Application of satellite observation for air quality modelling and assessments

Collaboration with the European Space Agency

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Outline

- Objectives
- Satellite missions and instruments
- Chemical weather model
- Observations and modelling
  - ACE
  - PCW satellite
  - PREMIER instrument
  - M55 flights from Kiruna
  - Phoenix – Mars exploration
  - NOMAD – Mars exploration
  - Sentinel 4 and 5 instruments
- EcoForecast.eu

Science questions

- What is the role of aerosol in climate change?
- Can we accurately predict air quality and apportion pollution among sources?
- How well do we understand the global ozone budget? [BrO]
- Quantify the role of ozone on climate
- Improve weather and air quality forecasts

Past and Present Satellite Projects

- Voyager Mission to the outer planets (UV Spectr.)
- WINDII (UARS)
- MOPITT (Tropospheric AQ)
- OSIRIS/ODIN (upper trop and middle atmosphere)
- ACE (Upper Trop and middle atmosphere)
- Phoenix scout mission to Mars

- PCW – Polar communication and weather CSA – 2016?
- PREMIER – ESA - 2016
- ExoMars – ESA/NASA/Roscosmos – 2016 or 2018
- Sentinel 4 and 5 ESA – 2020

How to contribute

- Instrument design and hardware
- Platform
- Delivery vehicle
- Data retrieval – inversion
- Modelling and data assimilation
  - Chemical weather model

Approach – the GEM-AC model

- On-line implementation of stratospheric, tropospheric chemistry and aerosols in the Canadian weather forecast model the Global Environmental Multiscale (GEM) model
  - Model top at 60 km
  - Chemistry: 75 gas phase species, 194 chemical reactions, 45 photochemical reactions
  - Aerosol microphysics
  - Climate physics
  - Ozone and water from chemistry used in radiation calculation

Modelling – Motivation

- To develop a state-of-the-art multiscale chemical-dynamical model of the atmosphere that will be used to :
  - Study tropospheric and stratospheric chemistry in the context of air quality and climate change on urban, regional and global scales
  - Facilitate chemical weather forecasting and data assimilation of chemical species
  - Provide simulated atmospheric quantities (model atmosphere) for instrument design and retrieval algorithm testing
- To share the developed modelling system with other researchers, encouraging collaboration and training

Modelling tools

- Meteorological
  - Weather forecasts
  - Climate simulations

Models
- ECMWF
- NCEP, NCAR
- UK Met Office
- Meteo-France
- Environment Canada

- Atmospheric chemistry
  - Air quality
  - Chemical weather

Models
- AURAMS – Environment Canada
- MESSy – MPI-C Mainz, Germany
- WRF/Chem – NOAA & NCAR, USA
- GEOS-Chem – USA
- WACCM, NCAR, USA
- GEM-AQ – York U & WUT

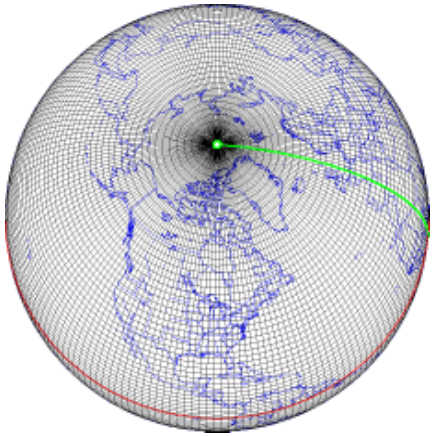
- Coupled chemistry clima

The GEM model

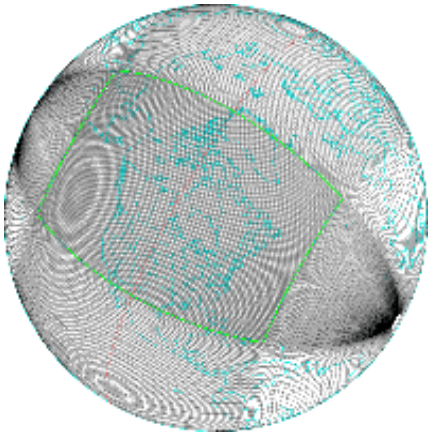
Global Environmental Multiscale Model

Canadian operational weather forecast model (Côté et al., 1998) from Environment Canada

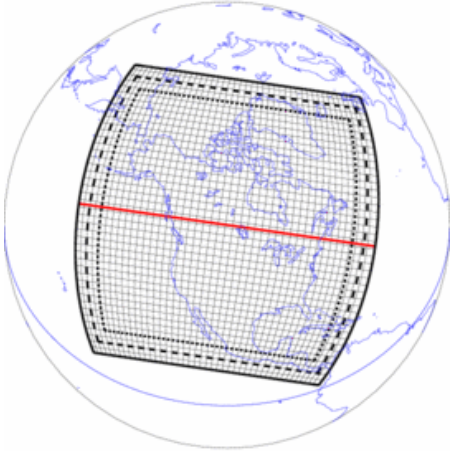
Global uniform



Global variable

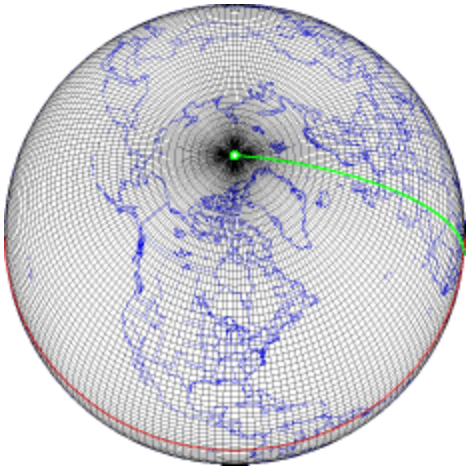


Limited area



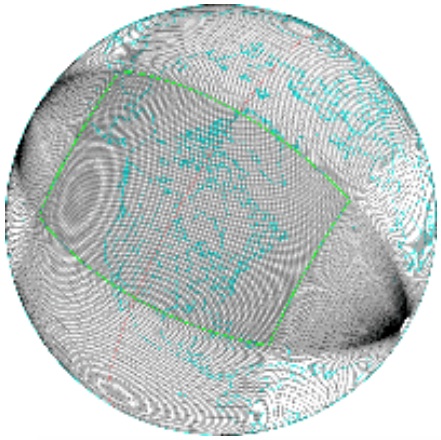
Global weather forecast

- Operational global uniform resolution
  - 0.22 x 0.22 deg (~25km) global horizontal resolution
  - 5 and 10 day forecasts
  - Seasonal and ensemble forecasts
  - Model top at 0.1 hPa (~60km)
  - 80 hybrid levels - higher resolution in the first 5 km and in the UTLS

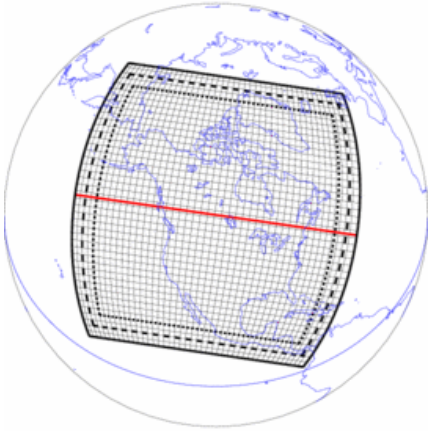


Regional weather forecast

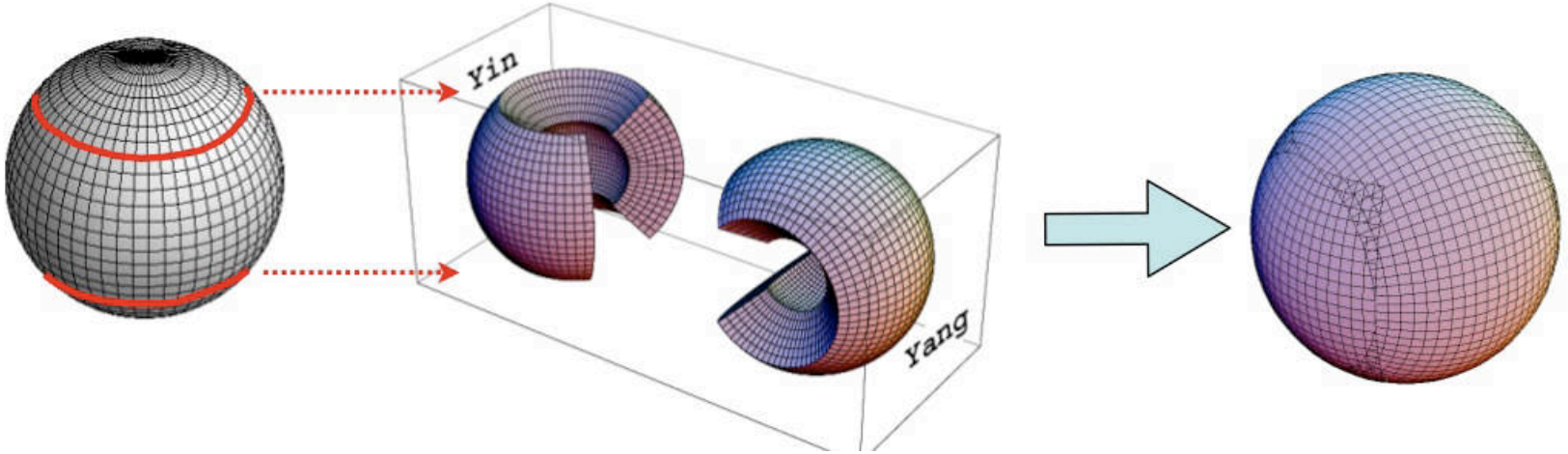
- Operational global variable resolution
  - ~10km resolution in the central region (over NA)
  - 2 day forecasts

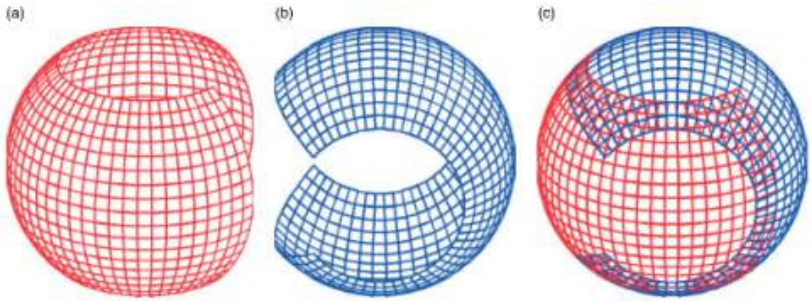


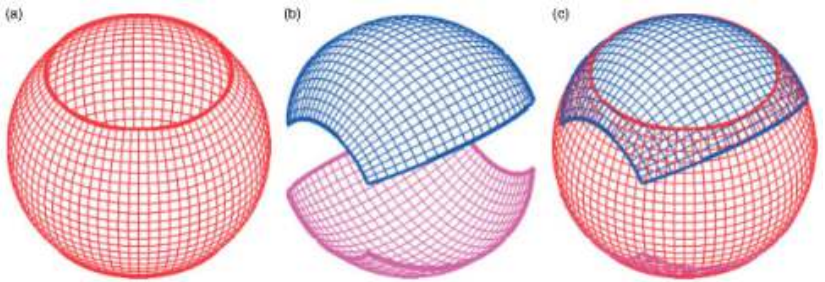
- Limited area
  - 3, 2, 1 km … down to 200m for emergency response applications
  - Short term forecasts (several hours to 2 days)



GEM on Yin Yang grid







GEM processes

- Advection
  - Hybrid levels (sigma with transition to pressure surfaces)
  - Two time level semi-Lagrangian semi-implicit
- Physics
  - Diffusion
  - Deep convection
  - Cloud microphysics
  - PBL & surface schemes
  - Solar and IR radiation
  - Gravity waves
- 4D-Var data assimilation

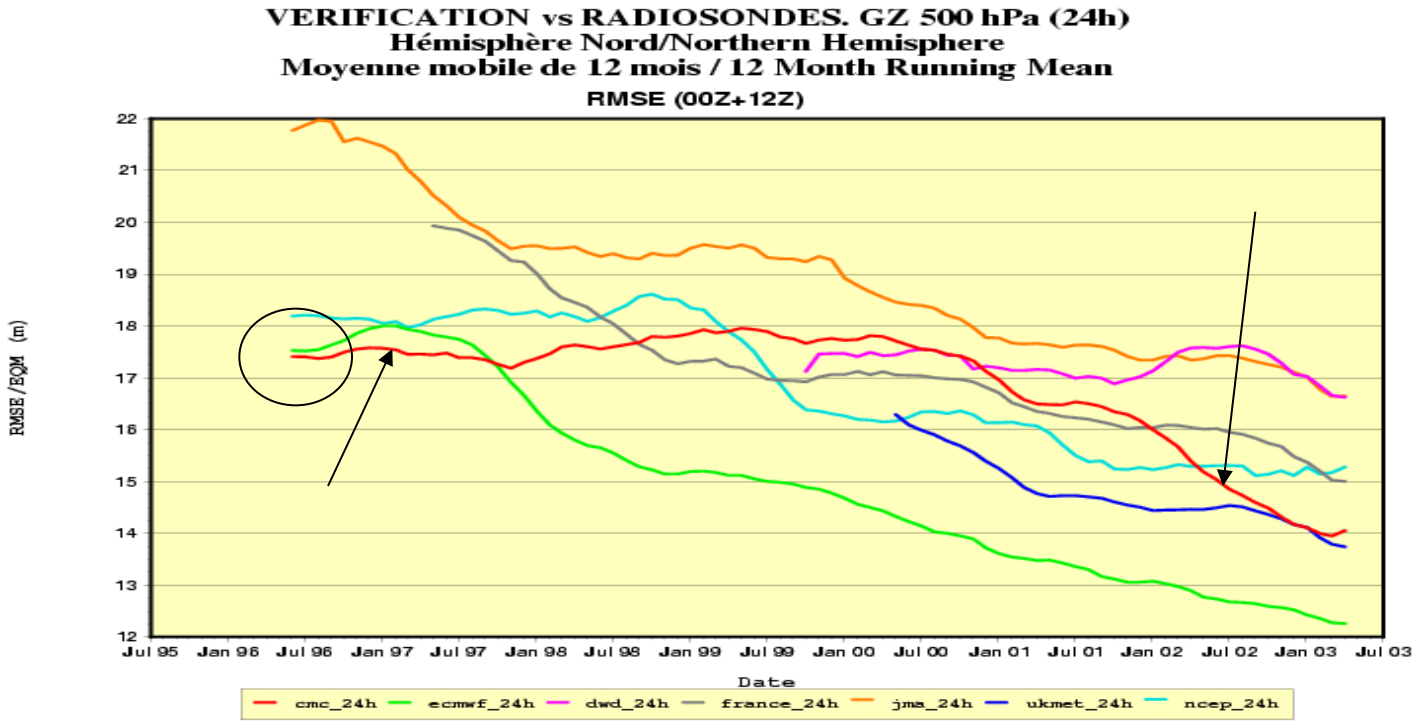
Forecasting

- Initial conditions in 3D (latitude, longitude, height) are required to start the model
  - Initial state of the atmosphere is given by:
    - Pressure
    - Temperature
    - Wind
    - Humidity
    - Surface data (albedo, snow, vegetation type, …)
    - Geophysical data (topography, surface type, …)

Atmospheric observations

- Initial state of the atmosphere is derived from observations
  - Conventional – at regular time intervals 0, 6, 12,18 GMT some observations are hourly
    - Synoptic observations (p, T, wind, humidity, cloud cover, precipitation…)
    - Radiosonde (p, T, wind, humidity) at 0 and 12 GMT
  - Satellite
    - Observations from a variety of orbits and sensors – p, T, wind, humidity are derived for input to weather prediction models
- Data assimilation methods are used to prepare objective analysis

GEM skill score – long term



CMC NCEP UK MetOffice ECMWF

GEM-AC Modules

- On-line implementation
  - Tracer transport
  - Tracer convection
  - Tracer vertical diffusion
  - Gas phase chemistry (~75 species, ~240 reactions)
  - Photodissociation rates (J values from MESSy)
  - Wet chemistry
  - Dry and wet deposition
  - Aerosol chemistry and physics
  - Anthropogenic, Biogenic and Fire emissions
  - Lightning NOx emissions

GEM-AC Applications

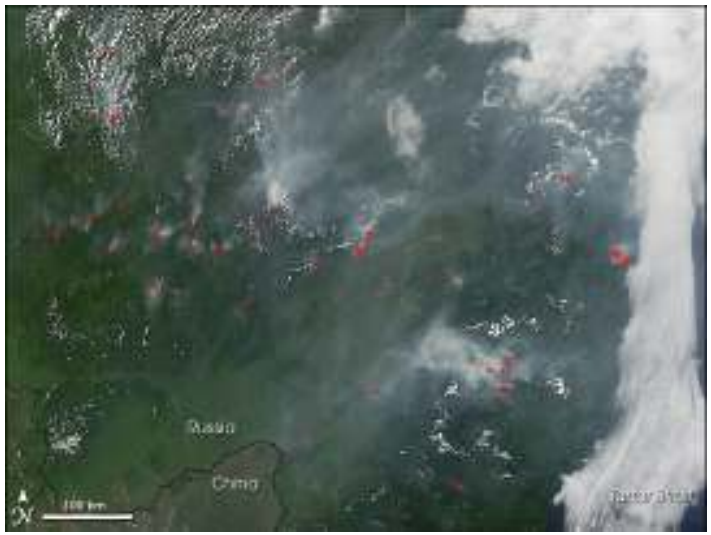
- Analysis of reactive bromine production and ozone depletion in the Arctic boundary layer using 3-D simulations with GEM-AQ: inference from synoptic-scale patterns, Toyota et al., ACP 2011.
- Hydrogen cyanide in the upper troposphere: GEM-AQ simulation and comparison with ACE-FTS observations, Lupu et al., ACP 2009
- GEM-AQ, an on-line global multiscale chemical weather modelling system: model description and evaluation of gas phase chemistry processes, Kaminski et al., ACP 2008.
- Formation and transport of photooxidants over Europe during the July 2006 heat wave - observations and GEM-AQ model simulations, Struzewska and Kaminski, ACP 2008.
- 6 HTAP publications…

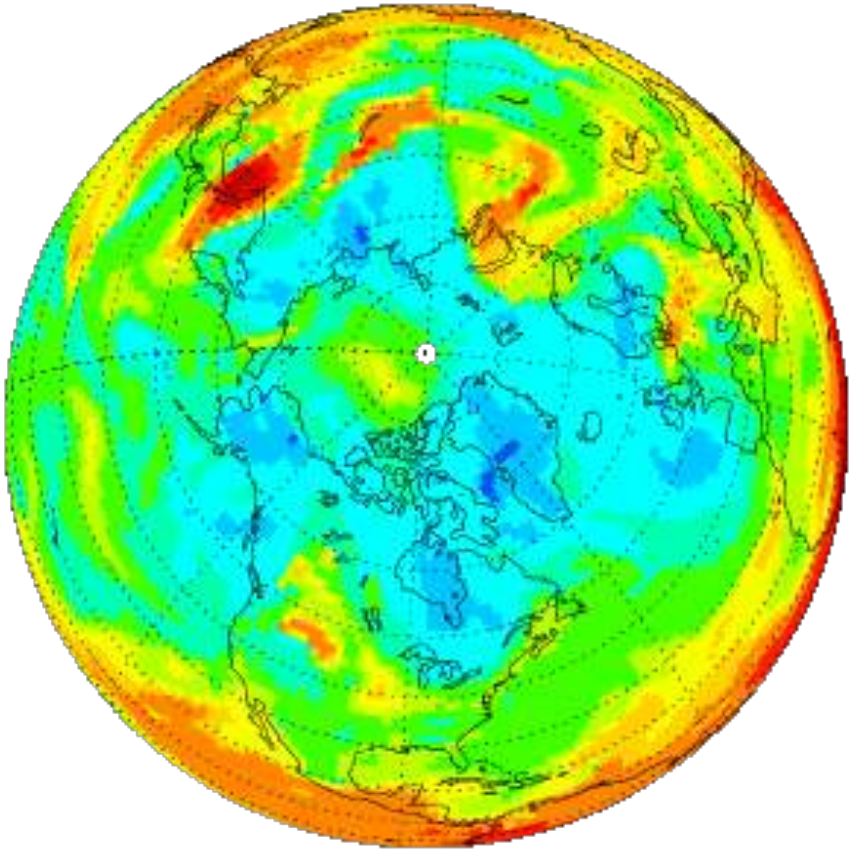
GEM-AQ HCN volume mixing ratio at 600 hPa over the Arctic on 19 August 2006 at 0400 UTC. The HCN plume swirling around the North Pole originated from forest fires in Siberia.

GEM-AQ CO volume mixing ratio at 600 hPa on 21 January 2006 at 0900 UTC illustrating wintertime transport of mid-latitude pollution into the Arctic troposphere.

Smoke event at Eureka (23–24 July 2007)

Fires burning
North of Khabarovsk, Russia

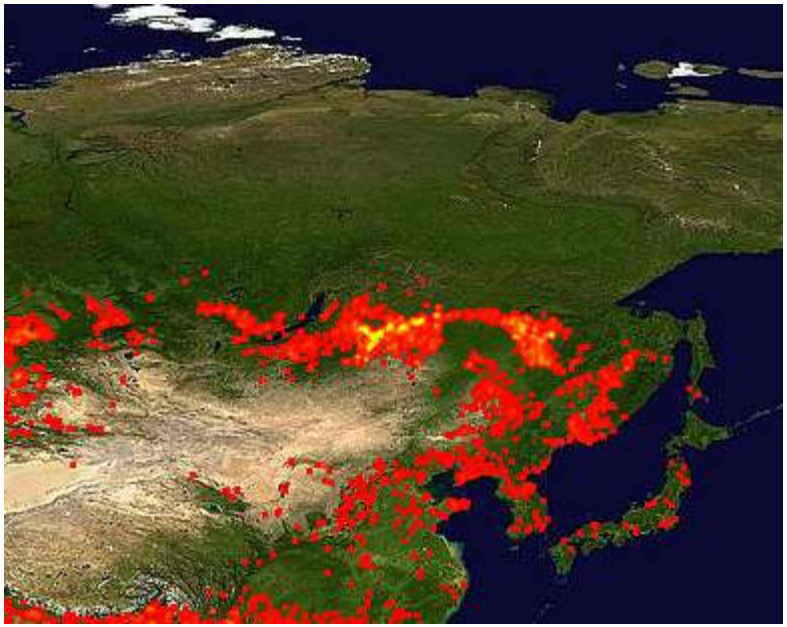


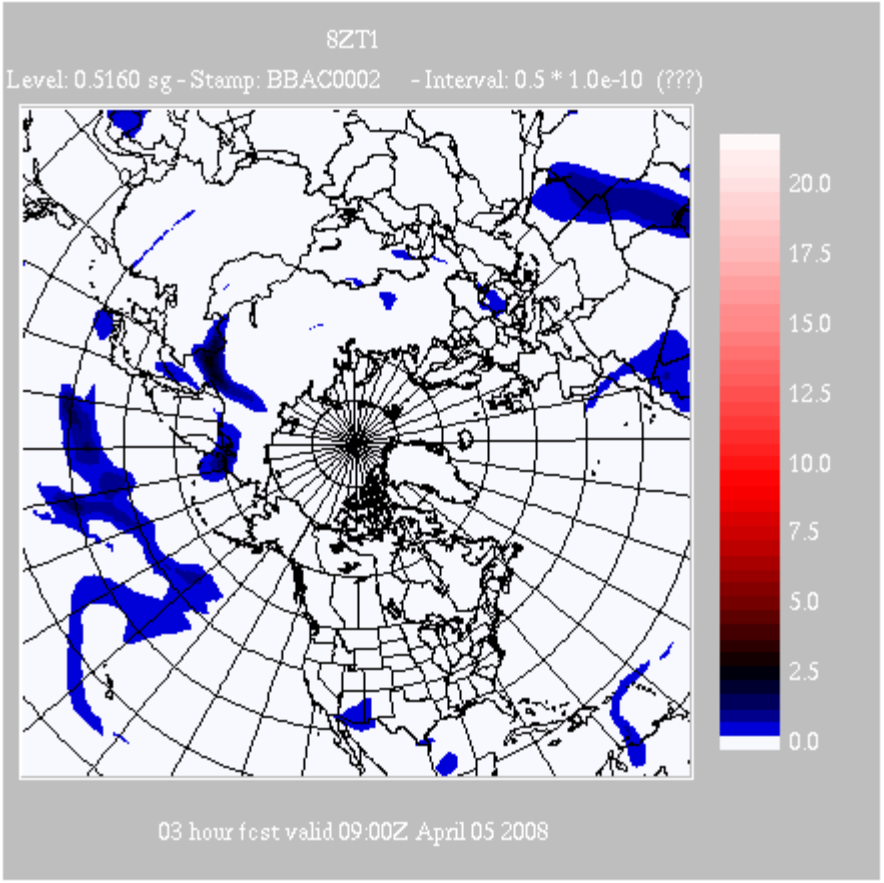


Smoke column animation for July 16–24

Smoke event at Eureka (12 April 2008)

Fires burning
East of Lake Baikal, Russia
at the beginning of April



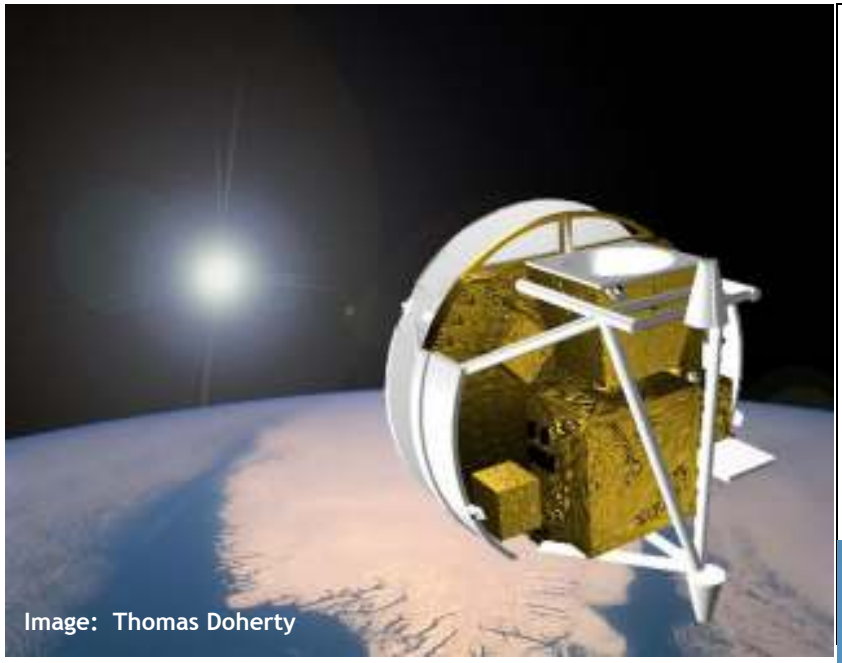


HCN at ~500 hPa for April 4–14

ACE on SCISAT-1

Atmospheric Chemistry Experiment (ACE) Satellite Mission

to measure atmospheric composition: profiles of trace gas species, clouds and aerosol extinction and temperature / pressure



- Size: 1.12 m dia. x 1 m
- Total mass: 152 kg
- Total power: 70 W (from a single solar panel)
- Launch date: August 12, 2003
- Launch vehicle: Pegasus XL
- Orbit: 74° inclined circular orbit at 650 km
- FTS: 2.2 to 13.3 μm, resolution 0.02 cm^{-1}

ACE Data Products

- ACE-FTS profiles:
  - Tracers: H_2O, O_3, N_2O, NO, NO_2, HNO_3, N_2O_5, H_2O_2, HO_2NO_2, N_2
  - Halogen-containing gases: HCl, HF, $ClONO_2$, CFC-11, CFC-12, CFC-113, COF_2, $COCl_2$, COFCl, CF_4, SF_6, CH_3Cl, CCl_4, HCFC-22, HCFC-141b, HCFC-142b
  - Carbon-containing gases: CO, CH_4, CH_3OH, H_2CO, HCOOH, C_2H_2, C_2H_4, C_2H_6, OCS, HCN and pressure / temperature from CO_2 lines
  - Isotopologues: Minor species of H_2O, CO_2, O_3, N_2O CO, CH_4, OCS
  - Research species: ClO, acetone, PAN (peroxyacetyl nitrate), etc.
- MAESTRO profiles:
  - O_3, NO_2, optical depth and aerosol (water vapor being developed)
- IMAGERS profiles:
  - Atmospheric extinction at 0.5 and 1.02 microns (aerosols in v3.0)

ACE-FTS (ABB-Bomem)

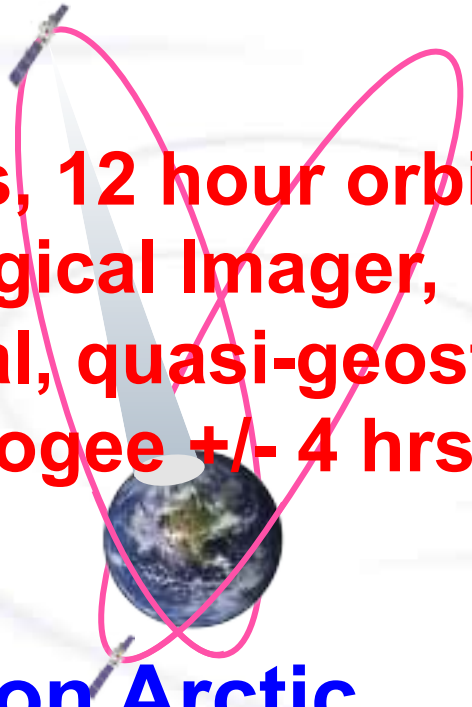
The ACE-FTS is the main instrument on SCISAT-1.

