ECMWF Research and Development Activities

Erland Källén

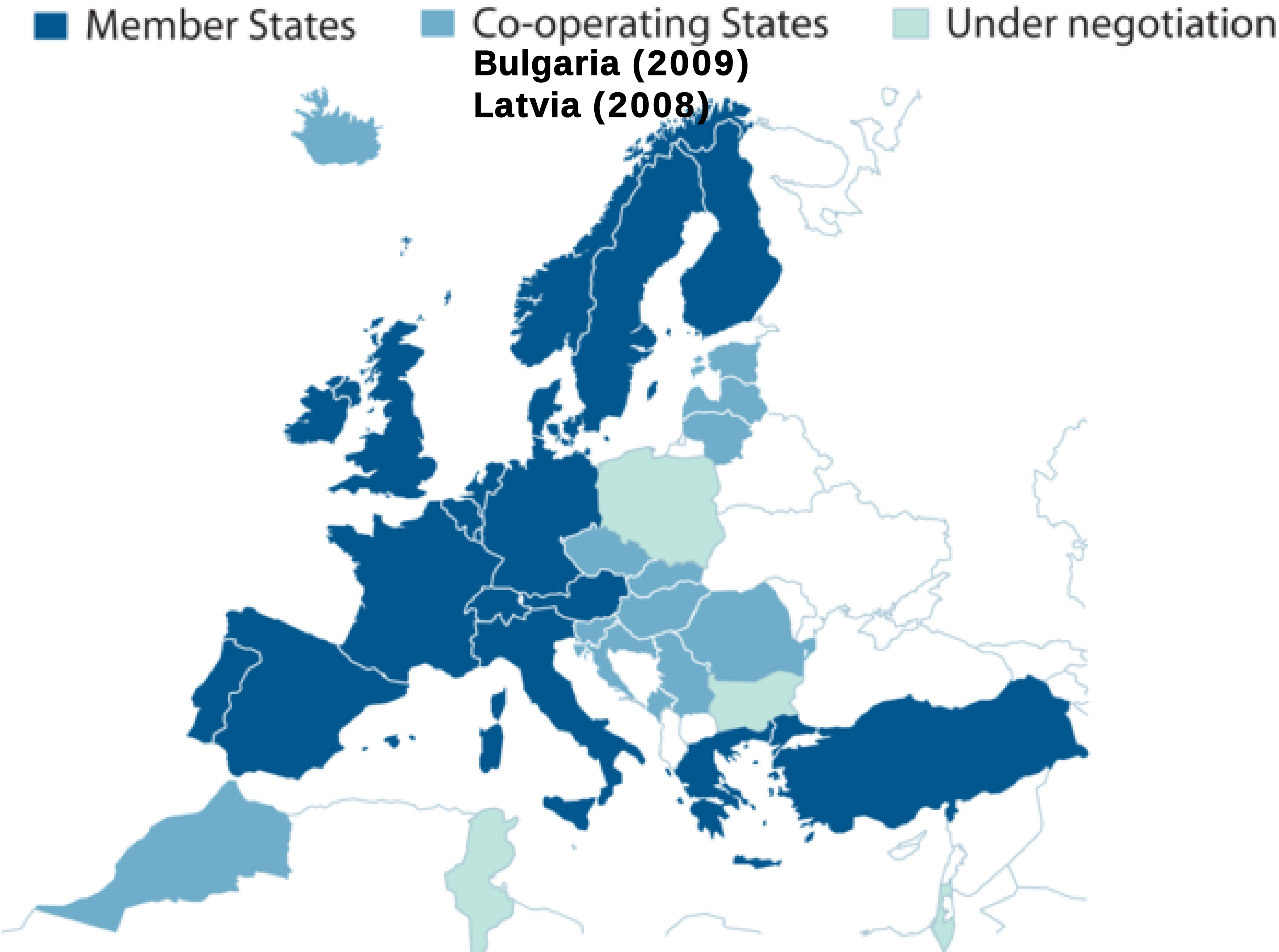
Head of Research, ECMWF

erland.kallen@ecmwf.int

and Research Department colleagues

Outline

- Introduction
  - Forecast model performance
  - Data
    - Data assimilation
    - Reanalysis
  - Model
    - Physical aspects
    - Numerical aspects
  - Probabilistic Prediction System
    - Ensemble prediction
    - Seasonal and monthly forecasting
- Outlook


Member States
Co-operating States
Under negotiation
Bulgaria (2009)
Latvia (2008)

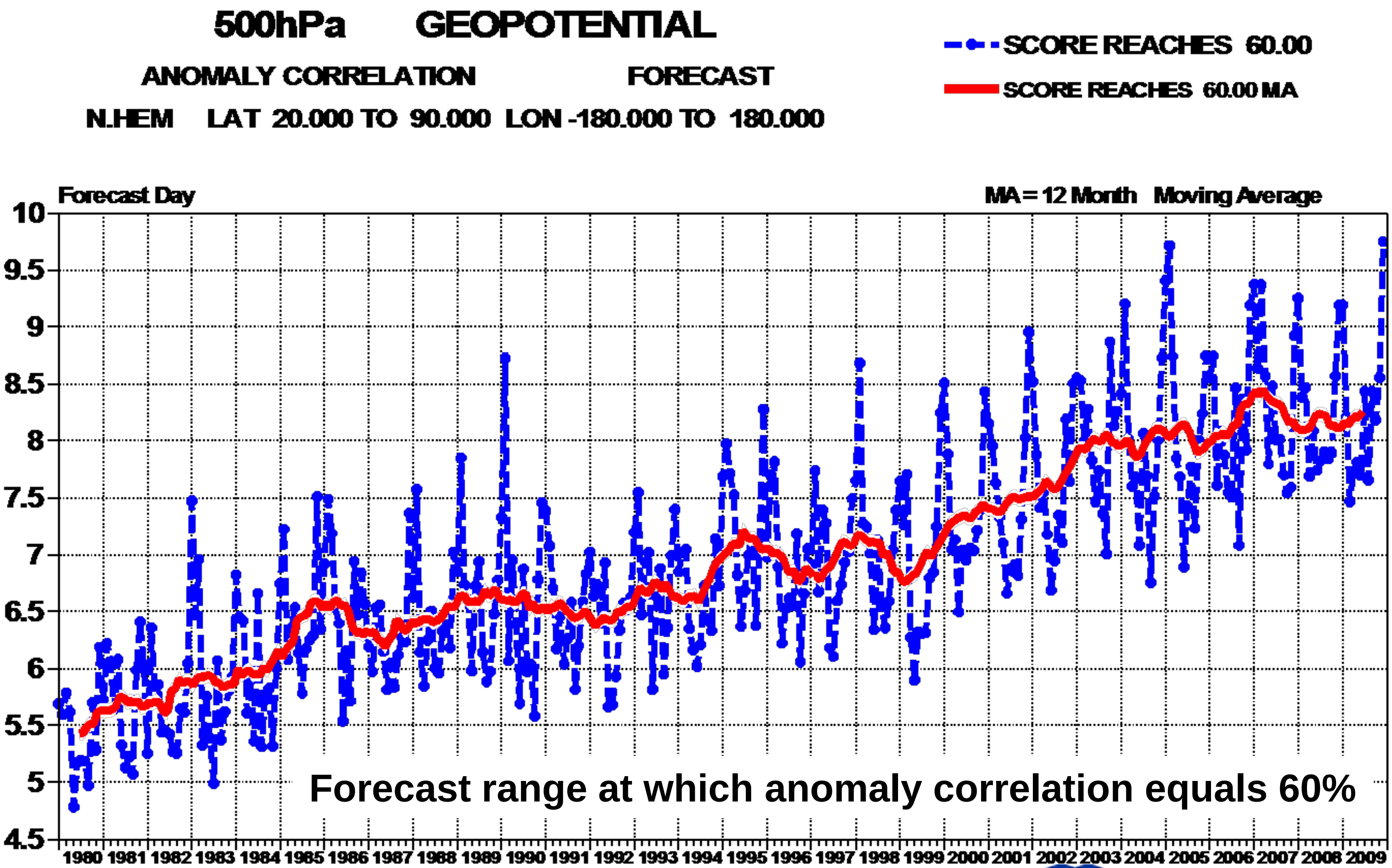
Outline

- Introduction
  - **Forecast model performance**
  - Data
    - Data assimilation
    - Reanalysis
  - Model
    - Physical aspects
    - Numerical aspects
  - Probabilistic Prediction System
    - Ensemble prediction
    - Seasonal and monthly forecasting
- Outlook

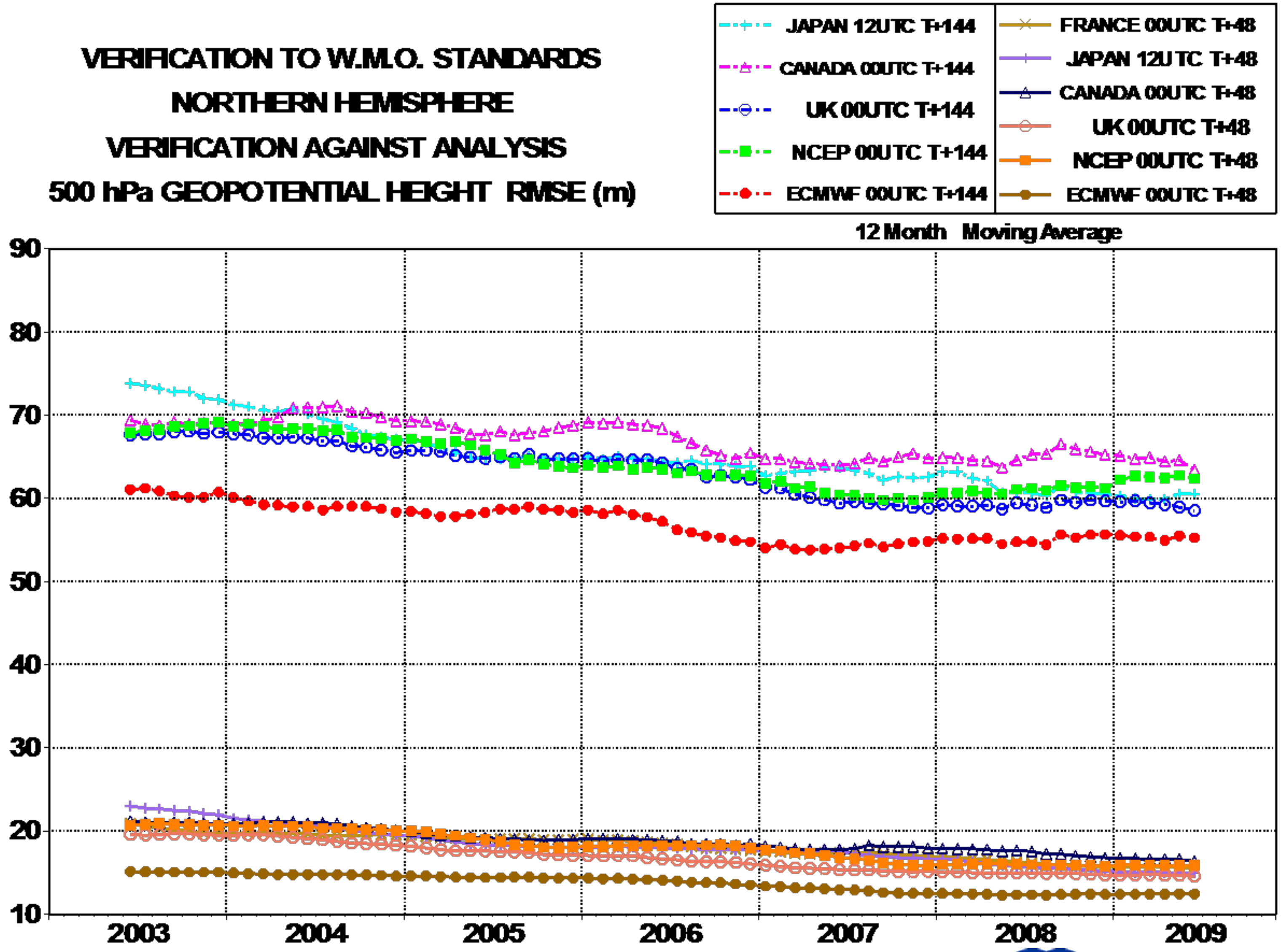
The operational forecast system (from 26 January 2010):

- **High resolution deterministic forecast: twice daily**
  16 km 91-level, 10 days ahead
- **Ensemble forecast (EPS): twice daily**
  51 members, 32/50 km 62-level, 15 days ahead
- **Ocean waves: twice daily**
  - **Global: 10 days ahead at 30 km**
  - **European Waters: 5 days ahead at 25 km**
  - **Ensemble: 15 days ahead at 50 km**
- **Monthly forecast: once a week**
  51-members, 32/50 km 62 levels
- **Seasonal forecast: once a month**
  41-members, 125 km 62 levels, to 7 months ahead

