



Ensemble Approach to Air Quality: Why ??

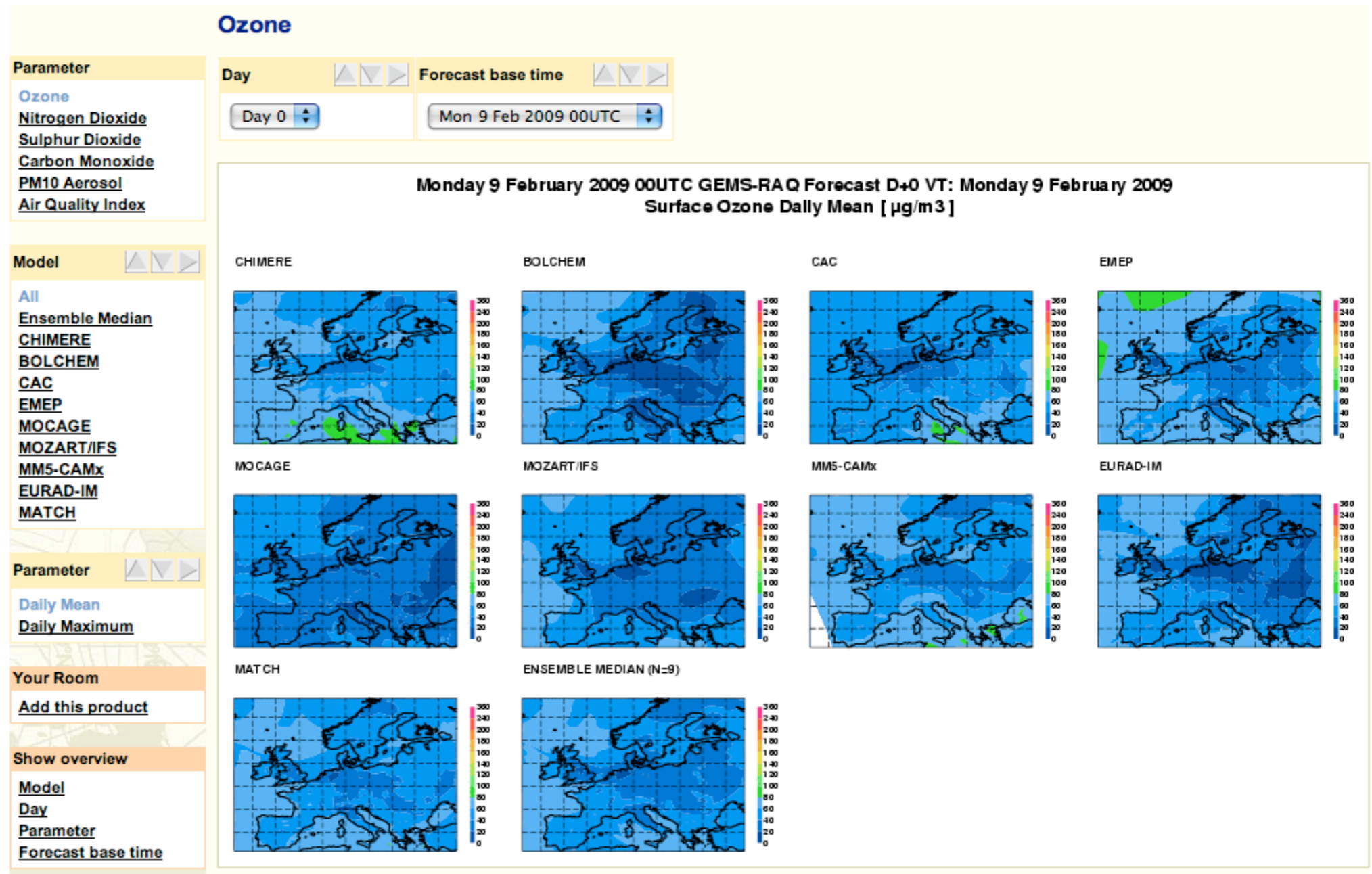
Henk Eskes

- Short introduction: Ensemble AQ forecast for Europe
- Why the ensemble approach?

MACC: continuation of GEMS + PROMOTE

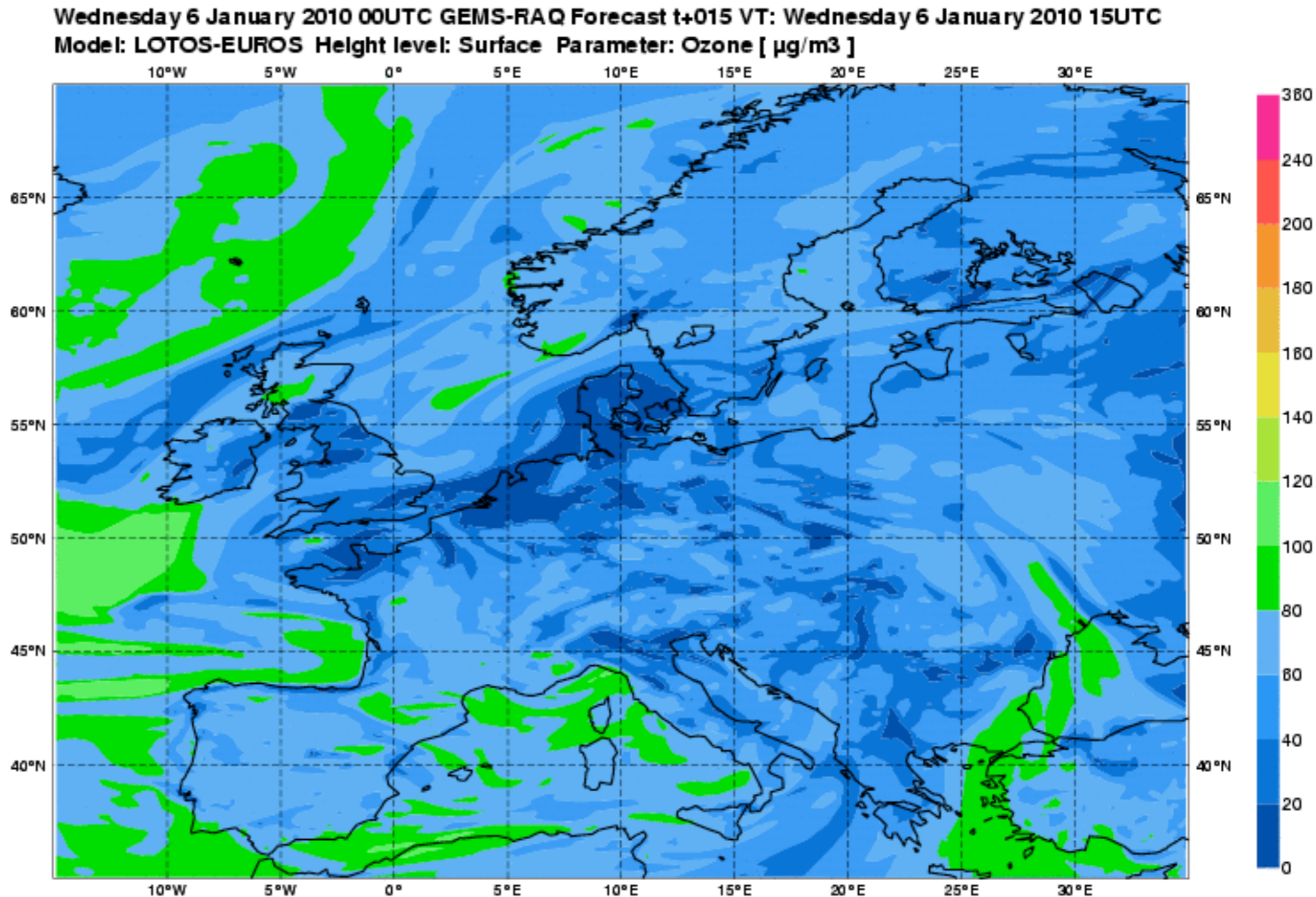
MACC: June 2009 - October 2012

October 2009: KNMI and TNO contribute to the European ensemble air quality forecast with Lotos-Euros



