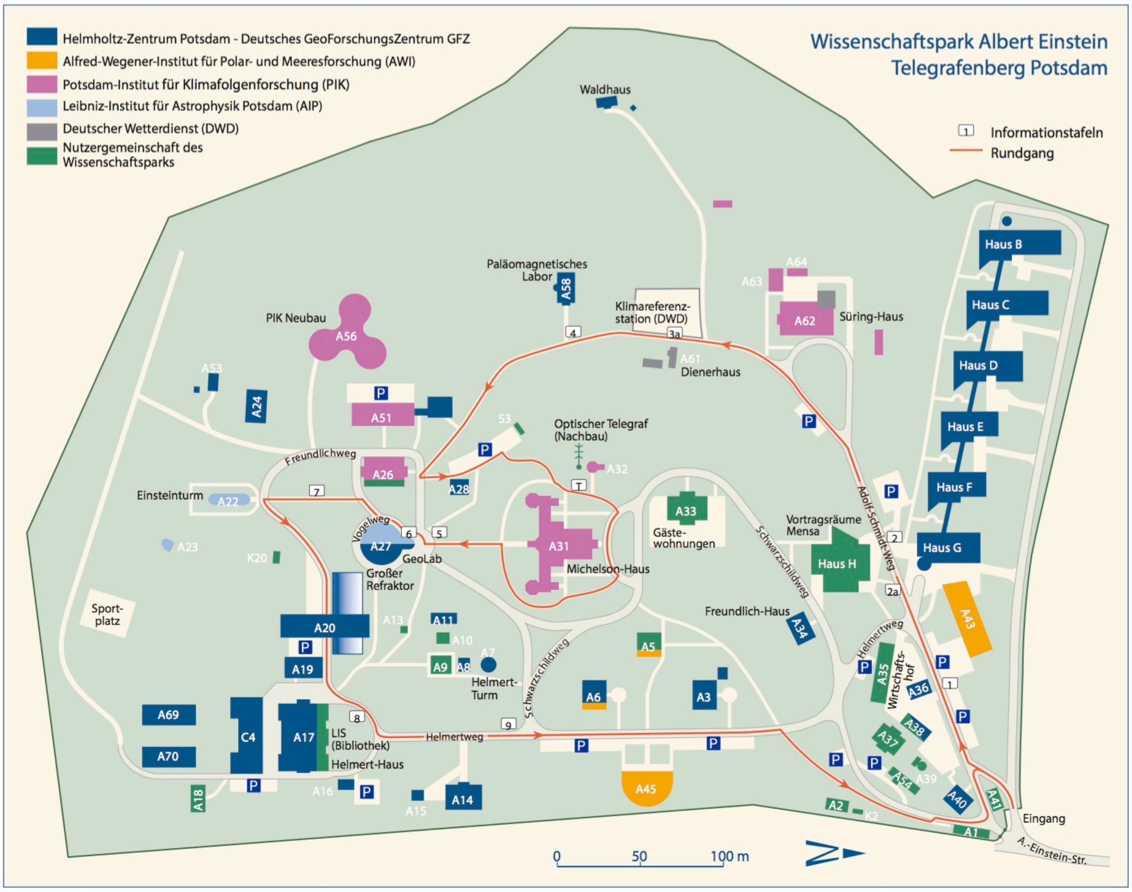
StratoClim Final Meeting

May 2019
Alfred Wegener Institute
Helmholtz Center for Polar and Marine Research
Telegrafenberg, Potsdam
Germany

Venue

The Final StratoClim meetings will be held at **Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research in Potsdam, Germany.** AWI Potsdam is located at Telegrafenberg, the historic science campus Albert Einstein, just north of the main railway station in Potsdam. The meeting will take place at the conference rooms in the Haus H.



If you are arriving by plane to Tegel (TXL) airport, take bus line X9 or 109 to station 'Zoologischer Garten' in Berlin, follow the signs to the regional train platforms, then take the regional train RE1 to Potsdam main station ('Potsdam Hauptbahnhof').

If you are arriving by plane to Schönefeld (SFX) airport, take the regional train RB 22 to 'Potsdam Hauptbahnhof'.

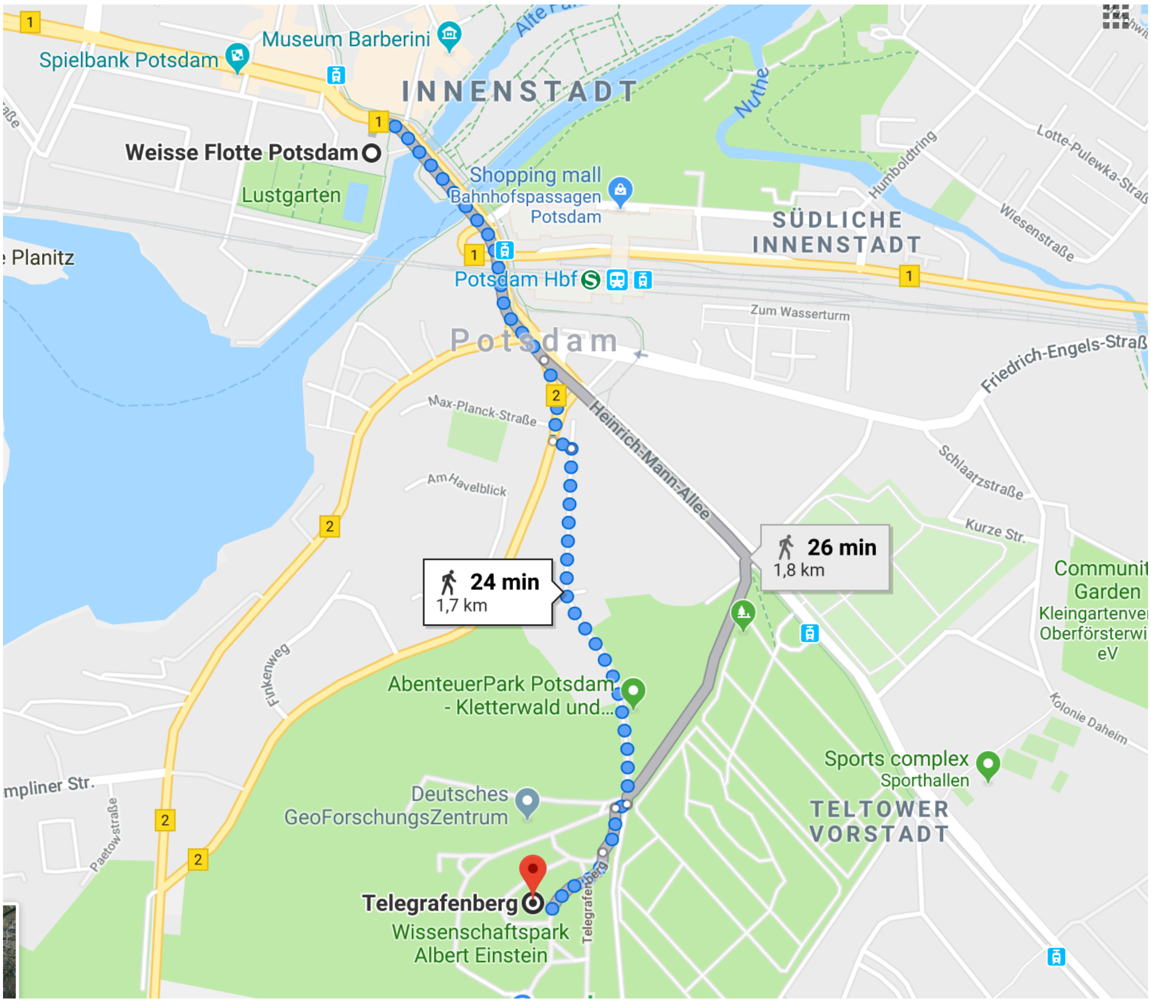
If you come by train, change at the Berlin central station ('Berlin Hauptbahnhof')(or any other major train station) to the regional train RE1.

From Berlin, you can also connect to Potsdam with the suburban train (S-Bahn) line S7.

To connect from either of the airports or from Berlin city, you will need a Berlin ABC ticket (2,80€). The ticket must be validated on the platform in the red or yellow validation machines before boarding the trains.

Joint Dinner

We will have a joint meeting Dinner on **Wednesday 22 May** on a cruise ship at the River Havel. The ship will leave from the pier, Weisse Flotte Potsdam, Lange Brücke 6 (next to the Mercure hotel and close to Potsdam main train station) at 19.00. All participants are requested to meet at the pier at 18:50 at the latest.



Presentations

Oral presentations

Oral presentations are allocated 15 minutes each and will be in a format 12+3, allowing few questions at the end of each presentation.

Keynote presentations are allocated 30 minutes each and will be in a format 25+5, also allowing questions at the end of the presentation.

Presentations should be submitted as powerpoint or PDF files and brought to the venue in a USB stick.

All oral presenters are welcome, and in fact encouraged, to bring their slides also as a poster (see the guidelines for size etc. below), in order to facilitate discussions during the breaks and poster sessions.

Poster presentations

Posters should be in a max. A0 size and preferably in portrait format.

Each poster will be shortly introduced in the beginning of the poster session on Wednesday May 22, between 15:30 - 16:00.

Each introduction is allocated 1 minute and should include 1 slide (ppt/pptx, pdf) highlighting the objectives of the study and main results. These poster introduction slides should be submitted via email to leenakaisa.viitanen@awi.de by Monday 20 May at the latest.

Agenda summary

StratoClim Final Annual Meeting and Open Science Meeting - May 20–24, 2019

Agenda Summary

	Monday May 20	Tuesday May 21	Wednesday May 22	Thursday May 23	Friday May 24
9.00 - 10.00			Welcome and overview	Aerosols / particle formation	Global Implications 90min.
10.00 - 11.00		Paper writing groups - Campaign Overview paper, Lead: Fred Stroh	Transport and dynamics	Coffee and POSTERS	Coffee break
11.00 - 12.00			Coffee break; Transport and dynamics	Convection and clouds	Impact studies; SAB feedback
12.00 - 13.00					Future prospects for Geophysica
13.00 - 14.00		LUNCH	Networking lunch	Networking lunch	Networking lunch
14.00 - 15.00	Paper writing groups - stratospheric water contents, Lead: Thibaut Dauhut	StratoClim publication plans	Aerosols / particle formation	Convection and clouds	
15.00 - 16.00		StratoClim Data; EU reporting	Poster presentations	Coffee break	
16.00 - 17.00		Coffee break; Paper writing groups - Transport pathways, Lead: Thomas Peter	Poster session w/ snacks	Global Implications	
17.00 - 18.00	Paper writing groups - Convection and water vapour, Clouds, Lead: Sergey Khaykin			Poster session	
18.00 - 19.00		Executive Group meeting			
19:00			Joint Meeting Dinner		

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Agenda

Monday 20.05.2019	StratoClim final annual meeting	
13:30	Paper writing meeting (Stratospheric water contents)	Lead: Thibaut Dauhut
17:00	Paper writing meeting (Convection and water vapour, Clouds, Water vapour intercomparison)	Lead: Sergey Khaykin

Tuesday 21.05.2019	StratoClim final annual meeting	
10:00 - 13:00	Paper writing meeting (Campaign overview paper)	Lead: Fred Stroh
13:00 - 14:00	**LUNCH**	
14:00 - 15:00	StratoClim publication plans	Open discussion
15:00 - 15:30	StratoClim Data	Klaus Gottschaldt
15:30 - 16:00	EU reporting	Leena Viitanen
16:00 - 16:30	**COFFEE**	
16:30 - 18:00	Paper writing meetings	- Transport pathways, Lead: Thomas Peter
18:00	**Executive Committee meeting**	

Wednesday 22.05.2019	StratoClim Open Science Meeting	
09:00 - 09:20	**Welcome and StratoClim overview presentation**	**Markus Rex Fred Stroh**
09:20 - 09:45	**Meteorological / convective overview of the Aircraft campaign period**	**Bernard Legras**
09:45 - 13:00	**TRANSPORT AND DYNAMICS** Conveners: Michael Volk, Bärbel Vogel, Rolf Müller, Bernard Legras	
09:45 - 10:15	Invited Keynote: The Asian summer monsoon Chemical and Climate Impact Project (ACCLIP)	Laura Pan
10:15 - 10:30	CLaMS backward trajectory analysis of the airmass composition of the Asian Tropopause Aerosol Layer (ATAL) using COBALD Instrument Aerosol Back-Scatter Ratio measurements in August 2016, Nainital	Sreeharsha Hanumanthu
10:30 - 10:45	Isotopic composition of long-lived gases from whole air samples taken during the Kathmandu campaign	Maria Elena Popa
10:45 - 11:00	In situ tracer observations constraining key transport processes in the 2017 Asian Summer Monsoon anticyclone	Michael Volk
11:00 - 11:30	**COFFEE**	
11:30 - 12.00	Invited Keynote: The UTLS Asian monsoon observed by SAGE III_ISS	Bill Randell
12:00 - 12:15	Lagrangian simulations of the transport of young air masses to the top of the Asian monsoon anticyclone and into the tropical pipe	Bärbel Vogel
12:15 - 12:30	Study on airborne HNO3 and HCN measurements with Lagrangian back-trajectories in the Asian Summer Monsoon Anticyclone	Yun Li
12:30 - 12:45	Dehydration and low ozone in the tropopause layer over the Asian monsoon caused by tropical cyclones Lagrangian transport calculations using ERA-Interim and ERA5 reanalyses data	Dan Li
12:45 - 13:00	Three-Dimensional modelling study of the StratoClim campaign 2016-2017 data	Giorgio S. Taverna
13:00 - 14:00	**LUNCH**	

