TM5-MP CH_4 inversion updates at VU

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35th International TM5 Meeting

Wageningen, 21-22 October 2024

VU VRIJE UNIVERSITEIT AMSTERDAM
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Department of Earth Sciences
Earth and Climate Cluster

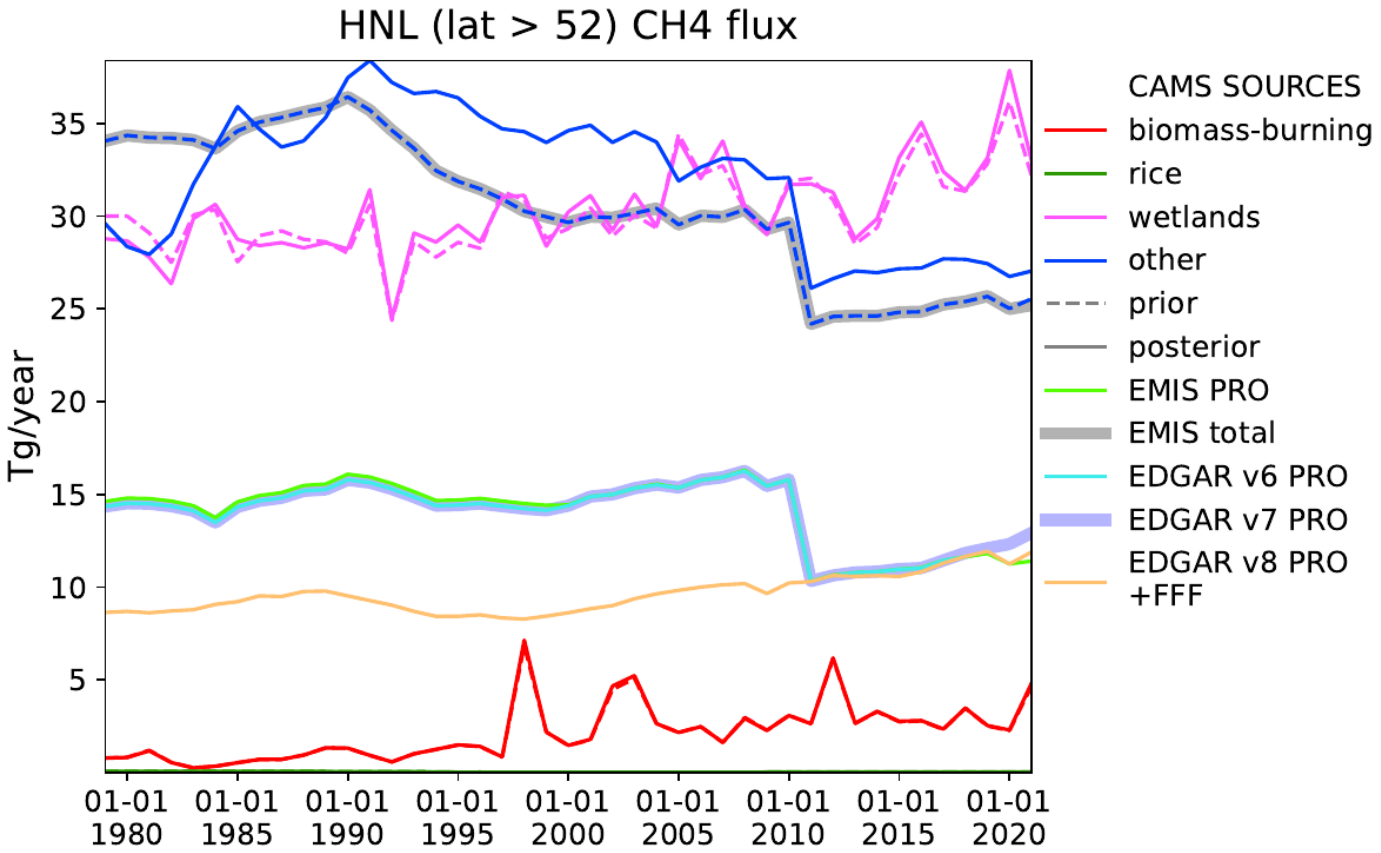
Outline

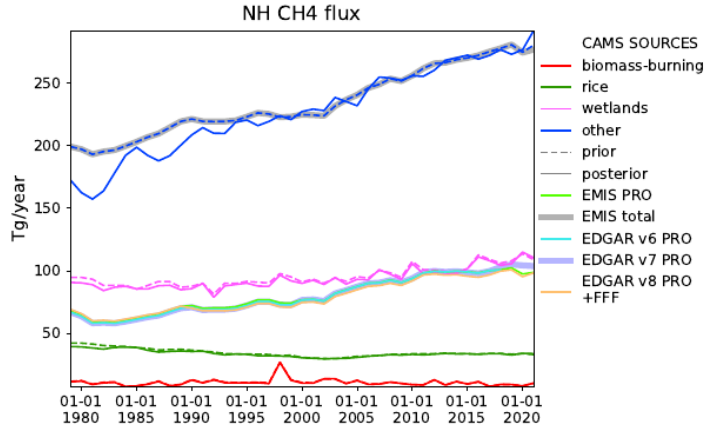
- Long term trends in the CAMS v22 inversion
- Increasing model resolution
- Advection test code and GPU programming
- Conclusions
- Outlook

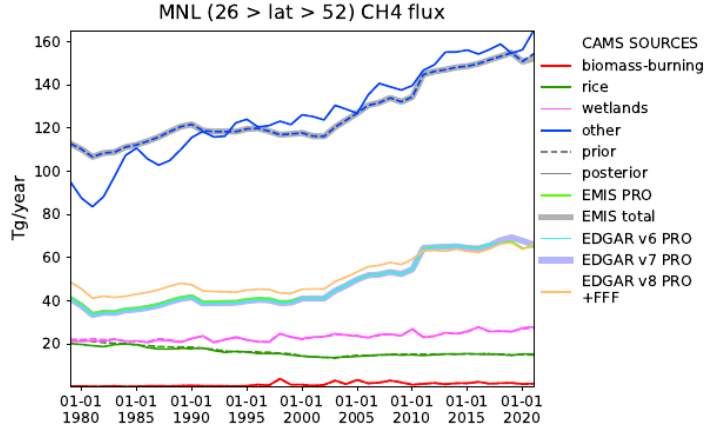
Long term trends in CAMS inversion

- Part of the MethaneCAMP project
- CAMS inversion uses four sources
  - Biomass burning, Rice (= EDGAR AGS), Wetlands, and Other (= mostly EDGAR, termites, soil sink etc.)
- EDGAR data (plots on next slide)
  - EMIS = preprocessed emission databases used in CAMS
  - CAMS v21 uses EDGAR v6 (CAMS v22 uses v7, and CAMS v23 will use v8)
  - Sector PRO (fuel exploitation) is used in CAMS and is the sum of PRO_COAL, PRO_OIL, and PRO_GAS
  - If you add all EMIS sources excl. PRO_... you end up with the prior (consistency check)
  - EDGAR v6 has PRO and FFF separate (Fossil Fuel Fires), EDGAR v8 has PRO_FFF
  - Both EDGAR v6 PRO and EDGAR v8 PRO_FFF in the following plots have been read directly from the EDGAR databases, so did not go through the CAMS pre-processing

