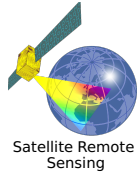
Estimation of stratospheric NO_2 from nadir-viewing satellites: The MPI-C TROPOMI verification algorithm

Steffen Beirle, Christoph Hörmann,
Marloes Penning de Vries, Holger Sihler, and Thomas Wagner



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- Object of research (Strat. chemistry & dynamics)
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- CTMs (directly, scaled, or assimilated)
- Nadir measurements (Reference Sector and advancements)

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Outline:

1. The TROPOMI verification algorithm
2. Results for OMI and comparison to other algorithms

Part I: The TROPOMI verification algorithm

Modified reference region approach:

1. Identify “unpolluted” pixels:
   - Remote
   - Clouds (Leue et al., 2001; Bucsela et al., 2013)
   - Low total column
2. Smooth/interpolate

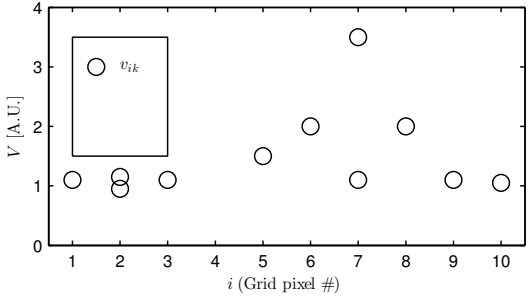
Part I: The TROPOMI verification algorithm

Modified reference region approach:

1. Identify “unpolluted” pixels: Assign pixel **weights**
   - Remote (Polluted regions: low weights)
   - Clouds shielding the troposphere: high weights
   - Low total column (negative trop. column: high weight)
2. Smooth/interpolate by **weighted convolution**

Weighted convolution

- For each satellite pixel k in grid pixel(i, j):
  $w_{ijk} = w_P \times w_C \times \ldots$
- $C_{ij} := \sum w_{ijk} \times V_{ijk}$
- $W_{ij} := \sum w_{ijk}$
- $\Rightarrow V_{ij} = \frac{C_{ij}}{W_{ij}}$ (weighted mean)
- Now: smooth W and C (e.g. convolution with Gaussian)
- $\overline{V}_{ij} := \frac{\overline{C}_{ij}}{\overline{W}_{ij}}$



(advancement of “Normalized Convolution” (Knutsson and Westin, 1993))

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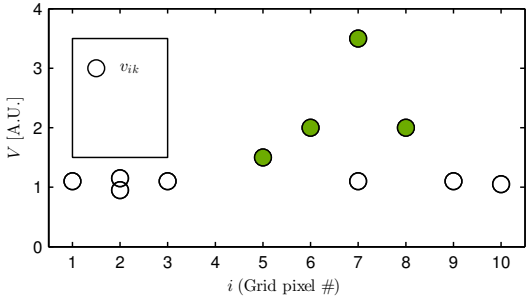

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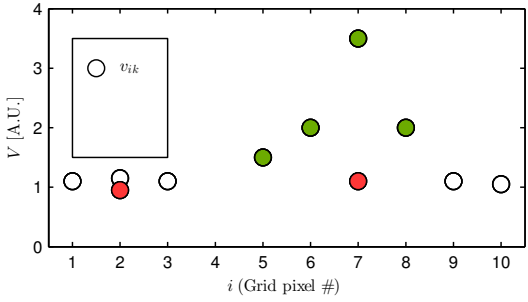

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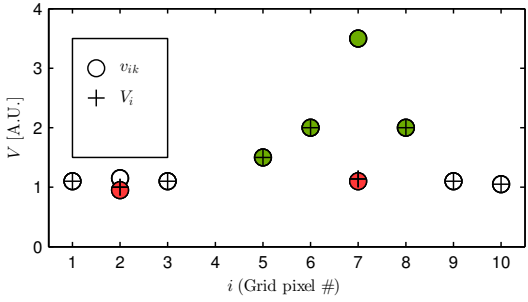

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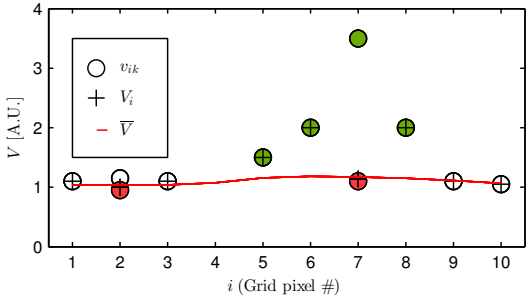


(advancement of “Normalized Convolution” (Knutsson and Westin, 1993))

Weighted convolution

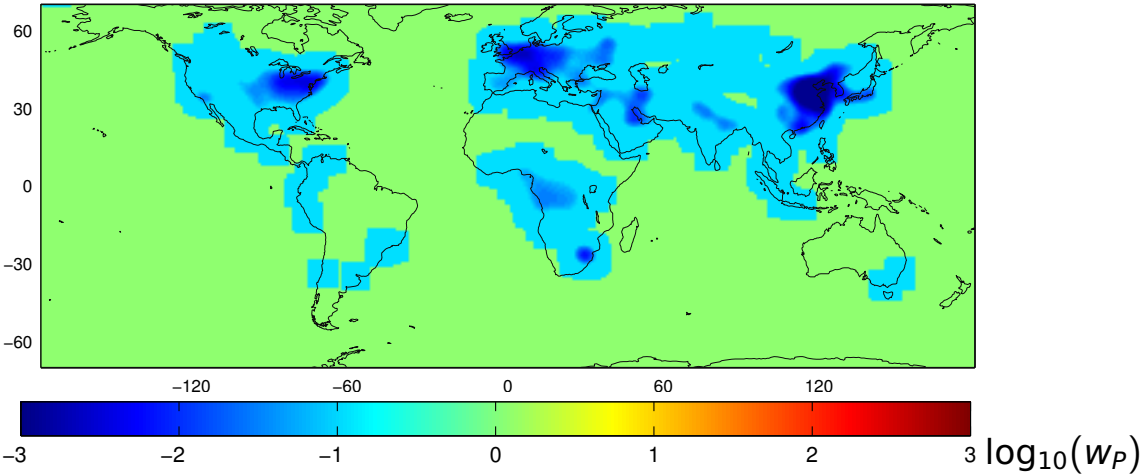
- Very flexible set-up
- Few a-priori, no models
- Easily extendible (w_{flash}, w_{fire} etc.)
- Convolution can be extended to 3d (over time)
- Above clouds, the true stratospheric is observed (no need for an a-priori tropospheric background)

