Global and regional Earth-System (atmosphere) Monitoring using Satellite and in-situ data (GEMS)

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- Olaf Stein, MPI Meteorology, Germany
• Integrated Project of the 6th EC Framework Programme
• part of the GMES (EC&ESA) Atmosphere theme
• 31 consortium members
• 4 years (started in March 2005)

• coordinated by the European Centre for Medium-Range Weather Forecasts ECMWF
New information requirements
- Policy
  - Kyoto Protocol
  - Montreal Protocol
  - CLRTAP
- GMES Service Elements users
  - Regional Air-Quality
  - Monitoring & Forecast
- Environment Agencies
- Air quality users
- Health Agencies
- Science

Improved Earth observations
- Instruments:
  - satellite
  - in-situ
  - air-borne
  - Atmosphere
    - composition
    - dynamics
  - Land surface
    - biomass burning
    - vegetation
  - Ocean

GEMS system
- Global real-time operational assimilation and forecast capability of aerosols, greenhouse gases and reactive gases.
- Improved forecasts for regional air quality from an ensemble of European air quality models.

GEMS products
- Information on atmospheric composition:
  - Greenhouse gases
  - Reactive gases
  - Aerosols
  - Regional air quality
- Monitoring, Assessment and Prediction
  - Current status
  - Sources, sinks, and transport
  - Impact of global change

objectives and products
Prime Objectives

• Creation of an operational system for greenhouse, reactive gases, and aerosols in the troposphere and in the stratosphere on the regional and on the global scale by early 2009.

• Production of near-real-time and retrospective analyses of global monitoring, and medium and short range forecasts of atmospheric chemistry and dynamics.

• Information relevant to the Kyoto and Montreal protocols, to the UN Convention on Long-Range Trans-boundary Air Pollution.
GEMS themes

Greenhouse Gases (GHG)

Global Reactive Gases (GRG)

Aerosols (AER)

Regional Air Quality (RAQ)

Production (PRO) & Validation (VAL)
GEMS Project structure

Three individual global model systems

- GHG
- AER
- GRG

11 separate regional systems

- RAQ

Implementation into the ECMWF weather forecast model
Construction of assimilation systems for GHG, GRG, and AER

Global assimilation systems implemented in the ECMWF model

GHG
AER
GRG
RAQ

11 separate regional systems

Separate reanalysis

In-situ and satellite data

Users

- Policy
- GMES Projects
- Regional Air-Quality Monitoring & Forecast
- Environment Agencies
- Health Agencies
- Science

Unification of global GEMS assimilation system at ECMWF

GHG
AER
GRG
RAQ

Unified Analysis

Operational System
Greenhouse Gases (GHG)

Theme coordinator: Peter Rayner, LSCE, France

- Development of the first operational system to use satellite and in-situ data to monitor the concentrations of greenhouse gases, and their associated surface sources and sinks, and to attribution of these sources and sinks to controlling processes.

Carbon fluxes from the terrestrial biosphere on August 10, 2003 (heat wave in Europe) as simulated by the model ORCHIDEE
3-month CO$_2$ reanalysis with AIRS

Monthly mean total column CO$_2$ after 3 month assimilation shows small but significant changes to a simulation with free-running CO$_2$.

Too early to draw conclusions.
Flux increments (kgC/m² over 3 months)

- In-situ obs + satellite obs. (ocean zoom)
- In-situ obs + free run (ocean zoom)
- First Hessian eigenvectors
- In-situ obs + satellite obs
- In-situ obs + free run

GHG
Modelling of fire emissions

CO$_2$ emission from fires
[kg/m$^2$/s] 12UTC 20 August 2003 (GFEDv3-8d)

Model CO$_2$ 12UTC 20 August 2003 500hPa
Excess CO2 due to Fires [ppm]
Excess CO2 due to Fires II [ppm]
No AIRS data in assimilation
No fire emissions in model

AIRS data in assimilation
No fire emissions in model

X-sections of CO$_2$ in plumes in 4 assimilations

No AIRS data in assimilation
Fire emissions in model

AIRS data in assimilation
Fire emissions in model
Comments on CO$_2$ progress

- Results shown are preliminary and unvalidated

- The assimilated AIRS data have a clear effect on the synthesis inversions

- The AIRS data can detect the synoptic-CO$_2$ impact of African biomass burning

- Simple modelling of the emission from the biomass burning enhances the assimilated signal
Global Reactive Gases (GRG)

Theme coordinator: Martin Schultz, FZ Jülich, D

- Set-up an operational data assimilation system for chemically reactive gases within the ECMWF operational system providing global products on a day-by-day basis.

CO concentration above Europe at ~5 km altitude.

