sibilities were distributed. In six weeks a questionnaire about the respective model configurations and low *vs.* high-top model runs from the same model will be circulated to the modelling groups. For a first intercomparison of the results a small, dedicated workshop will be held in England in summer 2013 with a lot of time to discuss and write up the current research.

The next joint SOLARIS-HEPPA Workshop will be held in Baden-Baden, Germany, from 5-9 May 2014, and will be hosted by the Karlsruhe Institute of Technology.

Acknowledgements

We would like to acknowledge the tremendous contribution of Kuni Kodera to solar influence studies. He now retires from the SOLARIS leadership, after having initiated solar intercomparison studies with GCMs under GRIPS (GCM Reality Intercomparison Project for SPARC) in the mid 1990's. He will continue to be an essential advisor of our future activities.

Additionally, we would like to thank WCRP/SPARC for its support, as well as sponsorship from NCAR, CU Boulder, SCOSTEP/CAWSES, NASA/Living With a Star, ATOC, and IAGA.We especially thank the local organising committee for an excellent venue and organisation of the meeting.

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U.S. - Japan Bilateral Workshop on the Tropical Tropopause Layer: State of the Current Science and Future Observational Needs, 15-19 October 2012, Honolulu, HI, USA

A. Gettelman[1], K. P. Hamilton[2], G. A. Morris[3], F. Hasebe[4], H. B. Selkirk[5]

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The Tropical Tropopause Layer (TTL) is the dominant region for entry of tropospheric air into the global stratosphere. The TTL is a several kilometre thick layer in which air has characteristics of both the troposphere and stratosphere (**Figure 18**). Despite significant theoretical advances and a rapidly growing archive of observations, important science questions related to the control of humidity and the chemical composition of air entering the stratosphere remain unanswered. Many different processes are involved, including convective transport, large-scale ascent, atmospheric waves, and cloud microphysical processes. Further progress requires better analysis of current observations and new observational campaigns in which *in situ* observations on both balloons and aircraft platforms are coordinated with satellite observations.

To this end, a bilateral Japan-US workshop was held at the University of Hawaii (Honolulu), from 15–19 October 2012. The workshop assembled scientists from Japan, the United States, and several other countries, with the goal of catalysing new collaborations and studies of the TTL. The workshop was sponsored by the National Science Foundation's 'Catalyzing New International Collaborations Program' (Award #1158805). The overall objectives for the workshop were three-fold: 1) coordination of TTL campaigns planned for the next few years; 2) development of new collaborations involving the next generation of Japanese and U.S. scientists; and 3) dissemination of educational materials on the TTL developed for this workshop to faculty and students worldwide.

The workshop focused on refining science questions and coordinating planned TTL observation and analysis campaigns in the Tropical Western Pacific, to ensure that the scientific impact of the combined effort will be greater than the sum of individual projects. Catalysing specific cooperation and collaboration for field projects maximises the coordination of observations, enables joint analysis of the data and leaves a legacy of important data sets for the community. Such effort ultimately improves knowledge of the climate system and atmospheric chemistry, while training the next generation of U.S. and Japanese scientists who establish lasting collaborations. An innovative electronic tutorial component to the workshop including archived presentations and posters is now available on the world wide web (**http://scholar.valpo.edu/ttlworkshop**).

