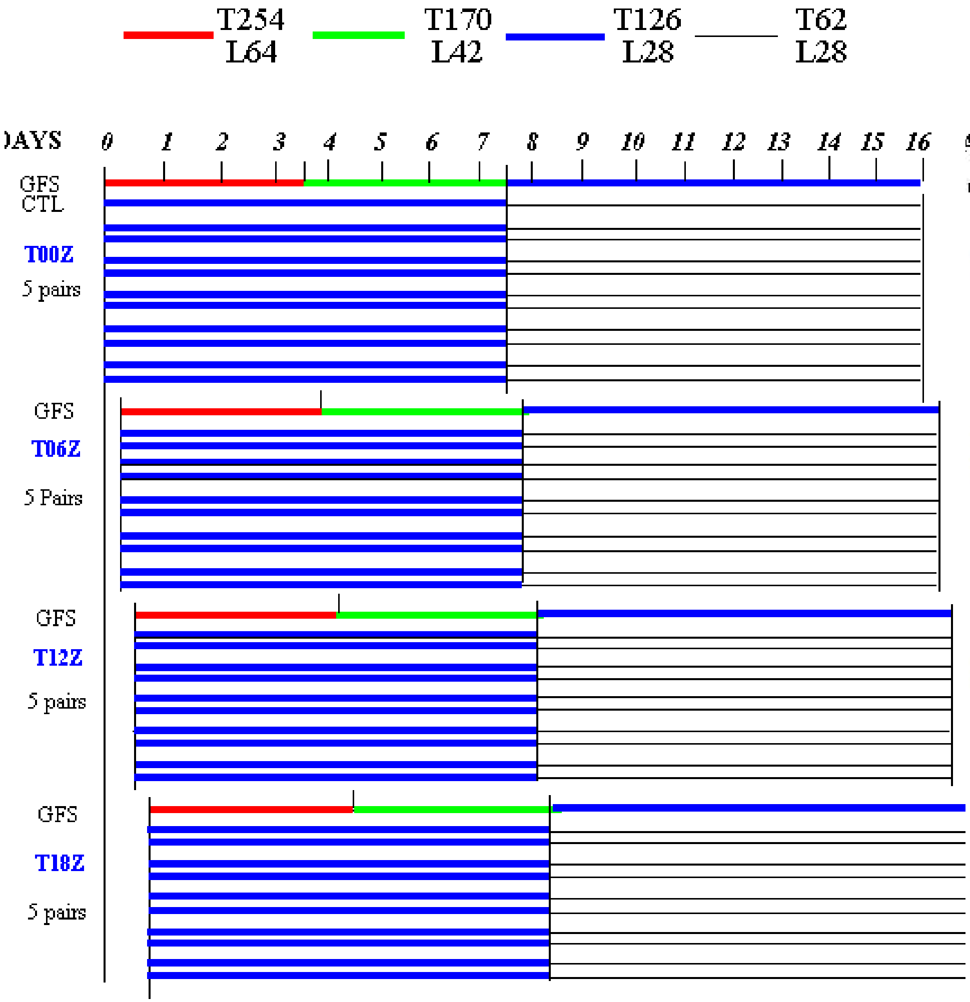
Recent Implementation

Changes - 1

- Extend T126 portion of forecast after 180 hours (see new configuration)
  - This change is intended to improve ensemble support for 5-10 days and week-2 forecast by providing high resolution (T126) and continue (no resolution change) forecast
  - Results:
    - Increased spread for week-2 forecast
    - Improving probabilistic skill beyond 180 hours

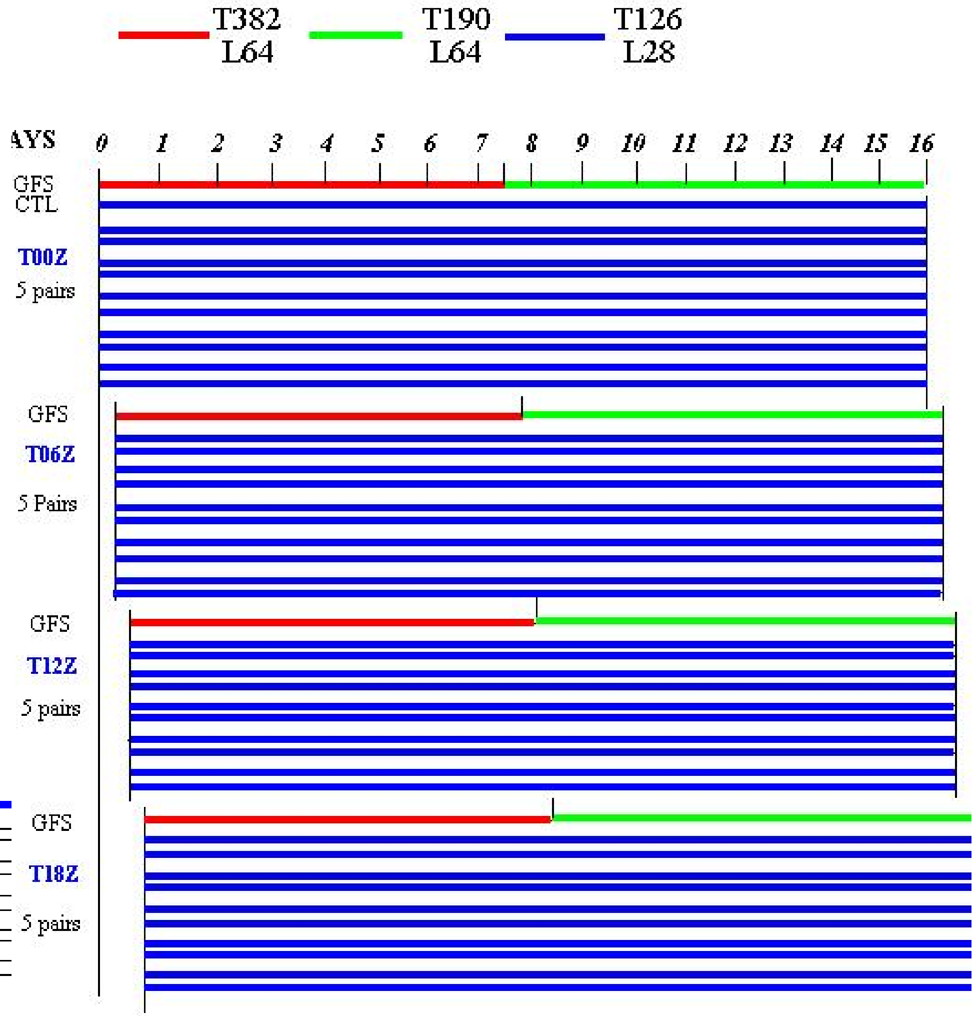
NCEP GLOBAL ENSEMBLE FORECAST SYSTEM

CURRENT CONFIGURATION
MARCH 2003



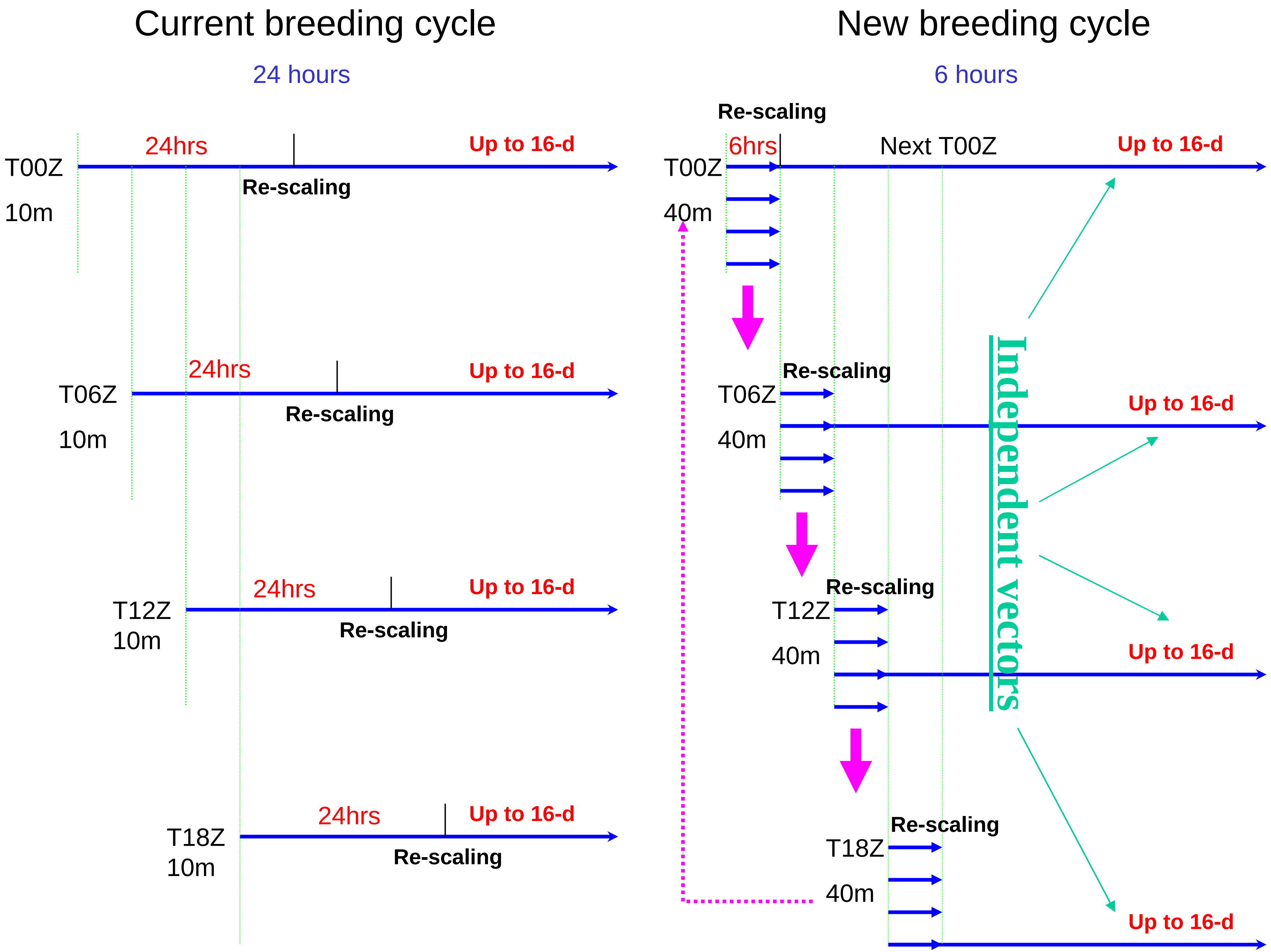
NEW

NCEP GFS and Ensemble Configuration
(Will be implemented by July 2005)



Recent Implementation
Changes - 2

- Initial perturbation (breeding cycle)
  - This change is intended to enable for relocation of perturbed tropical storm. Tuning initial perturbation size is for reducing spread for short-range forecast
  - Results:
    - Decreased spread for short-rang (1-3) forecast
    - Improving forecast skill for first 3 days
    - Improving probabilistic forecast skill for short lead-time

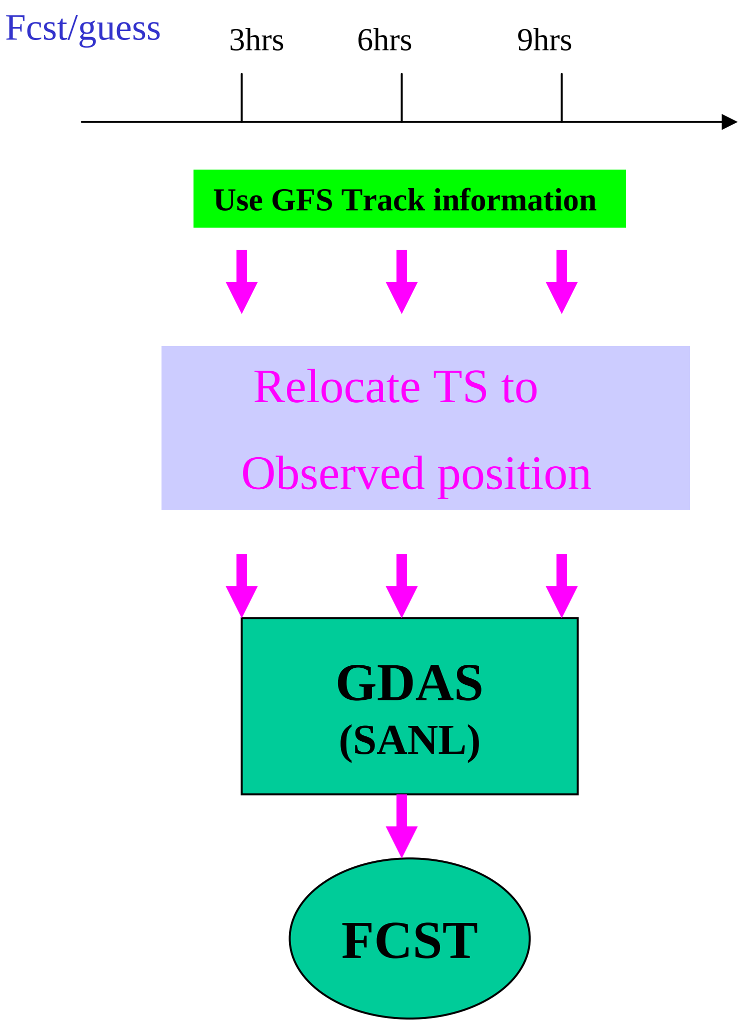


Current breeding cycle
24 hours
T00Z
10m
24hrs
Up to 16-d
Re-scaling
T06Z
10m
24hrs
Up to 16-d
Re-scaling
T12Z
10m
24hrs
Up to 16-d
Re-scaling
T18Z
10m
24hrs
Up to 16-d
Re-scaling
New breeding cycle
6 hours
Re-scaling
6hrs
Next T00Z
Up to 16-d
T00Z
40m
Re-scaling
T06Z
40m
Up to 16-d
Independent vectors
Re-scaling
T12Z
40m
Up to 16-d
Re-scaling
T18Z
40m
Up to 16-d

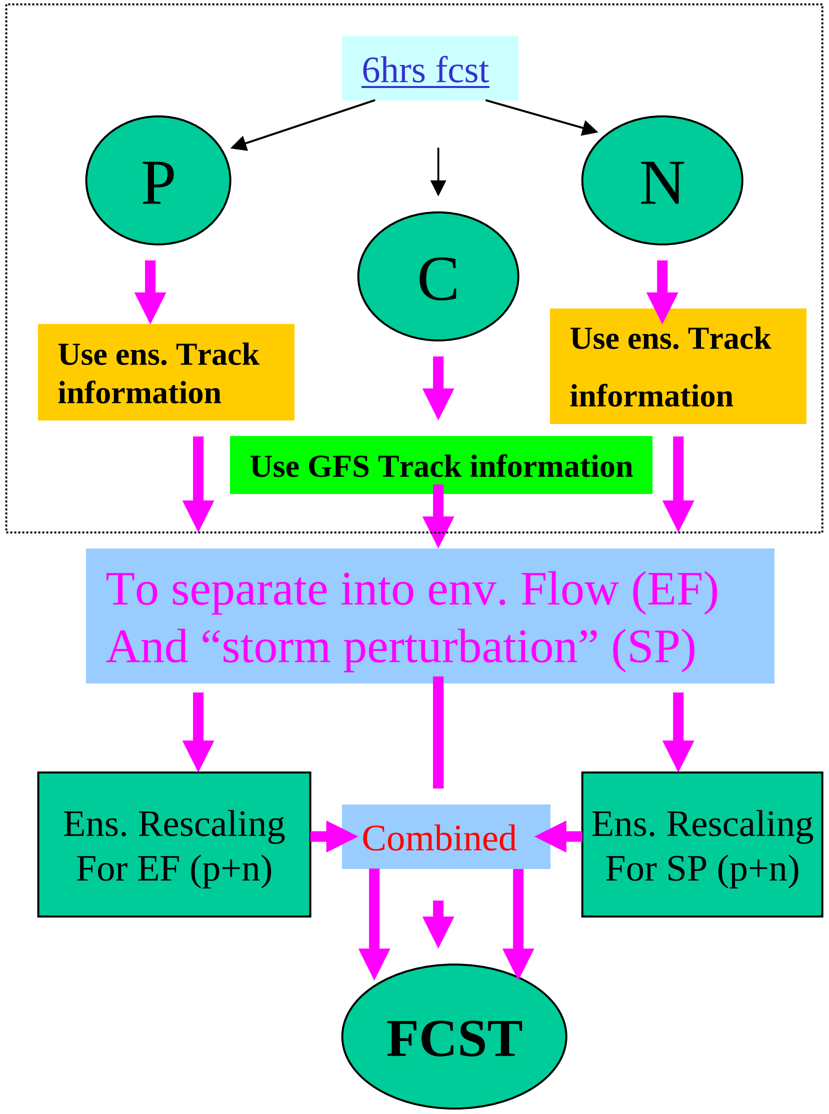
Recent Implementation
Changes - 3

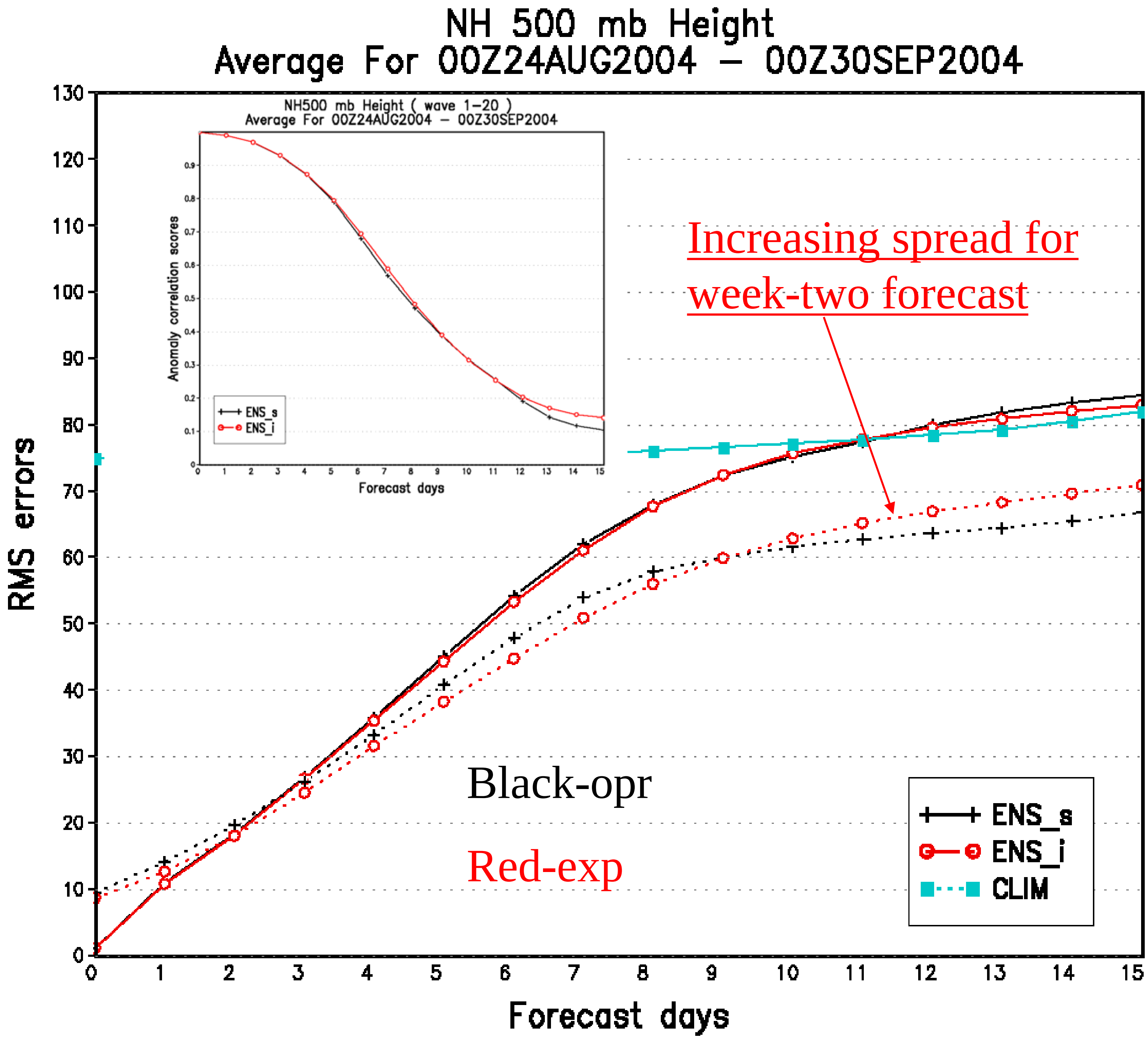
- Relocation of perturbed tropical storm
  - This change is intended to reduce track forecast error and uncertainty for short lead-time (1-3 days)
  - Results:
    - Reducing mean track errors by 10% for 12-48 hours
    - Reducing the ensemble track spread, that was too large, for short lead-time
    - Improving track forecast skill

