Quantifying contributions of land carbon fluxes variability and atmospheric transport variability to atmospheric CO_2 variability

Eunjee Lee[1,2]

Randal D. Koster[2], Lesley Ott[2], Fan-Wei Zeng[2,3], Sarith Mahanama[2,3], Tomohiro Oda[1,2], Benjamin Poulter[4], Brad Weir[1,2]

[1] Goddard Earth Sciences Technology and Research, Universities Space Research Association

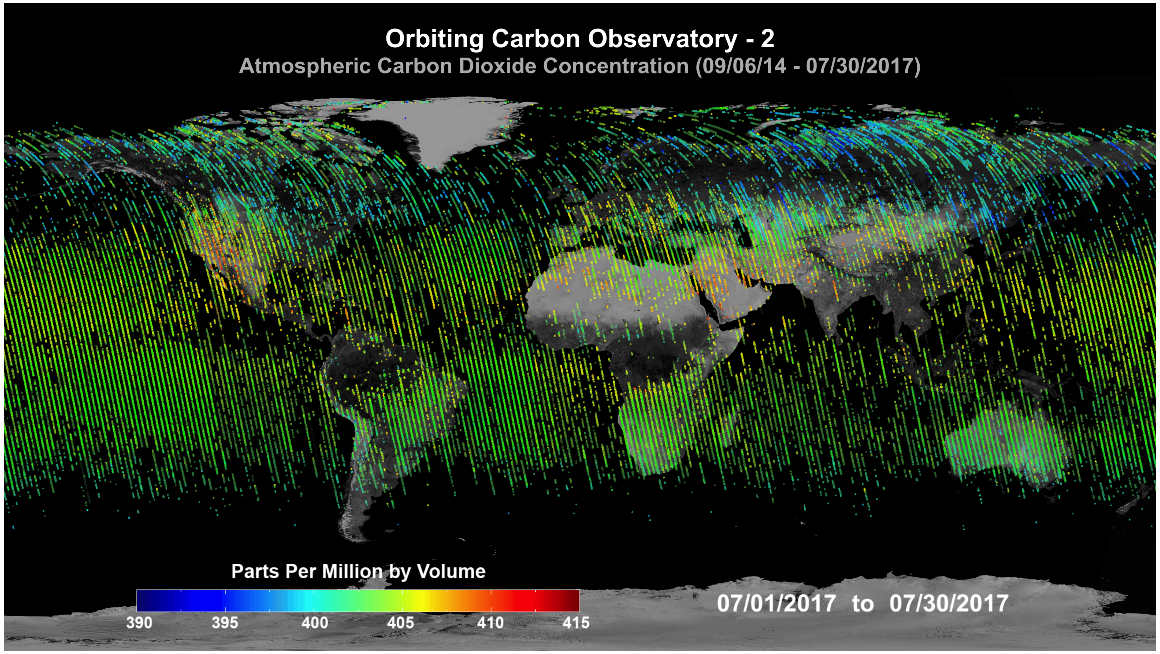
[2] Global Modeling and Assimilation Office, NASA Goddard Space Flight Center

[3] Science Systems and Applications, Inc.

[4] Biospheric Sciences Laboratory, NASA Goddard Space Flight Center

Motivation
Interaction between the land carbon cycle and climate

What determines the variability of CO_2 in the atmosphere?



https://ocov2.jpl.nasa.gov/galleries/gallerydataproducts/

Overview

1. Response of atmospheric CO_2 to land carbon flux anomaly: Case of a Spring drought

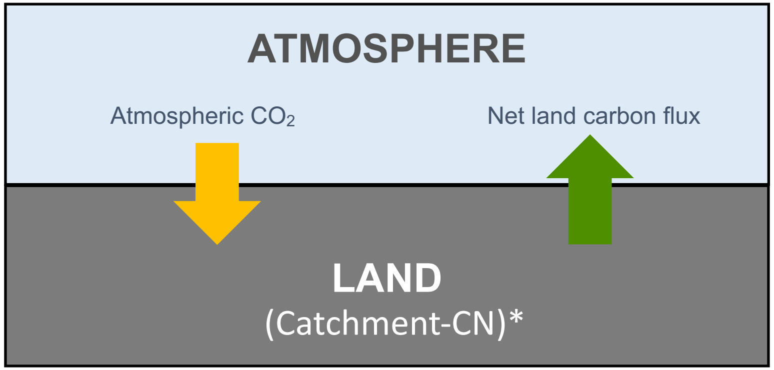
2. In what regions and seasons does the land carbon flux variability dominate the variability of atmospheric CO_2? How high into the atmosphere is the land carbon flux variability felt?

