Forecasting an Atmospheric River event with a Stochastic Multi-scale Atmospheric Model

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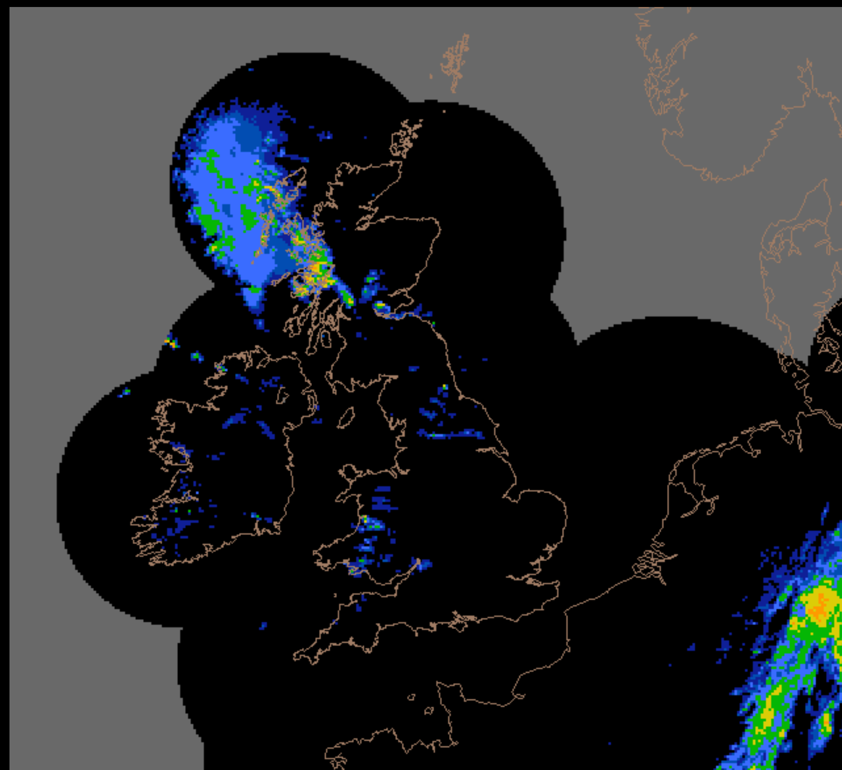
ECMWF

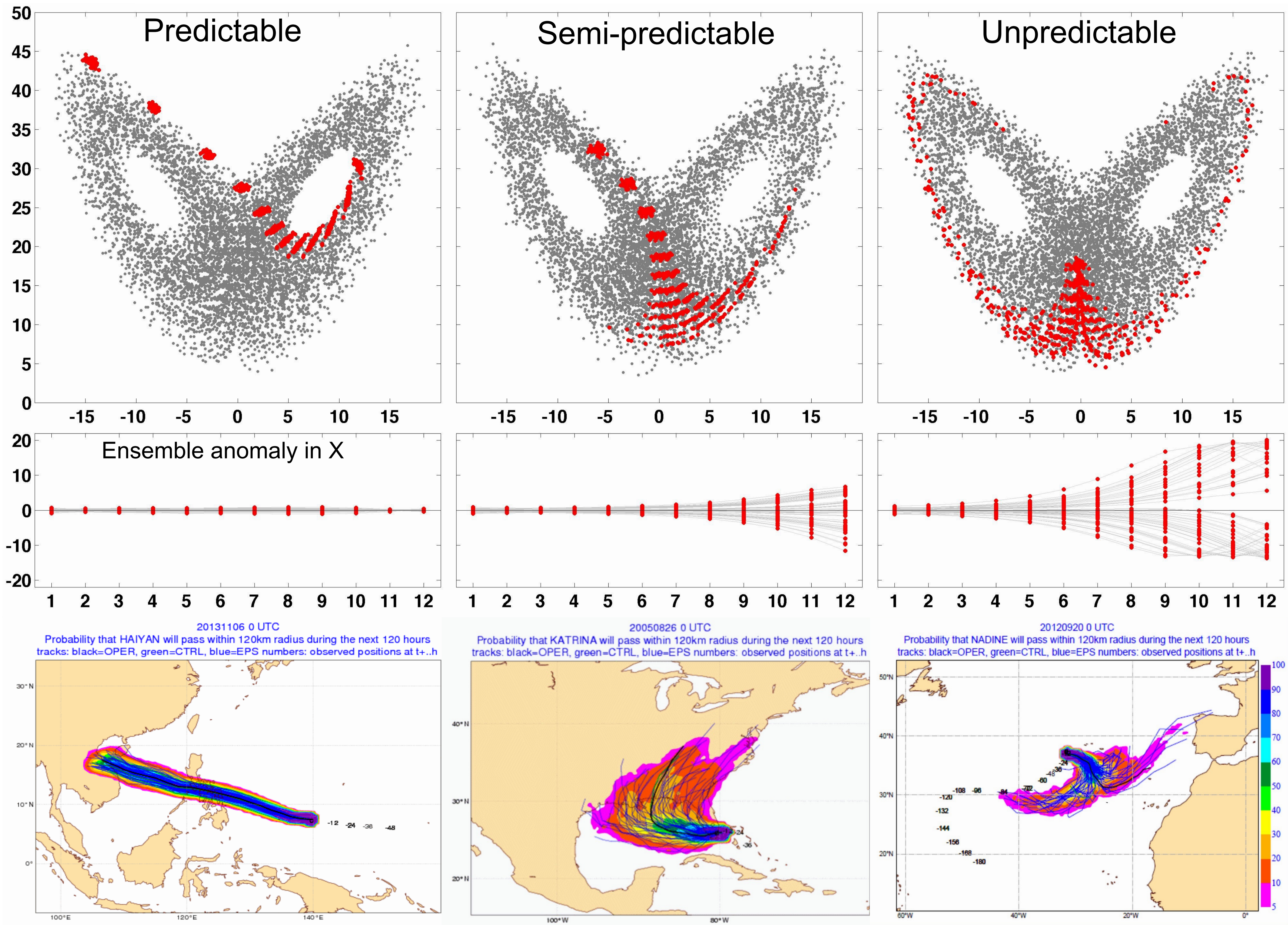
ITV REPORT 7 December 2015 at 3:27pm

Storm Desmond breaks UK rainfall record



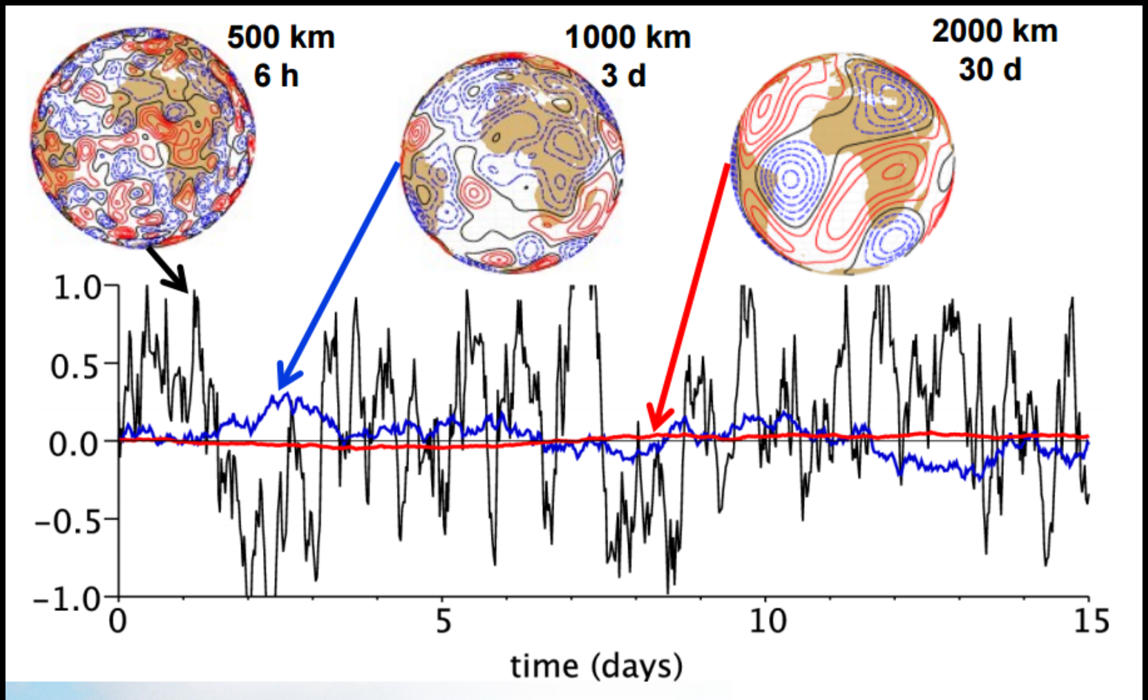
Outline

- Ensemble forecast and modeling uncertainty
- Operational stochastic parameterizations at ECMWF
- Multi-scale stochastic modeling
- Forecast results for Storm Desmond Atmospheric River


Predictable
Semi-predictable
Unpredictable
Ensemble anomaly in X
20131106 0 UTC
Probability that HAIYAN will pass within 120km radius during the next 120 hours
tracks: black=OPER, green=CTRL, blue=EPS numbers: observed positions at t+..h
20050826 0 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
20120920 0 UTC
Probability that NADINE will pass within 120km radius during the next 120 hours
tracks: black=OPER, green=CTRL, blue=EPS numbers: observed positions at t+..h

Stochastic parameterization to represent model error

Stochastically Perturbed Parameterization Tendencies (SPPT)



- The net parameterized physics tendency:

$$X = X_U, X_V, X_T, X_Q$$

coming from : (radiation schemes, gravity wave drag, vertical mixing, convection, cloud physics)

- Perturbed with multiplicative noise $X' = (1 + \mu r) X$

Buizza et al. 1999, Palmer et al. 2009

Stochastic Kinetic Energy Backscatter (SKEB)

- Simulates a missing and uncertain process
- Parameterizes upscale transfer of energy from sub-grid scales

Shutts and Palmer 2004, Shutts 2005

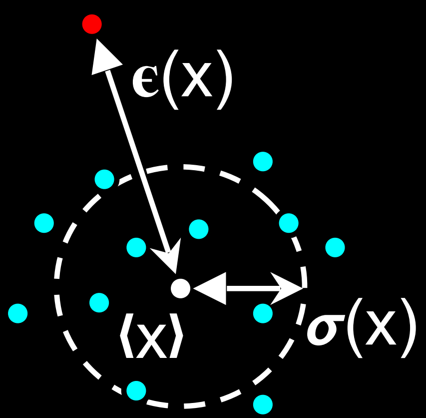
$$F_\phi = \left(\frac{b_R D_{tot}}{B_{tot}} \right)^{1/2} F^*$$

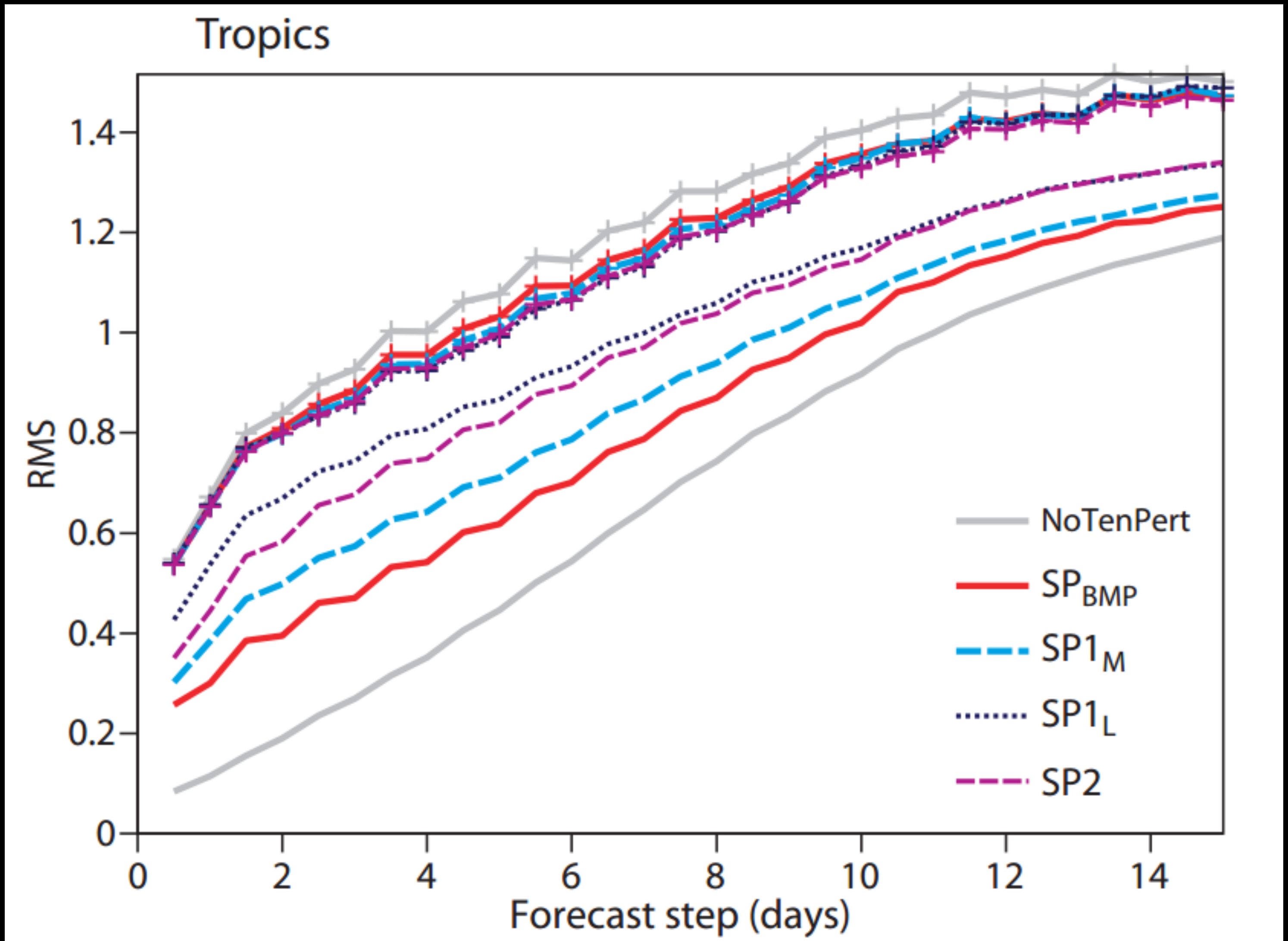
F^* is the 3D random pattern

B_{tot} is the mean KE input by F^*

D_{tot} is the dissipation rate

Why do we need Model Error Representation?





- The grey line (with markers) shows the Root Mean Square error for Z500 forecasts with no stochastic perturbations and the other colors are for experiments with different stochastic perturbations.
- Spread is least and error is maximum for experiment with no perturbations.

