First inversion results for CO...

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Outline

(1) TM5 CO simulations for 2004
(2) Comparison with surface data
(3) Comparison with MOPITT data

(4) Inverting CO emissions:

- Vertical profile for BB emissions
- Adjoint modeling
- State vector
- First results

TM5 CO forward

Sources and sinks

- Direct CO emissions:

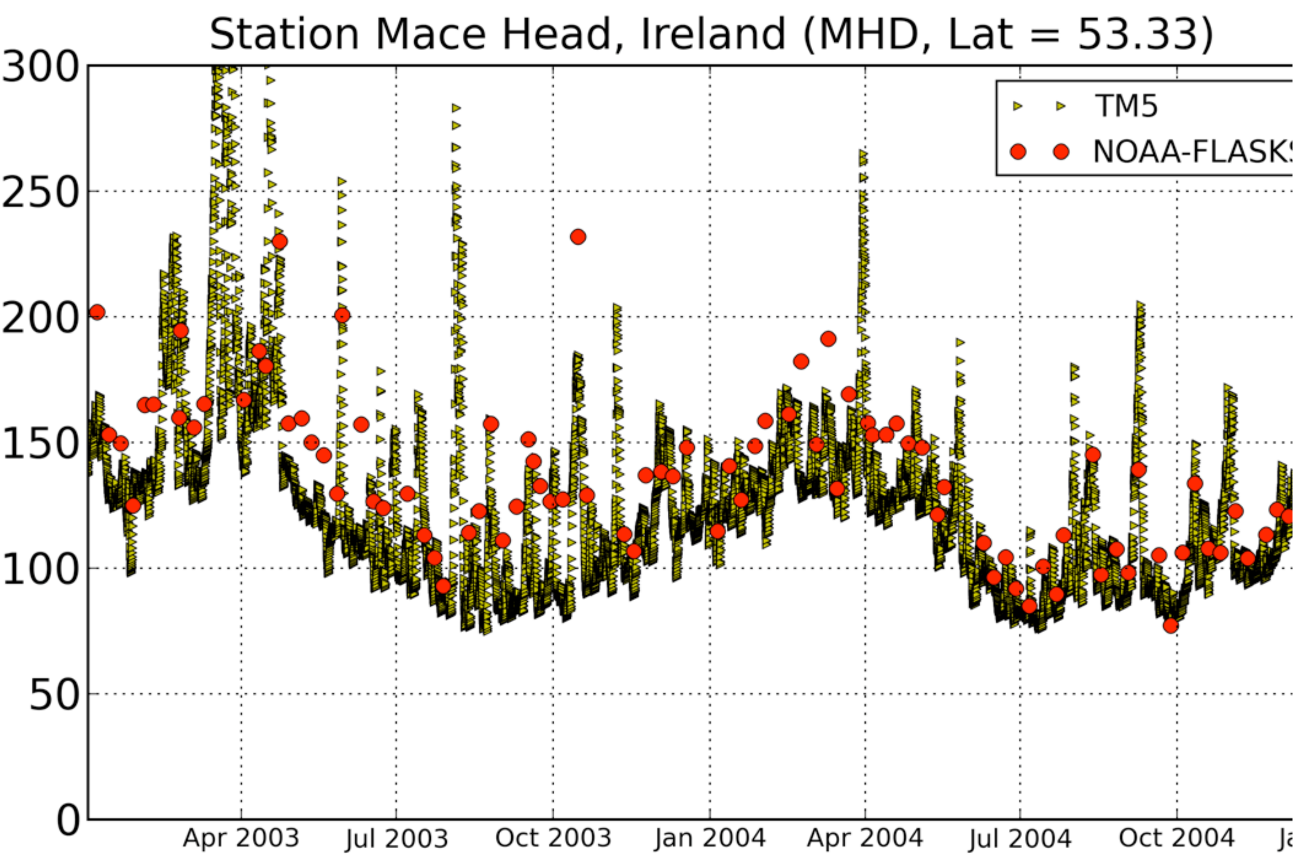
  EDGAR3 (Fossil fuel/biofuel combustion)
  GFED3 (Biomass burning)

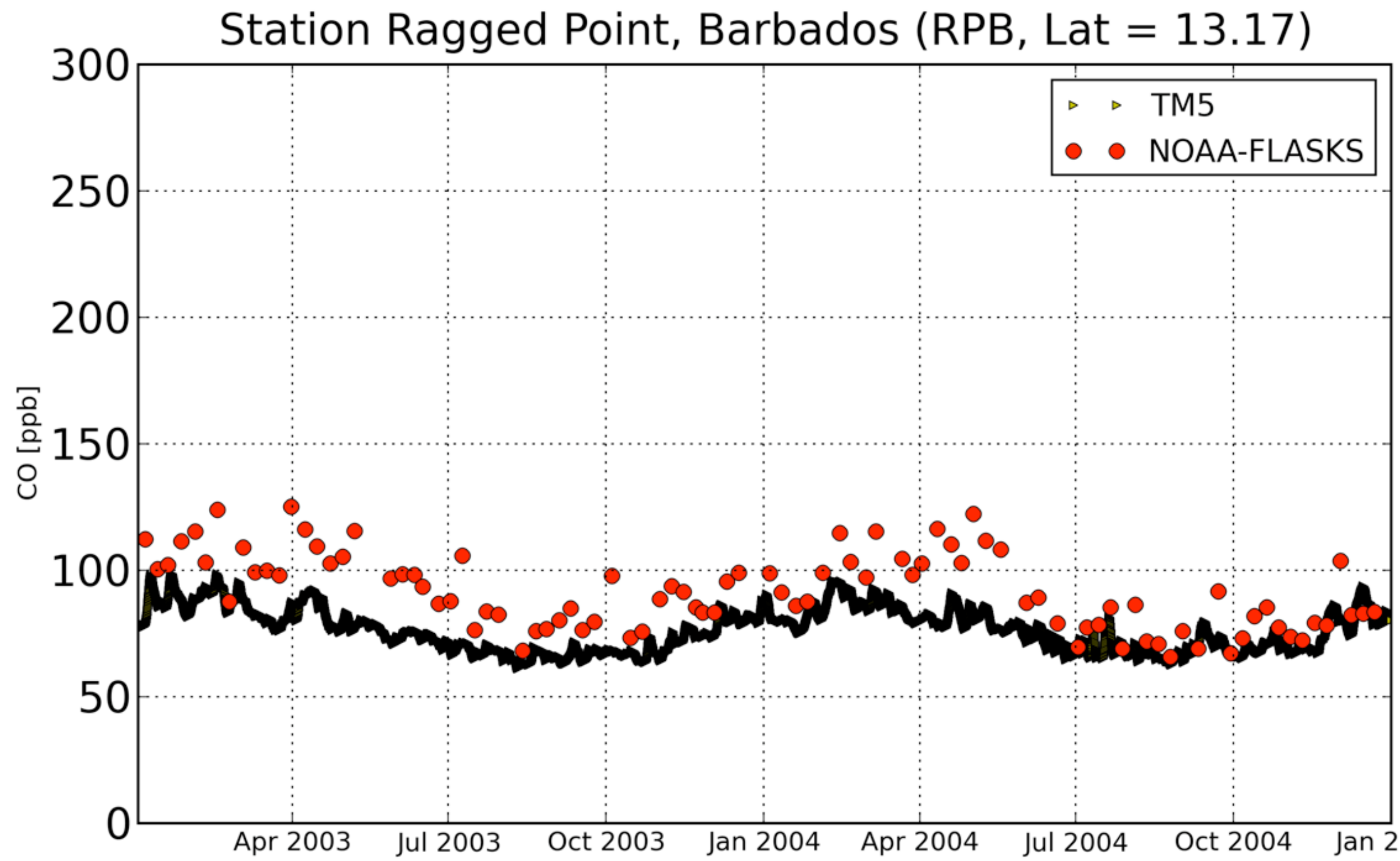
- CO from atmospheric oxidation of:

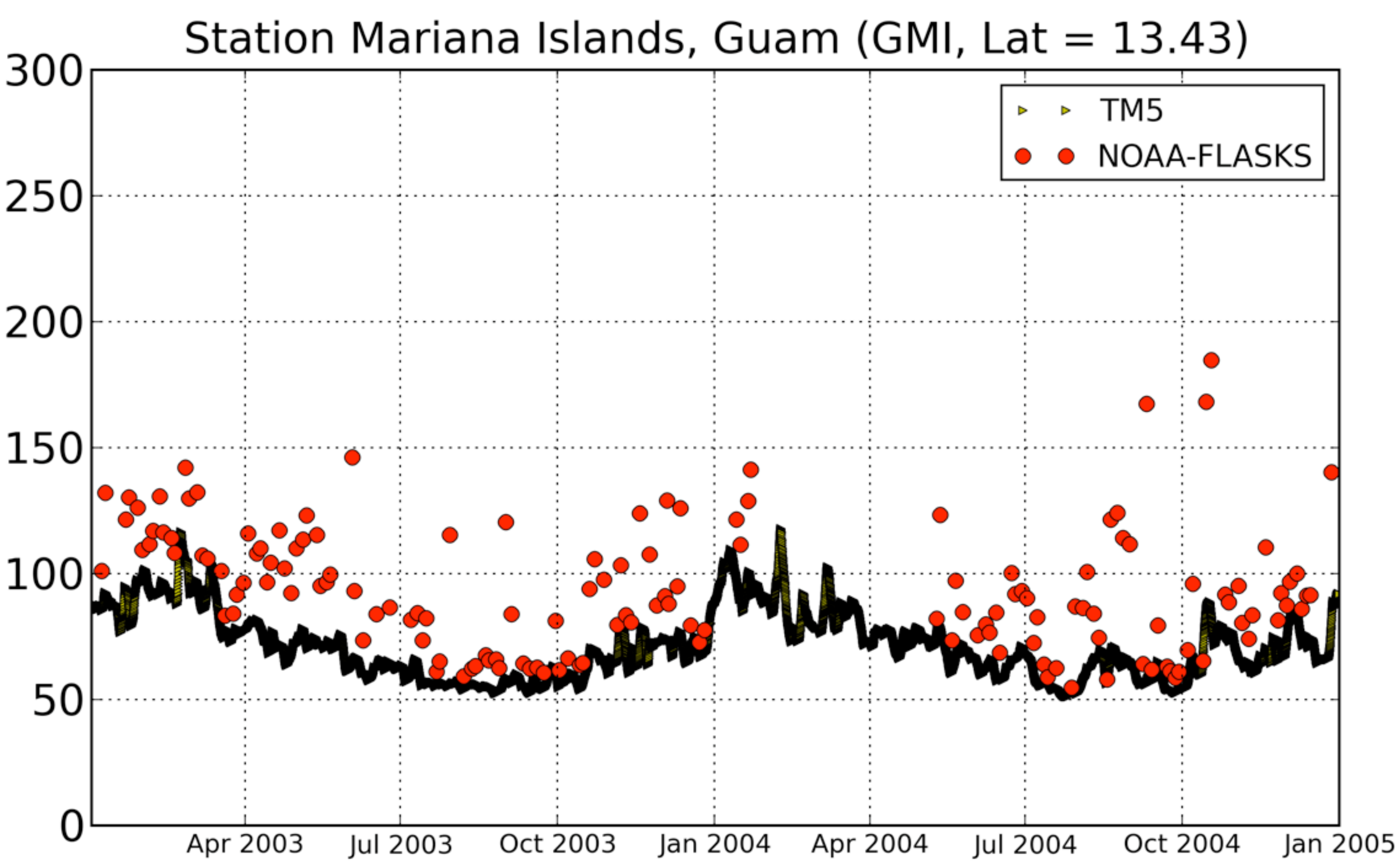
  CH_4=1800 ppb + OH --> CO
  ISOP(NO_x) + OH --> CO

