Optimizing transport properties in TM5

Master thesis with W. Peters, WUR

22-04-2013, Emma van der Veen

With thanks to
S. Basu (SRON)
S. Houweling (SRON)
K. Masarie (NOAA)

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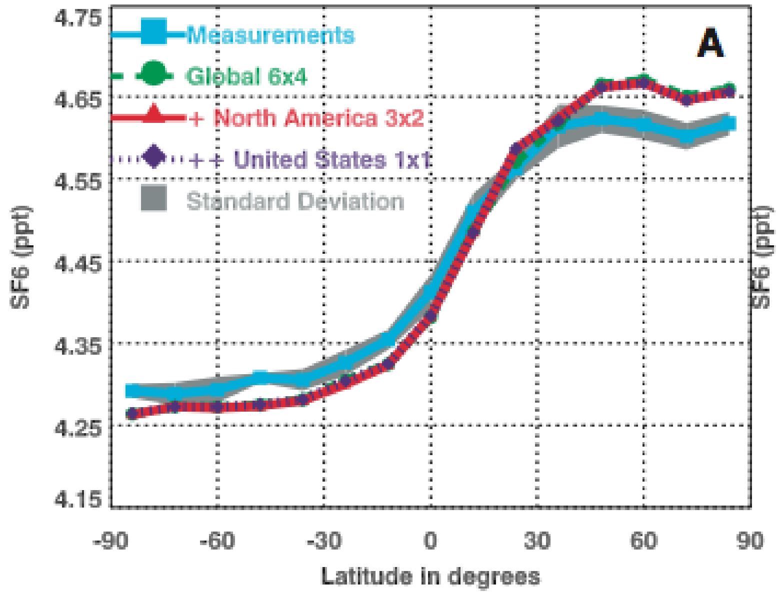
TM5: overestimation north-south gradient

- Peters et al. (2004)



TM5: overestimation north-south gradient

- Peters et al. (2004)
- Presentation of P. Bergamaschi

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SF6 stations

01/01/2001	observed	TM3 (KNMI)	TM3 (MPI)	IMAGES (BIRA IASB)	TM5 (JRC)
BRW	4.85	4.80	4.77	4.92	4.82
SPO	4.50	4.37	4.34	4.34	4.36
NH-SH	0.35	0.43	0.43	0.58	0.46

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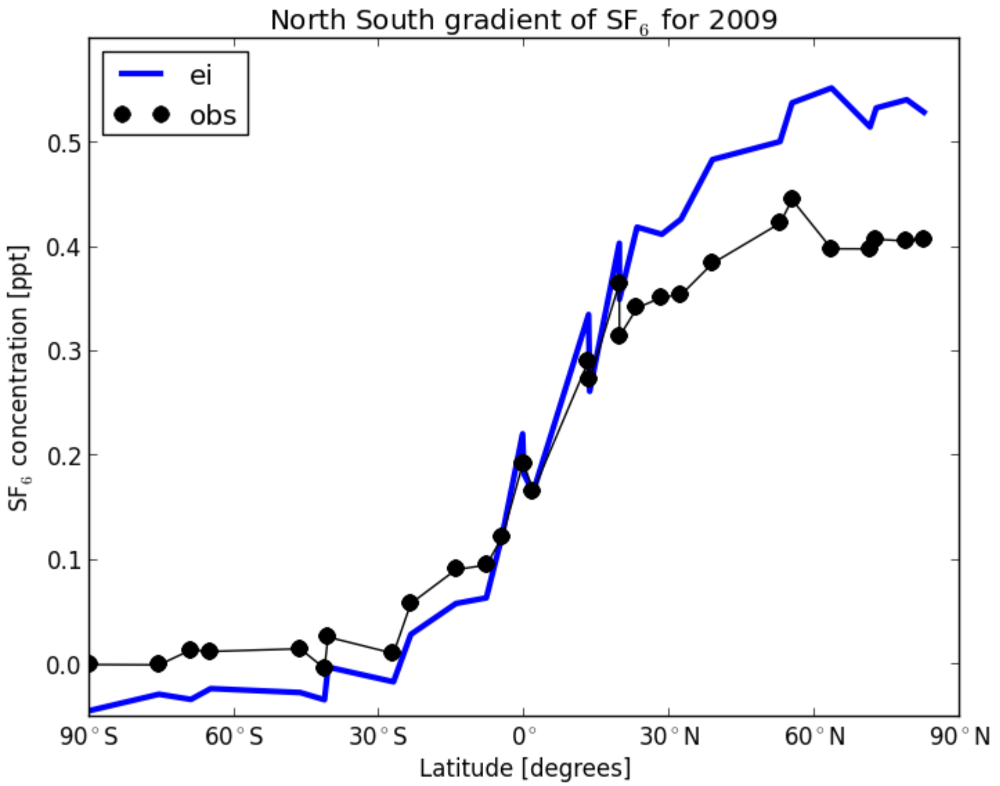
TM5: overestimation north-south gradient

- Peters et al. (2004)
- Presentation of P. Bergamaschi
- This research



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Research aim

- Increase horizontal/interhemispheric transport
- Link enhanced transport to convective updrafts

(Prather et al., 1987) and (Zipser, 1969)

1. Adjust horizontal slopes
2. Parameterize horizontal diffusion (δ)
3. Optimize δ with Ensemble Kalman Filter (CTDAS)
4. Validate with independent aircraft data

SF_6

- Purely anthropogenic, no biological interactions
- Long atmospheric lifetime (~3000 years)
- Nearly constant (known) emissions (~0.20 $ppt \cdot yr^{-1}$)

1. Adjusting horizontal slopes

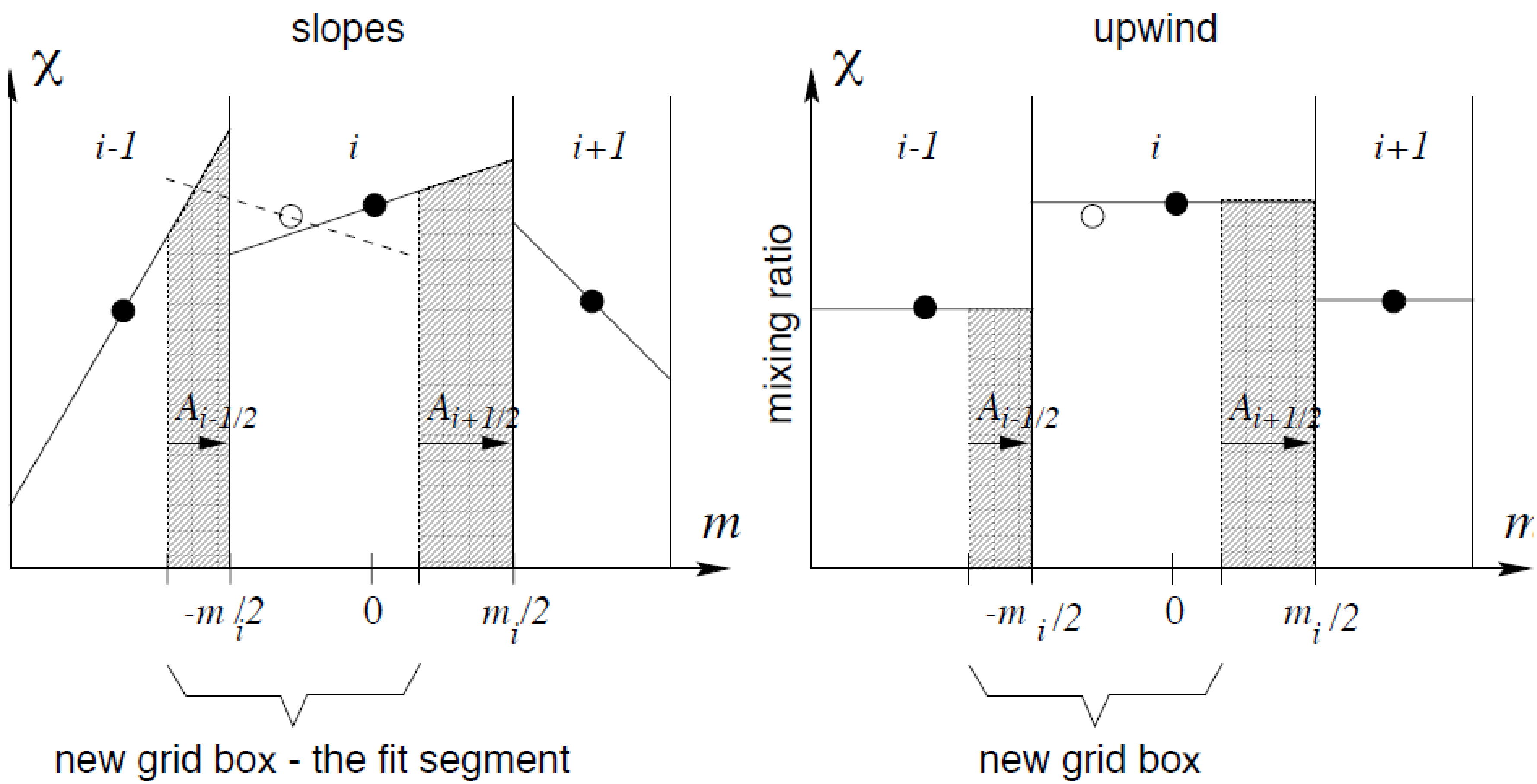

Figure from Berkvens et al., 1999

1. Adjusting horizontal slopes

- Slopes horizontal:
  - $rxm(l) = \sum_{k=1}^{l_{max}} (C(l,k) - scav) \cdot rxm(k)$
  - $rym(l) = \sum_{k=1}^{l_{max}} (C(l,k) - scav) \cdot rym(k)$
- With C is convection matrix $(l_{max} \times l_{max})$
  - *C(l,k)* = fraction of air of layer *k* → layer *l*
  - *C(l,l)* = fraction of air that remains in layer *l*

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1. Adjusting horizontal slopes

- Slopes horizontal:
  - $rxm(l) = \sum_{k=1}^{l_{max}} (C(l,k) - scav) \cdot rxm(k)$
  - $rym(l) = \sum_{k=1}^{l_{max}} (C(l,k) - scav) \cdot rym(k)$
- But, slopes vertical:
  - $rzm(l) = C(l,l) \cdot rzm(l)$

