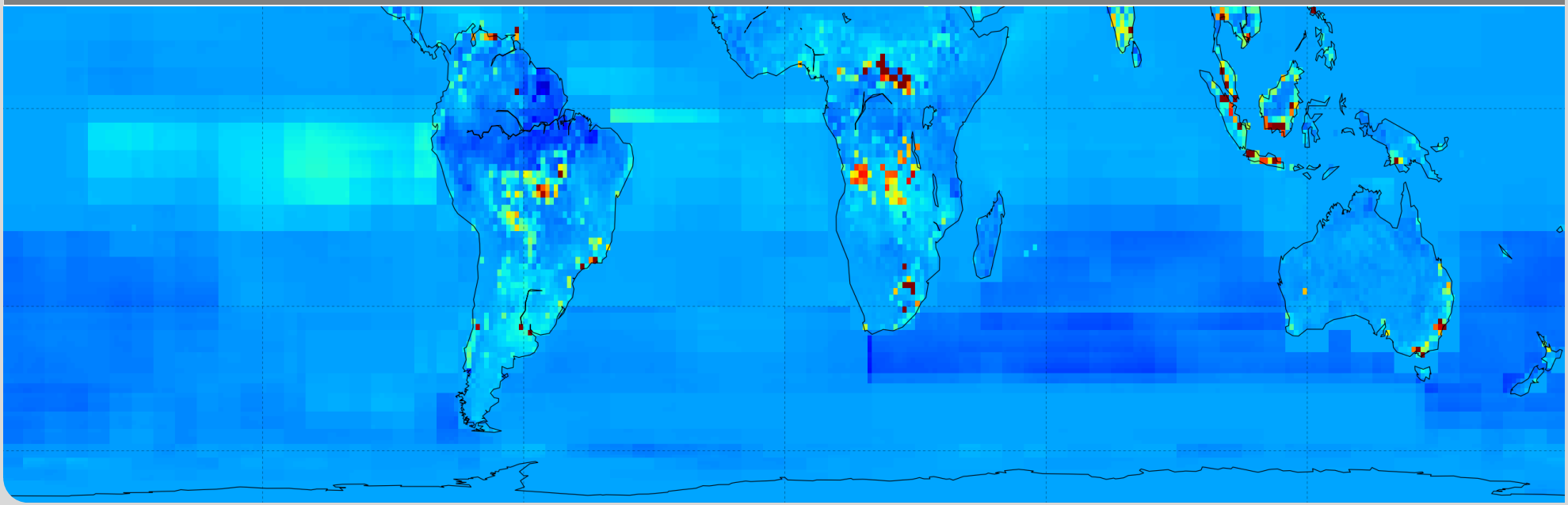
Karlsruher Institut für Technologie

Remote Sensing of GreenHouse Gases for Carbon Cycle Modelling

# Comparing Carbontracker and TM5-4DVar

Arne Babenhauserheide | 8. November 2013

IMK-ASF, REMOTEC GHG-GROUP, VIA ANDRÉ BUTZ



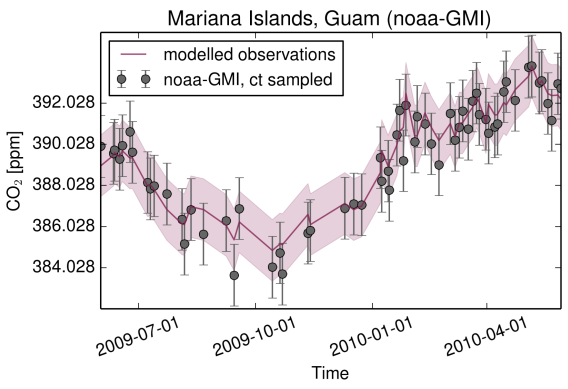
# Surface Flux Modelling

## Why?

- understand climate change
- quantify sources and sinks of greenhouse gases

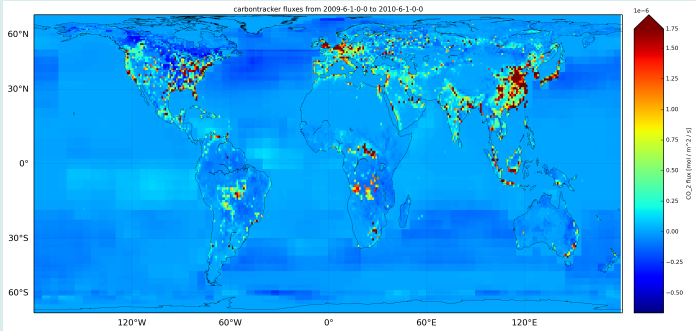
## Have

- Gas Measurements
- Flux Models
- Tracer Transport




## Need

- Surface Fluxes



# Compare 2 models

## Carbontracker

- Ensemble Kalman Smoother.
- Optimizes biosphere regions.
- TM5 with multiple tracers.

## TM5-4DVar

- 4D Variational method with Conjugate Gradients (“newton on adjoint”).
- Optimizes on grid (6$x$4°).
- TM5 adjoint.

## Parameters

- Sensitivity to the density of Measurements.
- Model-specific settings: Speed vs. Quality.

# Conceptual: Optimal Estimation

## Task: Minimize the cost-function

$$J = (\mathcal{H}(\vec{x}, \vec{C}) - \vec{y})^T R^{-1} (\mathcal{H}(\vec{x}, \vec{C}) - \vec{y}) + \vec{C}' \quad (1)$$

*With $\vec{x}$ as the surface fluxes, $\mathcal{H}$ as observation operator mapping fluxes to modelled observations, $\vec{y}$ as observations $R$ as the observation covariance, $\vec{C}$ as requirements of the observation operator and $\vec{C}'$ as additional constraint to keep the model physically sane.*

# Harmonize inputs

$$\hat{\vec{y}}, \hat{\vec{x}} = f(\vec{x}, \vec{y}, \vec{C}_0, H, \vec{M}) \tag{2}$$

with inversion method $f$ (Carbontracker or TM5-4DVar).

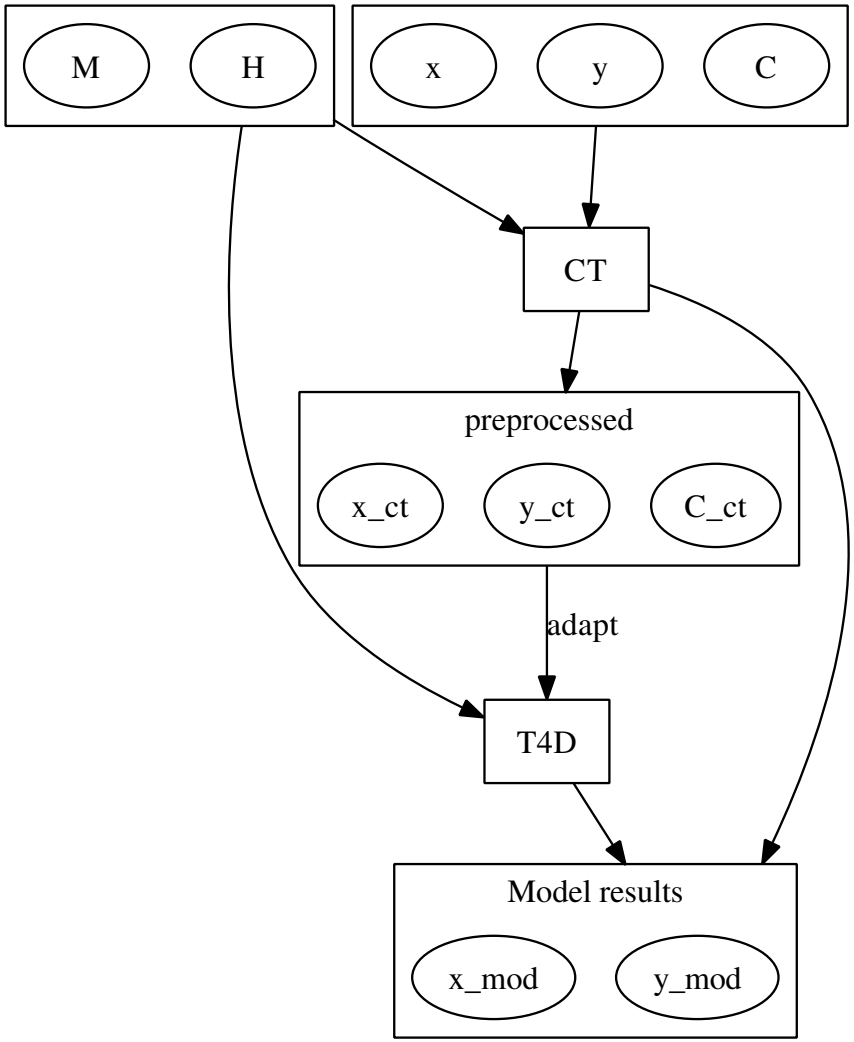
## Input

- $\vec{x}$: prior fluxes (several models)
- $\vec{y}$: observations (obspack)
- $\vec{C}_0$: initial $CO_2$ field (prior run)
- $\vec{H}$: transport model (TM5)
- $\vec{M}$: meteo data (ECMWF EI)

## Output

- $\hat{\vec{y}}$: modelled observations (for validation)
- $\hat{\vec{x}}$: modelled fluxes (result)

