esa

climate change initiative

LONG-LIVED GREENHOUSE GAS
PRODUCTS PERFORMANCES

Sensitivity of historical climate model simulations to the OLLGHG climatology

Federico Fabiano and Alessandro Montanarini (CNR-ISAC)

lolipop
cci

The EC-Earth3 climate model

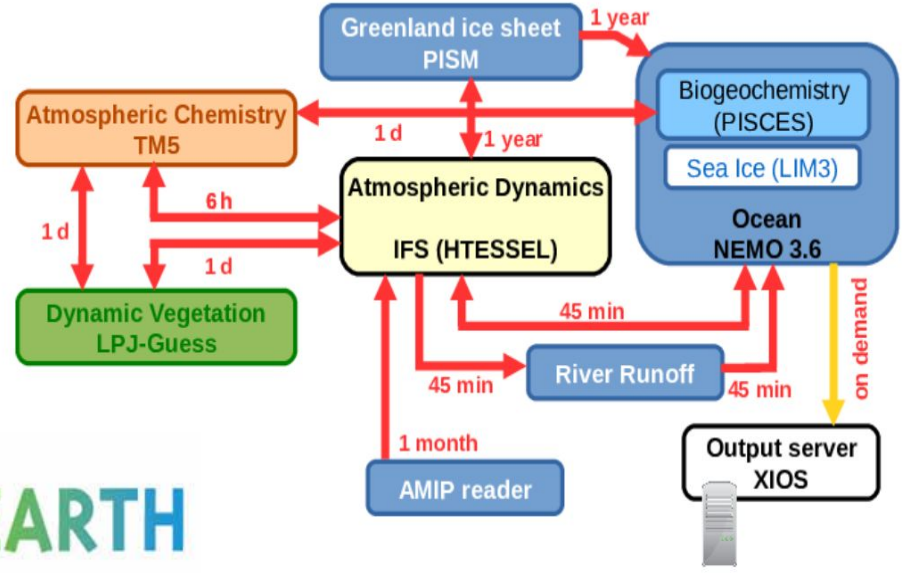
What is the impact of an updated latitude-height climatology of minor GHGs in climate models?

- Evaluate the **sensitivity of the simulated climate** to changes in the distribution of minor GHGs
- **Implement an updated climatology** of GHGs in the EC-Earth climate model

EC-Earth3 is a Coupled Atmosphere-Ocean General Circulation Model, which includes:

- atmospheric model IFS cy37;
- ocean model NEMO v3.6;
- Sea-ice model LIM2

EC-Earth participated in the last climate model intercomparison project **CMIP6**

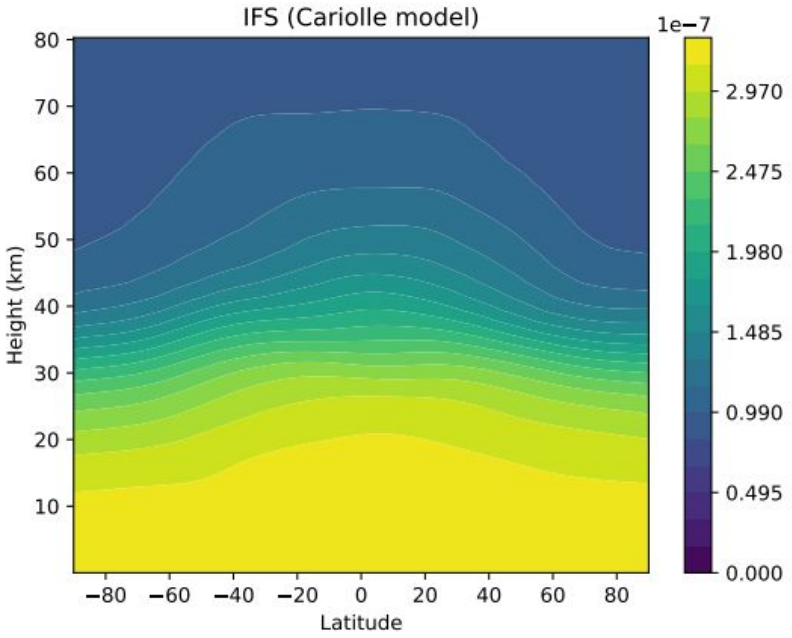


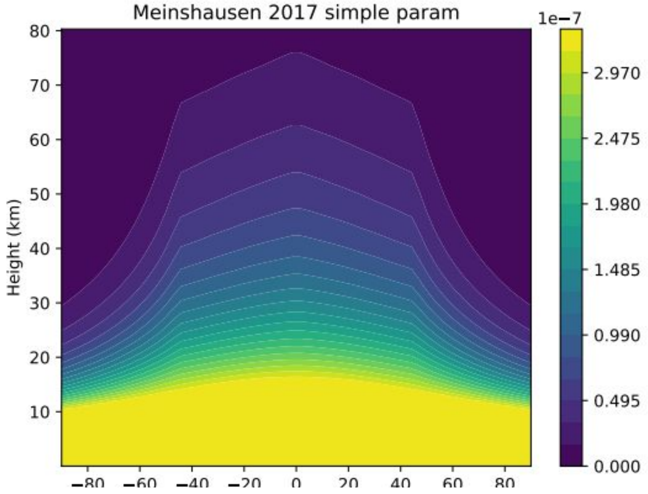
New climatologies of minor GHGs in EC-Earth3

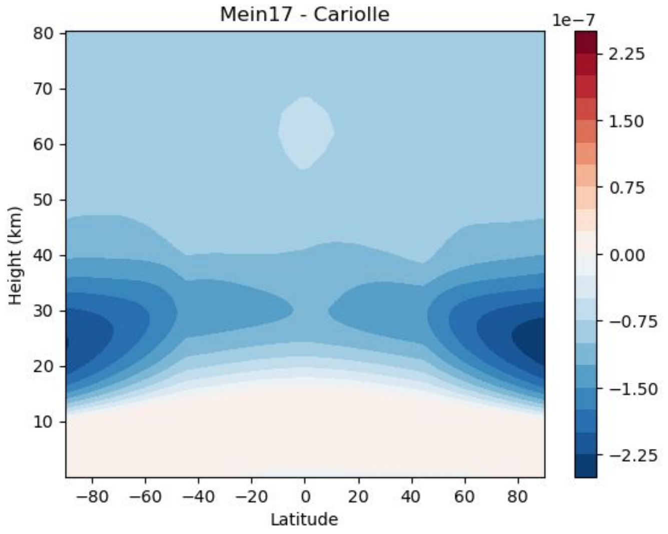
- In EC-Earth3, the lat/height distribution of the minor GHGs is hardcoded. The distribution is taken from the MOBIDIC model (**Cariolle and Brard, 1984**; Cariolle et al., 2007)
- The climatology of N_2O and CFC-11 has been retrieved from the code and compared to:
  - 1) simple parametrization in **Meinshausen et al., 2017** (Mein17);
  - 2) climatology from **CESM-WACCM AerChemMIP** historical simulation (1990-2014);
- Focus on N_2O;
- ‘Mein17’ simple formula does not include seasonal variations (fixed tropopause), the WACCM climatology is preferred for the first test case;

