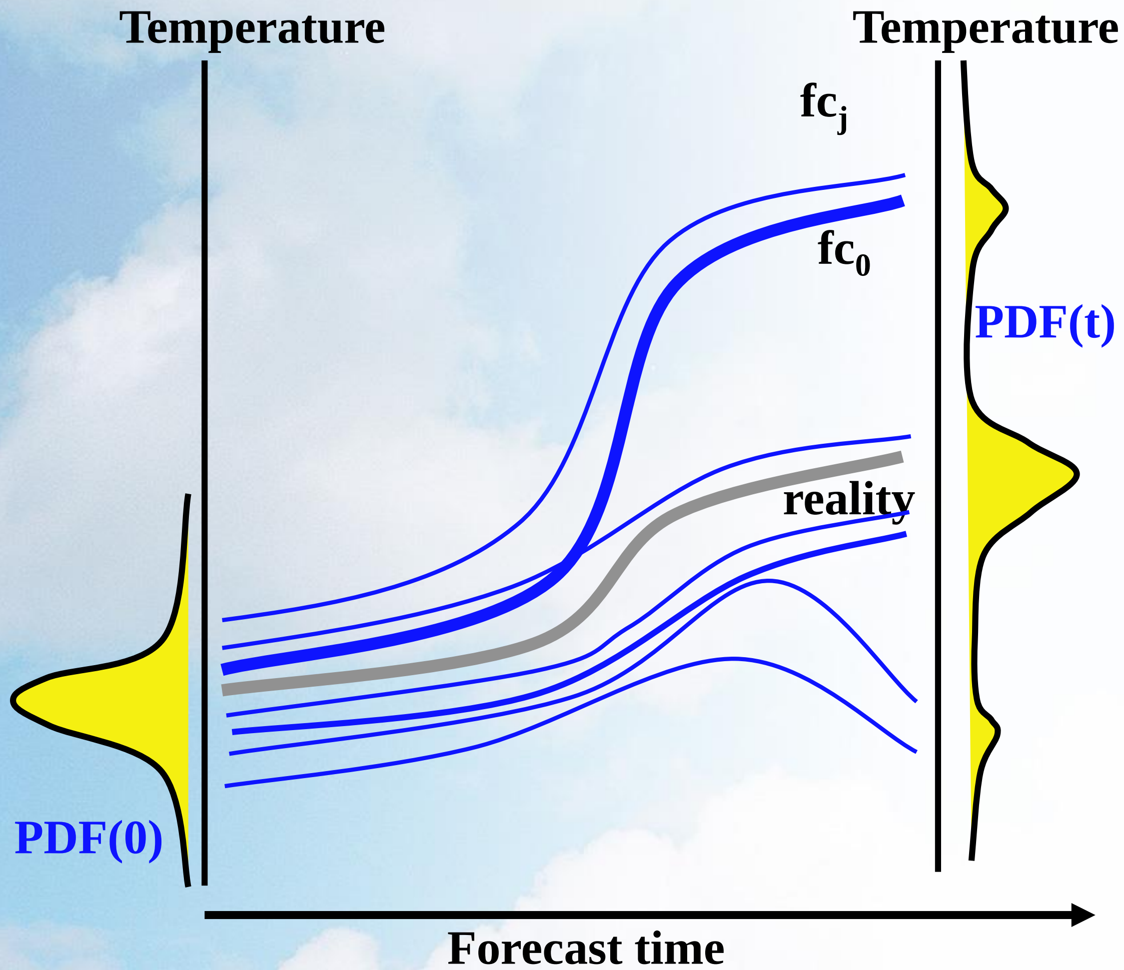
Combining EDA and SVs to initialise Ensemble forecasts

Simon Lang

Ack: Martin Leutbecher, Elias Holm, Massimo Bonavita, Roberto Buizza, Sarah-Jane Lock

3. Ensemble prediction systems



Sources of Uncertainty:

- **Initial Conditions**
- **Model Formulation**

The ECMWF Ensemble:

- 51 Members (50 perturbed + control member without perturbations), TCo639 (~ 18 km) to day 15
- 91 vertical levels
- Coupled to NEMO ocean model (1/4 degree) and LIM2 ice model
- Initial perturbation via an ensemble of data assimilations and singular vectors, 5 member ocean data assimilation
- Model error representation (SPPT, ~~SKEB~~)

ECMWF

Reliability of the ensemble spread

- Consider ensemble variance ("spread") for an M-member ensemble

$$\frac{1}{M}\sum_{j=1}^{M}(x_j - \overline{x})^2$$

and the squared error of the ensemble mean

$$(\overline{x} - y)^2$$

- Average the two quantities for many locations and/or start times.
- The averaged quantities have to match for a reliable ensemble (within sampling uncertainty).

How to construct initial perturbations:

Methods that rely on the dynamics only, e.g.:

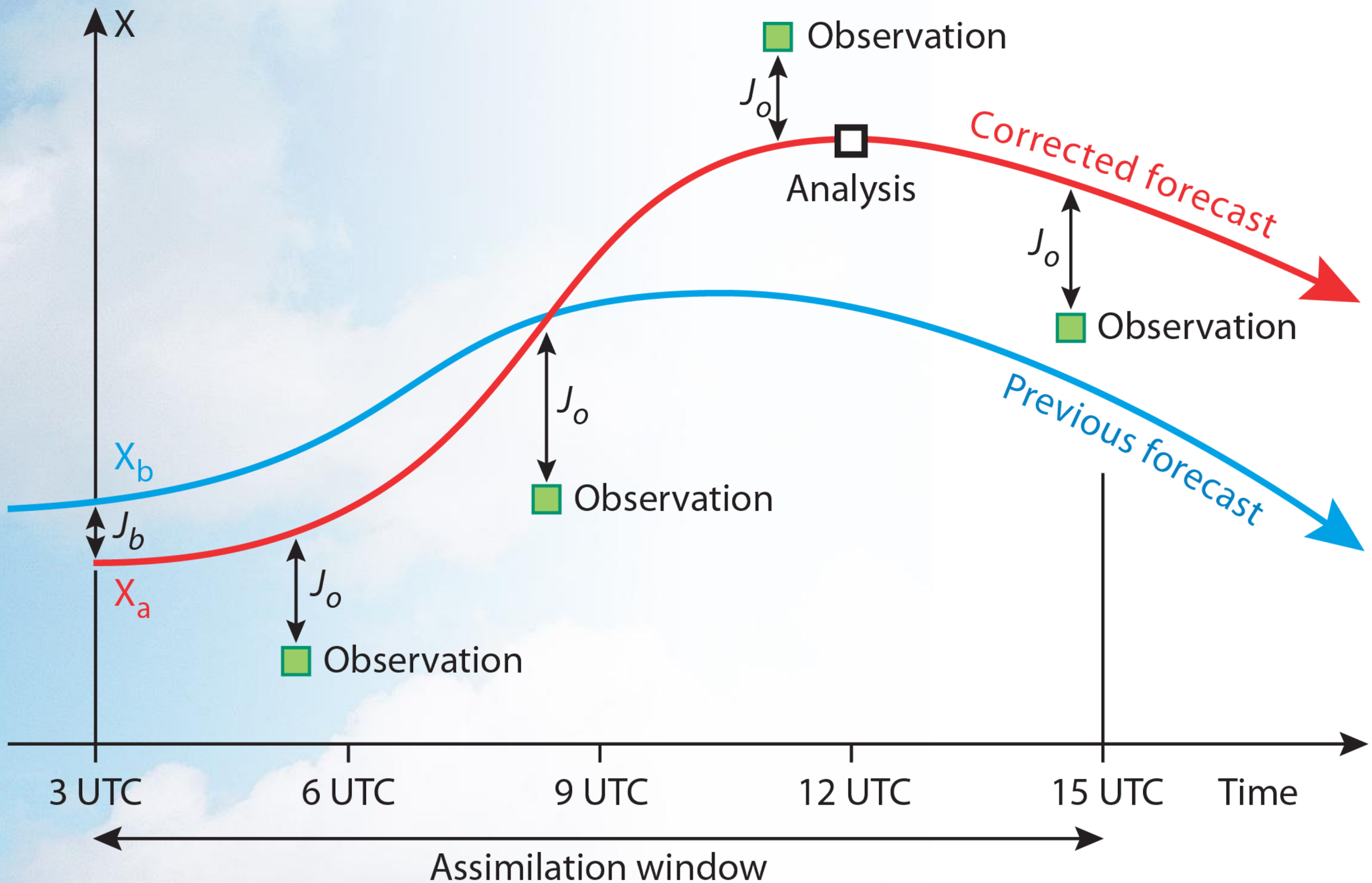
- bred vectors
- singular vectors (with total energy norm)

Ensemble data assimilation methods, e.g.:

- Ensemble of 4D-Var data assimilations (EDA)
- Ensemble Kalman Filter

ECMWF: combination of EDA and singular vectors

4D-Var assimilation



The Ensemble of Data Assimilations

- 25 perturbed ensemble members + 1 control, TCo639 outer loops, 137 levels, TL191/TL191 inner loops. (HRES DA: TCo1279 outer loops, TL255/TL319/TL399 inner loops).
- Observations randomly perturbed according to their estimated error covariances (R)
- SST perturbed with climatological error structures
- Model error representation via Stochastically Perturbed Parametrization Tendencies (SPPT, see Sarah-Jane's Talk)

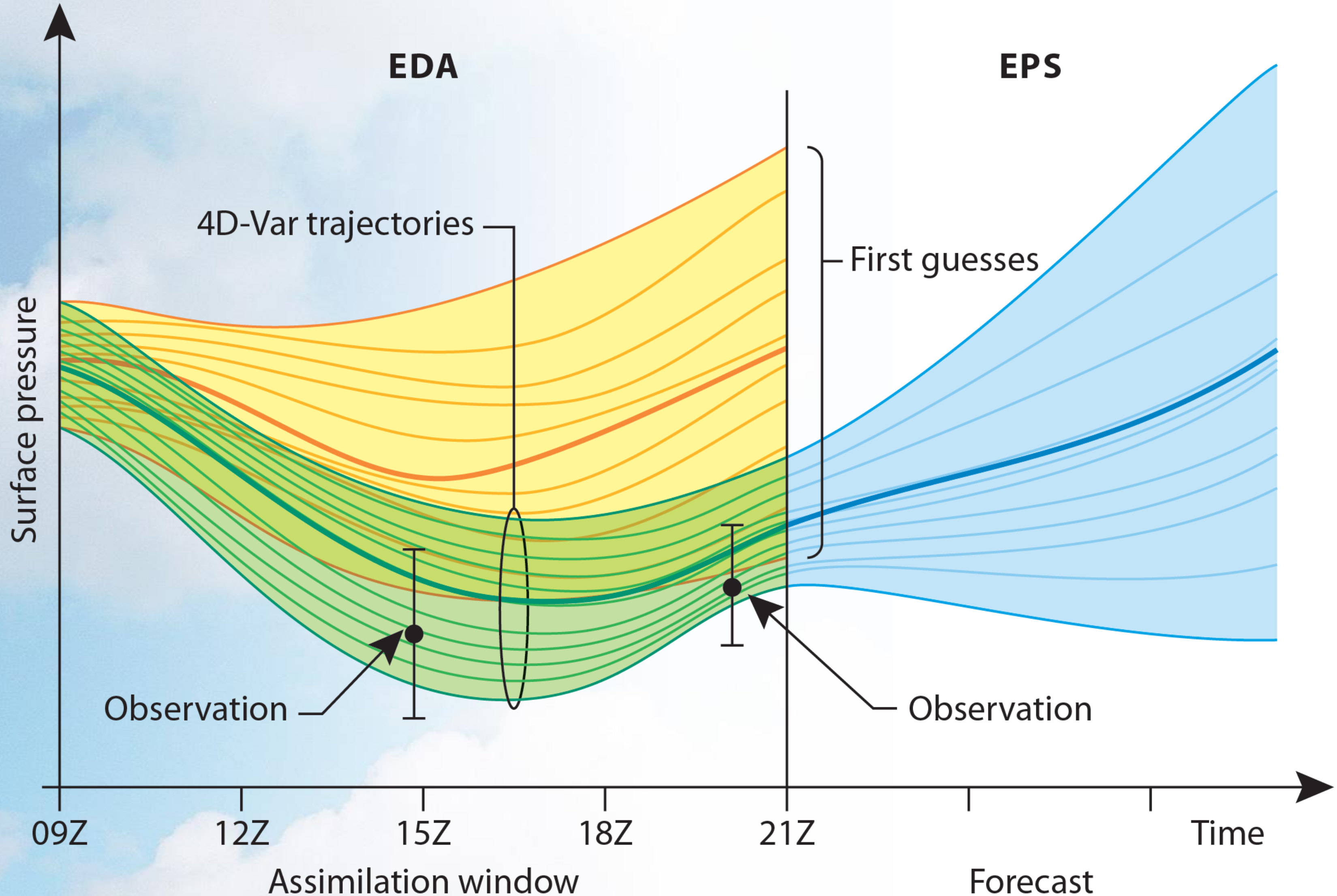
The EDA simulates the error evolution of the 4DVar analysis cycle:

→ uncertainty estimates to initialize ensemble forecasts

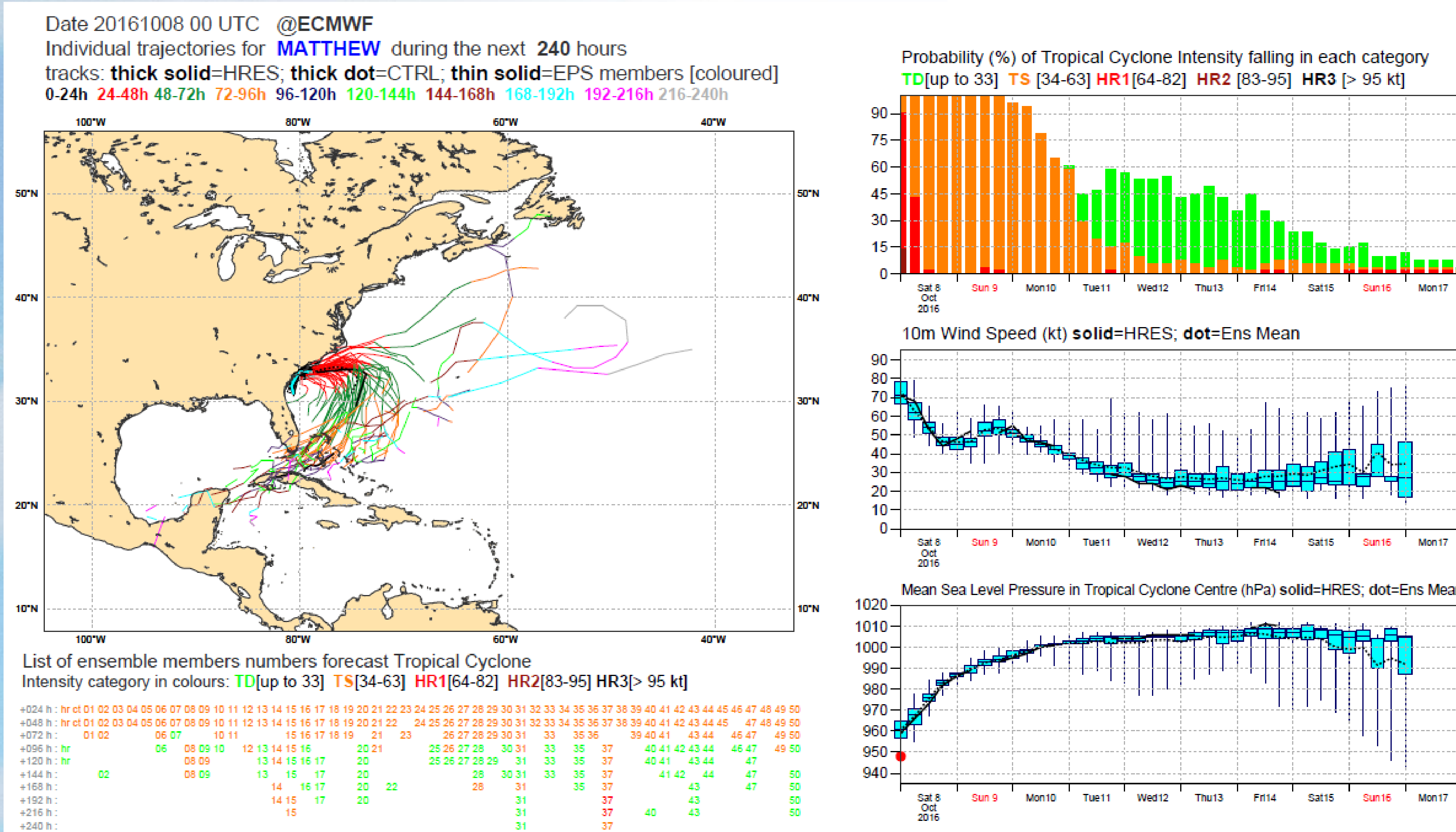
→ Flow dependent estimates of background error covariances for use in 4D-Var

