

# Global Correlations Between Ecosystems and PBL Mixing

A new analysis based on 1,137,452  
CALIPSO LIDAR soundings

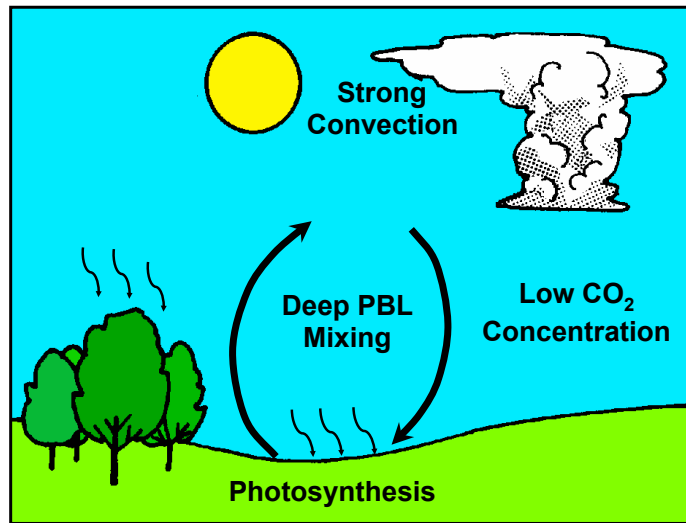
# Rectifier Analogy



- Covariance between surface fluxes and atmospheric transport of CO<sub>2</sub> produces near-surface concentration timeseries with truncated minima
- The effect is analogous to an electronic rectifier produced by a diode.

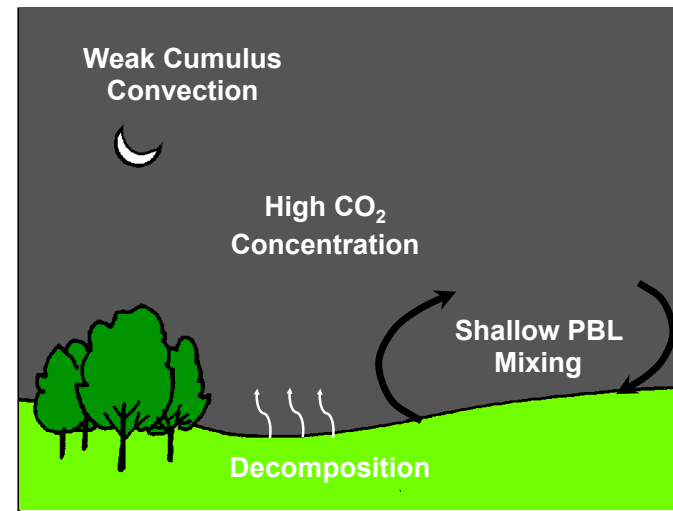
# Diurnal Rectifier Forcing

Mid-day



**Dilution** of photosynthesis signal through deep mixing  
**Transport** of low-CO<sub>2</sub> air into upper troposphere

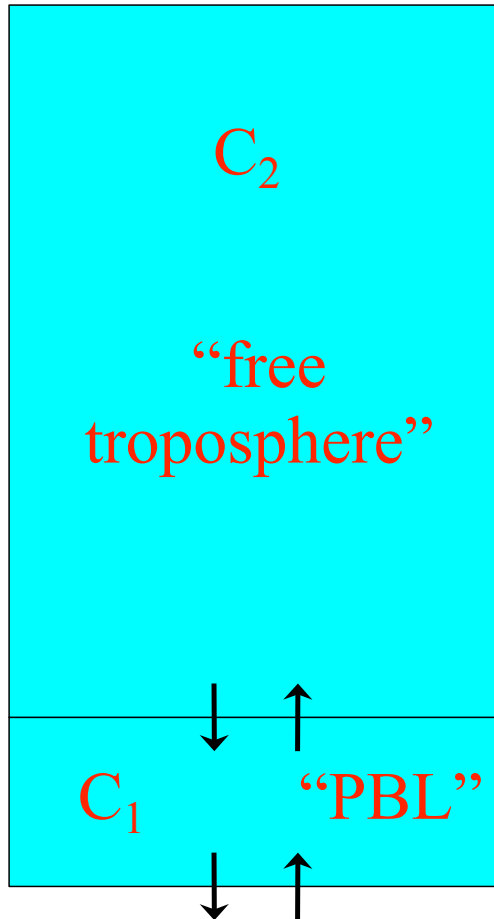
Midnight



**Accumulation** of respiration signal near the surface  
**Elevated** CO<sub>2</sub> in lower troposphere

*Daily mean:  
Accumulation of CO<sub>2</sub> near the ground, depletion aloft*

# Conceptual Rectifier Model



Surface flux

$$\frac{\partial C_1}{\partial t} = F - \frac{(C_1 - C_2)}{\tau}$$
$$\frac{\partial C_2}{\partial t} = + \frac{(C_1 - C_2)}{\tau}$$

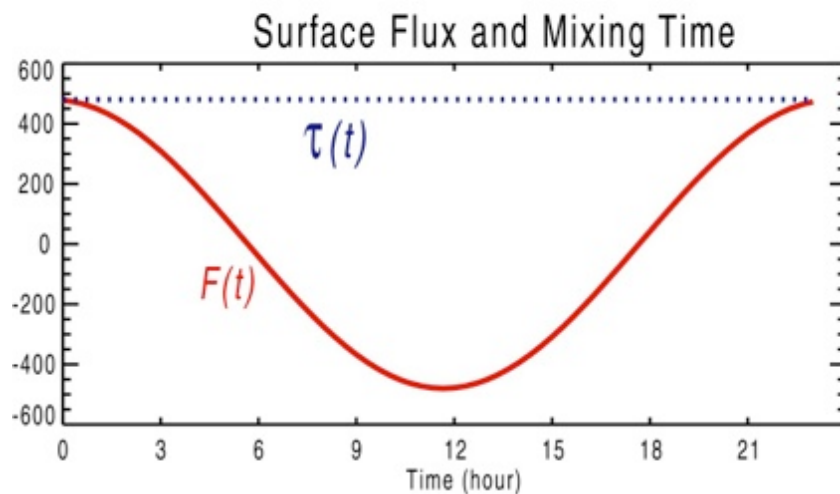
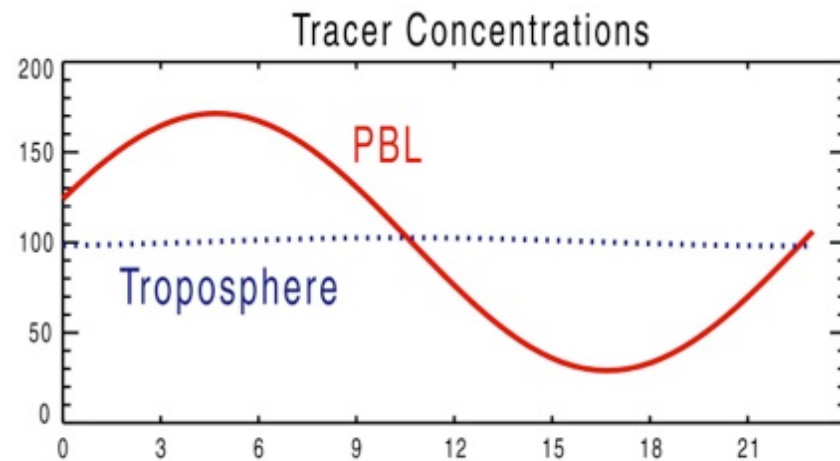
where

$F$  is the surface flux

$\tau$  is the "mixing time scale"

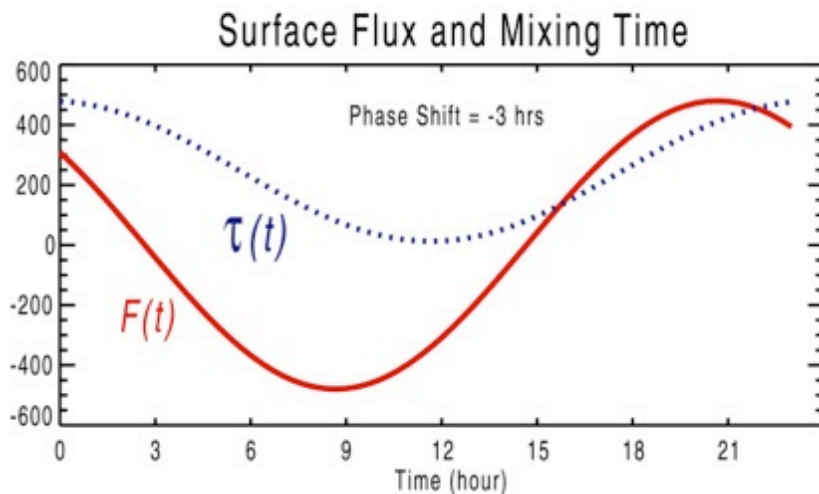
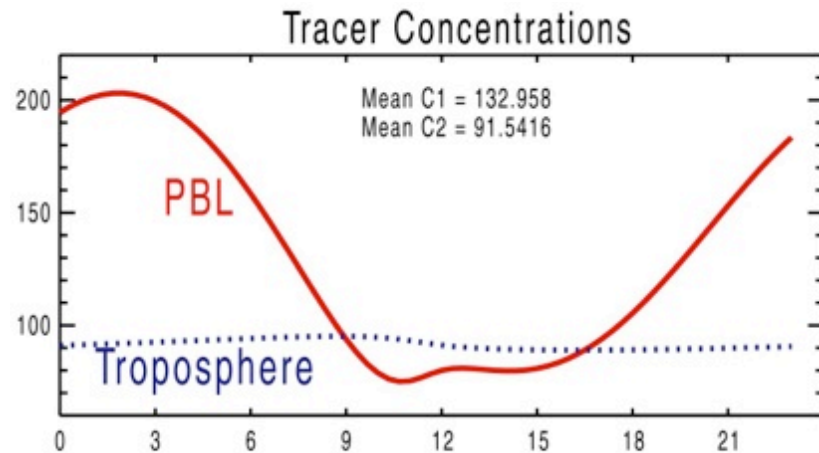
mixing

# Two-Box Model: No Rectification



- Sinusoidal surface fluxes
- Mixing time scale is **constant**
- Result is a sinusoidal **diurnal cycle** of PBL concentration
- Damped sinusoidal variations in the troposphere are out of phase with PBL

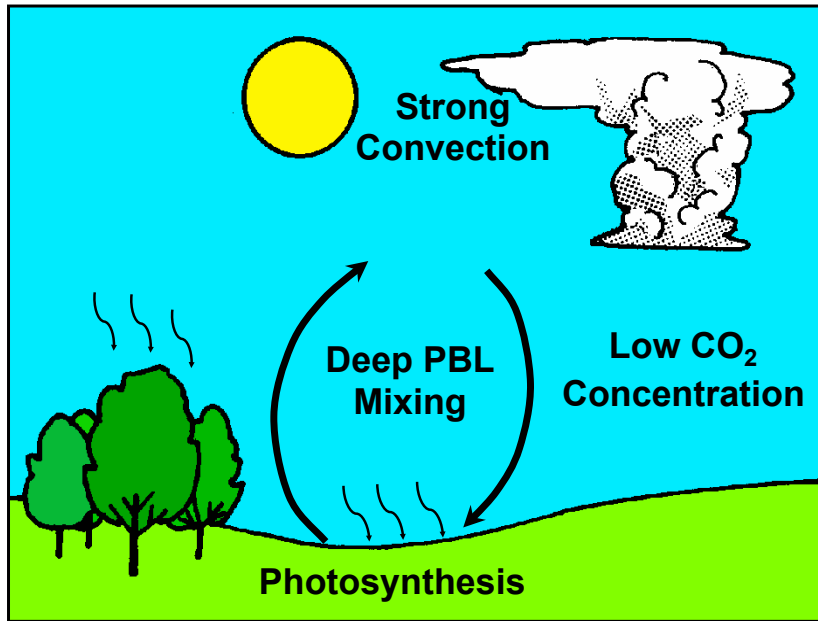
# Two-Box Rectifier Forcing



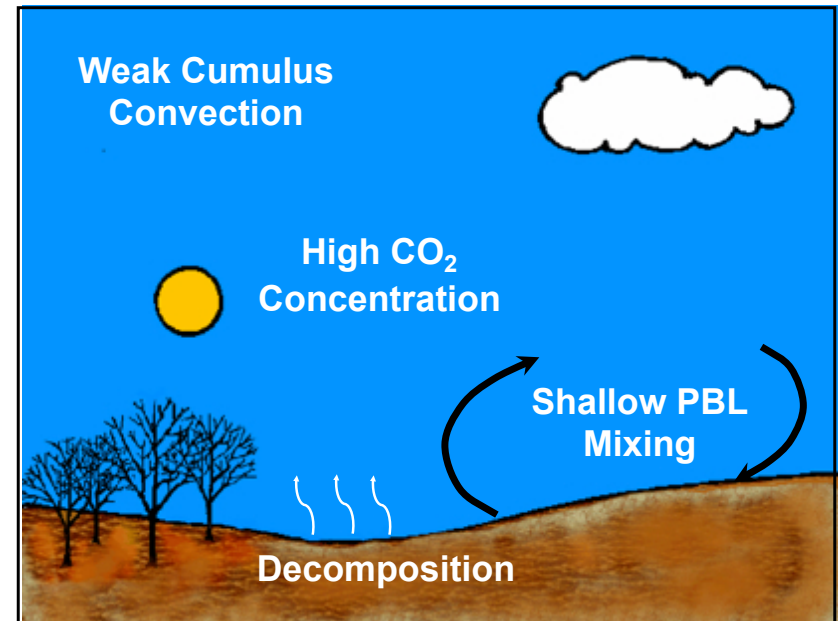
- Diurnal cycles of flux and mixing are **correlated**
- Classic “**rectified**” signal
- Phase lag maximizes rectification ... reflects tracer “capacity” of PBL
- **Diurnal mean** in lower box is 133% of global mean