Regulation screws:

- Definition of weights
- Convolution Kernel

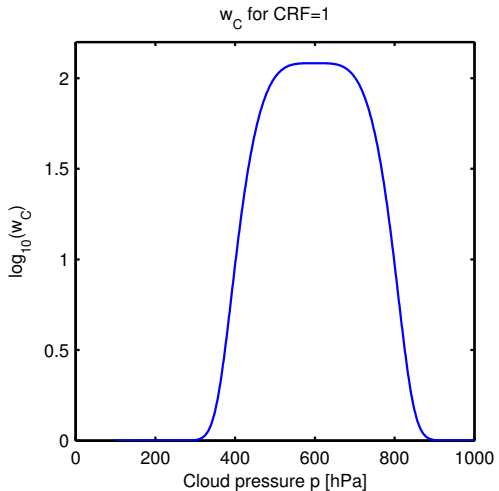
Weighting factors: w_P (Pollution)

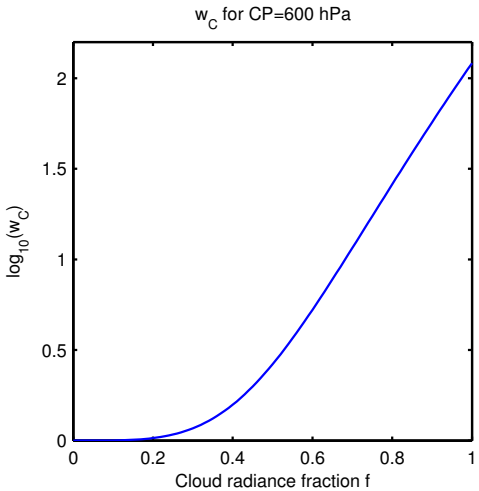
- Tropospheric NO_2 climatology P
  (here: mean SCIAMACHY TVCD)
- Pollution threshold: 10^{15} molec/cm^2
- Smooth & widen by convolution with Gaussian ($\sigma = 2^o$)
- $w_P = \frac{0.1}{P^3}$



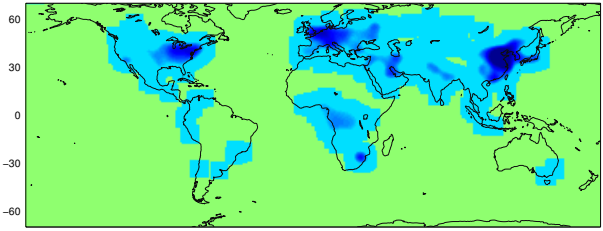
Weighting factors: w_C (Clouds)

- Idea: clouds shield troposphere -> high weight
- Exclude low clouds (albedo/multiple scattering)
- Exclude high clouds (deep convection/lightning NO_x, saturation)
- $w_C = (1 + 10 \times f^4 \times e^{-\frac{(p-600)^4}{2\times 150^4}})^2$
- f: Cloud radiance fraction; p: Cloud pressure

