ROM SAF Climate Data Records: Products, Applications, and Plans

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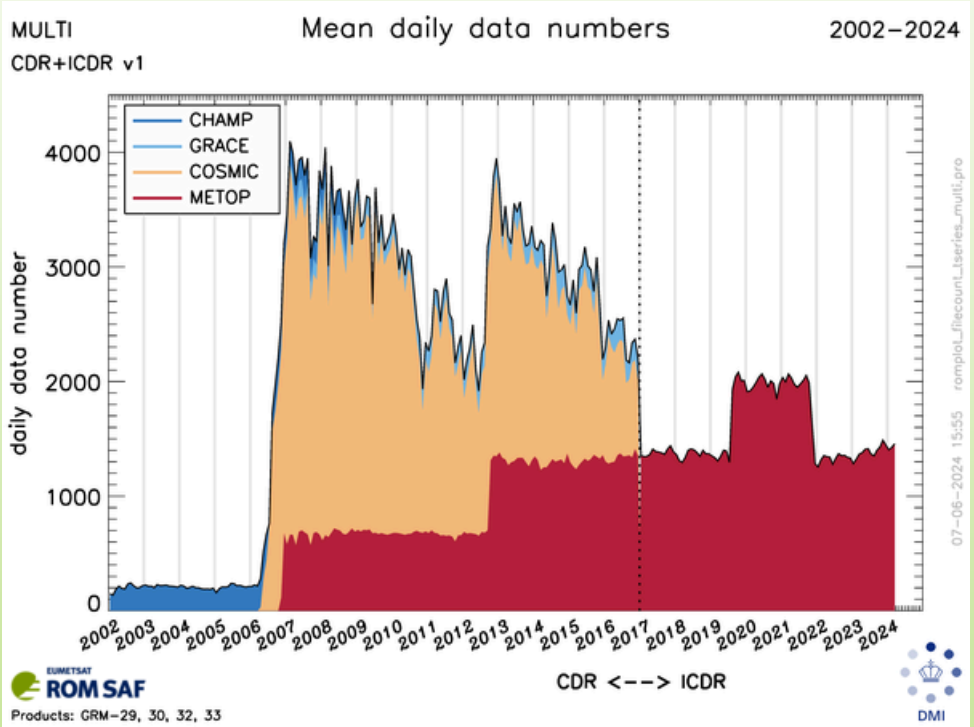
Outline

- ROM SAF climate data records: product portfolio & data dissemination
- Evolution of the ROM SAF climate products
- Applications and use of ROM SAF climate data records
- Conclusions

ROM SAF climate data records

– based on reprocessing #1 –



Climate data record (CDR v1)

- CHAMP, GRACE, COSMIC-1, Metop, MULTI
- Input data from EUMETSAT (Metop) and from UCAR (CHAMP, GRACE, COSMIC)
- Reprocessed 15+ years, Sep 2001 to Dec 2016
- Released in February 2019

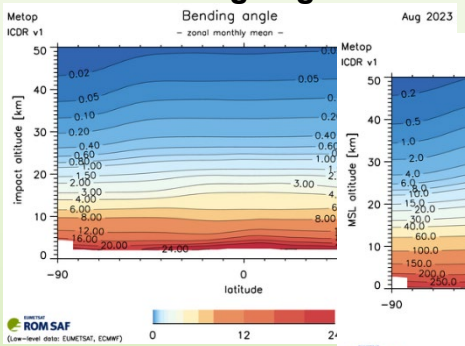
Interim climate data record (ICDR v1)

- Metop
- Input data from EUMETSAT Secr.
- Processed 7+ years, Jan 2017 to Apr 2024
- First release in May 2019
- New data added monthly

