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A model inter-comparison study focussing on episodes with elevated PM10 concentrations

R. Stern[1]

P. Builtjes[1,2], M. Schaap[2] , R. Timmermans[2], R.Vautard[3], A. Hodzic[4], M. Memmesheimer[5], H. Feldmann[5], E. Renner[6], R. Wolke[6], A. Kerschbaumer[1]

(1) Freie Universität Berlin, Institut für Meteorologie, Germany

(2) TNO, Apeldoorn, The Netherlands

(3) LSCE/IPSL Laboratoire CEA/CNRS/UVSQ, 91191 Gif sur Yvette Cedex, France

(4) LMD/IPSL Ecole Polytechnique 91198 Palaiseau Cedex, France

(5) Rheinisches Institut für Umweltforschung an der Universität zu Köln, Germany

(6) Leibniz-Institut für Troposphärenforschung, Leipzig, Germany

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Status PM10 Modelling

Most models underestimate observed PM10 concentration levels !!!

Result of several long-term model performance studies in Europe:

EURODELTA, CITYDELTA, REVIEW OF THE UNIFIED EMEP MODEL

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Do we know the reasons ??

Severals suspects:

- **Underestimation or missing of sources**

- **Uncertainties in the treatment in aerosol chemistry and microphysics**

- **Inaccurate meteorological predictions**

It is very difficult to attribute the PM underestimation to a certain source of error, in particular with long-term studies !!

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Objective of this study

Assessment of the ability of models to reproduce PM10 concentrations under highly-polluted conditions

Why episodes?

- It is easier to examine processes
- European air quality problem: Violation of the PM10 short-term limit value (daily mean PM10 concentration > 50 µg/m3).

Models as tools for air quality planning should be able to predict the high PM concentrations !!

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Five 3-d chemical transport models of different complexity

- CHIMERE, France

- LOTOS-EUROS (LOng Term Ozone Simulation-EURopean Operational Smog) model, The Netherlands

- EURAD (European Air Pollution Dispersion model), Germany

- LM-MUSCAT (Multi-Scale Chemistry Aerosol Transport), Germany

- RCG (REM-CALGRID), Germany

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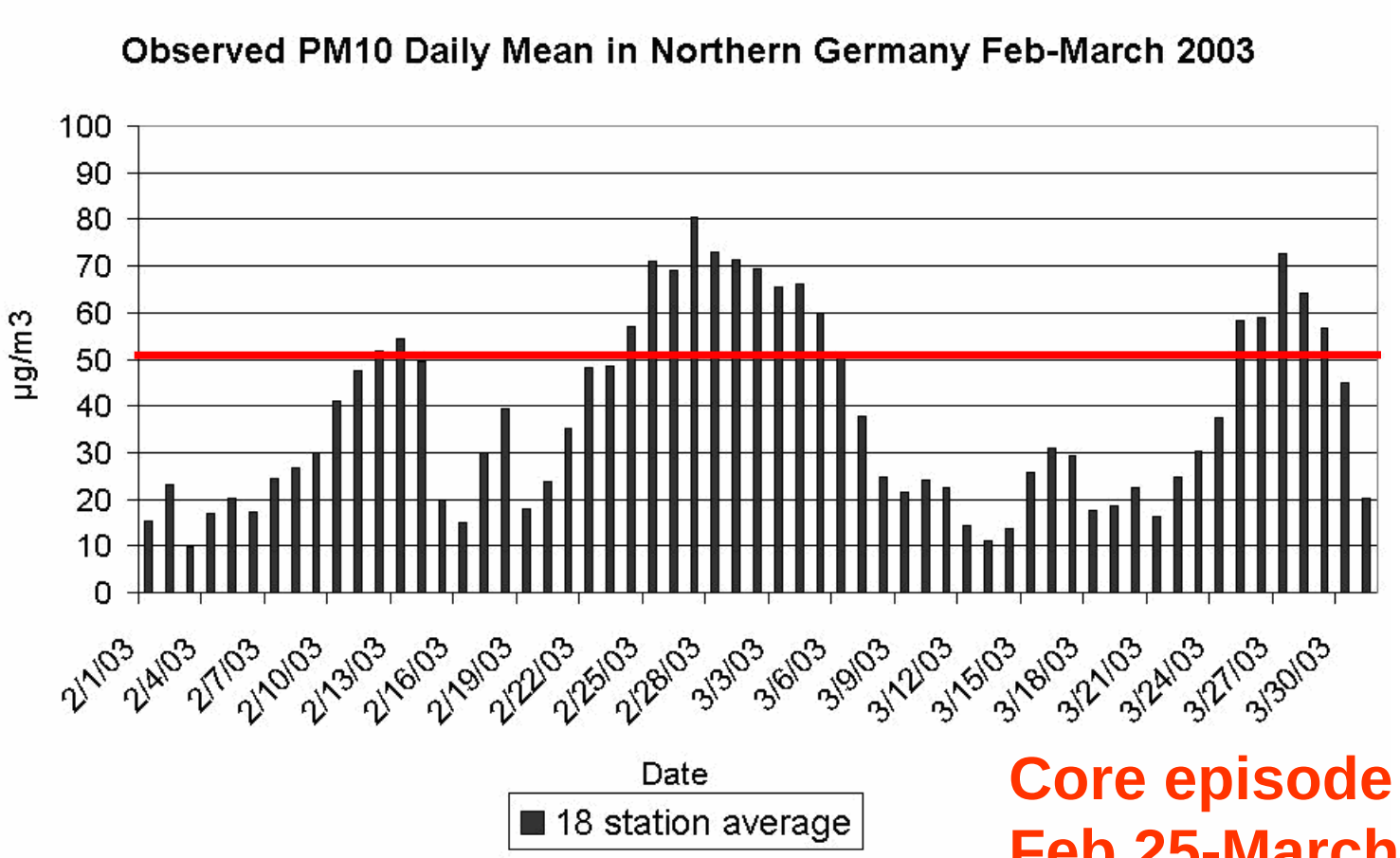
Selected time period:
January 15 thru April 5 2003 containing three distinct episodes
NORTHERN GERMANY



Core episode
Feb 25-March 5

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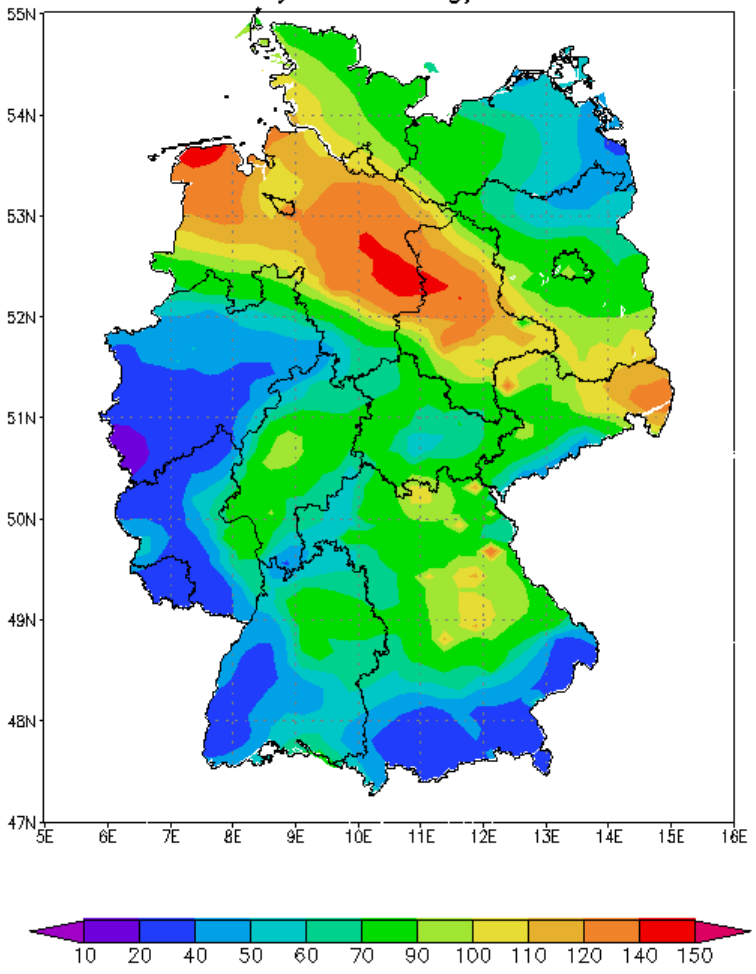
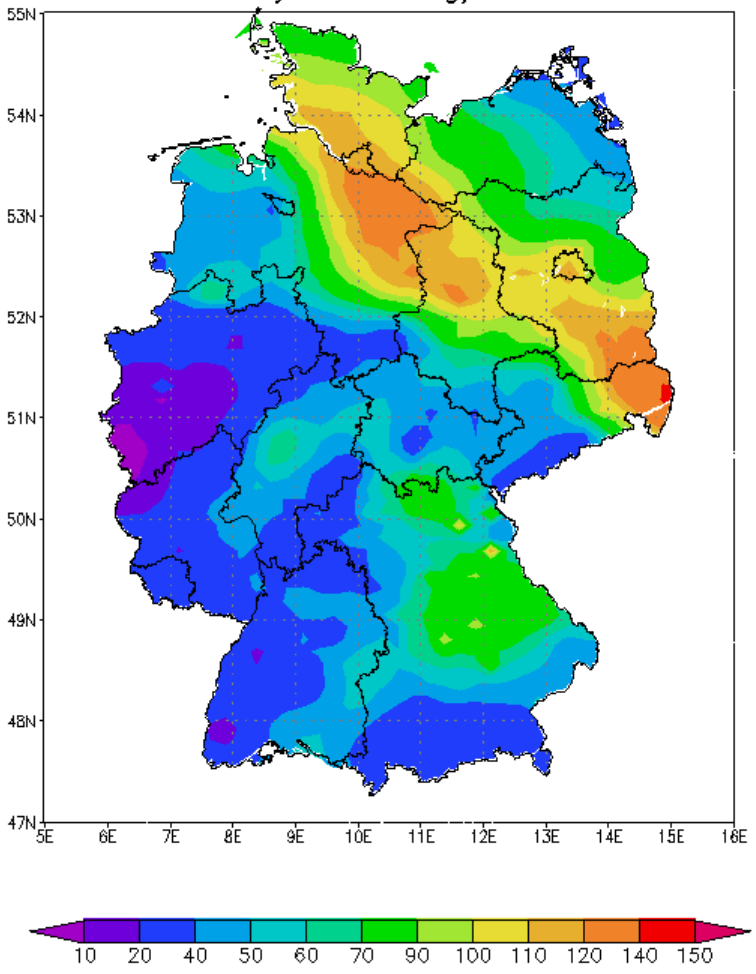
Core episode: very pronounced PM10 concentration gradient across Germany over several days

OI OBS: PM10 daily mean ug/m3, 28 FEB 2003



OI OBS: PM10 daily mean ug/m3, 01 MAR 2003



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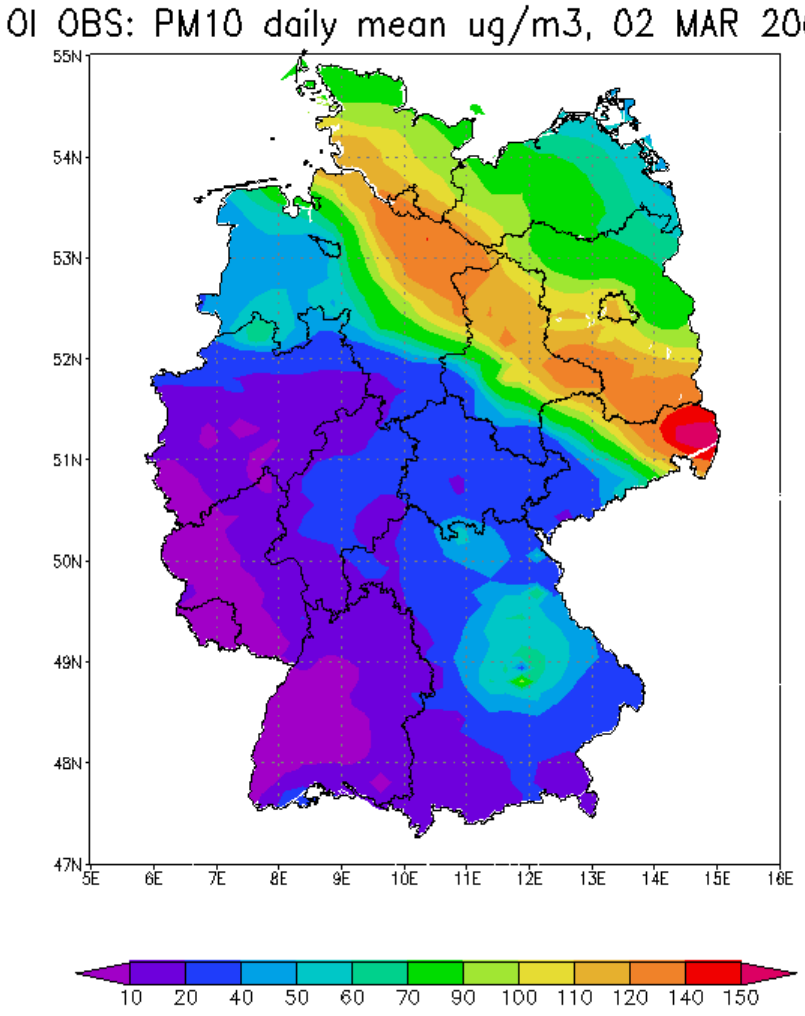
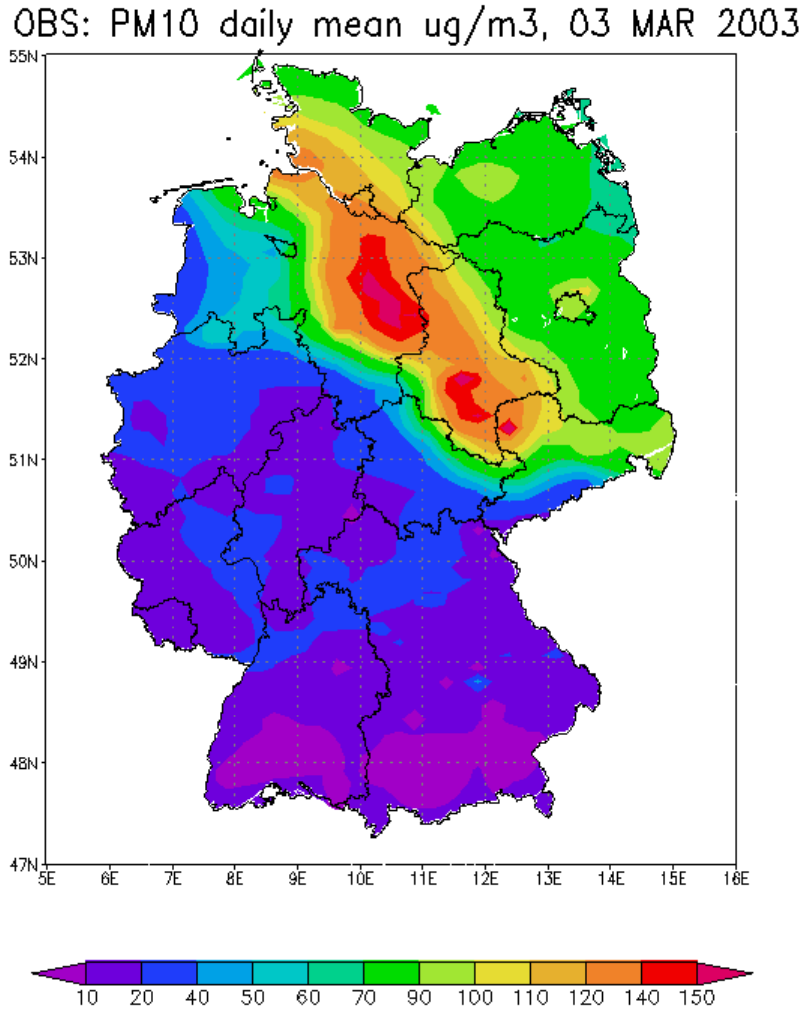
Core episode:
Observed daily mean PM up to 200 µg/m3 at rural background stations





