Testing six inverse methods in a realistic pseudo-data study

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Research Question

What is the best choice of inverse system to retrieve CO_2 fluxes over a limited time and space domain?

Are certain methods unsuitable?
What are the pitfalls of each method?
What can we expect in the best case?

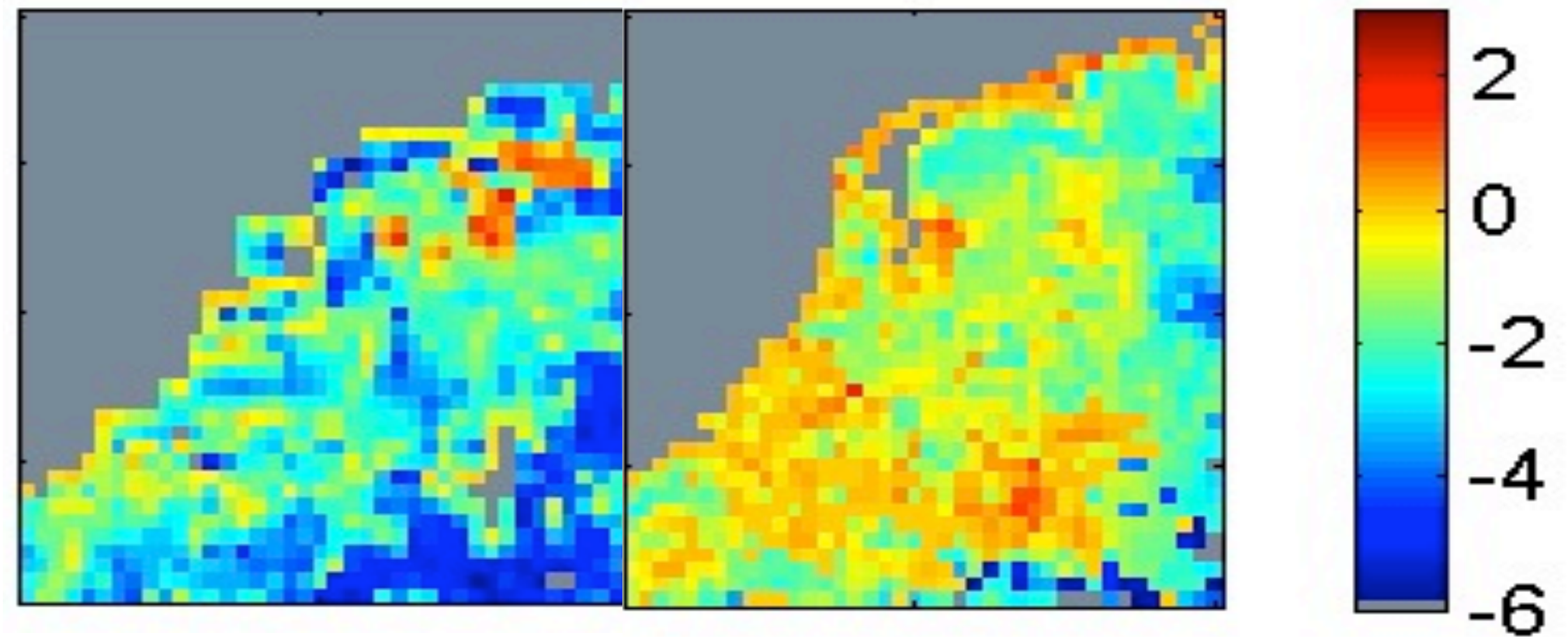
Setup

- RAMS regional atmospheric model
  - Europe+Netherlands at 10km resolution
  - period June 1st to June 15th 2006
  - 4 towers sampled in afternoon hours
  - driven by FACEM biospheric CO_2 fluxes
- Ensemble Kalman filter inversion
  - a-priori 5PM biospheric CO_2 fluxes
  - six methods to optimize fluxes

FACEM vs 5PM

resolution	15km	10km
meteorology	ECMWF	RAMS
LAI	MODIS-2008	MODIS-2006
soil map	IGBP-DIS	UN-FAO
land-use	SYNMAP	Corine2000

FACEM vs 5PM



truth vs prior

6 inverse methods

??? What to optimize ???

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- scaling factors for NEE per land-use type (Peters et al.)