It is a high spectral resolution (0.02 cm-1) Fourier Transform Spectrometer (FTS) operating from 2.2 to 13.3 μm (750-4400 cm-1) with a Michelson interferometer that was custom designed and built by ABB-Bomem in Quebec City.

Interferometer-side

Input optics-side

Polar Communications & Weather
(PCW) Mission



2 satellites, 12 hour orbits, Meteorological Imager, operational, quasi-geostationary around apogee +/- 4 hrs

Focus on Arctic

PCW Mission

- Provide Arctic data
- To improve meteorological data
  - T, P, H2O, ice clouds
- To improve understanding of impact of northern nations on air quality
  - Measuring gaseous species data
  - Aerosols
- To improve estimates of GHG gases sources

Viewing geometry from Molnyia orbit locations. The 3 views are for an apogee at 90°W longitude. Images have been scaled to show approximate angular size difference due to altitude change over the 8 hr period they span. Note that rotation of the Earth almost exactly compensates for satellite motion in longitude.

Air quality – summer Hi-Pressure

Apogee – 4 hours

Boreal Forest burning/Volcanoes

Apogee

East coast Low Pressure Bomb

Apogee + 4 hours

Viewing geometry from Molnyia orbit locations. The 3 views would be for the alternate apogees which would occur at 90°E. Images have been scaled to show approximate angular size difference due to altitude change over the 8 hr period they span. Note that rotation of the Earth almost exactly compensates for satellite motion in longitude.

Monsoon, meteorology + AQ

Siberian Fires

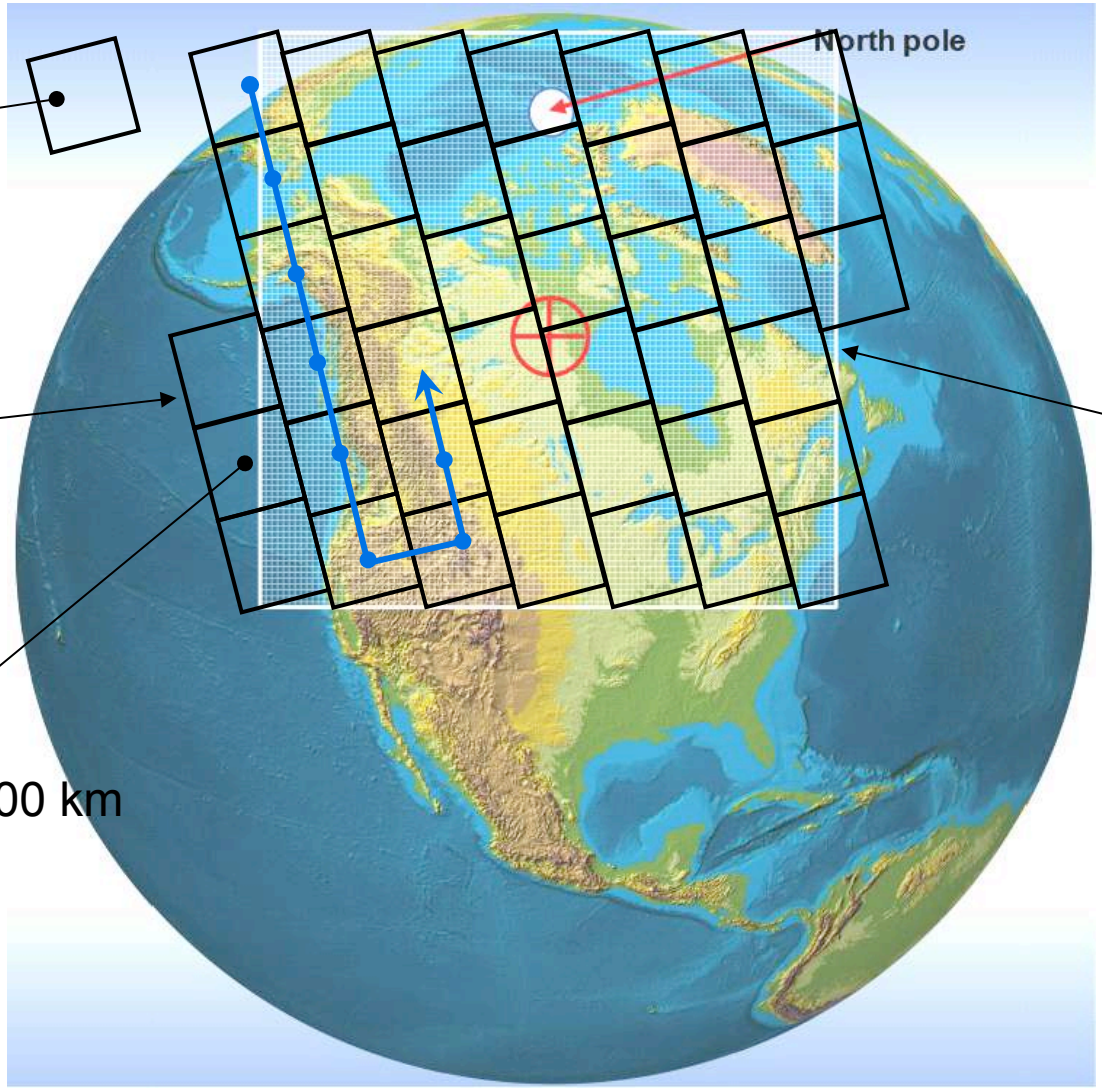
Dust Storms over China -> Canada

Apogee – 4 hours

Apogee

Apogee + 4 hours

IR-Sounder description
Scan pattern

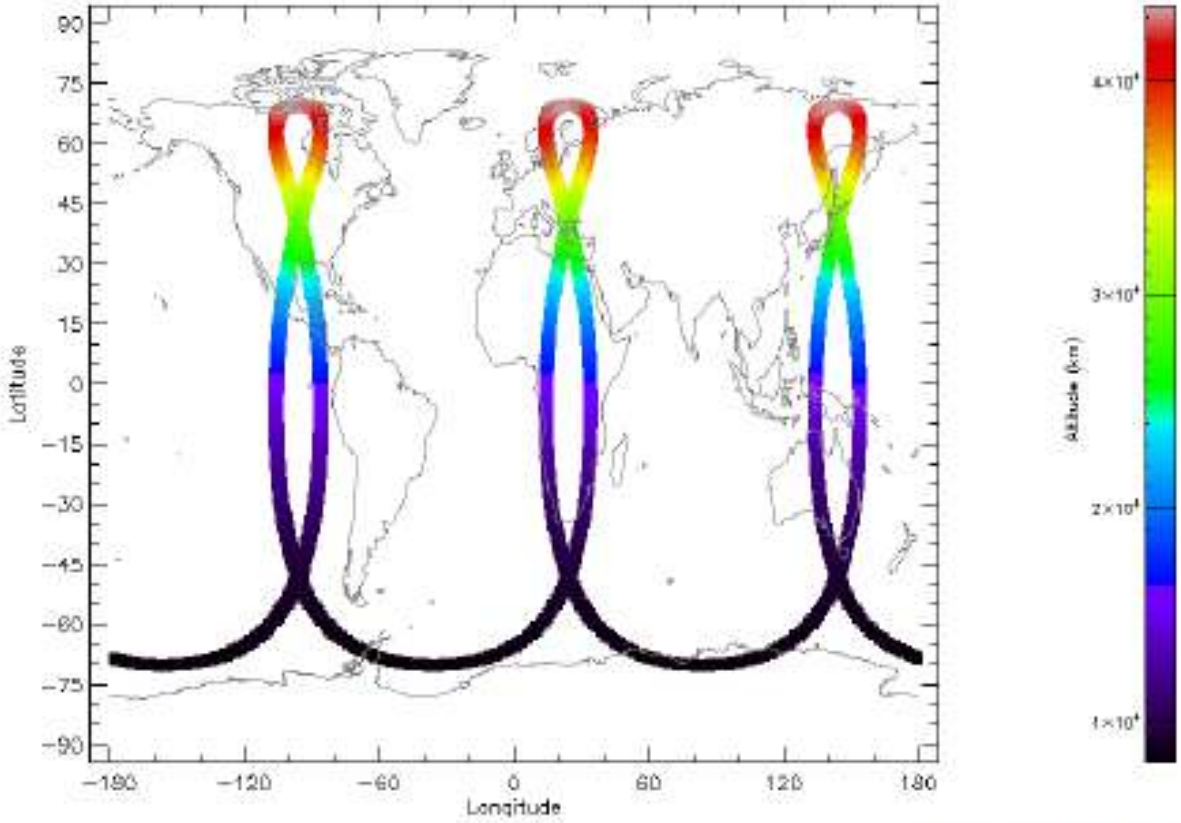


GIFOV at nadir at 37600 km

10 x 10 km all bands

Nominally 1 hr repeat

16hrs orbit is very good alternative candidate for PCW

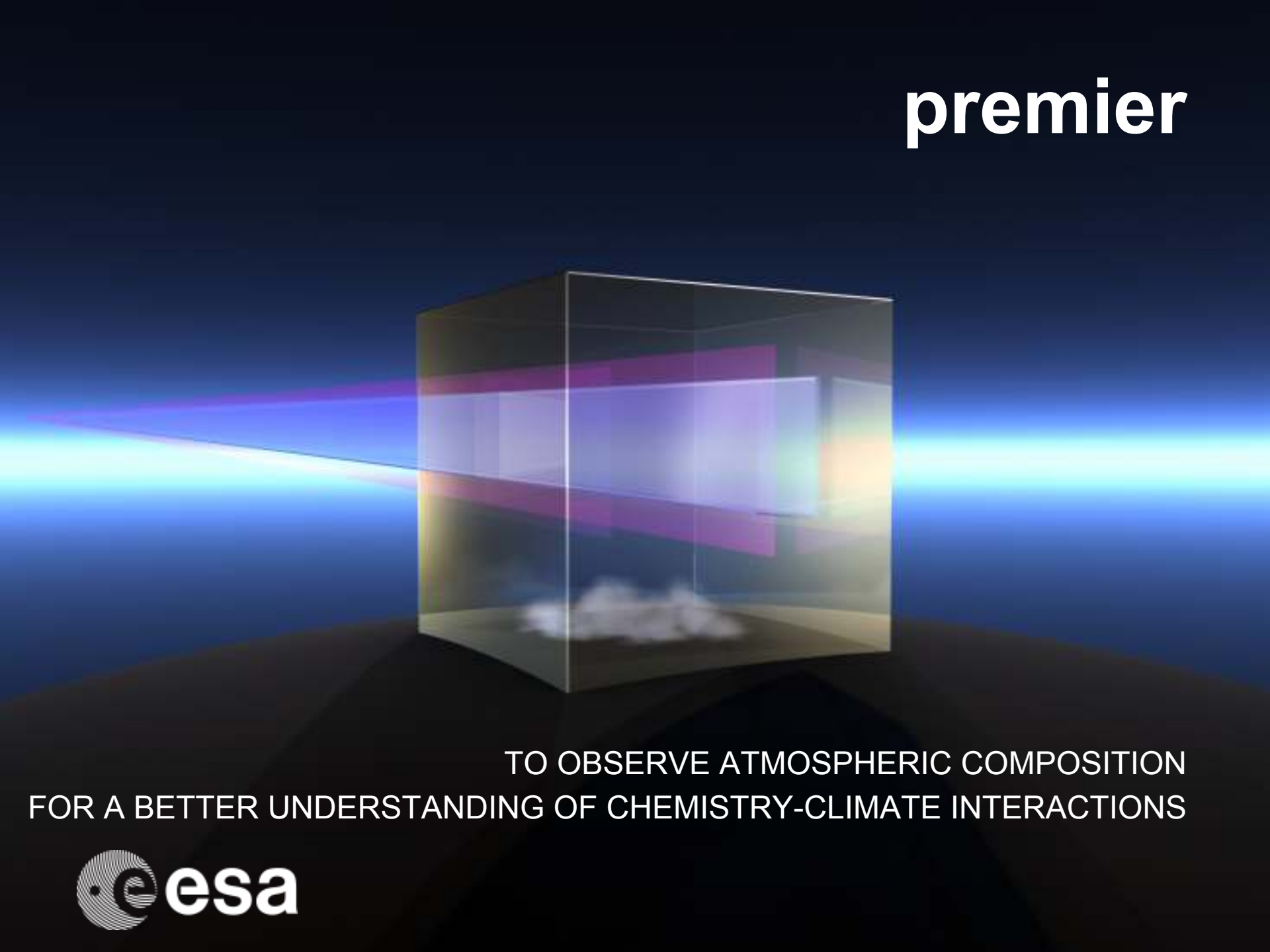


Three APogee (TAP) orbit

Suggested apogees: 95⁰W; 25⁰E, 145⁰E

A. Trishchenko, L. Garand, and L.Trischtchenko, Submitted to *J. Atmos. Ocean.Tech.*, March, 2011

premier



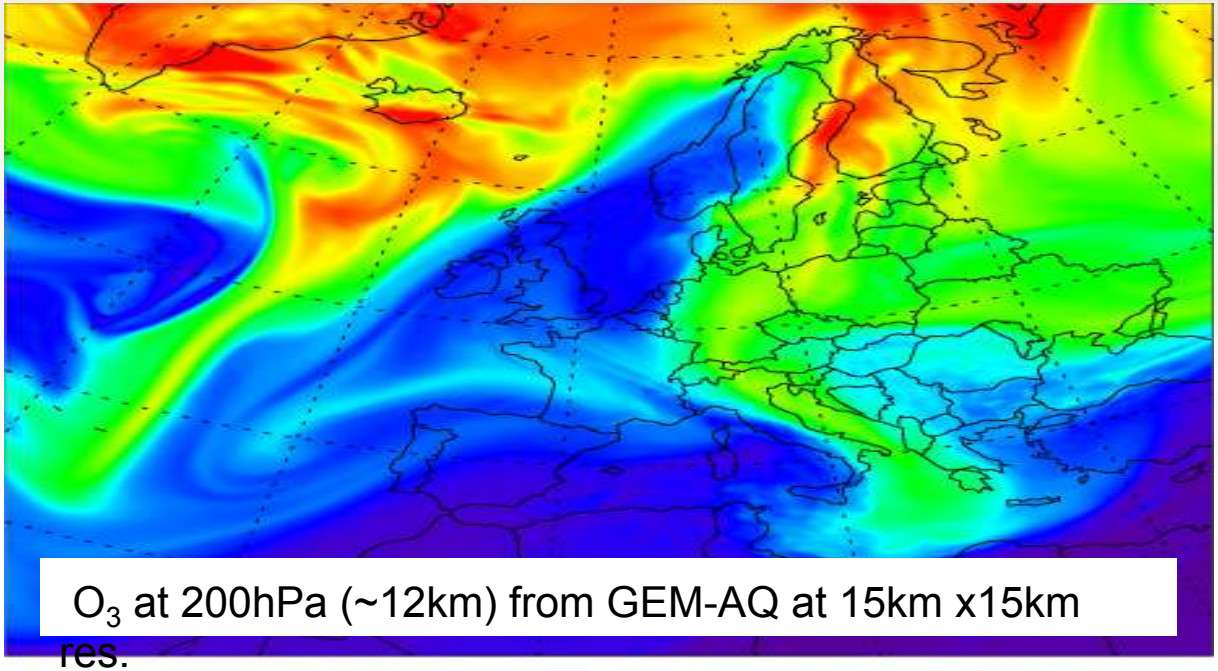
TO OBSERVE ATMOSPHERIC COMPOSITION
FOR A BETTER UNDERSTANDING OF CHEMISTRY-CLIMATE INTERACTIONS

esa

ESA Explorer Mission PREMIER

- PRocess Exploration through Measurements of Infrared and millimetre-wave Emitted Radiation (PREMIER)
- One of 3 from originally 24 Earth Explorer mission-proposals selected by ESA for a phase-A study.
- The primary mission aim is to:
  - explore processes controlling the composition of the mid/upper troposphere and lower stratosphere
  - observing trace gas, particulate and T distributions in this region down to finer scales than any previous satellite mission

Geophysical data requirements



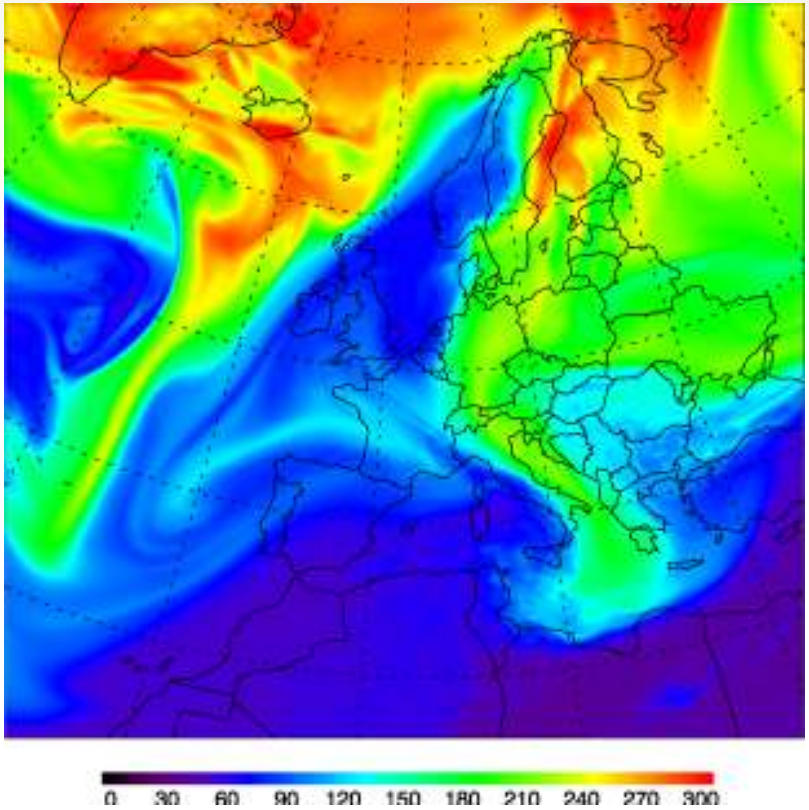
O_3 at 200hPa (~12km) from GEM-AQ at 15km x15km res.

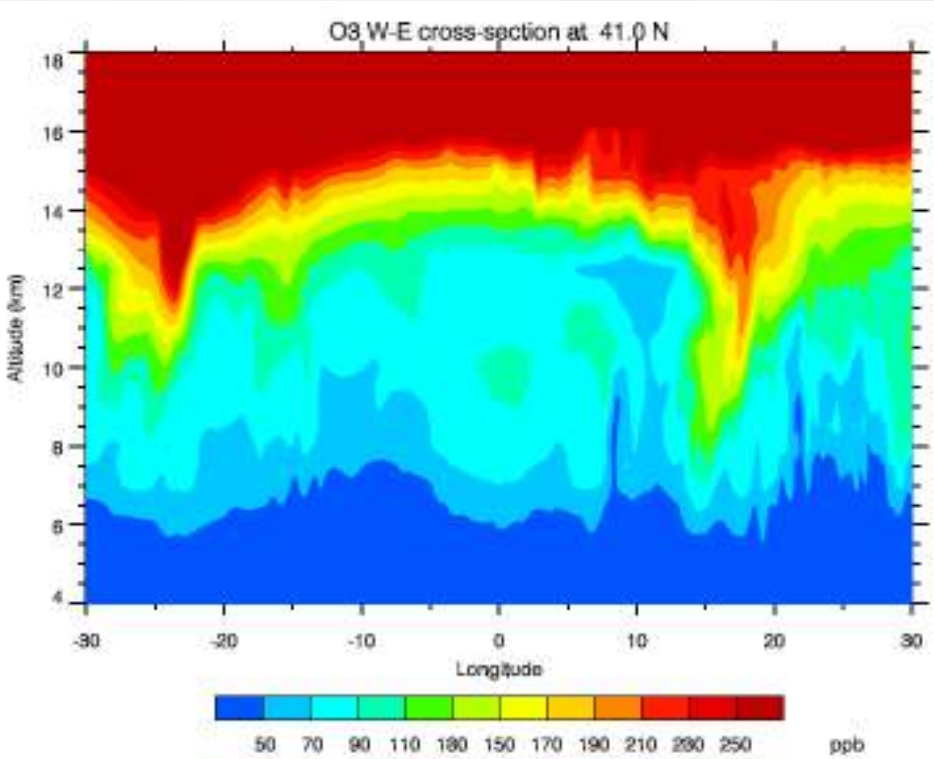
– Trace gas distribution in this key region are controlled by a complex interplay between different transport and mixing processes operating at fine scales

→ *Driving stringent observational requirements which substantially exceed capabilities of current and planned missions*

Ozone field – simulation at 15-km horizontal resolution

O3 (ppb) at 12.5 km asl





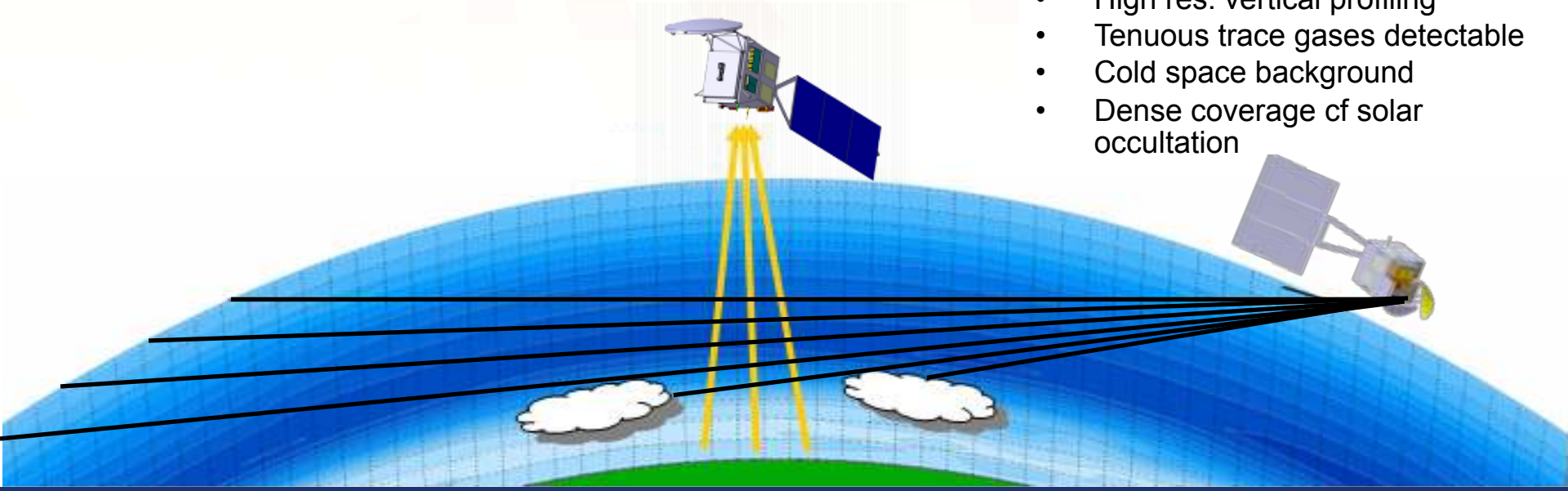
Observation techniques

Nadir-sounding

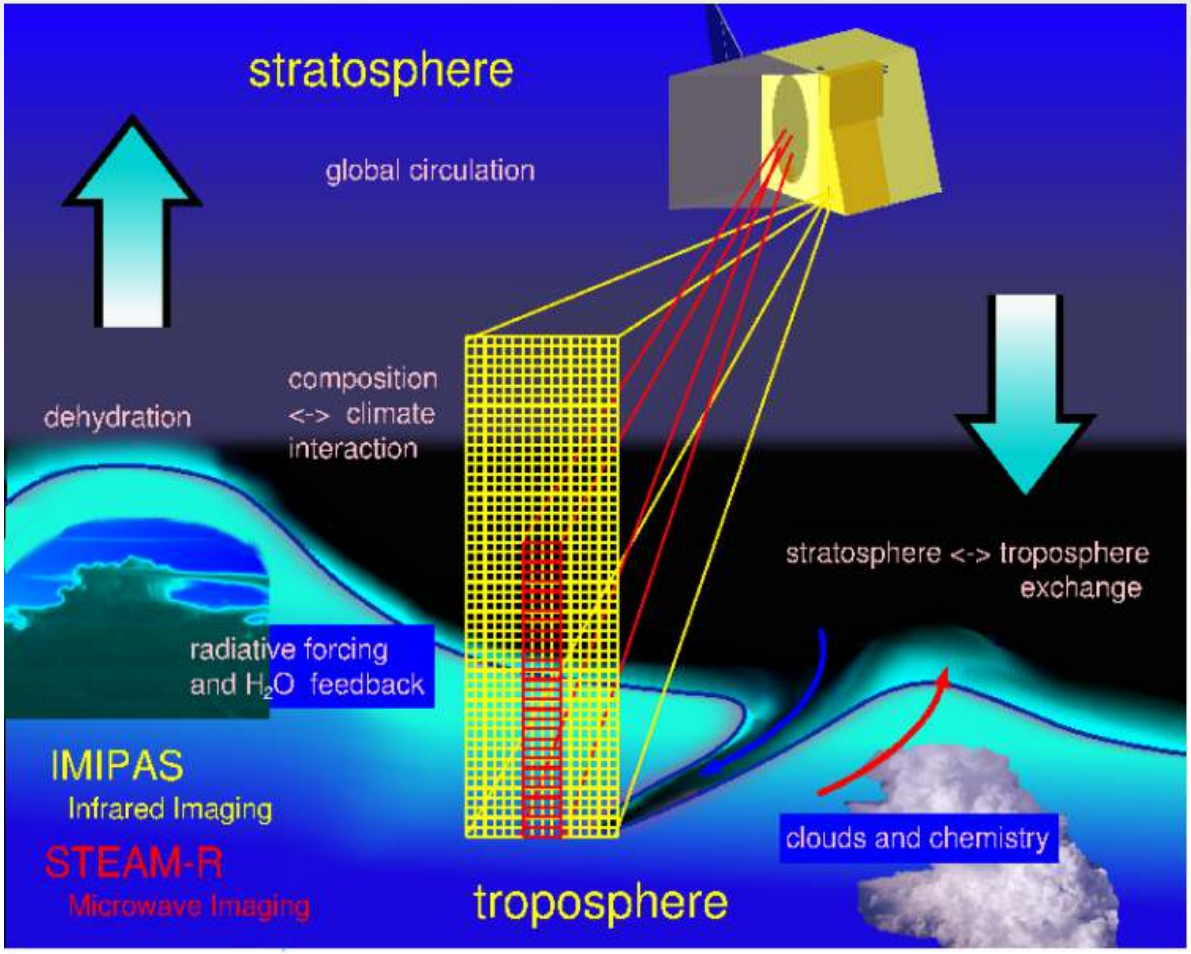
- Near-surface layer seen between clouds *but*
- Little or no vertical resolution

