Science questions and measurement strategies within the European research project StratoClim

Stratospheric and upper tropospheric processes for better climate predictions

- EU funded project
- ~12 million € budget
- 28 partners from 11 European countries
- Associated partners from India, Nepal, Bangladesh
- Five year project: 2014 - 2018

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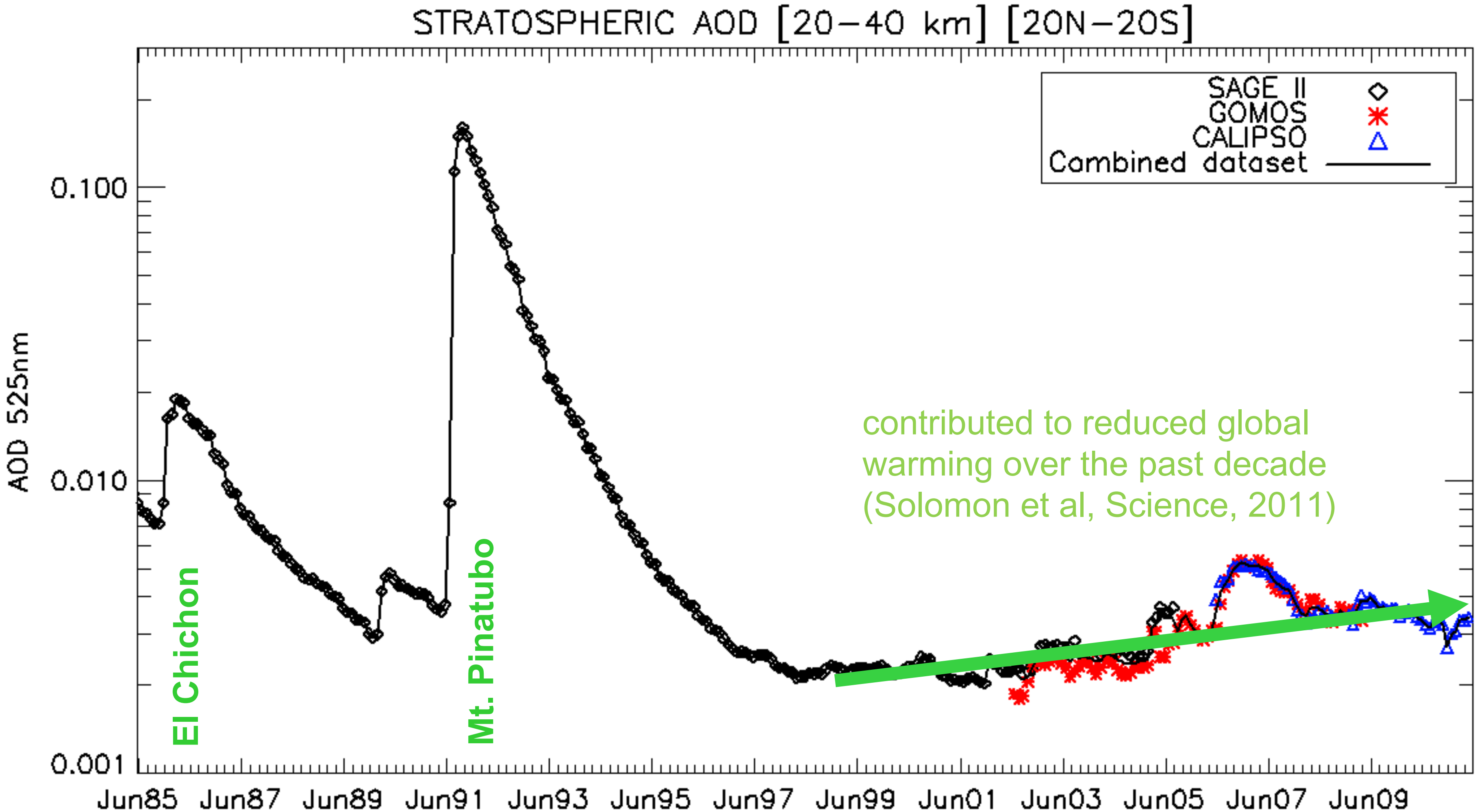
Representation of stratospheric ozone and stratospheric aerosol in global models

	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 –

Overarching goal:

To improve climate projections by including 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 –

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 t
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 field activities combined with satellite data analysis and process modeling

Input of sulfur into the stratosphere

Total input of sulfur into stratosphere =

direct injection by volcanic eruptions

+ flux of sulfur containing species across the tropical tropopause

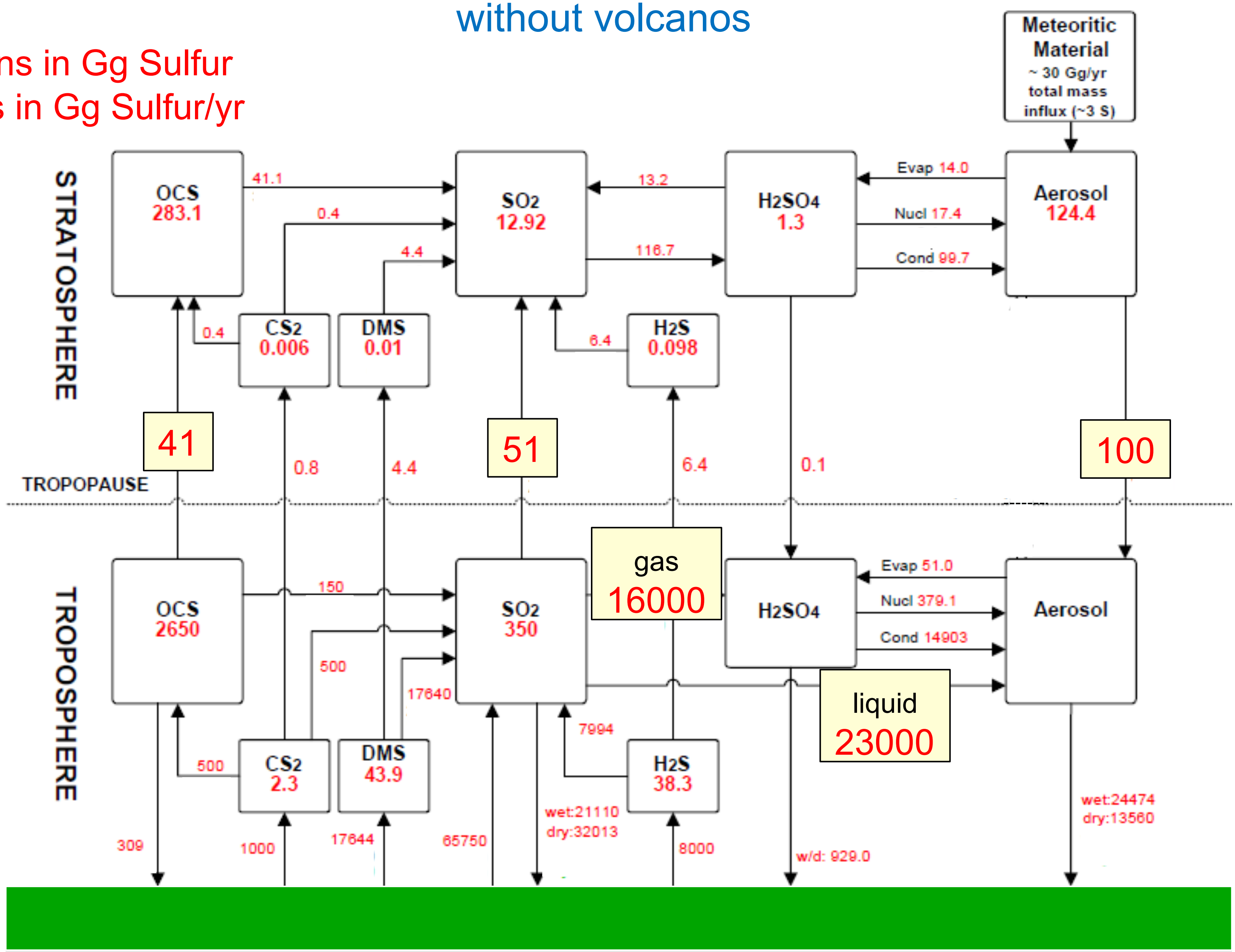
- COS ←
  - biogenic & biomass burning emissions
  - breakdown product of CS_2
- SO_2 ←
  - breakdown product of DMS & CS_2
  - anthropogenic emissions
  - volcanic emissions into troposphere
- sulfate aerosol (formed from SO_2 via OH)

largely removed by wet depostion

Global sulfur budget in SOCOL

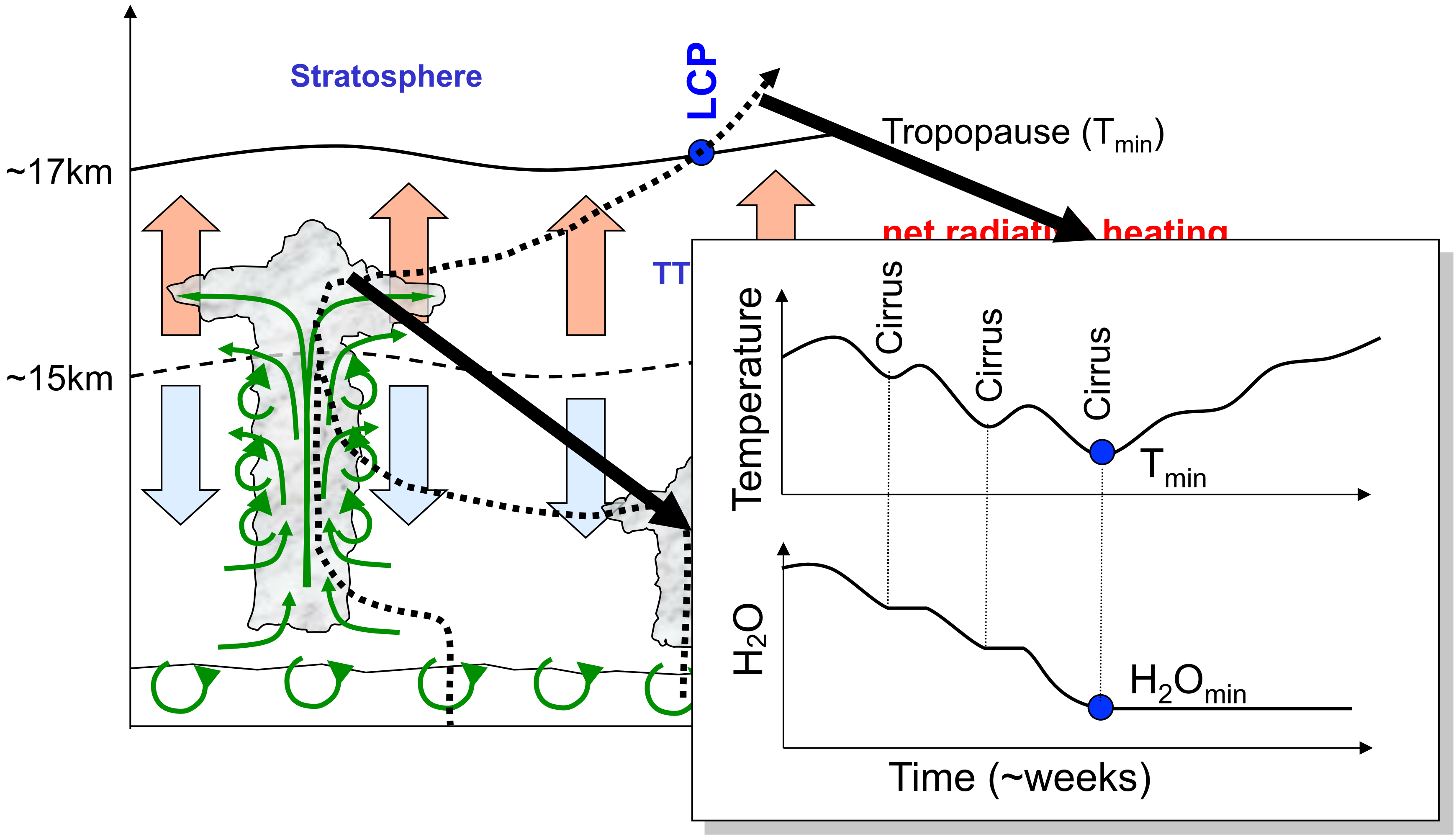
without volcanos

Burdens in Gg Sulfur
Fluxes in Gg Sulfur/yr

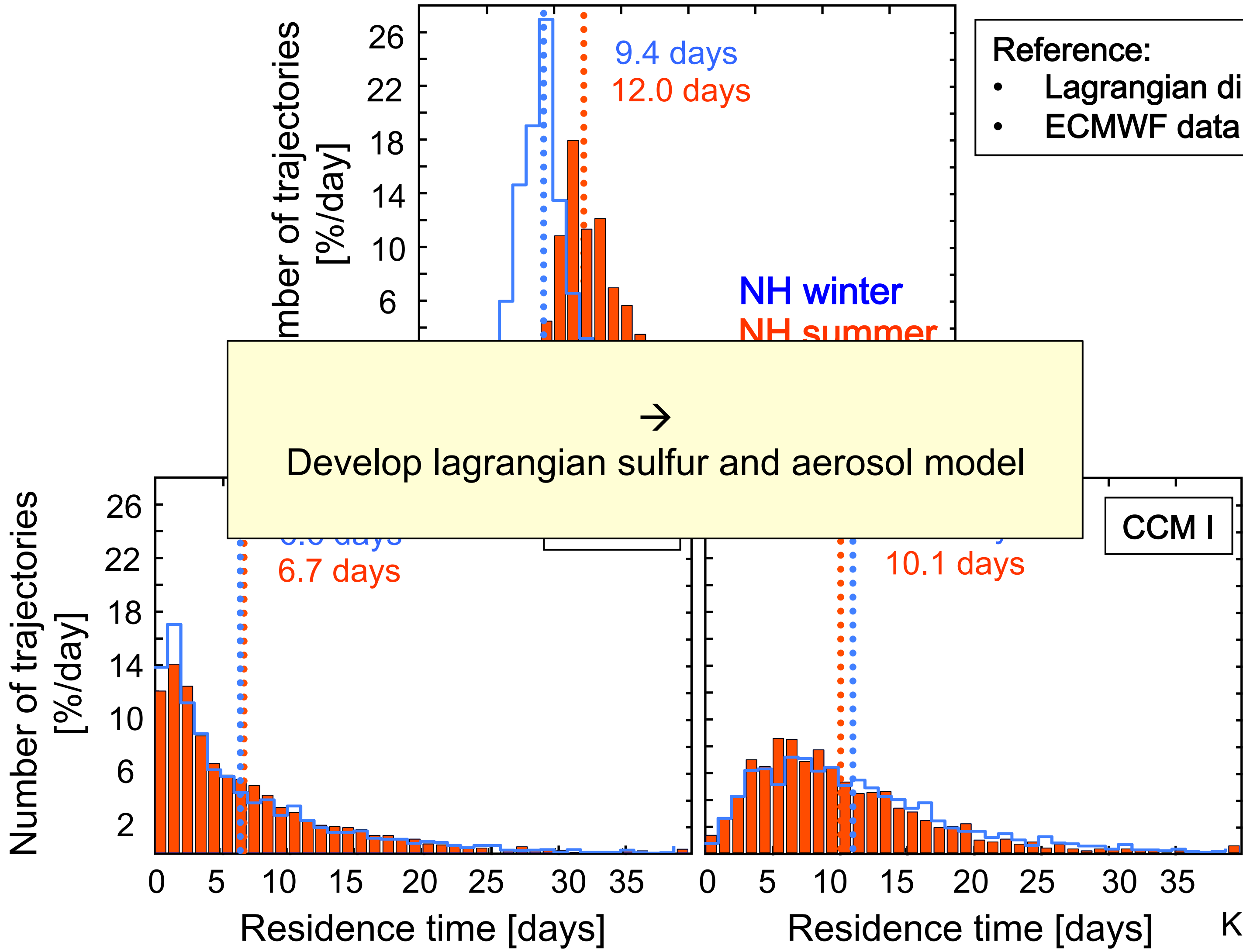


Jian-Xiong Sheng et al., 2015

Transport into the Stratosphere



Residence time in upper TTL
(between 385-395 K)



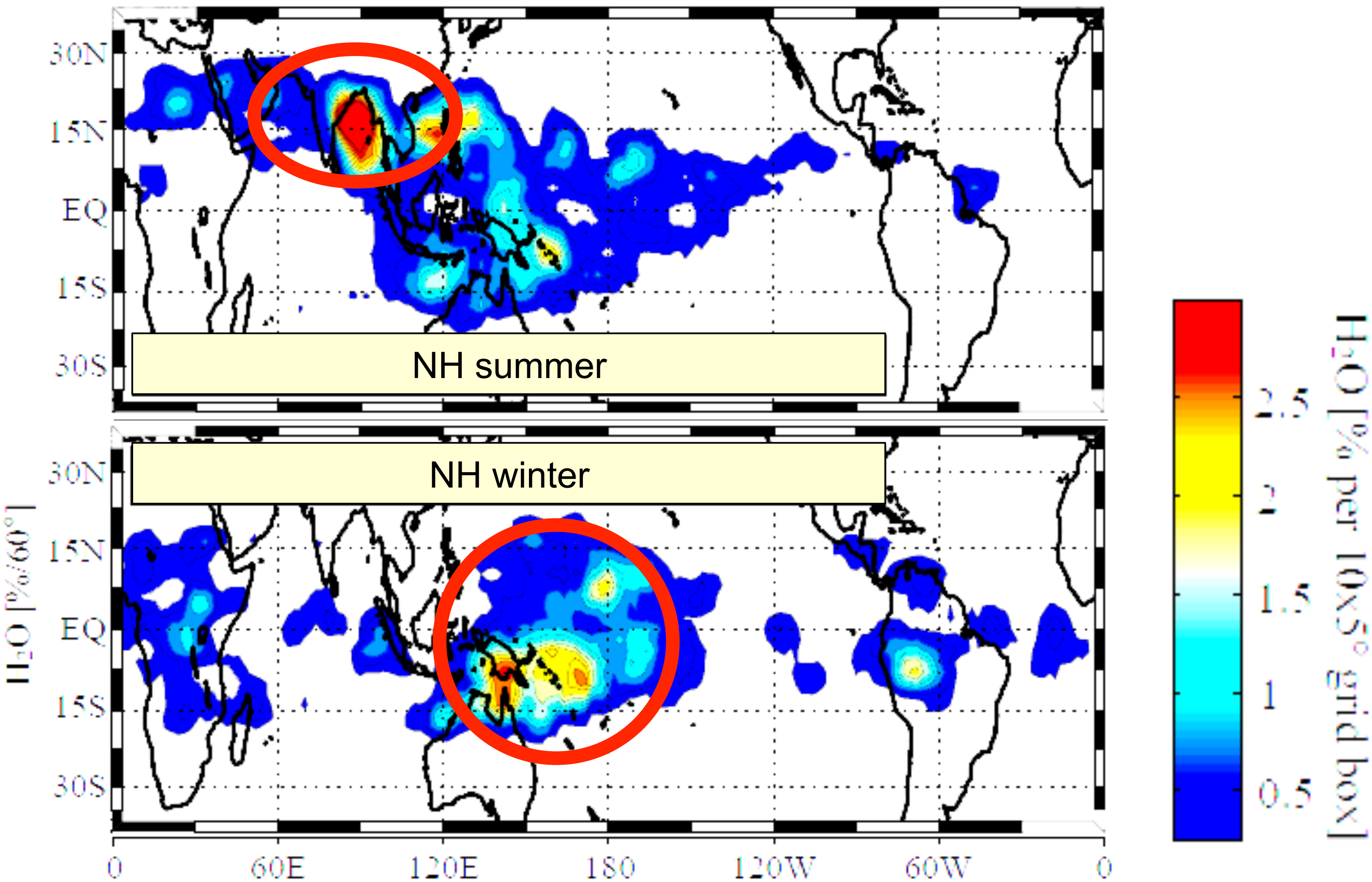
Reference:
- **Lagrangian diabatic transport**
- **ECMWF data**

→
Develop lagrangian sulfur and aerosol model

Kremser et al., 2009

Source regions for stratospheric air

Based on ATLAS



Kremser et al. (2009)

StratoClim
Planned field activities

Aircraft campaign in Asian Monsoon (AM)

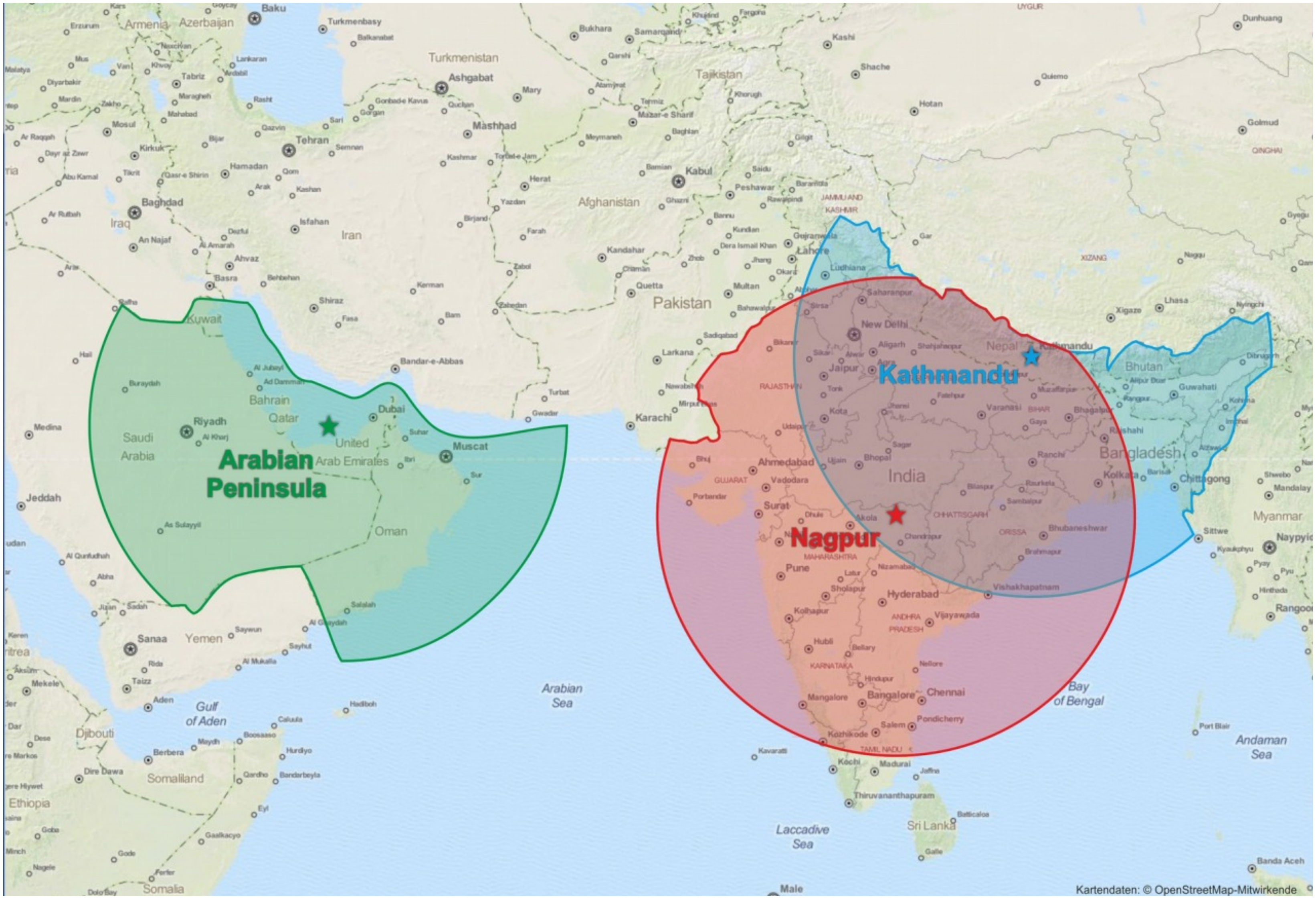
Research Station in Western Pacific (WP) warm pool region

Palau

High altitude research aircraft Geophysica

Max. Altitude:	~20km
Range:	3500km
Max. Payload Weight:	2,000kg
Wing Span:	37.46m

Operation areas



Aircraft campaign with Geophysica

- Full coverage of TTL and lowest stratosphere (up to ~20km altitude)

- Summer 2016 in the area of the Asian Monsoon

- New instruments include:
  - SO_2/H_2SO_4 CIMS instrument (sensitive to background conc.)
  - Cavity-enhanced spectrometer for COS
  - aerosol mass spectrometers (single particle and bulk)

- Measurements will include (active species, aerosol/microphysics, tracers):
  O_3, nitrogen oxides, active halogen species
  COS, SO_2, H_2SO_4, H_2O, HDO
  CN, aerosol size distribution (0.4-3500µm), imager, optical properties
  chemical composition (MS for bulk and single particle), filters
  CO, CO_2, large set of traces, whole air sampler

StratoClim
Planned field activities

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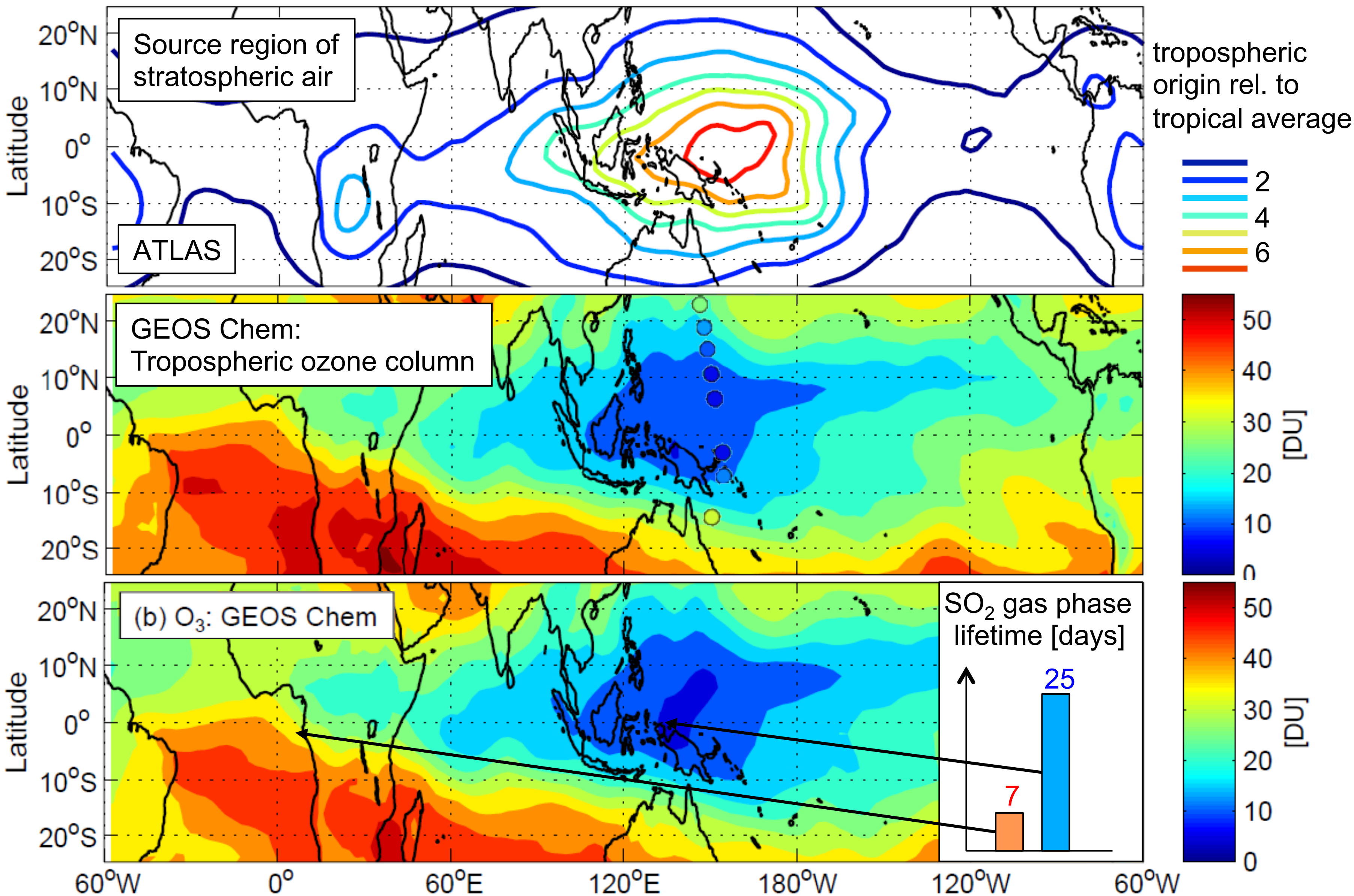
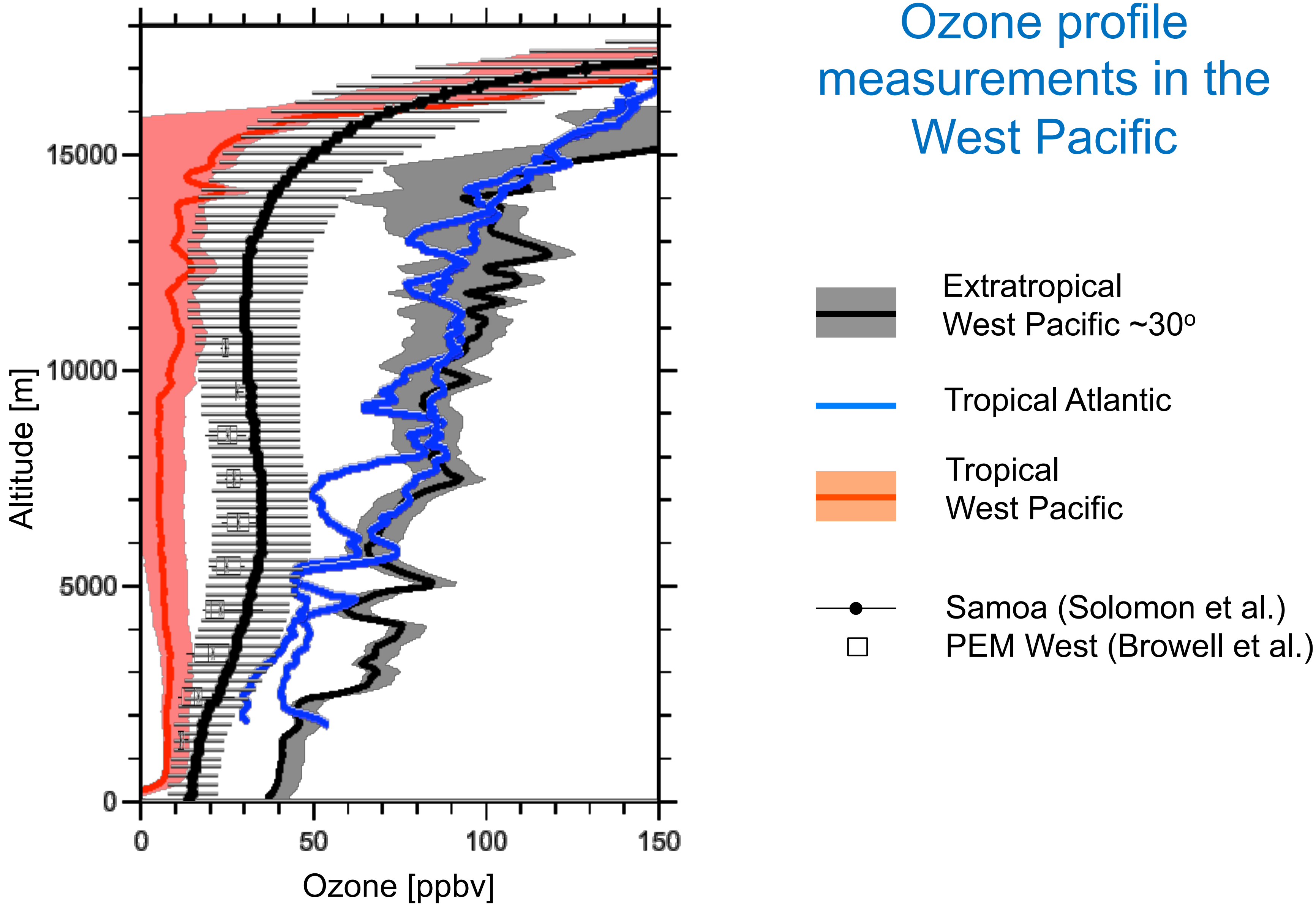
Palau

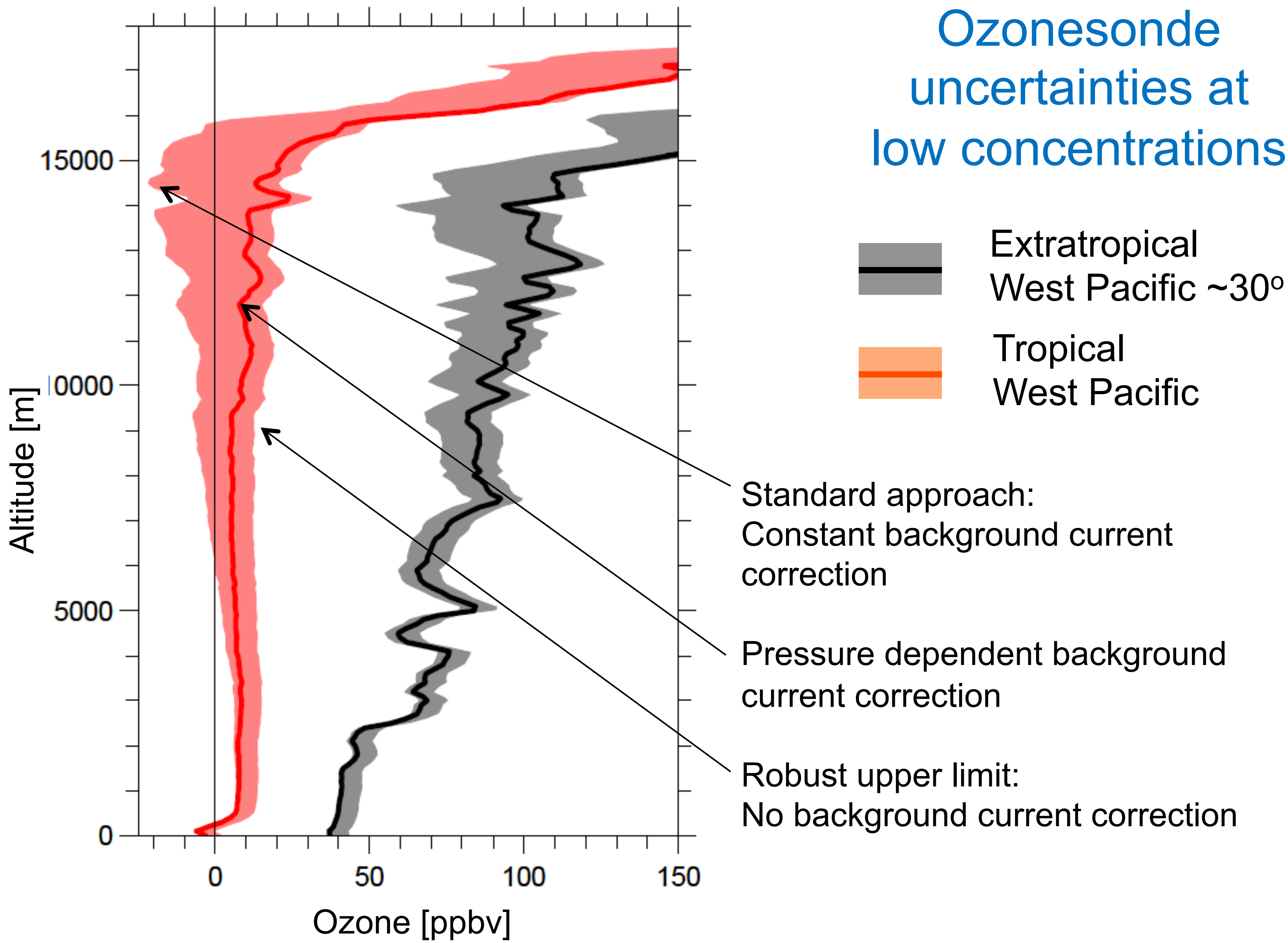
Tropospheric columns (October 2009)



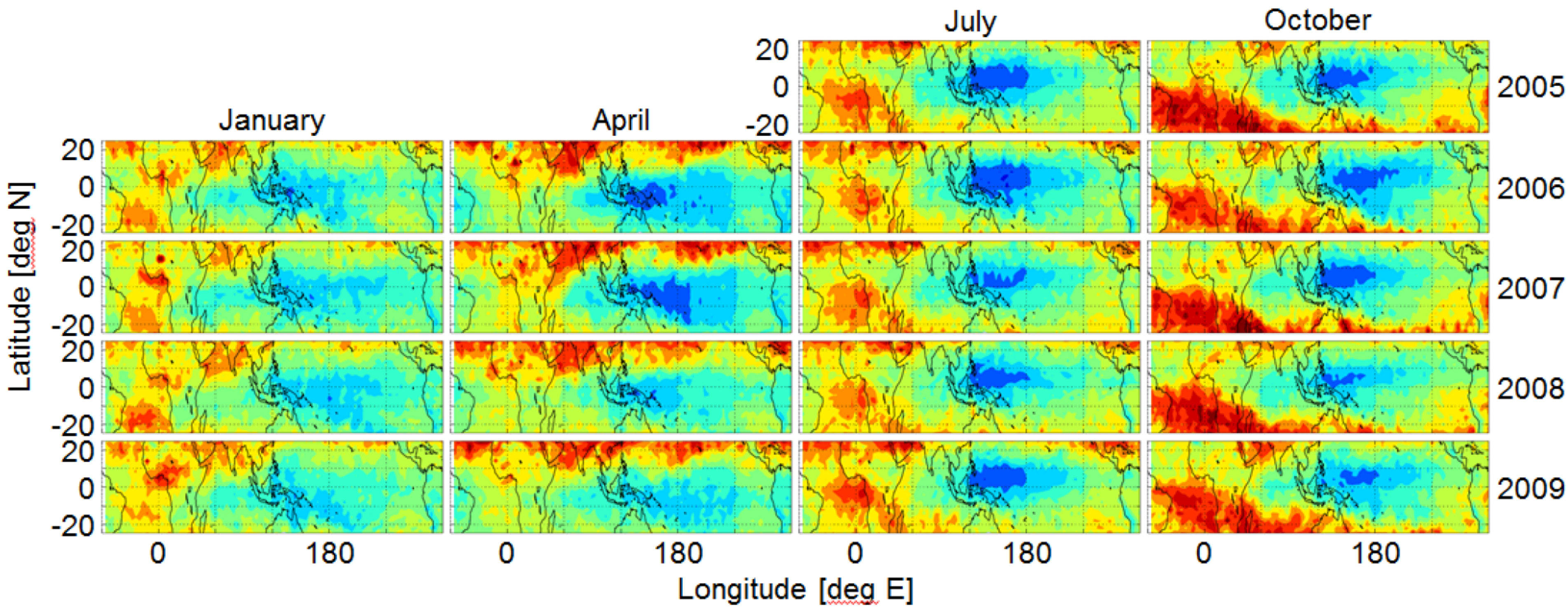
Ozone profile measurements in the West Pacific



Ozonesonde uncertainties at low concentrations



Multi-annual TES data set



- Minimum is persistent
- Exists year round (strongest in NH summer & fall)
- Is affected by ENSO (follows the warm pool)

Rex et al., 2014

Tropical West Pacific ground station

- Location: Palau (close to center of warm pool)

- 2-3 years of initial operation during 2015 – 2017

- 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), improved for in-flight measurements of background current
  - UV-diode ozone spectrometer sondes for better detection limit
  - Water vapour sondes (CFH)
  - Backscatter sondes (COBALD)
  - aerosol lidar

END

StratoClim
Role of aerosols at higher atmospheric levels

DACCIWA
Aerosols in air quality and climate in West Africa

BACCHUS
Interaction between aerosols and clouds

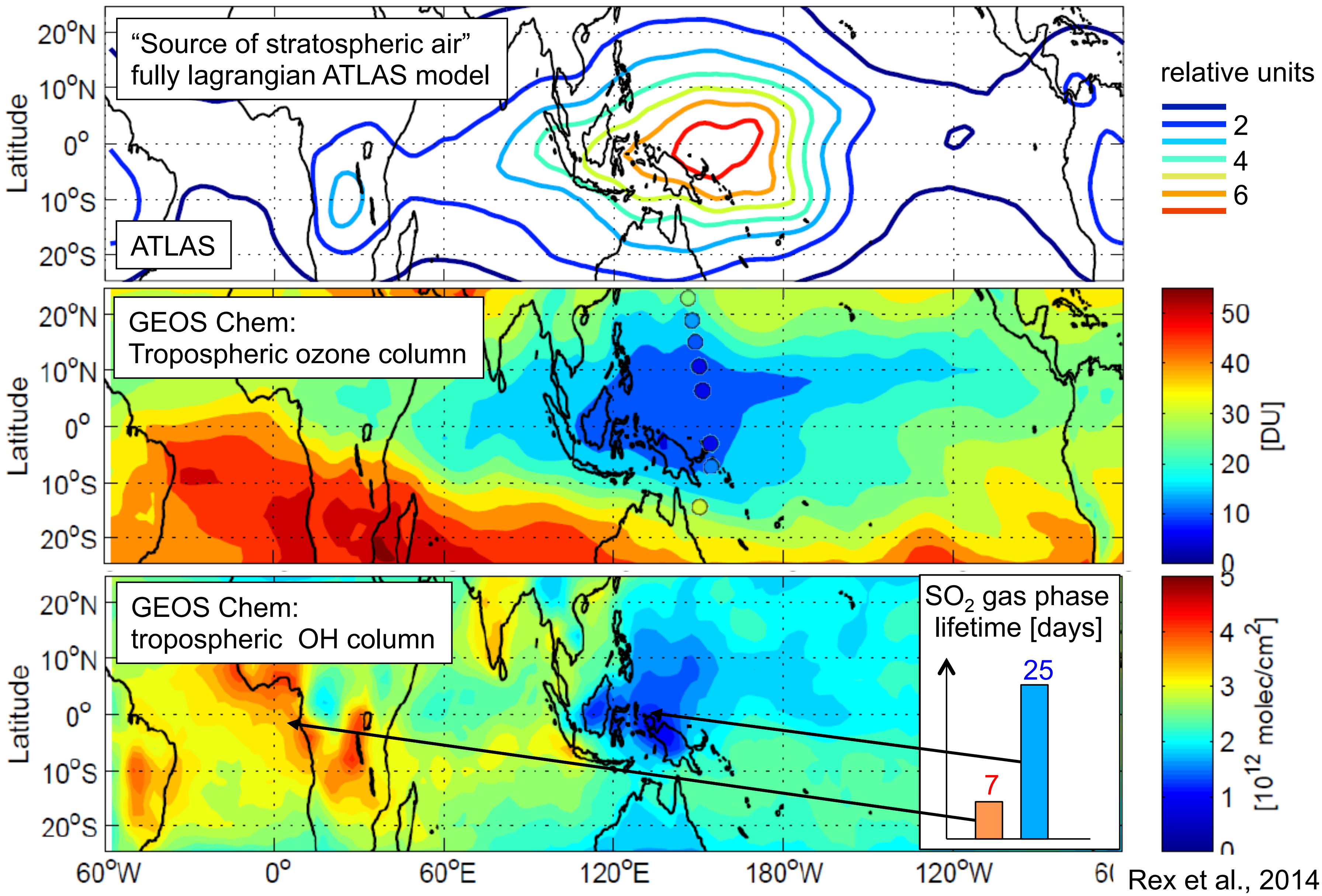
ClimPol
Pathways to Policy implementation

IPCC 2013: Aerosol processes are major driver of uncertainties in current climate projections

=> New European Research Cluster

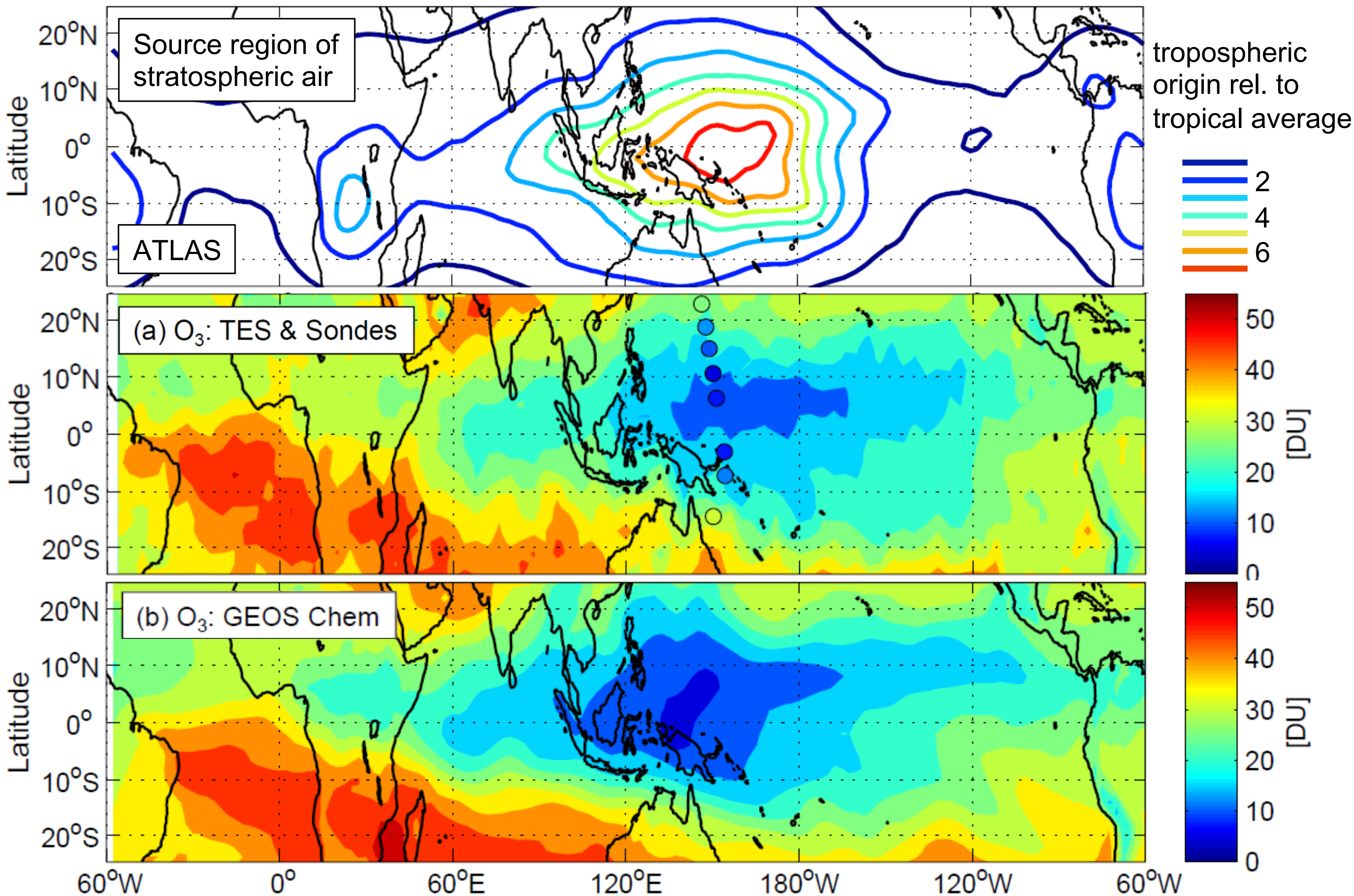
- 2013 – 2018, Budget: ~36 Mill. €
- Jointly coordinated by:
  - Peter Knippertz (KIT)
  - Ulrike Lohman (ETH)
  - Markus Rex (AWI)

Processes at stratospheric entry point in NH winter



Rex et al., 2014

Tropospheric columns (October 2009)



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

Concept: StratoClim combines

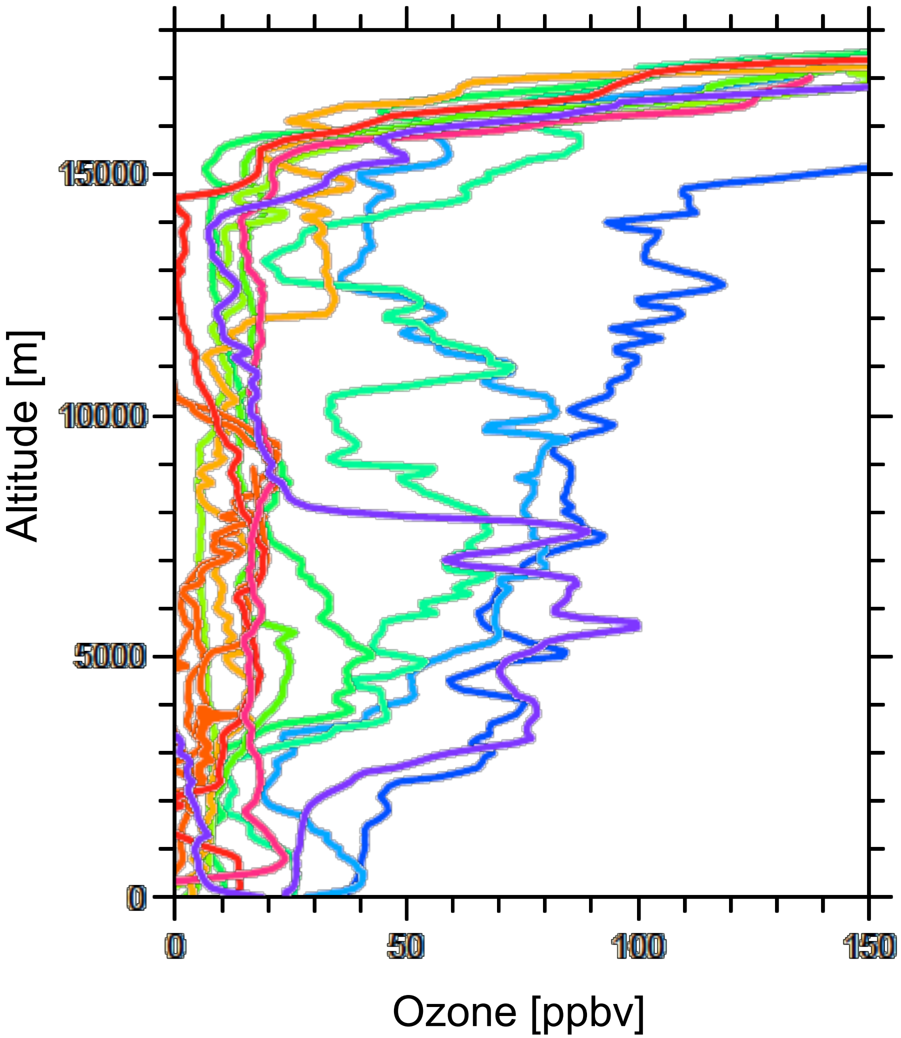
(1) Tropical aircraft campaign
(2) Tropical measurement station
(3) Satellite data analysis & development of new products
(4) Process and regional modeling
(5) Global modeling
(6) Studies of the socioeconomic implications and a public outreach program

Collaboration

Towards building a strong Asian/European community on atmospheric composition research:

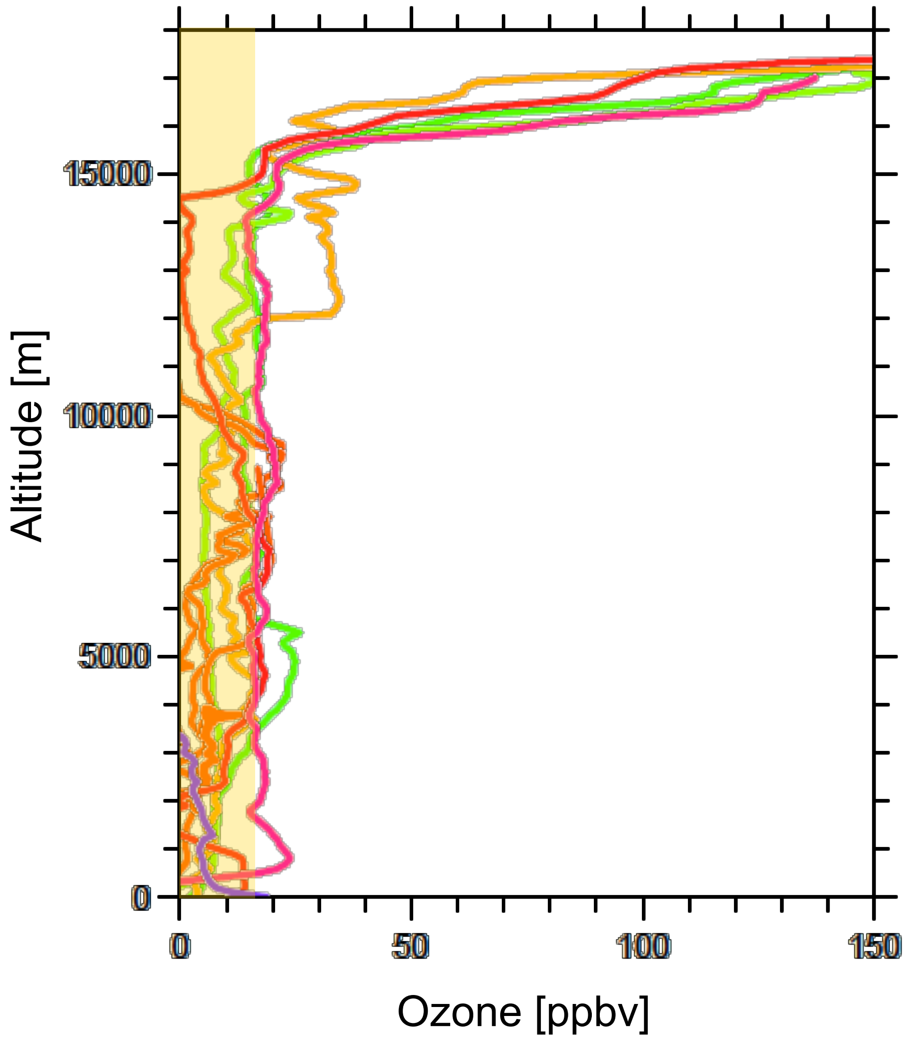
- Collaborations in the South Asia region. Focus on:
  - Measurement activities that characterize the composition of air at lower levels (ground stations, balloon and aircraft campaigns).
  - Capacity building / outreach and awareness programs

Ozone profile measurements in the West Pacific



091011: 33.5°N
091012: 26.2°N
091013: 23.1°N
091014: 18.8°N
091015: 14.9°N
091016: 10.5°N
091017: 6.2°N
091018: 1.1°N
091019: 3.1°S
091020: 7.2°S
091021: 11.8°S
091022: 14.4°S

Ozone profile measurements in the West Pacific



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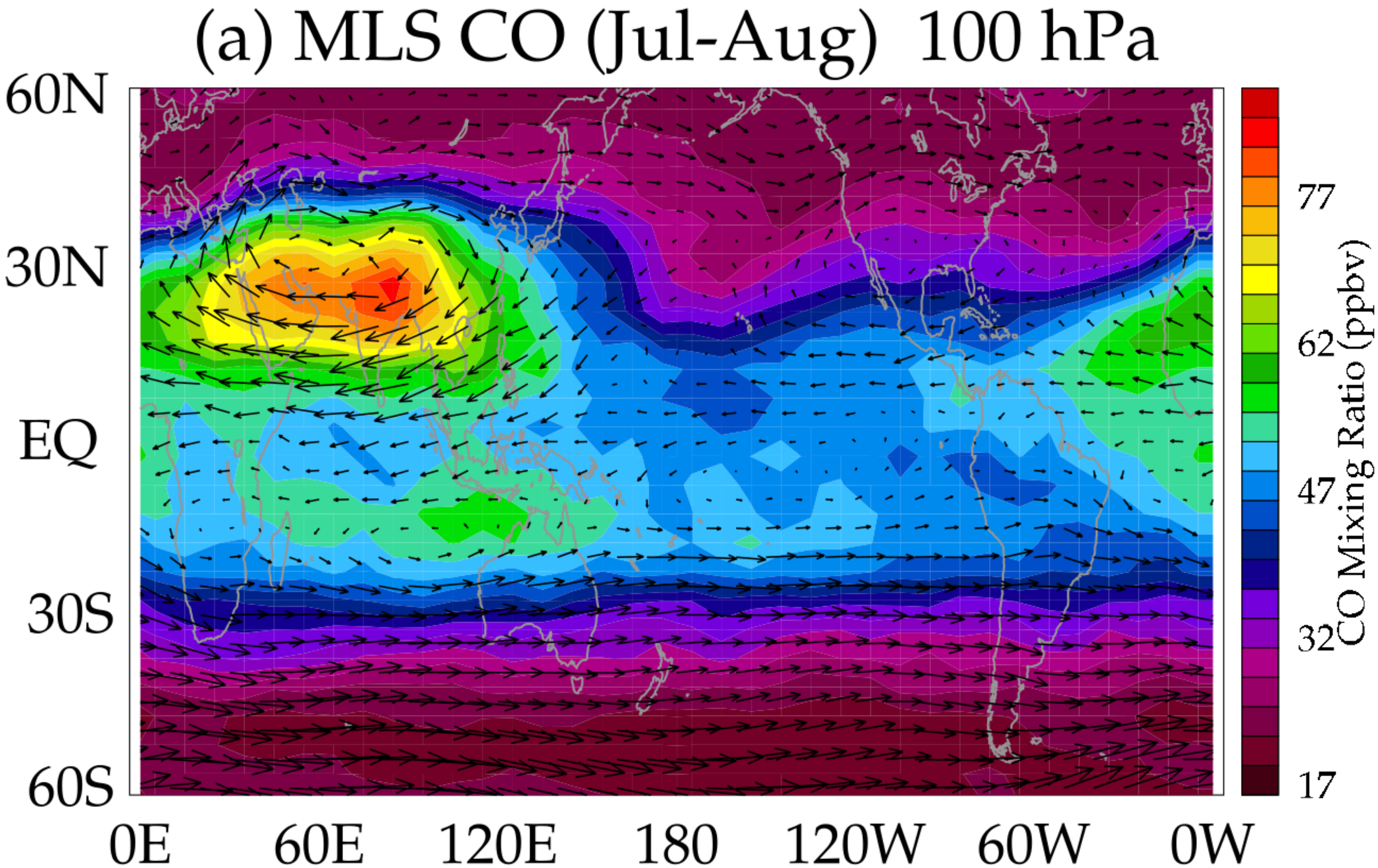
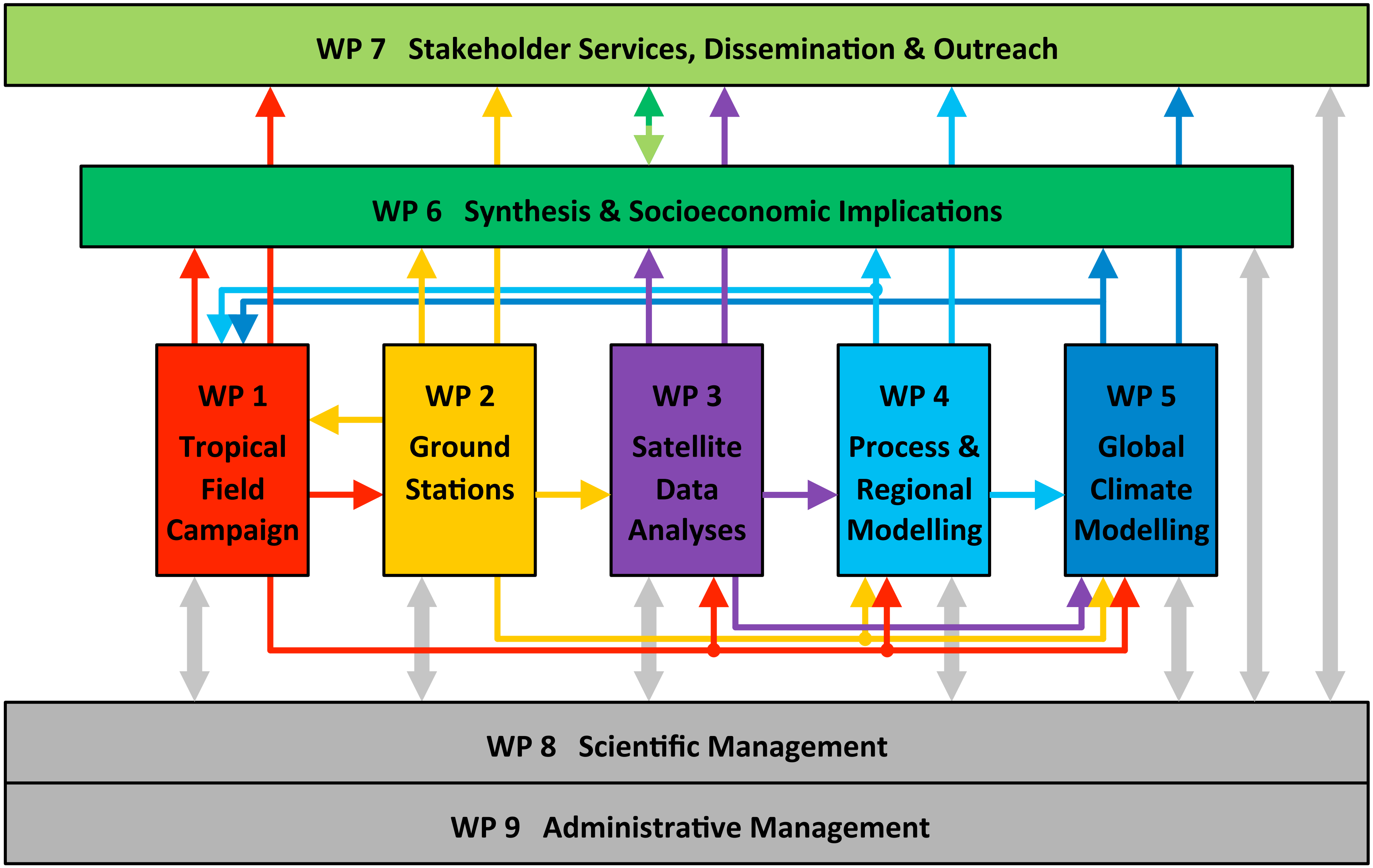
091017: 6.2°N
091018: 1.1°N
091019: 3.1°S
091020: 7.2°S
091021: 11.8°S
091022: 14.4°S

Troposph. ozone below 15~20 ppbv

The Asian Monsoon anticyclon
CO data




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

Payload

IN SITU INSTRUMENTS, GAS PHASE				
FOZAN	O_3	Ulanovsky, CAO	Dye chemiluminescence+ECC	(Ulanovsky et al., 2001; Yushkov et al., 1999)
FISH	H_2O (total)	Krämer, JUELICH	Lyman-a	(Zöger et al., 1999)
FLASH	H_2O (gas phase)	Khaykin, CAO	Lyman-a	(Sitnikov et al., 2007)
SIOUX	NO, Noy, Particle Noy	Schlager, DLR	Chemiluminescence, Au converter, subsonic inlet	(Voigt et al., 2005)
HALOX t.b.d.	ClO, BrO	Stroh, FZJ	Chemical Conversion Resonance Fluorescence	(von Hobe et al., 2005)
HAGAR	N2O, CFC12, CFC11, CH4, H2, SF6, Halon1211, CO2	Volk, BUW	Gas Chromatography (GC) with electron capture detector (ECD) IR absorption	(Homan et al., 2010; Werner et al., 2010)
WAS	Long lived trace gases and isotopo-logues	Röckmann, UTRECHT	Whole air sampling with lab GC and MS analysis	(Kaiser et al., 2006; Laube et al., 2010)
COLD	CO	Viciani, CNR	TDL	(Viciani et al., 2008)
STRATOMAS	H2SO4 / SO2	Schlager, DLR	CIMS	
AMICA	OCS, CO, CO_2, HCN(t.b.d.)	von Hobe, JUELICH	ICOS	
CHIWIS	H_2O / HDO ratio	Moyer, Univ. Chicago	CEAS	

Payload

PARTICLE INSTRUMENTS				
COPAS	Condensation nuclei (CN-total, CN-non-volatile)	Weigel, MPI-C	2-channel CN counter, one inlet heated	(Weigel et al., 2009)
FSSP	Cloud particle size distrib. (0.4-47µm)	Borrmann, MPI-C	Laser-particle spectrometer	(de Reus et al., 2009)
CCP	Cloud particle size distrib. (3-47µm)	Borrmann, MPI-C	Laser-particle spectrometer	
CIP	Cloud particle size distrib. (25-1600µm) Particle Images	Borrmann, MPI-C	Laser-particle spectrometer	(Baumgardner et al., 2001)
MAS	Aerosol optical properties	Cairo, CNR	Multi-wavelength Scattering	(Buontempo et al., 2006)
HAPACO	Particle Filter Collection, Electron microscopy, nano-SIMS	Ebert, TU-Darmstadt		
ERICA	Aerosol chemical composition	Borrmann, MPI-C	Bulk phase and single particle Aerosol Mass Spectrometer	
PIP	Particle size	Borrmann, MPI-C	Laser Particle Spectrometer	

Payload

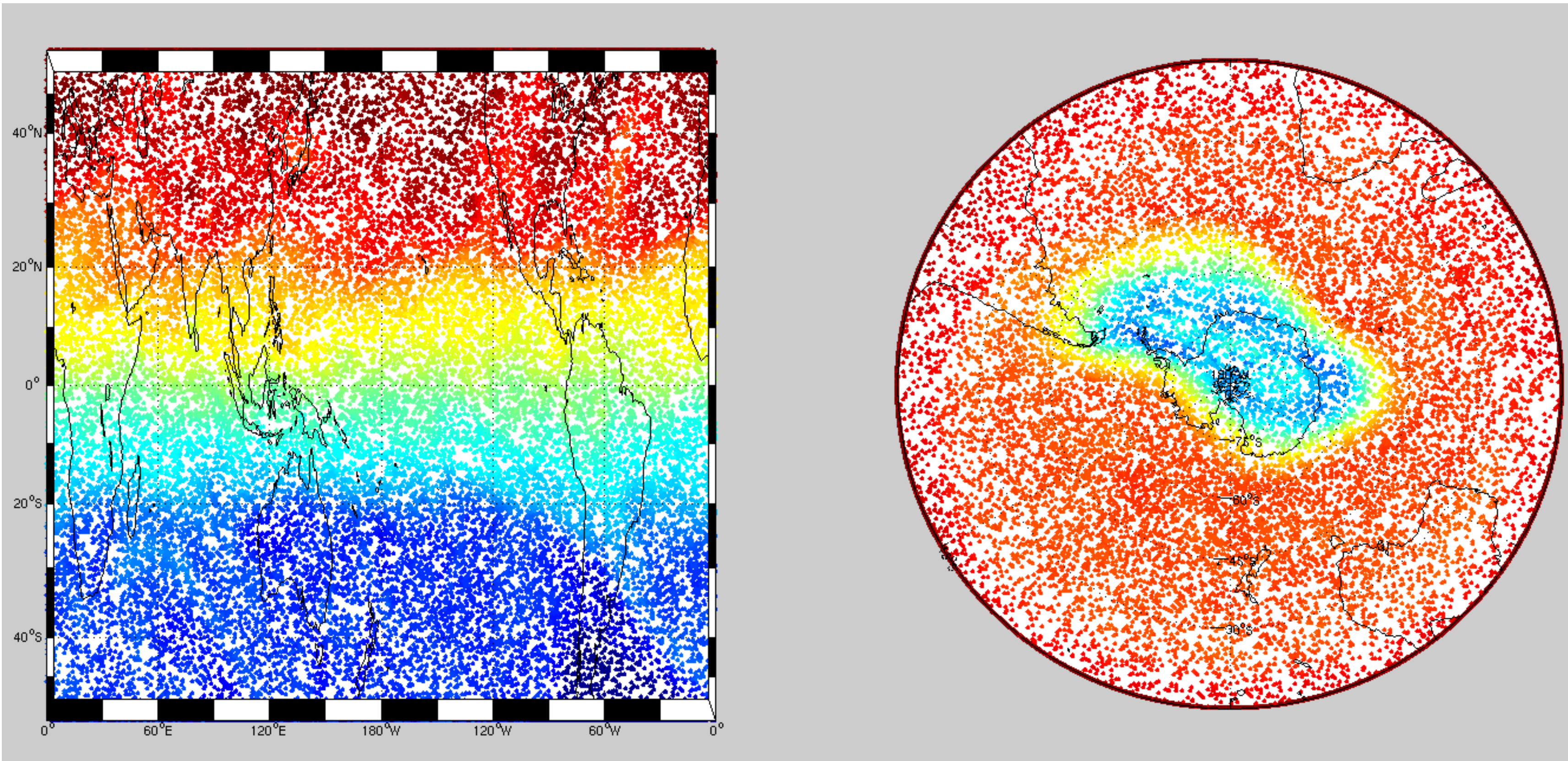
REMOTE SENSING INSTRUMENTS				
MAL 1	Remote Aerosol Profile (2km upwards from aircraft altitude)	Mitev, CSEM	Microjoule-lidar	(Matthey et al., 2003)
MAL 2	Remote Aerosol Profile (2km downwards from aircraft altitude)	Mitev, CSEM	Microjoule-lidar	(Matthey et al., 2003)
GLORIA	Cloud Index, T, HNO_3,O_3,$ClONO_2$, CFCs,H_2O and minor species	FelixFriedl-Vallon, KIT PeterPreusse, JUELICH	Imaging FTIR limb sounder	(Riese et al., AMT, 2014)
MARSCHALS	O_3, H_2O, CO, HNO_3, N_2O	Moyna, RAL	Millimetre Wave spectrometer in limb geometry	(Moyna et al., 2006)
PHYSICAL PARAMETERS				
Rosemount probe (TDC)	T, P, horiz. Wind	Beliaev, MDB	PT100, 5-hole probe	
Aircraft Data System (UCSE)	T, P	Beliaev, MDB		

Payload

OPTIONAL INSTRUMENTS (Integration depends on available resources (weight, space, time)				
ISAF	Formaldehyde	TomHanisco, NASA GFC	Resonance Fluorescence	
MTP	T profiles	NN, DLR	Microwave Temp. Profiler	
ASTRO	T, P H2O profiles	Cairo, CNR	GPS occultation	
OFCEAS	several tracer species sets available	Valery Catoire, LPCE, Orleans	Cavity Enhanced Spectroscopy	
FUNMASS	t.b.d. (e.g. HCl, HNO3, ClNO3)	Stroh, JUELICH	TOF-CIMS	

ATLAS: Lagrangian Chemical Transport Model

~20km altitude, 20 model days, dynamical tracer (PV), ~50km resolution run

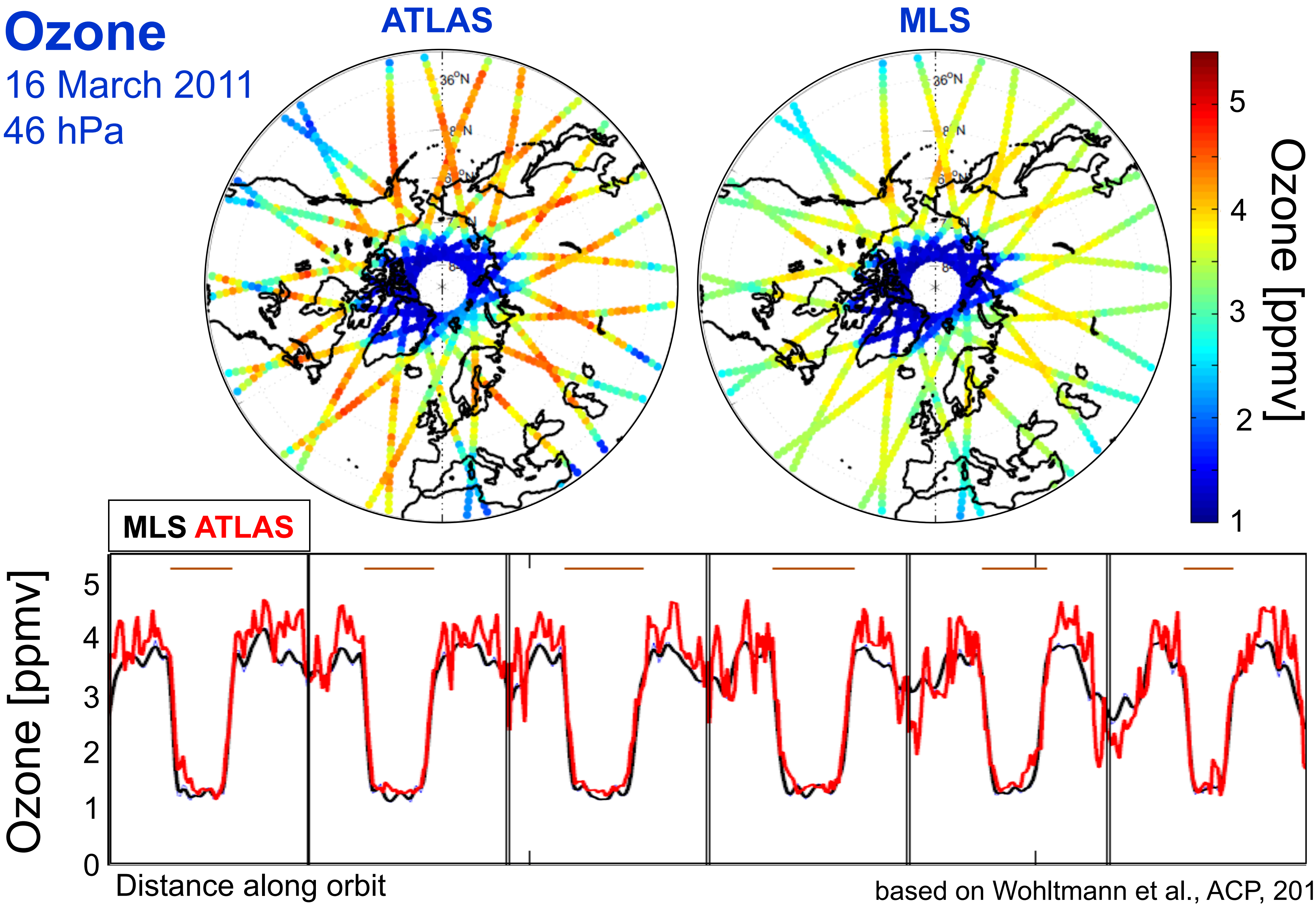


- Detailed homogeneous and heterogeneous chemistry (49 species, 170 reactions)
- Lagrangian particle sedimentation scheme
- No numerical diffusion, sophisticated 3d mixing scheme
- Fully parallel architecture fairly long integrations feasible

Wohltmann & Rex, 2009; Wohltmann, Lehmann, and Rex, 2010

Ozone

16 March 2011
46 hPa



based on Wohltmann et al., ACP, 2013

Computational effort to calculate ozone changes

ATLAS solves a set of 49 coupled differential equations based on 55 initial and boundary conditions.

ΔO_3 calculated at each time step and each grid point: For a 100-year model run the system needs to be solved ~2.5 trillion (10^{12}) times.

Computational effort is much too large to be included in ESMs

But: Virtually all of these calculations are redundant!

From ATLAS to SWIFT

(Approach for polar winter is different, c.f. Rex et al., ACP, 2014)

Values of ΔO_3 form a hypersurface in the 55 dimensional parameter space.

Development of SWIFT:

1. Linear combinations reduce the number of dimensions such that ΔO_3 still forms a compact hypersurface in the reduced space.
2. Shape of hypersurface is characterized by full runs of ATLAS.
3. An automatic procedure constructs a closed polynomial expression that approximates its shape.
4. SWIFT solves this expression to give results very similar to those of ATLAS.

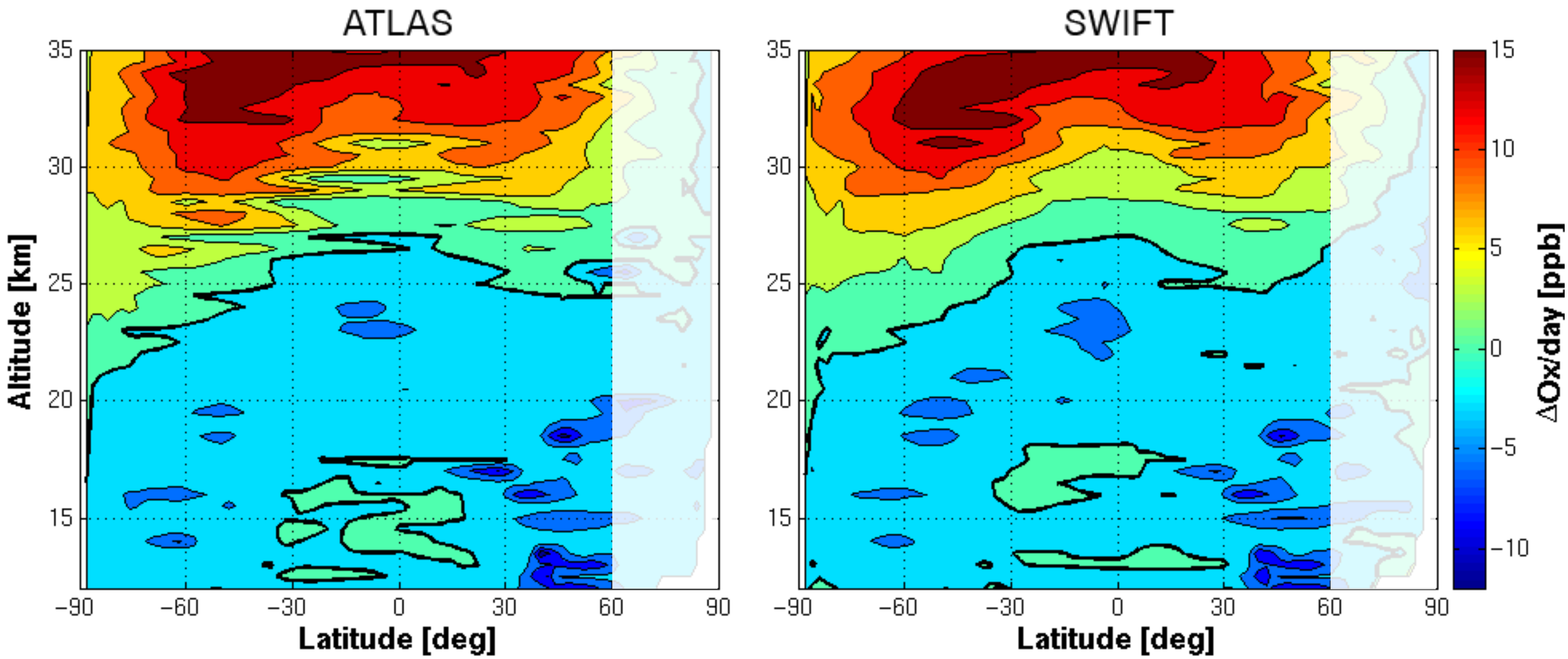
SWIFT: Fast ozone chemistry for climate models

Monthly means of ozone change rates, January 2011, without polar module

Numerical effort

~2 weeks / year on 48 processors

~ Seconds / year on 1 processor



SWIFT: Rex et al., ACP, 2014
Figure: Kreyling et al, PhD project

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