APARC

Atmospheric Processes And their Role in Climate

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This time we have chosen a special conference picture for the title of the APARC Newsletter: The international workshop on Stratosphere-Troposphere Interactions and Prediction of Monsoon weather EXtremes (STIPMEX) was held in India in early June 2024, framed by traditions and rituals. The photo shows the Bharatanatyam dance form in the cultural program of the STIPMEX workshop. Details of the scientific part of it can be found in this newsletter, along with more workshop reports, insights into the latest APARC activity LEADER, and a report on the launch of EarthCARE. Enjoy!

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WCRP World Climate Research Programme
WORLD METEOROLOGICAL ORGANIZATION
unesco Intergovernmental Oceanographic Commission
International Science Council

Personal reflections on the outlook for APARC

As we settle into the boreal summer season, when many colleagues will be looking forward to a well-earned vacation and possibly some time to focus on research, we reflect on a busy few months for APARC. The annual WCRP Joint Scientific Committee meeting took place in May in hybrid format; APARC's progress in the last year and future plans were well received by the JSC and our JSC liaisons Cristiana Stan and Tercio Ambrizzi. Several large workshops involving APARC sponsorship have taken place in recent months, including the Stratosphere-Troposphere Interactions and Prediction of Monsoon weather EXtremes (STIPMEX) meeting in Pune in June (see meeting report), the AMS Middle Atmosphere and AOFD Conferences in Burlington in June (see panel discussion report), and most recently the Quadrennial Ozone Symposium and associated LOTUS and A-RIP workshops held in Boulder in July. These busy and stimulating times sit alongside the ever-growing concern about how far and how fast the climate system is being pushed from its equilibrium; human caused global warming is now > 1.3 °C above predindustrial levels (Forster et al., 2024). Despite this "writing on the wall", the role of WCRP as an international advocate championing the importance and value of climate science research remains paramount. The co-chairs have been reminded of this, as Olaf Morgenstern recently experienced a restructuring of his government-funded employer in New Zealand that led to his role being dissolved and his relocation to a new position in Germany. This appeared to be driven by the desire of the organisation to become more commercial and leaner, at the expense of basic research. Other positions targeted in the same round of redundancies were about maintaining New Zealand's long-term atmospheric and climate observations which represent internationally significant datasets covering the sparsely sampled southern mid- and high latitudes, putting these observations at risk. While personal, this example is a stark reminder that maintaining a strong community of atmospheric and climate scientists within APARC depends on our ability to make the case at local, national and international levels that investments in our field are necessary, as part of a wider strategy to limit climate change. We are confident that APARC and the wider community we are part of will continue to strongly advocate for research in our field, but we should be cognizant of the potential for fast paced evolution in the face of a rapidly changing global environment.

Reference:

Forster, P. M., et al.: Indicators of Global Climate Change 2023: annual update of key indicators of the state of the climate system and human influence, Earth Syst. Sci. Data, 16, 2625–2658, https://doi.org/10.5194/essd-16-2625-2024, 2024.

APARC co-chairs Olaf Morgenstern, Amanda Maycock and Karen Rosenlof

Goals, plans and science outline for a 3-year Limited-term cross-activity focused project on

Large Ensembles for Attribution of Dynamically-driven ExtRemes (LEADER)

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Introduction

The long-predicted climate change signal is emerging outside the noise in many regions. These changes in climate are accompanied by changes in extreme events that impact society. While early warnings of such changes are now potentially possible through, e.g., operational decadal predictions, there are several challenges: there is a lack of understanding of the dynamical mechanisms that enable such projections, there is evidence that global models underestimate some predictable signals, and these models suffer from biases. A better understanding of the causes of regional changes in climate is needed both to attribute recent events and to gain further confidence in forecasts.

In order to meet these needs, a new Large Ensemble Single Forcing Model Intercomparison Project (LESFMIP) has begun (Smith et al., 2022, see Table 1). These coordinated model experiments will enable the impacts of different external drivers to be isolated. These experiments form a bedrock of the analysis plan of the World Climate Research Program (WCRP) Lighthouse Activity on Explaining and Predicting Earth System Change (EPESC). The science that arises from the LESFMIP will allow for ongoing attribution statements to the WMO State of Climate and Global Annual to Decadal Climate Update in 2025 and beyond. But in order to achieve this goal, the scientific community needs to better understand how best to use this model output, and also to communicate with operational centres which diagnostics are required for future analysis. Specifically, output from these experiments cannot be taken at face value; rather, we need to account for model errors and the under-representation of certain forced predictable signals in forecasts (Scaife and Smith, 2018), while exploiting differences between models to diagnose the real-world situation. The large-ensemble will allow for isolating weak signals that otherwise would be buried under internal variability, while also offering a testbed for methods to extract predictable signals with correct amplitude.

Many of the phenomena that can lead to seasonal to decadal predictability of near-surface extremes involve dynamical processes and/or composition changes in the atmosphere. These phenomena include changes in external forcing such as solar variability, volcanic eruptions, and ozone depleting substances; and internal variability such as the Quasi-Biennial Oscillation, the stratospheric polar vortices, and changes in the storm tracks and jet streams. These phenomena bridge multiple existing APARC activities, and hence motivate the need for a limited term cross project focused activity to (1) coordinate the analysis and (2) ensure visibility of APARC science in WMO State of Climate and Global Annual to Decadal Climate Updates and in IPCC reports.

A new APARC activity

To meet this need, a new APARC activity is being launched: Large Ensembles for Attribution of Dynamically-driven ExtRemes (LEADER). LEADER will coordinate analysis of the LESFMIP output, and then write publications in 2025 and 2026. These publications will examine the scientific feasibility of using the LESFMIP output to provide attribution statements to WMO State of Climate and Global Annual to Decadal Climate Updates. Furthermore, these publications will directly feed into the upcoming 2026 UNEP/WMO

Table 1: *LESFMIP coordinated model experiments. Target ensemble size is 50 members, with a minimum of 10 members. Forcings are those defined by the 6th Coupled Model Intercomparison Project (CMIP6, Eyring et al., 2016) along with the ssp245 scenario from 2015 onwards as in the DAMIP simulations (Gillett et al., 2016). Phase 2 experiments are tentatively scheduled to be completed by July 2025. Adapted from Table 1 of Smith et al. (2022).*

Experiment name	Description	Phase	Start year	End year	Notes
1. Single forcing historical simulations					
1.1 hist-GHG	Well-mixed greenhouse-gas-only historical simulations	1	1850	2020	As DAMIP but with larger ensembles (10 members minimum with a target of 50 members). To fully capture the effects of volcanic forcing and solar forcing in models with prescribed ozone, ozone changes associated with solar and volcanic forcing should be prescribed in the hist-volc and hist-sol simulations, as in the DAMIP simulations. Note that ozone changes should not be prescribed in hist-GHG.
1.2 hist-aer	Anthropogenic-aerosol-only historical simulations	1	1850	2020	
1.3 hist-sol	Solar-only historical simulations	1	1850	2020	
1.4 hist-volc	Volcanic-only historical simulations	1	1850	2020	
1.5 hist-totalO3	Ozone-only historical simulations	1	1850	2020	
1.6 hist-lu	Historical simulations with only land use changes	1	1850	2020	New experiment
1.7 hist-All	All forcings	1	1850	2020	Similar to previous large ensembles, repeated to allow additivity of forcings to be assessed by comparing with single forcing historical runs
2. Single forcing projections					
2.1 fut-GHG	As 1.1 but with updated forcings	2	2015 onwards	2024 onwards	Ongoing start dates (yearly max frequency) as updated forcings become available. Each simulation to be 10 years long to enable improved attribution of recent changes and attribution of forecast signals. This will be especially important in the event of a future major volcanic eruption, but will also allow deviations in aerosol and GHG emissions and other forcings from the scenario used in experiment set 1 to be assessed. Note that ozone changes should not be prescribed in fut-GHG.
2.2 fut-Aer	As 1.2 but with updated forcings	2	2015 onwards	2024 onwards	
2.3 fut-sol	As 1.3 but with updated forcings	2	2015 onwards	2024 onwards	
2.4 fut-volc	As 1.4 but with updated forcings	2	2015 onwards	2024 onwards	
2.5 fut-totalO3	As 1.5 but with updated forcings	2	2015 onwards	2024 onwards	
2.6 fut-lu	As 1.6 but with updated forcings	2	2015 onwards	2024 onwards	
2.7 fut-All	As 1.7 but with updated forcings	2	2015 onwards	2024 onwards	

Scientific Assessment of Ozone Depletion report (specifically on the role of ozone for circulation changes) and the 7th assessment report of the IPCC. This LTCF will therefore directly address the strategic aim of APARC to foster engagement with IPCC and other influential international assessments.

LEADER will have two phases. During phase 1 analysis will focus on the historical runs, while during phase 2 analysis will focus on the real-time decadal forecasts (Table 1). Specifically, each WG will consider a specific science process and its role in operational decadal predictions, and so feed into operational capabilities and attribution statements. The activity will transition from phase 1 to phase 2 once data from the decadal forecasts are available (circa July 2025). Updates will be posted to the LEADER webpage hosted by APARC [https://www.aparc-climate.org/activities/leader-large-ensembles-for-attribution-of-dynamically-driven-extremes/].

LEADER will organise 8 working groups (WGs) that will focus on the specific science research questions. Those interested in joining the analysis are strongly encouraged to contact the LEADER co-chairs Chaim Garfinkel (chaim.garfinkel@mail.huji.ac.il) and Scott Osprey (scott.osprey@physics.ox.ac.uk). The rest of this article briefly describes the motivation and key research questions for each of the 8 WGs.

LEADER WGs:

1) Role of annual to decadal variability of the polar vortex for surface climate:

During eight consecutive winters in the 1990s no SSWs occurred in the NH and the polar vortex was anomalously strong (Domeisen, 2019). It is not clear whether this period of quiescence was a simple consequence of year-to-year variability, or whether it was forced. Moreover, decades with a weaker vortex feature colder temperatures over Greenland and warmer temperatures over Siberia (e.g., Garfinkel et al., 2017; Butler et al., 2023). In the SH SSW events are rare, with only two occurring, and only one a major SSW. The most recent event was followed by extreme hot and dry conditions in Australia which preceded devastating bushfires (Lim et al., 2020). The large ensembles available in LESFMIP allow for constraining the role of internal variability vs. external forcings for SSW droughts in the 1990s and in other decades, and also the associated downward impacts.

Specific research questions include: How often do decades with a strong or weak vortex occur in each of the single forcing experiments? What sea surface temperature and stationary wave patterns are associated with such decades? Do these models capture the downward impact from the vortex to the surface accurately, including the impact on extreme events? Do they capture the regionality of the surface impacts (e.g. cold in northern Eurasia, cold and dry in Australia)? What distinguishes models which simulate more decadal variability from those which simulate fewer? Is it related to biases in e.g., tropospheric stationary waves? In upward wave propagation through the tropopause? To mean-state biases in the polar vortex?

Will it be feasible to predict operationally on A2D timescales surface climate impacts associated with an extended period (a year to a decade) with an increased likelihood for fewer/more SSW, or a stronger or weaker vortex?