Wednesday 22.05.2019	StratoClim Open Science Meeting	
14:00 - 17:00	**AEROSOLS AND PARTICLE FORMATION** Conveners: Stephan Borrmann, Beiping Luo, Michael Höpfner	
14:00 - 14:30	Invited Keynote: New measurements of size-dependent aerosol composition in the lower stratosphere (invited external keynote)	Daniel Murphy
14:30 - 14:45	In-situ measurements of aerosols and clouds within the Asian Monsoon Anticyclone and the ATAL particle physical properties and chemical composition	Stephan Borrmann
14:45 - 15:00	Aircraft- and space-borne infrared remote sensing measurements of aerosols and aerosol precursor gases in the Asian monsoon upper troposphere	Michael Höpfner
15:00 - 15:15	Aircraft observations and model simulations of convective transport of sulfur and reactive nitrogen species in the Asian Summer Monsoon region	Hans Schlager
15:15 - 15:30	Overview of 10-year sounding water vapor, ozone and particle campaign (SWOP) at Lhasa and Kunming during the ASM (2009-2018)	Jianchun Bian
15:30 - 16:00	Poster presentations	All poster authors
16:00 - 17:30	**POSTER SESSION** **w/ coffee**	
19:00	**Joint meeting dinner**	

THURSDAY 23.05.2019	StratoClim Open Science Meeting	
09:00 - 09:45	**AEROSOLS AND PARTICLE FORMATION** Conveners: Stephan Borrmann, Beiping Luo, Michael Höpfner	
09:00 - 09:15	Characterization of the aerosol microphysical properties under the influence of the Asian Monsoon Anticyclone	Christoph Mahnke

THURSDAY 23.05.2019	StratoClim Open Science Meeting	
09:15 - 09:30	High resolution simulations of deep convective uplift of Chinese pollutants into the Asian Monsoon Anticyclone	K.-O. Lee
09:30 - 09.45	Regional modelling of transport of aerosols and trace gases during the StratoClim flight campaign in summer 2017	T. Onishi
09:45 - 11:00	**coffee and POSTERS**	
11:00 - 15:15	**CONVECTION AND CLOUDS** Conveners: Thomas Peter, Francesco Cairo, Sergey Khaykin, Martina Krämer	
11:00 - 11.30	StratoClim Keynote: The dual role of the Asian convection in cross-tropopause transport of water hydration versus dehydration	Sergey Khaykin
11:30 - 12:00	Invited Keynote: Direct influence of deep convection on water vapor concentration in the tropical lower stratosphere	Eric Jensen, Rei Ueyama
12:00 - 12:15	Convective sources and transport patterns into the stratosphere during the 2017 StratoClim campaign	Silvia Bucci
12:15 - 12:30	Effect of deep convection on UTLS temperature and water vapor in the Asian summer monsoon anticyclone	Simone Brunamonti
12:30 - 12:45	Lidar measurement of thin cirrus and aerosol at Palau Island	Francesco Cairo
12:45 - 13:45	**LUNCH**	
13:45 - 14:15	Invited Keynote: Impacts of gravity waves on cirrus clouds in the tropical upper troposphere: observations and theories	Aurélien Podglajen
14:15 - 14:30	Understanding the sources and the aactors behind the variability of cirrus clouds over the Asian Summer Monsoon region	Ajil Kottayil
14:30 - 14:45	In-situ measurements of HDO:H2O isotopic ratios in the Asian Summer Monsoon	Elisabeth Moyer

THURSDAY 23.05.2019	StratoClim Open Science Meeting	
14:45 - 15:00	Convective hydration of the lower stratosphere during the StratoClim aircraft campaign as seen from a Meso-NH convection-permitting simulation	T. Dauhut
15:00 - 15:15	In-situ formed cirrus clouds observed during STRATOCLIM Field campaign and their nucleation mechanism	Beiping Luo
15:15 - 15:45	**COFFEE**	
15:45 - 17:15	**GLOBAL IMPLICATIONS** Conveners: Claudia Timmreck, Martin Dameris, Chiara Cagnazzo	
15:45 - 16:15	Invited Keynote: Using Aura MLS to place the 2017 Asian Summer Monsoon into context	Michelle Santee
16:15 - 16:30	Quantification of water vapour transport from the Asian monsoon to the stratosphere Coffee Break	Matthias Nützel
16:30 - 16:45	Using chemical and idealised tracers to investigate interannual variability and trends in Asian monsoon transport	James Keeble
16:45 - 17:00	Role of the 2018 Sudden Stratospheric Warming on the abrupt end of the western European drought	Natalia Calvo
17:00 - 17:15	Temporal variability and zonal extent of the Asian monsoon anticyclone	Philip Rupp
17:15 - 19:00	**POSTER SESSION**	

FRIDAY 24.05.2019	StratoClim Open Science Meeting	
09:00 - 10:30	**GLOBAL IMPLICATIONS** Conveners: Claudia Timmreck, Martin Dameris, Chiara Cagnazzo	
09:00 - 09.30	StratoClim Keynote: Stratospheric aerosol 1990 to 2017, transient simulation of radiative forcing and comparison of aerosol properties with the STRATOCLIM Asian Monsoon aircraft campaign	Christoph Brühl
09:30 - 09:45	Agung eruption 1963 — one or two eruptions, does it matter?	Ulrike Niemeier

FRIDAY 24.05.2019	StratoClim Open Science Meeting	
09:45 - 10:00	The influence of ENSO on the QBO in climate models	Federico Serva, Bo Christiansen
10:00 - 10:15	An overview of recent findings from halogenated trace gas observations in the troposphere and stratosphere	Johannes Laube
10:15 - 10:30	Survey of lightning activity over the South Asian monsoon region: possible link to enhanced air pollution	Imre Janosi
10:30 - 11:00	**COFFEE**	
11.00 - 11:30	**SOCIO-ECONOMIC IMPACTS** Conveners: Kain Glensor, Neil Harris	
11:00 - 11:30	Marginal Benefit to South Asian Economies from SO2 Emissions Mitigation and Subsequent Increase in Monsoon Rainfall	Kain Glensor
11.30 - 12.00	**SAB Feedback and closing remarks**	**SAB representatives, Markus Rex**
12:00 - 13:00	**Future prospects for Geophysica (funding and collaborations)**	**Open discussion**
13:00 - 14:00	**LUNCH**	

List of Posters

PRESENTING AUTHOR	TITLE
Katrin Müller	Balloon-borne tropospheric ozone measurements from a new station in Palau
Karina E. Adcock	Aircraft-based observations of ozone-depleting substances in the upper troposphere and lower stratosphere in and above the Asian summer monsoon
Qian Li	Distribution and variation of CO in UTLS over Tibetan Plateau
Ingo Wohltmann	Ozone and water vapour balloon sonde measurements at Bhola Island Bangladesh
Sören Johansson	Pollution trace gas distributions derived from GLORIA measurements during the StratoClim campaign and comparison with model calculations and trajectories – now still missing in the sessions
Bernard Legras	Confinement of air in the Asian monsoon anticyclone and pathways of convective air to the stratosphere during summer season
Mathias Palm	Measurements of OCS and other trace gases in Palau using the solar absorption FTIR spectrometry
Annika Günther	Stratospheric sulphur: MIPAS/Envisat measurements and chemical transport model simulations of carbonyl sulphide, sulphur dioxide, and sulphate aerosol
Pasquale Sellitto	The characterisation of secondary sulphate aerosols from thermal infrared satellite instruments in low earth and geostationary orbit
Ingo Wohltmann	Model calculations of the contribution of tropospheric SO2 and DMS to the stratospheric sulfur budget
Francesco Cairo	An analysis of optical and microphysical properties of Cirrus clouds during STRATOCLIM
Hameed Moqadam	Evolution of cirrus clouds in the Asian monsoon tropical tropopause layer: a case study from the StratoClim aircraft campaign
Oliver Schlenczek	Microphysics of anvil outflows in Asian summer monsoon Characterization of hydrometeor sizes, variability, and shapes by holographic in-situ measurements
Clare Singer	Intercomparison of in-situ water vapor measurements during StratoClim
Teresa Jorge	Understanding unphysical water vapor measurements with Cryogenic-cooled Frost Point Hygrometer
Yann Poltera	An improved time lag parameterization for RH measurements with RS41
Claudia Timmreck	Modeling the climatic effects of large explosive volcanic eruptions: Current status and new challenges
Francesco Cairo	Analyses of Geophysica measurements of the Asian summer monsoon campaign in 2017 and comparison with respective data derived from Chemistry-Climate-Model simulations
Franziska Hanf	Systematic errors in South Asian monsoon precipitation; Process-based diagnostics and sensitivity to entrainment in NCAR models

Abstracts

TRANSPORT AND DYNAMICS

Invited Keynote

The Asian summer monsoon Chemical and Climate Impact Project (ACCLIP)

Laura Pan
National Center for Atmospheric Research, Boulder CO, USA

Motivated by the need to characterize the global impact of Asian monsoon on atmospheric composition, the ACCLIP campaign is planned as a coordinated research program of airborne, balloon, ground based, and supporting satellite measurements. The behavior of ASM as a transport pathway, the chemical content in the UTLS outflow of the ASM air mass, the amount and the properties of UTLS aerosols associated with the ASM, and the stratospheric water vapor enhancement due to the ASM are among the key scientific foci of the project. The airborne field campaign is planned to take place in July-August of 2020 using two research aircraft: the NSF/NCAR GV and the NASA WB-57, with the aircraft operation based in Japan. This overview will discuss the current status of planning and how the project will complement the StratoClim project.

CLaMS backward trajectory analysis of the airmass composition of theAsian Tropopause Aerosol Layer (ATAL) using COBALD Instrument Aerosol Back-Scatter Ratio measurements in August 2016, Nainital

S. Hannumanthu[1], B. Vogel[1], R. Müller[1], S. Fadnavis[2], S. Brunamonti[3], T. Jorge[3], P. Oelsner[4], Manish Naja[5], Bhupendra B. Singh[2], K. Ravi Kumar[6], Sunil Sonbawne[2], Hannu Jauhiainen[7], H. Vömel[8], Frank G. Wienhold[3], Ruud Dirksen[4], T. Peter[3]

1 Forschungszentrum Jülich (FZJ), Institute of Energy and Climate Research – Stratosphere (IEK-7), Jülich, Germany
2 Indian Institute of Tropical Meteorology (IITM), Pune, India
3 Institute for Atmospheric and Climate Science (IAC), Swiss Federal Institute of Technology (ETH), Zürich, Switzerland 4 Deutscher Wetterdienst (DWD) / GCOS Reference Upper Air Network (GRUAN) Lead Center, Lindenberg, Germany 5 Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital, India
6 Centre for Atmospheric Sciences, Indian Institute of Technology (IIT), Delhi, India
7 Vaisala Oyj, Vantaa, Finland
8 Earth Observing Laboratory, National Center for Atmospheric Research, Boulder, CO, USA

In 2016, during the StratoClim campaign COBALD balloon measurements were conducted from 2nd - 31st of August at Nainital, India. In normal conditions Asian Monsoon has its peak in August. Our COBALD measurements are the first such measurements at the foothills of the Himalayas. We used COBALD instrument Aerosol backscatter measurements (ABSR) to detect the ATAL in 15 successful launches. We employed the Chemical Lagrangian Model of the Stratosphere (CLaMS) Backward Trajectory Module to look for source regions of the air-masses sampled by the measurements to detect potential boundary layer source regions, which are contributing to the formation of the ATAL. We find altitudes of the ATAL existence to be highly variable in space and time. Most of the data also show strong cirrus structures in the Upper Troposphere (UT). We considered 40-Day backward trajectories for the analysis. We fixed (80-140) hPa as the ATAL maximum variable range out of the observed data from our15 launches.

Our results show that although there are day to day variations in the contribution of Asian Monsoon Boundary Layer (BL) air-masses to ATAL, on average (40-50)% of the sources are from BL within a 40 days time period. (10 - 20)% percent of the trajectories are ending in the Lower Troposphere (LT) in this 40-day time period. Further, the rest of the sources (30-40)% are strongly variable between the Upper Troposphere (UT) and Lower Stratosphere (LS). These trajectories are old air-masses. The BL source are convective sources which can be tropical cyclones of the west pacific and a major contribution is from Asian monsoon influenced convection over the East and South Asian monsoon systems.

The potential Asian Boundary Layer (BL) sources lifted to Upper Troposphere during the monsoon season by convection are mainly from, 1) Foothills of Himalayas and Ganges plains 2) Tibetan Plateau 3) East Asia and North-West Pacific Ocean. But once the air-masses reached 360 K by August, they tend to show a slow adiabatic transport inside the core of the anticyclone. We also observed that BL origins from different source regions to UT are changing w.r.t. to change in core AMA location due to east-west oscillations over the Asian region.

Isotopic composition of long lived gases from whole air samples taken during the Kathmandu campaign

Maria Elena Popa, Carina van der Veen, Amzad Laskar, Rahul Peethambaran, Getachew Agmuas Adnew, Michel Bolder, Thomas Röckmann

Utrecht University, Institute for Marine and Atmospheric Research Utrecht (IMAU)

Geophysica flights out of Kathmandu, Nepal, during the STRATOCLIM aircraft campaign provided a unique opportunity to obtain air samples for isotope analysis from the rarely sampled tropopause region in the Asian monsoon anticyclone. In 6 flights almost 100 samples were collected, both below and above the tropopause. These samples were analysed for the stable isotopic composition of CH4, N2O, CO, H2, and CO2. Additionally, on selected samples we measured the clumped CO2 and O2 isotopic signatures, and the Δ17O anomaly in O2 and CO2.
We will present an overview of the data acquired, with focus on the most interesting aspects. Characteristic isotope signatures in stratospheric samples provide information on the isotope effects associated with stratospheric photochemistry in this important region for troposphere-stratosphere exchange. The tropospheric samples allow identifying source categories for these gases, and are compared to a set of samples that was collected at the surface in the Kathmandu region.

