Source-sink inversions of CO_2 from surface and satellite networks

Sensitivity of inverted fluxes to TM5 resolution

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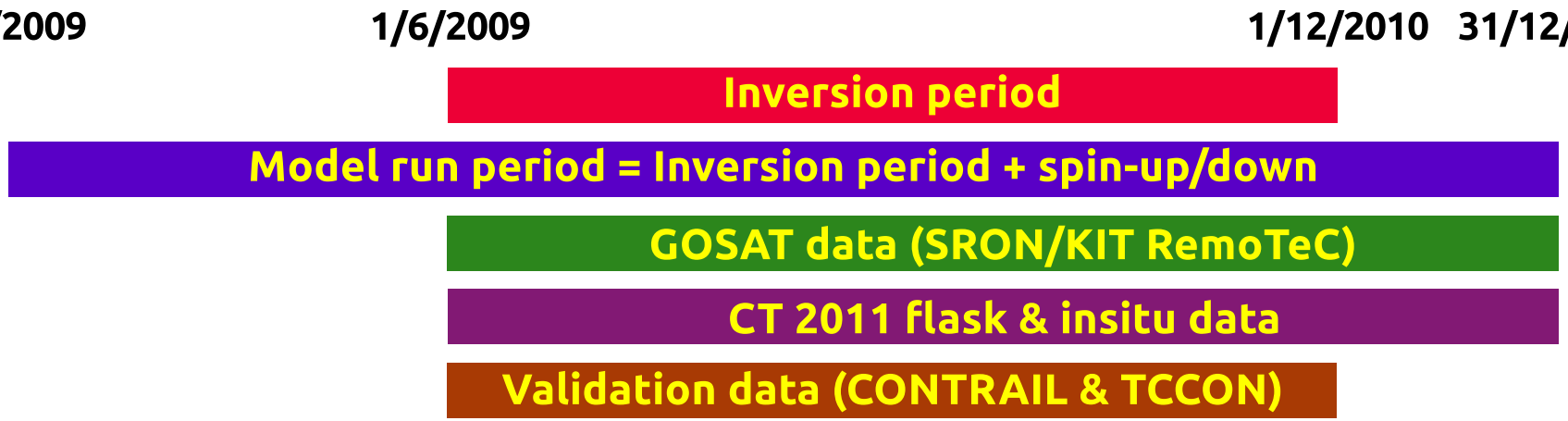
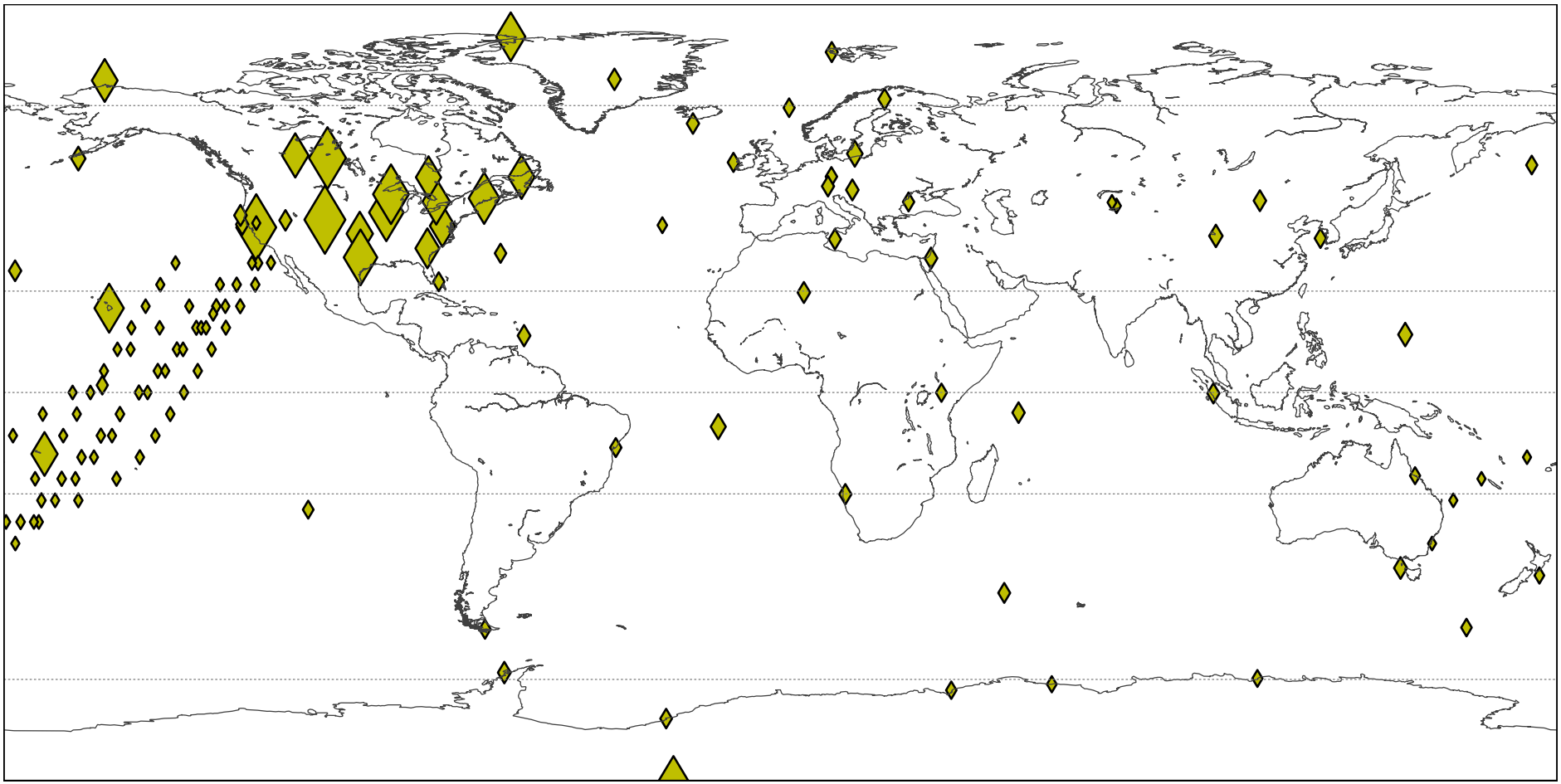
SRON
Netherlands Institute for Space Research

KIT
Karlsruhe Institute of Technology

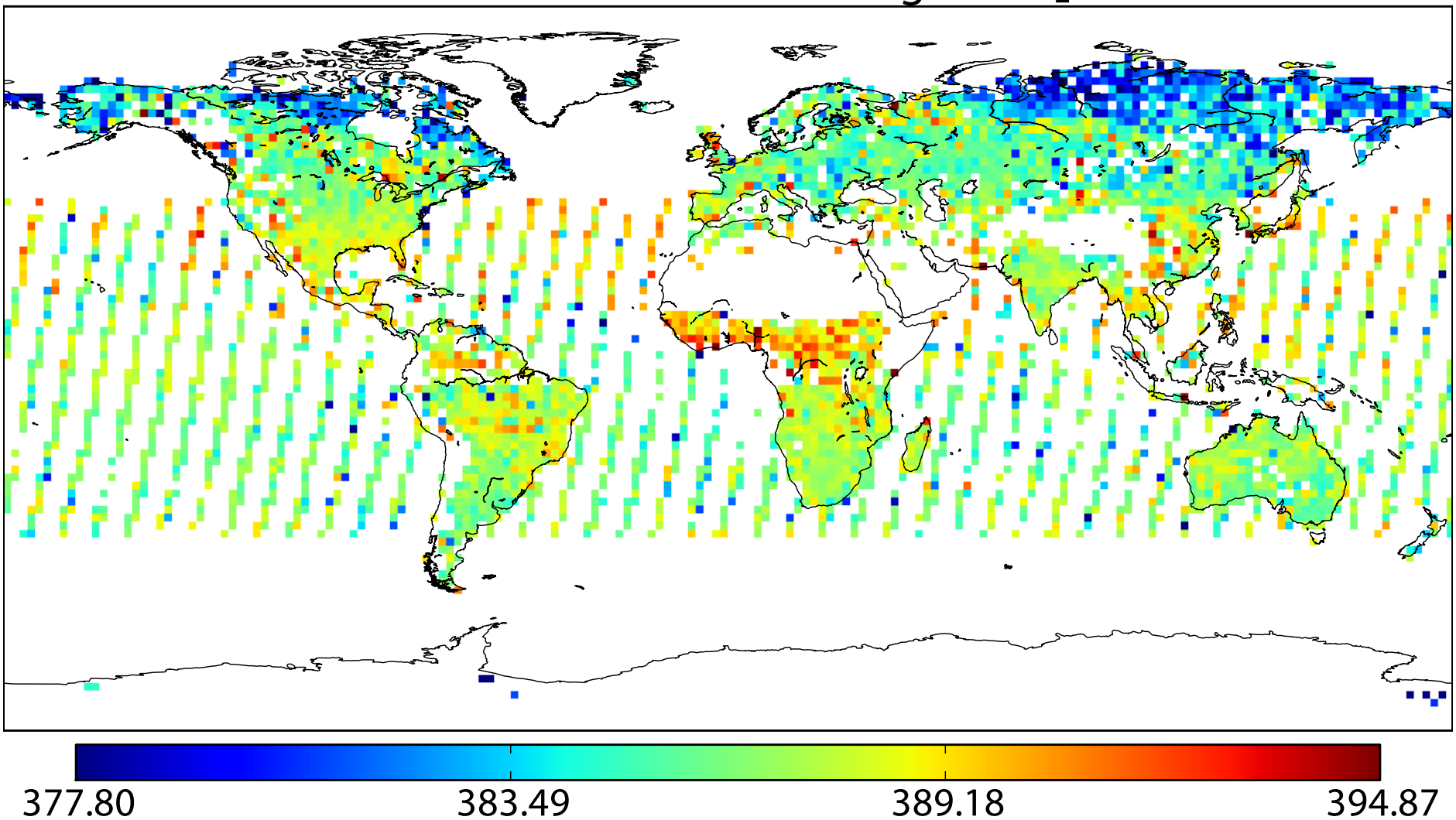
Nth TM5 Meeting, Utrecht
October 17, 2012



- **Inversion method:** 4DVAR
- **Transport model:** TM5 & adjoint TM5 (global 6° × 4°, 25 vertical layers)
- **Initial CO_2 field:** Flask-optimized CO_2 atmosphere sampled at 00:00 on Mar 1, 2009
- **Optimized:** Monthly mean flux @ 6° × 4°. Fossil fuel & land use change imposed, terrestrial biosphere and oceanic fluxes optimized.