- scaling factors for GPP and R per pixel (Zupanski et al., Lokupitiya et al., Schuh et al.), partly coupled

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- scaling factors for GPP and R per land-use type
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- scaling factors for GPP and R per land-use type, fully coupled
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- scaling factors for GPP and R per pixel (Zupanski et al., Lokupitiya et al., Schuh et al.), partly coupled
- biosphere model parameters (Rayner et al.)

scaling factors for NEE

- each land-use type has one scaling factor to be optimized for a 2-week period
- its value scales the hourly NEE curves in each pixel of the domain
- simple, little risk of aliasing, easy to balance obs and unknowns
- amplitude scaling, difficult to change sources to sinks, physical interpretation difficult, aggregation errors, zero crossing

scaling factors for GPP+R

- each land-use type has two scaling factors to be optimized for a 2-week period: GPP and R
- its value scales the hourly GPP or R curves in each pixel of the domain
- closer to processes, more freedom, no zero crossing
- aliasing, loss of diurnal cycle, aggregation errors

pixels vs land-use

- in a pixel inversion each box has its own scaling factors
- prescribed correlations constrain solution
- more freedom, no hard boundaries to sub-domains
- many parameters, correlations need to be chosen

biosphere model parameters

- each plant-functional type has four optimizable parameters
- their values control the hourly GPP and R in each pixel of the domain as a function of driver data
- very close to processes, easy upscaling
- aliasing, model structure errors, non-linearity

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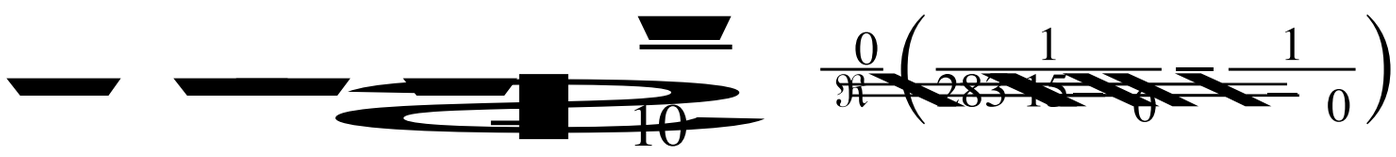
non linear inversions are very tricky and require extra careful reality checks!!!

5PM structure

- Gross Primary Production
  - Farquhar et al: GPP=*min*(W_c, W_j)
  - W_c = f(C_i, V_{max},...) *enzyme limited*
  - W_j = f(C_i,α,...) *light limited*
- Ecosystem Respiration (R)



