

Recent Global CO₂ Flux Inferred From Atmospheric CO₂ Observations And Its Regional Analyses

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Outline

- Introduction
- Inversion technique: models and datasets
- 6-year inverted CO₂ fluxes
- Conclusions

Estimating Terrestrial Carbon Flux Distribution

- **Direct measurement: Fluxnet**

- Limited locations
- Short time series

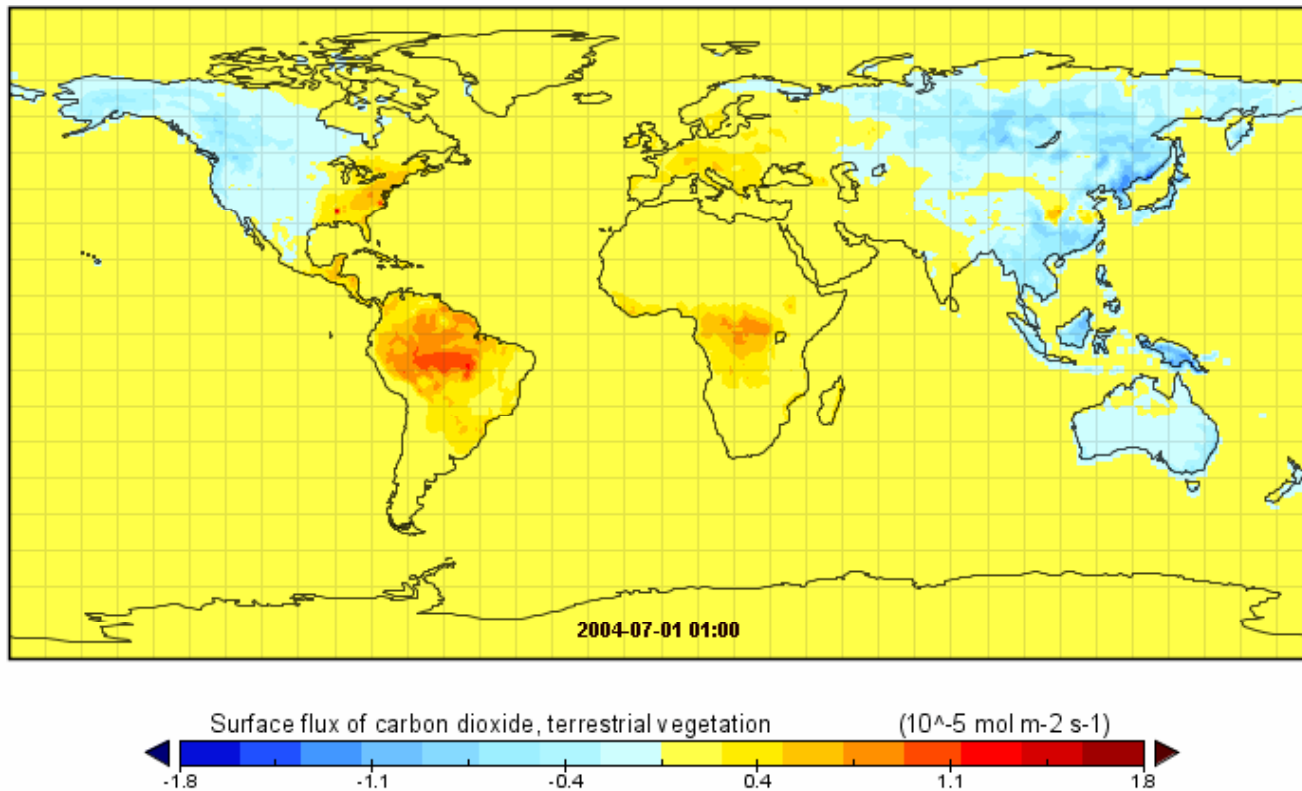
- **Terrestrial ecosystem modeling** [Sellers et al., 1986 and 1996; Running and Coughlan, 1988; Running and Gower, 1991; Prentice et al., 1992; Potter and Klooster, 1999; Chen et al., 1999; Jones et al. 2001]

- Parameters

- **Atmospheric inversion** [Rayner et al., 1999, 2008; Keeling et al., 2001; Roedenbeck et al., 2003; Peylin et al., 2005; Baker et al., 2006, Gurney et al., 2004, 2008; Peters et al., 2007, 2010]

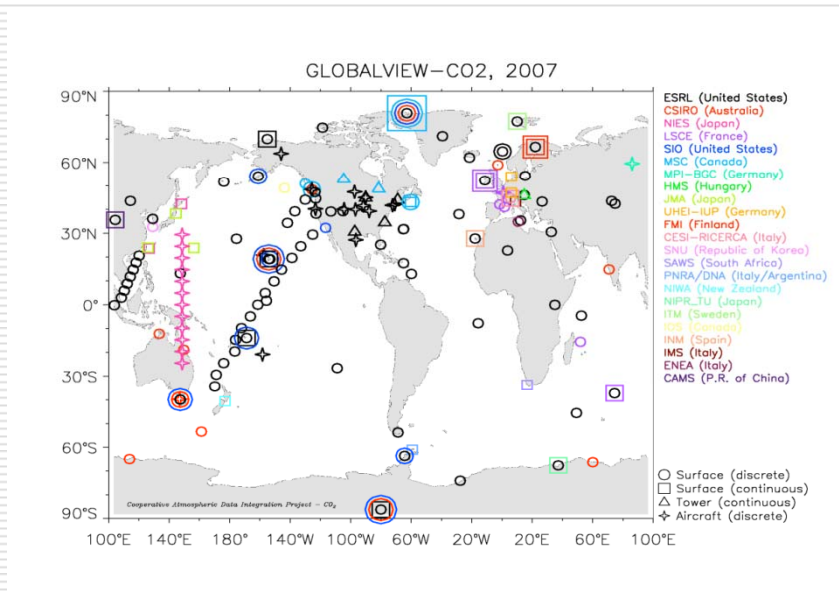
- Measurement sites too sparse

The Boreal Ecosystem Productivity Simulator (BEPS)

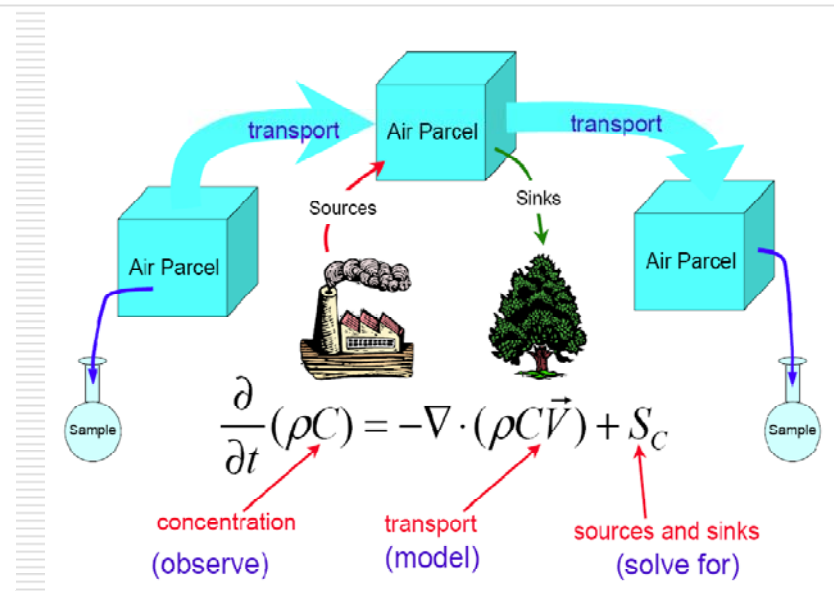


Chen et al., 1999

CO₂ Concentration Observations & Surface Flux Inversion



Source: GLOBALVIEW-CO₂: Cooperative Atmospheric Data Integration Project - Carbon Dioxide. NOAA ESRL, Boulder, Colorado



Source: S. Denning

Bayesian Formalism

- Use data, c , prior flux estimates, s_p , and model (with transport operator M) to estimate fluxes, s
- Estimate obtained by minimizing:

$$J = \frac{1}{2}(\mathbf{M}\mathbf{s} - \mathbf{c})^T \mathbf{R}^{-1}(\mathbf{M}\mathbf{s} - \mathbf{c}) + \frac{1}{2}(\mathbf{s} - \mathbf{s}_p)^T \mathbf{Q}^{-1}(\mathbf{s} - \mathbf{s}_p)$$

