Uncertainties in Integrating the Land and Atmospheric Constraints for North American Carbon Budgets

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Atmosphere-land Interactions Research
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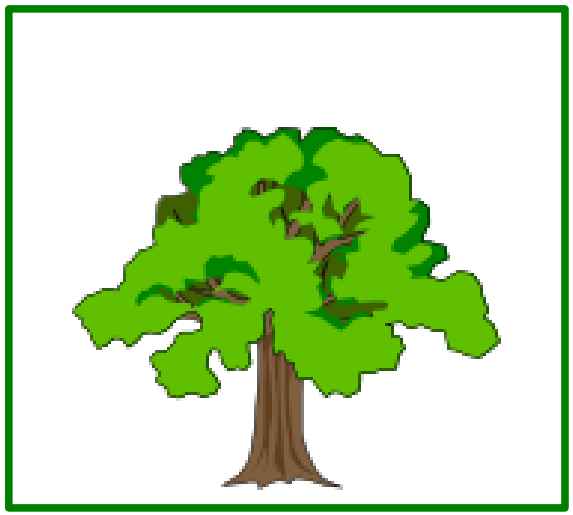
Meeting the Top-down and the Bottom-up

Atmospheric Model

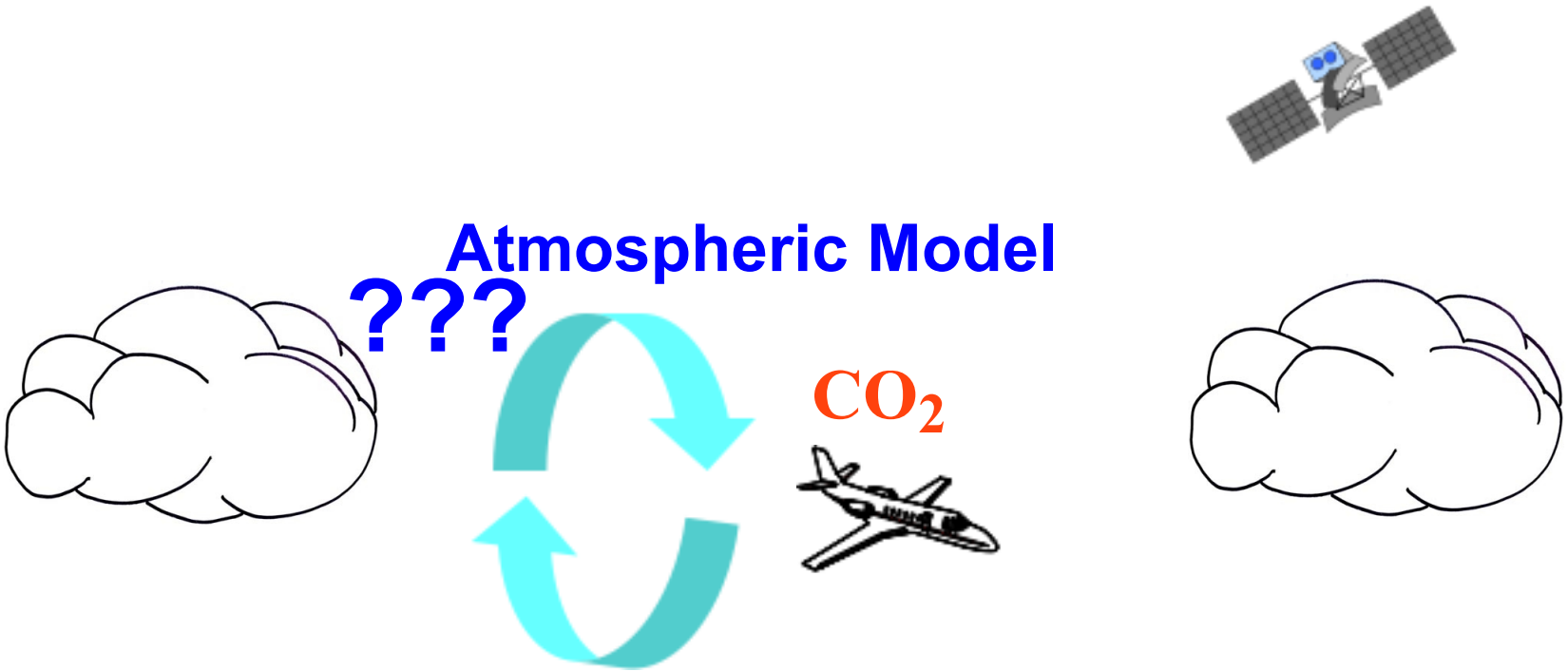
CO_2

Biospheric Model

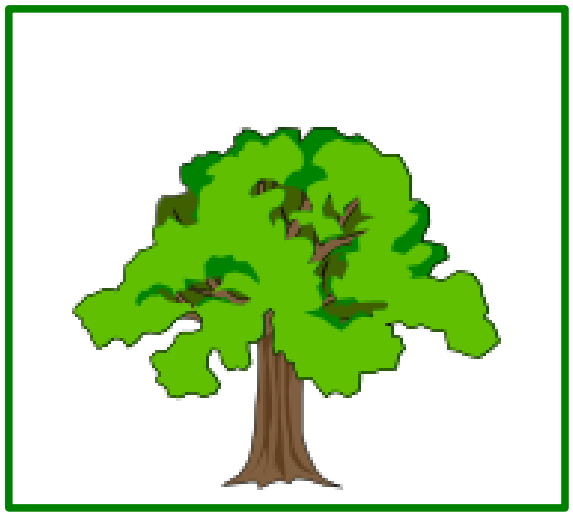


Agriculture

Meeting the Top-down and the Bottom-up



Biospheric Model



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Agriculture

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Outline

- Uncertainties in biospheric modelling
- Uncertainties in agricultural component
- Uncertainties in atmospheric modelling
- Summary

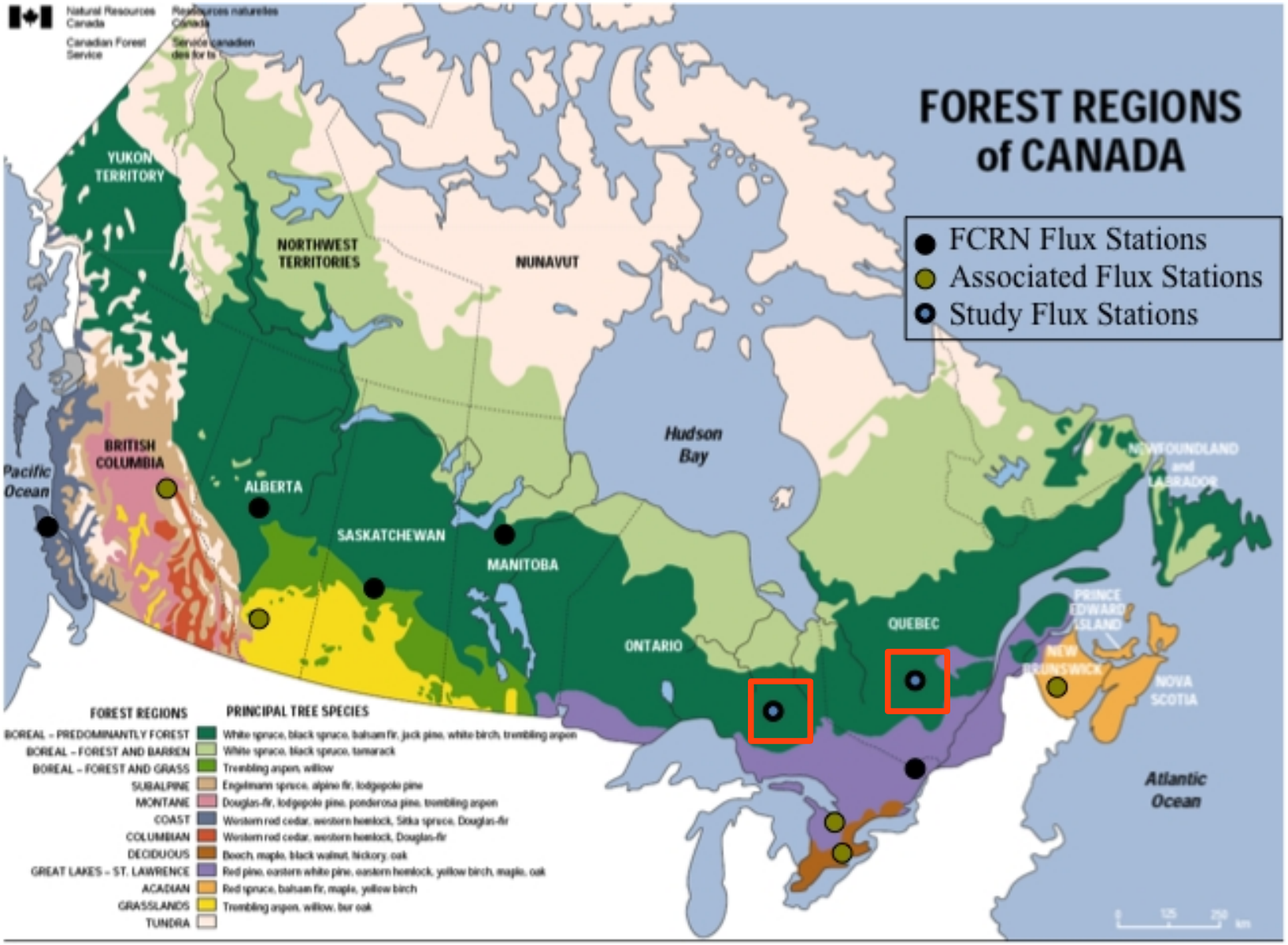
Outline

- **Uncertainties in biospheric modelling**
- **Uncertainties in agricultural component**
- **Uncertainties in atmospheric modelling**
- **Summary**

Lin, J.C., M.R. Pejam, E. Chan, S.C. Wofsy, E.W. Gottlieb, H.A. Margolis, and J.H. McCaughey. Attributing uncertainties in simulated biospheric carbon fluxes to different sources of error, Global Biogeochemical Cycles, In Review.

Motivation

We must use computer-based biospheric models to scale up in space.



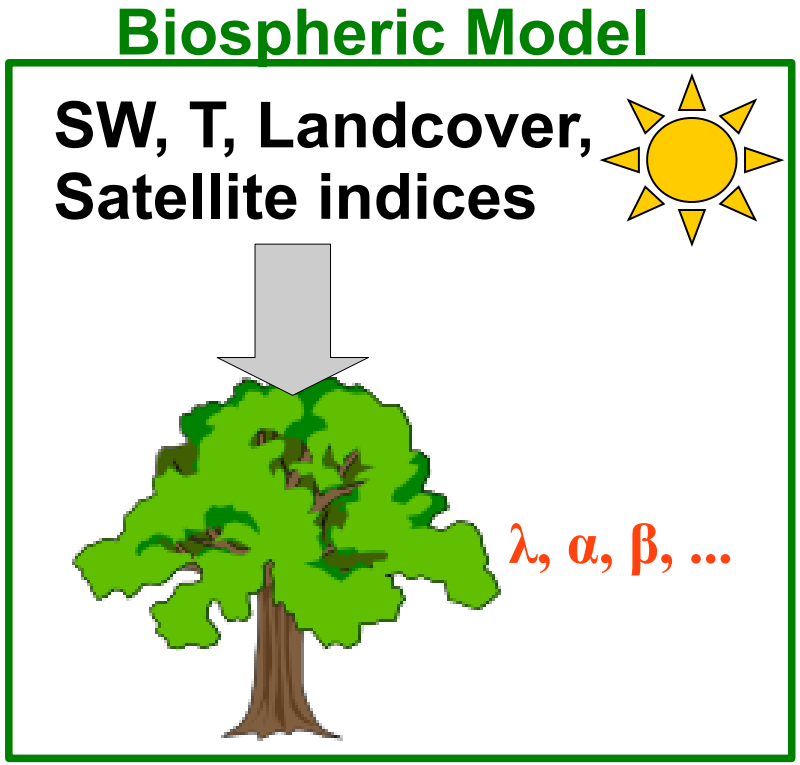
Q: What are the sources of uncertainty in these biospheric models?

Objectives

- Introduce a **general framework to quantify errors** in biospheric models. This has surprisingly been lacking!

- Framework **"unmixes" contributions** to the total uncertainty in simulated carbon and **attributes total error to different factors** (including distinction between **biases** vs **random** errors)

Schematic of Error Analysis Framework for Biospheric Models



Driving Dataset

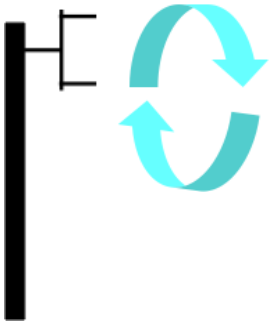
Model Parameters

Δ: biases
δ: random errors

$\Delta_{sim,}\ \delta_{sim}$
Simulation errors arising from errors in either driving dataset or model parameters

Missing processes, Misrepresentation

$\Delta_{mis,}\ \delta_{mis}$



Observations

$\Delta_{obs,}\ \delta_{obs}$

Framework for Quantifying Biospheric Model Errors

The simulated biospheric flux F_{sim} is a function of various drivers and model parameters (x_j):

$$F_{\mathrm{sim},i} = f(x_1, x_2, x_3, .. x_j)$$

Under a first-order approximation, the simulation error is given by:

$$\epsilon_{\mathrm{sim}} \approx \sum_j \frac{\partial F_{\mathrm{sim}}}{\partial x_j} \epsilon_{x_j}$$

For any single variable x_j, the equation above partitions the error into contributions by different variables.

For instance, for temperature (T):

$$\sigma_T = \sigma\left(\boxed{\frac{\partial F_{\mathrm{sim}}}{\partial T}}[T_{sim} - T_{true}]\right) \qquad \Delta_T = \overline{\frac{\partial F_{\mathrm{sim}}}{\partial T}[T_{sim} - T_{true}]}$$

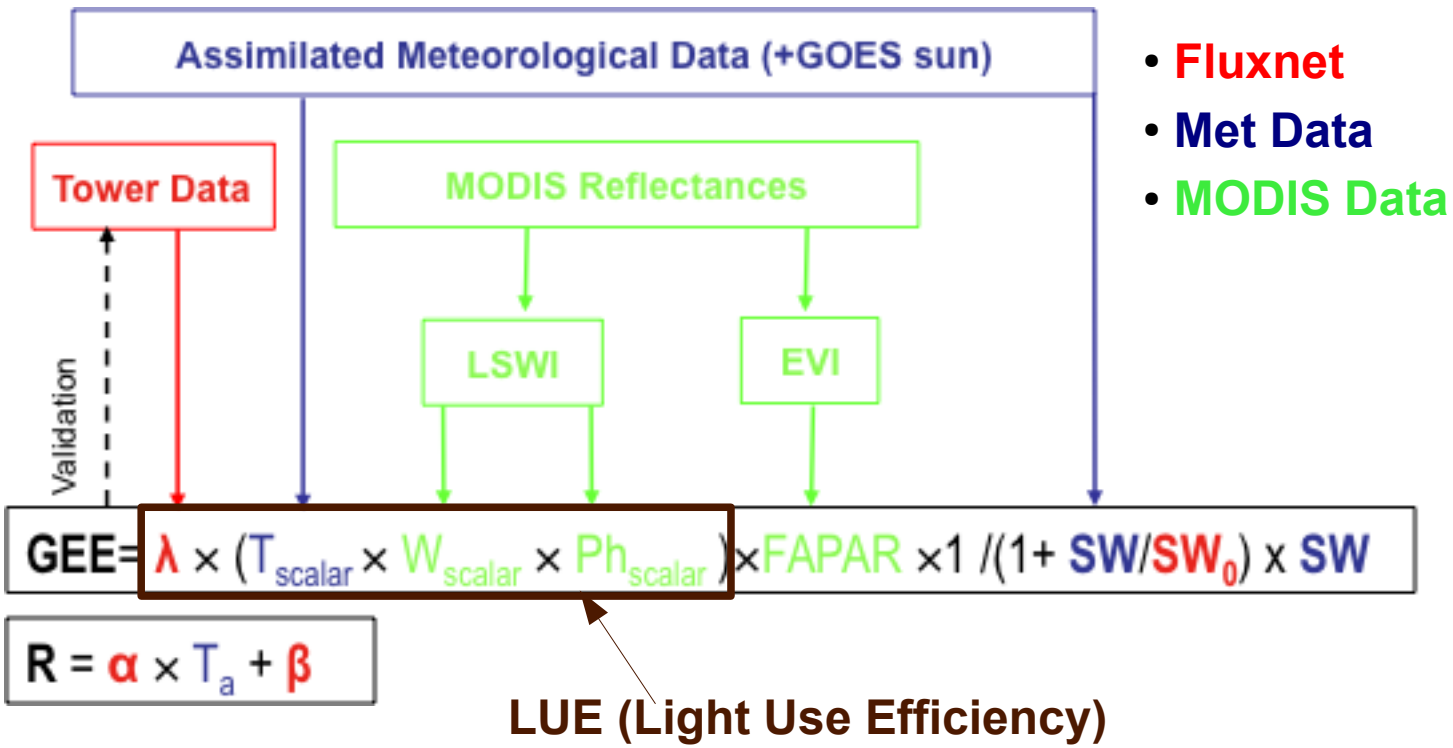
Given by biospheric model. In case of VPRM, can derive analytically!