Part I

Response of atmospheric CO_2 to land carbon flux anomaly: Case of a Spring drought

[Question] To what extent do land carbon flux changes induced by a regional Spring drought affect atmospheric CO_2?

Connecting the land and atmospheric branches of the Carbon cycle
Simulating Land-Atmosphere feedback



A coupled land-atmosphere model in the NASA GEOS system:

(i) allows modeled atmospheric CO_2 to affect land surface carbon uptake, and

(ii) uses modeled net CO_2 uptake at the land surface as a source or sink for the atmospheric CO_2,

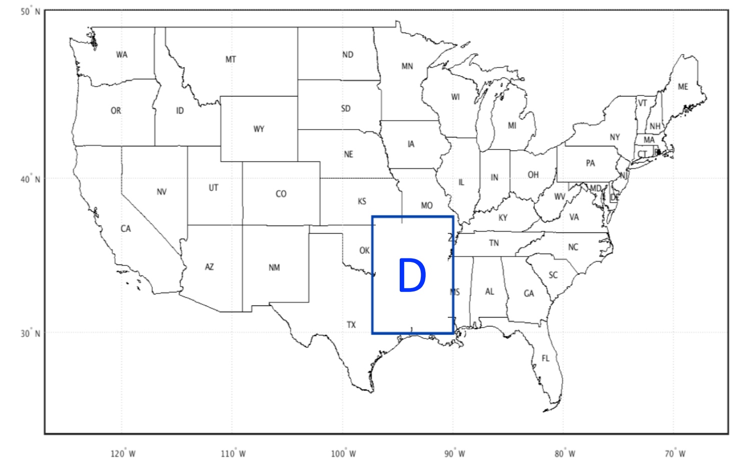
(iii) enables **carbon cycle feedbacks** alongside **water & energy cycle feedbacks**

* e.g. Koster et al. (2014), Lee et al. (2018)

Experimental design

- Six-month **free running** AGCM simulations

- Control ensemble vs. Drought ensemble
  - **Control** ensemble is with no imposed drought
  - **Drought** ensemble is with an artificially imposed meteorological drought over 7º x 7º domain in US (boxed area) from April to June, followed by a 3-month recovery period

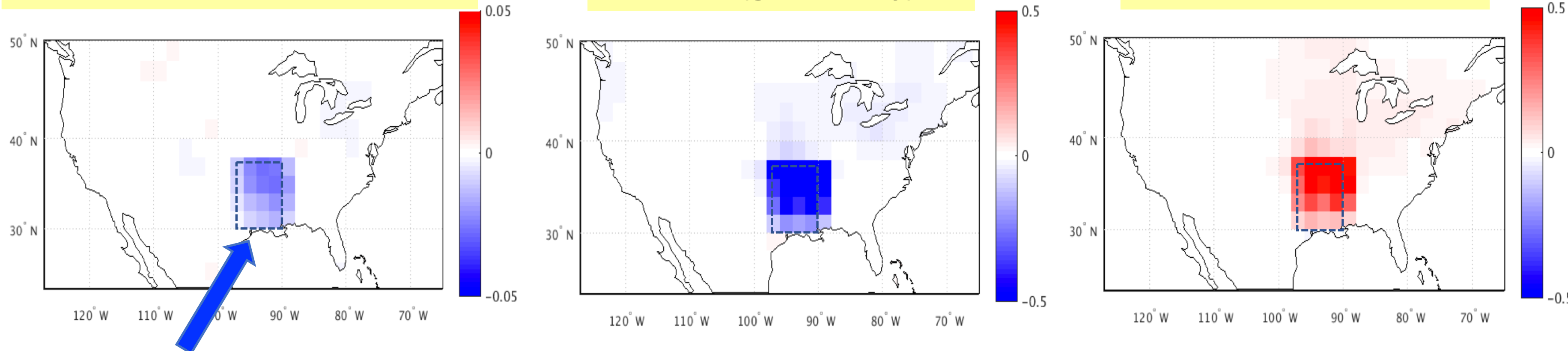


- Each suite consists of **80-member ensembles**
  - 2012 SST was applied for all members
  - Slightly different initial conditions were applied with atmospheric perturbations (temperature and humidity)

