Inverse modeling of CO emissions

With a focus on biomass burning

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Outline

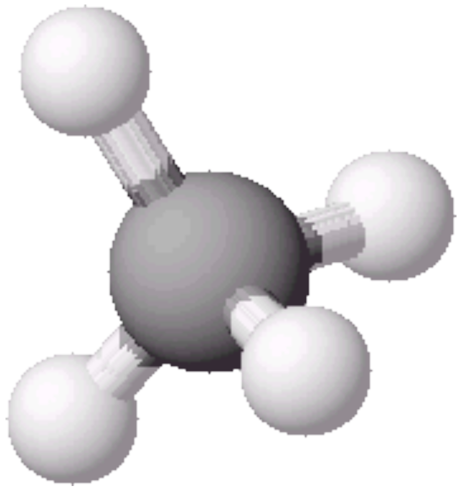
- CO from biomass burning (COBB):
  Introduction to the project
- 4DVAR - Optimization of CO emissions
- Results and experiments
- Conclusions & Outline

Project Goal:

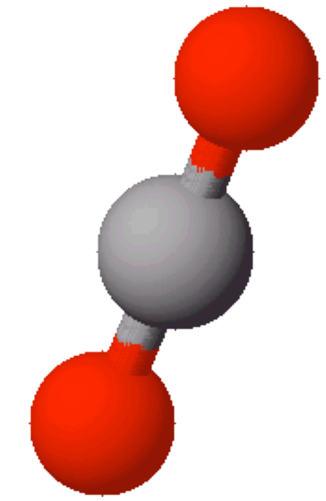
Study the magnitude, trend and variability in biomass burning.

Fire emitted species: CO_2, CH_4 (greenhouse gases)

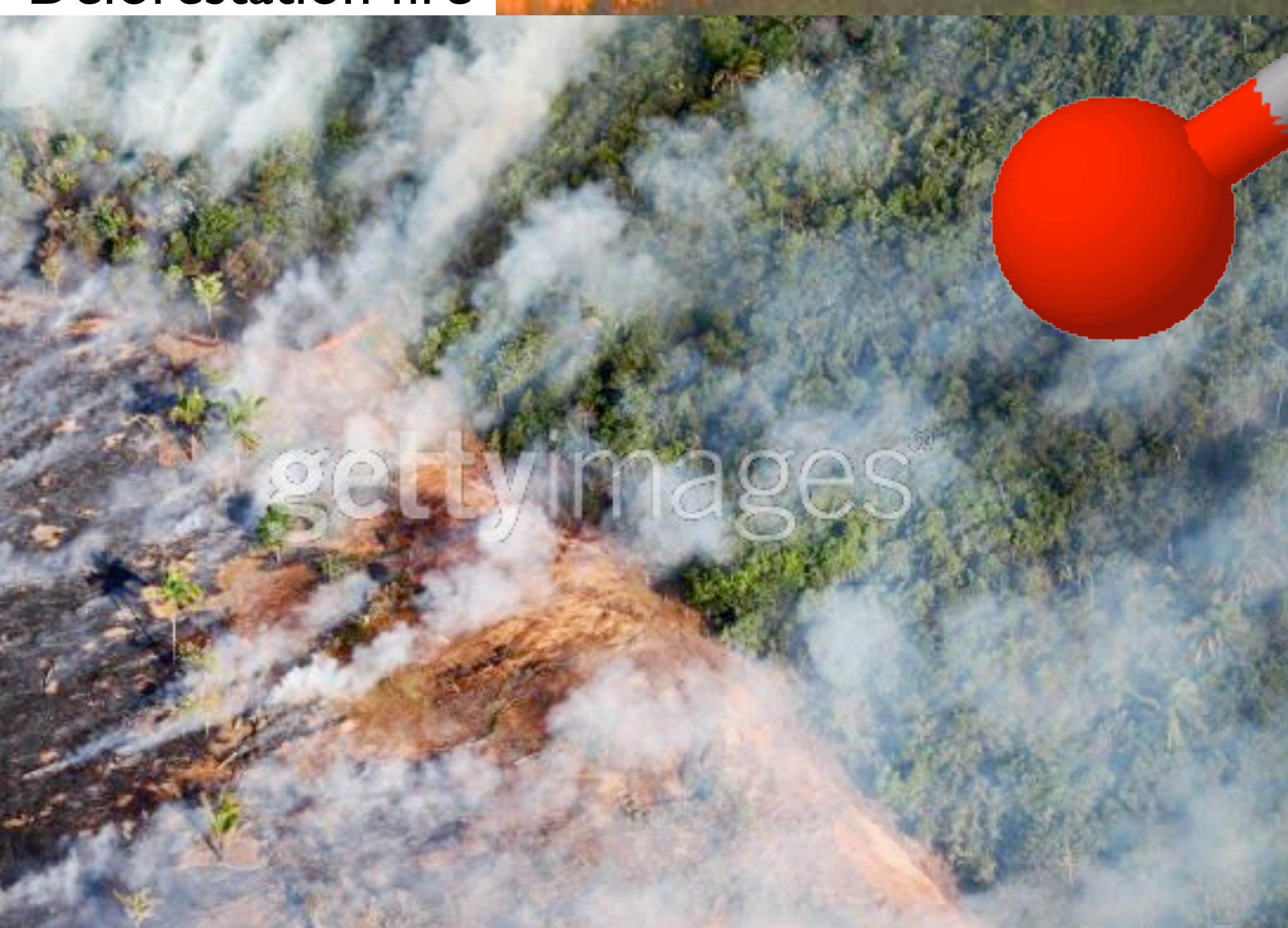
CO, NOx, NMVOCs, aerosols



Boreal forest fire



Deforestation fire

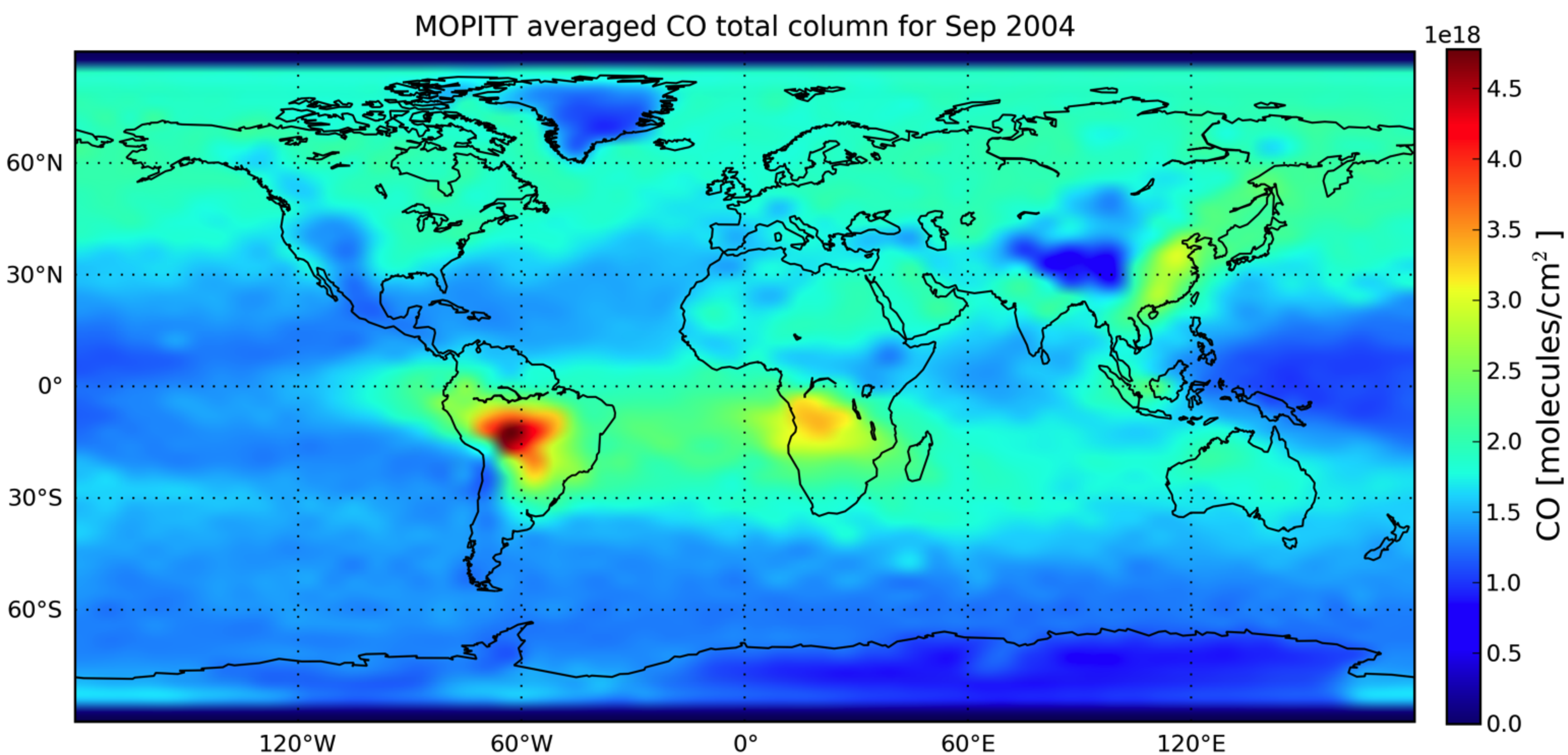


Savannah fire

Why do we use CO as a tracer?

CO: 2 month lifetime meaning

- concentration gradient due to emissions
- intercontinental transport of CO



CO: sources & sinks

- Fossil fuel & biofuel combustion
- Biomass burning

2D emissions

Annual emissions = 1000-1500 Tg CO

- Oxidation of methane
- Oxidation of NMVOCs

3D emissions

Annual emissions = 1000-1500 Tg CO

Oxidation of CO by OH main sink: 90%
Additional 10% by dry deposition

How do we compute emissions of CO?