- monthly OH climatology (Spivakovsky, scaled by 0.92)
- Deposition

Simulating CO (2004)

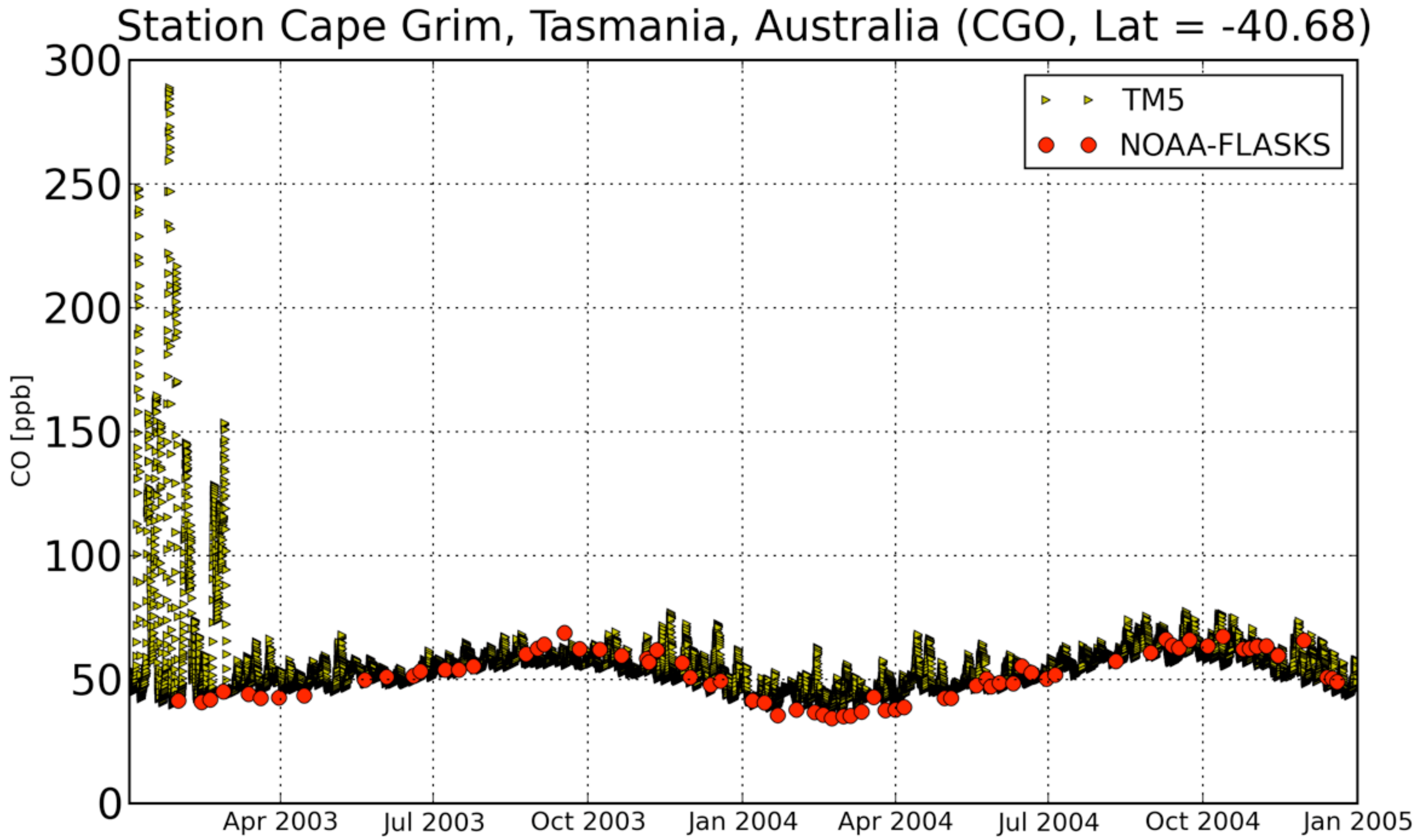




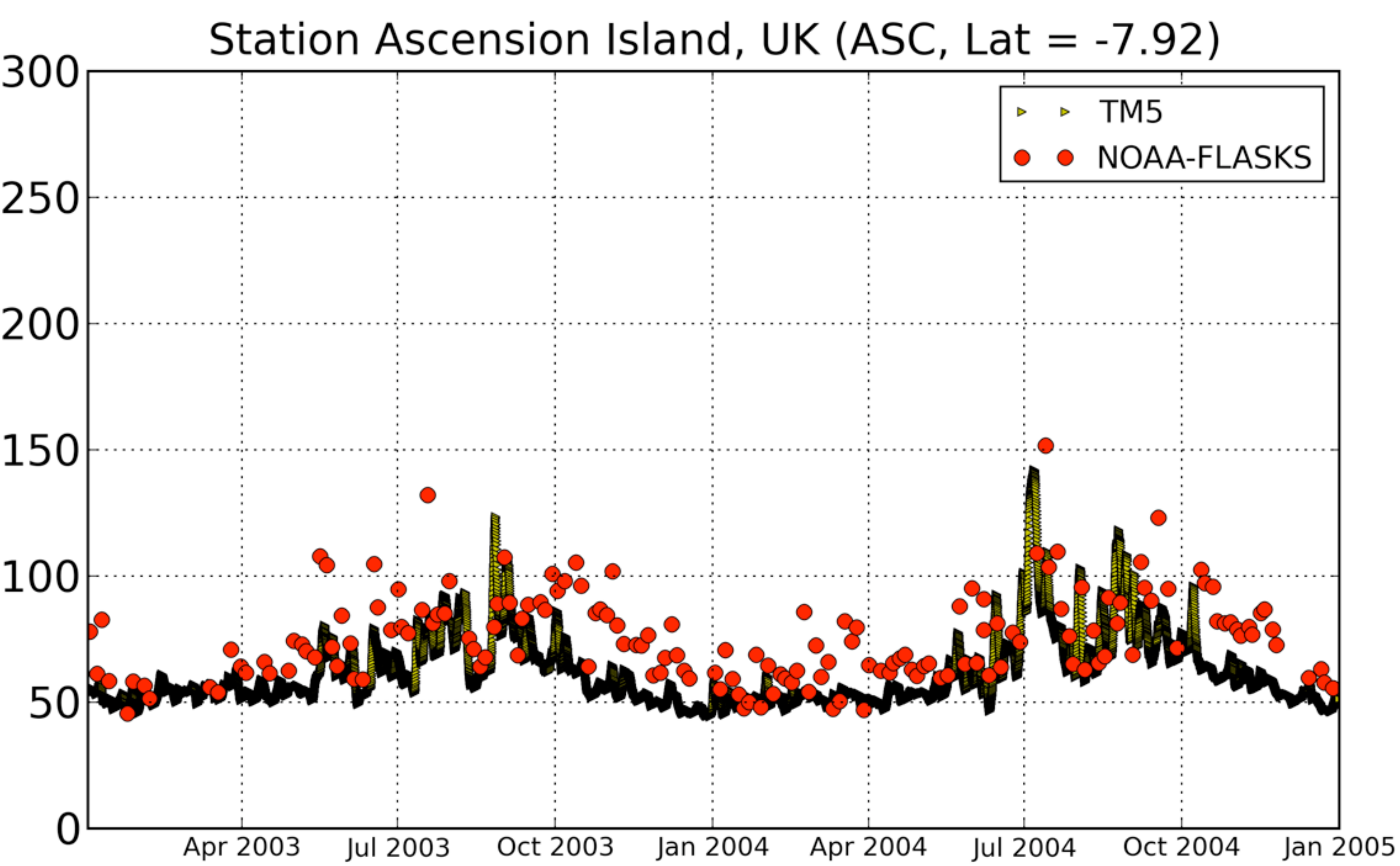


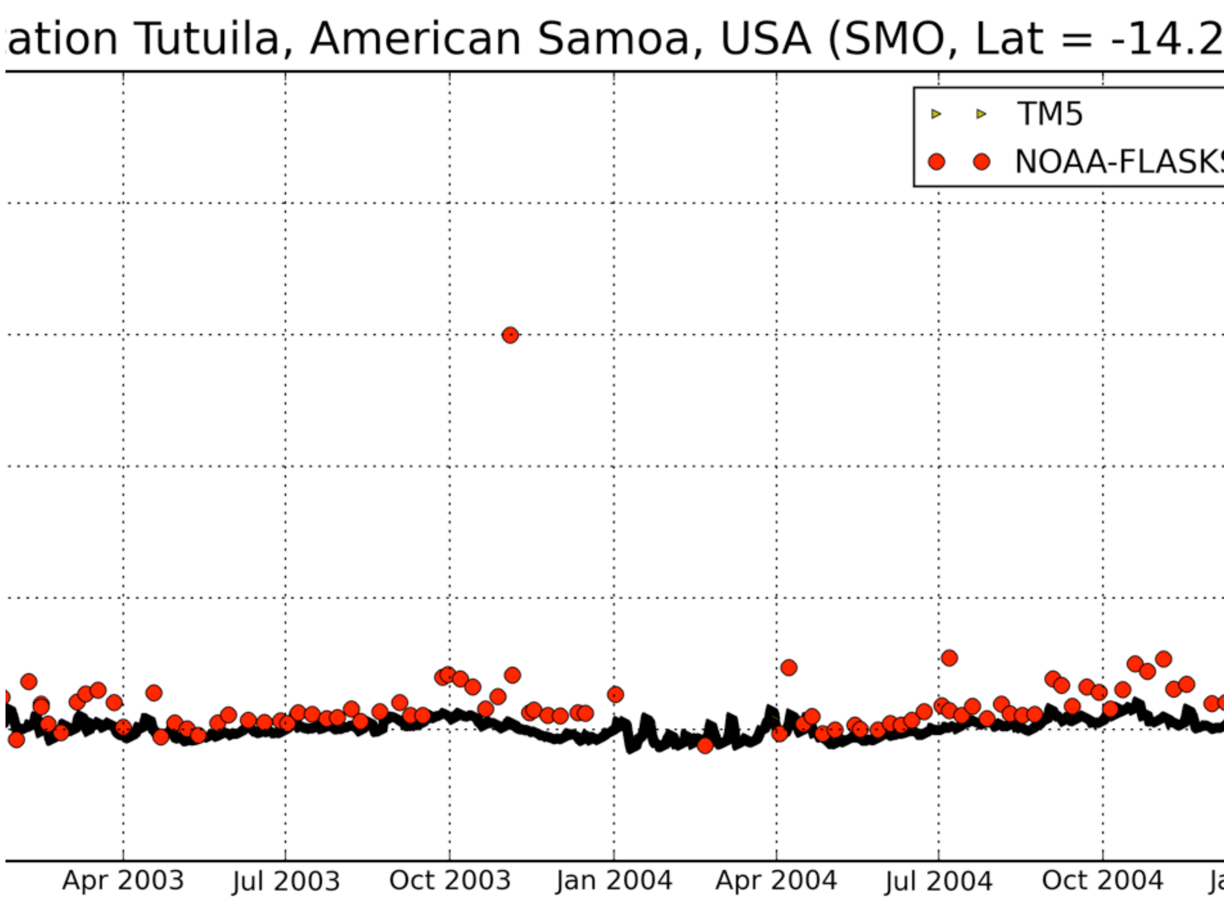
TM5 simulates seasonal cycle and some pollution events.

TM5 underestimates the CO mixing ratio on the NH by 20%



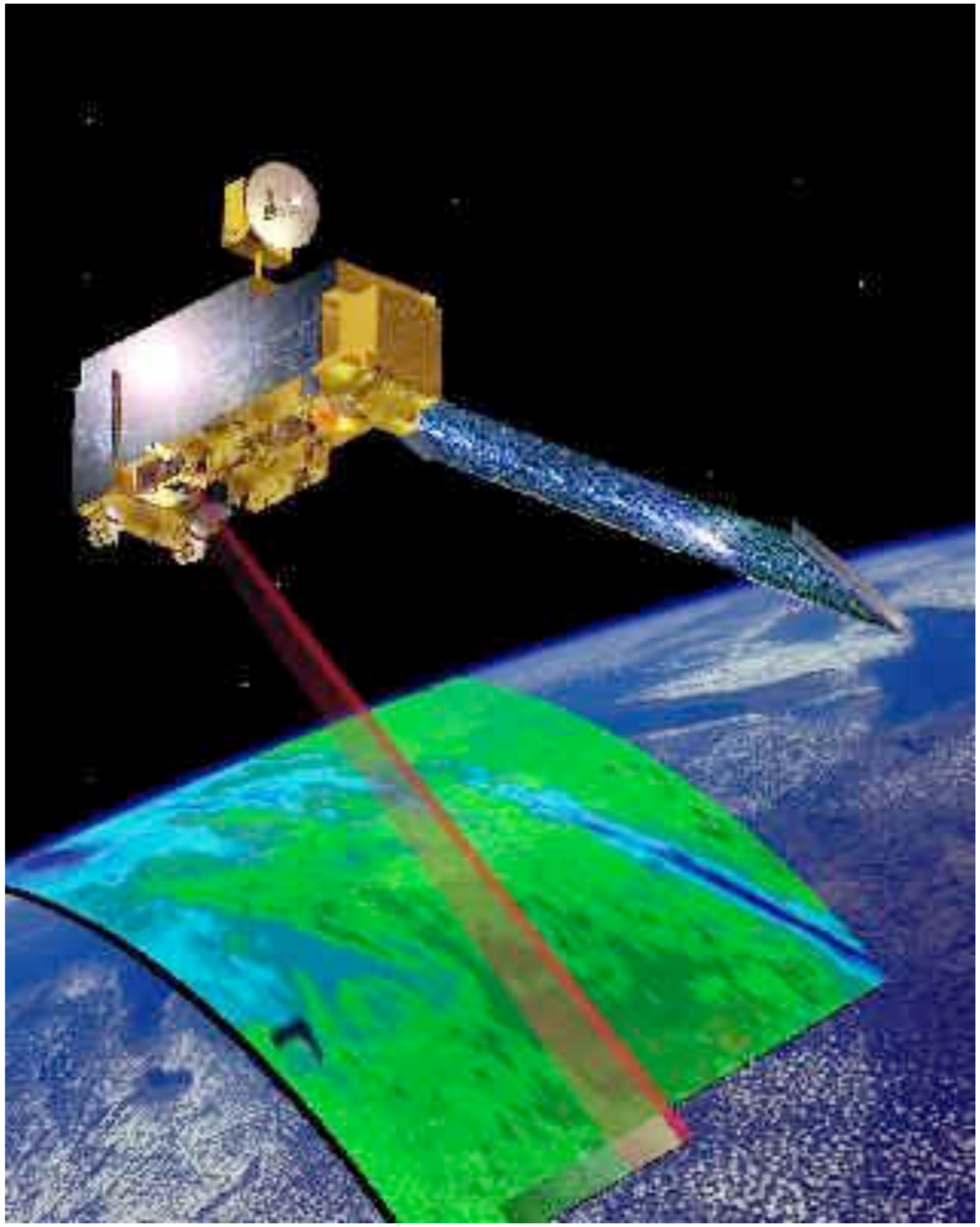