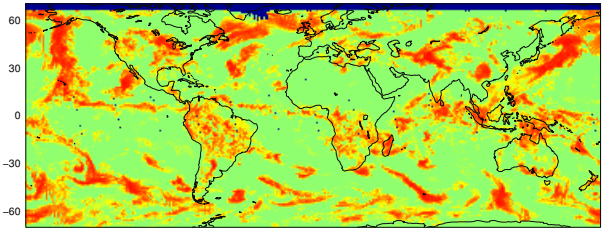




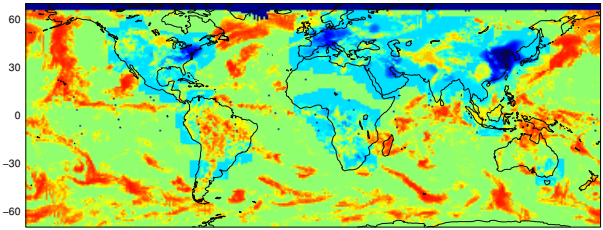
Weighting factors: $w_P * w_C$



w_P



w_C

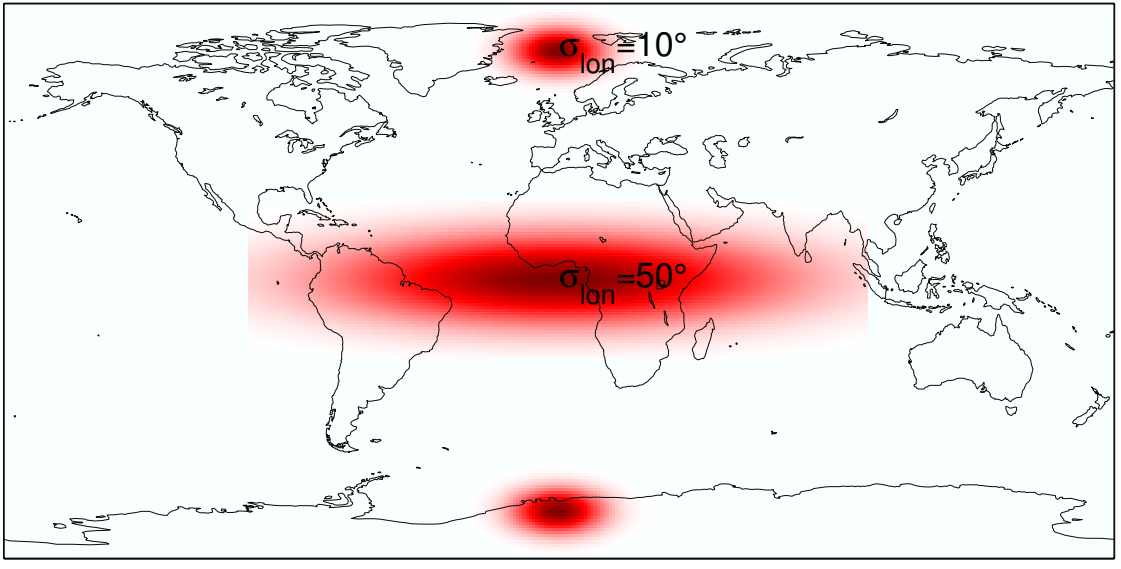


$w_P \times w_C$

$\log_{10}(w)$

Convolution Kernel

- 2d Gaussians
- $\sigma_{\text{lon}} > \sigma_{\text{lat}}$
- Broader Kernel at low latitudes



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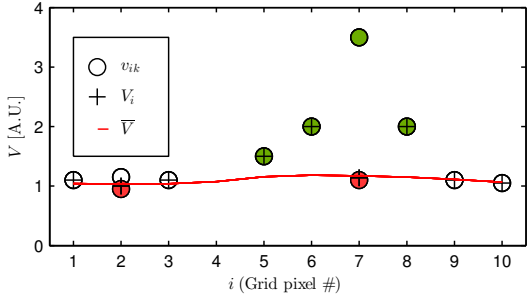
  Global stratospheric NO_2



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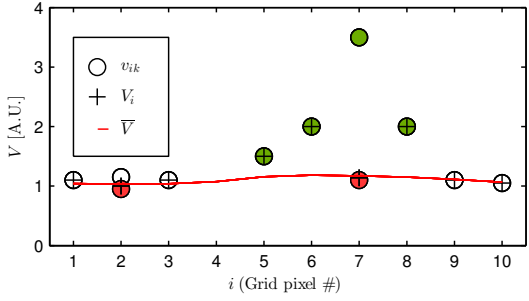
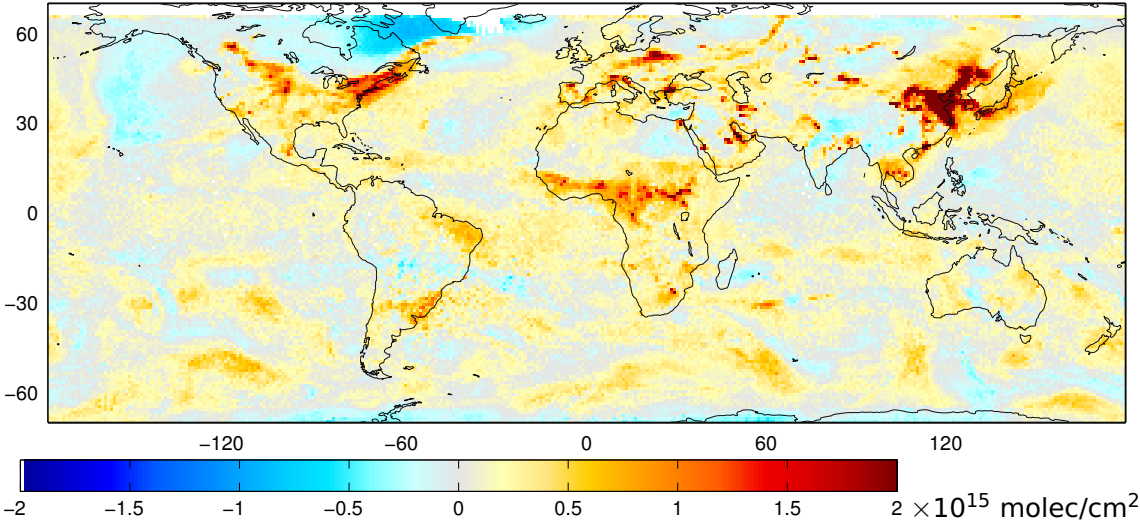


Tropospheric residue:

$T=V_{total}-V_{strat}$

(based on AMF_{strat})

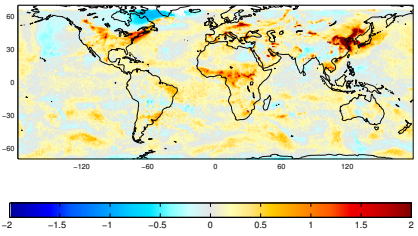
Weighting factors: w_T (Tropospheric residue)



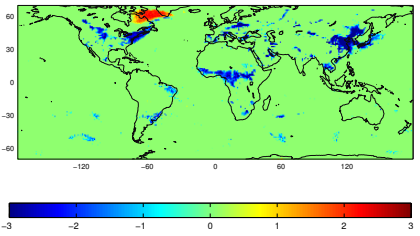
OMI, 1 Jan 2005

Weighting factors: w_T (Tropospheric residue)