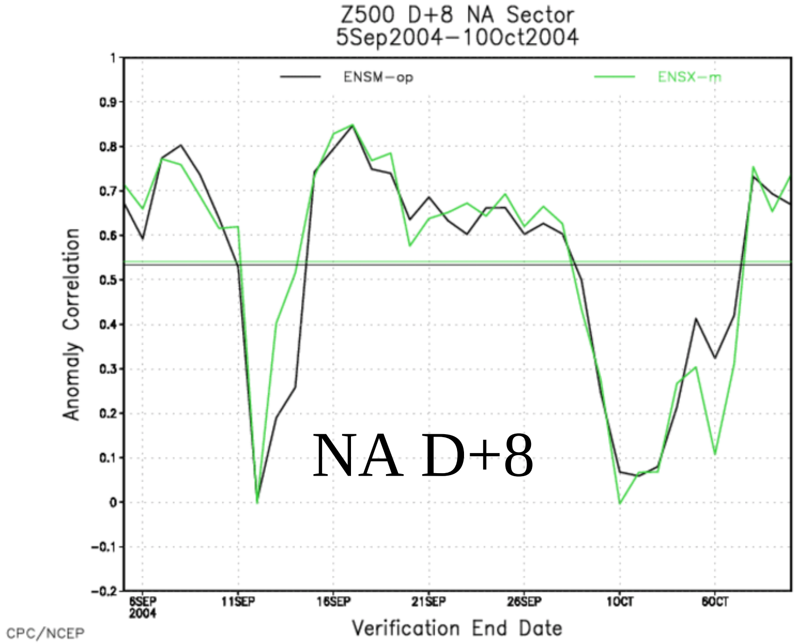
GFS TS relocation

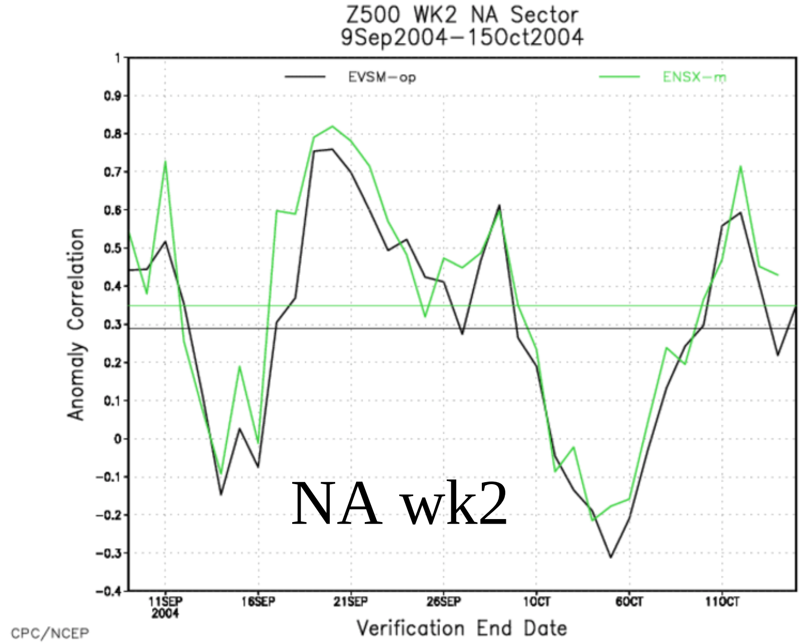


Ensemble TS relocation

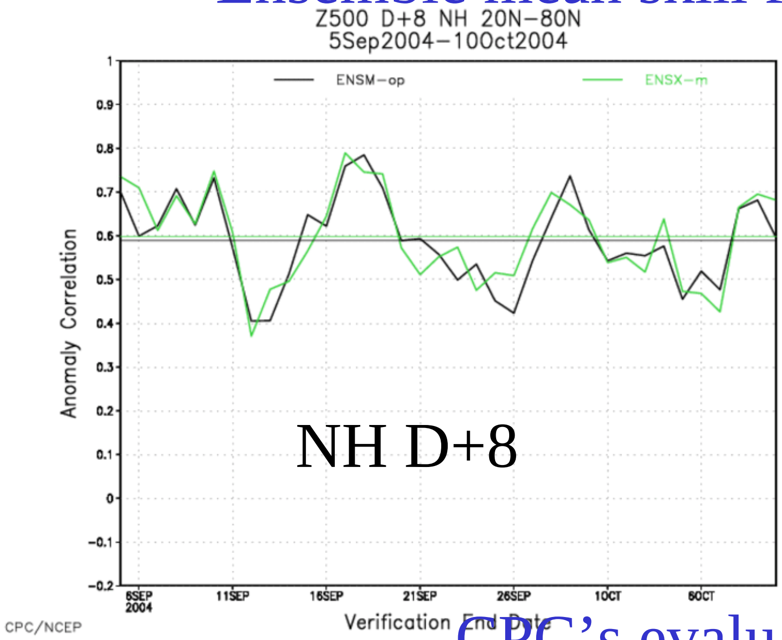



NH 500 mb Height
Average For 00Z24AUG2004 – 00Z30SEP2004
RMS errors
Forecast days
NH500 mb Height (wave 1–20)
Average For 00Z24AUG2004 – 00Z30SEP2004
Anomaly correlation scores
Increasing spread for
week-two forecast
Black-opr
Red-exp
ENS_s
ENS_i
CLIM



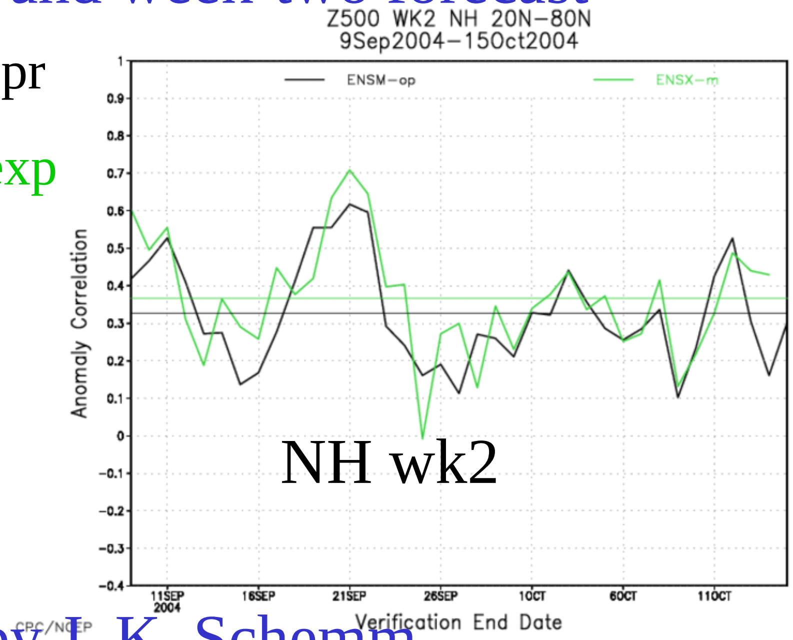


Ensemble mean skill for D+8 and week-two forecast

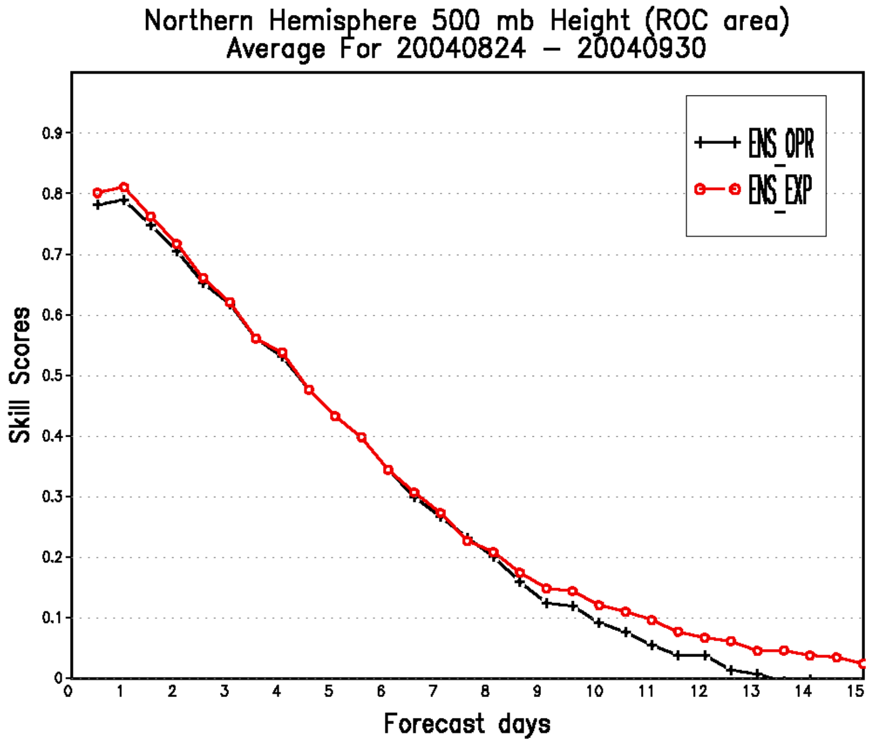


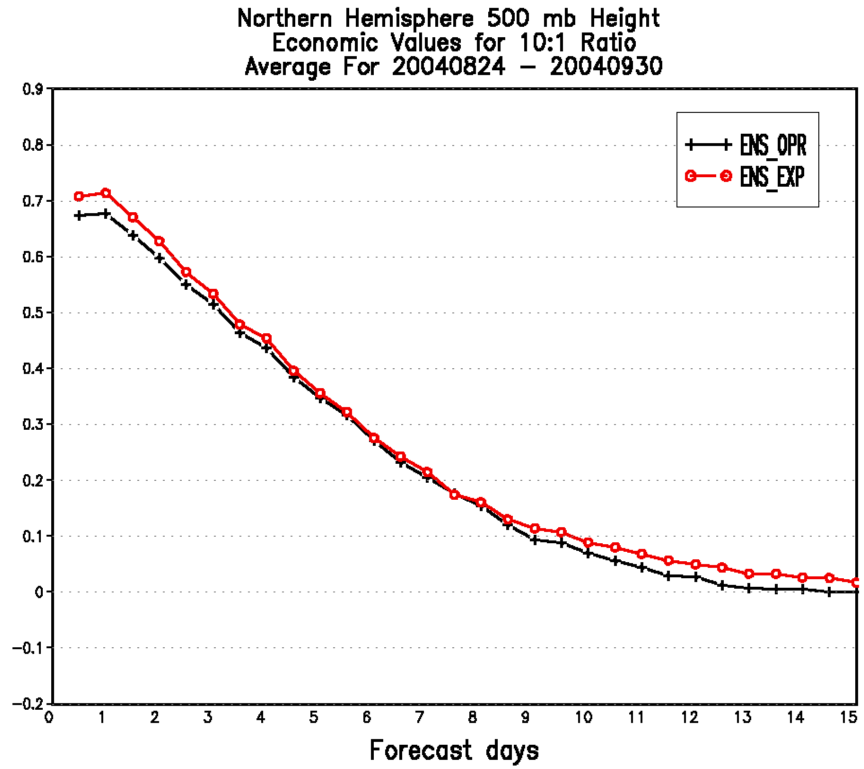
Black-opr

Green-exp



CPC's evaluation –by J. K. Schemm



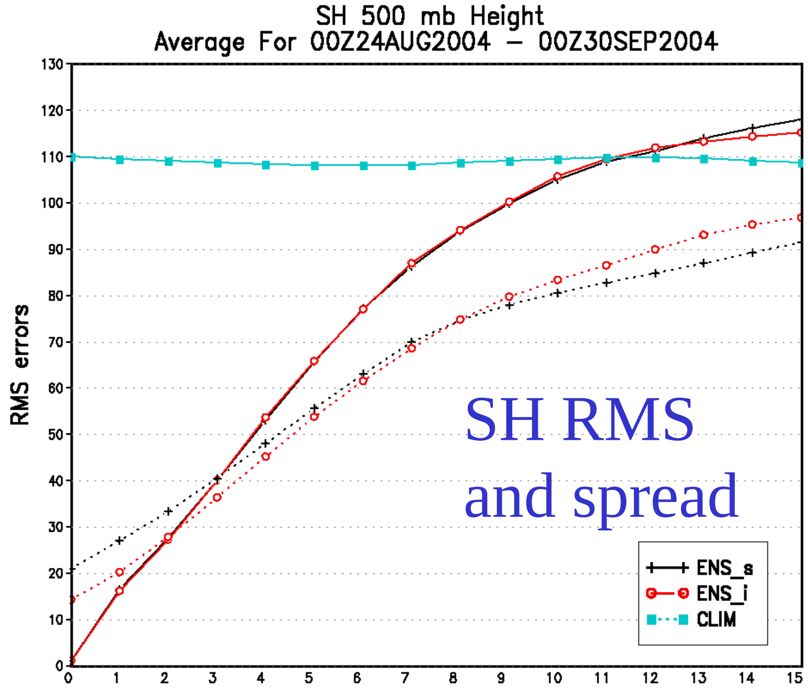


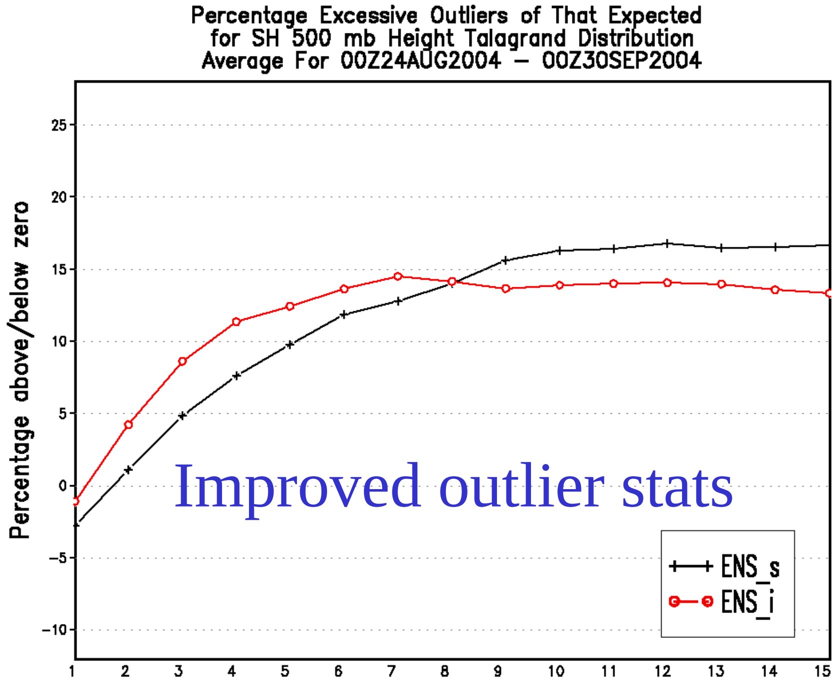
Northern Hemisphere 500hPa height probabilistic verification:

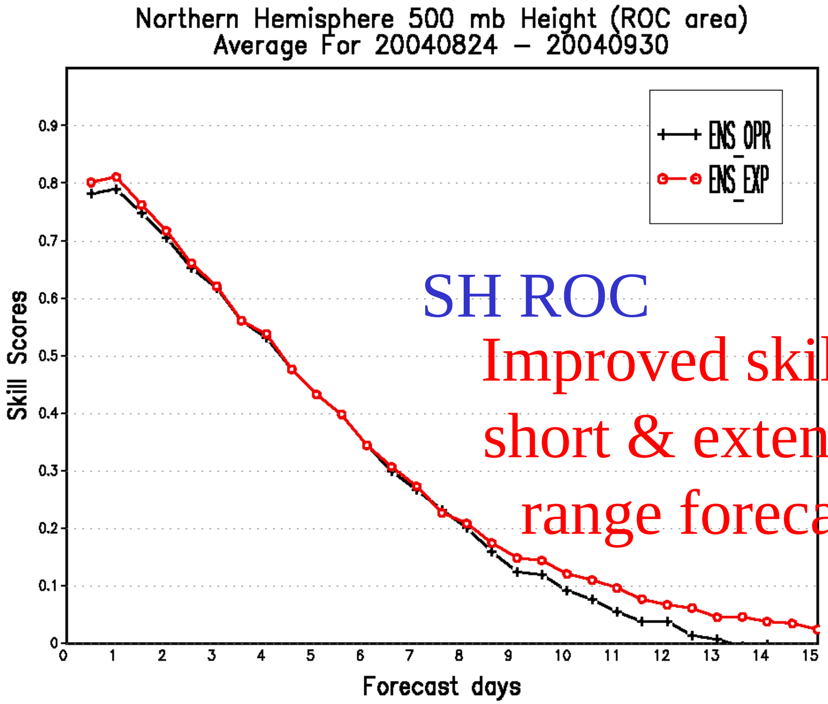
ROC (left) and EV (right)

Improvement for short-lead time due to 6-hr breeding cycle

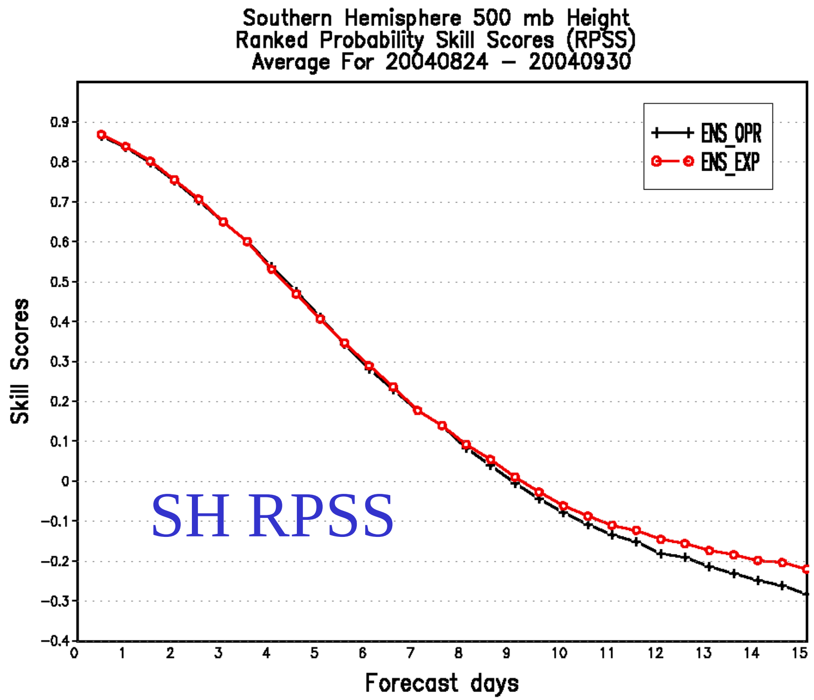
Improvement for extended forecast due to increased resolution





