Global Ensemble Forecast System

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December 15 2011

Highlights

- Why do we need ensemble?
- Ensemble initialization and cycling
- Stochastic physics
- Tropical storm relocation
- Multi-model ensemble application – NAEFS
- Future plan

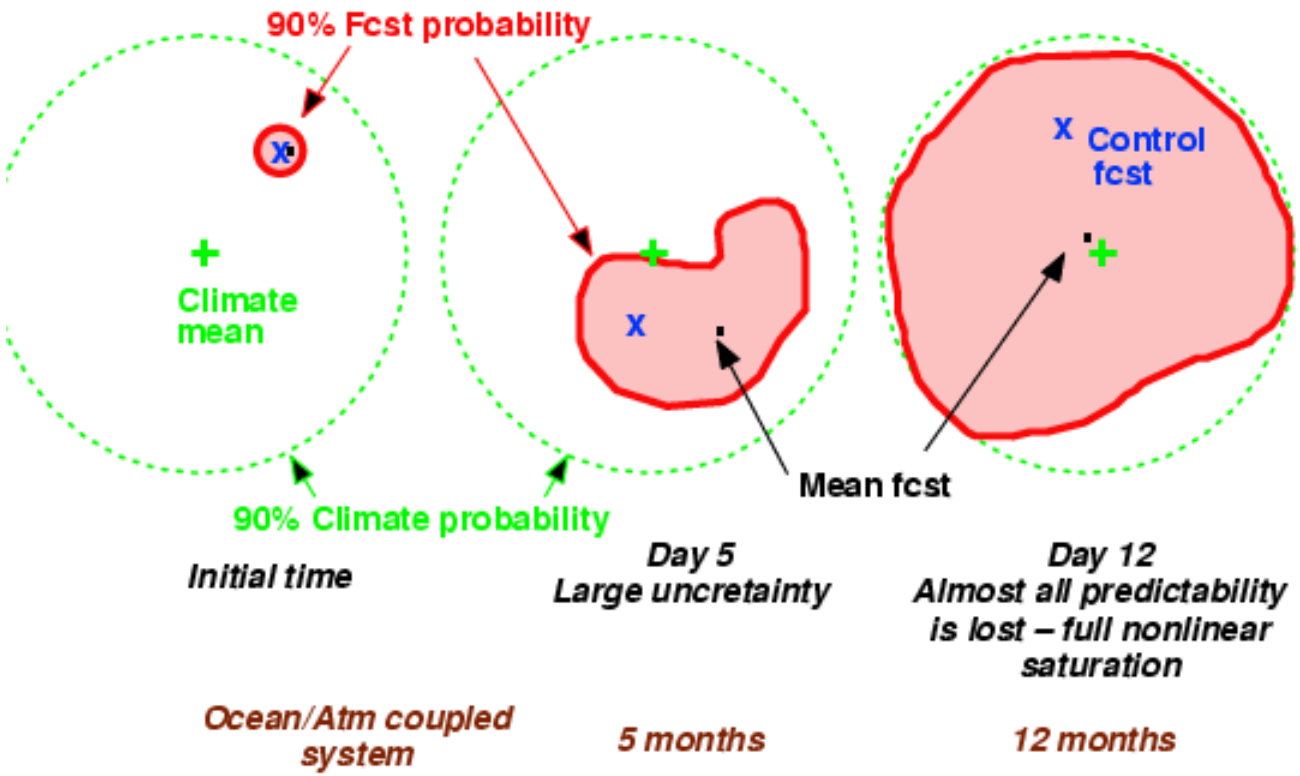
Scientific Needs – Ensemble forecast System Describe Forecast Uncertainty Arising Due To Chaos

ORIGIN OF FORECAST UNCERTAINTY

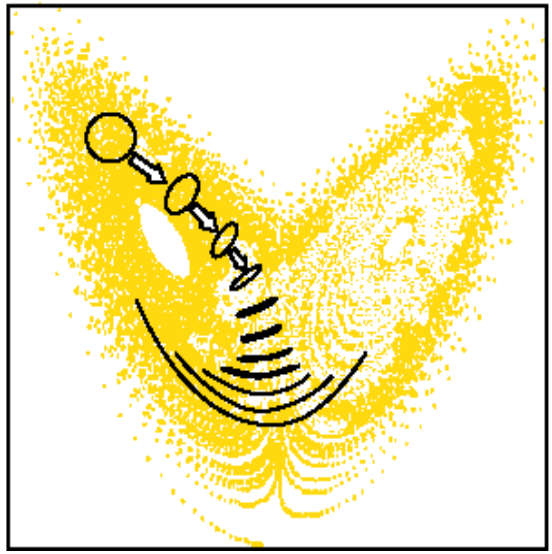
1) The atmosphere is a **deterministic system** *AND* has at least one direction in which **perturbations grow**

2) **Initial** state (and model) has **error** in it ==>

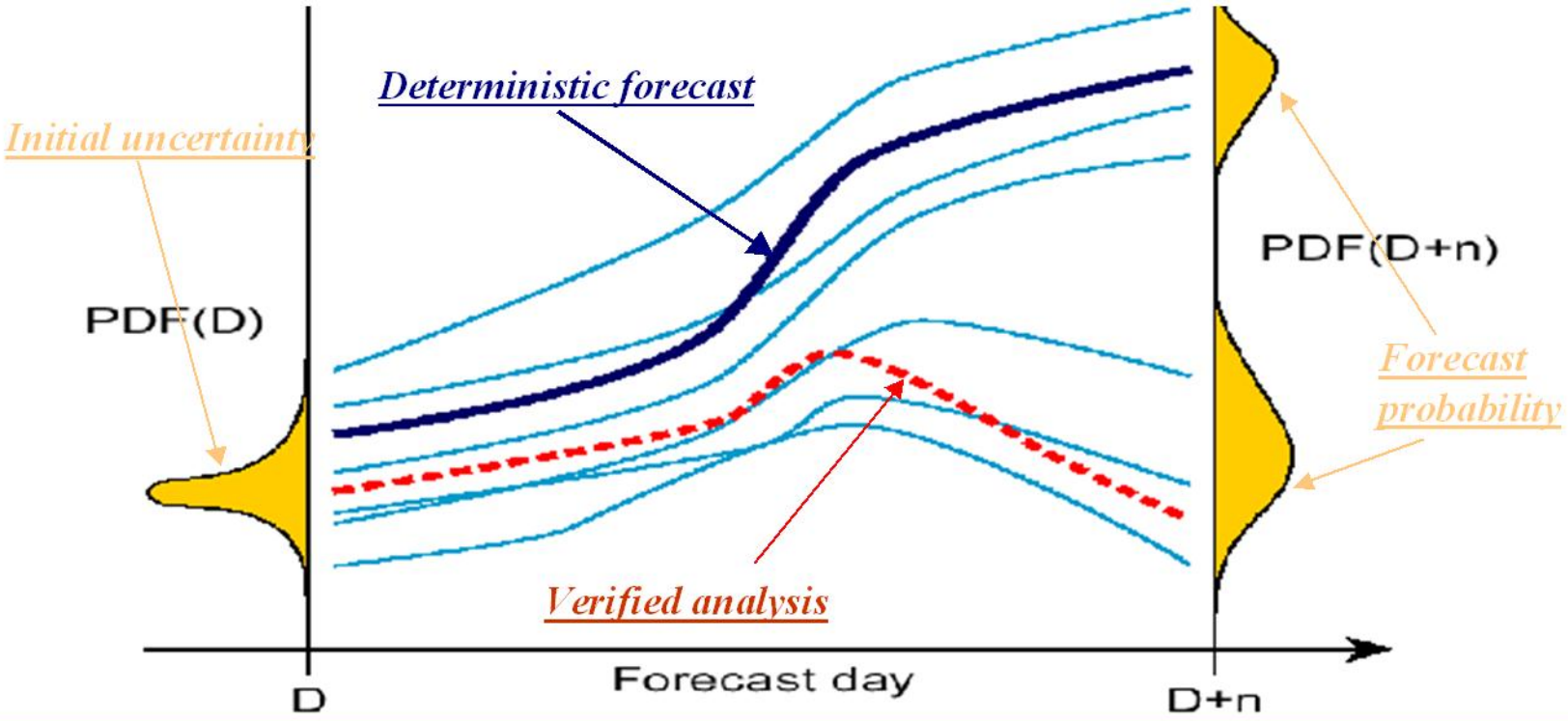
Chaotic system + Initial error =(Loss of) Predictability



Buizza 2002



What is the difference of deterministic and ensemble forecast?



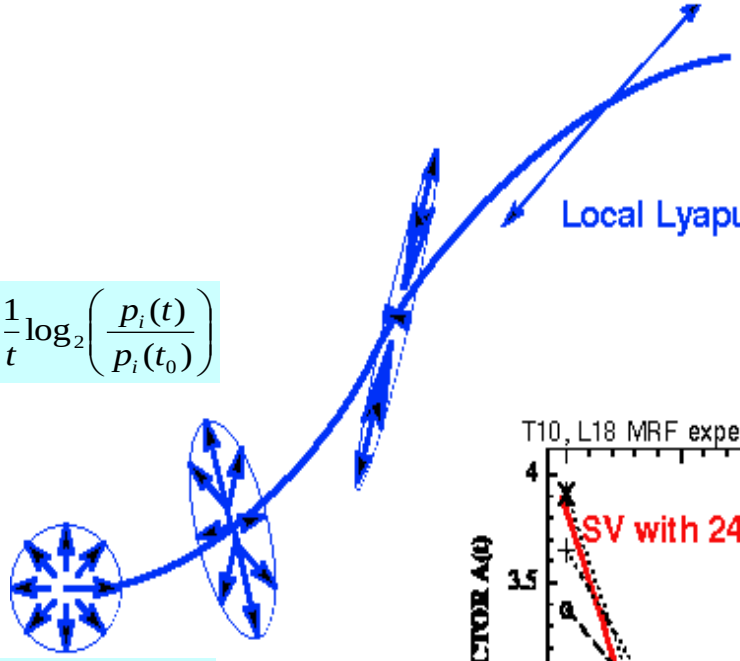
Schematic of Stochastic Prediction: The initial probability PDF(D) represents the initial uncertainties. From the best estimate of the initial state a single deterministic forecast (blue solid curve) is performed. This single deterministic forecast fails to predict correctly the future state (red dotted curve). An ensemble of perturbed forecasts (thin blue solid curves) starting from perturbed initial conditions designed to sample the initial un- certainties can be used to estimate the probability PDF(D+n) at future time, D+n.