Biospheric CO_2 Flux Model: Vegetation Photosynthesis and Respiration Model (VPRM)

Simple mathematical structure

Minimum of parameters
3 parameters (λ,α,β) x 11 vegetation classes; DO NOT vary with time or space

Rich temporal and spatial complexity of carbon flux captured with **remote sensing data** and fitting parameters (λ,α,β) to **Fluxnet eddy covariance data**



- **Fluxnet**
- **Met Data**
- **MODIS Data**

Mahadevan, P., S.C. Wofsy, D.M. Matross, X. Xiao, A.L. Dunn, J.C. Lin, et al., A Satellite-Based Biosphere Parameterization for Net Ecosystem CO2 Exchange: Vegetation Photosynthesis and Respiration Model (VPRM), Global Biogeochemical Cycles, 22, doi:10.1029/2006GB002735, 2008.

Observational Site: Chibougamau (Quebec)

Quebec Flux Station - Eastern Boreal Black Spruce

Investigators :

- Hank Margolis (Project Leader)
- André Beaudoin
- Pierre Bernier
- David Paré
- Chhun-Huor Ung

Site:	**Mature Black Spruce Forest**
Tower Type	Fixed Scaffolding
Latitude/Longitude	49.69247° N / 74.34204° W
Mean Air Temperature	0.0 °C
Mean Annual Precipitation	961.3 mm
Cover Type	90 - 100 yr old Black Spruce, Jack Pine, feather moss
Date Operations Began	June 2003
Frequency of EC Measurements	10 Hz
Frequency of Other Meteorological Sensors	2 sec, year round
Soil Respiration Measurements	30 min., automated soil respiration system

http://www.fluxnet-canada.ca

Observational Site: Groudhog River (Ontario)

Ontario Flux Station - Boreal Mixedwood Forest

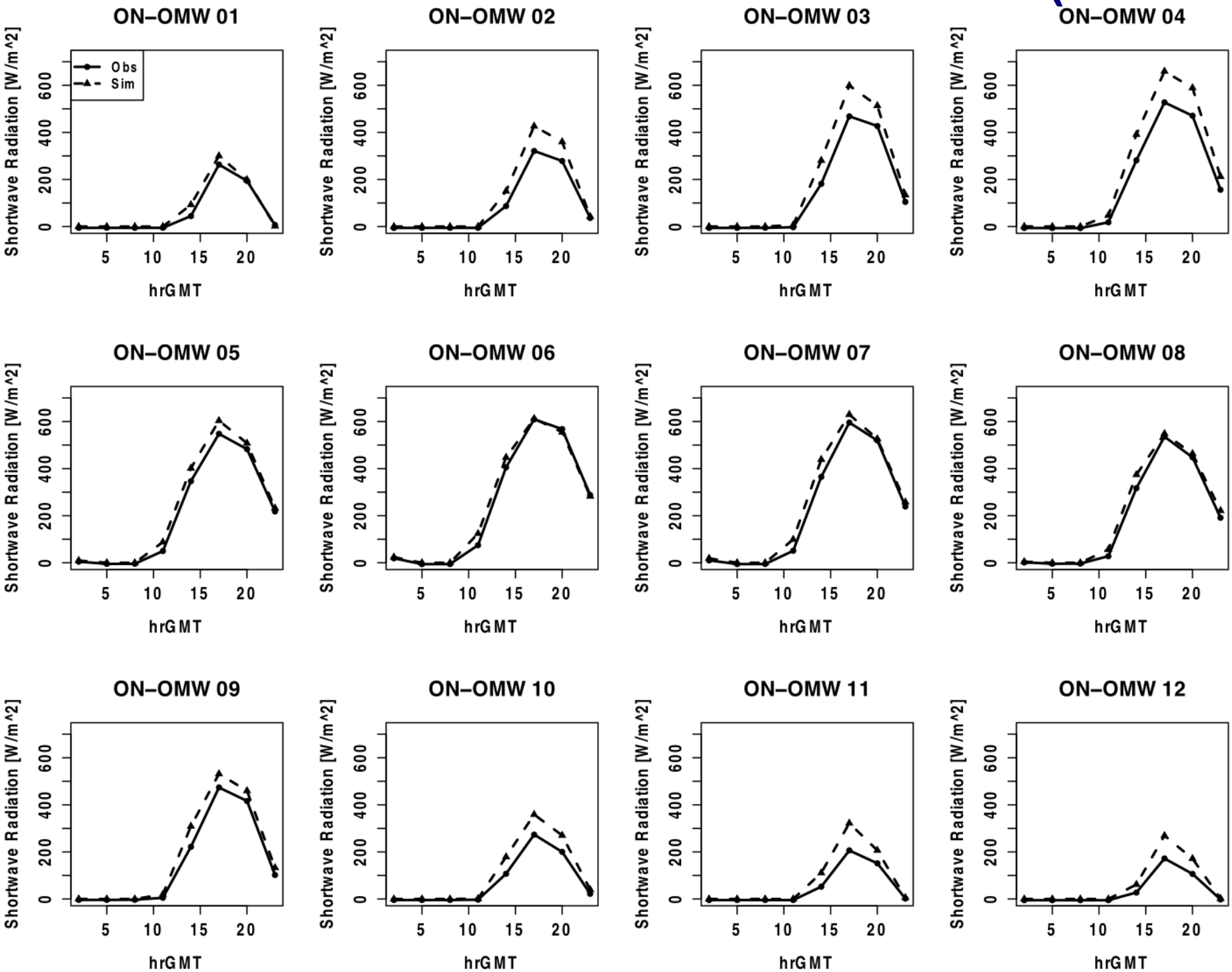
Investigators :

- Harry McCaughey (Project Leader)
- Altaf Arain
- James W. McLaughlin
- Nick Payne
- Neal Scott
- Al D. Cameron

Site:	Groundhog River Station
Tower Type	Double scaffold, 41 m tall
Latitude/Longitude	48.21738° N, 82.15553° W
Elevation	N/A
Mean Air Temperature	N/A
Mean Annual Precipitation	N/A
Cover Type	Boreal mixedwood (trembling aspen, black spruce, white spruce, white birch, and balsam fir as a main component of the understory)
Date Operations Began	July 2003
Frequency of EC Measurements	20 Hz continuous
Frequency of Other Meteorological Sensors	10 sec, 30-minute averages, year round
Soil Respiration Measurements	30 minute averages, automated soil respiration system

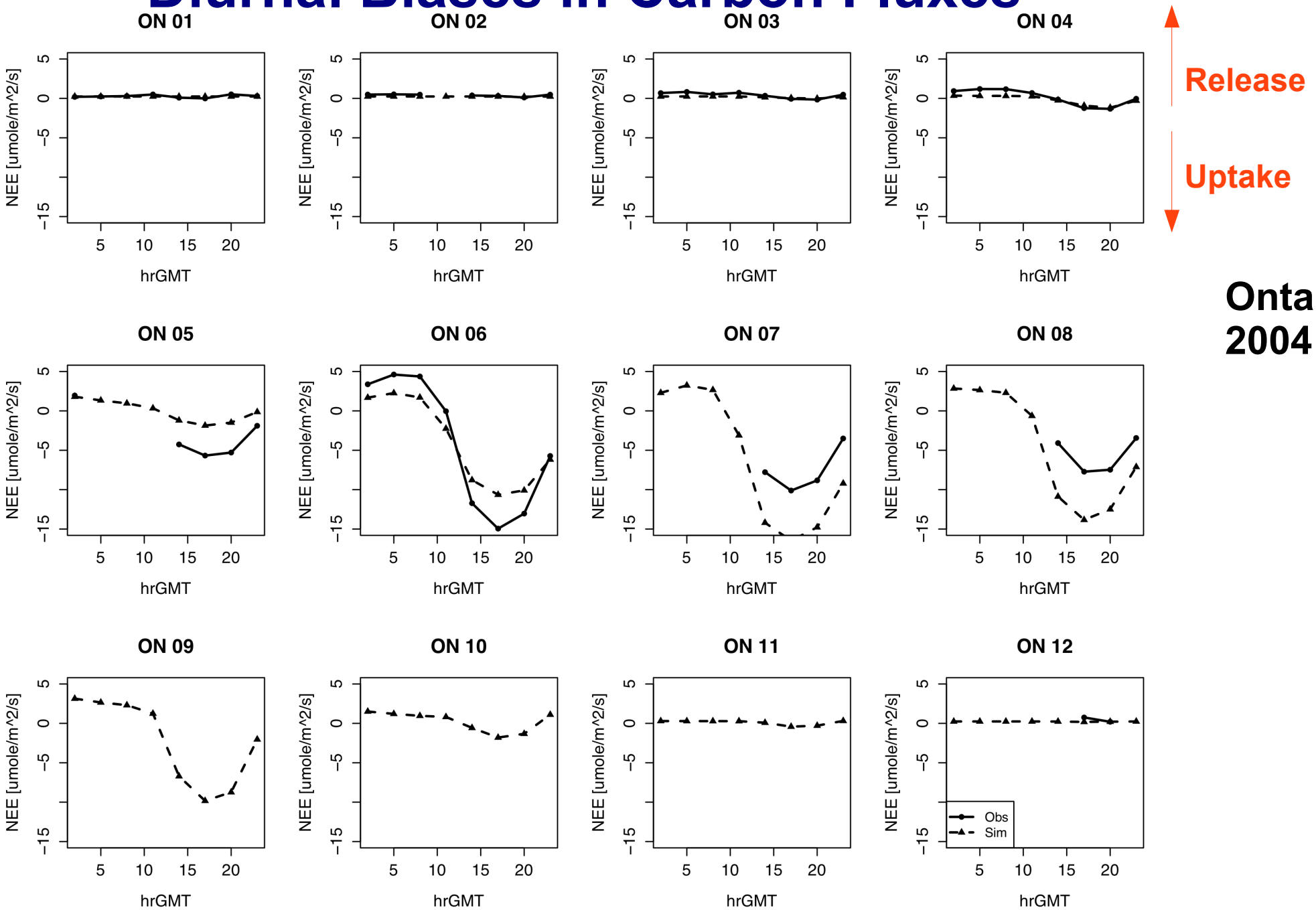
http://www.fluxnet-canada.ca

Diurnal Biases in SW Radiation (NLDAS)