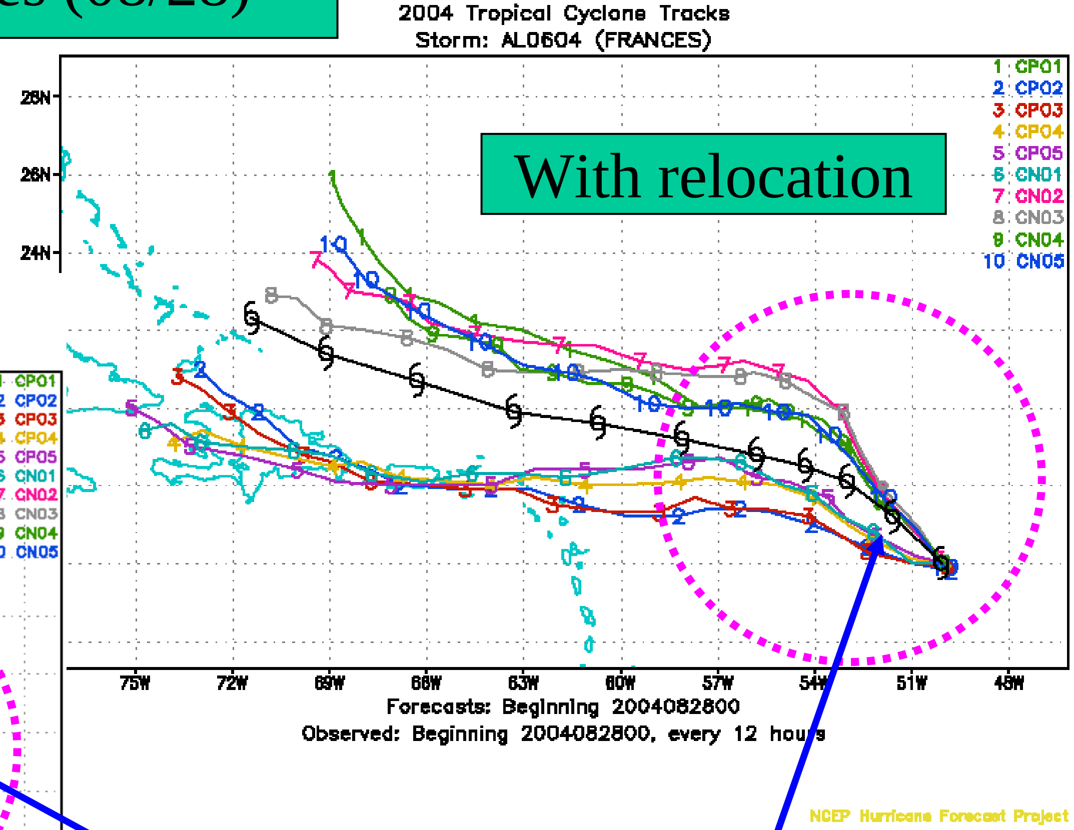


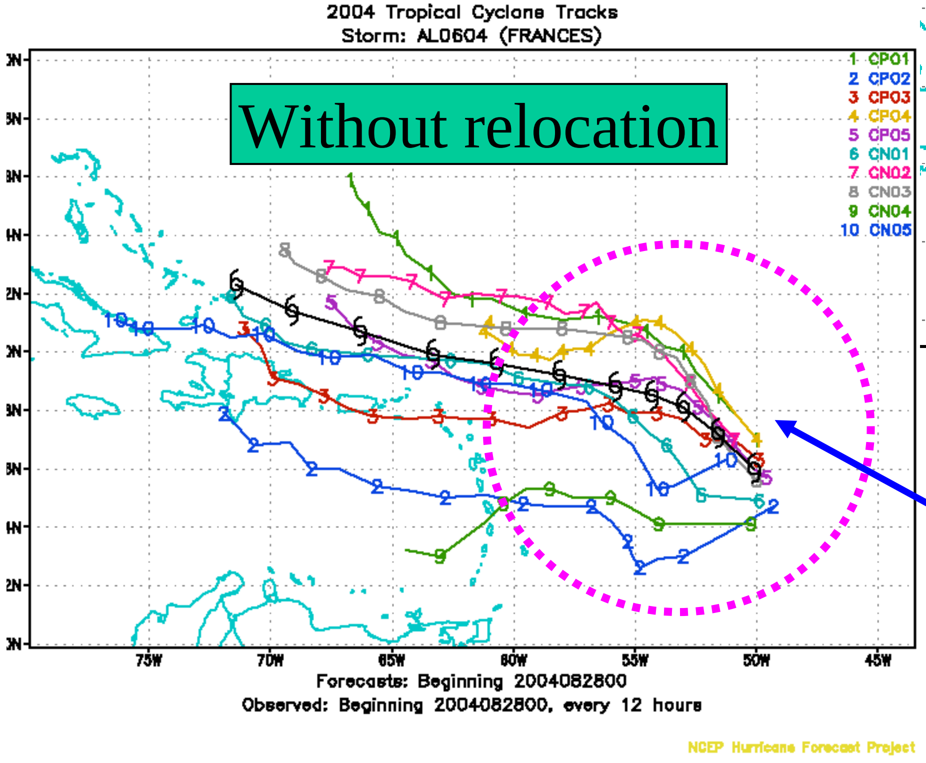
Improved skill for short & extended-range forecasts



Hurricane Track Plots (case 1)

Frances (08/28)



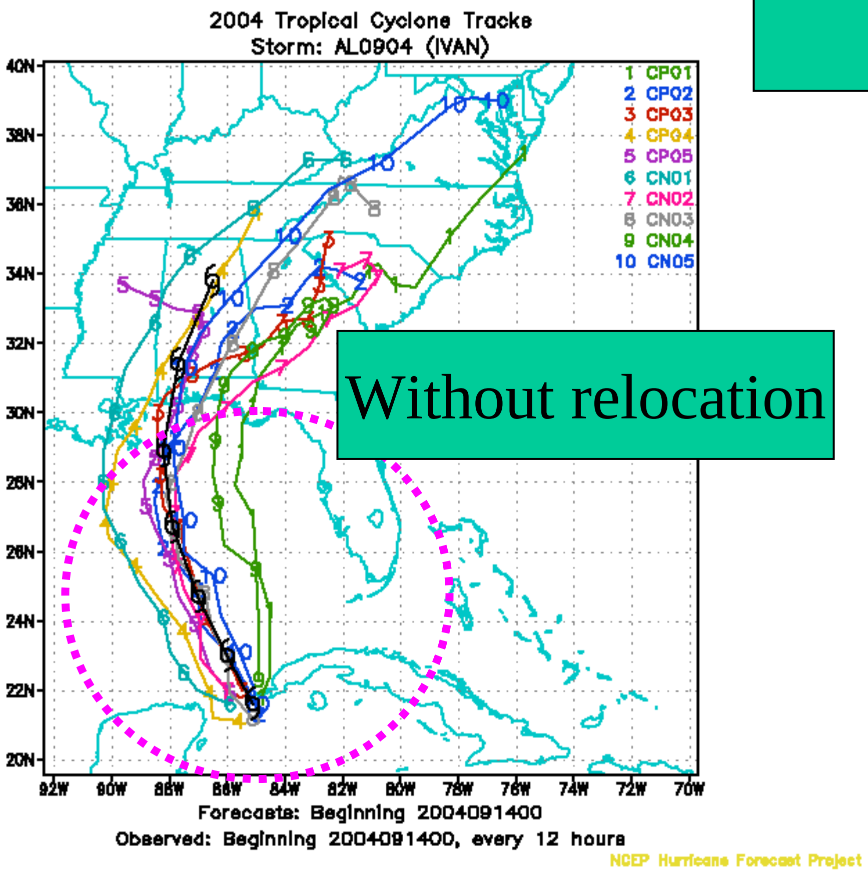


Reduced initial spread

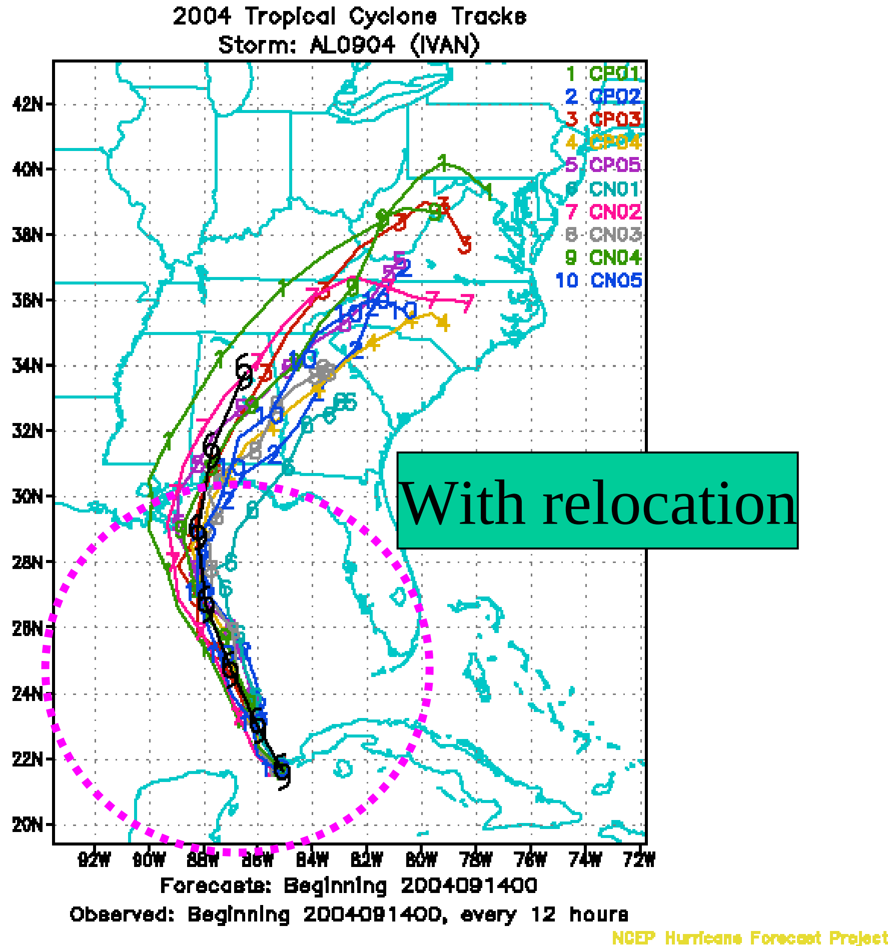
Large initial spread

Hurricane Track Plots (case 2)

Ivan (09/14)

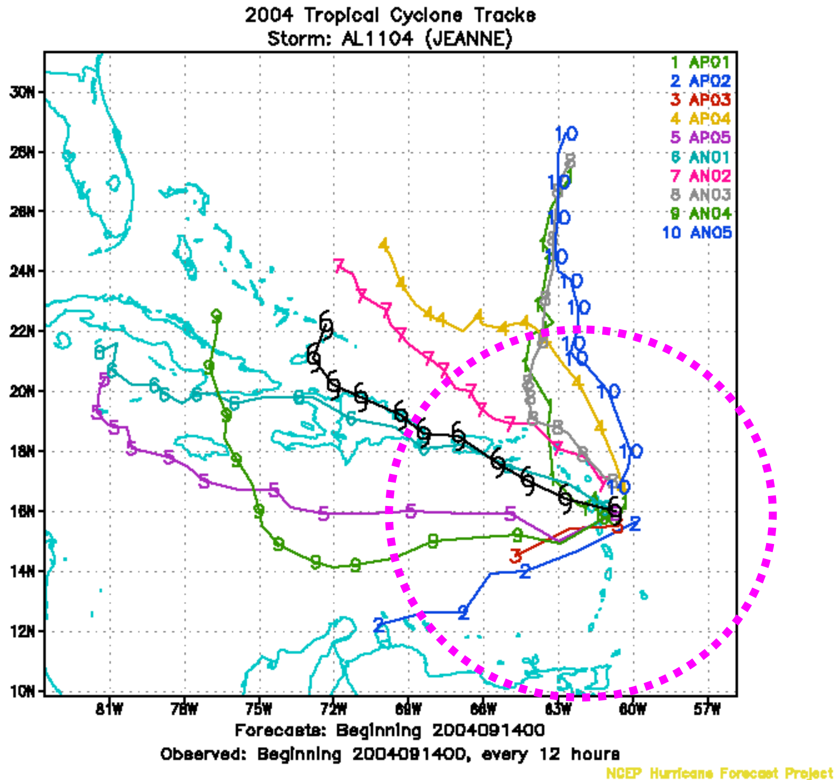


Without relocation



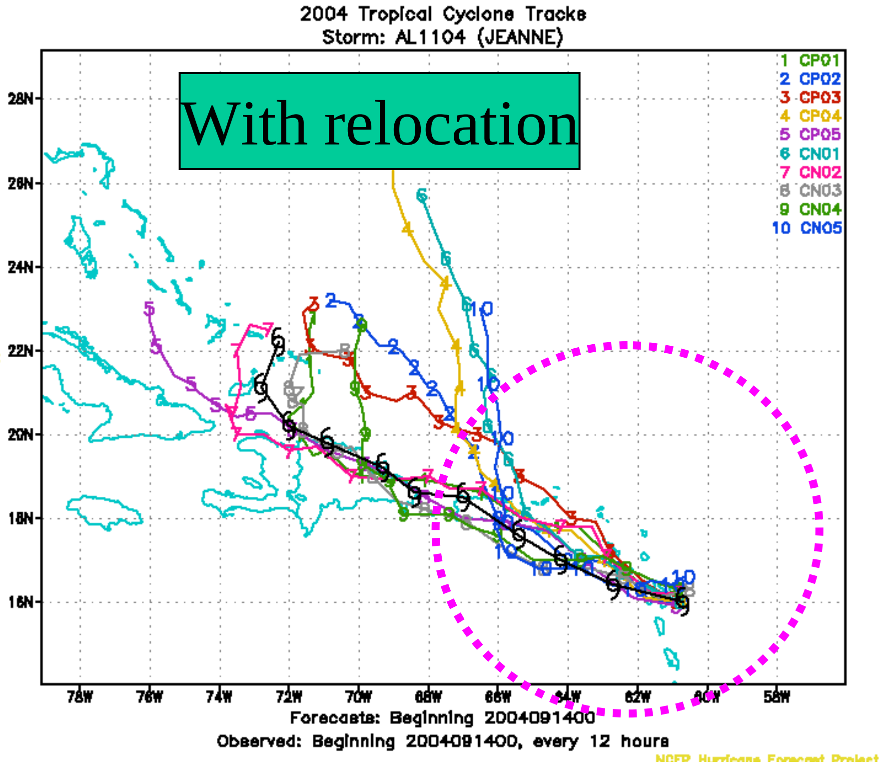
With relocation

Hurricane Tracks Plots (case 3)



Jeanne (09/14)

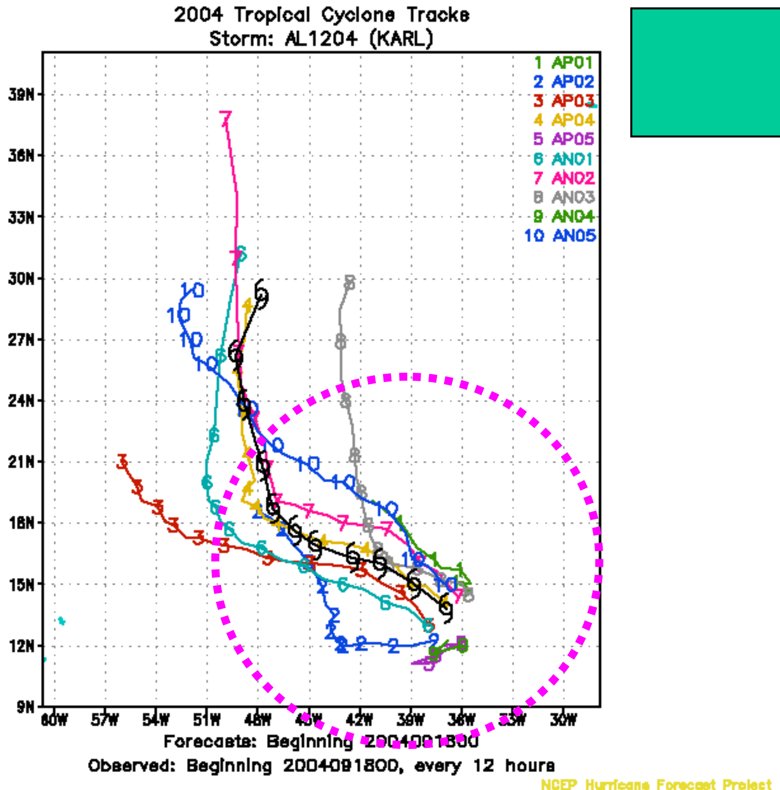
Without relocation



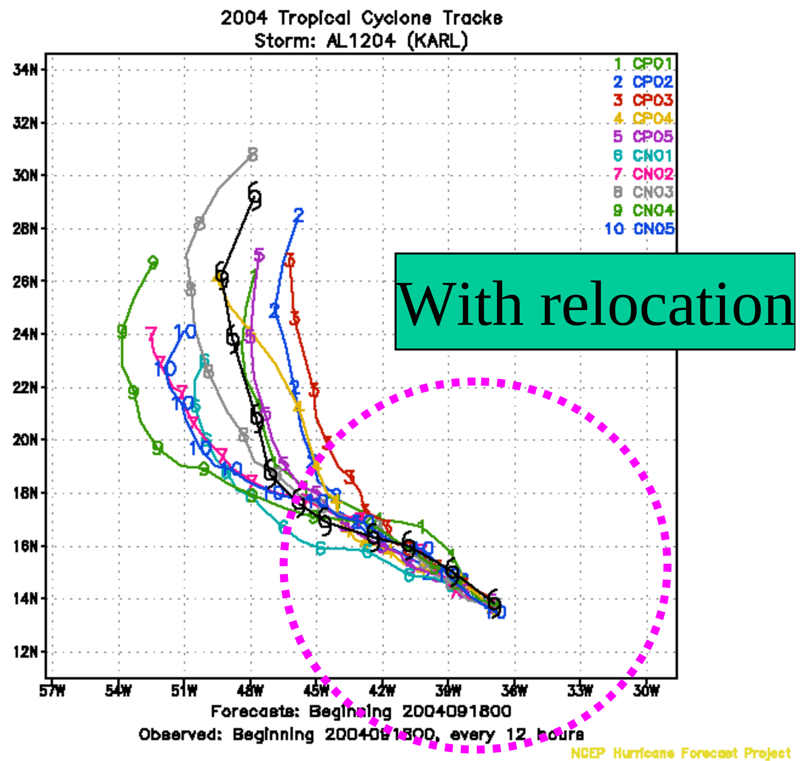
With relocation

Hurricane Tracks Plots (case 4)

Karl (09/18)