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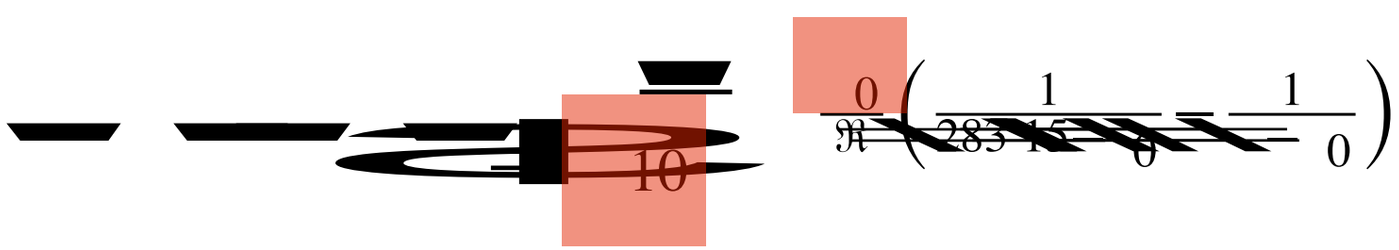
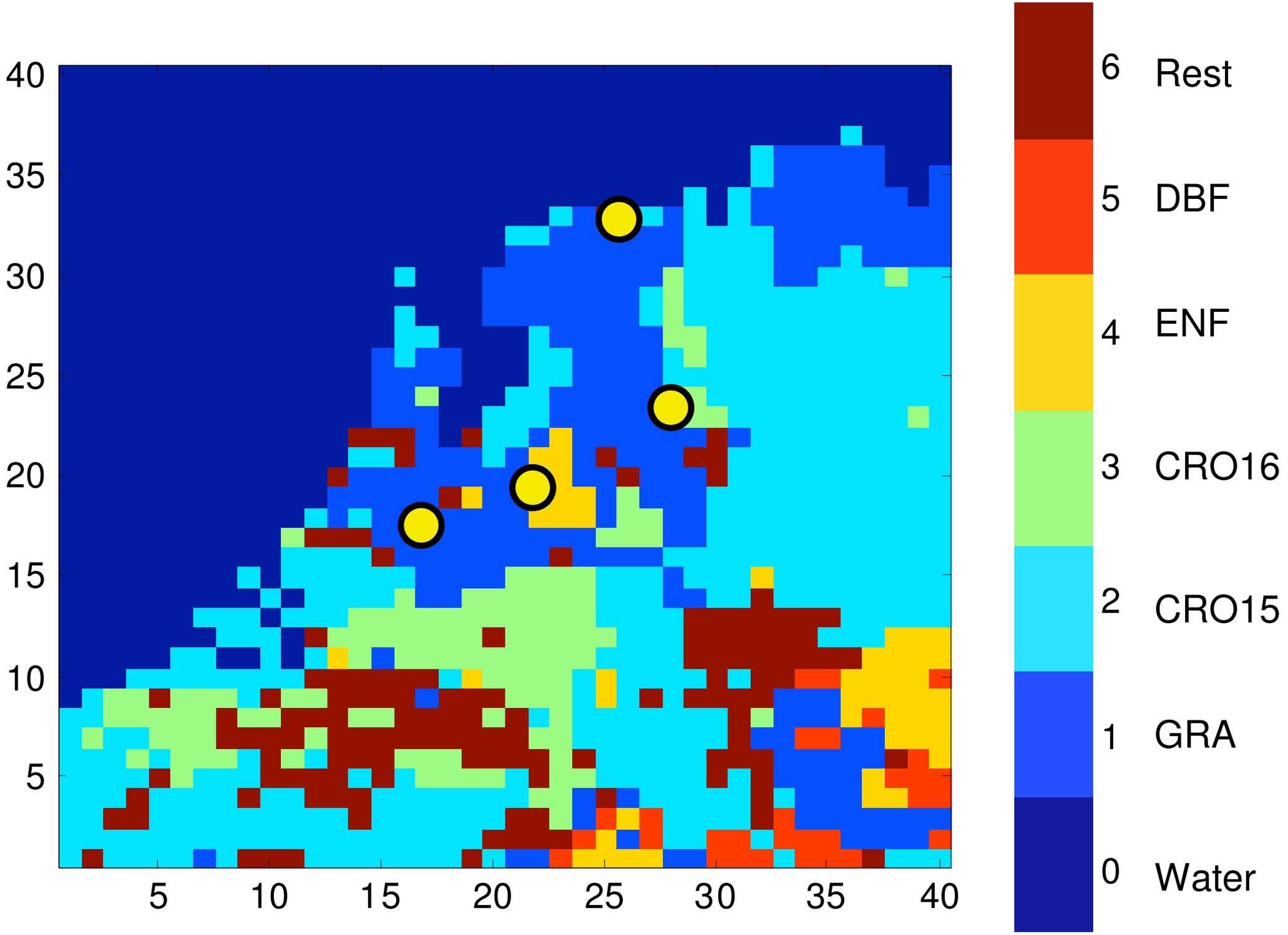