Ontario 2004

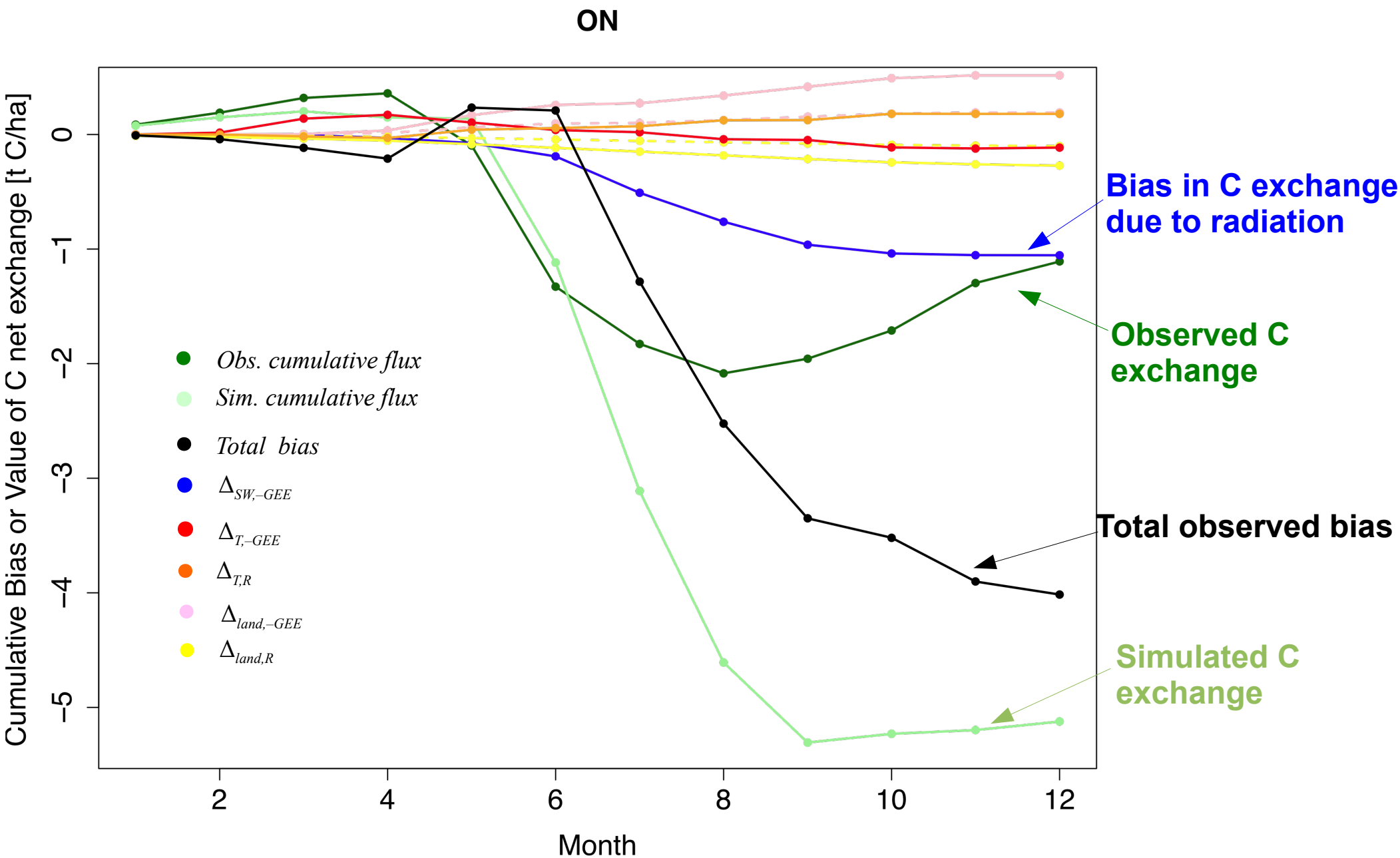
Diurnal Biases in Carbon Fluxes



Ontario 2004

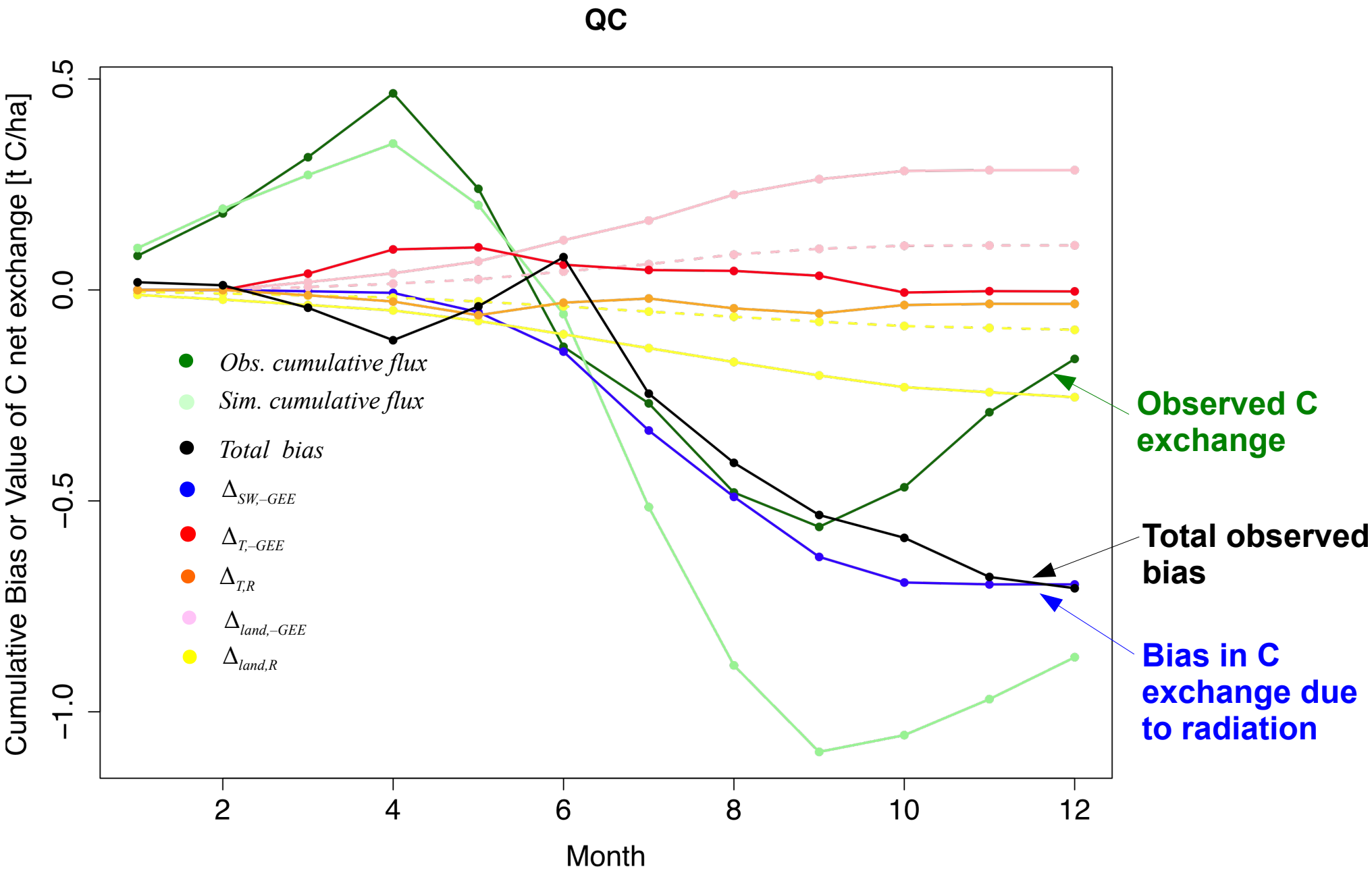
VPRM parameters fitted against other sites=> **independent comparisons**
-relevant for evaluation of uncertainties in **spatial scaling**

Cumulative Biases: Ontario



Significant errors in simulated C exchange can accumulate over annual timescales resulting from solar radiation!

Cumulative Biases: Quebec



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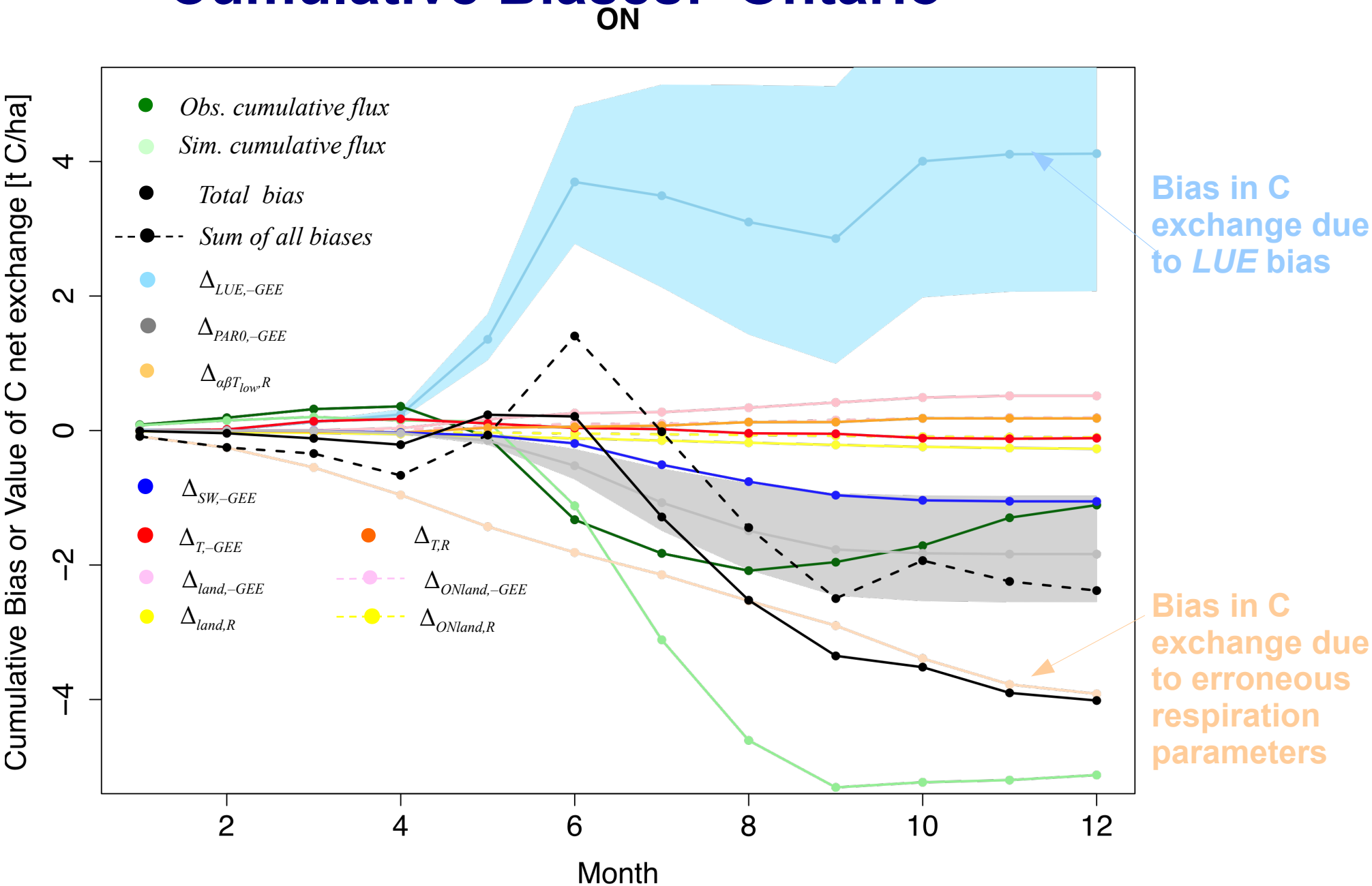
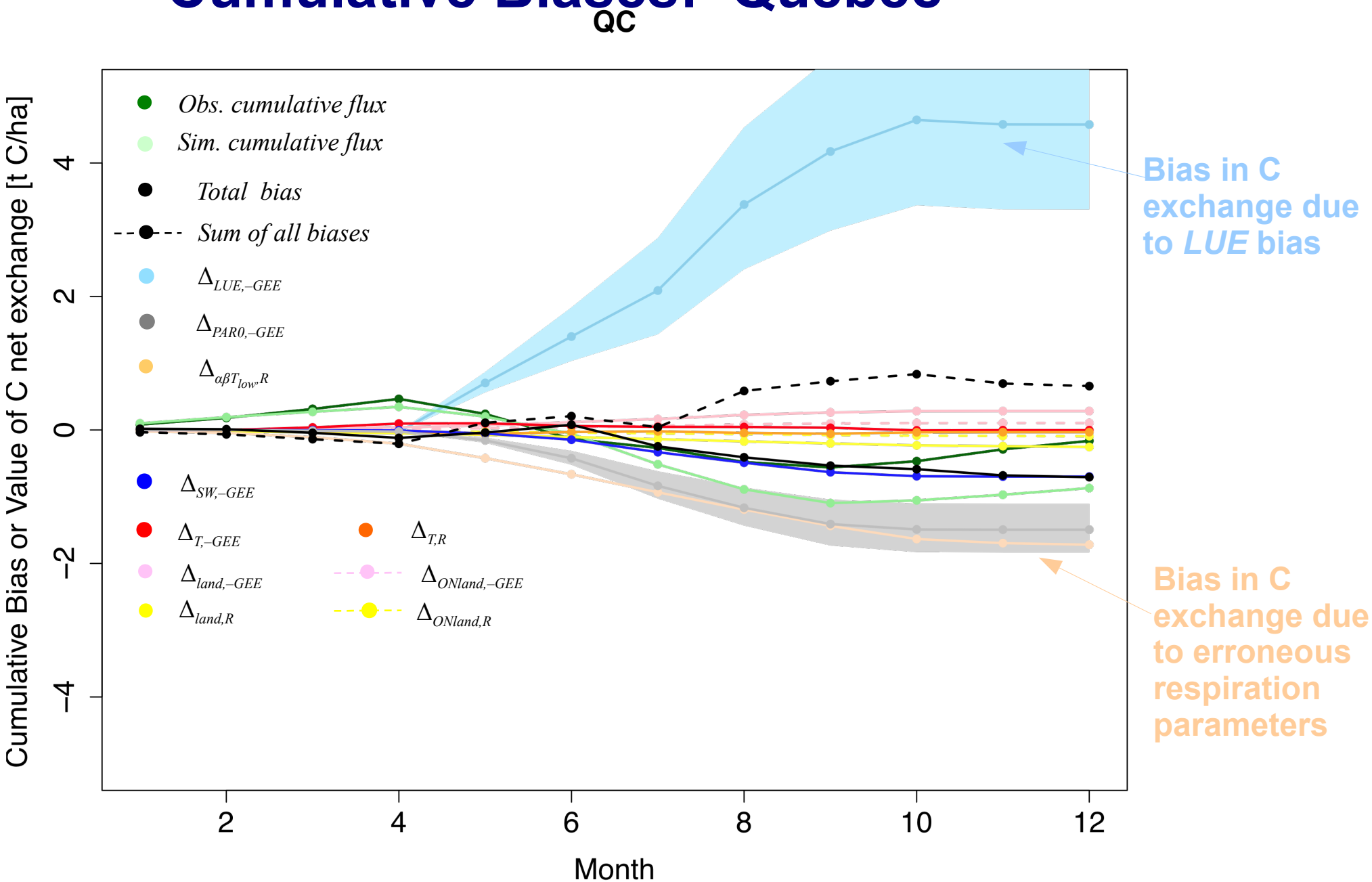


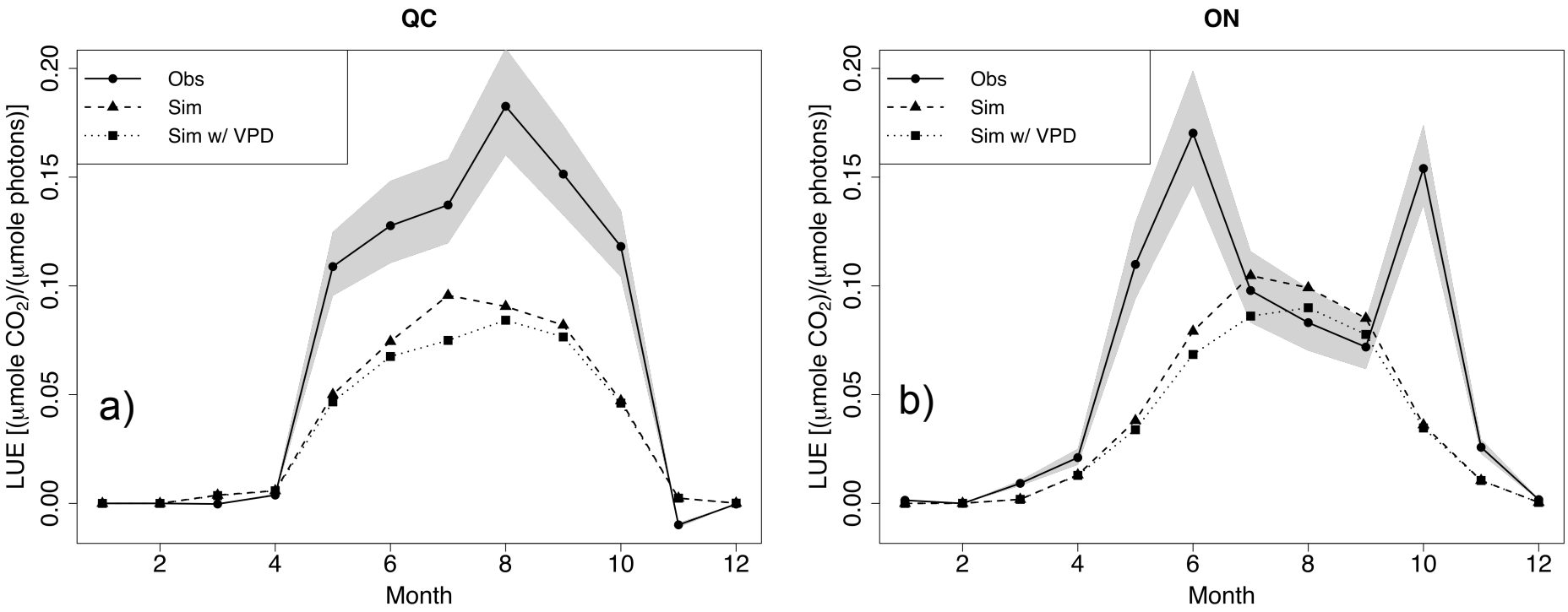
However, the dominant error results from model parameters or structure!

Cumulative Biases: Quebec

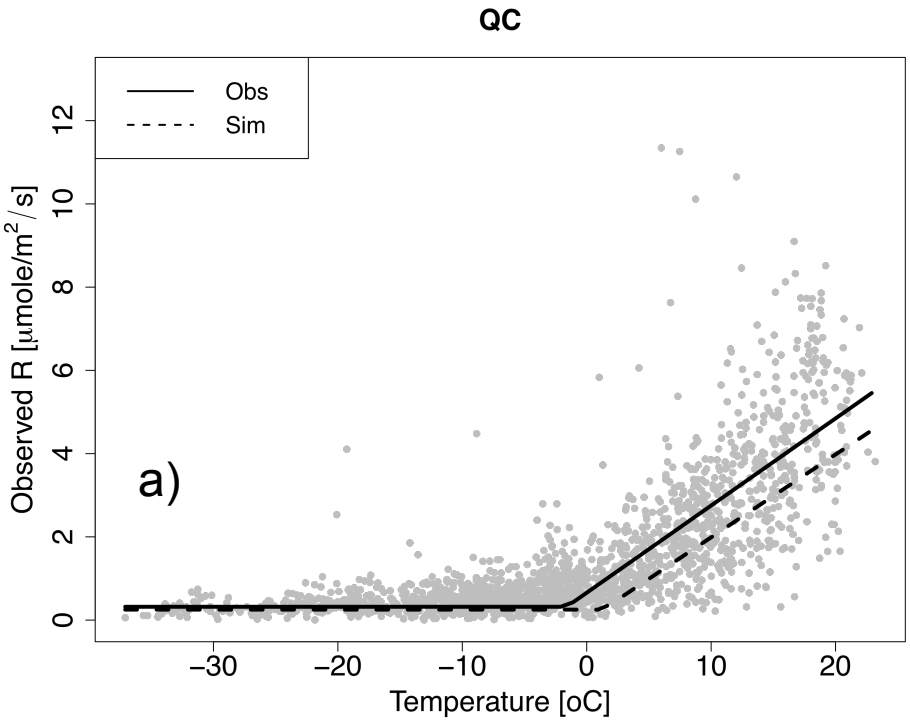


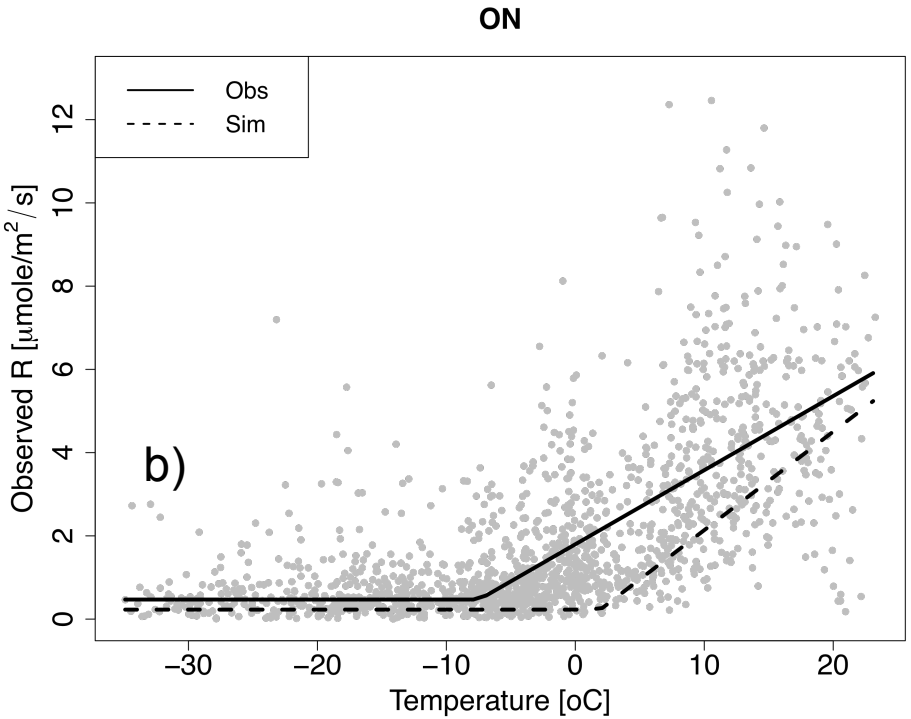
However, the dominant error results from model parameters or structure!