Bottom-up:

Using burnt area, fuel loads, emission factors and upscaling

Large discrepancies

Top-down:

Using atmospheric measurements to constrain emissions

Top-down approach

"Adjust emissions in such a way that the misfit between the model and observations is minimal"

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from a bottom-up inventory

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TM5

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surface sites, ship, aircraft, satellite

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Find the vector x that minimizes J:

$$\mathcal{J}(\mathbf{x}) = (\mathbf{y} - \mathbf{H}\mathbf{x})^\top \mathbf{R}^{-1} (\mathbf{y} - \mathbf{H}\mathbf{x})$$

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Far less measurements available than variables to optimize:
Problem is ill-conditioned.

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x = unknown emissions
x_b = prior emissions
B = a priori error covariance matrix

y = observations
H = TM5 model
R = observation error covariance matrix

- Run the model with prior emissions (Hx_b) and compare the output with the observations y.

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- Validate results: compare optimized emissions with a set of independent observations.

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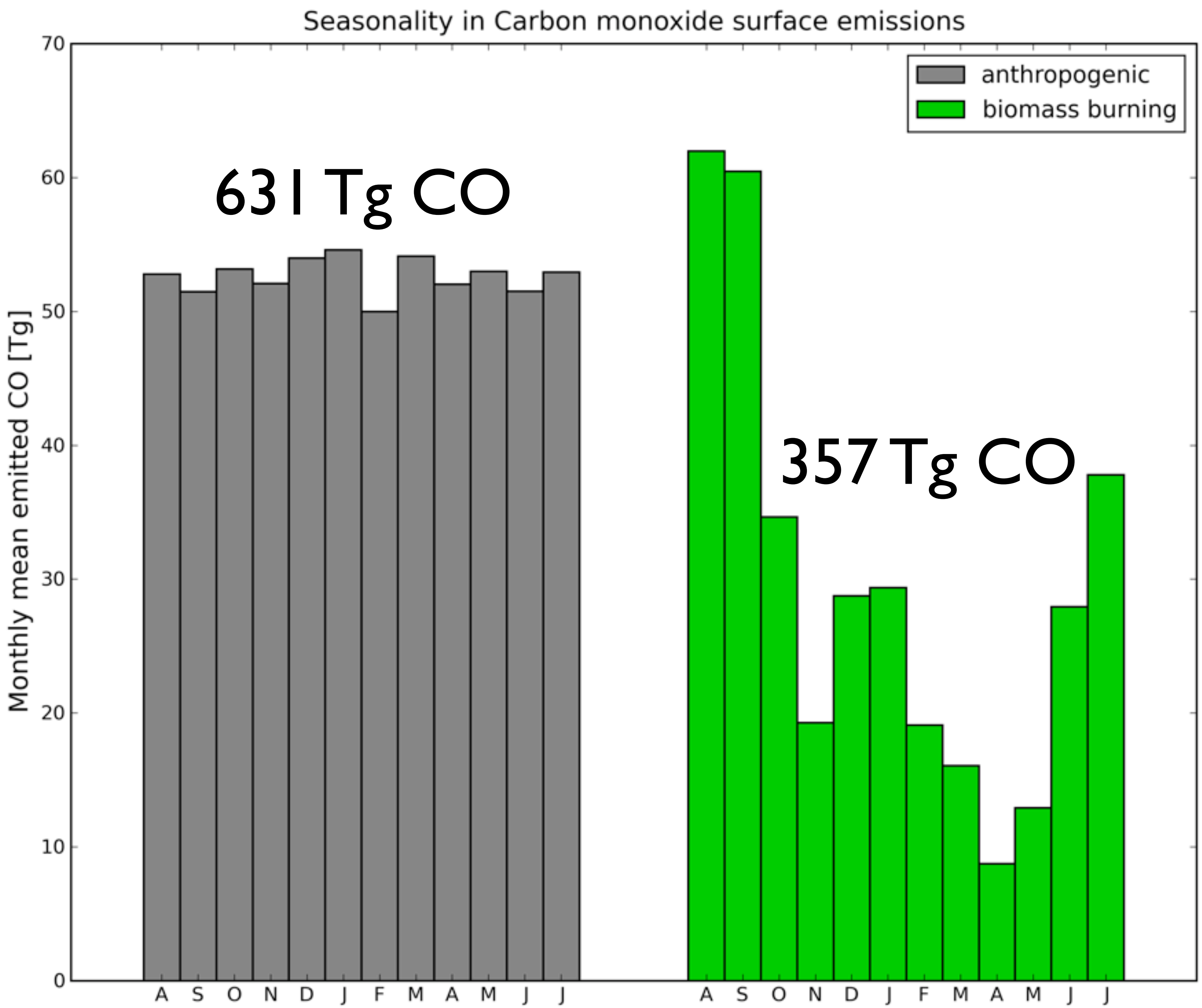
Prior emissions:



Direct sources:

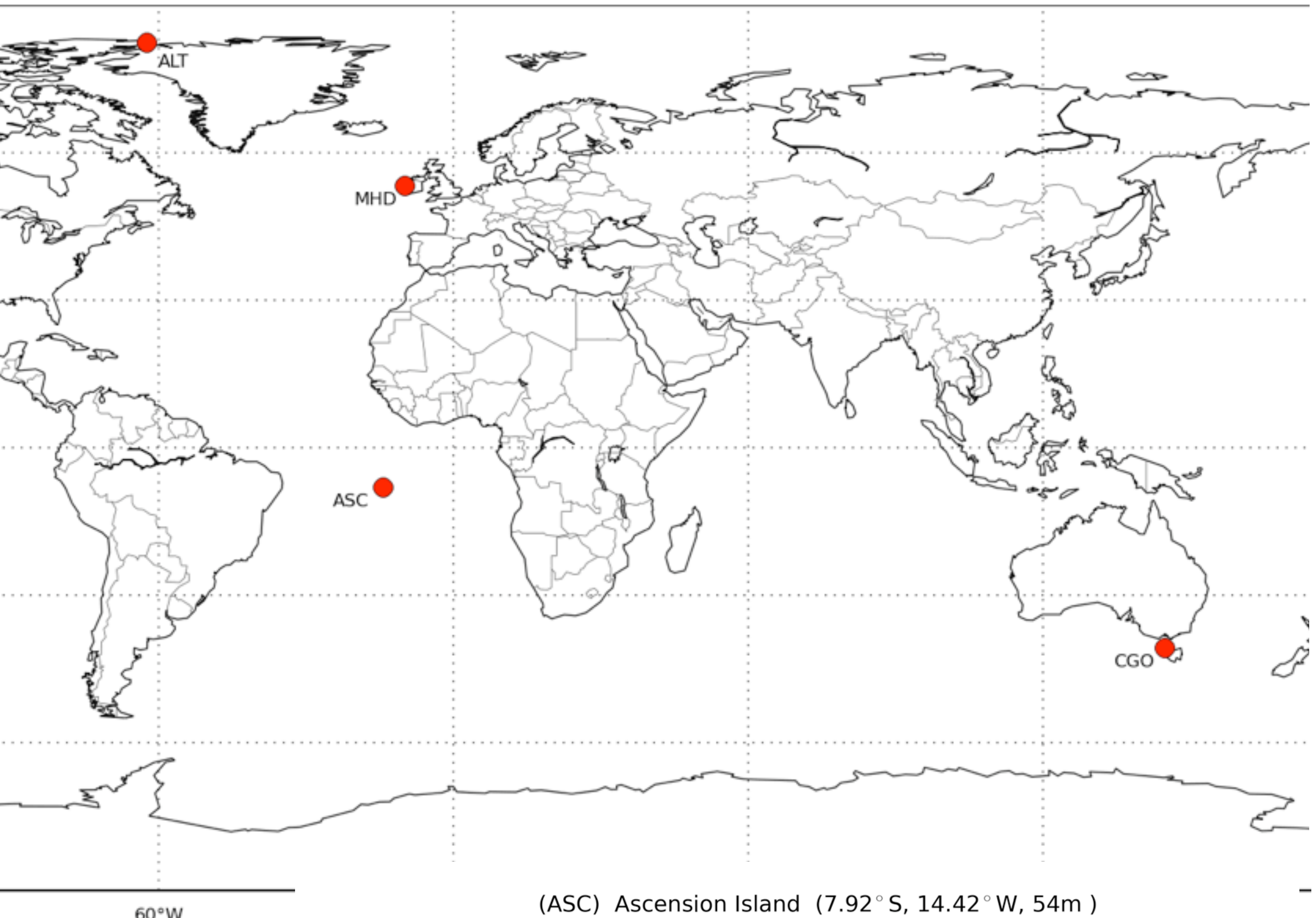
- Fossil fuel/biofuel combustion (anthropogenic) EDGARv3.2
- Biomass burning GFED3

Indirect sources:

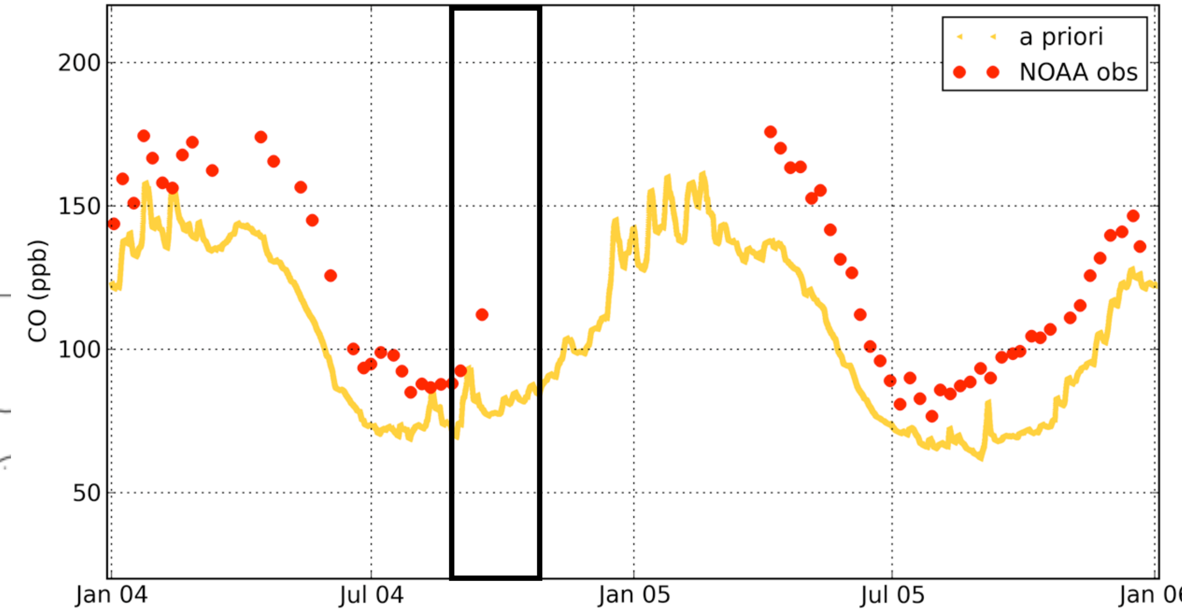
- CO from oxidation of CH_4
- CO from oxidation of NMVOC (not yet)

Forward simulation 2004-2006

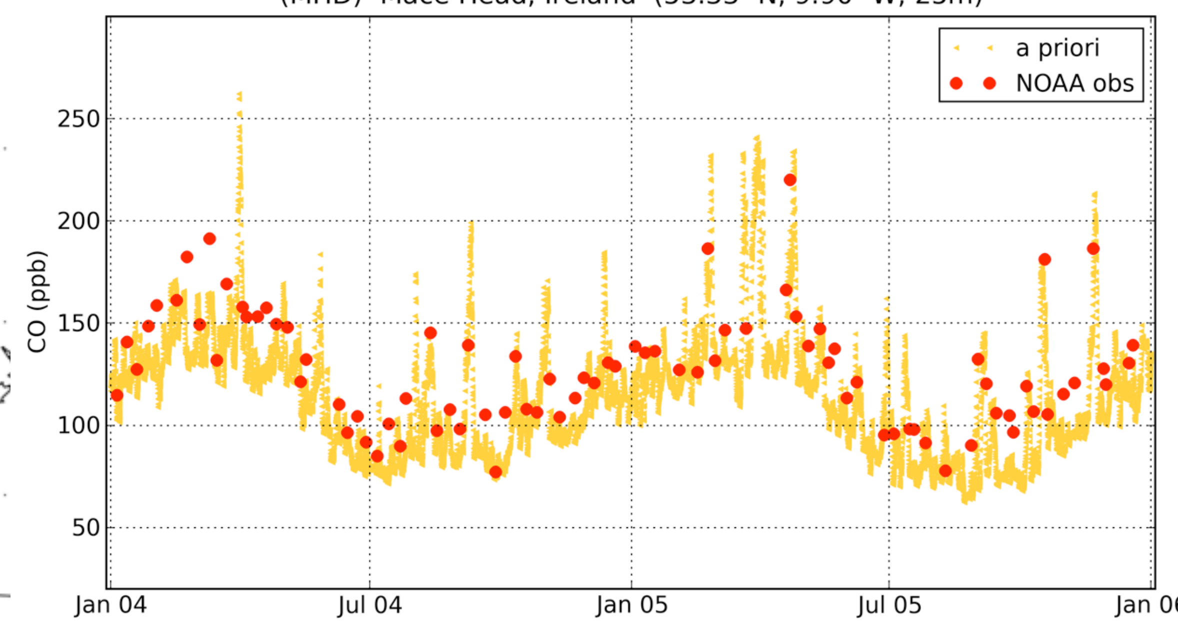
Surface network stations



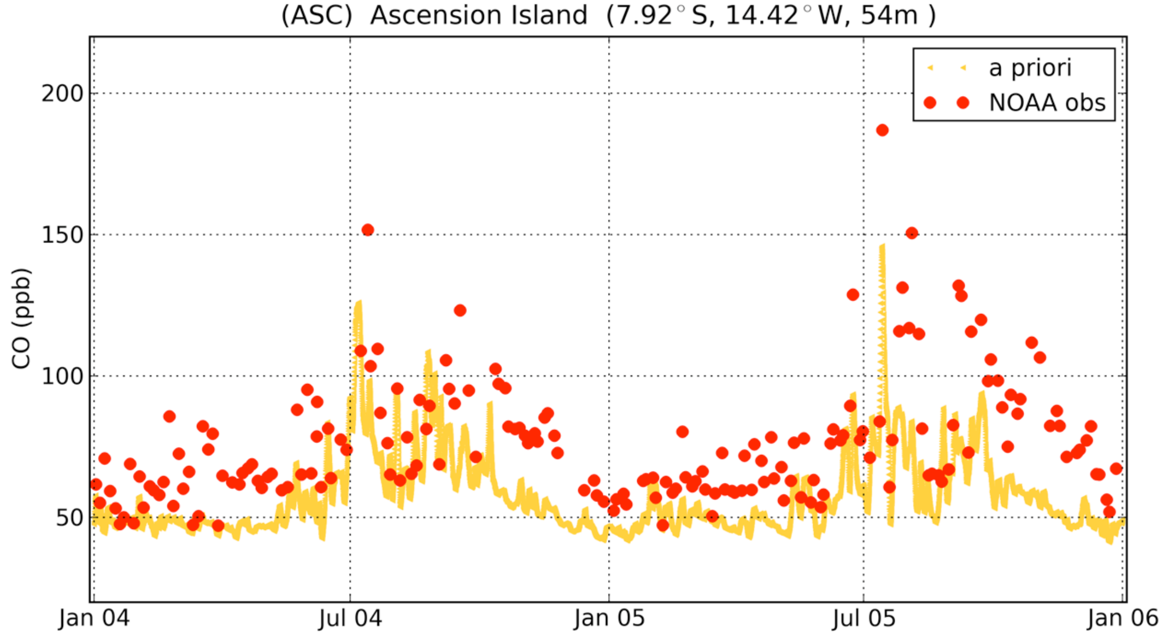
(ALT) Alert, Canada (82.45° N, 62.52° W, 210m)



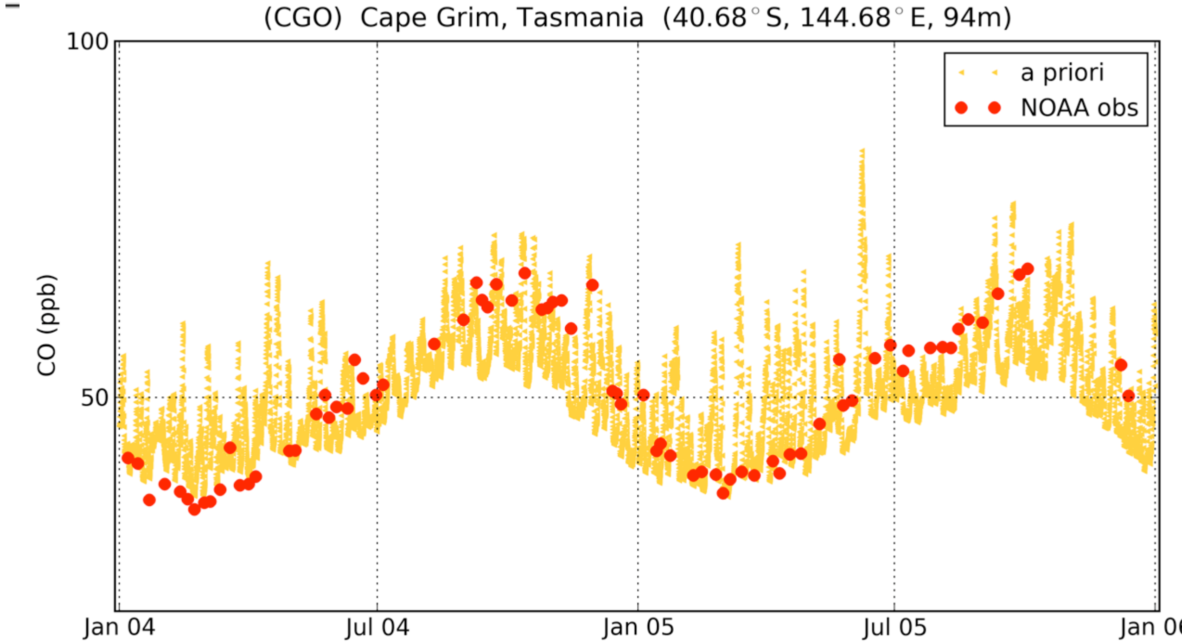
(MHD) Mace Head, Ireland (53.33° N, 9.90° W, 25m)



(ASC) Ascension Island (7.92° S, 14.42° W, 54m)