Impact of SPPT and SKEB on Ensemble Forecasts

TECHNICAL MEMORANDUM

598

Stochastic Parametrization and Model Uncertainty

Palmer, T.N., R. Buizza, F. Doblas-Reyes, T. Jung, M. Leutbecher, G.J. Shutts, M. Steinheimer, A. Weisheimer

Research Department

October 8, 2009

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European Centre for Medium-Range Weather Forecasts
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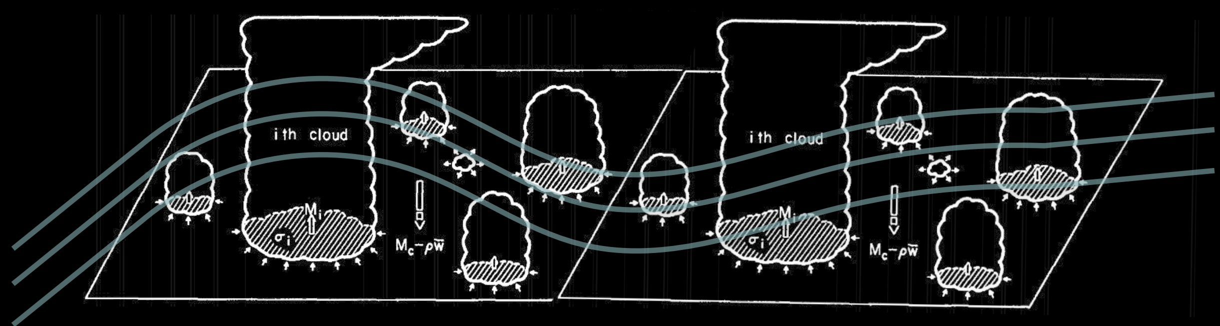
Centre européen pour les prévisions météorologiques à moyen terme

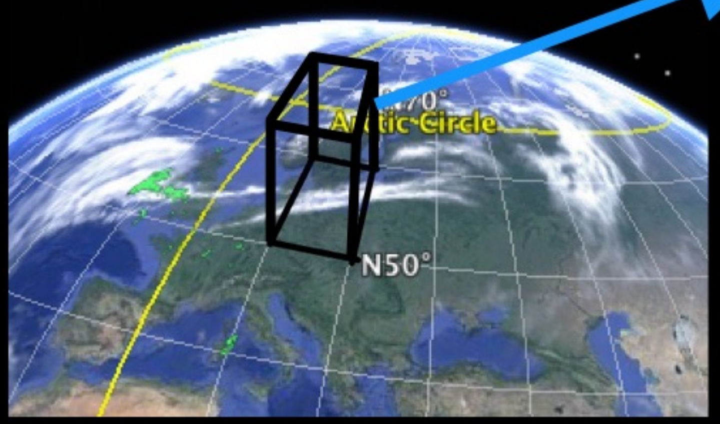
Multi-scale Modeling Framework

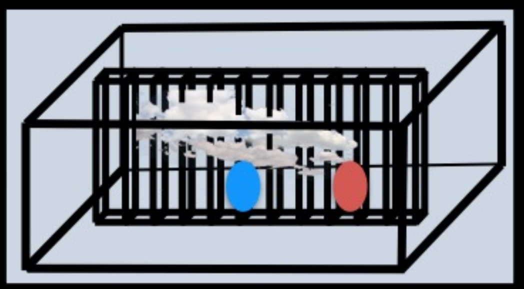


Conventional parameterization for deep convection assumes averaging over some putative ensemble of sub-grid processes in quasi-equilibrium with the resolved flow (eg. Arakawa and Schubert 1974)

Super-parameterization breaks a deadlock in convective parameterization by resolving some of the convective processes but yet acting as a parameterization.

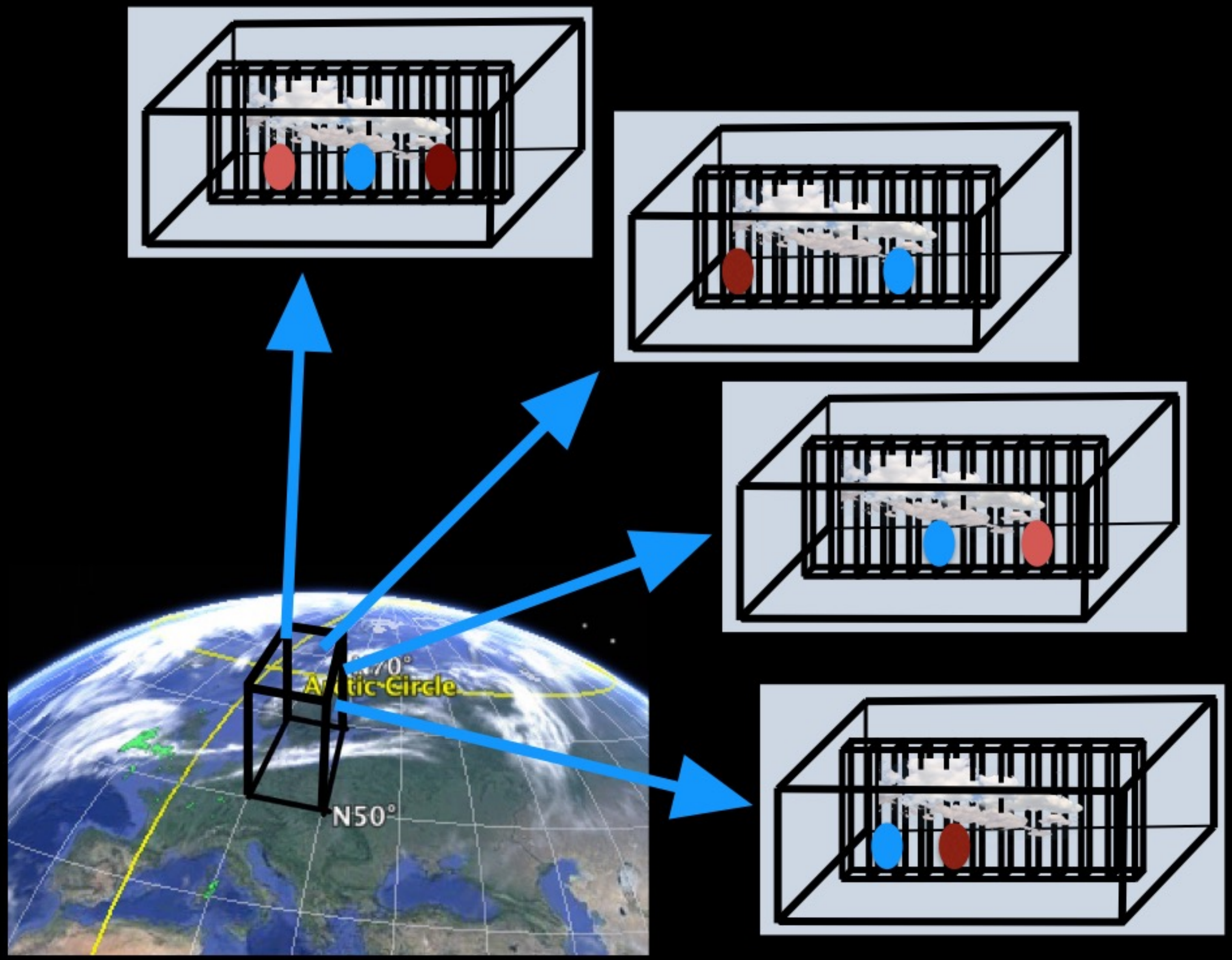
Grabowski, JAS, 2001
Randall, GRL, 2013





Stochastic Multi-scale Modeling

An approach to model uncertainty in sub-grid scale processes (Majda 2006)



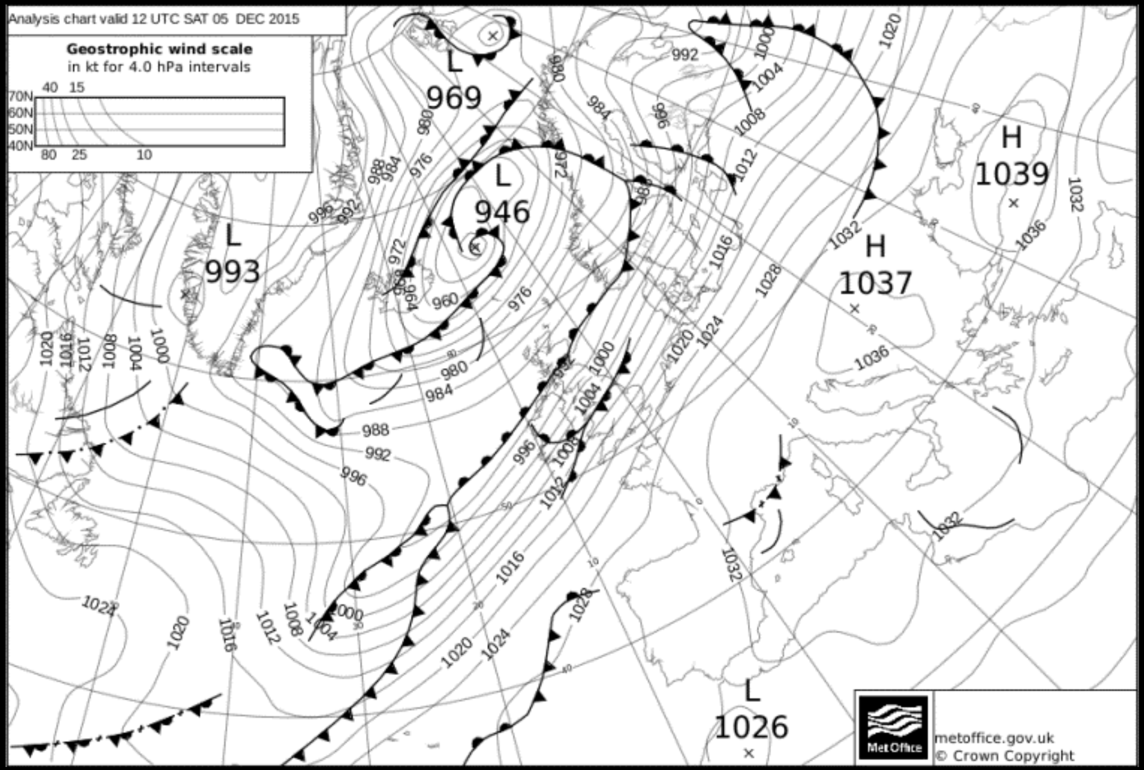
Perturbations to initial state in the Boundary Layer of the CRM

Subramanian et al. 2016

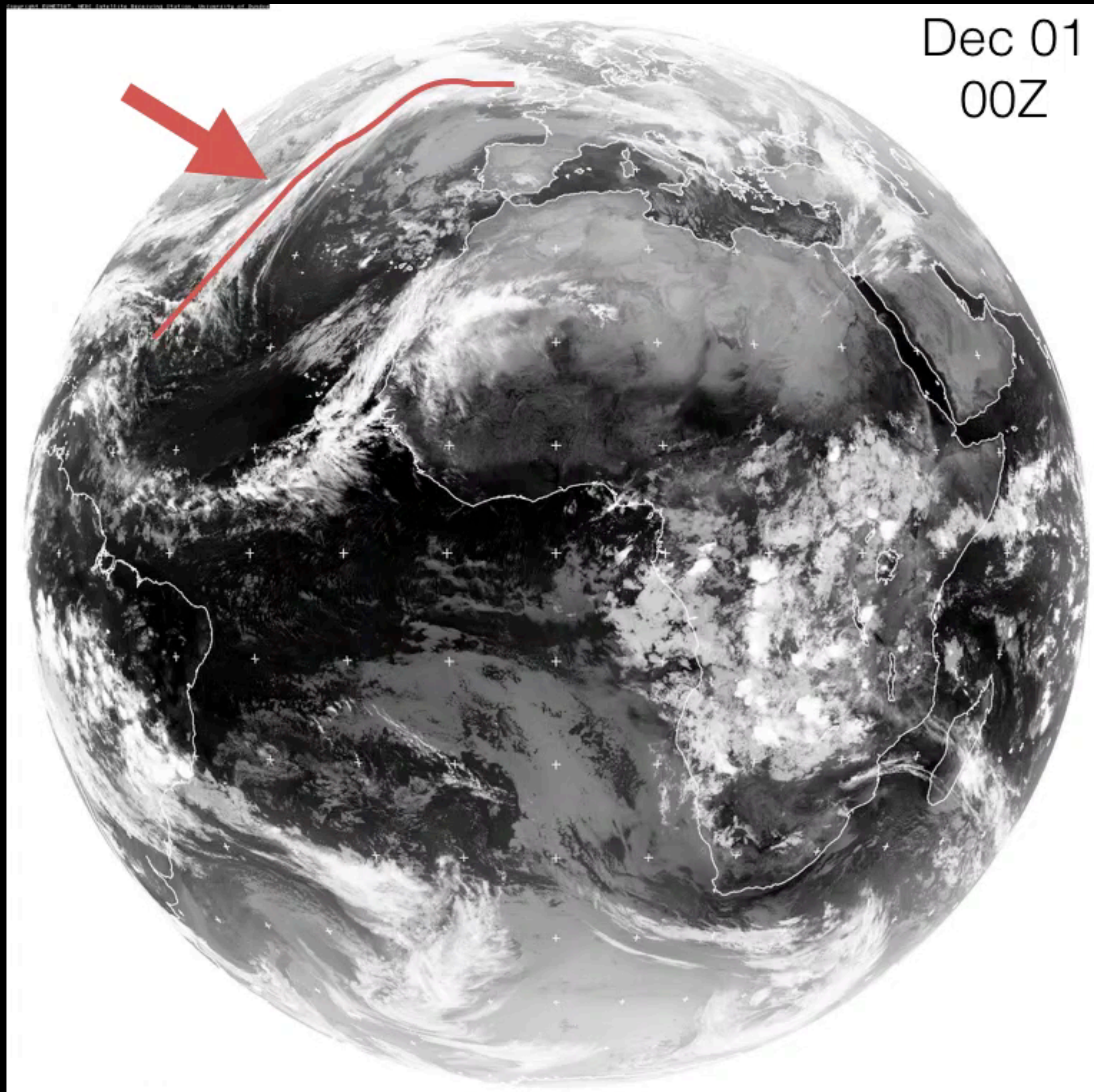
Storm Desmond Atmospheric River forecast

21 member ensemble forecasts

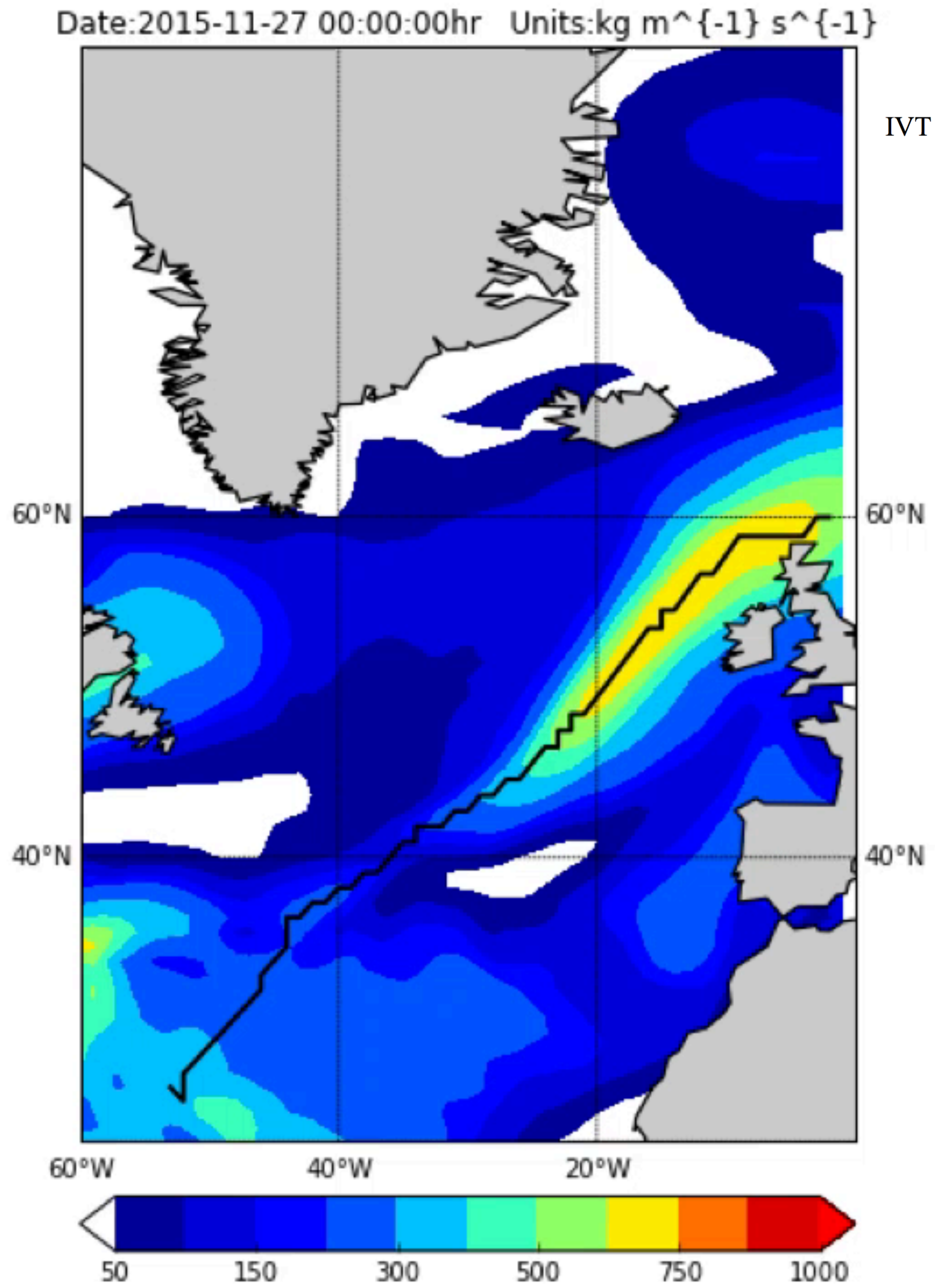
- No initial perturbations to the fields on the IFS grid.
- Two experiments conducted.
  - One with Stochastic Physics switched on to capture Model Error (IFS SPPT)
  - Second with only initial stochastic perturbations to the Super-Parameterization (IFS SSP)
- Each ensemble forecast for 10 days from 5 different start dates (27 Nov, 29 Nov, 1 Dec, 3 Dec, 5 Dec 2015)