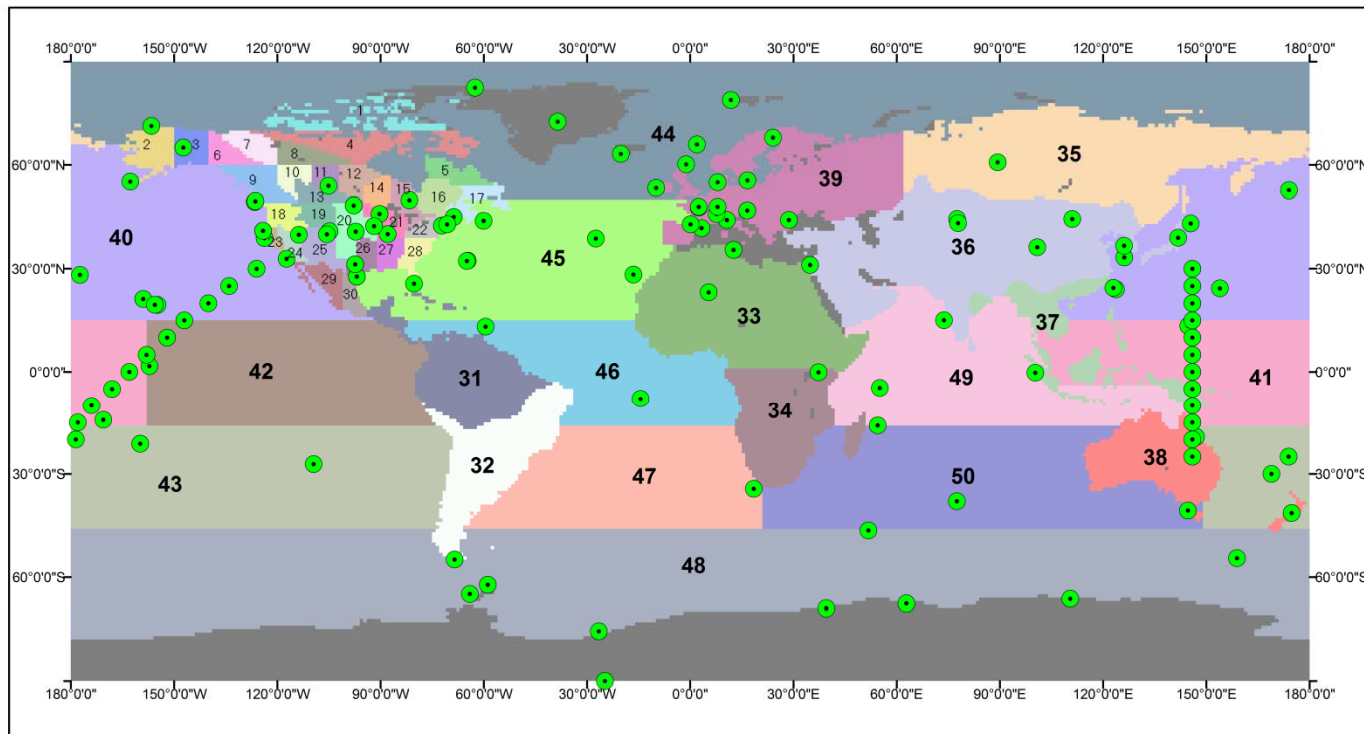
- Solution is $\hat{\mathbf{s}} = (\mathbf{M}^T \mathbf{R}^{-1} \mathbf{M} + \mathbf{Q}^{-1})^{-1} (\mathbf{M}^T \mathbf{R}^{-1} \mathbf{c} + \mathbf{Q}^{-1} \mathbf{s}_p)$

- Estimates, $\hat{\mathbf{s}}$ have covariance

$$\hat{\mathbf{Q}} = (\mathbf{Q}^{-1} + \mathbf{M}^T \mathbf{R}^{-1} \mathbf{M})^{-1}$$

Nested Global Inversion System

30 small regions in North America, 20 large regions for the rest of the globe (Transcom 3), and 208 CO₂ stations (GlobalView-2008)



Source: Deng et al. (2007)

TM5

- ❑ **Offline atmospheric transport model**

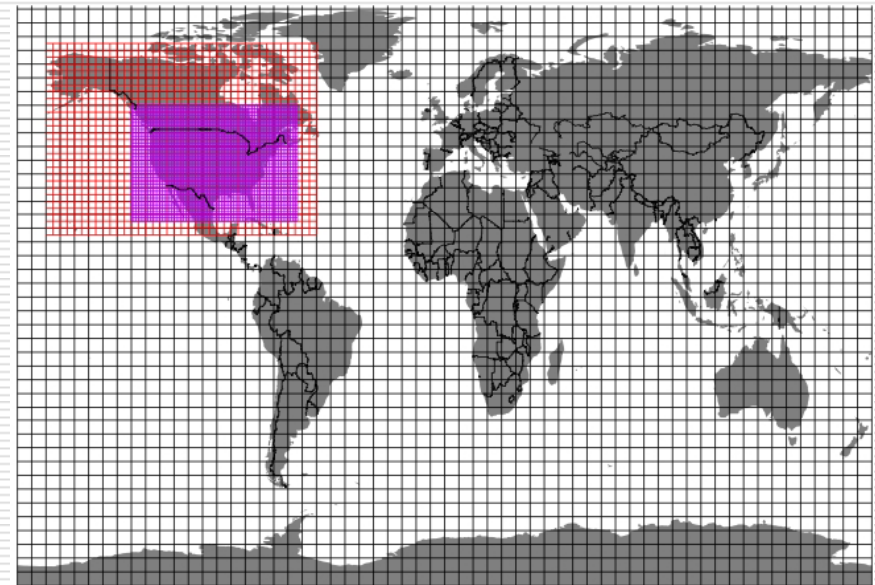
Krol et al. (2005)
Peters et al. (2004)

- ❑ **Meteorology from ECMWF**

- ❑ **Global simulation $6^\circ \times 4^\circ$**

- ❑ **Target area $1^\circ \times 1^\circ$**

- ❑ **25 vertical layers**

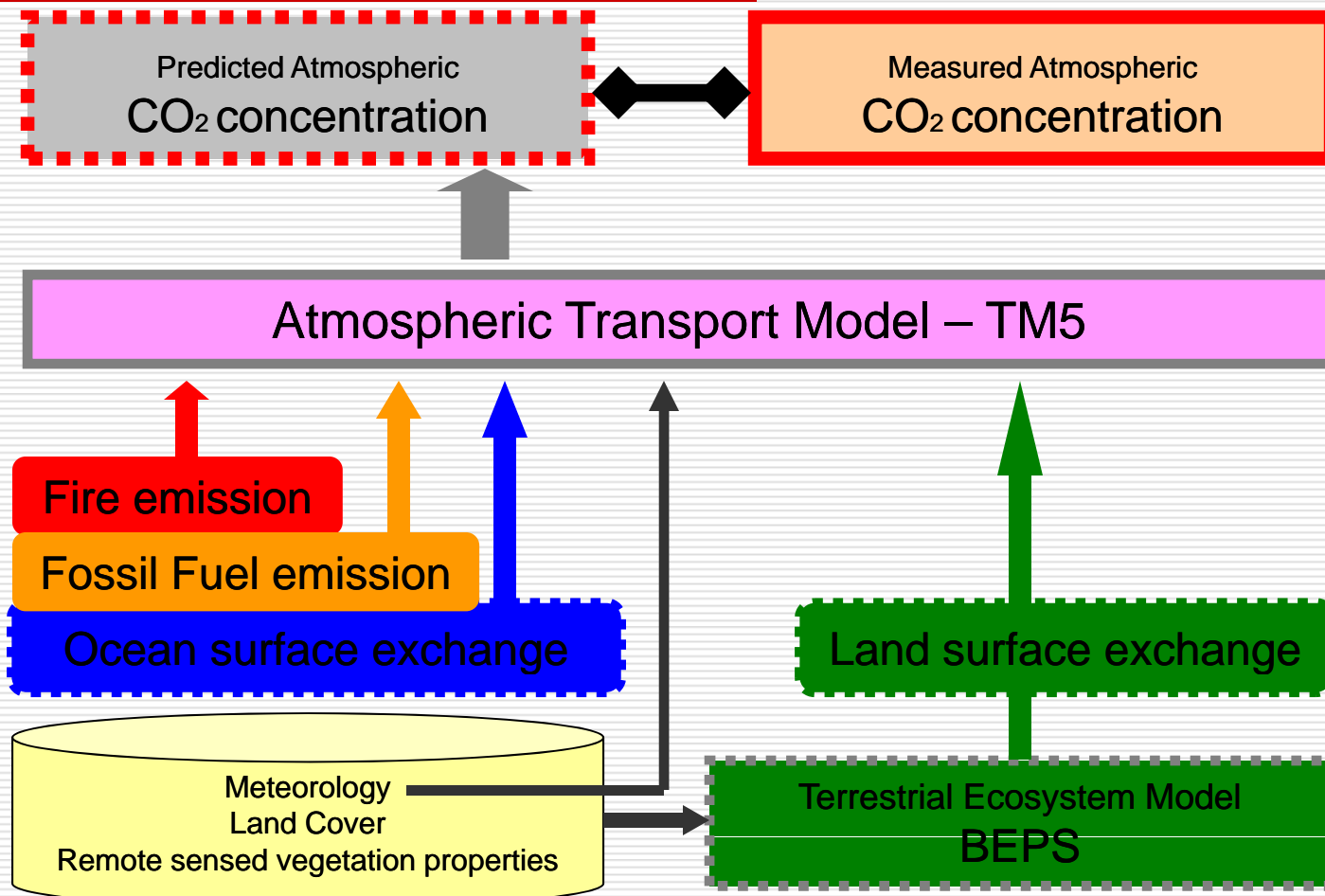


1 x 1 degrees US

3 x 2 degrees North America

6 x 4 degrees Global

Inversion technique



Key Datasets

- **Fossil Fuels**
 - **Carbon tracker** (J. B. Miller, <http://carbontracker.noaa.gov>)
- **Fires**
 - **The Global Emissions Fire Database version 2 (GFEDv2)**. (van der Werf et al., 2003; Giglio et al., 2006).
- **Ocean**
 - **Results of CO₂ fluxes using the OPA-PISCES-T model.**
 - **Forced by daily wind stress and heat and water fluxes from the NCEP reanalyzed data for 1948 to 2004.**
- **Biosphere**
 - **Hourly global NEE produced by the BEPS model with resolution 1° x 1° was produced for a five-year period (2000-2004).**
 - **Forced by NCEP reanalyzed meteorology and LAI derived from Remote sensing measurements.**

The model-data mismatch error (R)

