New Scientific Challenges for

ESA's *Living Planet Programme*

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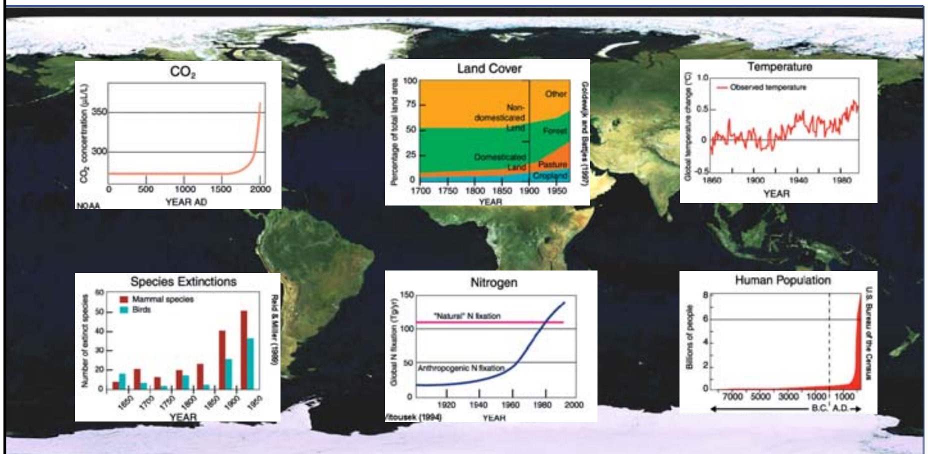
ISPMSRS'07, *Davos, 12 March 2007*

Aspects of Global Change

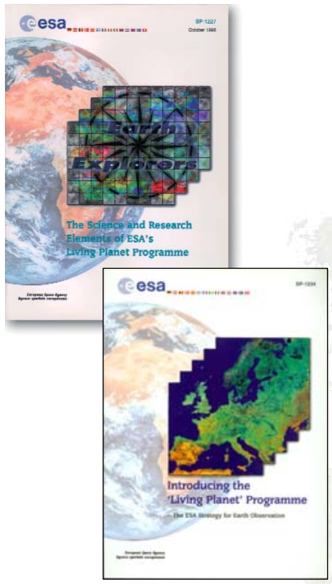


Based on information compiled by the International Geosphere-Biosphere Programme (IGBP).

(Image: MERIS mosaic)

- *Data Sources:*
- *Carbon Dioxide: NOAA.*
- *Land Cover: Goldewijk & Battjes, National Institute*
- *for Public Health and the Environment (RIVM),*
- *Netherlands, 1997.*
- *Temperature: Source unspecified.*
- *Species Extinction: Reid & Miller, World Resources*
- *Institute, Washington DC, 1989.*
- *Nitrogen: Vitousek, 1994,*
- *Human Population: US Bureau of the Census*

Previous strategy



- a new Earth observation strategy was introduced in the document SP-1227: **The Science and Research Elements of ESA's Living Planet Programme (1998)**
- the Earth Observation Envelope Programme containing **Earth Explorer** missions and **Development and Exploitation** components was started in 1998
- the scientific strategy was initially formulated with **nine candidate missions** that covered most fields of Earth science and through **data management and exploitation** programme elements
- implementation of the programme is based on continuous and close **interaction with the scientific community,**

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Achievements: Earth Explorers

- since then, two calls for Earth Explorer Opportunity missions and two for Core missions have been issued, with a total response of more than 80 proposals
- six missions have been selected for implementation: CryoSat, GOCE, SMOS, ADM/Aeolus, Swarm and EarthCARE. Missions implemented together with both ESA member states and international partners are among the selected ones.
- in addition a number of missions have been studied at pre Phase-A and Phase-A level
- six new mission concepts have been selected as candidates for the next EE Core mission

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The Earth Explorer Missions

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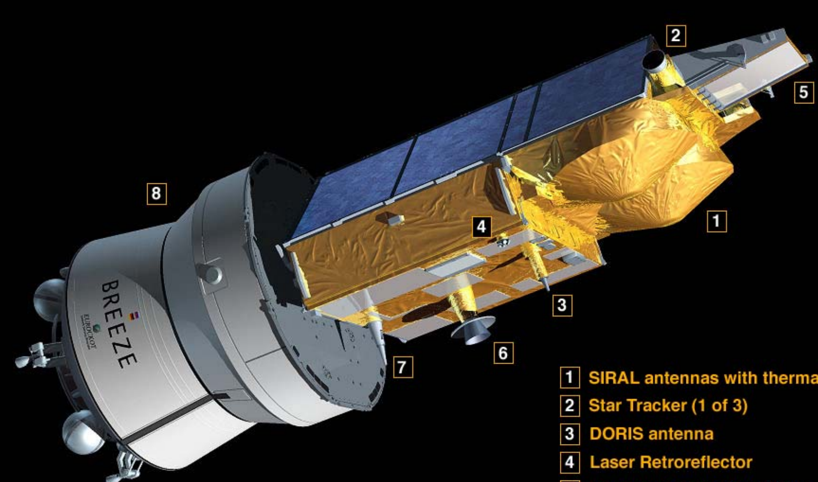
CryoSat
the satellite attached to the launcher upper stage



1. SIRAL antennas with thermal covers
2. Star Tracker (1 of 3)
3. DORIS antenna
4. Laser Retroreflector
5. Thermal radiator for SIRAL
6. X-band telemetry antenna
7. S-band TTC antenna
8. Breeze KM upper stage

The CryoSat mission

What are the scientific objectives?

Improve understanding of:

– impact of sea-ice thickness variations on climate

– mass balance of Greenland/Antarctic ice sheets

How are they achieved?

– *SAR interferometric* Radar Altimeter with *precise pointing* and *orbit determination*

– measurement of Arctic sea-ice thickness variations

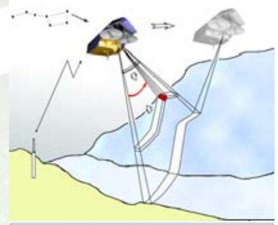
– measurement of temporal variations in ice-sheet elevation, including dynamic margins

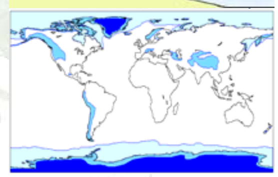
What are the benefits?

– improved parameterisation of sea-ice processes in coupled climate models

– reduced uncertainty in the ice-sheet contribution to global sea-level rise

–advances in cryosphere and climate studies





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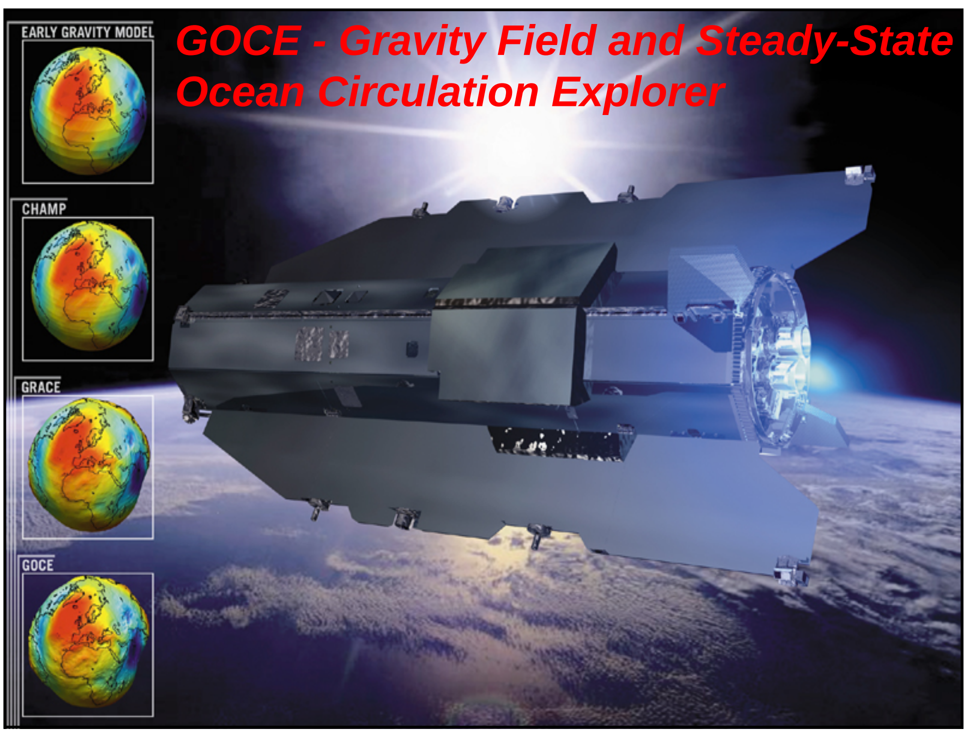
GOCE - Gravity Field and Steady-State Ocean Circulation Explorer



The GOCE Mission

What are the scientific objectives?