Atmospheric River event : Meteosat SEVIRI



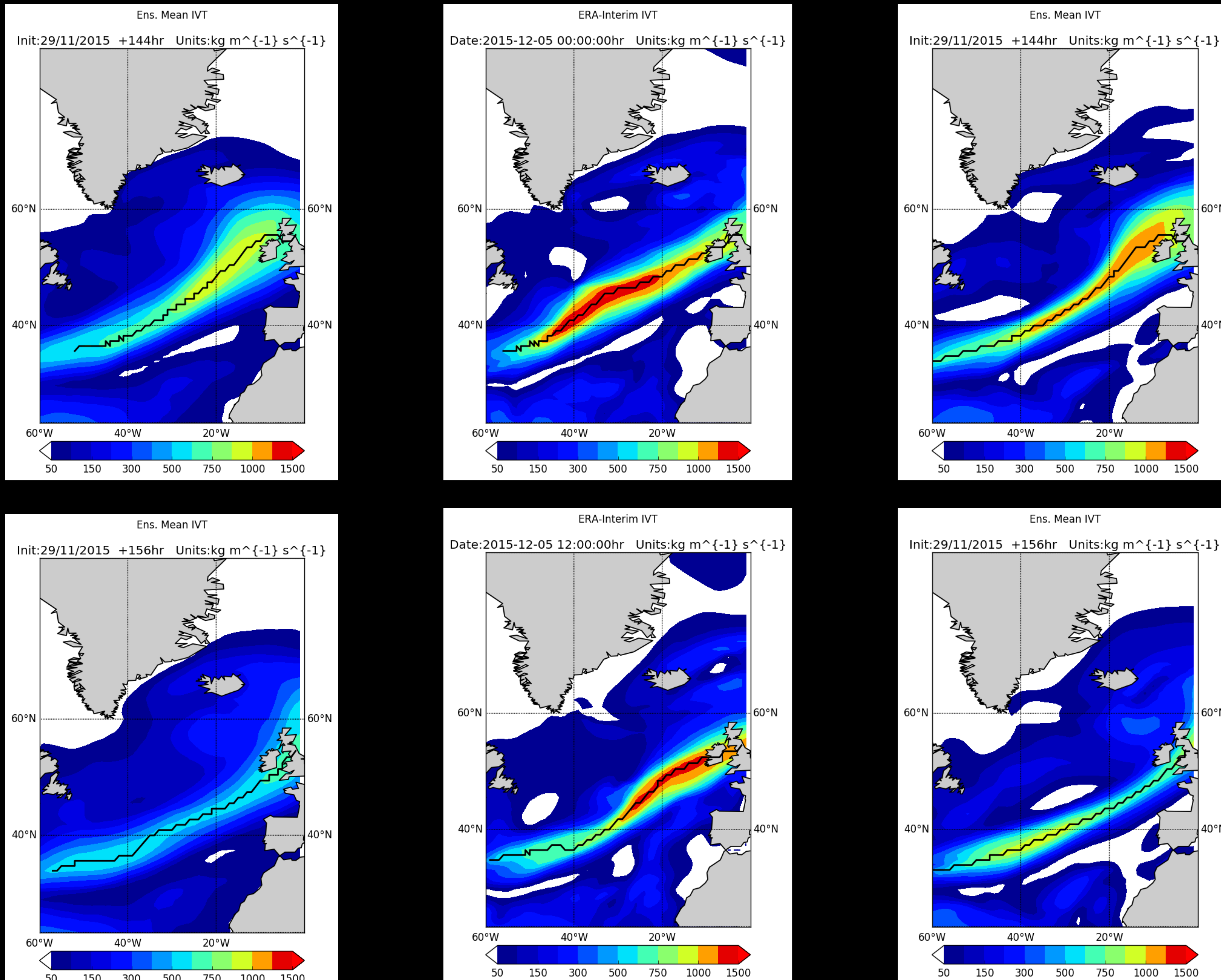
ERA Interim: Integrated Water Vapor Transport



$$\mathrm{IVT} = \sqrt{\left(\frac{1}{g}\int_{1000}^{300} qu\,\mathrm{d}p\right)^2 + \left(\frac{1}{g}\int_{1000}^{300} qv\,\mathrm{d}p\right)^2}$$

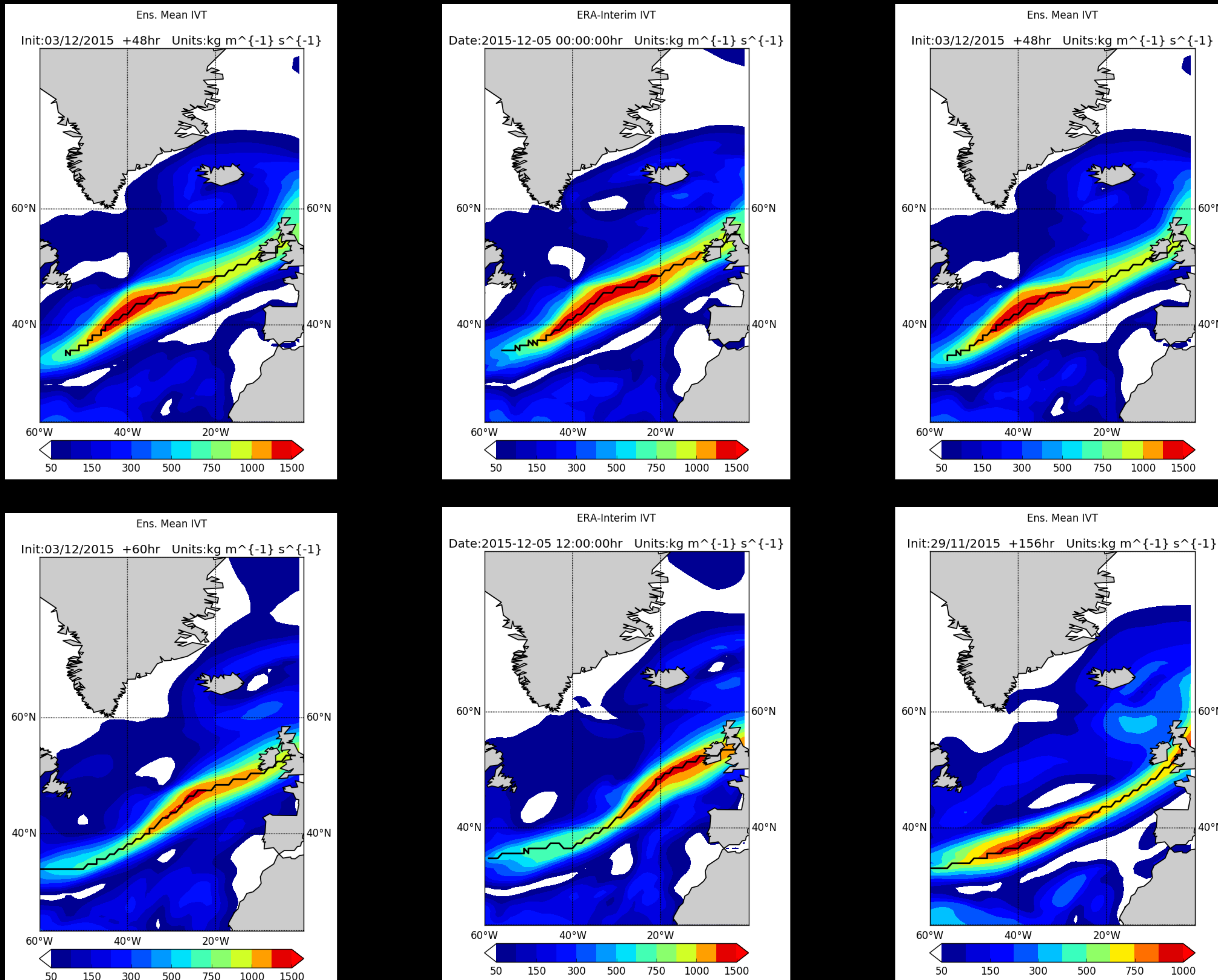
Integrated Water Vapor Transport : 6 day forecast

SPPT IFS | ERA-I | SSP IFS



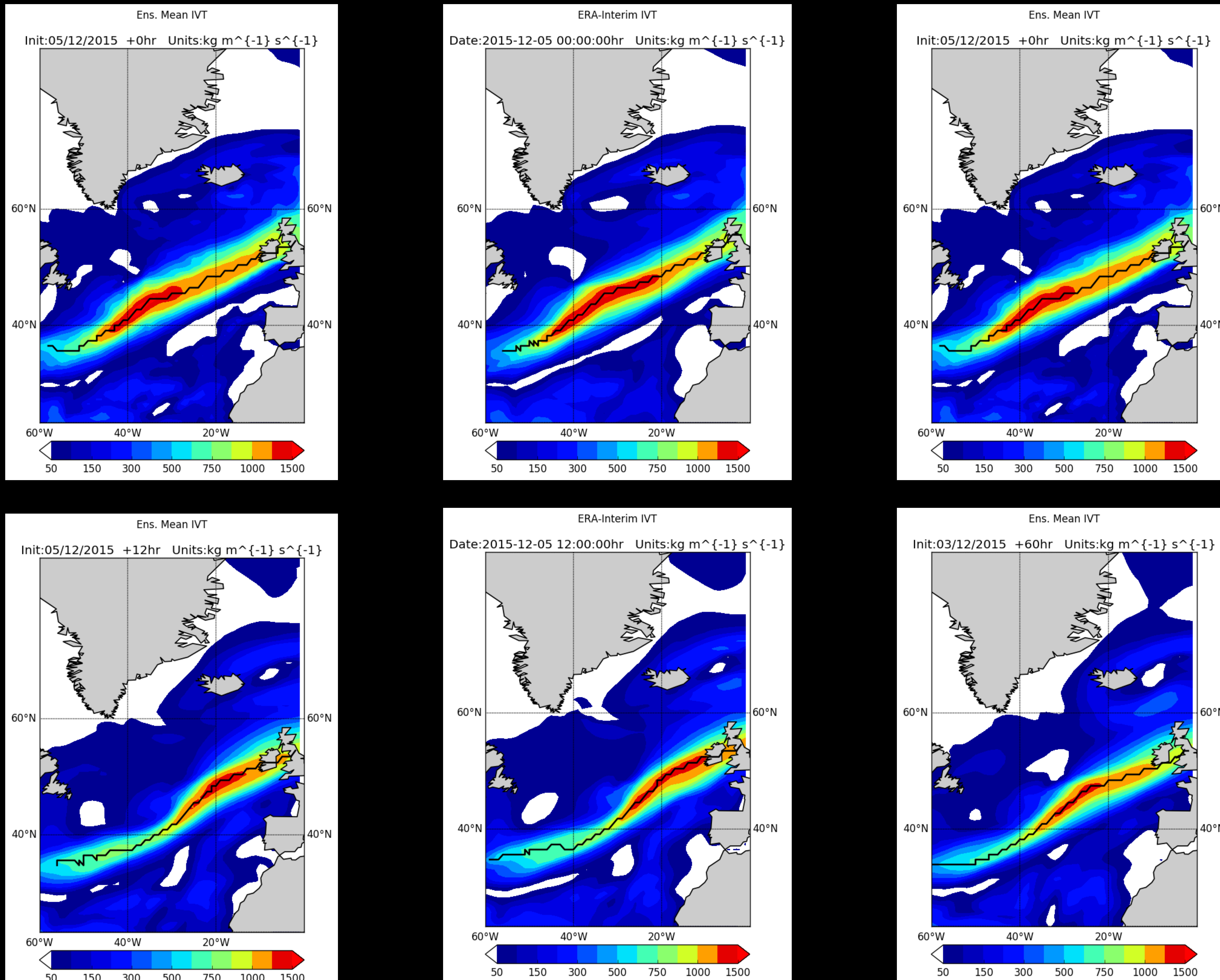
Integrated Water Vapor Transport : 3 day forecast