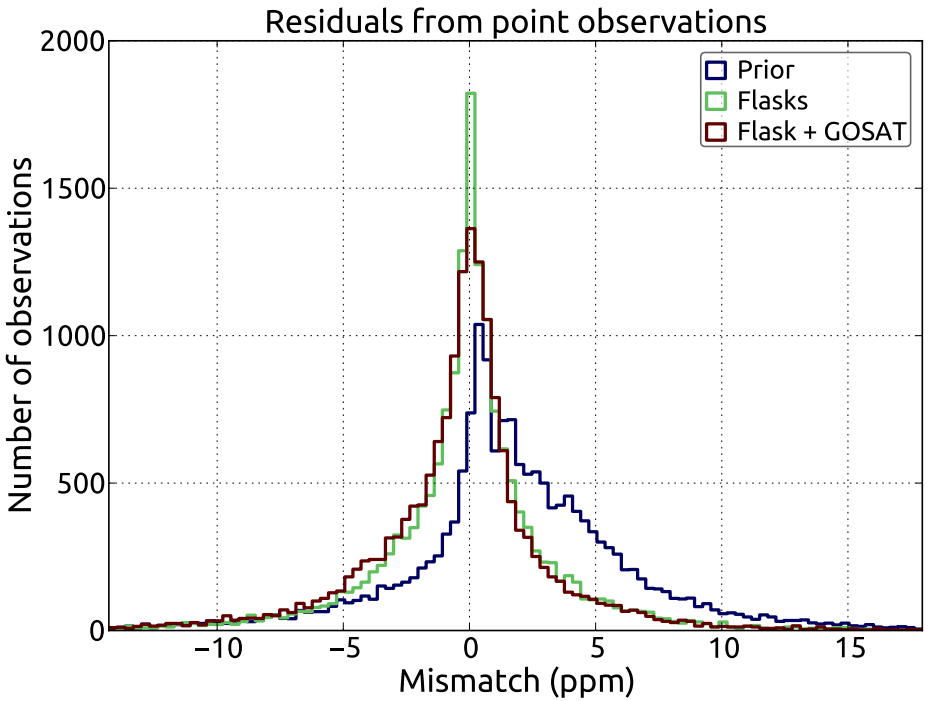


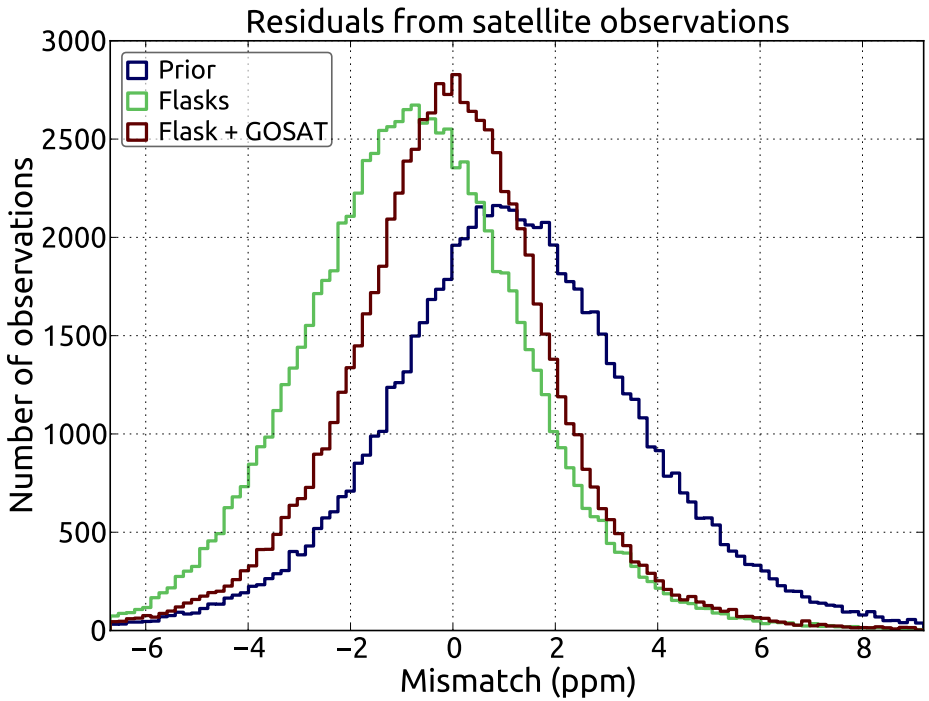
RemoTeC column averaged CO_2

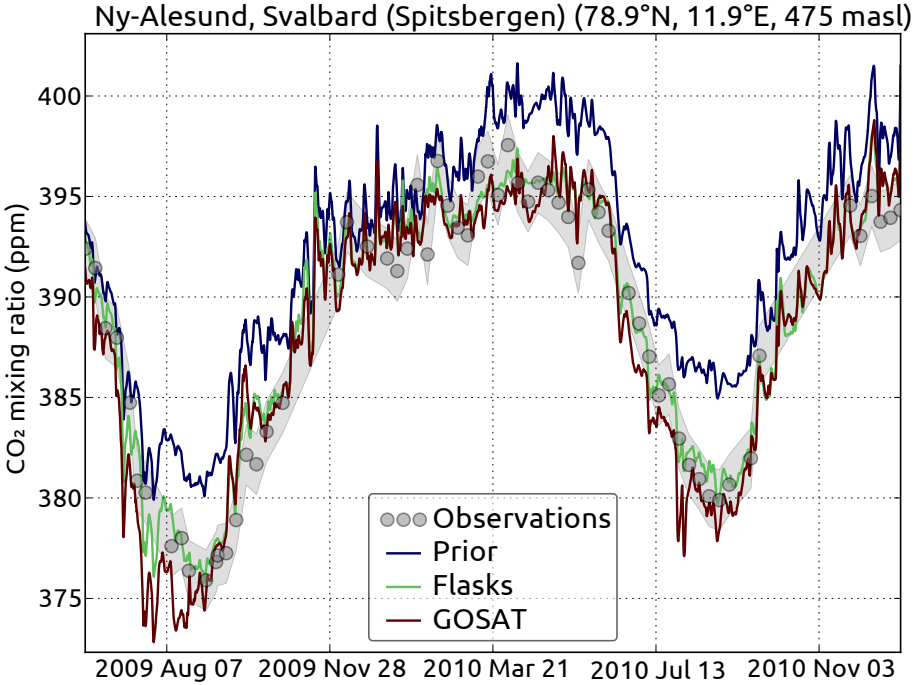


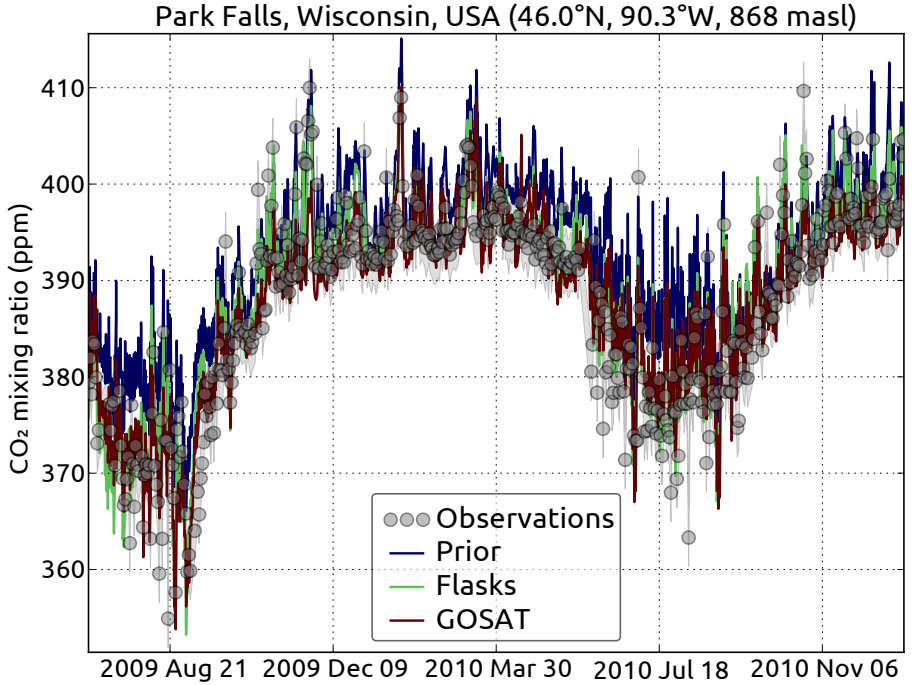
SRON/KIT RemoTeC retrieval of total column CO_2

77,769 X_{CO_2} observations


Residuals from point observations
Prior
Flasks
Flask + GOSAT
Number of observations
Mismatch (ppm)
2000
1500
1000
500
0
−10
−5
0
5
10
15


Residuals from satellite observations
Prior
Flasks
Flask + GOSAT
Number of observations
Mismatch (ppm)
3000
2500
2000
1500
1000
500
0
−6
−4
−2
0
2
4
6
8


Ny-Alesund, Svalbard (Spitsbergen) (78.9°N, 11.9°E, 475 masl)
CO₂ mixing ratio (ppm)
400
395
390
385
380
375
2009 Aug 07
2009 Nov 28
2010 Mar 21
2010 Jul 13
2010 Nov 03
Observations
Prior
Flasks
GOSAT


Park Falls, Wisconsin, USA (46.0°N, 90.3°W, 868 masl)
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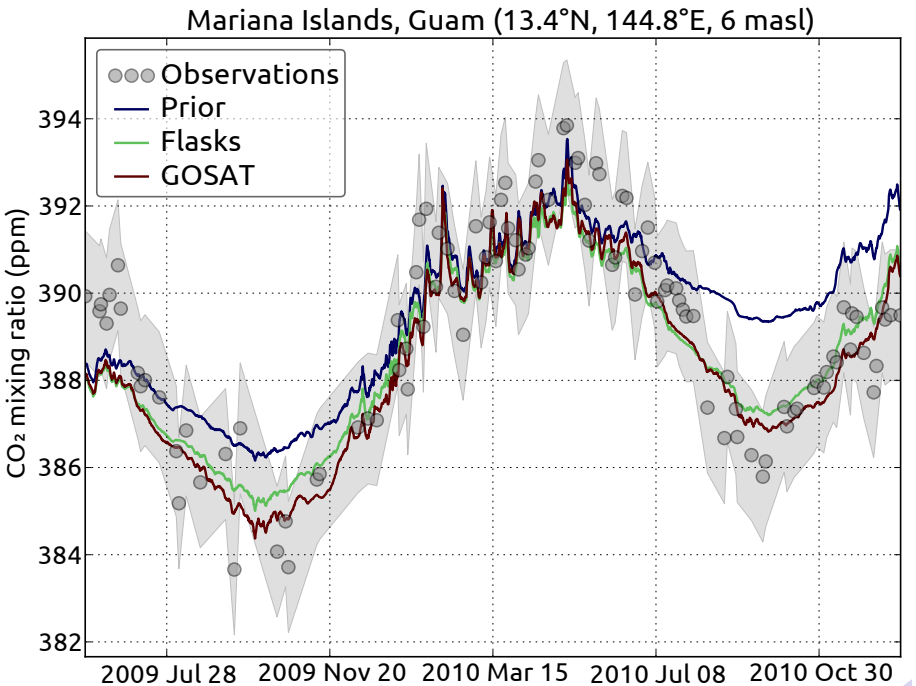
Mariana Islands, Guam (13.4°N, 144.8°E, 6 masl)
CO₂ mixing ratio (ppm)
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386
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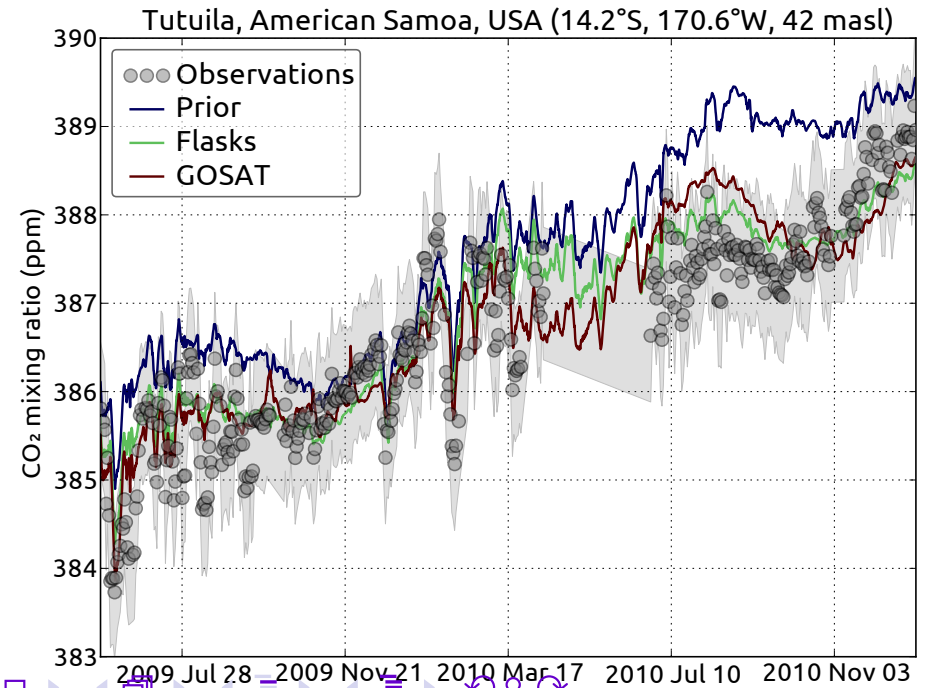
2010 Oct 30
Observations
Prior
Flasks
GOSAT


Tutuila, American Samoa, USA (14.2°S, 170.6°W, 42 masl)
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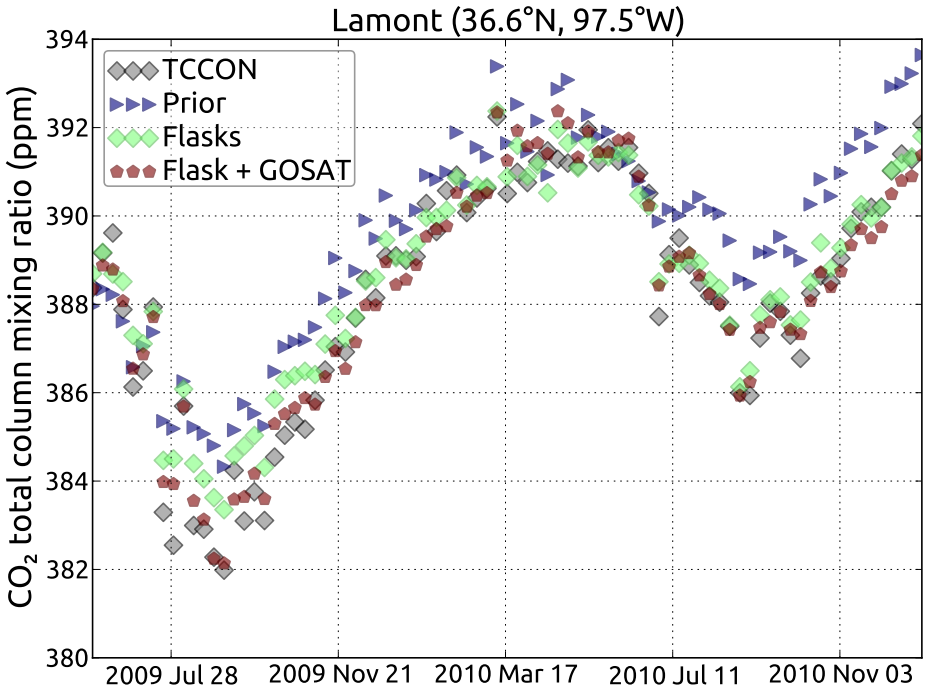
Lamont (36.6°N, 97.5°W)
TCCON
Prior
Flasks
Flask + GOSAT
CO_2 total column mixing ratio (ppm)
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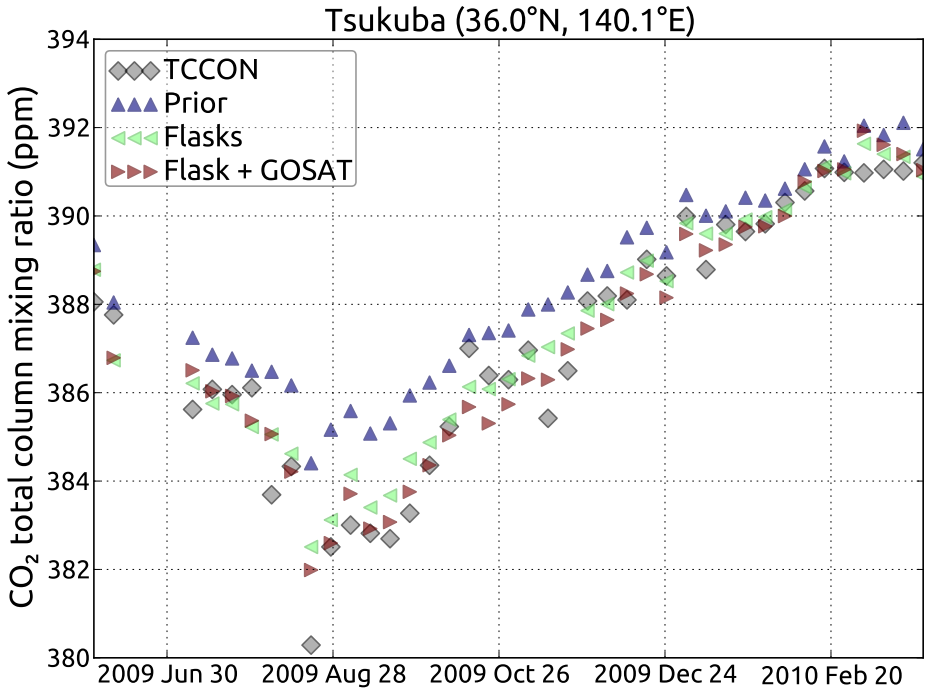
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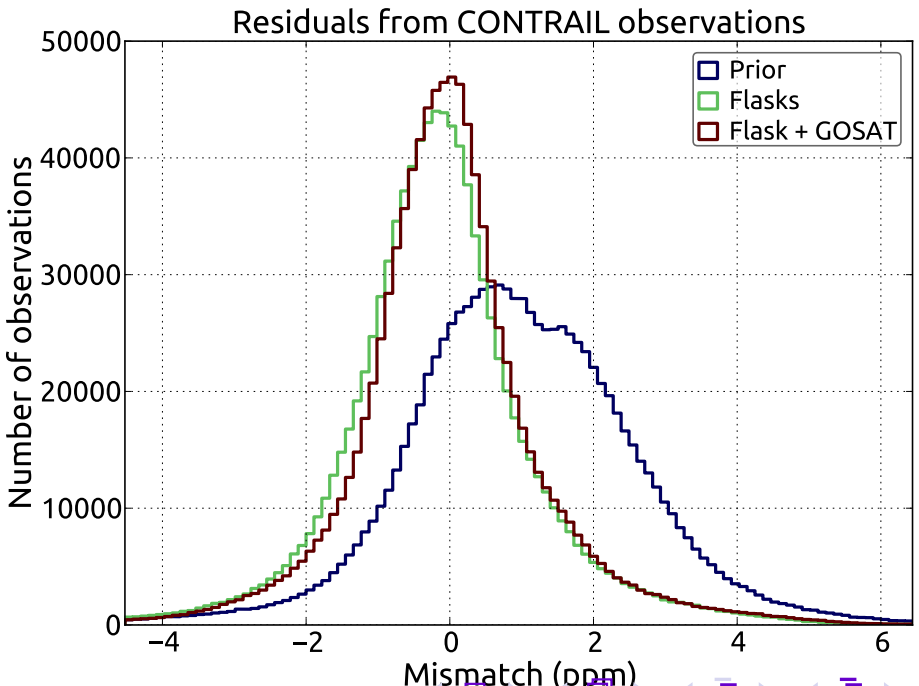
Residuals from CONTRAIL observations
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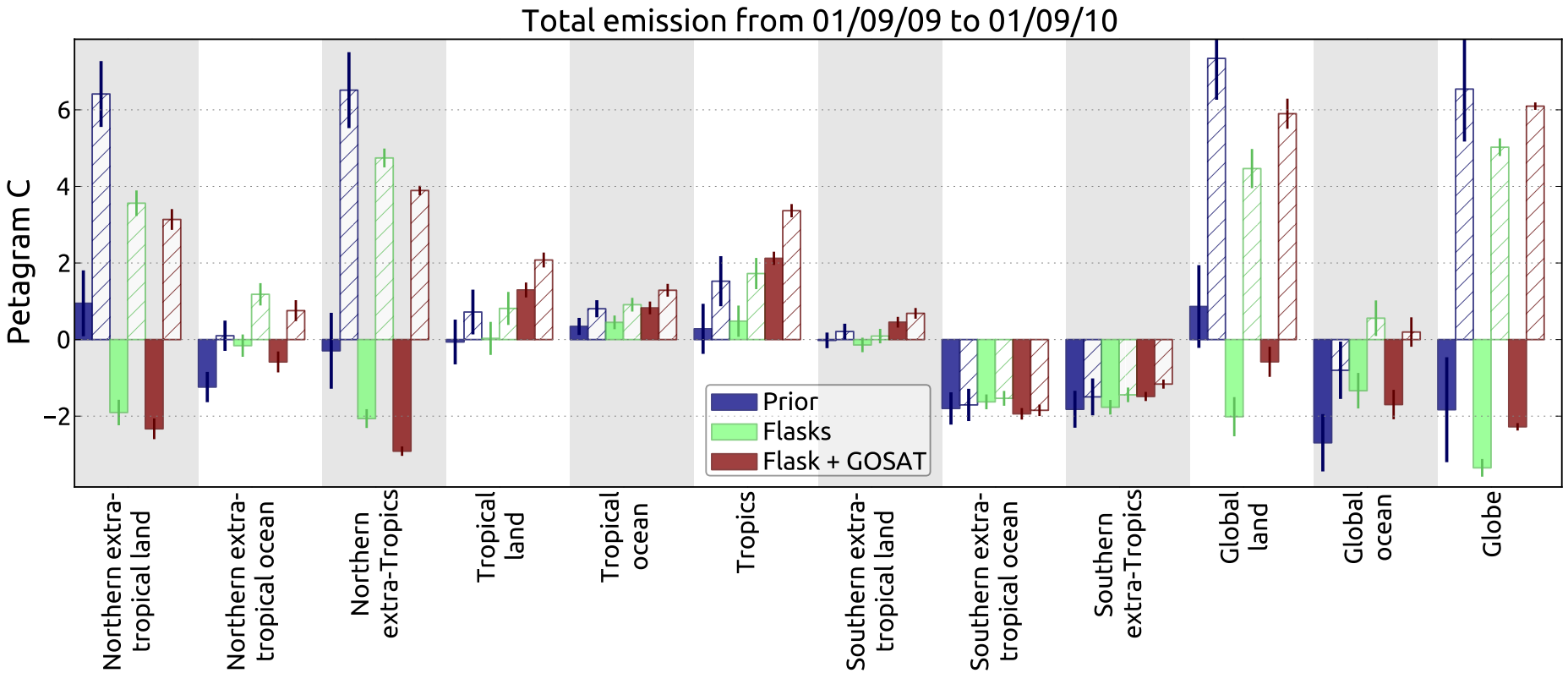
Flasks
Flask + GOSAT
Number of observations
50000
40000
30000
20000
10000
0
−4
−2
0
2
4
6
Mismatch (ppm)

