Space for Climate

Overview of ESA Earth Observation Missions & Programmes

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MREA Oct 2010, Lerici

Expanding European Observing Capability

Make the most of EO data …..

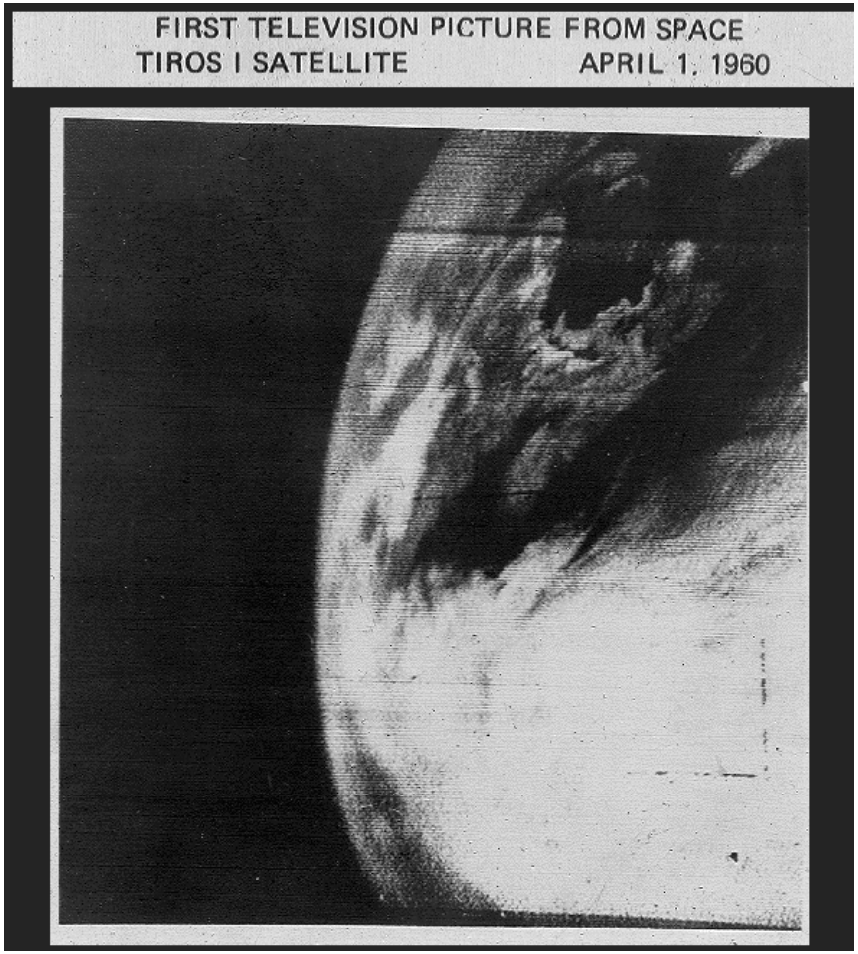
Mr. EO

Mr. Modeller

Miss. Science & Applications

"No one trusts a model except the man who wrote it;
Everyone trusts an observation except the man who made it."
Harlow Shapley

Monitoring Weather



New York Times.

CITY EDITION

NEW YORK, SATURDAY, APRIL 2, 1960. M FIVE CENTS

U.S. ORBITS WEATHER SATELLITE; IT TELEVISES EARTH AND CLOUDS; NEW ERA IN METEOROLOGY SEEN

2 CAMERAS USED

270-Pound Vehicle to Transmit Pictures for 3 Months

By RICHARD WITKIN

SENT BY SATELLITE: One of TV pictures from Tiros I

CLOUDS: White mass is cloud cover on U. S. and Canada

1,014 BILLS LEFT FOR ROCKEFELLER

Albany Weighs Effects of Legislative Session on Prestige of Leaders

By WARREN WEAVER Jr.

AREA: Same places as in TV photos, depicted on a globe

SENATE REJECTS A REFEREE CURB

Quarreling Marks Debate as Kefauver Plan Fails—Courts to Set Hearings

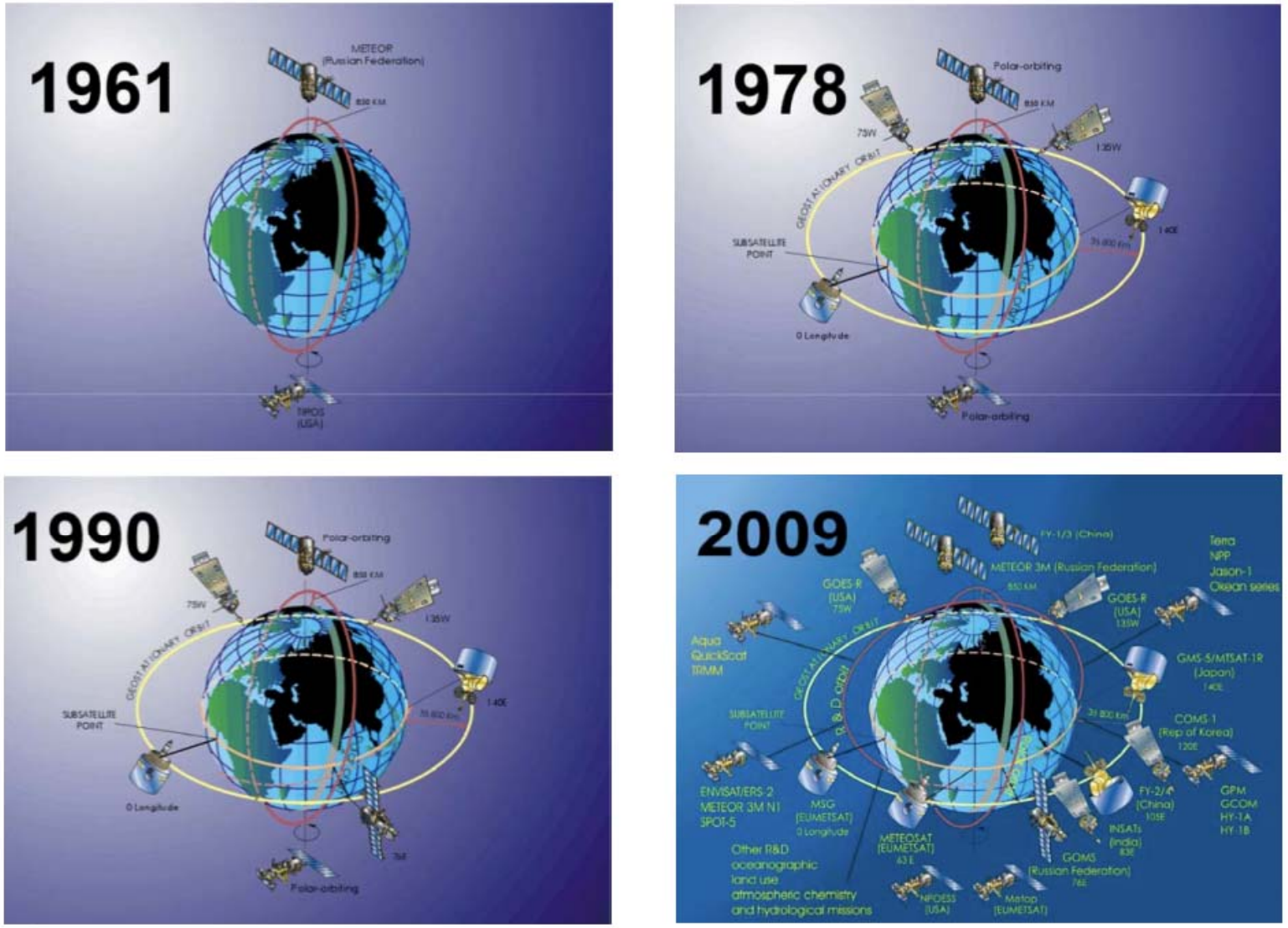
By RUSSELL BAKER

President Sees Photos

4

Courtesy: NASA

Operational Integrated Observing System for Weather



Courtesy WMP Space Office

European Space Agency
Agence spatiale européenne

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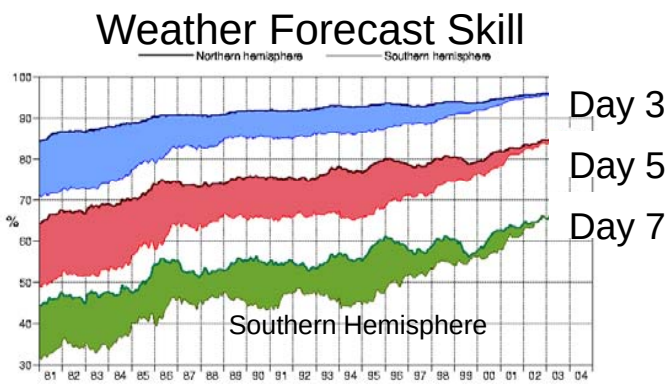
Numerical Weather Prediction (NWP)

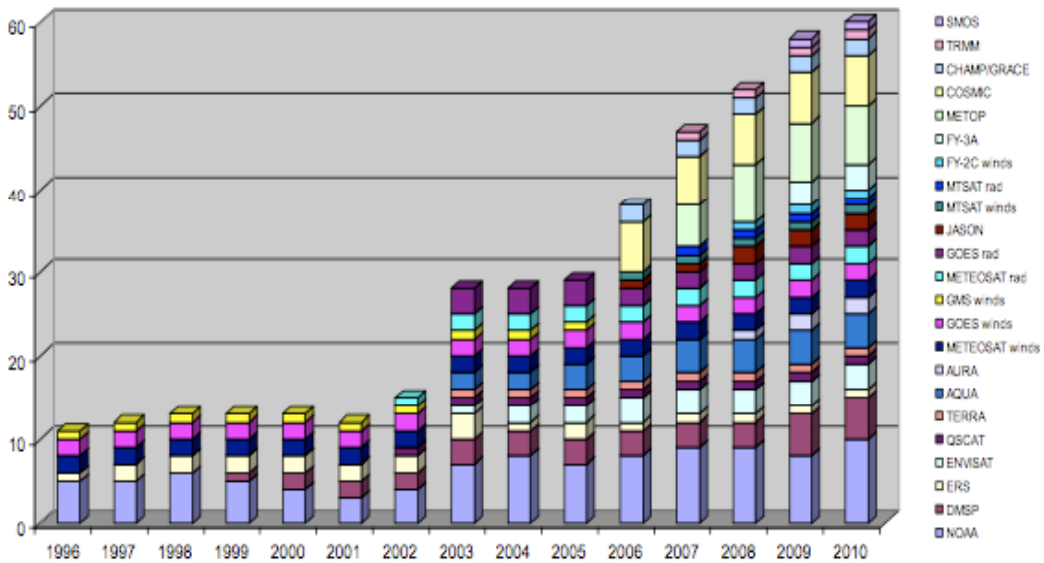


"EO is now the single most important component of the global observing system for NWP "

Jean-Noel Thepaut , Head of Data Analysis, ECMWF (European Center for Medium-Range Forecast)

8+ Millions radiance assimilated per day representing 95% of total data used! and 6% of total data screened.

Satellite observing system



Heterogeneous Data Streams

Different meaning, sampling, error

Data Assimilation

OI, Variational, Kalman handle

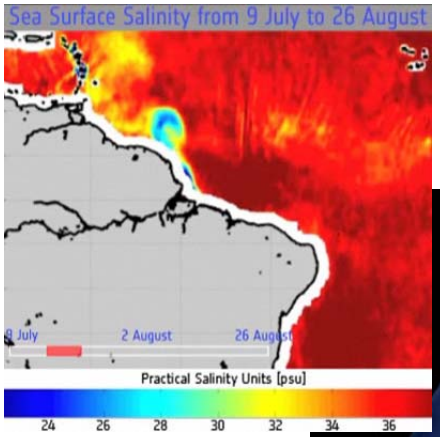
Observing Operators

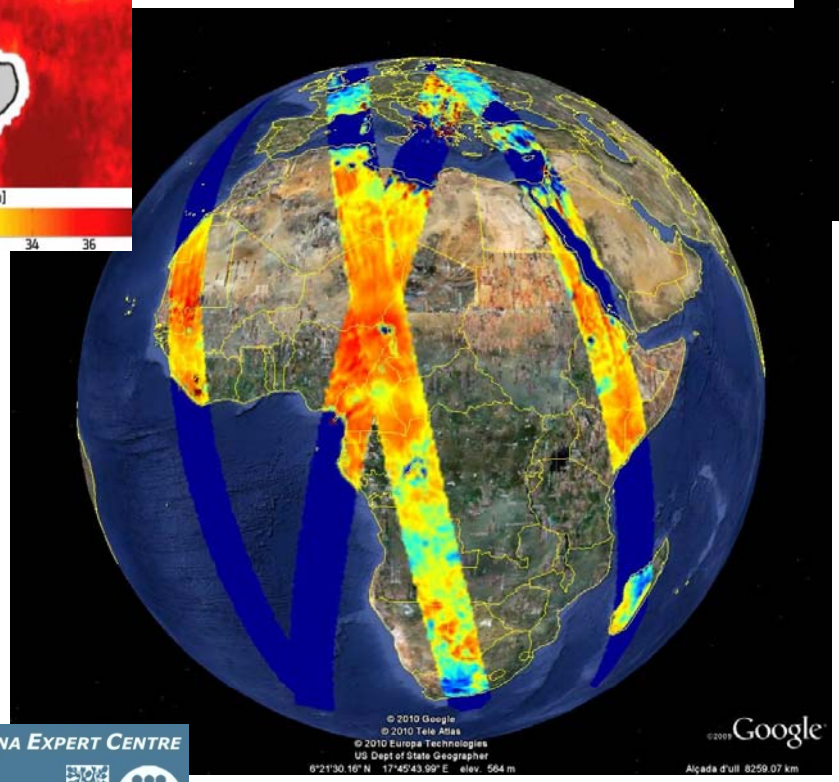
Temperature Spounding (TOVS) radiance

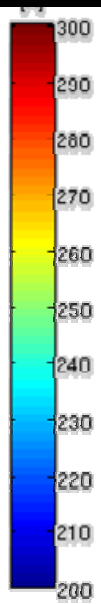
Fly the satellite into the model

Soil Moisture Ocean Salinity (SMOS)

From Brightness Temperature ……
to Soil Moisture (50km) &SSS (0.1psu?, 200km) ….







NRT exploitation of soil Moisture by Met offices (e.g.Assimilation @ ECMWF)

Watch out RFI! In L-band

Remote Sensing Laboratory UPC

Universitat Politècnica de Catalunya

SMOS Barcelona Expert Centre

Agence spatiale européenne

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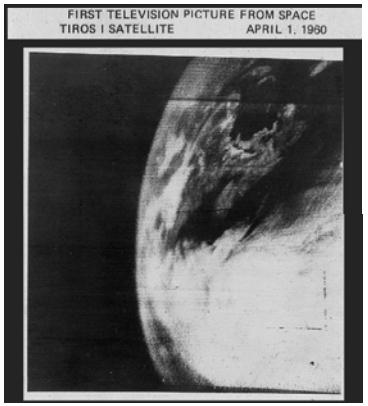
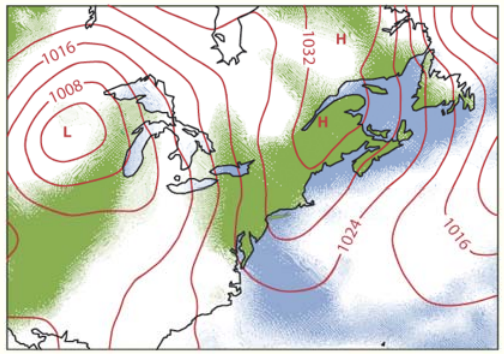
Atmospheric Reanalysis (ERA, NCEP, …)



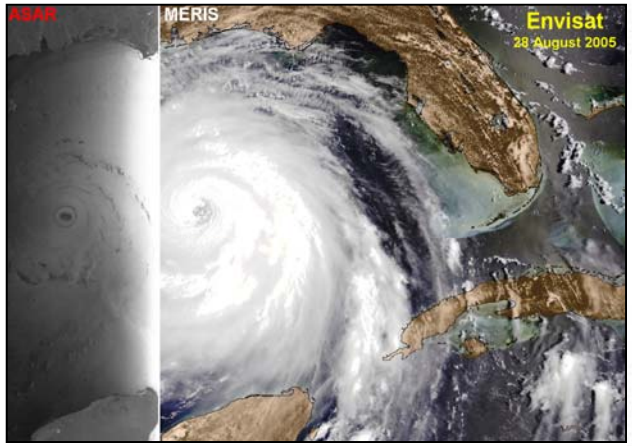


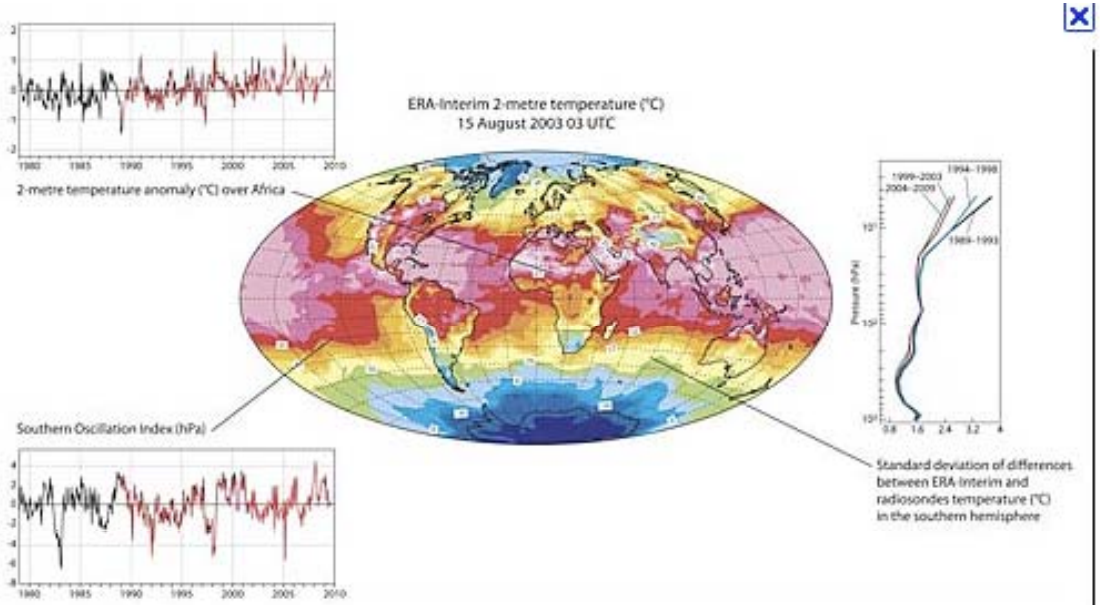
The ERA-40 product closest in time to 1608UTC on 2 April 1960, when the mis-labelled picture is now known to have been taken. The three-hour forecast of surface pressure and cloud cover valid at 1500UTC is shown