ECMWF

Ensemble assimilation and prediction

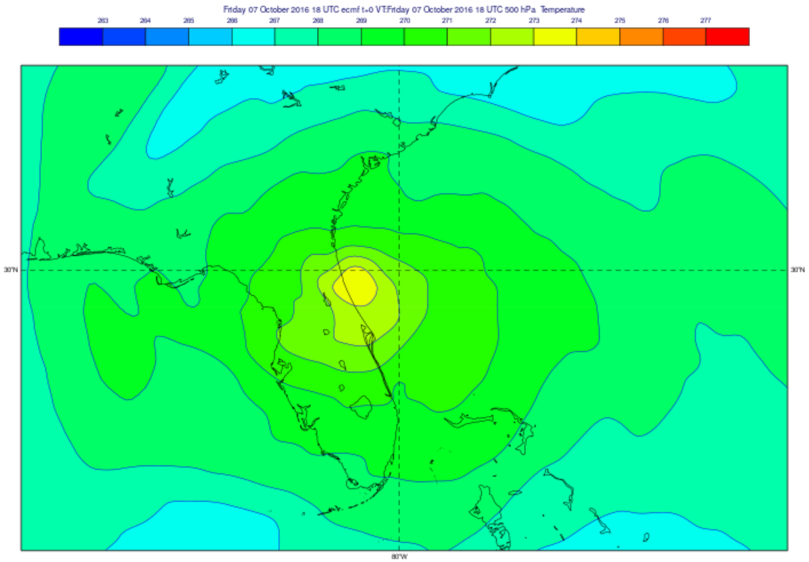


ECMWF

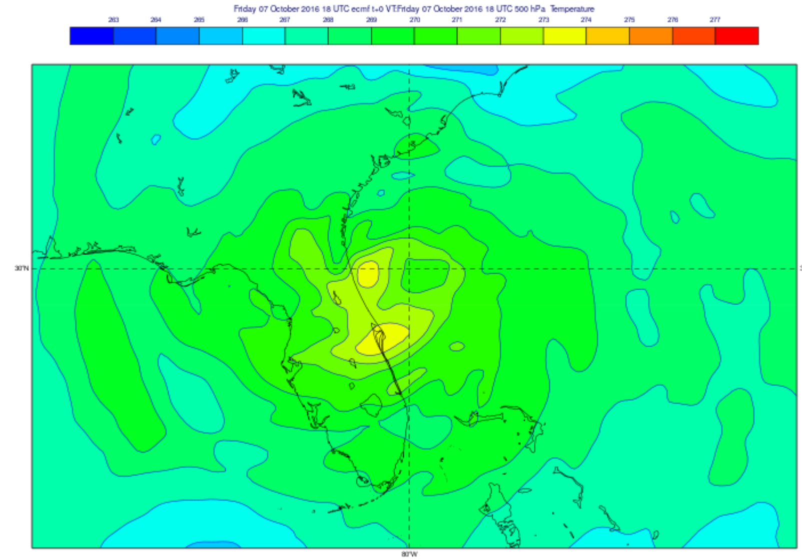

Date 20161008 00 UTC @ECMWF
Individual trajectories for MATTHEW during the next 240 hours
tracks: thick solid=HRES; thick dot=CTRL; thin solid=EPS members [coloured]
0-24h 24-48h 48-72h 72-96h 96-120h 120-144h 144-168h 168-192h 192-216h 216-240h
100°W 80°W 60°W 40°W
50°N 40°N 30°N 20°N 10°N
List of ensemble members numbers forecast Tropical Cyclone
Intensity category in colours: TD[up to 33] TS[34-63] HR1[64-82] HR2[83-95] HR3[> 95 kt]
Probability (%) of Tropical Cyclone Intensity falling in each category
TD[up to 33] TS [34-63] HR1[64-82] HR2 [83-95] HR3 [> 95 kt]
Sat 8 Oct 2016 Sun 9 Mon10 Tue11 Wed12 Thu13 Fri14 Sat15 Sun16 Mon17
10m Wind Speed (kt) solid=HRES; dot=Ens Mean
Mean Sea Level Pressure in Tropical Cyclone Centre (hPa) solid=HRES; dot=Ens Mean

EDA Mean

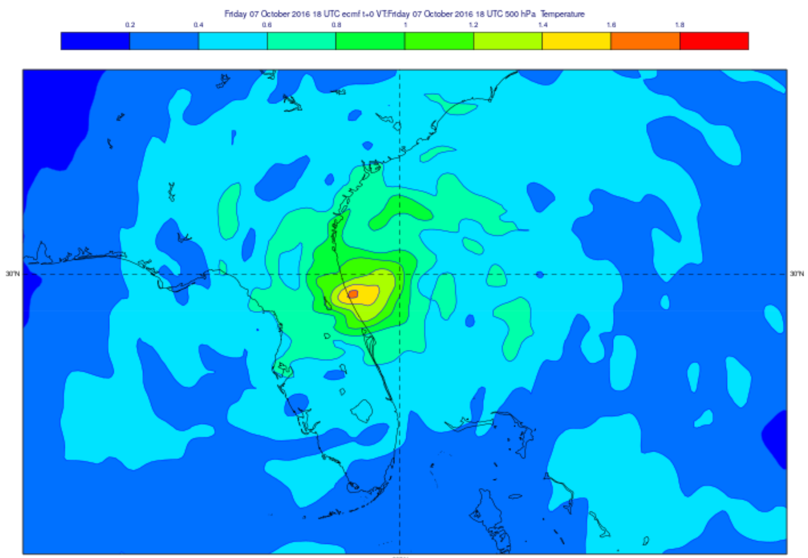
T 500hPa



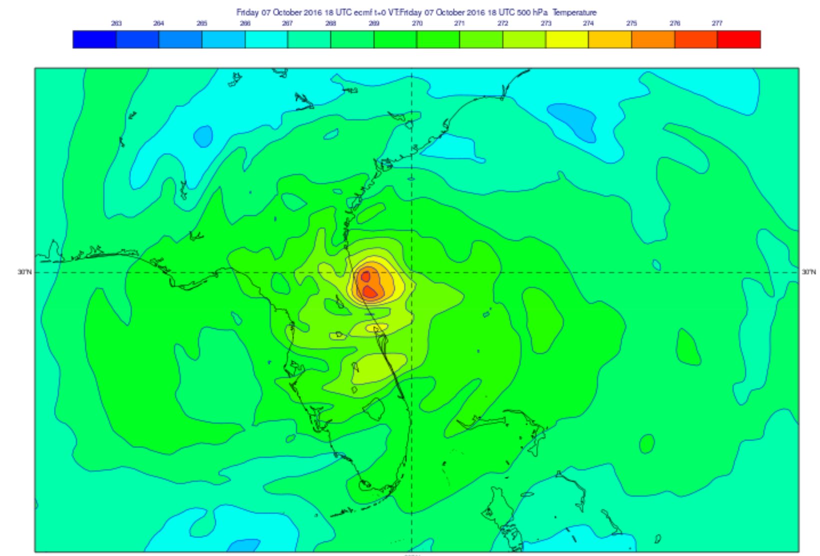
EDA Control member



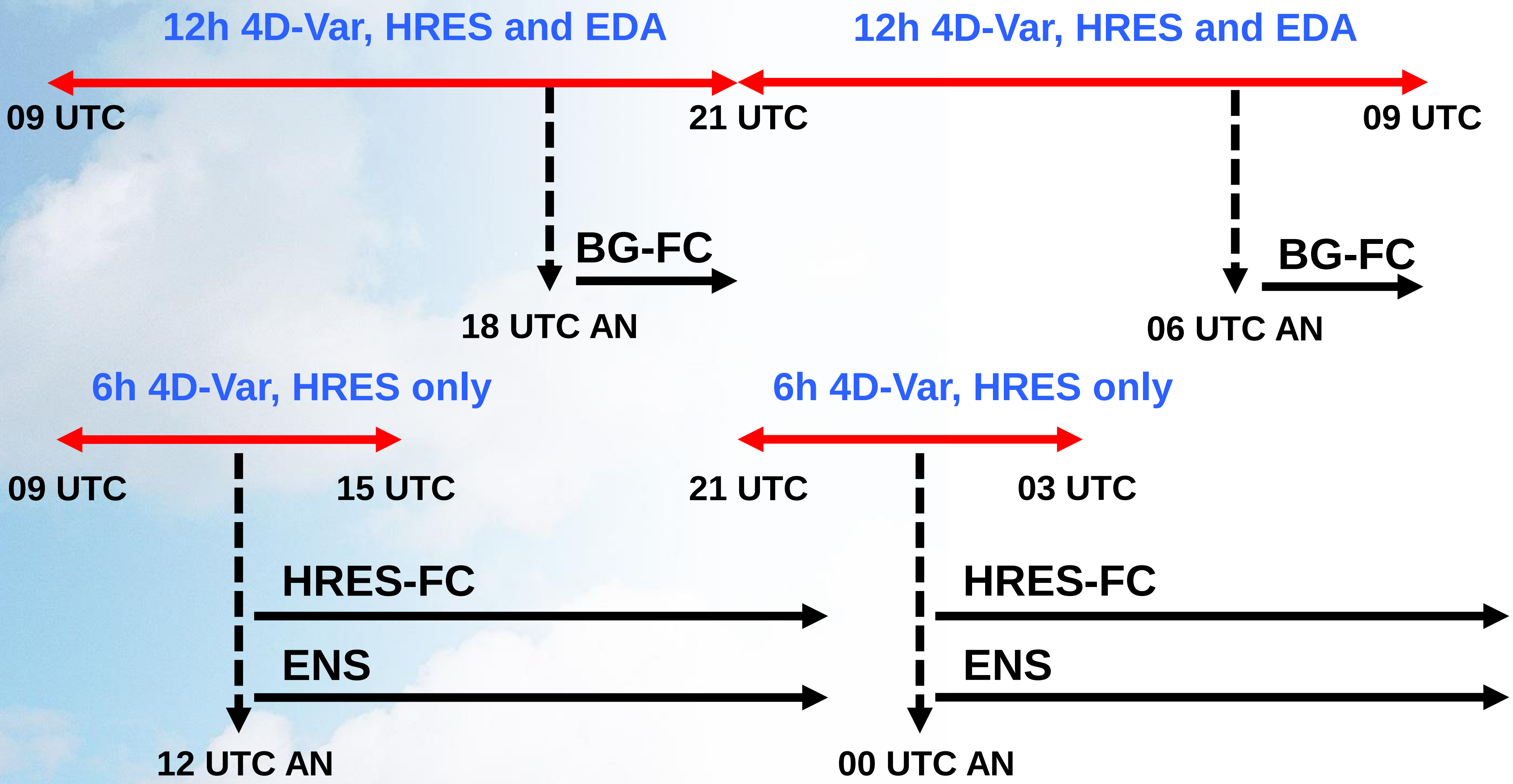
EDA StDev



HRES Analysis

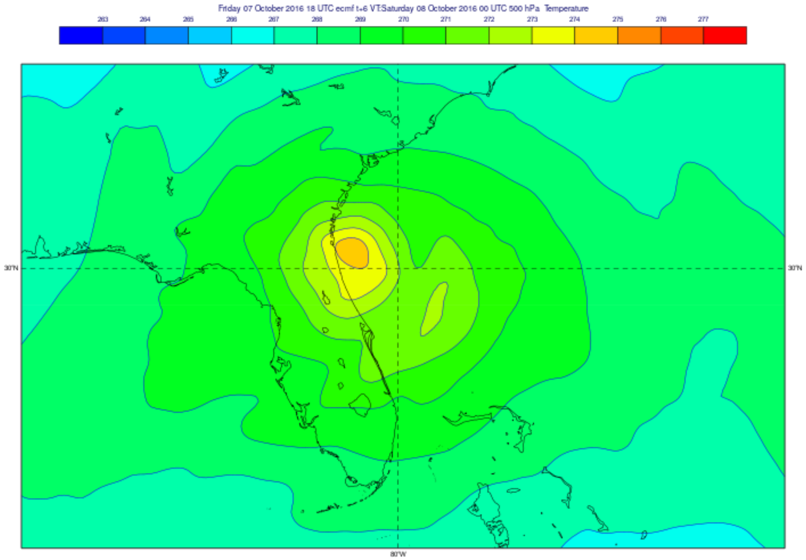


Early delivery Suite:

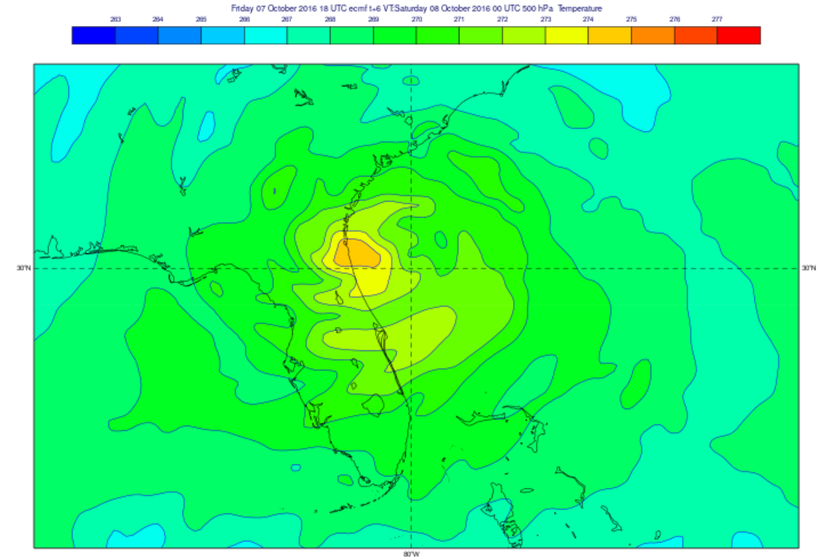


T 500hPa

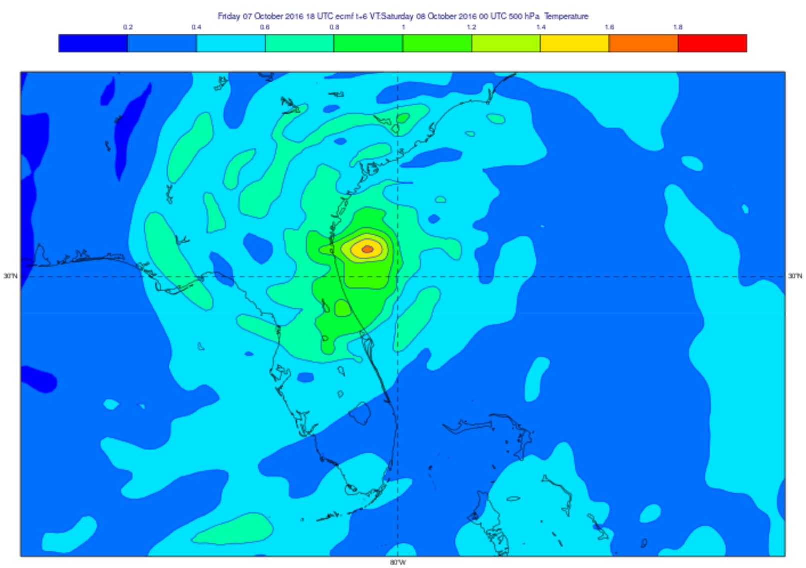
EDA Mean 18 UTC + 6h



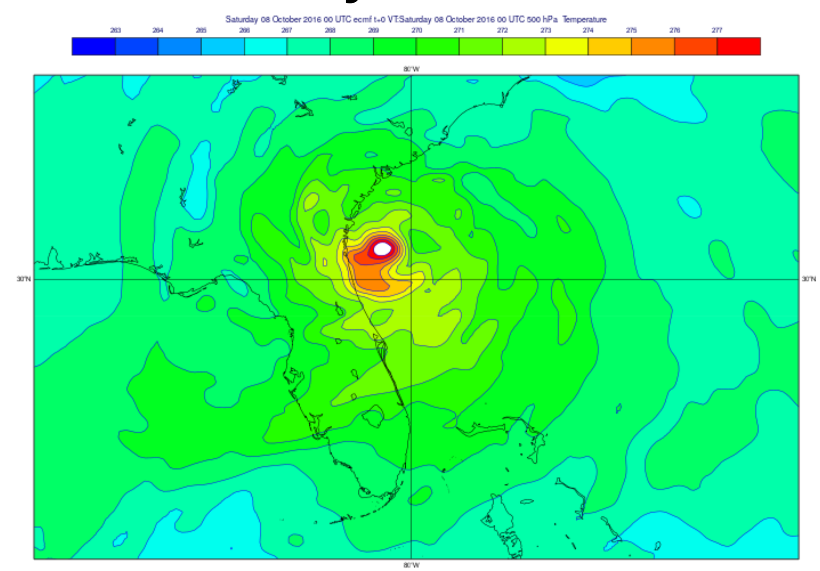
EDA Control 18 UTC + 6h



EDA StDev 18 UTC + 6h



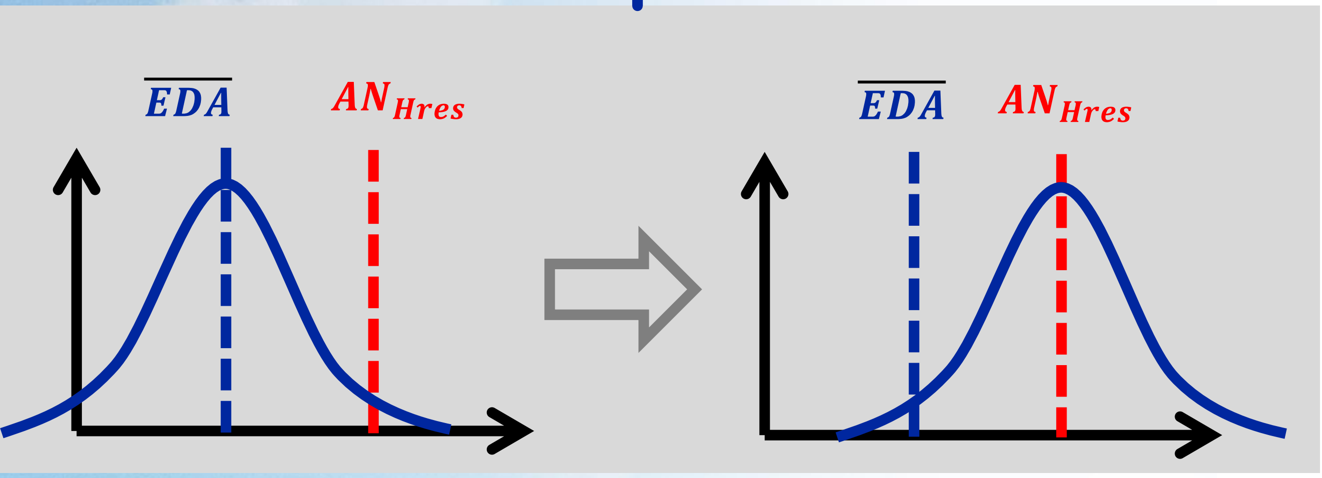
HRES Analysis 00 UTC



Generation of initial conditions for the ensemble:

$$AN_{pf} = AN_{Hres} \pm \left(EDA_i - \overline{EDA}\right) \pm SVPERT_j$$

$$i = 1..25$$
$$j = 1..25$$



EDA : 6h Forecasts

Re-centre EDA-Distribution on Hres-Analysis

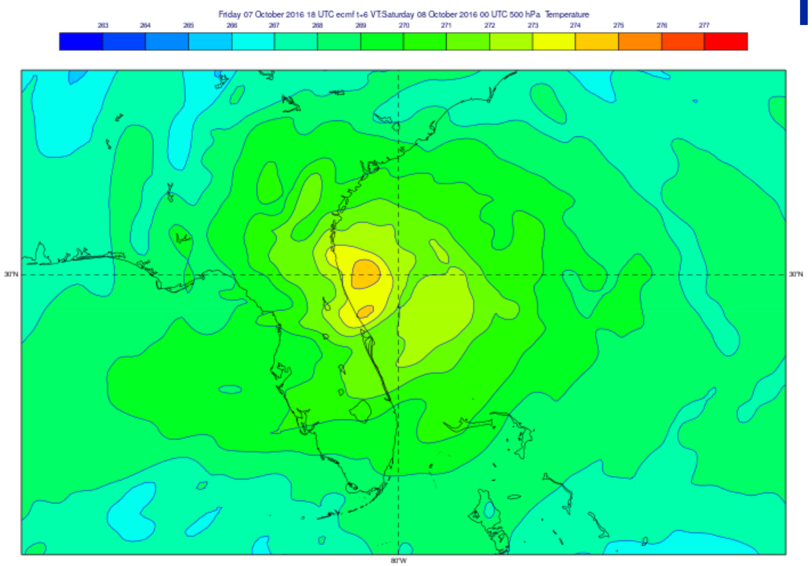
$$SVPERT_j = \sum_{l}^{NSET} \sum_{k}^{NSV_l} \alpha_{lk} SV_{lk}$$

α random number drawn from Truncated gaussian

NSET : nhem, shem, TCs1-6
NSV : 50 for nhem and shem, 5 for TCs

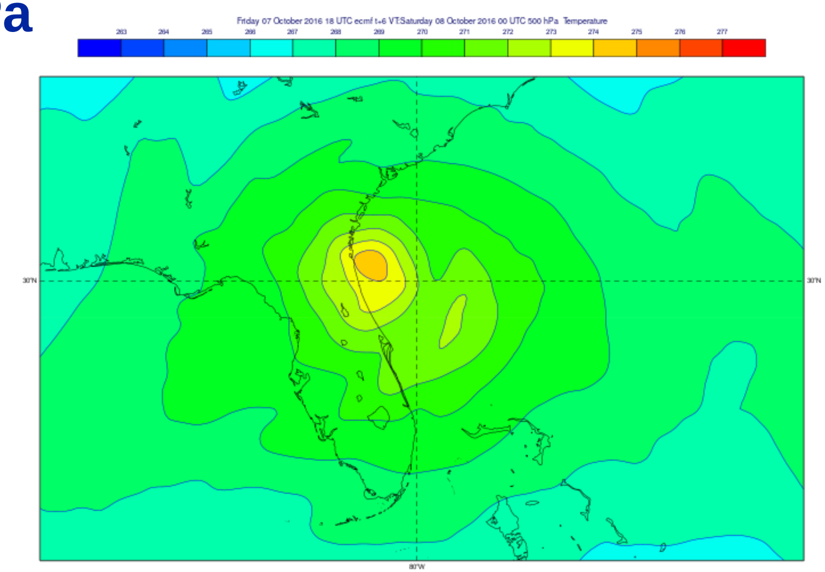
ECMWF

EDA Mem 1 18 UTC + 6h



T 500hPa

EDA Mean 18 UTC + 6h



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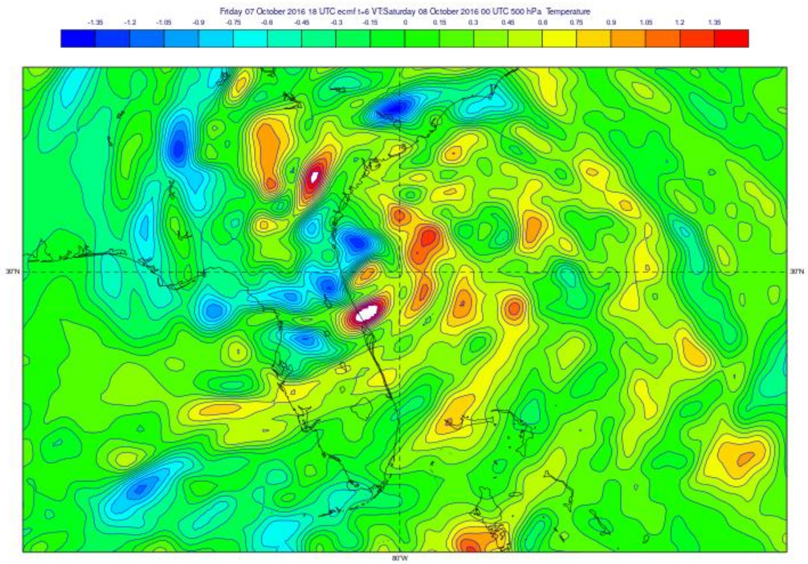
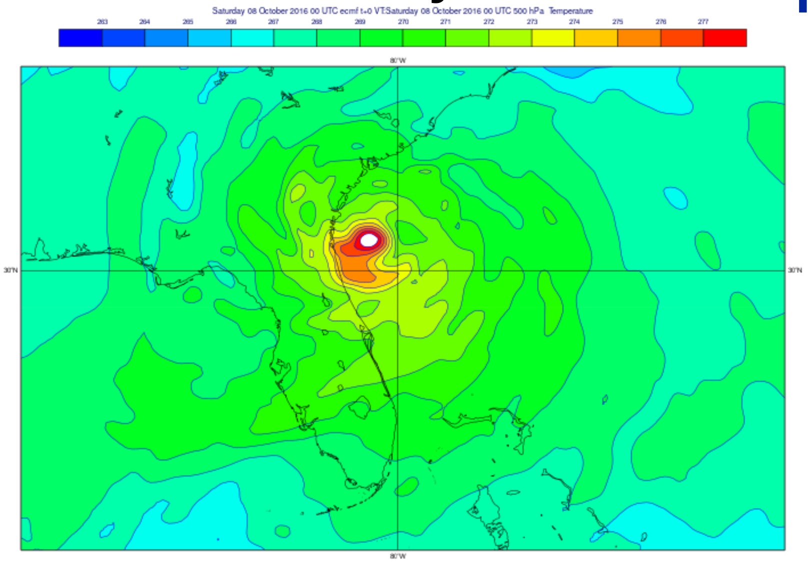
EDA Pert1 18 UTC + 6h



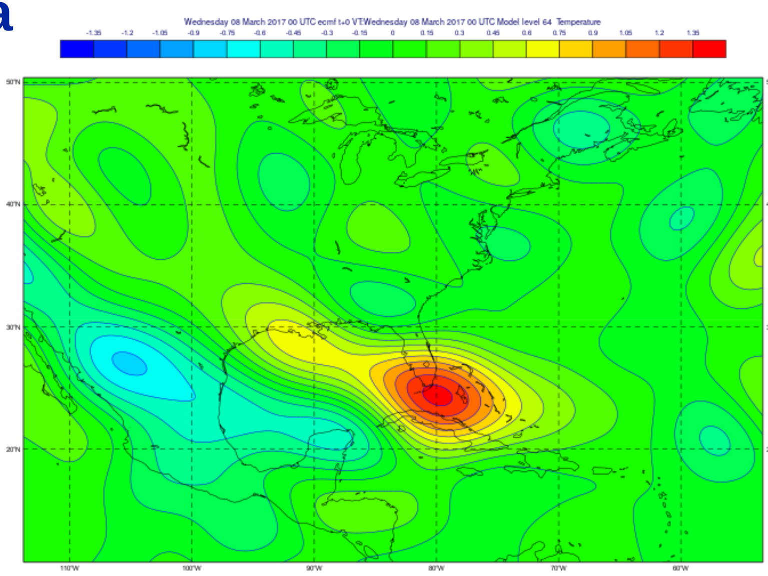
HRES Analysis 00 UTC

T 500hPa



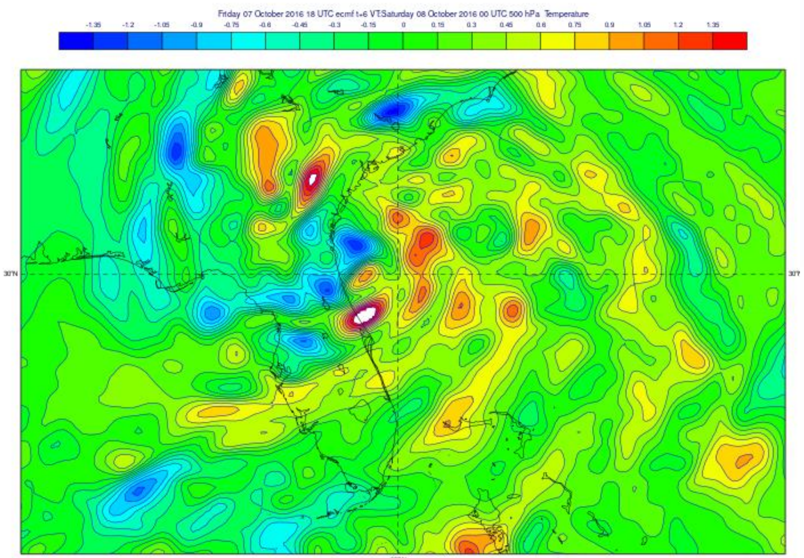
Singular Vector Pert 1

+



EDA Pert1 18 UTC + 6h

+



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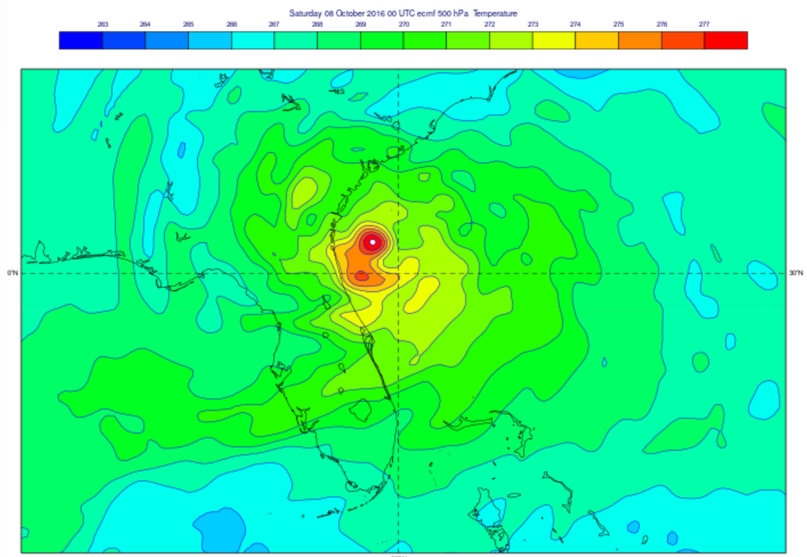
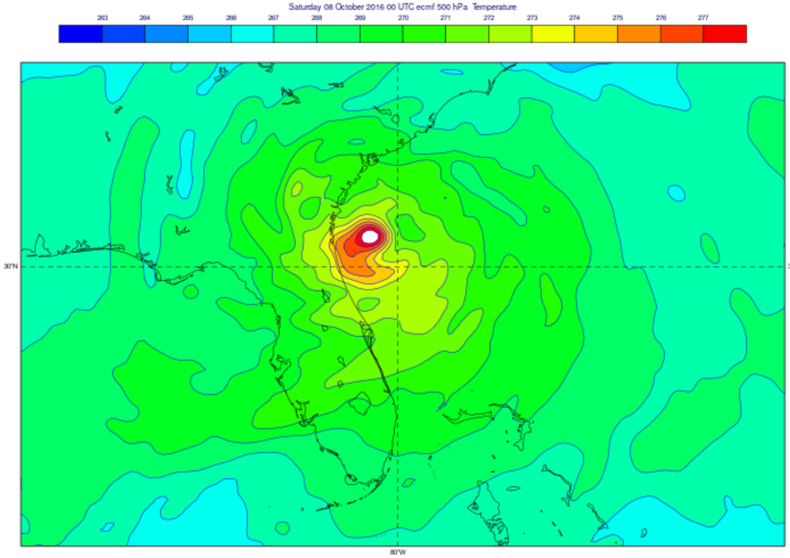
ENS Mem 1 00 UTC

