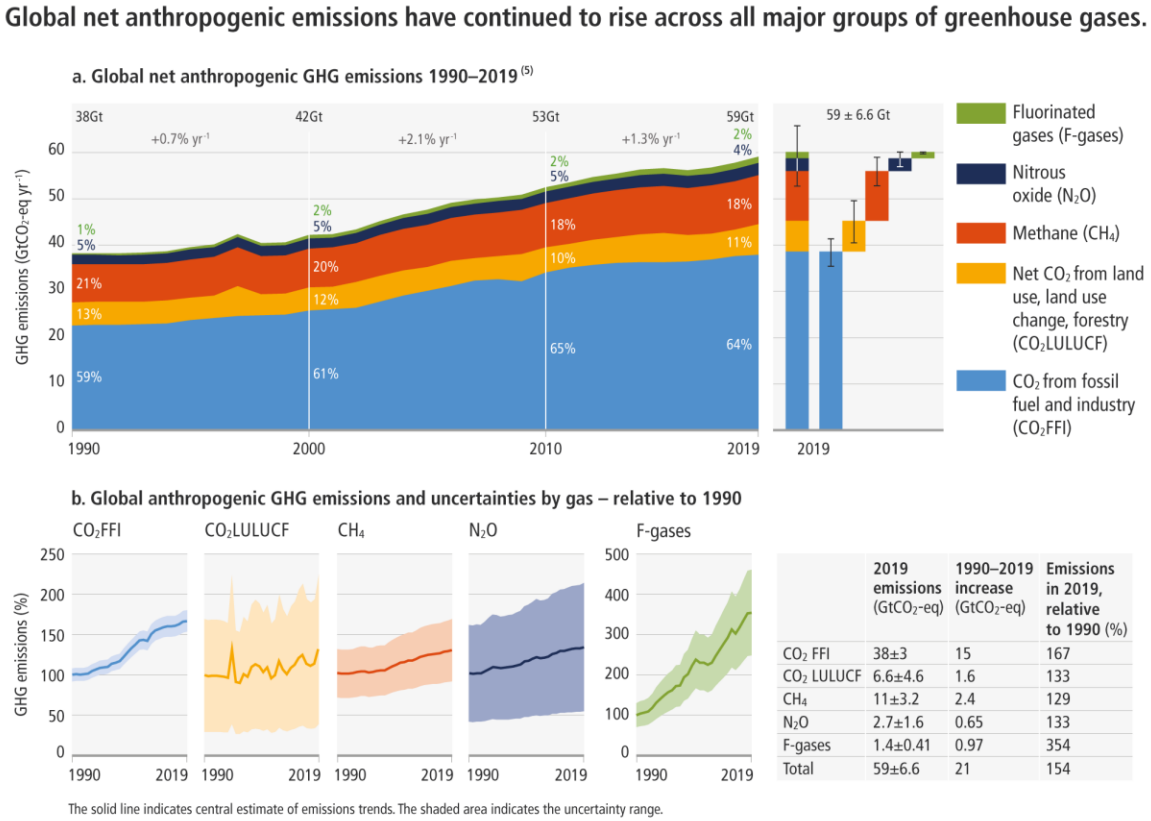
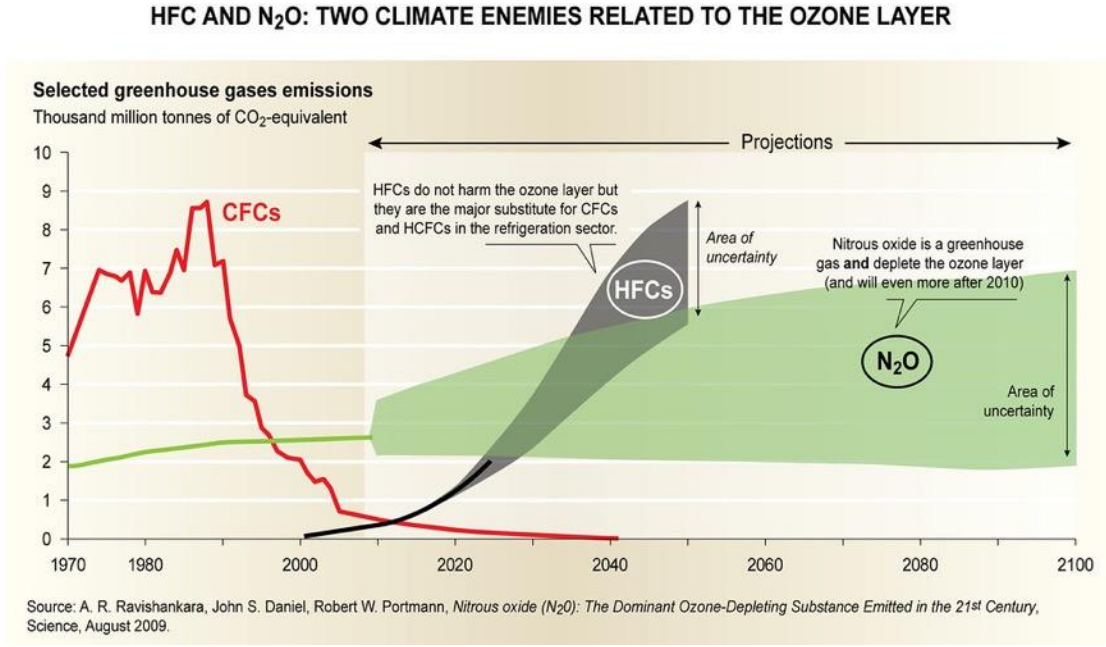
The LOng-LIved greenhouse gas PrOducts Performance (LOLIPOP) CCI+ project

Elisa Castelli, Bianca Maria Dinelli, Massimo Cardaci, Massimo Valeri, Gabriele Brizzi, Antonio Bruno, Martin Chipperfield, Cathy Clerbaux, Lieven Clarisse, Pierre Coheur, Martine De Mazière, Sandip Dhomse, Bart Dils, Federico Fabiano, Marco Gai, Maya George, Jeremy Harrison, Michaela Imelda Hegglin, Margherita Premuda, Piera Raspollini, Laura Saunders, Reinold Spang, Gabriele Stiller, Corinne Vigouroux, Kaley Walker, Simon Whitburn, Claire MacIntosh, Simon Pinnock

LOLIPOP: why Other Long-lived GHGs?