Land-use classes



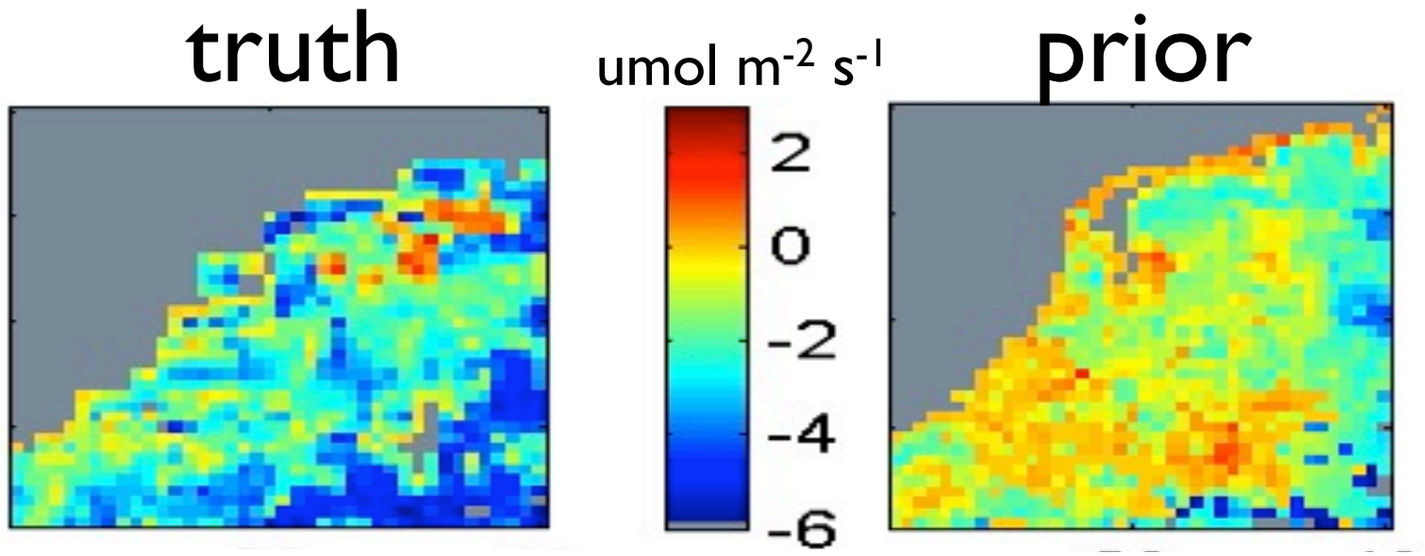
Covariances

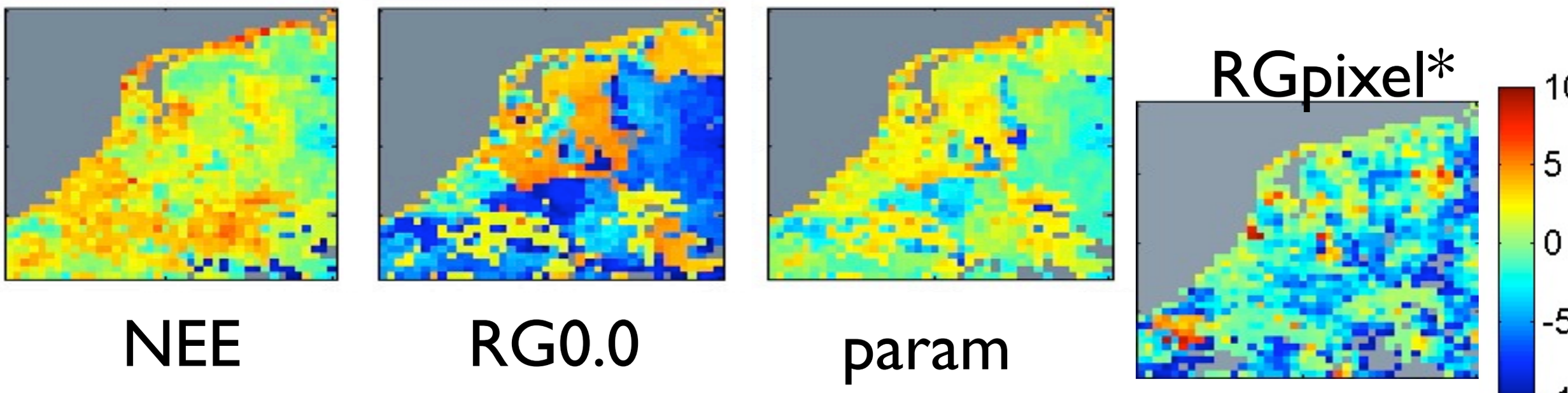
- The covariance in NEE was created from an ensemble of 5PM results with realistic parameter variations
- It was summed in time to make $\overline{\overline{\text{cov(NEE)}}}$
- all inversions were given the same $\overline{\overline{\text{cov(NEE)}}}$ per land-use type, and domain total
  - but hourly structure could be different(!)
- 2 inversions were given correlations (0.5 and 1.0) between R and GPP scaling factors

Overview

Type	Name	D.O.F. (~)
NEE, per land-use class	NEE	6
R+GPP, per land-use class, no correlations	RG0.0	12
R+GPP, per land-use class, partial correlations	RG0.5	9
R+GPP, per land-use class, full correlations	RG1.0	6
R+GPP, per pixel, spatial correlations	RGpixel	62
biosphere parameters	param	22