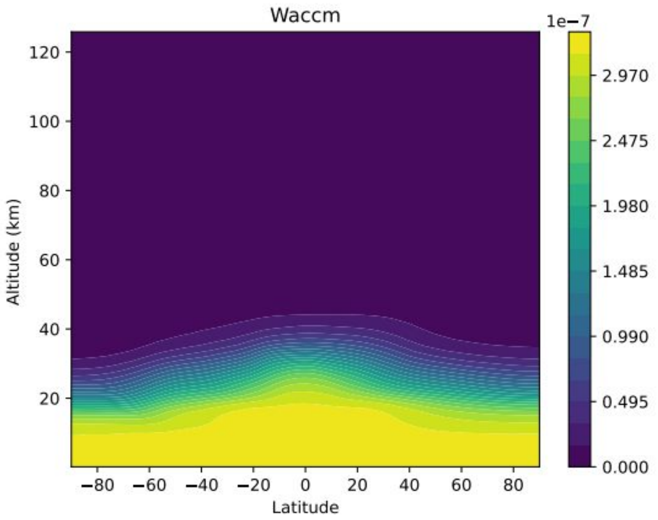
Latitude/height climatologies of N_2O

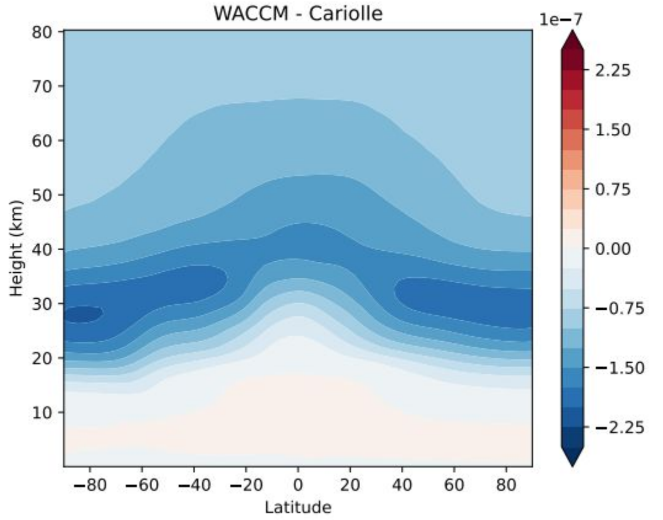
Original N_2O climatology implemented in EC-Earth3 (Cariolle model) vs Mein17 and WACCM climatologies