T



w_T



- Negative T:

  stratosphere overestimated

  -> high weight

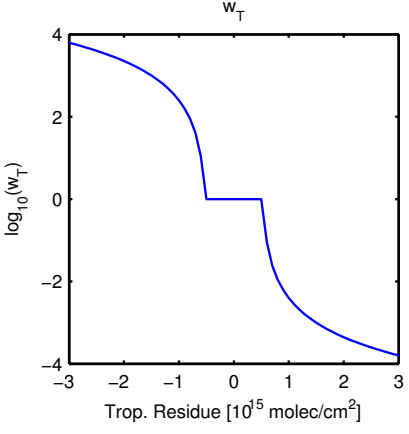
  if T<-0.5: $w_T=1+1000(T+0.5)^2$

- High T:

  tropospheric pollution

  -> low weight

  if T>0.5: $w_T=1/(1+1000(T-0.5)^2)$



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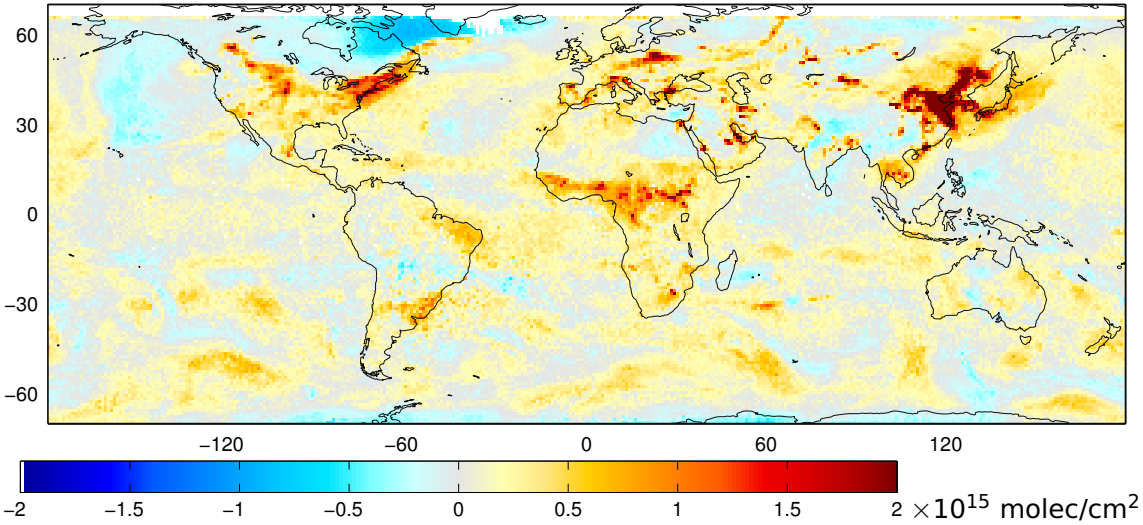

Tropospheric residue

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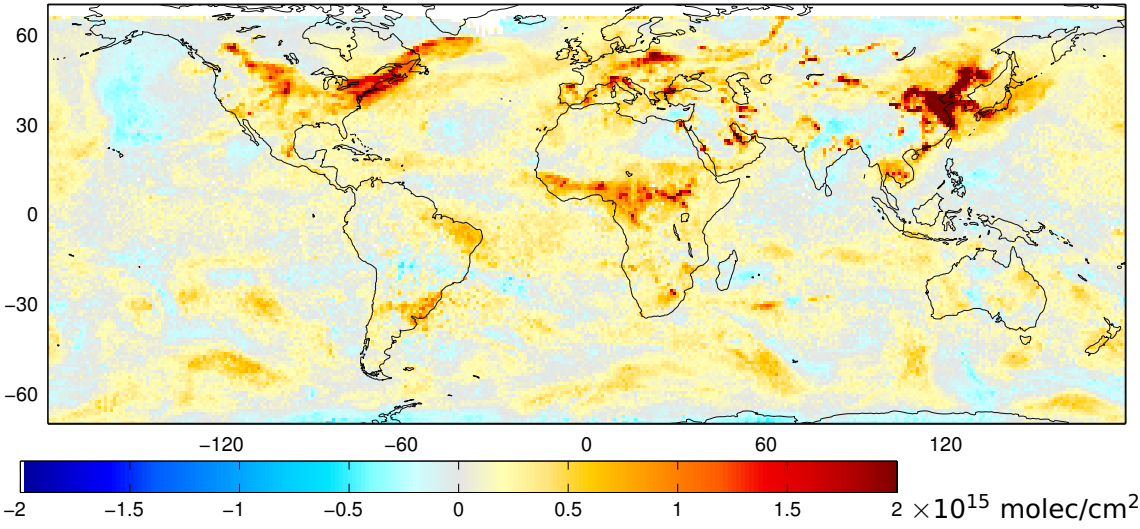
Weighting factors: w_T (Tropospheric residue)



Tropospheric residue after applying w_T

OMI, 1 Jan 2005

Part II: Results and comparisons

- Input: Total VCDs (strat. AMF)

  here: OMI data from NASA (de-striped, including high SZA)

- Quantities: Strat. VCD V, Trop. residue T

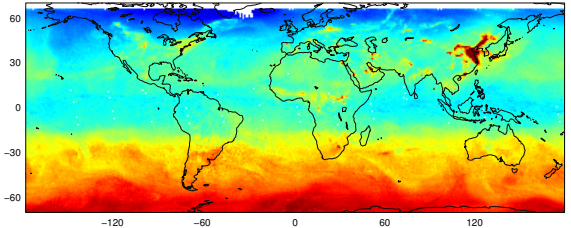
  (with strat. AMF -> TVCD higher by a factor of 2-4)