Ensemble initializations and cycling

LYAPUNOV, SINGULAR, AND BRED VECTORS

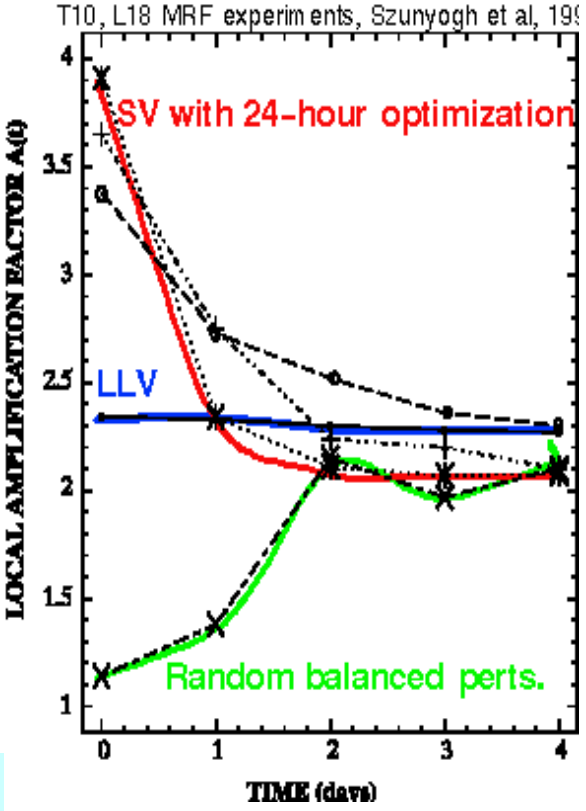
- **LYAPUNOV VECTORS (LLV):**
  - Linear perturbation evolution
  - Fast growth
  - Sustainable
  - Norm independent
  - Spectrum of LLVs
- **SINGULAR VECTORS (SV):**
  - Linear perturbation evolution
  - Fastest growth
  - Transitional (optimized)
  - Norm dependent
  - Spectrum of SVs
- **BRED VECTORS (BV):**
  - Nonlinear perturbation evolution
  - Fast growth
  - Sustainable
  - Norm independent
  - Can orthogonal (Boffeta et al)

$$\lambda_i = \lim_{t=\infty} \frac{1}{t} \log_2 \left(\frac{p_i(t)}{p_i(t_0)} \right)$$



$$\|x(t)\|^2 = < L^* E\ L\ x_0; x_0 >$$

$$\frac{dv}{dt} = av(1-v)$$



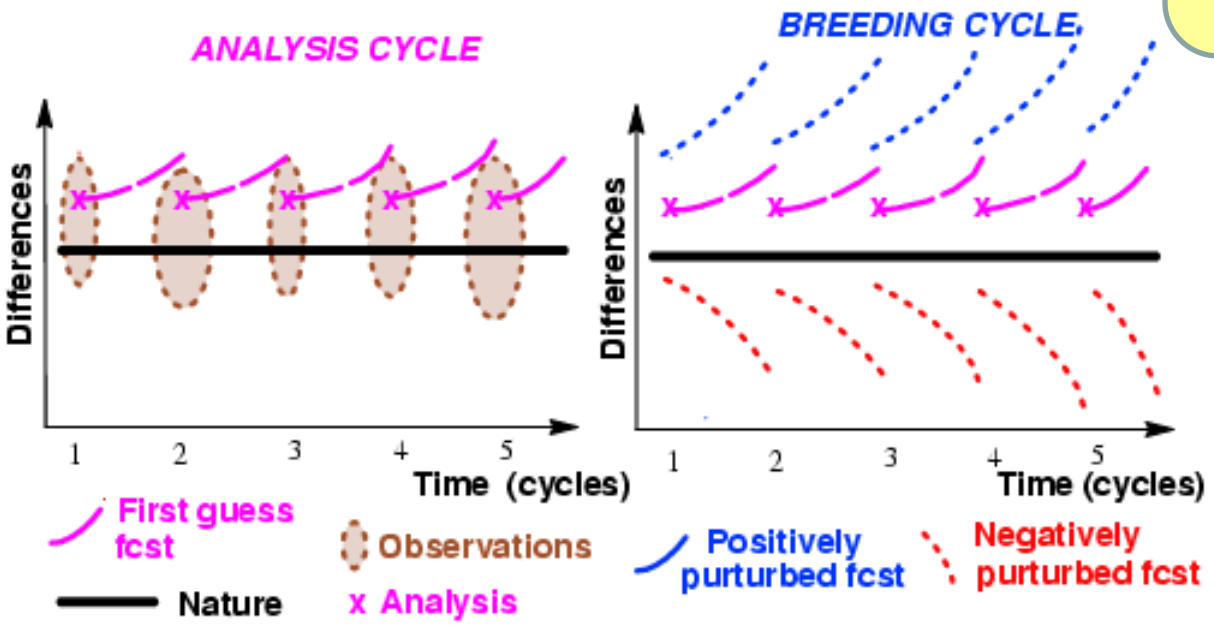
Courtesy of Zoltan Toth

ESTIMATING AND SAMPLING INITIAL ERRORS: THE BREEDING METHOD – 1992 at NCEP

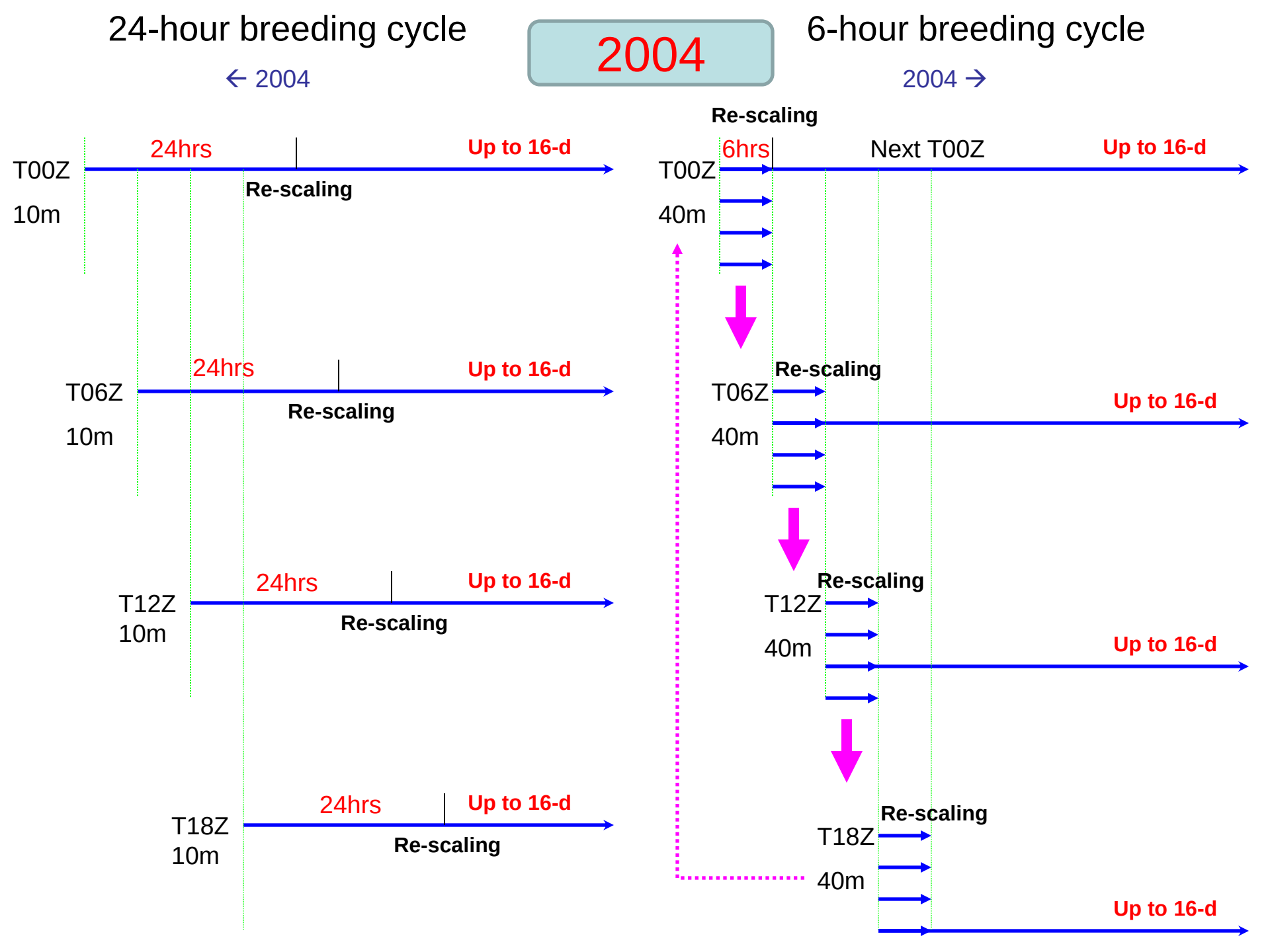
- **DATA ASSIM:** Growing errors due to cycling through NWP forecasts
- **BREEDING:** - Simulate effect of obs by rescaling nonlinear perturbations
  - Sample subspace of most rapidly growing analysis errors
    - Extension of linear concept of Lyapunov Vectors into nonlinear environment
    - Fastest growing nonlinear perturbations
    - Not optimized for future growth –
      - Norm independent
      - Is non-modal behavior important?