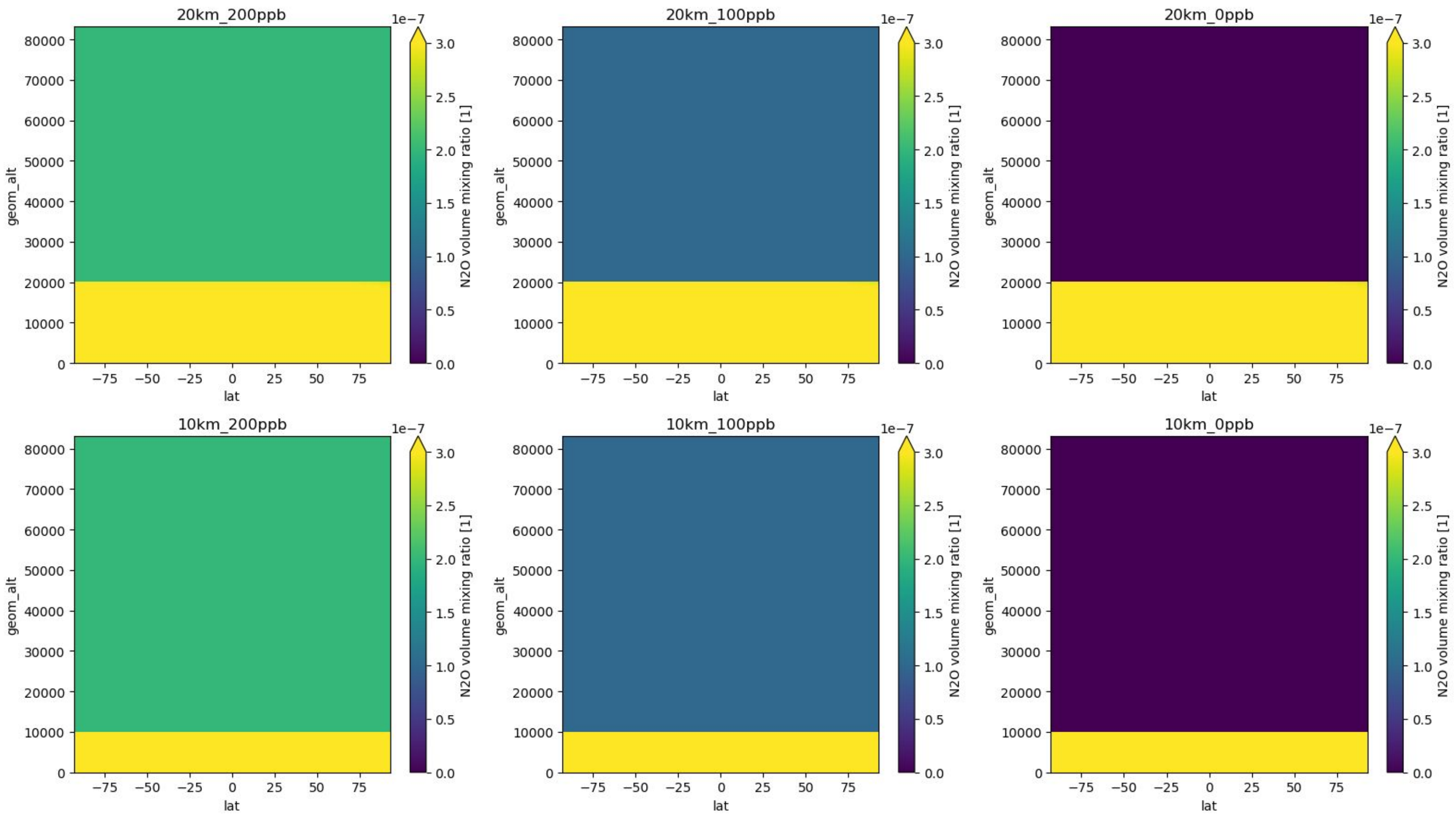




Offline sensitivity tests to N_2O concentration

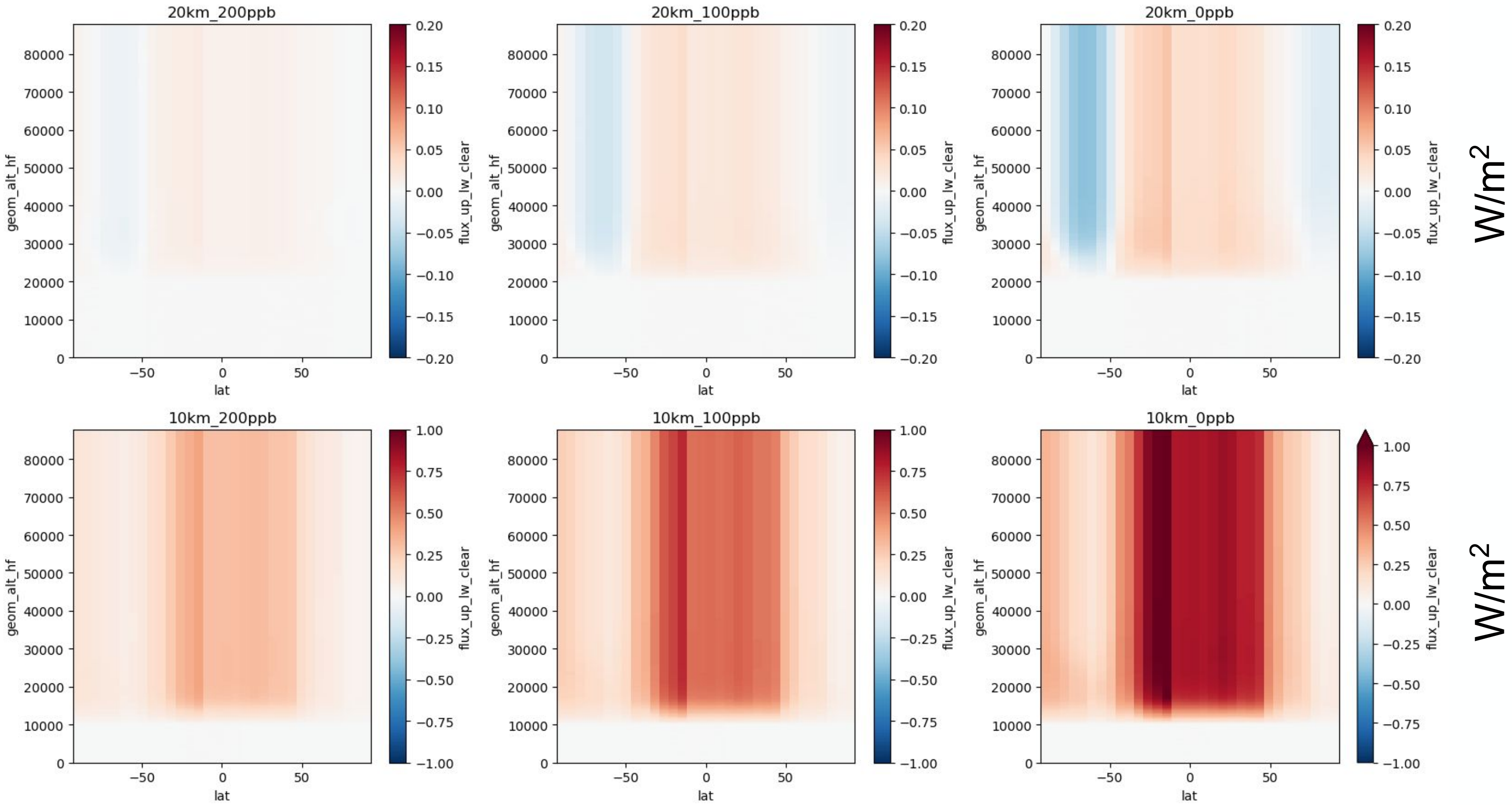
Offline sensitivity test

- a set of idealized vertical distributions for N_2O
- a calculation is performed with the **ecRad** program (fast radiative transfer model used in latest IFS)
- Using default test atmosphere
- Goal: assess the impact on longwave radiative fluxes



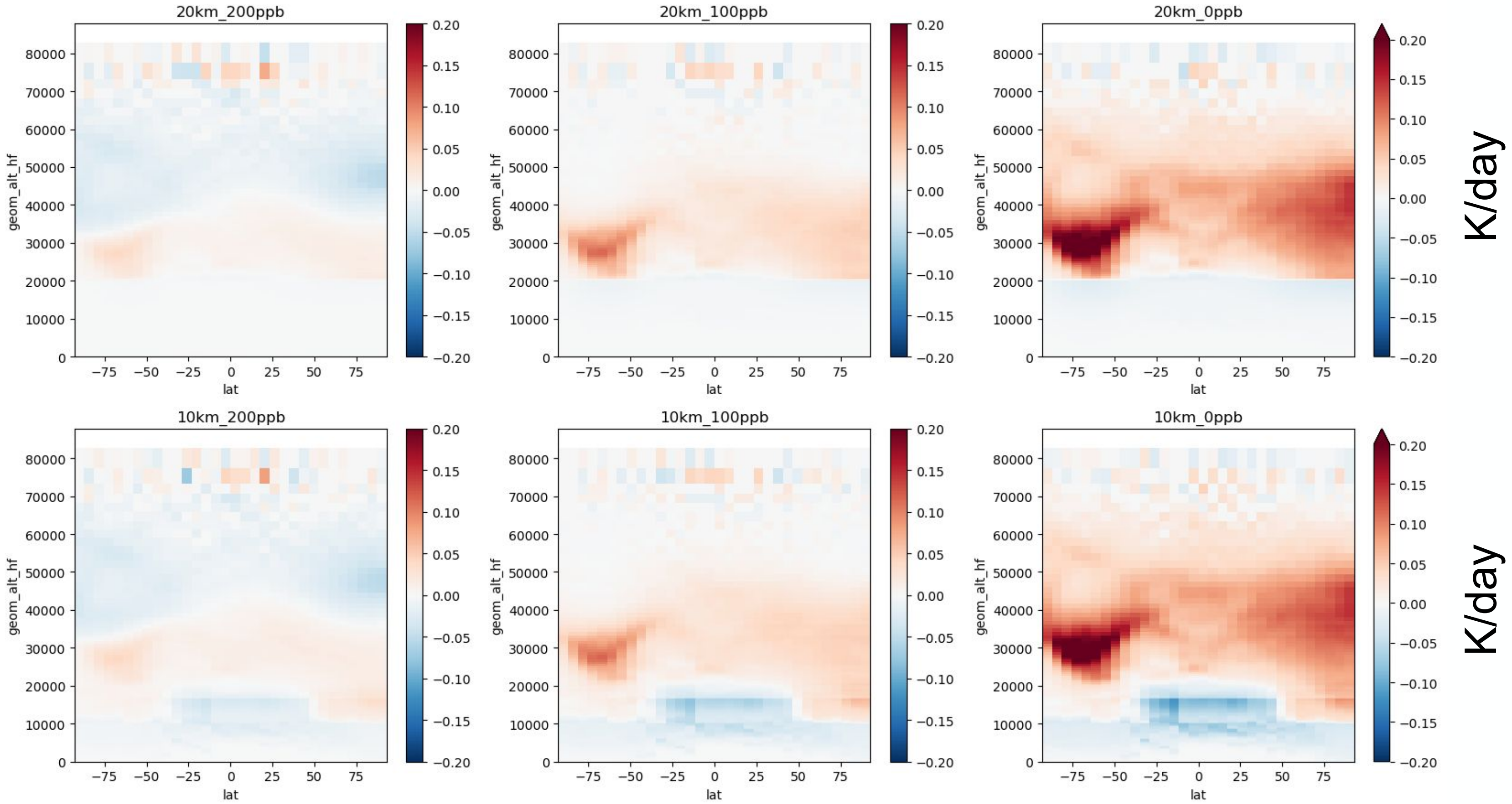
Offline sensitivity tests to N_2O concentration

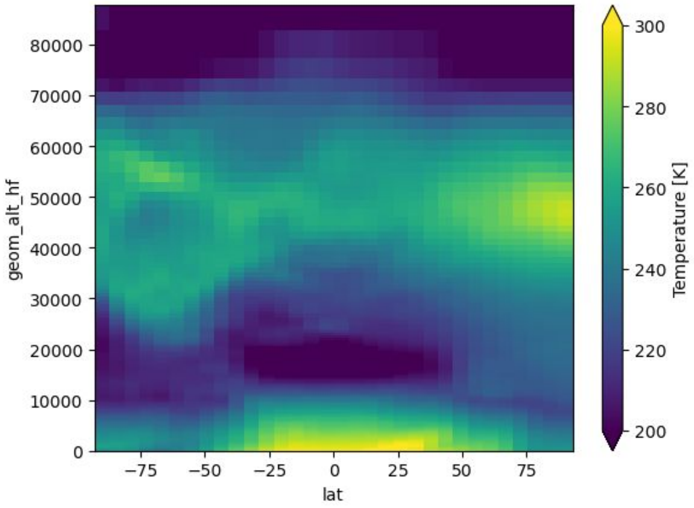
Perturbation of **upward longwave radiative flux** at each level, depending on the starting altitude and amplitude of the perturbation



Offline sensitivity tests to N_2O concentration

Estimate of the change in local **heating rate** at each level (due to LW radiation only)





Sensitivity of simulated climate to N_2O climatology

Second step: online tests with the EC-Earth3 climate model

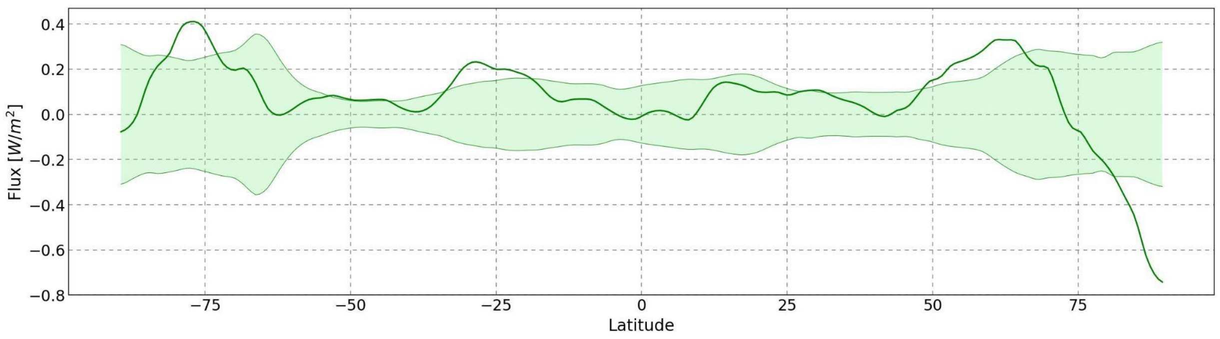
- The model code has been modified to take in input a custom distribution of N_2O
- Two simulations have been run:
  - ‘**control**’: control simulation, with original N_2O climatology (Cariolle model);
  - ‘**waccm**’: sensitivity simulation, with N_2O climatology from CESM-WACCM model;
- Simulation setup:
  - atmosphere-only mode, with prescribed sea-surface temperatures and sea-ice cover (from CMIP6 AMIP protocol);
  - spanning the 2000-2015 period;
  - evolution of global-mean GHG concentrations as in historical/AMIP CMIP6 protocol;

