Coupled data assimilation for atmospheric constituents

Progress of the GEMS and MACC projects towards the establishment of operational GMES services

Adrian Simmons
European Centre for Medium-Range Weather Forecasts





- **MACC is a component of Europe's Global Monitoring for Environment and Security (GMES) initiative**
  - covering atmosphere, land, ocean, emergency response and security

- **The atmospheric programme comprises**
  - developing operational space-based observation of constituents
  - strengthening the provision of complementary *in situ* observations
  - developing and operating associated data and information services

- **MACC is a 48-partner project co-funded by the European Union**
  - implementing core atmospheric monitoring and forecasting services
  - succeeding earlier EU-funded GEMS and ESA-funded PROMOTE projects

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MACC team at ECMWF

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MACC Management Board members from partner organizations

Olivier Boucher, CNRS-LMD
Hendrik Elbern, Univ. Köln
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Øystein Hov, met.no
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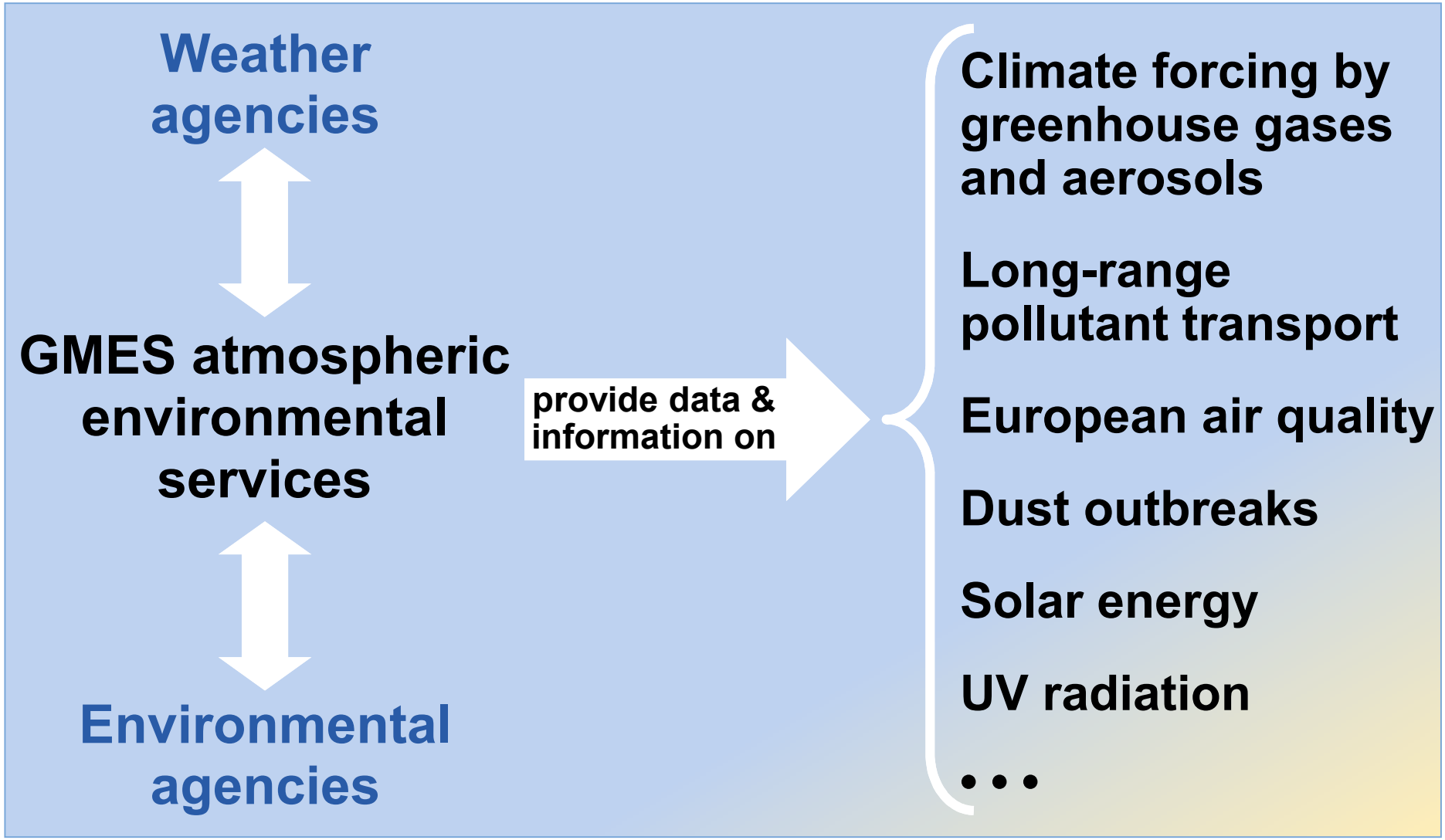
Thomas Holzer-Popp, DLR
Virginie Marécal, Météo-France
Martin Schultz, FZ Jülich

and all other team members

Atmospheric services relate to chemical and particulate concentrations



Emissions


USGS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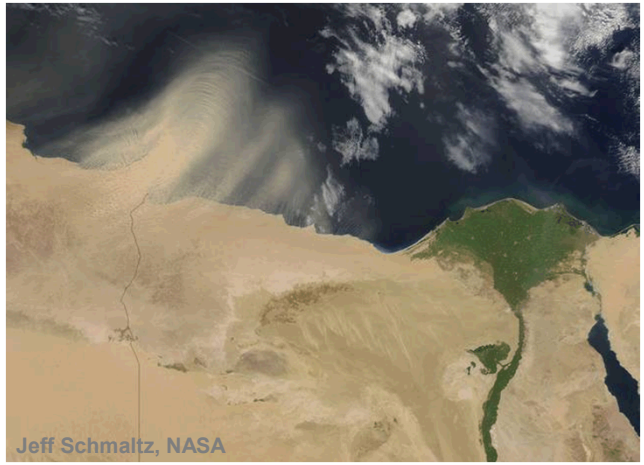
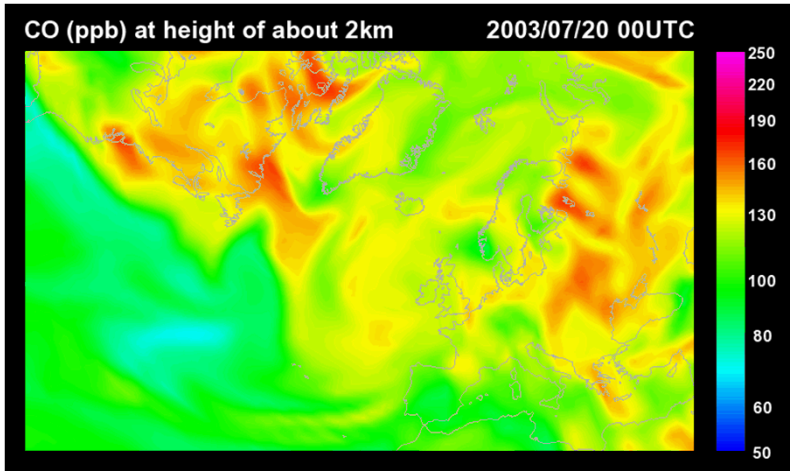
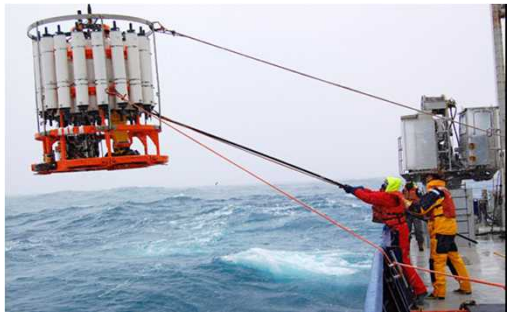

Jeff Schmaltz, NASA


© Brent Buffington

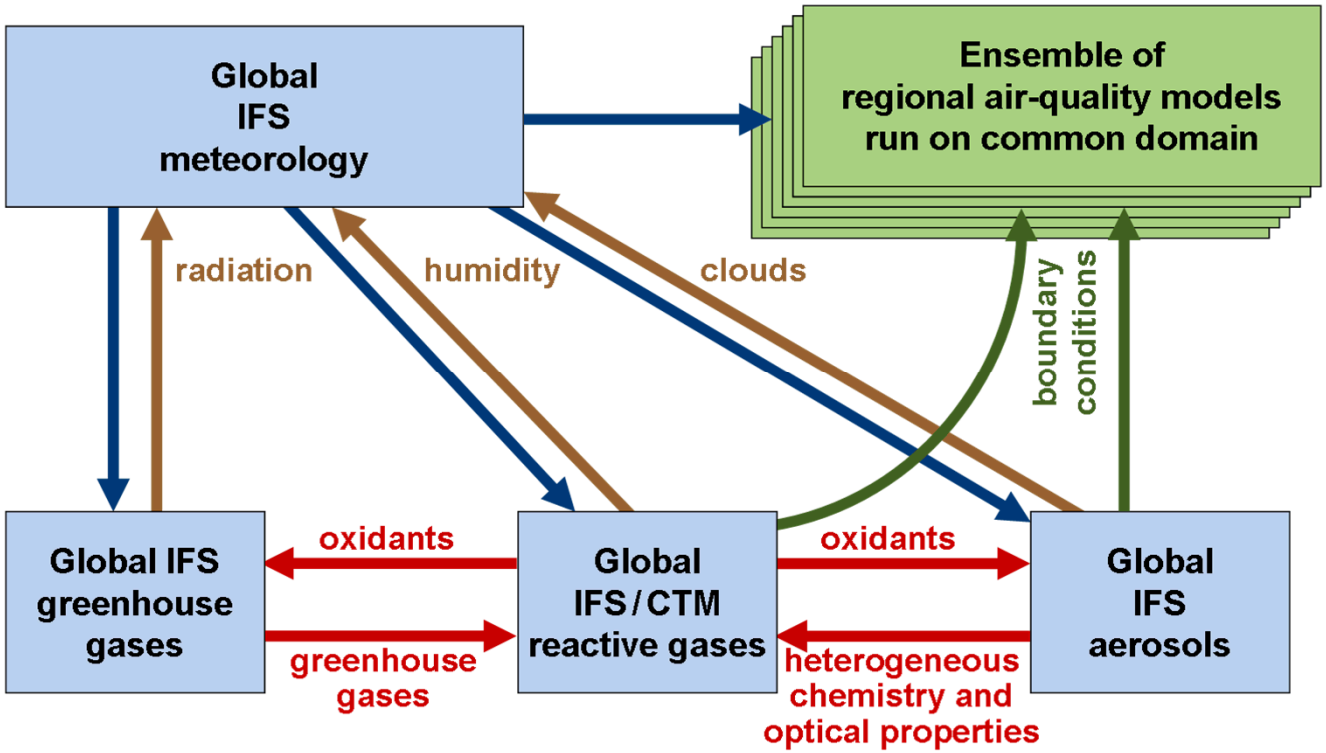
Processes

- **Transport by wind**
- **Chemical reactions**
  - dependent on sunlight, temperature, humidity, cloud particles, …
- **Deposition**
  - dependent on turbulence, rainfall, …
- **Uptake by vegetation, soils and oceans**
  - dependent on rainfall, temperature, wind, …





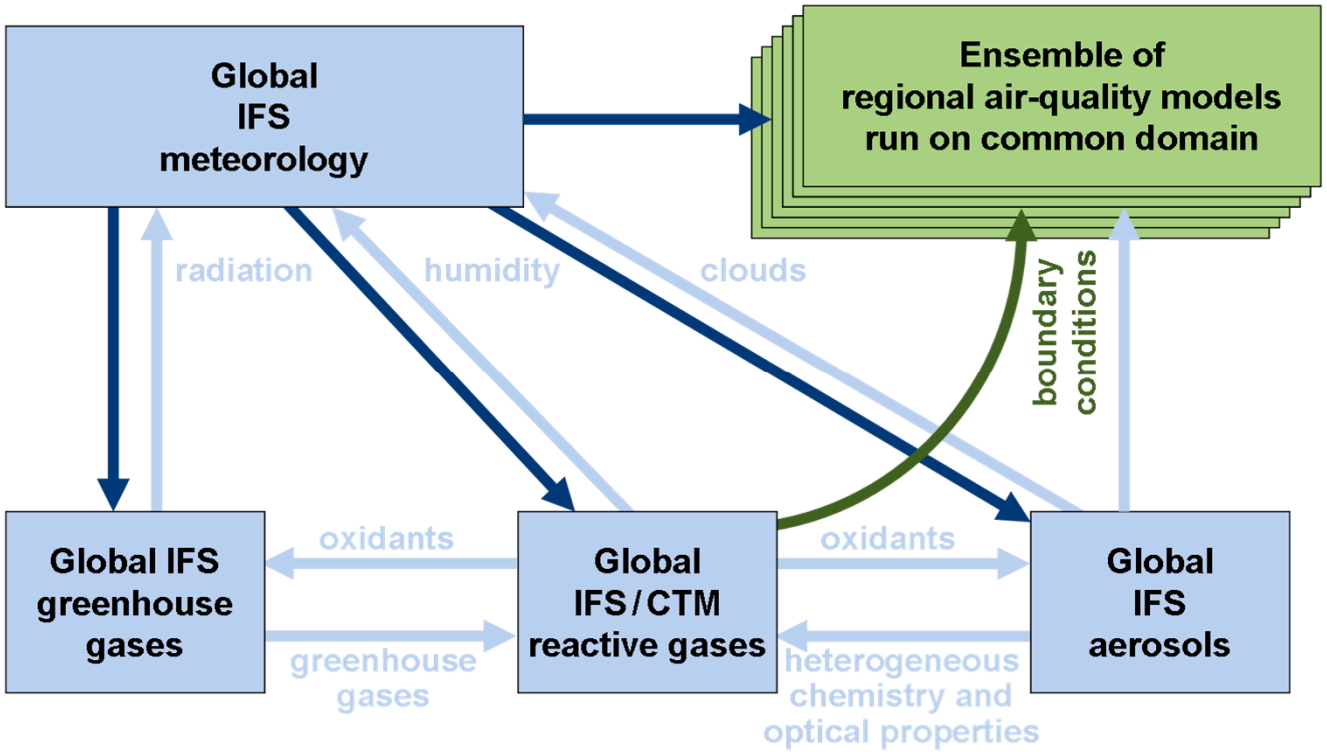
Global/regional system



Global system is based on the ECMWF Integrated Forecasting System (IFS), coupled to a global chemical transport model (CTM: MOZART, TM5 or MOCAGE)

