Can we predict the variability of ecosystem and carbon cycle

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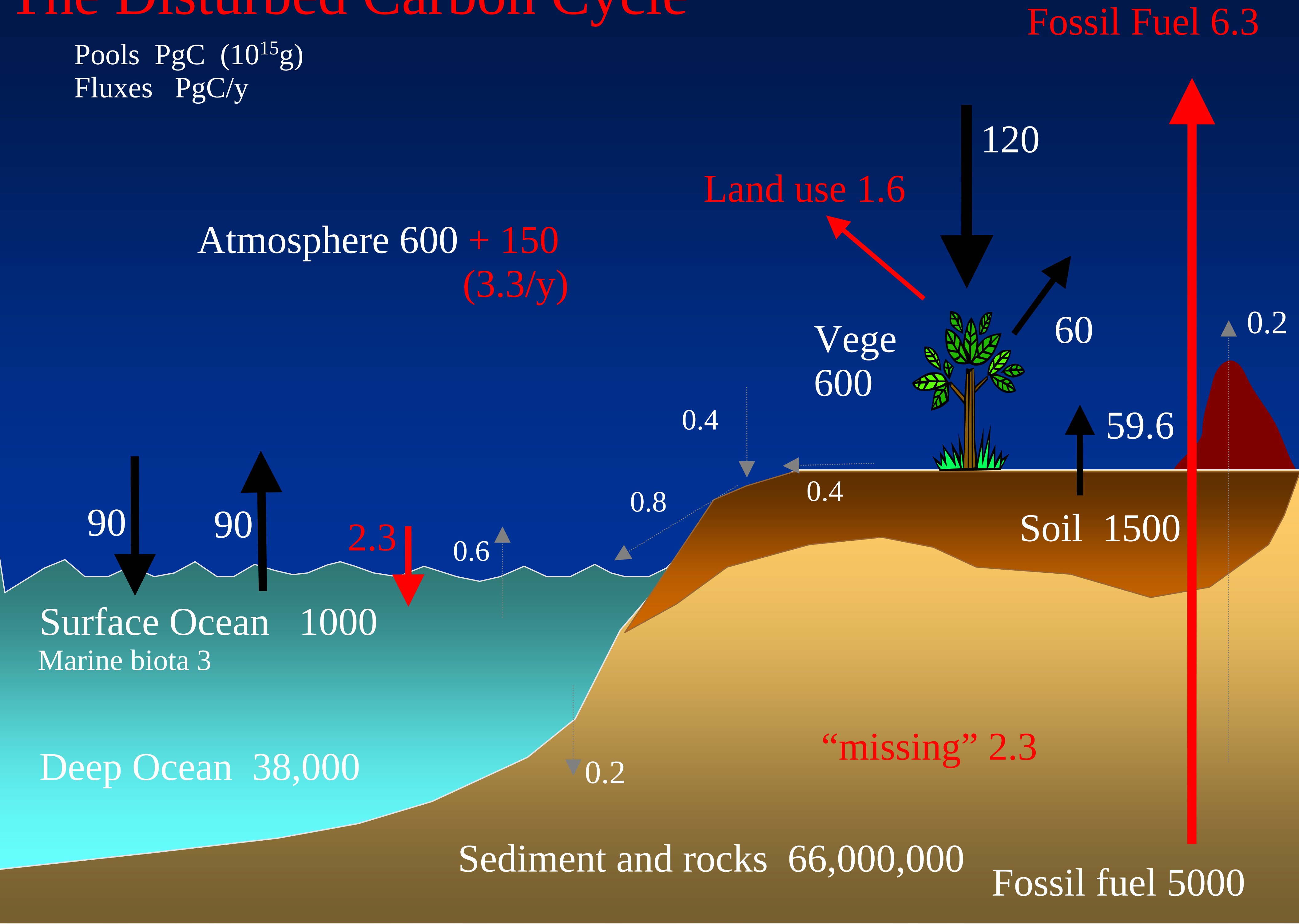
August 9, IGSNRR, China

The Disturbed Carbon Cycle

Pools PgC (10^{15}g)
Fluxes PgC/y



The “missing” carbon sink and the future of carbon sources and sinks

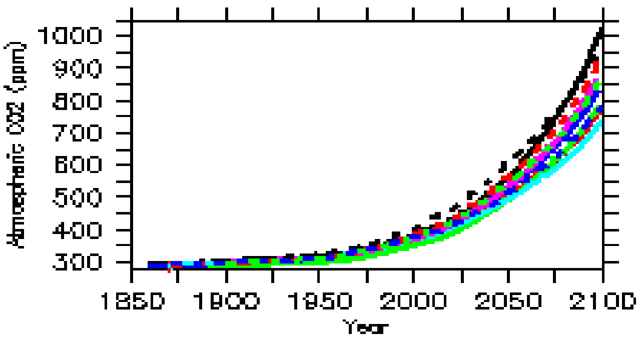
Fossil + Land-use = Atmosphere + Ocean + Land

	Fossil	Land-use	Atmosphere	Ocean	Land	
1990s:	6.3	1.6	3.3	2.3	2.3	Pg/y
2050s:	16	?	?	?	?	

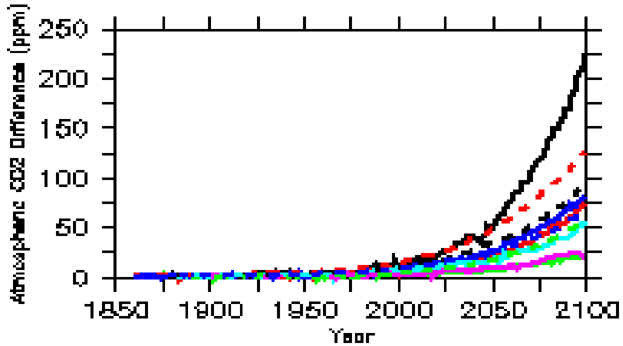
(IPCC A1B scenario)

The “missing” or ‘residual’ land carbon sink

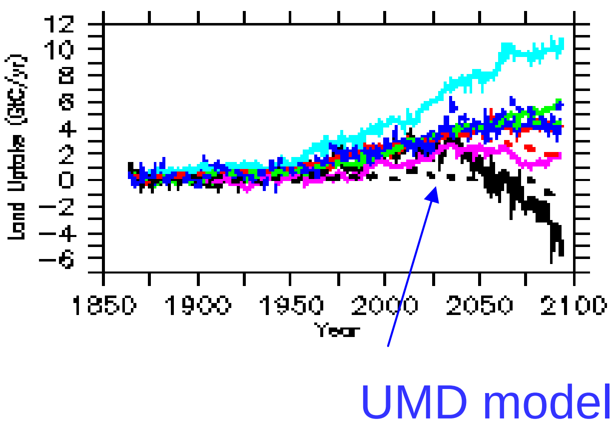
CO2



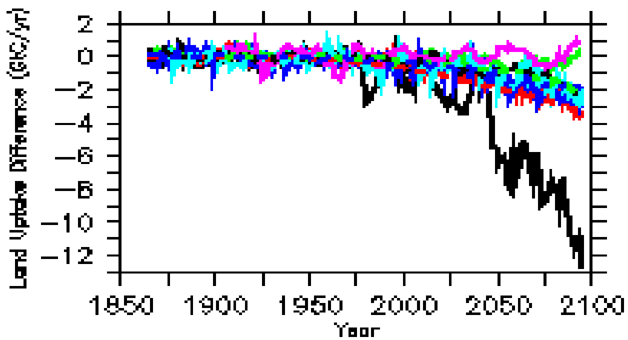
ΔCO2 from climate feedback



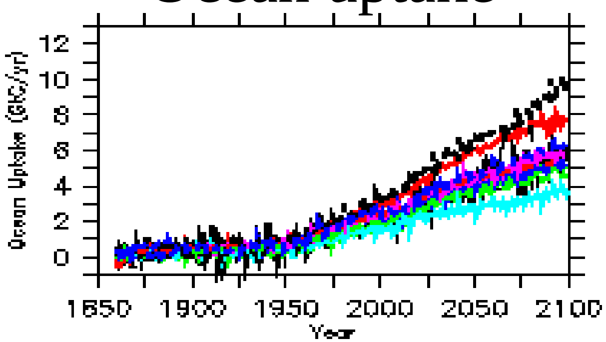
Land uptake



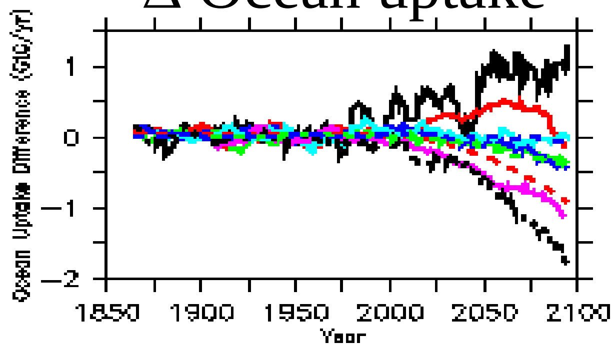
Δ Land uptake



Ocean uptake



Δ Ocean uptake



Friedlingstein et al., J. Climate in press

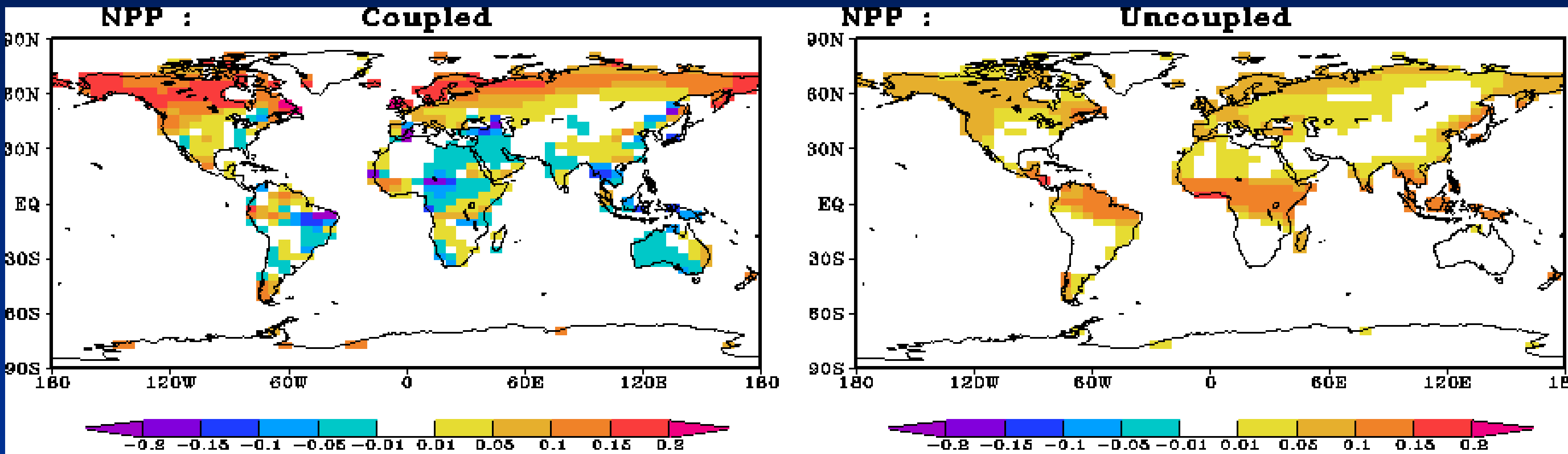
Enhanced global warming from carbon-climate interaction: the C4MIP results

--- UMD Earth System Model (CABO)

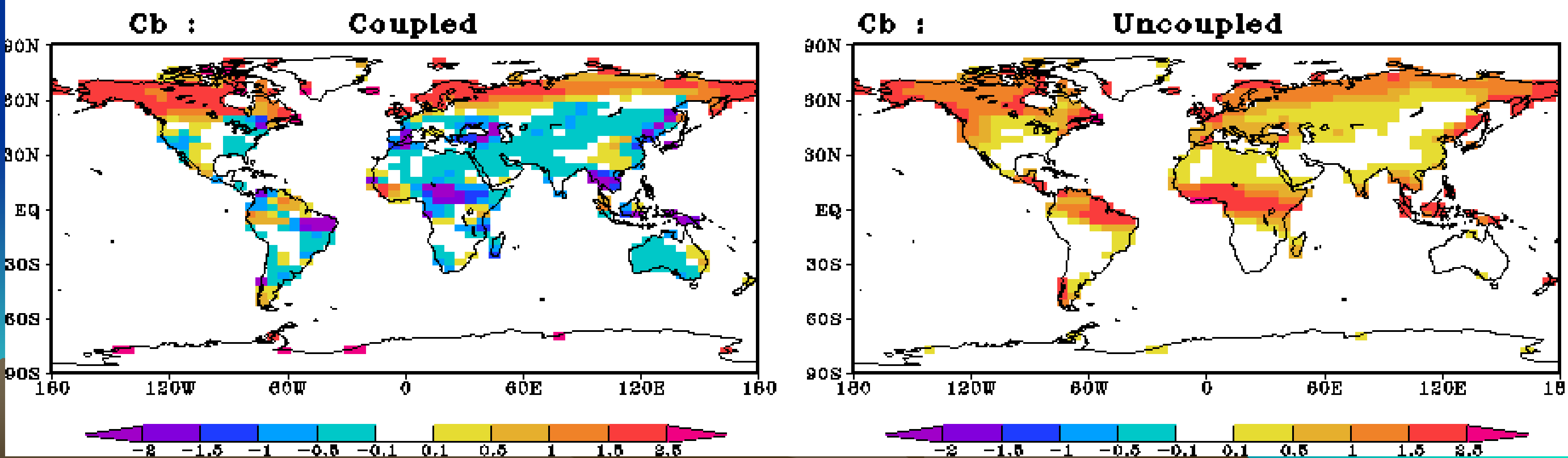
Major differences in land response: interannual variability as a testbed

Difference: 2071/2100 – 1850/79

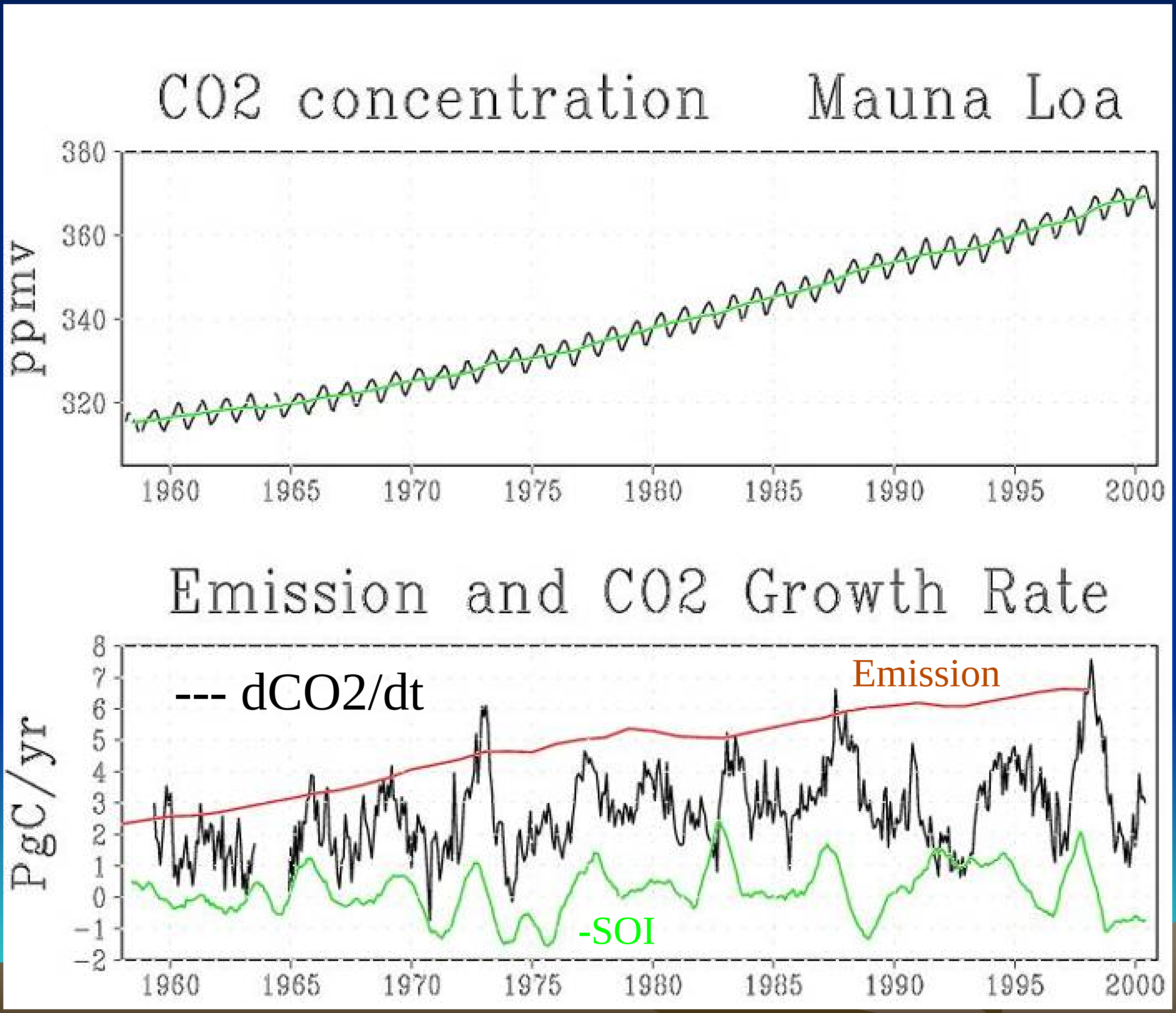
Net Primary Production



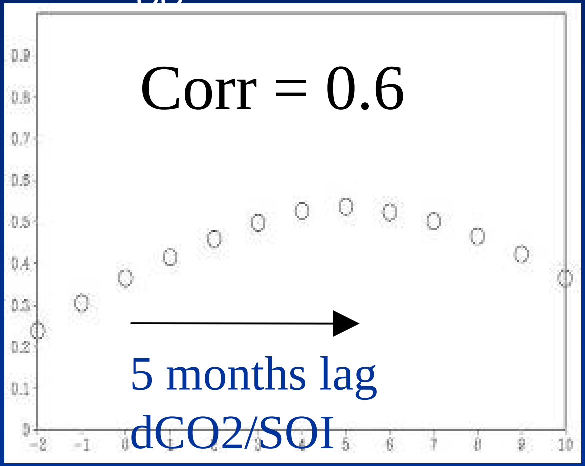
Total land carbon

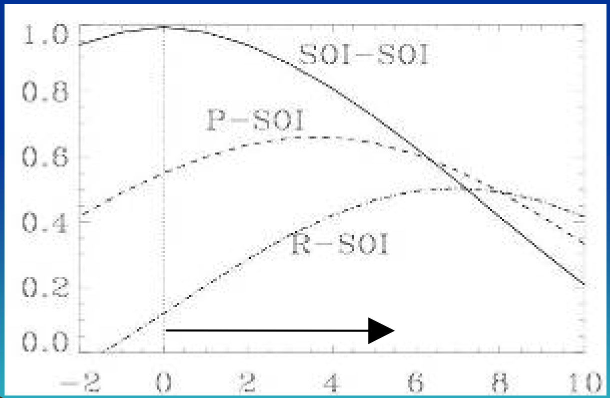


Atmospheric CO2 Variability 1958-2000

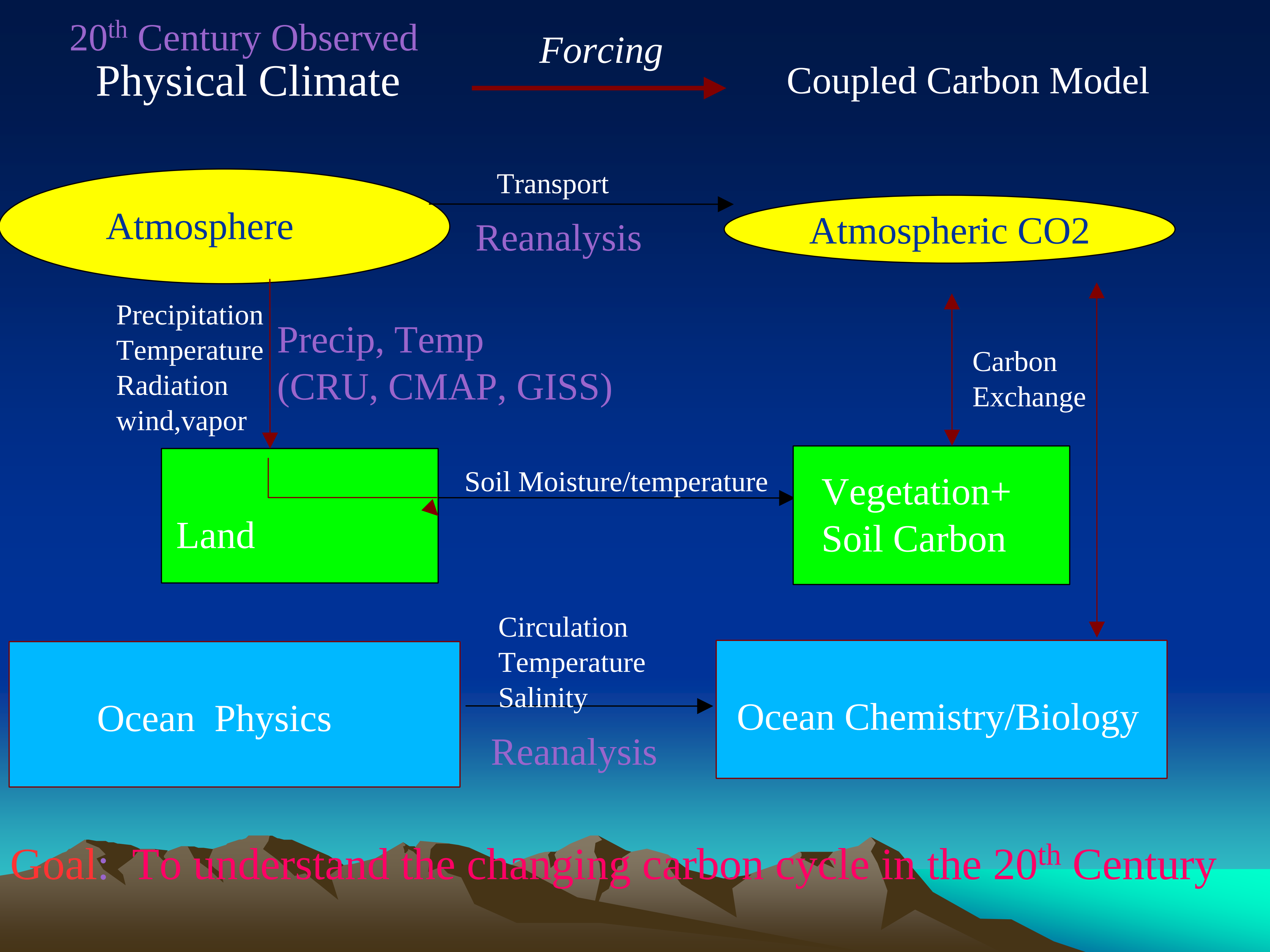


Lagged Correlations

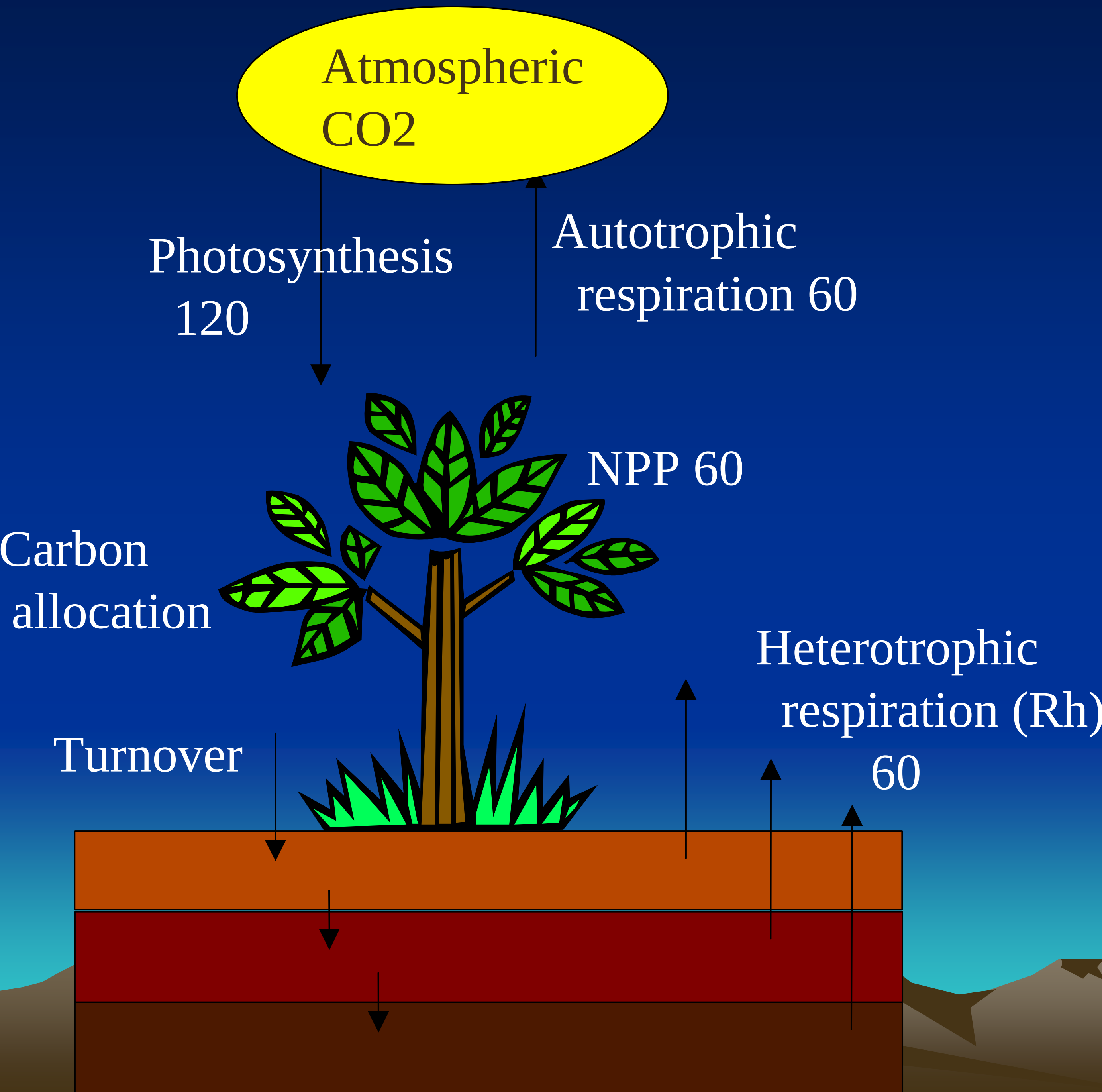




3-6 months lag
Hydrology/SOI


20th Century Observed
Physical Climate
Forcing
Coupled Carbon Model
Atmosphere
Transport
Reanalysis
Atmospheric CO2
Precipitation
Temperature
Radiation
wind,vapor
Precip, Temp
(CRU, CMAP, GISS)
Carbon
Exchange
Land
Soil Moisture/temperature
Vegetation+
Soil Carbon
Circulation
Temperature
Salinity
Ocean Physics
Reanalysis
Ocean Chemistry/Biology
Goal: To understand the changing carbon cycle in the 20th Century