In situ tracer observations constraining key transport processes in the 2017 Asian Summer Monsoon anticyclone

C.M. Volk (1), J. Wintel (1), T. Beckert (1), E. Gerhardt (1), V. Lauther (1), S. Viciani (2), F. D'Amato (2), A. Ulanovski (3), F. Ravegnani (4), F. Cairo (5)

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The Asian Summer Monsoon is a major agent for rapid transport of polluted air from the surface into the stratosphere. We present and analyse in situ tracer observations deep inside the Asian Summer Monsoon anticyclone (ASMA) and the overlying stratosphere up to 20 km altitude obtained over Nepal and India in July and August 2017 with the M55 Geophysica research aircraft. On board the aircraft long-lived tracers (N2O, CH4, CO2, H2, F12, F11, H-1211, SF6) were measured by the University of Wuppertal's High Altitude Gas AnalyzeR (HAGAR), CO by the Carbon Oxide Laser Diode (COLD), and O3 by the Fast Ozone ANalyzer (FOZAN). The deployment comprised eight scientific flights, including survey flights aimed at improving our understanding of large-scale transport and flights above and around mesoscale convective systems aimed at investigating their impact on the composition of the ASMA and on stratosphere-troposphere exchange.

We present an analysis of these measurements with regard to the principal transport processes controlling the chemical composition of the ASMA and tropical lower stratosphere. Vertical profiles and correlations between the various species, serving as stratospheric tracers, as boundary layer tracers, or age-of-air tracers, will be used to assess i) in-mixing of aged mid- latitude air inside the ASMA and the stratosphere above, ii) the impact of convection as a function of altitude, and iii) slow up-welling inside the ASMA. Comparisons will be made with data obtained with the Geophysica during the AMMA mission focused on the African Summer Monsoon, and the present observations will be put into a climatological context. The picture emerging from this analysis is that surface air delivered by convection up to at least 370 K potential temperature ascends coherently and in isolation inside the ASMA up to 400 K within about 3 months, but rapidly mixes with aged air above 410 K.

Invited Keynote

The UTLS Asian monsoon observed by SAGE III/ISS

William Randel

Atmospheric Chemistry Observations and Modeling Lab at National Centre for Atmospheric Research, Boulder, Colorado USA

The Stratospheric Aerosol and Gas Experiment III is a solar occultation satellite instrument on the International Space Station, making high vertical resolution measurements of ozone, water vapor, aerosols and other trace constituents since June 2017. We will highlight measurements made during the first 1.5 years from SAGE III/ISS, including observations of the UTLS Asian monsoon region during the summers of 2017 and 2018.

Lagrangian simulations of the transport of young air masses to the top of the Asian monsoon anticyclone and into the tropical pipe

Bärbel Vogel[1], Gebhard Günther[1], Rolf Müller[1], Reinhold Spang[1], Sreeharsha Hanumanthu[1], Dan Li[1,2,] Gabriele P. Stiller[3], and Fred Stroh[1]

1Forschungszentrum Jülich, Institute of Energy and Climate Research – Stratosphere (IEK-7), Jülich, Germany
2Key Laboratory of Middle Atmosphere and Global Environment Observation (LAGEO), Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China
3Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology, Karlsruhe, Germany
Correspondence: Bärbel Vogel (b.vogel@fz-juelich.de)

The Asian summer monsoon is the most pronounced circulation pattern in boreal summer associated with deep convection and with an upper level anticyclonic flow that extends from the upper troposphere into the lower stratosphere (UTLS). It is believed that the Asian monsoon circulation provide an effective pathway for tropospheric trace gases into the lower stratosphere. However, there is a longstanding debate about the transport mechanisms at the top of the Asian monsoon anticyclone and beyond into the tropical pipe.

We have performed backward trajectory calculations and simulations with the 3-dimensional Chemical Lagrangian Model of the Stratosphere (CLaMS) for two succeeding monsoon seasons using artificial tracers of air mass origin. With these tracers we trace back the origin of young air masses (age < 6 months) at the top of the Asian monsoon anticyclone and of air masses within the tropical pipe (6 months < age <18 months) during summer 2008. The occurrence of young air masses (<6 months) at the top of the Asian monsoon anticyclone up to ≈460 K is in agreement with satellite measurements of chlorodifluoromethane (HCFC-22) by the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) instrument. HCFC-22 can be considered as a regional tracer for continental eastern Asia and the Near East as it is mainly emitted in this region.

Our findings (Vogel et al., ACP, 2019, accepted) show that the transport of air masses from boundary layer sources in the region of the Asian monsoon into the tropical pipe occurs in three distinct steps. First, very fast uplift in ‘a convective range’ transports air masses up to 360 K potential temperature within a few days. Second, air masses are uplifted from about 360 K up to 460 K within ‘an upward spiralling range’ within a few months. The large-scale upward spiral extends from northern Africa to the western Pacific. The air masses are transported upwards by diabatic heating with a rate of up to 1–1.5 K per day, implying strong vertical transport above the Asian monsoon anticyclone. Third, transport of air masses occurs within the tropical pipe up to 550 K associated with the large-scale Brewer-Dobson circulation within ~ one year.

Our simulations show, that in the upward spiralling range air masses from inside the Asian monsoon anticyclone are mixed with air masses convectively uplifted outside the core of the Asian monsoon anticyclone in the tropical adjacent regions. To assess our simulations, we will present comparisons between CLaMS model results and airborne measurements of the Geophysica high-altitude aircraft during the StratoClim field campaign in Kathmandu (Nepal) in July/August 2017. The com- parisons of CLaMS and campaign data confirm transport pathways found in the CLaMS model in particular, transport of young air masses with an origin in India/China and in the tropical western Pacific to altitudes above the monsoon anticyclone (above 400K).

Study on airborne HNO3 and HCN measurements with Lagrangian back-trajectories in the Asian Summer Monsoon Anticyclone

Y. Li[1], T. Khattatov[1], B. Vogel[1], S. Bucci[2] , B. Legras[2], S. Viciani[3], F. D'Amato[3], F. Ravegnani[4], A. Ulanovsky[5], G. Stratmann[6], H. Schlager[6] and F. Stroh[1]

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Asian boundary air pollutants are rapidly uplifted by deep convection into the Asian Monsoon Anticyclone (AMA) in boreal summer and are confined within the anticyclonic domain in July – August. As air in the anticyclone enters into the lower stratosphere by crossing the tropical tropopause or spreads horizontally with the confinement weakening in the late monsoon season, the AMA is impacting the global atmosphere. We report here what we have obtained from the airborne measurements during the StratoClim Kathmandu campaign in the summer 2017. In-situ measurements of HNO3 and HCN were performed with the airborne Chemical- Ionization Time-of-Flight Mass Spectrometer FUNMASS on board of the high- altitude research aircraft M55-Geophysica. Because HCN is mainly emitted from biomass burning, it is an indicator for earth surface origins. While HNO3 is a stratospheric tracer due to oxidation of N2O and NOx. We study on the FUNMASS measurements from F6 and F7 along with the measurements of CO and O3 employing the Lagrangian models CLaMS and TRACZILLA. While CLaMS trajectories are calculated based on ERA-Interim as well as EAR5 data, TRACZILLA implements parameterization of convective activities based on ERA5. Observed signatures in the in-situ data are discussed along with the air mass origins derived from back-trajectories. Besides, an interesting enhancement of HCN in the lower stratosphere, correlated with changes in HNO3 and O3, was observed and is further discussed.

Dehydration and low ozone in the tropopause layer over the Asian monsoon caused by tropical cyclones: Lagrangian transport calculations using ERA-Interim and ERA5 reanalyses data

Dan Li[1,2], Bärbel Vogel[1], Rolf Müller1, Jianchun Bian[2,3], Gebhard Günther[1], Felix Plöger[1], Qian Li[2], Jinqiang Zhang[2,3], Zhixuan Bai[2], and Martin Riese[1]

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Low ozone/water vapour structures near the tropopause layer over Kunming (South China) were observed using balloon-borne measurements performed during the SWOP (sounding water vapour, ozone, and particle) campaign in August 2009 and 2015. Here, we investigate low ozone/water vapour structures using FengYun-2D, FengYun-2G, Aura Microwave Limb Sounder (MLS) satellite measurements and backward trajectory calculations driven by both ERA-Interim and ERA5 reanalyses data. Trajectories with kinematic and diabatic vertical velocities are calculated using the Chemical Lagrangian Model of the Stratosphere (CLaMS) trajectory module.

All trajectory calculations display that air parcels with low ozone/water vapour structures originate from the western Pacific boundary layer. Deep convection associated with tropical cyclones over the western Pacific transport boundary air parcels with low ozone into the cold tropopause region. Subsequently, the air parcels are mixed into the strong easterlies on the southern side of the Asian summer monsoon anticyclone. These air parcels are dehydrated when passing the coldest temperature region (<190 K) over the western Pacific and become dry during quasi-horizontal advection. Final, low ozone/water vapour structures in the subtropics were detected over Kunming by balloon-borne measurements. However, trajectory calculations display different vertical transport via deep convection depending on used reanalyses data (ERA-Interim, ERA5) and vertical velocity (diabatic, kinematic). Both the kinematic and the diabatic trajectory calculations using ERA5 data show faster and stronger vertical transport than ERA-Interim primarily due to ERA5's better spatial and temporal resolution, likely resolving more convective events. The kinematic trajectory calculations from the ERA5 data show the fastest and strongest vertical transport around the deep convection caused by tropical cyclones compared to other trajectory calculations.

Three-Dimensional modelling study of the StratoClim campaign 2016-2017 data

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The Asian Monsoon extends over an important region well known for the transport of climate-relevant gases from the troposphere to the stratosphere. Recent works by several groups have focused on quantifying processes which contribute to coupling in the upper troposphere-lower stratosphere (UTLS), including transport during the Asian Summer Monsoon (ASM). Troposphere-to-stratosphere transport in this region has been the focus of a number of recent campaigns, including the EU “StratoClim campaign” in Greece 2016 and Nepal 2017.

Anthropogenic compounds such as CO, very short-lived substances (VSLS), which destroy stratospheric ozone and sulphur compounds, which maintain the stratospheric aerosol layer, are among the important species involved in large convective systems transport such as the ASM. In this poster, StratoClim campaign CO, O3 and NOy data are analysed and compared with high resolution TOMCAT model results (1.1°x 1.1°, 60 levels from surface to 60 km) to try to understand the mechanisms of transport from surface to UTLS and above with a focus on the effect of convection and chemistry on the observed mixing raCos. Further comparisons will be extended to remote satellite data, where possible. The model is set up with detailed chemistry schemes and forced by ECMWF ERA-Interim reanalyses.

Balloon-borne Tropospheric Ozone Measurements from a New Station in Palau (Tropical West Pacific)

Katrin Mueller, Peter von der Gathen, Ingo Wohltmann, Ralph Lehmann and Markus Rex

Alfred Wegener Institute, Potsdam Germany

The West Pacific warm pool has been identified as the major source region for stratospheric air, coinciding with a tropospheric ozone minimum (Rex et al. 2014). The close coupling of ozone concentration and oxidizing capacity of the clean tropical troposphere influences the overall transport of chemical species to the stratosphere. To improve the limited availability of tropospheric ozone profiles from this key region, intensive campaigns and continuous measurements with ECC ozone sondes have been conducted at the new measurement station in Palau (7° N, 135° E) since early 2016 as part of StratoClim WP2. We present the comprehensive instrumental setup of the station and insights from the first three years of balloon-borne ozone measurements regarding seasonality and origin of air masses for specific cases with high/low ozone/water vapor mixing ratios, respectively.

Aircraft-based observations of ozone-depleting substances in the upper troposphere and lower stratosphere in and above the Asian summer monsoon

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Recent studies show that the Asian summer monsoon transports emissions from the rapidly industrialising nations in East and South Asia into the tropical upper troposphere. Here we present a unique set of measurements on over 100 air samples collected on multiple flights on the M55 Geophysica high altitude research aircraft over the Mediterranean, Nepal and northern India during the summers of 2016 and 2017 as part of the StratoClim project. These air samples were measured for a range of ozone-depleting substances, many of which were enhanced above expected levels, including the very short-lived chlorine containing compounds, dichloromethane (CH_2Cl_2), 1,2- dichloroethane (CH_2ClCH_2Cl) and chloroform ($CHCl_3$). Backward trajectories calculated with the trajectory module of the chemistry-transport model CLaMS, driven by horizontal winds from ERA- Interim reanalysis found fast transport times and source regions of the air masses in South Asia. We derive an Equivalent Chlorine (ECl) and Equivalent Effective Stratospheric Chlorine (EESC) and found that the long-lived ozone-depleting substances were comparable in our estimates to other estimates in the literature and the very short-lived substances were substantially higher. Our findings show that the Asian monsoon is transporting higher than expected mixing ratios of very short-lived ozone-depleting substances into the upper troposphere and lower stratosphere, potentially leading to an impact on the ozone layer. We also derive the stratospheric mean ages of the air from several inert trace gases, and fractional release factors for all compounds, and found they agree relatively well with results from previous aircraft campaigns in different regions.