Goal: Mechanistic understanding of drought impacts on CO_2 in a coupled system

Response of land carbon fluxes to drought (Drought minus Control during AMJ drought period)

Δ Root zone moisture (m^3/m^3) | **Δ GPP ($gC/m^2/day$)** | **Δ NEE ($gC/m^2/day$)**



Imposed drought area:
no rainfall during AMJ

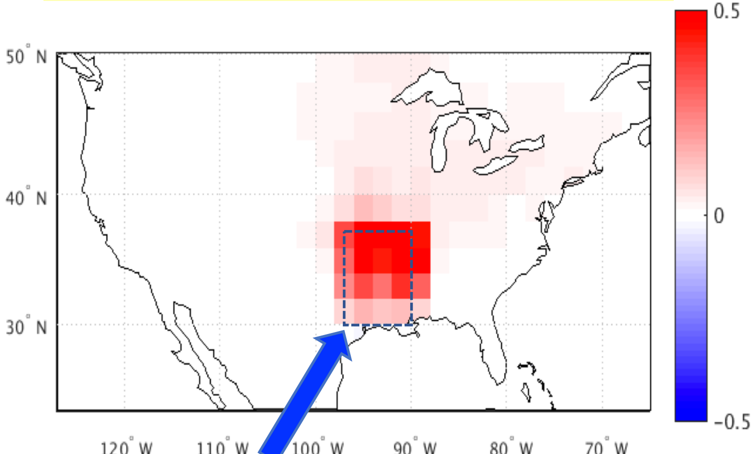
Imposed drought leads to lower soil water and leaf area index (LAI)

⇨ Reduced GPP and reduced net carbon uptake by land

Lee et al. (in prep)

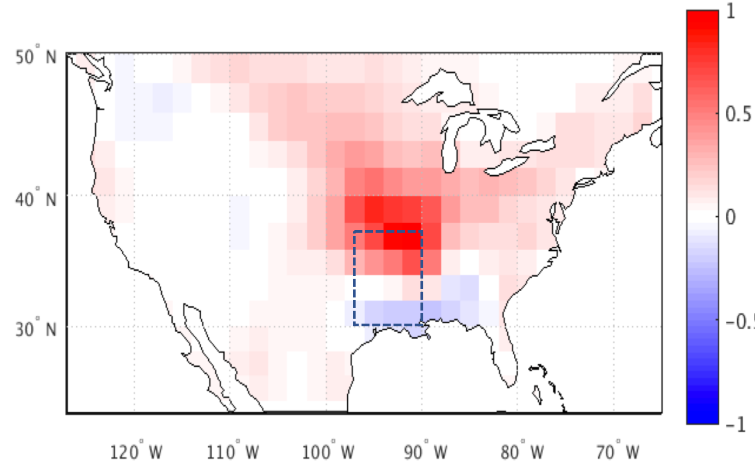
Land flux and atmospheric CO_2 anomalies (Drought minus Control during AMJ drought period)

Δ NEE due to drought (gC/m²/day)



Imposed drought area:
no rainfall during AMJ

Δ surface CO_2 due to drought (ppm)

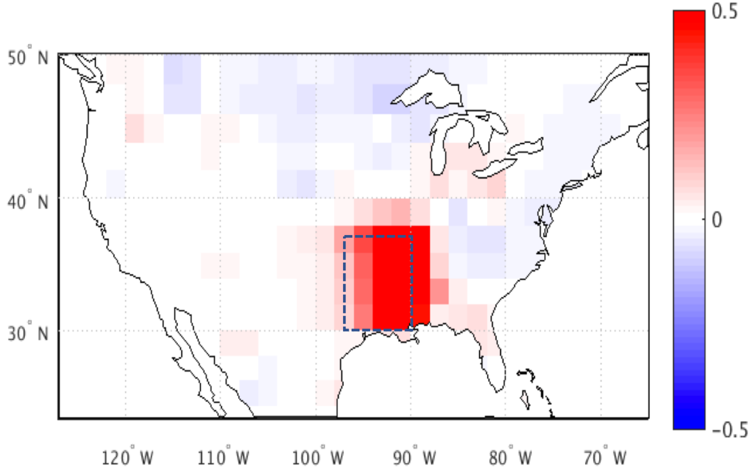


The impact of the drought is seen both inside and outside the imposed drought region ⇨ atmospheric transport moves the extra CO_2 around