2) Identifying the forced response of the Southern Hemispheric atmospheric circulation to greenhouse gases, aerosols, and ozone, and associated surface impacts on extremes:

It is well known that ozone depletion and recovery has a substantial impact on atmospheric circulation. The quadrennial WMO Ozone Assessments include a chapter on surface climate impacts from ozone depletion, and it is anticipated that this WG will write a paper feeding into the 2026 Assessment using the runs exclusively forced by ozone. The added advantage of using the LESFMIP models is the large ensemble size, which will allow better quantification of internal variability and surface extremes. Specific research questions include: what is the role of internal variability in the apparent discrepancy between models and observations in the magnitude of the jet shift and Hadley Cell expansion? What is the role of ozone depletion/recovery for sea ice trends? For precipitation changes over South America, Australia, and South Africa? For surface temperature extremes?

Generations of coupled general circulation models have predicted a robust large-scale circulation response to increased greenhouse gases (albeit with considerable spread in magnitude), with subsequent impacts on extreme temperature, precipitation and wind events. In particular, projected changes include: a poleward shift of the Hadley cell subtropical edge, storm tracks and jets; an acceleration of the subtropical jet, and a strengthening of Southern storm tracks. Some of these predicted changes have begun to emerge in recent observations. Additionally, the connection between the trends in the large-scale circulation to emerging trends in extremes is largely unknown. This WG will use the new 'historical greenhouse gases only' large ensemble (and others as relevant) to properly quantify, attribute and understand these emerging large-scale circulation signals, and their connection to trends in extremes. The WG will also address emergent discrepancies between modelled and observed trends, including the underestimation of trends in storm track strength and position across the Southern Hemisphere (Chemke et al., 2022).

This WG will be organised in conjunction with an EPESC WG dedicated to the Southern Hemisphere circulation.

3) Identifying the forced response of the Northern Hemispheric atmospheric circulation to greenhouse gases, aerosols, and ozone, and associated surface impacts on extremes:

There is a large inter-model spread in NH vortex responses in the all-forcing CMIP simulations, leading to uncertainty in surface climate projection (Karpechko et al., 2022). There is only a limited understanding of why this might be. Part of the uncertainty in previous studies is likely due to internal variability that cannot be quantified with small ensemble sizes. Therefore, examining large ensembles where internal variability plays a smaller role in the inter-model spread, together with an examination of the response to individual forcings (e.g., greenhouse gases only versus aerosol only), may lead to improved understanding of the forced polar vortex response to climate change.

Forced changes in the tropospheric jets and storm tracks are projected to occur in the Northern Hemisphere, leading to extreme temperature, precipitation and wind events. These changes have typically been more difficult to isolate in the Northern Hemisphere than in the Southern Hemisphere. However, there are some indications of an acceleration of the subtropical jet, a weakening of the storm tracks in Northern summer, an eastward extension of the Atlantic storm track, but more muted changes in the winter storm track and jet position due to competing effects (Woollings et al., 2023; Blackport and Fyfe, 2022). Some of these predicted changes are already emerging in observations. This WG will use the new single-forcing large-ensemble to properly quantify, attribute and understand these emerging large-scale circulation signals and their connection to trends in extremes. The WG will also address discrepancies between modelled and observed trends in e.g. Greenland blocking and the eastward extension of the jet (Blackport and Fyfe, 2022).

This WG will be organised in conjunction with an EPESC WG dedicated to the North Atlantic circulation and ocean changes.

4) Surface response to solar variability:

Solar variability has been proposed to influence the Earth's climate from the middle atmosphere to the surface through at least two mechanisms (Gray et al., 2010). However, the surface response simulated in models is weak compared to observations, though it is conceivable that the "detected" solar signals in observations may be aliased by the strong internal variability and the relatively short length of the observational record. The large ensemble of LESFMIP and the 'solar-only' experiment will allow an isolation of the solar-forced response from the internal variability. This WG will quantify the "initial" middle atmospheric response to the solar signal, in addition to the downward coupling processes and surface responses.

This WG will be organised in conjunction with SOLARIS-HEPPA.

5) Surface response to Pinatubo and other large eruptions:

Explosive volcanic eruptions produce a temporary enhancement of the stratospheric aerosol layer and an associated surface cooling. This direct response to the volcanic radiative forcing is modulated by dynamical responses in the coupled ocean-atmosphere-sea ice system, yielding spatio-temporal complexity to post-eruption anomalies in both the troposphere and stratosphere. In the stratosphere, eruptions are known to influence the Brewer-Dobson circulation and entry of stratospheric water vapour. In the troposphere, two prominent pathways contributing to the surface response to volcanic eruptions are discussed in the scientific literature: a top-down pathway involving the post-eruption strengthening of the stratospheric polar vortex, and a bottom-up pathway involving a delayed ENSO response to the initial surface cooling and subsequent global teleconnections. It has been argued that models underestimate the forced vortex response to volcanic eruptions. Uncertainties are at least partly associated with the dependence of the response on the magnitude and spatial structure of the eruption, on the initial conditions, and on the background mean climate state. This WG will utilise the 'volcano-only' simulations to better constrain the role of internal variability vs. the volcanic forcing for the ENSO and stratospheric responses to volcanic eruptions.

This WG will be organised in conjunction with SSiRC and the CMIP6-VolMIP activity.

6) QBO influences on surface climate:

The QBO influences surface climate through at least three distinct mechanisms, though models tend to underestimate the magnitude of these effects (Rao et al., 2020). Moreover, the period and/or amplitude of the QBO has been shown to be affected by volcanic eruptions and greenhouse gases (Butchart et al 2020; Brown et al., 2023). At least three of the LESFMIP models have a spontaneous QBO. We will use these models to answer the following questions: How have large volcanic eruptions affected the QBO? How has decadal variability in sea surface temperatures affected the QBO? Is there a role for internal variability in reconciling the apparent discrepancy between models and observations in the magnitude of the surface response to the QBO? Is there a relationship between QBO disruption events (such as the ones in 2016 and 2020) and rising GHG concentrations?

This WG will be organised in conjunction with QBOi.

7) Identifying the forced response of the Asian monsoon to greenhouse gases, aerosols, and ozone, and associated surface impacts on extremes:

Climate forcing agents have profound impacts on the Asian monsoon with effects that extend well beyond the boundaries of the core monsoon region. For example, increases in atmospheric moisture content associated with greenhouse gas-driven global warming are expected to intensify monsoon rainfall (Katzenberger et al., 2021), particularly in the heaviest rainfall events, while recent increases in atmospheric aerosols have weakened the summer monsoon (Li et al., 2016). By contrast, the East Asian winter monsoon has been weakened by greenhouse gas-driven warming in the middle and lower troposphere, while aerosols appear to strengthen the cold and dry conditions associated with this system (Miao et al., 2018). In addition to the role of the monsoon in surface climate, the upper-level anticyclone above the Asian summer monsoon is among the most influential sources of water vapour and tropospheric pollutants to the global stratosphere. Persistent biases in model representations of the monsoon anticyclone make it difficult to assess possible future changes in this circulation and how these changes may influence troposphere-to-stratosphere transport and stratospheric composition (Singh et al., 2022). Apparent competition between the influences of greenhouse gases and aerosols, along with demonstrated sensitivities to both internal variability and natural forcings, complicate our ability to attribute and quantify the causes of both historical and possible future changes in the Asian monsoon system.

This WG will use the new single-forcing large-ensemble to study how these different components of the Asian monsoon system respond to individual climate forcing agents in the presence of internal variability. This WG will be organised in conjunction with ACAM.

8) Role of external forcings and internal variability for atmospheric temperature trends:

Temperature trends in both the troposphere and stratosphere are influenced not just by GHGs, but also a wide range of other anthropogenic and natural forcings (Aquila et al., 2016). Large ensembles are needed to fully constrain the magnitude of forced temperature trends, particularly in the troposphere and UTLS (Santer et al., 2019). There is an apparent long-standing discrepancy between modelled and observed temperature trends in the stratosphere, though this discrepancy has lessened with more recent analysis of the satellite record (Maycock et al., 2018). The LESFMIP models will enable a reassessment of the attribution of temperature trends. Stratospheric temperature trends may also reveal the effects of mitigation more rapidly than tropospheric trends, due to the smaller internal variability, and this would be an important aspect of a potential operational A2D system. There are also outstanding differences in modelled and observed temperature trends in the upper troposphere though some of the apparent discrepancy may be due to internal variability (Po-Chedley et al., 2021). The drivers of these trends will be isolated in the single forcing experiments to examine their relative strength.

This WG will be organised in conjunction with ATC.

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TPChallenges International Conference Report

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Dates:
11 -14 March 2024

Scientific Organising Committee:
Peter Hoor, Joachim Curtius, Christiane Voigt, Ulrich Achatz, Peter Spichtinger, Andreas Engel, Holger Tost

Local Organising Committee:
Elisabeth Licht, Aurelia Müller

Host Institution:
Johannes Gutenberg University, Mainz, Germany

Number Of Participants:
more than 140 participants

Contact:
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Conference Website:
https://tp-challenges2024.uni-mainz.de

Logos/Sponsors:

Overview

From 11-14 March 2024 an international meeting focusing on the status of the upper troposphere/lower stratosphere (UTLS) was held at the Johannes-Gutenberg University Mainz, Germany. The meeting was linked to the DFG-funded collaborative research center "The Tropopause in a Changing Atmosphere" (TPChange, www.tpchange.de), which started on 1 July 2021 and which connects interdisciplinary aspects of UTLS relevant research from aerosol and ice particles over small scale dynamics and gravity waves to large scale processes. More than 140 participants including PhDs and PostDocs came together to discuss recent developments of the field. The program included more than 25 talks with four keynote contributions and a lot of time for poster discussions. The key note talks were given by Christina Williamson (FMI, Finland), Andrew Gettelman (PNNL, USA), Albert Hertzog (CNRS, France), and Bill Randel (NCAR, USA) and tighly linked to the research areas of TPChange.
The program also included several poster sessions and social events from guided tours to a joint conference dinner. Thus, there was plenty of room for a lively scientific and informal interaction between senior scientists and emerging young researchers.

1st Conference Day

After a brief welcome of the vice-chancellor of the Johannes Gutenberg University, Stephan Müller-Stach, **Peter Hoor** opened the meeting and pinpointed the history on UTLS relevant research at the Johannes Gutenberg University and the Max-Planck-Institute for Chemistry in Mainz. Christian Junge, Hans Pruppacher, and Paul Crutzen who received the nobel prize in 1995 are linked to UTLS relevant research in Mainz. He further pointed out the relevance of the UTLS for climate and circulation and the challenges arising from the coupling of processes across scales and between different disciplines of UTLS research.
The first keynote talk was given by **Andrew Gettelman** (PNNL, Boulder) highlighting the role of the UTLS for climate and key challenges in the representation of UTLS processes in global models. Particularly the interaction between ice super-saturation, ice formation and the role of aerosol remain a big challenge for climate models leading to different responses to anthropogenic perturbations. On the large scale the structure of the stratosphere is affected in a warmer atmosphere by an upward

shift of the tropopause and a widening of the tropics. **Christina Williamson** (FMI, Helsinki) continued the aerosol keynotes by highlighting the role of the Asian summer monsoon for the UTLS aerosol budget. She presented results from the ACCLIP measurement project over East Asia, showing that anthropogenic pollution enhances new particle formation in the UTLS over this particular region. **Dan Murphy** (NOAA, Boulder) showed new results of metallic aerosol components in the LMS presenting strong evidence for space debris from re-entering rocket engines to become part of the lower stratospheric aerosol with unknown consequences for ice formation or the stratospheric heterogeneous chemistry. **Yafang Cheng** (MPI-C Mainz) showed that aerosol from wildfires may interact with dynamics to form isolated PV-anomalies associated with smoke vortices which can persist over weeks and affect ozone chemistry in the mid stratosphere. **Dan Cziczo** (Purdue, Laffayette) reported on DCOTTS results of aerosol measurements in the UTLS over the US and pointed out that aerosols from biomass burning may enter the lower stratosphere in overshooting convention within pyro-cumulus and consequently contribute significantly to the background UTLS aerosol. **Troy Thornberry** (NOAA, Boulder) closed the morning session by presenting a new balloon borne data within the B2SAP project to measure stratospheric aerosol profiles with the POPS instrument. Recent results highlight the capability of the payload to provide unprecedented details of the stratospheric aerosol size distribution and perturbations by fires or volcanic eruptions.