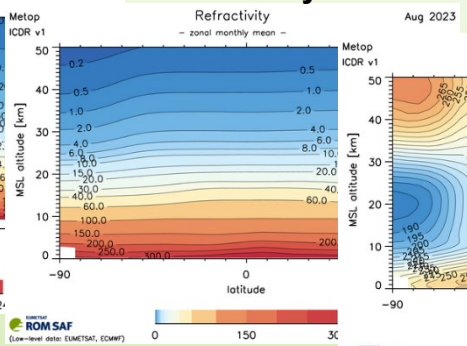
ROM SAF climate data records

– geophysical variables –

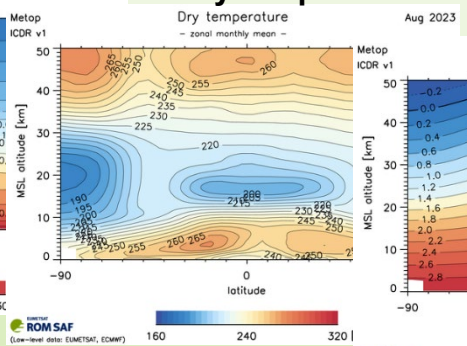
Bending angle



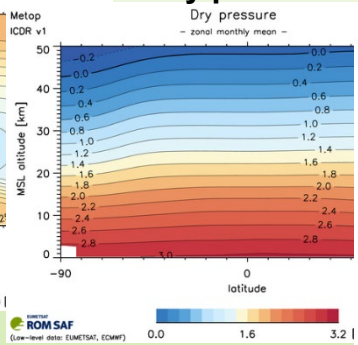
Refractivity



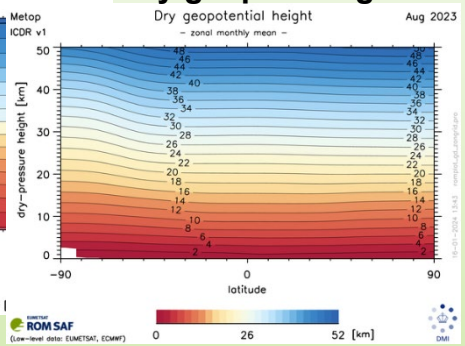
Dry temp



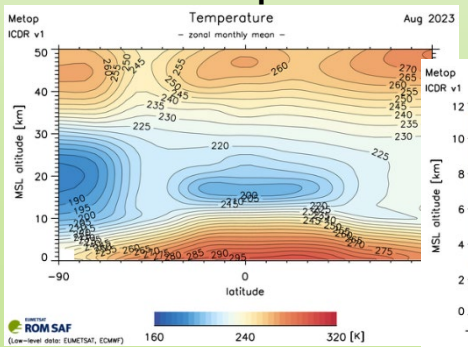
Dry pressure



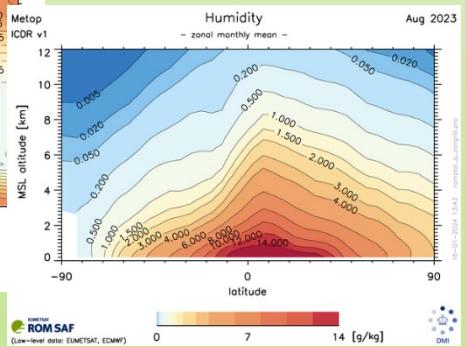
Dry geopot. height

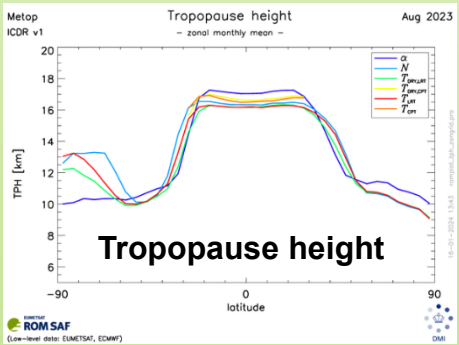


1DVar Temperature



1DVar Humidity





+ 1DVar pressure profiles

+ 1DVar surface pressure

ROM SAF climate data records

– CDR version 1 products –

Product ID	Product	CDR / ICDR	Ver.	Time coverage	Frequency
GRM-29-R1	Metop CDR v1.0 Level 1b & 2 profiles Metop CDR v1.0 Level 3 grids	CDR	1.0	200612 - 201612	Reprocessing cycle
GRM-29-I1	Metop ICDR v1 Level 1b & 2 profiles Metop ICDR v1 Level 3 grids	ICDR	1.x	201701 – *present*	Monthly
GRM-30-R1	COSMIC-1 CDR v1.0 Level 1b& 2 profiles COSMIC-1 CDR v1.0 Level 3 grids	CDR	1.0	200607 – 201612	Reprocessing cycle
GRM-32-R1	CHAMP CDR v1.0 Level 1b & 2 profiles CHAMP CDR v1.0 Level 3 grids	CDR	1.0	200109 – 200809	Reprocessing cycle
GRM-33-R1	GRACE CDR v1.0 Level 1b & 2 profiles GRACE CDR v1.0 Level 3 grids	CDR	1.0	200703-201612	Reprocessing cycle
GRM-28-R1	Multi-mission CDR v1.0 Level 3 grids	CDR	1.0	200109-201612	Reprocessing cycle

- Separate products for the satellite missions + a multi-mission gridded monthly-mean data record
- The CDR and ICDR products include both profiles and grids
- Includes a Metop ICDR that is updated monthly

ROM SAF climate data records

– CDR version 2 products –

Product ID	Product	CDR / ICDR	Ver.	Time coverage	Frequency
GRM-29-R2	Metop CDR v1.0 Level 1b & 2 profiles Metop CDR v1.0 Level 3 grids	CDR	2.0	200612 - 202212	Reprocessing cycle
GRM-29-I2	Metop ICDR v1 Level 1b & 2 profiles Metop ICDR v1 Level 3 grids	ICDR	2.x	202301 – *present*	Monthly
GRM-30-R2	COSMIC-1 CDR v1.0 Level 1b& 2 profiles COSMIC-1 CDR v1.0 Level 3 grids	CDR	2.0	200607 – 201911	Reprocessing cycle
GRM-32-R2	CHAMP CDR v1.0 Level 1b & 2 profiles CHAMP CDR v1.0 Level 3 grids	CDR	2.0	200109 – 200809	Reprocessing cycle
GRM-33-R2	GRACE CDR v1.0 Level 1b & 2 profiles GRACE CDR v1.0 Level 3 grids	CDR	2.0	200703-201711	Reprocessing cycle
GRM-28-R2	Multi-mission CDR v1.0 Level 3 grids	CDR	2.0	200109-202212	Reprocessing cycle

- Version 2 will include the same range of products as version 1, but with important processing updates, longer time series, and with the 1D-Var variables based on ERA5 instead of ERA-Interim;
- Expected improvements:
  - same ERA reanalysis throughout the CDR+ICDR time series (at least until ERA6)
  - more accurate humidity estimates due to improved error covariance descriptions in the 1DVar retrievals
  - reduced stratospheric biases due to the kappa correction and reduced errors in the orbit determination
  - less smoothing below 7 km

ROM SAF climate data records

– CDR version 3 products –

- Planned for in 2026-2027, towards the end of CDOP-4.
- Version 3 will include additional satellite missions: Sentinel-6, COSMIC-2, and Metop-SG. The precise list is yet to be determined.
- 1D-Var variables based on ERA6 ?
- Improved error and uncertainty estimation, consistently implemented along the processing chain from low-level data (Level 0/1) to profiles (Level 2) and gridded data (Level 3).
- Improved long-term stability.
- New Level 3 zonal grids, e.g., higher temporal and spatial resolution, and specific synoptic times.

ROM SAF climate data records

– Level 3 grids –

Horizontal grids

Physical variable	lat	lat-lon
Bending angle	✓	*RE4*
Refractivity	✓	*RE4*
Dry temperature	✓	*RE4*
Dry pressure	✓	*RE4*
Dry geopotential height	✓	*RE4*
Temperature	✓	*RE4*
Specific humidity	✓	*RE4*

Vertical grids

Physical variable	Impact altitude	MSL altitude	Geopot. height	Pressure (height)
Bending angle	✓			
Refractivity		✓		*RE2*
Dry temperature		✓		*RE2*
Dry pressure		✓		*RE2*
Dry geopotential height				✓
Temperature		✓		*RE2*
Specific humidity		✓		*RE2*

Temporal grid: Currently monthly. Higher time resolution and separation into synoptic times will be explored for reprocessing 3, and one or several lat-lon grids are envisaged for reprocessing 4 in CDOP-5.

Horizontal grid: Currently a 5° latitude grid. Higher resolutions will be explored for reprocessing 3.