1. Adjusting horizontal slopes

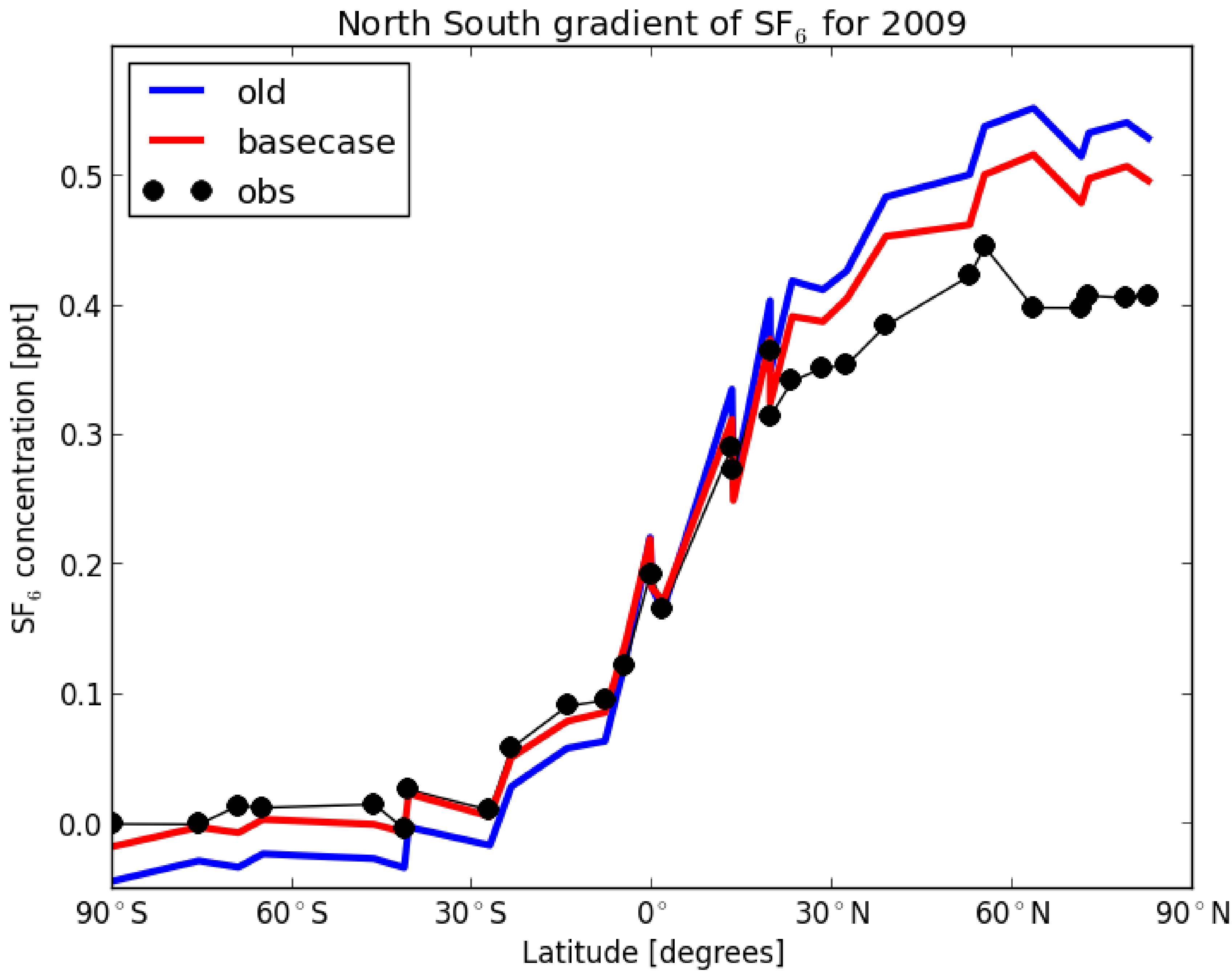
- Slopes horizontal:
  - $rxm(l) = \sum_{k=1}^{l_{max}} (C(l,k) - scav) \cdot rxm(k)$
  - $rym(l) = \sum_{k=1}^{l_{max}} (C(l,k) - scav) \cdot rym(k)$
- But, slopes vertical:
  - $rzm(l) = C(l,l) \cdot rzm(l)$

$\rightarrow$ less conservative!

1. Adjusting horizontal slopes

- Slopes horizontal:
  - $rxm(l) = \sum_{k=1}^{l_{max}} (C(l,k) - scav) \cdot rxm(k)$
  - $rym(l) = \sum_{k=1}^{l_{max}} (C(l,k) - scav) \cdot rym(k)$

- Basecase:
  - $rxm(l) = C(l,l) \cdot rxm(l)$
  - $rym(l) = C(l,l) \cdot rym(l)$



North South gradient of SF6 for 2009
old
basecase
obs
SF6 concentration [ppt]
0.0
0.1
0.2
0.3
0.4
0.5
90°S
60°S
30°S
0°
30°N
60°N
90°N
Latitude [degrees]

2. Parameterizing horizontal diffusion

Thanks to Sourish Basu and Sander Houweling

- Diffusion coefficient:
  - $K = A \cdot \frac{E_{\uparrow}+E_{\downarrow}+D_{\uparrow}+D_{\downarrow}}{m}$ in $[m^2/s]$
- Constraint:
  - Cloud top (l_2) – cloud base (l_1) > 500 hPa
- Note:
  - $l_1 = 0 \quad \Rightarrow \quad K = 0$ (phlb(i,j,l))
  - $l_2 > l_{max} \Rightarrow \quad l_2 = l_{max}$ (entu(i,j,l), etc.)

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2. Parameterizing horizontal diffusion

Analogous to Prather et al., 1987

- Fluxes:
  - $F_{x,i+1/2} = \frac{\Delta t}{\Delta x^2} \cdot \frac{K_i + K_{i+1}}{2} \cdot \frac{m_i + m_{i+1}}{2} \cdot \left(\frac{rm_i}{m_i} - \frac{rm_{i+1}}{m_{i+1}} \right)$
  - $F_{y,j+1/2} = \frac{\Delta t}{\Delta y^2} \cdot \frac{K_j + K_{j+1}}{2} \cdot \frac{m_j + m_{j+1}}{2} \cdot \left(\frac{rm_j}{m_j} - \frac{rm_{j+1}}{m_{j+1}} \right)$
- Tracer mass:
  - $rm_{i,j}{}^{n+1} = rm_{i,j}{}^{n} + F_{x,i-1/2} - F_{x,i+1/2} + F_{y,j-1/2} - F_{y,j+1/2}$
- Slopes:
  - $rxm_i{}^{n+1} = rxm_i{}^{n} \cdot \max\left\{0{,}1 - 2 \cdot K \cdot \frac{\Delta t}{\Delta x^2}\right\}$
  - $rym_j{}^{n+1} = rym_j{}^{n} \cdot \max\left\{0{,}1 - 2 \cdot K \cdot \frac{\Delta t}{\Delta y^2}\right\}$

2. Parameterizing horizontal diffusion

Analogous to Prather et al., 1987

- Fluxes:
  - $F_{x,i+1/2} = \frac{\Delta t}{\Delta x^2} \cdot \delta \cdot \frac{K_i + K_{i+1}}{2} \cdot \frac{m_i + m_{i+1}}{2} \cdot \left(\frac{rm_i}{m_i} - \frac{rm_{i+1}}{m_{i+1}} \right)$
  - $F_{y,j+1/2} = \frac{\Delta t}{\Delta y^2} \cdot \delta \cdot \frac{K_j + K_{j+1}}{2} \cdot \frac{m_j + m_{j+1}}{2} \cdot \left(\frac{rm_j}{m_j} - \frac{rm_{j+1}}{m_{j+1}} \right)$
- Tracer mass:
  - ${rm_{i,j}}^{n+1} = {rm_{i,j}}^{n} + F_{x,i-1/2} - F_{x,i+1/2} + F_{y,j-1/2} - F_{y,j+1/2}$
- Slopes:
  - ${rxm_i}^{n+1} = {rxm_i}^{n} \cdot \max\left\{0, 1 - 2 \cdot \delta \cdot K \cdot \frac{\Delta t}{\Delta x^2}\right\}$
  - ${rym_j}^{n+1} = {rym_j}^{n} \cdot \max\left\{0, 1 - 2 \cdot \delta \cdot K \cdot \frac{\Delta t}{\Delta y^2}\right\}$

2. Parameterizing horizontal diffusion

Analogous to Prather et al., 1987

- Fluxes:
  - $F_{x,i+1/2} = \frac{\Delta t}{\Delta x^2} \cdot \delta \cdot \frac{K_i + K_{i+1}}{2} \cdot \frac{m_i + m_{i+1}}{2} \cdot \left(\frac{rm_i}{m_i} - \frac{rm_{i+1}}{m_{i+1}} \right)$
  - $F_{y,j+1/2} = \frac{\Delta t}{\Delta y^2} \cdot \delta \cdot \frac{K_j + K_{j+1}}{2} \cdot \frac{m_j + m_{j+1}}{2} \cdot \left(\frac{rm_j}{m_j} - \frac{rm_{j+1}}{m_{j+1}} \right)$
- Tracer mass:
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- Slopes:
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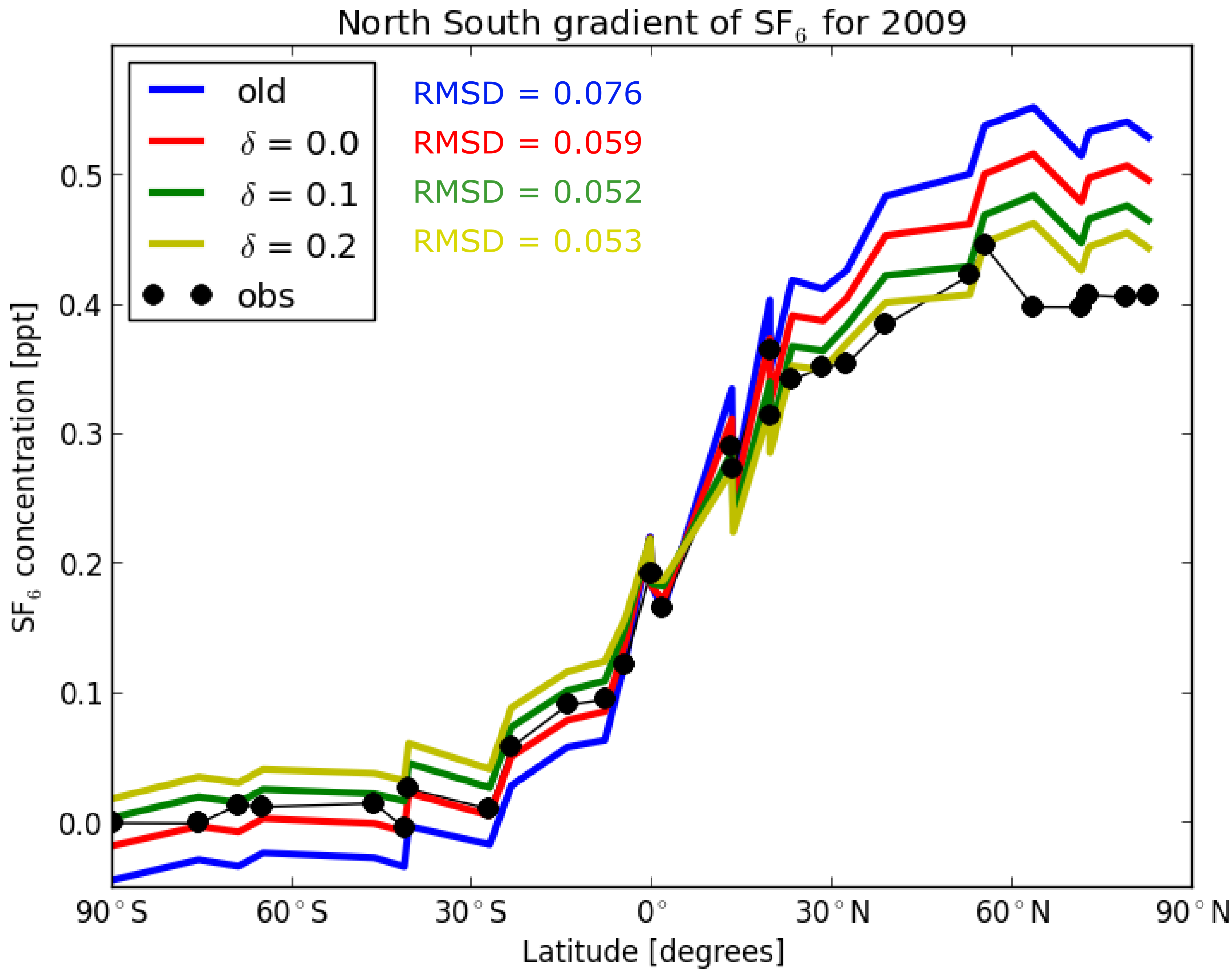
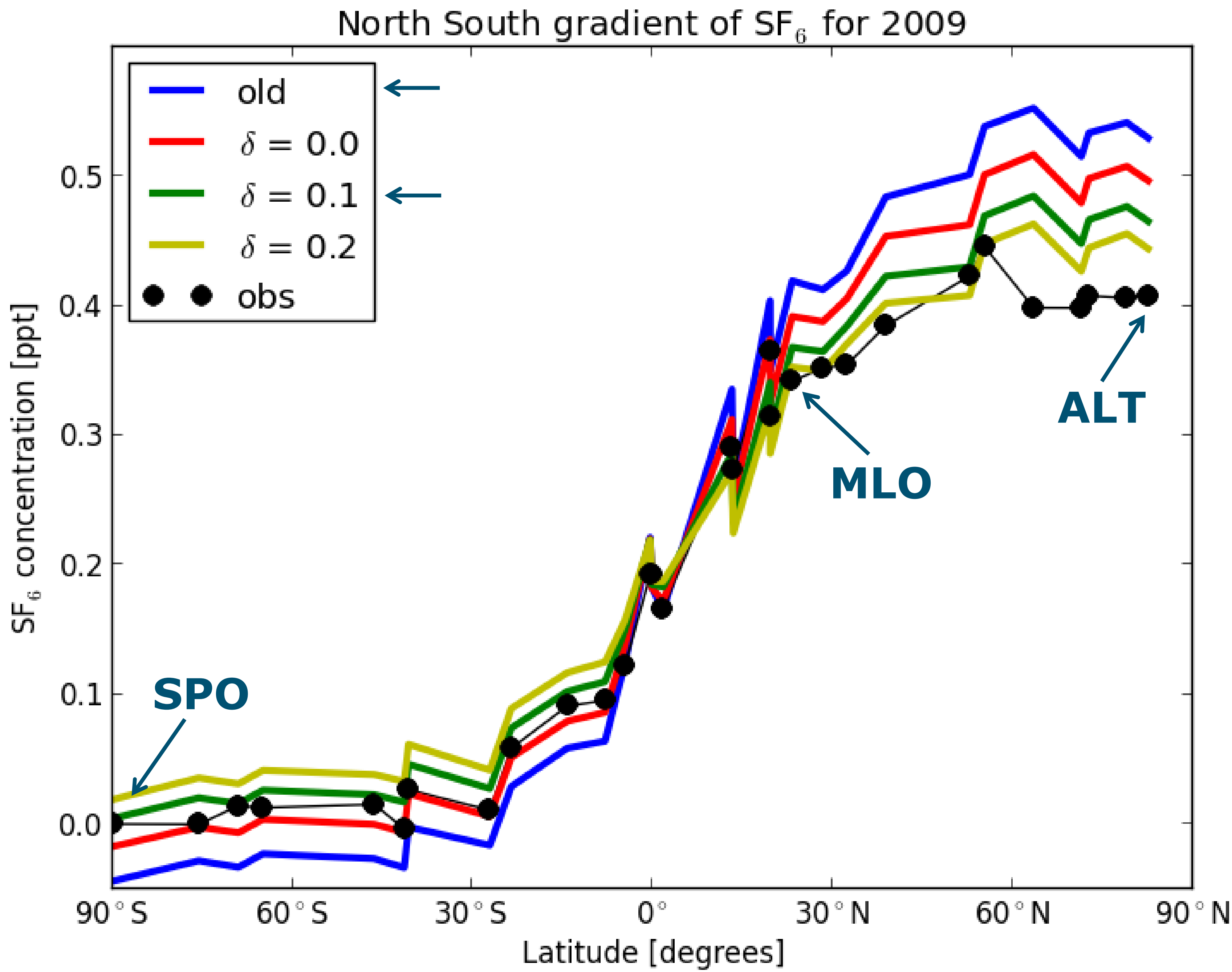
  - ${rym_j}^{n+1} = {rym_j}^{n} \cdot \max\left\{0, 1 - 2 \cdot \delta \cdot K \cdot \frac{\Delta t}{\Delta y^2}\right\}$