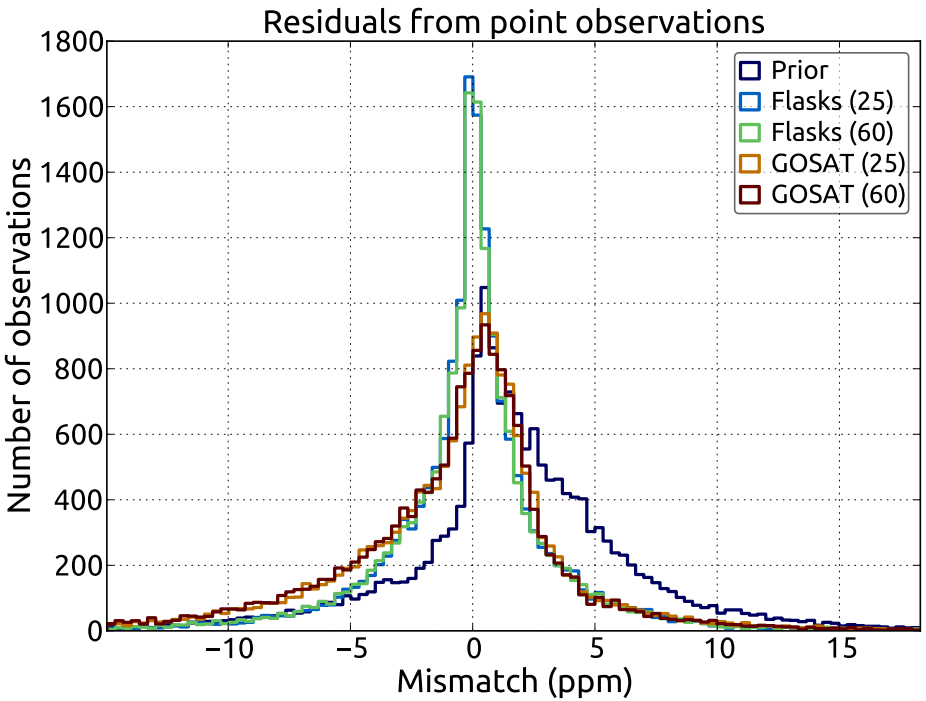


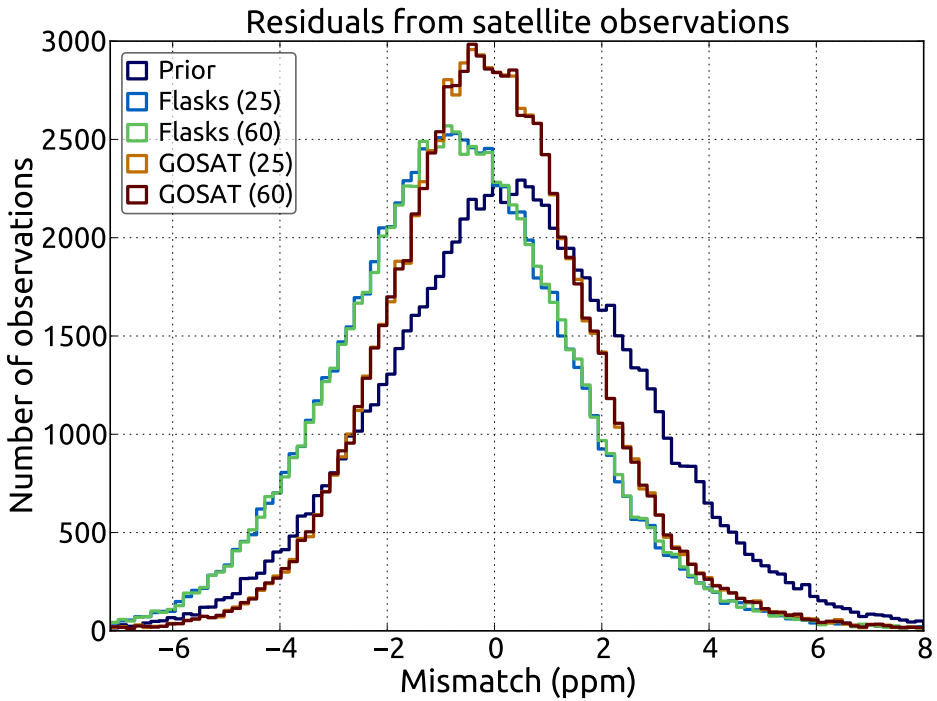
- Poleward carbon flux increased
- Global budget different, due to more carbon in the flask + GOSAT inversion in the free troposphere

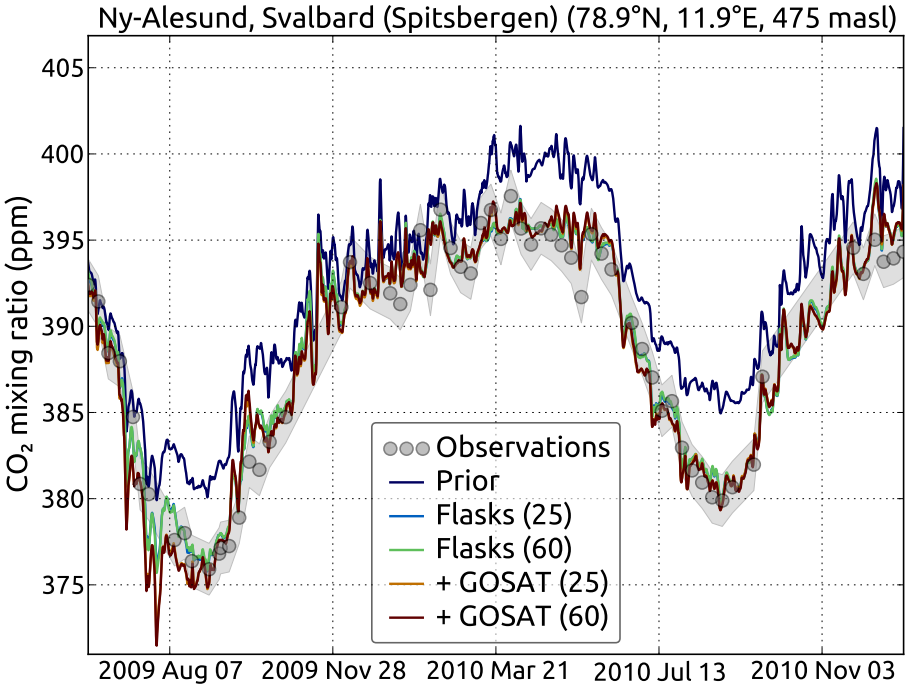
Sensitivity to transport model resolution

- TM5 run at a host of lateral (6°× 4°, 3°× 2°, 1°× 1°, nested zoom) and vertical (25, 34, 60, 91 ... layers)
- No one expects transport to be identical at different resolutions, so how does resolution affect atmospheric inversions?
- Change lateral resolution to 3°× 2°
- Run at the fulll 60 layers possible with ERA Interim meteo
- *Some use an earlier version of RemoTeC, so don't expect the same results as before ...*

- Instead of re-gridding ECMWF ERA Interim meteo fields to 25 layers, run at the maximum possible 60 layers