SPPT IFS | ERA-I | SSP IFS



Integrated Water Vapor Transport : 1 day forecast

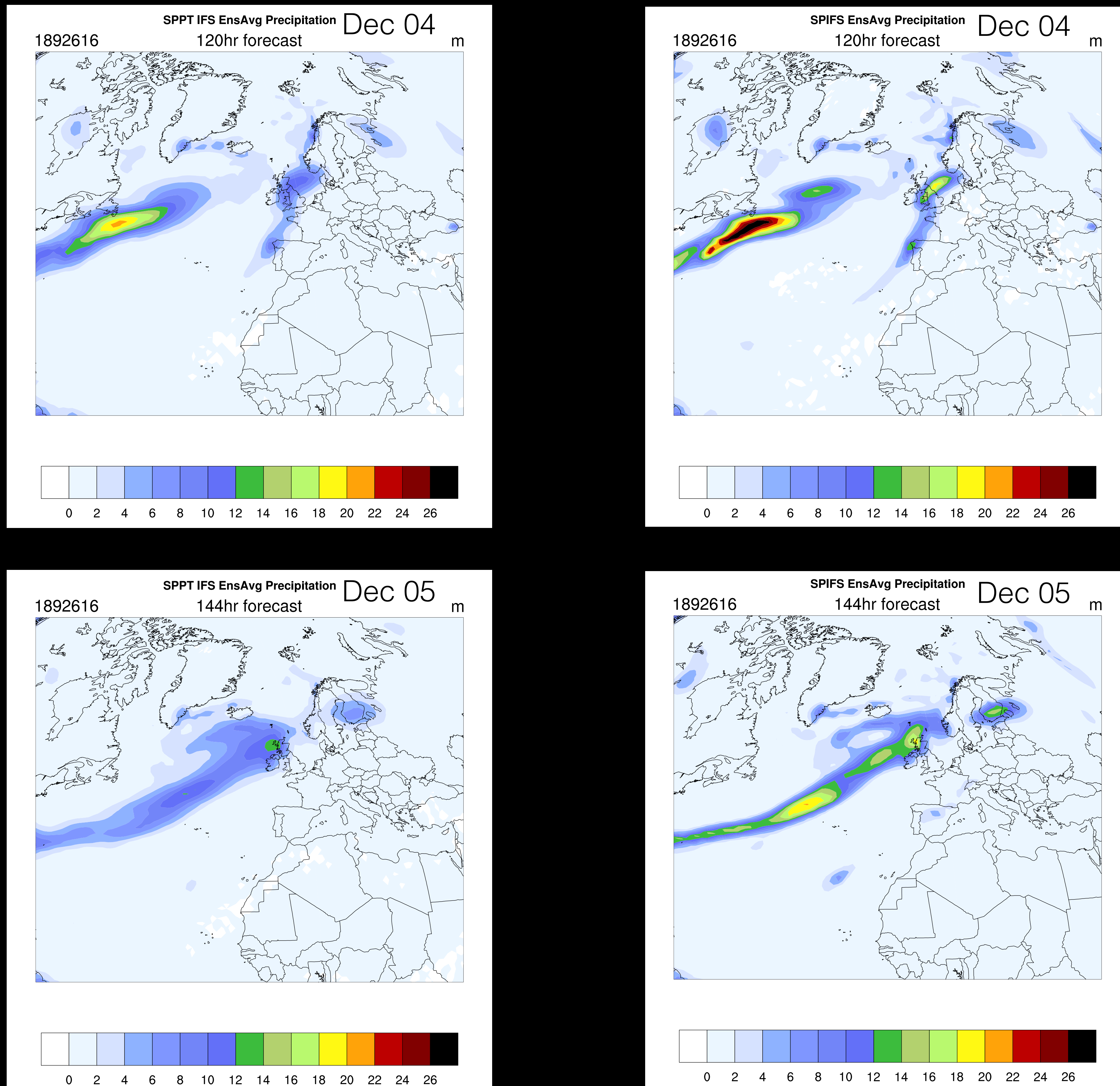
SPPT IFS | ERA-I | SSP IFS



Ensemble mean precipitation

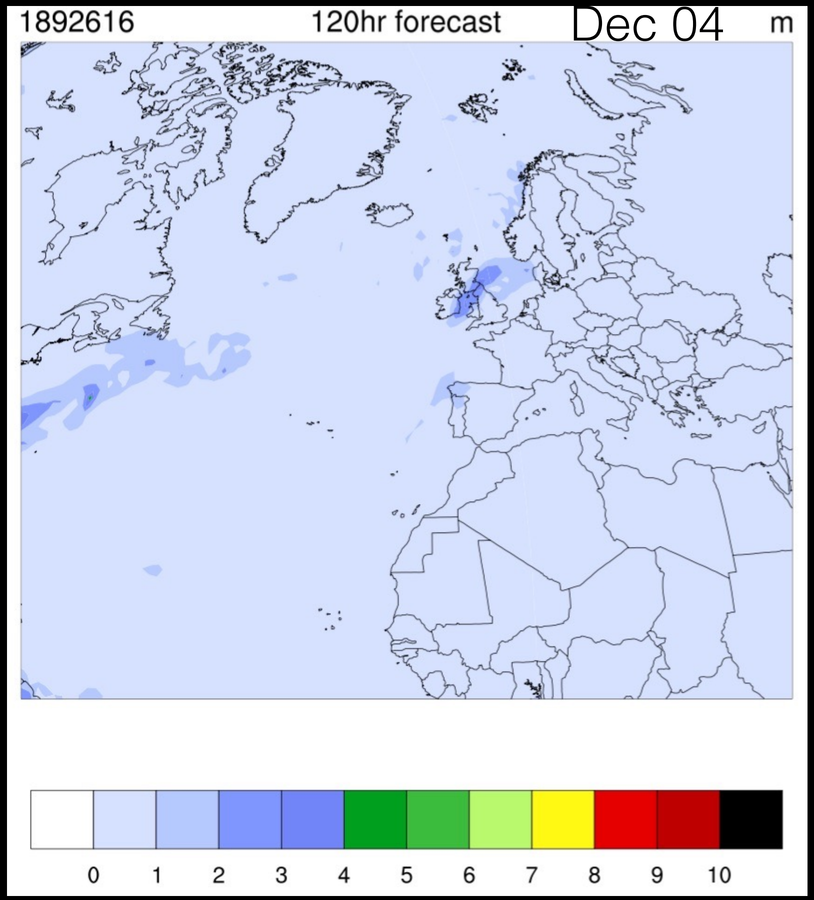
SPPT IFS

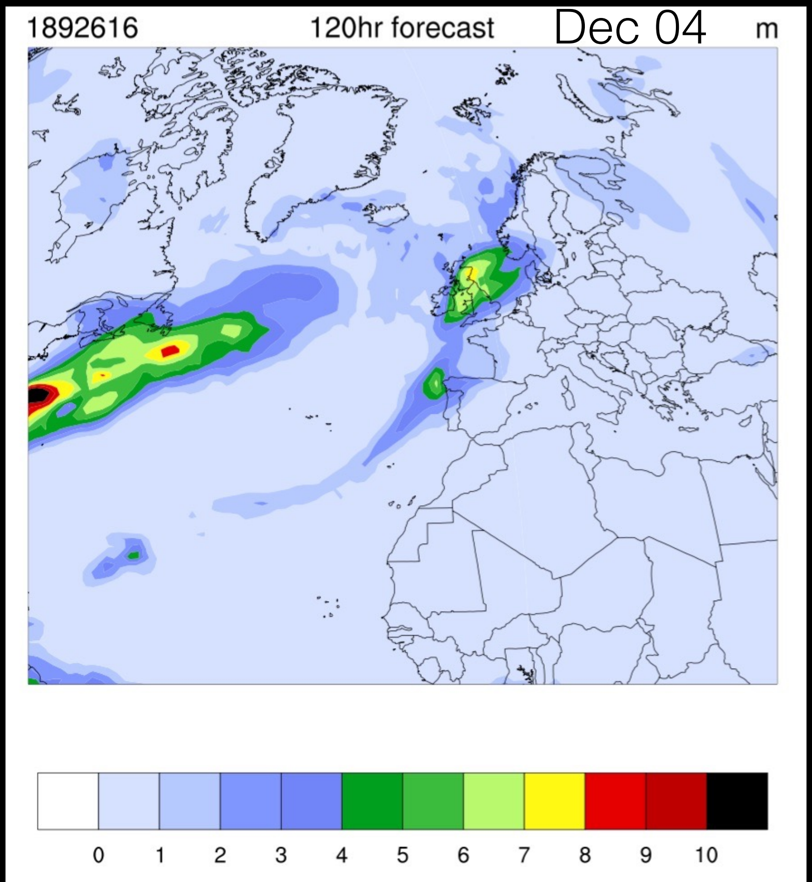
SSP IFS

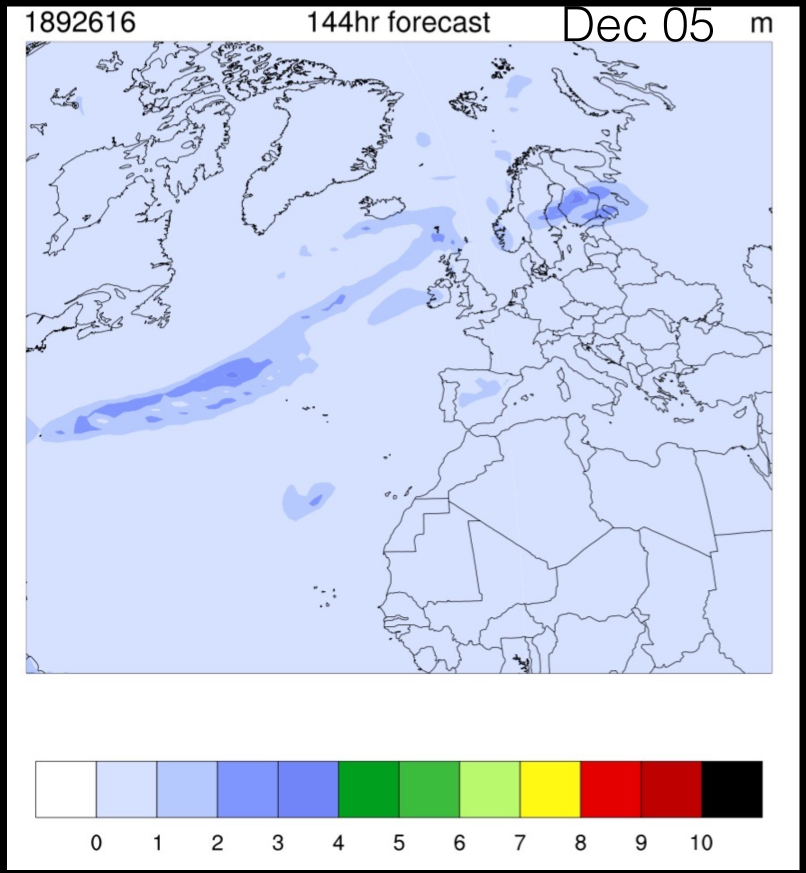


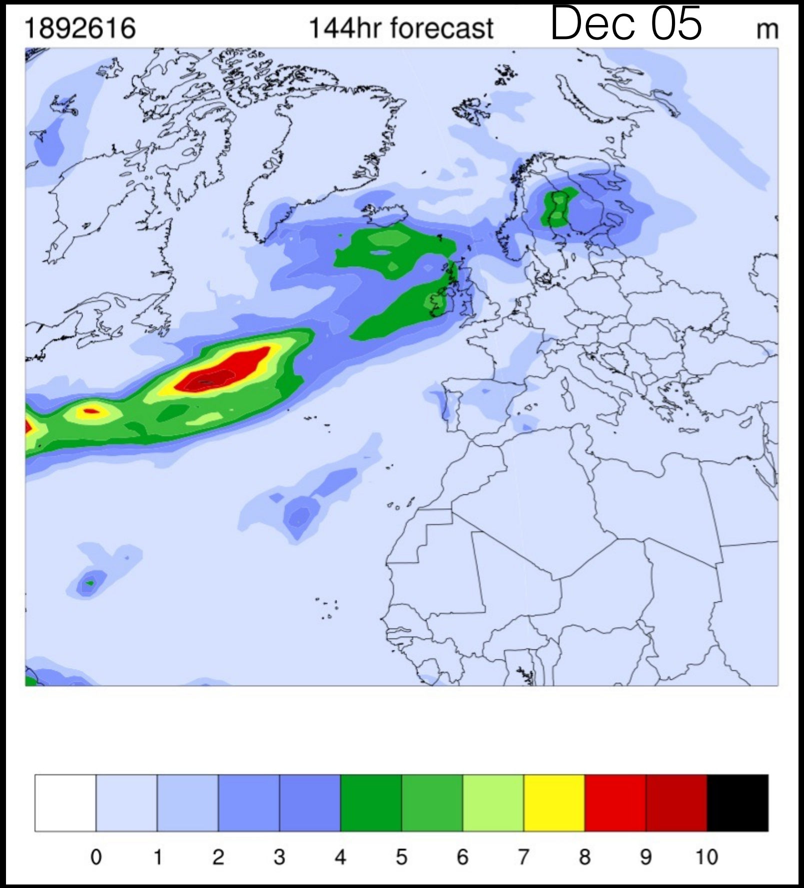
Ensemble Std precipitation

SPPT IFS | SSP IFS







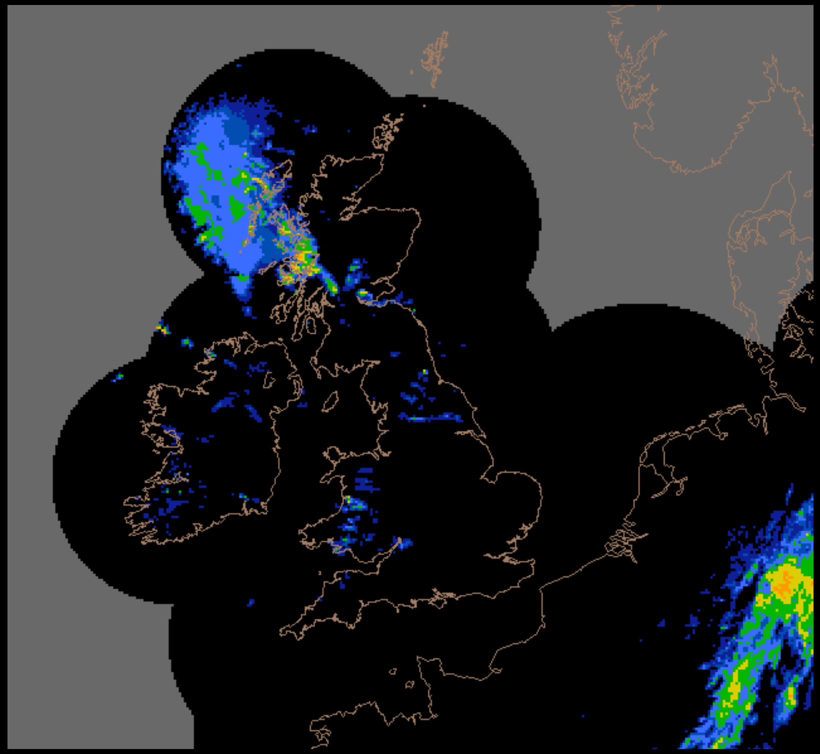


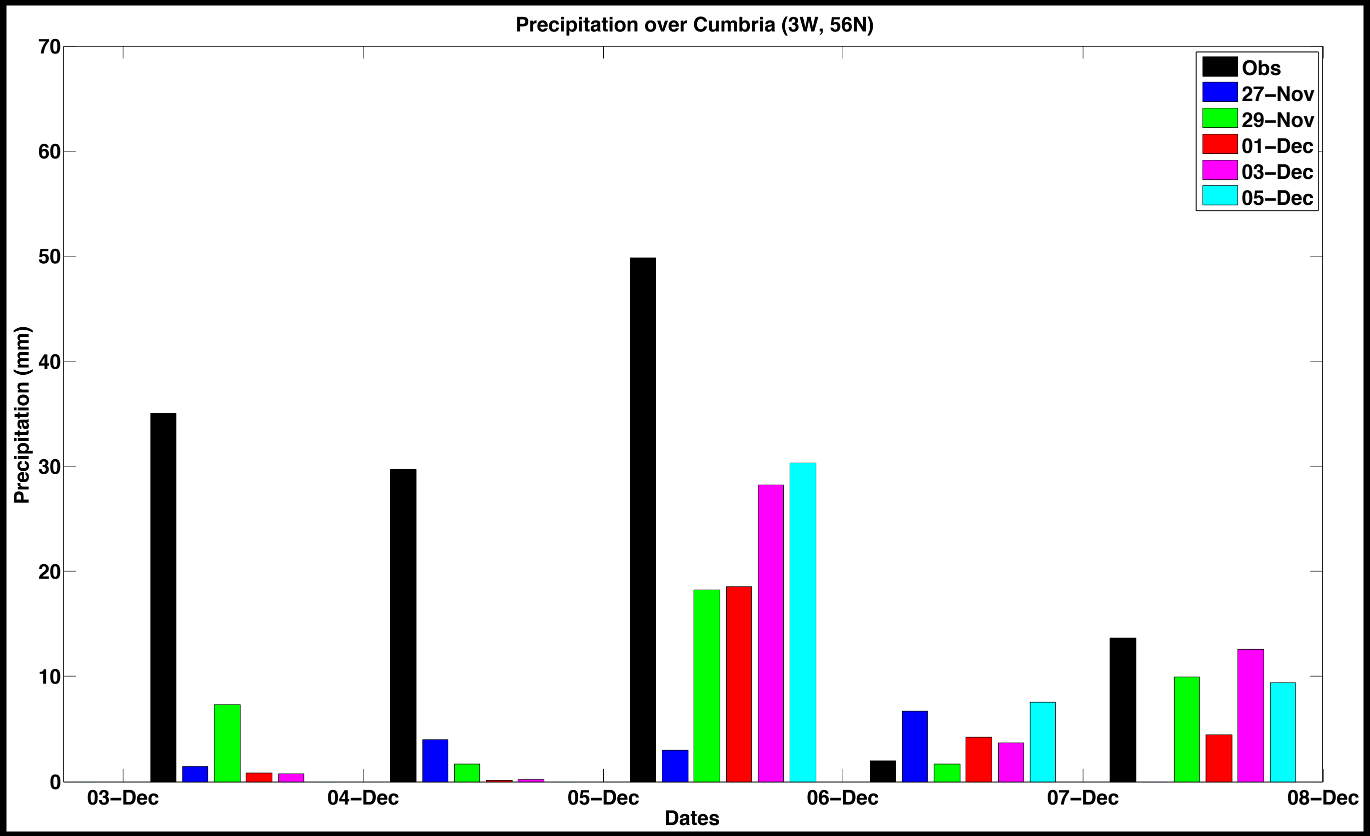
Forecast of precipitation over Cumbria,UK