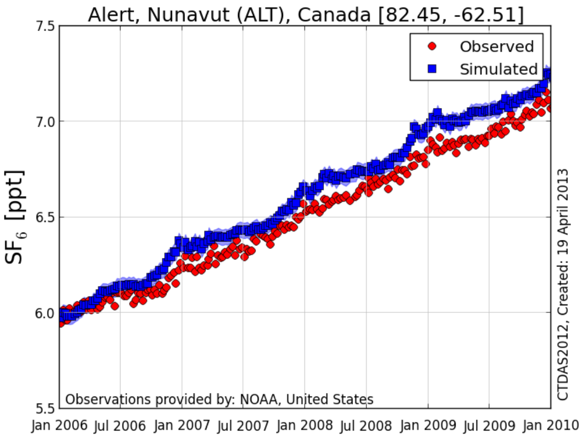
→ optimize dscale (δ) with CTDAS



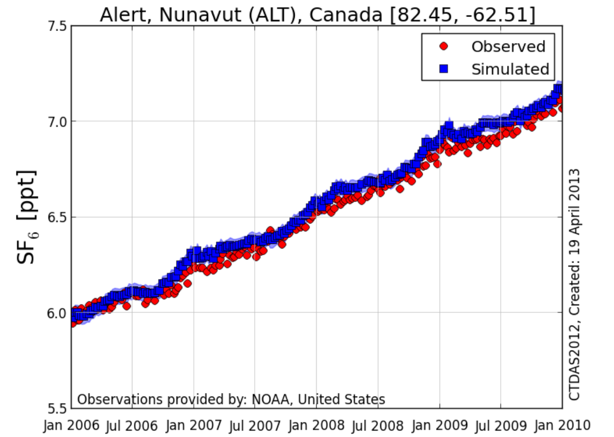
North South gradient of SF_6 for 2009
old
δ = 0.0
δ = 0.1
δ = 0.2
obs
RMSD = 0.076
RMSD = 0.059
RMSD = 0.052
RMSD = 0.053
SF_6 concentration [ppt]
0.0
0.1
0.2
0.3
0.4
0.5
90°S
60°S
30°S
0°
30°N
60°N
90°N
Latitude [degrees]

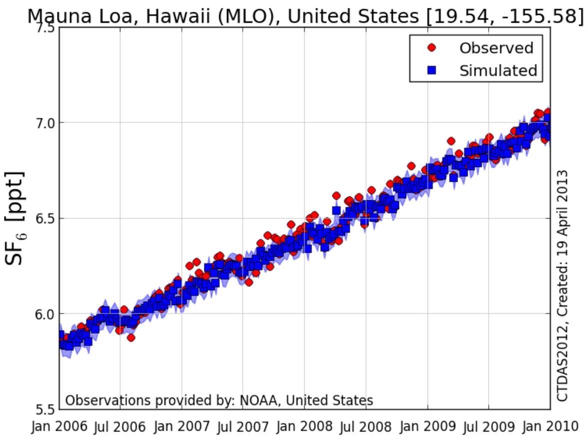

North South gradient of SF_6 for 2009
old
δ = 0.0
δ = 0.1
δ = 0.2
obs
SPO
MLO
ALT
SF_6 concentration [ppt]
0.0
0.1
0.2
0.3
0.4
0.5
90°S
60°S
30°S
0°
30°N
60°N
90°N
Latitude [degrees]

Old → δ=0.1

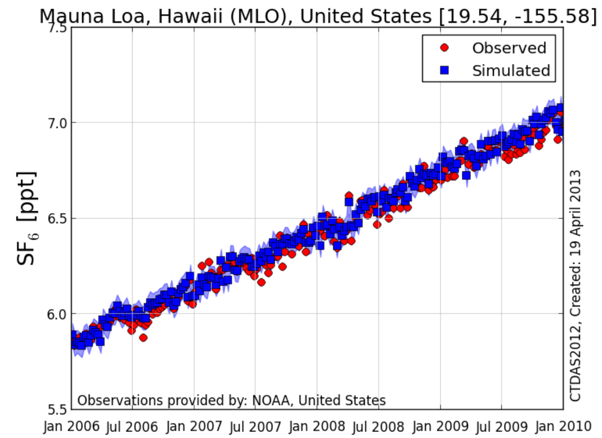


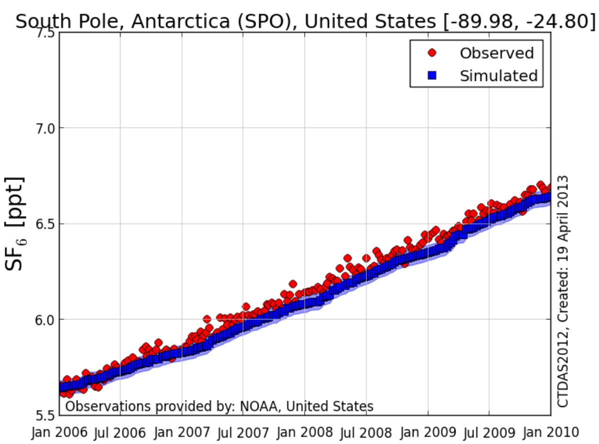
ALT



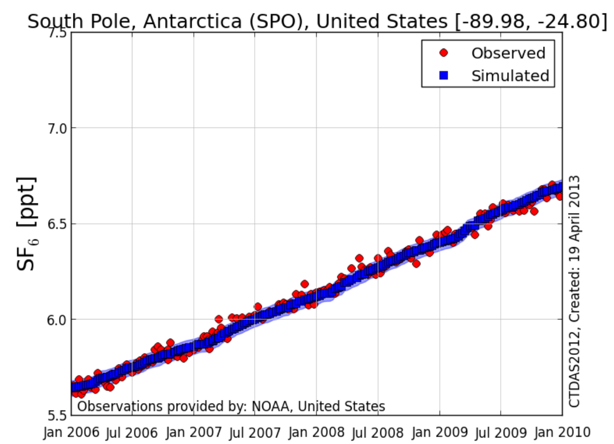


MLO



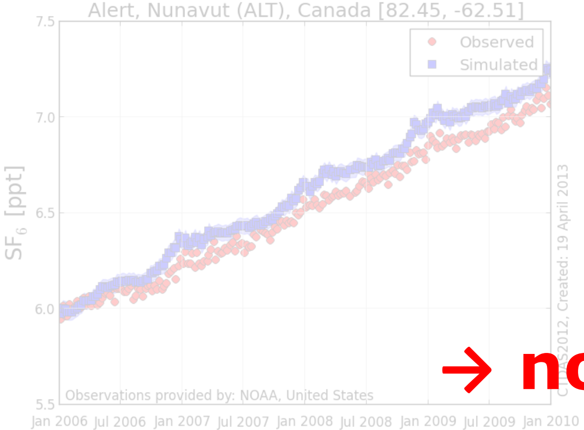


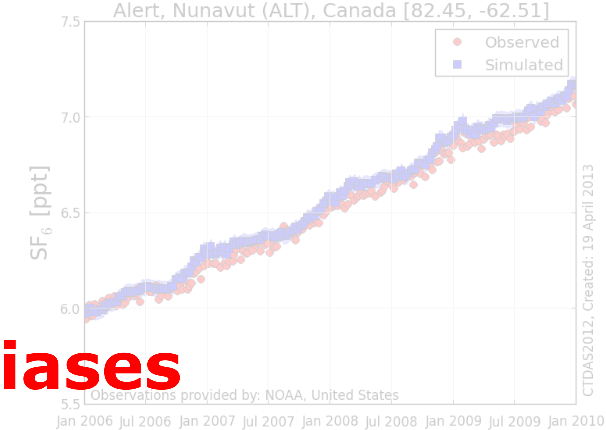
SPO



Old → δ=0.1

→ no systematic biases in emissions!