Regional ensemble comprises a set of seven nationally developed CTMs, run on a common European domain

Global/regional system



"Climatologies" of CO_2, CH_4 and O_3 from GEMS analysis for 2003-2007 currently used in radiation parameterization of operational ECMWF system

Fully interactive ozone/radiation coming soon

Global data assimilation

- **Based on the 4D-Var scheme of the IFS**

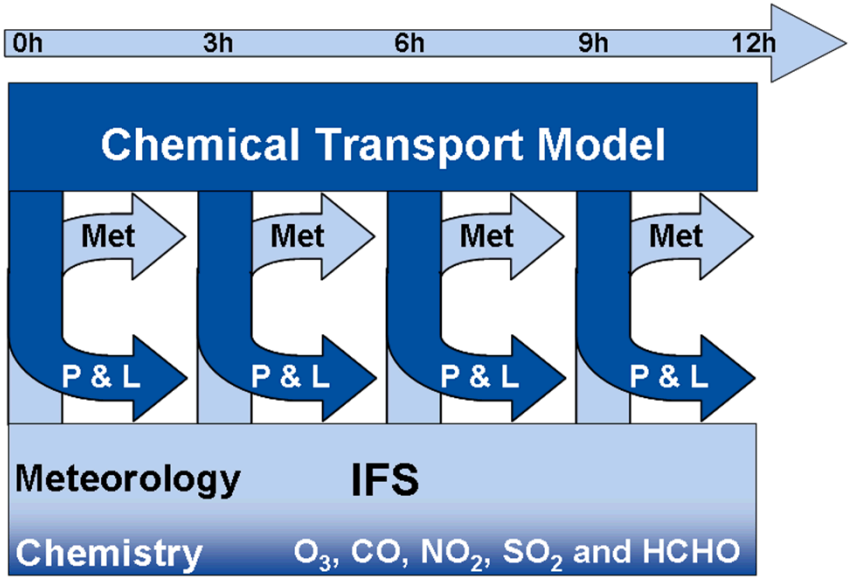
- **CO_2 , CH_4 and aerosols are incorporated in the IFS**

  Data assimilation has been developed for AIRS and IASI radiances, SCIAMACHY retrievals, MODIS aerosol optical depth, … GOSAT …

- **IFS also carries O_3, CO, NO_2, SO_2 and HCHO**

  Chemical production and loss come from the coupled CTM

  Data for assimilation come from GOME, GOME-2, IASI, MIPAS, MLS, MOPITT, OMI, SBUV/2, SCIAMACHY, …



- **Chemistry modules are being built fully into IFS**

Regional data assimilation

- **Data assimilation has been developed for all seven systems**

  Partners are FMI, INERIS/CNRS, KNMI/TNO, Météo-France/CERFACS, met.no, RIUUK, SMHI

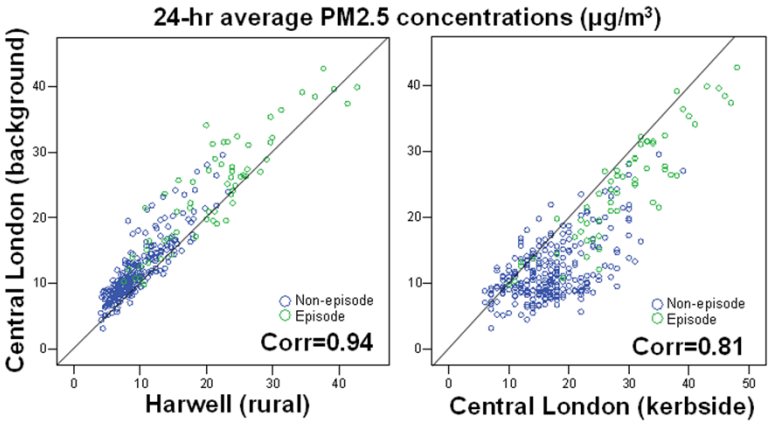
- **Methods and maturity vary**

  OI, 3D-Var, 4D-Var, EnKF

- **Surface measurements of air quality are primary assimilated data**

  Site representativity is a key issue

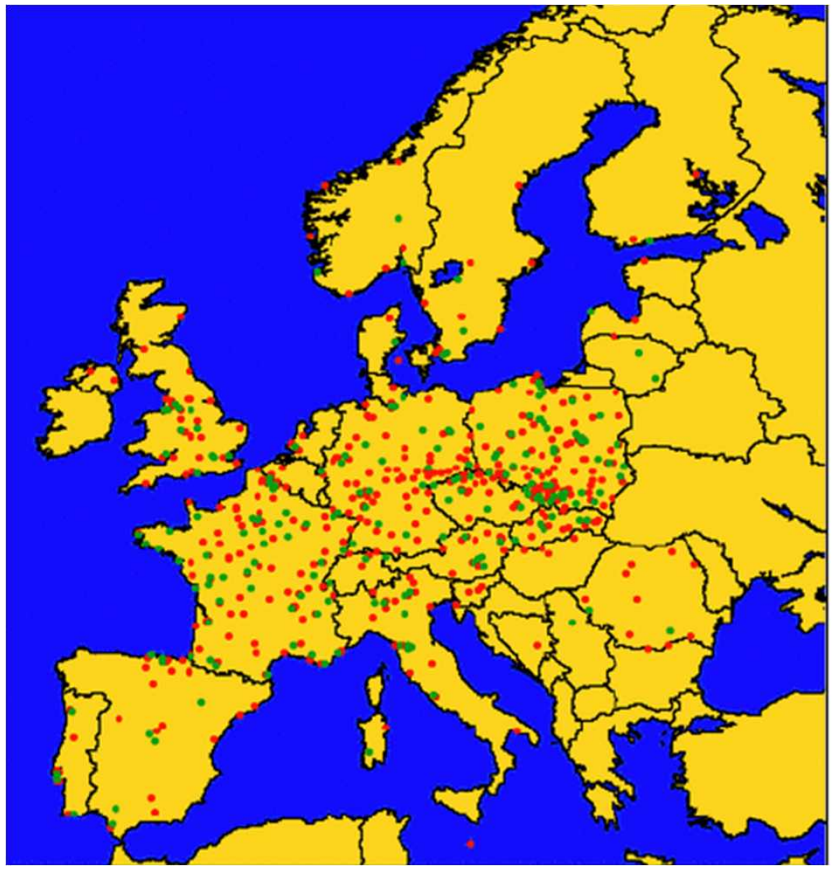
  Data access issues have had to be solved



- **Some use of satellite and other data, to be expanded in MACC-II**

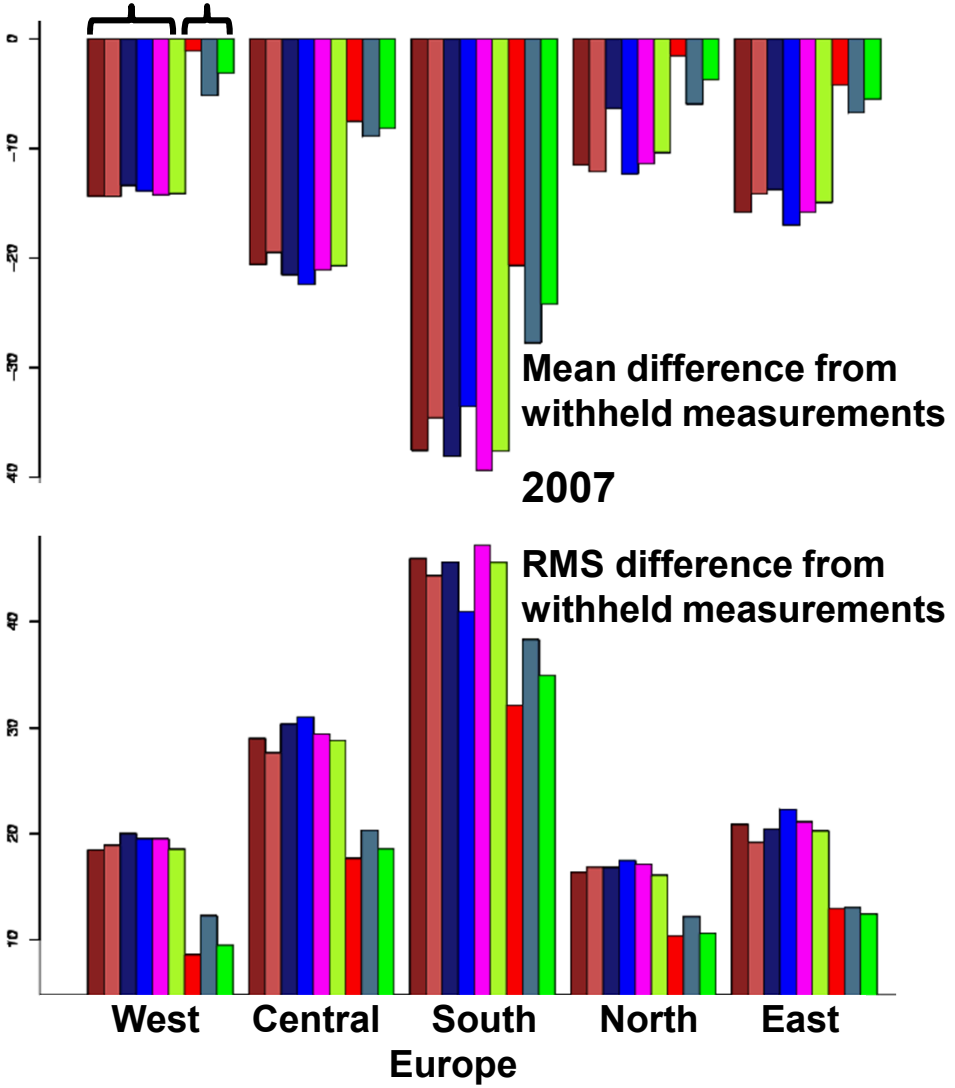
Regional analysis assessment

Background urban PM10 measurement sites
Red: assimilated
Green: withheld for validation