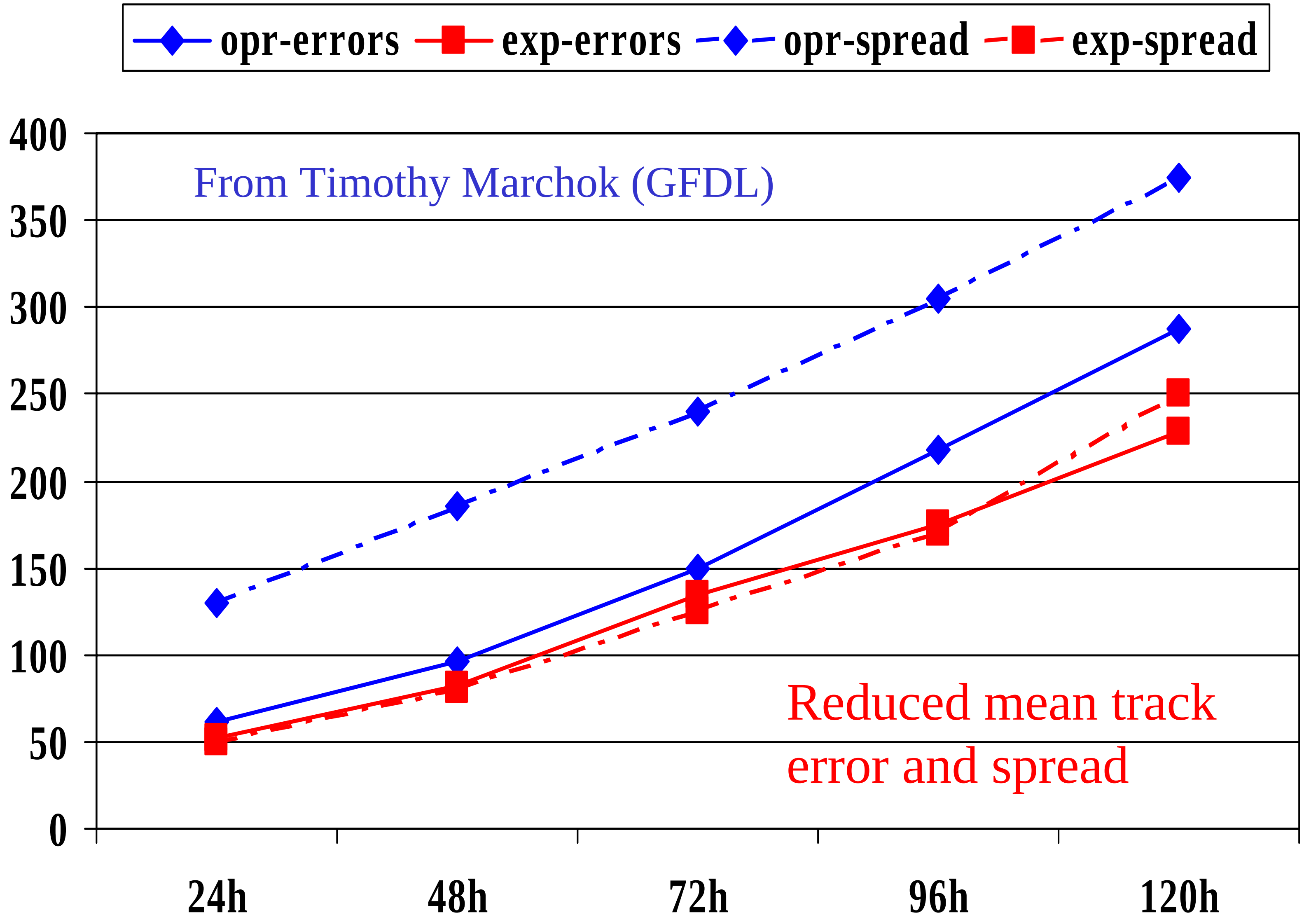
Without relocation



With relocation

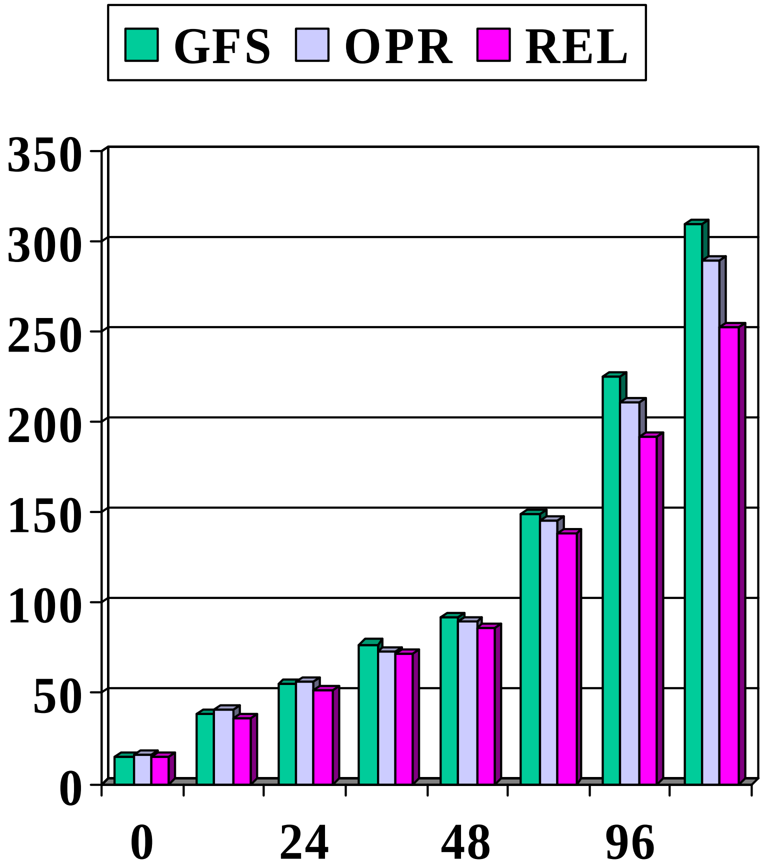
Track error and spread

2004 Atlantic Basin (8/23-10/1)

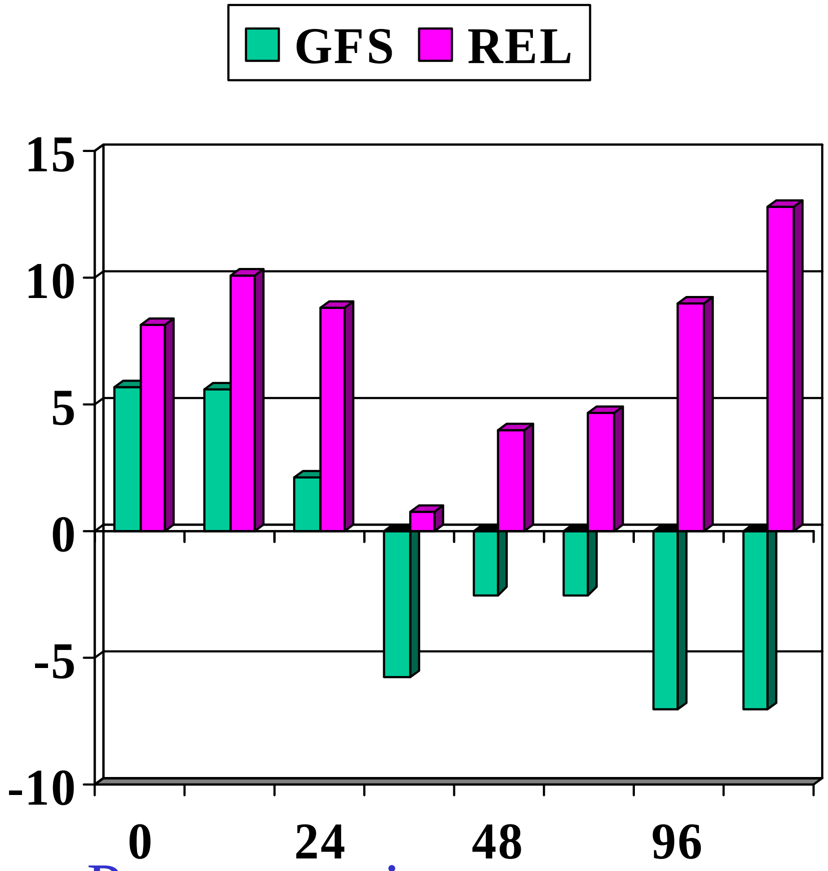


Hurricane track errors

2 basins (Atlantic and e-Pacific)



Track errors (miles)

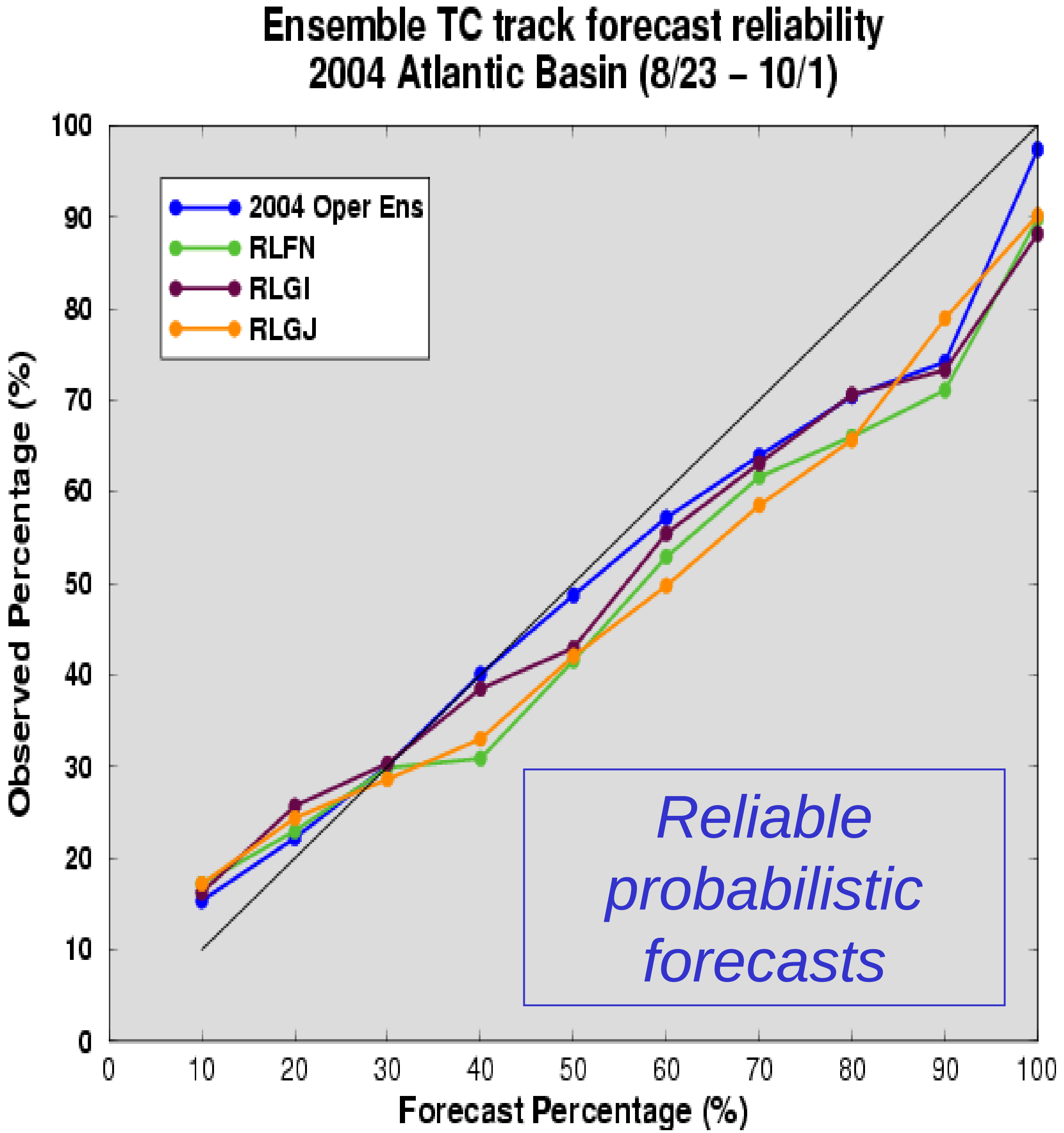


Percentage improvement to operational ensemble

Period: 20040824-20040930 (53-103 cases)

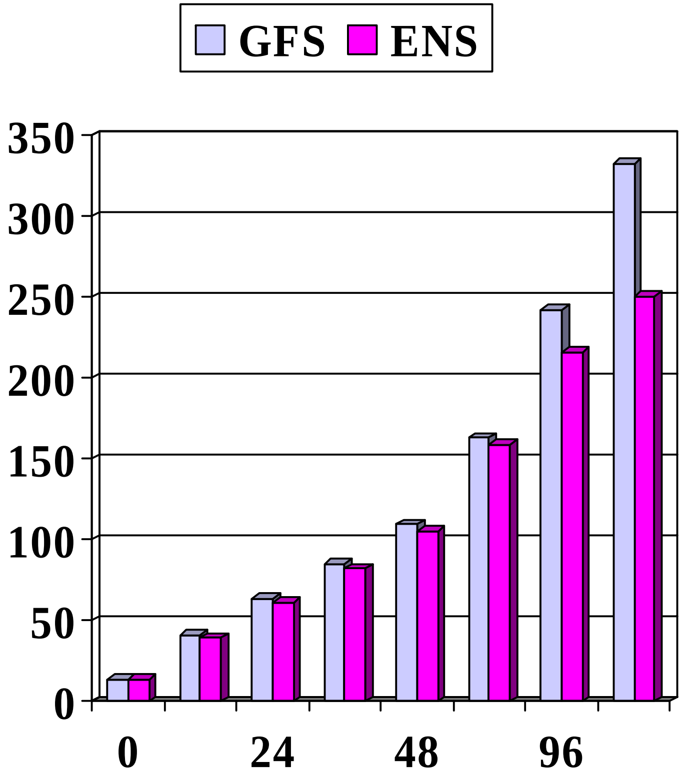
FORECAST PROBABILITY VS. OBSERVED FREQUENCY

When strike probability forecast is eg. 30%,
storm observed in 30% of all cases

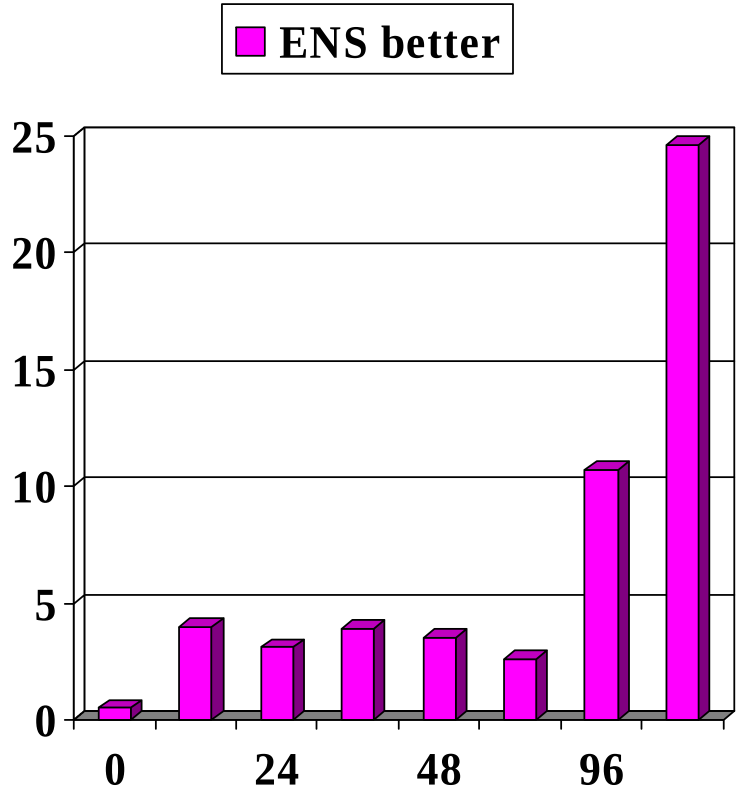


Hurricane track errors

Atlantic basins (up to October 2005)



Track errors (miles)



Percentage improvement to GFS

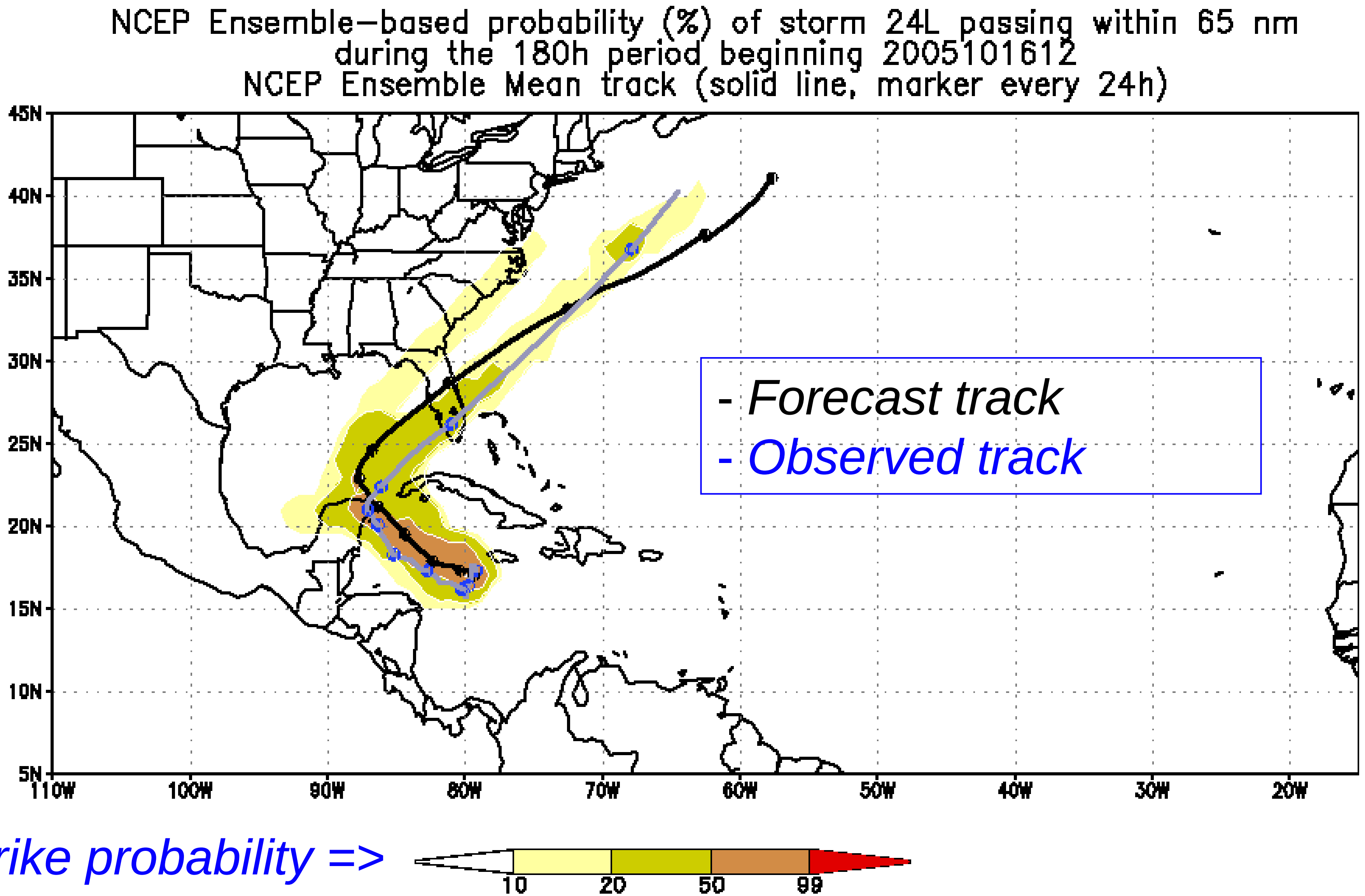
Period: for whole hurricane season of 2005 (up to October 27)