Improve understanding of

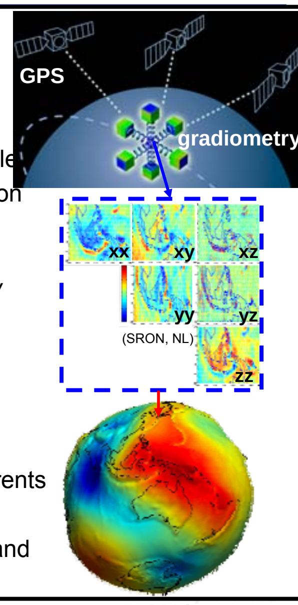
- global ocean circulation and transfer of heat
- physics of the Earth's interior (lithosphere & mantle)
- sea level records, topographic processes, evolution of ice sheets and sea level change

How are they achieved?

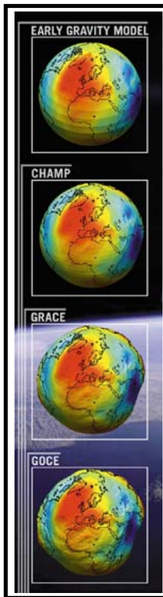
- Combination of *satellite gradiometry* and *high-low satellite-to-satellite tracking* at ± 250km altitude
- Improved model of the static gravity field and geoid to a resolution of 100km with 1mGal resp. 1-2cm accuracy

What are the benefits?

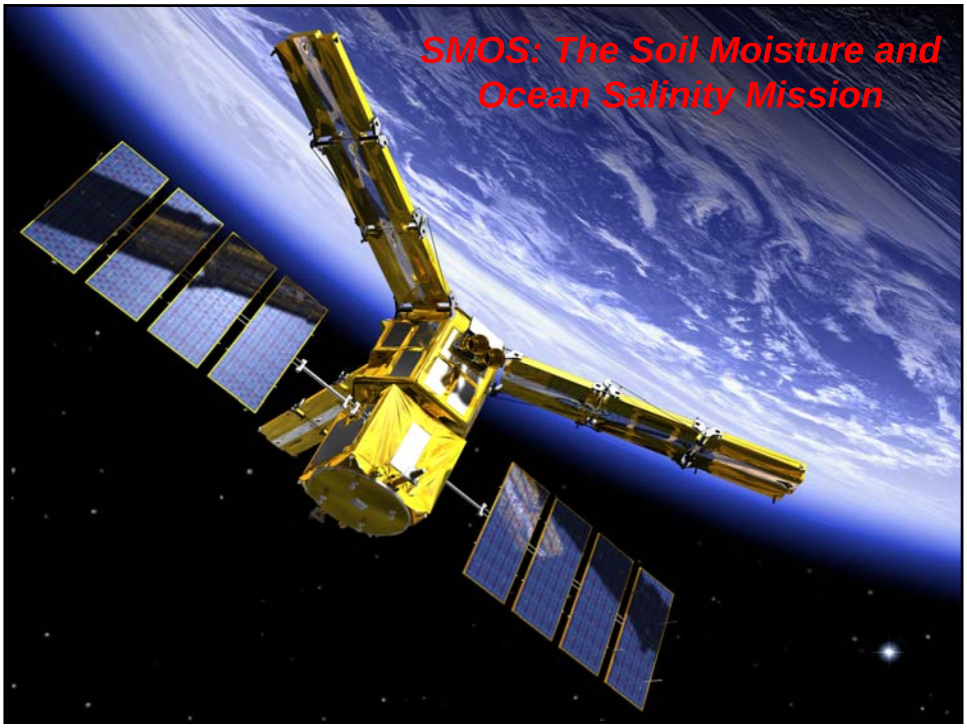
- An accurate marine geoid for absolute ocean currents
- Improved constraints for interior modelling
- Unified global height reference for land, sea, ice and surveying



GOCE: Uniqueness and Relevance



- Only mission with satellite gradiometry (3D) and drag-free control in low orbit (250km)
- GOCE will provide global static gravity field with homogeneous quality of unprecedented accuracy and resolution
- Key step in improving ocean, solid Earth and sea level modelling
- Large impact on national height systems and surveying applications on land and sea
- Essential benchmark technique for understanding mass distribution and change
- Element of IGGOS (Integrated Global Geodetic Observing System) and essential for WOCE, WCRP and CLIVAR



The SMOS Mission

What are the scientific objectives?:

To improve understanding of:

- the water cycle (and the Energy and Carbon Cycle), and
- its representation in mesoscale models (Hydrology, Oceanography and Climate).

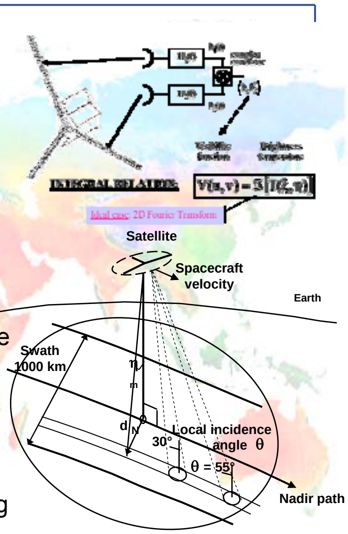
How are they achieved?:

Constraining models by global soil moisture and ocean salinity observations estimated from dual-pol., multi-angular, L-band brightness temperature measurement acquired by a 2D interferometer.

What are the benefits?:

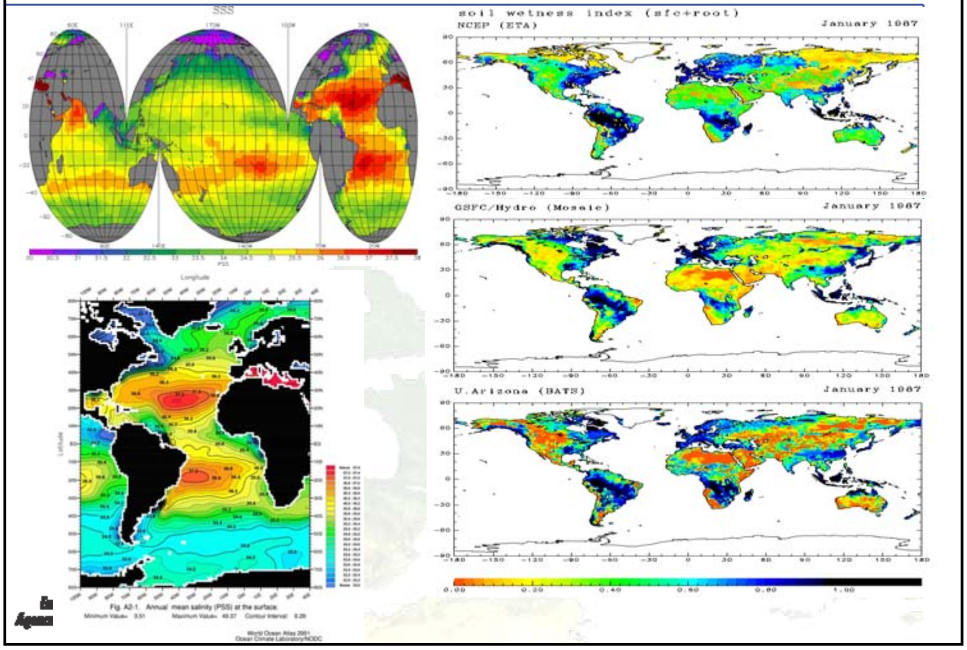
Enhancement of the model parameterisation will:

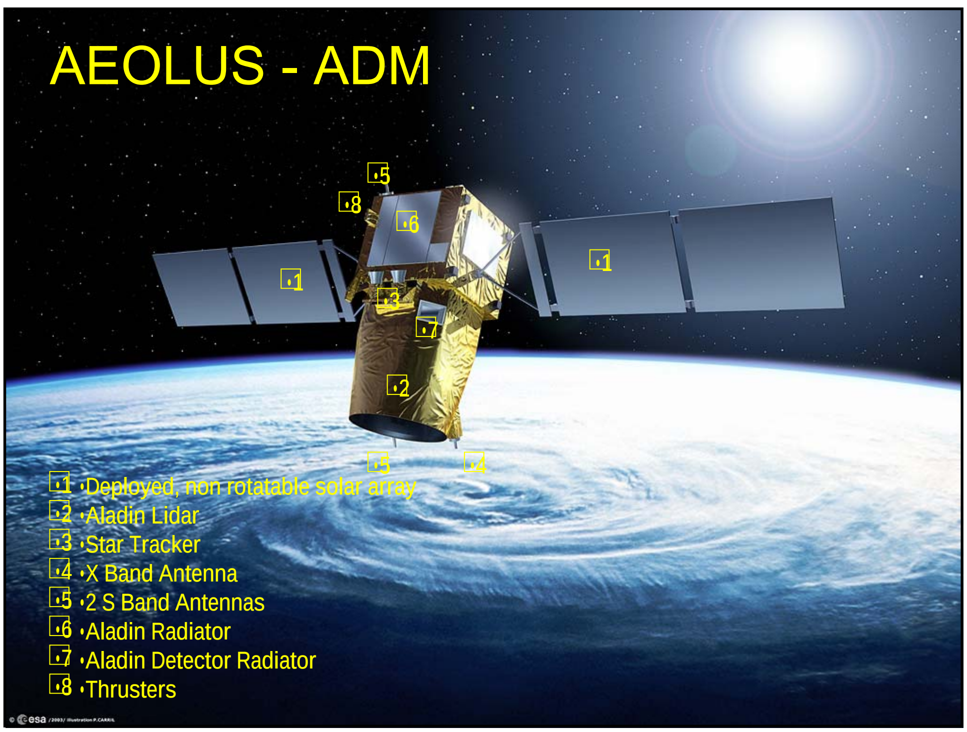
- improve the weather prediction
- improved ocean circulation/hydrology modelling
- better extreme event forecasting



$$Tb = f(\nu, p, \theta, T, sm/s, \sigma^0, ...)$$

SMOS – measuring soil moisture and ocean salinity





esa — *Atmospheric dynamics mission*

Aeolus Mission

What are the scientific objectives?

Improve understanding of

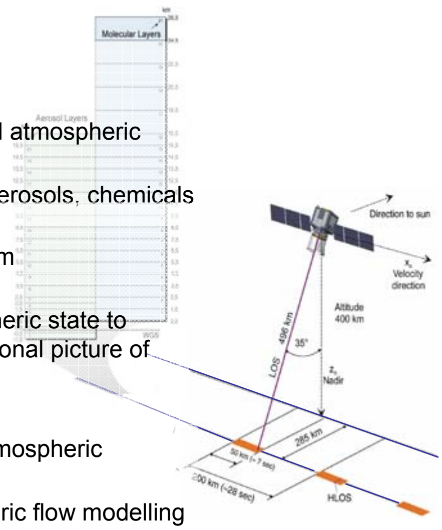
- atmospheric dynamics and global atmospheric transport
- global cycling of energy, water, aerosols, chemicals

How are they achieved?

- line of sight winds are derived from aerosol/molecular Doppler shifts
- Improved analysis of the atmospheric state to provide a complete three-dimensional picture of the dynamical variables

What are the benefits?

- Improved parameterisation of atmospheric processes in models
- Advanced climate and atmospheric flow modelling
- Better initial conditions for weather forecasting



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esa — ESA's **Magnetic Field** Mission

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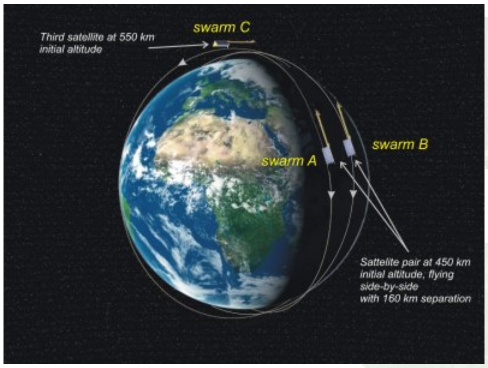
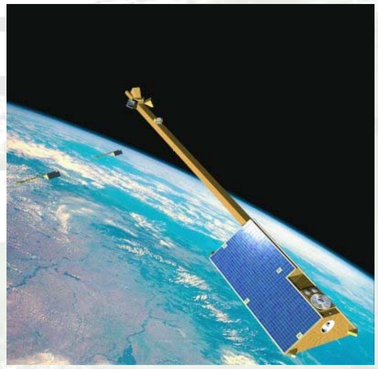
ESA's **Magnetic Field** Mission

The satellite constellation





- **3 satellites in three different polar orbits between 400 and 550 km altitude**
- High-precision and high-resolution measurements of the magnetic field
- GPS receivers, an accelerometer and an electric field instrument provide supplementary information for studying the Earth system.

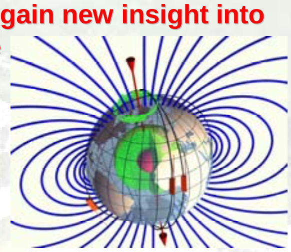
ESA's **Magnetic Field** Mission

The Earth's Magnetic Field and Environment Explorer

SWARM

Its objectives of the SWARM constellation are:

- **To provide the best-ever survey of the Earth's geomagnetic field and its variation in time**
- **To Use of the data obtained to gain new insight into the Earth's interior and climate**

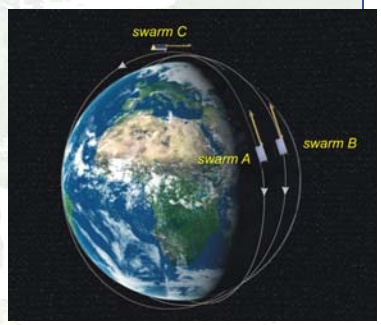


Swarm: Mission Requirements

Single satellite

- Magnetic field magnitude and vector components
- Electric field vector components
- Electron density
- Air drag
- Position, attitude and time

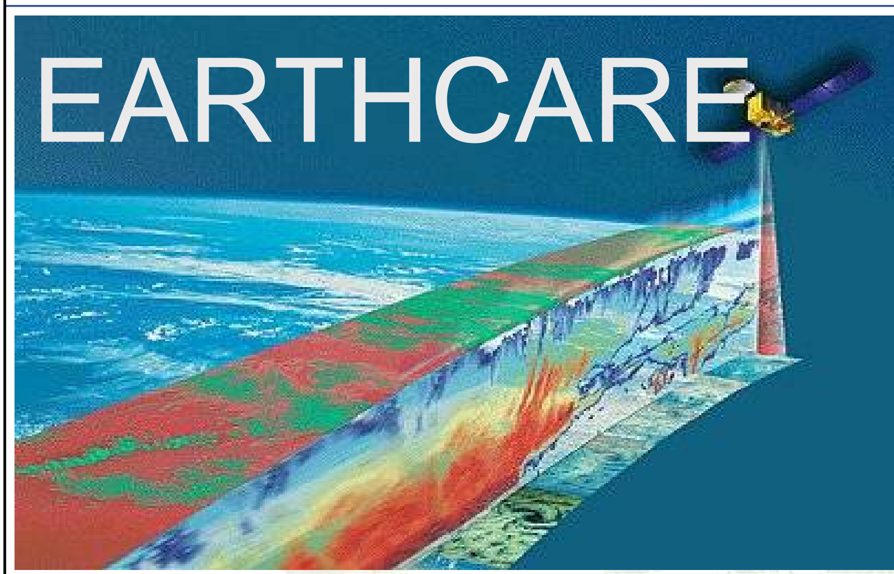
accurate enough at satellite altitude to measure the most demanding signals at finest spatial and fastest required temporal sampling



Constellation

- 3 satellites:
  - ❑ 2 side-by-side in low orbit
  - ❑ 1 in higher orbit
- three orbital planes with two different near-polar inclinations
- Near polar orbits for global coverage

