PROMOTE
Regional/local air quality forecast service

PROMOTE User Executive Board
Robert Höller (Umweltbundesamt, Austria)

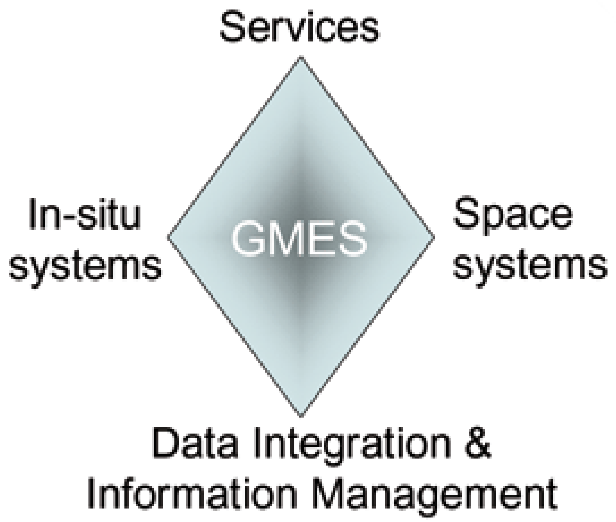
RIU EURAD model
H. Elbern, A. Strunk (Univ. Cologne, Germany)

Global Monitoring for Environment and Security (GMES)

- Joint EU-ESA initiative, initiated in 1998
- European contribution to GEOSS

- Initial period (2002-2003)
- Implementation period (2004-2008)

- www.gmes.info



GMES Infrastructure

GMES Service Elements (GSE)

GSE program formulated as ESA GMES contribution

- GMES-applicable capabilities in Europe already exist
  - target operational & sustainable information services
  - respond to the needs of users in support of policies
  - strong involvement of users
  - demonstration and operationalization of precursor services

- focus mainly on services using Earth Observation sources
  - draw on results obtained from present EO satellites and provide recommendations for future EO system

Stage 1 (2004 – 2006)

consolidate service portfolio

users: service level agreements, core users

Stage 2 (2006 – 2009)

up-scaling of portfolio (areas, periods, parameters)

users: service level agreements, user executive board

PROMOTE- GSE for Atmospheric Monitoring

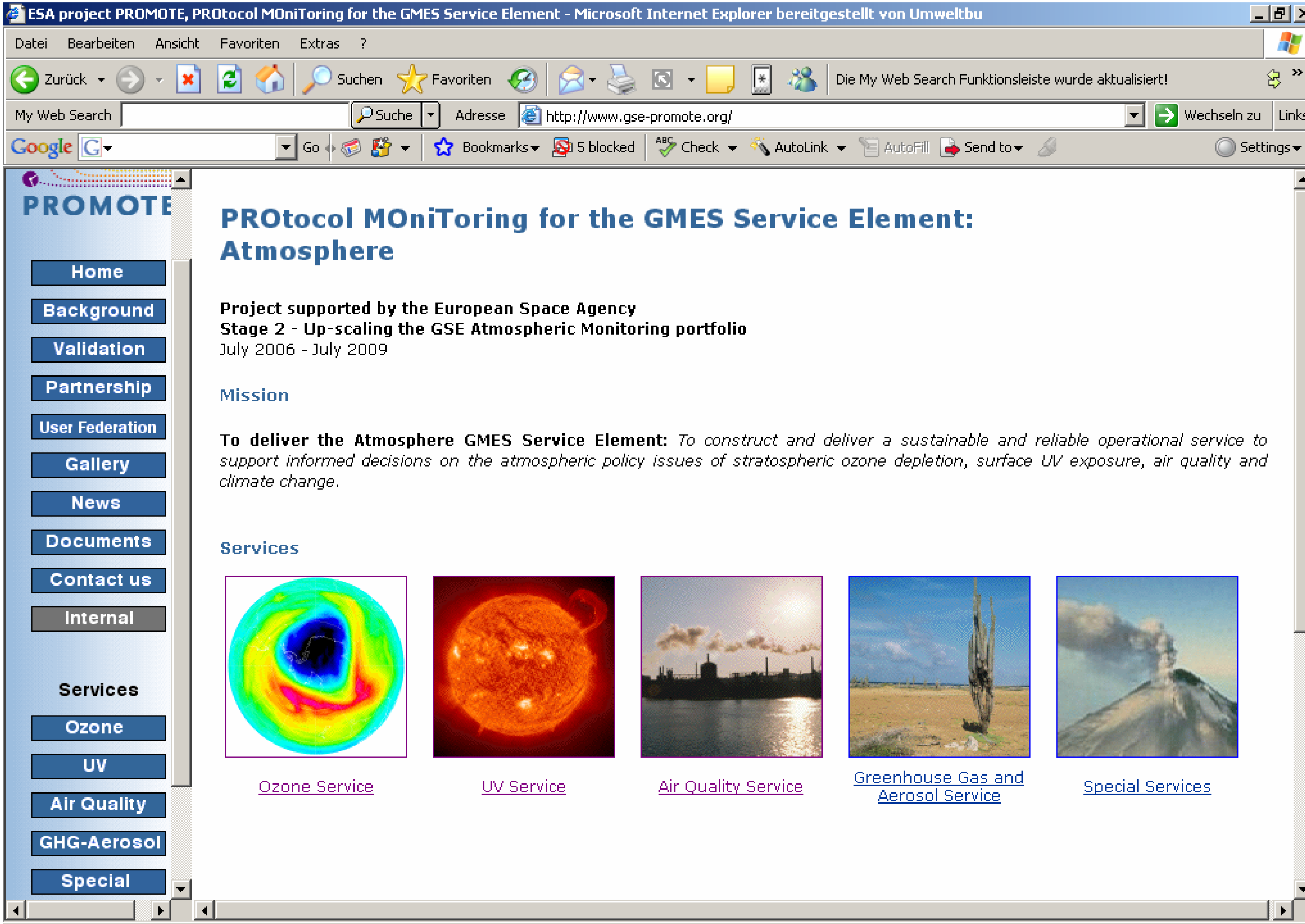
- PROMOTE* Mission:

  To deliver the Atmosphere GMES Service Element by constructing & delivering a sustainable & reliable operational service to support informed decisions in particular on atmospheric policy issues

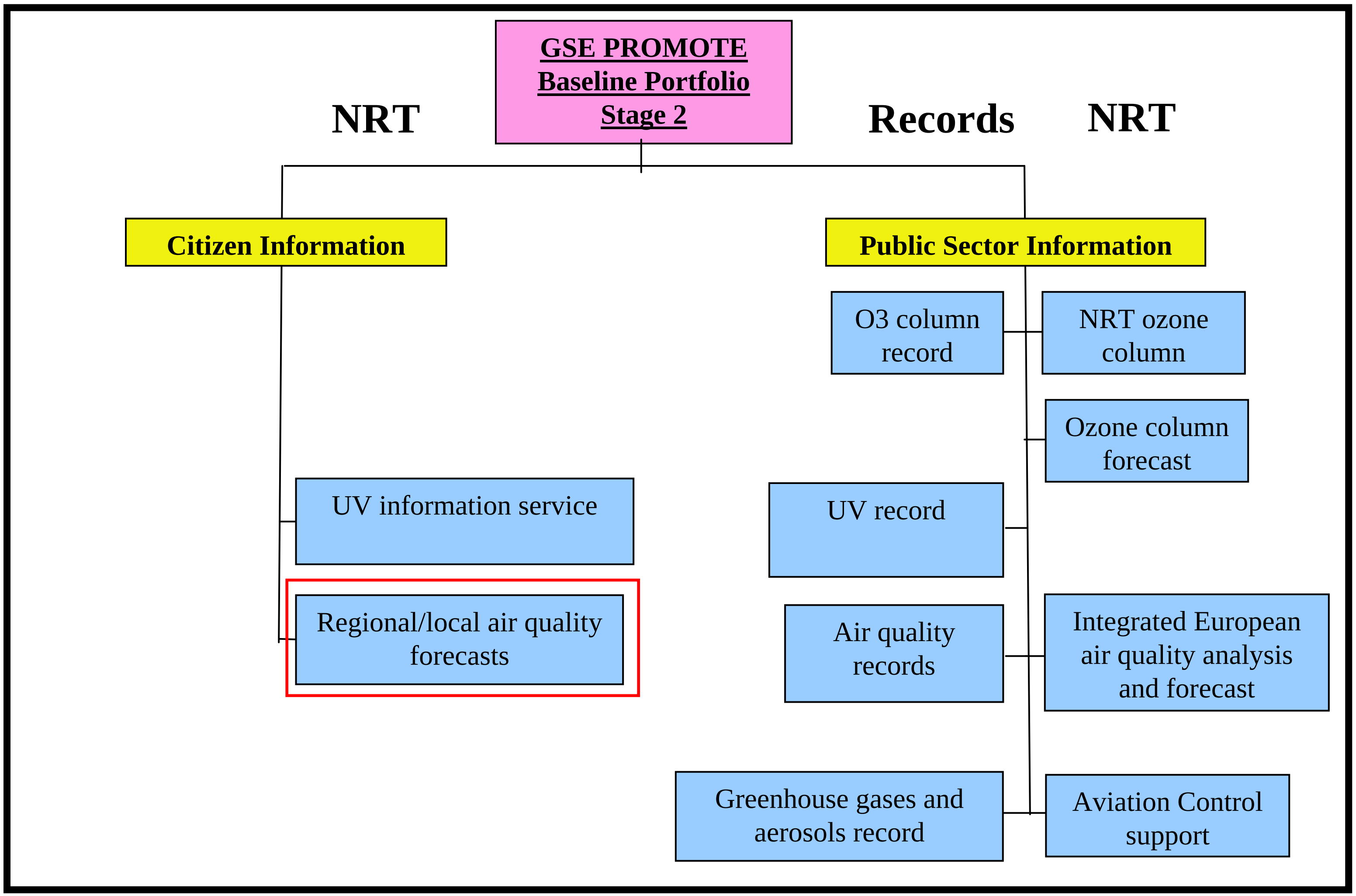
- Stage 1: 4 themes selected based on identifiable user requirements and maturity or promise of satellite and ground-based observations
  - Stratospheric Ozone
  - Surface UV Radiation
  - Air Quality
  - Greenhouse Gases and Aerosols

*Protocol Monitoring for the GMES Service Element for Atmosphere

PROMOTE Website: www.gse-promote.org



PROMOTE-Stage 2 (2006-2009) Baseline Service Portfolio



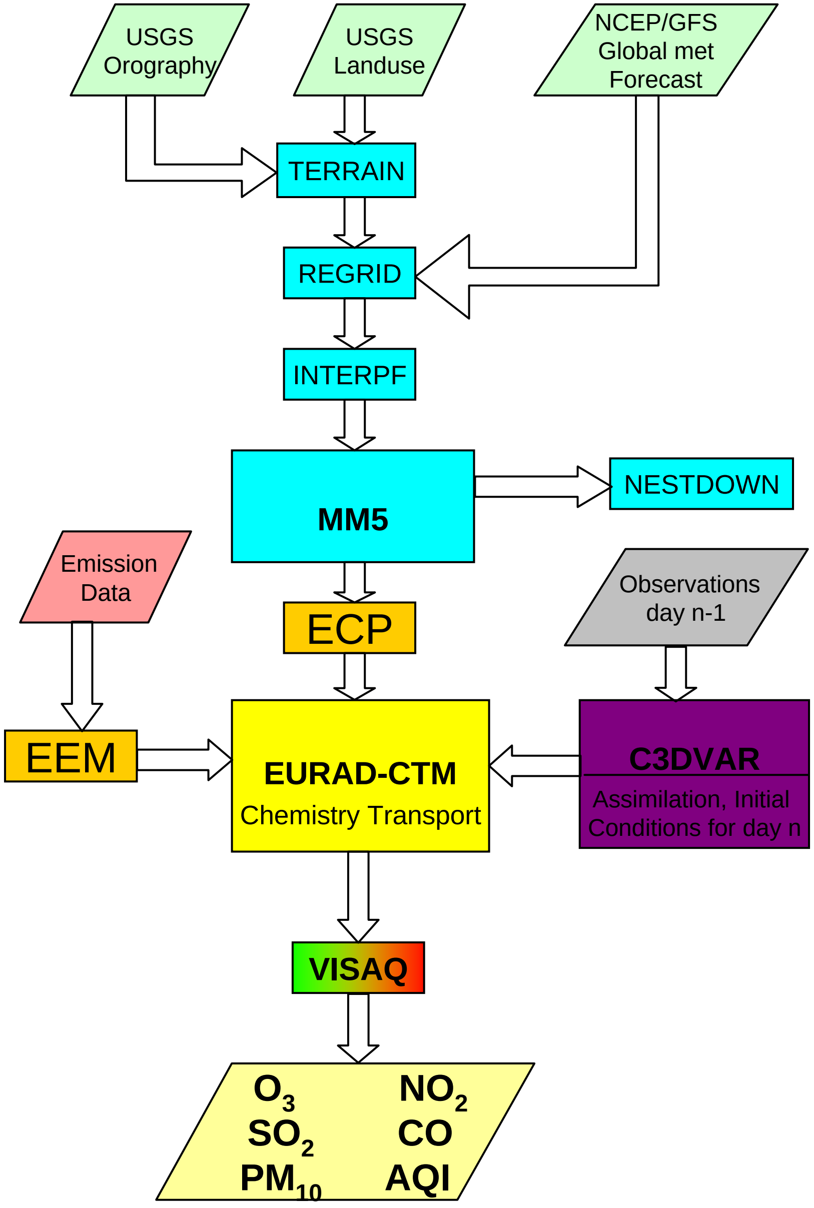
EURAD Forecast and Analysis System

- EURAD system development began at RIU (Rhenish Institute of Environmental Research) in early-1990s
  - Online operationally since 2001: **www.eurad.uni-koeln.de**
- Forecasting products: O3, NO2, SO2, CO, PM10, PM2.5, Benzene, Formaldehyde, Air Quality Index
- Output: max. 8 hour mean, 24 hour mean, animations, time series for certain regions
- 72 hour forecast cycle, starting at 00 UTC
- Validation process uses station data (2d variational technique), forecast skill scores are calculated and stored)

EURAD key features

- Continental and national capacity service
- Regional services on areas of interest
- Experiences as daily forecast providers for environmental agencies
- Forecasts tailored to individual demands of the environmental protection agencies (focal region, target resolution, species, visualisation species)
- Integrated advanced chemistry assimilation system
- Focalized and high resolution air quality forecasting by hemispheric/continental to regional (optionally 1km resolution) nesting techniques with integrated meteorological driver model
- advanced heterogeneous chemistry mechanisms with comprehensive aerosol and photooxidant modules