2006, 2007: Sourish

2008, 2009: match emissions to yearly growth rate trend at SPO and MLO

3. Optimizing δ with CarbonTracker

Setup

- Not optimizing fluxes, but transport/diffusion (δ)
- Observations
  - Flask measurements (NOAA)
  - mdm ~0.08 ppt (σ of polynomial fit)
- Model
  - A-priori value: δ=0.1
  - σ=0.5 → ~0.05 (semi-exponential PDF to avoid δ<0, Bergamaschi et al., 2009)
  - Cycle length
    - Yearly (lag = 1)
    - Seasonal (lag = 1,2)

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3. Optimizing δ with CarbonTracker

One global parameter

Cycle	Fixed prior	Lag	Mean δ ei	Mean δ od
365	No	1	0.15	0.10
90	No	1	0.08	-
90	Yes	1	0.09	0.08
90	No	2	0.08	0.06
90	Yes	2	-	0.08

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3. Optimizing δ with CarbonTracker

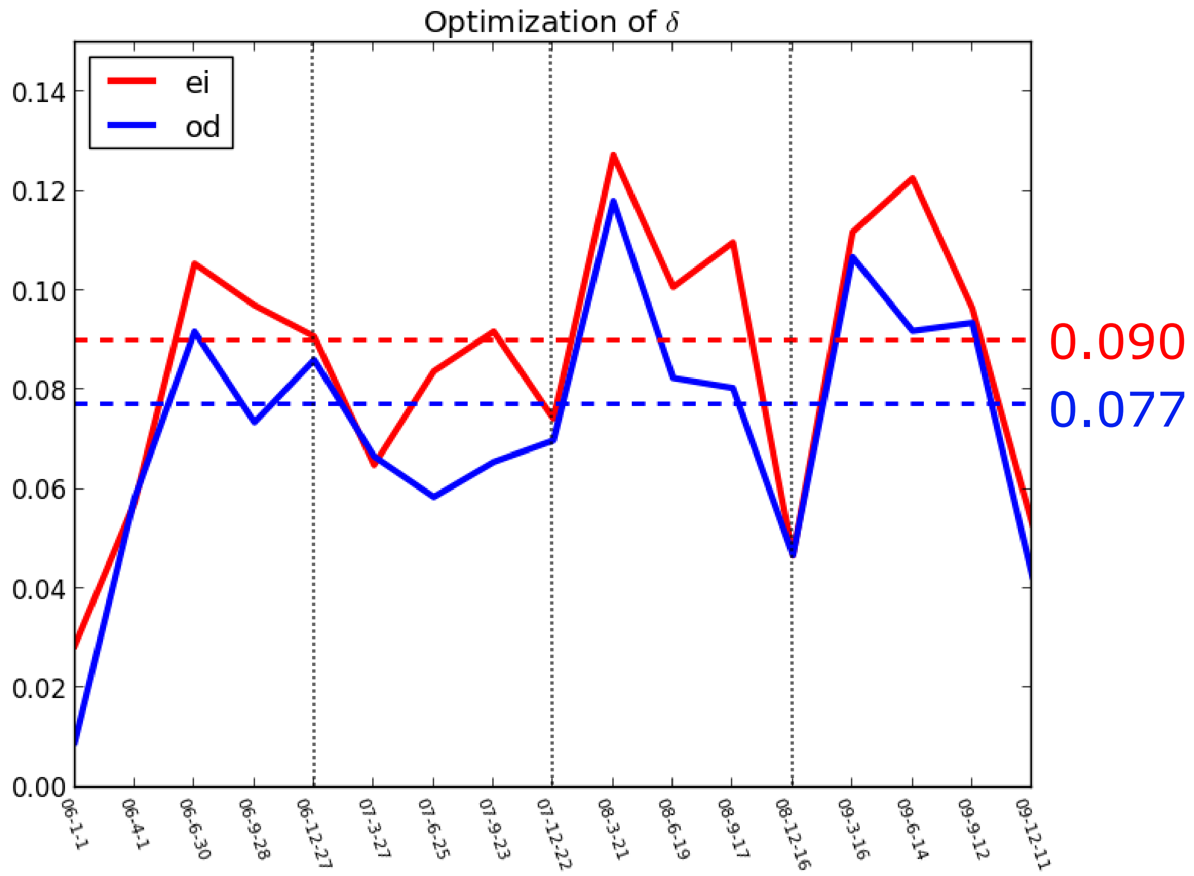
One global parameter

Cycle	Fixed prior	Lag	Mean δ ei	Mean δ od
365	No	1	0.15	0.10
90	No	1	0.08	-
90	Yes	1	0.09	0.08
90	No	2	0.08	0.06
90	Yes	2	-	0.08

→ δ=0.1 good guess
→ od slightly lower values, but comparable to ei

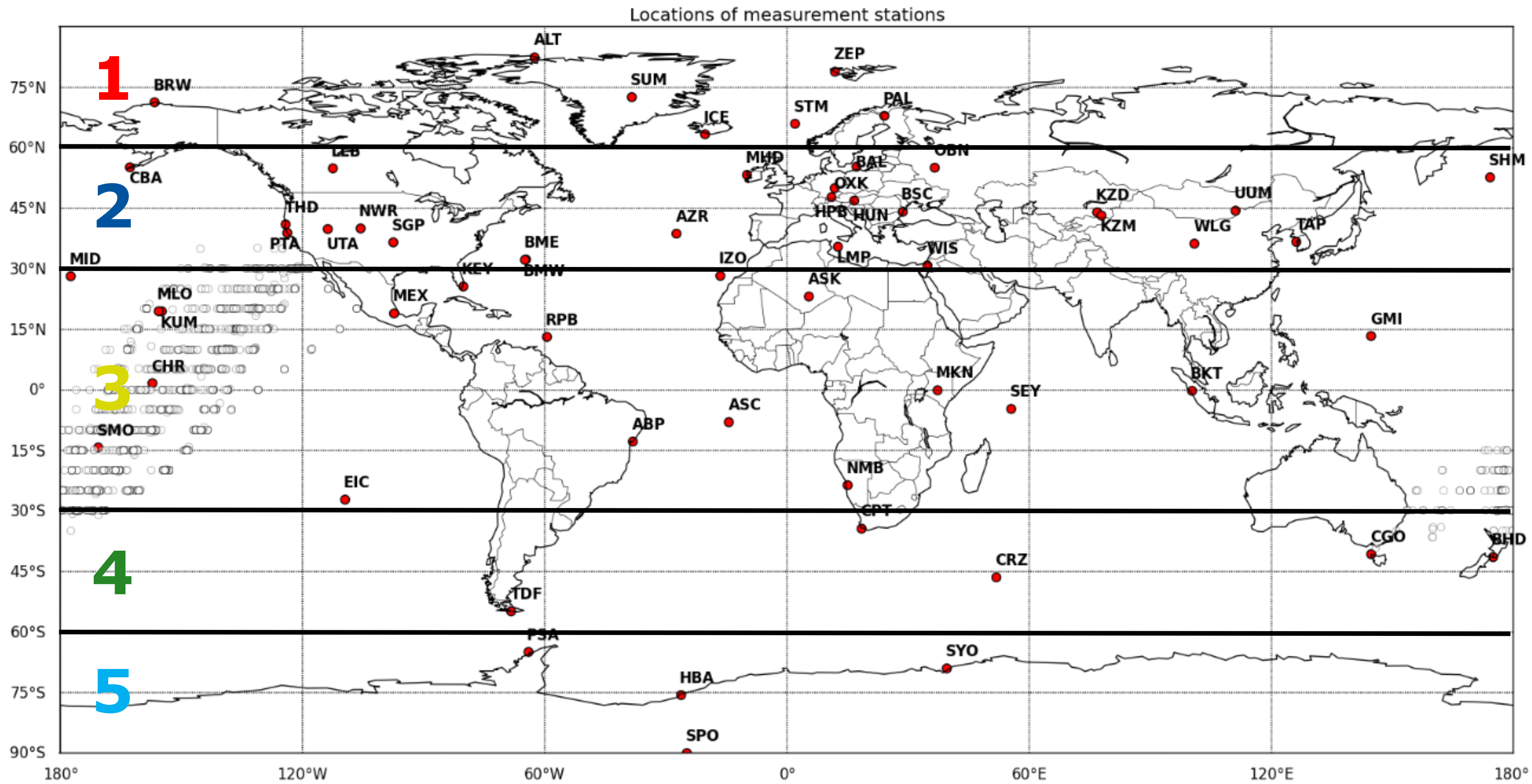
3. Optimizing δ with CarbonTracker

One global parameter



3. Optimizing δ with CarbonTracker

From one to five state vector parameters



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3. Optimizing δ with CarbonTracker

Five state vector parameters

	Cycle	Fixed	Lag	δ_1	δ_2	δ_3	δ_4	δ_5
ei	365	No	1	-	-	-	-	-
ei	365	Yes	1	0.15	0.37	0.10	0.13	0.13
od	365	Yes	1	0.09	0.38	0.07	0.19	0.13
ei	90	Yes	1	0.10	0.18	0.07	0.10	0.10
od	90	Yes	1	0.11	0.16	0.06	0.10	0.10

3. Optimizing δ with CarbonTracker

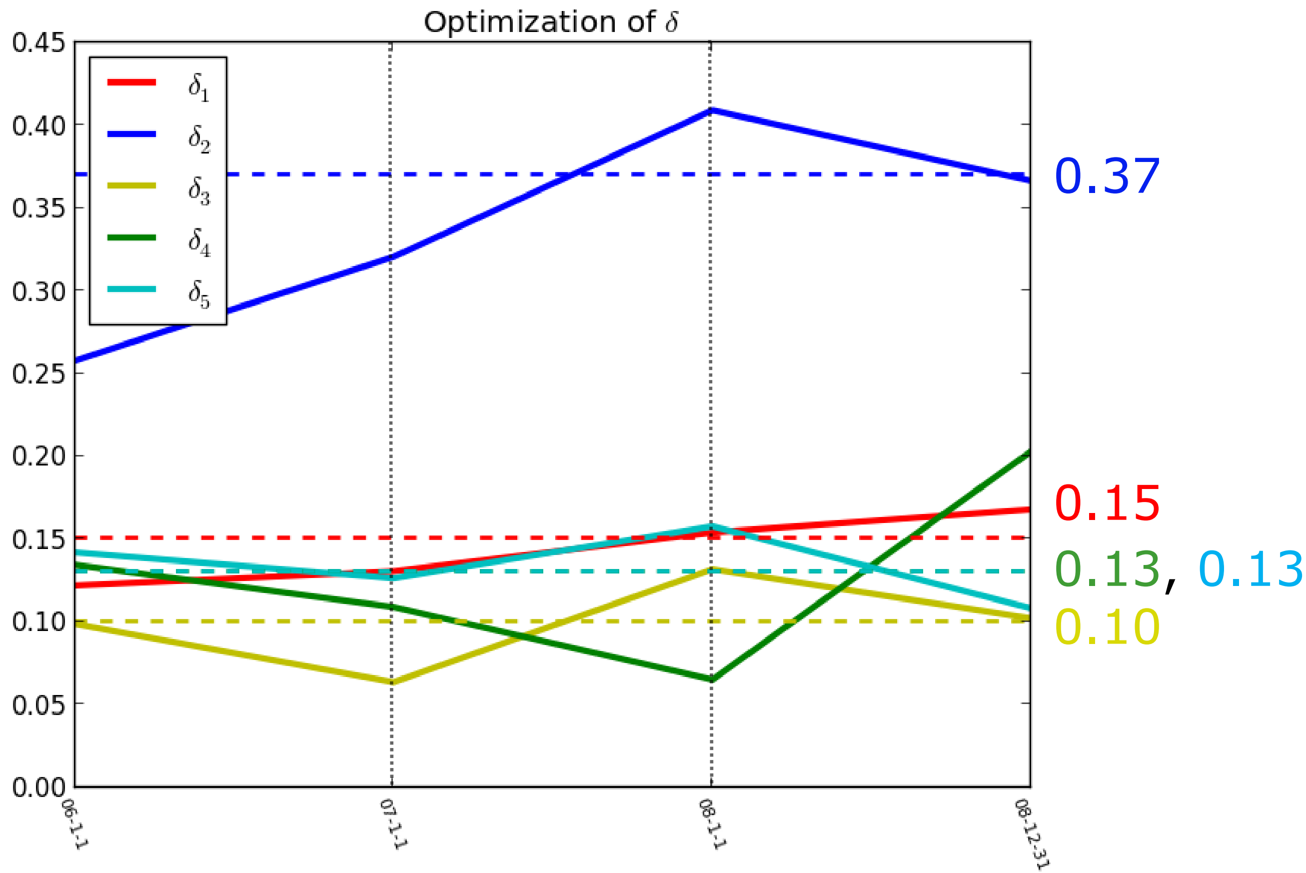
Five state vector parameters

	Cycle	Fixed	Lag	δ_1	δ_2	δ_3	δ_4	δ_5
ei	365	No	1	-	-	-	-	-
ei	365	Yes	1	0.15	0.37	0.10	0.13	0.13
od	365	Yes	1	0.09	0.38	0.07	0.19	0.13
ei	90	Yes	1	0.10	0.18	0.07	0.10	0.10
od	90	Yes	1	0.11	0.16	0.06	0.10	0.10