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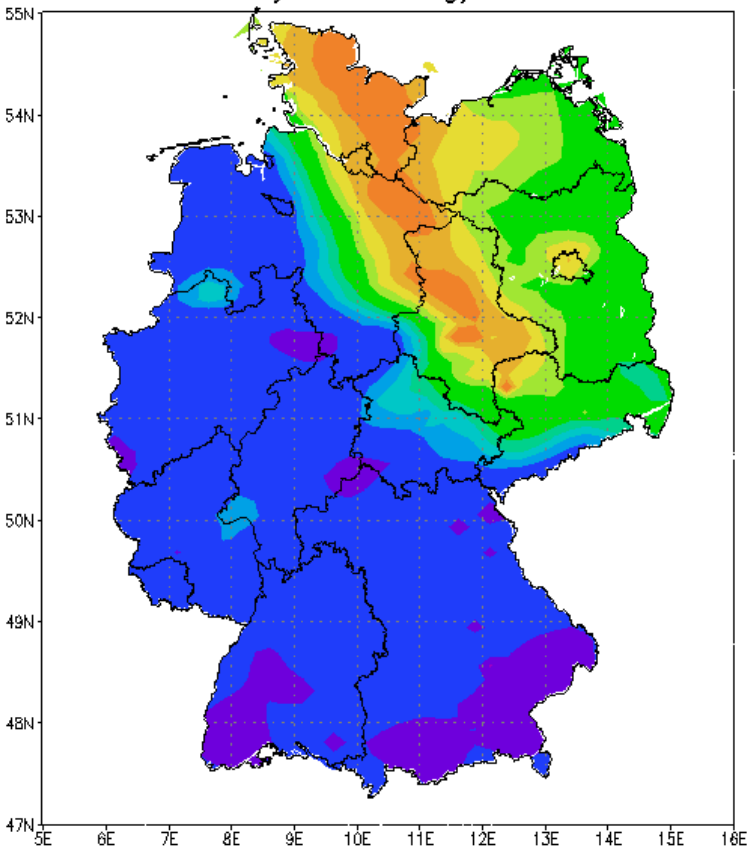
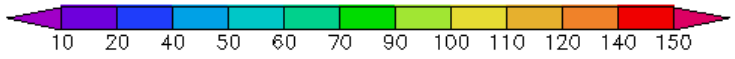
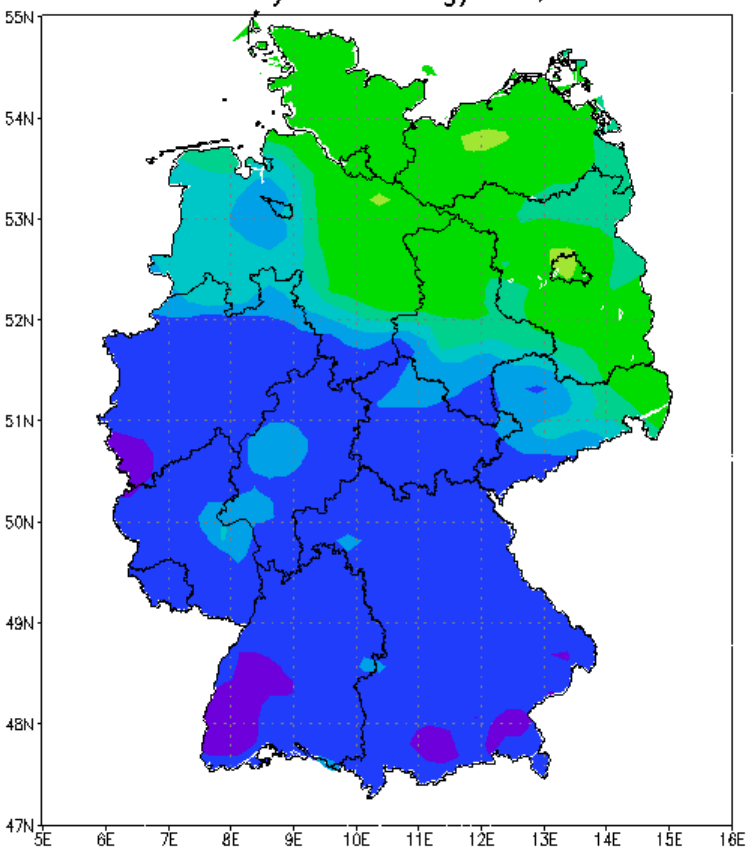
High PM10 field is moved to the Northeast by a frontal system

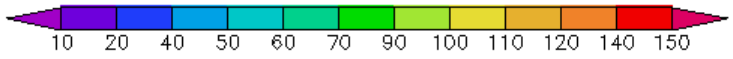
OI OBS: PM10 daily mean ug/m3, 04 MAR 2003





OI OBS: PM10 daily mean ug/m3, 05 MAR 2003





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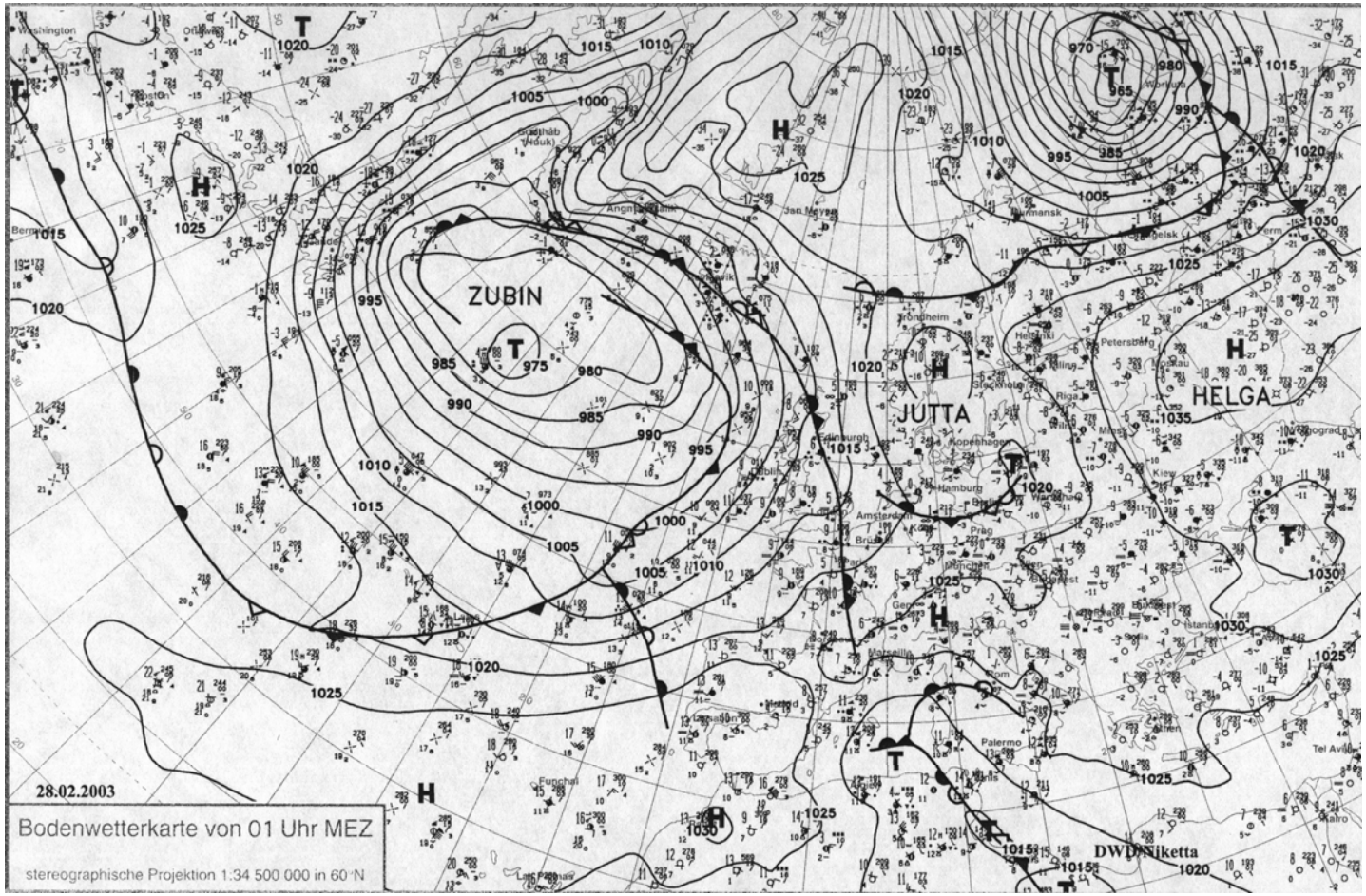
All episodes are connected with high pressure systems, stable conditions, low wind speeds

Feb 28



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Model configurations

All models used the same emissions data base including time factors and height distribution and were applied on the regional scale covering the central parts of Europe

- **Horizontal resolutions between 25 and 35 km**
- **Vertical layers**
  - EURAD: 15 below 2 km,
  - CHIMERE: 8 up to 500 mb;
  - RCG: 5 up to 3 km,
  - LM-MUSCAT: 17 below 4 km
  - LOTOS-EUROS: 4 up to 3 km.
- **Different meteorological drivers**

  - prognostic NWP model: MM5 (EURAD, CHIMERE), LM (LM-MUSCAT)

  - diagnostic interpolation scheme of observations coupled with a PBL model:

  RCG, LOTOS-EUROS

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Evaluation against observations at rural stations in the belt of high PM concentrations in Northern Germany

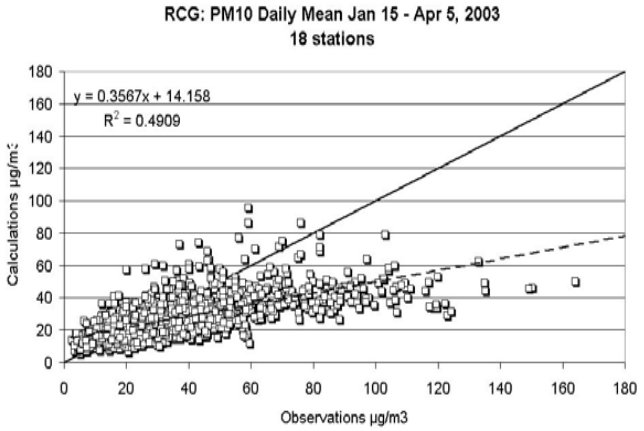
18 stations PM10, 4 stations PM2.5

4 stations: SO4, total nitrate (HNO3+NO3) and total ammonia (NH3+NH4)

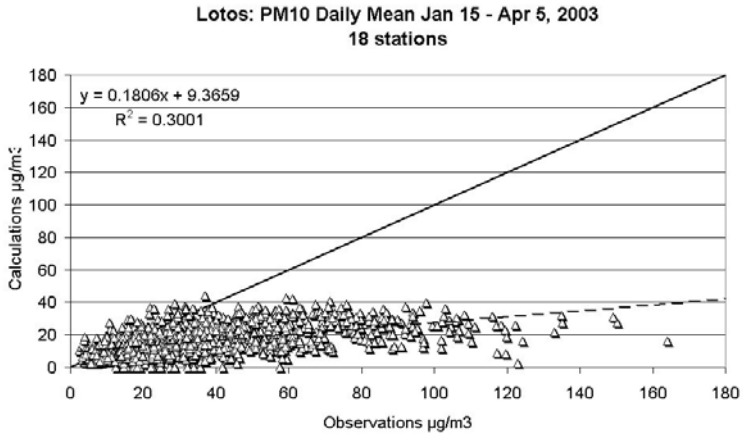
1 research site (Melpitz): SO4, NO3, NH4, EC, OM, NH3

