Using Satellite Observations to Constrain Carbon Flux Estimates

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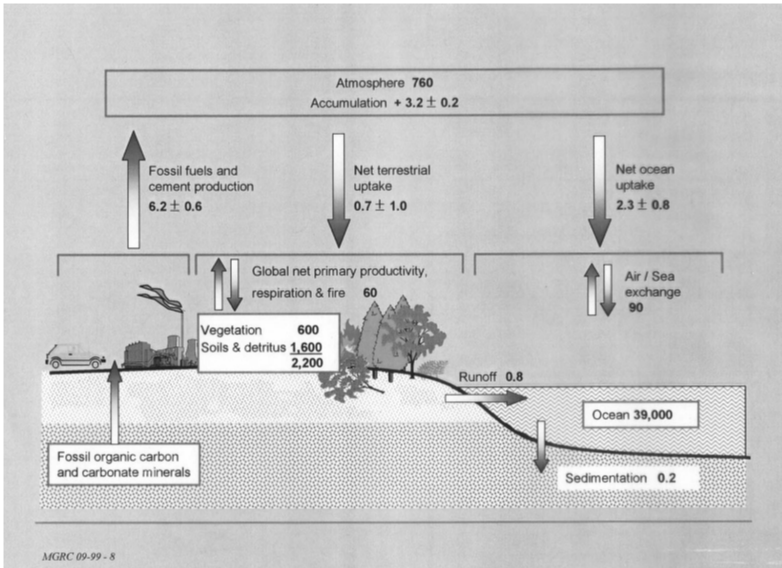
& National Centre for Earth Observation

Lecture content

- The global carbon cycle and its components
- Carbon cycle models
- Atmospheric observations of CO2 and CH4
- Using satellite data to improve estimates of carbon fluxes from the land
- Using satellite data to improve estimates of carbon fluxes from the ocean
- Challenges

The Global Carbon Cycle



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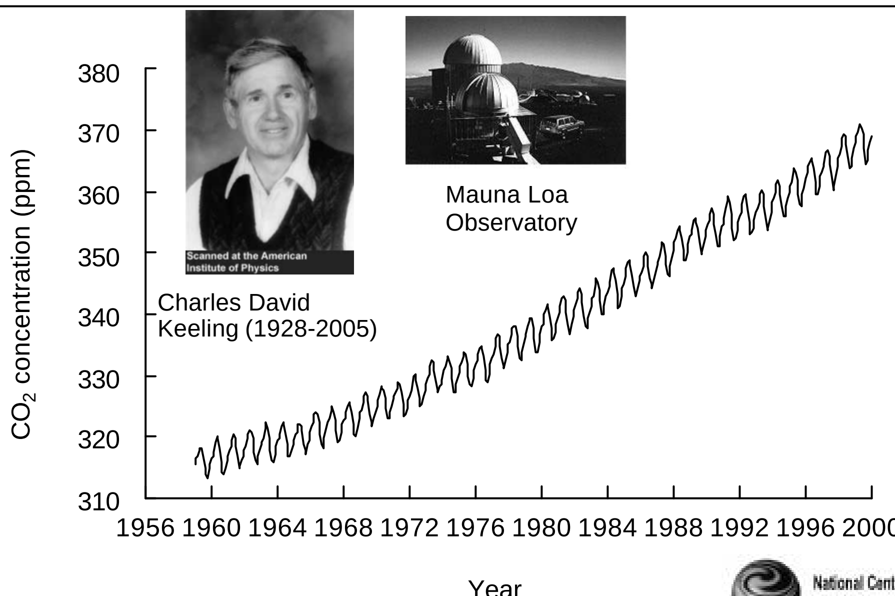
Atmospheric CO_2: the Keeling Curve



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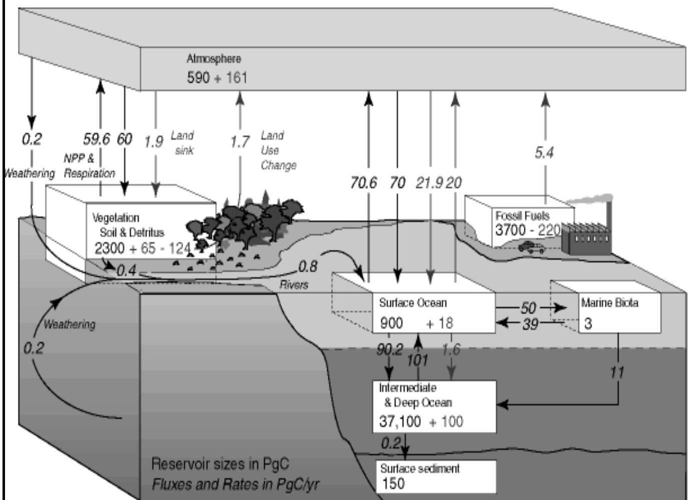
Natural and anthropogenic components of the carbon cycle



Need to quantify and spatialise:
- **Reservoirs**
- **Processes**
- **Sources**
- **Sinks**
- **Change**

- **Black** = preindustrial sizes of reservoirs
- **Red** = changes resulting from human activities

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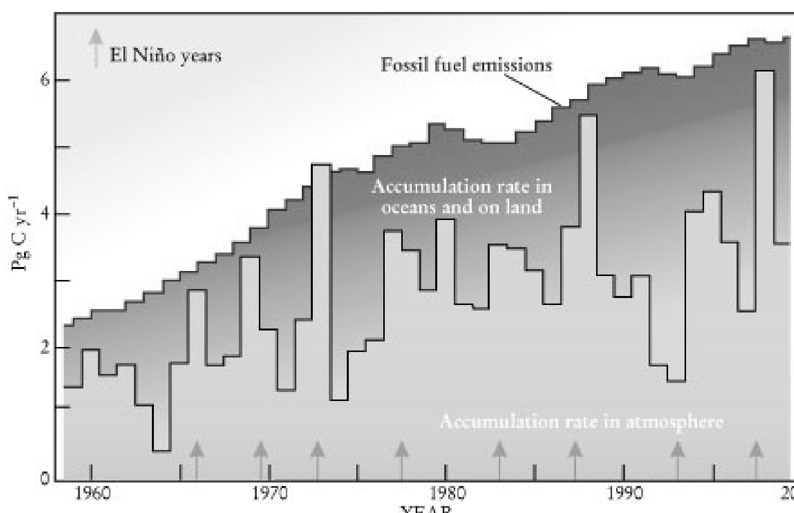
Sarmiento, J.L. and Gruber, N. (2002).

CO_2: emissions vs atmospheric increase



From: 'Sinks for Anthropogenic Carbon', Physics Today, August 2002, Jorge L. Sarmiento and Nicolas Gruber

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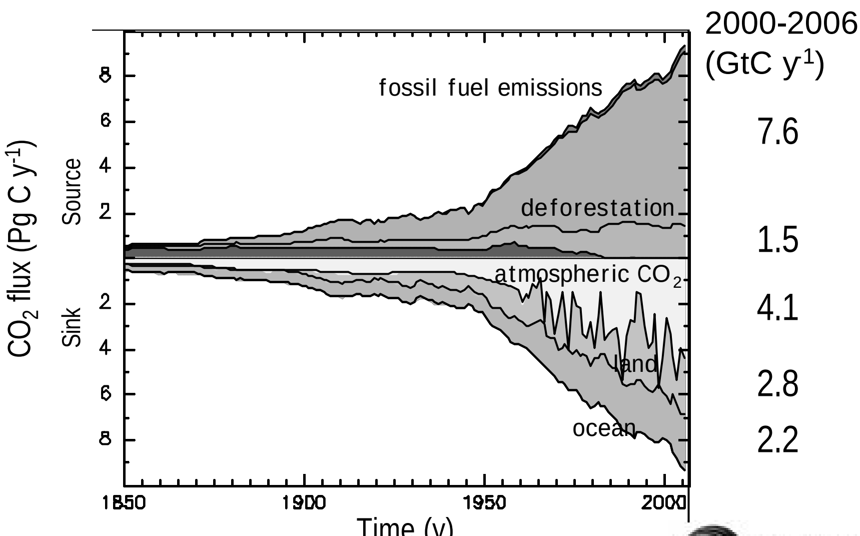
Perturbation of Global Carbon Budget (1850-2006)