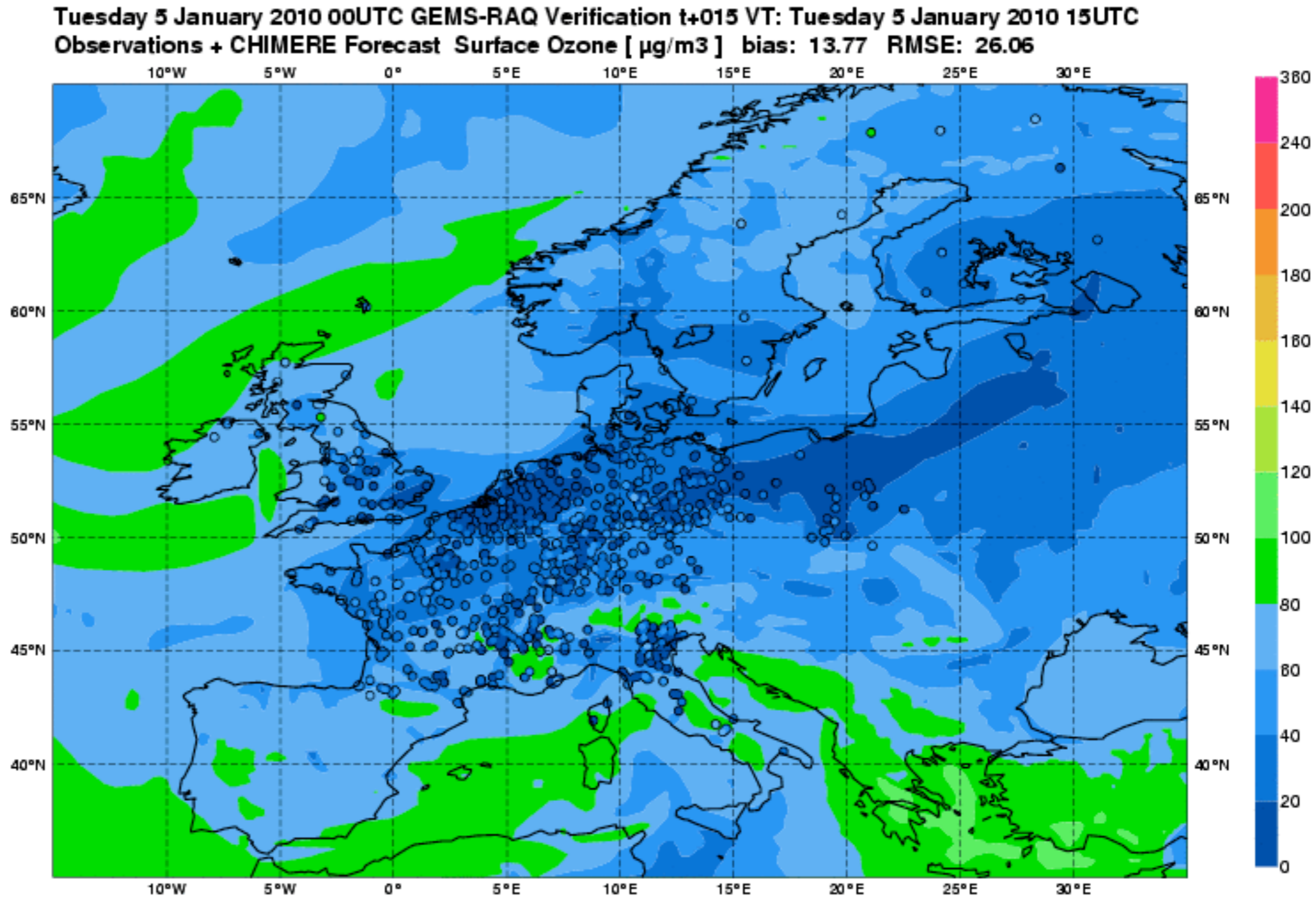
MACC: LOTOS-EUROS example

Surface ozone
6 jan 2010,
15 utc
15 km resol



MACC: verification example

Surface ozone
5 jan 2010,
15 utc
CHIMERE

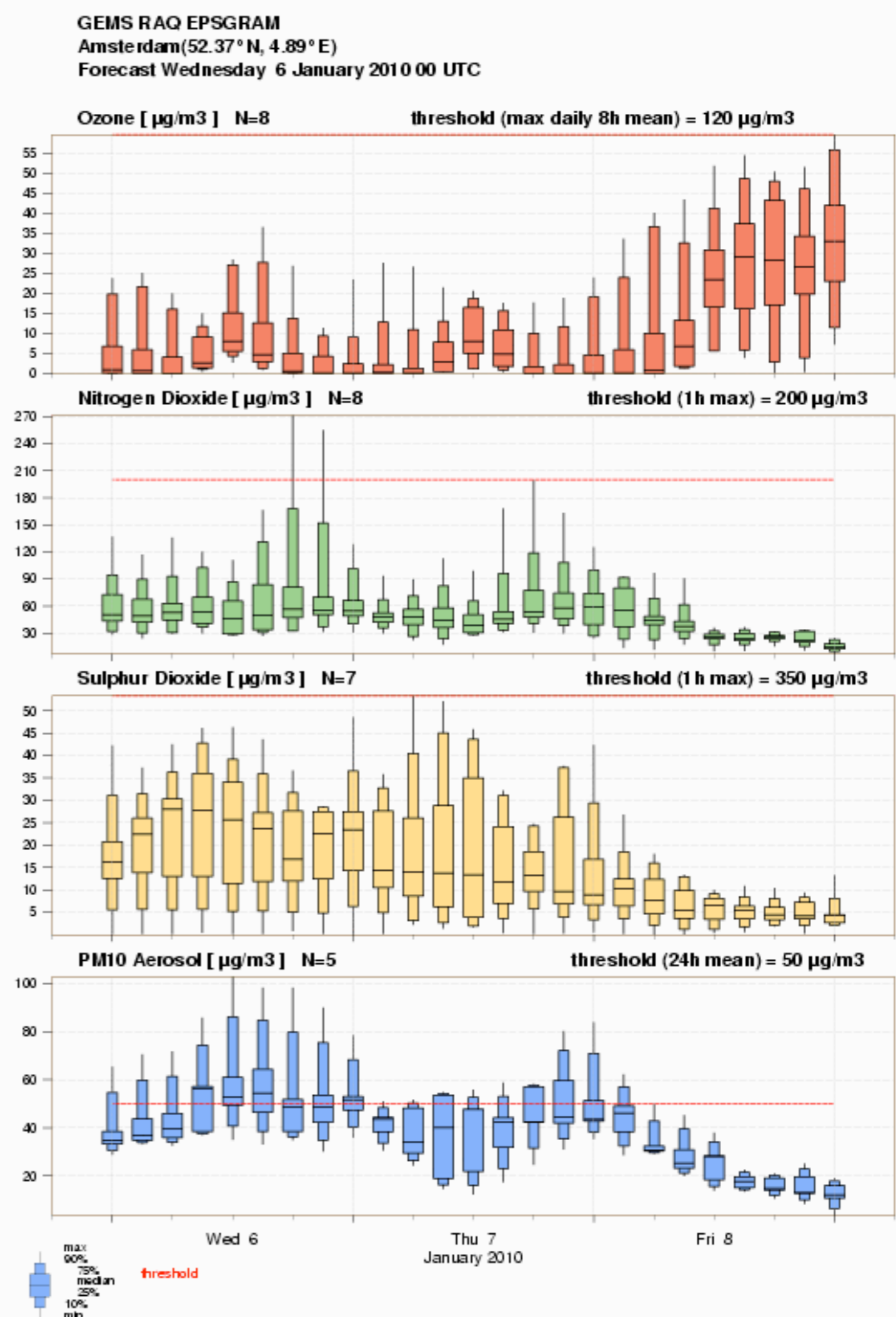


MACC: AQ ensemble

EPSgram

Amsterdam

Forecast Wed 6 - Fri 8 jan 2010





Air Quality forecasts

Are there benefits to use a model ensemble ?

Is the ensemble better than the best model ?

**Is the spread in the model values a measure of
uncertainty?**

Is the mean/median of the models a good model?

Motivation for the ensemble approach:

- “The estimate of the range of uncertainty is crucially needed by users of any information service”: provide accurate time-dependent errors estimates
- Kalnay 2002 (meteorology):
 - Improve forecast by ensemble averaging
 - Indication of reliability of forecast
 - Quantitative basis probabilistic forecasting
- Model process errors more important than initial state
- Several multi-model ensembles have shown that:
 1. spread is often quite representative of uncertainty
 2. Median of models often performs better than best model
- Bringing together models leads to improvement of the individual models

A fundamental difference:

- In NWP the uncertainty in the **initial state** is the first thing to consider. Ensembles often consist of multiple perturbed initial states and a single NWP model. Model tends to **diverge** when small perturbations are added to the initial state (chaos).