The afternoon session was opened by **Joachim Curtius** (Goethe University, Frankfurt/Main) who showed results from the HALO mission CAFE Brazil providing new insights into the nucleation of particles over the pristine Amazon rain forest. The diurnal interplay between isoprene, organo-nitrates and convection leads to new particle formation in the tropical upper troposphere. **Andrew Rollins** (NOAA, Boulder) showed results from ACCLIP and the impact of convectively uplifted NOx and SO2 and their impact on ozone production. They find strongly enhanced ozone production in the Asian Summer Monsoon upper tropospheric air mass being twice as high as outside the monsoon anticyclone. **Philipp Joppe** (MPI C, Mainz) presented abnormal correlations of sulfate aerosol and ozone in the UTLS and diagnosed recent cross tropopause mixing. The SO2 was traced back to a volcanic eruption 40 days before and formed sulfate aerosol which caused the observations. Analyzing aerosol size distributions from over 400 flights from IAGOS-CARIBIC, **Markus Hermann** (Tropos, Leipzig) derived seasonally resolved climatologies of small and Aitken mode particles and demonstrate the impact of different transport processes on the aerosol size distribution and their climatological abundance. **Alexandra Laeng** (KIT, Karlsruhe) closed the session showing the impact of Siberian wildfires on the aerosol distribution derived from satellite observation from different platforms on the NH LMS.

The evening session was opened by **Charios Benetatos Kostas Eleftheratos** (National and Kapodistrian University, Athens) who derived trends from 40 years of HIRS brightness temperature measurements from satellites. They conclude on a slight positive trend of upper tropospheric humidity in the extratropics with no evident trends in the tropics.
Jackson Seymore (JGU, Mainz) presented new results from wind tunnel laboratory experiments showing the impact of freezing on ice and trace gas partitioning important for estimates of the transport efficiency of organics in convection. **Martanda Gautam** (JGU, Mainz) showed the role of freezing for secondary organic aerosol formation important in convective updrafts. He determined retention coefficient in freezing droplets and found a sensitivity of the retention to Henrys constant for small droplets. **Dario Sperber** (DLR, Oberpfaffenhofen) presented a new method for forecasting ice supersaturation without taking into account saturation adjustment. They get a much more realistic representation of the supersaturation in ICON compared to the case when using saturation adjustment. **Adrienne Jeske** (JGU, Mainz) closed the session presenting a new approach to study the effect of convection in global models to parameterize turbulent entrainment and detrainment in global simulations using a so called "convective exchange matrix" .

2nd Conference Day

The second day of the conference started with a session on the tropical tropopause and lower stratosphere. The first three talks centered around ice clouds in the tropical transition layer. **Albert Hertzog** (CNRS, Paris) started with an invited talk on the recent deployment and initial results from long-duration balloon flights during STRATEOLE-2. He highlighted the key role of gravity waves on the formation of ice clouds from a combination of observations and idealized modeling and closed his talk with the prospect of future deployments to better characterize small scale processes in the tropical transition layer. **Peter Spichtinger** (JGU, Mainz), also using idealized models, focused on the dissipation processes of the ice clouds. The dissipation is sensitive to the thermodynamic environment and to local (gravity wave) dynamics with non-linear superposition of the processes at play. **Qiang Fu** (Washington State University, Seattle) then showed recent results on the temperature control of cirrus cloud variability and the role of the Quasi-Biennal Oscillation on the clouds and their radiative forcing, especially during boreal spring and summer. **Petr Šácha** (Charles University, Prague) then switched topics to show recent results on the kinematic factors that control changes in the tropical upwelling in the upper troposphere and lower stratosphere. Using CMIP 6 model and reanalysis data he concluded that the models agree well on the vertical shift of the tropopause and changes in the vertical advection, while the results are less consistent for reanalysis systems. **Troy Thornberry** (NOAA, Boulder) concluded the session presenting the goals and first results of the SABRE mission with a focus on aerosol microphysics and composition in the lower stratosphere. They found significant contributions of organic-sulfate particle and also biomass burning aerosol signatures deep in the stratosphere.

After a coffee break **Martin Riese** (FZ, Jülich) opened the second session of the day with an overview talk of the PHILEAS mission. PHILEAS took place in late boreal summer and was stationed in Germany and Alaska with a focus on the composition changes in the lower stratosphere related to the Asian Summer Monsoon anticyclone and biomass burning. The following talks focused on specific results from the PHILEAS mission. **Franziska Köllner** (JGU, Mainz) presented first in-situ observations of ammonium nitrate originating from the Asian monsoon region in the extratropical lower stratosphere. Using observations of atmospheric tracers with varying chemical lifetime **Michael Volk** (Bergische University, Wuppertal) highlighted the enhancements of air pollutants in filaments of air from the Asian Summer Monsoon as well as the different pathways of air masses from East Asia to North America, distinguishing between the fast, convectively driven transport up to 370 K potential temperature and the slower upwelling above. **Jan Kaumanns** (FZ, Jülich) analyzed two consecutive flights during PHILEAS and presented a novel diagnostic to study mixing processes of trace species using tomographically imaged filaments with the GLORIA instrument in combination with a classification scheme to separate between tropospheric, stratospheric and mixed air masses. **Wolfgang Woiwode** (KIT, Karlsruhe) concluded the morning sessions with highlights of trace gas observations from GLORIA and comparisons to model forecasts.

After an extended lunch break with an associated poster session **Christian Rolf** (FZ Jülich) concluded the PHILEAS session. He presented evidence that the lower stratosphere was already influenced by air from the Asian Summer Monsoon at the start of the campaign in early August. Switching slightly the topic, **Bärbel Vogel** (FZ Jülich) compared observed carbon dioxide with Lagrangian reconstructions of such profiles in the Asian Summer Monsoon region for time period of the STRATOCLIM mission in 2017. The goal was to identify sources of carbon dioxide in East and South Asia and to study transport time scales in the UTLS region. **Johannes Degen** (Goethe University, Frankfurt/Main) also used observations of carbon dioxide, but from quasi-regular AirCore soundings to analyze the propagation of the seasonally varying signal of carbon dioxide into the lower stratosphere which is evident up to 20 km altitude. Furthermore, he showed that the chemistry climate model EMAC captures the distribution and variability of carbon dioxide in the UTLS well, even in a relatively coarse model resolution. The final talk of the second day was given by **Prashant Singh** (Goethe University, Frankfurt/Main) who presented results from high resolution simulations over the Third Pole region. He demonstrated that the moisture flux shows enhanced values up to 100 hPa in high resolution simulations which is not evident in low resolution simulations or ERA5. After this talk the attendees spread over the city of Mainz to participate in one of the guided tours.

3rd Conference Day

The first session on Wednesday covered topics centered around gravity waves and turbulence in the UTLS. **Ulrich Achatz** (Goethe University, Frankfurt/Main) presented ongoing work on the three dimensional, transient nature of gravity wave propagation in gravity wave parameterizations. He concluded that taking this into account might have only little effect on the extratropical zonal mean circulation, but is important for the intermittency of gravity waves, the gravity wave momentum flux and the Quasi-Biennal Oscillation. **Dominika Hájková** (Charles University, Prague) talked about the controlling factor of the orographic gravity wave parameterization on the resolved stratospheric circulation in CMIP6 models. She highlighted how differences between the models in this parameterization lead to differences in the refractive index and thus to wave propagation and breaking.

Figure 1: *Group picture of the participants of the TPChallenges International Conference in Mainz, Germany. Image credits: E. Licht.*

Andreas Dörnbrack (DLR, Oberpfaffenhofen) presented a case study on very small scale trapped gravity waves at the tropopause. Using airborne observations and idealized 3D modeling he showed that these waves are the result of downward propagating secondary waves with sources in the middle to upper stratosphere. **Victor Avsarkisov** (University of Hamburg) gave the last talk in the first session on kinetic energy and helicity spectra in stratified flows. Derived from theory and also analyzed with high resolution balloon borne observations he demonstrated that both spectra should be considered when analyzing turbulence in stratified flows. The next topic on synoptic scale processes covered four talks. **Tuule Müürsep** (ETH, Zürich) presented new insights from the Lagrangian perspective on how radiation changes potential vorticity in air parcels in the UTLS and potential consequences on stratosphere troposphere exchange. The contribution from **Cornelis Schwenk**, presented by **Annette Miltenberger** (both JGU, Mainz), disentangled the role of various cloud processes within a warm conveyor belt and their impact on the UTLS moisture budget. Their results indicate that convectively lofted air masses contain less water vapor, but larger ice crystals and the convective outflow produces longer lived cirrus clouds than slower ascending air masses.

After a coffee break **Maicon Hieronymus** (JGU, Mainz) introduced a new approach to identify the parameters most sensitive for cloud formation in a model. Using algorithmic differentiation in an analysis of one warm conveyor belt he demonstrated that the geometry of hydrometeors, CCN activation, rain evaporation, and fall speeds are most important in various stages during the cloud lifetime. The session was concluded with a talk by **Falco Monsees** (University of Bremen) on an approach to use satellite ozone observations in the Arctic to identify cyclone pathways and strengths.

Ryan Williams (University of Reading) changed topic to stratospheric processes and showed that SSWs have a mutual impact on the ozone and water distribution at the tropopause and downward transport during Polar Night Jet -Oscillation (PJO)-events, i.e. when polar cap temperature anomalies maximize. The contribution by **Gloria Manney** (NWRA, Boulder/ New Mexico Institute of Mining and Technology, Socorro) was presented by **Michaela Hegglin** (FZ, Jülich/Univerity of Reading) showing trend analysis of the UTLS jet and the importance for regional differences and relation to ENSO. They used a new feature detection algorithm (CAVE-ART) to identify coupling effects between the polar vortex and UTLS jets. **Katharina Turhal** (FZ, Jülich) presented studies and trend analyses of the tropopause based on the PV gradient definition and identified robust trends from different reanalysis data. She showed the relations to ENSO and QBO and vertical trend structure. **Frederik Harzer** (LMU, Munich) presented an evaluation of ozone based metrics to derive trends of the tropical width. They showed that trends derived form the gradient of ozone are consistent with a shift of the subtropical jet in the CMPI 6 models.

The afternoon session was opened by **Luis Milan** (NASA-JPL, Pasadena) who presented recent results from OCTAV-UTLS. Using a variety of coordinate systems, he demonstrated that dynamical coordinates – showing that using dynamical coordinates – particularly adiabatic coordinates - best account for the effect of transport barriers on the mapping of ozone gradients. **Paul Jeffery** (University of Toronto) presented a new approach to identify and quantify sampling biases based on multiplatform climatologies in the same coordinate framework to derive sampling biases. **Irina Petropavlovskikh** (CIRES/NOAA, Boulder) analyzed ozone sondes in dynamical coordinates and derived negative trends in the LMS when accounting for tropopause height trends. **Sarah Bauchinger** (Goethe University, Frankfurt/Main) compared different tropopause definitions for the analysis of aircraft data (IAGOS-CARIBIC) showing a variability reduction of SF6 trends when using dynamical coordinates.