Biases in Light Use Efficiency (LUE)

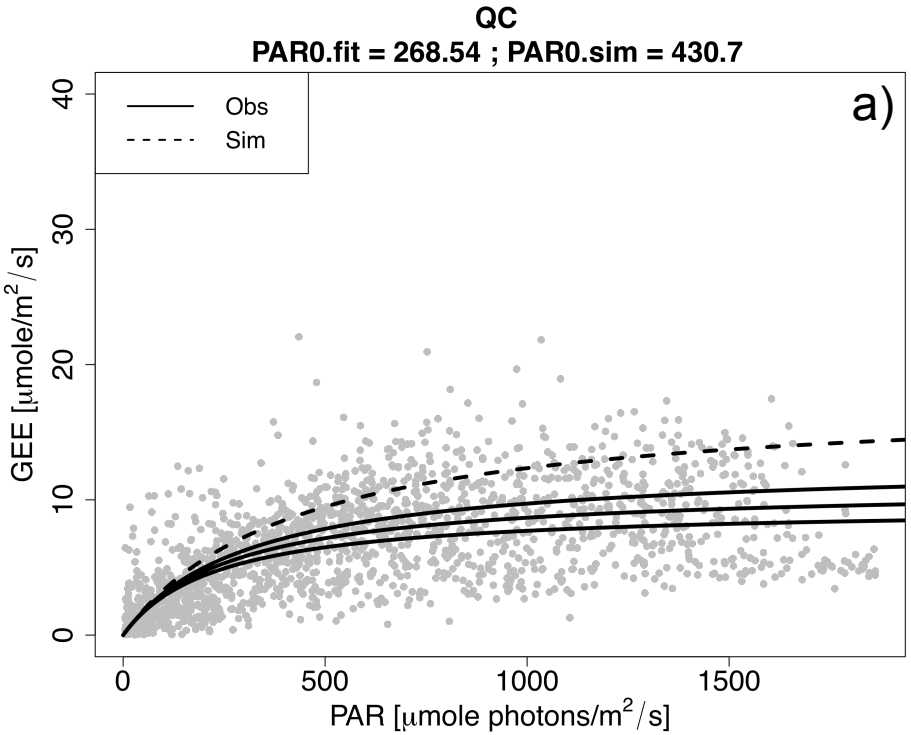


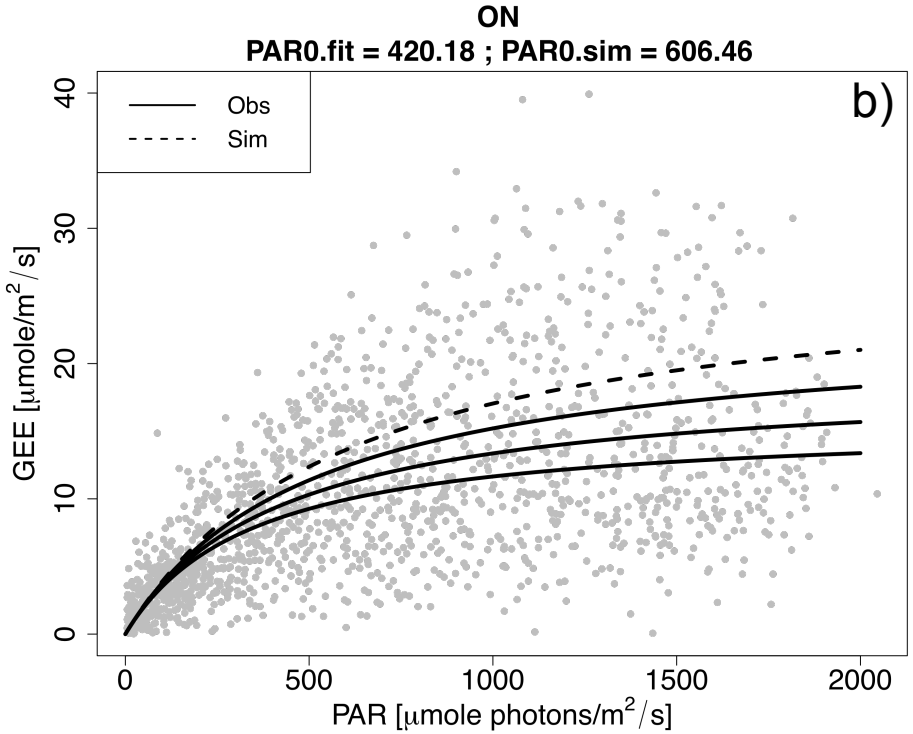
Biases in Temperature Dependence of Respiration





Biases in PAR Relationship





Outline

- Uncertainties in biospheric modelling
- **Uncertainties in agricultural component**
- Uncertainties in atmospheric modelling
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Focus on Agricultural Census (Inventory) Data

Rare source of information that provides REGIONAL SCALE information

Two key pieces of information for carbon models from **agricultural census (inventory) data**:

1) area covered by croplands at the >1-10 km scale;

2) measure carbon uptake (from **crop production**)

$$GPP = \sum_{i=1}^{N} \frac{\boxed{P_i} \times (1 - MC_i) \times C}{HI_i \times f_{AG\,i} \times HA_i \times GE_i}$$

Chan, E.C. and J.C. Lin, What is the value of agricultural census data in carbon cycle studies?, Submitted to JGR-Biogeosciences, 2010.

Agricultural Census Divisions in Southern Ontario, CANADA

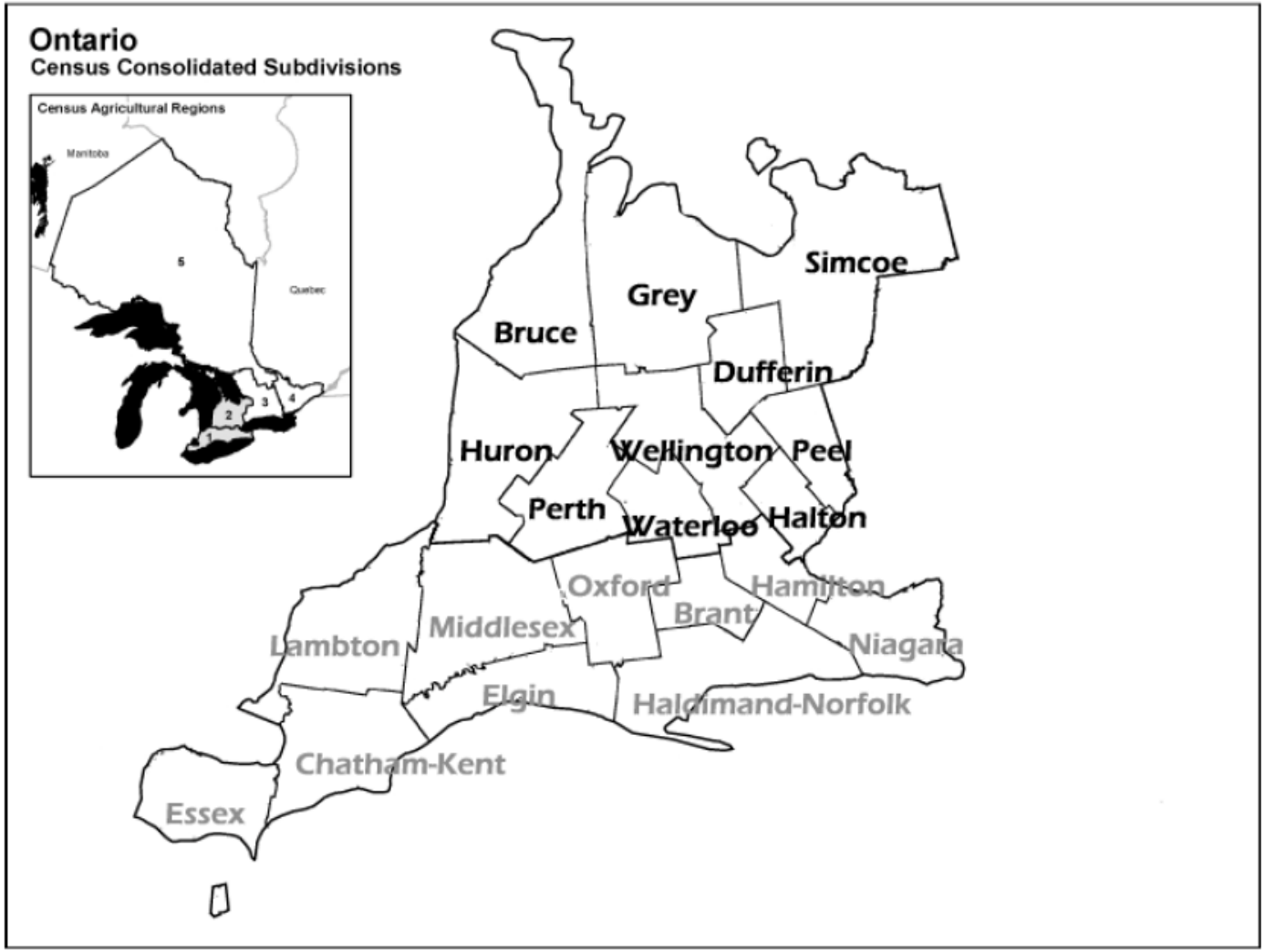


Figure 1. Map of census divisions in southwestern Ontario. Region 1 - southern Ontario (in gray); Region 2 - western Ontario (in black) [Reproduced from the Census of Agriculture 2006 Ontario reference map].

Agricultural Census Divisions in Southern Ontario, CANADA

FOODLAND ONTARIO

Cropland Fraction: Census versus Satellite Data

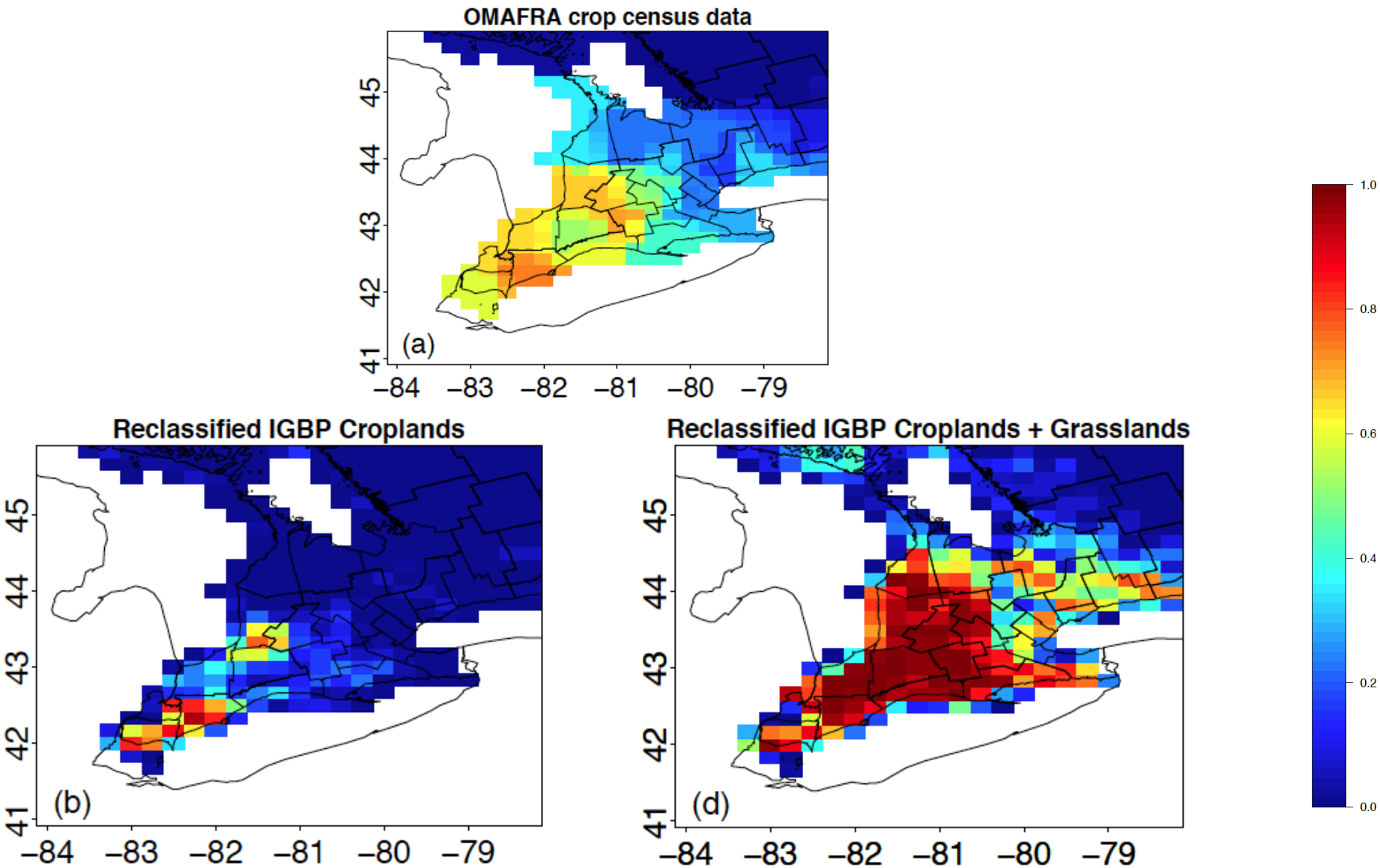
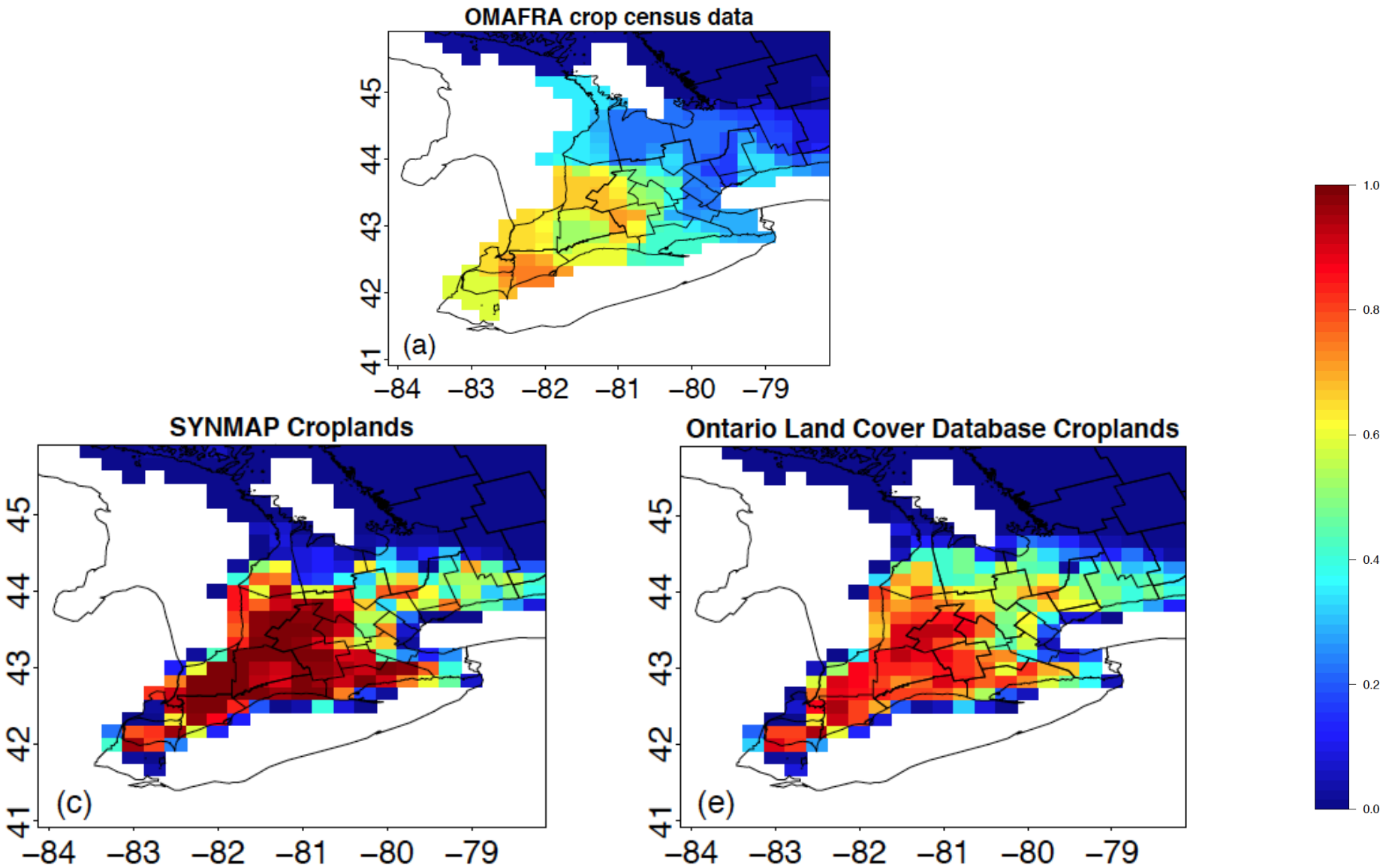