- A regional AQ model tends to **converge** to a well-defined (boundary layer) state after a couple of days, independent of the 3D concentration field at the start of the integration.
- In atmospheric chemistry (especially regional scale) the uncertainty is especially related to uncertainty in **model** input data, physical parameterizations, or from gaps in our knowledge of the chemistry and physics of the atmosphere and its interaction with the surface.

NWP: ensemble based on initial state perturbations (ECMWF EPS)

AQ: ensemble based on independent models

Model processes



3D Transport
Randvoorwaarden
Aerosol processen
Heterogene chemie
Fotolyse
Biogene uitstoot

Tubulente menging in de atmosfeer
Gasfase chemie
Secundair organisch aerosol
Anthropogene uitstoot
Natte verwijdering
Droge verwijdering

The modelling of all these processes is uncertain !
Do modelling errors behave randomly, so that they can cancel
in an ensemble mean?

Ensemble forecasts: why ?

Krishnamurti, Science 1999

Superensemble of ~30 meteorological models

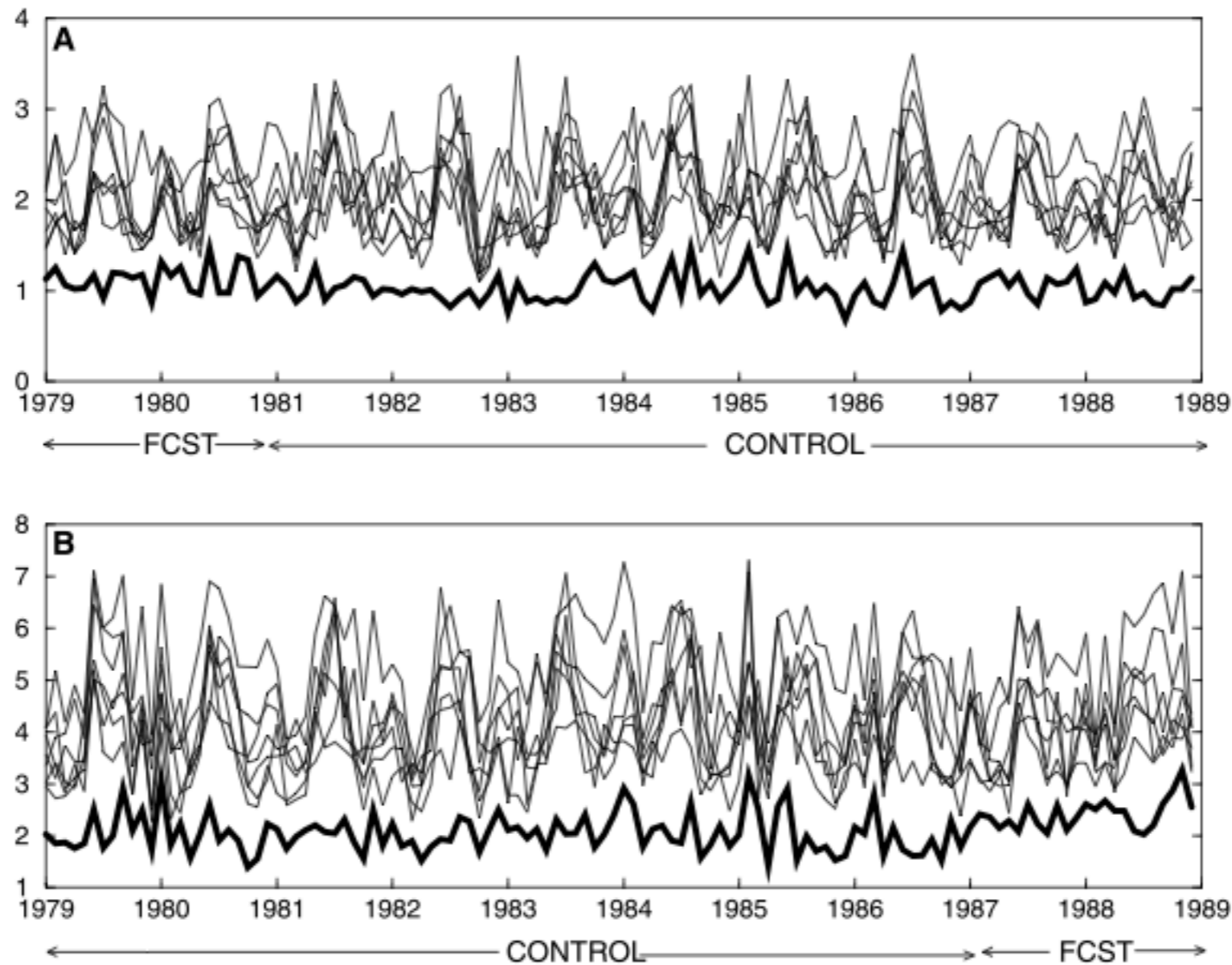


Fig. 1. Asian monsoon domain average rms error for the superensemble (heavy line) and the selected AMIP models (thin lines) for 850-hPa meridional wind (A) and precipitation (B). Units in (A) are ms^{-1} and units in (B) are mm day^{-1} .