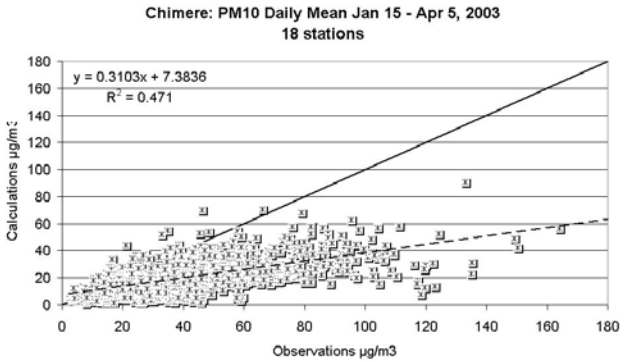
In addition: NO2, SO2 at the 5 stations with PM components

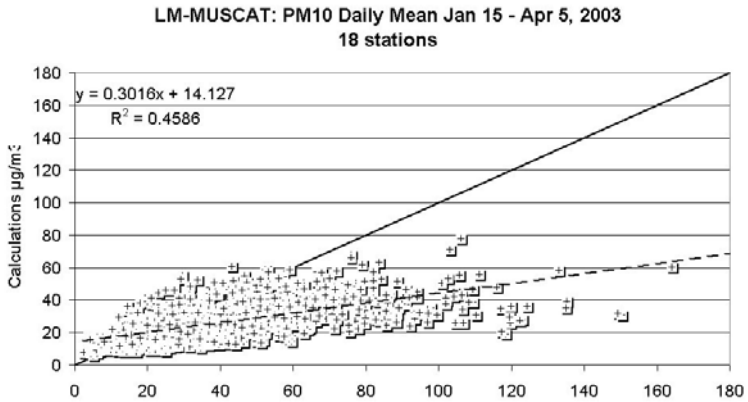
Focus on the 5 stations with PM composition data



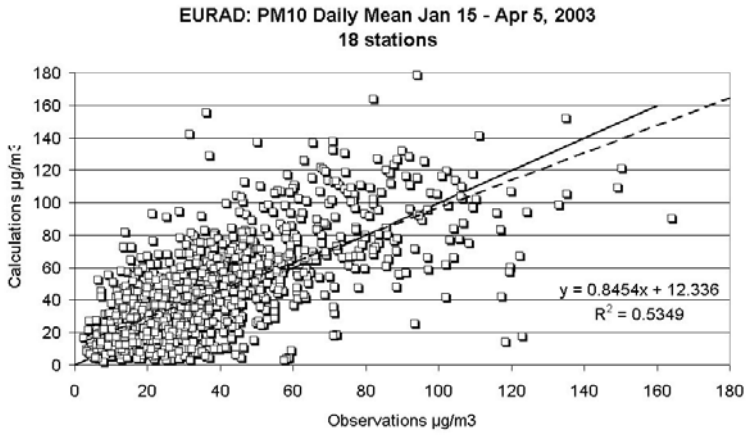
Scatter of daily mean PM10 18 stations







4 models (RCG, LOTOS, CHIMERE, LM-MUSCAT) clearly underestimate observed PM10 peaks !!!!



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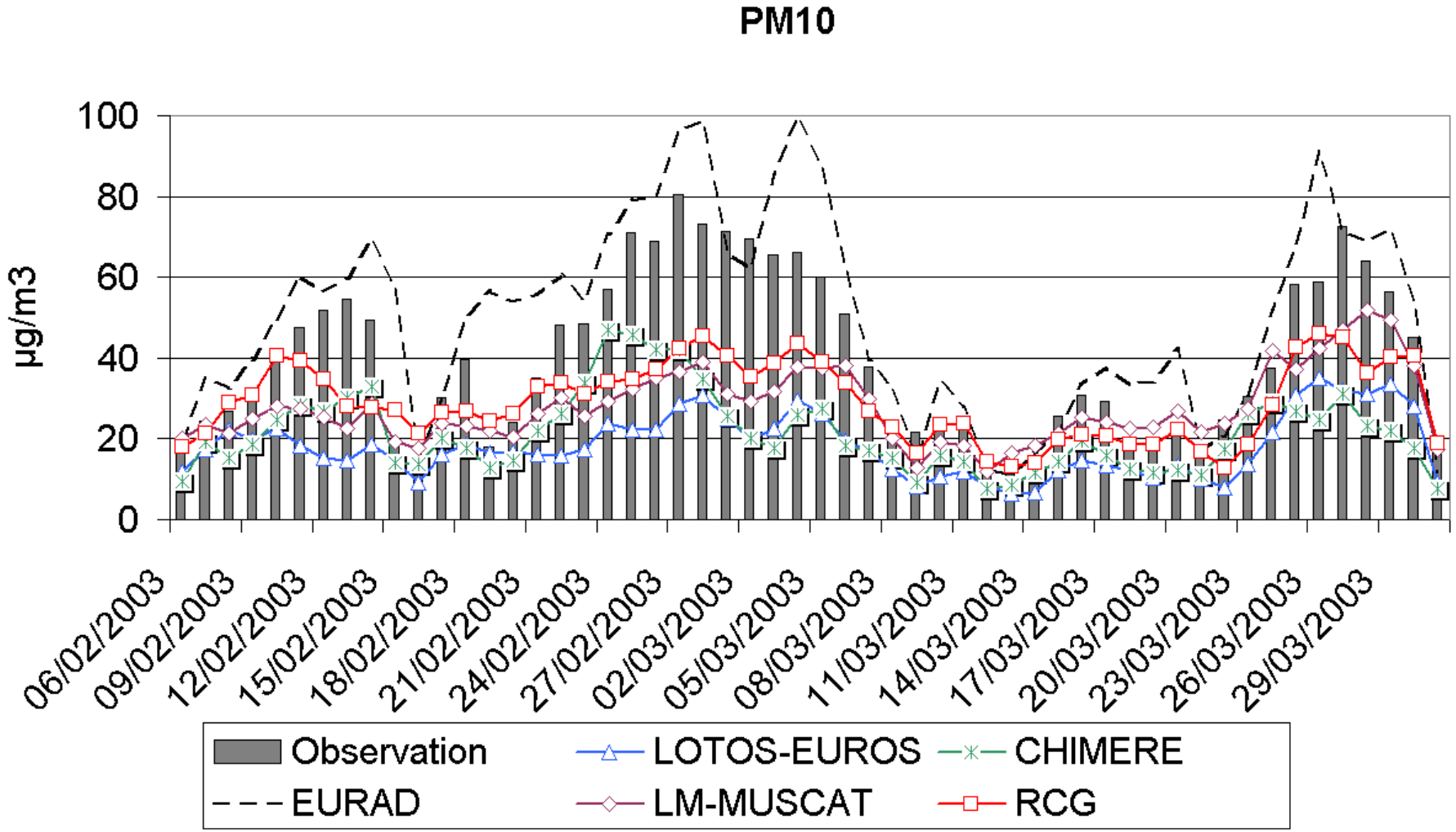
All models recognize the episodes, but do not get the peak values (only EURAD)



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Analysis of precursor and primary PM concentrations

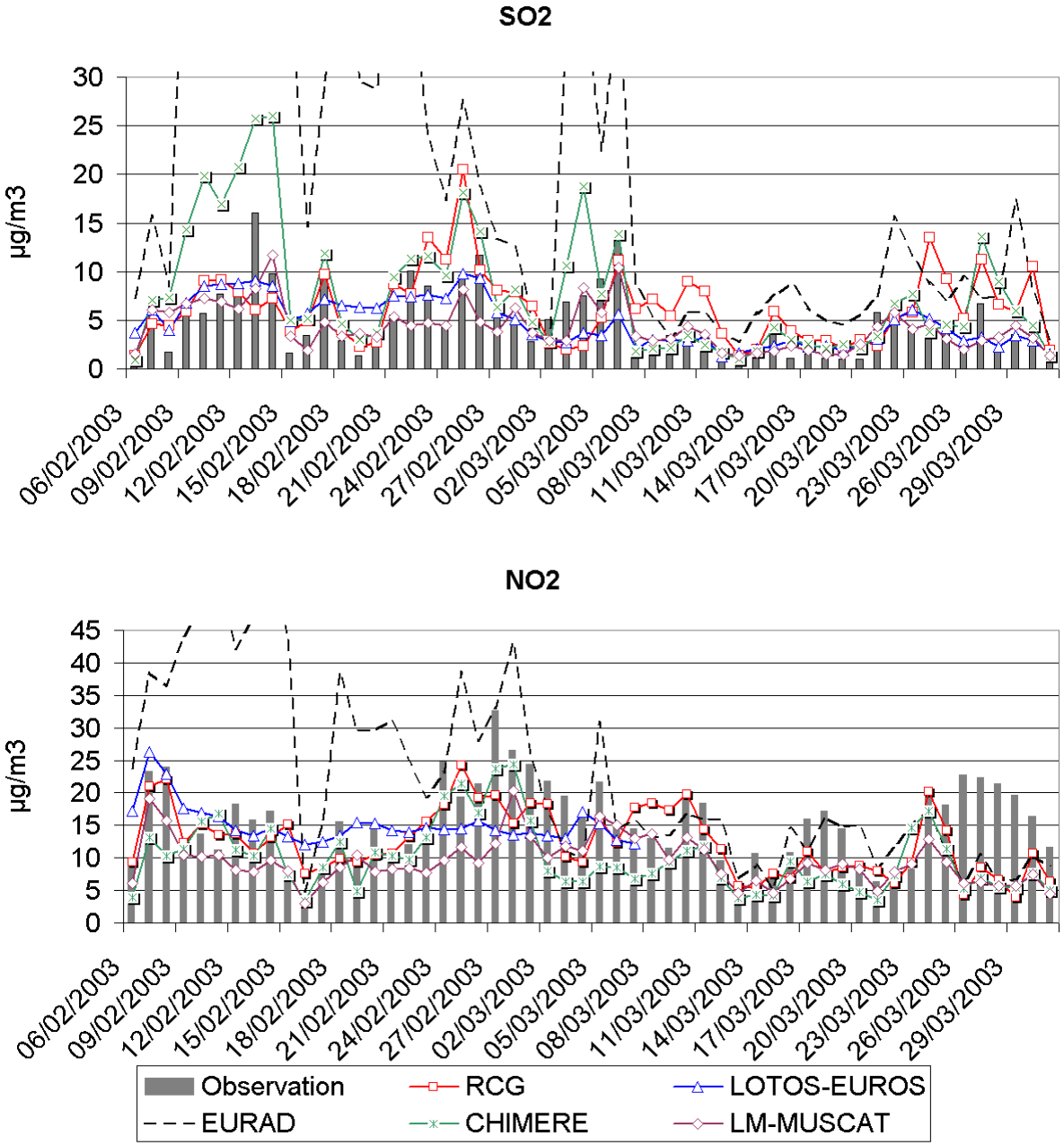
SO2: tendency to overestimate, in particular the low values (EURAD more pronounced)

NO2: tendency to underestimate observed peak concentrations (EURAD partly strong overestimation)

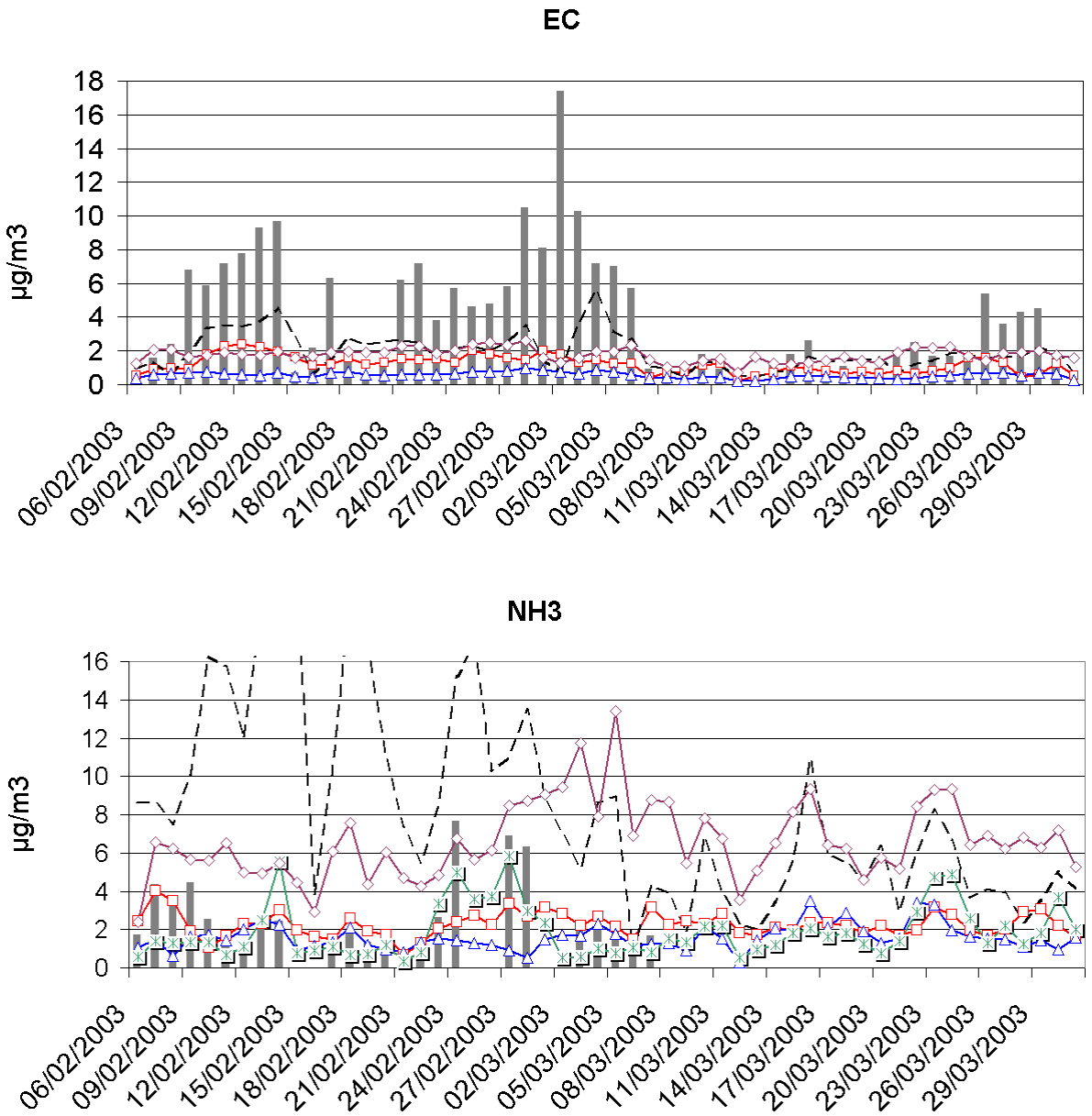
NH3 : RCG, CHIMERE, LOTOS right order of magnitude, LM-MUSCAT and in particular EURAD overestimate (only 1 station)

EC: All models strongly underestimate (only 1 station)

Example: MELPITZ, but the picture is similiar at other stations



MELPITZ



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Analysis of secondary PM components

SO4: underestimation of the observed peaks, timing problems.