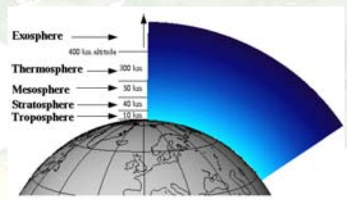
ESA's **Cloud & Aerosol** Mission



The Earth Clouds, Aerosols and Radiation Explorer

EarthCARE is a joint European (ESA) – Japanese (JAXA) mission with the objective:

- **to quantify and thus improve understanding of cloud-aerosol-radiation interactions**
- **to include such parameters correctly and reliably in climate and weather prediction models**



Expected Scientific Output

- Vertical **profiles of natural and anthropogenic aerosols** on a global scale, their radiative properties and interaction with clouds
- Vertical **distribution of atmospheric liquid water and ice** on a global scale, their transport by clouds and radiative impact
- Cloud overlap in the vertical, cloud-precipitation interactions and the **characteristics of vertical motion within clouds**
- The **profiles of atmospheric radiative heating and cooling** through a combination of retrieved aerosol and cloud properties

Six new Earth Explorer missions (2006)

1. **BIOMASS** – to take global measurements of forest biomass.
2. **TRAQ** (TRopospheric composition and Air Quality) - to monitor air quality and long-range transport of air pollutants.
3. **PREMIER** (PRocess Exploration through Measurements of Infrared and millimetre-wave Emitted Radiation) – to understand processes that link trace gases, radiation, chemistry and climate in the atmosphere.
4. **FLEX** (FLuorescence EXplorer) – to observe global photosynthesis through the measurement of fluorescence.
5. **A-SCOPE** (Advanced Space Carbon and Climate Observation of Planet Earth) – to improve our understanding of the global carbon cycle and regional carbon dioxide fluxes.
6. **CoReH2O** (Cold Regions Hydrology High-resolution Observatory – to make detailed observations of key snow, ice and water cycle characteristics.

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New Earth Explorers (1)

BIOMASS – the mission aims at global measurements of forest biomass. The measurement is accomplished by a space borne P-band synthetic aperture polarimetric radar. The technique is mainly based on the measurement of the cross-polar backscattering coefficient, from which forest biomass is directly retrieved. Use of multi-polarization measurements and of interferometry is also proposed to enhance the estimates. In line with the ESAC recommendations, the analysis for this mission will include comparative studies to measure terrestrial biomass using P- or L-band and consideration of alternative implementations using L-band.

TRAQ – the mission focuses on monitoring air quality and long-range transport of air pollutants. A new synergistic sensor concept allows for process studies, particularly with respect to aerosol-cloud interactions. The main issues are the rate of air quality change on regional and global scales, the strength and distribution of sources and sinks of tropospheric trace gases and aerosols influencing air quality, and the role of tropospheric composition in global change. The instrumentation consists of imaging spectrometers in the range from ultraviolet to short-wave infrared.

New Earth Explorers (2)

PREMIER – Many of the most important processes for prediction of climate change occur in the upper troposphere and lower stratosphere (UTLS). The objective is to understand the many processes that link trace gases, radiation, chemistry and climate in the atmosphere – concentrating on the processes in the UTLS region. By linking with MetOp/ National Polar-orbiting Operational Environmental Satellite System (NPOESS) data, the mission also aims to provide useful insights into processes occurring in the lower troposphere. The instrumentation consists of an infrared and a microwave radiometer.

FLEX – The main aim of the mission is global remote sensing of photosynthesis through the measurement of fluorescence. Photosynthesis by land vegetation is an important component of the global carbon cycle, and is closely linked to the hydrological cycle through transpiration. Currently there are no direct measurements available from satellites of this parameter. The main specification is for instruments to measure high spectral resolution reflectance and temperature, and to provide a multi-angular capability.

New Earth Explorers (3)

A-SCOPE – The mission aims to observe total column carbon dioxide with a nadir-looking pulsed carbon dioxide DIfferential Absorption Lidar (DIAL) for a better understanding of the global carbon cycle and regional carbon dioxide fluxes, as well as for the validation of greenhouse gas emission inventories. It will provide a spatially resolved global carbon budget combined with diagnostic model analysis through global and frequent observation of carbon dioxide. Spin-off products like aerosols, clouds and surface reflectivity are important parameters of the radiation balance of the Earth. A contribution to Numerical Weather Prediction is foreseen in connection with accurate temperature profiles. Investigations on plant stress and vitality will be supported by a fluorescence imaging spectrometer.

CoReH2O – The mission focuses on spatially detailed observations of key snow, ice, and water cycle characteristics necessary for understanding land surface, atmosphere and ocean processes and interactions by using two synthetic aperture radars at 9.6 and 17.2 GHz. It aims at closing the gaps in detailed information on snow glaciers, and surface water, with the objectives of improving modelling and prediction of water balance and streamflow for snow covered and glacierised basins, understanding and modelling the water and energy cycles in high latitudes, assessing and forecasting water supply from snow cover and glaciers, including the relation to climate change and variability.

EE-7 candidate missions - summary

Mission	Proposers	Objective	Instrumentation and orbit	Evaluation
BIOMASS	**T. Le Toan (F) and S. Quegan (UK)** + 32 researchers from I, F, A, S, CDN, FIN, D, NL, US, Br, JP	Forest biomass & extent, deforested areas, flooded forests, subsurface imaging in arid areas, Antartic ice cover, soil moisture, sea surface characteristics (salinity, low frequency surface roughness)	P-band (432-438 Mhz) SAR, fully polarimetric or HH/HV polarizations Sun-synchronous, dawn-dusk orbit at 580 km	Unique long wavelength sensor Need process models for above ground biomass assimilation Concerns about ionospheric effects, biomass levels above 150 ton/ha, and radio frequency interference
TRAQ	**P. Levelt (NL) and C. Camy-Peyret(F)** + 125 researchers from A, B, CDN, CH, D, DK, F, FIN, GR, IE, IT, N, NL, UK, US, CHN, JP	Air quality: megacities emissions, long range transport, diurnal cycle, long-term trends, forecast Sources and sinks of trace gases and aerosols influencing air quality Climate impact of change in tropospheric composition	UV-VIS-NIR nadir grating imaging spectrometer TIR+SWIR FTS cloud imager multi-viewing polarization-resolving imaging radiometer Drifting low Earth orbit	Innovative mission concept with new orbit and new strategy for synergistic use of multiple sensors for retrieval of tropospheric gas-phase and aerosol compounds; great potential for understanding air chemistry and processes; information on air quality for users and decision makers
PREMIER	**B. Kerridge (UK)** + 60 researchers from D, B, UK, F, S, CH, Gr, I, CDN, Pol, US, Bul, Ind	Convective transport, thin cirrus, tropical tropopause layer; stratosphere-troposphere exchange; gravity waves and global circulation; UT humidity and cirrus; radiative forcing by tropospheric O_3 and CH_4, stratospheric O_3 and water vapour; chem-climate interaction (OH chemistry); processes linking clouds and aerosols to atmospheric chemistry and global climate	Limb imaging FTIR for trace gases and particles Push-broom mm/sub-mm wave limb-sounder Sun-synchronous orbit, loose formation flight with Metop to support tropospheric applications	The mission offers greatly improved understanding of UTLS chemistry and climate processes Synergy with MetOp/NPOESS data The timely availability of the Swedish contribution of STEAM-R is mandatory
FLEX	**J. Moreno (E)** + 77 researchers from B, NL, UK, D, F, E, FIN, CDN, I, CH, AUS, US, JP, Czech	Chlorophyll fluorescence for photochemical processes and terrestrial carbon sequestration, bio/geophysical quantities from reflectance and thermal infrared measurements to get vegetation variables for interpretation of fluorescence measurements, and to monitor vegetation health, using fluorescence as an early indicator of stress.	Imaging Spectrometer (480-760nm), resolution 0.1nm, Multi-Angular Vegetation Imaging Spectrometer (400-2400nm), dual-view TIR spectrometer with 3 channels in the 8.8-12 μm band Sun-synchronous orbit	Ambitious proposal on chlorophyll fluorescence, multi-spectral and thermal remote sensing Highly precise atmospheric correction together with sub-pixel cloud masking is mandatory
A-SCOPE	**P. Flamant (F)** + 19 researchers from NL, F, UK, D, E, I, US	Mapping sources and sinks of CO_2 Global carbon cycle and regional CO_2 fluxes Low bias CO_2 data, aerosol and cloud information Contribution to NWP in connection with accurate T profiles Plant stress and vitality	Laser Absorption Spectroscopy (LAS) sensors for CO_2 and O_2 column soundings ATLID type DIAL for CO_2, canopy height, aerosol/clouds layers Fluorescence imaging spectrometer for photosynthesis, plant stress and vitality. Camera for cloud and ground backgrounds Sun-synchronous orbit	Would eliminate three sources of bias for OCO and GOSAT: measure by night as well as by day (sampling time bias); will measure at high latitude; lidar will provide a clear indication of scattering material in the optical path. Potentially significant sources of bias remaining, such as surface pressure and terrain variability Programmatic assumptions of the NASA contribution need to be clarified.
CoReH2O	**H. Rott (A)** + 33 researchers from D, F, UK, N, I, FIN, US, CDN, A, NL, DK	Estimation of snow and ice masses and their temporal variations for climate modelling and hydrological and NWP modelling	2 SAR instruments in Ku-band (17.2 GHz) and X-band (9.6Ghz) on 2 different satellites with VV + VH polarization Dawn/dusk orbit	Snow water equivalent and snowcover of unique importance Cost boundary condition may be met only by implementing the mission with a single satellite