Ensemble forecasts: why ?



Delle Monache and Stull, *Atm. Env.* 2003

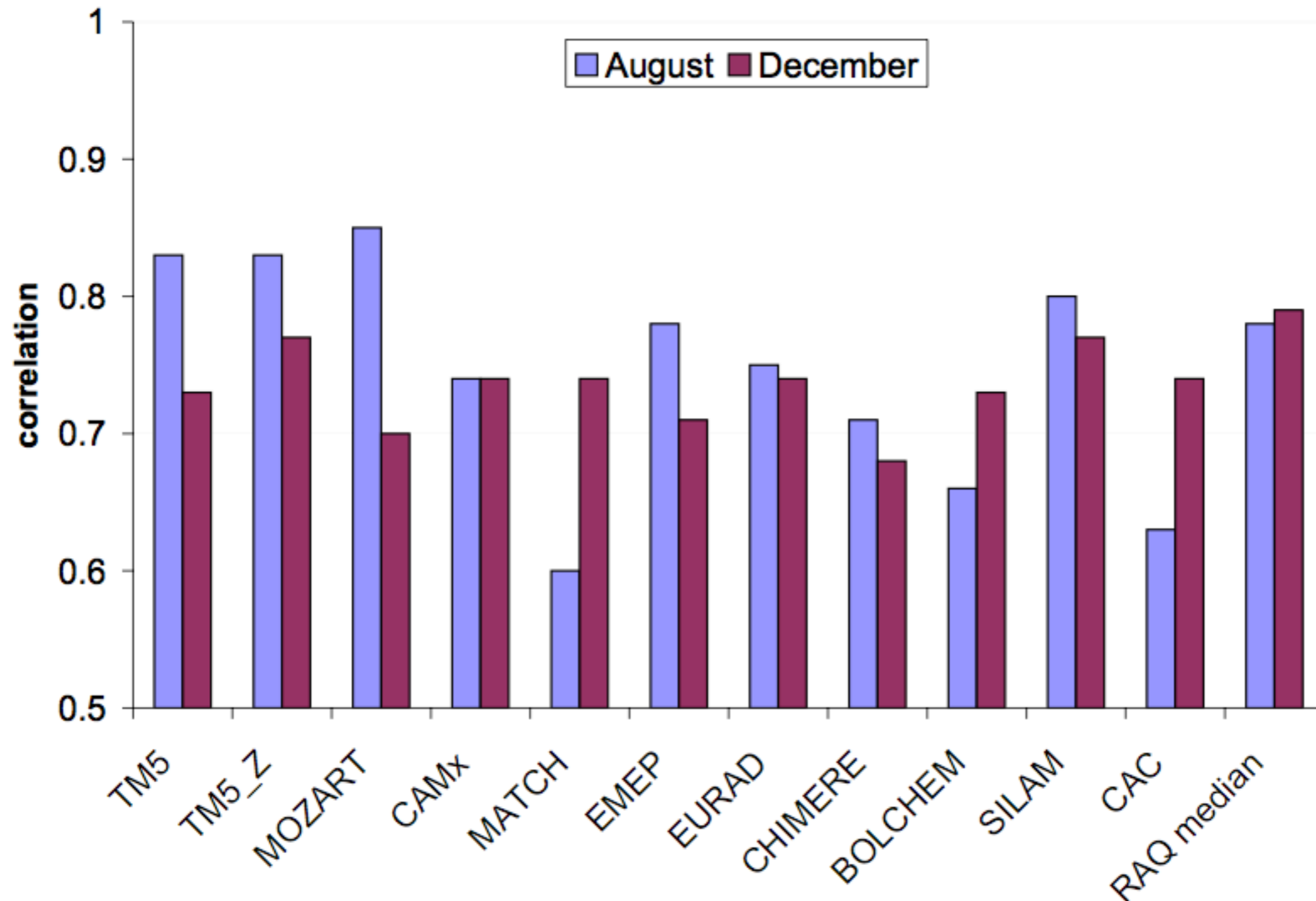
EURAD, REM3, EMEP, LOTOS ensemble

"The ensemble gives consistently the best or second best forecast"

"Performances from all models are quite erratic compared to the smoother behavior of the ensemble .. ensemble .. take into account most of the uncertainties by filtering out unpredictable components"

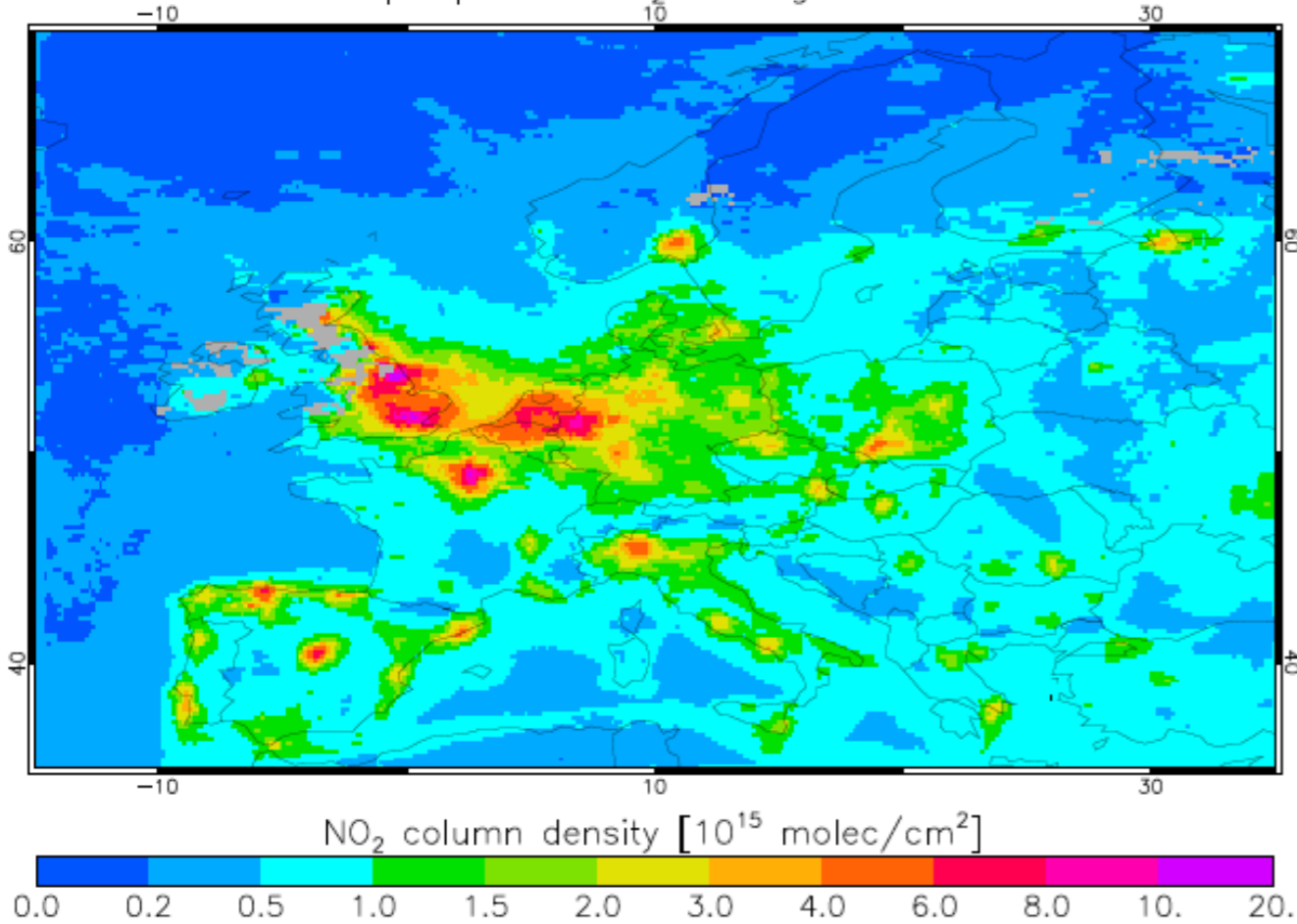
Ensemble forecasts: why ?