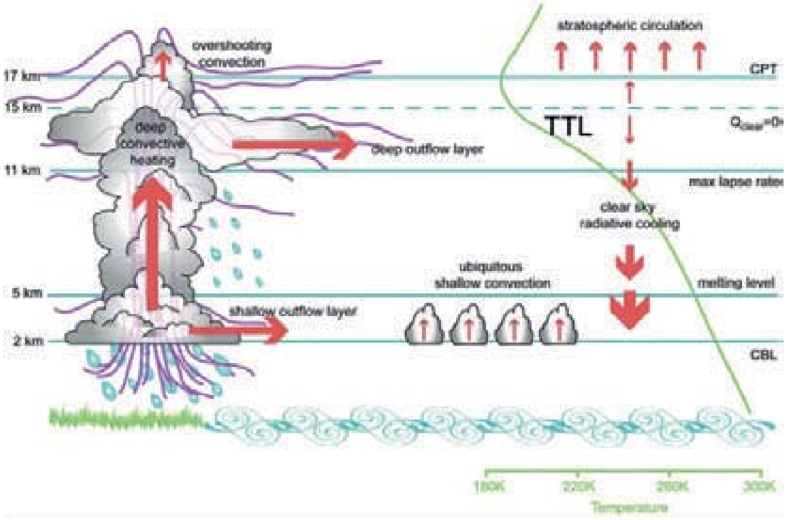

Figure 18: Schematic of the tropical atmosphere and the Tropical Tropopause Layer (TTL). Figure from L. Pan (personal communication). Original from Pendlebury, 2007 (for SPARC).

Science questions

There were several common themes among the tutorials and projects presented at the workshop, broken down into a series of critical topics and science questions. Many of these questions are being addressed in some way by upcoming campaigns in the TTL (see section on campaign descriptions).

The **boreal summer Asian Monsoon**, marked by a large anticyclone in the TTL, dominates the June-September season and has profound implications both regionally and globally. Observations indicate that tropospheric air (with high water vapour and CO content) is found even at high altitudes in the anticyclone (Randel and Park, 2006). An example is shown in **Figure 19**, where high water vapour is seen in the region of the anticyclone, which is not coincident with regions of deep convection. Exactly how air with water vapour, trace gases and aerosols is transported from the boundary layer into the TTL and stratosphere is not well understood. There are simulations on the impact of the Asian Monsoon for the global TTL (*e.g.*, Gettelman *et al.*, 2004), but monsoon effects are not well characterised from observations. There are several campaigns with components all or partly in the June-September time frame that will try to constrain tracer budgets and observe convective transport in the region (see below). Several current and proposed projects (see below and **Table 1**) are focused on the Asian Monsoon. These projects include: StratoClim (Thailand), ATTREX (Global Hawk, Australia, 2014), SEAC4RS (cloud, chemical tracers, regional/global air quality), SWOP (soundings of O_3 and H_2O) and SEACIONS (O_3).

Wave processes are critical in the TTL, and occur at small to global scales. Several important aspects of TTL waves were discussed. It is important to quantify mixing associated with horizontal Rossby wave-breaking from mid-latitudes in the TTL (Waugh, 2005). **Figure 20** shows an example of the relationship between a large-scale equatorial Kelvin wave and TTL cirrus formation with variations in temperatures,

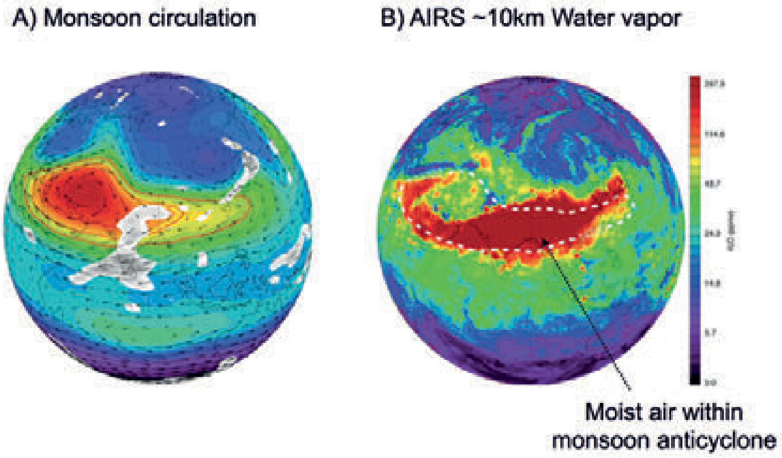

Figure 19: Based on Randel & Park 2006, JGR, Figure 1. (**a**) June-August climatological Monsoon Circulation (Streamfunction) and wind vectors. Also shown are low values of outgoing longwave radiation representing deep convective clouds. (**b**) AIRS 150hPa water vapor (contours).