Observations from E-Obs

Ensemble mean precipitation

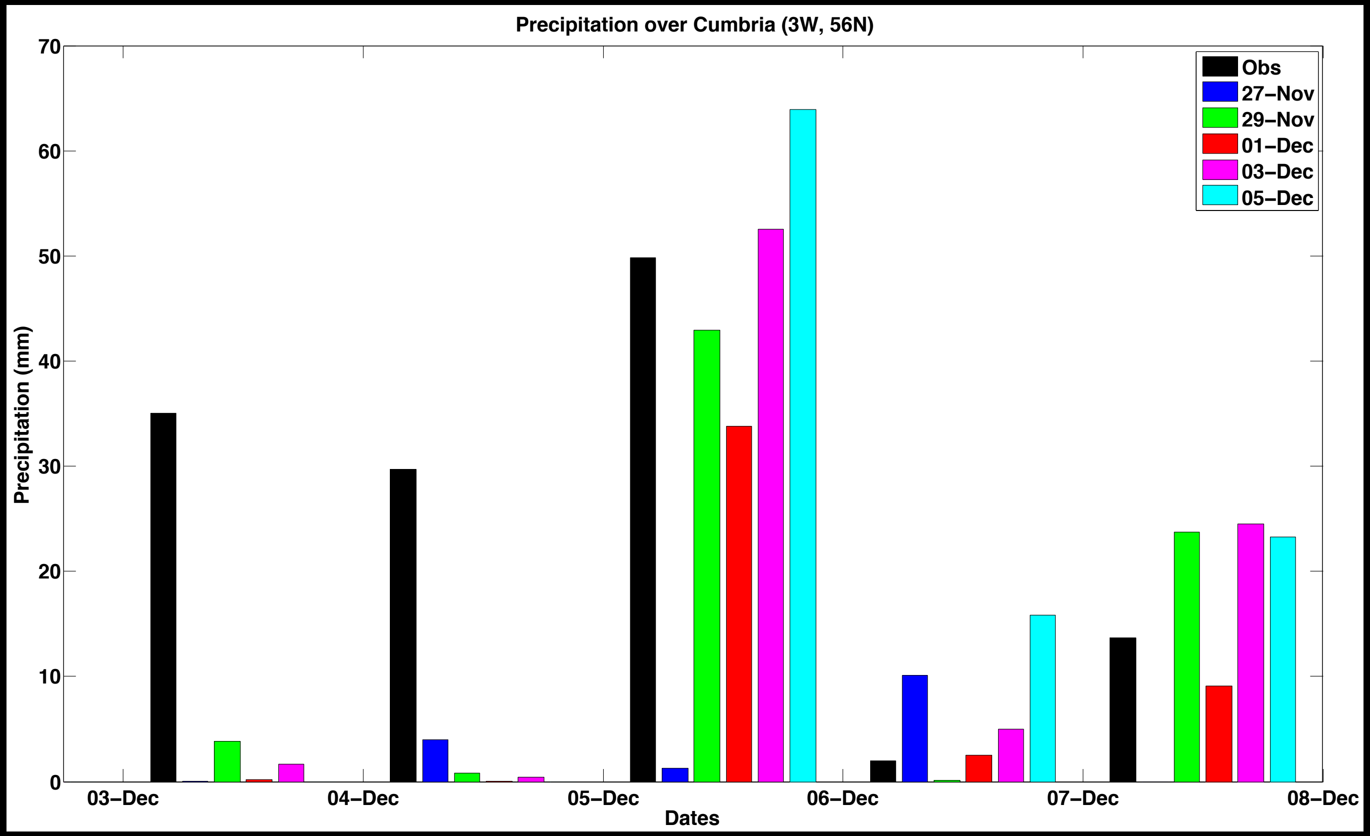
IFS SPPT



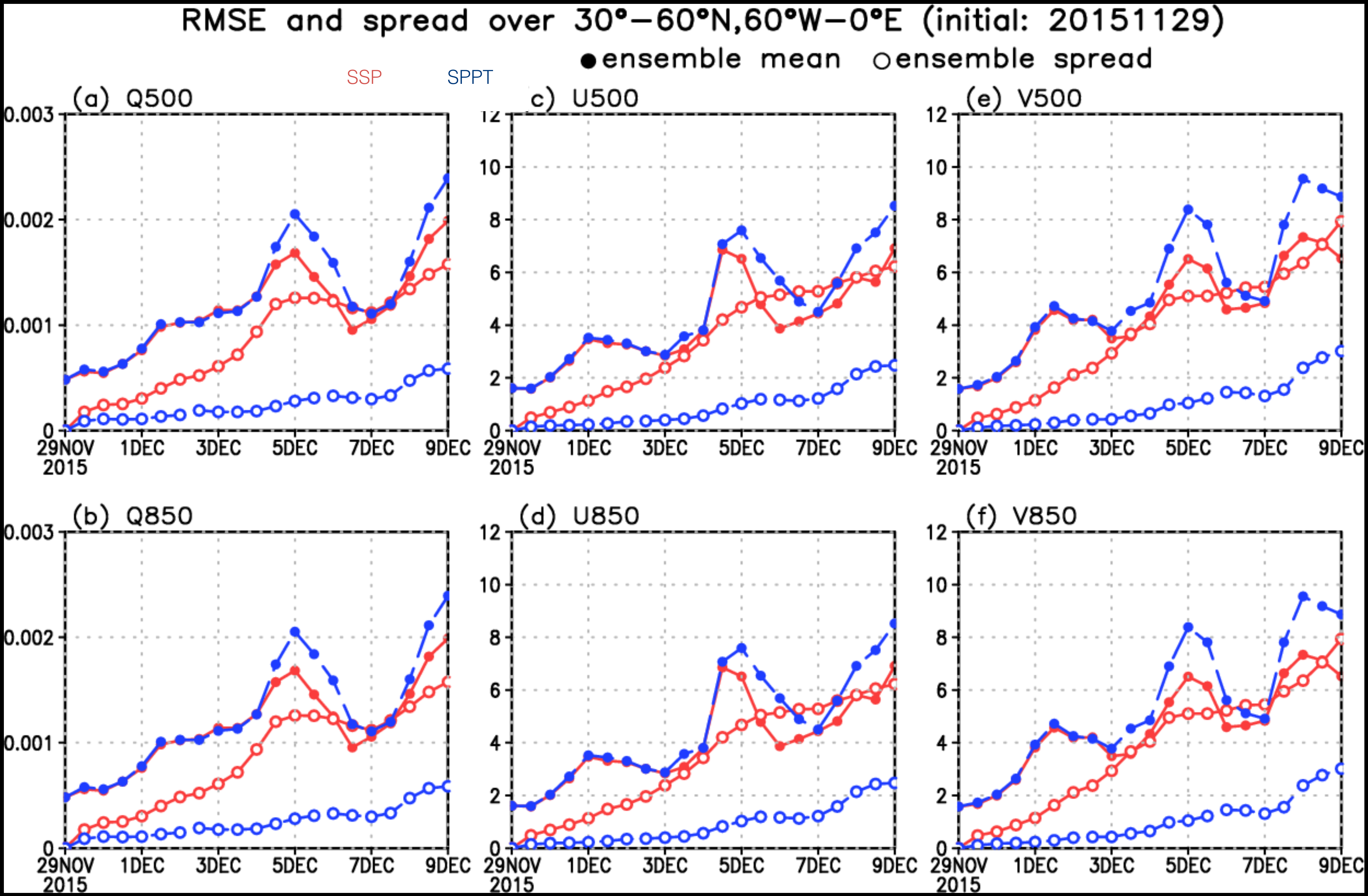


Ensemble mean precipitation

IFS SSP



RMSE and Ensemble Spread for Q, U, V

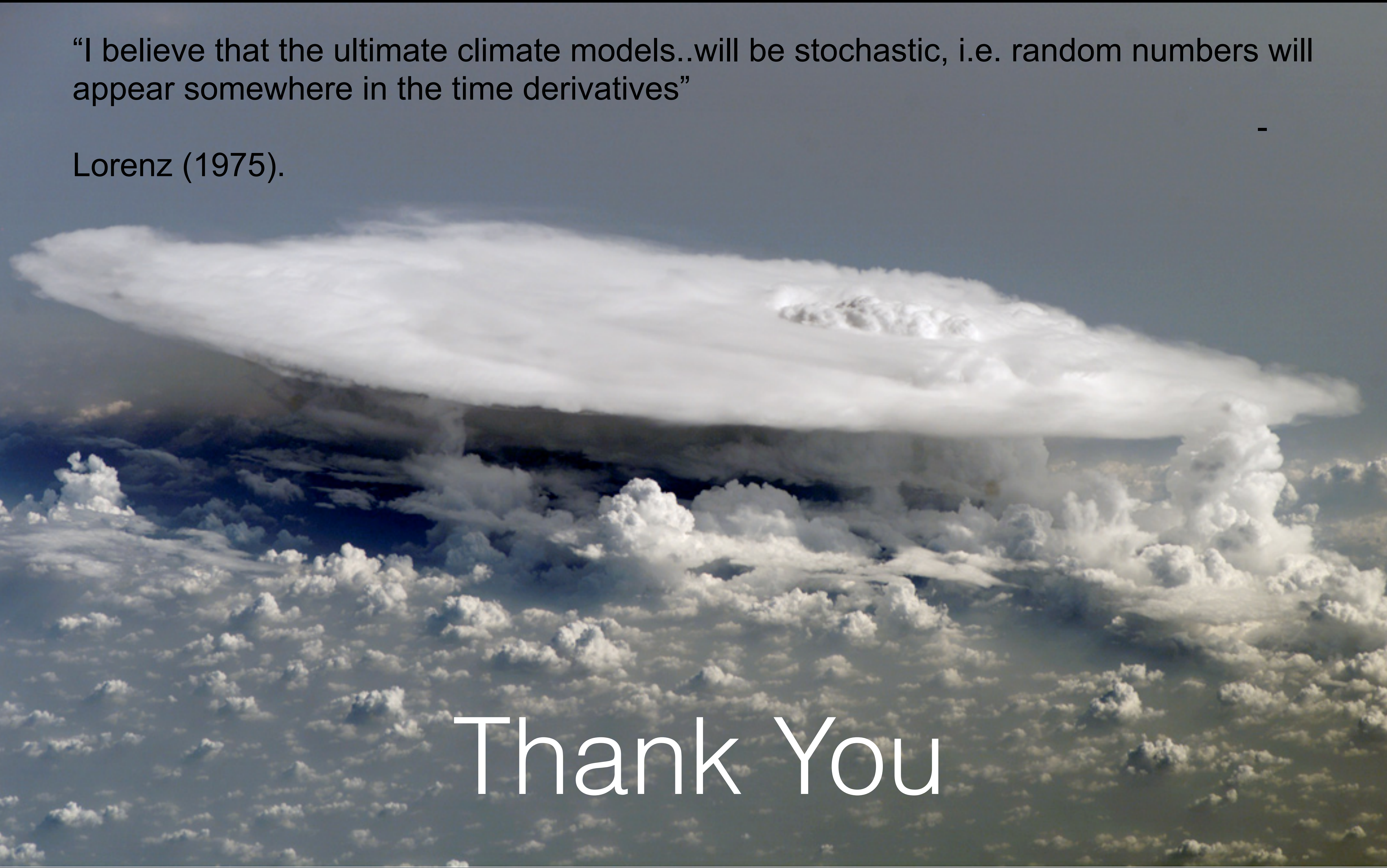


Summary

- Day 1 and 2 forecasts were similar for both approaches
- Day 5 and longer forecasts were more reliable with SSP
- Stochastic super-parameterization gives more reliable forecast for convective events
- Further approaches to quantify uncertainty in the CRM and model the same for a SP-IFS ensemble forecasting system is being explored.
- Impacts of stochastic super-parameterization in IFS on longer term variability (S2S) via nonlinear rectification will also be studied.

“I believe that the ultimate climate models..will be stochastic, i.e. random numbers will appear somewhere in the time derivatives”

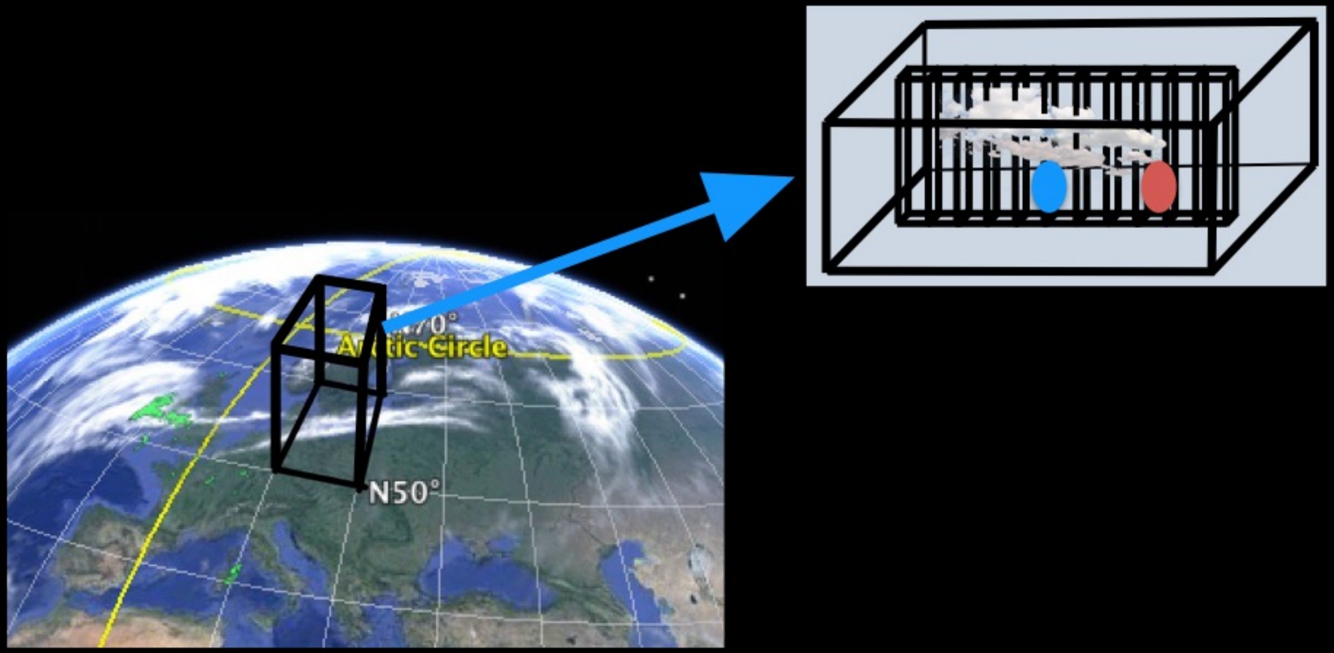
\- Lorenz (1975).