good agreement between TM5 and observations on the remote SH.



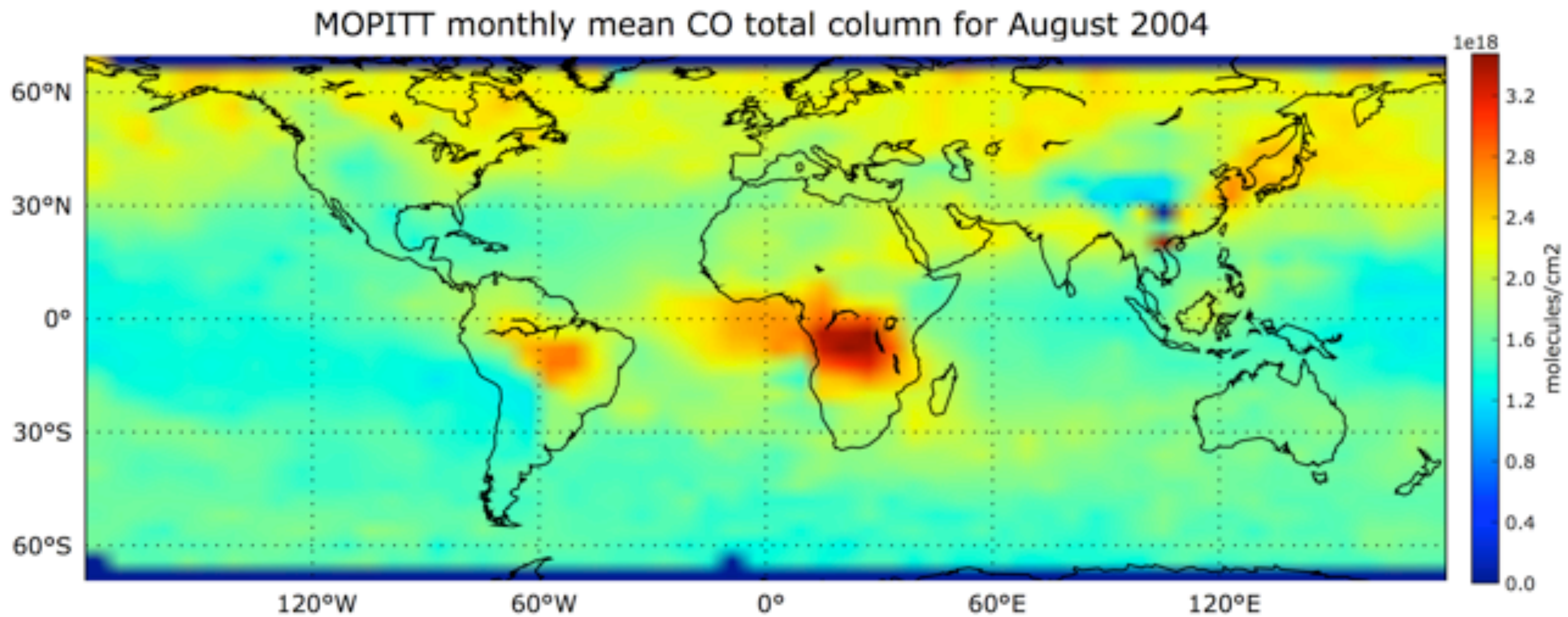


MOPITT

- Launched in 1999 on board Terra satellite (NASA).
- Measures upwelling infrared radiation from the surface to calculate total column observations and profiles of CO in the troposphere.
- Sensitive in the middle troposphere (700 - 350 hPa.)