# Seasonal Rectifier Forcing

Summer



Autumn



**Dilution** of photosynthesis signal through deep mixing

**Transport** of low-CO<sub>2</sub> air into upper troposphere

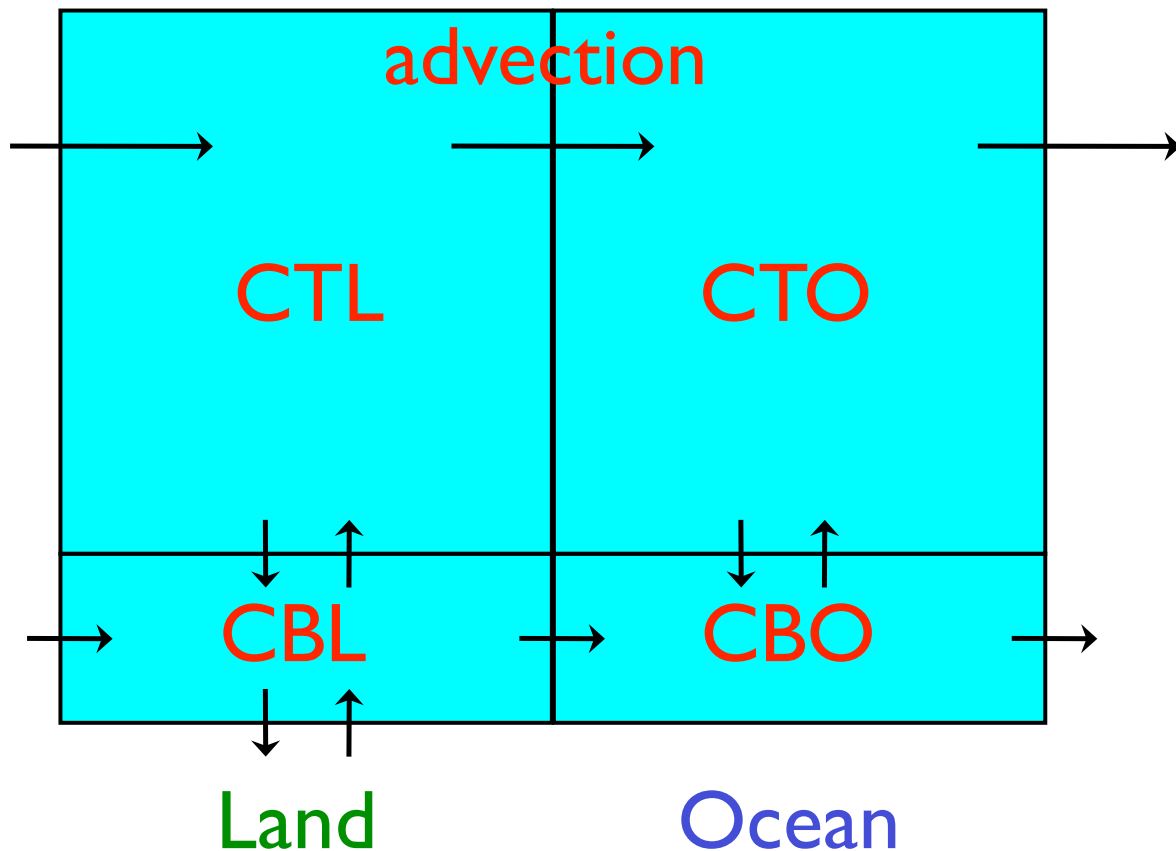
**Accumulation** of respiration signal near the surface

**Elevated** CO<sub>2</sub> in lower troposphere

*Annual mean: Accumulation of CO<sub>2</sub> near the ground, depletion aloft*

# Four-Box Model

(analogous to surface CO<sub>2</sub> network?)

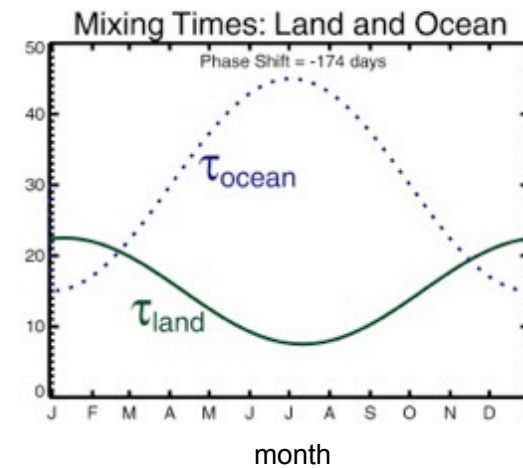
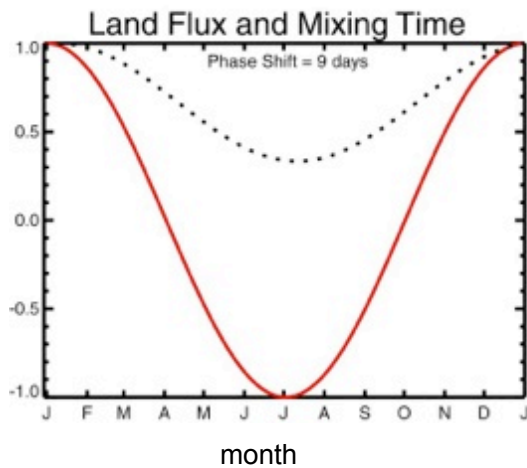
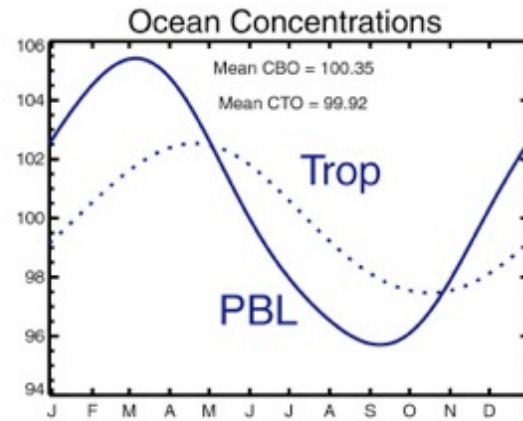
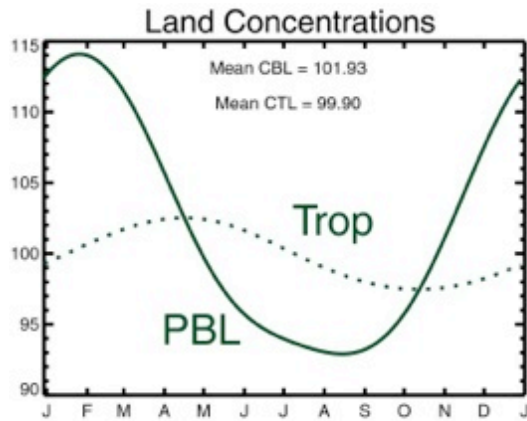


- Forcing over land is identical to two-box model
- No surface flux over ocean
- **Advection** between land and ocean ... cyclical boundaries
- Wind speed is 5x faster in troposphere than PBL



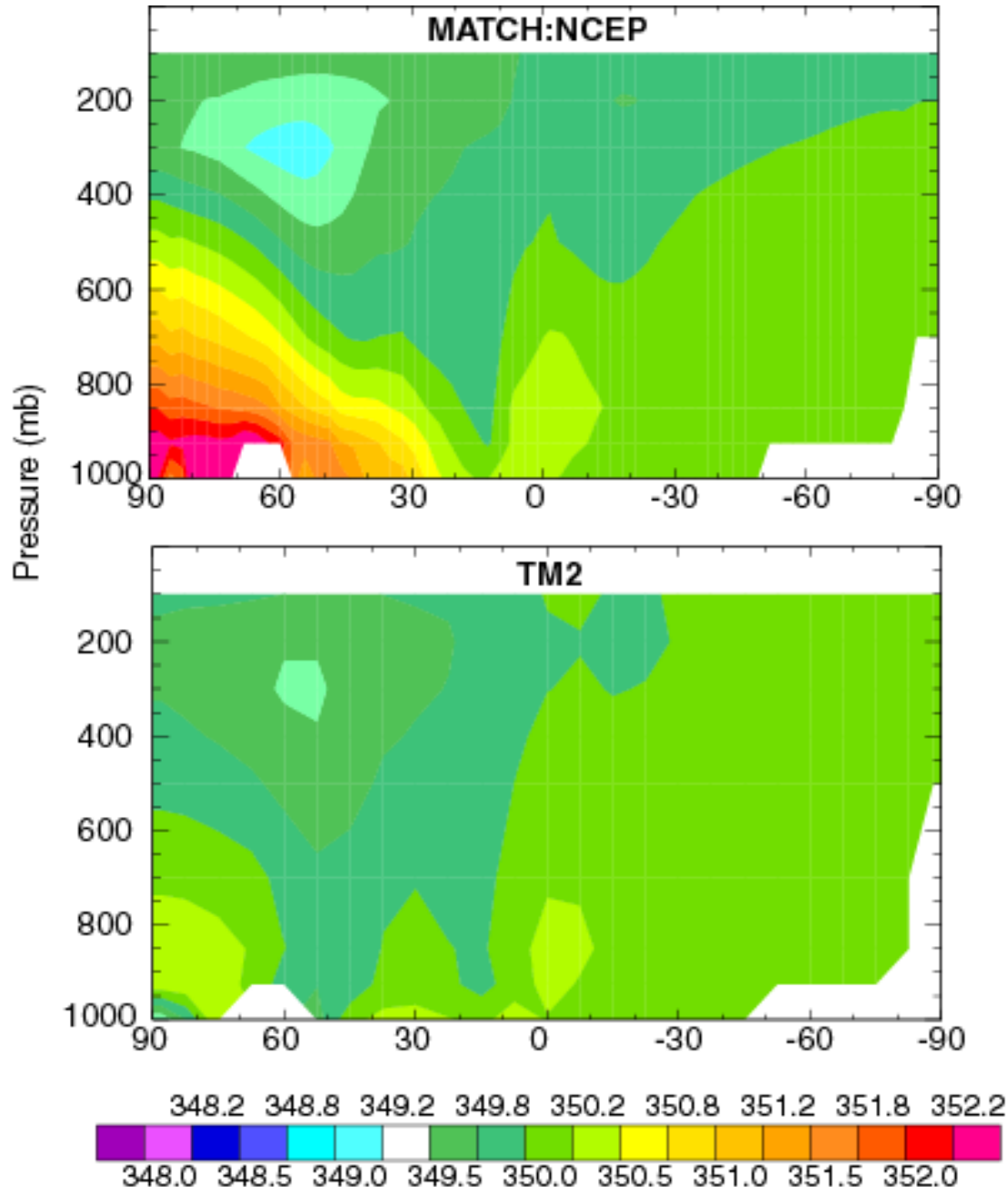
# Seasonal Rectifier

## 4-Box Model



- Rectifier forcing on land is diluted by mixing over ocean (where  $F = 0$ )
- Vertical mixing over ocean has opposite seasonality relative to land
- Depending on parameter choices, free tropospheric advection and marine mixing can obliterate signal in MBL

# Global Rectifier Response

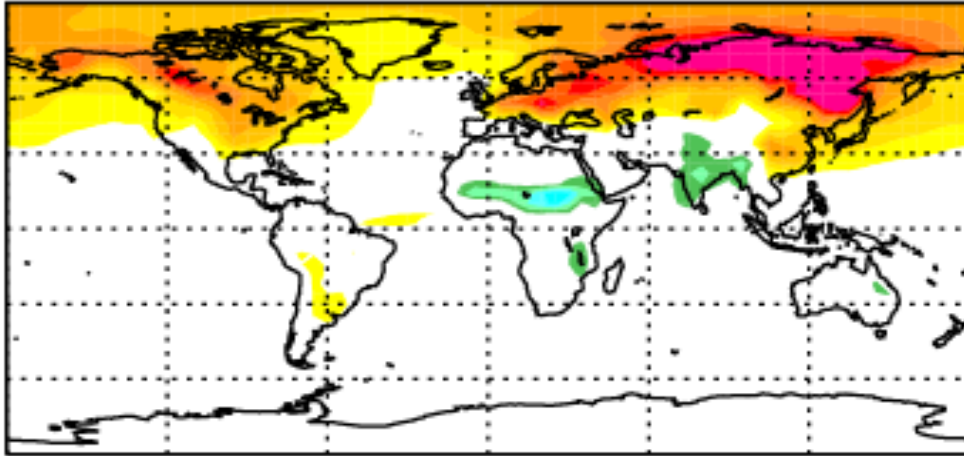


- Very strong model dependence!
- Elevated CO<sub>2</sub> near surface over seasonal land
- Depleted CO<sub>2</sub> aloft over land
- Not much going on in SH (mostly ocean)