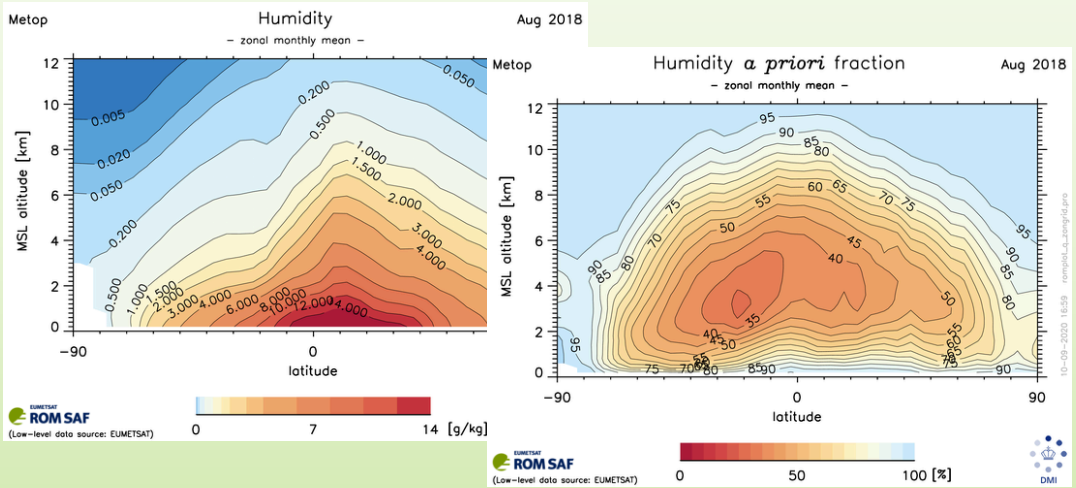
Vertical grid: Currently averaged on fixed mean-sea level altitudes, except for *dry geopotential height* (on pressure) and *bending angle* (on impact altitude). For reprocessing 2, some of the variables will in addition be provided on pressure levels, which is useful in applications related to climate models.

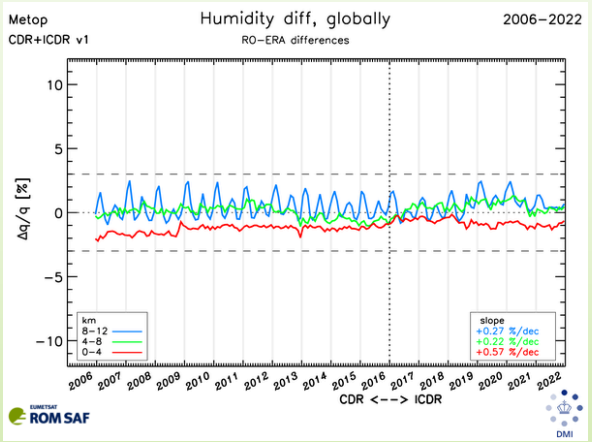
Evolution of the ROM SAF products

- Longer time series, more satellite missions
- Improved error and uncertainty estimation, working towards SI traceability
- Decreasing known biases, thereby extending the useful vertical coverage of the RO climate data
- Improving long-term stability
- Making the gridded data better fit for purpose: larger range of grid types, additional products (CAN)
- Exploring new ways of making the ROM SAF data available to users (cloud services)
- Providing climate monitoring and demonstrational data products in support of climate science (PBL height, SSW events, stratospheric winds, atmospheric heat content, decadal variability and trends, etc.)

Evolution of the ROM SAF products

– Humidity –





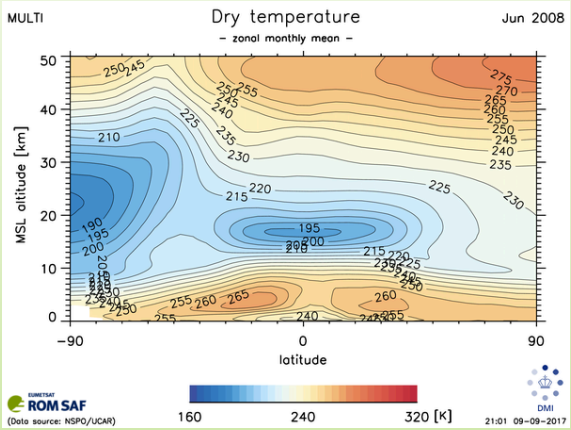
- There is an interest in RO-based humidity data: the GRUAN community, Copernicus C3S, ESA-CCI, and previous ESA projects (GlobVapor) as well as SAF federated activities;
- RO-based humidity have high resolution, but limited vertical coverage and small observational information content where atmosphere is dry.
- The long-term stability of RO-based humidity is affected by the 1D-Var background.
- Improving stability by a homogeneous CDR-ICDR chain, and exploring new ways of reducing impacts from bias shifts in the background

Evolution of the ROM SAF products

– New CAN products –

Level 3 CDR

Monthly means for June 2008



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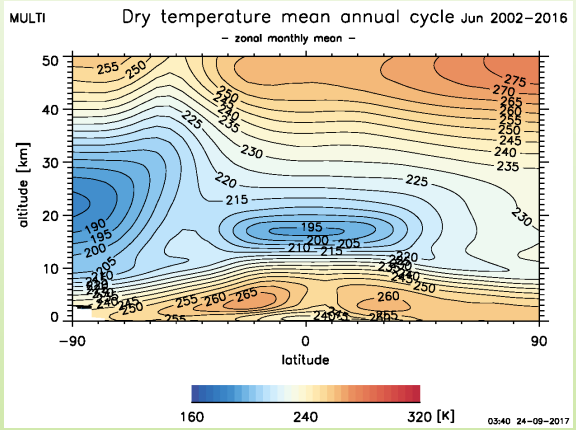
climate normals

Means over all June months 2007-2016



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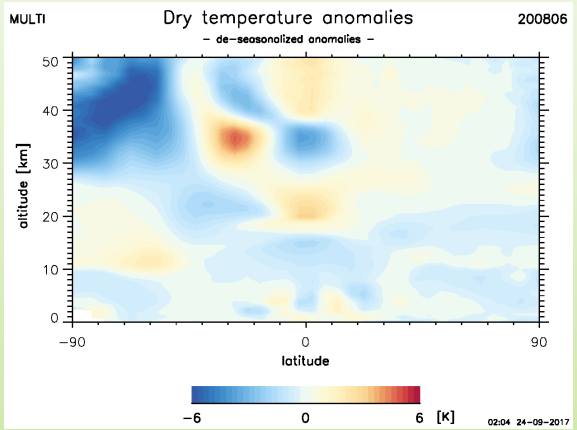
climate anomalies

Monthly mean anomalies for June 2008



- Currently, the ROM SAF Level 3 products only include the CDRs (panel to the left). However, climate anomalies (panel to the right) are commonly generated for various purposes.
- The new EUMETSAT CAN service (under development) will require normals and anomalies as input from the SAFs.