The VEgetation-Global Atmosphere-Soil Model (VEGAS)



4 **Plant Functional Types**:
- Broadleaf tree
- Needleleaf tree
- C3 Grass (cold)
- C4 Grass (warm)

3 Vegetation carbon pools:
- Leaf
- Root
- Wood

3 Soil carbon pools:
- Fast
- Intermediate
- Slow

VEGAS II

Photosynthesis:

Light (PAR, LAI, Height), soil moisture, temperature, CO2

Respiration:

Temperature, soil moisture, lower soil pools slower decay

Competition:

Net growth, shading => fractional cover

Fire:

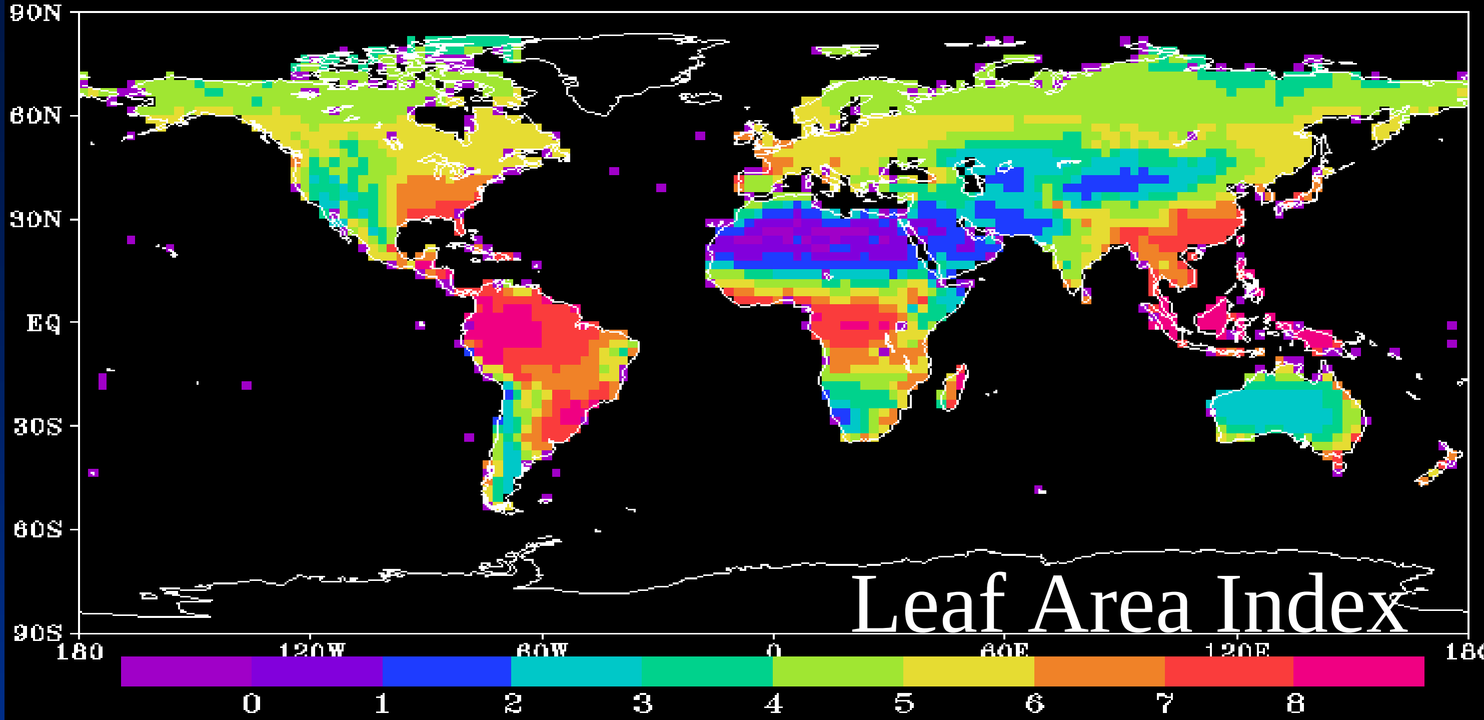
moisture, fuel load, PFT dependent resistance

Wetland/CH4:

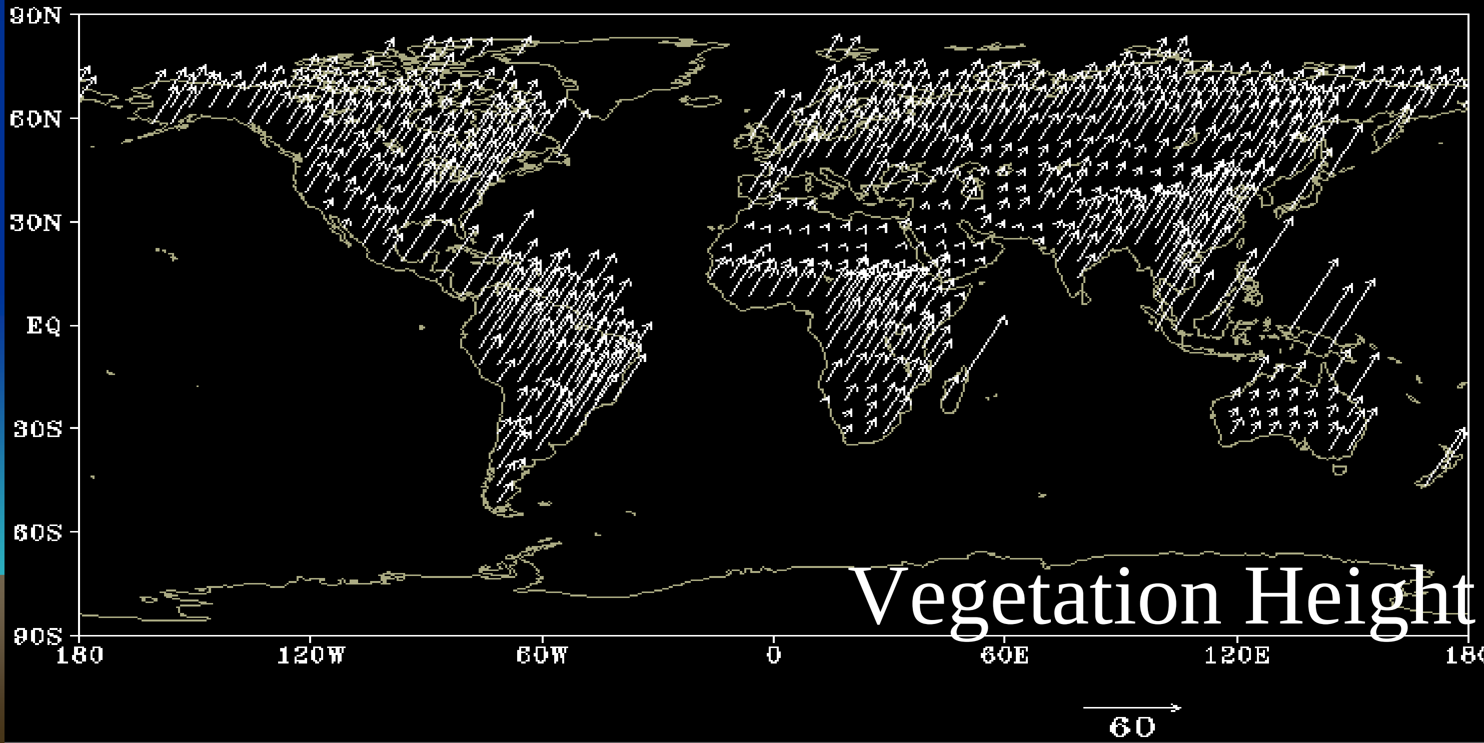
moisture, topography gradient

Carbon 13:

C3/C4 competition: temperature, CO2

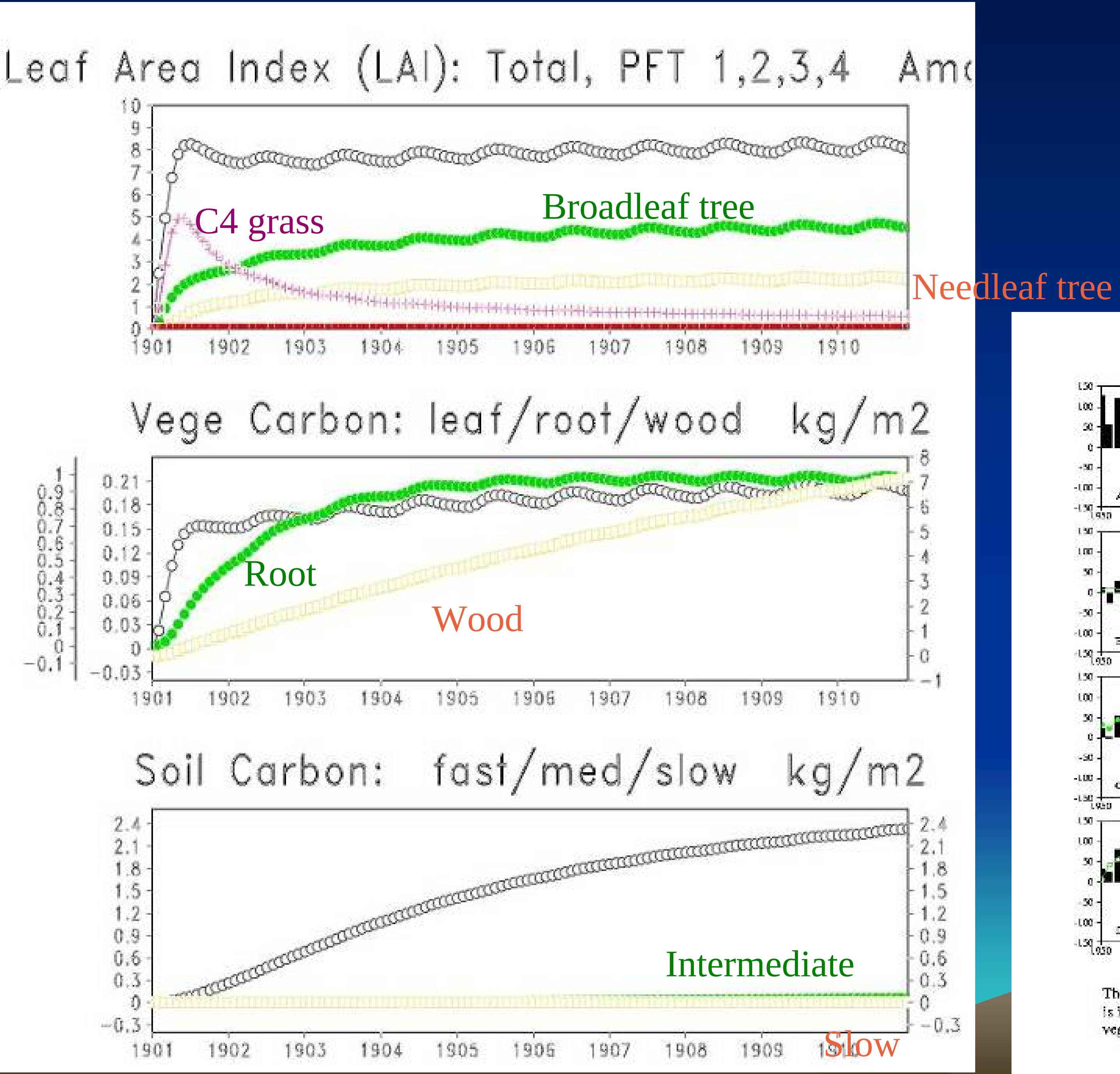


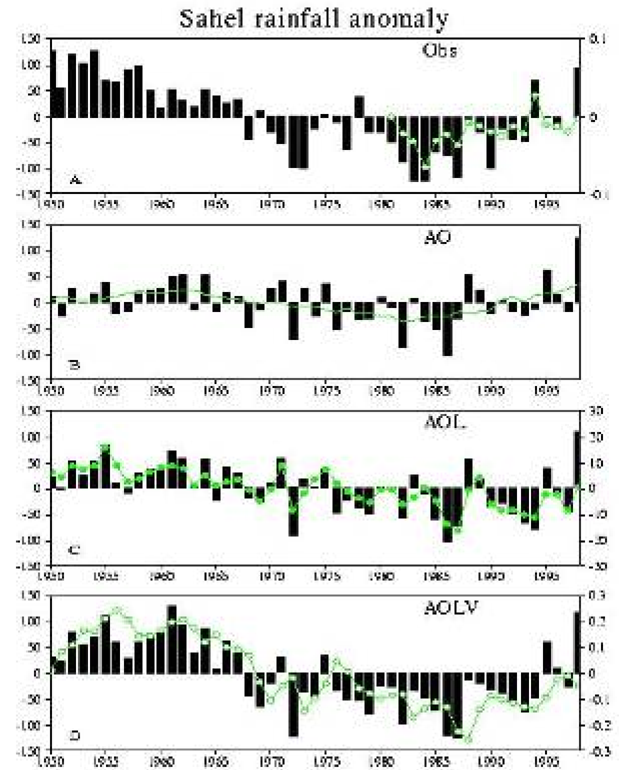
Leaf Area Index



Vegetation Height

Vegetation Dynamics over the Amazon after disturbance

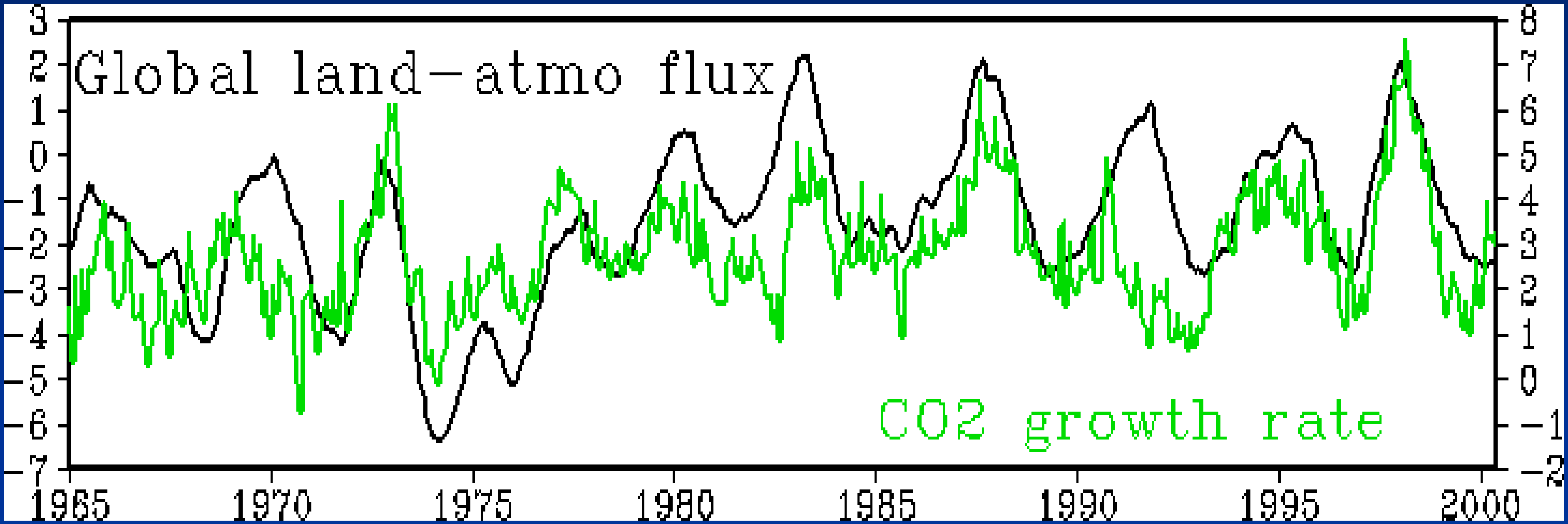




The dramatic drying trend in the Sahel from the 1950s to the 1980s is initially forced by SST (b), but amplified by soil moisture (c) and vegetation(d). Zeng, et al. 1999: Science, vol 286, 1537-1540.

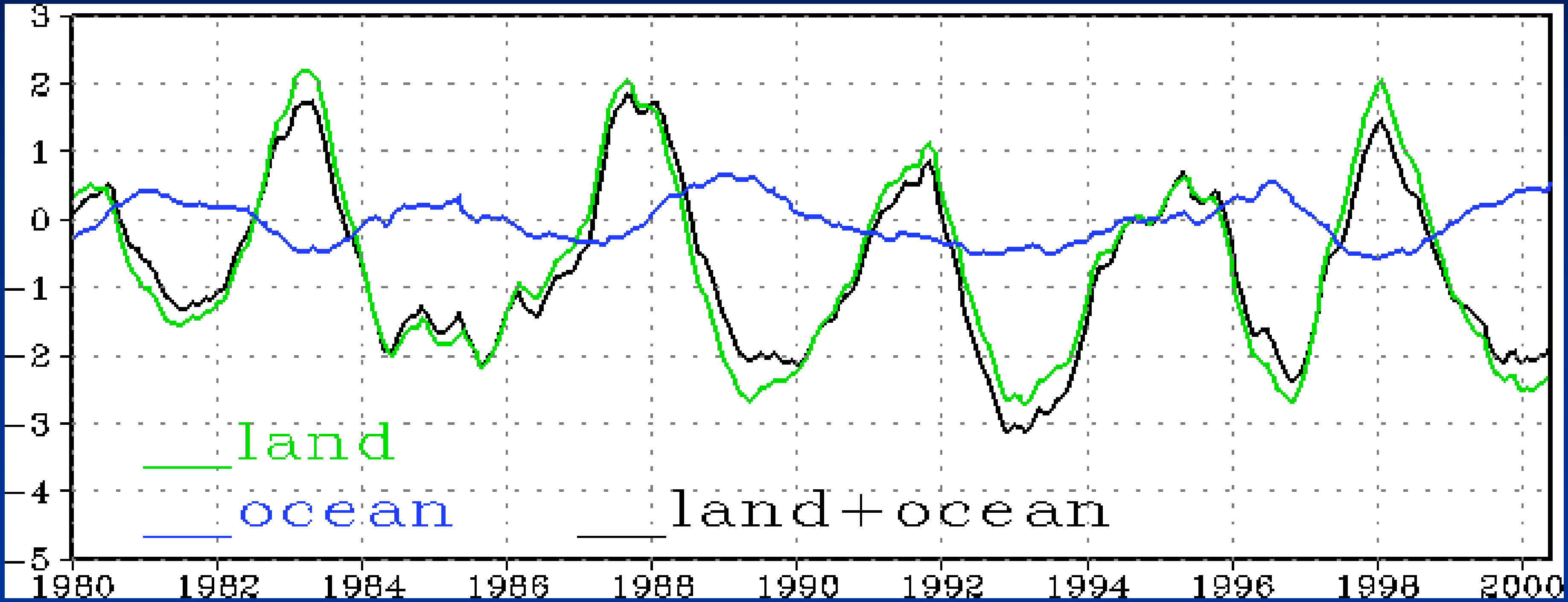
Mechanisms of Interannual Variability I

Modeled land-atmo flux vs. MLO CO2 growth rate



Terrestrial carbon model forced by observed climate variability

Land vs. ocean fluxes

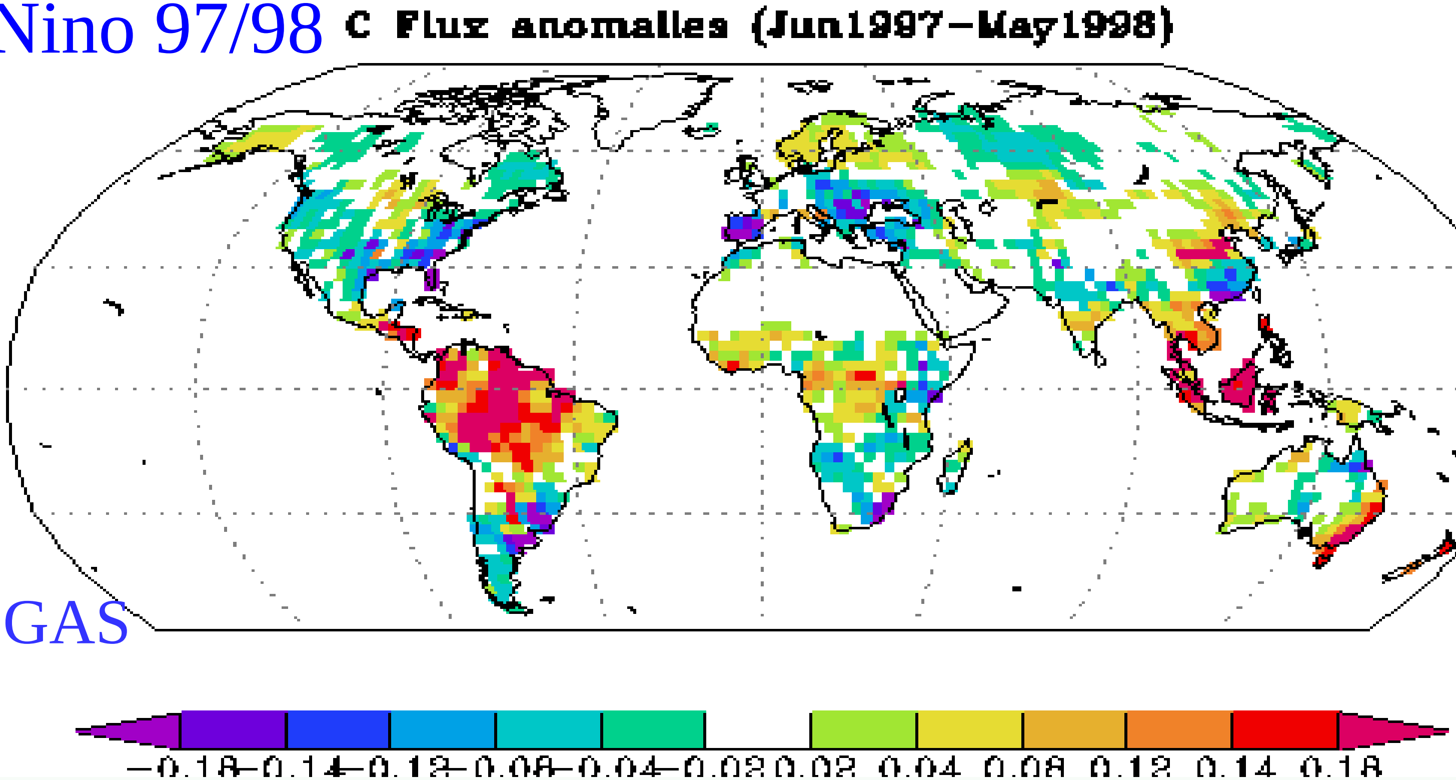


Land: VEGAS
Ocean: HAMOCC

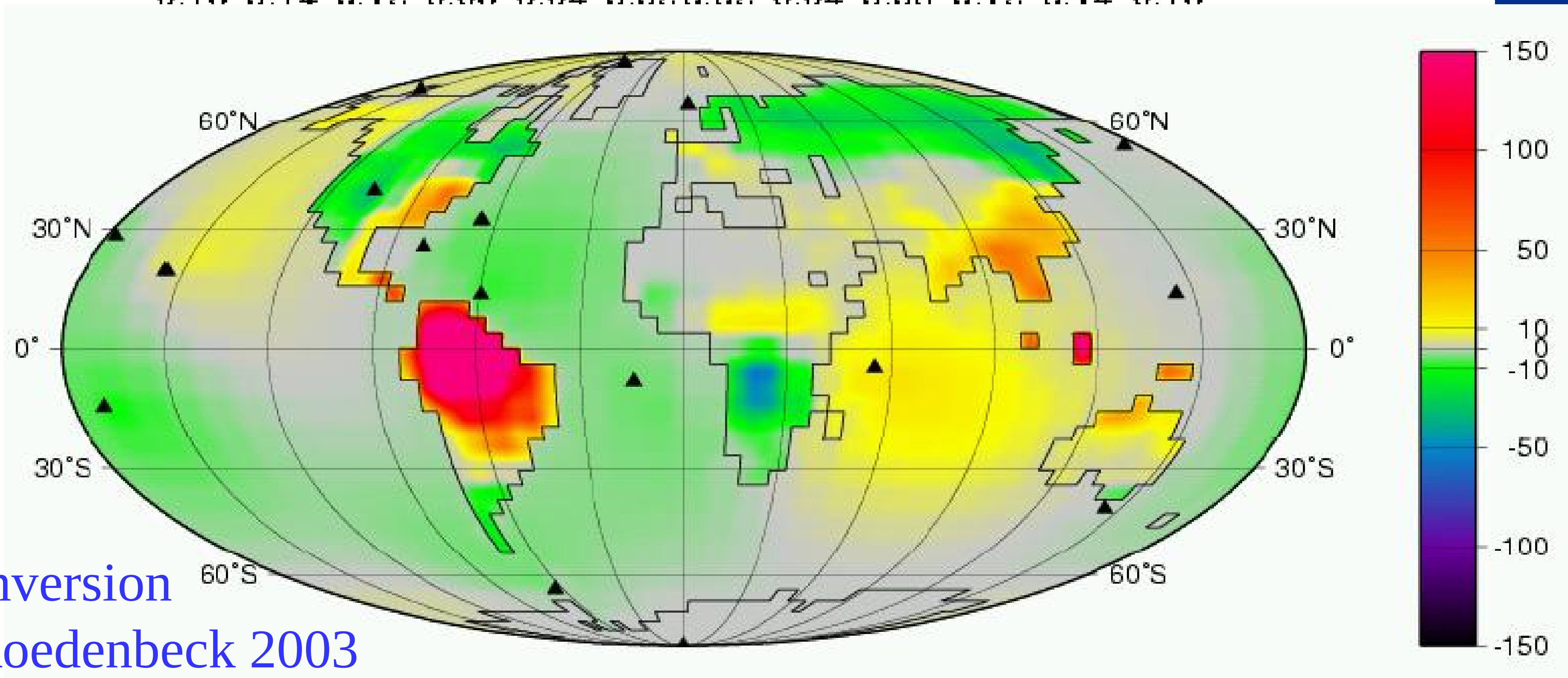
Land contributes to most of the interannual variability, with significant contribution from ocean