- Nitrous oxide (N_2O) and halogenated carbon compounds (CFCs, HFCs, HCFCs, PFCs) are considered by GCOS as ECVs.
- These gases have **long atmospheric lifetimes,** exhibit **significant global warming potentials** and provide a major contribution to **radiative forcing** uncertainty estimates. Nitrous oxide and chlorine-containing OLLGHGs are also the main source of anthropogenic **ozone depletion** and are regulated internationally under the 1987 UN Montreal Protocol.

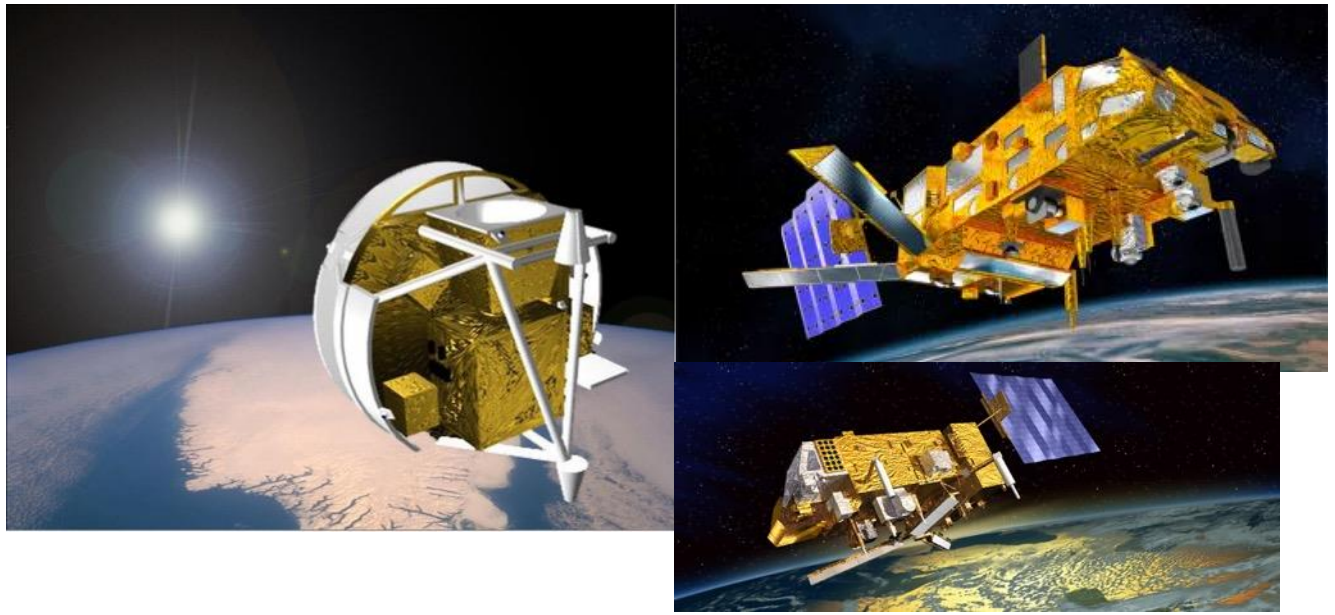


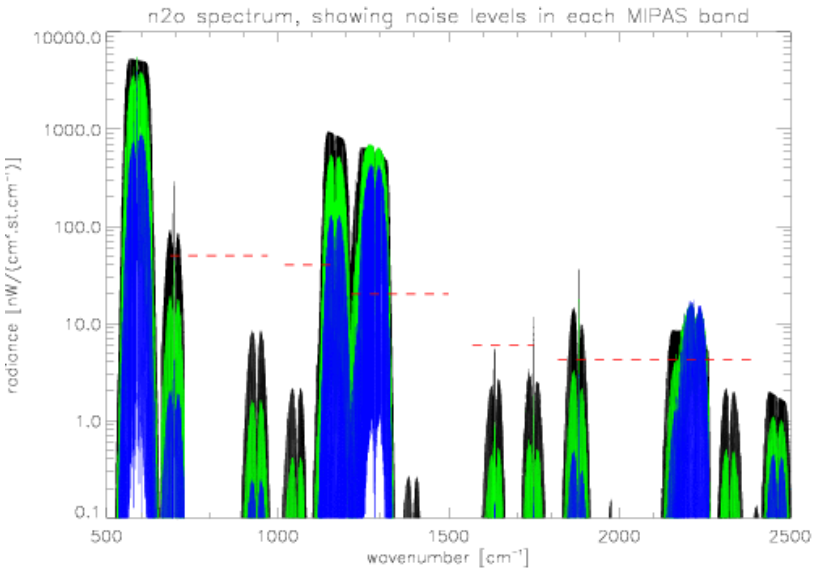


Source:https://www.ipcc.ch/report/ar6/wg3/figures/summary-for-policymakers/IPCC_AR6_WGIII_FigureSPM1.png

LOLIPOP: an ESA CCI+ project

- Several satellite instruments provide information on the abundance and distribution of OLLGHGs (Envisat MIPAS, Scisat ACE-FTS, MetOp IASI, and Aura HIRDLS).
- They can provide a valuable multi-mission resource for monitoring and understanding the role OLLGHGs in the atmosphere over the last two decades.



