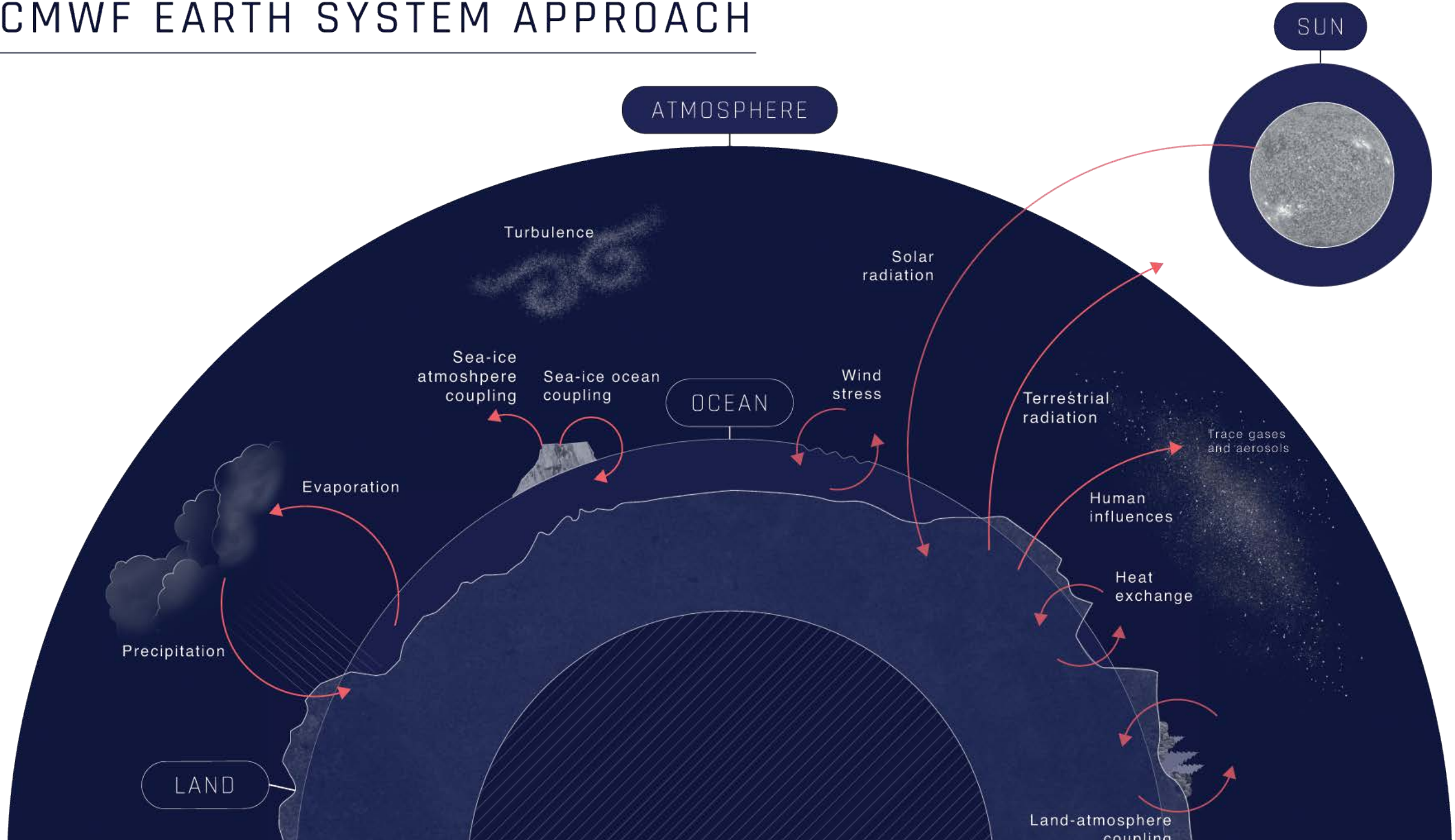
ECMWF Ensemble Forecasts

Simon Lang and colleagues

ECMWF

ECMWF EARTH SYSTEM APPROACH



Medium range (day 0 - 15)**:**

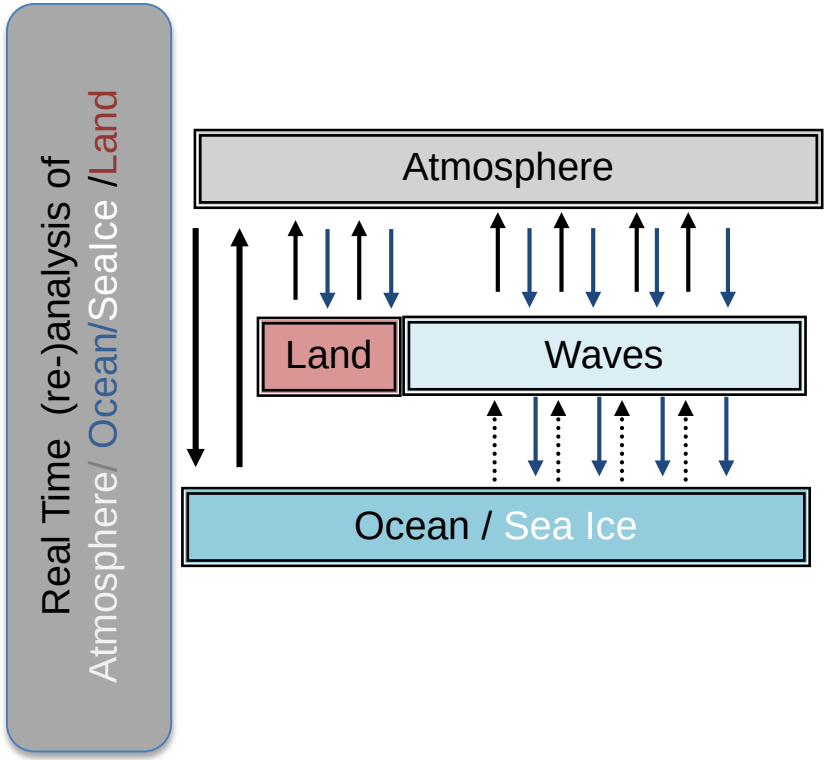
- 51 Members (50 perturbed + control member without perturbations), TCo639 (~ 18 km), 91 vertical levels
- Coupled to NEMO ocean model (1/4 degree) and LIM2 ice model
- Coupled to WAM wave model
- initial conditions from deterministic analysis, TCo1279 (~ 9 km), 137 levels, ocean data assim. (ORAS5), wave data assim.
- Initial perturbation via an ensemble of data assimilations (EDA) and singular vectors (SVs), 5 member ocean data assimilation
- Model error representation via SPPT

Extended range (day 15 - 46)**:**

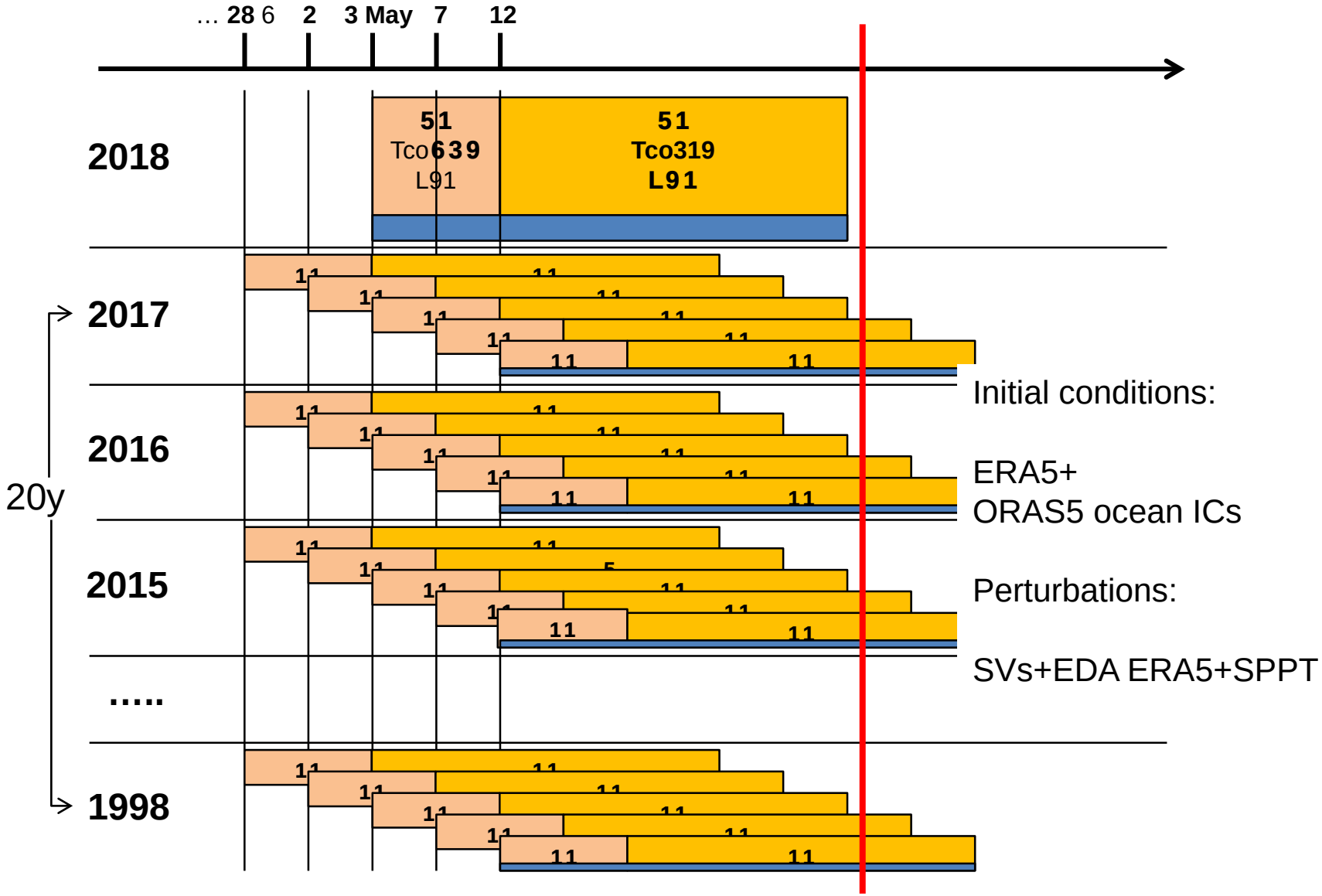
- continuation of the medium range system, twice a week
- TCo319 (~ 36 km)

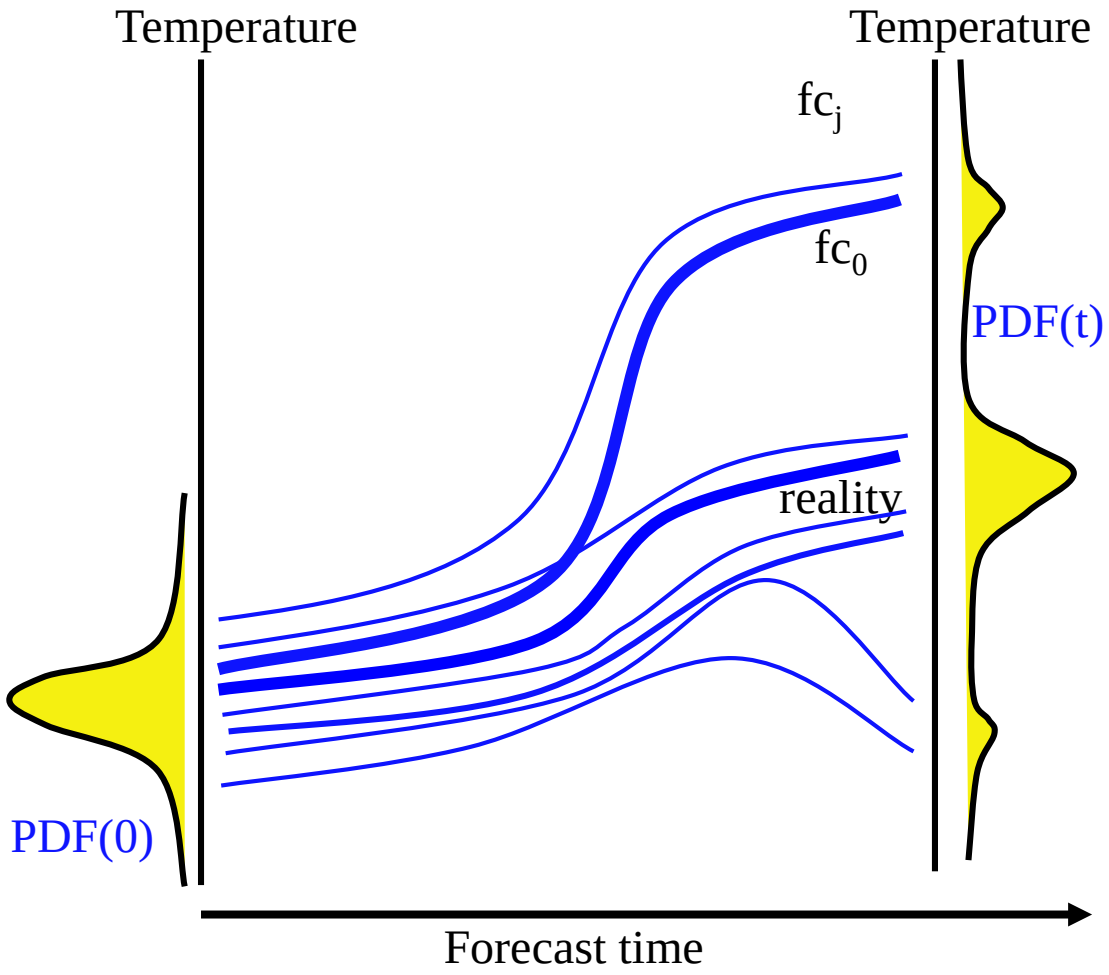
Seasonal (month 2 – 7, SEAS 5)**:**

- TCo319 (~ 36 km)
- additional SST perturbations, …
- Model error representation via SPPT, SKEB
- different model cycle, …