4Dvar with bias correction

Helps spotting problems

In EO data

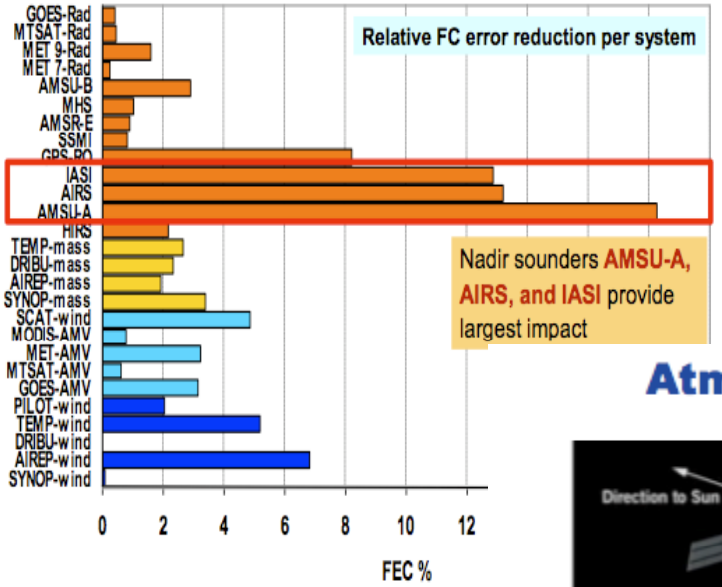




Courtesy ECMWF

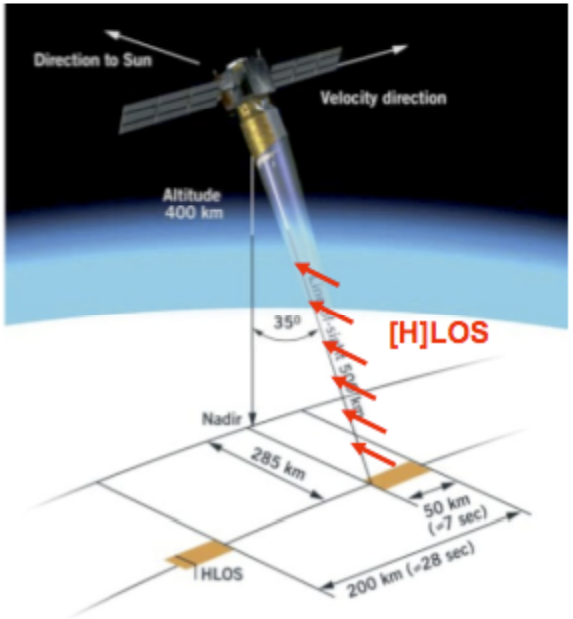
Observing System Experiments (OSEs)

Impact of various observing systems



OSSEs using synthetic data

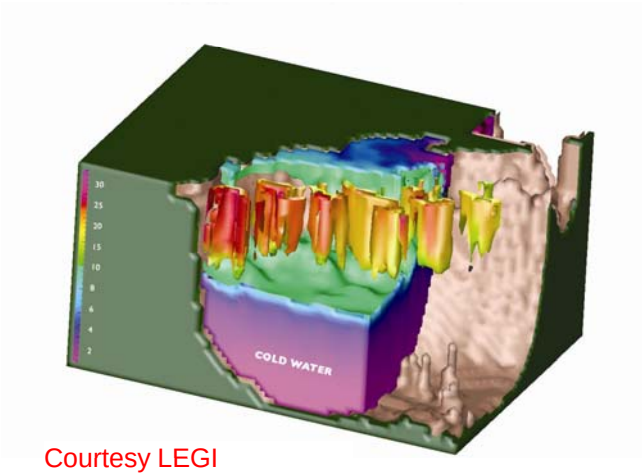
Atmospheric Dynamics Mission ADM-Aeolus



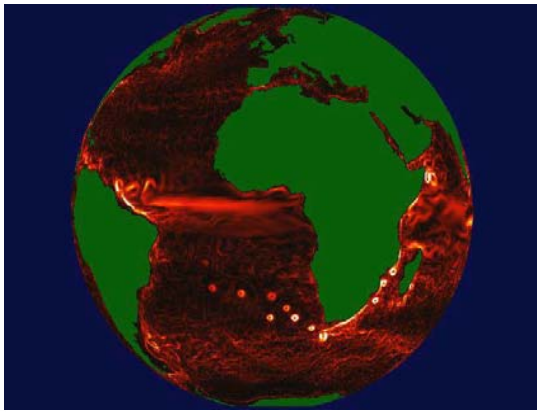
- ESA Earth Explorer
- **Doppler wind lidar** to measure line-of-sight (LOS) wind profiles in the troposphere to lower stratosphere (up to 30 km)
- **Vertical resolution** from 250 m - 2 km
- **Horizontal averages** over 50 km every 200 km
- Requirements on **random error** of horizontal LOS wind:
  - <1 m/s (z=0-2 km, for Δz=0.5 km)
  - <2 m/s (z=2-16 km, for Δz= 1 km
- **First wind lidar in space**; will also give information on aerosol/cloud optical properties.
- Launch: not before end of 2012

Courtesy Niels Bormann - ECMWF

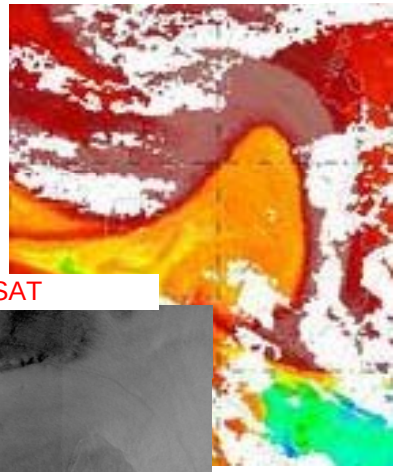
Operational Oceanography - 4D vision of the ocean



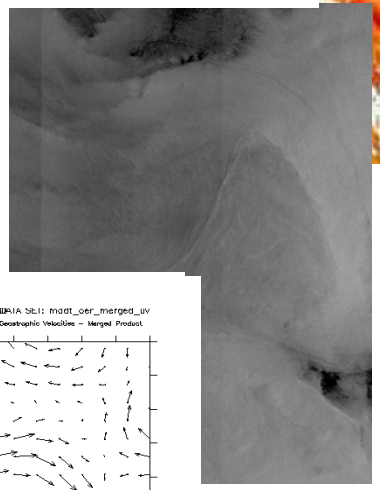
Courtesy LEGI



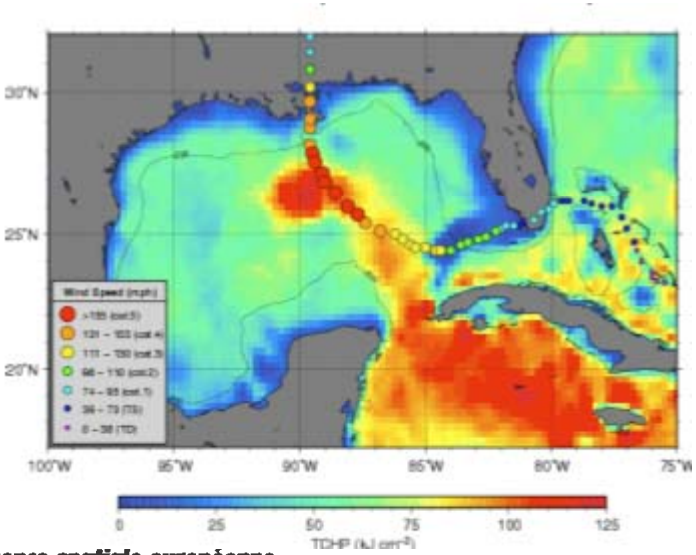
SST AVHRR



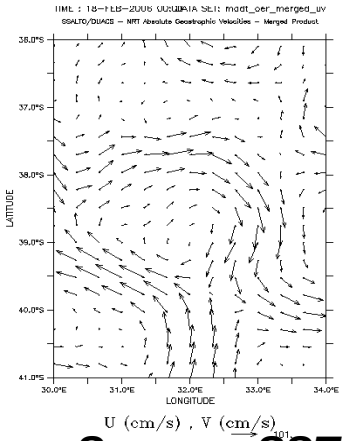
ASAR ENVISAT



Revolution of high-precision altimetry



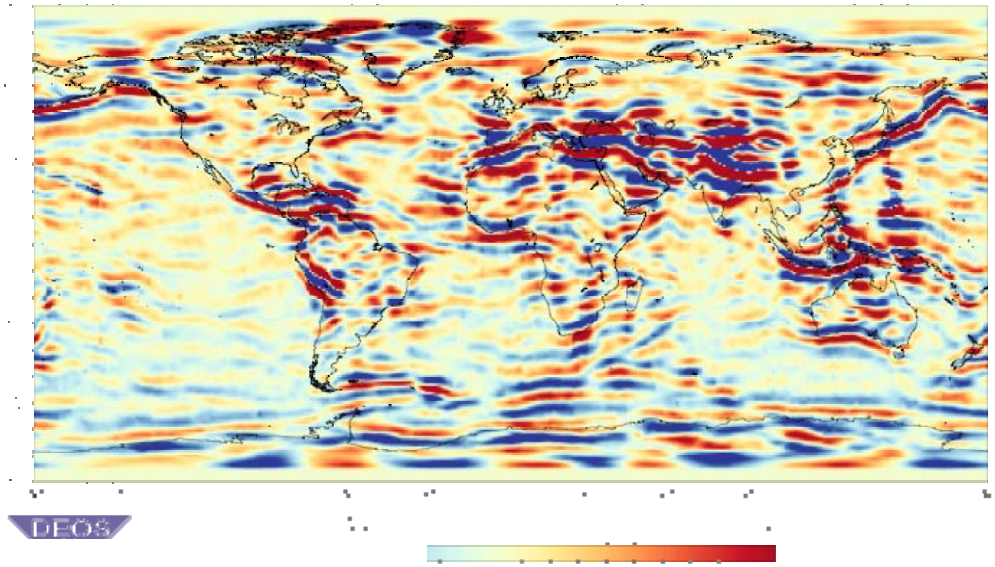
ASAR RA



Sensor Synergy SST, SSH, Ocean Colour Roughness, Wind,

Gravity Field & steady-state Ocean Circulation (GOCE)

L1b gravity gradients (e.g. Uxx)
from GOCE @ 260+km altitude since 2009
1-2cm geoid 100km resolution

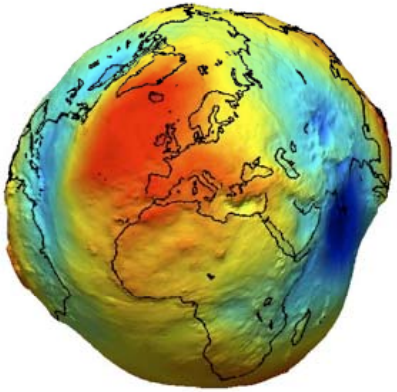


GOCE Main Objectives

global ocean circulation and transfer of heat

+ physics of the Earth's interic

+ sea level records, ice sheets and sea level change

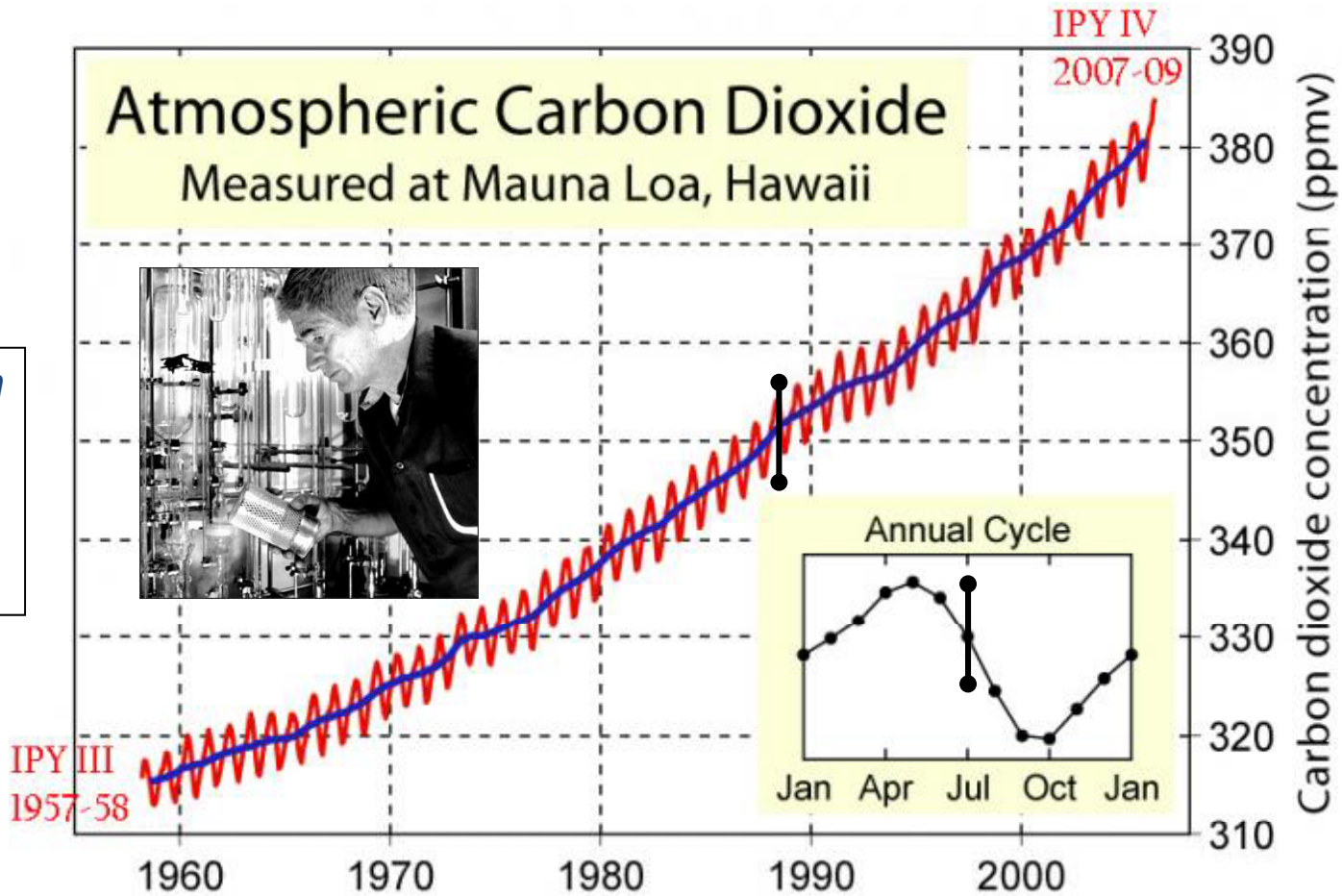


… to a global picture of the **GEOID** of unprecedented details

The Missing Link ..

Monitoring Climate

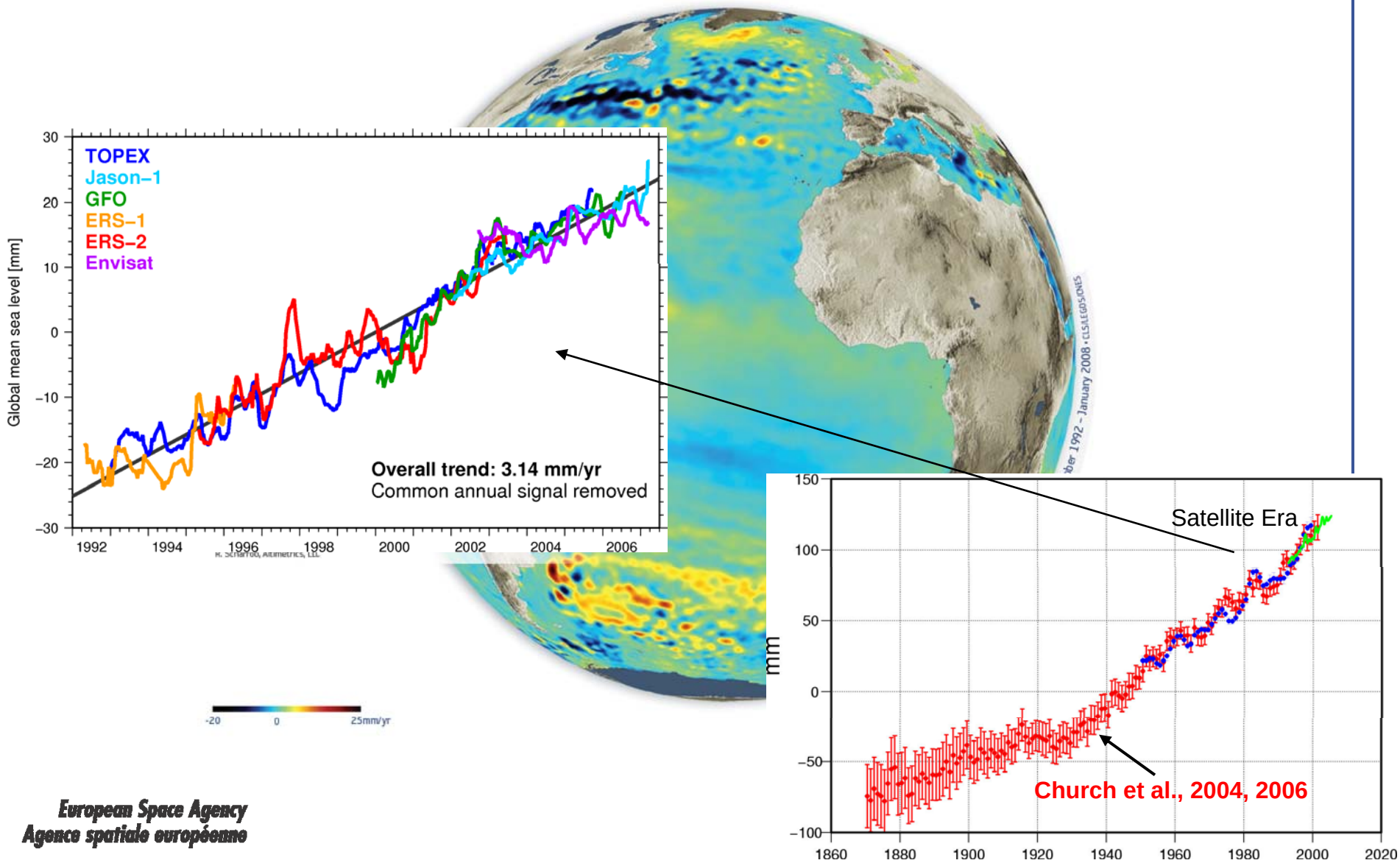
- *Long-term*
- *Global*
- *Accurate*
- *Stable*
- *Error Bar*