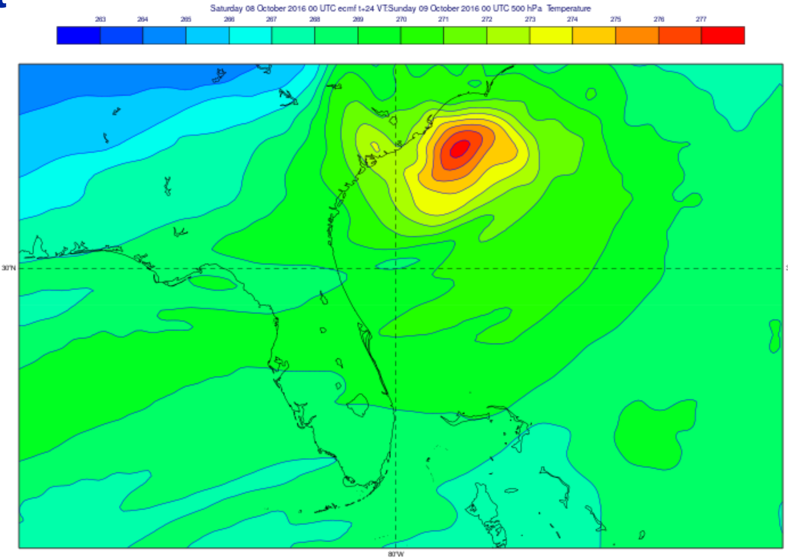


T 500hPa

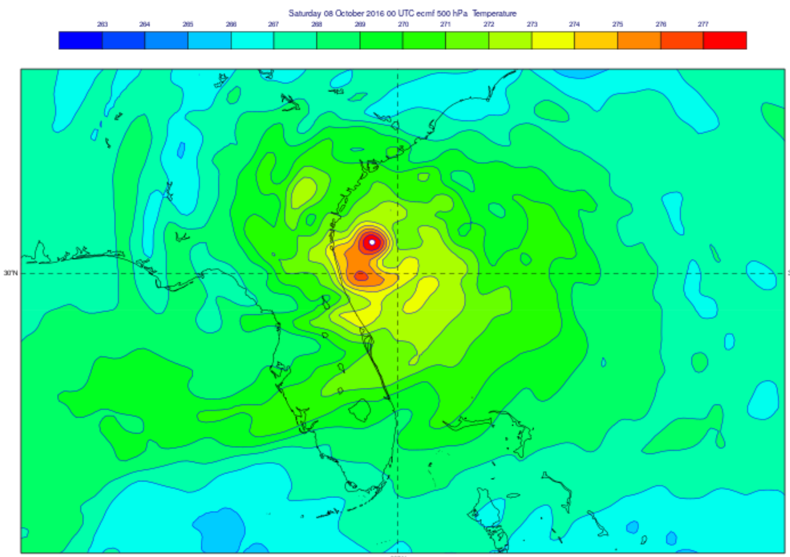
ENS Control 00 UTC



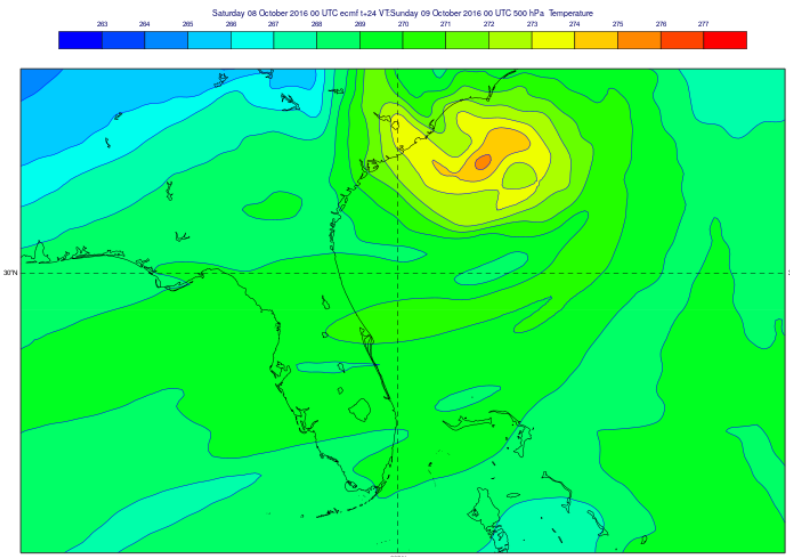
ENS Control 00 UTC + 24h



ENS Mem 1 00 UTC

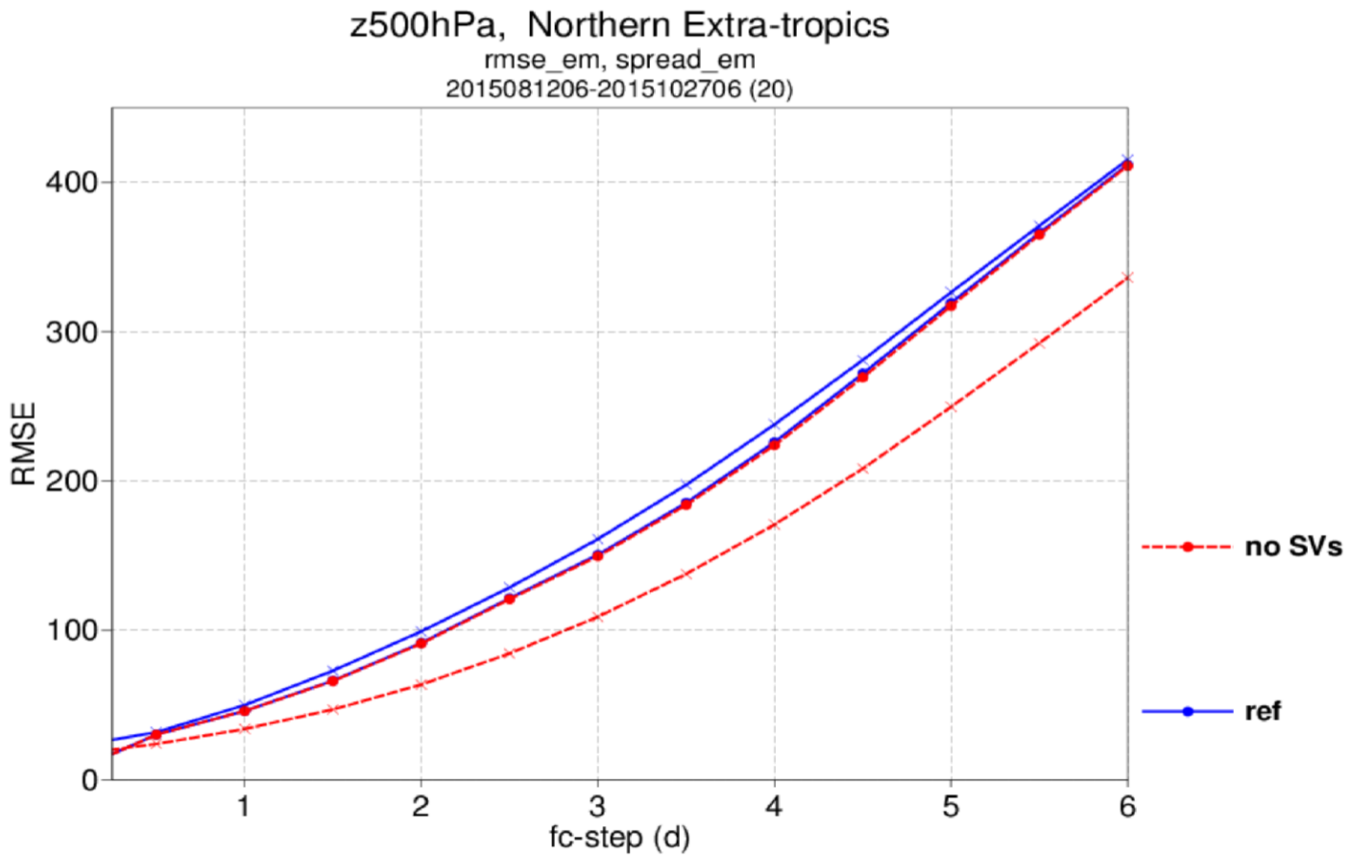


ENS Mem 1 00 UTC + 24h



Why Singular Vectors?

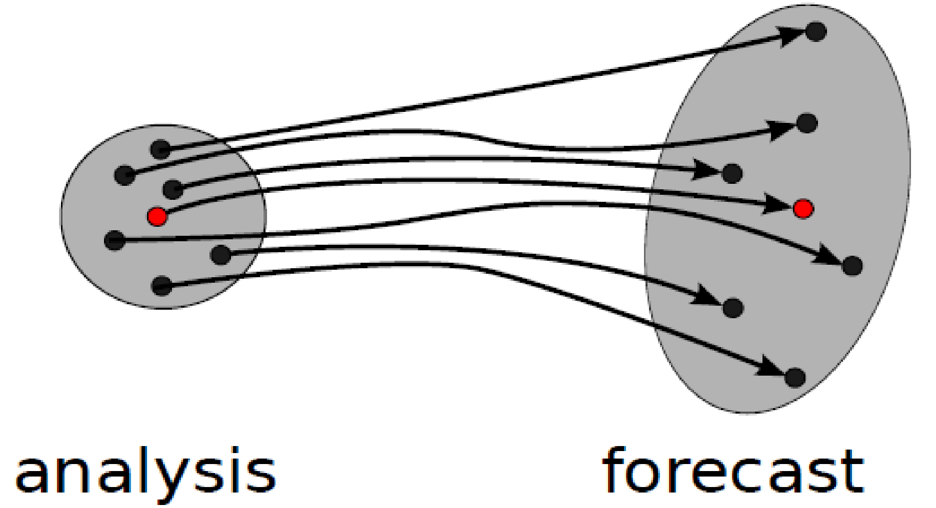
Impact of SVs on ENS



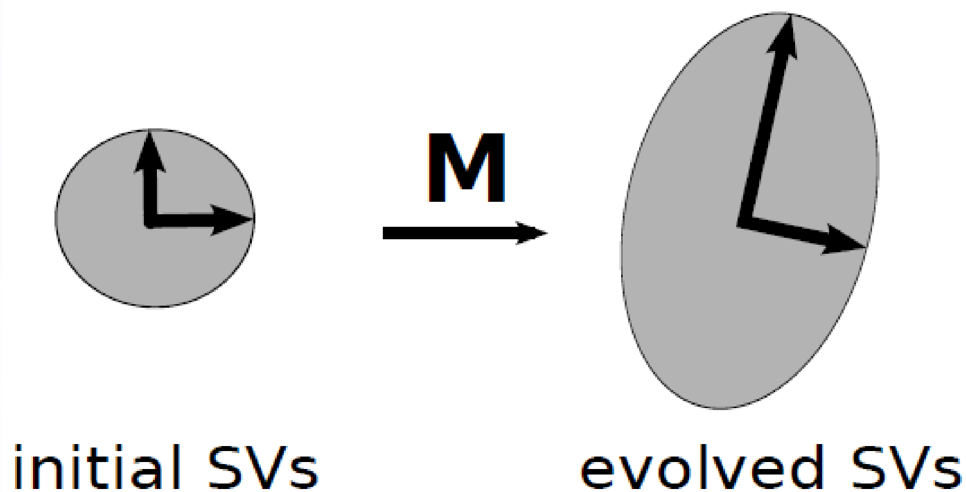
Oper like setup, TCo399, 20 Initial dates

Singular Vectors?

Directions of fastest growth over a finite time interval (optimisation interval)



EDA + Model Uncertainty representation produce substantial spread in the directions of the leading SVs but ensemble still under dispersive (Leutbecher and Lang (2013))



Singular Vectors?

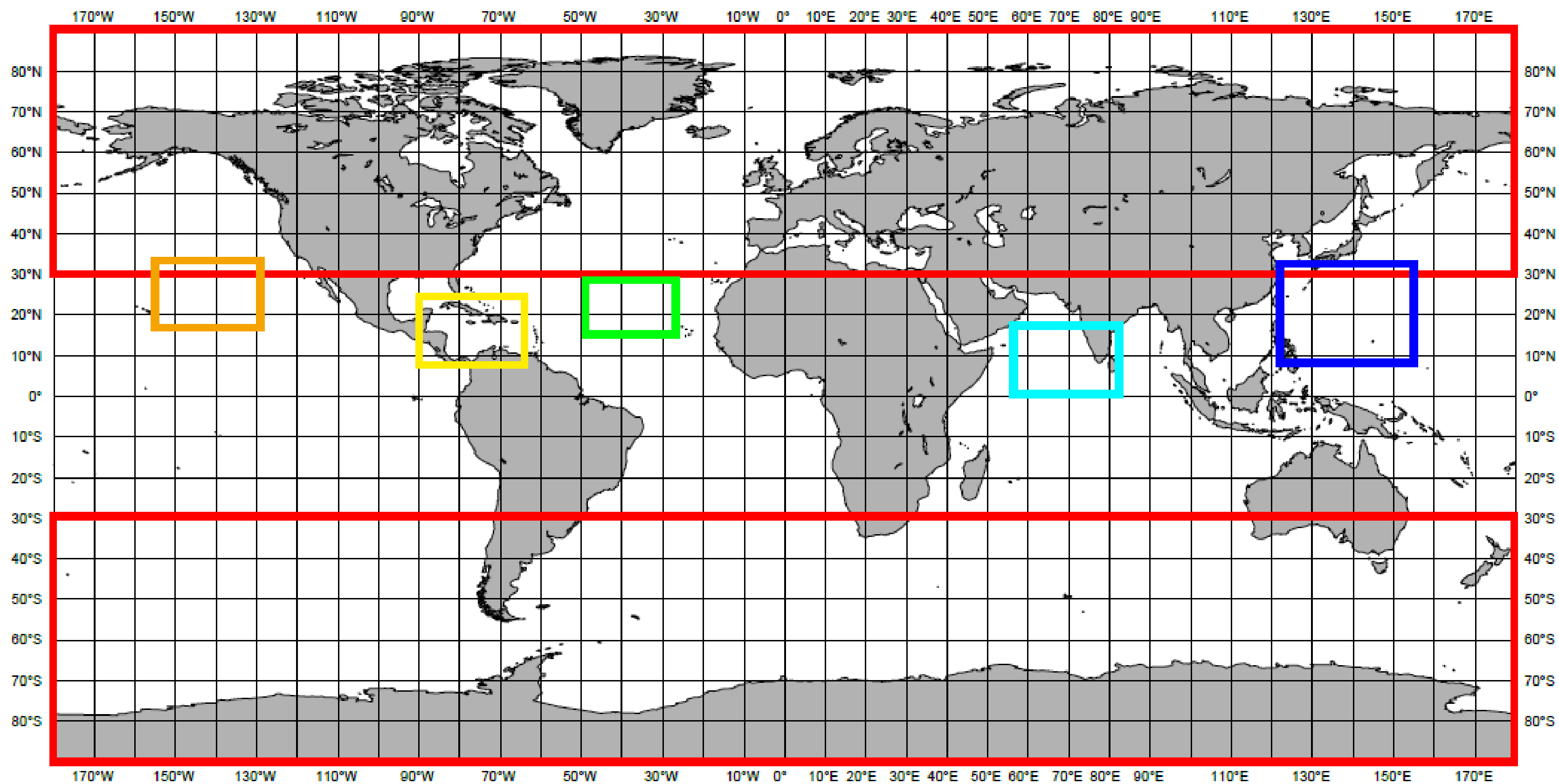
Singular vectors are computed by solving an eigenvalue problem (e.g. Leutbecher and Palmer, 2008):

$$\boldsymbol{C_0^{-1/2} M^* P^* C_1 P M C_0^{-1/2} v = \sigma^2 v}$$

- C_0 and C_1 initial and final time metrics
- $M(0,t)$ linear propagator from time 0 to t and its adjoint M^*
- P and P^* local projection operator and its adjoint