Distribution and variation of CO in UTLS over Tibetan Plateau

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The distribution and variation of CO in UTLS over Tibetan Plateau is generally considered being under the controlling of Asian Summer Monsoon (ASM) system. One of the main controlling factors is the influence by upward transport of air pollutants in lower atmosphere. Under the impacts of ASM system and through the dynamical transport processes, the surface emitted CO enter upper world and may cause further effects on the atmospheric chemical and dynamical systems in UTLS. By using the high-resolution surface emission data, the state-of-the-art remote sensing observations, and the 3-D global atmospheric chemical transport model simulations, we focus on the analysis of distribution and variation of CO in UTLS and upward transport from lower atmosphere in Tibetan Plateau region. Also, we further investigate the different effects induced by faster transport of deep convections and slower transport of large-scale processes which, both are involved in the ASM system. Moreover, we conduct an exploration of the contribution of each individual surface emission regions and emission varieties to the distribution of air pollutants in UTLS.

Key words: CO, Tibetan Plateau, Asian Summer Monsoon, UTLS, Surface emissions, Dynamical transport

Ozone and water vapour balloon sonde measurements at Bhola Is-and, Bangladesh

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As part of the StratoClim campaign, balloon sonde measurements of ozone and water vapour were performed at the site of Bhola Island, Bangladesh in the summer monsoon seasons of 2016 and 2017. We give an overview over the data set and interpret the data with the help of a backward trajectory analysis of ensemble trajectories, which include a simulation of convection and diffusion. We examine the source regions of the measured air masses and the origin of the observed filamentary structures and use satellite data (e.g. AIRS CO, MODIS fire counts) to complement our results.

Pollution trace gas distributions derived from GLORIA measurements during the StratoClim campaign and comparison with model calculations and trajectories

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We will present trace gas and aerosol measurements obtained by GLORIA (Gimballed Limb Observer for Radiance Imaging of the Atmosphere) instrument that has been operated on the Geophysica research aircraft during the StratoClim campaign in area of the Indian subcontinent with basis in Kathmandu, Nepal in July/August 2017.
We will show retrievals of two-dimensional trace-gas distributions derived from GLORIA observations performed with high spectral resolution. Targeted gases are, amongst others, O3, HNO3, PAN and C2H6. We will present an analysis of retrieval performance including diagnostics of spatial resolution and an estimated error budget. For a first scientific analysis, comparisons to atmospheric model simulations from the CAMS (Copernicus Atmosphere Monitoring Service), CLaMS (Chemical Lagrangian Model of the Stratosphere) and EMAC (ECHAM5/MESSy Atmospheric Chemistry) models will be discussed. Further, state of the art trajectories of the TRACZILLA and ATLAS models will be analysed to estimate the origin of pollutants, measured in the UTLS region.

Confinement of air in the Asian monsoon anticyclone and pathways of convective air to the stratosphere during summer season

Bernard LEGRAS and Silvia BUCCI

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We investigate the impact of Asian monsoon convection during summer 2107 and its internal confinement of convective air by performing forward Lagrangian trajectories from the top of convective clouds. The cloud types and altitude are characterized from the infrared channels of MSG1 and Himawari at full resolution based on the operational SAF NWC cloud product. We retain all thick clouds above 250 hPa in June-August 2017 in the Asian monsoon domain from which we initiate trajectories that are integrated forward for up to two months. We use both ERA5 and ERA-I reanalysed winds and both vertical velocities and radiative heating rates for vertical motion.

We obtain consistent results among all these experiments and also a number of differences between ERA5 and ERA-Interim and between diabatic and kinematic trajectories.

We find in all cases that the proximity of the mean cloud detrainement level and the separation level between ascending and descending motion at 350-355 K generates two advection branches, a lower branch where parcels descend over subsiding regions of the Hadley-Walker circulation and an upper branch where parcels ascend in the monsoon region. The lower branch shows large discrepancies between kinematic and diabatic trajectories since diabatic motion is descending also in the monsoon region while kinematic motion is not. Consequently, more parcels escape to the lower branch in the diabatic calculations than in the kinematic calculations. There are much less qualitative differences in the upper branch, where all calculations exhibit a confinement of parcels within the Asian monsoon anticyclone with an escape rate of 12 days which is due to horizontal motion. However, the vertical confinement depends on the vertical propagation speed and this is the fastest for ERA- Interim diabatic and the slowest for ERA-Interim kinematic. The two versions of ERA5 lay between these extremes and are very close.

The convective sources for the lower branch are mainly located over the maritime regions and the south of Asia. They are shifted to continental convection, concentrating in north India and the Tibetan plateau for the upper branch. The age of air distribution shows a minimum at the core of the anticyclone up to 380 K due to the constant renewal by fresh convection, the maximum ages being found at the periphery of the anticyclone. The convective sources over the Tibetan plateau are the most likely to find their way to the tropopause but contribute only to 8% of the total influence in the lower stratosphere. The maritime sources, that provide only a weak contribution to the confinement, are making the major contribution to the global entry to the stratosphere.

The cloud effects are significantly different in the ERA5 and ERA-Interim. The ERA5 has, on the average, lower clouds than ERA-Interim but shows stronger penetrative convection. In particular it exhibits a very deep convective flux over the Tibetan Plateau which is perhaps not realistic.

The calculations suggest that, due to the fast lateral escape of air rising from lower levels, the most penetrative clouds are a major provider to the confined region in the lowermost stratosphere.

Measurements of OCS and other trace gases in Palau using the solar absorption FTIR spectrometry.

Justus Notholt and Mathias Palm

University of Bremen, Institute of Environmental Physics

We present trace gas measurements obtained 2016 and from 2018 onwards of several trace gases, including OCS and discuss the implications towards atmospheric transport in the Pacific Warmpool.

The ration OCS/N2O shows a clear enhancement in Palau as compared to other sites in the tropics and extra tropics. This points to a enhancement of OCS in the upper troposphere/lower stratosphere and thus supports the notion of the Pacific warmpool being the major pathway for OCS to reach the stratosphere. Other trace gases which can be obtained include HCl as a tracer for

stratospheric transport and CO as a tracer for tropospheric pollution. Time series of this gases in comparison to other tropic stations are presented and discussed.

Invited Keynote

New measurements of size-dependent aerosol composition in the lower stratosphere

Daniel Murphy and coworkers

NOAA Chemical Sciences Division

We have made new measurements of the composition of aerosol particles in the lower stratosphere as a function of size. These measurements are made by combining single particle mass spectrometry with optical particle counter data. Particles formed in the stratosphere are consistently larger than particles transported up from the troposphere. The data also yield quantitative abundances for particles in the lower stratosphere and show that tropospheric particles play an important role in the lower stratosphere, with probable anthropogenic influence. There is possible evidence of occasional transport from Asia into the lowermost stratosphere. Such transport does not appear to be consistently important.

In-situ measurements of aerosols and clouds within the Asian Monsoon Anticyclone and the ATAL: particle physical properties and chemical composition

Stephan Borrmann[1,2], Francesco D'Amato[3], Oliver Appel[2], Anneke Batenburg[2], Antonis Dragoneas[2], Ralf Weigel[1], Jacob Fugal, Andreas Hünig[2], Christoph Mahnke[2], Sergej Molleker[2], Max Port[2], Oliver Schlenczeck[4], Silvia Viciani[3], Bärbel Vogel[5], Fred Stroh[5], Markus Rex[6], and the StratoClim science teams

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During the 2017 StratoClim field campaign the Russian high altitude research aircraft M-55 "Geophysica" operated in the UTLS of the Asian Monsoon Anticyclone and the Asian Tropopause Aerosol Layer at altitudes up to 20 km. Extensive in-situ chemical composition measurements were performed on the submicron ambient aerosol adopting the newly developed aerosol mass spectrometer ERICA (i.e., ERc Instrument for the chemical Composition of Aerosols). The new instrument combines the two available techniques for particle mass spectrometry (i.e. (1.) laser ablation and (2.) flash-vaporization/electron impact ionization) in one apparatus. These complementary methods provide both, qualitative and quantitative information on the chemical composition of the sampled aerosol in real time from direct reading measurements. By means of the flash-vaporization/electron impact ionization particle mass spectrometer the aerosol content of nitrate, sulfate, organics and ammonia can be quantified as long as the materials evaporate when flash heated to 600 °C. For the non-volatile components such as soot, mineral dust, some inorganic materials and metals the laser ablation part provides qualitative information from the positive and negative ion mass spectra simultaneously recorded for each individual analyzed particle. In addition a four channel condensation particle counter provided measurements of number concentration and volatility of aerosol particles as small as 6 nm. Also –besides a variety of cloud particle instruments– a modified UHSAS optical particle counter was operated on "Geophysica" delivering aerosol size distributions from 60 nm to 1 micrometer particle diameter. Some of the key results from the 2017 StratoClim campaign in Kathmandu, Nepal, as well as from the 2016 test campaign in Kalamata, Greece, are discussed in the presentation.

Aircraft- and space-borne infrared remote sensing measurements of aerosols and aerosol precursor gases in the Asian monsoon upper troposphere

Michael Höpfner[1], Jörn Ungermann[2], Robert Wagner[1], Reinhold Spang[2], Martin Riese[2], Gabriele Stiller[1], Silvia Bucci[3], Felix Friedl-Vallon[1], Sören Johansson[1], Lukas Krasaukas[2], Bernard Legras[3], Thomas Leisner[1], Ottmar Möhler[1], Rolf Müller[2], Tom Neubert[4], Johannes Orphal[1], Peter Preusse[2], Markus Rex[5], Harald Saathoff[1], Fred Stroh[2], and Ingo Wohltmann[5]

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Strong convection within the Asian monsoon system quickly transports polluted air masses from the boundary layer into the upper troposphere where secondary aerosol formation might take place. Here we present remote sensing observations by limb sounding systems providing vertical and horizontal distributions of atmospheric trace gases and aerosol particles. Beside the identification of trace-gases, characteristic signatures in the mid-infrared spectral region are used to infer information about composition and phase of aerosol particles. We will show an analysis of aerosol and aerosol precursor gases in the Asian monsoon upper troposphere from a combination of two satellite limb sounders, CRISTA on SPAS in August 1997 and MIPAS on Envisat, from 2002-2011. In addition, limb- imaging measurements obtained with the GLORIA instrument on board the Geophysica high-altitude aircraft during the Asian monsoon field campaign of the StratoClim project in summer 2017 provided the opportunity to obtain vertical profiles of aerosol mass and trace gases from similar spectral information as the satellite observations - albeit with strongly improved vertical and horizontal resolution. The analysis of aerosol spectra are supported by AIDA cloud and aerosol chamber laboratory observations. Further, we analyse the airborne dataset with the help of trajectory calculations combined with temporally and locally connected satellite data of nadir-pointing instruments, like IASI, to infer the underlying composition in the lower troposphere, and geostationary satellites to deduce the presence of convective influence.

Aircraft Observations and Model Simulations of Convective Transport of Sulfur and Reactive Nitrogen Species in the Asian Summer Monsoon region

Hans Schlager, Greta Stratmann, Heinfried Aufmhoff, Jule Heuchert, Mariano Mertens, Matthias Nützel, Patrick Jöckel, Martin Dameris

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We present measurements of SO2, NO, HNO3, and NOy in the upper troposphere and lower stratosphere (UTLS) in the region of the Asian Summer Monsoon (ASM) performed with the Geophysica high-altitude research aircraft in summer 2017. The composition of the ASM anticyclone is strongly determined by input from frequent deep convection in this region. Our aircraft observations revealed two main convective outflow layers with enhanced trace gas mixing ratios located at altitudes between 12-14 km and 16-18 km. In these outflow layers, mean SO2 and NO mixing ratios of 200-300 ppt and 0.9 – 1.3 ppb, respectively, were detected. In very fresh convective outflow we found NO mixing ratios of up to 20 ppb produced by lightning. Interestingly, increased mixing ratios of SO2 and reactive nitrogen species were also found above the cold point tropopause resulting from overshooting convection. In the vicinity of the tropopause we measured uptake of HNO3 in ice particles. For conditions with very low temperatures at the tropopause, we potentially also observed uptake of HNO3 in nitric acid trihydrate (NAT) particles. In order to diagnose the contribution of emissions from different source regions in south-east Asia to the observed trace gas distributions, we performed model simulations with the chemistry-climate model EMAC using tagged emissions in the different source regions. Further, we applied a source apportionment method implemented in EMAC to analyze the contribution of lightning-NOx to the budget of reactive nitrogen in the ASM anticyclone.

Overview of 10-year sounding water vapor, ozone and particle campaign (SWOP) at Lhasa and Kunming during the ASM (2009-2018)

Jianchun Bian[1], Zhixuan Bai[1], Dan Li, Qian Li[1], Jinqiang Zhang[1], Yuejian Xuan[1] , Holger Voemel[2], Laura L. Pan[2], Dale Hurst[3], Ru-shan Gao[3], Samuel Oltmans[3], Shang Liu[3], Emrys Hall[3], Allen Jordan[3], Frank Weinhold[4], Thomas Peter[4], Weiguo Wang[5], Yunjun Duan[6], Bianba[7]

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Asian summer monsoon (ASM) circulation is recognized to be a significant transport pathway for surface pollutants to enter the global stratosphere, and therefore has great impact on the global climate. This topic has attracted great attention during the past decade. Most of these investigations, however, are largely based on satellite observations and/or model simulations. During the last ten summers (2009-2018), IAP/CAS has led an international collaboration to conduct balloon-borne water vapor (CFH hygrometer), ozone (ECC ozonesonde), and particle (COBALD and POPS) measurements at Kunming, Lhasa, and Shiquanhe. Totally, we have got over 100 profiles of ozone, water vapor and backscatter ratio of particles, and a few profiles of aerosol size distribution (size bin between 140-3000nm) from surface to lower stratosphere. In this presentation, we'll present some key characteristics of these measurements in the upper troposphere and lower stratosphere. These measurements are key to study the transport pathway and microphysical processes within the ASM anticyclone.