Suitable Sampling Frequency
To capture trends and cycles

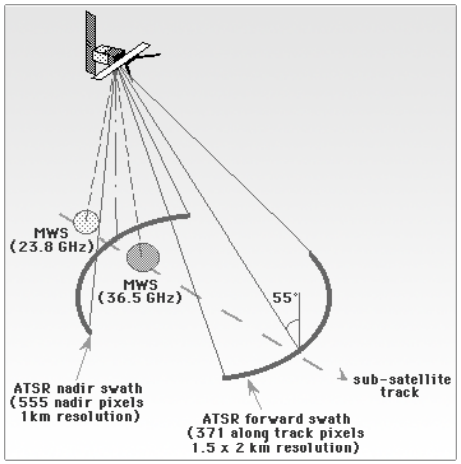
Courtesy Scripss Inst, NOAA

Vital Sign of Change: Global Mean Seal Level Rise

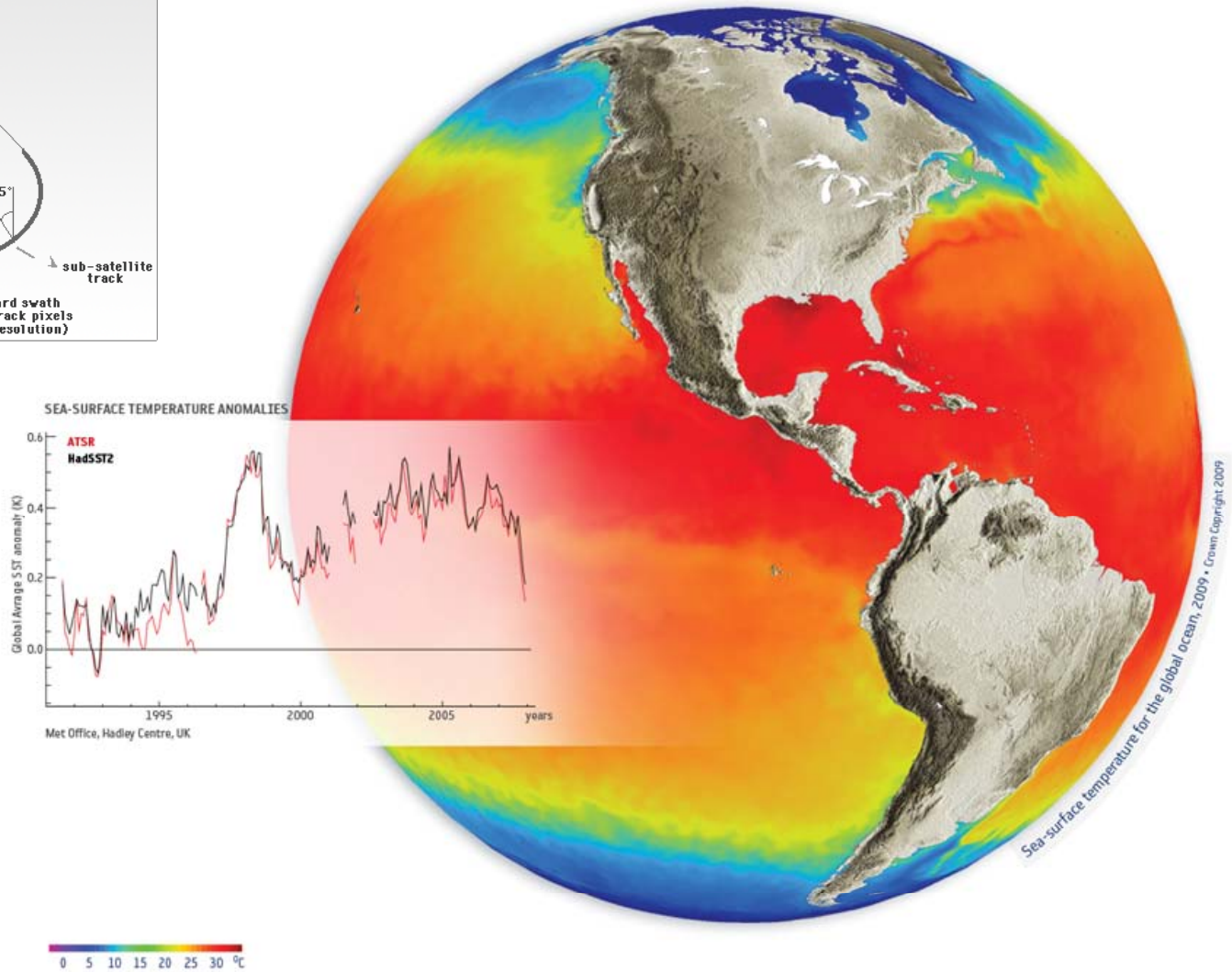


European Space Agency
Agence spatiale européenne

Vital Sign of Change: Global Ocean Warming



AATSR
High Accuracy
0.3K
Needed to
Capture
Climate Signal



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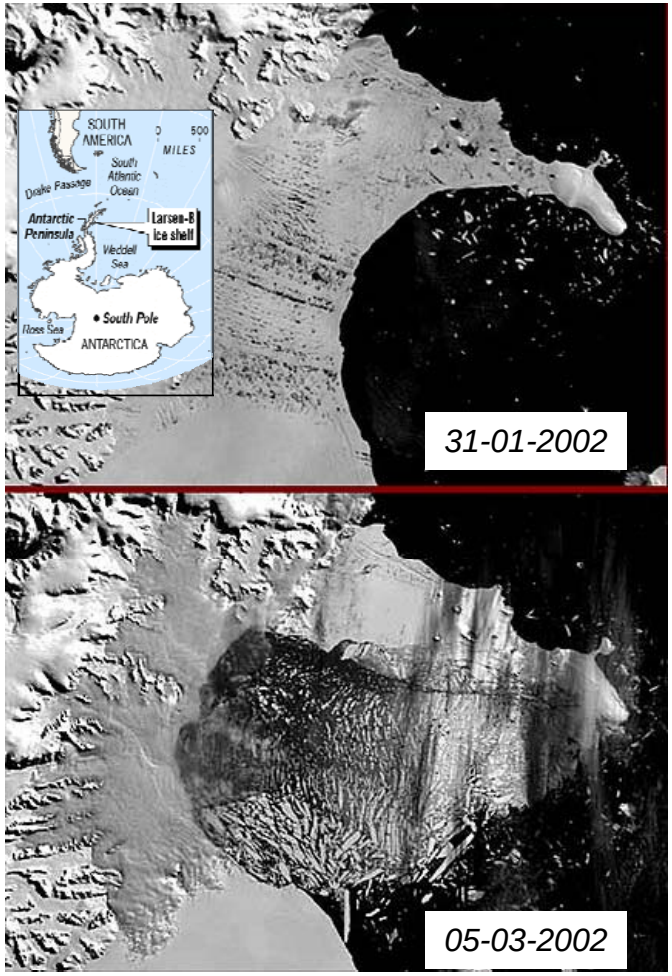
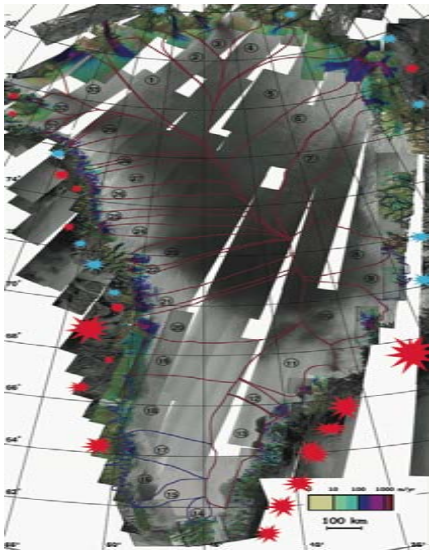
Vital Sign of Change: Ice melting on land and ocean

Collapse of Larsen B ice shelf, Antarctica



© NASA, NSDIC

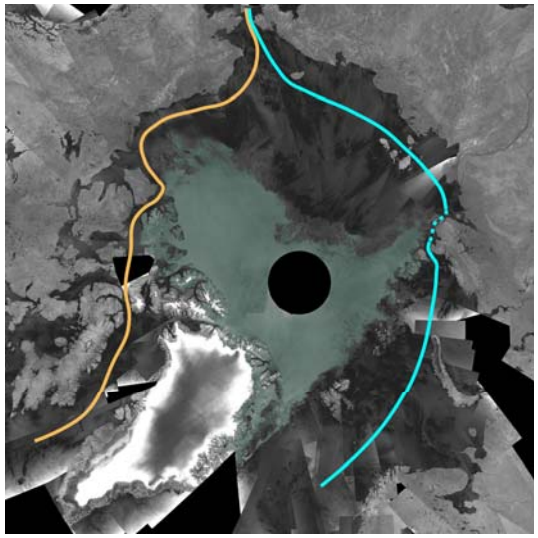
Melting of Greenland ice sheet



Courtesy
Eric Rignot, Kanagaratnam

2/3 loss due to dynamic thinning

Melting / Thinning of sea-ice



"***Greenland's contribution to sea-level rise has been doubling between 1995 and 2005***"
Eric Rignot

GCOS Requirements - Climate Vital Signs

UNFCCC (article 4.1g) has long recognised need for global obs of climate for science (IPCCC) and climate policy (adaptation & mitigation). GCOS articulates the UNFCCC information requirements (GCOS-82, 2003). 45 ECV resulting from scientific concensus, (feasible, high impact). 35 ECV with strong EO component.

Domain	Essential Climate Variables	
Atmospheric (over land, sea and ice)	**Surface:**	Air temperature, Precipitation, Air pressure, Surface radiation budget, Wind speed and direction, Water vapour.
	Upper air:	Earth radiation budget (including solar irradiance), Upper-air temperature (including MSU radiances), **Wind speed and direction**, Water vapour, **Cloud properties**
	Composition:	**Carbon dioxide, Methane, Ozone, Other long-lived greenhouse gases, Aerosol properties**
Oceanic	**Surface:**	**Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Current, Ocean colour**, Carbon dioxide partial pressure.
	Sub-surface:	Temperature, Salinity, Current, Nutrients, Carbon, Ocean tracers, Phytoplankton
Terrestrial	River discharge, Water use, Ground water**, Lake levels, Snow cover, Glaciers and ice caps**, Permafrost and seasonally-frozen ground, **Albedo, Land cover** (including vegetation type), **Fraction of absorbed photo-synthetically active radiation (FAPAR), Leaf area index (LAI), Biomass, Fire disturbance, Biomass, soil moisture**	

Drivers for Space Agencies

a global political framework

- GEOSS
  - coordinated global earth observations
  - data sharing principles
- CEOS
  - satellite component
  - virtual constellations
- GCOS
  - authoritative requirements for climate
  - climate monitoring principles

for global earth observations

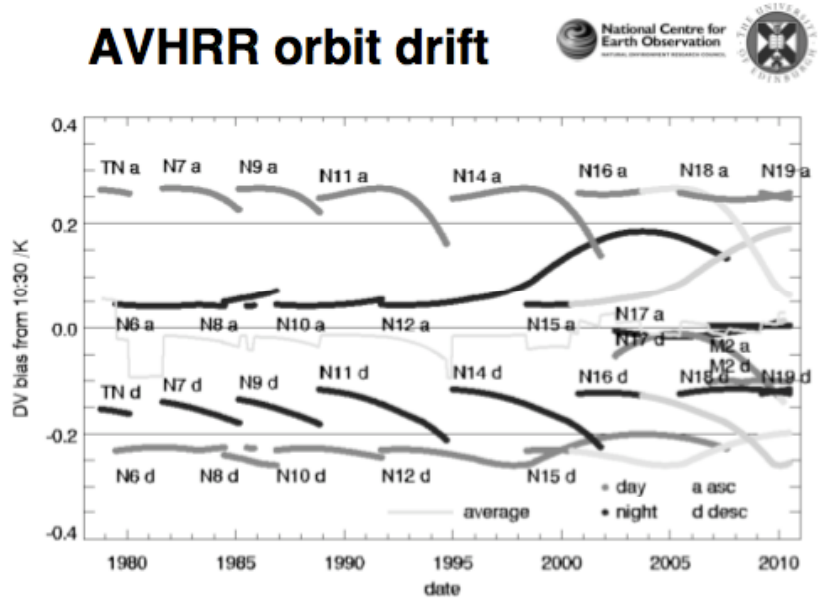
Courtesy
Mark Doherty

Inadequacies of Climate Observing System

SUB-OPTIMAL OBS SYSTEM FOR CLIM (GCOS-82)

Multi-purposes obs do not necessarily meet:

- GCOS monitoring principles (best practices)
- Stringent requirements for climate monitoring



IMPLICATIONS

- Potential Irreversible Gaps (e.g. continuity)
- Miss-out signal (e.g. too small)
- Miss-interpret signal (artifact)

GCOS Implementation Plan (GCOS-92, 2004)

NEED TO RE-PROCESS

- Context of new knowledge (algorithms)
- New data
- Better calibration

ESA CCI climate change initiative

ESA Climate Change Initiative (CCI): Objectives

The objective of Climate Change Initiative is to realize the full potential of the **long-term global Earth Observation archives** that **ESA** together with its **Member states** have established over the last thirty years, as a significant **and** timely contribution to the **ECV** databases required by **UNFCCC**.

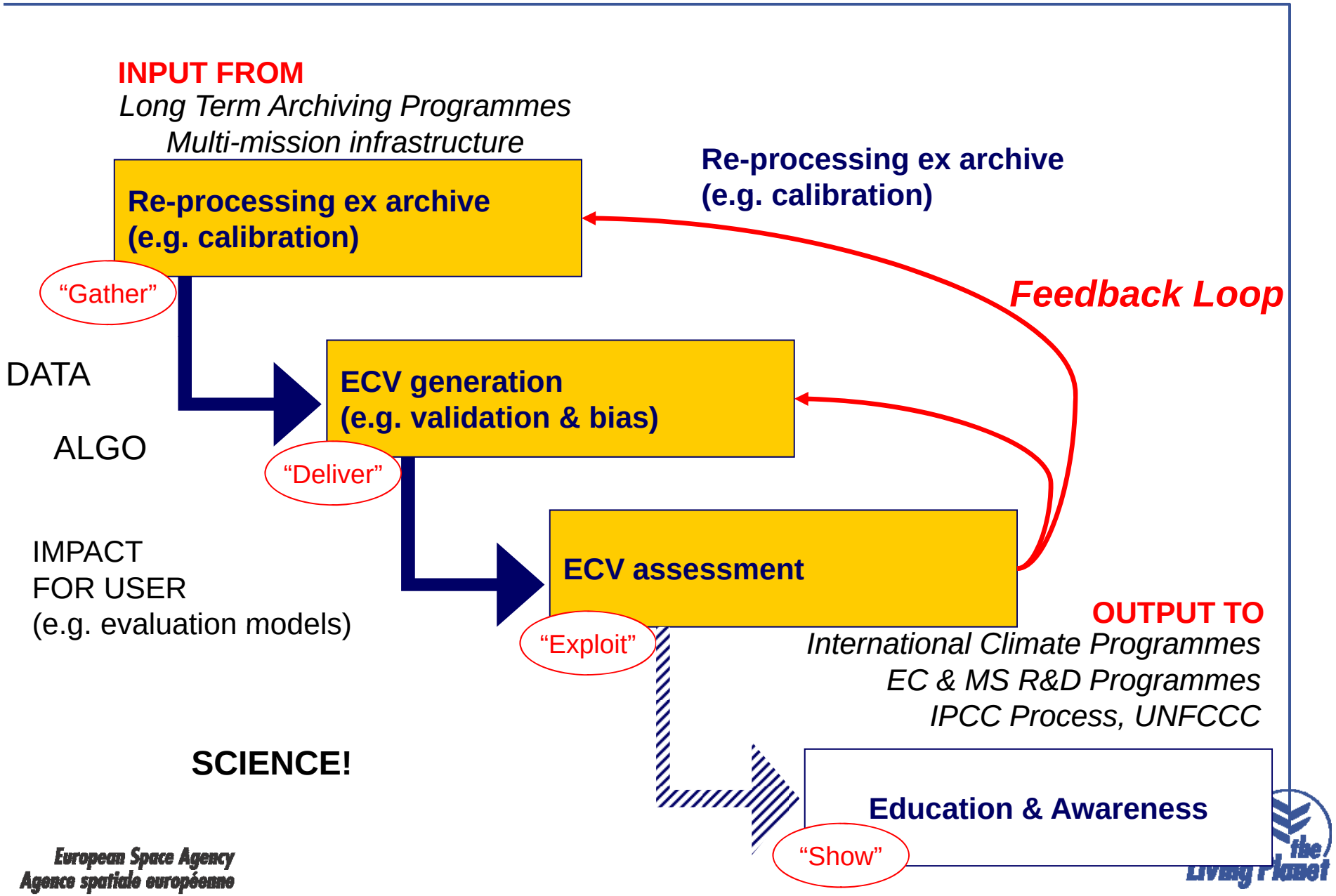
It will ensure that full capital is derived from ongoing and planned ESA missions for climate purposes, including **ERS, Envisat, the Earth Explorer** missions, relevant ESA-managed archives of **Third-Party Mission** data and, in due course, the **GMES Space Component**.

