Stratospheric and upper tropospheric processes for better climate predictions
– StratoClim –

Overarching goal:

To improve climate projections by improving the representation of the main climate relevant processes of the UTS in Earth System Models and assess the role of the UTS in surface climate change.

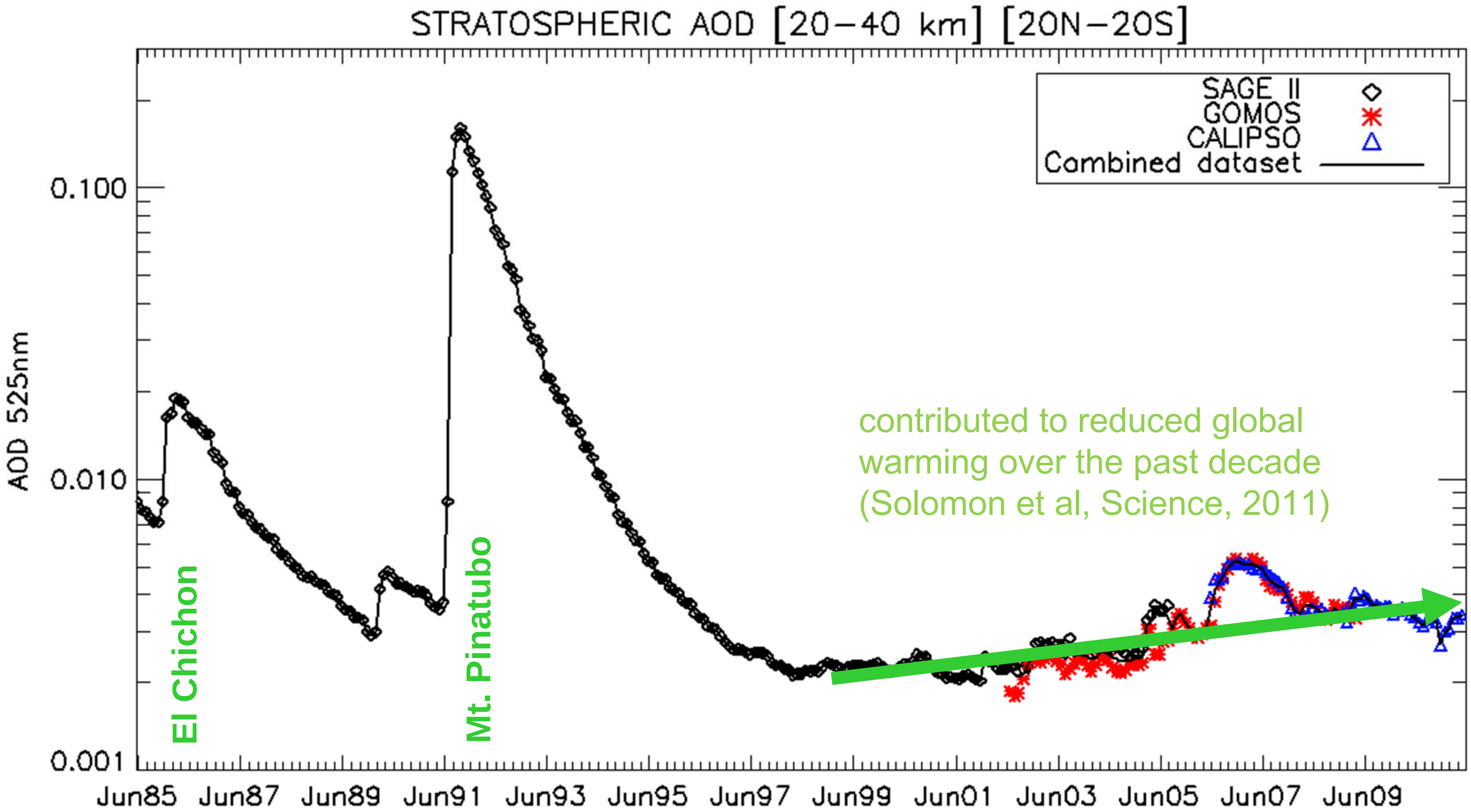
Stratospheric and upper tropospheric processes for better climate predictions – StratoClim –

- 28 partners
- 11 countries
- 11.3 million Euro budget
- Started 1st December 2013
- Runs until end of March 2018

Representation of stratospheric ozone and stratospheric aerosol in global models

	ozone	aerosol
CTMs	OK	mostly prescribed
CCMs	mostly OK, but weaknesses for polar loss	mostly prescribed
ESMs	mostly prescribed	mostly prescribed

Tropical mean stratospheric aerosol



update of Vernier et al., 2011

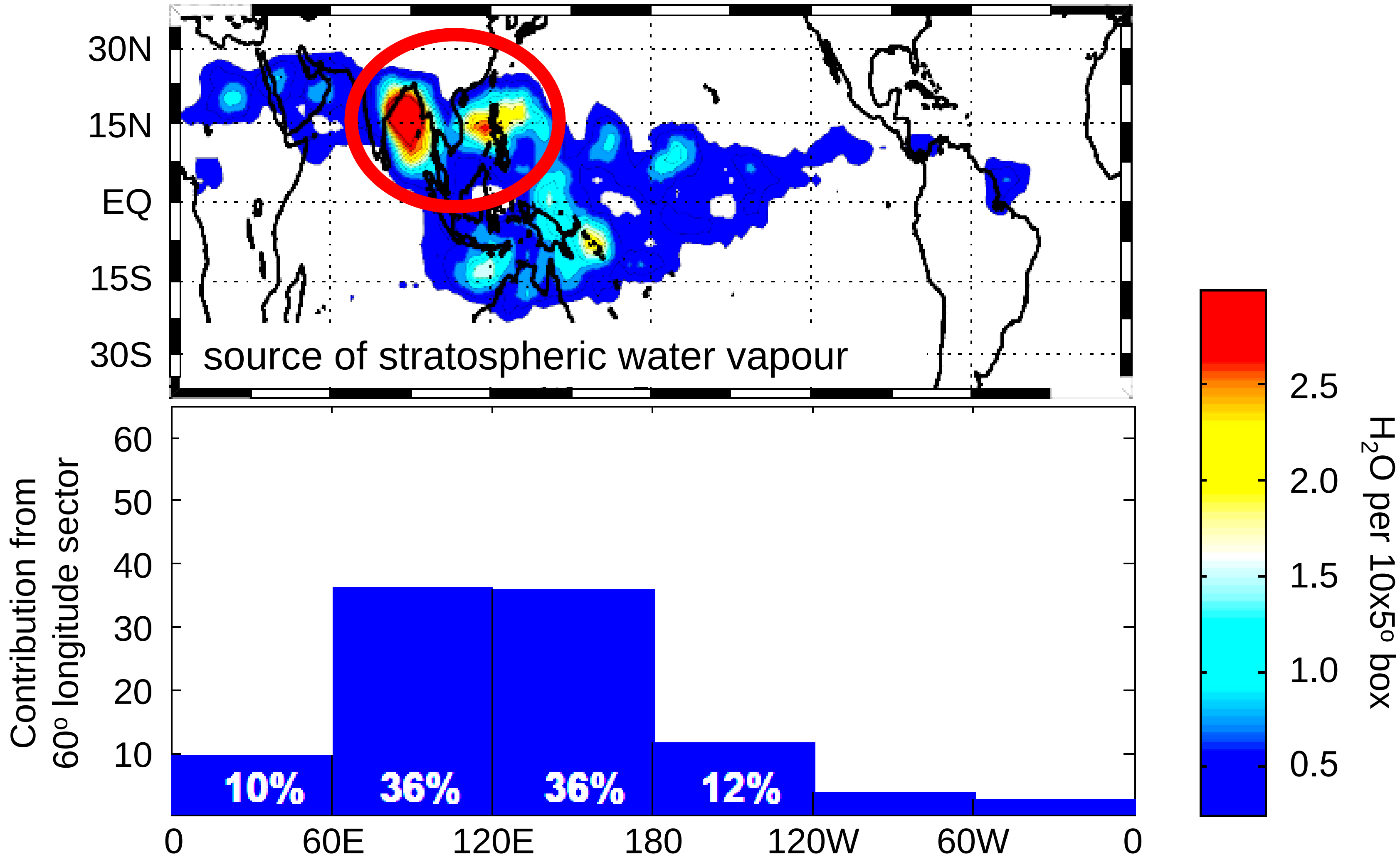
Stratospheric and upper tropospheric processes for better climate predictions – StratoClim –

Main objectives:

- To improve understanding of the processes that determine the UTS sulfur and aerosol budget, including non-sulfate aerosol,
- to develop and to improve detailed schemes for stratospheric sulfur and aerosol in CTMs and CCMs,
- to develop fast schemes to … ozone in ESMs,
- to assess the impact of climate change on stratospheric aerosol and ozone and the effect of such changes on surface climate.

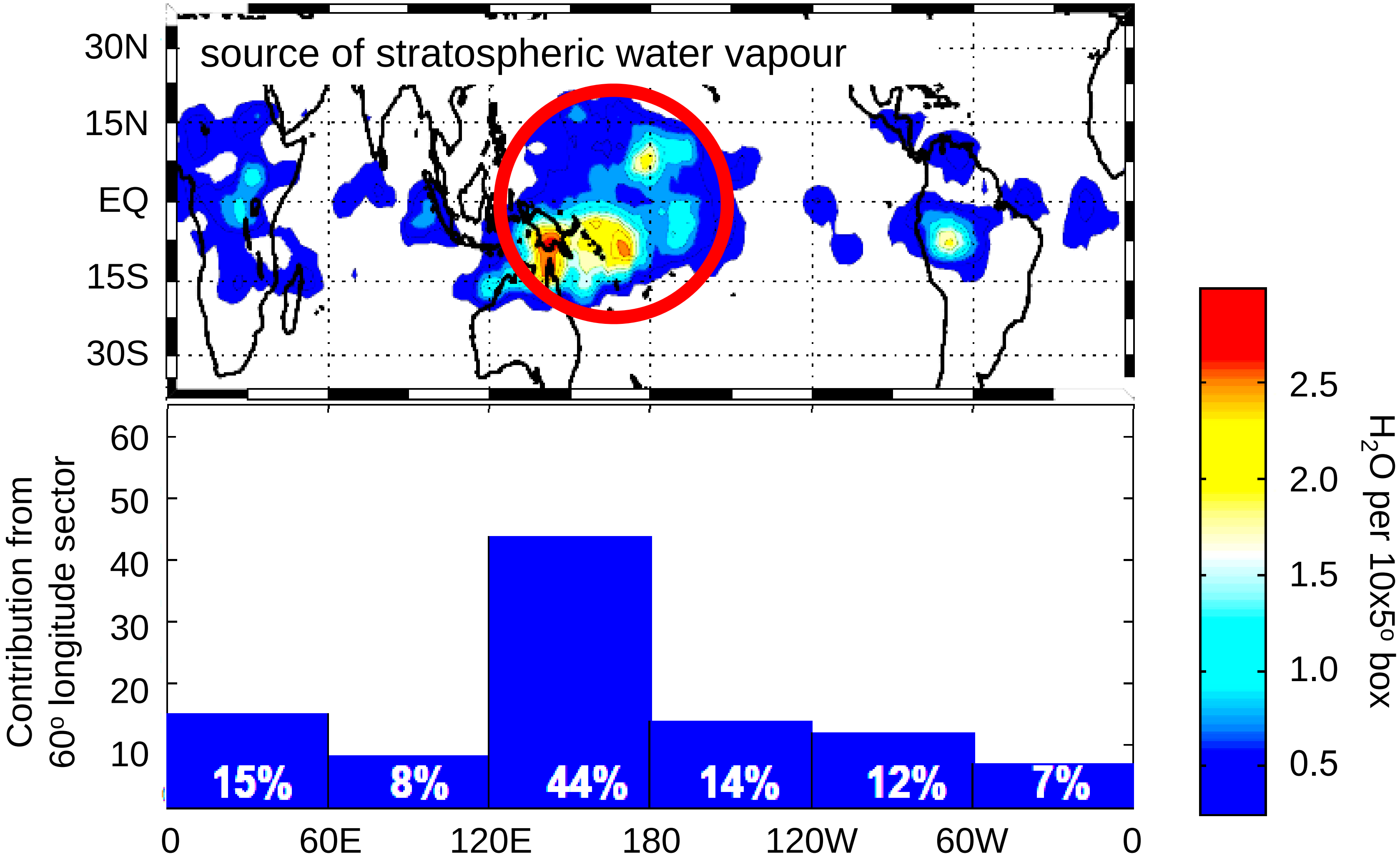
will be addressed by <u>field activities</u> combined with satellite data analysis and process modeling

Source regions for stratospheric air
- NH summer -



Kremser et al. (2009)

Source regions for stratospheric air
- NH winter -



Kremser et al. (2009)

