ATMOSPHERIC ECVS

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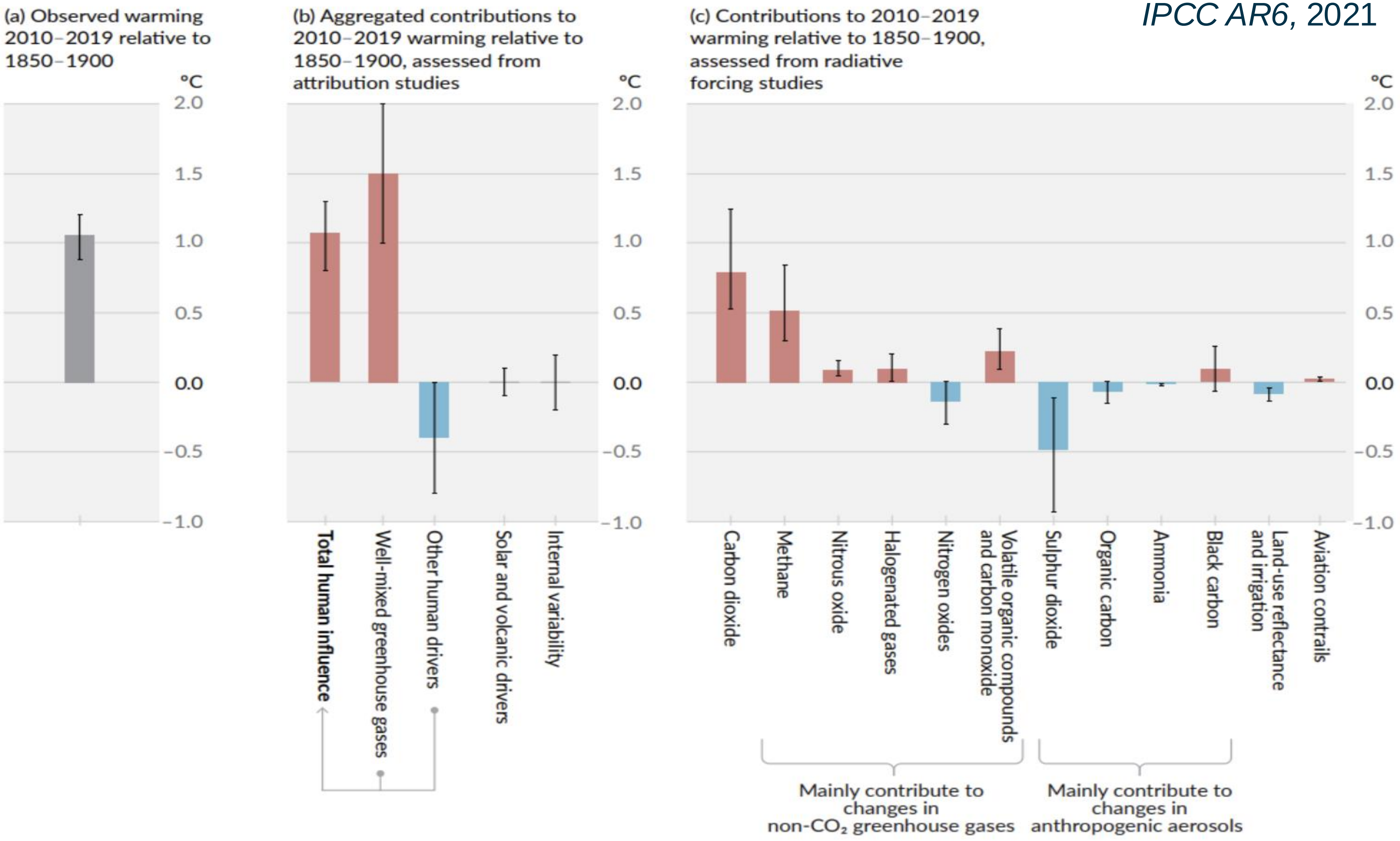
CLIMATE CHANGE INITIATIVE MID-TERM REVIEW

MOTIVATION – ATMOSPHERIC ECVS

- **Atmospheric composition changes are a key driver of climate change.**
- **Global warming** of the climate system between pre-industrial time and 2010s attributed to different climate forcers.
- **Well-mixed greenhouse gases (GHGs)** led to a positive climate forcing, **aerosol** (from short-lived pollutant emissions) to a negative forcing.
- In this framing, **ozone** is not shown explicitly but is an important intermediary and the third most important GHG!
- **H_2O (also via clouds)** is strongest natural GHG, constitutes a positive feedback to CO_2-induced warming, and helps determine climate sensitivity.

IPCC AR6, 2021



SCIENCE QUESTIONS

Climatology, trends, and variability

- What are observed trends and variability in long-lived greenhouse gases (including ozone, water vapour, clouds) and shorter-lived precursors?
- What are the anthropogenic and natural drivers behind these trends and variability?
- Can we explain the past evolution and their contributions to climate radiative forcing? Can we help reduce critical uncertainties?

Quantifying emissions

- How can these observations be exploited to quantify both GHG and precursor emissions?
- How can disentangle anthropogenic (e.g., industry, transport) and natural emissions (e.g., wetlands, forests)?