Table 1: Current and proposed projects and campaigns:

CAMPAIGN/ PROGRAM	Status (Oct. 2012)	SCIENCE FOCUS	Region of Study	Deployment base; site(s)	Key observations	Primary platform(s)	Observational program	Duration	Lead organi-zations	Science Leadership (present/not present)
JF 2013										
SOWER 2013	**Go**	TTL water vapor and ozone	**Pacific warm pool**	Biak [1°S, 136°E]	Water vapor/ozone [CFH/ECC]	Balloon; ground-based lidar	Approx. 5 launches	One week	Hokkaido University; Kyoto University	**F. Hasebe (PI) and M. Fujiwara; M. Shiotani**
ATTREX (1)	**Go**	TTL structure and microphysics	**Eastern and central equatorial Pacific**	NASA-DFRC [southern California]	Water vapor, ozone, temperature, ice microphysics	Global Hawk (high-alt UAV)	Up to 6 long-duration (>24-hours) flights	Six weeks	NASA ARC	**E. Jensen (PI) and L. Pfister**
JJA 2013										
SEAC4RS	**Go**	Summer monsoon: tropospheric aerosols and chemistry; upper-level anticylcone; biomass burning	**Southeast Asia**	Singapore *(tentative)*	Aerosol, atmospheric composition, radiation and microphysical measurements	DC-8 (to 12 km) & ER-2 (high altitude)	coordinated and separate flights	6-7 weeks	NASA	B. Toon (PI), **E. Jensen**
SEACIONS	**Go**	Vertical structure and variability of ozone, water vapor		Kuala Lumpur, Malaysia; Ha Noi and Bac Lieu, Viet Nam; SEAC4RS site	Ozone, water vapor	Balloon	launches daily or every other day; concident with SEAC4RS	6-7 weeks	Penn State Univ.	**A. Thompson (PI) and H. Selkirk**
SWOP	**Go**	TTL structure and microphysics	**Tibetan plateau**	Lhasa [29.7°N, 91°E]	Ozone [ECC], water vapor [CFH], aerosols [COBALD]	Balloon	balloon sonde profiles		Inst. Atmos. Physics (IAP), China	**J.-C. Bian (PI)**, H. Vömel
Palau 2013	**Go**	TTL microphysics	**Pacific warm pool**	Koror, Palau [7.4°N, 134°E]; Guam, Yap [9.5°N,138°E]	Water vapor, cloud particle imaging	Balloon	CFH & HYVIS @ Koror; 4X daily radiosondes @ Guam, Yap & Koror		JAMSTEC; NOAA	J. Suzuki (JAMSTEC) **B. Ward (NOAA)**
DJF 2013/4										
ATTREX (2)	**Go**	TTL structure and microphysics	**Pacific warm pool**	Guam [13.5°N, 145°E]	Water vapor, ozone, temperature, ice microphysics	Global Hawk (high-alt UAV)	long-duration (>24-hours) flights; up to 6	Six weeks	NASA ARC	**E. Jensen (PI) & L. Pfister**
CAST-Airborne	**Go**	TTL composition and transport; VSL species in tropical troposphere; role of cirrus in tropics		Guam/Chuuk	Ozone, WV, CO, Halocarbons,NMHCs, OVOCs, DMS, CO2, CH4, N2O, BrO, Black carbon	BAe146	sample PBL to 4-6 km	Jan 2014	Univ. of Cambridge; Univ. of Manchester; NCAS (UK)	**N. Harris and G. Vaughan (PIs)**
CAST-SONDE	**Go**			Chuuk [7.5°N, 153°E]	Ozone	Balloon; lidar	up to 60 ozonesondes	Jan 2014		
CONTRAST	**In final review**	Role of deep convection in TTL chemistry -> chemistry-climate interactions		Guam	Ozone, water vapor, CO, CH4,CO2,H2CO,NOx, Br species, NMHC, VOCs, aerosols, clouds, MTP, UV/VIS	NCAR GV (to 45 kft)	convective outflow, jet crossing flights	Jan-Feb 2014	NCAR; U. Miami; U. Maryland	E. Altas, R. Salawitch, and **L. Pan** (Co-Pis)
SOWER 2014	**Proposed**	TTL water vapor and ozone		Tarawa [1.4°N, 173°E]; Biak; Kototabang [0.2°S, 100°E]	Water vapor/ozone [CFH/ECC]; *ice particles [OPC]; water vapor [FLASH-B] (tentative)*	Balloon; ground-based lidar	approx. 5 launches	One week	Hokkaido University; Kyoto University	**F. Hasebe (PI) and M. Fujiwara; M. Shiotani**
