Ensemble aerosol forecasts and assimilation at ECMWF

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Acknowledgements: Massimo Bonavita and Lars Isaksen

Disclaimer/Background

- This is all brand new research, poorly understood by the authors
- Largely motivated by this workshop and by the ongoing collaboration with the ICAP members!!!
- Also, at one point we had promised the EU to look into creating background error statistics using the Ensemble Data Assimilation system developed for NWP applications at ECMWF, in lieu of current statistics based on NMC method (forecast differences)
- EDA has not been developed for Ensemble Aerosol Prediction

  (…but it was too tempting to resist!)
- Extremely preliminary results!!!!!!!!!
- We're interested in learning from your experience

Outline

- The Ensemble Data Assimilation system in use operationally at ECMWF
- How it was used to generate aerosol forecasts for the Monitoring Atmospheric Composition and Climate (MACC) Prediction system used at ECMWF
- Preliminary results and verification
- Where we see the potential of this system

Operational Ensemble Data Assimilation

- 10 ensemble members using 4D-Var assimilations

  T399 outer loop, T95/T159 inner loop (reduced number of iterations)

- Most observations randomly perturbed

- For cloud track wind (AMV) correlations taken into account

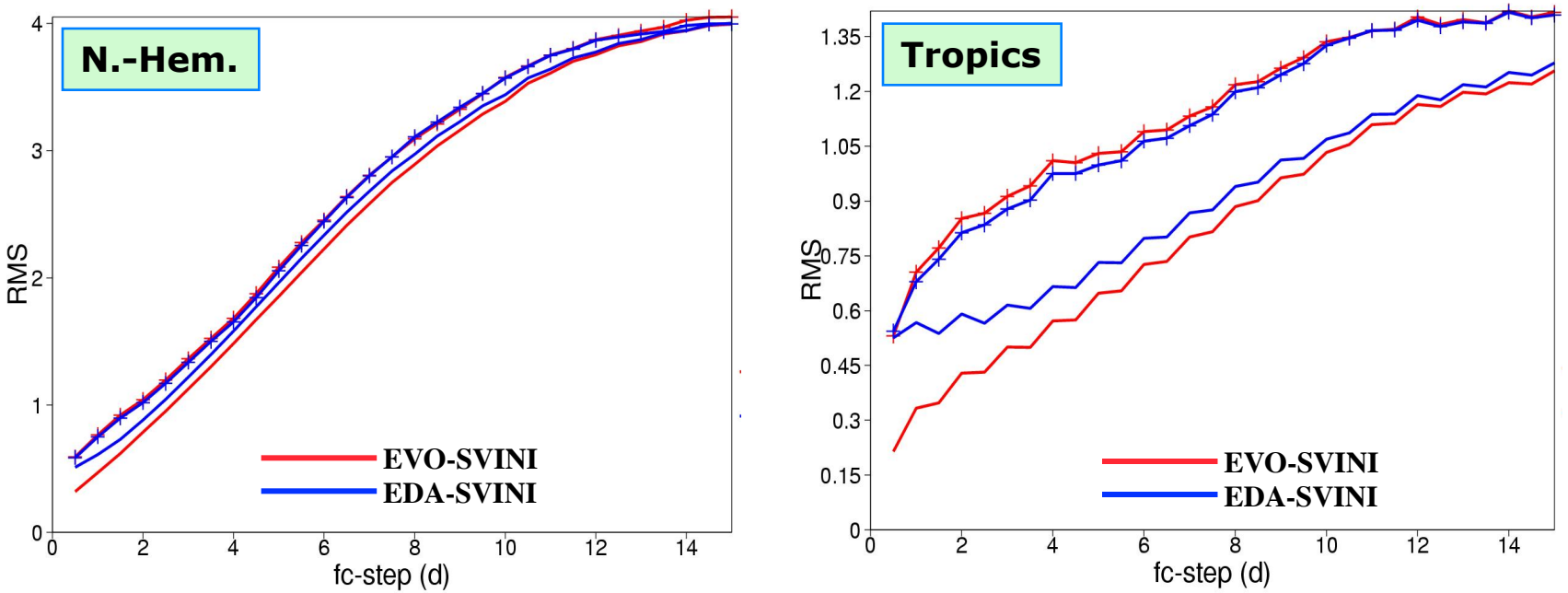
- SST perturbed with realistically scaled structures

- Model error represented by the Stochastically Perturbed Parametrization Tendencies (SPPT) method used in EPS

- All 10^7 conventional and satellite observations used

Use of EDA in the EPS

- The Ensemble Prediction System 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 lower error when EDA is used.