TM5 vs. MOPITT

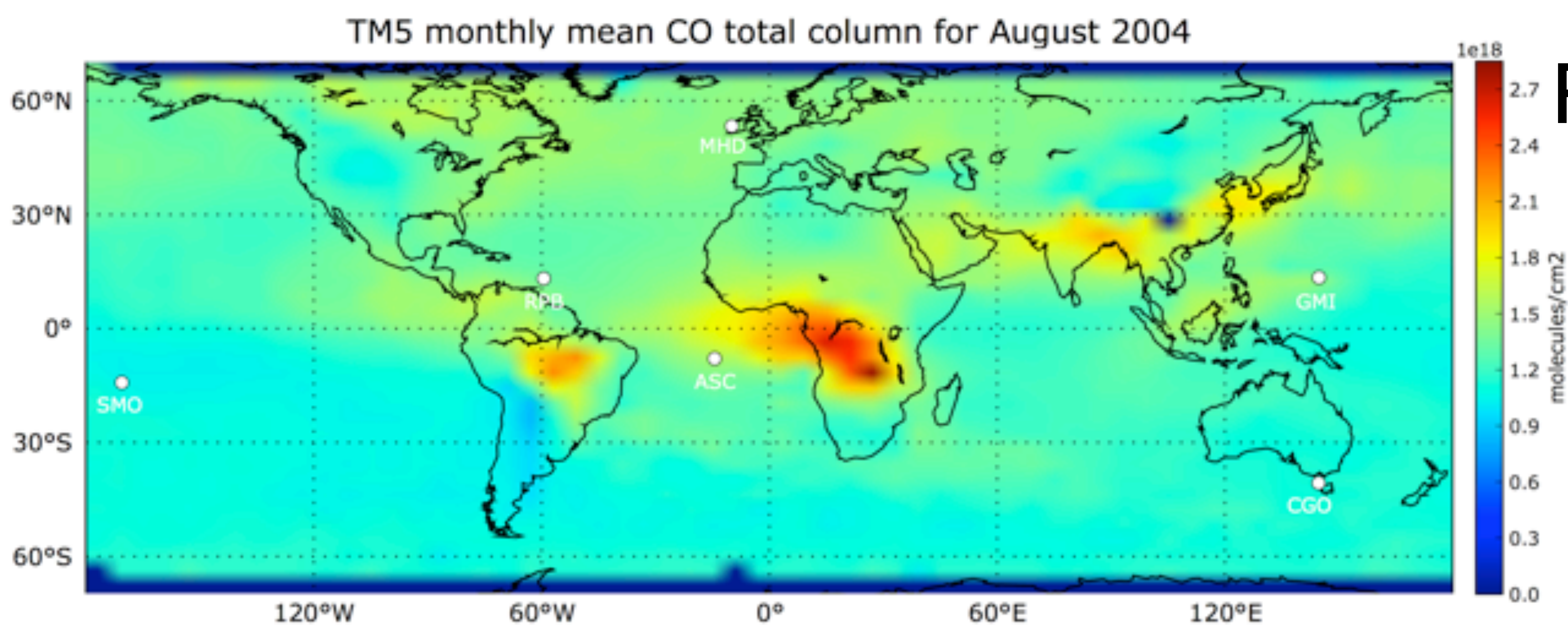


hotspots from BB are in good agreement

MOPITT is 30% higher than TM5

Main differences are observed in NH

Possible explanations



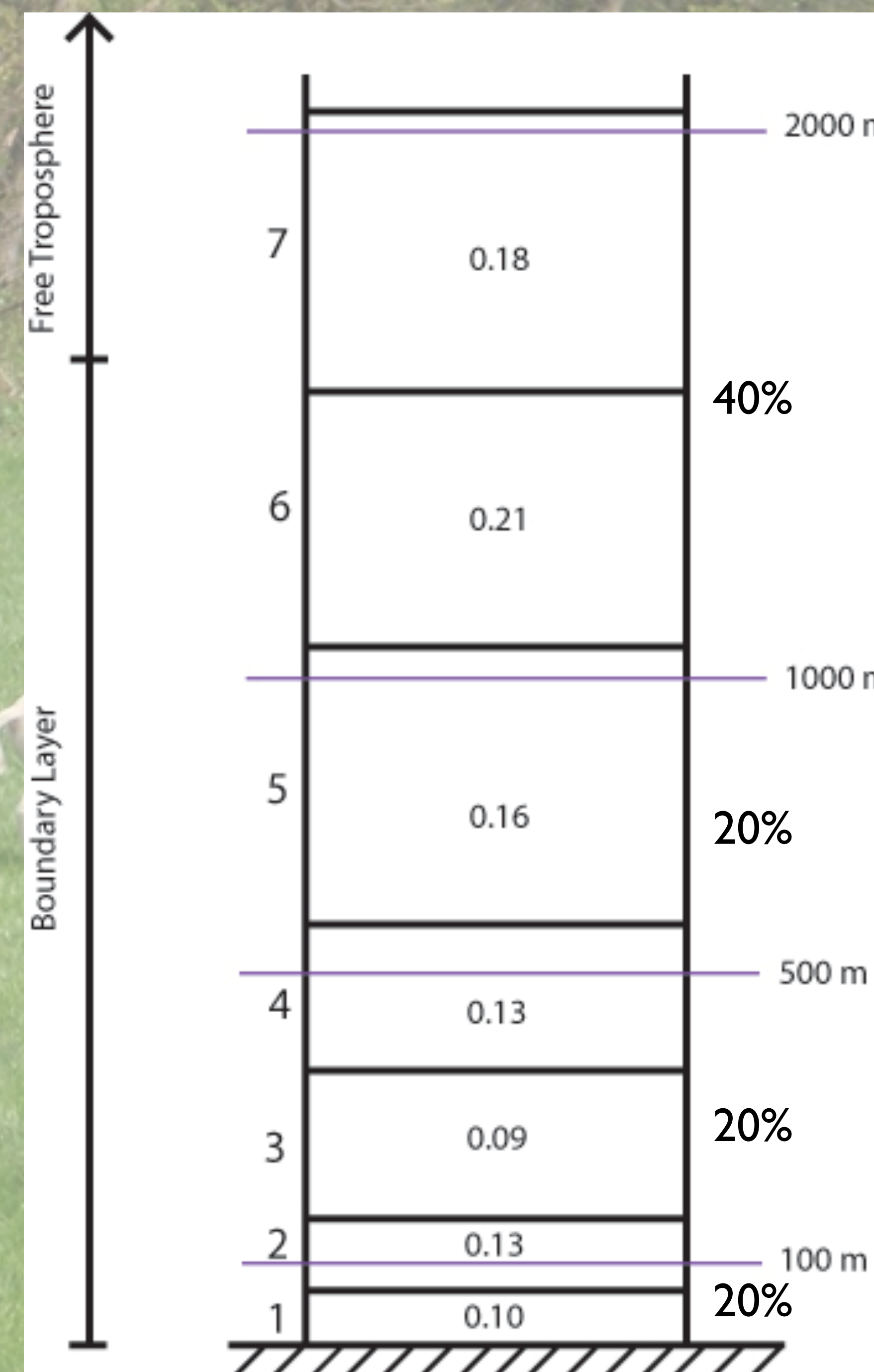
Positive bias in MOPITT

Vertical transport in TM5

CO from NMHC too low.

Something new...(1)

Introduce vertical profile for biomass burning CO emissions *fvert.*



$$\hat{E}_{bb}(i,j,l) = E_{bb}(i,j) * fvert(i,j,l)$$

Adjoint modeling

for biomass burning emissions only

Forward:

$$rm(i,j,l)^{n+1} = rm(i,j,l)^n + E_{bb}(i,j) * fvert(i,j,l) * \Delta t$$

$$\begin{aligned} drm^{n+1} &= drm^n + dE * fvert * \Delta t \\ dE^{n+1} &= dE^n \end{aligned}$$

$$\begin{pmatrix} drm \\ dE \end{pmatrix}^{n+1} = \begin{pmatrix} 1 & fvert * \Delta t \\ 0 & 1 \end{pmatrix} \begin{pmatrix} drm \\ dE \end{pmatrix}^n$$

Adjoint:

$$\begin{pmatrix} adrm \\ adE \end{pmatrix}^{n} = \begin{pmatrix} 1 & 0 \\ fvert * \Delta t & 1 \end{pmatrix} \begin{pmatrix} adrm \\ adE \end{pmatrix}^{n+1}$$

$$\begin{aligned} adrm(i,j,l)^n &= adrm(i,j,l)^{n+1} \\ adE(i,j)^n &= adE(i,j)^{n+1} + adrm(i,j,l) * fvert * \Delta t \end{aligned}$$

Something new...(2)

We don’t optimize the indirect CO emissions from methane and NMVOCs but use a factor *emult*.

Example:

```
kr = zfarr(2.65e-12,-1800.,1/t(i,j,l))
x = kr*1800e-9*L_CO(region)%d3(i,j,l)*dtime*m(i,j,l)*xmco/xmair
x = emult(1,i_month)*x
rm(i,j,l,n) = rm(i,j,l,n)+x
```

A priori we have: emult = 1,
we let the 4DVAR system optimize emult.

Statevector

We want to optimize:

- anthropogenic CO emissions (2d), monthly
- biomass burning CO emissions (2d), monthly
- natural CO emissions (2d), monthly
- factors n_emult (2), monthly
- initial 3D CO field (3d)

Running on the global 6x4 degree grid (2700 gridboxes, 25 vertical layers) gives 2700(25+3*n_month)+2 parameters to optimize.