Le Quéré et al. 2009

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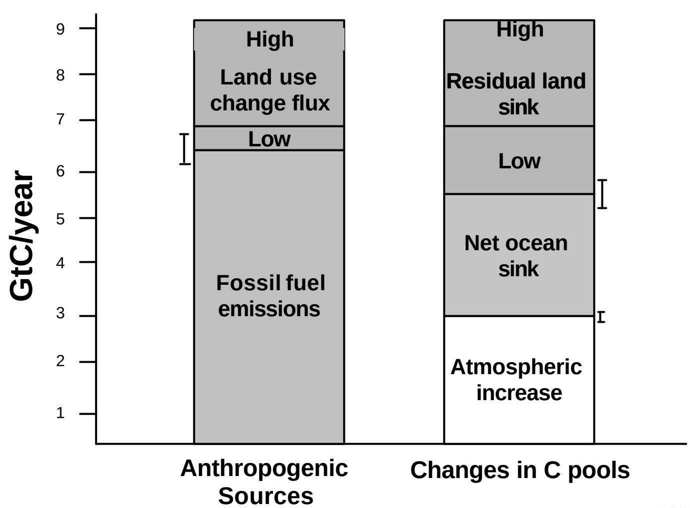
The mean global carbon cycle for the 1990s



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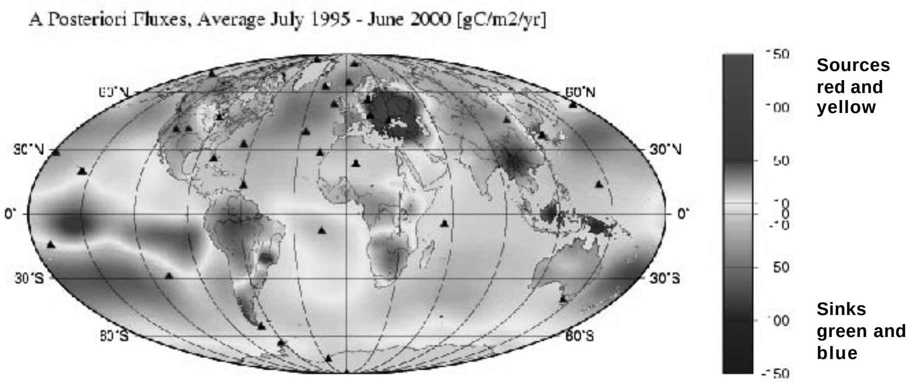
Global distribution of sinks over the period 1982-2001 (flask inversion method)



Fossil fuels not included

Roedenbeck et al. (2003) Atmos Chem Phys Discussions 3, 2575-2659.

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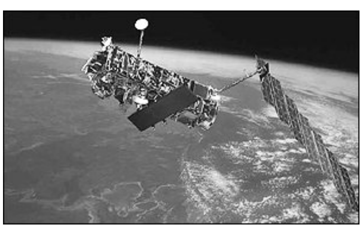
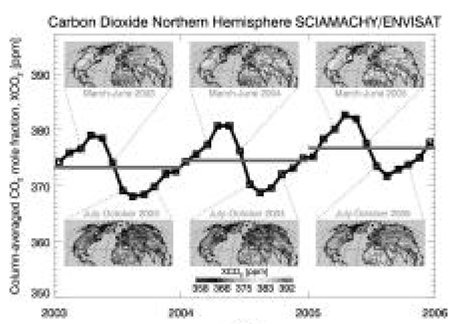
Atmospheric carbon dioxide from space



First global satellite observations of total atmospheric CO2 (SCIAMACHY/ ENVISAT)



Buchwitz et al, 2007

C-theme May 2009

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SCIAMACHY SWIR WFDOAS ASIAN CO, CO2 and CH4 in 2003

Four data products: Vertical columns of CH4, CO, CO2, and O2 from SCIAMACHY nadir observations using appropriate spectral windows in the near-infrared

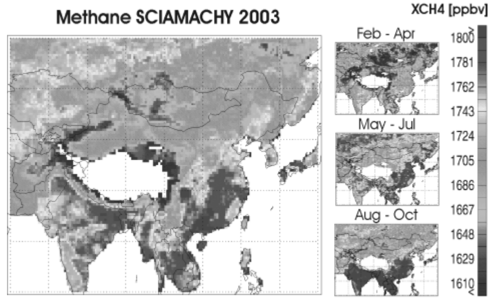
Data products:

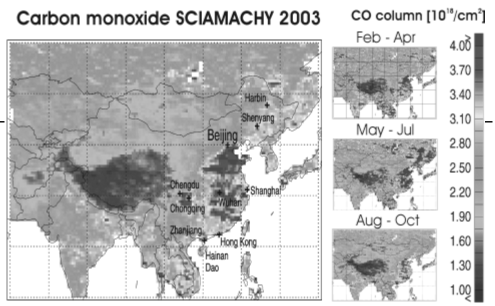
Methane VMR (XCH4 = CH4-column/aircolumn)

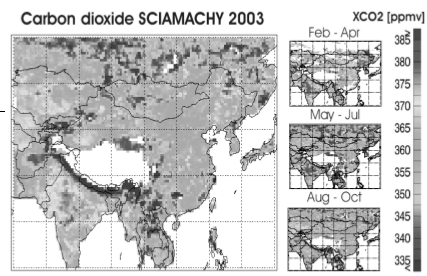
Carbon monoxide column (molecules/cm²)

Carbon dioxide VMR (XCO2 = CO2-column/aircolumn)

Details latest versions: de Beek et al., ACPD, 2006





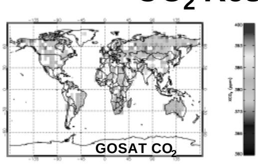


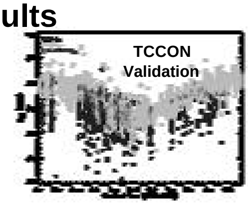
GOSAT: dedicated C cycle satellite

JAXA's next generation greenhouse gas satellite with improved precision and accuracy: launched 23/01/09

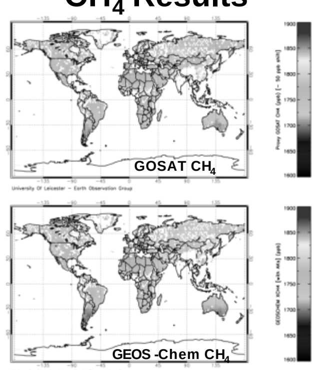
- ❑ **More than 1 year of global observations of CO_2 and CH_4 columns are now available**
- ❑ **First comparisons to GEOSChem and Carbontracker show good correlation of large scale patterns**

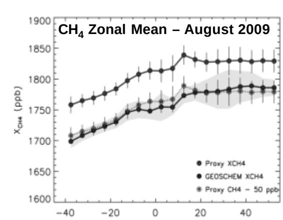
CO_2 Results



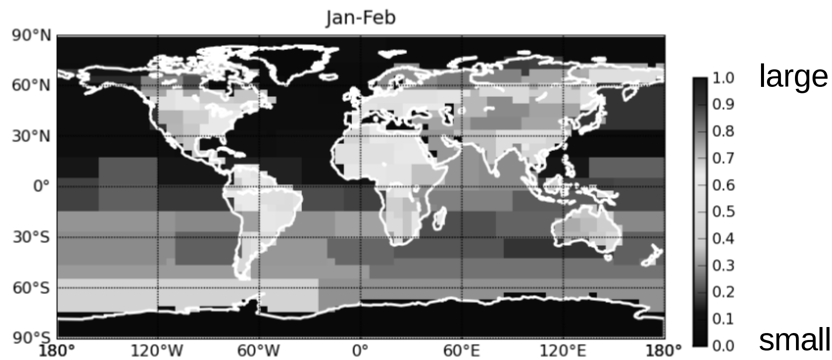


CH_4 Results





Expected Improvement in CO_2 Flux Estimates from GOSAT



(L. Feng, P. Palmer – U Edinburgh)