Long-range transport
- polluted air from the US
- clean tropical air

influences European air quality.

12 days in February 2002 simulated by the global model MOZART
unit: ppbv
Model evaluation of total Ozone column

unit: [Dobson], model not filtered to satellite overpass

Satellite: SCIAMACHY

Model: MOZART with ECMWF meteorology
Model evaluation of tropospheric NO$_2$ column

Satellite: SCIAMACHY

Model: MOZART with ECMWF meteorology

time: summer 2003 (months 5-8)
unit: [10$^{15}$ molecules/cm$^2$]

model not filtered to satellite overpass

Model agrees reasonably well with satellites.
Model evaluation of CO and O₃ with airborne observations from MOZAIC

Vertical profiles ~55 flights (before heatwave)

MOZAIIC measured
MOZART modelled

Ozone

Time series (850 hPa)

Ozone

heatwave

measured
modelled

CO

measured
modelled

O₃ (ppb)

CO (ppb)

July
August

Peak of 2003 heat wave unsuccessful!

GRG Model evaluation of CO and O₃ with airborne observations from MOZAIC

Vertical profiles ~55 flights (before heatwave)

MOZAIIC measured
MOZART modelled

Ozone

Time series (850 hPa)

Ozone

heatwave

measured
modelled

CO

measured
modelled

O₃ (ppb)

CO (ppb)

July
August

Peak of 2003 heat wave unsuccessful!
Model evaluation of O₃ with surface networks

O₃: model vs. GAW & EMEP, monthly mean for August 2003

Observed O₃ concentration generally matched by the MOZART model, but not during heat wave in August 2003.
First assimilation of CO

Assimilation of total column CO data from MOPITT

Free running

Assimilation MOPITT data

Difference between free and assimilated run

Assimilation of MOPITT CO columns leads to reduced values in tropics and increased values in extra tropics

time: 15-30 July 2003 (mean)
unit: \([10^{18} \text{ molecules/cm}^2]\)
First assimilation of NO₂

Assimilation of total column NO₂: Use of NOₓ=NO₂+NO

Free running

Assimilation SCIAMACHY data

Difference between free and assimilated run

preliminary results

time: instantaneous fields
unit: \([10^{15} \text{ molecules/cm}^2]\)
Aerosols (AER)

Theme coordinator: Olivier Boucher, Met Office, UK

- Set-up an operational data assimilation system for aerosols within the ECMWF operational system providing global products on a day-by-day basis.

Data courtesy of Eumetsat

Desert dust from SEVIRI and from the ECMWF model
First assimilation of aerosols

Free running

Assimilation of MODIS AOD

MODIS aerosol optical depth (AOD)

Assimilation increases aerosol optical depth over Western Africa, India, and East Asia. Improvements are also seen over the oceans.
Model evaluation of dust

Extensive intrusion of Saharan dust into Europe

dust aerosol optical depth @ 550 nm
12 hour forecast for 00UTC 5 May 2006
ECMWF model with new aerosol model

trajectories for air parcels
finishing over South England on May 5

ECMWF model forecast
5 days back Trajectories
Univ of Athens forecast
Regional Air Quality (RAQ)

Theme coordinator: Vincent-Henri Peuch, Meteo France, F

- Production of regional forecasts of chemical species and air quality indices based on an ensemble of air-quality models on the European scale

European partner institutes
- MeteoFrance, France
- MetOffice, UK
- CNRS, INERIS, France
- FMI, Finland
- DMI, Denmark
- NKUA, Greece
- ISAC, Italy
- met.no, Norway
- FRIUUK, Germany
- SMHI, Sweden

European Center of Medium Range Weather Forecasts

GEMS
- GEMS web site
- regional air quality archives

AER
- AER
- UMAQ
- CHIMERE
- SILAM
- MATCH
- CAC
- UAM-V
- BOLCHEM
- EMEP
- EURAD
- MATCH

GRG
- GHG
- AER
- GRG

Global system
Forecast from three European air quality model systems

daily maxima of surface ozone [ug/m3] for 20/10/2006

CHIMERE (CNRS-INSU and INERIS)
MOCAGE (Météo-France)
EURAD (Rhenish Institute for Environ. Research, Univ. Köln)
Summary of GEMS progress

GREENHOUSE GASES

• CO₂ in ECMWF assimilation system
• variational flux inversion blends flask-data & satellite information
• re-analysis runs evaluated and first production runs made

REACTIVE GASES

• ECMWF model extended to include multiple chemical species
• chemical tracers implemented into assimilation system
• CTMs implemented at ECMWF and coupled to IFS
• re-analysis runs evaluated and first assimilation runs