R can be defined with the error standard deviation of month i by

$$R_{ii} = \sigma_{const}^2 + GVsd^2$$

$GVsd$ - from the average monthly variability (var) files of
GLOBALVIEW-CO₂ 2008

$$\sigma_{const} = \begin{cases} 0.15 & \text{Antarctic} \\ 0.3 & \text{oceanic sites} \\ 1.5 & \text{land and tower sites} \\ 1.25 & \text{mountain sites} \\ 1.0 & \text{aircraft samples} \end{cases} \quad w_{ii} = 1 / (1 + 0.6(n - 1))$$

$$J = \frac{1}{2} ((\mathbf{M}\mathbf{s} - \mathbf{c})\mathbf{W})^T \mathbf{R}^{-1} ((\mathbf{M}\mathbf{s} - \mathbf{c})\mathbf{W}) + \frac{1}{2} (\mathbf{s} - \mathbf{s}_p)^T \mathbf{Q}^{-1} (\mathbf{s} - \mathbf{s}_p)$$

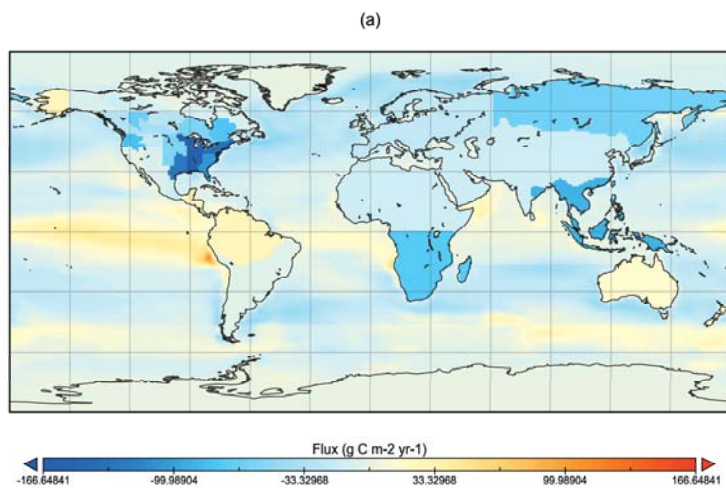
The *a priori* uncertainties

- Land 2.0 Pg C/year
- Ocean 0.67 Pg C/year
- Distribution
 - Land regions according to NPP from BEPS
 - Ocean regions according to Baker (2006)

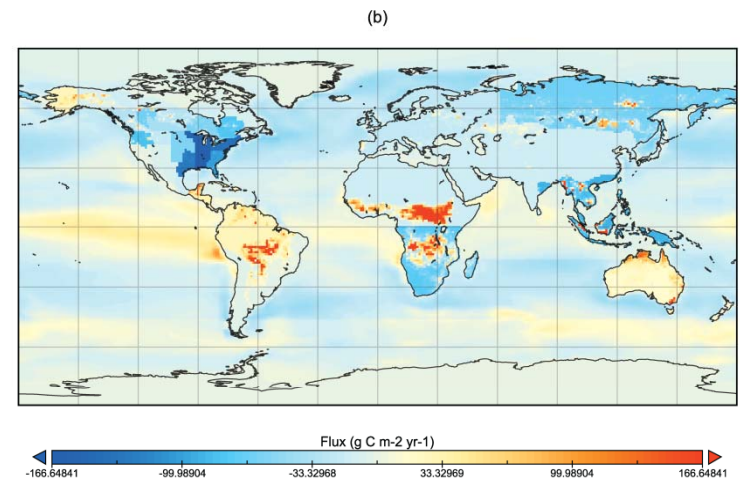
Improved Inversion Model

- the diurnal variation of PBL modeled by TM5.
- the diurnal variation of terrestrial surface flux modeled by BEPS.
- annually balanced BEPS flux, and zero *a priori*, so any inverted annual source or sink is driven by the CO₂ concentration observations.

Global mean distribution (2002-2007)

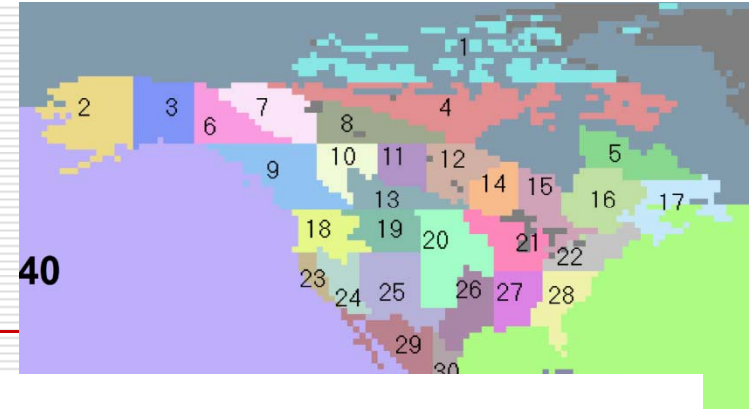


-2.35 ± 0.25
 -0.62 ± 0.47
 -0.67 ± 0.34

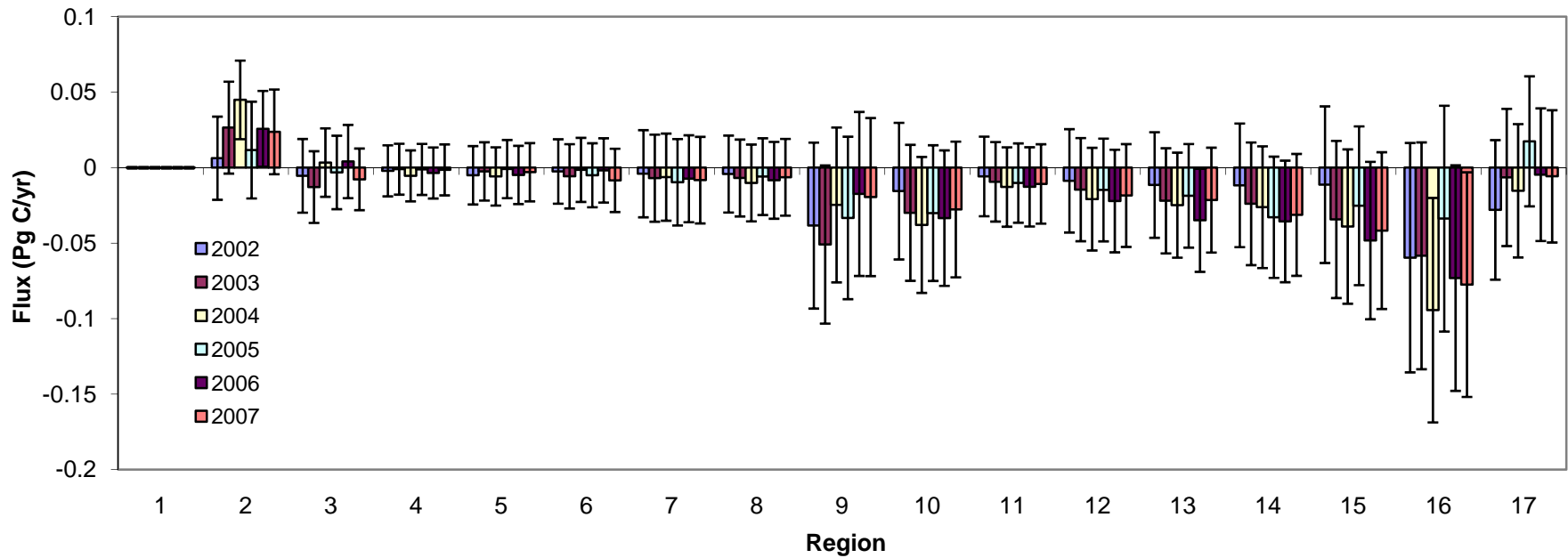


~
 0.81 ± 0.47
 0.22 ± 0.34

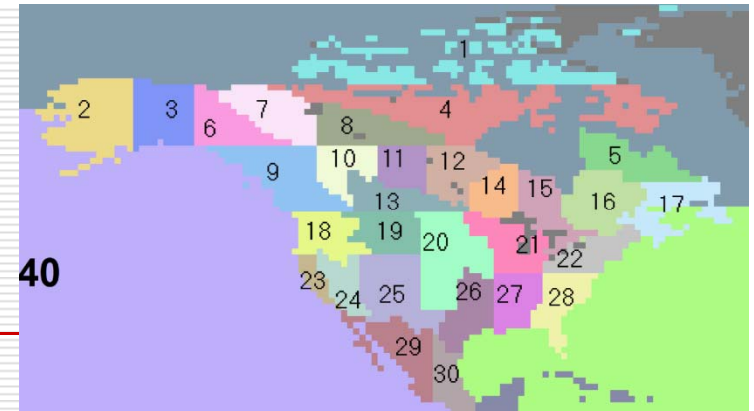
Inverted CO2 fluxes (R1-17)