LOTOS underestimates

NO3, NH4: underestimation of the observed peaks, timing problems. EURAD strongly overestimates

OM : RCG underestimates, EURAD, LM-MUSCAT overestimate

(no data from CHIMERE, LOTOS, only 1 station)

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Melpitz

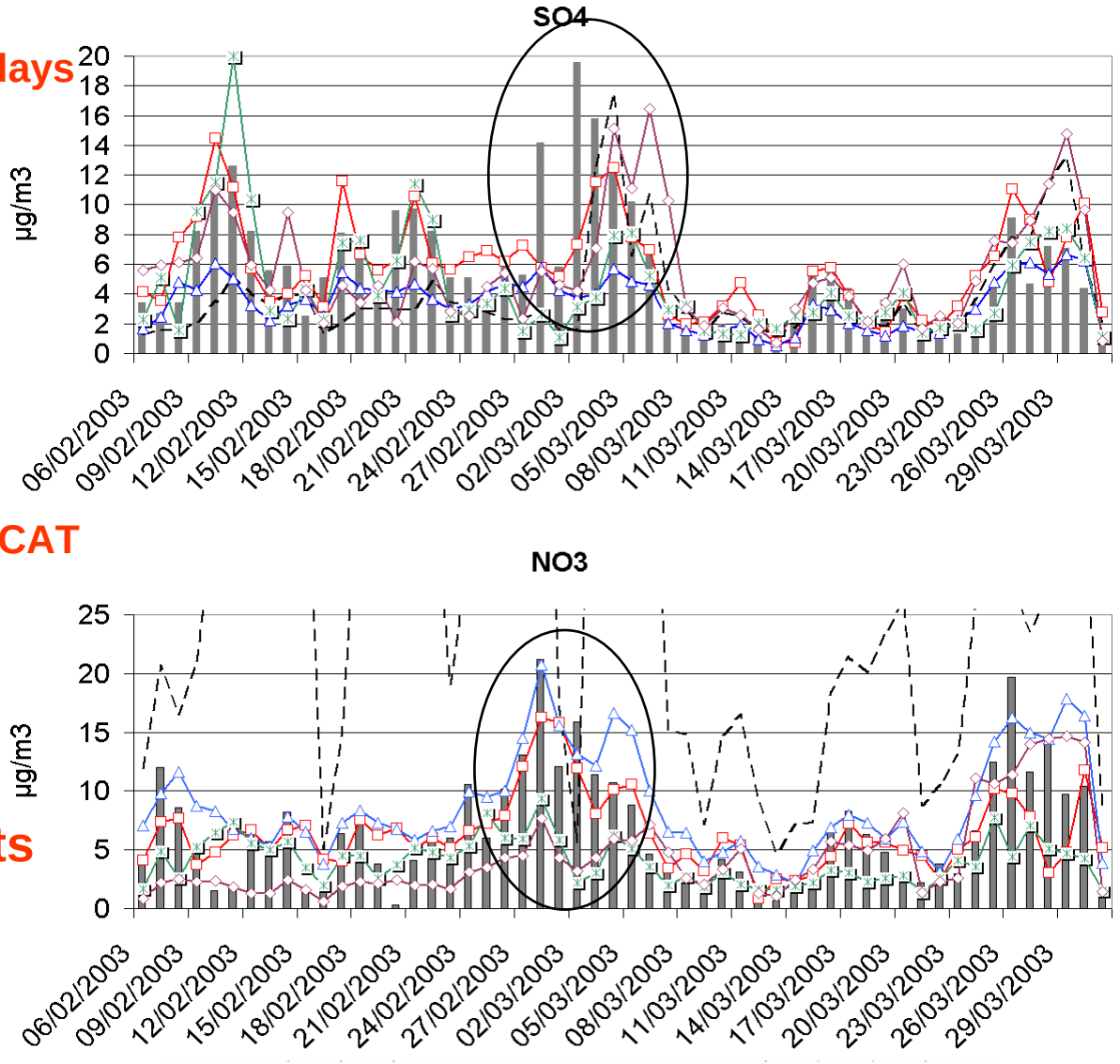
SO4, NO3 peak at different days

Problems with the position of the front ?

More pronounced for the prognostic drivers

EURAD, CHIMERE, LM-MUSCAT

Quite a scatter between model results



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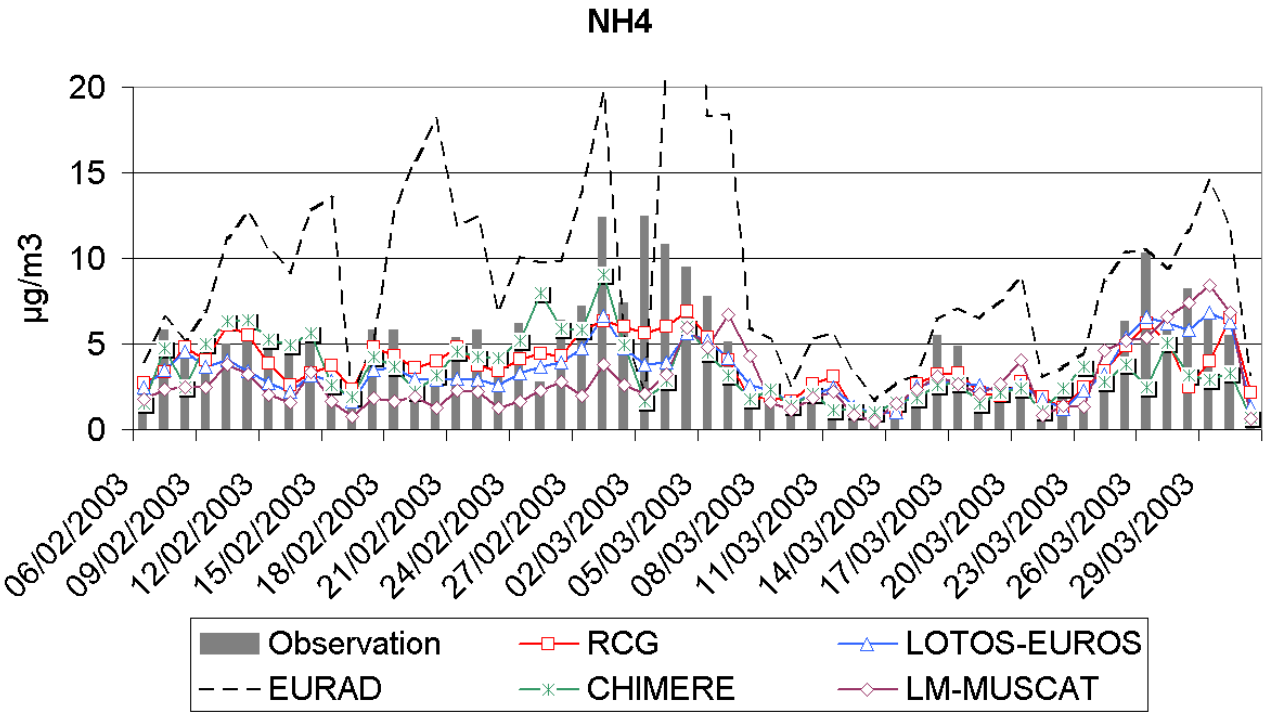

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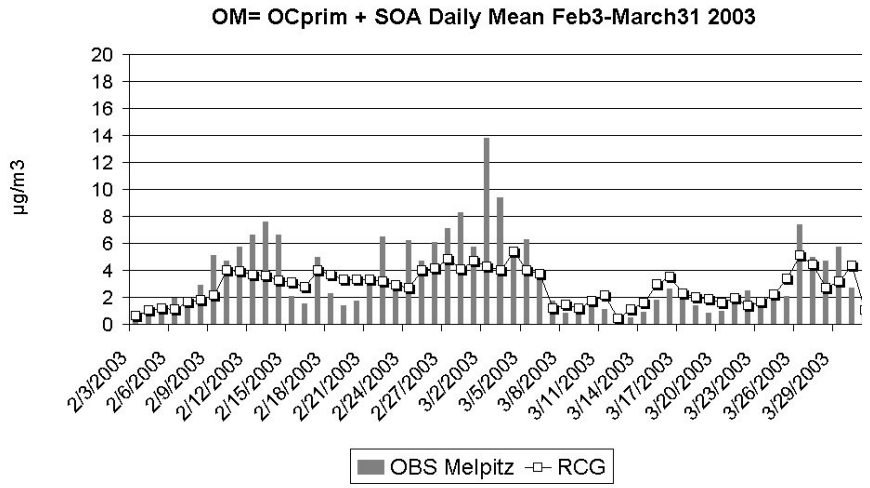
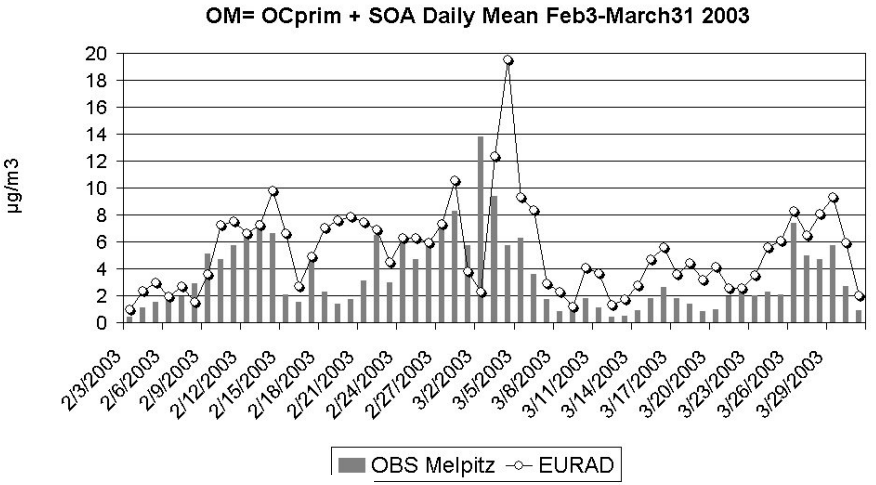
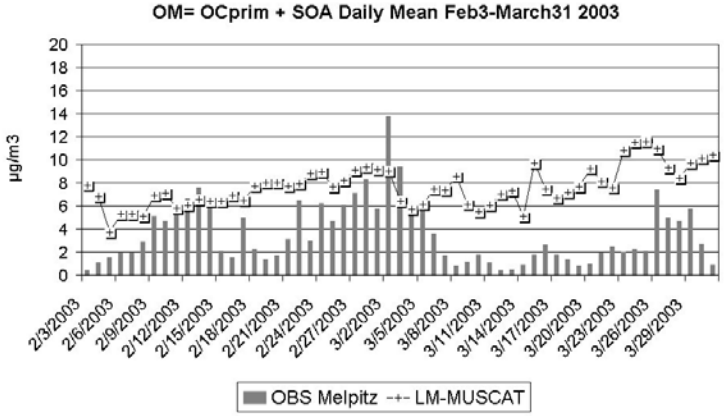
Melpitz