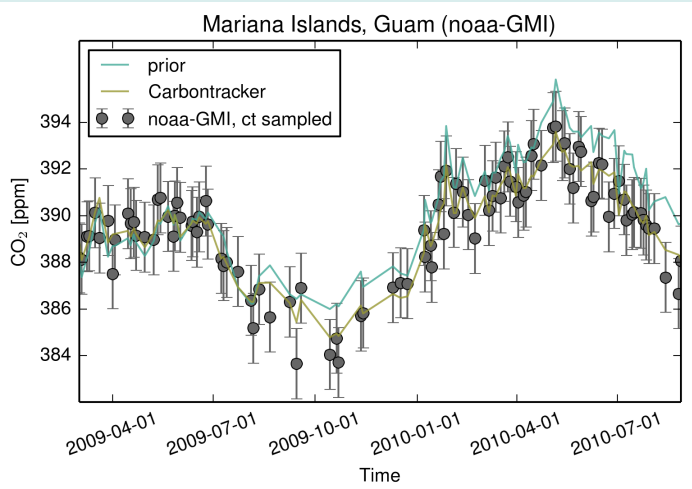
# Process

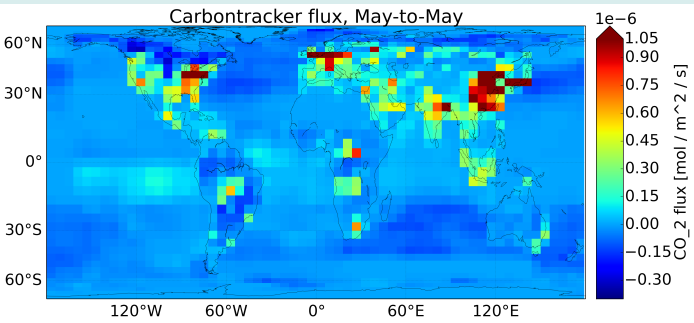



*[. . . details]*

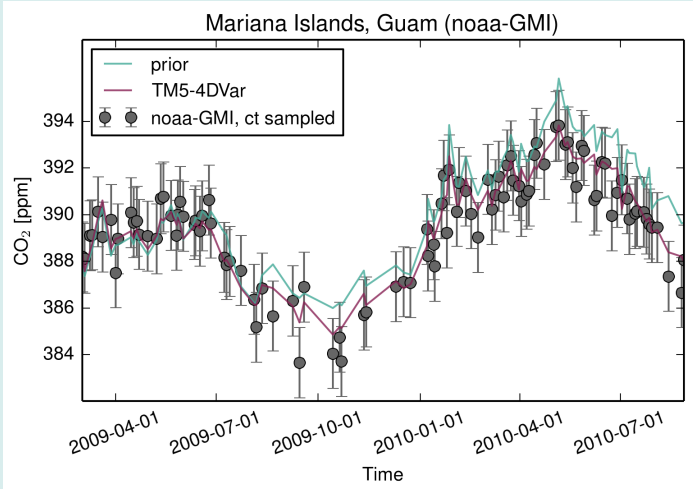
# Base Run

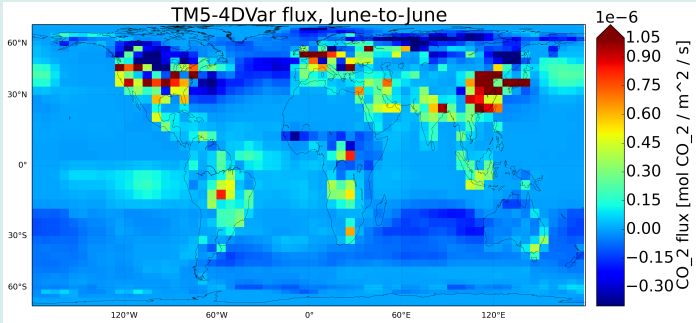
## Carbontracker



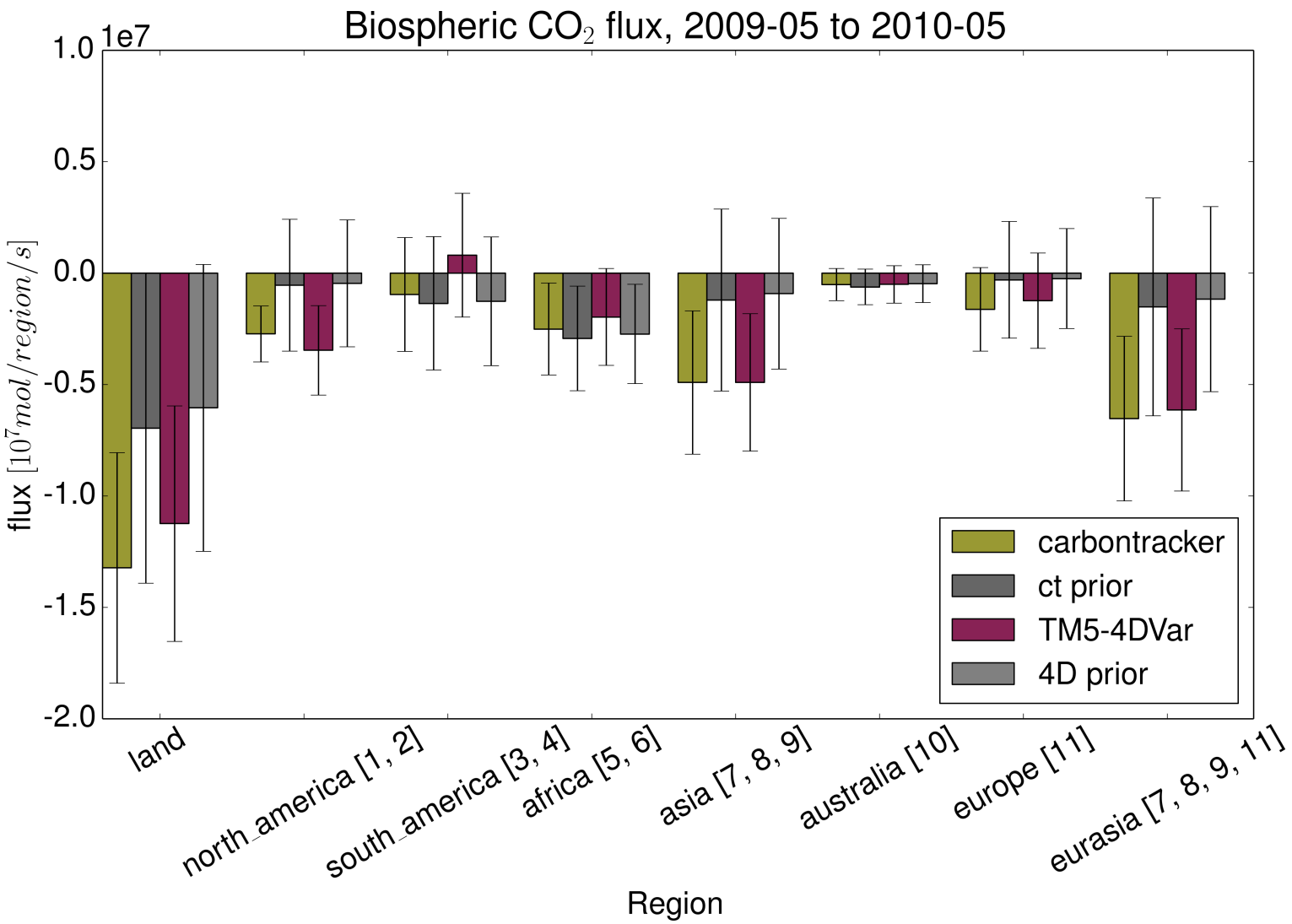




## TM5-4DVar

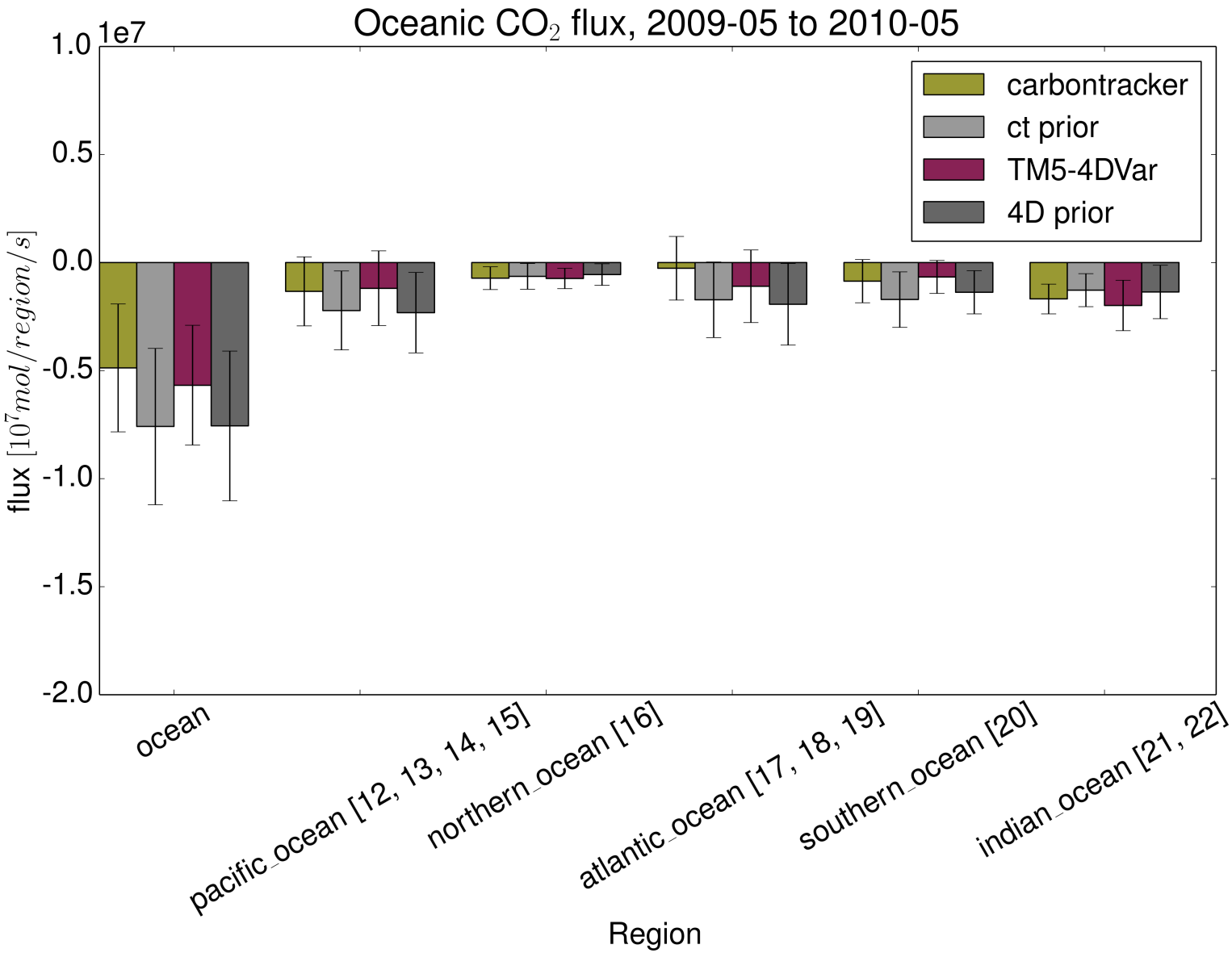


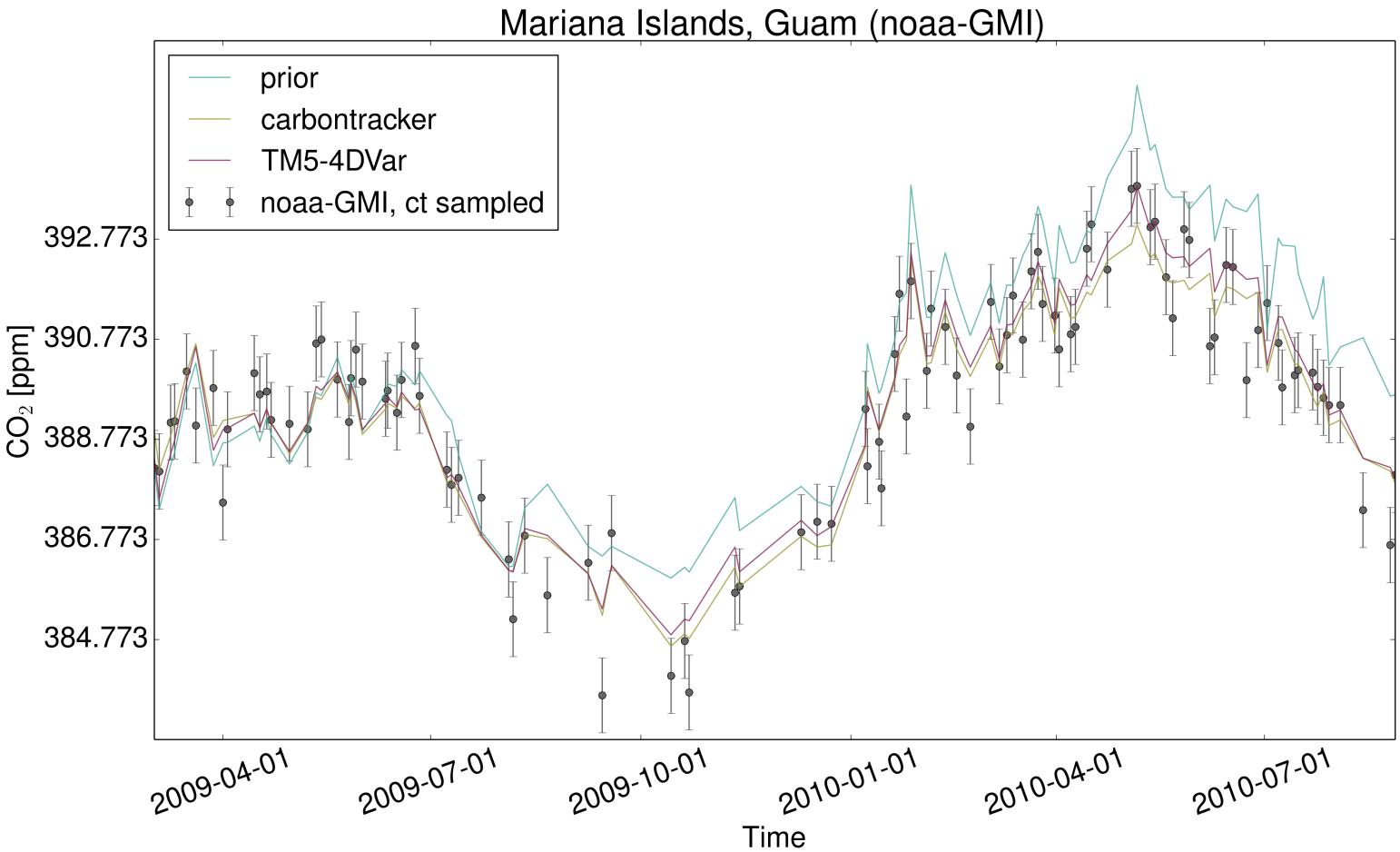
# Biosphere Fluxes



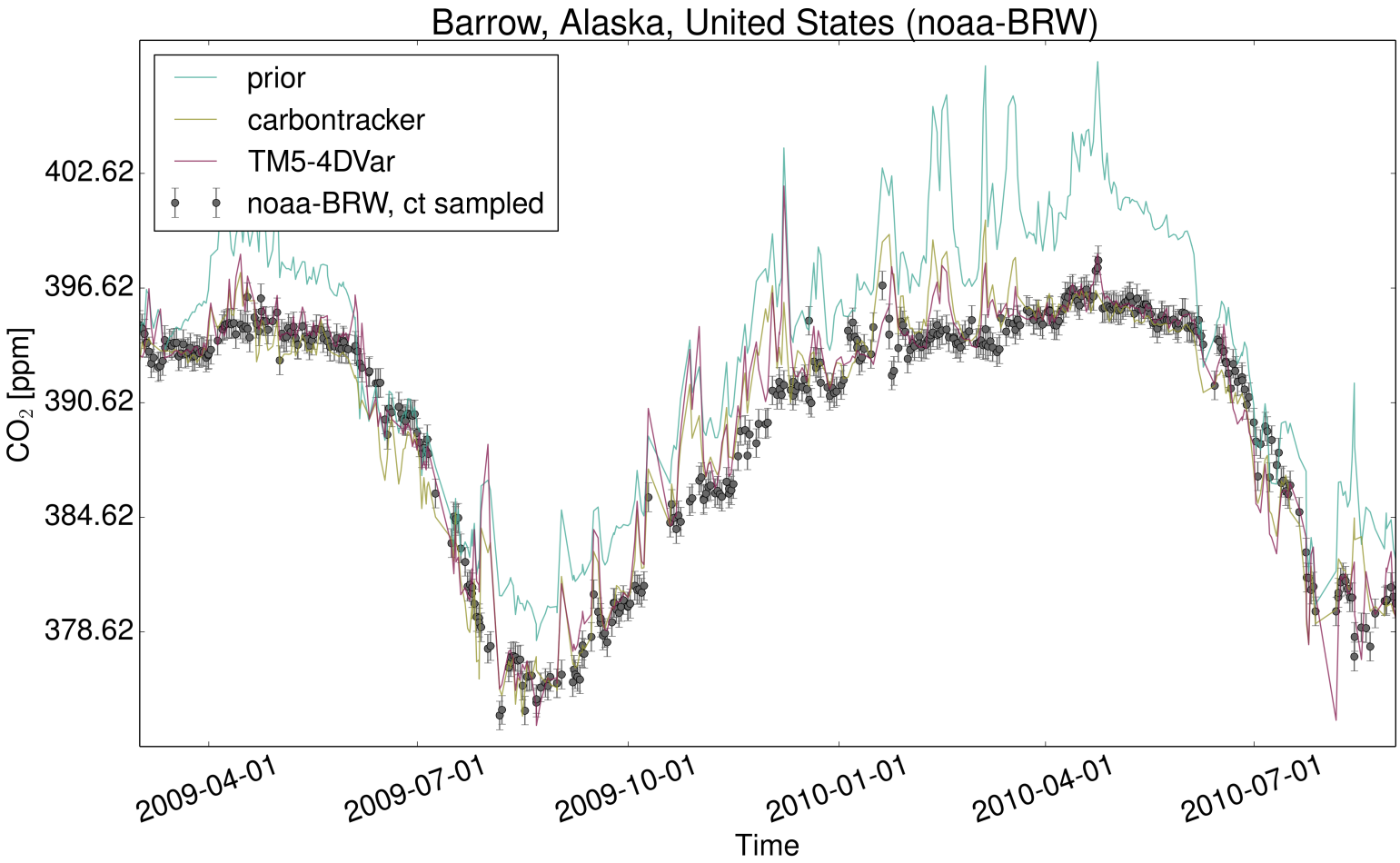