# Surface Rectifier Response

MATCH:NCEP regrided

Global Mean = 350.6



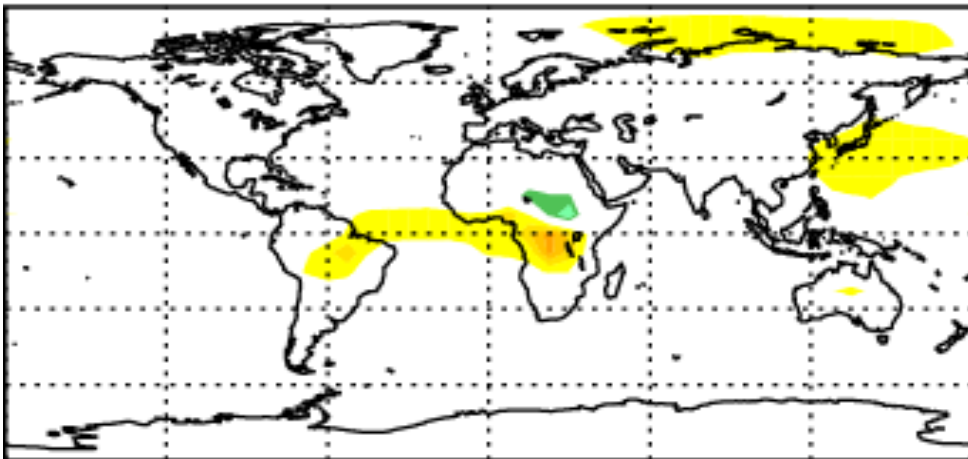
346.0 347.1 348.2 349.4 350.5 351.5 352.6 353.8 354.9



345.5 346.6 347.7 348.8 349.9 351.0 352.1 353.2 354.3

TM2

Global Mean = 350.09



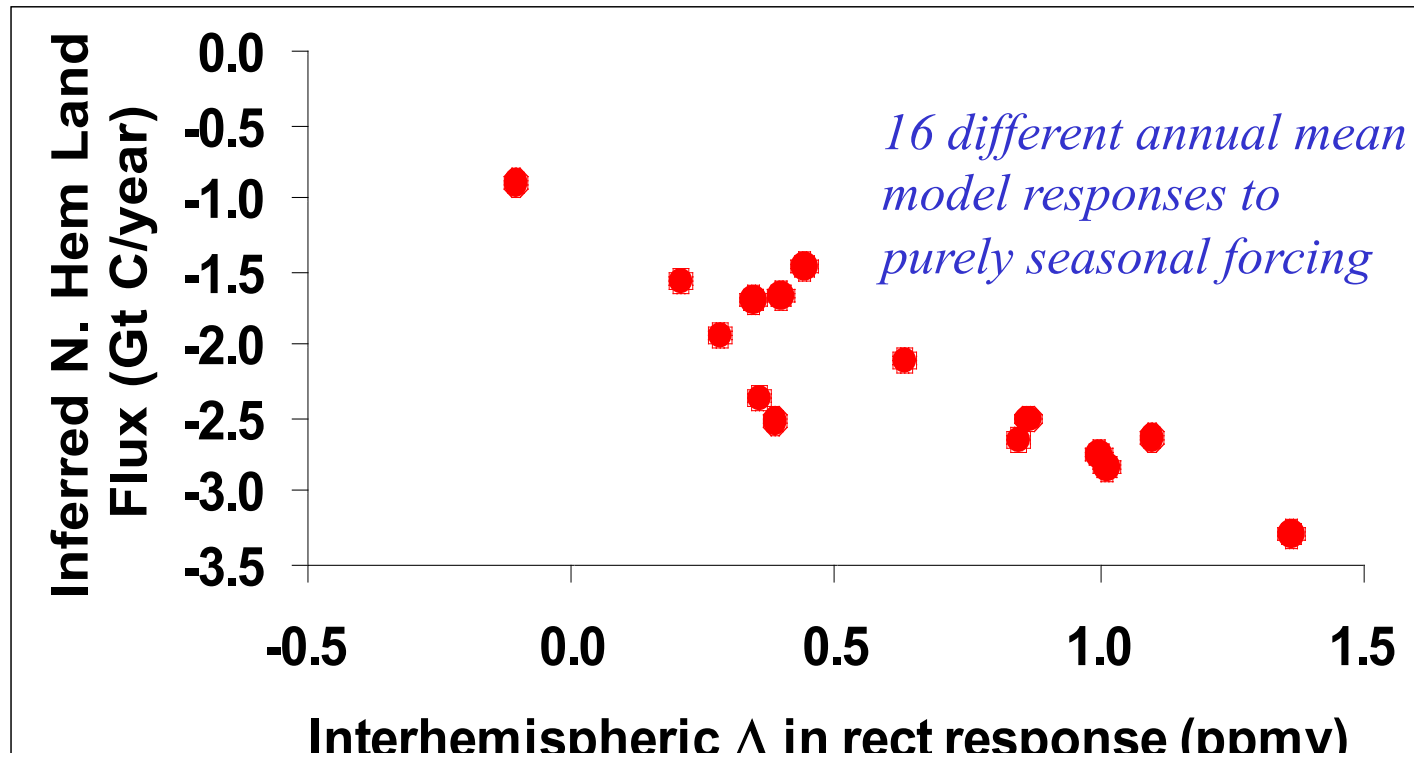
345.1 346.3 347.5 348.7 349.9 351.1 352.3 353.5 354.7



344.5 345.7 346.9 348.1 349.3 350.5 351.7 352.9 354.1

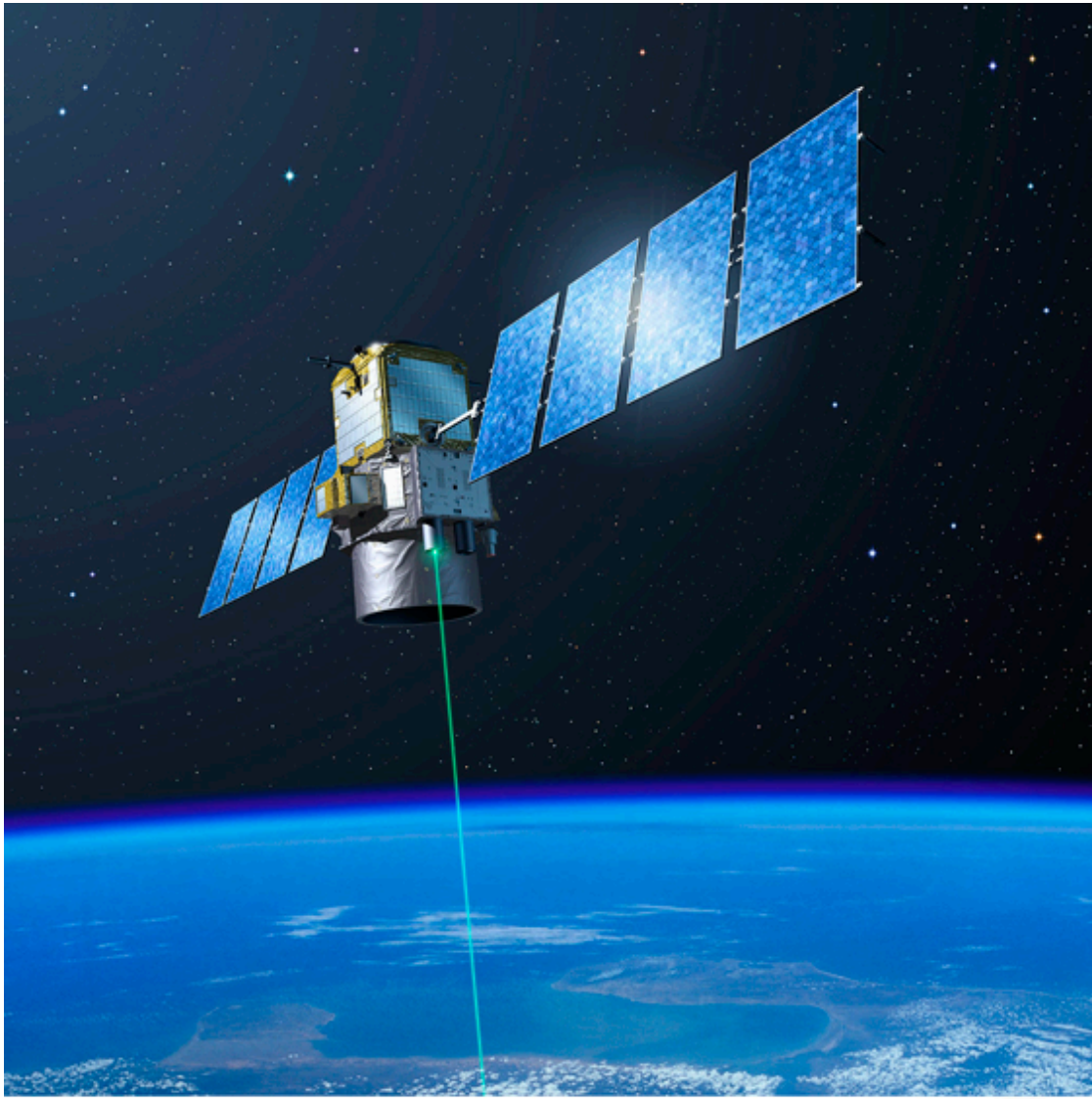
- Differences in vertical structure among models produce huge differences in annual mean surface [CO<sub>2</sub>]
- These differences are interpreted by the inversion as differences in surface fluxes
- Remember, they were produced by a flux field that integrates to zero at every grid cell in the annual mean!

# Rectifier Controls Inversion Result



Rectifier response is the major source of uncertainty in NH sink,  
but can't observe directly in atmosphere

# CALIPSO LIDAR Sounder



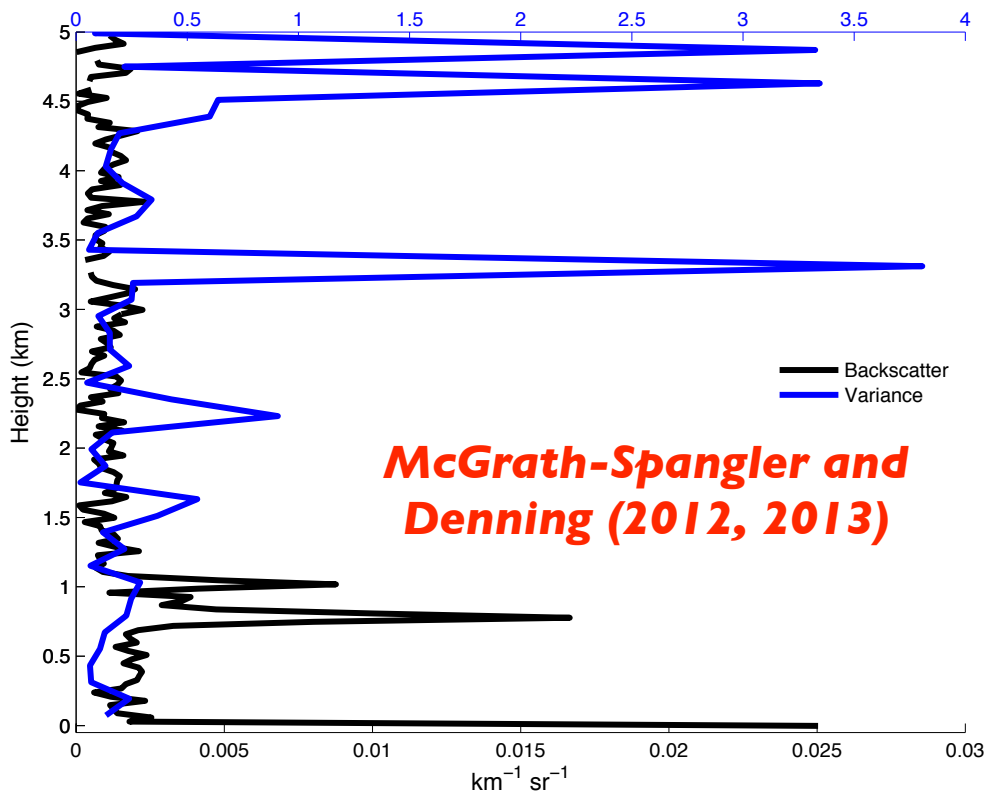
- Launched mid-2006
- 705 km A-Train orbit
- mid-day overpass
- 532 nm laser ranging
- millions of soundings per month