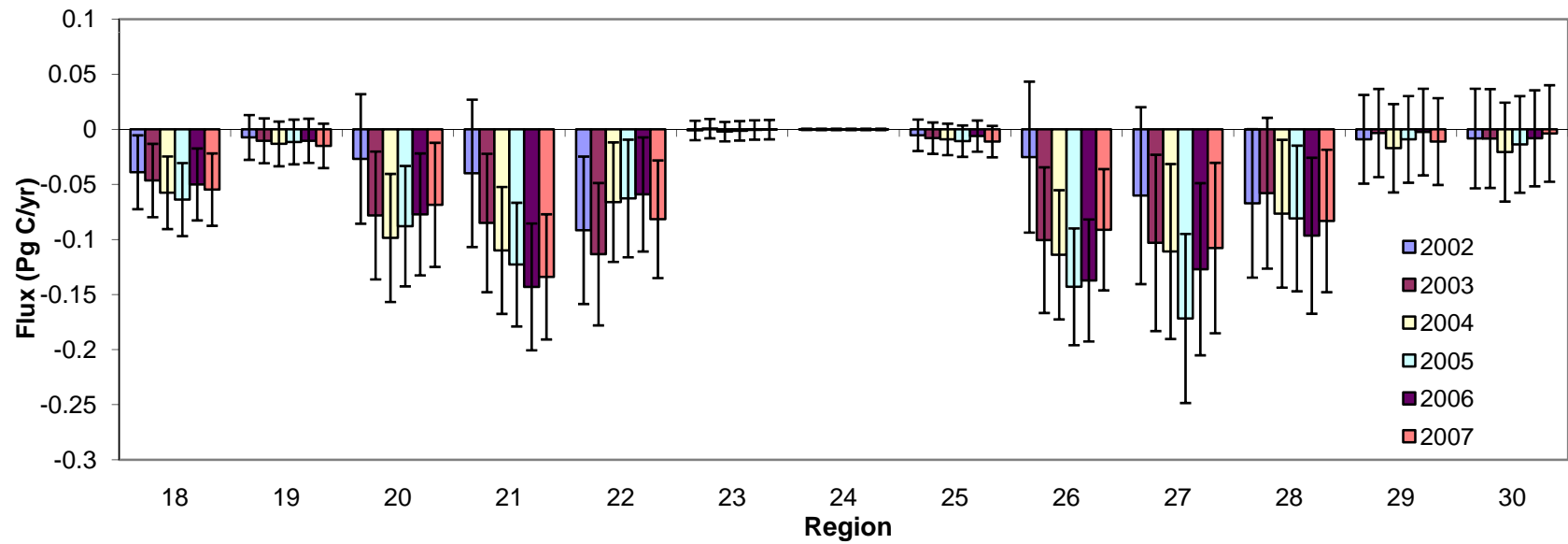
(a)



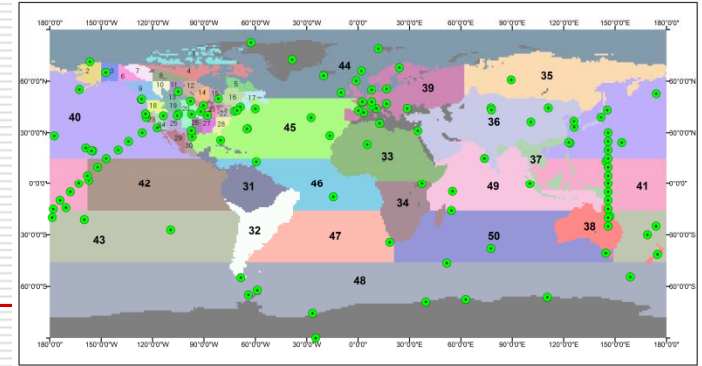
Inverted CO₂ fluxes (R18-30)



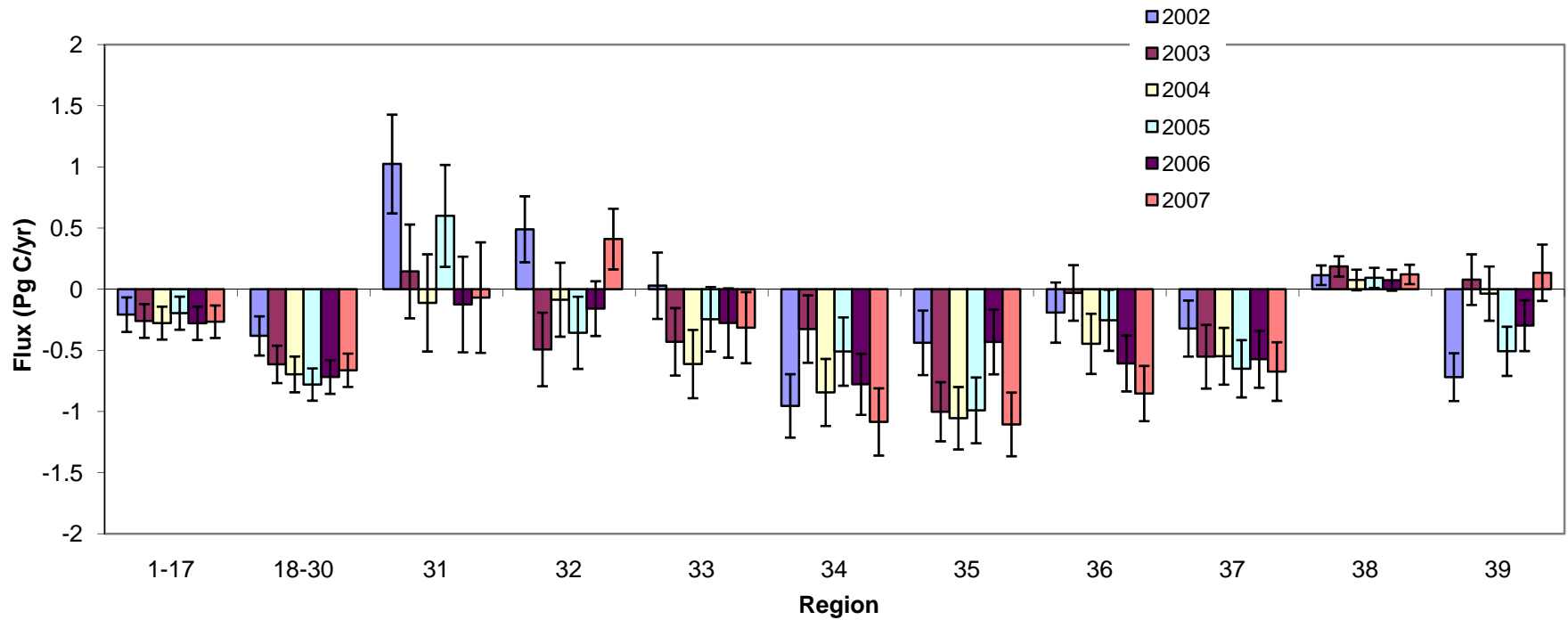
(b)



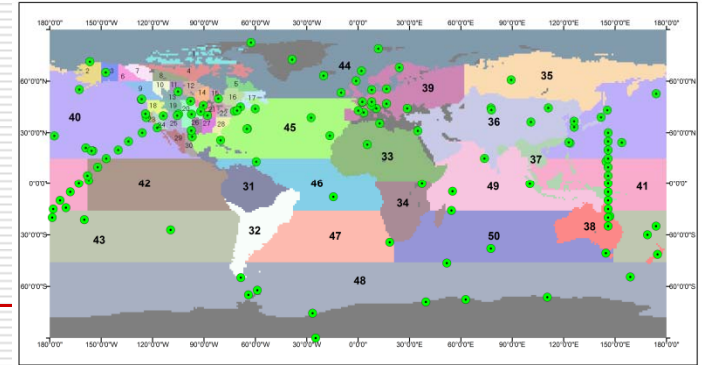
Inverted CO₂ fluxes (R18-30)



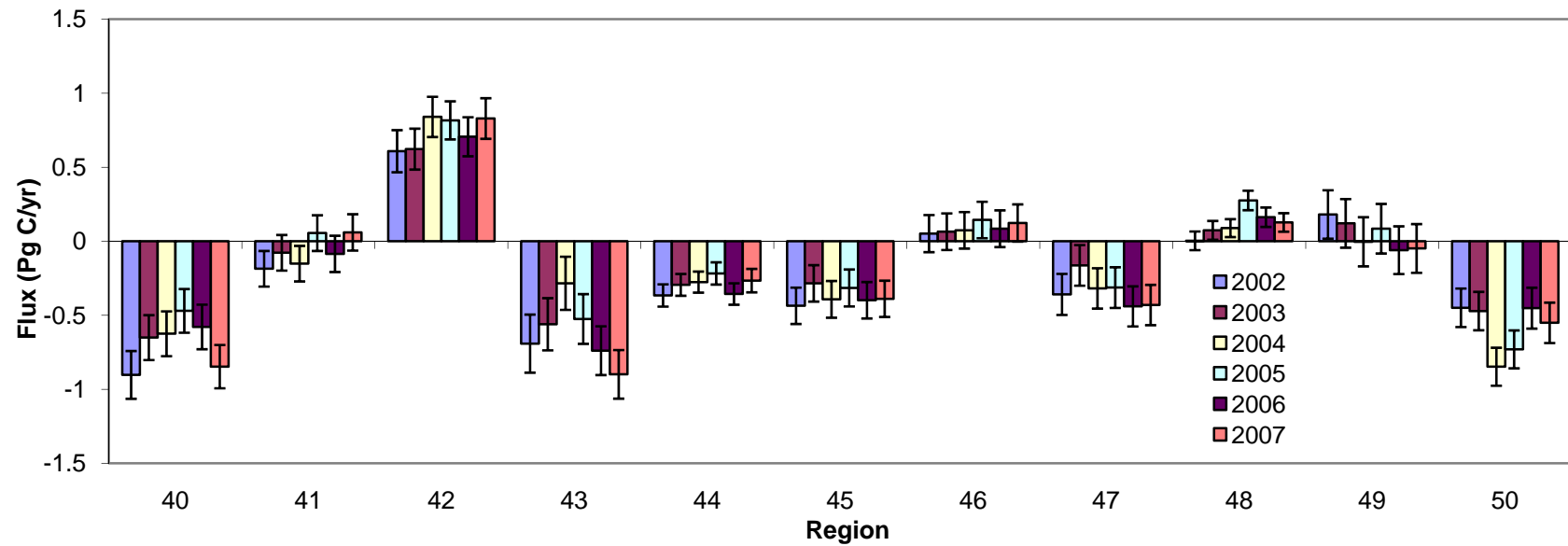
(c)