Vincent Huijnen: comparison of GEMS AQ models with OMI NO2

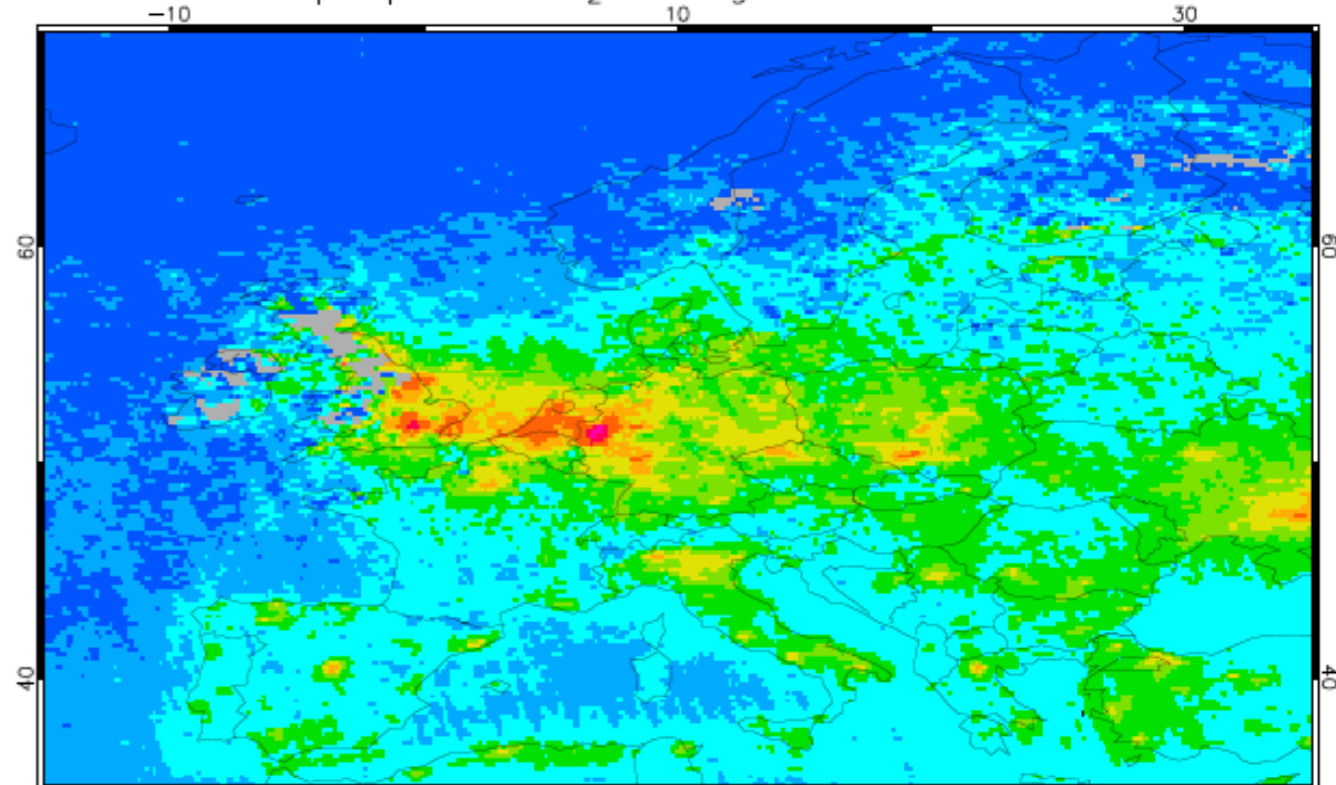


Ensemble forecasts: why ?

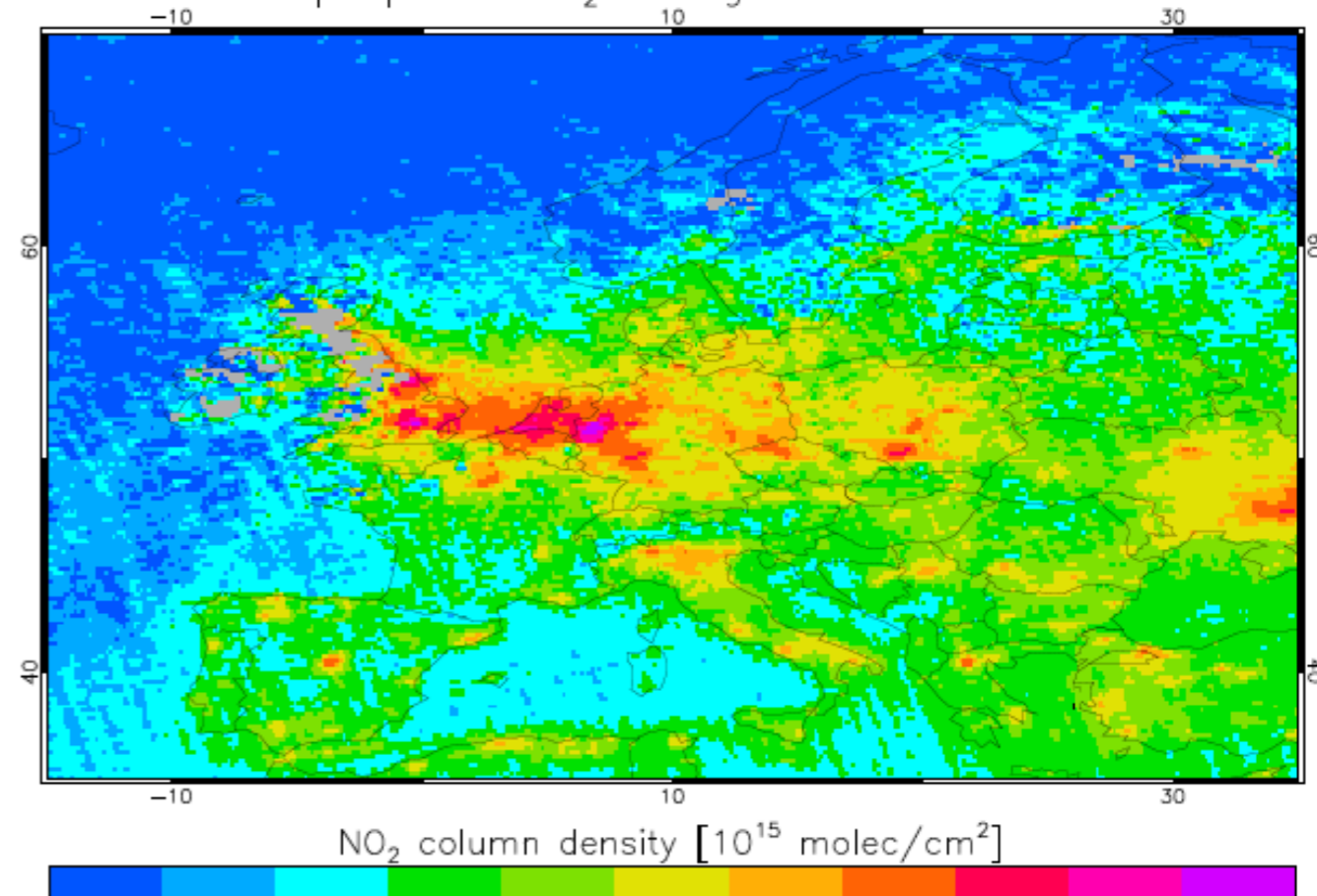
median model tropospheric NO₂ – Aug 2008 RAQ models