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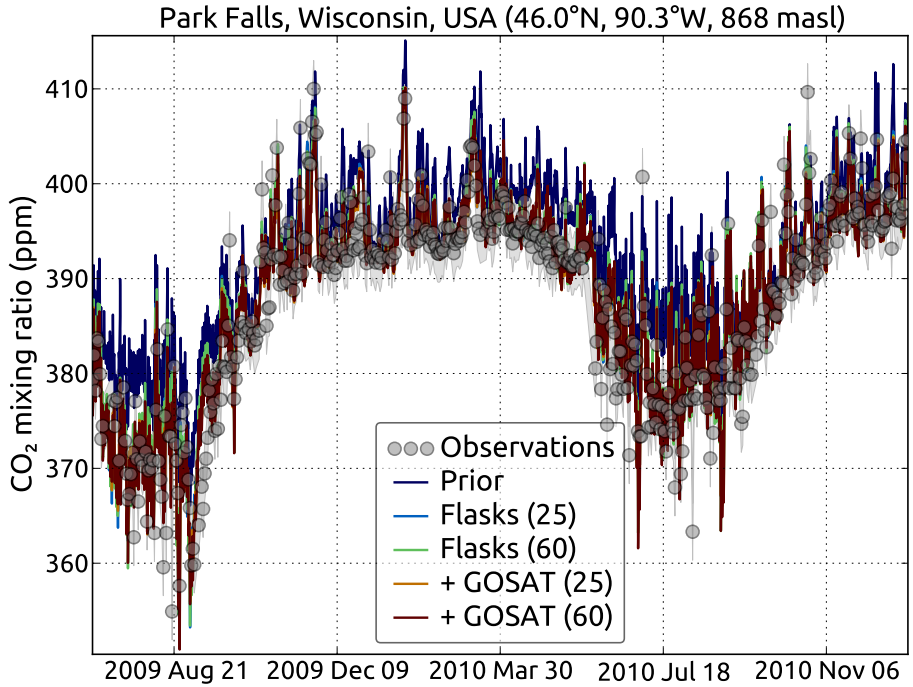
Flasks (60)
+ GOSAT (25)
+ GOSAT (60)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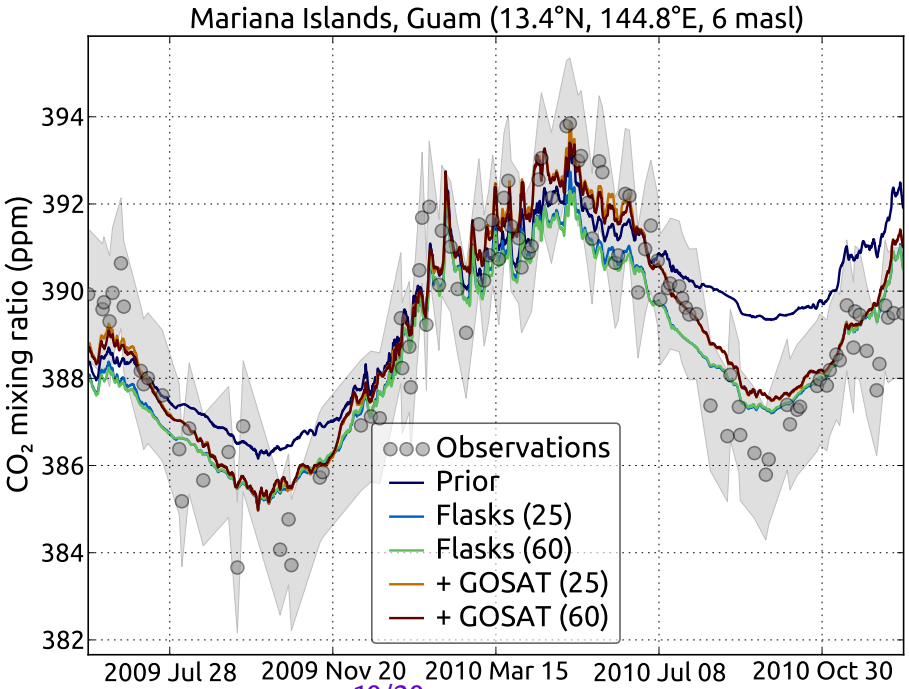
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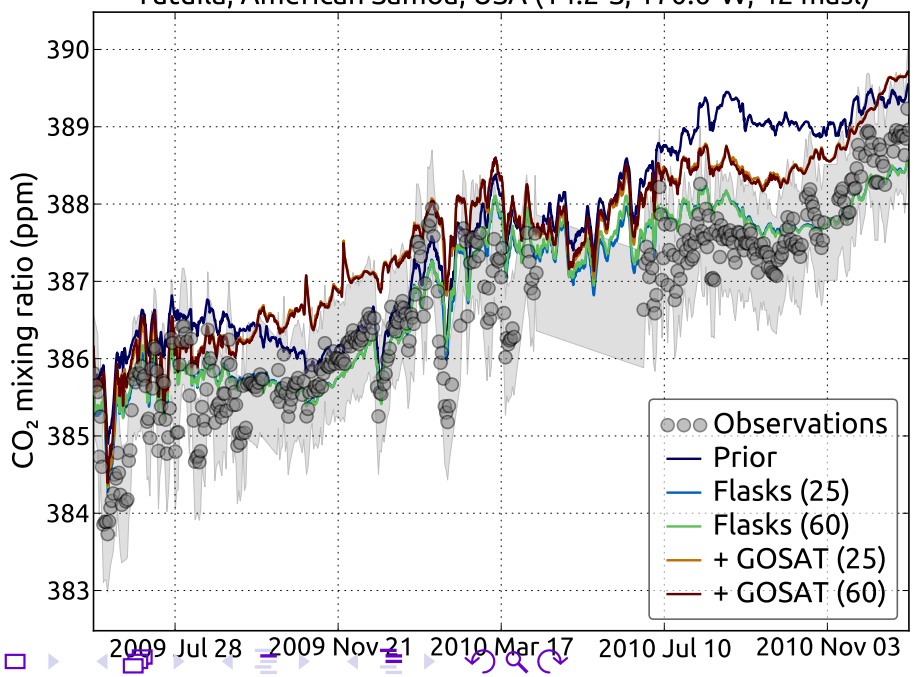
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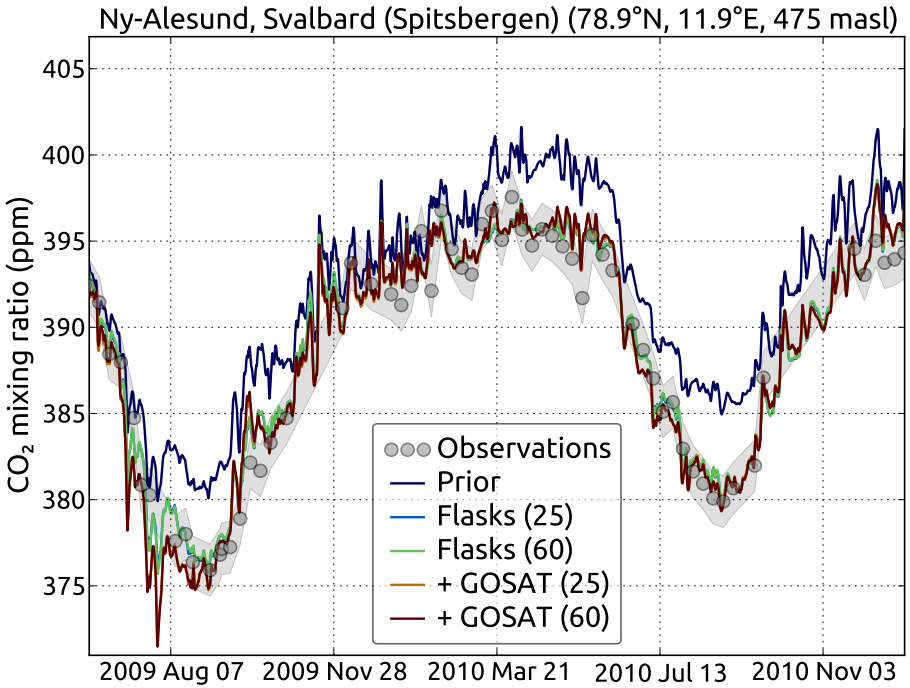
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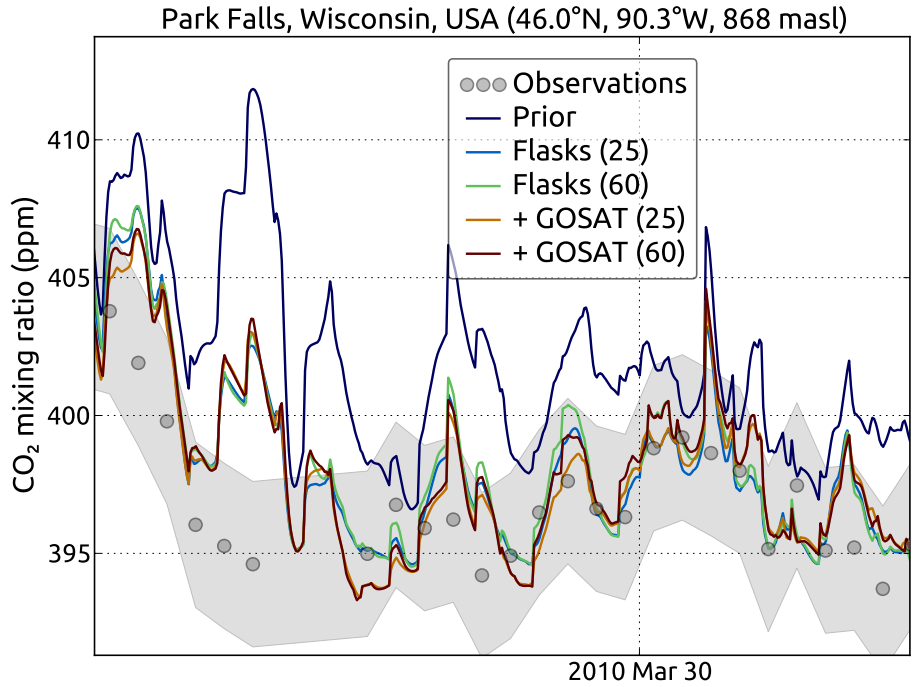
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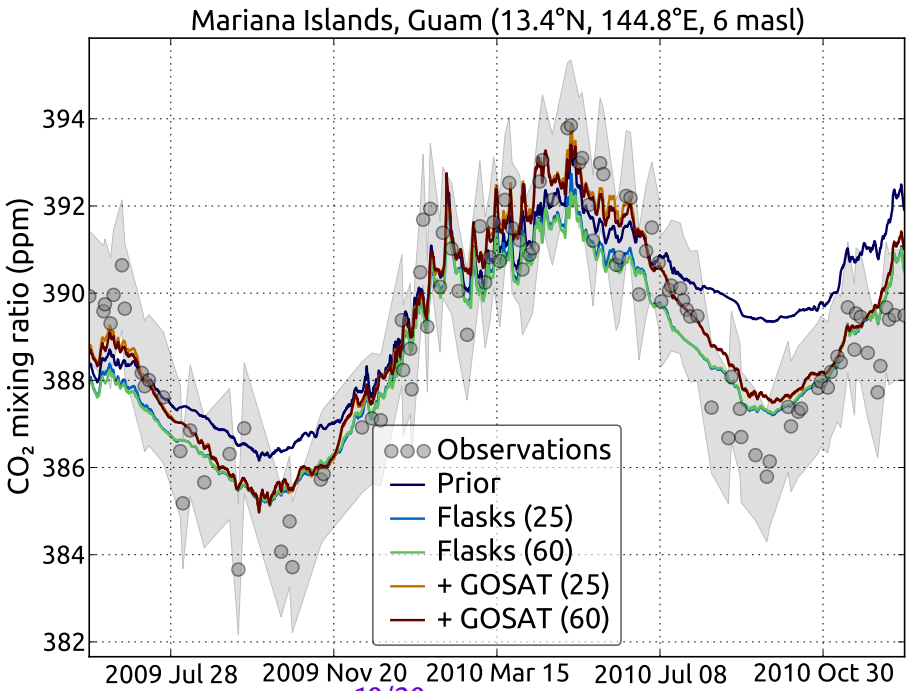
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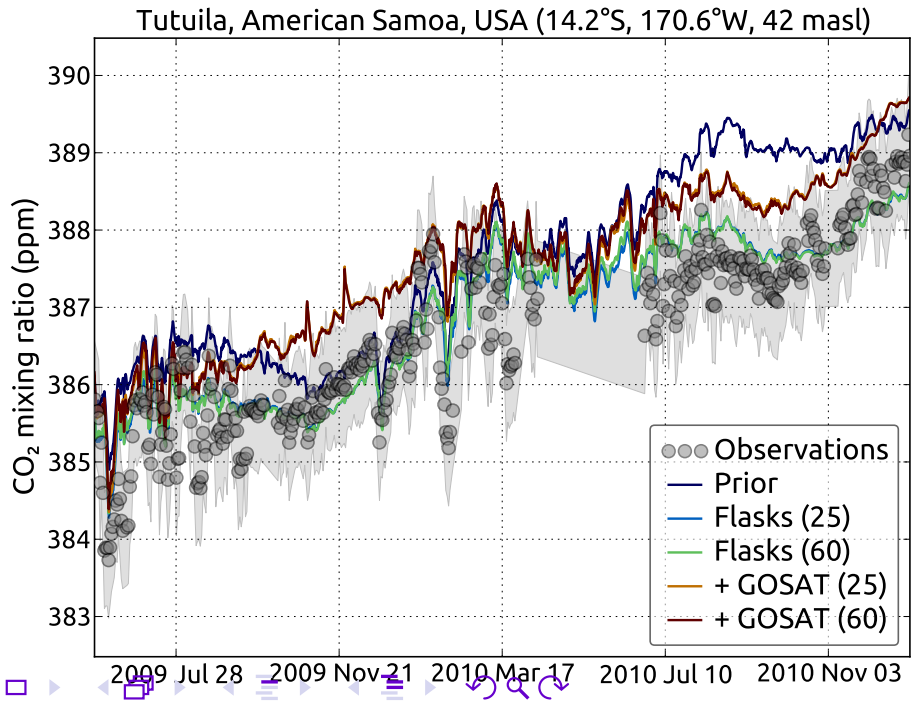
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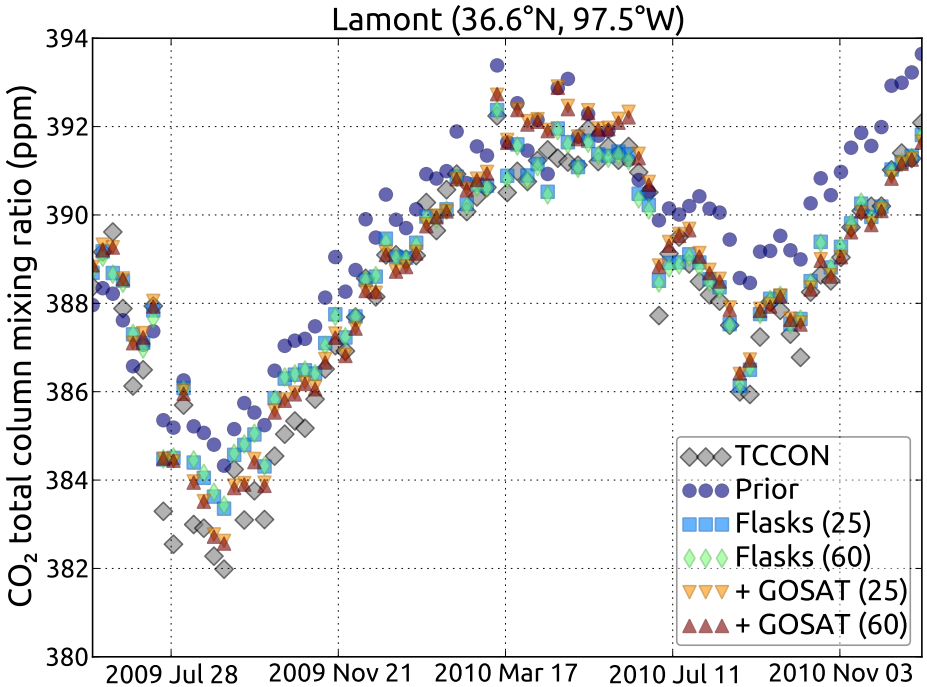
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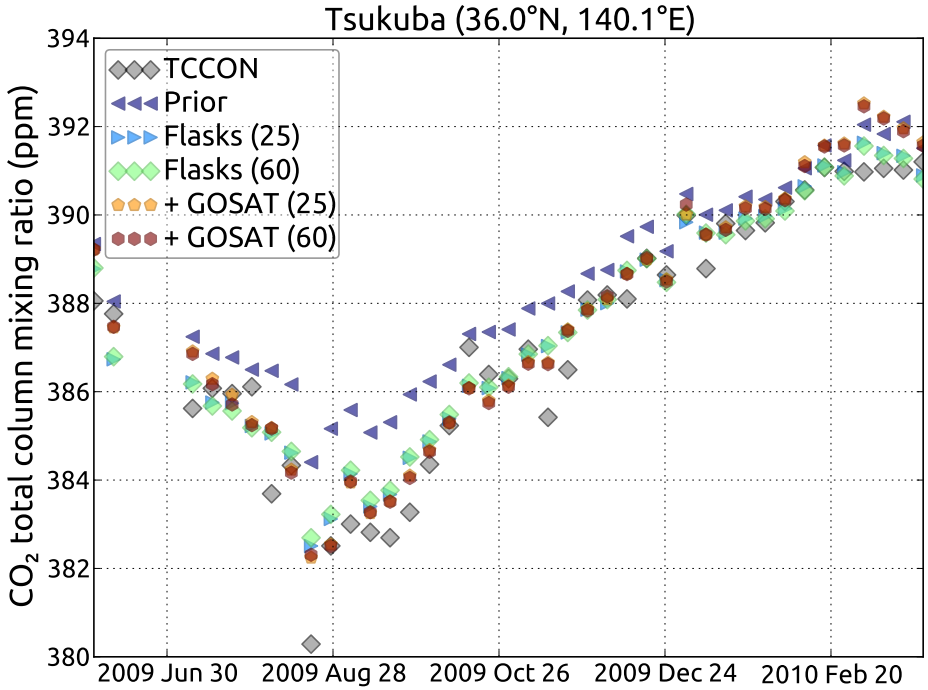
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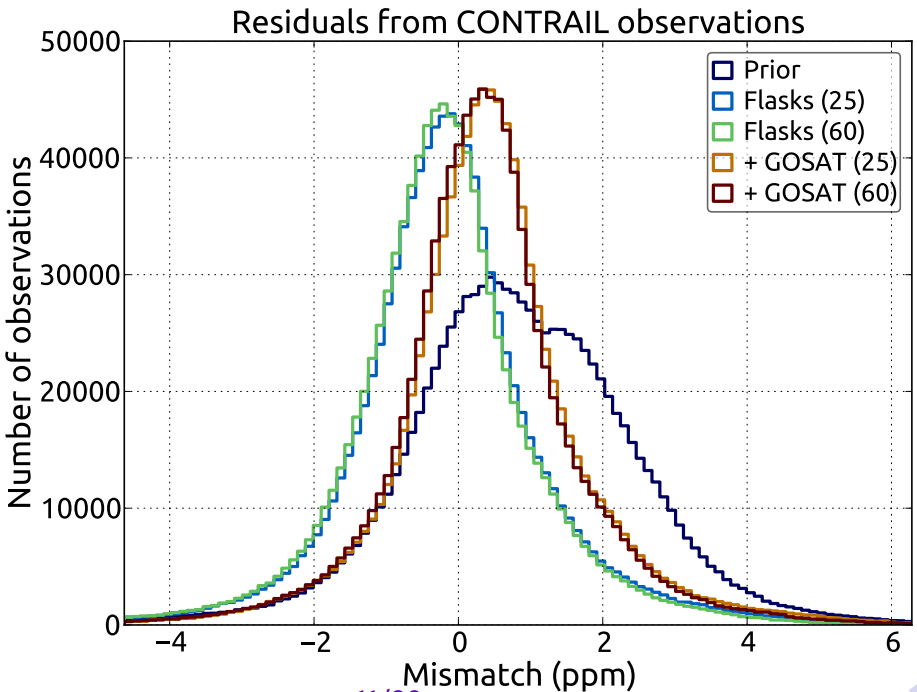
Residuals from CONTRAIL observations
Number of observations
50000
40000
30000
20000
10000
0
−4
−2
0
2
4
6
Mismatch (ppm)
Prior
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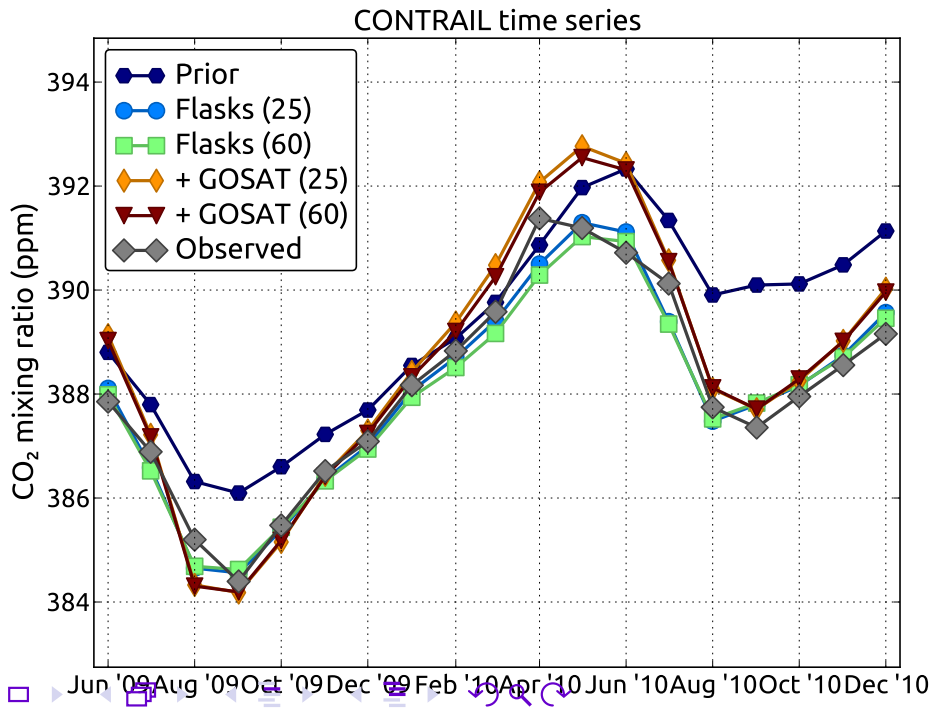
CONTRAIL time series
CO_2 mixing ratio (ppm)
394
392
390
388
386
384
Jun '09
Aug '09
Oct '09
Dec '09
Feb '10
Apr '10
Jun '10
Aug '10
Oct '10
Dec '10
Prior
Flasks (25)
Flasks (60)
+ GOSAT (25)
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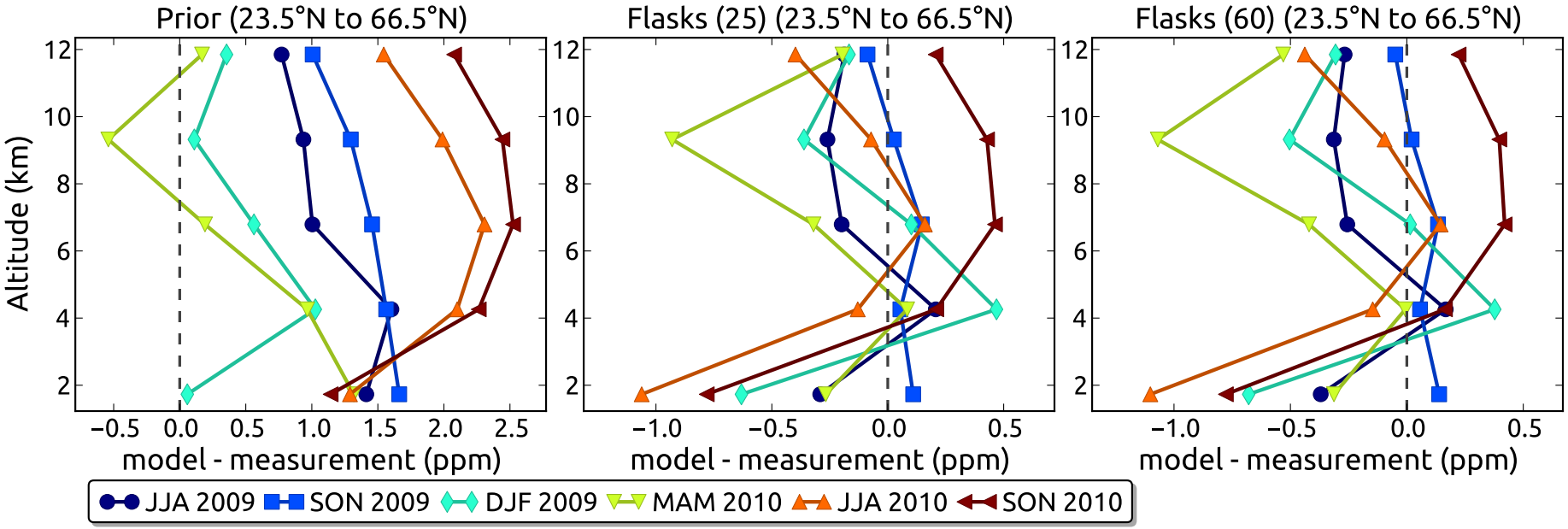
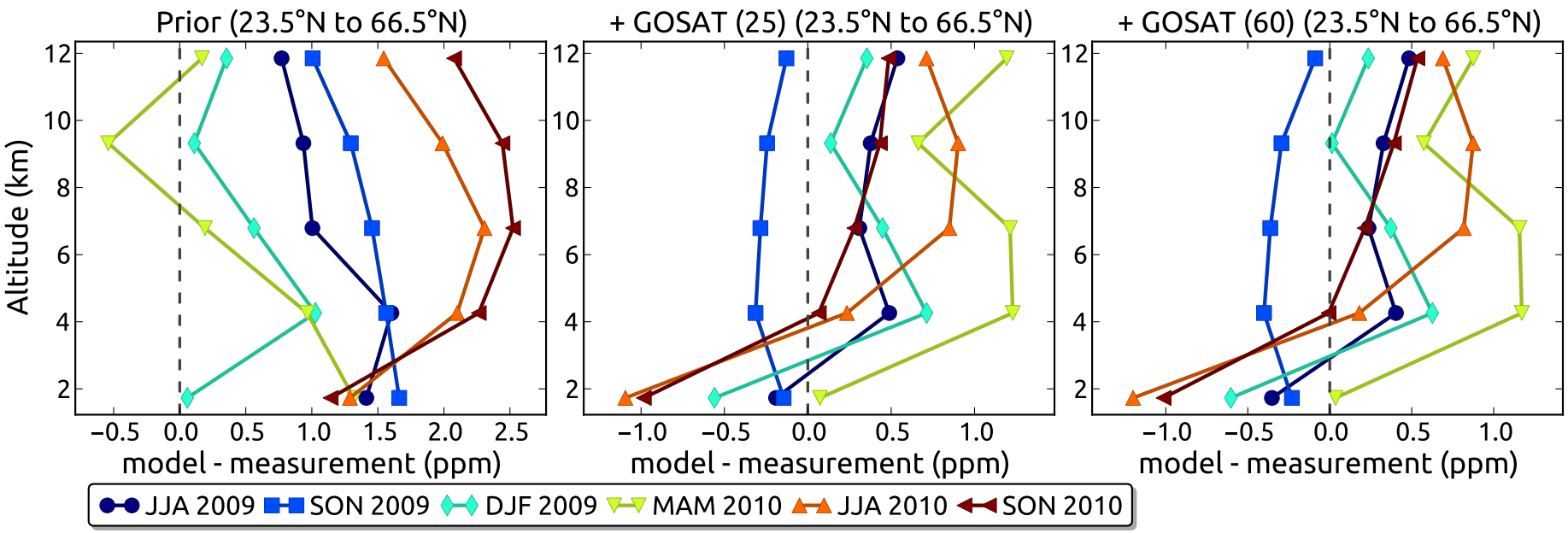
Observed