Thank You

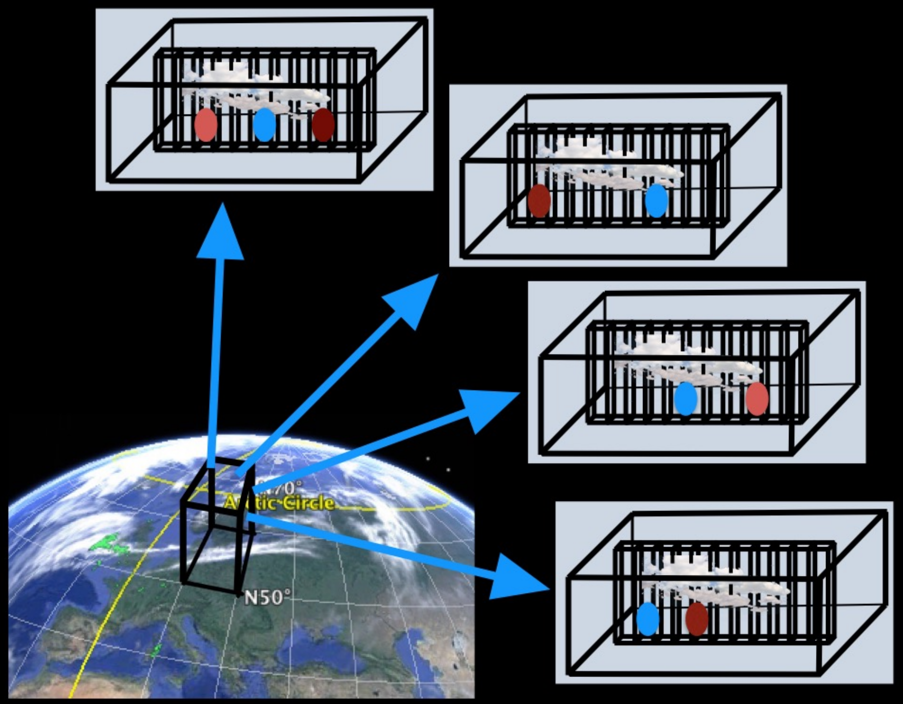
Multi-scale Modeling Framework

- Super-parameterised IFS model
- Run for 3 years (Aug 2000 until Sep 2003)
- Uncoupled ECMWF IFS used for simulations and comparison with T159 resolution.
- Super-parameterised CRM dimensions : 32 x 91; 4 km horz. resolution in CRM



Stochastic Multi-scale Modeling

- The uncertainty in sub-grid scale convection is propagated in time by the process model (Cloud resolving model).
- Currently uncertainty in the CRM is only prescribed at the initial state
- This approach is better in quantifying the uncertainty from sub-grid scale processes, such as convection, as it is evolved by the process model.
- This process driven uncertainty modeling for ensemble forecasts can inform improvements to SPPT like schemes which combine all model errors into one term.



Model Equations

Anelastic momentum equations

$$\frac{\partial u_i}{\partial t} = -\frac{1}{\bar{\rho}}\frac{\partial}{\partial x_j}(\bar{\rho} u_i u_j + \tau_{ij}) - \frac{\partial}{\partial x_i}\frac{p'}{\bar{\rho}} + \delta_{i3} B + \epsilon_{ij3} f(u_j - U_{gj}) + \left(\frac{\partial u_i}{\partial t}\right)_{l.s.}$$

Continuity equation

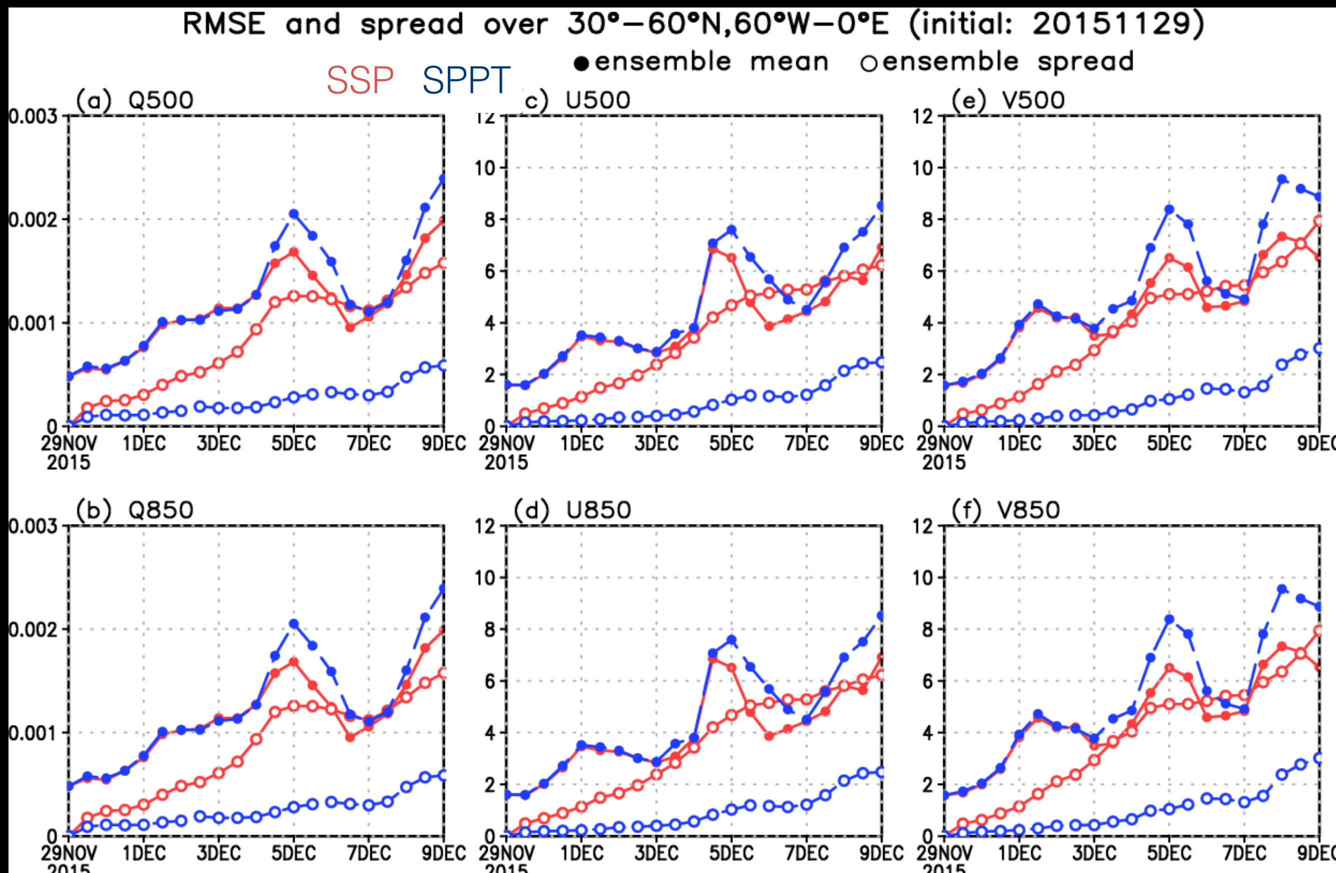
$$\frac{\partial}{\partial x_i}\bar{\rho} u_i = 0$$

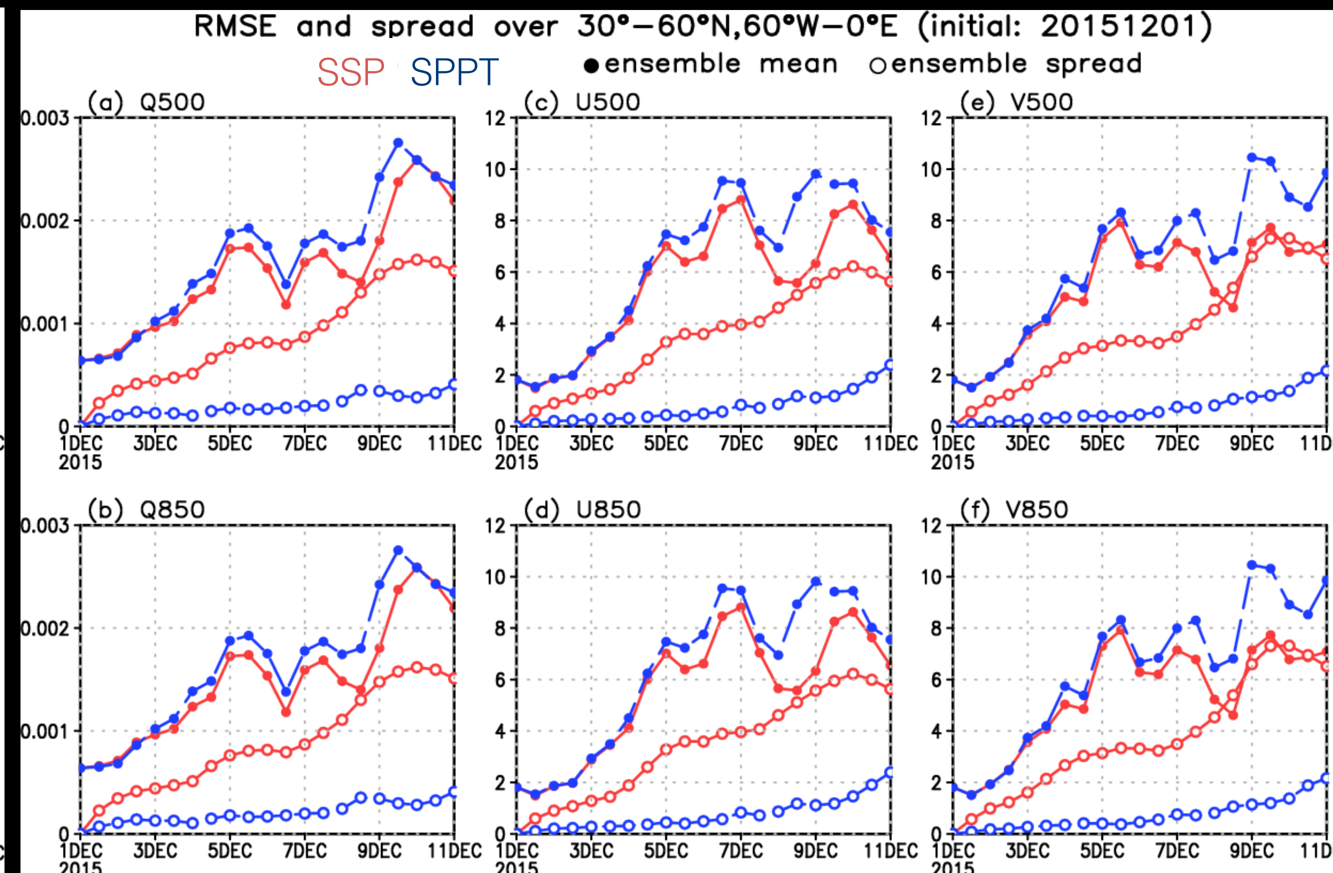
Conservation of moist static energy

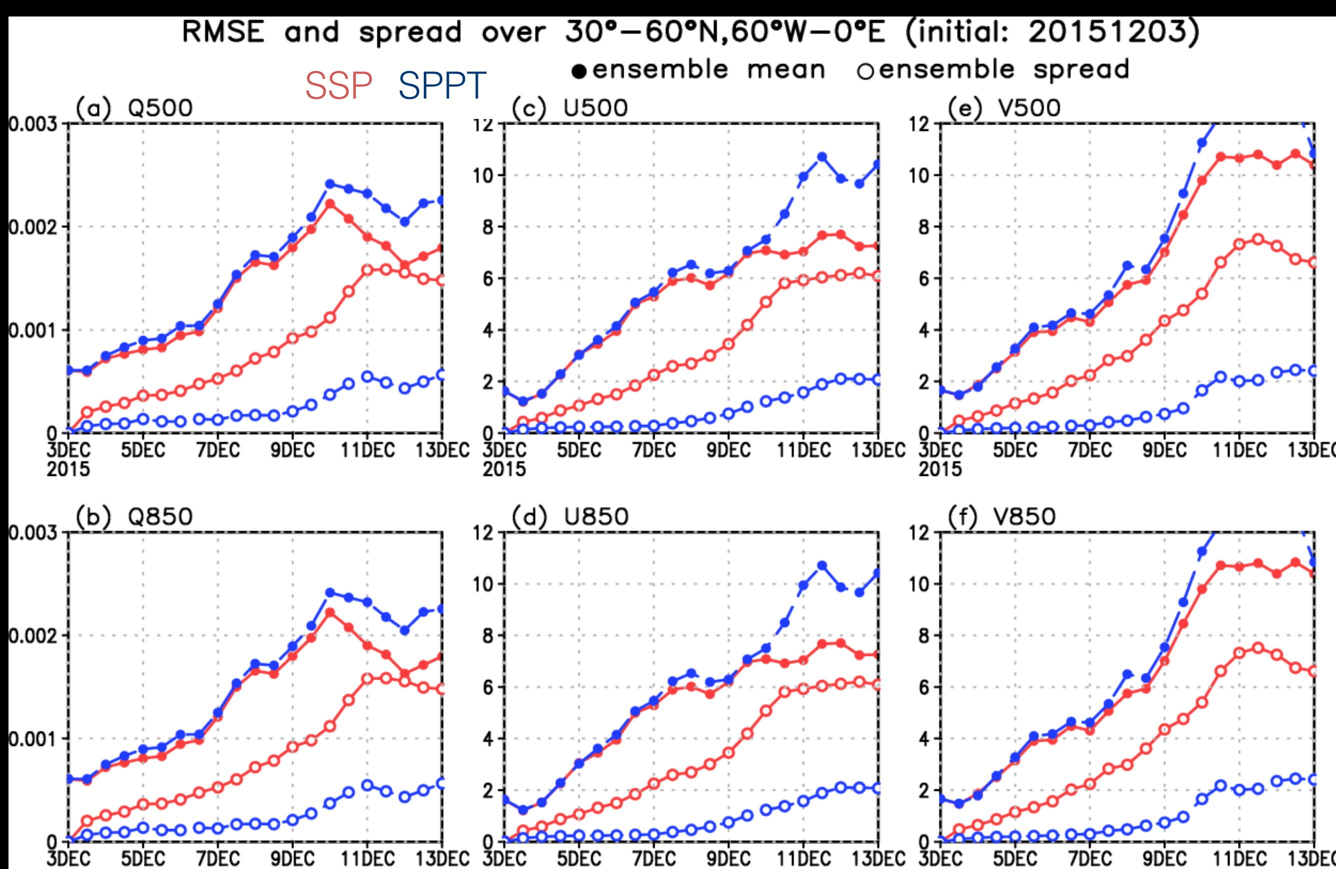
$$\frac{\partial h_L}{\partial t} = -\frac{1}{\bar{\rho}}\frac{\partial}{\partial x_i}(\bar{\rho} u_i h_L + F_{h_L i}) - \frac{1}{\bar{\rho}}\frac{\partial}{\partial z}(L_c P_r + L_s P_s + L_s P_g) + \left(\frac{\partial h_L}{\partial t}\right)_{rad} + \left(\frac{\partial h_L}{\partial t}\right)_{l.s.}$$