- Datasets:

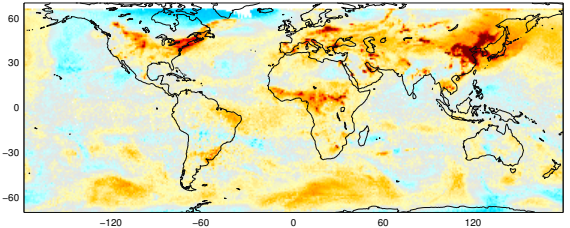
  MPIC, DOMINO, NASA

Results: 1 Jan. 2005, MPIC

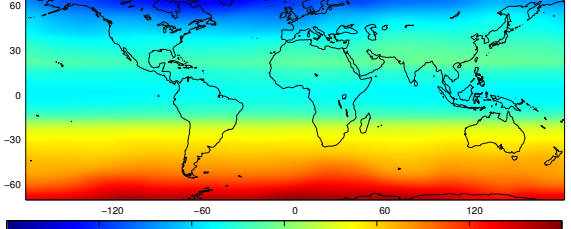
Total column V*



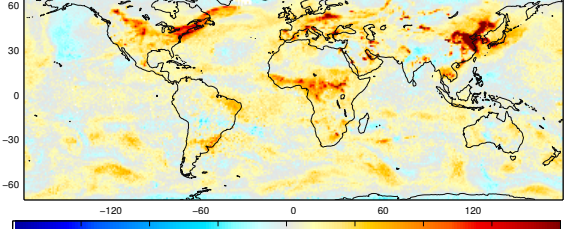
Trop. Residue T (Reference Sector)



V_{Strat}



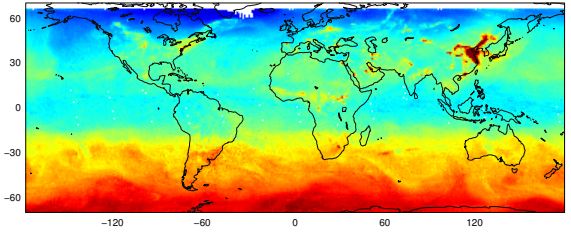
T



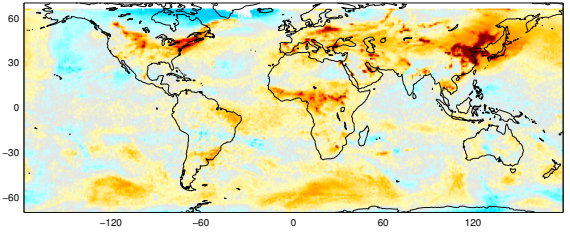
$\times 10^{15}$ molec/cm^2

Results: 1 Jan. 2005, DOMINO v2

Total column V*



Trop. Residue T (Reference Sector)



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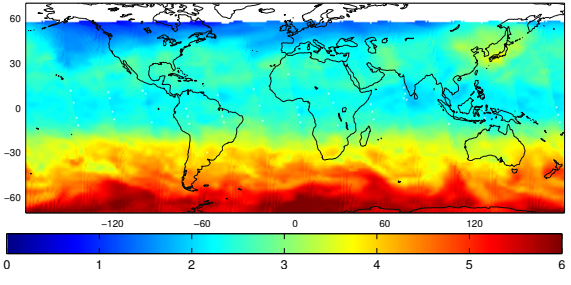
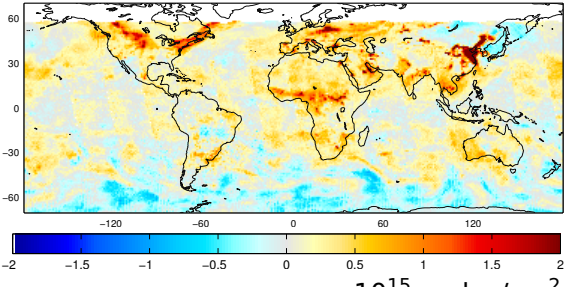


T



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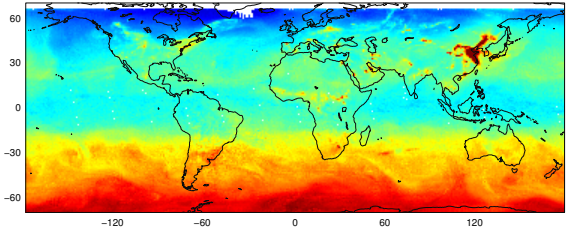
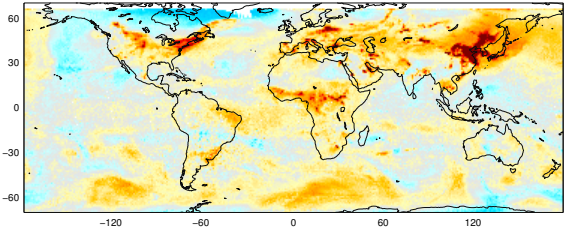


Trop. Residue T (Reference Sector)



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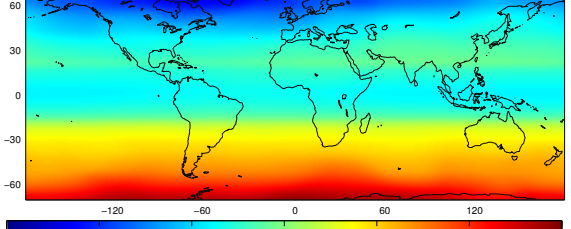
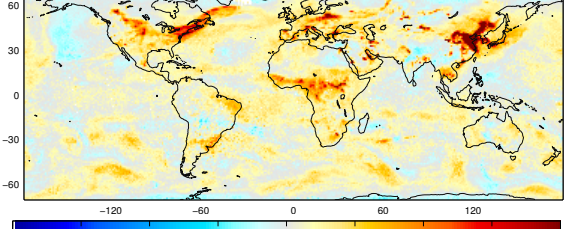


