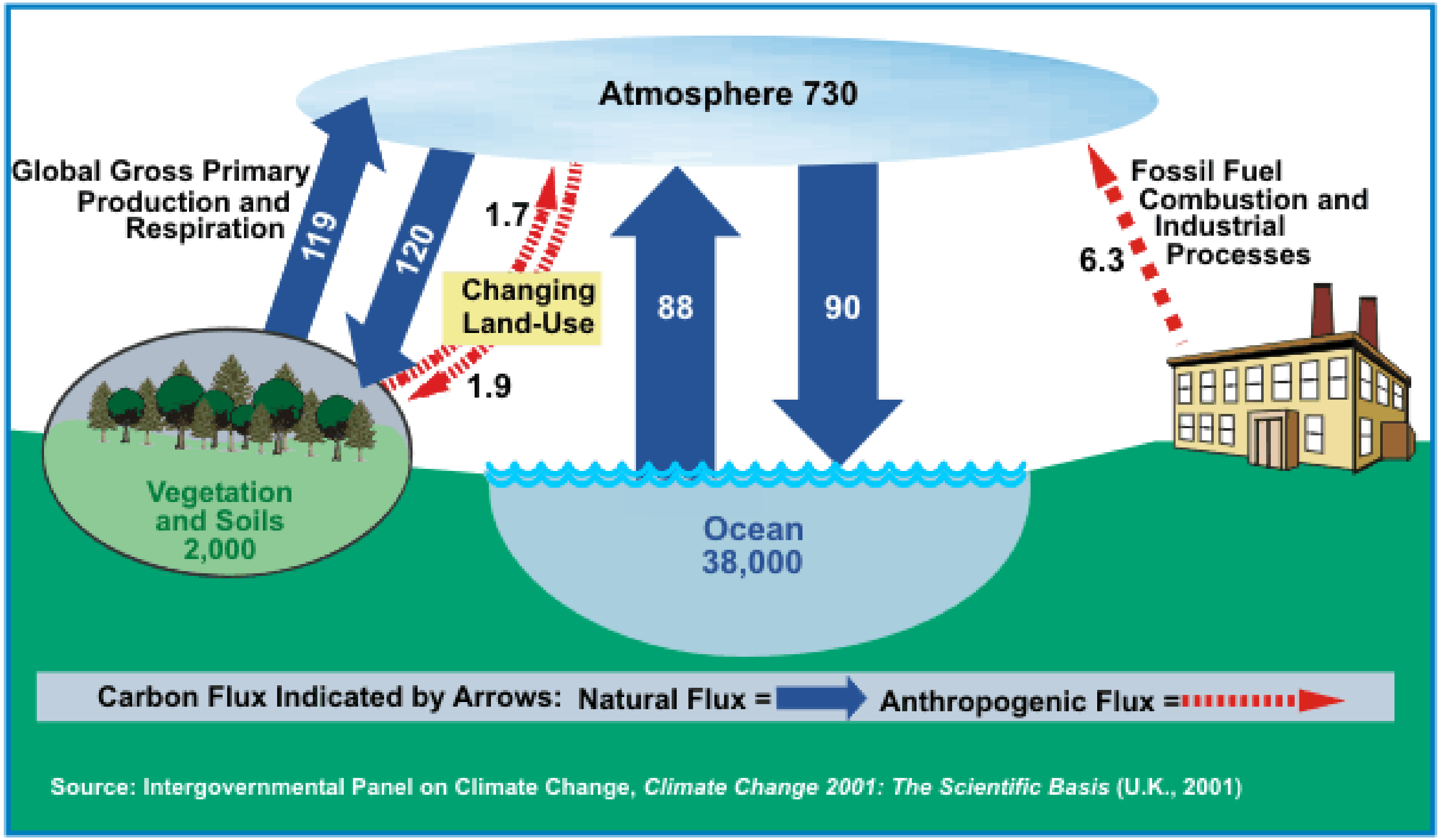
The Carbon Cycle and CCI: Where next?

Shaun Quegan (University of Sheffield)
Centre for Terrestrial Carbon Dynamics
& National Centre for Earth Observation

- The global carbon cycle and its relation to climate
- Carbon cycle models
- Focus on fire to illustrate key issues for CCI
- Challenges

Natural and perturbed carbon cycle



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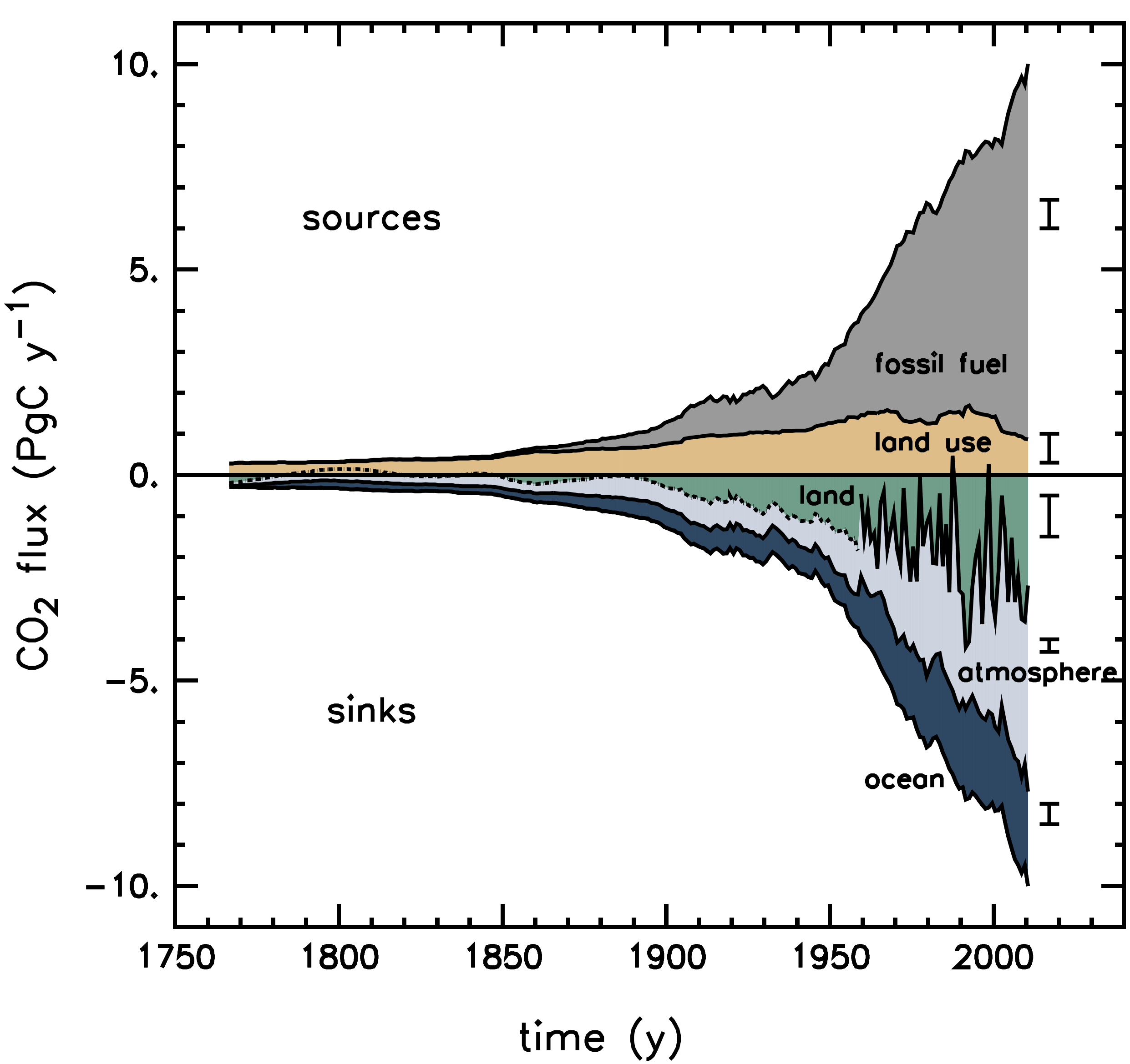
Perturbation of the Global Carbon Budget: 1850-2010



2000-2010

($PgC\ y^{-1}$)

7.9±0.5

1.0±0.7

2.5±1.0
(Residual)

4.1±0.2

2.3±0.5
(5 models)

Global Carbon Project 2011; Updated from Le Quéré et al. 2009, Nature G; Canadell et al. 2007, PNAS

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Key questions

1. Where are the major sources and sinks, and what is their likely long-term behaviour?
2. What are the key processes, and how will they change & interact in a changing climate?
3. What observing networks are needed to monitor and understand the carbon cycle and how does the CCI fit?
4. Can we manage the system?