Sensitivity of simulated climate to N_2O climatology

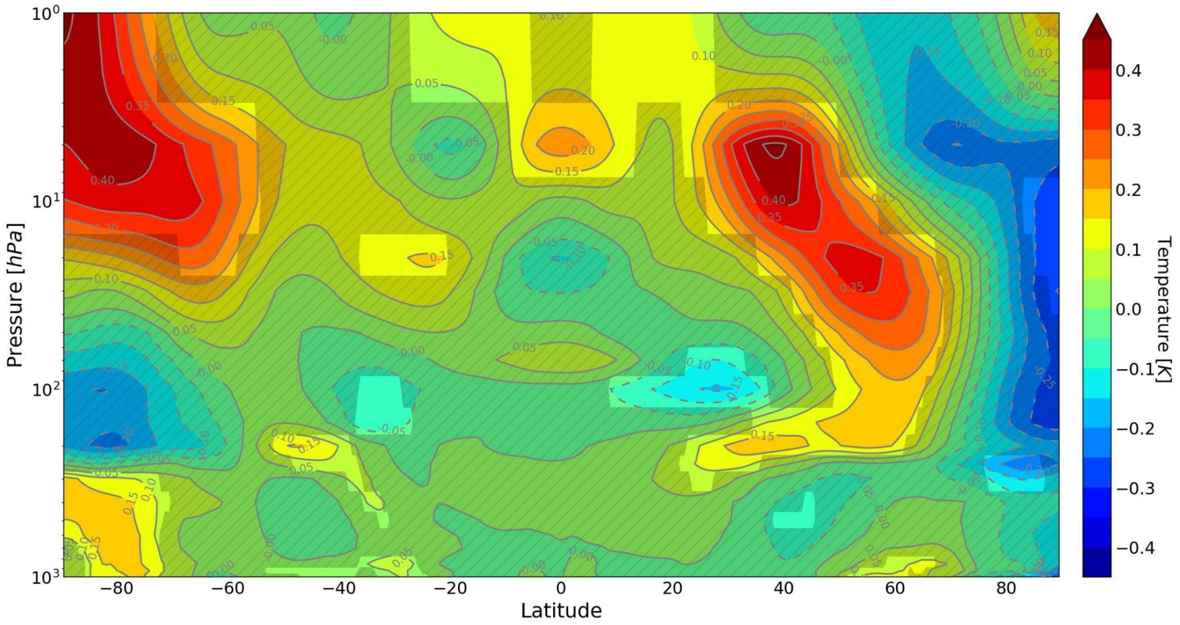
Results from first test case

- Some differences are seen in the vertical temperature structure and fluxes, but largely not significant
- Signal is small: need to increase S/N ratio

OLR difference



3D temperature difference

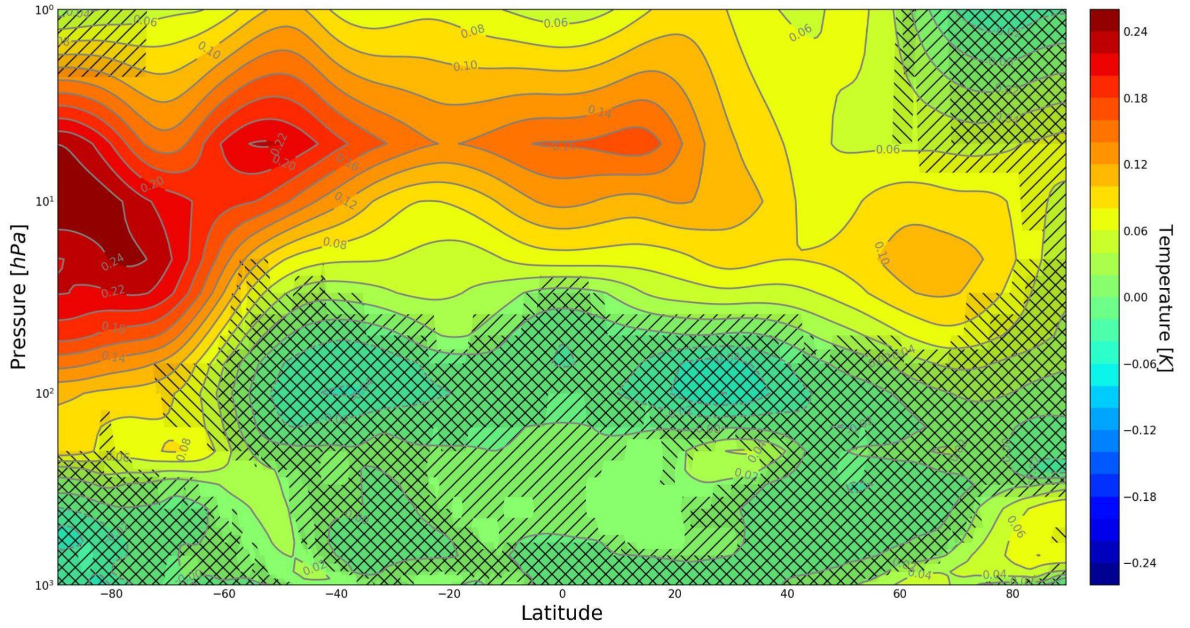


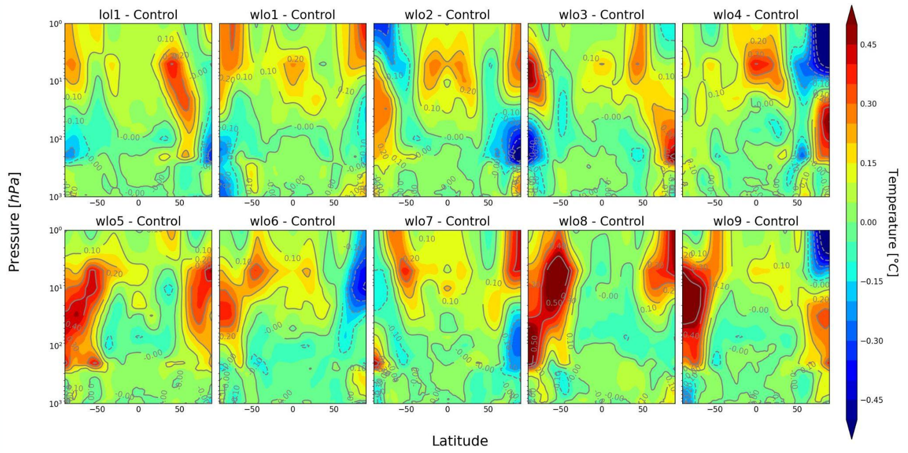
(Credits: A. Montanarini)

Sensitivity of simulated climate to N_2O climatology

Ensemble analysis - Vertical temperature differences

- To increase the signal-to-noise ratio, **9 additional simulations** have been performed both for the control and WACCM experiments, perturbing the initial conditions;
- New results are based on the **two 10-member ensembles**;
- The perturbed (WACCM clim.) ensemble shows **significant warming** in the low- to mid-stratosphere to stratopause (**up to 0.2 K**);
- The agreement of most members on the sign of change further enhances the robustness of the results;