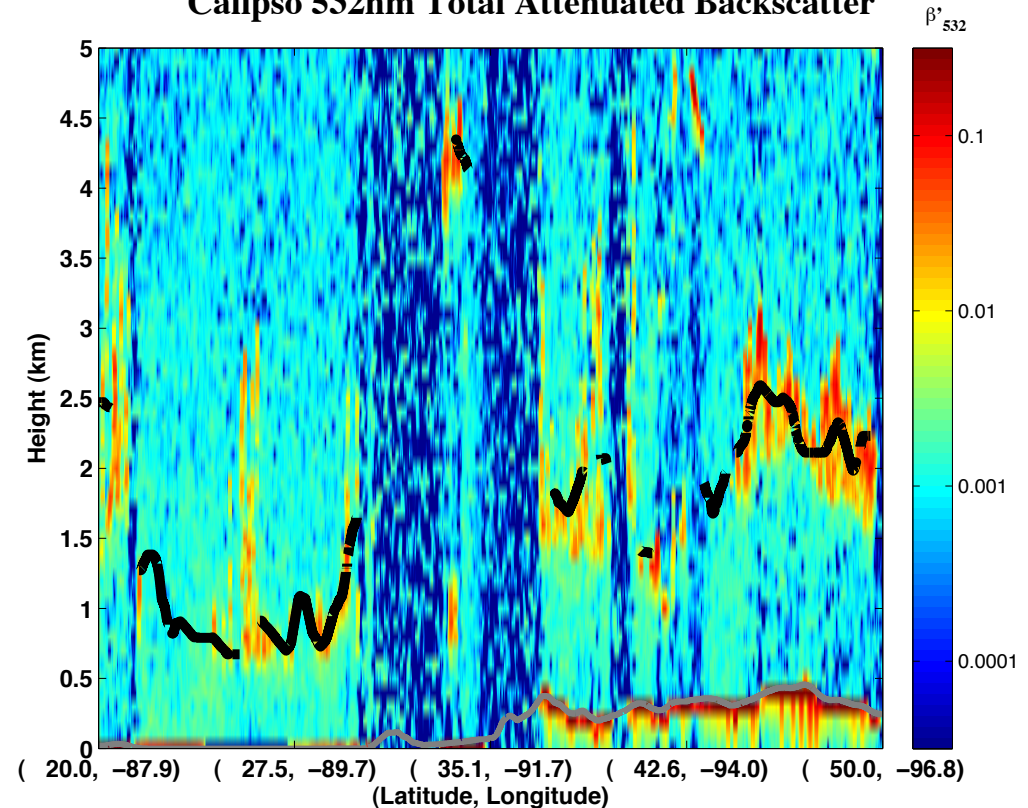


# Boundary-Layer Retrieval

CALIPSO 532nm Total Attenuated Backscatter



Calipso 532nm Total Attenuated Backscatter

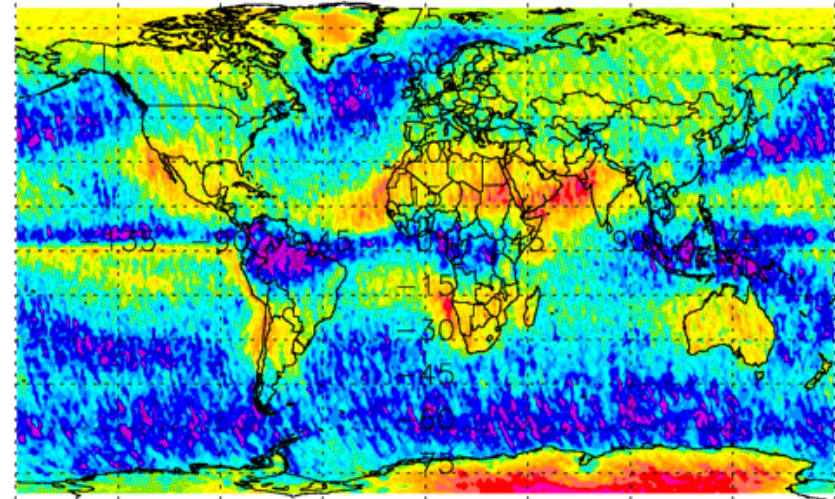
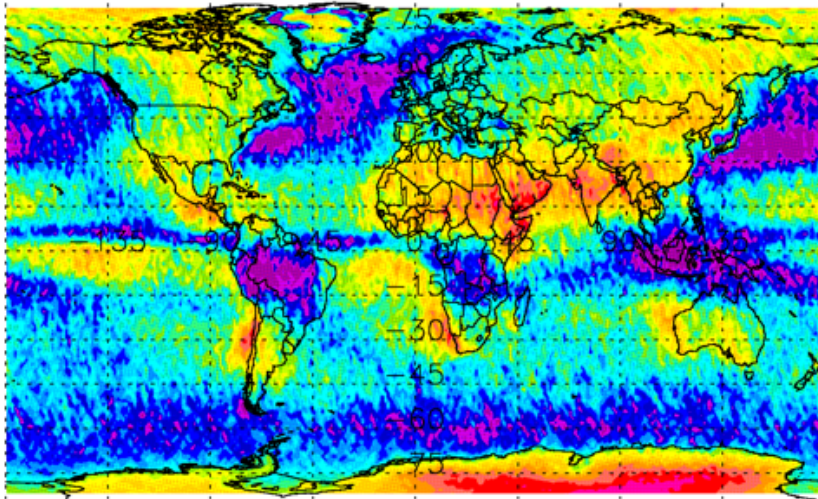


- Search upwards from 500 m to 5 km
- Find lowest co-occurrence of maximum backscatter and vertical variance
- Thick clouds = missing data

# Global Retrieval

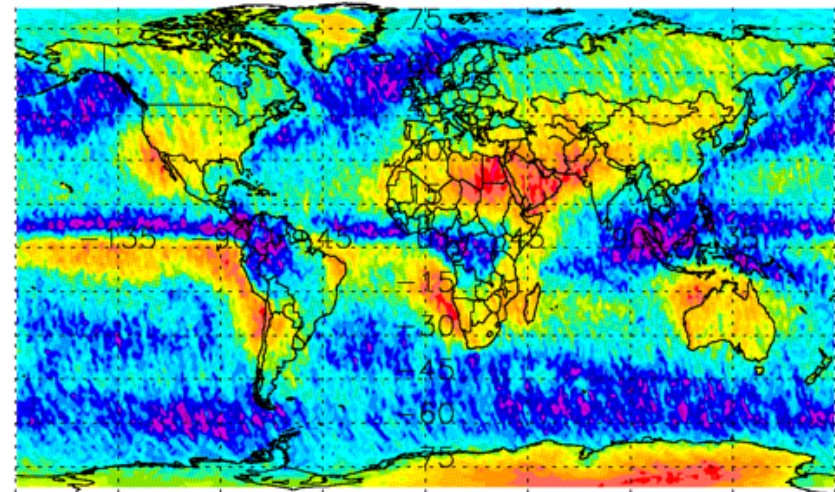
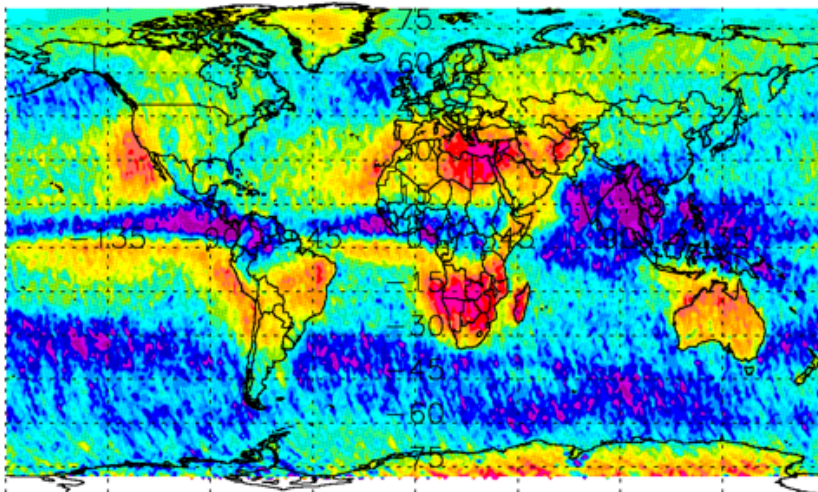
DJF