OMI mean tropospheric NO₂ – Aug 2008 OMI



OMI mean tropospheric NO₂ – Aug 2008 OMI



Vincent Huijnen:
comparison of GEMS AQ
models with OMI NO₂

Ensemble forecasts: why ?

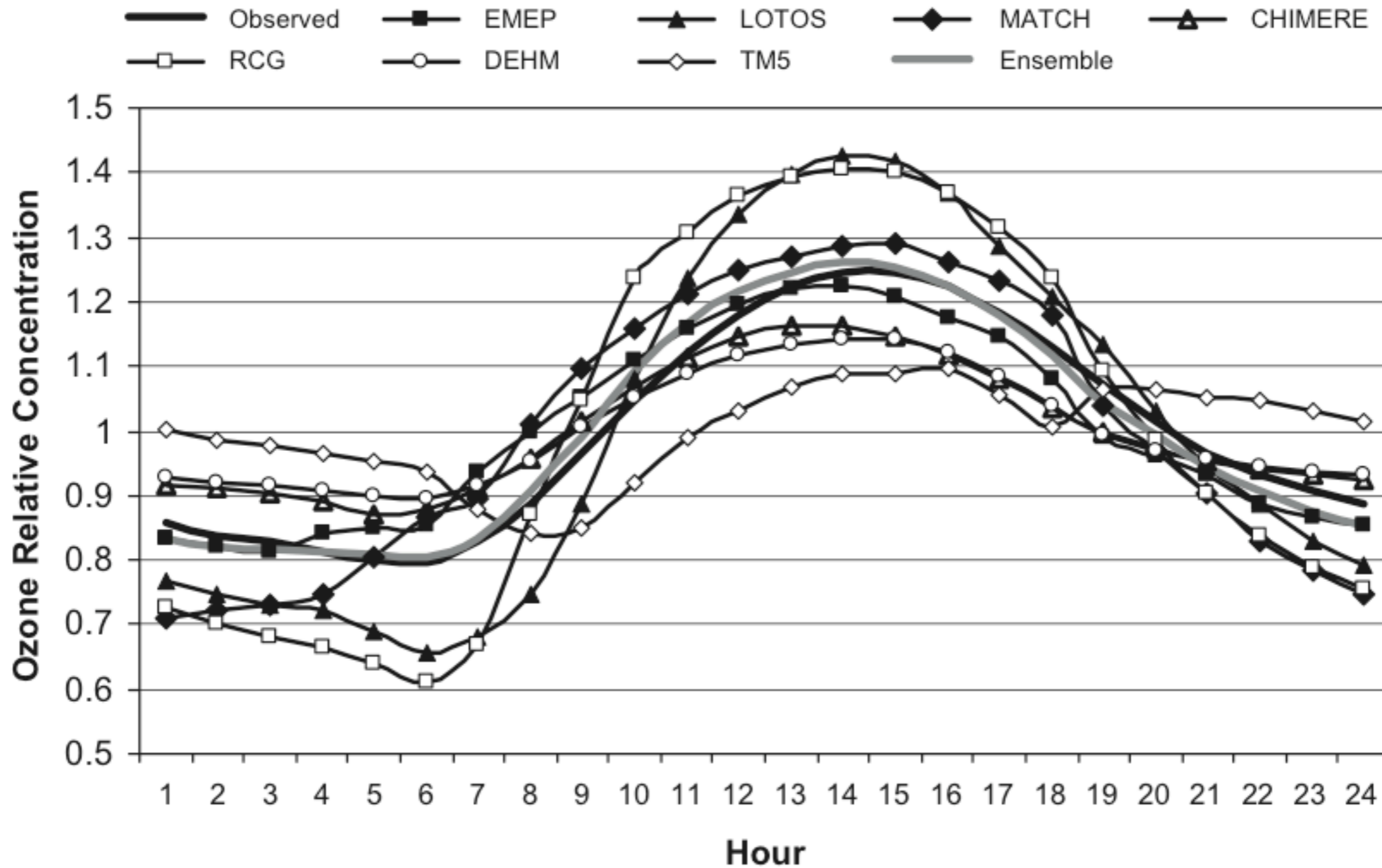
Van Loon et al, *Atm. Env.* 41 (2007)

EMEP, LOTOS-EUROS, CHIMERE, RCG, MATCH, DEHM and TM5
ensemble (EuroDelta experiment)
(Same emissions used)

" The ensemble average concentrations almost always exhibit a closer proximity to observations than any of the models. We also show that the spread of the model ensemble is fairly representative of the uncertainty in the simulations. "

" the ensemble model has a theoretical skill, superior to that of any individual model "

Ensemble forecasts: why ?



Van Loon et al, *Atm. Env.* 41 (2007)

Ensemble forecasts: why ?