Evolution of the ROM SAF products

– New CAN products as part of CDR version 2 –

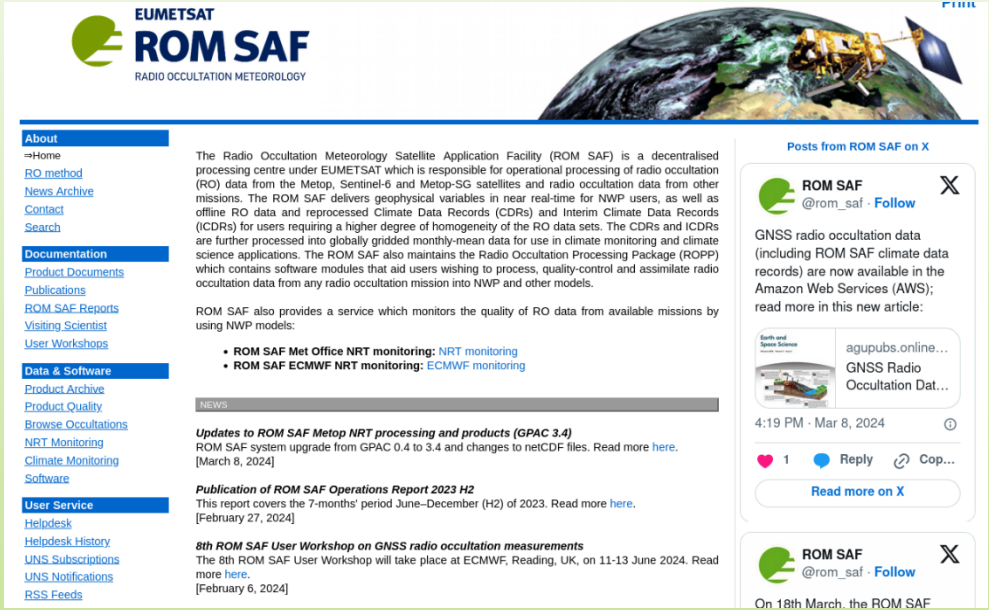
Product ID	Product	CDR / ICDR	Ver.	Time coverage	Frequency
GRM-281-R2	Multi-mission CDR v2.0 climate normals	CDR	2.0	200201 - 202212	Reprocessing cycle
GRM-282-R2	Multi-mission CDR v2.0 climate anomalies	CDR	2.0	200201 - 202212	Reprocessing cycle
GRM-292-R2	Metop CDR v2.0 climate anomalies	CDR	2.0	200612 – 202212	Reprocessing cycle
GRM-292-I2	Metop ICDR v2.0 climate anomalies	ICDR	2.0	202301 – *present*	Monthly

- Following reprocessing 2, the CAN products will include bending angle, refractivity, dry temperature, and dry geopotential height;
- Following reprocessing 3, the range of CAN products will be extended with humidity, and possibly other variables.
- The products will be made available through the EUMETSAT CAN service (currently under development), but will also be provided directly from the ROM SAF.

Data dissemination

– main outlet: ROM SAF web page –

https://rom-saf.eumetsat.int



Climate Data Records (CDRs)

Mission	Time period	DOI	Product ID	Data access
Metop	200610 - 201612 200612 - 201612	10.15770/EUM_SAF_GRM_0002	GRM-29-R1	Profile data Gridded data
COSMIC	200604 - 201612 200607 - 201612	10.15770/EUM_SAF_GRM_0003	GRM-30-R1	Profile data Gridded data
CHAMP	200109 - 200809 200109 - 200809	10.15770/EUM_SAF_GRM_0004	GRM-32-R1	Profile data Gridded data
GRACE	200703 - 201612 200703 - 201612	10.15770/EUM_SAF_GRM_0005	GRM-33-R1	Profile data Gridded data
Multi	200109 - 201612	10.15770/EUM_SAF_GRM_0001	GRM-28-R1	Gridded data

Information and limitations: README_CDR

Interim Climate Data Records (ICDRs) - *extending the CDRs in time*

Mission	Time period	DOI	Product ID	Data access
Metop	20170101 - 20240430 201701 - 202403	10.15770/EUM_SAF_GRM_0006	GRM-29-I1	Profile data Gridded data

Information and limitations: README_ICDR

Data dissemination

– alternative outlets –

- **Copernicus Climate Data Store**

  Currently: Level 3 Metop humidity; Planned for: Level 3 multi-mission dry temperature;
  Currently delivered by DMI through a brokering arrangement, but planned to be handed over to the ROM SAF during 2025.

- **Registry of Open Data on the AWS Data Exchange**

  Level 1B and 2 Metop, COSMIC-1, CHAMP, GRACE CDR and Metop ICDR;
  ROM SAF data provided along with data from other processing centers;
  Managed by the Atmospheric and Environmental Research, Inc. (Stephen Leroy).

- **EUMETSAT CAN Service**

  New planned Level 3 climate anomaly and normal (CAN) products;
  ROM SAF data will be delivered to the new EUMETSAT CAN service currently under development in a joint effort together with the other SAFs and EUMETSAT Secretariat.

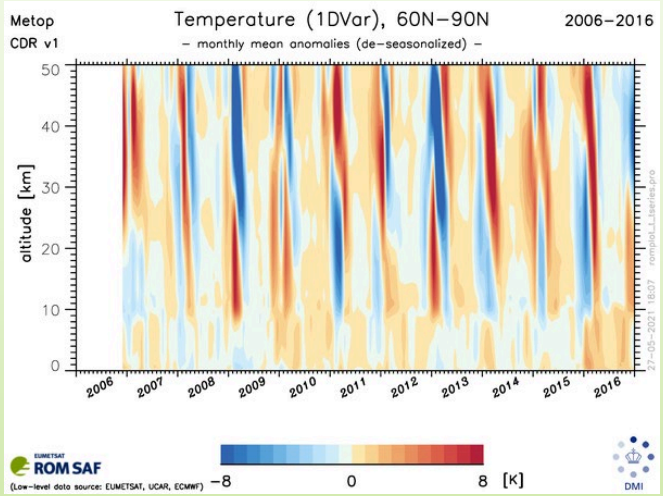
Use of ROM SAF climate data records

Examples of applications involving ROM SAF climate data records:

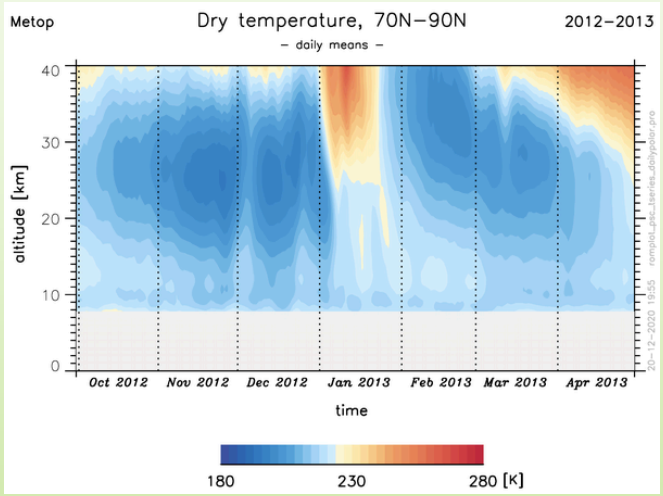
- *reanalysis*
- *atmospheric monitoring*
- *evaluation of/comparison with MSU/AMSU, IASI, AIRS, and GRUAN data*
- *equatorial stratosphere: QBO, mean zonal winds*
- ***polar stratosphere: polar vortex variability, SSW events, ozone depletion***
- ***atmospheric trends, contributions to IPCC assessments***
- ***climate model testing***
- ***migrating diurnal tides in the stratosphere***

Monitoring Arctic stratosphere

– Sudden Stratospheric Warmings –



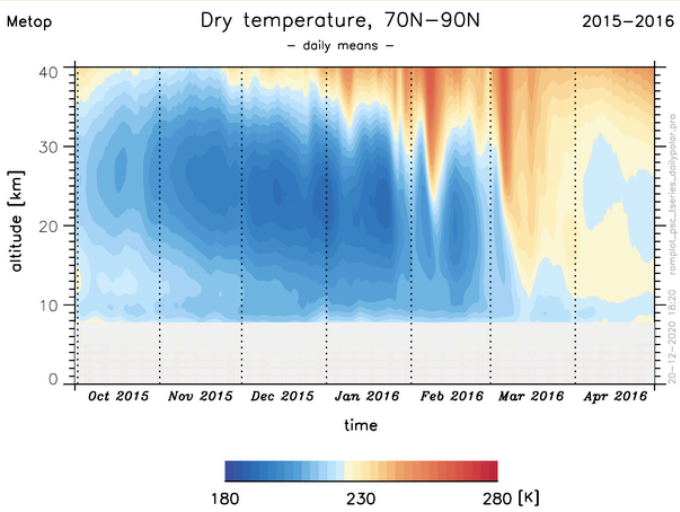
Temperature anomalies in the Arctic stratosphere is dominated by polar vortex build-up and breakdown related to Sudden Stratospheric Warming (SSW) events.

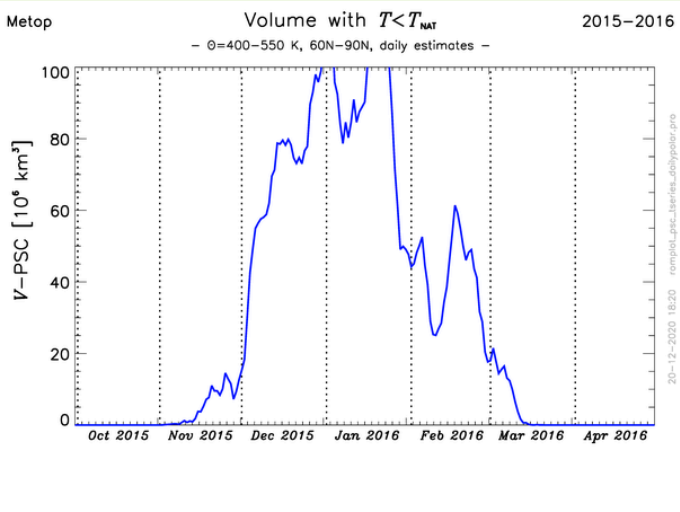


SSW in the winter of 2012-13, associated with rapid breakdown of a polar vortex followed by build-up of a new vortex.

Monitoring Arctic stratosphere

– Polar Stratospheric Clouds and ozone depletion –





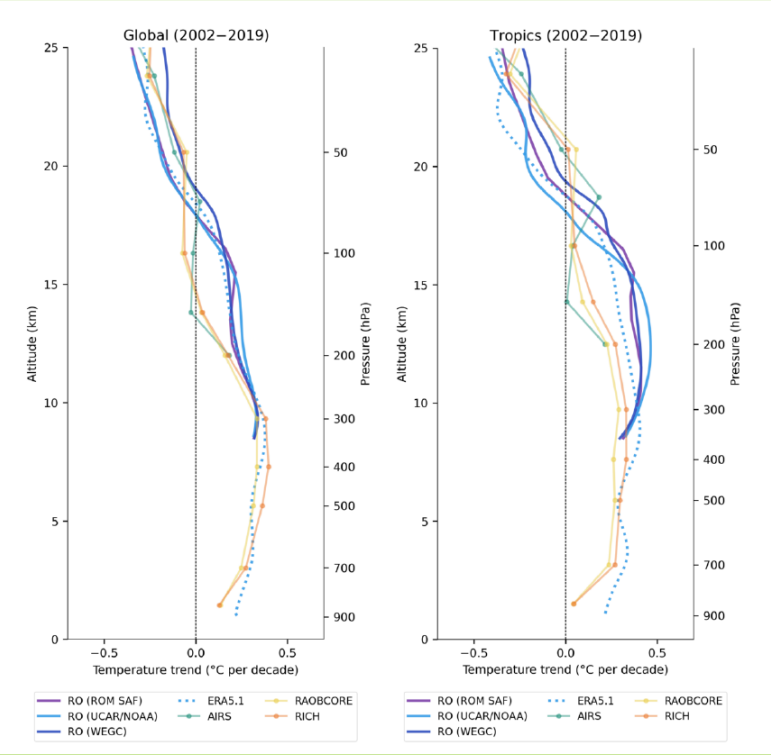
Temperatures in the Arctic stratosphere were extremely low during the 2015-2016 winter, before breakup of the polar vortex.

Polar Stratospheric Clouds (PSCs) are associated with very low temperatures, below about -85 C at altitudes between 15 and 30 km.

Volume of air in the Arctic stratosphere with temperatures T lower than T_{NAT}. Associated with PSC formation and ozone depletion. Sun-light is also an important factor for the ozone chemistry.