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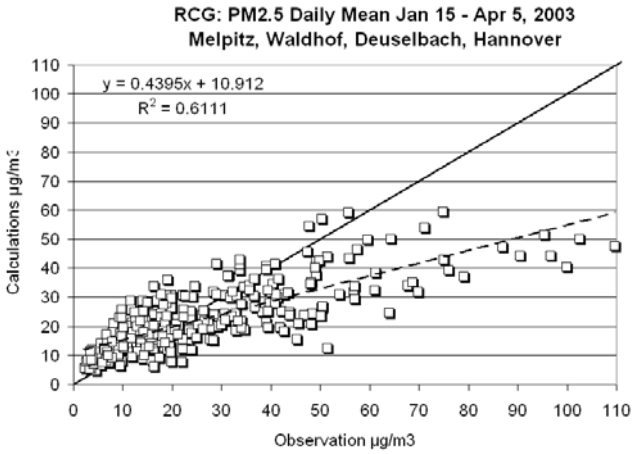
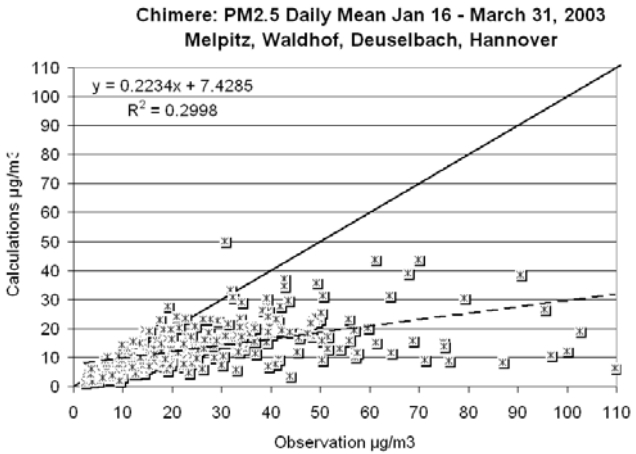
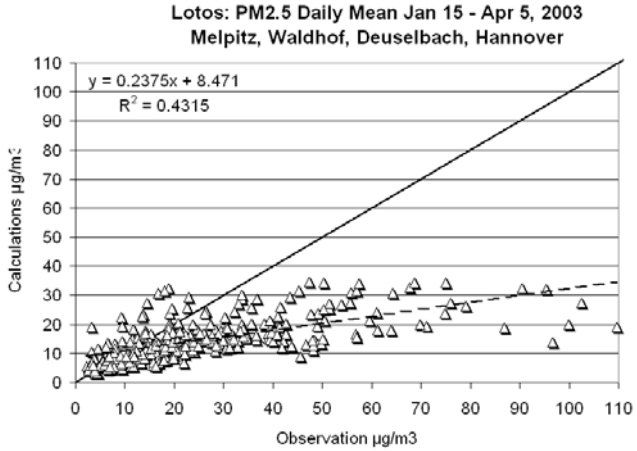
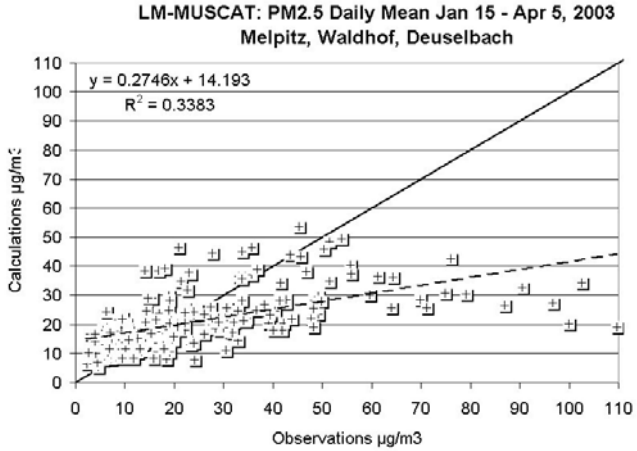
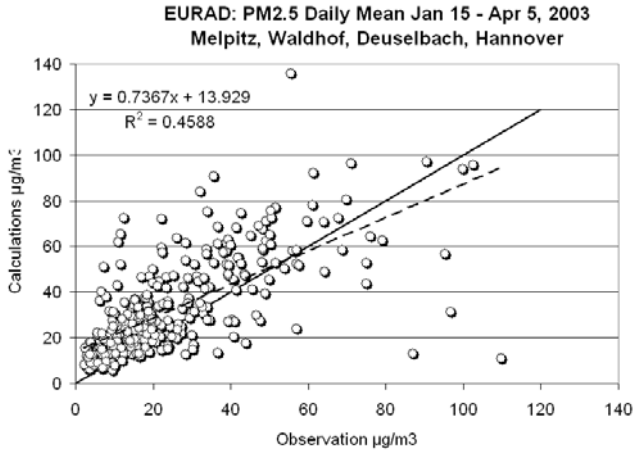
PM2.5 daily mean











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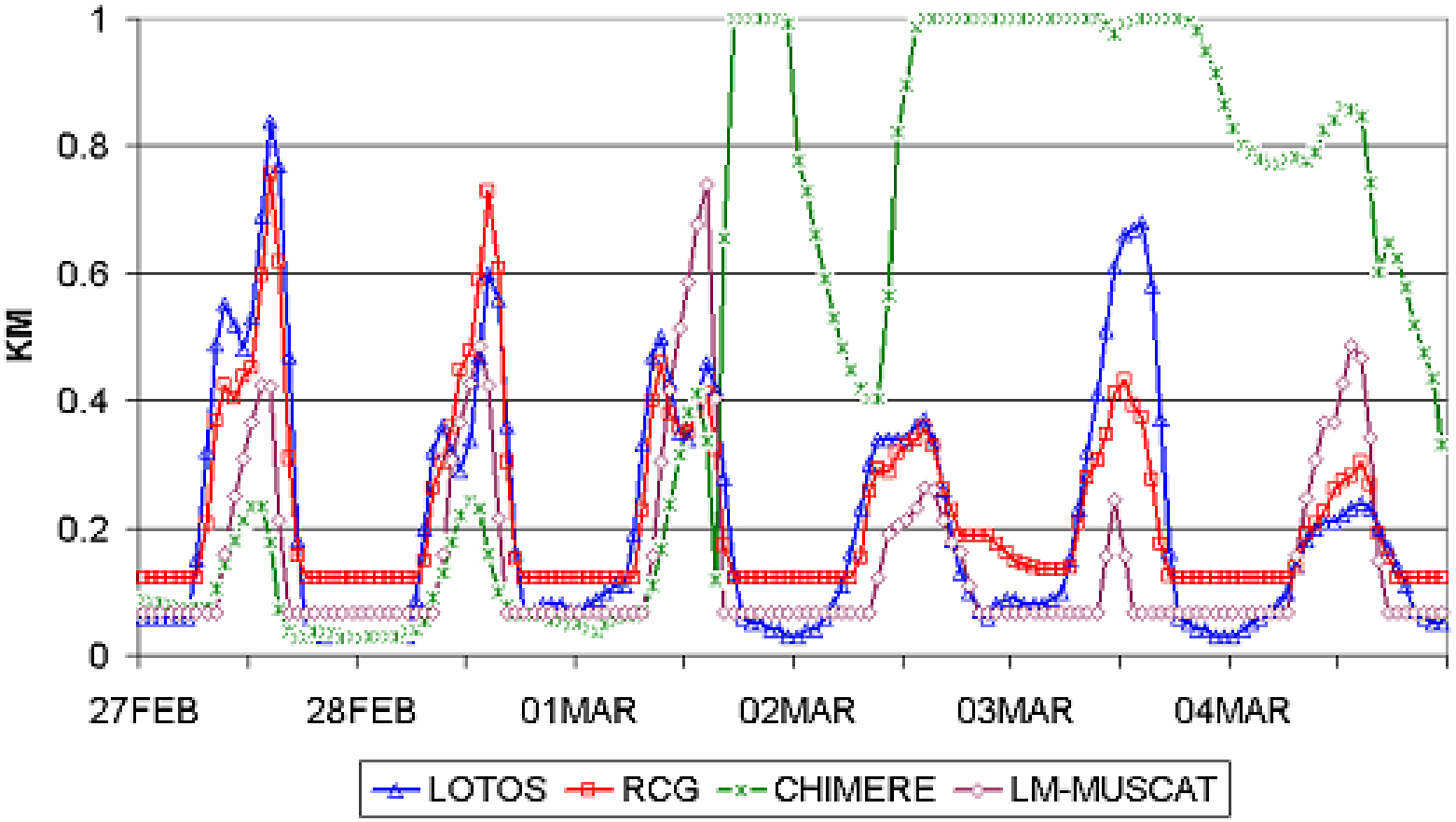
Melpitz: Hourly Mixing heights core episode



Factor 2 to 5 difference !!

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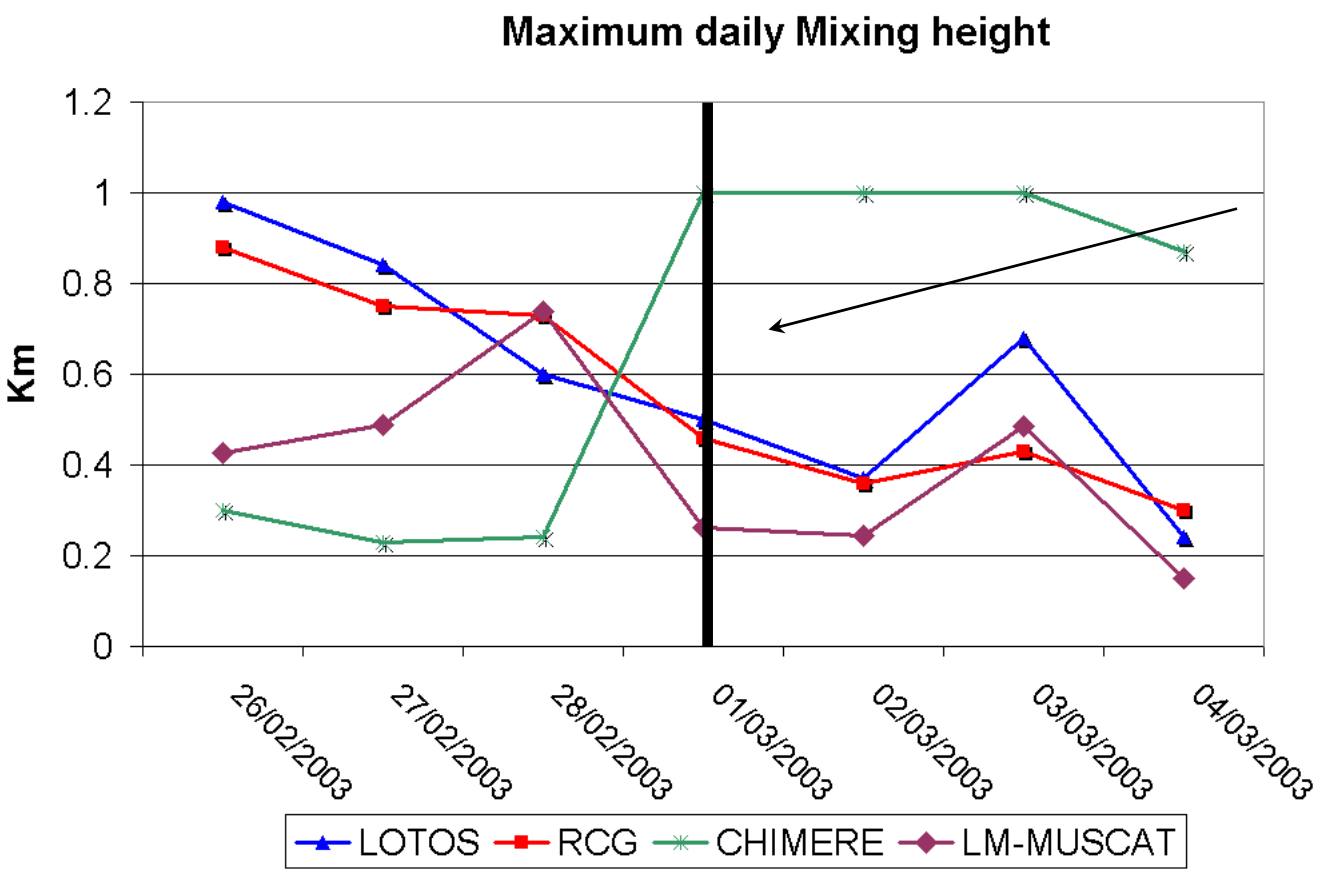
Melpitz: Maximum daily mixing heights, core episode



Observed PM peak

Different trends !!

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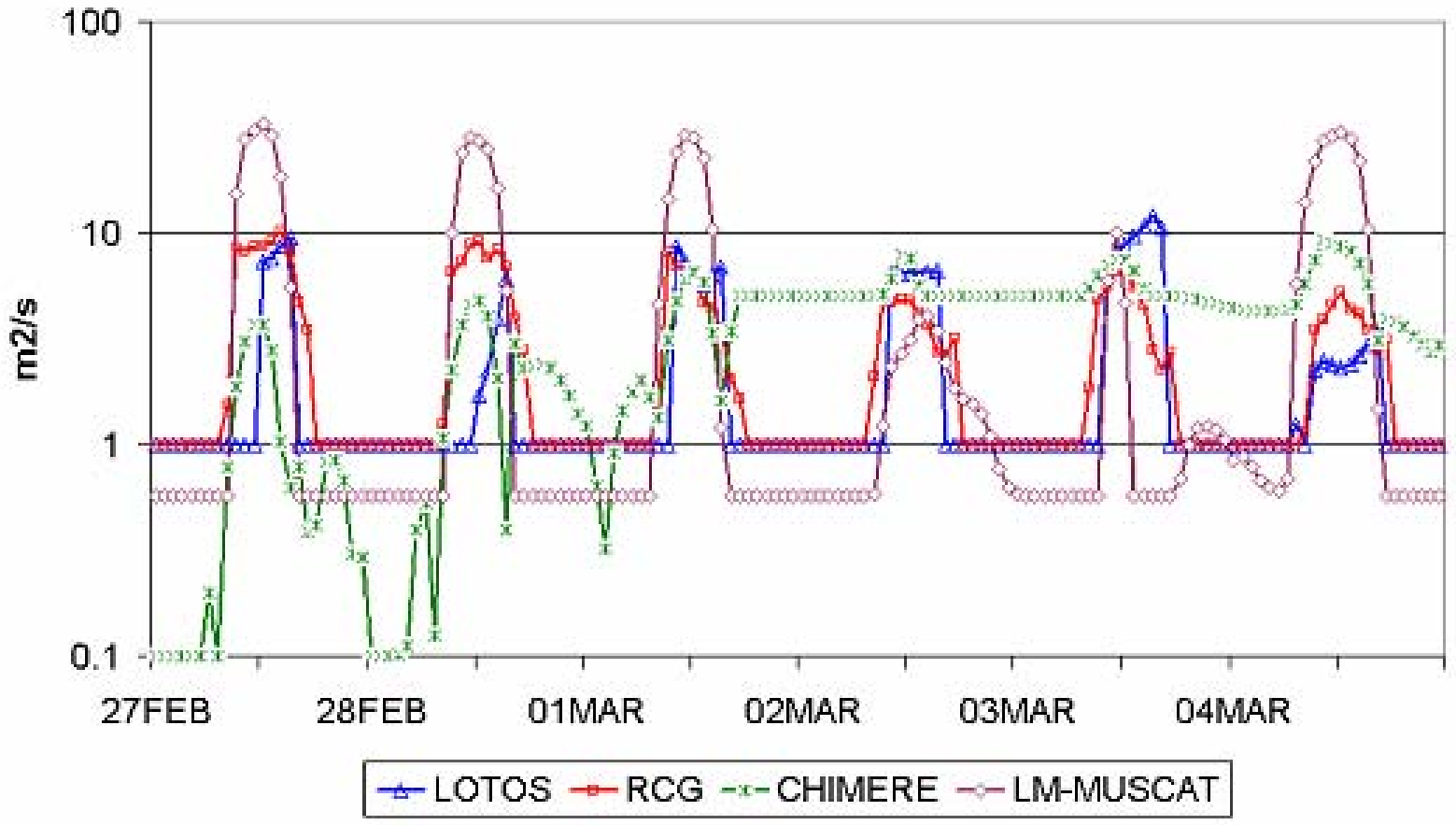
Melpitz: Vertical exchange coefficient Kz between layer 1 and layer 2: core episode



Factor 2 and more difference for meteorological key parameters !!