→ stronger transport in region 2

3. Optimizing δ with CarbonTracker

Five state vector parameters



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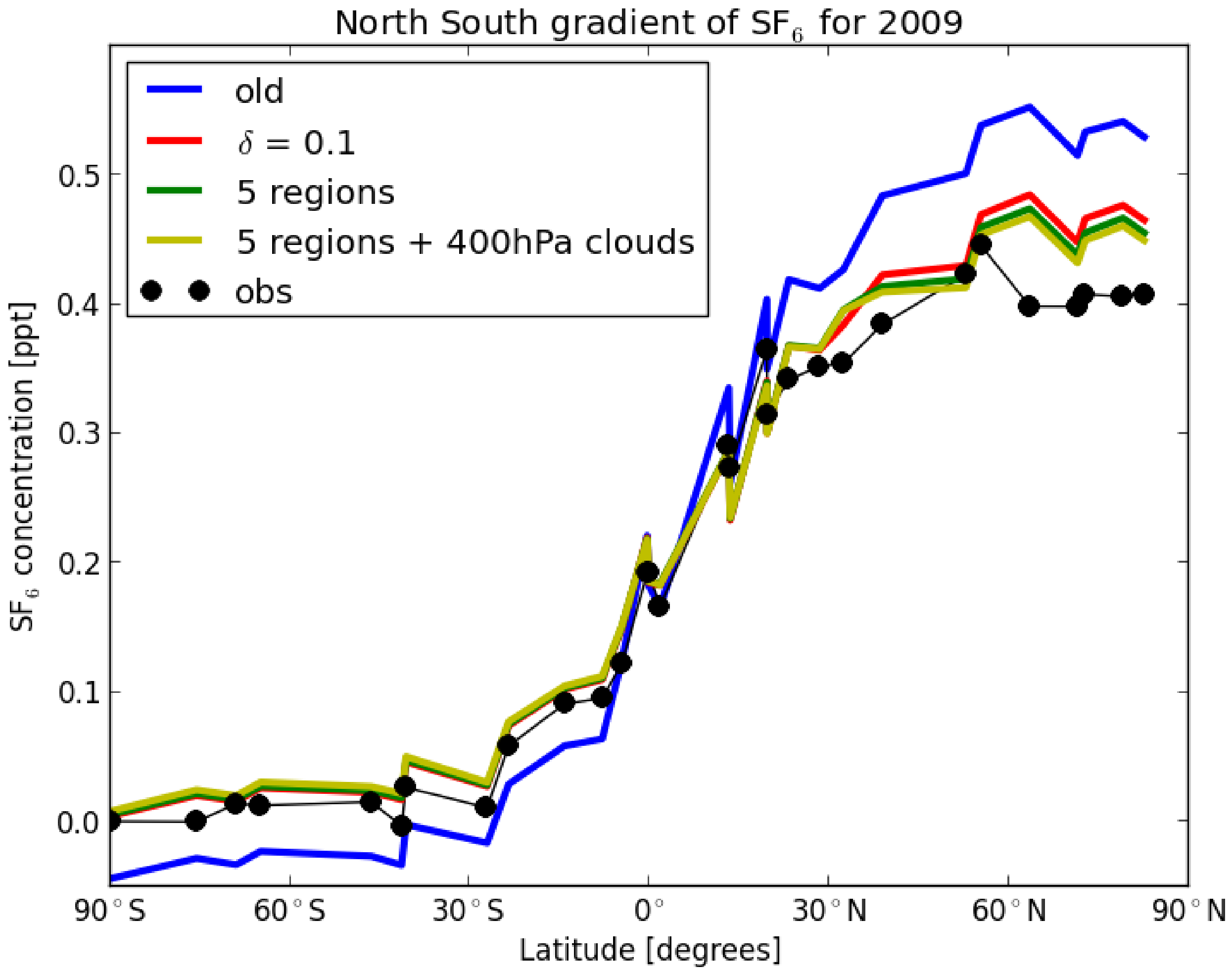
→ could signal be dominated by emissions?

3. Optimizing δ with CarbonTracker



→ regions approach does improve N-S gradient, more research needed though

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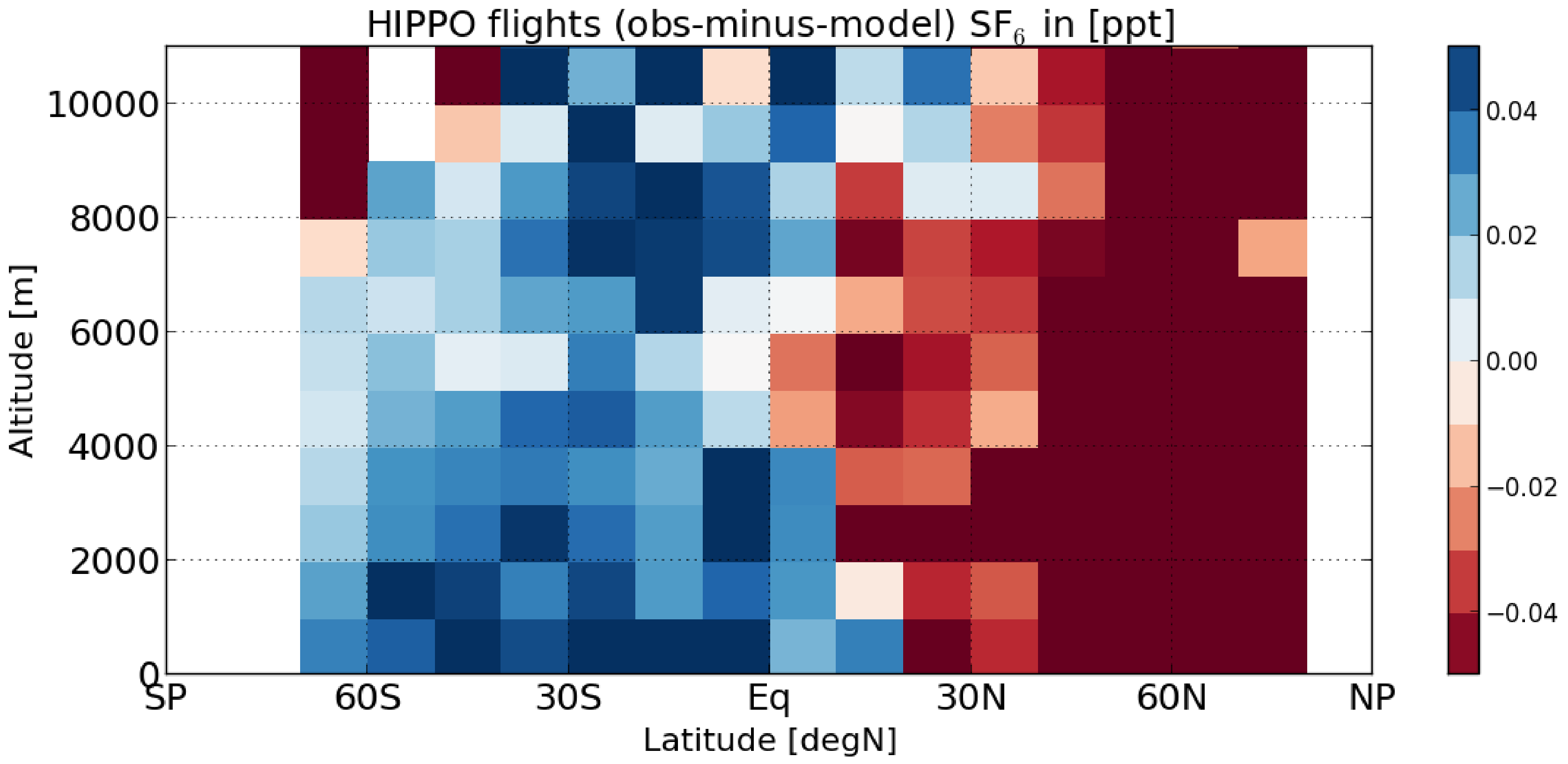
4. Validation with HIPPO data

HIPPO = HIAPER Pole-to-Pole Observations

- Three-year flight campain (2009-2011)
- Pole-to-pole measurements
- Measurements from 300 up to 14.000 meter