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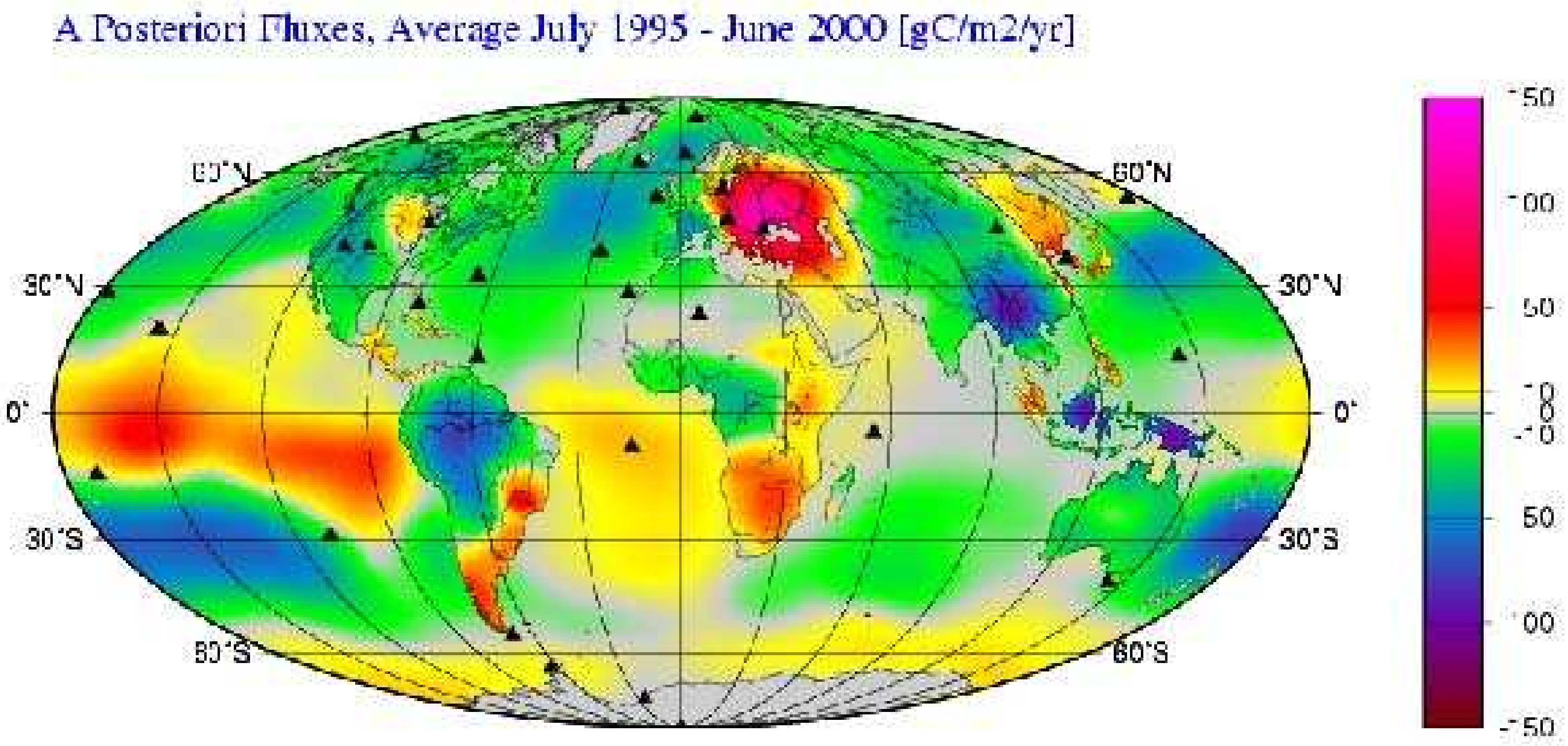
Global distribution of sinks over the period 1982-2001 (flask inversion method)



Sources red and yellow

Sinks green and blue

Fossil fuels not included

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

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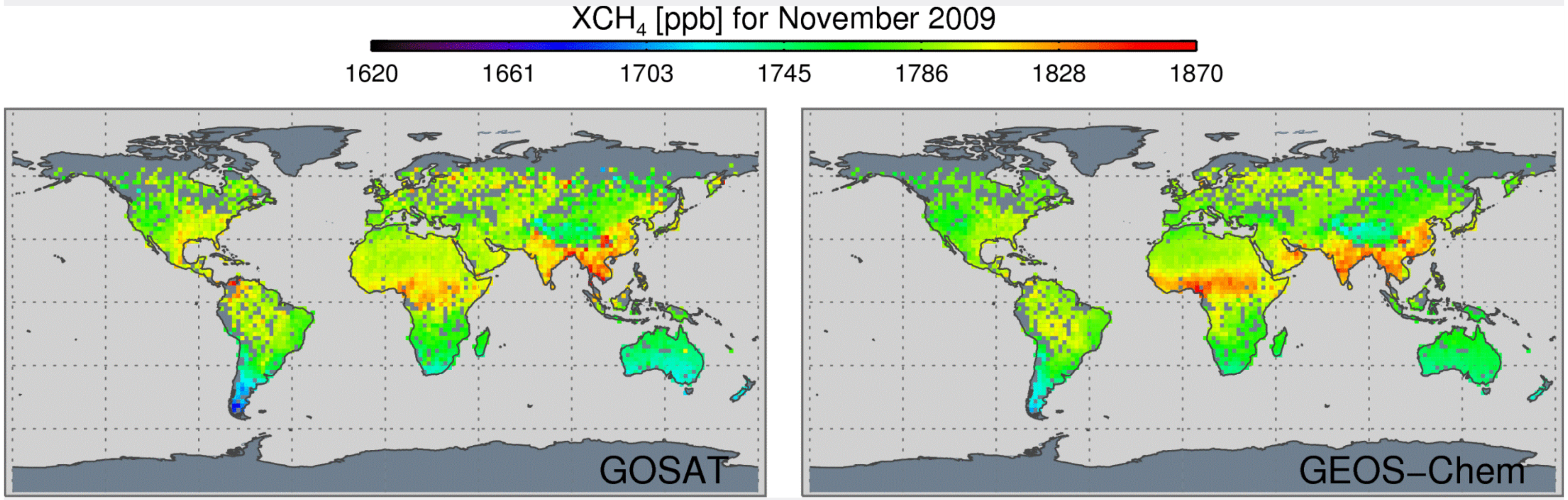
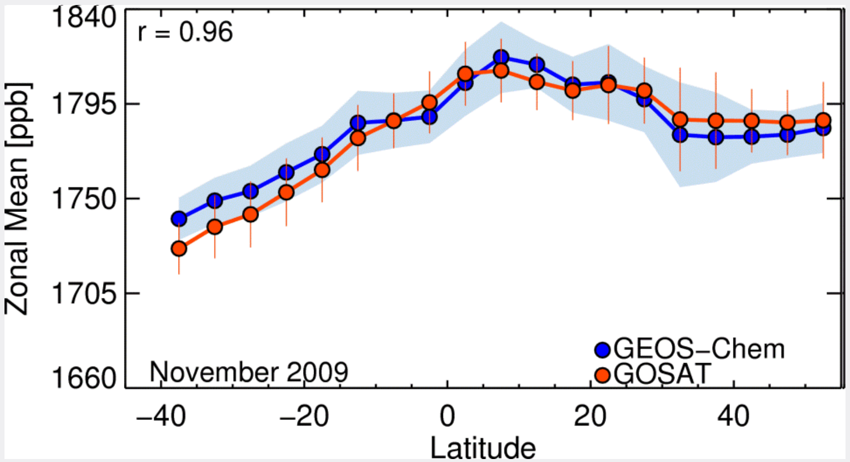
Global Monthly GOSAT X_{CH4} (Proxy)



- Key features
  - India/China – September – Rice paddies
  - Alaska/Boreal Asia – NH Summer – Wetlands/Wildfires
  - Africa/S. America – Biomass burning