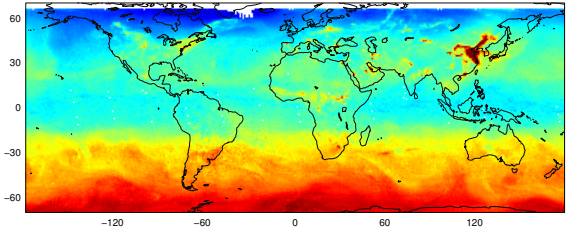
T



$\times 10^{15}$ molec/cm^2

Results: 1 Jan. 2005, NASA

Total column V*



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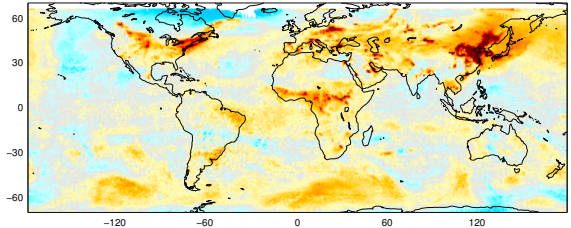
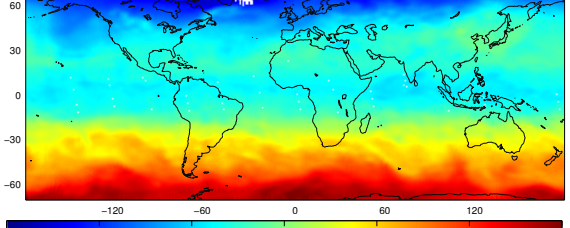
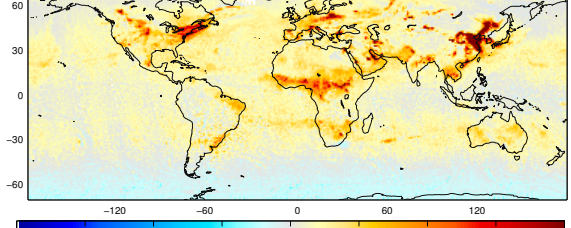


V_{Strat}



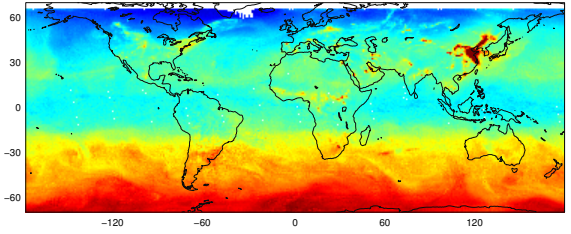
T



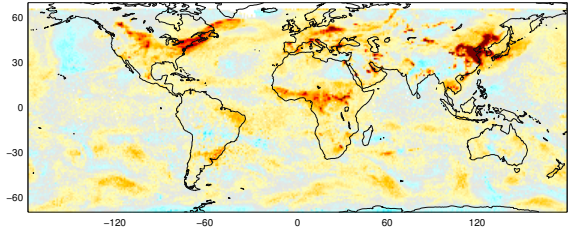
$\times 10^{15}$ molec/cm^2

1 Jan. 2005

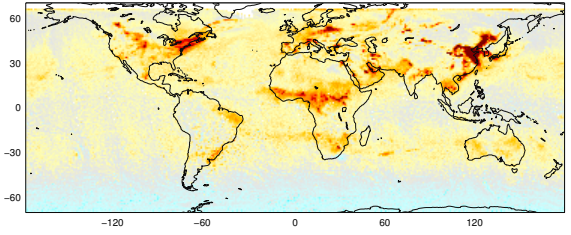
V*



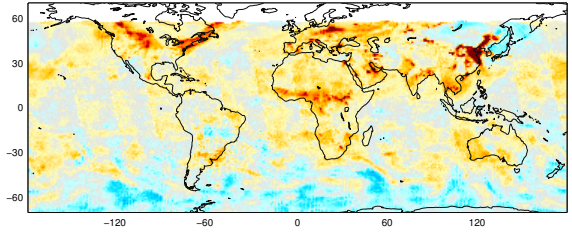
T (MPI-C)

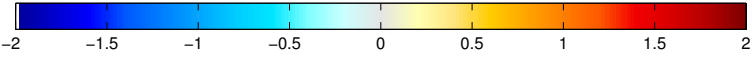


T (NASA)



T (DOMINO v2)





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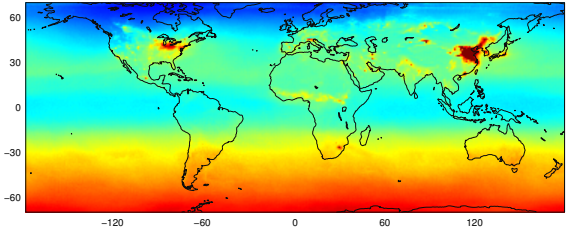
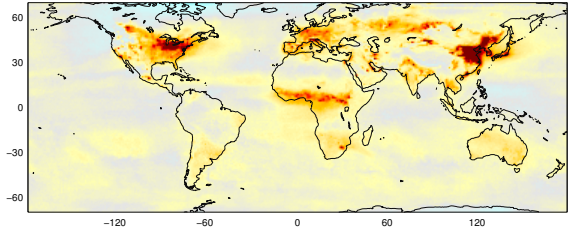
January 2005