Courtesy of Laurence Rouïl, INERIS

Without & with assimilation of PM10 measurements

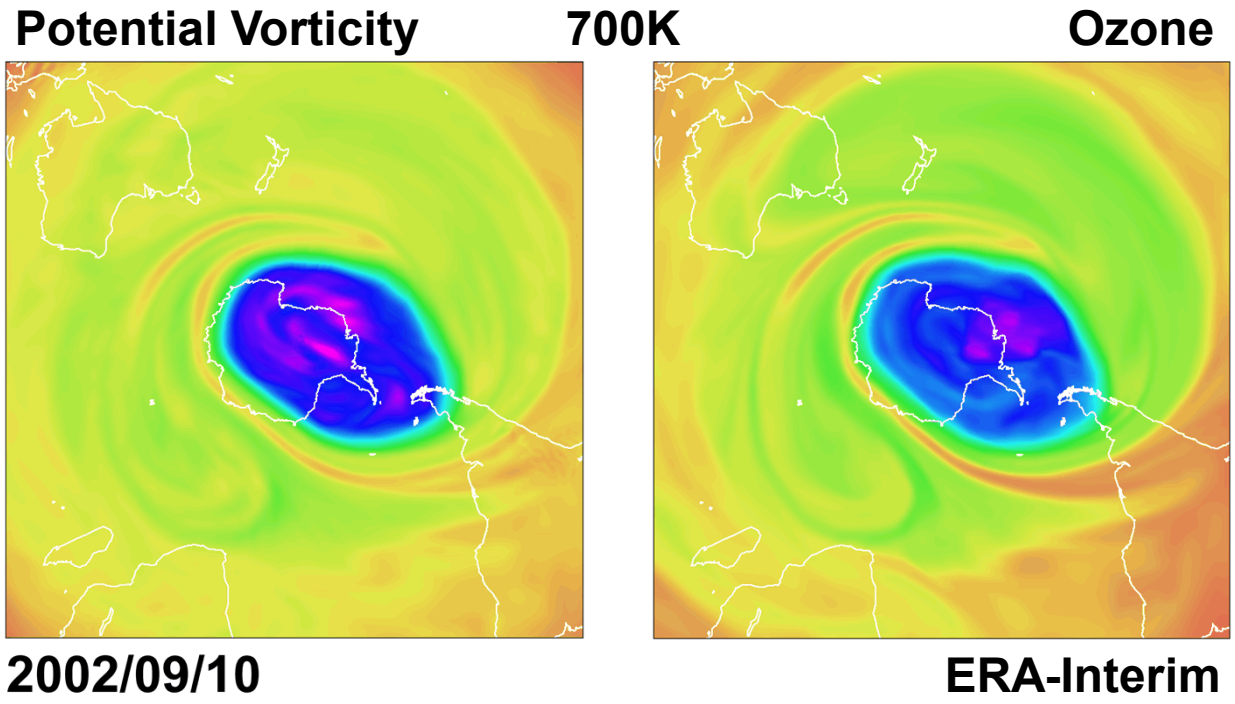


Primary production streams

- **Near-real-time analysis and forecasting**
  - global system
  - ensemble of regional systems
- **Delayed-mode analysis**
  - global system is run again about six months behind time
  - allows assimilation of delayed data
  - particularly for estimation of surface flux corrections for greenhouse gases and aerosols
- **Reanalysis**
  - global, for 2003-2010
  - regional, 2007 onwards, for annual assessment of European air quality

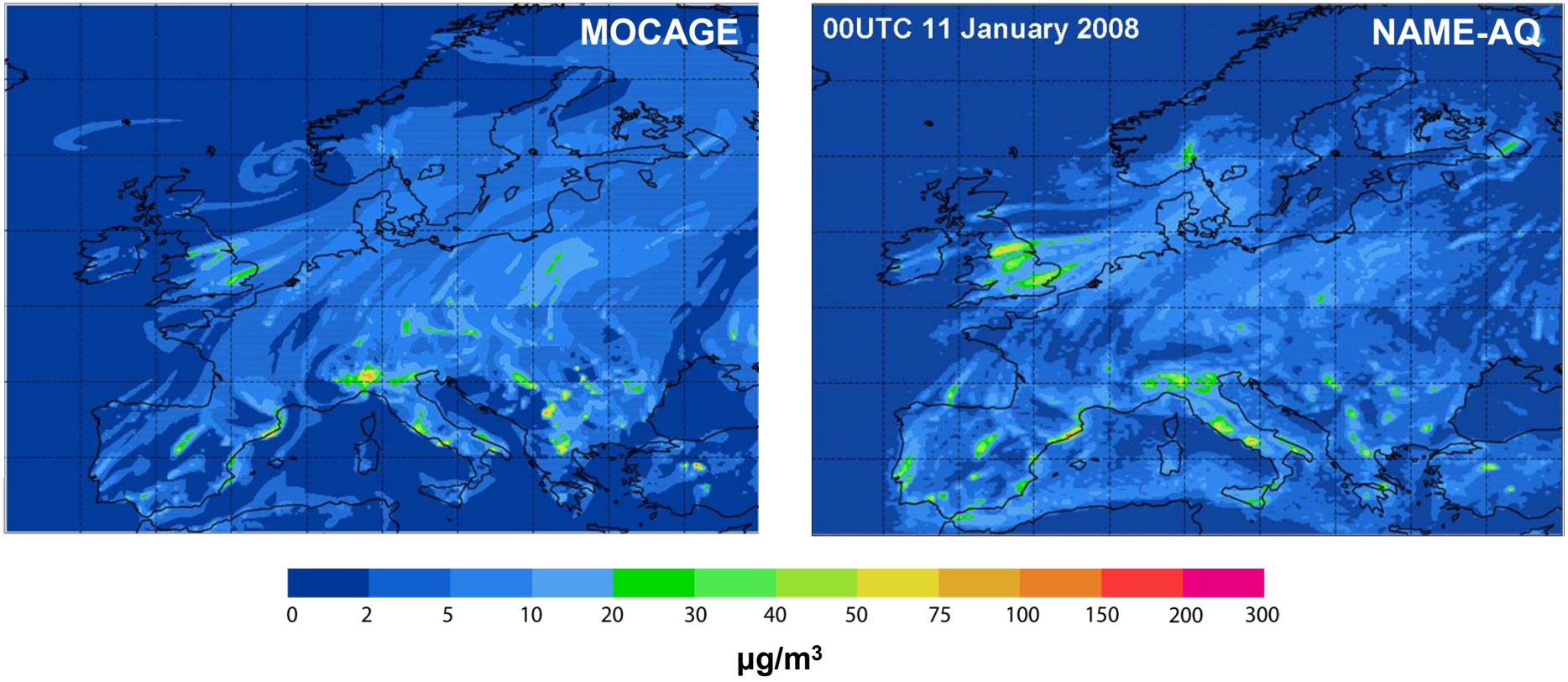
Extracting wind information in 4D-Var

- **Demonstrated from upper tropospheric humidity observations**
  - by Thépaut (1992)
- **An early motivation for assimilating lower stratospheric ozone data**
  - proposed by Riishøjgaard (1996), investigated by Hólm (1999)
  - demonstrated by Semane et al. (2009) using MLS data



Two of the first three members of the GEMS regional ensemble

3-day forecasts of surface NO_2 from 00UTC 11 January 2008

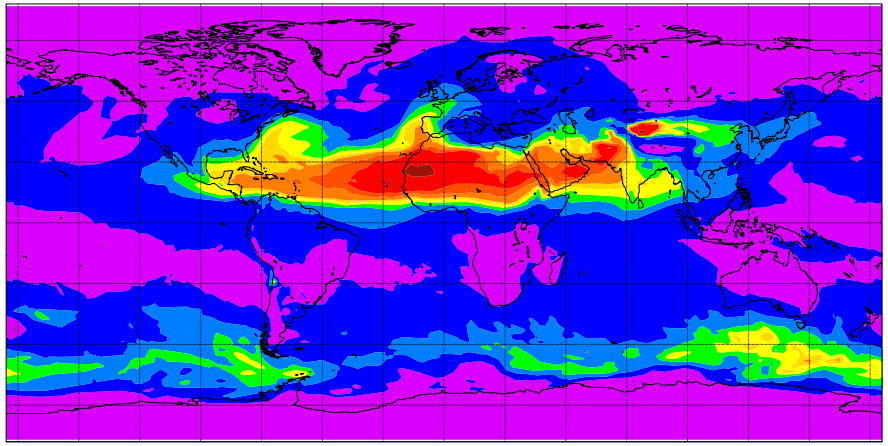


Global 4D-Var formulation

- **Resolutely univariate**
  - not only through J_b
  - link from tracer observation to wind increment via adjoint of tracer advection is cut
- **J_b is predominantly from application of "NMC" method**
  - following Parrish and Derber (1992)
  - variances adjusted to avoid large increments at uppermost levels
- **Ozone J_b is taken from ECMWF operational system**
  - from ensemble of data assimilations
  - based on much simpler O_3 chemistry
- **No chemistry in inner-loop model**
  - O_3 and CO are first candidates for this

An early test of aerosol data assimilation

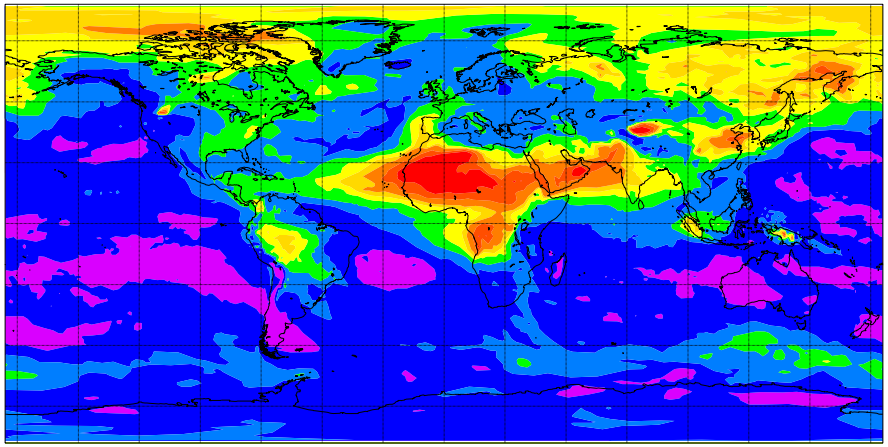
without assimilation of aerosol data

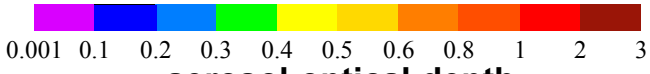


Assimilation increased values over north-east Asia, Central Africa and America, and reduced values over tropical Atlantic and Southern Ocean

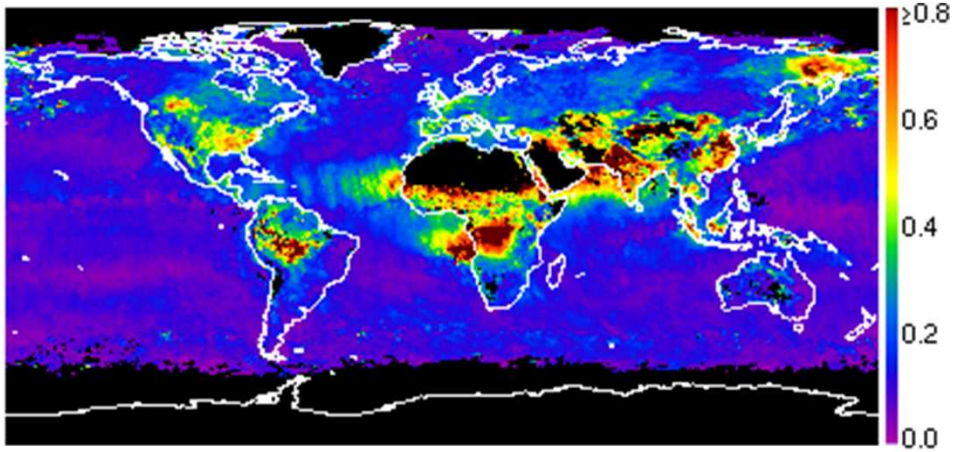
Accumulation in Arctic required investigation (Benedetti et al., 2009)