First results

Optimize emissions, ini-conc &
n_emult for 1 month (June 2004)

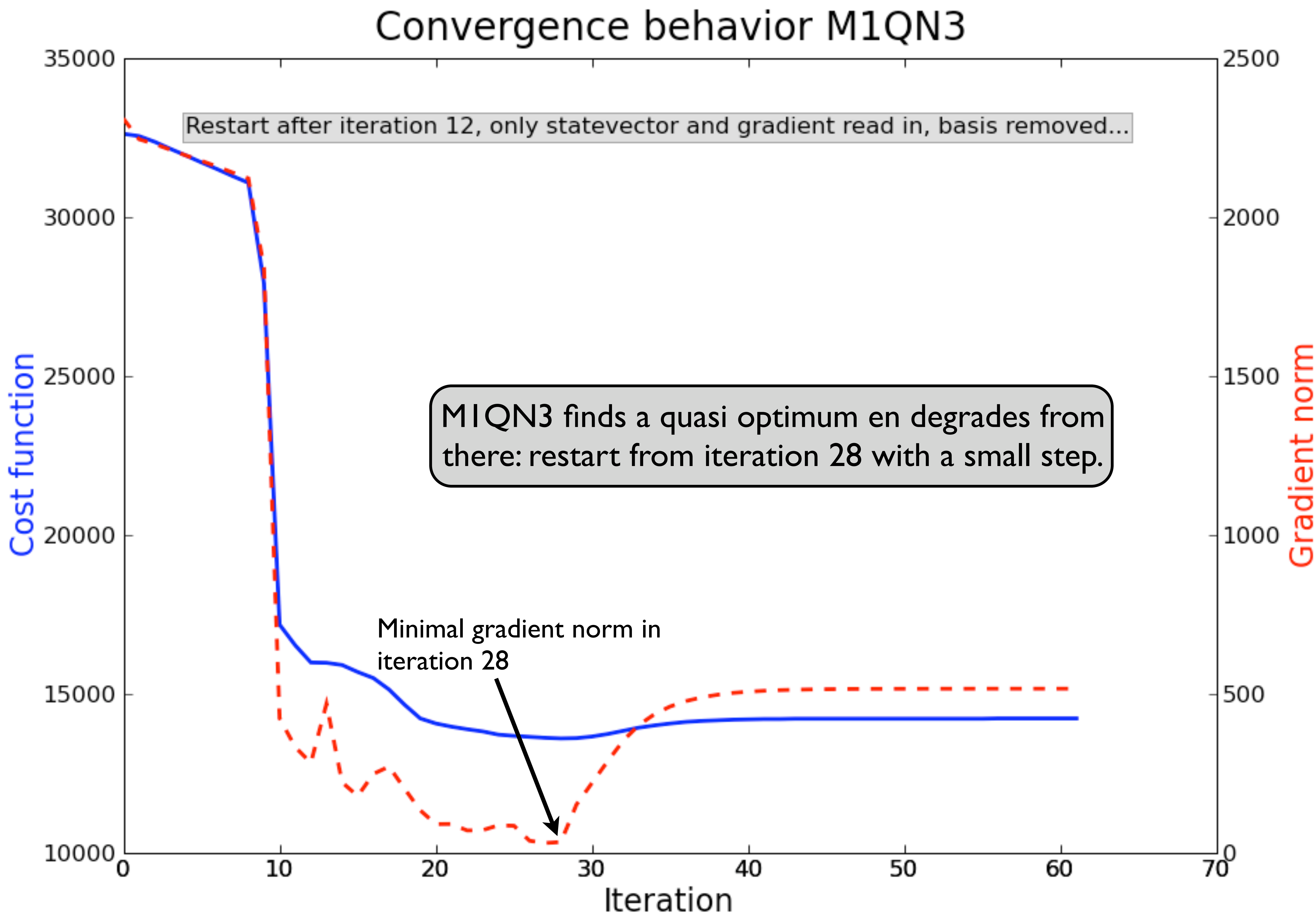
Minimization of J performed by M1QN3 method

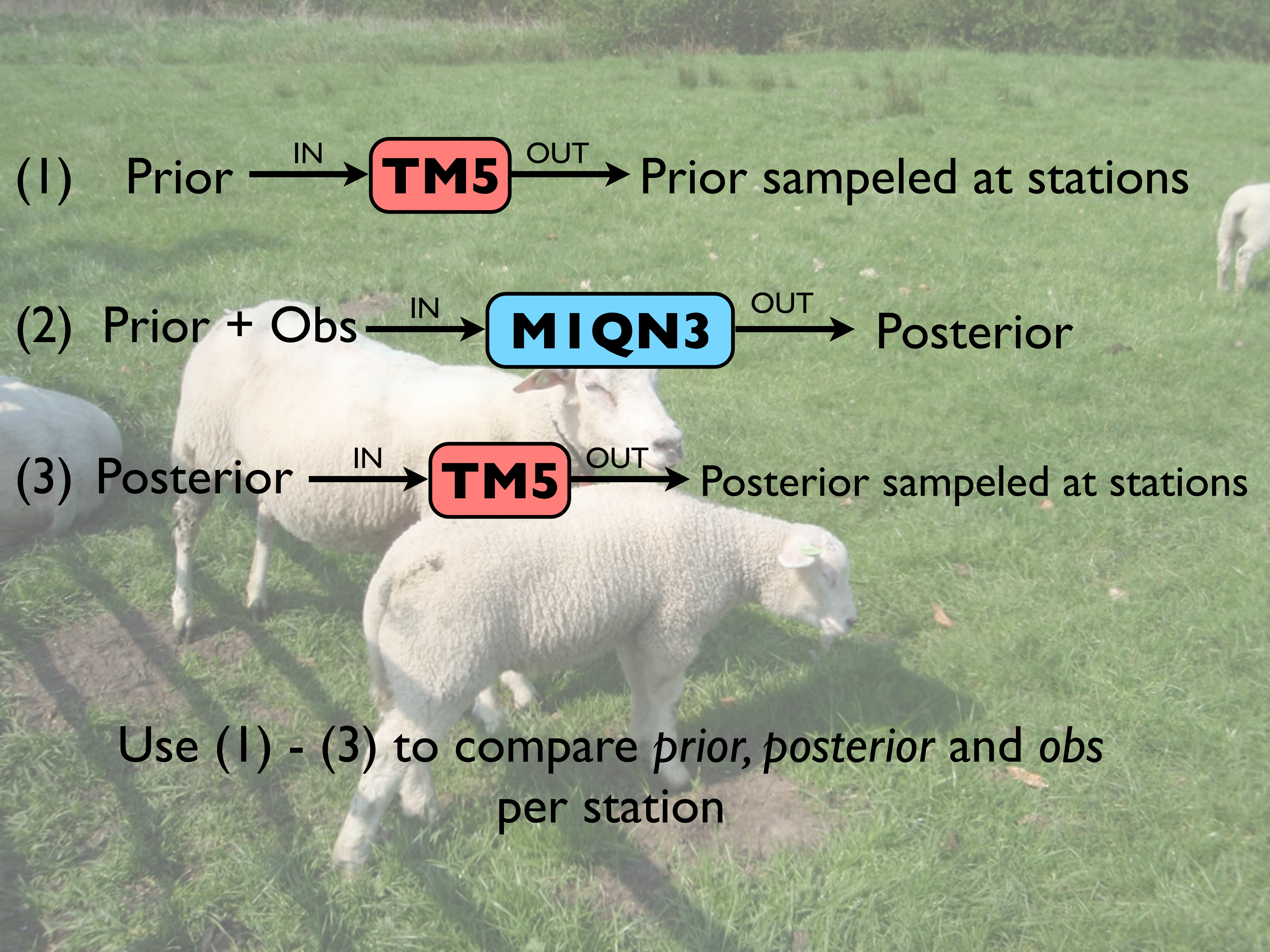
$$\mathcal{J}(\mathbf{x}) = \frac{1}{2}(\mathbf{x}-\mathbf{x_{prior}})^\top \mathbf{B}^{-1}(\mathbf{x}-\mathbf{x_{prior}}) + \frac{1}{2}(\mathbf{Hx}-\mathbf{y})^\top \mathbf{R}^{-1}(\mathbf{Hx}-\mathbf{y})$$

We show figures of:

- Cost function/gradient
- prior & posterior vs. observations at stations
- Prior/Posterior CO emissions

Cost function




(1) Prior
IN
TM5
OUT
Prior sampeled at stations
(2) Prior + Obs
IN
M1QN3
OUT
Posterior
(3) Posterior
IN
TM5
OUT
Posterior sampeled at stations
Use (1) - (3) to compare *prior*, *posterior* and *obs* per station

Observations

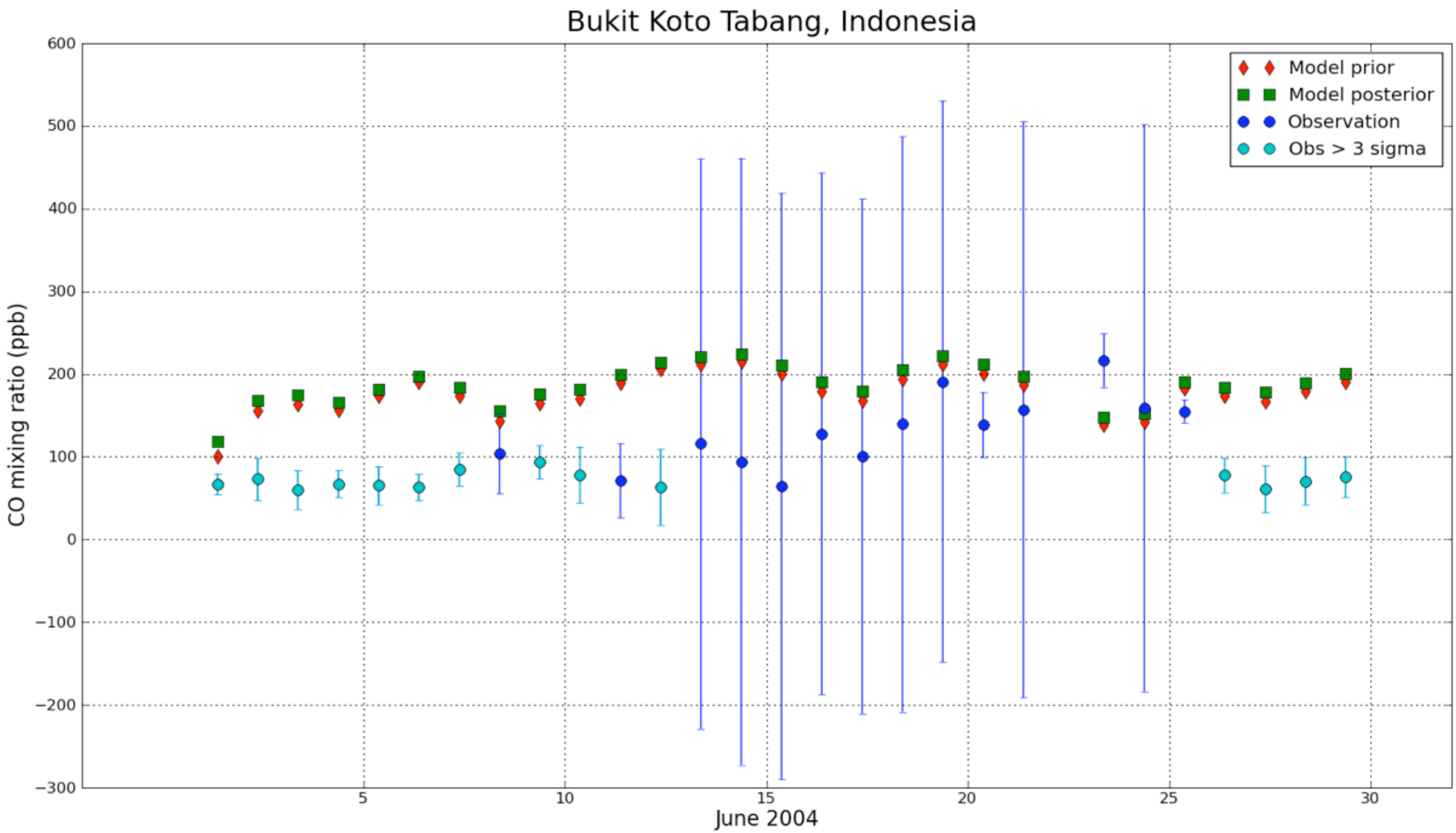
mean$\sqrt{\frac{(y_{obs} - y_{posterior})^2}{\sigma^2}}$