MAM

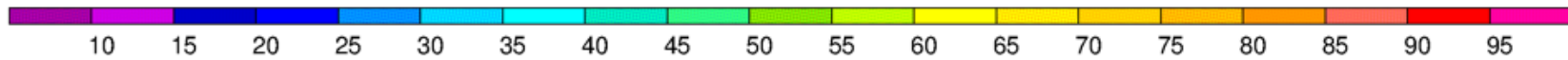


JJA

SON



Percent

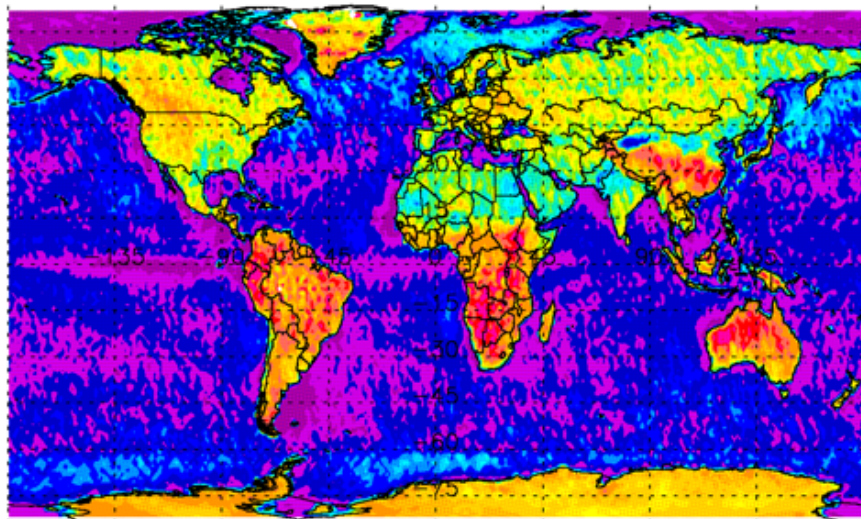


**McGrath-Spangler and Denning (2013)**



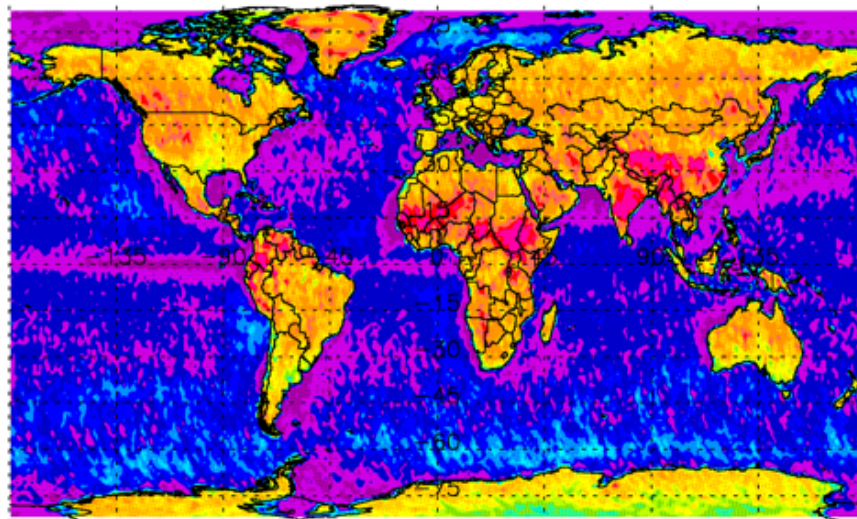
# Global Climatology

DJF

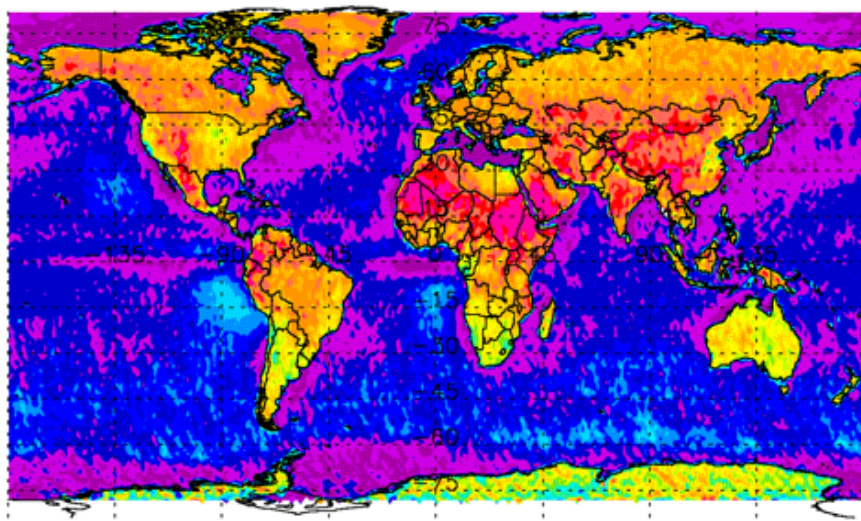


J

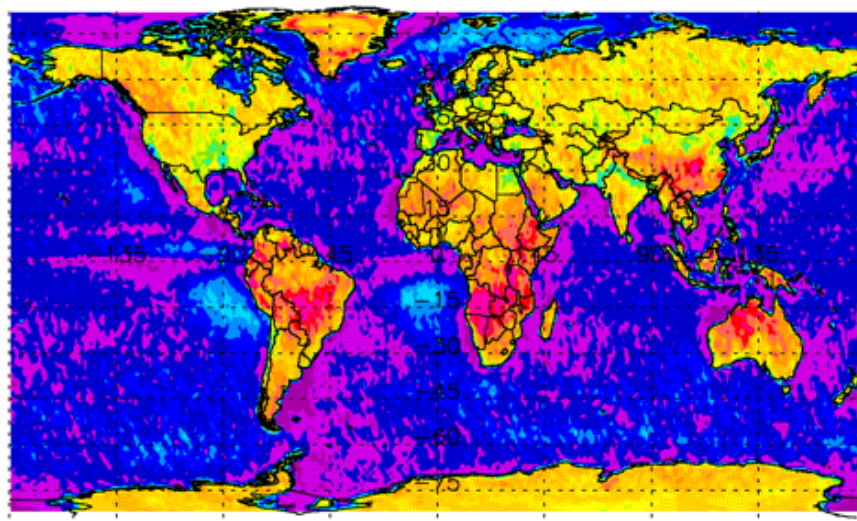
MAM



JJA



SON

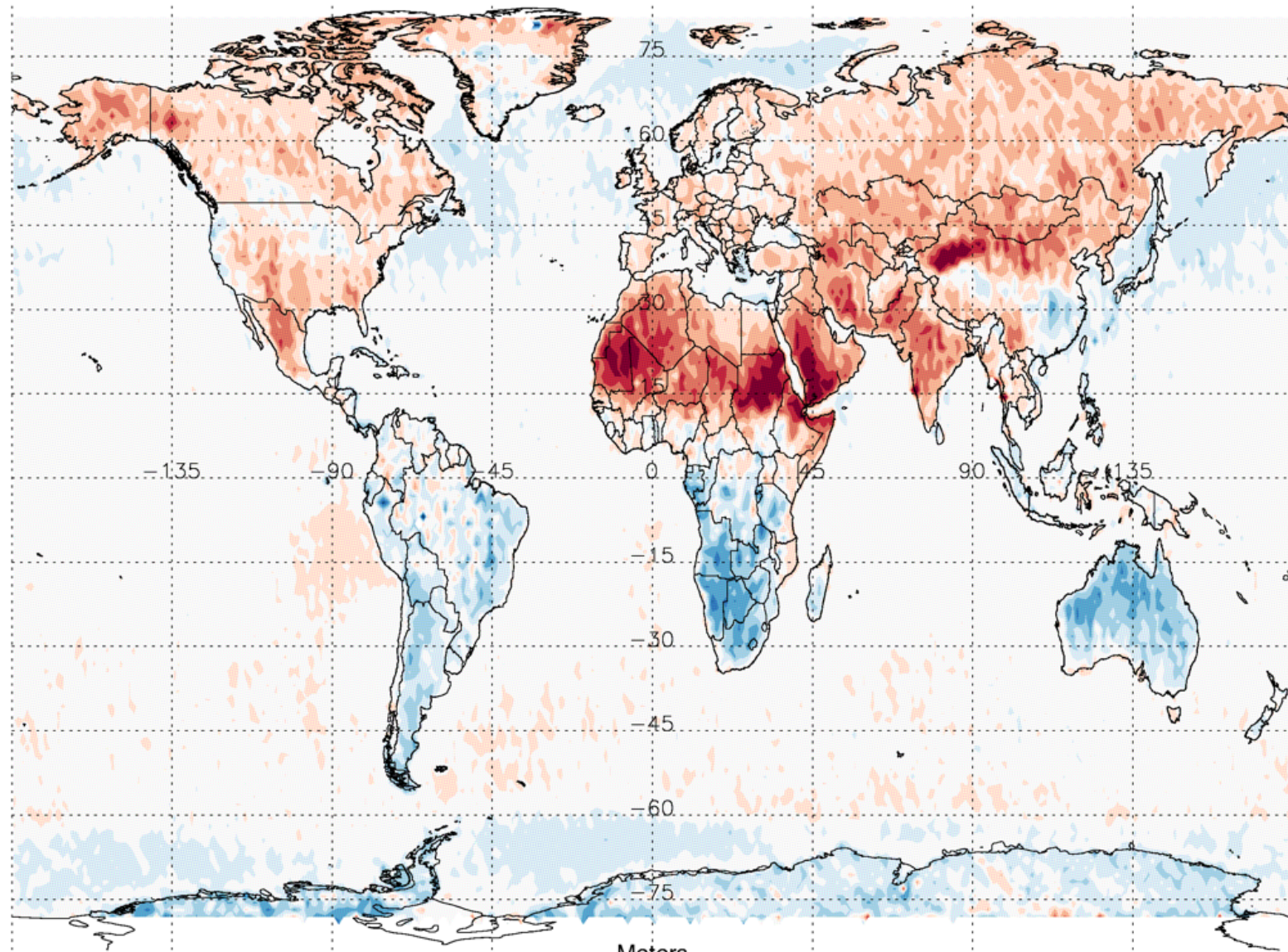


Meters

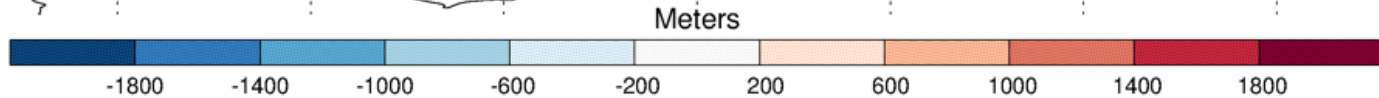




# Seasonal Cycle of PBL Depth



JJA  
minus  
DJF

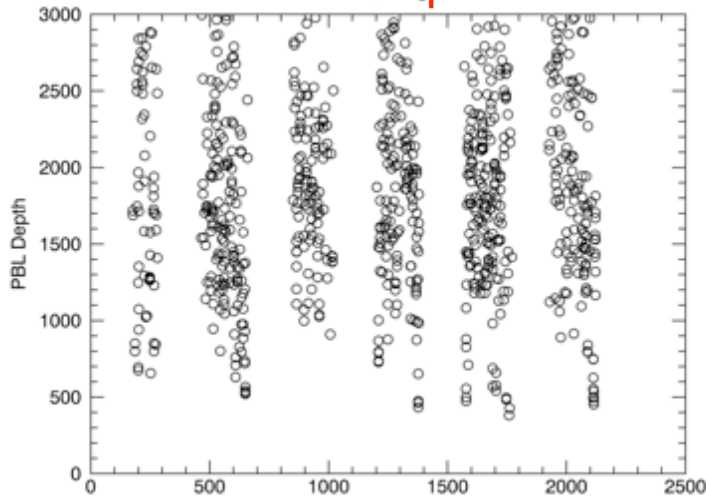


# Matching SiB and CALIPSO

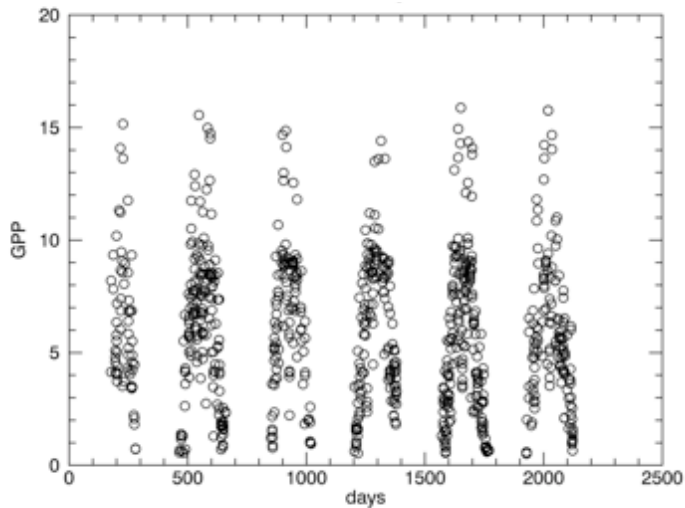
- Gather a list of successful PBL retrievals
- Match each one over land to a SiB grid cell in space and time
- Average all PBL retrievals for each cell for each hour ( $N = 1,137,452$ )
- Create a database of GPP, Resp, NEE, and PBL Depth at over a million places and times
- Sampling bias: only mid-day, clear-sky snapshots (not representative of means!)