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Achievements: Exploitation

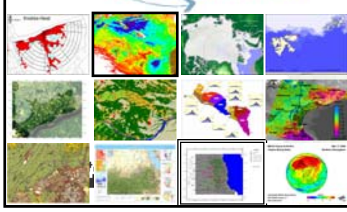
- more than 1,500 scientific teams are being provided with satellite data from ERS-1/2, Envisat and Third Party missions.
- users are provided with software toolboxes that ease their work
- a versatile multi-mission ground segment has been implemented, drawing on Member State facilities
- a continuous programme of workshops, summer schools and training courses has been developed
- new scientific results form the basis for implementation of new applications and services

Achievements: Exploitation

- **develop user communities** for both institutional and commercial applications
- support European companies to develop and **demonstrate information products**
- support value adding and servicing companies in establishing **useful and cost effective services**.

EARTHOBSERVATION MARKETDEVELOPMENT

- building **industrial partnerships** to conduct pre-commercial service trials with customers
- marketable **service portfolios** developed with non-EO service suppliers engaged
- better understanding of the prospects for EO in **emerging market sectors**



- the **GMES service element** has established service partnerhips
- builds largely on **scientific achievements**
- forms the **space basis for the GMES component**

Europe's expanding capacity

1991	1995	2002
ERS 1 →	ERS 2 →	ENVISAT

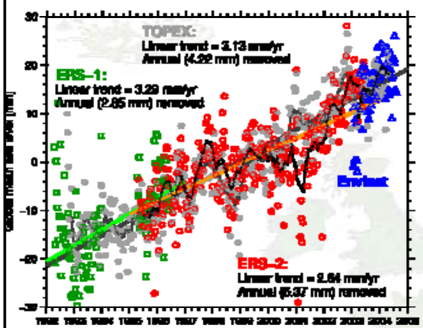
Oceans
Sea Ice
Cryosphere
Land Surface
Climatology

→ + *Global Ozone*
+ *Terrestrial biosphere*

→ + *Ocean colour*
+ *Atmospheric chemistry*

Science of Global Climate Change

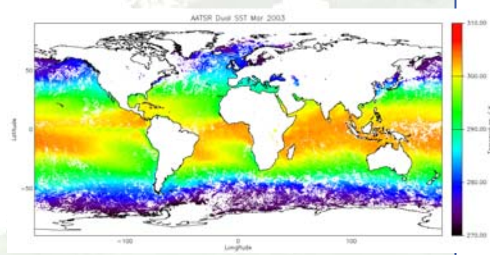
Sea Level rise



Altimetry measurements
Trend +3 mm/yr

Courtesy of Remko Scharroo, NOAA,US

Sea Surface temperature rise



ATSR/AATSR measurements
Trend 0.13±0.03°C/decade

Courtesy of David Llewellyn Jones, Univ. Leicester, UK

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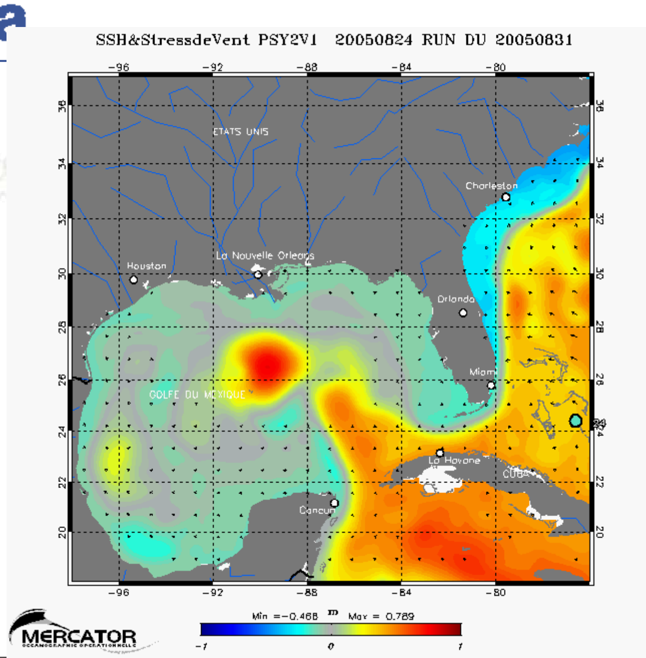

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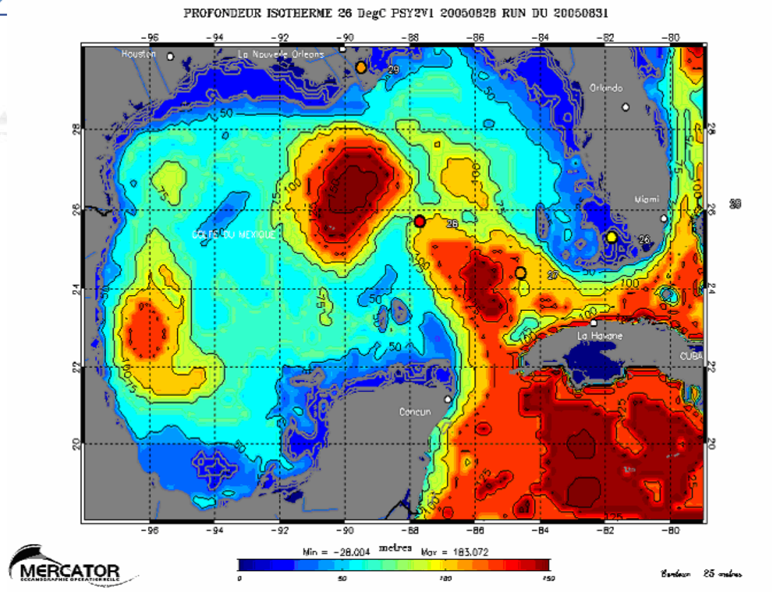

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Greenland ice velocities: Envisat vs Radarsat-1 background missions

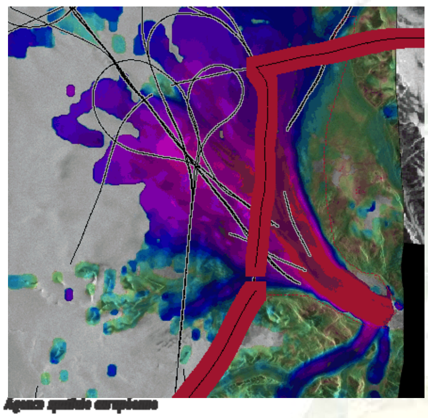
Eric Rignot[1] and Pannir Kanagaratnam[2]

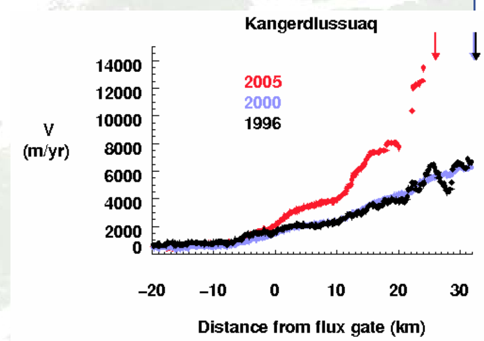
[1]Jet Propulsion Laboratory, Caltech
[2]University of Kansas, CReSiS.