The EURAD System of Models



- **MM5**
  - Penn State/NCAR Mesoscale Model
  - predicts necessary meteorological variables
  - Initial and boundary conditions from NCEP/GFS global forecast
- **EEM**
  - EURAD Emission Model
  - predicts temporal and spatial distribution of emission rates of major pollutants
  - Interpolates from yearly data to seasonal and daily variations
- **EURAD-CTM**
  - EURAD Chemistry Transport Model
  - Transport, chemical transformation, and deposition (wet and dry)

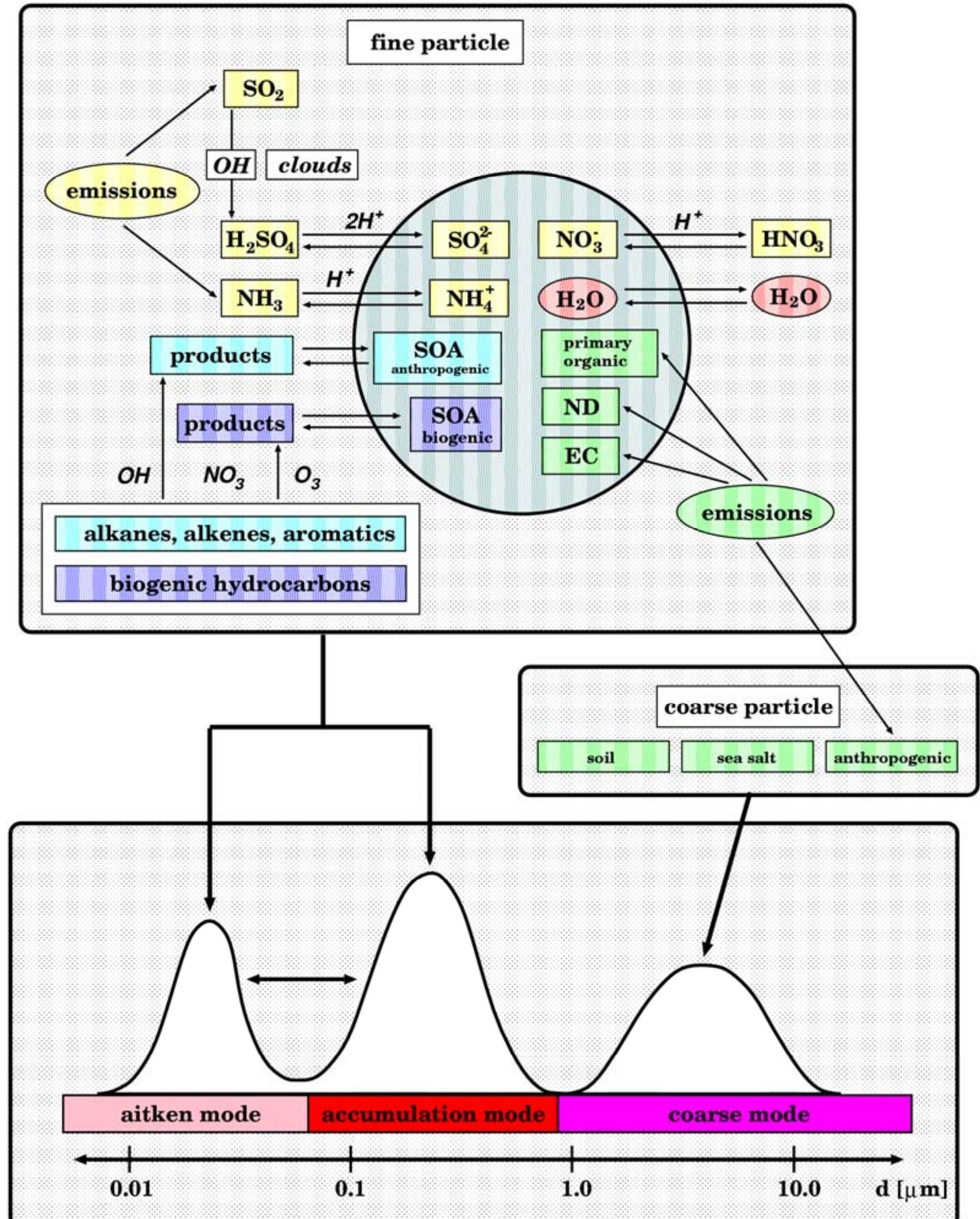
Aerosol Chemistry in **MADE**

Modal **A**erosol **D**ynamics
for **E**URAD/**E**urope
(Ackerman et al., 1998,
Schell 2000)

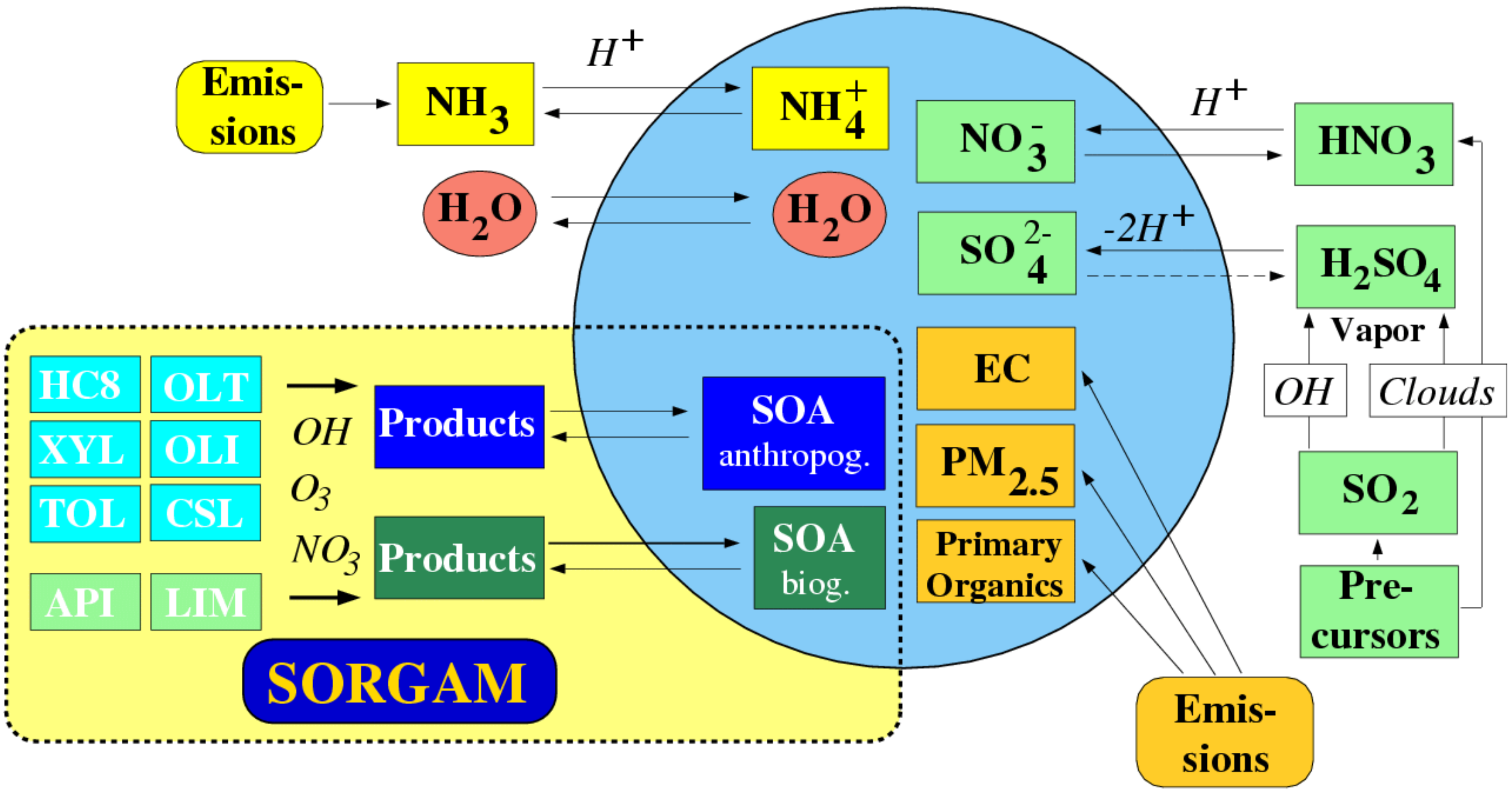
$$dM_i^k/dt = nuk_i^k + coag_{ii}^k + coag_{ij}^k + cond_i^k + emi_i^k$$

$M_i^k := k^{th}$ Moment of i^{th} Mode

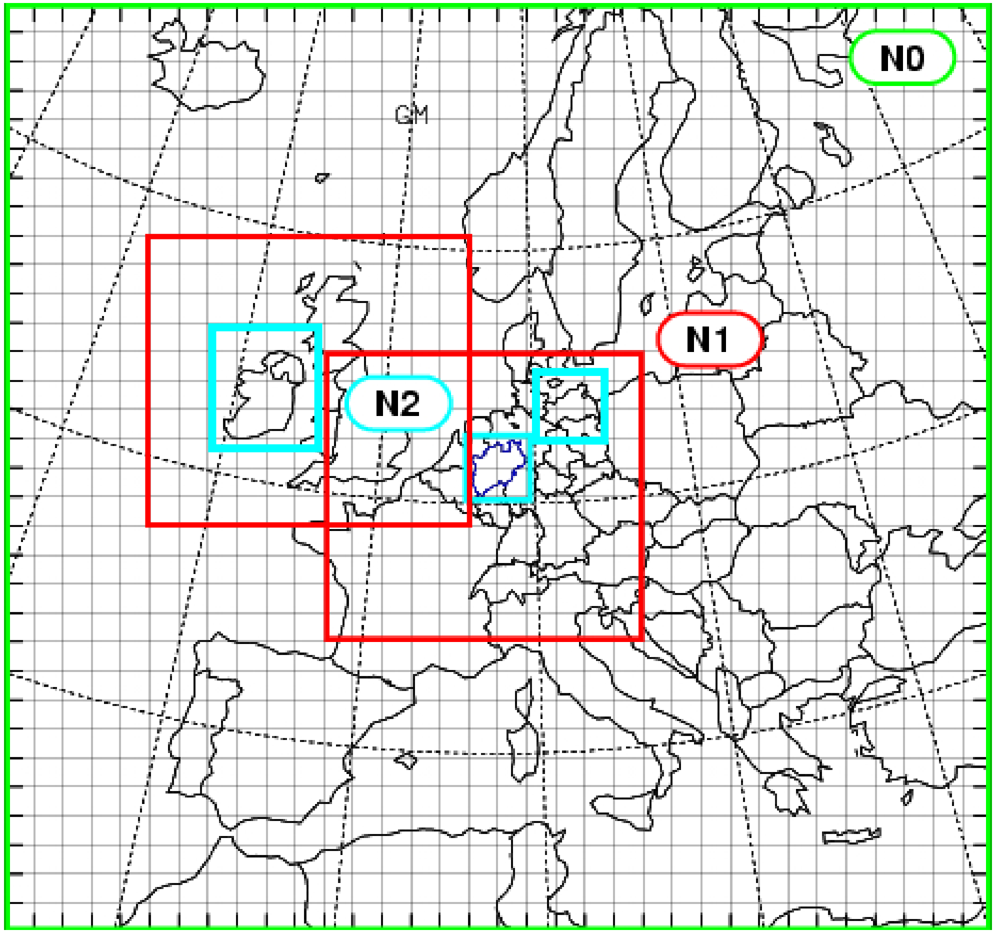
The Future:
Bridge from optical to chemical properties
assimilation of aerosol
By satellite retrievals: e.g.
MERIS MODIS
AATSR+SCIAMACHY,...



Example: chemical complexity: The EURAD Secondary ORGanic Aerosol Model (SORGAM) as part of the MADE Aerosol Chemistry



PROMOTE-1 EURAD Nested Scales



nesting technique with integrated meteorological driver model

N0: Continental Scale
- **125 km resolution**

N1: Regional Scale
- **25 km resolution**

N2: Local Scale
- **2 German States**
- **Ireland**
- **5 km resolution**

N3: City Scale
- **1 km resolution**
- **City of Neuss, DE**

EURAD forecast and 3D-var assimilation

Configuration parameters
(details to be determined)

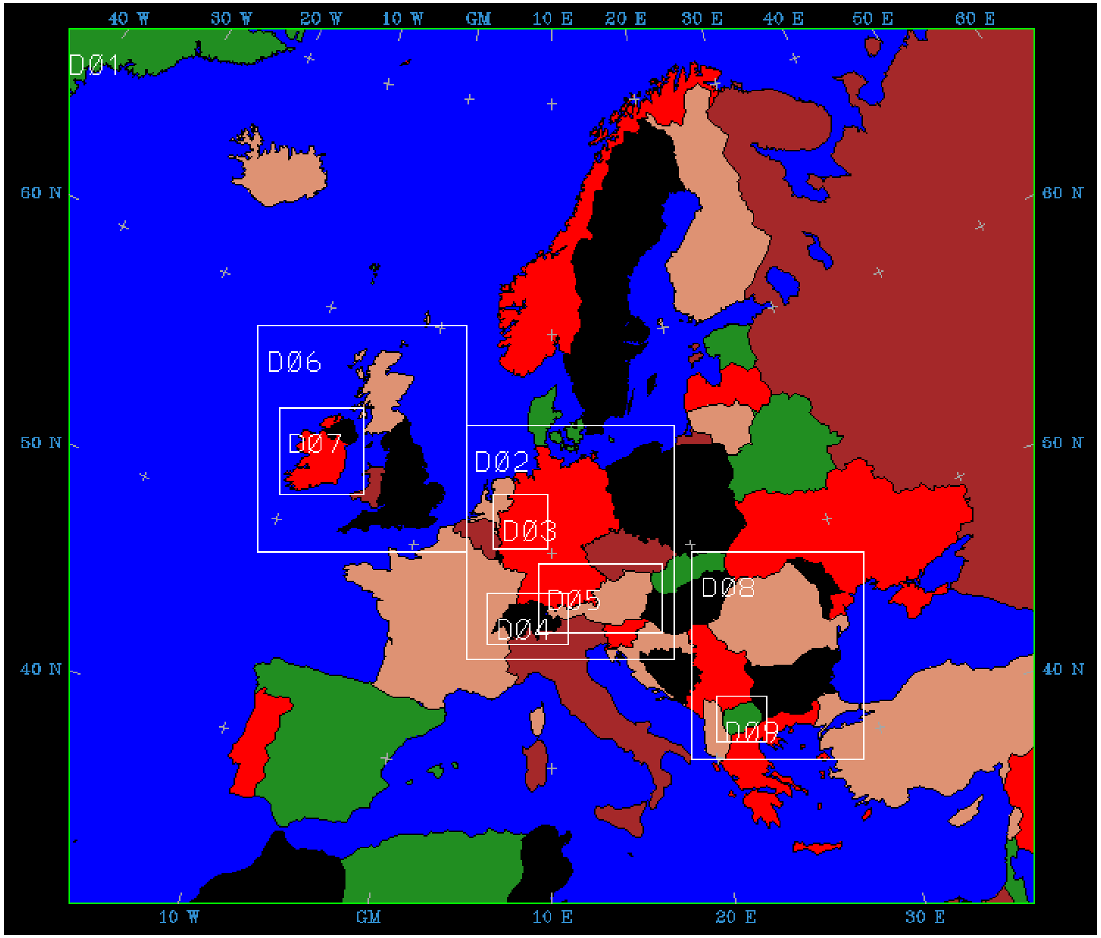
<u>Integration domain EU27</u>
<u>horizontal resolution:</u>