Ensemble spread and Ensemble mean RMSE for 850hPa T

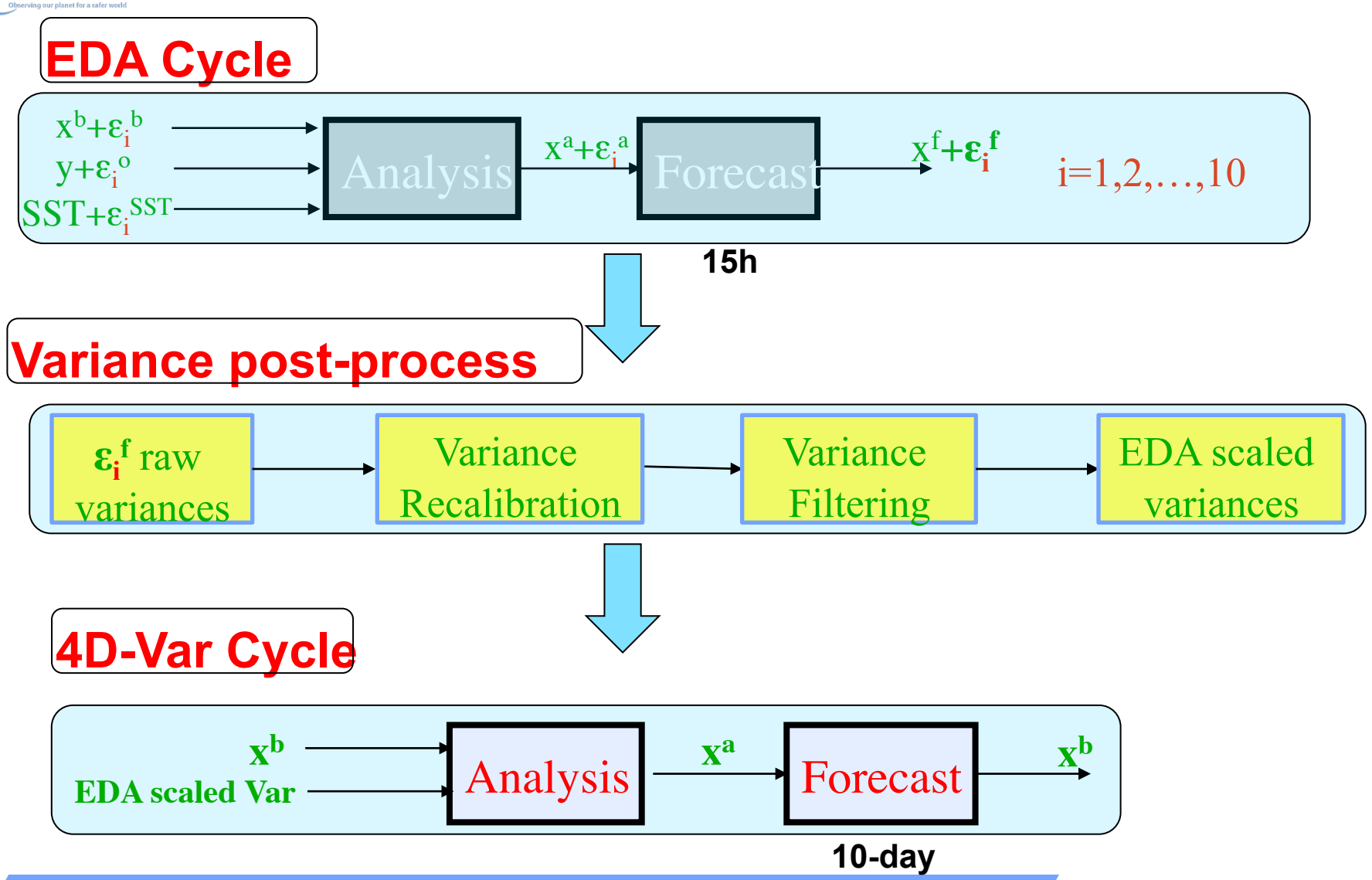
Use of EDA in 4D-Var for flow-dependent Quality Control and background error estimation

- We want to use EDA perturbations to simulate 4D-Var flow-dependent error covariance evolution
- We start with the diagonal of the B (P^f) matrix, i.e.:

"Estimate the background error variance with the spread (variance) of the EDA short range forecasts"

- This has been tried before (Kucukkaraca and Fisher, 2006, Fisher 2007, Isaksen et al., 2007) but results have been inconclusive