# Very noisy data!

PBL Depth

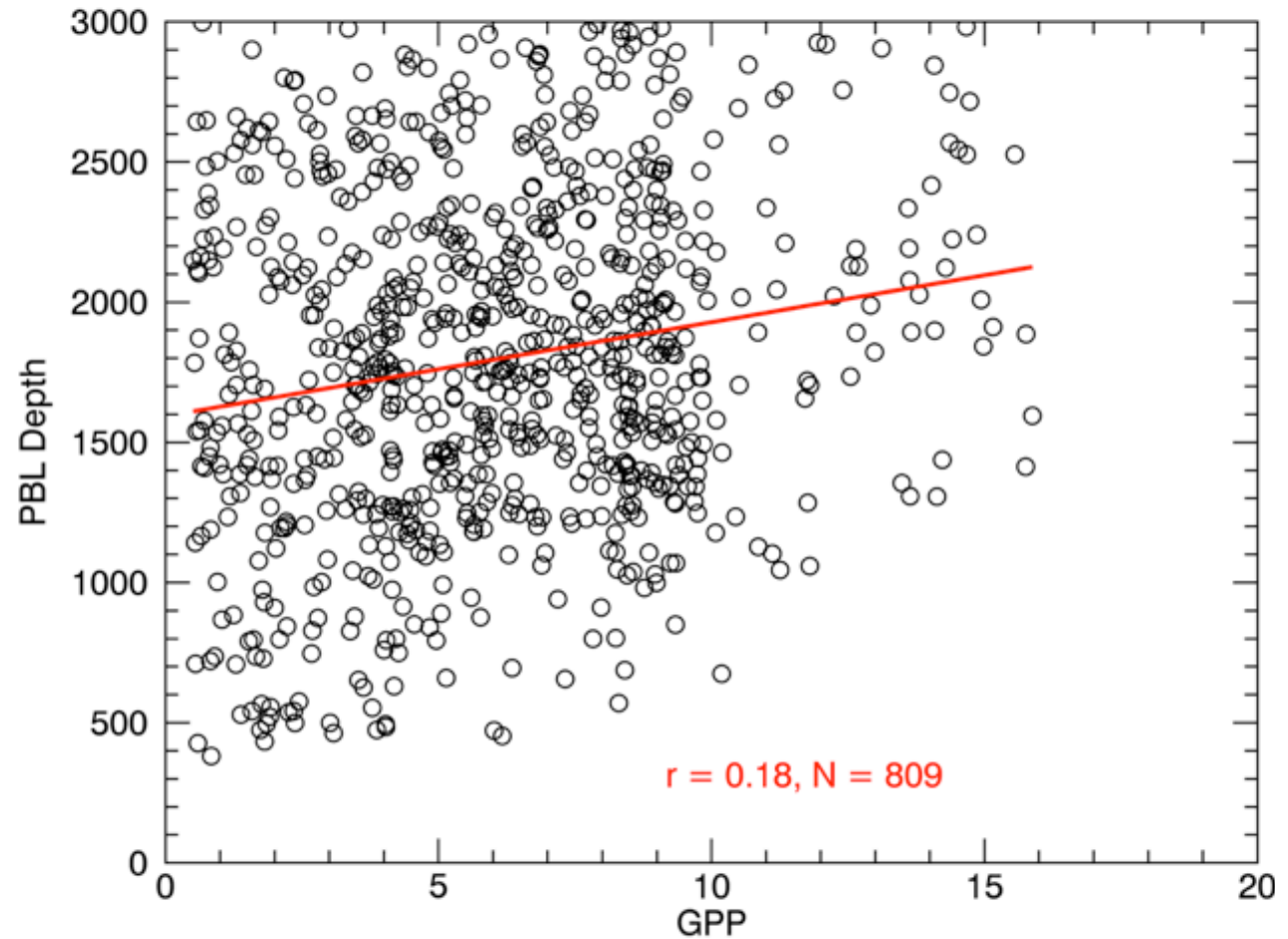


GPP



## Central Siberia

Latitude from 55 to 60, Longitude from 80 to 85



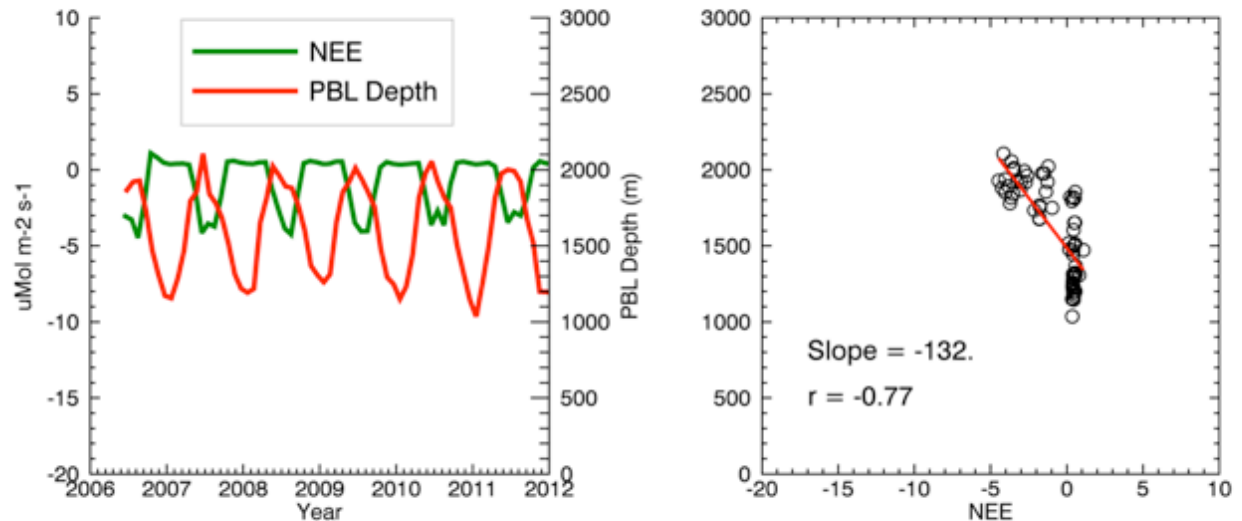


# Monthly Means from Individual Samples

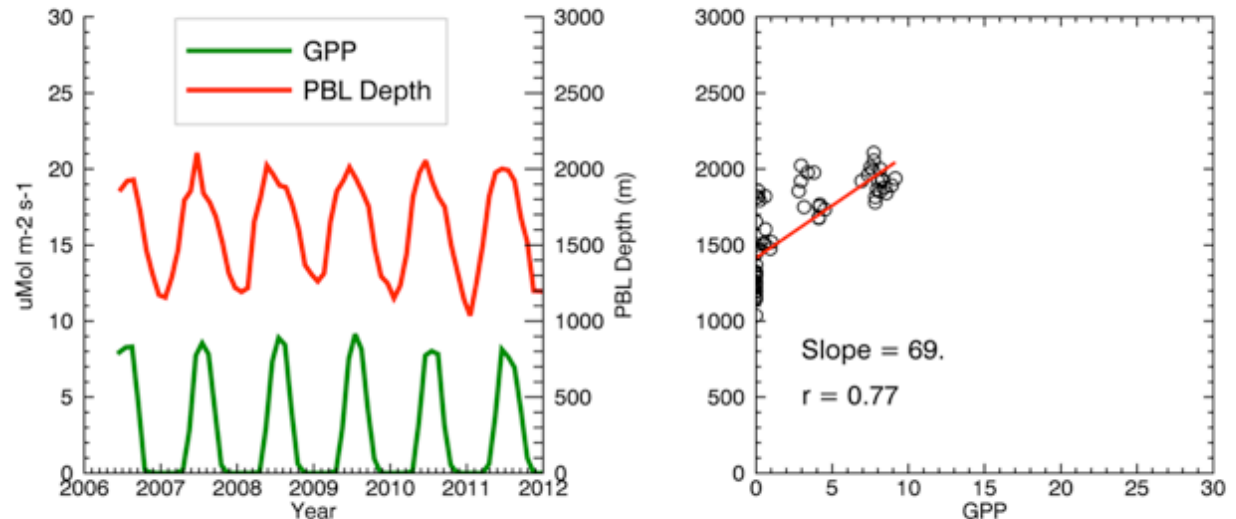
- Not monthly mean SiB fluxes!
- Much smoother behavior of PBL depths
- Correlated fluxes and PBL depths

## Russian Boreal Forest

Correlation of Simulated Fluxes with Observed PBL Depths



Latitude 55 to 65, Longitude 65 to 150  
Total Number of Soundings = 50430

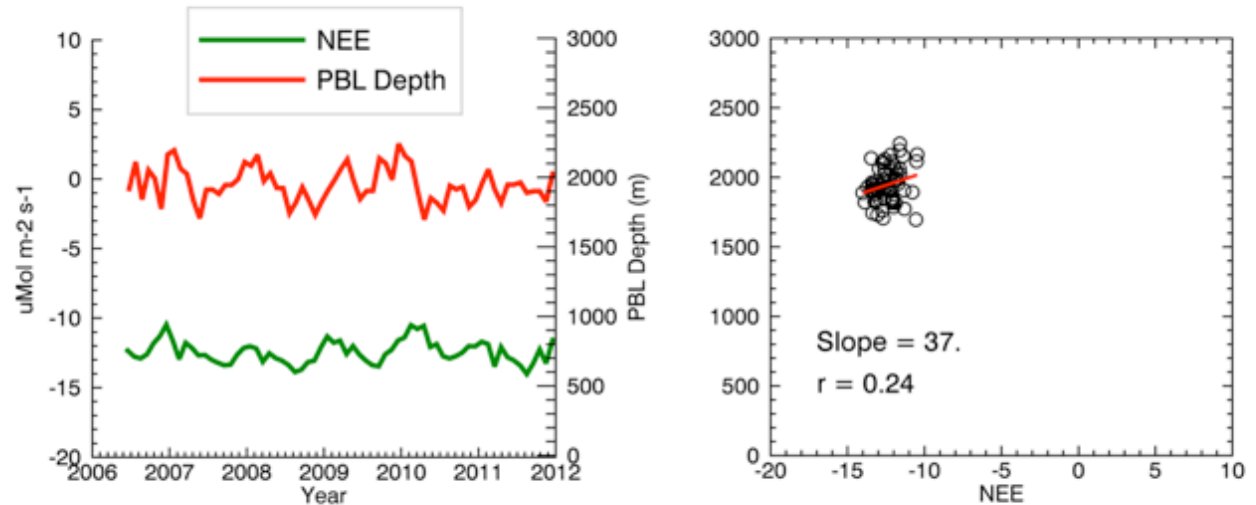


# Amazon Tropical Forest

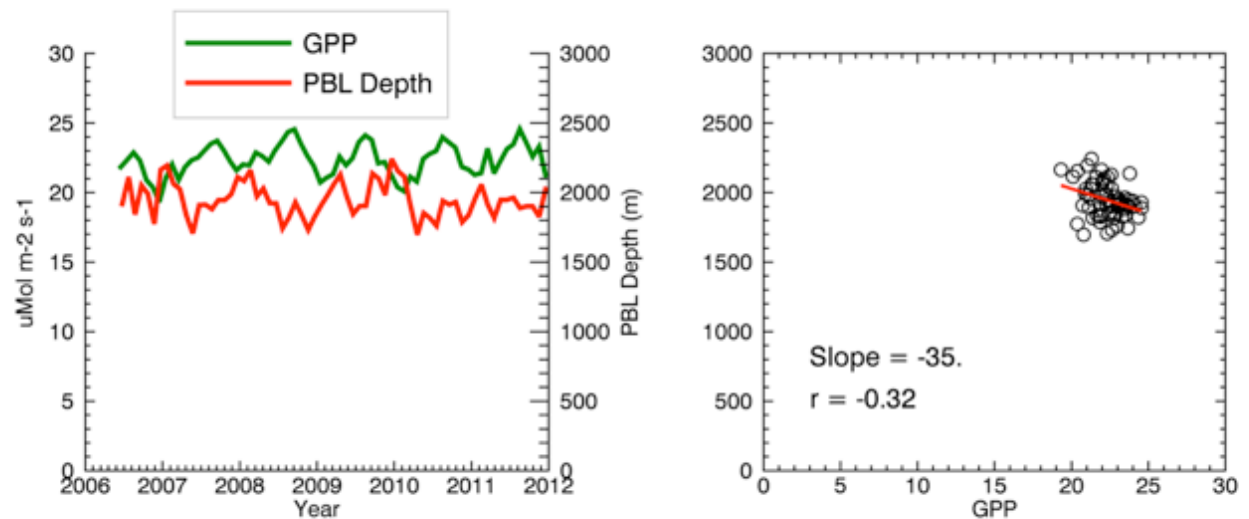
## Monthly Means from Individual Samples

- Not much seasonal variation of midday, clearsky biology or PBL
- Weak correlations

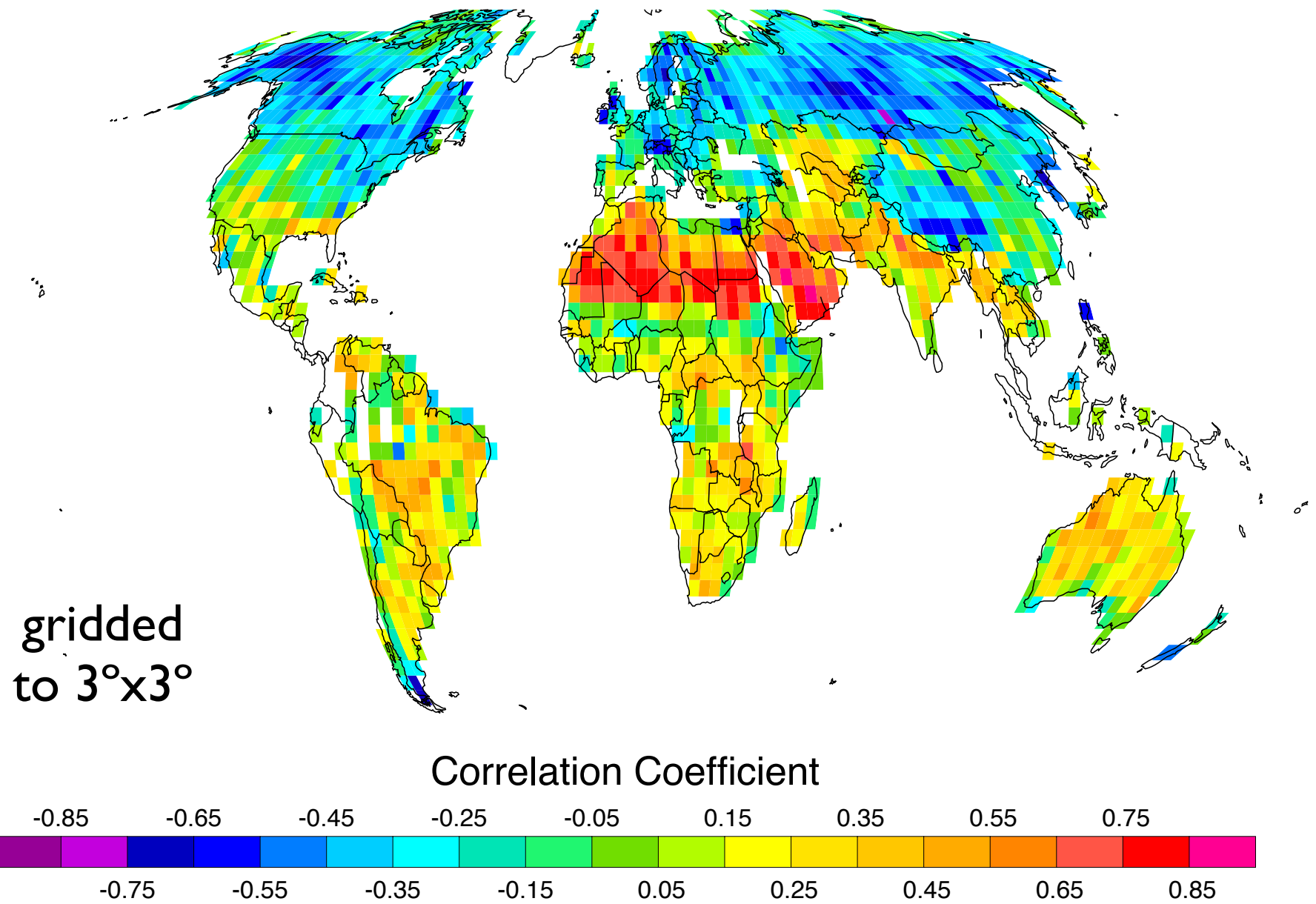
Correlation of Simulated Fluxes with Observed PBL Depths