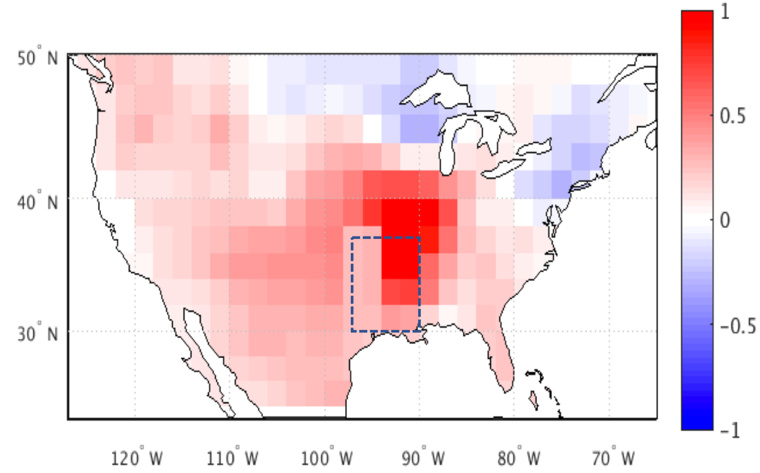
Lee et al. (in prep)

Land flux and atmospheric CO_2 anomalies (Drought minus Control during JAS recovery period)

Δ NEE due to earlier drought (gC/m²/day)



Δ surface CO_2 due to earlier drought (ppm)



Even after the drought ends, impacts on NEE and atmospheric CO_2 persist and (for CO_2) are far-reaching

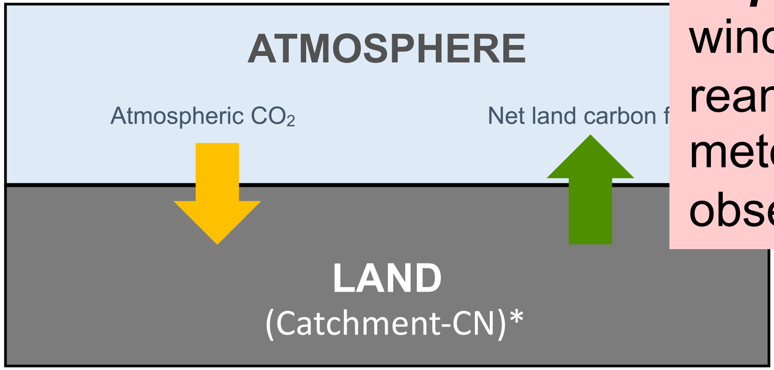
Lee et al. (in prep)

Part II

The impact of land carbon flux variability on atmospheric CO_2 variability

[Questions]
In what regions and seasons does the land carbon flux variability dominate the variability of atmospheric CO_2? How high into the atmosphere is the land carbon flux variability felt?

Connecting the land and atmospheric branches of the Carbon cycle
Simulating Land-Atmosphere feedback



Replay technique with T, wind, pressure of MERRA-2 reanalysis. The simulated meteorology is similar to the observed meteorology.