Forecast scores
Z500, time series of day when ACC=0.6, N.Hem



WMO standard scores
Z500 RMSE, N.Hem., intercomparison



ECMWF

Outline

- Introduction
  - Forecast model performance
  - **Data**
    - **Data assimilation**
    - Reanalysis
  - Model
    - Physical aspects
    - Numerical aspects
  - Probabilistic Prediction System
    - Ensemble prediction
    - Seasonal and monthly forecasting
- Outlook

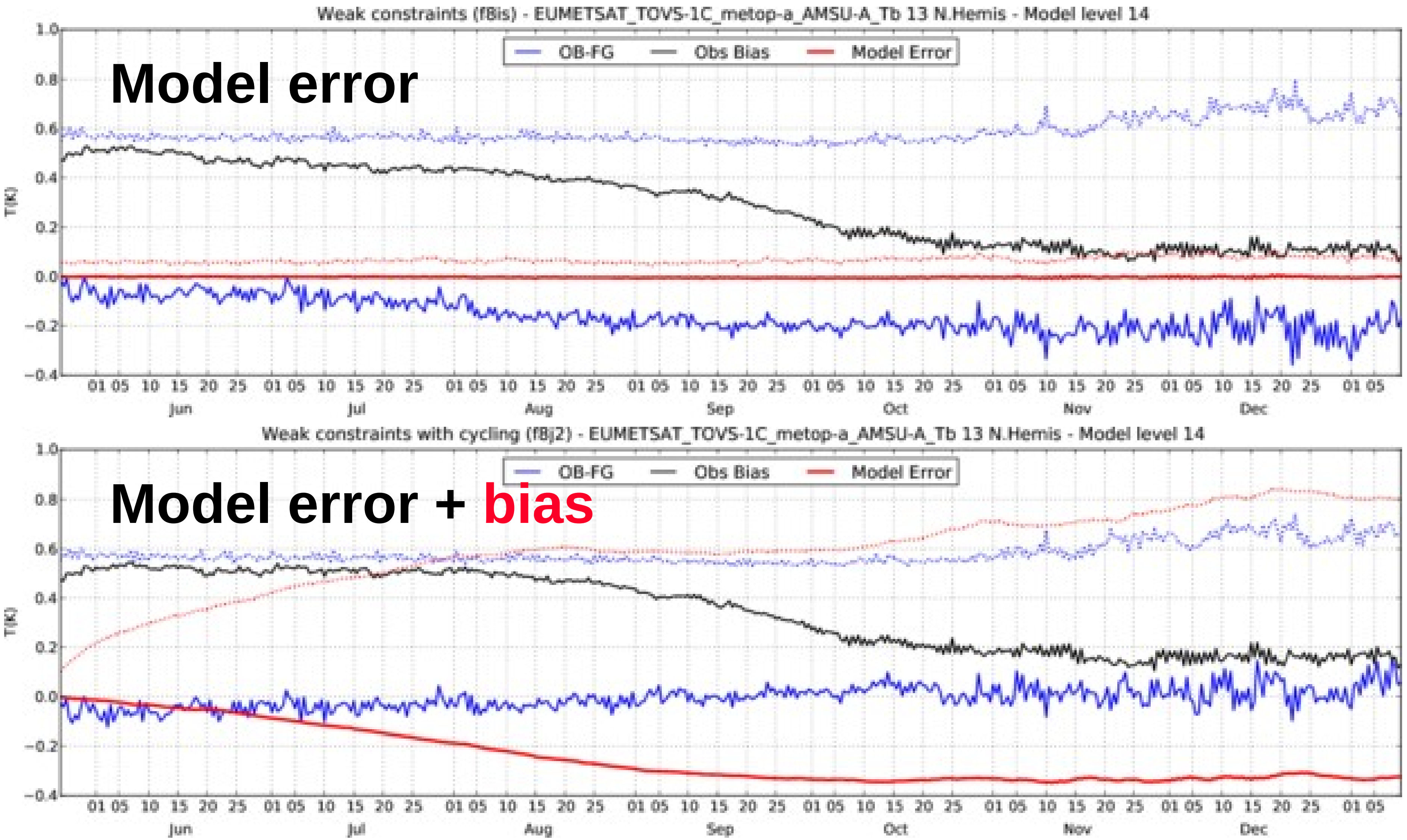
Weak constraint 4DVAR

- **Only applied in stratosphere**
- **Cost function including model error and bias:**
  - **Model error**
  - **Model bias (cycled)**

$$J(\mathbf{x}_0, \boldsymbol{\eta}) = \frac{1}{2}\sum_{i=0}^{n}[\mathcal{H}(\mathbf{x}_i) - \mathbf{y}_i]^T \mathbf{R}_i^{-1}[\mathcal{H}(\mathbf{x}_i) - \mathbf{y}_i] + \frac{1}{2}(\mathbf{x}_0 - \mathbf{x}_b)^T \mathbf{B}^{-1}(\mathbf{x}_0 - \mathbf{x}_b) + \frac{1}{2}(\eta - \eta_b)^T \mathbf{Q}^{-1}(\eta - \eta_b)$$

$$\mathbf{x}_i = \mathcal{M}_i(\mathbf{x}_{i-1}) + \boldsymbol{\eta}_i$$

Weak constraint 4DVAR

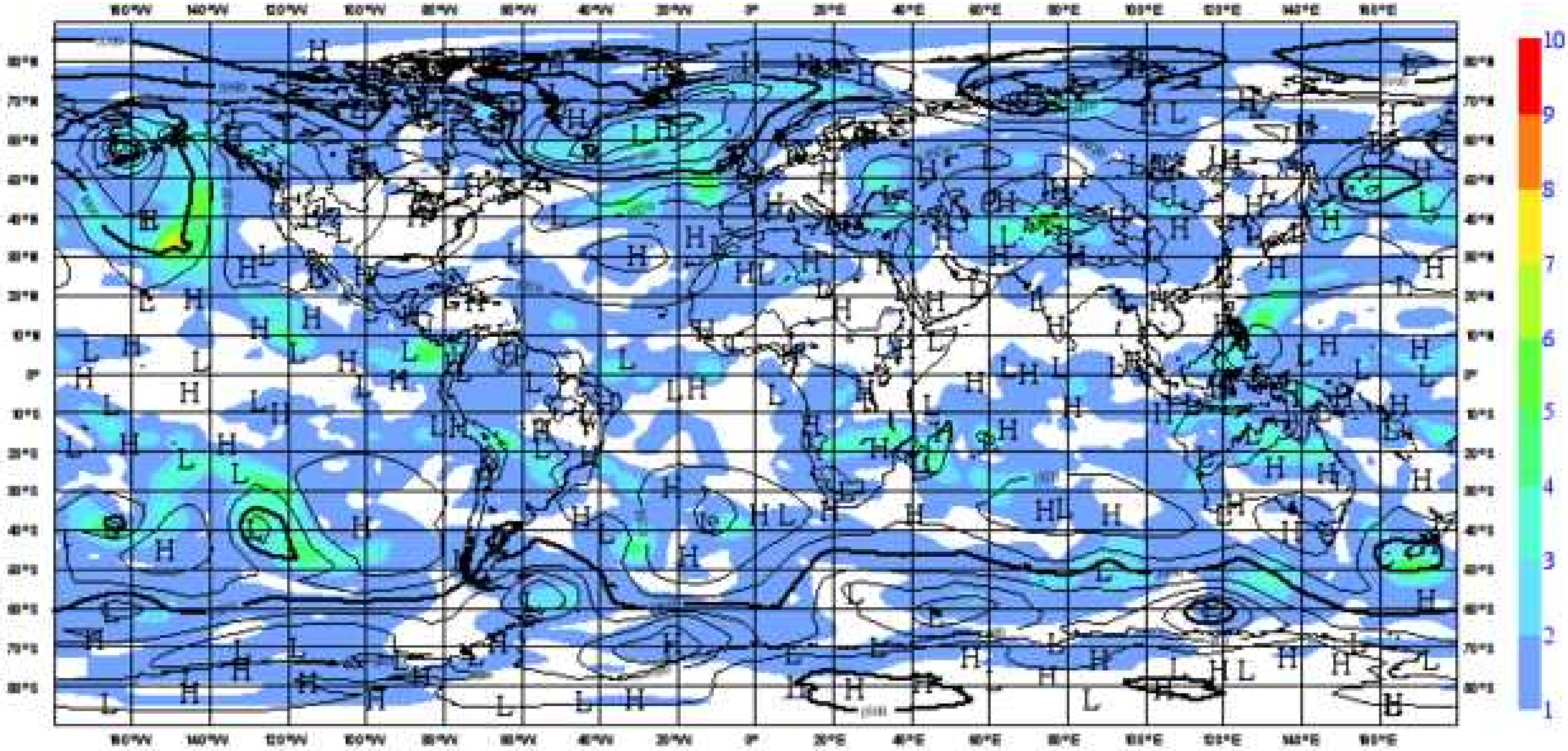


Ensembles of Data Assimilation (EDA)

- **Control + 10 ensemble members using 4D-Var assimilations**
  - **T399 outer loop**
  - **T95/T159 inner loop (reduced number of iterations)**
- **Model error**
  - **Spectral backscatter (SPBS) method**
  - **Stochastically Perturbed Parametrization Tendencies**
- **Randomly perturbed observations and SST fields**
- **EDA operational for**
  - **EPS perturbations: Q2 2010**
  - **Flow dependent variance in 4DVAR: Q3 2010**

Ensemble spread, filtered

Vorticity at 500 hPa, +9h

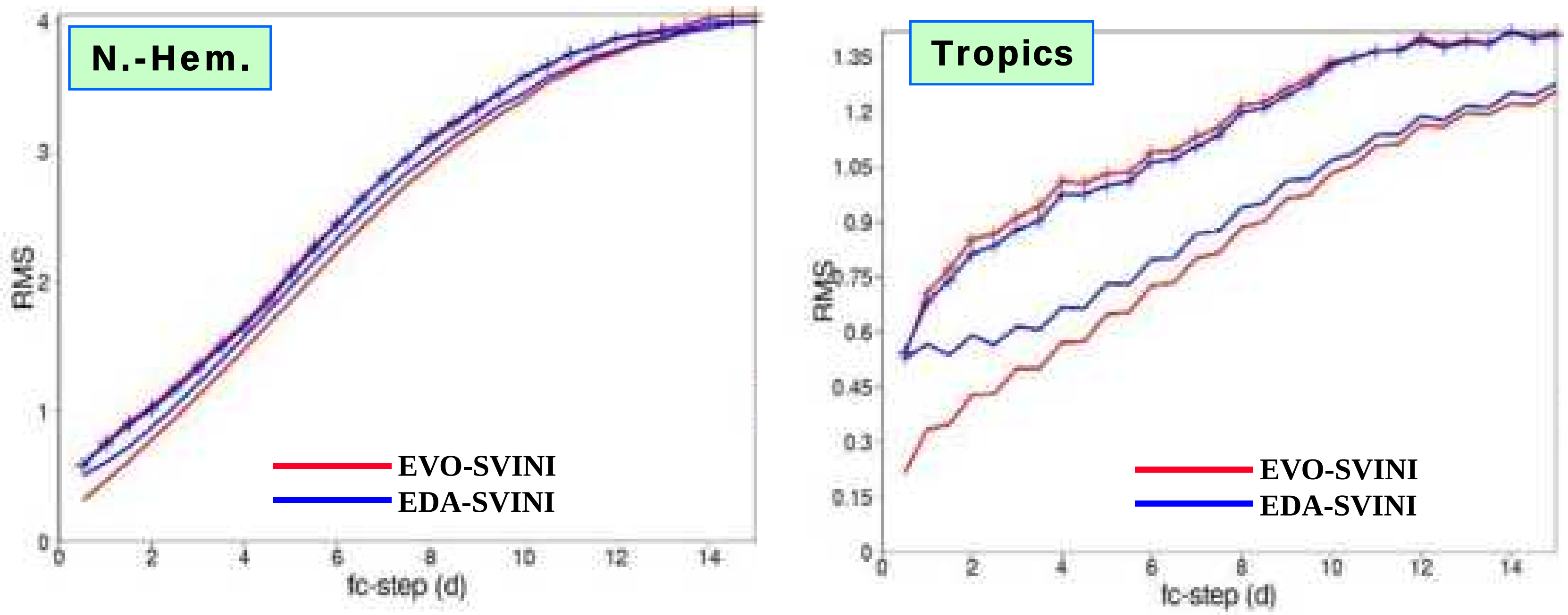


ECMWF

Improving Ensemble Prediction System by including EDA perturbations for initial uncertainty

The Ensemble Prediction System (EPS) benefits from using EDA based perturbations. Replacing evolved singular vector perturbations by EDA based perturbations improve EPS spread, especially in the tropics.