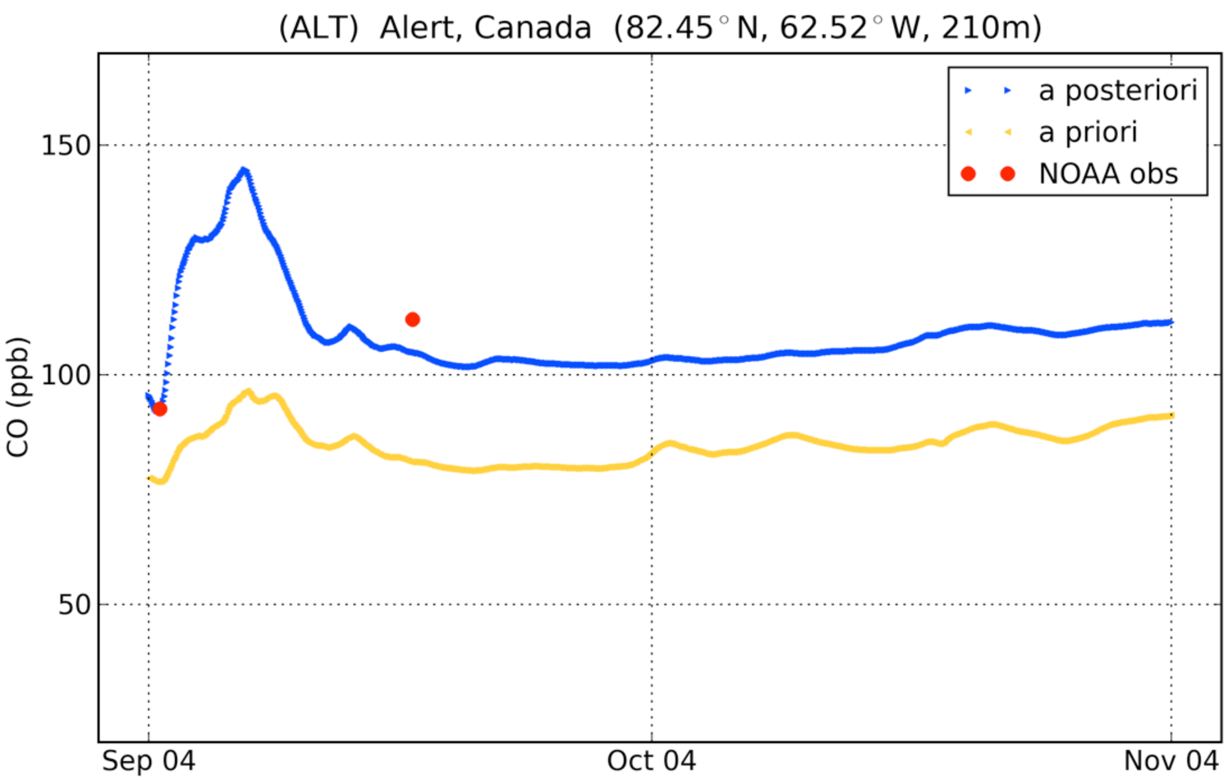


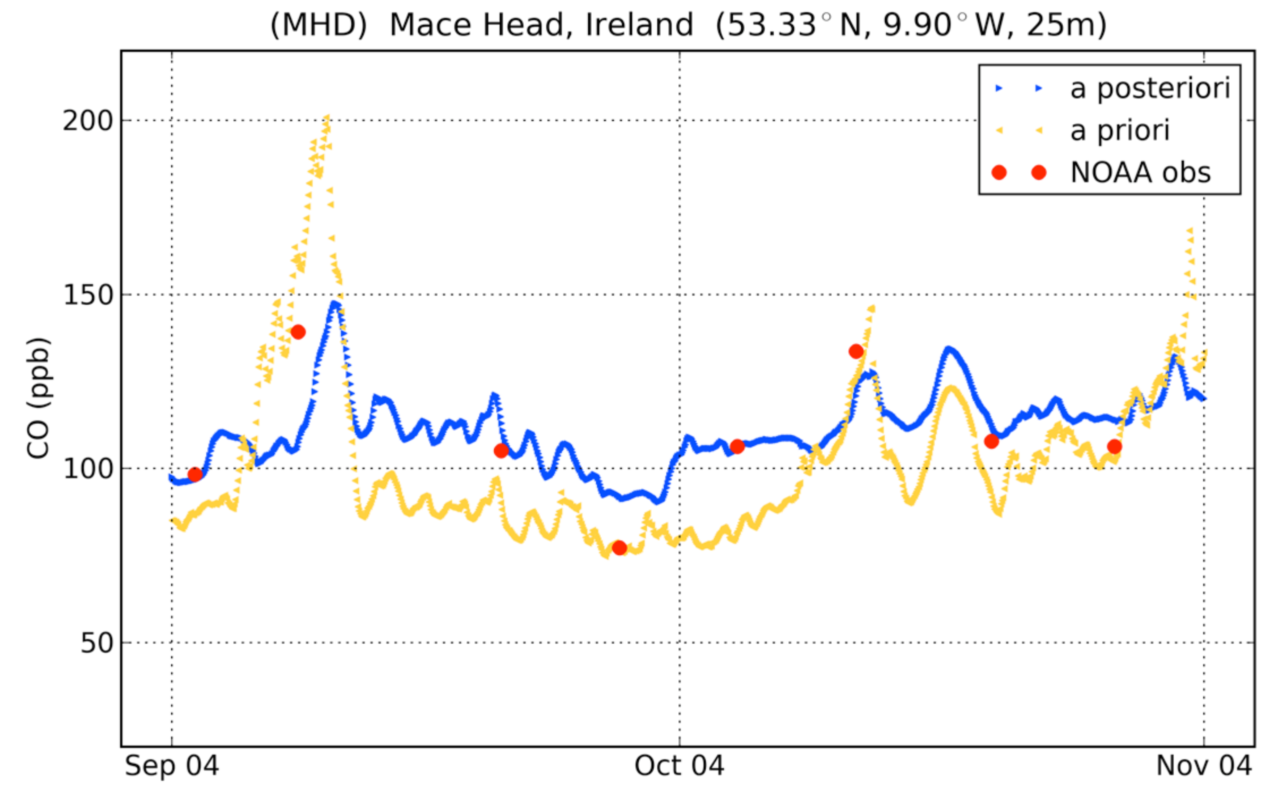
(CGO) Cape Grim, Tasmania (40.68° S, 144.68° E, 94m)