References

1. Toth and Kalnay: 1993 BAMS
2. Tracton and Kalnay: 1993 WAF



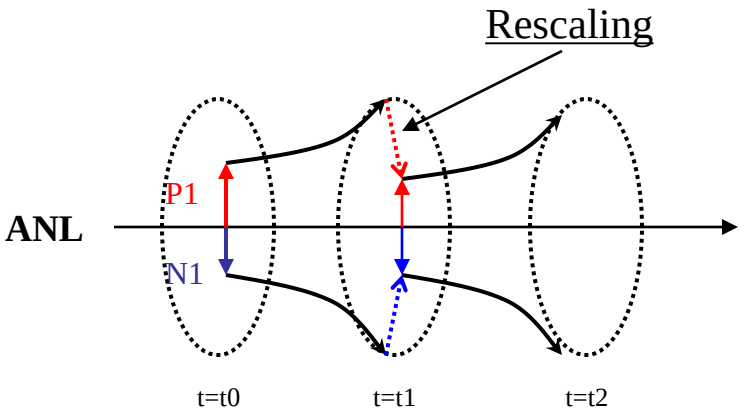
Courtesy of Zoltan Toth

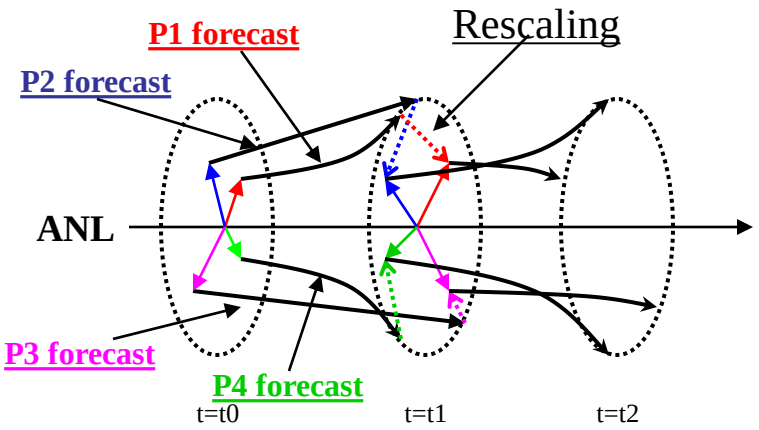

24-hour breeding cycle
← 2004
2004
6-hour breeding cycle
2004 →
T00Z
10m
24hrs
Up to 16-d
Re-scaling
T06Z
10m
24hrs
Up to 16-d
Re-scaling
T12Z
10m
24hrs
Up to 16-d
Re-scaling
T18Z
10m
24hrs
Up to 16-d
Re-scaling
Re-scaling
T00Z
40m
6hrs
Next T00Z
Up to 16-d
Re-scaling
T06Z
40m
Up to 16-d
Re-scaling
T12Z
40m
Up to 16-d
Re-scaling
T18Z
40m
Up to 16-d

Bred Vector (←2006)

Ensemble Transform with Rescaling (2006 →)

2006 at NCEP

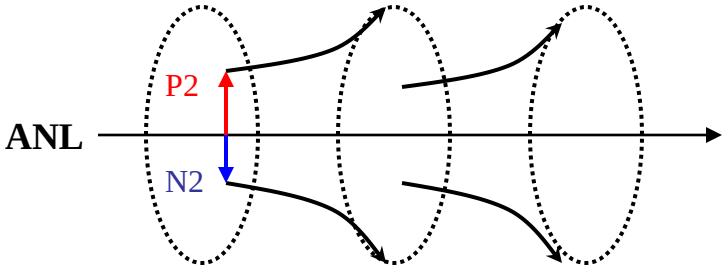




P#, N# are the pairs of positive and negative

P1 and P2 are independent vectors

Simple scaling down (no direction change)



P1, P2, P3, P4 are orthogonal vectors

No pairs any more

To centralize all perturbed vectors (sum of all vectors are equal to zero)

Scaling down by applying mask,

The direction of vectors will be tuned by ET.

References:

1. Wei and et al: 2006 Tellus
2. Wei and et al: 2008 Tellus

Stochastic Physics

-Ensemble Stochastic Total Tendency Perturbation (STTP) Scheme at NCEP

Ensemble Stochastic Total Tendency Perturbation (STTP) Scheme (*Hou, Toth and Zhu, 2006*)

NCEP operation – Feb. 2010

Formulation:

$$\frac{\partial X_i}{\partial t} = T_i(X_i;t) + \gamma \sum_{j=1,\ldots,N} w_{i,j} T_j(X_j;t)$$

Simplification: Use finite difference form for the stochastic term

Modify the model state every 6 hours:

$$X_i^{'} = X_i + \gamma \sum_{j=1}^{N} w_{i,j}(t)\left\{\left[\left(X_j\right)_t - \left(X_j\right)_{t-6h}\right] - \left[\left(X_0\right)_t - \left(X_0\right)_{t-6h}\right]\right\}$$

Where w is an evolving combination matrix, and γ is a rescaling factor.

Reference:

1. Hou and et al: 2008 AMS conference extended paper
2. Hou and et al: 2010 in review of Tellus

Stochastic Total Tendency Perturbation (STTP) Scheme Application

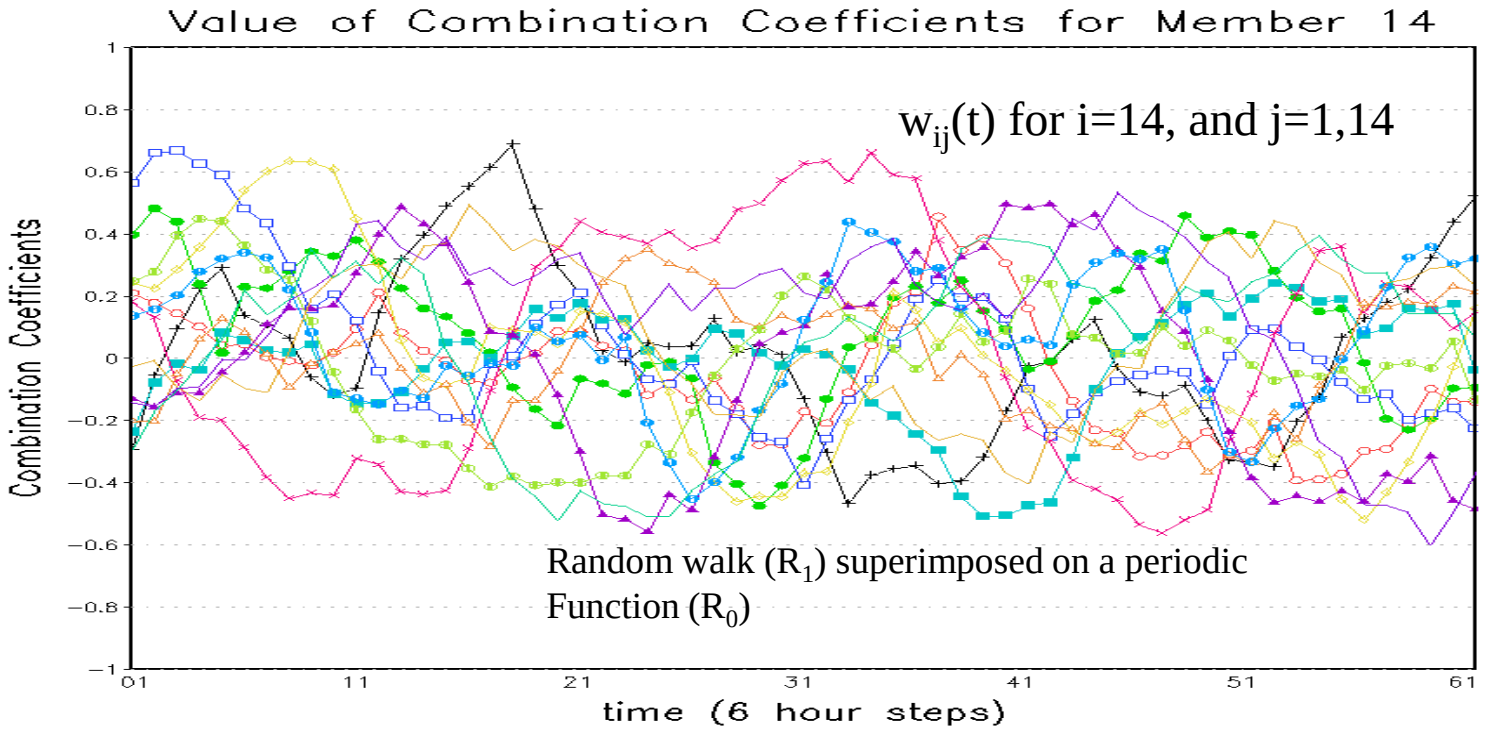
Generation of Stochastic combination coefficients:

- **Matrix Notation** (N forecasts at M points)