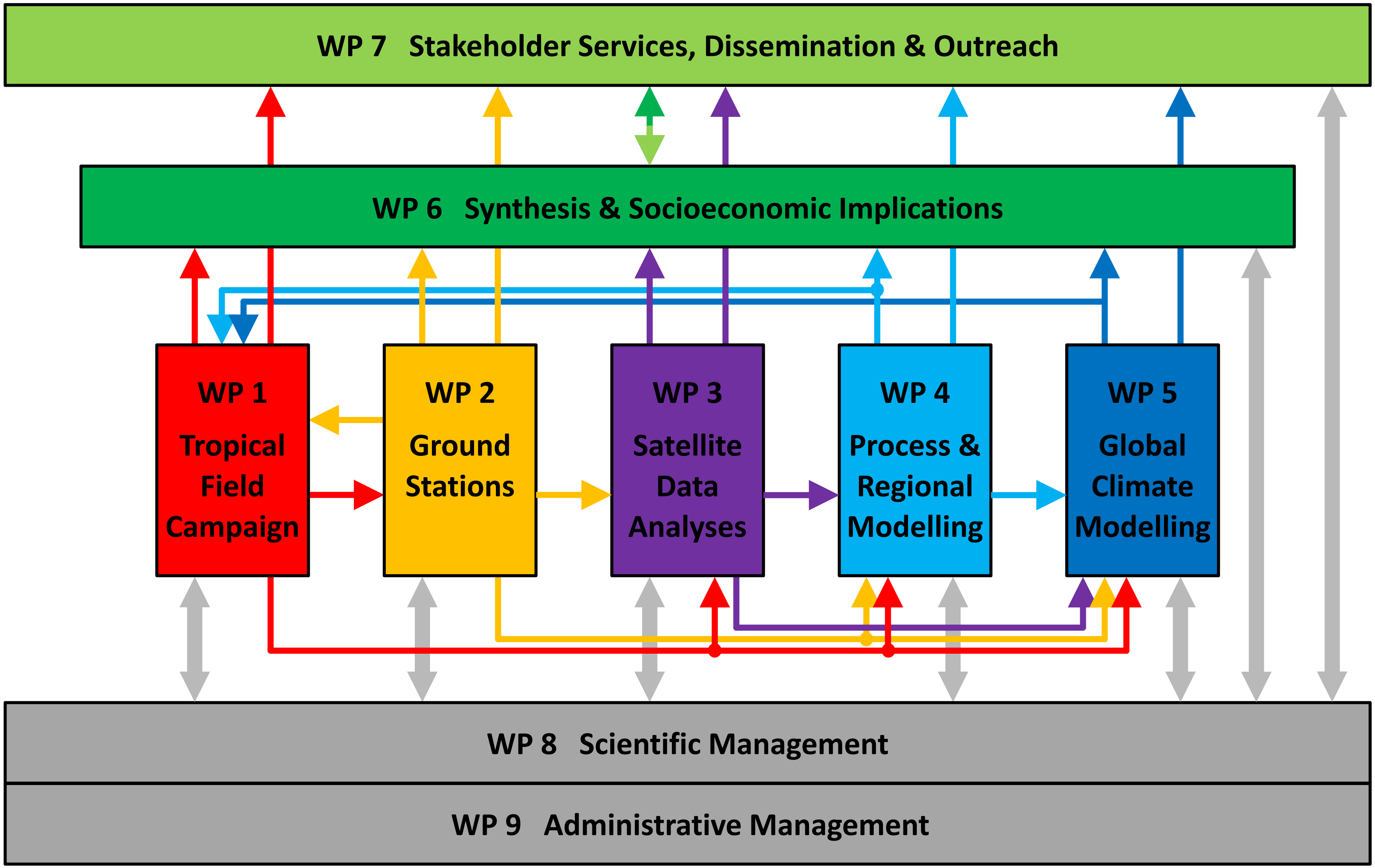
StratoClim
Planned field activities

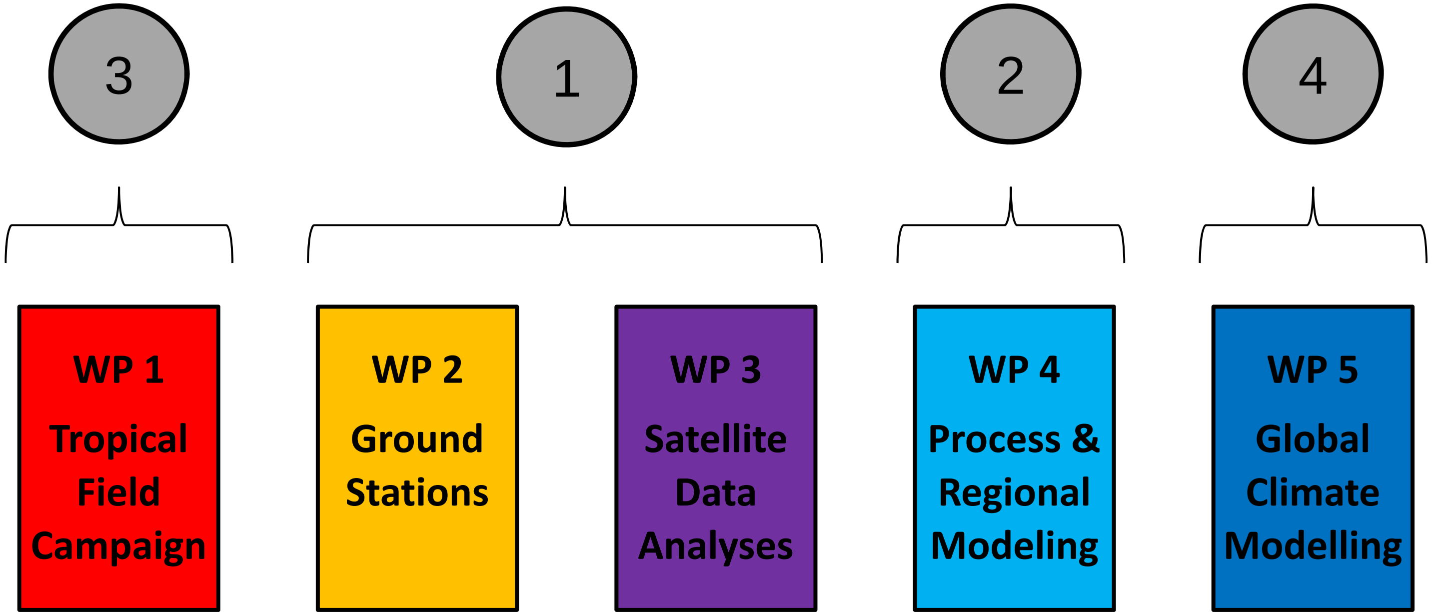
Key regions that determine the stratospheric composition:

NH summer:
Asian monsoon (AM)

NH winter:
Western Pacific (WP) warm pool

Palau


WP 7 Stakeholder Services, Dissemination & Outreach
WP 6 Synthesis & Socioeconomic Implications
WP 1 Tropical Field Campaign
WP 2 Ground Stations
WP 3 Satellite Data Analyses
WP 4 Process & Regional Modelling
WP 5 Global Climate Modelling
WP 8 Scientific Management
WP 9 Administrative Management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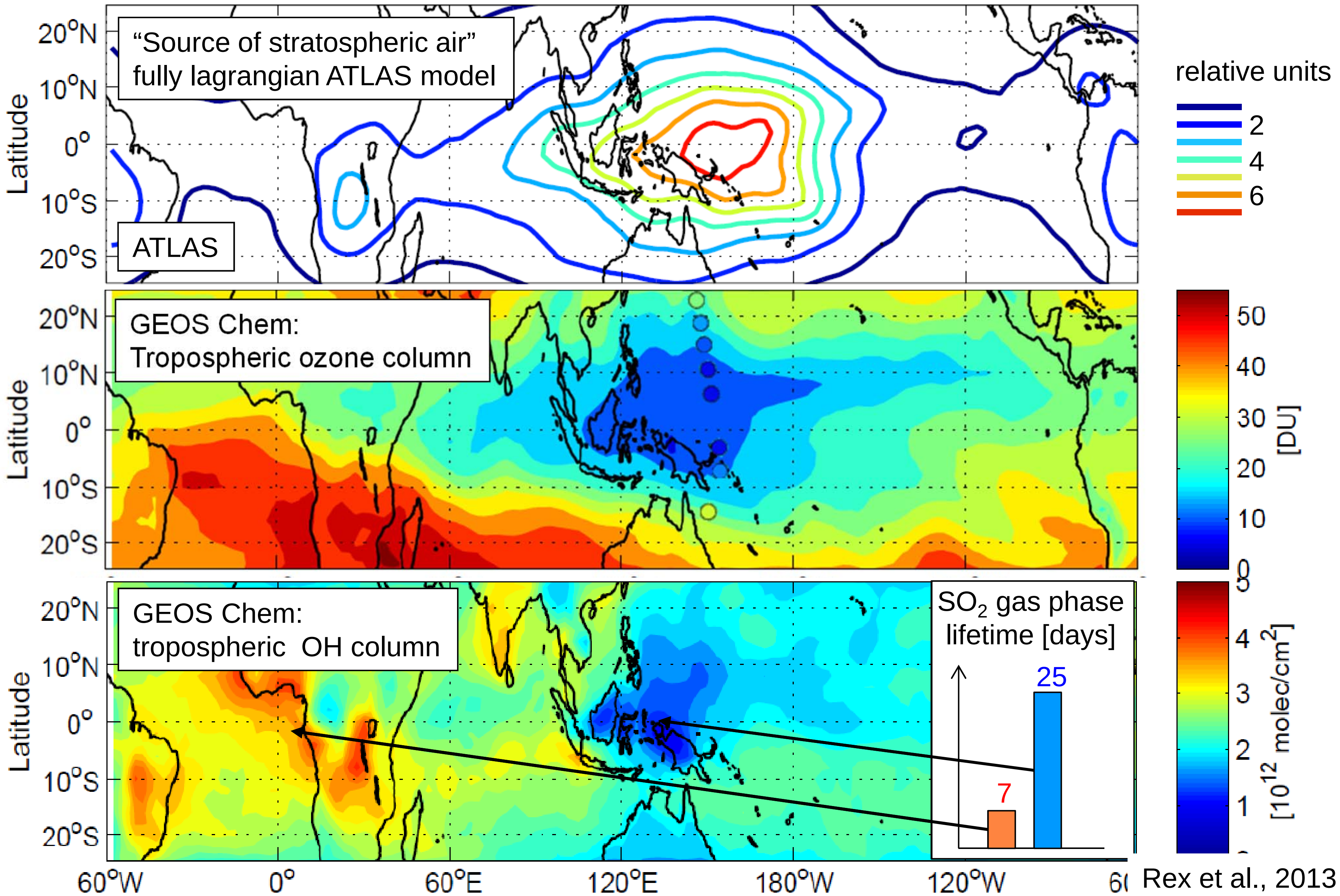
WP 1
Tropical Field Campaign
WP 2
Ground Stations
WP 3
Satellite Data Analyses
WP 4
Process & Regional Modeling
WP 5
Global Climate Modelling

Processes at stratospheric entry point in NH winter



Rex et al., 2013

StratoClim : Field activities

Tropical ground station:

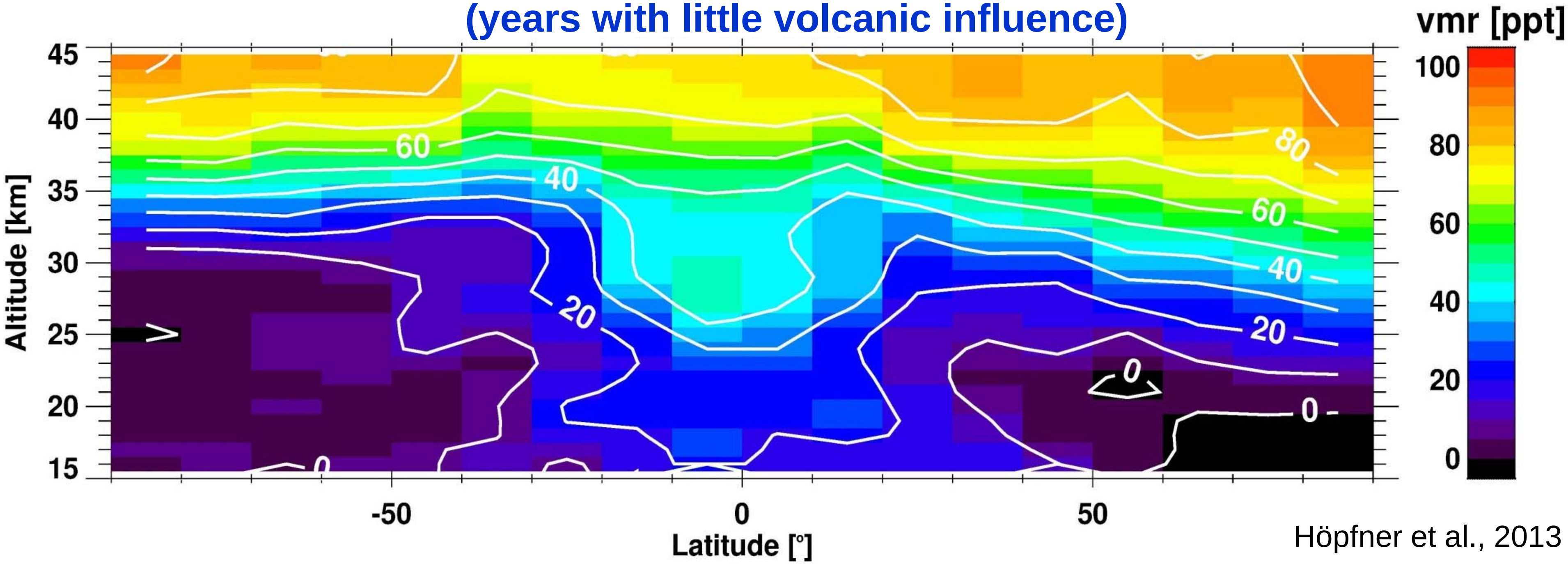
- Location: likely Palau (close to center of warm pool)
- 2-3 years of initial operation during 2014 – 2016
- Instrumentation:
    - Fourier Transform Infrared Spectrometer for e.g.:
        - O_3, CO, C_2H_2, C_2H_6, CH_2O, HCN, COS, NO, NO_2
        - profiles (~3-5 independent layers), tropospheric & total columns
    - Ozonesondes (ECC)
    - New UV-diode ozone spectrometer sondes for better detection limit
    - Water vapour sondes (CFH)
    - Backscatter sondes (COBALD)
    - Multi-wavelength aerosol & cloud lidar (ComCAL)

Satellite data analysis (sulfur containing species)

New global fields of **SO_2 and COS** from **MIPAS/Envisat** will be retrieved and analyzed by **CTMs:**

- 10 years of global observations of **SO_2, COS** and other tracers and particles from 6 to 50 km altitude (first global long term record of stratospheric SO_2).
- Sensitive to SO_2 background conditions; volcanic enhancements and plume transport are seen as clear signals.