# Ocean Fluxes



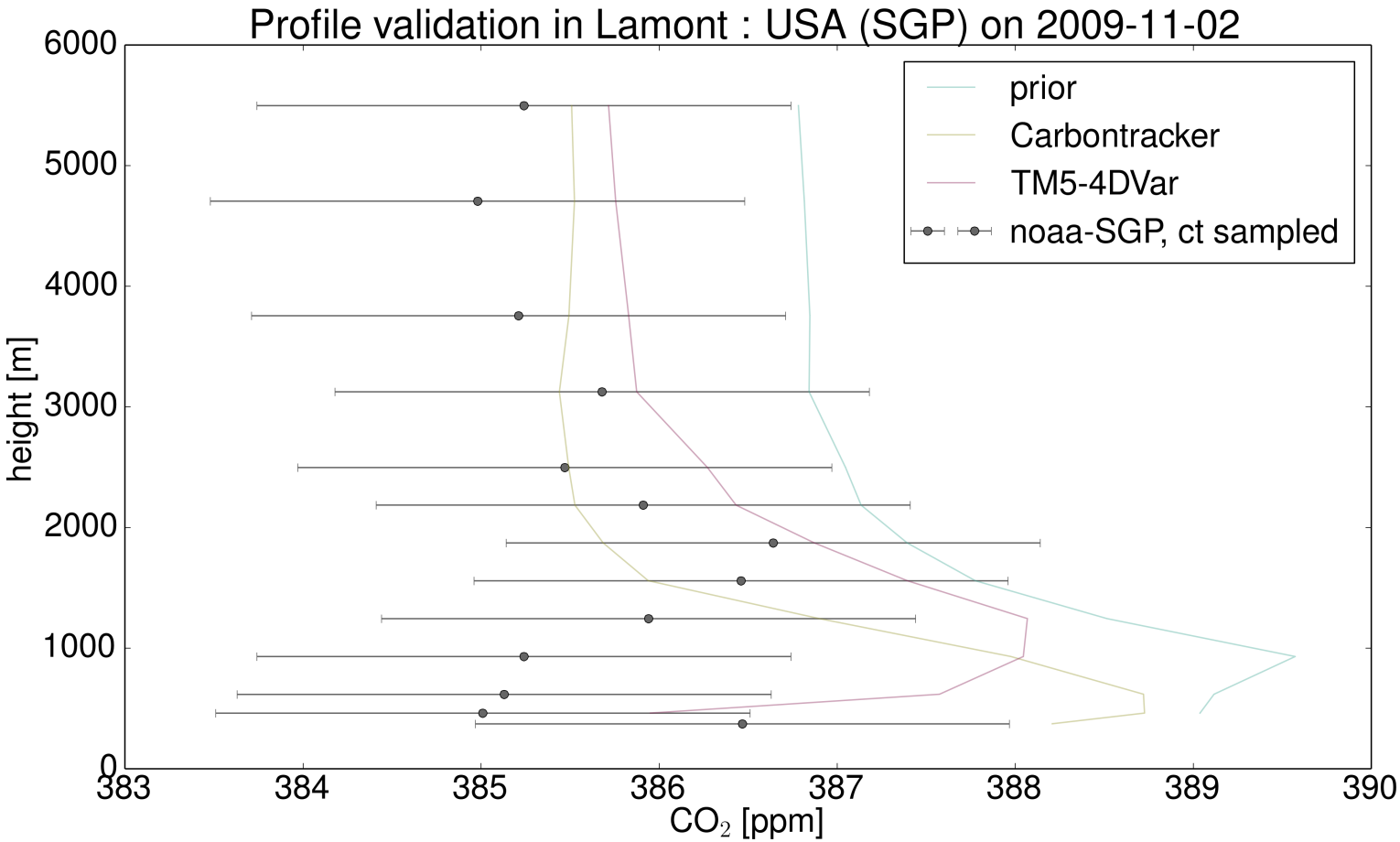
# Validation in Guam



# Validation in Barrow



# Aircraft validation




*[Mean Profile Residuals]*

# Sensitivity Tests

## CT

- cycle: 3, 7, 20 days
- lag: 3, 5, 10 cycles
- ensemble: 5, 50, 150, 300 tracers

## TM5-4DVar

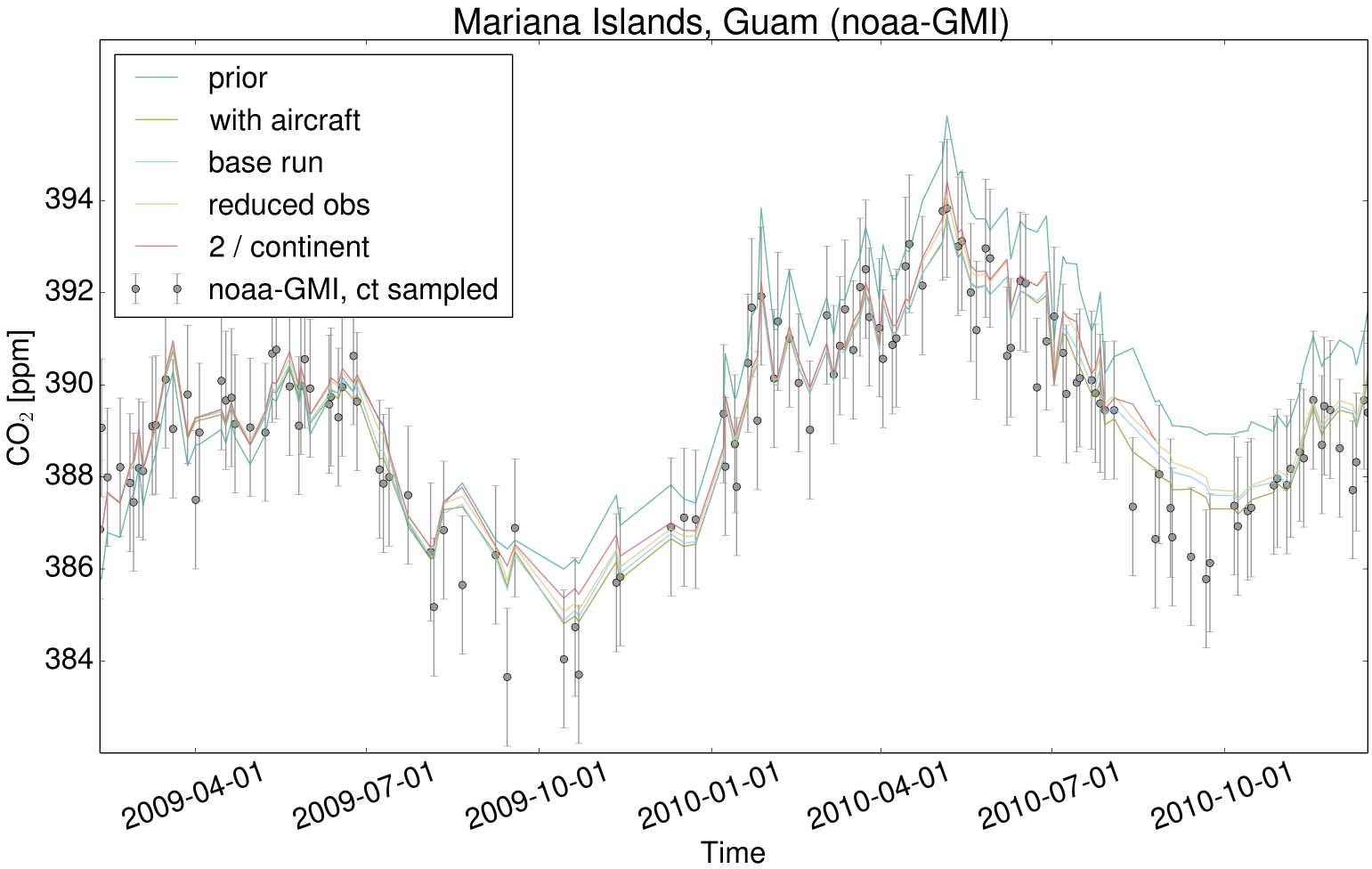
correlation length:

- temporal (ocean/bio):
  - 6months/3m, 3m/1m
- spatial (ocean/bio):
  - 6000km/1000km, 3000km/500km