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What have we learned ?

- **All models recognize the embedded episodes but 4 out of 5 models underestimate the PM peak concentrations**
- **Large differences between models in the aerosol precursor concentrations and primary PM components point to different transport/mixing characteristics** (PBL key parameter, vertical exchange mechanism, grid layout)
- **Different SIA formation might be more related to differences in the input to the aerosol modules** (concentrations, met. variables) **than to different module formulations** (EURAD: NO3, NH4 overestimation due to NH3 overestimation or module problem or both?)
- **EURAD has the PM peaks right but for the wrong reason (NO3, NH4 overestimation)**

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Analysis of observed PM10 composition at Melpitz

- During episodes there is an increase of primary and secondary pollutants
- SIA (fine mode) contribution to total PM10 decreases with increasing PM10 concentrations

  (days with PM10 < 50 µg/m3 55%, > 50 µg/m3 46%)

- EC, OM, unacc. mass contributions to total PM10 increase with increasing PM10

Episodes seem not to be LRT dominated

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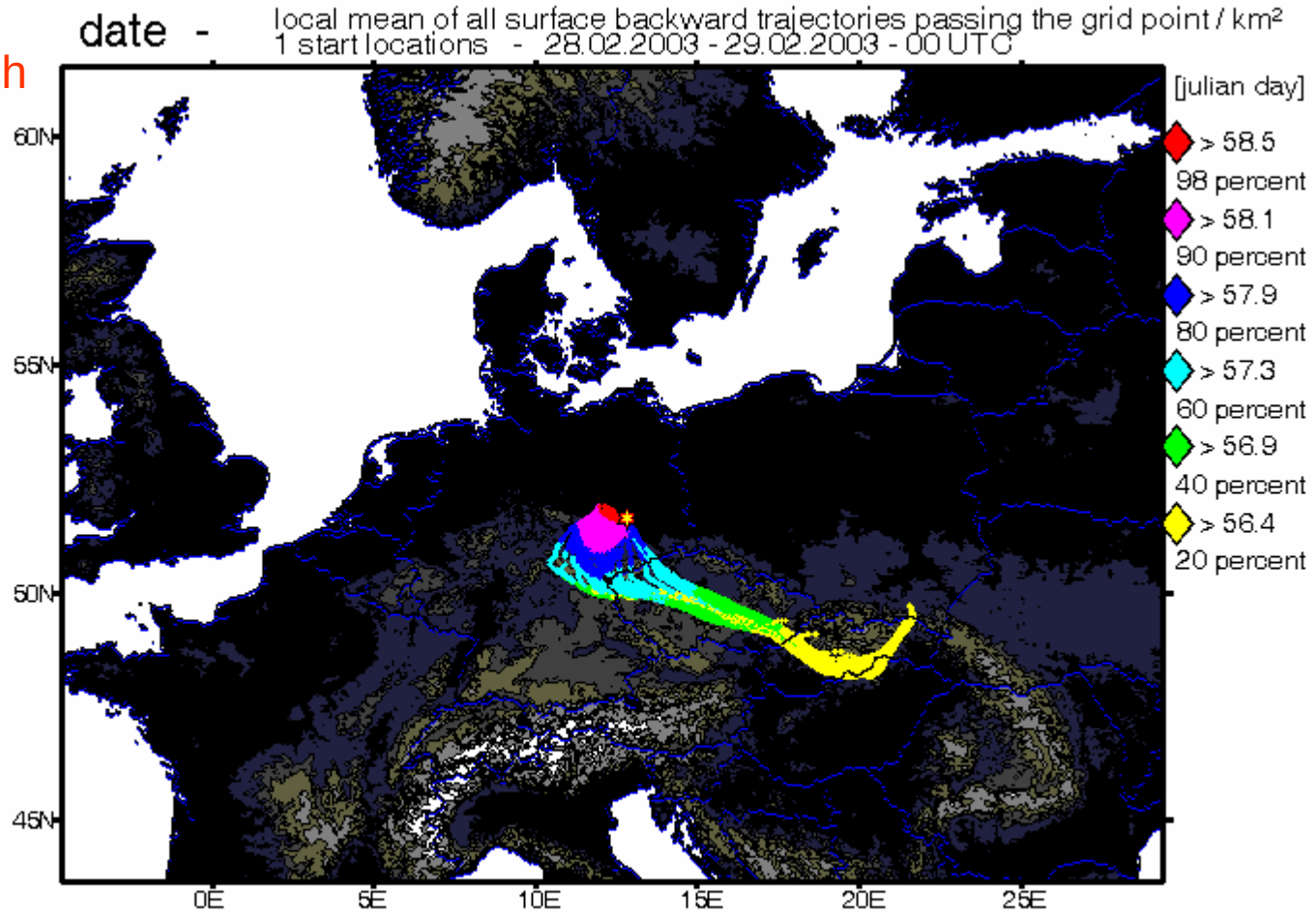
Backward trajectory bundle at Melpitz in the FS Saxonia

Trajectory started each 10 min over 72 hours:

All trajectories stay about 2 days over Saxonia indicating stagnant conditions



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Analysis of PM10 peak underestimation of the models

- **Increasing underestimation of primary and secondary pollutants with increasing PM10 concentrations**

- **Underestimation of EC, unaccounted mass is considerably larger than the underestimation of SIA at days with observed PM10 > 50µg/m3**

Have we problems to simulate stagnant weather conditions ?

Parameterization of the stable boundary layer is still poor !!!

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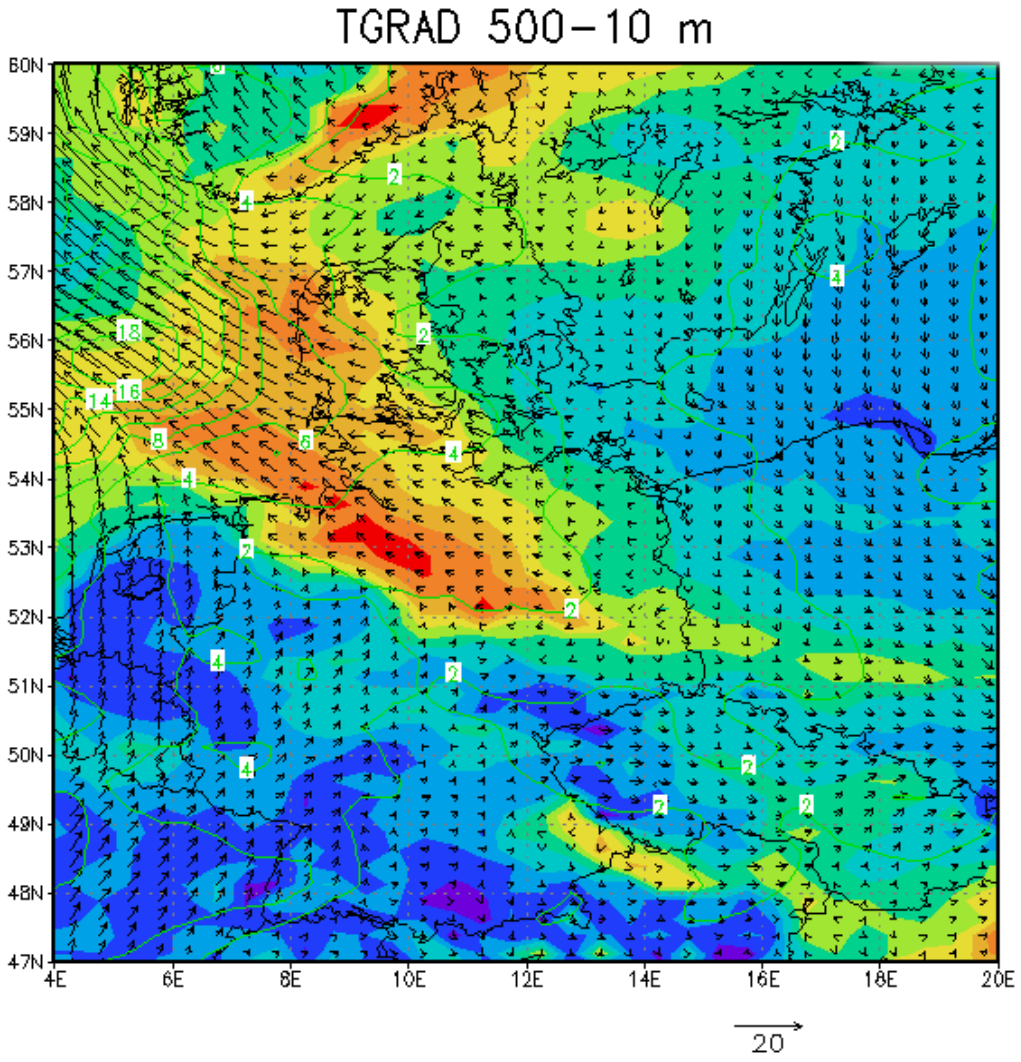
Vertical temperature gradient at Feb 28, 12 UTC, 2003

Green, yellow, red:
areas with stable conditions

BASED ON OBSERVATIONS



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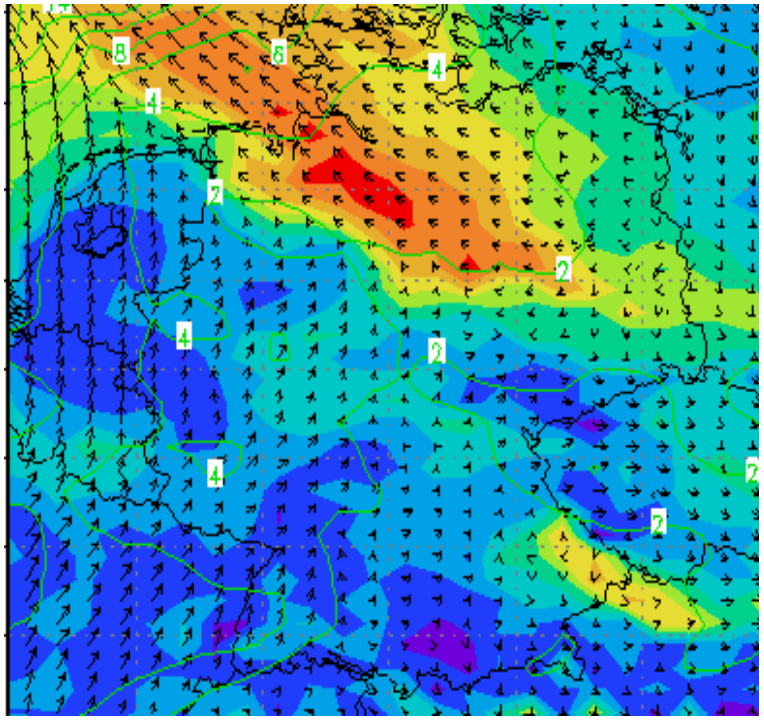
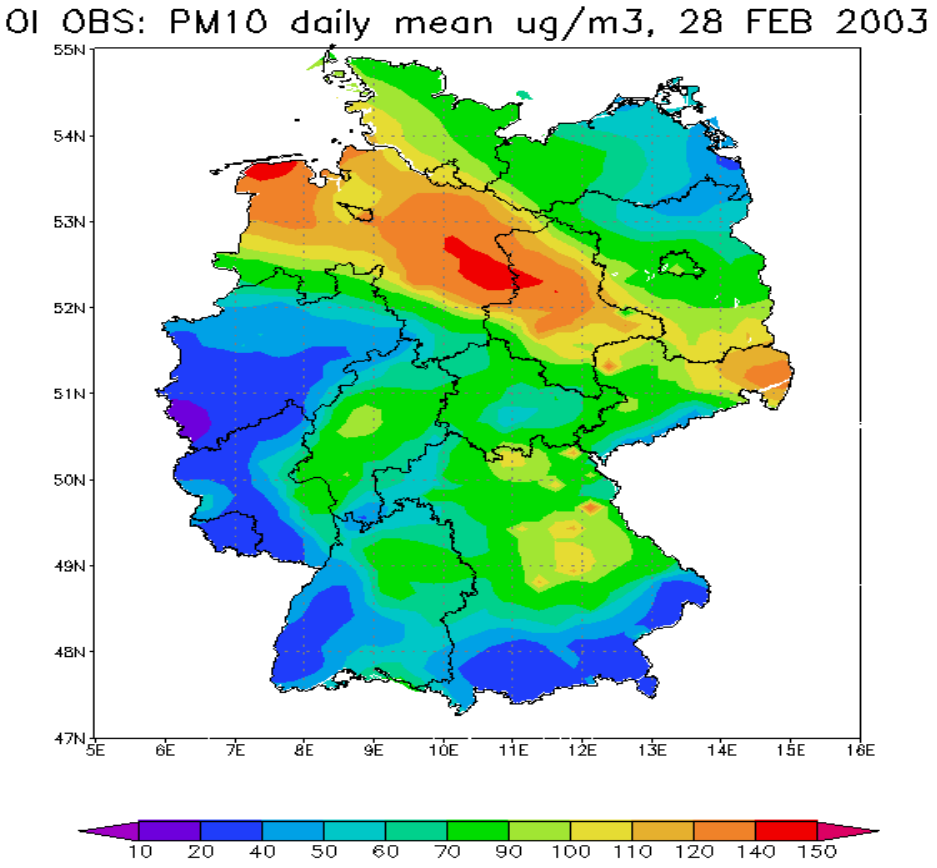
Stability pattern at Feb 28