mean(posterior-obs)

mean(prior-obs)

mean$\sqrt{\frac{(y_{obs} - y_{prior})^2}{\sigma^2}}$

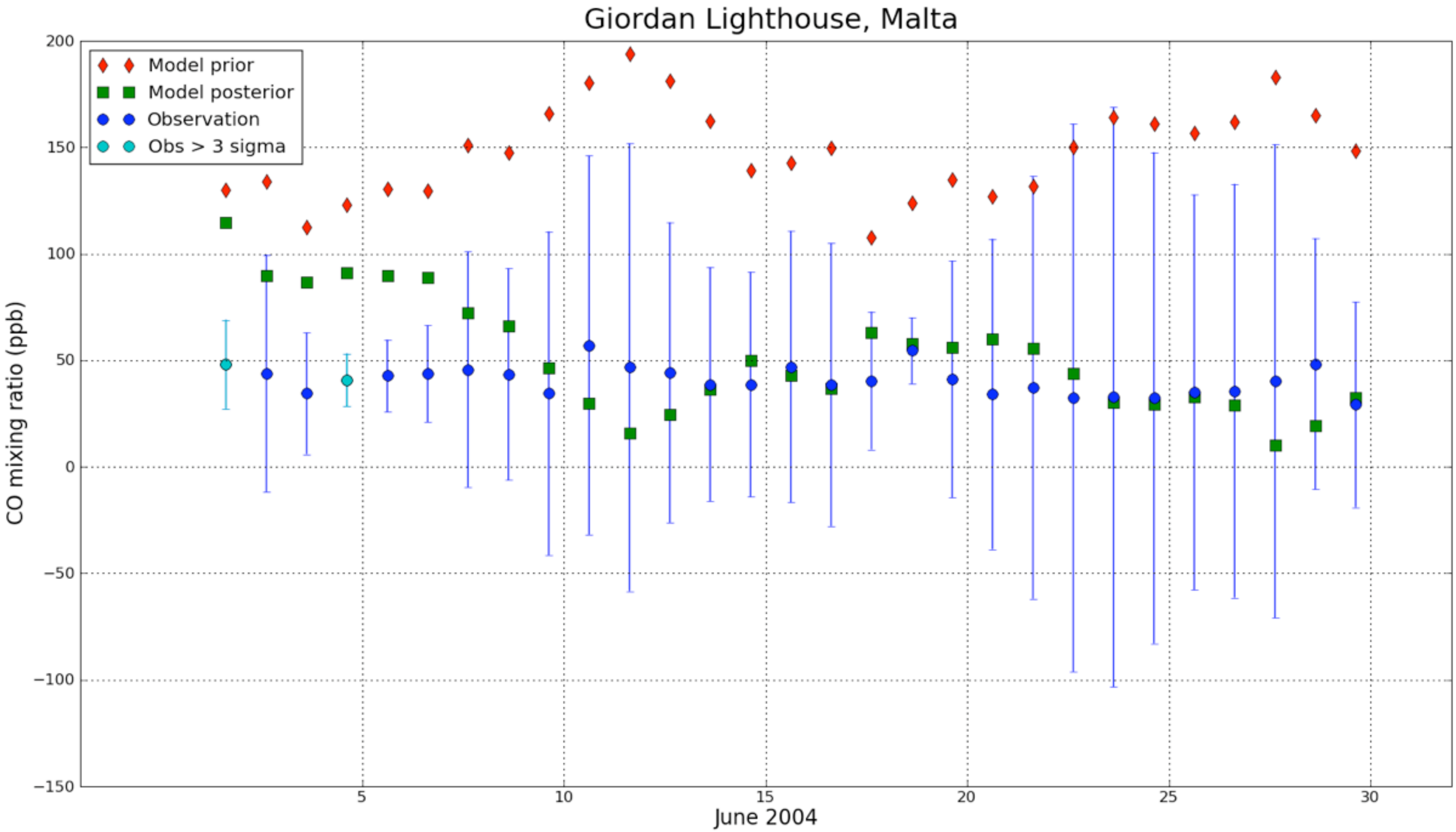
Year	Station	Lat	Lon	height	TP	pi_res (ppb)	po_res (ppb)	pi-x2 (sigma)	po-x2 (sigma)	ndata	nrej
2004	ALT_WDC_000	82.45	-62.52	210.0	CM	-20.69	8.63	12.00	5.89	24	20
2004	BKT_WDC_000	-0.20	100.32	864.5	CM	74.91	85.21	2.50	2.80	28	14
2004	CDL_WDC_000	53.87	-104.65	489.0	CM	-24.58	1.23	5.26	1.80	28	5
2004	FSD_WDC_000	49.88	-81.57	210.0	CM	-28.76	-19.42	5.59	3.24	28	12
2004	GLH_WDC_000	36.07	14.22	167.0	CM	107.09	10.99	2.19	0.68	29	2
2004	HPB_WDC_000	47.80	11.02	985.0	CM	115.34	84.75	5.04	3.71	29	21
2004	JFJ_WDC_000	46.55	7.98	3578.0	CM	-24.56	-14.29	6.24	3.70	29	18
2004	KOS_WDC_000	49.58	15.08	534.0	CM	-26.23	-49.14	1.17	1.95	28	4
2004	MHD_AGA_000	53.33	-9.90	25.0	CM	-15.02	-4.42	1.58	0.58	29	0
2004	MKN_WDC_000	-0.062	37.30	3678.0	CM	-5.82	-0.20	3.18	2.32	12	3
2004	MNM_WDC_000	24.28	153.98	8.0	CM	-48.23	-14.54	24.30	7.26	22	20
2004	PAY_WDC_000	46.82	6.95	490.0	CM	-11.83	-59.15	0.33	1.26	29	0
2004	RIG_WDC_000	46.07	8.45	1031.0	CM	-21.41	-44.14	2.36	4.83	27	18
2004	RYO_WDC_000	39.03	141.82	260.0	CM	-49.55	1.34	1.03	0.88	29	2
2004	SNB_WDC_000	47.05	12.95	3106.0	CM	81.19	86.14	19.16	20.34	29	29
2004	SSL_WDC_000	47.92	7.92	1205.0	CM	-28.85	-40.41	3.12	4.42	29	16
2004	WSA_WDC_000	43.93	-60.02	5.0	CM	-3.35	-48.13	0.64	1.95	20	5
2004	YON_WDC_000	24.47	123.02	30.0	CM	-31.21	22.39	0.61	0.65	24	1
2004						3.99	1.38	5.24	3.85	473	190



sigma = sum of obs_error + (local) model representativeness error.

observation - posterior > 3 sigma, reject observation.

Year	Station	Lat	Lon	height TP	pi_res (ppb)	po_res (ppb)	pi-x2 (sigma)	po-x2 (sigma)	ndata	nrej
2004	BKT_WDC_000	-0.20	100.32	864.5 CM	74.91	85.21	2.50	2.80	28	14



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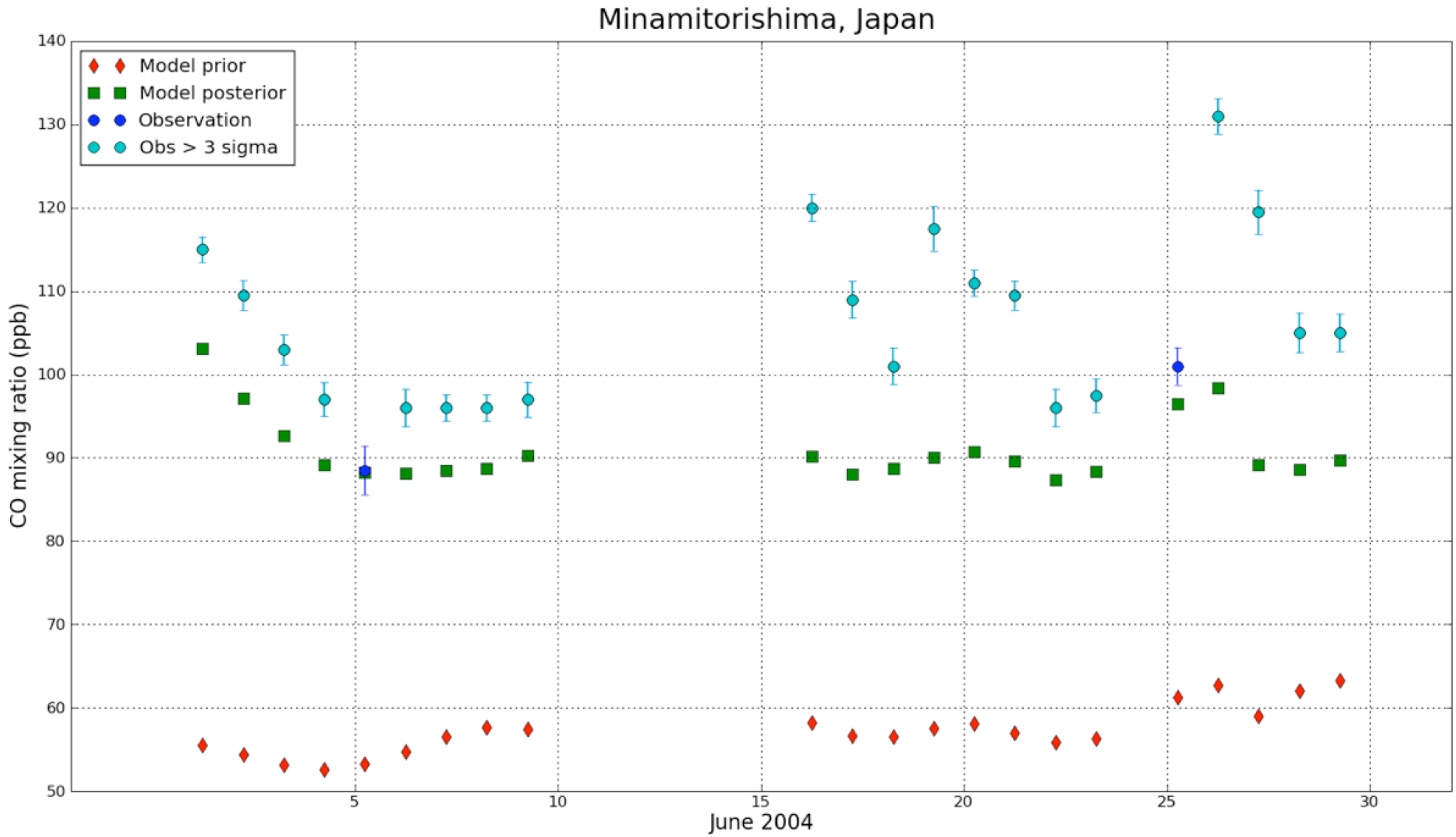
Year	Station	Lat	Lon	height	TP	pi_res (ppb)	po_res (ppb)	pi-x2 (sigma)	po-x2 (sigma)	ndata	nrej
2004	GLH_WDC_000	36.07	14.22	167.0	CM	107.09	10.99	2.19	0.68	29	2