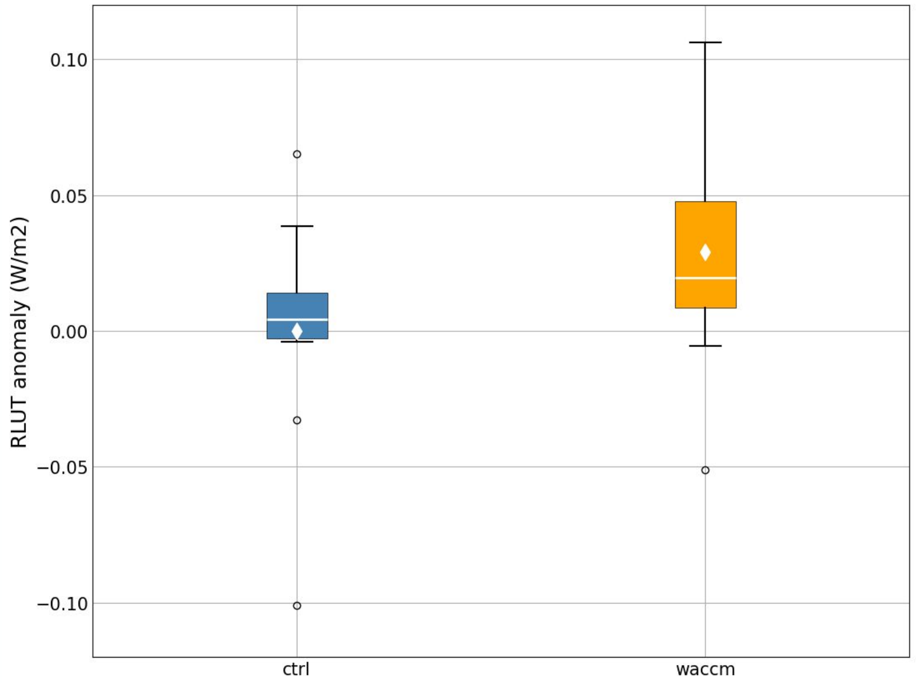


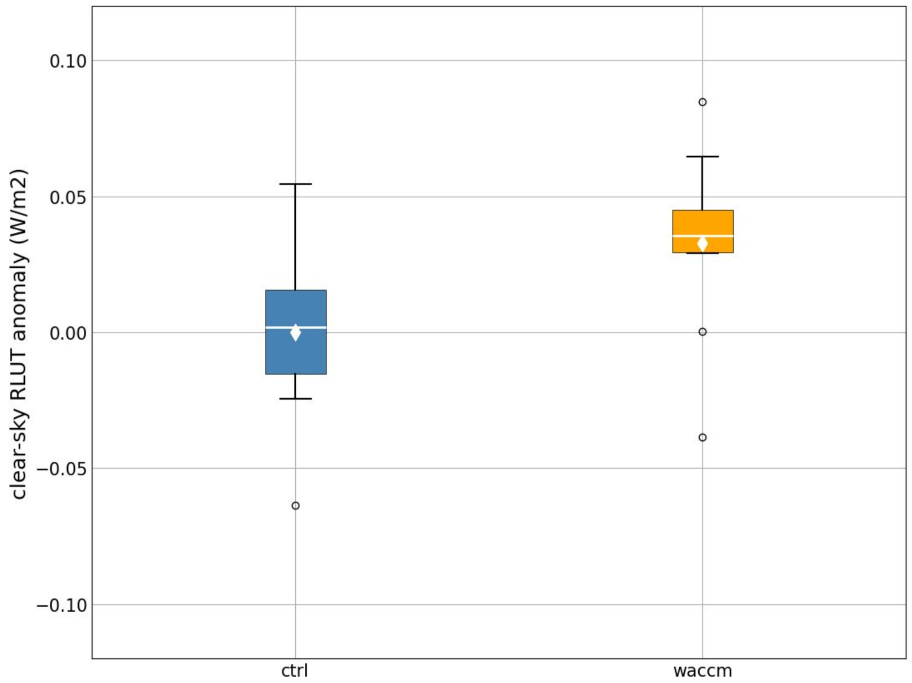


Sensitivity of simulated climate to N_2O climatology

Ensemble analysis - OLR differences

- The perturbed ensemble shows **a significant increase in the global mean OLR** at TOA;
- The average anomaly is small: about **0.04 W/m²** in clear-sky



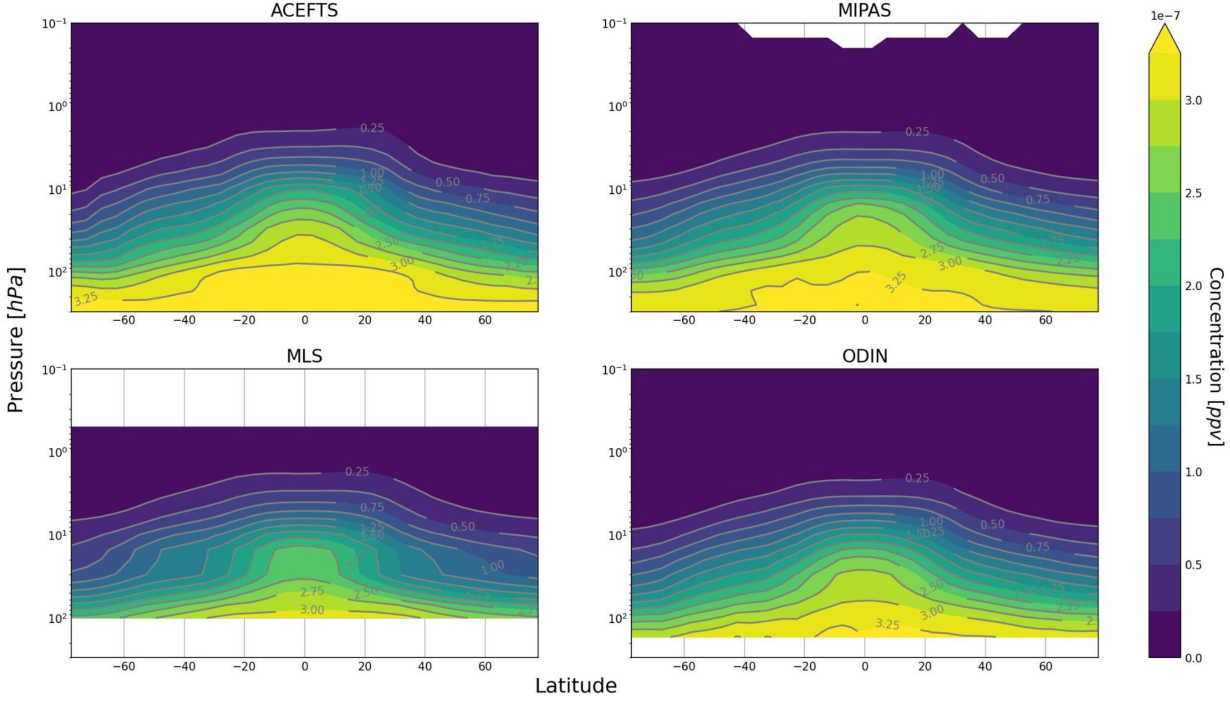


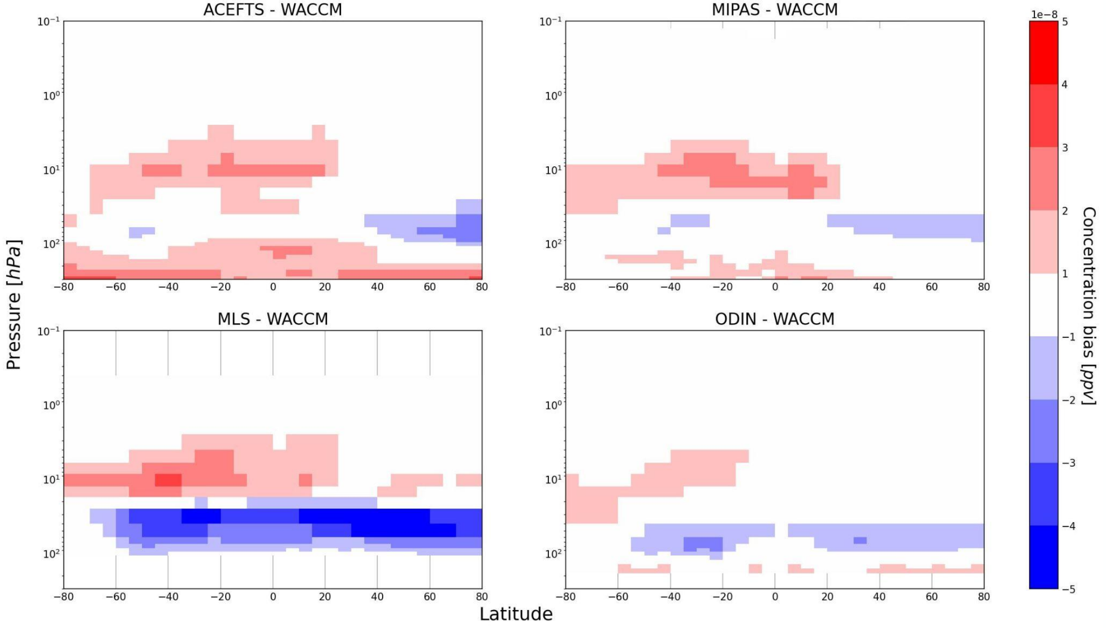
New satellite climatologies of N_2O from LOLIPOP