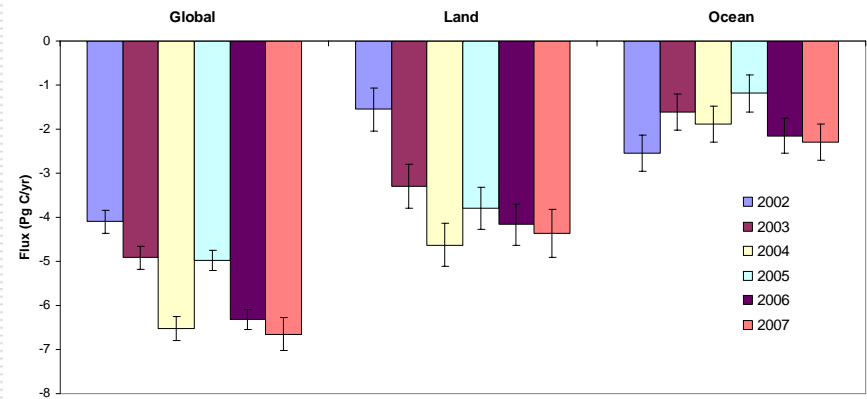
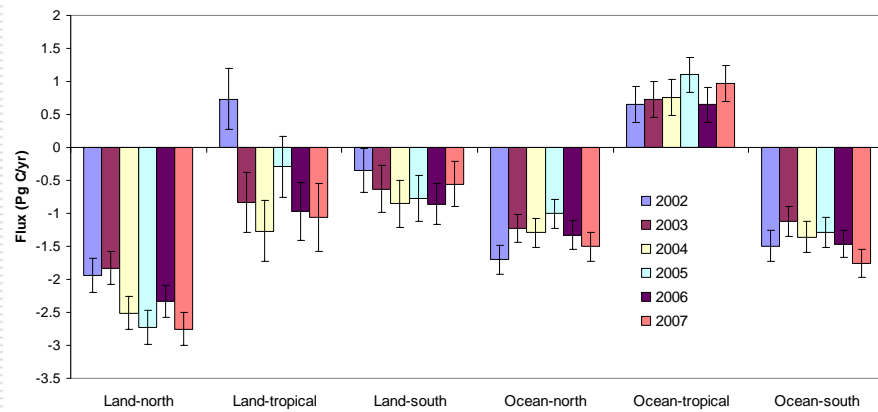
Inverted CO₂ fluxes



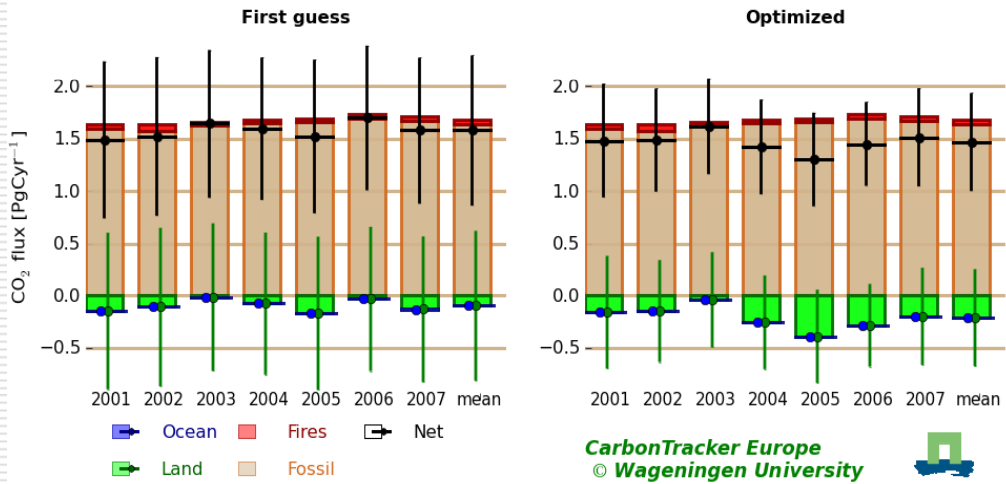
(d)



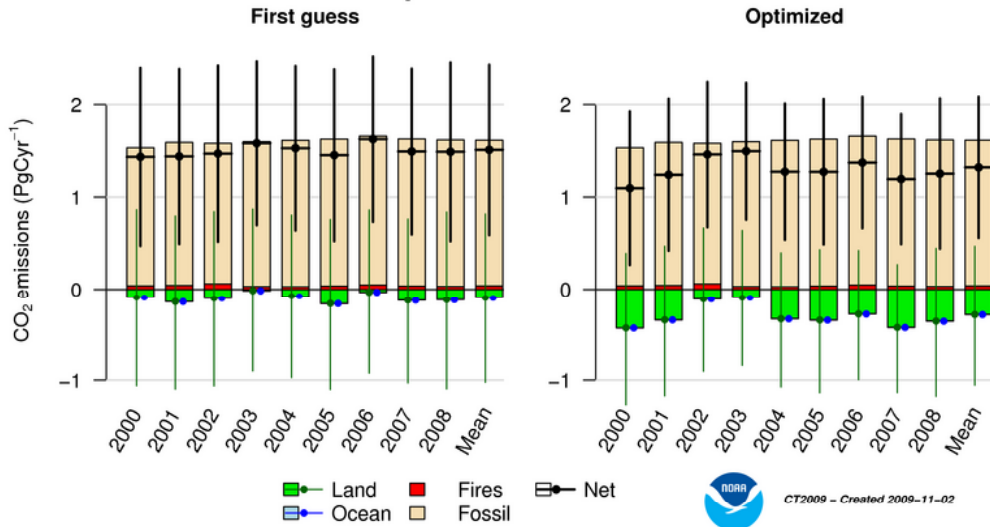
Interannual Variabilities



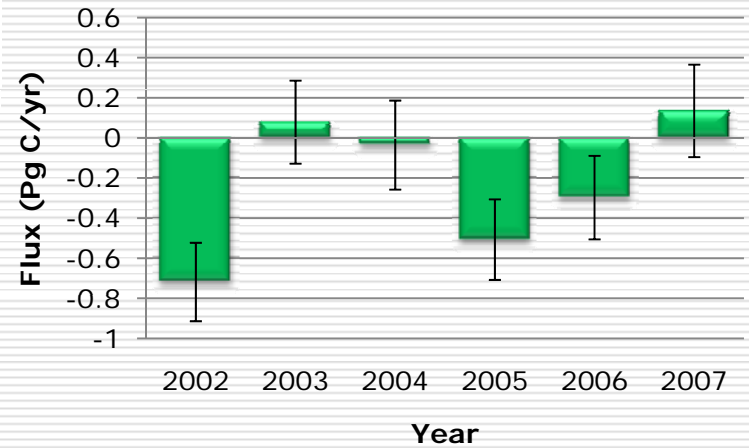
Annual CO₂ balance for Europe



Europe annual total emissions

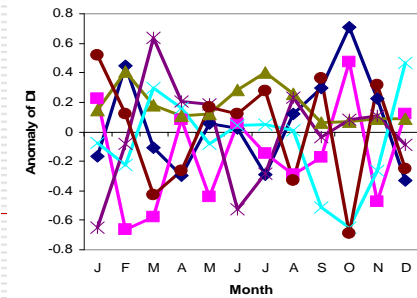
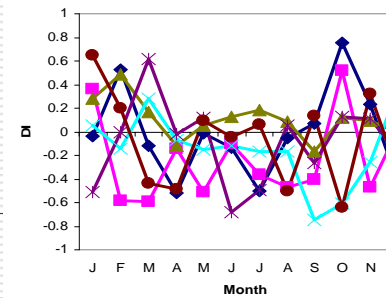
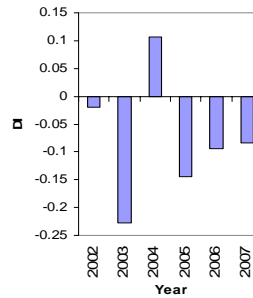
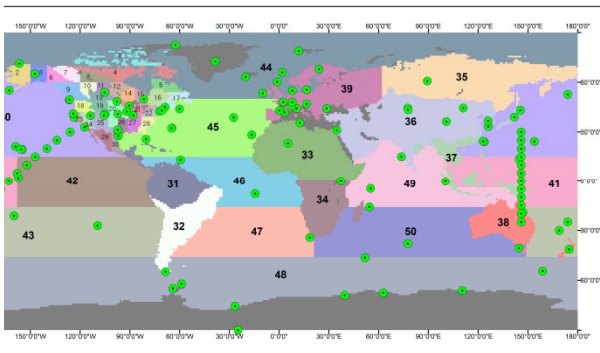
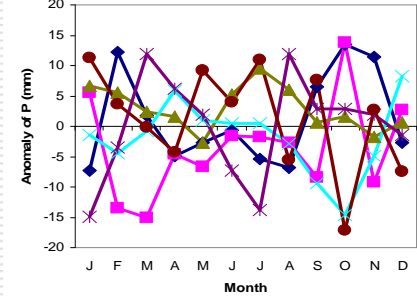
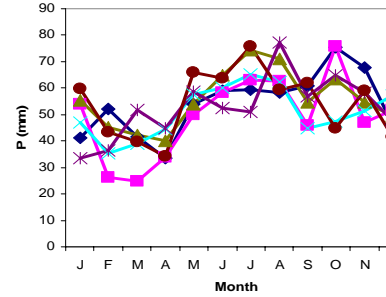
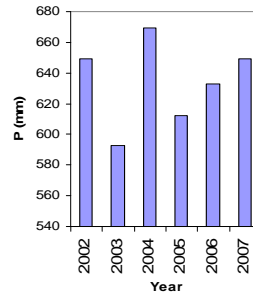
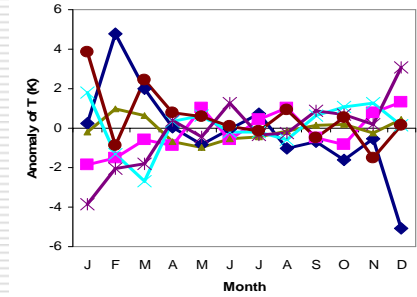
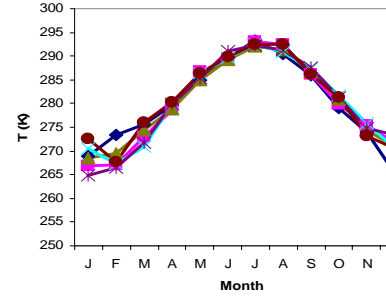
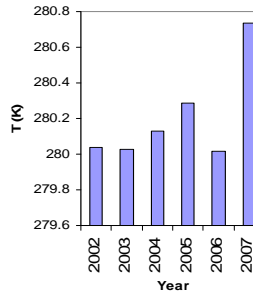
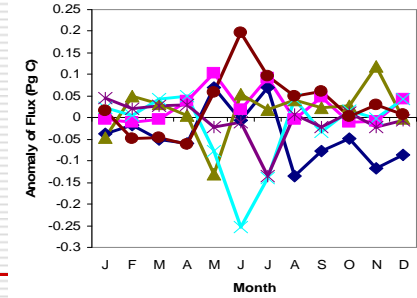
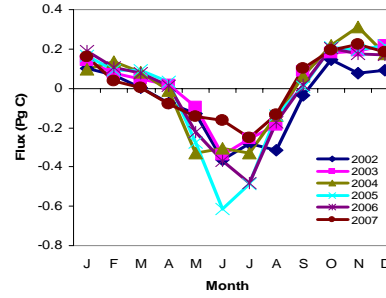
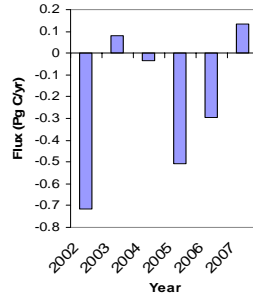