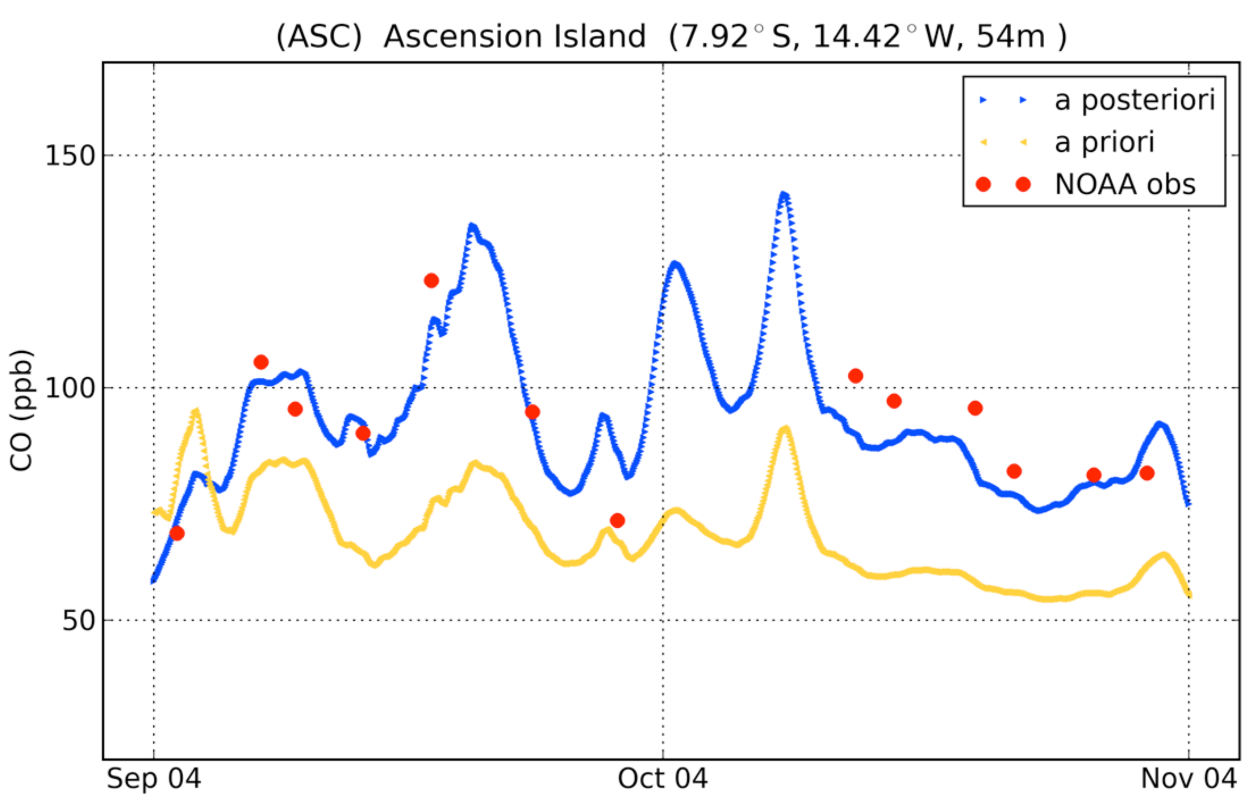


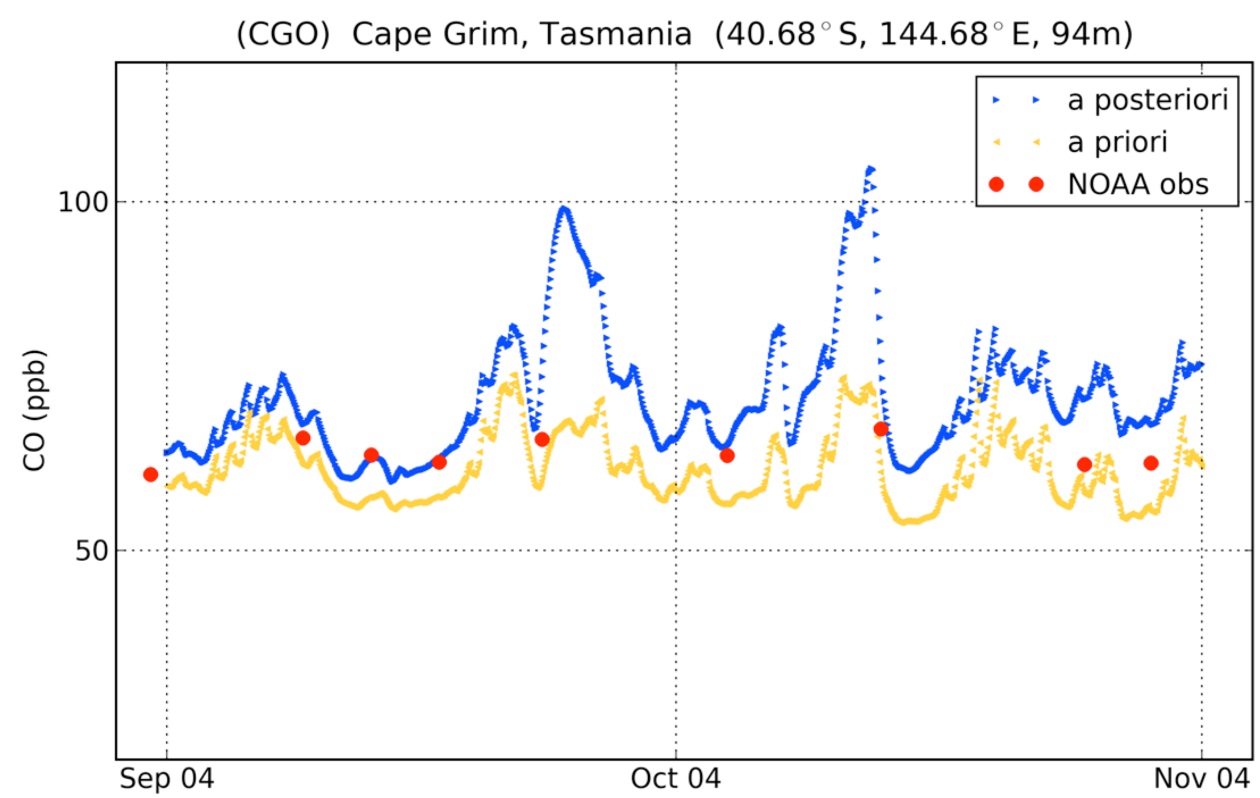
Optimize emissions iteratively: start with $x=x_b$
change x to find minimum of $J(x)$