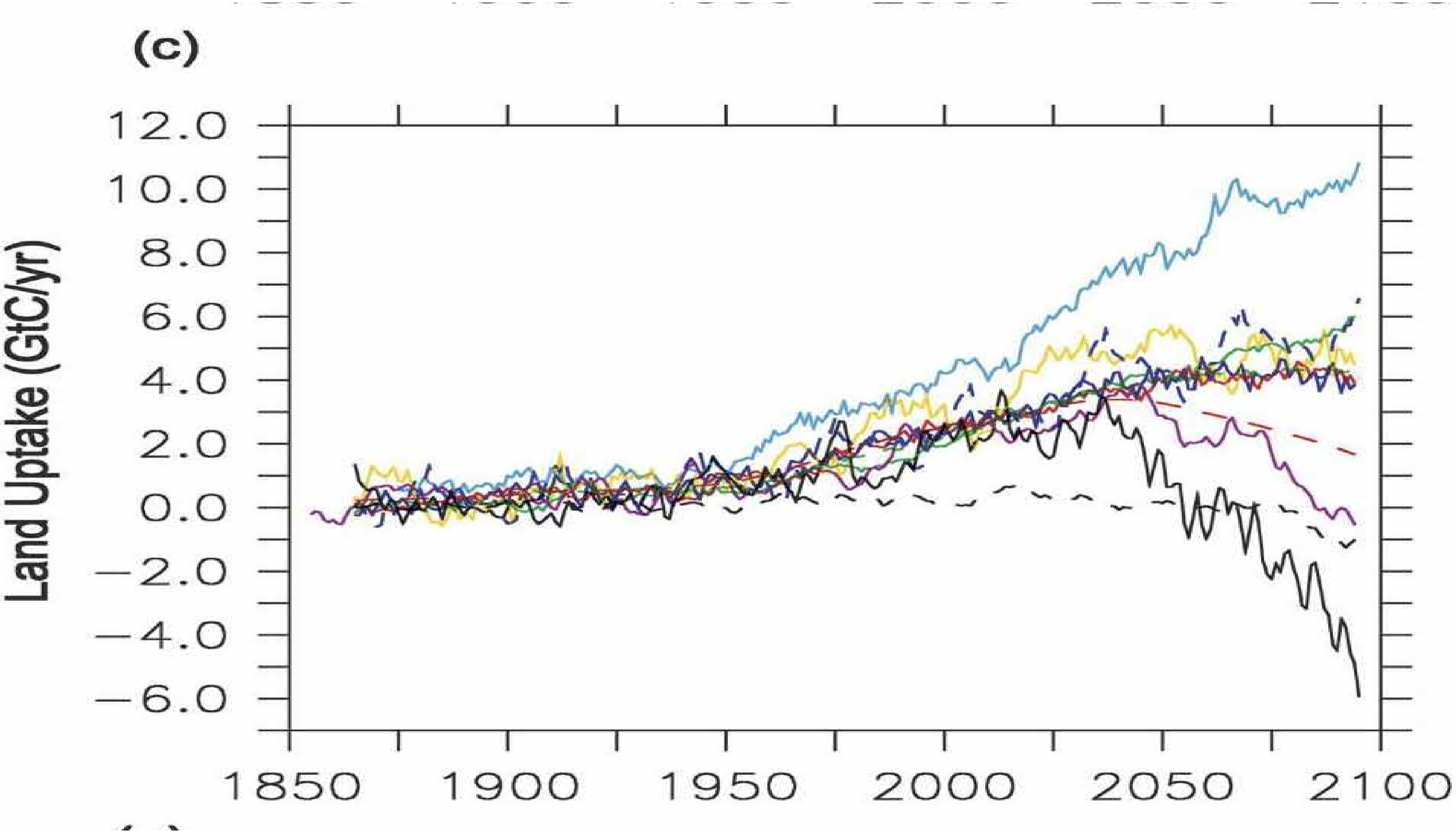


Updated version of Parker et al., 2011 GRL

Challenge: assimilate satellite estimates of CO_2 and CH_4 into climate models to improve their parameterisations.

Already in CCI through the Carbon Cycle Data Assimilation Scheme??

The C4MIP comparison of coupled models



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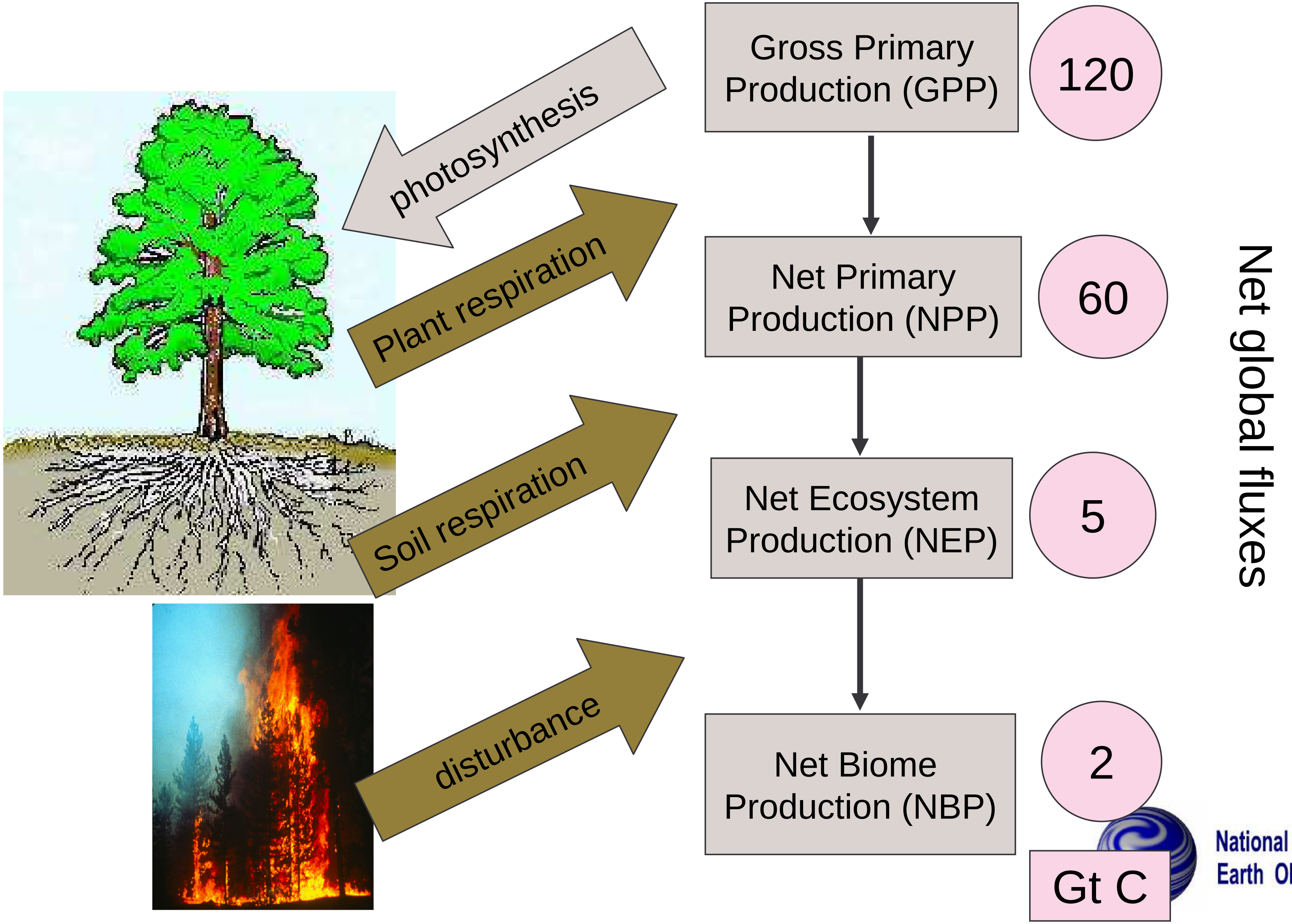
Models

- Carbon cycle models were developed 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
- Coupled models take account of climate-carbon cycle feedbacks (major source of climate prediction uncertainty)