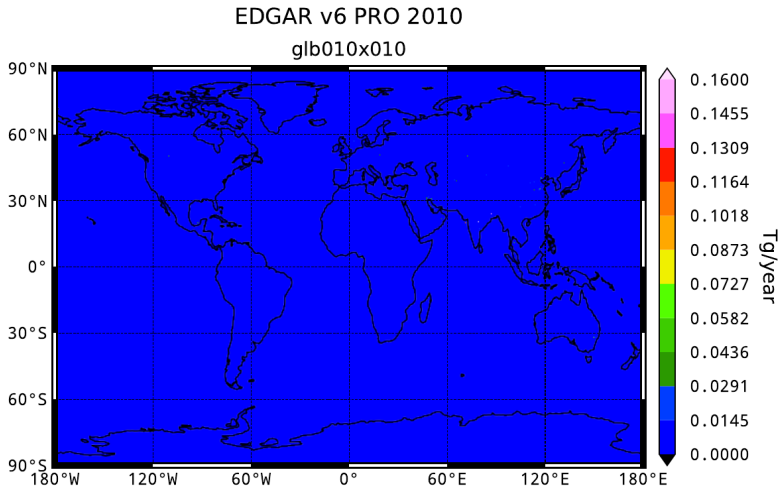
Long term trends in CAMS inversion

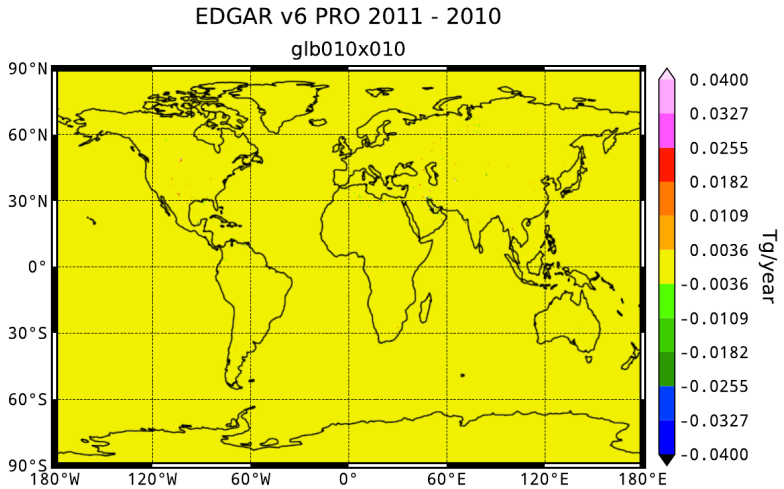


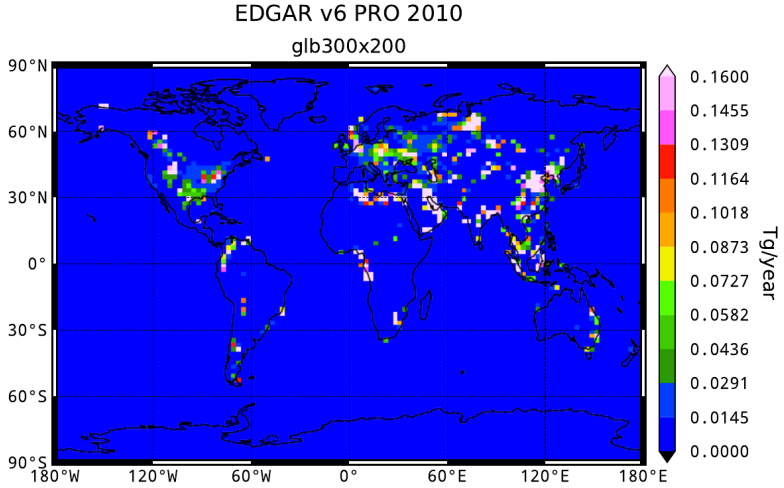


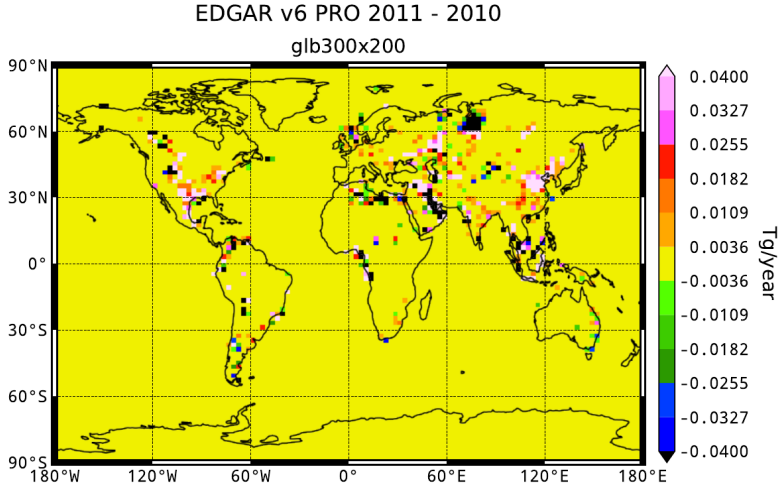


EDGAR v6: 2011-2010

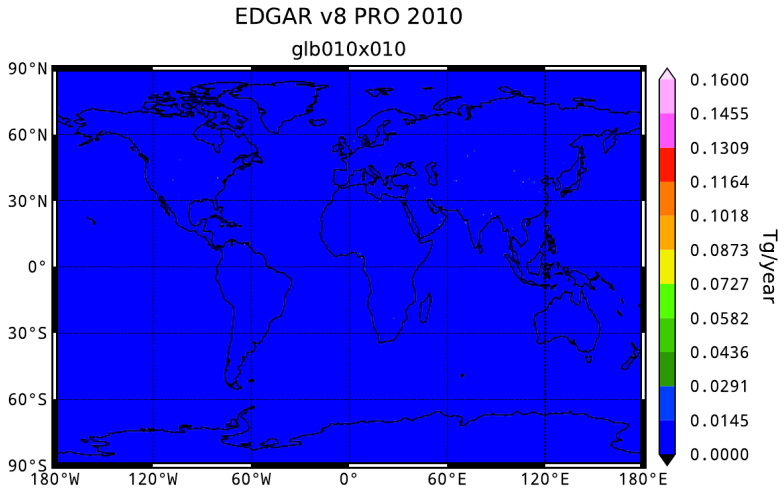