with assimilation of aerosol data



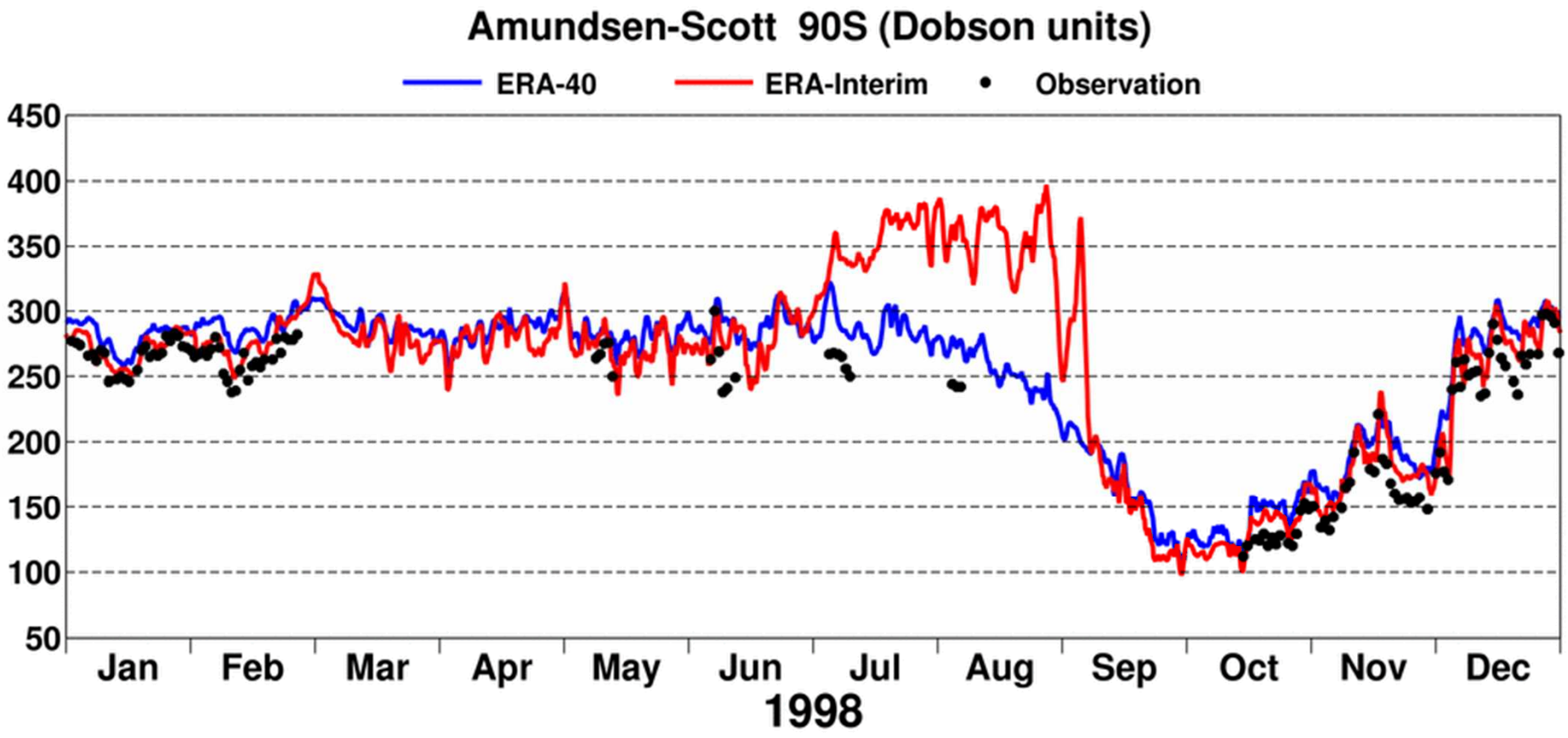


MODIS observations



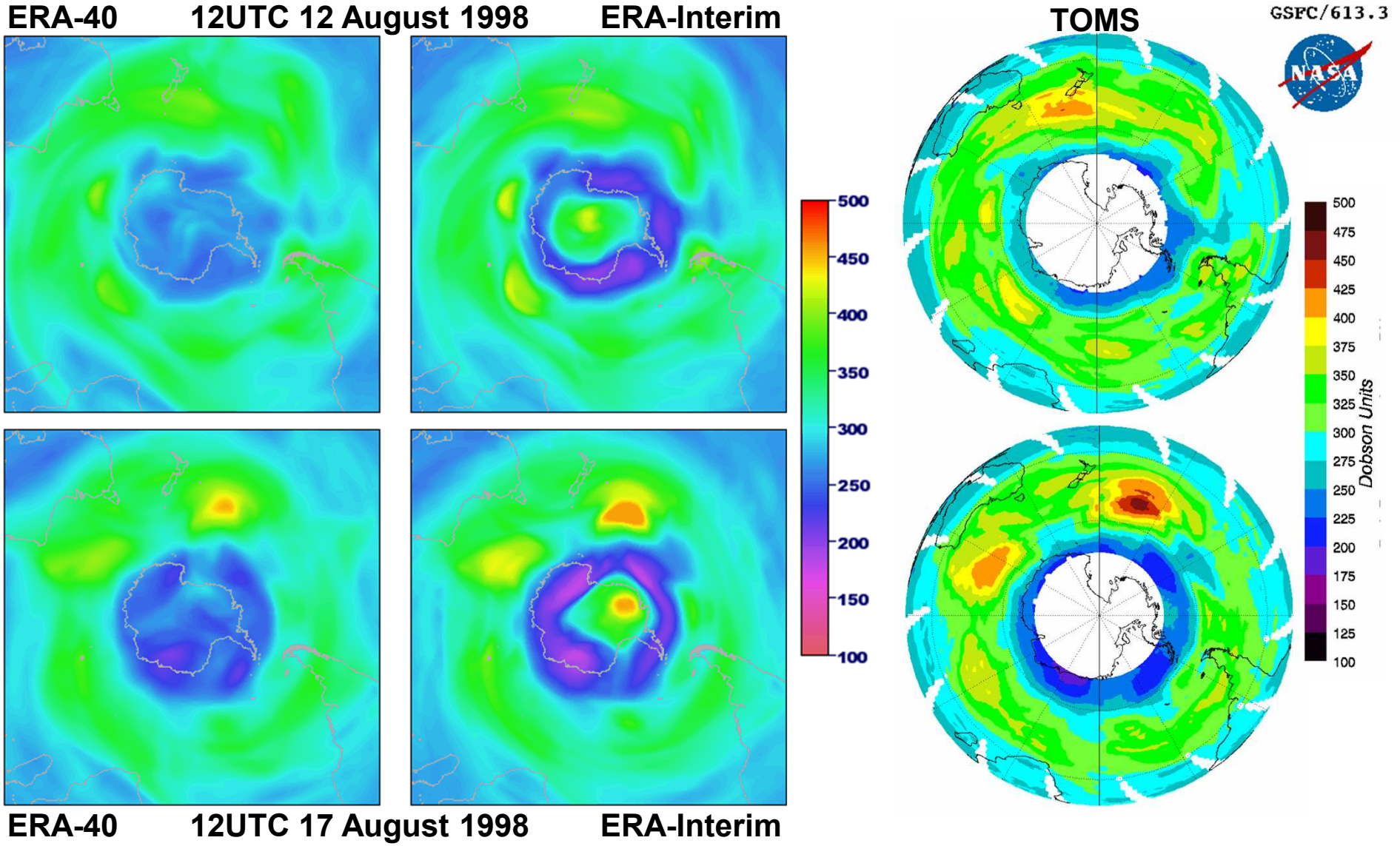
Experiments are averaged from 1 to 15 August 2003

Total column ozone



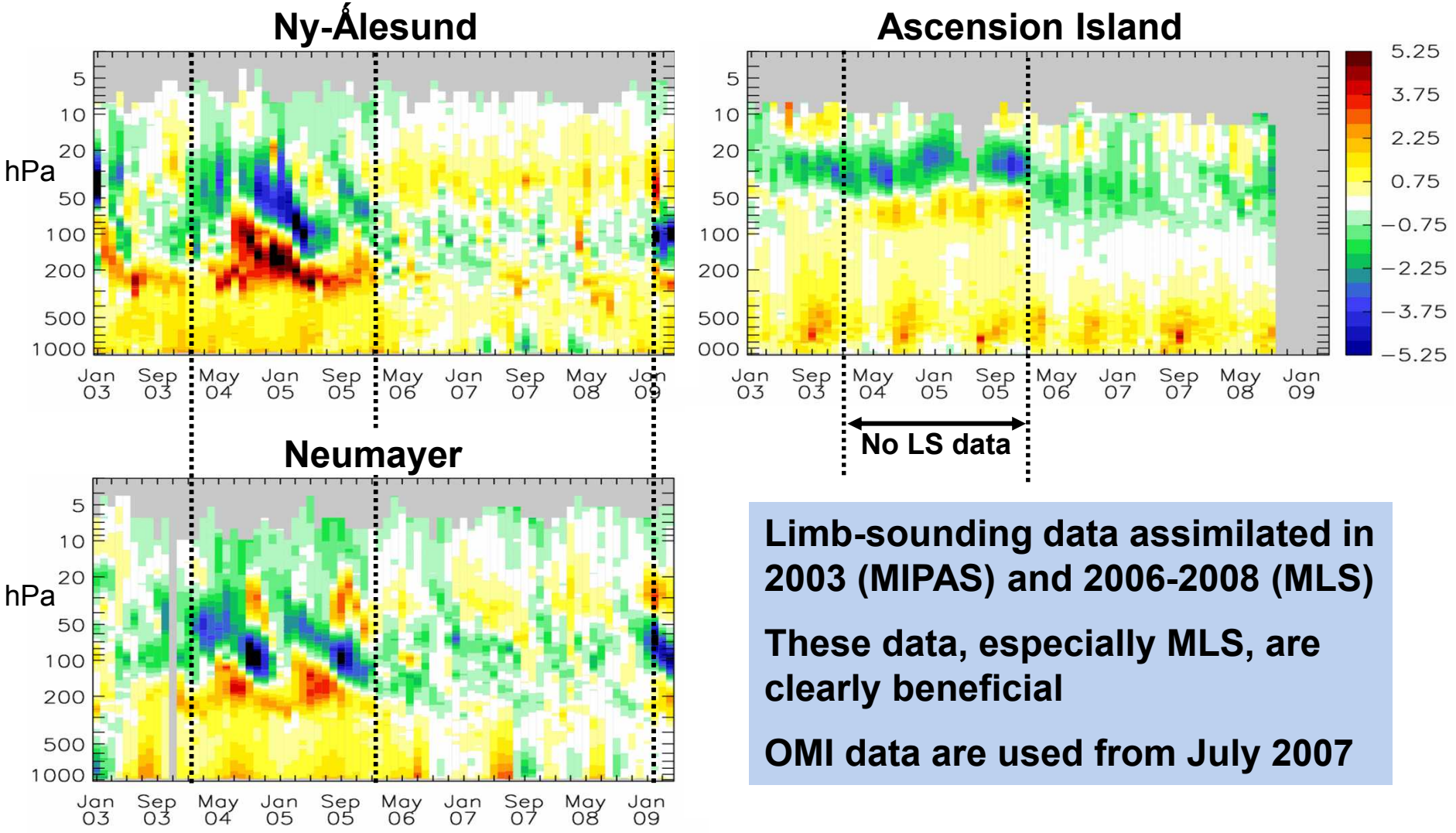
Dobson spectrophotometer observations from NOAA/ESRL

Total column ozone



Comparison with ozonesonde data

Pressure/time cross-sections of monthly-mean (ozonesonde-analysis) values



Limb-sounding data assimilated in 2003 (MIPAS) and 2006-2008 (MLS)

These data, especially MLS, are clearly beneficial

OMI data are used from July 2007

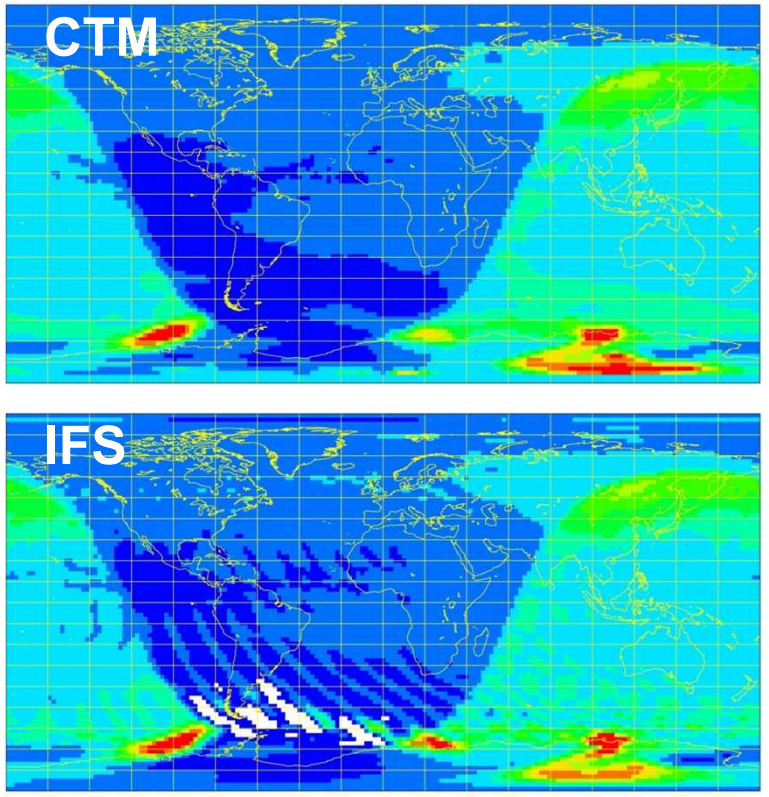
Control variables

- Fast conversion between NO_2 and NO is problematic in coupled IFS/CTM approach (Flemming et al. 2009; Inness et al., 2009)

- Chosen control variable is log([NO_X]), where [NO_x] = [NO] + [NO_2]