Is regional air quality model diversity representative of uncertainty for ozone simulation? Vautard, 2006, 2008

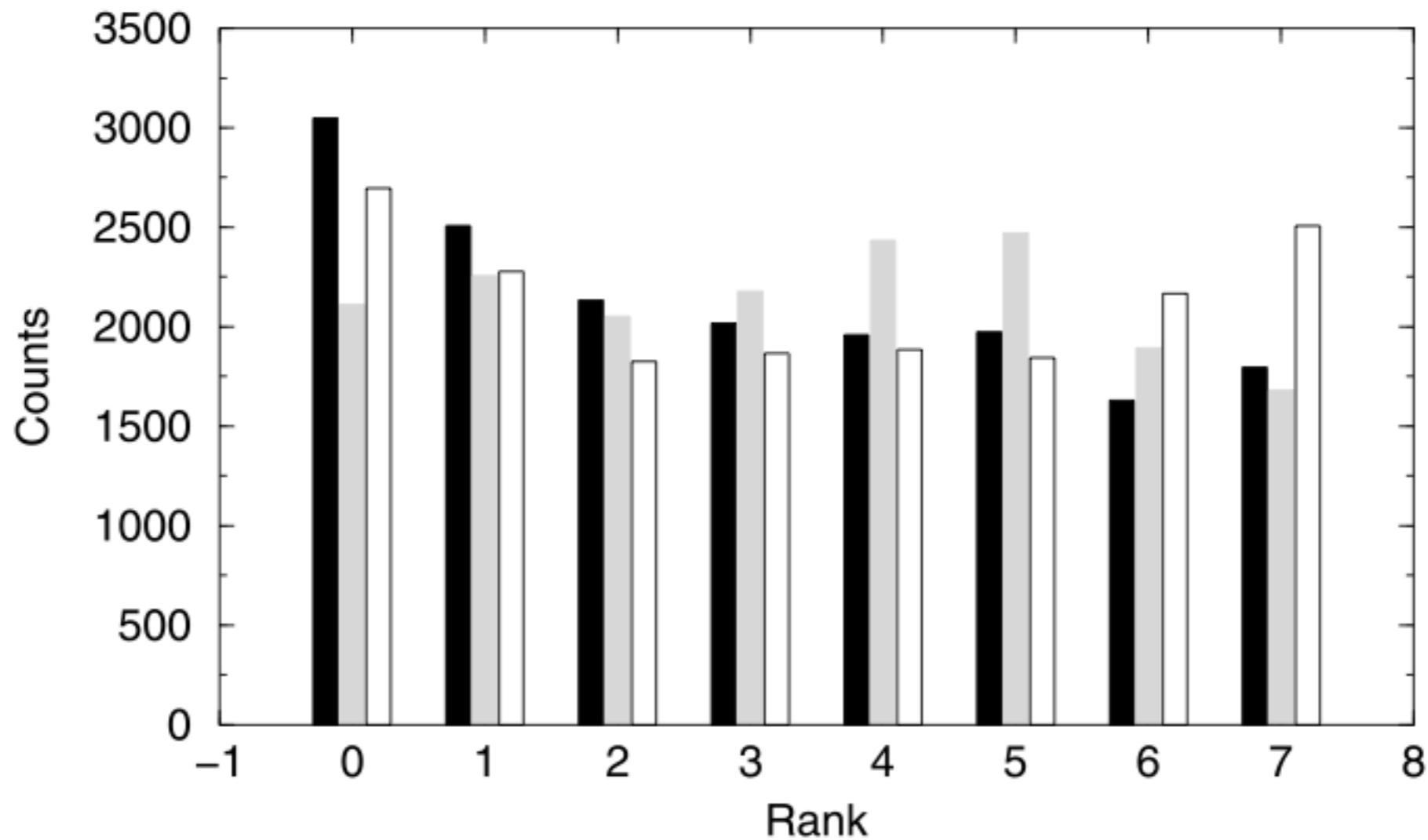
Ensemble of 7 regional air quality models (EuroDelta)

" .. results allow for optimism about the ability of this ensemble to simulate the uncertainty of the impact of emission control scenarios."

" when ensemble bias is removed at each monitoring station the spread of simulated values is fairly representative of the uncertainty, that is, of the spread of the simulation errors, and this spread is partly due to the spread of individual model systematic biases "

" The good correspondence between ensemble spread and uncertainty also indicates that, for ozone daily maxima, regional air quality models developed in Europe are complementary and their (unintentional) diversity reflect the uncertainty in our knowledge of air quality processes. "