Global “Natural” Land Carbon Fluxes



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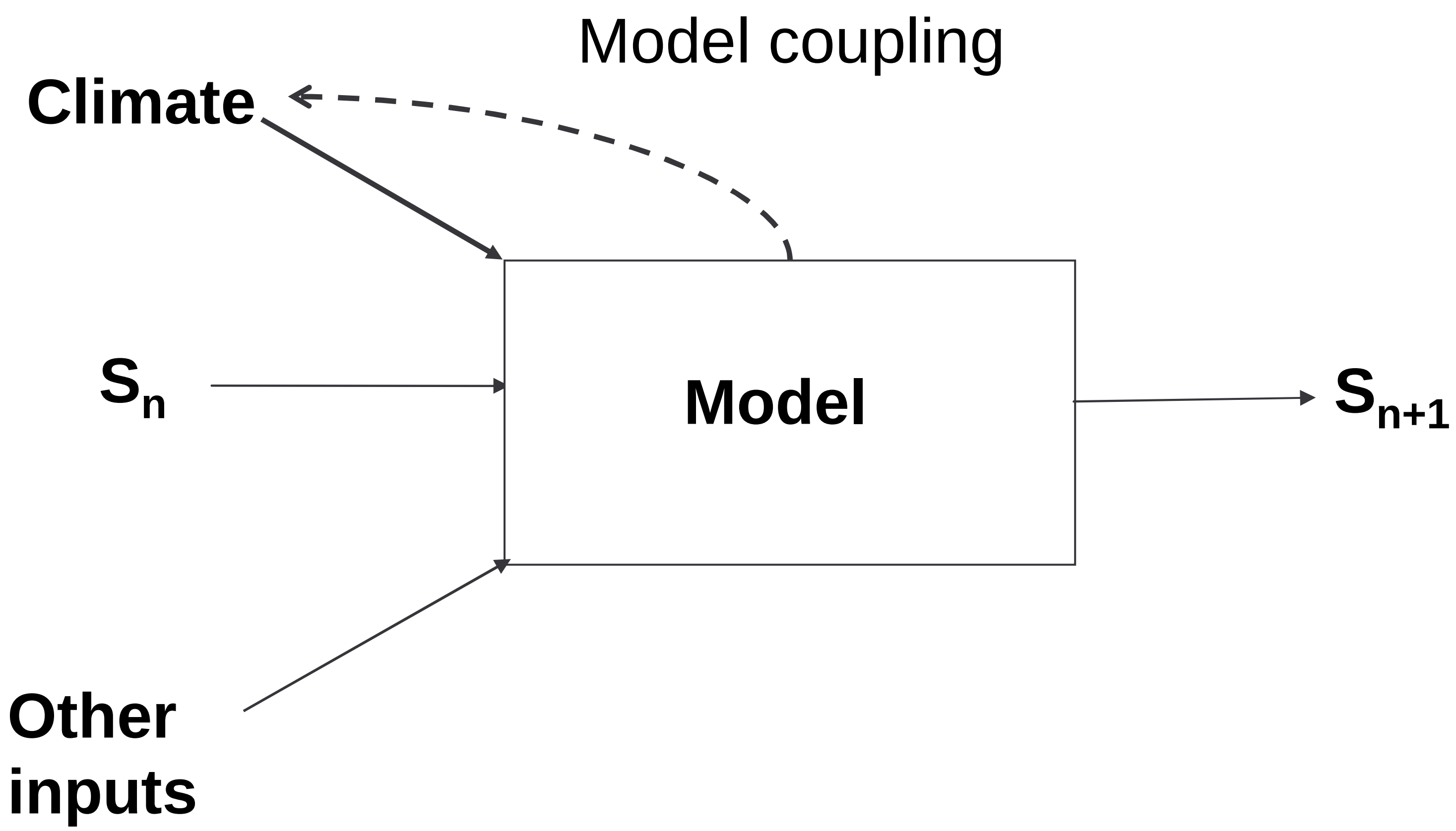
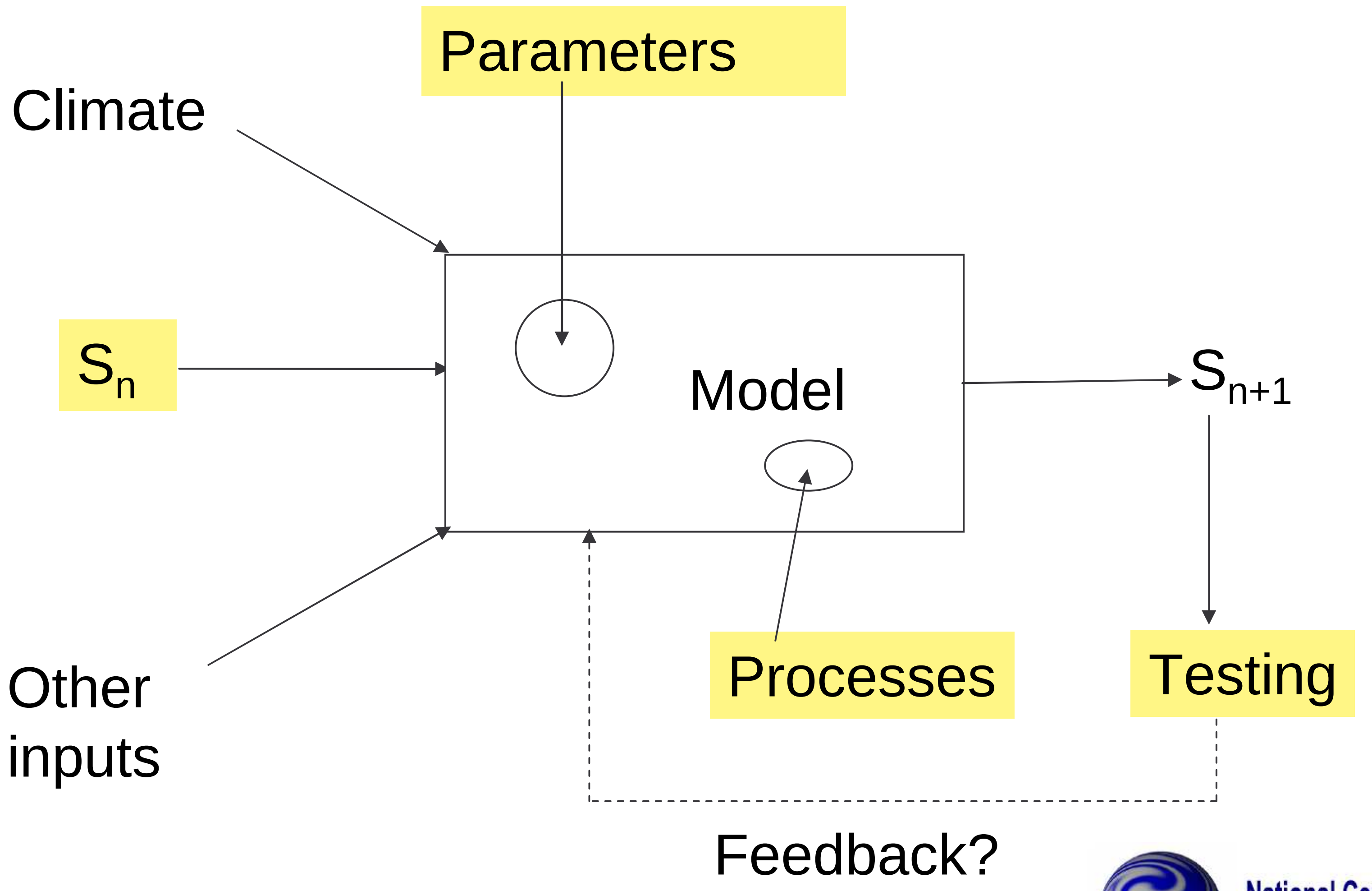
Simplified structure of a carbon flux model



How can data affect a carbon flux model?



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Essential Climate Variables

Atmospheric

- Surface – Air temperature, Precipitation, Pressure, Surface radiation budget, Wind speed and direction, Water vapour
- Upper Air – Earth radiation budget (including solar irradiance), Temperature, Wind speed and direction, Water vapour, Cloud properties
- Composition – **CO_2, CH_4** and other long-lived greenhouse gases (N_2O, CFCs, HCFCs, HFCs, SF_6 and PFCs), Ozone and Aerosol

Oceanic

- Surface – **Sea-surface temperature**, Sea-surface salinity, Sea level, Sea state, Sea ice, Surface Current, **Ocean colour,** Carbon dioxide partial pressure, **Ocean acidity**, **Phytoplankton**.
- Sub-surface: Temperature, Salinity, Current, Nutrients, CO_2 partial pressure, Ocean acidity, Oxygen, Tracers.

Terrestrial

- River discharge, Water use, Ground water, Lakes, Snow cover, Glaciers and ice caps, Ice sheets, Permafrost and seasonally-frozen ground, Albedo, **Land cover**, **Fraction of absorbed photosynthetically active radiation (fAPAR), Leaf area index (LAI),** Above ground biomass**,** Soil carbon**, Fire disturbance, Soil moisture**, (*Land Surface Temperature*)

Red: relevant to C cycle
Bold: predominantly space-based measurements

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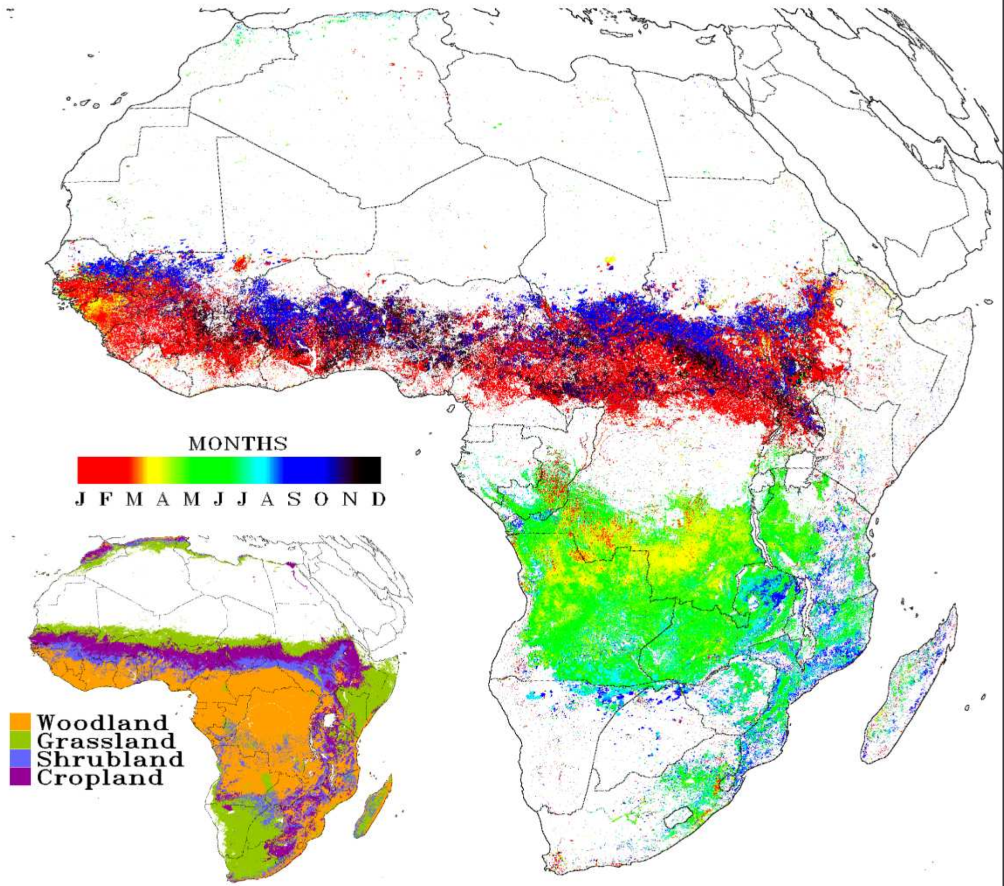
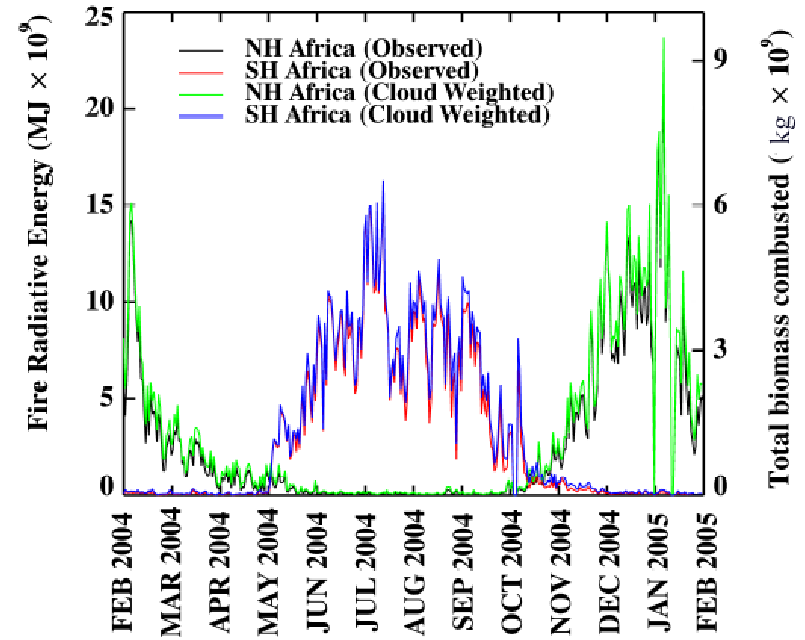
Estimating C Emissions from Radiative Energy