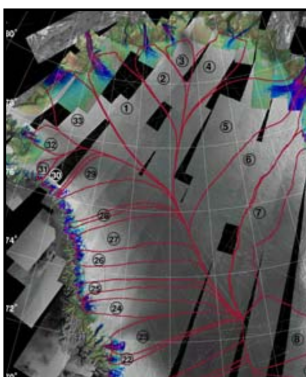
Kangerdlussuaq Gletscher, east Greenland.

- Mass loss in 1996, stable speed since 1962/1988, but changes after 1996 (Thomas et al., GRL 2001).
- 210% increase in velocity in 2005, 10 km ice-front retreat.
- Mass loss = 36±2 km³ ice/yr in 2005

<table>
<tr><th>Glacier</th><th>Input
km³/yr</th><th>Outflow
km³/yr</th><th>Balance
km³/yr</th></tr>
<tr><td>Kangerdlussuaq
(51 M km²)</td><td>22.6±2</td><td>27.8±1</td><td>-5.2±2 | -5.2 | -35.8</td></tr>
</table>







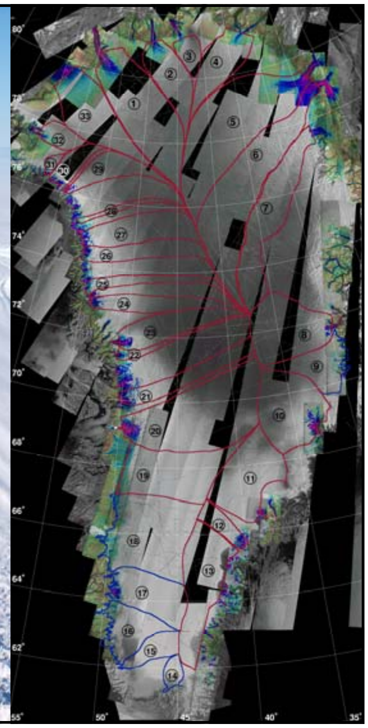
Ice sheet mass balance

- Greenland ice sheet loss from ice dynamics increased by a factor 3 in 10 years.
- Enhanced melt from Hanna et al. JGR 2005 increases loss by 35 to 57 km³/yr.
- Ice dynamics contributes 2/3 of Greenland ice loss vs 1/3 for enhanced surface melt.
- Monitoring ice dynamics and progression further north is essential.

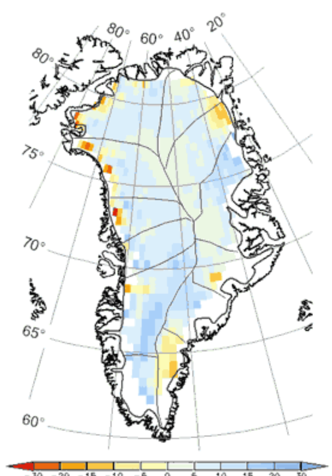
<table>
<tr><th>Area</th><th>Area
(M km²)</th><th>Discharge
(km³/yr)</th><th>Input
(km³/yr)</th><th>Balance (96 | 00 | 05)
(km³/yr)</th></tr>
<tr><td>North</td><td>465</td><td>49.5</td><td>50.0</td><td>-4.8 | +0.5 | -2.4</td></tr>
<tr><td>East</td><td>213</td><td>160.8</td><td>110.0</td><td>-31.8 | -50.8 | -118.4</td></tr>
<tr><td>West</td><td>521</td><td>168.0</td><td>145.0</td><td>-21.5 | -23.0 | -36.8</td></tr>
<tr><td>Total</td><td>1,199</td><td>378 ±12</td><td>305 ±30</td><td>-58 ±32 | -73 ±32 | -158 ±32</td></tr>
<tr><td>Total + δmelt</td><td>1,199</td><td></td><td></td><td>-93 ±34 | -119 ±34 | -215 ±35</td></tr>
</table>

Conclusions

- A first mapping of Greenland ice velocities has been achieved with Radarsat-1 HH-polarization 2000 background mission.
- We can do as well with Envisat ASAR if we operate at HH-polarization, with short baselines.
- Comparison of these data with ERS-1/2 1996, Envisat ASAR 2004/2005 and Radarsat-1 2005 has been used to detect glacier speed up in Greenland and determine how the boundary of acceleration has been migrating northward.
- Mass loss from Greenland is revised upwards from these results which show dominant role of ice dynamics.
- Contribution to sea level rise of GrIS is 0.65 mm/yr in 2005, or twice that in 1995.

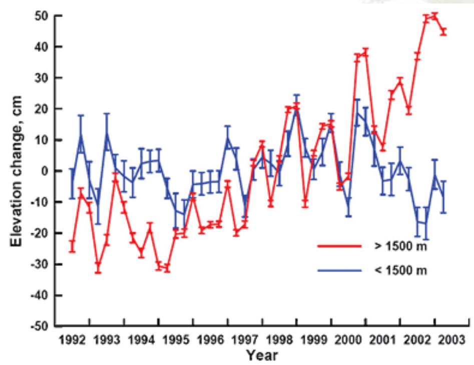


esa



Greenland ice-sheet elevation change in cm/year (see colour scale) derived from 11 years of ERS-1/ERS-2 satellite altimeter data, 1992-2003,

O. M. Johannessen, K. S. Khvorostovsky, M. W. Miles and L. P. Bobylev (2005): Recent ice sheet growth in the interior of Greenland. Science (In Press, and October 20, 2005 issue of Science Express).



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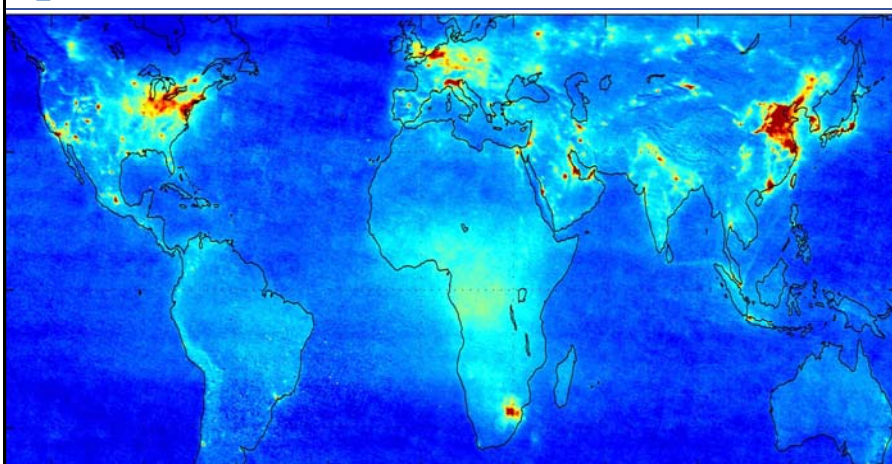
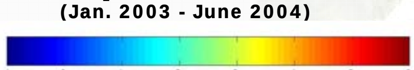
Atmosphere NO_2 concentration



NO_2 from SCIAMACHY
(Jan. 2003 - June 2004)

Courtesy of Steffen Beirle, Univ. Heidelberg, D



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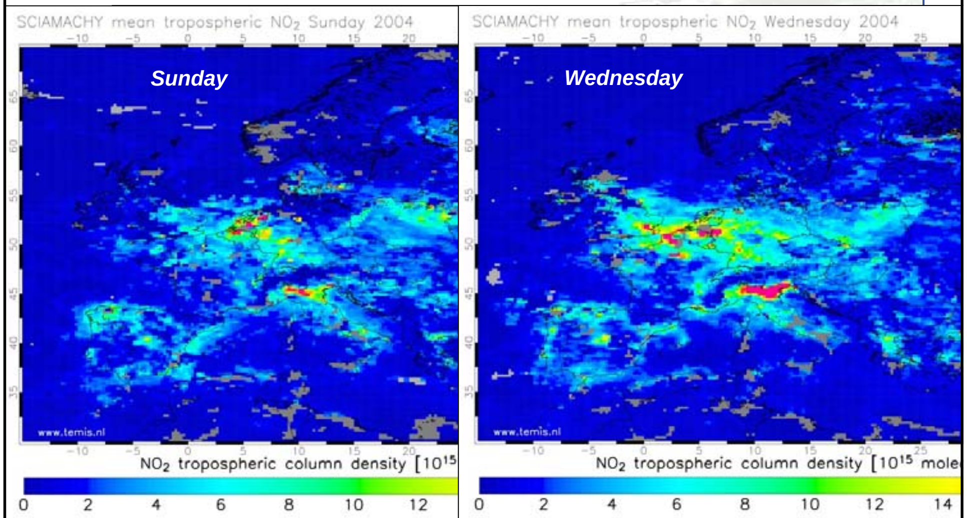
1e15 molec/cm²

NO2 CONCENTRATION

NO_2 concentration ***Sunday and Wednesday – Year 2004***



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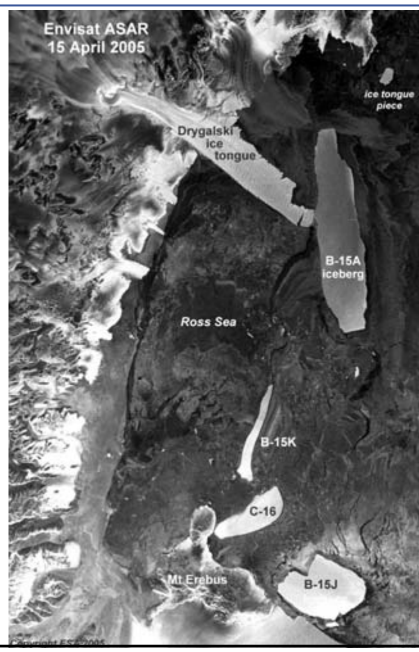
Cryosphere: Ice movement in Antarctica



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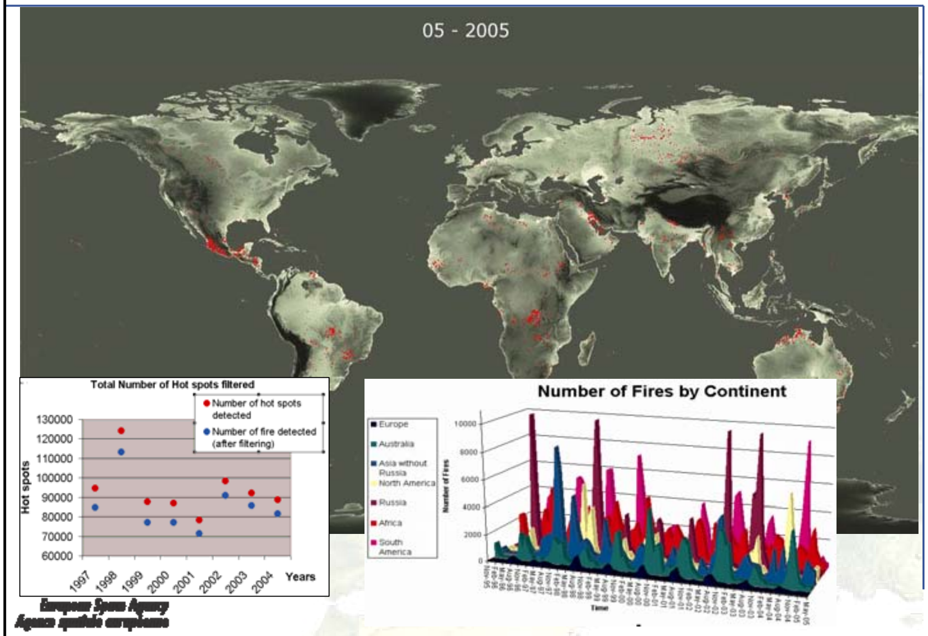
Fires Monitoring

GLOBCARBON



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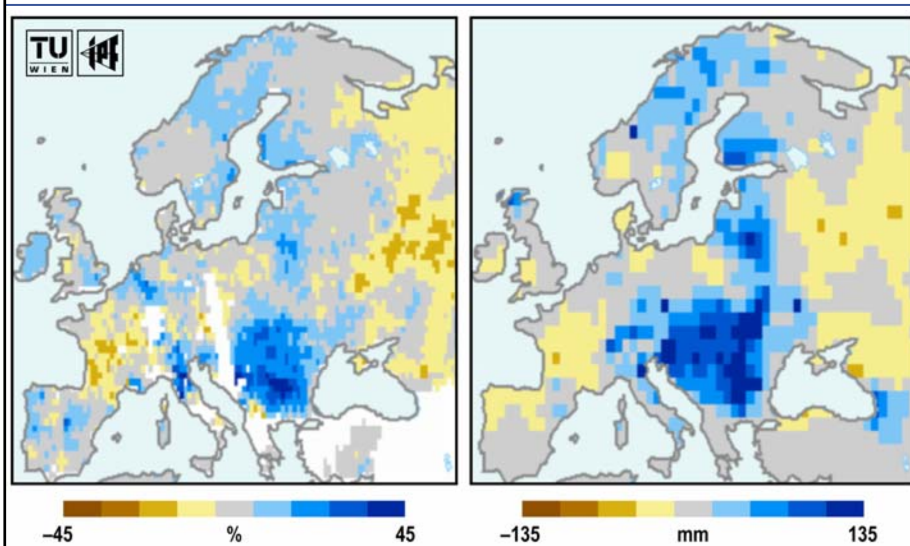
Land: Soil moisture, August 2005



Left image: Soil moisture anomaly from ERS scatterometer
Right image: Precipitation anomaly from rain gauges

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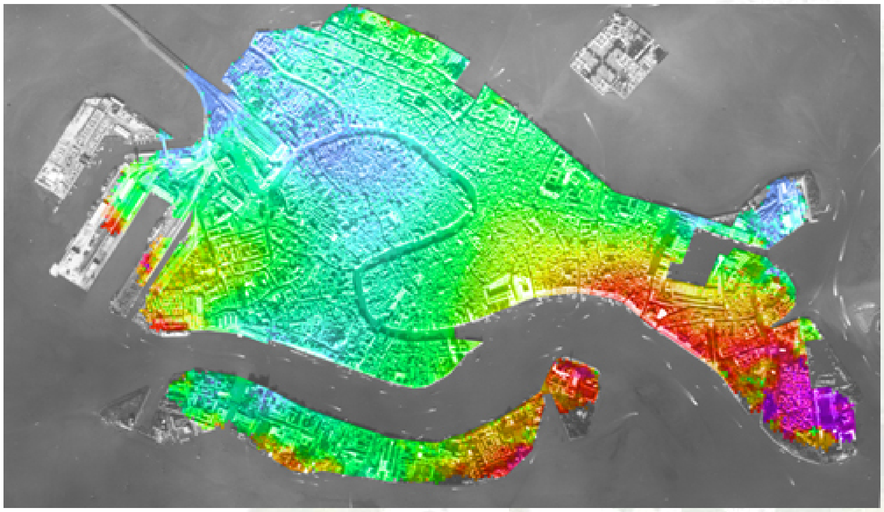
Solid Earth: Subsidence in Venice



Up to 2 mm per year in the period 1992-1996

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Science review of the EOEP

- in 2005 a committee consisting of six external scientists and six ESAC members undertook a thorough review of the scientific value of the Earth Observation Envelope Programme
- the review report was extremely positive in evaluating the science output of the EOEP
- the report contained eleven recommendations to the Agency. These are all currently being implemented.