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Models

- Carbon flux models developed mainly to investigate the response of the land and ocean to climate change
- Intended to be predictive, hence parameterised rather than data driven.
- Designed for a data-poor environment
- Recent extension of land models to full climate-land surface coupling to take account of climate-carbon cycle feedbacks

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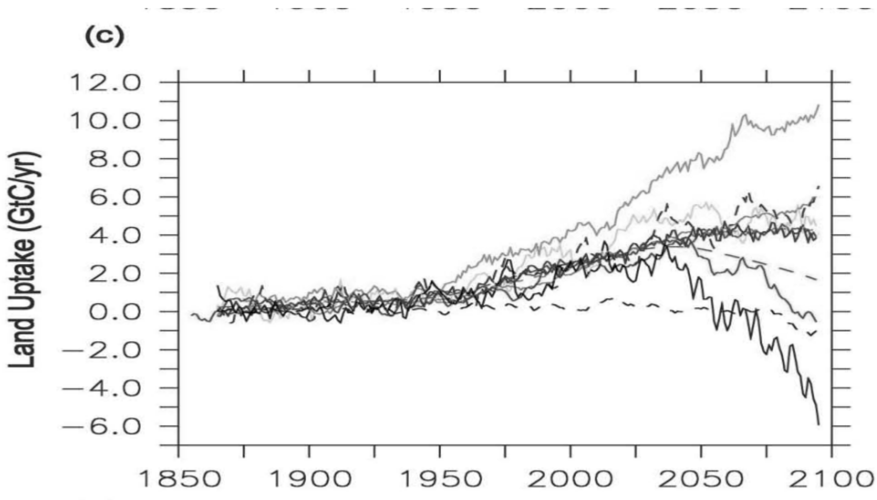
The C4MIP comparison of coupled models



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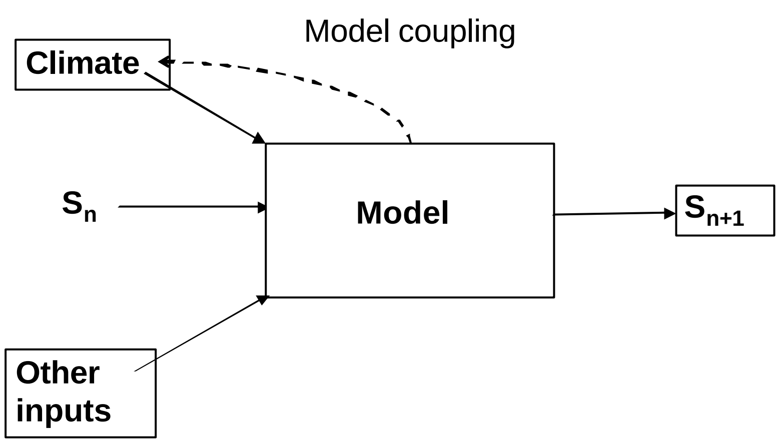
Simplified structure of a carbon flux model



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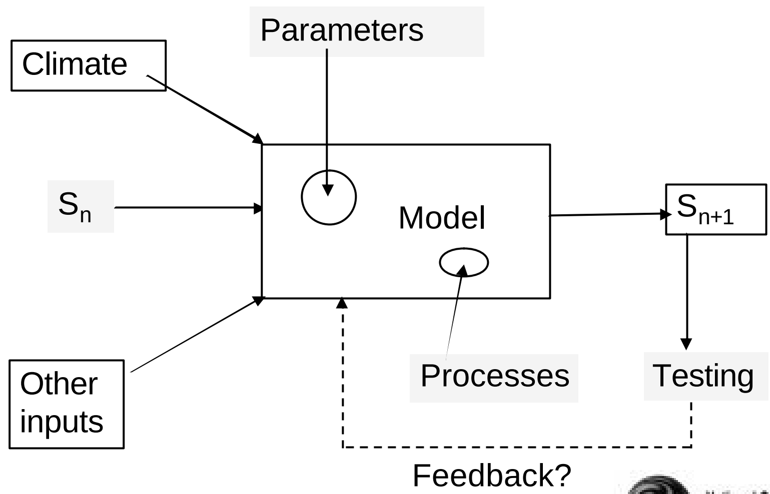
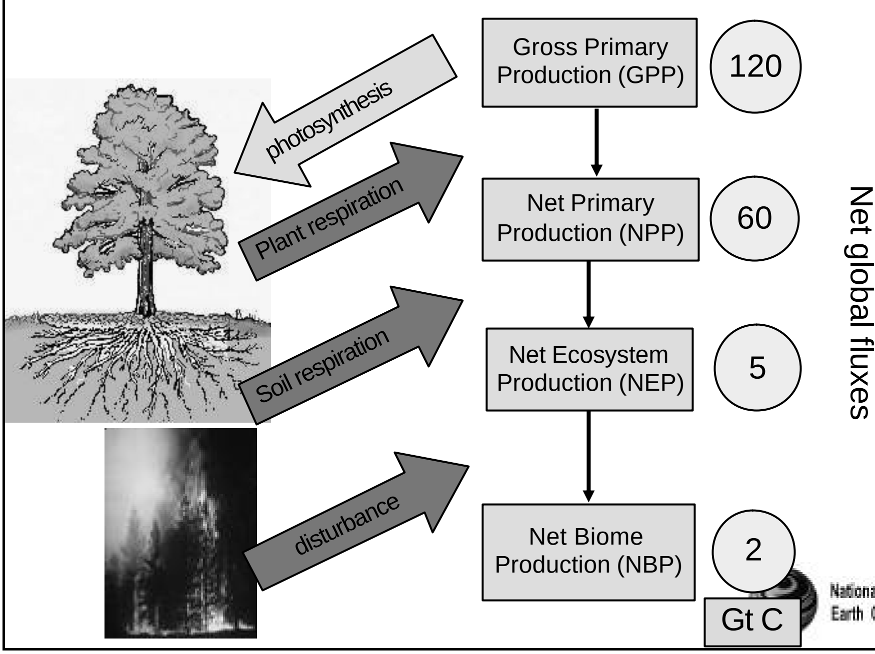
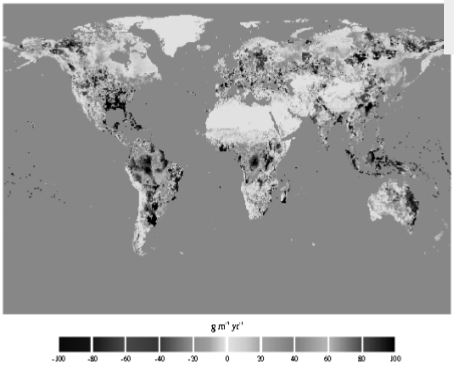
How can EO data affect a carbon flux model?