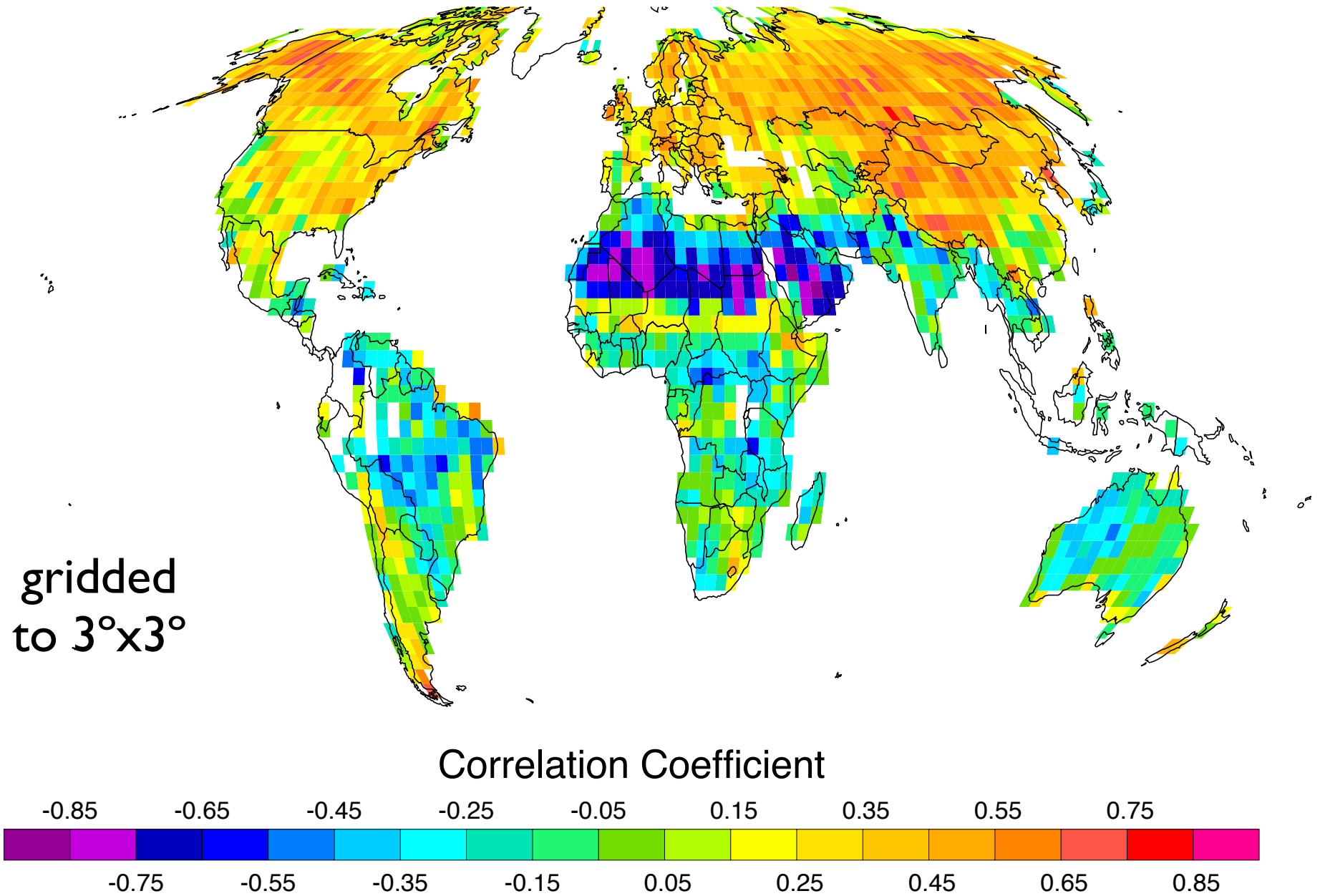
Latitude -5 to 5, Longitude -70 to -55  
Total Number of Soundings = 4985