Note: ensemble TS relocation was implemented by Aug. 17th 2005

ENSEMBLE FORECASTING - QUANTIFYING UNCERTAINTY

STRIKE PROBABILITY

At any point, how many members of ensemble had a storm within 65 nm radius

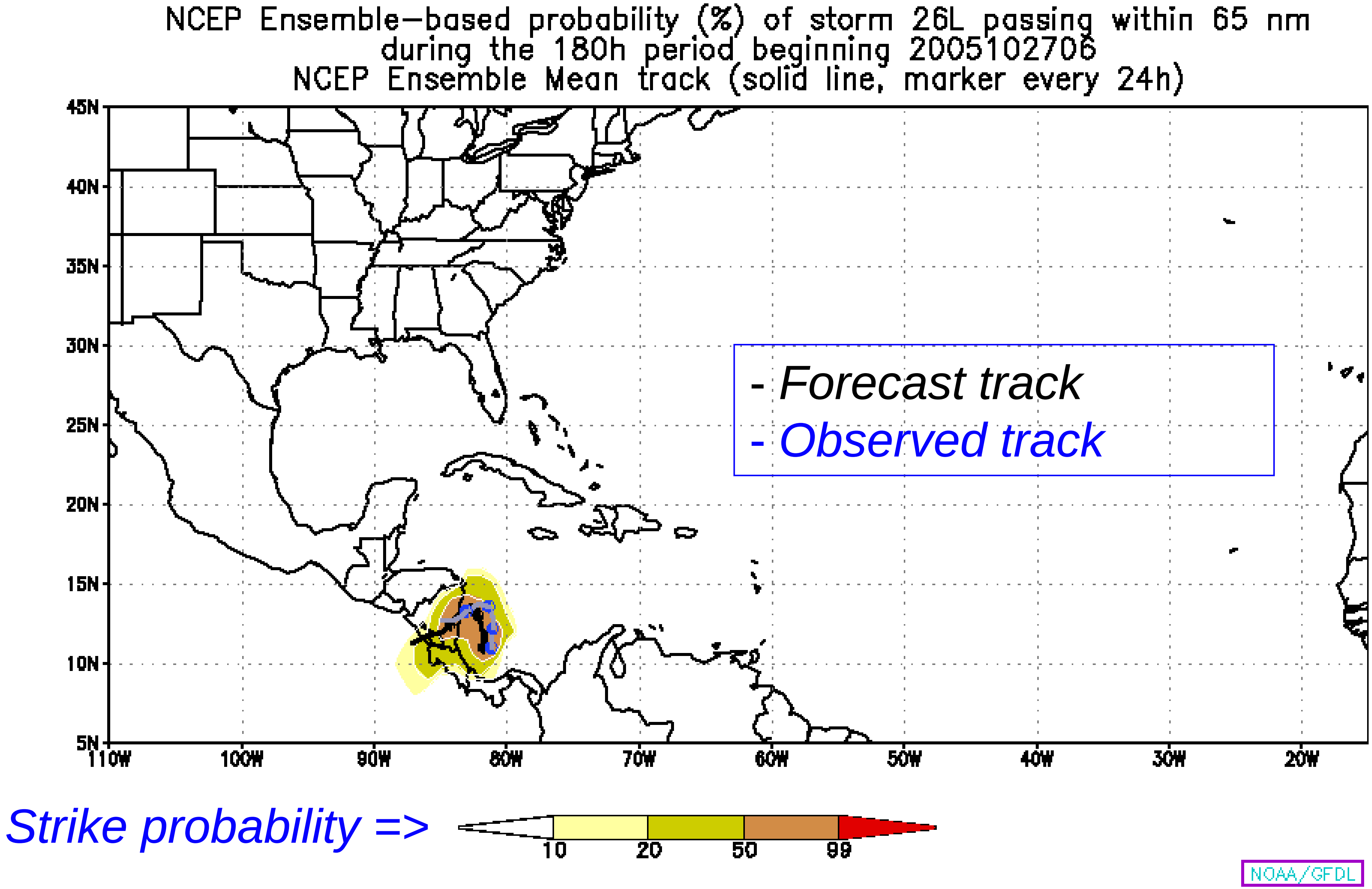


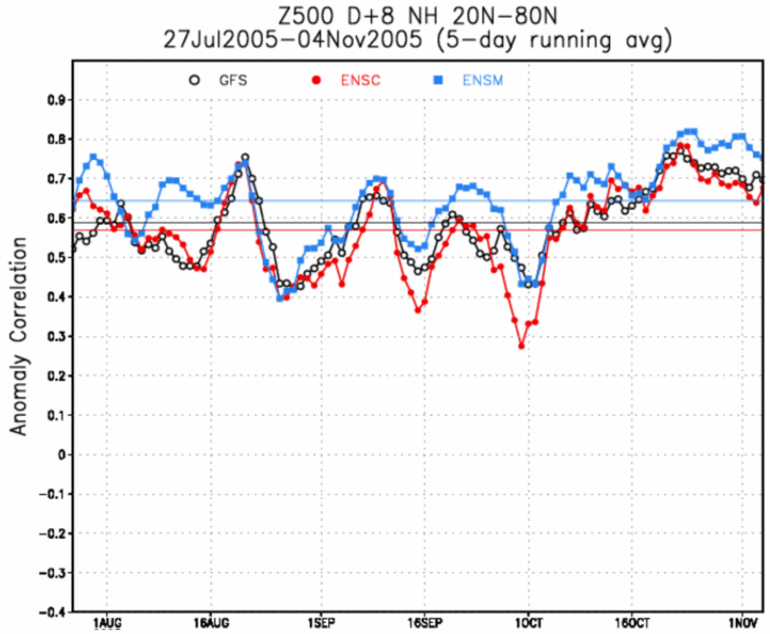
Strike probability =>

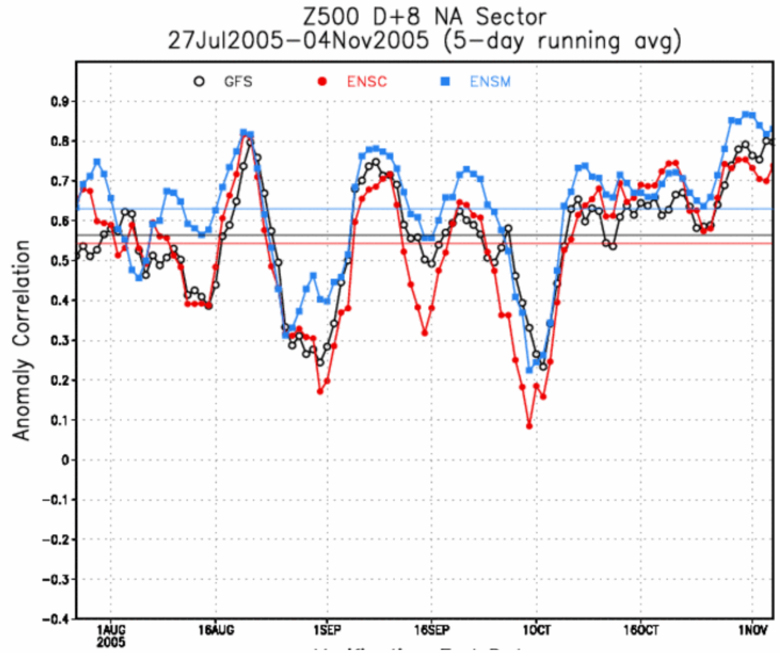
HURRICANE BETA

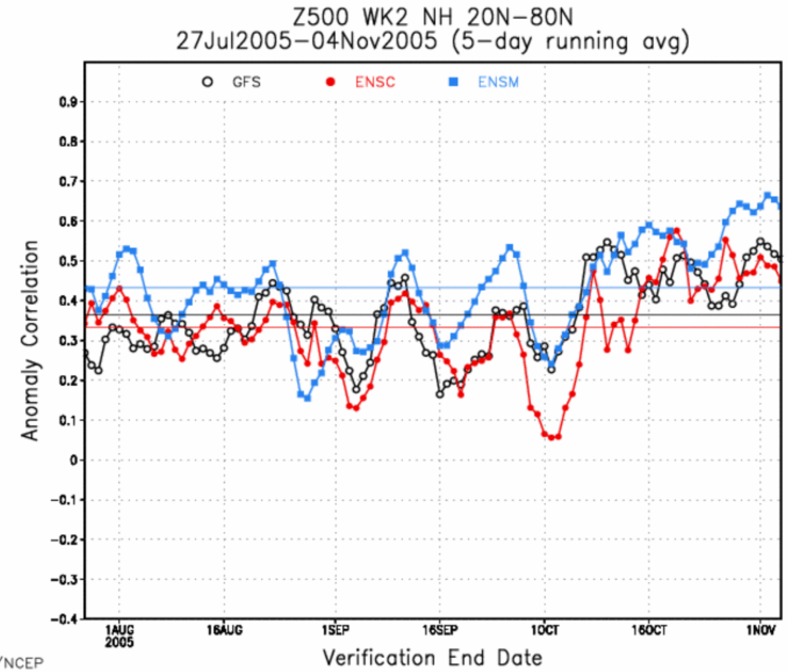
STRIKE PROBABILITY

Probability of storm within 65 nm vicinity of any point on map

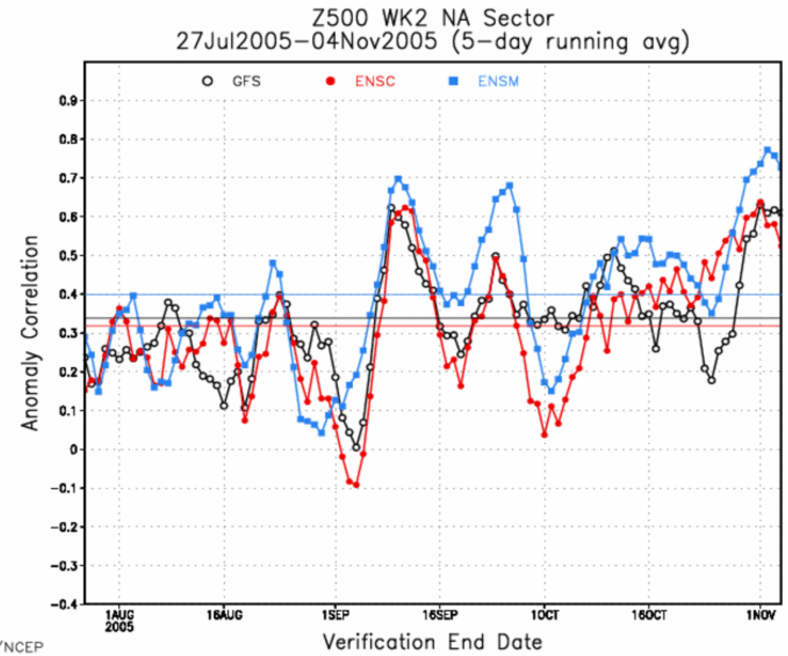




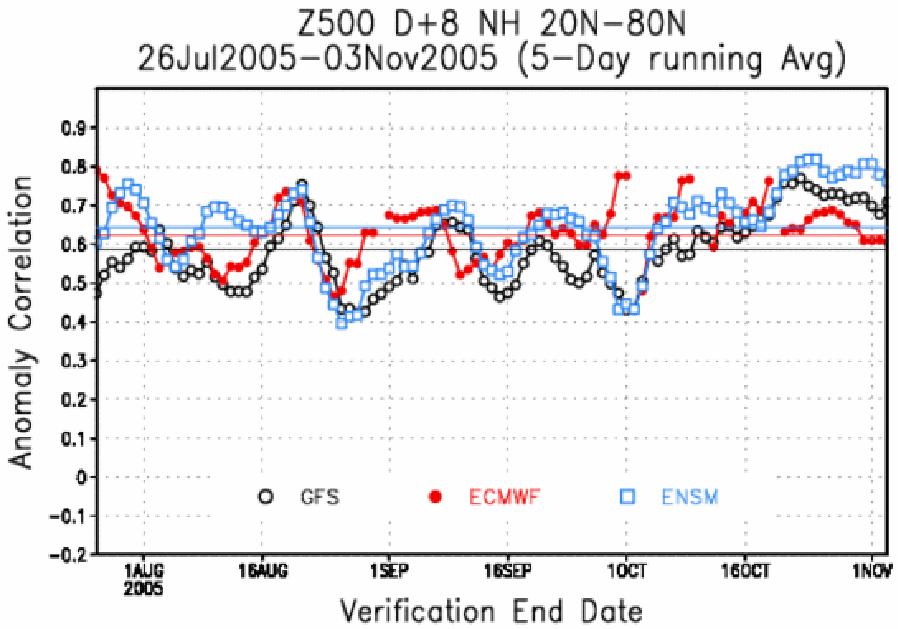


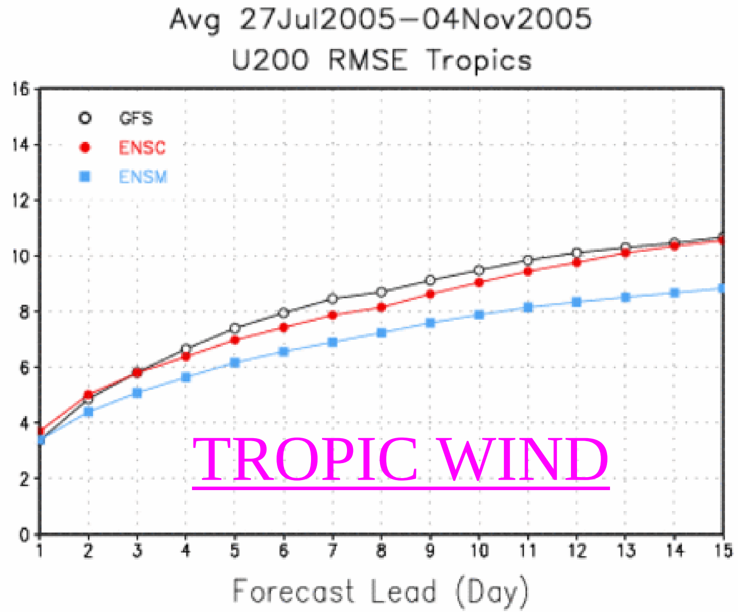


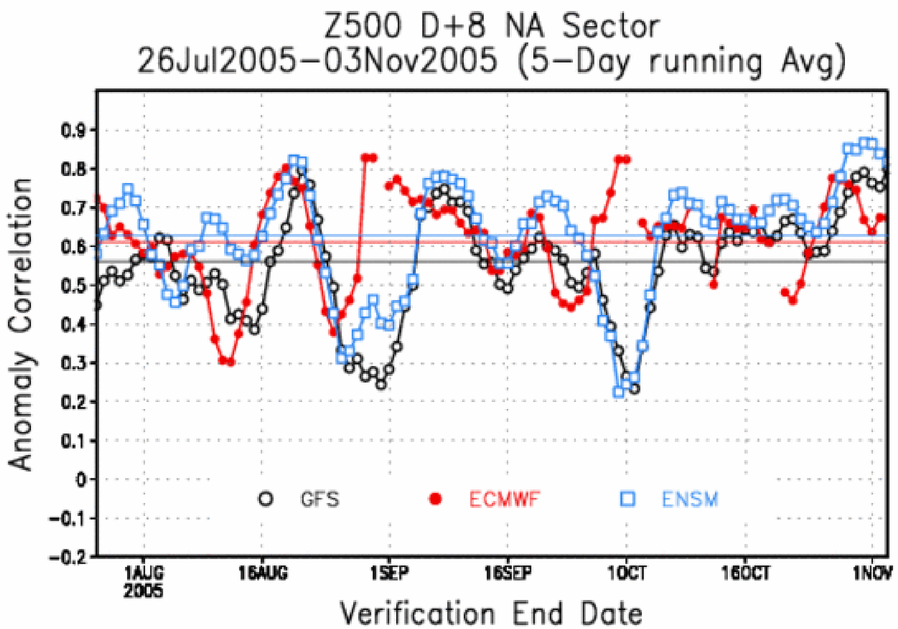
CPC/NCEP

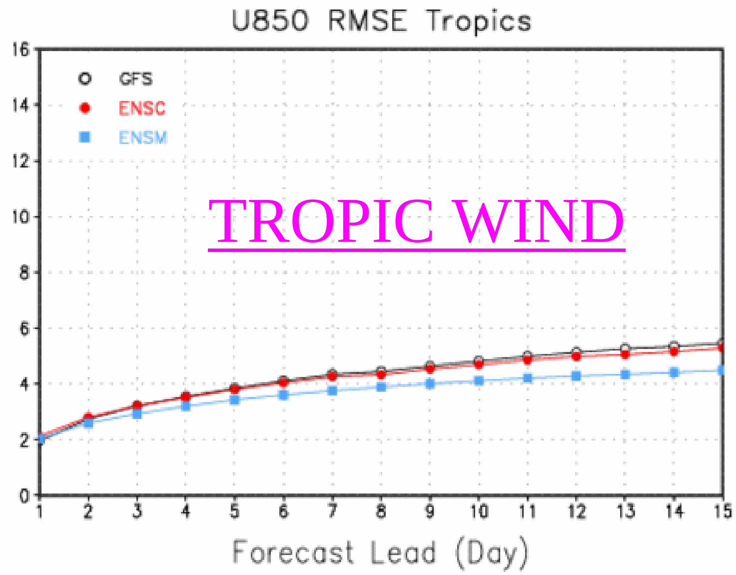


CPC/NCEP


Z500 D+8 NH 20N-80N
26Jul2005-03Nov2005 (5-Day running Avg)
Anomaly Correlation
GFS
ECMWF
ENSM
1AUG 2005
16AUG
1SEP
16SEP
1OCT
16OCT
1NOV
Verification End Date


Avg 27Jul2005-04Nov2005
U200 RMSE Tropics
GFS
ENSC
ENSM
TROPIC WIND
Forecast Lead (Day)


Z500 D+8 NA Sector
26Jul2005-03Nov2005 (5-Day running Avg)
Anomaly Correlation
GFS
ECMWF
ENSM
1AUG 2005
16AUG
1SEP
16SEP
1OCT
16OCT
1NOV
Verification End Date


U850 RMSE Tropics
GFS
ENSC
ENSM
TROPIC WIND
Forecast Lead (Day)

NAEFS

- PARTICIPANTS
- PROJECT DESCRIPTION
- TIMELINE
- IMPLEMENTATION SCHEDULE
- CONCEPT OF OPERATIONS
- NAEFS & THORPEX
- BASIC PRODUCTS
- END PRODUCTS
- DETAILS – RESOURCE ISSUES
- FUTURE EXPANSION
- NEW NWP PARADIGM
- Visit: http://wwwt.emc.ncep.noaa.gov/gmb/ens/NAEFS.htm