A coupled land-atmosphere model in the NASA GEOS system:

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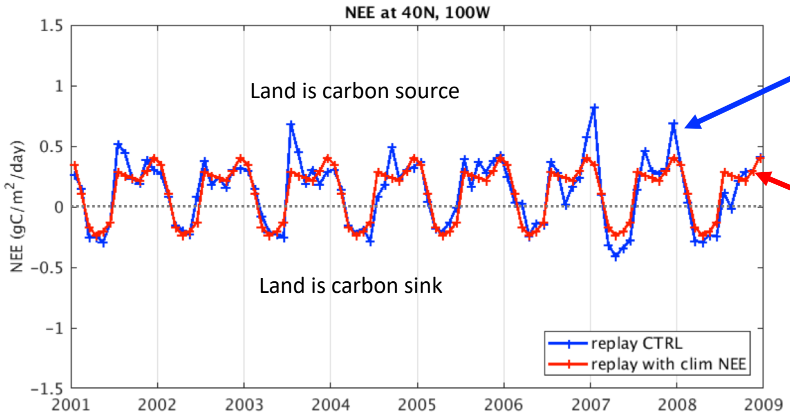
* e.g. Koster et al. (2014), Lee et al. (2018)

Experimental design

	CTRL	EXP
Atm, Ocn, Land	Replay of temperature, pressure and wind from MERRA-2; Ocean SST is prescribed	
Land carbon flux to Atmosphere	Simulated NEE fluxes from Catchment-CN	15-year **climatological NEE**; 3-hourly mean is applied



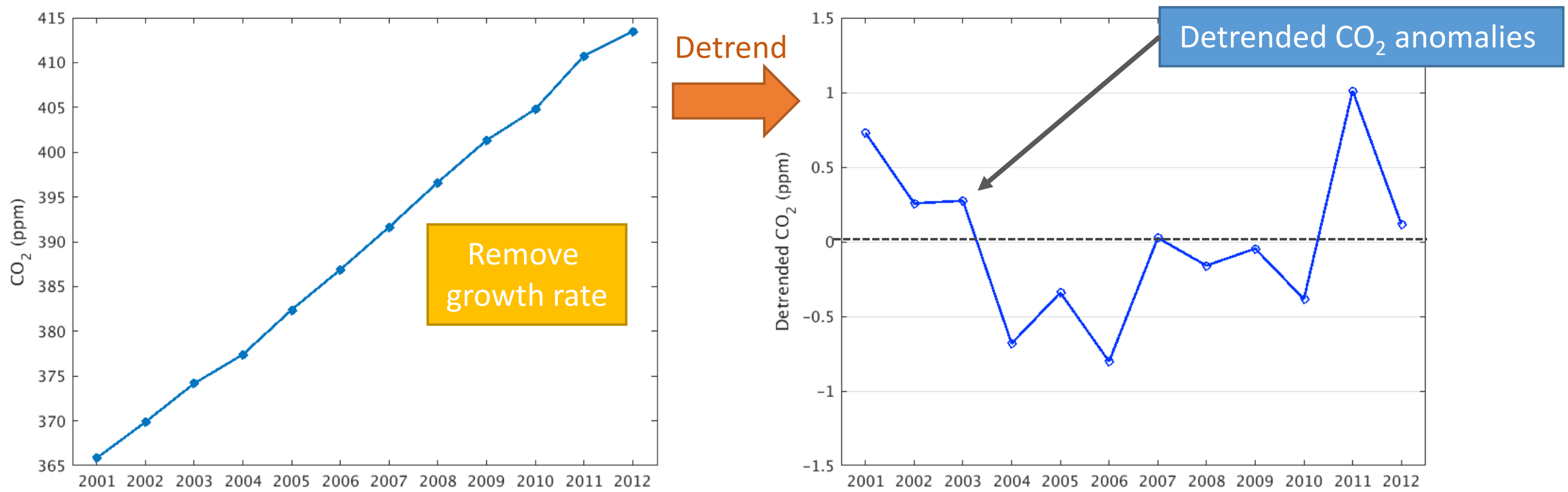
CTRL: NEE as computed from the model during the 15-yr simulation

EXP: Climatological NEE (based on Control simulation) prescribed every year at grid cell

Analysis metric: standard deviation of detrended CO_2

[STEP 1] Detrend CO_2 time series

Example: CO_2 from CTRL at 40N, 100W
(at 925mb pressure level in April)