- Uses diagnostic relationship for NO and NO_2 increments, based on:

$$\frac{[NO_2]}{[NO_X]} = \frac{k[O_3]}{J_{NO_2} + k[O_3]}$$



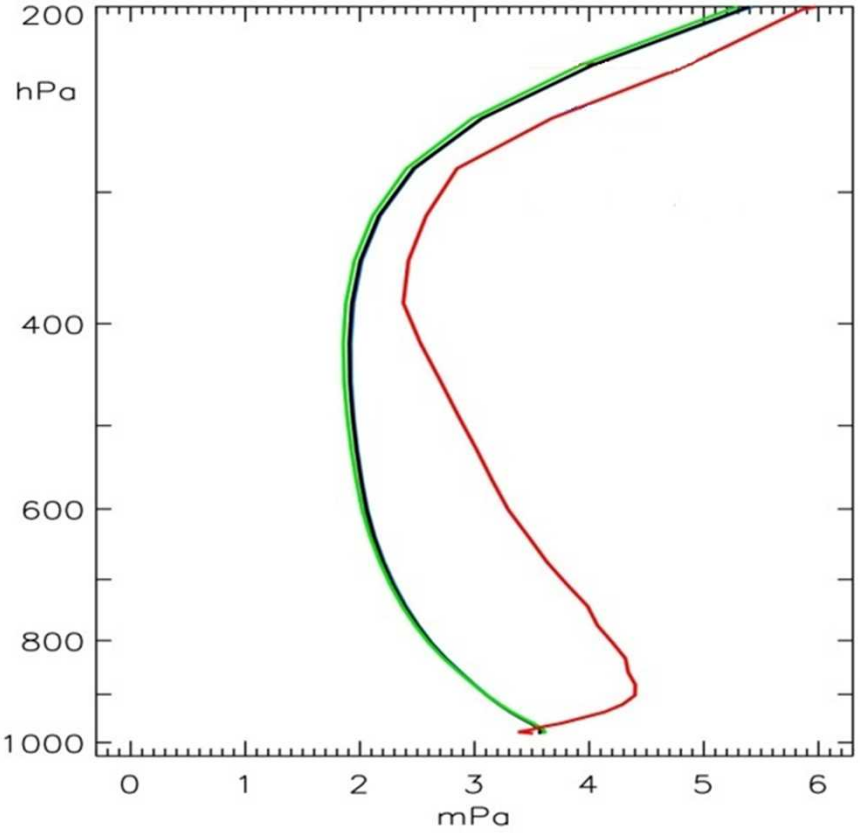
15h NO_2 forecast at 5hPa

where k is rate of reaction $NO + O_3 \rightarrow NO_2 + O_2$

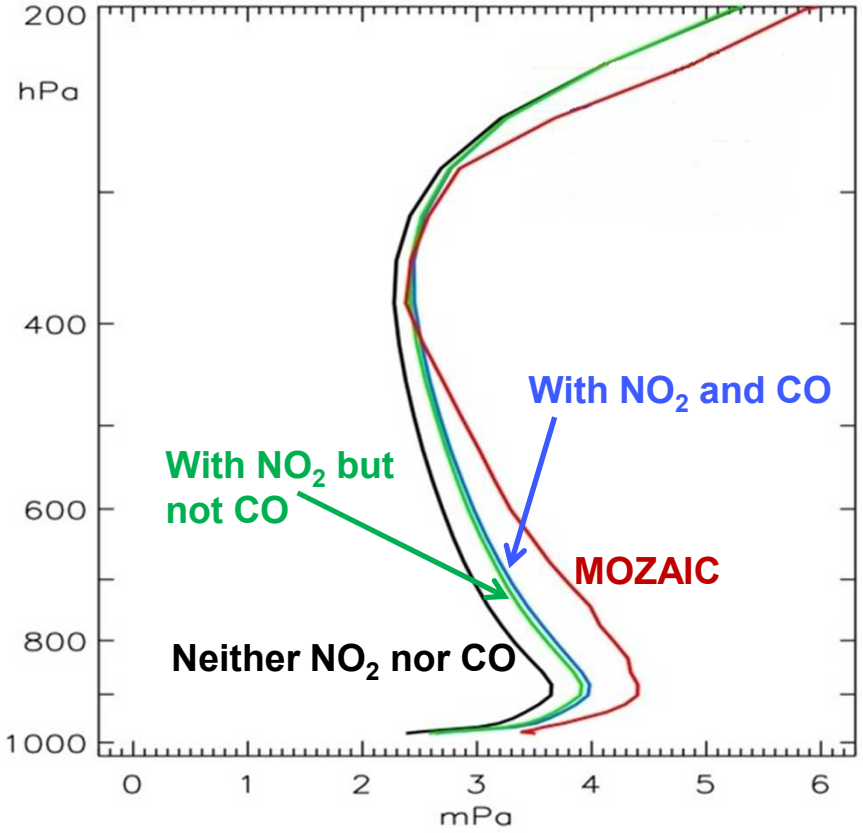
J_{NO_2} is photolysis rate, dependent on surface albedo, solar zenith angle, overlying ozone, cloud optical properties, temperature

Chemical coupling in background forecast for ozone analysis

Mean ozone profiles for 371 ascents or descents of MOZAIC aircraft Frankfurt, February to June, 2003



Operational IFS ozone scheme



MACC IFS/MOZART chemistry

Dust forecasting

BBC Low graphics | Help

NEWS LIVE BBC NEWS CHANNEL

News Front Page

Page last updated at 10:42 GMT, Wednesday, 23 September

Desert dust storm chokes Sydney

Sydney's red dust has been blown from the outback

A large stretch of Australia's east coast, including the largest city Sydney, has been shrouded in red dust blown in from the desert outback.

Visibility in Sydney was so bad that flights were diverted and harbour ferry traffic disrupted.

ABC News

NewsRadio Now playing

Video

News Home | Just In | Australia | World | Business | Entertainment | Weather

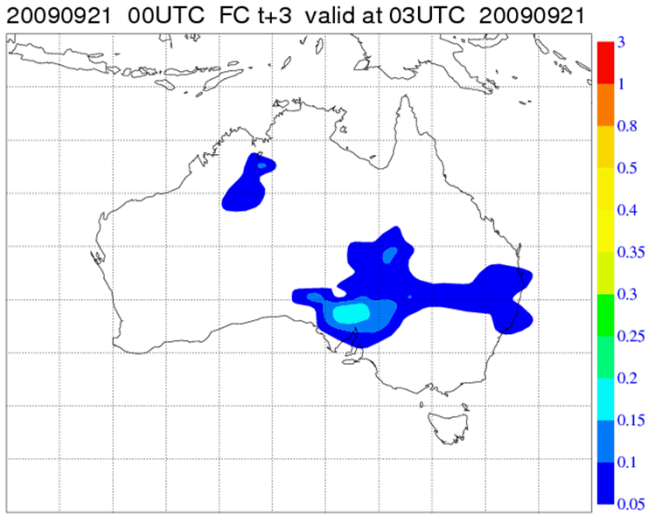
Dept admits error in air quality forecast

Posted 11 hours 54 minutes ago
Updated 11 hours 51 minutes ago

The New South Wales Environment Department has admitted its forecast for air quality in Sydney today was wildly wrong after a dust storm prompted hundreds of emergency calls due to breathing difficulties.

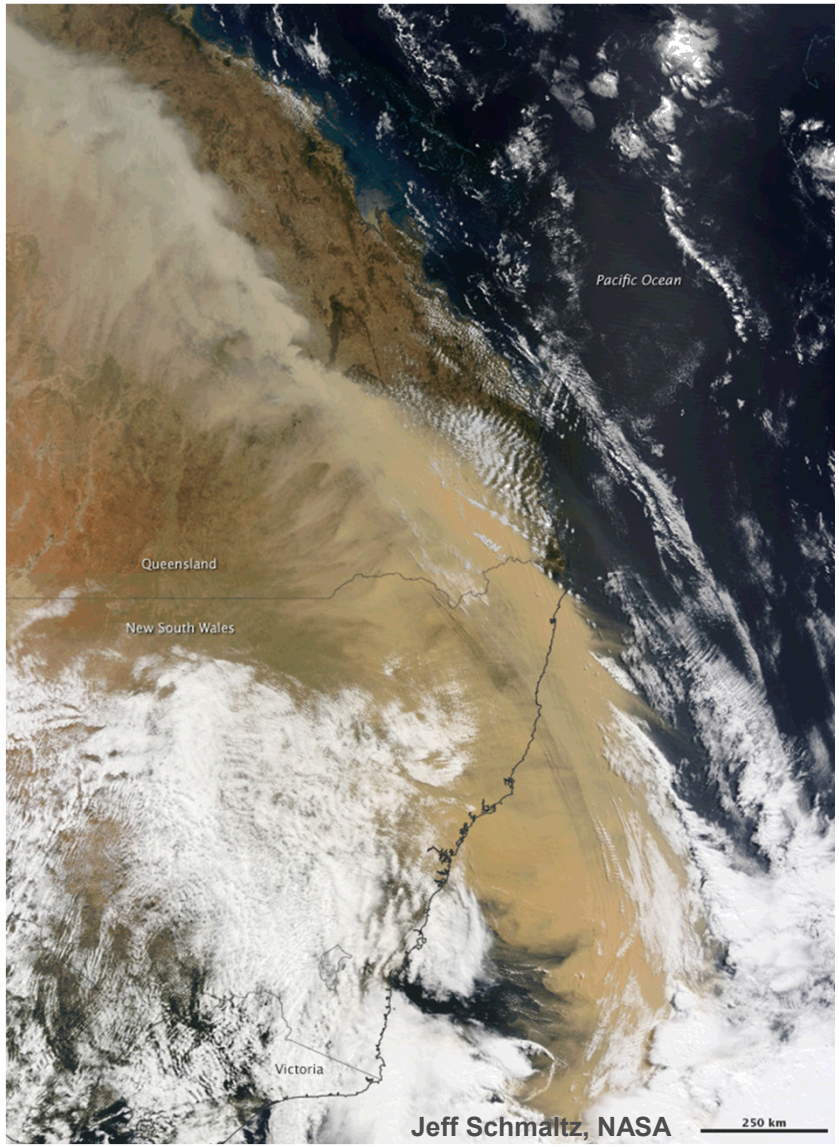
Audio: Respiratory expert Dr Christine Jenkins speaks to ABC Local Radio (ABC News)

Until this morning, the department's website was forecasting conditions would be good.

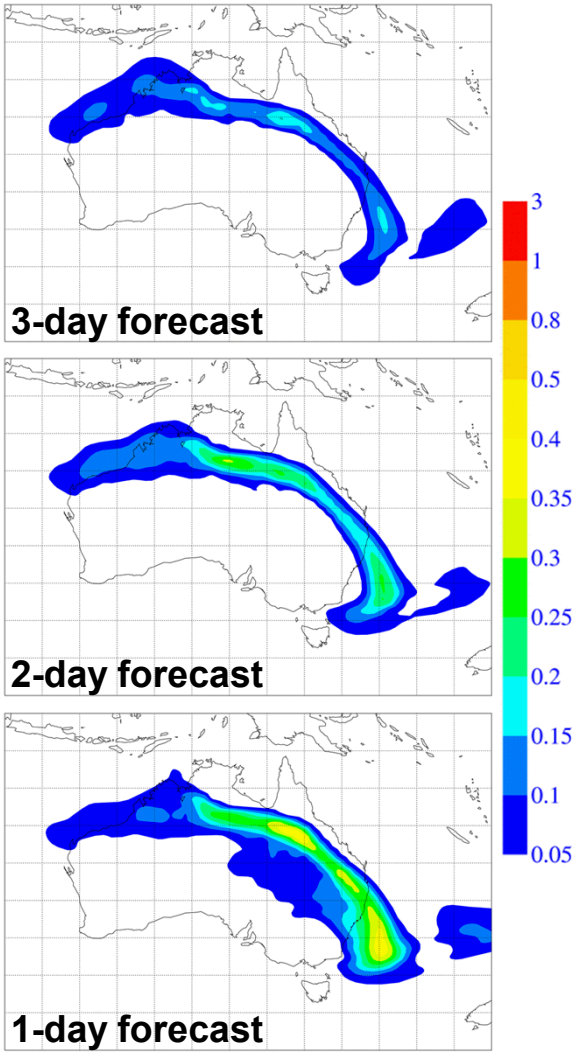


MACC dust aerosol optical depth

Australian dust storm



Dust aerosol optical depth 00UTC 23 September



Dust-band is consistently located in successive forecasts, but intensity is lower at longer ranges

