Space for Climate:
The measurement challenge

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CONTENT OF THE TALK

(1) Climate Science & Applications:
The Observational Challenge

(2) The role of Space & the European response

(a) Earth Observation (EO) capability in Europe
(b) ESA Climate Change Initiative (CCI)

(3) Focus on Carbon

(4) Concluding Remarks

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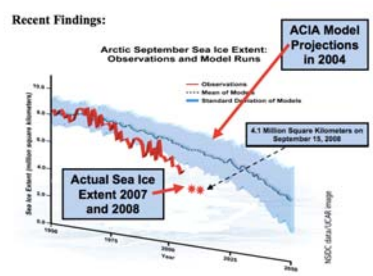
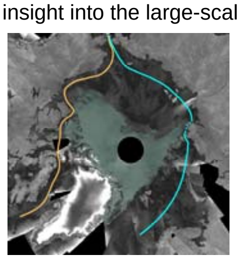
WHY MONITORING CLIMATE? To advance our scientific understanding ...

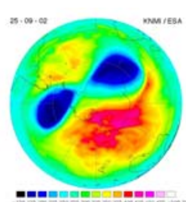
Observations are the foundation of any scientific developments,

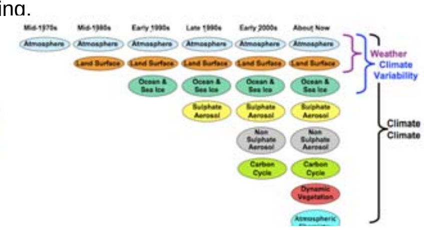
- **Testing hypothesis (e.g. process, feedback)**
- **Monitoring (e.g. changes, hot spots)**
- **Attribution (e.g. causal relationship)**
- **Validation of Models (e.g. parameterisations)**
- **Assessment of their performance (e.g. skill)**
- **Forecast (e.g. Projections, Predictions)**

In the particular case of climate change, obs together with models, are the 2 elements of knowledge to get insight into the large-scale Experiment we are running.



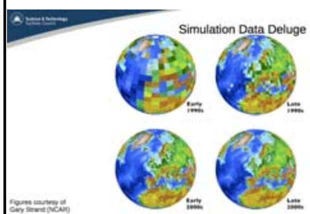


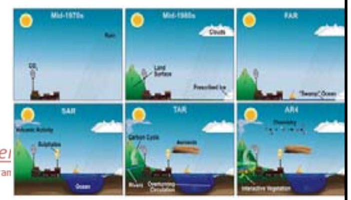


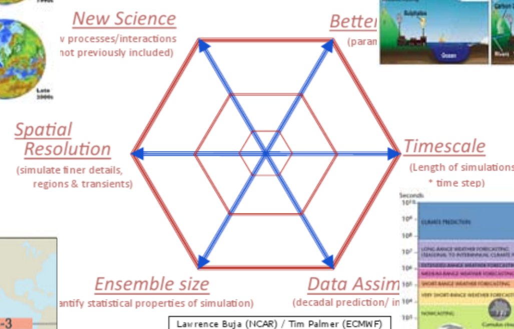


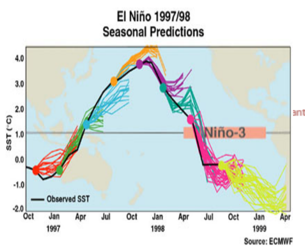
Courtesy IPCC, KNMI, Metoffice, ECMWF, NSDIC

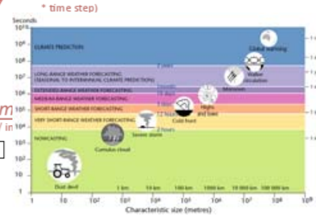
WHY MONITORING CLIMATE?
Climate Models need more & more Data ..





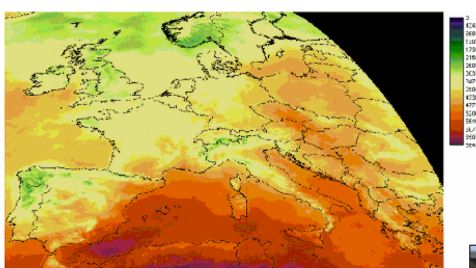


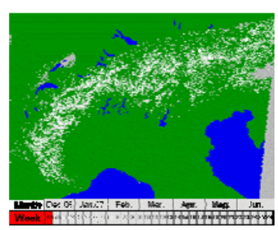




Courtesy Tim Palmer, NCAR, ECMWF, Metoffice

WHY MONITORING CLIMATE?
To support applications ....





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.

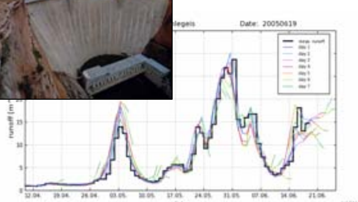
Scheint die Sonne? Ausflüglern reicht für die Antwort ein flüchtiger Blick aus dem Fenster. Will man jedoch eine Solaranlage bauen, braucht man genaue und langfristige Informationen zur Sonnenstrahlung. Deshalb vertiefen sich Ingenieure von Solarunternehmen in bunte Karten aus dem All, in so genannte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

Wo es auf der Sunshine-Map ... ist es warm u...

FINANCIAL TIMES DEUTSCHLAND

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



Courtesy DLR, CGS

OBSERVATIONAL REQUIREMENTS
Essential Climate Variables (ECV)

- 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)

- ECV analogous to vital sign in for human health (temperature, blood press)

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 irradiances), 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 (for biological activity), 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 photosynthetically active Radiation (fAPAR), Leaf area index (LAI), Biomass, Fire disturbance. Soil moisture.

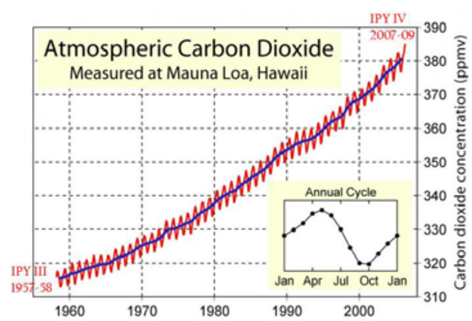
GCOS – 107 Systematic Observation Requirements for Satellite-Based Product for Climate Page 81

PRODUCTS REQUIREMENTS
Climate Data Record (CDR)

GCOS requirements for CDR:

- Long-term (with sufficient frequency)
- Global (but also regional / local).
- Accurate (need to capture small signal),
- Error Bar (bias!)
- Traceability of processing chain (documents)

much more stringent than NWP!
(in particular on *accuracy* and *stability* needed!



Keeling curve, which epitomises climate change

Courtesy Scripss Inst, NOAA

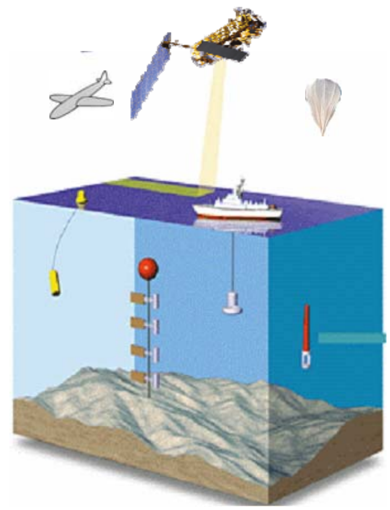
THE INTEGRATED OBS SYSTEM
Global Climate Observing System (GCOS)

From In-situ & Remote sensing sensors …

From Research & Operational Infrastructures …

With different physical meanings (e.g. pt, profile, EO) ..

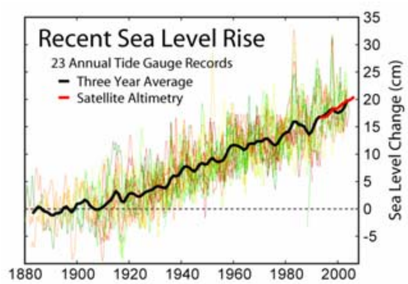
With different sampling / errors characteristics …



Courtesy Mercator, GCOS

ADEQUACY of OBS SYSTEM FOR CLIMATE

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

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THE UNIQUE VANTAGE POINT FROM SPACE The vital role of EO for GCOS

Unique characteristics of EO …
- Global view, with regional details
- Uniform in space and time
- Archive (can go back in time)

Vital role of EO recognised by GCOS Satellite Supplement (GCOS-107, 2006), which identified more than 35 ECV with strong EO component.

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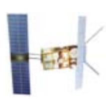
Expanding European EO Capabilities

Earth Watch Missions


ERS 1
1991

ERS 2
1995


ENVISAT
2002


Family of Sentinels
2011+

USER Driven OPERATIONAL
GMES Space Component
-Sentinel 1 (SAR)
-Sentinel 2 (Multispectral Img)
-Sentinel 3 (Glob Ocean / Land)
-Sentinel 4 (Chemistry geo)
-Sentinel 5 (Chemistry polar)

Earth Explorers


GOCE
Mar 2009


SMOS
Nov 2009


CRYOSAT 2
Apr 2010


SWARM


ADM-Aeolus


EarthCARE

EE7

Met Missions operated by EUMETSAT


Meteosat
1977

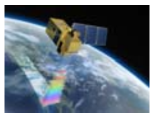
MSG-1
2002

Metop-A
2006

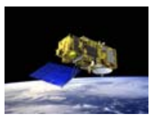
MSG+
MTG
Post-EPS

GMES user-driven Sentinels

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

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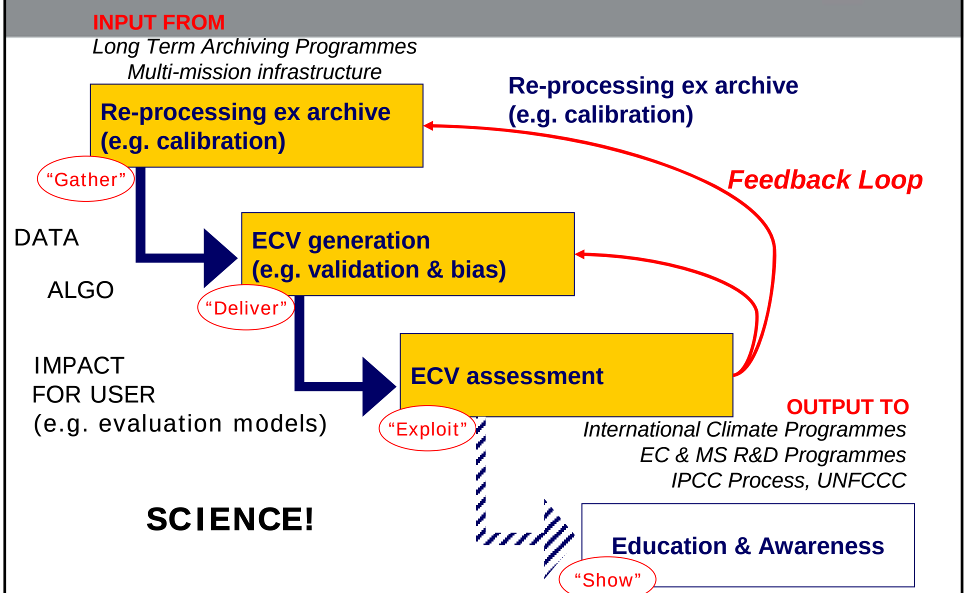
CCI RATIONALE & OBJECTIVE

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
Starting NOW for 11 ECVs (including GHG & land cover)

CCI Steps: Value Chain & Feedback Loop



INTERNATION COLLABORATION

- **GCOS**: which represents the scientific and technical requirements of the Global Climate Observing System on behalf of **UNFCCC and IPCC.**
- **International Climate Research Programmes**, which represent the collective interests and priorities of the worldwide climate research communities
- **CEOS:** which serves as a focal point for Earth Observation related activities of Space Agencies in the **GEO** framework
- **Individual Partner Space Agencies** (e.g. EUMETSAT)
- **EC and National Research Programmes** which establish research priorities and provide resources for climate research community within Europe
- **Individual end-user organizations** in ESA member states and worldwide, climate research, monitoring and modelling practitioners who are active in the IPCC processes

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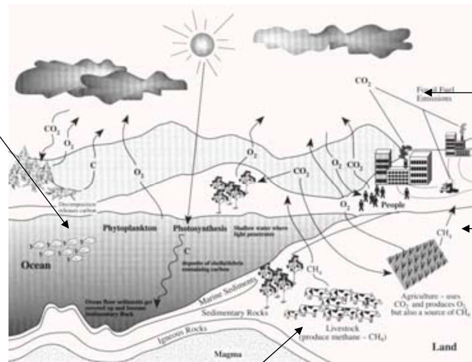
CARBON CYCLE
Multiple views from Space

ECV Ocean Colour

Carbon Cycle

Reservoir (stock)

Exchanges (fluxes)



ECV GHG concentration

ECV Land Cover

Other **proxy of human activities** (e.g. night light, NOx production, infrastructure)

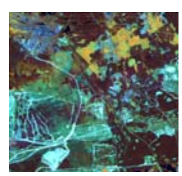
FOREST MONITORING

Optical / Radar Satellite Missions
- Envisat (Meris, ASAR)
- Rapideye
- KOMPSAT,
- **Sentinel 2**

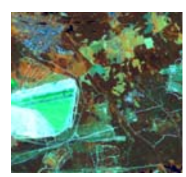
Sustainable Forest Management
- Forest Monitoring (e.g. land cover, biodiversity)
- Baseline Monitoring (e.g. back in archive)
- Illegal Logging (e.g. clear cut, road system)

Proxy of Carbon Stock
- Need in-situ sampling
- Use EO for optimal sampling
- BIOMASS mission

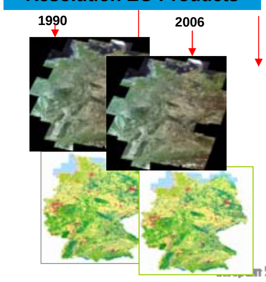
1990 (baseline)



2002 (Landsat)



Standardised High Resolution EO Products



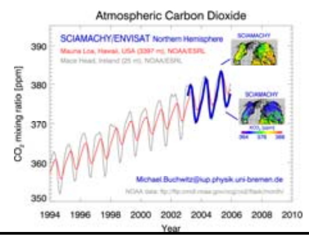
ATMOSPHERIC REMOTE SENSING of CARBON
Satellite Missions for CO2 / CH4 concentration

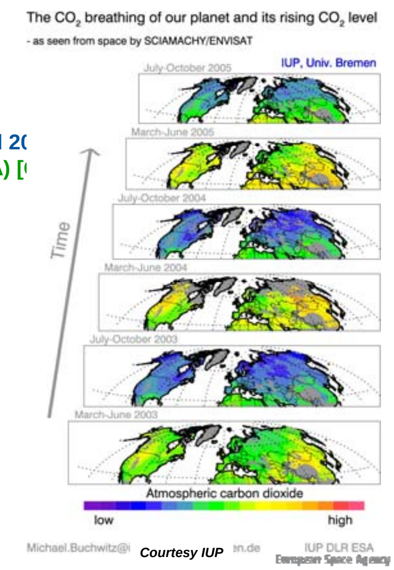
Principle of remote sensing of CO2/CH4
Passive Near IR (e.g. issue of night, ocean) / Thermal IR
Active LIDAR

Multi-purposes Satellite missions
- **SCHIAMACHY / Envisat (ESA) [CO2, CH4] launched 20**
- **IASI / Metop [CO2] (EUMETSAT) - AIRS / Eps (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 launched 2014

Gap in Carbon EO missions ..