→ Global SF_6 profile

Current TM5



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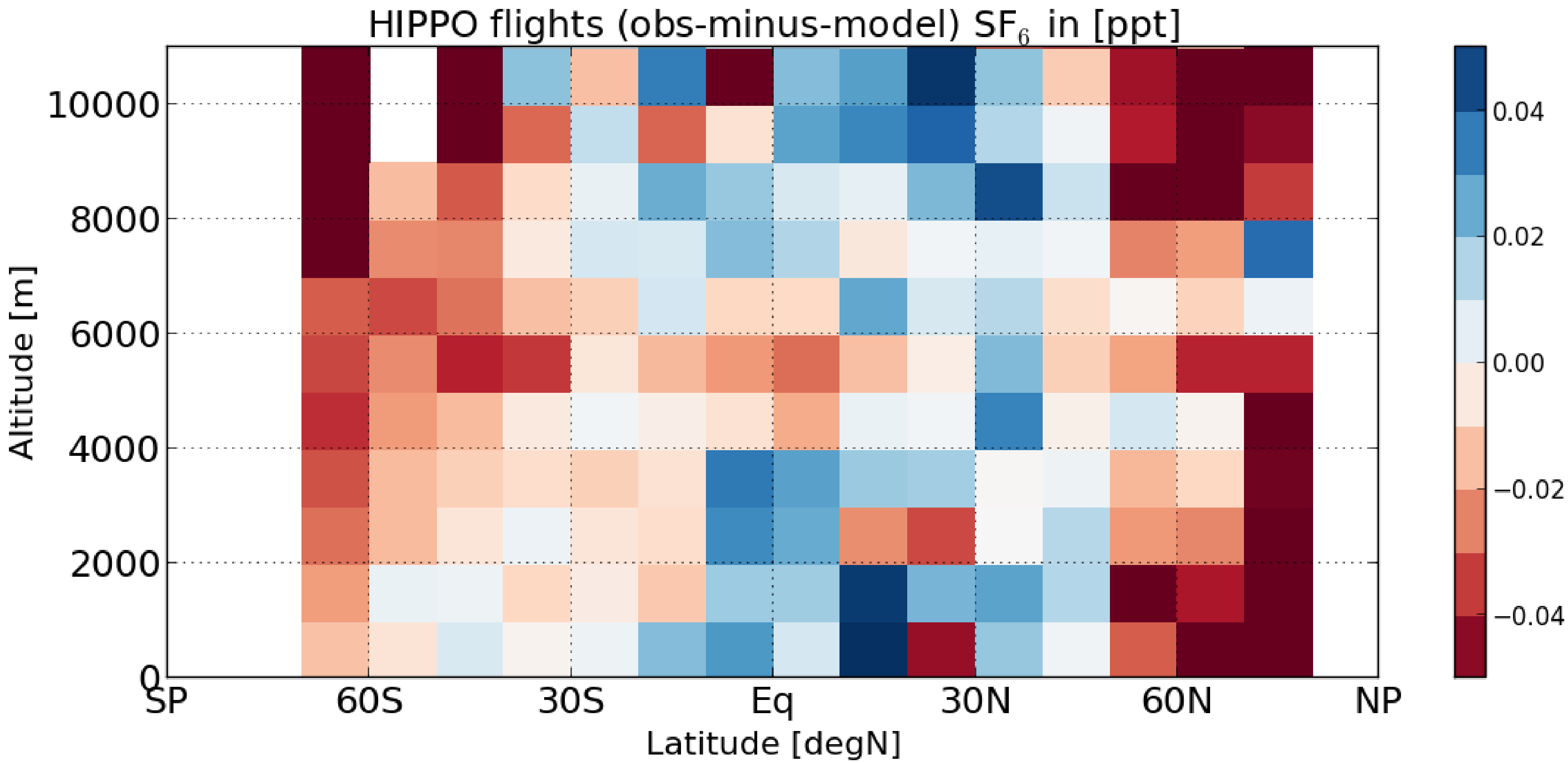
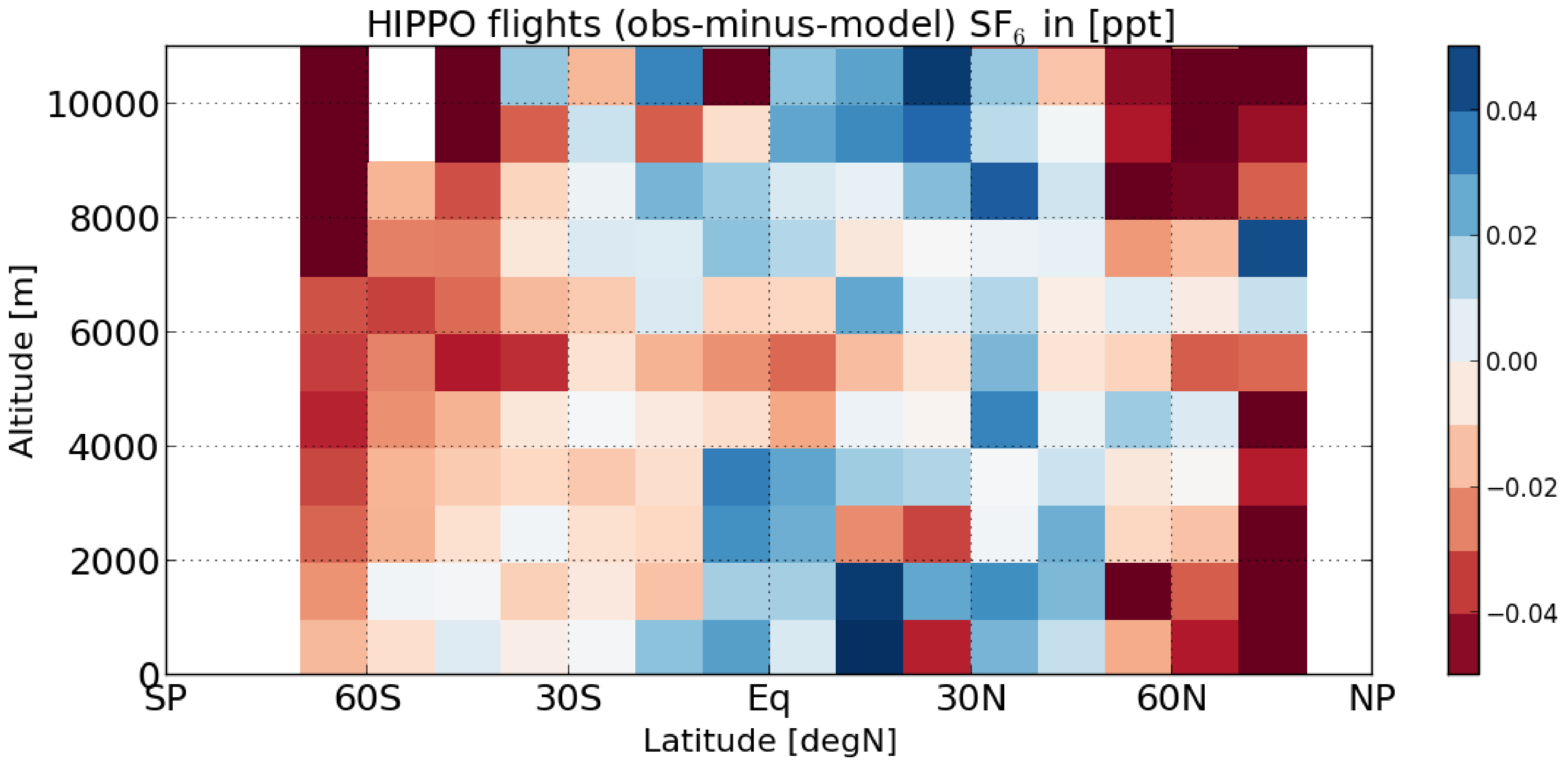
New slopes + δ=0.1



New slopes + δ optimized for 5 regions



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Discussion

- Emissions are not perfect
- Regions 1 and 5 little affected (no deep convection)
- Scheme is resolution dependent
- Horizontal transport does not solve it all: vertical?!

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Conclusions

- Parameterizing horizontal diffusion (Prather et al., 1987) improves the global distribution of SF_6
- One global optimized parameter ≈ $\delta=0.1$
- 5 optimized parameters improve, but more research needed

- Practical solution for 6°x4° grid:
  - New horizontal slopes ($rxm(l) = C(l,l) \cdot rxm(l)$)
  - Diffusion parameterization with $\delta=0.1$

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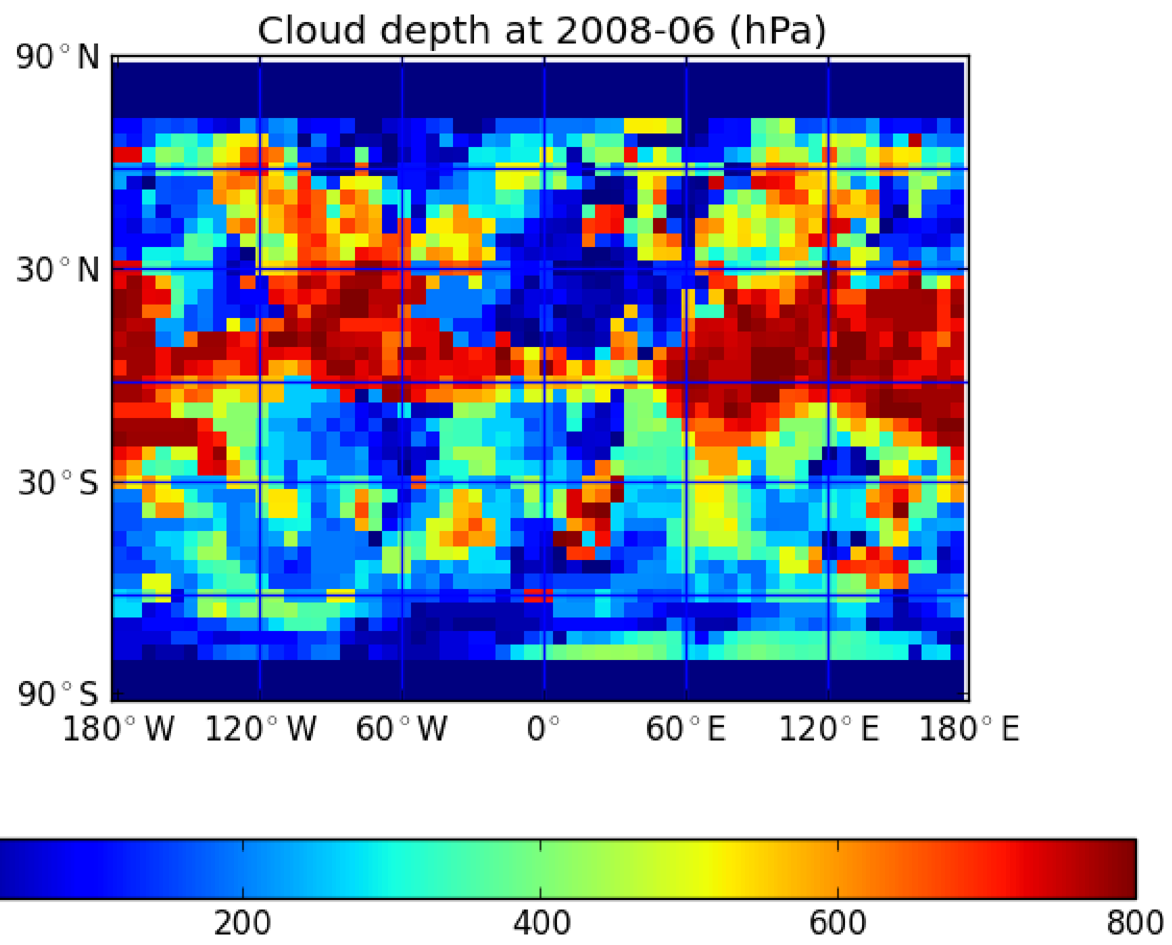
Questions?

Thanks for your attention!

State vector prior and ensemble members

- Prior x^p:
  - $\mu = 0.1$
- Ensemble members $x^{p\prime}$:
  - $x \sim N(0{,}0.5)$:
  - If $x < 0$ $\rightarrow$ $x^{p\prime} = x^p \cdot e^x$
  - If $x \geq 0$ $\rightarrow$ $x^{p\prime} = x^p \cdot (1 + x)$

$$\Rightarrow 0.0 < x^{p\prime} \leq 0.2$$



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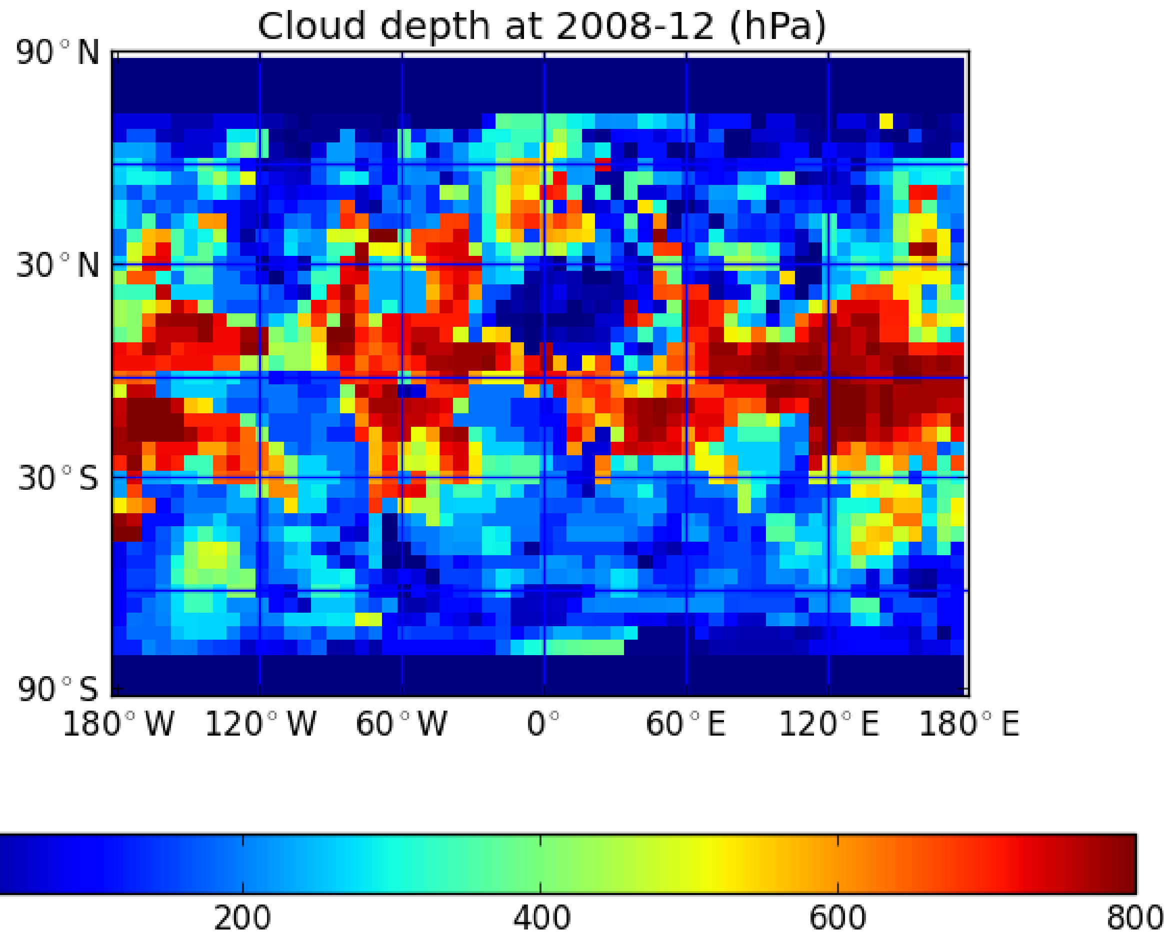