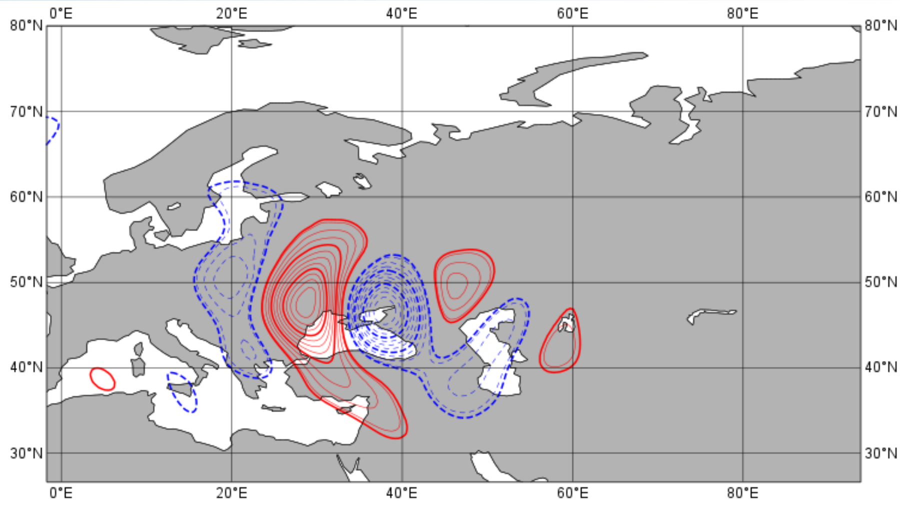
$$\frac{1}{2}\int_{p_0}^{p_1}\int_S\left(u^2+v^2+\frac{c_p}{T_r}T^2\right)\mathrm{d}p\,\mathrm{d}s+\frac{1}{2}R_d T_r p_r\int_S(\ln p_{\mathrm{sfc}})^2\,\mathrm{d}s$$