coarse grid:	45 km
nest level 1:	15 km
nest level 2:	5 km

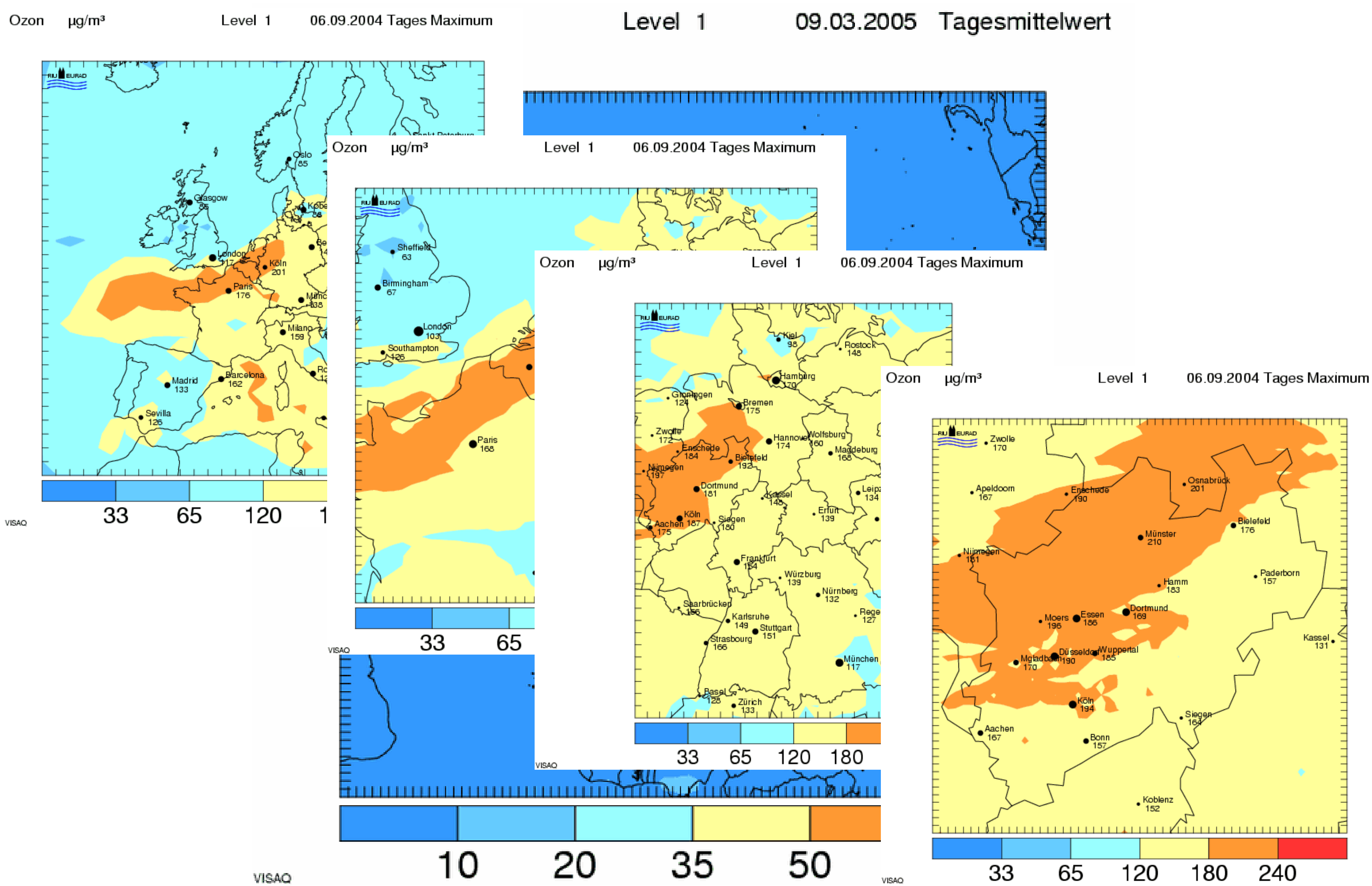
<u>Constituents:</u>
O3, CO, NO2, SO2, PM10, PM2.5, AQ index

Present status (on schedule):
•fine scale emission processing
•operationalisation

nest grid
configuration: > 20% EU population

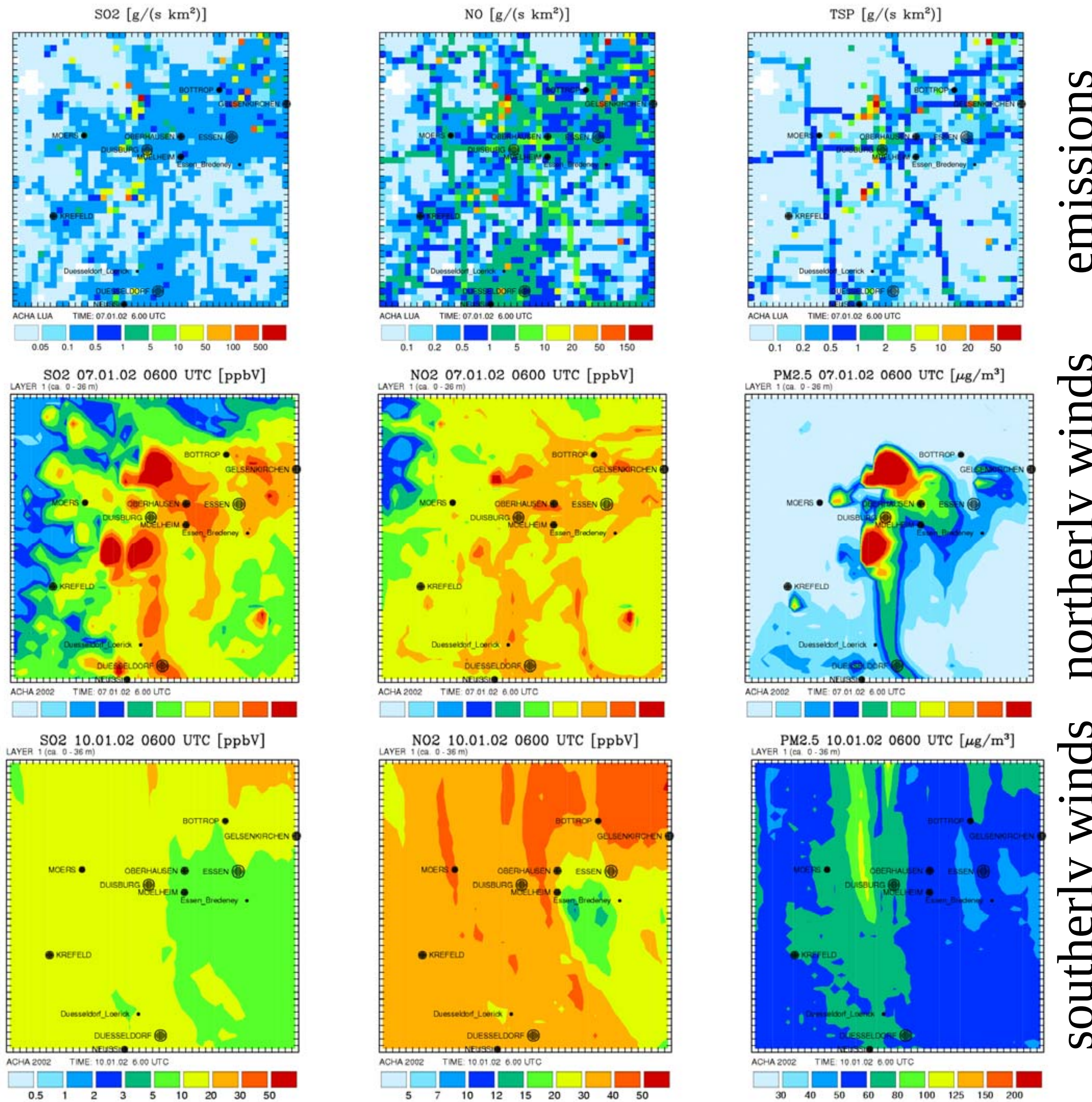


EURAD Ozone Forecast in Different Domains



Local EURAD-CTM forecast

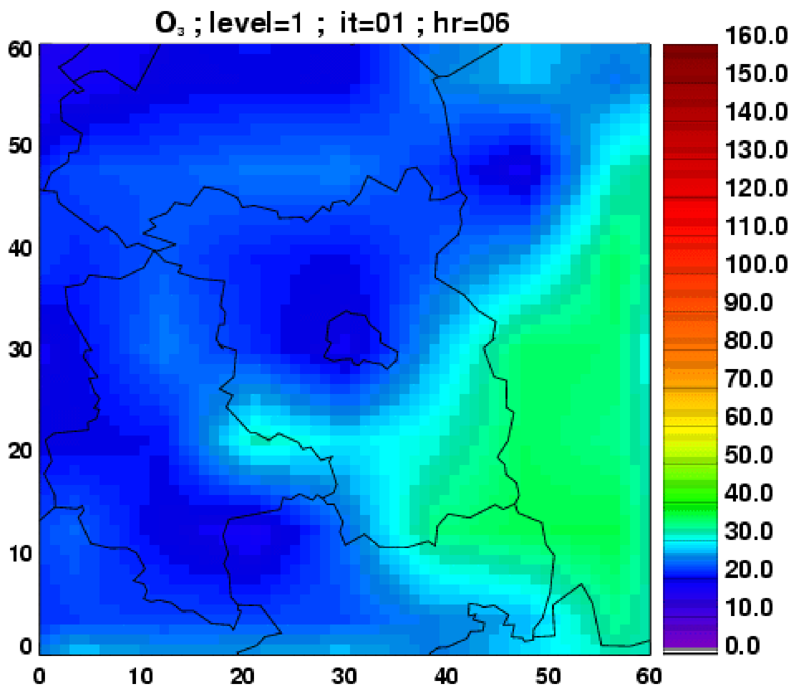
Ruhr area
1km resolution



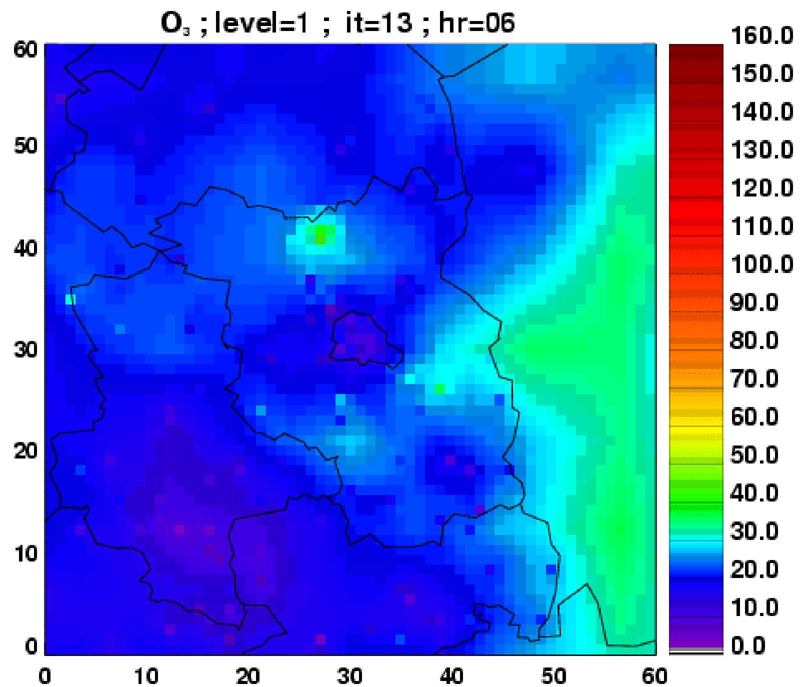
Is there a sustained effect of data assimilation?
surface ozone Nest 2:

(6 km res.,20.→21. 07.1998)