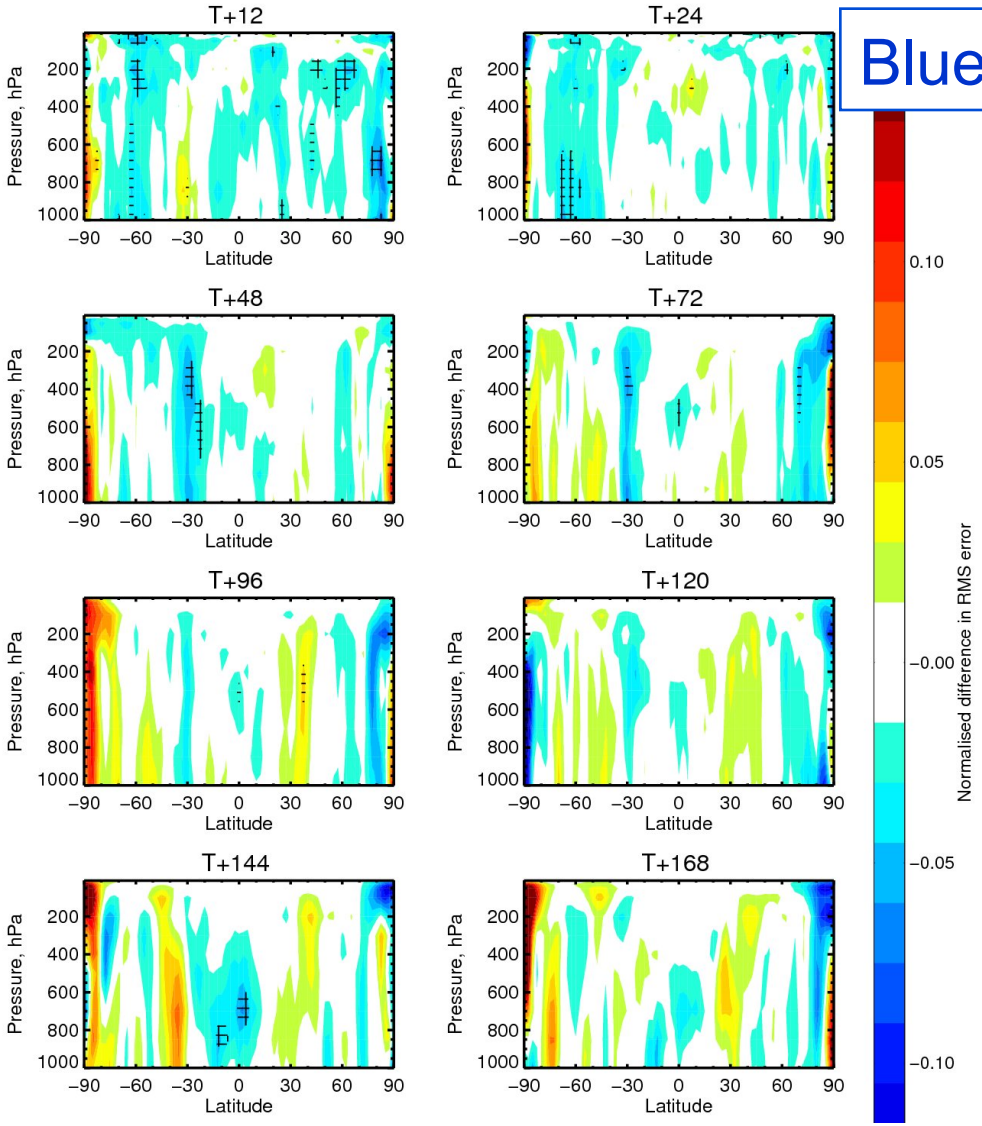
Operational Implementation



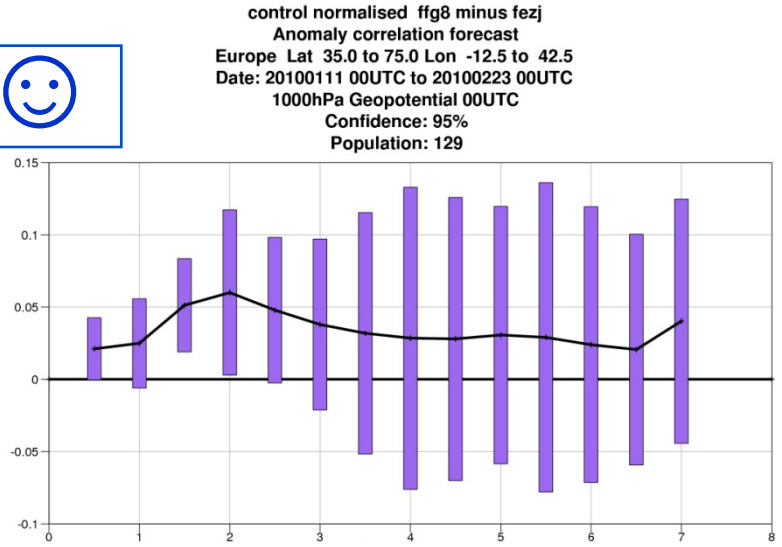
Forecast improvements from EDA based variances in 4D-Var

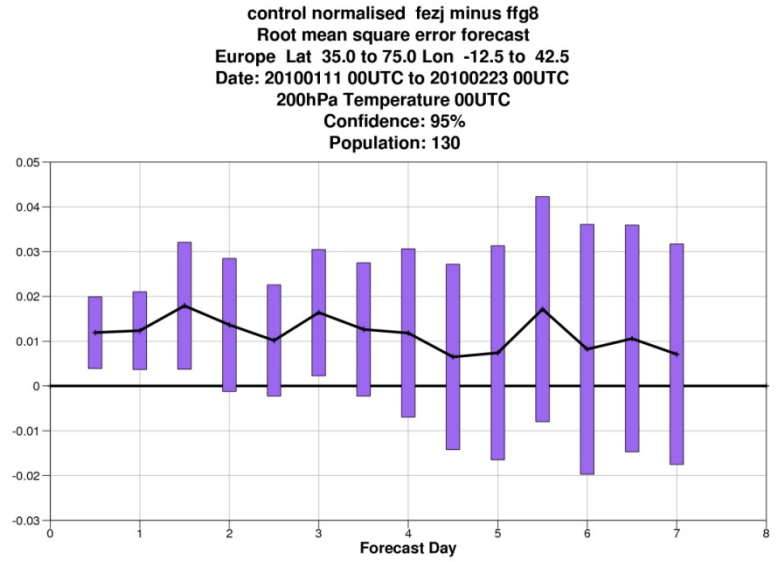
RMS forecast errors in Z(fffn–ff4o), 3–Apr–2010 to 8–May–2010, from 29 to 36 samples.

Point confidence 99.5% to give multiple–comparison adjusted confidence 90%. Verified against own–analysis.



Blue= ☺





Ensemble Data Assimilation for MACC Aerosol Forecasts

- 10 ensemble members using 4D-Var assimilations

  T159 outer loop, T95/T159 inner loops (reduced number of iterations)

- Most observations randomly perturbed (including aerosol obs), AMV correlations accounted for

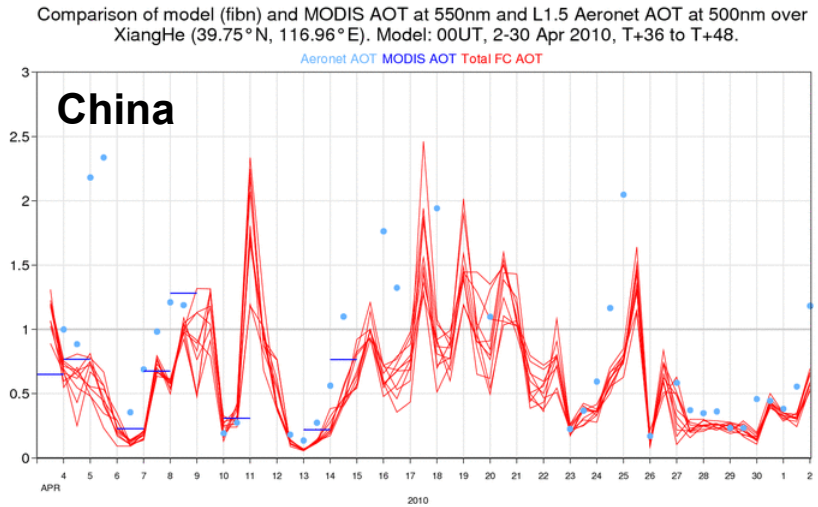
- Same treatment for model error and SST perturbations