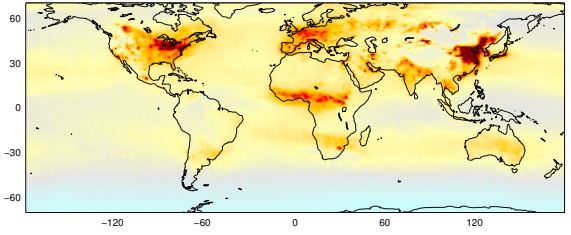
V*



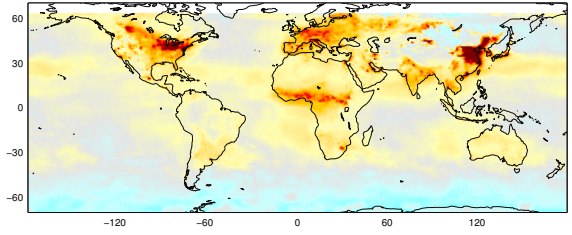
T (MPI-C)

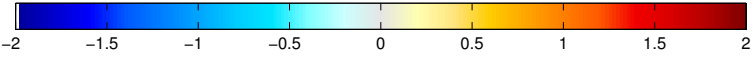


T (NASA)



T (DOMINO v2)

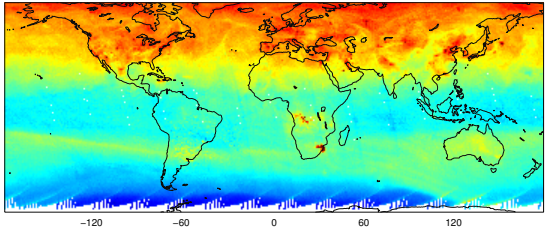




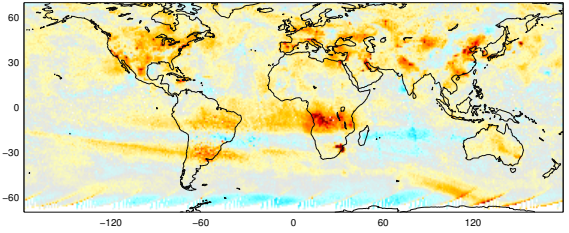
$\times 10^{15}$ molec/cm^2

19 July 2005

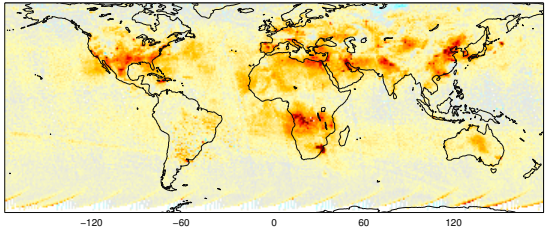
V*



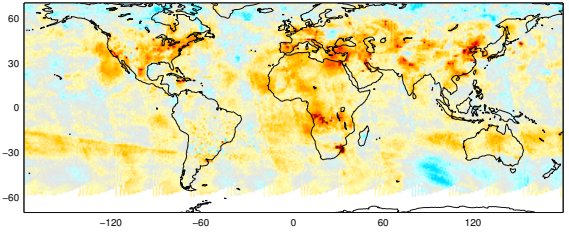
T (MPI-C)

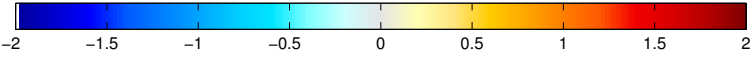


T (NASA)



T (DOMINO v2)

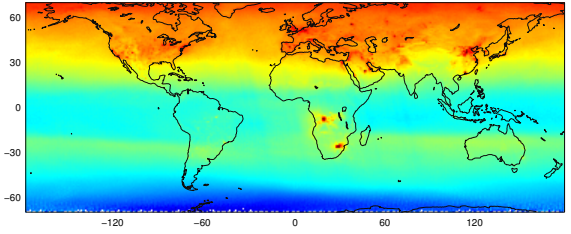




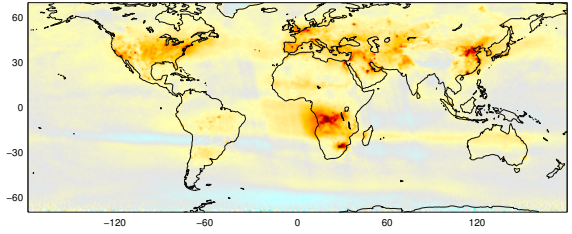
$\times 10^{15}$ molec/cm^2

July 2005

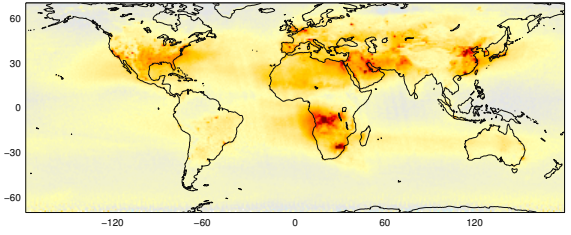
V*



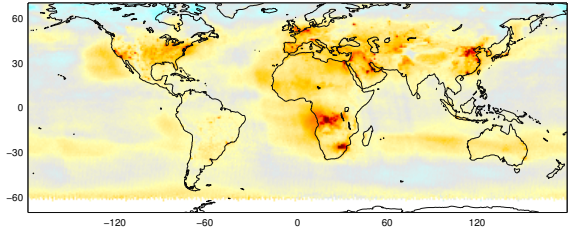
T (MPI-C)