CCI Programme following Ministerial Council in 2008,

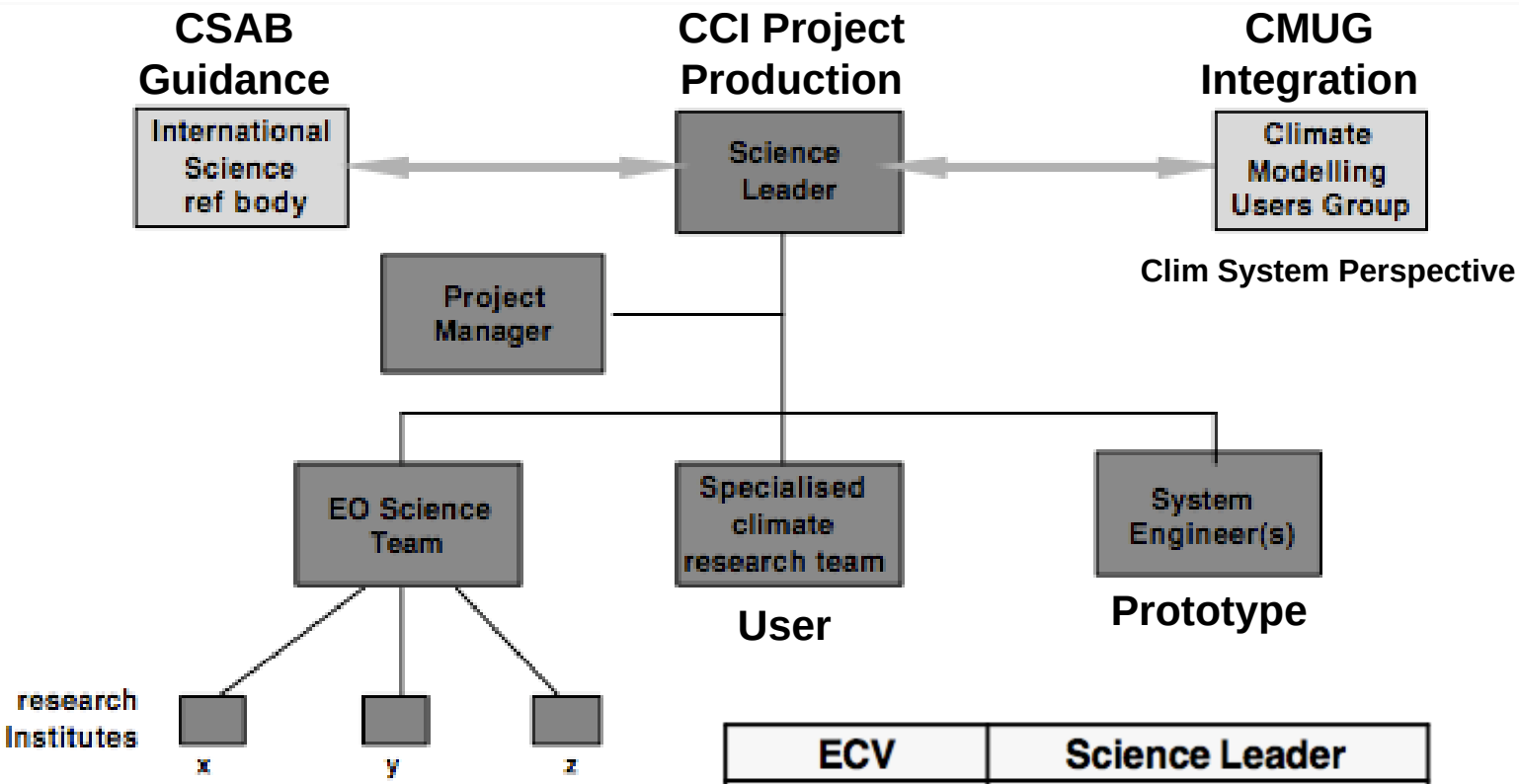
about 75MEUR over 6 years

First step focus on **11 ECVs**

CCI Steps

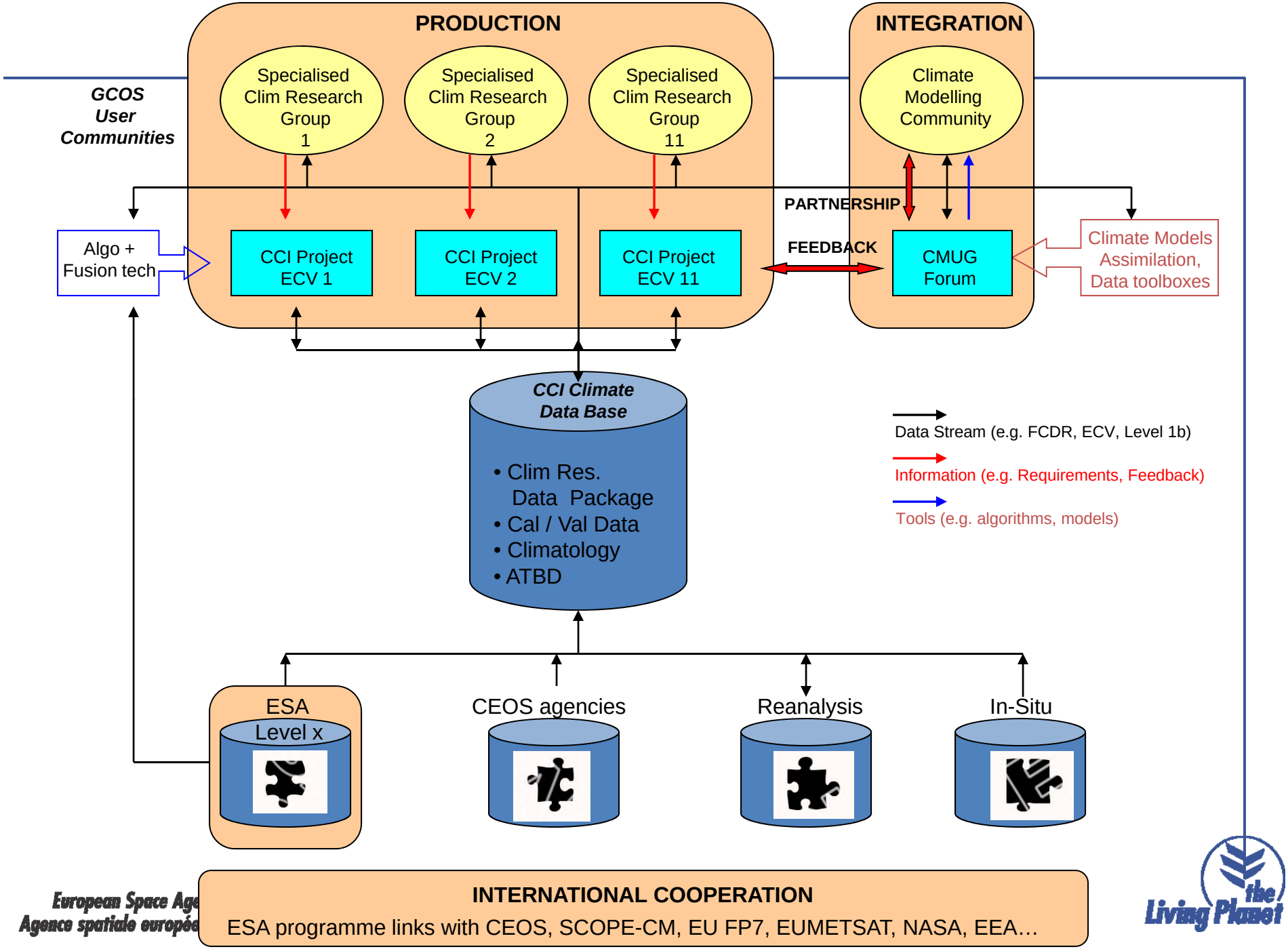

INPUT FROM
Long Term Archiving Programmes
Multi-mission infrastructure
Re-processing ex archive
(e.g. calibration)
Re-processing ex archive
(e.g. calibration)
Feedback Loop
"Gather"
DATA
ALGO
ECV generation
(e.g. validation & bias)
"Deliver"
IMPACT
FOR USER
(e.g. evaluation models)
ECV assessment
"Exploit"
OUTPUT TO
International Climate Programmes
EC & MS R&D Programmes
IPCC Process, UNFCCC
SCIENCE!
Education & Awareness
"Show"

CCI Elements of a Programme



Algo (retrieval, merging), Round Robin Validation

ECV	Science Leader
Cloud	*DWD*
Ozone	*BIRA*
Aerosol	*DLR/FMI*
GHGs	*U Bremen*
SST	*U Edinburgh*
Global Land Cover	*UCL*
Sea level	*CLS*
Ocean Colour	*PML*
Glaciers	*U. Zurich*
Fire Disturbance	*U.Alcala*


PRODUCTION
INTEGRATION
GCOS User Communities
Specialised Clim Research Group 1
Specialised Clim Research Group 2
Specialised Clim Research Group 11
Climate Modelling Community
PARTNERSHIP
FEEDBACK
Algo + Fusion tech
CCI Project ECV 1
CCI Project ECV 2
CCI Project ECV 11
CMUG Forum
Climate Models Assimilation, Data toolboxes
CCI Climate Data Base
• Clim Res. Data Package
• Cal / Val Data
• Climatology
• ATBD
Data Stream (e.g. FCDR, ECV, Level 1b)
Information (e.g. Requirements, Feedback)
Tools (e.g. algorithms, models)
ESA Level x
CEOS agencies
Reanalysis
In-Situ
INTERNATIONAL COOPERATION
ESA programme links with CEOS, SCOPE-CM, EU FP7, EUMETSAT, NASA, EEA…
European Space Age
Agence spatiale europée
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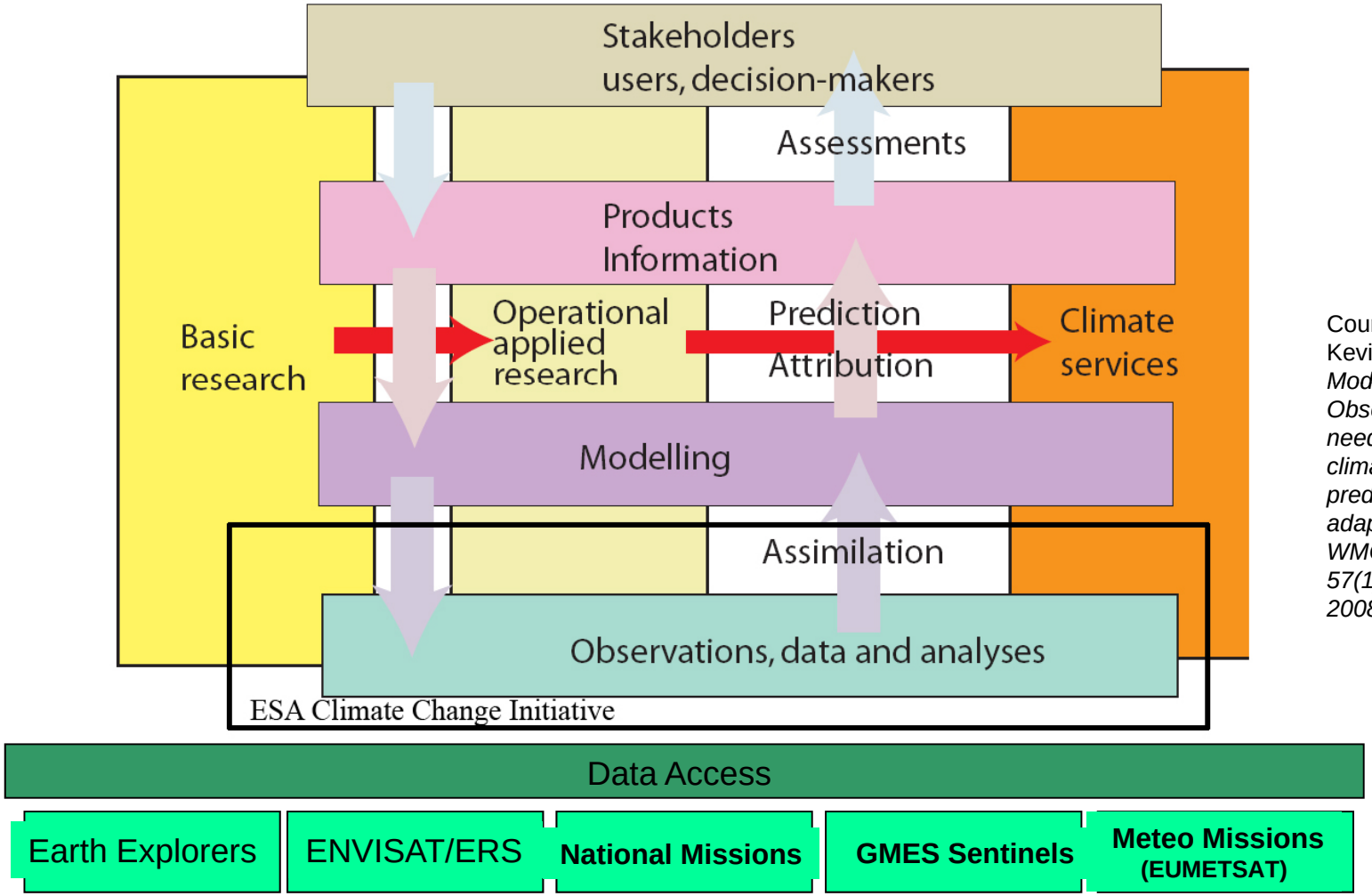
CCI Challenges - International Scientific Collaboration



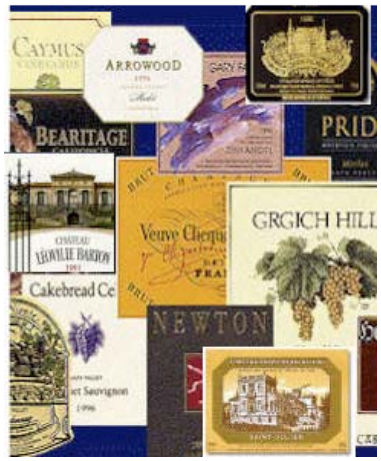
Courtesy Kevin Trenberth *Modified from Observational needs for climate prediction and adaptation, WMO Bulletin 57(1), January 2008*)

Collaboration with Climate Research Programmes, **CEOS** agencies, GEO, EC (FP7), National Programme, WMO WCC3, Met Offices,

CCI Challenges – Product Traceability & Transparency

Data Set Proliferation issue, need for D.O.I, Netcdf CF format, openDAP, e.g. CMIP5 models

Labels



Products

Tools & Format

Storage / Access

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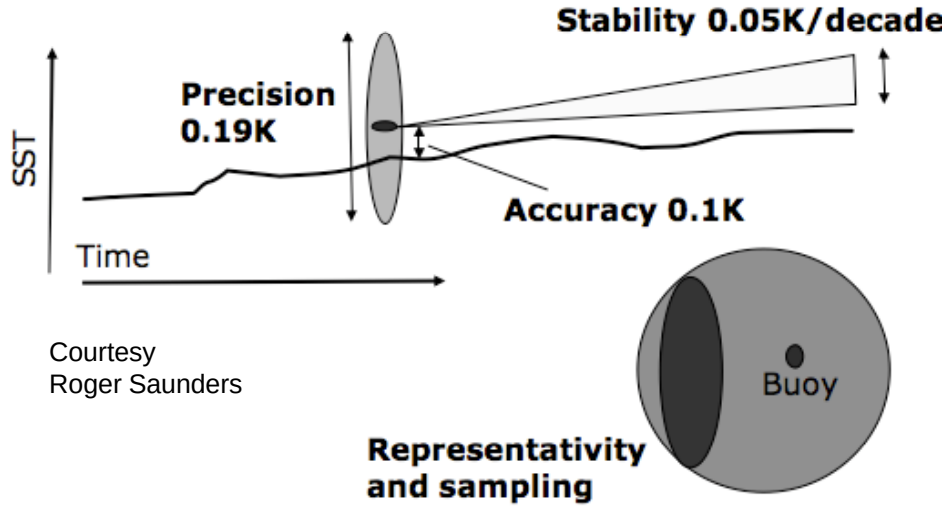
CCI Challenges - Characterisation of Errors



Courtesy
Roger Saunders

Detect – Characterise - Explain, Correct Errors …

(e.g. aliasing, diurnal sampling, correlation Cov Matrix, Ground Truth, ….)

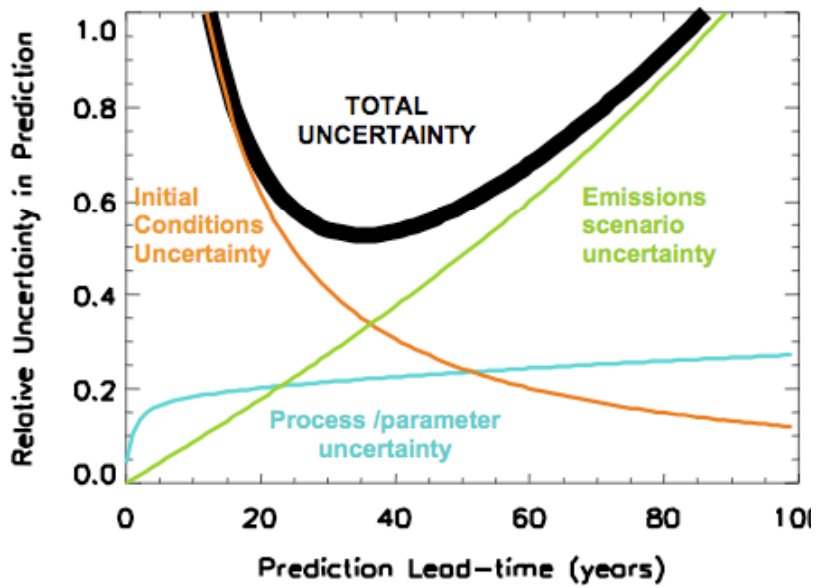
Errors associated with CDRs (from BIPM meeting)

- ***Accuracy*** is the measure of the non-random, systematic error, or bias, that defines the offset between the measured value and the true value that constitutes the SI absolute standard
- ***Precision*** is the measure of reproducibility or repeatability of the measurement without reference to an international standard so that precision is a measure of the random and not the systematic error. Suitable averaging of the random error can improve the precision of the measurement but does not establish the systematic error of the observation.
- ***Stability*** is a term often invoked with respect to long-term records when no absolute standard is available to quantitatively establish the systematic error - the bias defining the time-dependent (or instrument-dependent) difference between the observed quantity and the true value.
- ***Representativity*** is important when comparing with or assimilating in models. Measurements are typically averaged over different horizontal and vertical scales compared to model fields. If the measurements are smaller scale than the model it is important. The sampling strategy can also affect this term.

Global mean sea level trend: current error budge

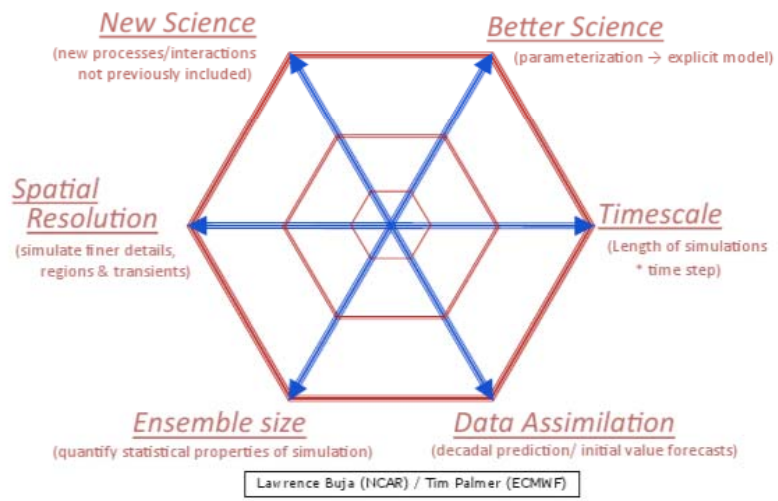
Source	Trend error (mm/yr)
Orbit (Beckley et al., 2007; Ablain et al., 2009)	0.3
Wet atmos. (radiometer drift) (Ablain et al.)	0.3
Mission bias (Ablain et al.)	0.25
Dry atmos. (pressure fields) (Ablain et al.)	0.1
Sea state bias (Ablain et al.)	0.1
Quadratic sum (1 sigma)	*~0.5*
Tide gauge calibration (Micthum and Nerem; Beckley et al.; Ablain et al.)	0.4

CCI Challenges – Confrontation with Climate Models



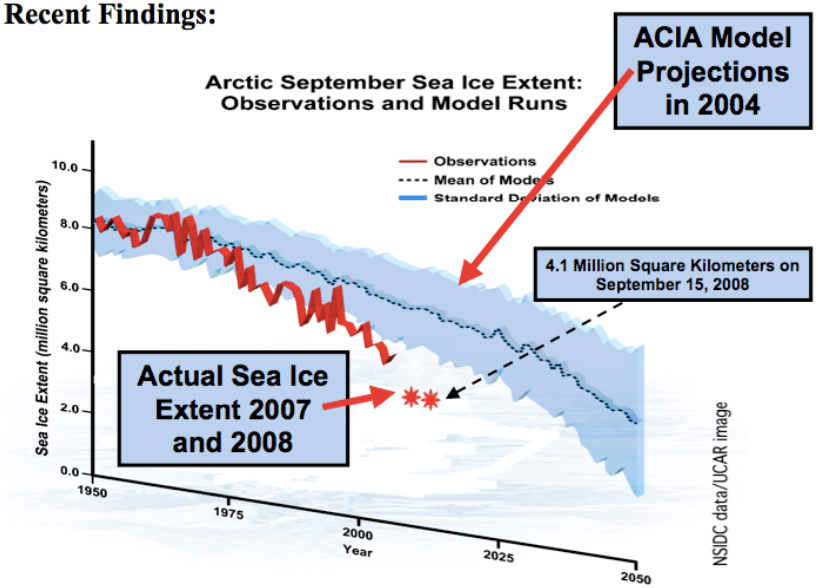
Courtesy Cox & Stephe
Science

Using more computing: and the common factor is?