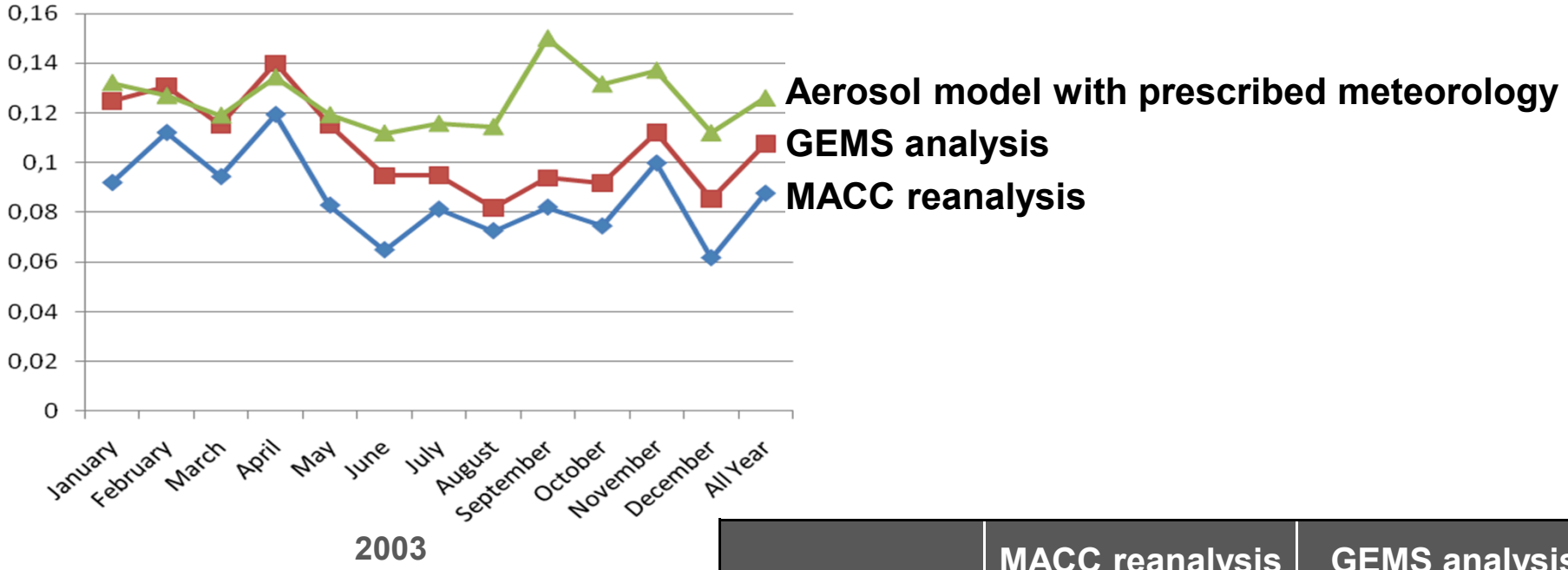
Underestimation of dust in background forecast is corrected by assimilating MODIS and other data

Possible factors:

- parameterization of dust mobilization or sedimentation
- resolution of global system (~125km grid)
- soil moisture analysis
- aerosol retrieval over bright surfaces

Measures of improvement of aerosol assimilation from reanalysis

RMS error of AOD over 18 AERONET stations

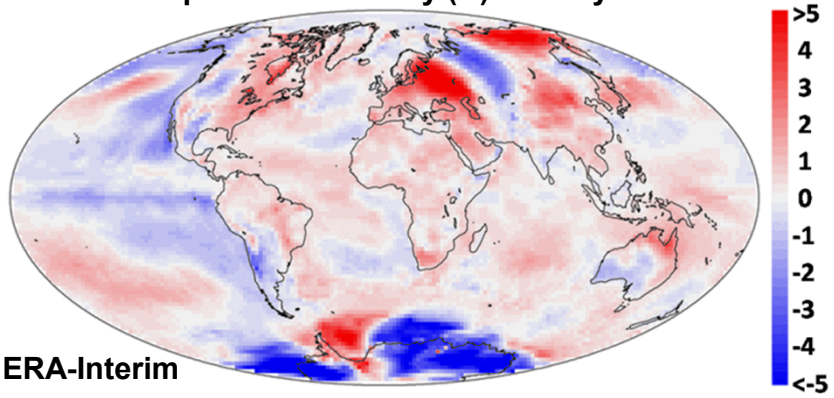


	MACC reanalysis	GEMS analysis
OBS mean	0.211	0.211
MODEL mean	0.216	0.264
RMS error	0.088	0.107
Mean BIAS	0.005	0.053
Correlation	0.858	0.830
SDEV	0.087	0.094

Courtesy of Nicolas Huneuus, LSCE

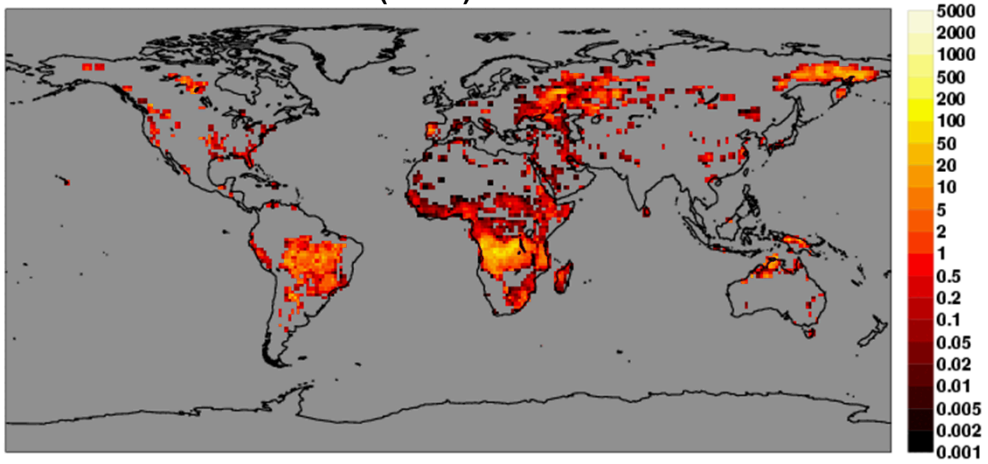
2010 fires over Russia

2m temperature anomaly (C) for July 2010

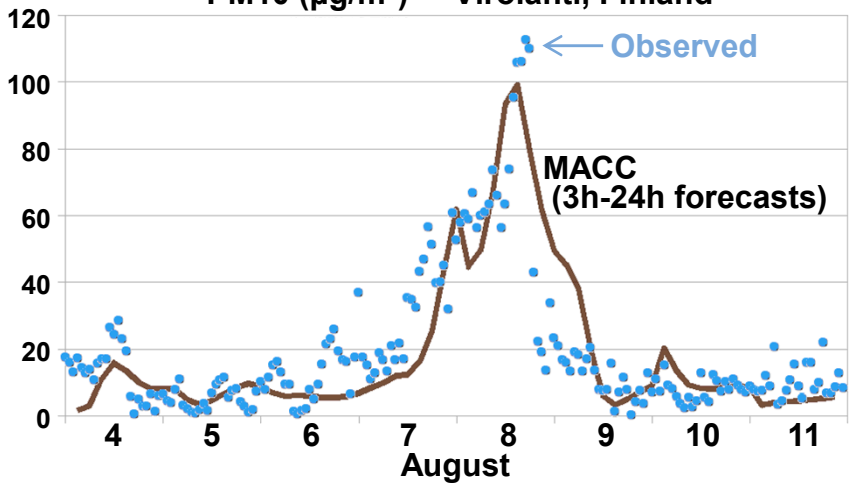


ERA-Interim

Fire Radiative Power (Wm^{-2}) from SEVIRI and MODIS

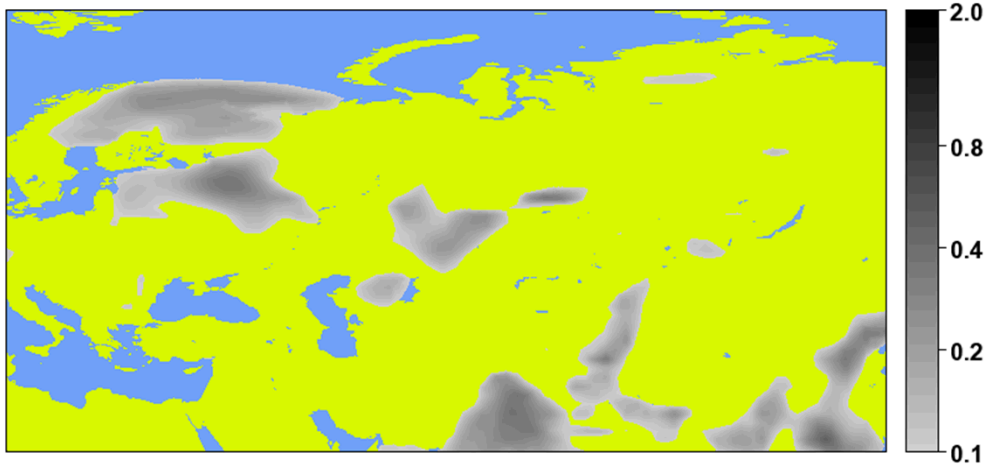


PM10 ($\mu g/m^3$) Virolahti, Finland



2010072603

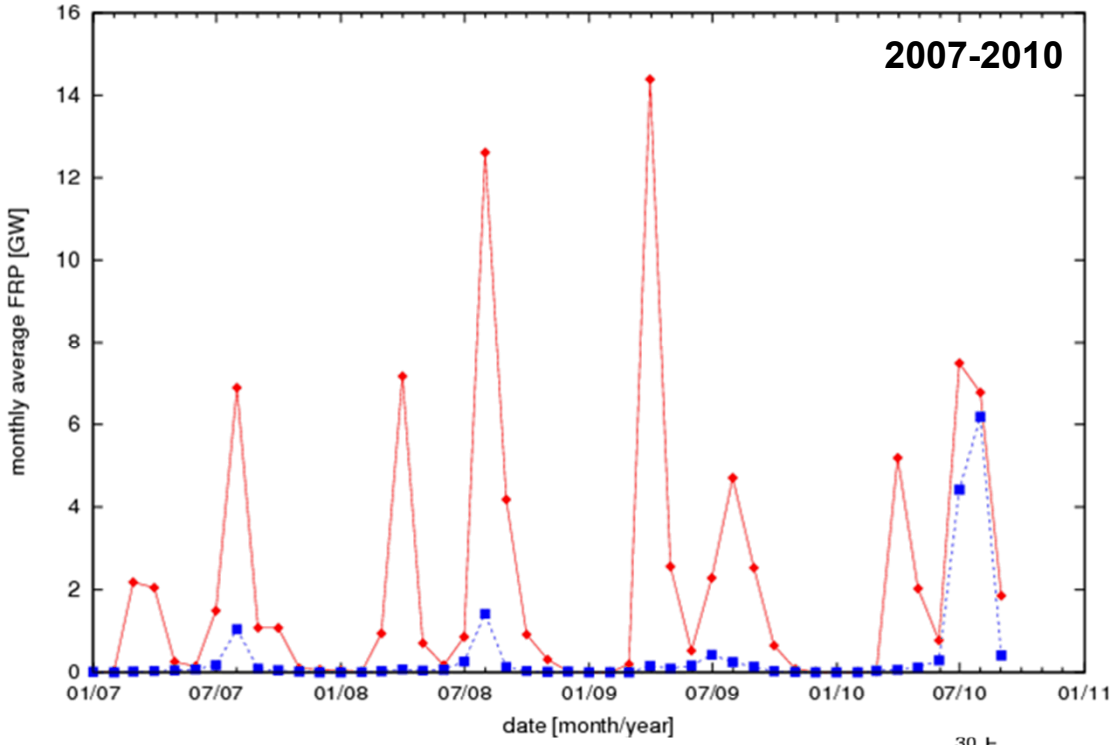
Aerosol optical depth due to black carbon and organic matter



Kaiser et al. (2011)

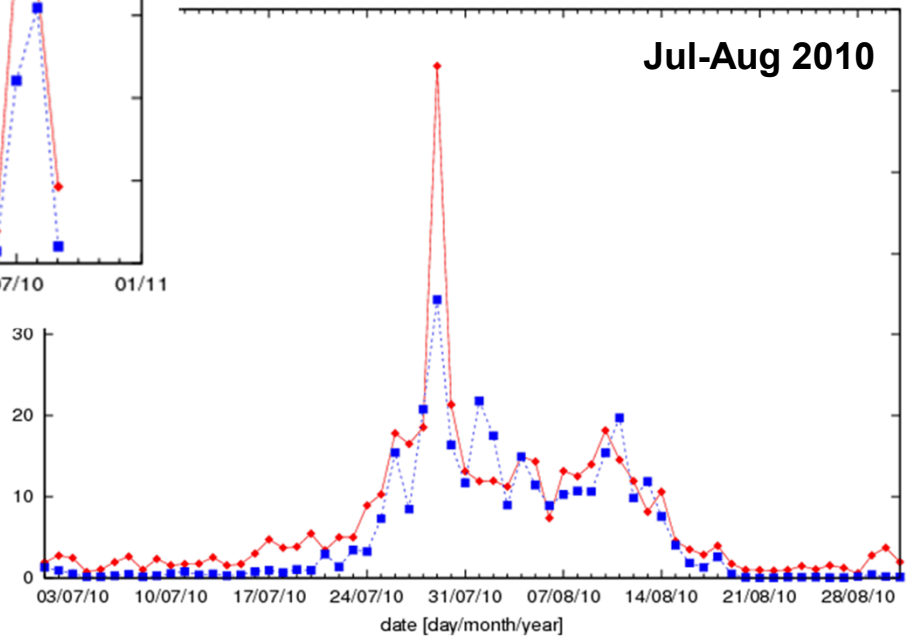
2010 fires over Russia

Fire radiative power from MODIS, east of Moscow (50-60N, 35-55E)