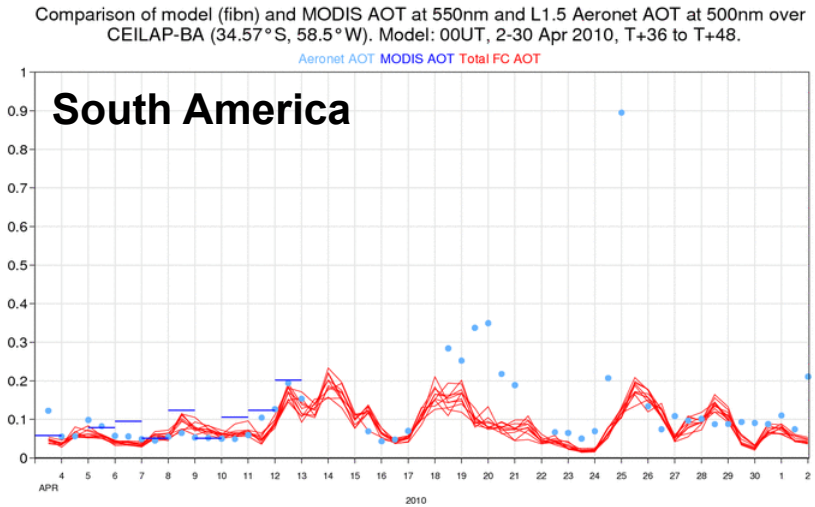
- All 10^7 conventional and satellite observations used plus MODIS

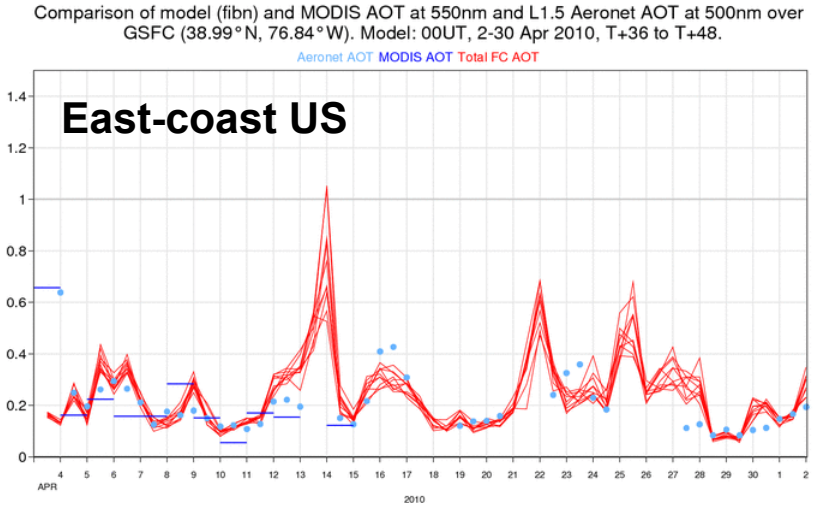
Aerosol Optical Depths at 550 nm from Terra and Aqua

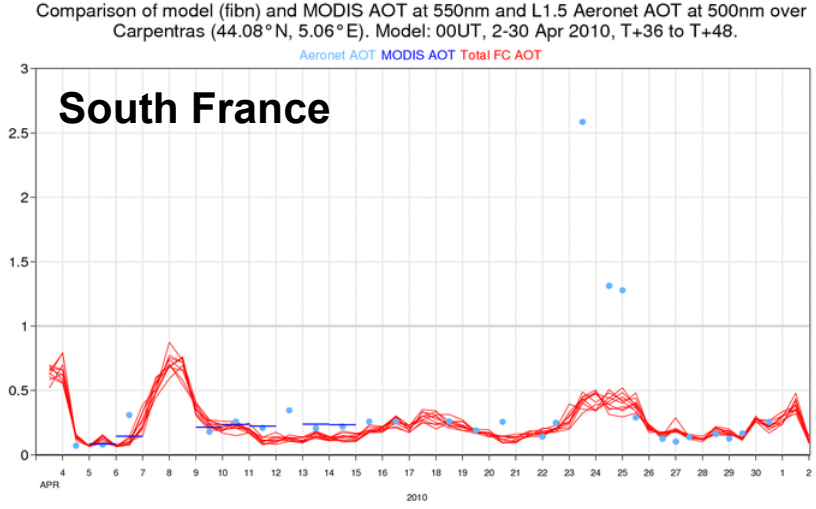
- Run in "EPS" mode with 4-day forecasts from the single ensemble members (unlike operational configuration)

Preliminary verification (1)