Last Conference Day

The Thursday started with **Bill Randel** (NCAR, Boulder) giving an invited overview talk on water vapor transport and feedbacks in the UTLS, showing that lower stratospheric water (anomalies) and the tropical pipe are under control of the tropical cold point. He presented an analysis showing the good agreement between water vapor and age spectral reconstruction with a very good agreement of the 'young' peak, but less with aged tail. He also showed that the Hunga Tonga eruption affected stratospheric water vapor and the decay of the water vapor perturbation will last for several years until being removed from the stratosphere. **Mathias Kohl** (MPI-C, Mainz) presented a new setup with the EMAC model to consistently simulate aerosol from the surface to the stratopause and pointed out the importance of volcanic eruptions for the correct LMS sulfate budget. He also present simulations of the PHILEAS campaign highlighting the importance of nitrate and organics for the correct aerosol budget in the ATAL and its export to the extratropical lowermost stratosphere (LMS). **Hauke Schmidt** (MPI-M, Hamburg) analyzed the relation between tropical upwelling and climate sensitivity. Their results show that a strengthened BDC leads to a negative feedback on climate sensitivity most likely from an adiabatic cooling effect in the TTL overweighing the warming effect in the extratropical LMS. **Felix Plöger** (FZ, Jülich) analyzed the impact of LMS water on the circulation and showed that increased LMS water vapor may lead to a local cooling, an upward shift of the subtropical jets, a poleward shift of the eddy driven jet and a strengthening of the BDC. **Moritz Witt** (DLR, Oberpfaffenhofen) analyzed the effect of free running to specified dynamics simulations on the distributions of water vapor and ozone distributions. They concluded on stronger isentropic transport and less stratospheric water for the free running simulation, which also better agrees with Swoosh data. Finally, **Thomas Birner** (LMU, Munich) presented his 'ramblings' on the BDC pointing out open aspects of the BDC like the non-geostrophic processes affecting the BDC like gravity wave induced momentum fluxes and insufficient observations to constrain the BDC and mutual trends. He suggested new metrics to conclude on BDC trends such as temperature trends or tropopause height trends to better constrain trend estimates of the BDC.

The meeting highlighted the importance of lower stratospheric processes for the understanding of key uncertainties of the UTLS in the climate system. A major aspect are the factors controlling lower stratospheric water, particularly in the extratropics, involving small scale dynamics, cloud microphysics as well as the large scale circulation, which couple across scales via radiation. A second key uncertainty in UTLS research is related to significant gaps concerning the distribution, composition and impact of UTLS aerosol and their impact on radiation and climate. The broad range of processes and scales require an integral effort from observations and modeling as well as partially new metrics to estimate the potential relevance of these processes on the Earth system.

Next APARC and APARC related meetings

Find more meetings at: www.aparc-climate.org/meeting

16 - 20 September 2024
HEPPA-SOLARIS Meeting
University of Leeds, UK.

18 - 20 September 2024
SSiRC Meeting
ISSI Bern, Switzerland.

14 – 16 October 2024
ESA Water Vapor Climate Change Initiative
Jülich, Germany

28 - 30 October 2024
APARC SSG Meeting
Jülich, Germany

28 October - 01 November 2024
WCRP International Conference on Reanalysis
Tokyo, Japan

09 - 13 December 2024
AGU Meeting
Washington, D.C, USA

2nd International Workshop on The Atmospheric Impacts of the 2022 Hunga Eruption

Graham Mann[1], Bernard Legras[2], Yunqian Zhu[3], William Randel[4] and Paul A. Newman[5]

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Dates:
22 -24 April 2024

Scientific Organising Committee:
Yunqian Zhu, Graham Mann, Paul A. Newman, William Randel

Local Organising Committee:
Clair Duchamp, Sergey Khaykin, Bernard Legras, Aurélien Podglajen, Hélène Rouby, Pasquale Sellitto

Host Institution:
Ecole Normale Supérieure - PSL University, Paris, France

Number Of Participants:
72 in-person and 20 online participants

Contact:
G.W.Mann@leeds.ac.uk

Conference Website:
https://sparc-ht24.sciencesconf.org/

Logos/Sponsors:

Overview

This 2nd Hunga impacts workshop took place in Paris from Monday 22 April to Wednesday 24 April 2024 (the week after EGU), the 1st workshop in May 2023 having been an online event. Part of the APARC cross-activity focus project "Hunga impacts on the atmosphere" (established in February 2023), the workshop links with a 2025 Hunga impacts assessment report, this scheduled to feed into the next WMO/UNEP Scientific Assessment of Ozone Depletion report in 2026.

The workshop had 72 in-person and 20 online attendees, and a format where the first 2 days were an "open science workshop". After community announcements at AGU and via SPARC activity email-lists a total of 56 Abstracts had been submitted, the science programme organised to align with the 7 chapters of the 2025 report.

The 3rd day of the workshop (Wednesday 24 April) was organised differently, the morning session mostly for the 2 chapter co-lead authors to meet with their co-author teams, but with some time set aside for attendees to hear about the chapter plans, and provide additional input or comments. In the afternoon, the full set of chapter teams met in plenary, to present their plans, and co-ordinate planning and any over-lapping areas.

1st Workshop Day

An invited talk by **Larry Mastin** (US Geological Survey) began the workshop, this 1st session focused on *Initial plume evolution, explosivity & emissions* (chapter 1 of the report). The talk presented analysis of the Hunga plume, re: how steam generated from the underwater eruption had boosted the vertical extent of the plume, as well as making the eruption more explosive. **Simon Carn** (Michigan Tech. Univ.) presented updated analysis of SO_2 measurements from satellite UV sensors, new estimates substantially higher than the published 0.4-0.5 Tg, at least 0.8 Tg now thought to have been emitted. **Nickolay Krotkov** (NASA GSFC) presented UV satellite retrievals of sulphate aerosol, a substantial amount present in the first days after the eruption (suggesting direct injection), this sulphur was additional to that in the measured SO_2.

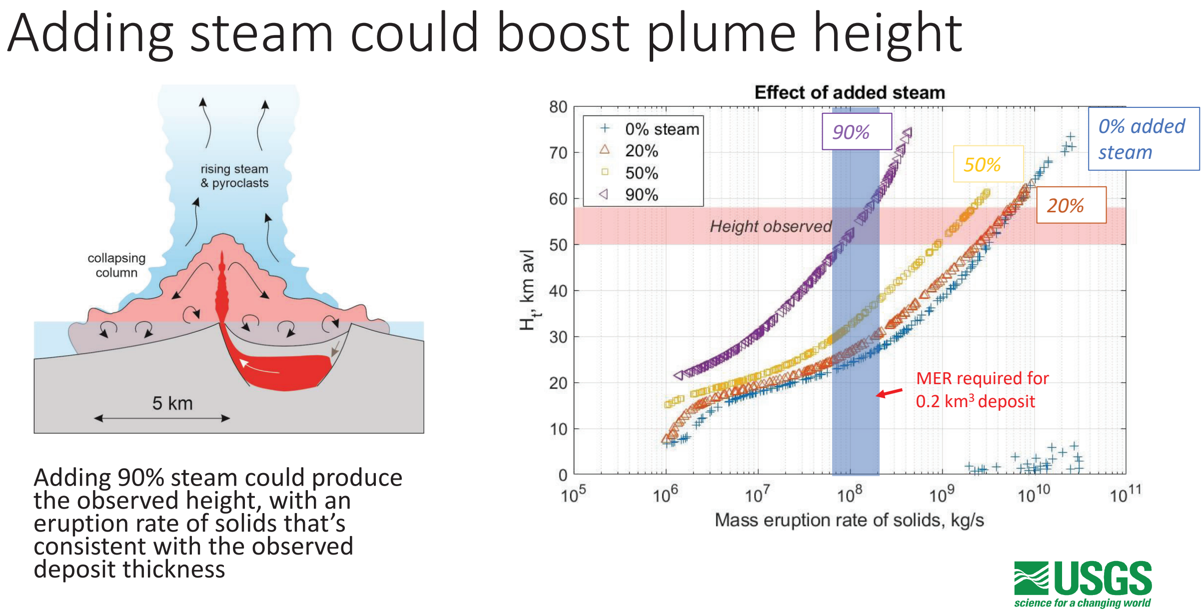

Figure 2: *Slide from invited talk from Larry Mastin (USGS) re: plume-rise thermodynamics gave 58 km vertical-extent for VEI5 water-rich Hunga eruption (steam-boosted plume). Figures 3 and 5 from his recent Bulletin of Volcanology paper (Mastin et al., 2024).*

Akos Horvath (Univ. Hamburg) presented modelling of Lamb waves from the eruption, comparing to observations from GOES-R geostationary satellite measurements. The final two talks discussed chemistry of the initial plume, **Bernard Legras** (LMD-IPSL) presenting analysis of the rapid SO_2 conversion to sulphate, the IASI satellite able to track both aspects independently. An early-phase removal of ash was also discussed, the mechanism via sedimenting ice during the first days after the eruption, a very low depolarization measured from CALIOP satellite lidar in the following days. **Yunqian Zhu** (NOAA CSL) discussed SO_2 oxidation, also analysing whether emitted HCl caused early-phase in-plume ozone depletion.

The 2nd and 3rd sessions of the workshop aligned to the progression of the plume of water vapour and aerosol, as it dispersed meridionally, (chapter 3 of the report). **Elizabeth Asher** (NOAA GML) kicked off the session, observations showing the layer of volcanic aerosol gradually separated from the water vapour (March to June 2022) after an initial phase where both rapidly descended together (first 3 weeks post-eruption). The size distribution of the aerosol determines how rapidly particles sediment (relative to the vertical air motion), and effective radius derived from satellite measurements was compared to balloon soundings from Lauder New Zealand. **Alexandre Baron** (NOAA CSL) then presented further comparisons of the balloon particle counter measurements to UV to mid-visible lidar Angstrom coefficients, and for the later period, through into mid-2023.

Large-scale variations in size distributions derived from AERONET network of sun photometers, were presented by **Marie Boichu** (CNRS/Univ. Lille), showing consistent and widespread large effective radius ~0.4-0.5 μm throughout 2022. Such particle sizes are unprecedented in the AERONET record, and compare to ~0.3 μm after 2019 Raikoke, the Hunga aerosol reaching this size earlier post-eruption than after Pinatubo. **Peter Colarco** (NASA GSFC) gave the first global modelling talk, using GEOS-CCM to simulate the unusual initial descent of the volcanic plume, caused by strong local radiative cooling from infrared emission by water vapour.

Sergey Khaykin (LATMOS UVSQ/Sorbonne) gave an overview of the progression of the Hunga aerosol, also comparing 2022 La Reunion lidar measurements to Mauna Loa lidar measurements after the 1982 El Chichon eruption. The talk discussed how stratospheric AOD in 2024 has returned to near pre-eruption levels, illustrating the different residence time of volcanic aerosols, compared to the continuing water vapour enhancement. Global aerosol microphysics simulations of the Hunga volcanic aerosol were presented by **Graham Mann** (Univ. Leeds). The UM-UKCA model resolves the presence of meteoric aerosol in the background stratospheric aerosol, and partitioning of volcanic sulphur to different types affects sedimentation and strat-trop exchange after moderate eruptions.