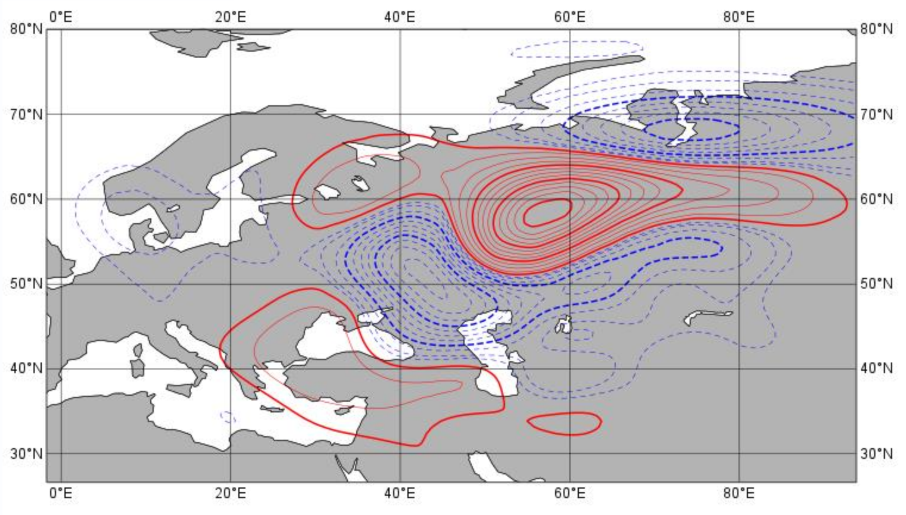
SV-Opt Regions

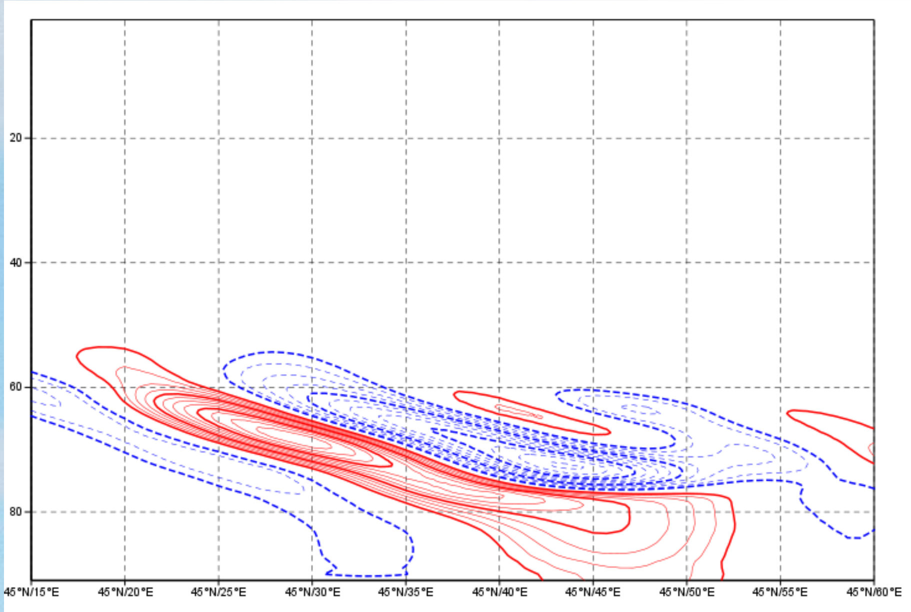


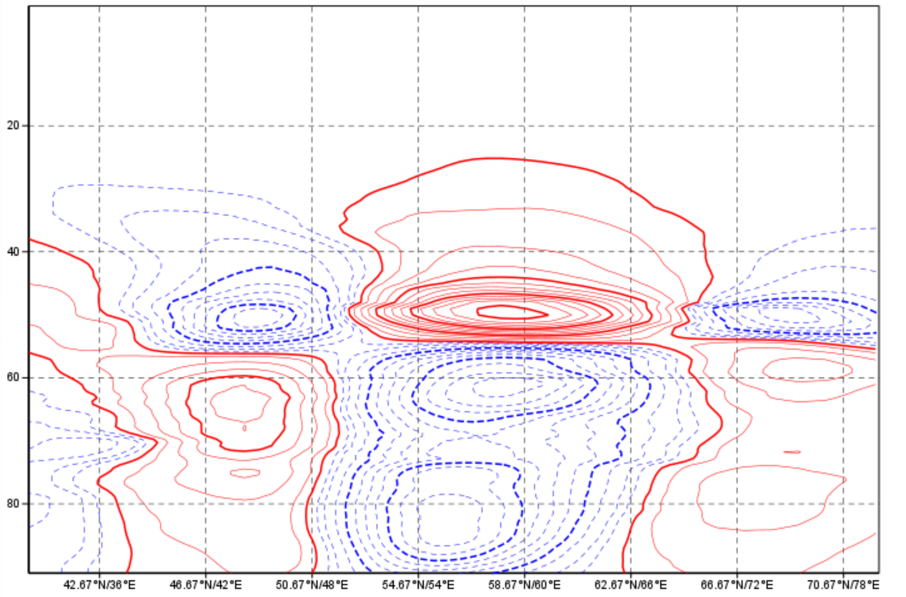
Initial SV, T mlevel 68

evolved SV, T mlevel 49

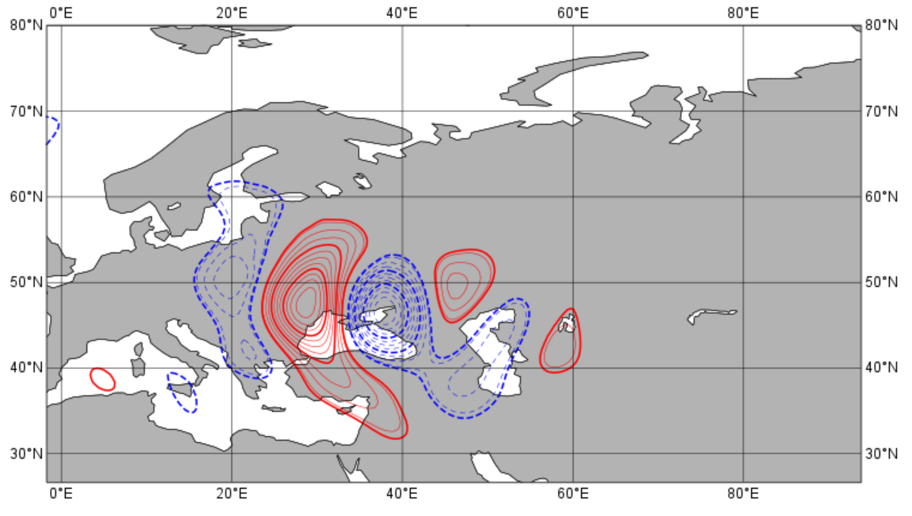




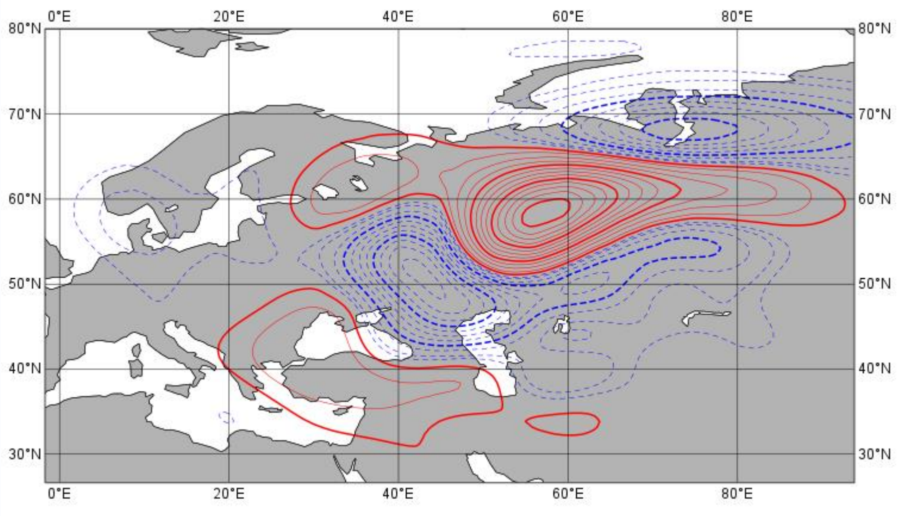




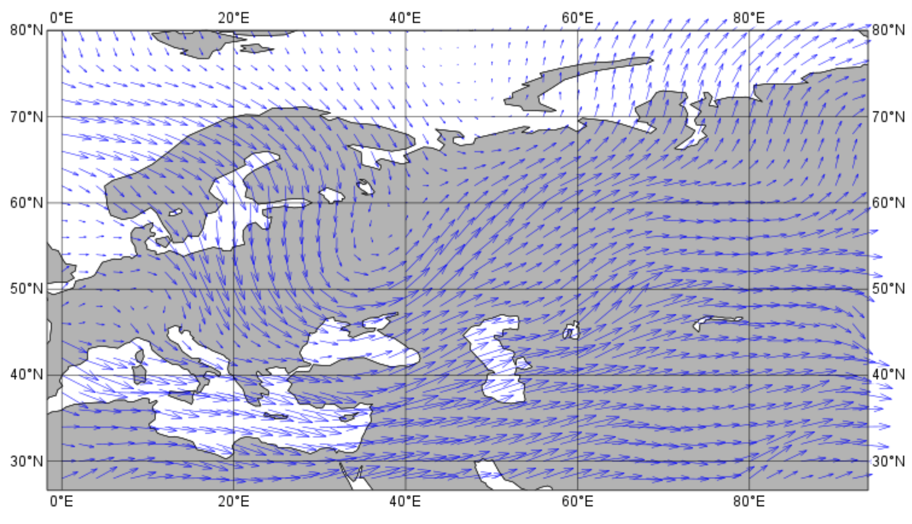
Initial SV, T mlevel 68



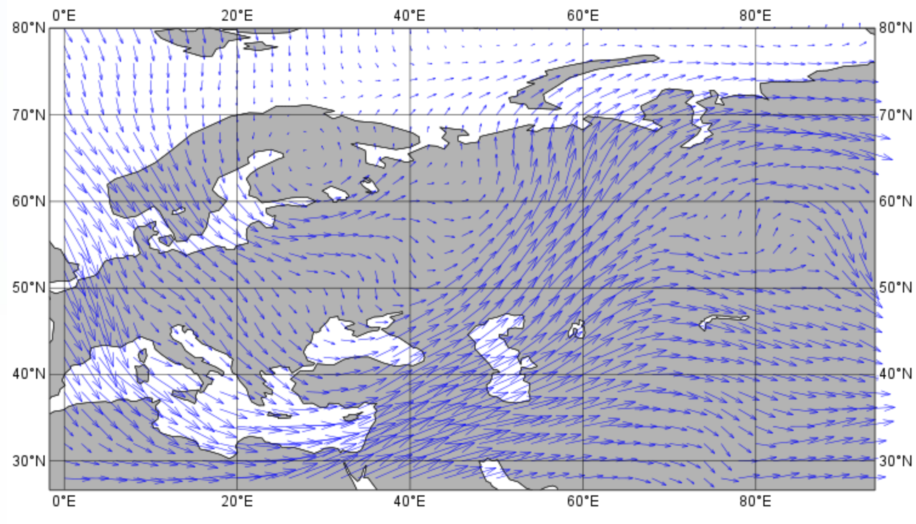
evolved SV, T mlevel 49



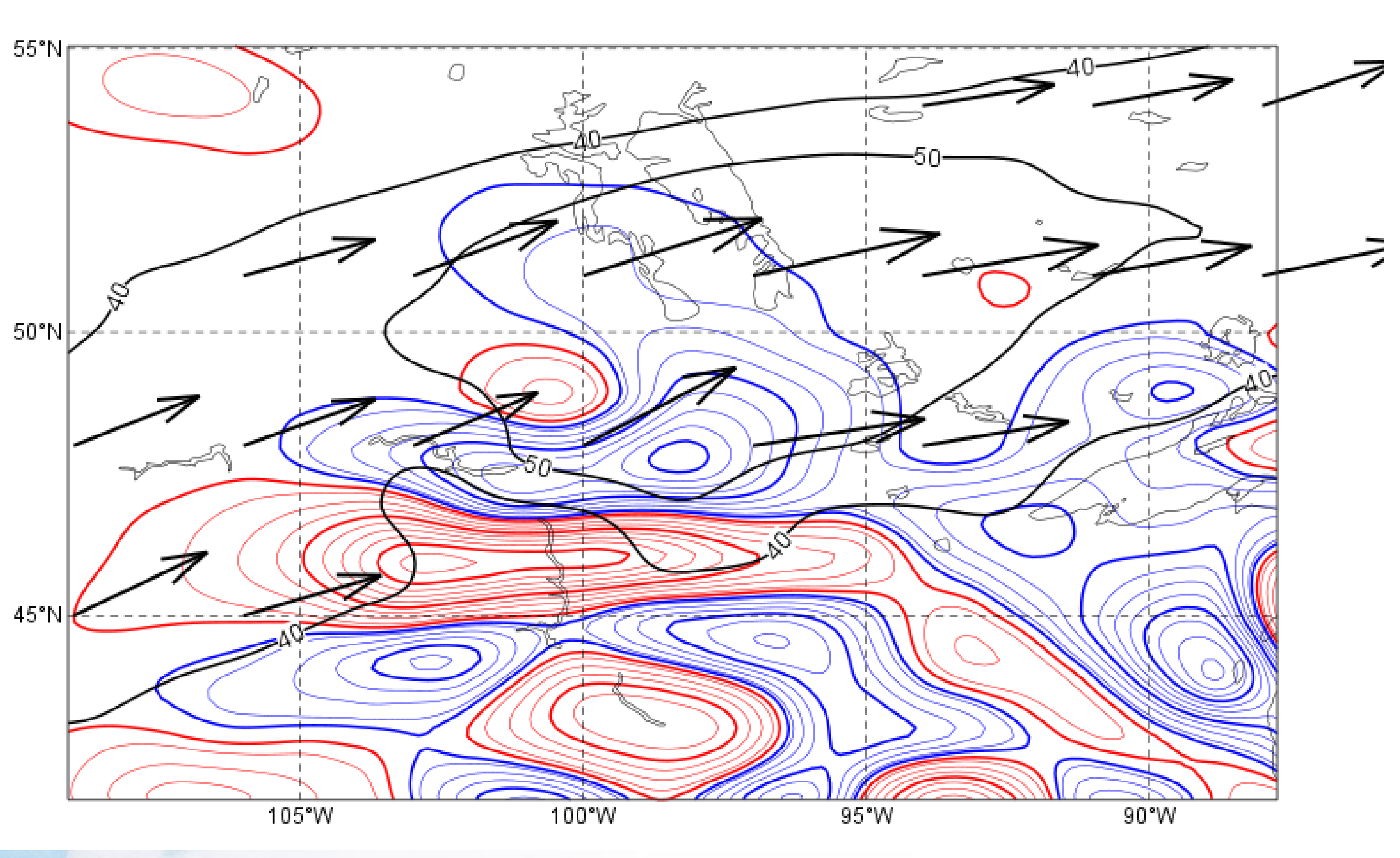
Analysis, Wind 200hPa



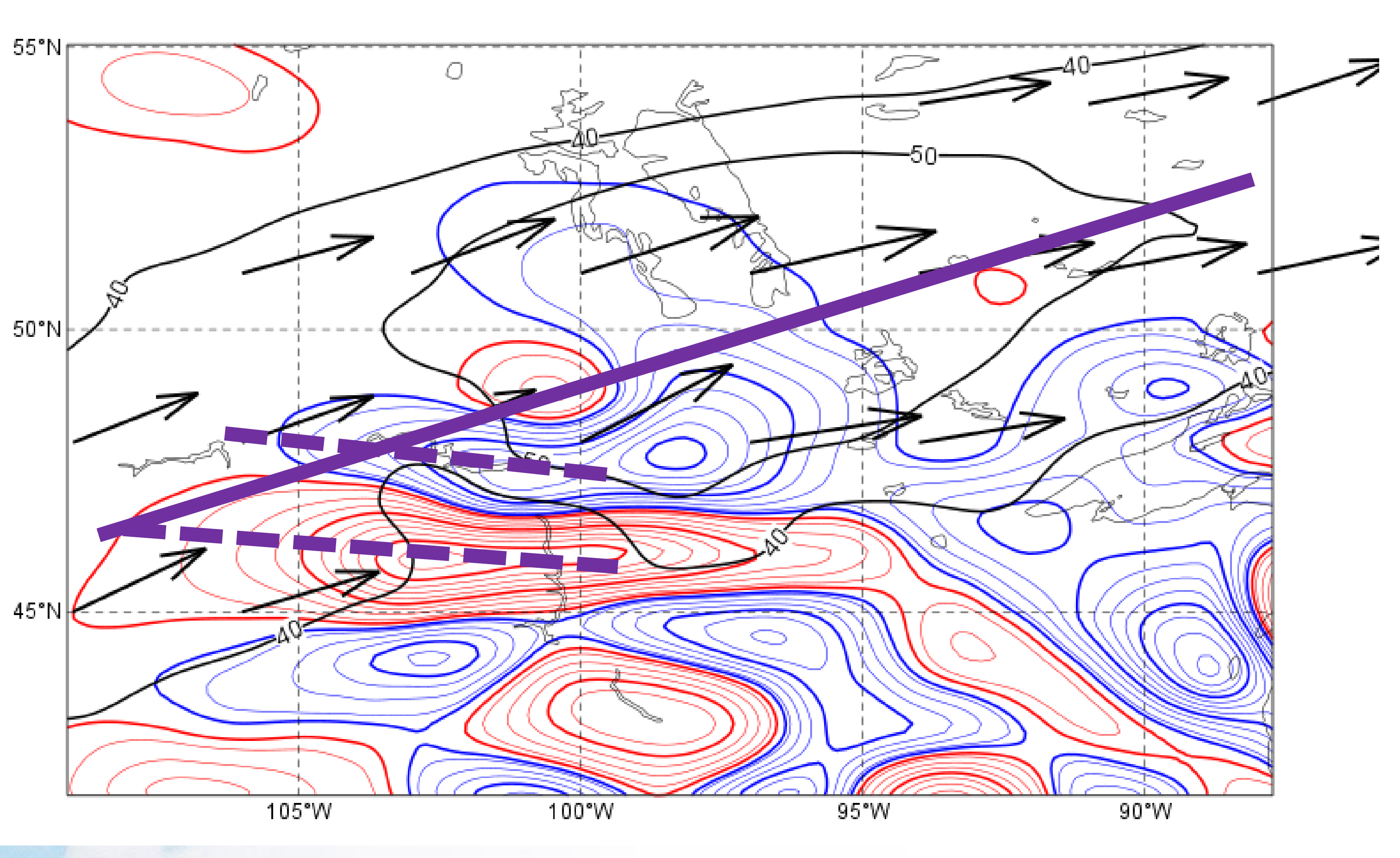
48h Fcst, Wind 200hPa



Analysis Increments (beginning of window), Vo mlevel 78



Analysis Increments (beginning of window), Vo mlevel 78



Singular vector ensemble perturbations

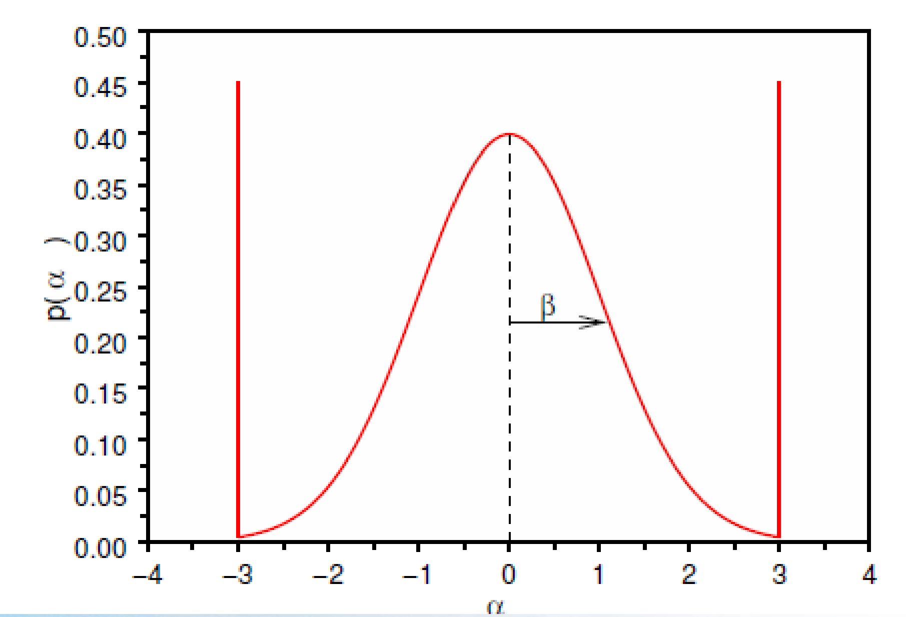
$$AN_{pf} = AN_{Hres} \pm \left(EDA_i - \overline{EDA}\right) \pm SVPERT_j$$

$$i = 1..25$$
$$j = 1..25$$

$$SVPERT_j = \sum_{l}^{NSET} \sum_{k}^{NSV_l} \alpha_{lk}\, SV_{lk}$$

α random number drawn from Truncated gaussian

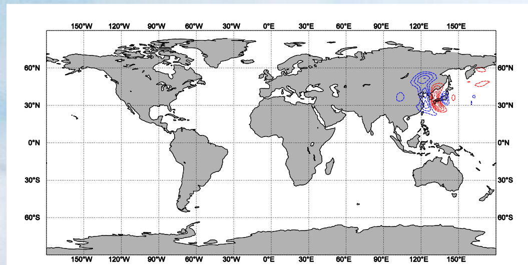
NSET : nhem, shem, TCs1-6
NSV : 50 for nhem and shem, 5 for TCs



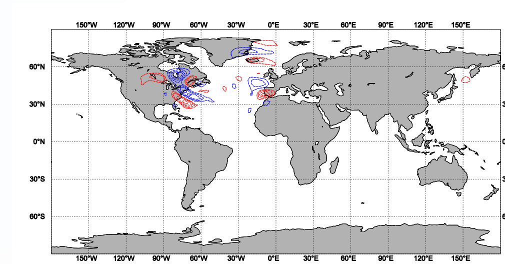
β : standard deviation of Gaussian for a set of singular vectors depends on the EDA ensemble standard deviation of the day

Combine SVs to construct Perturbations:

SV_1

$\alpha_1 \times$ 

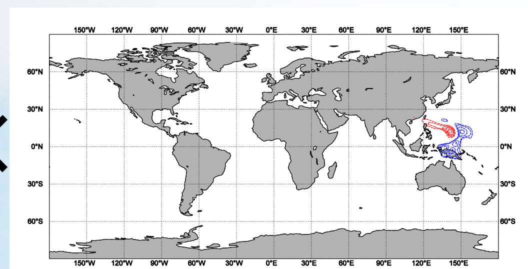
SV_2

$+ \alpha_2 \times$ 

SV_{50}

$+ \cdots$

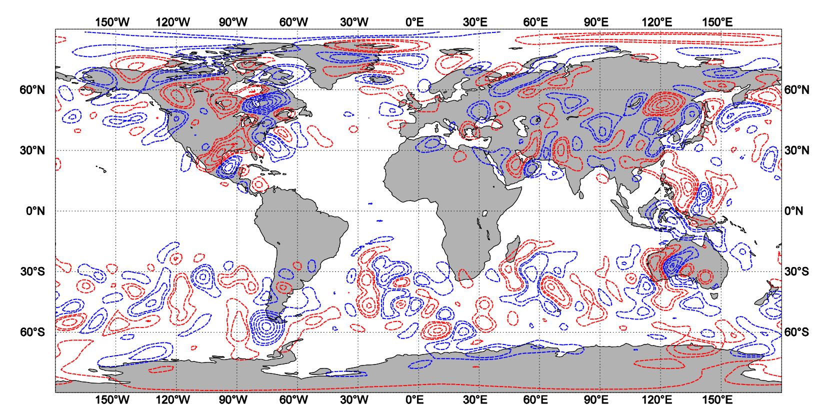
SV_{TC1}

$+ \alpha_{TC1} \times$ 

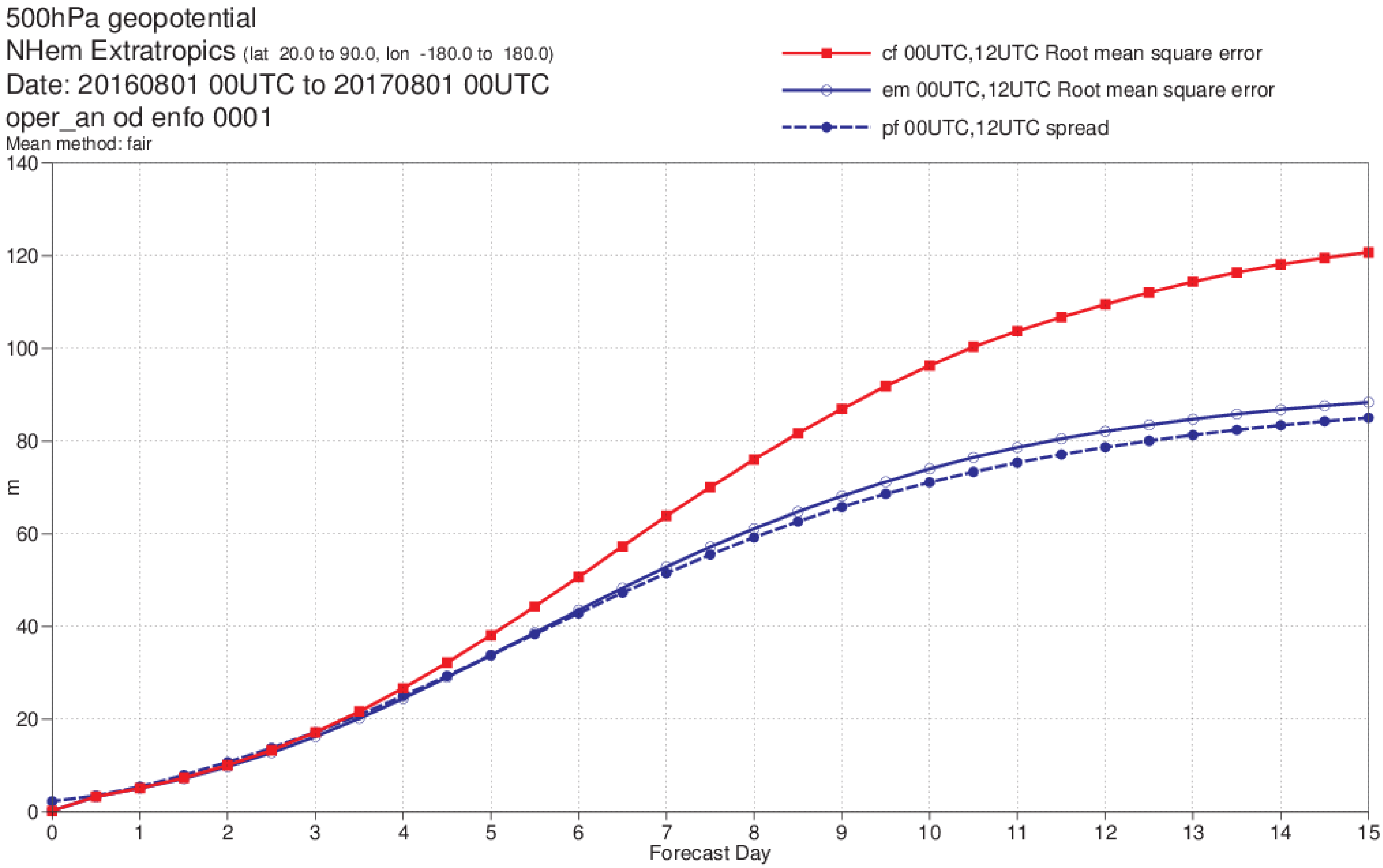
SV_{TCn}

$+ \cdots$

SVPERT 1

$=$ 

Ensemble Spread vs Error



How to improve?