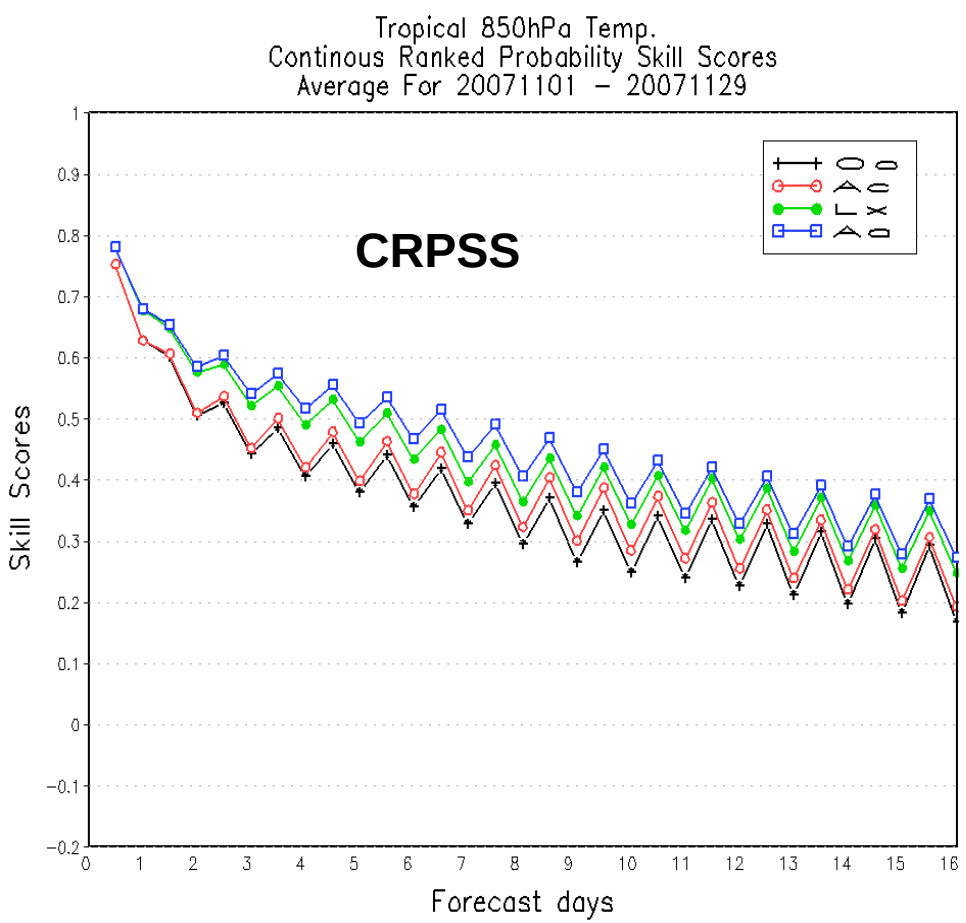
  S (t) = P(t) W(t)

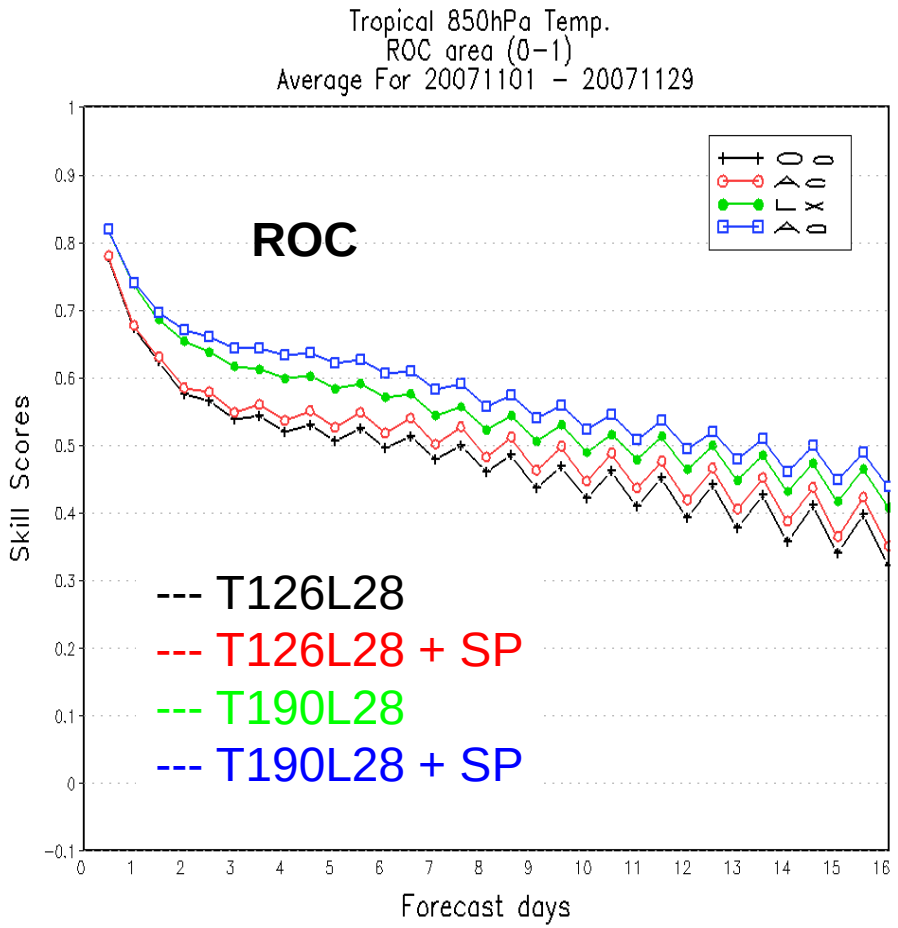
  MxN MxN NxN

- As P is quasi orthogonal, an orthonormal matrix W ensures orthogonality for S.
- **Generation of W matrix:** (**Methodology and software provided by James Purser**).
  - a) Start with a random but orthonormalized matrix W(t=0);
  - b) $W(t)=W(t-1)\ R_0\ R_1(t)$
- R_0, R(t) represent random but slight rotation in N-Dimensional space



Experiments for 2009 Operational Implementation
T126L28 vs. T190L28 resolution, Nov. 2007 Cases
SPS works with both resolutions