Results: flux maps





NEE

RG0.0

param

Results: flux maps

red: > +2

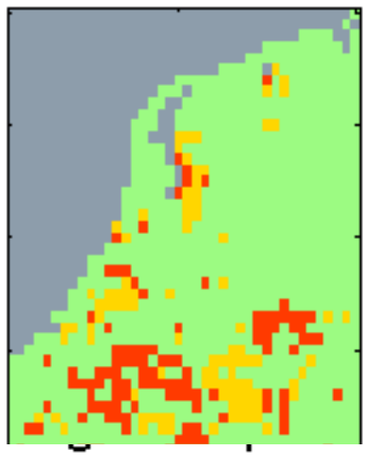
orange: +1 to +2

green: -1 to +1

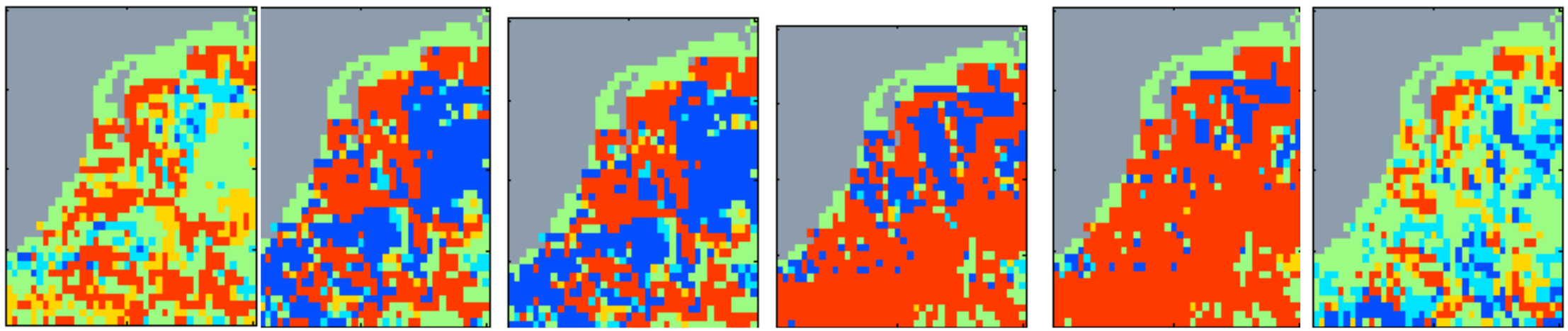
lightblue: -1 to -2

blue: < -2

prior

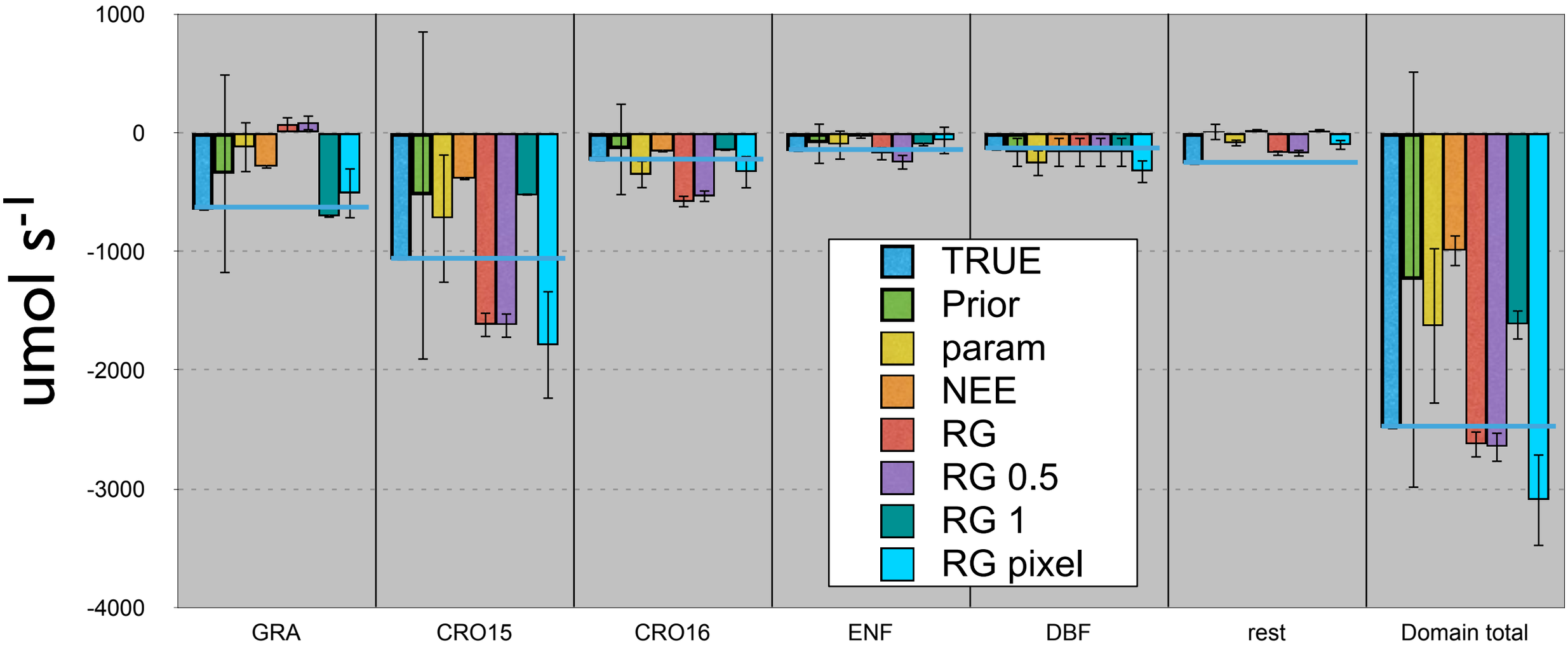


NEE difference / standard deviation



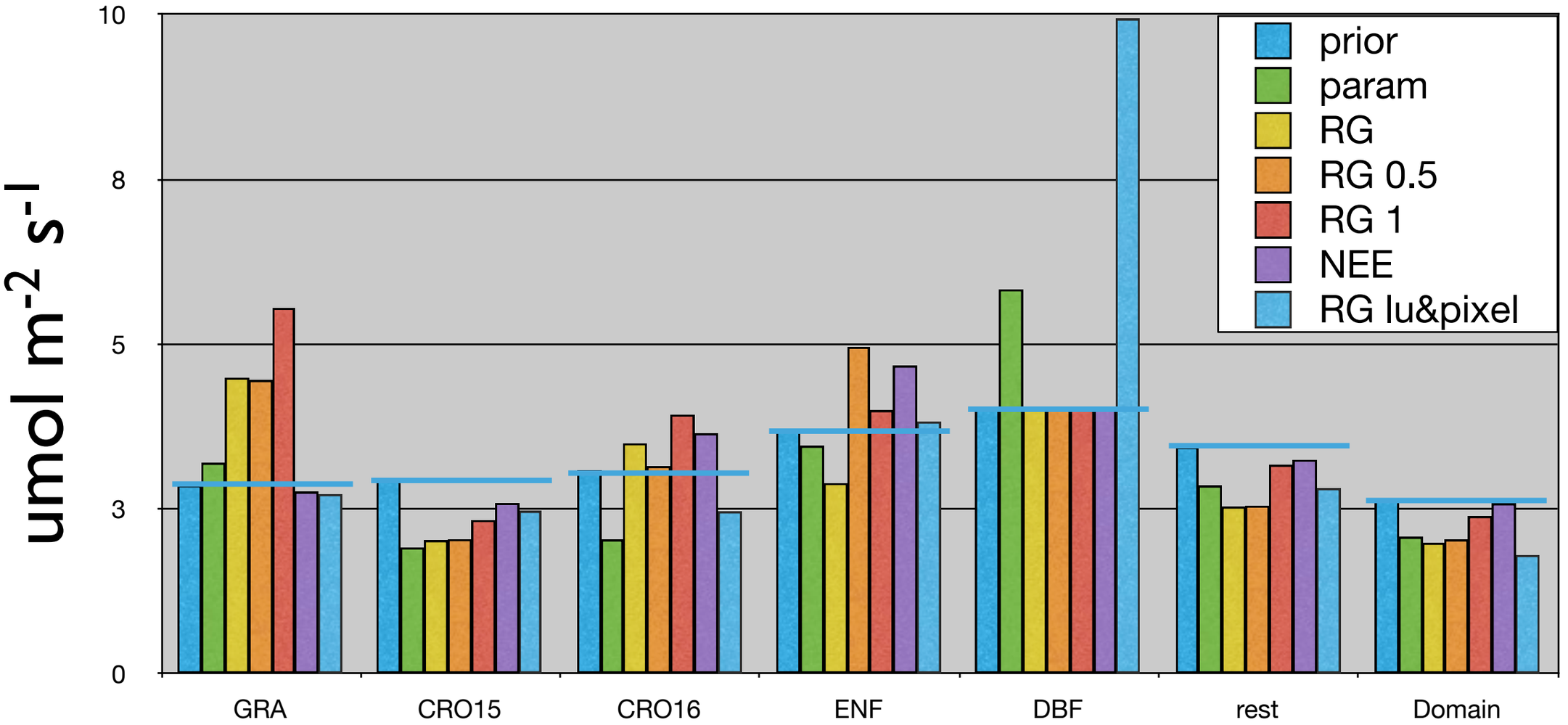
Param RG0.0 RG0.5 RG1.0 NEE RGpixel

Results: time average NEE



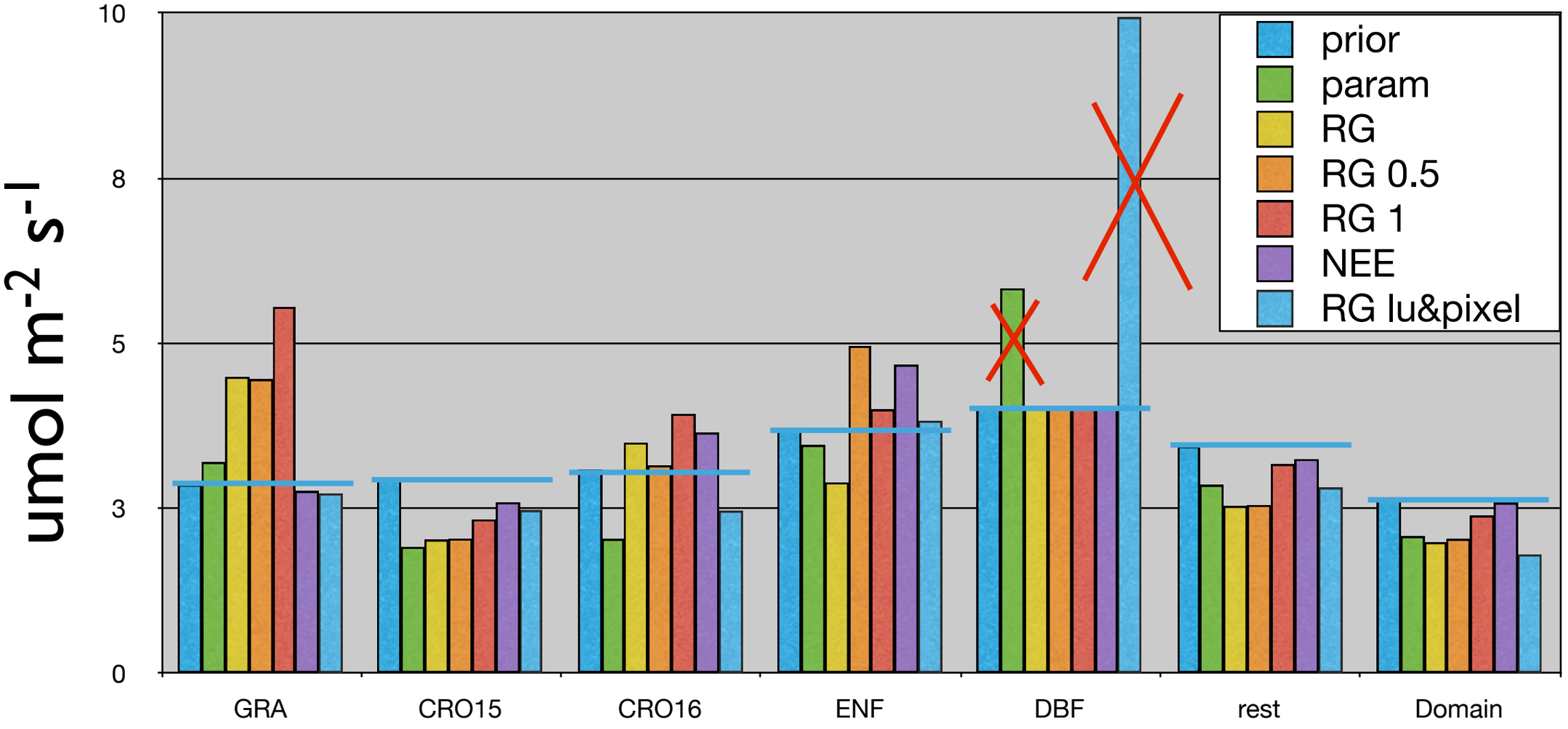
- All except NEE have improved over full domain
- No inversion with "correct" domain average
- RG0.0 and RG0.5 are right for the wrong reasons
- Biosphere parameter and RGpixel inversion most honest

Results: RMSD NEE



- NEE inversion shows least improvement from prior
- Other inversions mostly improve
- RGpixel best on total domain
- biosphere parameter best on largest land-use class