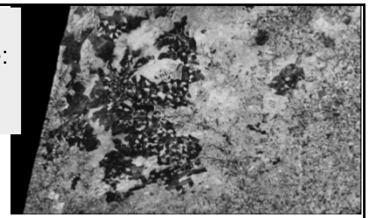
The land component of the C cycle: natural fluxes



Model: 20th century changes in productivity

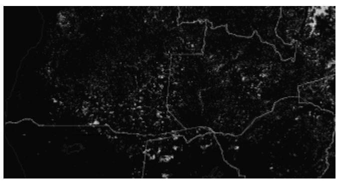


ERS coherence: forest age, biomass

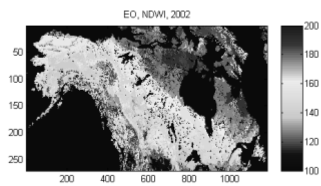


Seawifs fAPAR

SPOT-VGT LC



MODIS burnt area



SPOT-VGT budburst

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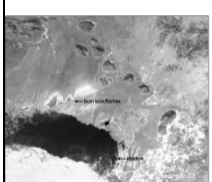
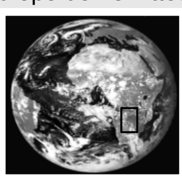
Space Measurements of Carbon Emissions from Biomass Burning

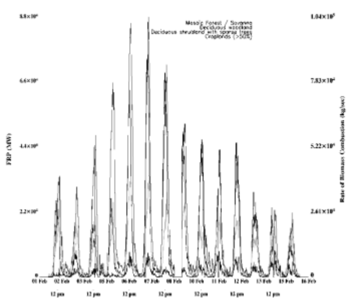


MSG SEVIRI

Vegetation releases fixed amount of energy when burned
A proportion emitted as radiation – detectable by satellite



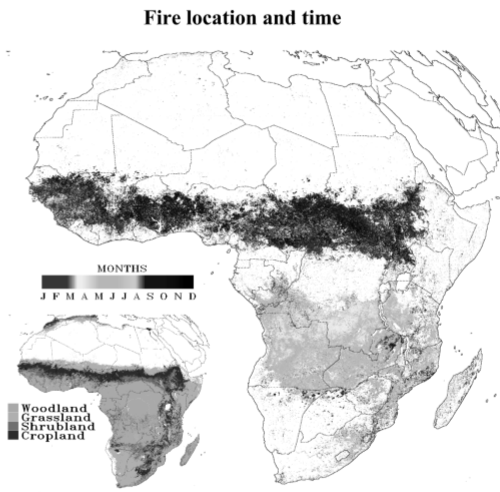
Diurnal cycle in emissions



NOAA, 2005-12-11

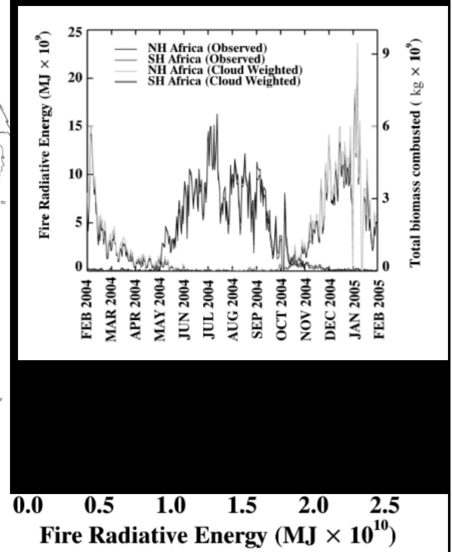
Estimating C Emissions from Radiative Energy

Fire Seasonality and Location



[Very strong seasonal cycle]

Temporal Emissions Variation

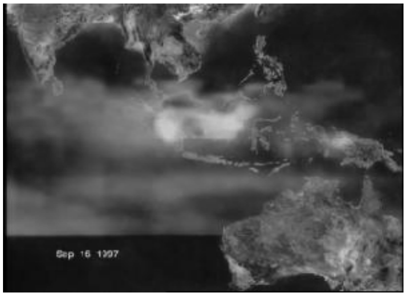


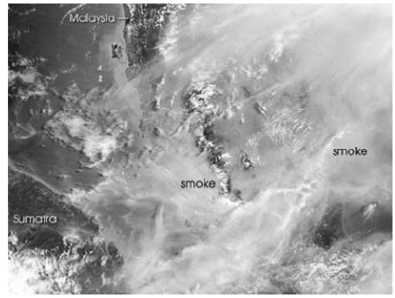
Short-Term Emissions Estimation as Model Drivers

Observed Geostationary FRP [W/m^2] (red)
Modelled (blue)

J. Kaiser (ECMWF)

Tropical peatland fires in Borneo





Haze from Indonesian peat-land fires blankets SE Asia.

0.81 – 0.95 billion tonnes of carbon were emitted from peatland fires during 1997/98.

16th August 2005: "Smoky haze chokes Southeast Asia …. Again hundreds of fires burn deep into the underlying peat spreading smoke across the region"

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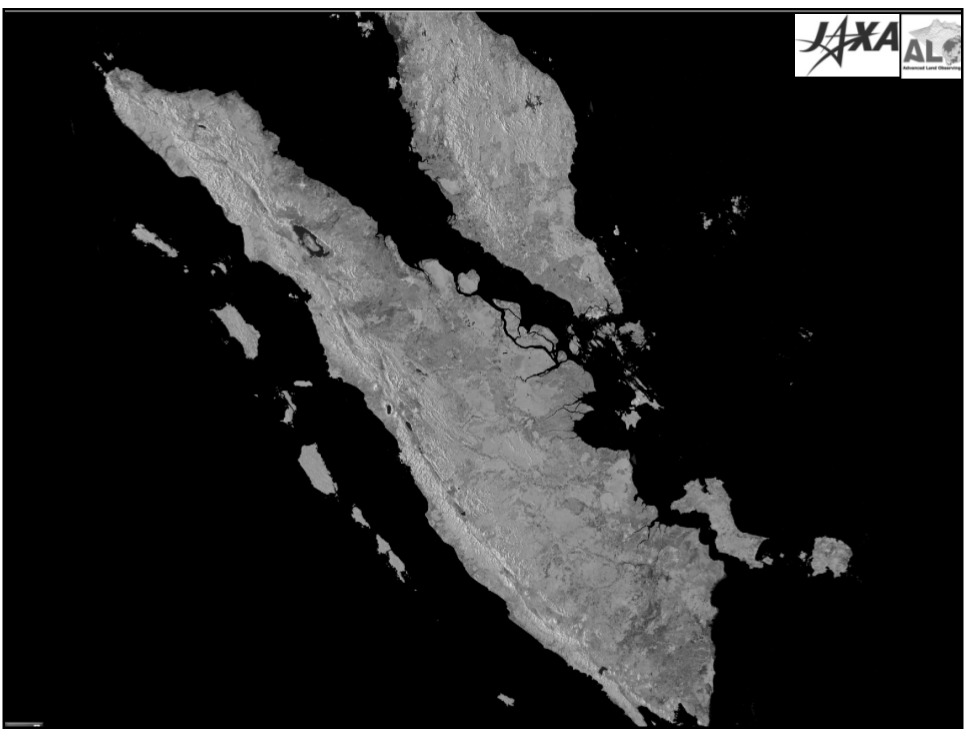
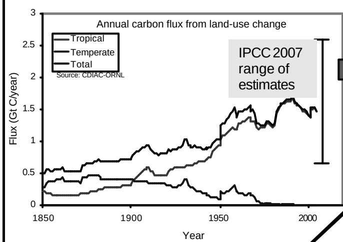
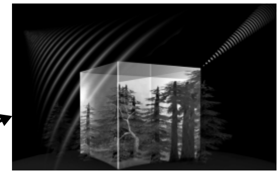


Improving estimates of tropical deforestation flux and REDD



Carbon emitted = Biomass x Area deforested x 0.5 (IPCC Good Practice Guide)

The ESA BIOMASS mission



Challenges:

1. Improve area estimates
2. Improve biomass estimates
3. Provide REDD methodology
4. More realistic flux model

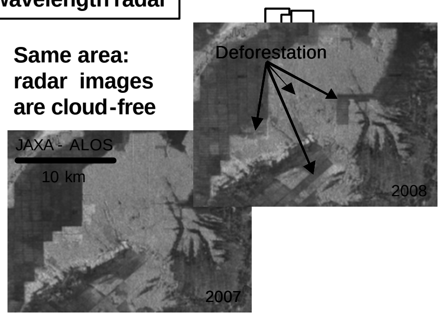
Use ALOS long wavelength radar

Link to:

- ecosystem models
- fire observations
- GOSAT atmos. measurements
- soil processes