REMOTE SENSING of C SOURCES / SINKS
Top-down approach

Observable
(e.g. *Radiance*)

Retrieved
Geophysical
Parameter
(e.g. *concentration*)

Infer

Infer

Target
Quantity
of interest
(e.g. *carbon flux*)

Observation Operator including two steps

- Retrieval Issue (e.g. aerosol, clouds)
- Inversion Issue (e.g. Model + Data …)

Underdetermined Inverse Problem
Need for Strong constrains from Data

REMOTE SENSING of C SOURCES / SINKS
The Underdetermined Inverse Problem

Observable
(e.g. *Radiance*)

Infer

Retrieved
Geophysical
Parameter
(e.g. *concentration*)

Infer

Target
Quantity
of interest
(e.g. *carbon flux*)

Poor constrains from data

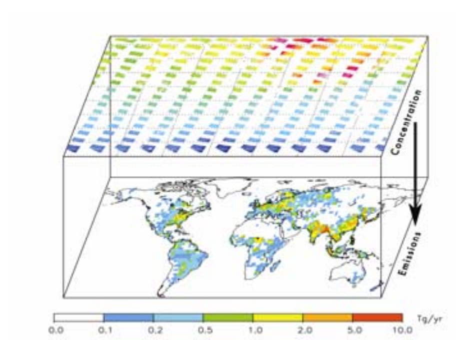
REMOTE SENSING of C SOURCES / SINKS
The Carbon Cycle Data Assimilation (CCDAS)

Using multiple obs constraints

- Model of atmosphere transport (e.g. TM3)
- Model of vegetation processes (e.g. BETHY)

+ In-situ data (e.g. flux tower) but sparse

+ EO Data on
- Atmo C concentration (e.g. Envisat)
- Land phenology (Envisat / MERIS),
- Land hydrology (SMOS), …to come ..



Inferring Carbon fluxes from space
requires much more data than carbon

The more data constrains the better ….
Global coverage of EO is essential

Courtesy KNMI, Fastopt

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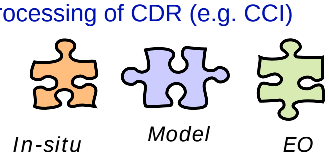
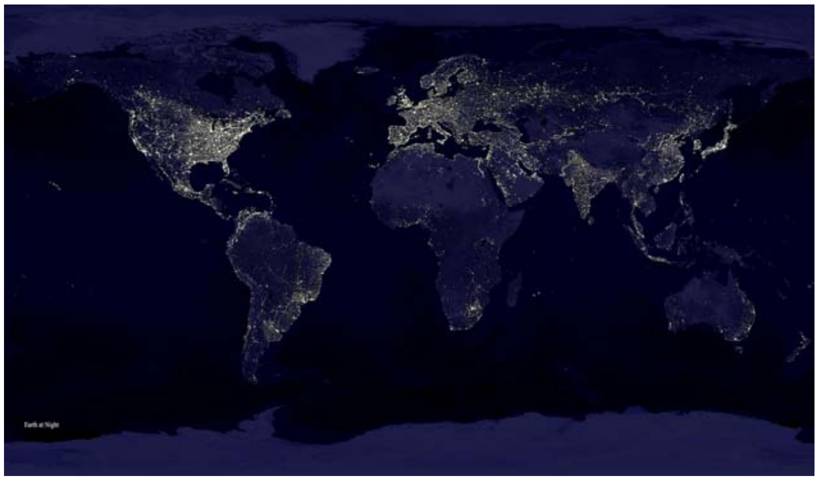
CONCLUSIONS

- Growing Need for CDR to support Science & Applications .. But ...
  .... Enormous challenges to observe properly ECVs .. (GCOS IP)
- Quantifying Carbon is a complex^3 & multivariate problem

- Need for an integrated approach to build trust in climate information system (including carbon), which requires more of ...
  - EO data from space (e.g. issue of gap in C missions)
  - In-situ data from optimized network (e.g. ICOS) + Remote Sensing
  - Better models to interpret (e.g. inversion, CCDAS) / synthesise data
  - Data assimilation techniques
  - Continuous re-processing of CDR (e.g. CCI)



THANK YOU FOR YOUR ATTENTION



Earth by night, courtesy DMSP, NOAA