Datasets from different instruments vary both in spatial and temporal coverage, but substantially agree on average climatology

Differences with WACCM around 10 ppb; MLS shows the largest difference, up to 50 ppb

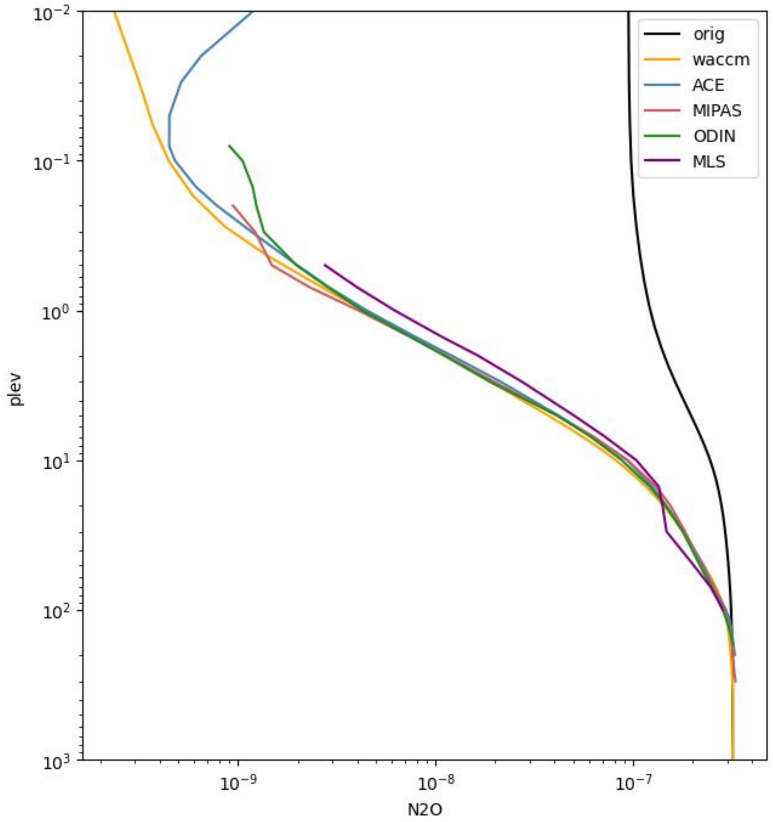
N2O Concentration

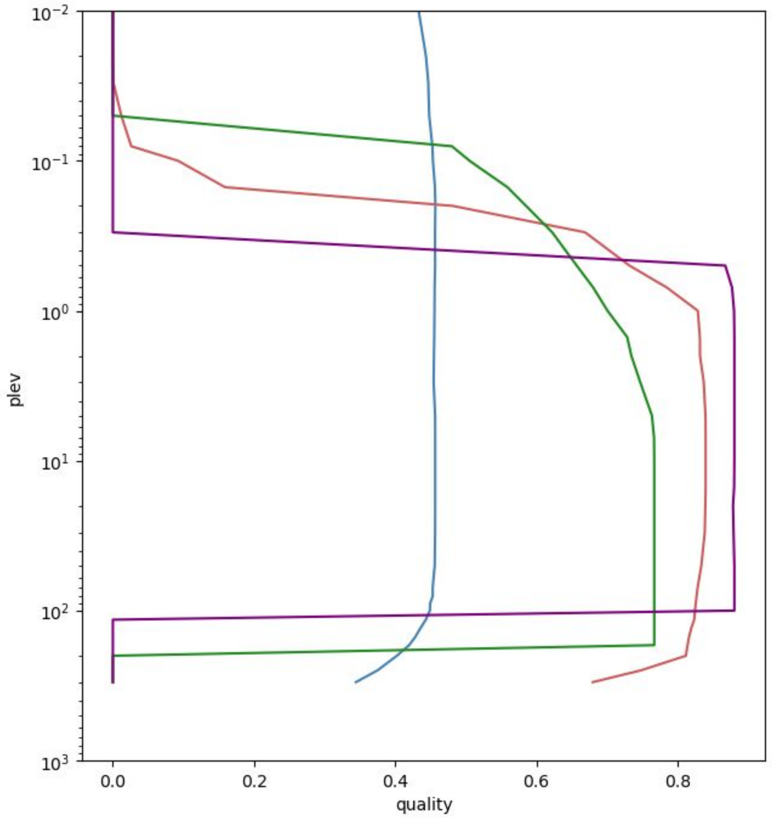




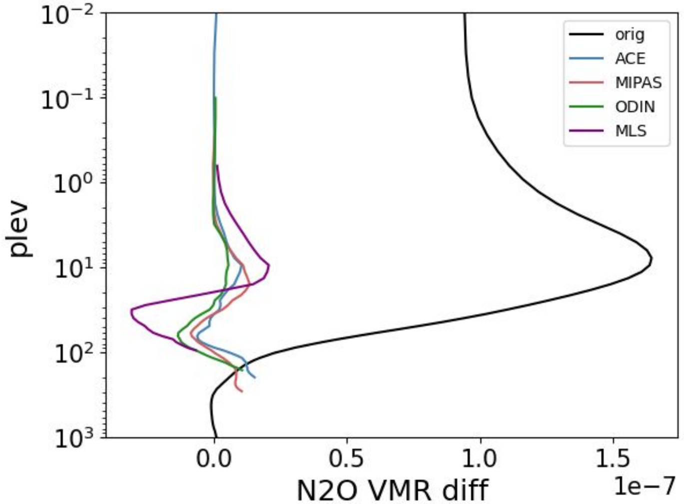
New satellite climatologies of N_2O from LOLIPOP

Apart from MLS, which shows a spurious behaviour, ACE, MIPAS and ODIN agree well (and with WACCM) on the global average vertical profile of N_2O