Prior (23.5°N to 66.5°N)
Flasks (25) (23.5°N to 66.5°N)
Flasks (60) (23.5°N to 66.5°N)
Altitude (km)
model - measurement (ppm)
JJA 2009
SON 2009
DJF 2009
MAM 2010
JJA 2010
SON 2010


Prior (23.5°N to 66.5°N)
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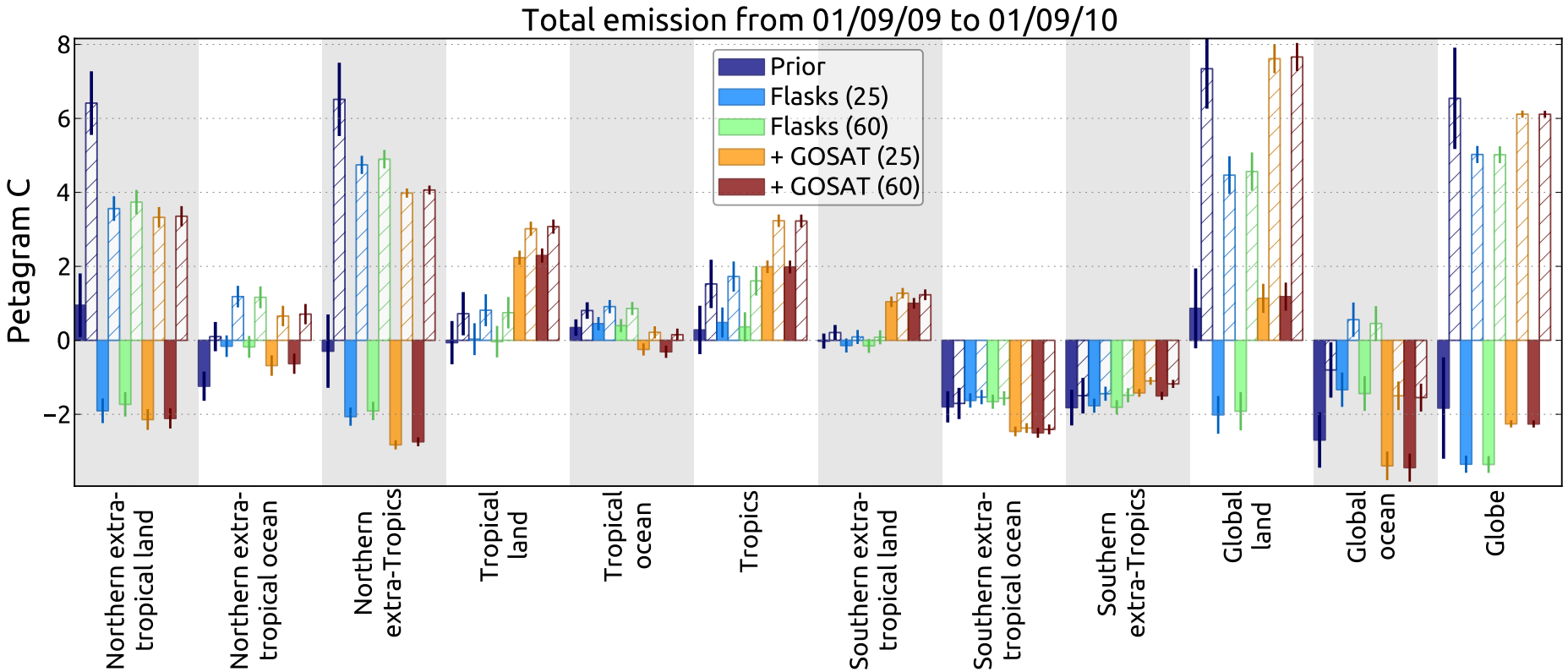

- Changing the vertical resolution seems to change optimized fluxes very little
- This holds even for GOSAT inversions, where the observations have information from the free troposphere!

- Run TM5 at global $3° \times 2°$, estimate monthly $3° \times 2°$ fluxes
- Apparently, n_{state} has increased from 2700/month to 10800/month, but there are spatial correlations:

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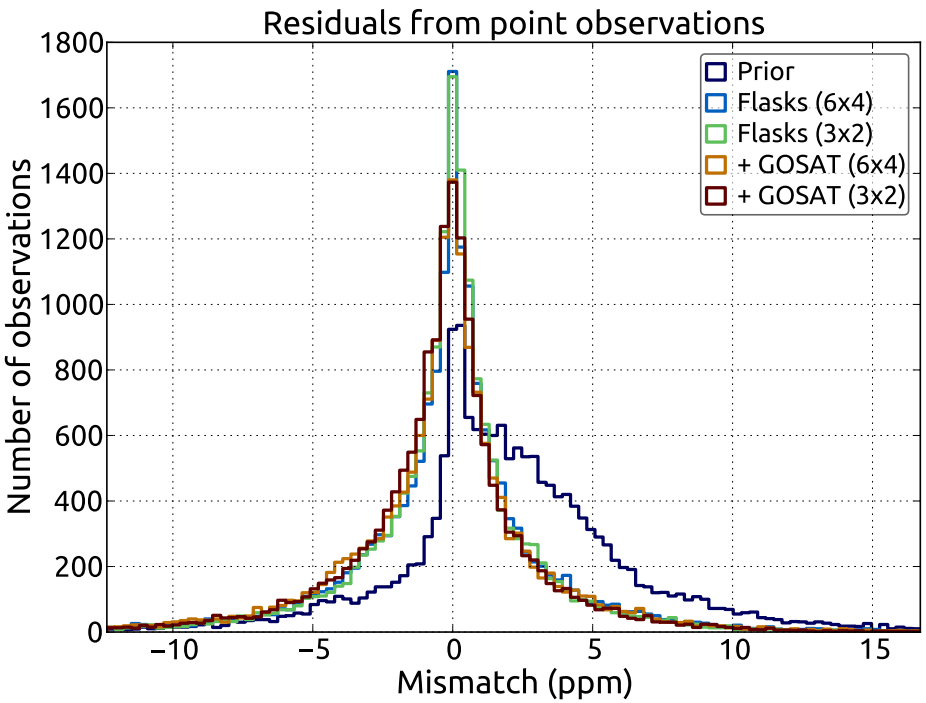