Modeling results supported by in-situ data and inversion

El Nino 97/98



VEGAS



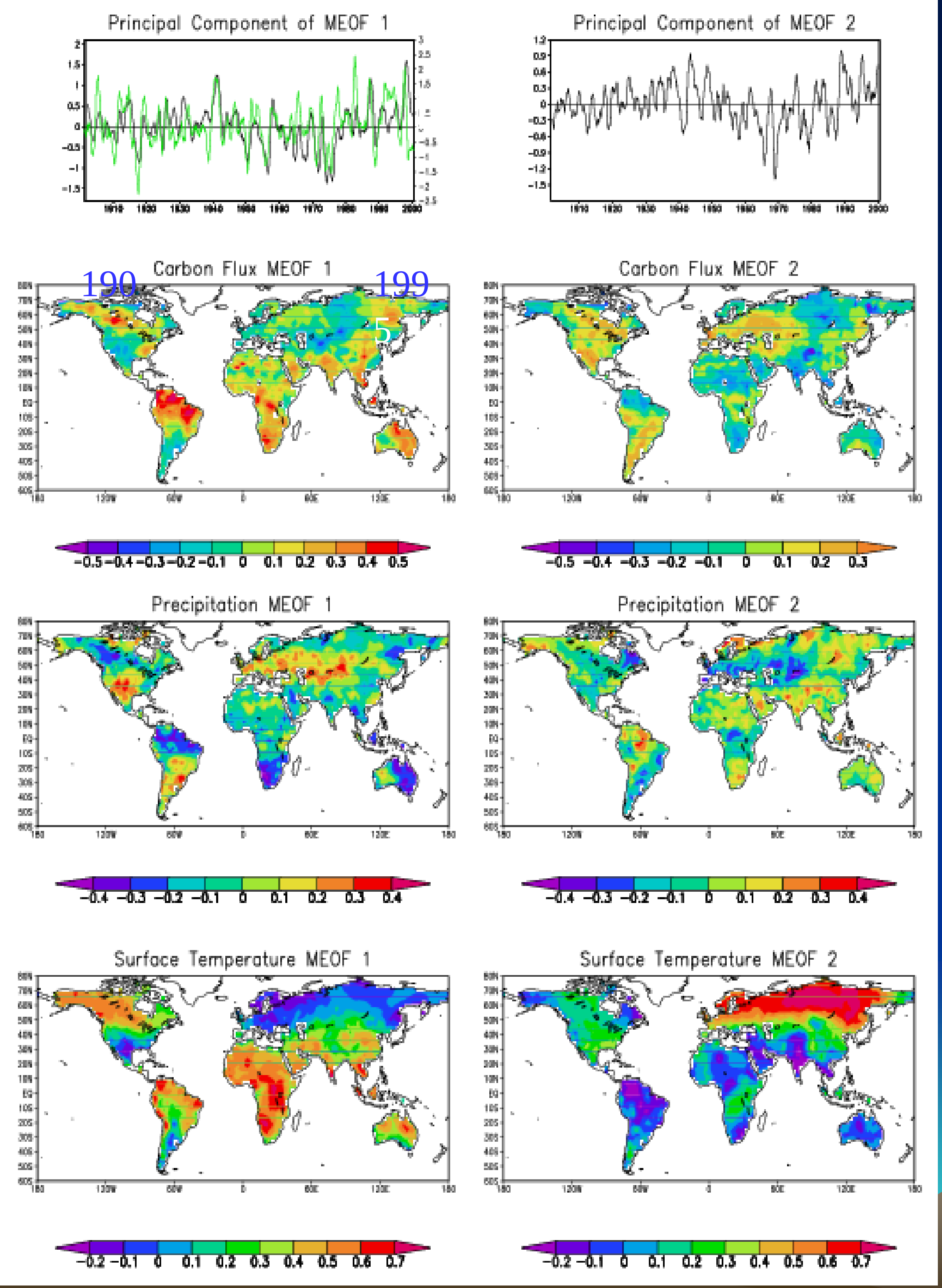
Inversion
Roedenbeck 2003

PC1

C flux

Precip

Temp



Spatial patterns from multi-variate EOF analysis

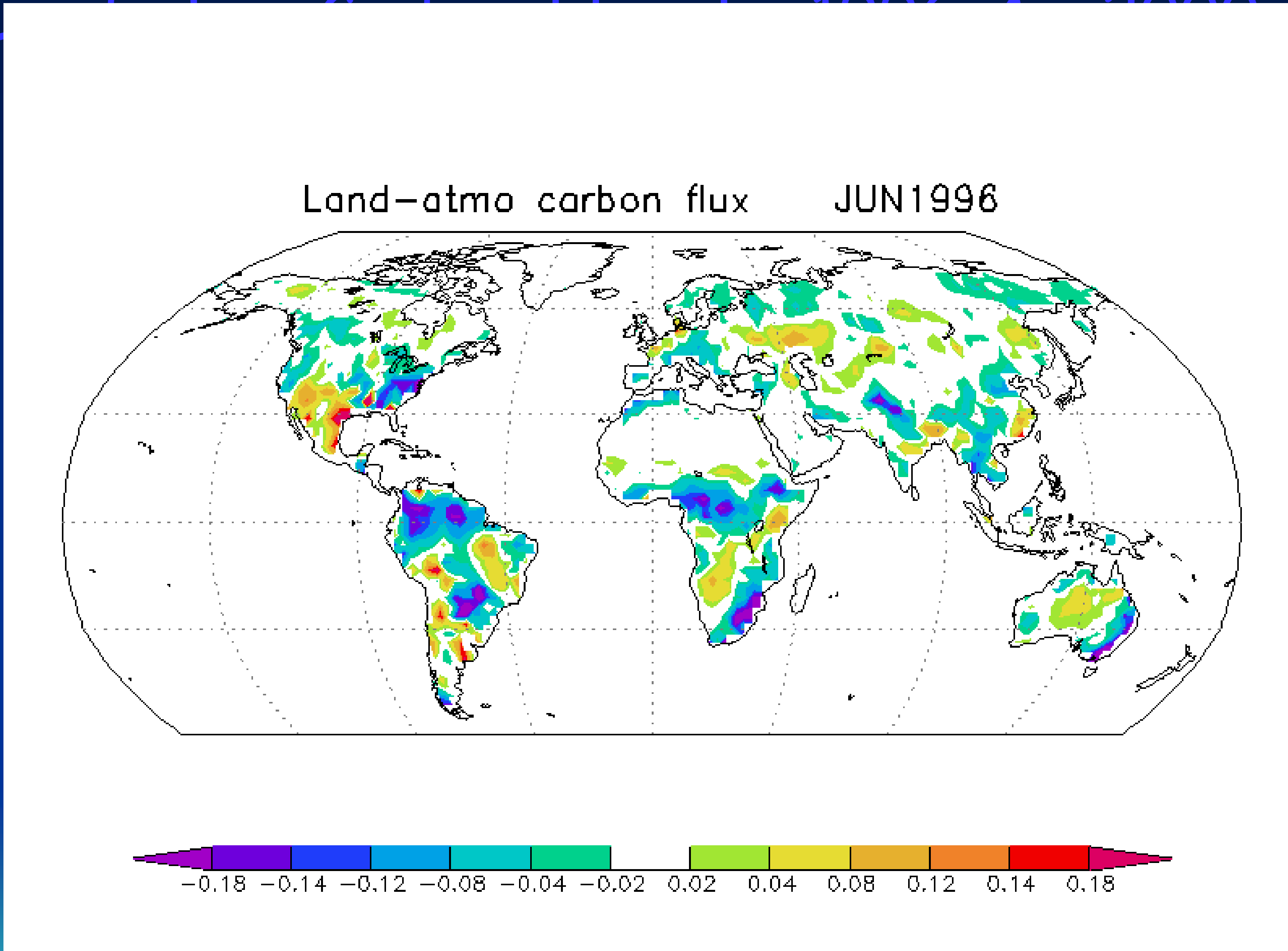
Tropics during El Nino

1) Drier and warmer conditions coexist at tropical locations

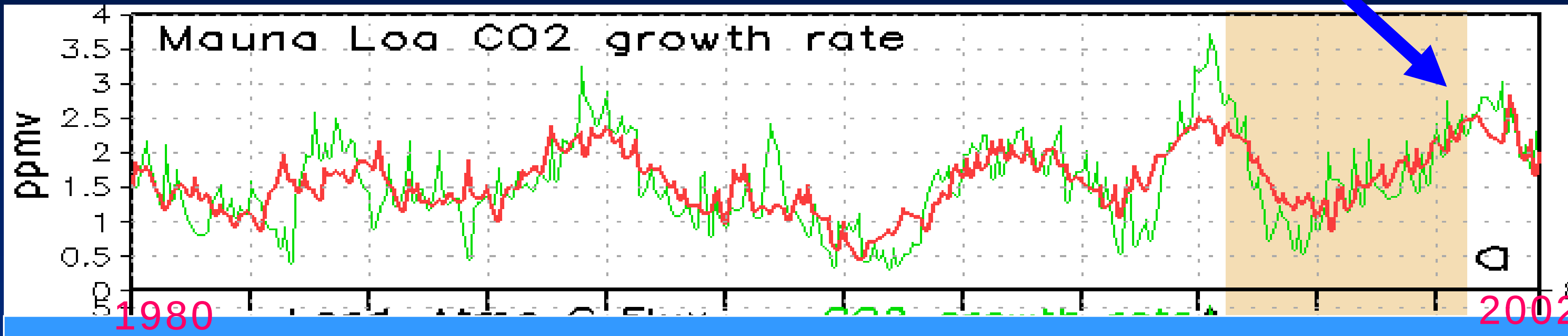
1+) Drier and warmer across much of tropical land during El Nino

2) Less precip
=> Less growth (lower NPP) and more fire
=> Less C uptake

Higher T
=> more respiration (higher Rh)
=> more C release


Land-atmo carbon flux JUN1996
−0.18 −0.14 −0.12 −0.08 −0.04 −0.02 0.02 0.04 0.08 0.12 0.14 0.18

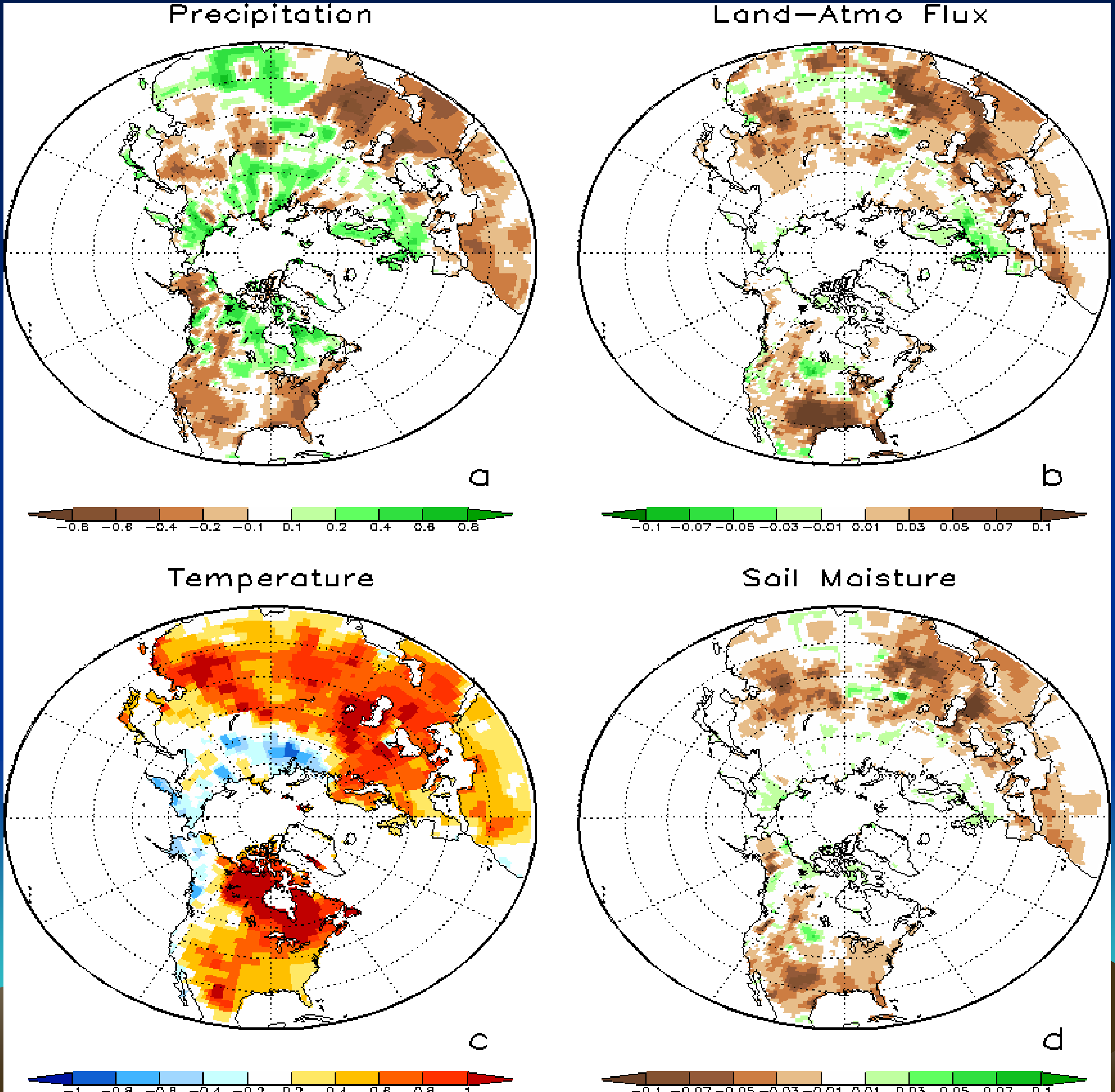
Recent Anomalous growth in CO2



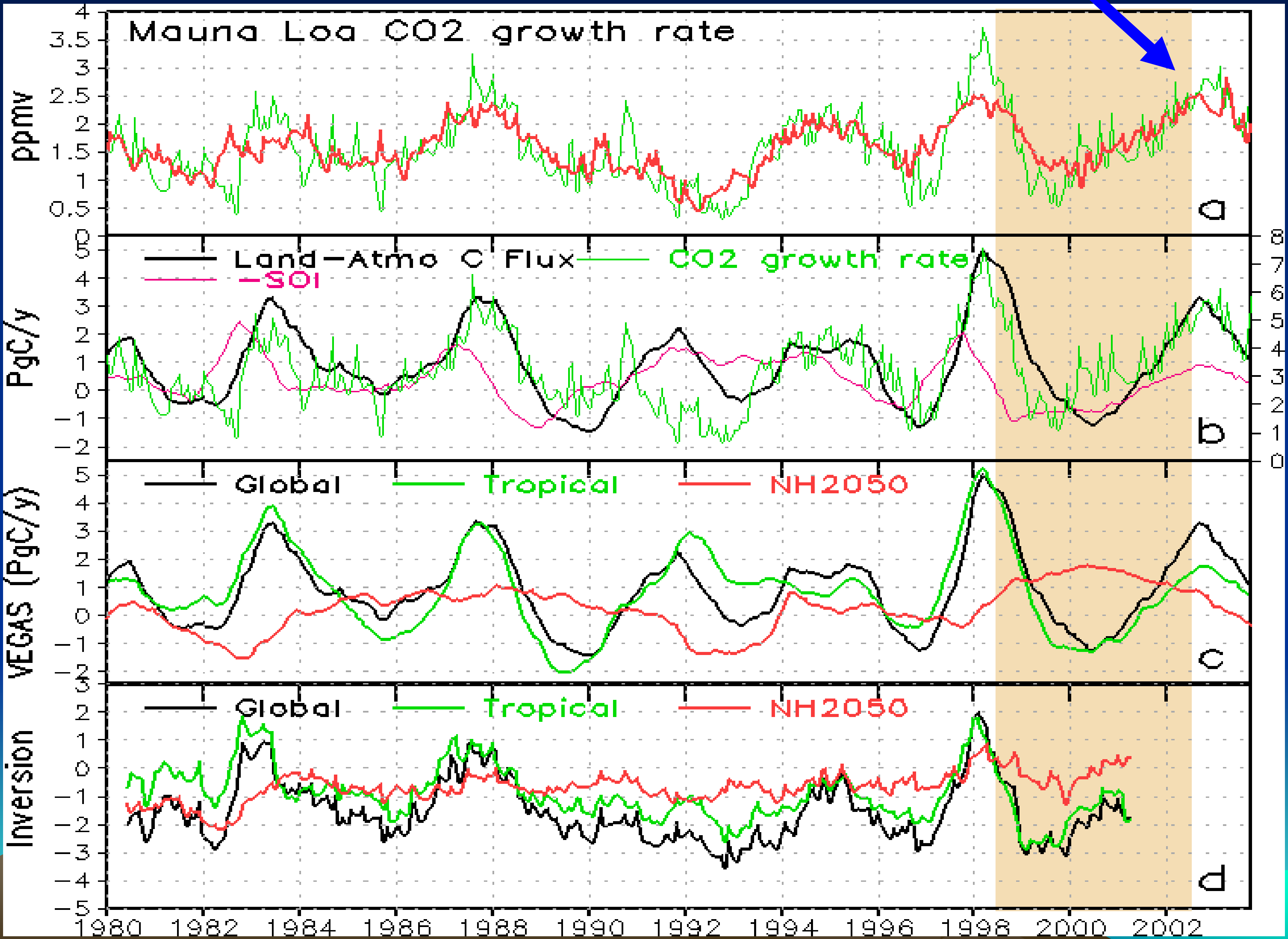
Proposed explanations:

1. Fire in Siberia, North America, and other places
2. Accelerated carbon emission from China, India
3. Mid-latitude drought

Mid-latitude Drought: 1998-2002



Recent Anomalous growth in CO2



Conclusions: variability

- The high correlation between CO_2 and ENSO is mainly due to a ‘conspiracy’ between climate anomalies and plant/soil physiology
- Recent anomalously large CO_2 growth can be explained by a (so far) unusual midlatitude drought, a possible glimpse into a warmer world
- Understanding the mechanisms and processes underlying such interactions provides crucial insight into the fate of anthropogenic CO_2 and the degree of future climate change
- Such variability may be predictable!

Seasonal-interannual Prediction of Ecosystem and Carbon Cycle

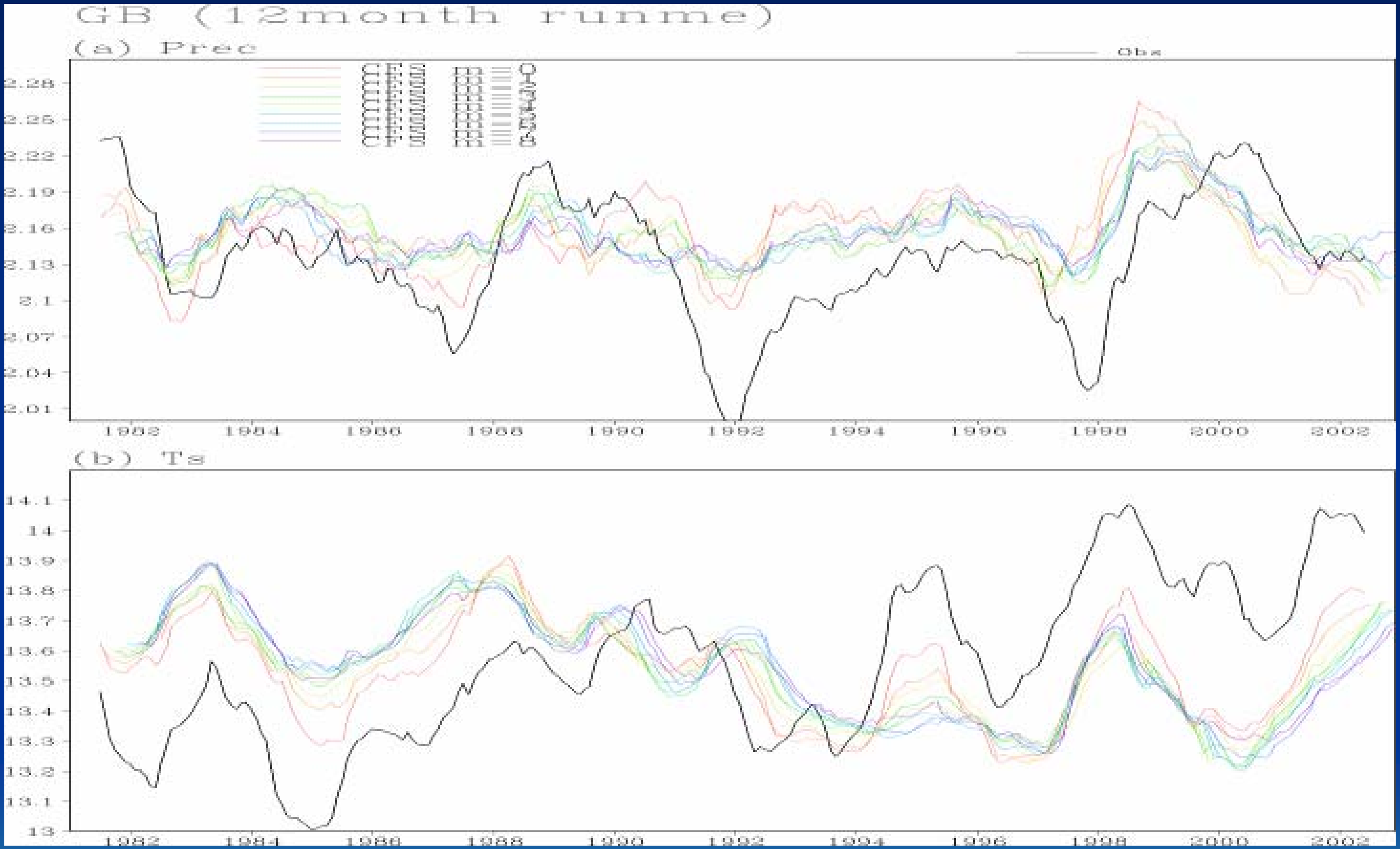
Two strands of recent research made this a real possibility

- Significantly improved skill in atmosphere-ocean prediction system, such as CFS at NCEP
- Development of dynamic ecosystem and carbon cycle models that are capable of capturing major interannual variabilities, when forced by realistic climate anomalies

A pilot study at U Maryland:

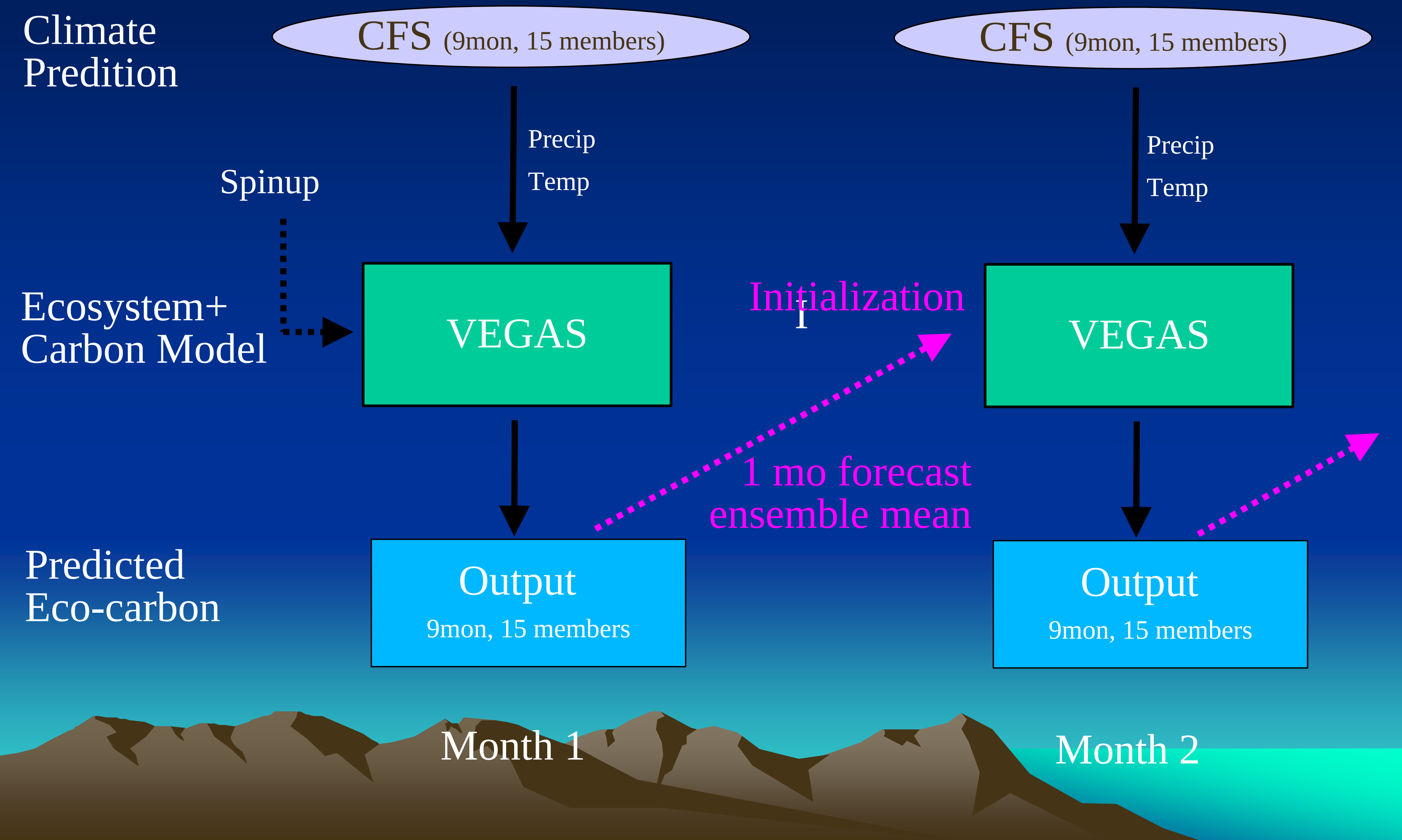
1. Feasibility study using a prototype eco-carbon prediction system
2. Dynamic vegetation as an interactive component?