The Ensemble Mean has slightly lower error when EDA is used.

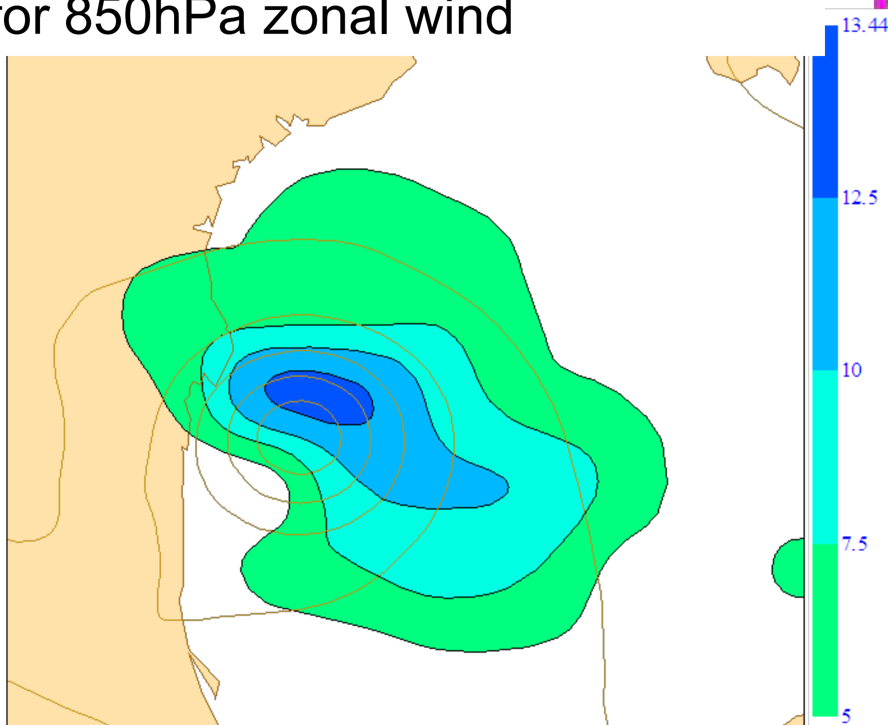


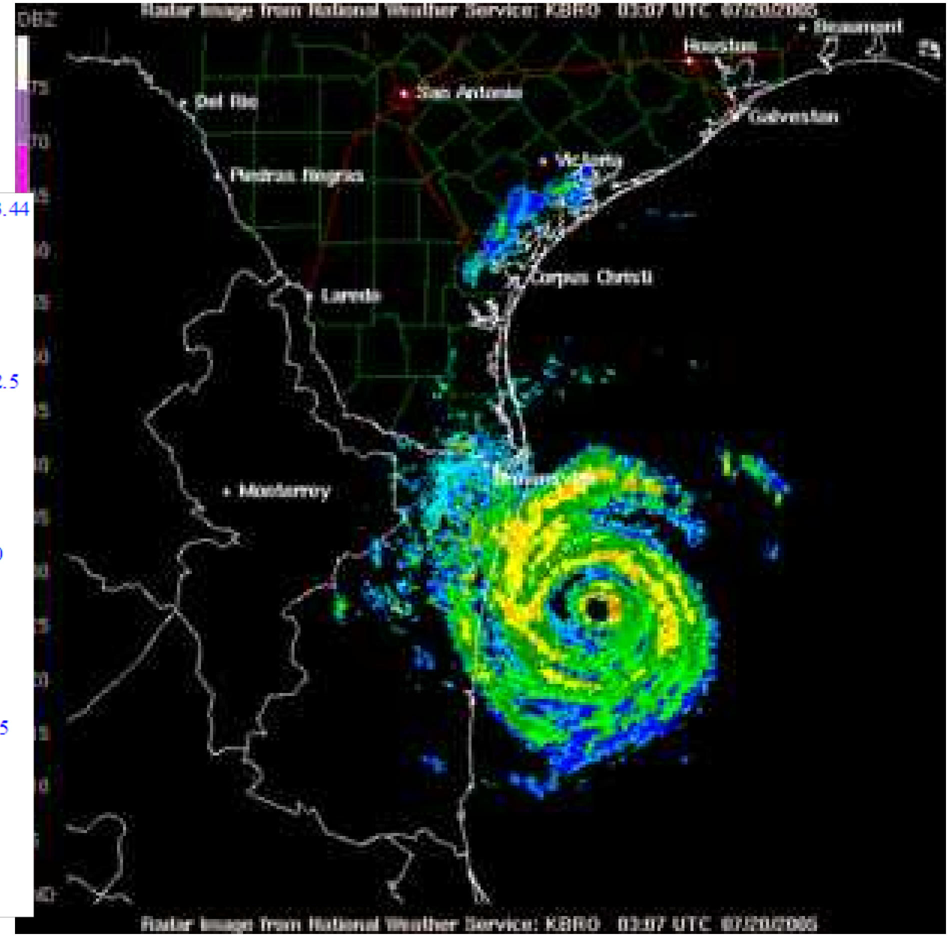
Ensemble spread and Ensemble mean RMSE for 850hPa T

Flow-dependent background error estimates from EDA

Tropical cyclone Emily near Mexico 00UTC 20 July 2005

T399 EDA experiment:
Background error estimate 13m/s
for 850hPa zonal wind





The contours represent the mean sea level pressure field (5hPa interval).

ECMWF

Why implement Ensembles of Data Assimilation?

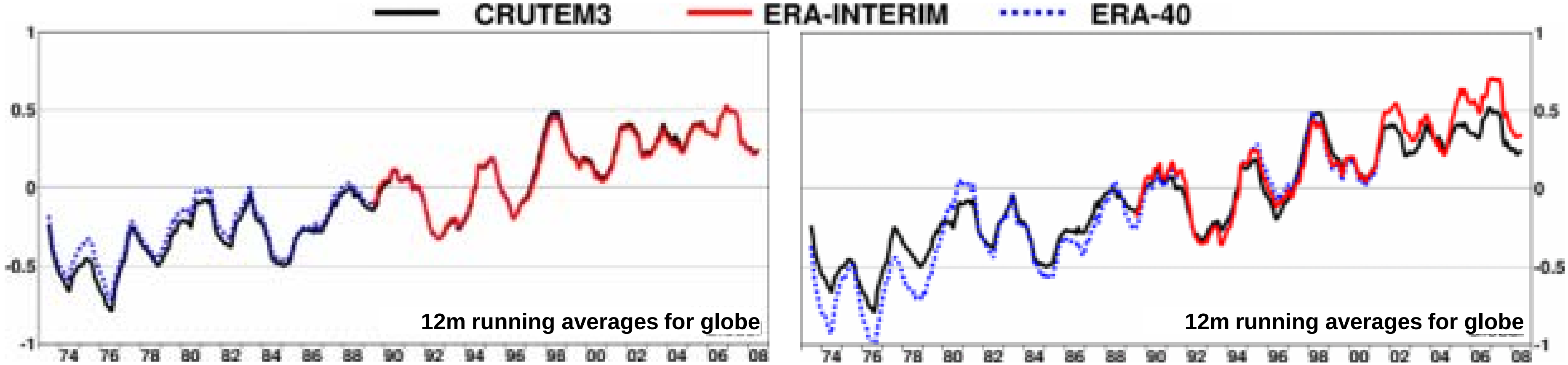
- **To improve the initial perturbations in the Ensemble Prediction**
- **To estimate analysis uncertainty**
- **To calculate static and seasonal background error statistics**
- **To estimate flow-dependent background error in 4D-Var - "errors-of-the-day"**
- **To improve QC decisions and improve the use of observations in 4D-Var**

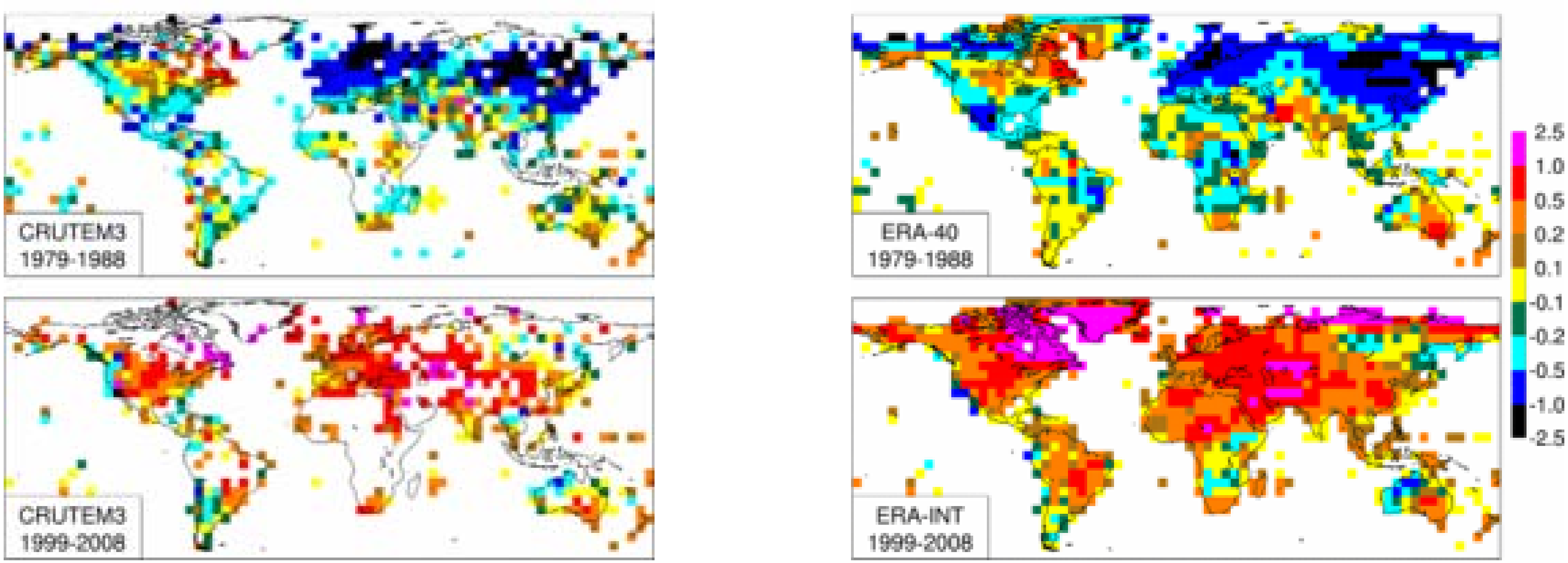
Outline

- Introduction
  - Forecast model performance
  - **Data**
    - Data assimilation
    - **Reanalysis**
  - Model
    - Physical aspects
    - Numerical aspects
  - Probabilistic Prediction System
    - Ensemble prediction
    - Seasonal and monthly forecasting
- Outlook

T_{2m} anomalies (K) relative to 1989-1998

ERA sampled as CRUTEM3 (Brohan et al., 2006) **ERA over land, not sampled**





ECMWF

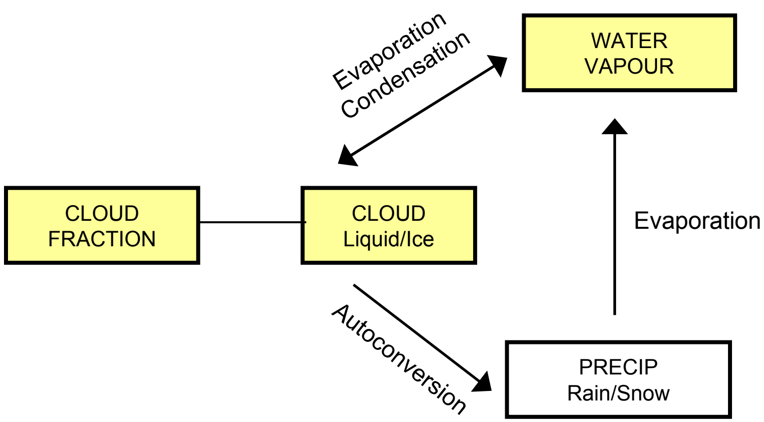
Outline

- Introduction
  - Forecast model performance
  - Data
    - Data assimilation
    - Reanalysis
  - **Model**
    - **Physical aspects**
    - Numerical aspects
  - Probabilistic Prediction System
    - Ensemble prediction
    - Seasonal and monthly forecasting
- Outlook