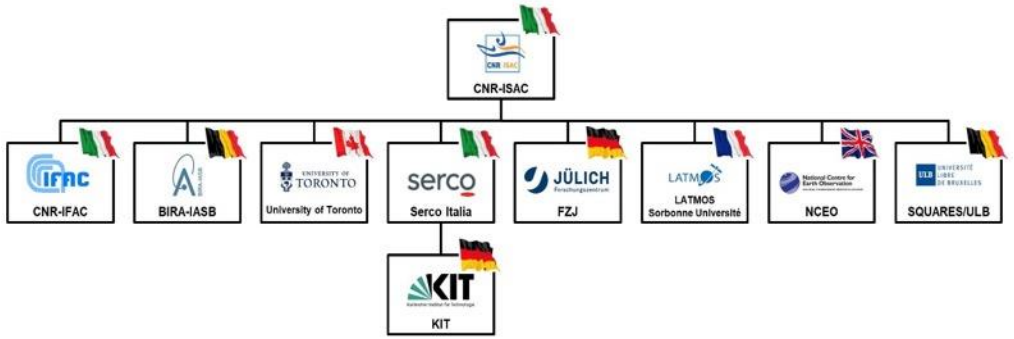


Source:https://eodg.atm.ox.ac.uk/MIPAS/species/n2o.html

- To foster the full exploitation of these satellite data, in November 2023 ESA started the **LOng-LIved greenhouse gas PrOducts Performance (LOLIPOP)** project.

ESA Technical Officers:
Simon Pinnock
Claire MacIntosh

lolipop cci



LOLIPOP: Main objectives and tasks

Objectives:

To determine if the actual set of satellite measurements is good enough to be used in climate science and services

If **YES**→ the construction of a harmonized and consistent dataset of satellite measurements can go ahead.

If **NO**→ to suggest actions to either improve the quality of satellite measurements of the OLLGHGs (through new retrieval techniques applied to existing satellite missions) or to develop dedicated satellite missions for their monitoring.

Tasks:

- Analyse the **state-of-the-art of the satellite measurements** of the OLLGHGs. (*what is available?*)
- Analyse the **users' needs** (*what is needed?*)
- **Assess the satellite measurements** of the OLLGHGs**,** providing users with guidance on dataset applications. (*quality?*)
- Investigate the **benefit of the use of satellite observations** in end user applications through **three case studies;** (*possible benefits?*)
- Disseminate the project results to the user community
- Organise a user workshop to collect feedback
- Provide suggestions for future work on the OLLGHGs

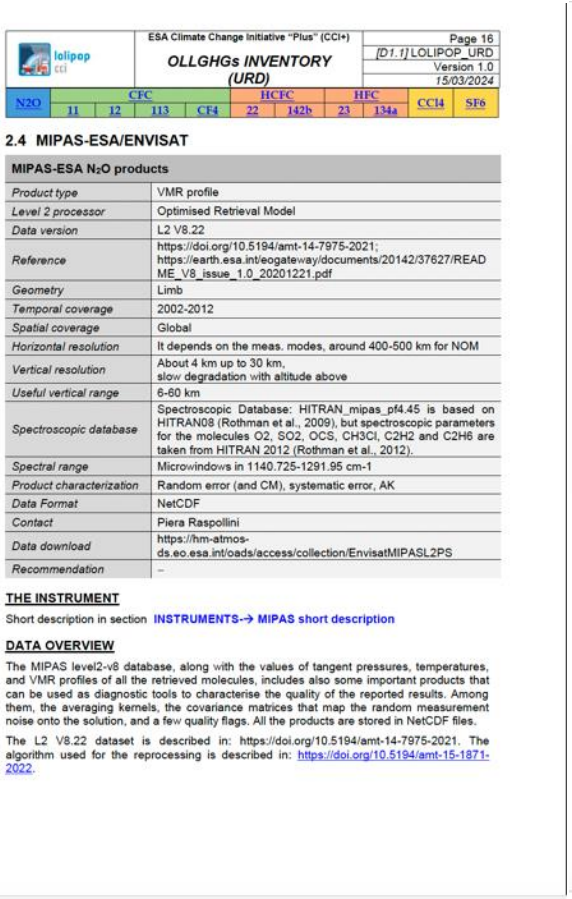
State-of-the-art: Inventory of satellite products on OLLGHGs

What is available?

- An inventory of the available datasets from limb and nadir satellite measurements has been performed for **11 OLLGHGs**: N_2O, CFC-11, CFC-12, CFC-113, CF_4, HCFC-22, HCFC-142b, HFC-23, HFC-134a, SF_6, CCl_4.

For each instrument, a **Summary Table** that contains information on:

- the type of product
- the observation geometry
- the temporal and spatial coverage
- the characterization of the product
- the data format



2.4 MIPAS-ESA/ENVISAT

MIPAS-ESA N_2O products	
Product type	VMR profile
Level 2 processor	Optimised Retrieval Model
Data version	L2 V8.22
Reference	https://doi.org/10.5194/amt-14-7975-2021; https://earth.esa.int/eogateway/documents/20142/37627/README_V8_issue_1.0_20201221.pdf
Geometry	Limb
Temporal coverage	2002-2012
Spatial coverage	Global
Horizontal resolution	It depends on the meas. modes, around 400-500 km for NOM
Vertical resolution	About 4 km up to 30 km, slow degradation with altitude above
Useful vertical range	6-60 km
Spectroscopic database	Spectroscopic Database: HITRAN_mipas_pf4.45 is based on HITRAN08 (Rothman et al., 2009), but spectroscopic parameters for the molecules O2, SO2, OCS, CH3Cl, C2H2 and C2H6 are taken from HITRAN 2012 (Rothman et al., 2012).
Spectral range	Microwindows in 1140.725-1291.95 cm-1
Product characterization	Random error (and CM), systematic error, AK
Data Format	NetCDF
Contact	Piera Raspollini
Data download	https://hm-atmos-ds.eo.esa.int/oads/access/collection/EnvisatMIPASL2PS
Recommendation	–