Fire Seasonality and Location



[Very strong seasonal cycle]

Temporal Emissions Variation



→ *NH Africa 362 - 414 Tg*

→ *SH Africa 402 - 440 Tg*

0.0 0.5 1.0 1.5 2.0 2.5

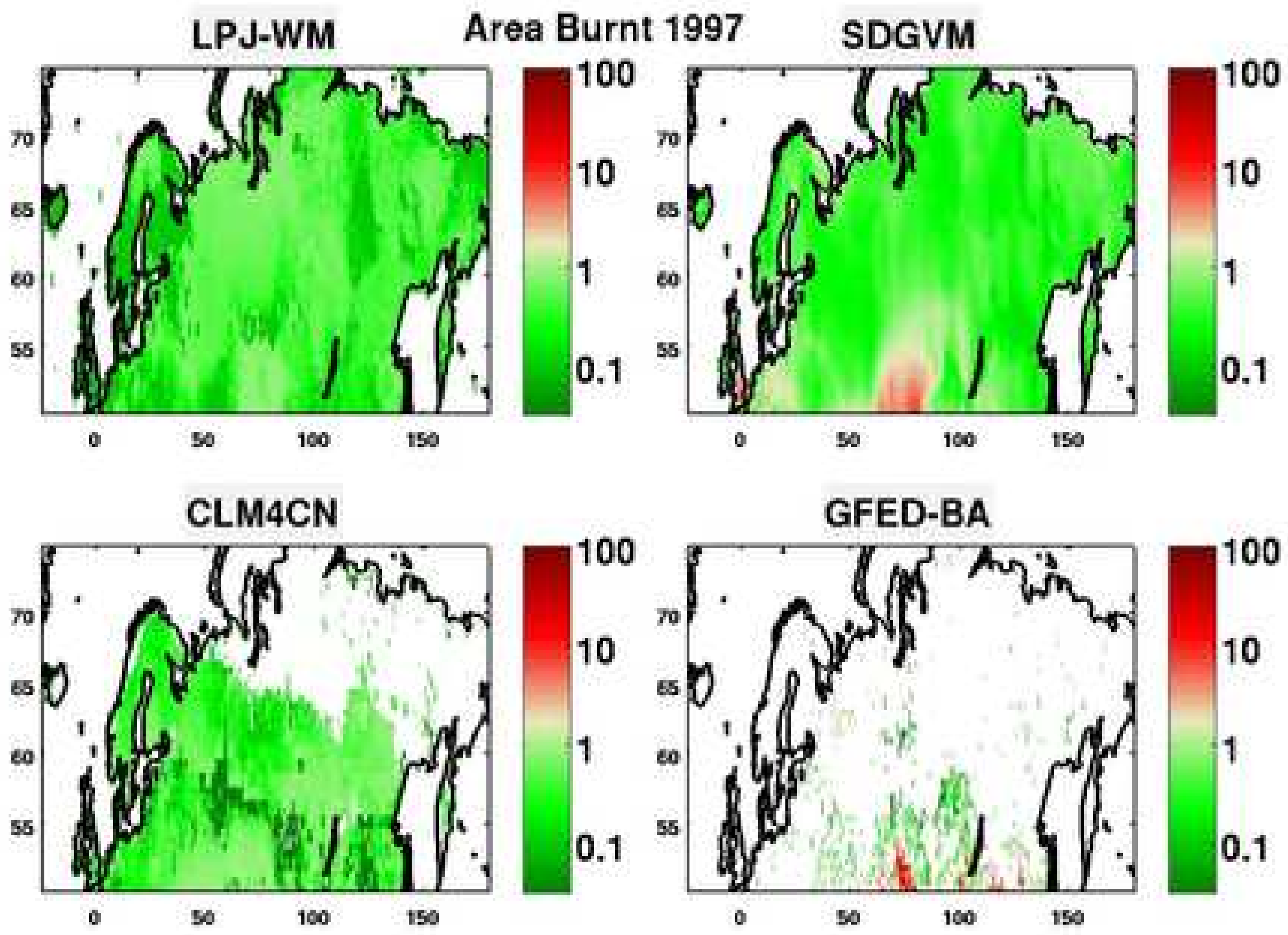
Fire Radiative Energy (MJ × 10^{10})

Short-Term Emissions Estimation as Model Drivers

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

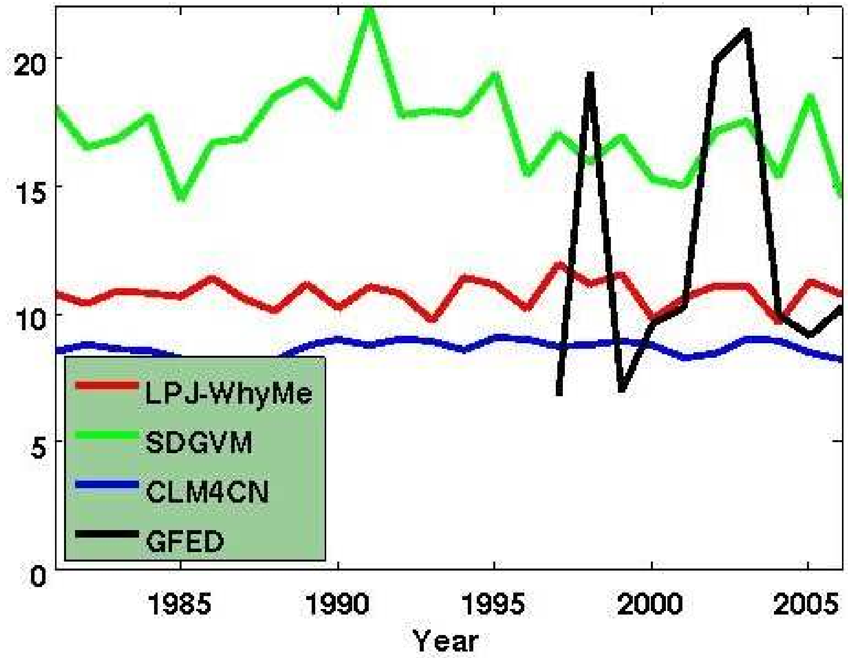
Modelled (blue)