ECMWF

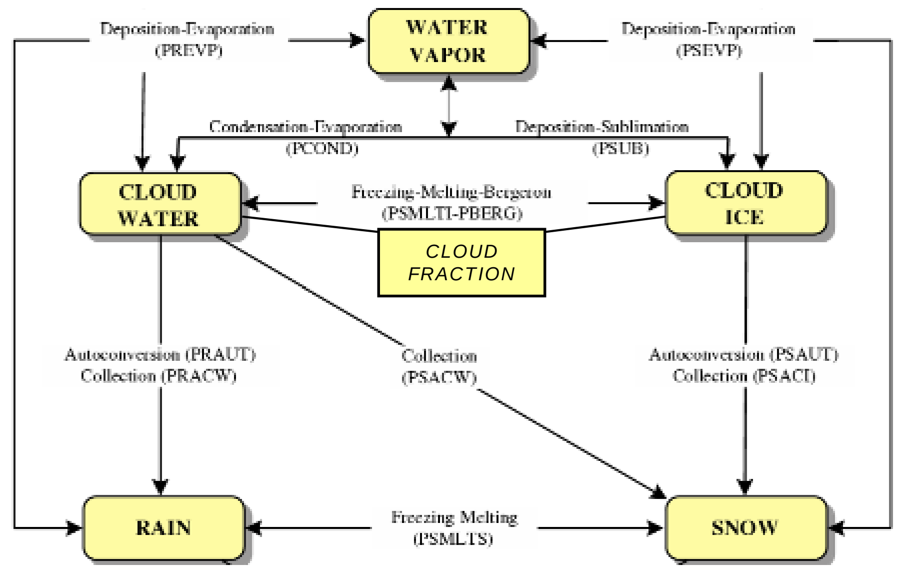
New prognostic cloud microphysics scheme

Current Cloud Scheme



- 2 prognostic cloud variables + w.v.
- Ice/water diagnostic Fn(T)
- Diagnostic precipitation

New Cloud Scheme

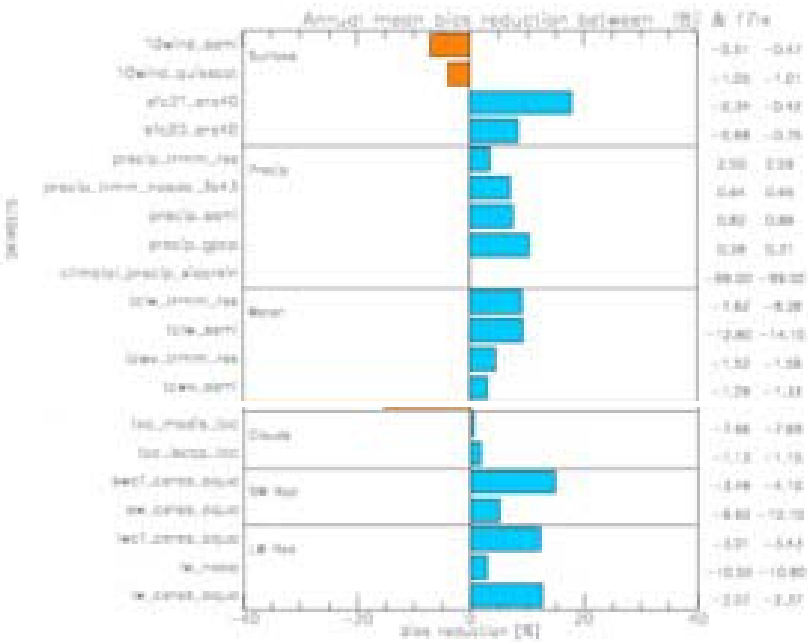


- 5 prognostic cloud variables + water vapour
- Ice and water now independent
- More physically based, greater realism
- Significant change to degrees of freedom
- Change to water cycle balances in the model
- More than double the lines of “cloud” code!

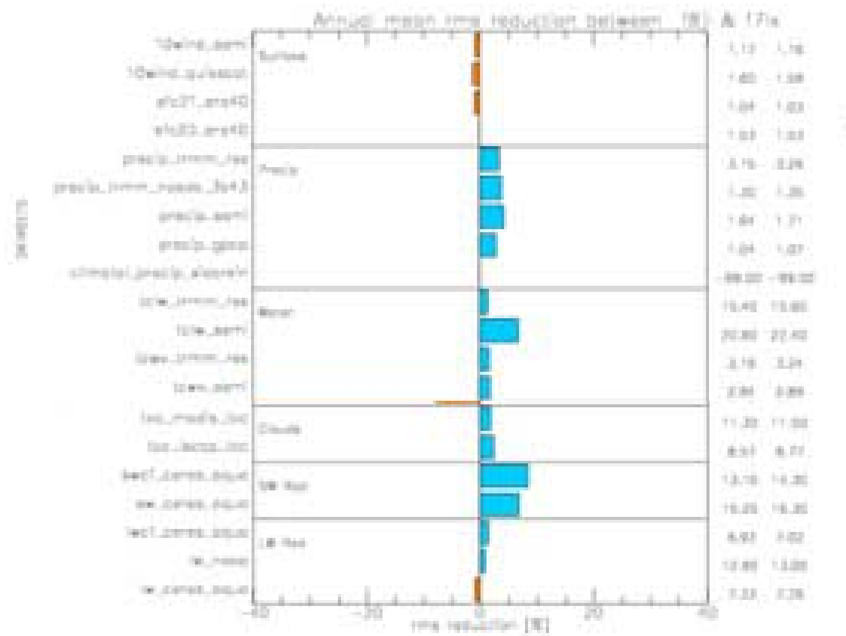
New prognostic cloud microphysics

Model Climate versus observed datasets

Annual mean Bias



Annual mean RMS



Blue = new model is closer to observations

The “climate” of the model is generally improved

Land surface model evolution

2000/06	2007/11	2009/03	2009/09		2010

TESSEL

Van den Hurk et al. (2000)
Viterbo and Beljaars (1995),
Viterbo et al (1999)

Up to 8 tiles (binary Land-Sea mask)

GLCC veg. (BATS-like)

<u>ERA-40 and ERA-I scheme</u>

Hydrology-TESSEL

Balsamo et al. (2009)

Global Soil Texture (FAO)

New formulation of Hydraulic properties

Variable Infiltration capacity & surface runoff revision

NEW SNOW

Dutra et al. (2009)

Revised snow density

Liquid water reservoir

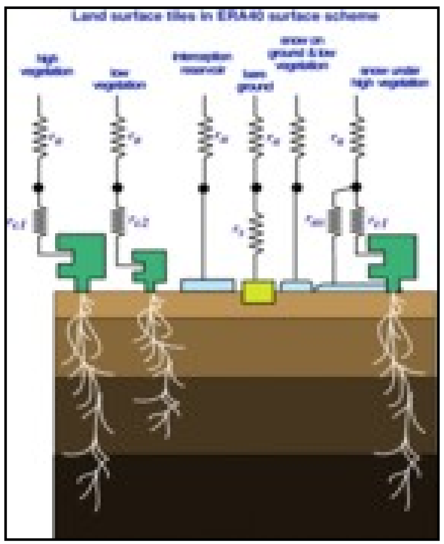
Revision of Albedo and sub-grid snow cover

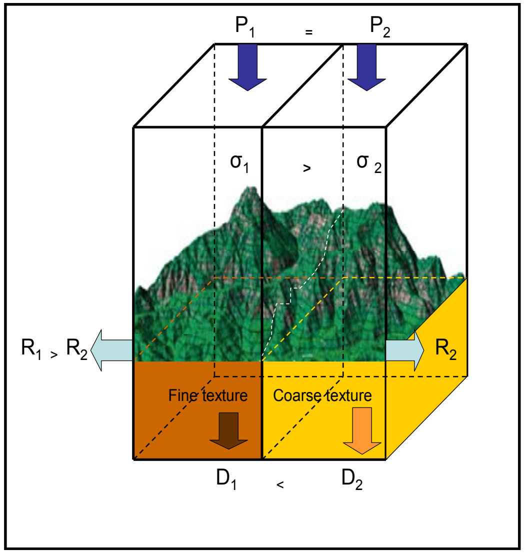
FLAKE

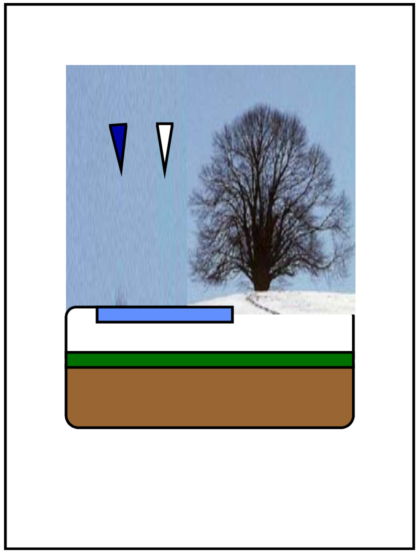
Mironov et al (2009),
Dutra et al. (2009),
Balsamo et al. (2009)

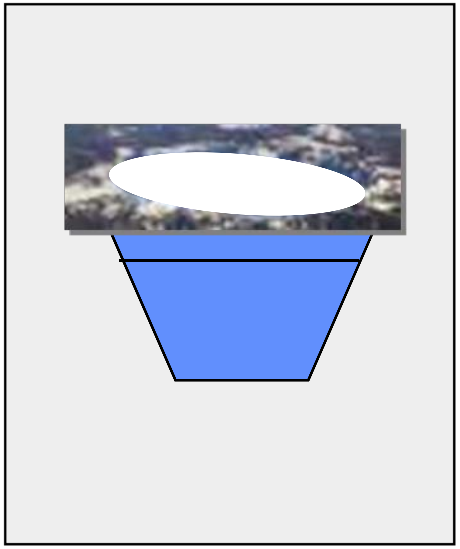
Extra tile (9) to account for sub-grid lakes

