Global Earth-system Monitoring using Space and in-situ data - GEMS

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Scope of the Presentation

• Overall GEMS Objectives:
  • Exploit huge investments in satellite data
  • Extend NWP Modelling and Data Assimilation capabilities to atmospheric composition on global and regional scales
  • Provide a new range of services for Europe, with Global & Regional Deliverables

• Progress since Spring 2005 start of GEMS
• Challenges
• Schedule for Transition to Operations in 2009
**GMES: Motivations for GEMS**

- **TREATY ASSESSMENT & VALIDATION**
  - Conventions (Kyoto, Montreal, LRTAP) and IPCC need best estimates of sources/sinks/transforms of atmospheric constituents.

- **BETTER OPERATIONAL SERVICES**
  - Improved forecasts: excess deaths in summer 2003 heatwave: -18K in France, at least 33K in western Europe.

- **SCIENCE**
  - GEMS will synthesise all available satellite & in-situ data into accurate 'status assessments', and will meet many needs of the GCOS Implementation Plan.
Environmental Concerns have triggered $25B for New satellite missions in 2001-2008

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<thead>
<tr>
<th>N. America</th>
<th>Europe / Collabs.</th>
<th>Asia / Collabs.</th>
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<td><strong>TERRA</strong></td>
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<td><strong>AQUA</strong></td>
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<td><strong>CALIPSO</strong></td>
<td><strong>GOCE</strong></td>
<td><strong>Underline:</strong></td>
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<td><strong>CLOUDSAT</strong></td>
<td><strong>ADM</strong></td>
<td><strong>info on composition</strong></td>
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<td><strong>OCO</strong></td>
<td><strong>CRYOSAT</strong></td>
<td><strong>Red:</strong>  in orbit</td>
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<td><strong>SMOS</strong></td>
<td><strong>Black:</strong> Planned</td>
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Organisation of the GEMS Project

GEMS is organised in 6 projects

- Reactive Gases
- Greenhouse Gases
- Aerosol
- Regional Air Quality
- Validation
- Data input (Assimilation, Evaluation)

GEMS Global System

Coordination

System Integration

Products, User services
GEMS Regional Deliverables:  
- Regional Air-Quality Forecasts  
- Improved services for health sector  
- Mapping of regional sources / deposition

- **Regional Air Quality: initial & boundary conditions**
  - Provide initial and boundary conditions for operational regional air-quality and ‘chemical weather’ forecast systems

- **Improved monitoring and forecast services for the health sector**
  - UV exposure and skin cancer
  - Heat stress and drought
  - Acute pollution events
  - Respiratory and Cardiovascular disease
  - Future
    - Vector borne and zoonotic disease (cf. malaria experience)

- **Regional estimation of sources/sinks of CO2, O3, aerosol...**
Functional Sketch of the GMES Air Quality Service

Global Core Service
- Emissions Inventory
- Global Forecast Pollutant Concentration Fields
- AQ Data
- Weather Data

National / Regional Air Agencies
- O3/NO2 Data / Movies
- Regional Forecast Pollutant Concentration Fields
- Media
- Public
- City-specific AQI forecasts

Commercial Air Quality Providers

AQI Data / Movies

Global Core Service

National / Regional Air Agencies
The GEMS system

- Distributed system for Research and Operations.
- Many Regional Systems
- Many Global CTMs
- A Global Weather system
Ensemble Regional Air Quality Forecasts

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

Example: Surface ozone daily maxima (in 10-6 g.m-3): forecast for 20/10/2006 from the models CHIMERE (CNRS-INSU and INERIS), MOCAGE (Météo-France), and EURAD (Rhenish Institute for Environmental Research, Univ. Köln).
Global Operational System

- By 2009, at ECMWF, an operational global monitoring/forecast system for atmospheric composition, combining all remotely sensed and in-situ data to create 3-dimensional global distributions [50km (H), 1km (V), 6 hours] of key atmospheric trace constituents:
  - greenhouse gases (initially including CO₂, and progressively adding CH₄, N₂O, plus SF₆ and Radon to check advection accuracy),
  - reactive gases (initially including O₃, NO₂, SO₂, CO, HCHO, and gradually widening the suite of species),
  - aerosols (initially a 15-parameter representation, later ~ 30)