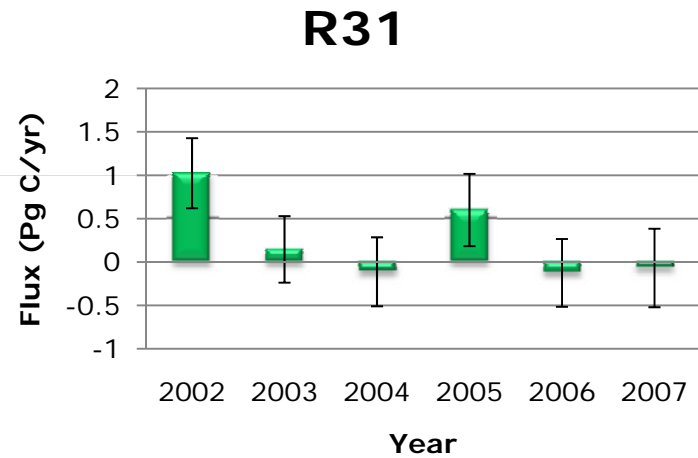
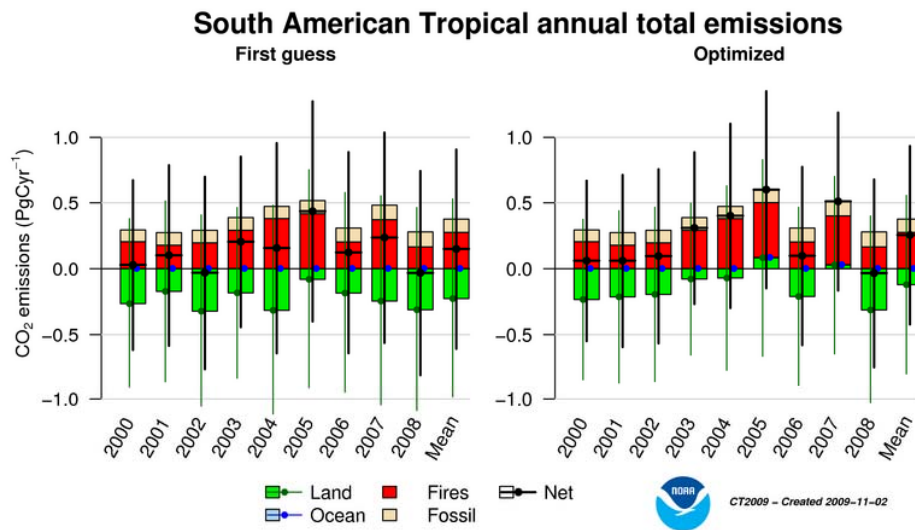
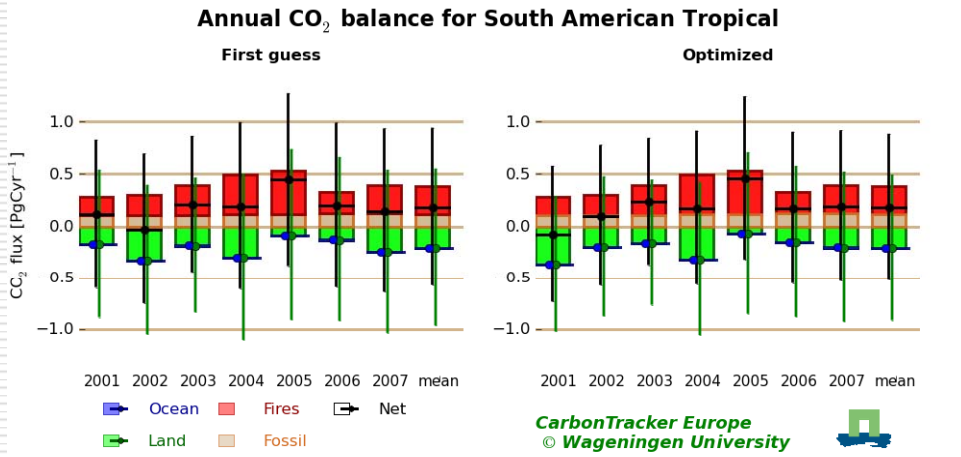
R39



R39

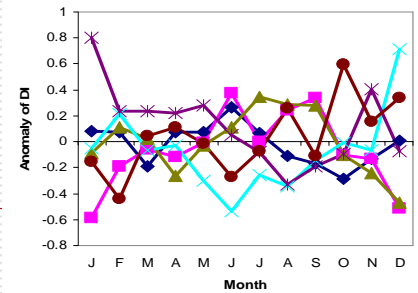
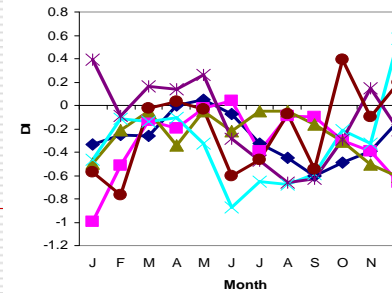
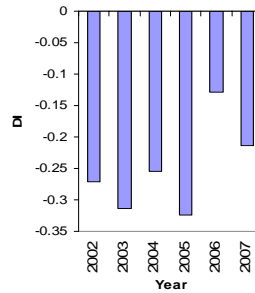
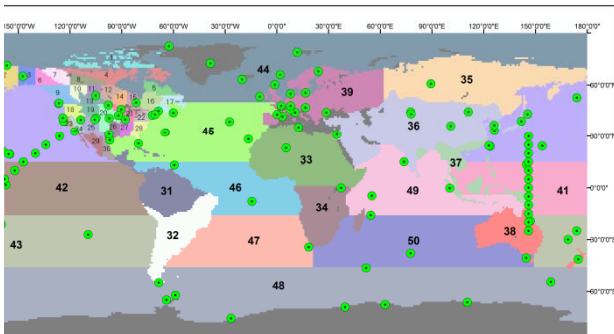
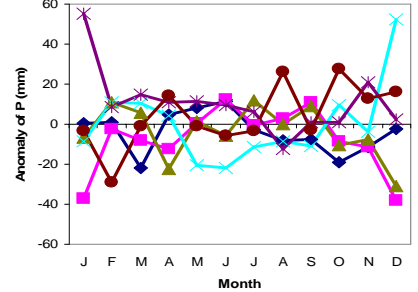
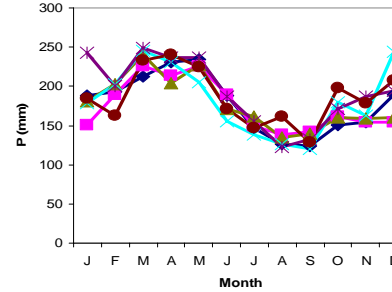
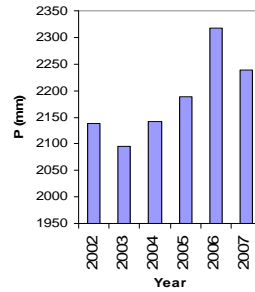
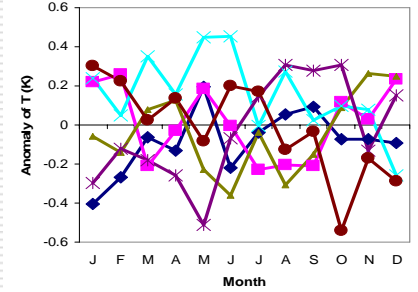
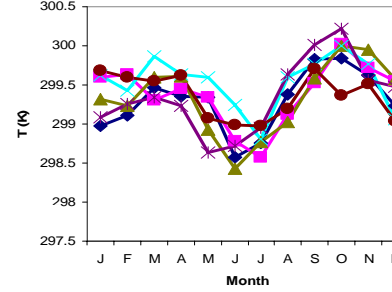
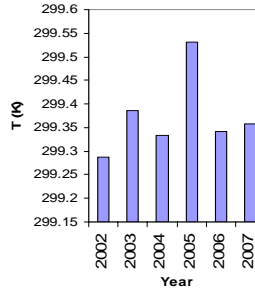
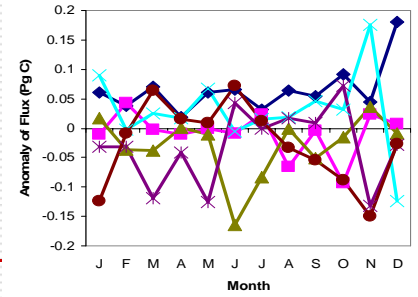
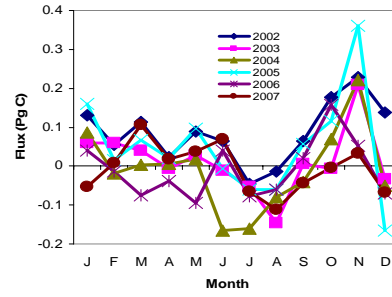
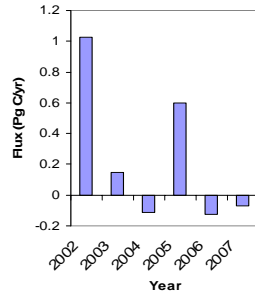
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 2003