Role of aerosol

- The contribution of aerosol to radiative forcing remains highly uncertain due to their complex radiative properties depending strongly on particle type. Can we characterise particles from space and help constrain their radiative effect?

Feedbacks and interactions

- Climate change drives various feedback mechanisms in the Earth system. Can we effectively monitor and identify these feedbacks to deepen our understanding of atmospheric composition changes and their role in the broader climate system?

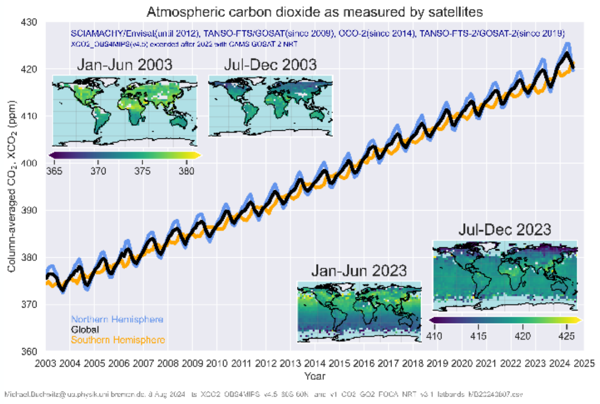
OBSERVATIONAL CHALLENGES

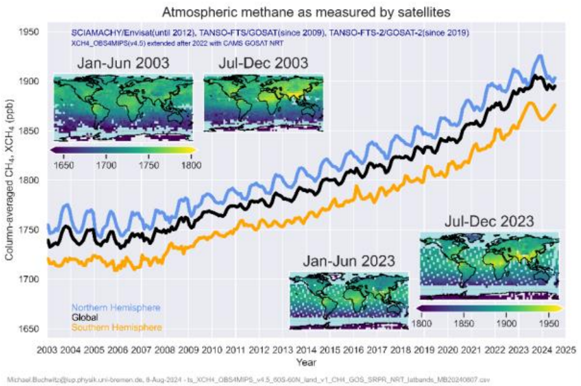
- **Understanding climate change** requires long-term observations of high-quality, well-characterised uncertainty, and high stability.
- **Extending climate data records backward** in time for consistent trend analysis.
    - Need for historical data rescue (large effort for little return? Depends on perspective!)
- **Addressing inter-sensor calibration** to harmonise historical and current datasets.
- **Improving vertical, horizontal, and temporal resolution** for tracking regional trends (from global to local).
    - Importance for regional climate information (which IPCC still struggles with).
- **Handling sampling biases** including temporal (e.g., due to diurnal cycle) and spatial under-sampling, an issue especially also for short-lived precursors.
- **Addressing interferences** between cloud and aerosol retrievals (also including surface reflectance).
    - Particularly over the higher latitudes which pose most challenges for retrieval algorithms, but which at the same time are very sensitive to climate change.
- **Meeting accuracy, precision, and stability requirements** as defined by GCOS.

Greenhouse gases (GHG) – Michael Buchwitz (IUP-B)

Focus:

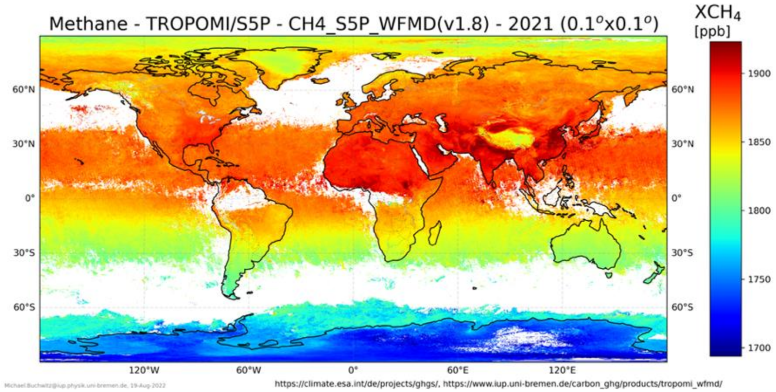
- **Generate new and improve old** CO_2 and CH_4 products.
- Sensors: **OCO-2, GOSAT-2, TROPOMI/Sentinel-5 Precursor (S5P), PRISMA, EnMAP.**
- Past products **from SCIAMACHY, GOSAT, and IASI** are generated operationally within C3S.

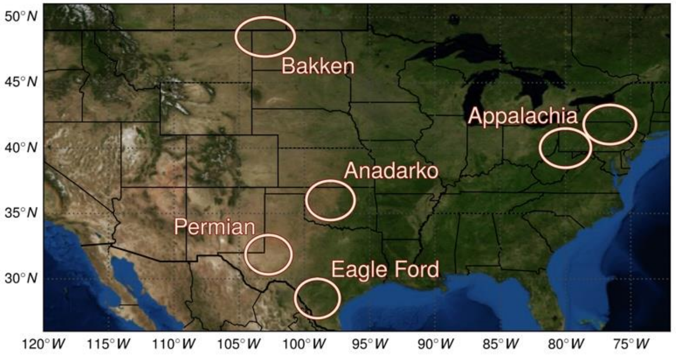




Highlight:

Methane observations have achieved such **precision** that we can now use them to identify **methane leaks and super-emitters** from space. With this, Sentinel-5P has brought invaluable data to the fight against climate change.