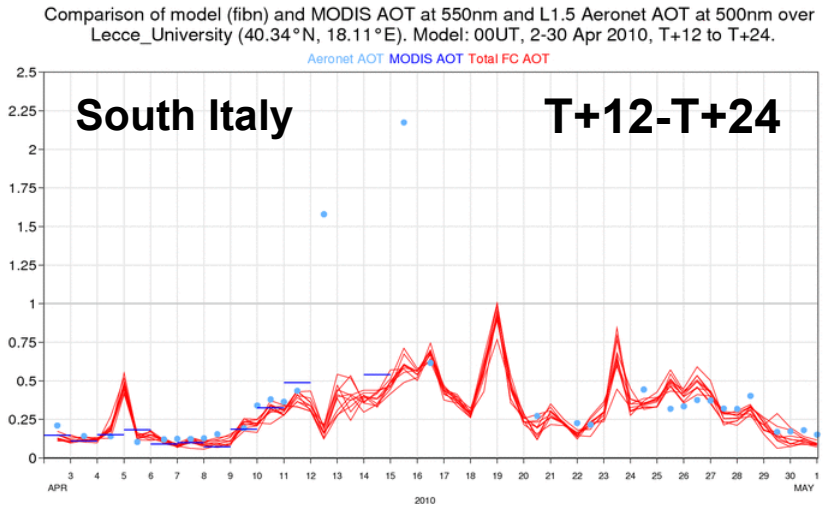


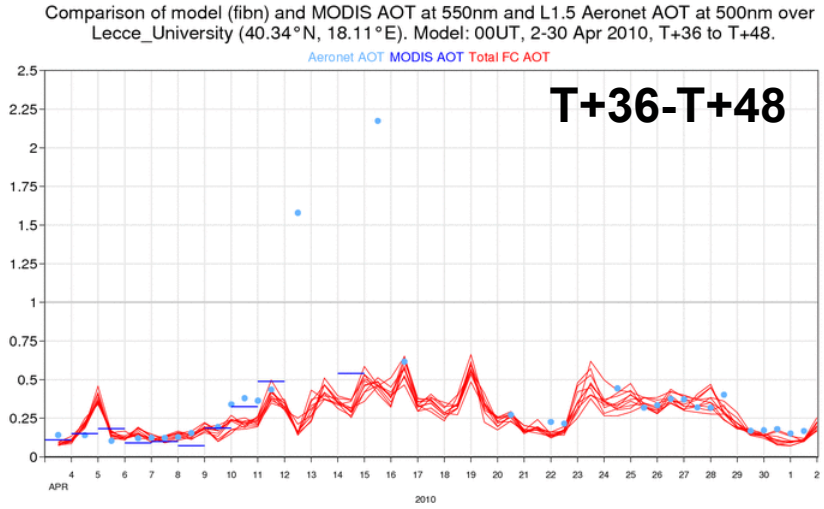


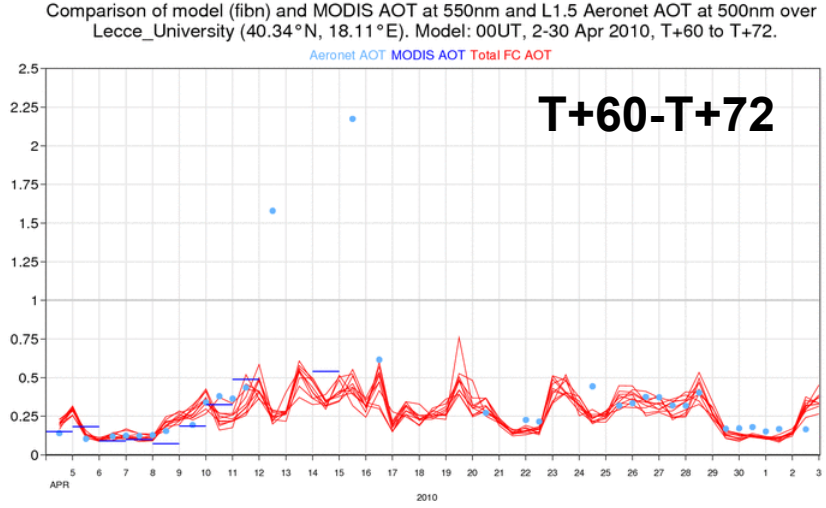


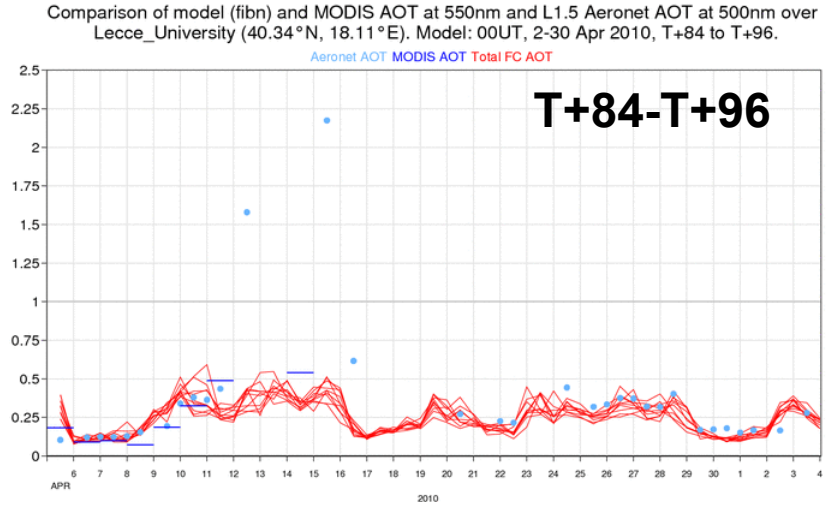
Spread is low, esp in well observed regions

Preliminary verification (2)