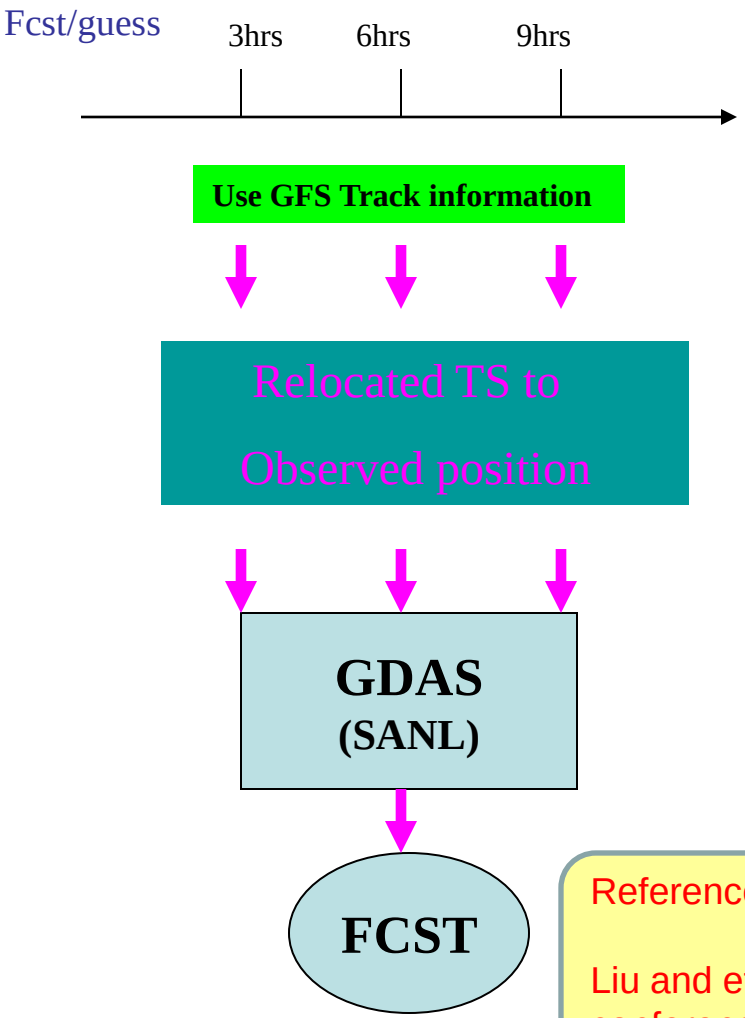




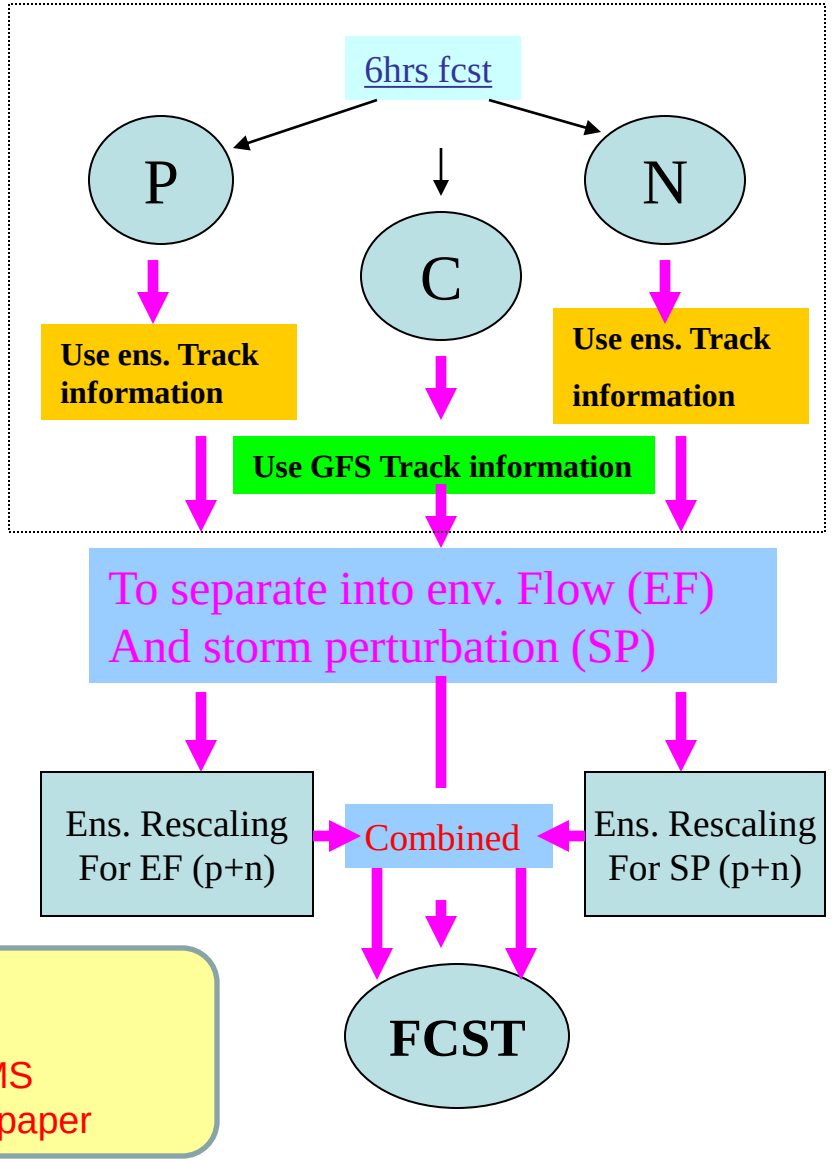
Ensemble tropical storm relocation

2005

GFS TS relocation



Ensemble TS relocation

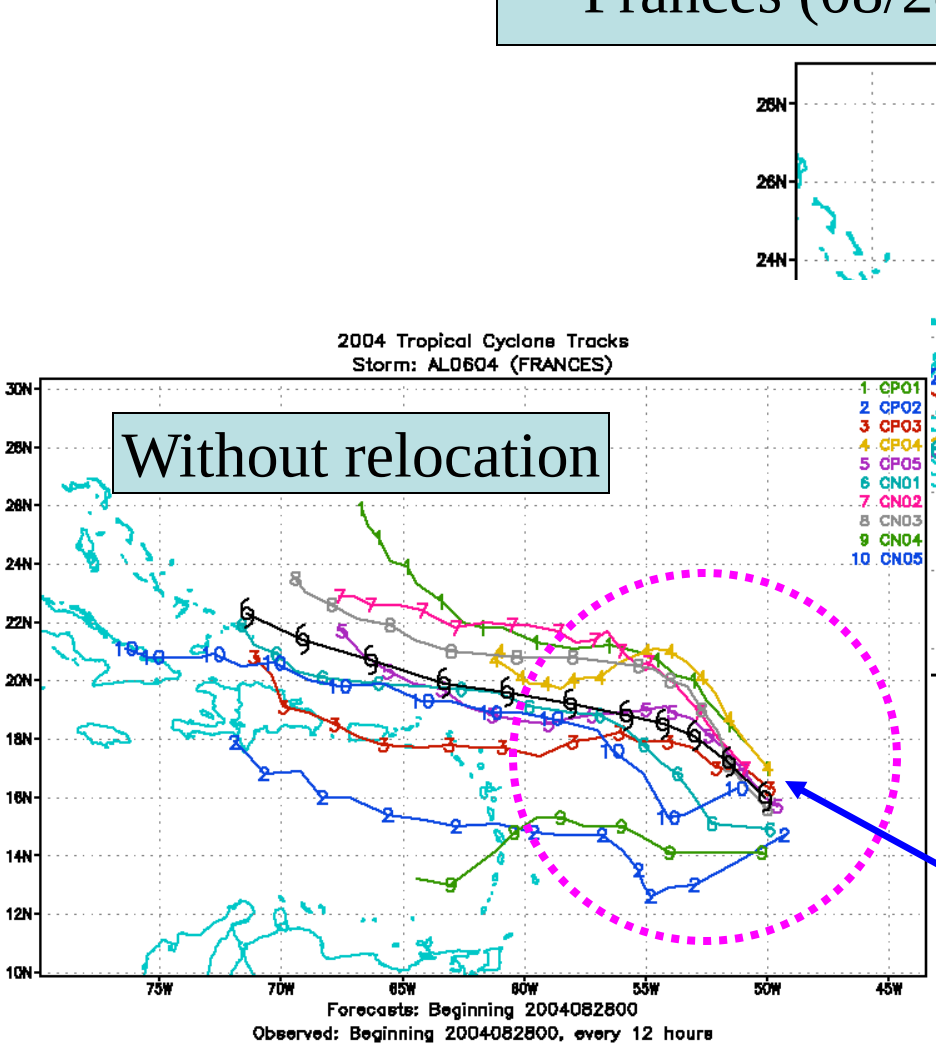


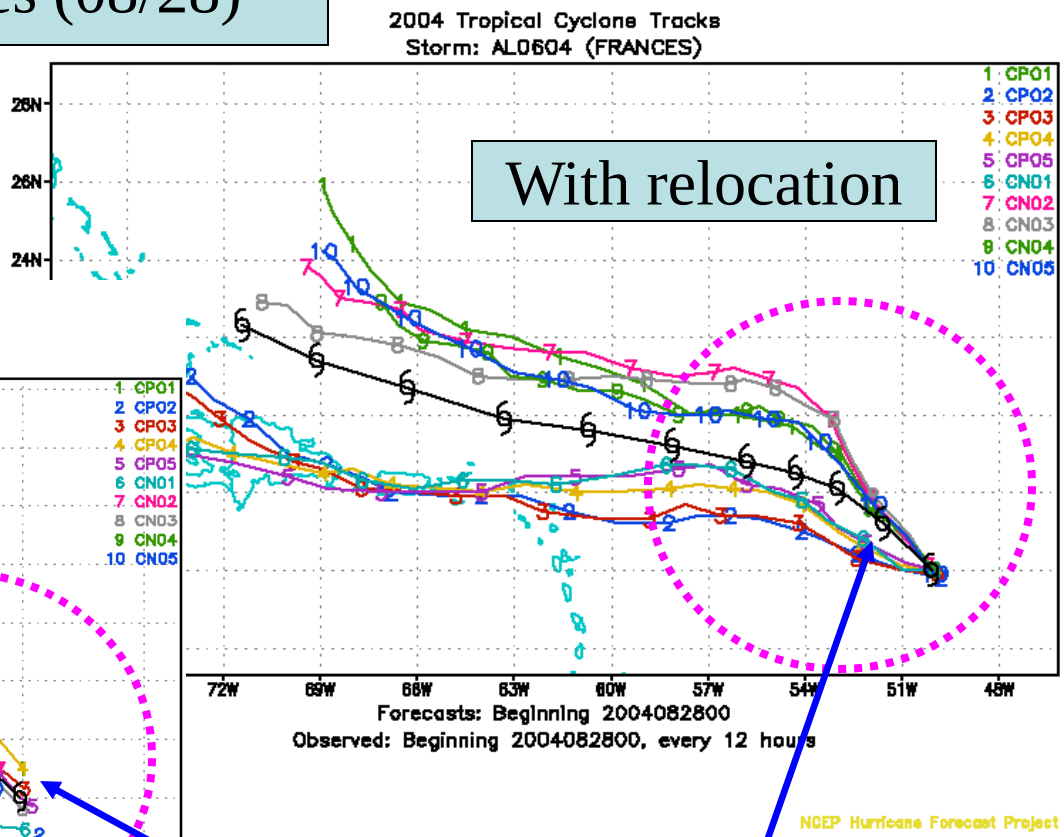
Reference:

Liu and et al: 2006 AMS conference extended paper

Hurricane Track Plots (case 1)

Frances (08/28)