Characterization of the aerosol microphysical properties under the influence of the Asian Monsoon Anticyclone

Christoph Mahnke [1,2], Stephan Borrmann [1,2], Ralf Weigel [2], Francesco Cairo [3], Armin Afchine [4], Martina Krämer [4], Jean-Paul Vernier [5], Terry Deshler [6], Fred Stroh [4] and the StratoClim science team

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During the StratoClim 2017 measurement campaign in Nepal, within the Asian Monsoon Anticyclone (AMA), measurements of the aerosols' microphysical properties up to UT/LS altitudes were successfully completed with a modified version of the commercially available (Droplet Measurement Technologies Inc.) aerosol spectrometer UHSAS-A. Technical rearrangements of parts of the UHSAS-A were developed and implemented, which improve the instrument's measuring performance and extend its airborne application range to the extreme ambient conditions in the stratosphere at heights of 20 km. The measuring techniques used for this purpose were critically characterized.

Within the AMA region, extreme values of the particle mixing ratio (PMR) ranging between 6 mg-1 and about 10000 mg-1 were measured with the UHSAS-A (particle diameter range: 65 nm to 1000 nm). The median of the PMR for all measuring flights was about 1300 mg-1 almost at the ground, with high variability towards tropopause altitudes. At levels of 370 K potential temperature, the median PMR maximally reaches about 700 mg-1. Between 450 K and 475 K, median PMR between 40 mg-1 and 50 mg-1 were observed. The aerosol size distributions (measured by the UHSAS-A) were extended by an additional diameter size bin obtained from the 4-channel Condensation Particle Counting System (COPAS), i.e. for aerosol diameter between 10 nm and 65 nm. Coagulation schemes, covering the submicron aerosol diameter range down to the ultrafine aerosol mode, may allow for analyzing how the altering of the aerosol size distribution occurs within the TTL region.

Comparisons of the UHSAS-A measured aerosol particle size distributions with balloon-borne measurements (by Deshler et al.) at altitudes of up to 20 km were made. These show that the size distributions measured during the StratoClim 2017 campaign fit well within the range of the compared balloon-borne measurements during the Asian Monsoon season over India (Hyderabad) in 2015 and the USA (Laramie) in 2013. Further analyses of measured particle size distributions by means of backscatter ratio show remarkable consistency with CALIOP satellite observations of the ATAL during the StratoClim mission period.

High resolution simulations of deep convective uplift of Chinese pollutants into the Asian Monsoon Anticyclone

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During the Asian Summer Monsoon, Asian pollution uplifted by deep convection into the upper troposphere and lower stratosphere where is trapped within the Asian Monsoon Anticyclone. The composition of the Aerosol Tropopause Asian Layer (ATAL) remains highly uncertain because of the lack of in-situ measurements. The StratoClim airborne campaign in July–August of 2017 has provided unprecedented airborne measurements of the Asian UTLS with the Geophysica aircraft. During the same period, UTLS composition has been documented from commercial aircrafts with the In-service Aircraft for a Global Observing System (IAGOS). To understand the role of deep convection in the transport and formation pathways of the ATAL aerosols, we have performed a mesoscale simulation with Meso-NH model using a full chemistry scheme. The simulation domain covers India and China (58–122.9°E, 8.8–40.9°N) at a 15 km horizontal resolution. Comparison between observations and simulations show that the model succeeds in reproducing the overshooting clouds, the uplift of aerosols and their transport pathway. Deep convection initiates on 7 August over the Sichuan basin, and develops up to 18.2 km altitude across the tropical tropopause layer. The signature of deep convection is evidenced by the enhanced amount of boundary layer pollutants (CO ≥ 180 ppbv) above 15 km. The uplifted CO propagates towards the west with the strong easterly winds south of the AMA. Large amounts of aerosols from the Sichuan basin at the foot of the Tibetan plateau are also uplifted by deep convection. For instance, POA (primary organic aerosol) concentrations of up to 15 ?g m–3 are simulated up to 6 km in the Sichuan basin. Above, POA particles are scavenged inside of the convective clouds and decrease to concentrations of ~6 ?g m–3 at 15 km. The uplifted POA also travels westward to the south of Kathmandu but its concentration gradually decreases. To quantify the impact of Sichuan emissions upon the AMA, a simulation with no emissions over Sichuan was performed. The sensitivity experiment shows that more than 35% of the uplifted CO in the convection region is originating from the Sichuan basin. This episode of Sichuan convection contributed to ~2% CO and less than 1% BC and POA of the entire AMA. A detailed analysis of the simulations output will be given at the conference with an emphasis on the impact of deep convection on the 3D aerosol distributions.

Regional modelling of transport of aerosols and trace gases during the StratoClim flight campaign in summer 2017

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Unprecedented growth in anthropogenic emissions, combined with deep convection associated with the Asian summer monsoon (ASM), gives rise to transport of aerosols and trace gases into the upper troposphere and lower stratosphere (UTLS). Anthropogenic emissions from Himalayan-Gangetic Plain and China as well as dust emissions from desert regions are entrained into two convective zones over southern?? China and southern side of the Himalayas, and contribute to the Asian Tropopause Aerosol Layer (ATAL). During a high altitude aircraft campaign in summer 2017 as part of the EU StratoClim project, measurements of chemical and aerosol composition were carried out over Nepal, northern India and the Bay of Bengal in the UTLS up to 20km. In this study, we examine different anthropogenic emissions and their contributions to UTLS composition during the ASM period of the flight campaign in July-August 2017. The WRF-Chem model, ver. 3.8.1, was run over 2 domains with 100km and 33.3km horizontal resolution for parent and nested domains, respectively. The parent domain stretches from the Arabian Peninsula and eastern Europe in the west to Japan and Indonesia in the east and the nested domain covers India, Himalayan-Gangetic Plain, Indochina and China, encompassing the main convective zones. The model is nudged with meteorological analyses from GFS and anthropogenic emissions are from ECLIPSE and REAS v2.1 inventories. Natural emissions are also included (e.g. dust). The model was run with detailed gas phase and aerosol treatments (SAPRC99 coupled with VBS and MOSAIC aerosols). Simulated spatial and vertical distributions of clouds, trace gases (e.g. CO, ozone) are compared with measured aircraft data. We investigate the impact of convective uplift from different emission regions on the vertical distribution of aerosols in the ATAL through comparison with available observations (ERICA aerosol composition, aerosol backscatter and lidar).
Key words: Asian Monsoon Anticyclone, convection, aerosols, aircraft data, regional modelling

Stratospheric sulphur: MIPAS/Envisat measurements and chemical transport model simulations of carbonyl sulphide, sulphur dioxide, and sulphate aerosol

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Stratospheric aerosol, in which sulphur is by far the most common element, has the potential to exhibit a cooling effect on Earth surface temperatures by backscattering incoming solar radiation. This potential, and an increased stratospheric aerosol loading during the last decade, caused rising interest in stratospheric sulphur during the last years. The main precursors of stratospheric sulphate aerosol are gaseous carbonyl sulphide (OCS) and sulphur dioxide (SO2). From MIPAS/Envisat (Michelson Interferometer for Passive Atmospheric Sounding aboard the Environmental Satellite), datasets of gaseous OCS and SO2 and, as a new data set, sulfate aerosol volume densities are available for Jul 2002–Apr 2012. After filtering, validation and de-biasing of the new aerosol data set, the observational data have been compared to an isentropic chemical transport model (CTM) in which a sulphur scheme has been implemented. In a case study on the volcanic eruptions of Kasatochi in 2008 and Sarychev in 2009, which both erupted during boreal summer at 50N, consistency between MIPAS SO2 and sulphate aerosol could be demonstrated in terms of volcanic mass and transport patterns. Calculations of e-folding lifetimes of stratospheric volcanic sulphur after the eruption of Sarychev resulted in average lifetimes of roughly three months. Besides sedimentation that plays an important role, especially in the peak amounts of volcanic sulphate aerosol, sensitivity simulations with the CTM show that the dominant process governing the lifetime of sulphur in the extra-tropical lower stratosphere after the two eruptions was transport by the Brewer-Dobson circulation. Additionally, parts of the emitted sulphur were transported towards the Equator where they were lifted in the tropical pipe. Several patterns of primarily non-volcanic stratospheric sulphur seen in the MIPAS data, such as decrease of OCS in the stratosphere by photolysis, or formation of SO2 from OCS in the Tropics at 25–35 km, could be confirmed by model simulations. Some patterns that are seen in the new MIPAS aerosol data, such as elevated sulphur mole-fractions in the Tropics at above 22 km, extending towards lower altitudes at high-latitudes, could be ascribed to sulphur released from OCS. In terms of stratospheric sulphur mass, consistency has been demonstrated between the MIPAS data sets of OCS, SO2 and liquid-phase H2SO4. Simulations of background conditions with OCS as the only sulphur source, in combination with simulations of volcanic sulphur with a relatively high frequency of volcanic injections (98 individual identified eruptions within approximately 10 years), can explain the stratospheric sulphur masses which were derived from MIPAS retrievals. Under background conditions, modelled sedimentation of sulphate aerosol is a main factor of uncertainty, with relatively strong impact on the absolute amounts of sulphate aerosol. Finally, the importance of

relatively small and medium sized volcanic contributions as the main source of short-term to decadal scale variability over the MIPAS period has been illustrated.

The Characterisation of Secondary Sulphate Aerosols from Thermal Infrared Satellite Instruments in Low Earth and Geostationary Orbit

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We have developed a theoretical basis for the observation of secondary sulphate aerosols (SSA) from thermal infrared (TIR) nadir-viewing satellite instruments [1]. The sensitivity of TIR observations to the chemical composition (sulphuric acid mixing ratio) and the size distribution (effective number concentration and radius) of idealised SSA layers has been analysed. Both high-spectral resolution, IASI (Infrared Atmospheric Sounding Interferometer)-like and broadband radiometers, MODIS (Moderate Resolution Imaging Spectroradiometer) and SEVIRI (Spinning Enhanced Visible and InfraRed Imager)-like pseudo-observations are generated using forward radiative transfer calculations. Then, the impact of the extinction of these idealised aerosol layers on the brightness temperature spectra observed by the different simulated satellite instruments has been analysed. The dependence of the aerosol spectral signature to the chemical and microphysical properties of the layers, as well as the role of interfering parameters, in particular co-existing sulphur dioxide [2], are here discussed. The information content (degrees of freedom and retrieval uncertainties) of synthetic satellite observations is estimated for the different instrumental configurations. High spectral resolution and broadband spectral features approaches are proposed and discussed. First tests on the detection and tracking of volcanic SSA plumes from both explosive events with stratospheric injection of the plumes (Nabro volcano eruption, summer 2011, analysed using the high-temporal-resolution geostationary SEVIRI observations [3]) and smaller tropospheric events (different recent medium-sized eruptive events of Mount Etna observed by IASI) have been performed. Finally, future perspectives on the combined estimation of SO2 and SSA amounts in volcanic plumes, as well as multi-spectral/instrumental coupling for volcanic plumes observations are discussed.

Model calculations of the contribution of tropospheric SO2 and DMS (dimethyl sulfide) to the stratospheric sulfur budget

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The tropospheric chemistry of SO2 and DMS (dimethyl sulfide) and their transport to the stratosphere are investigated by running a chemical box model along trajectories ascending from the boundary layer to the tropopause. The trajectory model is driven by ECMWF ERA-Interim data. Convective transport is simulated by a new scheme that randomly displaces air parcels vertically. The probability of displacement is derived from ERA-Interim con- vective entrainment rates, mass fluxes and detrainment rates. The chemistry model includes the gas phase reactions SO2+OH and DMS+OH and the liquid phase reactions SO2+H2O2 and SO2+O3 and uses background fields of OH, O3 and H2O2 obtained from a GEOS-Chem CTM run.

Our model simulations show that in the lower tropical stratosphere the contribution of tropospheric SO2 (and DMS) to the aerosol formation is comparable to that from the photolysis of OCS (carbonyl sulfide). In the simulated years (2009 and 2010) significant fractions of the tropospheric SO2 reaching the lower stratosphere are emitted by anthropogenic sources in Asia and degassing volcanos in Papua New Guinea.

StratoClim Keynote

The dual role of the Asian convection in cross-tropopause transport of water: hydration versus dehydration

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The study tackles the question of the role of deep (overshooting) convection on transport of water into the lower stratosphere using the unique set of Geophysica measurements (H2O, IWC, HDO/H2O, CO, backscatter in situ/remote), ensemble trajectory modeling coupled with BTD-based overshoot detection/tracking scheme and a large variety of satellite observations (MSG/Himawary, CALIOP, CATS, MLS, OMPS-LP, GNSS-RO) together with high-resolution ECMWF and ERA5 fields.

Among the key outcomes is that tropopause-overshooting convection above subtropical Asia is the key contributor to the moist pool in the lower stratosphere within the Asian summer anticyclone. At the same time, deep convection above Southern slopes counteracts the moistening of ASMA through convectively-induced CPT cooling.

The study also describes the preconditions for formation of laminar clouds above the tropopause and mechanism of their formation. The analysis suggests that convectively-induced cooling in the Southern part of ASMA may lead to a widespread formation of cirrus up to 415 K level, whereas the structure of these clouds is modulated by gravity waves, likely of both convective and orographic origin.