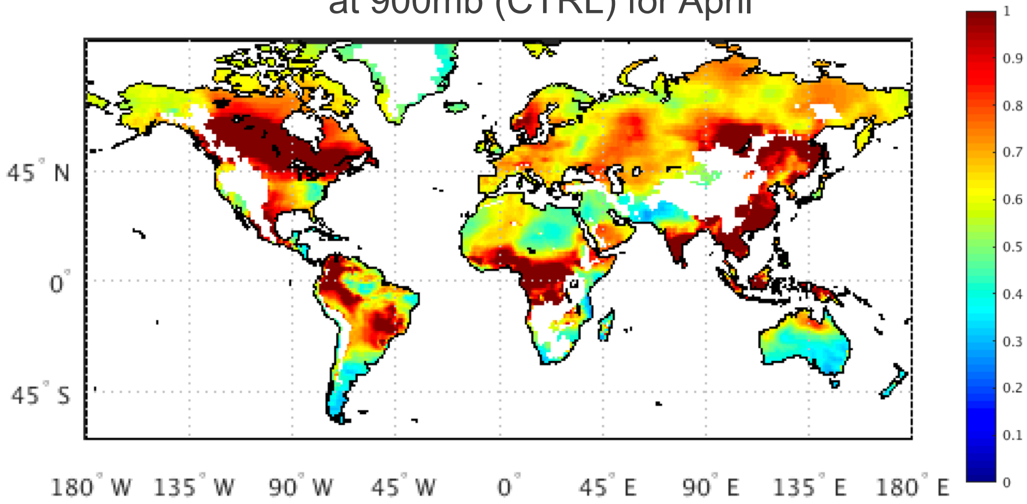


Analysis metric: standard deviation of detrended CO_2

[STEP 1] Detrend CO_2 time series

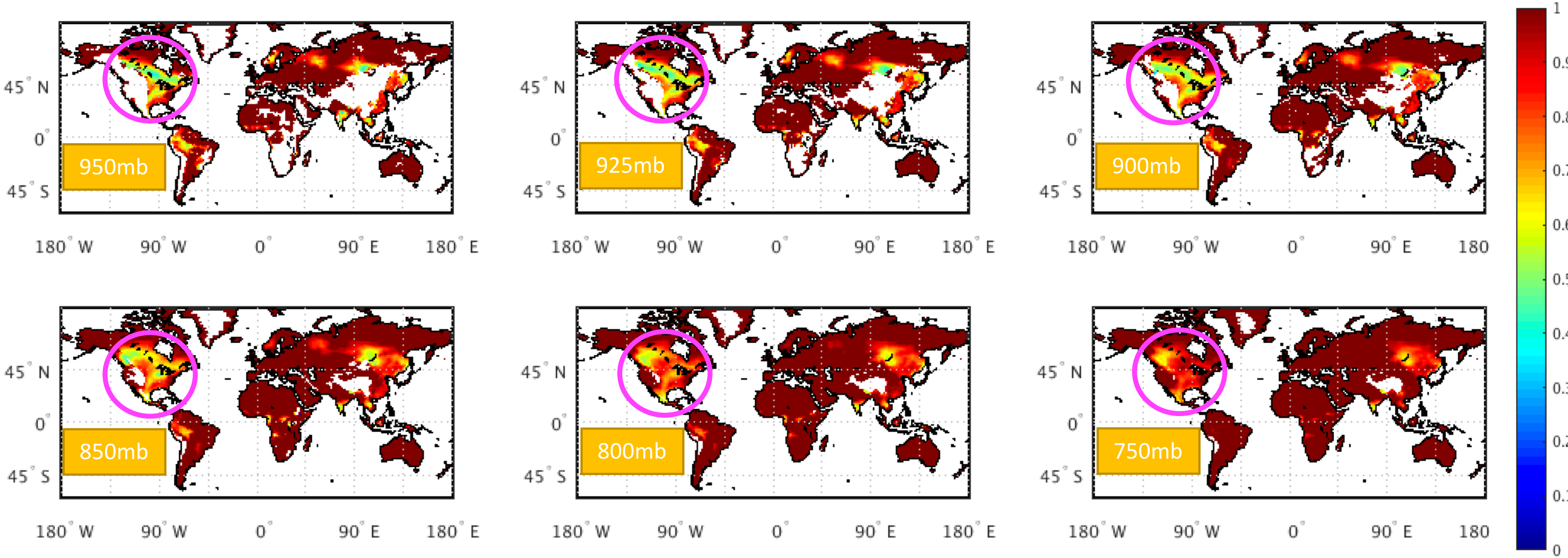
[STEP 2]
Compute the standard deviation of detrended CO_2 anomalies
(Repeat for each grid cell, pressure level, and month in both CTRL and EXP)