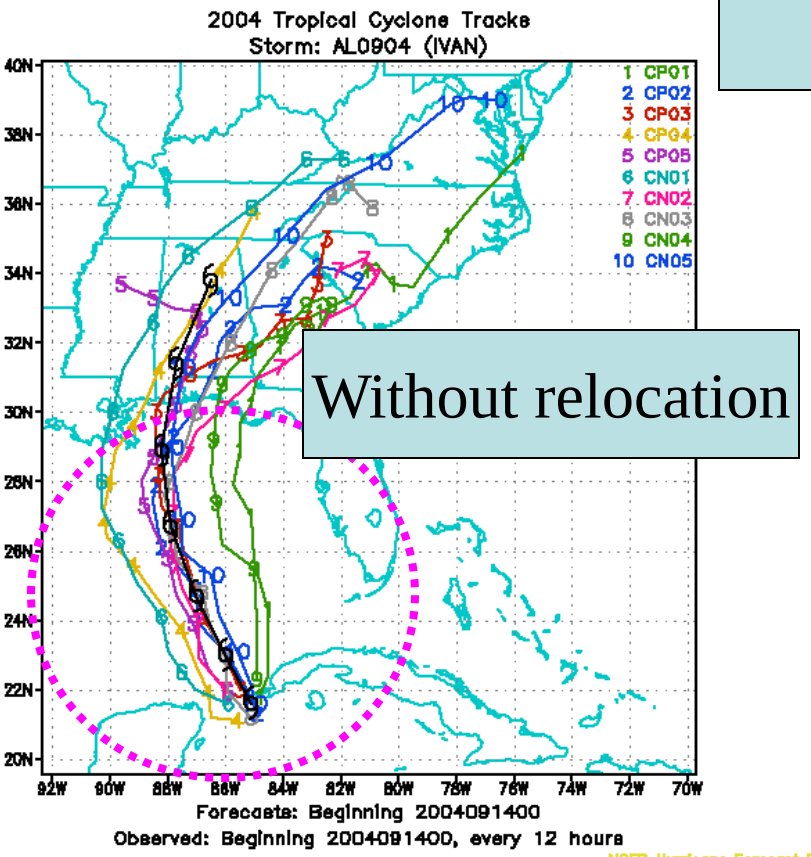


Reduced initial spread

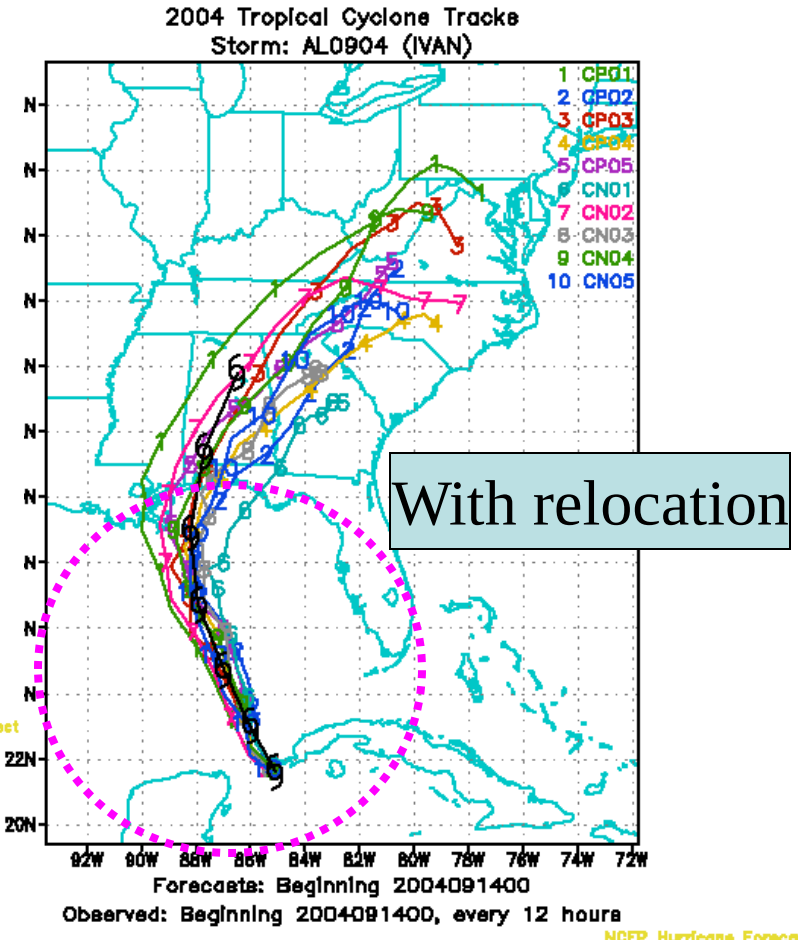
Large initial spread

Hurricane Tracks Plots (case 2)

Ivan (09/14)



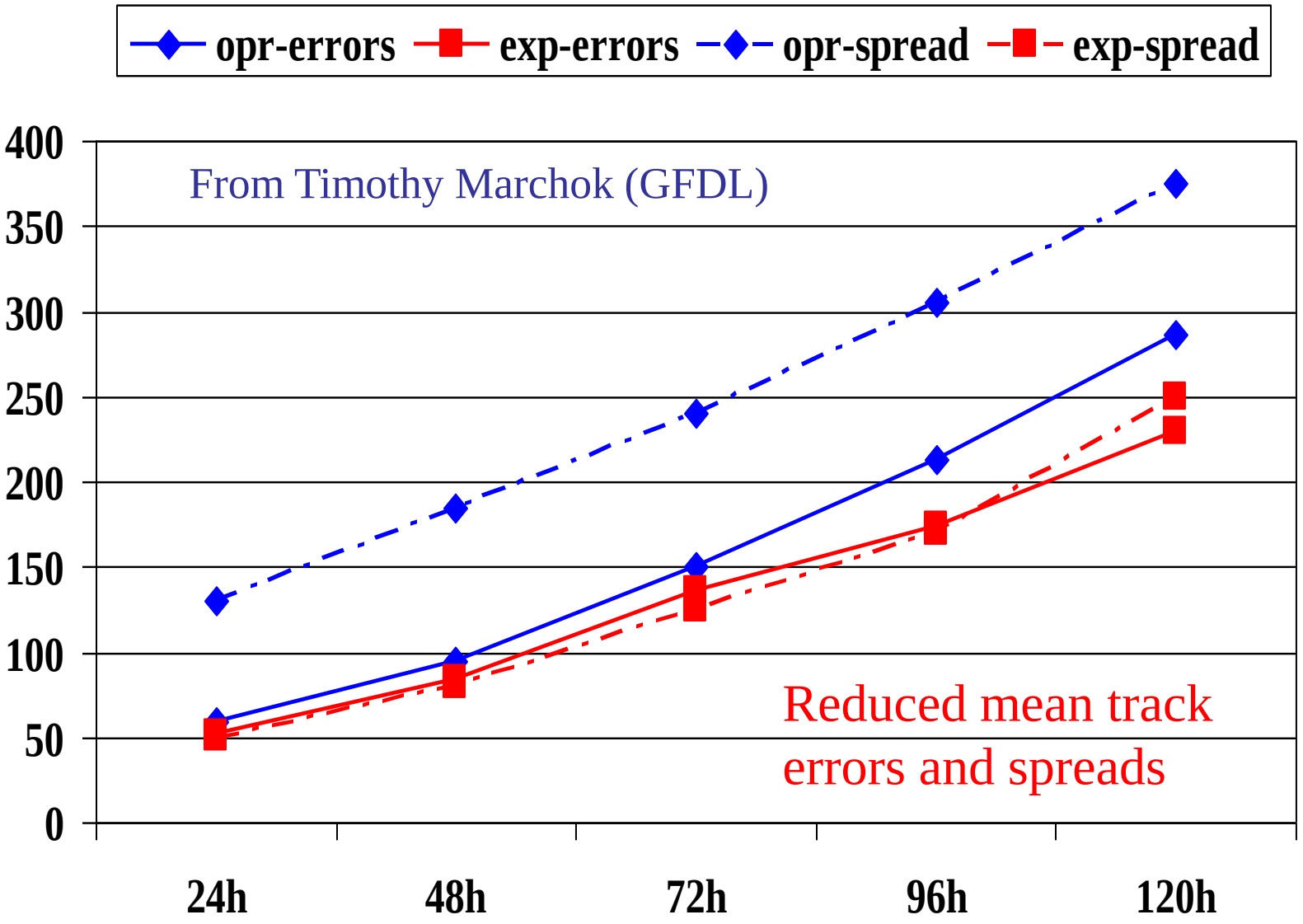
Without relocation



With relocation

Track errors and spreads

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

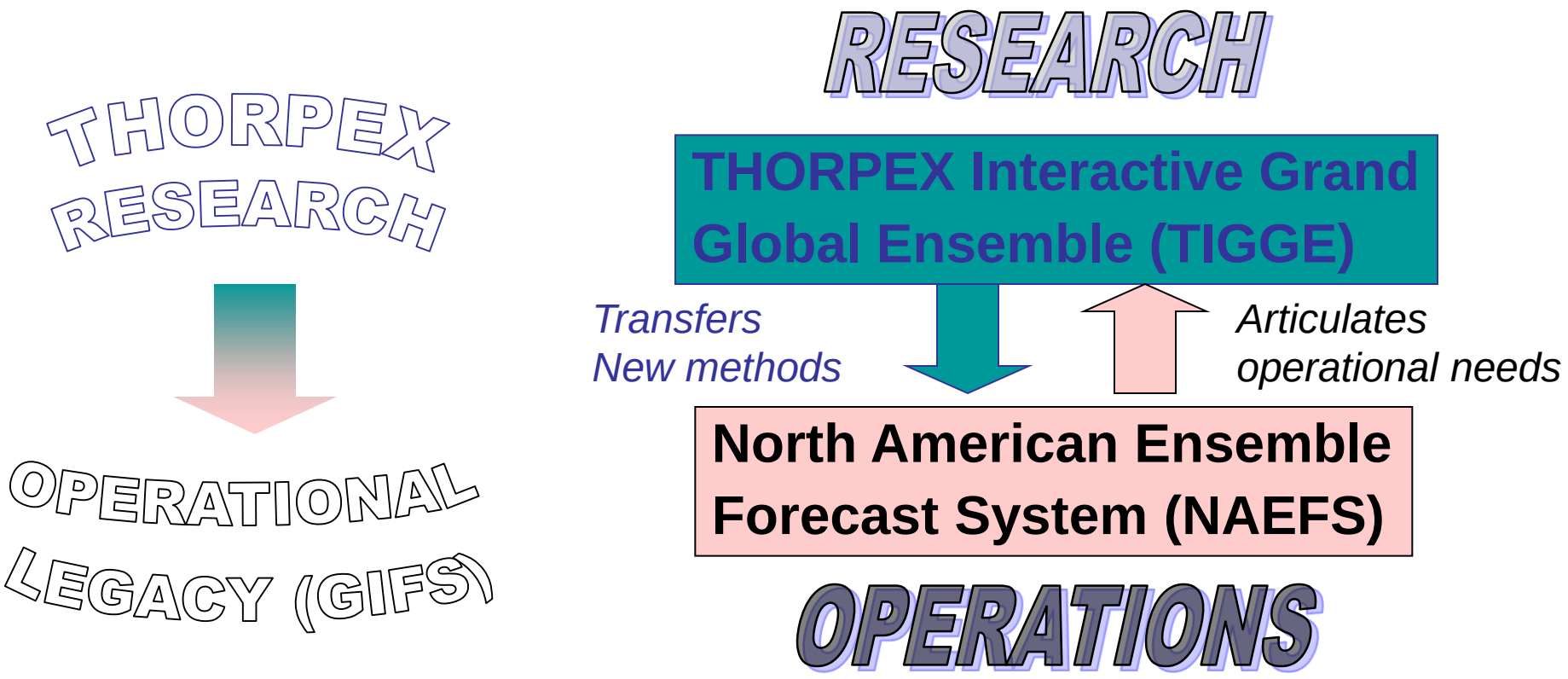


NAEFS and post process

Multi-model ensembles

NAEFS & THORPEX

- Expands international collaboration
  - Mexico joined in November 2004
  - FNMOC joined in January 2011
  - KMA may join in the future
- Provides framework for transitioning research into operations
  - Prototype for ensemble component of THORPEX legacy forecast system:
    Global Interactive Forecast System (GIFS)