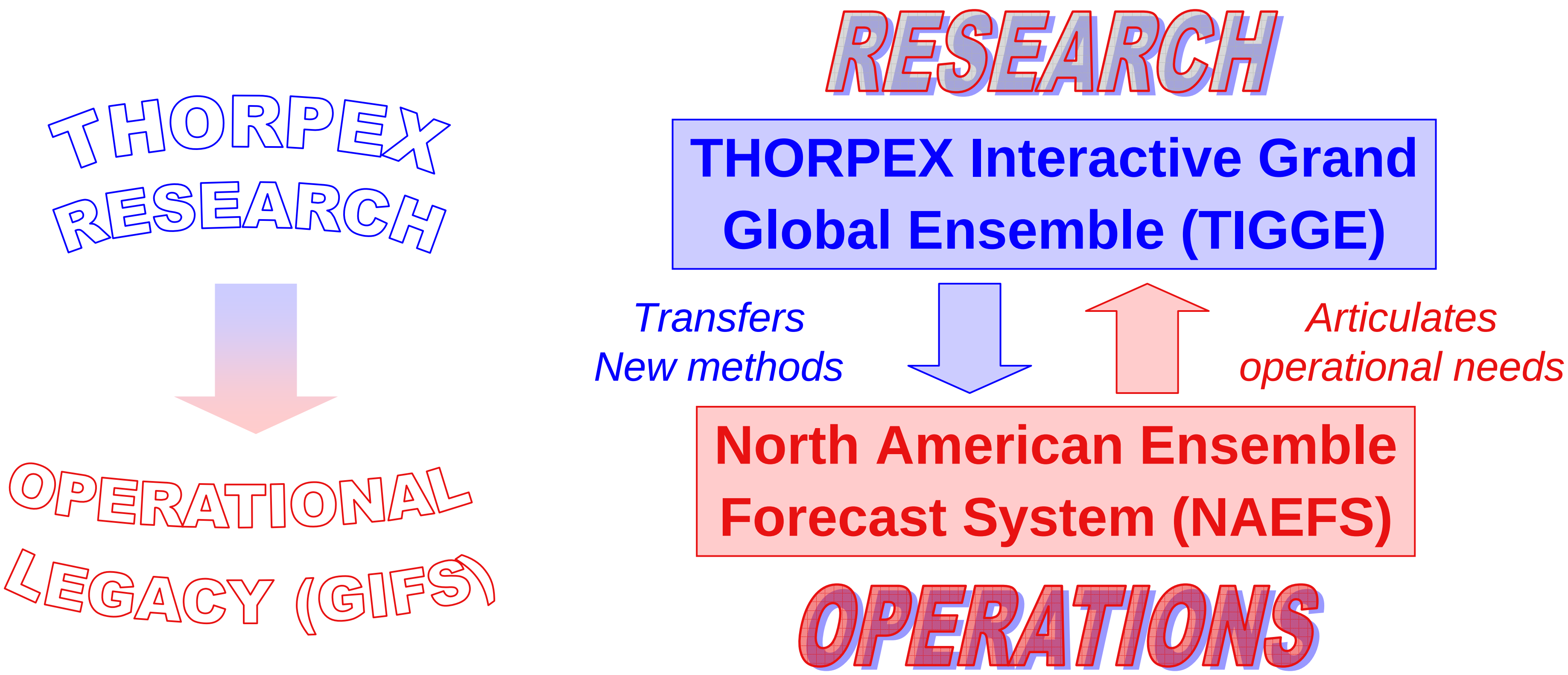
CONCEPT OF OPERATIONS

1. Exchange ~50 selected variables
   – Use GRIB2 to reduce volume of data
2. Generate basic products using same algorithms/codes
   – Reduce systematic error
     • Bias estimation
   – Combine two ensembles
     • Determine weights
   – Express forecast in terms of climatological anomalies
     • Prepare & compare forecast with reanalysis climate distribution
3. Generate center-specific end products
4. Evaluate & provide feedback for improvements
   – Verification using same algorithms
   – User feedback

2. MSC-NCEP basic production suite
   – Same algorithms/codes used at both centers
     • Duplicate procedures provide full backup in case of problems at either end
     • If one component of ensemble missing, products based on rest of ensemble
   – Basis for different sets of center-specific end products
     • Ensures consistency between end products even if their format is different
   – All basic products to be made available via ftp to user and research community

NAEFS & THORPEX

- Expands international collaboration
  - Mexico joined in November 2004
  - UK Met Office to join in 2006
- Provides framework for transitioning research into operations
  - Prototype for ensemble component of THORPEX legacy forecst system:
    Global Interactive Forecast System (GIFS)



LIST OF VARIABLES IDENTIFIED FOR ENSEMBLE EXCHANGE BETWEEN MSC - NCEP

Parameter	CMC	NCEP
Ensemble	8 SEF, 8 GEM	10 paired
Grid	2.5x2.5 deg (144x73) & 1.2x1.2 deg (300x151)	2.5x2.5 deg (144x73) & 1.0x1.0 deg (360x181)
Domain	Global	Global
Format	WMO GRIB Format	WMO GRIB Format
Hours	0, 12, 24, 36, 48, . . . ,216, 228, 240	0, 6, 12, 18, 24, ……., 360, 366, 372, 378, 384
GZ	200, 250, 500, 700, 850, 925, 1000	200, 250, 500, 700, 850, 925, 1000
TT	200, 250, 500, 700, 850, 925, 1000	200, 250, 500, 700, 850, 925, 1000
E	Tdd at 200, 250, 500, 700, 850, 925, 1000	RH at 200, 250, 500, 700, 850, 925, 1000
U, V	200, 250, 500, 700, 850, 925, 1000	200, 250, 500, 700, 850, 925, 1000
TT Sfc	12000, redefined in GRIB file as 2m AGL	2m
U, V Sfc	Redefined in GRIB file as 10m AGL	10m
ES	Tdd at 12000, redefined in GRIB file as 2m AGL	RH at 2M
MSLP	(PN) level 0	PRMSL
PR (total precip)	Level 0 , I.e. at surface	Level 0, I.e.at surface
NT (total cloud cover)	Level 0	Column
IH (total precipitable cover)	Level 0	Column
Sfc Pres	(SEF) (P0) level 0 at surface	Sfc Pressure
Model Topography	Model Topography	Model Topography at t=0 and t=192
CAPE	Most unstable layer	Most unstable layer
Precip Type	4 accumulations processed into 4 bitmaps	4 bitmap variables for 4 types
Tmax	2m derived from hourly	2m
Tmin	2m derived from hourly	2m
WAM	Later	Later

Black: data presently exchanged
Blue: data exchanged & processed by NCEP June 2004

Red: data added in September 2004
Green: data to be exchanged later

R. Wobus
R. Hogue

Basic Products

Post-Processing

- Bias corrected forecasts
  - Consider 35 variables in the first phase
- Statistical weights
  - Consider 35 variables in the first phase
- Anomaly forecasts
  - Consider 19 variables in the first phase
- GRIB2
- NAWIPS grids and graphics
- NDGD grids

List of Variables for Bias Correction/weights for CMC & NCEP Ensembles

	CMC & NCEP
Ensemble	CMC (8 SEF, 8 GEM), NCEP (GFS)
GRID	1x1 deg (360x180 lat-lon)
DOMAIN	Global
FORMAT	WMO Grib Format
HOURS	6 hourly out of 384 hours (current 240 hours for CMC Ensemble)
GZ	200, 250, 500,700, 850 ,925,1000
TT	200, 250, 500,700, 850 ,925,1000
U,V	200, 250, 500,700, 850 ,925,1000
TT	2m
U, V	10m
MSLP	Sea Level Pressure
Sfc Pres	Surface Pressure
Tmax	2m
Tmin	2m

Review of Recent Results

- First moment correction:
  - Previous results: kept reinitializing the prior, based on 40-day flat average difference
  - Current system: keeps cycling the bias estimate after initializing the prior, which starts from July 1, 2003. Choose decaying weight 10%, 5%, 2%, 1%, 0.5% and 0.25%, respectively, and apply on 500 mb height of NCEP & CMC ensemble
    - Northern and Southern Hemisphere: the smaller weigh is better for longer lead time, and larger weight is better for shorter lead time
    - Tropical region: 2% is the best one among the six weight factors

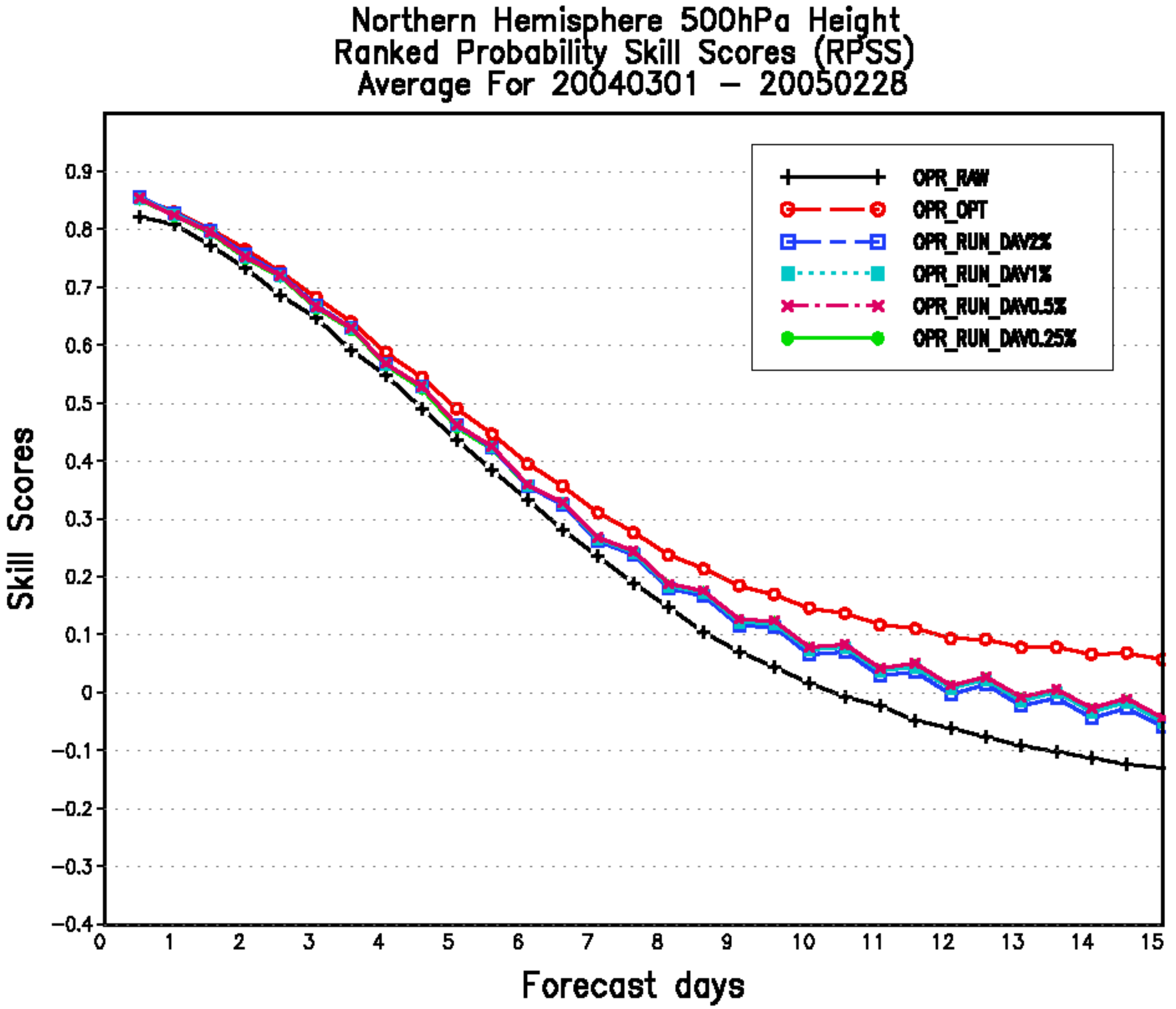
- Bias correct CMC member individually & bias correct CMC member in 2 groups (8 SEF member & 8 GEM member) due to CMC multi-model ensemble and each model & member has its own physics parameterization
  - applying the bias correction scheme on each member is the better approach though the differences are small between the two methods

- Combined ensemble, use equal weight for all members (5 NCEP & 5 CMC member)

Ongoing Development & Testing Plans for Implementation

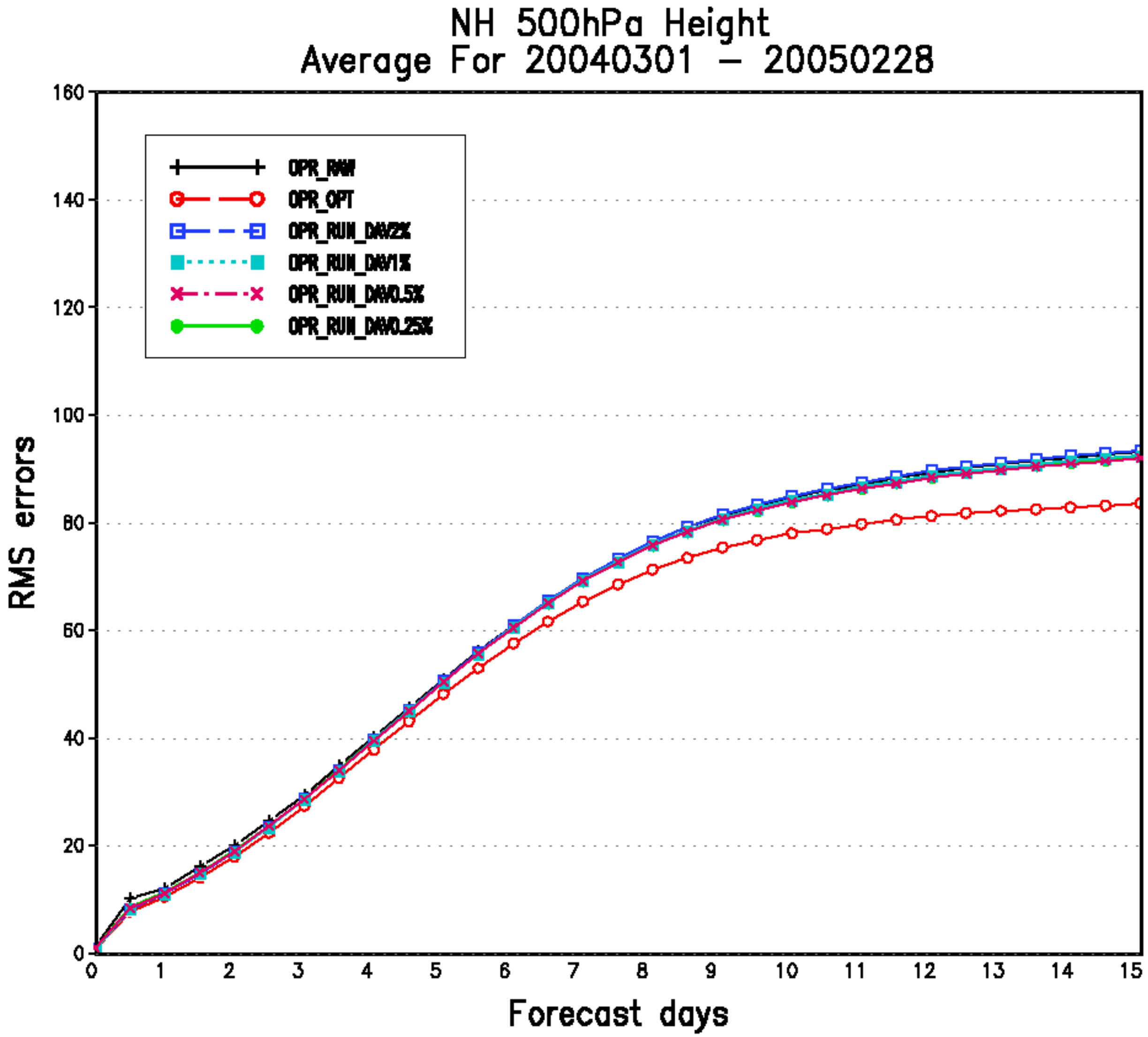
- ## Bias correction
  - First moment correction
    - choose a fixed weigh factor (2 % as a default), or vary it as a function of lead time and location (how to determine variations?)
    - apply bias correction scheme
      - 35 variables (NCEP & CMC)
      - on 1 x1 degree ensemble data (NCEP & CMC)
      - on 00z and 12Z (NCEP & CMC, 06 &18Z for NCEP)
  - Second moment correction
    - may not be included in next spring operational implementation
- ## Weighting
  1. BMA method: only tested for surface temperature
  2. Use frequency of “best member of ensemble” statistics

NCEP RPSS: 500mb Height, Northern Hemisphere
2004 Annual Mean

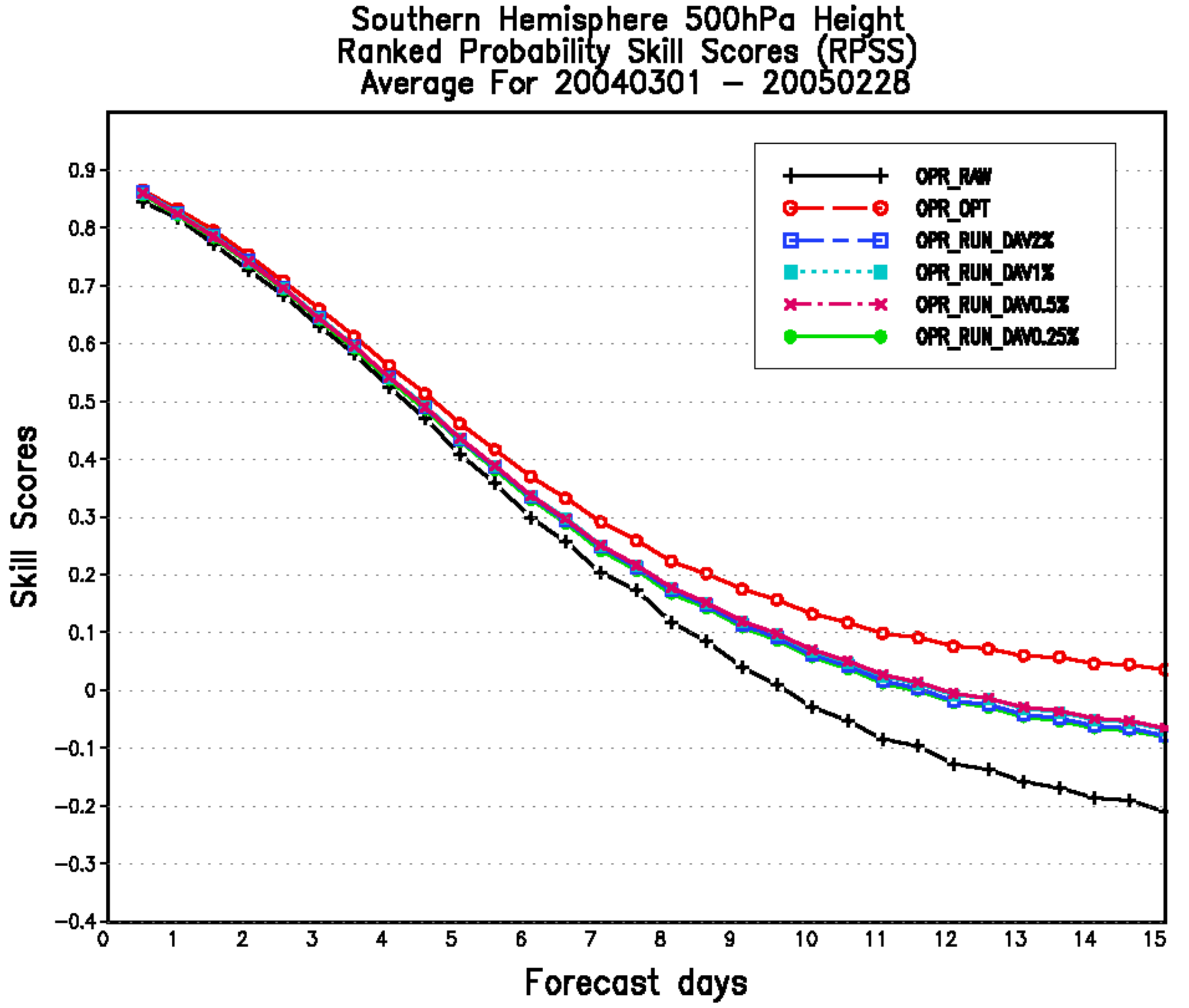


http://www.emc.ncep.noaa.gov/gmb/wx20cb/Bias_Correction_Algorithm/1st_2nd_Moments/Training_1month/Plot_Comb_Post/z500_2004_ncep_annual/