Contribution to the IPCC AR6 report

– observed temperature trends in the troposphere and UTLS –



From ROM SAF VS40 report (Florian Ladstädter)

Decadal temperature trends as function of height:

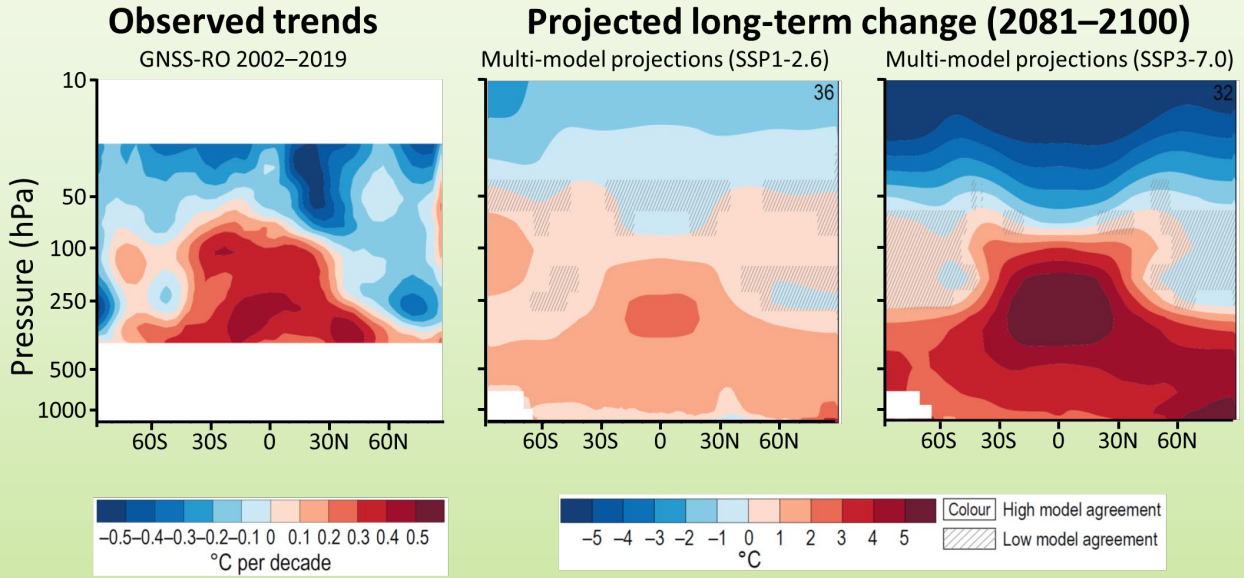
- RO data: ROM SAF, WEGC, UCAR/NOAA
- Radiosonde data: RAOBCORE, RICH
- IR-based data: AIRS
- Reanalysis: ERA5

There are *"faster temperature trends in the tropics in the upper troposphere than … near the surface."* Hence, we observe the tropospheric amplification expected from theory.

Another conclusion is that there is *"some spread between different data types … near 15 km."* However, it is also noted that "*these differences are reduced to near zero if a subset of radiosonde data … is used.*" These differences are discussed in Steiner et al. (2020).

Contribution to the IPCC AR6 report

– observed and projected temperature trends –



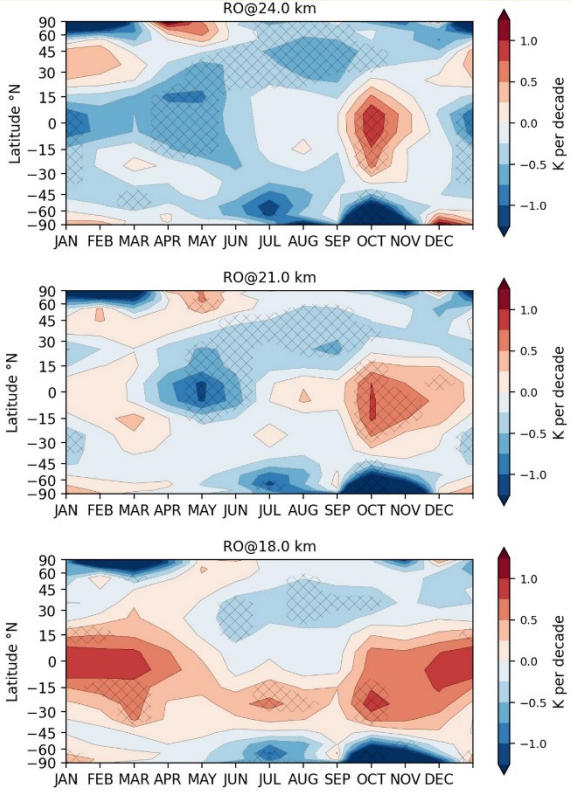
From IPCC AR6 WG 1, Technical Summary

Observed decadal trends in ROM SAF RO data (*left*) compared to projected temperature changes in CMIP6 models (*right*) over a roughly 85 year time period.

Two emissions scenarios: SSP1-2.6 (middle-low) and SSP3-7.0 (middle-high).

Contribution to the IPCC AR6 report

– seasonality of observed temperature trends –



From Ladstädter, Steiner, and Gleisner (2023)

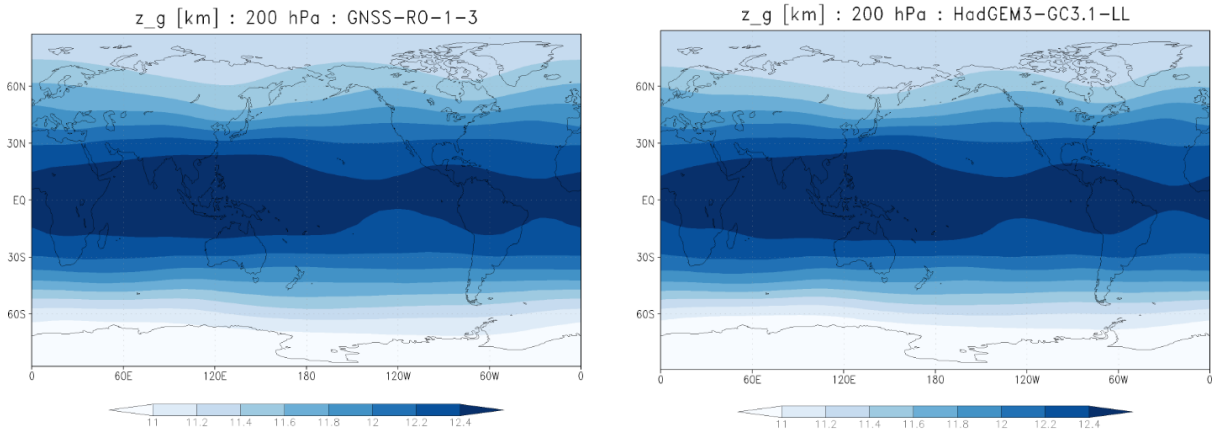
Temperature trends at 24 km, at 21 km, and at 18 km.