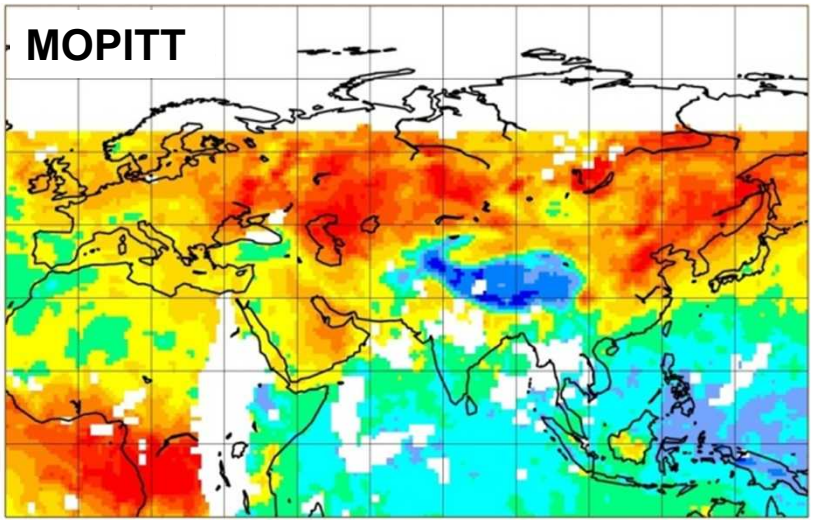
Day (04-16UTC)
Night (16-04UTC)

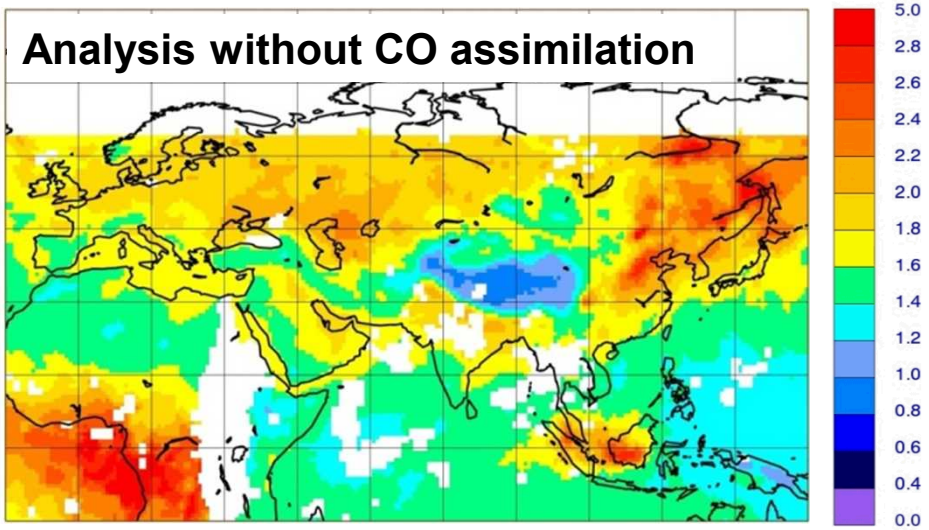
Large night-time values are indicative of peat fires

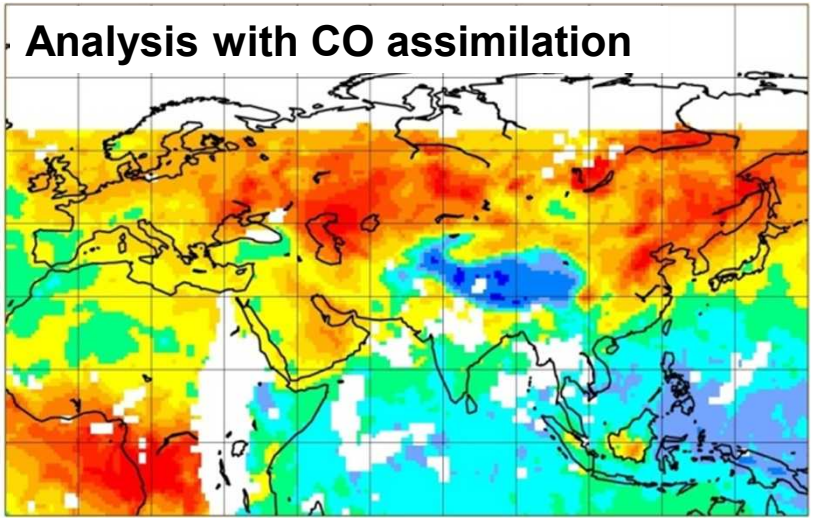


Modelled emissions were those appropriate to woodland fires

2010 fires over Russia



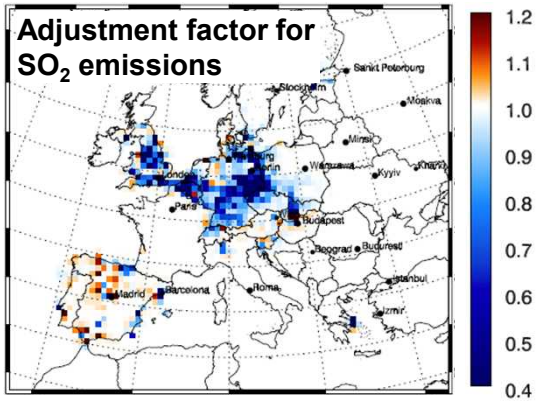




CO (10^{18} molec/cm^2)
Averaged from 1-17 August 2010

The challenge of estimating emissions

- **Generalization of 4D-Var to determine corrections for the emissions over the assimilation window, as well as determine the initial state and possibly bias corrections**
  - for fast-reacting gases important for air quality



  - for more slowly varying greenhouse gases

doi:10.5194/acp-7-3749-2007

Emission rate and chemical state estimation by 4-dimensional variational inversion

H. Elbern[1], A. Strunk[1], H. Schmidt[1,*], and O. Talagrand[2]

[1]Rhenish Institute for Environmental Research at the University of Cologne, Köln, Germany

[2]Laboratoire de Meteorologie Dynamique, Paris, France

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 114, D22301, doi:10.1029/2009JD012287, 2009

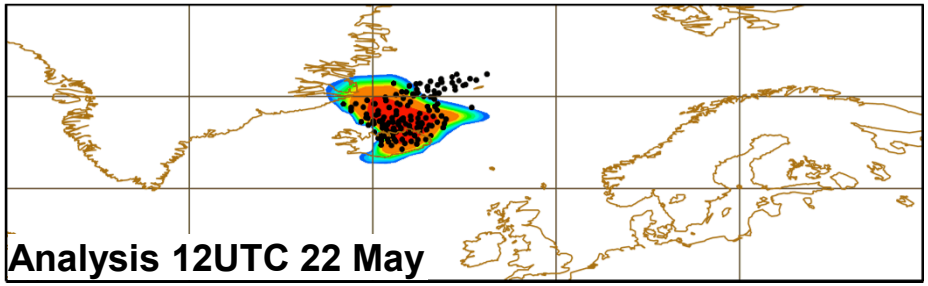
Inverse modeling of global and regional CH_4 emissions using SCIAMACHY satellite retrievals

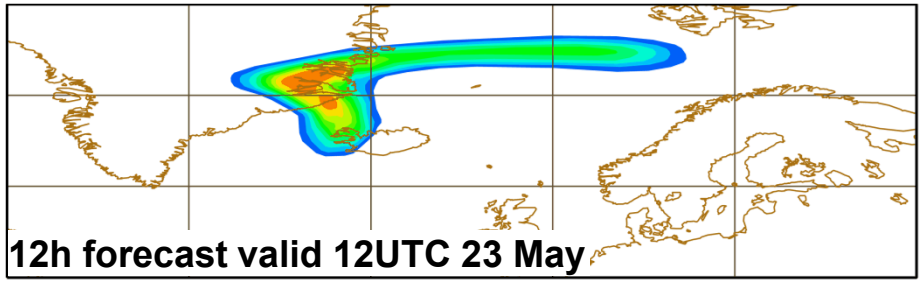
Peter Bergamaschi,[1] Christian Frankenberg,[2] Jan Fokke Meirink,[3] Maarten Krol,[2,4,5] M. Gabriella Villani,[1] Sander Houweling,[2,5] Frank Dentener,[1] Edward J. Dlugokencky,[6] John B. Miller,[6,7] Luciana V. Gatti,[8] Andreas Engel,[9] and Ingeborg Levin[10]

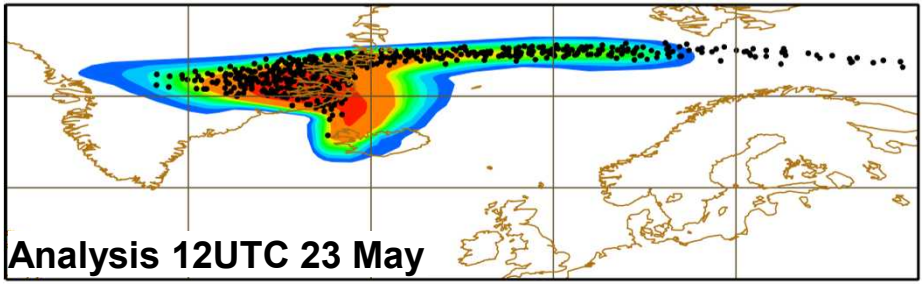
The challenge of estimating emissions: Grimsvötn, 2011