Limb-emission sounding

- High res. vertical profiling
- Tenuous trace gases detectable
- Cold space background
- Dense coverage cf solar occultation

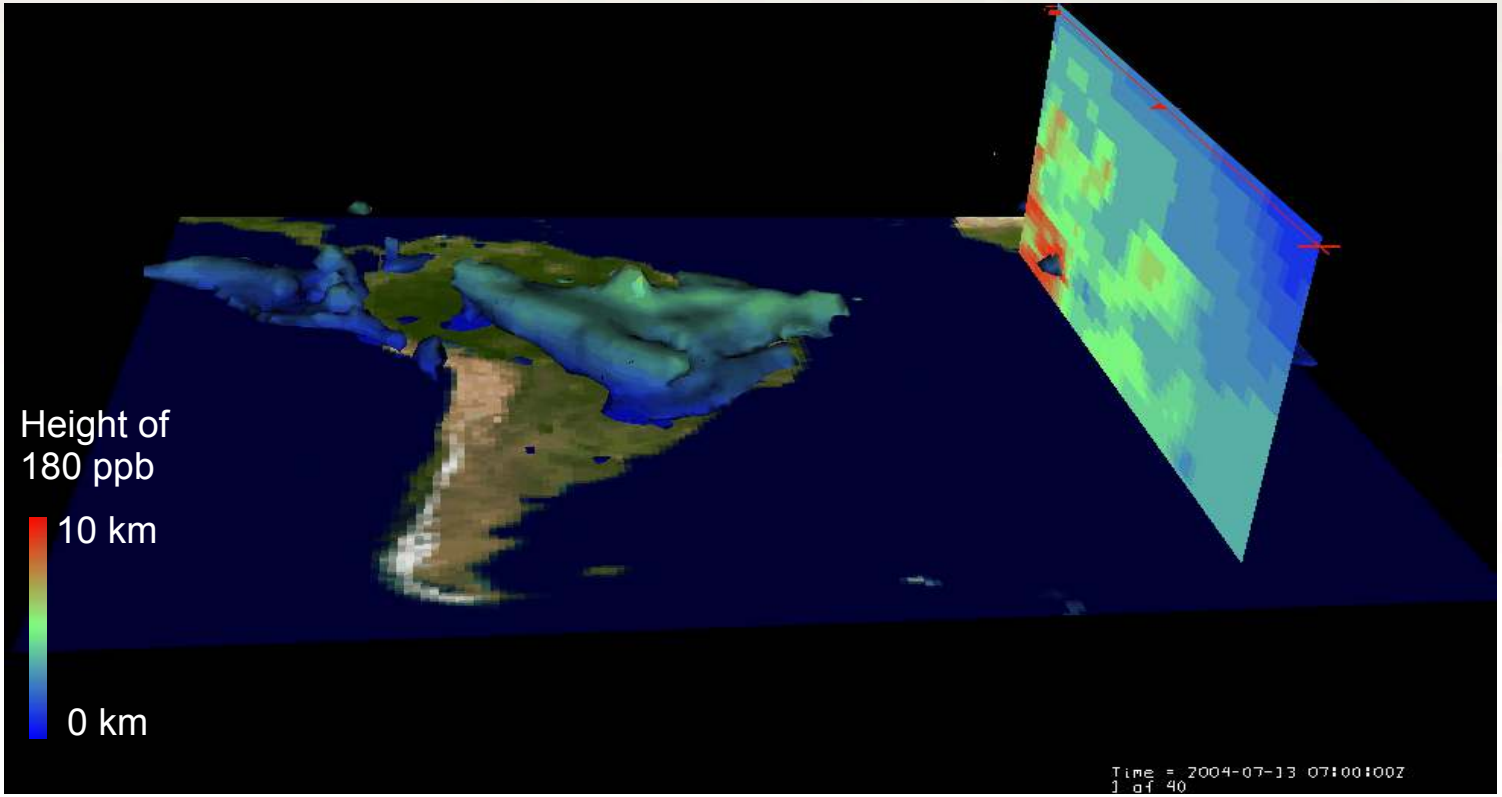


PREMIER observations



Plumes from tropical burning, boreal forest fires and industrial emissions

Model CO – 13th to 18th July '04

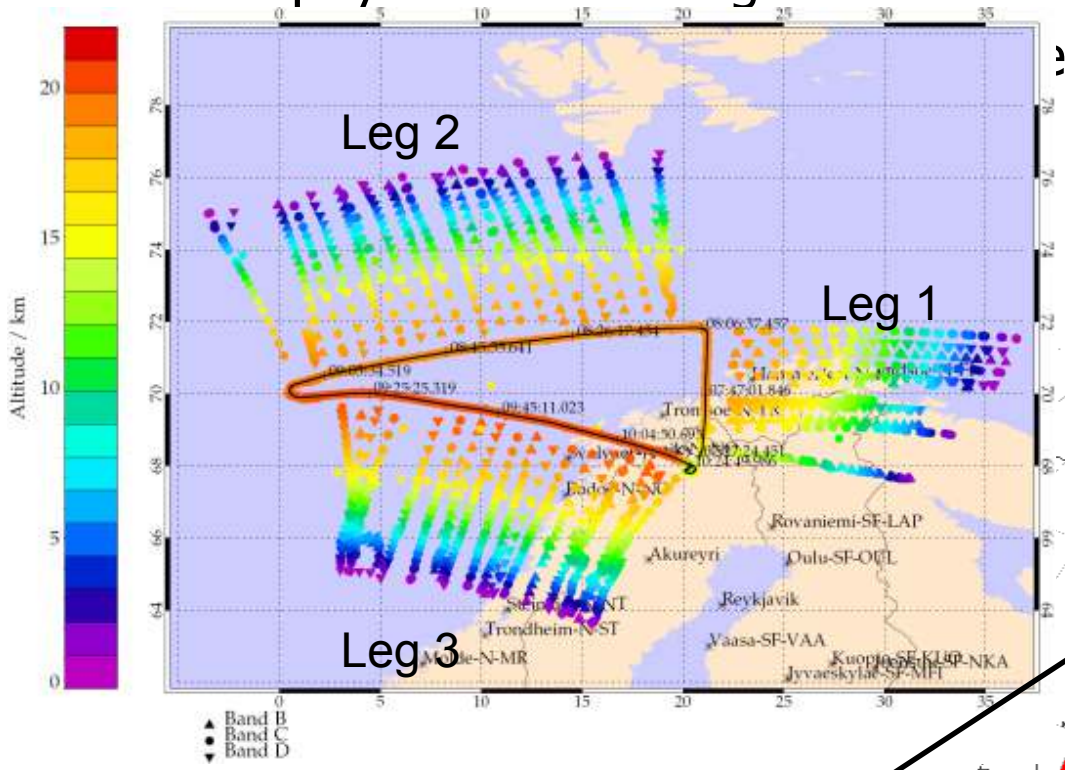


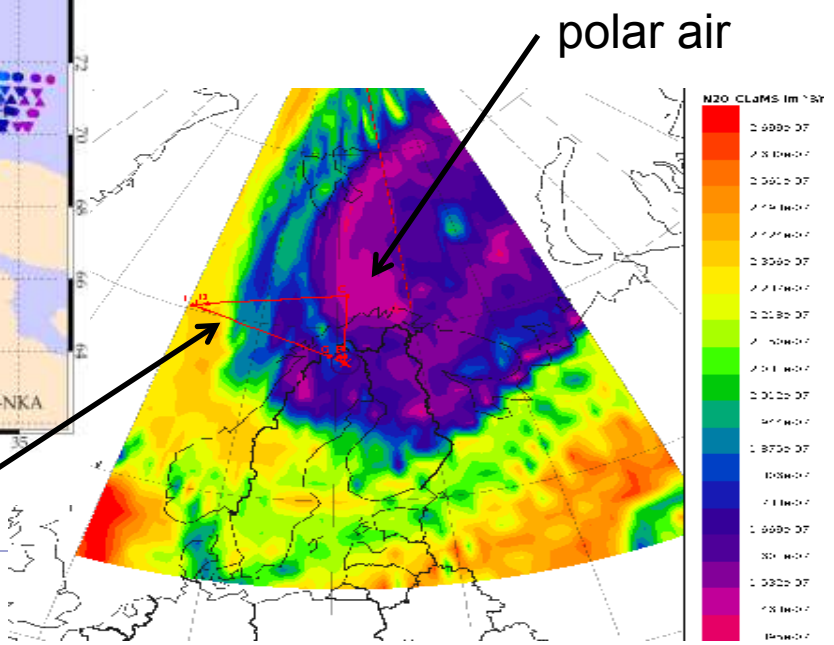
– Biomass burning and anthropogenic sources of CO, other organics and nitrogen compounds generate O_3 in the height-range important to climate.

– *To quantify O_3 production & radiative forcing, precursor plumes must be observed*

MARSCHALS Data Analysis for PREMIER_Ex

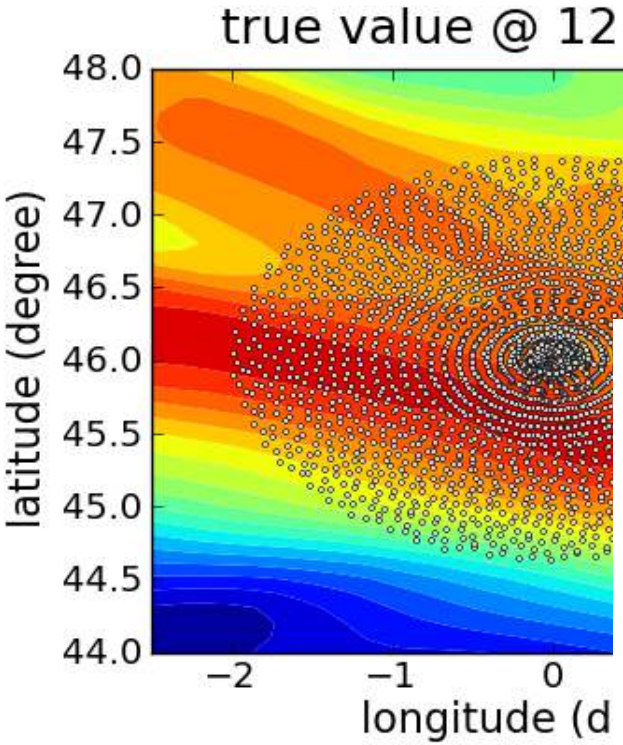
- Geophysika aircraft flight on 10th Mar'2010 from Kiruna
  - & polar air
    - Filaments of mid-latitude & polar air are interleaved

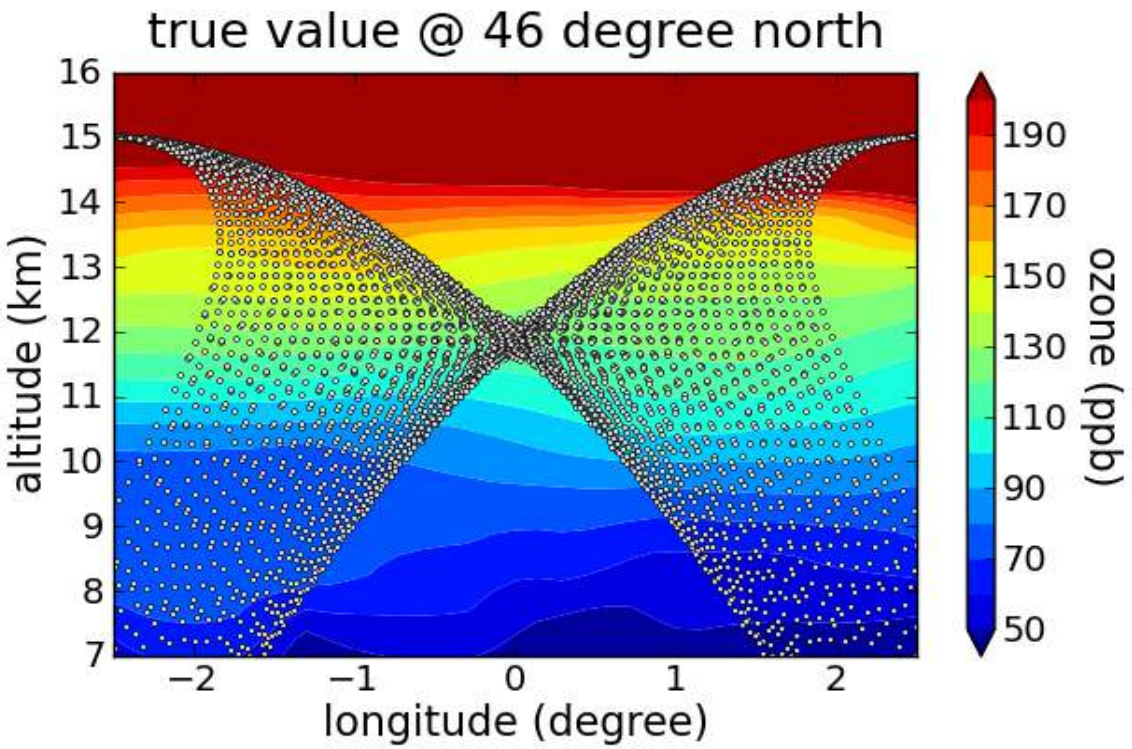




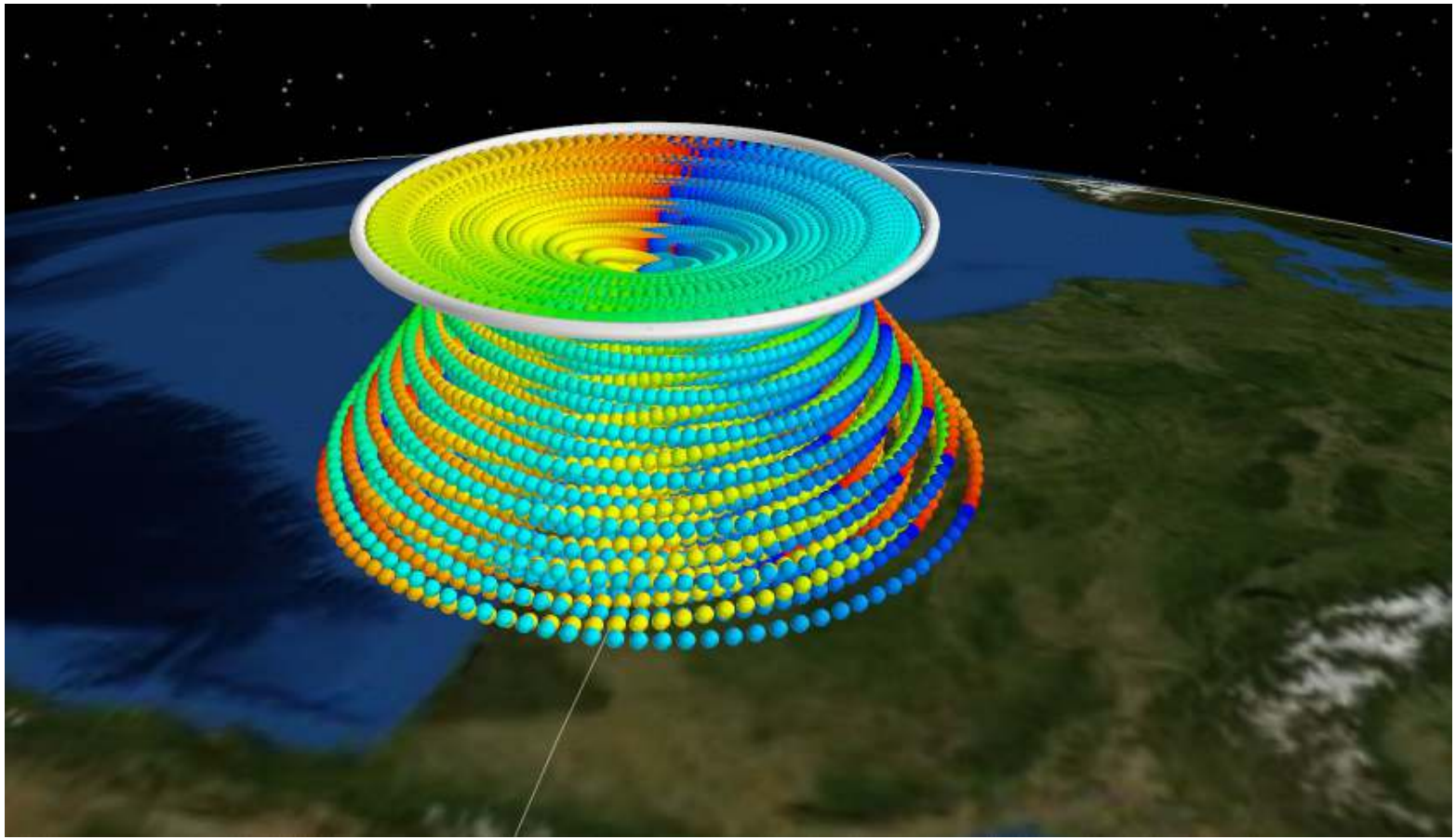
GLORIA - Global Limb Radiance Imager of the Atmosphere