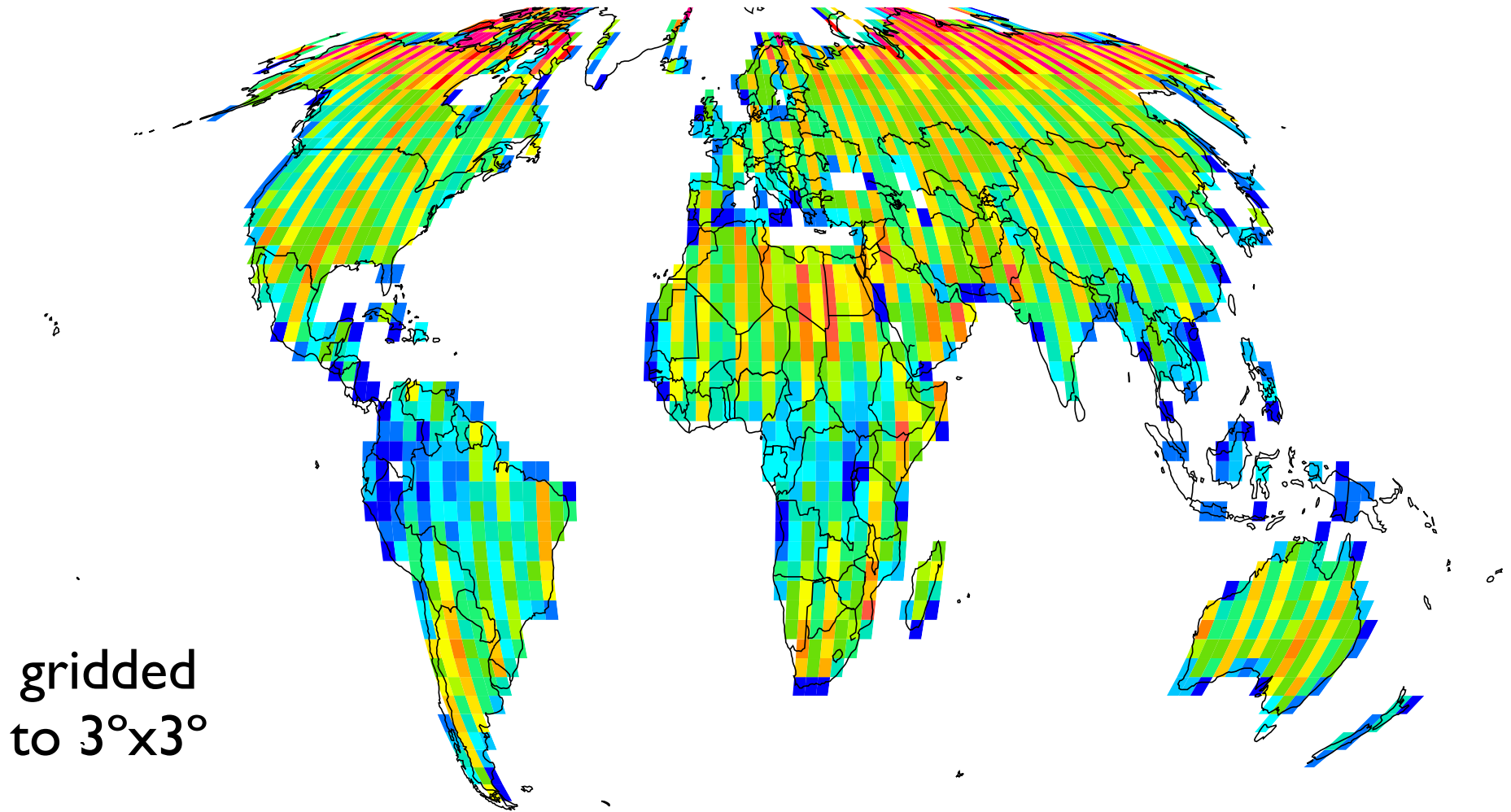
# Observed PBL Depth vs Simulated NEE



# Observed PBL Depth vs Simulated GPP

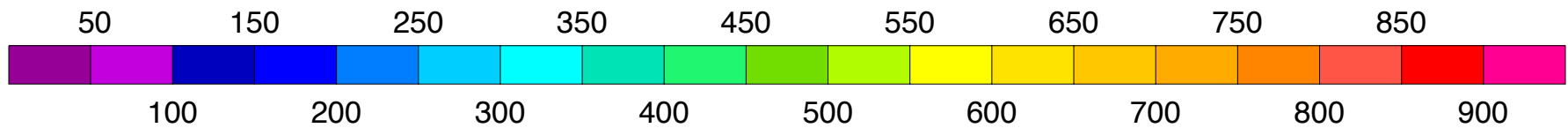


# Number of Valid Soundings Per Grid Cell



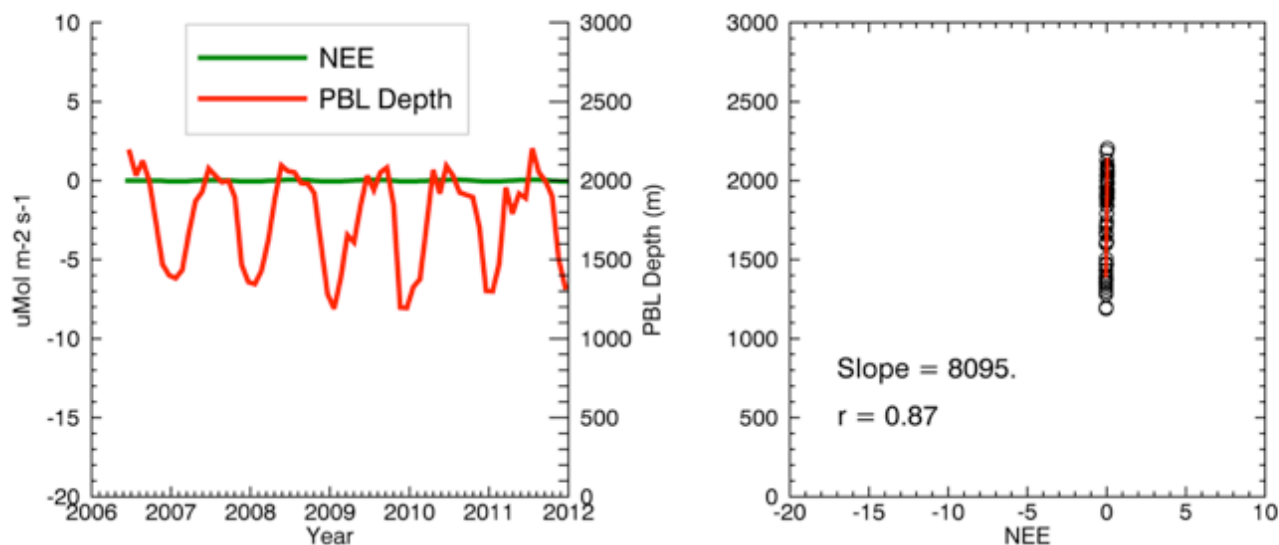
gridded  
to 3°x3°

Number of Soundings Per Grid Cell

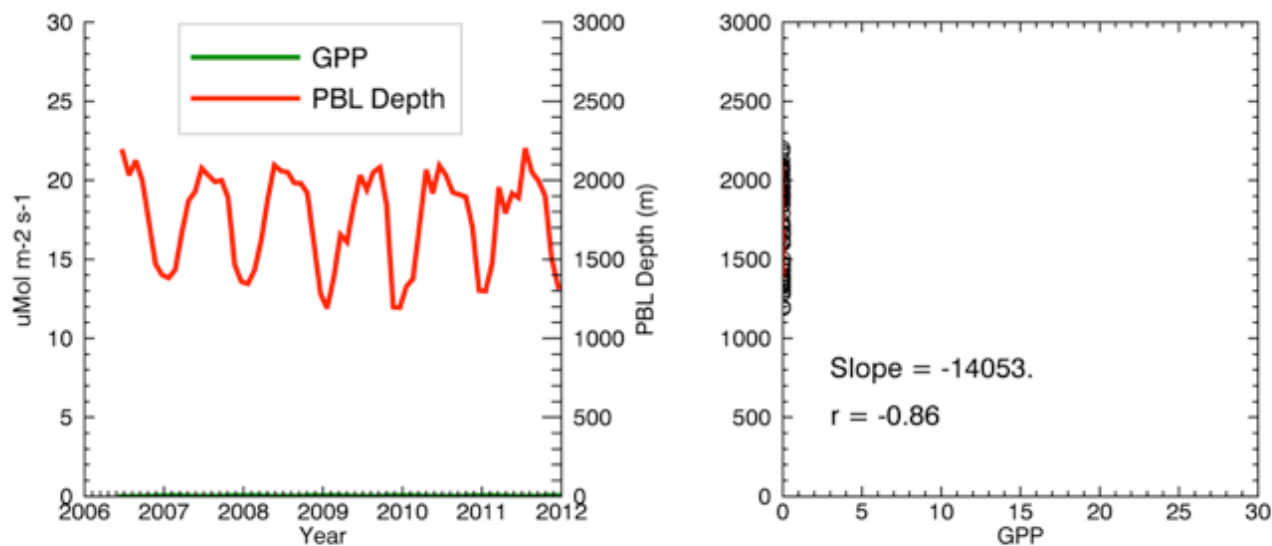




### Correlation of Simulated Fluxes with Observed PBL Depths



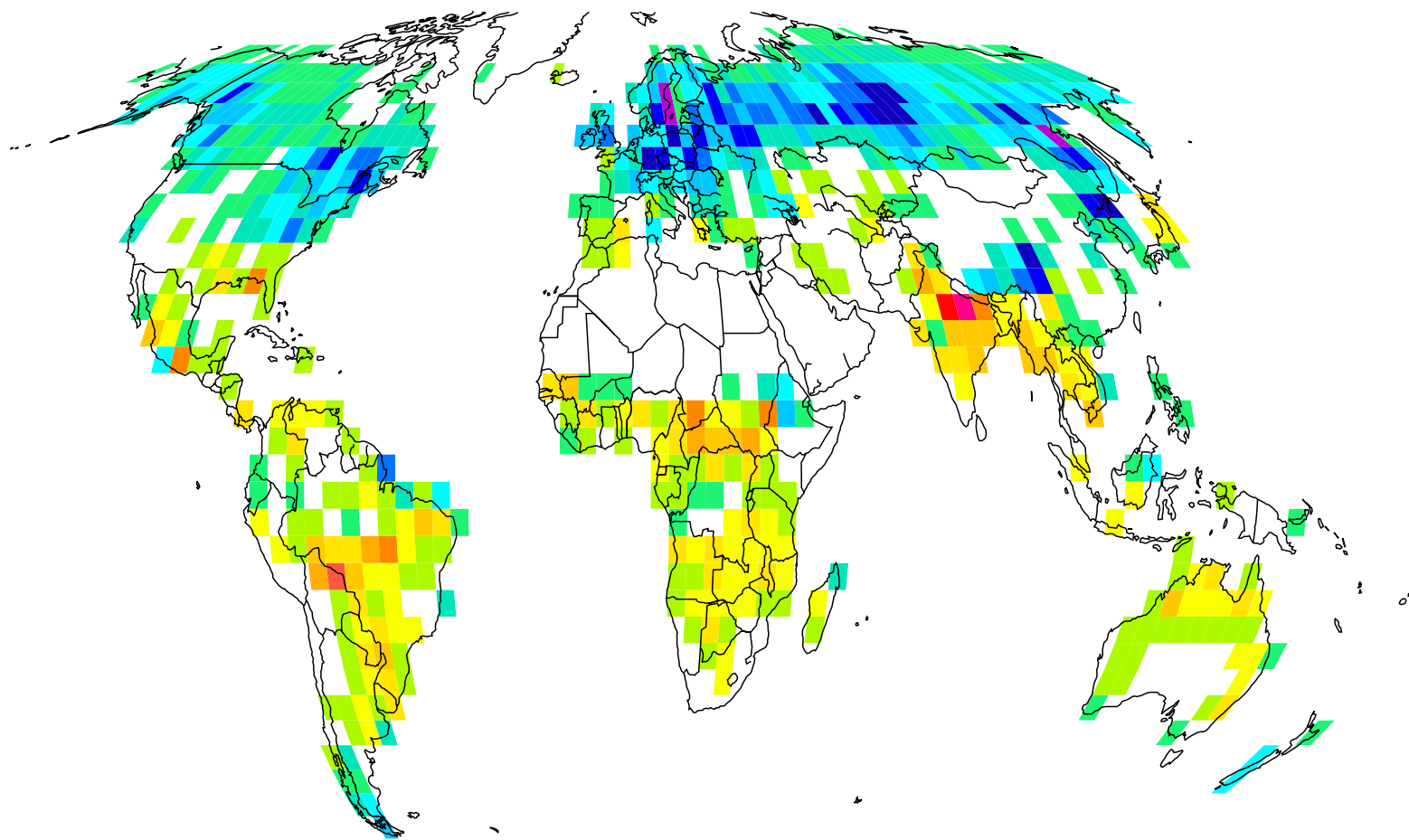
Latitude 20 to 30, Longitude 0 to 20  
Total Number of Soundings = 12764



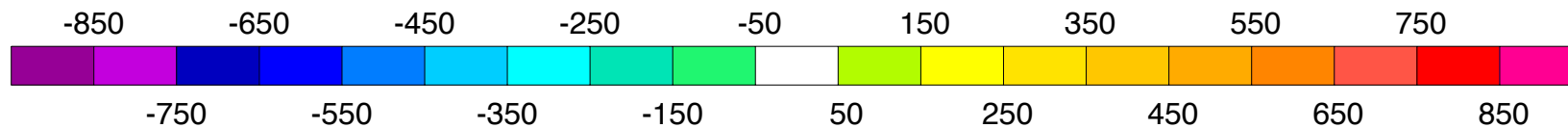
# Sahara

- Almost no flux
- High but meaningless correlations

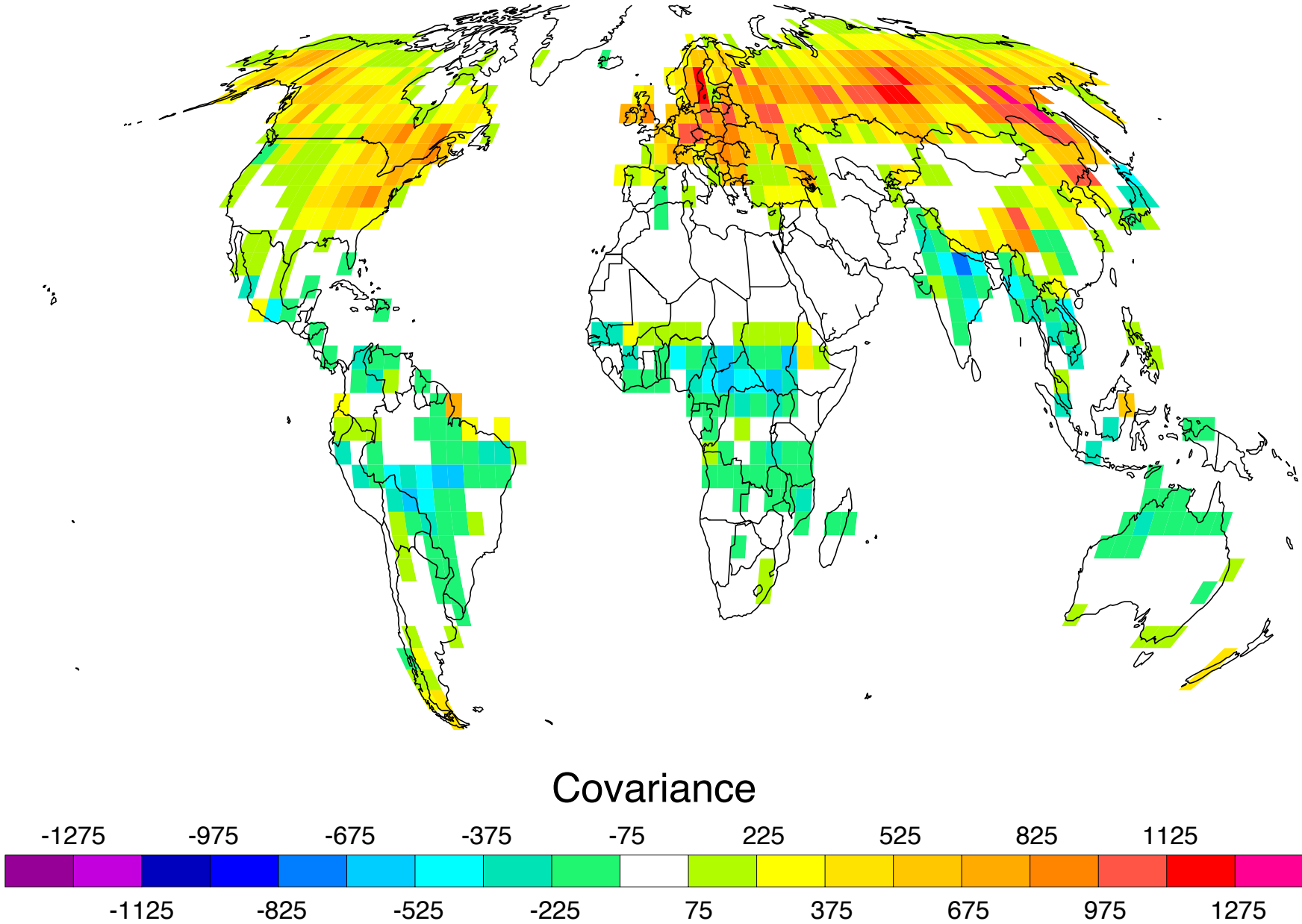
# Simulated NEE vs Observed PBL Depth



Covariance

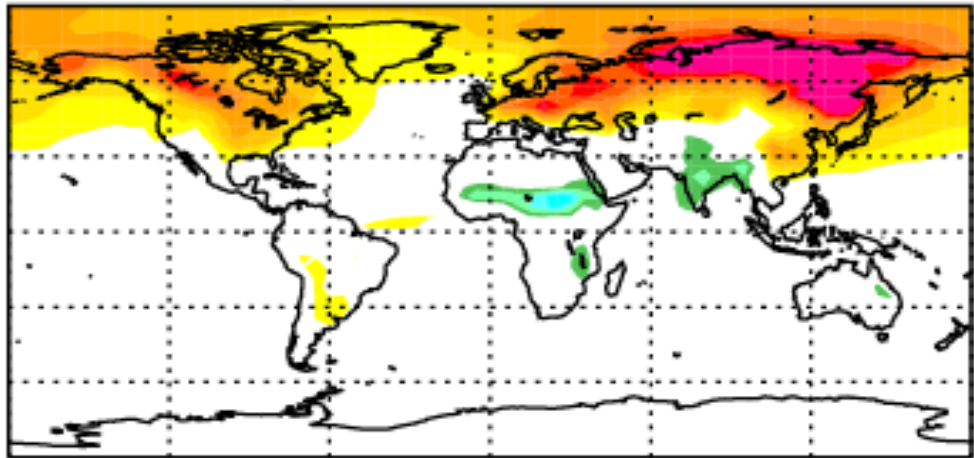


# Simulated GPP vs Observed PBL Depth



# Simulated Rectifier CO2 Response

MATCH:NCEP regrided Global Mean = 350.6

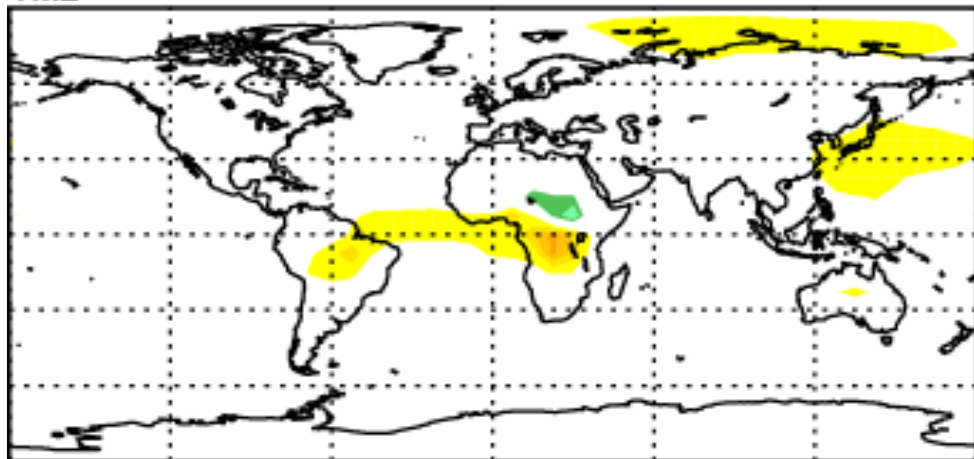


346.0 347.1 348.2 349.4 350.5 351.5 352.6 353.8 354.9



345.5 346.6 347.7 348.8 349.9 351.0 352.1 353.2 354.3

TM2 Global Mean = 350.09



345.1 346.3 347.5 348.7 349.9 351.1 352.3 353.5 354.7

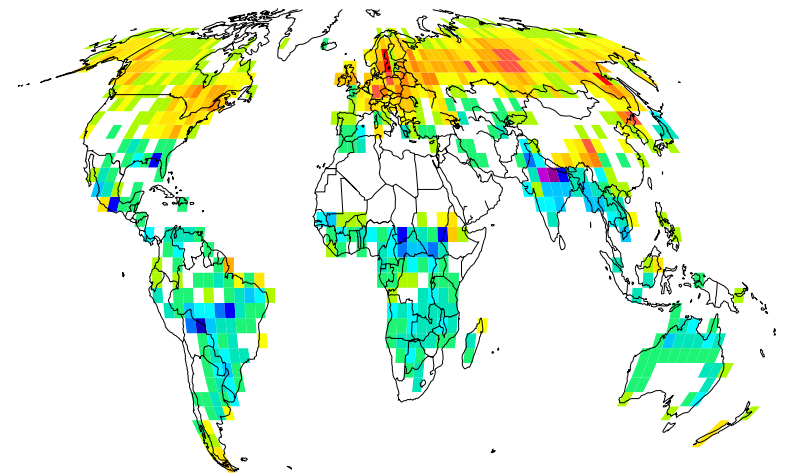


344.5 345.7 346.9 348.1 349.3 350.5 351.7 352.9 354.1

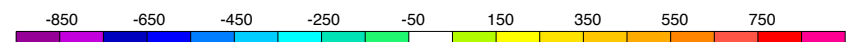
# Speculative Comparison

*Preliminary results suggest strong rectifier simulated by MATCH much more realistic than weak rectifier simulated in TM2*

## Observed Rectifier Forcing Simulated NEE vs Observed PBL Depth



-Covariance



-850 -750 -650 -550 -450 -350 -250 -150 50 150 250 350 450 550 650 750 850