- Retrospective Analysis
  - Provide a retrospective analysis of all accessible in-situ and remotely sensed data on atmospheric dynamics and composition for the ENVISAT-EOS era (1999-2007)

- Sources, Sinks and Transports
  - Monthly/seasonal maps of the sources, sinks and inter-continental transports, of CO₂, O₃ and many other trace gases and aerosols, based on in-situ & satellite data
GEMS tasks at ECMWF

- **Greenhouse gases**
  - Start on $CO_2$, then $CH_4$, $CO$ and $N_2O$
  - Develop modelling and data assimilation, and use analyses to infer sources and sinks for $CO_2$ and $CH_4$

- **Reactive gases**
  - Couple main forecast model with global CTMs
  - Carry $O_3$, $CO$, $NO_2$, $SO_2$ and $HCHO$ in main model and develop data assimilation

- **Aerosols**
  - Add to model, based on externally-produced parameterizations
  - Develop assimilation of retrievals, then radiances

- Integrate above components, and run past periods

- Provide boundary conditions and technical support for regional air-quality prediction
Comparisons with surface $CO_2$ measurements from NOAA/CMDL network - Seasonal cycle

From model run with meteorological fields corrected every 12 hours and specified climatological surface fluxes of $CO_2$
First three-month reanalysis assimilating AIRS data

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.
A reanalysis of 2003 for Chemical Transport Model intercomparison

10 August 2003 12UTC Surface: 2 metre temperature

17 February 2003 12UTC 10hPa height

17 February 2003 12UTC 850K ozone

Ozone profile retrievals from both GOME and MIPAS assimilated
Ozone Hole 1 Oct 2003 in ECMWF assimilation

- a) Ozone hole in Southern Hemisphere assimilation on 1 October 2003;
- b) Vertical cross section of ozone partial pressure along 8W in a); the partial pressure of ozone is almost zero at 15km, over a wide area. Sharpness due to MIPAS;
- c) Comparison of (independent) ozonesonde profile data at Neumayer (70.7S 8.3W) with the assimilated field; the agreement is remarkable.
Assimilation of total column NO$_2$ from SCIAMACHY

Background field (with no tendencies applied in IFS, and initial data from CTM)

Unit: $10^{15}$ mol/cm$^2$

Analysis

Active observations
Assimilation of total column CO from MOPITT

Unit: $10^{18}$ mol/cm$^2$
First version of aerosol model (sea salt and desert dust)

Aerosol optical depth at 0.55 micron

00UTC 5 May 2006
Comparison of aerosol optical depth with MODIS observations

Forecast run

Analysis run

Mean fields 1-15 August 2003
New aerosol model

- Implementing aerosol model of Huneeus and Boucher
  - Model has four prognostic variables representing:
    - Coarse dust (0.5 – 10 mm)
    - Coarse sea-salt (0.5 – 10 mm)
    - Aerosols with fine emission: dust, sea-salt, black carbon, organic matter
    - Sulphate aerosols from precursor emissions
  - Many source fields

[Images of world maps showing distribution of black carbon emissions: biogenic and fossil fuel]
Inclusion of fire emissions

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

Model $\text{CO}_2$
12UTC 20 August 2003
500hPa
**Data acquisition and coding**

- **Current acquisitions**
  - MODIS Aerosol (Terra & Aqua) from NASA for 2003 and 2004
  - GOME $O_3$ profile from RAL for 1995-2003
  - SCIAMACHY NO$_2$ from KNMI for 2003 and 2004
  - MOPITT CO from NASA for 2003 and 2004
  - AURA TES CH$_4$ and CO from NASA for July 2005
  - GOME HCHO from KNMI for December 2001

- **To come:**
  - CO$_2$, SO$_2$ and HCHO from SCIAMACHY, NO$_2$ from OMI, SAGE aerosol, …

- Datasets are being converted to BUFR code
- BUFR to ODB conversion is under test
- Data from AERONET are being acquired in near-real-time
- Ongoing work on BUFR definitions and netCDF/GRIB issues
Challenges/issues

- **Greenhouse gases**
  - Modelling: mass conservation, inter-hemispheric transport, methane sinks, ...
  - Data assimilation: bias correction, QC, Jb statistics, ...
  - Suitability for source estimation?

- **Reactive gases**
  - Computational efficiency of CTMs and coupling
  - Scientific aspects of coupling: use of NO$_x$ and O$_x$, ...
  - Delay to development of data assimilation and extended analyses
  - Jb development yet to be undertaken, ...