Findings from the BraVo field campaign were presented by **Jean-Paul Vernier** (NASA Langley), a series of balloon soundings from Sao Paulo measuring the composition of the volcanic aerosol, with a signature of marine aerosol apparent within the particle size-range sampled. Co-analysis with Sao Paulo ground-based lidar measurements, tracked the progressing Hunga aerosol vertical profile through 2022. **Landon Rieger** (Univ. Saskatchewan) presented analysis of OSIRIS satellite measurements, with also monitoring from the USASK retrieval of OMPS-LP aerosol extinction, the methods using a tomographic method to better resolve the depth of the Hunga aerosol layers.

The properties of the umbrella cloud after the eruption were presented by **Kristen Fauria** (Vanderbilt University), with analysis of volcanic ash deposits and mapping of the extent of the ashfall. She gave an estimate of 1.8 ± 0.4 km^3 of total ashfall, with ten times more material on the sea floor. **Corinna Kloss** (FZ Juelich) presented a global view of observations from the several LOAC balloon campaigns, the early-phase from Reunion Island, later soundings from South Africa (September 2022) and a 2nd South Africa campaign in February 2024.

Completing the 1st day the workshop, the last two talks in the 2nd meridional dispersion session gave a definitive global perspective from satellite measurements of the first two years of the eruption. **Clair Duchamp** (LMD- IPSL) presented analysis of SAGE-III-ISS aerosol measurements, including the key metric of effective radius and the global mass burden of volcanic aerosols, both very stable until November 2022. **Luis Millan** (NASA JPL) gave an overview of the continuing evolution of the Hunga water vapour enhancement, which reached the upper stratosphere and the mesosphere through the tropical upwelling, redistributing mass equally in both hemisphere by February 2023. He explained recent observations indicating enhanced tropopause entry in 2024, this extra source of water vapour offsetting part of the removal during 2022-2023 and discussed the extension of the enhanced water vapour until the end of the decade at least.

Day two of the workshop began with a session aligned to stratospheric temperatures and dynamics (chapter 4 of the report), **Larry Coy** (NASA GSFC) presenting how the strong water vapour cooling induces changes to the stratospheric mid-latitude and tropical circulation. **Matthias Stocker** (Wegener Center for Climate & Global Change) further discussed the temperature changes, including through to the later period, and the role of QBO and ozone variability alongside the Hunga aerosol and water impacts.

Two global modelling talks analysed the longevity of the Hunga stratospheric water vapour increase, with **Eric Fleming** (NASA GSFC, SSAI) presenting results from the GSFC 2D chemistry-climate model, analysing a modest mid-latitude ozone loss and how the QBO progression was affected by, and combined with the water vapour cooling. **Ewa Bednarz** (NOAA CSL) then presented initial analysis of the 10-year WACCM6-MAM co-ordinated HT-MOC model experiment 1, to analyse the longevity of the Hunga enhancement to stratospheric water vapour. The ensemble integrations are designed to explore inter-model influence of polar vortex and the QBO variability.

Ghouse Basha (NARL, Gadanki, India) analysed stratospheric temperatures, with the progressing global dispersion of the water vapour and aerosol, with the remaining excess water vapour in tropical stratospheric reservoir transported up into the upper stratosphere during 2023. **William Randel** (NCAR) also analysed global temperature impacts, the cooling of the stratosphere and mesosphere further explored, into early 2024, attributing to water vapor and ozone a cold anomaly of about 0.5 K, from satellite data and model simulations.

The Hunga impacts on stratospheric chemistry session (chapter 5) began with a talk by **Jun Zhang** (NCAR) re: mid-latitude ozone impacts, analysing heterogeneous chlorine activation on volcanic aerosol in WACCM simulations, including diagnosing deficit from observed tracer-tracer correlations with N_2O. **Christoph Bruehl** (MPI Chemistry, Mainz) presented EMAC model simulations to quantify stratospheric chemistry impacts from Hunga, alongside impacts from 2019 Raikoke and 2019/20 Australia & Canada wildfires.

An overview of the polar ozone impacts from Hunga was presented by **Michelle Santee** (NASA JPL), from a satellite measurement perspective. The Hunga water vapour only reached high southern latitudes after the November 2022 Antarctic vortex break-up, the talk discussing impacts on chemical processing, dehydration and denitrification in the 2023 Antarctic winter, extra water vapour likely having raised PSC temperature threshold and generated a very early formation.

Figure 3: *Group photo of in-person Hunga impacts workshop attendees gathered at Ecole Normale Superieure, PSL University, Paris.*

Xin Zhou (Chengu Univ) presented modelling to assess the longevity of the Hunga water vapour, simulations in the TOMCAT chemistry transport model demonstrating that dehydration each Antarctic winter represents an important removal process for how rapidly the Hunga excess water vapour will be removed. **Marcel Snels** (CNR, Rome) presented lidar observations of PSCs from Concordia station on the Antarctic plateau. Enhanced ice PSCs were measured in September 2023, the measurement days corresponding with enhanced stratospheric water vapour. **Luke Oman** (NASA GSFC) presented GEOS-CCM general circulation model projections of the water vapour longevity, exploring also impacts on hydroxyl concentrations in the stratosphere, increased due to the enhanced water vapour, and thus shortening SO_2 lifetime.

Aligned to chapter 6 of the 2025 Hunga report (upper atmosphere effects & H_2O transport in deep BDC branch), **Sandra Wallis** (Univ. Griefswald) presented modelling in the UA-ICON model, to quantify Hunga impacts on the mesosphere, related to a hypothesis of increased polar mesospheric clouds (PMCs) observed after Krakatau. **Wandi Yu** (LLNL) also analysed H_2O vapour transport to the upper atmosphere, from WACCM model simulations for HT-MOC model experiment 1. Although an enhancement in mesospheric water vapour was seen from the eruption, the magnitude was not sufficient to trigger additional PMCs.

The final 4 talks of the workshop were on the topic of the net radiative effects from the Hunga eruption, and magnitude of surface cooling/warming from the eruption (chapter 7). **Georgiy Stenchikov** (King Abdullah Univ, Saudi Arabia) introduced the instantaneous and effective radiative forcing metrics, presenting results from WRF-Chem interactive stratospheric aerosol and water vapour Hunga simulations. The model predicted well temporal variation in effective radius, and the analysis included to benchmark the online radiative effects to offline line-by-line radiative transfer calculations.

Mark Schoeberl (Science & Technology Corp.) presented analysis of the net radiative effects from the Hunga aerosol and excess stratospheric water vapour, within QBO and strat-ozone variations, finding both 2022 and 2023 were net cooling overall. Pasquale Sellitto (LISA-IPSL) presented analysis of the IASI co-retrievals of SO_2 and stratospheric aerosol optical depth and radiative effects analysis showing the first month post-eruption was net warming (+0.2 Wm^{-2}), +0.8 Wm^{-2} stratospheric water vapour, offset by -0.6 Wm^{-2} volcanic aerosol radiative forcing. **Gunnar Myhre** (CICERO, Univ. Oslo) analysed the eruption's stratospheric water vapour forcing, factoring in the effects to 2004-2022 hindcasts in CESM2-CAM6.

Since the 2023 workshop, a consensus has emerged that the eruption's radiative effects were net cooling in 2022 and 2023. However, one of the key questions remaining highly uncertain, is the magnitude of the longer-term net radiative effects from the eruption. After the open science workshop, a discussion session was held, for the Hunga Tonga Model-Observation Comparisons multi-model activity (HT-MOC) for stratosphere-resolving chemistry-climate models. HT-MOC experiment 1, has models running 10-year interactive projection ensembles for the longevity of the Hunga excess water vapour in the stratosphere, experiment 2 to assess 2022 meridional transport of water vapour and aerosol, and 2023 Antarctic ozone loss.

Within the poster sessions, discussions continued re: differences among satellite retrievals of aerosol extinction during the Hunga period with posters on the different OMPS-LP retrievals from NASA GSFC (**Ghassan Taha**) and Univ. Bremen (**Christine Pohl**), and aligned to the earlier talk from chapter 2 lead-author **Adam Bourassa** (Univ. Saskatchewan). A poster comparing the OMPS-LP aerosol extinction products to SAGE-III-ISS aerosol measurements was presented by **Mahesh Kovilakam** (NASA LaRC). The analysis links with a new activity from the ISSI stratospheric aerosol measurements international team, this scoping the future integration of OMPS-LP into the GloSSAC satellite-based stratospheric aerosol climatology.

The role of internal climate variability, within Hunga's climate impacts, was explored in poster by **Davide Zanchettin** (Univ. Venice), aligned to the multi-model HT-MOC experiment 1 projections. Other key poster discussions involved analysis to understand the role of feedbacks in the climate system, **Yi Huang** (McGill University) inter-comparing three different metrics of the Hunga radiative forcing: instantaneous radiative forcing, stratospheric adjusted forcing and effective radiative forcing, a key question being the influence of cloud feedbacks.

ESA Water Vapour Climate Change Initiative (WV_cci)
2nd User Workshop

Following the success of the first ESA Water Vapor Climate Change Initiative User workshop, we are pleased to announce a 2nd User workshop

Dates: Monday 14 (1 pm CEST) – Wednesday 16 October 2024 (3 pm CEST)
Topic: Challenges around atmospheric water vapour
Location: Forschungszentrum Jülich (Germany) and online
Website: https://events.spacepole.be/event/196/

Abstract submission deadline: Thursday 15 August 2024
Registration deadline: Sunday 1 September 2024

Topics of the workshop include:

- Discuss challenges related to the generation of water vapour CDRs.
- Show-case climate applications of water vapour CDRs.
- Collect and update user requirements for atmospheric water vapour.
- Present and discuss results from climate analysis, climate applications, and process studies using water vapour CDRs.
- The effect of the Hunga Tonga – Hunga Ha'apai eruption on the stratosphere and resulting impacts on the troposphere
- Water vapour in NWP models.

More details on the project are available at: https://climate.esa.int/en/projects/water-vapour/

A Report on Stratosphere-Troposphere Interactions and Prediction of Monsoon weather EXtremes (STIPMEX) Workshop

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Dates:
2 -7 June 2024

Scientific Organising Committee:
Suvarna Fadnavis, Dr. R. Krishnan, Dr. M. Mohapatra

Host Institution:
Indian Institute of Tropical Meteorology

Number Of Participants:
310 in-person participants from 25 different countries and about 500 online participants

Contact:
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Conference Website:
https://sparc-extreme.tropmet.res.in/

Logos/Sponsors:

Overview

The international workshop on "Stratosphere-Troposphere Interactions and Prediction of Monsoon weather EXtremes (STIPMEX) was held at the Indian Institute of Tropical Meteorology, Pune, India, during 2 - 7 June 2024. The workshop theme acknowledges the strong linkages between processes related to stratosphere-troposphere interactions and challenges in predicting monsoon weather extremes. A better understanding of such linkages and their implementation in atmospheric models is imperative, especially with the growing concern about the Asian summer monsoon (ASM) and the related rise in extreme precipitation events over the Asian and Indian regions during the past decade. STIPMEX has brought together international and national experts in the fields of stratosphere-troposphere research and extreme weather prediction to exchange knowledge and recent findings and to discuss how better representation of stratospheric processes can help to improve the skills of weather forecasts. A capacity building component was included through dedicated training given to students and early career scientists and academicians.