Invited Keynote

Direct influence of deep convection on water vapor concentration in the tropical lower stratosphere

Eric Jensen and Rei Ueyama

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It is well known that stratospheric humidity is primarily controlled by freeze drying (ice crystal growth and sedimentation) of air ascending across the cold tropical tropopause. The strong correlation between lower stratospheric humidity and tropical cold-point tropopause temperatures supports this basic understanding. However, the suggestion of an important source from deep convection that extends above the tropical tropopause has persisted. We will present anecdotal evidence from high-altitude aircraft campaigns (including StratoClim) over the past few decades indicating localized enhancements in lower stratospheric H2O concentration attributable to deep convection. Although these events show that direct convective hydration of the lower stratosphere can occur, they are rare, and quantifying their impact on the overall budget of stratospheric water vapor has proven challenging.

In the second part of the talk, we will present detailed modeling of the processes controlling water vapor near the tropical tropopause as a method for constraining the influence of deep convection. The model uses trajectory calculations based on analysis winds and temperatures along with a one-dimensional ice microphysics model. High frequency waves are superimposed on the analysis temperature fields. The locations, times, and cloud-top potential temperatures of deep convection extending into the tropical tropopause layer are determined from geostationary infrared satellite measurements. The IR cloud top heights are adjusted to agree statistically with CloudSat/CALIPSO measurements. We both saturate the model up to the cloud tops and add detrained ice crystals to the model. The detrained ice has a very small effect. Our simulations, along with other calculations using a different modeling approach, indicate that the overall impact of convection on lower stratospheric humidity is no more than a few percent (~0.25 ppmv). We will discuss the uncertainties in these calculations and the general implications for the importance of deep convection on the stratospheric water vapor budget.

Convective sources and transport patterns into the stratosphere during the 2017 StratoClim campaign

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This work details the effect of the deep convective transport on the Asian Monsoon Anticyclone stratosphere, basing on the analysis of the features observed during the StratoClim campaign. Starting from the aircraft measurements of trace gases, we describe the relative contribution of different source region, the state of mixing and the age of the air parcels along the observations. The analysis is based on TRACZILLA Lagrangian simulations computed on meteorological fields from ECMWF (operational model, ERA-Interim and ERA5) at 3h and 1h resolution, using both kinematic and diabatic vertical velocity approaches. The diagnostic of the convective sources and mixing in the air parcel samples have been derived by integrating the trajectories output with high-resolution observations of convective cloud top from the MSG1 and Himawari geostationary satellites. We observed that the ERA5 simulations provide a better reproduction of the air masses evolution respect to ERA-Interim and also shows a better agreement between the diabatic and kinematic results.

The 8 flights took place mostly during a break phase of the monsoon and a large variety of transport conditions and convective intensity were observed. A small convective contribution was observed from maritime regions, in particular from the South Pacific and the Bay of Bengal that, in fact, was not particularly active during the period of the campaign. Nevertheless, during specific flights the aircraft sampled a large convective influence from continental sources from the Tibetan Plateau, Pakistan, China and India. Here we discuss the details of flights 6 and 8: during flight 6 chinese air was observed in thin filamentary structures of polluted air, characterized by peaks in CO (measured by COLD) and other anthropic tracers, mostly associated with young convective air (age less than few days) and in correspondence of the observation of probable newly formed cloud particles. Observed air from continental India, on the contrary, was linked to lower concentration of trace gases and to air masses recirculating within the anticyclone, with average ages between 10 and 20 days. Flight 8 represents instead an interesting case study for possible overshooting transport: the aircraft passed just above a large and intense convective system, sampling some distinct plumes (also carrying some anthropic features) and the trace of very clear air from a big typhoon system from the Pacific.

Effect of deep convection on UTLS temperature and water vapor in the Asian summer monsoon anticyclone

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Deep convection plays a crucial role in transporting water vapor to the stratosphere, as it lifts moist air from the surface to the upper troposphere-lower stratosphere (UTLS). Nevertheless, the transient perturbations of the UTLS thermodynamic structure and water vapor occurring near and above the top of active convective systems are poorly understood. In the Asian summer monsoon (ASM) region, widespread deep convection induces a persistent anticyclonic vortex in the UTLS, known as ASM anticyclone, which increases the efficiency of its transport to the stratosphere. Here we analyze the effects of deep convection on UTLS temperature and water vapor using 134 balloon- borne measurements of temperature (T), water vapor (H2O), and ozone (O3), collected at five stations in the ASM region (India, China and Nepal) during eight intensive campaign periods over the monsoon seasons 2013-2017. The profiles are sorted according to their O3 mixing ratio at the cold-point tropopause (CPT) into convectively active (low CPT O3) and quiescent periods (high CPT O3), and the T and H2O distributions of these two ensembles are studied as a function of potential temperature (θ). The lapse-rate minimum (LRM, defined as minimum dT/dθ) is used to identify the mean convective outflow level. In the troposphere, convective periods are characterized by a warm anomaly of 3-6 K extending from the average cloud bottom (θ ≈ 335 K) to the LRM (θ ≈ 363 K), due to latent heat release and mixing, and higher H2O in the same region (up to + 250 % below the LRM). Above the LRM, convective periods show a strong cold anomaly (- 4 K) compared to quiescent periods, encompassing the CPT and extending up to θ ≈ 400 K, accompanied by a transient cooling (- 2 K) and lowering of the CPT (from θ ≈ 390 K during quiescent to θ ≈ 380 K during convective periods), and a significant dry anomaly of 1.5 ppmv (≈ 30%) in H2O mixing ratio. The cold anomaly above the LRM is attributed to mixing of cold air from overshooting updrafts, undergoing strong adiabatic cooling as they penetrate above the outflow level. Lower T result in 30% higher ice saturation on average in this layer (θ ≈ 370-400 K), suggesting that the dry anomaly is due to enhanced in-situ cirrus formation during convective periods. Above the CPT, a cold anomaly of ≈ 1.2 K between convective and quiescent periods persists up to θ ≈ 500 K (25 km altitude), which is consistent with an inertial (adiabatic) lifting of ≈ 120 m of the UTLS air column during convectively-active periods. No significant difference in T or H2O is observed for θ > 500 K.

Lidar measurement of thin cirrus and aerosol at Palau Island (7°N 134°E)

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A polarization diversity elastic backscatter lidar has been deployed in the equatorial island of Palau in Feb- Mar 2016. The system was operated unattended in the Atmospheric Observatory of Palau Island, from 15 February to 25 March 2016, working automatically 8 hrs per night, delivering 3650 atmospheric profiles (5 min average). Each profile extends from 1 to 30 km height. Here the dataset is presented and discussed in terms of the temperature structure of the UTLS, as derived from co-located PTU soundings. During the timeframe of the campaign it was found that the main convective outflows peaks roughly 3 km below the Cold Point Tropopause, its occurrence associated with cold anomalies in the upper troposphere (UT). When warm UT anomalies occur, presence of particles is restricted to a 5 km wide layer centered 5 km below the CPT. Particles have been detected above the CPT. These particles are depolarizing, with depolarization values generally lower than those encountered in the TTL. Results show a correlation between presence of optically detectable particles and cold anomalies above the Cold Point.

Invited Keynote

Impacts of gravity waves on cirrus clouds in the tropical upper troposphere: observations and theories

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Gravity and equatorial waves are an ubiquitous and salient feature of the tropical Upper-Troposphere-Lower Stratosphere, where they cover a wide range of spatial (a few hundred meters to several thousand km) and time scales (minutes to days). Through temperature and wind fluctuations, waves crucially influence the formation and life cycle of cirrus clouds. This in turn has major impacts on the stratospheric water vapor burden as well as the global radiation budget.
While the effect of waves on high altitude cloudiness has been acknowledged for more than two decades, recent space-borne measurements and in situ campaigns (including ATTREX, POSIDON and Stratoclim) have since then shed new light on the topic. In particular, they have provided evidence that cloud microphysical properties and large-scale structures are decisively affected by small-scale and large-scale waves. Two main processes are believed to be responsible for those interactions: homogeneous ice nucleation triggered by fast cooling events, and ice crystals growth and sedimentation in the large-scale perturbations induced by the waves. This presentation will review the relations between gravity waves and cirrus from both theoretical and observational perspectives, focusing on recent progress and observations. The implications for the stratospheric water vapor budget and tropical high cloud cover will also be discussed.

Understanding the Sources and the Factors Behind the Variability of Cirrus Clouds over the Asian Summer Monsoon Region

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Clouds play a major role in maintaining the Earth's radiant energy balance through cooling the Earth system by reflecting the solar shortwave radiation and warming its atmosphere by trapping the Earth emitted long wave radiation. Optically thin clouds such as cirrus, allow solar radiation to pass through them and emit less longwave radiation due to their lower temperatures. The net effect of such upper level cirrus clouds is inducing a warming effect in the Earth's atmosphere. Therefore, from climate point of view, in-depth studies are necessary to understand the factors affecting the variability of cirrus clouds. In this work we use cloud observations (2006-2017) from CALIPSO satellite to generate the climatology of cirrus clouds' distribution over the Asian summer monsoon region (ASMR). Cirrus clouds show a clear seasonal variation with the maximum incidence observed during the northern hemispheric summer. A transport model has been used to trace the convective sources of cirrus clouds during the Asian summer monsoon (June-August) and it is found that the major convective sources of cirrus is located over central India and Bay of Bengal. The presence of tropical easterly jet during the monsoon season is found to be responsible for the large-scale distribution of the cirrus clouds over the Indian sub-continent away from the major convective sources. In addition, the aspects influencing the variability of cirrus clouds over ASMR are also explored. It is shown that deep convection and presence of water vapor in the upper troposphere are found to modulate the strength of cirrus clouds over ASMR.

In-situ measurements of HDO/H2O isotopic ratios in the Asian Summer Monsoon

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The Asian monsoon represents one of the main pathways by which water vapor enters the UT/LS. Satellite measurements of the HDO/H2O ratio of UT/LS water, a tracer of convective origin, have suggested differences in transport behavior between the Asian and North American monsoons, with strong UT/LS enhancement occurring only over North America. We report here the first in-situ measurements of the HDO/H2O ratio in the Asian monsoon, that help resolve this discrepancy. The Chicago Water Isotope Spectrometer (Chi-WIS) participated in the July/August 2017 StratoClim campaign, measuring water vapor and its isotopic composition in the upper troposphere and lower stratosphere. These measurements can help to diagnose the importance of overshooting convection in water transport by the Asian monsoon and to characterize the extent to which convection-driven water vapor perturbations propagate to higher altitudes and contribute to the overall stratospheric water budget.

Convective hydration of the lower stratosphere during the StratoClim aircraft campaign as seen from a Meso-NH convection-permitting simulation

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The impact of convection on the lower stratosphere humidity is investigated using a Meso- NH convection-permitting simulation with a 2.5-km grid spacing run from 0000 UTC 6 to 11 August 2017. Comparison with satellite observation shows that the simulation captures the daytime evolution of the convective activity and the large extent of high clouds very well. The hydration patch that was measured to the south of Kathmandu on 8 August during flight #7 is reproduced. We show that this hydration patch is generated by convective overshoots that occurred over the Sichuan Basin 1.5 day before. Overshooting clouds develop up to 19 km, hydrating the lower stratosphere up to 20 km with more than 6000 tons of water vapour. Interestingly, this transport is associated with low ratio of tropospheric air in the stratosphere (up to 10 % locally). After 12 h, while most of the ice either sublimates or falls out, the subsequent hydration patch still presents water vapour contents up to 15 ppmv. The continuous turbulent mixing later spreads and dilutes the hydration patch during its advection in the southern branch of the Asian monsoon anticyclone.
Over South-East Asia, the overshooting activity is ubiquitous over Gange Valley, Sichuan Basin and Tibetan Plateau, where it injects water vapour into the lower stratosphere. Thus, the water vapour field shows a strong diurnal cycle up to the cold point tropopause. However, humidity in the moist layer (contents larger than 5 ppmv, from 390 to 430 K) varies a lot in the last three days. The results show that convective overshoots compete with wave activity and turbulent mixing in driving the evolution of this moist layer in the lower stratosphere.

In-situ formed cirrus clouds observed during STRATOCLIM Field campaign and their nucleation mechanism

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In-situ aircraft measurements provide information on size and number densities of cirrus cloud particles. Krämer et al. (2009) reported that at low temperatures the observed ice number densities are much smaller than the expected ones assuming homogeneous nucleation. Optically thin cirrus clouds were also reported aby in-situ and remote sensing instruments like Lidar (ground based, air borne or space borne) and in-situ backscatter instruments (MAS on Geo- physica and COBALD on balloons) in the tropopause region and in particular during the STRATOCLIM field campaign in Kathmandu 2017. The optical thinness of the tropopause cirrus clouds are consistent with the low ice number density measured by in-situ instruments, mostly airborne.
We used the column version of ZOMM (Zurich Optical and Microphysical Model) to simulate the cirrus clouds measured by MAL on Geophysica, COBALD on balloons, and space borne LIDAR CALIOP on satellite CALIPSO.
The homogeneous nucleation leads much too high backscatter ratios and much too high ice number densities of the cirrus clouds. Heterogeneous nucleation with sufficient high number densities of ice nucleating particles may explain the low ice number densities and the small optical depth. The question is which type of aerosol particles are the heterogeneous ice nuclei. We present here a case study suggesting that heterogeneous nucleation on meteoritic smoke particles (MSP) or viscos organic aerosol may act as ice nuclei, leading to observed low ice number density and low LIDAR backscatter ratios.