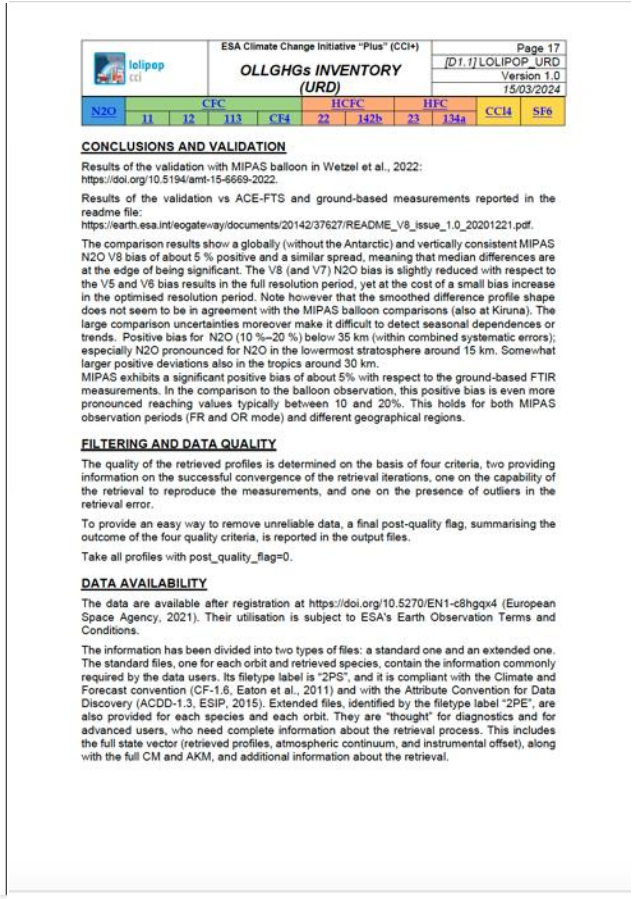
THE INSTRUMENT

Short description in section INSTRUMENTS--> MIPAS short description

DATA OVERVIEW

The MIPAS level2-v8 database, along with the values of tangent pressures, temperatures, and VMR profiles of all the retrieved molecules, includes also some important products that can be used as diagnostic tools to characterise the quality of the reported results. Among them, the averaging kernels, the covariance matrices that map the random measurement noise onto the solution, and a few quality flags. All the products are stored in NetCDF files.

The L2 V8.22 dataset is described in: https://doi.org/10.5194/amt-14-7975-2021. The algorithm used for the reprocessing is described in: https://doi.org/10.5194/amt-15-1871-2022.



CONCLUSIONS AND VALIDATION

Results of the validation with MIPAS balloon in Wetzel et al., 2022: https://doi.org/10.5194/amt-15-6669-2022.

Results of the validation vs ACE-FTS and ground-based measurements reported in the readme file: https://earth.esa.int/eogateway/documents/20142/37627/README_V8_issue_1.0_20201221.pdf.

The comparison results show a globally (without the Antarctic) and vertically consistent MIPAS N2O V8 bias of about 5 % positive and a similar spread, meaning that median differences are at the edge of being significant. The V8 (and V7) N2O bias is slightly reduced with respect to the V5 and V6 bias results in the full resolution period, yet at the cost of a small bias increase in the optimised resolution period. Note however that the smoothed difference profile shape does not seem to be in agreement with the MIPAS balloon comparisons (also at Kiruna). The large comparison uncertainties moreover make it difficult to detect seasonal dependences or trends. Positive bias for N2O (10 %–20 %) below 35 km (within combined systematic errors); especially N2O pronounced for N2O in the lowermost stratosphere around 15 km. Somewhat larger positive deviations also in the tropics around 30 km.
MIPAS exhibits a significant positive bias of about 5% with respect to the ground-based FTIR measurements. In the comparison to the balloon observation, this positive bias is even more pronounced reaching values typically between 10 and 20%. This holds for both MIPAS observation periods (FR and OR mode) and different geographical regions.

FILTERING AND DATA QUALITY

The quality of the retrieved profiles is determined on the basis of four criteria, two providing information on the successful convergence of the retrieval iterations, one on the capability of the retrieval to reproduce the measurements, and one on the presence of outliers in the retrieval error.

To provide an easy way to remove unreliable data, a final post-quality flag, summarising the outcome of the four quality criteria, is reported in the output files.

Take all profiles with post_quality_flag=0.

DATA AVAILABILITY

The data are available after registration at https://doi.org/10.5270/EN1-c8hgqx4 (European Space Agency, 2021). Their utilisation is subject to ESA's Earth Observation Terms and Conditions.

The information has been divided into two types of files: a standard one and an extended one. The standard files, one for each orbit and retrieved species, contain the information commonly required by the data users. Its filetype label is "2PS", and it is compliant with the Climate and Forecast convention (CF-1.6, Eaton et al., 2011) and with the Attribute Convention for Data Discovery (ACDD-1.3, ESIP, 2015). Extended files, identified by the filetype label "2PE", are also provided for each species and each orbit. They are "thought" for diagnostics and for advanced users, who need complete information about the retrieval process. This includes the full state vector (retrieved profiles, atmospheric continuum, and instrumental offset), along with the full CM and AKM, and additional information about the retrieval.

Other information on

- instruments
- dataset validation
- quality of the data
- availability of the data

Document available in the LOLIPOP web site https://climate.esa.int/en/projects/long-lived-greenhouse-gas-products-performances-lolipop/

Users' needs - Literature review

What is needed?

- Despite being GCOS variables, no GCOS requirements are given for OLLGHG apart from N2O
- A review of the user needs has been performed through both a **literature review** and a **survey** distributed among the possible users
- The **literature review** highlighted that
    - there are three main groups of applications that will benefit from and improved OLLGHGs dataset:
      Climate model applications, Chemistry-climate models, Emission inversion
    - there is the need to monitor the OLLGHG concentrations for climate change mitigation

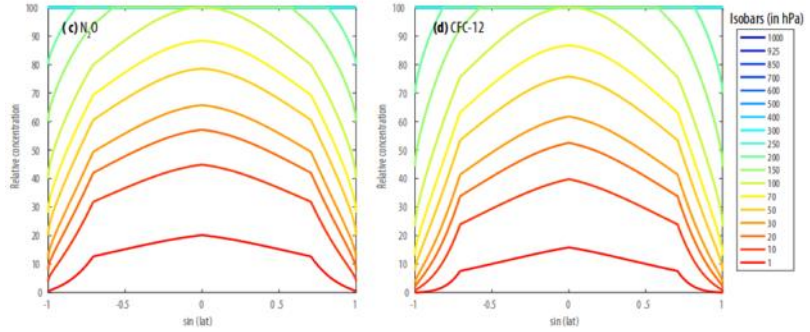


Figure 2: Assumed latitude-height distribution of N_2O (left) and CFC-12 (right) in Meinshausen et al. (2017). The gases are assumed to be well mixed below about 250 hPa.

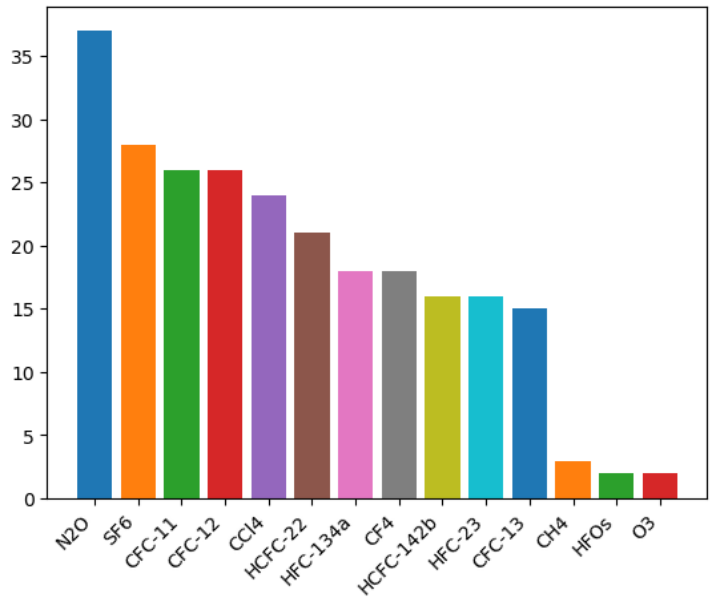
Document available in the LOLIPOP web site https://climate.esa.int/en/projects/long-lived-greenhouse-gas-products-performances-lolipop/

Users' needs - Survey

What is needed?

- The **survey** highlighted that the two communities (climate/chemistry modelling and chemistry/emissions/transport studies) have different needs

Priority list



<u>Requirements related to applications</u>

1) **Horizontal resolution**:
   - low (few degs lat/lon) for climate applications and general chemistry modeling;
   - very high (0.1 deg) for emission/transport studies

2) **Vertical resolution/range**: < 3 km (~ 1 km). At least include the troposphere and stratosphere, the higher the better.

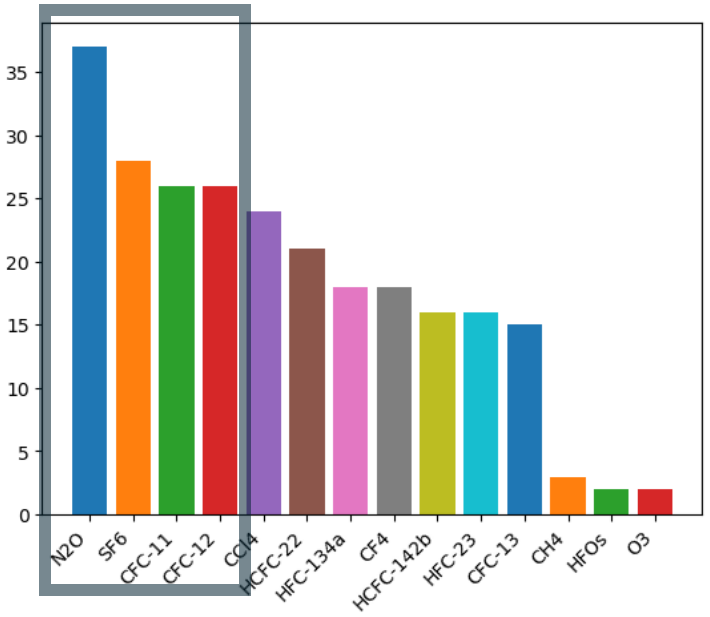
3) Similar **accuracy** requirements: 10% (2-5%). Stricter requirement for N_2O (up to ~0.1 ppb).

Document available in the LOLIPOP web site https://climate.esa.int/en/projects/long-lived-greenhouse-gas-products-performances-lolipop/

Selected molecules - Needs

- Based on the outcomes of the literature review, users' needs and satellite products inventory, a selection of the data to be included in the homogenization and validation exercise has been performed.
- Selection based on:
  - priority of the species of interest
  - products with an elevated level of maturity.

Priority list



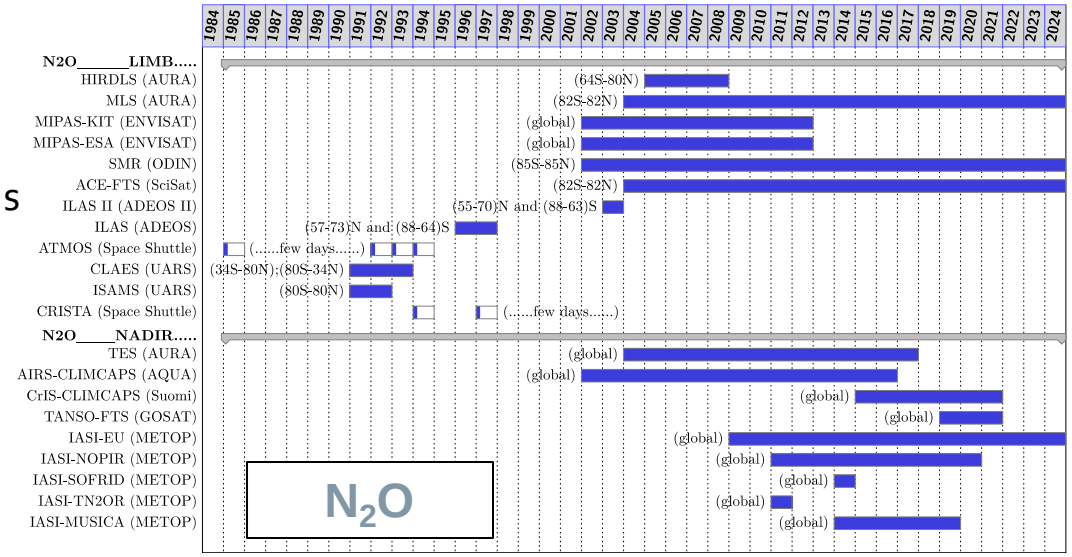
- **N_2O, SF_6, CFC-11** and **CFC-12**, retrieved from both limb and nadir measurements, have been selected for the harmonization and validation exercise

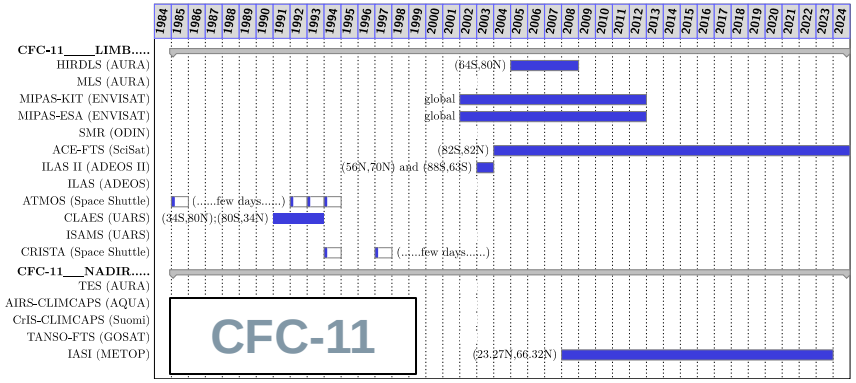
- Main focus on the data measured after 2002