Work in progress





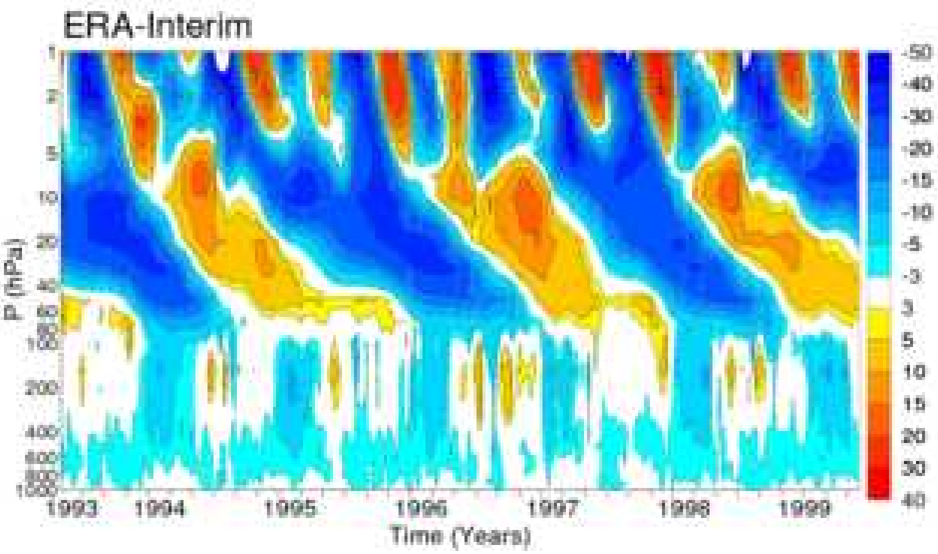


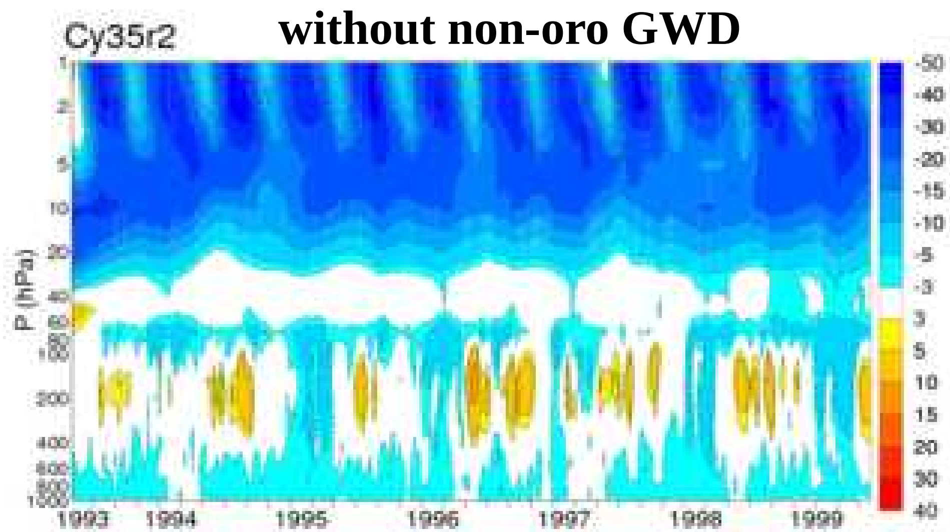


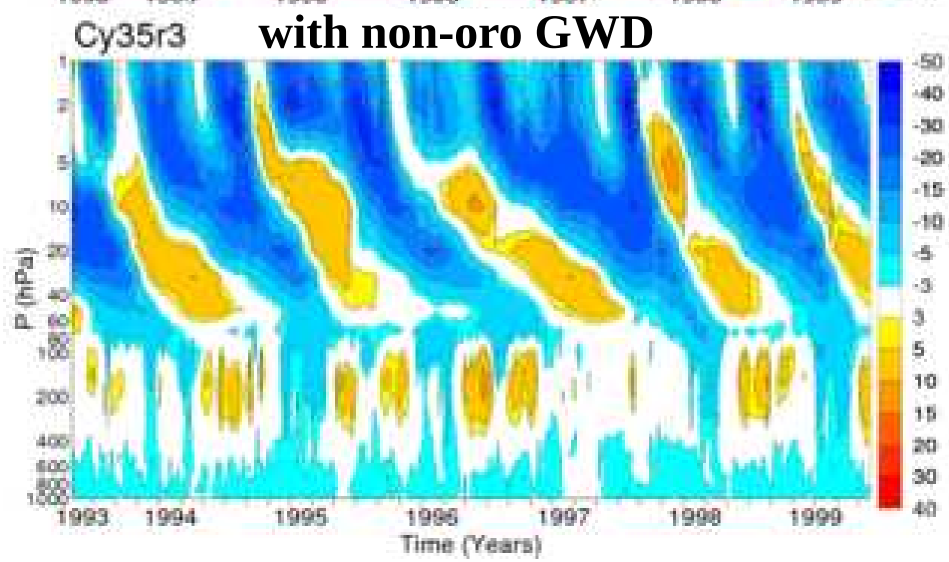
ECMWF

Non-orographic gravity wave drag implemented in Sep 2009

– improves QBO in fc



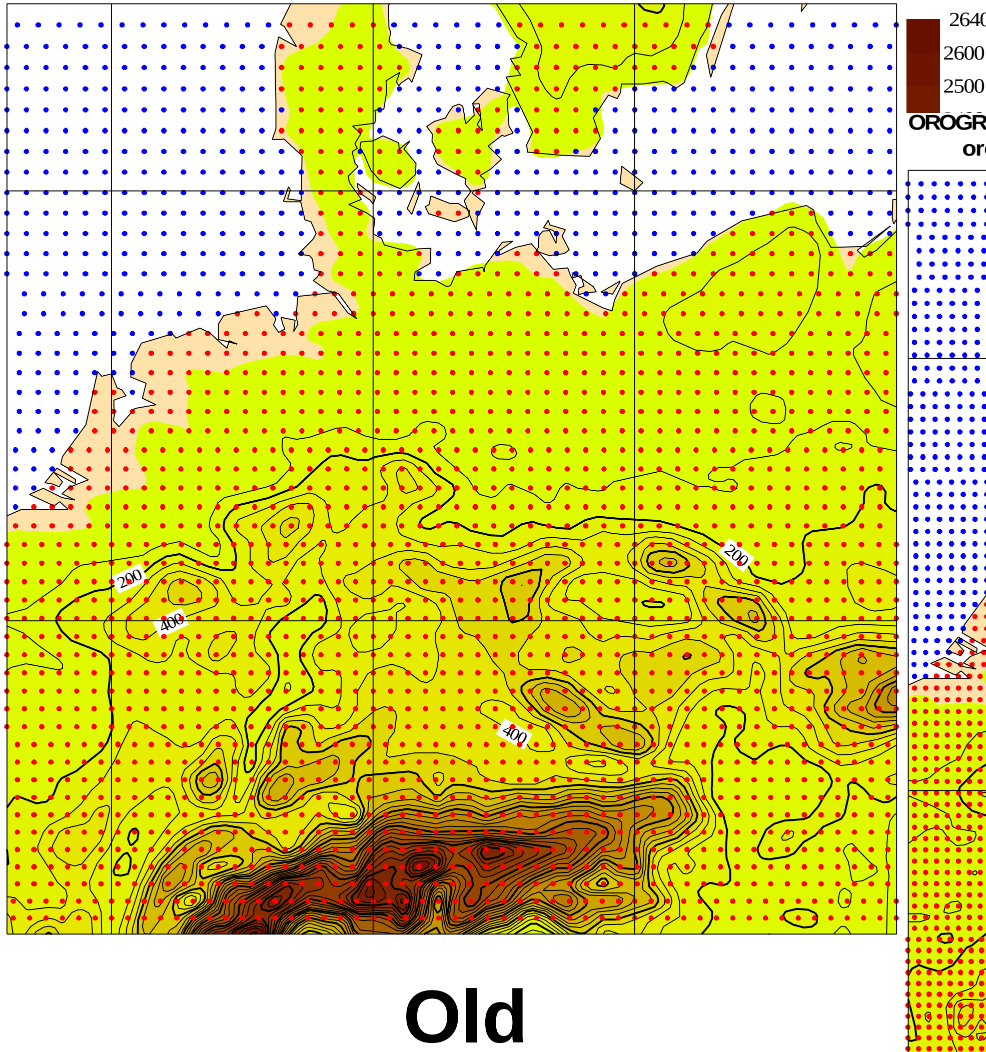


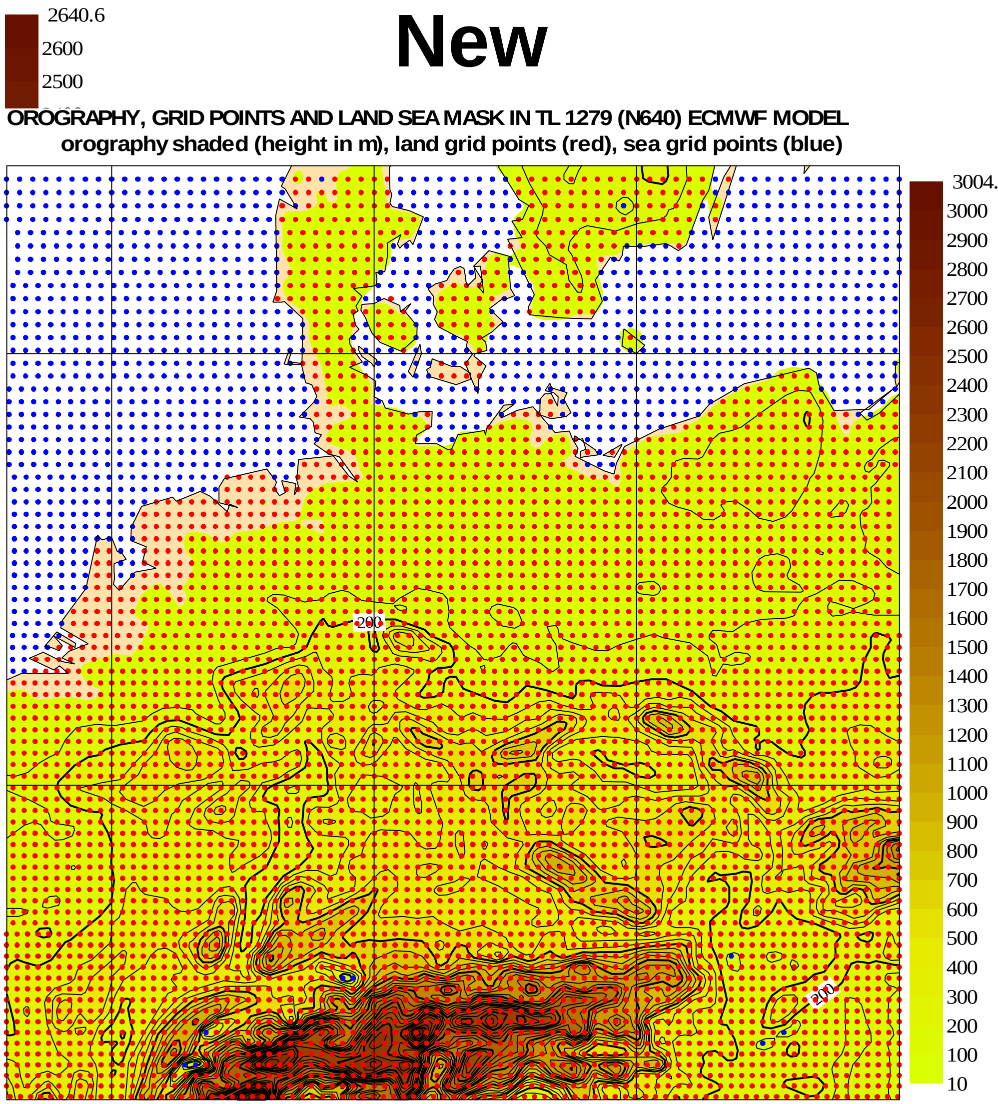


Outline

- Introduction
  - Forecast model performance
  - Data
    - Data assimilation
    - Reanalysis
  - **Model**
    - Physical aspects
    - **Numerical aspects**
  - Probabilistic Prediction System
    - Ensemble prediction
    - Seasonal and monthly forecasting
- Outlook

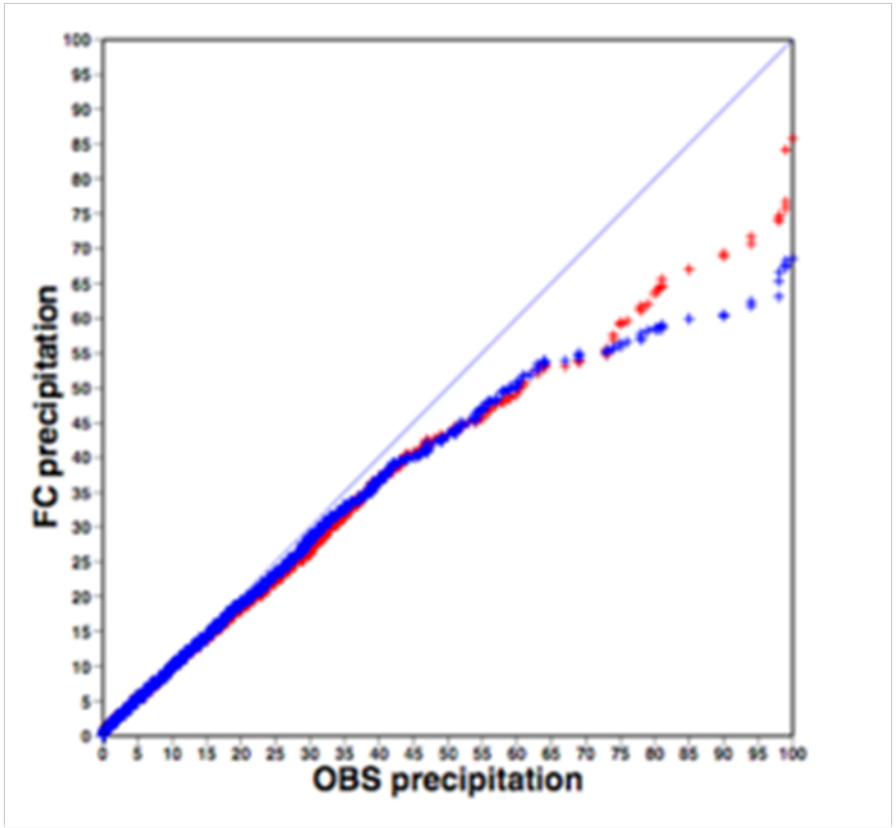
Model grids for T799 (25 km) and T1279 (16 km)





T1279 resolution performance (36r1)

- **Intense rainfall events better**
- **Orographic enhancement of rainfall stronger**
- **Convective systems more intense**