Much combined science to be done

Same area: radar images are cloud-free



CTCD Centre for Terrestrial Carbon Dynamics

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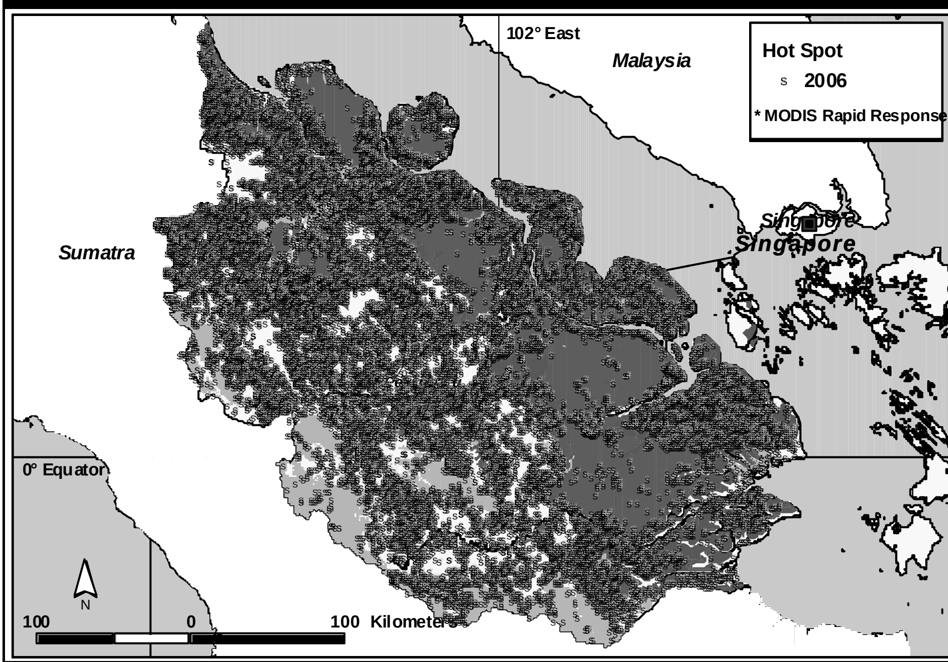
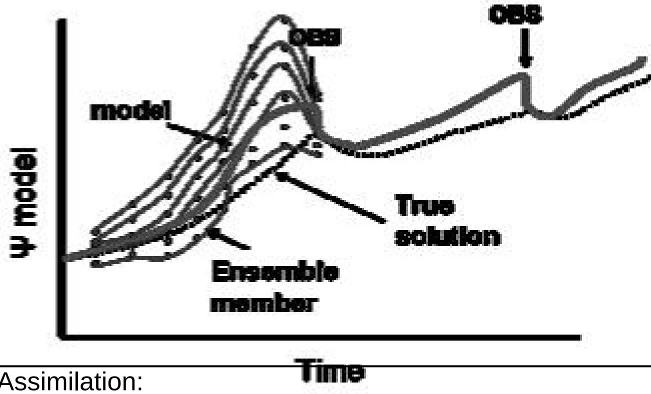
Riau has burned almost everywhere



Integration of EO with models

Models include processes, interpolate beyond view (space, time)



- Data Assimilation:
  - Uses observations to constrain/correct model variables & parameters
  - Test model processes
  - 'Improve' model forecasts

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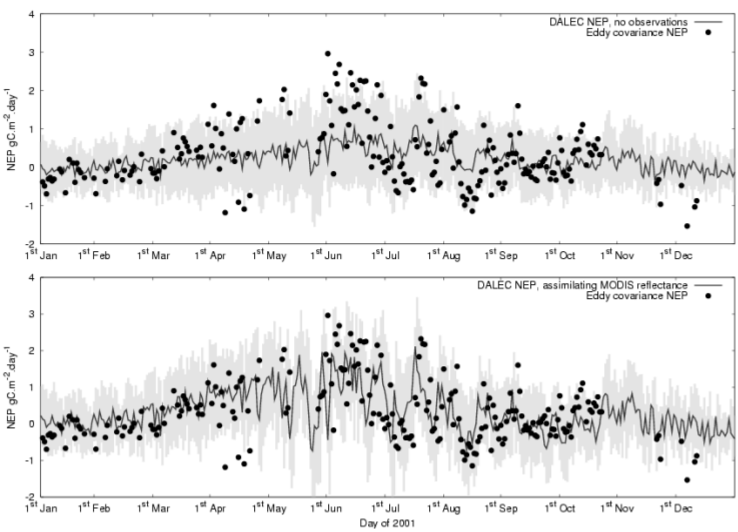
Courtesy of Ricardo Torres

Data assimilation to improve estimates of Net Ecosystem Production

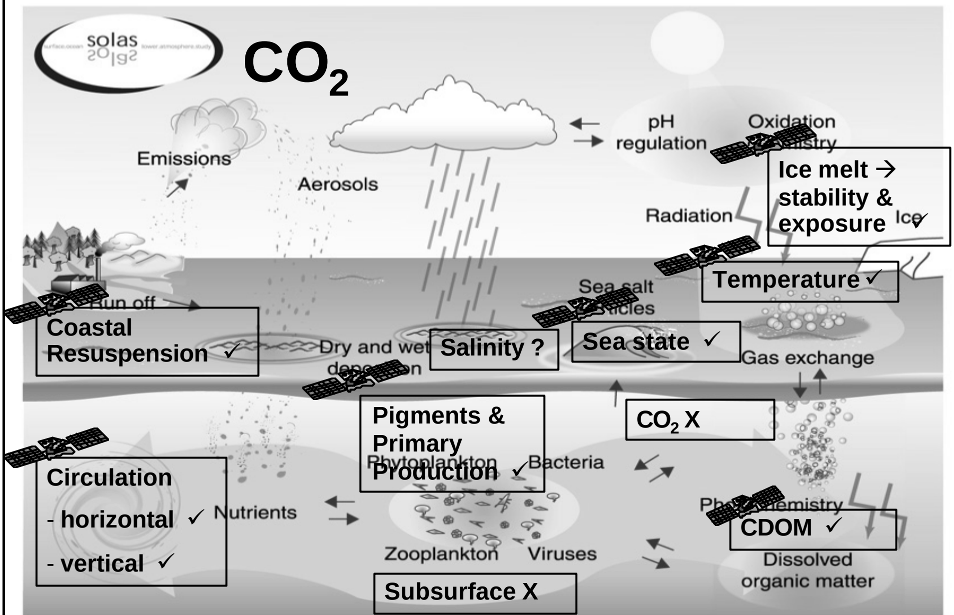
No assimilation

Assimilating MODIS

(red/NIR)



Processes influencing air-sea carbon dioxide fluxes

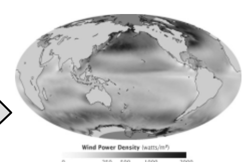


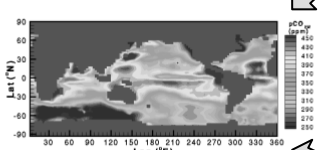
How can we measure CO_2 exchange with the ocean?

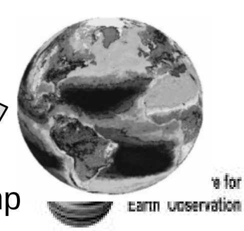
Solubility pump

- Directly by satellites?
  - Not yet
- Indirectly by satellites?
  - Temperature ✓
  - Sea state/winds ✓
  - Algal biomass ✓

Models





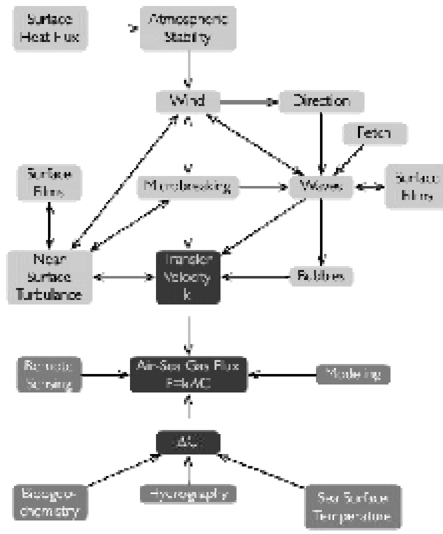


Also need direct measurements – only available in situ

Biological pump

Physical gas exchange processes

- Gas transfer velocity (K)
  - directlyrelated to sea state processes
  - indirectlyrelated to wind
- Wave height/slope reflects history (direction, fetch) and damping (slicks)
- Whitecapping reflects turbulence, bubbles, microbreaking