The ENS re-forecast suite to estimate the M-climate





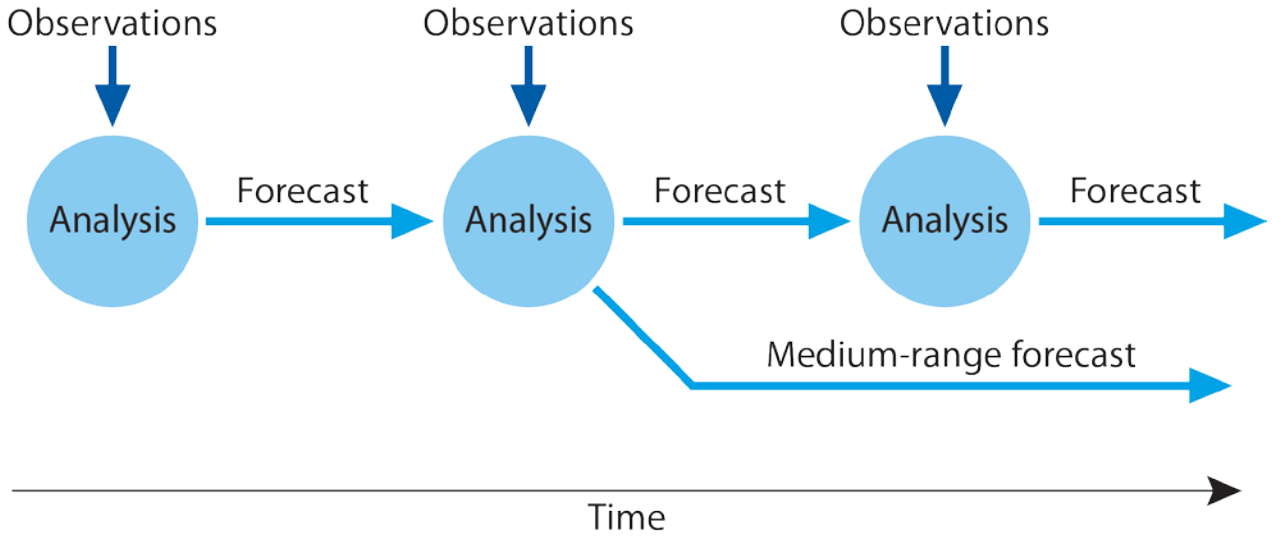
from R. Buizza

Sources of Uncertainty:

- Initial Conditions
- Model Formulation

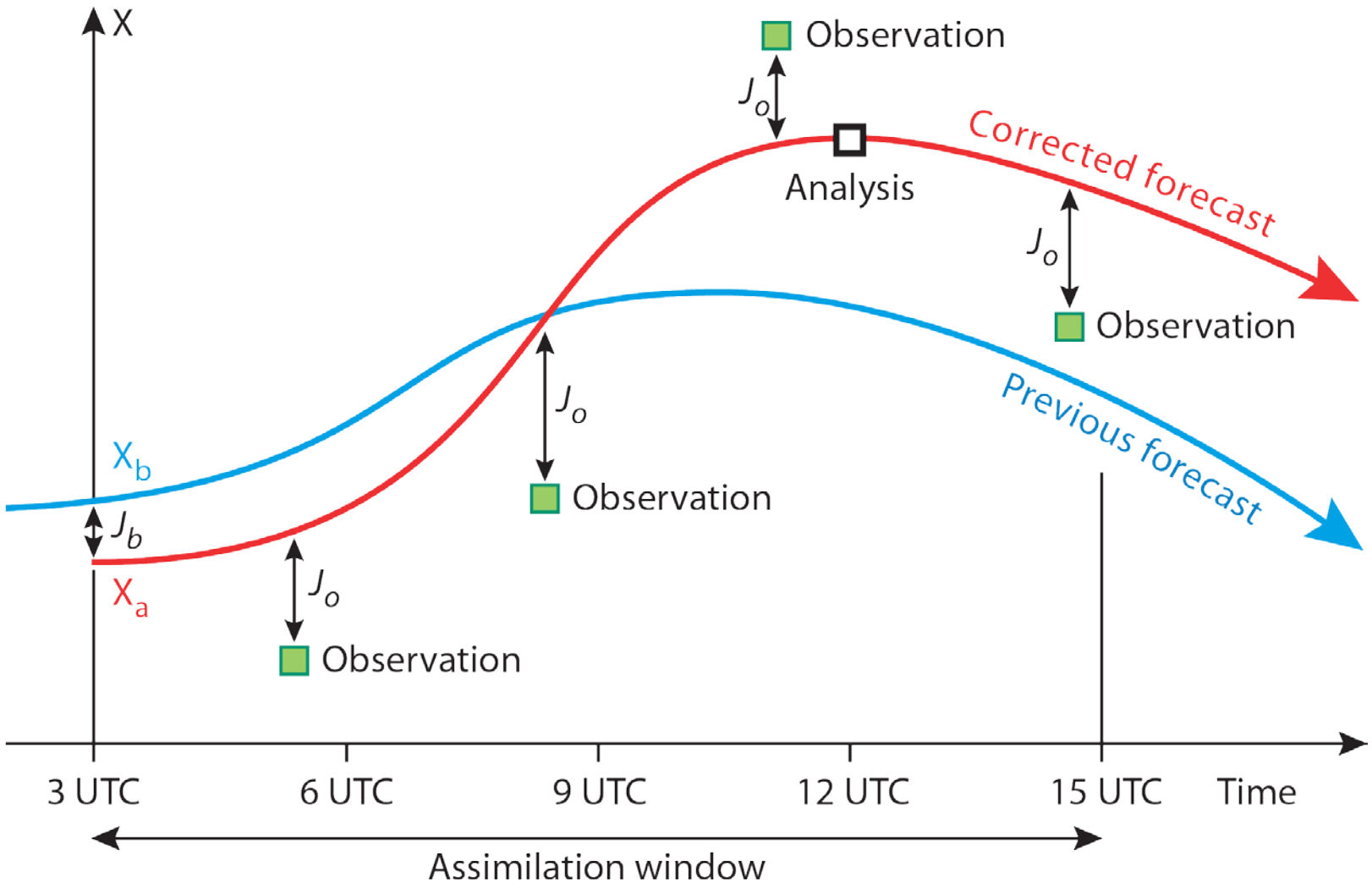
Starting the Medium-Range Forecast – the 'Analysis'

Analysis: 3 dimensional virtual image of the atmosphere at a given time.

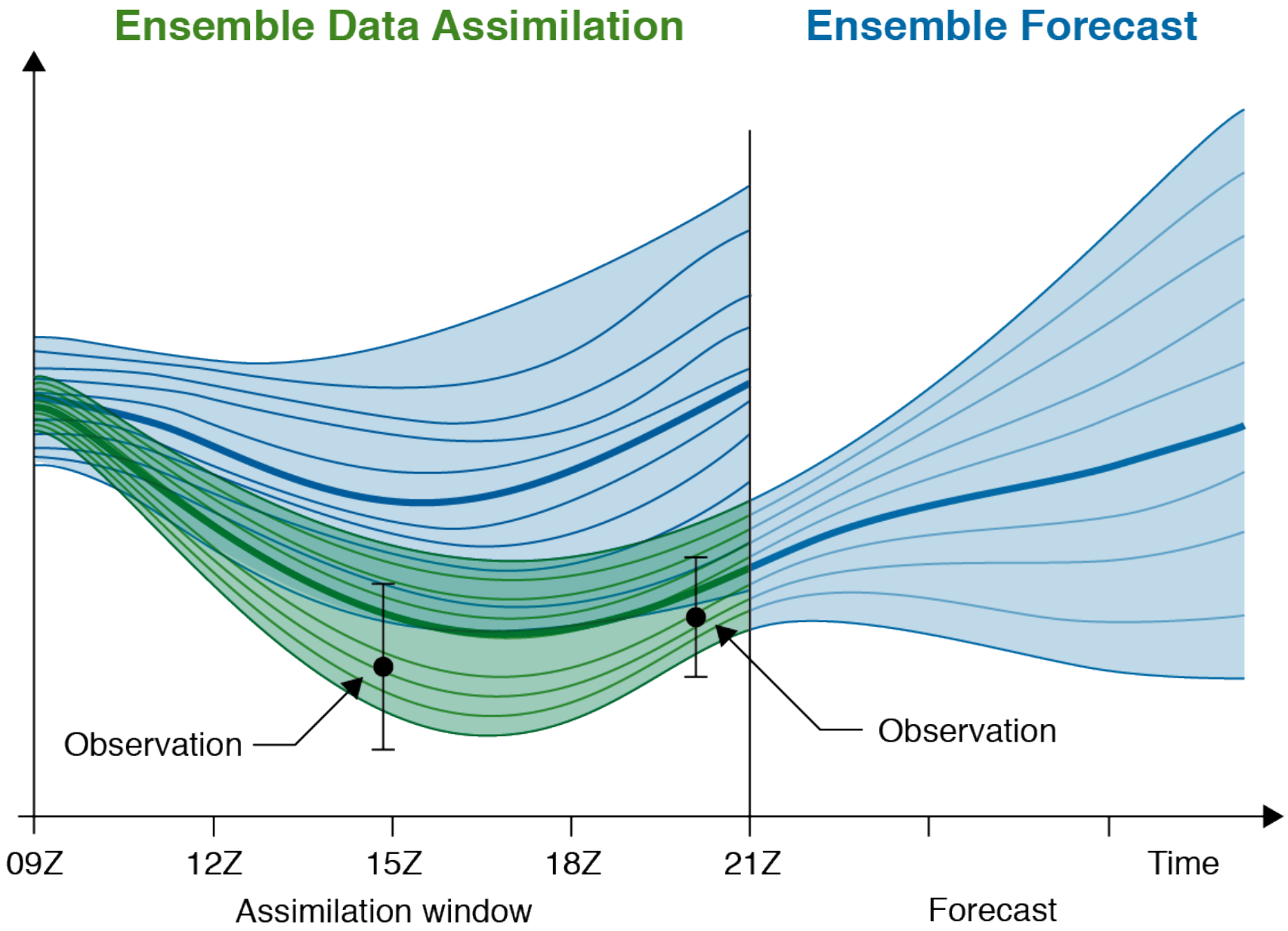


- The short range forecast from the previous analysis is our 'first estimate' of the current state of the atmosphere.

Initial conditions: 4D-Var assimilation



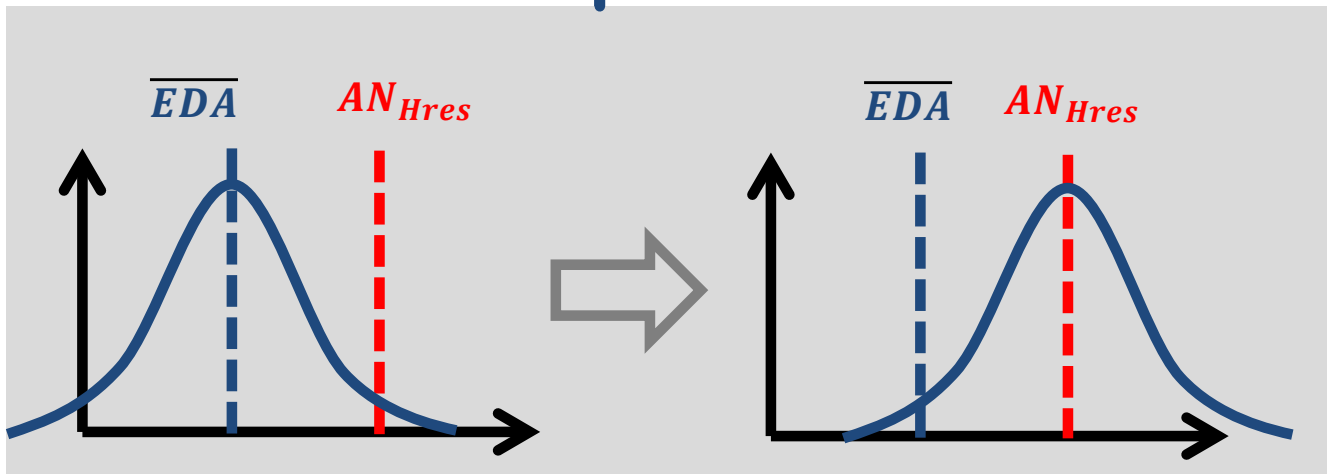
ECMWF


Ensemble Data Assimilation
Ensemble Forecast
Observation
Observation
09Z
12Z
15Z
18Z
21Z
Time
Assimilation window
Forecast

ECMWF

Generation of initial conditions for the ensemble:

$$AN_{pf} = AN_{Hres} + \left(EDA_i - \overline{EDA}\right) + \left(SVPERT_j - \overline{SVPERT}\right) \qquad \begin{matrix} i = 1..50 \\ j = 1..50 \end{matrix}$$



EDA : 6h Forecasts

Re-centre EDA-Distribution on Hres-Analysis

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

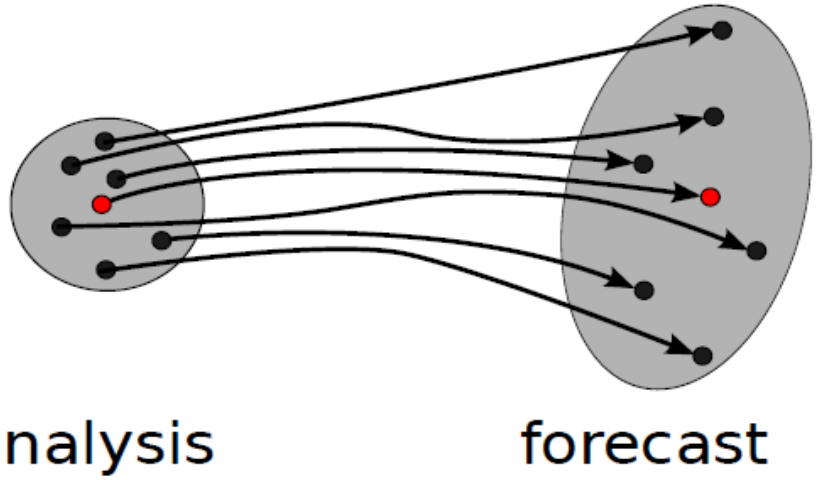
α random number drawn from Truncated gaussian

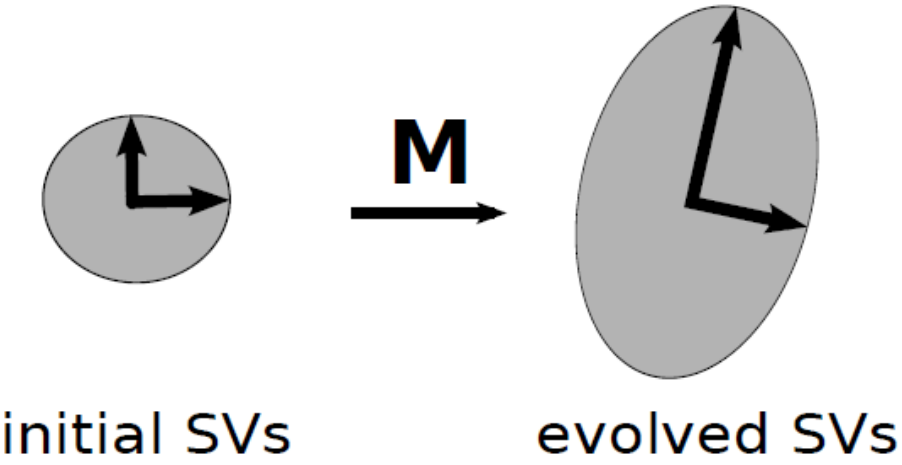
NSET : nhem, shem, TCs1-6
NSV : 50 for nhem and shem, 5 for TCs