Horizontal and vertical scans

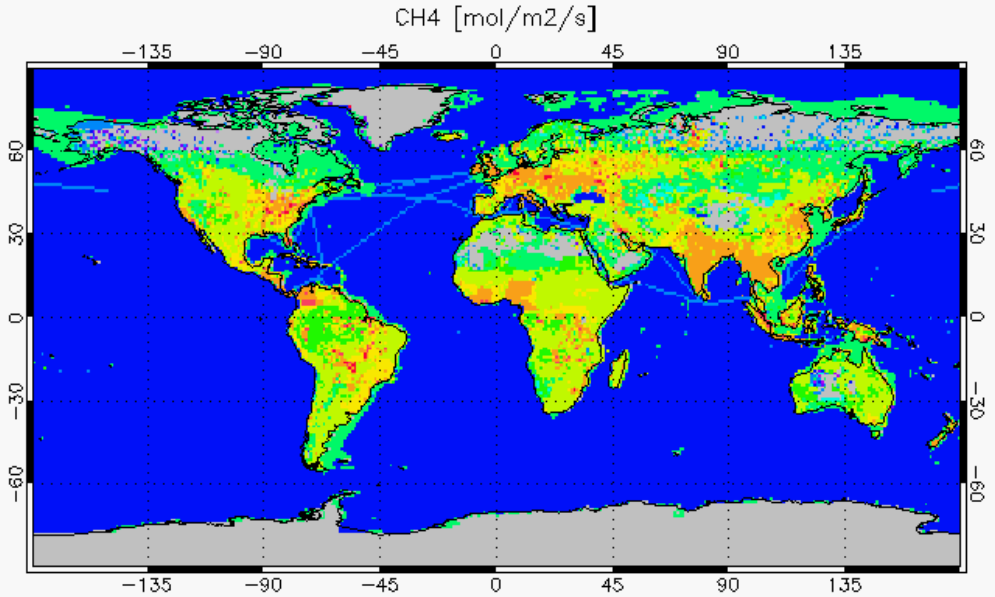




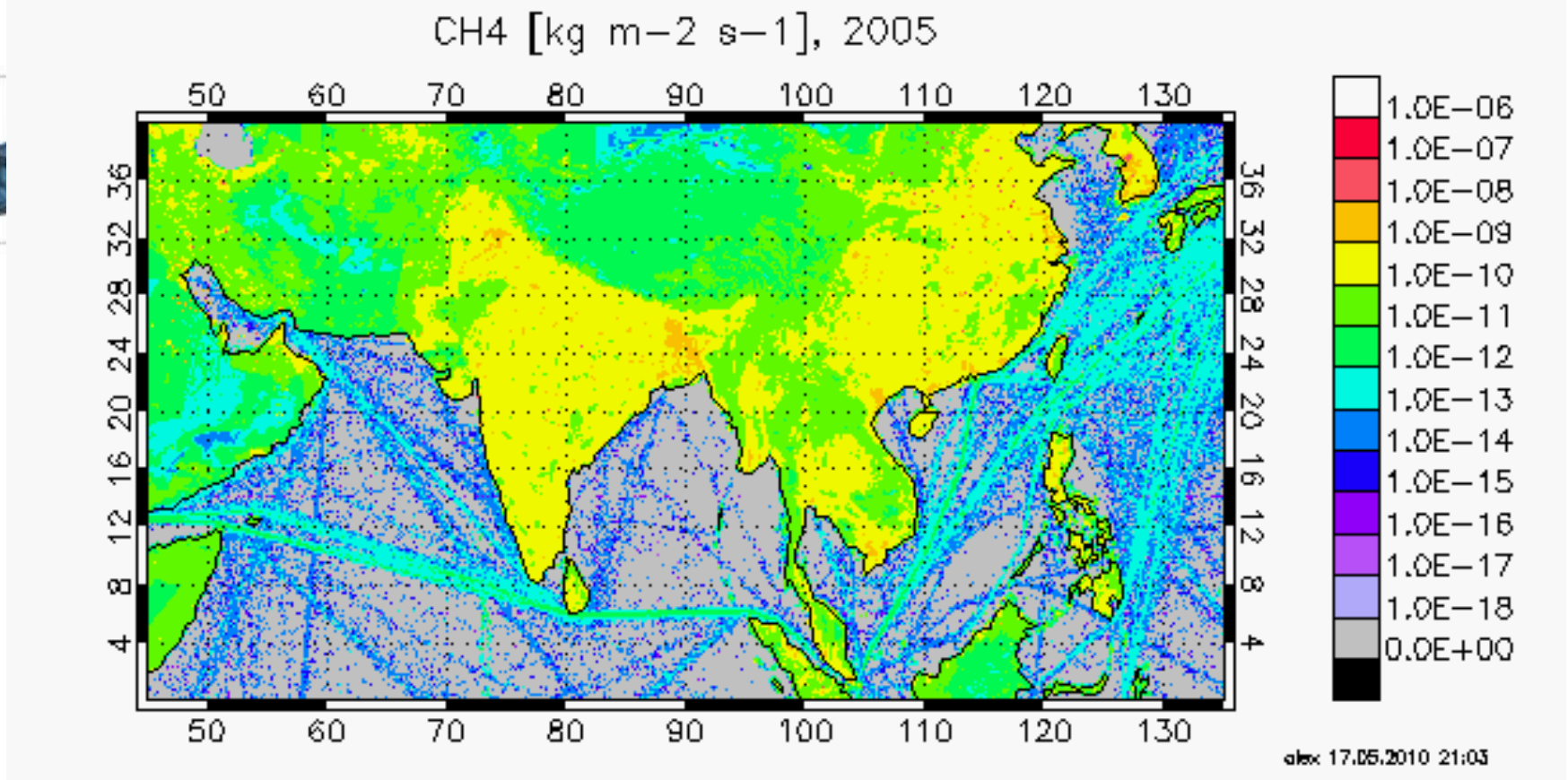
3D composition



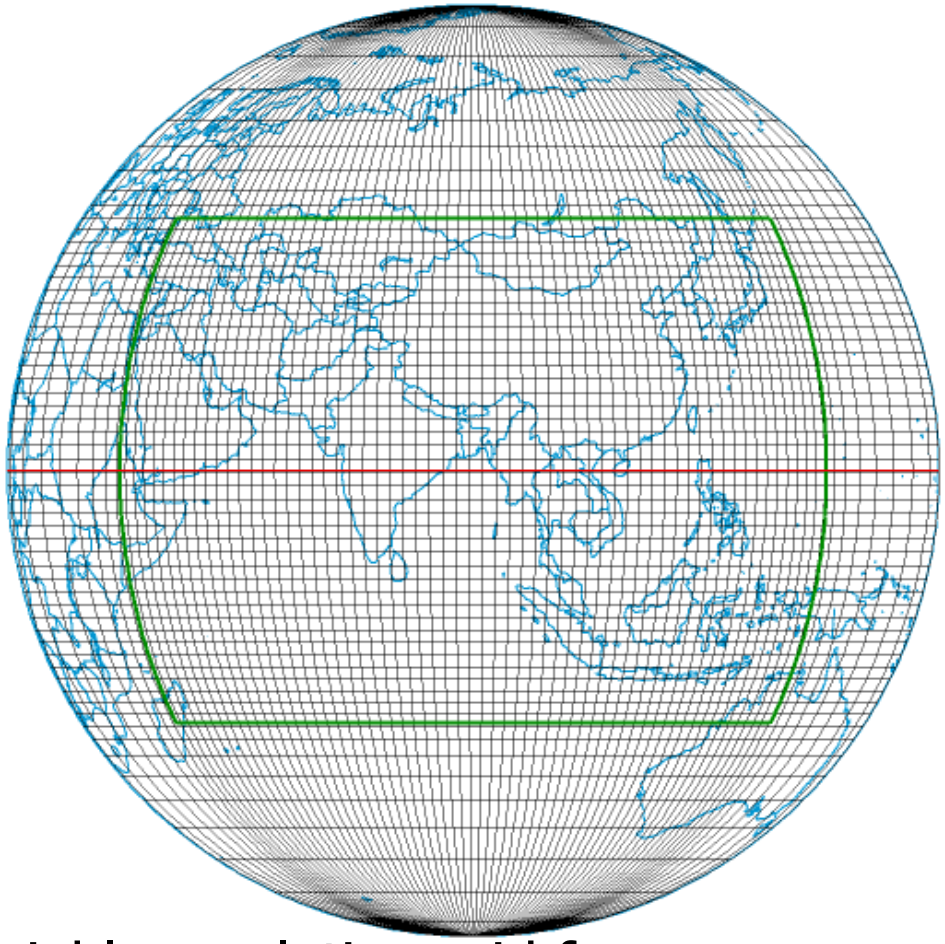
Methane Emissions



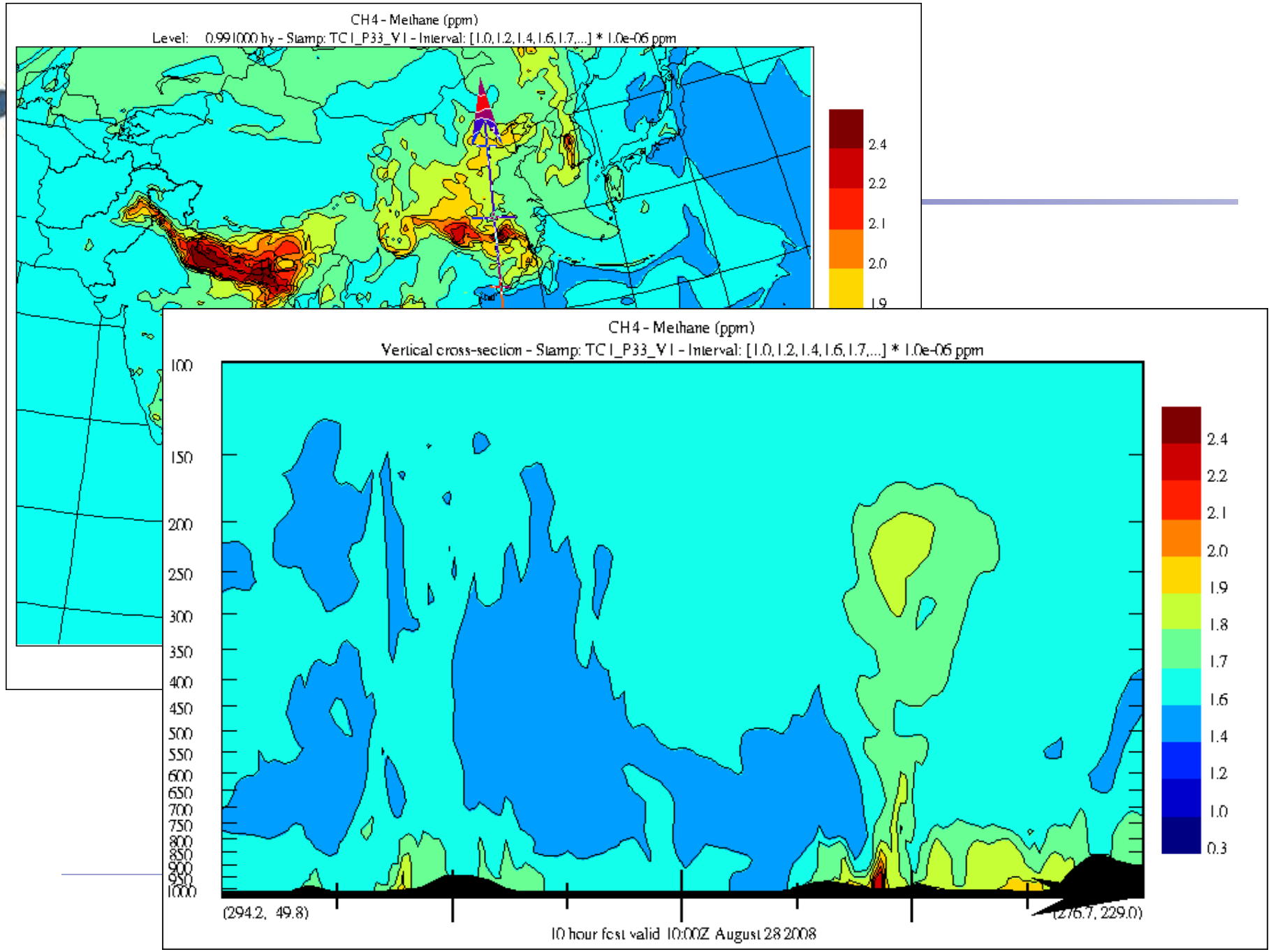
- Anthropogenic: based on EDGAR 3.2 (annual)
- Natural: GISS inventory, REAS rice, oceans and mud volcanoes (monthly)
- Wetland: based on ORCHIDEE model (monthly)
- Biomass burning: GFEDv2 (monthly)
- (Emission data courtesy of Prabir Patra, JAMSTEC, Japan)

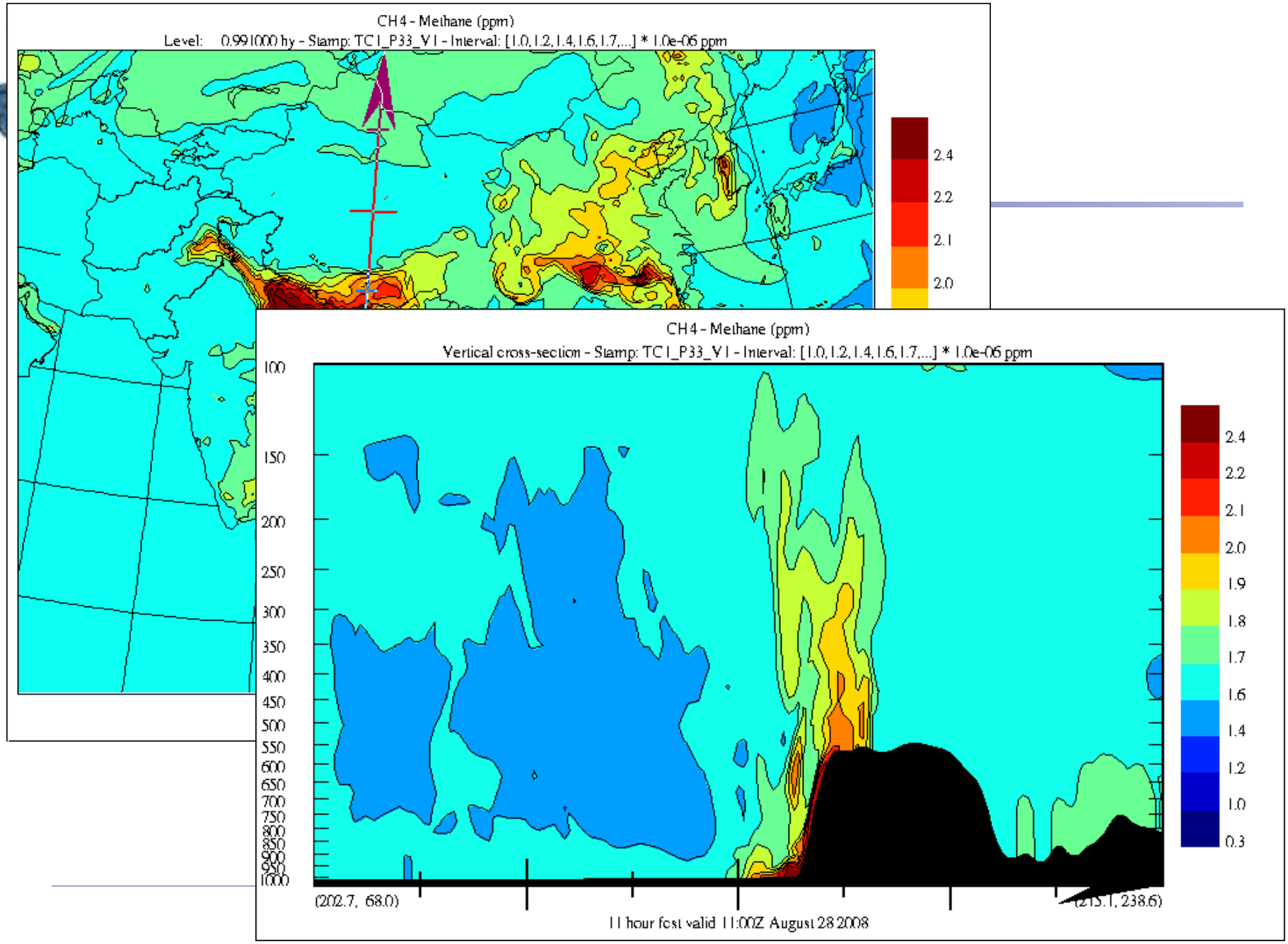


Total anthropogenic methane emissions for year 2005 from EDGAR v4 (agricultural soils, agricultural waste burning, livestock, road transportation, ships, production of oil and gas, residential, waste, etc). The grid is 0.1 x 0.1 degrees.



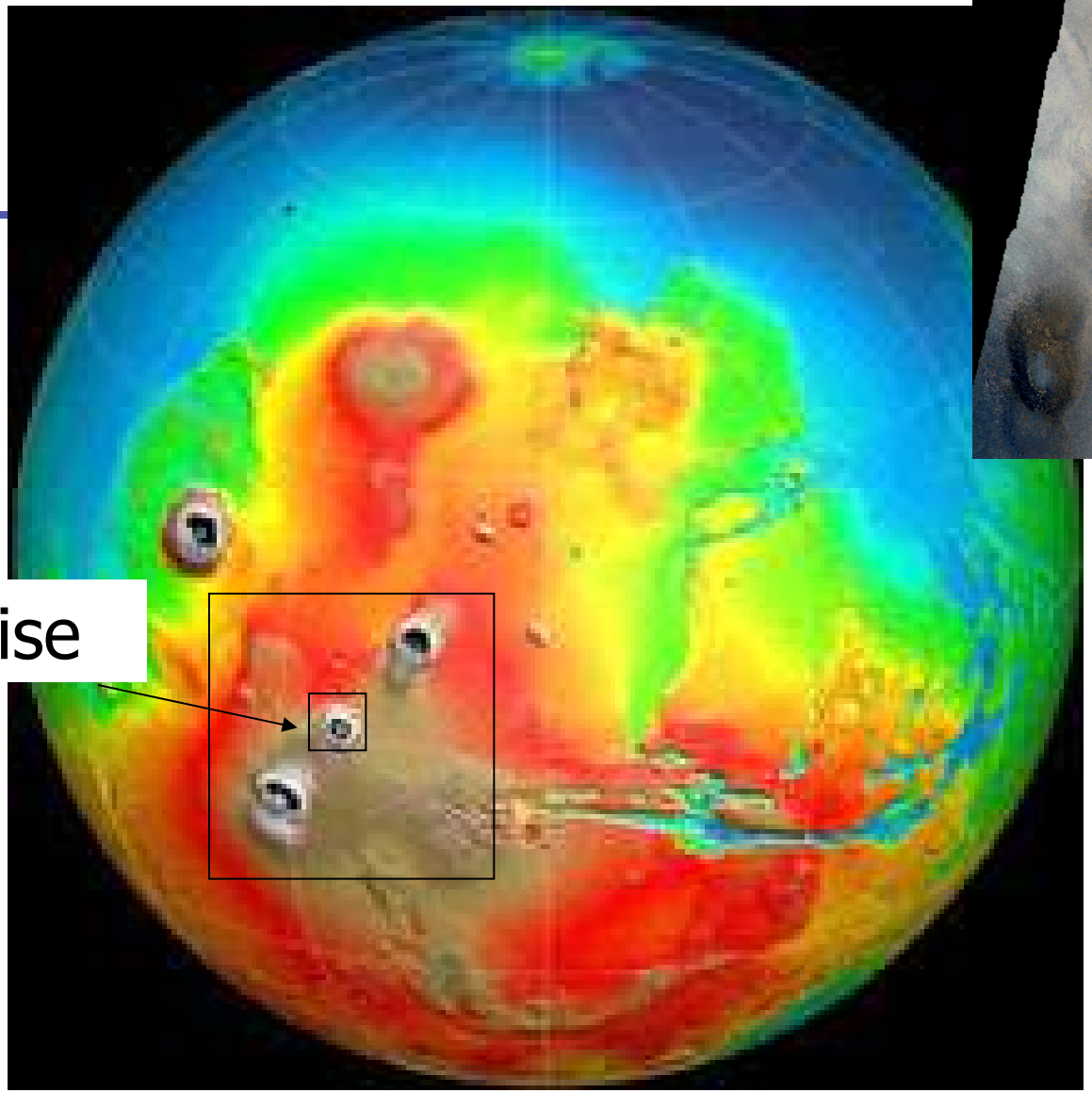
- Global variable resolution grid for monsoon
- ~30km horizontal resolution in the core (uniform resolution part of the domain)
- Every 3rd line is plotted


CH4 - Methane (ppm)
Level: 0.991000 hy - Stamp: TC1_P33_V1 - Interval: [1.0,1.2,1.4,1.6,1.7,...] * 1.0e-06 ppm
2.4
2.2
2.1
2.0
1.9
CH4 - Methane (ppm)
Vertical cross-section - Stamp: TC1_P33_V1 - Interval: [1.0,1.2,1.4,1.6,1.7,...] * 1.0e-06 ppm
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
2.4
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.4
1.2
1.0
0.3
(294.2, 49.8)
(276.7, 229.0)
10 hour fcst valid 10:00Z August 28 2008

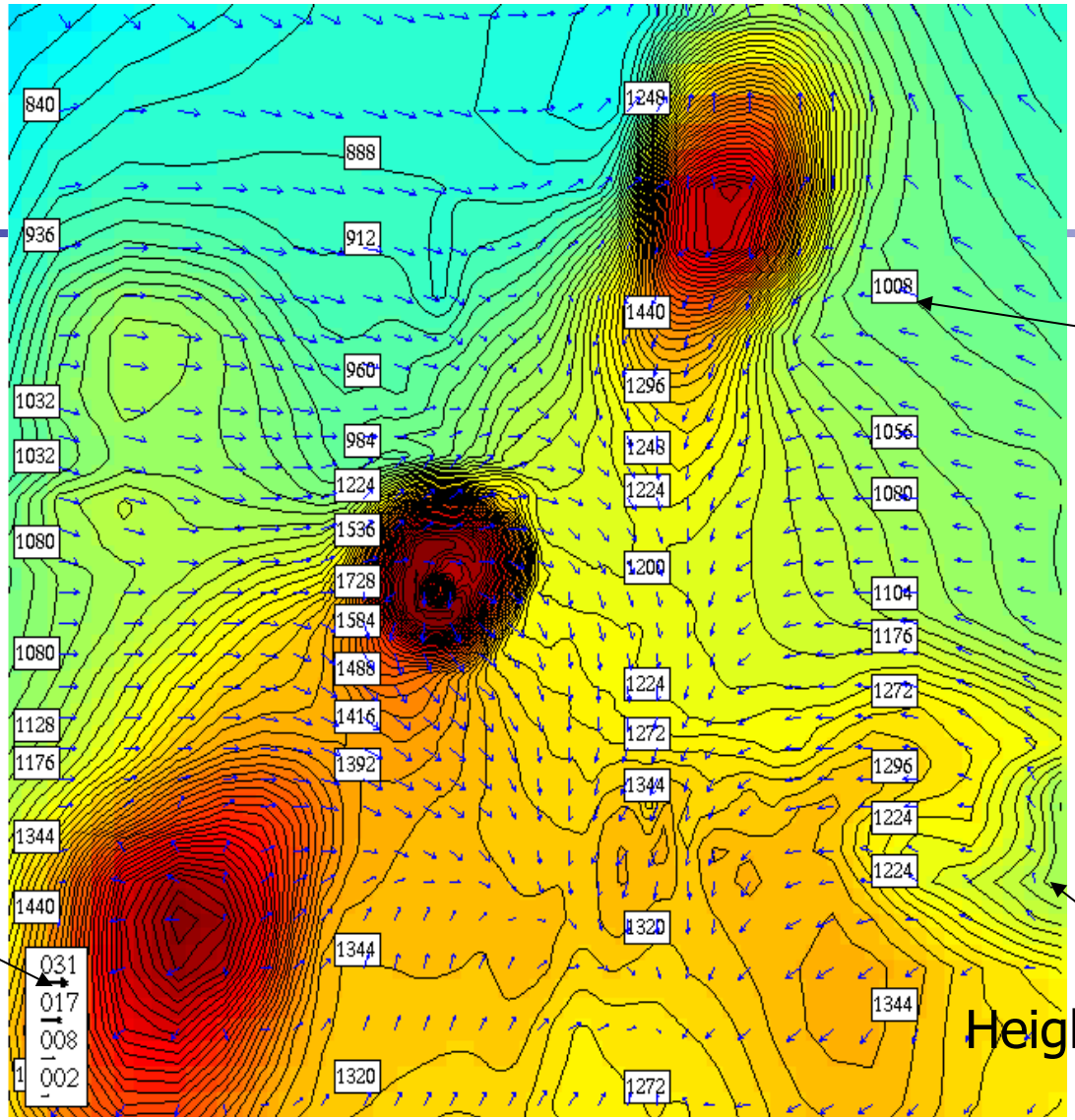

CH4 - Methane (ppm)
Level: 0.991000 hy - Stamp: TC1_P33_V1 - Interval: [1.0,1.2,1.4,1.6,1.7,...] * 1.0e-06 ppm
2.4
2.2
2.1
2.0
CH4 - Methane (ppm)
Vertical cross-section - Stamp: TC1_P33_V1 - Interval: [1.0,1.2,1.4,1.6,1.7,...] * 1.0e-06 ppm
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
2.4
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.4
1.2
1.0
0.3
(202.7, 68.0)
(213.1, 238.6)
11 hour fcst valid 11:00Z August 28 2008

GEM – Mars …dynamics

- Modification to the NWP core to account for:
  - Different atmospheric composition – CO_2 - 95 %
  - Surface pressure 10hPa
  - Orbit 1.52 AU from Sun
  - ½ the power from the Sun than Earth
  - Variation of solar energy along elliptical orbit is about 40% - Earth 7%
  - Orbital year is about 2 Earth years
  - Length of Martian day is very similar to Earth day
  - Inclination of rotational axes is 25° - similar to Earth (for the next millennium!)



Tharsis Rise



10.08 km

Winds (knots)

Height contours(10)