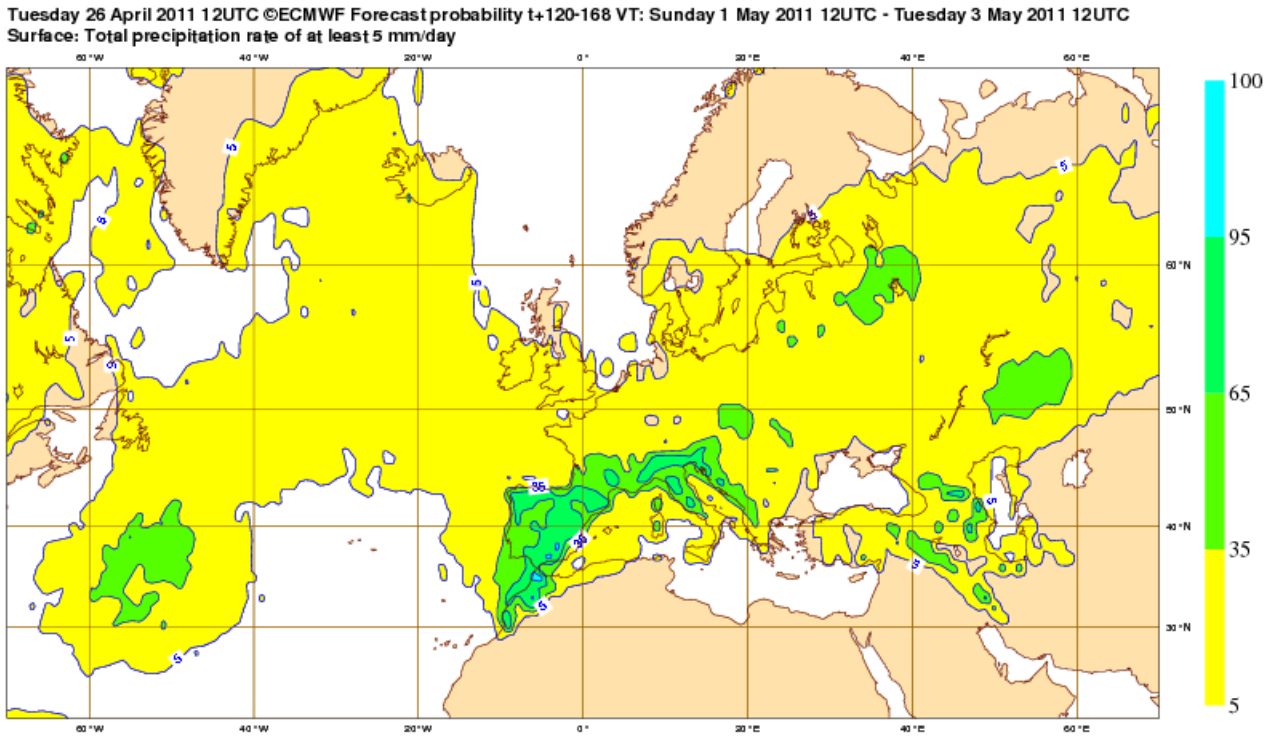




Need to go to longer ranges to exploit benefits of ensemble!

Envisaged potential: Probability maps

Example taken from the operational ECMWF Ensemble Prediction System : Probability of surface precipitation exceeding 5mm/day (day 5-7)

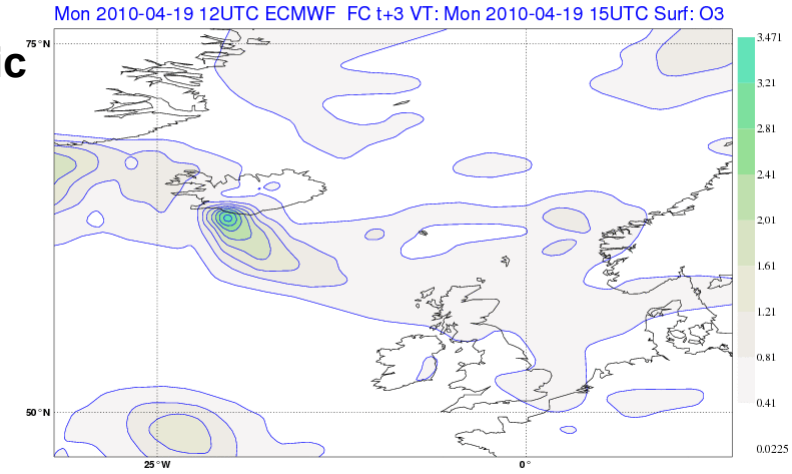


Side note: the maps is NOT upside down: for once, the forecast showed higher probability of heavy precipitation over Spain and Italy than over the UK!!!!

Envisaged potential: Volcanic Plume Forecasts

Eyjafjallajokull eruption (Iceland, April 2010)

- Deterministic 10-day forecast for the volcanic plume
- Source specified ad hoc
- MODIS observations assimilated