Singular Vector Perturbations

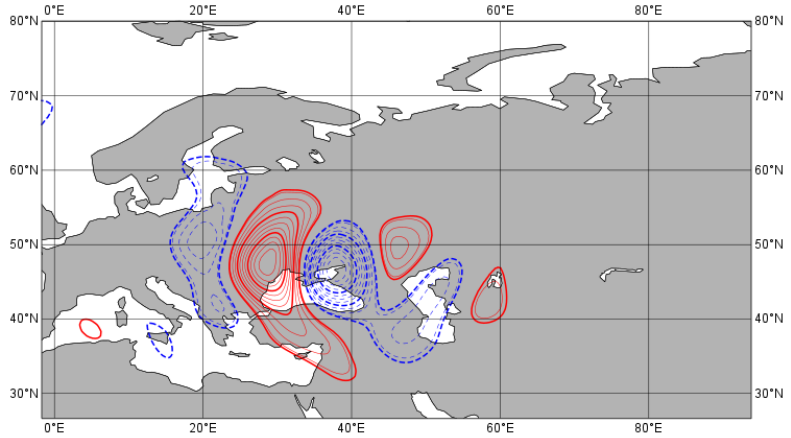
Directions of fastest growth over a finite time interval (optimisation interval)

Justification: EDA + Model Uncertainty representation produce substantial spread in the directions of the leading SVs but ensemble still under dispersive (Leutbecher and Lang, 2014, QJRM)

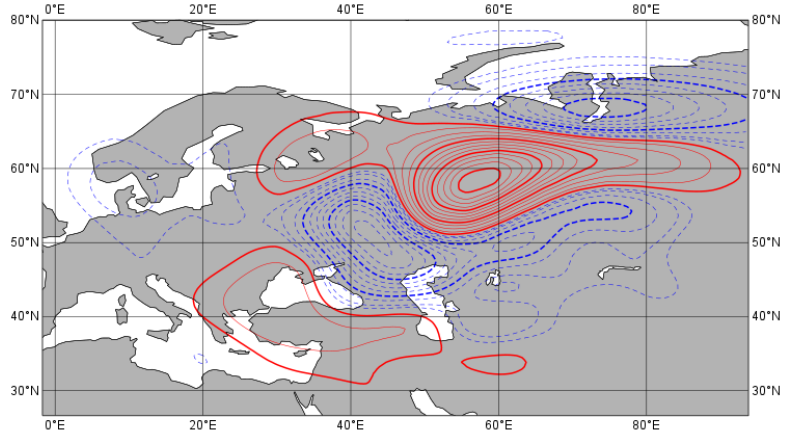




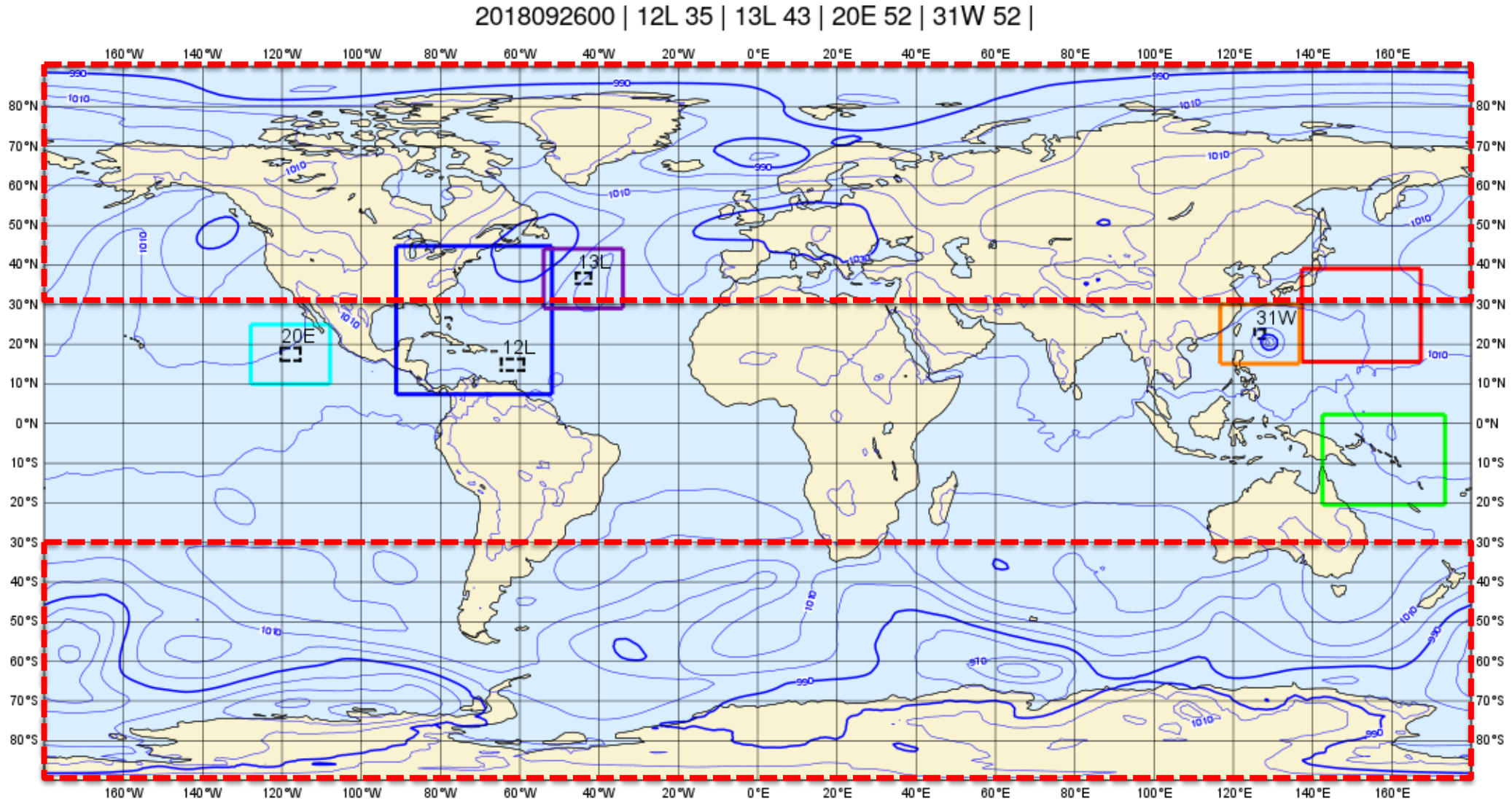
Initial SV, T mlevel 68



evolved SV, T mlevel 49



SV Target Areas



Model Error Representation: SPPT

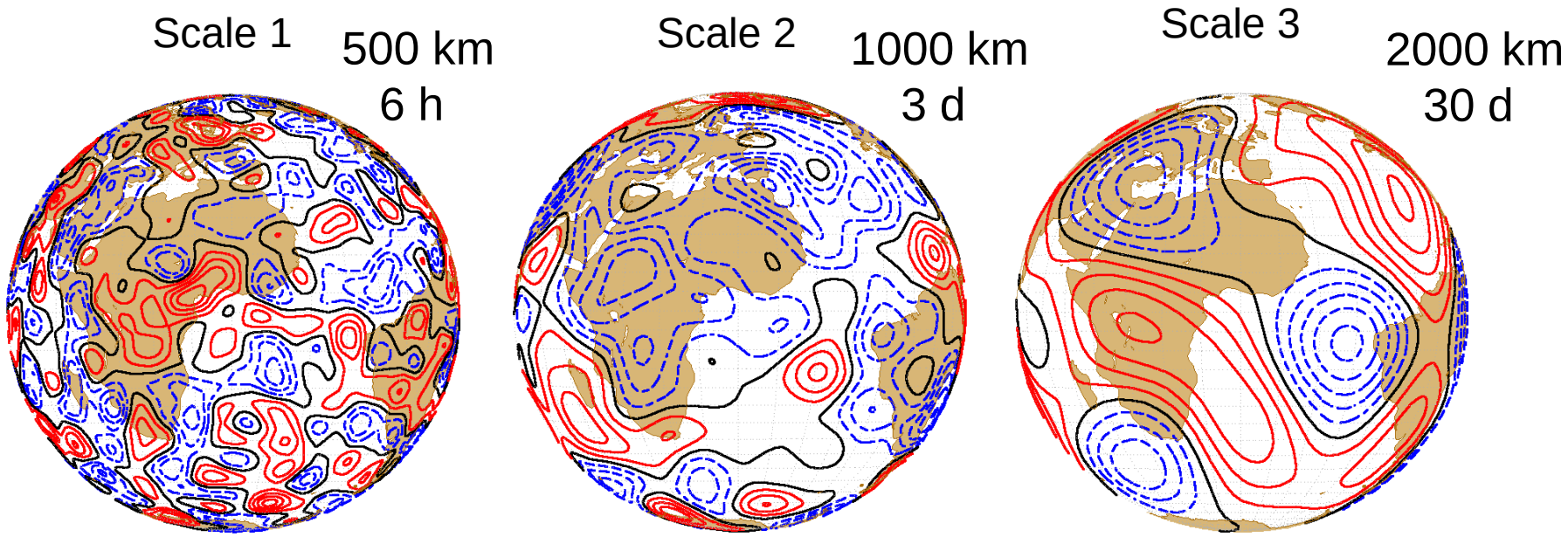
See Leutbecher et al., 2017 for details

Perturb model tendencies during the forecast:

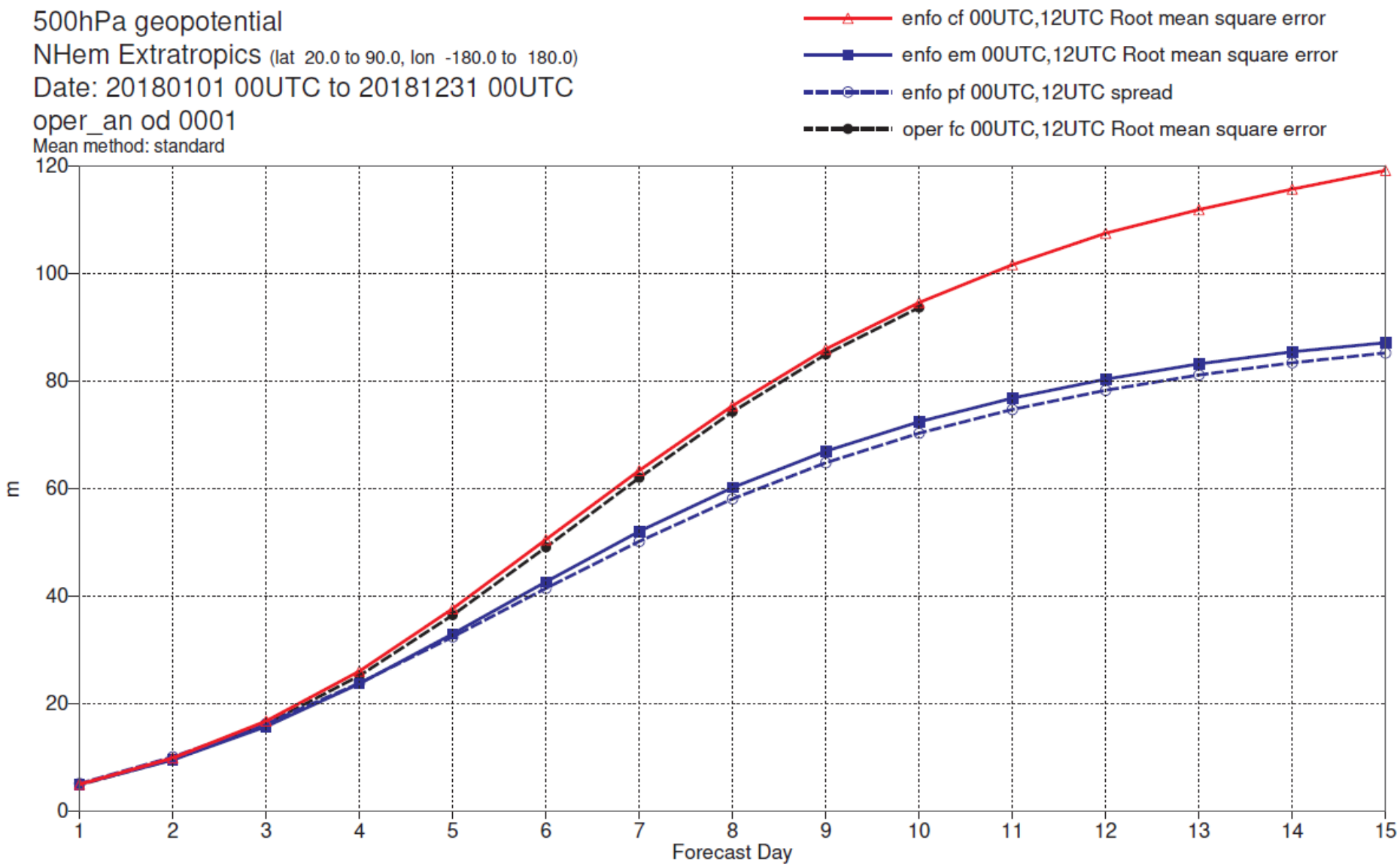
$$\boldsymbol{x}_p = \boldsymbol{x} + \boldsymbol{\alpha x}$$

$\boldsymbol{x}$ sum of tendencies from parametrization schemes (convection, radiation, cloud etc.)