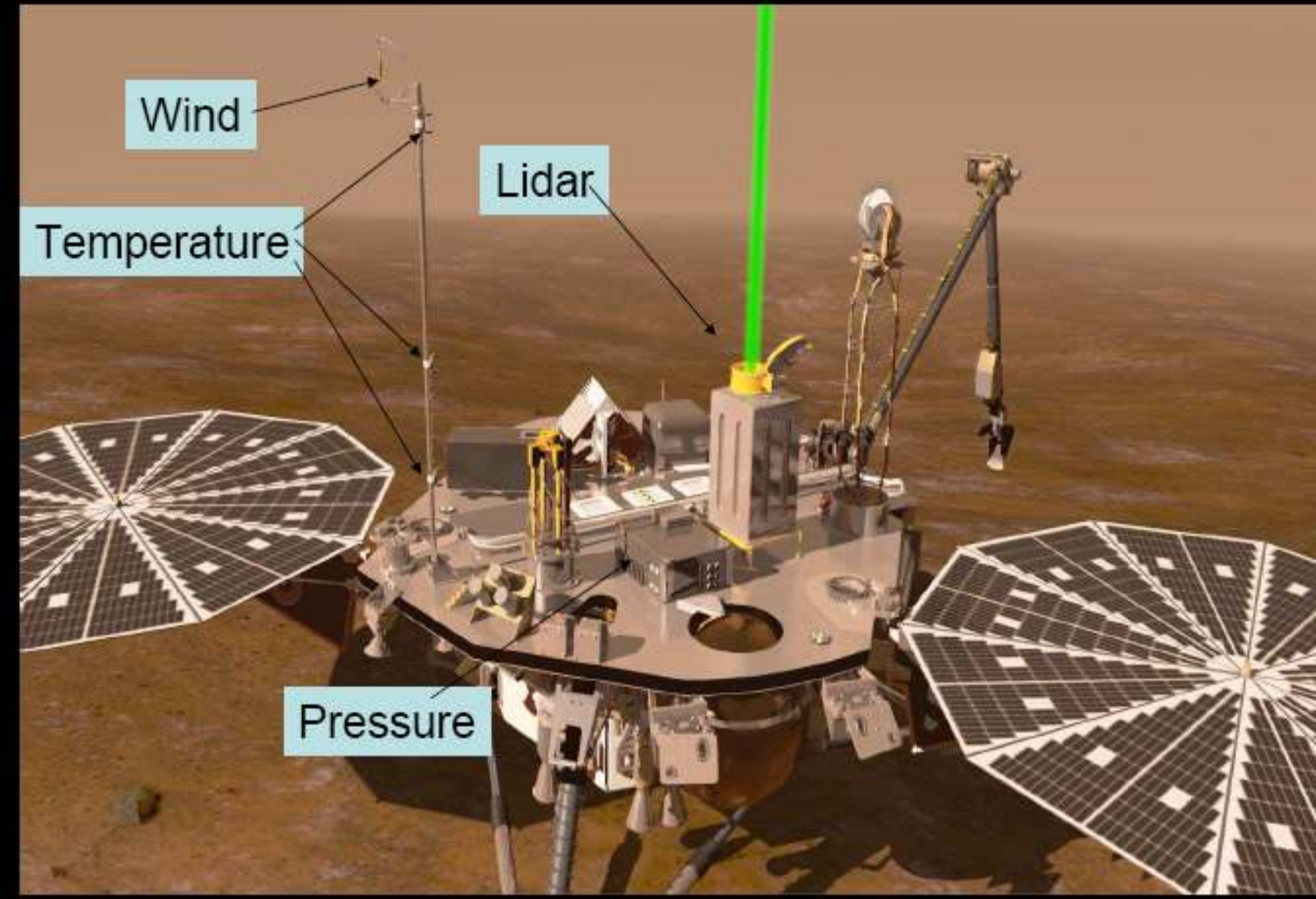
Tharsis Montes Region

The Phoenix Mission to Mars

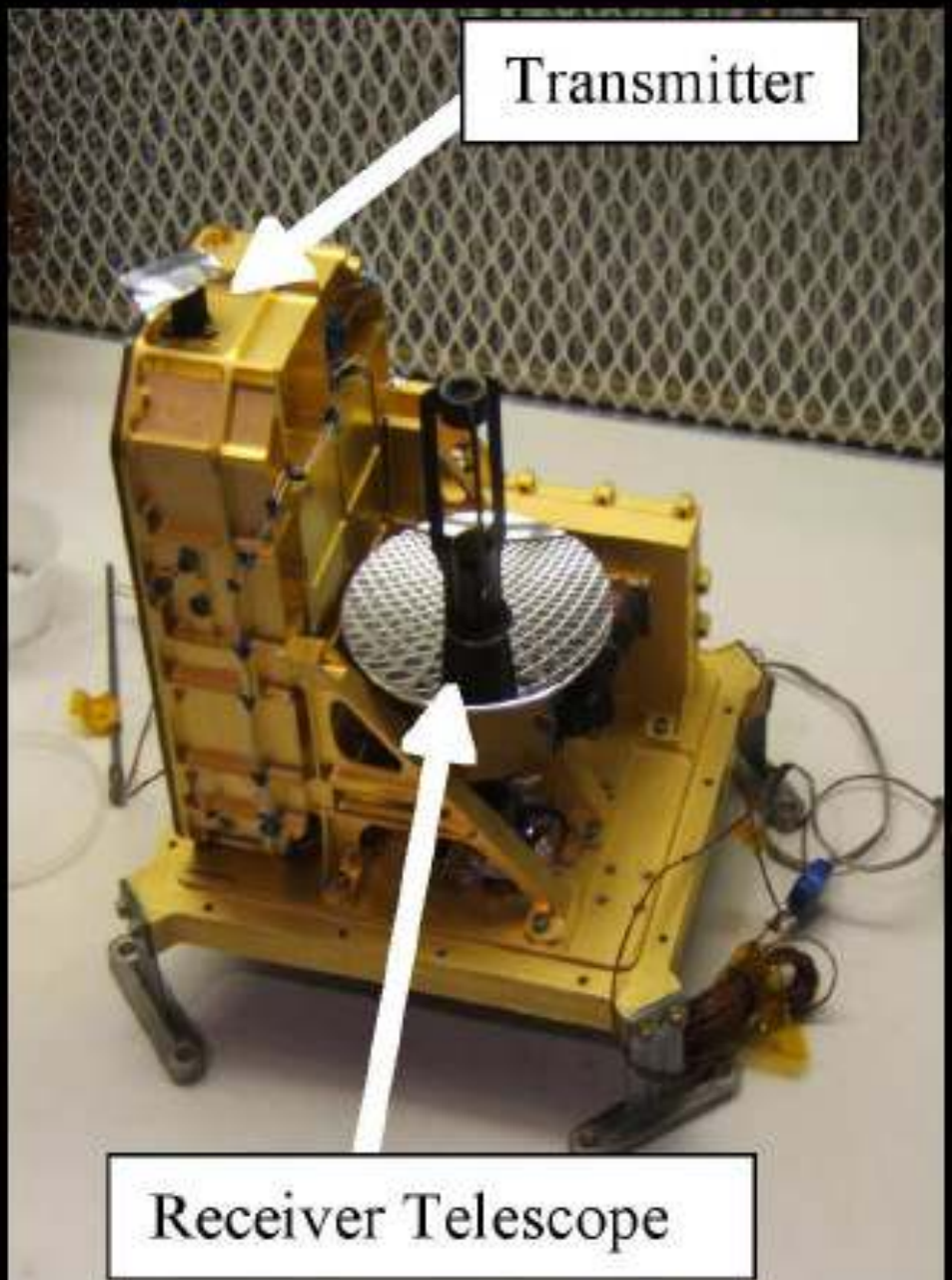
Launch: 4 August 2007

Landed: 25 May 2008

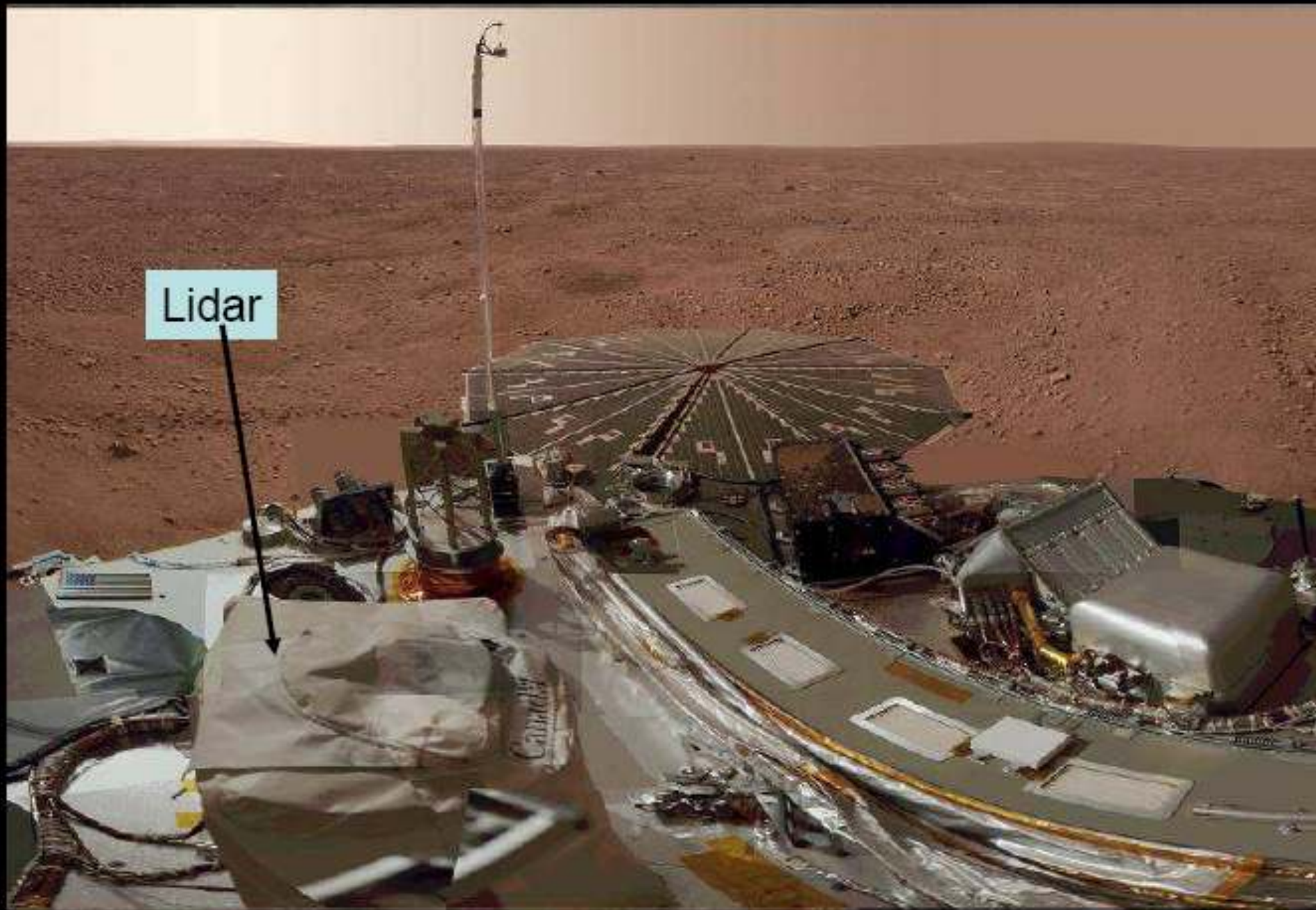
Canadian Contribution

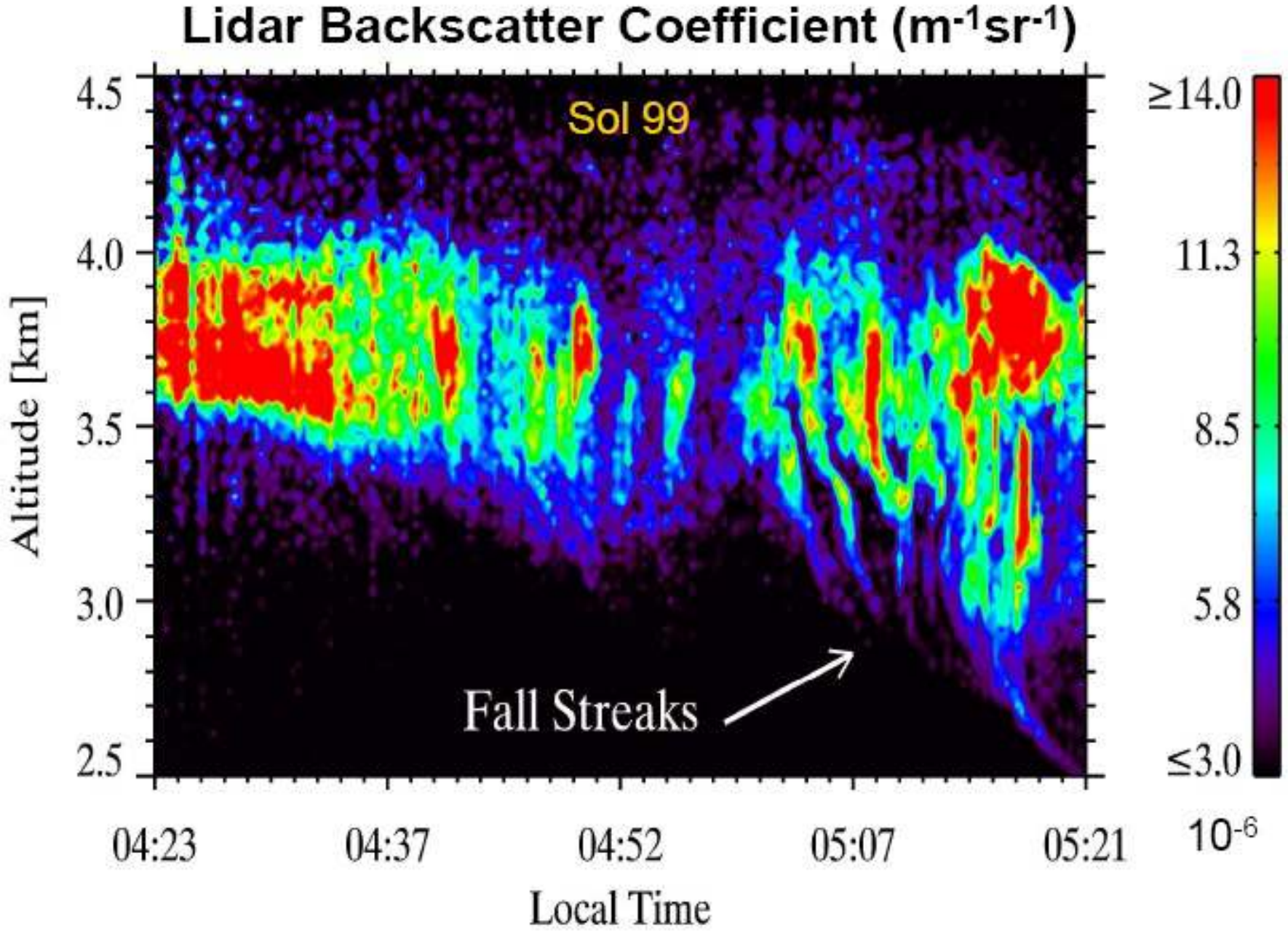


Phoenix Lidar



Lidar on Phoenix




Lidar Backscatter Coefficient (m-1sr-1)
Sol 99
Fall Streaks
Altitude [km]
4.5
4.0
3.5
3.0
2.5
04:23
04:37
04:52
05:07
05:21
Local Time
≥14.0
11.3
8.5
5.8
≤3.0
10-6

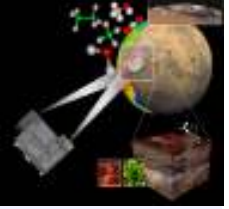
NOMAD on ExoMars TGO

Nadir and Occultation for MArs Discovery

Ann Carine Vandaele (PI)
IASB-BIRA, Belgium

J.-J. Lopez-Moreno (co-PI), M. Patel, G. Bellucci, F. Daerden, and the NOMAD team

NOMAD Team



- PS : Dr. F. Daerden (IASB-BIRA)

- NOMAD Team:

Allen M., Alonso-Rodrigo G., Altieri F., Aparicio del Moral B., Barrero-Gil A., Bellucci G., Berkenbosch S., Biondi D., Bolsee D., Bonnewijn S., Clancy T., Daerden F., Depiesse C., Delanoye S., Drummond R., Formisano V., Funke B., Fussen D., García-Comas M., Geminale A., Gérard J.-C., Gillotay D., Giuranna M., González-Galindo F., Jeronimo Zafra J., Kaminski J., Karatekin O., Leese M., López Moreno J.J., López-Puertas M., López-Valverde M., Mahieux A., Mateshvili N., Meseguer J., Morales R., Mumma M., Neary L., Neefs E., Patel M.R., Perez-Grande I., Ringrose T., Ristic B., Robert S., Rodriguez Gomez J., Saggin B., Sanz R., Sanz Andres A., Sindoni G., Smith M., Vandaele A.C., Villanueva G., Whiteway J., Wilquet V.

ExoMars Trace Gas Orbiter

2016

TECHNOLOGY OBJECTIVE

➟ Entry, Descent, and Landing (EDL) of a payload on the surface of Mars.

SCIENTIFIC OBJECTIVE

➟ To study Martian atmospheric trace gases and their sources.

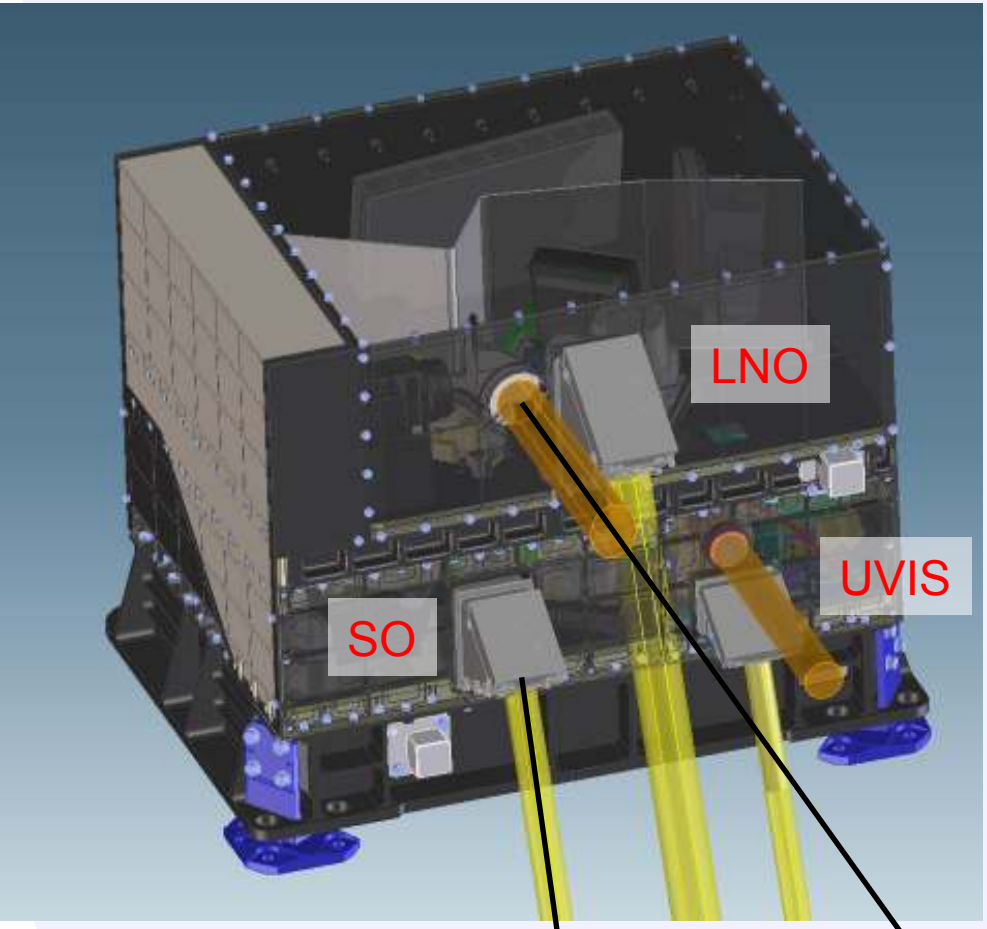
➟ Provide data relay services for landed missions until 2022.

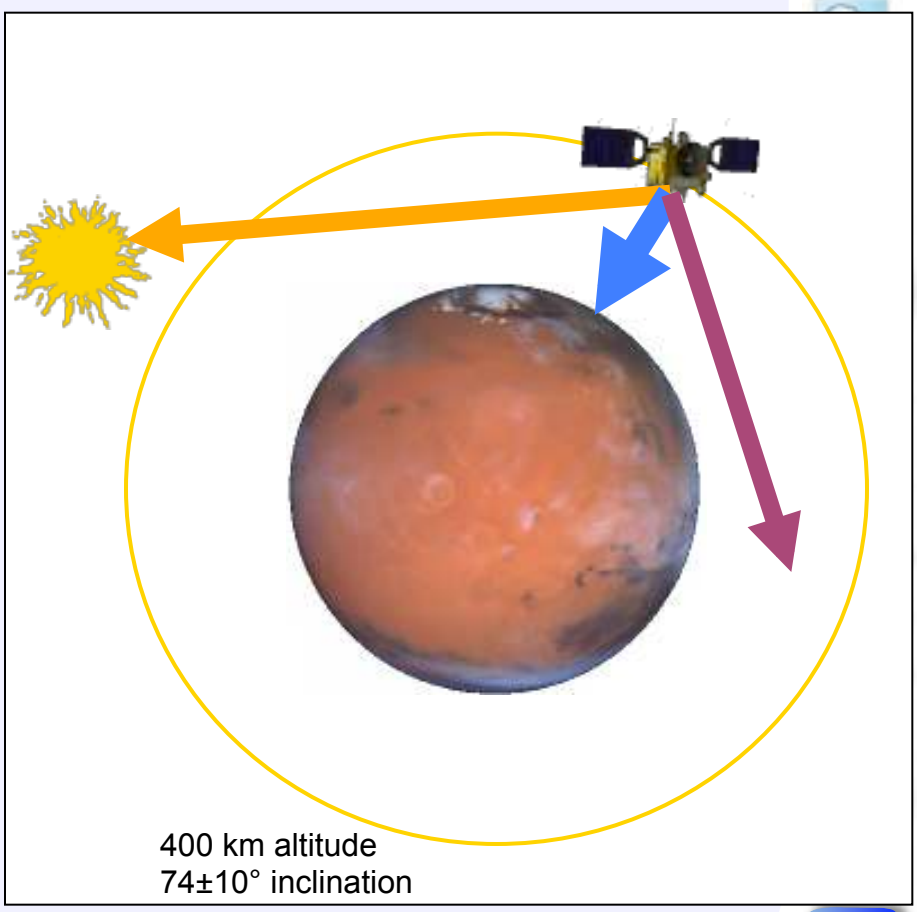
Launch window	7th -27th Jan 2016
Mars orbit insertion	19/10/2016
Science Operations	1 Martian year Nov 2017 – Oct 2019
End of Mission	31/12/2022

NOMAD

The NOMAD spectrometer suite

- 3 channels - UV & IR - Solar Occultation, Limb & Nadir

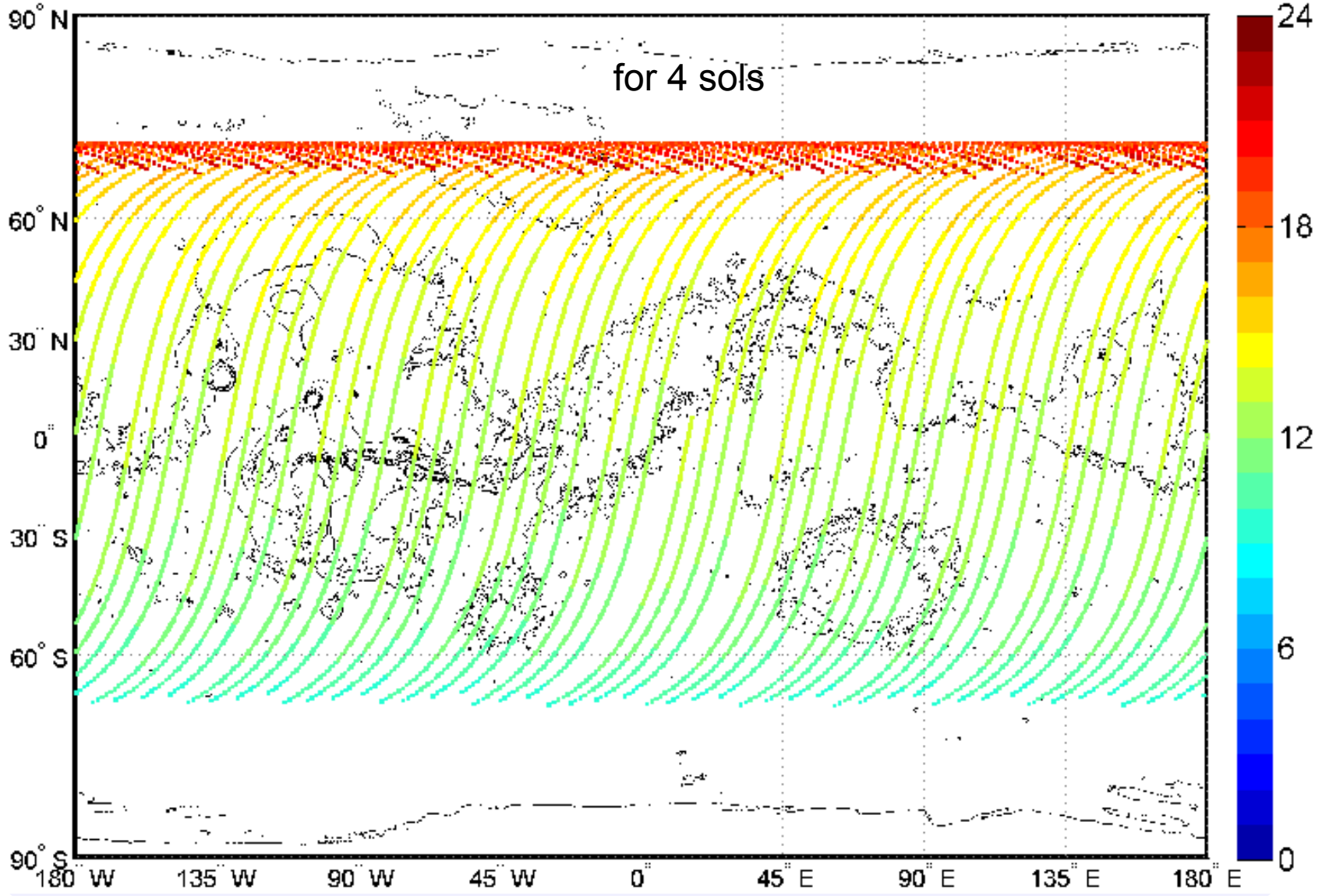




EMTGO Science objectives

1. **Detection of broad suite of atmospheric trace gases and key isotopes**
   - H_2O (HDO), HO_2, NO_2, N_2O, CH_4, C_2H_2, C_2H_4, C_2H_6, H_2CO, HCN, H_2S, OCS, SO_2, HCl, CO, O_3 , … + isotopologues
2. **Characterization of their spatial and temporal variation:**
   - Large latitude-longitude coverage: MAPPING of key trace gas species and isotopologues, to determine regional sources and seasonal variations;
   - Correlated observations with environmental parameters (temperature, dust and ice aerosols)
3. **Localization of sources and sinks:**
   - Determine if particular gases are emanating from specific areas on or near to the surface of Mars.
   - Requires simulations using circulation models constrained by maps of trace gases and environmental parameters
4. **High-resolution surface imaging related to sources/sinks**

NOMAD nadir coverage and local time



Detection Limits

Species	*Current Knowledge*	*NOMAD Detection limits*
CH_4	0-60 ppb	14 ppt
H_2O	< ppt (variable)	2.5 ppb
CO	< 1300 ppm	20 ppb
HDO	D/H =5.6 SMOW	1.7 ppb (i.e. 6 ppm H_2O)
$^{13}CH_4$ **CH_3D**		20 ppt (i.e. 2 ppb CH_4) 70 ppt (i.e. 100 ppb CH_4)
CO, CO_2 isot		2 % accuracy
HCN	3 ppb	0.06 ppb
H_2CO	< 3 ppb	0.1 ppb
HO_2		6 ppb
H_2S	< 100 ppb	4 ppb
C_2H_2	< 2 ppb	0.3 ppb
C_2H_4	< 500 ppb	3 ppb
C_2H_6	< 400 ppb	0.03 ppb
OCS	< 70 ppb	0.5 ppb
N_2O		7 ppb
NO_2		0.03 ppb
SO_2	< 2 ppb	0.1 ppb (UVIS)
O_3		50 ppt (UVIS)

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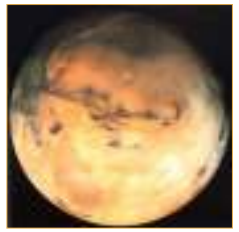

Modelling the Martian atmosphere with GEM-Mars

Lori Neary, Frank Daerden

Belgian Institute for Space Aeronomy

BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AER

belspo .be

GEM-Mars dynamical core

- Based on GEM v4.2.0
- Typical horizontal resolution of 4°x4° but can go higher – hydrostatic/non-hydrostatic formulation
- 103 vertical levels up to ~150 km

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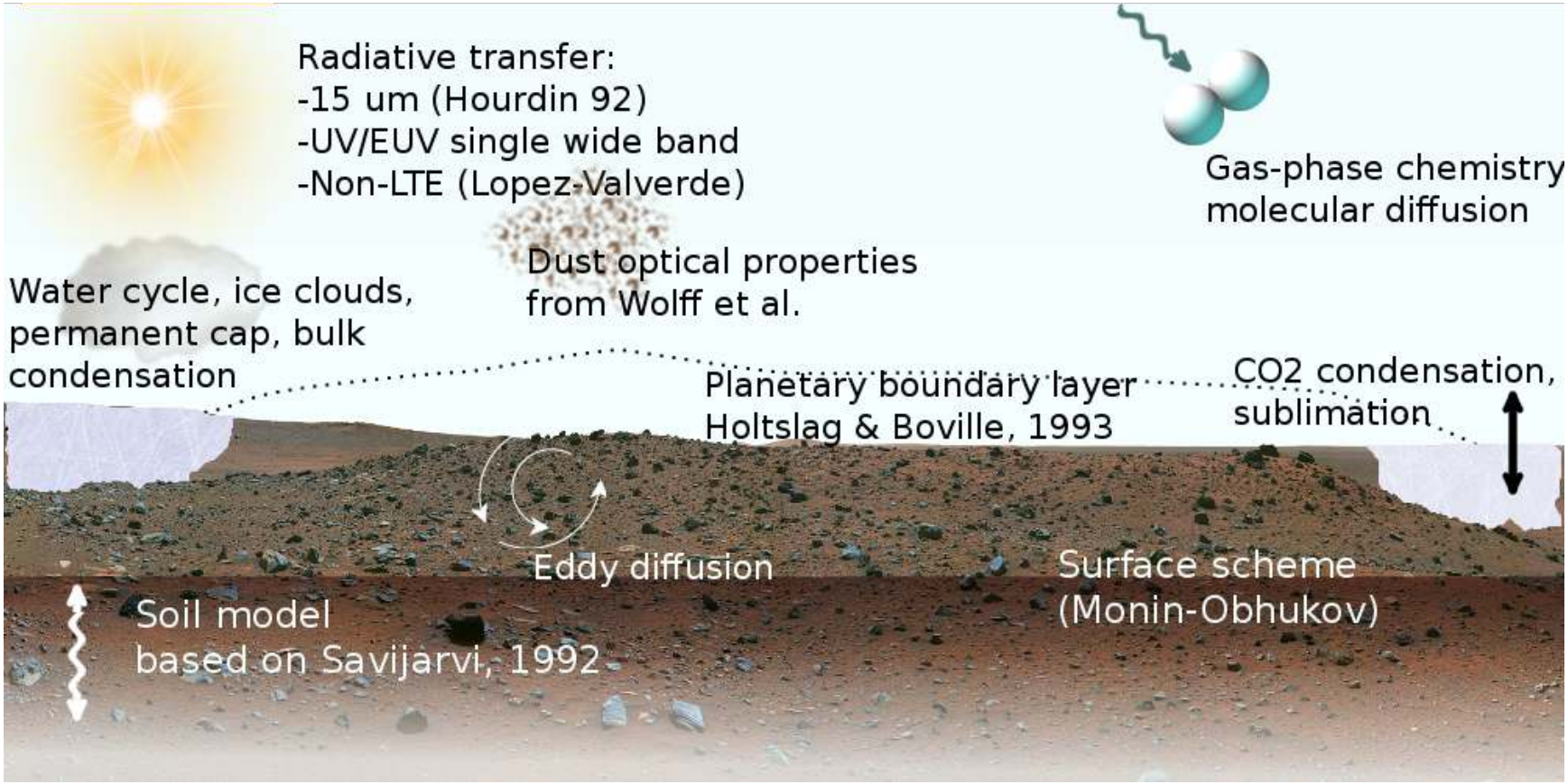
GEM-Mars physical parameterizations