Mean meridional distribution of SO_2 during Dec/Jan/Feb (years with little volcanic influence)



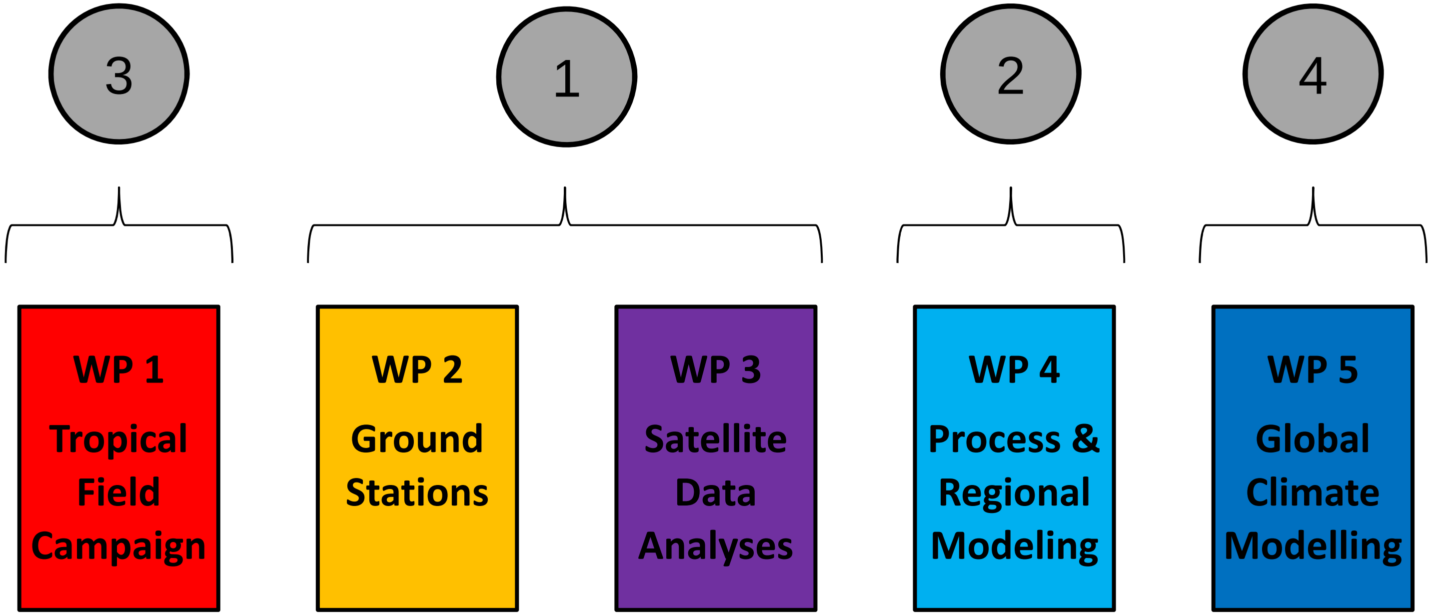
Höpfner et al., 2013

Satellite data analysis (aerosol)

- Global fields of **sulfate aerosols** in the UTS from combining data from high spectral resolution infrared sounders **(IASI, GOSAT, SAGE III, ACE-FTS**) → with MIPAS **SO_2 and COS** fields this will allow to close the stratospheric sulfur budget.

- Spaceborne lidar observations (**CALIOP**) will be used to document local enhancement of sulfate aerosols & lagrangian modeling **will trace them to convection and to volcanic eruptions**.

- The **altitude of anvils and overshooting clouds** will be derived from observations from **geostationary satellites (SEVERI**, later a **MSG successor** to Meteosat 7); information about the distribution of detraining clouds in the UTS will feed into global modeling activities.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2
4
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Mitglied der Helmholtz-Gemeinschaft

JÜLICH
FORSCHUNGSZENTRUM

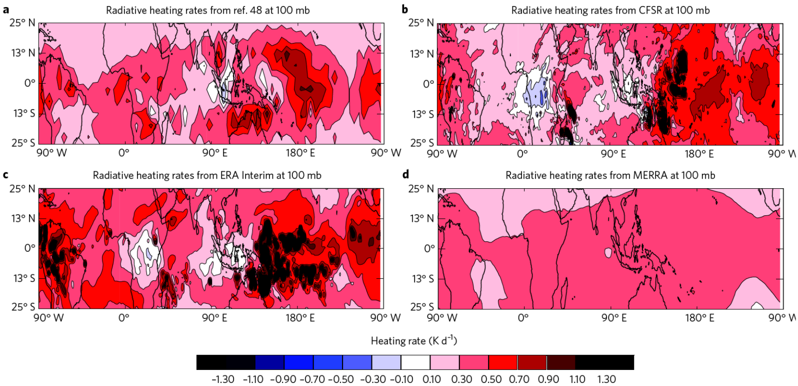
The Asian Monsoon and process modelling in StratoClim

Potsdam, 5 December 2013 | Rolf Müller and Bernard Legras

Workpackage Process Studies: Objectives

- Pathways of transport of tropospheric air into the stratosphere
  - Slow versus fast pathways
  - The most relevant pathways for individual species.
- Chemical composition and spectrum of age of air in the tropical tropopause layer
- Assess the quality of large-scale vertical velocities in meteorological (re)analyses based on airborne measurements of IR spectral radiances.

Vertical velocities at 100 hPa in Boreal Winter



From: Randel and Jensen, Nature Geosci., 2013

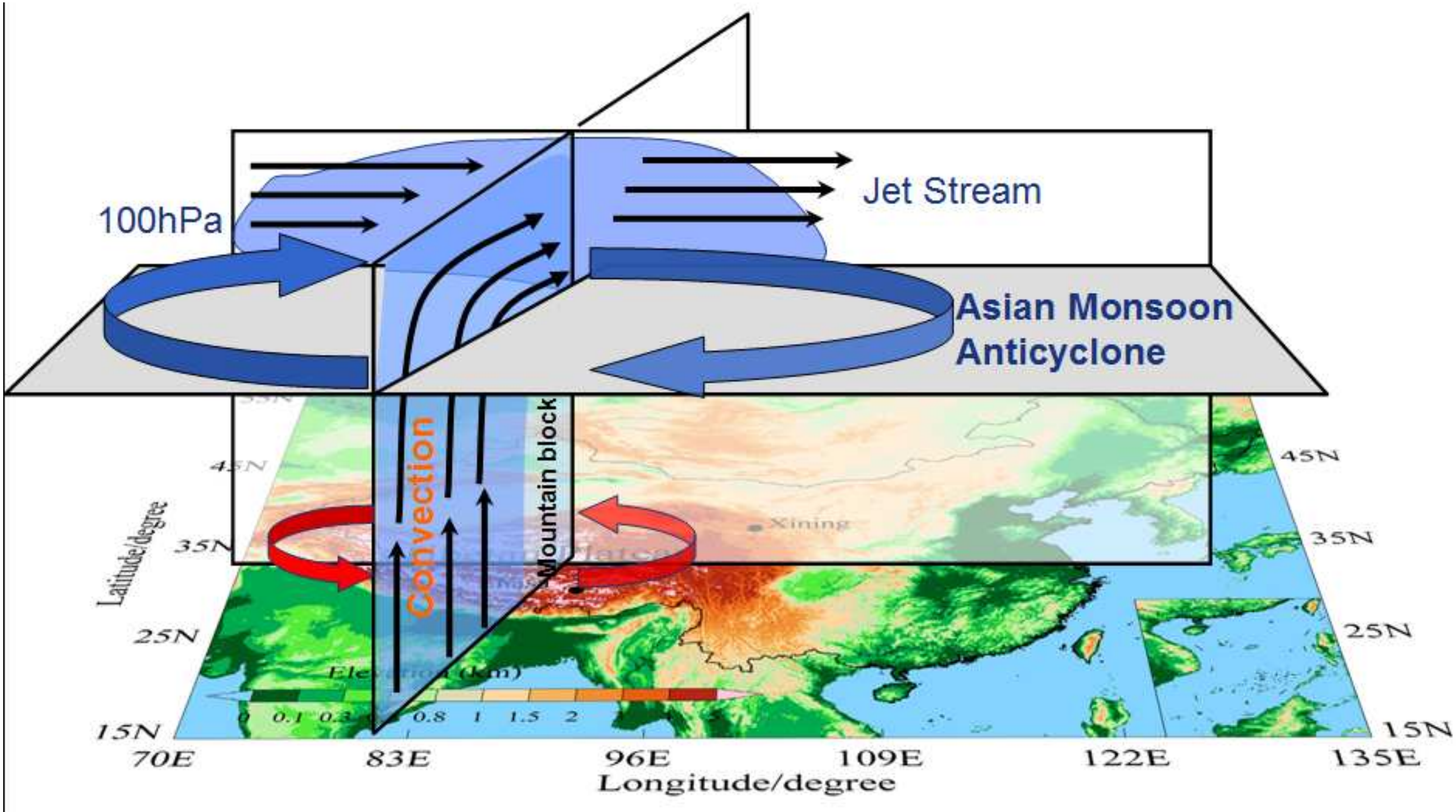
Workpackage Process Studies: Objectives

- Composition of the aerosol in the tropical stratosphere
  - The ATAL aerosol layer observed above the Asian monsoon
  - Ultra-fine particles at the bottom of the tropical tropopause layer
- Impact of tropical processes on the entire stratosphere (in particular on ozone and water vapour)
- Ground flux of sulphur containing source gases

Workpackage Process Studies: Objectives

- Transport pathways in deep and mesoscale convective systems
- Overshooting convection and its impact on stratospheric composition
- Impact of unresolved small-scale variability of vertical velocity on cloud formation processes

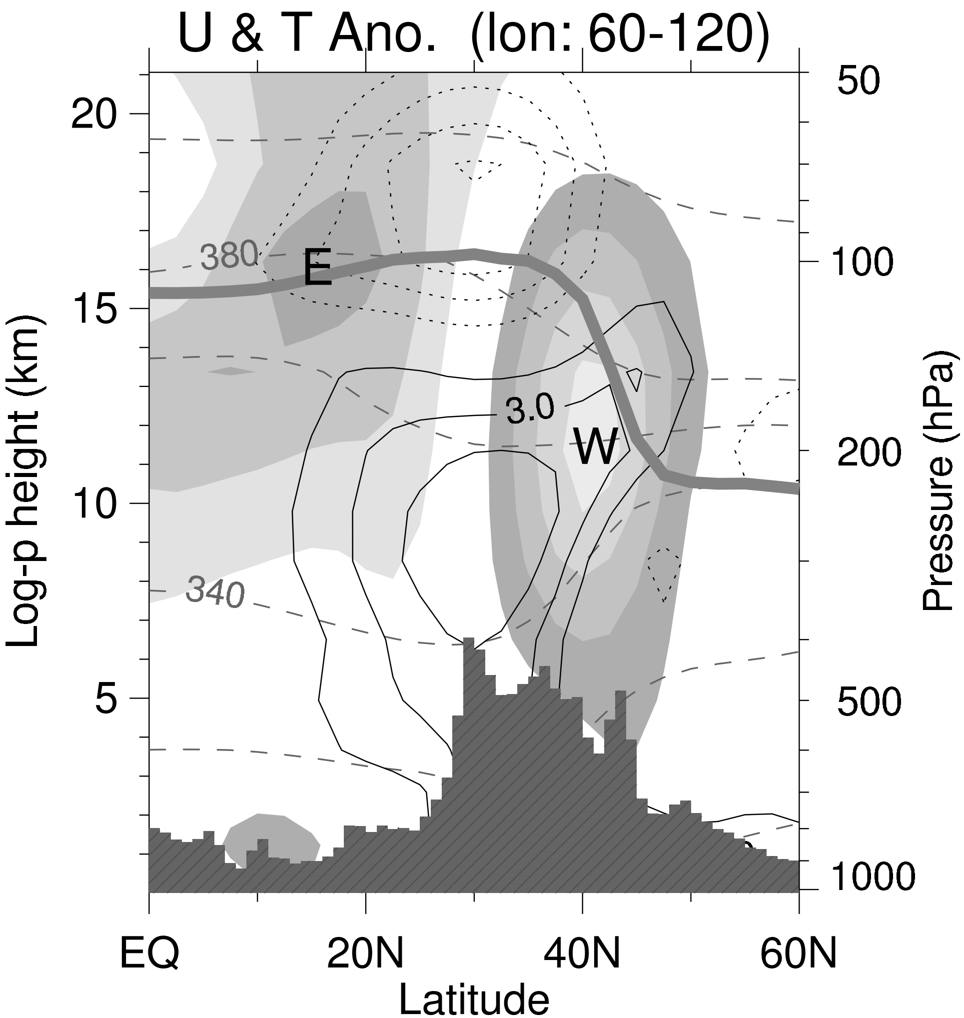
Tropospheric cyclone drives the anticyclone above



courtesy of Yong Wang

Summer convection + Coriolis force +
Kelvin's circulation theorem ⇒
Convergent flow in the troposphere ⇒ cyclone
Divergent flow in the UTLS ⇒ anticyclone

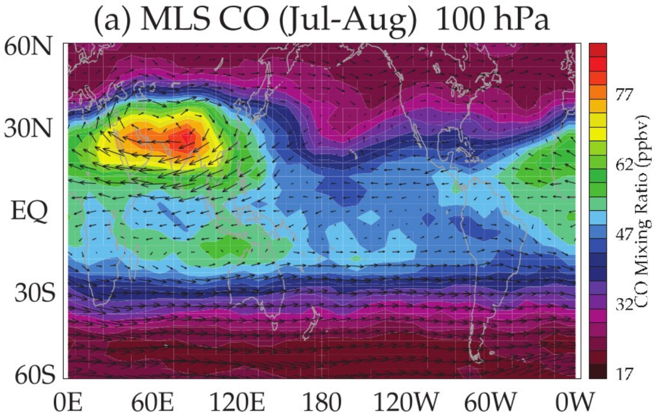
...this high pressure system in the upper troposphere extends well into the lower stratosphere up to about 20 km (or $\theta = $420 K)
Randel and Park, JGR, 2006



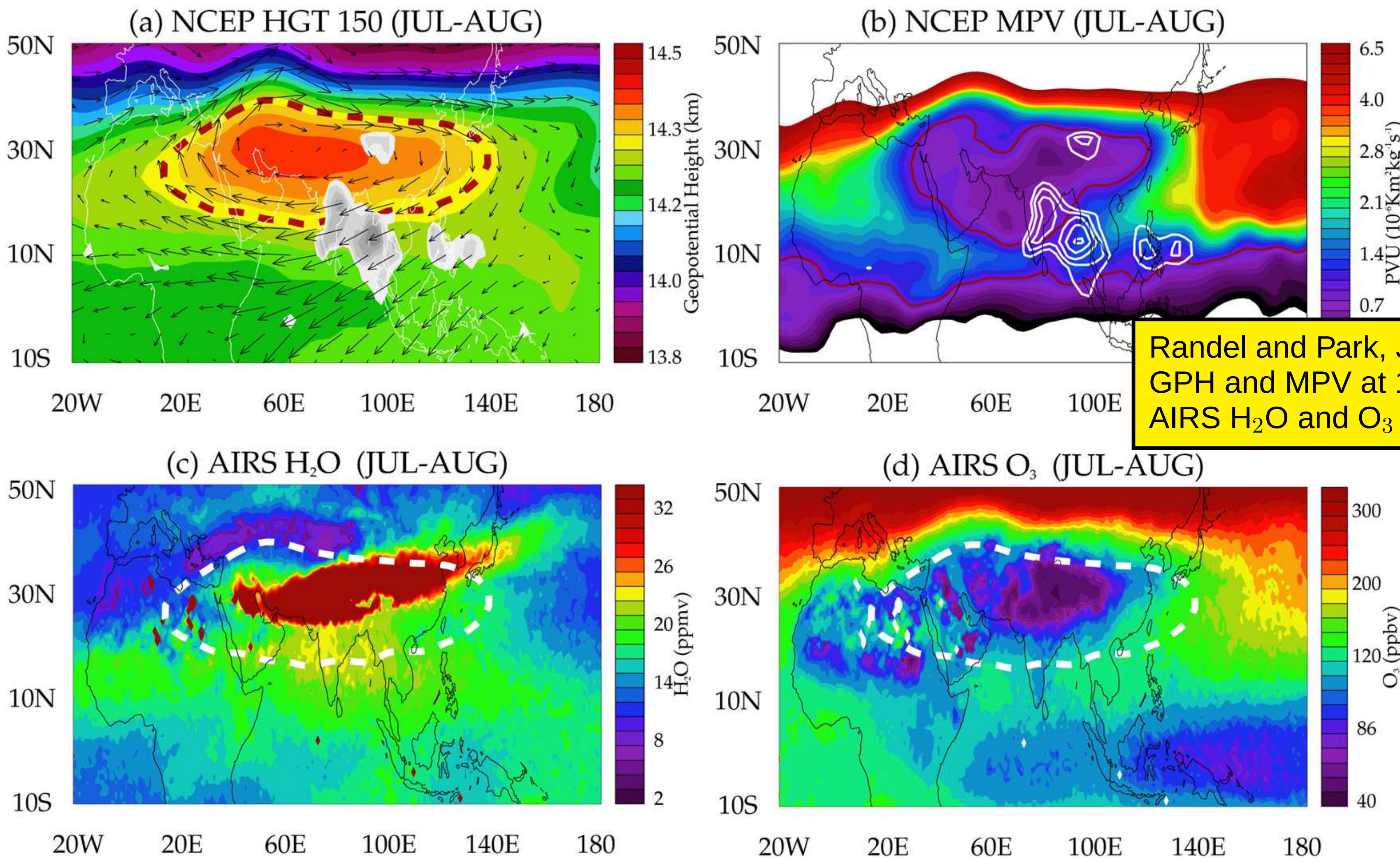
Park et al., JGR, 2007:
strongly isolated anticyclone between 12 and 20 km, (from ACE-FTP data)
Haynes and Shuckburgh, JGR, 2000:
weak and permeble NH STJ during summer (from the effective diffusivity concept)
Dethof at al., QJRMS, 1999:
Bannister at al., QJRMS, 2004:
Gettelman et al., JGR, 2004:
Levine et al., JGR, 2007:
James et al., GRL, 2008:
strong contribution to the moist phase of the tape-recorder

2-month (July and August) aver-age NCEP zonal wind (shaded) and temperature anomalies (thin lines, deviation from zon. mean)

CO in the Asian Monsoon



Park et al., JGR, 2007

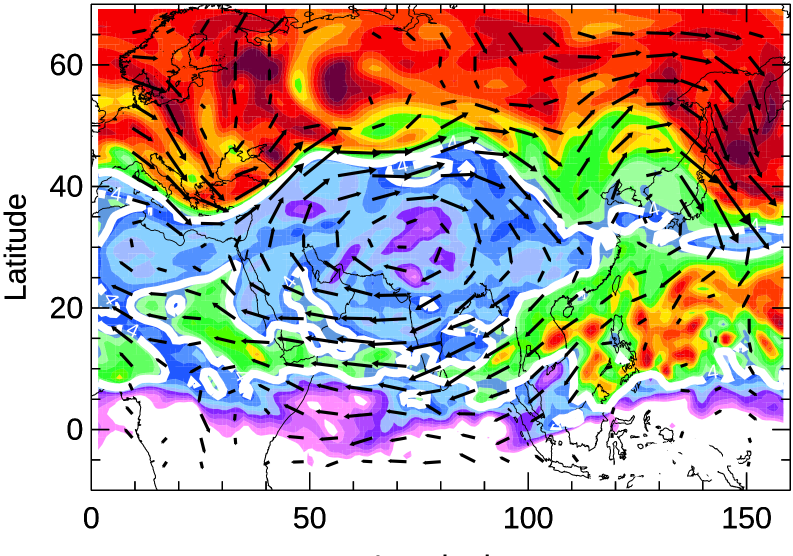


Randel and Park, JGR, 2006:
GPH and MPV at 150 hPa
AIRS H_2O and O_3 at 360 K

Asian summer monsoon anticyclone
≈ nearly stationary disturbance of the subtropical jet during summer

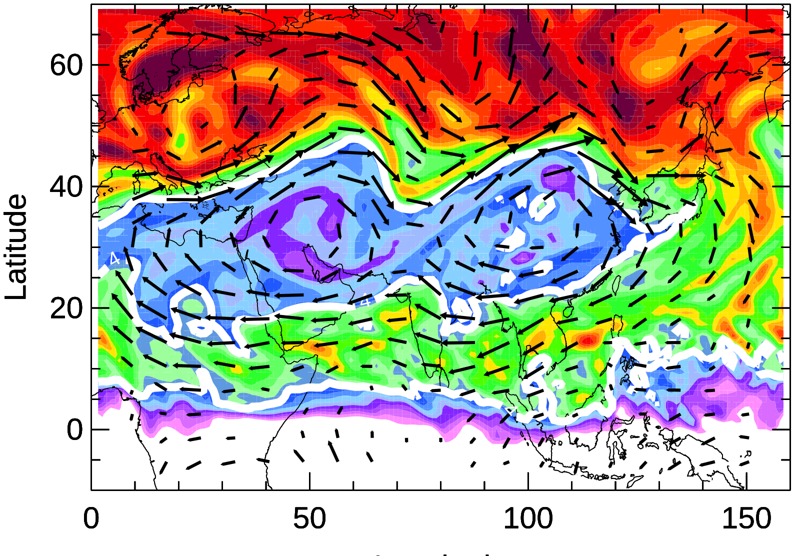
The Asian Monsoon Circulation: June

ECMWF PV/380K/110626

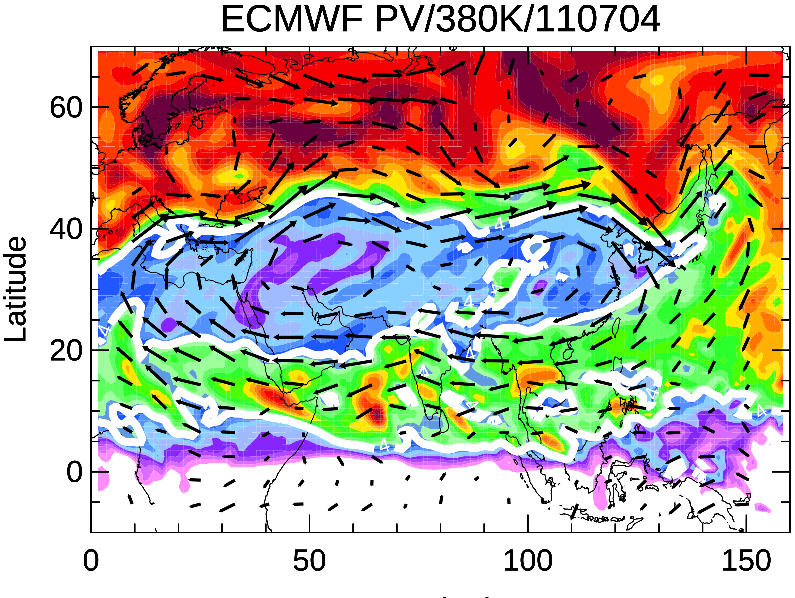


The Asian Monsoon Circulation: July

ECMWF PV/380K/110703

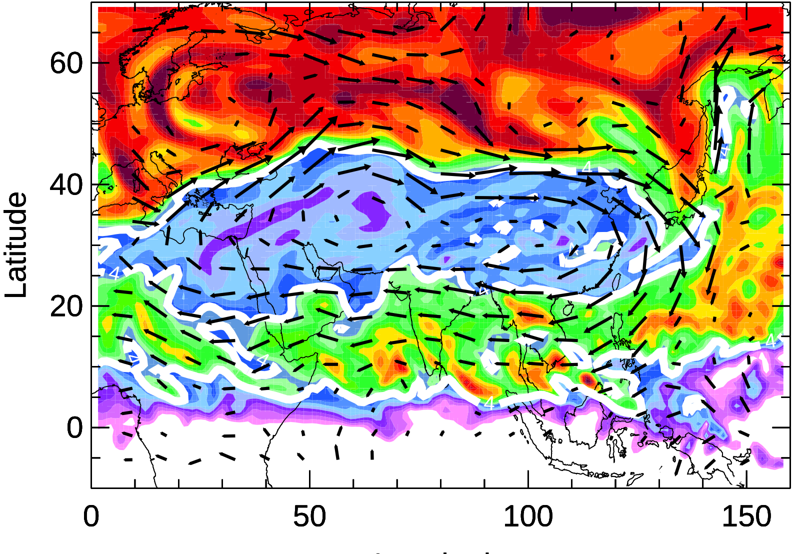


The Asian Monsoon Circulation: July



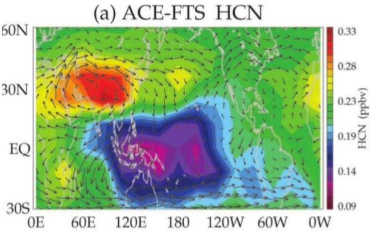
The Asian Monsoon Circulation: July

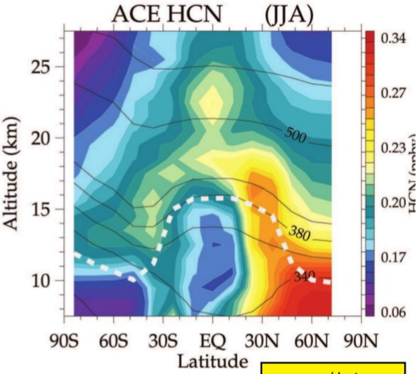
ECMWF PV/380K/110705



Upward transport of HCN in the Asian Monsoon

HCN at 13.5 km, JJA
Randel et al., Science, 2010
...the monsoon circulation provides an effective pathway for pollution from Asia, India, and Indonesia to enter the global stratosphere...
...mainly SO_2, but also H_2O

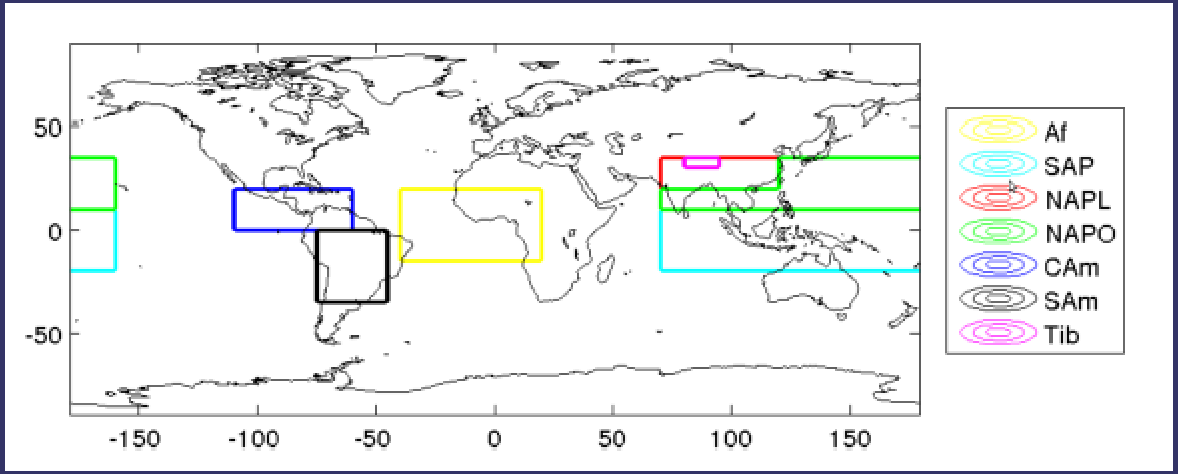


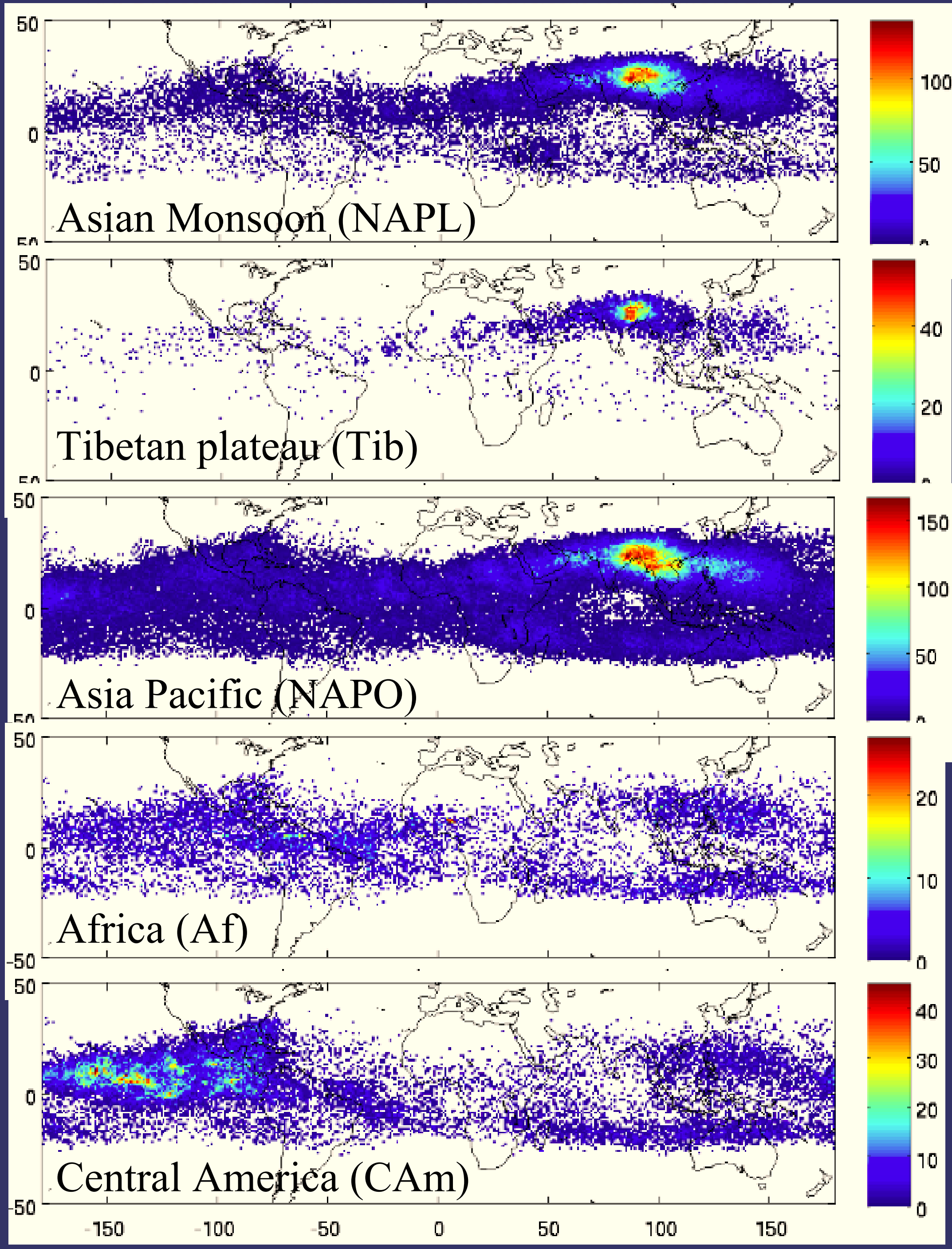


averaged between
0 and 100 E

A Proportion of parcels reaching 100 hPa over July 2005
B Proportion of clouds with BT < 230K in 35S-35N
C Proportion of parcels from the 100 hPa surface

	A	B	C
1 Tibet (Tib)	71 %	1 %	5.3 %
2 Asian Monsoon Land (NAPL)	51 %	8 %	30 %
3 Asian Monsoon Ocean (NAPO)	38 %	24 %	42 %
4 Central America (CAm)	26 %	9.5 %	9.9 %
5 South Asia Pacific (SAP)	25 %	12 %	16 %
6 Africa (Af)	16 %	6.4 %	4.2 %
7 South America (Sam)	9 %	0.9 %	0.8 %



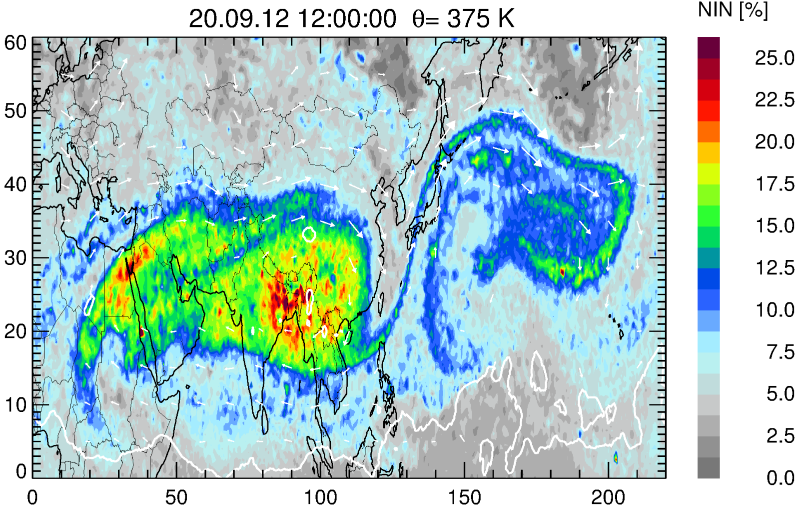


Distribution of parcels at final location (when reaching 100 hPa) according to the location of convective sources

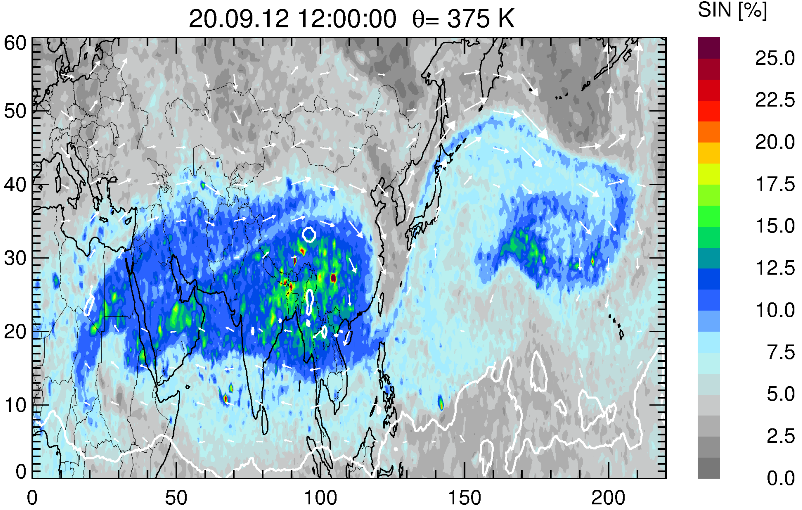
Asian Monsoon and Tibetan convection leads to trapping of parcels in the Asian Monsoon anticyclone

See also Bregmann et al., ACP, 2013 (Tibetan pipe)

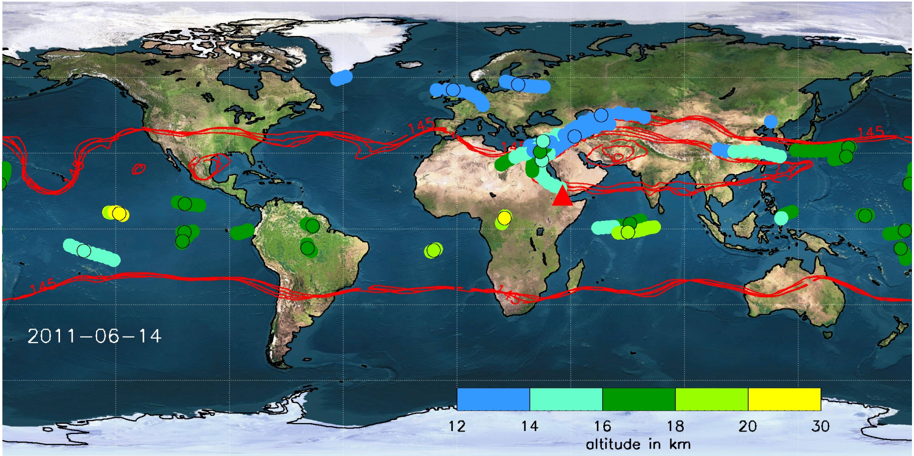
CLaMS: boundary tracer for Northern India



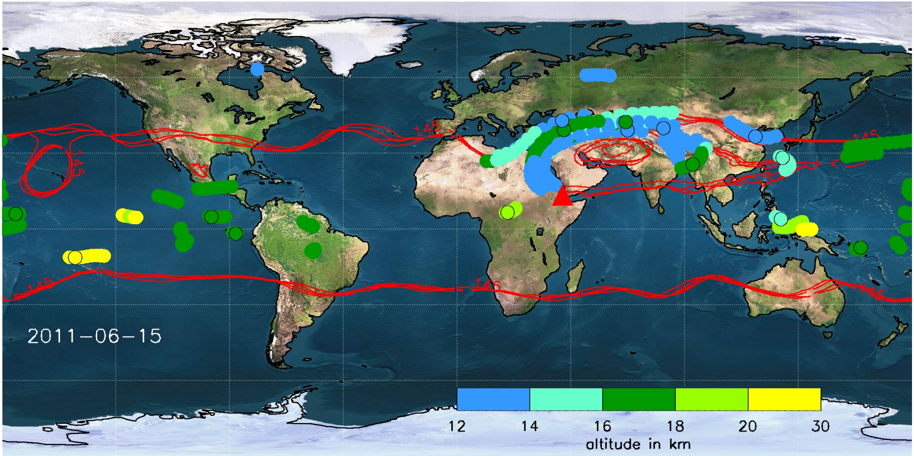
CLaMS: boundary tracer for Southern India



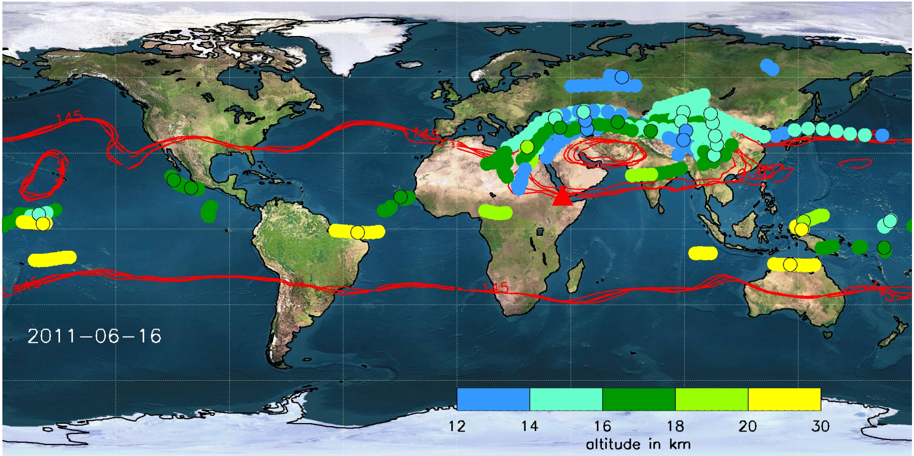
MIPAS observations of Nabro eruption



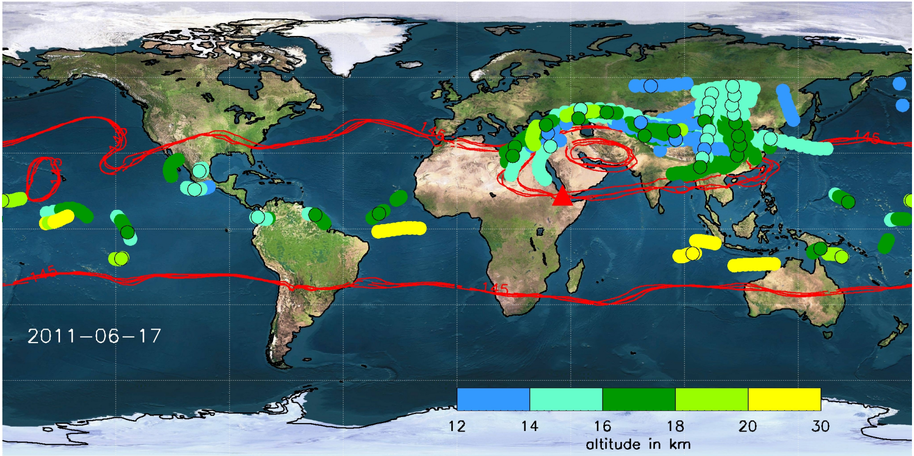
MIPAS observations of Nabro eruption



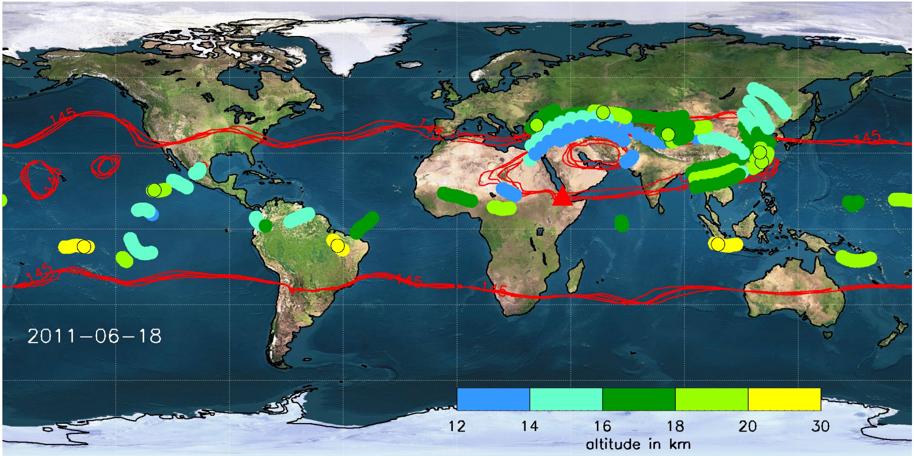
MIPAS observations of Nabro eruption



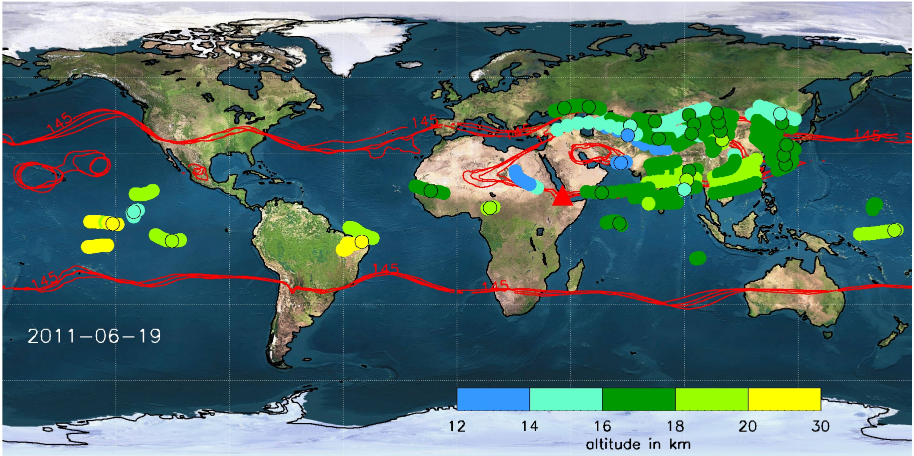
MIPAS observations of Nabro eruption



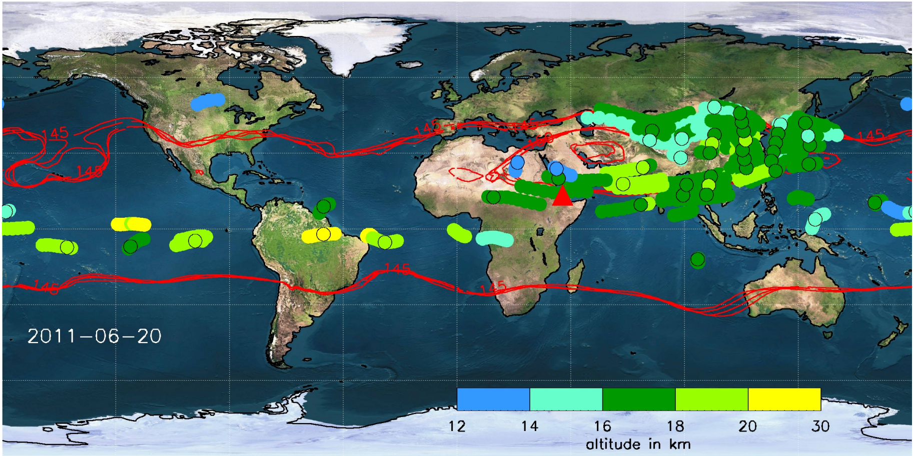
MIPAS observations of Nabro eruption



MIPAS observations of Nabro eruption



MIPAS observations of Nabro eruption



Workpackage Process Studies

- Contribute to the optimal definition of geographic location and flight strategy for the tropical field campaign
- New modules for stratospheric ozone and aerosols for Earth System Models
- Contribute to assessments of the social economic implications of the results

The StratoClim Aircraft Field-Campaign (WP 1)

Fred Stroh[1], Hans Schlager, Francesco Cairo (WP Leaders)

and the StratoClim AFC-Team

[1] Institute for Energy and Climate Research (IEK-7), Forschungszentrum Jülich, f.stroh@fz-juelich.de

Main Goal of the StratoClim AFC:

- Provide

  Accurate high-quality data sets

- of

  Microphysical, chemical and dynamical processes

- dominating the

  Transport and transformations of key climate and ozone relevant trace gases and aerosols/clouds

- throughout the

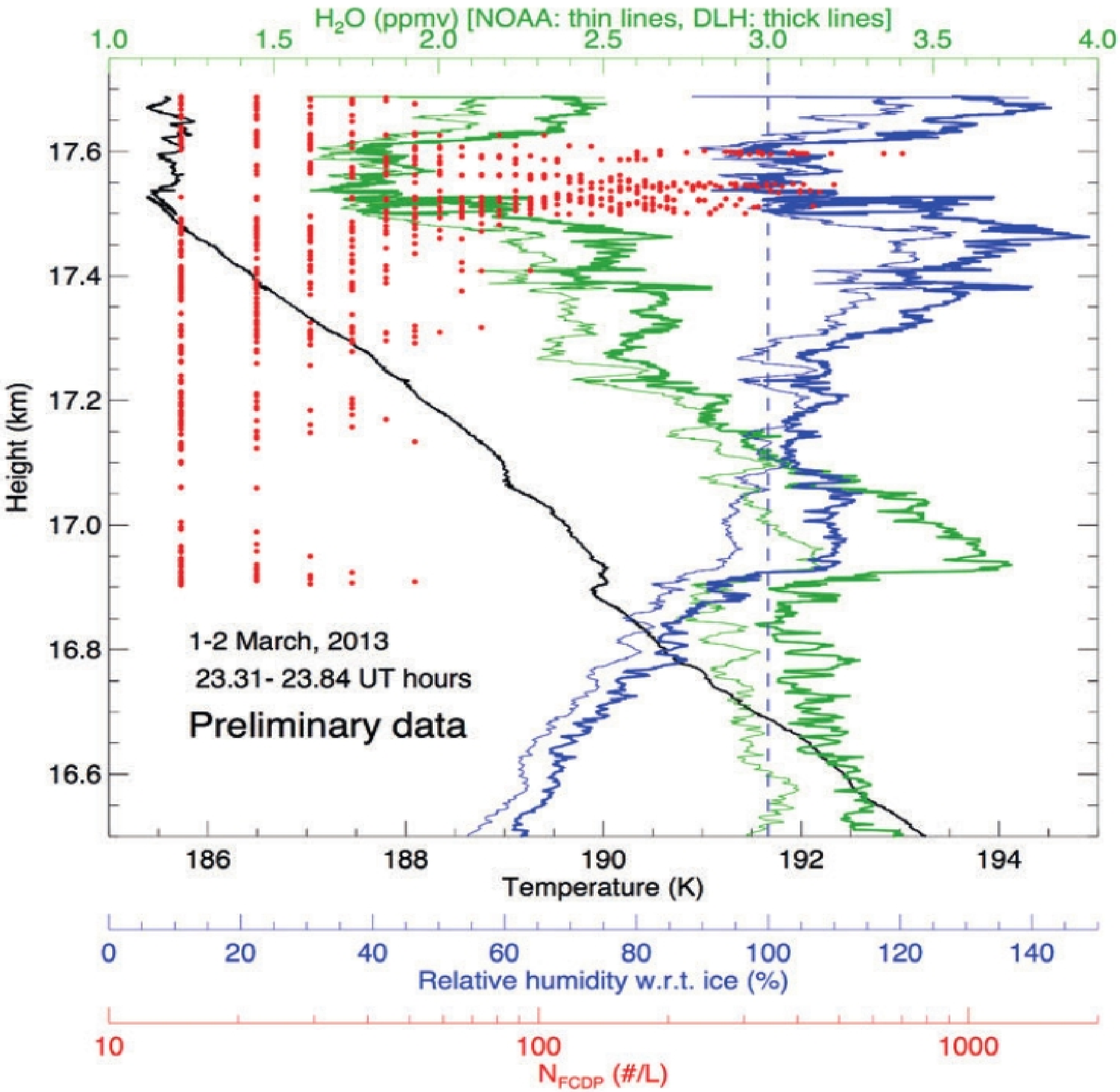
  Tropical Upper Troposphere / Lower Stratosphere

- in order to

  Improve the representation of these processes within CTMs (WP4) and ultimately CCMs/ESMs (WP5)

  to enable more reliable predictions of a future atmospheric state

Motivation for the aircraft measurements



from Jensen et al., SPARC newsletter No. 41, 2013

ATTREX Global Hawk temperature, water vapour, and ice particle density measurements in the tropical pacific region.

==> Highly vertically resolved and accurate data sets are neccessary in order to understand drying of upwelling air masses in the TTL !

(Jensen et al., 2013)

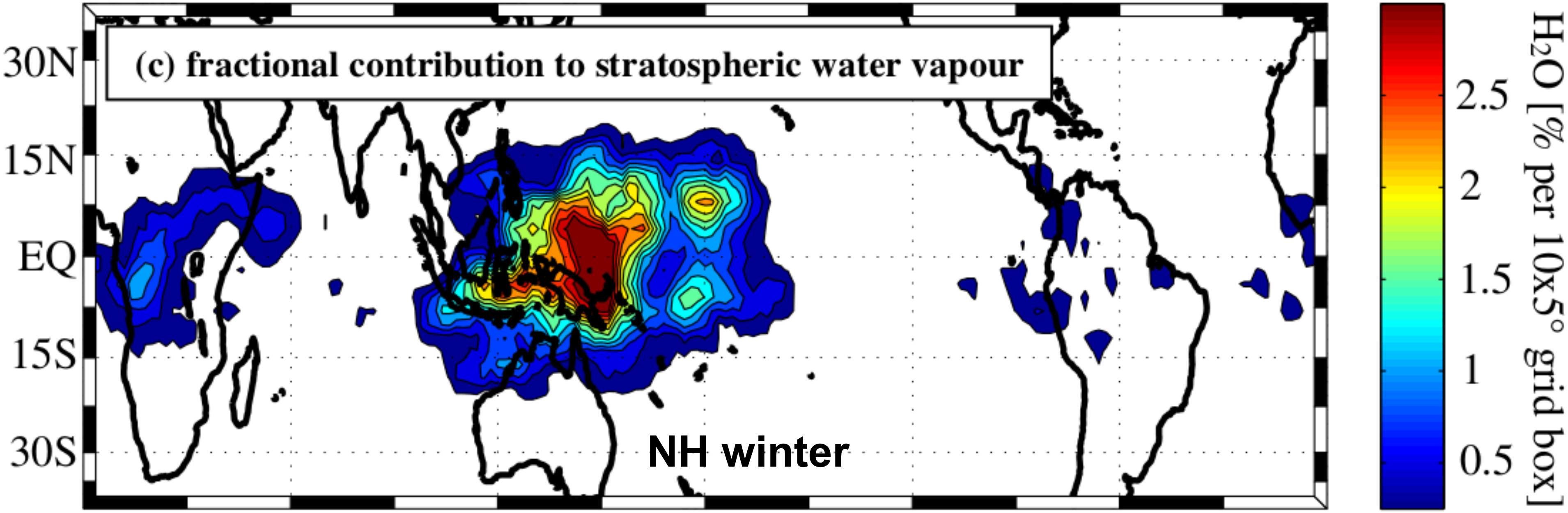
StratoClim AFC major target processes

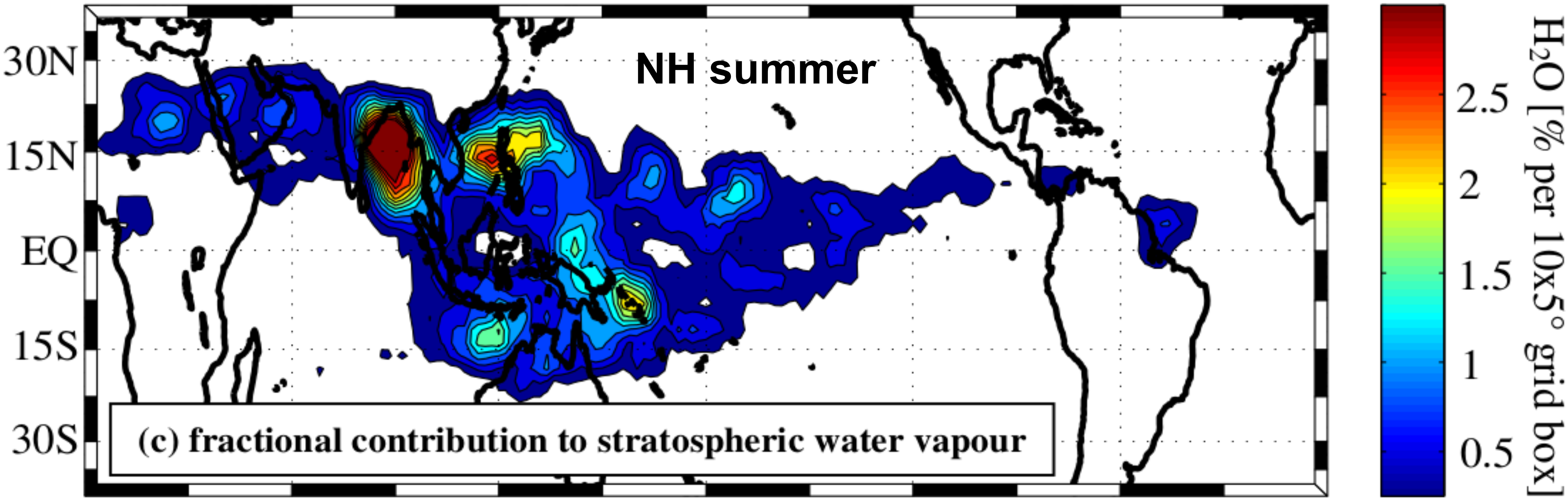
- The dynamics of transport of tropospheric air through the TTL and into the lower stratosphere and/or stratospheric overworld. What are the major pathways?
- The mechanisms of New Particle Formation (NPF) feeding the stratospheric Junge layer as well as TTL subvisible cirrus clouds which both are important parameters of the earth's radiative budget.
- The input of water vapour and other natural and man-made trace gases, especially sulfur species (OCS, SO_2), but also bromine VSLS into the upper TTL and stratosphere and their chemical transformations. These species or their product gases impact NPF and the tropical ozone budget.

Aircraft

- M55-Geophysica
- Alt. Range: 0 - >20 km
- Max. distance: 3000 km
- Extensive scientific payload
  - *Aerosol, Chemistry, Dynamics*
  - *In-situ, remote-sensing*
  - *25 instruments or more ...*
- Proven capabilities in many successful campaigns:
  - *INDOEX, EUPLEX, TROCCINOX, SCOUT-O3, AMMA, RECONCILE, and several more ...*
- Platform is specialized in smaller to medium scale process studies (spatial and temporal)
- Aircraft payload upgrade to suit tropical science objectives
- Extensive aircraft overhaul ongoing

StratoClim AFC Location



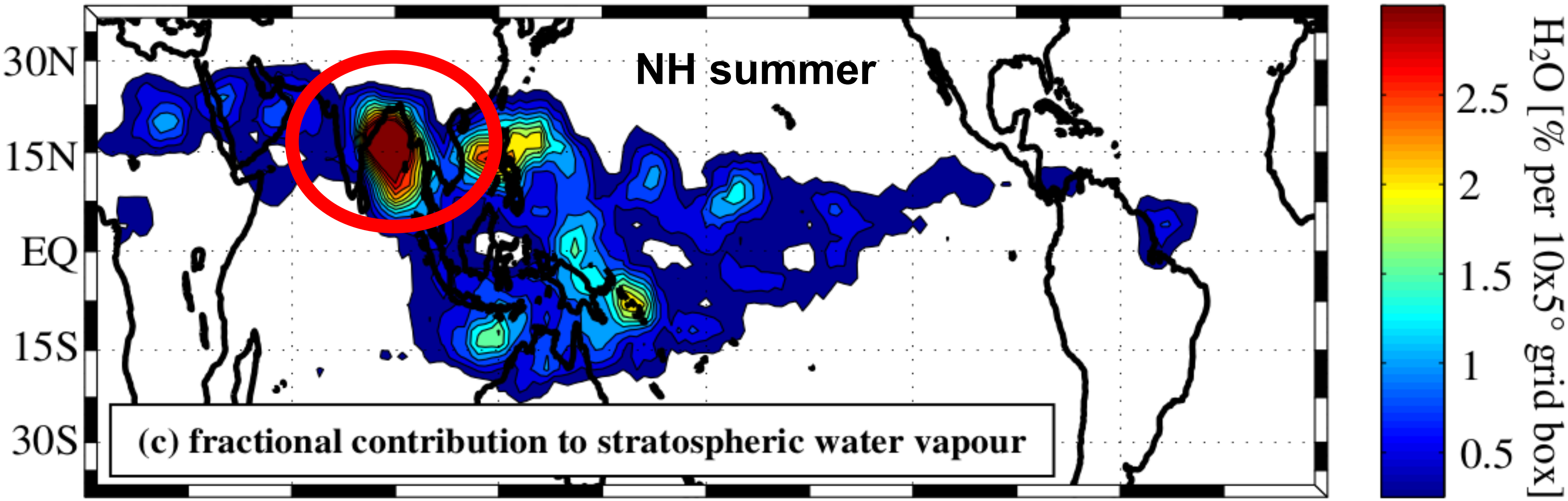


from Kremser et al. 2009, ERA-40 data

StratoClim AFC Location

Asian Monsoon (AM):

- is a reliable met. Phenomenon
- is more confined than the large scale ascent region in WP
- guarantees clear signatures from strongly polluted SE-Asian region as opposed to 'clean' WP warm pool air



from Kremser et al. 2009, ERA-40 data

StratoClim AFC dynamics payload

- **HAGAR:** (U Wuppertal) Gas chromatograph for CFC11/12, CH_4, N_2O, SF_6, Halons, also includes a Lycor CO_2 (mostly high accuracy and precision)
- **COLD:** (CNR Bologna) QCL CO measurement (fast CO, tropospheric tracer)
- **WAS:** (U Utrecht, Norwich, Frankfurt) Whole air sampler with 20 samples, analyzed for >40 non- and mainly halogenated species (VSLS!)
- **FOZAN:** (CAO Moscow/CNR) ECOC O_3 measurement (stratospheric tracer)
- **AMICA:** (FZ Jülich) Dual channel QCL ICOS measurement of CO, CO_2, OCS, and possibly HCN

- **Many tracers with very different atmospheric life times and air mass origin signatures (bio mass burning, ...)**

StratoClim AFC water vapour payload

- **FISH:** (FZ Jülich) Established Lyman-alpha photofragment total water instrument
- **FLASH:** (CAO Moscow) Established Lyman-alpha water vapour instrument (gas phase only)
- **H2O Isotopologues:** (U Chicago) LGR QCL ICOS H2O/HDO instrument (supplies condensation/evaporation history)

- **All measurements neccessary to characterize freeze drying/condensation and evaporation processes**
- **Additional very important information for NPF, (super)saturation in cirrus etc.**

StratoClim AFC sulfur payload

- **SO_2 / H_2SO_4 Mass Spectrometer:** (DLR) New instrument for SO2 (CIMS) and sulfuric acid (passive MS) measurements (alternatively) at species background concentrations.
- **AMICA:** (FZ Jülich) Dual channel QCL ICOS measurement of CO, CO_2, OCS, and possibly HCN
- **Cover major source gas and most relevant intermediate species towards (new) particle formation.**

StratoClim AFC microphysics payload *

- **COPAS:** (MPI-C Mainz) Volatile and non-volatile CCN counter
- **FSSP, CCP, CIP:** (MPI-C Mainz) Laser particle spectrometers for small to large particle sizes
- **MAS:** (CNR Rome) Backscatter sonde, particle optical properties
- **Filter Sampler:** (MPI-C Mainz) Electron microscopy and nano-SIMS of sample CCN, elemental and isotopic composition
- **AMSHA:** (MPI-C Mainz) Aerosol volatile fraction mass spectrometer (bulk), chemical composition (sulfate, nitrate, ...)
- **ALABAMA (tbd):** (MPI-C Mainz) Single particle elemental composition by mass spectrometry
- **Almost complete chemical and physical characterization of liquid (solid) phase !**

* in cooperation with the ERC Advanced Grant EXCATRO of MPI-C (Borrmann)

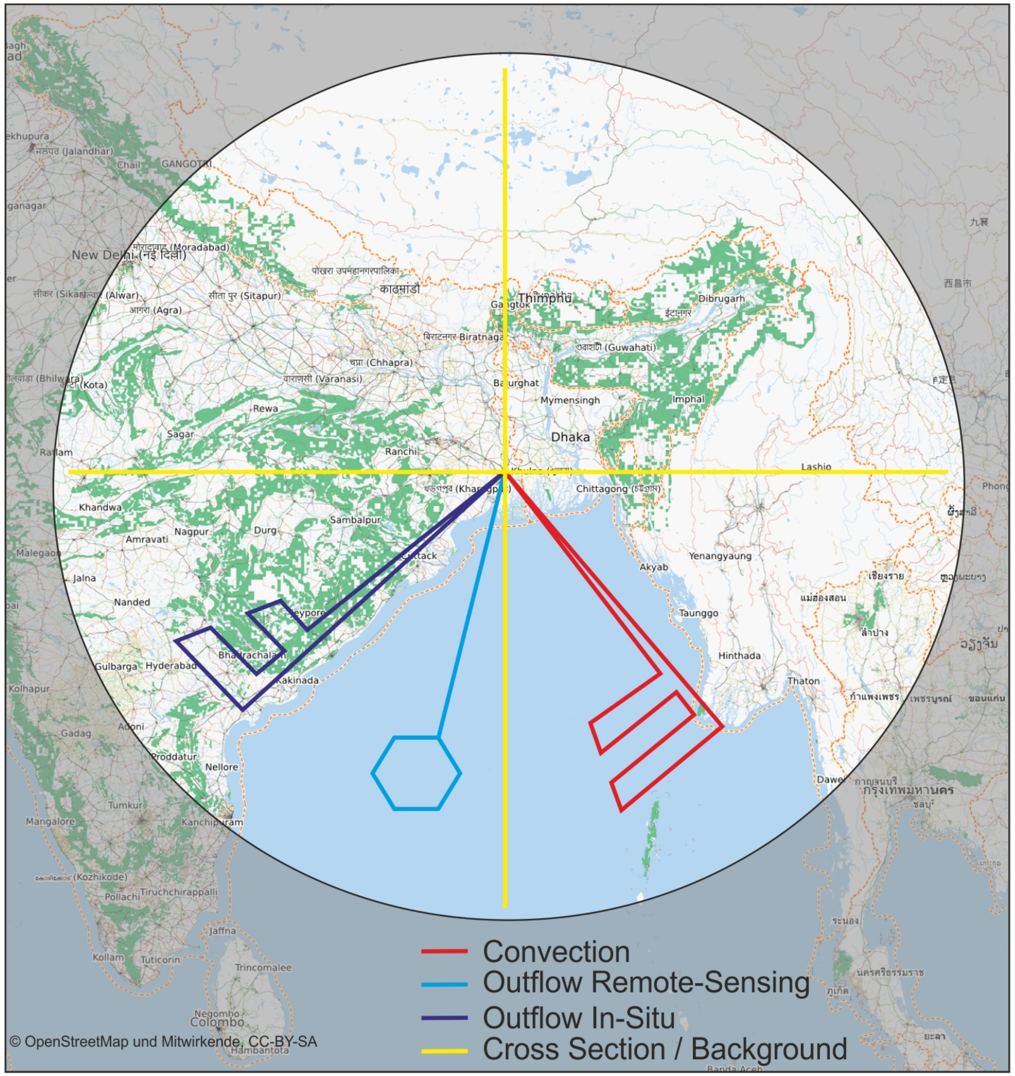
StratoClim AFC remote sensing payload

- **MARSHALS:** (RAL UK) FIR limb scanning spectrometer, 2D measurements of O_3, CO, HCl, HNO_3 and others (between 8 and 50 km, low vertical resolution). Not impaired by thin clouds.
- **MAL:** (CSEM Neuchatel) Diode laser back scatter lidar instruments, ca. 8 km down- and upwards the aircraft.
- **GLORIA:** (FZ Jülich / KIT) New Imaging MIR limb spectrometer, 2D (wide chemical variety, e.g. enhanced SO_2) and 3D measurements of O_3, H_2O, HNO_3, CFC11/12, PAN (5-20 km, <200m vertical resolution). Integrated and tested in 2011. Reduced quality measurements in presence of clouds.

- **First IR instrument with 3D measuring capability at (very) good spatial resolution.**

StratoClim AFC features a truly unrivalled and almost complete science payload onboard a versatile and robust stratospheric research aircraft !

Geography … range of Geophysica



Logistical Considerations

- AM campaign will as a minimum require **overflight and measurement permits for India.**
- Campaign base in India would be optimal but has proven to be difficult to obtain.
- Major activities by Jülich/HGF are ongoing, signature of MoU with Indian Ministry of Earth Sciences (MOES) is pending (January 2014)
- Close cooperation with IITM established, common proposal submitted to MOES.
- Flights possible into Chinese territory ?
- Base in Thailand seems realistic (BUT: SEACA^{4}RS and current political problems).
- Katmandhu, Nepal, seems to be a feasible base but is far north.
- Base on Arabian peninsula – with emphasis on AM outflow – is another option.
- Cooperation with other – tropospheric – airborne measurements would be a great add-on (HALO-OMO, Indian aircraft, GV, ...).
- Western pacific campaign location must be explored, as independent backup option …

Upcoming synergistic / competing activities

- **SEAC4RS**: NASA DC-8 and ER-2, first Thailand 2013 then rescheduled for Aug/Sept 2014 from Singapur now shifted to Mid-American region.
- **ATTREX**: NASA, Global Hawk
  - *Jan/Feb 14 from Guam*
  - *Jun/July 14 from Australia*
- **CONTRAST**: GV (Hiaper), Guam with ATTREX
- **CAST**: UK, FAAM Bae, Guam with ATTREX
- **HALO**:
  - *OMO-Asia, now scheduled for Aug/Sept 15, Maledives*
- **Indian trop. Aircraft**:
  - *IITM Cooperation ongoing, parallel coordinated measurements likely*
- **GV**: revived SEAC4RS activity (Laura Pan), t.b.d.

Aircraft Campaign Resources

- 78 Geophysica flight hours, ca. 18 flights
- Either:
  - *8-10 flights for instrumented transfers (AM)*
    ==> 8-10 local research flights
  - *6 flights for non-instrumented transfers (AM)*
    ==> ca. 12 local research flights
- 40 total campaign days (Moscow-Moscow!)
  ==> ca. 30 days at local base (3 days/flight)
- Relay flights possible ...

Stratospheric and upper tropospheric processes for better climate predictions

StratoClim

Global climate modelling

John Pyle, Chiara Cagnazzo, Martin Dameris

Potsdam, December 5, 2013

Objectives

- to substantially improve our quantitative knowledge of **air mass transport pathways between the troposphere and stratosphere**, including chemical processing along these pathways, with particular **focus on the Asian Monsoon** region;
- to quantify depletion/recovery of the **stratospheric ozone layer** in response to changing concentrations of ozone depleting substances (ODSs) and GHGs, including **focus on the Arctic region**;
- to understand **UTS variability** in chemical and microphysical composition, dynamical and thermal structure within the **context of climate change**;
- to upgrade the understanding of intra-seasonal, inter-annual, and decadal **variability of water vapour** in the upper troposphere and stratosphere (UTS);
- to understand intra-seasonal, inter-annual, and decadal **variability of stratospheric sulfur aerosol** and to assess impact of enhanced stratospheric aerosol loading in connection with climate change;

Objectives

- to improve the understanding of **dynamical interactions between the stratosphere and the troposphere**, particularly mechanisms of coupling in the Arctic and North Atlantic-European region from intra-seasonal to decadal and centennial timescales;
- to improve the understanding of the **interaction between stratospheric changes and tropospheric composition**, including surface processes;
- to evaluate **feedbacks** between the **stratospheric ozone layer** (polar variability, polar long-term depletion, global variability and future super recovery), **climate and surface** weather patterns;
- to provide tools and knowledge for climate services to the public;
- to contribute to the optimal definition of geographic location and flight strategy for the tropical field campaign;
- to contribute to the assessments of the social economic implications of the results.

Description of work

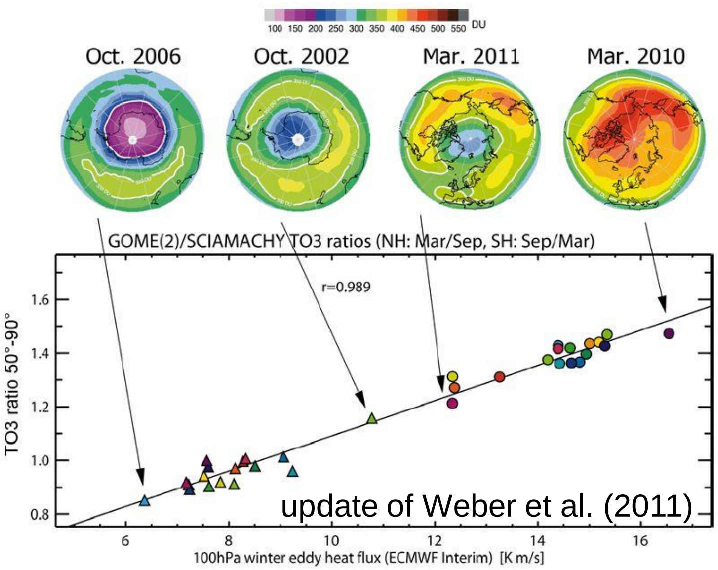
Main objectives:

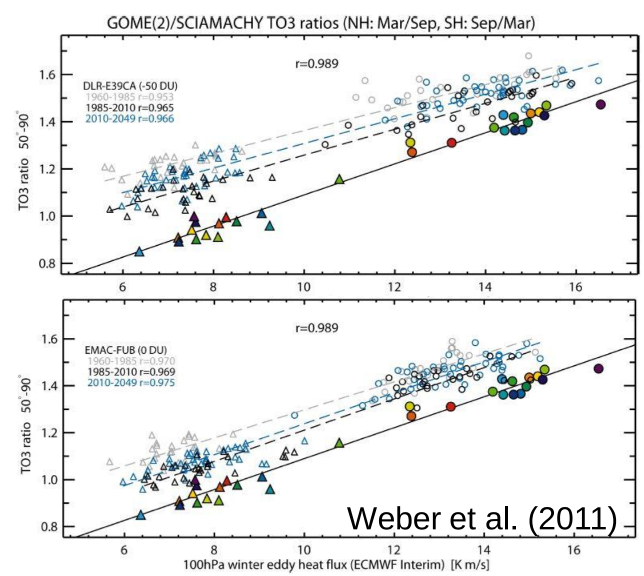
- ➢ Entry pathways
- ➢ Variations in UTS on different timescales
- ➢ Impacts on tropospheric climate and composition

- Use existing data of CCM and ESM simulations, e.g., from CMIP5, CCMI, for first analyses and exploitation.
- Improved CCMs and ESMs will then be used to perform a new set of scenario simulations.

Description of work

- Investigation of **air mass exchange from the troposphere into the stratosphere**, in particular in the Asian monsoon region, detection and quantification of trace substance transport (e.g. aerosol, very short-lived halogens, water vapour), based on observations and (nudged) CCM simulations from the recent past to the present day.
- Analysis of **depletion/recovery of the stratospheric ozone layer in a changing climate**, focus on Arctic region determining the role of dynamical and chemical processes in a future atmosphere with enhanced GHG concentrations and decreasing amount of ODSs.

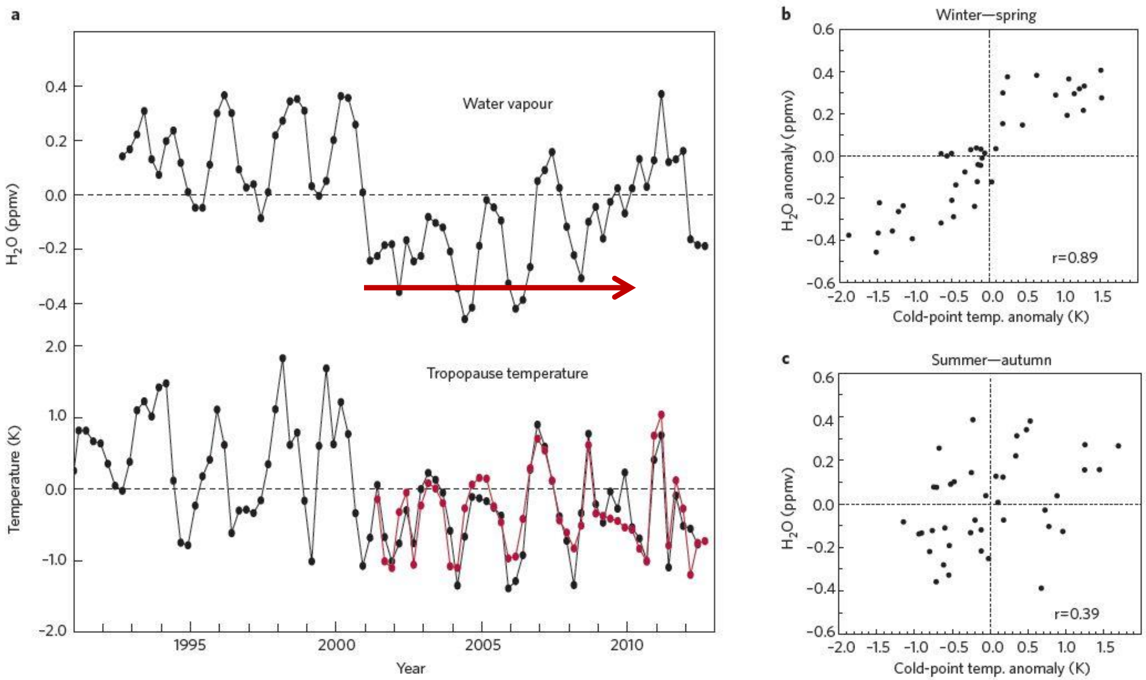




Comparison with CCM results

Description of work

- Examination of **dynamical and chemical coupling processes connecting the troposphere and stratosphere** under present and future climate conditions; quantification of internal variability as well as long-term change, e.g. the Brewer-Dobson circulation (BDC), sudden stratospheric warmings (SSWs) and air mass transport in the stratosphere and exchange with the troposphere.
- Investigations of dynamical and chemical processes determining intra-seasonal, inter-annual, and decadal **variability of water vapour in the UTS**.



Contributed to reduced warming over the past decade (Solomon et al., Science, 2010)

Randel & Jensen, 2013

Description of work

- Analysis of unperturbed and enhanced **stratospheric aerosol loading under present and future climate conditions**, i.e. impact of volcanic eruptions, intensified anthropogenic emissions, investigation of the sulfur budget contributions to studies with respect to geo-engineering.
- Exploration of the **impact of stratospheric changes on tropospheric composition and surface climate** on different time scales. Investigation of modes of variability characterising dynamical connections between the stratosphere and troposphere; links between extreme polar vortex conditions, anomalous surface weather events, oceanic circulation and sea-ice variability; the change in tropospheric oxidising capacity, consequences on changes in stratospheric composition and structure; variations and changes in cold spell events associated to stratosphere changes will be used to evaluate socio-economic impacts of these changes over Europe.
- **Seasonal-decadal climate simulations** considering fast/simplified stratospheric ozone chemistry schemes; targeted simulations with and without interactive ozone schemes. Decadal CCM simulations with complex chemistry schemes will be carried out for comparison purposes.

Strategy

- Make use of existing (multi-decadal) simulations which have been prepared for IPCC 5AR (CMIP5) and for WMO ozone assessment (CCMI). [E.g. CCMI REF-C1 (hindcast 1960-2010); REF-C2 (forecast 1960-2100; REF-C1SD ("nudged" 1980-2010).]
  - Preparation of climatological studies including internal variability on different temporal scales; development of suitable diagnostic tools.
  - Comparison with observations; evaluation of model quality.
- Definition of major uncertainties of global models regarding mentioned StratoClim objectives; preparation of plan how to improve the model systems.
- Discussion with measurement team and process modellers about information to be derived from observations needed for the models.
- Active support of field campaign preparation phase (e.g. provision of data sets (model results and observations) relevant for planning of aircraft measurements.

Strategy

- Continuation of the ´nudged´ CCM runs (CCMI REF-C1SD) until the time of the field campaign (summer 2015).
- Comparison of model data (i.e. REF-C1SD_cont) with respective measurements (including data from ground stations and satellite instruments); active support of campaign data interpretation.
- Sensitivity studies based on REF-C1SD_cont aiming to provide the best possible agreement of model data with observations.
- Use of improved global model systems for long-term (multi-decadal) simulations (repetition of REF-C1, -C2), e.g. implement new emission data, transformation schemes, etc.
- Detailed process-oriented studies (including further sensitivity studies), in particular investigating the **role of the stratosphere in the climate system**.
- Provision of new **improved** ensemble of **climate model projections**.