Burned Area, Models & Data

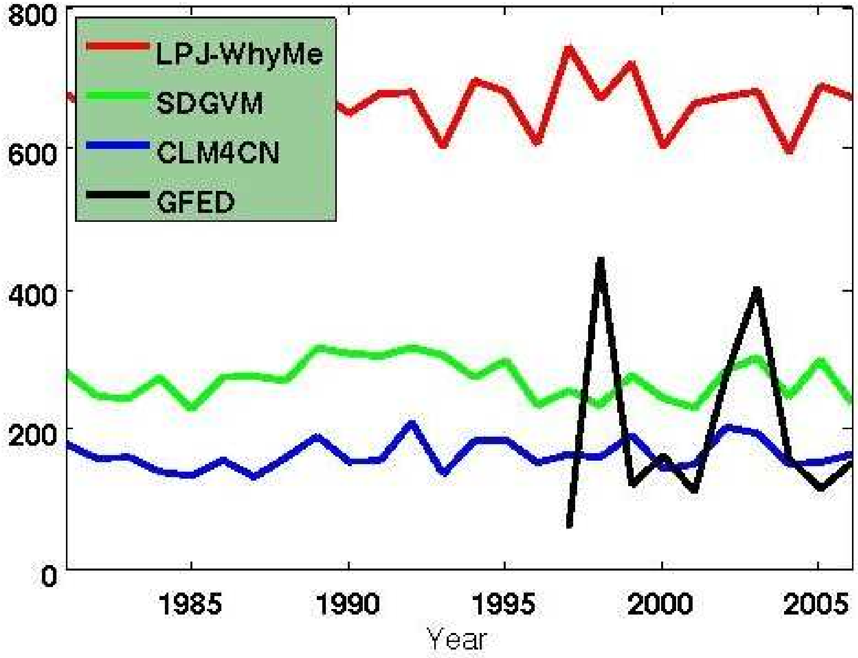


Burnt Area and Emissions

Burnt Area (Mha yr^{-1}), 50º- 75º N



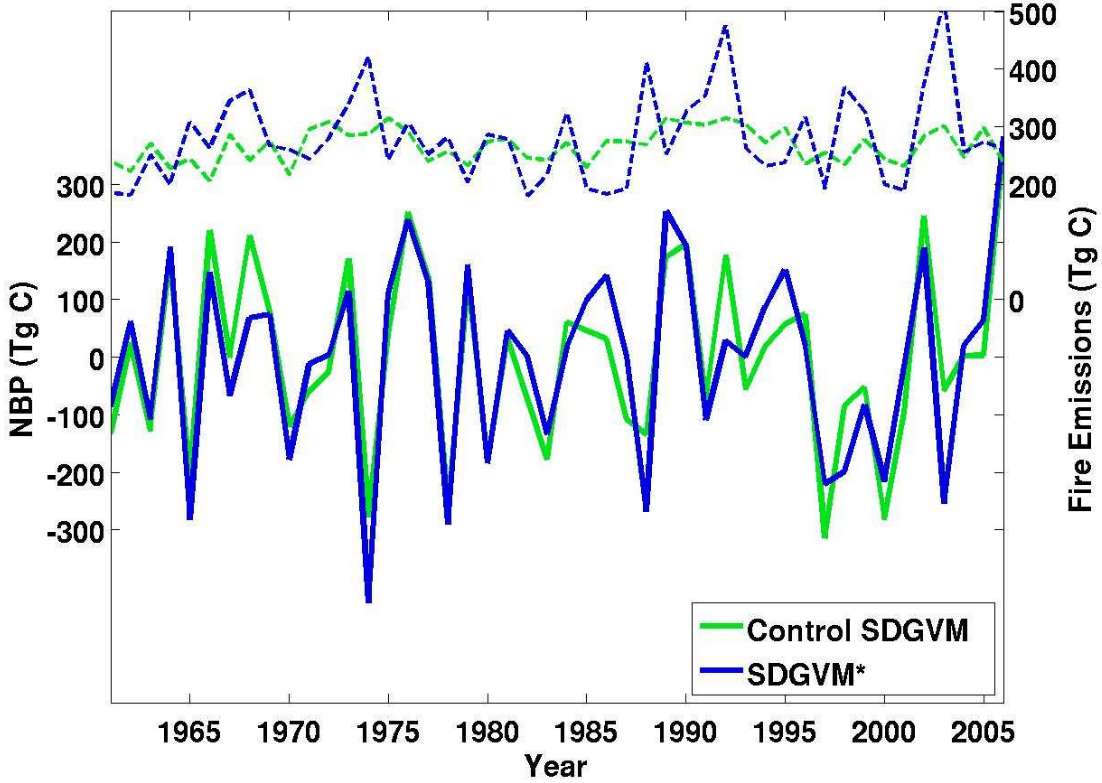
Fire Emissions (TgC yr^{-1}), 50º- 75º N



1. **Is FRP consistent with GFED emissions?**
2. **Are FRP and GFED consistent with atmospheric measurements and inversion?**
3. **Models do not capture the temporal & spatial variability of fire:**
   - Does it matter for climate?

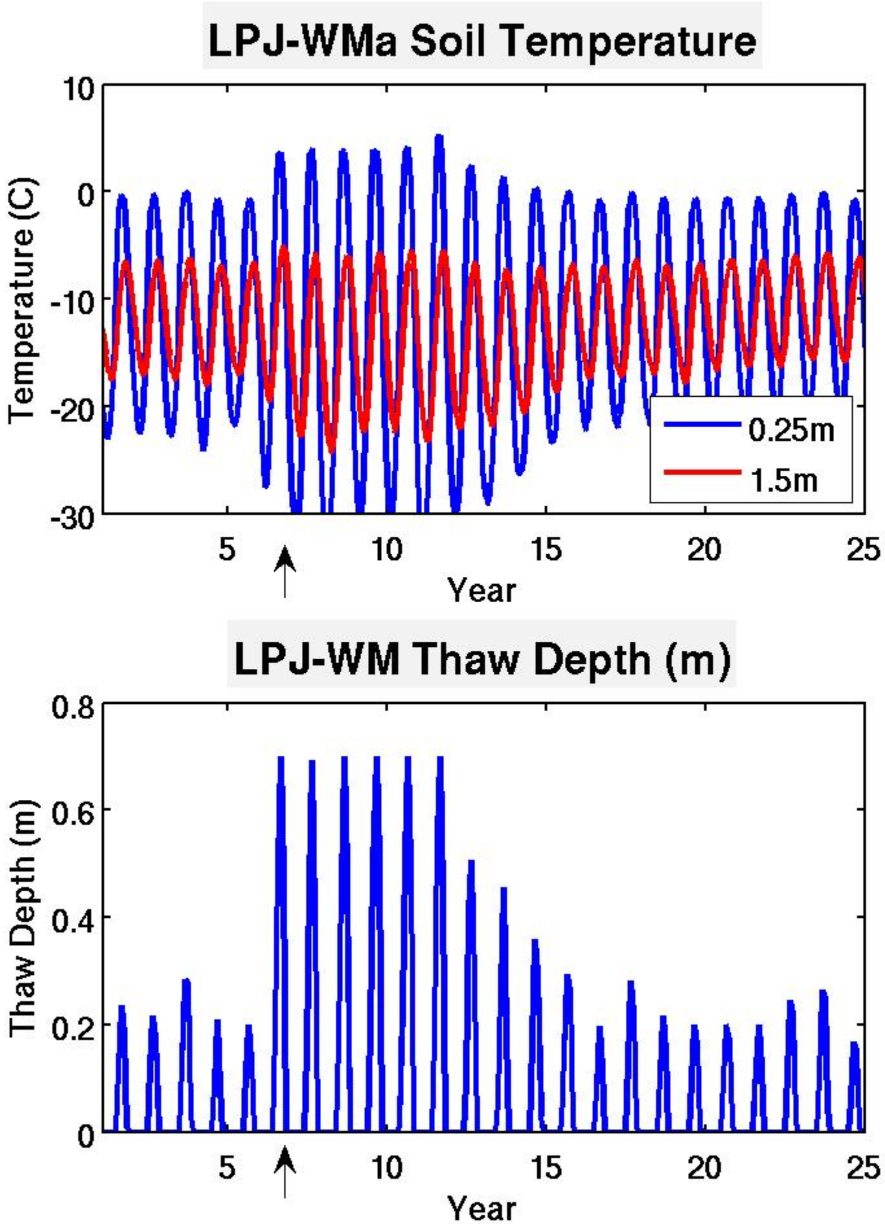
Fire as a factor in the variability of net land-atmosphere flux

For each grid cell, the model was modified to exhibit similar variability to data.



Variance of fire emissions increased but the inter-annual variability of NBP remained largely unaffected:
i.e. fire is not a key control of the IAV of net boreal carbon flux.

Response of permafrost to enhanced variability in fire



More severe fires remove the insulating effect of the litter and moss layers, increasing the active layer and mobilising GHGs: getting the spatio-temporal statistics of fire wrong causes a driver of climate change to be omitted.