The workshop was supported by MOES, WMO, WWRP, APARC, WCRP, ACAM, WGTMR, Forschungszentrum Jülich, Germany, and SSiRC. There was an overwhelming response to this workshop with about 310 participants from India and another 24 countries (see Figure 4), and an additional ~ 500 online participants.

The workshop began on 2 June with hands on training given to 120 students. The training covered a broad scope from observations to modelling and included (1) preparation and launching of a balloon sonde carrying several state-of-the-art instruments including a RS41 for met parameters, an ozone sonde, a Cryogenic Frost Point Hygrometer (CFH) for water vapour, and a Compact Optical Backscatter Aerosol Detector (COBALD), (2) simulations and analysis of chemistry-climate model and reanalysis data for understanding the stratosphere-troposphere interactions process understanding, (3) specialised talks from international experts on scientific challenges required for improving the skills of weather forecasts and (4) hands-on experience with ECMWF forecast outputs.

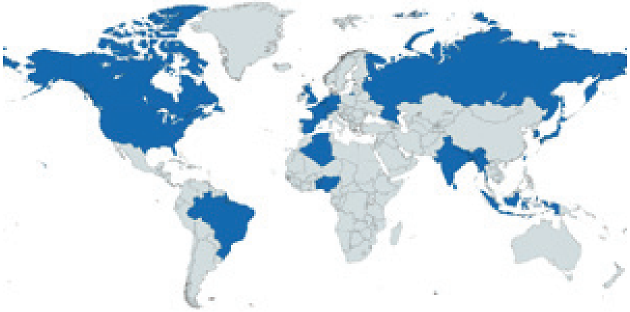

Figure 4: *The 24 countries (blue) where participants were from.*

Figure 5: *Attendees of the STIPMEX Hands-on training.*

Figure 6: *Attendees of the STIPMEX Hands-on training.*

During 3 - 7 June, there were 33 invited talks, of which 16 % were given by women, 44 orals (23 % by women) and 144 poster presentations (43 % by women). There was large interaction during the oral and poster sessions on Stratosphere-Troposphere interaction processes and Monsoon weather Extremes.

Keynote talks

There were 5 keynote presentations during the workshop, one in the STI theme and 4 in the extreme weather theme. The keynote in the STI theme was delivered by **Michael Höpfner**. In his talk, Höpfner presented a comprehensive overview of the Asian Tropopause Aerosol Layer (ATAL) and insights gained from multi-platform observations. He concluded his talk highlighting potential areas for significant progress within the atmospheric community. The first keynote presentation on the extreme weather theme was given by **D.R. Pattanaik** on the operational challenges in predicting heavy rainfall events. He emphasised advancements in forecasting heavy rainfall across India while also addressing ongoing challenges and potential areas of improvement. In the second keynote presentation, **Xubin Zeng** provided an overview of the GPEX project under WCRP. Stressing the timeliness for involvement in field campaigns, dataset development, modelling for process understanding, and capacity building, he underscored some of the project outcomes related to mesoscale convective systems, tropical cyclones, monsoons, and atmospheric rivers. In his keynote presentation, **Dev Niyogi** presented an overview of their work on Cities, Urban digital twins and weather/climate extremes. He highlighted that the AI/ML methods could be used effectively to overcome the challenges modelling community faces. The subgrid-scale processes can be emulated and improved based on training from observation and high-resolution model simulation. The last keynote was presented by **Vimal Mishra** on the Early Warning System of Hydrological Extremes in India. He emphasized that future advancements in extreme weather prediction hinge on the use of higher-resolution models, which can forecast rainfall and temperature with greater accuracy. Additionally, he noted that human influence on land use changes and policies must be considered alongside these technological improvements.

Invited talks

In addition to the keynotes, there were 18 invited talks on the STI theme and 15 on the extreme weather theme. **Greg Carmichael** presented the GAW initiative for atmospheric composition measurements by coordinated operation measurements. **Mijeong Park** highlighted the critical role of the cold point tropopause, convection, and waves in transporting water vapour to the stratosphere. **R. Krishnan** illustrated the impact of major volcanic eruptions on the coupling between the El Niño Southern Oscillation and the Indian monsoon. **Simone Tilmes** demonstrated the significant impact of stratospheric aerosols on the climate, detailing their efficiency, effects, and associated uncertainties. **Bala Govindasamy** discussed the potential impact of stratospheric aerosol geoengineering on tropical monsoon rainfall. **M. Venkat Ratnam** presented

Figure 7: *Attendees of the International Workshop STIPMEX.*

the variability of the Asian summer monsoon anticyclone (ASMA). **Ren Smith** highlighted key findings from the 2022 ACCLIP campaign and role of monsoon convection in facilitating the transport of pollution to the UTLS. **Jean-Paul Vernier** provided an overview of the inter-annual variability of the ATAL, using various satellite and airborne measurements. **Marc von Hobe** highlighted the significant impact of stratospheric composition on surface weather and climate. **Manish Naja** presented the impact of convection, transport, and stratosphere-troposphere exchange on the variability of tropospheric ozone over Nainital, India. S**uvarna Fadnavis** presented a study on the influence of the elevated aerosol layer in the UTLS within the ASMA on Indian summer monsoon rainfall. **Peter Hitchcock** delivered an overview of the SNAPSI project, illustrating how the stratosphere enhances sub-seasonal predictions. **David Plummer** highlighted the challenges and the imperative for conducting multi-model intercomparisons of chemistry-climate models. **Rolf Müller** showcased the reconstruction of high-resolution, in-situ vertical profiles obtained from recent airborne and balloon-borne campaigns in the sparsely monitored Asian monsoon region. **Bärbel Vogel** elucidated the pathways through which Asian summer monsoon air enters the northern lower stratosphere, drawing on findings from the PHILEAS campaign in 2023. S**eok-Woo Son** provided an overview of the impact of the QBO-MJO connection on South Asian precipitation. **T. G. Shepherd** stressed the importance of exploring the narrative of climate risk, integrating the highest quality information from various sources. **Bhupendra Bahadur Singh** discussed the evolution of hydro-meteorological extremes during the monsoon season in India. **Vijay Tallapragada** described the NOAA's next-generation unified forecast system (UFS) for research and operation spanning from medium range to sub-seasonal to seasonal scale. **Kerry Emanuel** emphasized on global warming's impact on CAPE. **Estibaliz Gascon** discussed advancements in extreme weather prediction, highlighting ECMWF's strategy, products, and the Destination Earth initiative. **Pankaj Kumar** emphasised that achieving optimal model complexity and performance necessitates extensive experimentation and fine-tuning. **Fanglin Yang** talked about the development of the NOAA unified forecast system. **Takuya Kawabata** discussed the forecasting of severe local storms with advanced DA and ensemble methods. **Paul Davies** elucidated the dynamics and interactions of extreme weather and large-scale atmospheric processes. **Saulo Freitas** highlighted that the inclusion of spatio-temporal interaction between different convective events improves the model convection. **R. Ashrit** presented the use of an AI-based hybrid approach that can help to improve monsoon predictions. **P. Mukhopadhyay** pointed out the challenges models encounter in predicting the intensity of extreme rainfall events and stressed the need for higher resolution. **W. K. Tao** discussed the development and application of cloud-resolving models to enhance precipitation process studies. **Toru Terao** presented the aspects of the Asian summer monsoon circulation and precipitation, focusing on the influence of high moist static energy air masses. **Pierre Gentine** emphasized how AI can enhance our understanding of climate processes and drive new discoveries through improved emulation. **Sisir K. Dash** emphasized the significant impact of extreme weather on the power sector. **V.K. Kodali** discussed the IFLOW system, which integrates multiple models to provide flood warnings and identify vulnerable areas.

Figure 8: *Attendees of the training sessions of STIPMEX.*

Breakout Discussions

The major recommendations during the discussion were testing models with high tops in the mesosphere, with the full stratospheric processes for extreme weather prediction. There was also a recommendation on high-resolution modelling, Quantum Computing, along with hybrid AI/ML and physics-based models to tackle challenges faced by the global modelling community for extreme weather prediction. Physics-based approaches must go hand-in-hand with AI/ML-based approaches to tackle scientific problems. Many colleagues from both communities also identified a need for more observations from various platforms. In particular, more ground based observations of greenhouse gases and chemical tracers over India and other underrepresented regions in Asia, Africa and South America would help to constrain and improve atmospheric models. During discussions, it became evident that quite a few existing observations currently remain invisible to modelers and the international community, which is an issue that needs to be addressed.

Papers presented in this international workshop will be published in special issue of the Copernicus Journals Atmospheric Chemistry and Physics and Weather and Climate Dynamics

Figure 9: *Inauguration of the STIPMEX workshop.*

Figure 10: *Acknowledging Jean-Paul Vernier as an invited speaker.*

Figure 11: *Poster session at the STIPMEX workshop.*

Call for Proposals:

WCRP 2024 Global South Fellowship: focus on Africa

The World Climate Research Programme (WCRP) announces a research fellowship with a focus on Africa. The fellowship is available through WCRP's new Global South Fellowship program.
The objective of the Global South Fellowship program is to give early to mid-career researchers* from the Global South the benefit to develop their own WCRP related research activity, thereby boosting climate research activities in their own region. Fellowship topics can address a wide range of scientific questions outlined in the WCRP Science and Implementation Plan as formulated through priorities of WCRP activities (Core Projects and Lighthouse Activities).

For this 2024 call, WCRP is soliciting research proposals from early to mid-career candidates from the African continent. Such proposals must be supported by a host institution guaranteeing that a successful candidate will undertake the fellowship project full-time during the agreed period of the fellowship at the institution. Successful projects should address aspects of critical gaps in WCRP related African climate research, enhance climate action for and in Africa, help build a community of practice, and create the potential for leaving a strong legacy to build upon in the longer-term. As an example, proposals could catalyze development of community of practice for the climate-policy interface. Another example would be thematic idea of climate literacy, or the non-congruence of climate information for policy makers and different stakeholders. Successful projects should propose research that has the clear potential to be transformative and a develop a foundation for African researchers to lead a WCRP (legacy) project. The proposal should include links to relevant WCRP core activities, where appropriate.

Award details:
The WCRP leadership has allocated CHF 50K for a Global South Fellowship with focus on Africa. The award is intended to support the salary of one researcher. Each proposal needs to provide a detailed description of the research project, accompanied by a budget explaining how the resources will be utilized and over what duration, as well as whether there are any other resources that may be leveraged. The fellowship is intended to ideally start in late 2024 (subject to negotiations). The proposal should be accompanied by a letter of commitment written and signed by the host institution. Eligible costs can include (1) salary of the candidate comparable to host institution cost of employment; (2) travel support to a relevant WCRP meeting and essential local travel for research purposes; (3) purchase of an approved laptop. If necessary, institutional overhead can be negotiated. However, no equipment can be covered.
The successful applicant of this open call will be selected by the WCRP fellowship selection committee based on the submitted proposal and an oral/online interview, both of which must be outstanding and be clearly aligned with WCRP strategic objectives. The fellowship selection committee will consist of JSC members and leading members from the African research community.
Interested candidates are strongly encouraged to review WCRP's Science and Implementation Plan and the description of WCRP's Core Projects and Lighthouse Activities therein and build their project in consultation with the co-chairs of relevant WCRP groups.