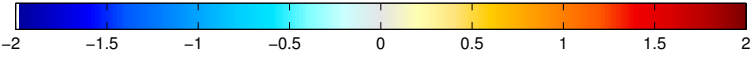


T (NASA)



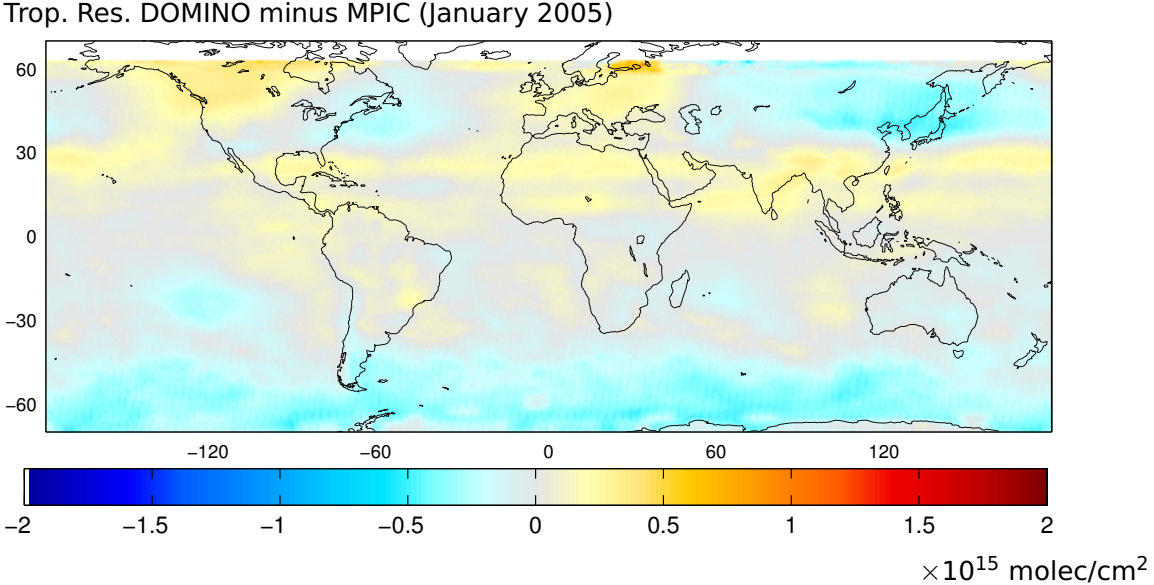
T (DOMINO v2)



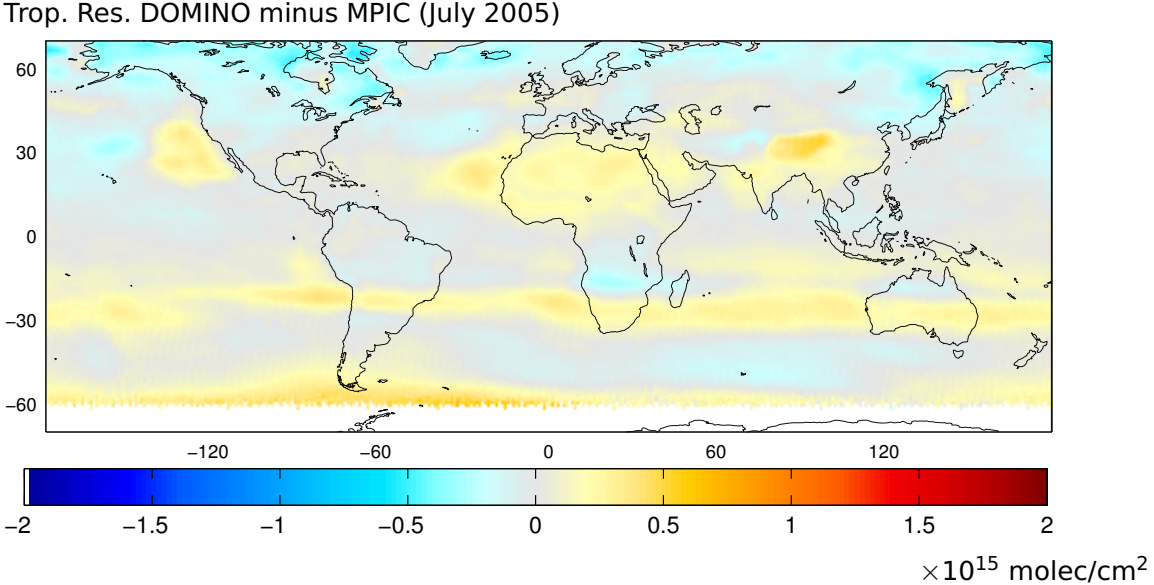


$\times 10^{15}$ molec/cm^2

Difference Jan 2005



Difference July 2005



Summary II: Intercomparison

- General challenge: remove strong gradients (polar vortex, filaments at mid lats), but preserve tropospheric signals (LRT)
- Differences in monthly mean T below about 0.2 (typical) / 0.5 (regional) $\times 10^{15}$ molec/cm^2 (stratospheric AMF!)
  -> keep in mind for studies on e.g. soil emissions!

Next steps:

- Compare to models
- Compare to independent measurements (SCIAMACHY limb)

Summary I: The MPIC verification algorithm

Based on nadir measurements:

- few a-priori, independent from models

Weighted convolution:

- Powerful and flexible set-up
- Easy to extend: further weights (e.g. fires, lightning, etc.), 3d
- Well suited for TROPOMI: more clouded pixels!
- S4?

Next steps:

- Systematic variation of weighting factor definition and convolution Kernel
- Apply to other instruments (GOME2/SCIA)