Courtesy Tim Palmer, Julia Slingo, NCAR, ECMWF, Metoffice

Recent Findings:



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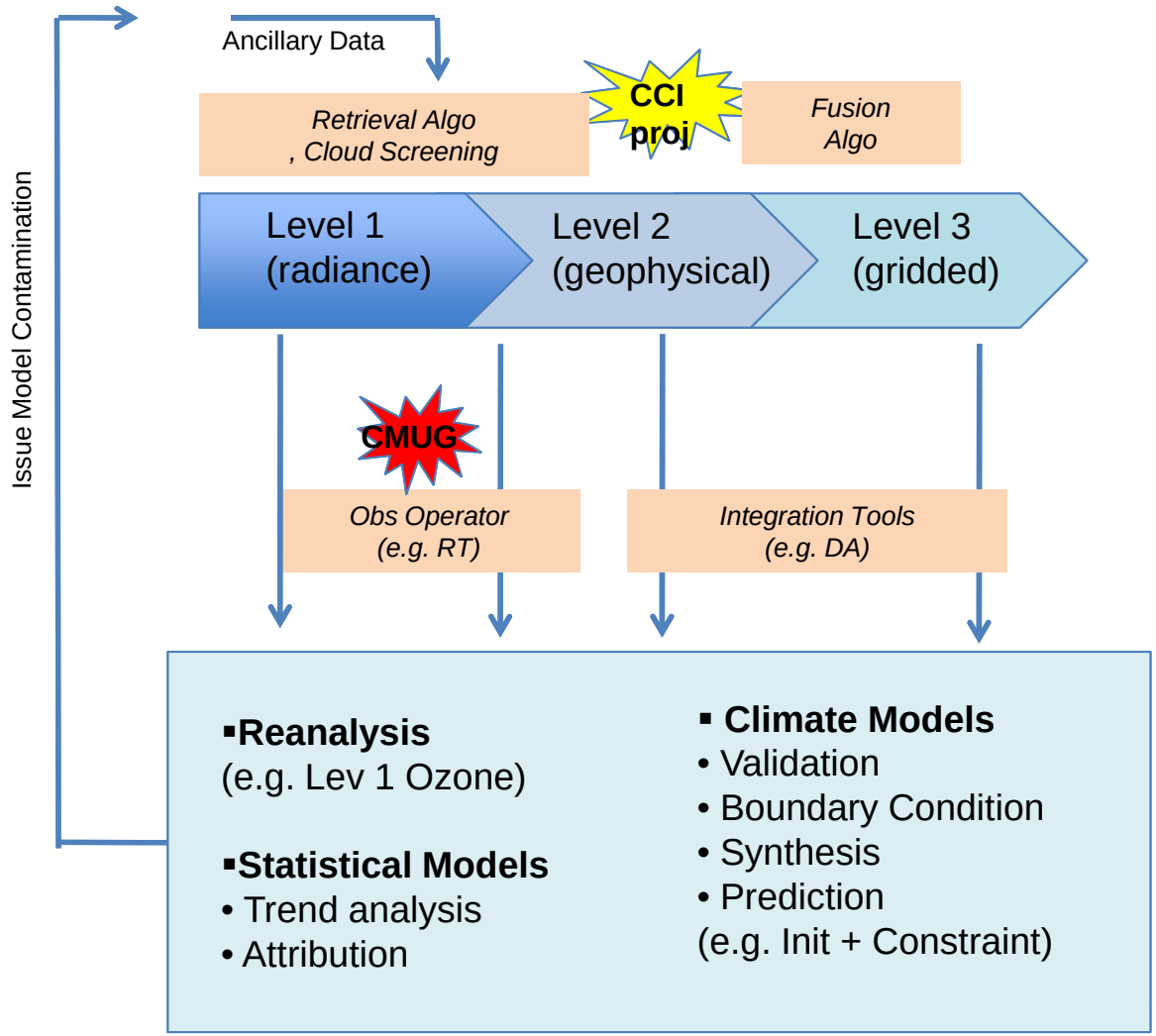
CCI Challenges – Confrontation with Climate Models

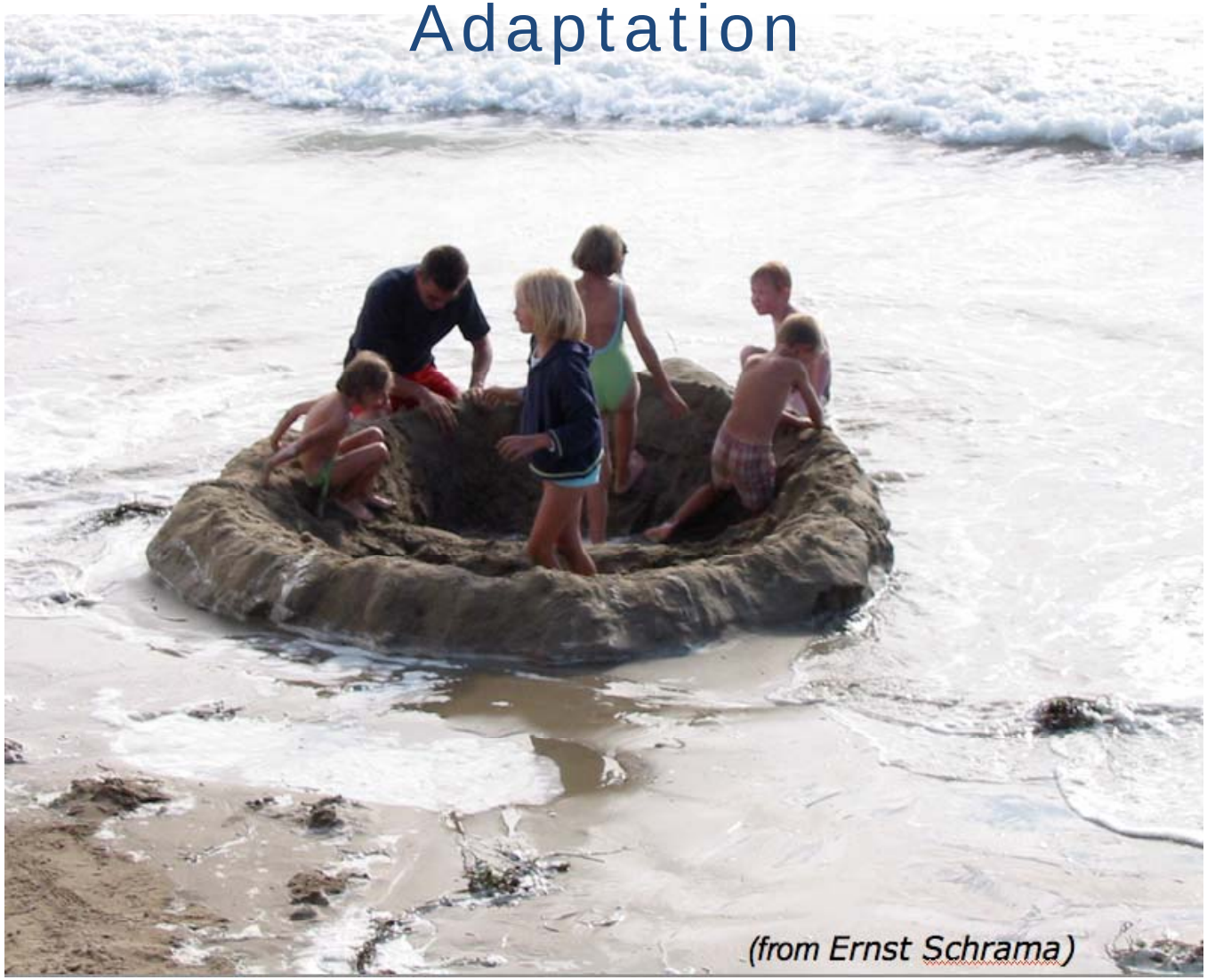


Courtesy PP Mathieu

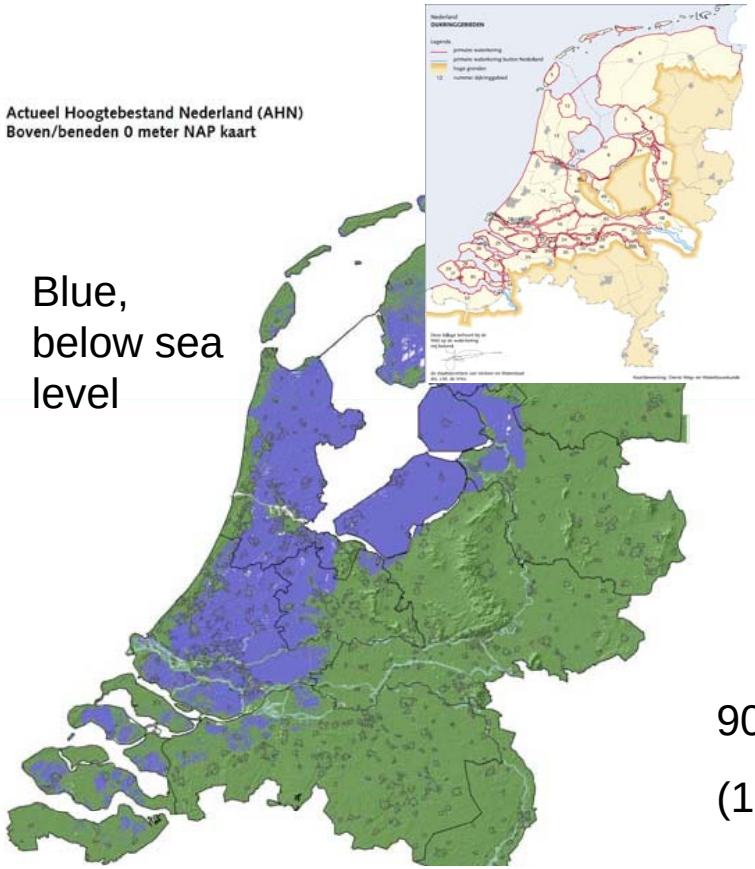
Climate Services

Adaptation

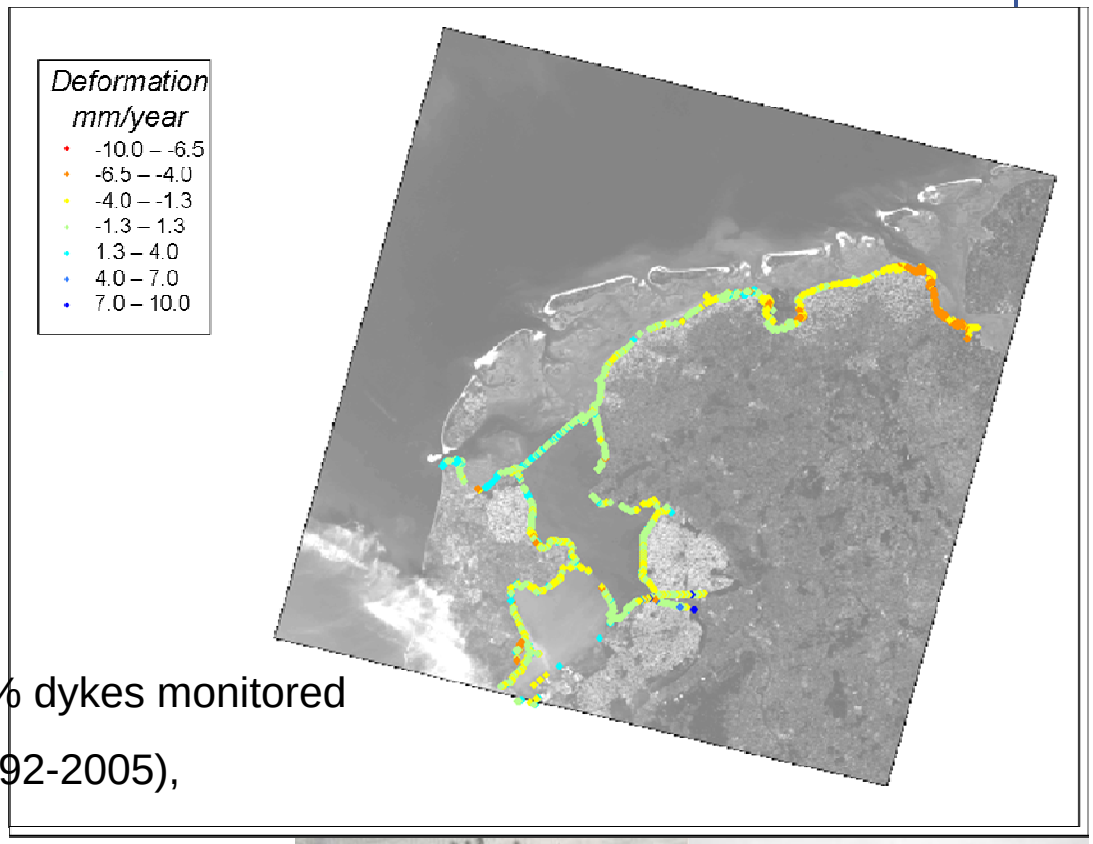
WCC-3
WMO
Global
Framework
for
Climate
Services



Monitoring Dykes, The Netherlands



Blue, below sea level

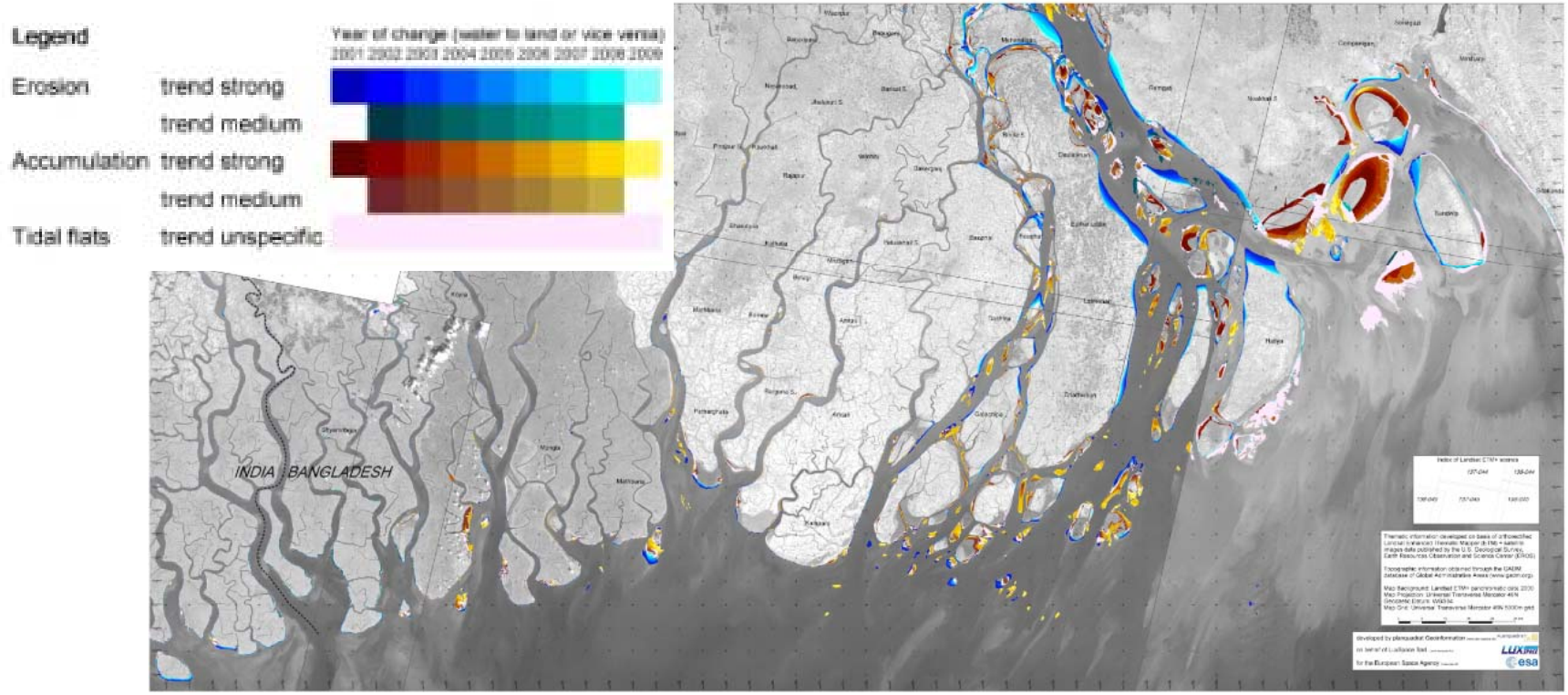


90% dykes monitored (1992-2005),

17000 km of water barriers: 3565 km primary water barriers (big rivers, sea, Ijsselmeer, Markermeer), 14000 km regional water barriers

Courtesy R. Hansen Delft Institute of Earth Observation and Space Systems

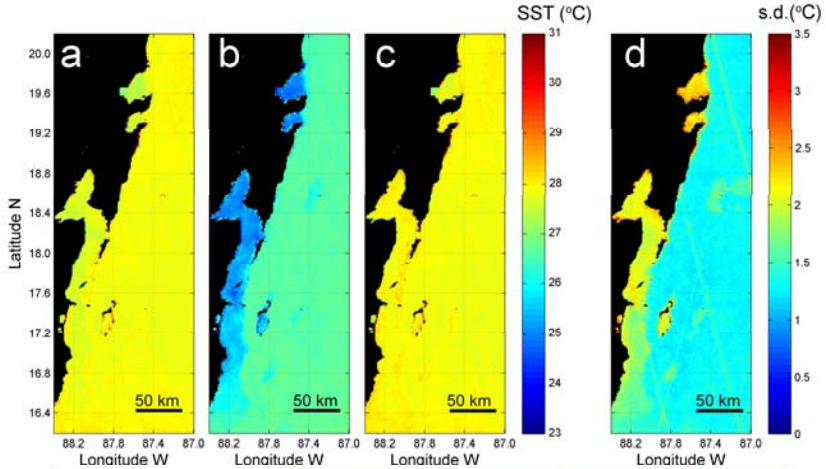
Coastal Erosion, Bangladesh



- Technically challenging (large tidal effects to de-couple)
- Project completing, preliminary results (under evaluation),
- High dynamic land loss & gain; trend towards erosion in East
- 2 separate studies, use of Landsat, SPOT, QuickBird, IKONOS