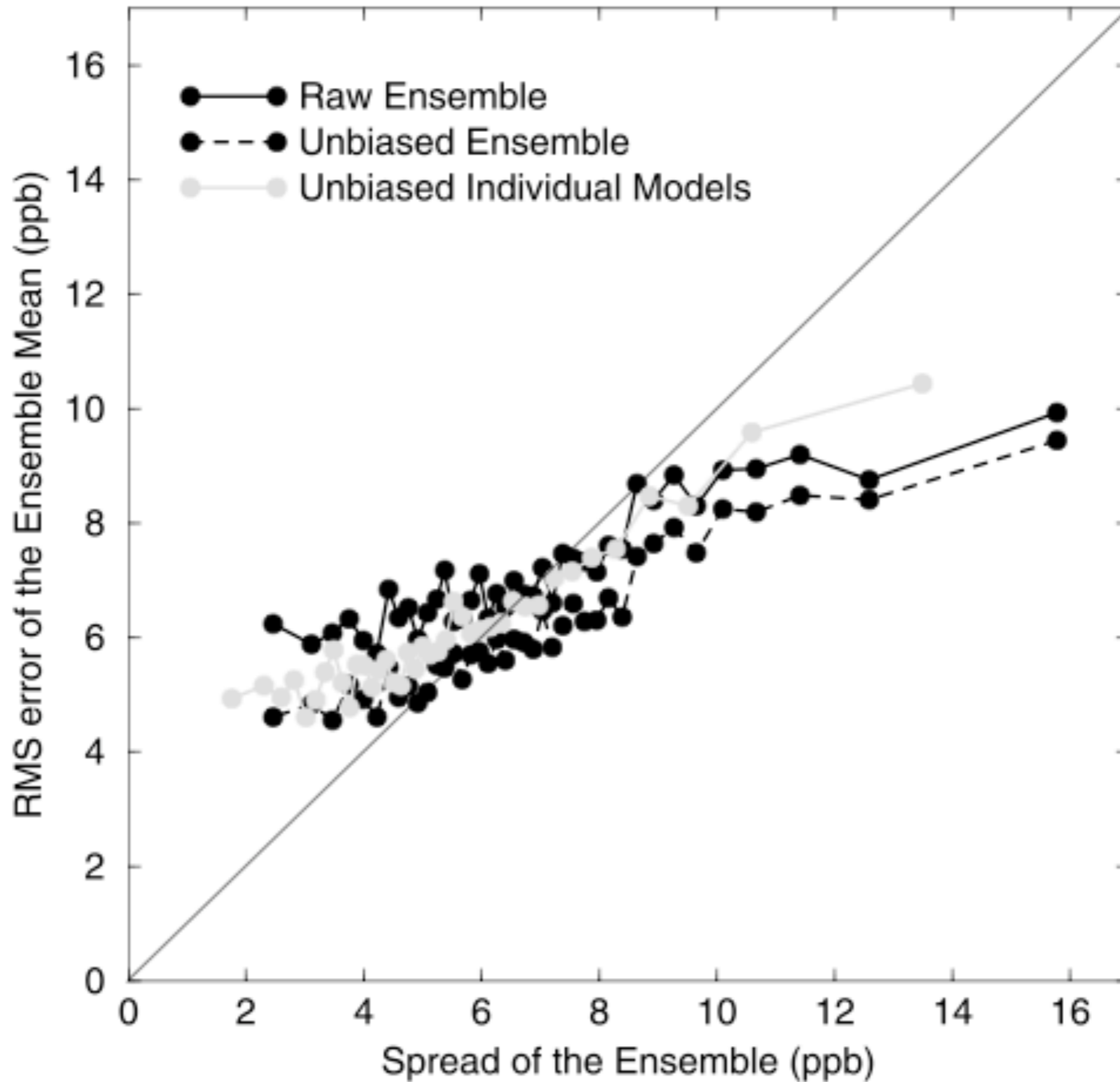
a) Rank Histogram of Summertime O3 max

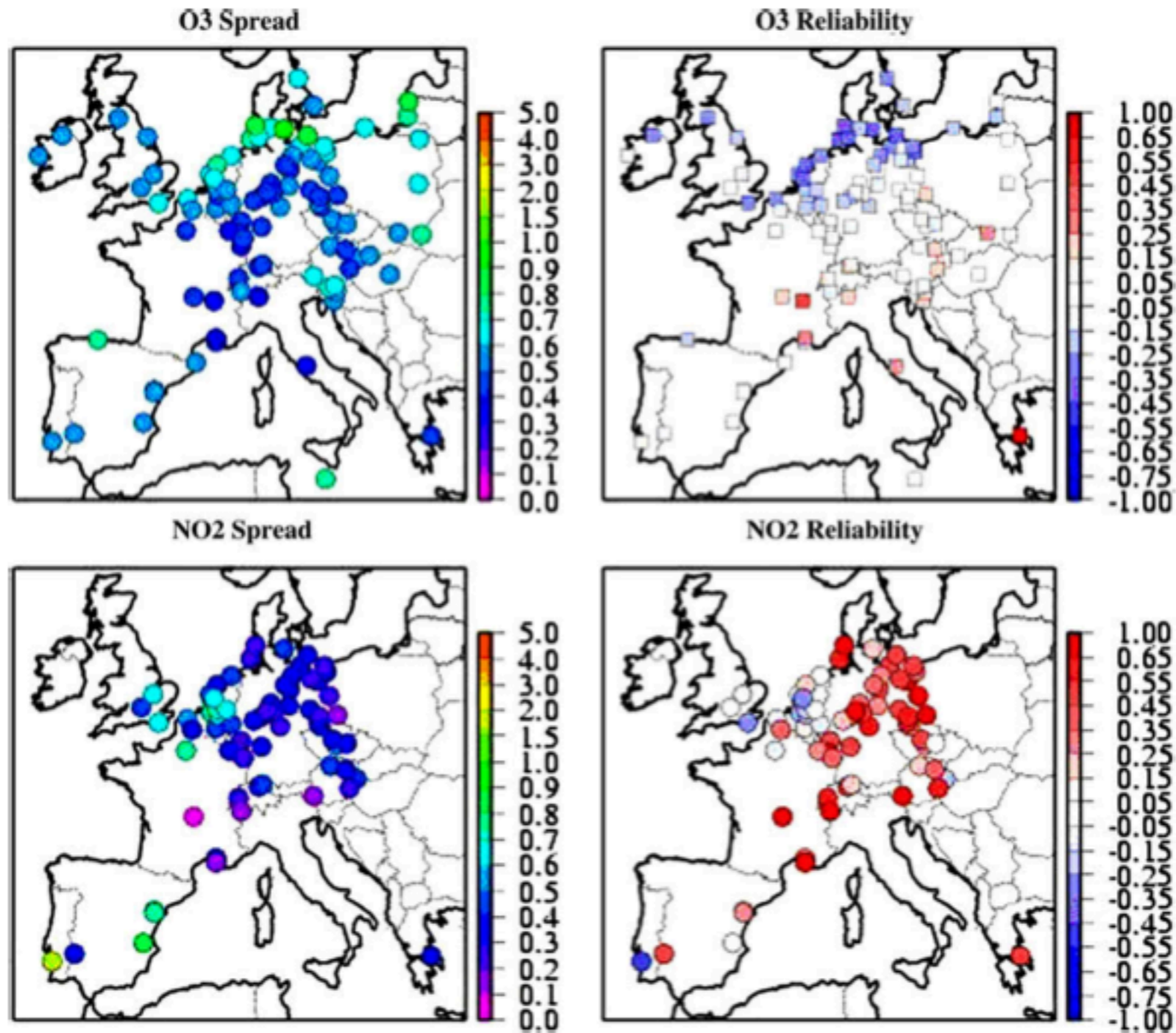


- Spread models represents uncertainty quite reasonably
- Models do not reproduce full dynamical range observed

Spread–Skill Relation

O3 Daily Maxima





- Coastal areas and mountains are difficult for models
- Models perform well in NW Europe, away from the coast

Ensemble forecasts: why ?

Delle Monache, et al. JGR 2006

Ensemble based on CMAQ

" ... both meteorology and emission perturbations are needed to have a skillful probabilistic forecast system: the meteorology perturbation is important to capture the ozone temporal and spatial distribution and the emission perturbation is needed to span the range of ozone concentration magnitudes. Emission perturbations are more important than meteorology perturbations for capturing the likelihood of high ozone concentrations."

Ensemble forecasts: why ?



Galmarini et al, Atmos.Env., 2004

(Ensemble dispersion forecasting)
(ETEX-1)

“At present we are not in the position of providing a rigorous explanation on why the median model should perform better than the single models.”

Ensemble forecasts: why ?

Riccio et al. ACP 2007

“Seeking for the rational basis of the Median Model:
the optimal combination of multi-model ensemble results”

(Dispersion models)

Theoretical approach based on Bayesian statistics

Defining weights for individual models (Bayesian model average)

Importance of model dependence

“ We recover some interesting results, supporting the heuristic approach called “median model”, originally introduced in Galmarini et al. (2004a, b)”

.. the “Median Model” results provide an estimate that is superior to any single deterministic model simulation ...

Ensemble forecasts: MACC

A few questions related to MACC:

In MACC the models use the same emissions, the same boundary conditions and the same meteorological forecast.

- Is the ensemble spread underestimating uncertainty ?
- In forecast mode the uncertainty in the meteorological forecast seems to be a major contribution to the uncertainty. How important is this in comparison to the model spread ?

Conclusions

Ensemble air quality forecasts

- There are several examples where the ensemble median is superior as compared to the best model
- Model errors seem to average out
- Possible to provide theoretical support for the median approach (Bayes theorem) (Krishnamurti - weighted approach higher skill than ensemble average)
- There are several examples where the spread of the models provides a reasonable representation of the uncertainty
- When one starts to look at details (maps) things are not so clear ...
- Ensembles can be created with multiple models, or with one model (perturbing emissions, met fields etc ...)
- Interesting analysis techniques, e.g. rank diagrams

MACC

- Ensemble of 6-7 models, with same meteorology, same emissions, same boundary conditions
- Ensemble spread will therefore not represent all aspects of the modelling uncertainty
- Focus on model improvement and development
- Possible extensions:
 - coupling to ECMWF EPS
 - introduce spread of emissions and boundary conditions