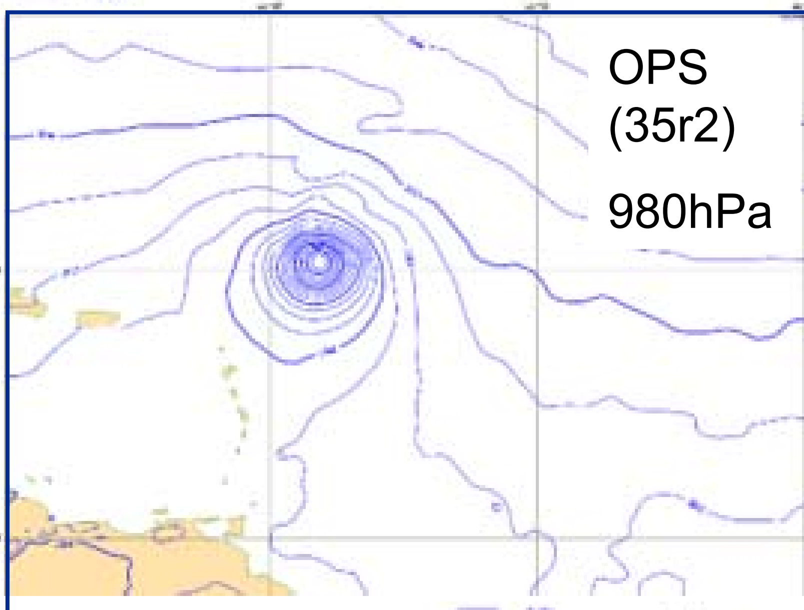
quantile-quantile plot for precipitation T+90-114:

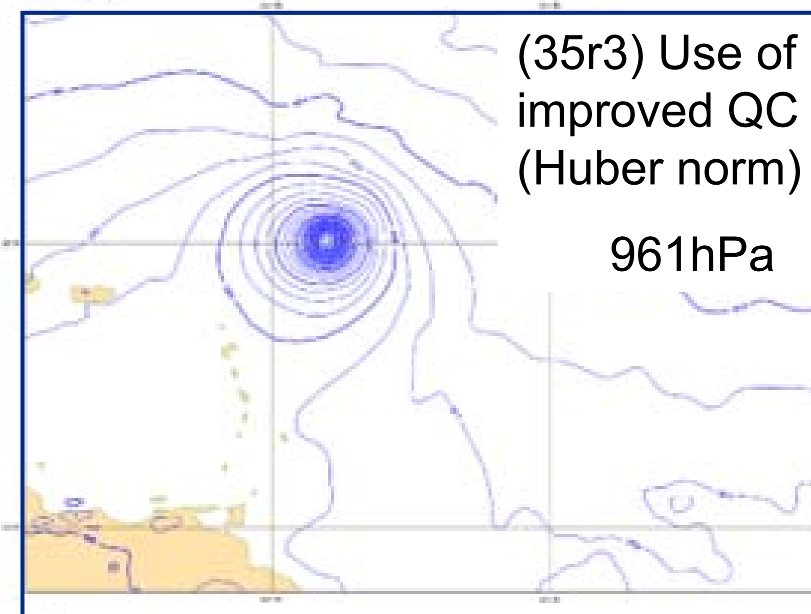
T799 (old) and T1279 (new)

for October to November over Europe

T1279 Tropical cyclone analyses improved

Improved Huber norm QC also beneficial

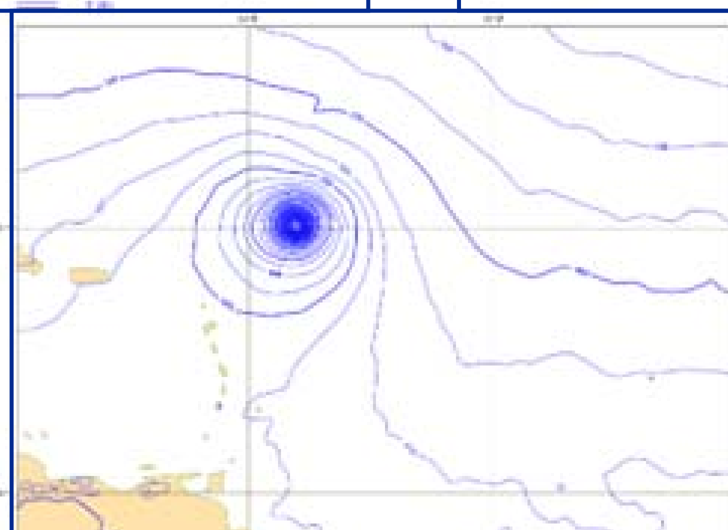




Hurricane Bill,

20 Aug. 2009

Observed MSL pressure~944hPa



(36r1) High-res system
T1279+T159/T255/T255

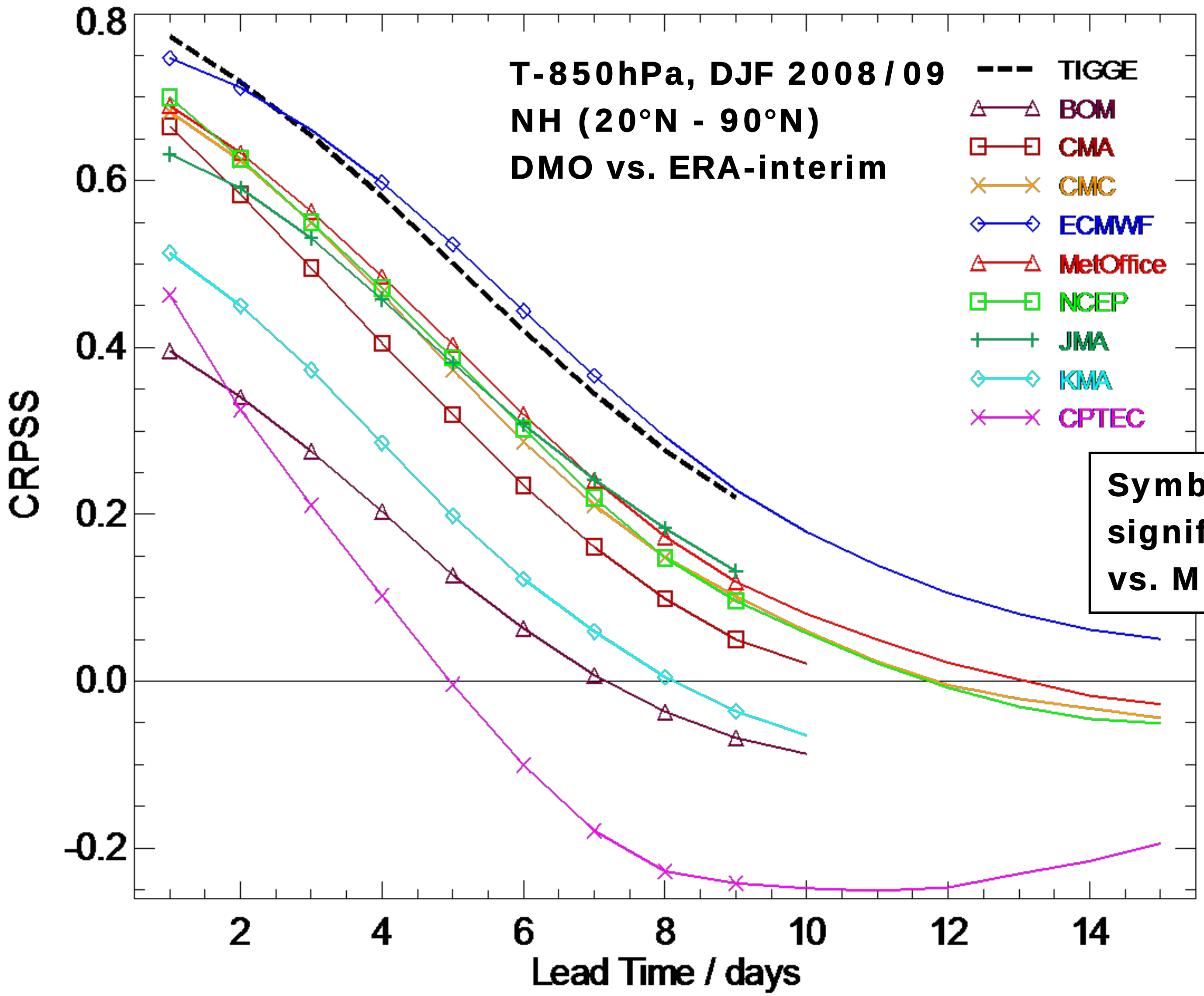
945hPa

ECMWF

Outline

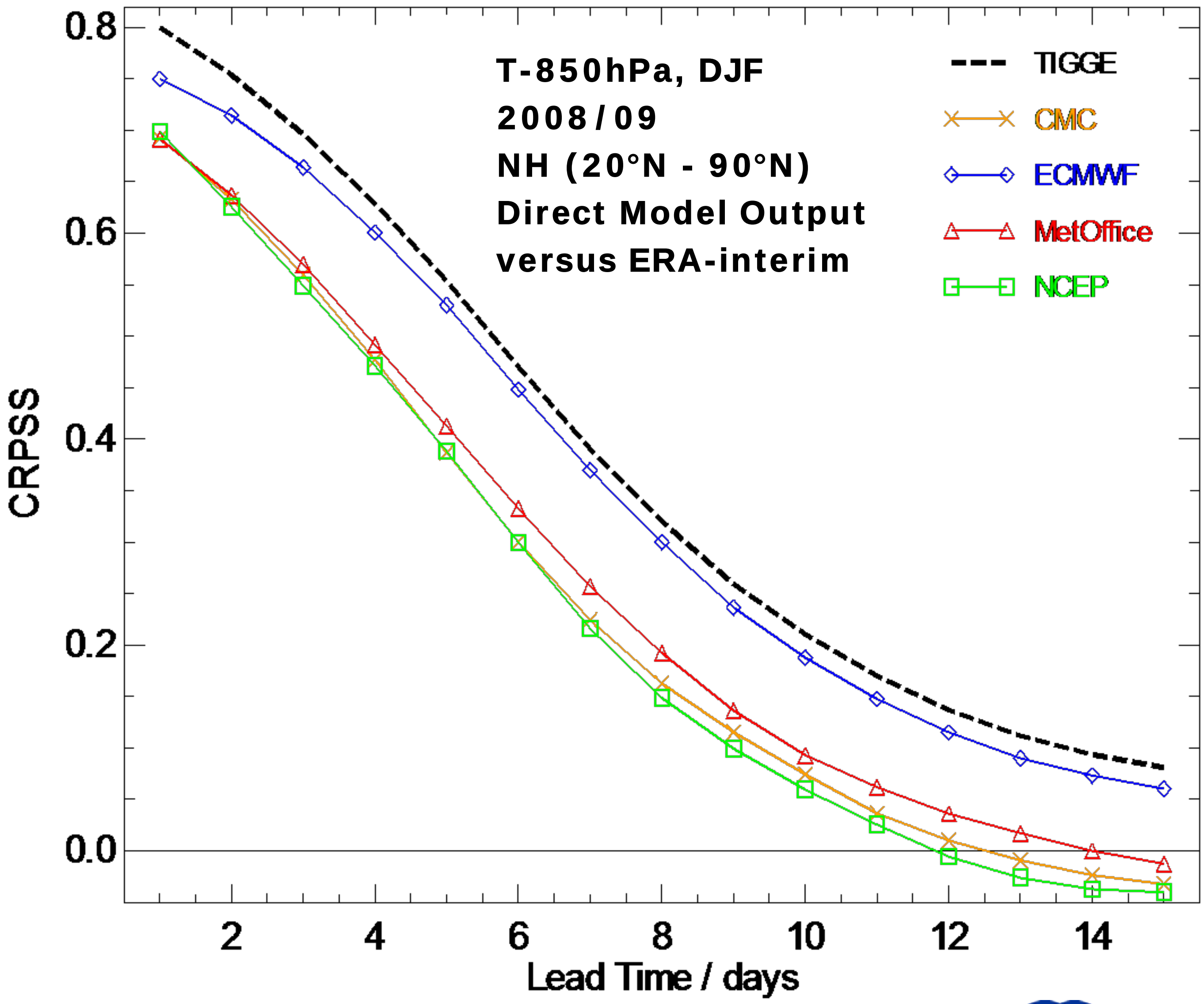
- Introduction
  - Forecast model performance
  - Data
    - Data assimilation
    - Reanalysis
  - Model
    - Physical aspects
    - Numerical aspects
  - **Probabilistic Prediction System**
    - **Ensemble prediction**
    - Seasonal and monthly forecasting
- Outlook