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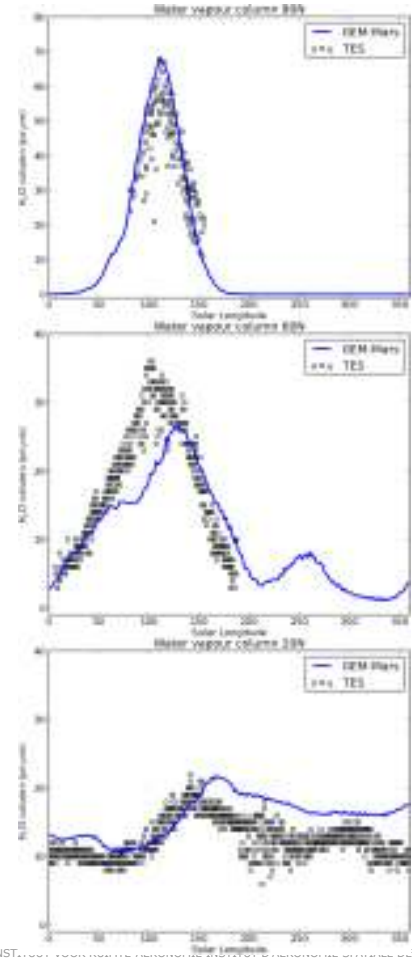
GEM-Mars gas-phase chemistry

- 13 species: O_3,O_2, $O(^1D)$, O, CO, H, H_2, OH, HO_2, H_2O, H_2O_2, $O_2(a^1\Delta_g)$, and CO_2
- 15 photolysis and 31 chemical reactions
- Chemical mechanism and rate coefficients based on the work of García-Muñoz et al., 2005
- Species transported and mixed by resolved circulation, eddy diffusion and in the upper atmosphere, molecular diffusion

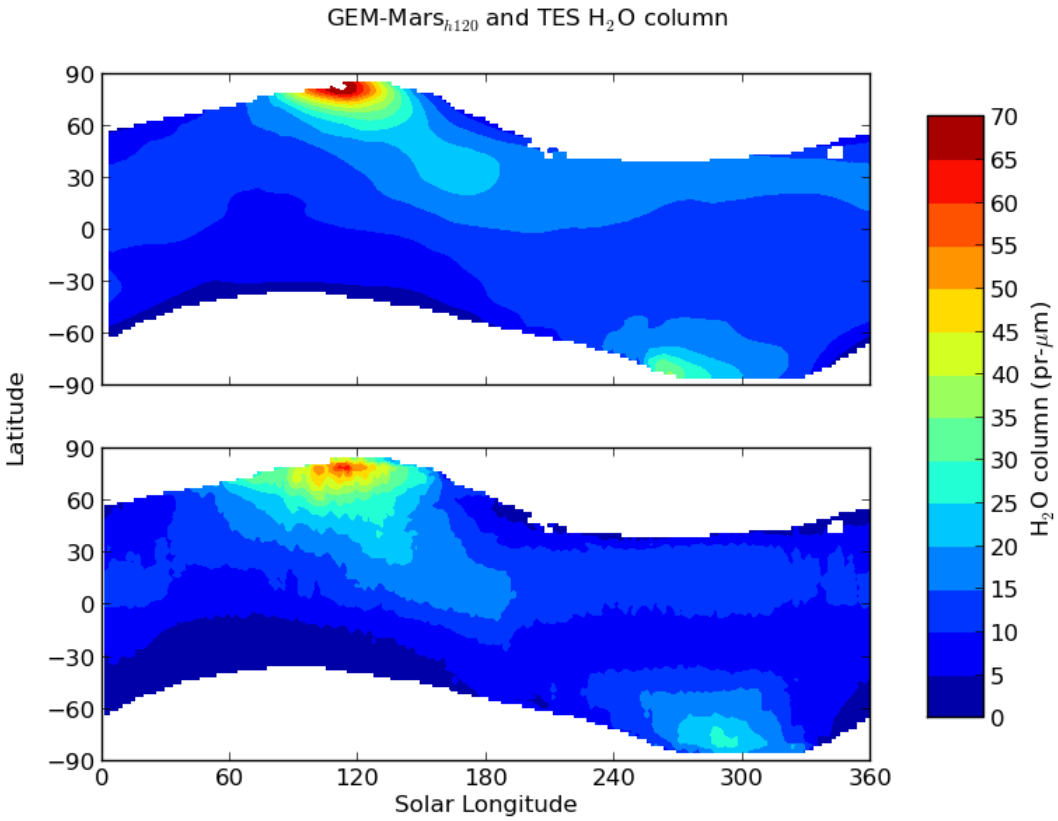
Water Cycle



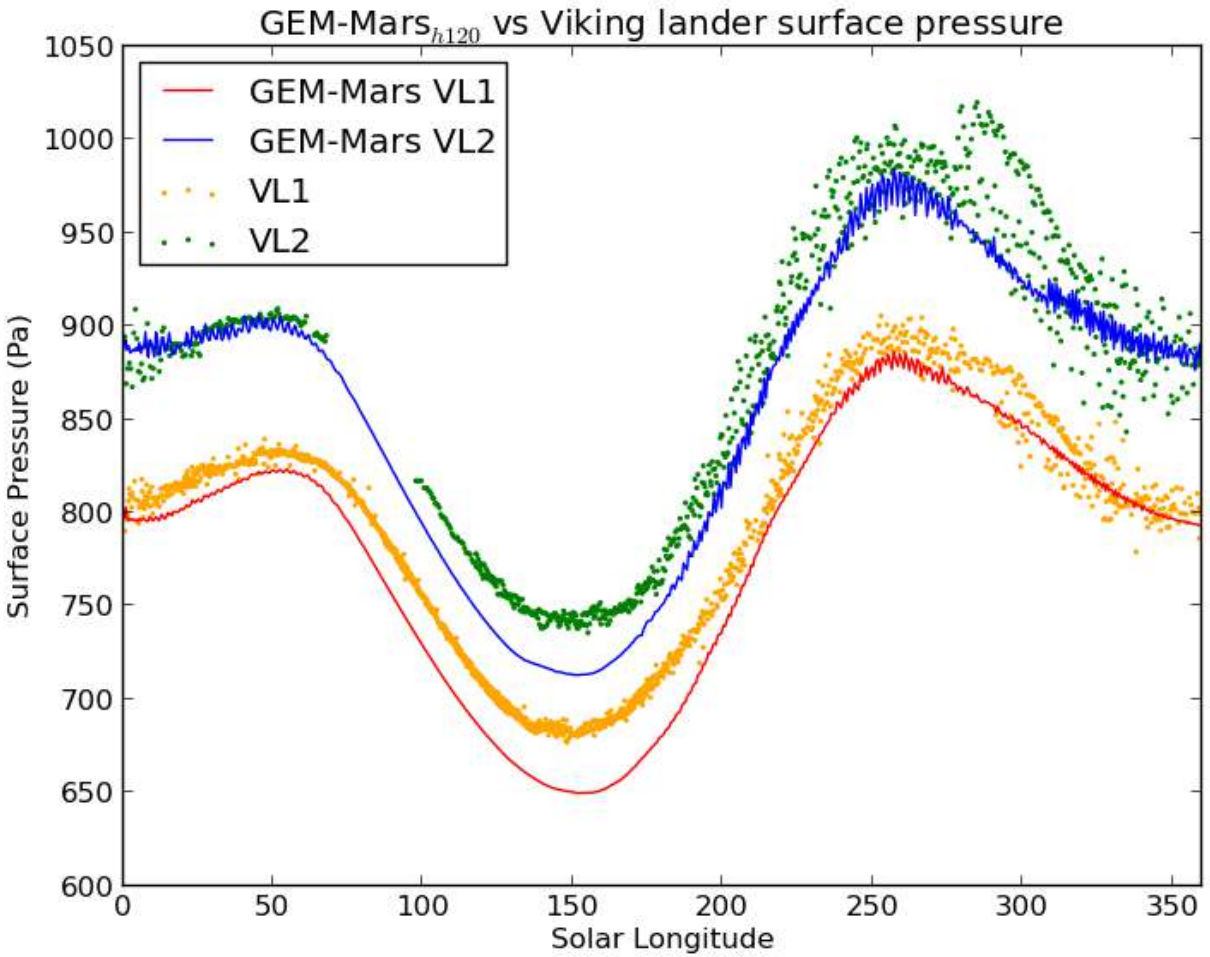
80°N

60°N

20°N



CO_2 cycle



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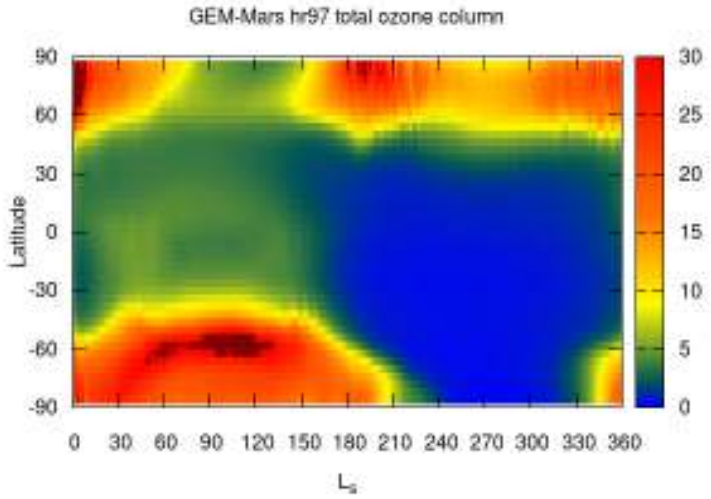
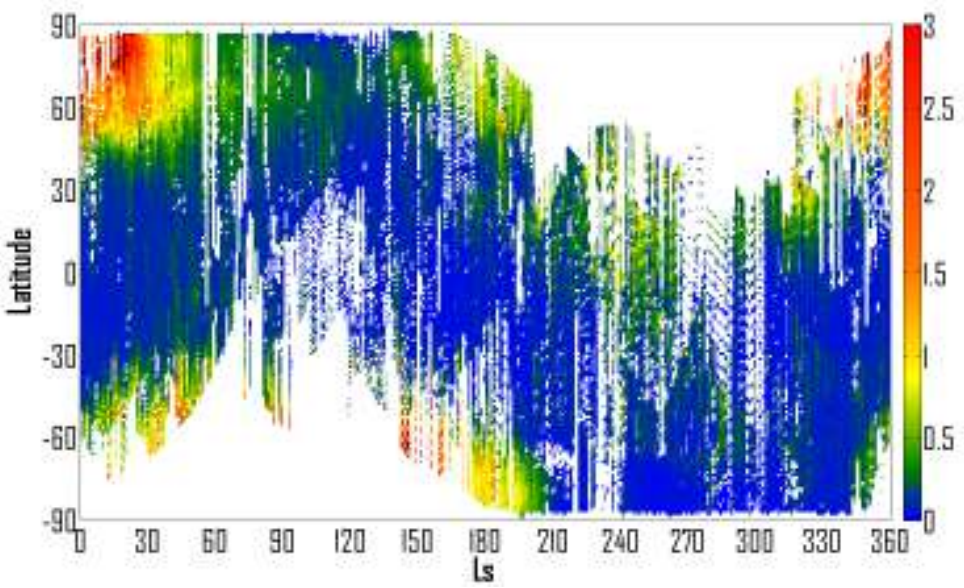
Total column ozone





BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AER

Implementation Status of ESA's Copernicus Atmospheric Service Sentinel-4/-5, and 5p

Presented by

Jacek W. Kaminski, EcoForecast Foundation

on behalf of
Sentinel-4/-5 MAG

Background: Copernicus
The European contribution to GEOSS

Services Component – led by EC

- Produces information services in response to European policy priorities in environment and security
- Relies on data from **in-situ** and **space component**

In-situ Component – led by EEA

- Observations mostly within national responsibility, with coordination at European level

Space Component – led by ESA

- Sentinels - EO missions developed specifically for Copernicus

Plus Contributing Missions - EO missions built for purposes other than Copernicus but offering part of their capacity to Copernicus

Copernicus – Space component … 2/2

1. The Sentinels carry a range of technologies, such as radar and multi-spectral imaging instruments for land, ocean and atmospheric monitoring:

2. Sentinel-1 will provide all-weather, day and night radar imagery for land and ocean services,
3. Sentinel-2 will provide high-resolution optical imagery for land services,
4. Sentinel-3 will provide high-accuracy optical, radar and altimetry data for marine and land services,

5. **Sentinel-4 and Sentinel-5** will provide data for atmospheric composition monitoring from geostationary orbit and polar orbit, respectively.
6. **Sentinel-5 Precursor** will bridge the gap between Envisat (Sciamachy data in particular) and Sentinel-5

7. The **Sentinel-4 and Sentinel-5** will be instruments carried on the next generation of Eumetsat meteorological satellites: Meteosat Third Generation (MTG) and MetOp Second Generation, also known as Post-EPS.

Role of the Mission Advisory Group: advise on

- Fitness for purpose of Sentinel-4/-5 data for Copernicus Atmosphere Services
- Compatibility of system specifications with mission requirements
- Instrument calibration
- Specification of Level-1/-2 products, quality requirements, and quality indicators
- Study and campaign requirements, end-to-end product calibration/validation, retrieval algorithms and quality indicator verification and validation,
- Data quality requirements for the Level-1/Level-2 interface
- Data processing, archiving, retrieval and product delivery
- Promoting the missions

Background: Copernicus Space Component

Sentinel-1: SAR imaging

Land surface properties, sea-ice, all weather, day/night

2014

Sentinel-2: Multispectral imaging

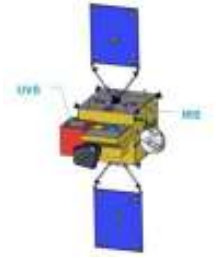
Land applications: urban, forest, agriculture, etc.

2014

Sentinel-3: Ocean and global land monitoring

Ocean color, vegetation, sea/land surface temperature, altimetry

2014



Sentinel-4: Geostationary imaging

Atmospheric composition monitoring

2020

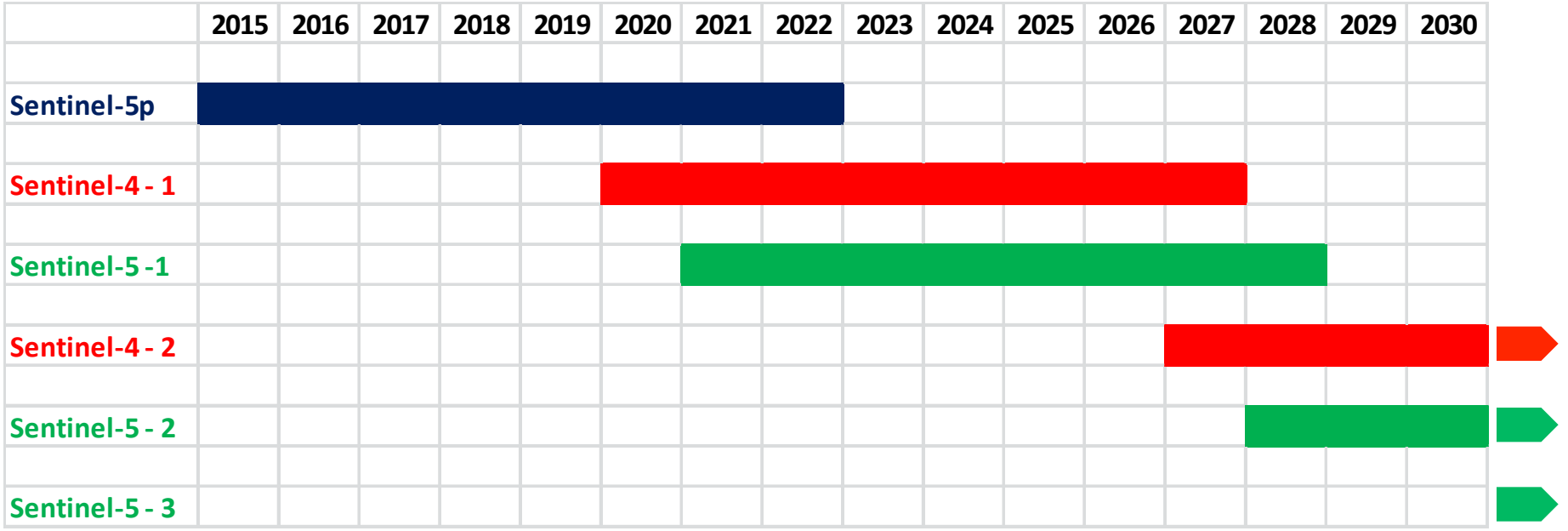
Sentinel-5Precursor and -5: Low Earth orbit imaging

Atmospheric composition monitoring

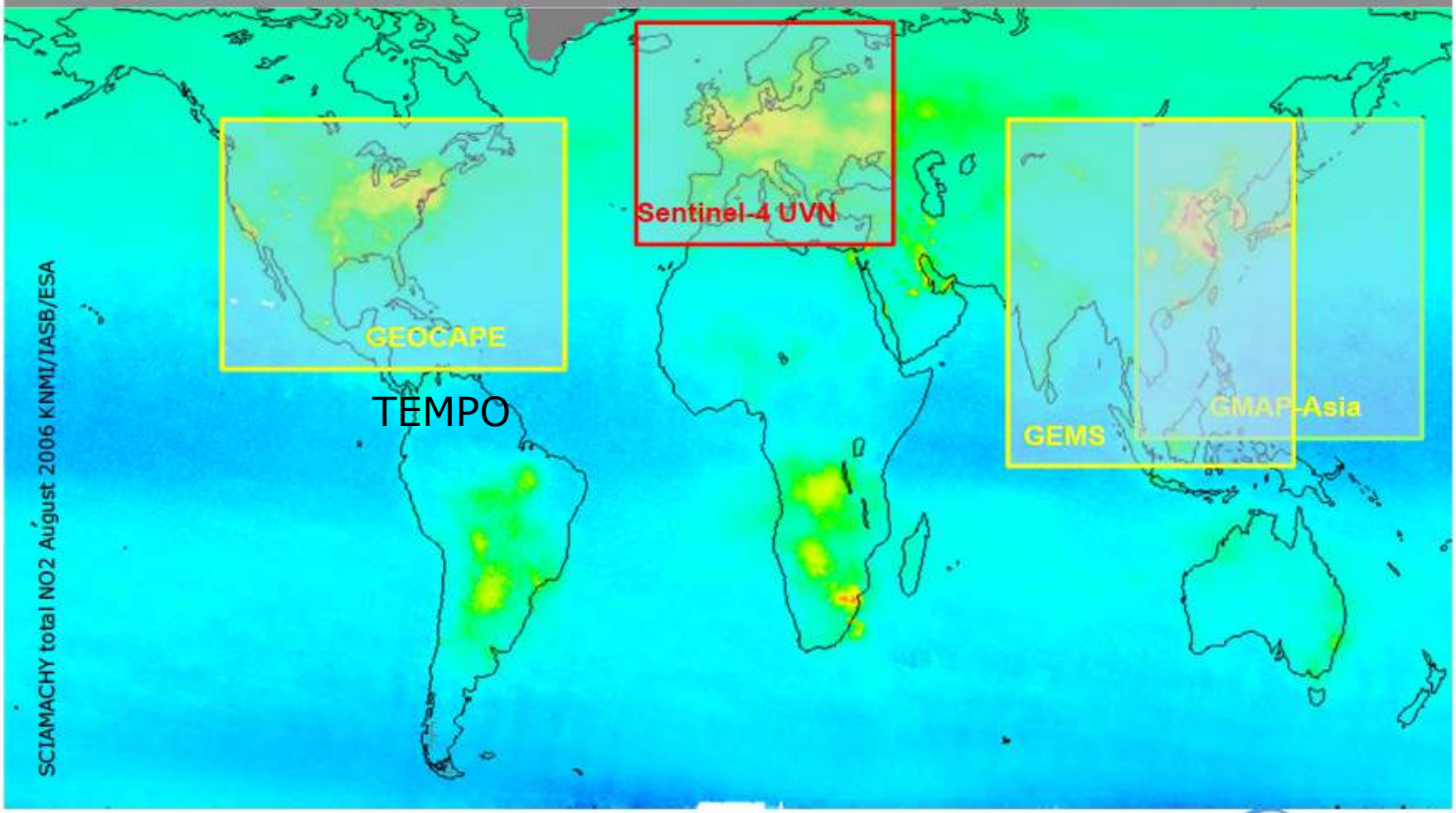
2015

2020+

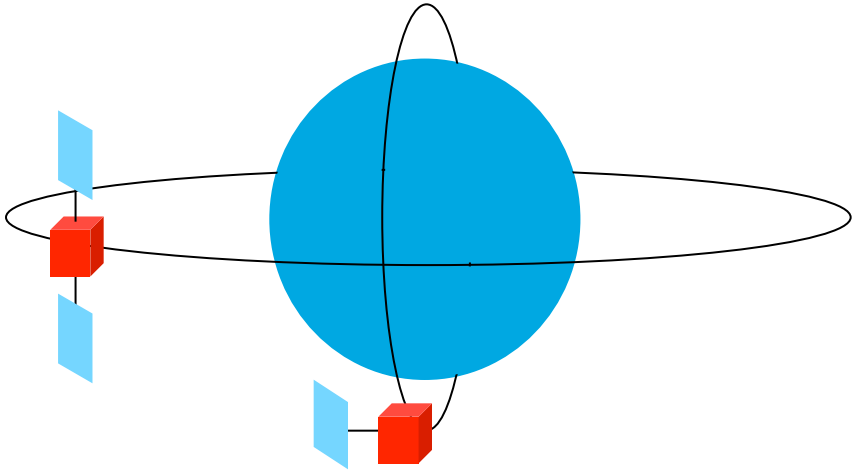
Launch Schedule of Atmospheric Sentinels



Current International Plans for Geostationary Air Quality Missions



Identified Elements: LEO + GEO



Low Earth Orbit (LEO)

- Daily revisit time global coverage
- Climate, air quality, ozone & UV
- Tropospheric & stratospheric composition

→ Sentinel-5 Precursor (S5p)

→ Sentinel-5 (S5)

GEOstationary (GEO)

- Hourly revisit time over Europe
- Mainly air quality
- Diurnal cycle of tropospheric composition

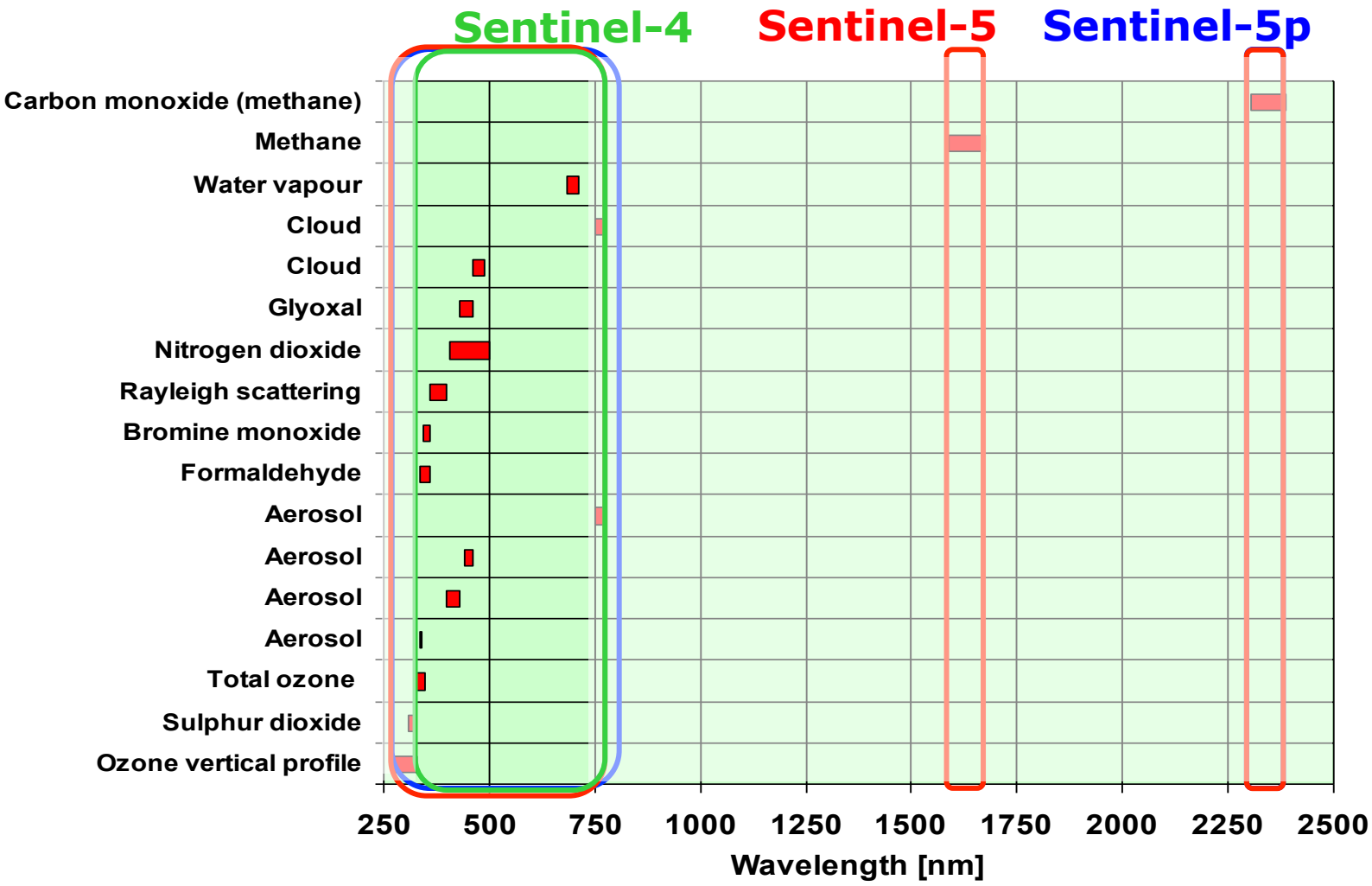
→ Sentinel-4 (S4)

Implementation

Mission		Sentinel-4	Sentinel-5	Sentinel-5 Precursor
Instrument		**UVN**: UV-Vis-Near infrared spectrometer on MTG-S	**UVNS**: UVN-Shortwave infrared spectrometer on MetOp-SG	**TROPOMI**: UVNS spectrometer on dedicated platform
Utilisation of data	imager	**FCI**: Flexible Combined Imager on MTG-I	**VII**: Visible/Infrared Imager on MetOp-SG	**VIIRS**: Visible Infrared Imager Radiometer Suite on Suomi-NPP/JPSS
	thermal infrared	**IRS**: InfraRed Sounder on MTG-S	**IAS**: Infrared Atmospheric Sounder on MetOp-SG	-
	other	-	**3MI**: Multi-viewing, Multi-channel, Multi-polarisation Imager on MetOp-SG	-

UVN = Ultraviolet + Visible + Near infrared; UVNS = UVN + Short wave infrared

Mission Elements: Summary of Observation Requirements - UV-Vis-NIR-SWIR Bands



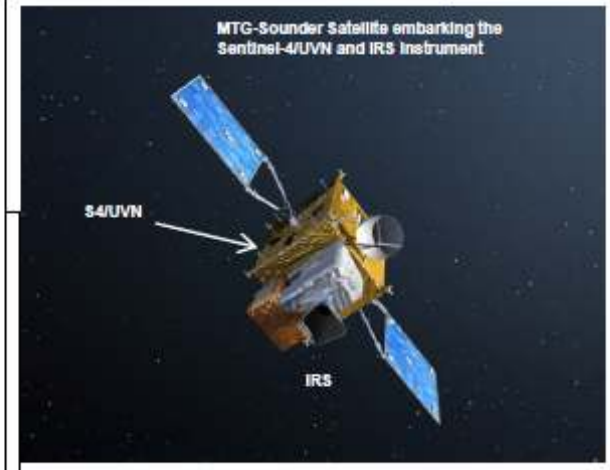
MTG – S4 Mission Architecture

esa

Launch Segment

Launch Vehicle
(A5, Soyuz, Proton)

Observatory Segment

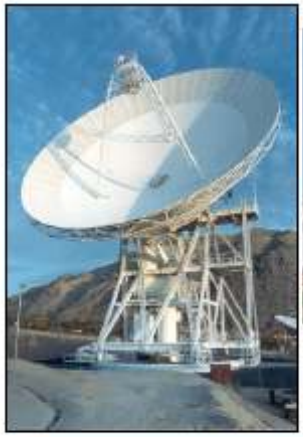


Two MTG-Sounder (MTG-S) S/Cs

Four MTG-Imager (MTG-I) S/Cs

Payload
1- Flexible Combined Imager,
2- Lightning Imager;
3- Infra-Red Sounder;
4- Sentinel-4/UVN → on MTG-S

Ground Segment

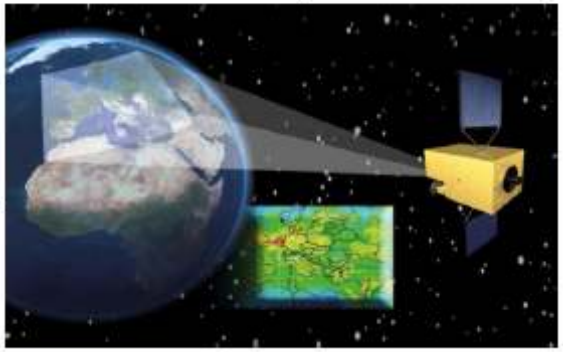


Flight Operations Segment

P/L Data Ground Segment

Ground Station(s)

Orbit:
Geostationary



Sentinel-4 / UVN Mission Objective: To monitoring continuosly the atmospheric composition and air quality of Europe (O_3, NO_2, SO_2, HCHO and aerosol optical depth at a fast revisit time of ~1 hour.