Results: RMSD NEE



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- Other inversions mostly improve
- RGpixel best on total domain
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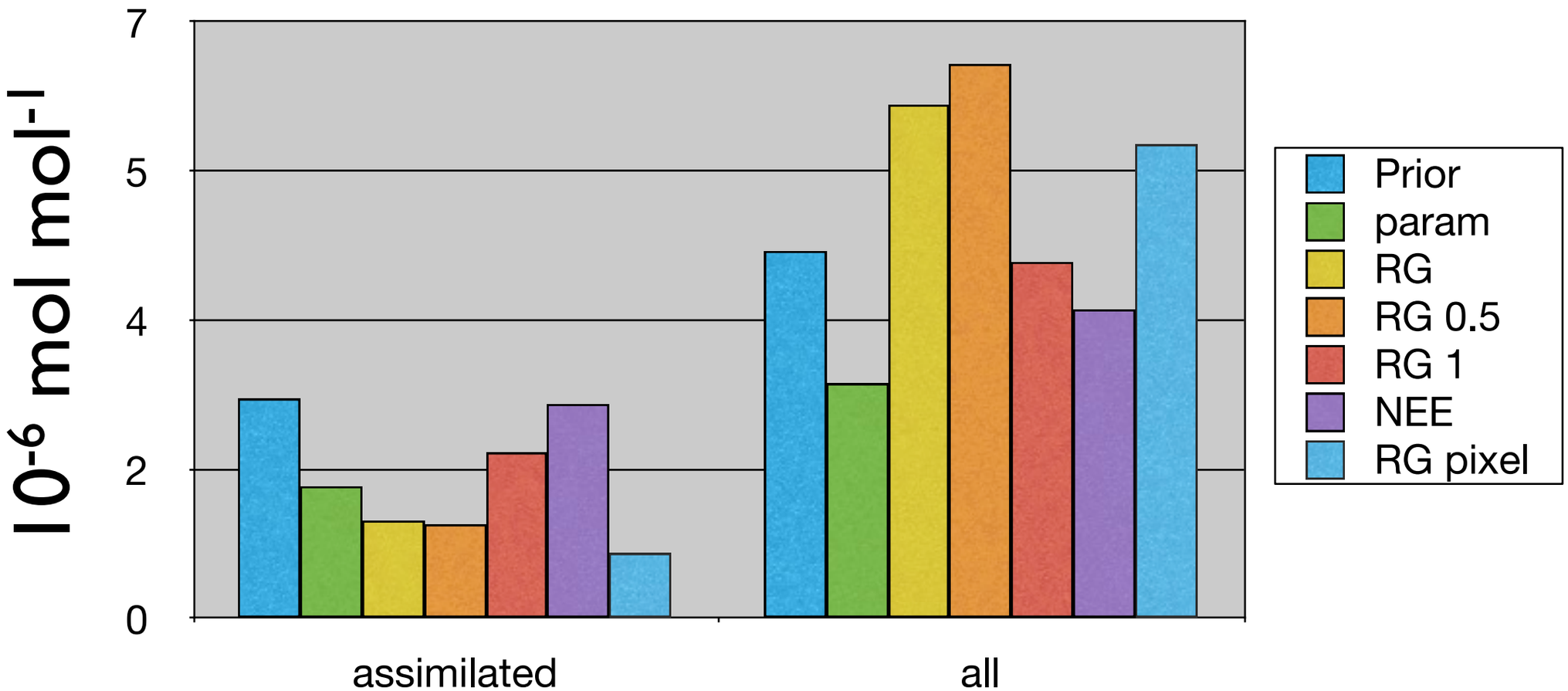
Results: RMSD CO_2 mole fractions



- NEE inversion does well against full CO_2 record
- RGpixel highest contrast between assimilated and all
- Other RG inversions also struggle
- biosphere parameter improves both metrics

Conclusions

- All inverse methods perform well in an 'ideal' experiment (not shown)
- All inverse methods deteriorate quickly when a-priori model structure (5PM) does not capture reality (FACEM) well
- Disadvantages of NEE inversion clear in this regional study
- Advantages of RGpixel inversion also clear, but CO_2 mole fraction results worrisome (propagation of wrong CO_2?)
- Biosphere parameter inversion seems to combine best of both worlds, but non-linearity is an issue to deal with
- Nighttime flux data (or a very good nocturnal PBL model) will be needed to obtain process information on GPP and R

Research Question

What is the best choice of inverse system to retrieve CO_2 fluxes over a limited time and space domain?

Are certain methods unsuitable?
What are the pitfalls of each method?
What can we expect in the best case?

Research Answer

→ Biosphere parameters or RGpixel

Are certain methods unsuitable?

NEE inversion works poorly

What are the pitfalls of each method?

NEE → not enough freedom, aggregation errors
All → overconfidence due to lack of model structure error
RG → unrealistic R and GPP fluxes that cancel each other*
bioparam → non-linearity of solution

What can we expect in the best case?

A reasonable domain integrated value and a reasonable land-use class integrated value, coupled with a CO_2 field that satisfies all observations. The limit is set by the unavoidable errors in biosphere model structure.

5PM structure