BATTREX (A)	**Proposed**	TTL structure and dynamics		TWP Manus [2°S,147°E]	Water vapor, ozone, aerosols; temp and winds	Balloon	CFH/EEC/COBALD Radiosondes 4,8X daily	Six weeks	Valparaiso Univ.; Penn State Univ.; NWRA; ARM	**G. Morris (PI); A. Thompson, J. Alexander (Co-Is)** and Chuck Long (Co-Is)
JJA 2014										
ATTREX (3)	**Go**	TTL structure and microphysics	**Pacific warm pool**	Townsville [19.3°S, 147°E]	Water vapor, ozone, temperature, ice microphysics	Global Hawk (high-alt UAV)	up to 6 long-duration (>24-hours) flights	Six weeks	NASA ARC	**E. Jensen (PI) and L. Pfister**
BATTREX (B)	**Proposed**	TTL structure and dynamics		TWP Manus [2°S,147°E]	Water vapor, ozone, aerosols; temperature and winds	Balloon	CFH/EEC/COBALD Radiosondes 4,8X daily	Six weeks	Valparaiso Univ.; Penn State Univ.; NWRA; ARM	**G. Morris (PI); A. Thompson, J. Alexander (Co-Is)** and Chuck Long (Co-Is)
DJF 2014/5										
SOWER 2015	**Proposed**	TTL water vapor and ozone	**Pacific warm pool**	Tarawa [1.4°N, 173°E]; Biak; Kototabang [0.2°S, 100°E]	Water vapor/ozone [CFH/ECC]; *ice particles [OPC]; water vapor [FLASH-B] (tentative)*	Balloon; ground-based lidar	approx. 5 launches	One week	Hokkaido University; Kyoto University	**F. Hasebe (PI) and M. Fujiwara; M. Shiotani**
StratoClim (airborne) (A)	**Proposed**	Processes that determine the TTL/LS sulfur and aerosol budget	**Pacific warm pool**	Phillipines	SO2/H2SO4 mass spec; COS and HCN; aerosol mass spec	M-55 Geophysica (high-alt)				**M. Rex**
JJA 2015										
StratoClim (airborne) (B)	**Proposed**	Processes that determine the TTL/LS sulfur and aerosol budget	**Asian monsoon**	Thailand	SO2/H2SO4 mass spec; COS and HCN; aerosol mass spec	M-55 Geophysica (high-alt)				**M. Rex**
Multi-year observational programs										
NOAA Water Vapor	**Continuing**	Long-term global trends in UT and/or LS WV, radiative impacts of WV trends, and response of WV to changing climate	**NH, Tropics, SH**	Boulder, CO; Hilo, HI; Lauder, NZ	Water vapor [FPH]; ozone [SHADOZ]	Balloon	monthly	Boulder, 1980+ Lauder, 2004+ Hilo, 2010+	NOAA ESRL/GMD	**D. Hurst (PI); K. Rosenlof**
SHADOZ	**Continuing**	Vertical structure and variability of ozone; tropospheric ozone	**Southern Hemisphere and Tropics**	11 stations active, 8 tropical	Ozone profiles [ECC]	Balloon	weekly and bi-weekly	since 1998	Penn State Univ; NASA, NOAA GMD	**A. Thompson (PI)**
Ticosonde	**Continuing**	Variability of tropical water vapor and ozone and covariance; validation of space-borne water vapor measurments	**Tropical Americas**	San José, Costa Rica [10°N, 84°W]	Water vapor [CFH], ozone [SHADOZ] and SO2 (new)	Balloon	weekly [ECC], semi-monthly [SO2], monthly [CFH]	ECC and CFH since 2005	NASA GSFC, Valparaiso Univ., Univ. de Costa Rica	**H. Selkirk (PI)**, H. Vömel, J. A. Diaz and **G. Morris** (Co-Is)
GRUAN	**Continuing**	Network of reference observations of RH, P, T & wind; ozone	**Global**	16 sites, 3 tropical; goal to expand to 30-40 worldwide	Water vapor [CFH, NOAA FPH, Snow White, FLASH-B]; PTU [RS92]	Balloon	once or twice per month	Long-term	Deutscher Wetterdienst	H. Vömel (lead)
StratoClim (ground)	**Proposed**	Processes that determine the TTL/LS sulfur and aerosol budget	**Pacific warm pool**	Palau	FTIR profiles of O3, CO, C2H2,HCHO,HCN, COS, NO, NO2; O3 sondes; Water vapor [CFH]; backscatter [COBALD]; aerosol lidar [CNR]	FTIR; Balloons; lidar		2-3 years, 2014-2016	Alfred Wegener Institute	**M. Rex (PI)**