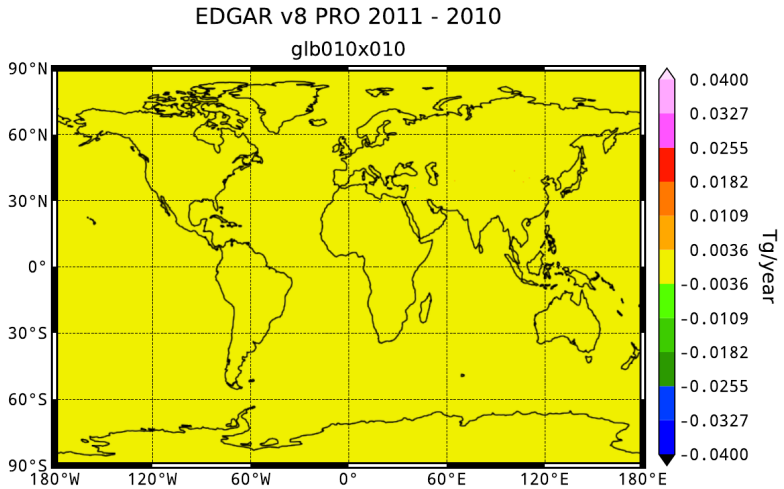


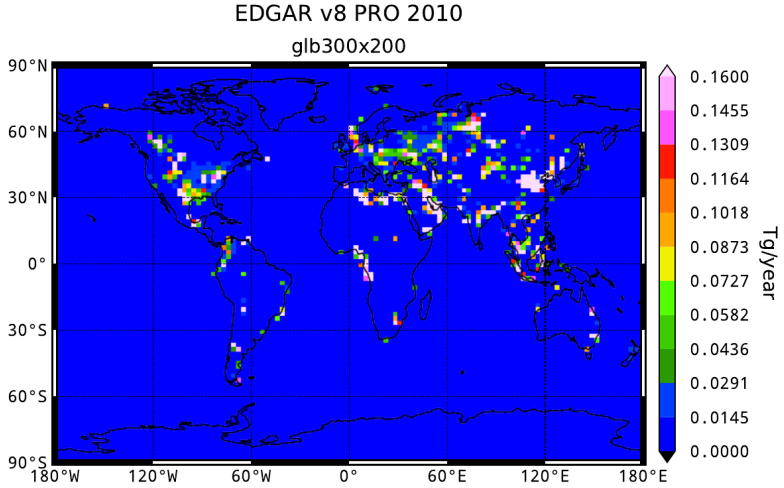


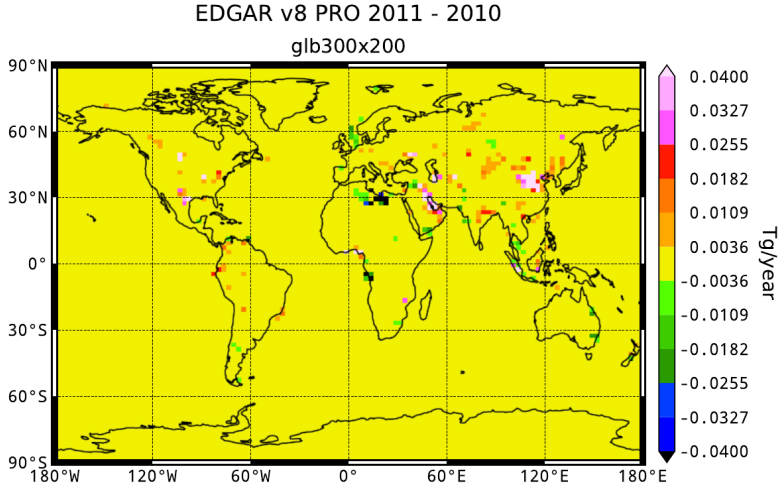


EDGAR v8: 2011-2010

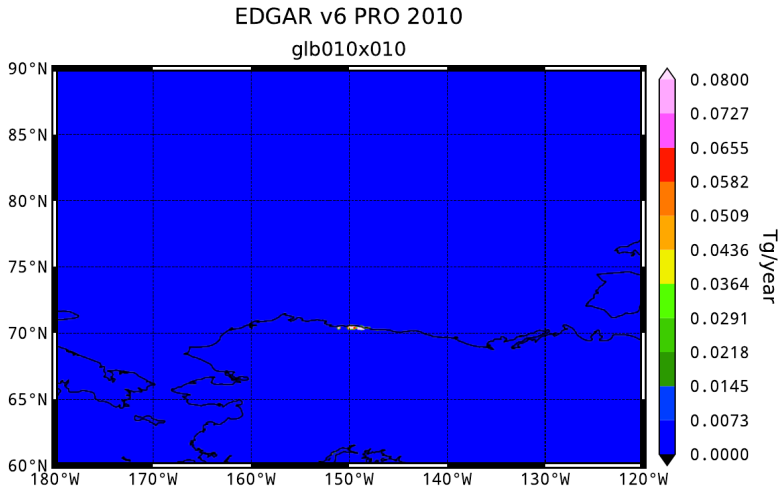


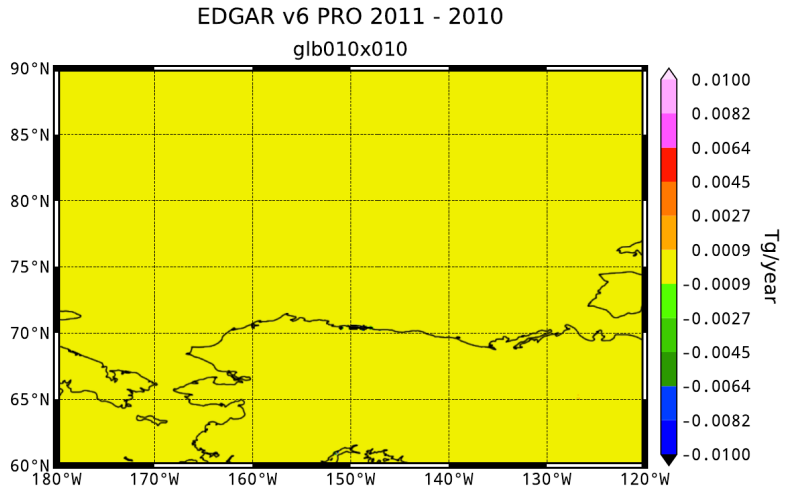


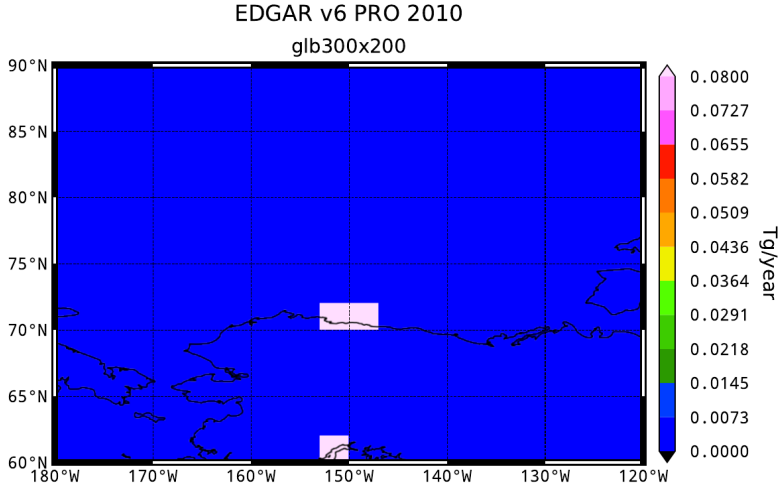


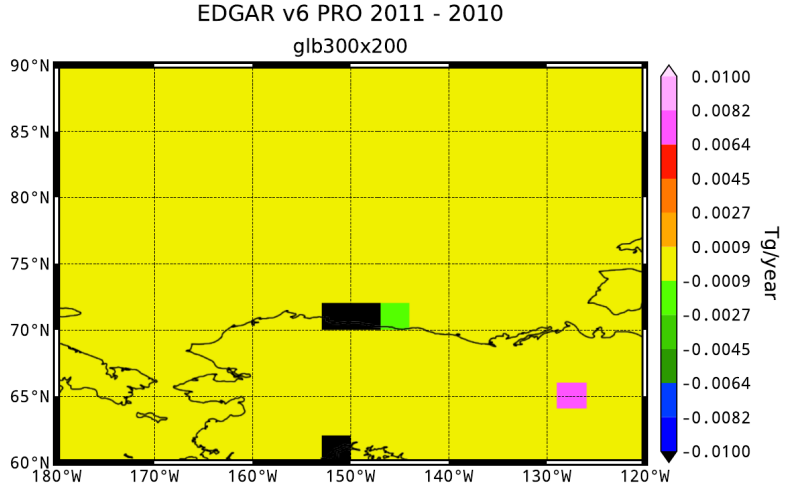