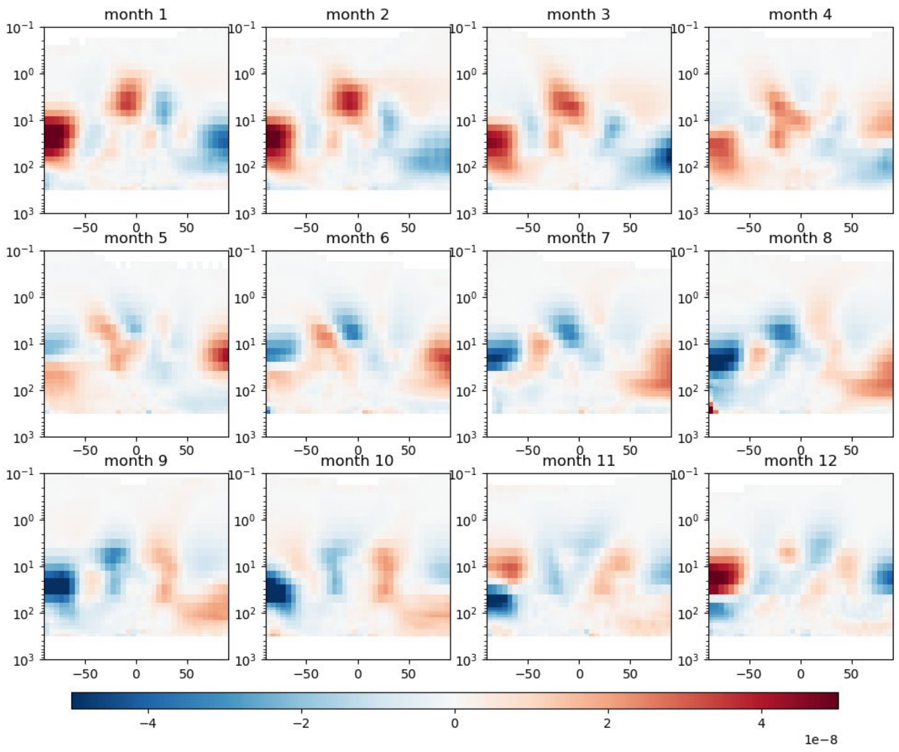


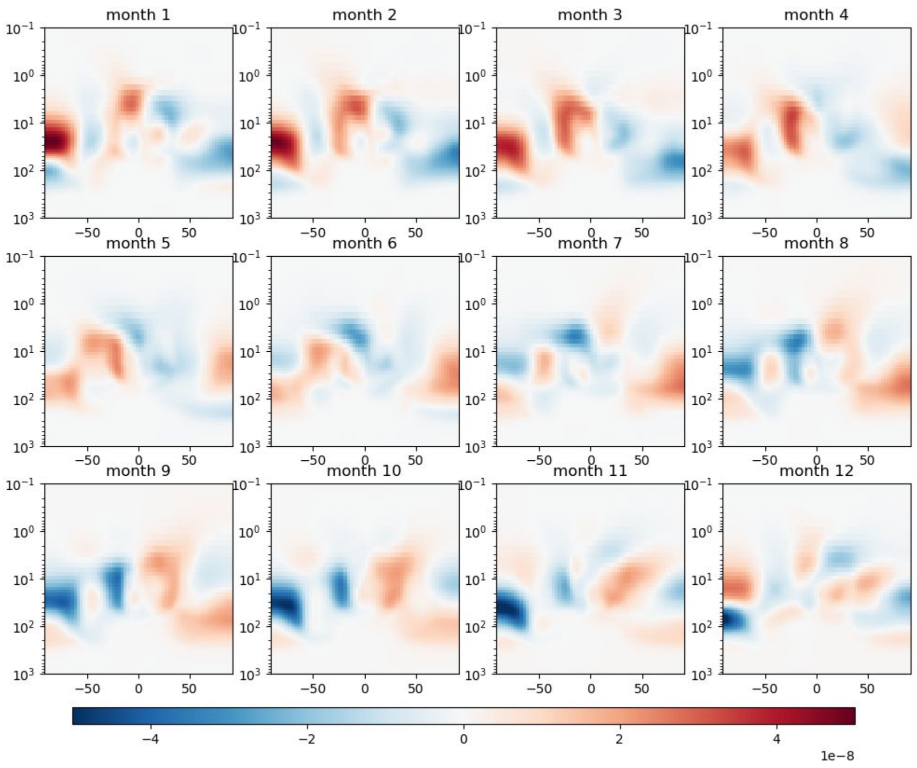


Differences with WACCM are about 1 order of magnitude smaller



MIPAS dataset is a promising candidate for an updated climatology of N_2O: regular coverage of all months/regions, well defined seasonal dynamics, showing a **good agreement with WACCM** climatology





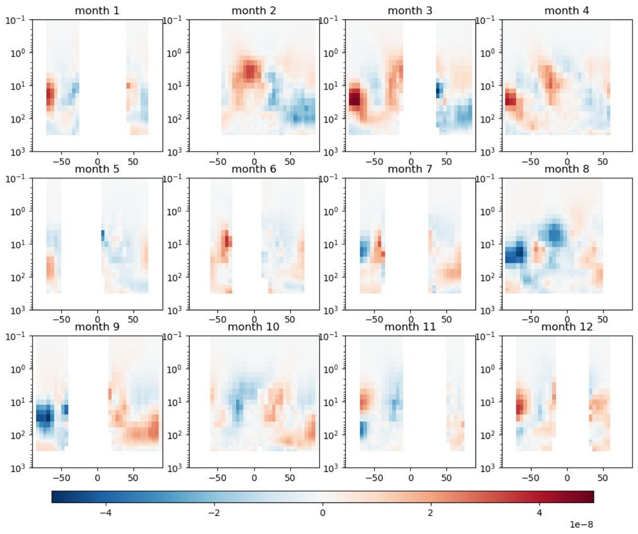
Conclusions

- The **sensitivity of the EC-Earth3 model climate** to the **climatology of N_2O** has been studied through offline calculations (with ecRad) and a set of sensitivity simulations
- Two **10-member ensembles** of 2000-2015 AMIP simulations have been run: a control ensemble with the original climatology and a perturbed ensemble with an updated climatology of N_2O (WACCM model);
- Results show a **small but significant change in the stratospheric temperatures**, peaking at the South pole (~0.2 K); **OLR is also affected** with a global anomaly of about 0.04 W/m^2 in clear-sky;
- New N_2O climatologies produced for the LOLIPOP project have been analyzed and compared to the WACCM climatology: the agreement is generally good, with differences generally below 10 ppb (original profile differs by about 100 ppb in the stratosphere)
- The impact of the vertical distribution of OLLGHG on the simulated climate is small but measurable, and realistic climatologies should be implemented in models