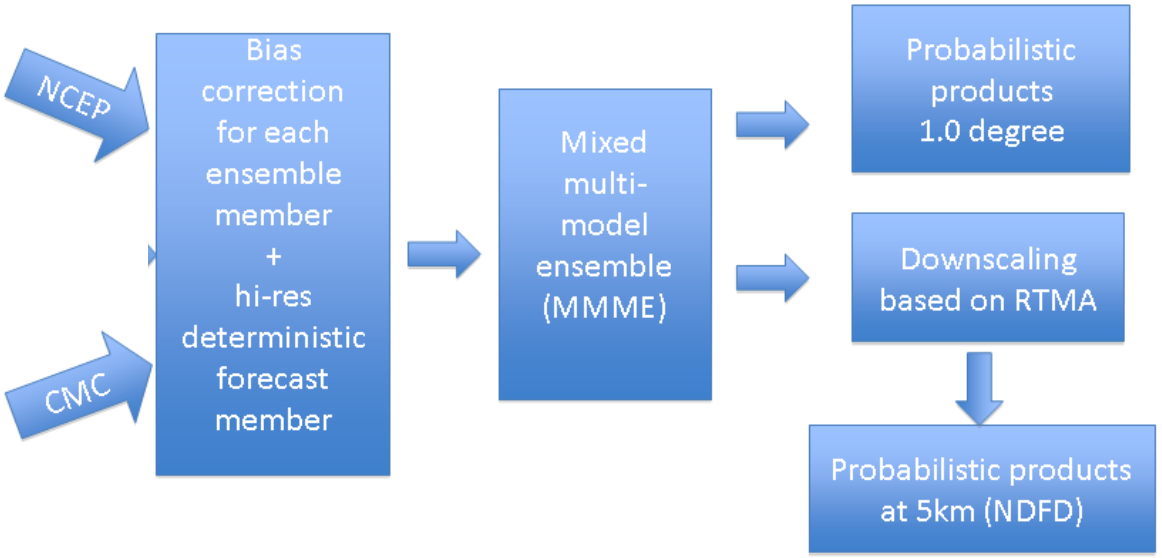


NAEFS/NUOPC Configuration

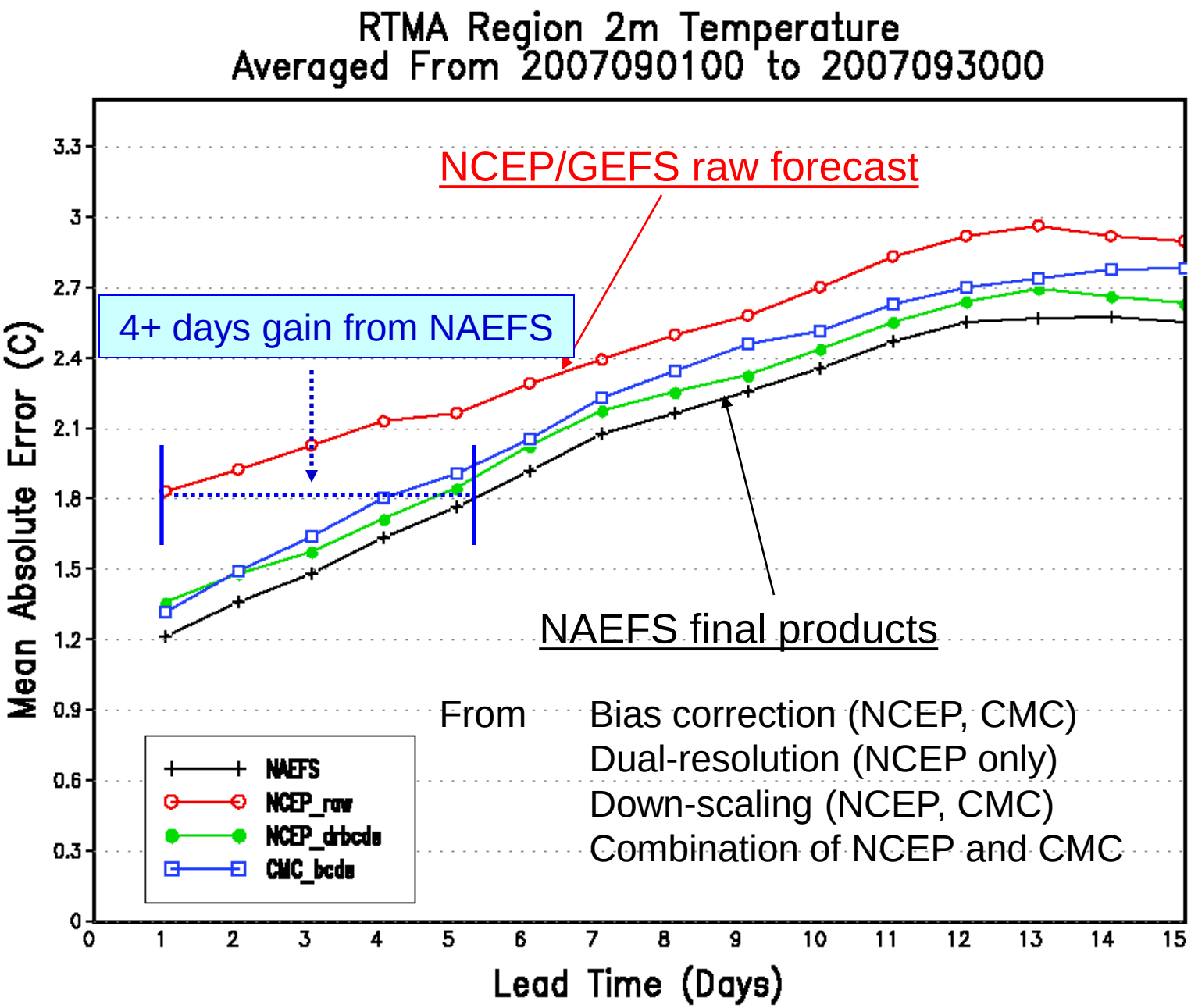
Updated: September 14 2011

	NCEP	CMC	FNMOC
Model	GFS	GEM	Global Spectrum
Initial uncertainty	ETR	EnKF	(9) Banded ET
Model uncertainty Stochastic	Yes (STTP)	Yes (multi-physics)	None
Tropical storm	Relocation	None	None
Daily frequency	00,06,12 and 18UTC	00 and 12UTC	00 and 12UTC
Resolution	T190L28 ~70km	L40 ~ 66km	T159L42 ~ 80km
Control	Yes	Yes	No
Ensemble members	20 for each cycle	20 for each cycle	20 for each cycle
Forecast length	16 days (384 hours)	16 days (384 hours)	16 days (384 hours)
Post-process	Bias correction for ensemble mean	Bias correction for each member	Bias correction for member mean
Last implementation	February 23rd 2010	August 17th 2011	September 14 2011

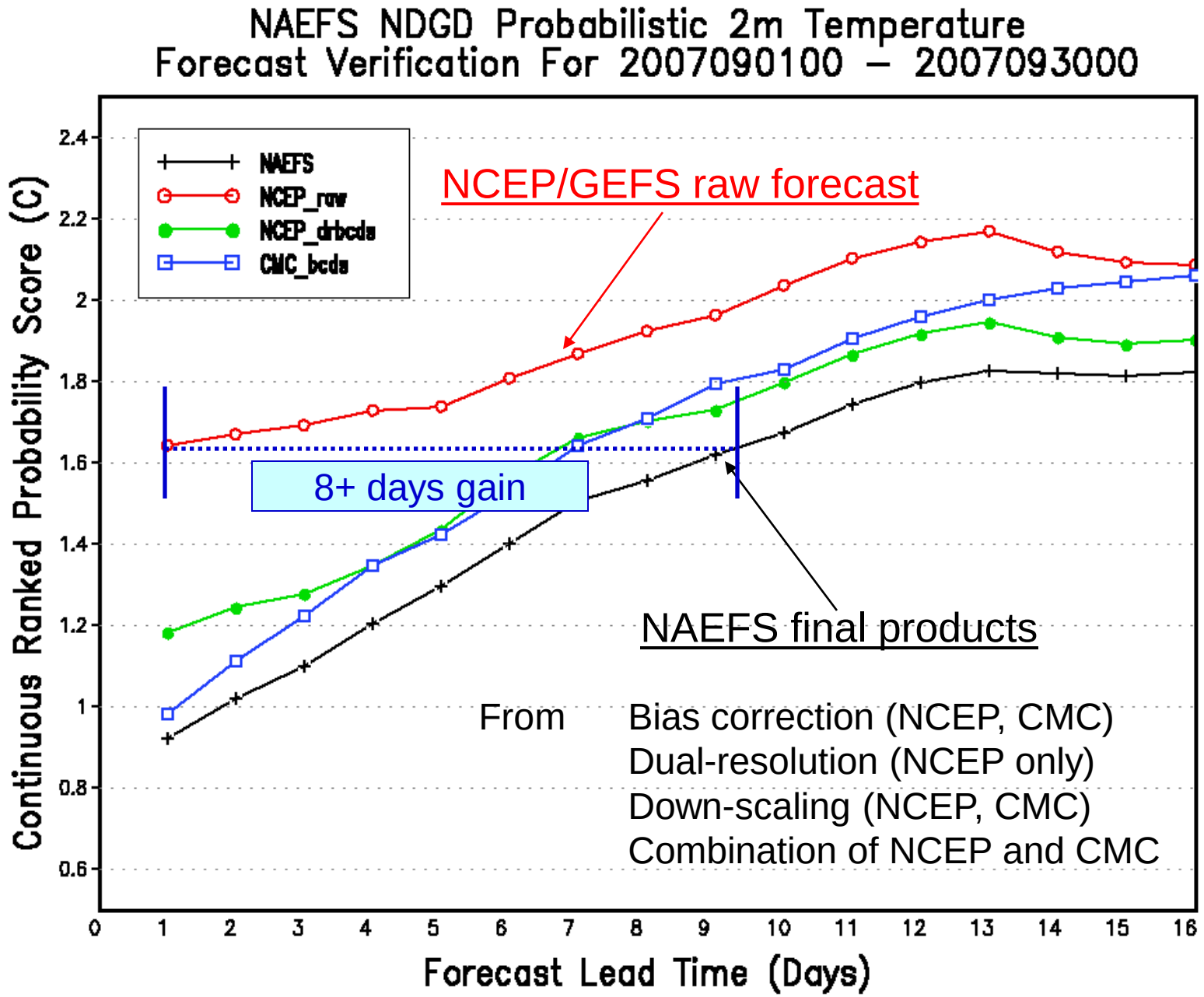
Current NCEP/EMC Statistical Post-Processing System