From http://www.uea.ac.uk/env/solas

Wade McGillis

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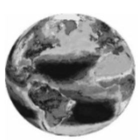
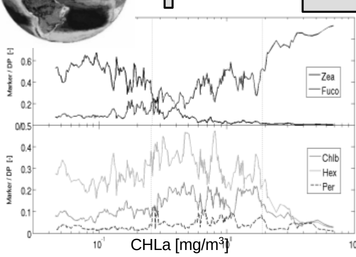
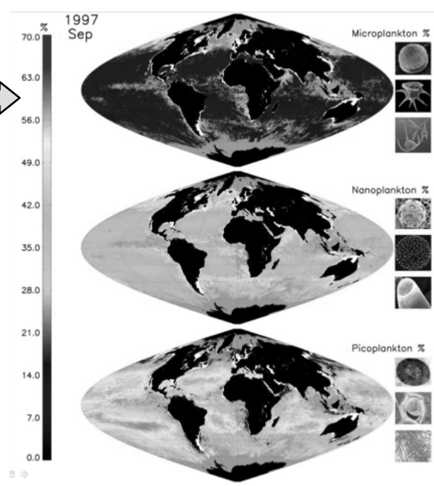
Biological carbon reservoir & Primary Production







Bigger cells (>20µm)

Medium cells (2-20 µm)

Smaller cells (<2 µm)

Size of algal cells regulates ecosystem processes:
- Primary production
- Length of food web
- Whole ecosystem production & respiration
- Carbon dioxide drawdown

Hirata et al., 2008 RSE;

Brewin et al., 2010 Eco Mod

PML PLYMOUTH MARINE LABORATORY

UNIVERSITY OF PLYMOUTH

Analysis & Optimization of Plankton Ecosystem Models

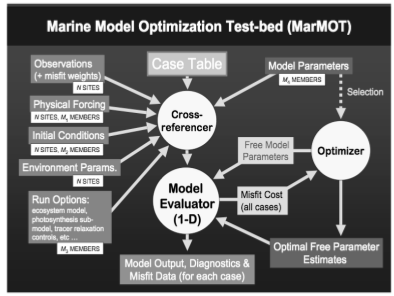
Weighting model-data misfit to allow for uncertainty in environmental inputs

▽

Robust multi-site calibration of models

▽

Intercomparison of models on the basis of structure & formulation



Ocean Surface pCO_2

JAN-DEC at 40°N 20°W

Role of satellite EO data:

- Provide many observations in all surface environments
- Test / optimise model parameters for applicability at basin-scales
- Provide contextual information for site-based time-series

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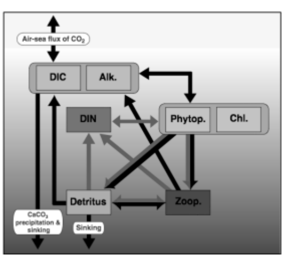
Courtesy of John Hemmings

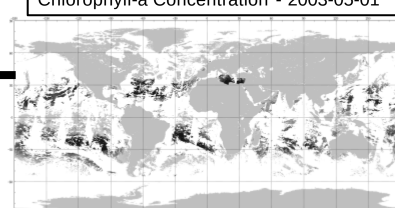
Oceans 2025

Assimilation of Ocean Colour Data in Met Office Carbon Cycle Models



DAILY 2-D CHLOROPHYLL ANALYSIS

Chlorophyll-a Concentration - 2003-05-01



ACRI & the GlobColour Team

Local 1-D balancing scheme for carbon and nitrogen pools

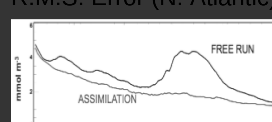
Courtesy of John Hemmings

Tests with synthetic data show potential for improving C fluxes

Ocean Surface pCO_2

JAN-DEC at 40N 20W

Dissolved Inorganic Carbon R.M.S. Error (N. Atlantic)



APR MAY JUN JUL AUG

Met Office

National Oceanography Centre, Southampton
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Summary & Challenges

- Carbon cycle
  - basic component of Earth system: atmosphere, land & ocean
  - a fundamental element of global change & climate warming
  - intimately related to water cycle, atmospheric chemistry & biodiversity
- A crucial issue is credibility of models. Need an integrated approach to using satellite EO with in situ observations and modelling systems
  - Recent advances in data assimilation provide route for this
- Exploit co-located sensors to improve local flux estimates:
  - Envisat → Sentinel-3
  - IR and OC radiometers, Altimeters, Scatterometers
- Build & exploit new sensors for carbon cycle monitoring:
  - Atmospheric greenhouse gases
  - Biomass

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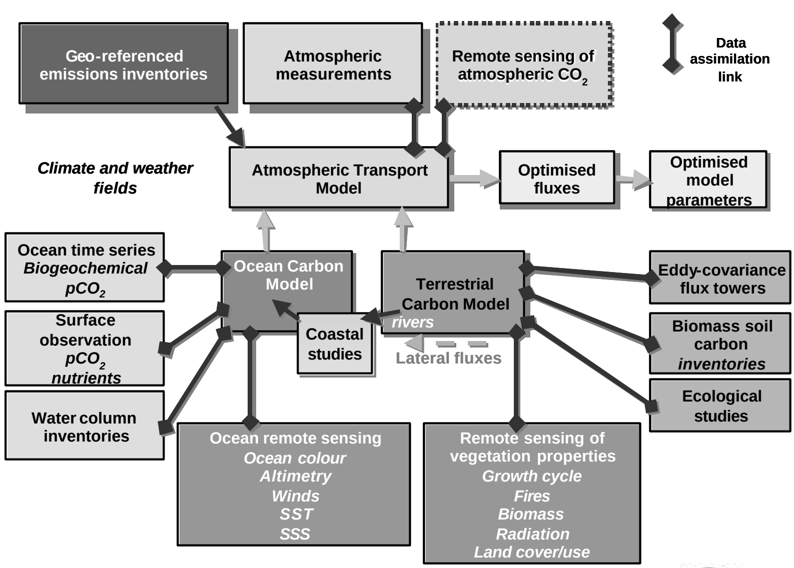
Global Carbon Data Assimilation System



Ciais et al. 2003 IGOS-P Integrated Global Carbon Observing Strategy

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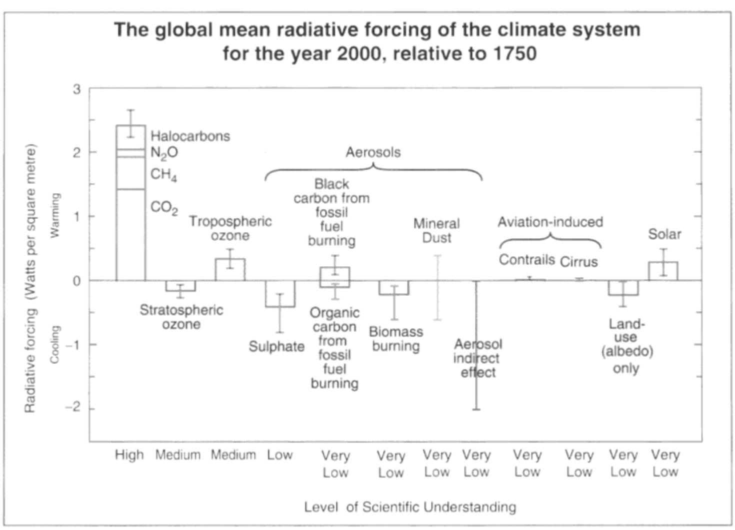
Radi



IPCC, Climate Change, 2001

Greenhouse gases

Gas	Radiative efficiency ($Wm^{-2}ppb^{-1}$)	Lifetime (years)	Global Warming Potential		
			Time horizon		
			20 yrs	100 yrs	500 yrs
CO_2			1	1	1
CH_4	3.7×10^{-4}	12.0	62	23	7
N_2O	3.1×10^{-3}	114	275	296	156