Universität Bremen Institut für Umweltphysik (IUP)

SRON Netherlands Institute for Space Research

aeronomie.be

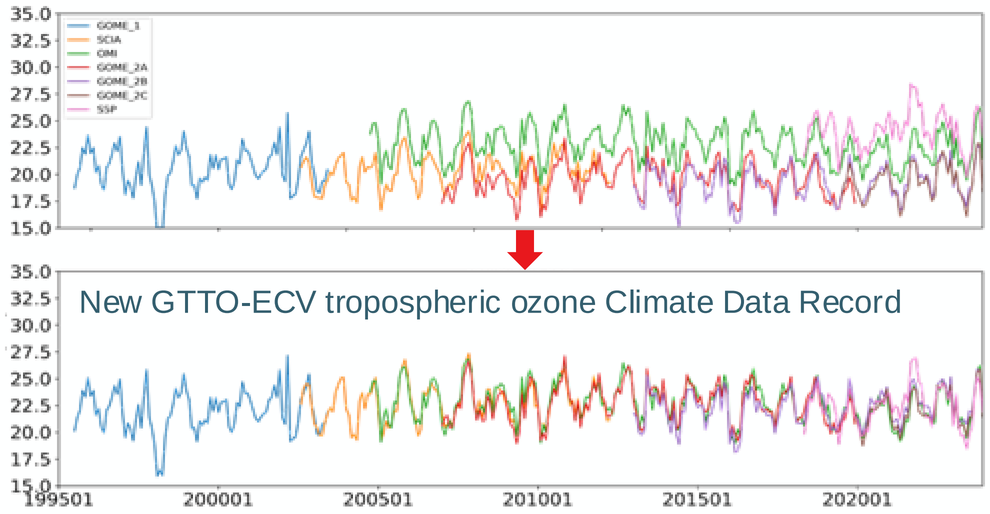
DLR

LSCE

Ozone (O_3) – Daan Hubert (BIRA-IASB)

Focus:

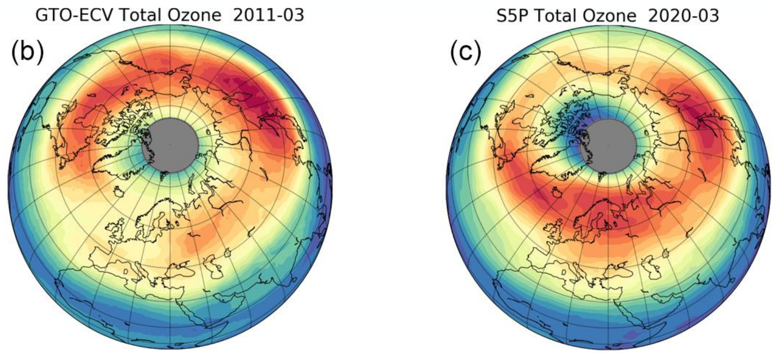
- **Improve well-established ozone data products** generated operationally in C3S, in support of WMO/UNEP Ozone and IPCC assessments.
- **New tropospheric ozone** data records using complementary techniques, in support of IGAC/TOAR.
- **New high-resolution ozone profile** product.



Highlights:

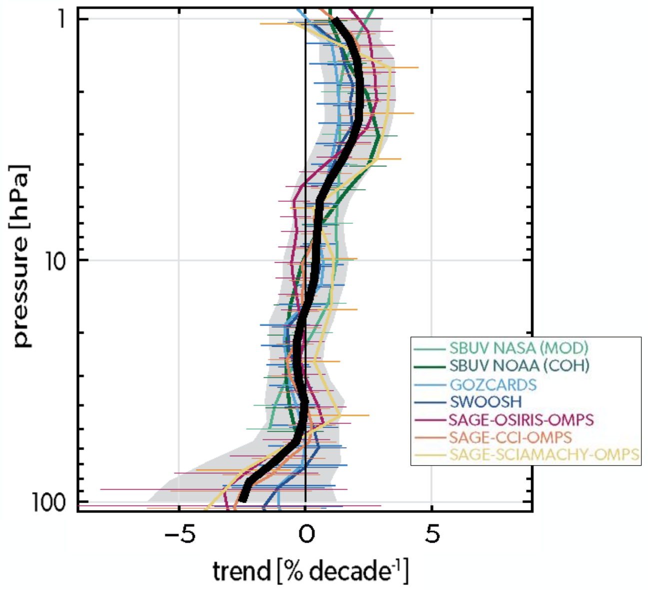
Dameris et al., ACP 2021

- Record **low ozone** detected over **Arctic** in spring 2020.



- SAGE-CCI-OMPS data record contributes to observational evidence for **recovery** of ozone in the **upper stratosphere**.