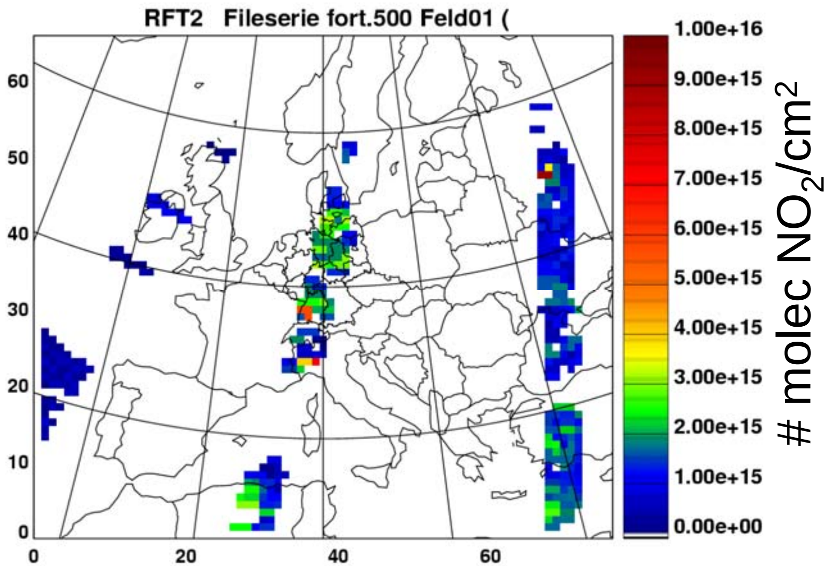
without assimilation



with assimilation

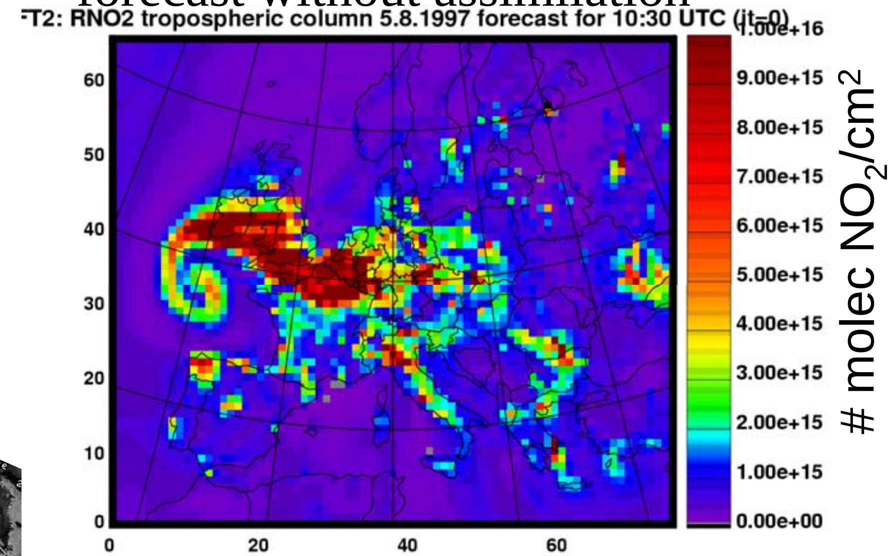


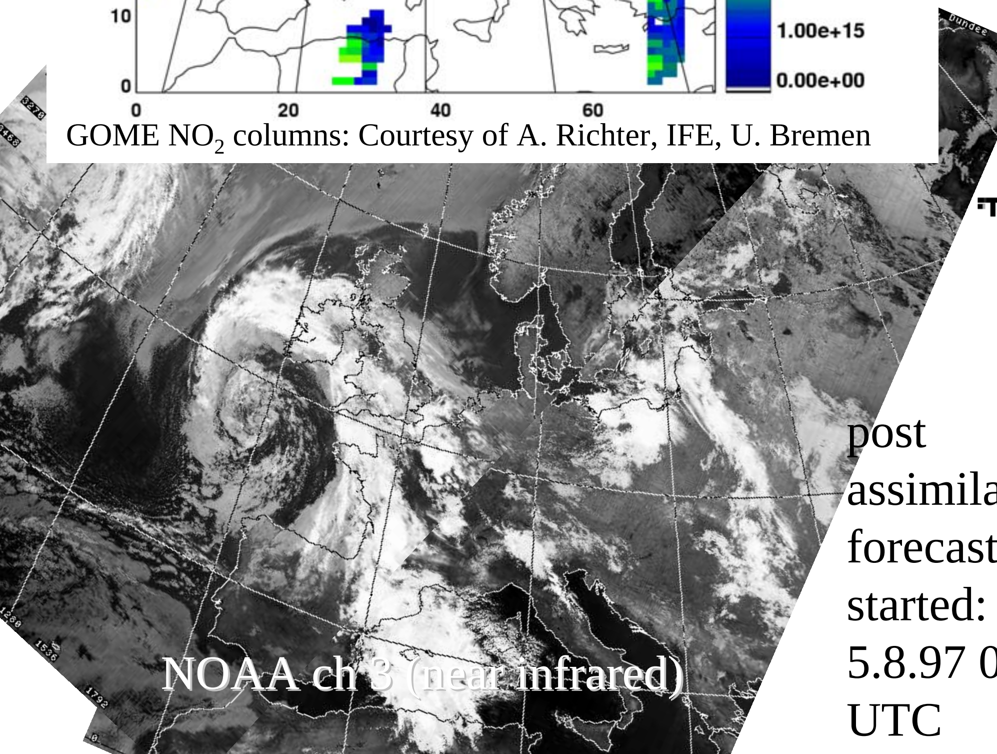
Assimilation of GOME NO_2 tropospheric columns, 5.8.1997



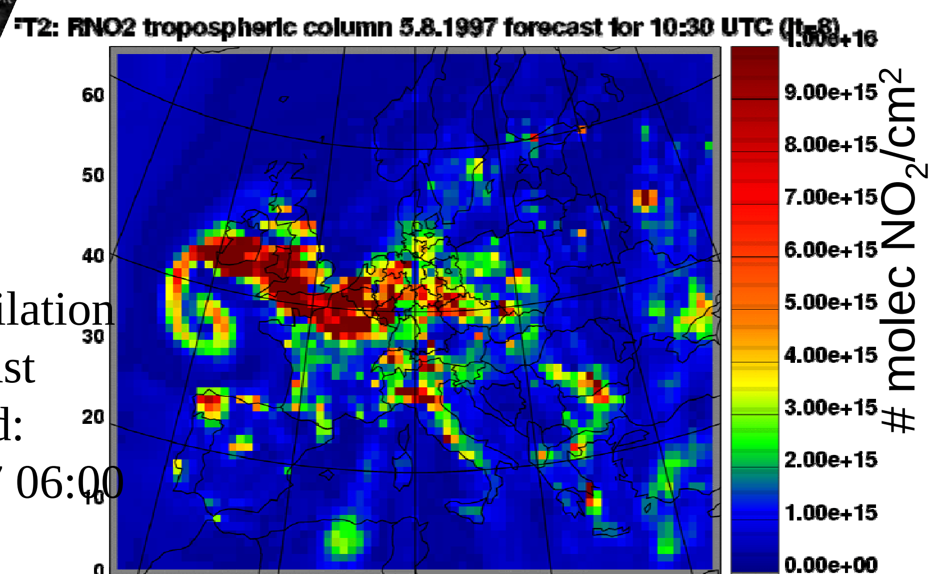
GOME NO_2 columns: Courtesy of A. Richter, IFE, U. Bremen

forecast without assimilation





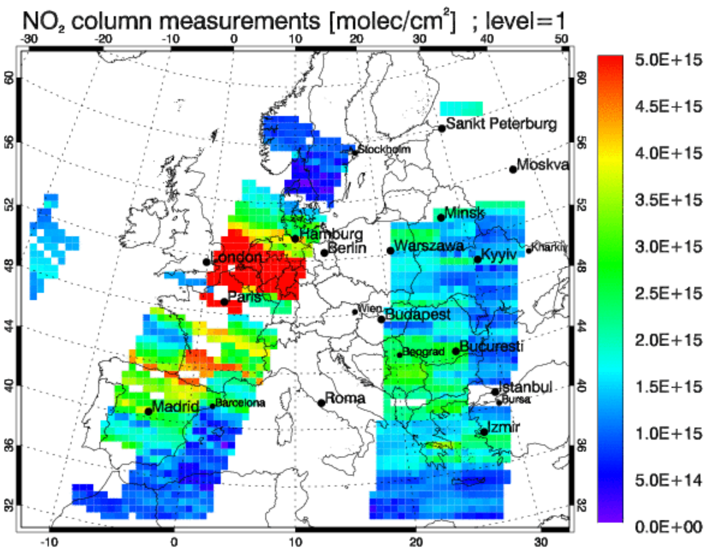
post assimilation forecast started: 5.8.97 06:00 UTC



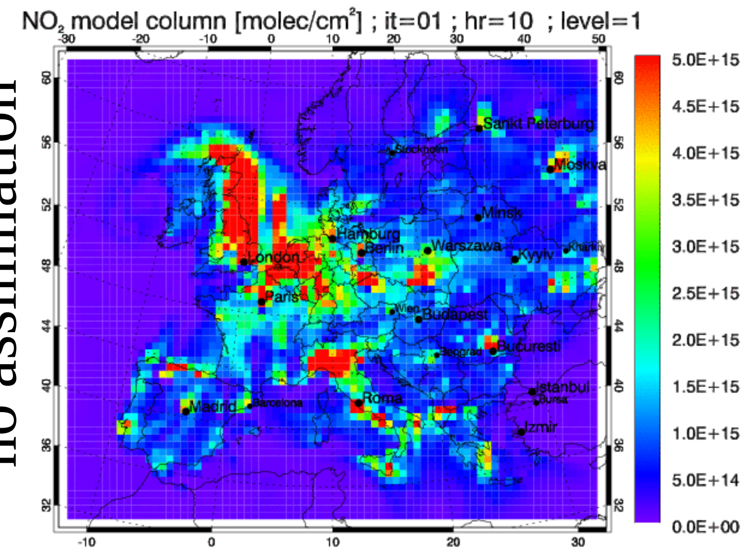
NO2 tropospheric column assimilation IFE: Example: BERLIOZ episode 20.7.1998

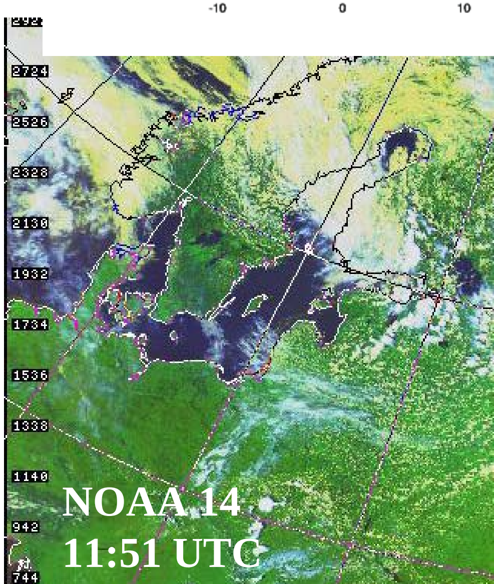
GOME retieval

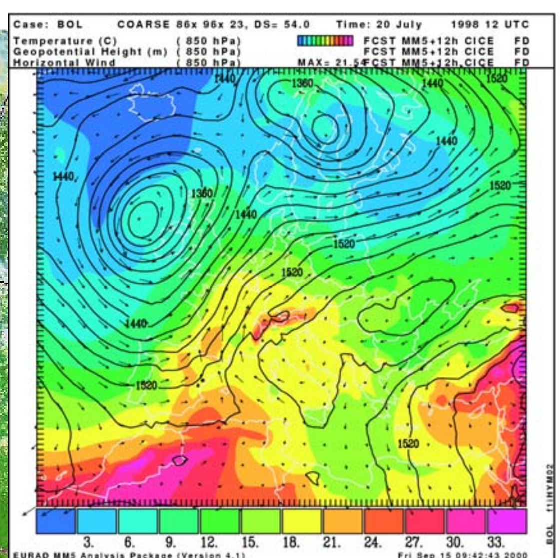
Courtesy: A. Richter, IFE Bremen



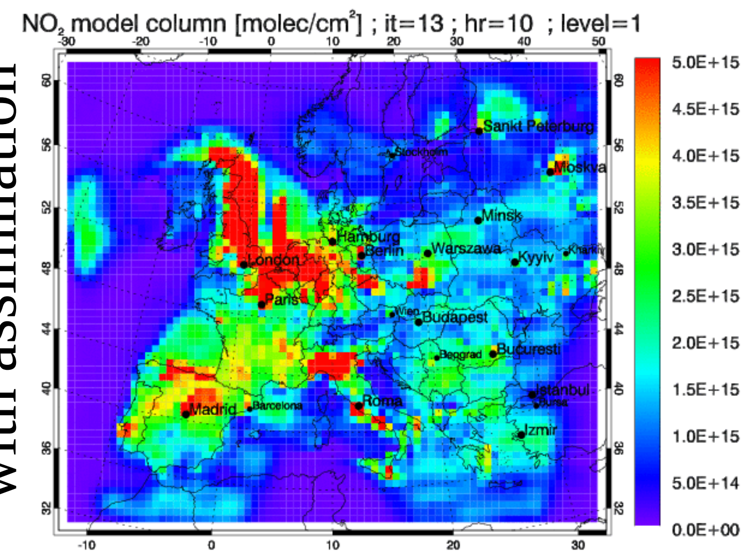
no assimilation







with assimilation

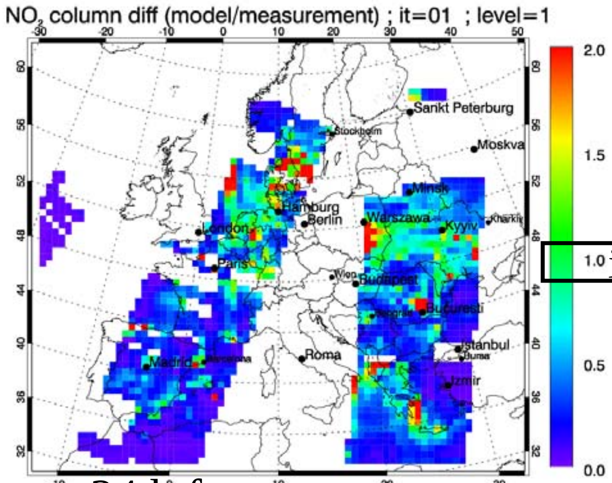


IUP Bremen GOME→GOME forecast validation **model/retrieval ratio** for BERLIOZ 20. (assimilated) + 21.(forecasted) 7.1998

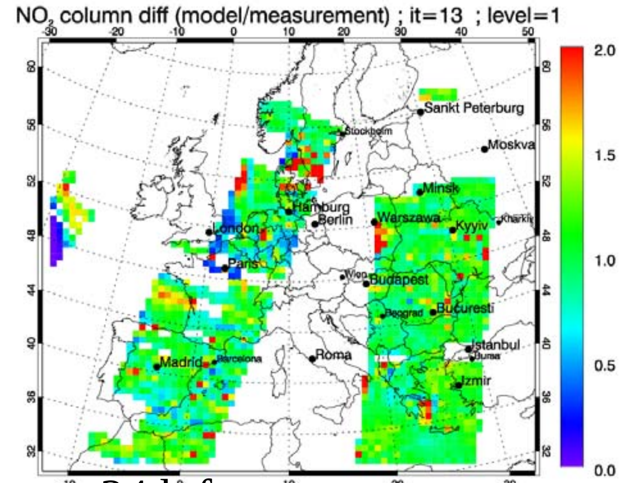
no assimilation

with assimilation

20.7.98

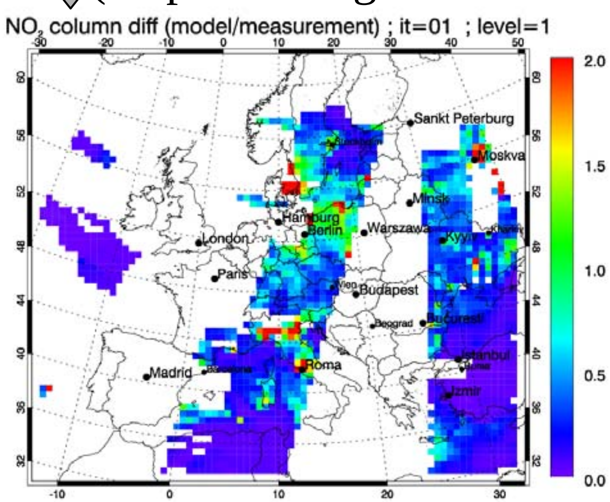


ideal

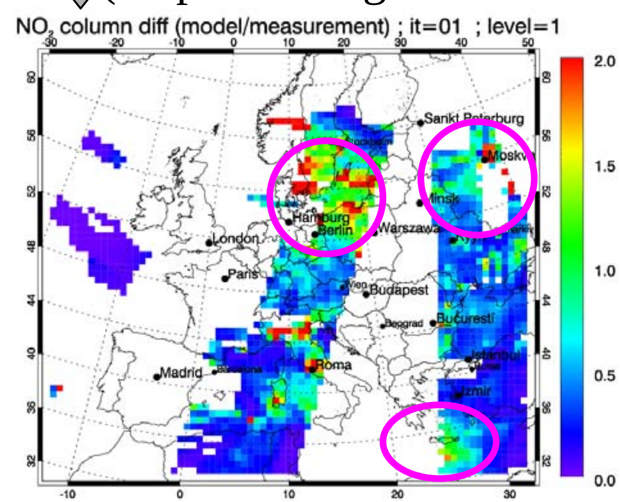


24 h forecast (no preceeding assimilation)