IPCC, Climate Change, 2001

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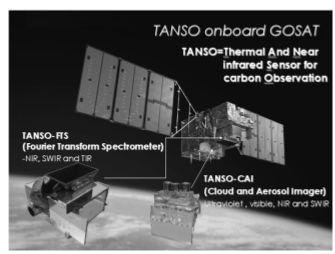
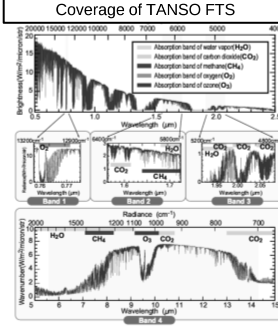
The GOSAT Satellite

- GOSAT satellite is first dedicated greenhouse gas sensor which carries 2 instruments:
- TANSO Fourier Transform Spectrometer (FTS):
  - Provides spectrally-resolved radiances for 4 shortwave-IR (polarized) and thermal-IR bands
  - Covers several absorption bands of CO_2, CH_4, O_3 and H_2O (and others) and O_2
- Cloud aerosol imager (CAI):
  - 4 broadband channels from UV to SWIR with high spatial resolution
  - Provides aerosol and cloud information required for the GHG retrieval

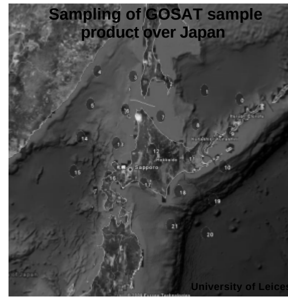


Coverage of TANSO FTS



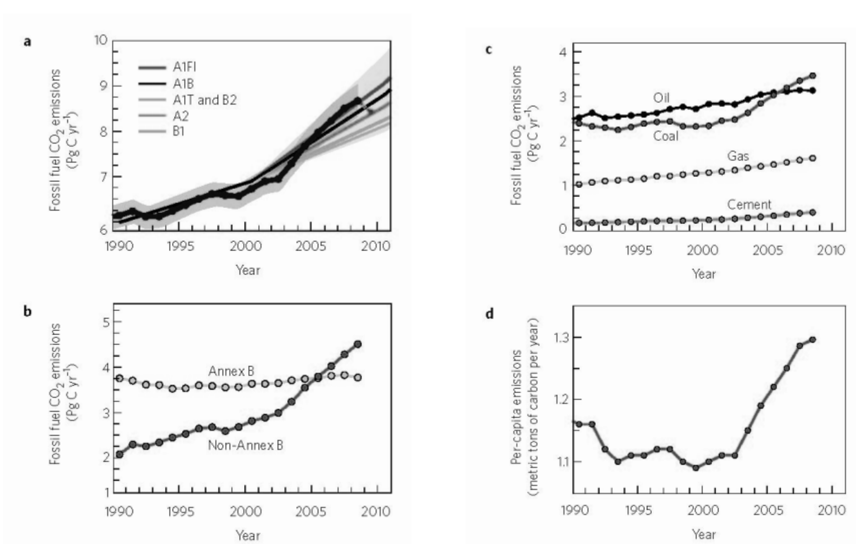
GOSAT Data

- GOSAT sampling strategy:
  - 3 day repeat cycle
  - Isolated soundings with ~100 km distance in-between
  - Relatively large footprints with 10.4 km diameter
  - Nadir sampling over land and sunglint sampling over ocean between 35°N and 35°S

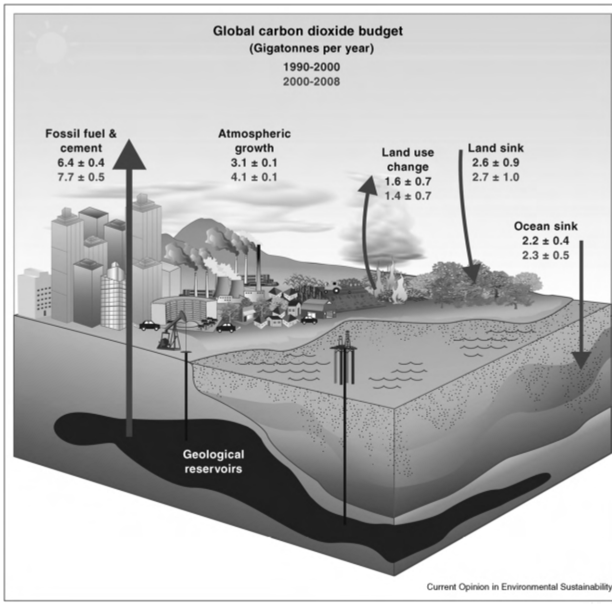


- Data availability and quality:
  - GOSAT FTS spectra, CAI data and L2 for SWIR CO_2 and CH_4 data are available
  - Initial calibration and validation has been carried out:
    - Improvements to calibration are still on-going and L1B data versions can differ significantly
    - No Muller Matrix available so far to treat polarization-sensitivity of the instrument -> *problem for aerosol retrieval !*
    - Problem with phase correction for thermal-IR channel

Global trends in CO2



Current estimates of fluxes of anthropogenic CO2



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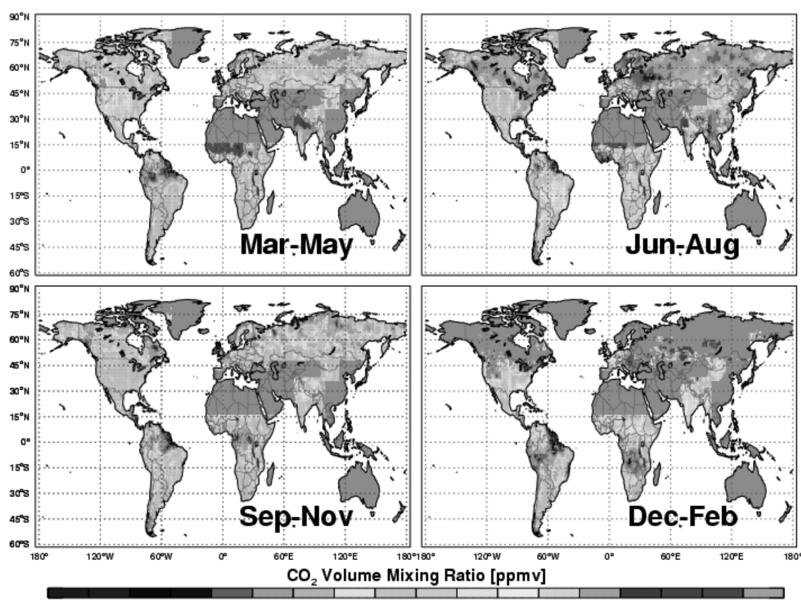
Seasonal variability in atmospheric CO2



Data

EO focus has been on producing geophysical products (fAPAR, LAI, snow water equivalent, soil moisture, etc.)

Implications:

- Deriving products often involves inverting a complex model, with no unique solution.
- Error properties of products often poorly characterised.

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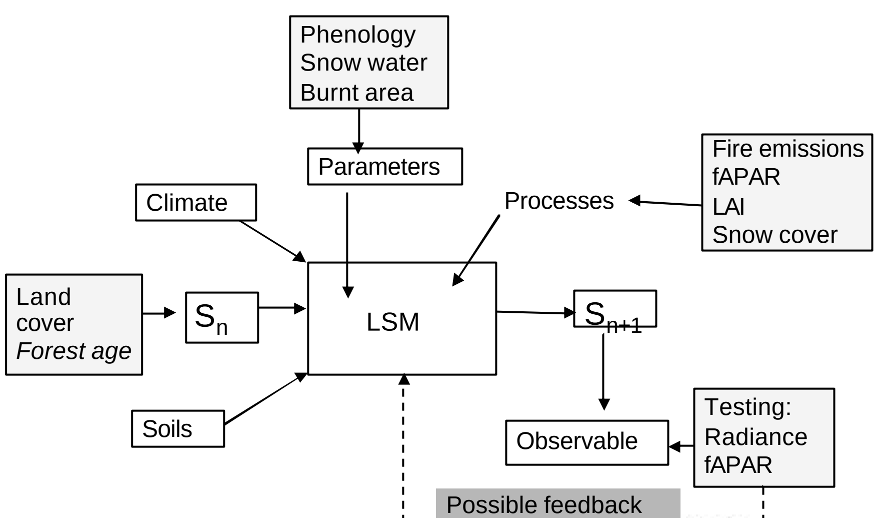
EO interactions with a Land Surface Model