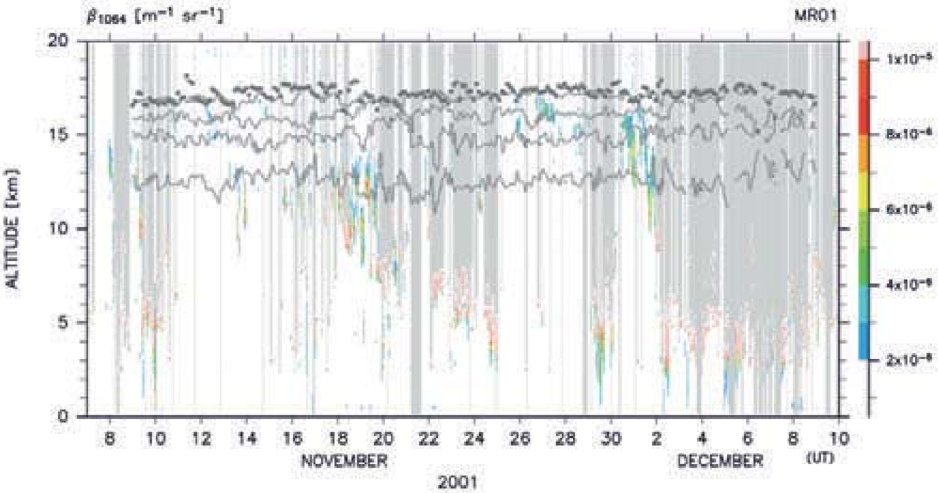

Figure 20: Lidar (Nd:YAG laser with 1064nm and 532nm) 1064nm backscattering coefficient in coloured contours and 3-hourly radiosonde measurements of the cold point tropopause (dots) and potential temperature surfaces (lines) from measurements taken from the R/V Mirai in the tropical West Pacific (2.0°N, 138.5°E). From Fujiwara *et al.*, 2009.

illustrating how waves are important for cloud formation and dehydration in the TTL. Planetary scale equatorial, Kelvin, Rossby, gravity and mixed Rossby-gravity waves, excited by stationary and moving convection, have a large impact on the climatology and intra-seasonal variability in the TTL. The impact of waves on horizontal and vertical transport has not been fully described or assessed. Smaller-scale gravity waves are also important for transport and mixing. These waves also feature strongly in driving the QBO and the Brewer-Dobson circulation. How they may change over time (see below) is a subject of investigation in models (Shepherd and McLandress, 2011; Garcia and Randel, 2008), and there is an urgent need for better observations. Several projects will focus on TTL waves, including BATTREX (gravity wave, turbulence, subtropical mixing, global scale model analysis) and ATTREX (slow, large-scale ascent, waves).

Cirrus clouds in the TTL radiatively impact tropospheric climate and the microphysical processes in these clouds help determine the water vapour content of air entering the stratosphere. These clouds are unique in many ways, and the ice nucleation mechanisms and aerosols that control large- and small-scale ice supersaturation continue to be highly uncertain, despite repeated observations of cirrus cloud microphysics (*e.g.*, Jensen *et al.*, 2009; Krämer *et al.*, 2009). Many questions remain. What factors contribute to the frequency and formation of supersaturated layers? What is the aerosol population of the TTL and how does it affect ice nucleation? How can we better characterise cloud presence and radiative impact? Can we simulate these processes from the cloud to global scale? We are beginning to understand some of our observations of clouds, number concentrations and ice supersaturation (see **Figure 21**), and the planned observations from a variety of platforms may enable us to make progress (see below). Initial results from new aircraft platforms in the TTL (Figure 21) illustrate relationships between cirrus cloud microphysics and environmental supersaturation: at some point ice concentrations are high enough to reduce relative humidity back to ice saturation, but high supersaturations may persist in thin clouds. Cirrus clouds are prevalent in all seasons in the TTL, but are critical for final dehydration in the 'cold' boreal winter. Projects that will address these questions include: ATTREX (cirrus), SOWER (lidar, aerosol, WV), BATTREX, CAST(aircraft), and TICOSONDE (H_2O).

Understanding the transport of chemical constituents into the stratosphere requires a comprehensive

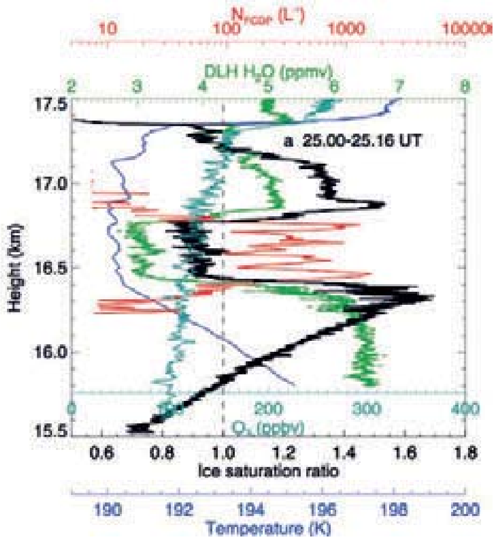

Figure 21: TTL Cirrus observations from ATTREX flight on 5-6 November 2011 near 10°N in the tropical eastern Pacific. Red: Particle number concentrations from the FCDP. Dark Blue: Temperature. Light Blue: Ozone. Black: ice saturation ratio. Green: Specific Humidity from DLH. E. Jensen and L. Pfiste , pers. communication, 2012.

understanding of the **TTL Chemical Budget** of transport, chemical production and chemical loss. We do not fully understand the role of deep convective transport and how it may alter the chemical environment in the TTL. The chemical transformations that occur in the TTL are not well characterised for key constituents, such as sulphur species, halogens or even ozone. **Figure 22** shows an example of very low ozone in the TTL (<20ppb) that occurs climatologically in the wet season due to convective transport of near-surface air into the TTL. In addition to being a tracer of convection, at low ozone concentrations, HO$_x$ chemistry (and thus chemical lifetimes of trace species) is altered. Changing HO$_x$ chemistry will affect the transport of species through the TTL into the stratosphere. Projects that will focus on looking at the chemical budget of the TTL include the multi-aircraft experiment of ATTREX-CAST-CONTRAST, SEAC4Rs and the proposed StratoClim project.