NCEP RMS: 500mb Height, Northern Hemisphere
2004 Annual Mean



NCEP RPSS: 500mb Height, Southern Hemisphere
2004 Annual Mean



Climate anomalies

Express bias-corrected forecasts (each member) in terms of climate percentile

- Forecasts bias corrected wrt NCEP & CMC oper. analysis
  - 1.0*1.0 (lat/lon) grid
- Climate based on NCEP/NCAR reanalysis data
  - 4 cycles (00UTC, 06UTC, 12UTC and 18UTC) per day
  - 40 years (Jan. 1st 1959 – Dec. 31th 1998)
  - 2.5*2.5 (lat/lon) grid
- Need to consider the systematic difference between reanalysis and oper. analysis (NCEP & CMC respectively)
- Variables (possible to add more)
  - Height: 1000hPa, 700hPa, 500hPa, 250hPa
  - Temperature: 2m, 850hPa, 500hPa, 250hPa
  - Wind: 10m, 850hPa, 500hPa, 250hPa
  - PRMSL, max/min temperature

Climate anomalies

PROCEDURE

- Determine climatological distribution for each day using reanalysis data
  - Use first few harmonics to describe annual variations
  - Compute all stats for 4 times per day
  - Estimate climate mean (first moment)
  - Estimate distribution around mean
  - Archive data to be used on daily basis
- Determine systematic difference between reanalysis and operational analysis fields
  - Use standard NAEFS “bias estimation” method
- Adjust bias corrected NAEFS forecasts by systematic difference between reanalysis & oper. analysis
- Compare bias corrected & adjusted NAEFS forecasts to reanalysis distribution
  - Express each forecast as percentile of climate distribution

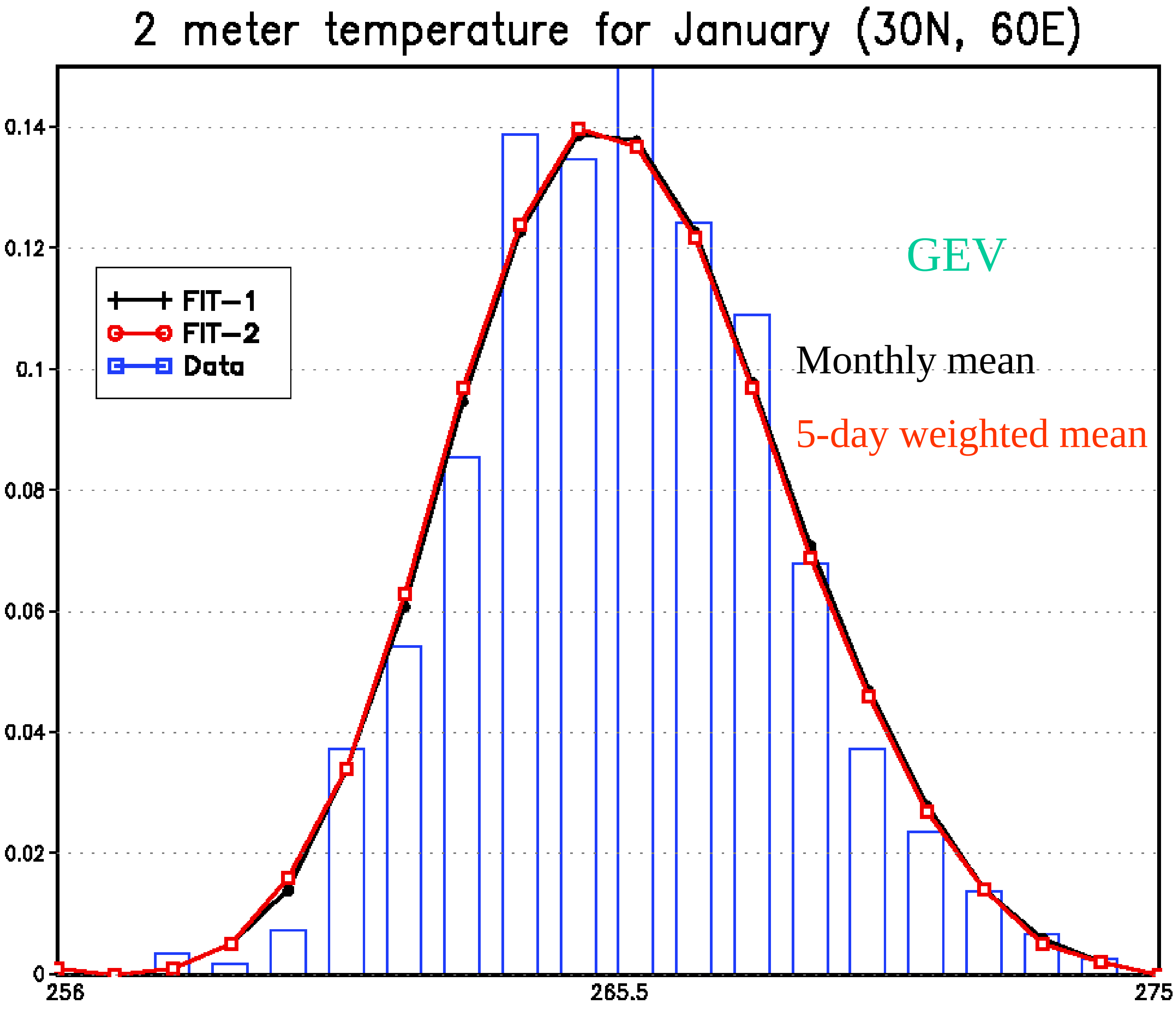
Estimating the climate mean

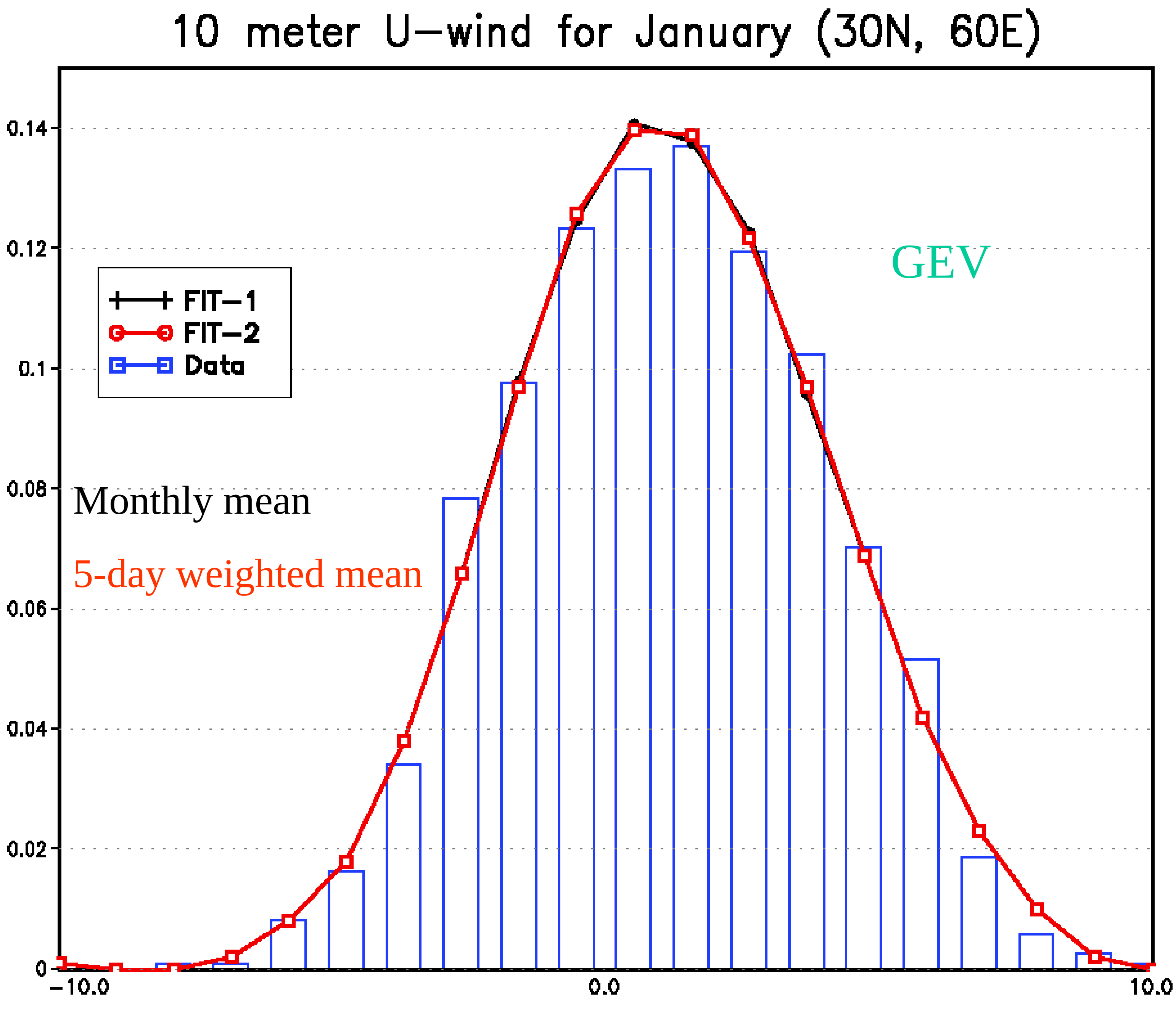
- To consider monthly mean (tested)
  - Monthly mean (large data samples – 1240)
    - Interpolate to daily (shifted from season)
- To consider daily mean (tested)
  - 5-day running mean for daily climatology
    - Data samples – 200
  - 5-day center weighted mean for monthly climatology
    - Data samples – 200
      - (d-2)*0.12+(d-1)*0.22+d*0.32+(d+1)*0.22+(d+2)*0.12
- To consider annual cycle (tested)
  - Fits the first 1-4 Fourier annual modes to daily data to obtain annual cycle.

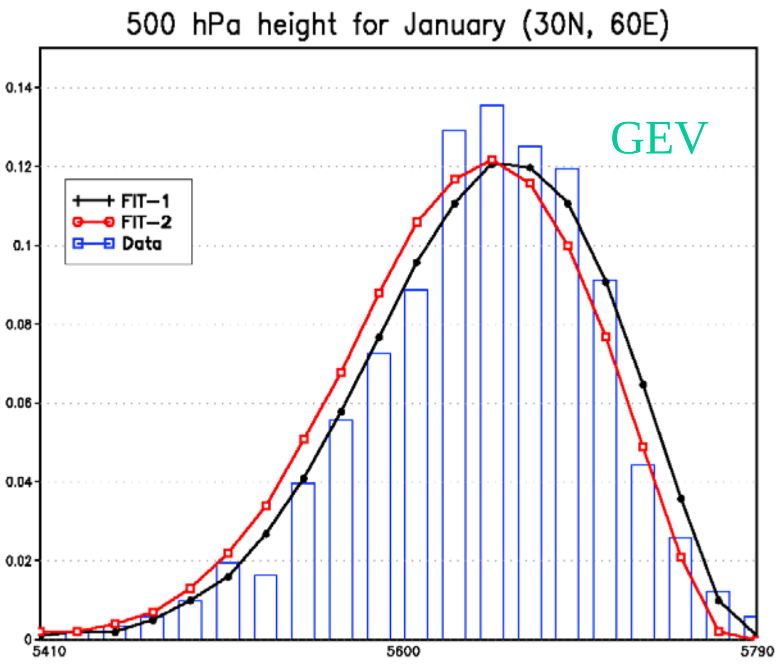
Higher moments (estimation)

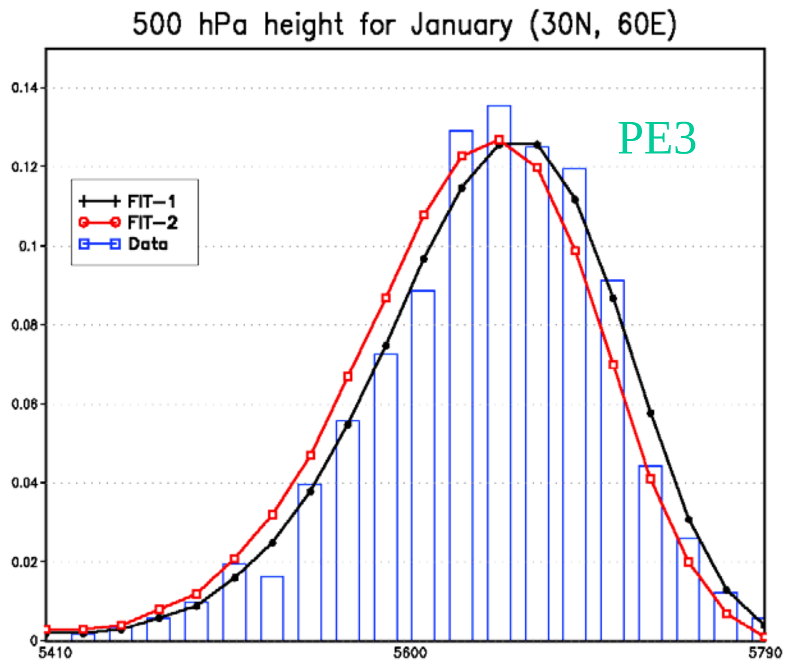
- work on the anomalies from mean

- To consider monthly (tested):
  - Data size of 40 (year) * 31 (dom for Jan) = 1240
  - Fitting distributions (three parameters)
    - Gamma, Pearson type-III, GE3 (generalized extreme-value)
- Compute a smooth standard deviation (tested)
  - Based on annual cycle
- Discussions and questions


2 meter temperature for January (30N, 60E)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
256
265.5
275
FIT-1
FIT-2
Data
GEV
Monthly mean
5-day weighted mean

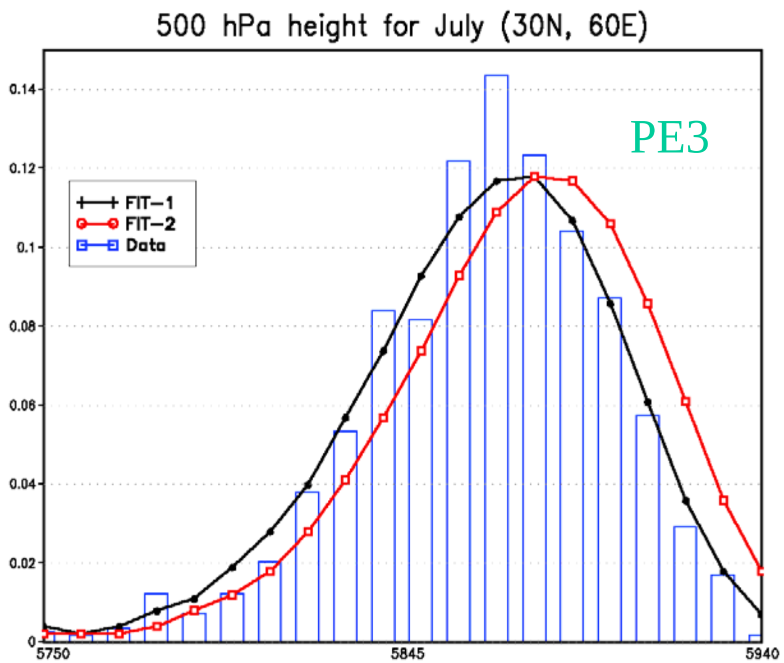

10 meter U-wind for January (30N, 60E)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-10.0
0.0
10.0
FIT-1
FIT-2
Data
GEV
Monthly mean
5-day weighted mean





Monthly mean

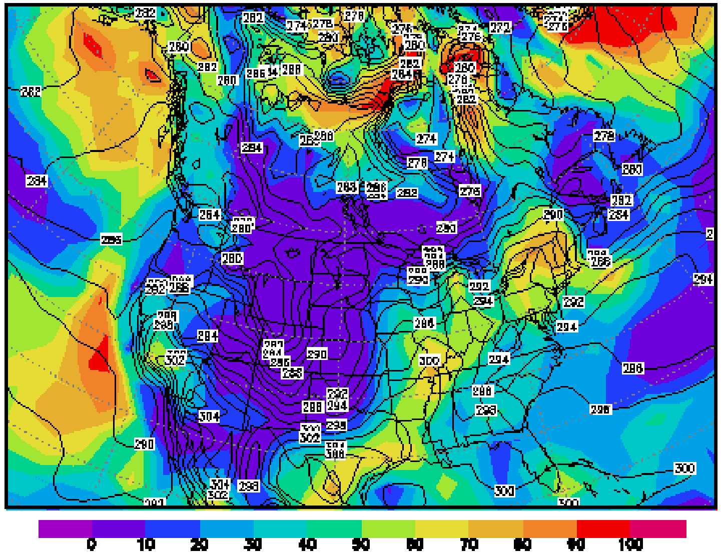
5-day weighted mean



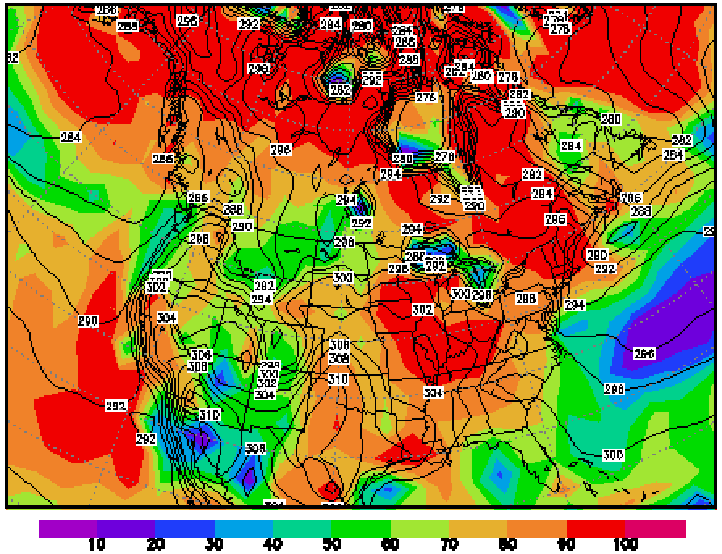
ENSEMBLE 10-, 50- (MEDIAN) & 90-PERCENTILE FORECAST VALUES (BLACK CONTOURS) AND CORRESPONDING CLIMATE PERCENTILES (SHADES OF COLOR)

2–meter temperature 5–day forecast (valid at 06/15/2005)