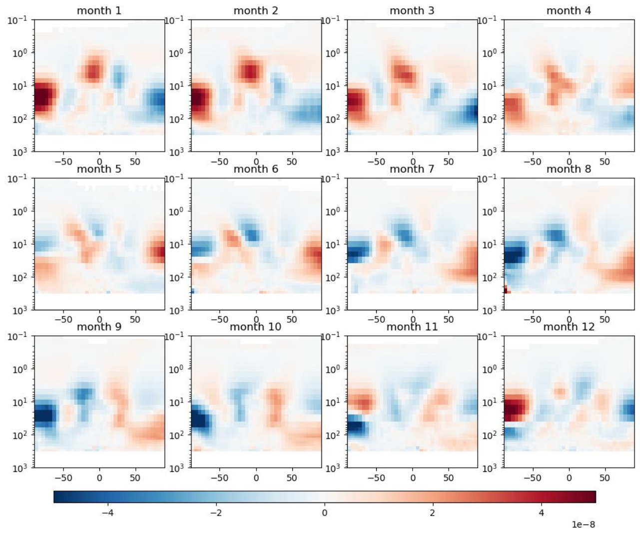
lolipop
cci

New satellite climatologies of N_2O from LOLIPOP

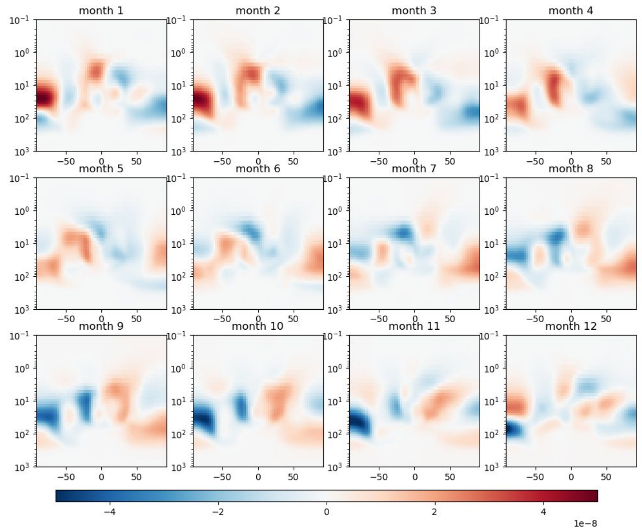
ACE



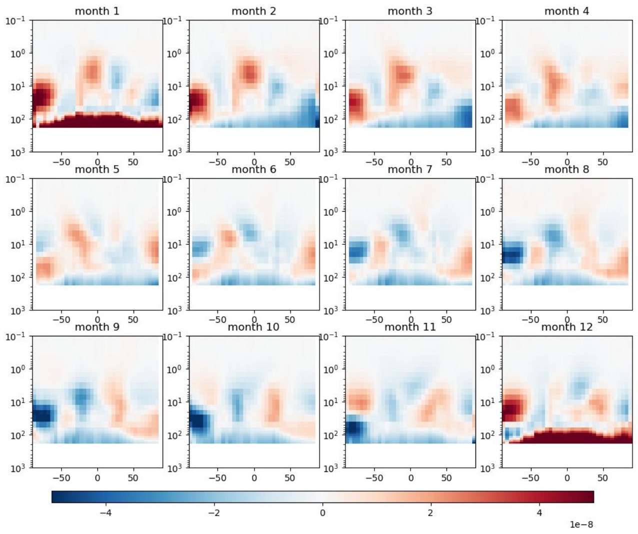
MIPAS



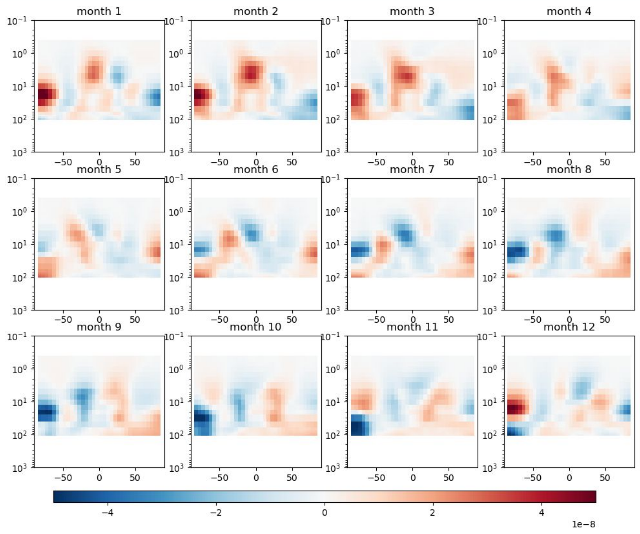
WACCM



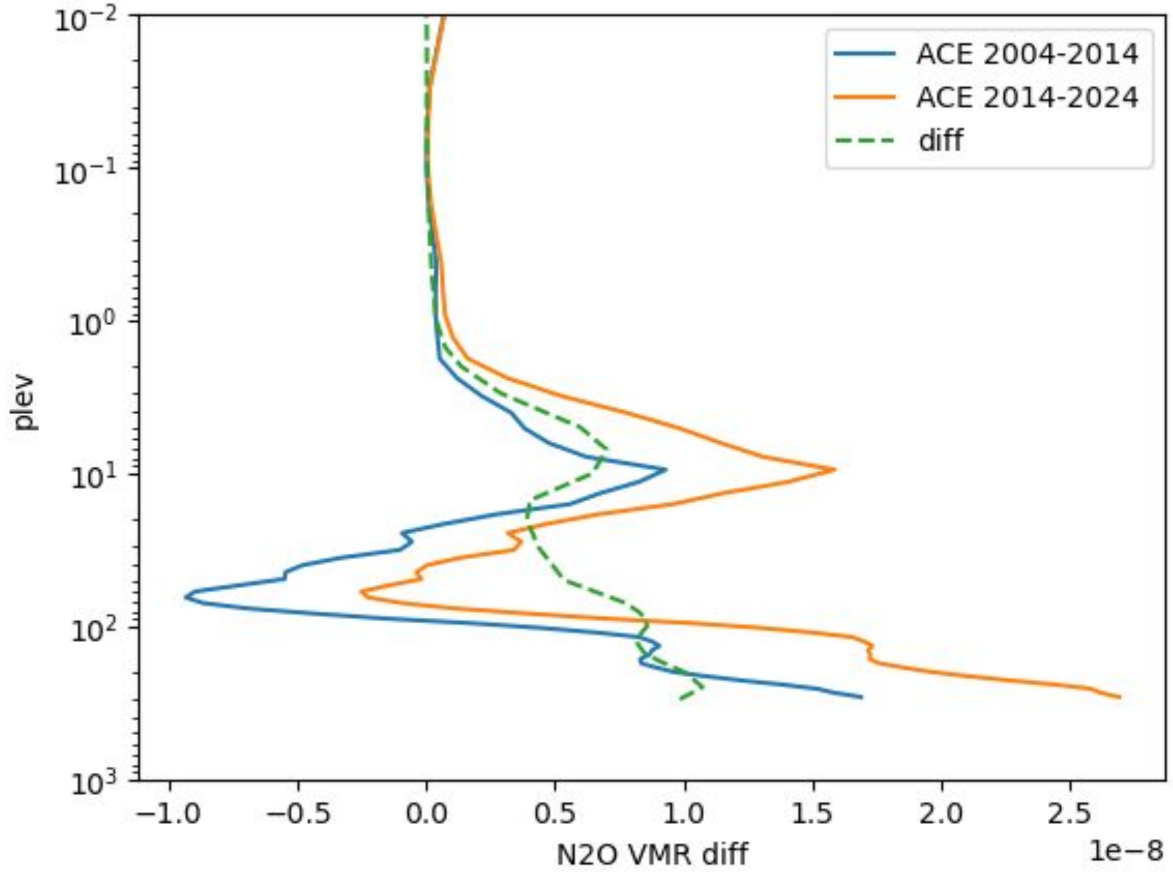
ODIN



MLS



New satellite climatologies of N_2O from LOLIPOP



WP 3100: Sensitivity of historical climate model simulations to the OLLGHG climatology

Simplified parametrization proposed in Meinshausen et al. (2017)

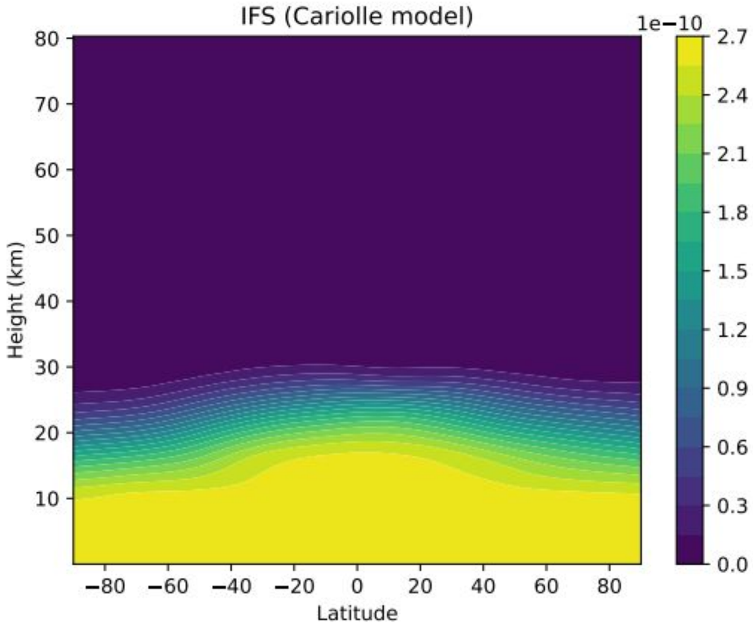
$$C(l, p, t) = \overline{C}\left(\text{global}, 1000\,\text{hPa}, \overline{t} - 1\ \text{yrs}\right) \cdot \left(\frac{p}{p_{\text{tropopause}}(l)}\right)^{s},$$

Table 11. Exponents "s" to estimate vertical gradient of concentrations for gases with stratospheric sinks in the stratospheric column – depending on the latitude "lat". See text. For HFC-134a and other species with stratospheric lifetimes shorter than 30 years, the CH_4 exponent parameterization can be used as approximation. This exponent scale parameterization is taken from the CESM, implemented by J. Kiehl.

	Tropics and mid-latitudes ABS(LAT) < 45°	Mid- to high latitudes, ABS(LAT) ≥ 45°
CH_4	0.2353	0.2353 + 0.0225489 × (abs(lat) − 45);
N_2O	0.3478 + 0.00116 × abs(lat)	0.40 + 0.013333 × (abs(lat) − 45)
CFC-11	0.7273 + 0.00606 × abs(lat)	1.00 + 0.013333 × (abs(lat) − 45);
CFC-12	0.4000 + 0.00222 × abs(lat)	0.50 + 0.024444 × (abs(lat) − 45)

WP 3100: Sensitivity of historical climate model simulations to the OLLGHG climatology

Reference CFC-11 climatology implemented in EC-Earth3 (annual mean) [used also for CFC-12 and other minor GHGs]



Comparison with Meinshausen et al. (2017) simple parametrization: