The MACC global reanalysis

An eight-year dataset (2003-2010) on atmospheric composition (and meteorology)

The ECMWF project team (Anna Agusti-Panareda, Angela Benedetti, Johannes Flemming, Richard Engelen, Antje Inness, Johannes Kaiser, Luke Jones, Jean-Jacques Morcrette, Miha Razinger, Adrian Simmons and Martin Suttie) and many other project members at partner institutions

with acknowledgment to Tony Hollingsworth (1943-2007)

MACC was a contribution to Europe's global monitoring initiative GMES

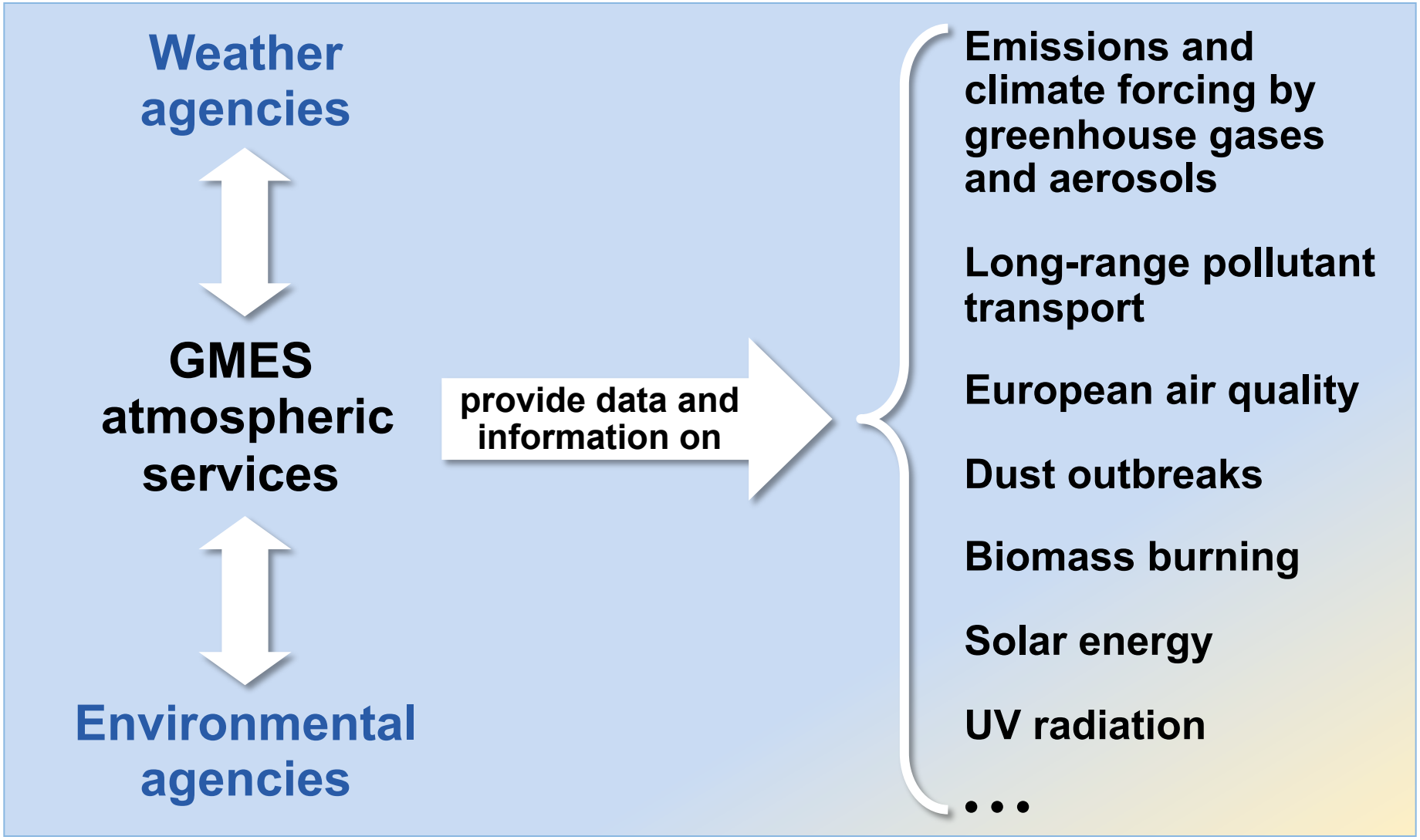
The atmospheric programme of GMES comprises

- implementing operational space-based observation of atmospheric composition
- strengthening complementary *in situ* observation
- developing and operating associated monitoring and forecasting services

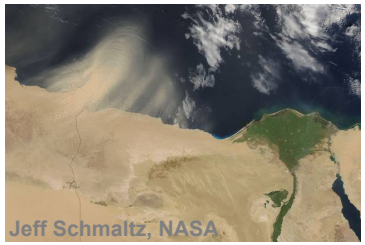
MACC was a 48-partner project co-funded by the European Union

- to be the pilot (2009-2011) for the atmospheric monitoring/forecasting services
- as the counterpart of the ocean-service project MyOcean
- building on earlier GEMS and PROMOTE projects of the EU and ESA
- with most activities continuing in MACC-II (2012 – 2014)

GMES atmospheric services relate to chemical and particulate concentrations



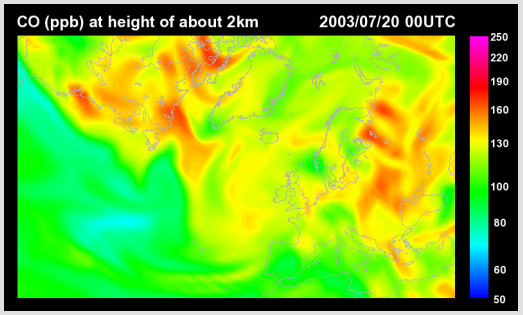
Emissions, and what follows



Transport by winds

Chemical reactions

– dependent on sunlight, temperature, humidity, cloud particles, …

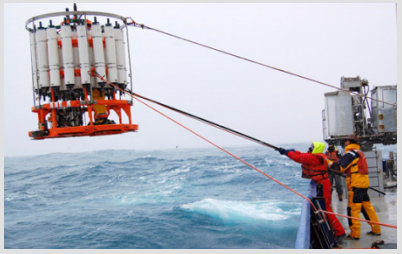


Deposition

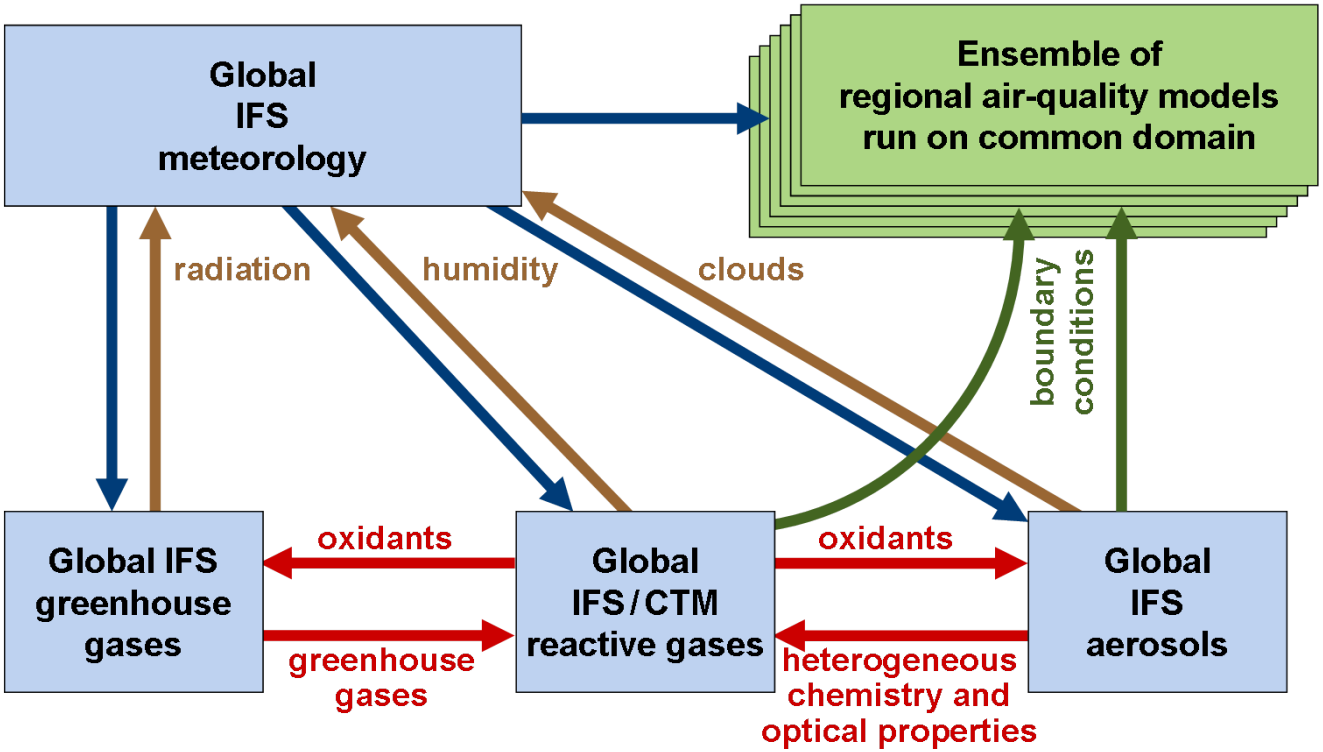
– dependent on turbulence, rainfall, …

Uptake by vegetation, soils and oceans

– dependent on rainfall, temperature, wind, …



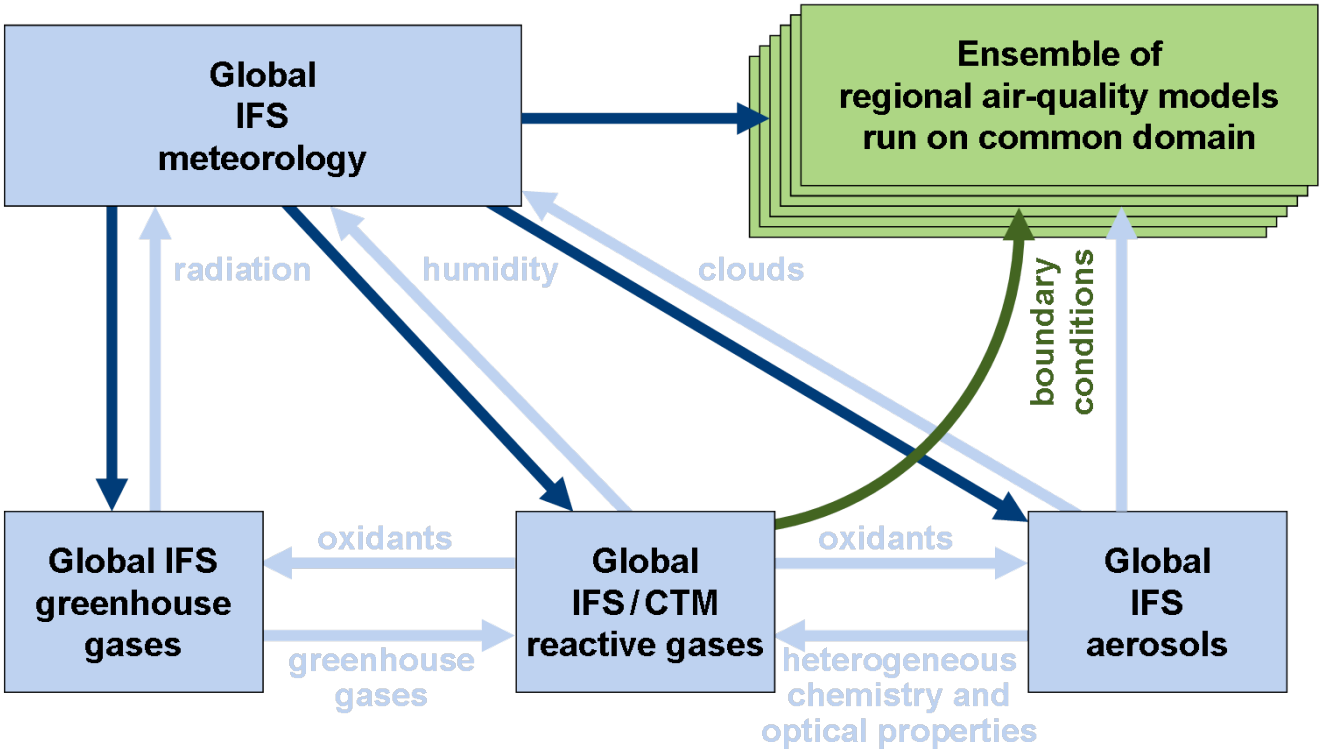
Global/regional system



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 seven CTMs run on a common European domain

Global/regional system



Monthly zonal-mean distributions of CO_2, CH_4 and O_3 from an earlier reanalysis undertaken in the GEMS project are used in the IFS's radiation scheme

Global data assimilation

Approach is based on the 4D-Var scheme of the IFS

Meteorological data are assimilated together with data on constituents

CO_2 , CH_4 and aerosols are incorporated in the IFS

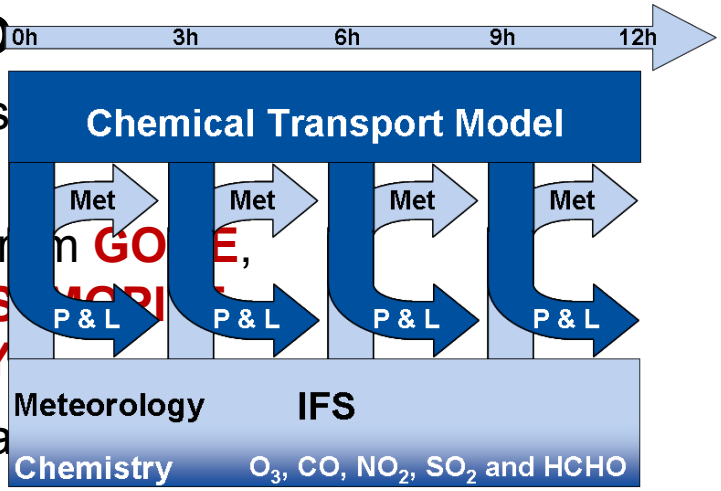
Assimilated data are **AIRS** and IASI radiances, **SCIAMACHY** retrievals, **MODIS** aerosol optical depth, GOSAT …

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

Chemical production and los
the coupled CTM

Data for assimilation come fr m **GO E**,
GOME-2, **IASI**, **MIPAS**, **MLS**
OMI, **SBUV/2**, **SCIAMACHY**

Chemistry is being incorpora



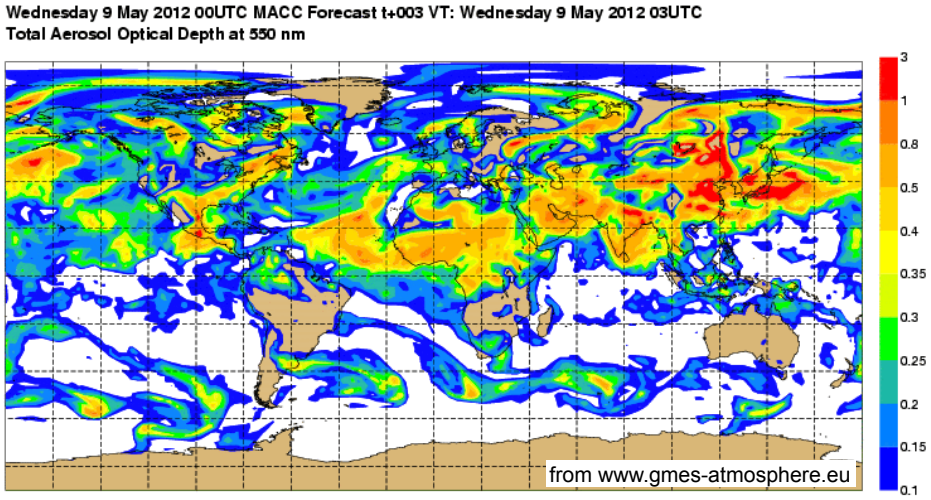
Emissions from fires are analysed

Based on fire radiative power products from **MODIS** and

Primary production streams

Daily monitoring and forecasting

- global system
- ensemble of regional systems



Delayed-mode analysis

- global system is run again about six months behind time for CO_2, CH_4 and aerosols
- allows assimilation of delayed data, and use of higher horizontal resolution
- particularly for estimation of surface-flux corrections

Reanalysis

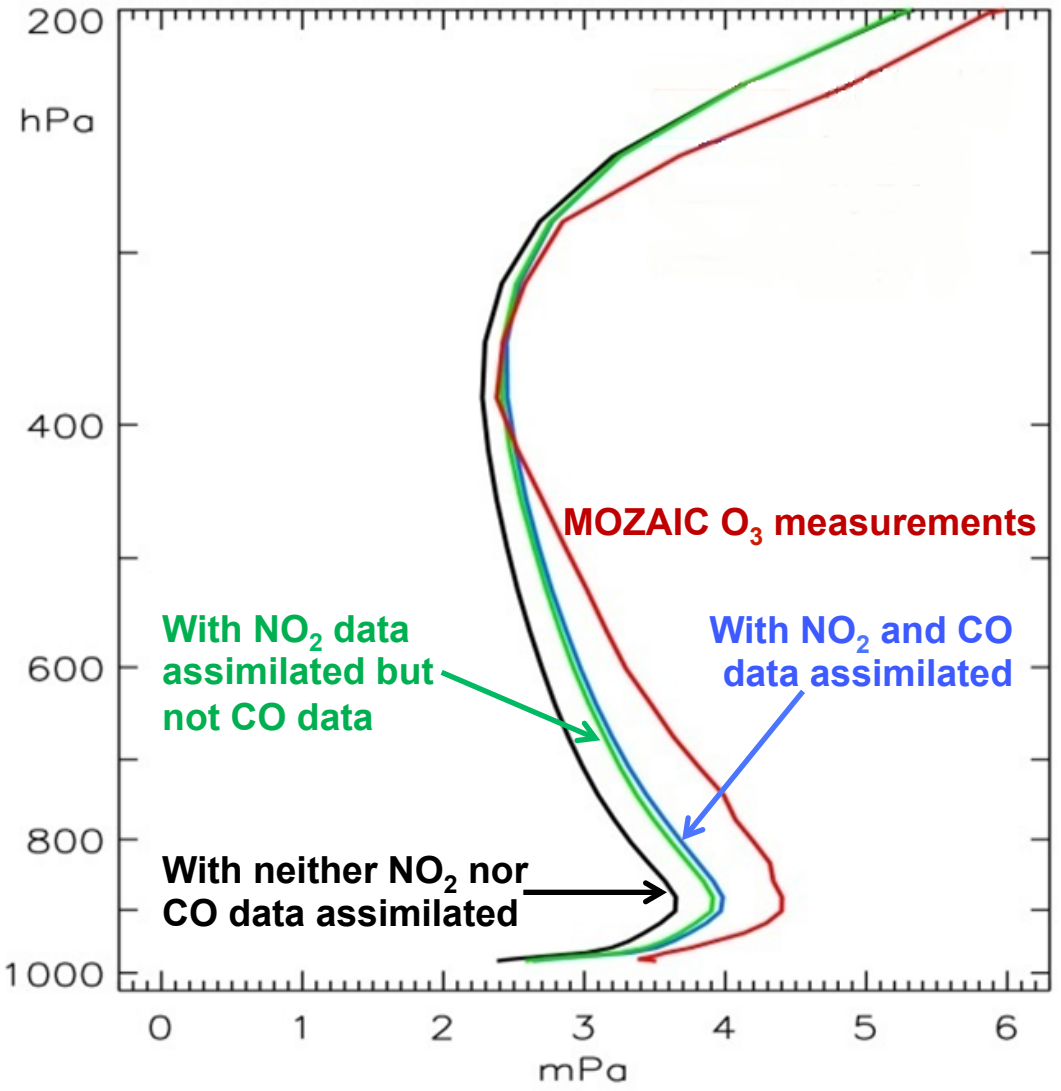
- global, for 2003-2010, using same resolution as ERA-Interim but newer (January 2010) version of forecasting system
- regional, 2007 onwards, using ensemble of regional systems assimilating validated air-quality data, for annual assessment of European air quality

Chemical coupling in background forecast for ozone analysis

Comparison of MACC analyses with mean ozone profile from 371 ascents or descents of MOZAIC aircraft at Frankfurt from February to June, 2003

Ozone data are assimilated in each of the three cases shown

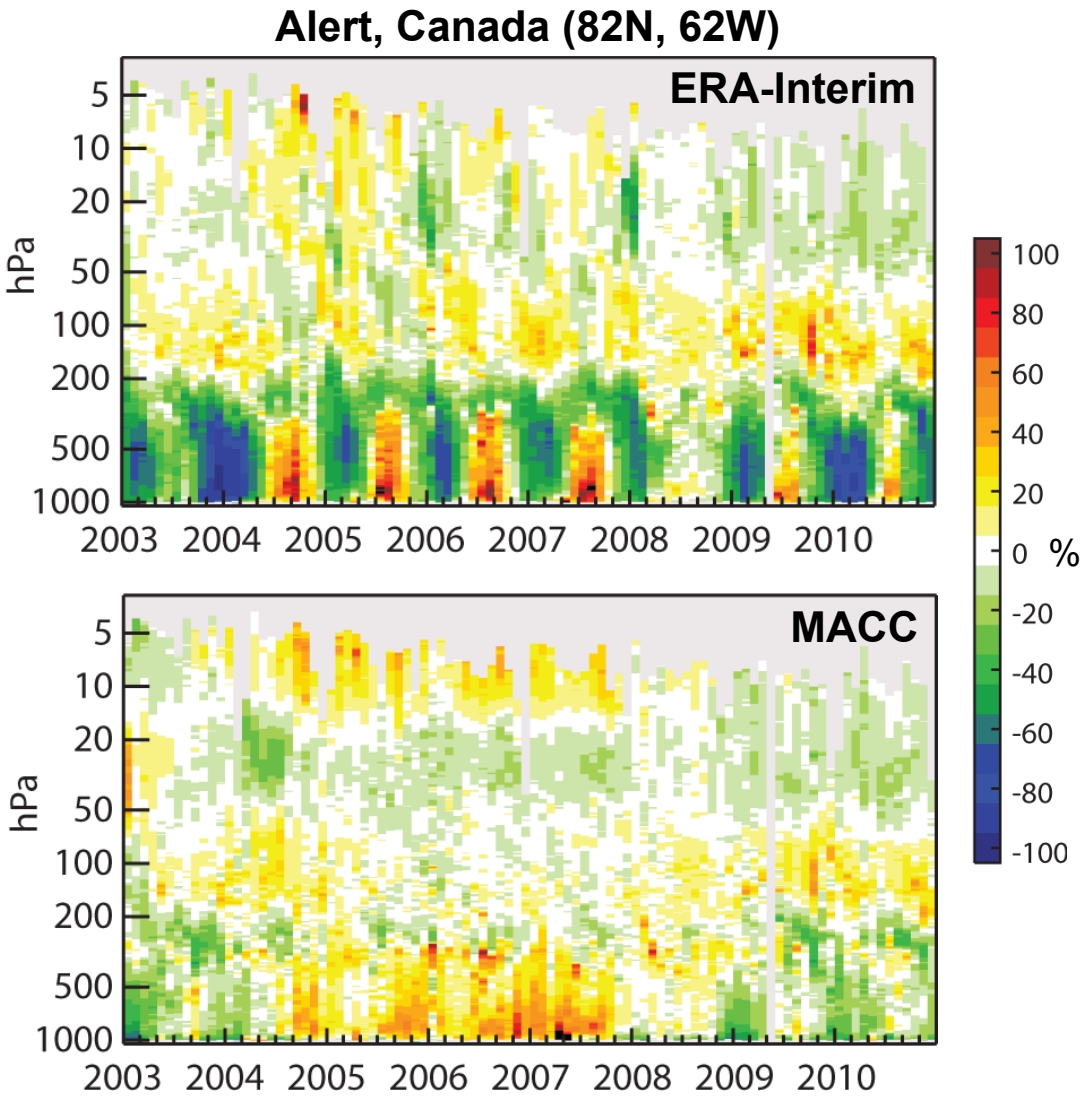
The analysis system is univariate for composition variables, but assimilation of NO_2 and to a lesser extent CO data improves the background forecast for ozone, and consequently the fit of the analysis to the independent MOZAIC data



Monthly-mean differences between reanalyses and ozonesonde data

The MOZART chemistry used by MACC generally outperforms the much simpler Cariolle scheme used in ERA-Interim

Bias correction of MLS data was turned off in MACC reanalysis from 1 Jan 2008 to prevent drift in lower tropospheric and upper stratospheric ozone



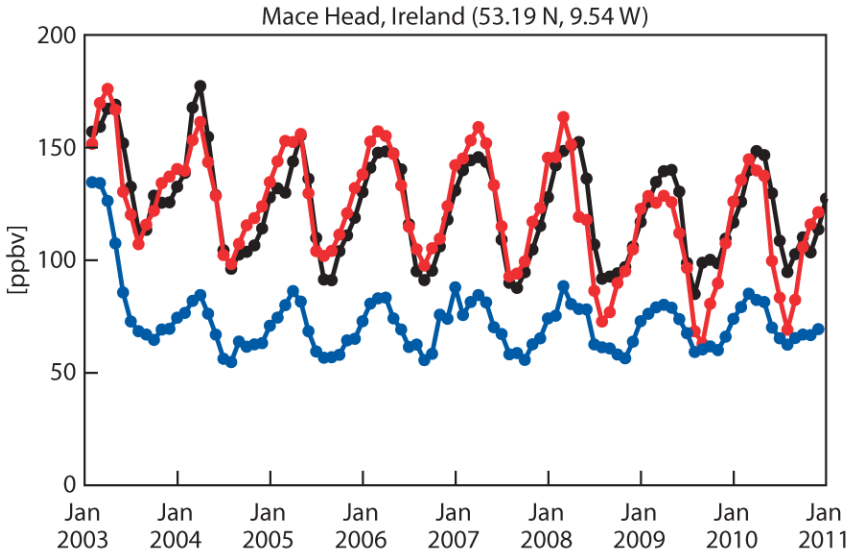
Monthly mean surface CO (ppbv)

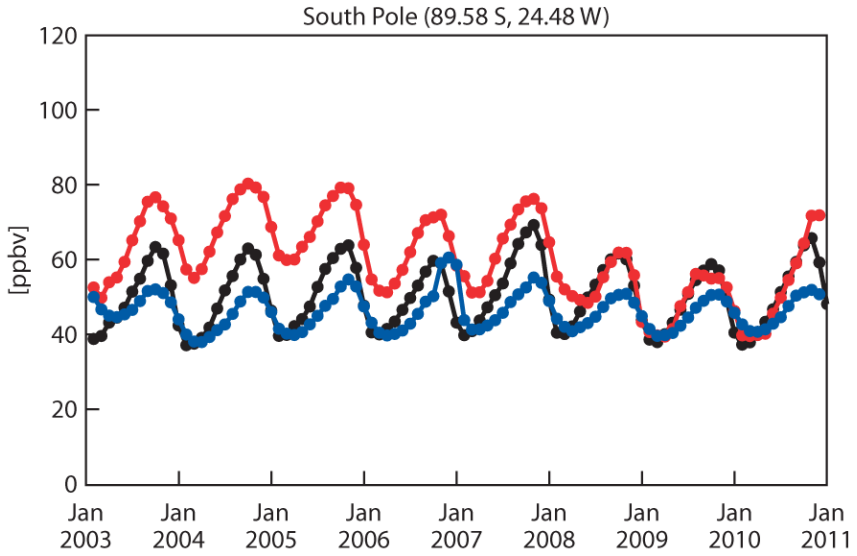
Station values from NOAA/ESRL
MACC reanalysis
Control run of MOZART CTM

Control run of CTM underestimates CO

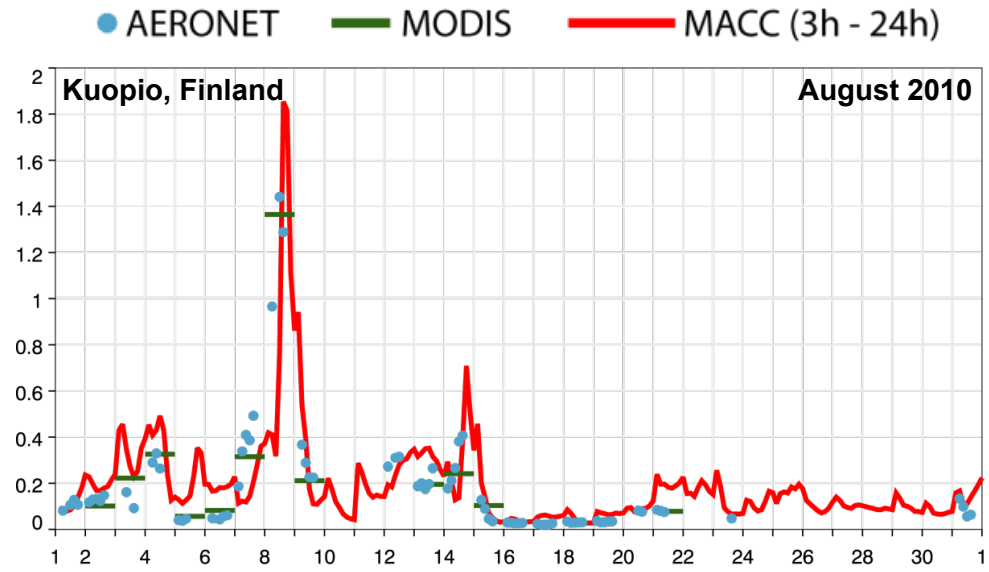
A problem with the model or the specified emissions?

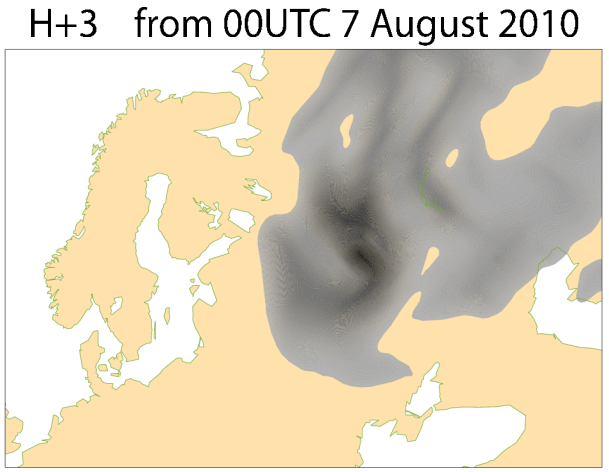
Changes in the reanalysis in 2008 most likely come from the assimilation of CO data from IASI (in addition to those from MOPITT)



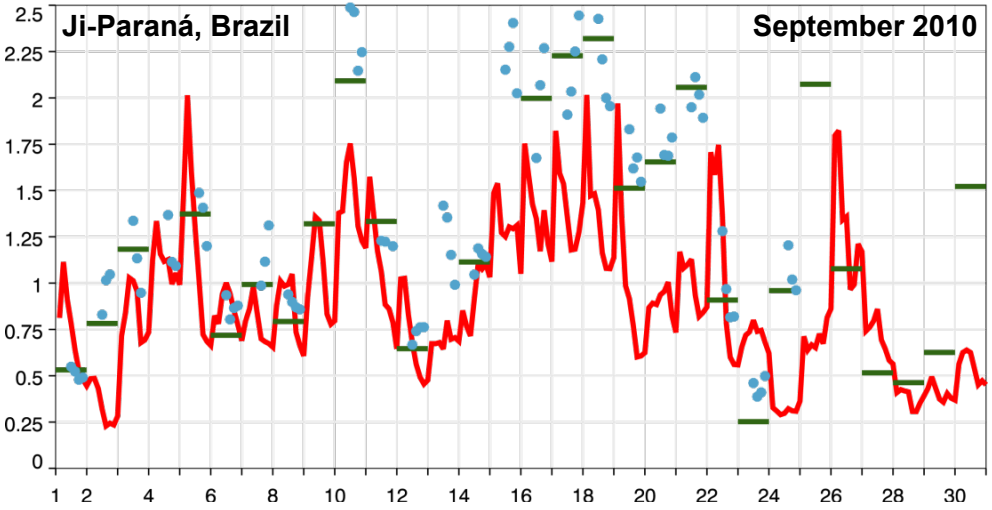


Comparison of aerosol optical depth at ~500nm with AERONET data



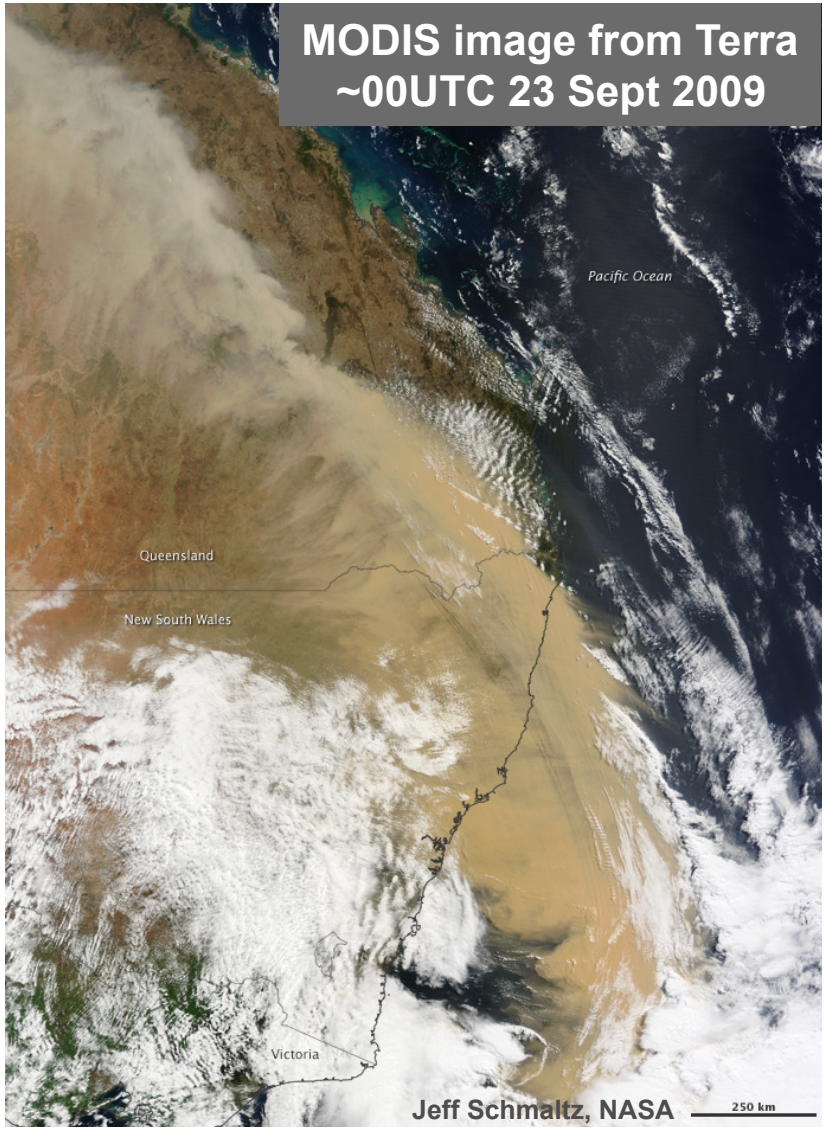


MACC 3-24h forecasts of smoke aerosol 7-9 August 2010



Bias of MACC 3-24h forecasts at AERONET sites for September 2010

Dust analysis

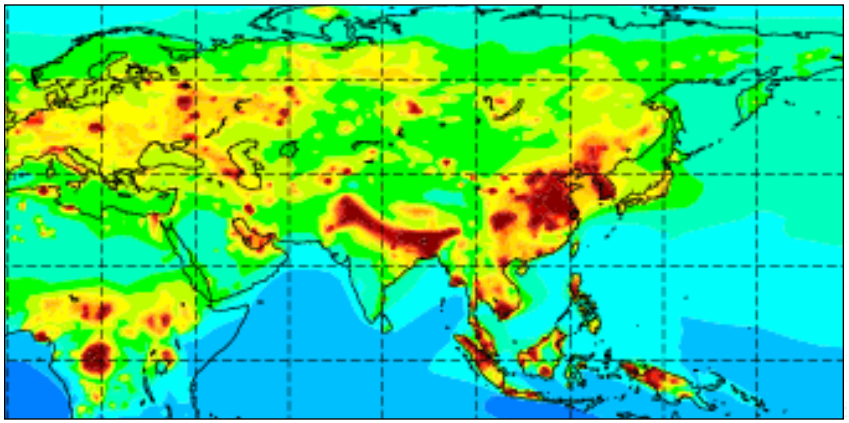


H+3 from 00UTC 21 September 2009

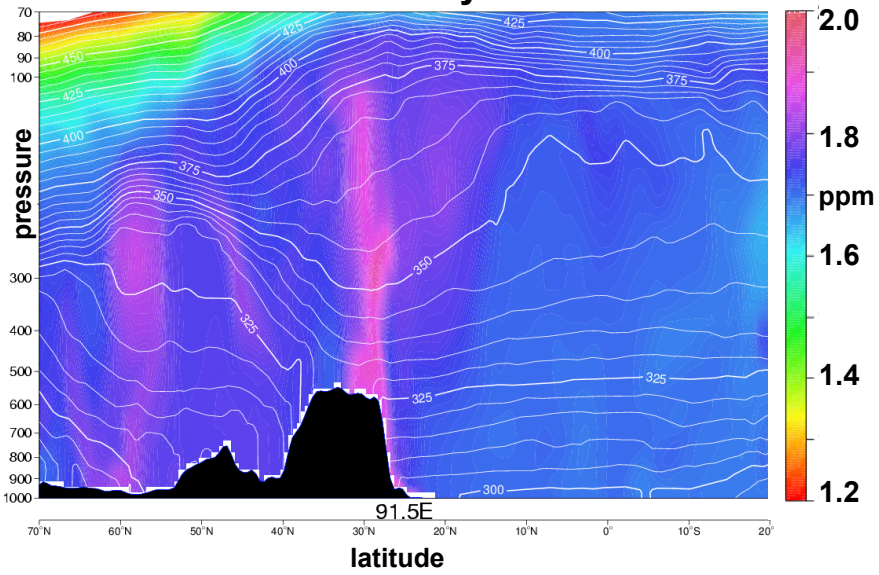
MACC dust aerosol optical depth

Methane in the Asian summer monsoon

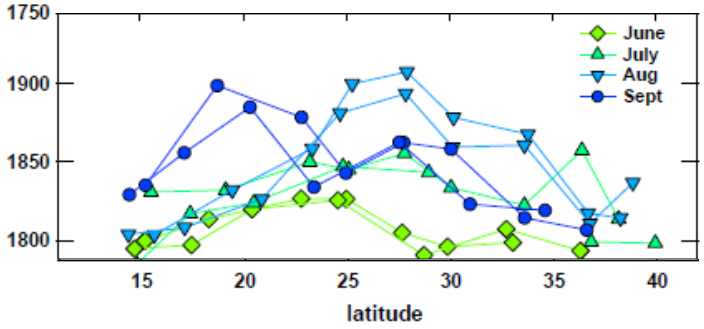
Mean surface values for July 2003

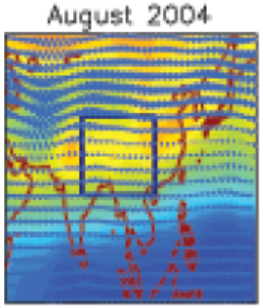


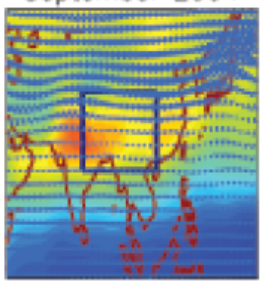