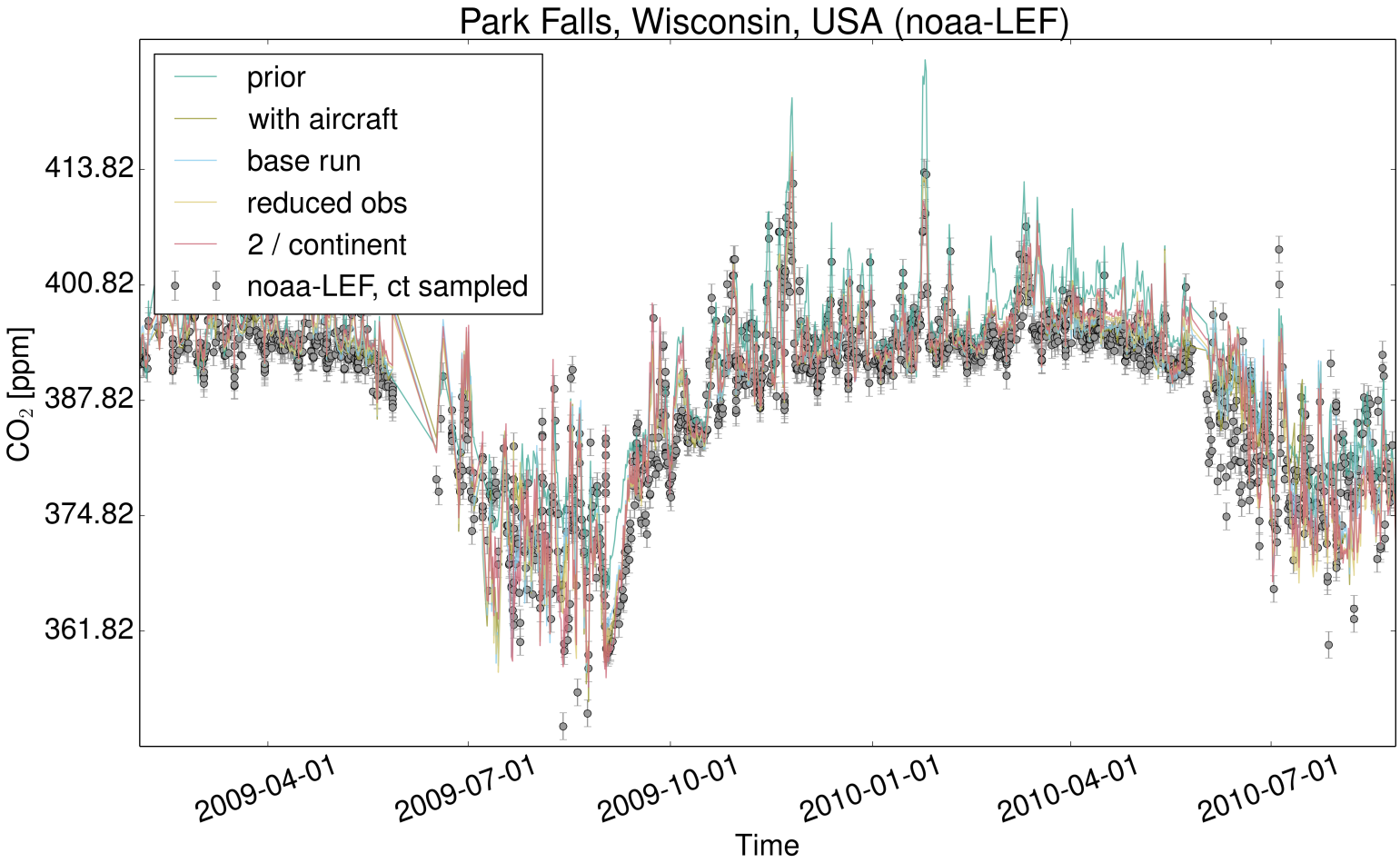
## Both

- Reducing Observations *[. . . Maps]*:
  - All stations + Aircraft
  - All stations
  - 50% of the stations
  - 2 stations per continent