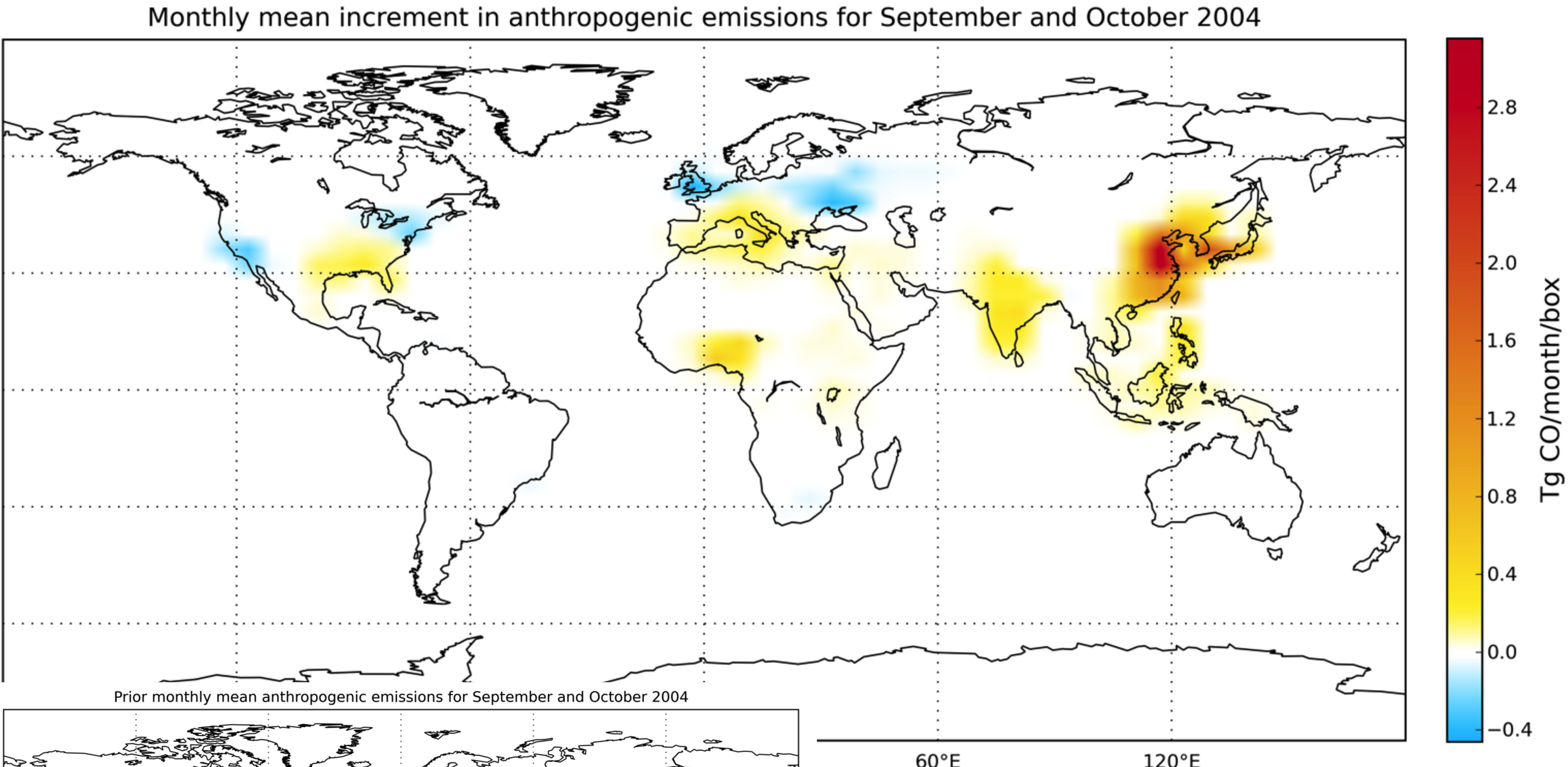
Improved fit with observations

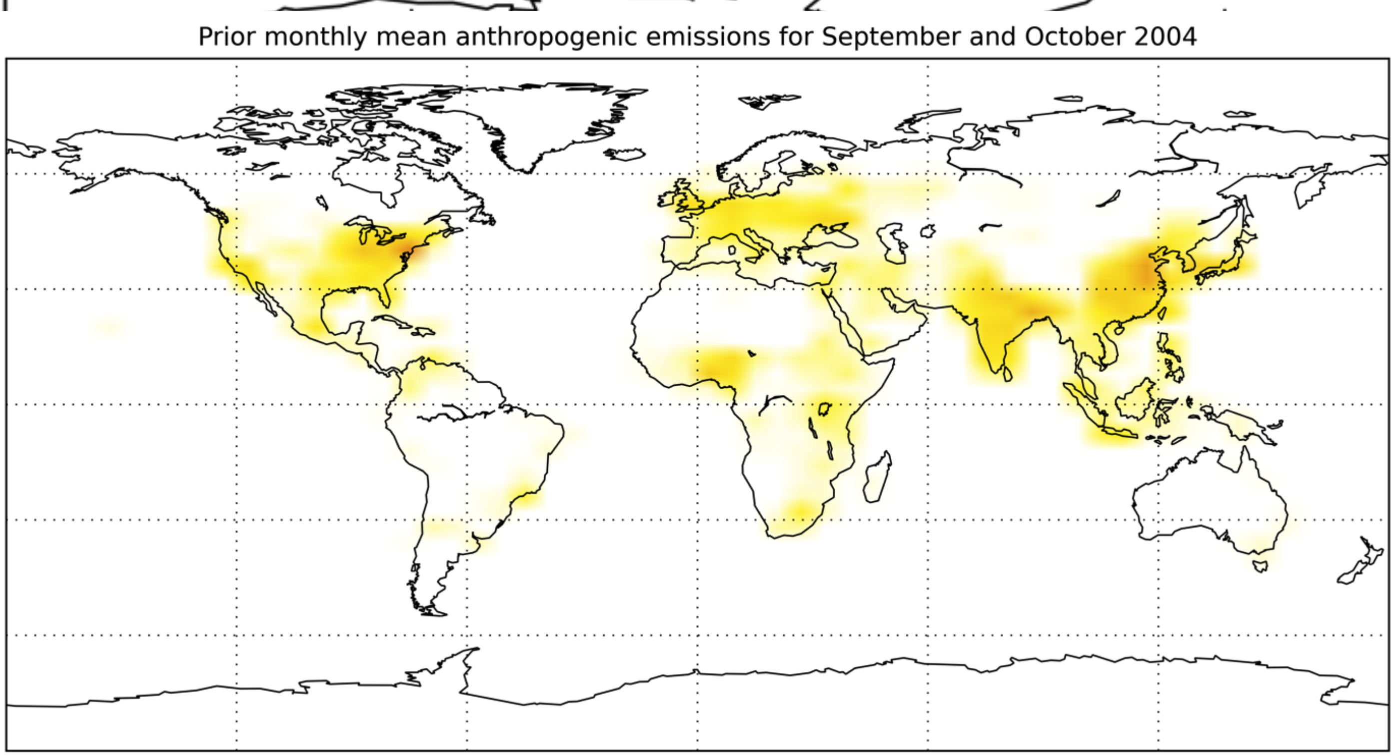






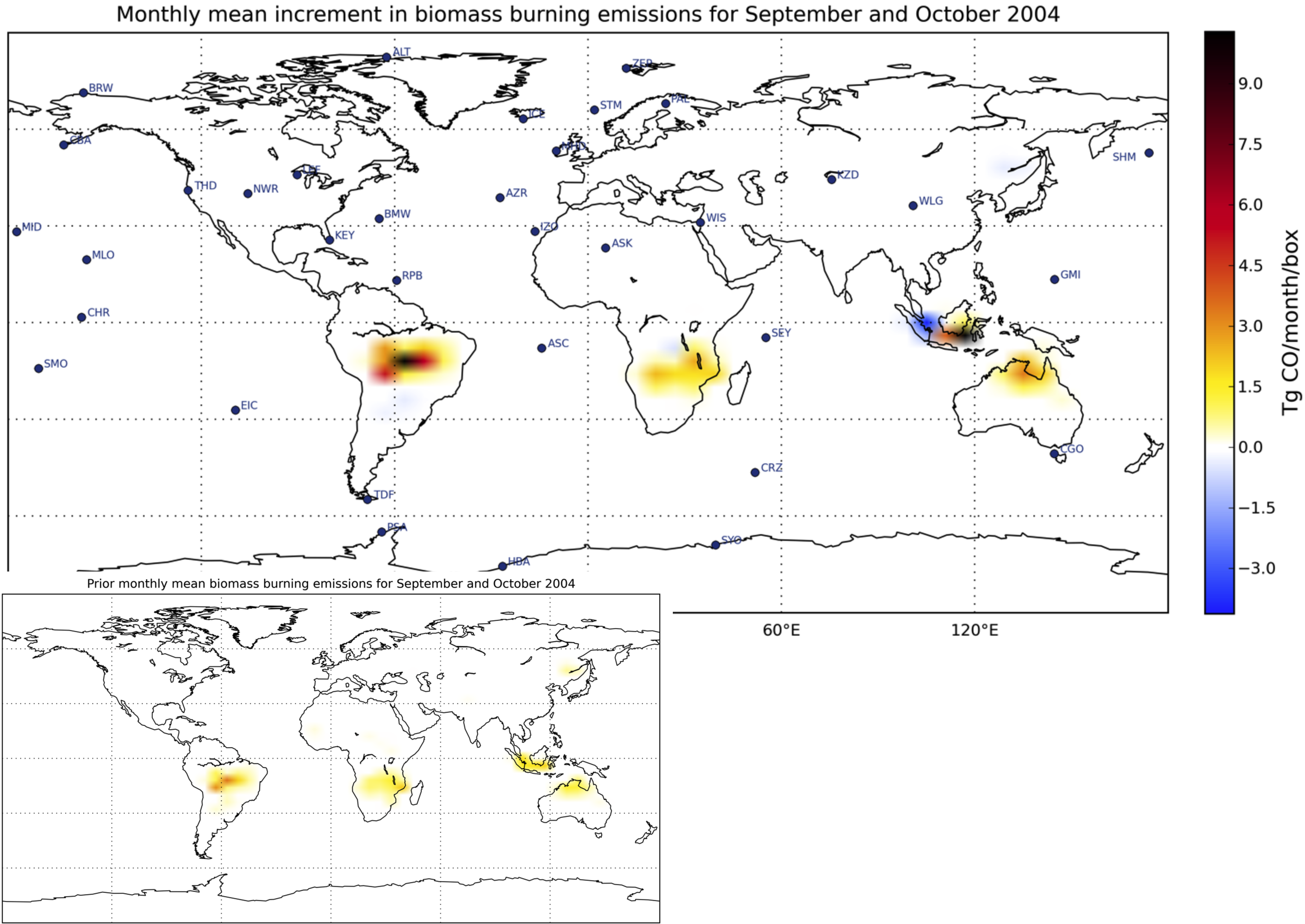






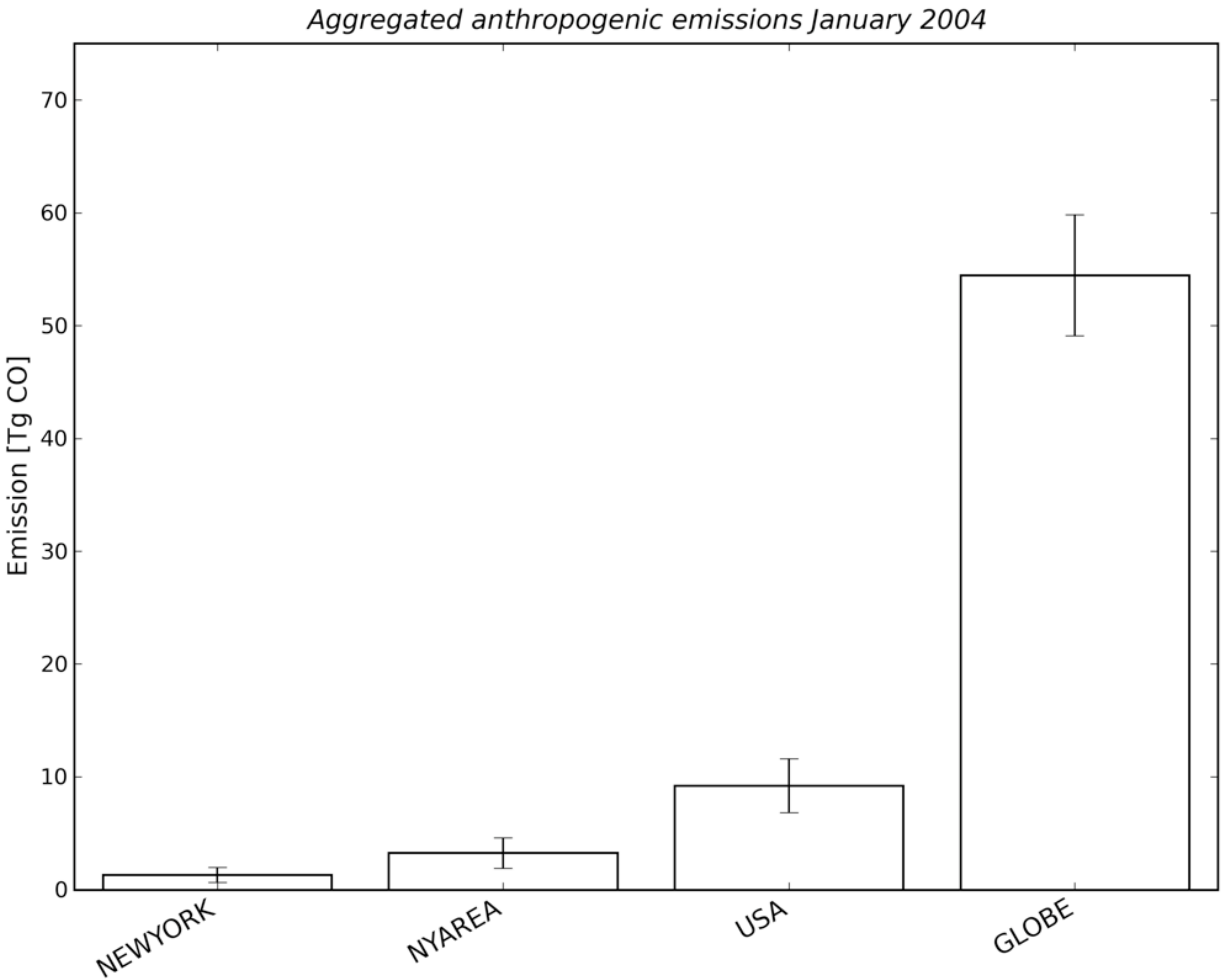
Top: anthropogenic emission increment

Bottom: prior anthropogenic emission

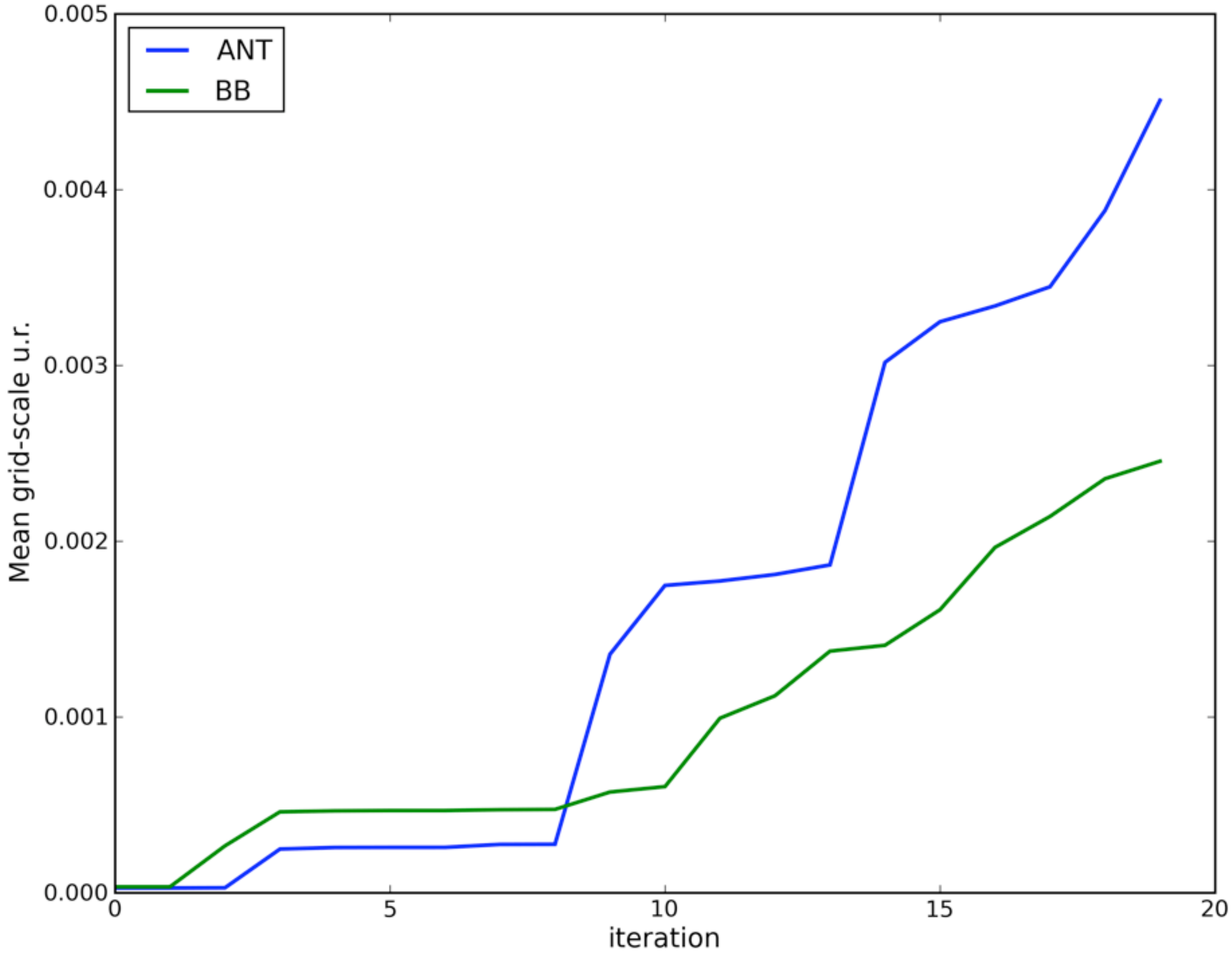

Monthly mean increment in biomass burning emissions for September and October 2004
ALT
ZEP
BRW
ICE
STM
PAL
CBA
MHD
SHM
LEF
KZD
THD
NWR
AZR
WLG
BMW
WIS
MID
IZO
KEY
ASK
MLO
RPB
GMI
CHR
SEY
ASC
SMO
EIC
CGO
CRZ
TDF
PSA
SYO
HBA
60°E
120°E
9.0
7.5
6.0
4.5
3.0
1.5
0.0
−1.5
−3.0
Tg CO/month/box
Prior monthly mean biomass burning emissions for September and October 2004

Uncertainty reduction: What about the errors?