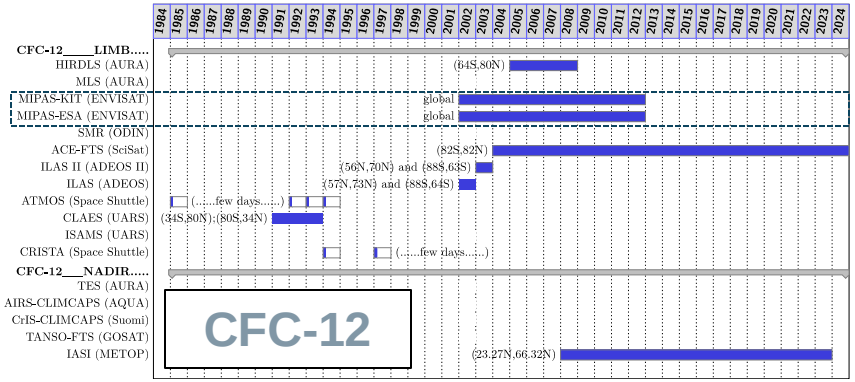
Selected molecules - Data

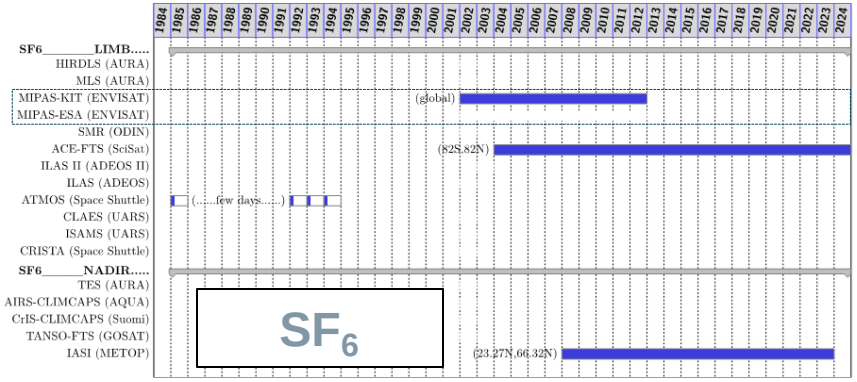
VMR profiles for limb observations

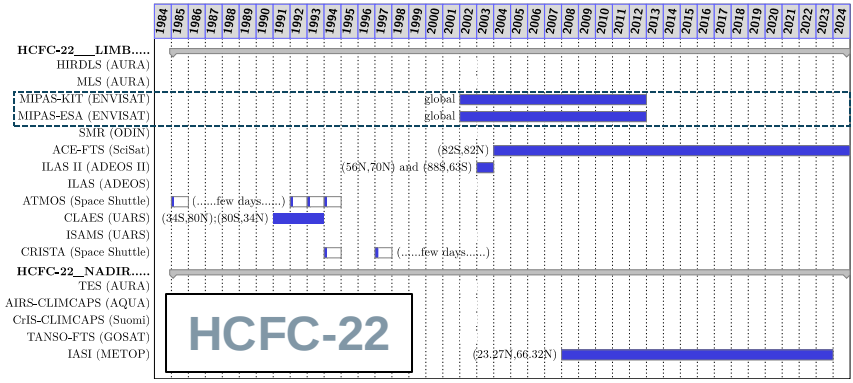
Total/partial columns or VMR profiles for nadir observations











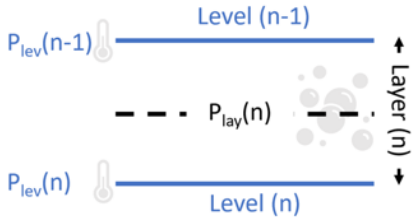
Assess the satellite measurements: Product harmonization and validation

Quality?

- Harmonization will be performed by converting all the data into a common format

Nadir

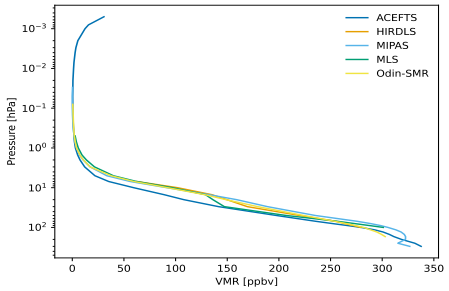
- Harmonize and convert file format so it abides by CCI standards
- Convert the content so that the quantity of interest matches with that of the reference data
- Account for different grids (level-based, layer-based, fixed pressure grids)
- Extract priority parameters
- Unify units



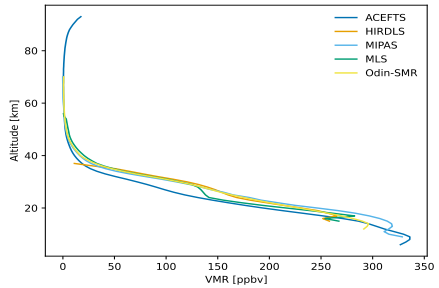
Limb

- Harmonize and convert file format so it abides by CCI standards
- Selection of mandatory variables from other CCI (ozone and water vapour)
- Different vertical grids: fixed altitude, fixed pressure, native

common pressure grid



common altitude grid



Assess the satellite measurements: Product harmonization and validation

Quality?

- Validation will use an "as uniform as possible" approach. Used metrics: average bias, scatter, correlation, long-term stability if feasible

Nadir

Collocation criteria: 100/500 km -- 2h

Reference datasets:

TCCON - Total Carbon Column Observing Network
XCO2, XCH4, XN2O, XHF, XCO, XH2O and XHDO only

NDACC - Network for the Detection of Atmospheric Composition Change

AGAGE- The Advanced Global Atmospheric Gases Experiment (since 1978)
CFC-11, CFC-12, CFC-113, $CHCl_3$, CCl_4, CH_3CCl_3, CH_4 and N_2O

validation/quality check on trends

Limb

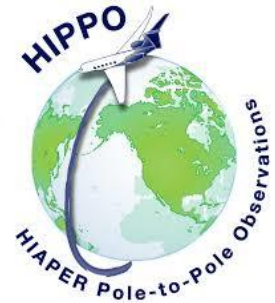
Collocation criteria: 500 km -- 6h

Reference datasets:

Solar occultation measurements - MkIV Balloon FTIR
N2O, CFC-11, CFC-12, CCl4, CF4, CFC-113, HCFC-22, HCFC-142b, SF6, and HFC-23

Limb emission measurements – MIPAS and GLORIA Balloon
N2O, CFC-11, CFC-12, CFC-113, HCFC-22, CCl4, CF4, and SF6

HIPPO - HIAPER Pole-to-Pole Observations
N2O, CFC-11, CFC-12, CFC-113, HCFC-22, HCFC-142b, HCF-23, CCl4, and SF6