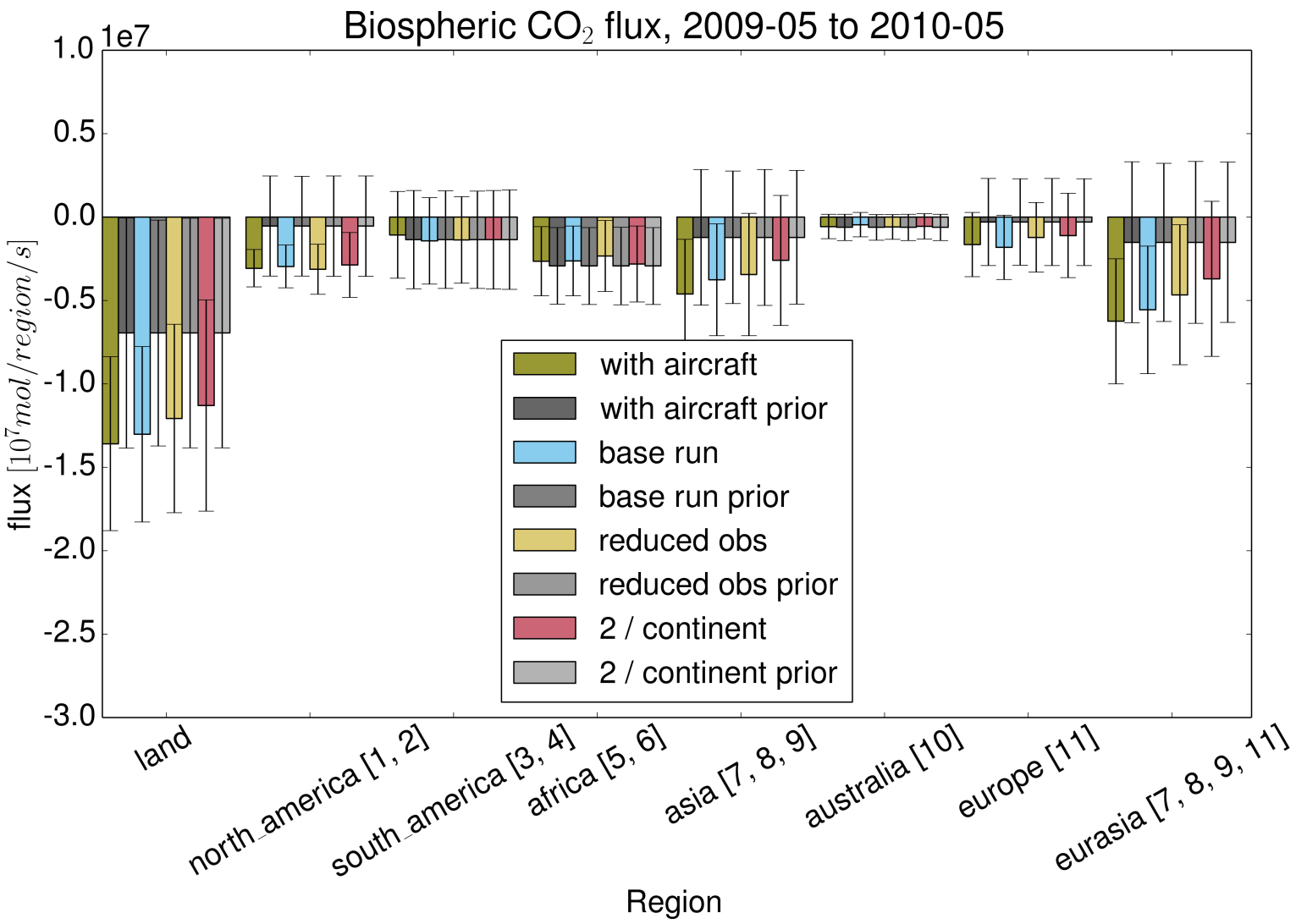
# Reduced observations, ocean



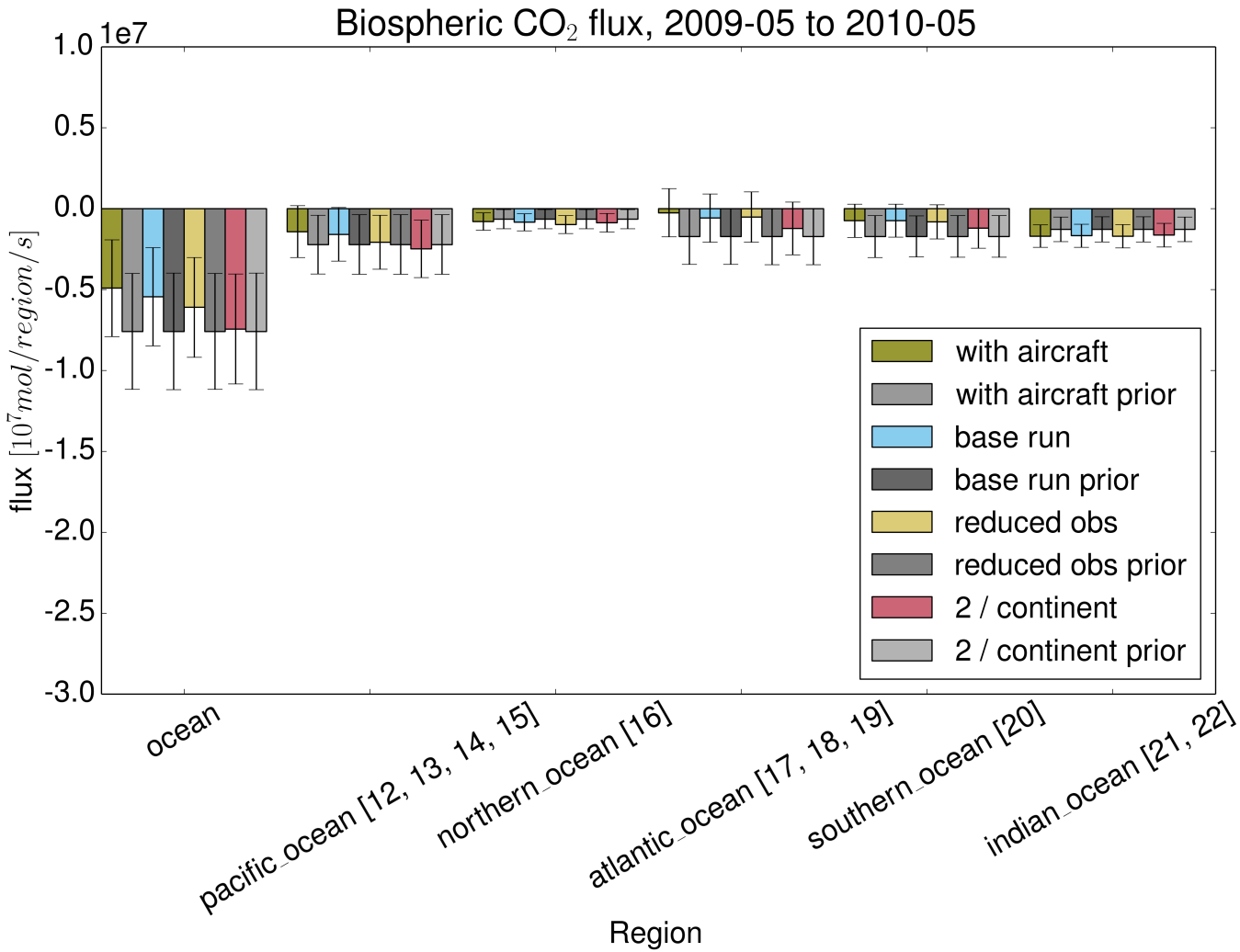
# Reduced observations, USA



# Reduced observations, land flux



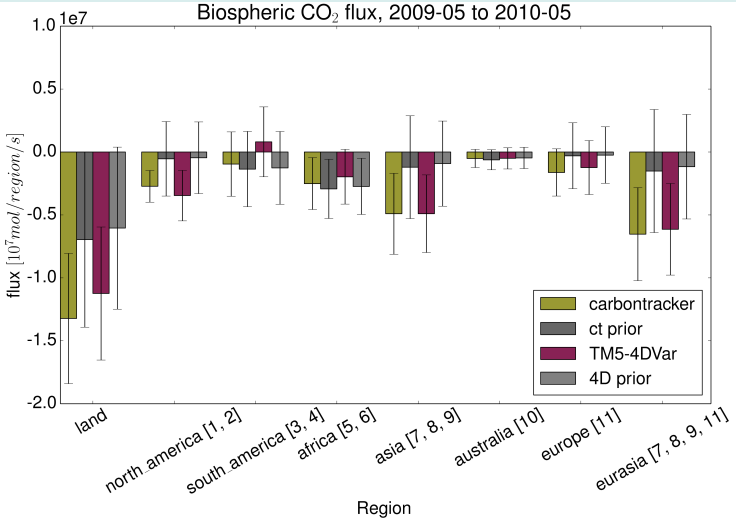
# Reduced observations, ocean flux



# Conclusions

## Base Runs

### Comparable




## Vertical profiles

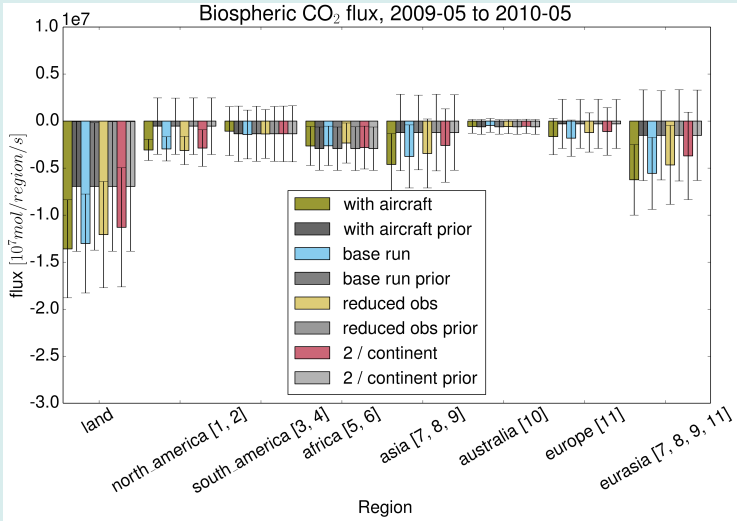
### Influences?

## Uncertainties

### Too Big?

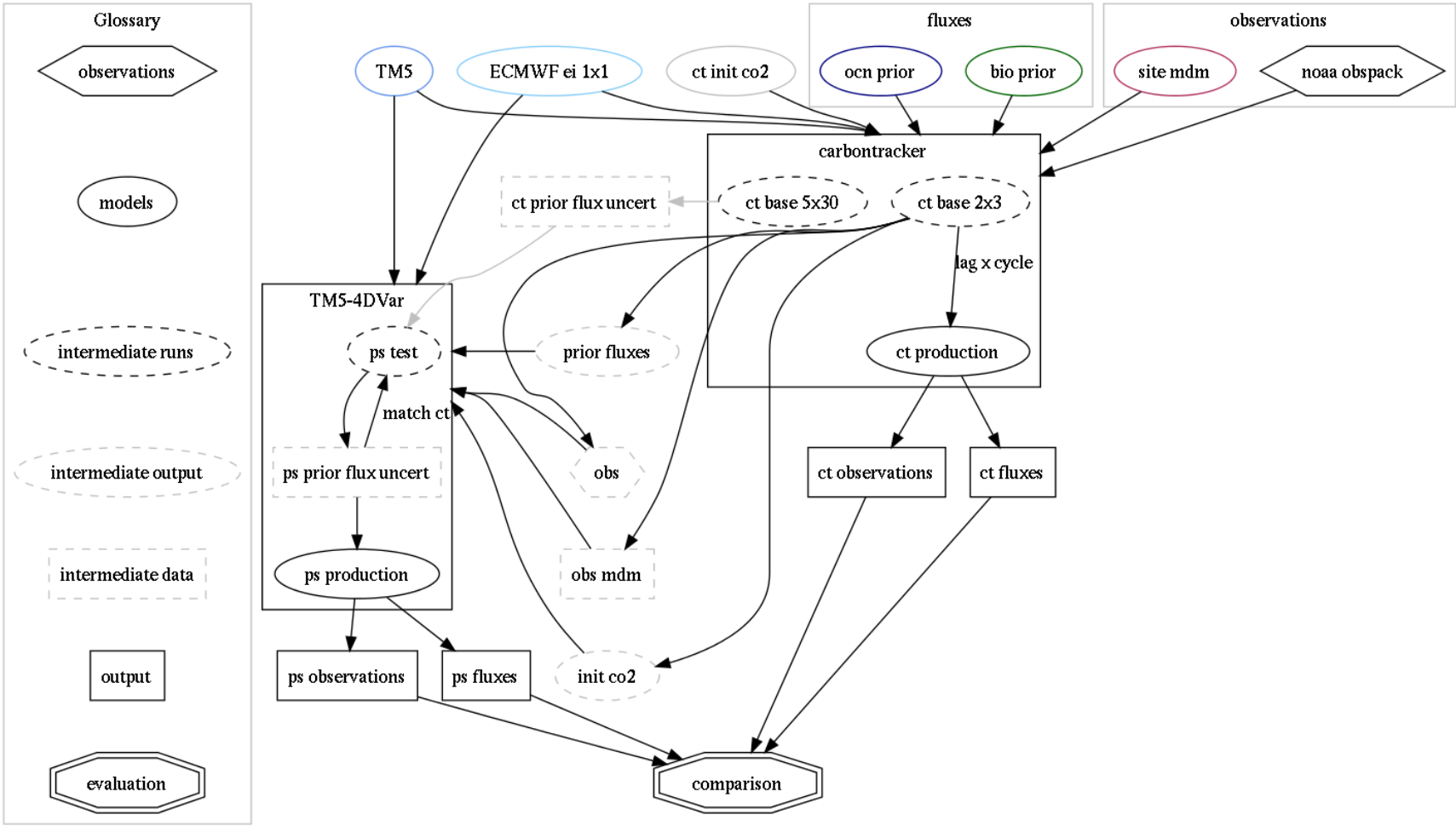
## Sensitivity

### Other tests?



# Thank you!

# Comparison: Process details




*[. . . abstract process]*

# Prior Flux Uncertainty

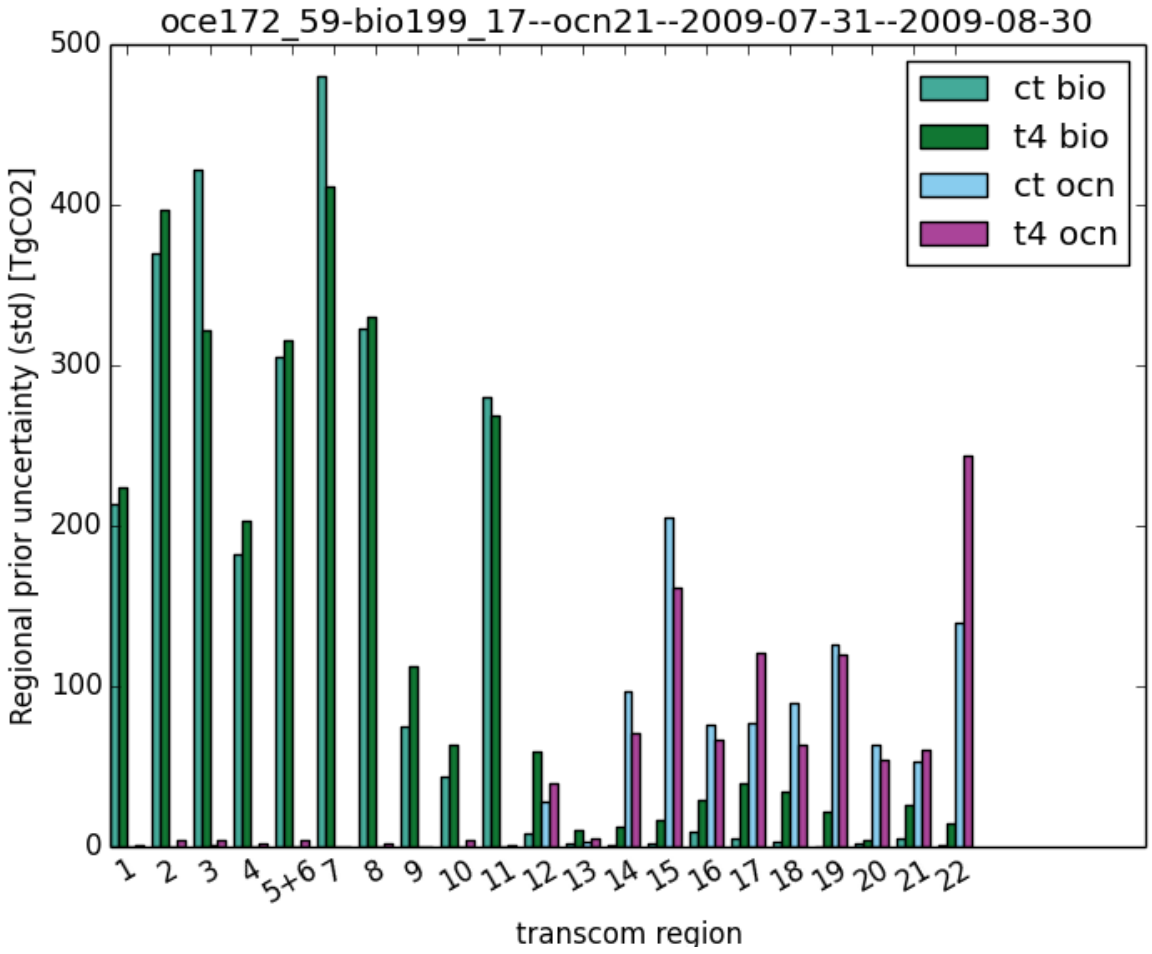
## Challenge: Different Uncertainty Definitions

- CT: Olson Bioregion Covariance
- TM5-4DVar: Relative Uncertainty plus spatial and temporal correlation length

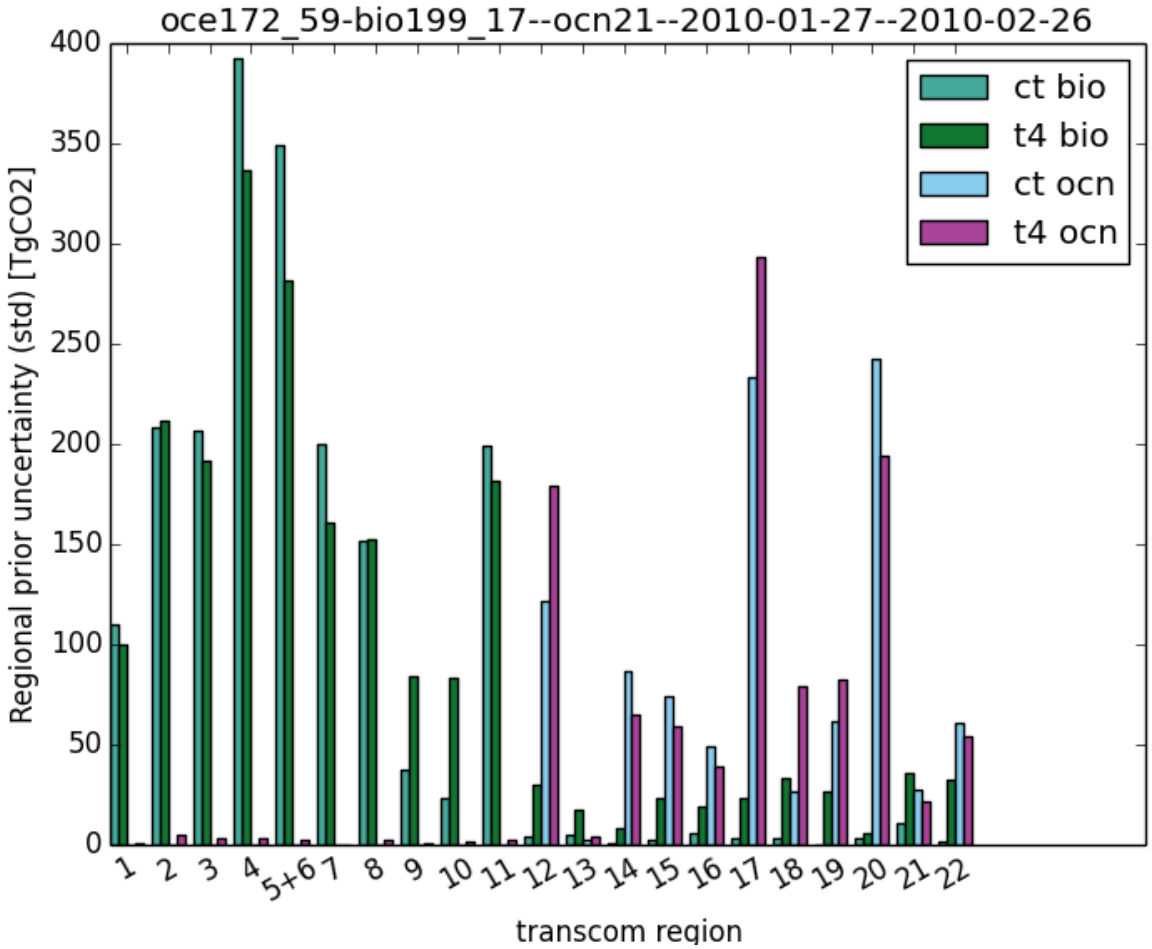
## Solution

- Carbontracker with cycle-length of 30 days.
- Adjust relative flux uncertainty in TM5-4DVar.
- Use monthly uncertainties on transcom regions.