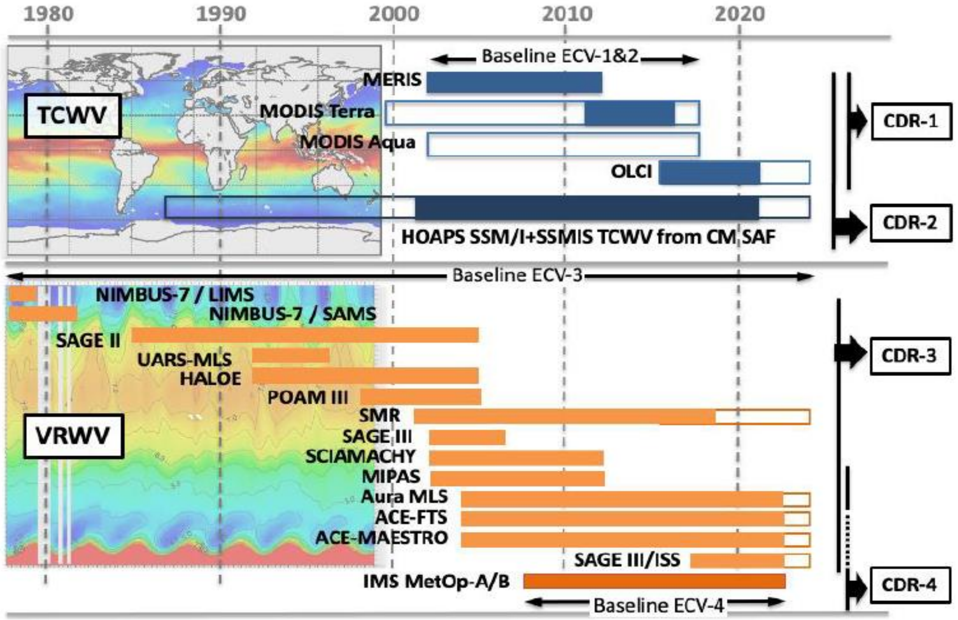
WMO Scientific Assessment of Ozone Depletion (2022)



Water vapour – Michaela Hegglin (University of Reading)

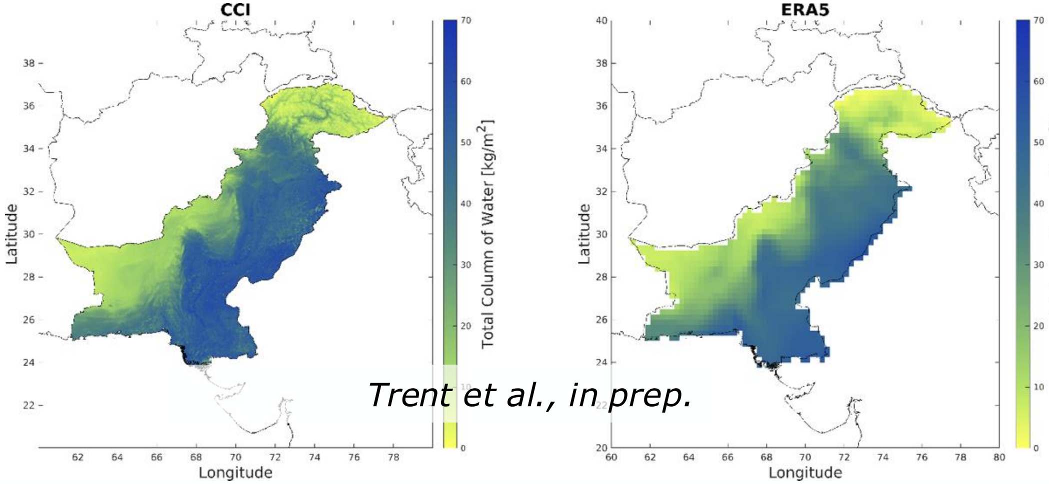
Focus:

- Improve merging algorithms.
- Extend datasets into the past and the present.
- Produce regional, higher-resolution products.
- Capitalise on climate data records through exciting user case studies.



Highlights:

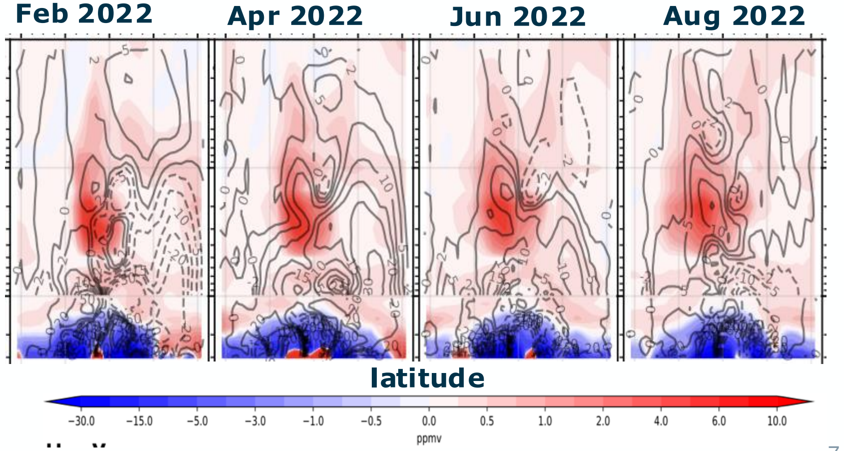
TCWV: New high-resolution product reveals greater detail of atmospheric WV distributions for flooding event Pakistan 2022.