12UTC 1 July 2003



CH_4 (ppb) from CARABIC flights between Frankfurt and Chennai

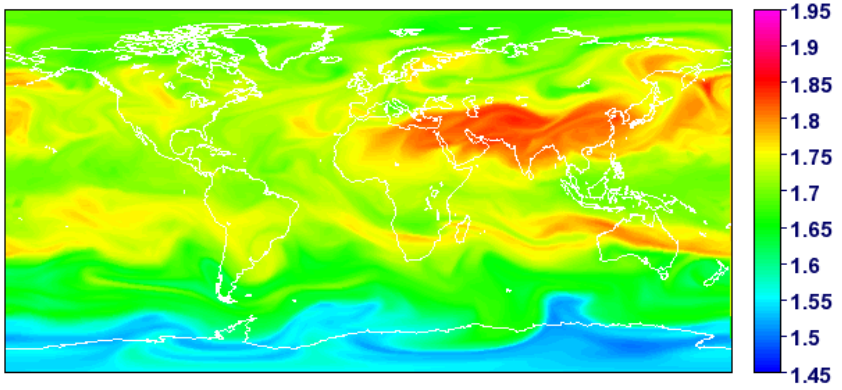






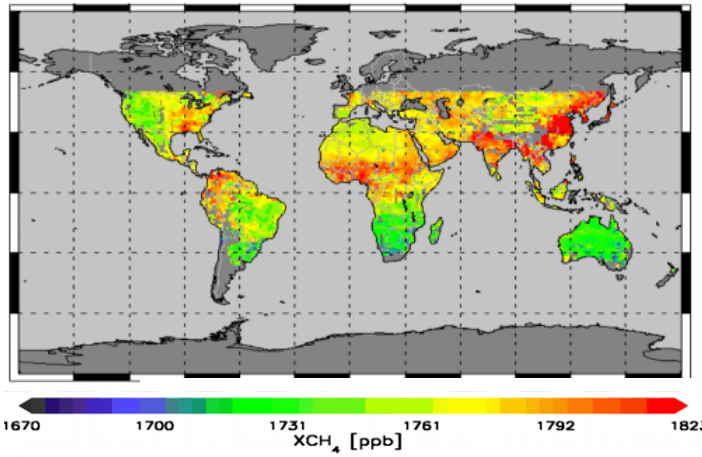
AIRS retrievals at 300hPa Xiong et al. (2009)

370K methane (ppm) for 2003080100

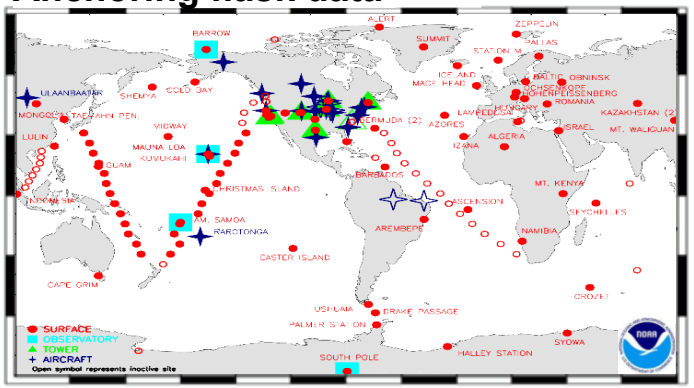


Estimating emissions
Methane from July 2009 to June 2010

ESA/SCIAMACHY satellite data

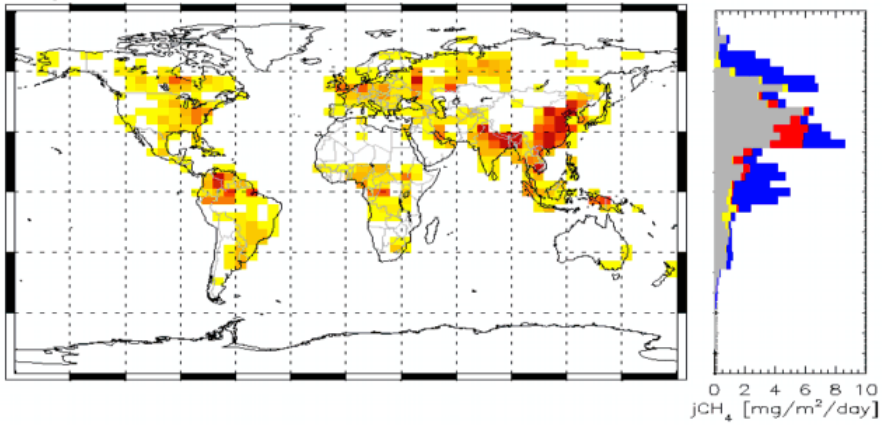


Anchoring flask data

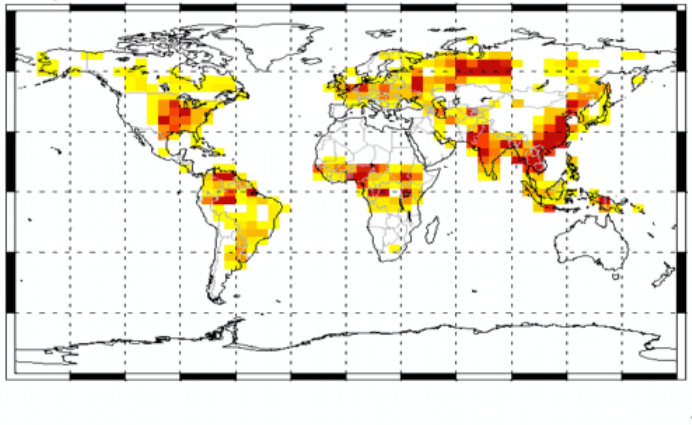


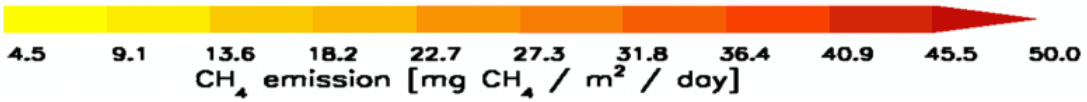
NOAA Earth System Research Laboratory global cooperative air sampling network

Prior modelled emissions



Adjusted emissions





Run from delayed-mode production stream by MACC partner Peter Bergamaschi, Joint Research Centre

Concluding remarks

MACC was a substantial effort of which global reanalysis was a part

The reanalysis was carried out with a relatively new system

- which shows a reasonable degree of success
- with data available from ECMWF public server and some partners' servers
- to be used with caution for some species (e.g. CO_2 and low-level O_3)
- to be extended beyond 2010 in MACC-II, but rerun only for limited periods
- to gain in computational efficiency from incorporating all chemistry in IFS

Future progress of the whole activity requires commitments

- from Europe to Sentinel satellite series as well as monitoring/forecasting service
- from nations to ground-based and airborne measurement systems for atmospheric composition
- with addressing the gap in provision of limb sounding a further need

There is scope for further integration of other Earth-system components