$\boldsymbol{\alpha}$ includes random time and space correlations, provided by a pattern generator

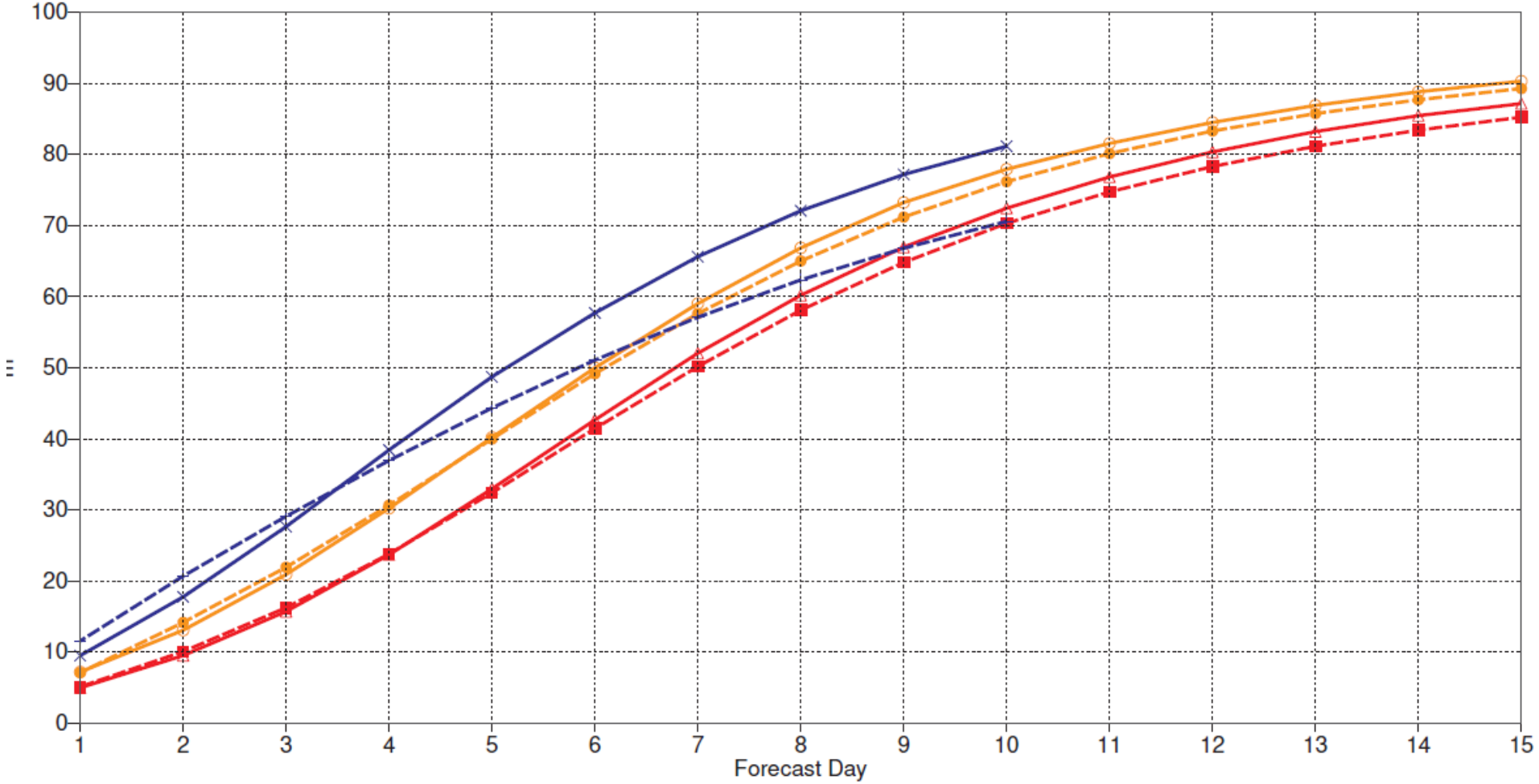


Same model uncertainty representation in ensemble forecasts and ensemble data assimilation


500hPa geopotential
NHem Extratropics (lat 20.0 to 90.0, lon -180.0 to 180.0)
Date: 20180101 00UTC to 20181231 00UTC
oper_an od 0001
Mean method: standard
enfo cf 00UTC,12UTC Root mean square error
enfo em 00UTC,12UTC Root mean square error
enfo pf 00UTC,12UTC spread
oper fc 00UTC,12UTC Root mean square error
m
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Forecast Day

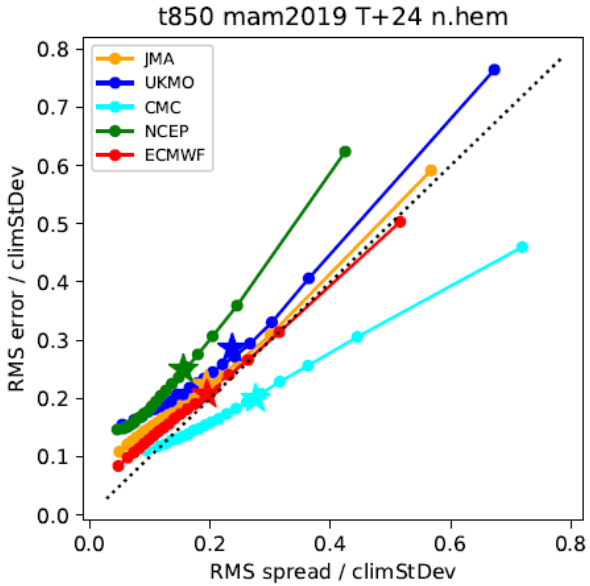
500hPa geopotential
NHem Extratropics (lat 20.0 to 90.0, lon -180.0 to 180.0)
Date: 20010101 00UTC to 20181231 00UTC
oper_an od enfo 0001
Mean method: standard

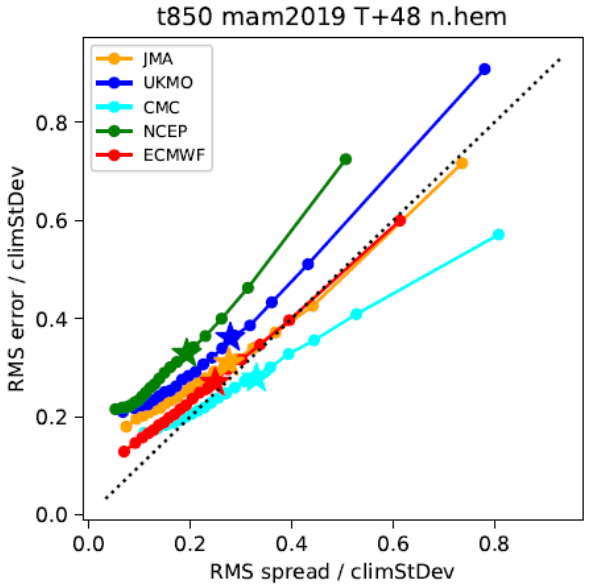
Solid : Error
Dashed : Spread
2001 2008 2018

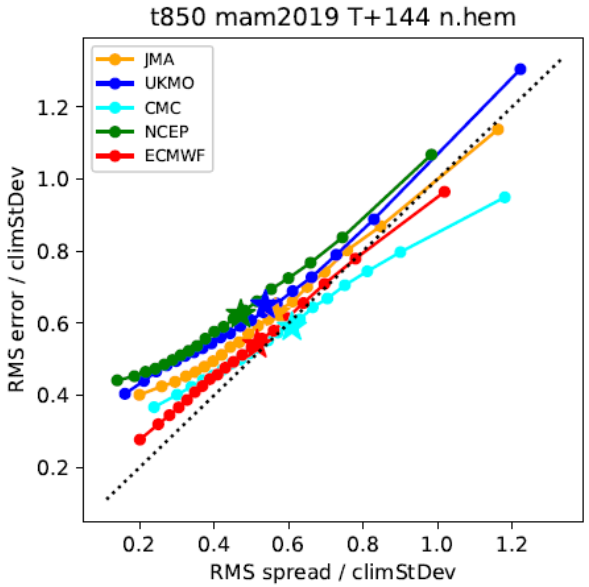


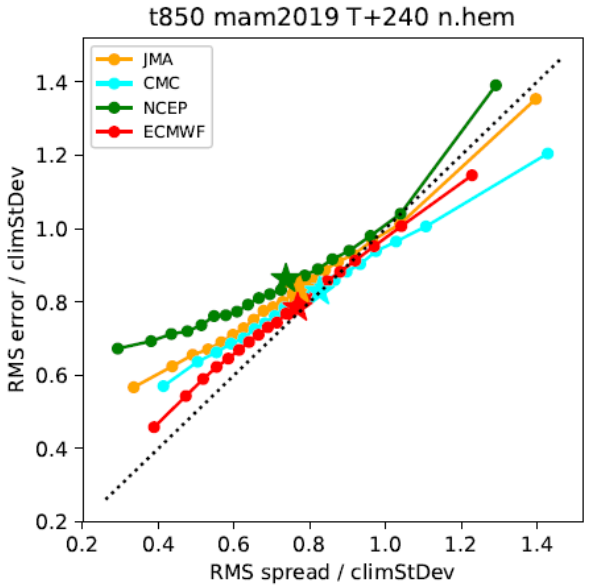
Reliability

n.hem

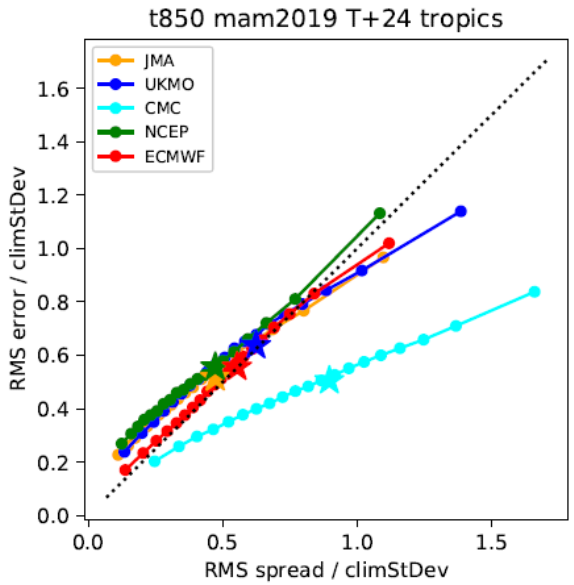


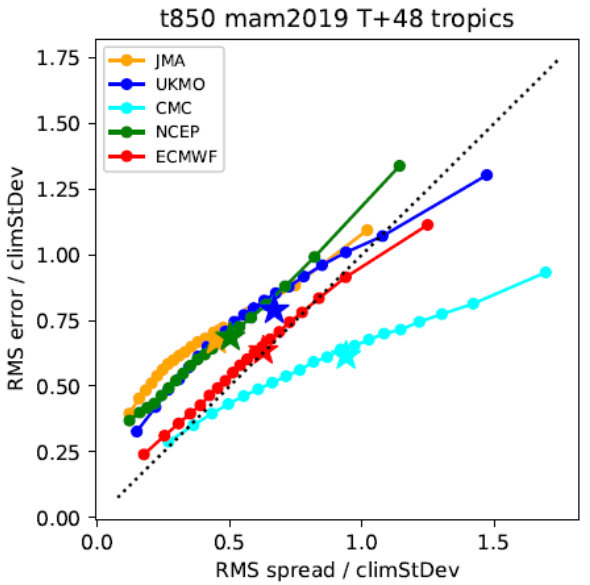


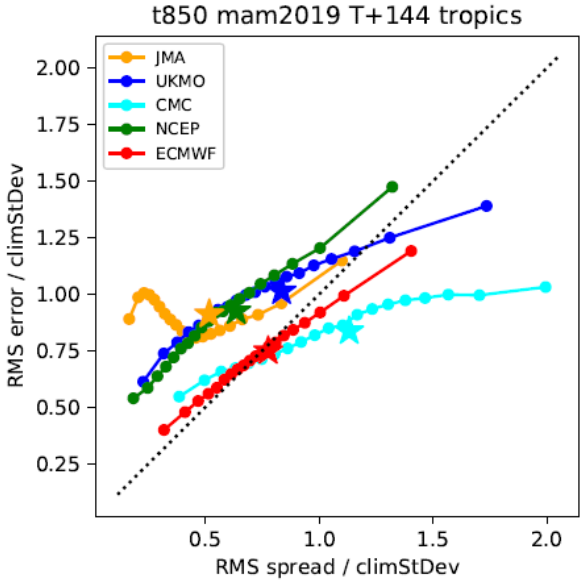


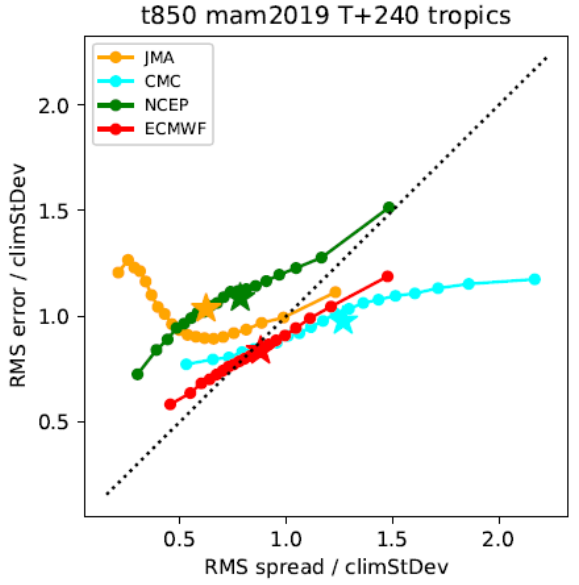


tropics

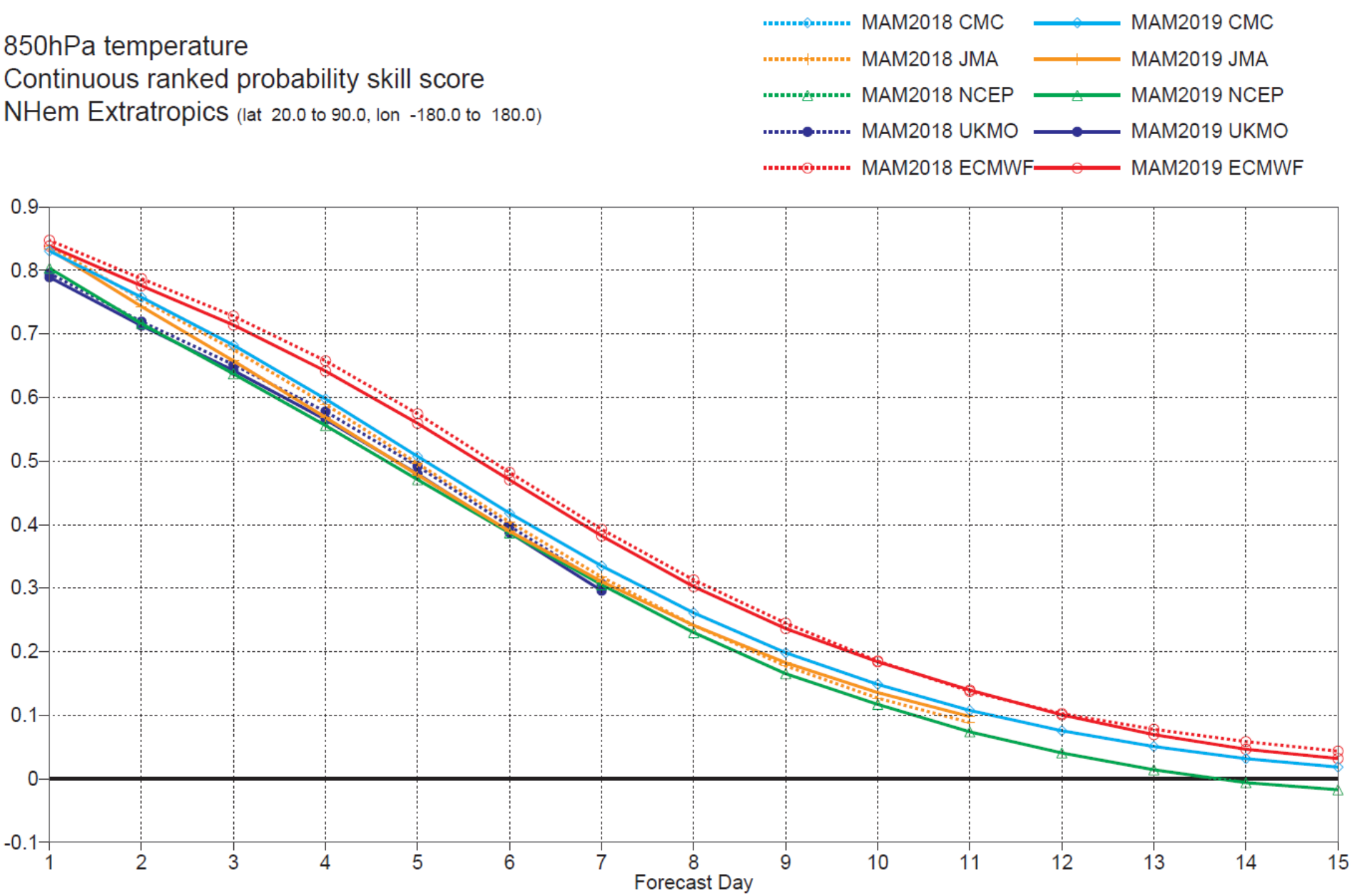




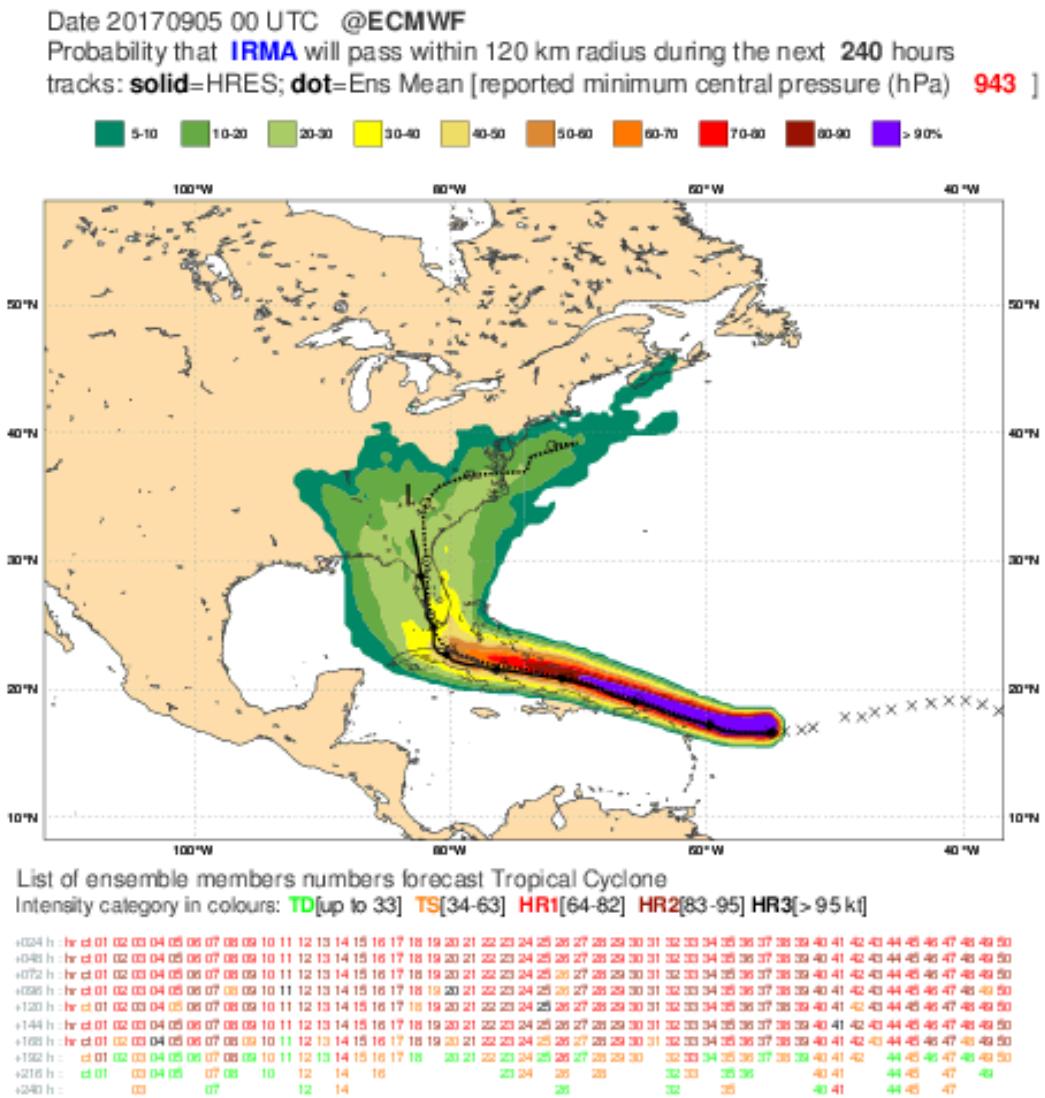


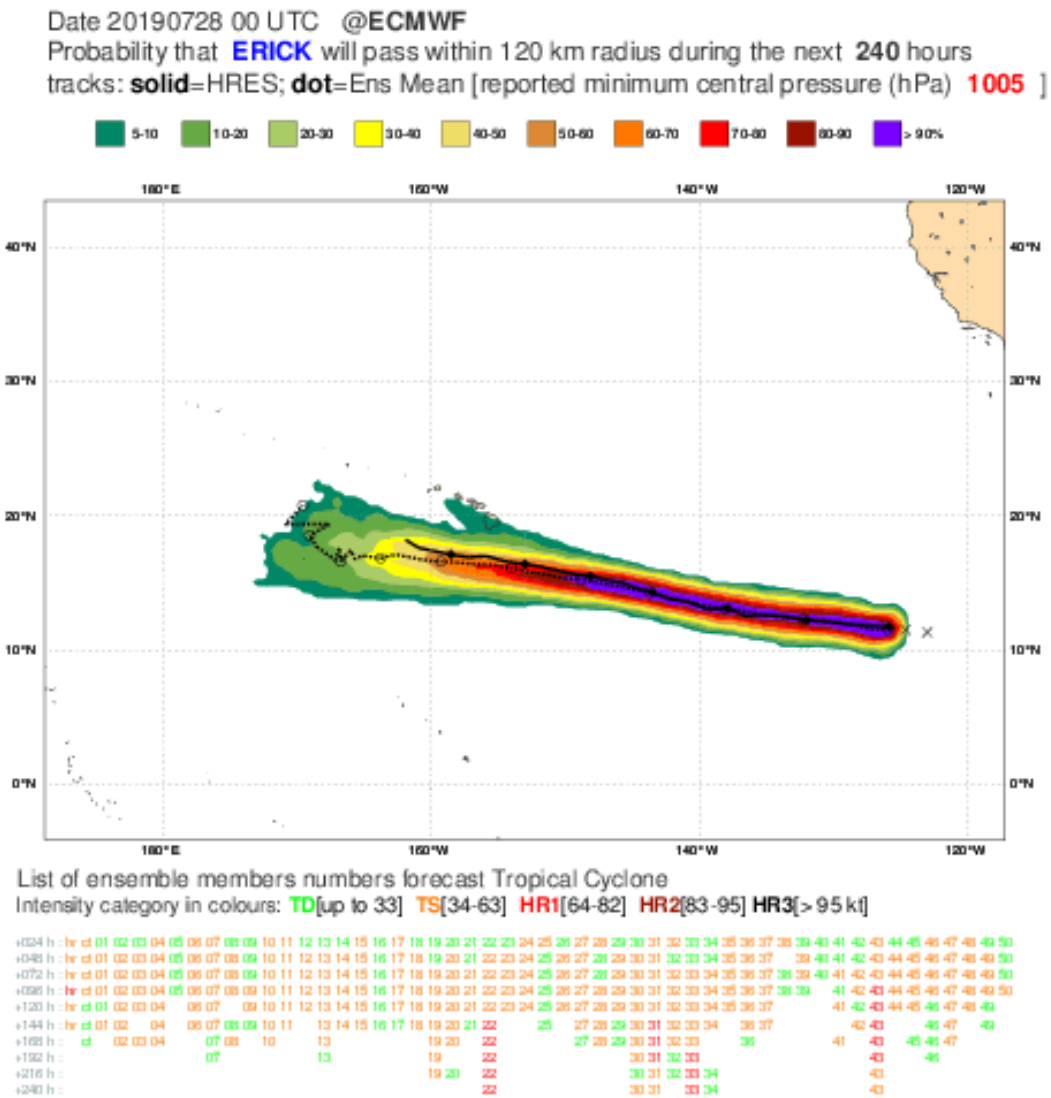


850hPa temperature
Continuous ranked probability skill score
NHem Extratropics (lat 20.0 to 90.0, lon -180.0 to 180.0)

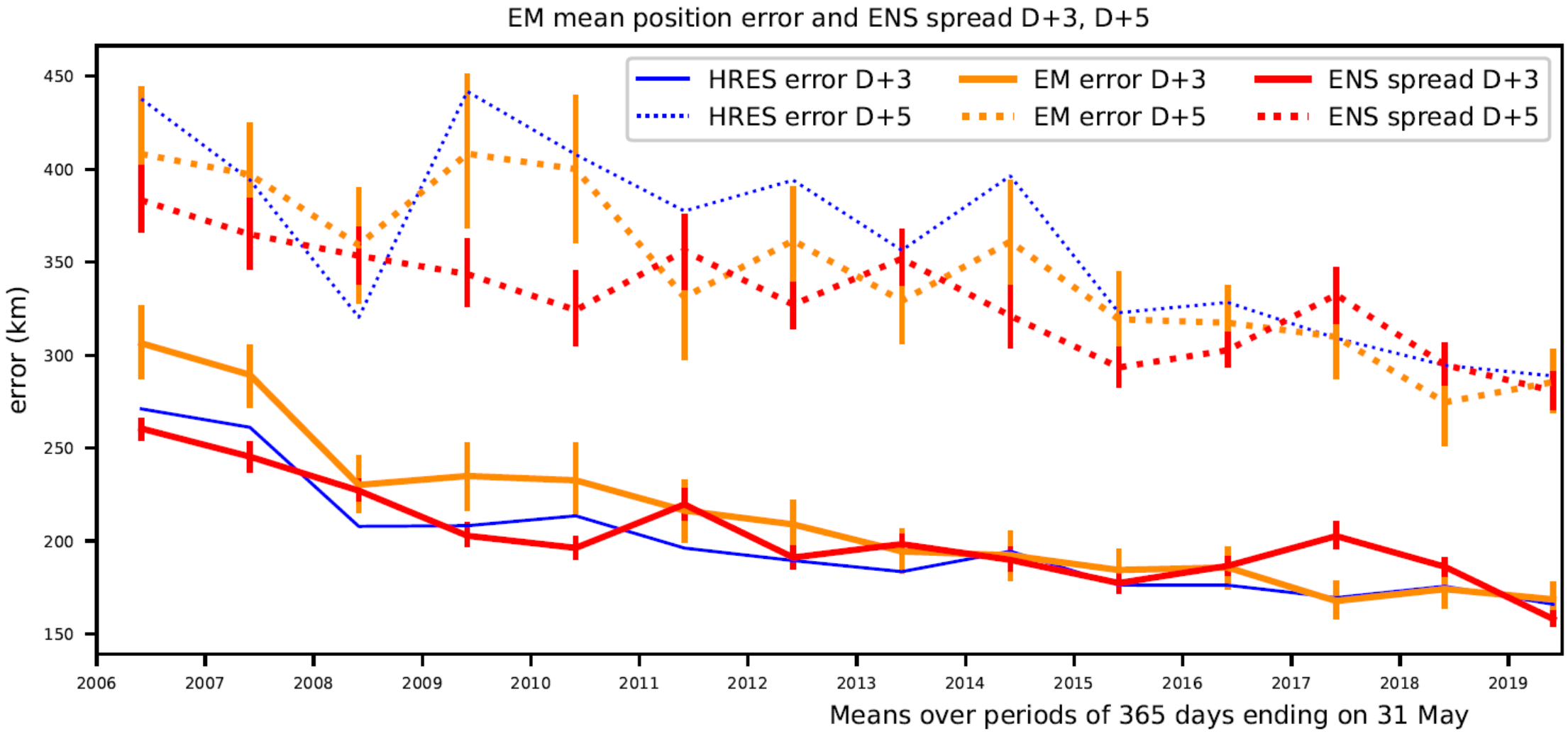


Example:Tropical Cyclone Forecasts

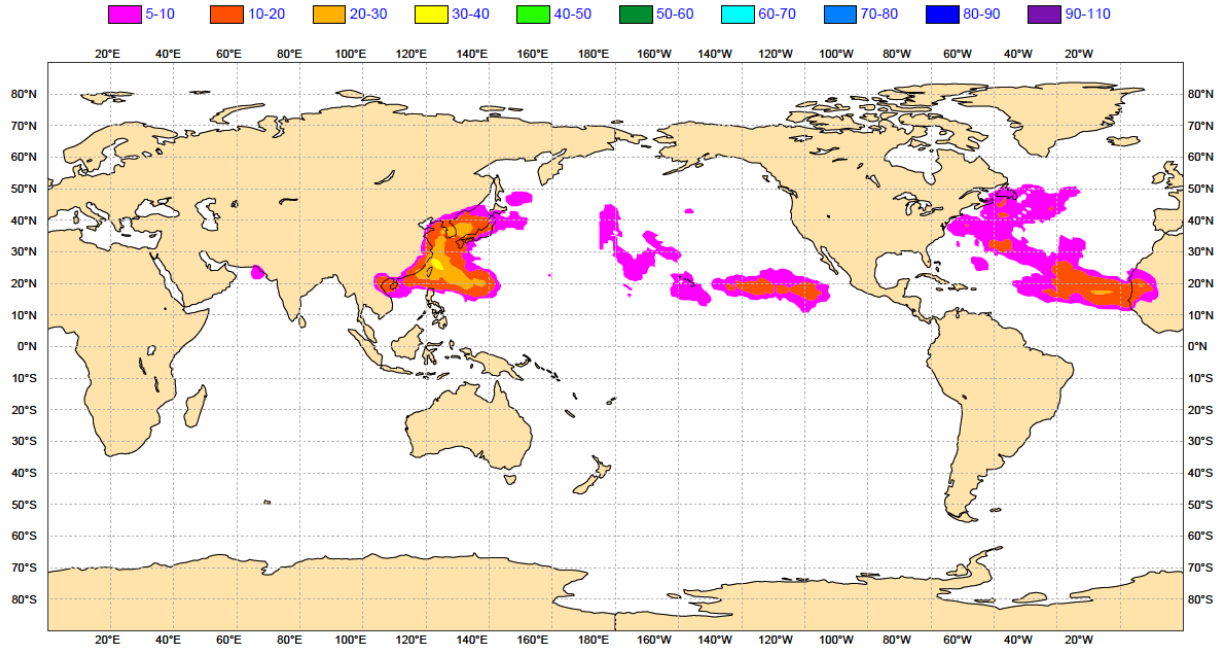




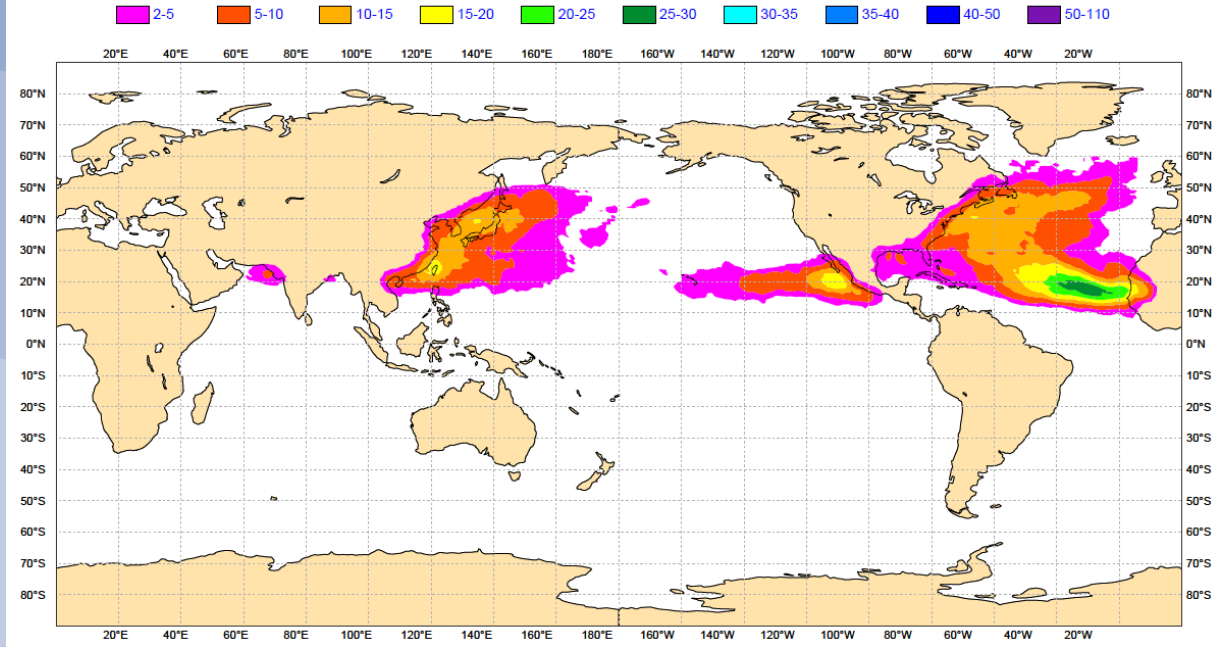
Tropical cyclone track error and spread



Weekly mean Tropical Storm Strike Probability. Date: 20190819 0 UTC t+(336-504)
Probability of a TS passing within 300km radius

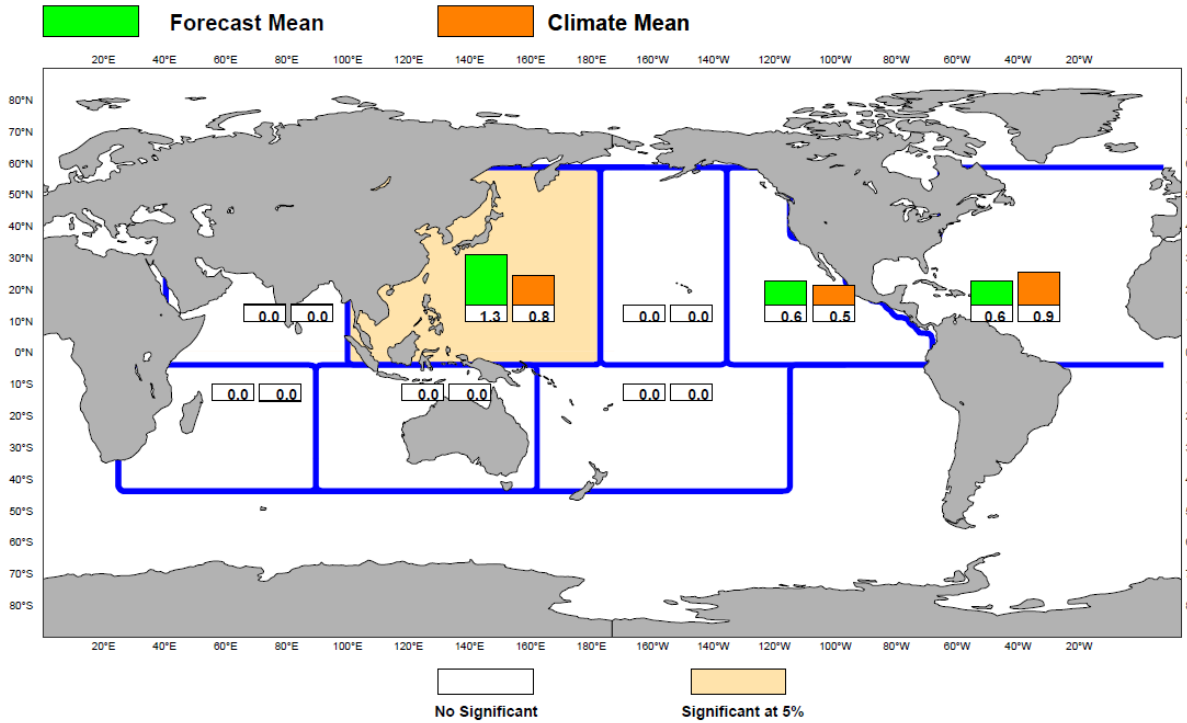


Weekly Mean Tropical Storm Strike Probability (climatology). Date: 20190819 t+(336-504)
Probability of a TS passing within 300km radius

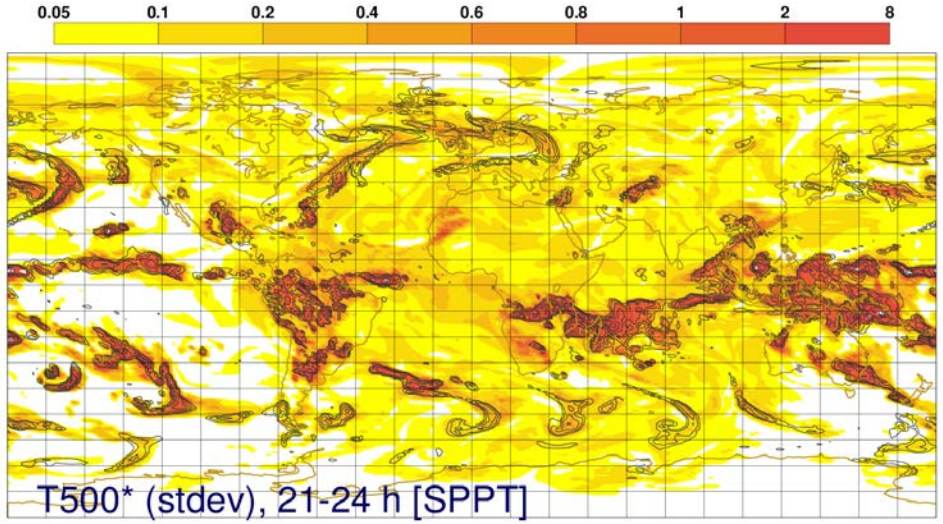


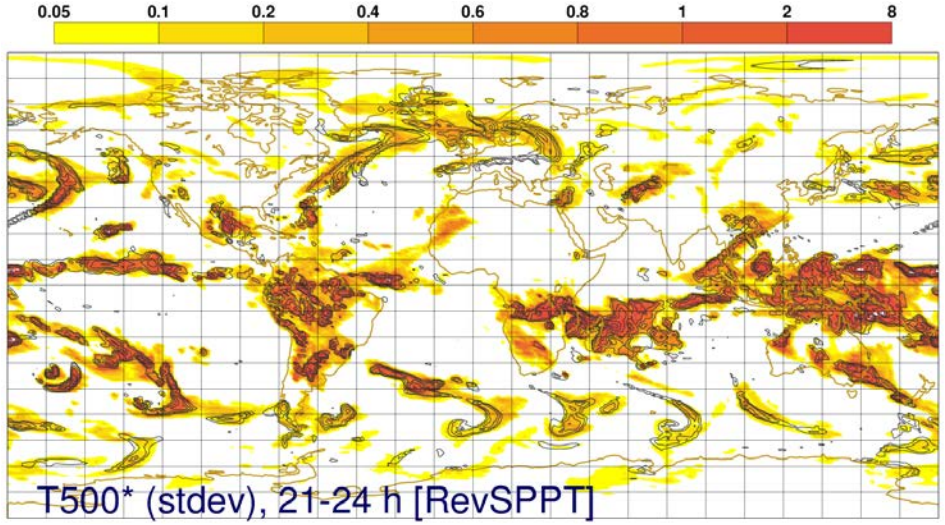
ECMWF Monthly Forecast
Tropical Storm Frequency
Forecast start reference is 19/08/2019
Ensemble size = 51,climate size =220

DAY 15-21
02/09-08/09/2019
Climate = 1999-2018

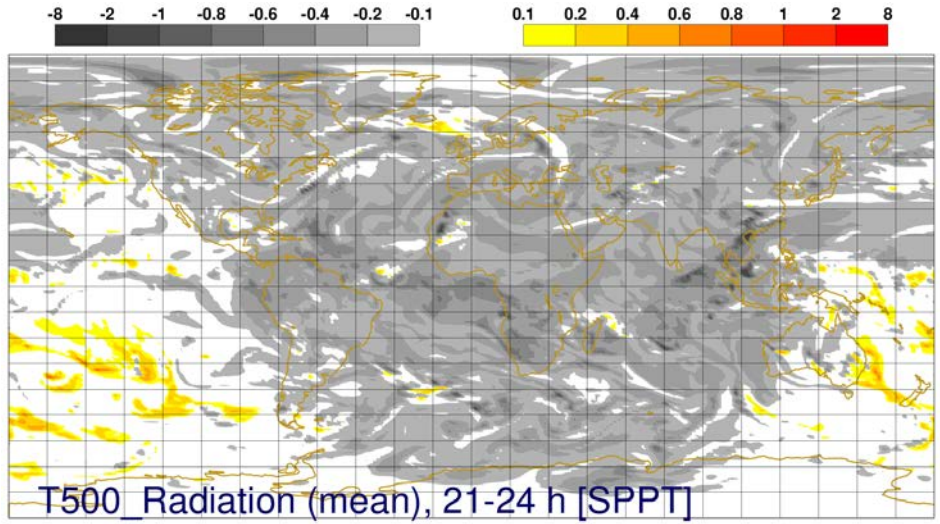


Change of model uncertainty representation





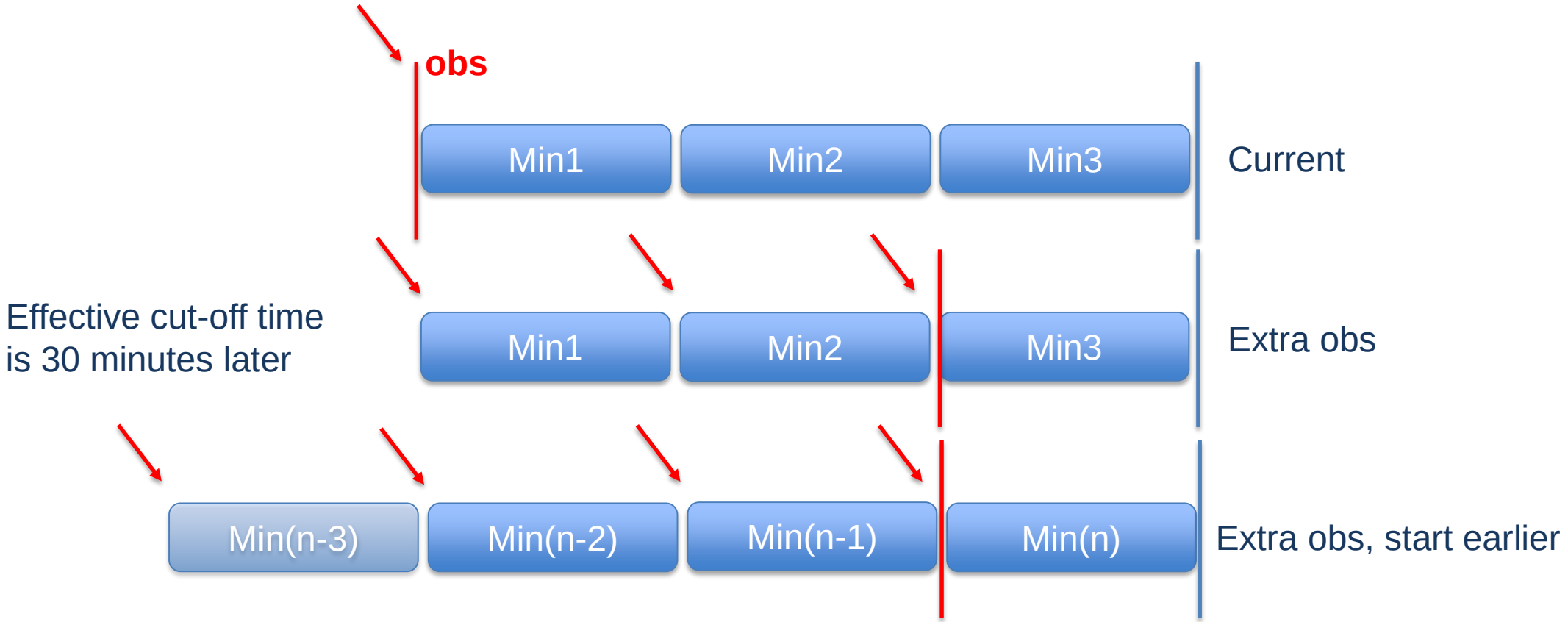
temperature tendency perturbations due to SPPT only (K/3h, shading)
precipitation (ens. mean, .5/1/2/4/8/... mm, black contours)
2015011000, t=+21–24 h



- radiative tendency in clear skies regions unperturbed
- activate perturbations in stratosphere
- weaker tapering of perturbations in boundary layer
- same SPPT configuration in EDA as in ENS
- cycling of random fields in EDA
- reduced amplitude of perturbations by 20%
- deactivate SKEB (2.5% cost saving)

See Lock et al. 2019, QJRM

Continuous data assimilation

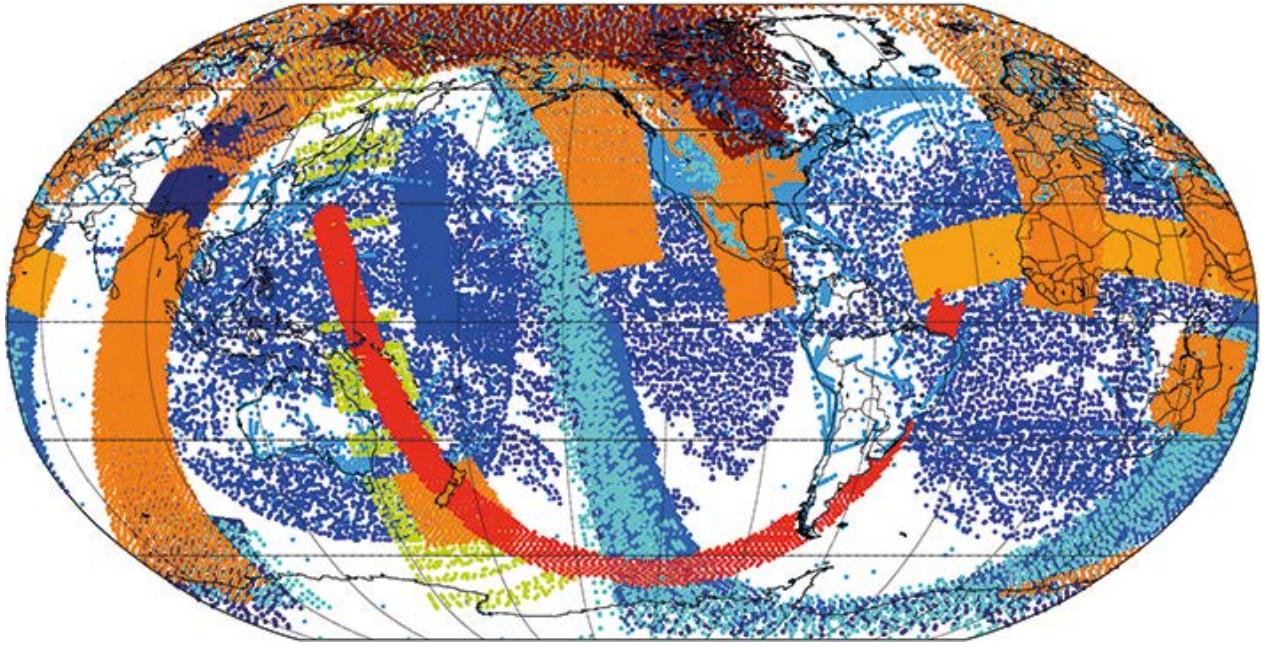


- Key point: Start running data assimilation **before** all of the observations have arrived:
  1. Most of the assimilation is removed from the time critical path
  2. Configurations which were previously unaffordable can now be considered

See Lean et al. 2019, ECMWF Newsletter No. 158

Continuous Data Assimilation

- Decouples observation cut off time from when we can start the assimilation
- Combines 3 main ideas:
  - Later observation cut off
  - Extend assimilation window (6 to 8 hours) to use all available observations
  - Use an extra 4D-Var outer loop



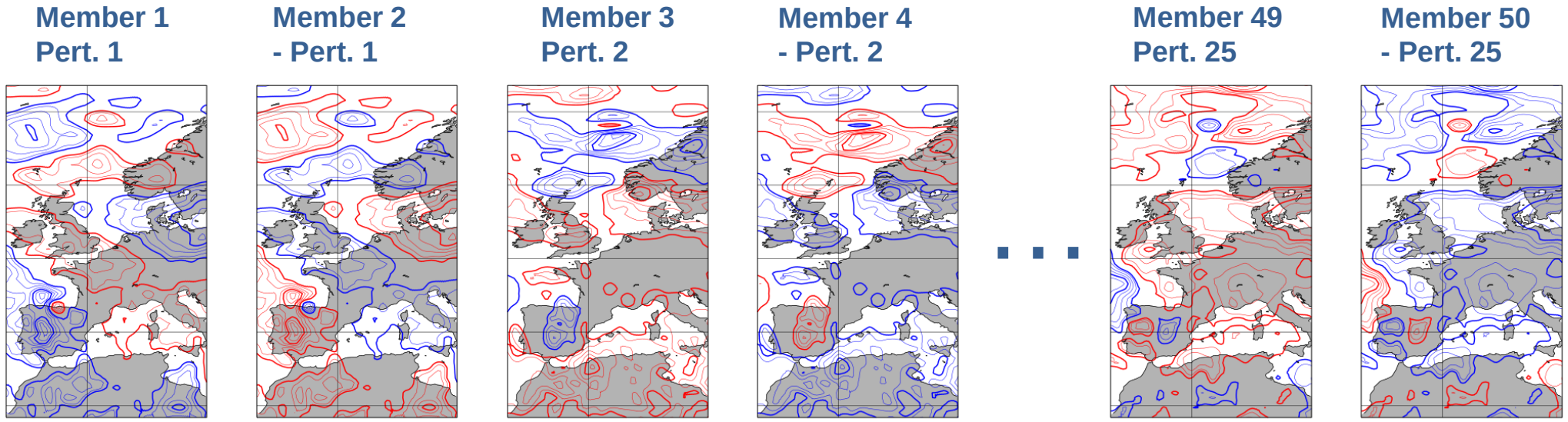
Example of extra observations assimilated in a single continuous DA cycle compared to the current operational setup. They include satellite observations from a large number of instruments as well as in situ measurements.

See Lean et al. 2019, ECMWF Newsletter No. 158

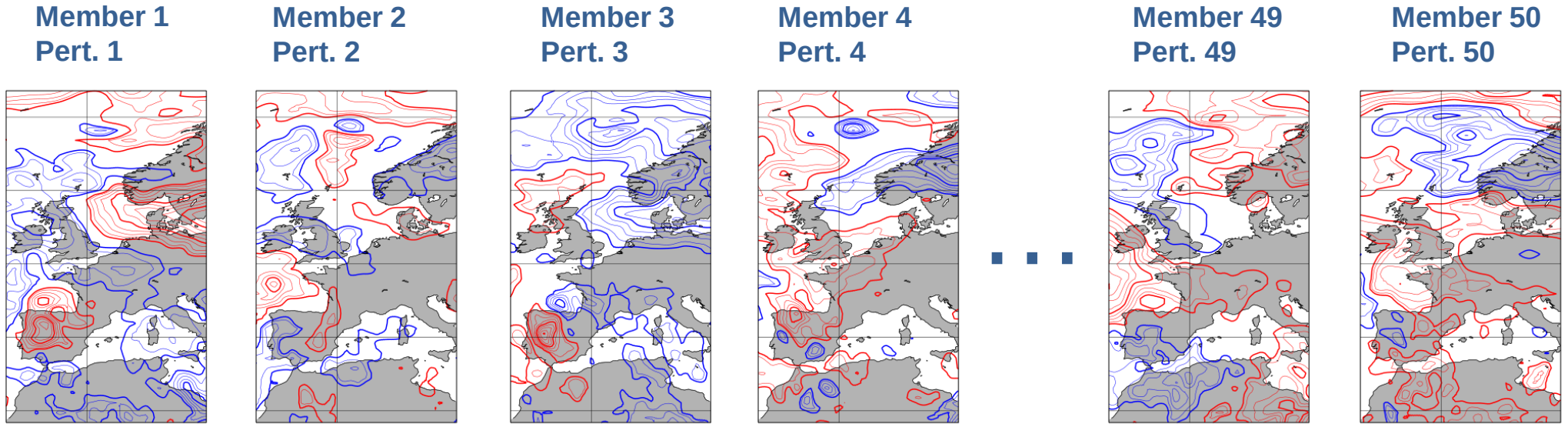
New way to perturb the ensemble initial conditions for 50 Ensemble Members

Old:
Plus-Minus
Symmetry with
Perturbations from
25-Member EDA

z500hPa

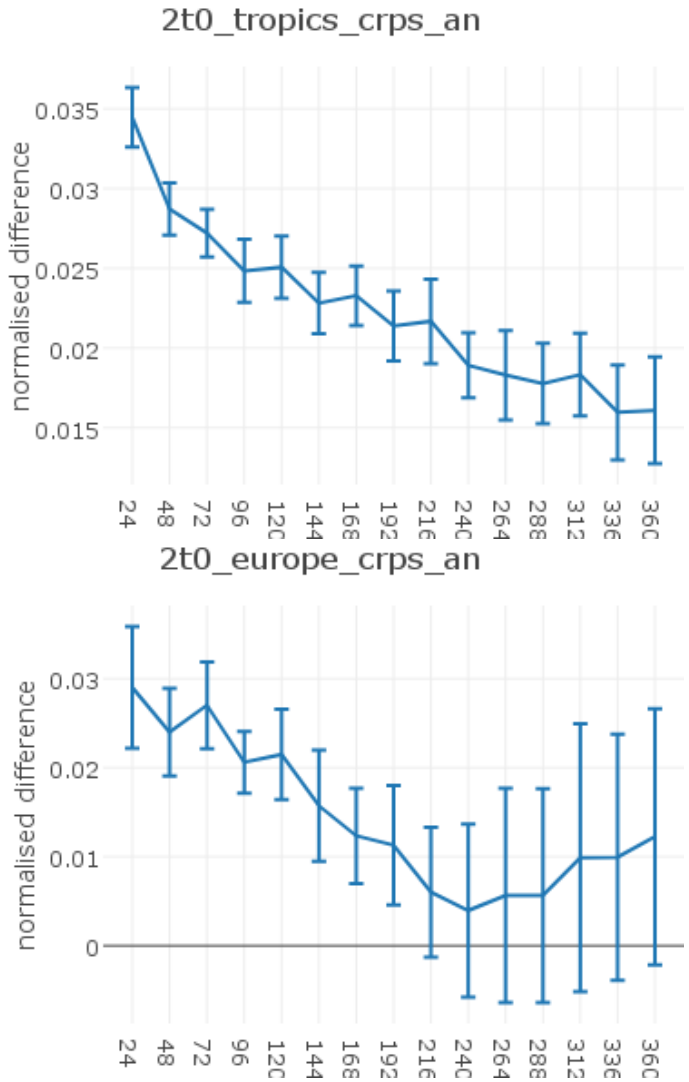


New:
Perturbations
from new
50-Member EDA



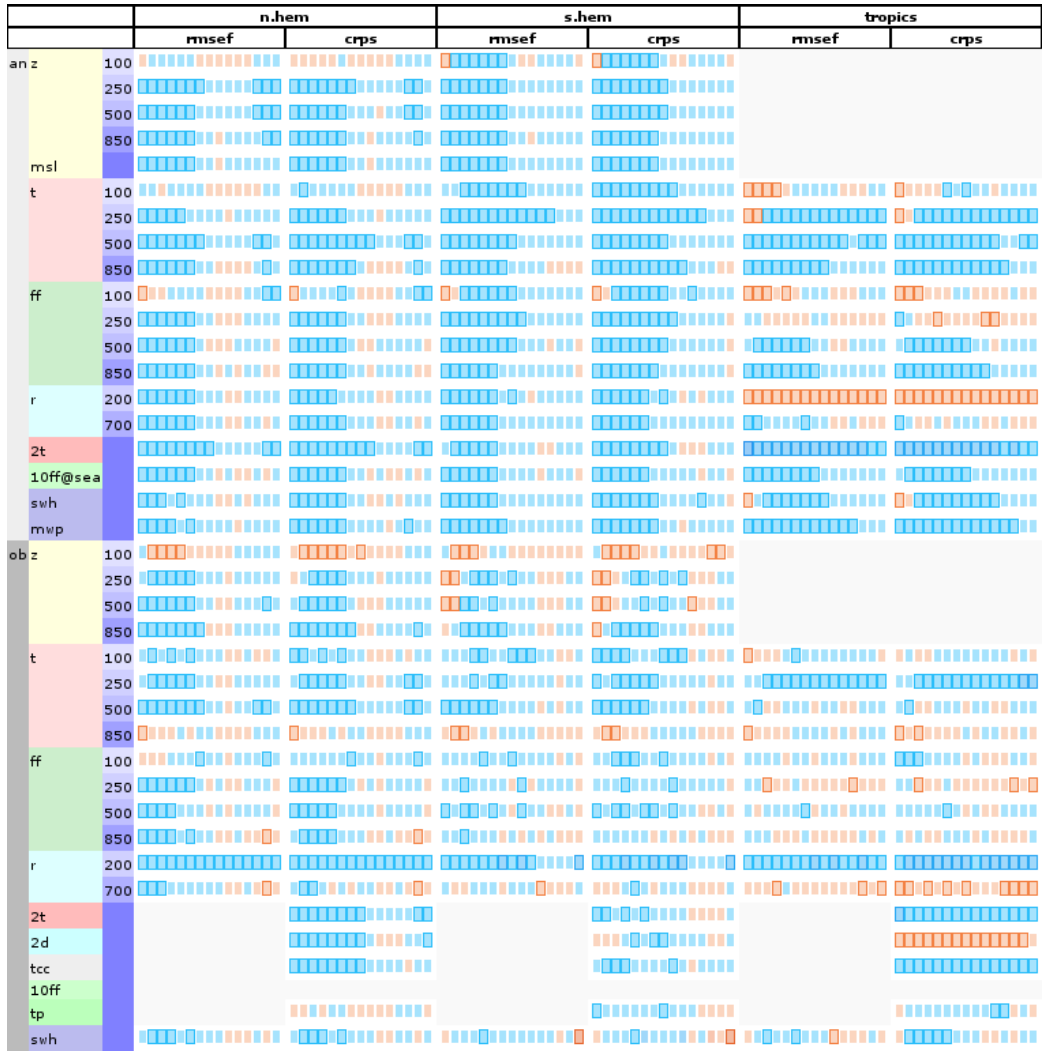
See Lang et al. 2019, ECMWF Newsletter No. 158

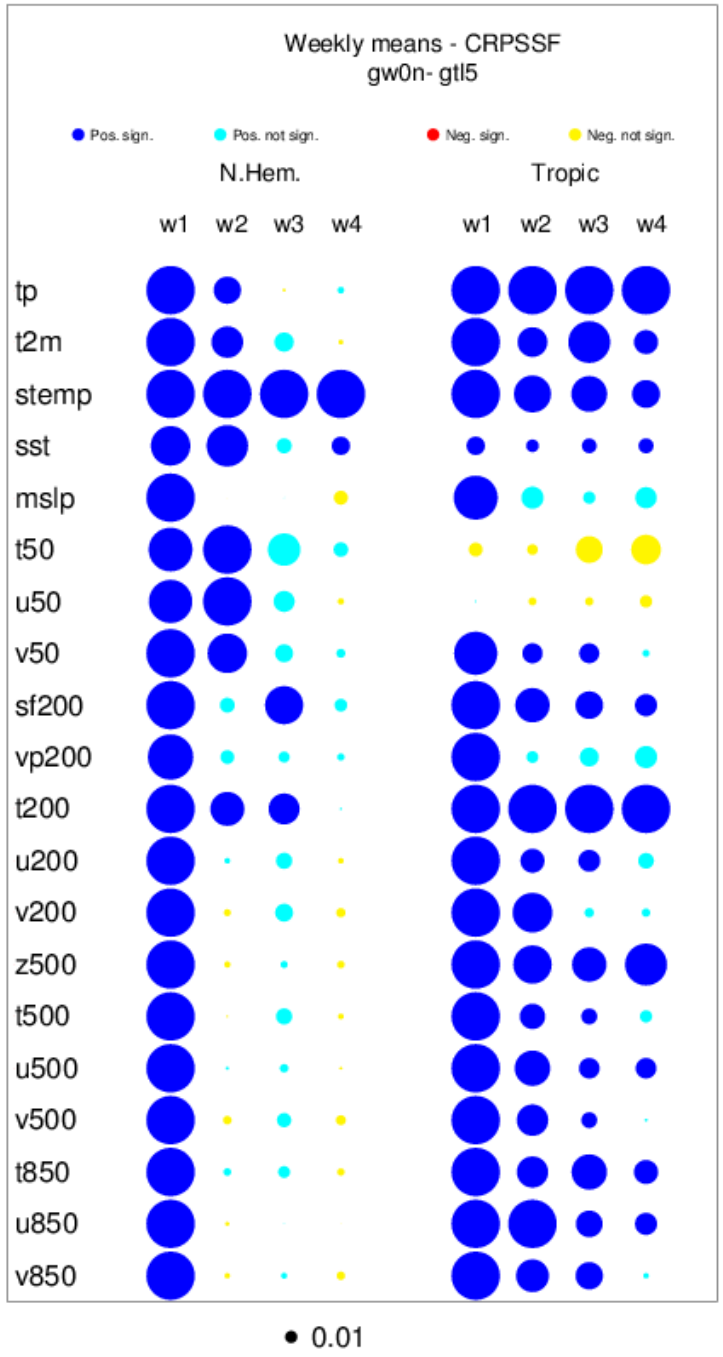
Impact of 1 hourly radiation on ENS



1 hourly radiation is better

1 hourly radiation is worse



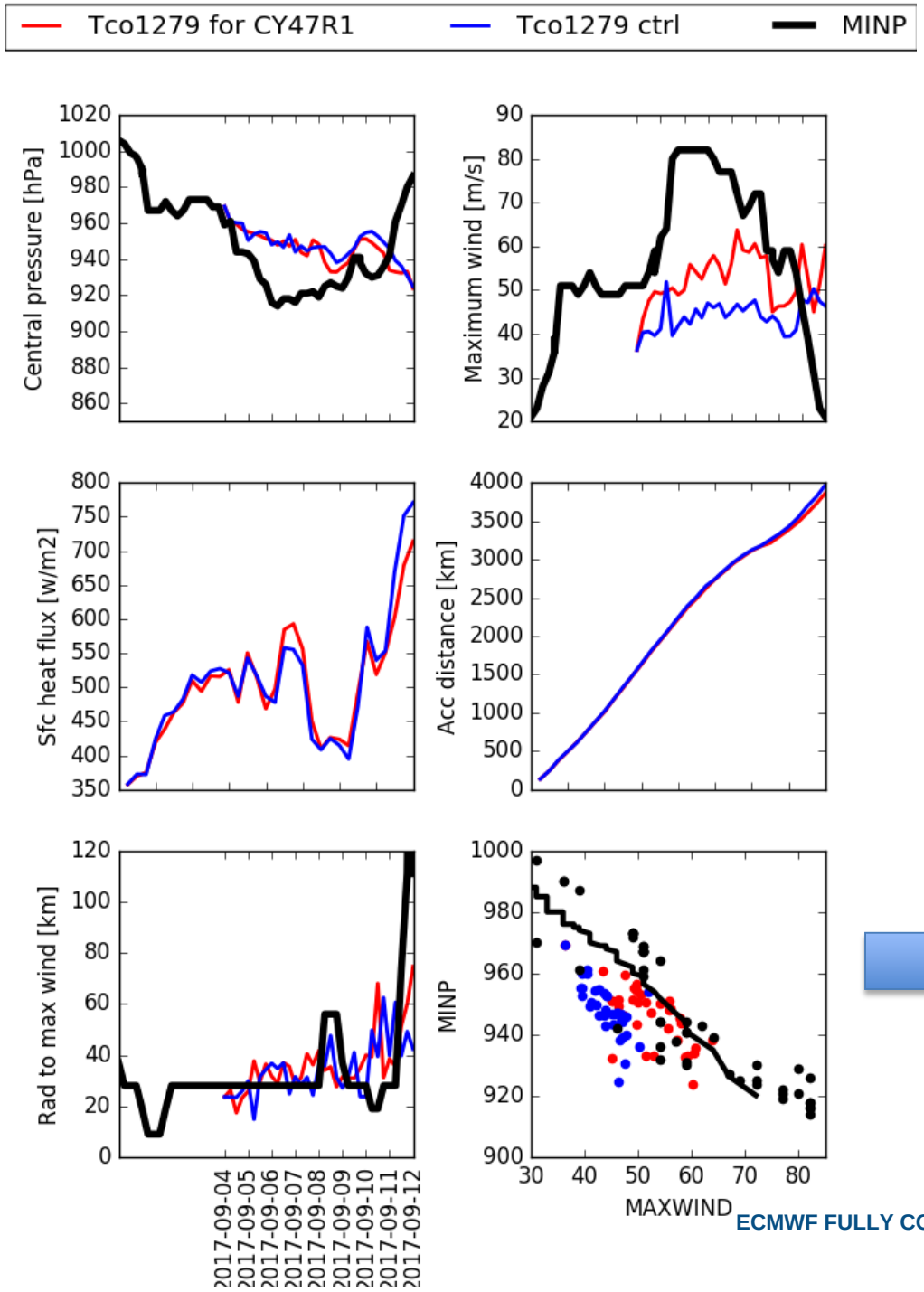


Scorecard of the difference of continuous ranked probabilistic skill scores (CRPSS) between experiment initialized with ERA5 and control over the northern Extratropics (left columns) and the tropics (right columns) for weeks 1 to 4. The size of the dots is proportional to the amplitude of the difference of skill score. The blue (red) colour indicates higher (lower) CRPSS when initializing from ERA5 than from ERA-Interim. Dark blue and dark red colours indicate that the difference is statistically significant at the 1% level of confidence, using a 10,000 resampling bootstrap procedure. The forecasts have been verified against their own re-analysis.

See Vitart et al. 2019, ECMWF Tech. Memo 841

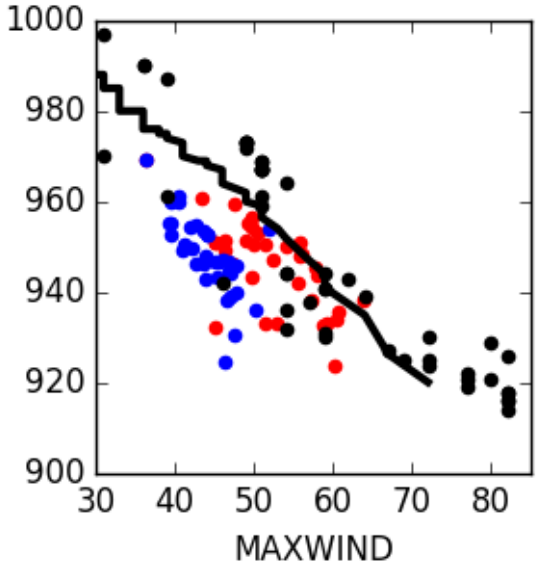
Irma, forecast from 20170904, 0 UTC:

From Jean Bidlot



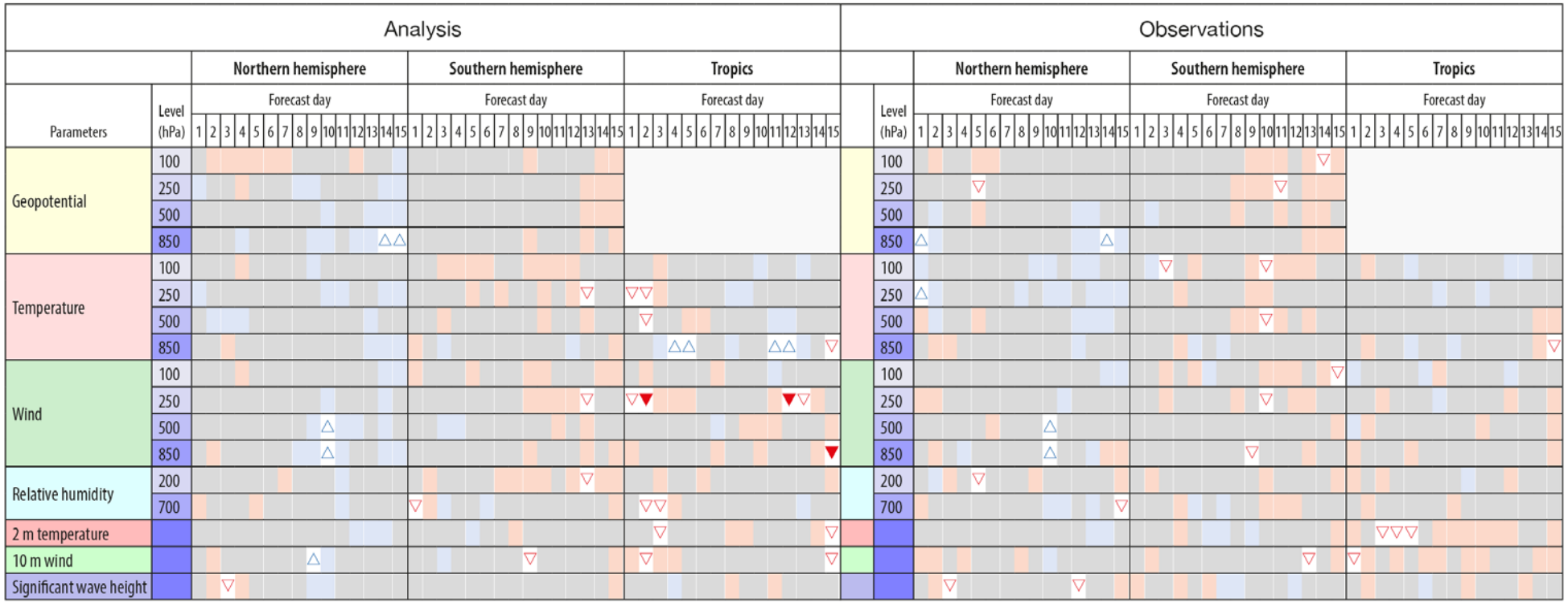
CY46R1 Charnock

Limitation on Charnock



Output every 6 hours

Single Precision - cost reduction, 30% – 40%



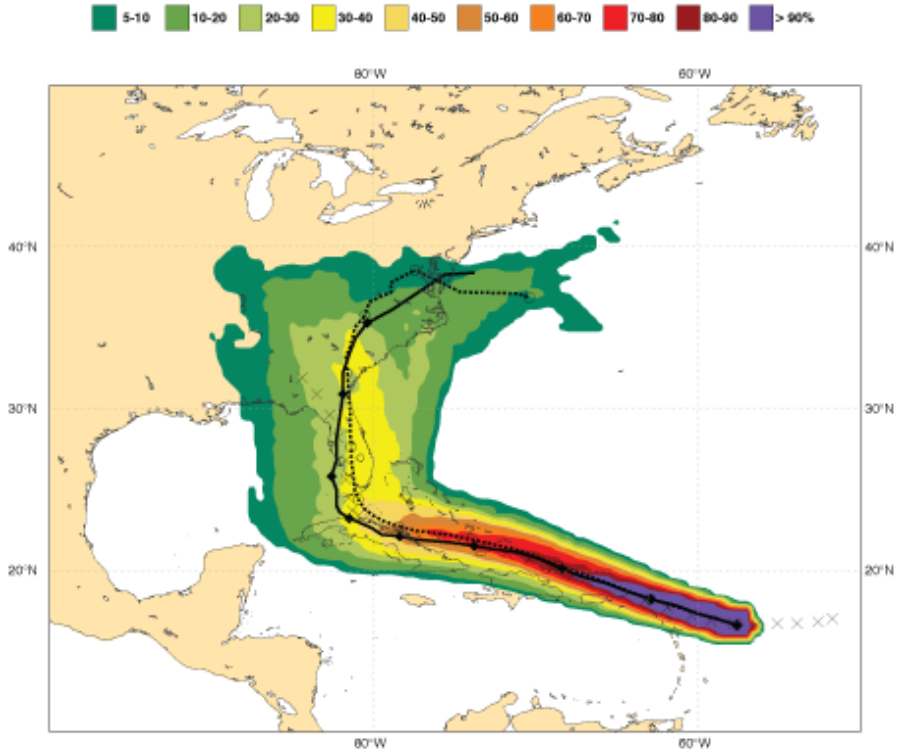
Symbol legend: for a given forecast step...

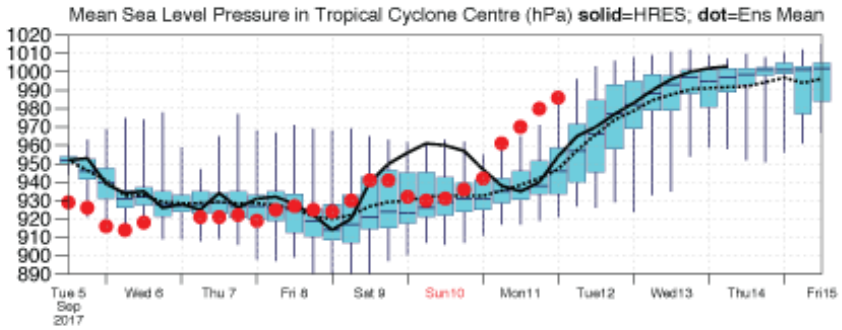
- ▲ SP better than DP statistically significant with 99.7% confidence
- △ SP better than DP statistically significant with 95% confidence
- SP better than DP statistically significant with 68% confidence
- no significant difference between DP and SP
- SP worse than DP statistically significant with 68% confidence
- ▽ SP worse than DP statistically significant with 95% confidence
- ▼ SP worse than DP statistically significant with 99.7% confidence

See Váňa et al. 2017, Mon. Wea. Rev. and Dueben et al. 2018, ECMWF Newsletter 157

5 km Ensemble

Date 20170905 12 UTC @ **ECMF**
Probability that **IRMA** will pass within 120 km radius during the next **240** h
tracks: **solid**=HRES; **dot**=Ens Mean [reported minimum central pressure (





18 km Ensemble

Date 20170905 12 UTC @ **ECMF**
Probability that **IRMA** will pass within 120 km radius during the next **240** hours
tracks: **solid**=HRES; **dot**=Ens Mean [reported minimum central pressure (hPa) **929**]