Trent et al., in prep.

VRWV: The Hunga-Tonga volcanic eruption has increased stratospheric WV by about 10% of its total mass leading to potential long-term impacts on climate.

Ye et al., in preparation

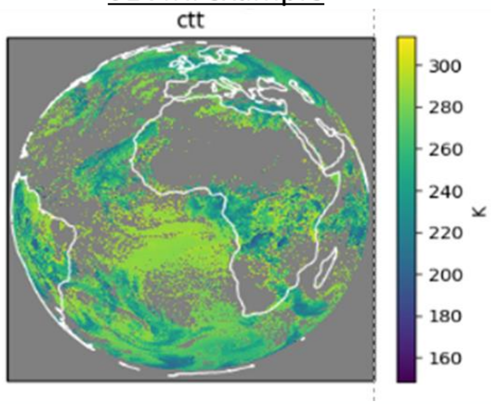


Cloud properties – Martin Stengel (DWD)

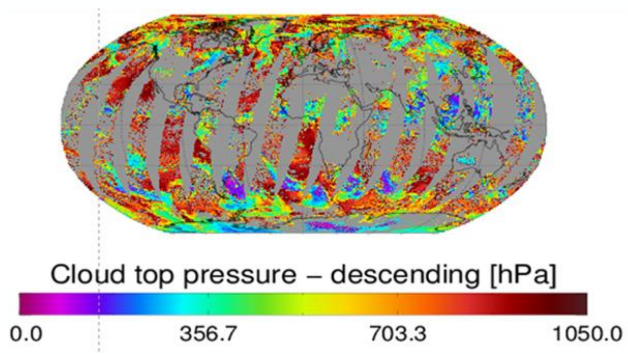
Focus:

- New phase just about to start up again.
- Further **improve cloud and radiative flux datasets** to facilitate local to global monitoring of climate change signals and feedbacks.
- Provide **observational insight in cloud processes** to guide model evaluation and development.

SEVIRI example

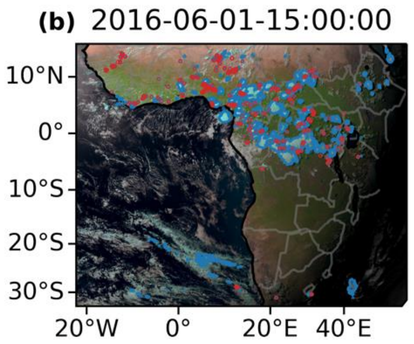


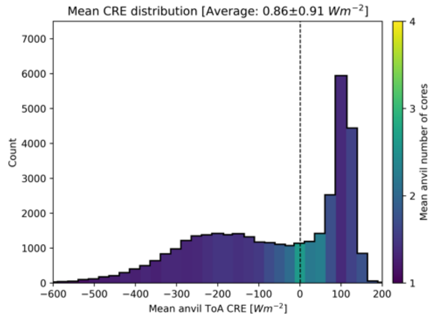
SLSTR example



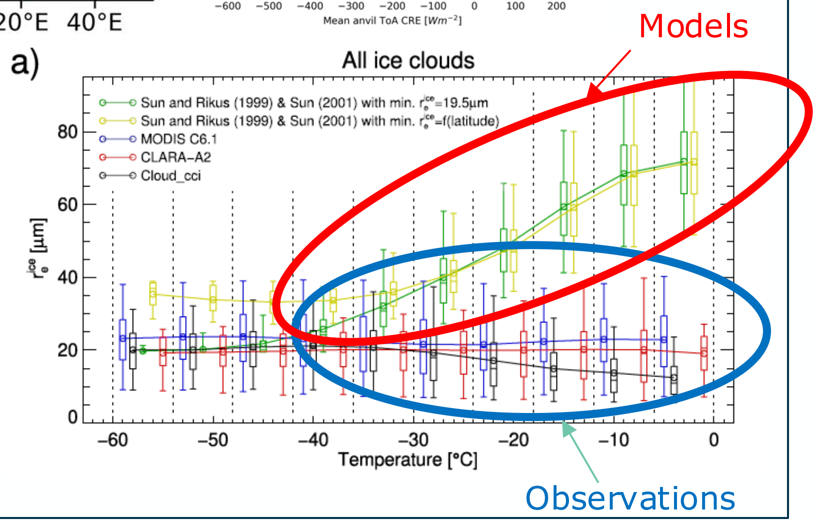
Highlight:

Cloud radiative forcing distribution of anvil clouds implies effect can vary between strong warming or cooling depending on specific conditions due to bimodal distribution.





Cloud properties: Systematic biases at the cloud top are revealed in models likely attributable to parameterisations of cloud ice particle effective radius.



Stengel et al., GRL 2023

Aerosol properties – Thomas Popp (DLR)

Focus:

CDR R&D:

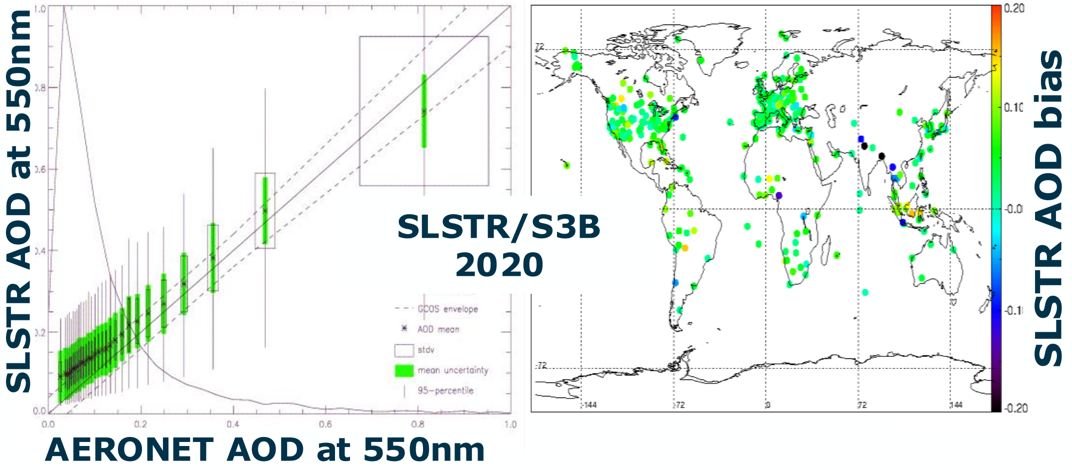
- Currently on hold.
- Evolve algorithms to further reduce bias of SLSTR AOD.
- Benchmark next C3S CDRs.

Link to the climate modelling community

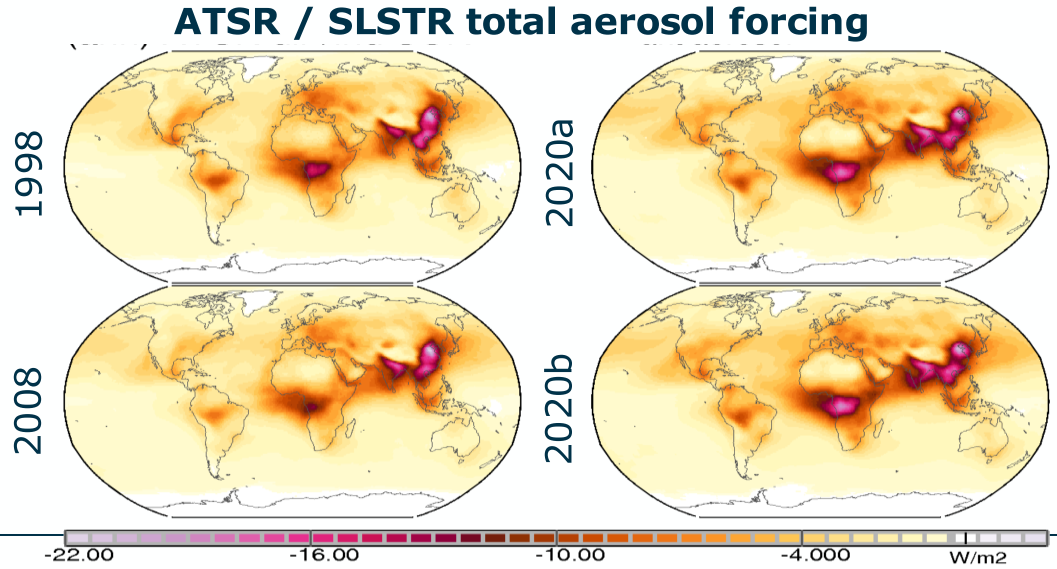
- Evaluate from user perspective.
- SLSTR data assimilation into CAMS (next reanalysis).
- Radiative forcing: initial feasibility study.
- New climate indicator aerosol / cloud cooling offset

Highlights:

Validation exercise. Swansea algorithm which is operationally produced in C3S2_313a (former Lot2) shows a clear bias reduction for SLSTR by ~30% (from 0.06 to 0.04)



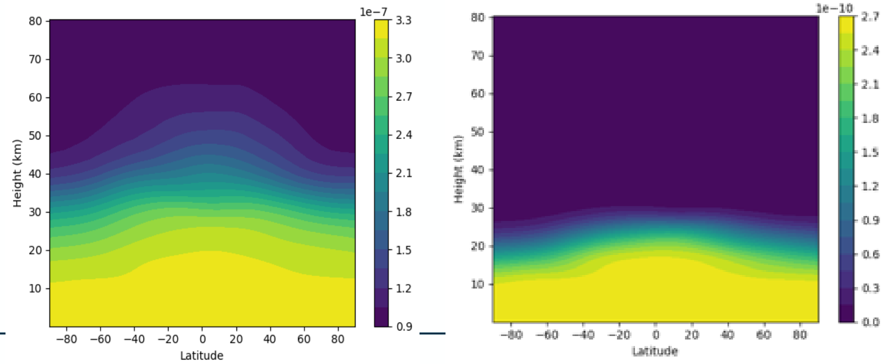
Aerosol forcing maps for 1998, 2008, 2020 (SLSTR / S3-A and SLSTR / S3-B). Further uncertainty reduction is needed in SLSTR to be useful for establishing a new climate indicator (see SATACI).



LOLIPOP – Elisa Castelli (ISAC CNR)

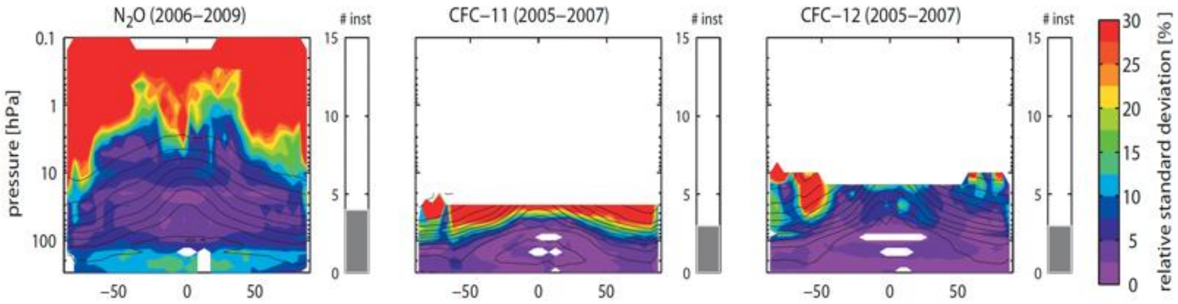
Focus:

- **N_2O and halogenated carbon compounds (CFCs, HFCs, HCFCs, PFCs)** have long atmospheric lifetimes, exhibit significant global warming potentials, and provide a major contribution to radiative forcing uncertainty estimates.
- N_2O and chlorine-containing GHGs are also the main source of anthropogenic ozone depletion.
- Determine if the actual set of satellite measurements is good enough to be used in climate science and services
- 3 user case studies to study radiative forcing.



Highlight:

- Inventory of available datasets from limb and nadir satellite measurements for 11 OLLGHGs: **N_2O, CFC-11, CFC-12, CFC-113, CF4, HCFC-22, HCFC-142b, HFC-23, HFC-134a, SF_6, CCl_4.**



- **No GCOS requirements** are given for OLLGHG apart from N_2O.
- A review of the user needs has been performed through both a literature review and a survey distributed among users.
  - → From literature review there is the need to monitor the OLLGHG concentrations for **climate change mitigation.**
  - → The survey highlighted two communities (climate/chemistry modelling and chemistry/emissions/transport studies)

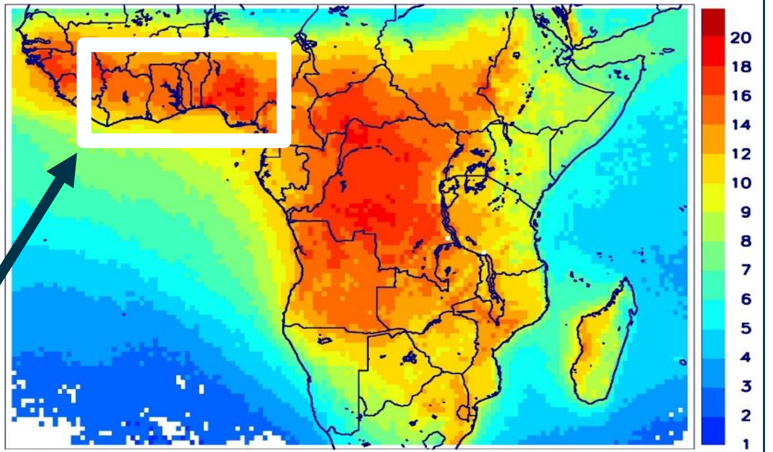
PRECURSORS – Michel van Roozendael (BIRA-IASB)

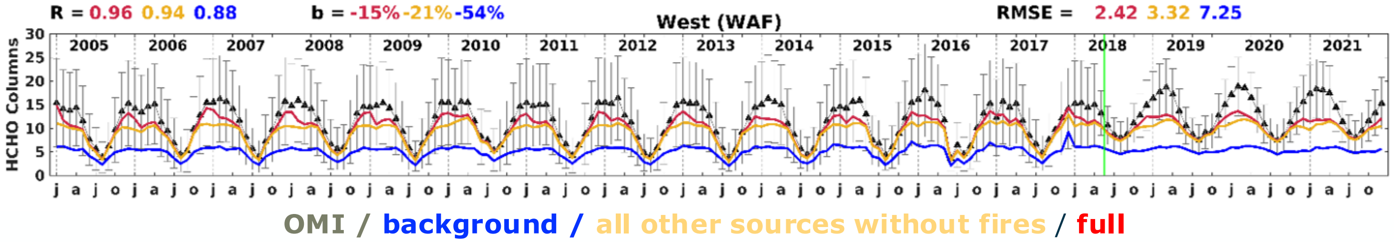
Focus

- Precursors for aerosols and ozone, including the short-lived atmospheric trace gases nitrogen dioxide (**NO_2**), sulfur dioxide (**SO_2**), carbon monoxide (**CO**), formaldehyde (**HCHO**), ammonia (**NH_3**), and glyoxal (**CHOCHO**).
- **OMI** (2004-2021) and **TROPOMI** (2018-2022)
- NO_2 L3 data has been generated with **consistent retrieval algorithms** and L3 processors.
- Quantify differences in spatial resolution, cloud inputs, and spatial coverage.
- Differences in overlapping period generally **<10%**

Highlight

- Excellent model prediction of **HCHO** interannual variability over African sub-regions.
- Demonstrates that BVOCs simulated by MEGAN and the background HCHO source can reproduce the observed variability fairly well.