EDGAR v6: 2011-2010

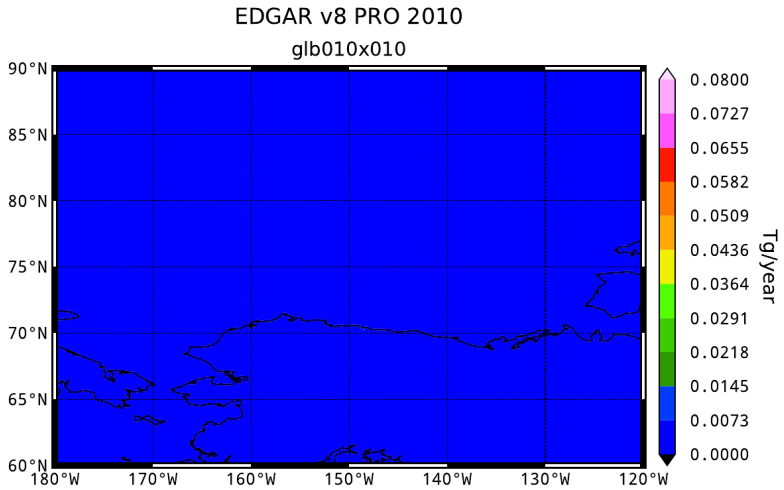


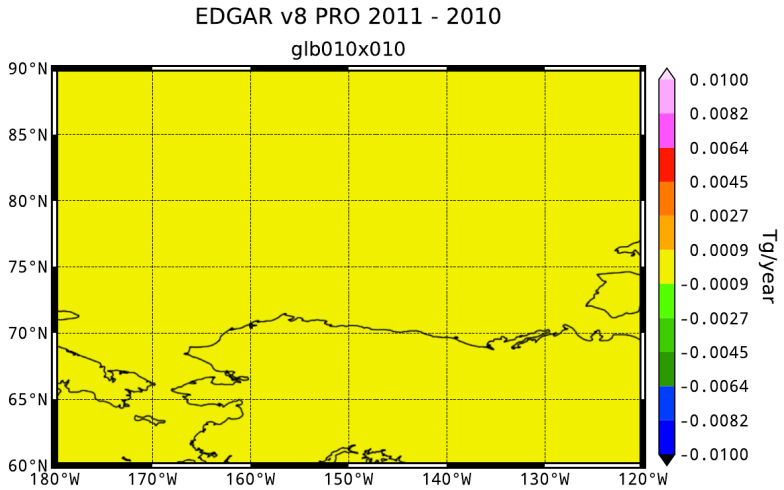


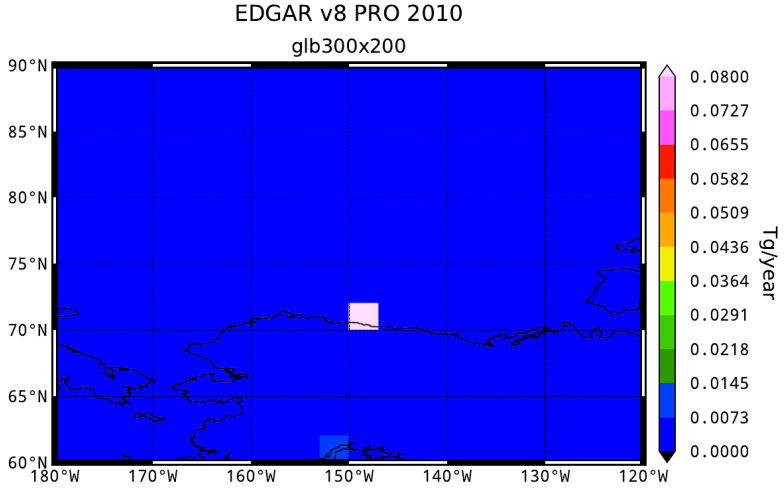


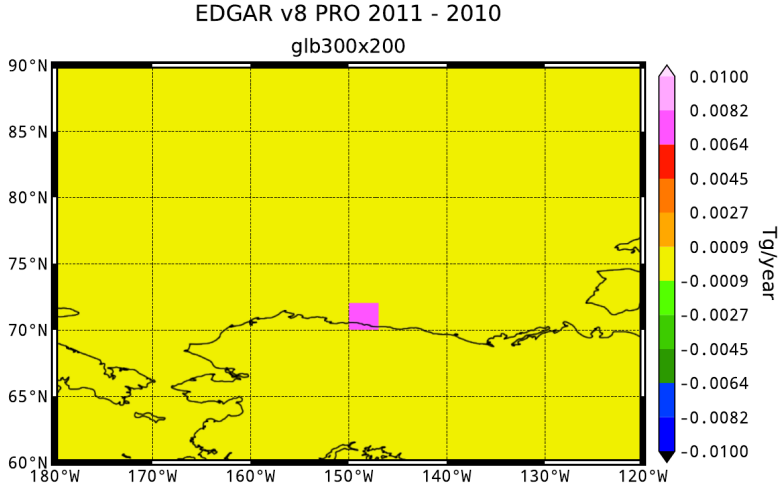


EDGAR v8: 2011-2010

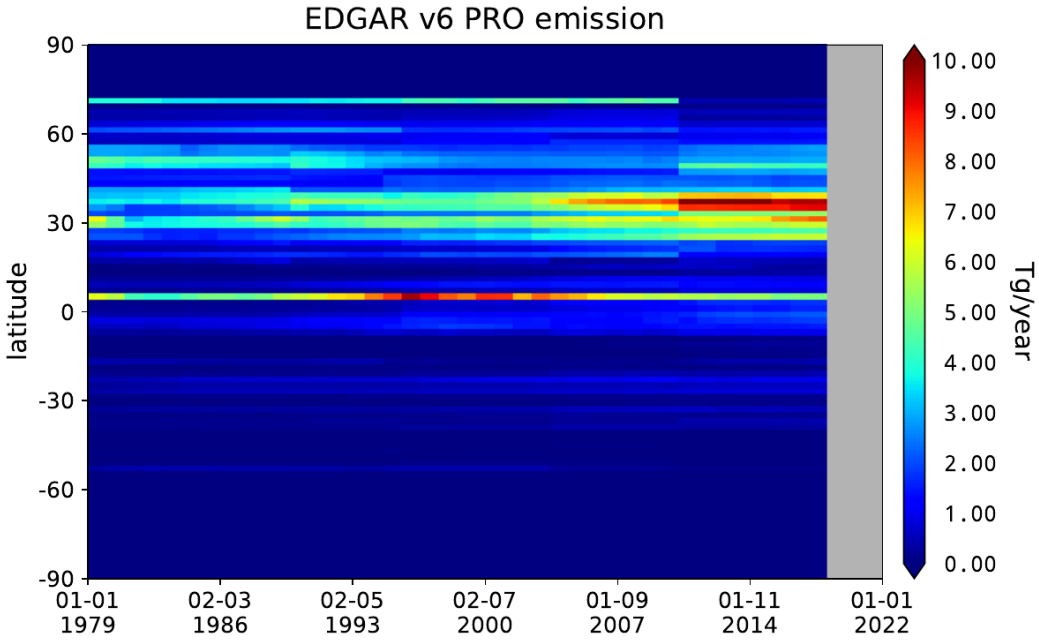