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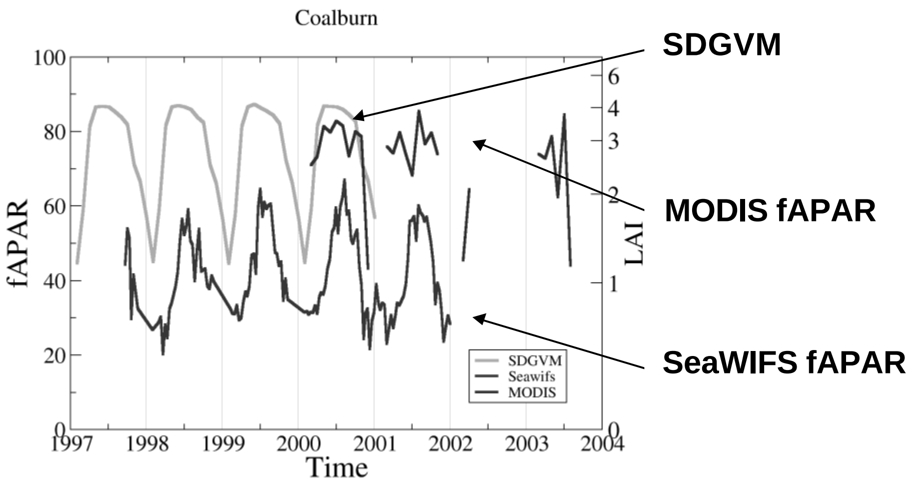
Comparing models and data



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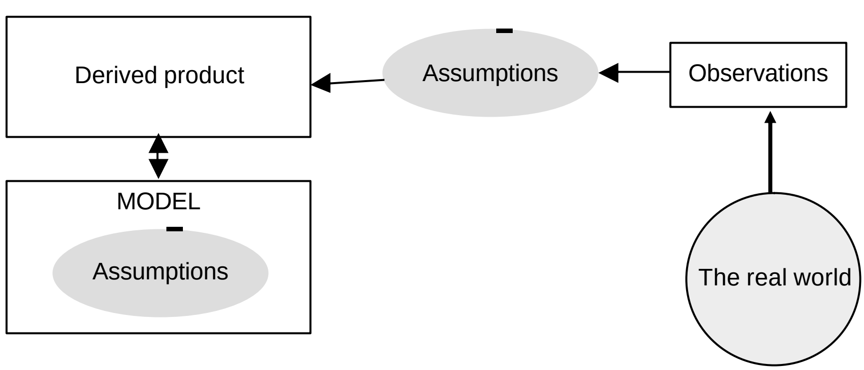
Are model and data representations consistent?



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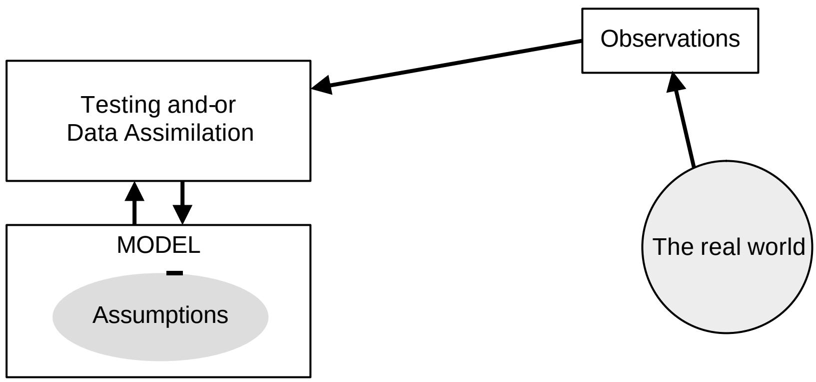
Resolving the inconsistency



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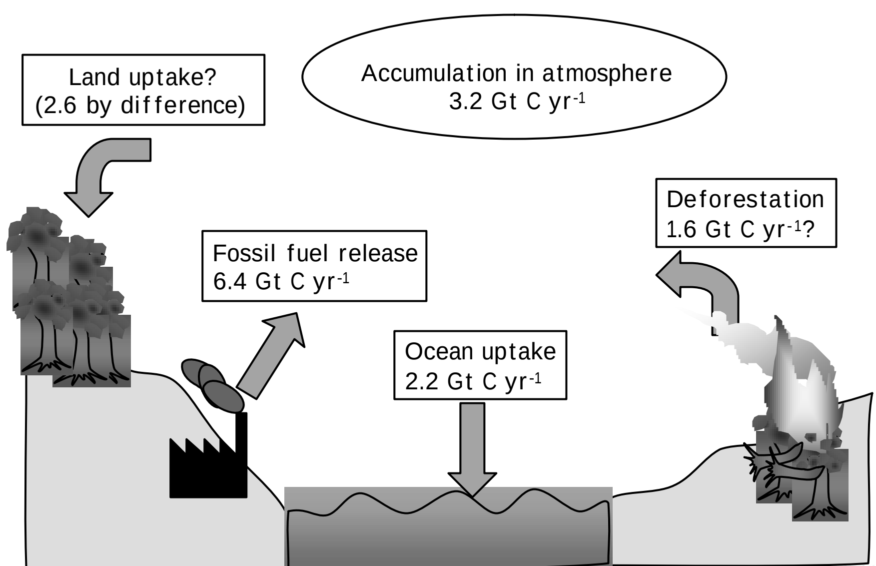
The C cycle: 1990s budget of anthropogenic CO2



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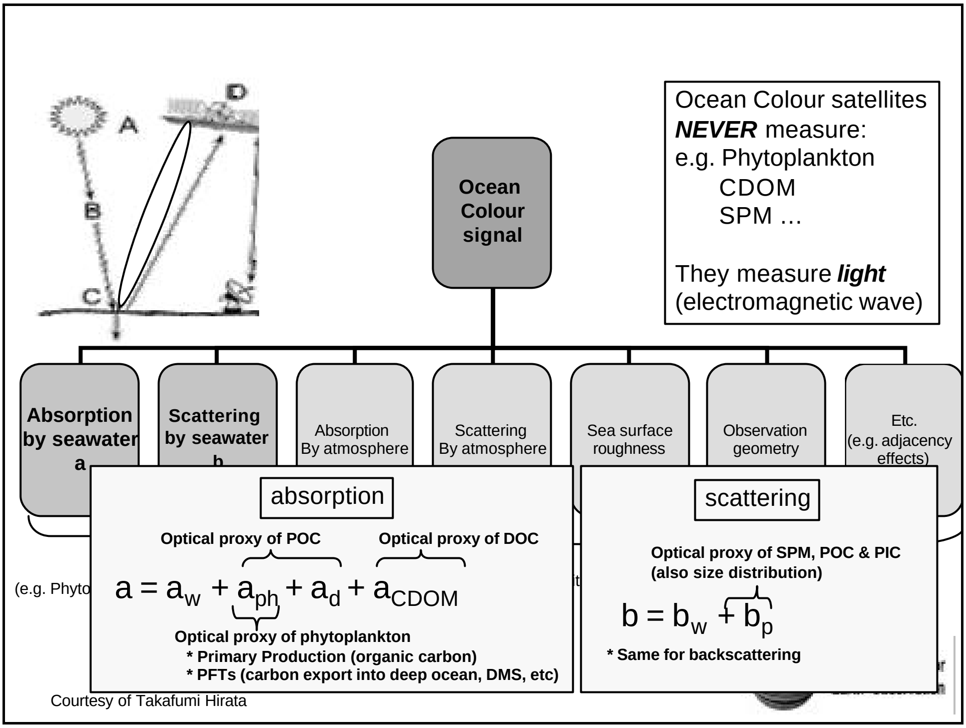

Courtesy of Takafumi Hirata