An analysis of optical and microphysical properties of Cirrus clouds during STRATOCLIM

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Three laser particle spectrometers (CCP measuring particle diameters 3-47 µm ; CIP measuring 25-1600 µm and NIXE-CAPS measuring 0.6-950 µm), designed to count and size particles in the micron range, a backscattersonde and a lidar that measure particle optical properties such as backscatter and depolarization ratio, respectively in-situ and remotely, at 532 nm are part of the payload of the research aircraft M55 Geophysica. During the Kathmandu STRATOCLIM campaign, measurements of particle size distributions and optical properties within cirrus cloud were performed. Scope of the present work is to assess and discuss the consistency between the particle volume backscatter coefficient observed by the backscattersonde and lidar and the same parameter retrieved by optical scattering theory applied to particle size distributions as measured by the particle spectrometers.

Evolution of cirrus clouds in the Asian monsoon tropical tropopause layer: a case study from the StratoClim aircraft campaign

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Cirrus clouds were detected in the the Asian monsoon tropical tropopause layer on 8 August 2017 during the aircraft field campaign StratoClim, that took place out of Khatmandu, Nepal. An analysis of the meteorological situation shows that the airmass containing the cirrus cloud originates from a huge overshooting convective draft above China into the stratosphere. Moist airmasses were then transported westward for two days until they reached the target area of the StratoClim campaign (Lee et al., 2018, ACPD). Ice particles were observed below, as well as above the cold point tropopause (CPT, here T: ~188K, Theta: ~380K, Alt: ~17.5km). They were embedded in a highly supersaturated environment (RHice: ~130%) and consist of few, large ice crystals between about 20 and 80 micron diameter. This indicates an aged cirrus cloud, where smaller ice crystals have grown into this size range and larger ones have already sedimented out.

However, from the measurements the evolution of the crystals cannot be deduced, though it is important to know, if the ice particles are convectivly induced from farther below (liquid origin), in-situ formed in the moist air transported from the overshoot in China, or, in-situ formed but disconnected from this event. Indications about the pathways of water vapor and, in particular, cirrus ice particles from the tropical upper troposphere (UT) to the lowermost stratosphere (LS) are of importance due to the high sensitivity of atmospheric radiative forcing to changes in greenhouse gases in this region (Riese et al., 2012, JGR).

In this study, simulations will be performed to reproduce the evolution of the observed cirrus, and thus to identify the source of water of the cirrus clouds and their environment. To this end, two models including ice microphysics will be used: First, the large-scale Lagrangian model ClaMS-Ice will be operated, following the cirrus evolution along air mass trajectories from the convective event over China to the flightpath on 8 August. Second, a trajectory-based inverse cirrus model is used, starting at the observations and simulating backwards the evolution of the cirrus cloud. First results from the inverse cirrus model simulations indicate that the cirrus are not convectivly induced (liquid origin), but formed in-situ only several hours before the measurements. To what extend they are influenced by the overshooting convection over China and the further water vapor transport will be investigated by means of ClaMS-Ice.

Microphysics of anvil outflows from deep convective clouds in the Asian summer monsoon: Characterization of hydrometeor sizes, variability, and shapes by holographic in-situ measurements

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During the StratoClim 2017 field campaign, airborne measurements of cloud and aerosol properties were conducted in several research flights aboard the M-55 Geophysica aircraft. This study on cloud microphysics focuses on Flights 6, 7 and 8 on 06 August, 08 August and 10 August 2017. From the airborne holographic cloud probe HALOHolo, several cloud events have been identified and characterized in terms of cloud microphysics and ambient meteorological conditions. Some of the cloud events could clearly be addressed to recent deep moist convection via analysis of satellite imagery and analysis of the time series data of carbon monoxide and Lidar backscatter intensity. During one of the flights, two events have been identified which originated from the same cloud. These two events allow an investigation of the microphysical evolution of the ice crystals in a time- frame around one hour between the two measurements. In addition, a series of convective overshoots has been sampled in another flight at constant altitude over more than an hour of flight time. While most of the ice crystals larger than 50 µm were found to be either irregular shapes or aggregates, there was always a non-negligible amount of pristine columns and plates found in each convective event. Here, we will present an overview of the individual convective events together with a summary of the similarities and differences between them.

Intercomparison of in-situ water vapor measurements during StratoClim

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We report on intercomparison between the three in-situ hygrometers on the Geophysica aircraft during StratoClim flights out of Nepal in July/August 2017. FLASH and FISH measured water vapor and total water, respectively, by Lyman-alpha photofragment fluorescence, and ChiWIS measured water vapor by tunable diode laser infrared absorption spectrometry. All three instruments have sensitivity over the range of mixing ratios in the upper troposphere, from several hundred ppm to a few ppm. StratoClim flights allowed sampling through this entire dynamic range, and allowed the determination of instrument response to rapid fluctuations in water concentration and to heavy loads of cloud ice. We also show comparison to co-located, but not simultaneous, in-situ measurements of water vapor by balloon-borne frost-point hygrometer and remote measurements from the Microwave Limb Sounder. We define specific conditions in which measurement is problematic, and show that over most flight segments instruments closely agree.

Understanding unphysical water vapor measurements with Cryogenic-cooled Frost Point Hygrometers

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During the 2016-2017 StratoClim balloon campaigns on the southern slopes of the Himalayas, 8 of 63 soundings with water vapor measurements by means of the Cryogenically-cooled Frost point Hygrometer CFH [Vömel et al., 2007; 2016] showed unphysically high water vapor measurements in the stratosphere. This is a normal occurrence when the troposphere is very moist, such as during tropical deep convection [Holger Vömel, personal communica- tion]. This requires a careful quality check of the CFH data before their use in scientific studies, representing a significant source of uncertainty, especially in the lower stratosphere.

In this study we aim at understanding the reasons behind this unphysical behavior. In the stratosphere. A simple mixing of the ambient air, which is dry (?H2O = 4-5 ppmv), with air that became saturated with respect to ice, might explain the contamination. This is consistent with the existence of ice, e.g. in the inlet of the instrument, which becomes a water vapor source under ambient conditions. This would mean the contamination starts in the troposphere as the pay- load passes through mixed phase clouds with super cooled droplets. The presence of super cooled droplets is essential because they will freeze on contact with any of the instruments surfaces, unlike water droplets in the boundary layer, which would readily evaporated once relative humidity falls below 100 %, or ice crystals which would just bounce off the surfaces.

We selected the cases of the dataset for this study showing unphysical water vapor measurements in the stratosphere and presence of clouds complying with mixed-phase criterion: a combination of relative humidity measurement from the RS41 and ice saturation from CFH within the temperature range of 0°C to -38°C that can support both liquid droplets and ice crystals, and cloud presence confirmed by aerosol backscatter measurements. The cloud conditions were evaluated with a simple liquid to ice diffusion model with prescribed initial ice and liquid droplet distributions based on Korolev et al. [2017]. Through a series of computational fluid dynamic (CFD) simulations considering the instruments geometry, flow and pendulum oscillations during ascent we have identified the most relevant surfaces for the contamination event, quantified the freezing efficiency of the super-cooled droplets based on size and estimated the total amount of water frozen on surfaces from cloud thickness, cloud glaciation times and the initially prescribed droplet size distributions. We perform closure by matching the estimated frozen water col- lected in the troposphere with the total evaporated water in the stratosphere up to the point when the instrument recovers regular behavior in the ascent (or by obtaining a lower limit when the instrument did not recover).

An improved time lag parameterization for RH measurements with RS41

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We analyzed a dataset of more than 60 tandem soundings of the Cryogenic Frostpoint Hygrometer (CFH) and the newest generation of Vaisala radiosonde RS41-SG in order to characterize the simple capacitive humidity sensor of the RS41 against the state-of-the-art fast-responding chilled mirror technology of the CFH. This unprecedented dataset was obtained during tandem launches in Lindenberg (Germany), Nainital (India) and Dhulikhel (Nepal). Relative to its predecessor RS92, the RS41 uses an improved humidity sensor, whose heating capability results in an optimized fast response and a low solar radiation error. However, a very similar time lag is assumed for RS41 as for RS92. We find that this leads to significant overcorrections affecting the reported humidities, especially in the UTLS. In addition, similar to RS92 also RS41 needs also an empirical correction factor (called “empirical bias”) at very low temperatures, possibly due to inaccuracies in the calibration model of the sensors. Using
CFH as reference, we determine the time lag and empirical bias of RS41 from more than 30 RS41-CFH tandem soundings in Nainital and Dhulikhel, spanning a wide range of atmospheric temperatures. We validate the derived quantities by means of the Lindenberg soundings. In contrast to previous empirical corrections, the derived time lag results in an Arrhenius law, in accordance with the physical law of diffusion. This time lag is a factor 2-3 smaller than the that used by Vaisala. The empirical bias can reach up to 10% at the lowest temperatures, similar as for RS92. Using our new parametrisation substantially improves the agreement with the reference instrument CFH. This permits to extend the accuracy of RS41 humidity measurements by several kilometers in altitude, spanning the tropopause region and reaching into the lower stratosphere.

Invited Keynote

Using Aura MLS to Place the 2017 Asian Summer Monsoon into Context

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The Aura Microwave Limb Sounder (MLS), launched in July 2004, makes simultaneous co-located measurements of trace gases and cloud ice water content (a proxy for deep convection) in the upper troposphere / lower stratosphere (UTLS) on a daily basis. With its dense spatial and temporal sampling, extensive measurement suite, and insensitivity to aerosol and all but the thickest clouds, Aura MLS is well suited to characterizing UTLS composition in the region of the Asian summer monsoon (ASM) and quantifying the considerable spatial and seasonal variations therein. In addition, the 14-yr MLS data record is invaluable for assessing interannual variability in the impact of the ASM on the UTLS. Here we examine MLS measurements of cloud ice and both tropospheric (CO, CH3Cl, CH3CN, CH3OH) and stratospheric (O3, HNO3, HCl) tracers, along with meteorological reanalyses, to place the 2017 ASM observed in detail by the StratoClim campaign into the context of other recent monsoon seasons, including 2018. The strong regional enhancement in UT CO typically seen over Asia in boreal summer – indicative of the trapping of surface pollution inside the ASM anticyclone – was considerably weaker than average in 2017. Although the anticyclone was particularly weakly polluted in 2017, CO enhancements have generally been smaller than the climatological norm since ~2014, not only inside the anticyclone, but also throughout the hemisphere. Analysis of the suite of MLS measurements suggests that factors other than changes in the severity of biomass burning or the strength of deep convection, such as the declining trend in anthropogenic emissions in the region reported in recent studies, may be playing a primary role in controlling year-to-year variations in the signature of pollution trapped in the anticyclone.

Quantification of water vapour transport from the Asian monsoon to the stratosphere

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Contact: Matthias Nützel (matthias.nuetzel@dlr.de) Abstract:

We have performed multiannual simulations with the chemistry-transport model CLaMS (Chemical Lagrangian Model of the Stratosphere) to investigate water vapour transport from the Asian monsoon region to the stratosphere. We assess the transport pathways and efficiency of water vapour transport from the Asian monsoon region to the stratosphere and make comparisons with other source regions (e.g. the tropics). Our analyses are related to the previously published work by Ploeger et al. (2017), who have analyzed mass transport from the Asian monsoon anticyclone to the stratosphere. The presented findings are related to the Final Meeting Sessions “Transport and dynamics” and “Global Implications” and have recently been published for discussion in Atmospheric Chemistry and Physics (Nützel et al., 2019).

Using chemical and idealised tracers to investigate interannual variability and trends in Asian monsoon transport

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The Asian summer monsoon acts as a transport pathway for anthropogenic surface pollution into the upper troposphere/lower stratosphere, and can have significant impacts on lower stratospheric composition. In this study, we investigate interannual variability and trends in Asian monsoon transport from 1960-2017 using an ensemble of UM-UKCA chemistry- climate model integrations. Modelled chemical species (CO, O3 and H2O) and dynamical quantities (PV, geopotential height) are used to explore the interannual variability in the strength of vertical transport; the extent to which vertical transport is confined within the core of the monsoon anticyclone; and to identify long-term changes in vertical transport associated with trends in the strength of the monsoon anticyclone. In addition, a number of idealised tracers have been implemented in the model to identify surface source regions of tropospheric airmassess entrained in the monsoon circulation. These idealised tracers are emitted from selected surface regions, with two tracers with different prescribed lifetimes (5 and 30 days) emitted from each region. The use of these tracers allows us to separate airmasses which have undergone rapid and slow uplift, and to identify changes in contribution of different surface source regions to the composition of airmasses within the Asian monsoon anticyclone.

Role of the 2018 Sudden Stratospheric Warming on the Abrupt End of the Western European Drought

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Southwestern Europe experienced extraordinary windy and rainy conditions in March 2018, which ended with the most severe drought since 1970 at continental scale. Two weeks earlier an extraordinary Sudden Stratospheric Warming took place, preceded by the strongest planetary wave activity on record. It was also remarkable in terms of strength and persistence of the easterly winds in the middle stratosphere. This study provides evidences of the link between the SSW and the weather shift over western Europe by using a weather regime approach and flow analogues. The timing of the downward propagation of the stratopsheric anomalies, the transition to and persistente of the negative NAO weather regime and the sudden precipitation increase are all consistent with the typical tropospheric state after SSWs. This is a clear example of stratopshere-troposphere dynamical coupling and ultimately can help to improve seasonal forecast predictions.

Temporal variability and zonal extent of the Asian monsoon anticyclone

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The Asian summer monsoon circulation has been the subject of continuous research for several decades. Much emphasis has been given to the lower level cyclone, but while various models and mechanisms have been proposed to explain certain features of the upper level anticyclone, like the zonal scale or time dependence, a comprehensive theory combining these characteristics is still lacking. Further do many qualitative and quantitative models for the monsoon anticyclone require a strong mechanical damping throughout the atmosphere to model a zonally confined response, as can be observed for the Asian monsoon. Such a strong dissipative process, however, is a questionable assumption in the upper troposphere/ lower stratosphere (UTLS), and thus different physical processes that can potentially confine the monsoon response need to be identified in order to obtain a realistic representation of the monsoon.