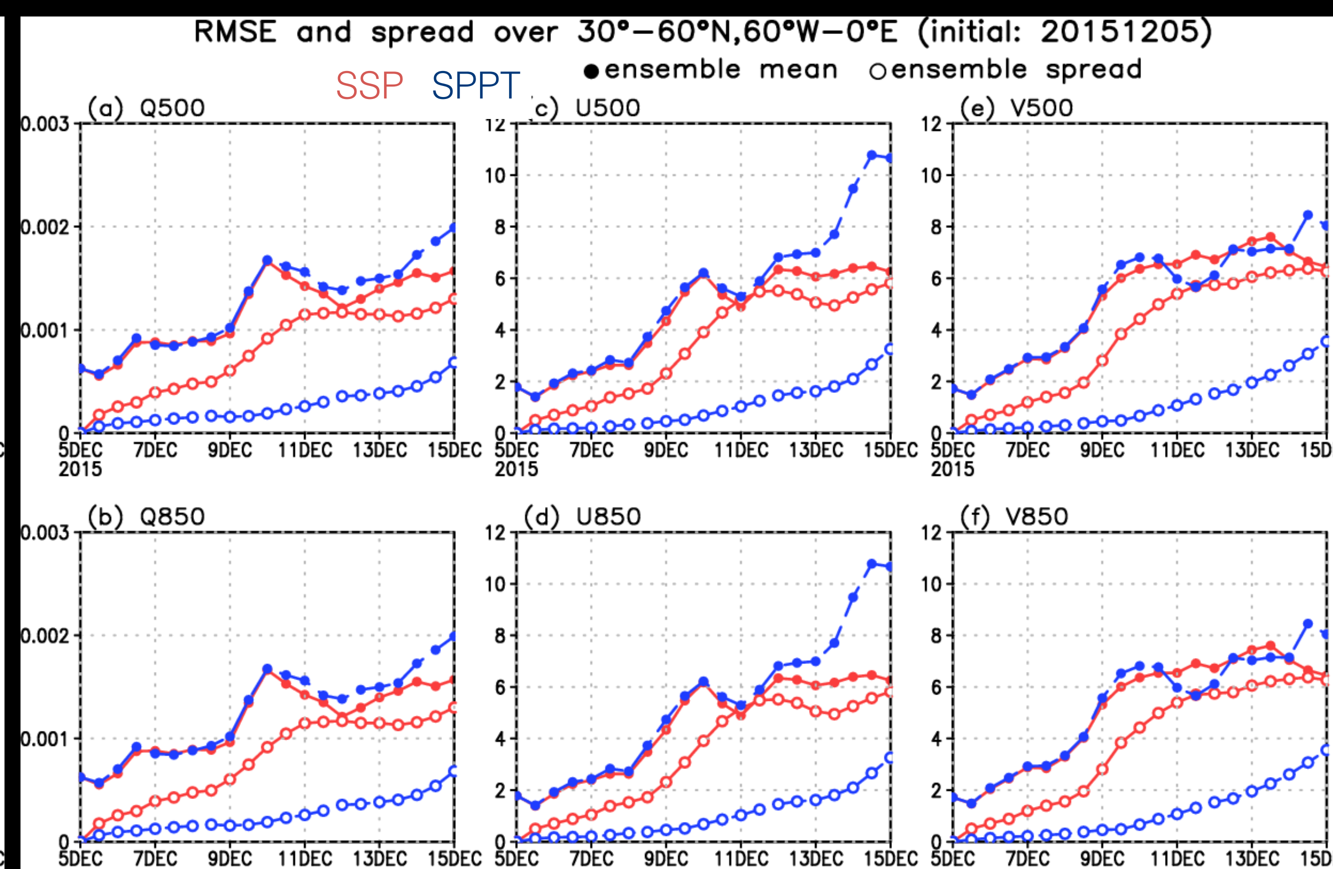
Subgrid-scale LES model for turbulence

RMSE and Ensemble Spread for Q, U, V



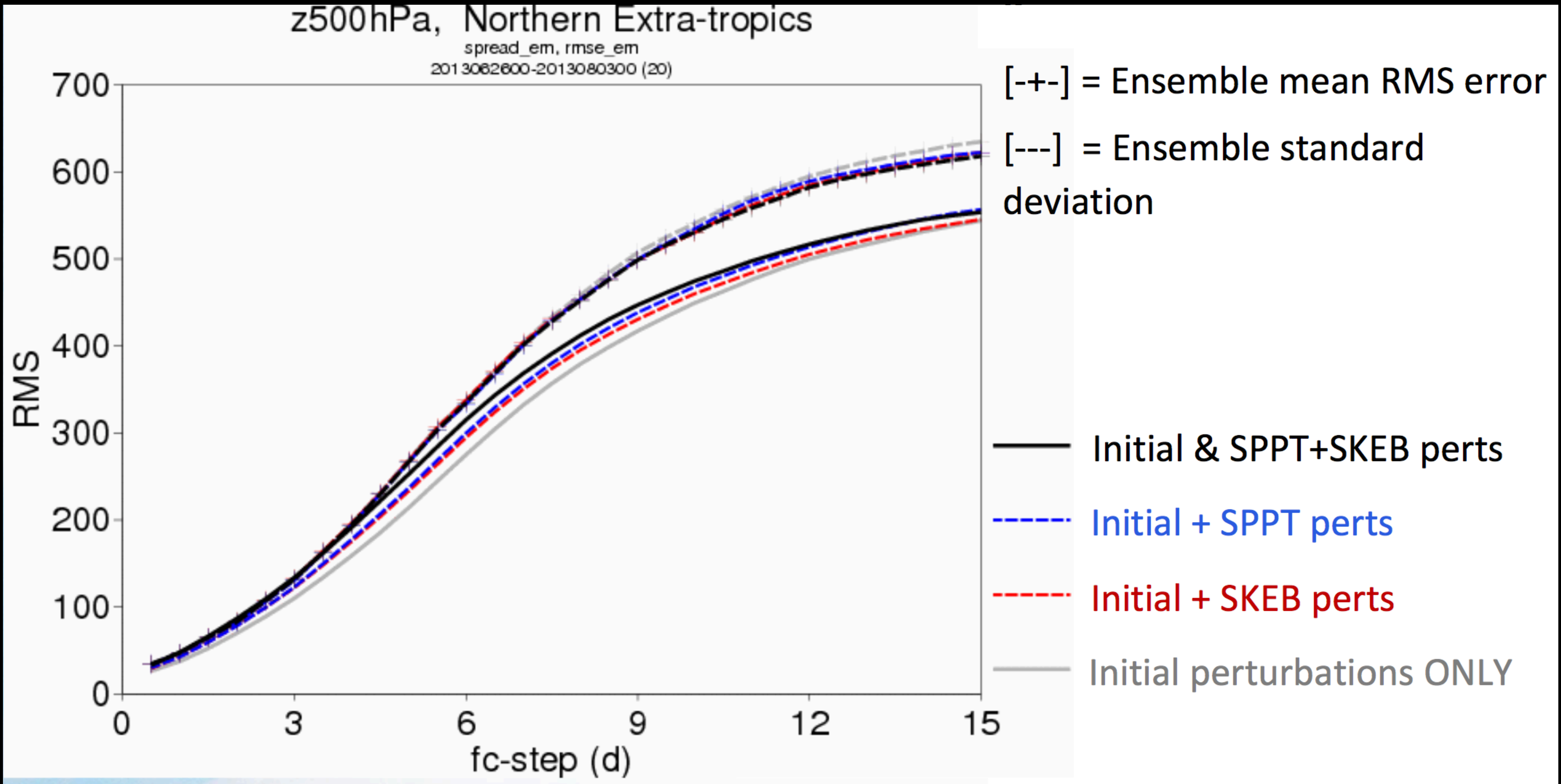






Impact of SPPT and SKEB on Ensemble Forecasts

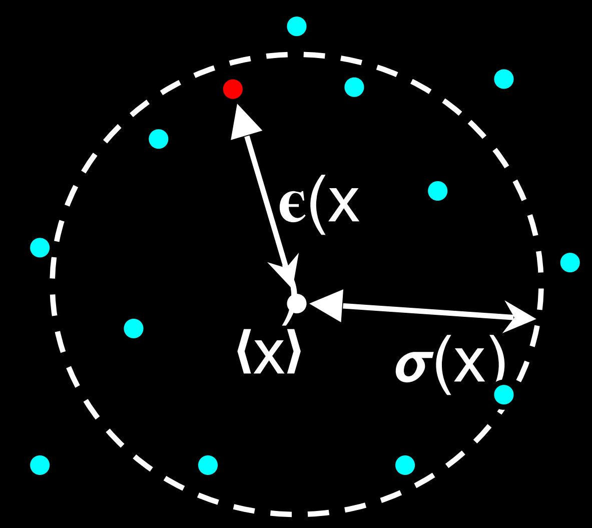
Improved forecast uncertainty in ECMWF IFS



from Sarah-Jane Lock (ECMWF)

Ensemble Reliability

In a reliable ensemble, ensemble spread is a predictor of the ensemble error



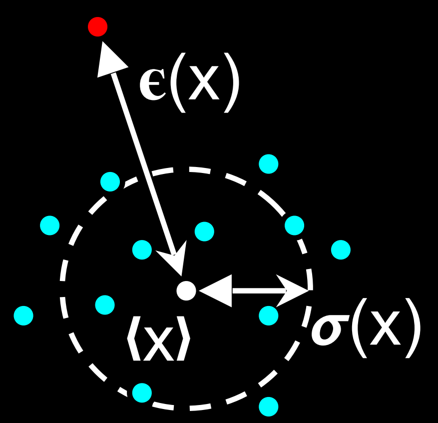
i.e. the average over many ensemble forecasts,

$$\epsilon(x) = \sigma(x)$$

Under-dispersive ensemble

For an under-dispersive ensemble,

$\epsilon(x) >> \sigma(x)$



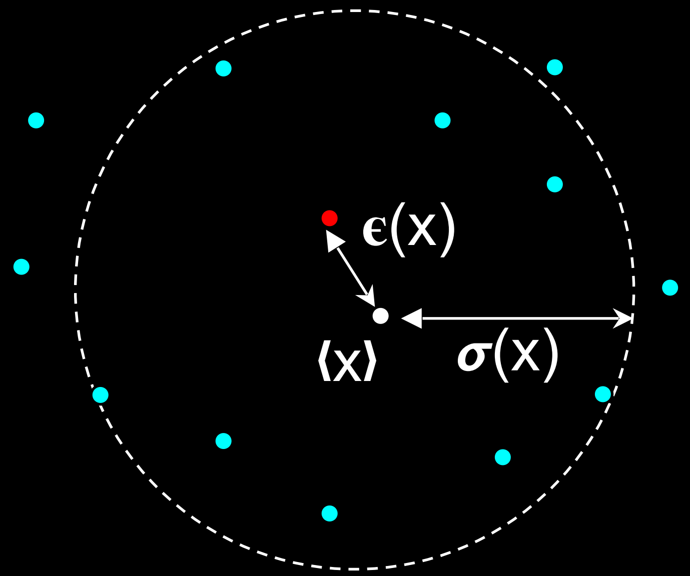
the ensemble spread isn't a good indicator of the ensemble error, and hence the ensemble is unreliable.

Modeling error in the ensemble is important to have a reliable forecast ensemble.