The NCEP Climate Forecast System (CFS, Saha et al. 2005)

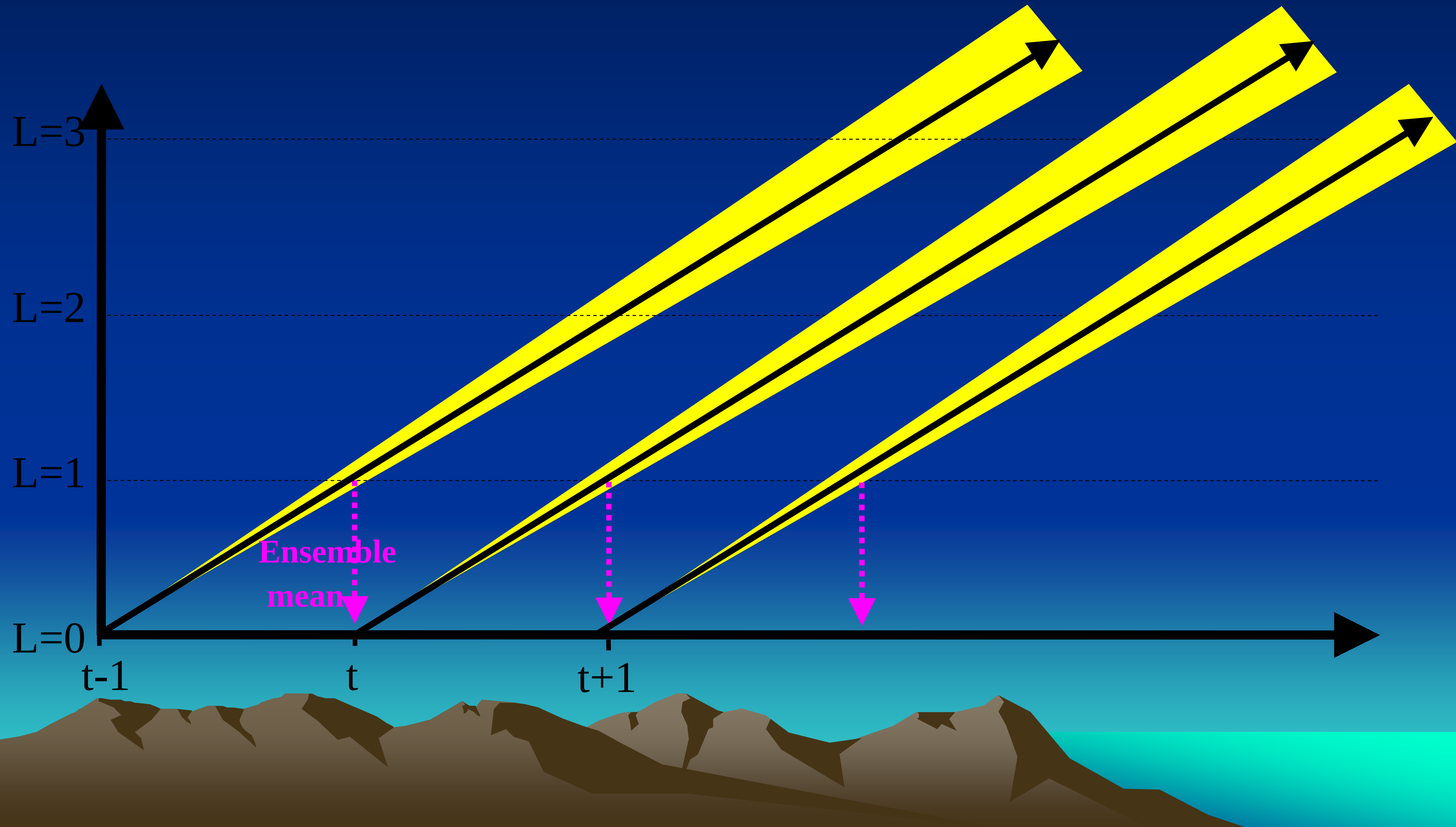


CFS captures major ENSO and other seasonal-interannual variability
no warming trend, why?

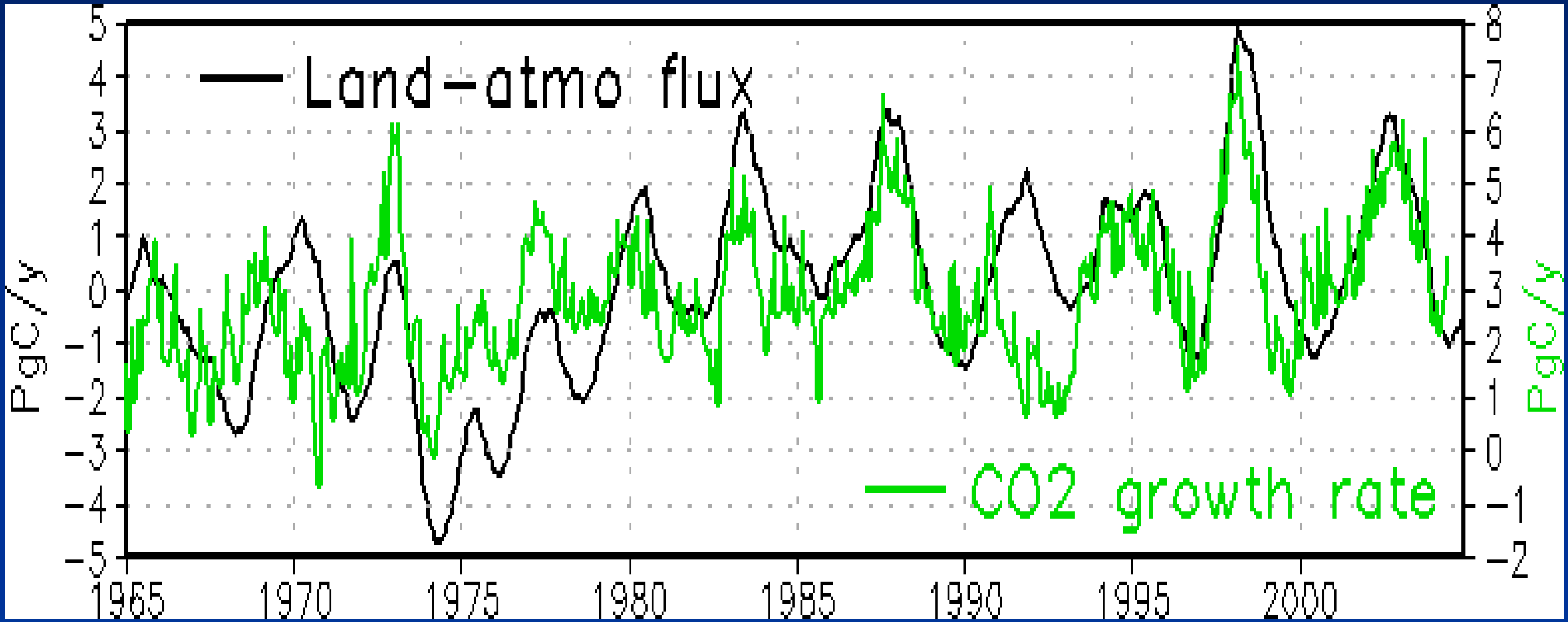
Forecasting Procedure I



Forecasting procedure II

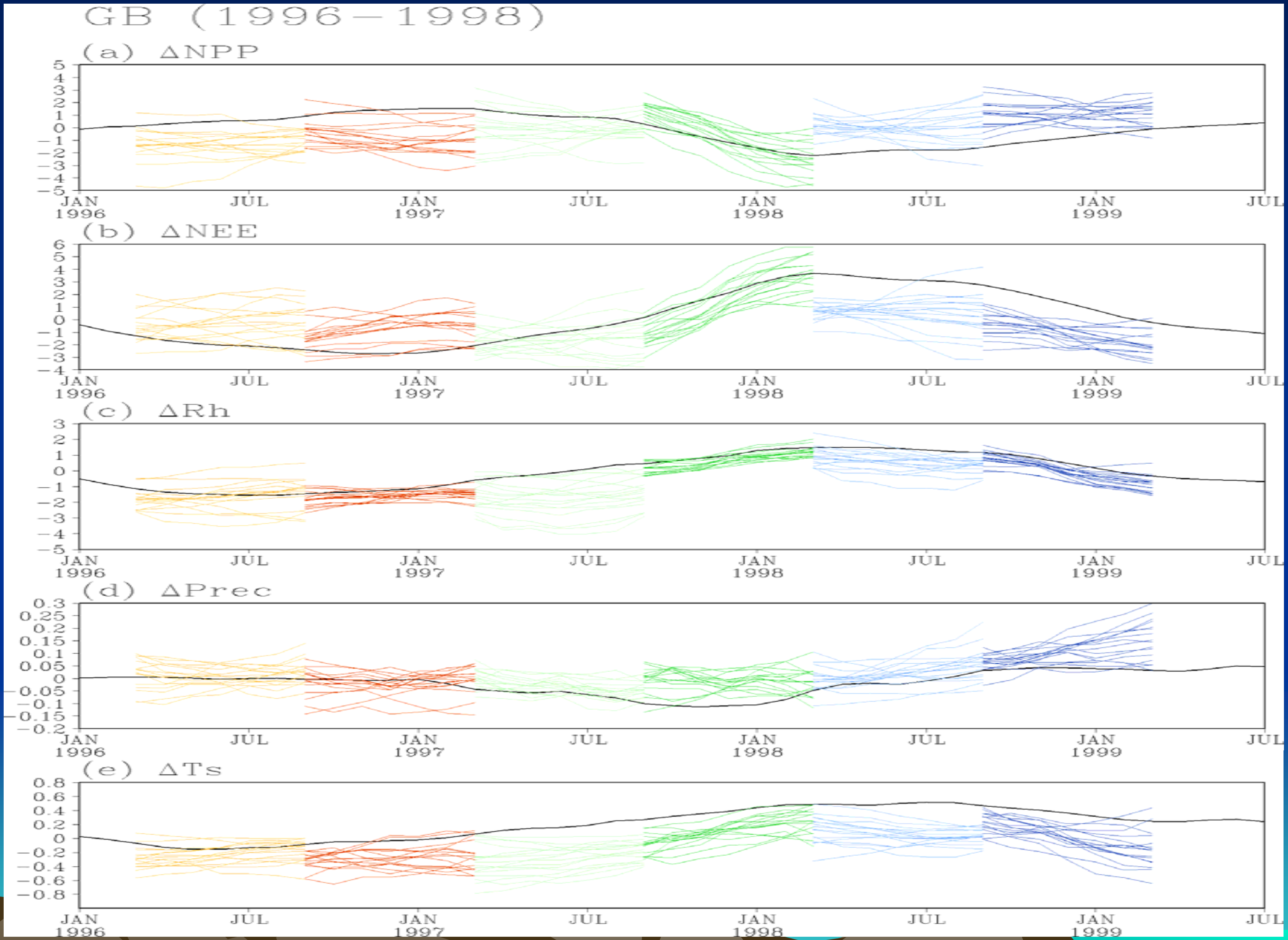


NEE('validation') and MLO CO2

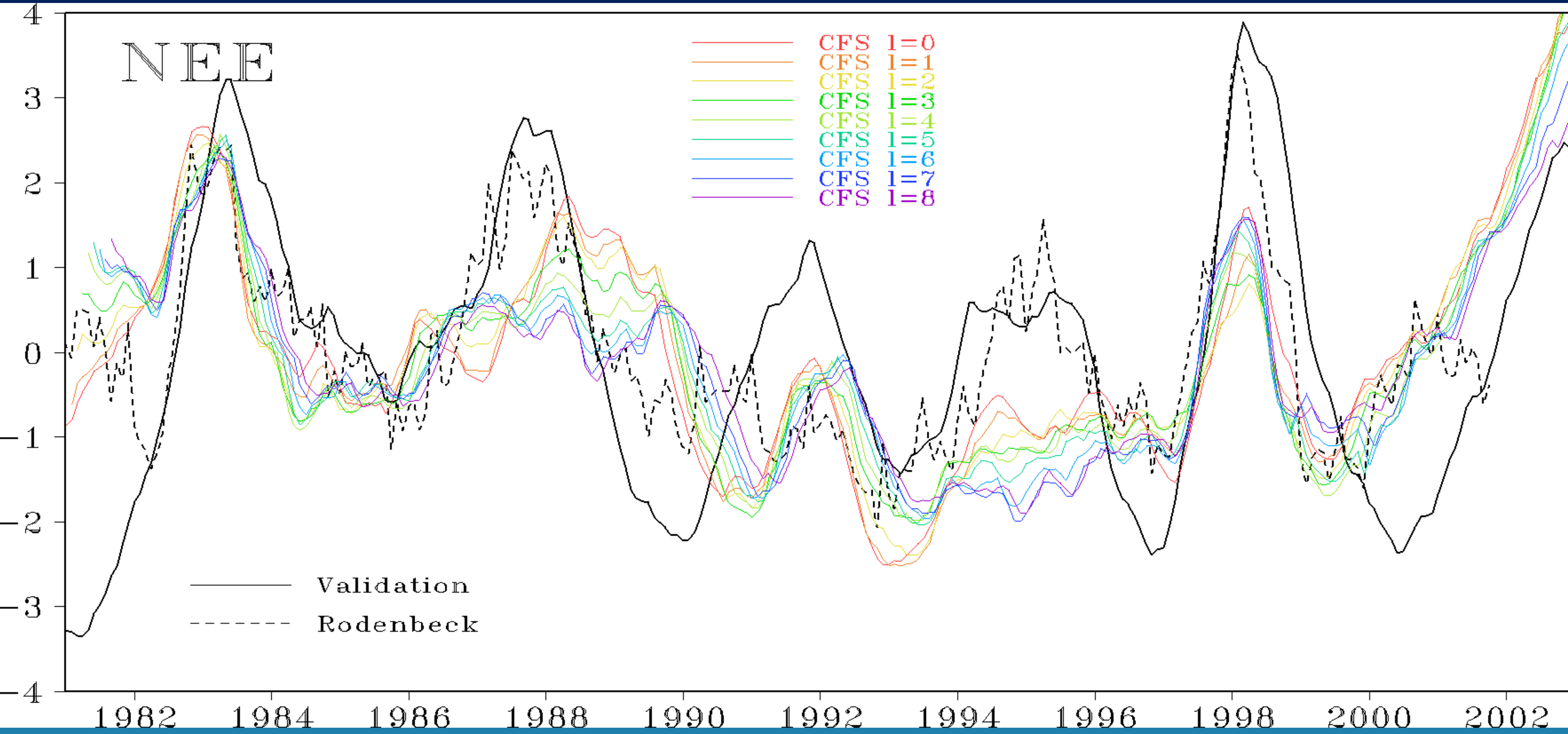


NEE (land-atmo C flux): VEGAS forced by observed climate (Precip, T)
This will be called 'observed' as there is no true observation available
Ocean contribution smaller, so NEE can be compared with MLO CO_2

Plumes: NPP, P, T etc.