Coral reef & Community Remote Sensing

- **Health indicators :** reef extent, reef rugosity, coral and macro-algal cover, coral population structure, coral mortality, coral bleaching, coral diseases, herbivorus**,**
- **Stress indicators :** Sedimentation, pollution, coastal development, over-fishing, ocean acidification, thermal stress



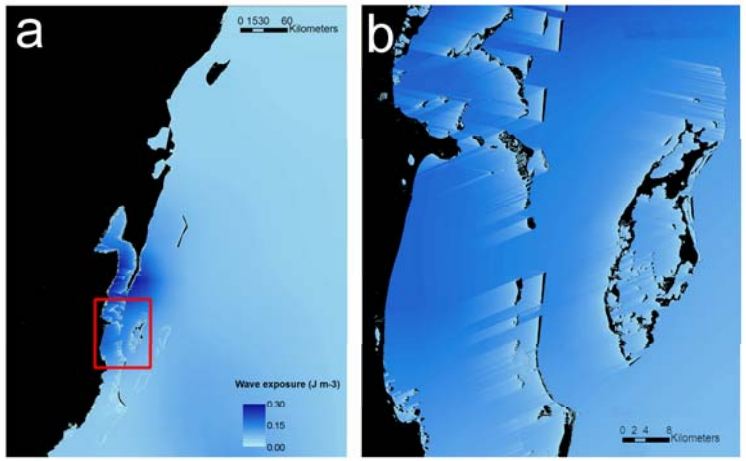
SST patterns (ATSR)

a. **Average**

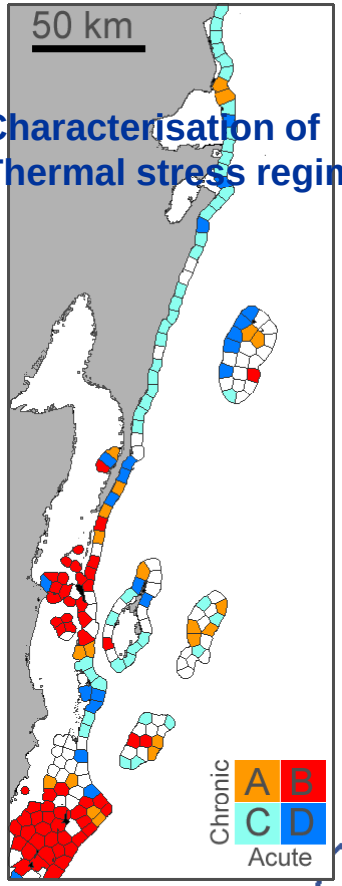
b. **Min monthly mean**

c. **Max monthly mean**

d. **Std Dev**



Wave exposure map (from shape of basin, wind-speed & direction (ERS Scatt)



Characterisation of Thermal stress regime

Courtesy Peter Mumby, Uni Exeter

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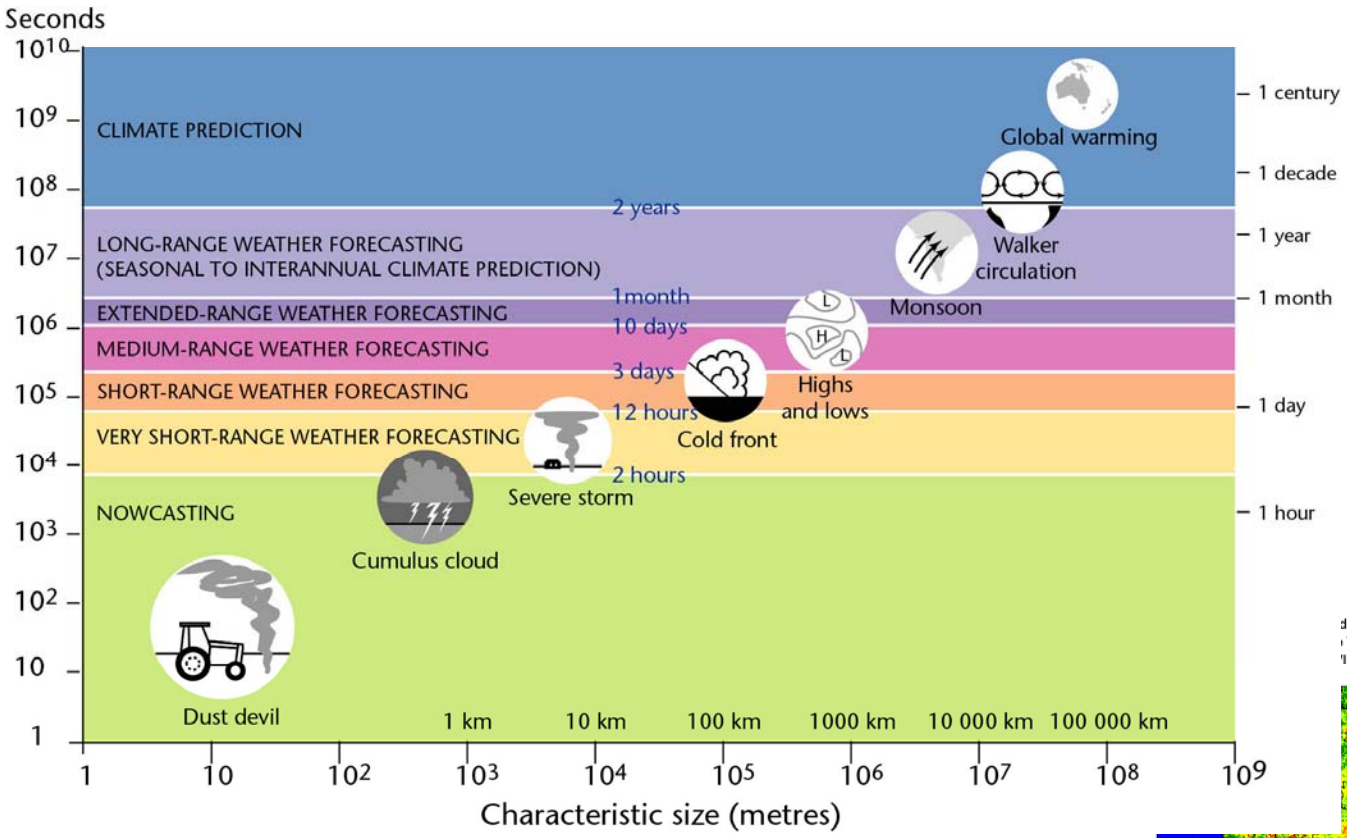
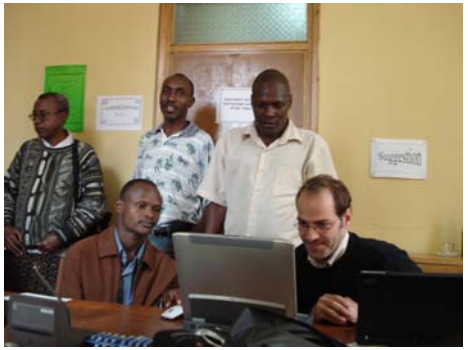
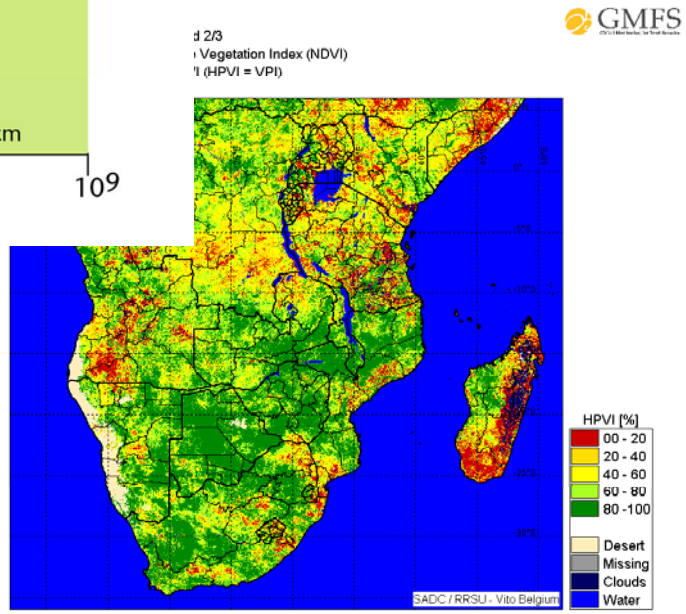
Decadal Prediction & Food Security







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Climate Services

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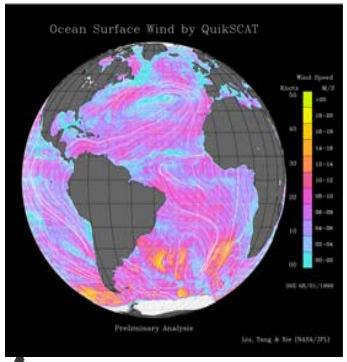
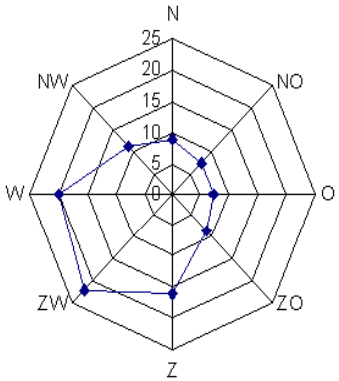
Offshore Wind Energy

High-res Regional Radar

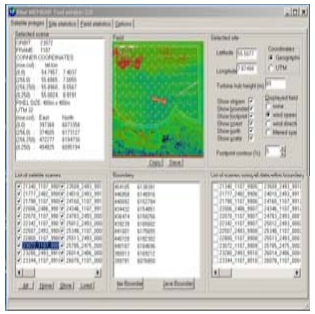
Low-res Global Scatterometer



Wind rose



Industry software



Risø DTU
National Laboratory for Sustainable Energy

Vestas

European Space Agency
Agence spatiale européenne

Courtesy RISOE

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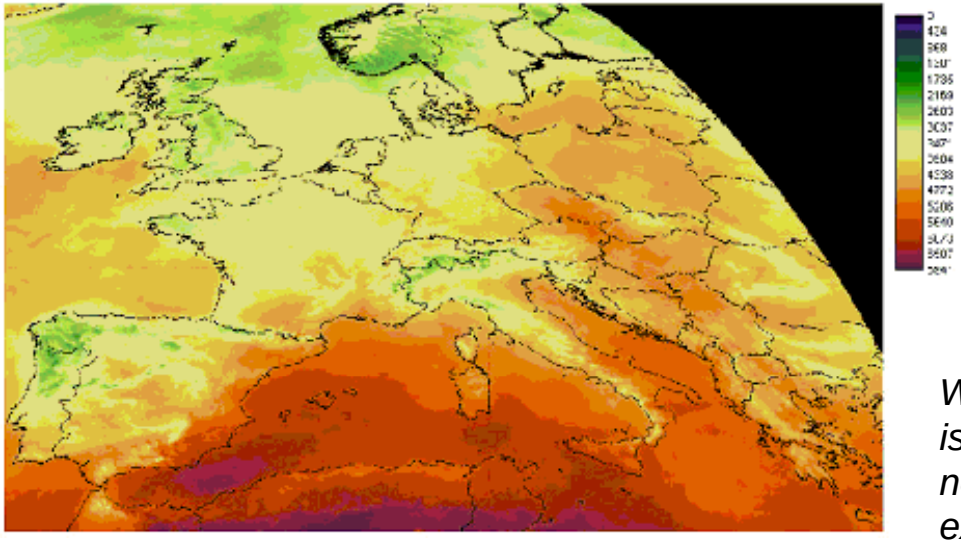
Solar Energy & the GRID



Dem Sonnenschein auf der Spur

von Ole Neugebauer

Mit Hilfe von Sunshine-Maps finden Solarunternehmen optimale Standorte, um ihre Anlagen möglichst profitabel zu machen. Die Daten dafür stammen aus dem All.

Scheint die Sonne? Ausflüglern reicht für die Antwort ein flüchtiger Blick aus dem Fenster. Will man jedoch eine Solaranlage bauen, braucht man genaue und langfristige Informationen zur Sonnenstrahlung: Deshalb vertiefen sich Ingenieure von Solarunternehmen in bunte Karten aus dem All, in so genannte Sunshine-Maps.

Hergestellt werden diese Karten vom Projekt Envisolar (Environmental Information Services for Solar Energy Industries), einem Verbund europäischer Institutionen und Unternehmen unter der Leitung des

Wo es auf der Sunshine-Map
ist es warm ur
de
nshine-
Maps. Laut ei
Unternehmen
r sich
schätzungsw

FINANCIAL TIMES
DEUTSCHLAND

Die Daten für die Sunshine-Maps kommen aus dem All: Der europäische Wettersatellit Meteosat

When a new market is opened, a site evaluation is not available, as usually other PV-operators do not publish their production values. We are now expanding into countries like Germany, Italy and Spain where we have no operation experiences. Investment costs of about 5 to 12 million Euros are planned. To assure the flow back of these investments we must be sure that we build the PV systems at locations with enough solar radiation. Therefore we will need satellite derived irradiance data.

Robert Kröni, Edisun Power AG director

Courtesy DLR, CGS

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Agence spatiale européenne

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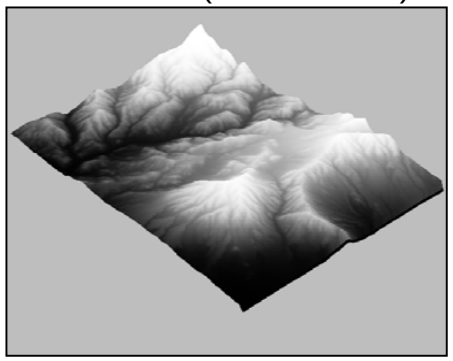
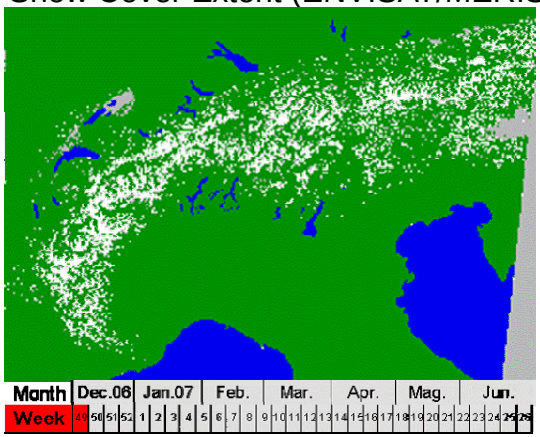
Hydropower Plants

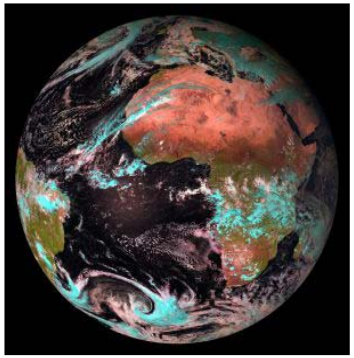
Digital Elevation Model
Land Cover (ENISAT/SAR)



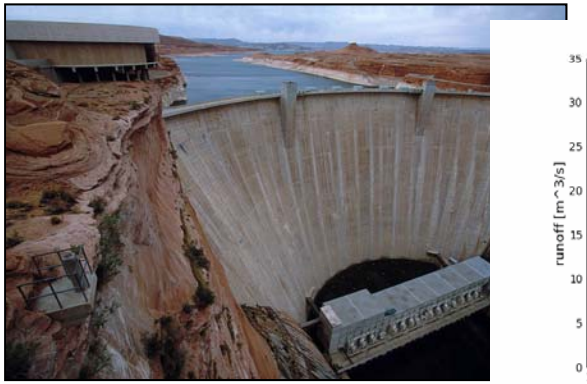
Snow Cover Extent (ENVISAT/MERIS)

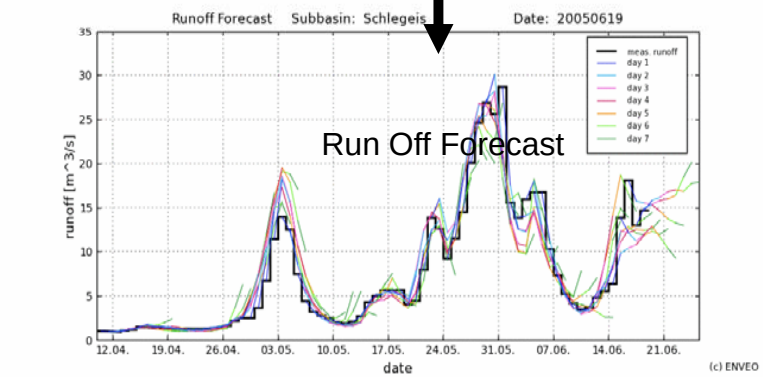


Weather Condition (MSG)



Hydrological Model





Verbund

Statkraft

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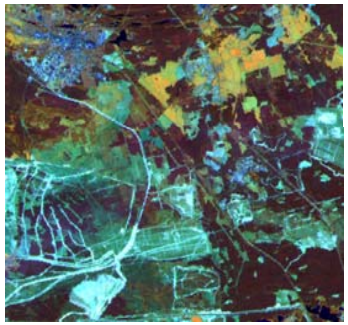
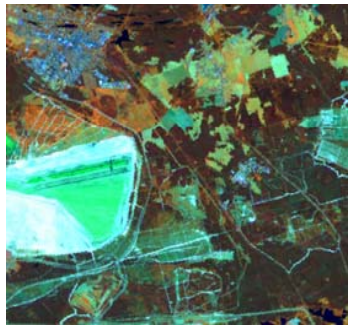
Courtesy ENVEO

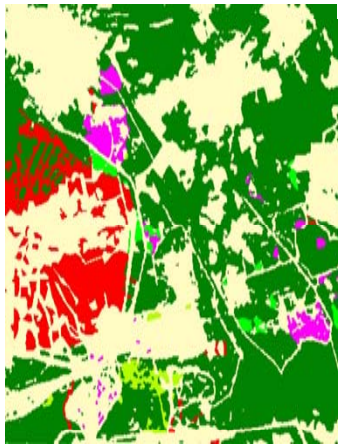
Reducing Emissions from Deforestation & Degradation

1990 (baseline)