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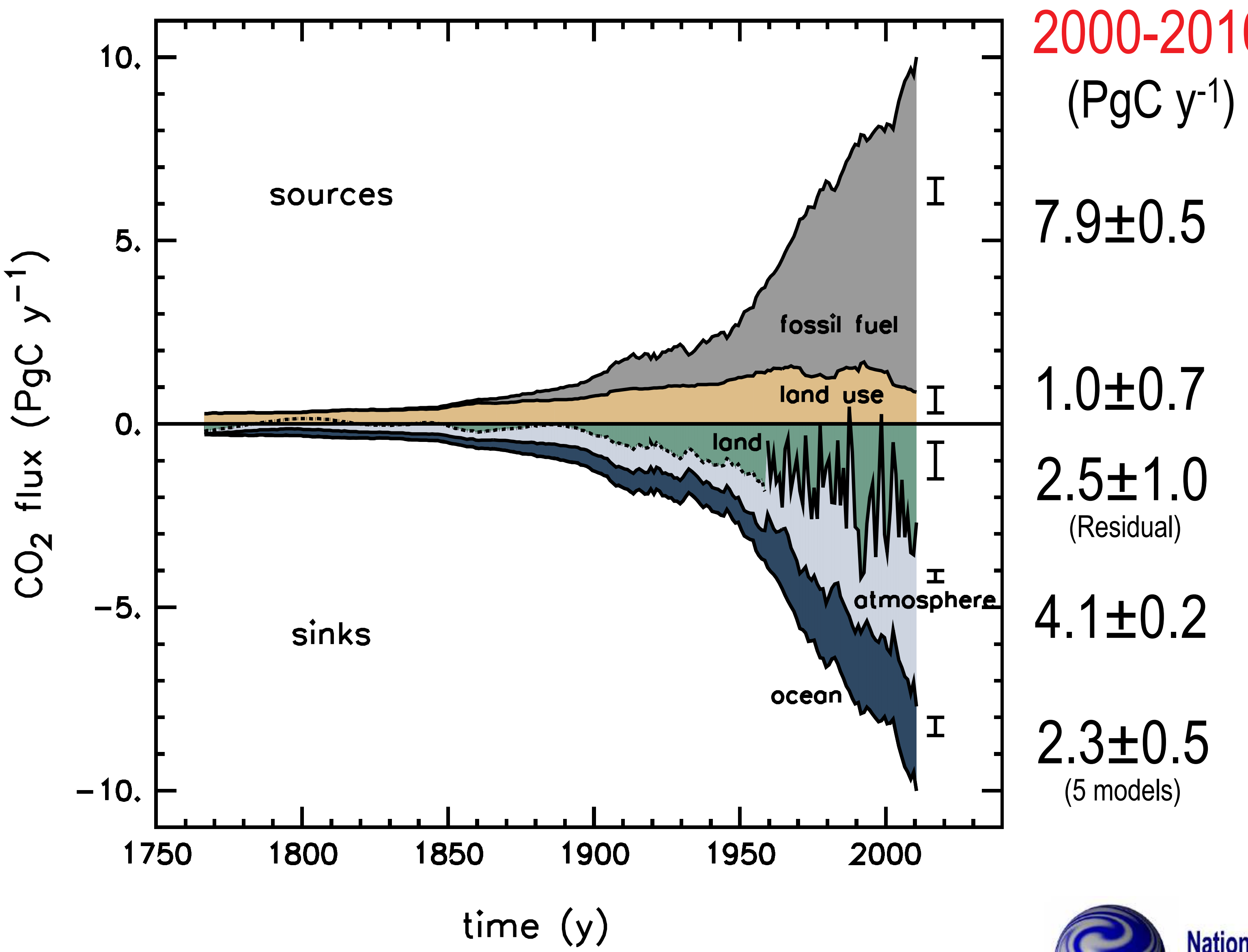

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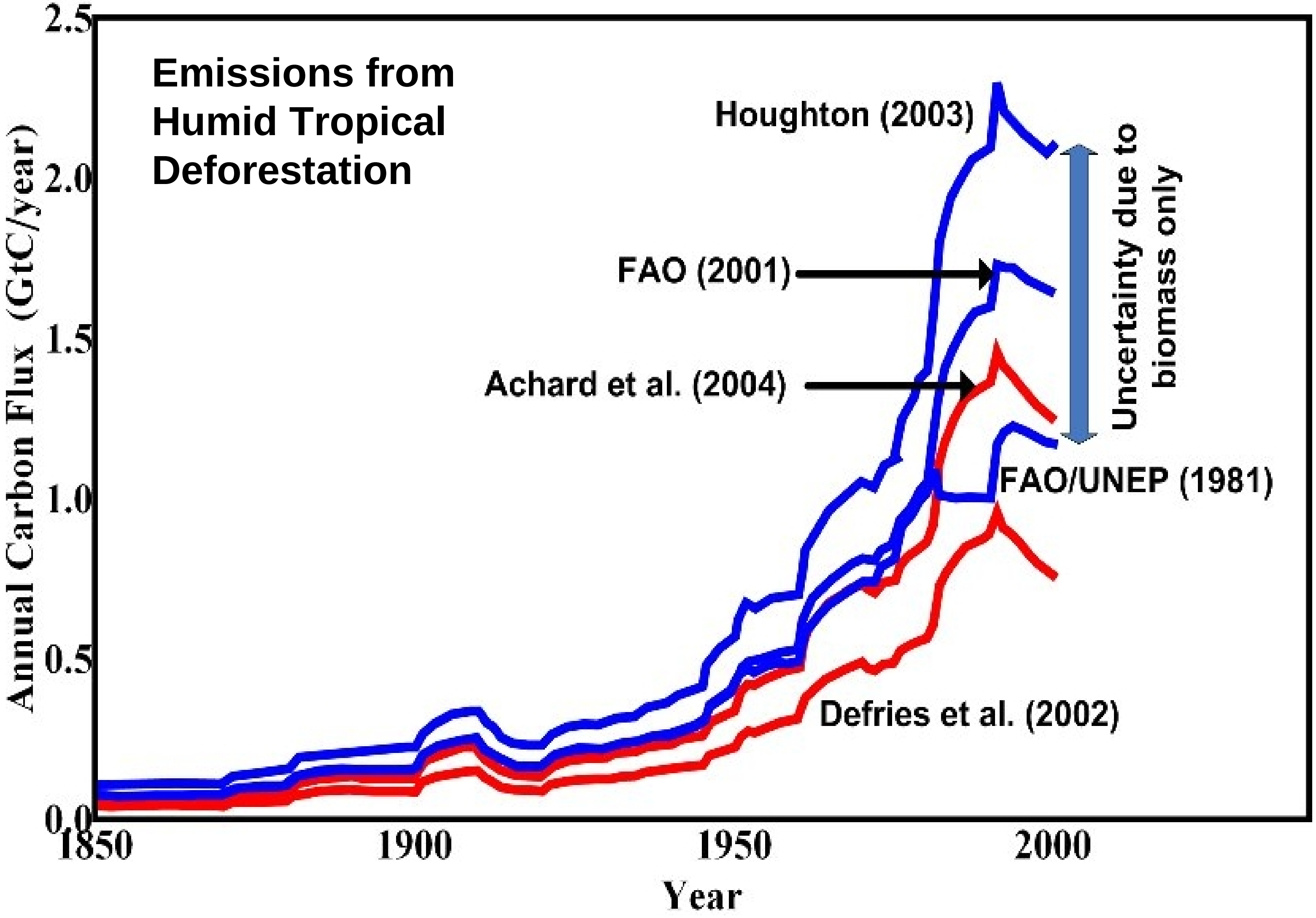
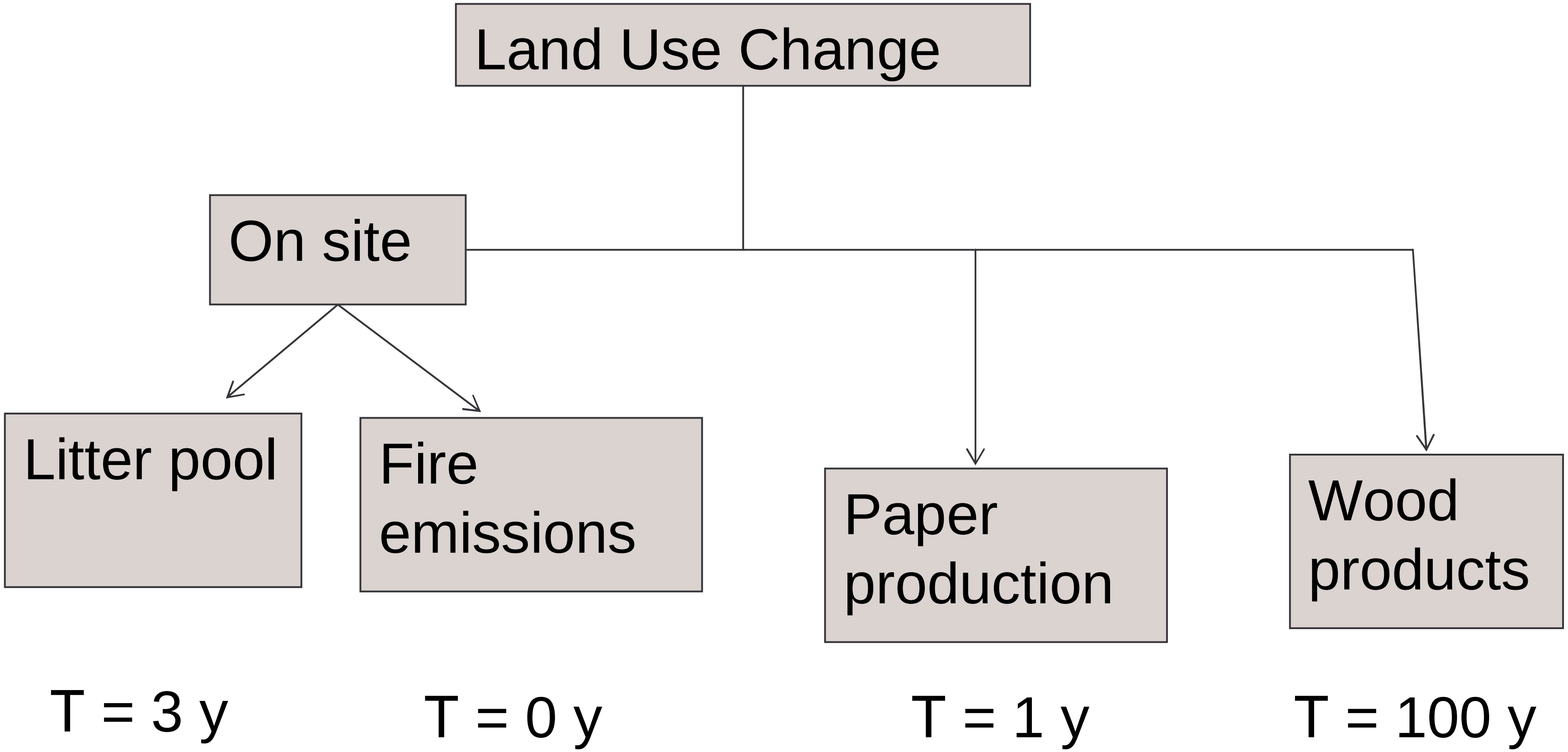
Uncertainty in emissions from humid tropics



Modelling the fate of carbon after disturbance



How consistent is this model schema with fire emissions data?