Improve SV perturbations:

- SV resolution
- Moist processes in SV computation
- Number of SVs

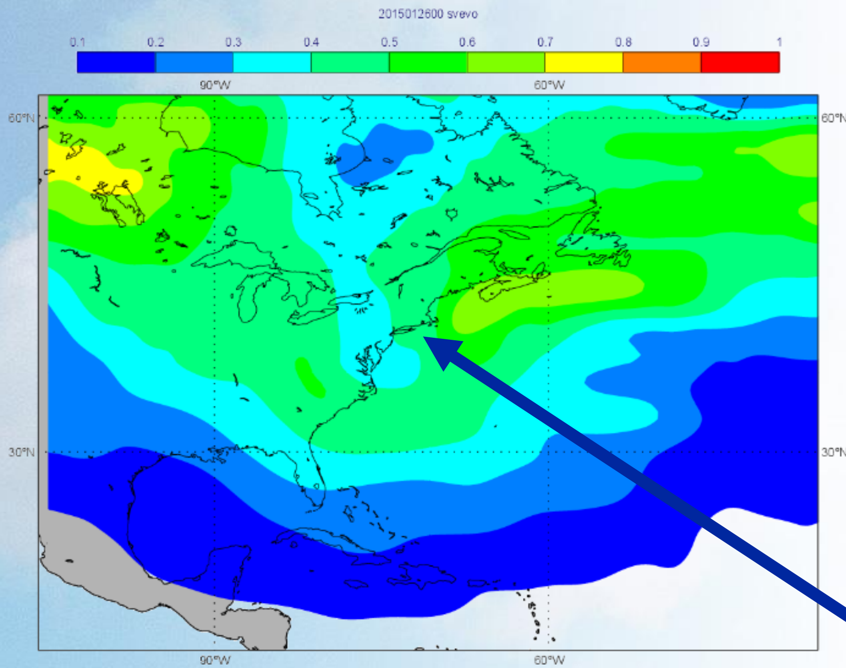
Improve EDA:

- Number of ensemble members
- Analysis quality and resolution
- Specification of observation errors
- Model uncertainty representation

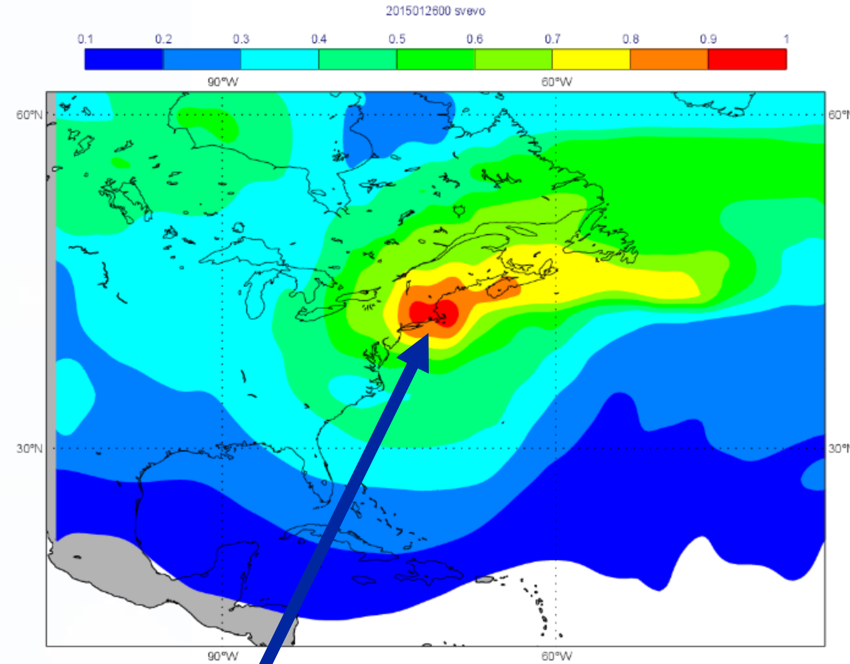
Singular Vector Configuration:

2015012600+48h

50 dry T42 evolved SVs



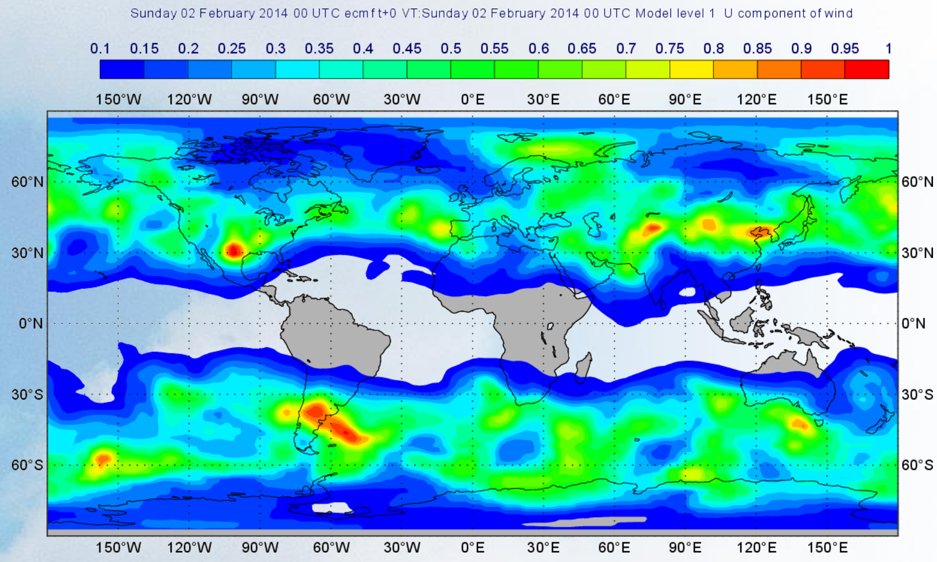
150 moist TL95 evolved SVs



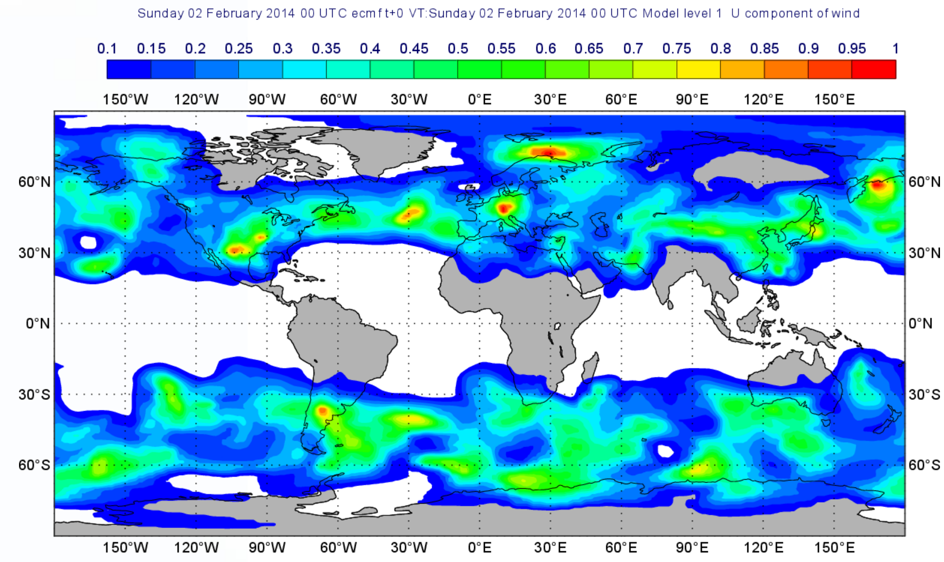
East coast blizzard, 27/28 Jan 2015

Normalised vertically integrated total energy: vte=vte/vte_max (global max)

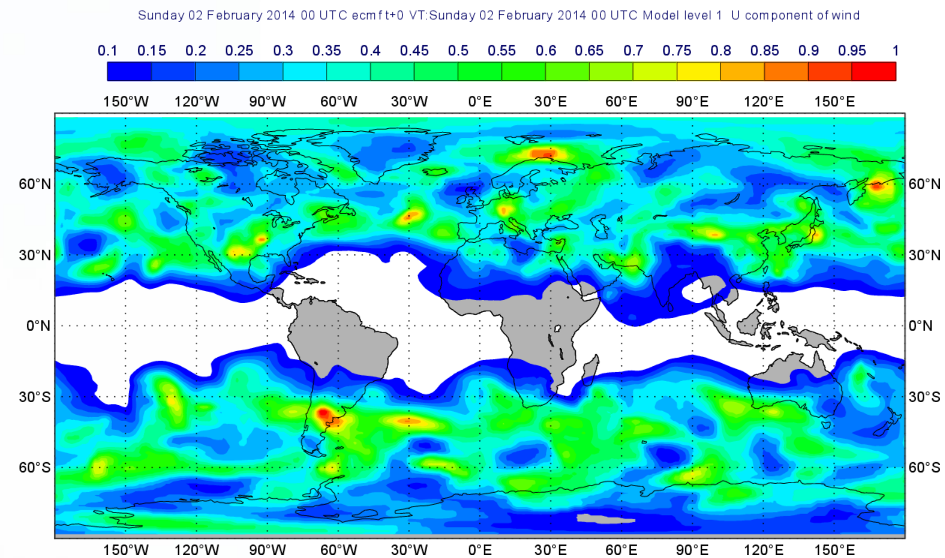
50 dry T42 initial SVs



50 moist TL95 initial SVs



150 moist TL95 initial SVs

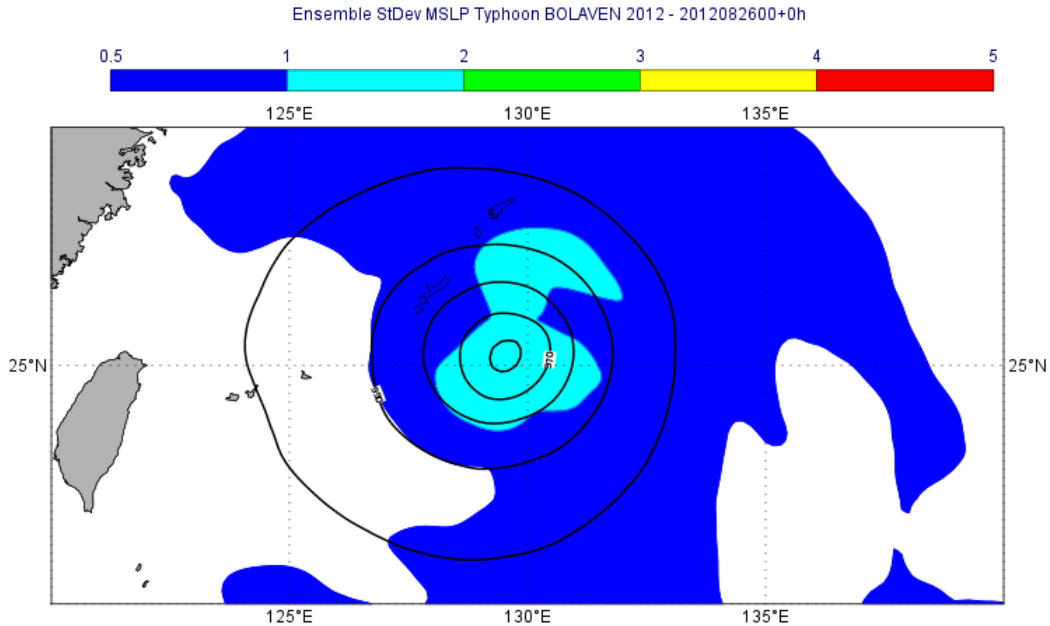


Normalised vertically integrated total energy: vte=vte/vte_max

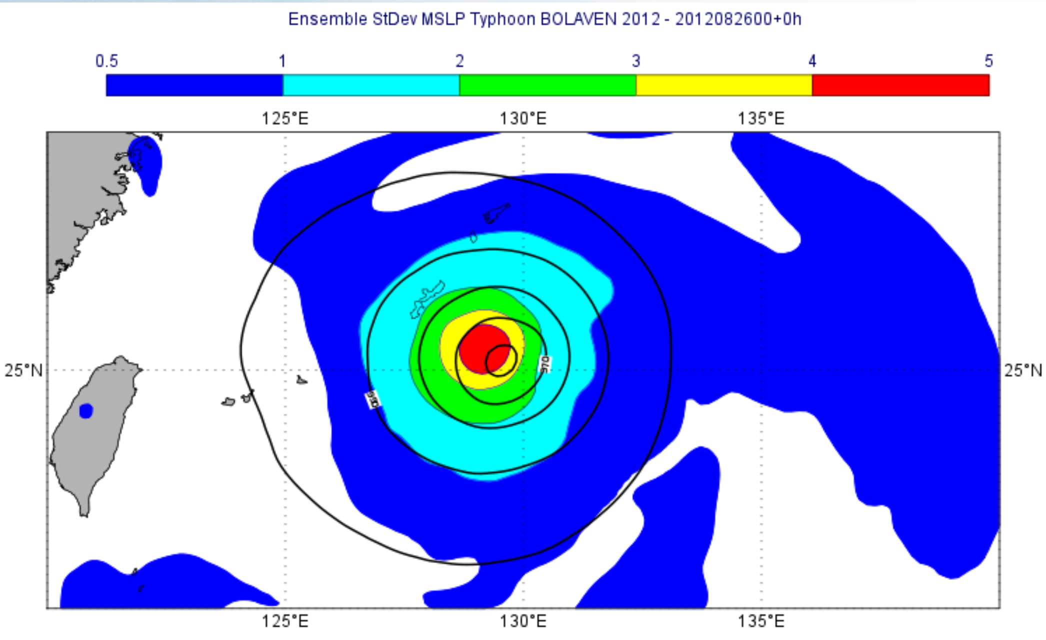
Date:
2014020200

Example: EDA Resolution

Typhoon BOLAVEN 2012
MSLP ENS StDev



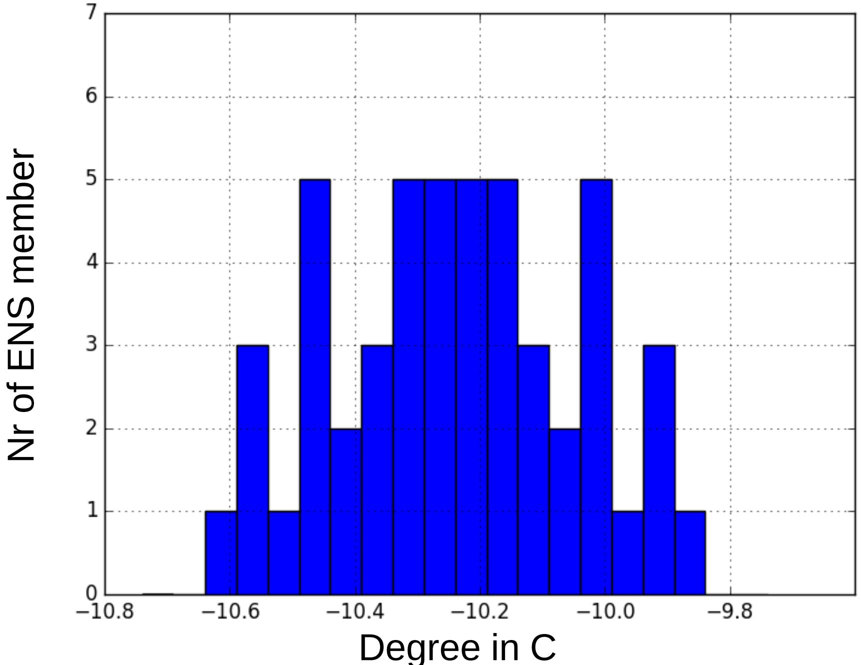
ENS with perturbations from TL399 EDA

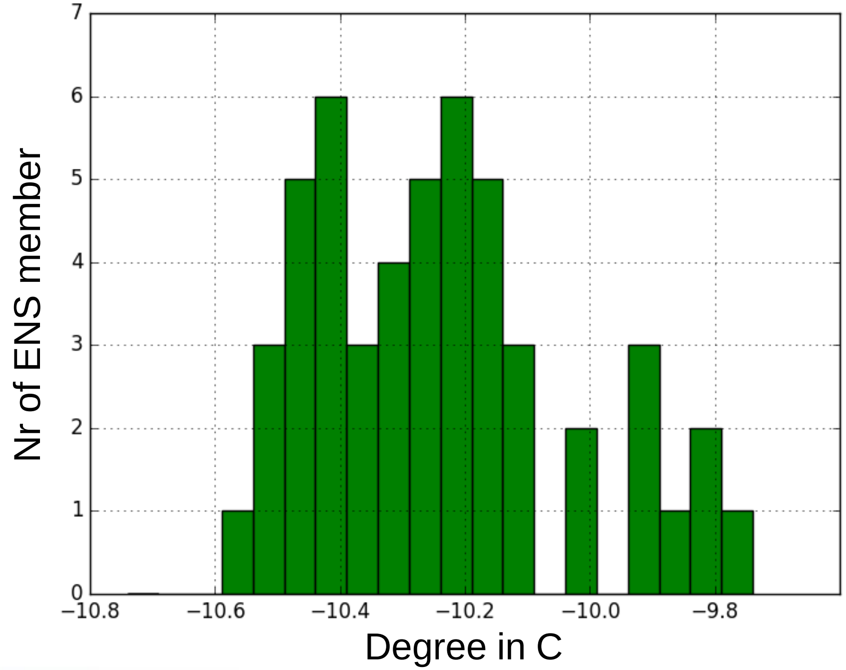


ENS with perturbations from TL639 EDA

ECMWF

ENS with 25 member EDA plus-minus vs. 50 member EDA





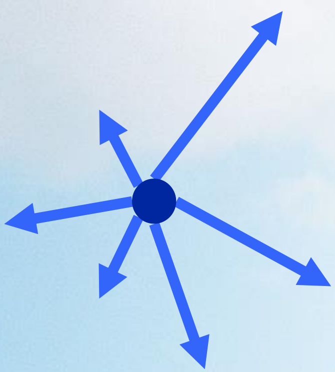
Grid Point Temperature values of Ensemble members at t=0

Re-centring with multiple centre analyses

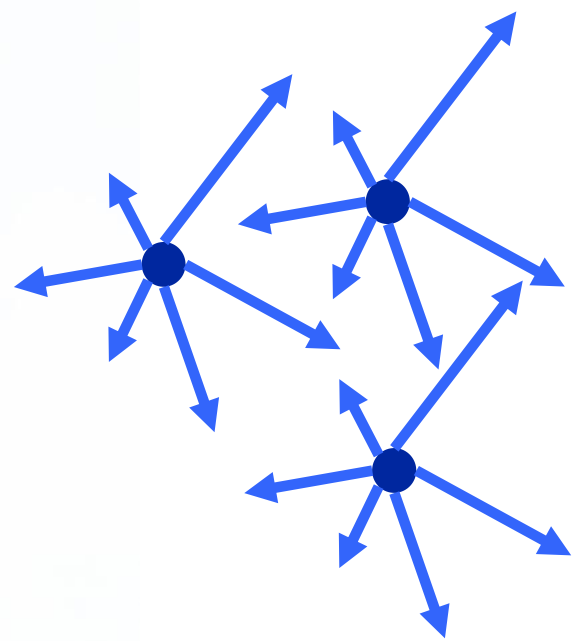
Wish: start from high quality real-time EDA (see Lang et. al 2015)
-> very expensive

Here: centre on a small number of HRES like analyses with different satellite obs selection for thinning (ECMWF's Data Assimilation Strategy 2017). No model unc. representation and obs perturbations in the centre analyses to limit sampling uncertainty.