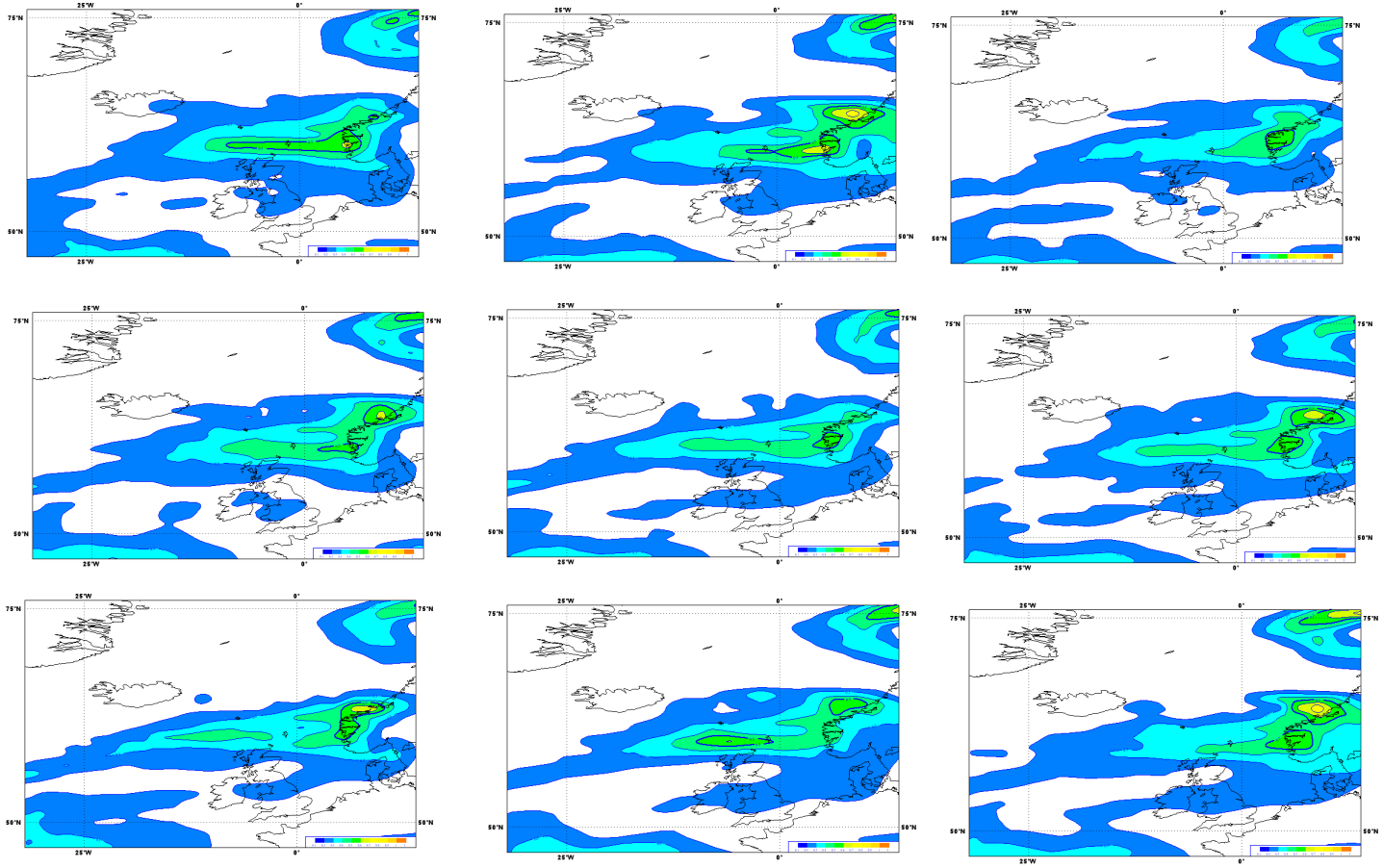


Total Aerosol Optical Depth (unitless)

- Could potentially design a system with 10+ ensemble members with perturbed observations and/or source and/or injection height
- Define probability maps of exceedance of aerosol concentration threshold at given level.
- This type of situations should be those where ensembles have largest potential