SATACI – Marta Luffarelli (Rayference)

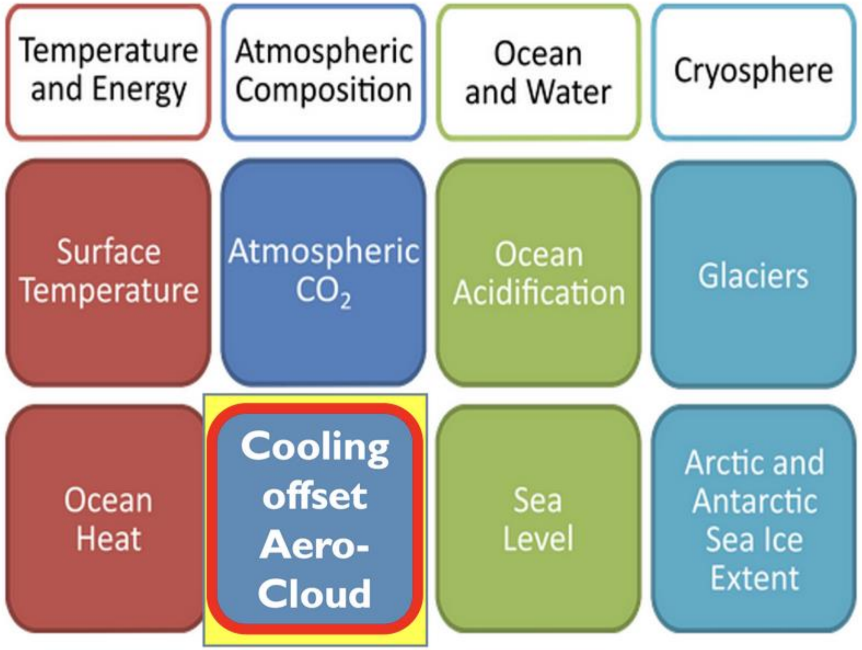
RAYFERENCE DLR Deutscher Wetterdienst Wetter und Klima aus einer Hand DWD Norwegian Meteorological Institute RAL Space

Focus

- New **x-ECV** study.
- Deepen our understanding of **aerosol-cloud interactions** (ACI) and the associated Radiative Forcing (RF), capitalising on the heritage from the ESA Climate Change Initiative (CCI) aerosol and cloud projects.
- Analyse satellite data to study **aerosol indirect effects** on liquid clouds and the relationship between dust and cloud glaciation.
- Develop a **new aerosol-cloud climate indicator** to complement existing World Meteorological Organization (WMO) climate metrics.

Highlight

- Feasibility study for a new climate indicator on aerosol-cloud cooling offset.



LINKS & INTERCONNECTIONS

- **CMIP Forcings Task Team,** to which the new **ESA CMIP-ozone project** (lead Forschungszentrum Jülich) contributes by creating an input ozone forcing for climate models; also, new **aerosol forcing** (Uni Exeter).

- **RECCAP2 / the global carbon budget**, to which atmosphere GHG concentrations offer constraints for the quantification of sources (including hotspots) and sinks from different Earth system components.

- **x-ECV** projects such as **SATACI** will help to create new links, not only in terms of science communities, but also in involving new **SMEs** in ESA projects.

- Strong links of the different projects with international organisations such as the **WCRP APARC** (World Climate Research Programme Atmospheric Processes And their Role in Climate) core project, **WCRP CMIP**, and **Futures Earth's IGAC** (International Global Atmospheric Chemistry) through different joint activities (e.g., also summer and training schools for capacity building).

- **Scientific links** via the radiation budget, atmospheric chemistry (percursors, aerosol, and ozone), microphysics (water vapour, aerosol, and clouds), and Earth-system nutrient, water, and energy cycles.

PRIORITIES FOR CLIMATE SPACE

- Continue R&D to generate **high-quality CDRs** (accuracy, resolution, time-coverage, sampling, stability)**.**
- **Exploit new LEO and GEO sensors** such as those from future atmospheric Sentinels (including CO_2-M) and GOES16/17, MSG/MTG, Kompsat, Himawari (among others).
- Leverage on **inter-sensor synergies to produce new value-added products** (e.g. based on new multi-instrumented platforms combining imagers and spectral measurements)
- Investigate new approaches based on **machine-learning** to improve data processing and interpretation.
- Enhanced operationalization of CDR production.
- Support for **x-ECV** studies by parent, fundamental CCI CDR producers seen as critical for success.
  - Clouds and aerosol (SATACI), but also others.
- Fully exploit the rich database ESA CCI offers in support of the **UNFCCC Paris Agreement** and **IPCC-related** climate and Earth system model studies **to address societal challenges**.
  - **Generate CDRs** relevant to the Paris Agreement, e.g. CO_2 and CH_4 from emission hot spots.
  - **Generate climate information** based on an improved understanding of climate sensitivity that is rooted in observations.