AEROSOL

• aerosol module implemented at ECMWF
• improved emissions
• re-analysis runs evaluated and first assimilation runs

REGIONAL AIR QUALITY

• interfaces between ECMWF archive and RAQ models created
• creation of high resolution emission inventory for Europe
• first simulations performed, extensive forecast model inter-comparison started

PRODUCTION & VALIDATION SYSTEMS WELL ADVANCED
## Schedule for GEMS, 2007-2013

<table>
<thead>
<tr>
<th>Year</th>
<th>Quarter</th>
<th>Task Description</th>
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<tbody>
<tr>
<td>2007</td>
<td>Q1-2</td>
<td>Reanalyse 2003-4 with Greenhouse gas system</td>
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<tr>
<td></td>
<td>Q2-3</td>
<td>Reanalyse 2003-4 with Aerosol system</td>
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<tr>
<td></td>
<td>Q3-4</td>
<td>Reanalyse 2003-4 with Reactive Gas system</td>
</tr>
<tr>
<td>2008</td>
<td>Q1</td>
<td>Prepare integrated GEMS system</td>
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<tr>
<td></td>
<td>Q2-4</td>
<td>Reanalyze as much as possible of 1999-2007 with the unified system</td>
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<tr>
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<td>global</td>
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<tr>
<td></td>
<td>Q1-2</td>
<td>Start near-real time running of the global GEMS system and the 12 regional systems</td>
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<tr>
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<td>regional</td>
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<tr>
<td>2009</td>
<td>Q2</td>
<td>Transition the research system to operations</td>
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<td>2010-12</td>
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<td>Learn how to use OCO &amp; GOSAT</td>
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<tr>
<td>2012-13</td>
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<td>Reanalyze the 2008-12 Kyoto commitment period using all available satellite &amp; in-situ data</td>
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</table>
End

Thank you for your attention!
Benefits of a parallel US effort on Greenhouse gases

• The initial GEMS / Greenhouse results show considerable scientific promise & opportunity

• There are major scientific advantages in having two independent teams address a big issue

• There are major political advantages in having two independent teams address a big issue

• What is needed to initiate a parallel US effort, of similar scope to GEMS / Greenhouse?
Summary of GEMS progress

- CO$_2$ implemented into ECMWF assimilation system
- variational flux inversion scheme developed to blend flask-data and satellite information in the data assimilation
- re-analysis runs evaluated and first assimilation runs

- meteorological model extended to include multiple chemical species
- chemical tracers implemented into assimilation system
- CTMs implemented at ECMWF
- re-analysis runs evaluated and first assimilation runs

- aerosol module implemented at ECMWF
- improved emissions
- re-analysis runs evaluated and first assimilation runs

- interfaces between ECMWF archive and RAQ models created
- creation of high resolution emission inventory for Europe
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Validation (VAL) & Production (PRO)
## Dependencies of GAS services on the elements of the global GEMS system

<table>
<thead>
<tr>
<th></th>
<th>Ozone</th>
<th>Aerosol</th>
<th>Greenhouse Gases</th>
<th>Winds &amp; Clouds</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Troposphere</td>
<td>Stratosphere</td>
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<tr>
<td>Air Quality Services</td>
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<td>Stratosphere</td>
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<td>Climate Services</td>
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<tr>
<td>Stratospheric Ozone &amp; solar radiation Services</td>
<td>X</td>
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</tbody>
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### Glossary

- **GEMS**: Global Environmental Monitoring System
- **GAS**: Global Atmosphere Services
- **Troposphere**: Lowermost layer of the atmosphere
- **Stratosphere**: Layer of the atmosphere above the troposphere
- **Ozonosphere**: Layer of the stratosphere where ozone is concentrated
- **Greenhouse Gases**: Gases that absorb and emit infrared radiation
- **Winds & Clouds**: Services related to atmospheric circulation and precipitation

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### Additional Notes

- **Air Quality Services**
  - Relate to pollutant levels and air quality indices
  - Depend on tropospheric and stratospheric elements

- **Climate Services**
  - Provide information on climate patterns and impacts
  - Also dependent on tropospheric and stratospheric elements

- **Stratospheric Ozone & solar radiation Services**
  - Focus on stratospheric ozone and solar radiation
  - Show strong dependencies on stratospheric elements
Global Reactive Gases (GRG)

Theme coordinator: Martin Schultz, FZ Jülich, D

• Set-up an operational data assimilation system for chemically reactive gases within the ECMWF operational system providing global products on a day-by-day basis.

Long-range transport
• polluted air from the US and siberian fires
• clean tropical air
influences European air quality.

6 days in May 2006 simulated by the global model MOZART
unit: ppbv

CO concentration above Europe at ~700 hPa