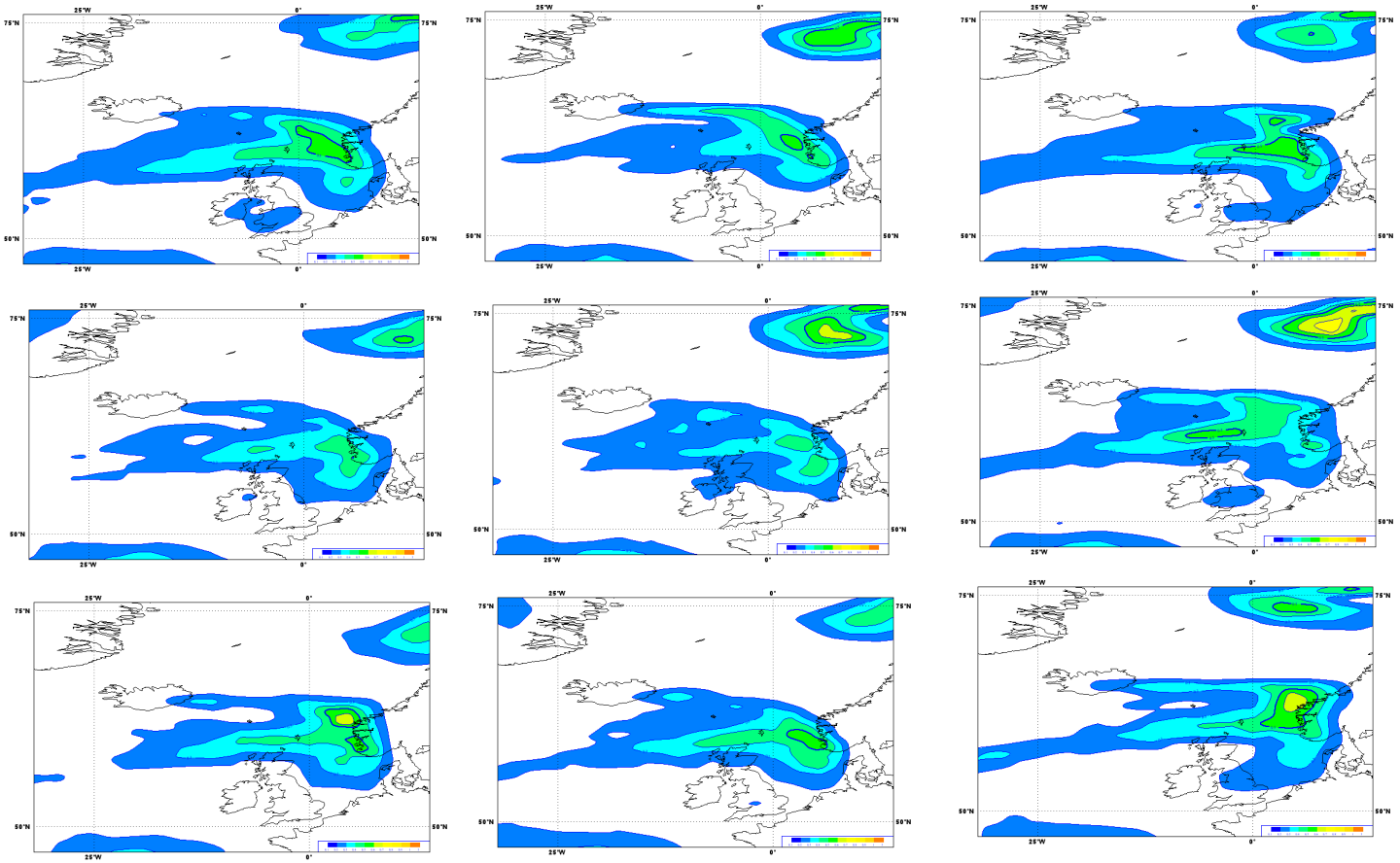
Ensemble results: Sea Salt plume ☺

24h AOD forecast valid on 17 April 2010, 00UTC



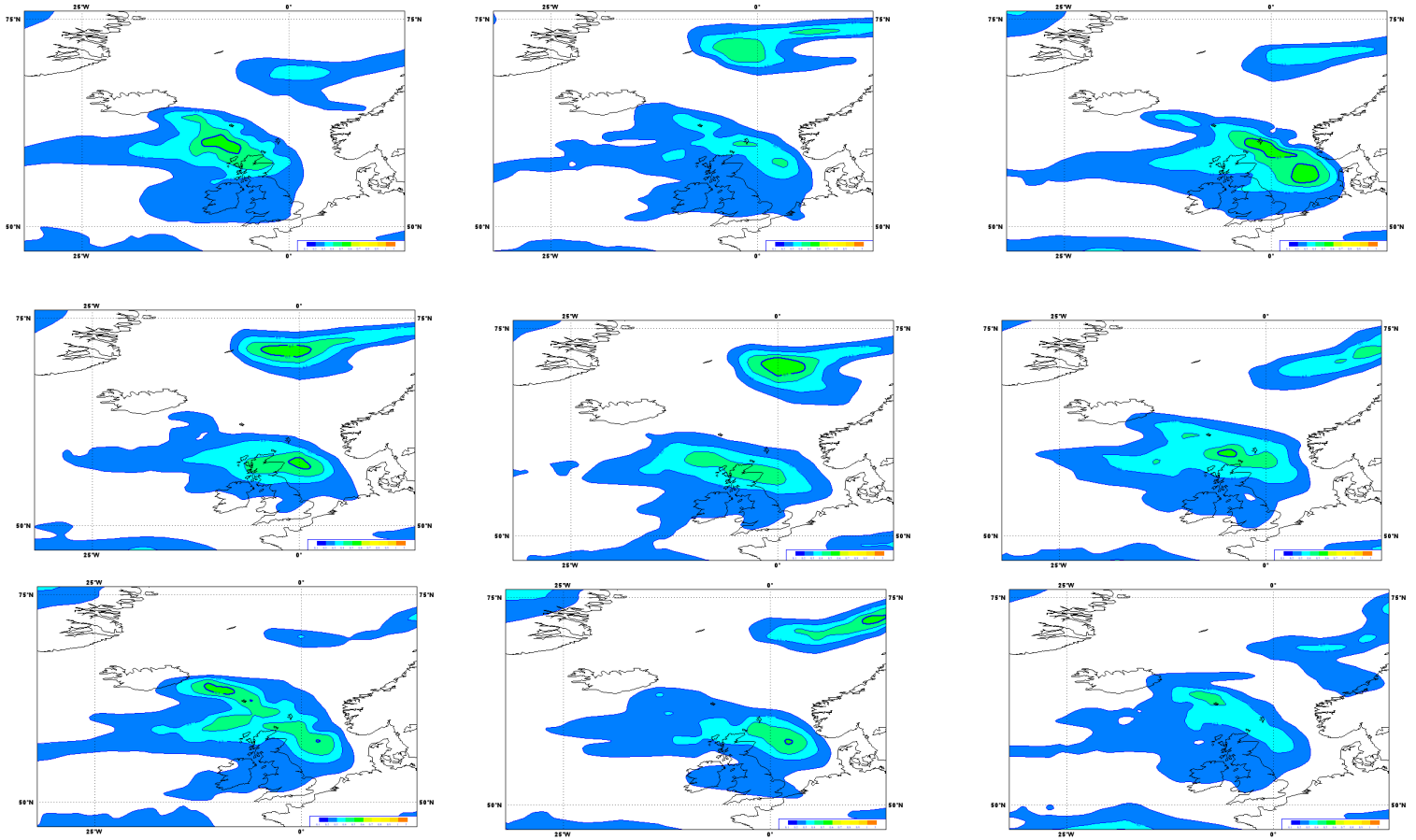
Ensemble results: Sea Salt plume ☺

72h AOD forecast valid on 17 April 2010, 00UTC



Ensemble results: Sea Salt plume ☺

96h AOD forecast valid on 17 April 2010, 00UTC



Summary

- Very early days of Aerosol Ensemble Forecasts at ECMWF
- Ensemble Data Assimilation system is a very powerful tool
- Demonstrated technical feasibility for AEF with EDA
- Need to understand added value of ensemble for aerosols also to justify additional cost
- Extremely useful for: volcanic eruptions, dust storms, high pollution events… what else?

Any questions or suggestions?