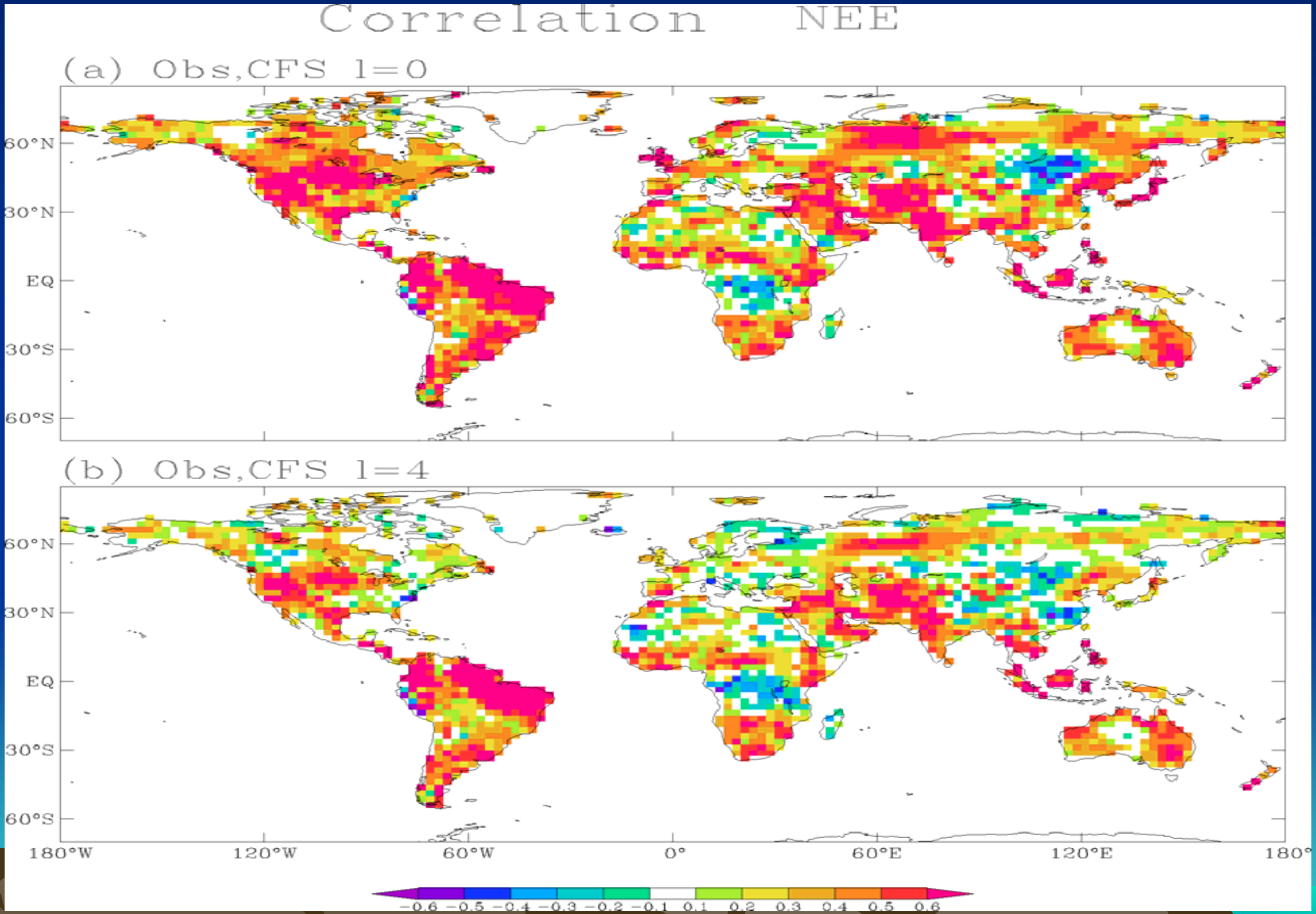


Predicted global cabon flux

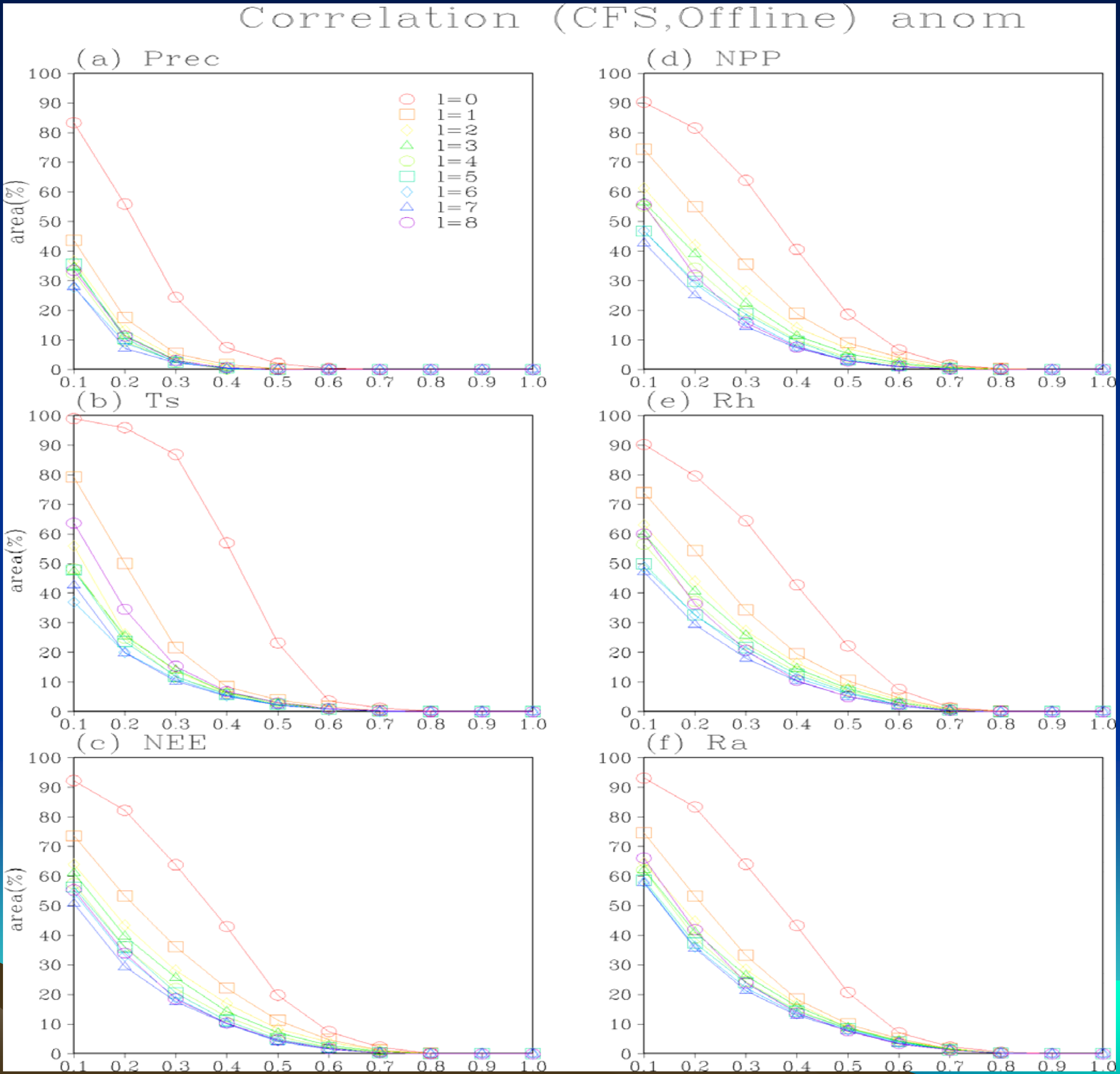


1. CFS/VEGAS captures most of the interannual variability, but
2. Amplitude is underestimated

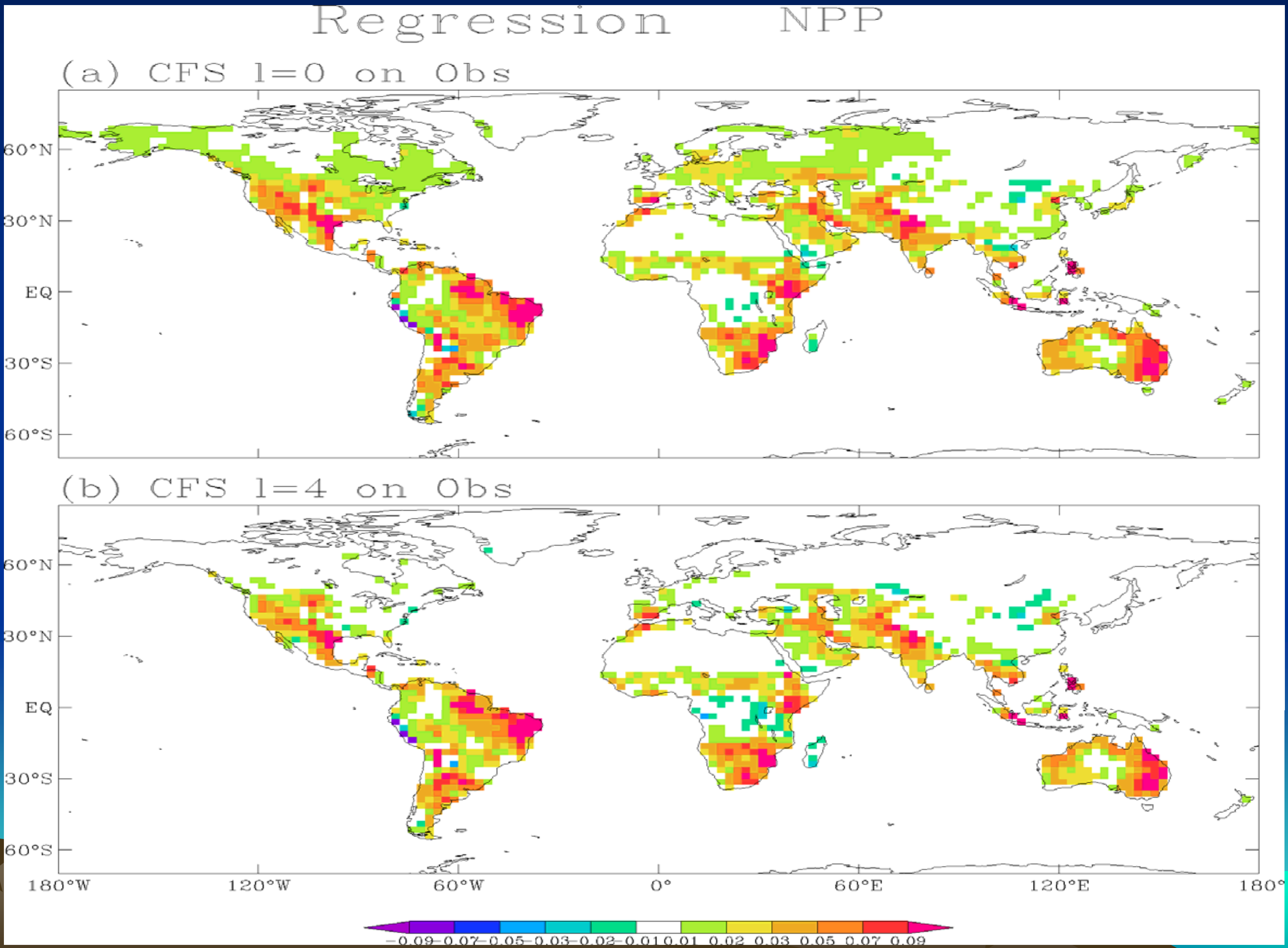
Anomaly Correlation NEE



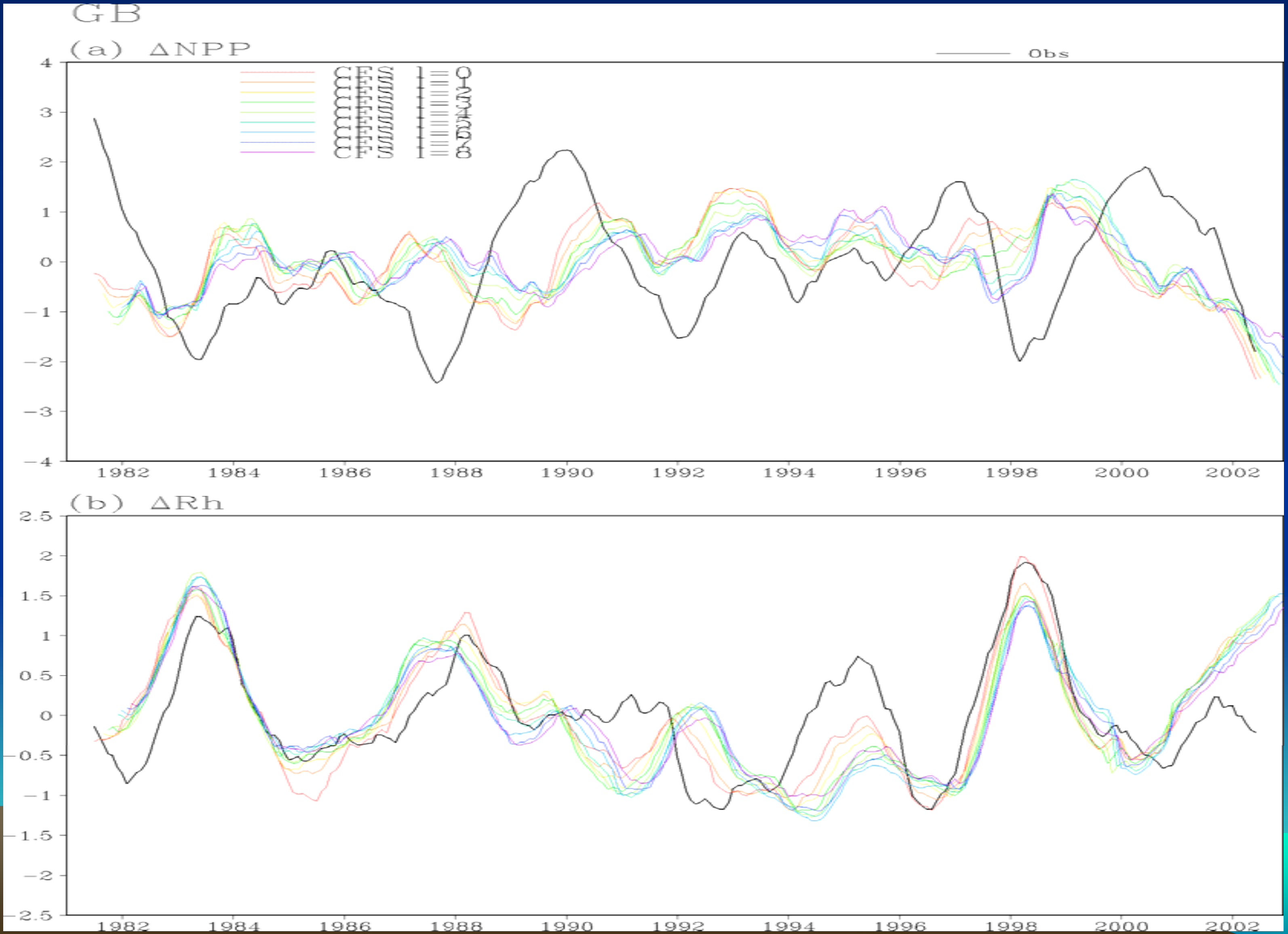
Summary of skill for anomaly correlation



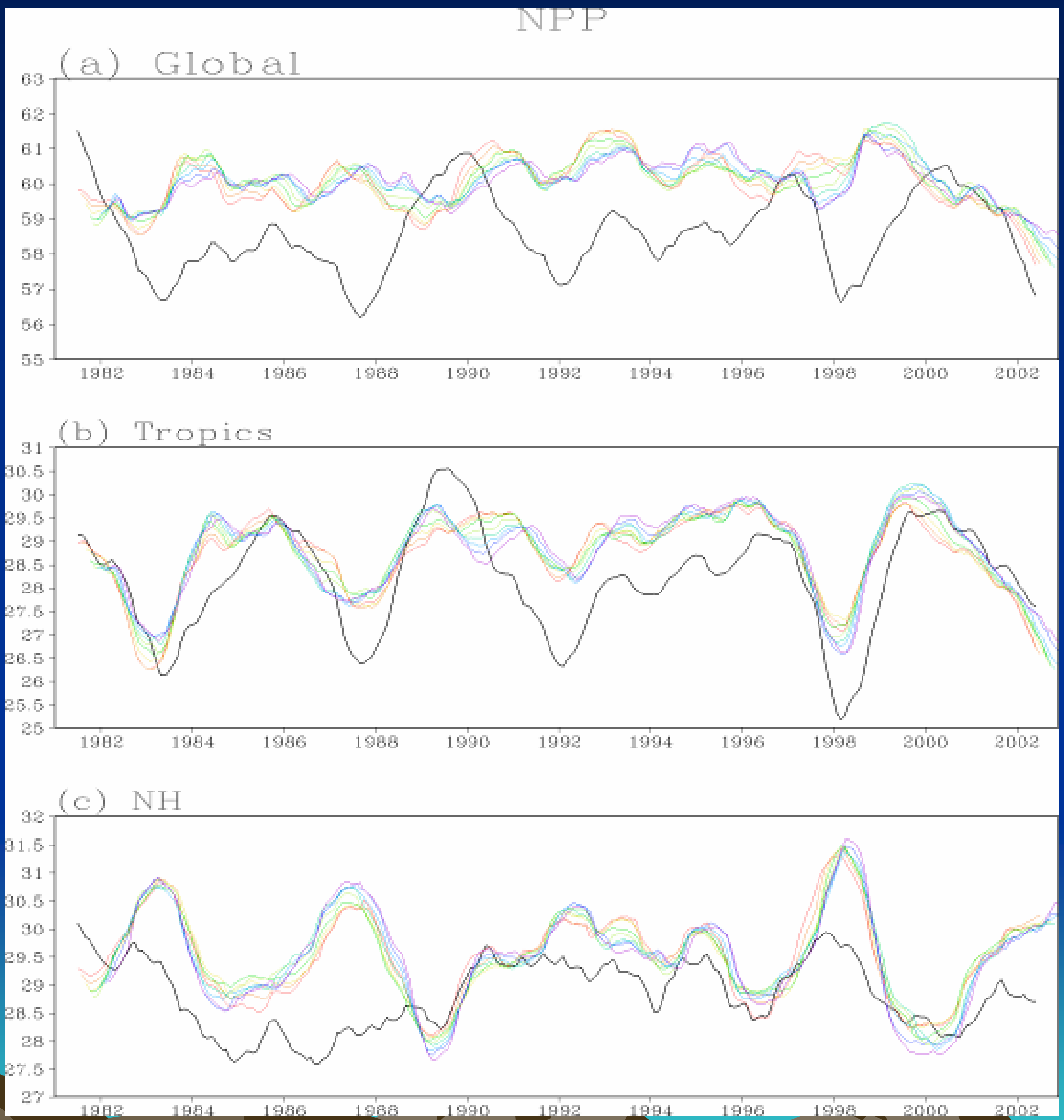
Predicted NPP vs. 'Validation' Regression



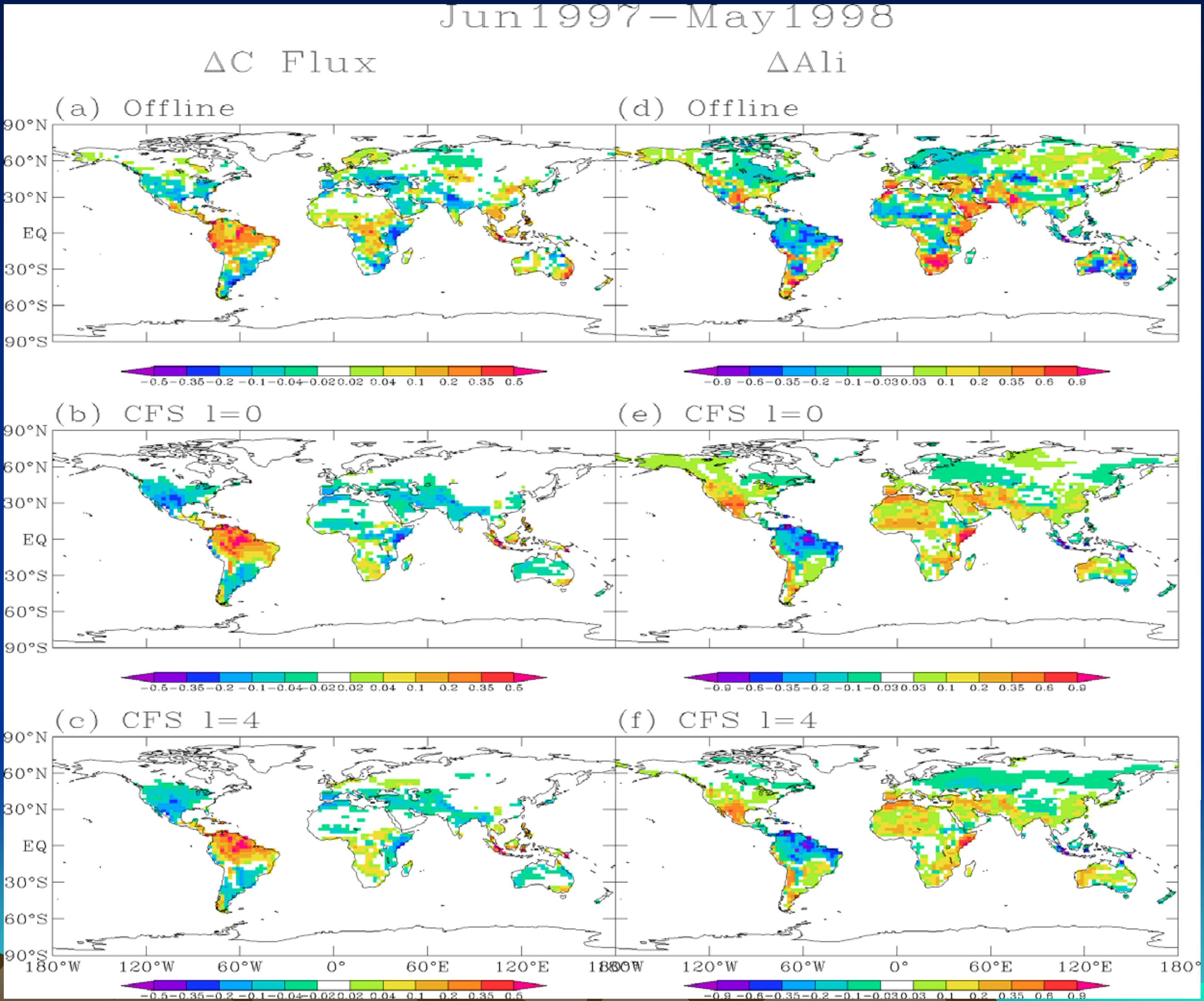
NPP and R_h (NEE=R_h-NPP)



Improvement of the prediction system: The NPP Problem

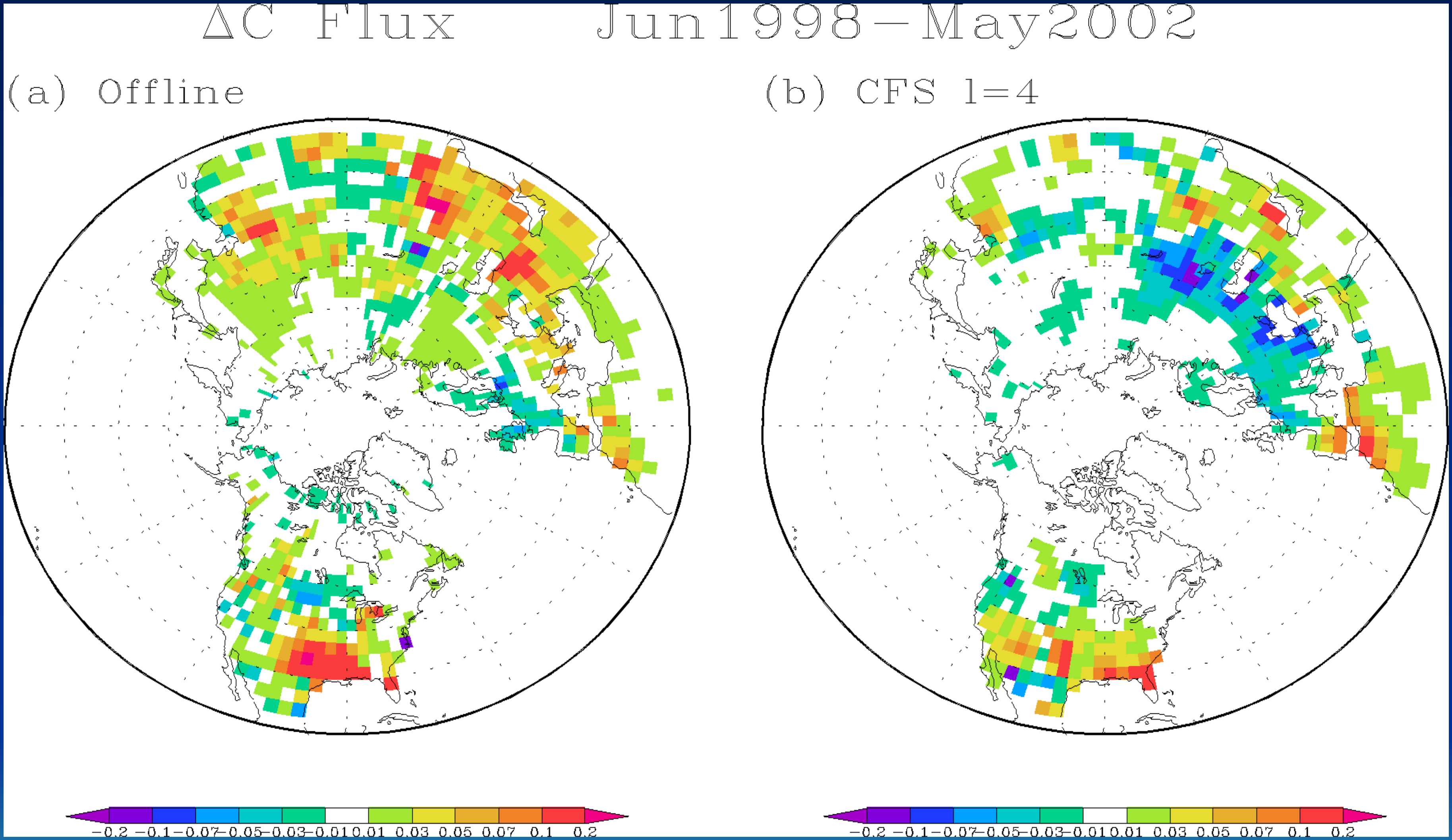


El Nino Jun97-May98   NEE/LAI



Combining statistical with dynamical method to improve the prediction

Beyond ENSO: 1998-2002 Midlatitude Drought

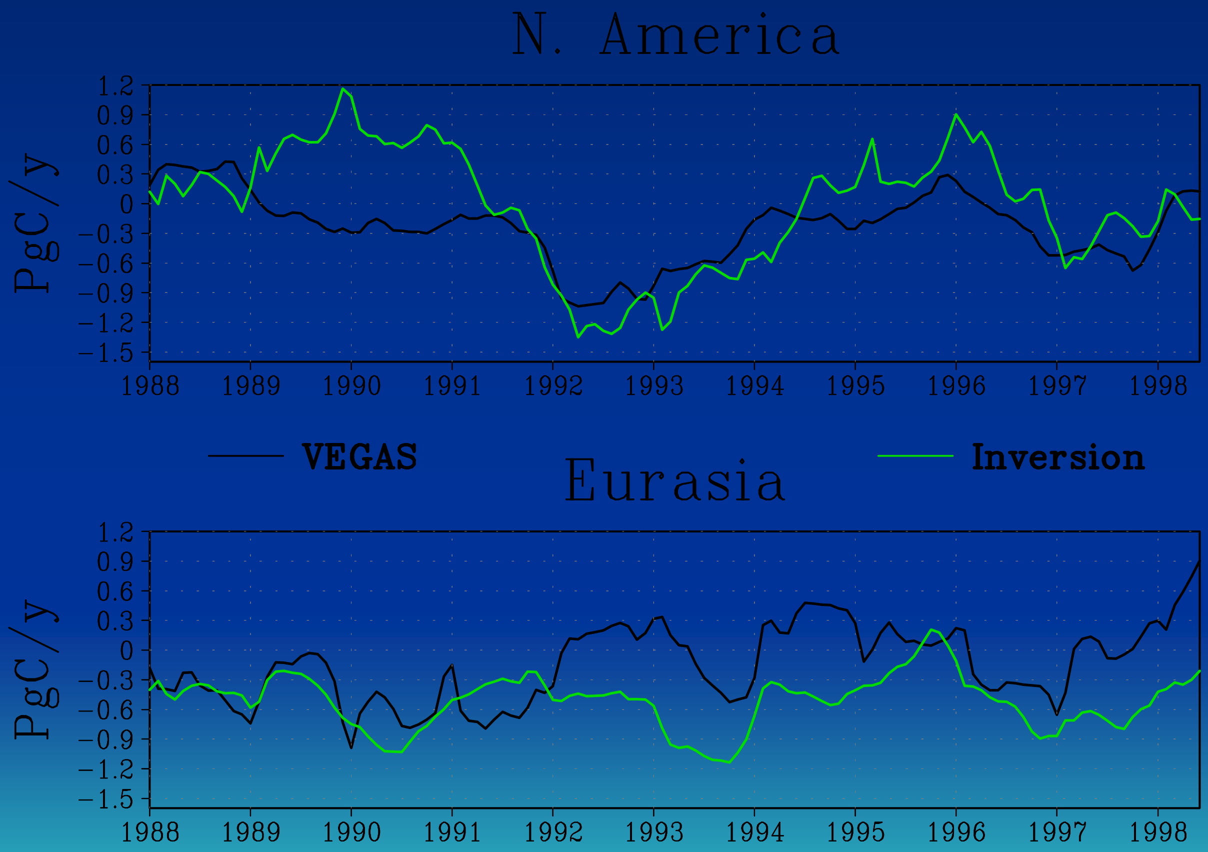


Other variability not related to ENSO or other known climate modes, can also be captured in a dynamical prediction system

Conclusions: prediction

- Encouraging results (better than expected)
- Issues
  - Overestimation at midlatitude screws up global NPP, and too small NEE compared to MLO CO2
  - Other analysis methods?
  - Terminology: forecast, hindcast, retrospective
- Implications of prediction
  - Applications to ecosystem and carbon cycle
  - A new framework for study eco-carbon response and feedback to climate
  - Identifying ways of incorporating eco-carbon dynamics in the next generation of climate prediction models

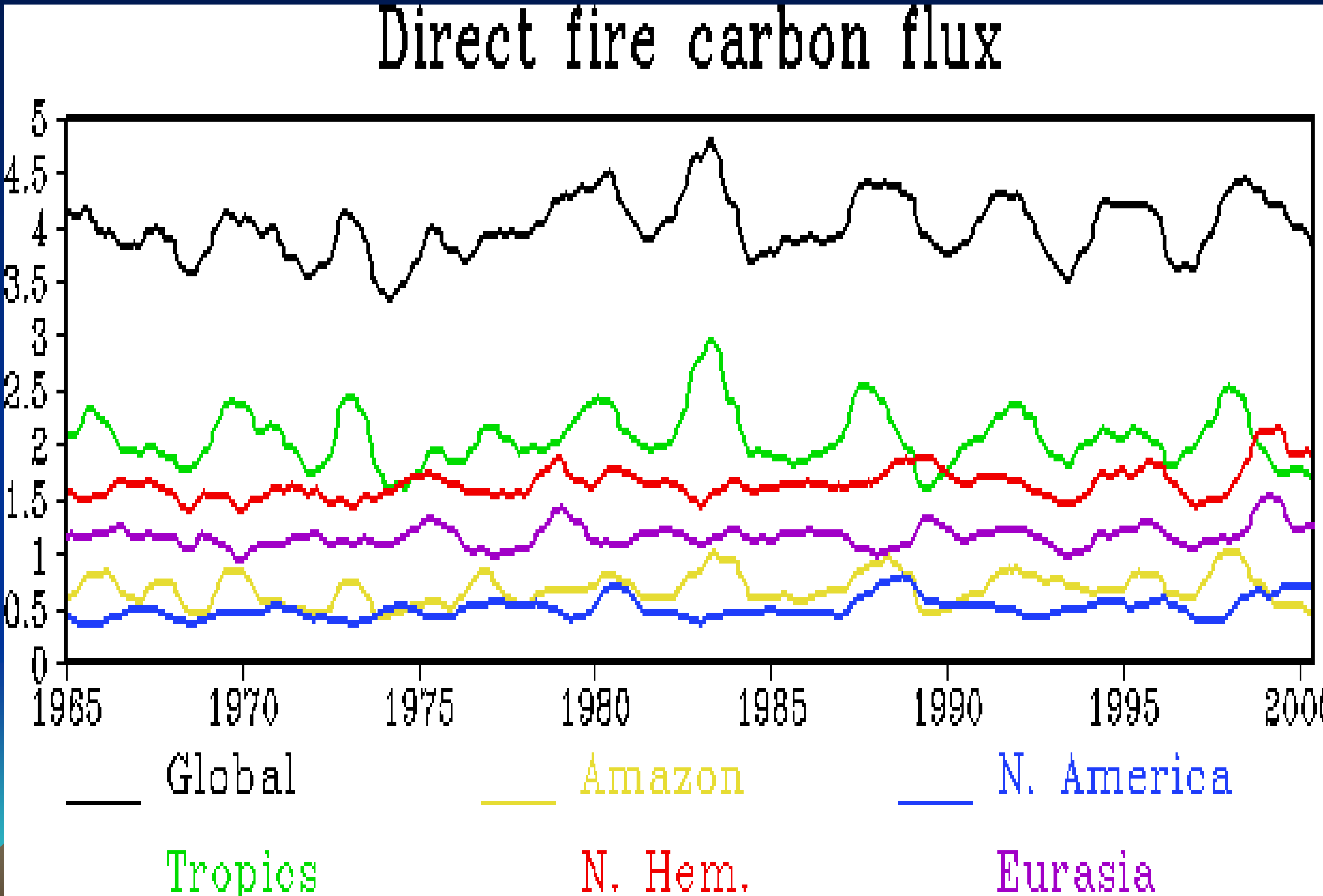
Extratropics: forward model comparison with atmo inversion