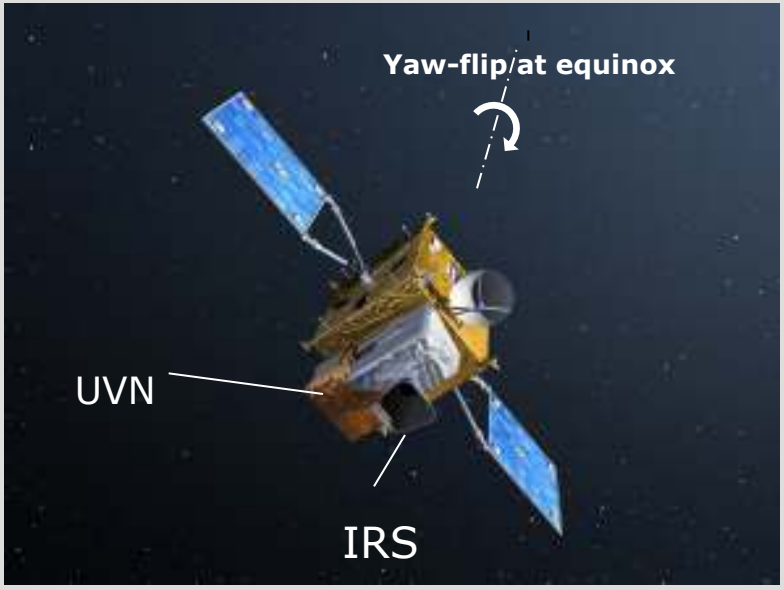
Mission Elements: Sentinel–4 GEO atmospheric mission

Application:

- Air quality

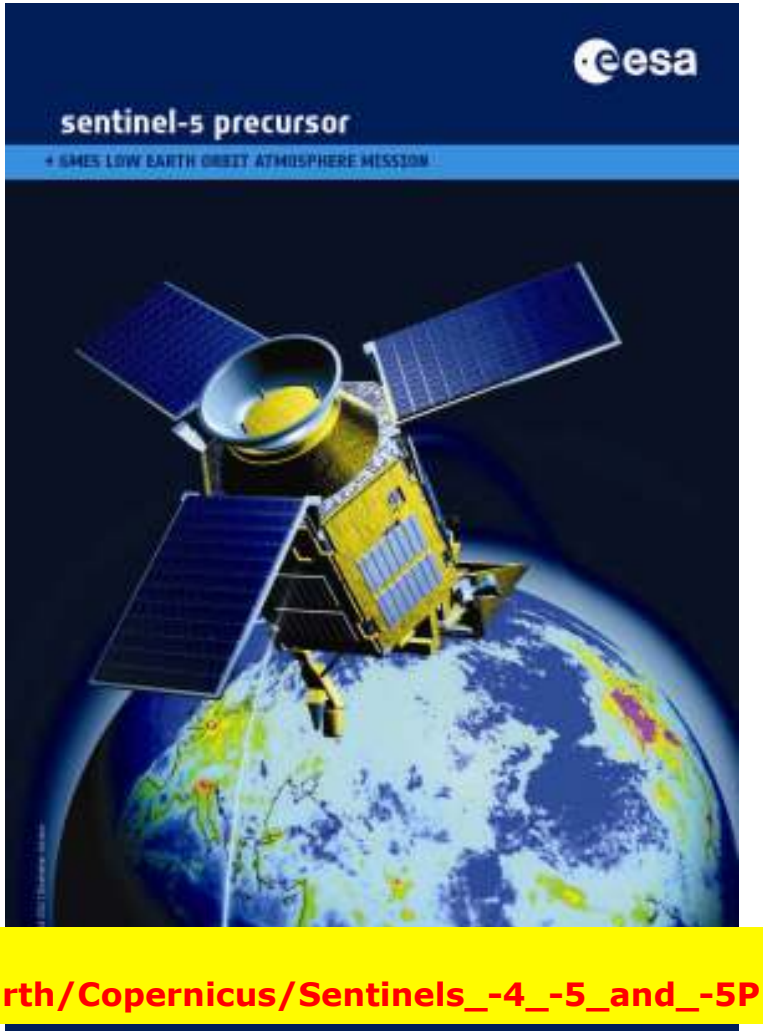
Instrumentation:

- UV-VIS-NIR spectrometer
- Use of thermal IR sounder (IRS) on MTG-S and of the imager (FCI) on MTG-I



- **UV-VIS-NIR with spectral bands 305 – 500 nm and 750 – 775 nm**
- **Spatial sampling of 8 km at 45°N and spectral resolution between 0.12 nm and 0.5 nm**
- **Geostationary orbit, at about 0° longitude**
- **Embarked on MTG-Sounder Satellite and operated by EUMETSAT**

Atmospheric Sentinel Flyers…



Flyers on S5p and S4 can be found at http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinels_-4_-5_and_-5P

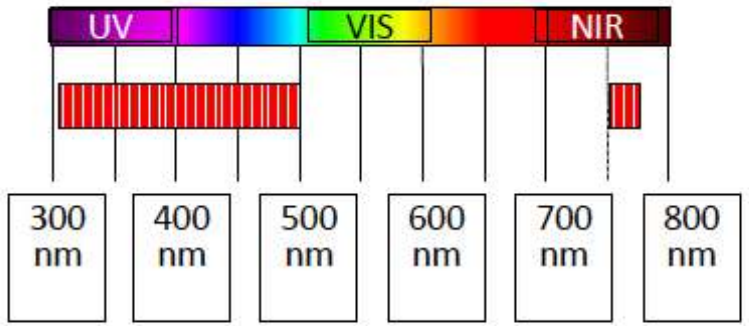
Next 7 years

- Selection of prime contractors
- Satellite building
- Instrument building
- Science studies
  - Model atmosphere – chemical composition
  - Instrument characterization
  - Inversion algorithms
- Operational software and command control

Sentinel-4/UVN: Key Requirements

Instrument Spectral Coverage

Band ID	Wavelength range [nm]	Spectral resolution [nm]	Spectral sampling ratio
UV	305 - 400	0.5	3
VIS	400 – 500	0.5	3
NIR	750 – 775	0.12	3



Spatial Sampling: 8 km at 45°N

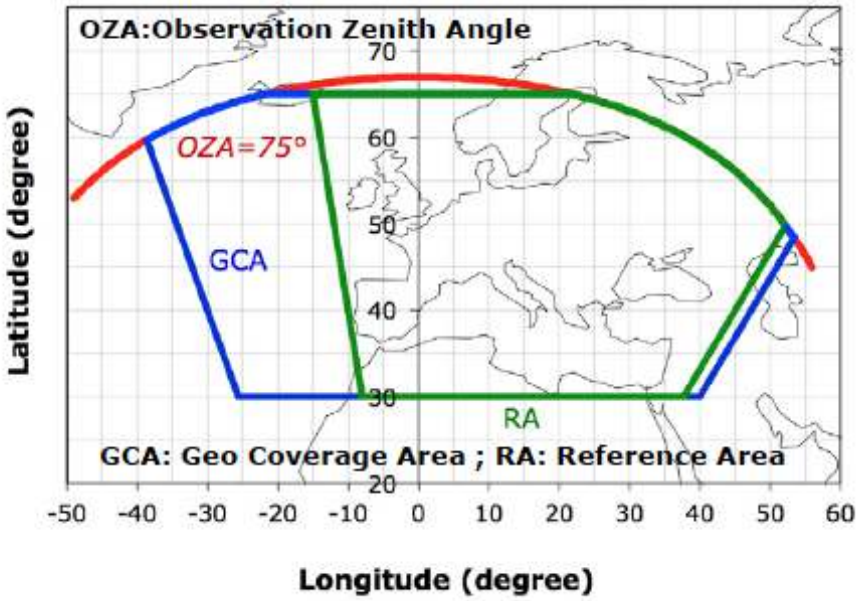
Coverage: Europe + Sahara

Repeat Cycle: 1 hour

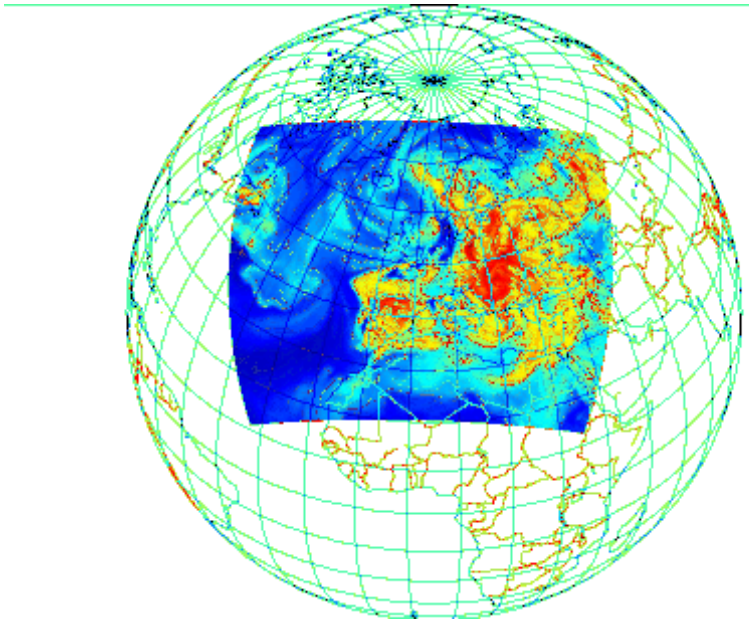
Low sensitivity to polarisation (1%)

Low level of spectral features (0.05%)

High radiometric accuracy: 3% (target), 2% (goal)



European Heat Wave July 2006

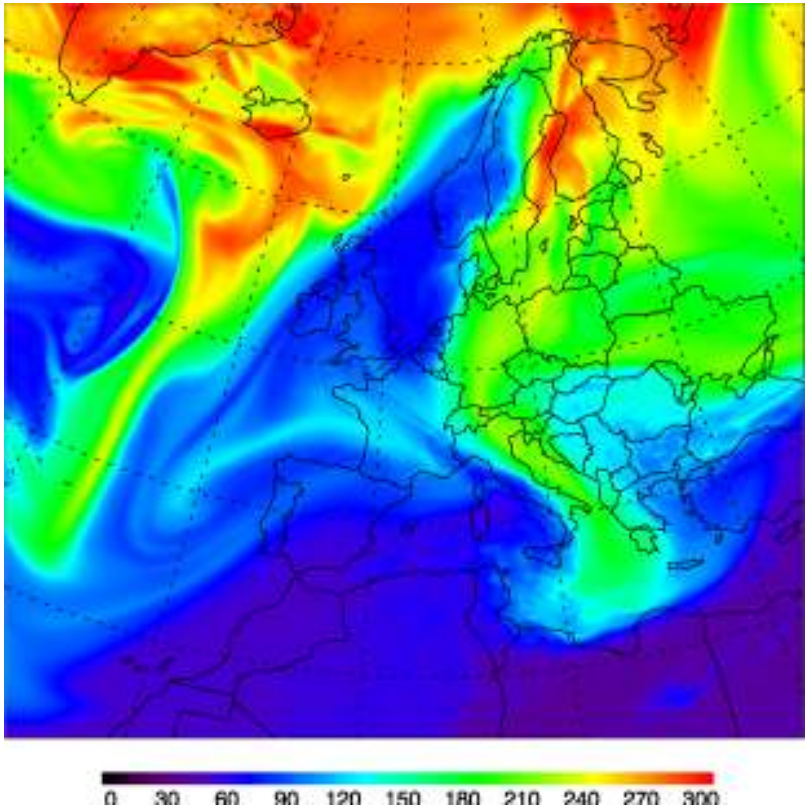


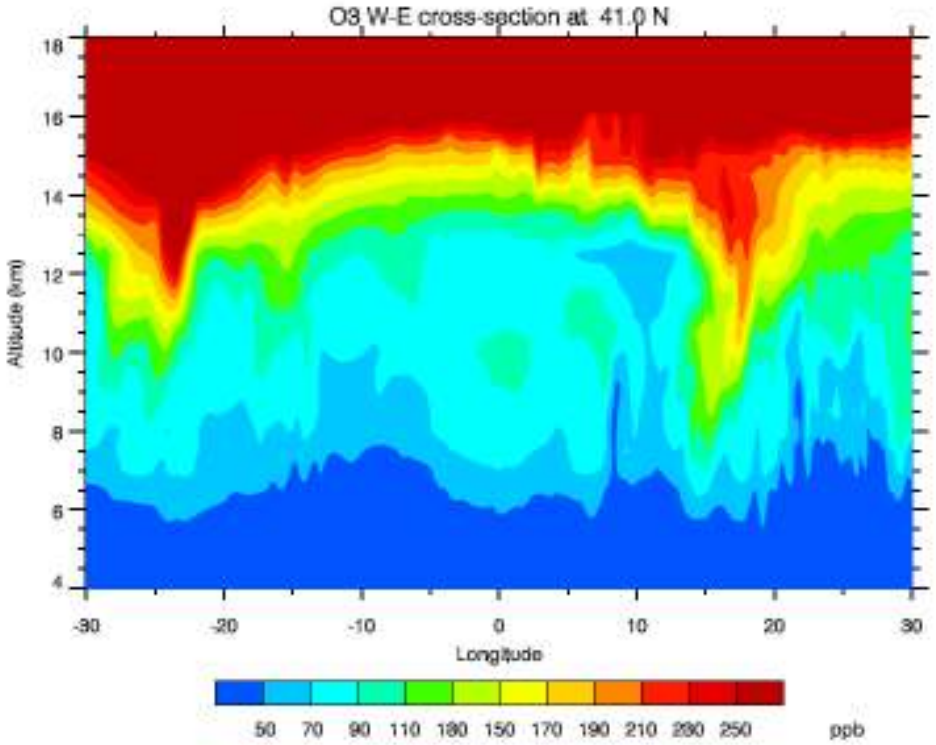
- 15km global variable resolution
- First 2 weeks of July 2006
- Daily time factors applied to EMEP emissions
- Modulation of biogenic emissions

Formation and transport of photo-oxidants over Europe during the July 2006 heat wave – observations and GEM-AQ model simulations, ACP 2008

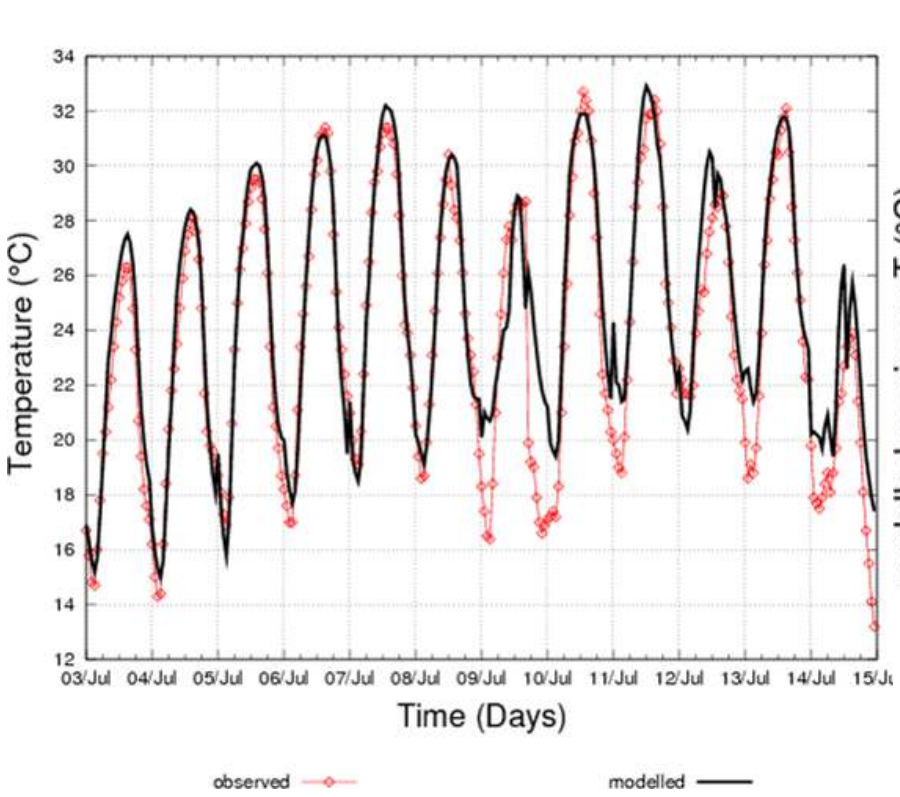
Ozone field – simulation at 15-km horizontal resolution

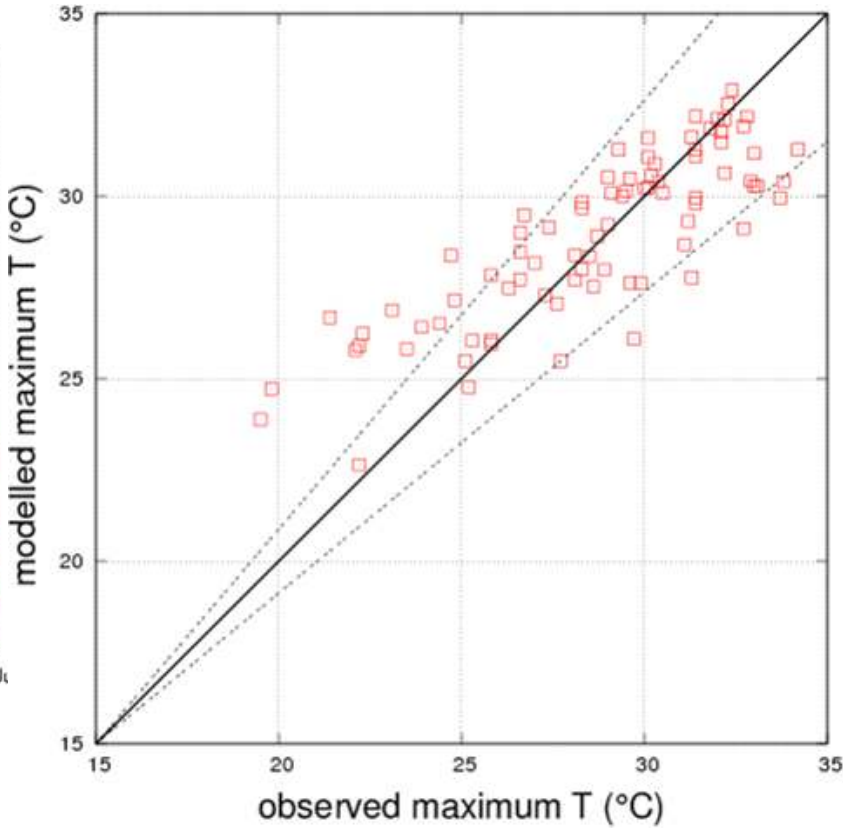
O3 (ppb) at 12.5 km asl





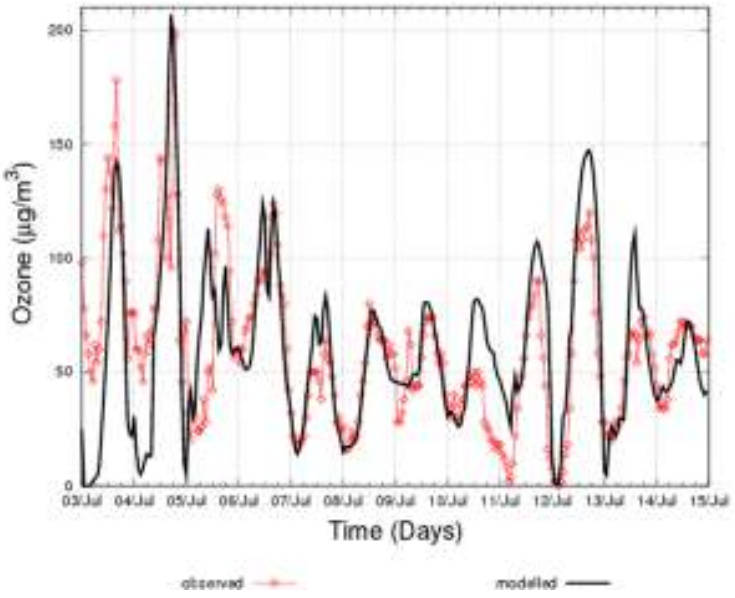
Temperature forecast in CE



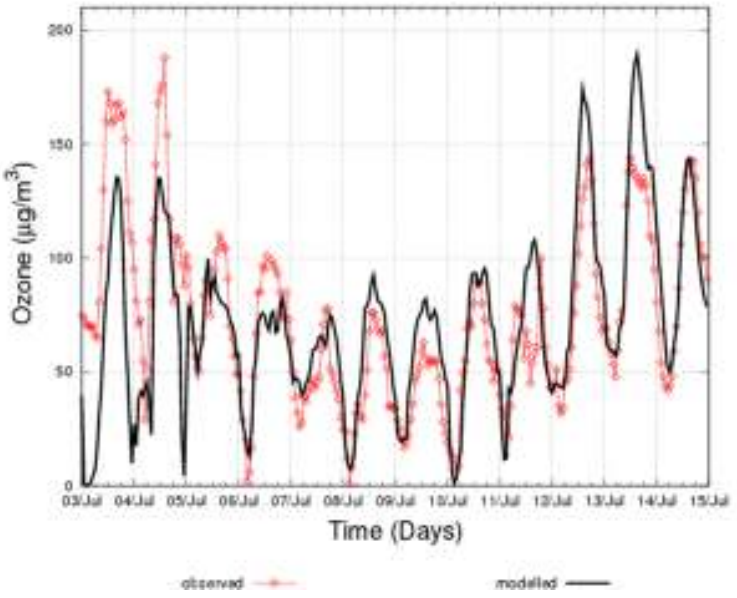


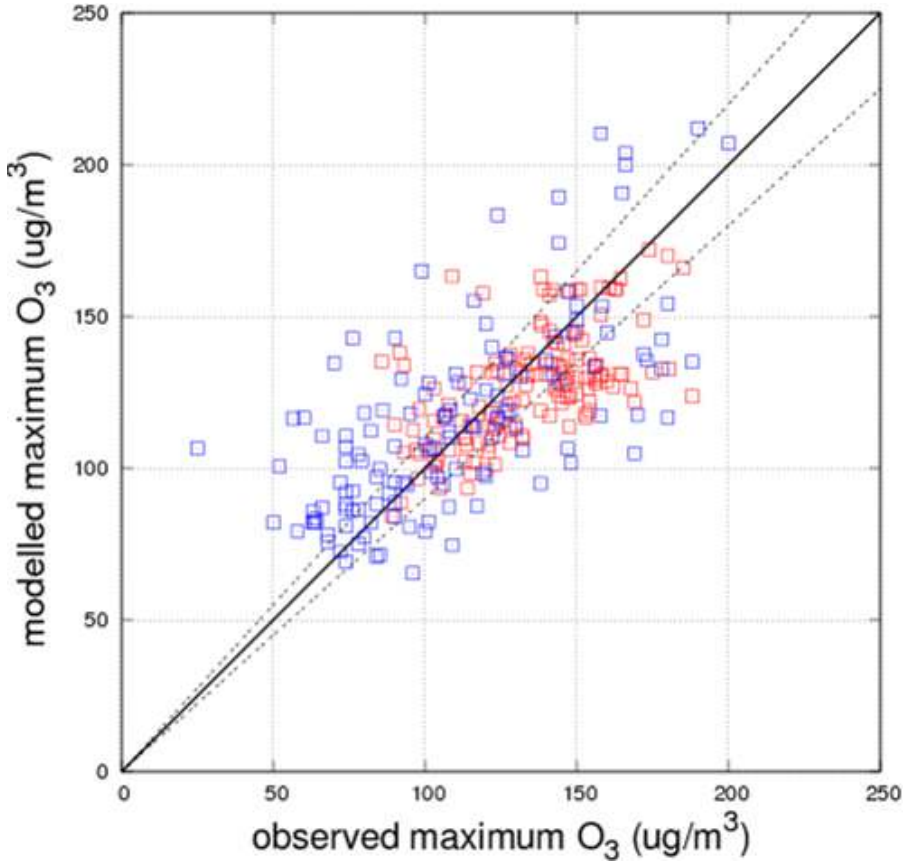
Ozone time series

Rochester, UK



Rambouilliet, France





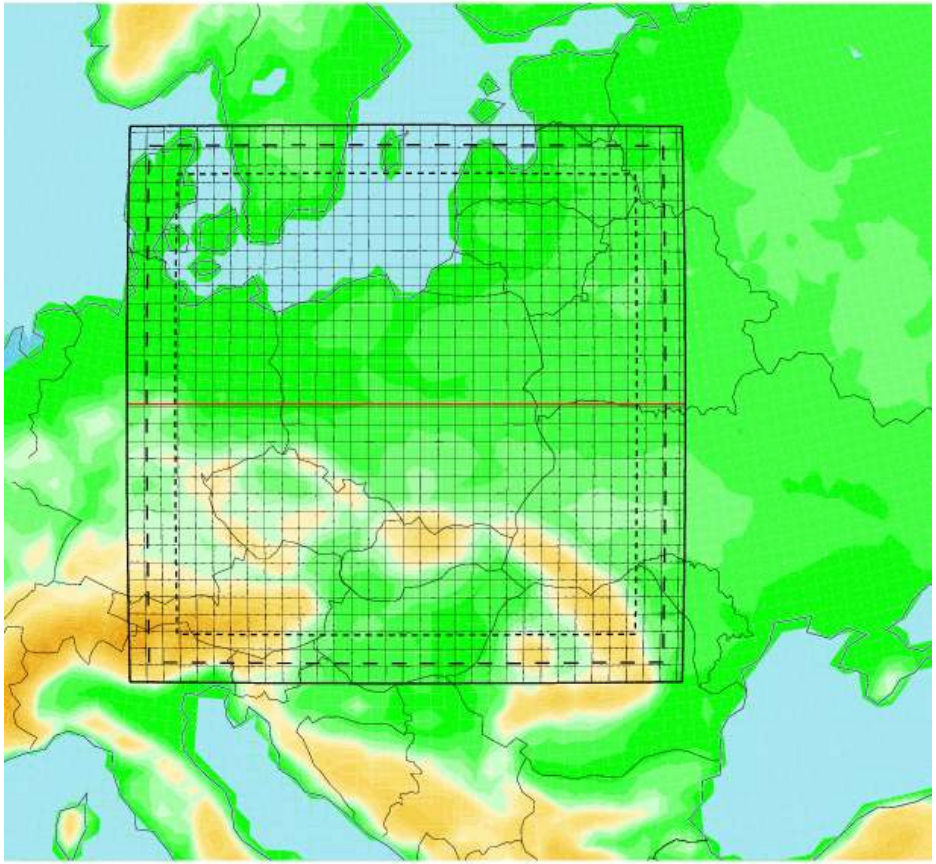
Summary

- Good model performance in extreme weather conditions
- Biogenic emission rates are not well known
- Health consequences