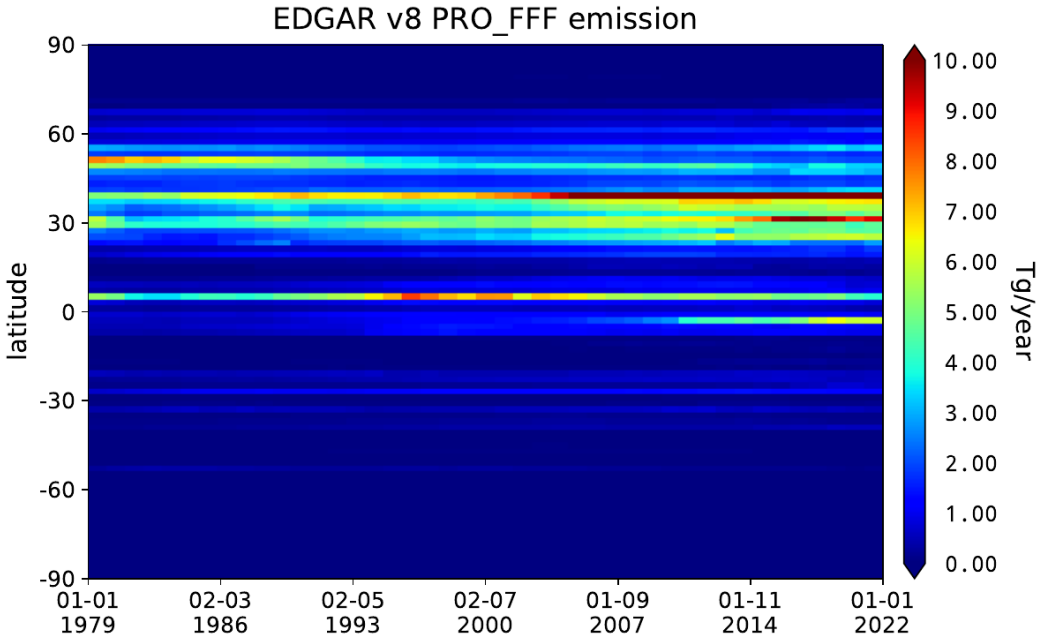




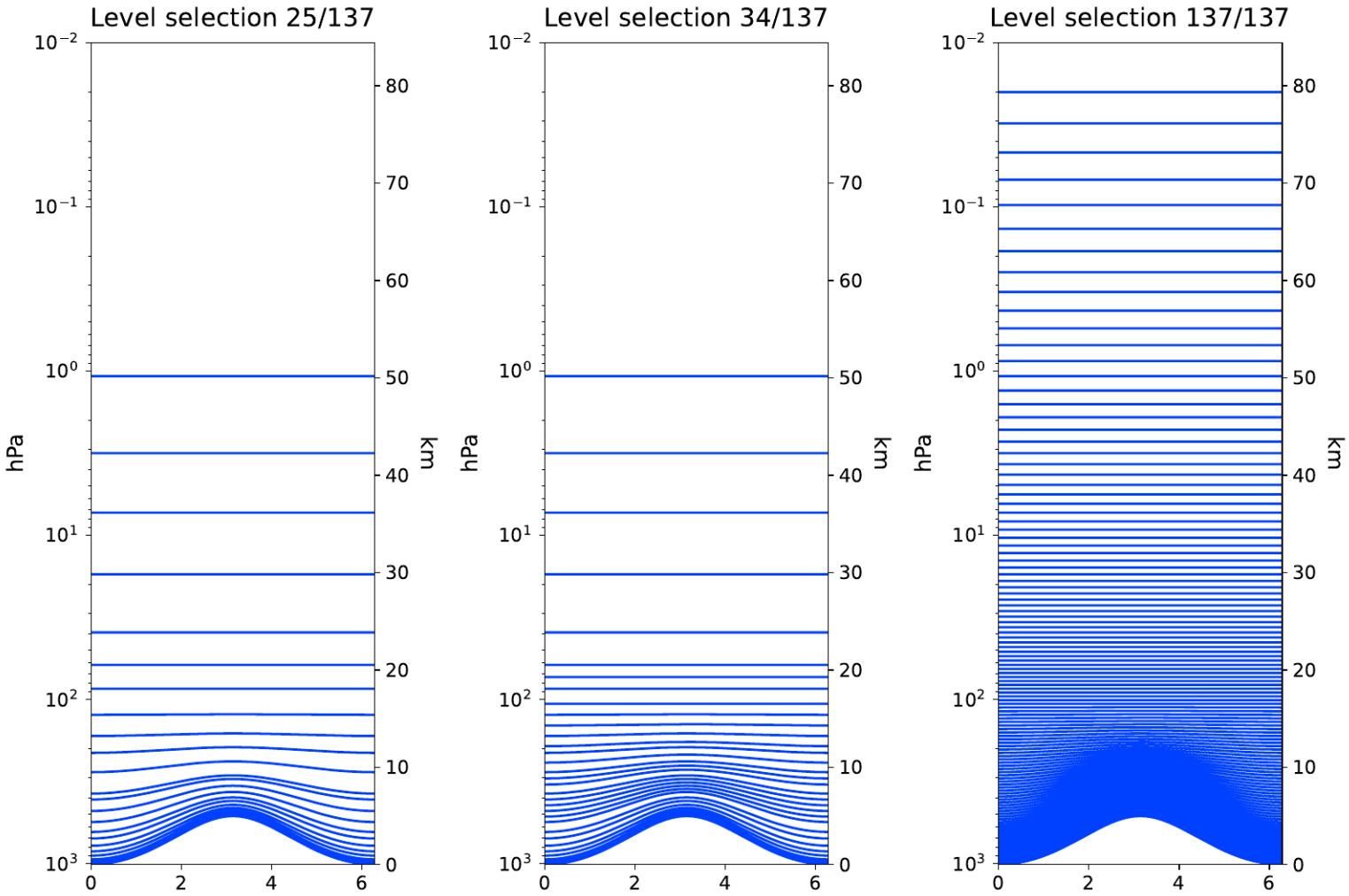


EDGAR v6/v8


EDGAR v6 PRO emission
latitude
90
60
30
0
-30
-60
-90
01-01 1979
02-03 1986
02-05 1993
02-07 2000
01-09 2007
01-11 2014
01-01 2022
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Tg/year