VEGAS

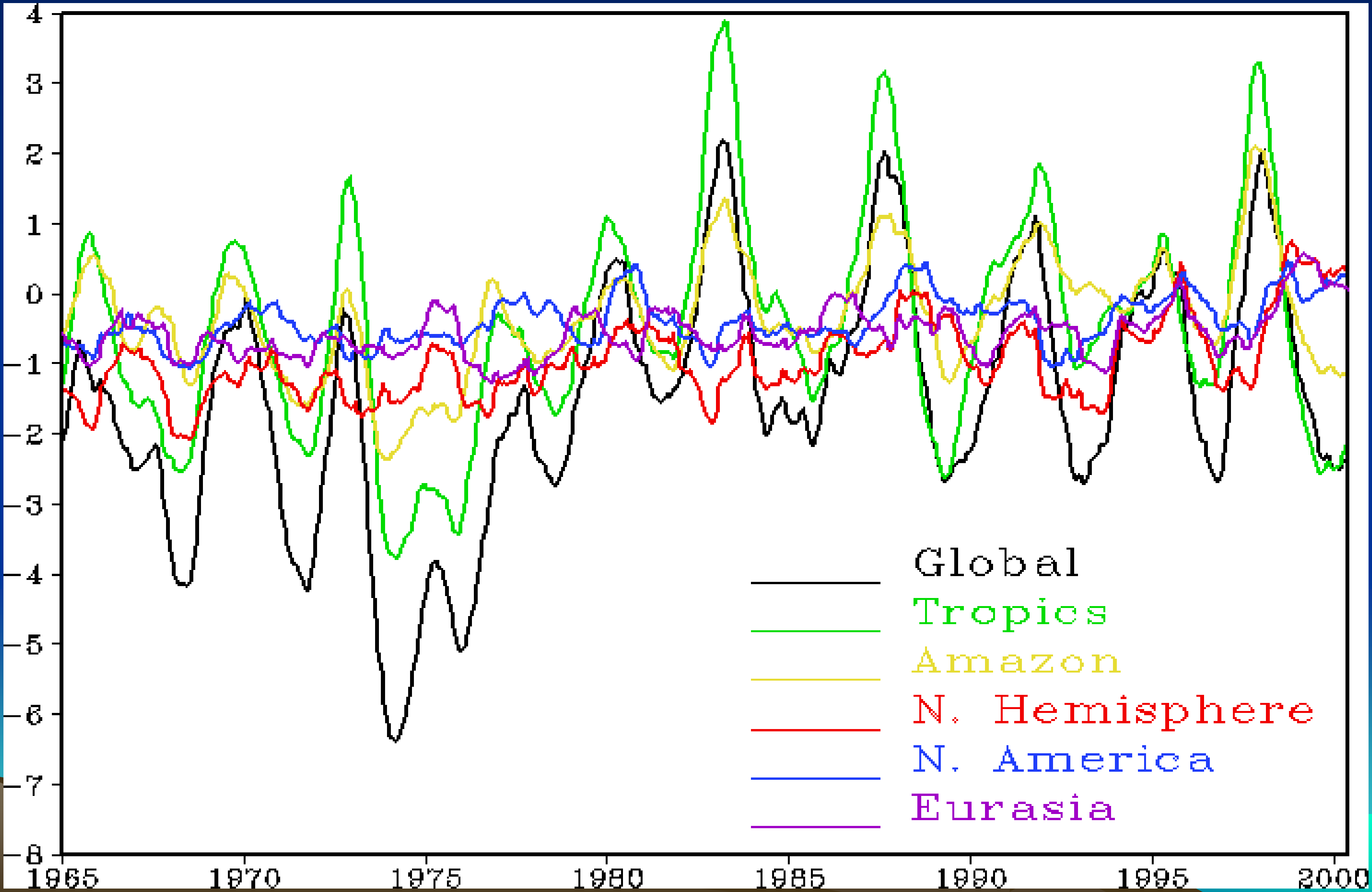
Atmo. Inversion

(Bousquet et al., 2000)

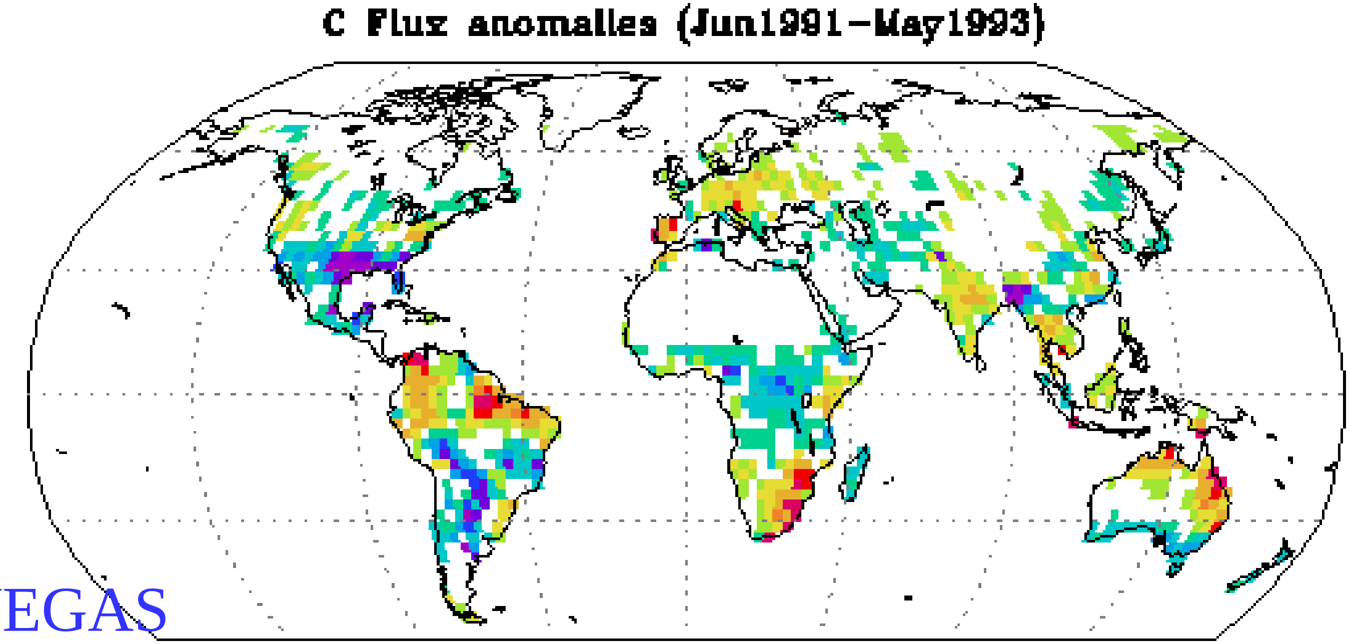


Direct fire carbon flux
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1965
1970
1975
1980
1985
1990
1995
2000
Global
Amazon
N. America
Tropics
N. Hem.
Eurasia

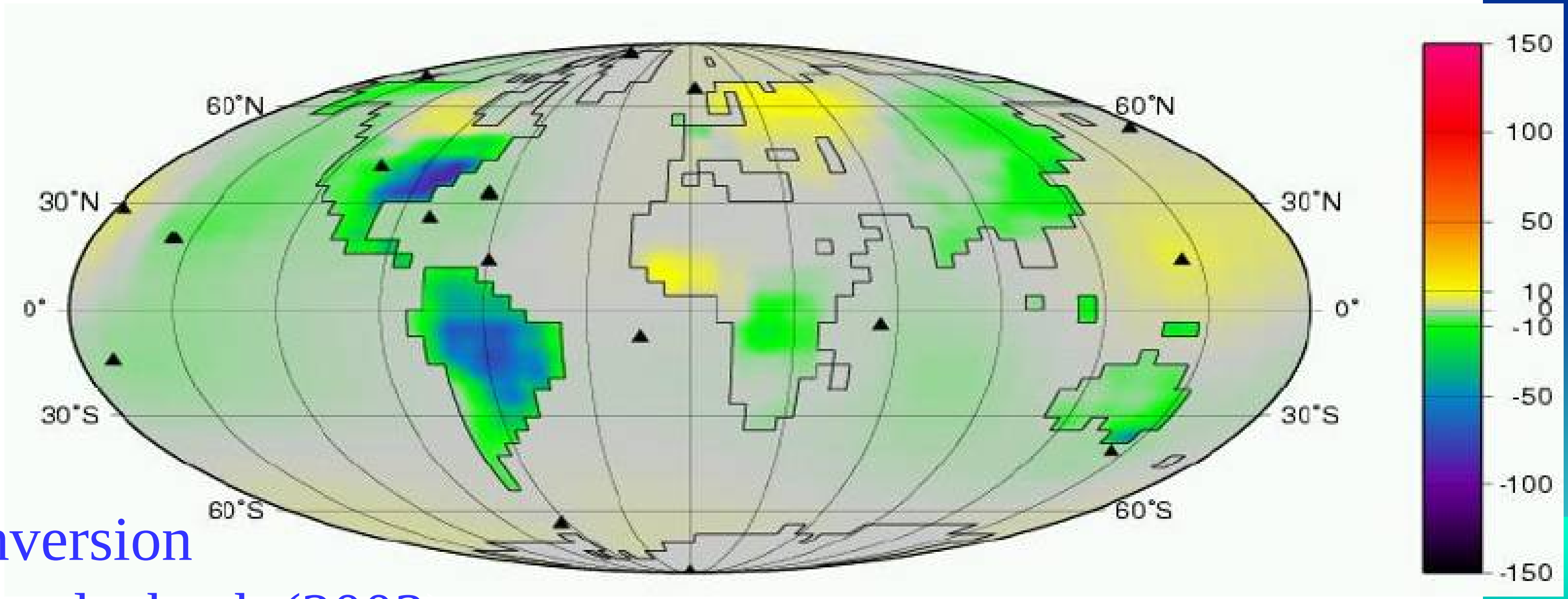
Carbon flux from various regions



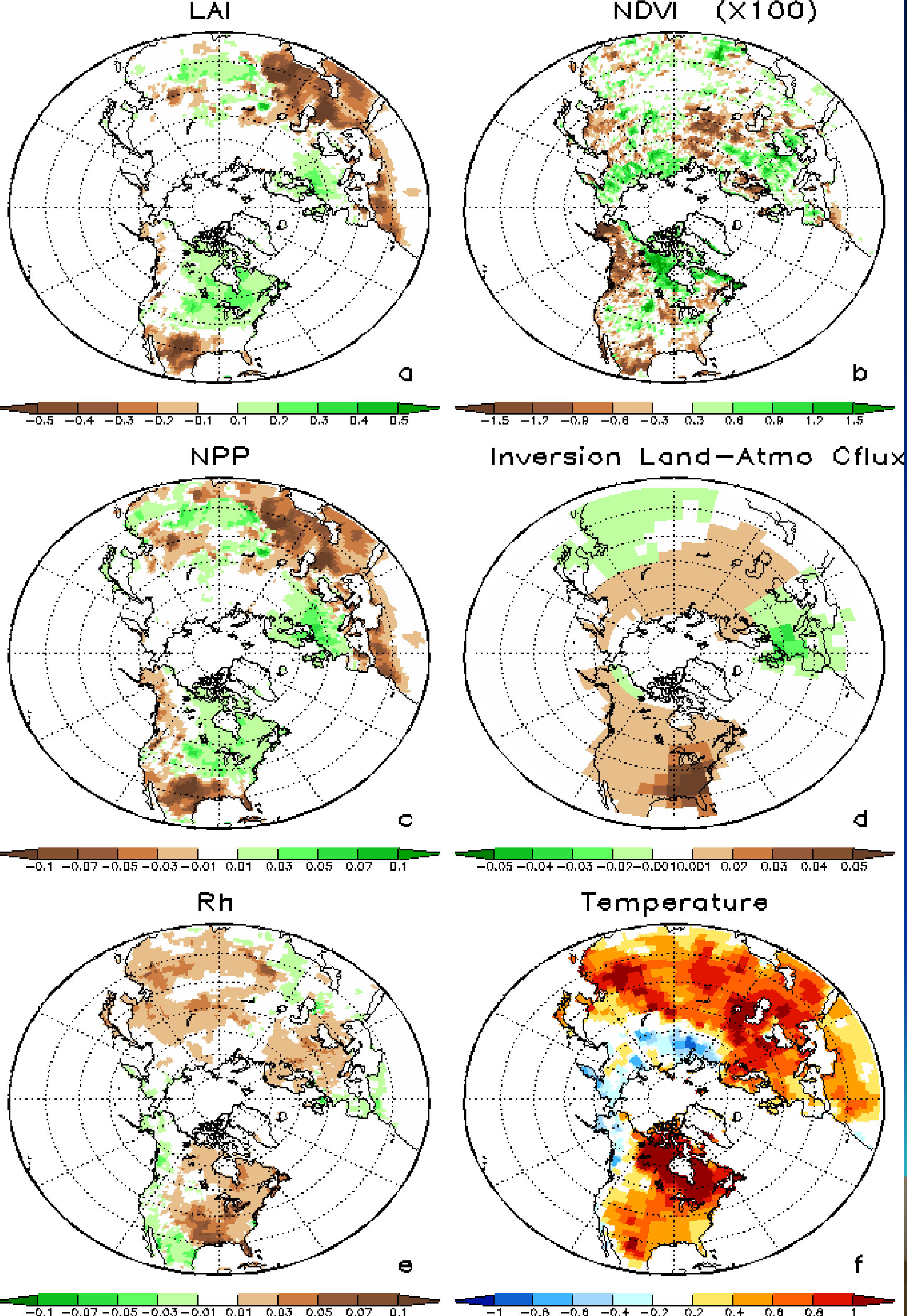
Post-Pinatubo   Jun1991-May1993



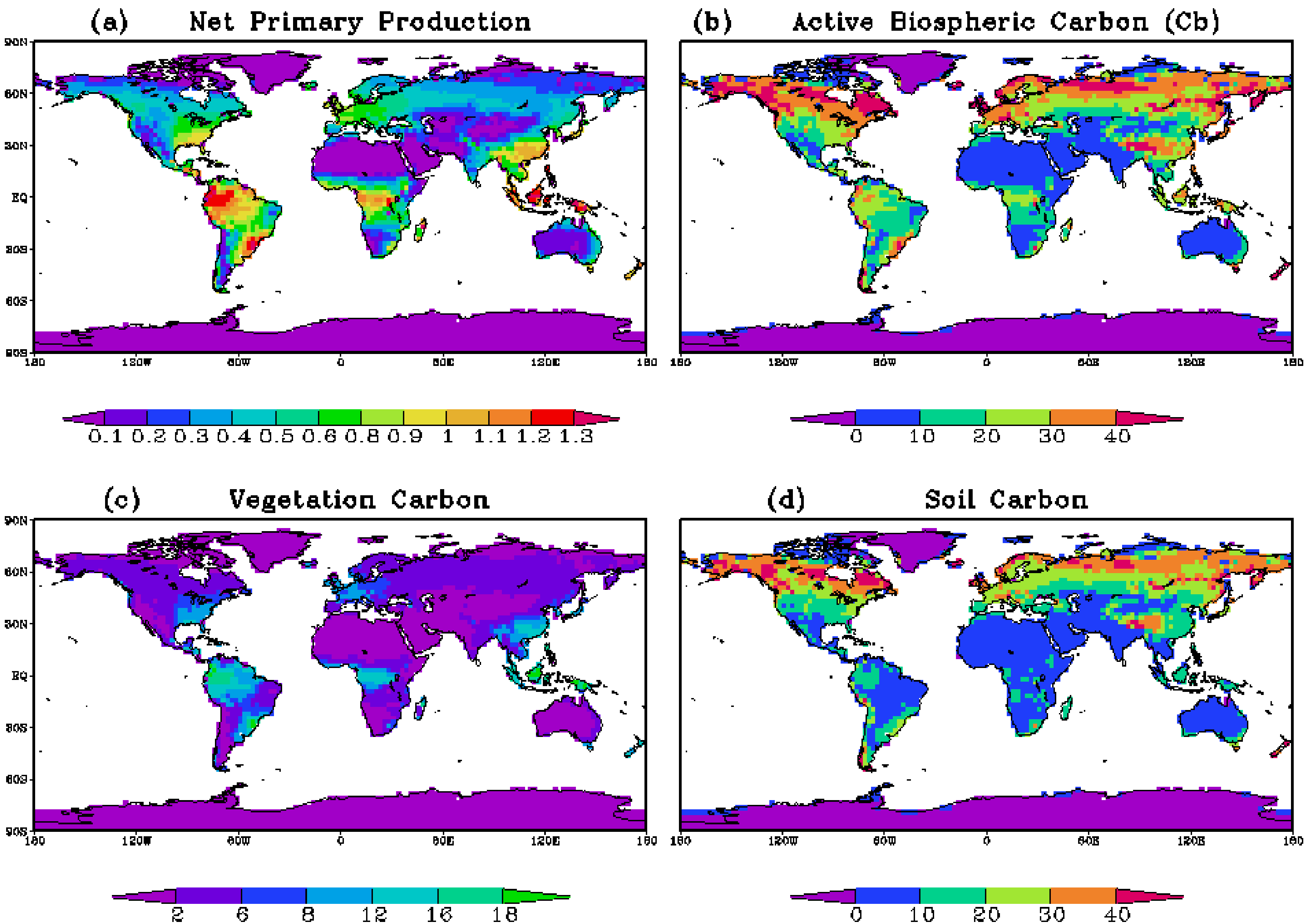
VEGAS



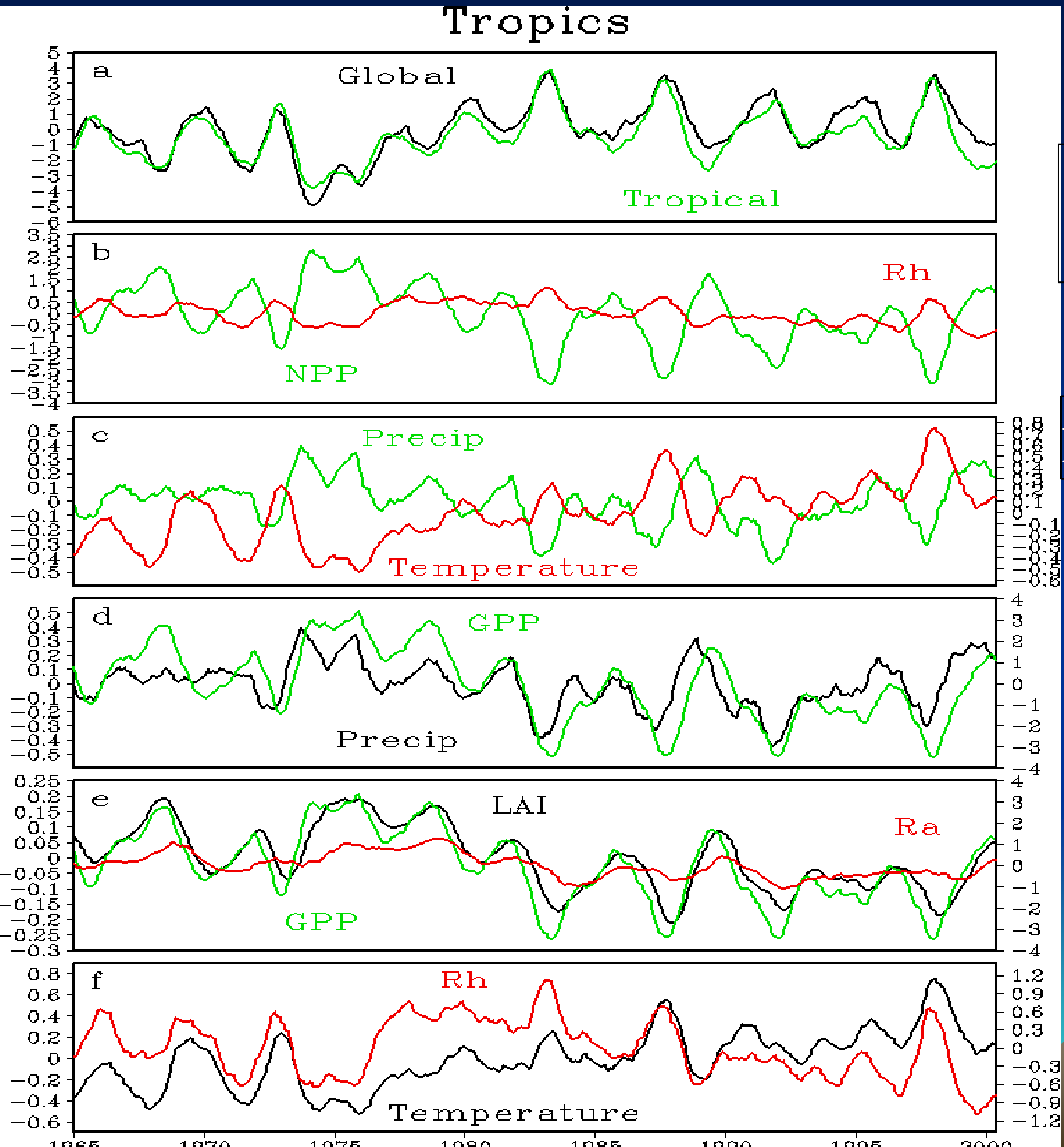
Inversion
Roedenbeck (2003


LAI
NDVI (X100)
a
b
NPP
Inversion Land-Atmo Cflux
c
d
Rh
Temperature
e
f

NPP and carbon pools



Why CO_2 correlates so well with ENSO: A ‘conspiracy’ theory



Tropics during El Nino

Precipitation decrease

Temperature increase

Out of phase

NPP decrease

Rh increase

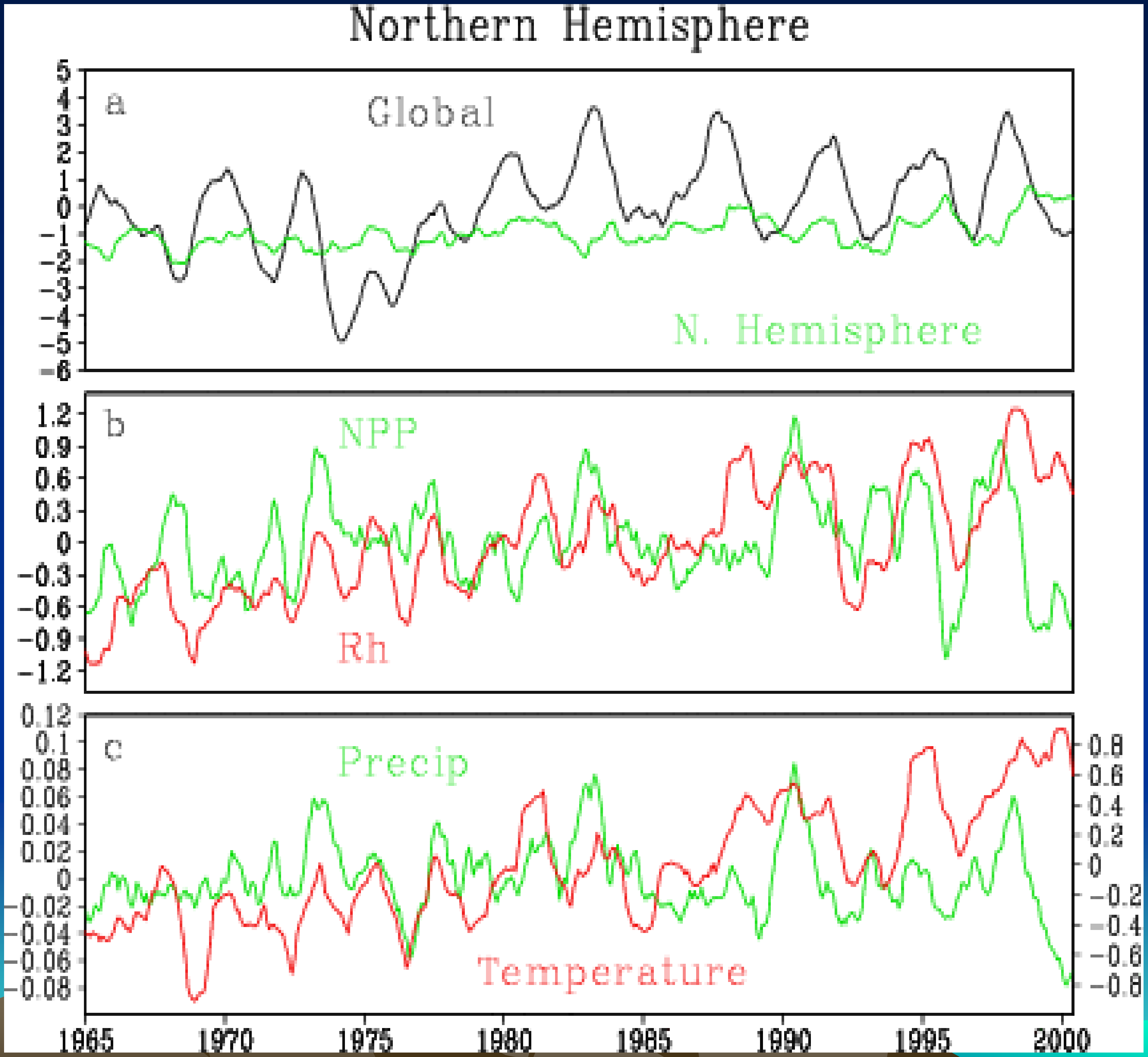
Additive

Land-atmo flux (Rh-NPP) increase

+

Spatially coherent climate anomalies

Large land-atmo C flux

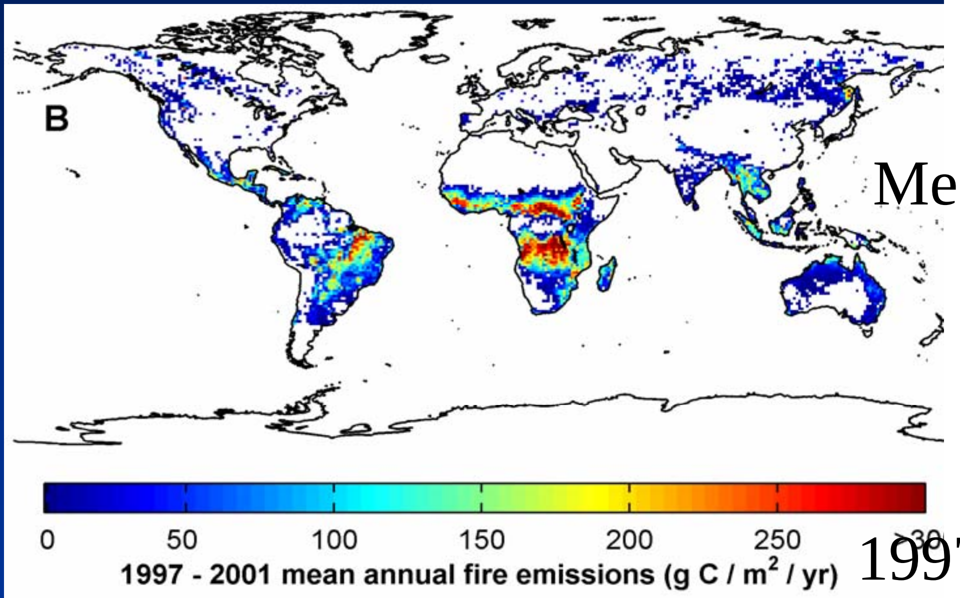

Northern Hemisphere
a
Global
N. Hemisphere
5
4
3
2
1
0
−1
−2
−3
−4
−5
−6
b
NPP
Rh
1.2
0.9
0.6
0.3
0
−0.3
−0.6
−0.9
−1.2
c
Precip
Temperature
0.12
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
1965
1970
1975
1980
1985
1990
1995
2000