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Summary of programme to date

• ERS-1/2, Envisat and the Earth Explorers under implementation already address a large number of scientific questions in Earth science

• a scientific review of the EOEP was undertaken in 2005, resulting in a very positive assessment of the achievements of the programme

• ESA Member States decided on the funding of the third slice of the EOEP in December 2005

• EOEP-3 contains a new budget line on science support that will allow new issues to be addressed

• the implementation of GMES pilot services is mature, and implementation of the GMES Space Component began in mid-2006

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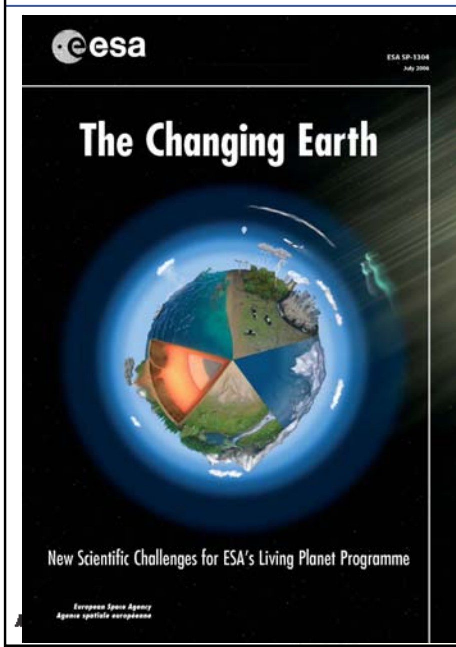
Scientific challenges for ESA's LPP



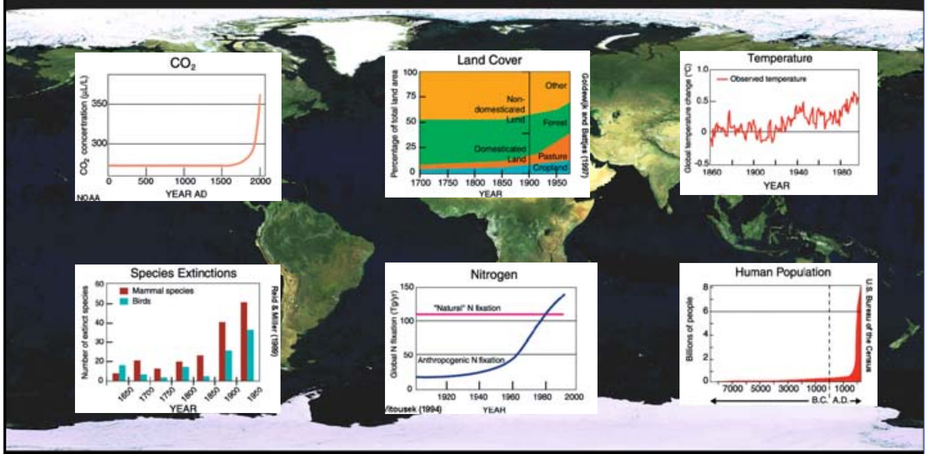
• an updated science strategy for ESA's Living Planet Programme has been formulated under the guidance of the Earth Science Advisory Committee

• a wide consultation on the strategy with the scientific community was undertaken at a workshop in February 2006

• the document addresses Earth science through the five topics: oceans, atmosphere, cryosphere, land and solid Earth and identifies the challenges for each of these

• particular emphasis is put on the Earth system approach, and on the effect of humankind on that system

Aspects of Global Change



Based on information compiled by the International Geosphere-Biosphere Programme (IGBP).

(Image: MERIS mosaic)

•Data Sources:
•Carbon Dioxide: NOAA.
•Land Cover: Goldewijk & Battjes, National Institute
•for Public Health and the Environment (RIVM),
•Netherlands, 1997.
•Temperature: Source unspecified.
•Species Extinction: Reid & Miller, World Resources
•Institute, Washington DC, 1989.
•Nitrogen: Vitousek, 1994,
•Human Population: US Bureau of the Census

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Characteristics of satellite observations

- They are **global**, enabling us to deal meaningfully with the overall properties of the system, whilst also providing observations of spatial heterogeneity.
- They are **repetitive and homogeneous**, so that time-varying phenomena can be discriminated. In many cases, long time-series are available, so that oscillations and trends can be recognised, and signatures of anthropogenic change can be distinguished from natural fluctuations.
- **Near-simultaneous** observations of many different variables can be made, allowing the state of the whole system to be diagnosed, and interrelations within the system to be identified.
- **Near-real-time** data delivery (i.e. within a few hours) can be ensured, which facilitates assimilation of satellite data into complex models of the behaviour of the Earth System.

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Ocean challenges

- Quantify the interaction between variability in **ocean dynamics, thermohaline circulation, sea level, and climate.**
- Understand physical and bio-chemical **air/sea interaction processes**.
- Understand **internal waves and the mesoscale** in the ocean, its relevance for heat and energy transport and its influence on primary productivity.
- Quantify **marine-ecosystem variability**, and its natural and anthropogenic physical, biological and geochemical forcing.
- Understand **land/ocean interactions** in terms of natural and anthropogenic forcing.
- Provide reliable model- and data-based **assessments and predictions** of the past, present and future state of the ocean.

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Atmosphere challenges

- Understand and quantify **the natural variability and the human-induced changes** in the Earth's climate system.
- Understand, model and forecast **atmospheric composition and air quality** on adequate temporal and spatial scale.
- Better quantification of the physical processes determining the **life cycle of aerosols** and their interaction with clouds.
- Observe, monitor and understand the **chemistry-dynamics coupling** of the stratospheric and upper tropospheric circulations (UTLS).
- Contribute to sustainable development through interdisciplinary research on **climate circulation patterns and extreme events.**

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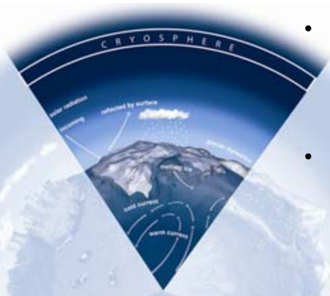
Cryosphere challenges



- Quantify **the distribution of sea-ice mass and fresh-water equivalent**, assess the sensitivity of sea ice to climate change, and understand thermodynamic and dynamic feedbacks
- Quantify the **mass balance of grounded ice sheets, ice caps and glaciers,** partition their relative contributions to global eustatic sea-level change, and understand their future sensitivity to climate change through dynamic processes.
- Understand the **role of snow and glaciers** in influencing the global water cycle and regional water resources
- Quantify the influence of **ice shelves, high-latitude river run-off and land ice melt** on global thermohaline circulation, and understand their sensitivity to future climate change.
- Quantify current changes taking place in **permafrost and frozen-ground regimes**, understand their feedback to other components of the climate system, and evaluate their sensitivity to future climate forcing.

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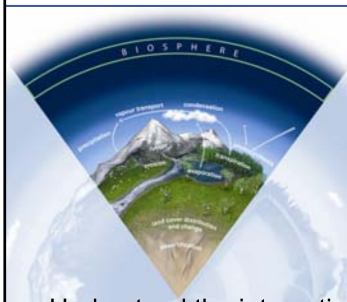
Land surface challenges



- Understand the role of terrestrial ecosystems and their interaction with other components of the Earth System for the **exchange of water, carbon and energy**, including the quantification of the ecological, atmospheric, chemical and anthropogenic processes that control these biochemical fluxes.
- Understand the interactions between **biological diversity, climate variability and key ecosystem** characteristics and processes, such as productivity, structure, nutrient cycling, water redistribution and vulnerability.
- Understand the pressure caused by **anthropogenic dynamics** on land surfaces and their impact on the functioning of terrestrial ecosystems.
- Understand the effect of land-surface status on the **terrestrial carbon cycle and its dynamics** by quantifying their control and feedback mechanisms for determining future trends.

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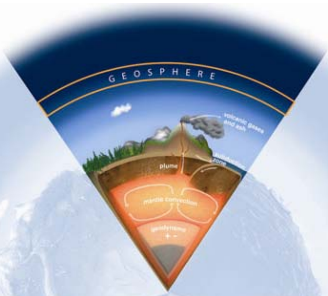
Solid Earth challenges



- Identification and quantification of physical signatures associated with **volcanic and earthquake processes** – from terrestrial and space-based observations.
- Improved knowledge of **physical properties and geodynamic processes in the deep interior**, and their relationship to Earth-surface changes.
- Improved understanding of **mass transport and mass distribution** in the other Earth System components, which will allow the separation of the individual contributions and a clearer picture of the signal due to solid-Earth processes.
- An **extended understanding of core processes** based on complementary sources of information and the impact of core processes on Earth System science.
- The role of **magnetic-field changes in affecting the distribution of ionised particles** in the atmosphere and their possible effects on climate.

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Conclusion

- The updated strategy will provide the scientific guidance for activities to be undertaken in ESA's Living Planet Programme
- Future calls for mission ideas and proposals will solicit responses that address challenges presented in the report
- The Earth Science Advisory Committee will have full visibility into how the strategy is implemented and will provide continuous guidance
- ESA will actively cooperate with its Member States and partner agencies and organisations in order to implement the strategy
- A strong scientific programme is a guarantee and prerequisite for development of new applications and operational services using space data

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