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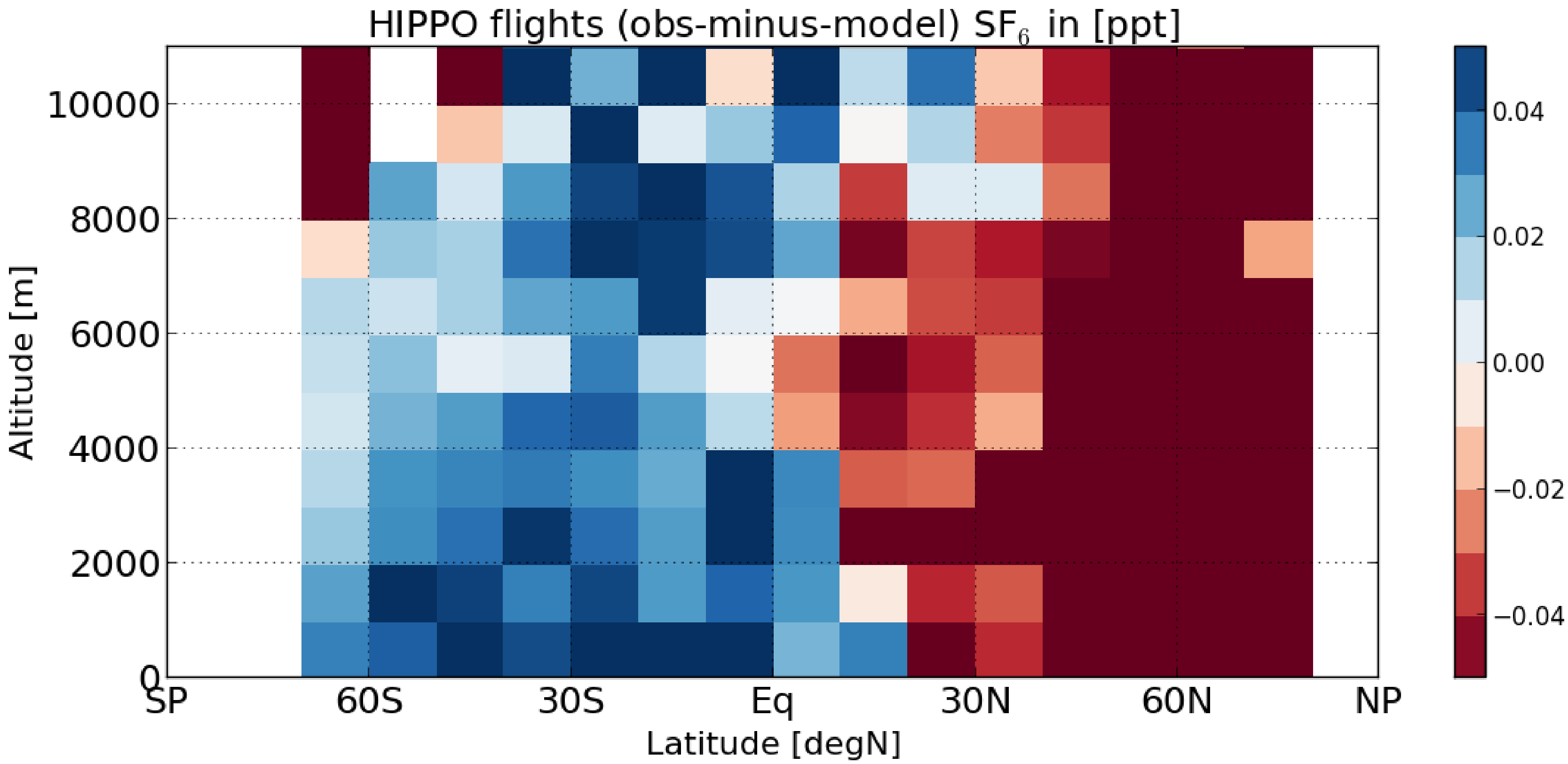
Current TM5



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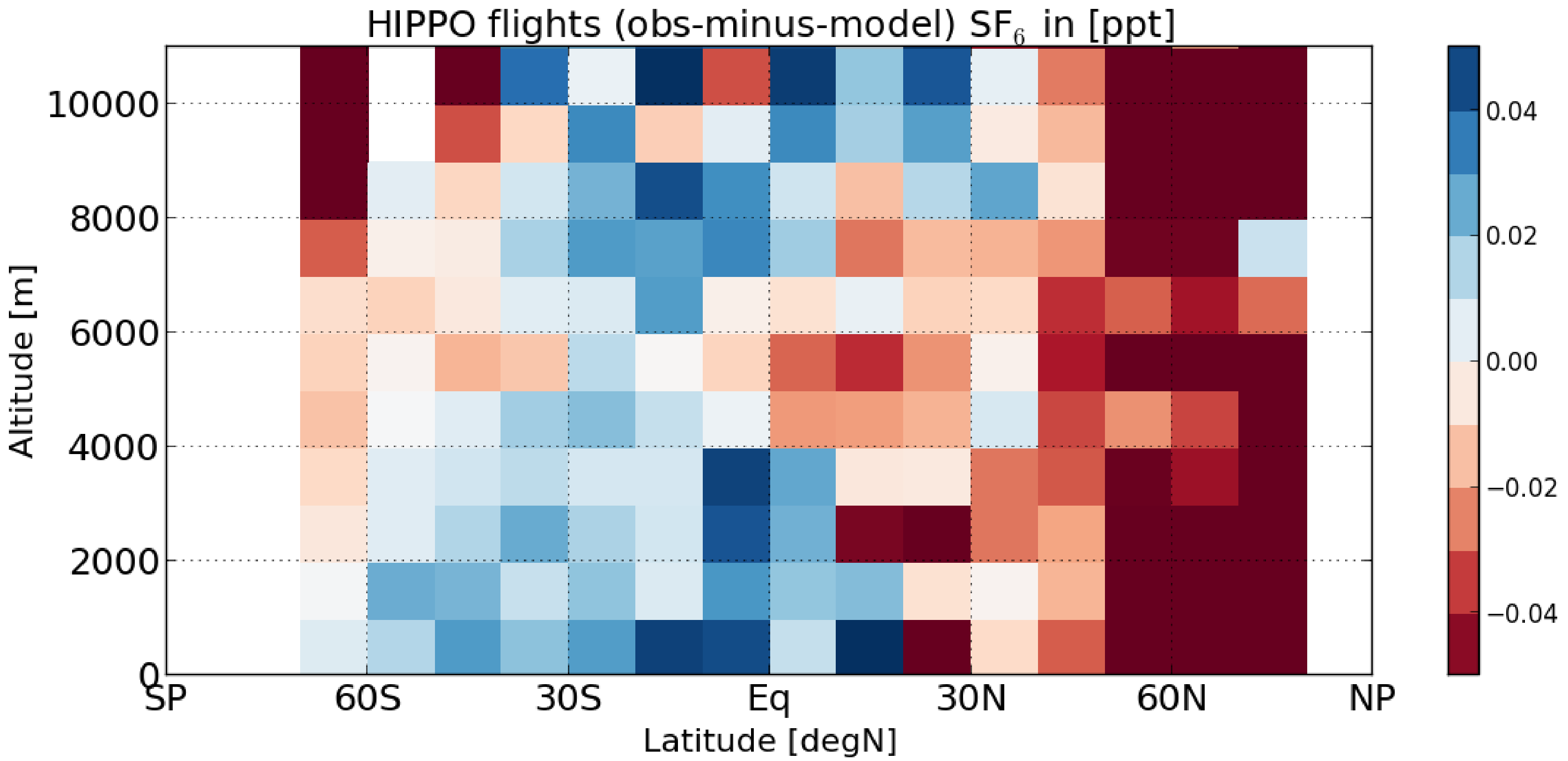
δ=0.0 (basecase)



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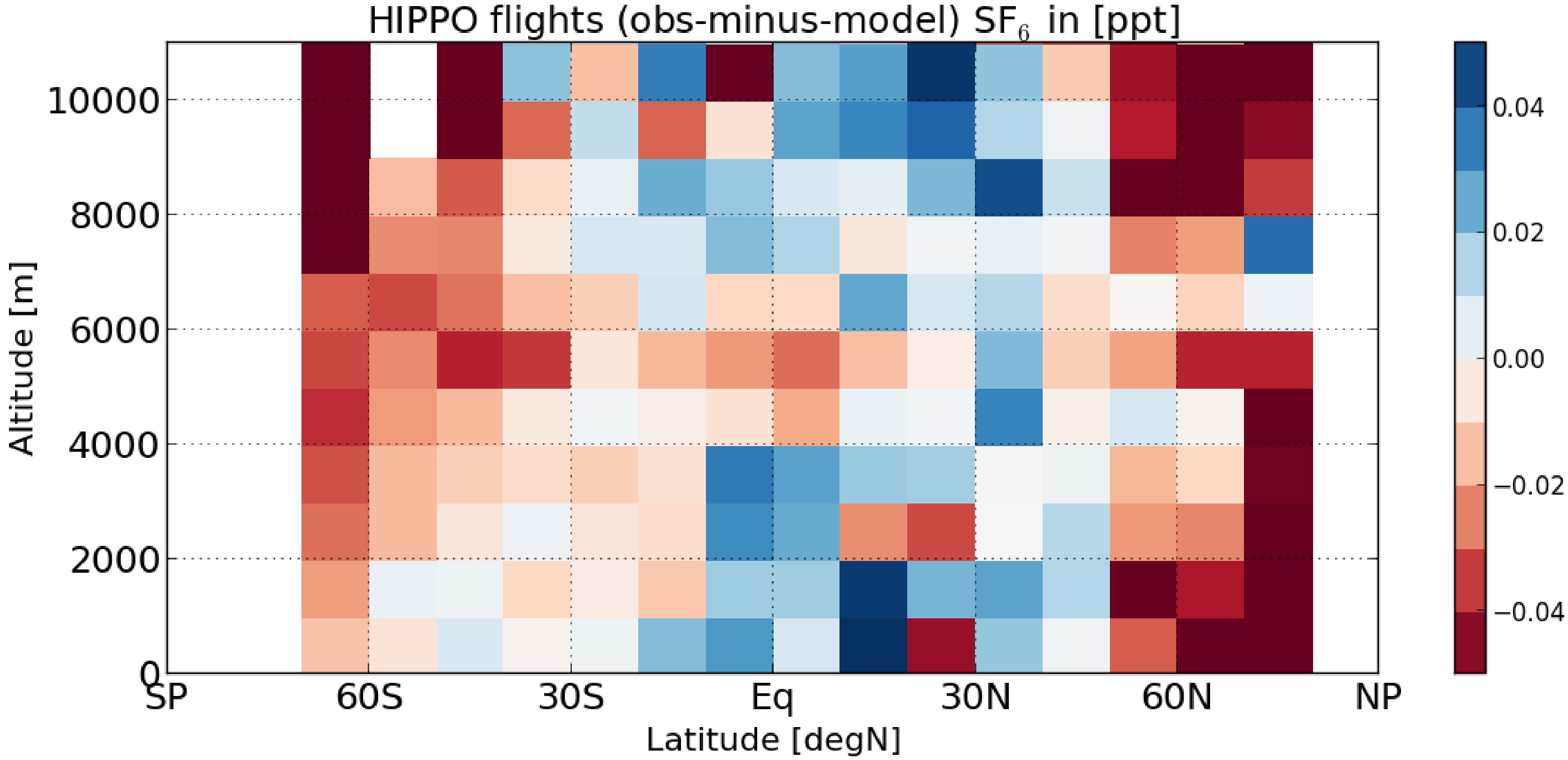
δ=0.1