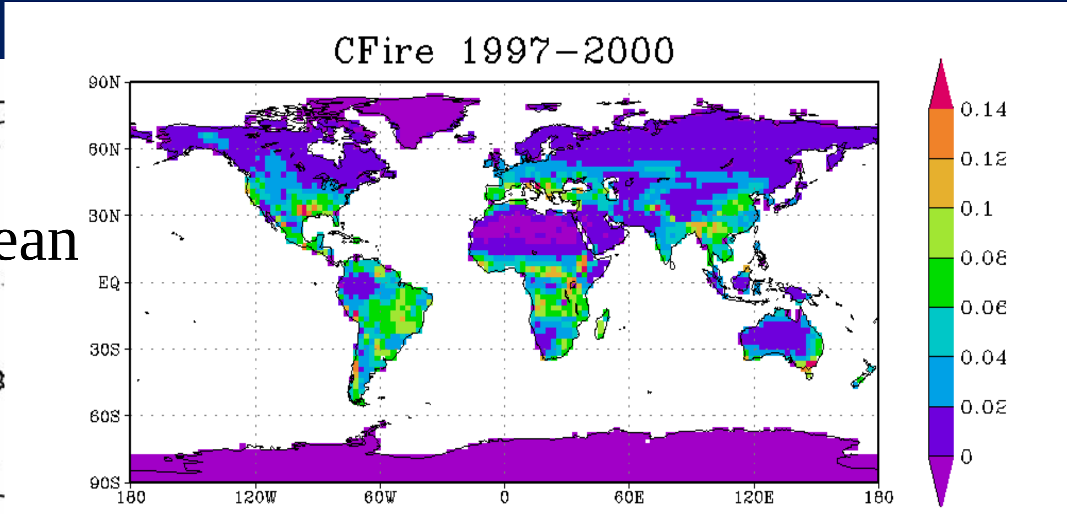
Fire carbon flux during 1997-98 El Nino

CASA (satellite fire, climate)

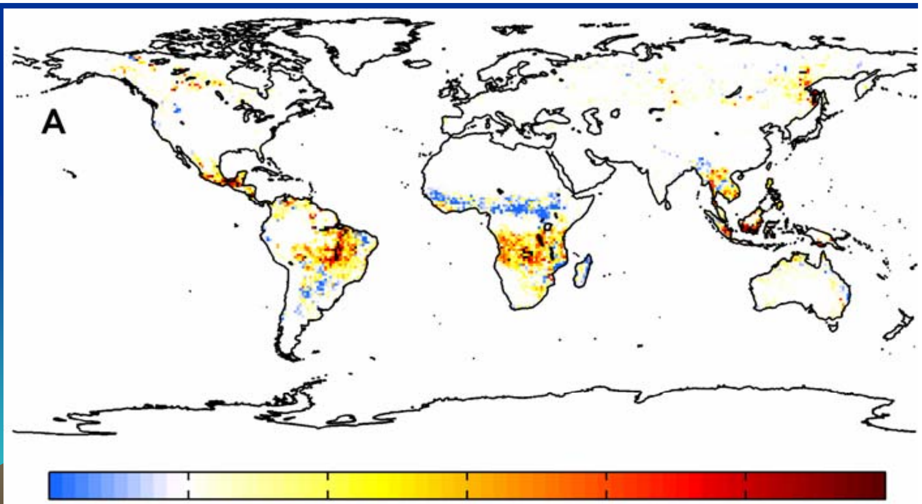
VEGAS (climate only)

Mean

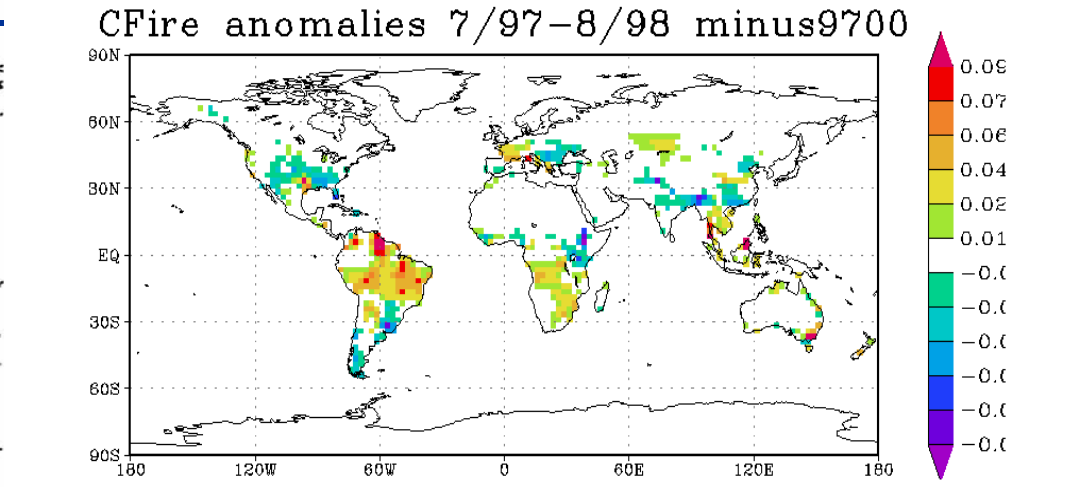




1997-98 El Nino Anomalies

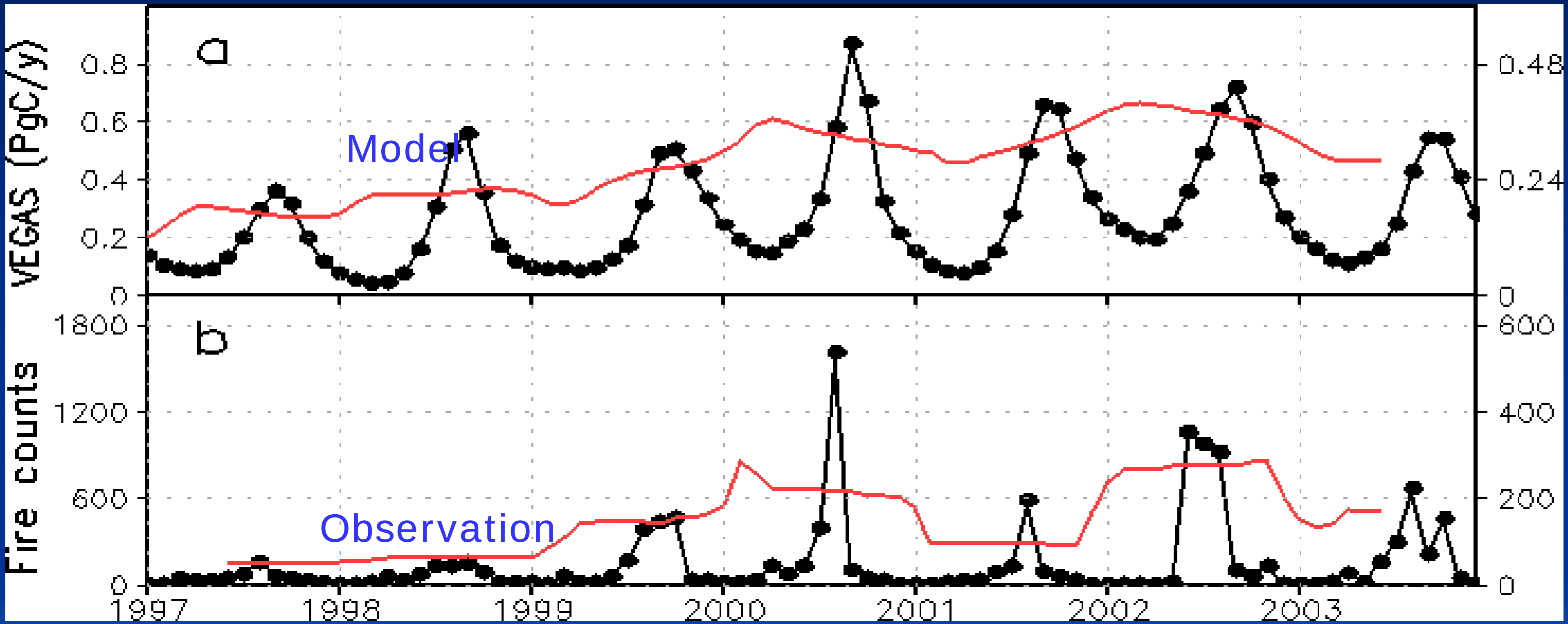


Input: satellite fire counts, climate

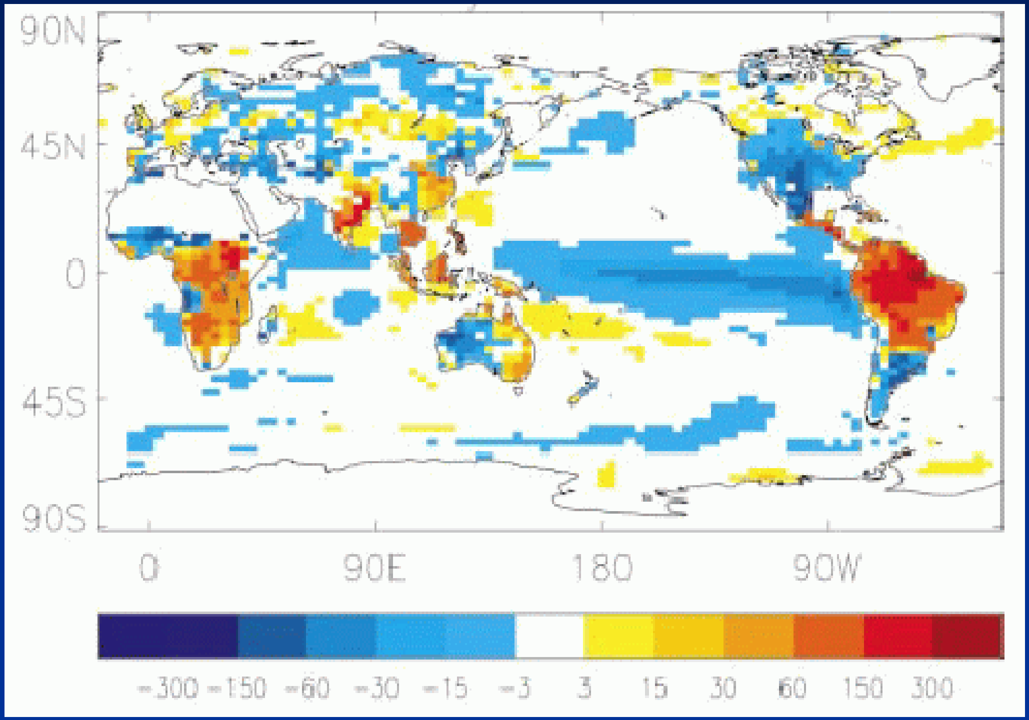


Input: climate only

Fire in the US:
Natural vs anthropogenic factors



El Nino-like climate under global warming? Carbon consequencies

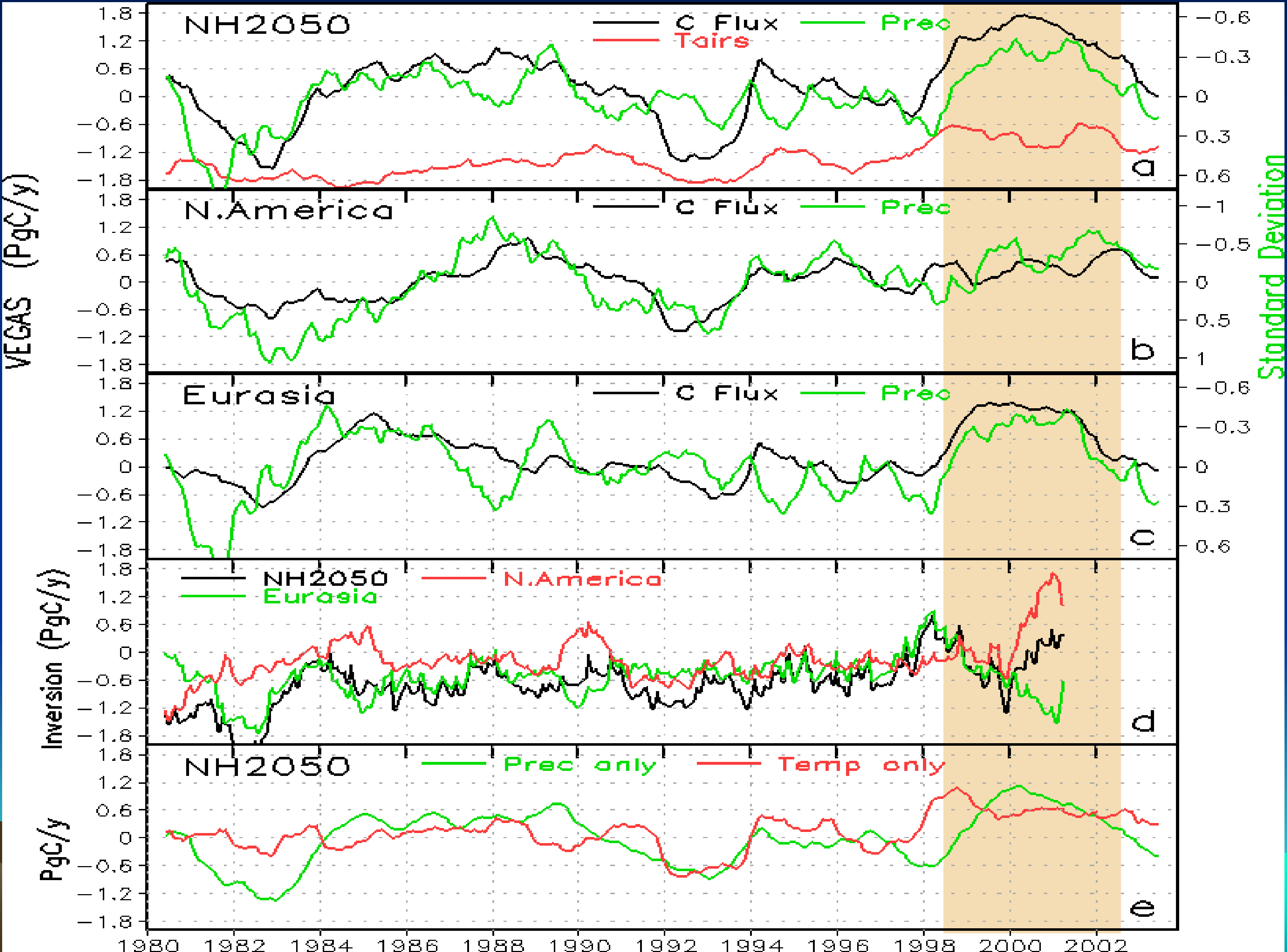


Similar processes may operate on interannual time scales and under global warming scenarios

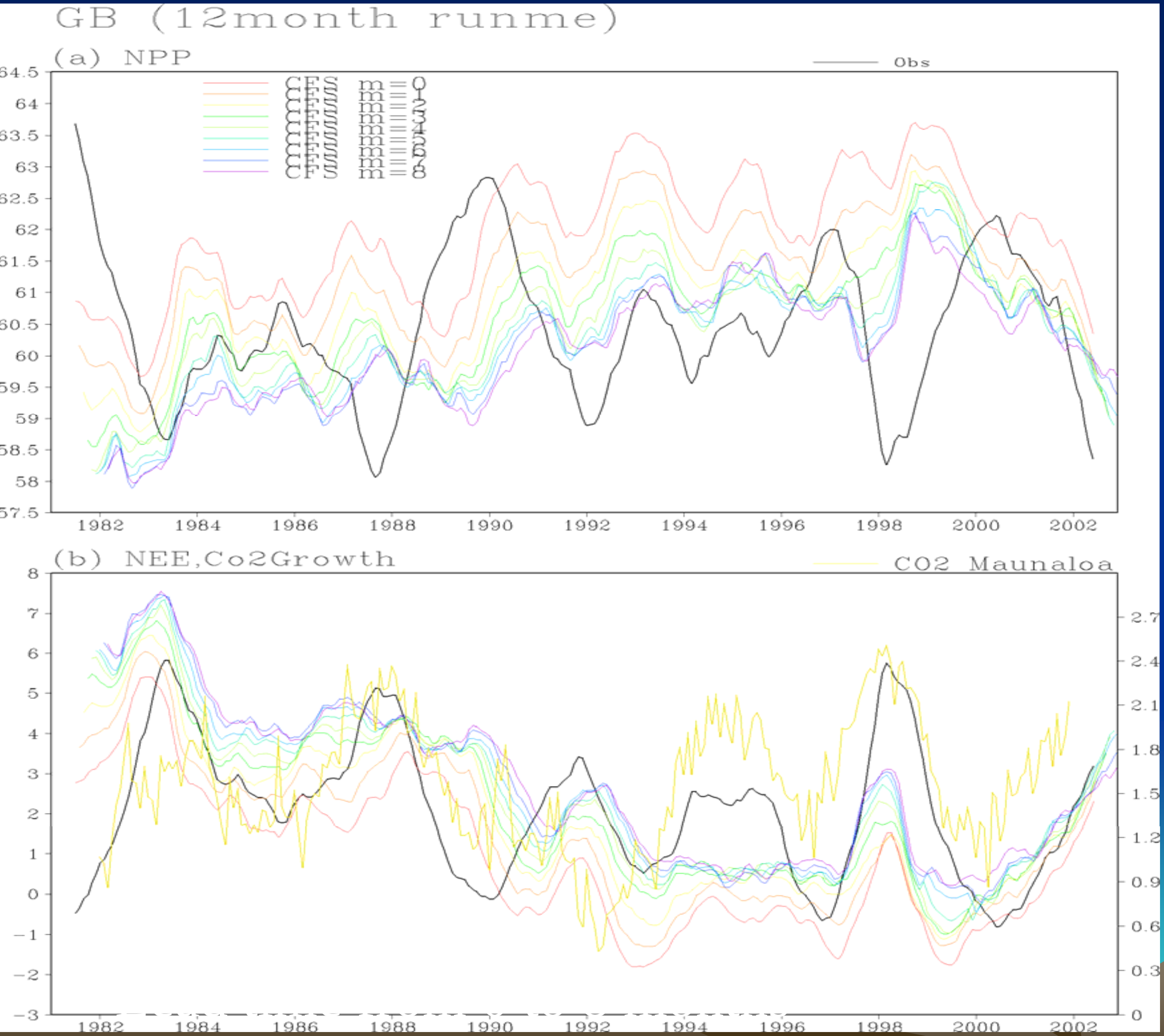
An Earth System Model at UMD

- Team Members
  - N. Zeng, R. Murtugudde, A. Busalacchi, R. DeFries (U of Maryland)
- Collaborators
  - J. Christian (CCCMA)
  - G. J. Collatz (NASA/GSFC)
  - M. Heimann , C. Roedenbeck (Max-Planck Inst.)
  - A. Mariotti, R. Iacono (ENEA)
  - R. Feely (PMEL)

Drying or Warming?