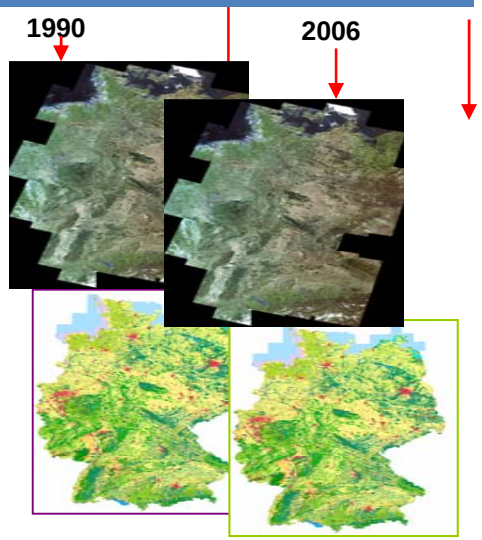
2002 (Landsat)





- Non-Forest - No Change
- Forest - No Change
- Forest 2002 - Settlement/Mine 1989
- Forest 2002 - Grassland 1989
- Forest 2002 - Cropland 1989
- Forest 1989 - Settlement/Mine 2002
- Forest 1989 - Grassland 2002
- Forest 1989 - Cropland 2002
- Forest 1989 - Water 2002

Standardised High Resolution EO Products

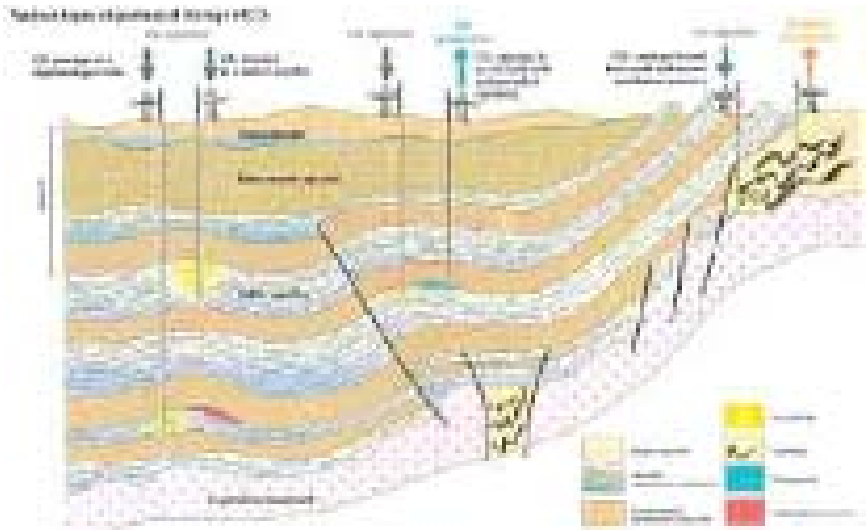


GMES Forestry service in Europe (e.g. change detetction)

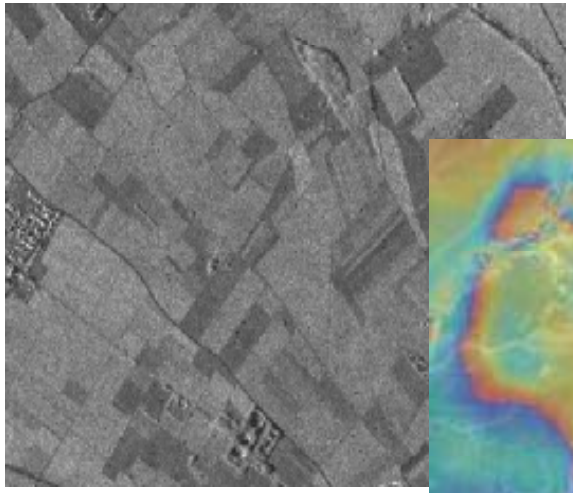
and also

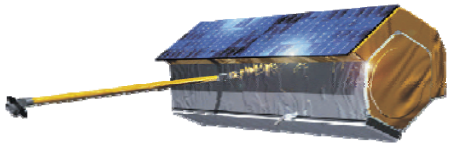
REDD pilot projects , Cameroon (member State of COMIFAC (Central African Forestry Commission)

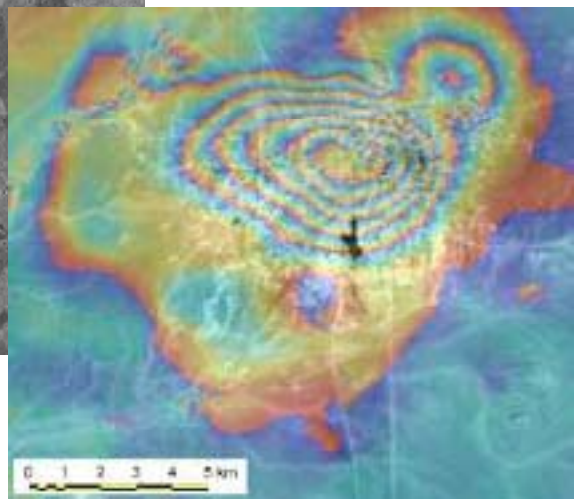
Carbon Capture & Storage (CCS)

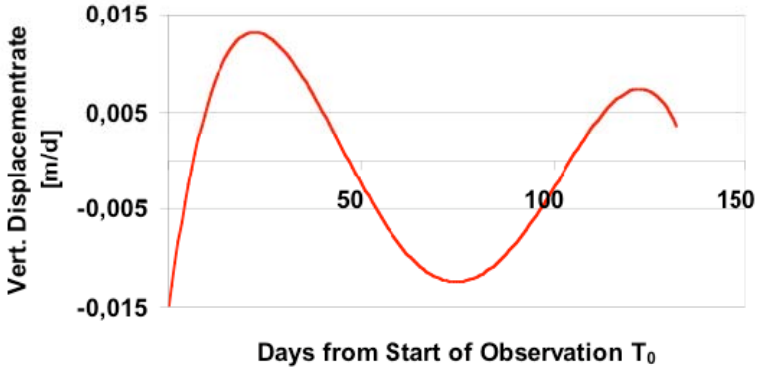


- Demonstrate potential of high-res SAR Interferometry for storage site motion monitoring in compliance with EU directive for CCS operation,
- Service trial in progress for gas storage site in Central Europe with a major O&G company and industry standards organisation.









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an EADS Astrium company

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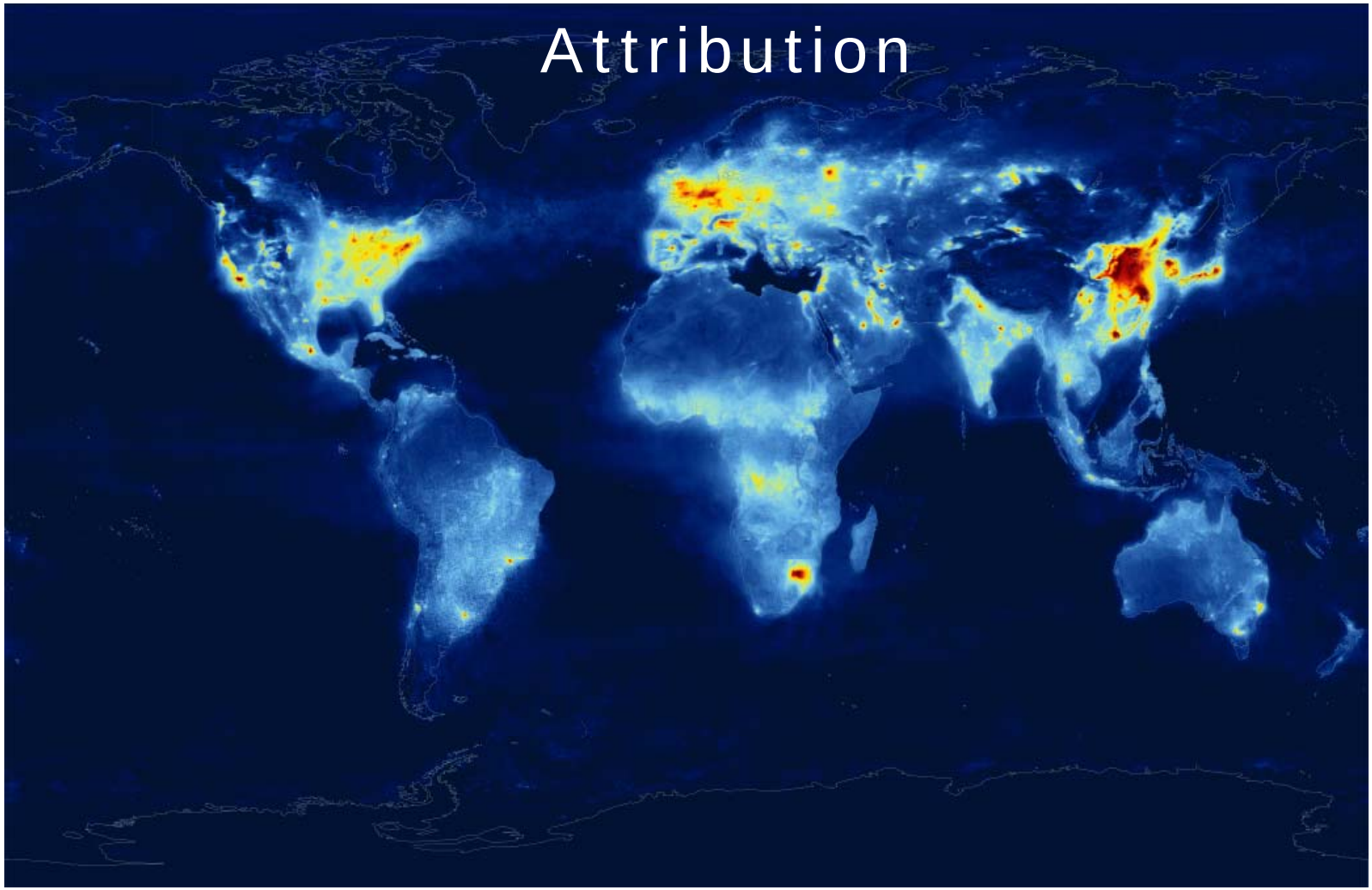
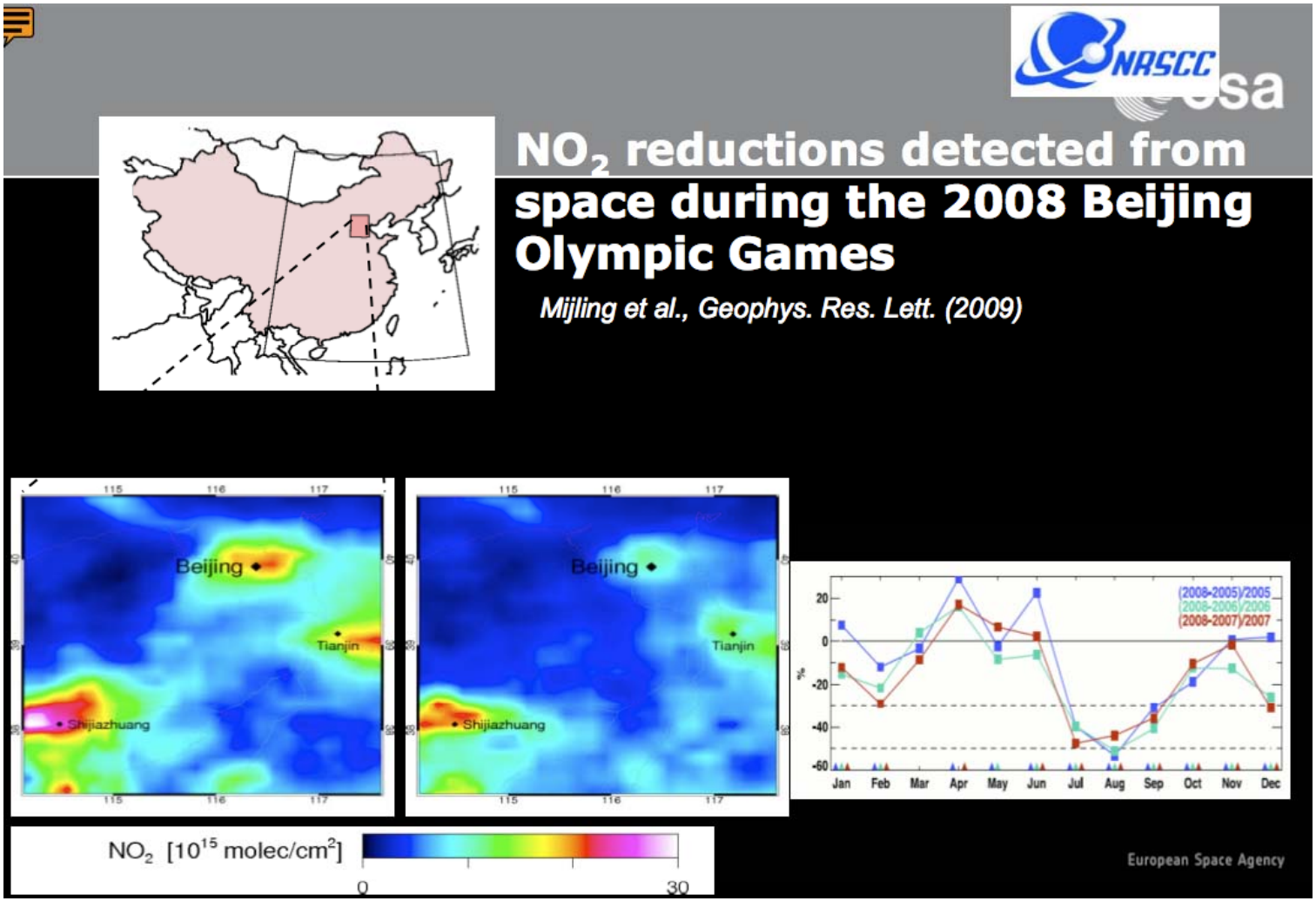
Climate Services



SCIAMACHY NO_2concentration, 2008 mean, Courtesy IUP

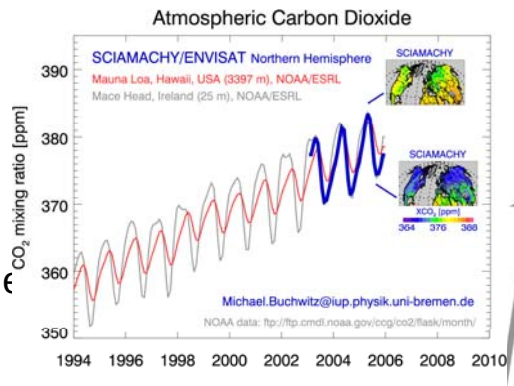
Identifying Pollution Sources

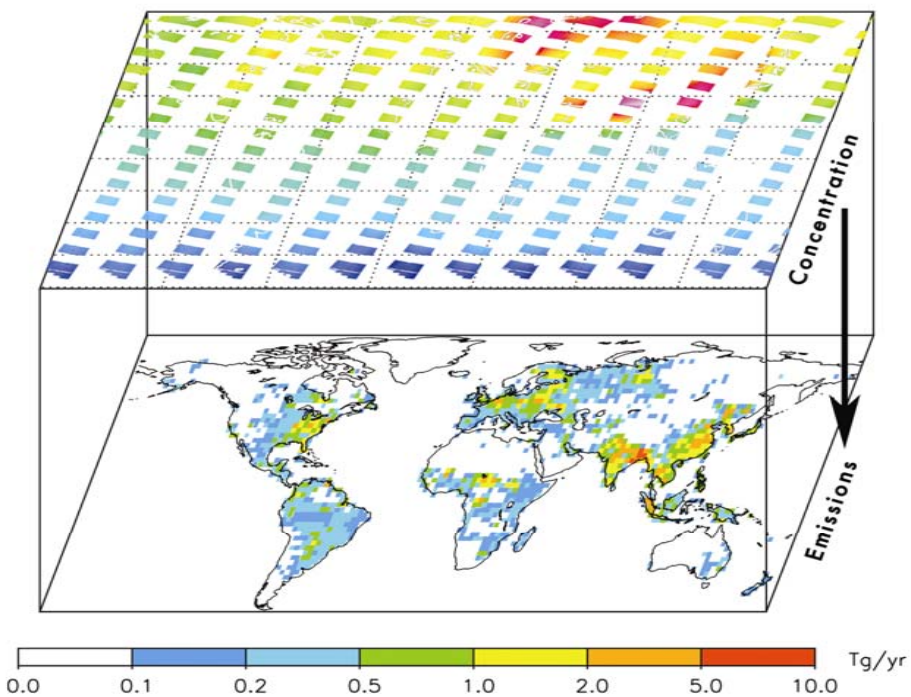


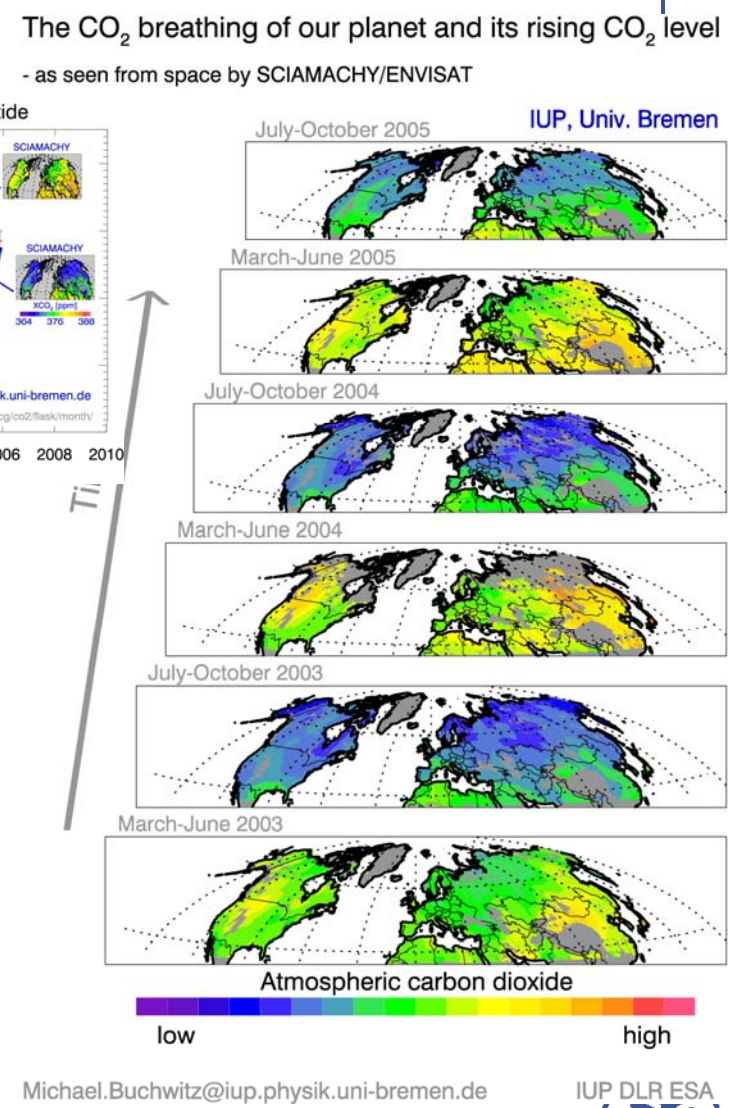
Quantifying Carbon Sources / Sinks

Multi-purposes Satellite missions
- **SCHIAMACHY / Envisat (ESA)**
- **IASI / Metop – AIRS (NOAA)**