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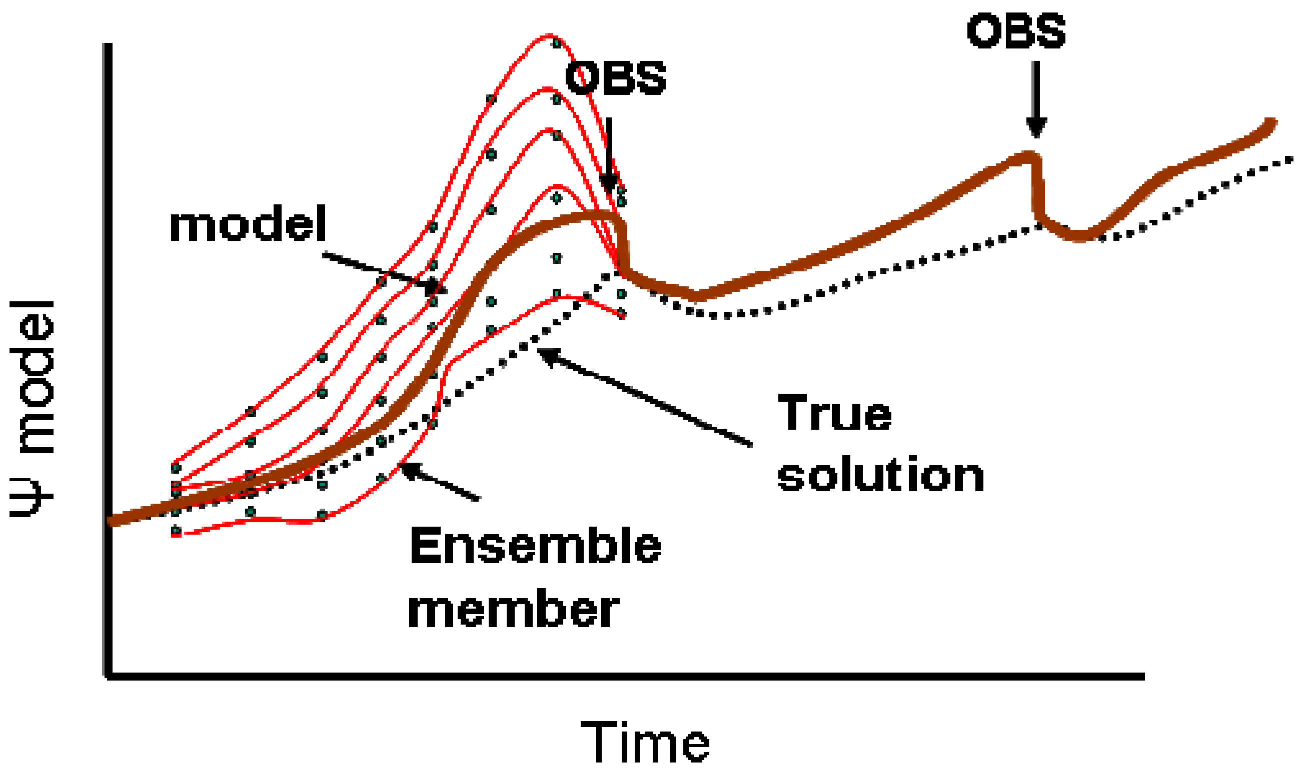
Integration of EO with models

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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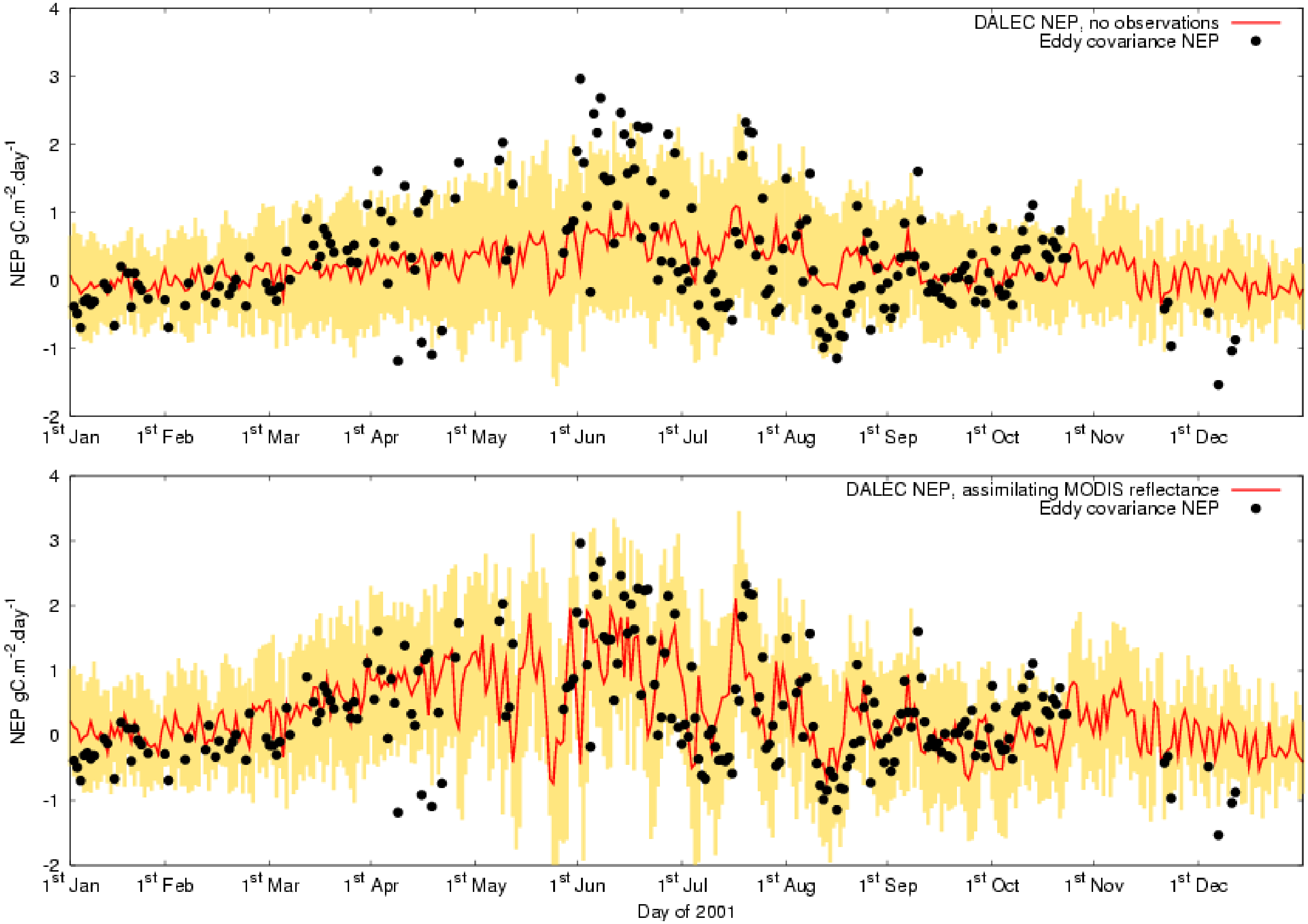
Courtesy of Ricardo Torres

Data assimilation (DA) to improve estimates of Net Ecosystem Production

No assimilation

Assimilating MODIS

(red/NIR)



Key point: assimilation of radiance in order to control uncertainty – key for meaningful DA but poorly known for products such as LAI and fAPAR

Summary & Challenges

1. Using EO data to measure and understand the carbon cycle is almost entirely an issue of model-data fusion
2. No new ECVs; some new sensors: Sentinels, BIOMASS (?), Carbosat (?), FLEX (?), so the issue is mainly to do better with the ones we've got
3. C cycle processes highly inter-connected: synergy of ECVs
4. Consistency of ECVs with each other and with models
5. Are ECVs fit for purpose? Answer is model-dependent.

   - Are models fit for purpose given the data?
6. Integration of EO data with in situ observations and models

   - Recent advances in data assimilation provide key route for this

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