Single Centre Analysis

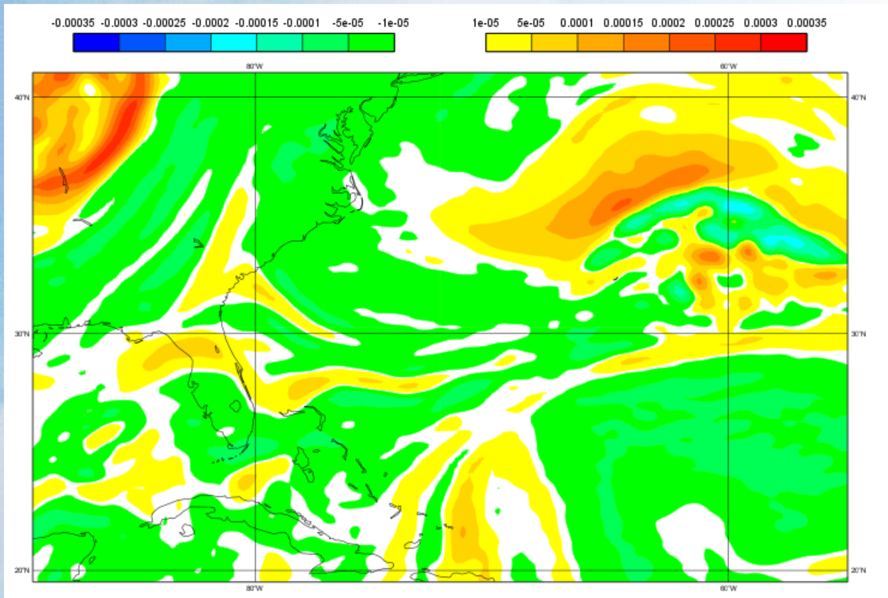


Multiple Centre Analyses

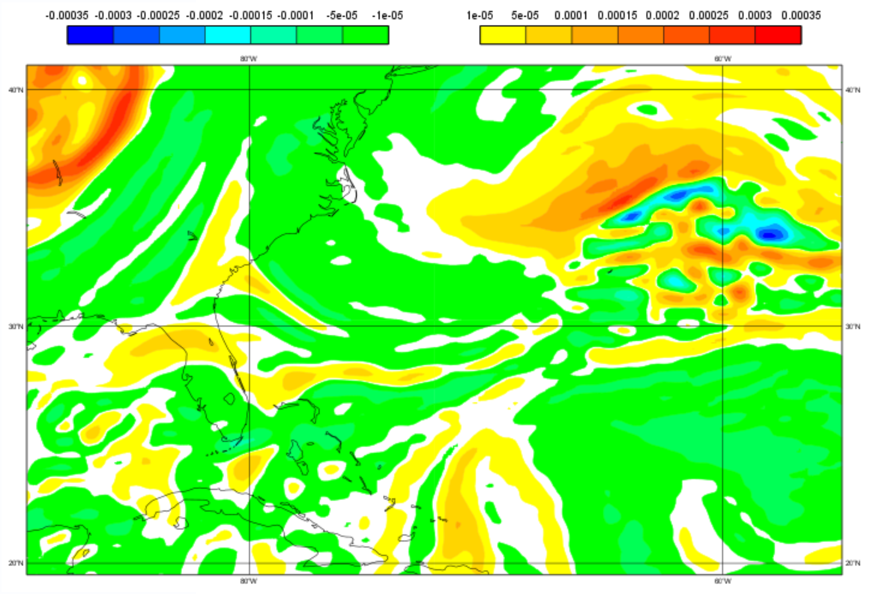


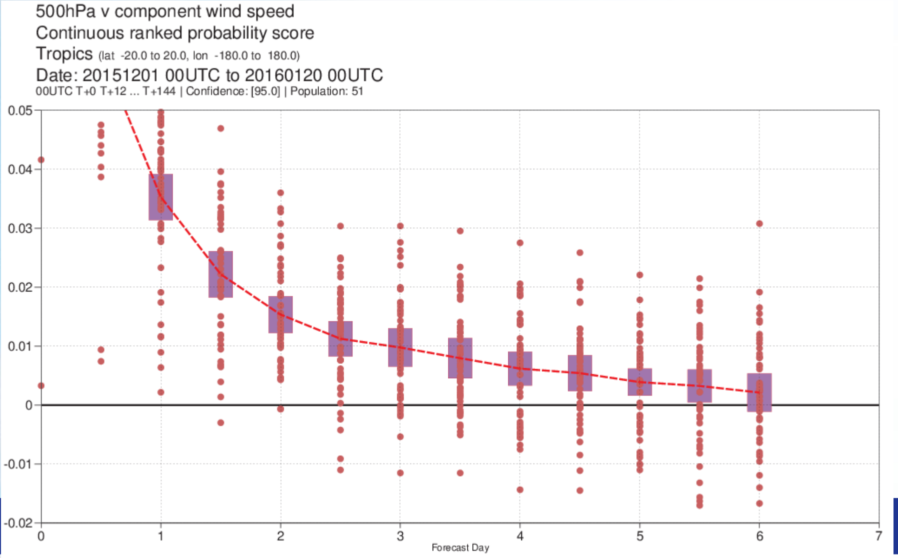
Re-centring with multiple centre analyses

5-Ana ENS Mean Step 0,
Vorticity 500hPa



Ref ENS Mean Step 0,
Vorticity 500hPa





Summary

- Combining SVs with EDA results in a quite reliable system
- In order to obtain the best forecast skill it is currently necessary to re-centre on the HRES analysis
- Use of SVs justified as long the ENS lacks spread in the directions of the SVs

Options to improve the perturbed ENS initial condition in the future:

- singular vector resolution, number and moist processes
- Increase the number of EDA members and quality of the members, model uncertainty in EDA, obs. perturbations

-> Big challenge: how to use the available computer resources in the most effective way?

References:

➢ Bonavita, M, Trémolet, Y, Holm, E, Lang, STK, Chrust, M, Janiskova, M, Lopez, P, Laloyaux, P, De Rosnay, P, Fisher, M, Hamrud, M, English, S. (2017), A Strategy for Data Assimilation. ECMWF Tech. Memo 800

➢ Leutbecher, M. and Lang, S. T. K. (2014), On the reliability of ensemble variance in subspaces defined by singular vectors. Q.J.R. Meteorol. Soc., 140: 1453–1466. doi:10.1002/qj.2229

➢ Lang, S. T. K., Bonavita, M. and Leutbecher, M. (2015), On the impact of re-centring initial conditions for ensemble forecasts. Q.J.R. Meteorol. Soc., 141: 2571–2581. doi:10.1002/qj.2543

Additional Slides

How can we adjust the ensemble spread?

Pert* = a x Pert + b x Z

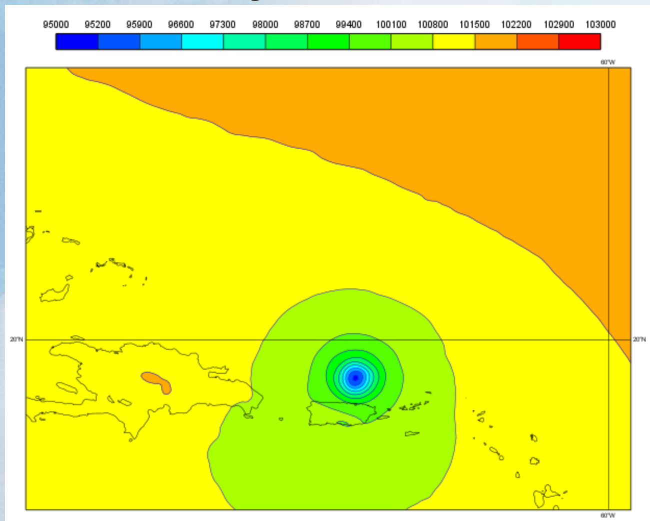
multiplicative inflation (a)

additive inflation (b x Z)

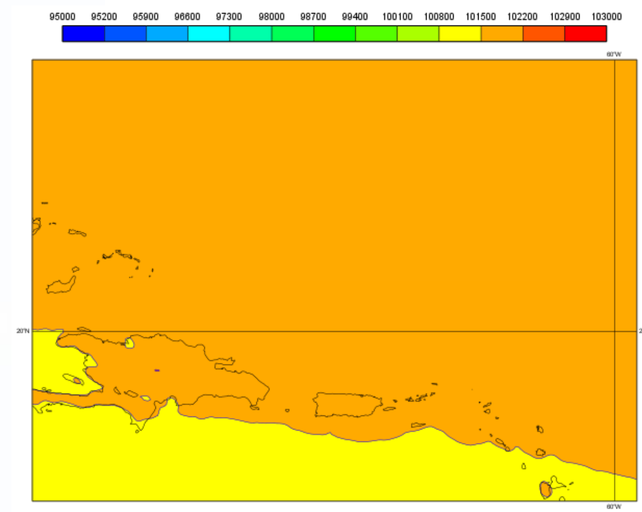
ECMWF

Flow dependency vs no flow dependency

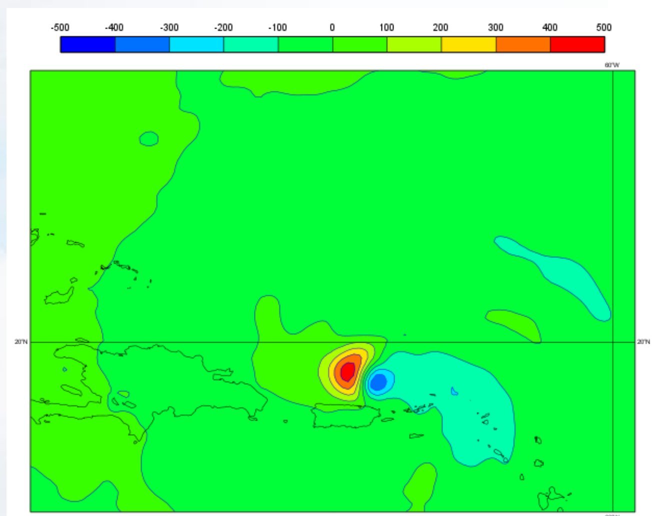
Analysis Irma



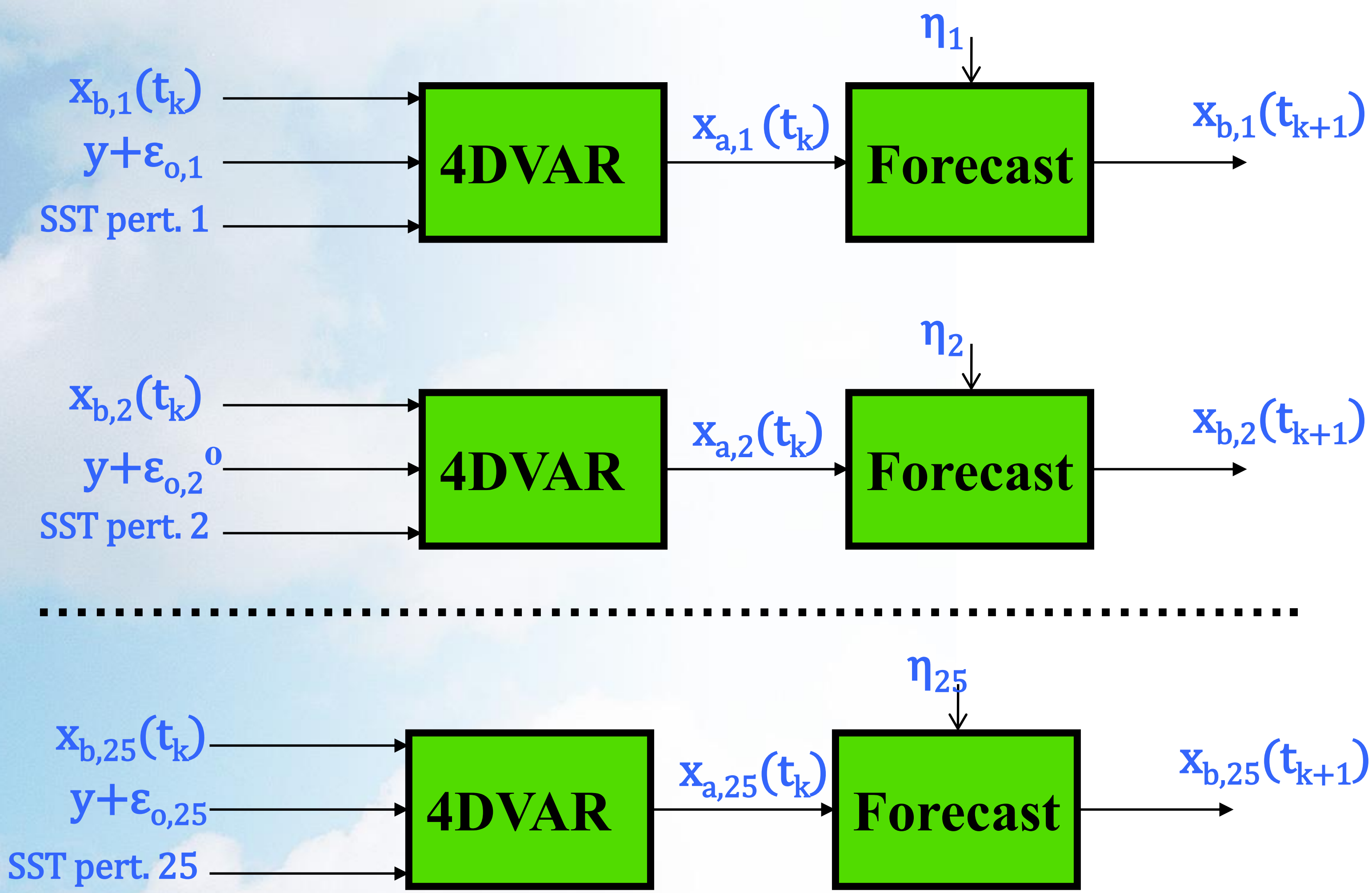
Analysis some other day



Perturbation
EDA member 1



The Ensemble of Data Assimilations



From M. Bonavita’s ECMWF DA training course lecture