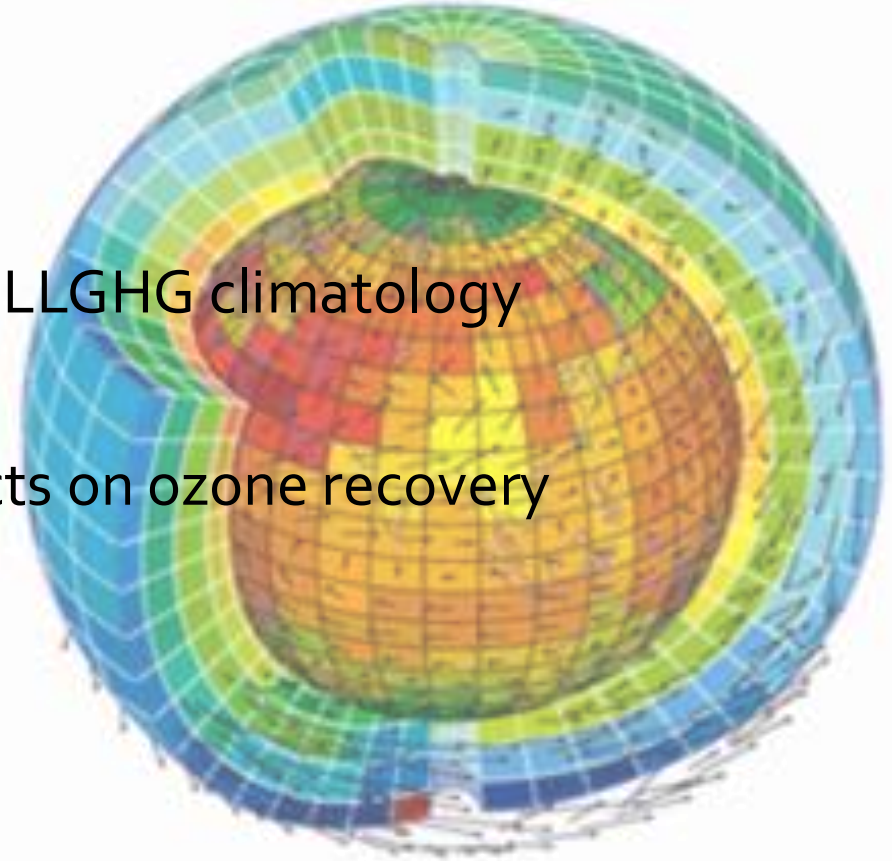
Benefits of the use of satellite observations :User Case studies

Possible benefits?

User case studies to demonstrate the potential benefits of an improved dataset of OLLGHG satellite observations

Three user case studies have been selected:

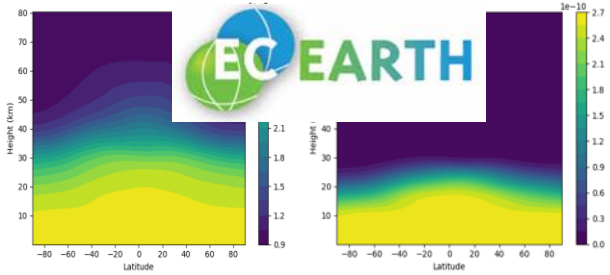
1. Sensitivity of historical climate model simulations to the OLLGHG climatology
2. Study of the radiative forcing of OLLGHG
3. Monitoring of stratospheric chlorine levels and their impacts on ozone recovery



Benefits of the use of satellite observations :User Case studies

1. Sensitivity of historical climate model simulations to the OLLGHG climatology

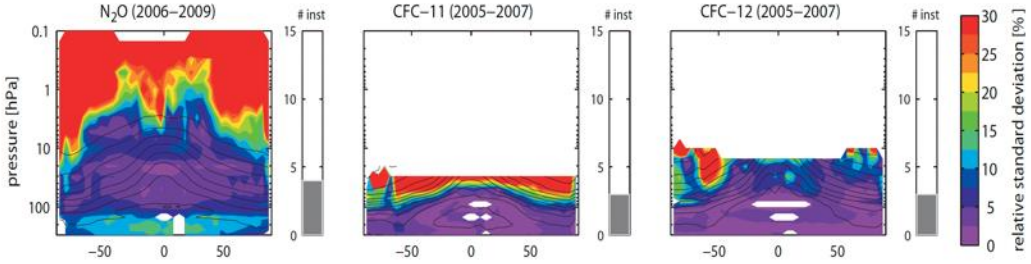
- Evaluate the **sensitivity of the simulated climate to** changes in the distribution of minor **GHGs**
- Implement an **updated climatology of GHGs in the EC-Earth** climate model



N_2O climatology in EC-Earth and CFC-11 climatology used also for CFC-12 and other minor GHGs

2. Study of the radiative forcing of OLLGHG

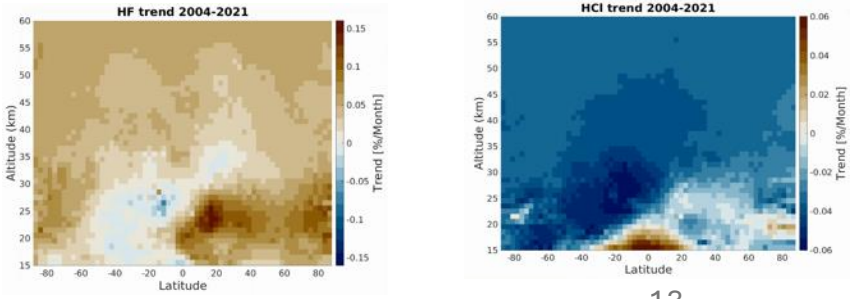
- **Estimate the RF** of long-lived GHGs using an off-line radiative transfer model, SOCRATES
- **Quantify uncertainties in RF** due to uncertainties and distributions of OLLGHGs.



Uncertainties in key OLLGHGs as derived from satellite

3. Monitoring of stratospheric chlorine levels and their impacts on ozone recovery

- Compare ACE-FTS, TOMCAT, ML-TOMCAT **chlorine datasets** to better understand **biases in the models**.
- Calculate **trends in chlorine OLLGHGs** to determine implications for **stratospheric O3**.
- Assess **stratospheric O_3 changes due** to the decreasing halogen source species.



A first look at trends from ML-TOMCAT

Conclusions/next steps

- In this first part we provided the state of the art of OLLGHG satellite measurements and of the user requirements – both via literature review and user survey – the documentation is available on the project web site

- The harmonization and validation of the OLLGHGs datasets (for both Nadir looking and Limb looking instruments) is on-going

- To demonstrate the potential benefits of the OLLGHGs dataset, three case studies were set-up, two are ongoing, one will start in November

- A user workshop will be organised next year