NPP/NEE original—A Drift Problem

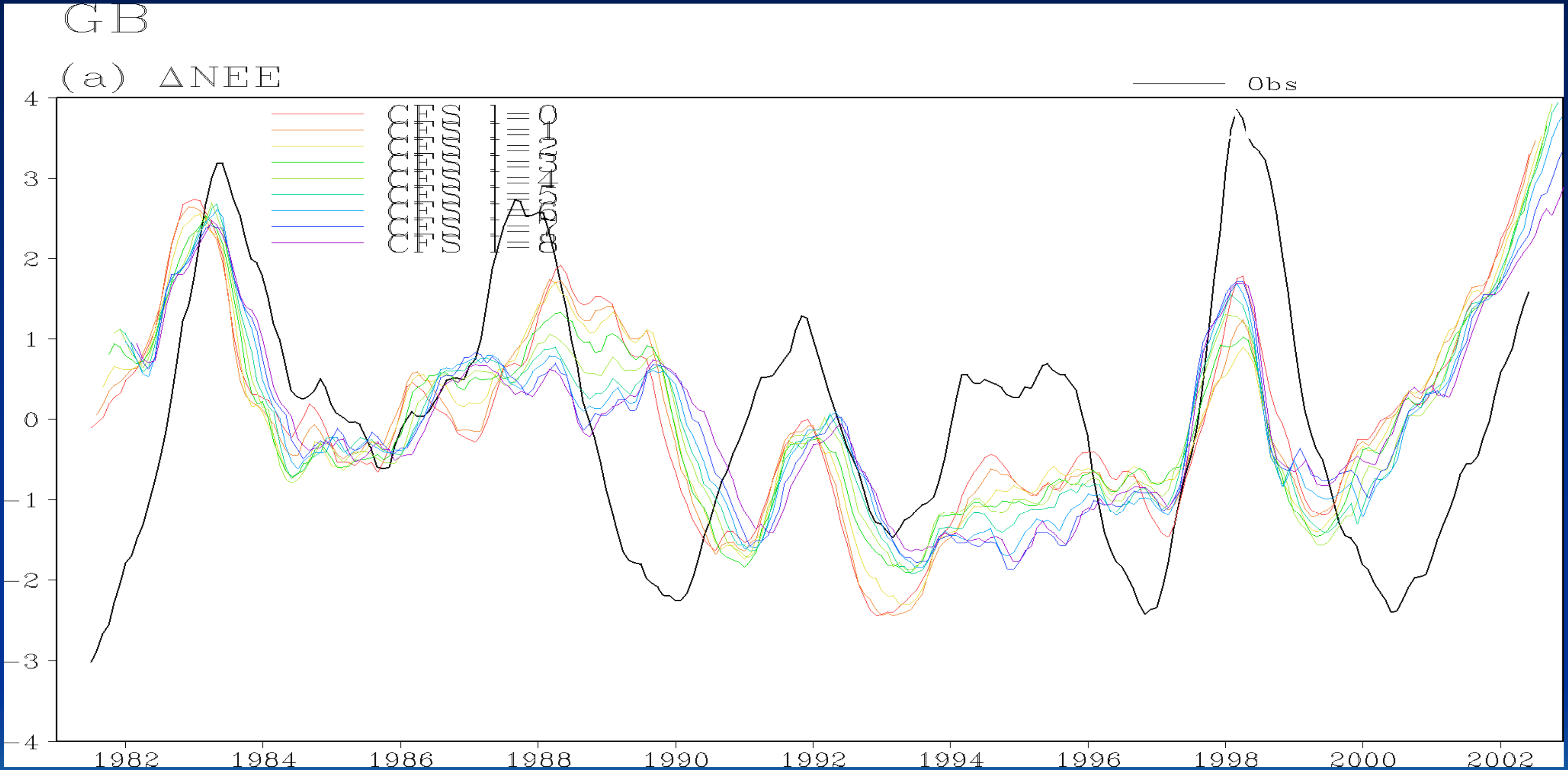


1. Model drift with lead time
 Fix:
    Removed climatology
    for each lead time (L)

2. Trend in Modeled NPP
 Detrended

3. No warming trend in CFS
 Detrended

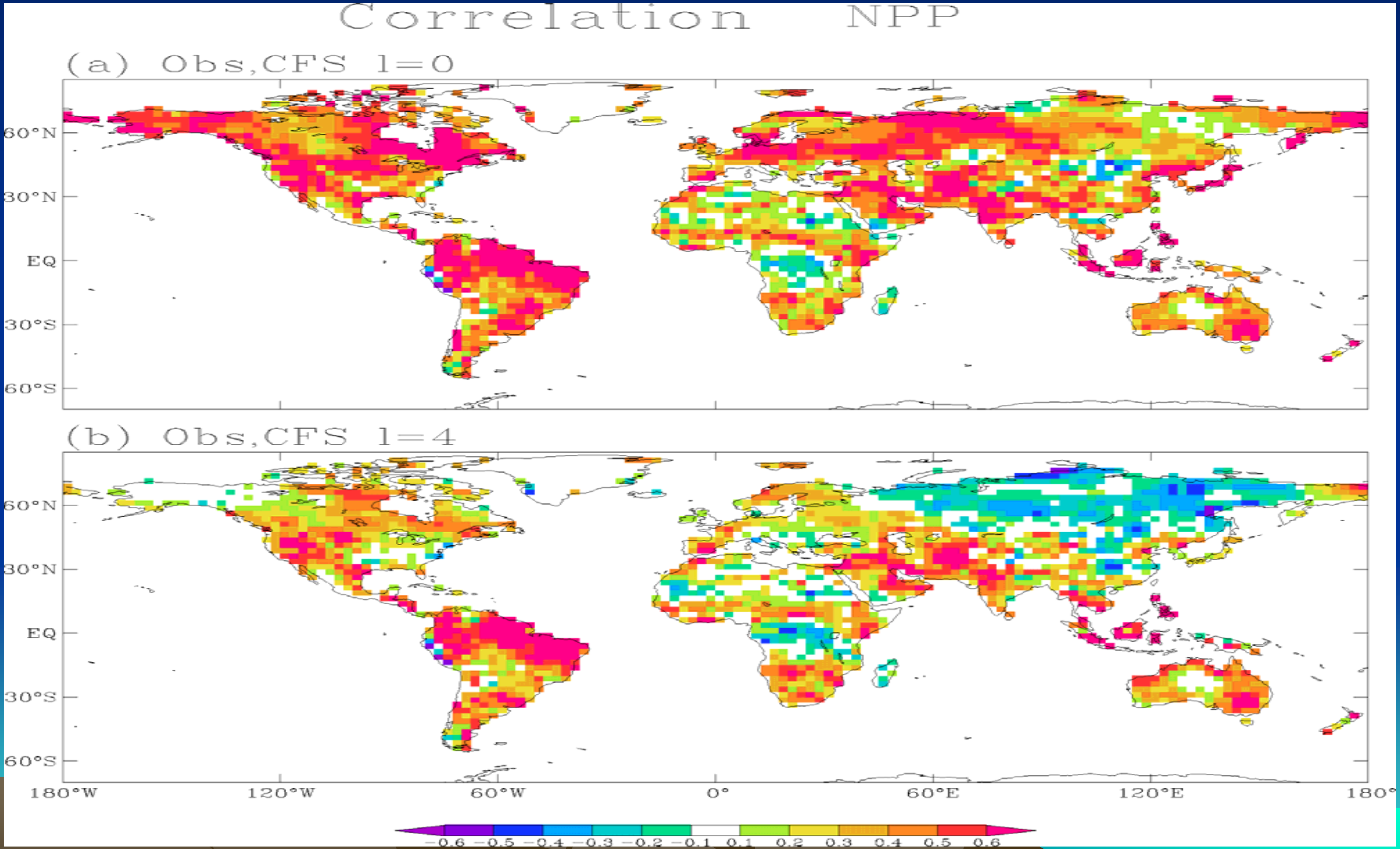
Predicted global cabon flux



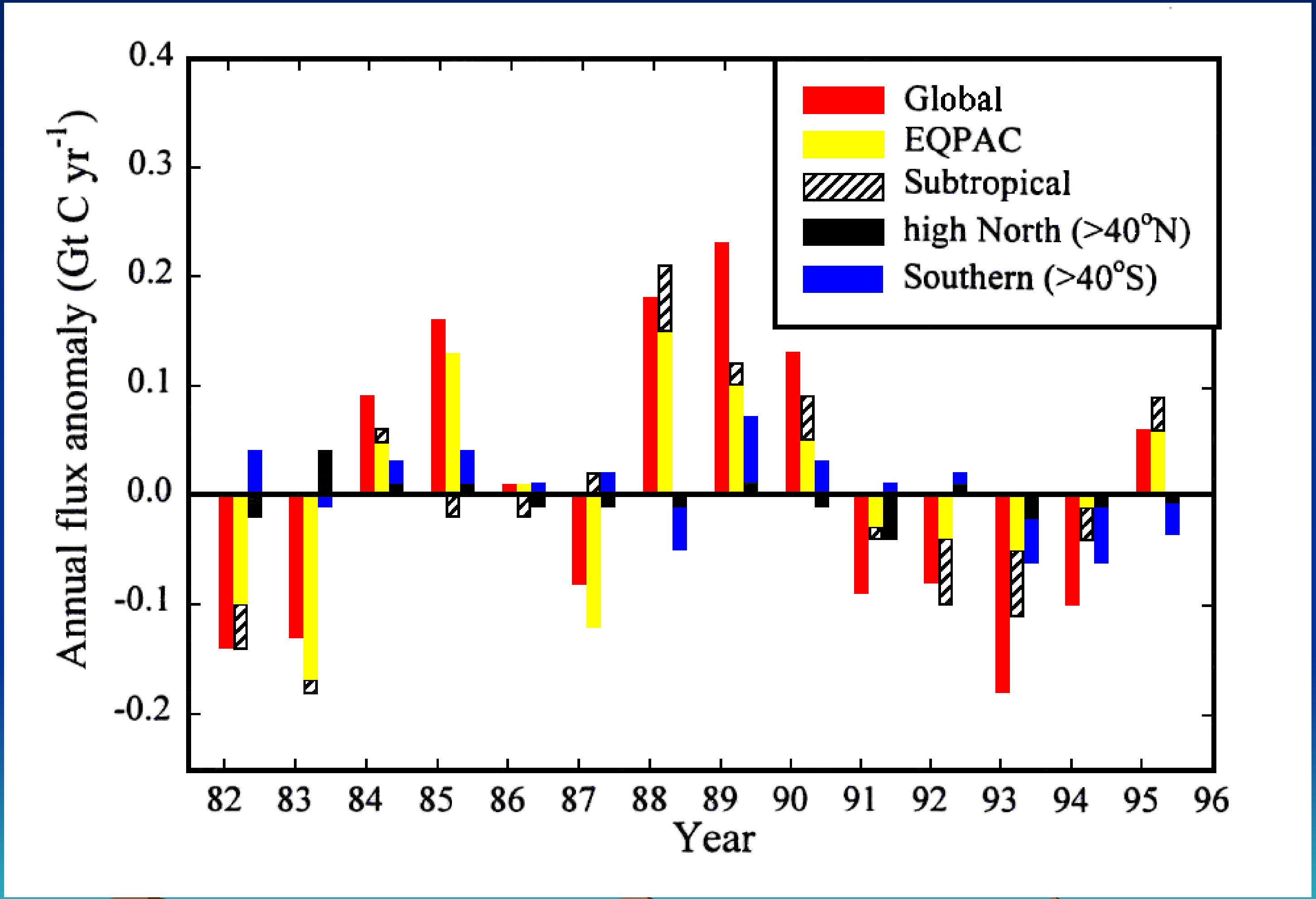
1. CFS/VEGAS captures most of the interannual variability, but...
2. Amplitude is underestimated

Prec and Temp

Anom Correlation NPP

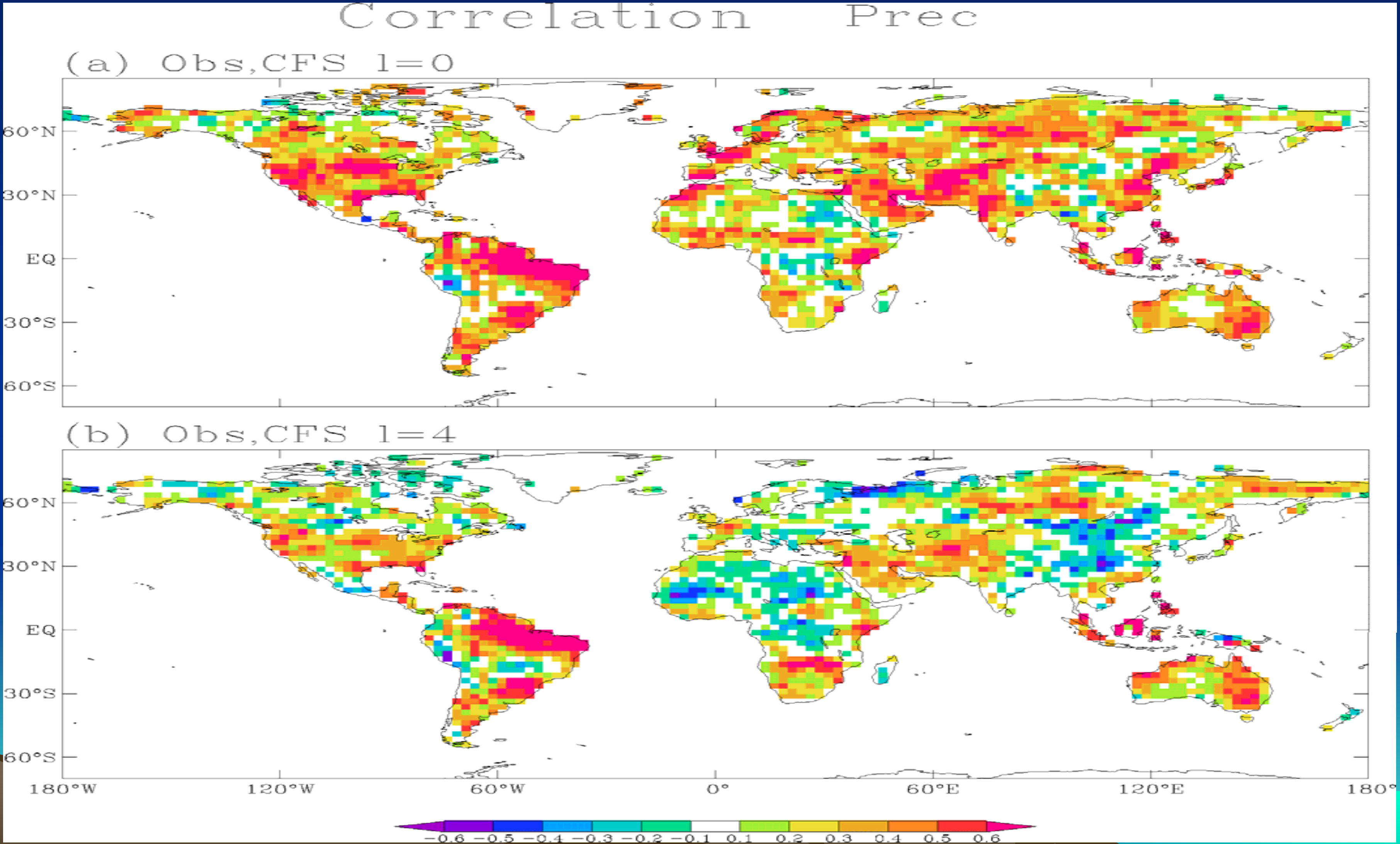


Oceanic CO2 flux 1982-96 based on pCO2 measurements

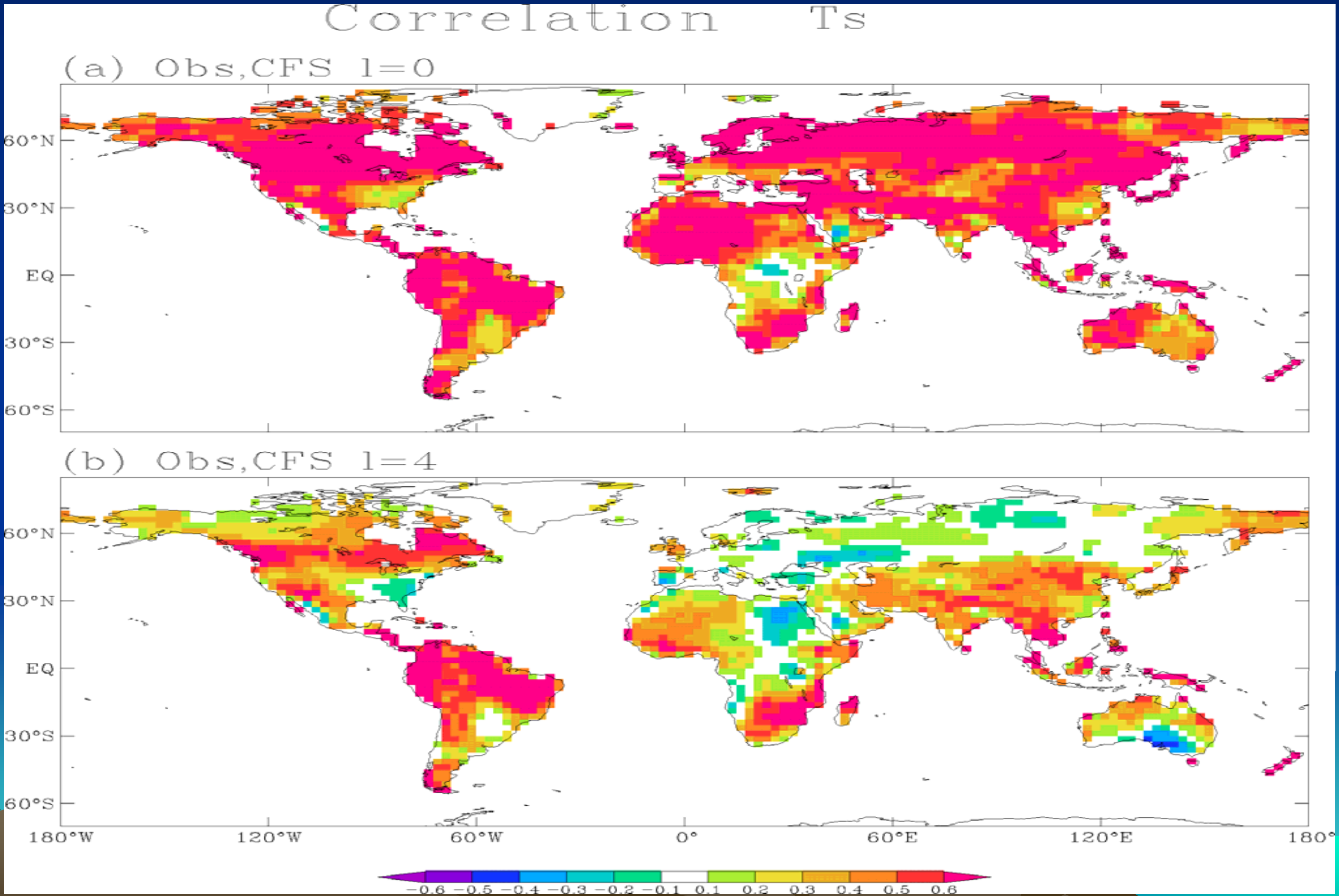


R. Feely (PMEL)

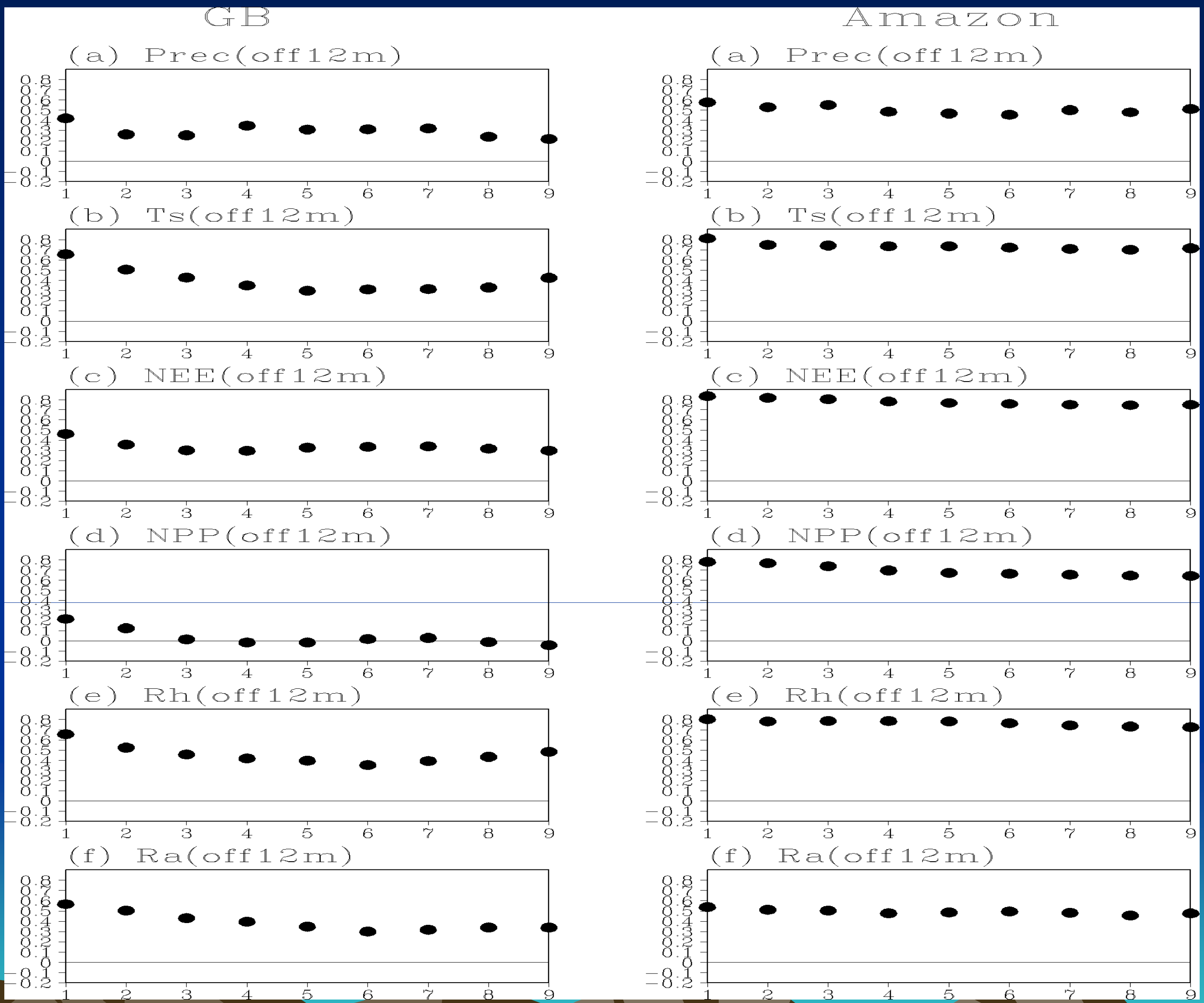
Anomaly correlation Precip



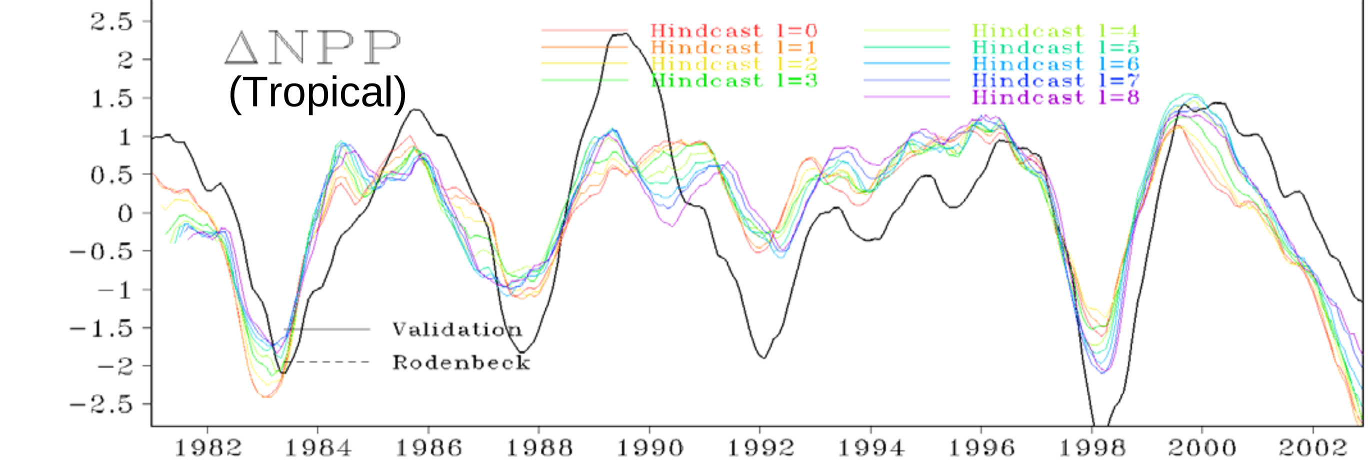
Anomaly Correlation Temperature

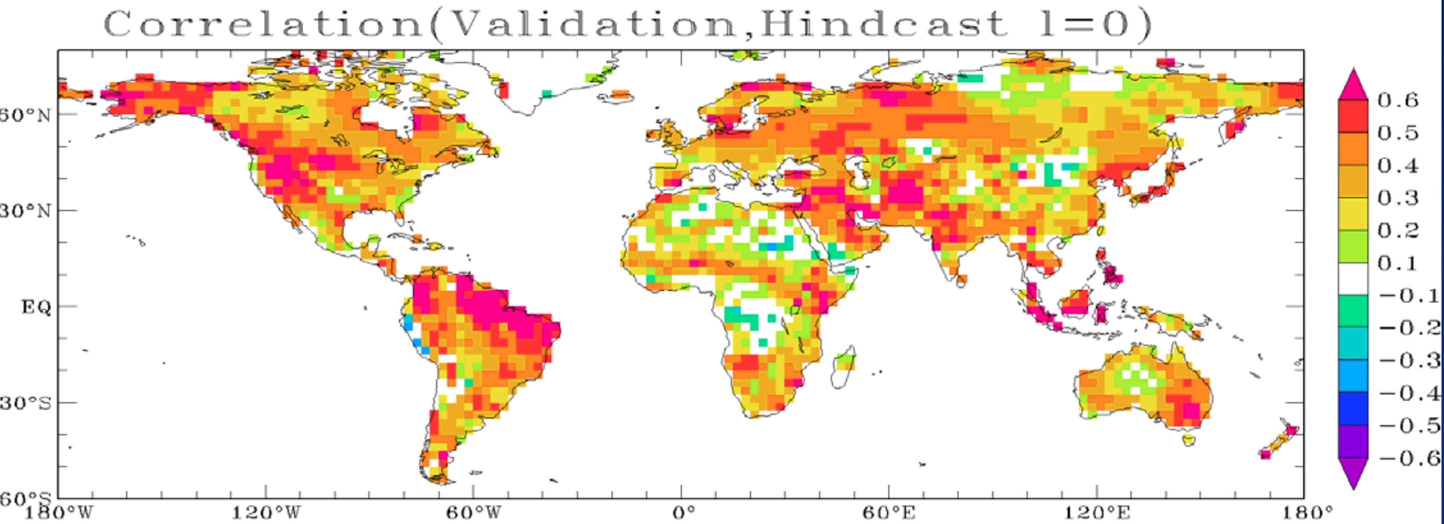


Skill P/T/NEE/NPP...

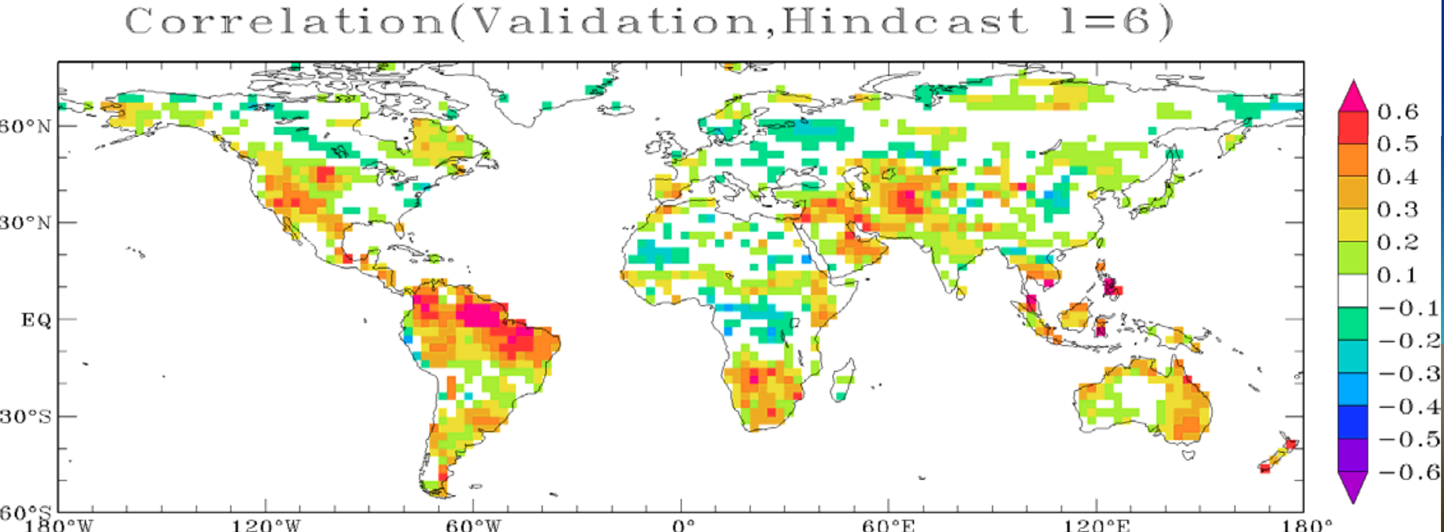


Predicted NPP vs. ‘Validation'





Lead = 0 month



Lead = 4 months