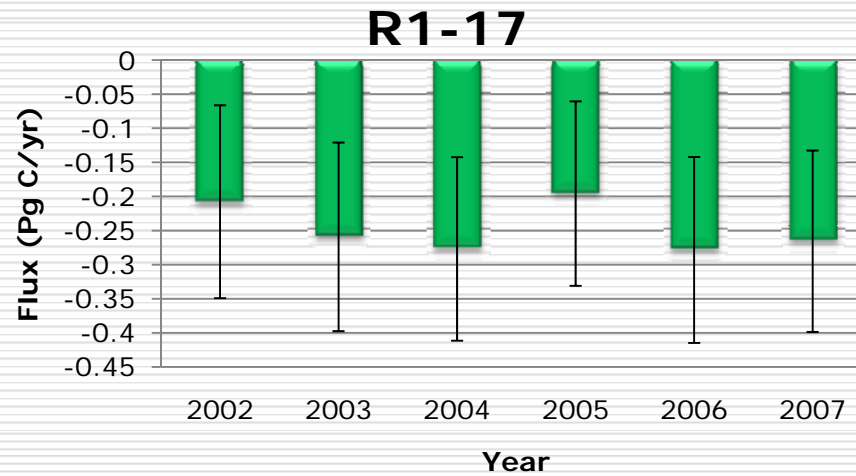
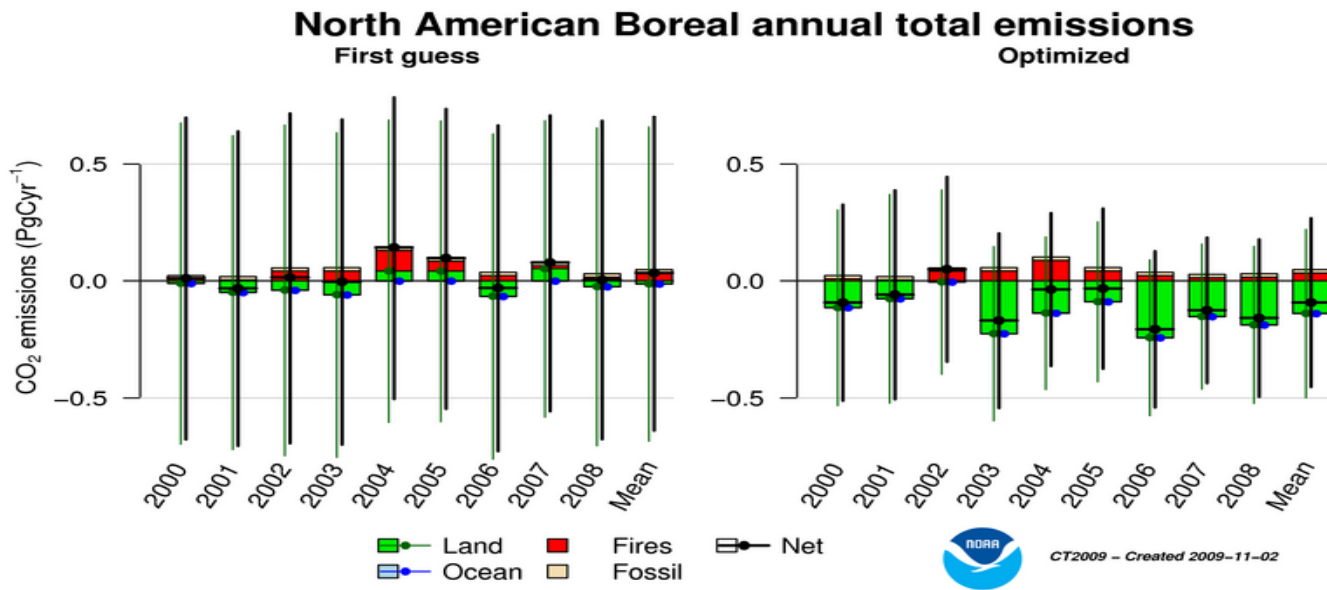




R31

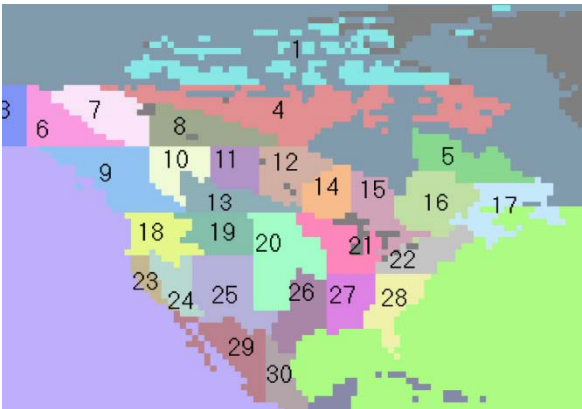
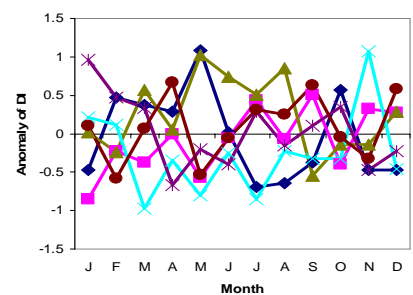
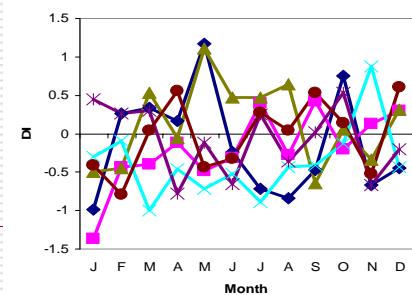
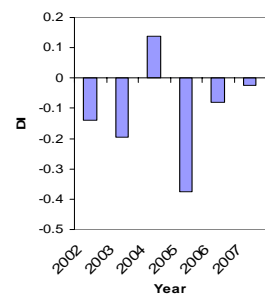
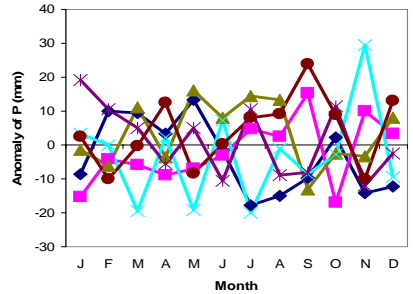
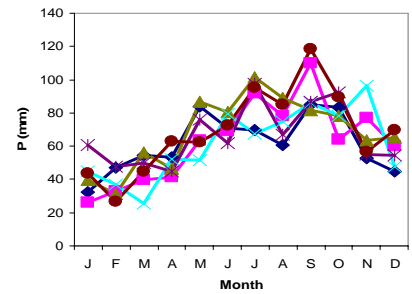
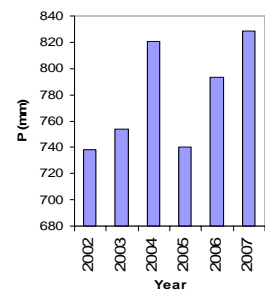
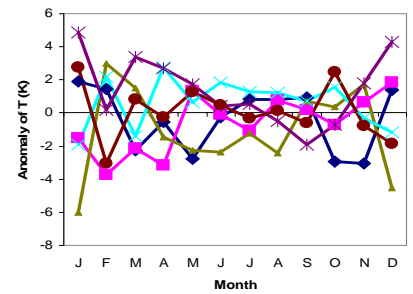
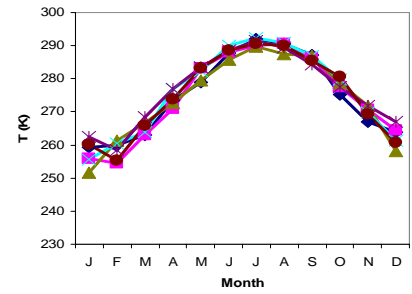
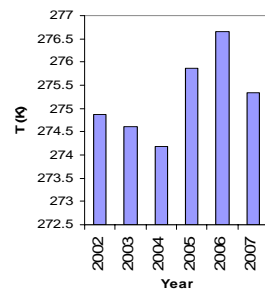
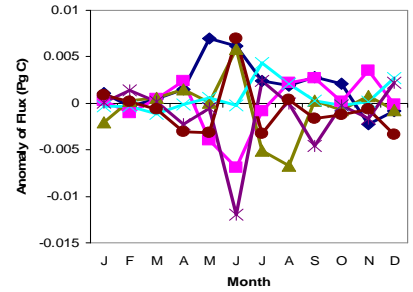
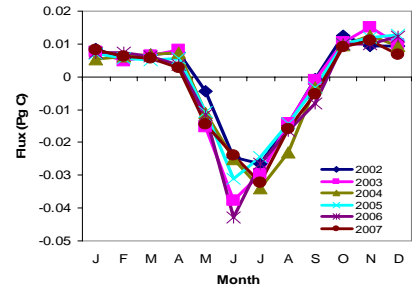
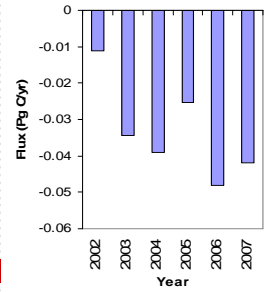
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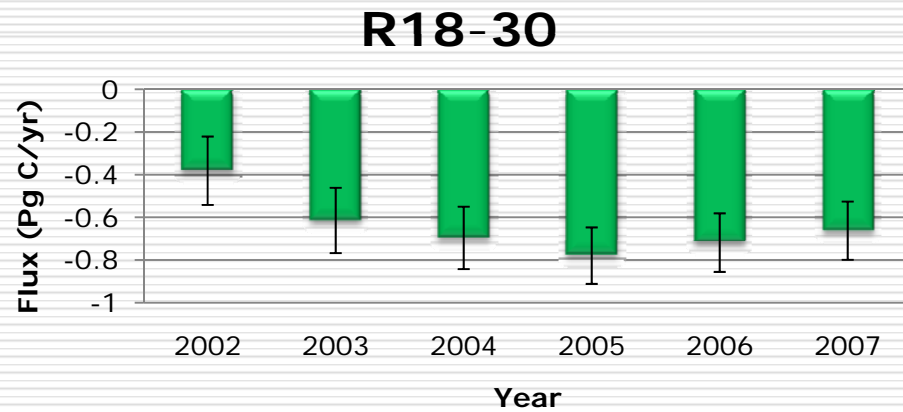
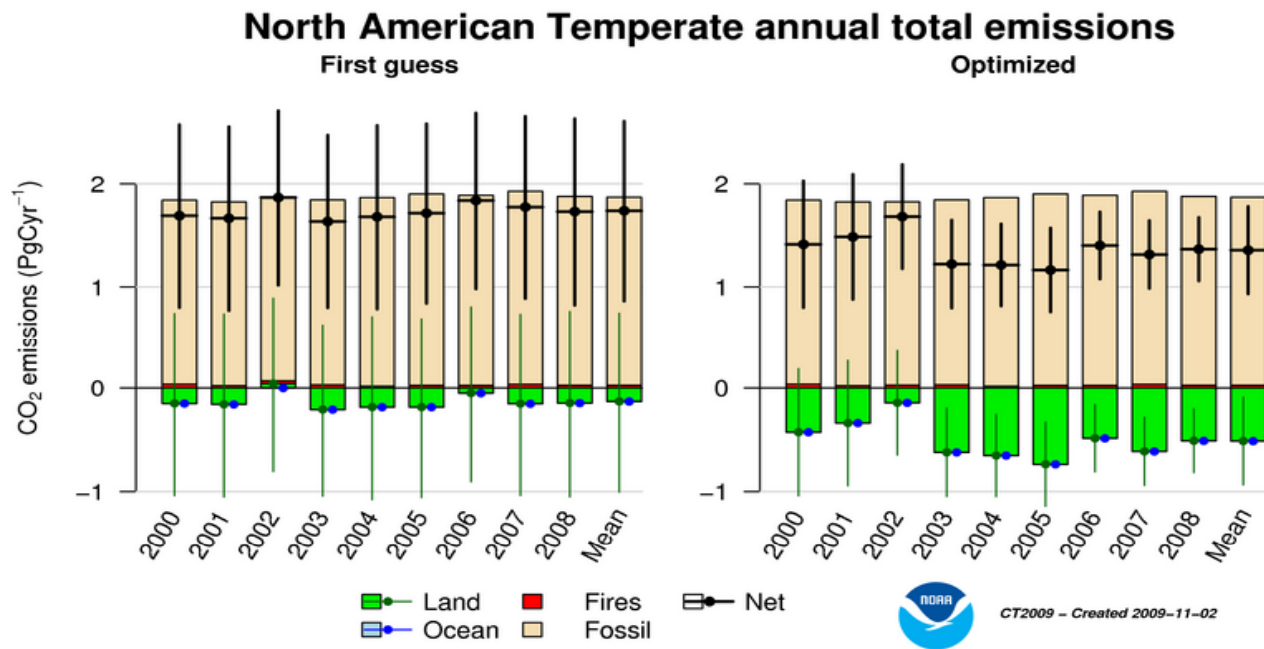