Comparing 9 TIGGE models & the Multi Model

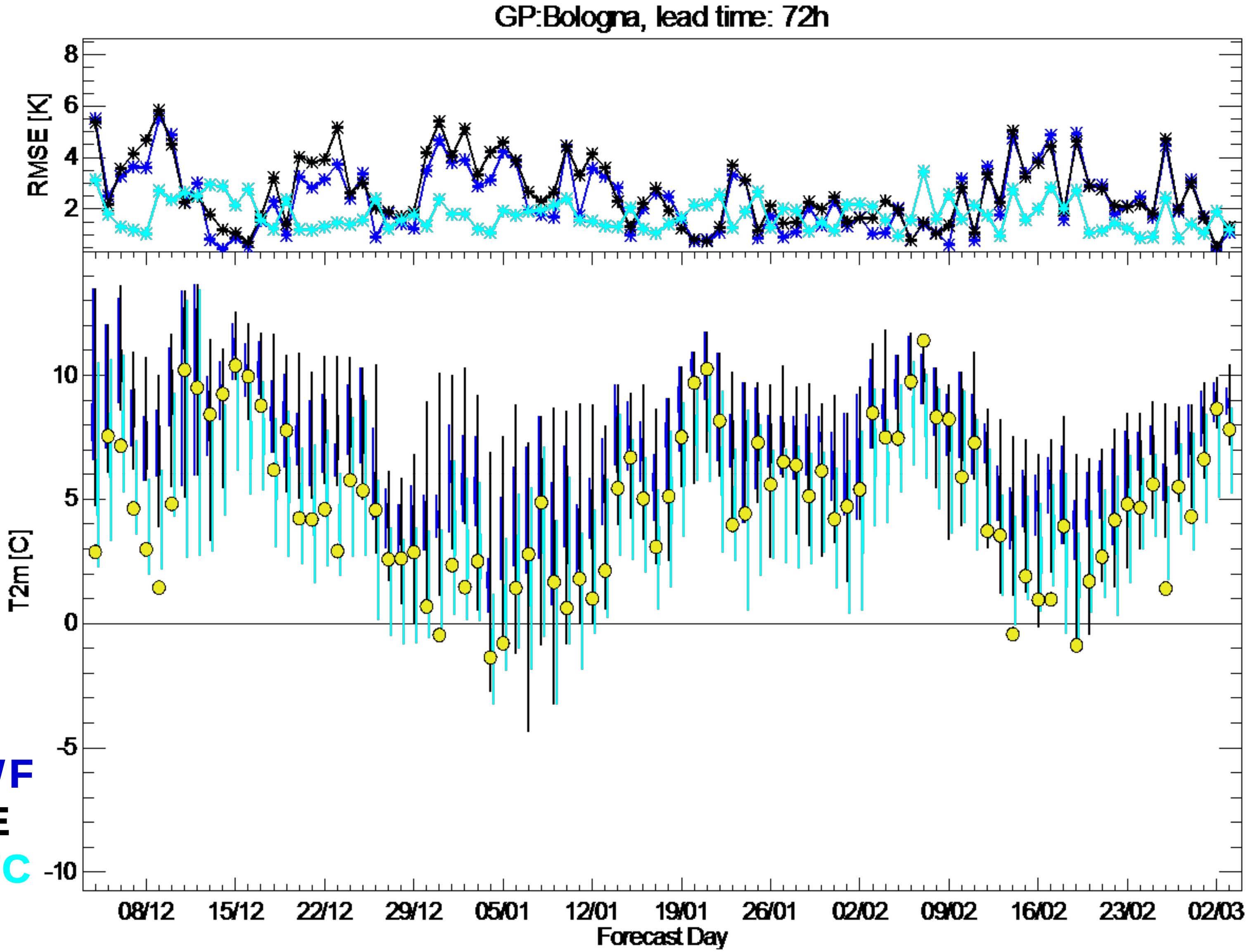


Symbols used for significance level vs. MM (1%)

Comparing 4 TIGGE models & the Multi Model

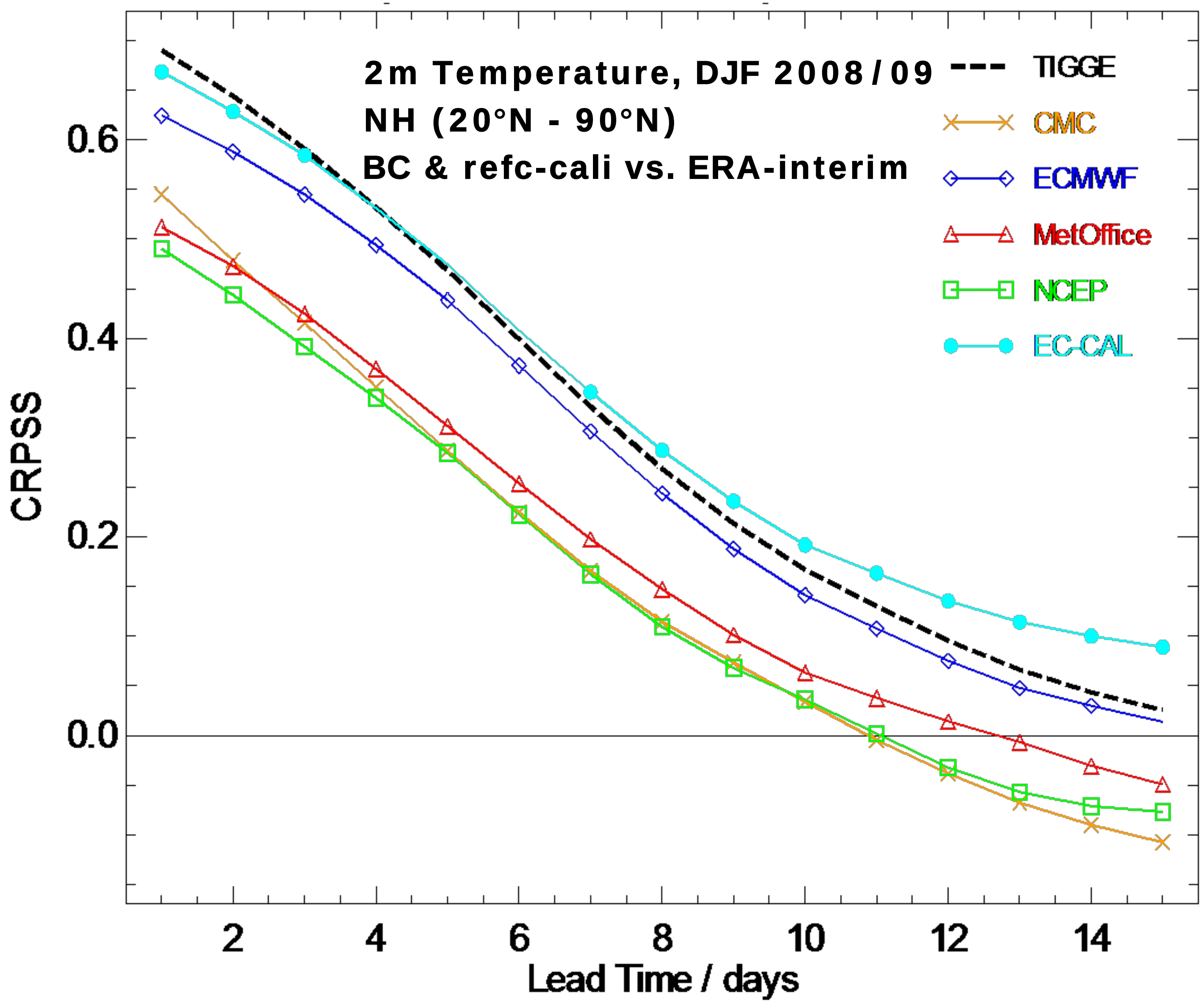


EPS Distribution 3 days lead time



OBS
ECMWF
TIGGE
EC-RFC

Comparing 4 TIGGE models, Multi Model and EC-calibrated

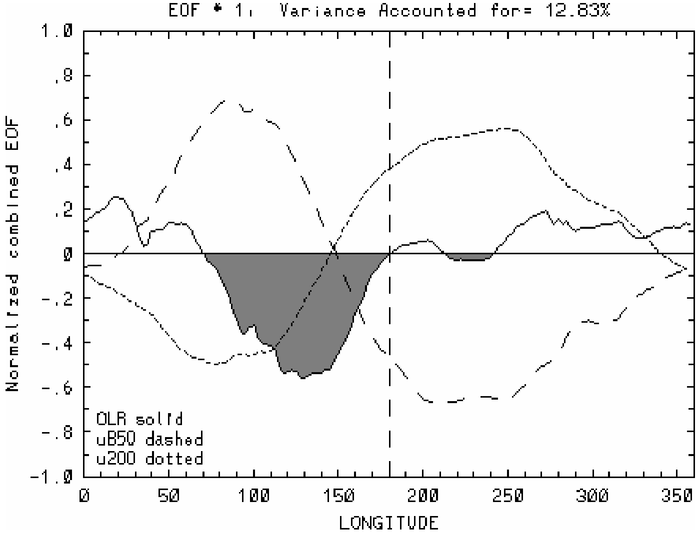


Outline

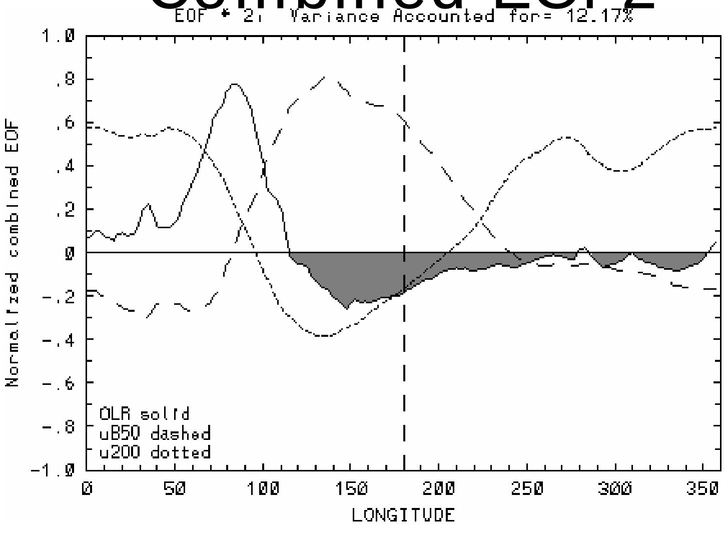
- Introduction
  - Forecast model performance
  - Data
    - Data assimilation
    - Reanalysis
  - Model
    - Physical aspects
    - Numerical aspects
  - **Probabilistic Prediction System**
    - Ensemble prediction
    - **Seasonal and monthly forecasting**
- Outlook

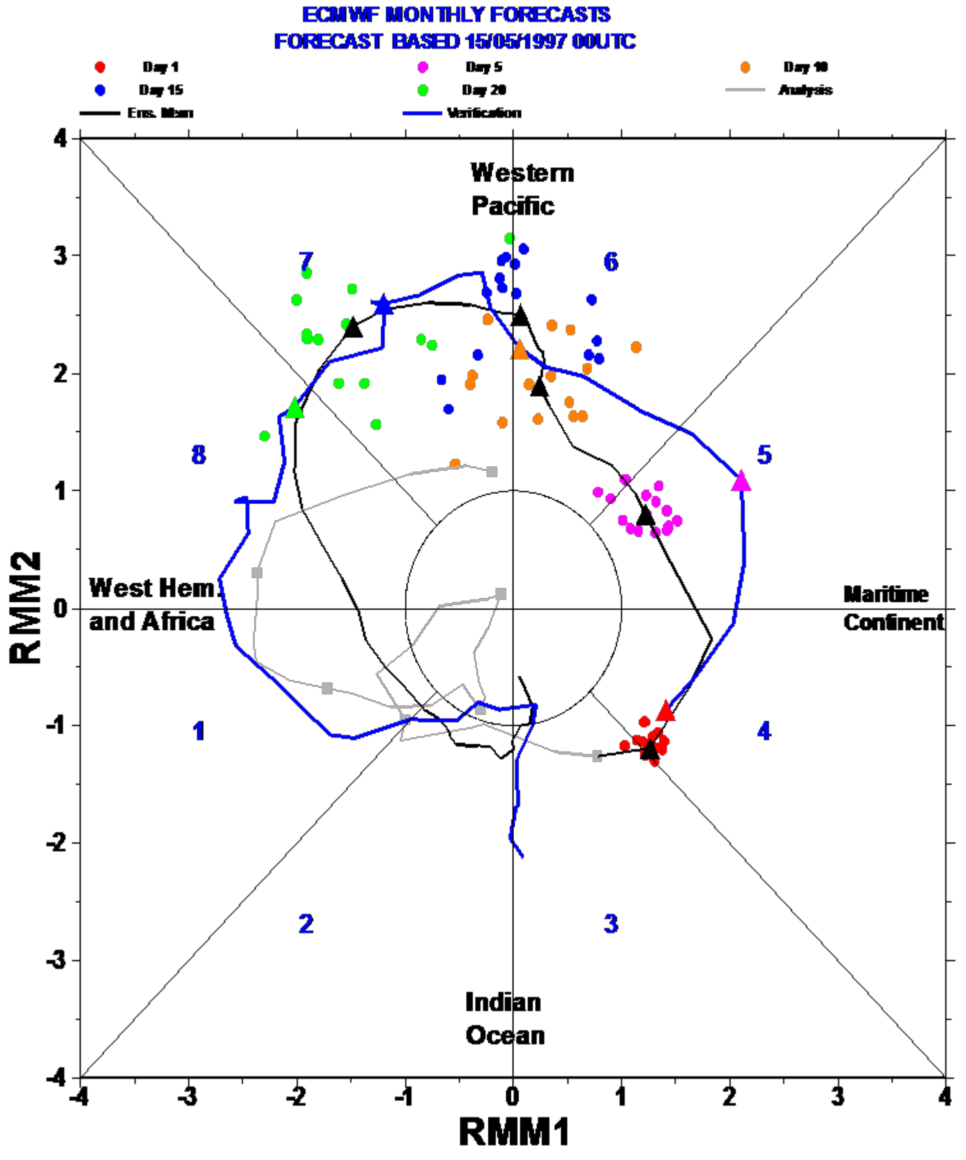
MJO Diagnostics - *Wheeler and Hendon (2004)*