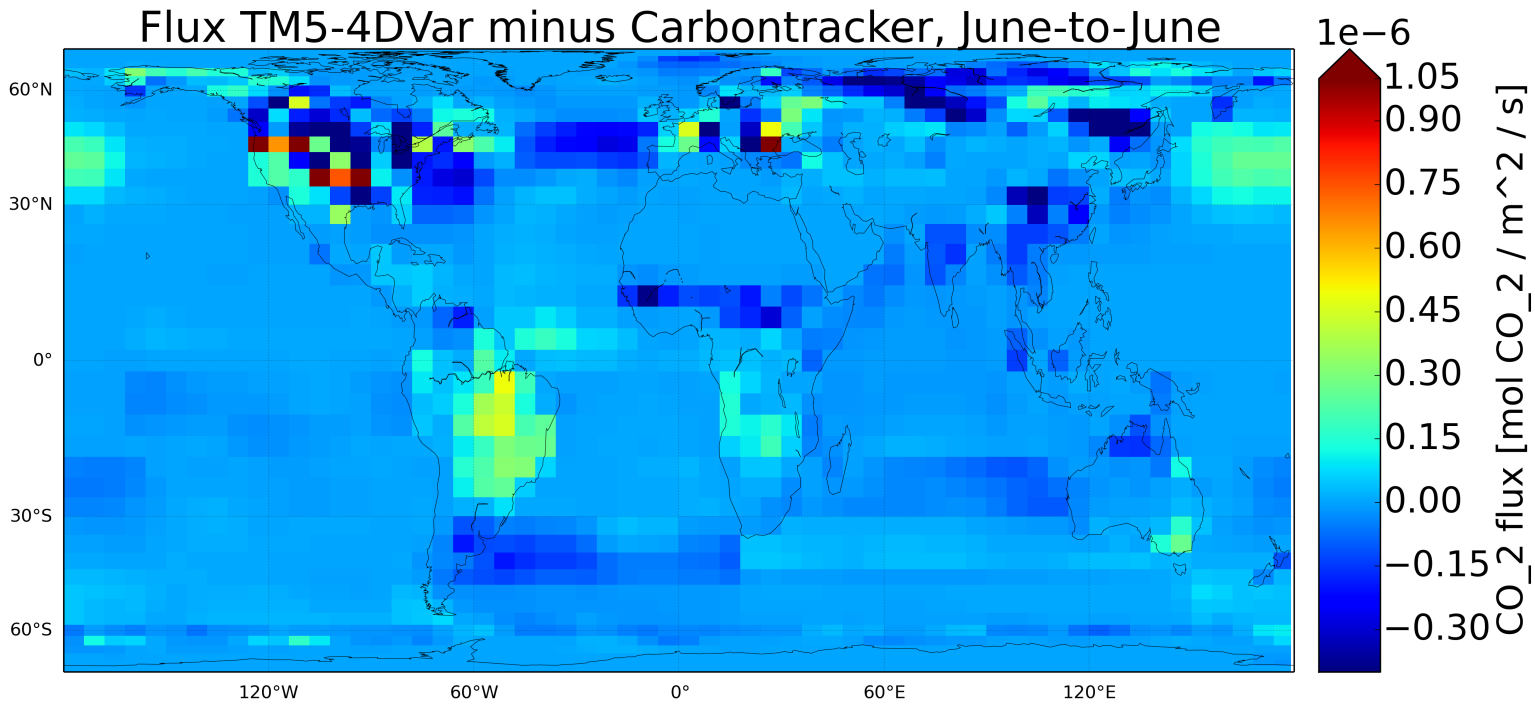
# Regional Uncertainty, August



# Regional Uncertainty, February 2010



# Base Run Diff



# Base run: Parameters

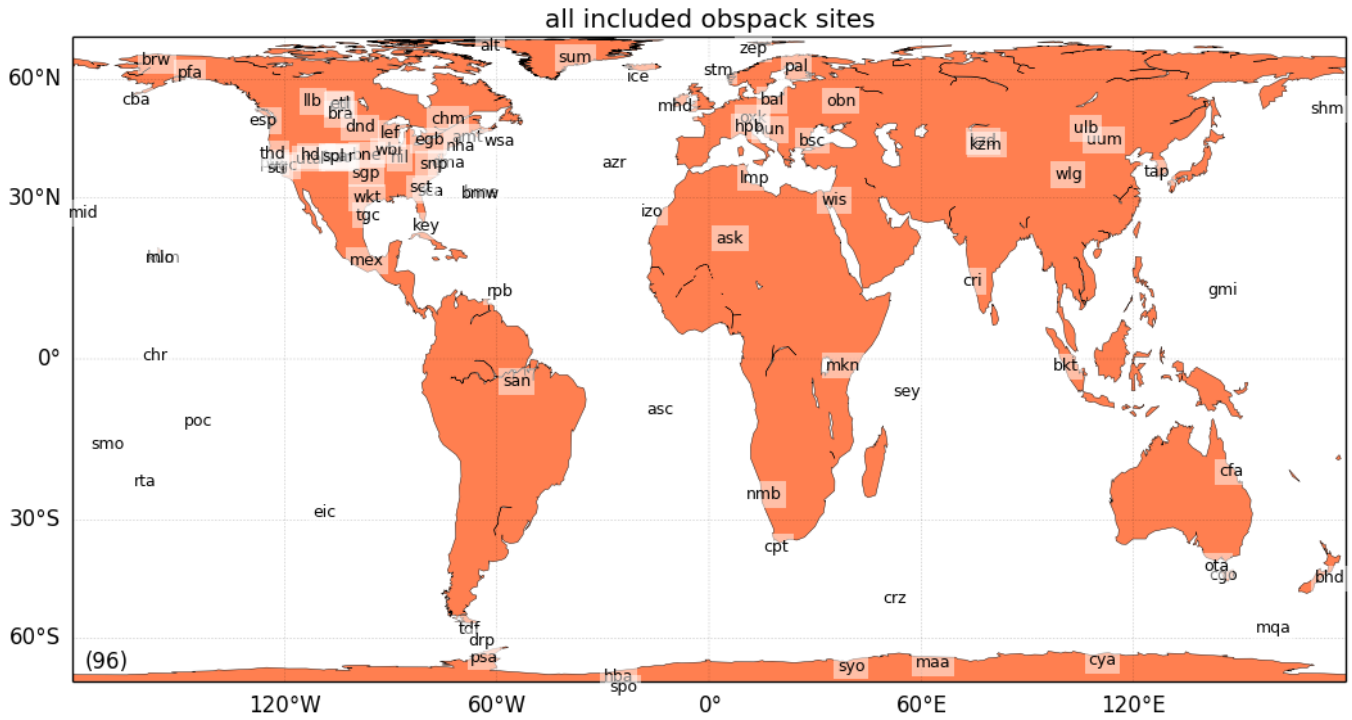
## Carbontracker

- cycle: 7 days
- lag: 5 cycles
- Ensemble: 300 tracers.

## TM5-4DVar

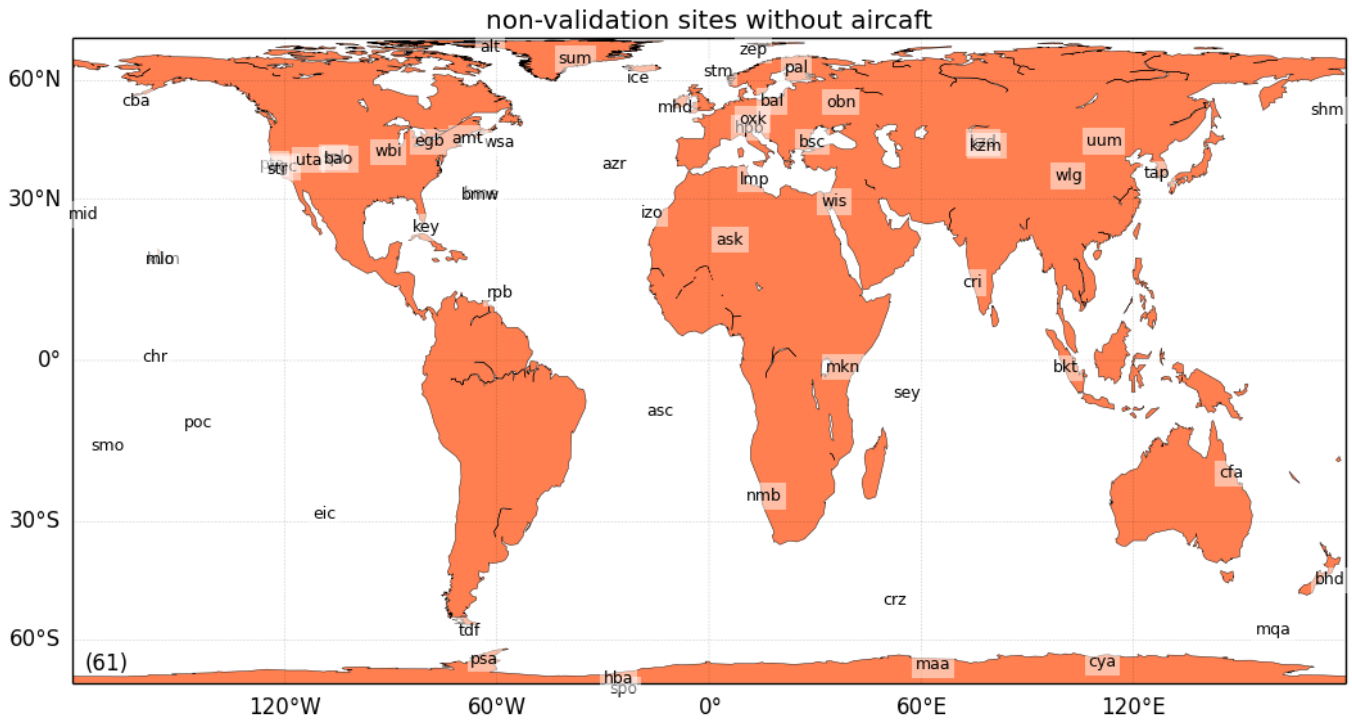
- uncertainty:
  - bio: 199.17%
  - ocean: 172.59%
- correlation length:
  - bio: 200km, 1 month
  - ocean: 1000km, 3 mo