24 h forecast (no preceeding assimilation)



verification forecasts 21.7.98



Assimilation of Aerosol observations

- In situ:

  EEA Airbase: Database of ground stations of EU member countries & states:

  - 450 stations for PM_{10} (2003)
  - No $PM_{2.5}$. (4 stations in UK only)

- Satellite measurements:

  SYNAER (SYNergetic AErosol Retrieval, DLR-DFD, [Holzer-Popp, 2001])*

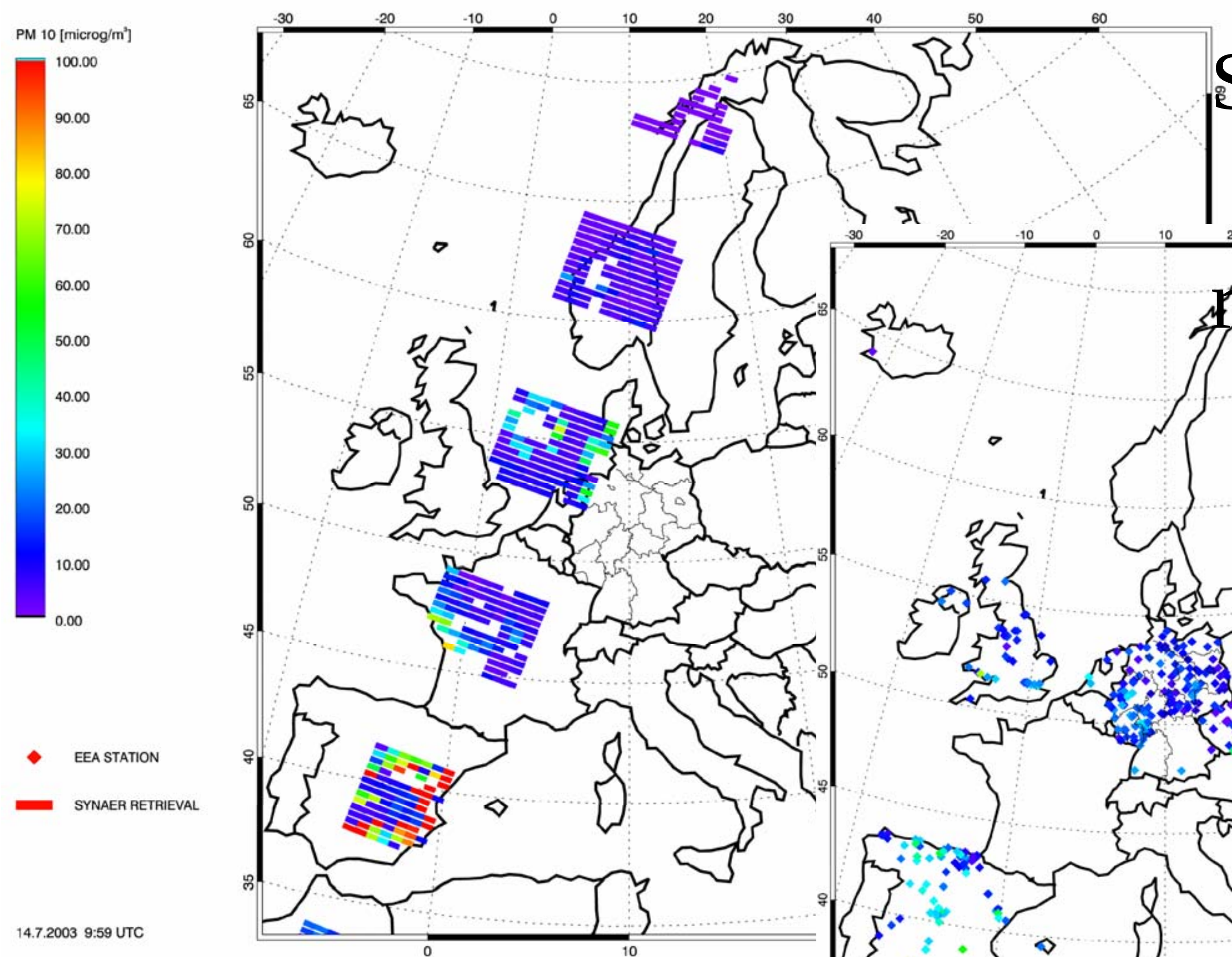
  - combines GOME&ATSR-2, SCIAMACHY&AATSR measurements

    aboard ERS-2/ENVISAT
  - ATSR-2/AATSR:

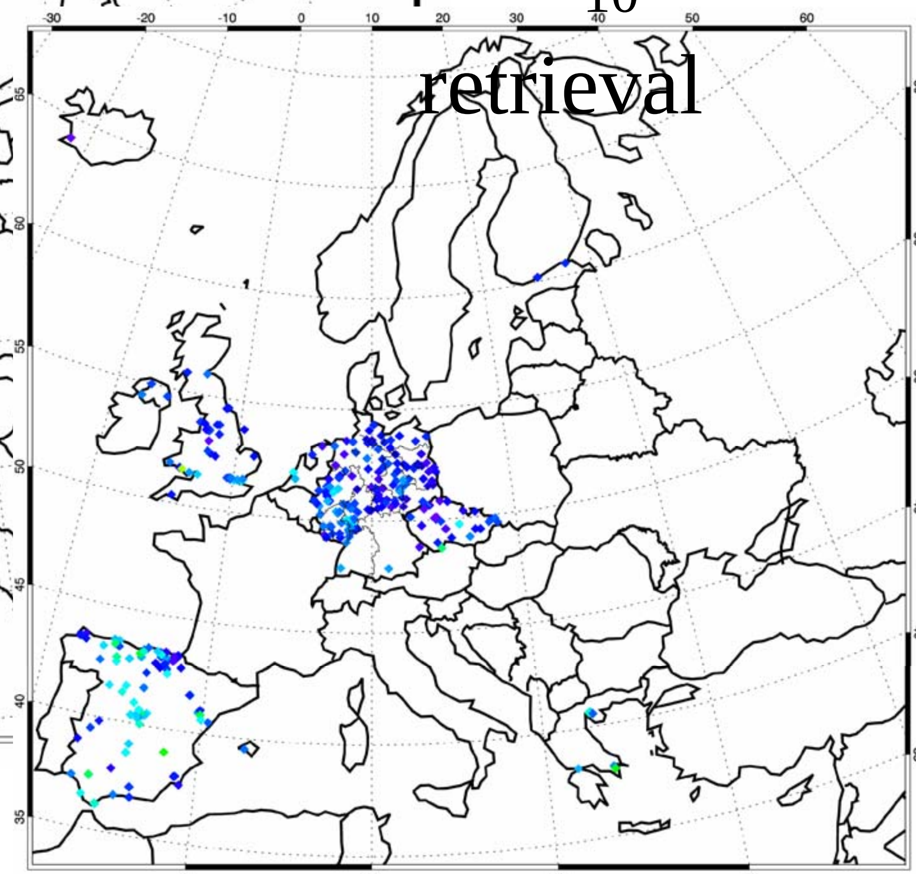
    dark field detection, BLAOT (Boundary Layer Aerosol Optical Thickness) and albedo are calculated
  - GOME/SCIAMACHY:

    Provides $PM_{0.5}$, $PM_{2.5}$ and PM_{10} columns and its composition (6 intrinsic species)

Aerosol observations (14.7.2003, ~10:00 UTC)

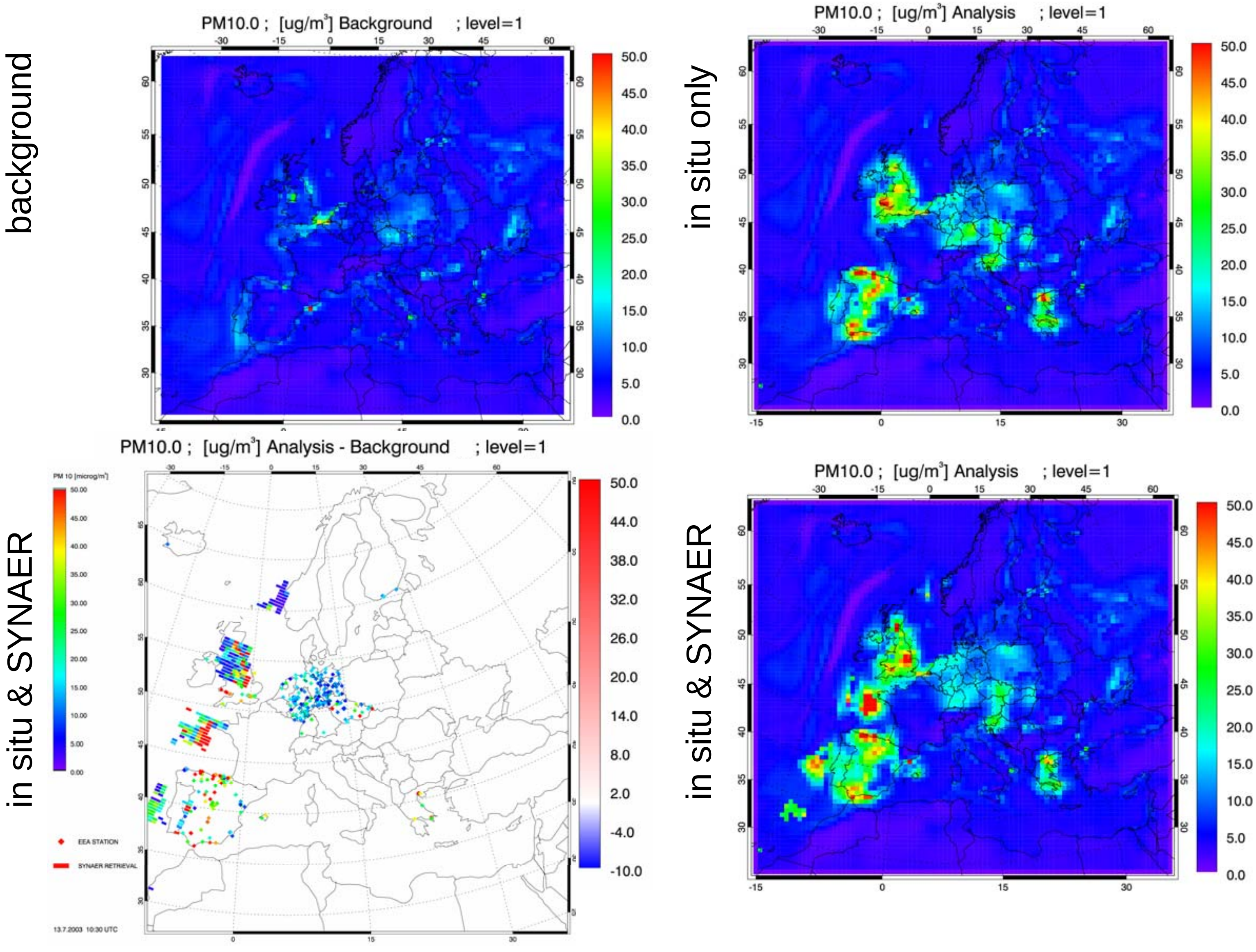


SYNAER PM_{10} retrieval



EEA PM_{10} stations

3D-var aerosol assimilation (13.7.2003)



Work schedule

- SLAs: LANUV, EMPA, UBA-A, available
- Macedonia within PROMOTE budget, SLA still pending
- model configuration in place
- fine scale emission under work (on schedule)
- operationalisation to be adapted
- ➔ on schedule

User “duties”

- Write assessment report once per year (3 times). Budget to cover costs is available
- Attend annual progress meeting (travel expenses are paid)

Additional material

GMES - atmosphere

- Consolidation/development
  - EC/FP6 research and development: Integrated Project GEMS
  - ESA/GSE demonstration service: PROMOTE

- Implementation
  - EC/FP7 pilot services (3 fast track + 2 other)
  - aiming at fusion of EC and ESA services „GAS“
  - dedicated satellites: ESA sentinel 4+5 (LEO+GEO)