SO_2

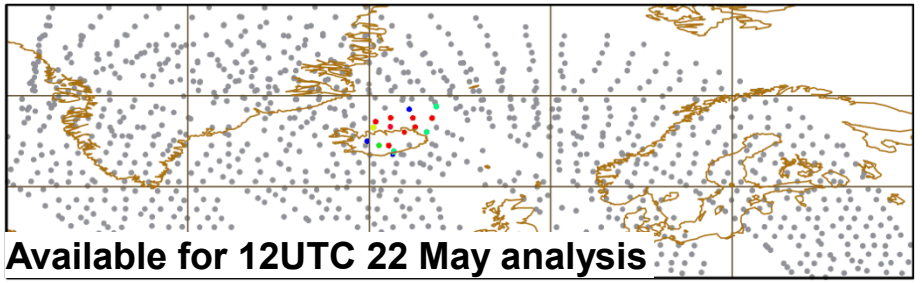
Model values and IASI detection

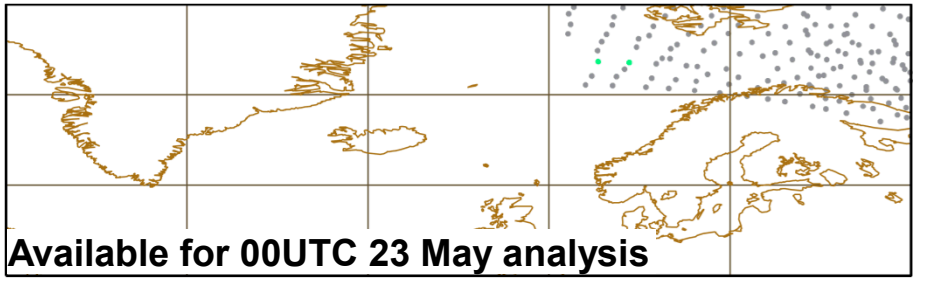


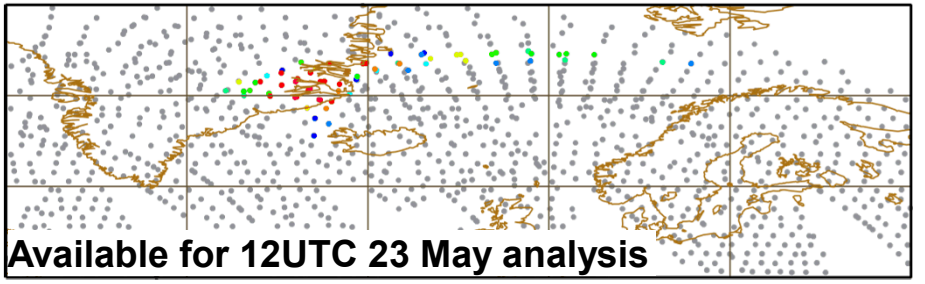




OMI observations



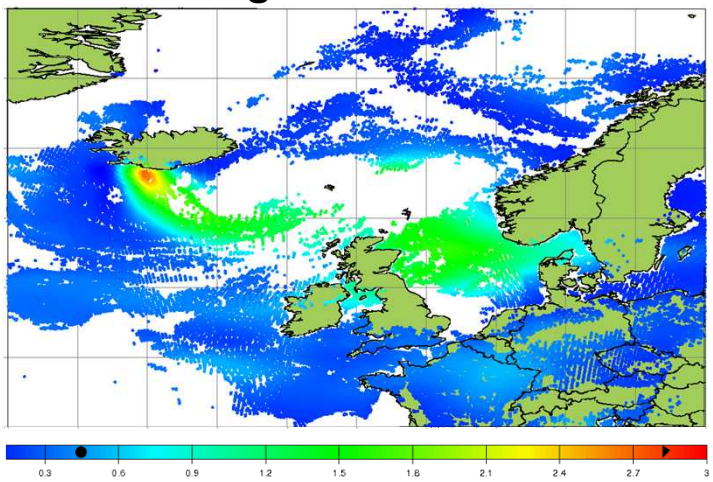




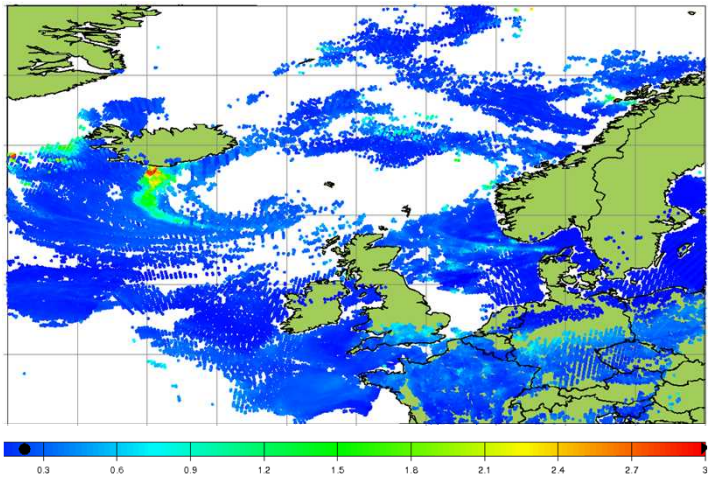
Eyjafjallajökull

Aerosol Optical Depth 12UTC 19 April 2010

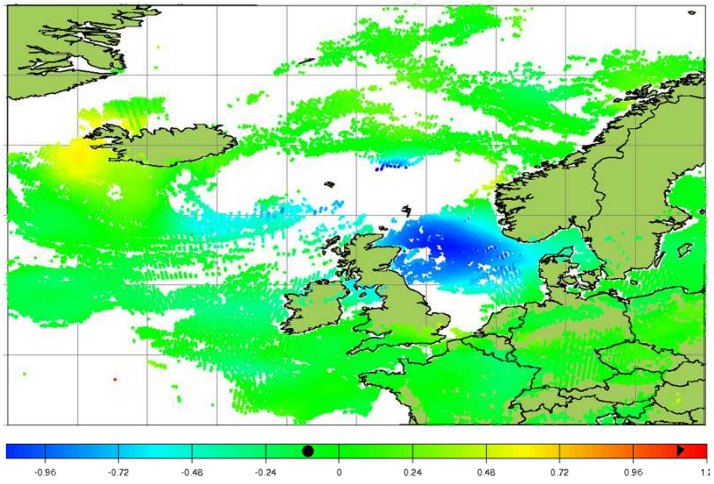
Background forecast



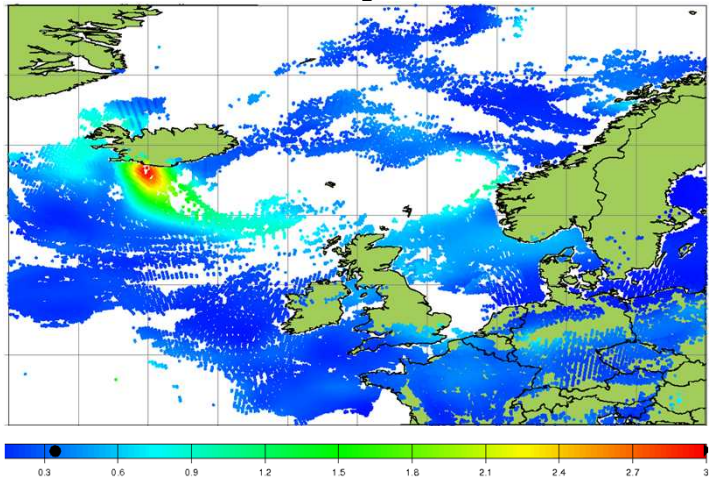
MODIS Terra and Aqua



Increment



Analysis



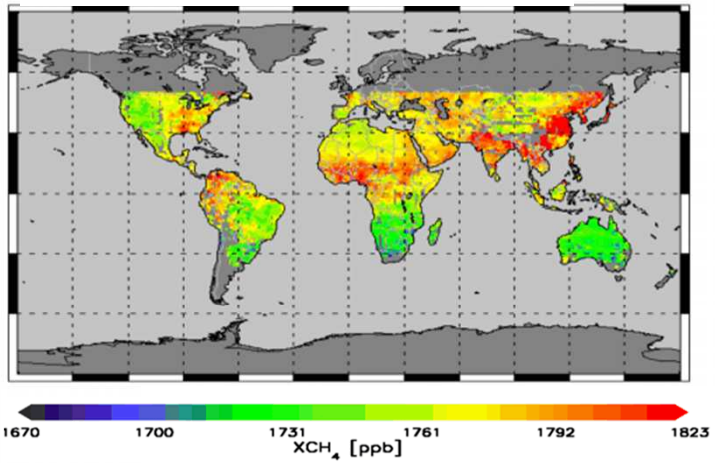
From run with volcanic source in model

Data assimilation was cycled with no data thinning but with variational quality control

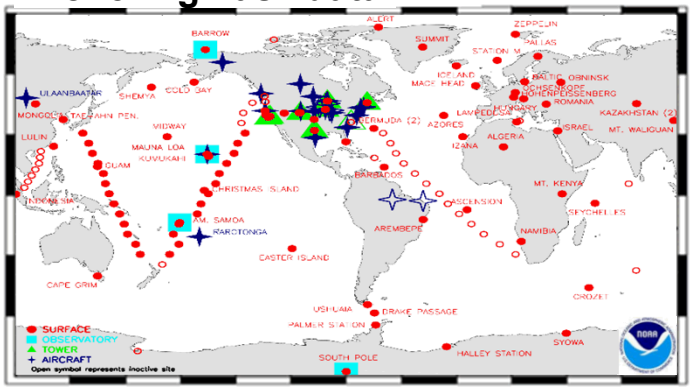
Variational quality control was switched off for the final cycle to force in all observations

A year of methane flux inversion

ESA/SCIAMACHY satellite data

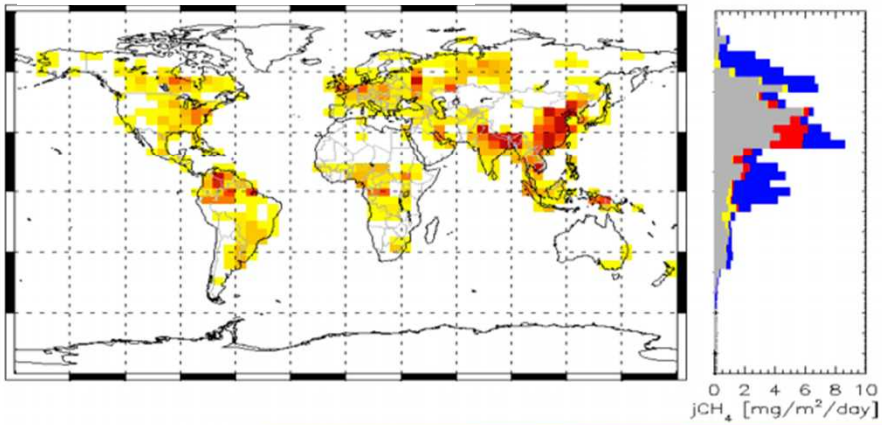


Anchoring flask data

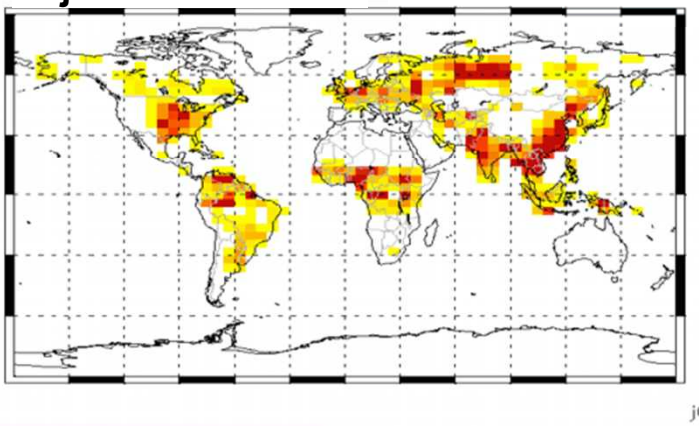


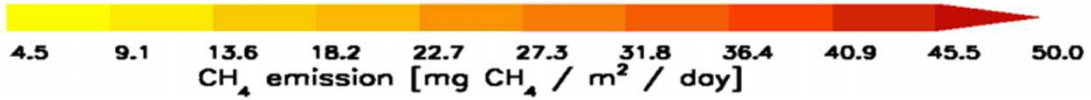
NOAA Earth System Research Laboratory global cooperative air sampling network

Prior modelled emissions



Adjusted emissions



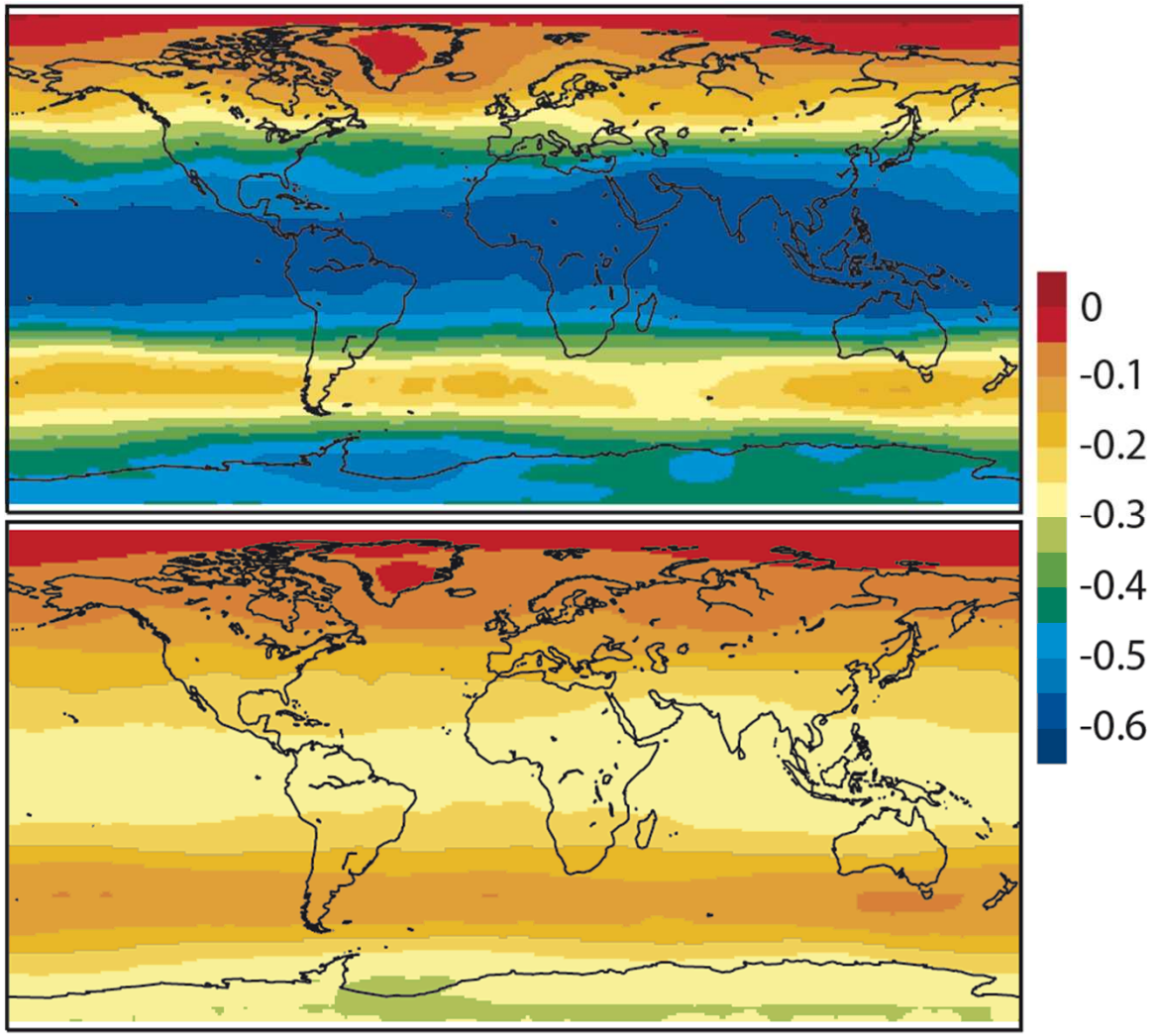


Courtesy of Peter Bergamaschi, JRC

Potential coupling through bias correction of infrared radiance data

Bias correction using fixed CO_2 of 377 ppm, the value prescribed in RTTOV

Bias correction using variable CO_2 modelled with MACC system



Mean bias correction (K) for August 2009 for AIRS channel 175 (699.7 cm^{-1}; maximum temperature sensitivity at ~ 200 hPa)

Engelen and Bauer (2011)

Concluding remarks

Deforestation fire, Brazil (M. O. Andreae)