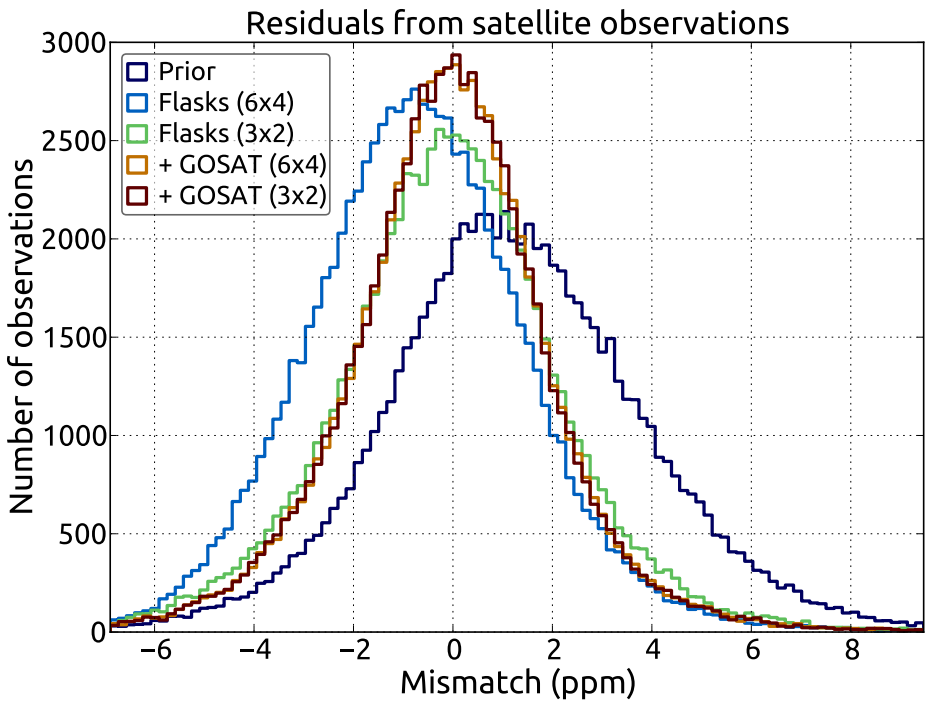

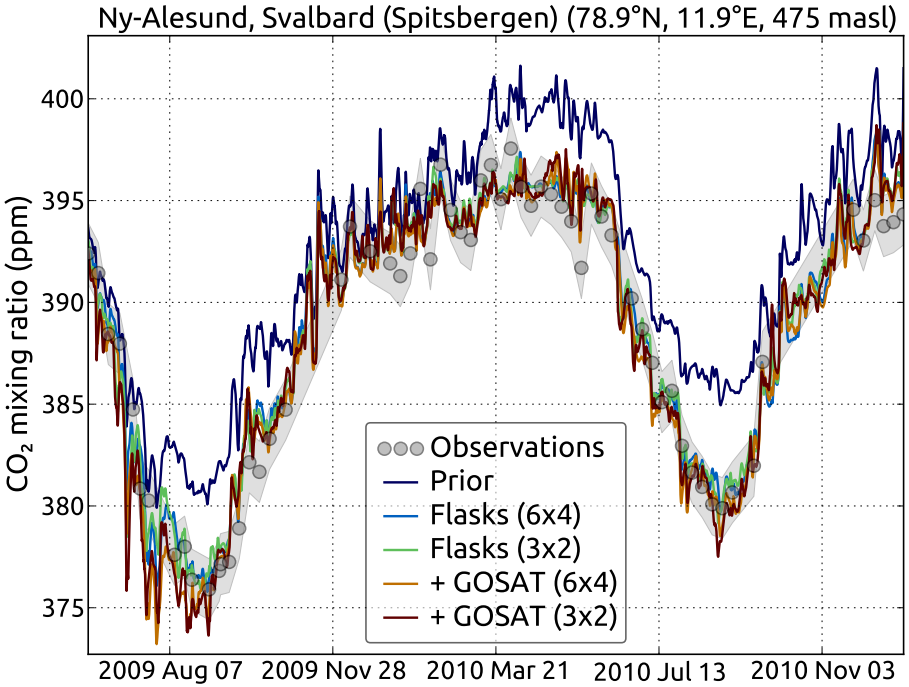
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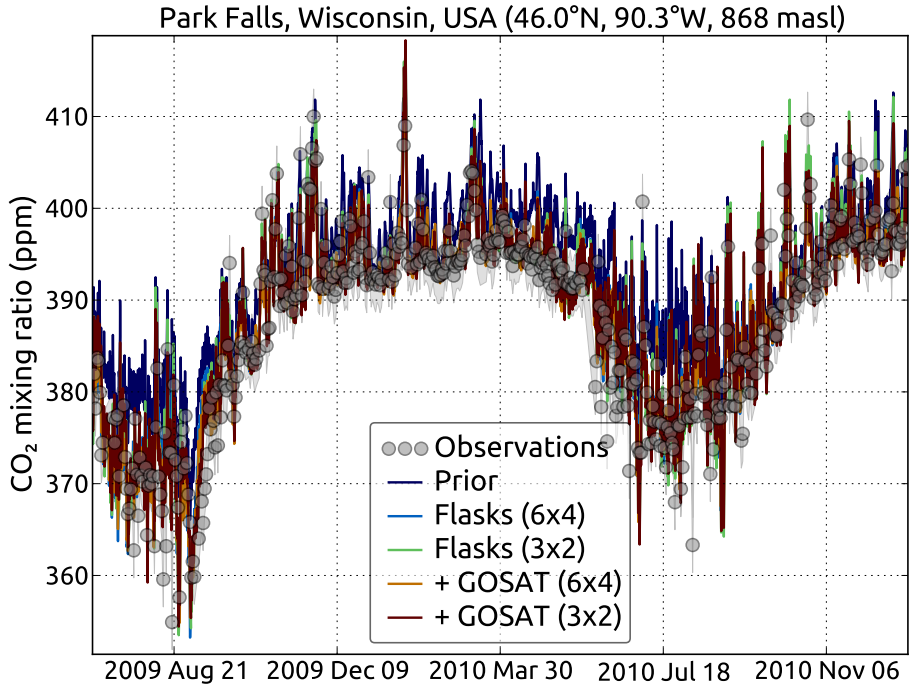
Observations
Prior
Flasks (6x4)
Flasks (3x2)
+ GOSAT (6x4)
+ GOSAT (3x2)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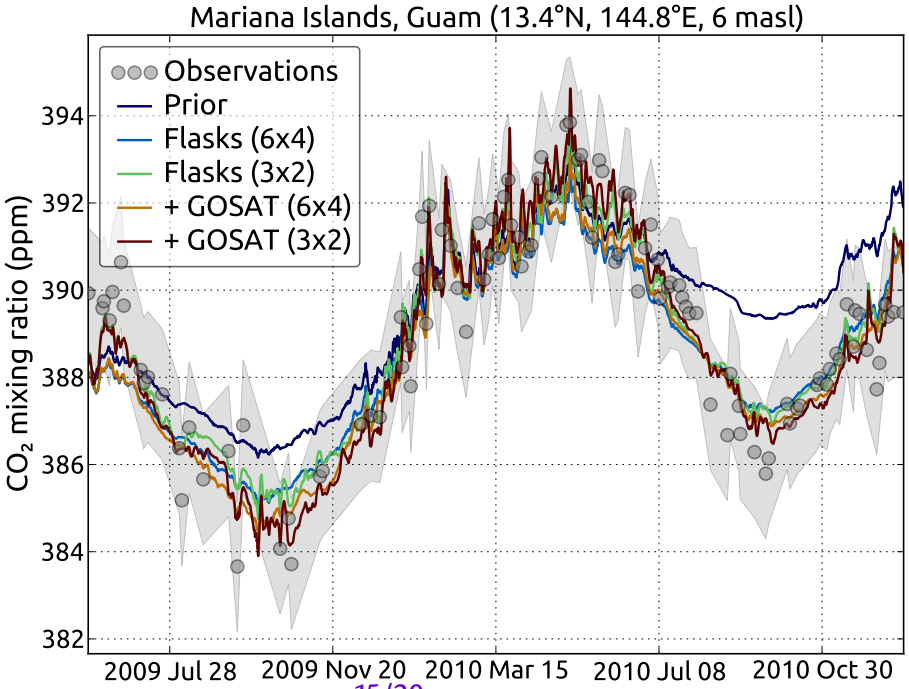
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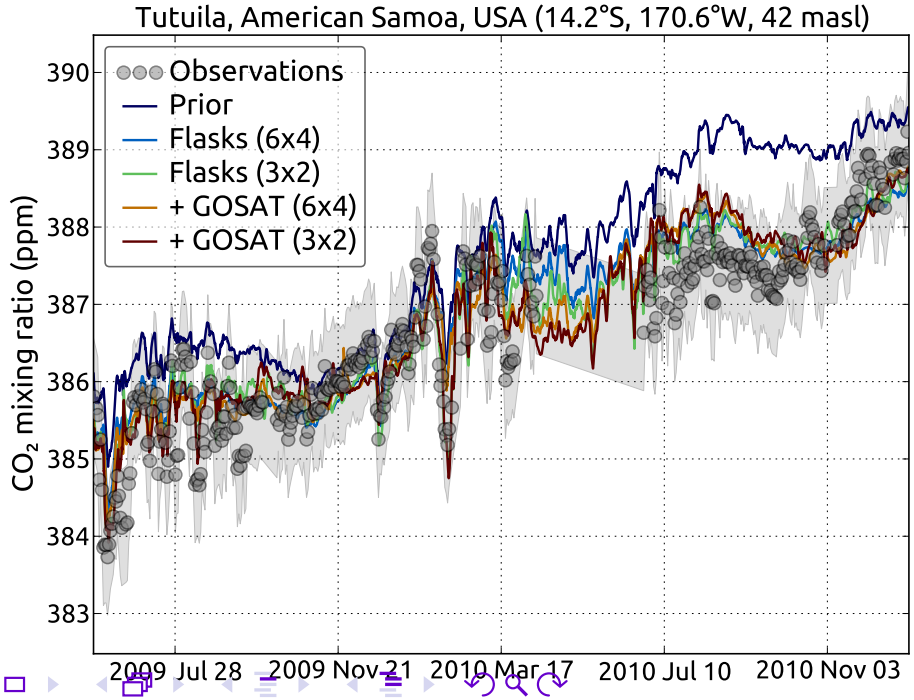
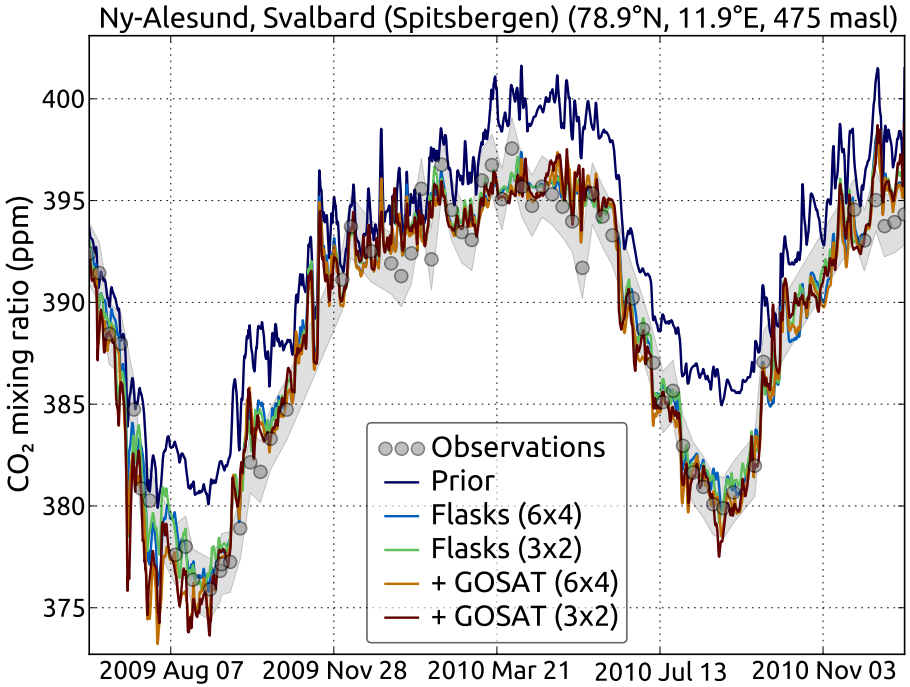
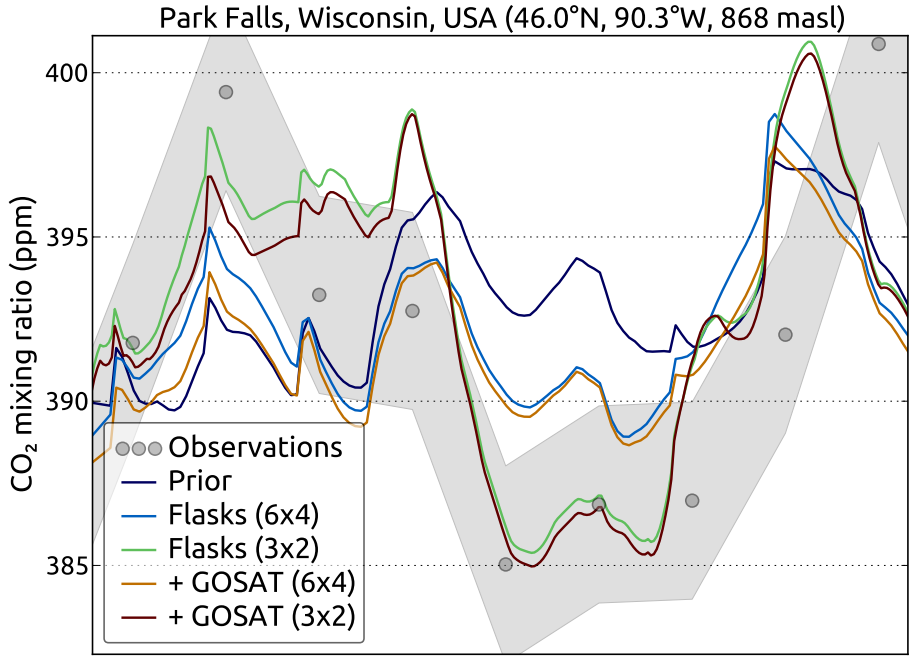
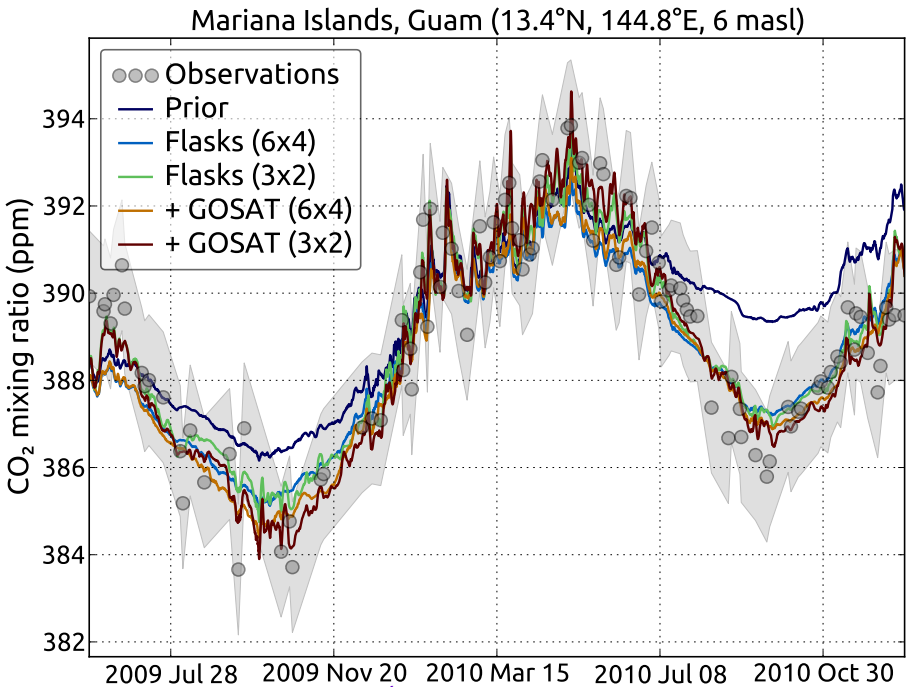
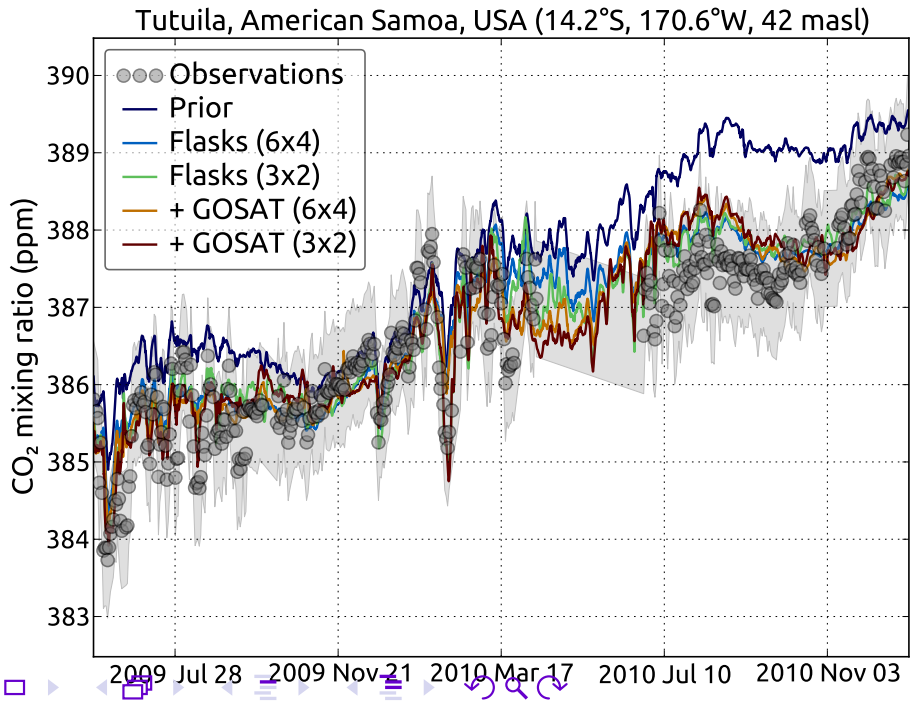
+ GOSAT (6x4)
+ GOSAT (3x2)