Combined EOF1



Combined EOF2



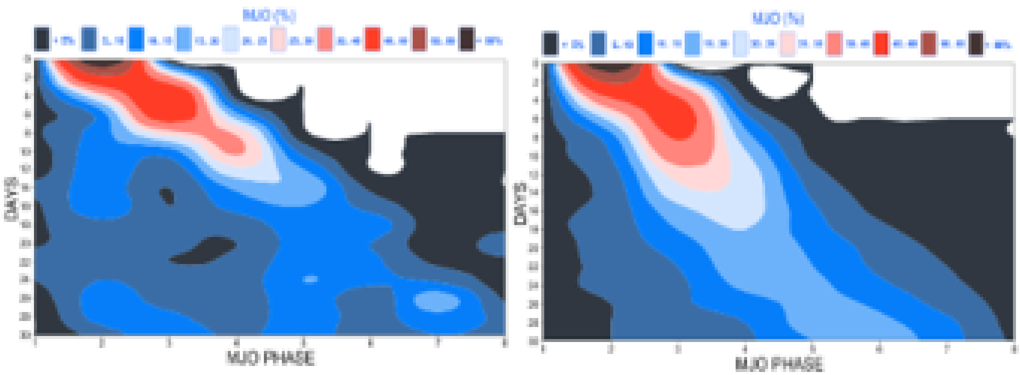


ECMWF

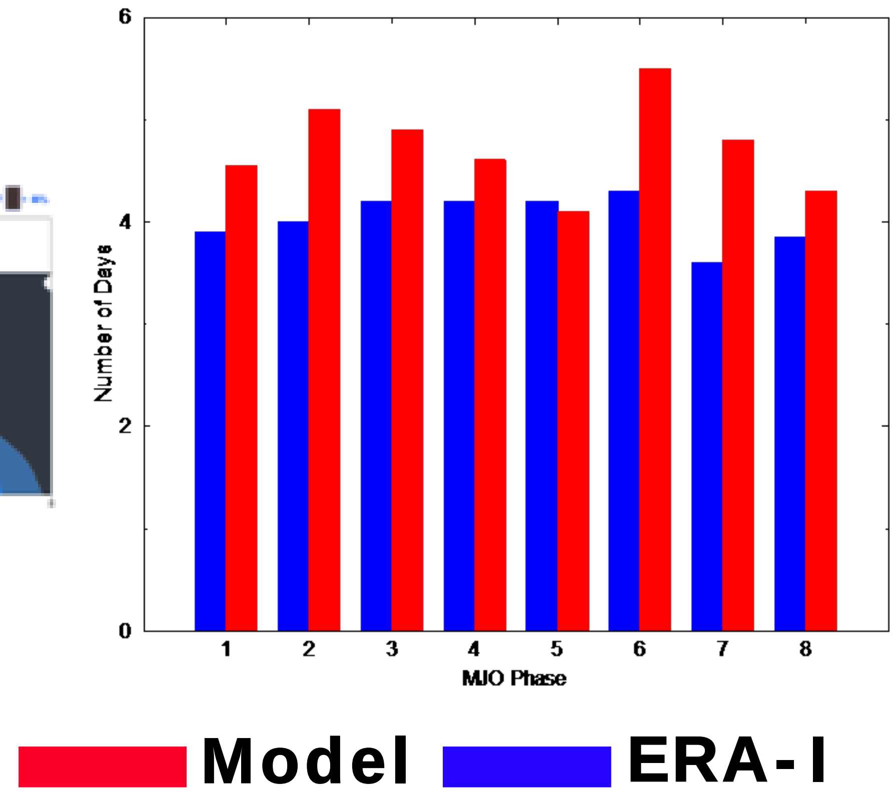
MJO propagation improved considerably in Monthly Forecast System - mainly due to new model physics

MJO Propagation

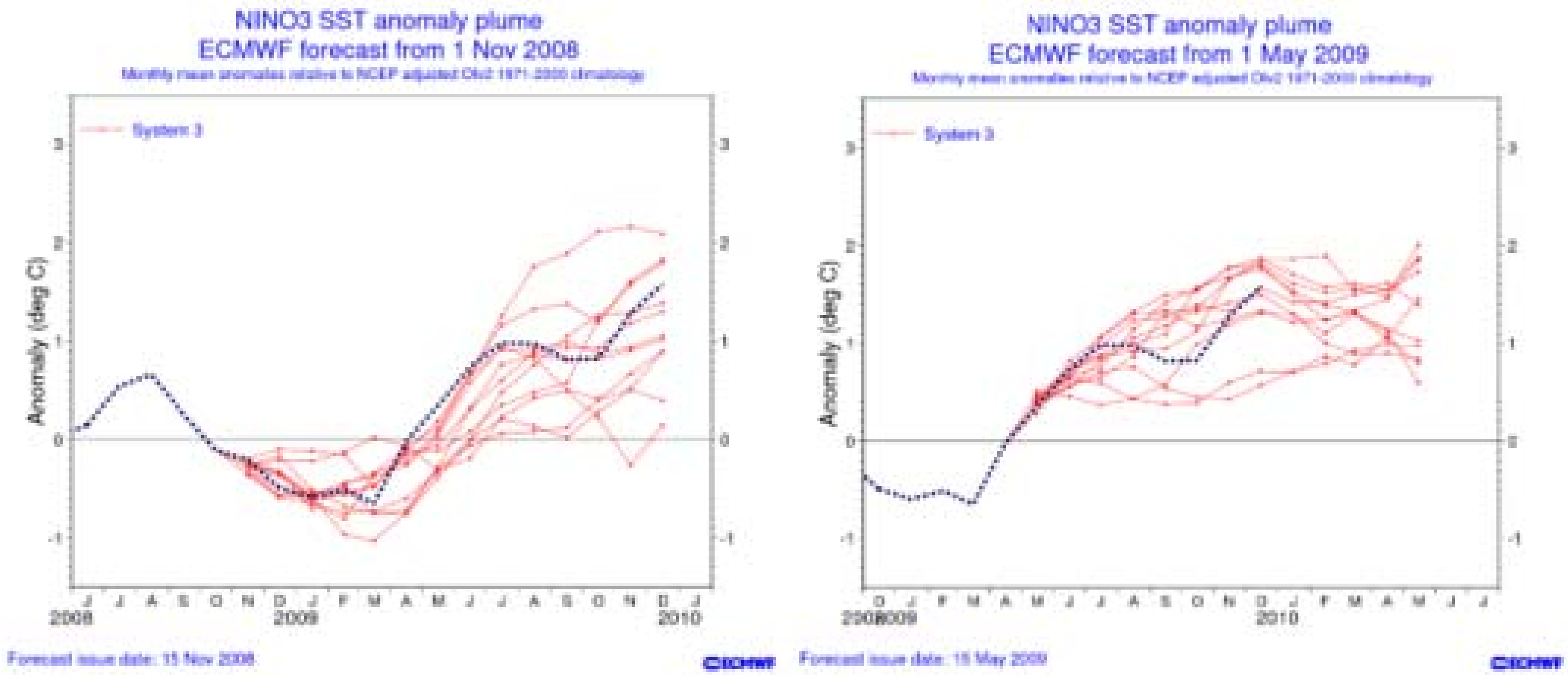
Analysis **Forecast**



Time spent in each phase of the MJO



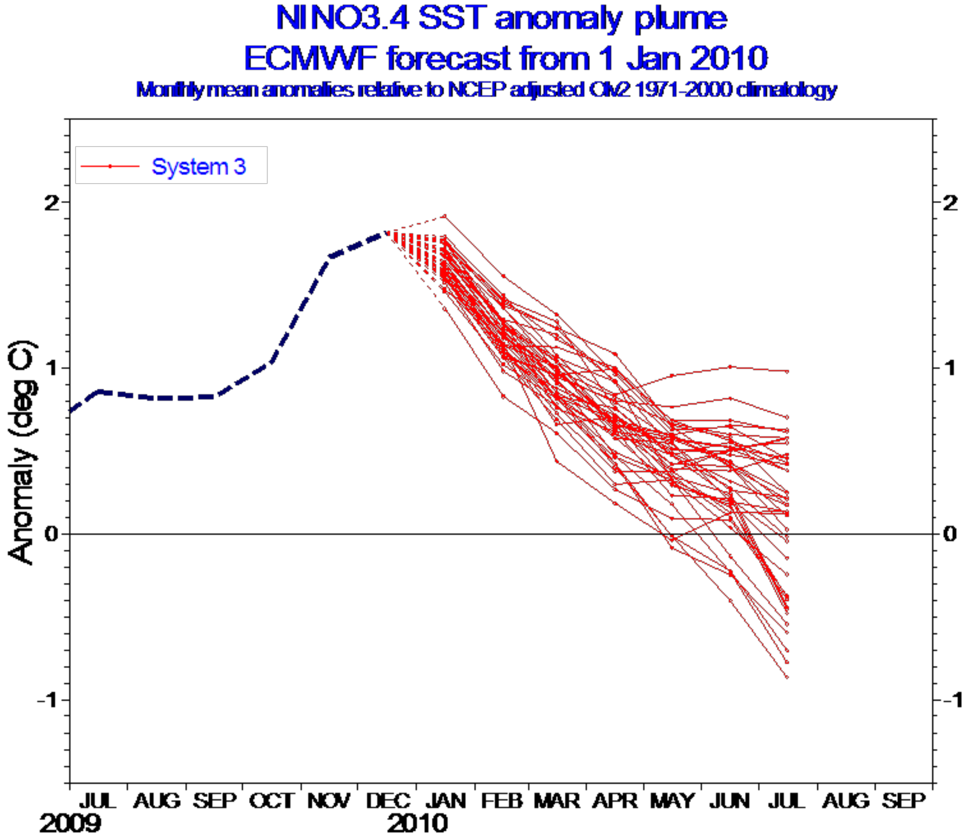
Seasonal forecast – Nino SST, annual range



ECMWF forecasts of SST anomalies over the NINO 3.4 region of the tropical Pacific from November 2008 (left) and May 2009 (right). The red lines represent the 11 ensemble members; dashed blue lines show the subsequent verification

ECMWF

Seasonal forecast – Nino SST, current forecast



ECMWF forecasts of SST anomalies over the NINO 3.4 region of the tropical Pacific from January 2010. The red lines represent the 11 ensemble members; dashed blue lines show the subsequent verification

Outline

- Introduction
  - Forecast model performance
  - Data
    - Data assimilation
    - Reanalysis
  - Model
    - Physical aspects
    - Numerical aspects
  - Probabilistic Prediction System
    - Ensemble prediction
    - Seasonal and monthly forecasting
- **Outlook**

ECMWF

Further developments (1/2)

- Long window 4D-Var
  - Extension of weak constraint to troposphere, extension of assimilation window to 24 hour
- Vertical resolution increase planned for later in 2010 (~136 levels TBD)
- EDA
  - To provide flow-dependent variances to deterministic 4D-Var
- More comprehensive cloud microphysics
- Modularisation of the IFS and scalability of the assimilation
- EKF for soil moisture analysis
- Upgrades to land surface model such as vegetation and lakes

Further developments (2/2)

- Assimilation of cloud/aerosols/rain
- Introduction of System 4 for seasonal prediction
- Flow dependent data selection and account for observation error correlations
- Optimisation of advanced sounder usage
- Interaction of ocean currents with ocean waves and of ocean waves and ocean mixing
- Non-hydrostatic dynamical core:
    - use of vertical finite elements
    - coupling of dynamics and physics
- Preparation for ERA-75

Thank you for your attention– questions?