Observed PM10 concentration field at Feb 28, 2003



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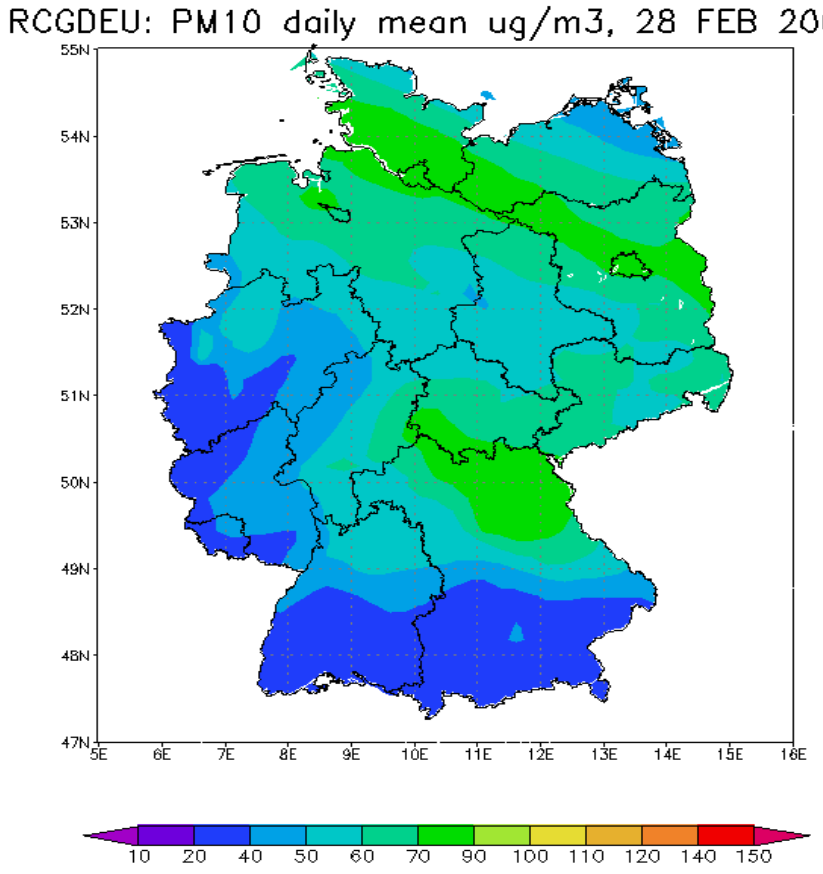
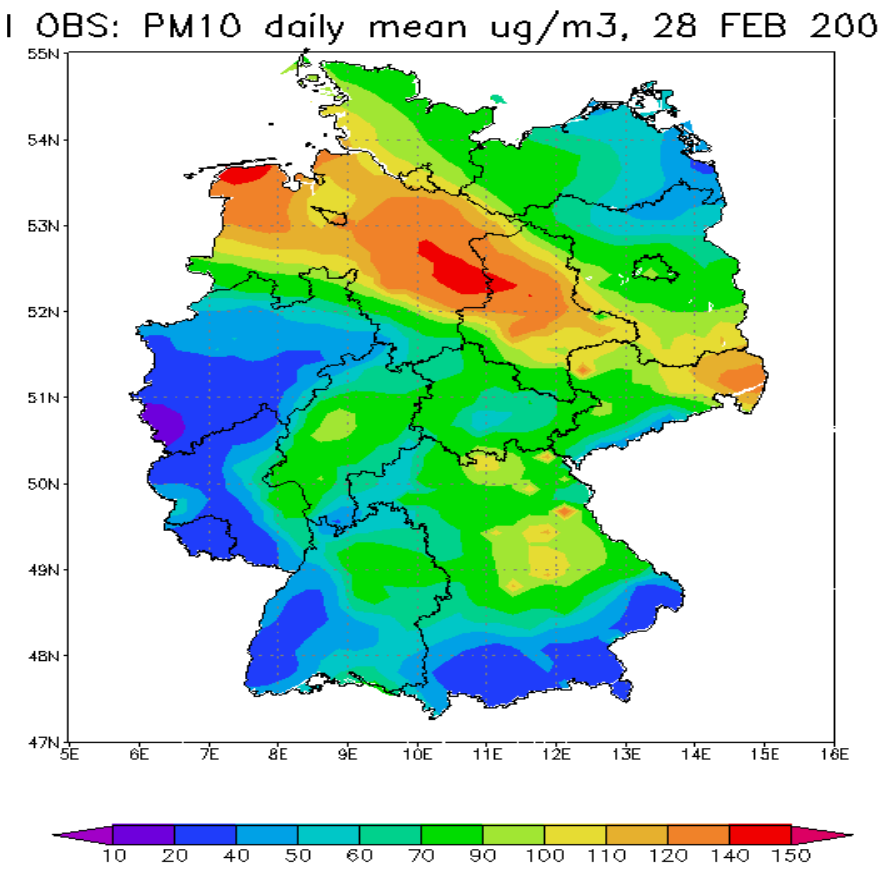
Calculated PM10 concentration field at Feb 28, 2003 REM-CALGRID model



Observed PM10 concentration field at Feb 28, 2003



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Conclusions

(European?) Models seem currently not to be able to simulate high PM10 concentrations (> 50 µg/m3), which are observed mostly in winter time

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Conclusion

The underestimation cannot be attributed to one single source of error

- **Missing sources** (unaccounted mass) **or underestimation** (probably EC emissions)
- **Uncertainties for key boundary layer parameters for inversion induced winter episodes** (underestimation of the strength of inversions, overestimation of mixing heights, missing calms with false wind directions etc**.)**

The error source „meteorological processes“ seems to have (at least) equal importance as the error sources „emissions“ or „physical/chemical processes“

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Additional Material

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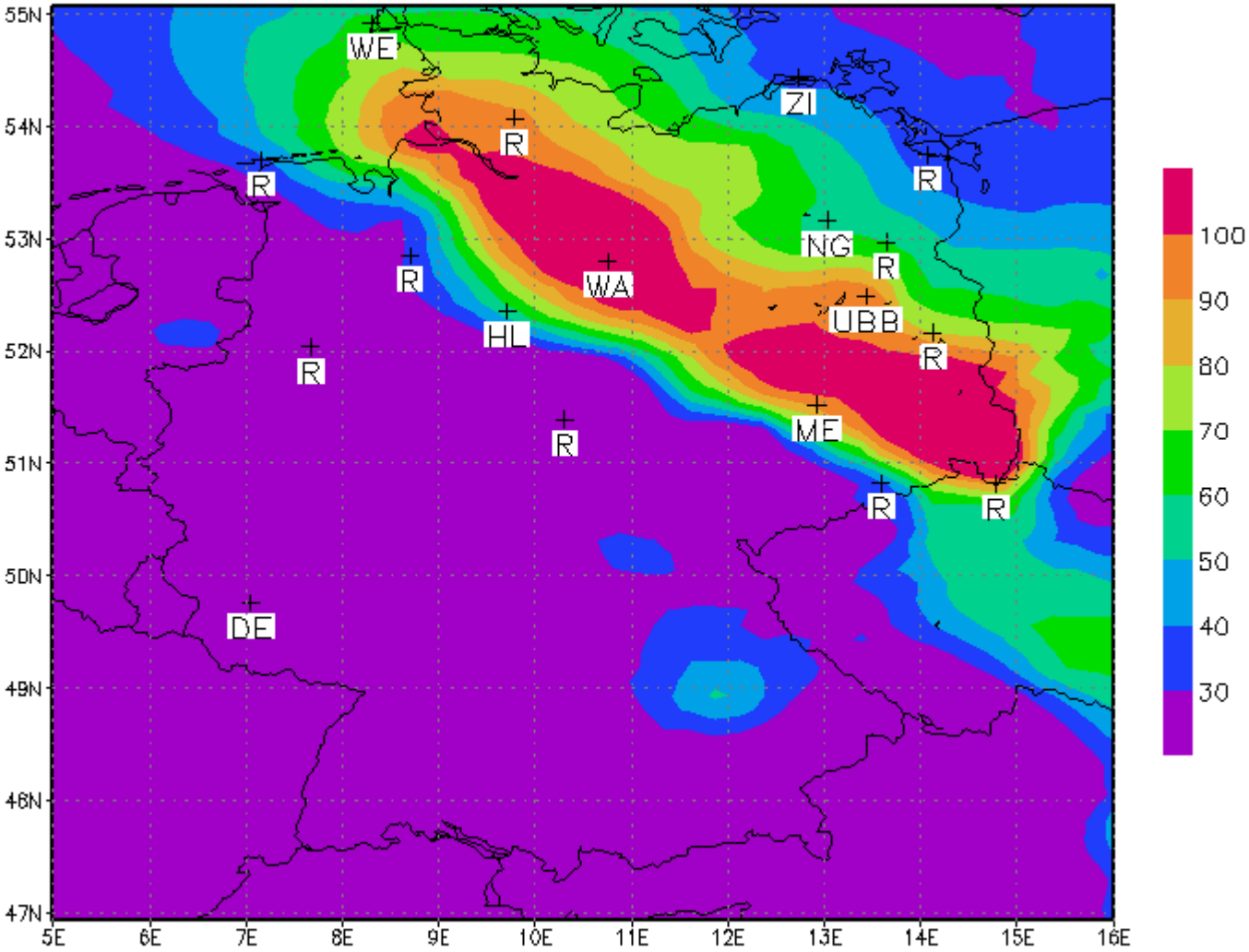
Observed PM10 concentration field at March 2, 2003 station labels indicate the location of the stations used for model evaluation



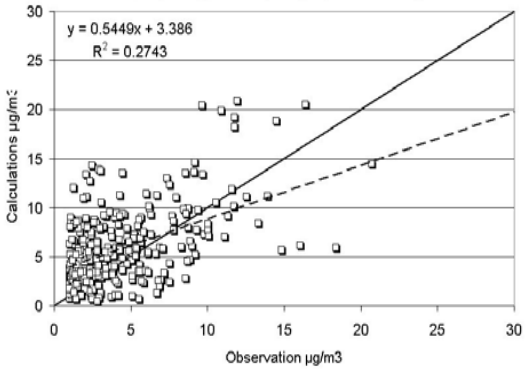
Dr. R. Stern, FU Berl

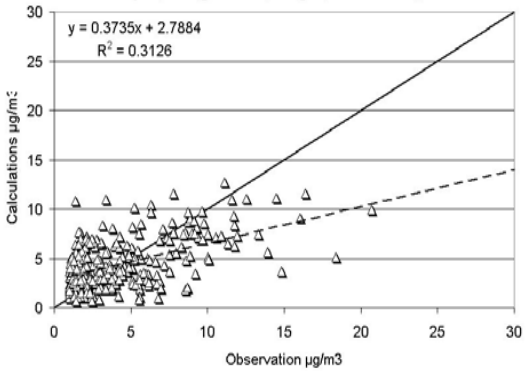
GrADS: COLA/IGES

2007-08-23-17:18

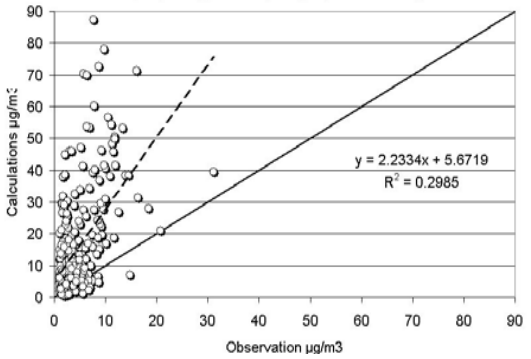
TrUmF
Troposphärische Umweltforschung
Institut für Meteorologie
Freie Universität Berlin

RCG: SO2 Daily Mean Jan 15 - Apr 5, 2003,
Melpitz, Neuglobsow, Zingst, Westerland, Deuselbach

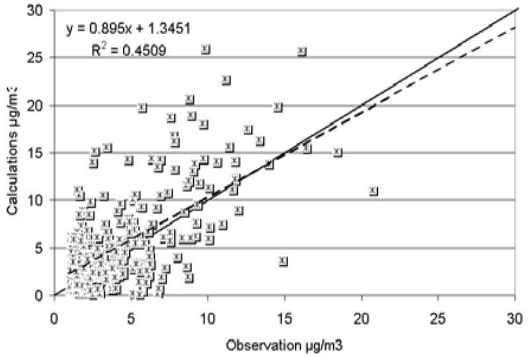




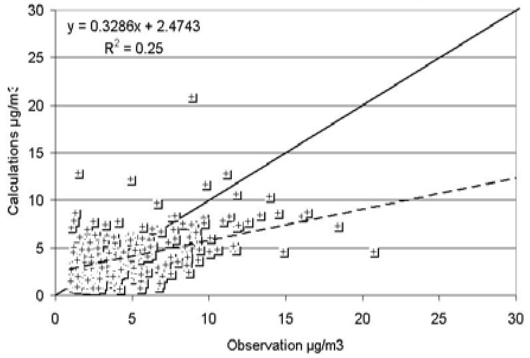
EURAD: SO2 Daily Mean Jan 15 - Apr 5, 2003,
Melpitz, Neuglobsow, Zingst, Westerland, Deuselbach



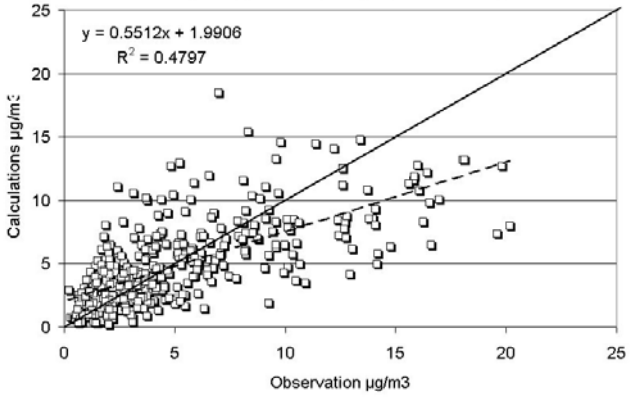
Chimere: SO2 Daily Mean Jan 16 - March 31, 2003,
Melpitz, Neuglobsow, Zingst, Westerland, Deuselbach