Dedicated Satellite research missions
- **GOSAT [CO2] (JAXA) launched 2009**
- OCO 1 [CO2] (NASA), launch 2009 failed,
- OCO 2 [CO2] (NASA) to be launched 2013
- CHARM [CH4] (CNES/DLR) lidar to be launche

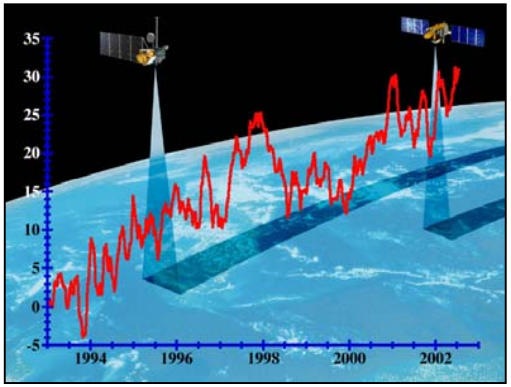




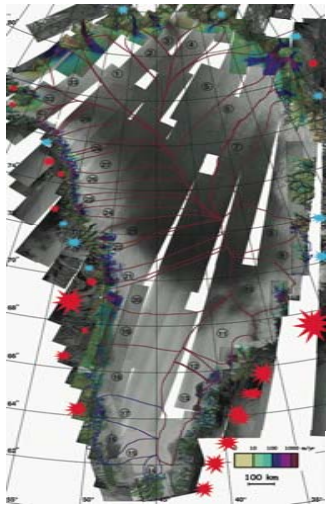


Courtesy IUP

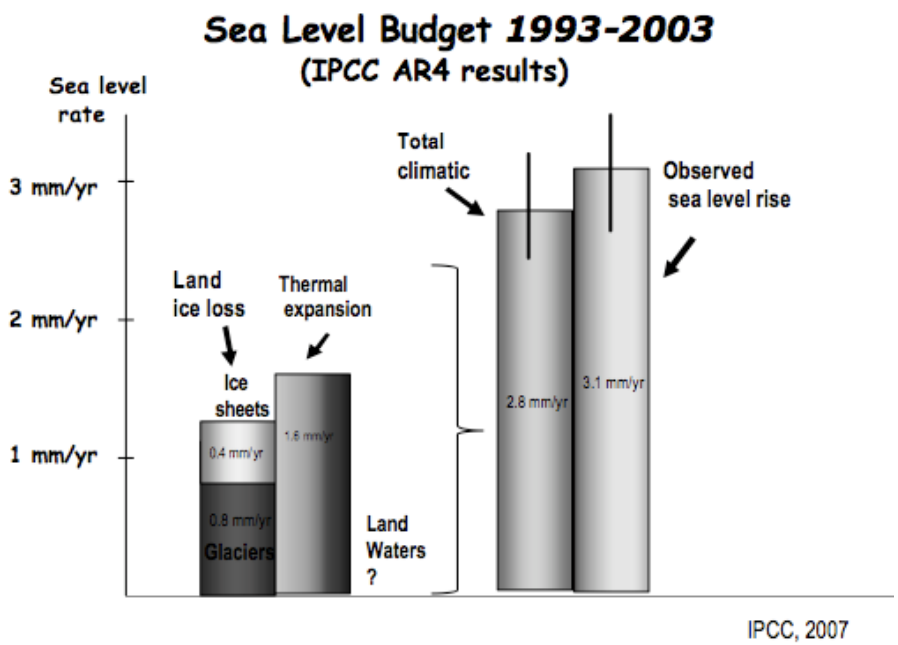
Closing Budget

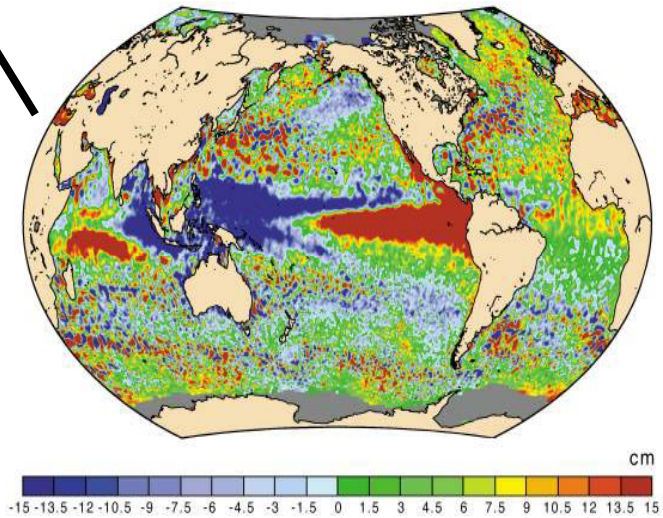


Attribution?
Ice melting?
vs.
Ocean warming

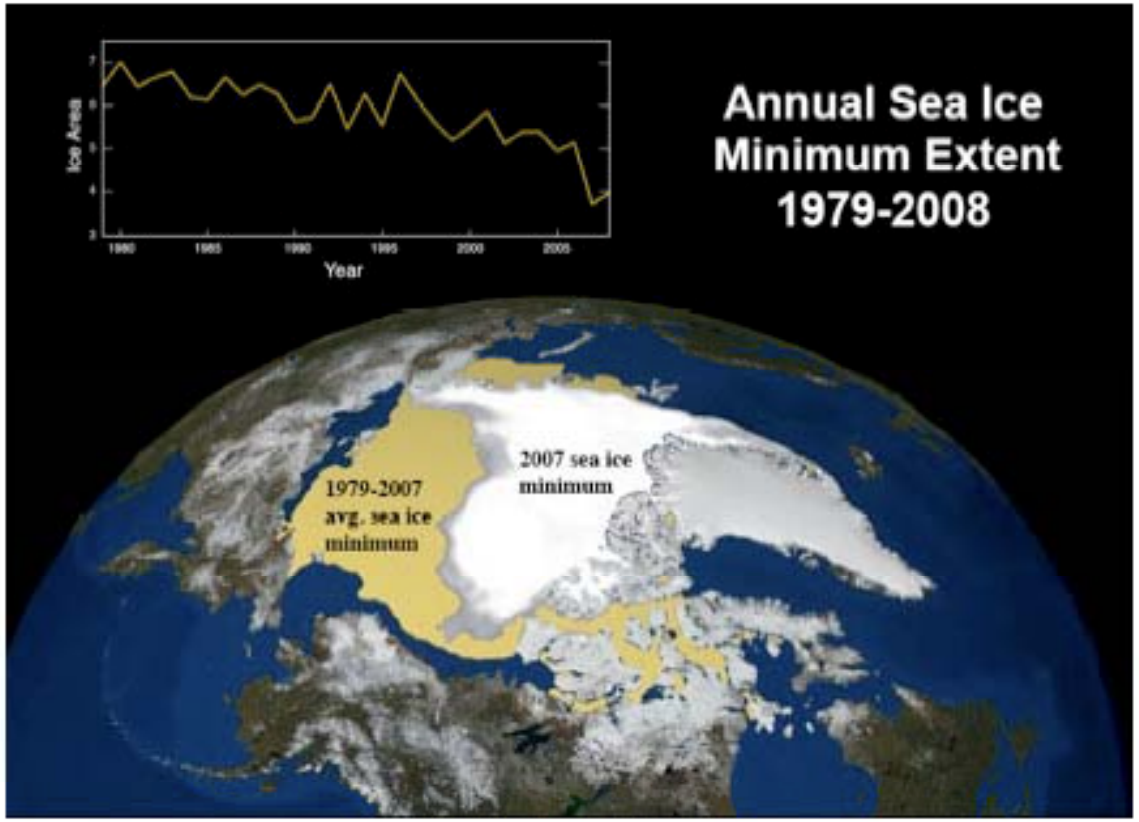


© Eric Rignot, JPL





Understanding Causal Relationship



Annual Arctic sea ice minimum extent as seen from space. 'Sea ice minimum extent' refers to the smallest amount of ice coverage in the Arctic, which occurs each year during the Arctic summer when temperatures are highest. Courtesy of Waleed Abdalati, University of Colorado.

NATURE|Vol 450|1 November 2007

Sea-ice decline due to more than warming alone

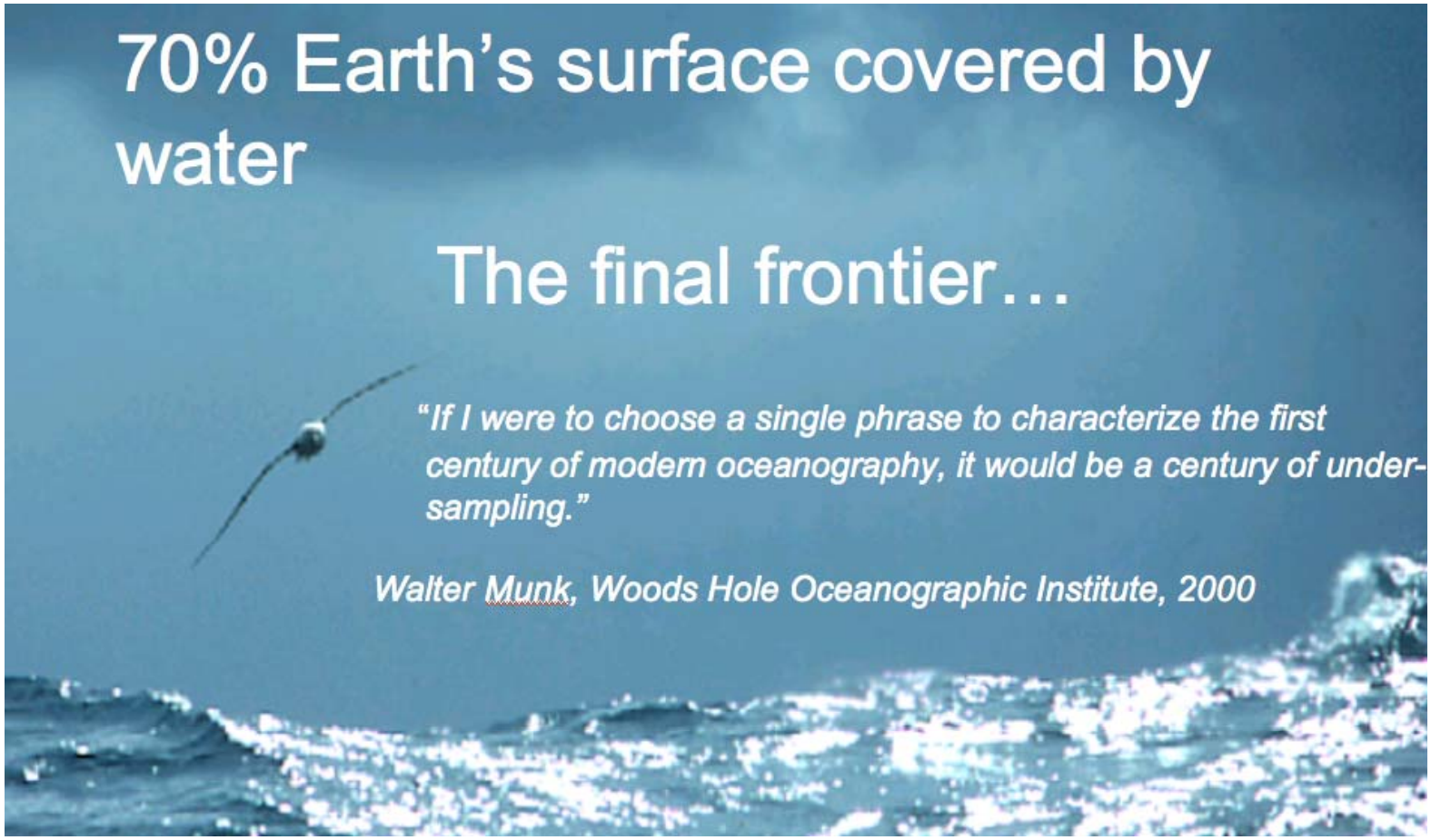
SIR — The dramatic loss of sea-ice cover over the Arctic this summer was widely reported, for example in your News story 'Arctic melt opens Northwest passage' (*Nature* **449,** 267; 2007), and frequently attributed to global warming. Although the gradual decline in sea-ice extent during the past four decades is in line with that expected from global warming, it is very unlikely that the loss of sea-ice cover this year is explicable solely in terms of temperature change.

Changing wind patterns are an important influence on the distribution of sea ice. Throughout summer 2007, exceptional pressure and wind patterns persisted over the Arctic Ocean. The observed migration of ice cover, from the Siberian and Beaufort seas northwards and eastwards into the Arctic Basin, was in line with the expected response to the anomalous winds. These Arctic wind anomalies were part of a global-scale pattern of highly unusual circulation this summer, the causes of which are as yet unclear.

The growing La Niña in the East Pacific undoubtedly had a major influence globally, and there is some evidence from past events that La Niña predisposes the circulation towards the type of exceptional patterns seen this summer.

Julia Slingo, Rowan Sutton
National Centre for Atmospheric Science, Walker Institute for Climate System Research, University of Reading, Earley Gate, Reading RG6 6BB, UK

Conclusions



Satellite Data as a tool to support climate change study

- **Modelling & Prediction** ..

  Through provision of CDR of ECVs
- **Mitigation** …

  Through Clean Energy resources assessment & REDD
- **Adaptation** (planned) ….

  By better management of changes
- **Attribution** …

  Through identification of sources and sinks
- **Quantify Uncertainties** ..

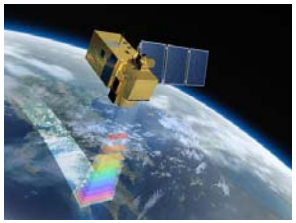
  Better Characterisation of Errors .. And truth ?

  New **Global Framework** to make it happen ..

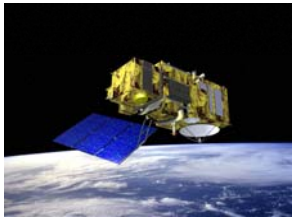
  ….. GCOS, CEOS, UNFCCC, WMO CC3 ….

The Sentinel Era – Observing Revolution ?

Sentinel 1 – SAR imaging
All weather, day/night applications, interferometry

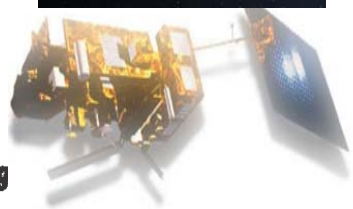


Sentinel 2 – Multispectral imaging
Land applications: urban, forest, agriculture, etc Continuity of Landsat, SPOT data



Sentinel 3 – Ocean and global land monitoring
Wide-swath ocean color, vegetation, sea/land surface temperature, altimetry

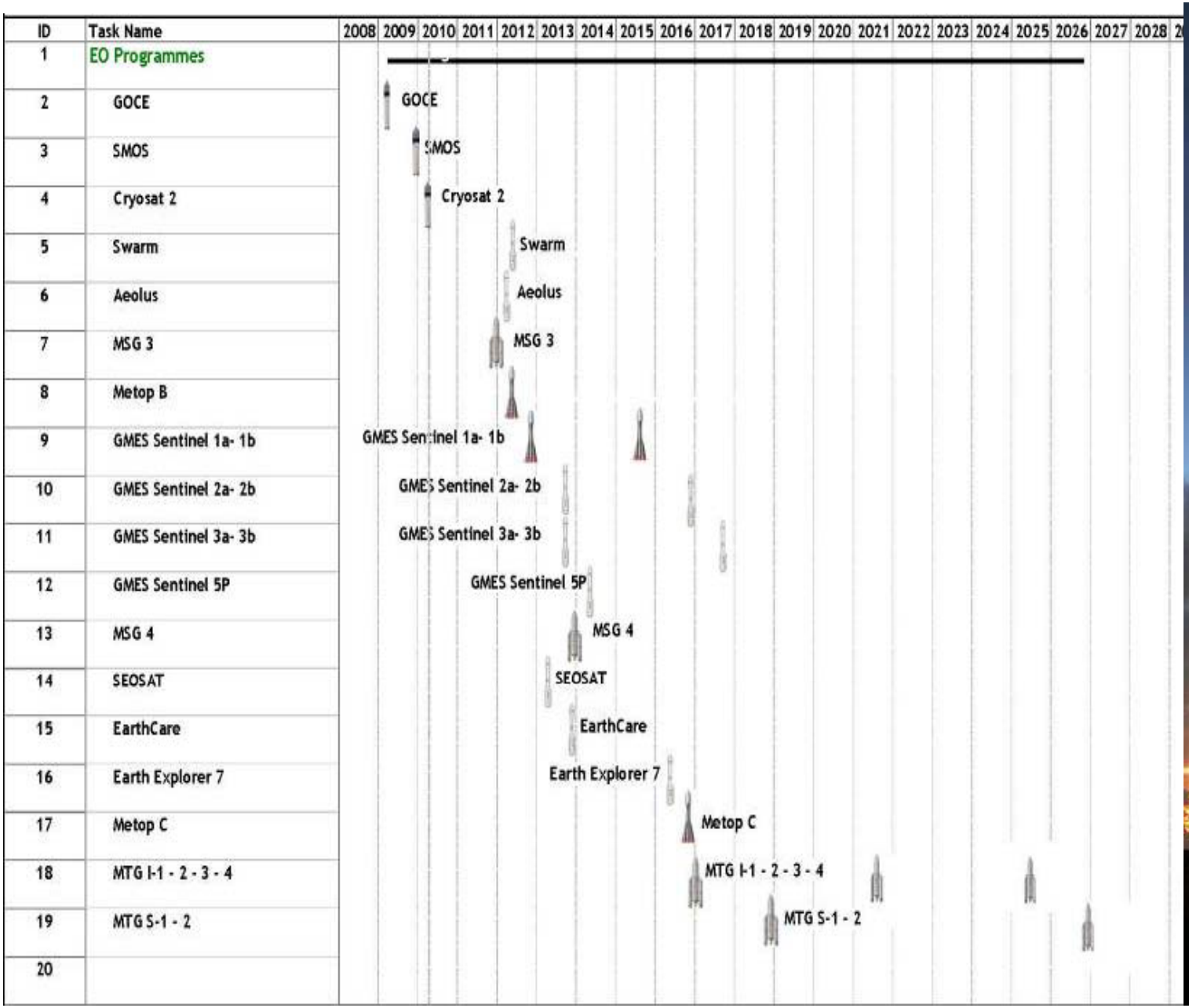
Sentinel 4 – Geostationary atmospheric
Atmospheric composition monitoring, trans-boundary pollution



Sentinel 5 – Low-orbit atmospheric
Atmospheric composition monitoring

FREE and OPEN Data Policy!

ESA Missions – Launch Schedule



Many thanks for your attention …

http://www.esa.int/eo