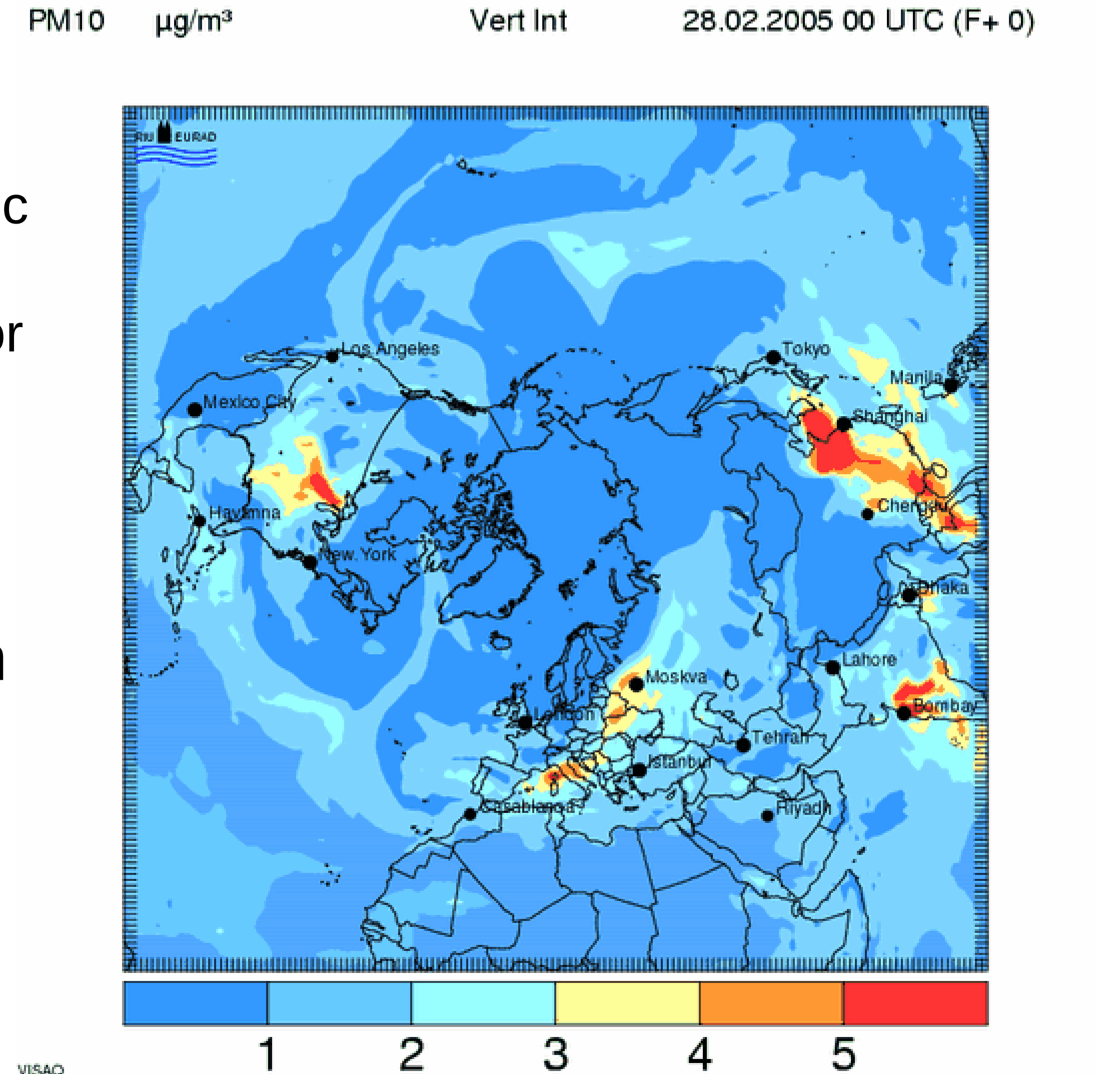
Hemispheric forecast PM_{10}

<u>Incentives</u>

•In readiness for tropospheric satellite data

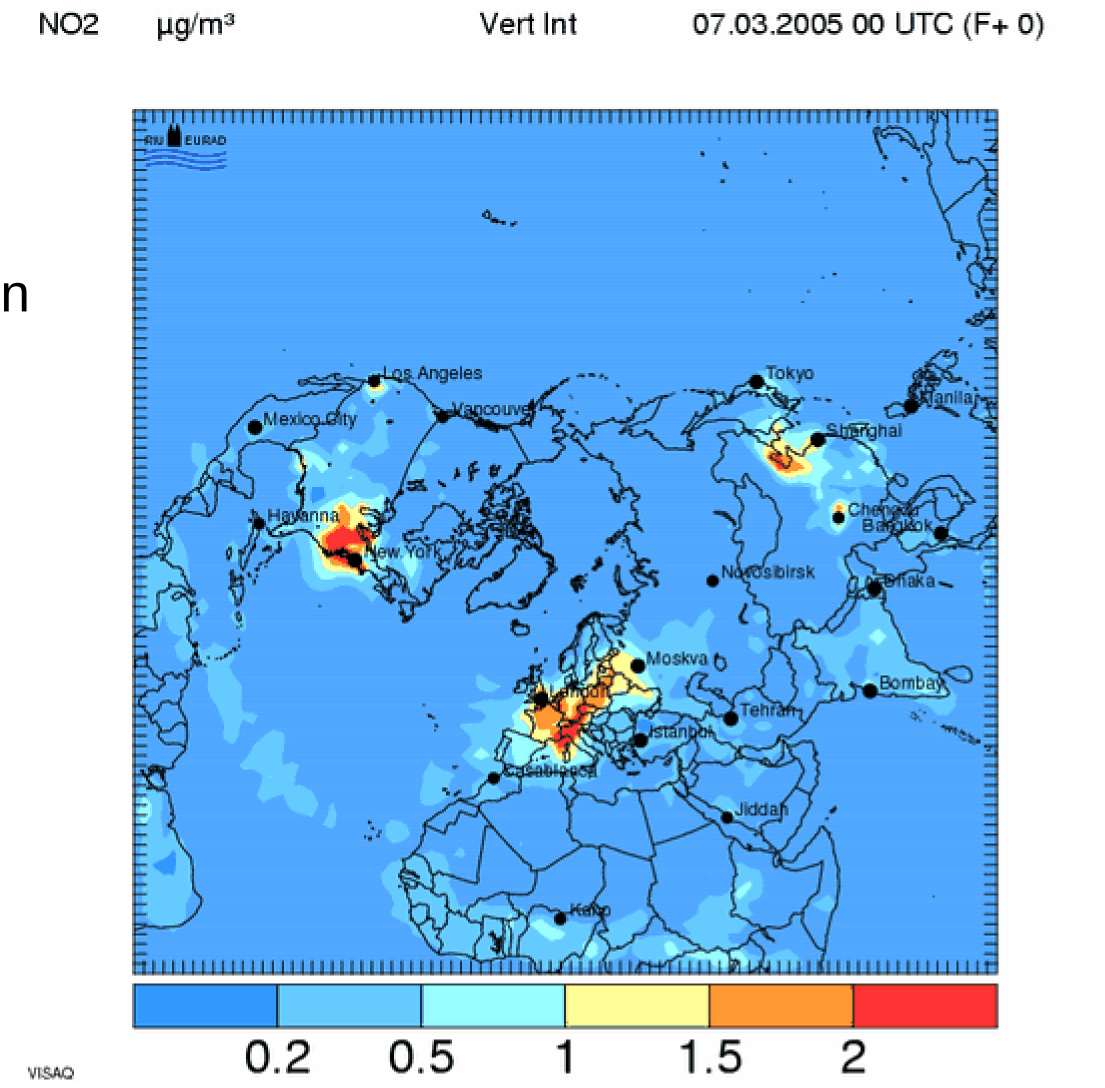
•boundary value provision for continental scale models for long range transported constituents

high resolution version
150 x 150 grid
Δx = 125 km



Hemispheric forecast NO2

low resolution version
90 x 90 grid
Δx = 250 km



Retrieval of aerosol mixture from space

- use of SYNergetic AERosol (SYNAER) retrieval algorithm for type identification (Holzer-Popp et al., JGR, 2002a,b),
- combination of GOME/SCIAMACHY and (A)ATSR to identify 1 of 48 mixtures of 6 aerosol types
  - water soluble -- insoluble
  - soot
  - mineral dust -- sea salt (2 modes)
- assimilation into EURAD-MADE for uniqueness

Importance of data assimilation

Hendrik Elbern

with essential contributions from

Achim Strunk, Lars Nieradzik, Elmar Friese, Zoja Milbers

Rheinisches Institut für Umweltforschung an der Universität zu Köln (RIU)

and

Helmholtz virt. Institut für Inverse Modellirung atmosphärischer Konstituenten (IMACCO)

User view: Target performance criteria for air pollution data assimilation (expectations we encounter)

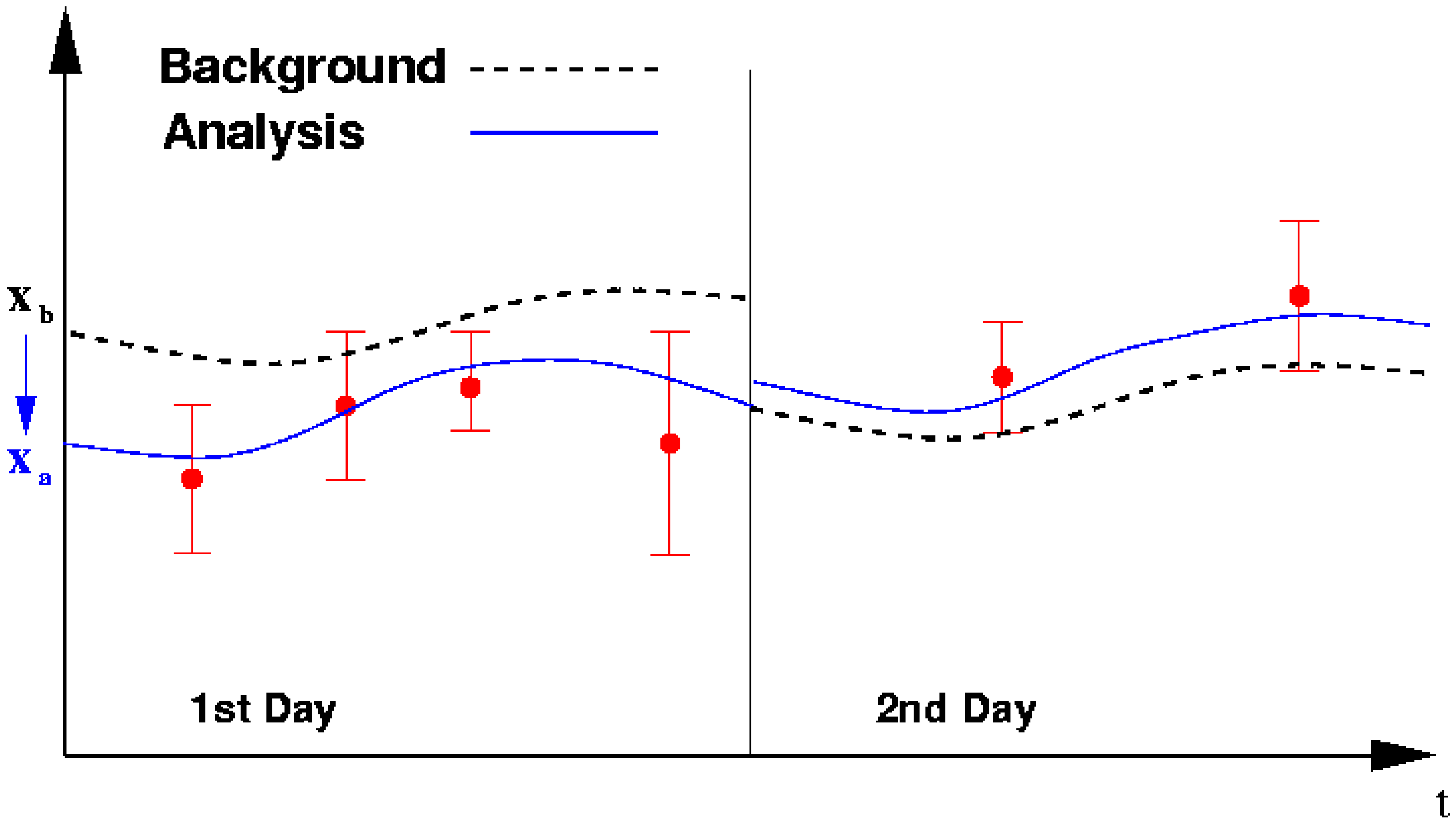
- Target area are urban agglomerations
  → point and line sources, high resolution
- Target forecasts are at least one day ahead and peak values
  → traditional initial value optimisation for DA obsolete
  → emission rate optimisation advisable
  → spatio-temporal DA algorithm pertinent
- target quality for monitoring is unbiased, and about 20% error margins
  → theoretical arguments suggest 4Dvar and Kalman Filter

Theoretical viewpoint: What might we expected from a target data assimilation method?

- provides BLUE (Best Linear Unbiased Estimator).
  Warning: purely spatial methods → ingested in models, do not!
- Potential for "consisteny" within the assimilation intervall (*O* (1 day))

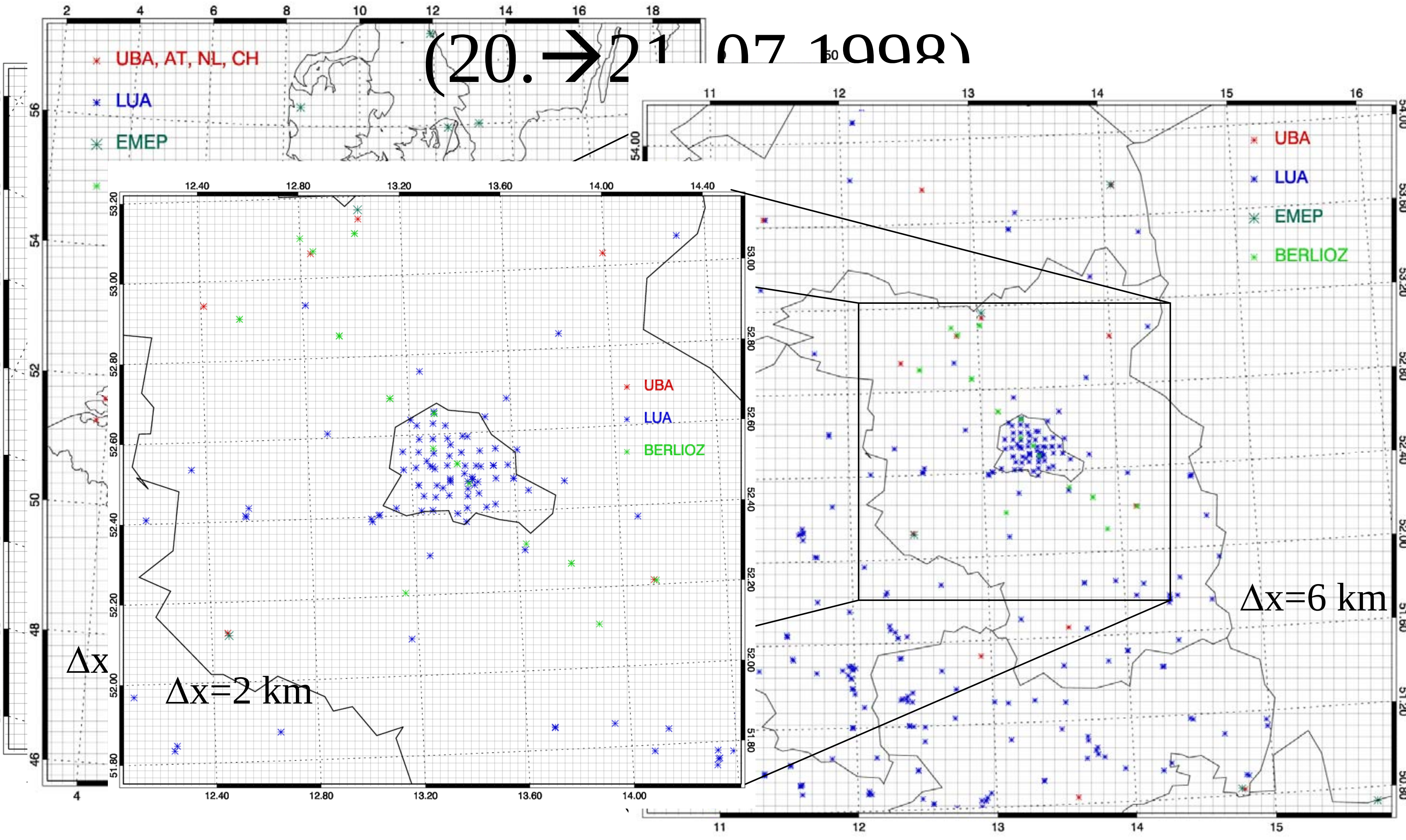
  Rem.: fast manifold perturbations (="initialisation problem") mitigated, but not removed.
- Allows to estimate analysis error margins and exploit temporal correlations (red noise)
  Re*m: error accumulation problem, e.g., budget calculations, stratospheric residence times (Brewer-Dobson circulation)*

The consistency promise of 4D-var?