Applications should be submitted only online through the link:
Application Form: https://airtable.com/app2qHWYfngYiwBD5/pagiynVBWuczWafM3/form
Proposal Template: https://wcrp-climate.org/images/Fellowship_Africa/ResearchProposal_template_July11_Final.docx

The deadline for submitting applications is 30 September 2024.
For more detailed information regarding this call and if you wish to find potential collaborators within WCRP, please contact Hindumathi Palanisamy (hpalanisamy@wmo.int) cc'ing Lian Xue (lxue@wmo.int).

Disclaimer: The research proposal must be supported by a host institution guaranteeing that a successful candidate will undertake the fellowship project full-time during the agreed period of the fellowship at the institution. The WCRP Fellowship for Africa agreement will be signed between WMO and the host institution only and not with any individual candidate.

Panel Discussion on "Future of Middle Atmosphere Science" at the AMS 22nd Middle Atmosphere Conference

25 June 2024
Panellists: Amanda Maycock[1], Peter Hitchcock[2], Jessica Neu[3]
Moderator: Pu Lin[4,5]
Text written by the AMS Middle Atmosphere Committee

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[2]Department of Earth and Atmospheric Sciences, Cornell University, Ithaca, New York, USA
[3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA
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[5]Geophysical Fluid Dynamics Laboratory (NOAA), Princeton, NJ, USA

As part of the AMS 22nd Middle Atmosphere (MA) Conference the AMS MA Committee organized a panel discussion broadly oriented at the "Future of Middle Atmosphere Science", centred around three main themes: uncertainties in future changes in the stratosphere (Dr. Amanda Maycock), the future of observational monitoring of the stratosphere (Dr. Jessica Neu), and the influence of the stratosphere on seasonal-to-subseasonal (S2S) surface weather prediction (Dr. Peter Hitchcock). In discussing gaps in our understanding of MA climate, Amanda identified a strong disconnect between the MA research community and the broader (largely tropospheric) climate community, despite growing evidence that the stratosphere affects Earth's surface, not only on climatic, but also S2S timescales, as emphasized by Peter. Amanda also stressed that the role of the stratosphere in climate feedbacks, specifically stratospheric water vapour, "is not in the top 10 list" of broader discussions of feedbacks within the climate system. Furthermore, Jessica pointed out that recent events like the Hunga Tonga-Hunga Ha'apai eruption highlight new ways in which the stratosphere impacts both surface climate and stratospheric composition, beyond historical chlorofluorocarbon-induced polar ozone depletion. Currently, however, climate indicators employed in climate assessments have little to no consideration of stratospheric change, while the unavoidable gap in the satellite network in the near future – exacerbated by the imminent decommissioning of NASA's Microwave Limb Sounder – will render trend detection in the stratosphere more challenging.

Moving forward, the panellists and their audience agreed on the need for the community to focus on better integrating MA science in the broader context of global climate change and on more creatively applying a broader range of observations in wake of potential gaps in satellite coverage. The panellists discussed more frequent and innovative sub-orbital measurement strategies, as well as the utilization of advanced tools such as machine learning techniques and ultra-high resolution model simulations. Improved communication of the exigency of MA research to the public, as well as to the broader climate science community, may also require modifying the conventional view of the atmosphere as distinct layers to better emphasize strong coupling between the troposphere and stratosphere, offering our expertise to evaluate climate mitigation strategies (e.g., stratospheric aerosol injection), and redesigning meetings around cross-disciplinary topics that demonstrate how the stratosphere is interconnected within the coupled Earth system. Promoting the use of specific stratospheric indicators as test cases for sensitive detection of anthropogenic climate forcing – as well as the impacts of future mitigation strategies – was also raised. Finally, the panellists noted that emphasis should also be placed on entraining early career leadership through more summer schools, outreach targeting less accessible universities, mentoring on an international level and rewarding more ambitious research focused on fostering connections across disciplines, agencies and between academia and government. As the advocacy of MA research and its significance may be challenged by other important priorities for advancing climate science, we as a community will be most effective by assuming a united voice.

The Earth Explorer EarthCARE is launched

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The Launch

On the 28 May the time has finally come that EarthCARE, the Earth Cloud Aerosol and Radiation Explorer, was launched and sent its first signals back to Earth. The mission comes just right in time to continue NASA's successful tandem missions CALIPSO/CloudSAT, which ended in 2023, and to start a new era of atmospheric satellite observations. The joined mission by the European Space Agency (ESA) and the Japanese Aerospace Exploration Agency (JAXA) was launched with a Falcon 9 from SpaceX in Vandenberg, California, US (Figure 12). The countdown ran like clockwork and the launch was perfect. About ten minutes after take-off separation took place and the EarthCARE satellite could be seen drifting away (Figure 13). This was a very emotional moment for the whole team. But the relieving moment was yet to come with the first signals acquired at the satellite receiving station in Hartebeesthoek, South Africa. The signal was received and EarthCARE told us it was well with all systems nominal and the solar array already deployed. As soon as the first instruments are running smoothly the work starts for the Calibration and Validation teams.

Figure 12: *ESA's EarthCARE satellite lifted off on a SpaceX Falcon 9 rocket from the Vandenberg Space Force Base in California, US, on 28 May, 15:20 local time. Image credits: ESA - S. Corvaja.*

What to expect from this mission?

EarthCARE is the most complex Earth Explorer mission ESA ever built, with an unprecedented accuracy of measurements in space. This mission will advance our understanding of the role that clouds and aerosols play in Earth's climate system, reflecting incident solar radiation back into space, as well as trapping infrared radiation emitted from Earth's surface. While the understanding of cloud and aerosol feedback mechanisms on climate and weather in numerical weather and climate models has steadily improved since EarthCARE was selected as the sixth of ESA's Earth Explorer Mission in 2000 (Illingworth et al., 2015), there are still few data sets of co-located observations that provide high-resolution vertical profiles of clouds and aerosols in parallel with high resolution radiation budget measurements for verification and further process understanding.

To answer key scientific questions, i.e., to better understand the role of aerosols and clouds and their radiative effect on climate, EarthCARE will provide important observables with its four instruments (Wehr et al., 2023):

- *Atmospheric LIDar* ATLID: This is one of two active remote sensing instruments and consists of a linearly polarized High Spectral Resolution Lidar (HSRL) operating at a wavelength of 355 nm designed to characterize aerosols, clouds and precipitation. It will provide vertical profile information from the ground to 40 km, with 100-500 m vertical resolution on 280 m horizontal sampling. The first Level 1 data product will be attenuated backscatter profiles.

- *Cloud-Profiling Radar* CPR: The second active remote sensing instrument is the first Doppler radar in space, designed and maintained by JAXA, which allows to detect also moving hydrometeors. It operates at 94 GHz with a 2.5 m deployable antenna and has a viewing range of -1 km to 20 km from nadir. The horizontal resolution is 800 m and a vertical resolution 500 m. The L1 data will be radar reflectance and doppler-velocity.
- *Multispectral Imager* MSI: This instrument will measure infrared and reflected radiation in a 150 km swath (-35 km to +115 km from the nadir point), 500 m resolution, in seven visible and thermal infrared spectral bands. It will complement the ATLID and CPR measurements along the flight path with additional information on aerosol and cloud characteristics. The first order data product will be radiances (VNS), brightness temperature (TIR).
- *Broad Band Radiometer* BBR: Entire solar backscatter (SW 0.25 μm to 4 μm) as well as terrestrial radiation (LW 4 μm to > 50 μm) is measured by the second passive remote sensing instrument. The instrument is an imaging radiometer with three telescopes with different fixed observation angles (0, ± 55°) with a spatial resolution of 10 x 10 km and a spatial sampling of 1 km. This measurement setup allows the signals to be traced back to different heights between the satellite and the ground, which in turn makes it possible to calculate the radiant flux. The first order data product (L1) will be solar and thermal TOA radiance.

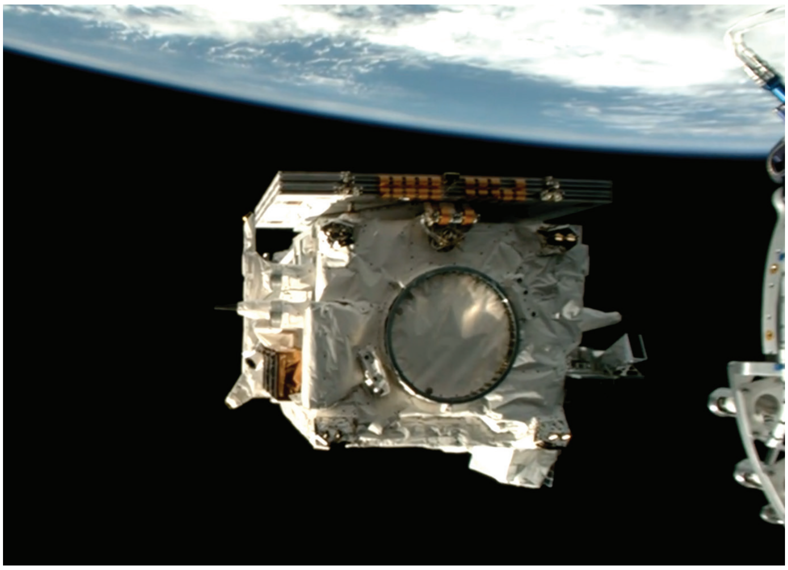

Figure 13: *Deployment of EarthCARE from its launcher, ten minutes after liftoff. Screenshot from ESA WebTV "Taking EarthCARE into orbit". Image Credits: SpaceX*

Table 2: *Satellite specifications of EarthCARE*

Body	Start-Configuration	4.2 m x 3.5 m x 2.5 m
	Flight-Configuration	17.2 m x 3.5 m x 2.5 m
Mass	Total	2.210 kg
Power	Total	1.560 W (on average)
Duration	planed	3 years
Orbit	Sunsyncronous	
	Local time	14:00 (Descending Note)
	Altitude	389 km
	Inclination	97°
	Re-Visit	25 Days

But you can expect more from EarthCARE than only four separate data products from the four instruments. Due to the simultaneous measurements there will be numerous synergistic data products related to clouds, aerosols and radiation. An overview on the different data types and levels that will be available after the commissioning phase is given in Figure 14. All that will be accessible through ESA's eogateway and a detailed description of the data products can be found in the AMT special issue by Wandinger et al. (2024) and in Eisinger et al. (2024), which comprises all the necessary information's for scientists.

For the fundamental questions of radiative closure, EarthCARE provides vertical profiles of clouds, aerosols and precipitation from the nadir angle, spatially resolved cloud-aerosol scenes spanning the satellite track, and fluxes of solar and thermal radiation. Some datasets might not be completely new in atmospheric science, but with its measurements and therefrom derived synergistic data, EarthCARE will set new standards for atmospheric observations. Here we want to name only a view highlights of these synergistic data products:

- AC-TC: This is a synergistic product of the instruments ATLID and CPR and provides a target classification of aerosol and cloud scenes.
- ACM-CAP: Cloud and aerosol properties from ATLID, CPR and MSI, providing liquid cloud-ice cloud-rain water content and effective radius or diameter, aerosol number concentration and extinction.