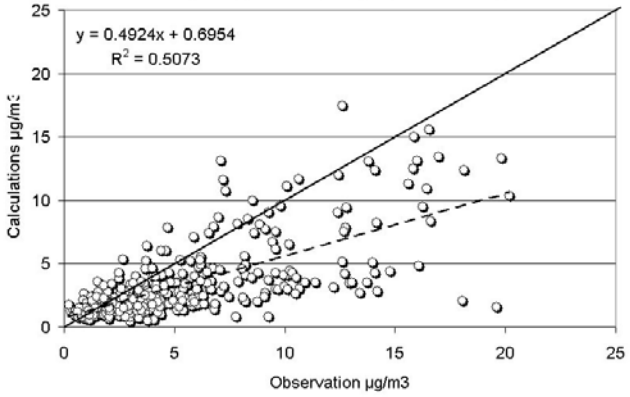
LM-MUSCAT: SO2 Daily Mean Jan 15 - Apr 5, 2003,
Melpitz, Neuglobsow, Zingst, Westerland, Deuselbach



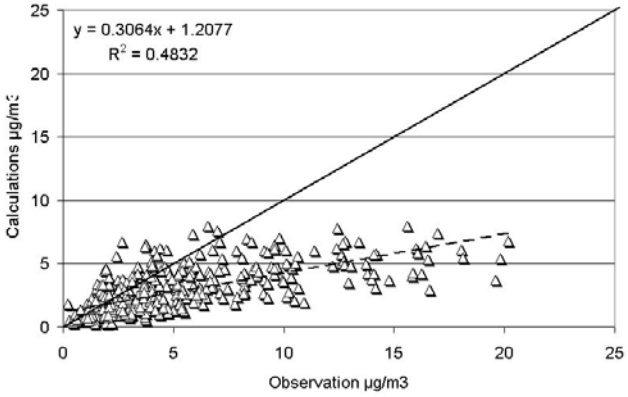
RCG: SO4 Daily Mean Jan 15 - Apr 5, 2003
Melpitz, Neuglobsow, Zingst, Westerland, Deuselbach



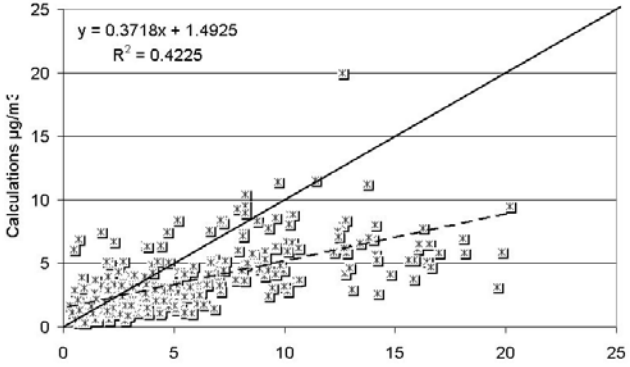
EURAD: SO4 Daily Mean Jan 15 - Apr 5, 2003
Melpitz, Neuglobsow, Zingst, Westerland, Deuselbach



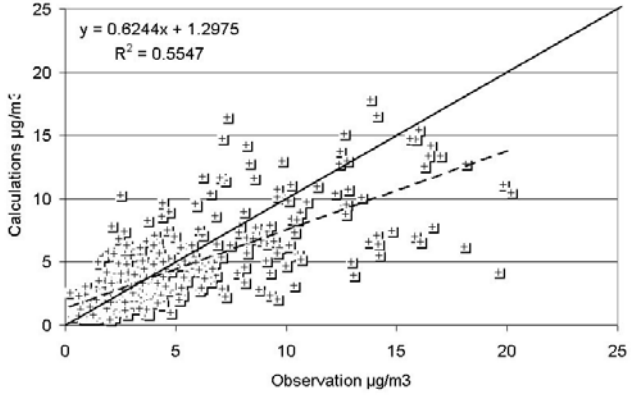
LOTOS-EUROS: SO4 Daily Mean Jan 15 - Apr 5, 2003
Melpitz, Neuglobsow, Zingst, Westerland, Deuselbach

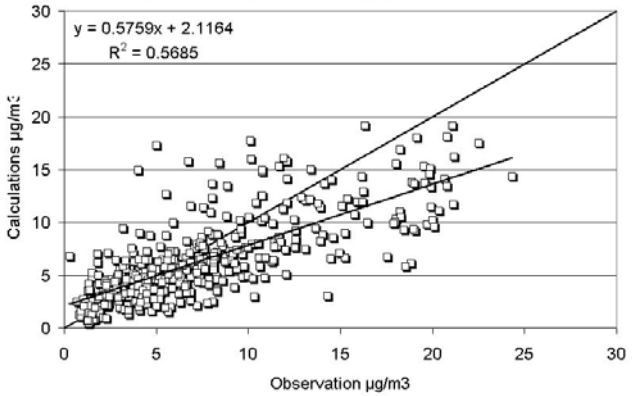


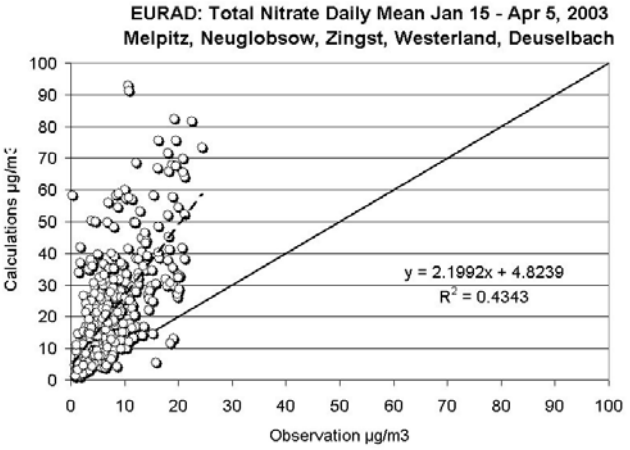
Chimere: SO4 Daily Mean Jan 16 - March 31, 2003
Melpitz, Neuglobsow, Zingst, Westerland, Deuselbach

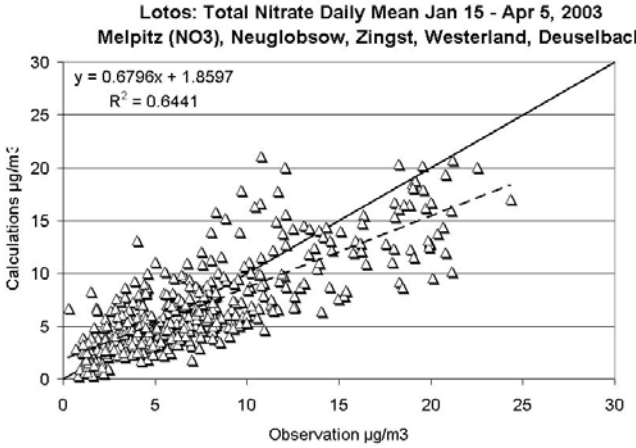


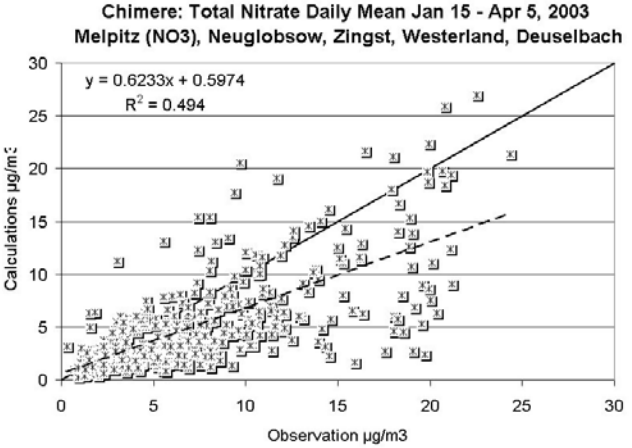
LM-MUSCAT: SO4 Daily Mean Jan 16 - March 31, 2003
Melpitz, Neuglobsow, Zingst, Westerland, Deuselbach

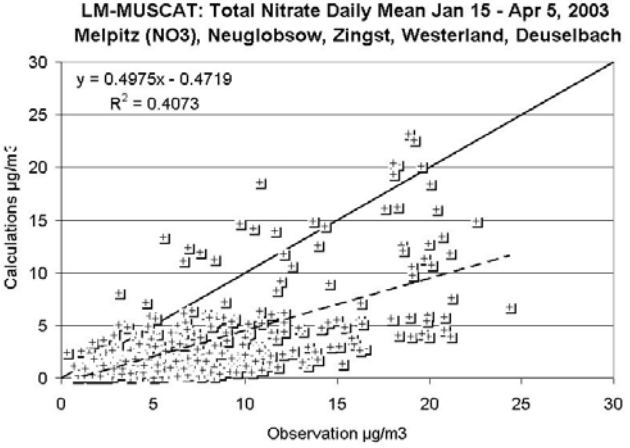



RCG: Total Nitrate Daily Mean Jan 15 - Apr 5, 2003
Melpitz (NO3), Neuglobsow, Zingst, Westerland, Deuselbach
y = 0.5759x + 2.1164
R2 = 0.5685
Calculations µg/m3
Observation µg/m3

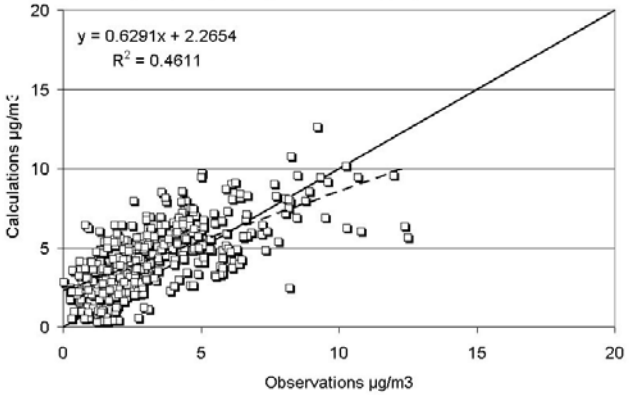

EURAD: Total Nitrate Daily Mean Jan 15 - Apr 5, 2003
Melpitz, Neuglobsow, Zingst, Westerland, Deuselbach
y = 2.1992x + 4.8239
R2 = 0.4343
Calculations µg/m3
Observation µg/m3


Lotos: Total Nitrate Daily Mean Jan 15 - Apr 5, 2003
Melpitz (NO3), Neuglobsow, Zingst, Westerland, Deuselbach
y = 0.6796x + 1.8597
R2 = 0.6441
Calculations µg/m3
Observation µg/m3

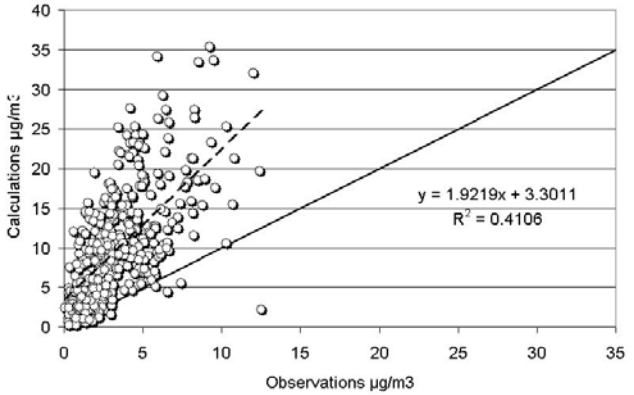

Chimere: Total Nitrate Daily Mean Jan 15 - Apr 5, 2003
Melpitz (NO3), Neuglobsow, Zingst, Westerland, Deuselbach
y = 0.6233x + 0.5974
R2 = 0.494
Calculations µg/m3
Observation µg/m3


LM-MUSCAT: Total Nitrate Daily Mean Jan 15 - Apr 5, 2003
Melpitz (NO3), Neuglobsow, Zingst, Westerland, Deuselbach
y = 0.4975x - 0.4719
R2 = 0.4073
Calculations µg/m3
Observation µg/m3

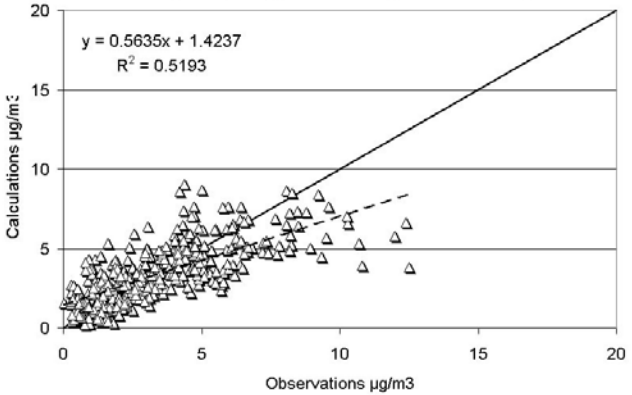
RCG: TNHX Daily Mean Jan 15 - Apr 5, 2003
Melpitz (NH4), Neuglobsow, Zingst, Westerland, Deuselbach



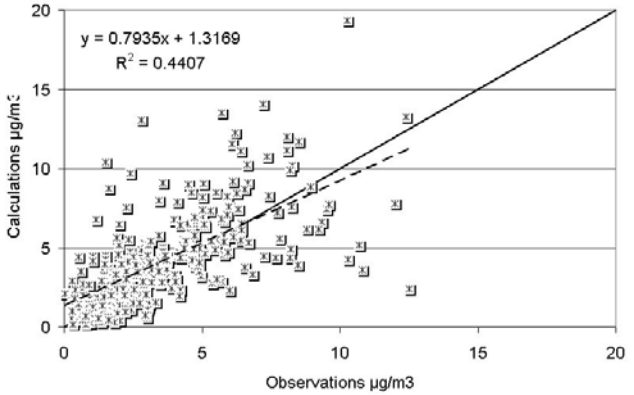
EURAD: TNHX Daily Mean Jan 15 - Apr 5, 2003
Melpitz (NH4), Neuglobsow, Zingst Westerland, Deuselbach



Lotos: TNHX Daily Mean Jan 15 - Apr 5, 2003
Melpitz (NH4), Neuglobsow, Zingst Westerland, Deuselbach



Chimere: TNHX Daily Mean Jan 15 - Apr 5, 2003
Melpitz (NH4), Neuglobsow, Zingst Westerland, Deuselbach



LM-MUSCAT: TNHX Daily Mean Jan 15 - Apr 5, 2003
Melpitz (NH4), Neuglobsow, Zingst Westerland, Deuselbach