Example: Standard deviation of detrended CO_2 anomalies at 900mb (CTRL) for April



Ratio of standard deviation of detrended CO_2 anomalies (EXP/CTRL)

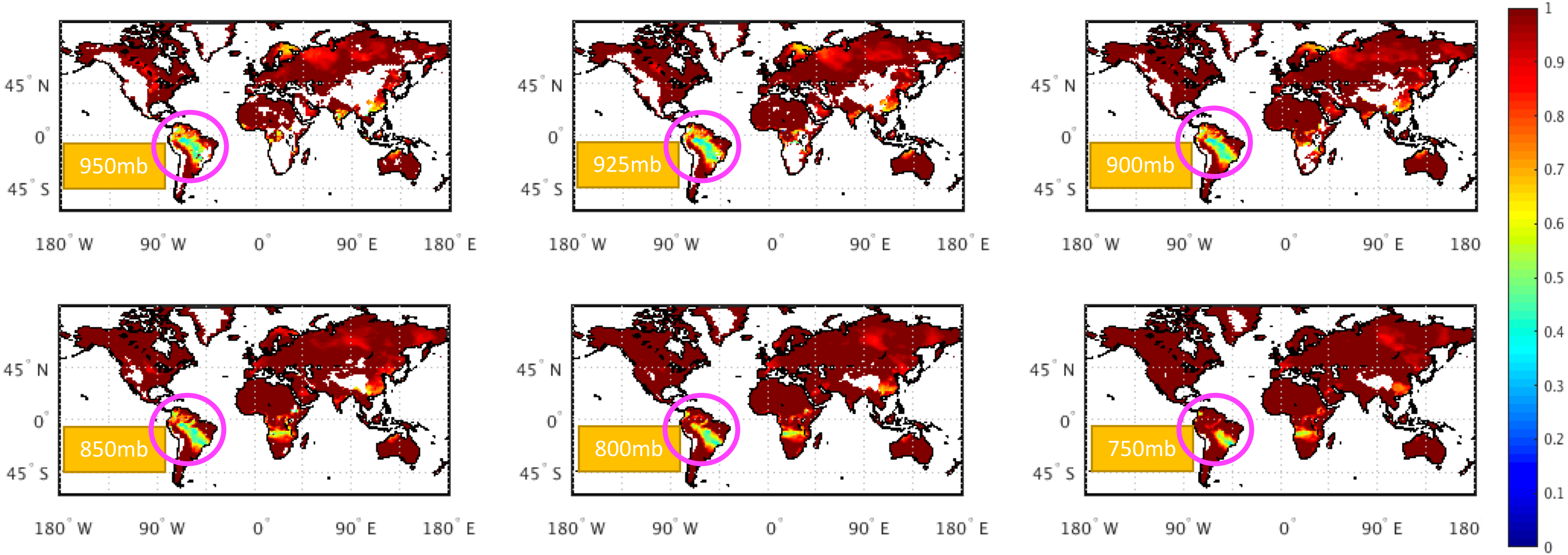
APRIL (NH growing season)



The results indicate that both land flux variability and transport variability affect CO_2 variability, with the former becoming less important higher in the atmosphere.

Ratio of standard deviation of detrended CO_2 anomalies (EXP/CTRL)

DECEMBER



The contributions of land flux variability to total CO_2 variability vary regionally and seasonally (e.g., North America in April; Amazon in December).

Summary

[Drought impact on land and atmospheric carbons]

1. An imposed drought affects local NEE and both local and remote CO_2. The effects persist after the drought ends.
2. The free running drought ensemble study illustrates the importance of atmosphere transport in defining the spatiotemporal variability in the atmospheric CO_2.

[Contribution of the land carbon variability to CO_2 variability]

1. An experiment has been devised to isolate the role of land carbon flux variability in determining atmospheric CO_2 variability.
2. The result shows that interannual variations in land carbon flux influence regional CO_2 variability in the lower and middle troposphere (up to 750mb) during the growing seasons (e.g., North America in April; Amazon in December)
3. Additionally, CO_2 variability is controlled in large part by atmospheric transport variability.

EXTRA Slides