Figure 2. Fractional coverage of croplands and other vegetation derived from various datasets: (a) agricultural census data from OMAFRA; (b) IGBP-DISCover "Croplands"; (c) SYNMAP "Croplands"; (d) IGBP-DISCover "Croplands+Grasslands" (which includes "Cropland/Natural Vegetation Mosaic"); and (e) Ontario Land Cover Database "Croplands"

Cropland Fraction: Census versus Satellite Data



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Relative Error is Smaller in Regions with More Croplands

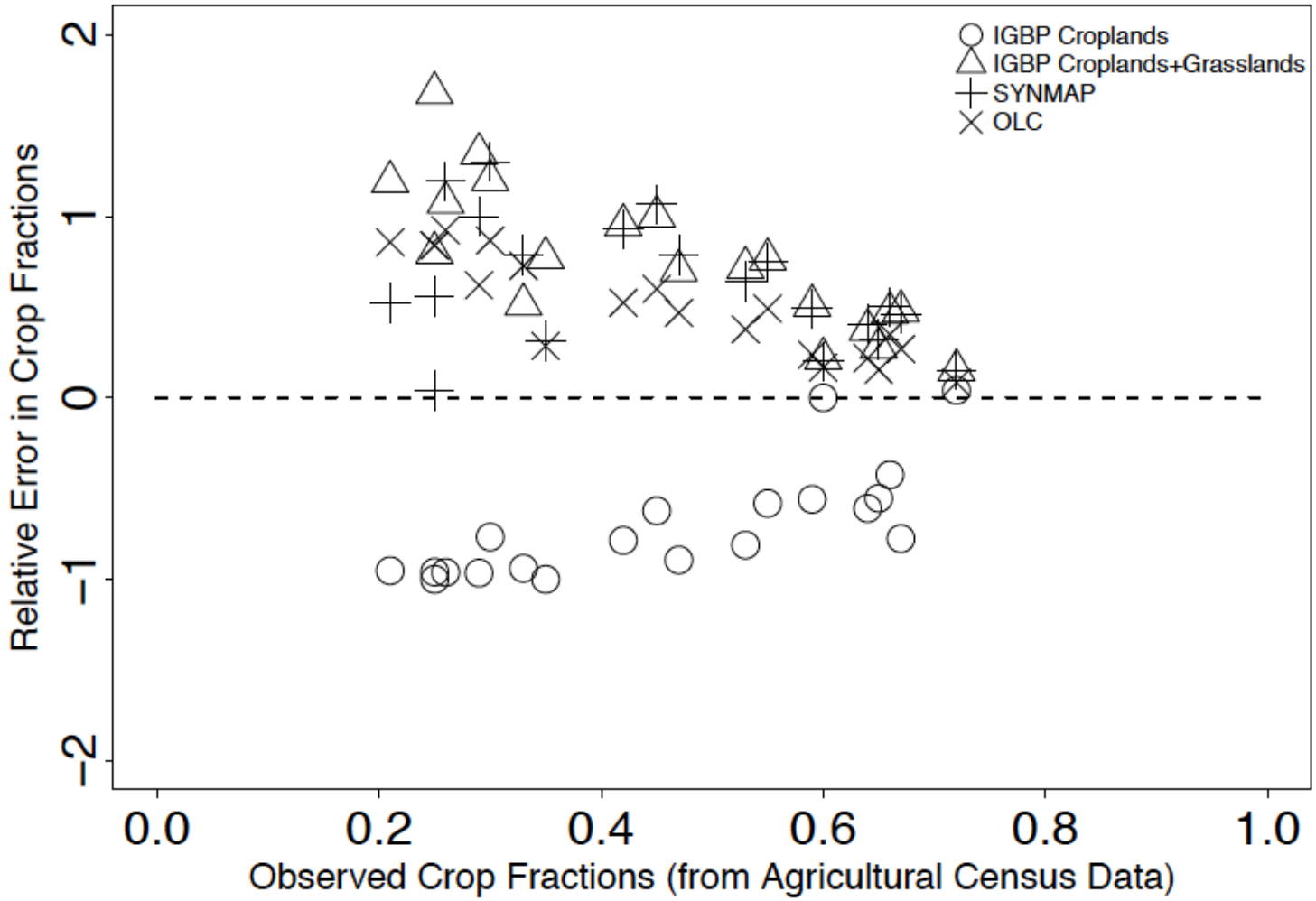
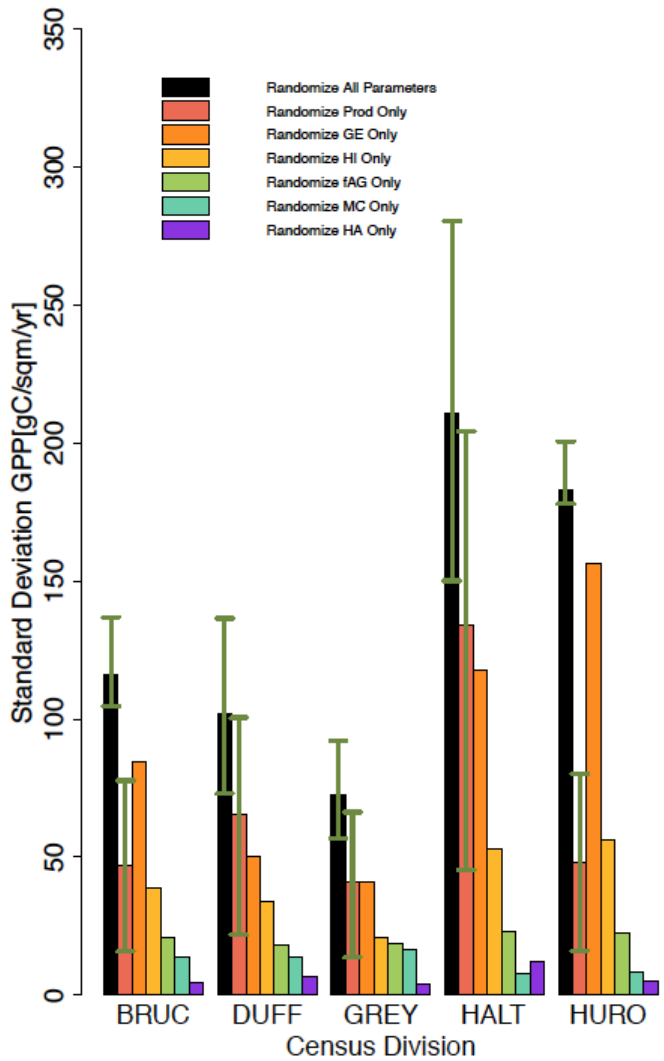


Figure 3. Comparison of relative errors in crop fractions. Relative error is calculated by dividing the crop fractions differences (i.e. satellite-derived fractions minus census data-derived fractions) by the census data-derived fractions.

Monte Carlo Analysis of Errors in Crop Census Data



$$GPP = \sum_{i=1}^{N} \frac{P_i \times (1 - MC_i) \times C}{HI_i \times f_{AG\,i} \times HA_i \times GE_i}$$

3 largest sources of uncertainties:
1) *GE* (growth efficiency)
2) *P* (harvest production)
3) *HI* (harvest index)

Figure 4b. Results of Monte Carlo analysis on the uncertainties in census data-derived *GPP*s for southern Ontario. Different colors illustrate how randomizing different parameters in the crop attribute-based model influence the uncertainties in *GPP* estimates. "Prod" represents harvest production; "GE" represents growth efficiency; "HI" represents harvest index; "fAG" represents fraction allocated above ground; "MC" represents moisture content; and "HA" represents harvested area. Green error bars explain how uncertainties in *GPP*s would change when only the uncertainty in provincial harvest production changes from 1% to 5%.

Results of Bayesian Inverse Analysis

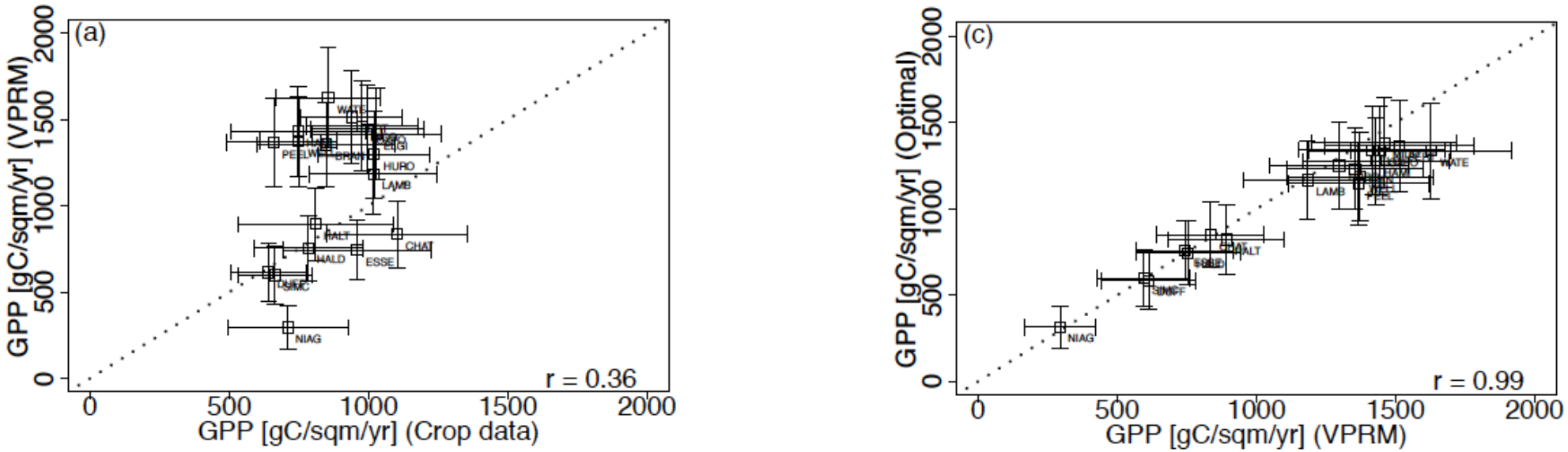


Figure 5. Comparison of *GPP* values between (a) a priori VPRM simulations and crop census data; (b) Bayesian optimized VPRM simulations versus crop census data; and (c) optimized versus a priori VPRM simulations. Error bars associated with the crop census-derived *GPP* are constructed from Monte Carlo analysis (Sect. 3.2; Fig. 3). The error bars associated with VPRM simulations are constructed via a method described in Sect. 2.6.

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- **Uncertainties in atmospheric modelling**
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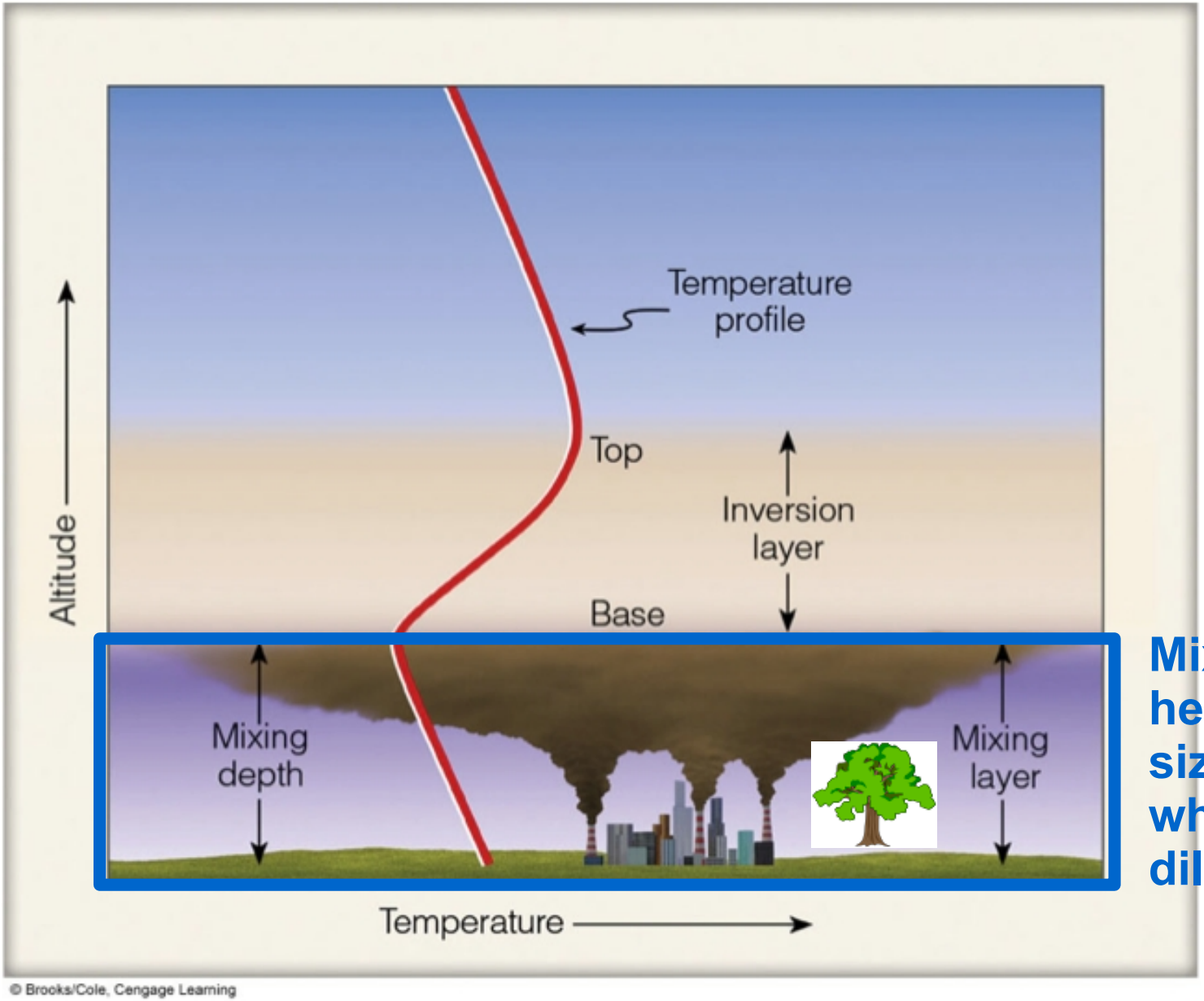
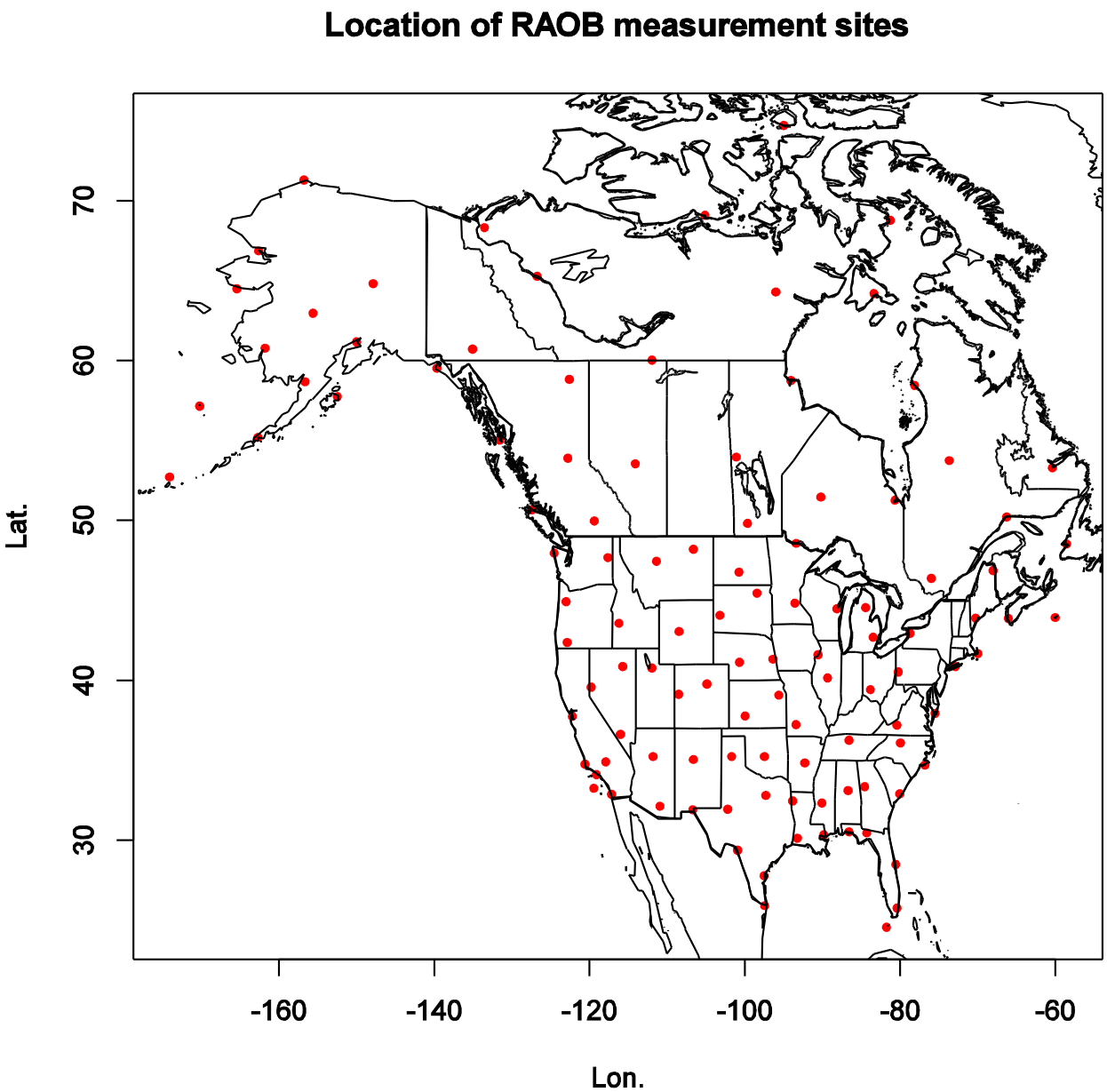
Atmosphere Serving as an Integrator. But need to know how big box is! (mixed-layer height, a.k.a. or "z_i")



Mixed-layer height controls size of box over which fluxes are diluted

Fig. 18.15 of *Meteorology Today*, by C. Donald Ahrens

RAdiosonde OBservation(RAOB) meteorology



Canada and conterminous U.S.A.

128 observation sites

NOAA ESRL GSD database

January, April, July, and October of 2004

The Atmospheric Models

Model	Grid spacing (km)
GDAS(FNL)	180 x 180
EDAS	40 x 40
WRF	36 x 36
NARR	40 x 36

Comparing the z_i from models & RAOB

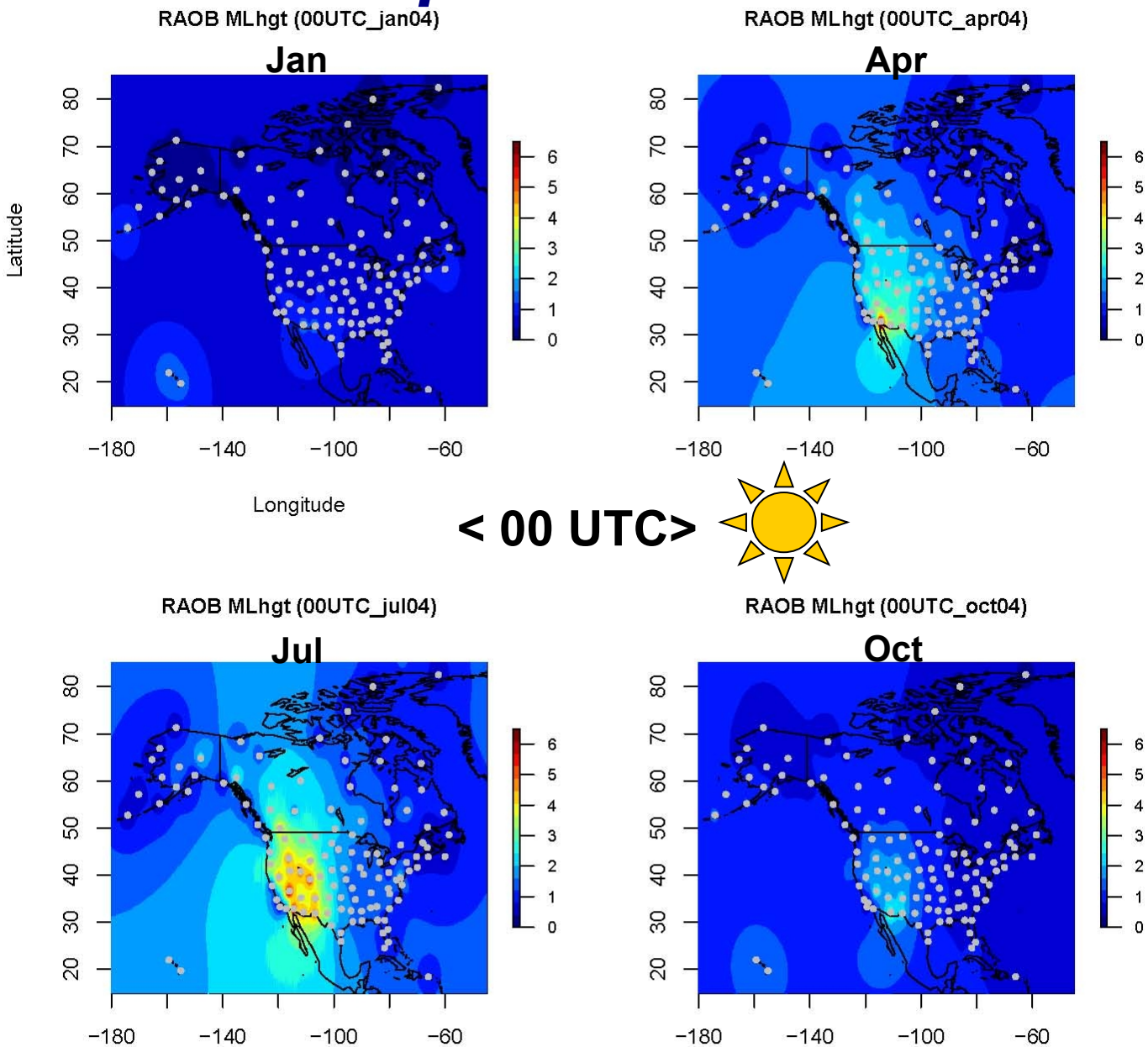
Direct comparison of models and RAOB(e.g., winds and temperatures) at pressure levels

***zi* determined with the bulk Richardson number method at Ric = 0.25**

$$Ri_b = \frac{(g/\theta_v)\Delta\theta_v \Delta Z}{(U_z)^2 + (V_z)^2}$$

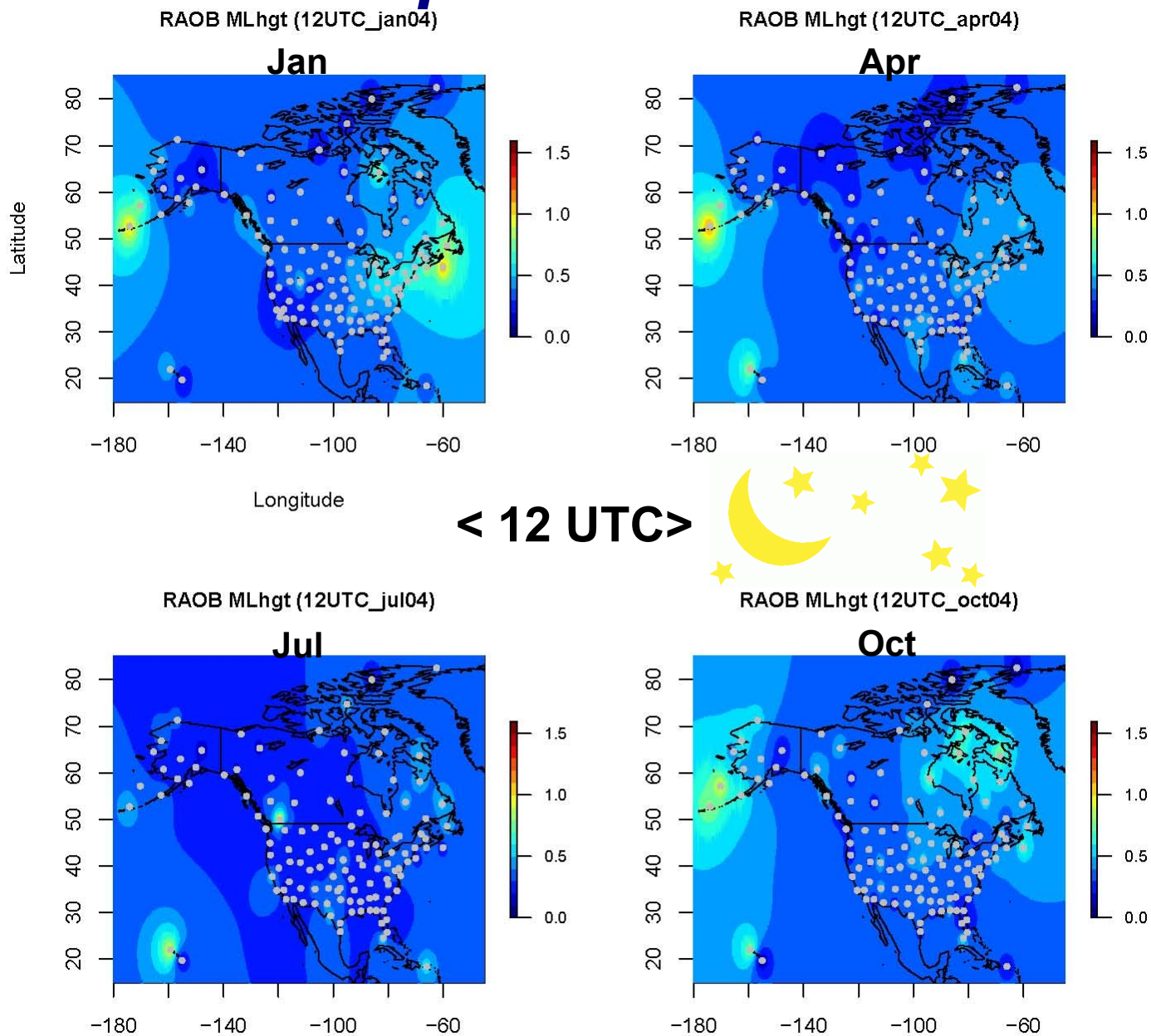
where, g for graviational acceleration, θ_v virtual potential temperature, Z altitude, U&V horizontal winds

RAOB observed mixing layer heights
- spatial view -



● indicates 128 RAOB locations

RAOB observed mixing layer heights
- spatial view -

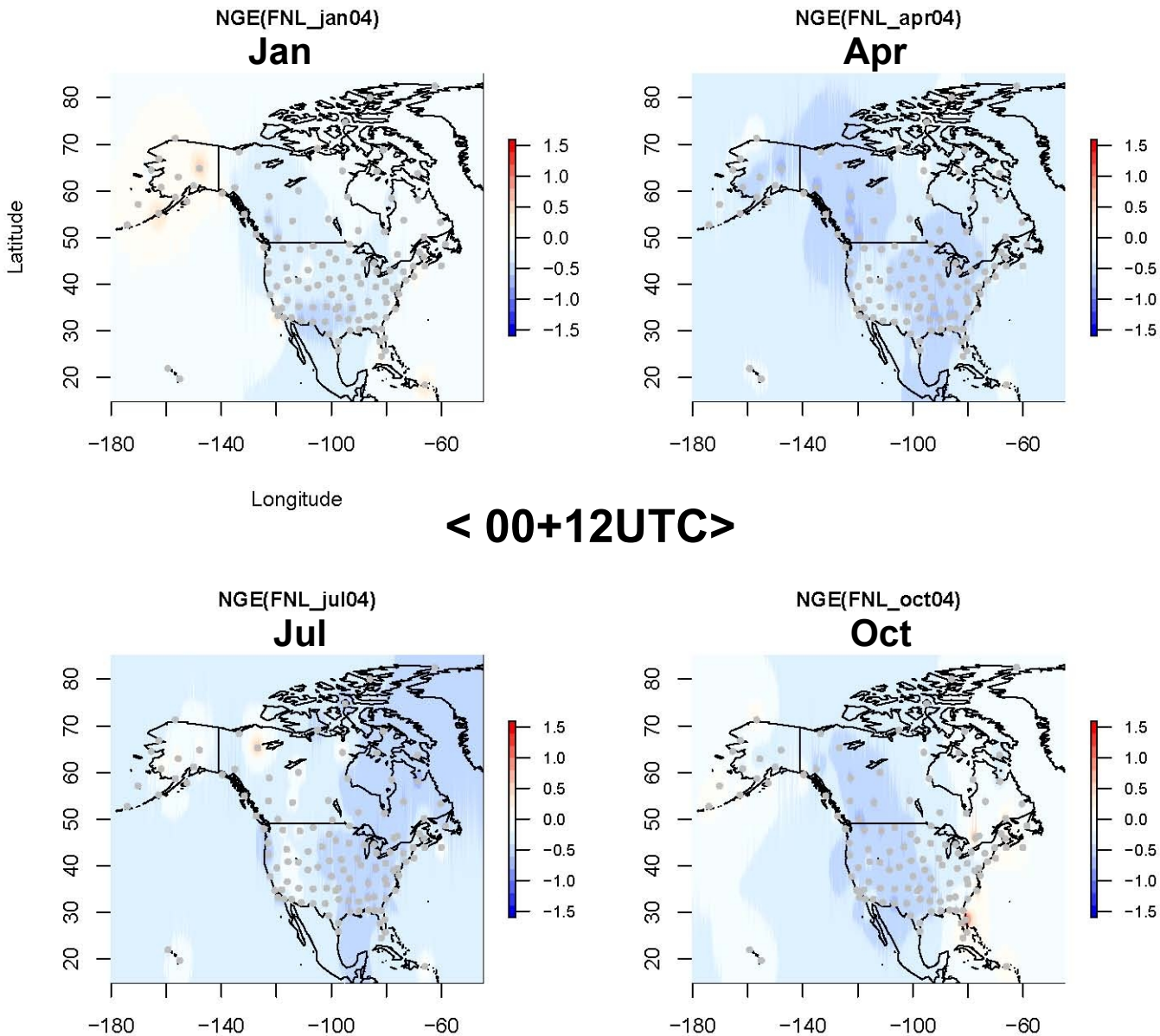


● indicates 128 RAOB locations

Spatial distribution of uncertainties in z_i

- GDAS(FNL) @ 180km -

$$NGE = \frac{mean(model) - mean(obs)}{mean(obs)}$$

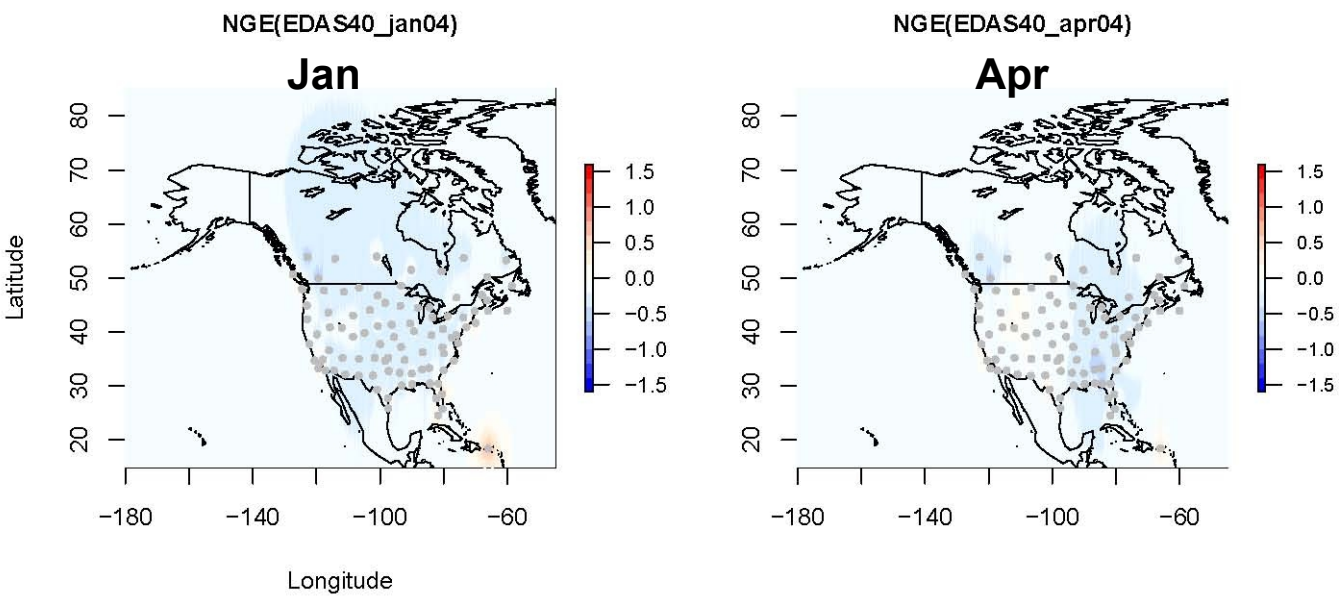


Underestimation is predominant in GDAS(FNL)

Spatial distribution of uncertainties in z_i

- EDAS @ 40km -

$$NGE = \frac{mean(model) - mean(obs)}{mean(obs)}$$



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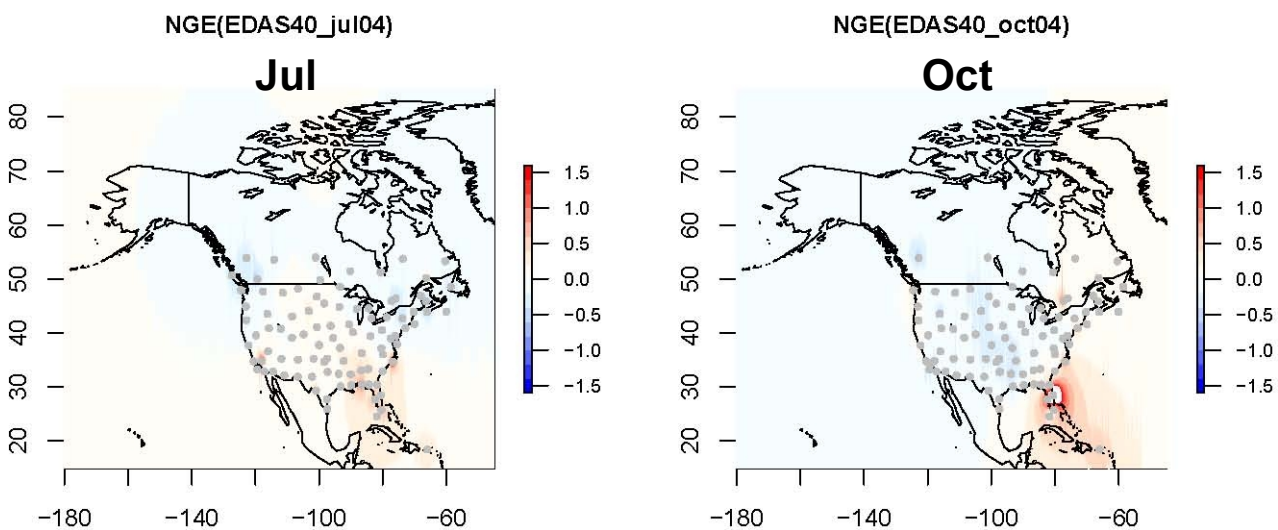
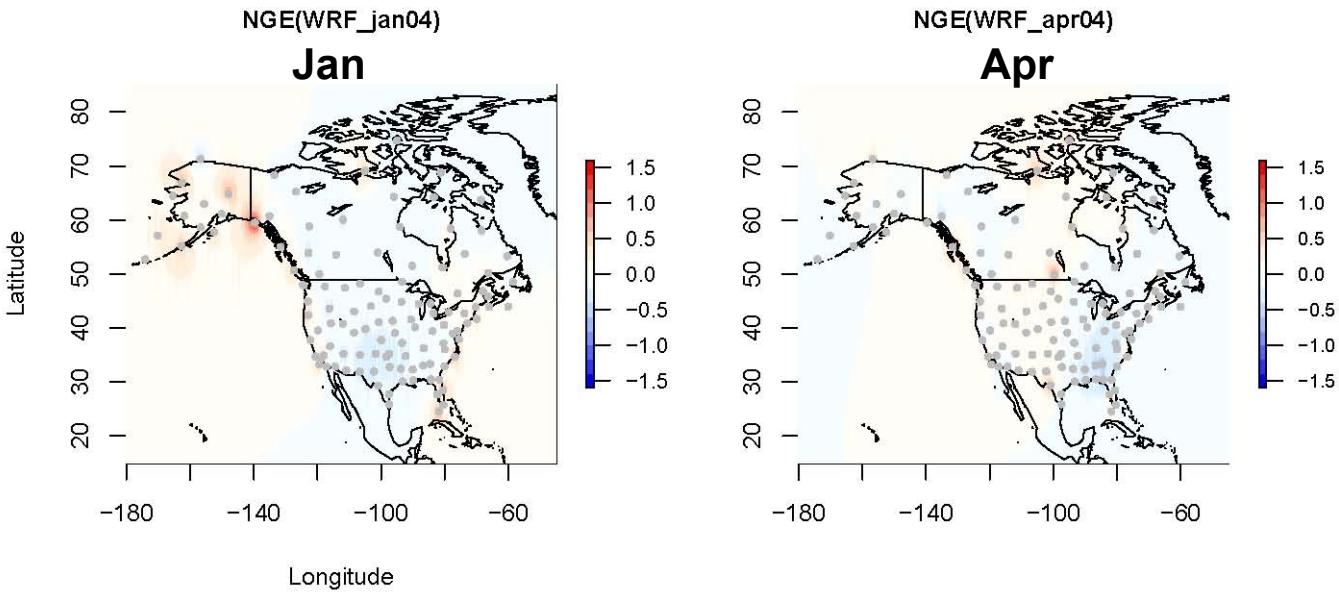


Uncertainties are smaller relative to the global model in general, but some areas show persistent hot spots

Spatial distribution of uncertainties in z_i

- WRF @ 36 km -

$$NGE = \frac{mean(model) - mean(obs)}{mean(obs)}$$



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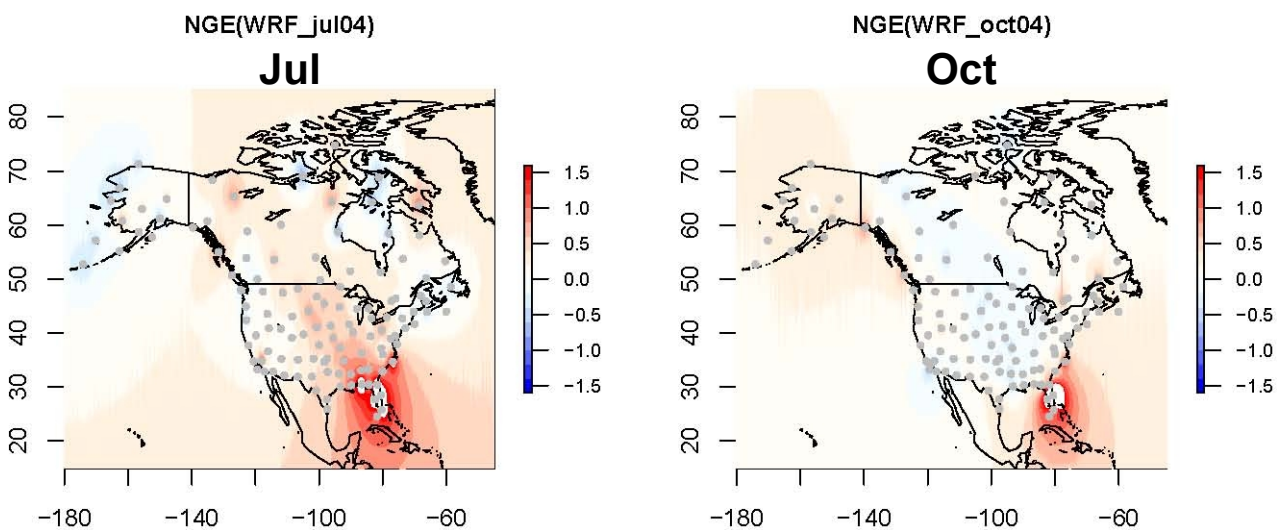
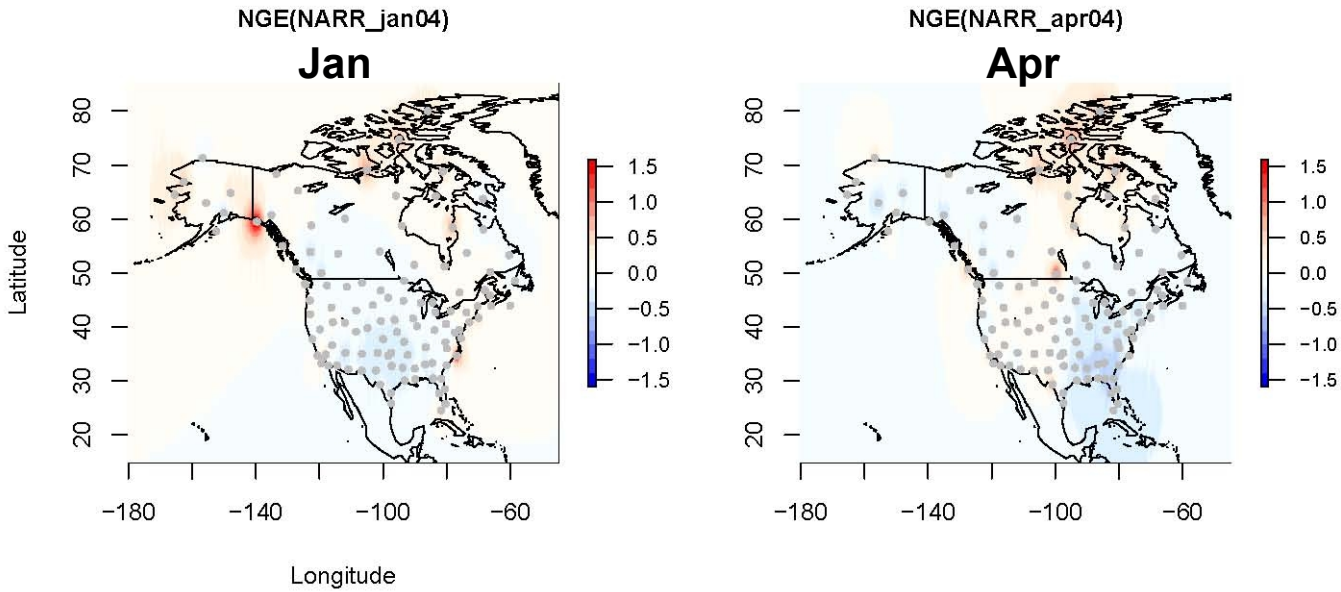


Spatial distribution of uncertainties in z_i

- NARR @ 40 km-

$$NGE = \frac{mean(model) - mean(obs)}{mean(obs)}$$



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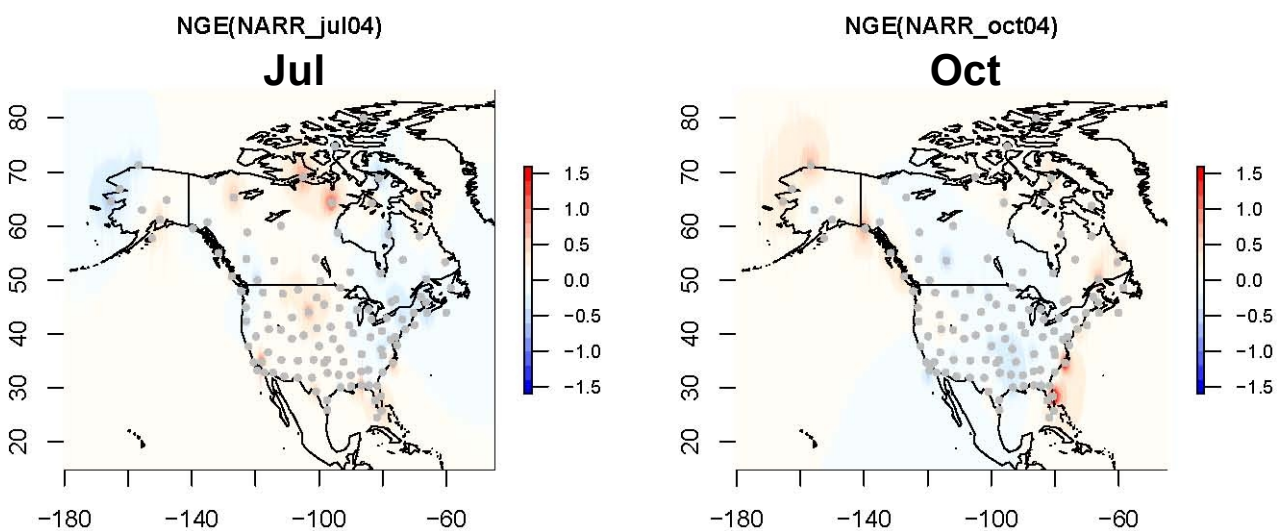
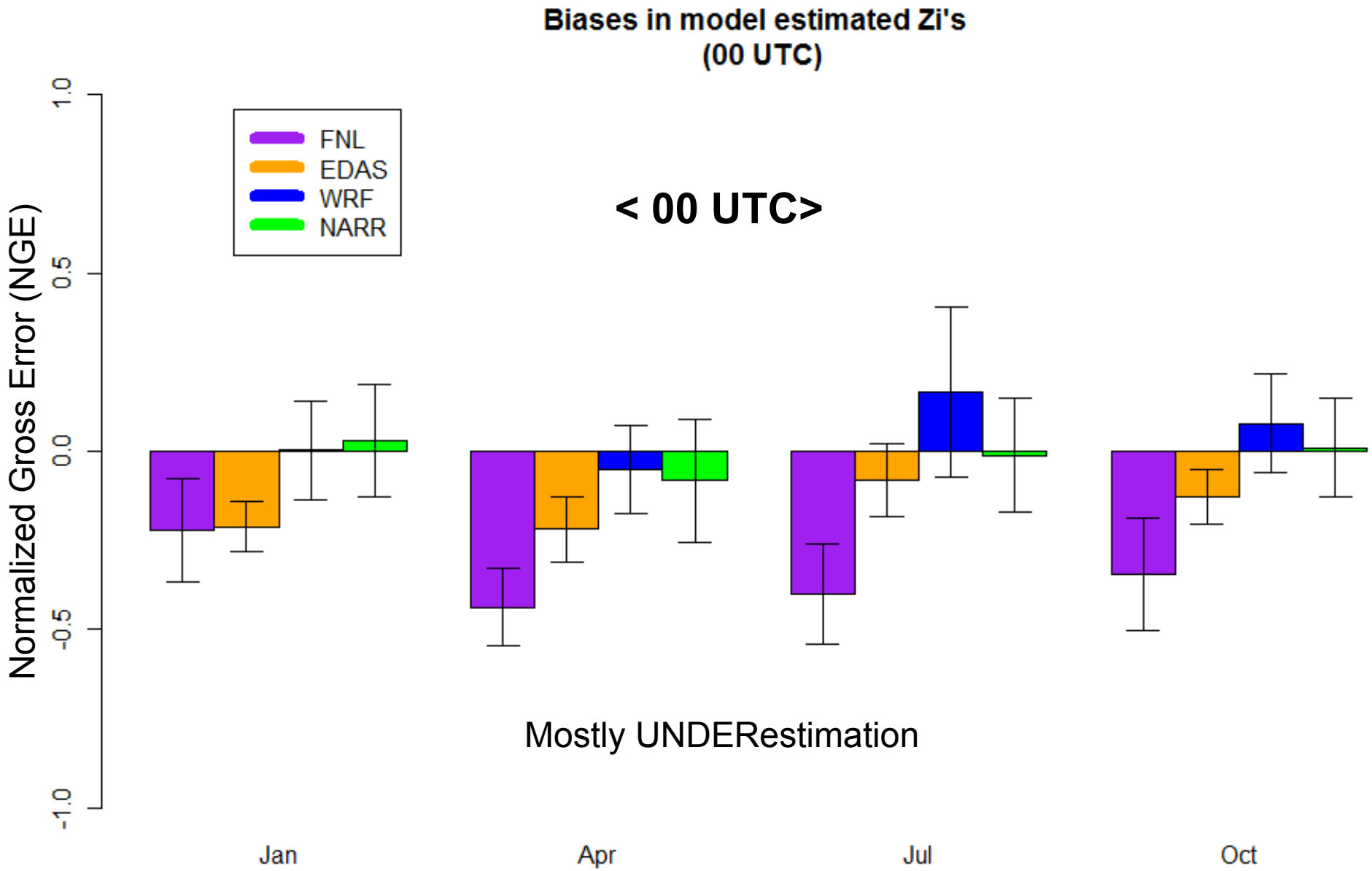


Overall magnitude of biases in z_i
- 00 UTC vs. 12 UTC -



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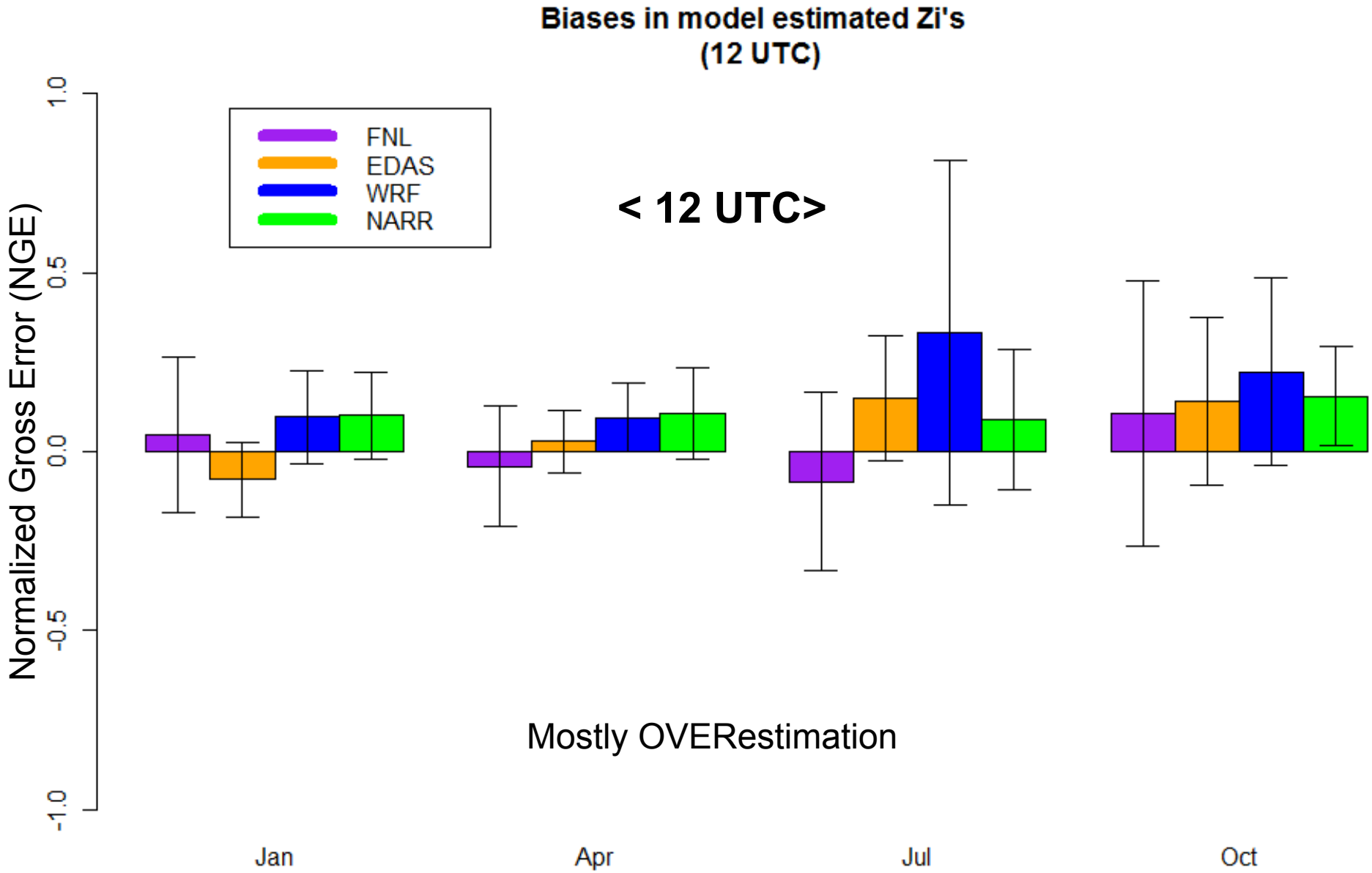

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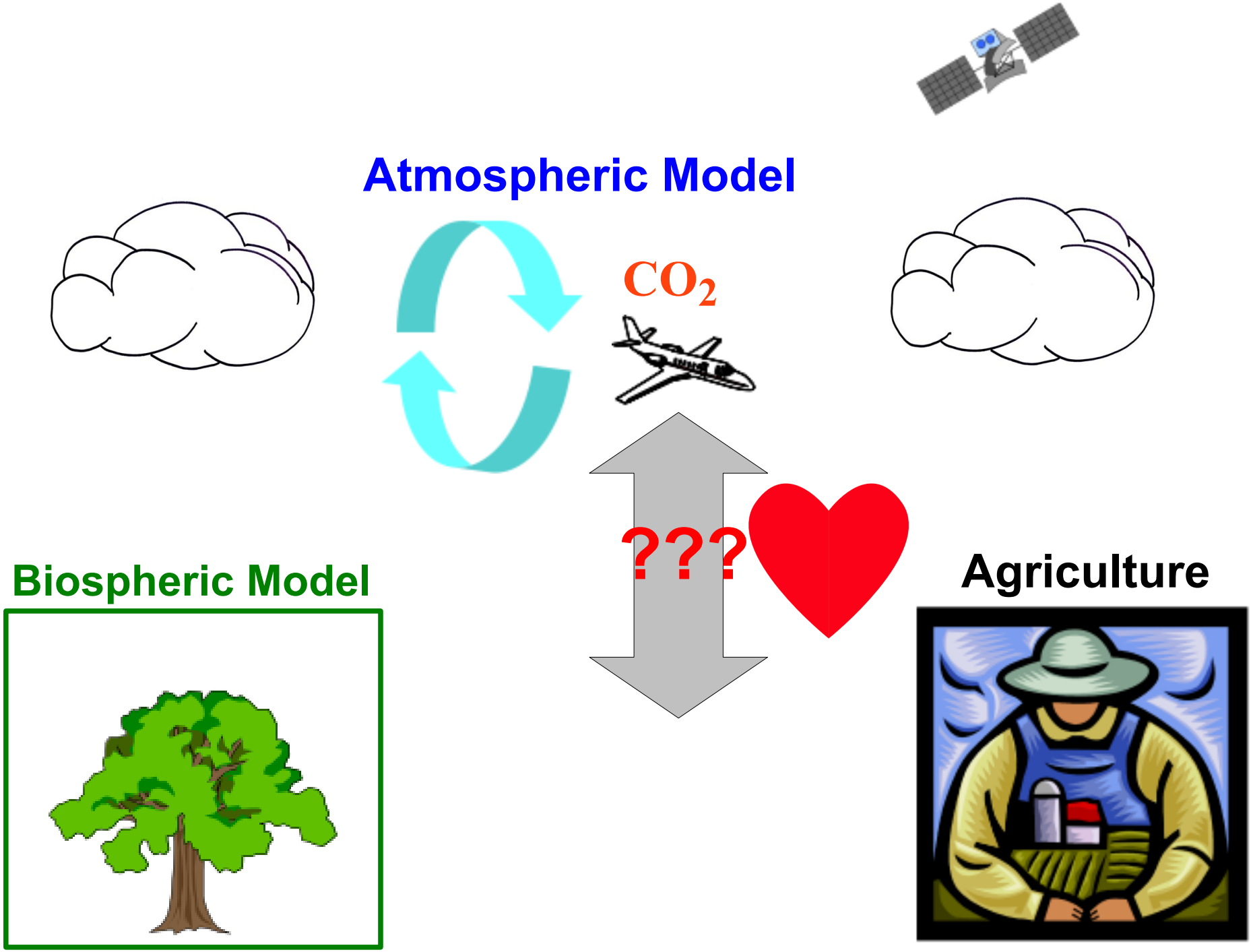
- **Summary**

Meeting the Top-down and the Bottom-up



Meeting the Top-down and the Bottom-up

- Radiation bias can accumulate to significant values over the year, such that the bias due to radiation **is as large as the annual uptake of carbon**!

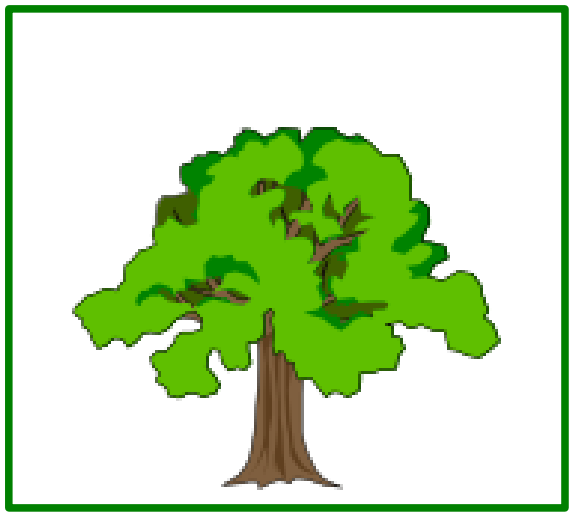
- Errors in **biospheric parameters result in greater biases**:

-Light-use-efficiency (LUE)

-Respiration-Temperature relationship

-PAR_0

Biospheric Model



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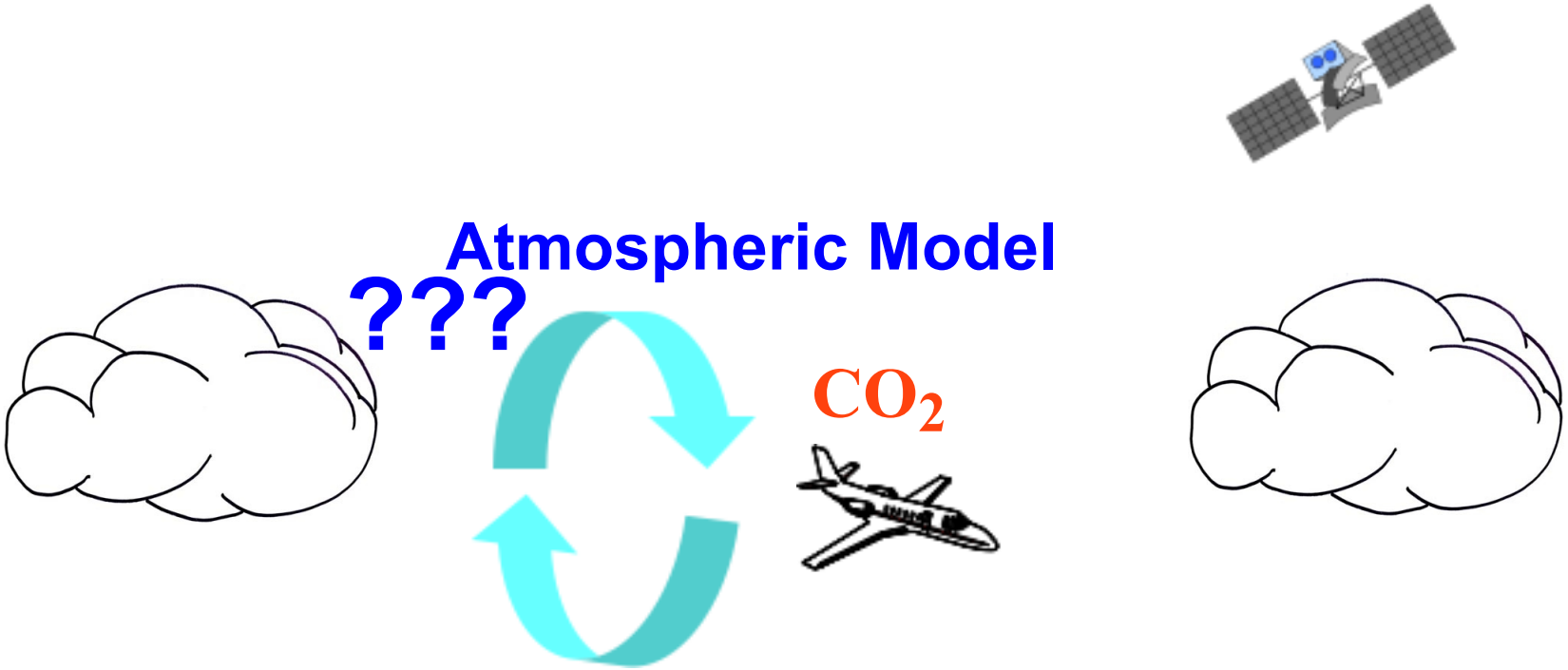
Meeting the Top-down and the Bottom-up

- Agricultural census data provided **valuable information on crop coverage**
- All three **satellite-based land cover datasets provide biased estimates** of cropland fractions over southern Ontario
- **Relative error decreases when cropland cover increases**, suggesting the error may be attributed largely to the difficulty of satellite data in distinguishing croplands embedded within a heterogeneous landscape.
- The **carbon uptake estimates (*GPP*)** based on the agricultural census data can be **subject to non-negligible uncertainties**.
- The biggest sources of uncertainty are (in order of significance) the growth efficiency (*GE*), harvest production (*P*), and harvest index (*HI*).

Agriculture

???

Meeting the Top-down and the Bottom-up



- **Biases in PBL height** exist in current atmospheric models.
- The exact magnitude of the **bias varies** between models and differs between locations and diurnally + seasonally

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