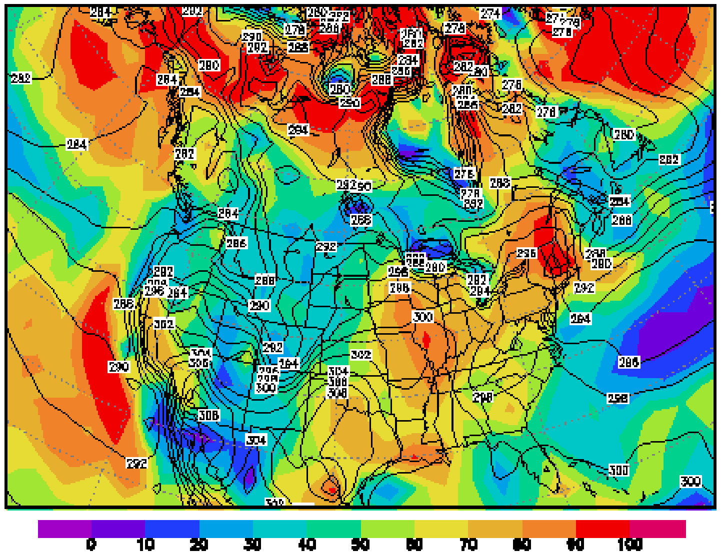
contour – 10% ens prob fcst, shaded – % of climatology



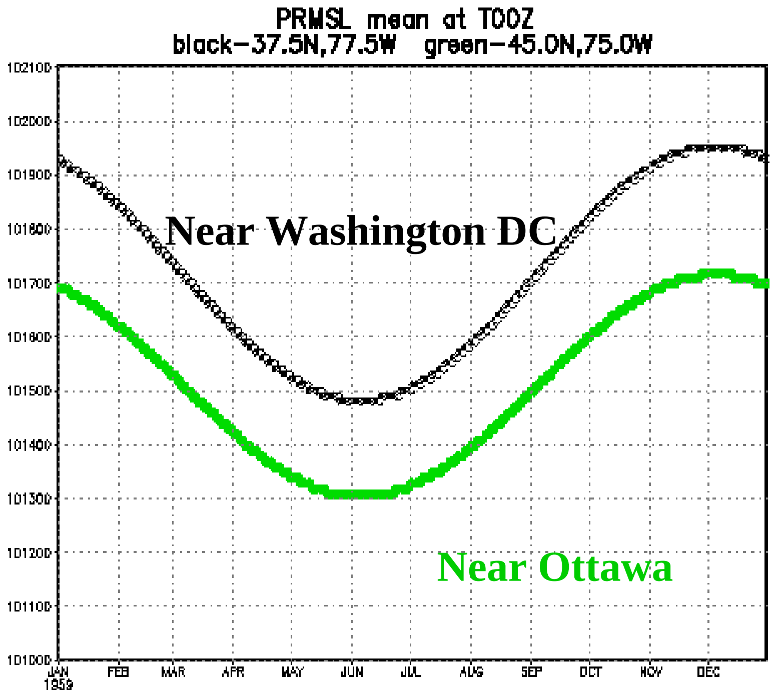
contour – 90% ens prob fcst, shaded – % of climatology

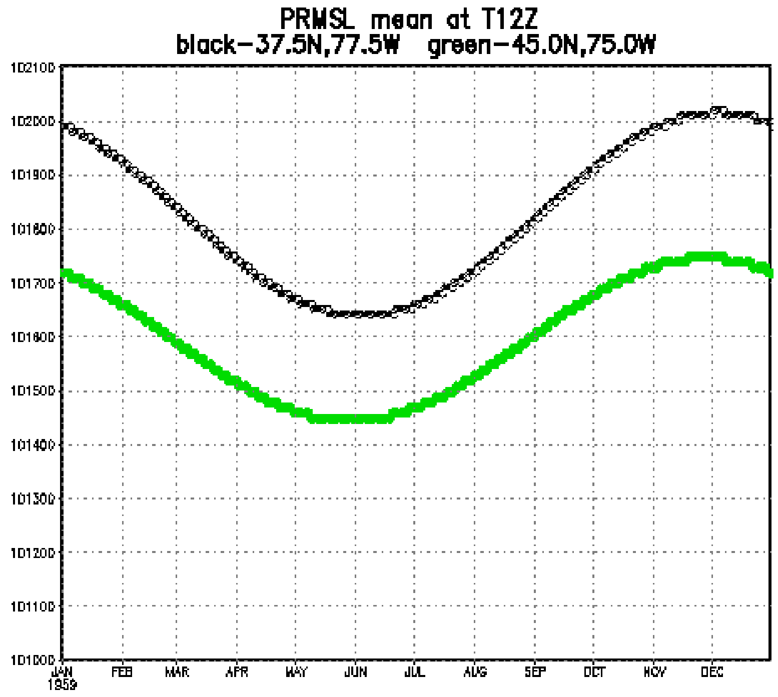


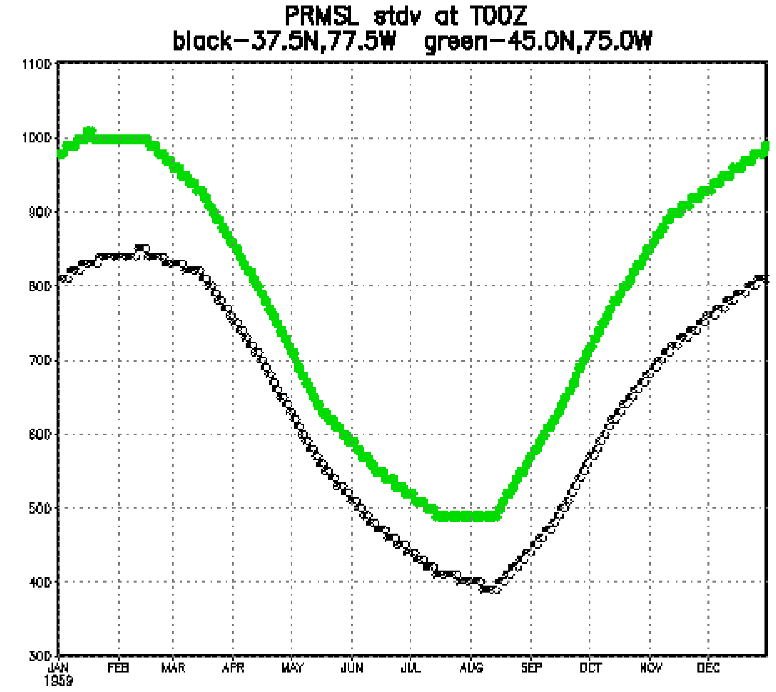
contour – 50% ens prob fcst, shaded – % of climatology

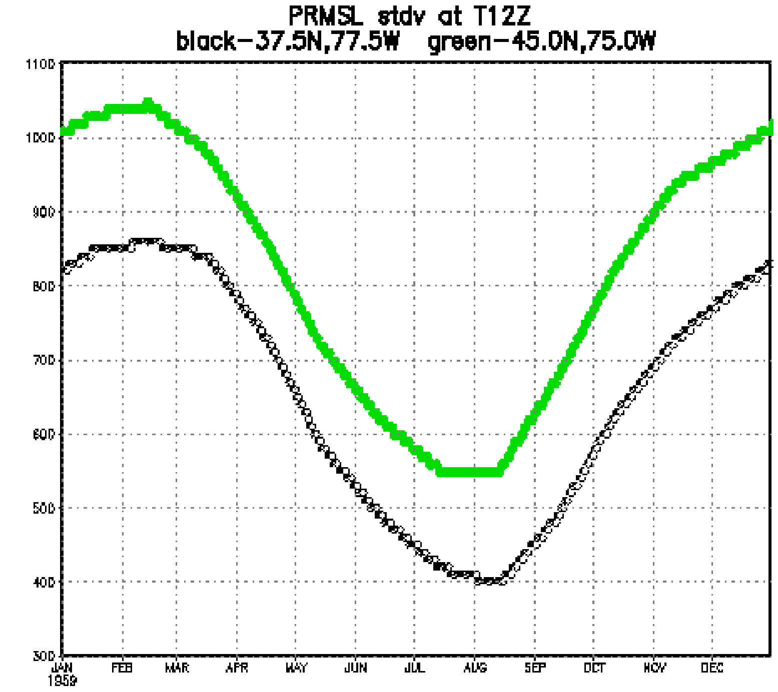


Example of probabilistic forecast in terms of climatology

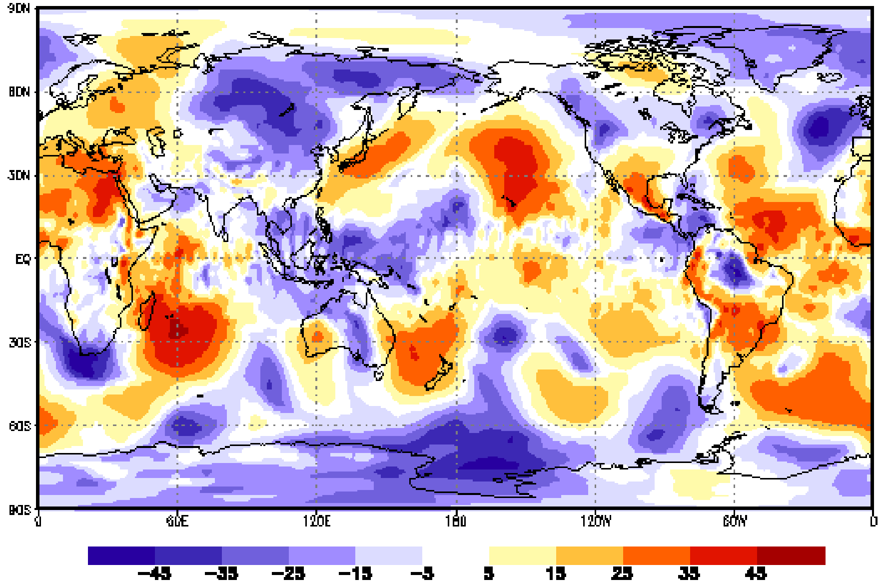

PRMSL mean at T00Z
black-37.5N,77.5W green-45.0N,75.0W
Near Washington DC
Near Ottawa
JAN 1959 FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC


PRMSL mean at T12Z
black-37.5N,77.5W green-45.0N,75.0W
JAN 1959 FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

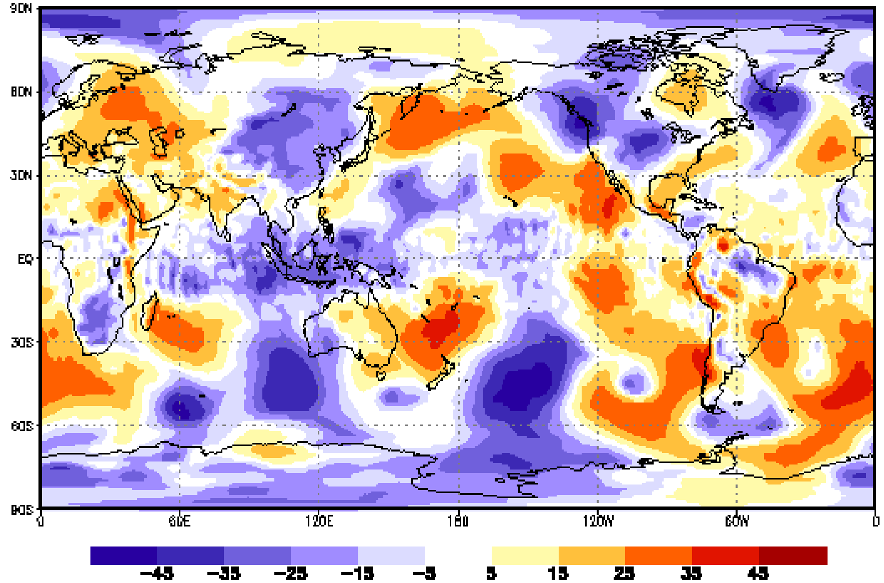

PRMSL stdv at T00Z
black-37.5N,77.5W green-45.0N,75.0W
JAN 1959 FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC


PRMSL stdv at T12Z
black-37.5N,77.5W green-45.0N,75.0W
JAN 1959 FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

PRMSL anomaly forecast (INI:2005110100 FCST: 24h)

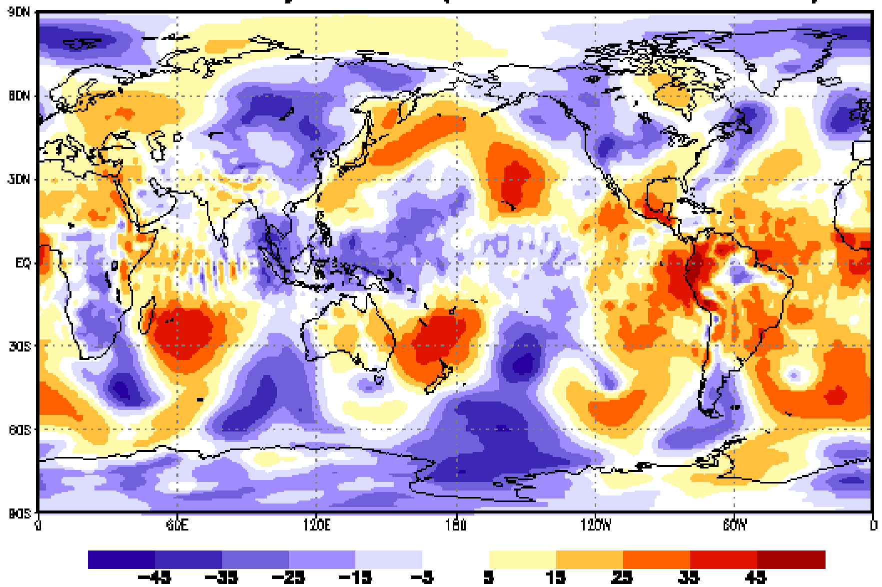


PRMSL anomaly forecast (INI:2005110100 FCST: 72h)

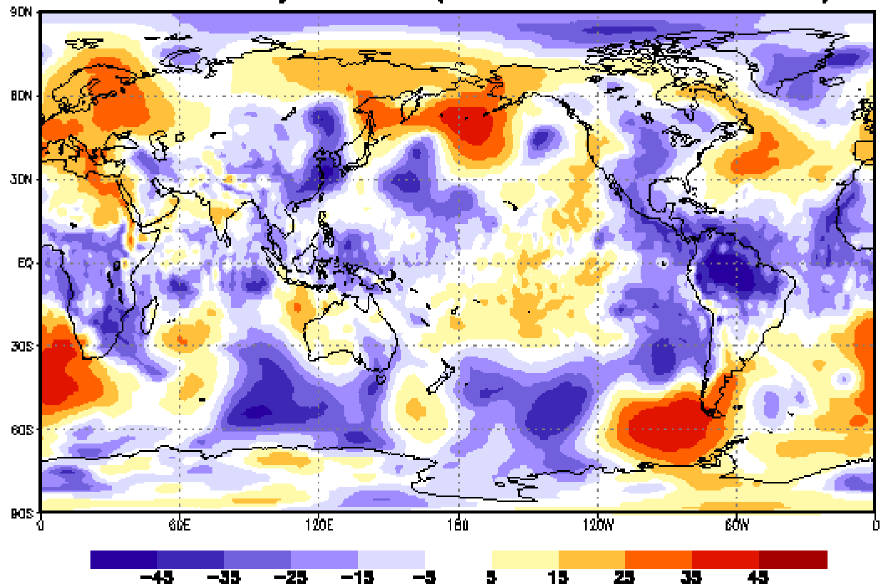


Based on raw forecasts, no climate and current analysis correction

PRMSL anomaly forecast (INI:2005110100 FCST: 48h)



PRMSL anomaly forecast (INI:2005110100 FCST: 120h)



NDGD FORECAST UNCERTAINTY RECOMMENDATION

- Provide 3 ensemble-based guidance products for inclusion in NDGD:
  - 10, 50, and 90 percentile values
    - SREF guidance out to day 3
    - NAEFS guidance out to 16 days
  - Use NDGD grid (5x5 km), with GRIB2 packing, minimal space overhead

- Approach
  - Solicit comments on specific proposal from NCEP Service Centers and regions/field
  - Use NAWIPS software (available soon?) to generate products
    - Work with NAWIPS group to provide algorithm:
      - Simple counting of members with linear interpolation now
      - Gaussian Kernel method in later implementation
  - Factor of 3 increase in disc space
    - D. Ruth positively inclined (WG member at NDFD Workshop)

NDGD FORECAST UNCERTAINTY - DOWNSCALING

- Ensemble uncertainty information
  - Sent on NDGD grid for convenience (if no big overhead)
  - Valid on model grids (32km for regional, 110 km for global ensemble)
  - How to bridge gap between model and NDGD grids?
- Anomaly uncertainty information – proposed methodology
  - Establish reanalysis climatology
    - In progress for global (NAEFS), methods can be transferred to regional reanalysis
  - Bias correct ensemble forecasts (wrt operational analysis)
  - Take 10-50-90 percentile values from bias corrected ensemble
  - (For establishing anomaly forecasts, adjust 10-50-90 percentile values to look like re-analysis)
  - Check climatological percentile corresponding to 10-50-90 forecast percentiles
- Provide climatological percentiles corresponding to 10-50-90 percentile forecast values as second set of guidance products

ENSEMBLE-BASED PRODUCTS FOR NDGD

- National Digital Forecast Database (NDFD)
  - Official NWS forecast, prepared by WFO offices (central guidance, coordination)
  - 5x5 (2.5x2.5) km grid, out to 7 days
  - Selected parameters (~15)
  - Available in digital format, query tools, etc
  - No (minimal) provision for information on forecast uncertainty
    - Recommendations from an NDFD workshop, Salt Lake City, 2003
  - Interactive Forecast Preparation System (IFPS) offers tools to work with NDFD grids (forecasters can manipulate gridded data, etc)
- National Digital Guidance Database (NDGD)
  - For posting numerical guidance products same way as NDFD
  - New system, possibility to complement NDFD with forecast uncertainty info
    - Based on global (NAEFS) and regional ensemble forecasts
- What forecast uncertainty info to post in NDGD?

NAWIPS grids data, graphic and GIF images

- Mean of selected members
  - Z500, z700, z850
- Spread of selected members
  - U10m, V10m
- Exceeding probabilities for selected threshold values
  - 10m wind speed: thresh 20, 34, 50, and 64 kts
  - Significant wave height at various values
- Spaghetti plots
  - Height: 200hPa, 300hPa and 500hPa
  - Psml
  - T2m: 0c isotherm
  - QPF: 0.01”, 0.25”, 0.5”, 1.0”, 2.0”, 3.0” and 4.0” (for 6-h and 24-h)
  - Snow: 1”, 2”, 4”, 6”, 8”, 12”, 18”, 24” (for 6-h and 24-h)
  - Freezing rain: 0.01”, 0.1”, 0.25”, 0.5”, 1.0” (for 6-h and 24-h)

END

THANKS!!!

Products (plan)

- Based on 4 different considerations
- Assuming the normal distributions of the 40 years climate data
  - PDF will be presented by first two moments (mean and standard deviation)
- Considering the differences between reanalysis and current GDAS
- Using bias corrected forecasts
- To calculate climate anomaly:
  - For 1x1 degree grid point globally.
  - For all 19 variables.
  - For each ensemble member.
  - In percentile (0-100%, 50%=normal).

Discussion

- How many modes we need to consider?
  - In general, more modes will be better
  - First two modes are enough for the heights
  - Surface variables and winds are challenging
- Are all variables normally distributed?
  - Depends on variables and geographical locations (?)
  - Most of them are quasi-normally distributed
    - Examples of 2-meter temperature and 10-meter u
    - Monthly distribution of 500hPa height has a little seasonal tilt
- Examples of time series for daily mean and standard deviation
  - Two physical locations (near Washington DC and Ottawa)
  - Are these plots enough to evaluate methods?
  - http://wwwt.emc.ncep.noaa.gov/gmb/yzhu/html/CLIMATE_ANOMALY.html

Ensemble Mean and Spread from Wave Ensemble

- For Significant Wave Height