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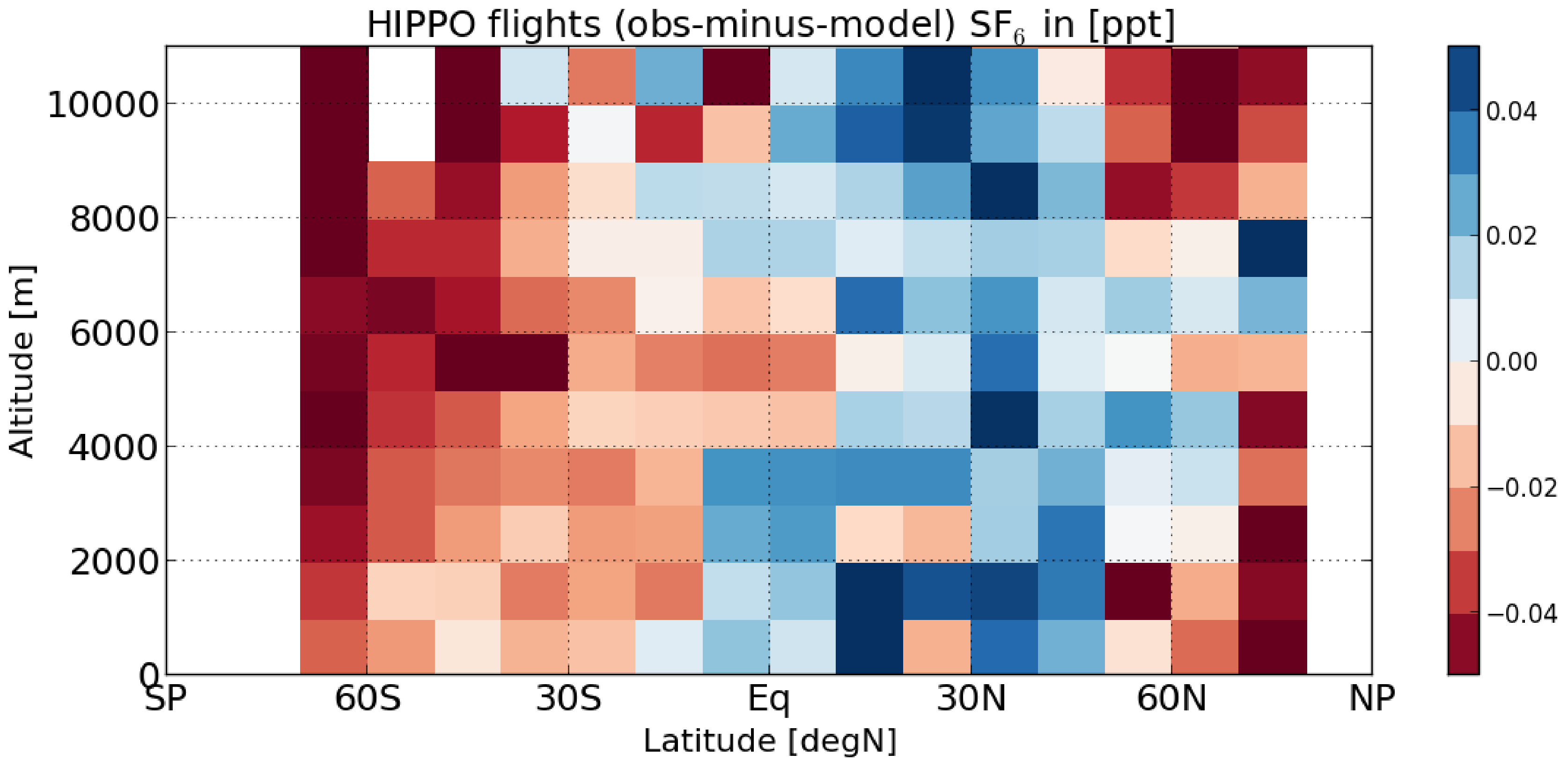
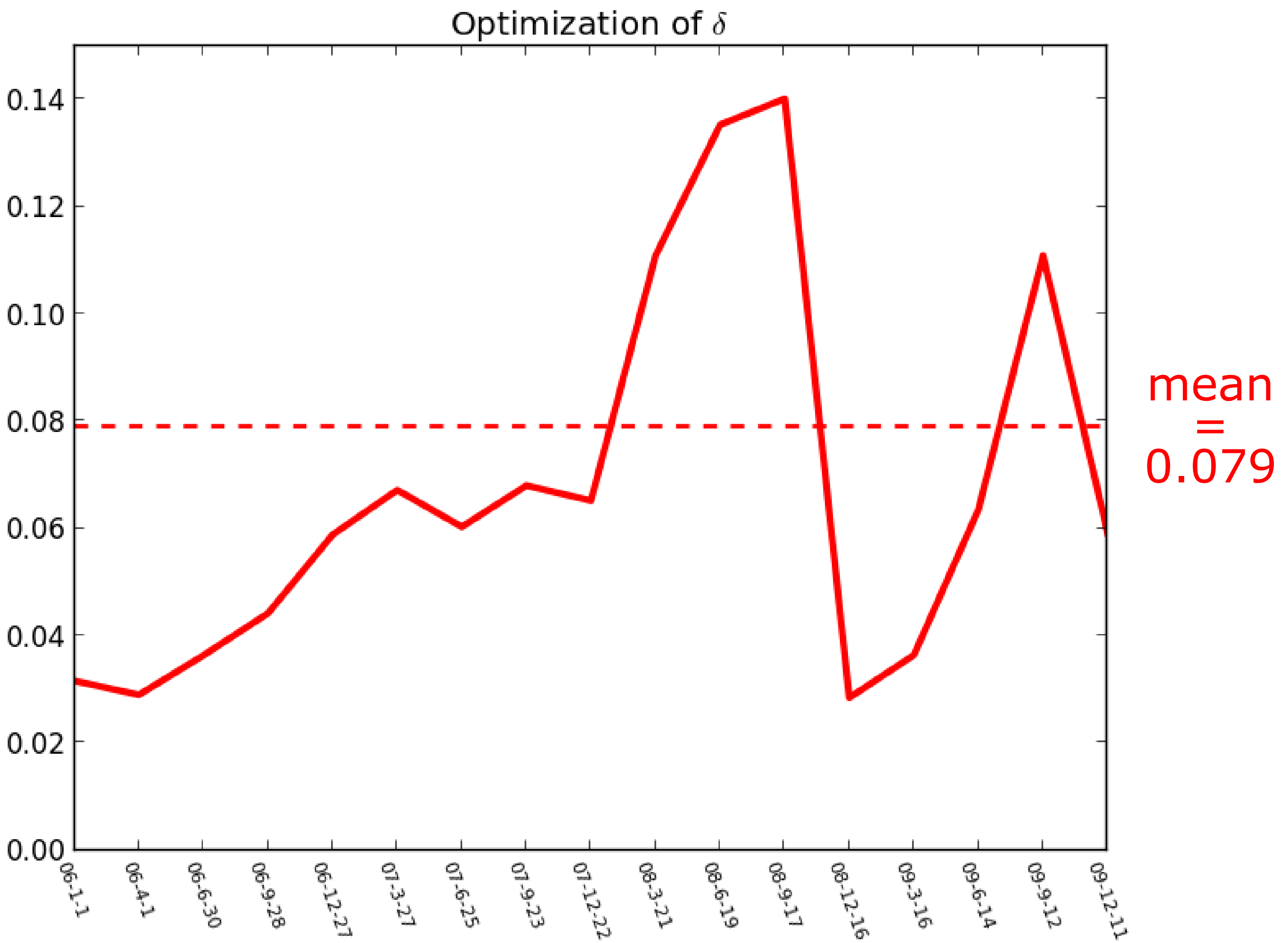
δ=0.2



HIPPO flights (obs-minus-model) SF_6 in [ppt]
Altitude [m]
10000
8000
6000
4000
2000
0
SP
60S
30S
Eq
30N
60N
NP
Latitude [degN]
0.04
0.02
0.00
−0.02
−0.04



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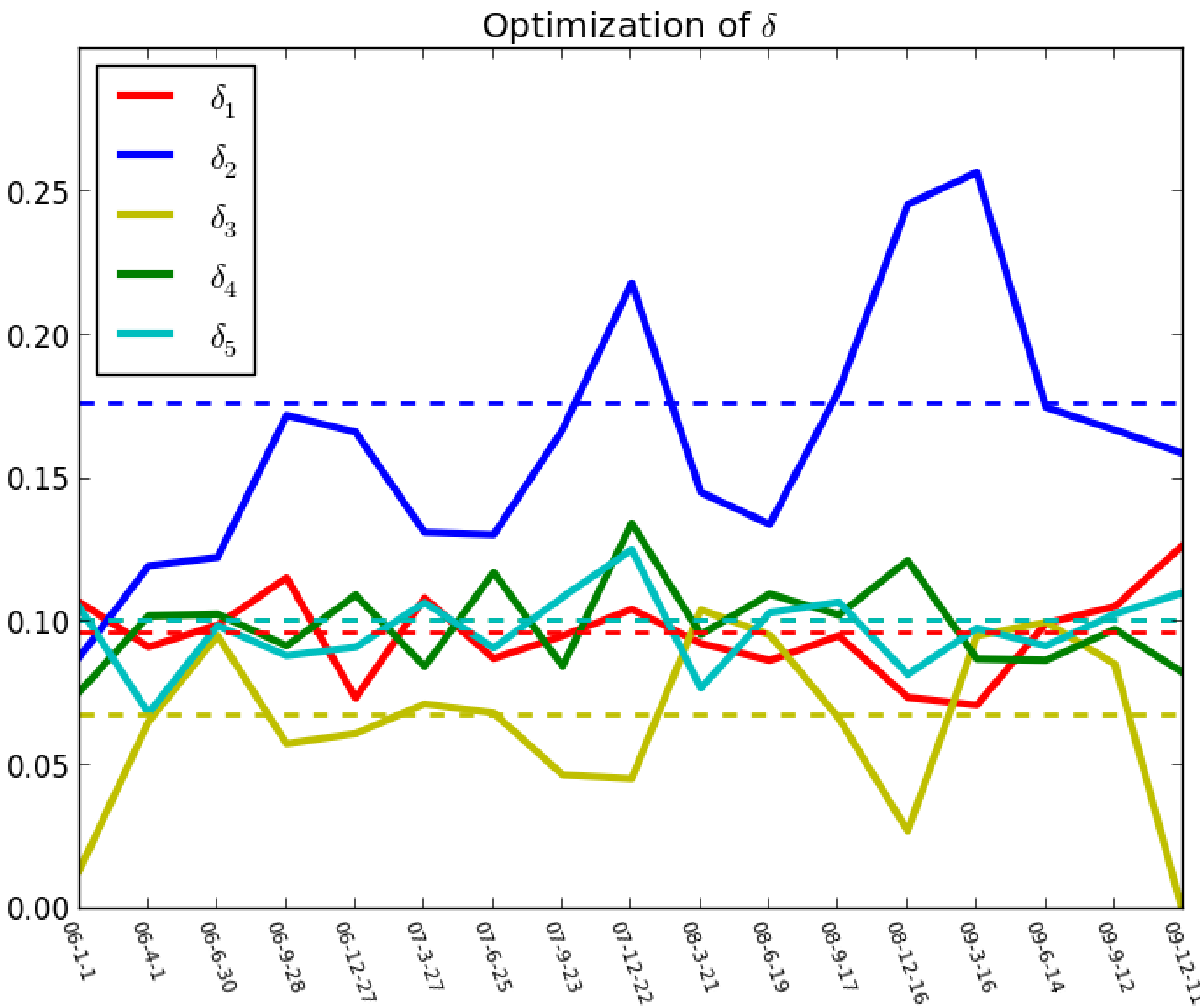
→ no fixed mean



0.176

0.10, 0.10

0.096

0.067

→ (too?) small seasonal variability

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