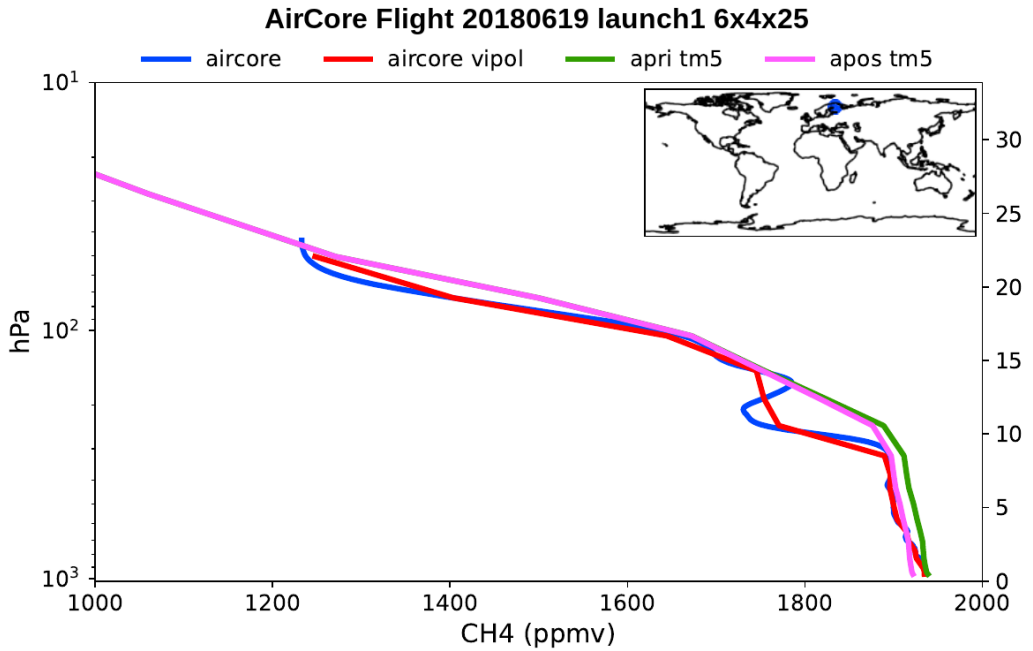

EDGAR v8 PRO_FFF emission
latitude
90
60
30
0
-30
-60
-90
01-01 1979
02-03 1986
02-05 1993
02-07 2000
01-09 2007
01-11 2014
01-01 2022
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Tg/year

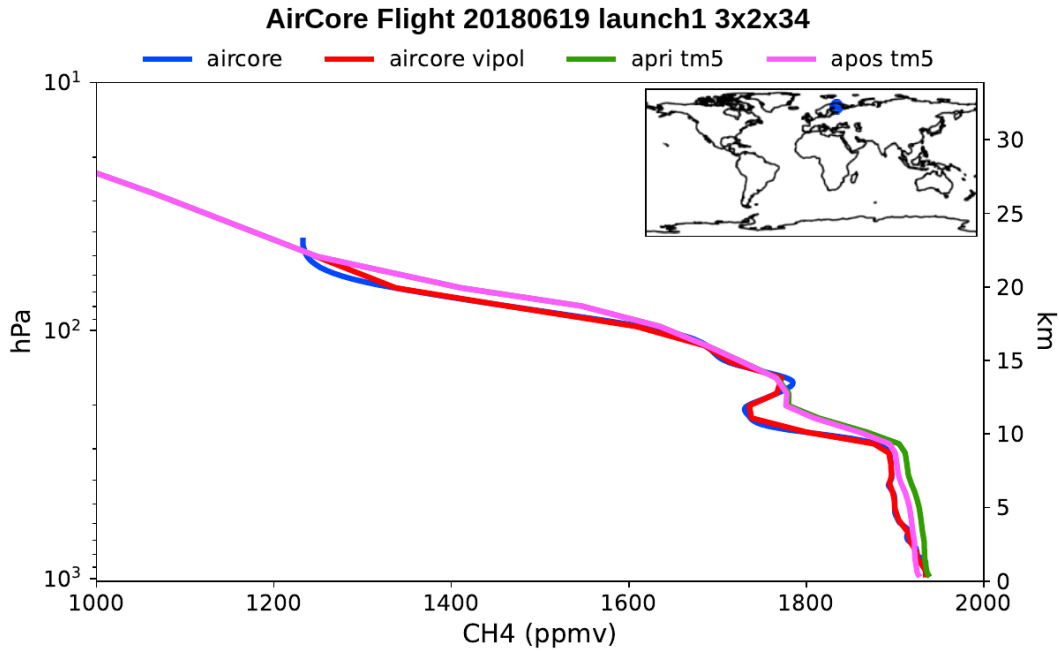
Increasing model resolution



Increasing model resolution: AirCore

- From 6×4×25 to 3×2×34 (lon × lat × layers) and 40 to 20 iterations
- Below: inversion using surface data only