- **Aerosols**
  - Establishment of new model
  - Partition of optical-depth information among species in data assimilation, use of aerosol physics in data assimilation, ...
  - Some delay to extended analyses
Plans: 2007-2009

- Further development of the global assimilation systems, esp. IFS/CTM coupling & new aerosol model (4Q 2006 - 1Q 2007)
- Separate analyses of (i) CO$_2$, (ii) some reactive gases & (iii) aerosols for 2003/4 (4Q 2006 - 3Q 2007)
- Refinement and integration of the global assimilation system (4Q 2006 - 3Q 2007)
- Extended reanalysis with integrated global system (4Q 2007 - 3Q 2008)
- Support daily running of regional air quality forecast models & multi-model ensemble forecasts (3Q 2007 - 1Q 2009)
- Preparation of global system for operations (4Q 2008 - 1Q 2009)
END

thank you for your attention!

www.ecmwf.int/research/EU_projects/GEMS
Time lines of committed and likely missions
2009-2019

Time Lines in 2009-2019 for

committed operational missions

& likely research missions

of importance to GEMS activities

Greenhouse Gases
Reactive Gases
Aerosol
Greenhouse Gas Provision

<table>
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<tr>
<th>GREENHOUSE Gases: Main Satellite Provision 2003-2019</th>
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<tr>
<td>Advanced Sounders</td>
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<tr>
<td>ENVISAT (SCIAMACHY)</td>
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<td>AIRS</td>
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<td>DOAS Sounders</td>
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<td>OCO</td>
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<td>GOSAT</td>
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NASA
Eur
NOAA
JAXA

Uncertainty
## Aerosol Provision

<table>
<thead>
<tr>
<th>AEROSOLS, Albedo, Ocean Colour, Vegetation:</th>
<th>Main Satellite Provision 2003-2019</th>
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<tr>
<td>V-IR Imager</td>
<td>MODIS (Terra)</td>
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<td>Uncertainty</td>
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**Satellite Provisions:**
- **MODIS (Terra)**: NASA, Eur, NOAA, JAXA
- **MODIS (Aqua)**: NASA, Eur, NOAA, JAXA
- **MERIS**: JAXA
- **AURA (TES, OMI)**: NASA, Eur, NOAA, JAXA
- **Polarimeter**
- **Parasol**: NASA, Eur, NOAA, JAXA
- **APS (Glory)**: NASA, Eur, NOAA, JAXA
- **V-IR Imager**
- **NPP/VIIRS**: NASA, Eur, NOAA, JAXA
- **NPOESS/VIIRS**: NASA, Eur, NOAA, JAXA
### Reactive Gas (UTLS & Air-Quality) Provision

#### Reactive Gases (O₃, N₂O, SO₂, CH₂O): Main Satellite Provision 2003-2019

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**Upr. Trop. - Lower Strat**

- **ENVISAT (MIPAS, SCIAMACHY, GOMOS)**: NASA, Eur, NOAA
- **AURA (TES, OMI)**: Uncertainty
- **GOME (Metop)**: JAXA
- **NPP/OMPS (~sbuv+toms)**
- **OMPS-Nadir (Npoess)**

**Lower Troposphere**

- **ENVISAT (SCIAMACHY)**
- **AURA (TES, OMI)**
Perspectives on GEMS satellite provision
2009-2019

- Sustainability of GEMS products, based on satellite provision 2009-2019
  - Greenhouse gases (GHG): Assuming 2008/9 OCO launch, GHG products should be sustainable throughout the period
  - Aerosol (AER): Assuming 2009/10 launch of VIIRS on NOAA's NPP, GHG products will be sustainable throughout the period
  - Global Reactive Gases (GRG)
    - Assuming launches of METOP (2006) and NPP (2009/10), GRG Stratospheric Ozone products will be sustainable throughout the period.
    - No committed Air-Quality mission beyond ENVISAT & AURA

- Actions for European scientists
  - Press for European Air-Quality missions: ESA by 2015, EUMETSAT by 2025
  - Urge NASA to extend the lifetime of EOS (TERRA, AQUA, AURA) as far as possible - each was launched with 15 years consumables.
  - Urge NASA to extend the lifetime of other A-train missions, + GLORY +OCO