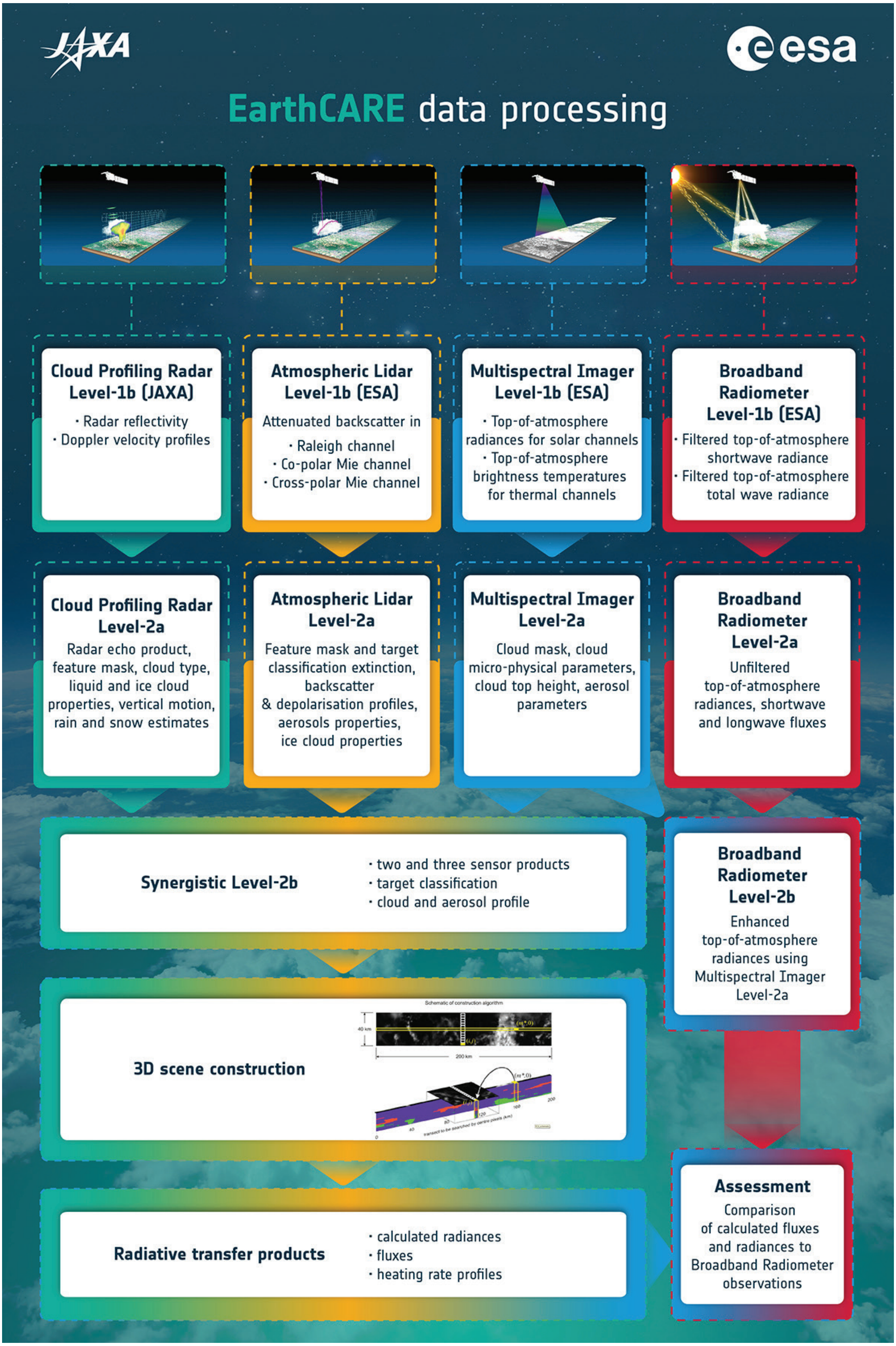

Figure 14: *Overview of the data products available after launch of EarthCARE, shown in a flow chart. Image credits: ESA*

- ACMB-3D: From all four instruments a 3D scene of the atmosphere is constructed.
- ACMB-DF: Radiative closure assessment, comparing broadband radiances and fluxes measured by BBR to broadband radiances and fluxes derived from radiative transfer models for the two atmospheres.

In general, the data processing chain is organized into levels from level 0 (L0) up to level 2 (L2). The time-sorted raw data from the sensors and housekeeping data are defined as L0 and will not be available to the public. The L1 data has four subclasses spanning data products from pre-processed data of the individual instruments, and calibrated data respective instrument "native"-grid, up to special data products for higher product levels. The L2 products, which refer to derived geophysical variables with the common or "native"- grid resolution, are separated into two EarthCARE specific sub-levels, being L2a: L2 data product derived from individual EarthCARE instruments; and L2b: L2 data products derived from synergistic measurements of EarthCARE instruments.

Data processing up to Level 1 products is managed by the respective space agency responsible for the instrument. This means that ESA is responsible for the Level 1 products of the instruments ATLID, MSI and BBR, while JAXA is for the Level 1 product of CPR. For the Level 2 products, independent algorithms for processing were developed by both JAXA and ESA. A detailed description of the individual products of the different levels can be found in Eisinger et al. (2024).

In addition to answer the key scientific questions on the Earth's radiation budget, EarthCARE data products will also be operationally used in ECMWF's Integrated Forecasting, which will improve the accuracy of weather forecasts.

What is EarthCARE without scientists?

Now that EarthCARE is launched and has completed its launch and early operations, it entered the commissioning phase. In this phase EarthCARE undergoes functional checks, the payload instruments are calibrated and characterized, and in-orbit performance verifications are made. This phase is meant to last about six months, before first Level 1b data will be released to the public towards early 2025. These activities are accompanied with many field campaigns to provide ground-based and airborne measurement data for calibration and validation of the satellite payload.

One of the largest efforts in this regard is the flight campaign PERCUSION (Persistent EarthCARE underflight studies of the ITCZ and organized convection), which is carried out by the German research aircraft HALO (High Altitude and LOng range, Figure 15). This aircraft is very well known by the APARC-Community and does not need any further introduction. However, for this campaign it is deployed with an EarthCARE-like payload, which consist of the following instruments:

- HSRL-Lidar (WALES): The high spectral resolution lidar on HALO measures profiles of aerosol and cloud backscatter, extinction and depolarization at 532 nm and is provided by the German Aerospace Center (DLR). It represents the ATLID instrument on EarthCARE.
- Cloud-Profiling Radar (MIRA35): The Doppler radar, jointly deployed by DLR, MPI Hamburg and University Hamburg, is operating at 35 GHz and represents EarthCARE's CPR.
- Hyper-Spectral Imager (specMACS): The Ludwig-Maximilians-University Munich (LMU) provides

Figure 15: *HALO in preparation for the next campaign in front of the hangar. Image credits: Andreas Minikin (DLR-FX).*

the hyper-spectral radiometer and it will validate the MSI instrument on EarthCARE.

- Radiometers: EarthCARE's BBR is validated with multiple instrumentation onboard HALO. University of Leipzig provides a long wave radiation imager (VELOX), but also HALO is equipped with a solar and terrestrial radiometer (BARCARDI).
- Additional Instruments: WALES provides additional water vapor profiles using differential absorption lidar (DIAL) technique and dropsondes will be provided by MPI Hamburg.

With this payload, HALO is the most complete airborne payload capable of mimicking EarthCARE. The great benefit of an airborne demonstrator is its targeted applicability. For example, measurements of various meteorological situations could already be carried out in dedicated pre-launch campaigns (Schäfler et al., 2018; Stevens et al., 2019; Stevens et al., 2021) for the characterization and pre-validation of EarthCARE algorithms and retrievals. During the validation of EarthCARE after launch, HALO makes it possible to carry out targeted coordinated underflights, which enables a quasi-direct comparison of the measurements.

The PERCUSION campaign, jointly led by the Max-Planck-Institute of Meteorology Hamburg and the DLR Institute of Atmospheric Physics, is one of seven sub-campaigns in a larger effort called ORCHESTRA (Organized Convection and EarthCARE Studies over the Tropical Atlantic) in which many other European institutes with various measuring platforms (e.g., ground-stations from EARLINET, FS METEOR vessel, drones, other aircrafts such as the Romanian INCAS King Air and French SAFIRE ATR-42) are involved. The overarching goal of the campaign is to better understand the physical mechanisms that organize tropical mesoscale convection and the impact of convective organization on climate and Earth's radiation budget.

The PERCUSION campaign itself is divided into three parts at three locations and follows a strict timetable to not only catch EarthCARE for coordinated underflights, but also to coordinate with other platforms for simultaneous measurements. Starting on 8 August, HALO will first be based at Sal on Cape Verde and after three weeks will move to Barbados for another three weeks of campaign activities. The third and final part of this campaign is fully dedicated to EarthCARE Cal/Val and will be carried out from HALO's homebase at DLR in Oberpfaffenhofen, Germany.

While HALO and other airborne platforms are providing valuable data for validating and calibrating EarthCARE, an additional large number of ground-based stations (LACROS/EARLINET/ACTRIS) equipped with similar instruments as the satellite payload will support the EarthCARE commissioning phase.

What happens next?

As soon as all instruments on EarthCARE are successfully calibrated and running smoothly, the mission will move into its operational phase. For the data user this means EarthCARE is ready to share its data with the public. But for EarthCARE this means a lot more.
At this stage the DISC Team (Data, Innovation, and Science Cluster) is now taking over the responsibility to study and improve the data quality of EarthCARE products. The DISC is ESA's data quality framework for the EarthCARE mission and is comprised of an international expert consortium with various key tasks:

- End-to-end system performance monitoring with the systematic routine quality control of the instrument performance as well as the Level 1 and Level 2 products.
- Long-term monitoring of the instrument performance as well as Level 1 and Level 2 products against the mission requirements.
- Assessment and optimisation of calibration and characterization of all instruments and baseline evolution of the operational calibration processing.
- Validation of the products in collaboration with the independent EarthCARE Validation team
- Maintenance and evolution of the ESA ground data processors in order to meet and if possible, exceed the required product quality.
- Coordination and support of outreach activities.

Scientific applications of EarthCARE data

There are various areas of application for the use of EarthCARE data, both in the field of observation and in the development of models. The mission does not only provide an extension of space borne lidar measurements from CALIPSO and radar measurements from CloudSAT. Due to the innovative combination of EarthCARE's remote sensing instruments, the large amount of synergistic Level 2 data will open up numerous new possibilities to effectively use the data and enlarge the scientific field on aerosols, clouds, its interactions and the implications for climate science.

For example, the synergistic lidar-radar products from ATLID and CPR will play a major role in further development of models and for reanalysis data. But EarthCARE data also has a wide range of applications with regard to validation of retrievals. By determining various physical cloud variables from the ATLID and CPR data, it is possible to determine basic data for radiative transfer calculations and subsequently calculate radiative closures. The further development of cloud retrievals can also be well advanced with EarthCARE data, as the range of synergistic data between ATLID, CPR and MSI means that the atmosphere structure in a 3-dimensional space is well represented and, for example, aerosol layers as well as mixed-phase clouds can be better characterized.

By combining EarthCARE data with aircraft measurements or other satellite data, such as CALIPSO, various observed phenomena can also be statistically analyzed also on a long-term trend. Special care must be taken when combining lidar data, as data conversion is required for different wavelengths (i.e., EarthCARE: 532 nm, CALIPSO: 355 nm).

These are only a view possible application, to name some. Of course, one can think of many more interesting studies you can do with the range of brand-new space borne data, EarthCARE will provide. In any case, a mission like this only gets successful with the great work of its scientists. So, let's make sure that EarthCARE achieve the success it deserves.

GO EarthCARE!

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