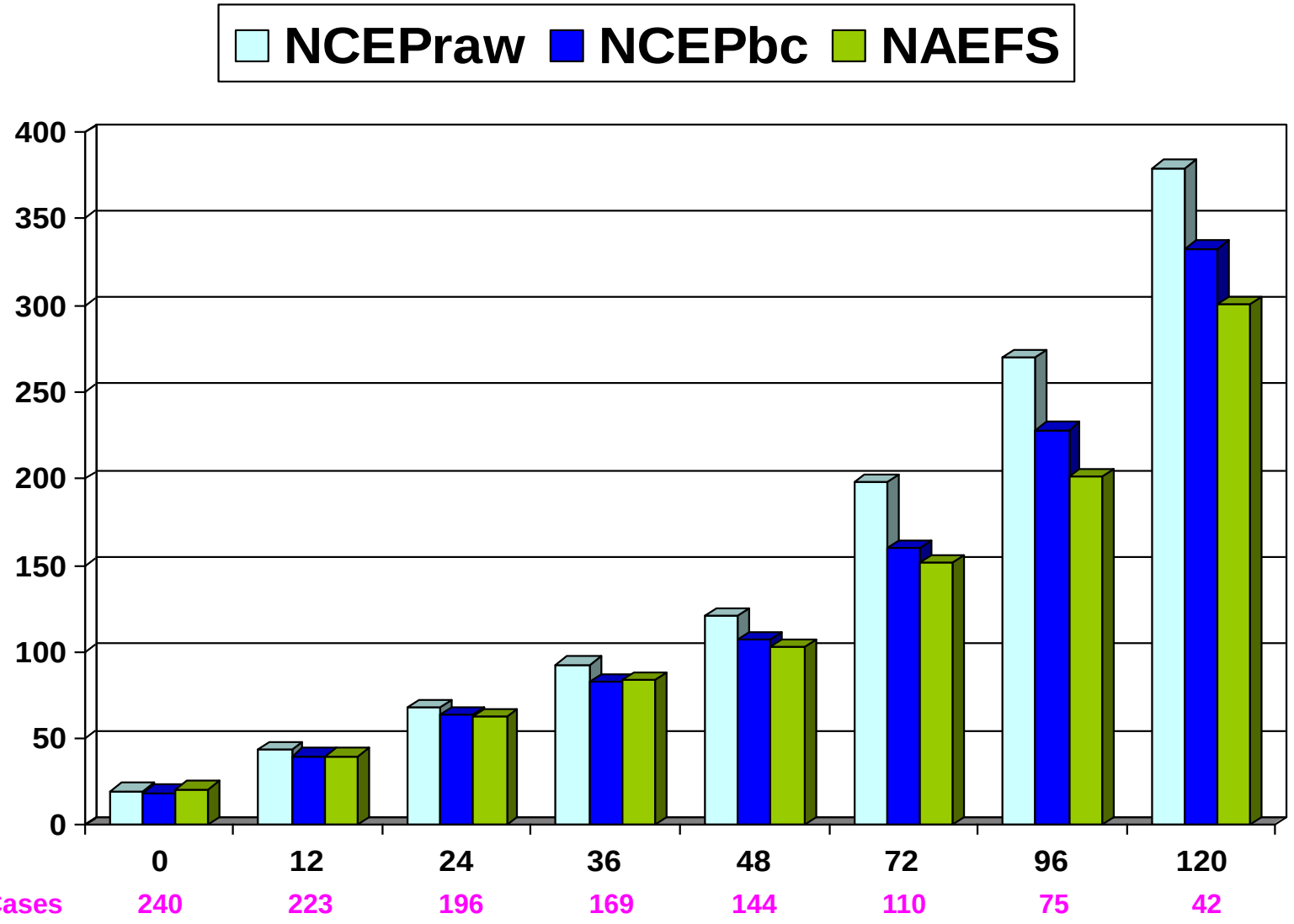
- Bias corrected NCEP/CMC GEFS and GFS forecast (up to 180 hrs), same bias correction algorithm
  - Combine bias corrected GFS and NCEP GEFS ensemble forecasts
  - Dual resolution ensemble approach for short lead time
  - GFS has higher weights at short lead time
- NAEFS products
  - Combine NCEP/GEFS (20m) and CMC/GEFS (20m), FNMOC ens. will be in soon
  - Produce Ensemble mean, spread, mode, 10% 50%(median) and 90% probability forecast at 1*1 degree resolution
  - Climate anomaly (percentile) forecasts also generated for ens. mean
- Statistical downscaling
  - Use RTMA as reference - NDGD resolution (5km), CONUS only
  - Generate mean, mode, 10%, 50%(median) and 90% probability forecasts



BO CUI, GCWMB/EMC/NCEP/NOAA


NAEFS NDGD Probabilistic 2m Temperature
Forecast Verification For 2007090100 – 2007093000
NAEFS
NCEP_raw
NCEP_drbcds
CMC_bcds
NCEP/GEFS raw forecast
8+ days gain
NAEFS final products
From
Bias correction (NCEP, CMC)
Dual-resolution (NCEP only)
Down-scaling (NCEP, CMC)
Combination of NCEP and CMC
Continuous Ranked Probability Score (C)
Forecast Lead Time (Days)
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Track forecast error for 2009 season (AL+EP+WP)



NAEFS is combined NCEP (NCEPbc) and CMC's (CMCbc) bias corrected ensemble and bias corrected GFS

Contributed by Dr. Jiayi Peng (EMC/NCEP)

Future

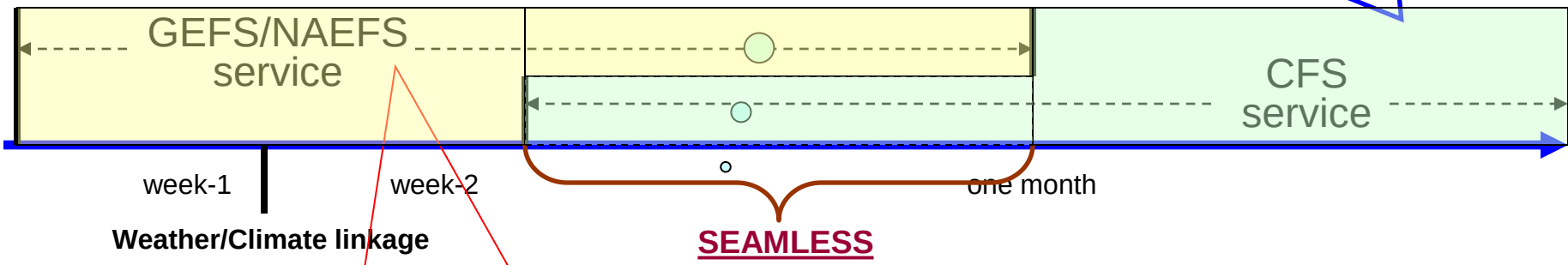
Future seamless forecast system

NCEP/GEFS will plan for T254L42 (2010 GFS version) resolution with tuned ETR initial perturbations and adjusted STTP scheme for 21 ensemble members, forecast out to 16 days and 4 cycles per day. **Extended to 45 days at T126L28/42 resolution, 00UTC only (coupling is still a issue?)**
NAEFS will include FNMOC ensemble in 2011, with improving post process which include bias correction, dual resolution and down scaling

Main products:

ENSO predictions???
Seasonal forecast???

Main event MJO



Main products:

1. Probabilistic forecasts for every 6-hr out to 16 days, 4 times per day: 10%, 50%, 90%, ensemble mean, mode and spread.
2. D6-10, week-2 temperature and precipitation probabilistic mean forecasts for above, below normal and normal forecast
3. **MJO forecast (week 3 & 4 …)**

Next Operational CFS will plan to be implemented by Q2FY2011 with T126L64 atmospheric model resolution (CFSv2, 2010version) which is fully coupled with land, ocean and atmosphere (GFS+MOM4+NOAH), 4 members per day (using CFS reanalysis as initial conditions, one day older?), integrate out to 9 months.

Future: initial perturbed CFS

Flow Chart for Hybrid Variation and Ensemble Data Assimilation System (HVEDAS) - concept