R15

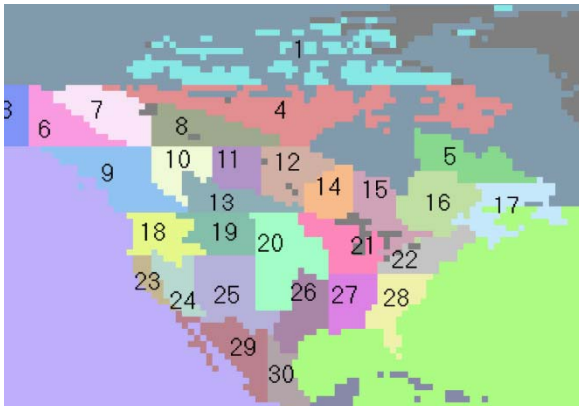
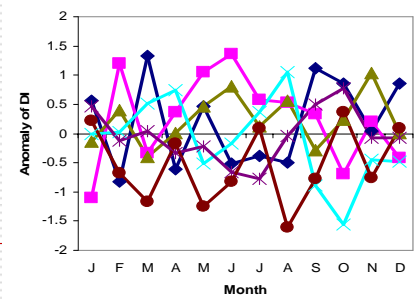
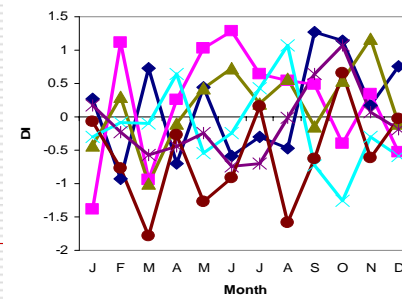
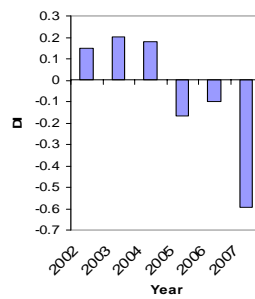
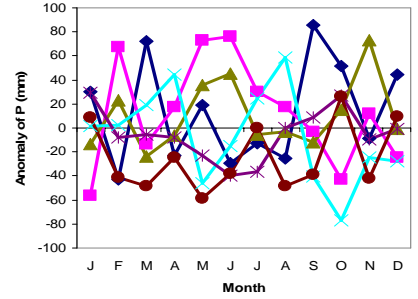
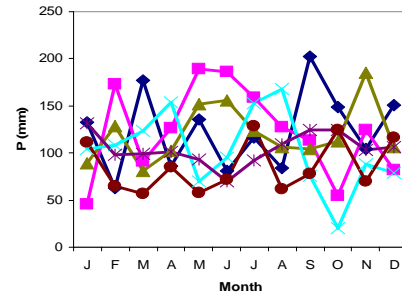
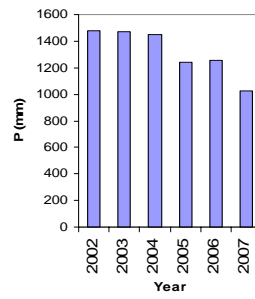
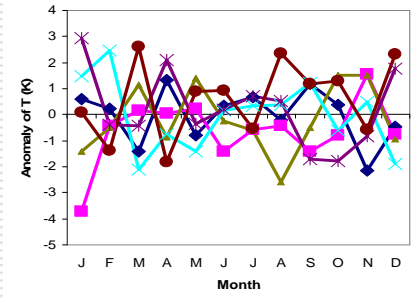
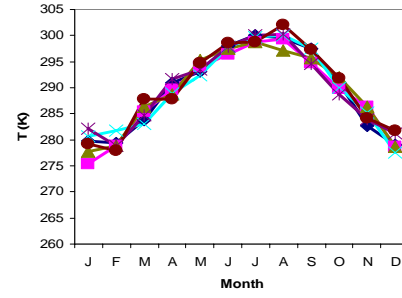
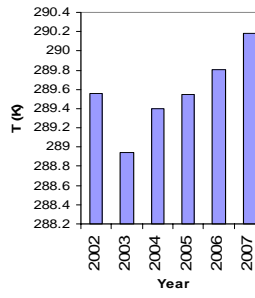
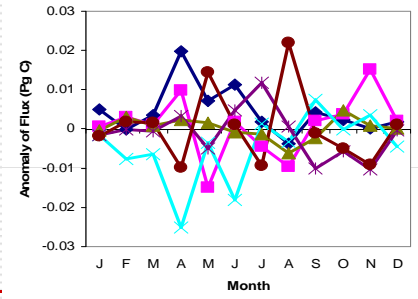
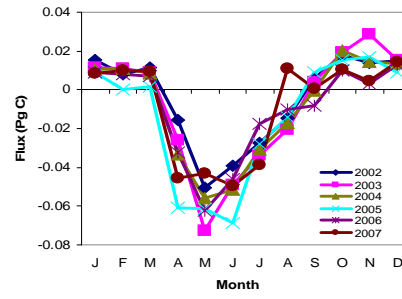
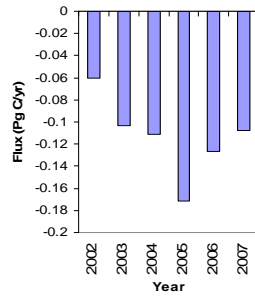
□ 2002
□ 2005





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□ 2002
 □ 2005



Conclusions

Acknowledgement

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□ **Supports**

- NSERC
 - Environment Canada
 - CFCAS
 - CCP
 - CGCS, UT
-

The End