Which is the requested resolution?

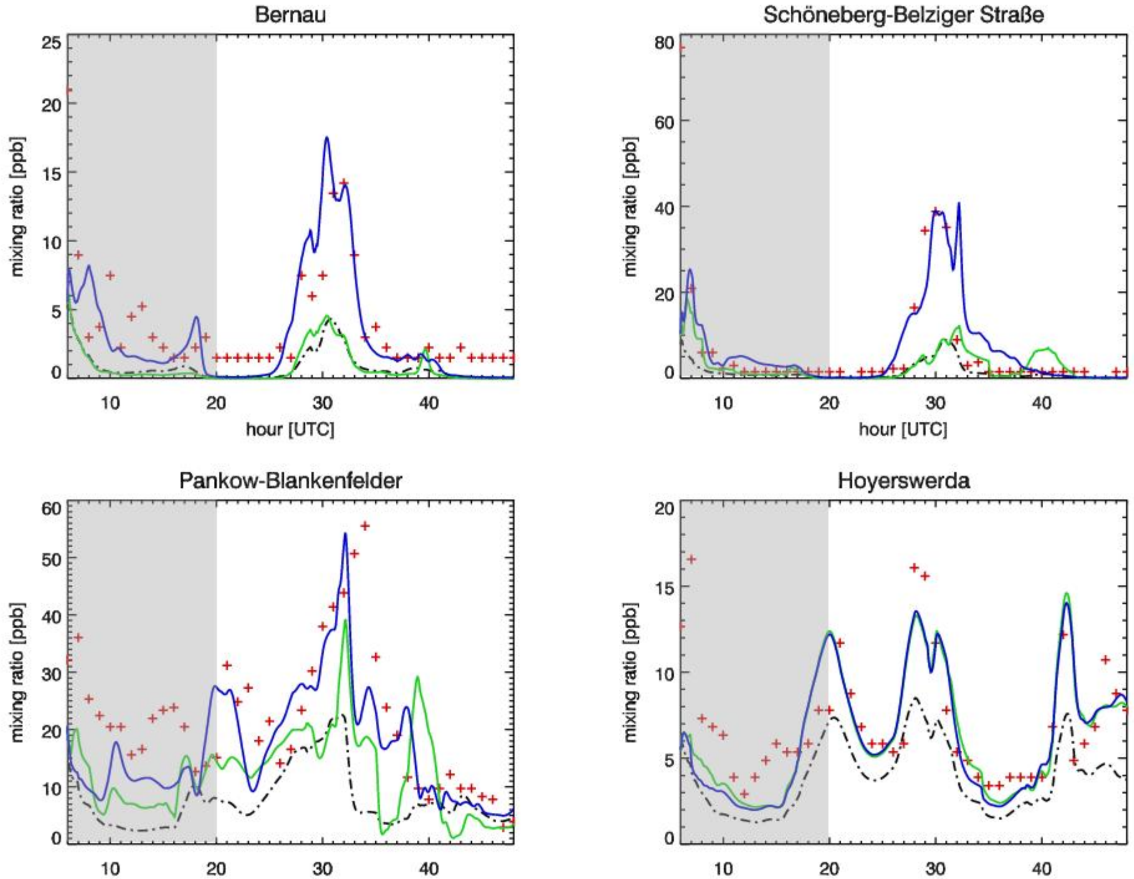
BERLIOZ grid designs and observational sites (20.→21.07.1998)



Some BERLIOZ examples of NOx assimilation

NO

NO_2



Time series for selected NOx stations (upper panel NO, lower panel NO_2) on nest 2.

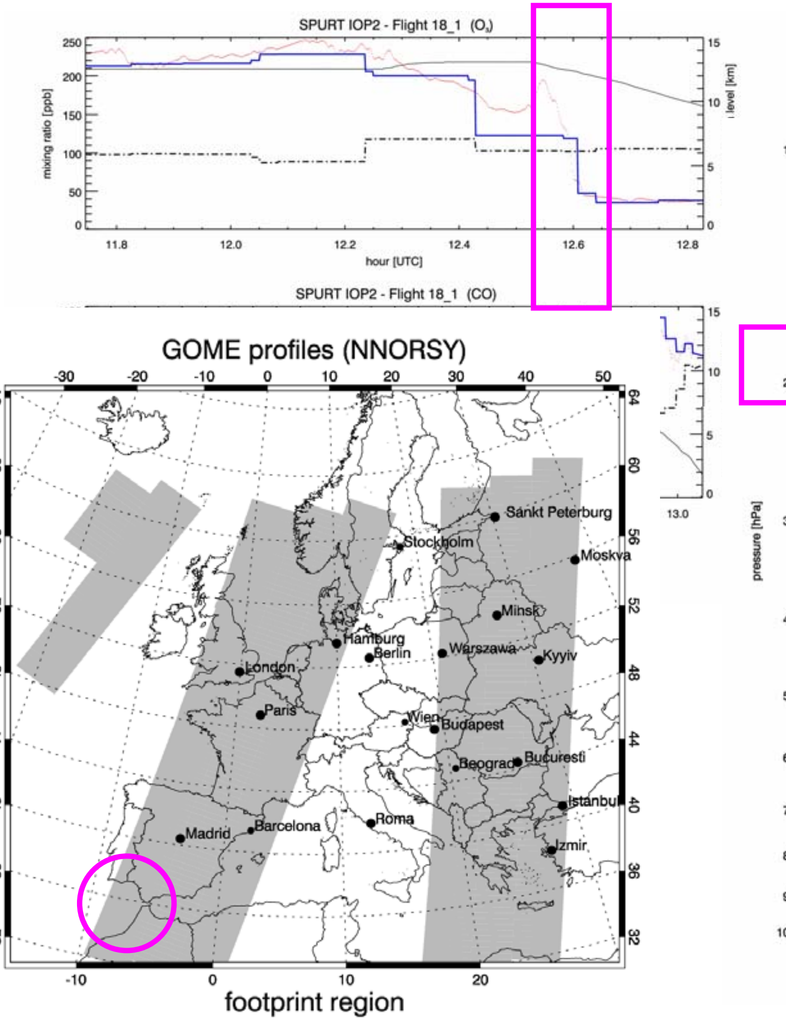
+ observations,

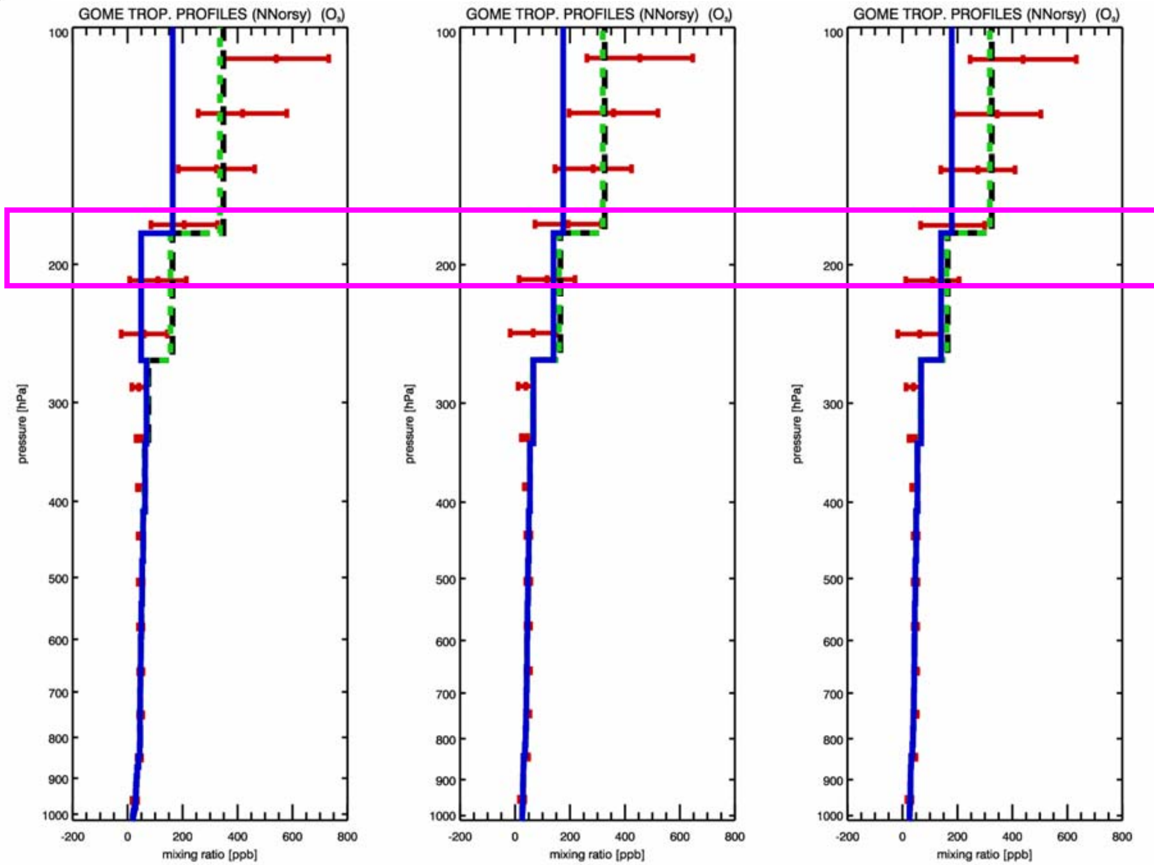
-- - no assimilation,_____ N1 assimilation (**18 km**), _____N2 assimilation.(**6 km**),

-grey shading: assimilated observations, others forecasted.

Comparison SPURT flight campaign with NNORSY retrivals

flight Germany→ canary Islands 17. Jan. 2002





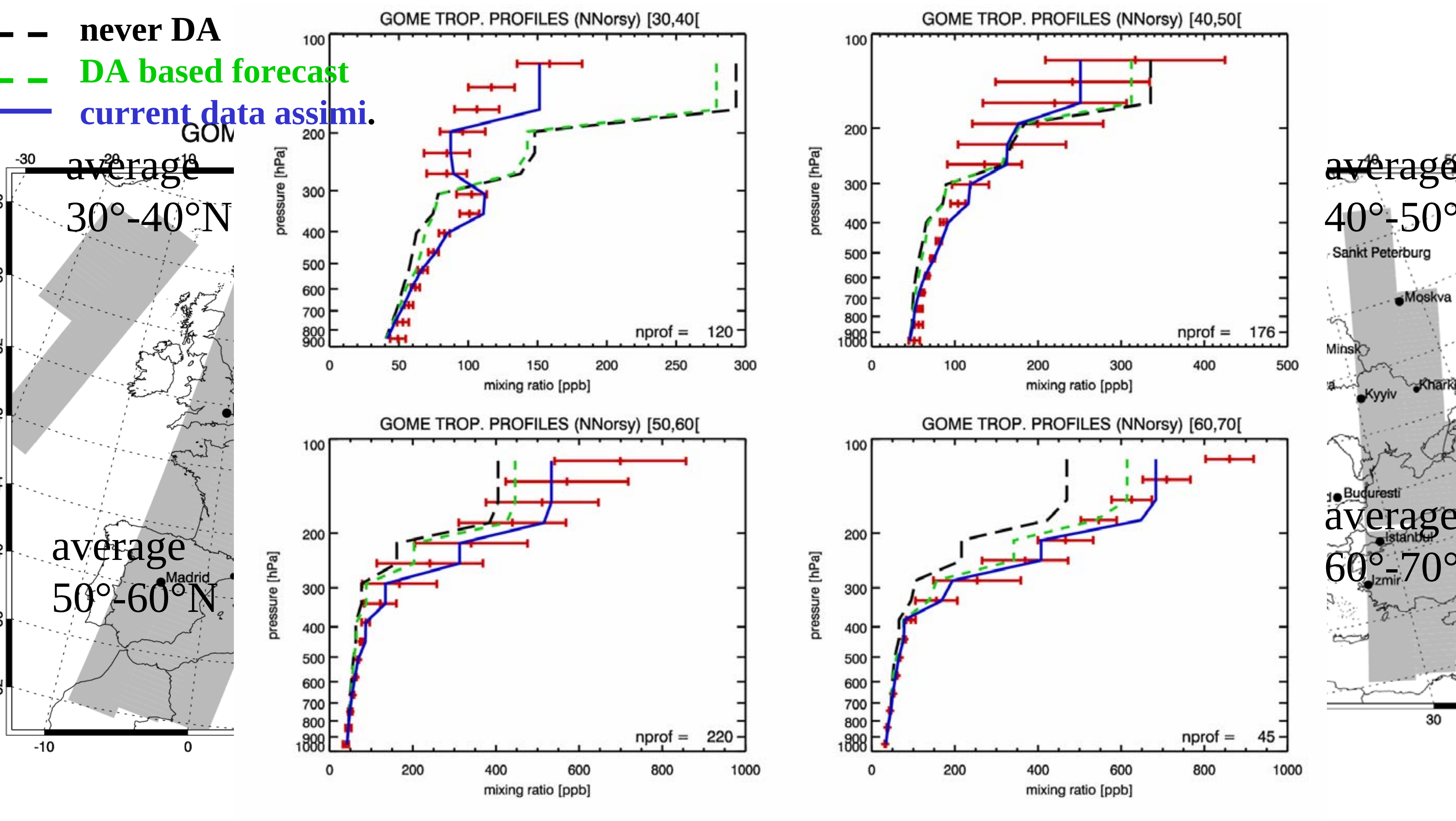
Which revisit cycle is useful for the middle and upper troposphere data assimilation?