EkoPrognoza.pl EcoForecast.eu

- Realizujemy prognozę zanieczyszczenia powietrza atmosferycznego dla obszaru Polski i Europy Środkowej, z wykorzystaniem modelu chemii atmosfery - GEM-AQ.
- Projekt zainicjowany został w ramach akcji COST ES0602.
- Prognoza chemiczna
- Prognoza meteo
- Prognoza dla Polski $\Delta x=5km$

5x5 km over Poland



EkoPrognoza.pl

PL EN

ekoprognoza

pogoda | indeks jakości powietrza | stężenia zanieczyszczeń

Europa | Polska | *** wybierz region ***

- **Strona główna**
- Fundacja EkoPrognoza
- Prace badawcze
- O prognozie
- Prawo a jakość powietrza
- Dla zainteresowanych
- Mapa serwisu
- Kontakt
- Linki
- Eko na komórkę
- Chemogramy

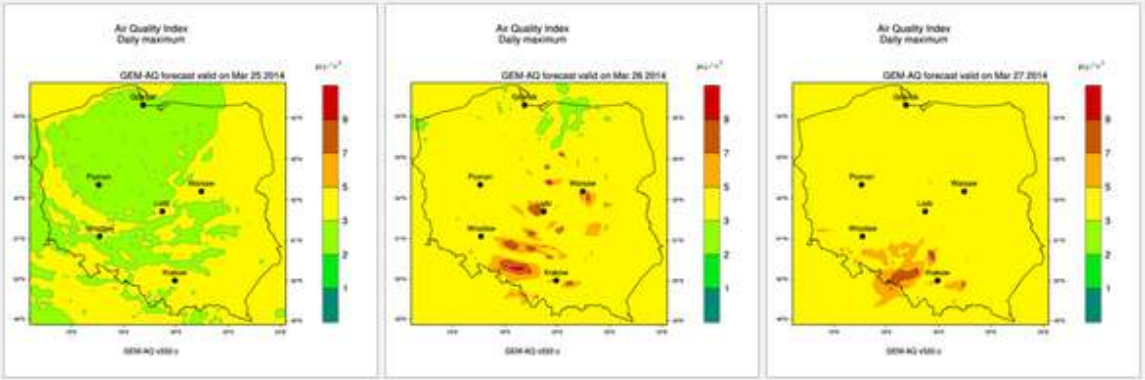
Witamy na stronie serwisu EKO-prognoza.

Prosimy o wypełnienie ANKIETY dotyczącej wiedzy o problemach zanieczyszczenia powietrza

Prognoza zanieczyszczenia powietrza atmosferycznego dla obszaru Polski i Europy Środkowej, z wykorzystaniem modelu GEM-AQ jest realizowana przez Fundację EkoPrognoza.

Uproszczony indeks jakości powietrza Polska

25.03.2014 | 26.03.2014 | 27.03.2014



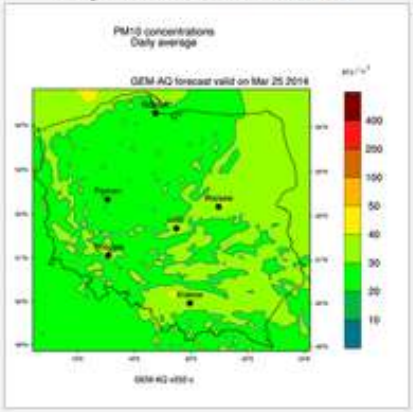
PM10

Europa | Polska | *** wybierz region ***

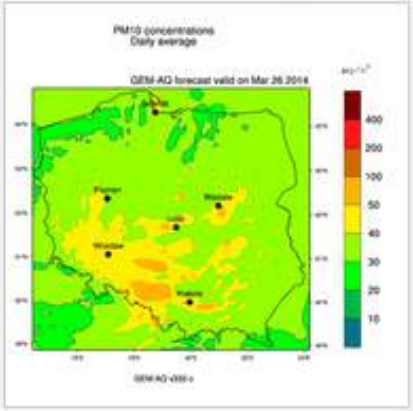
- Strona główna
- Ozon
- Dwutlenek azotu
- Dwutlenek siarki
- Tlenek węgla
- Pył PM10
- Pył PM2.5

Pył PM10 Polska

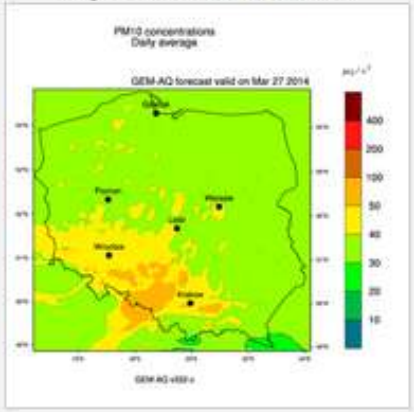
25.03.2014
stężenie średniodobowe



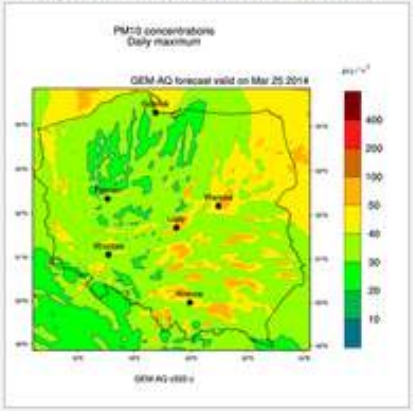
26.03.2014
stężenie średniodobowe



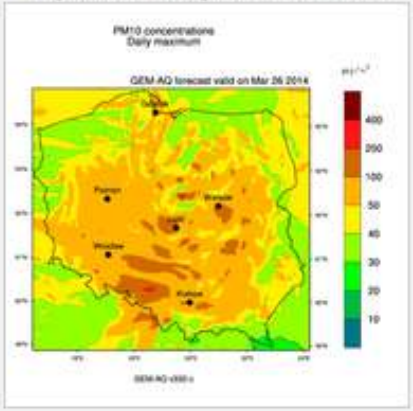
27.03.2014
stężenie średniodobowe



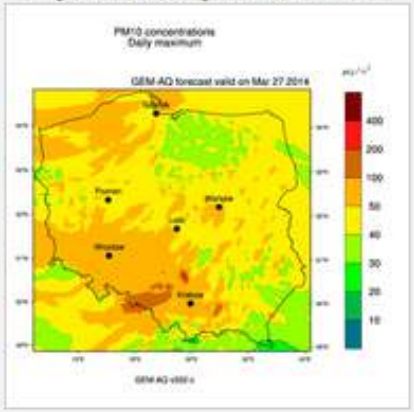
25.03.2014
stężenie maksymalne dobowe



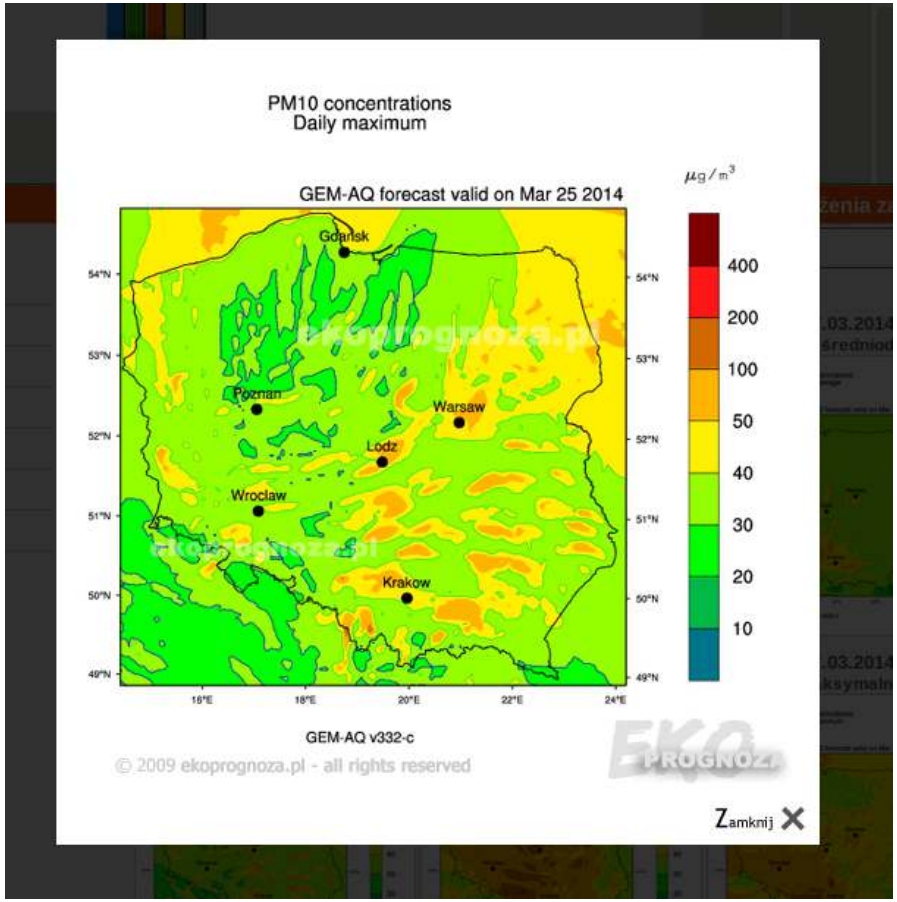
26.03.2014
stężenie maksymalne dobowe



27.03.2014
stężenie maksymalne dobowe



PM10


PM10 concentrations
Daily maximum
GEM-AQ forecast valid on Mar 25 2014
µg/m3
400
200
100
50
40
30
20
10
Gdansk
Poznan
Warsaw
Lodz
Wroclaw
Krakow
54°N
53°N
52°N
51°N
50°N
49°N
16°E
18°E
20°E
22°E
24°E
GEM-AQ v332-c
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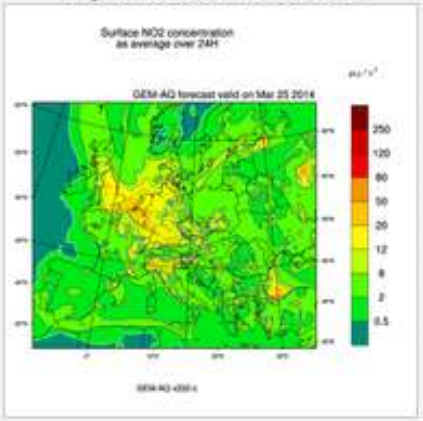
Zamknij

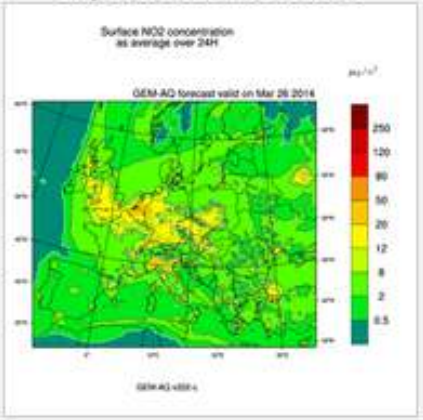
Strona główna
Ozon
Dwutlenek azotu
Dwutlenek siarki
Tlenek węgla
Pył PM10
Pył PM2.5

Dwutlenek azotu Europa

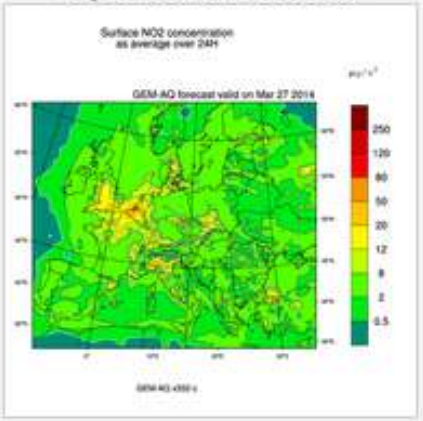
25.03.2014
stężenie średniodobowe



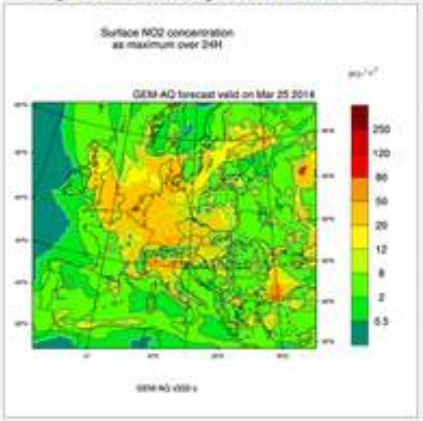
26.03.2014
stężenie średniodobowe



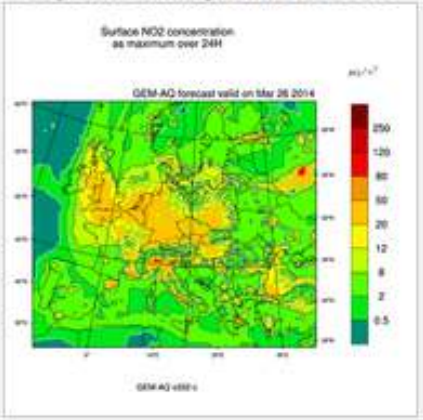
27.03.2014
stężenie średniodobowe



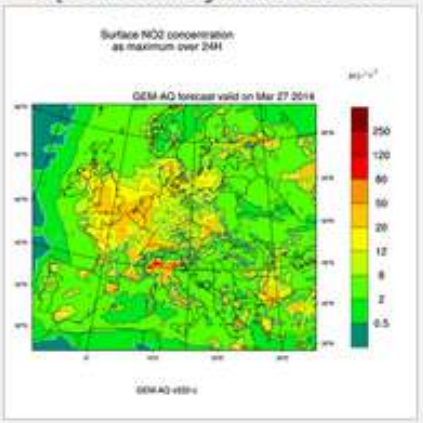
25.03.2014
stężenie maksymalne dobowe

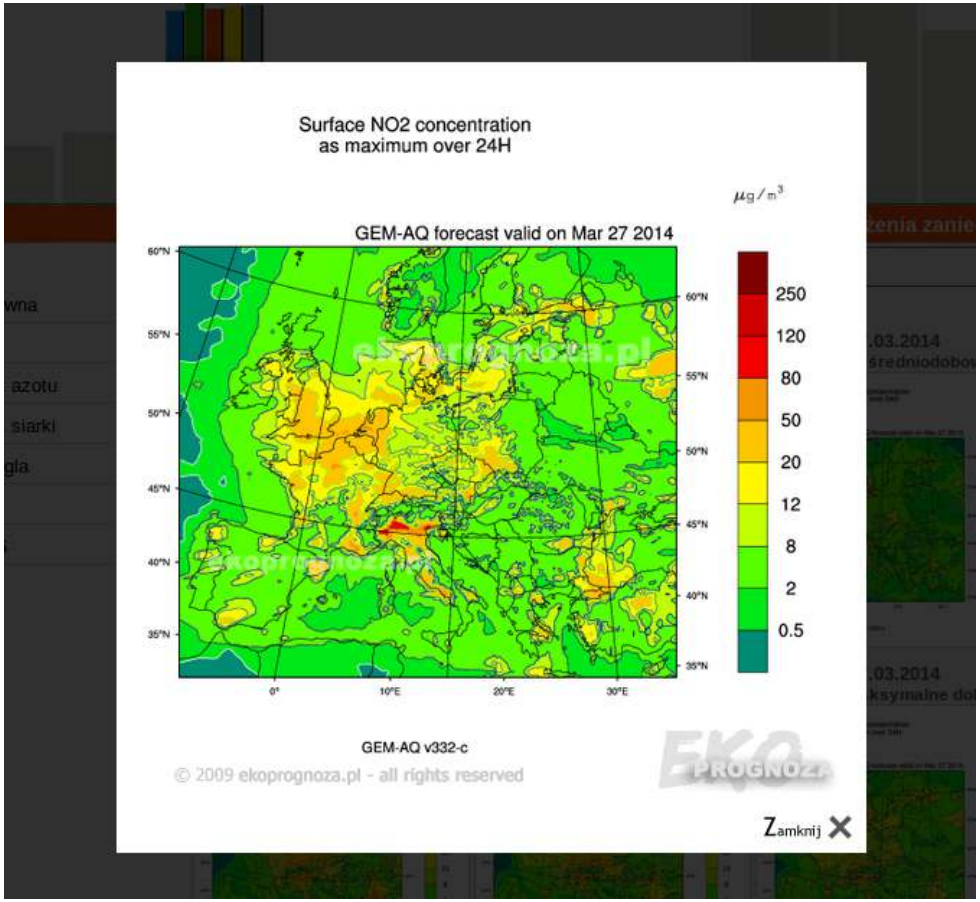


26.03.2014
stężenie maksymalne dobowe



27.03.2014
stężenie maksymalne dobowe




Surface NO2 concentration
as maximum over 24H
µg/m3
GEM-AQ forecast valid on Mar 27 2014
60°N
55°N
50°N
45°N
40°N
35°N
0°
10°E
20°E
30°E
250
120
80
50
20
12
8
2
0.5
GEM-AQ v332-c
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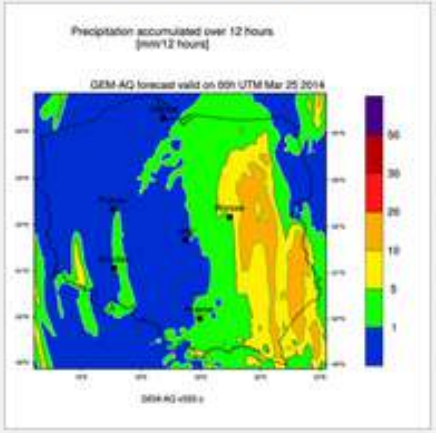
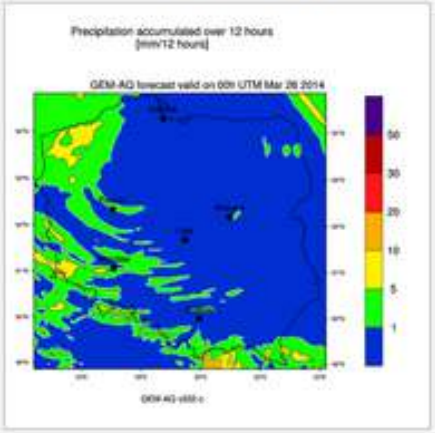
EKO PROGNOZA
Zamknij

Opad zakumulowany Polska

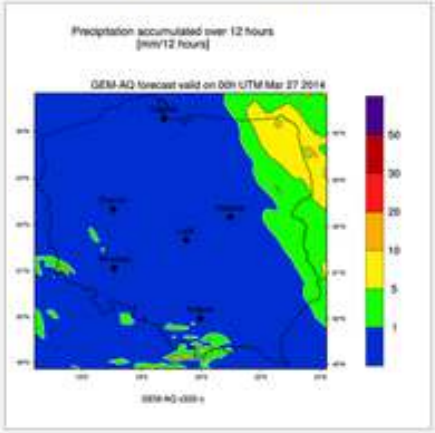
25.03.2014 00 UTC



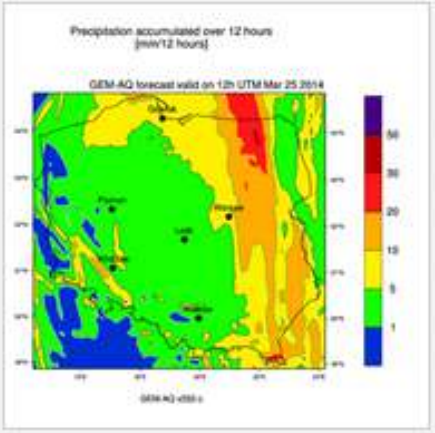
26.03.2014 00 UTC



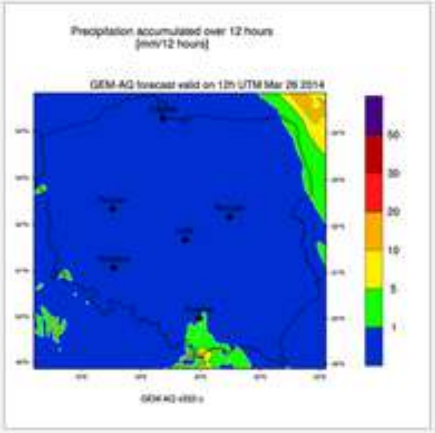
27.03.2014 00 UTC



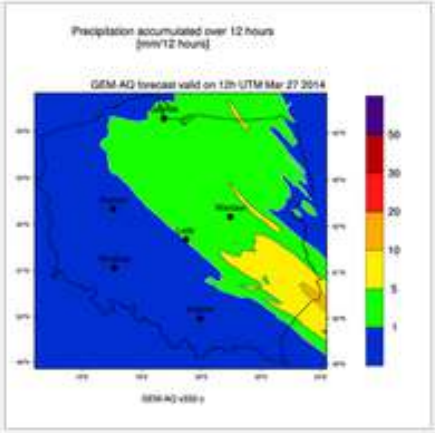
25.03.2014 12 UTC

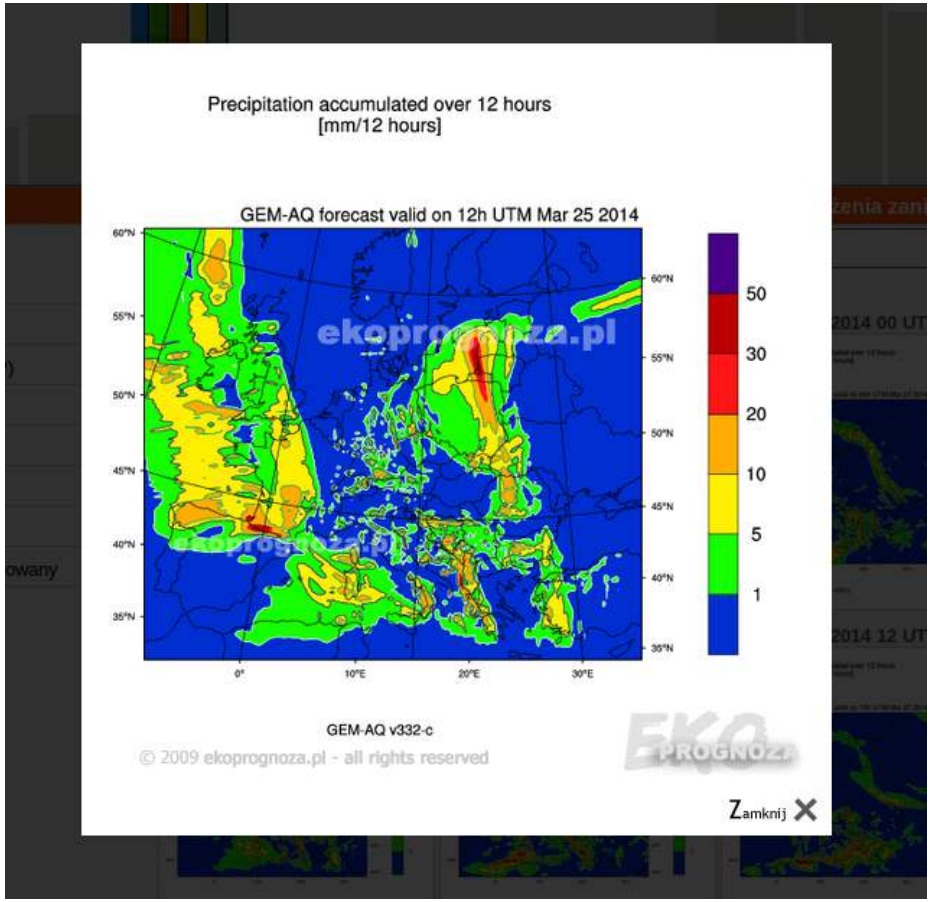


26.03.2014 12 UTC



27.03.2014 12 UTC




Precipitation accumulated over 12 hours
[mm/12 hours]
GEM-AQ forecast valid on 12h UTM Mar 25 2014
60°N
55°N
50°N
45°N
40°N
35°N
0°
10°E
20°E
30°E
50
30
20
10
5
1
GEM-AQ v332-c
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Zamknij

GEM-AC applications

- HCN from fires – comparison with ACE observations
- Hemispheric Transport of Air Pollution
- Combined tropospheric and stratospheric chemistry
- PCW – Arctic satellite
- PREMIER – ESA satellite
- Phoenix & ExoMars – missions to Mars
- Sentinel 4 and 5 - Eko-Prognoza.pl
  - AQ forecasting
  - AQ assessments
  - Data Assimilation

Fin