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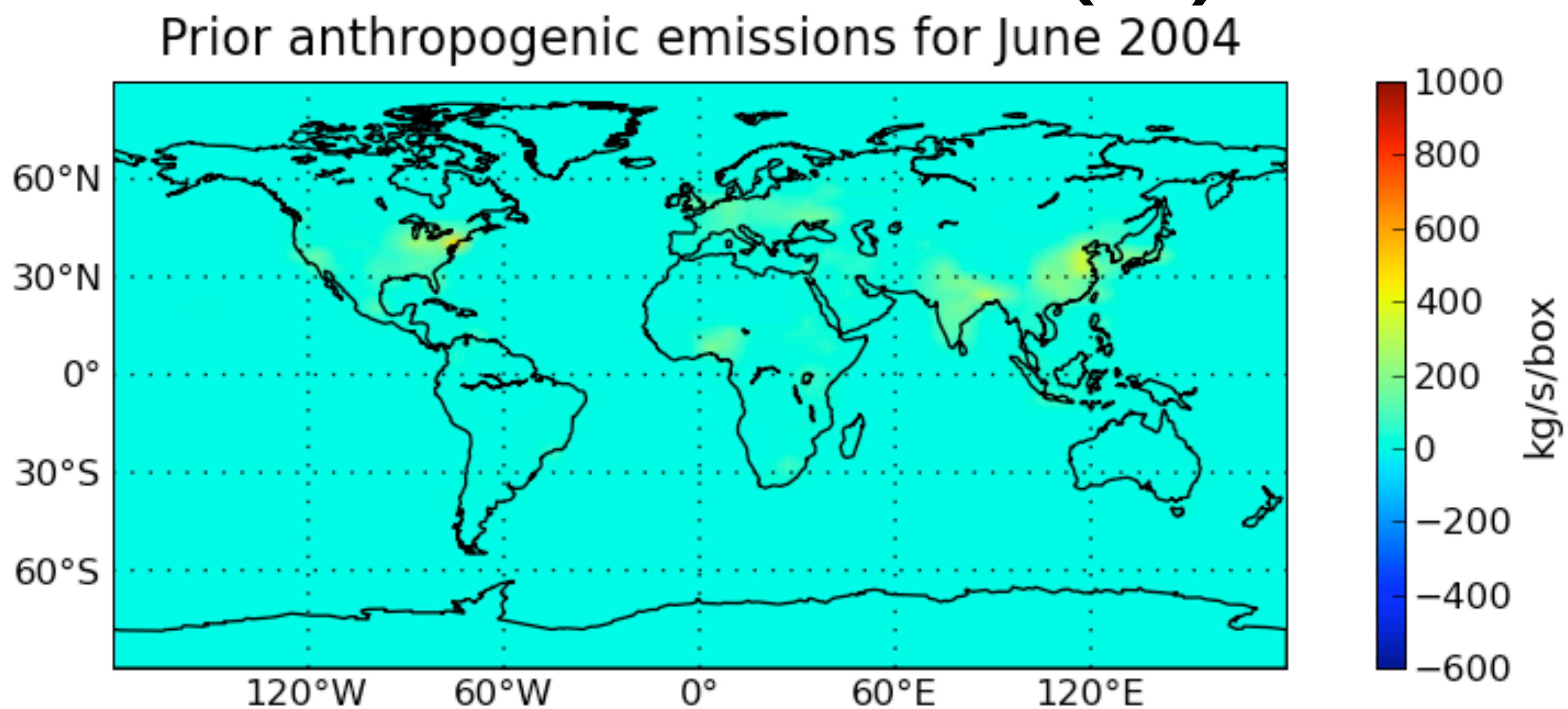
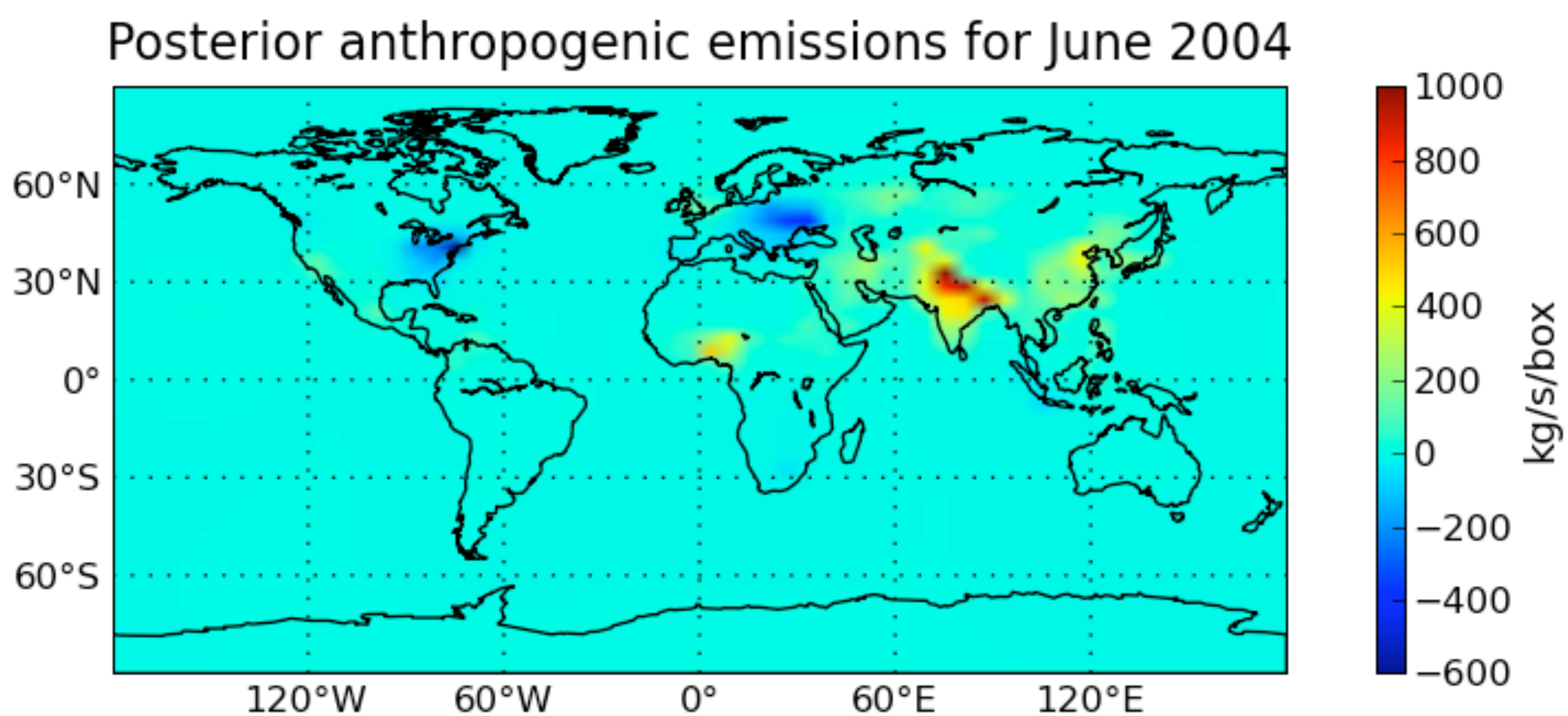
Year	Station	Lat	Lon	height	TP	pi_res (ppb)	po_res (ppb)	pi-x2 (sigma)	po-x2 (sigma)	ndata	nrej
	MNM_WDC_000	24.28	153.98	8.0	CM	-48.23	-14.54	24.30	7.26	22	20

Emissions (I)