# Sensitivity: Available Sites



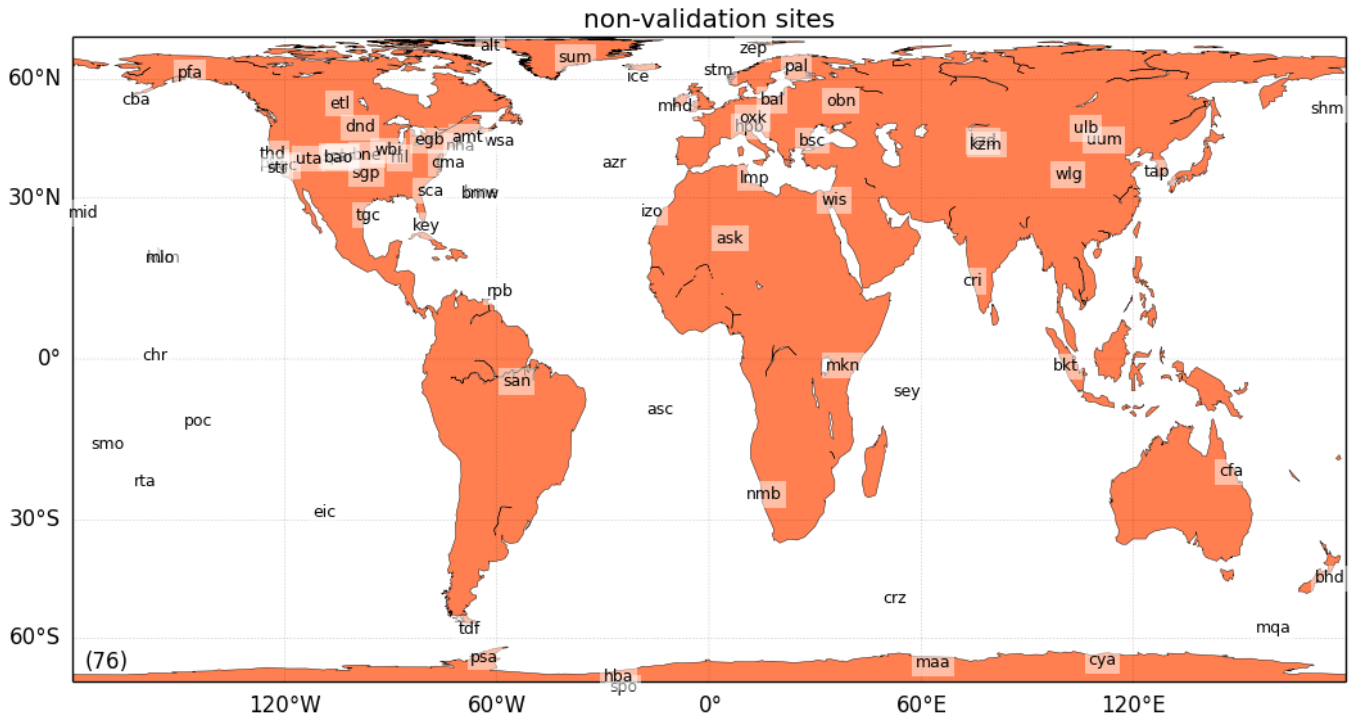

*96 sites we could use. [. . . Sensitivity Tests]*

# Sensitivity: Base Sites



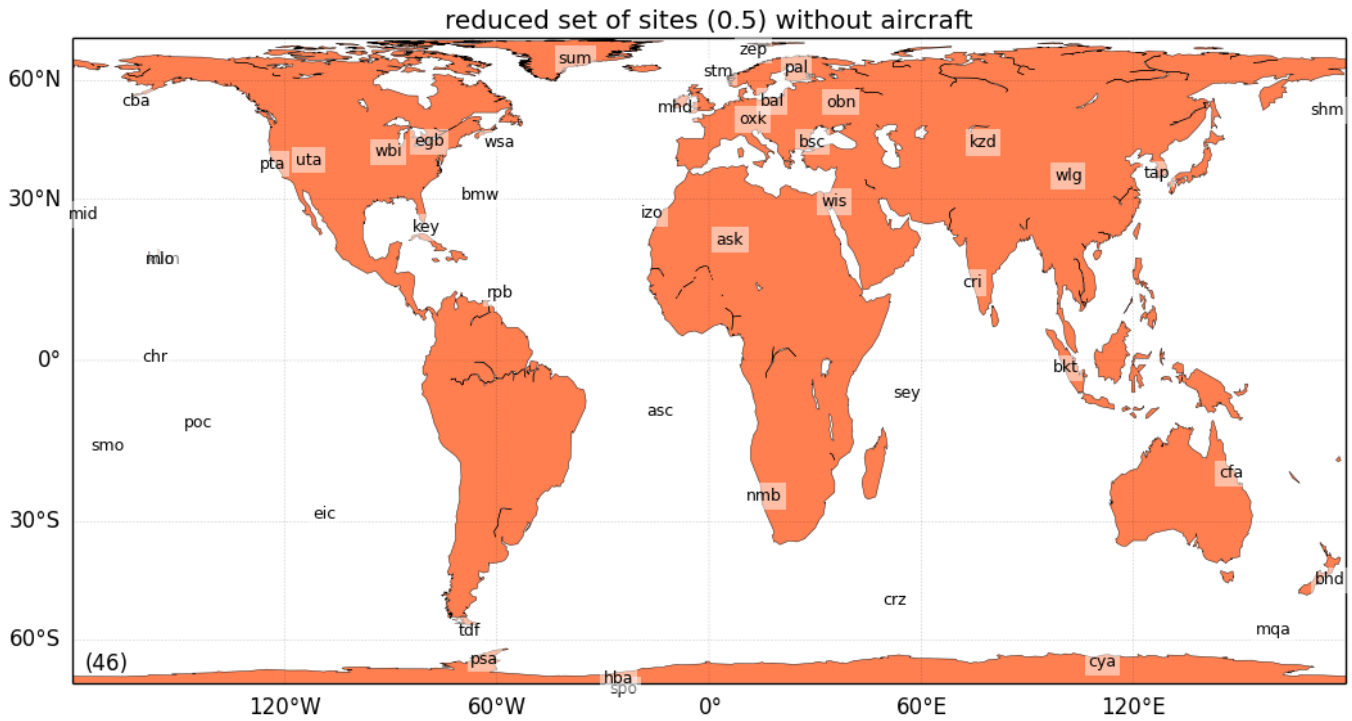

*61 sites: All without aircraft and validation.*

# Sensitivity: With aircraft



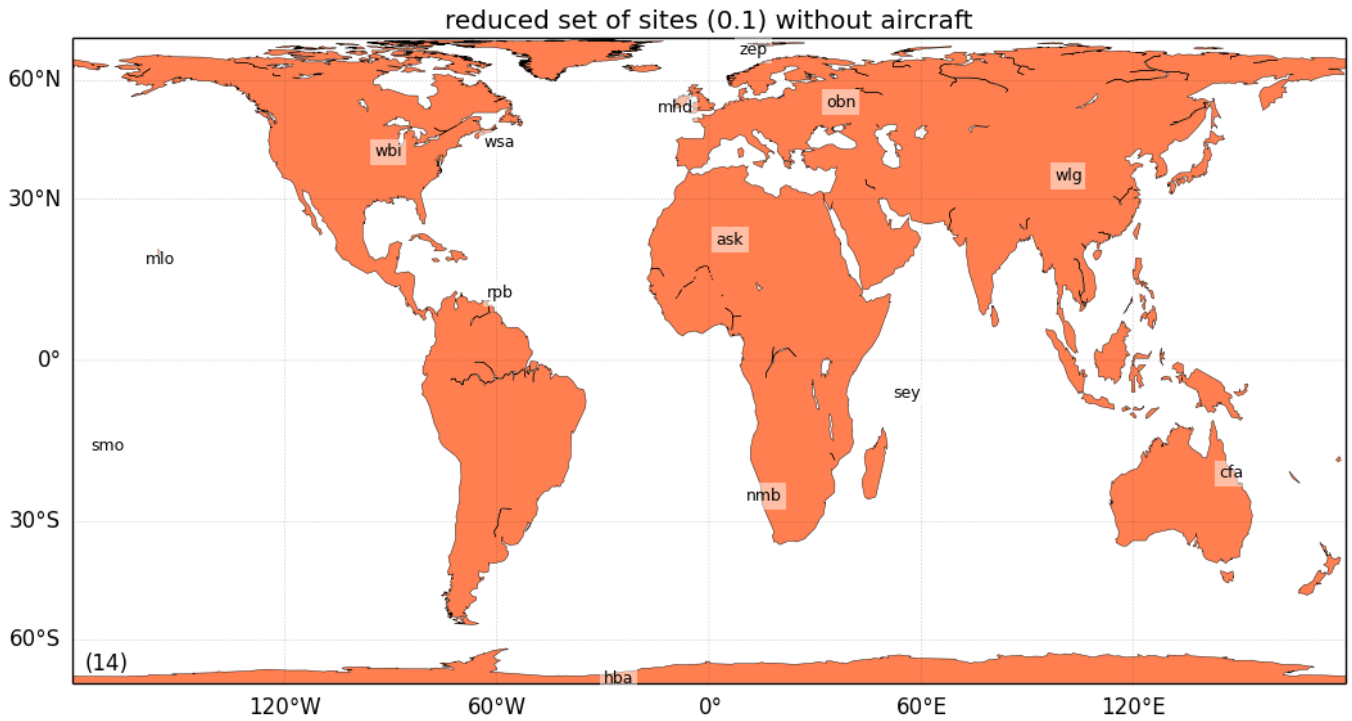

*76 sites. One in Southern America! (no ABP in 2010)*

# Sensitivity: Reduced set



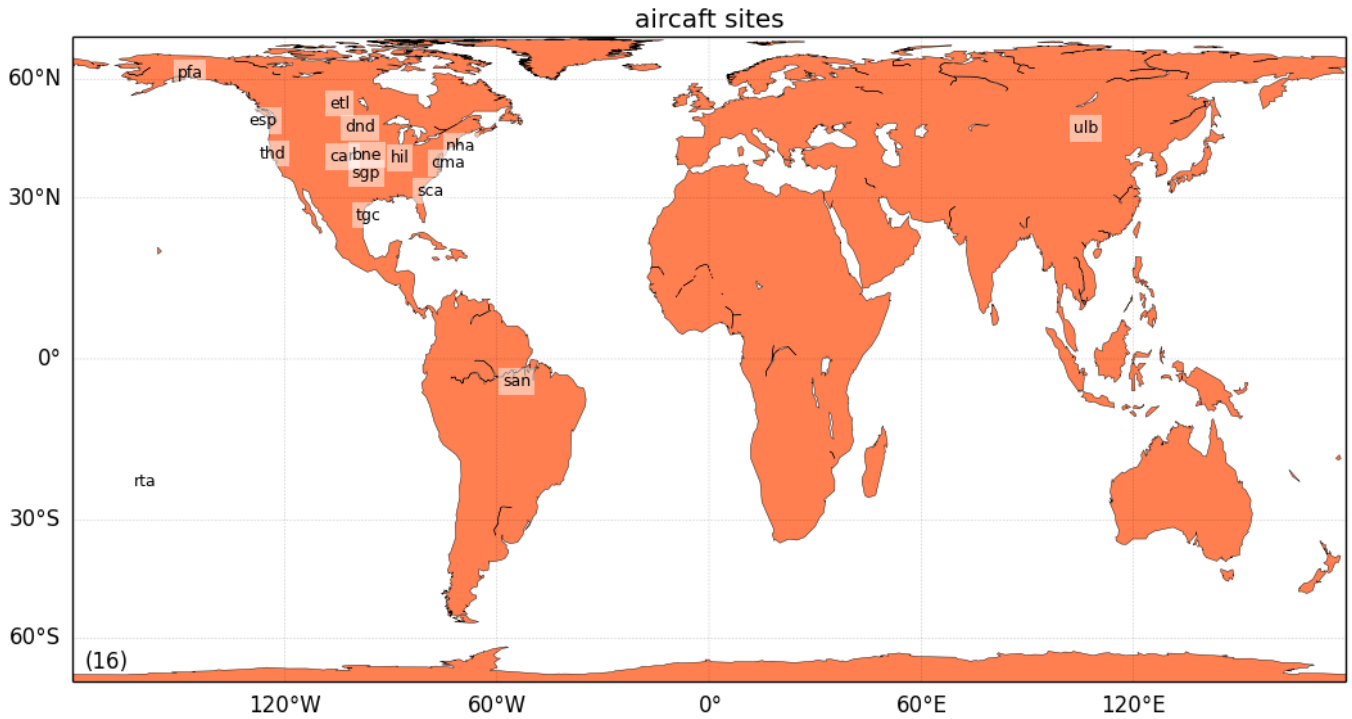

*46 sites. Reduced similar sites.*

# Sensitivity: 2 sites per continent

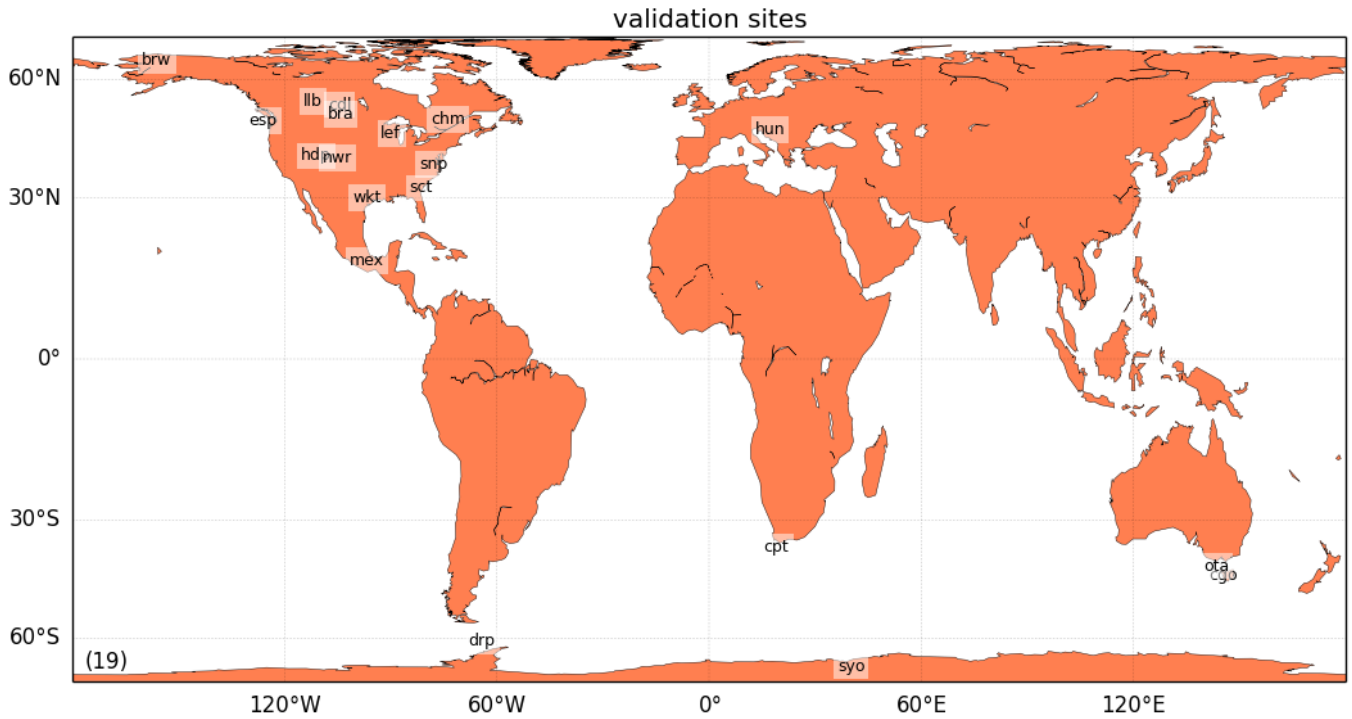



*14 sites.*

# Only aircraft sites



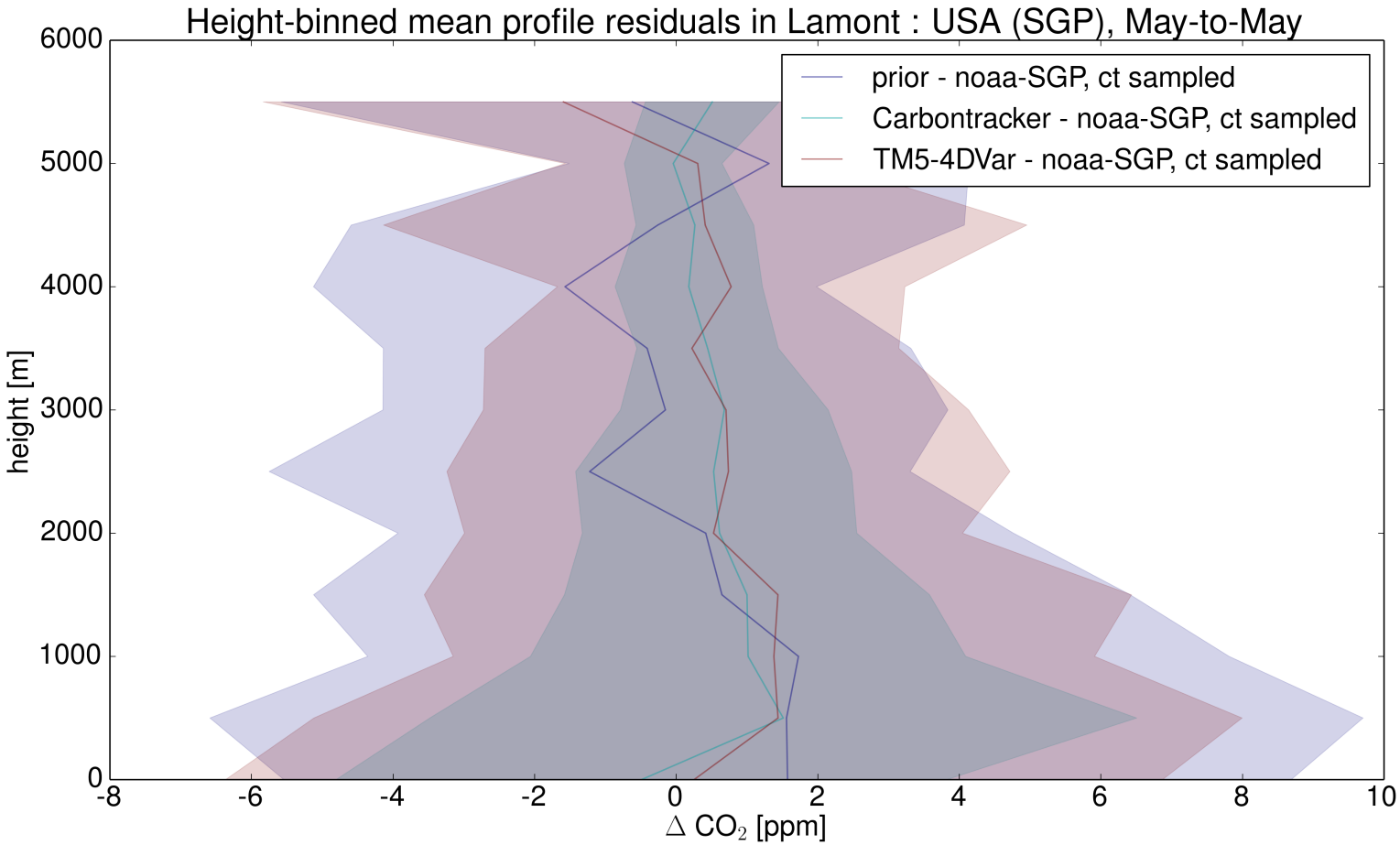
# Only validation sites



# TM5-4DVar uncertainty setup

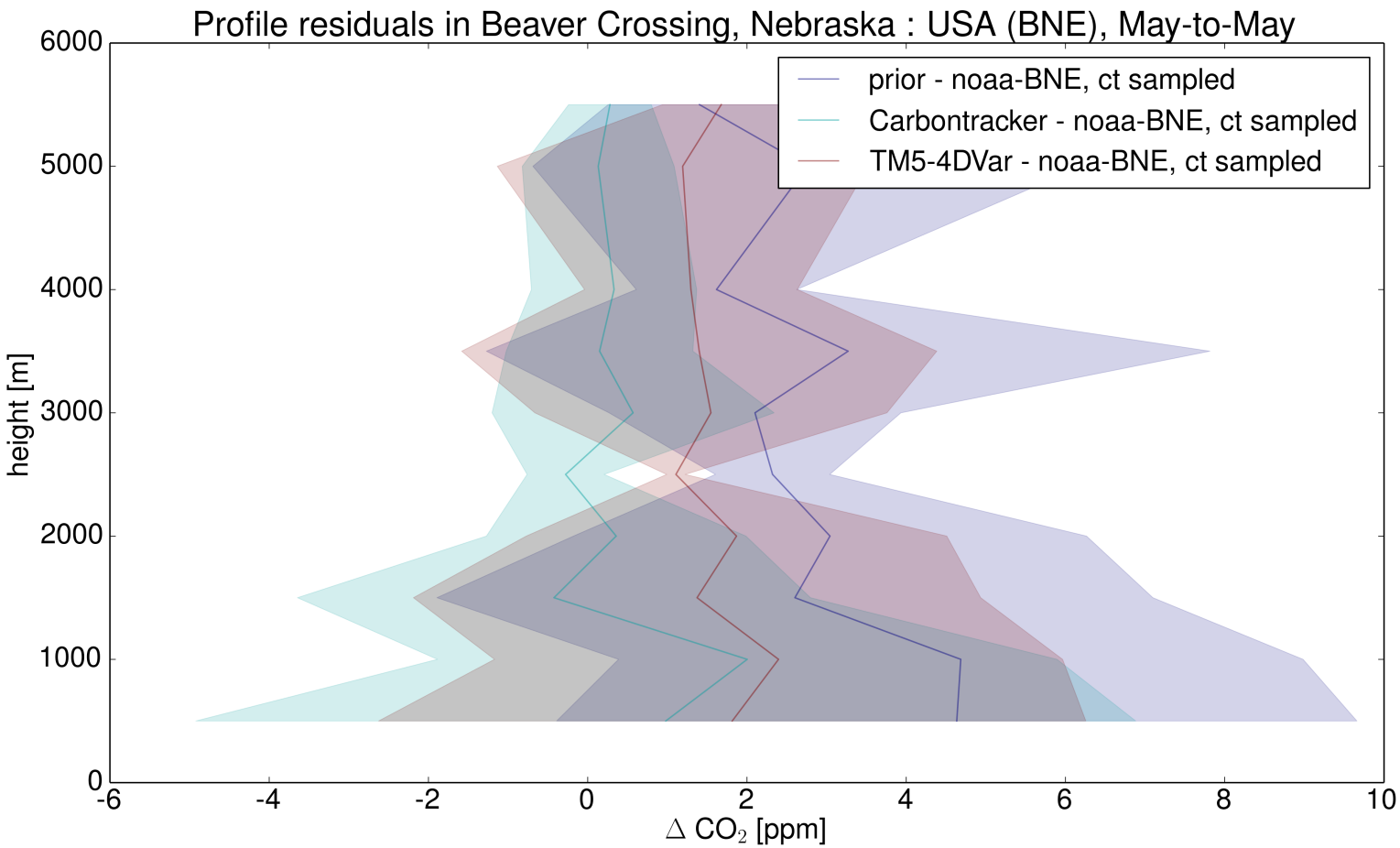
```
! category : Name ; uncertainty percent of abs. flux; spatial correlation of 1000 km Gaussian; temporal corre
! Caveat: read by fixed format Fortran: preserve the exact positions of the ; and the text! Hint: Use emacs a

! Giving uncertainties to match http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch7s7-3-1-3.html#table-7-
CO2.category1   : oceanic flux    ; 172.59 ; 1000.0-e ; 3.0-e-monthly ; 1 ; def-def-0
CO2.category2   : biosphere flux  ; 199.17 ;  200.0-e ; 1.0-e-monthly ; 1 ; def-def-0
CO2.category3   : fire emissions  ;   6.0  ;  250.0-e ; 1.0-e-monthly ; 0 ; def-def-0
CO2.category4   : fossil fuel     ;   6.0  ; 5000.0-e ; 3.0-e-monthly ; 0 ; def-def-0
```

# Mean Profile Residuals SGP




*[Base run: Aircraft validation]*

# Mean Profile Residuals BNE




*[Base run: Aircraft validation]*