NNORSY retrievals

never DA

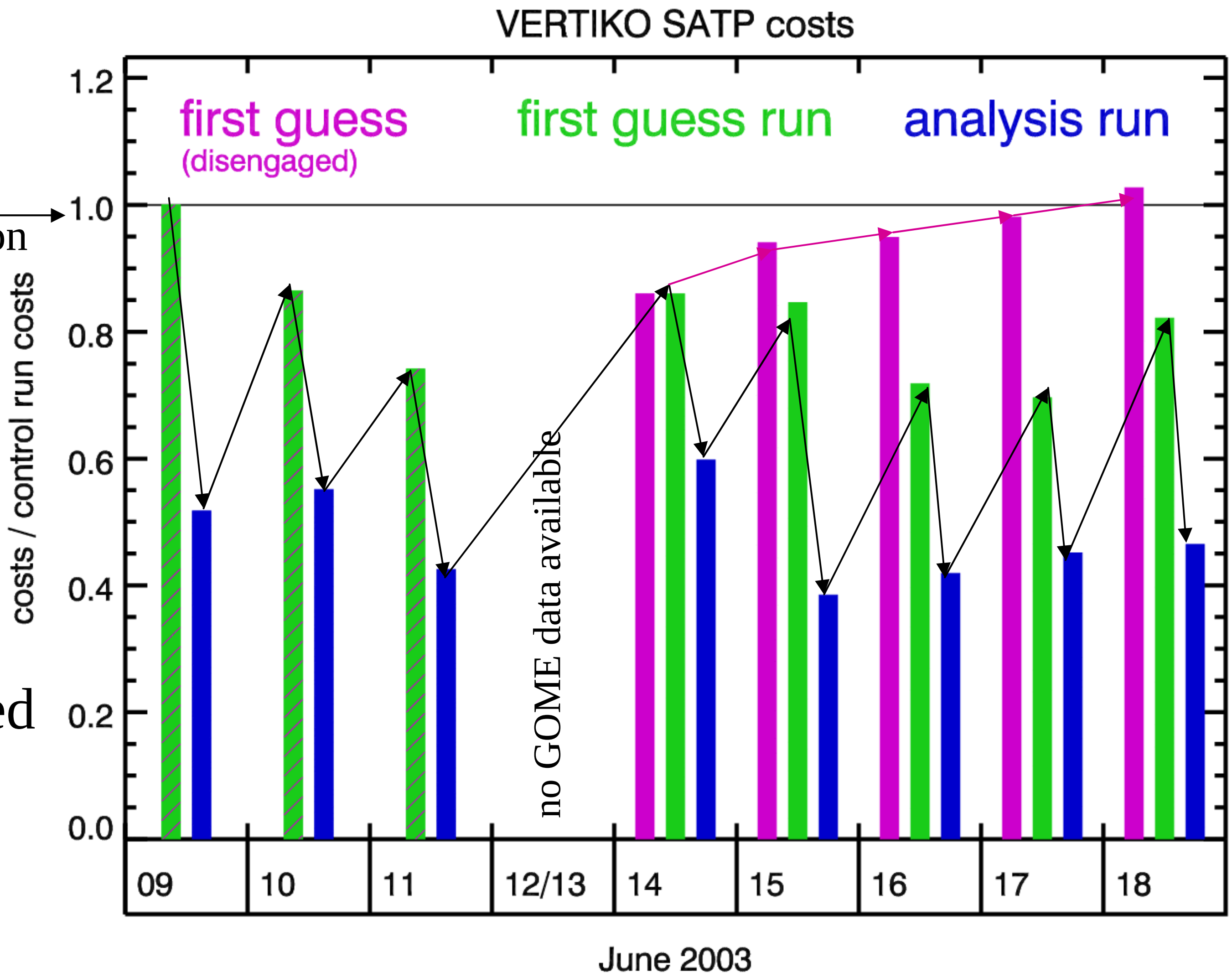
DA based forecast

current data assimi.



How long is satellite data assimilation sustained? (GOME retrievals)

ratio without any assimilation



normalized squared errors

SYNAER data validation
(and the problem with wildfires)

Date	# withheld stations	RMS [μg/m³] (improvement)			Remarks
		no assim.	In situ only	In situ & sat	
06.07.2003	-	-	-	-	no sat data
07.07.2003	**32**	**9.6**	**6.8 (29%)**	**6.9 (28%)**	wildfires
08.07.2003	**13**	**6.6**	**7.1 (-8%)**	**6.7 (-2%)**	wildfires
09.07.2003	-	-	-	-	no sat data
10.07.2003	**27**	**9.3**	**6.5 (30%)**	**6.9(26%)**	wildfires
11.07.2003	-	-	-	-	no sat data
12.07.2003	**29**	**1.9**	**1.4 (30%)**	**1.3 (32%)**	none
13.07.2003	**20**	**6.3**	**2.5 (61%)**	**1.9 (70%)**	none
14.07.2003	**49**	**7.3**	**5.5 (24%)**	**5.3(28%)**	wildfires

Need for biomass burning detection, injection, and emission modelling

General "State of the art problems" for data assimilation

- tropospheric satellite data assimilation show marginal to moderate performance increments after DA for gas phase
- more promising for aerosol phase
- DA algorithms without optimality criterion (e.g. BLUE) and model integration are of minor value
  - useful if forecast improvements are visible
  - for monitoring purposes misleading

Outlook (1)
expected benefits from satellite retrievals

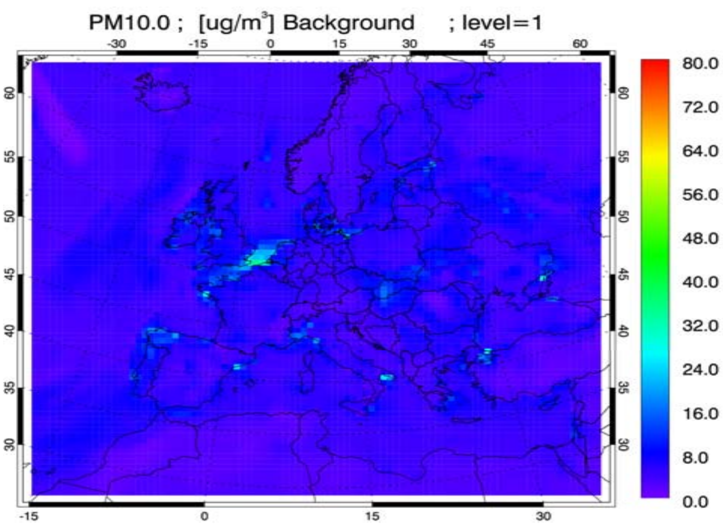
- gas phase constituent retrievals are expected to be most useful in “background” regions with coarse or not existing in situ observations
- with priority of populated areas (→boundary layer) aerosol retrievals appear to be most useful
- merge as many satellite retrievals as possible, including meteorological (convective cloud) information, when proceeding to higher resolutions

Outlook (2) for data assimilation algorithms

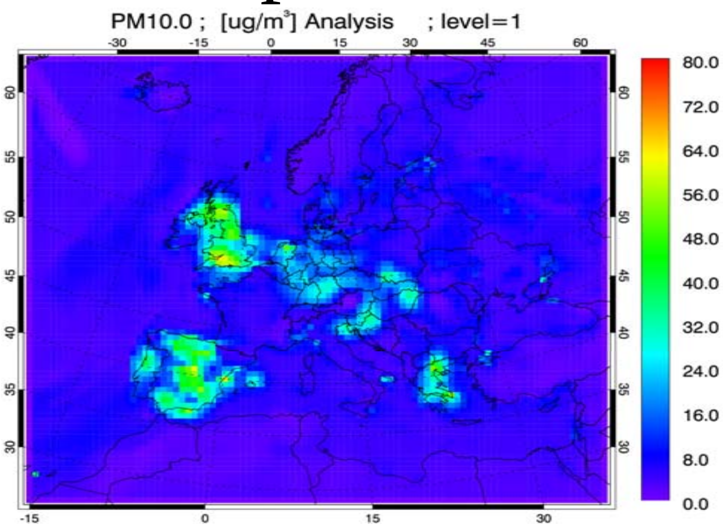
- advanced DA algorithms proceed to limits with
  - non-Gaussian error characteristics
  - small convective scale dynamics
- the smaller the scale, the tighter coupling to meteorological simulations required
- the aerosol composition problem will be a near future challenge (natural vs. anthropogenic)
- the resolution dilemma:
  - coarse resolutions (~50 km) inadequate
  - fine resolutions (~5km):
    - much more expensive,
    - much more ill posed

3Dvar aerosol assimilation (14.7.2003) biomass burning case in Spain

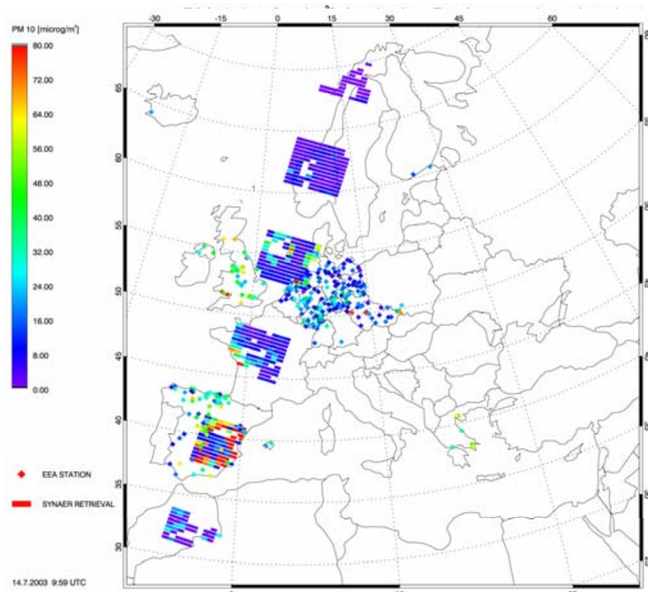
background



in situ only

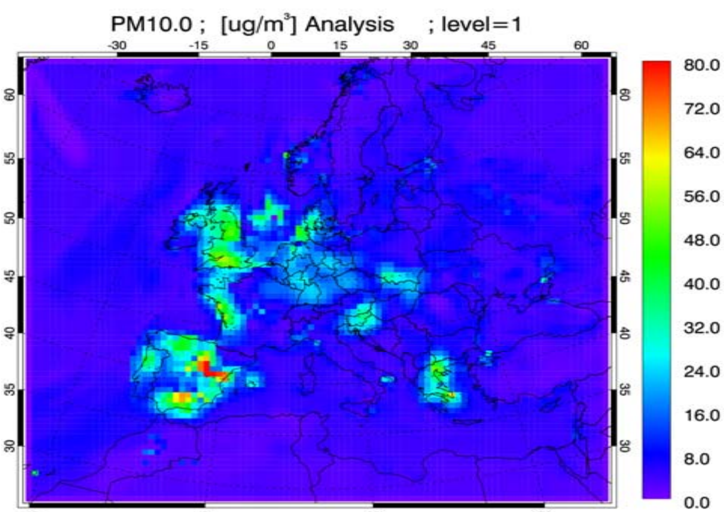


in situ & SYNAER

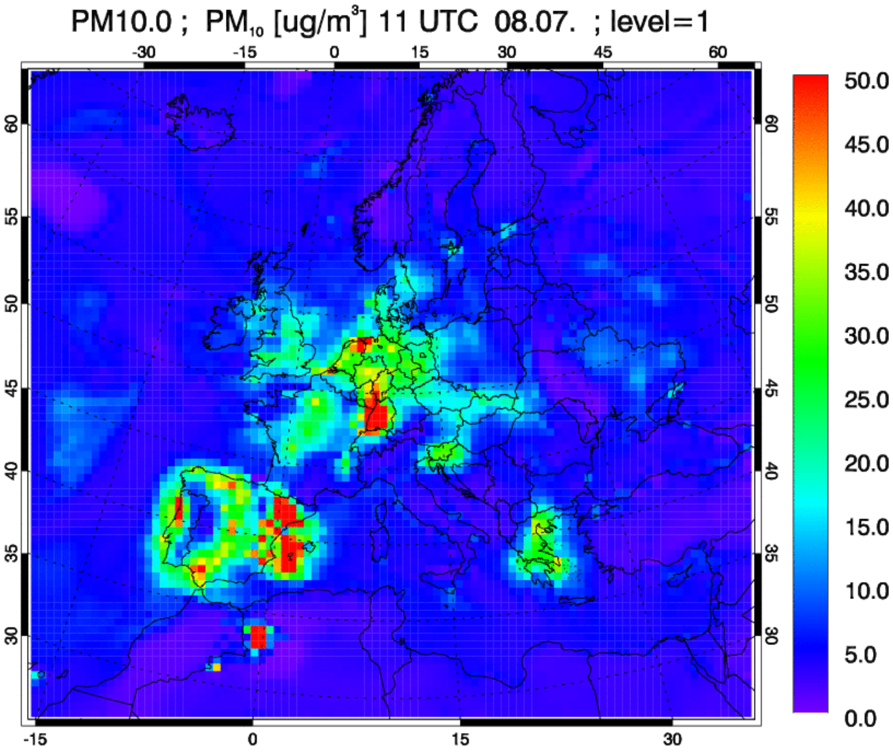


in situ & SYNAER

in situ & SYNAER

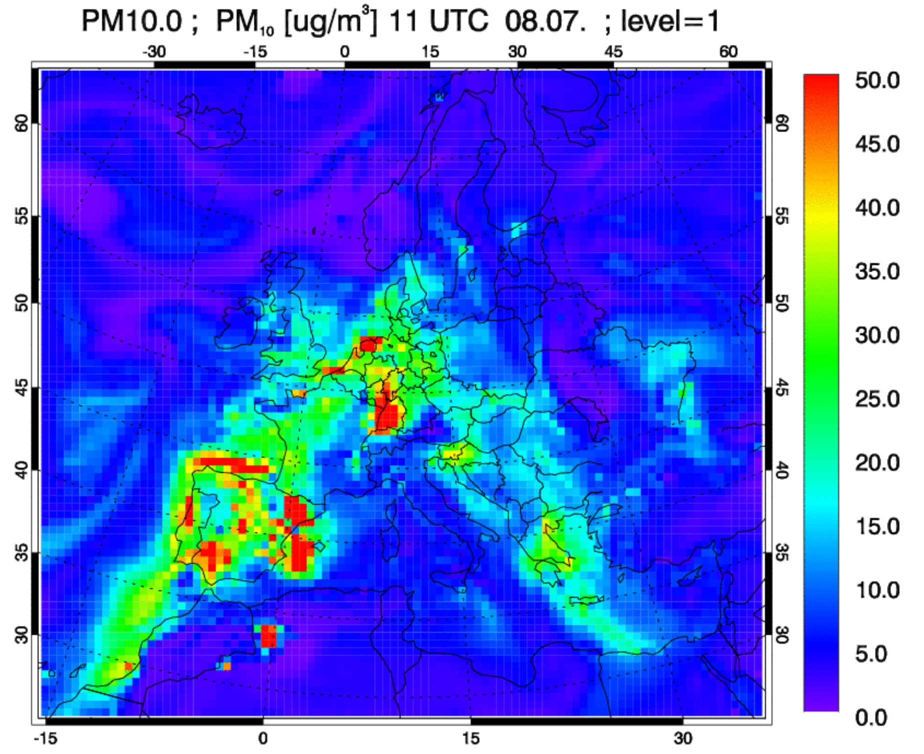


Do aerosol data assimilation effects accumulate?
14. July 2003



No previous assimilation

only 14. July 2003



assimilation on previous days 10 UTC

Accumulation of retrieval information over 14 days