The fundamental dynamical details of the structure and evolution of the circulation form an important basis for understanding the influence of the anticyclone on the weather- and climate-system. In particular the process of horizontal transport of trace gases, trapped inside isolated anticyclonic features shed from the main anticyclone has been a frequently discussed matter in recent literature, as the eddy can potentially carry pollutants across the mid-latitude tropopause into the stratosphere.

We modelled the monsoon flow as response to a steady imposed heat source using a dry general circulation model that, for some experiments, includes a simple representation of mid- latitude dynamics by imposing a thermal relaxation towards a baroclinically unstable stat. The use of an imposed heating to model the circulation allowed us to investigate the dependence of the flow on the details of the forcing and the background state. We found that for various idealised basic states and heating distributions we observe a range of different behaviours, many of which strongly resemble phenomena and features observed in re-analysis data in association with the monsoon. This includes the spontaneous emergence of temporal variability in the form of westward eddy shedding from the monsoon anticyclone. By varying the strength of the background mid-latitude dynamics we can further observe a transition of the system from a state with periodic westward eddy shedding to a state dominated by eastward shedding. Additionally the inclusion of mid-latitude dynamics can lead to a finite zonal length scale of the response, without the need for strong dissipation in the UTLS.

The presented study covers various observed features and behaviours of the Asian monsoon anticyclone and shows how they arise in a simple dynamical model for certain ranges of values of external parameters. The model behaviour allows us to gain insights into the fundamental drivers of the monsoon circulation and the physical processes that determine its structure and evolution.

StratoClim Keynote

Stratospheric aerosol 1990 to 2017, transient simulation of radiative forcing and comparison of aerosol properties with the STRATOCLIM Asian Monsoon aircraft campaign

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The chemistry-climate model EMAC with fully interactive stratospheric and tropospheric aerosol is used for a transient simulation from 1990 to 2017 as contribution to SPARC-SSIRC. Tropospheric meteorology is nudged to ERA-Interim. 3D-SO2 plumes from about 450 explosive volcanic eruptions derived from limb satellite observations by MIPAS, GOMOS, SAGE II and OSIRIS are added to the simulated SO2 from other sources (OCS, DMS, anthropogenic) at the time of the eruption, including the major eruption of Pinatubo. Comparison of simulated calculated stratospheric optical depth with satellite data points to the importance of Asian desert dust transported to the lowermost stratosphere during the Asian Summer Monsoon. From comparisons with instruments on the Geophysica aircraft we show that the simulated aerosol properties are realistic.

Agung eruption 1963 — one or two eruptions, does it matter?

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In 1963 a series of eruptions of Mt. Agung, a volcano on Bali, Indonesia (8.342o S, 115.58o E), resulted in the 3rd largest eruption of the 20th century and claimed 1900 lives. The eruption series lasted for 11 months from February 1963 to January 1964. Revising the literature, we realized that not only one of the eruptions was strong enough to inject SO2 into the stratosphere, a requirement to get a long lasting stratospheric sul- fate layer, but also a second one. This second eruption injected 2.3 Tg SO2 into the stratosphere on May, 16th, half of the 4.7 Tg SO2 of the first one on March 17th. The resulting sulfate layer caused a climatic impact by scattering and absorbing solar and terrestrial radiation which lead to a global temperature decrease of about 0.4 K in the tropical troposphere.

All recent volcanic emission data sets assume one large eruption phase for Mt. Agung, the one in March 1963, but neglect the second one. Instead they assume an injection of 7 Tg SO2 for this one eruption. Aerosol microphysical processes are non-linear and depend on the injection rate. Therefore, we raised the question, if we receive different volcanic forcing when simulating two medium eruptions instead of a single large eruption only?

We performed two experiments with the aerosol microphysical model HAM, coupled to the general circulation model ECHAM5, the first one with one eruption, and the second one with two eruptions. We will compare the results of the two experiments and explain the different results.

The influence of ENSO on the QBO in climate models.

F. Serva, B. Christiansen, C. Cagnazzo, and S. Yang

Observational studies have shown that the phase-speed and amplitude of the QBO are different in the warm and cold phases of the ENSO. Observations also indicate an alignment of the phase of the QBO in the years after strong warm ENSO events.

Here we present an analysis of the QBO/ENSO connection in atmosphere only (AMIP type) experiments (mainly with EC-Earth) and in ocean-atmosphere coupled simulations from a large multi-model ensemble. Both uncoupled and coupled experiments reproduce the observed long term mean QBO phase-speed and amplitude rather well. The uncoupled and most coupled models also reproduce the observed seasonal cycle in the phase-speed of the QBO.

The observed QBO phase-speed response to the phase of the ENSO is seen in both coupled and uncoupled versions of EC-Earth but not in other coupled models. For the uncoupled EC-Earth experiments this relationships improve with horizontal resolution. The absence of the QBO/ENSO relationship in the coupled models is probably related to an over-dependence on parameterized wave forcing. The alignment of the phase of the QBO in the years after strong warm ENSO events previously observed in an ensemble of 10 AMIP type model experiments has been confirmed in a much larger ensemble.

An overview of recent findings from halogenated trace gas observations in the troposphere and stratosphere

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Halogenated trace gases play a key role in the stratosphere, both through their impacts, e.g. as ozone-depleting substances and greenhouse gases or, in combination with tropospheric abundance trends, through their use as tracers of transport and/or chemistry. We here present a selection of recent results from air sample-based measurements of these gases in the troposphere and stratosphere with a highly sensitive and precise system based on gas chromatography and mass spectrometry. This system is capable of detecting more than 50 of these gases and we have analysed samples originating from a range of platforms spanning from ground level to 36 km. The presentation will include examples of i) globally relevant tropospheric long-term trends based on an air archive from the remote southern hemisphere, ii) distributions of gases in the upper troposphere and lower stratosphere (UT/LS) based on the CARIBIC aircraft project, iii) recent improvements in determining stratospheric trace gas lifetimes and semi-empirical Ozone Depletion Potentials (ODPs), and iv) new approaches to determining the mean age of air as a measure of the Brewer-Dobson circulation.

Key words: halogenated, observations, ODSs, mean-age

Survey of lightning activity over the South Asian monsoon region: possible link to enhanced air pollution

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Depending on the environmental conditions, aerosols from pollution plumes are able to invigorate or suppress convection-induced lightning activity. Fine aerosol particles can be activated to form cloud droplets on which excess supersaturation condenses and forms additional cloud water and latent heating, thus intensifying convective strength. Nevertheless aerosols cool the surface and warm the mid-level atmosphere through radiative effects which may be stronger than the microphysical effects. Case-based studies and a few works on decade long records of lightning activities and thermodynamic parameters have attempted to disentangle the various factors in order to identify anthropogenic impacts and long time trends in the observation. Here we provide a survey of lightning activities focusing on the geographic area of the South Asian monsoon which turns large parts of India from a kind of semi- desert into green lands. Data are evaluated from two identical spaceborne Lightning Imaging Sensors of the Tropical Rainfall Measuring Mission (17 years) and the International Space Station (2 years), furthermore from the ground base World Wide Lightning Location Network (14 years). An attempt is made to correlate the spatiotemporal structure of lightning patterns with atmospheric parameters such as the aerosol optical depth, convective available potential energy, total water column, etc. It is known that the monsoon strength index based on areal mean rainfall over the summer monsoon region exhibits strong interannual variability and a robust long-term trend, nevertheless preliminary results suggest that the lightning activity does not clearly reflect such tendencies. Possible explanations are shortly discussed.

Modeling the climatic effects of large explosive volcanic eruptions: Current status and new challenges

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Volcanic eruptions are a major natural driver of climate variability at interannual to multidecadal time scales and the wildcard in the future development of Earth's climate. They are also unique natural experiments that provide unprecedented insights into many involved in climate change processes. Understanding how the climate system responds to volcanic forcing can not only test our understanding of these processes but also advance our ability to interpret past records. Our current understanding of the climatic response to volcanic forcing is however limited as large uncertainties affect both the observational records, due to the limited number of observations, and the non-robust dynamical responses simulated by different climate models. The lack of agreement between model results is crucially determined by differences in models' characteristics and uncertainty in the eruption details and background climate as well as uncertainties in aerosol microphysics and transport. The multiple and varied nature of these factors prevents their contribution to uncertainty from being distinguished within existing transient simulations or non-coordinated multi-model experiments. For this reason, a couple of international model intercomparison activities have been established during the StratoClIm period. Here I will present specifically the Interactive Stratospheric Aerosol Model Intercomparison Project (ISA-MIP). The central aim of ISA-MIP is to constrain and improve interactive stratospheric aerosol models and reduce uncertainties in the stratospheric aerosol forcing by comparing results of standardized model experiments with a range of observations. Coordinated inter-model experiments are designed to investigate key processes which influence the formation and temporal development of stratospheric aerosol in different time periods of the observational record. Potential links to the StratoClim results will be discussed.

Analyses of Geophysica measurements of the Asian summer monsoon campaign in 2017 and comparison with respective data derived from Chemistry-Climate-Model simulations

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During the Asian Summer Monsoon (ASM) campaign in Kathmandu, Nepal, the research aircraft Geophysica collected data during 8 measurement flights in July and August 2017. A probability density function of Geophysica CO measurements is presented, showing different populations, depending on sampling altitude and day of sampling. In order to help analysing these observations and understanding the processes driving the observed concentration distribution and variability, we quantified the source/receptor links for all measured data. Based on the 3-D Lagrangian particle dispersion model (FLEXPART), we simulated the contributions of different sources from the EDGARv4.3.2 emission inventory database for all locations and times corresponding to the measured carbon monoxide mixing ratios along each StratoClim flight. Contributions are simulated from emissions occurring during the last 20 days before an observation, separating individual contributions from the different source regions. The main goal is to supply added-value products to the StratoClim project by evincing the geographical origin and emission sources driving the CO enhancements observed in the troposphere and lower stratosphere. Moreover, a comparison between Geophysica data and model data derived from a Chemistry-Climate Model simulation is made, where the dynamics have been specified to reanalyses (REF-C1SD). Such model data are suitable for a direct confrontation with the Geophysica data of the specific days and flight tracks. In addition, combination with information provided by other, free-running model simulations (REF-C1) allow classifying the Geophysica measurements regarding the specific period of measurements in comparison to other ASM seasons in recent years. In our presentation we will concentrate on CO data. Individual profiles will be compared as well as specific clusters of data will be investigated (e.g. measurements in July vs. August; cloud-free or cloudy situations; etc.). An overall classification of the ASM 2017 season with respect to climatological means will be provided.

Systematic errors in South Asian monsoon precipitation: Process-based diagnostics and sensitivity to entrainment in NCAR models

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In simulations of the boreal summer Asian monsoon, generations of climate models show a persistent climatological wet bias over the tropical western Indian Ocean and a dry bias over South Asia. Here, focusing on the monsoon developing stages (May-June), the time window when the errors begin to emerge, detailed process-based diagnostics are first applied to a suite of NCAR models and reanalysis products. Two primary factors are identified for the initiation and maintenance of the wet bias over the north-western Indian Ocean (NWIO; 5o- 15oN, 52o-67oE): (i) excessive tropospheric moisture, and (ii) restrained horizontal advection of the near surface cold/dry air couplet that originates offshore of Somalia. Second, guided by the diagnostics, we hypothesized that insufficient dilution of convective updrafts is one possible candidate for model bias, and performed a series of enhanced entrainment sensitivity experiments with NCAR CAM4. The results suggest that increasing entrainment leads to a drier free troposphere, arrests vertical extension of clouds, and weakens moisture convection and cloud-radiation feedbacks. Each factor leads to a reduced wet bias over WIO; moreover, the dry bias over South Asia is also reduced due to precipitation partitioning and changes to local circulation features. In CAM4, improved precipitation climatology due to increased entrainment suggests that insufficient dilution is one factor, but not the only one, that contributes to systematic errors. In climate models, realistic representation of boundary-layer processes arising out of local ocean atmosphere interaction processes off Somalia's coast deserves attention.

Marginal Benefit to South Asian Economies from SO_2 Emissions Mitigation and Subsequent Increase in Monsoon Rainfall

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Sulphate aerosols are dominated by SO2 emissions from coal-burning for the Indian electricity sector and they are thought to have a short term but significant, negative impact on South Asian Summer Monsoon rainfall. This reduction in precipitation in turn can lead to reduced economic outputs, primarily through smaller agricultural yields. By bringing together estimates of (a) the impact of sulphate aerosols on precipitation and (b) the observed relationship between monsoon rainfall and GDP, we present a methodology to estimate the possible financial cost of this effect on the Indian economy and on its agricultural sector. Our preliminary estimate is that the derived benefits could be large enough that around 50% of India's SO2 emissions could be economically mitigated at no cost or net benefit, although it should be noted that the large uncertainties in the underlying relationships mean that the overall uncertainty is also large. Comparison of the 1952–1981 and 1982–2011 periods indicates that the Indian economy may now be more resilient to variability of the monsoon rainfall. As such, a case could be made for action to reduce SO2 emissions, particularly in the crucial monsoon period. This would have a significant, positive effect on a crucial and large sector in India's economy and the effects would be visible almost instantly. The recent growth in renewable energy sources in India and the consequent, reduced increase in coal burning means that further financial costs have already been avoided. This impact should be further investigated so that it can be included in cost-benefit analyses of different fuel types in the region. The significant uncertainties associated with these calculations are discussed.

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