The seasonal variations of the trends reveal a quite complex picture, where variations of the ozone recovery and changes of the Brewer-Dobson circulation may play a role. At 18 km the main feature is an hemispheric asymmetry.

It should be noted that the time series are still short, and marginally significant at best.

Climate model testing

– HadGEM3 model integrations against RO observations –



- Annual mean 200 hPa geopotential height 2002 – 2014
- Obs4MIPS data produced by NASA-JPL on the ESGF (CHAMP+COSMIC)
- Met Office model forced with observed SSTs and sea ice (AMIP simulation)
- HadGEM3-GC3.1 is the Met Office model submitted to CMIP6

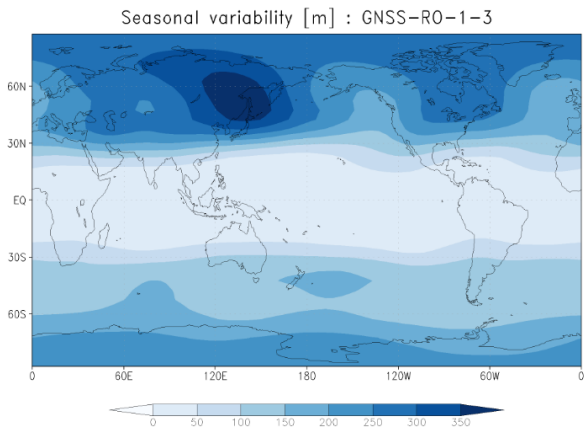
Data from the Met Office Hadley Center HadGEM3 model and RO data from NASA/JPL.

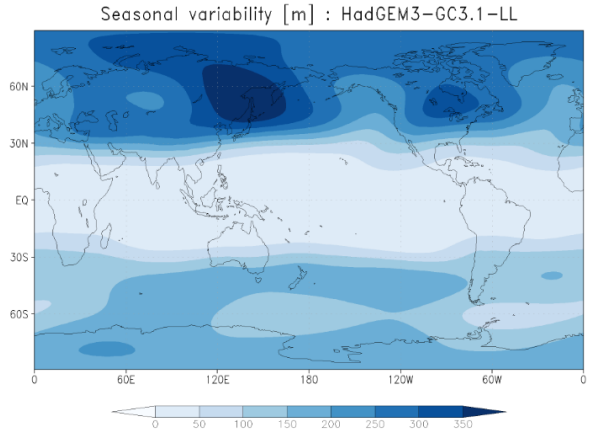
Similar comparisons with several CMIP5 models were made by *Ao et al. (2015)*.

From a presentation by Mark Ringer at the 7th ROM SAF User Workshop

Climate model testing

– HadGEM3 model integrations against RO observations –





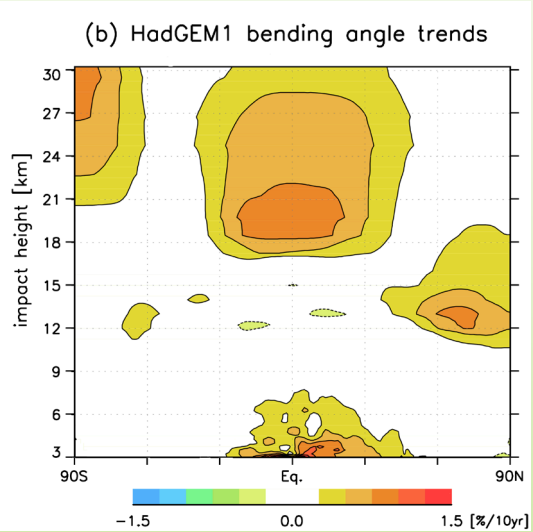
- Amplitude of the seasonal cycle: standard deviation about the annual mean
- Model overestimates seasonal variability over NH mid and high latitudes
- In the SH: overestimate over sub-tropics, underestimate at high latitudes

Data from the Met Office Hadley Center HadGEM3 model and RO data from NASA/JPL.

From a presentation by Mark Ringer at the 7th ROM SAF User Workshop

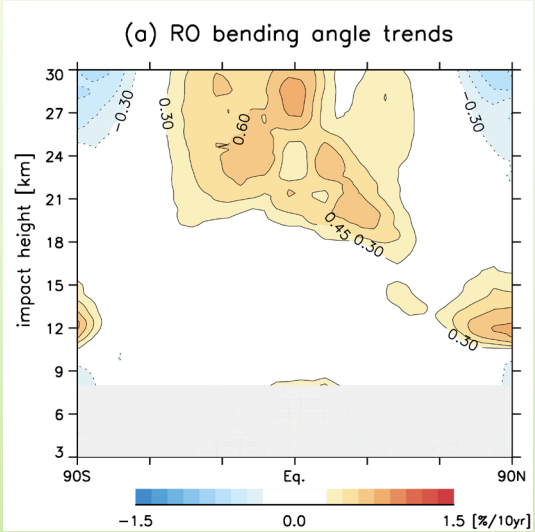
Bending angle trends

– testing climate model predictions made 15 years ago –



From Ringer and Healy (2008)

Bending angle changes from early 2000s to early 2020s. HadGEM1 climate model scenario integrations made in 2006.



From Gleisner et al. (2022)

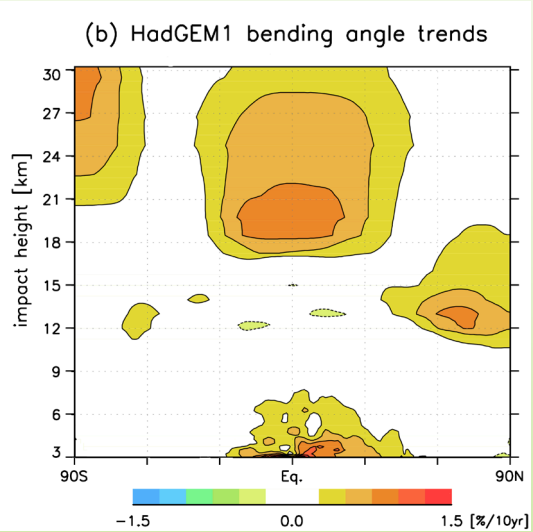
Observed bending angle trends based on ROM SAF climate data records 2002–2020.