Over-dispersive ensemble

For an over-dispersive ensemble,

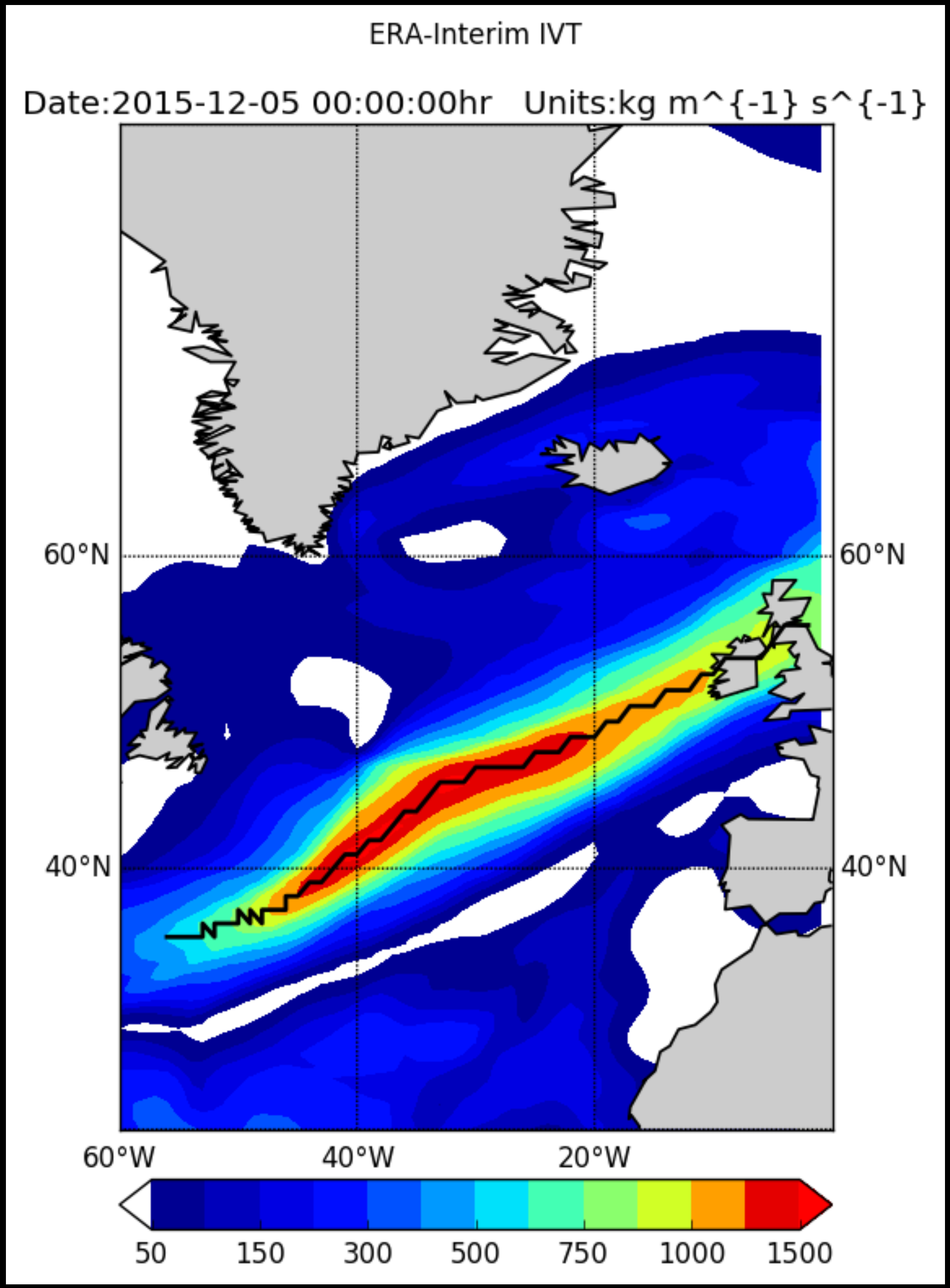
$$\epsilon(x) << \sigma(x)$$

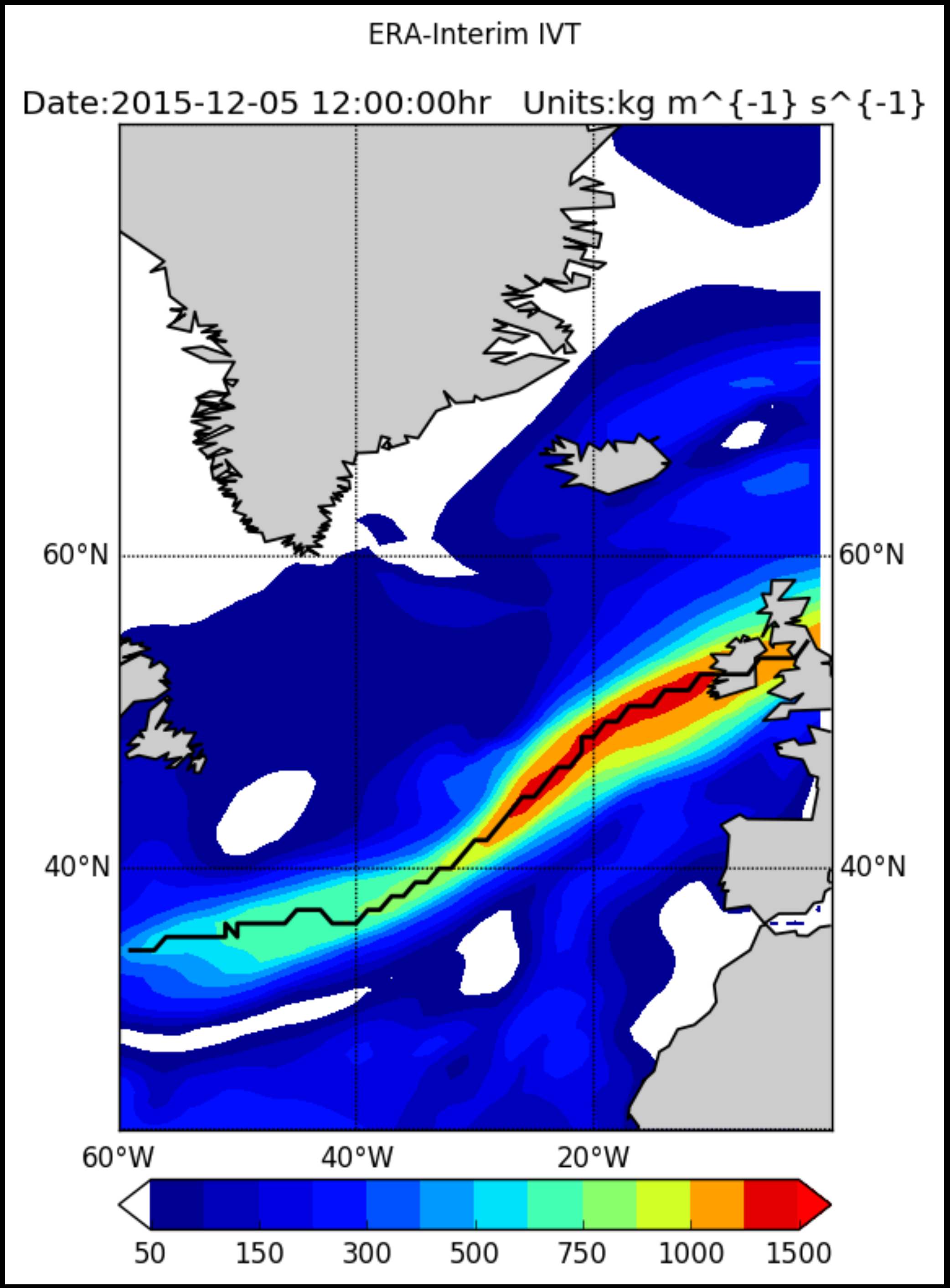


The ensemble spread over estimates the ensemble error, and hence the ensemble is unreliable.

Modeling error in the ensemble is important to have a reliable forecast ensemble.

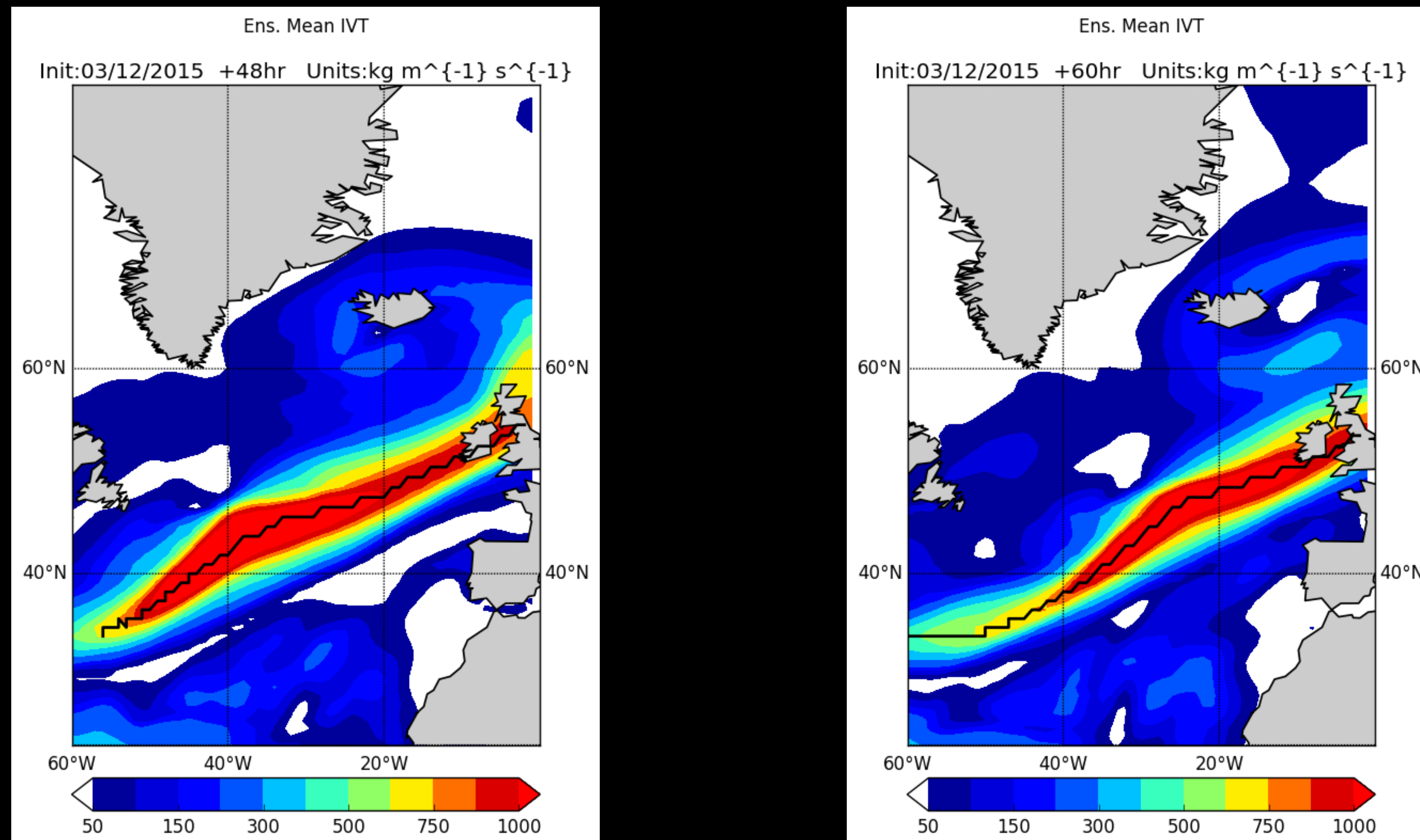
ERA Interim


ERA-Interim IVT
Date:2015-12-05 00:00:00hr Units:kg m^{-1} s^{-1}
60°N
40°N
60°N
40°N
60°W
40°W
20°W
50
150
300
500
750
1000
1500

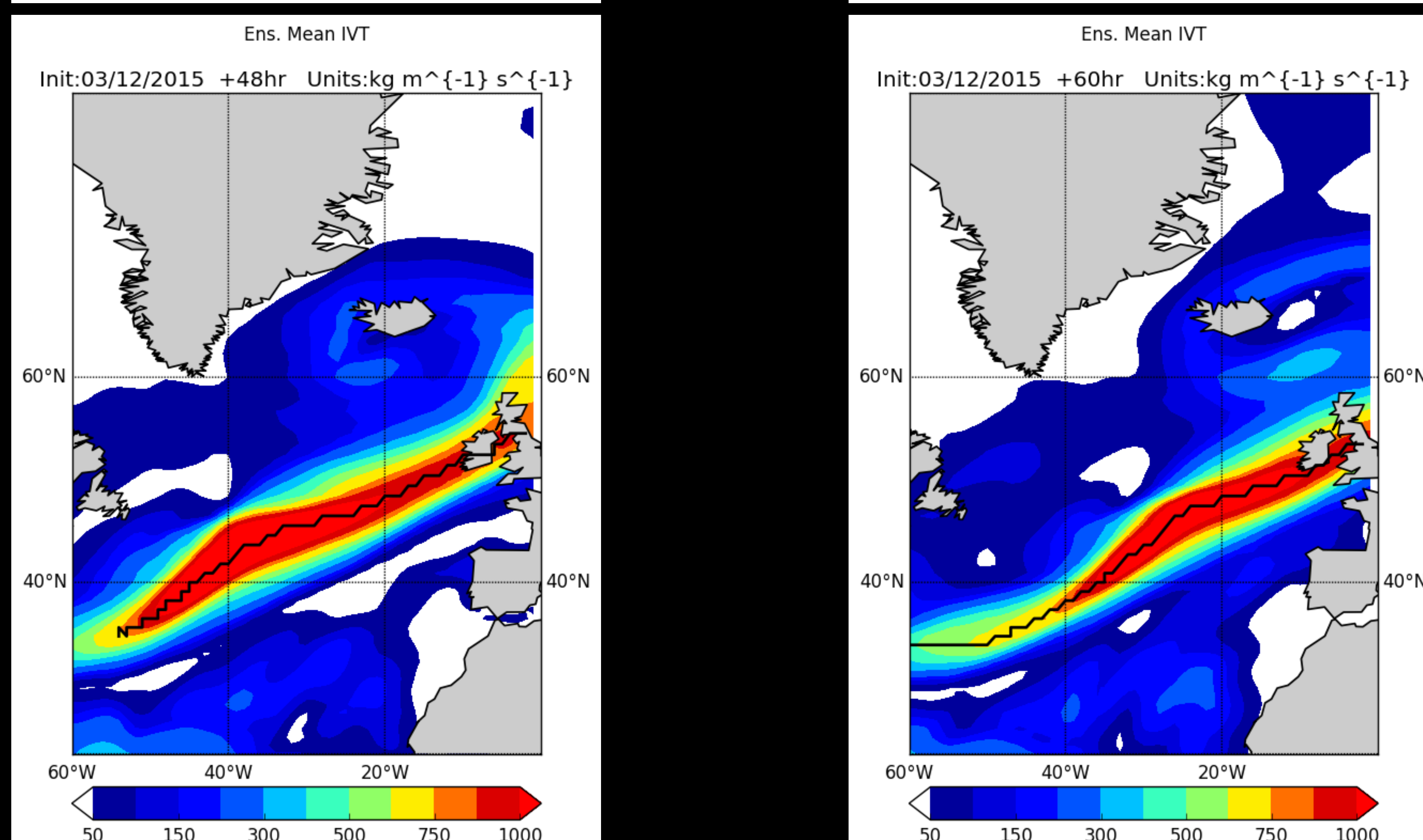

ERA-Interim IVT
Date:2015-12-05 12:00:00hr Units:kg m^{-1} s^{-1}
60°N
40°N
60°N
40°N
60°W
40°W
20°W
50
150
300
500
750
1000
1500

Integrated Water Vapor Transport : 2 day forecast

SPPT IFS

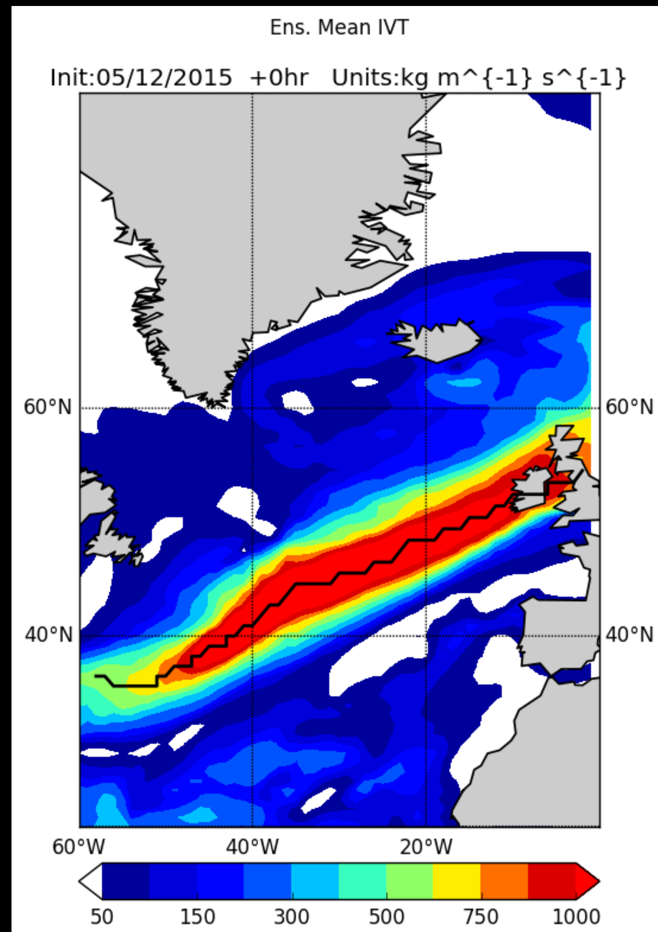


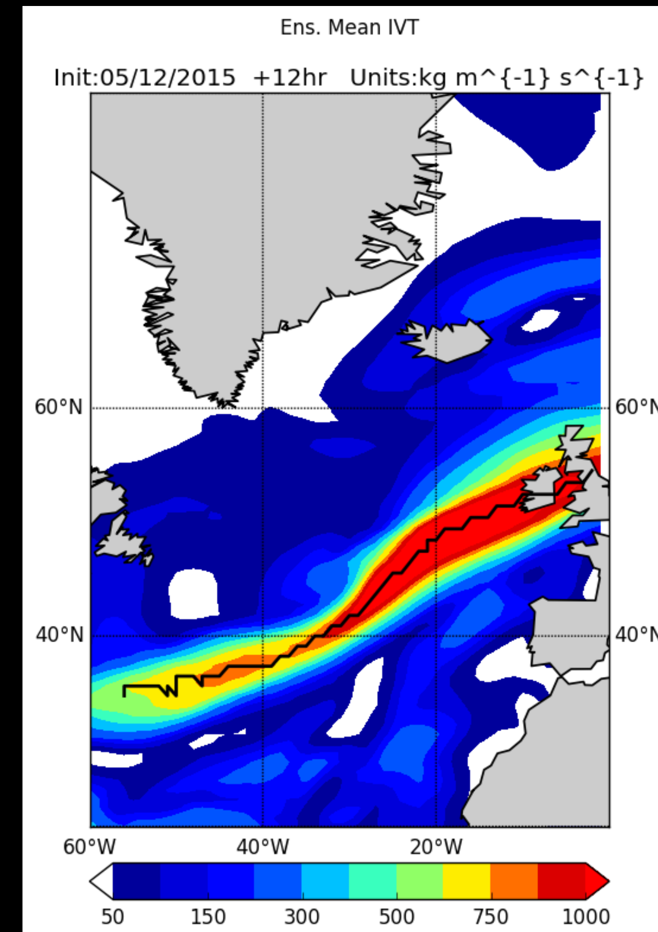
SSP IFS



Integrated Water Vapor Transport : 1 day forecast

SPPT IFS





SSP IFS