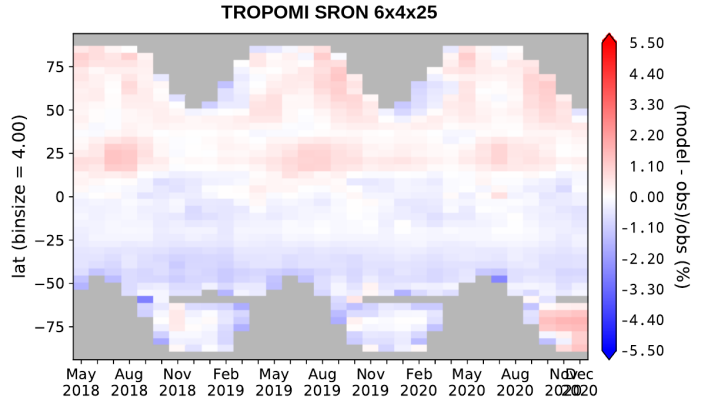


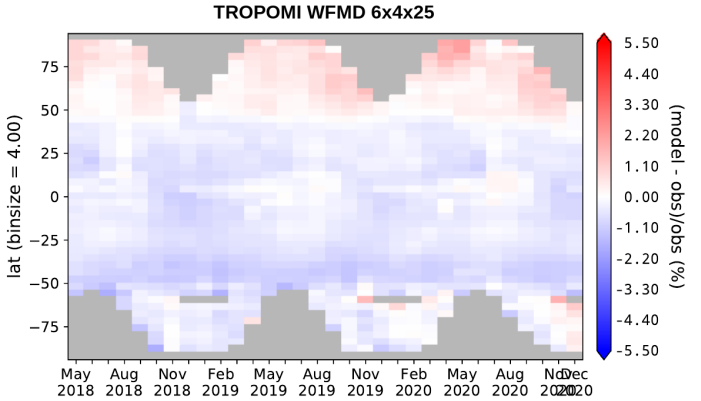


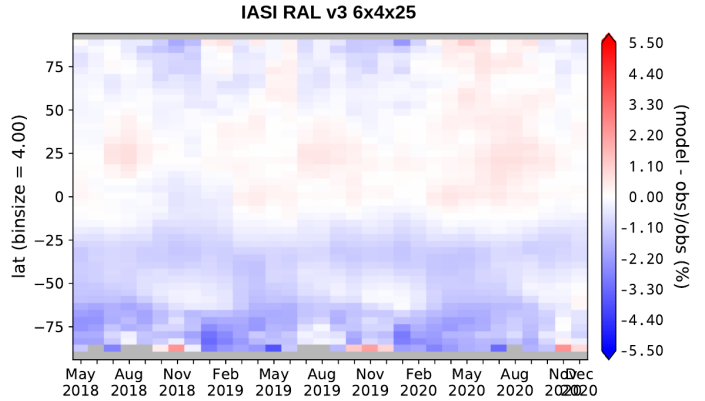
Increasing model resolution: L2 data

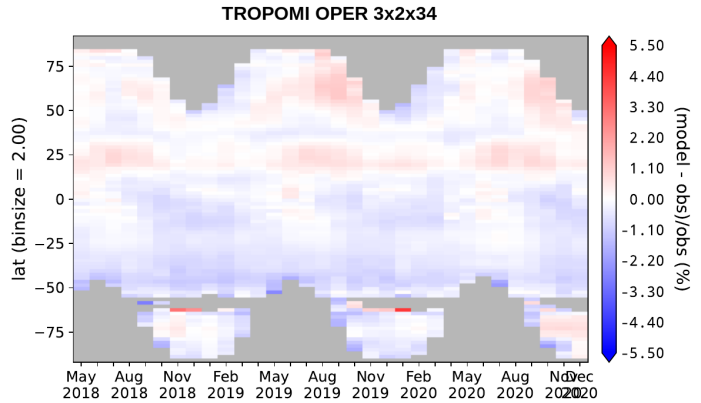
- TROPOMI operational
  - Lorente et al. (2022) AMTD: https://doi.org/10.5194/amt-2022-255
  - 3rd order polynomial fit
- TROPOMI Bremen WFMD v1.8
  - Schneising et al. (2019, 2023): 10.5194/amt-12-6771-2019, 10.5194/amt-16-669-2023
  - https://www.iup.uni-bremen.de/carbon_ghg/products/tropomi_wfmd/
- IASI RAL v3.0
  - Siddans et al. (2017): 10.5194/amt-10-4135-2017
  - From methane+ project extension, available since October 2nd, 2023
- SWIR-TIR RAL v2.0
  - Joint retrieval of TROPOMI and IASI, both total columns and subcolumns (up to 450 hPa ≈ 6km)
  - From methane+ project extension, available since October 2nd , 2023