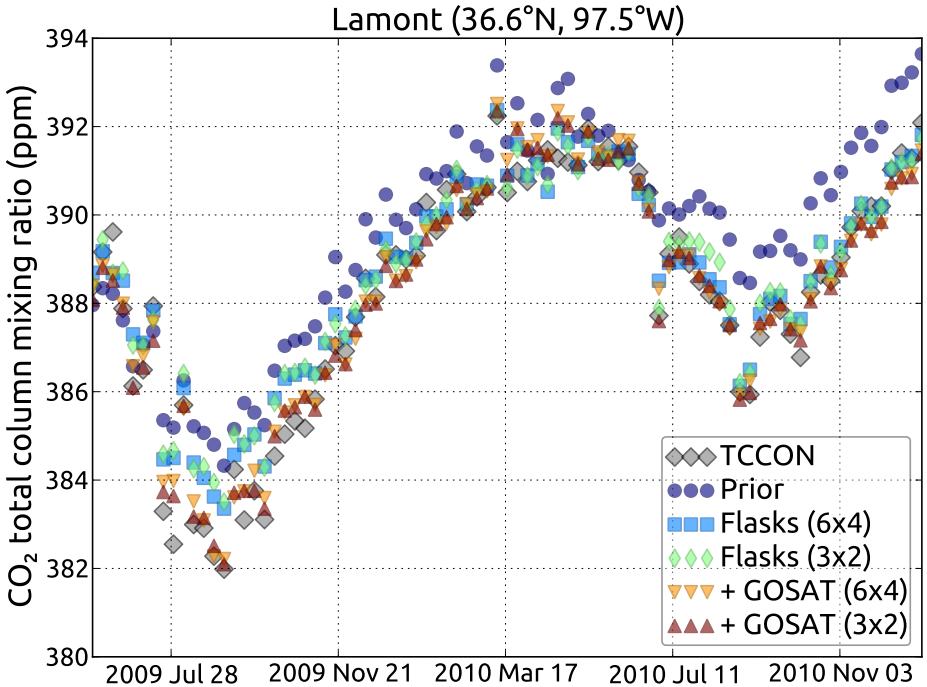

Tutuila, American Samoa, USA (14.2°S, 170.6°W, 42 masl)
CO2 mixing ratio (ppm)
390
389
388
387
386
385
384
383
2009 Jul 28
2009 Nov 21
2010 Mar 17
2010 Jul 10
2010 Nov 03
Observations
Prior
Flasks (6x4)
Flasks (3x2)
+ GOSAT (6x4)
+ GOSAT (3x2)

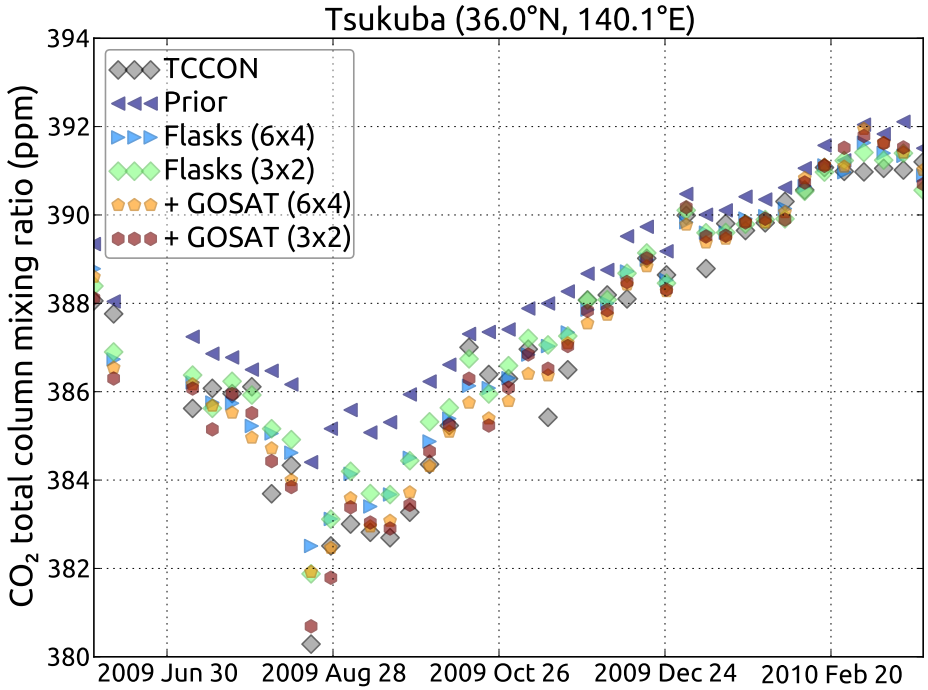

Ny-Alesund, Svalbard (Spitsbergen) (78.9°N, 11.9°E, 475 masl)
CO_2 mixing ratio (ppm)
400
395
390
385
380
375
2009 Aug 07
2009 Nov 28
2010 Mar 21
2010 Jul 13
2010 Nov 03
Observations
Prior
Flasks (6x4)
Flasks (3x2)
+ GOSAT (6x4)
+ GOSAT (3x2)

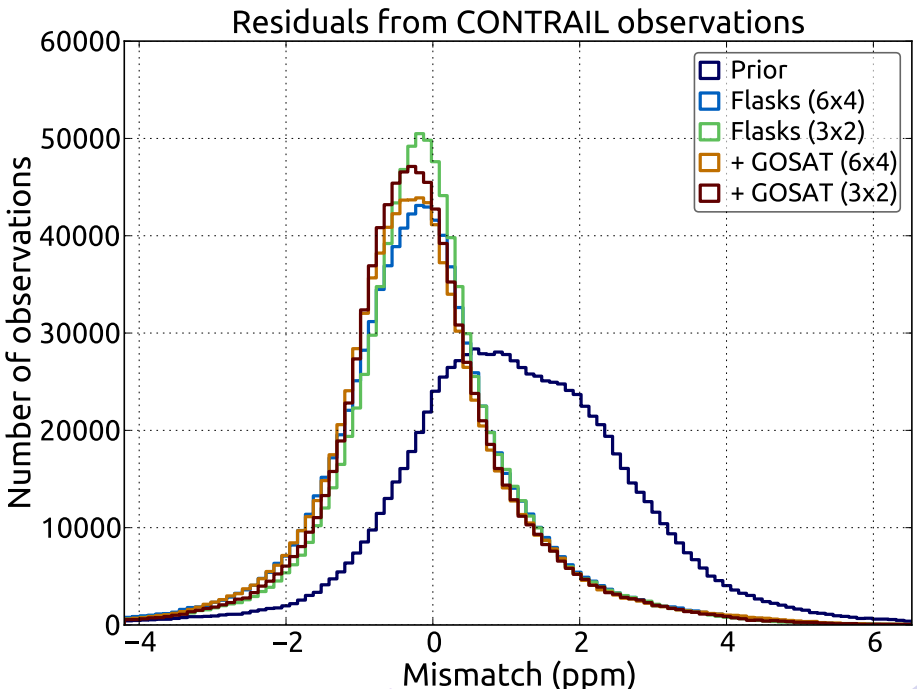

Park Falls, Wisconsin, USA (46.0°N, 90.3°W, 868 masl)
CO_2 mixing ratio (ppm)
400
395
390
385
Observations
Prior
Flasks (6x4)
Flasks (3x2)
+ GOSAT (6x4)
+ GOSAT (3x2)

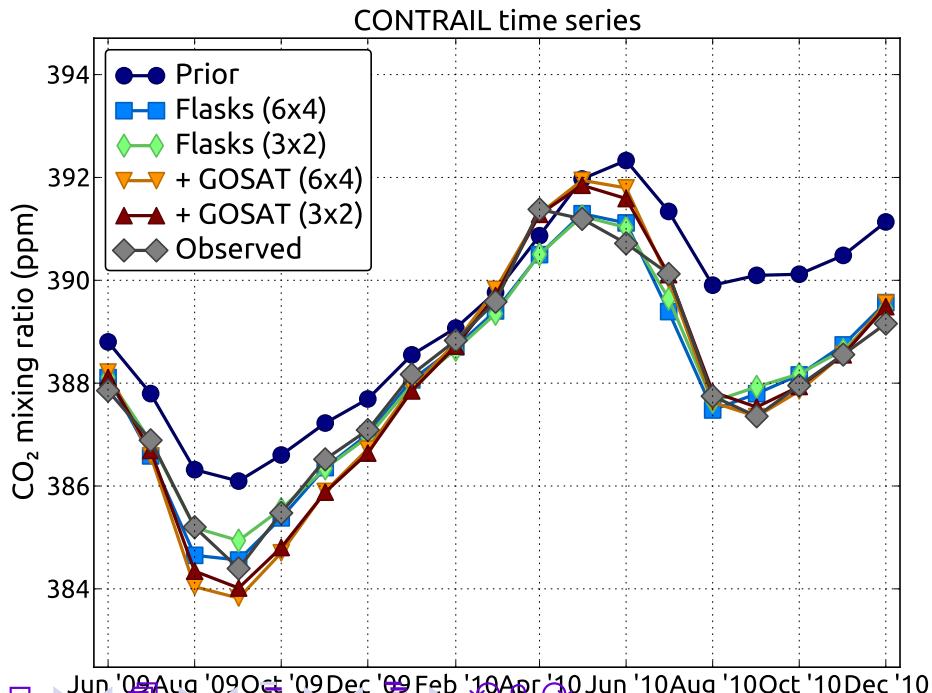

Mariana Islands, Guam (13.4°N, 144.8°E, 6 masl)
CO_2 mixing ratio (ppm)
394
392
390
388
386
384
382
2009 Jul 28
2009 Nov 20
2010 Mar 15
2010 Jul 08
2010 Oct 30
Observations
Prior
Flasks (6x4)
Flasks (3x2)
+ GOSAT (6x4)
+ GOSAT (3x2)

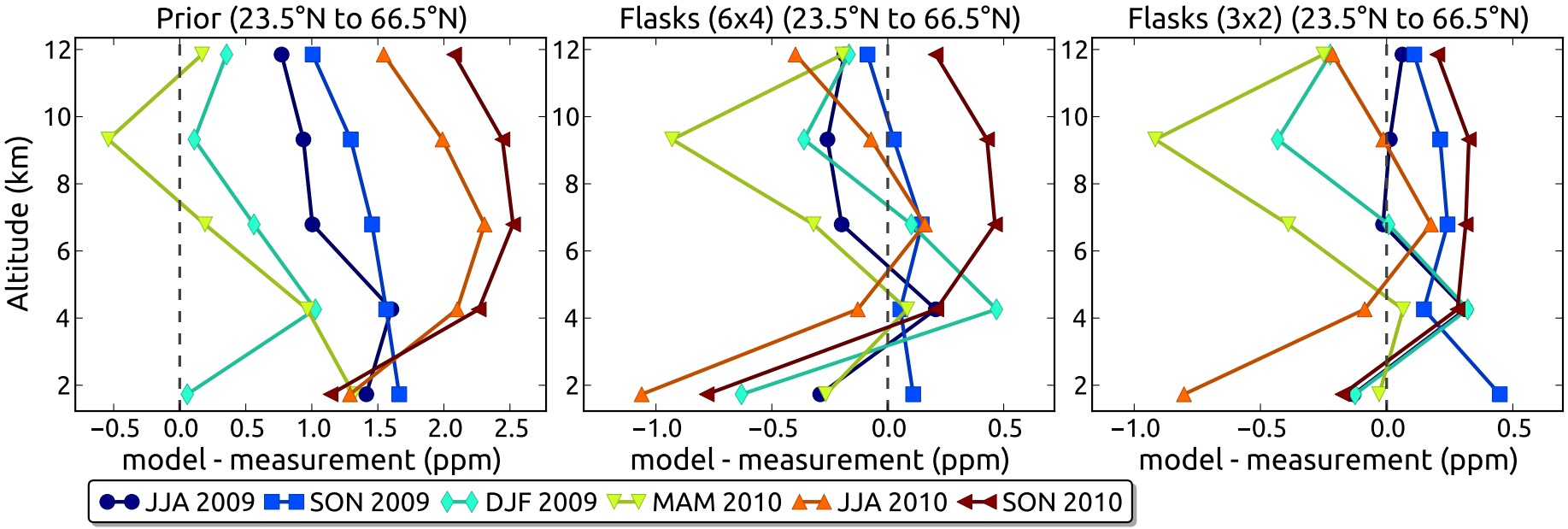

Tutuila, American Samoa, USA (14.2°S, 170.6°W, 42 masl)
CO_2 mixing ratio (ppm)
390
389
388
387
386
385
384
383
2009 Jul 28
2009 Nov 21
2010 Mar 17
2010 Jul 10
2010 Nov 03
Observations
Prior
Flasks (6x4)
Flasks (3x2)
+ GOSAT (6x4)
+ GOSAT (3x2)