The observed trends at low- and mid-latitudes are structurally very similar to those predicted in the HadGEM1 climate model scenarios, with the observed trends being slightly smaller.

Observations and model differ near the poles, consistent with the higher variability at high latitudes.

Bending angle trends

– testing climate model predictions made 15 years ago –



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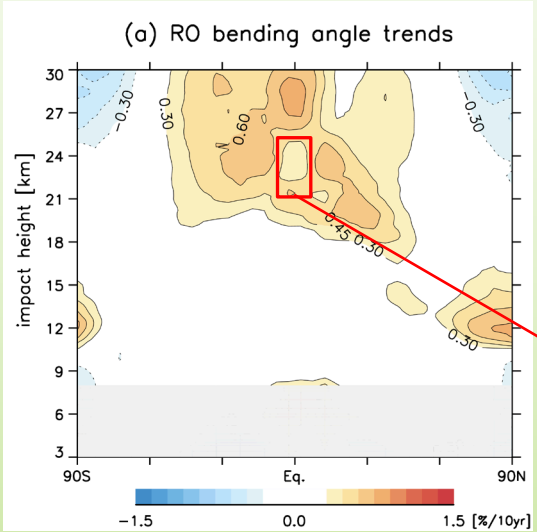
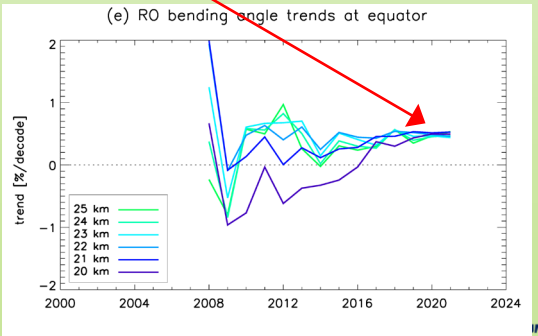


From Gleisner et al. (2022)

Observed bending angle trends based on ROM SAF climate data records 2002–2020.

Observed trends have converged with 20 years of data. This length seems to be enough to overcome the impacts of the natural variability on the trends in the low- and mid-latitude stratosphere.

*Consistent with the trend detection times stated in **Ringer and Healy** (2008): around 16 years in the low-latitude stratosphere, while up to 40 years would be required at high latitudes.*

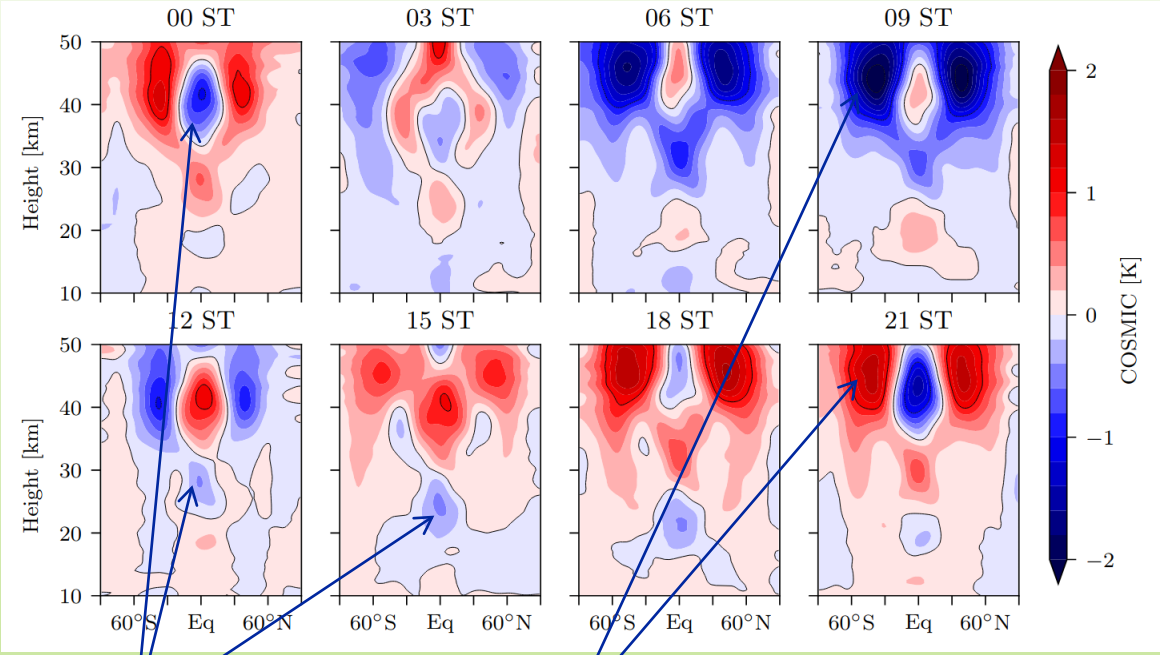


Migrating diurnal tides in the stratosphere

Atmospheric thermal tides can be studied with RO data that samples the whole diurnal cycle.

Leroy et al. (2021) fitted spherical harmonics to globally distributed RO data, including basis functions for representation of the local solar time domain.

Plots of the diurnal cycle, at 3-hour intervals, show a) the vertically propagating tides near the equator, and b) a vertically trapped oscillation in the mid-latitude upper stratosphere.



From ROM SAF VS38 report (Stephen Leroy)

Vertically propagating wave

Vertically trapped oscillation

Conclusions

- Version 1 of the ROM SAF climate data records was released 5 years ago.
- Preparations for reprocessing of version 2 is ongoing, with planned release in the beginning of next year. Version 3 is planned for in 2026-27.
- We plan for an evolution of the CDRs towards more satellite missions, better uncertainty estimates, smaller biases, improved temporal stability, and data products that are fit for purpose and that are made available to users where users are active.
- ROM SAF data is contributing to a range of applications important for climate: reanalysis, climate monitoring, as reference for validation of climate data, stratospheric winds, polar stratosphere, diurnal cycle and tides, etc.
- With longer RO time series there is great potential for testing climate models – still somewhat under-explored though.
- RO decadal trends as function of latitude and altitude were included in IPCC Assessment Report 6. The ROM SAF is ready to contribute also to the next IPCC assessment in collaboration with other RO processing centers.

END