Aggregated prior emission

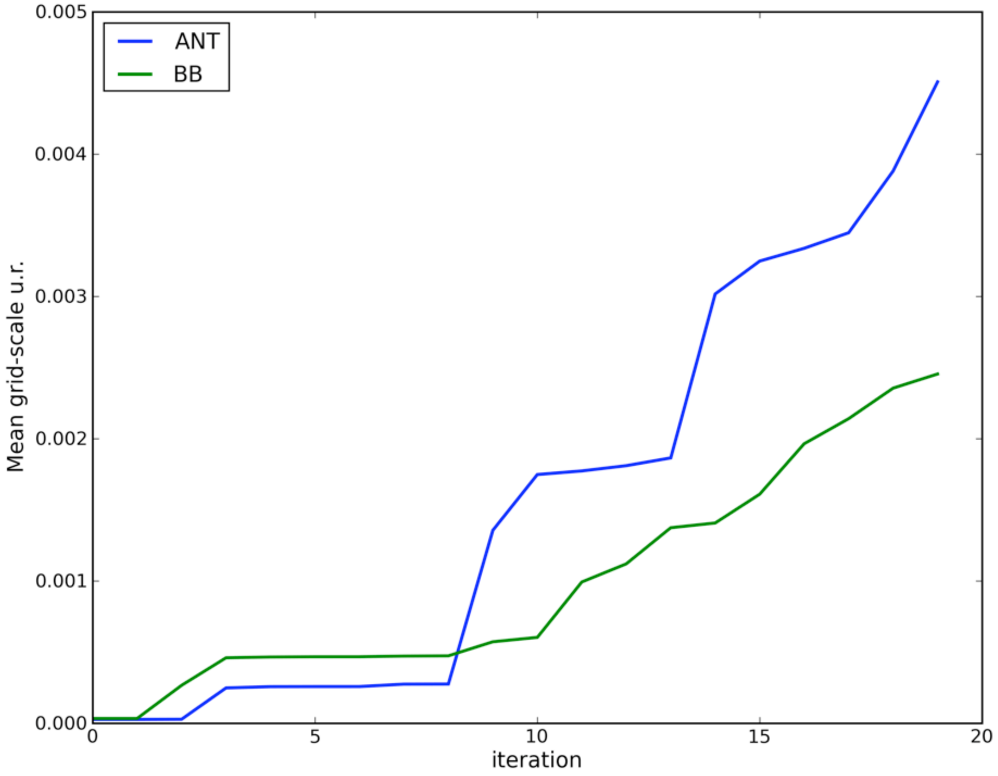


Uncertainty reduction



Convergence off 99% only

Uncertainty reduction



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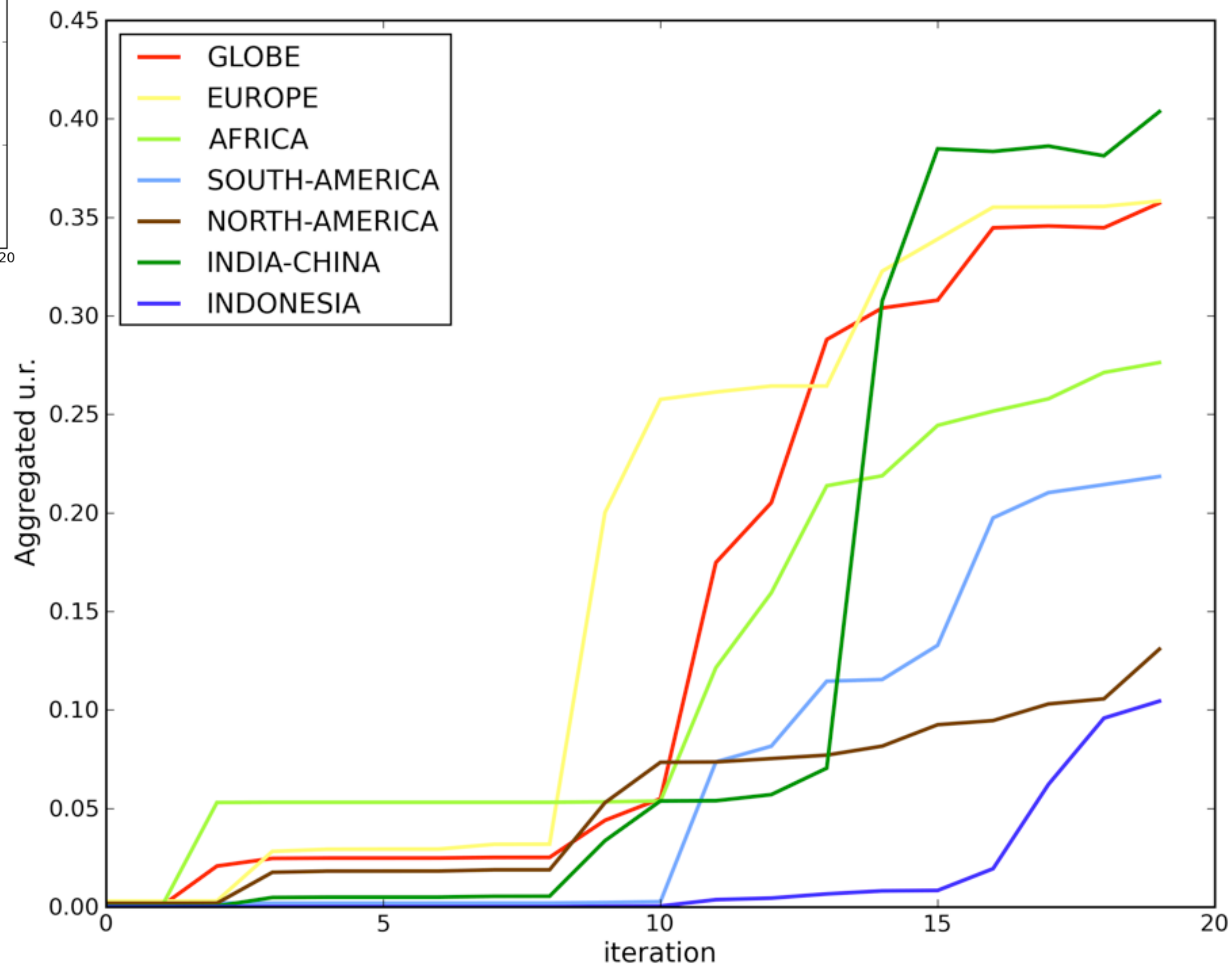
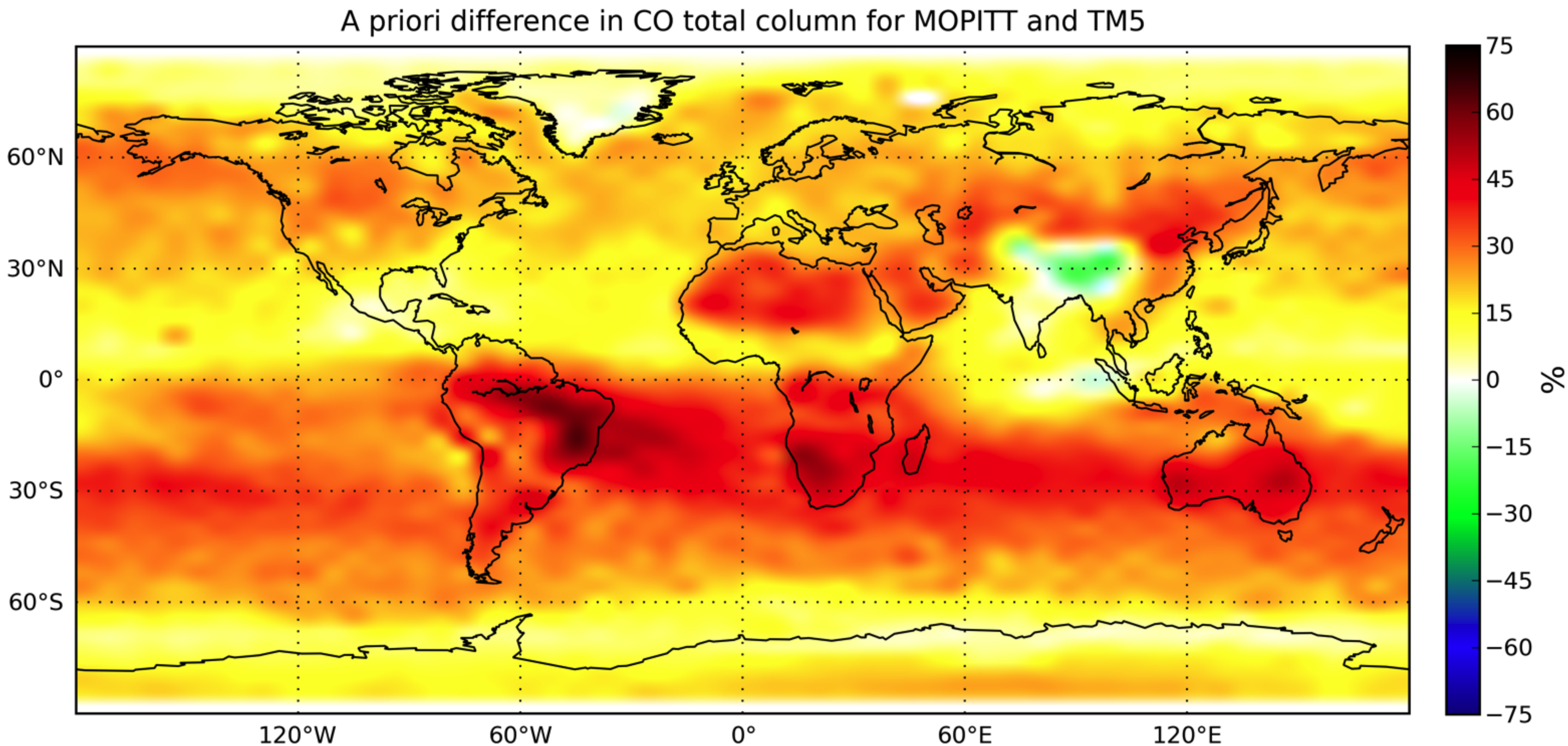
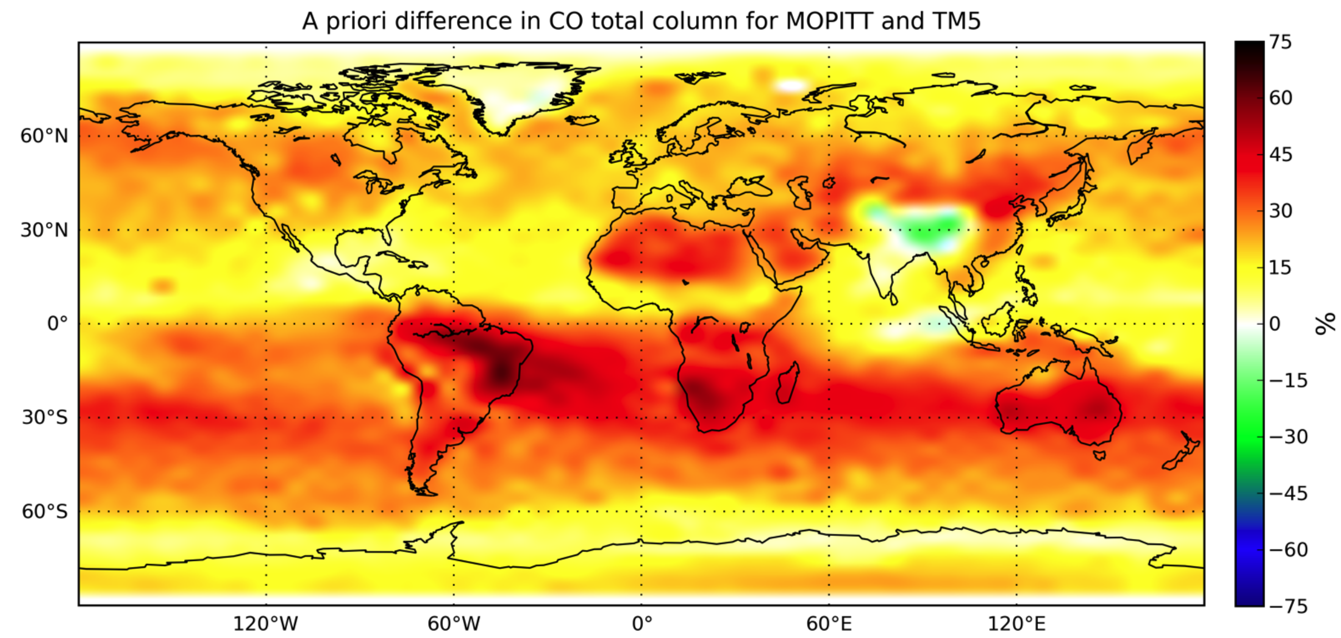


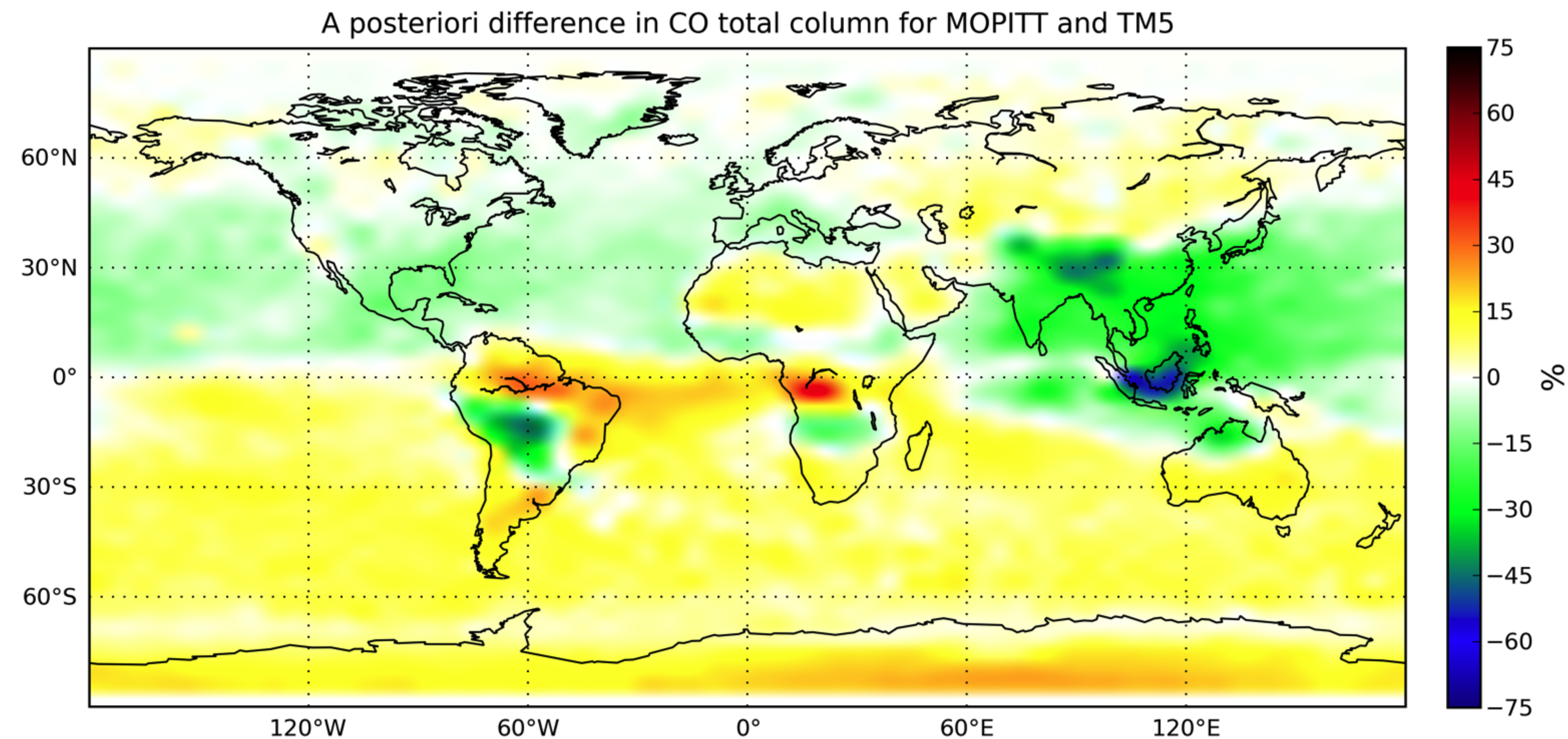
Validate results: compare optimized emissions with a set of independent observations



2-monthly mean CO total column: difference between MOPITT and TM5 (%)



Global mean difference decreases from 22% to 8%, large local differences remain.



CONCLUSIONS

- TM5-CO version nearly complete, CO from NMVOC to be implemented.

- Forward model agrees well with observations, too low on NH up to 25%.

- Inversion using station data improve agreement between observations and the model.

- Validation with MOPITT V4 shows that the optimized emissions are better in line, but large local differences remain.

Next...

- Include CO source from NMVOC oxidation.
- Apply a vertical distribution of biomass burning emissions.
- Optimize emissions for 1 or 2 years.
- Use satellite data (MOPITT/SCIAMACHY) to constrain emissions more.