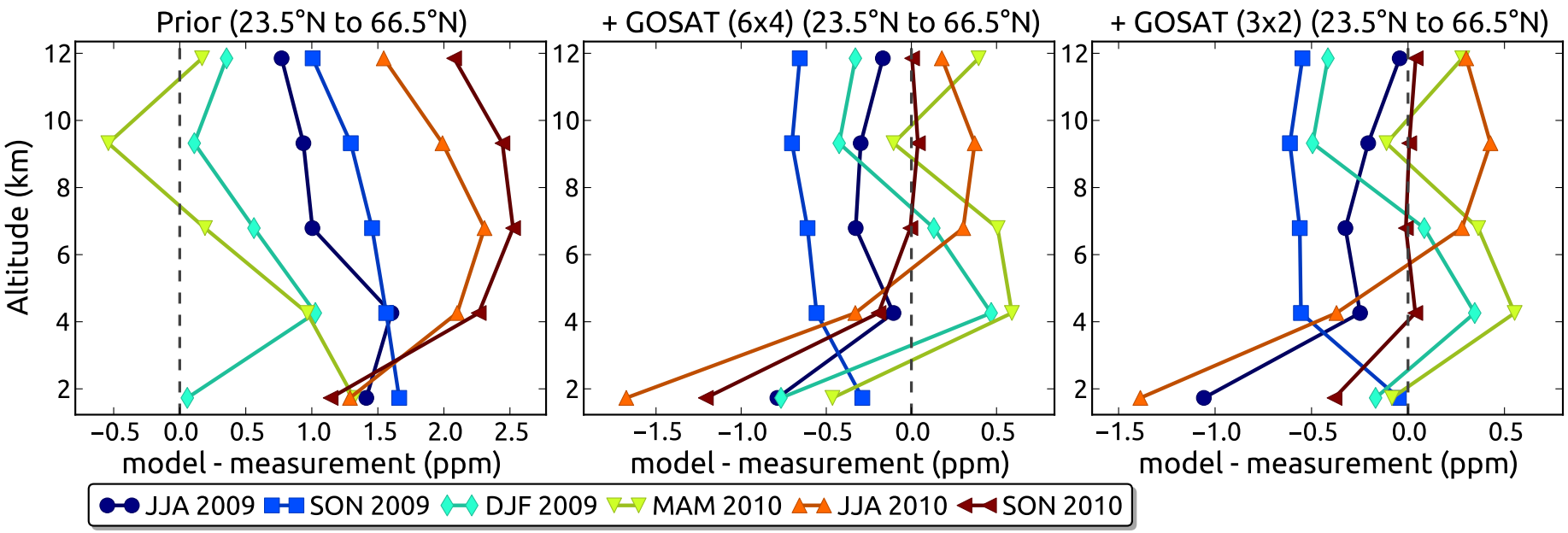

Lamont (36.6°N, 97.5°W)
CO_2 total column mixing ratio (ppm)
394
392
390
388
386
384
382
380
2009 Jul 28
2009 Nov 21
2010 Mar 17
2010 Jul 11
2010 Nov 03
TCCON
Prior
Flasks (6x4)
Flasks (3x2)
+ GOSAT (6x4)
+ GOSAT (3x2)

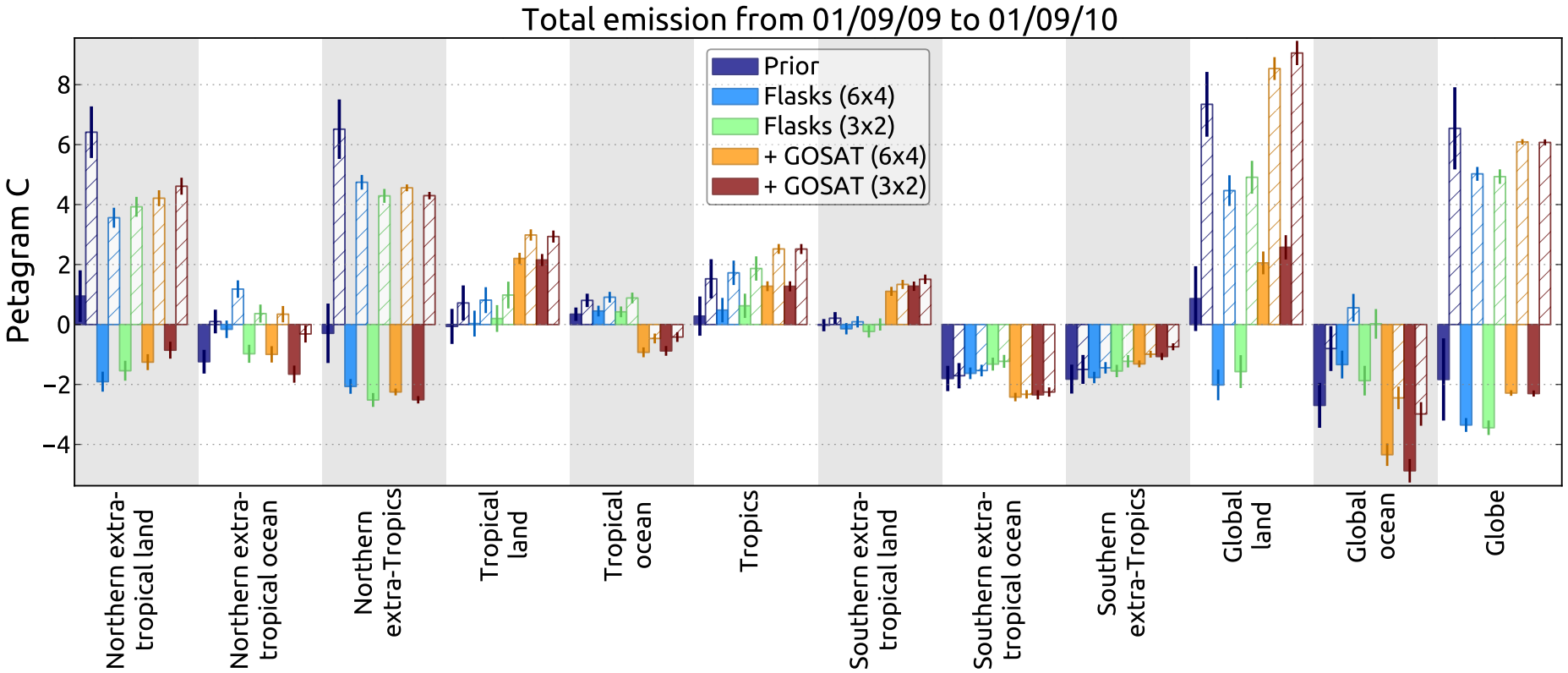

Tsukuba (36.0°N, 140.1°E)
CO_2 total column mixing ratio (ppm)
394
392
390
388
386
384
382
380
2009 Jun 30
2009 Aug 28
2009 Oct 26
2009 Dec 24
2010 Feb 20
TCCON
Prior
Flasks (6x4)
Flasks (3x2)
+ GOSAT (6x4)
+ GOSAT (3x2)


Residuals from CONTRAIL observations
Number of observations
60000
50000
40000
30000
20000
10000
0
−4
−2
0
2
4
6
Mismatch (ppm)
Prior
Flasks (6x4)
Flasks (3x2)
+ GOSAT (6x4)
+ GOSAT (3x2)

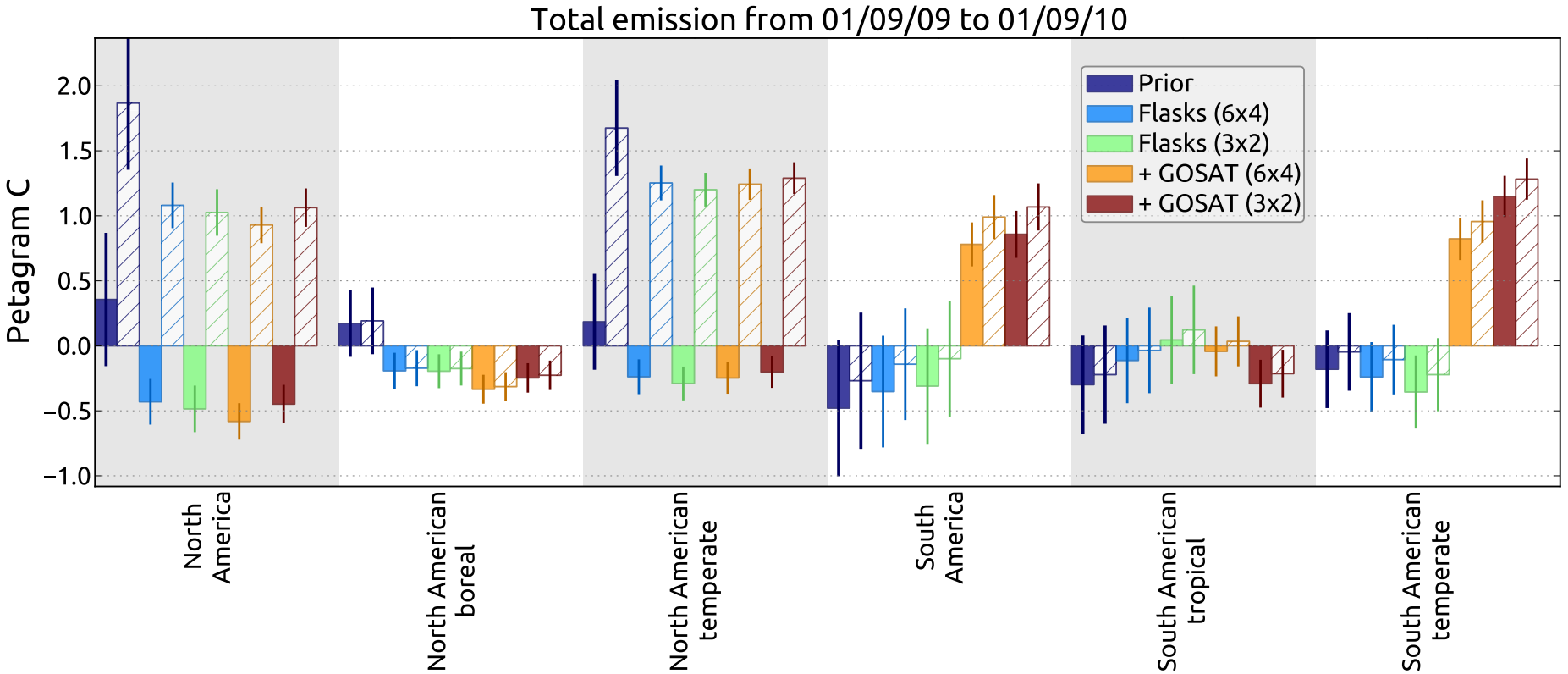

CONTRAIL time series
CO_2 mixing ratio (ppm)
394
392
390
388
386
384
Jun '09
Aug '09
Oct '09
Dec '09
Feb '10
Apr '10
Jun '10
Aug '10
Oct '10
Dec '10
Prior
Flasks (6x4)
Flasks (3x2)
+ GOSAT (6x4)
+ GOSAT (3x2)
Observed


Prior (23.5°N to 66.5°N)
Flasks (6x4) (23.5°N to 66.5°N)
Flasks (3x2) (23.5°N to 66.5°N)
Altitude (km)
model - measurement (ppm)
JJA 2009
SON 2009
DJF 2009
MAM 2010
JJA 2010
SON 2010


Prior (23.5°N to 66.5°N)
+ GOSAT (6x4) (23.5°N to 66.5°N)
+ GOSAT (3x2) (23.5°N to 66.5°N)
Altitude (km)
model - measurement (ppm)
JJA 2009
SON 2009
DJF 2009
MAM 2010
JJA 2010
SON 2010



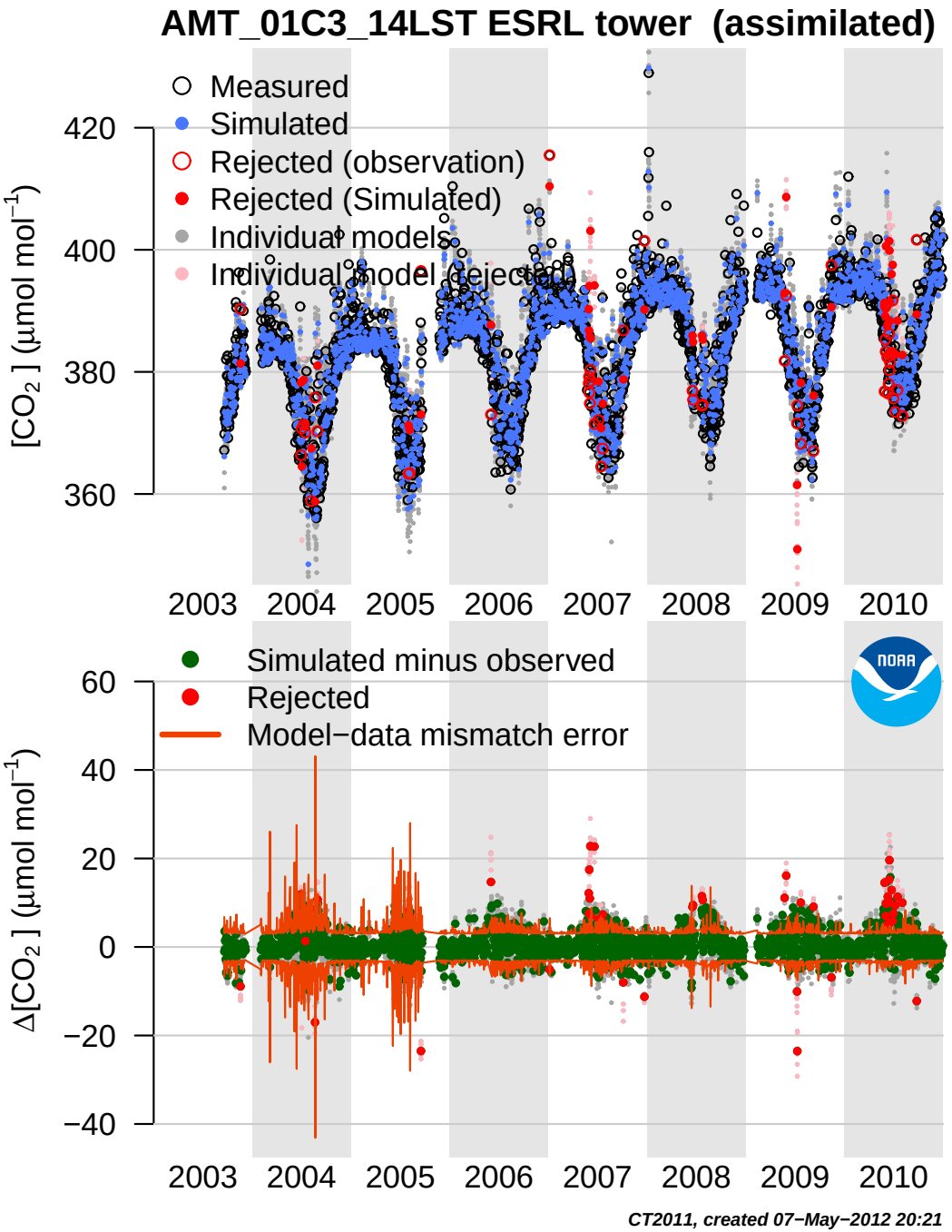
- Changing the horizontal resolution has more effect than changing the vertical resolution
- *Net land source is a retrieval issue that was fixed later*
- Surprisingly, North American fluxes don't change all that much!



- Changing the horizontal resolution has more effect than changing the vertical resolution
- *Net land source is a retrieval issue that was fixed later*
- Surprisingly, North American fluxes don't change all that much!

Conclusions

- Adding satellite measurements increase the tropical source and extra-tropical sink, thereby increasing the poleward carbon flux
- Changing the vertical resolution did not significantly affect the inversion, even when satellite data were assimilated
- *This conclusion might change if we drive TM5 by a different meteo set (OD) at a different resolution, a test to be done whenever TM5 OD meteo is available*
- Changing the horizontal resolution $6° \times 4° \rightarrow 3° \times 2°$ has a bigger, but still rather small, effect
- *Possibly because the increased resolution only adds 9.3% more degrees of freedom to the state vector*


AMT_01C3_14LST ESRL tower (assimilated)
Measured
Simulated
Rejected (observation)
Rejected (Simulated)
Individual models
Individual model (rejected)
[CO2] (µmol mol−1)
420
400
380
360
2003
2004
2005
2006
2007
2008
2009
2010
Simulated minus observed
Rejected
Model−data mismatch error
Δ[CO2] (µmol mol−1)
60
40
20
0
−20
−40
CT2011, created 07−May−2012 20:21