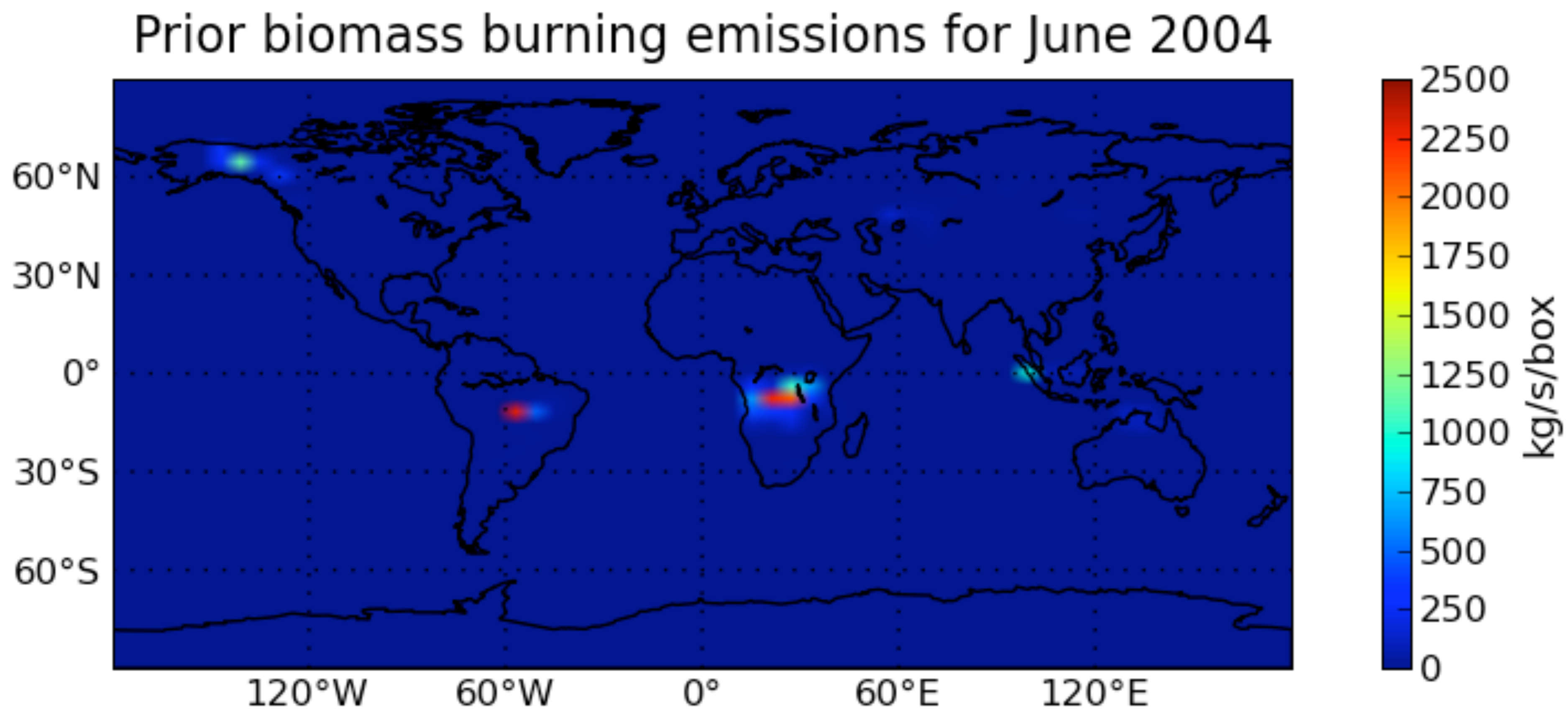




Posterior after 28 iterations

Emissions (2)

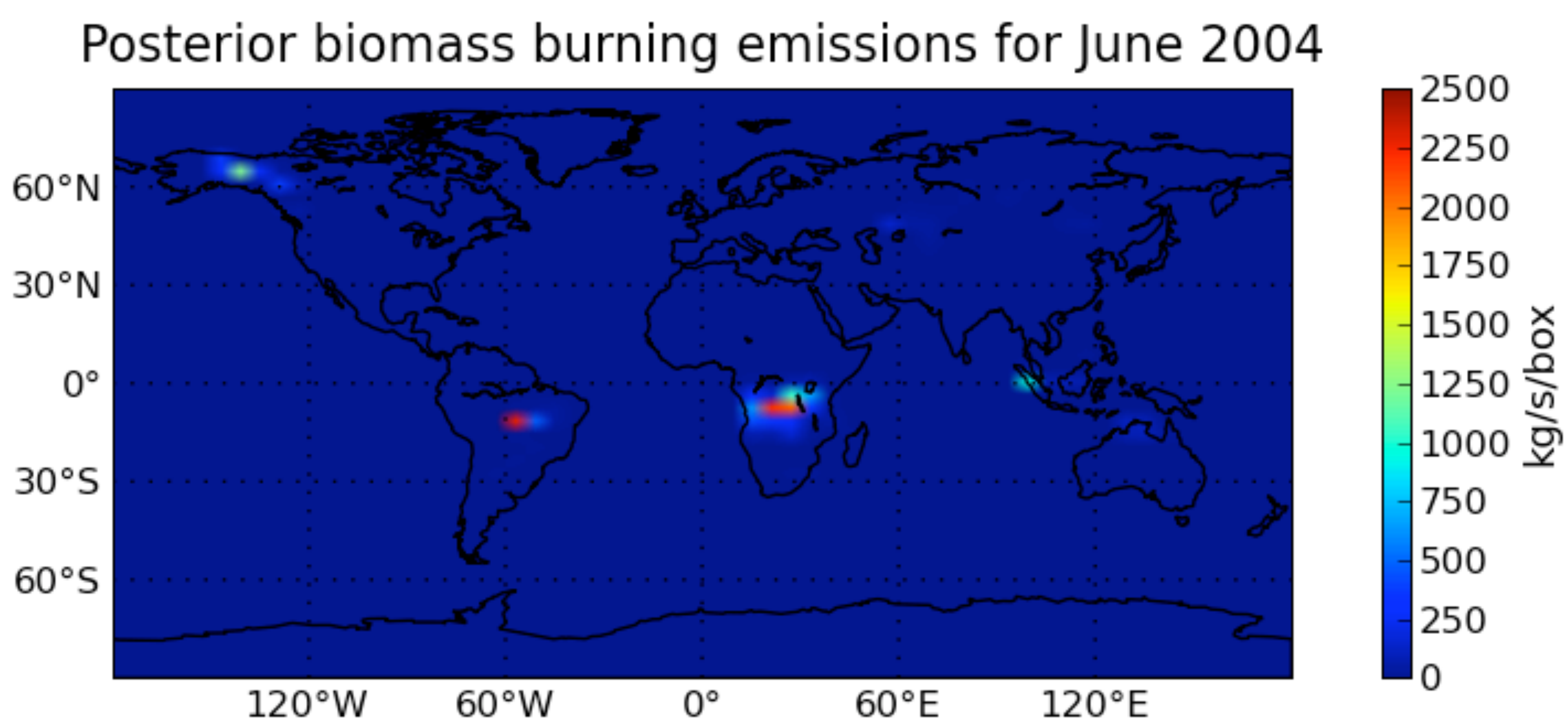
maximum emission = 2279 kg/s in box (20,21)



Posterior after 28 iterations

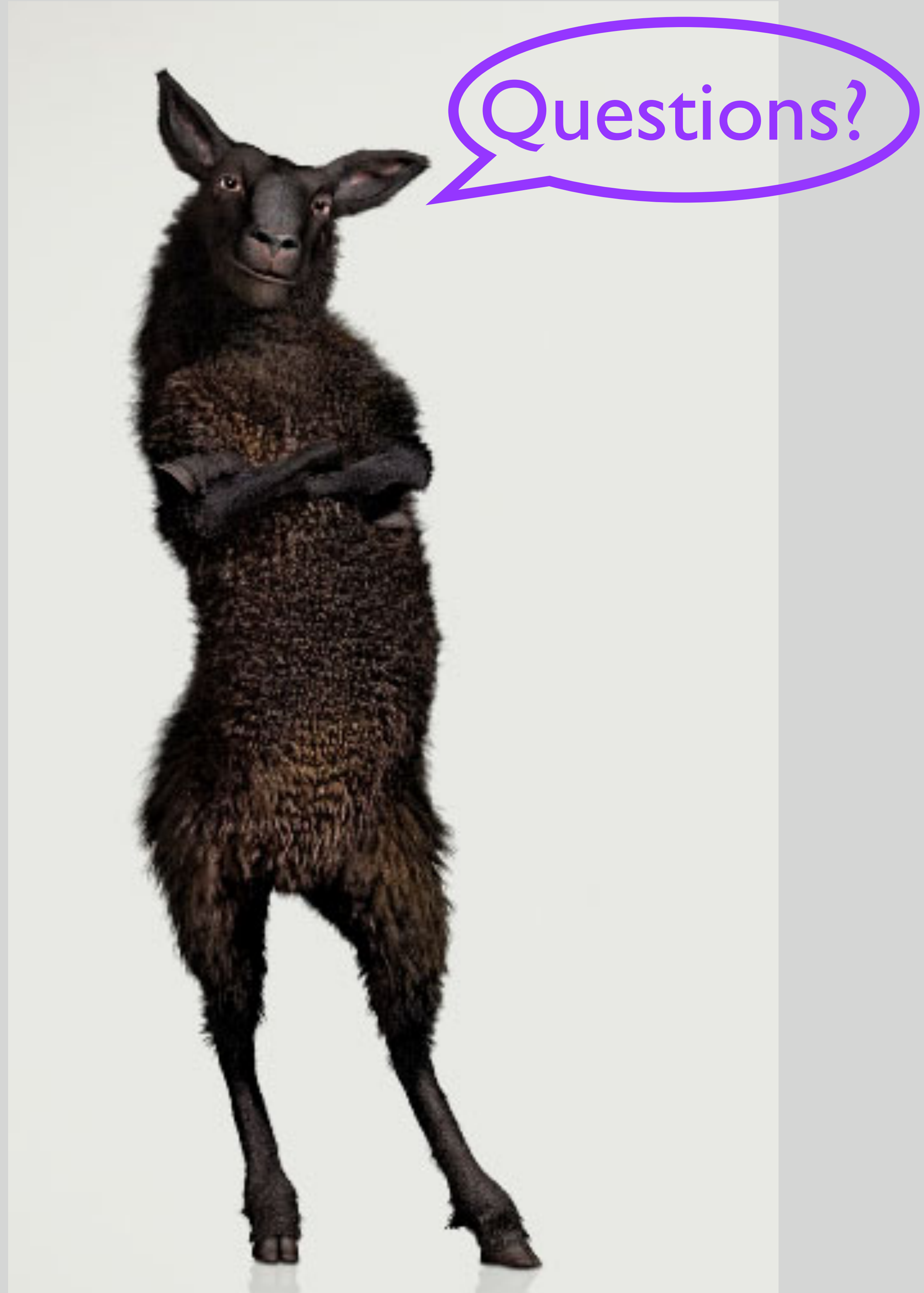
There are differences but so small that it is not visible...

maximum emission = 2276 kg/s in box (20,21)



Next

- Inclusion of CO emission from biogenic hydrocarbons (methanol, acetone, monoterpenes fields?)
- Solve problems with M1QN3
- Minimization with CONGRAD
- [Assimillate satellite data (MOPITT/SCIAMACHY)]


Questions?