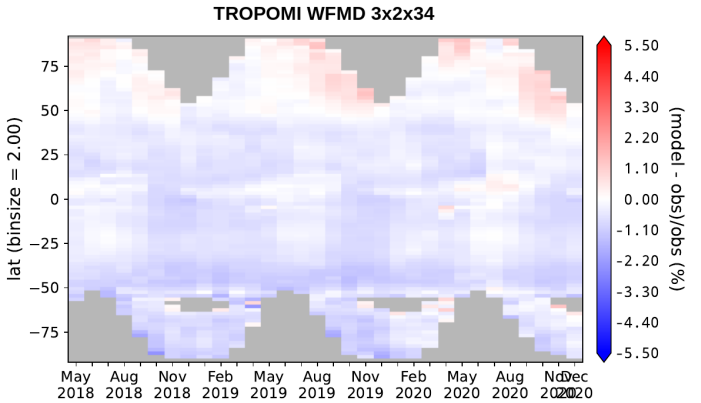
Bias wrt. surface only inversion

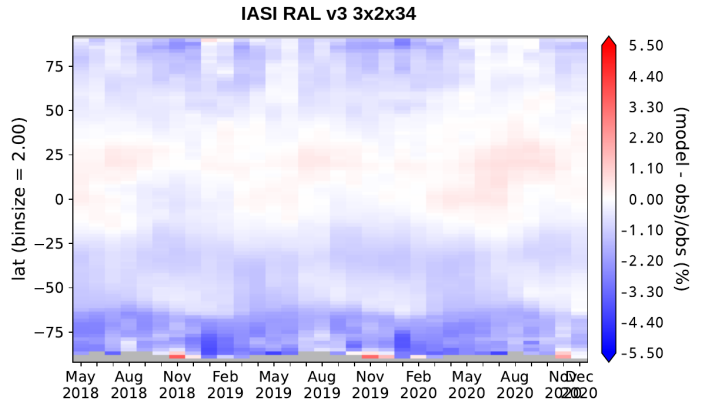




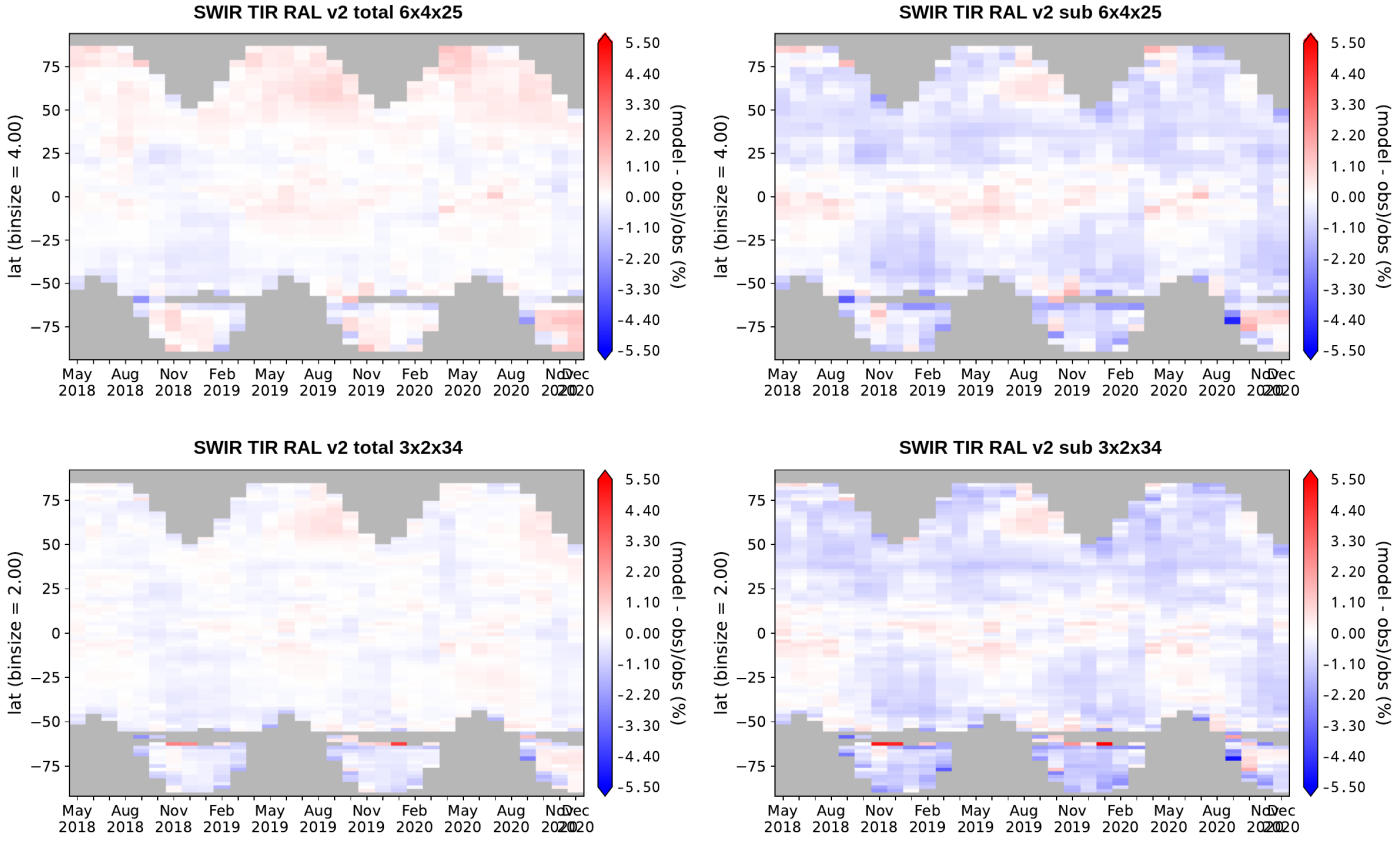






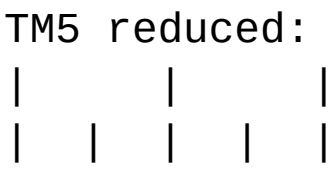


Bias wrt. surface only inversion

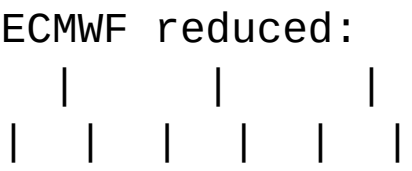


Advection and GPU programming

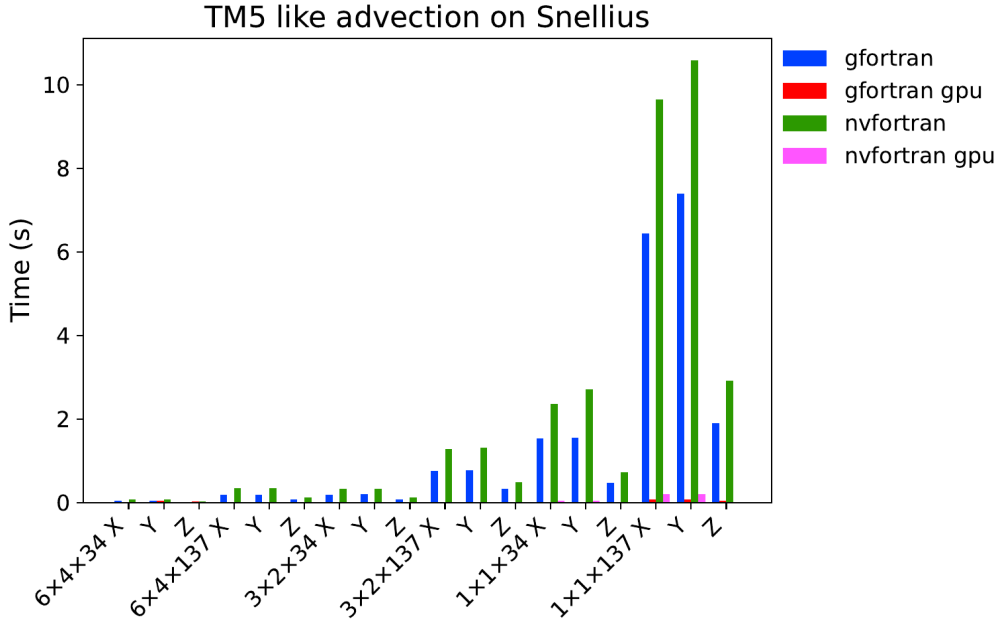
- Use a horizontally reduced grid like ECMWF
  - TM5 reduced:

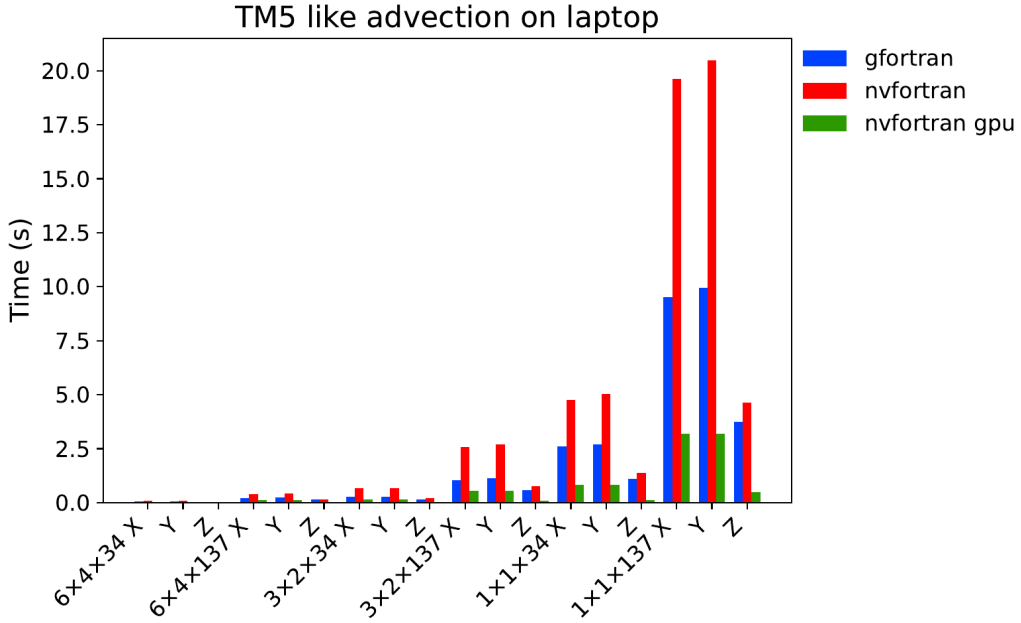
    

    ECMWF reduced:

    
  - In the TM5 reduced grid, cell boundaries always coincide going from equator to higher latitudes. In the ECMWF grid they may not coincide, which should give a smoother transition.
- The horizontal grid is stored as a vector, not as an array
- Grid definition saved as a nested derived data type
  - grid%cellx(:)%[a,b,c], grid%celly(:)%[a,b,c], etc
  - grid is of “type T_RedGrid3D”, cellx and celly are of “type T_RedGridCell”
- The advection is calculated in three functions: AdvectX, AdvectY, and AdvectZ.

Advection and GPU programming





Advection and gpu programming

- 6x4x34: horizontal 6x4 degres (lon x lat), vertical 34 layers
- On the genoa partition, gfortran is significantly faster than nvfortran
- The gpu code can be made working with gfortran 12.3.0
  - Explicitly perform “deep copy” of nested derived datatypes like e.g. grid%cellx(:)%[a,b,c]
  - Instead of

    !$acc exit data delete(self, self%cellx, self%celly)

    use two lines

    !$acc exit data delete(self%cellx, self%celly)

    !$acc exit data delete(self)
  - Use the compiler option -fdefault-integer-8. Don’t know why this helps, but it does...
- On gpu partition, the advection calculation with gfortran is about 2.5 times faster than nvfortran
  - Copying of data to and from gpu takes more than 90% of advection step
  - Initialising arrays with random numbers is much slower for gfortran

Conclusions

- Long term trends
  - use EDGAR v8 instead of v6 or v7
- Increasing model resolution to 34 layers
  - improves the fit between TM5 and AirCore
  - reduces the bias between satellite measurements and an inversion using only surface data
- GPU programming
  - advection test code can be run with either gfortran or nvfortran
  - gfortran produces faster code, except for intrinsic functions for which nvfortran is faster

Outlook (1)

- SmartMethane project
  - incorporate TM5-MP adjoint into the Commumity Inversion Framework
- CAMS2_55_bis project
  - port current satellite inversion code to TM5-MP
  - merge with Arjo’s CAMS code
  - increase model resolution to 1×1 degree (and ??? layers)
  - use GPU in doing so
  - First step: diffusion coefficients.

Outlook (2)

- Uncertainty Quantification for Data Assimilation (UQDA)
  - Use Monte Carlo ensemble approach
  - Draw e.g. 20 samples from prior emission and observation distributions specified by the mean and covariance matrices
  - To reduce computational cost, do this for a limited period (e.g. a year) and / or coarse resolution
- Literature
  - Chevallier et al. (2007); https://doi.org/10.1029/2006JD007375
  - Stanley et al. (2024); https://doi.org/10.5194/acp-24-9419-2024
- TM5 community
  - Mihai Alexe, Peter Bergamaschi, Arjo Segers; “Uncertainty quantification for CH_4 emission estimates in TM5-4DVAR”; 23rd TM5 meeting in 2015
  - Work has been done on uncertainty estimates for CO_2 by S. Basu.