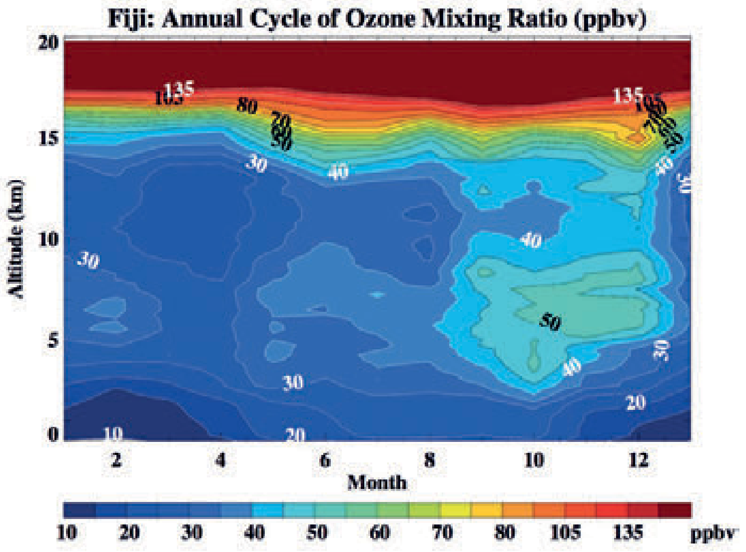

Figure 22: Annual cycle of tropical ozone at Fiji from ozonesonde data showing low ozone in the UT seen climatologically from sondes (adapted from Figure 3 of Thompson *et al.*, 2011).

Large-scale Transport in the TTL, governing the transport of trace species into the stratosphere, is also not fully understood. The transit time for air affects the distribution of short-lived species that enter the stratosphere, and the chemical budget of the TTL (see above). Critical to this is understanding the roles of overshooting convection, large-scale upwelling and horizontal mixing, for determining the lifetime of air in the TTL and how it varies in space and time. Trajectory studies and new data (*e.g.*, Schoeberl *et al.*, 2012; Wang *et al.*, 2012) show the locations of the last dehydration due to large-scale transport, and the advection of air in planetary-scale circulations (**Figure 23**), which vary with different modes of variability in the tropics, such as differences with the El Niño-Southern Oscil-

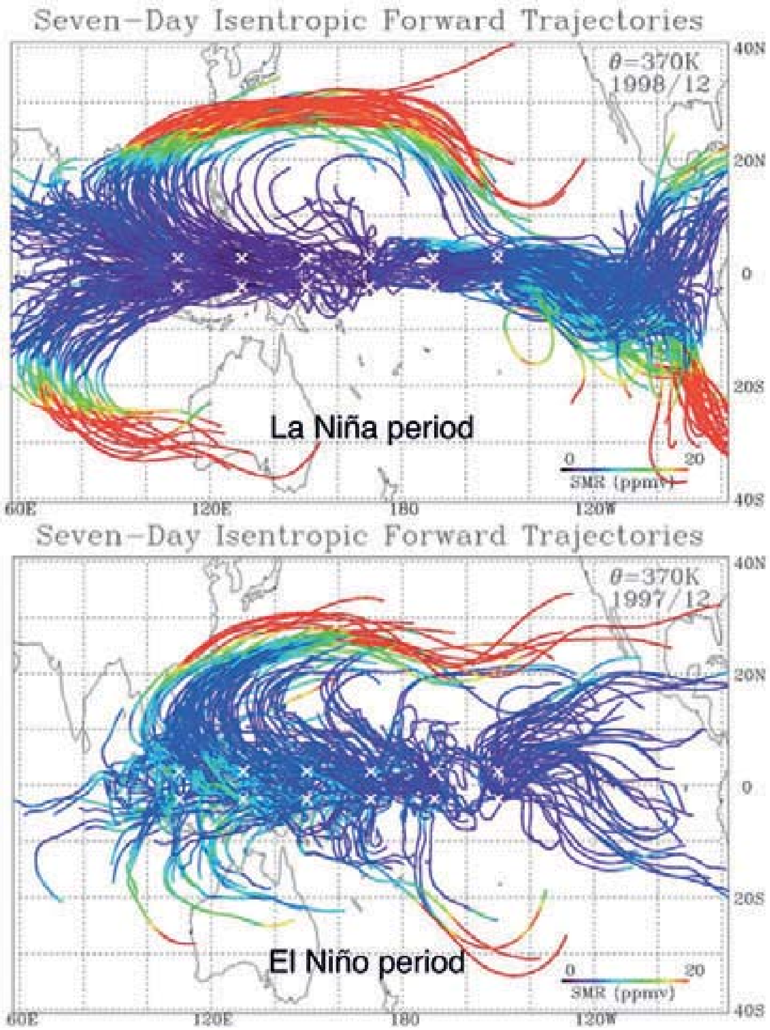

Figure 23: Large scale transport along trajectories in the TTL during a La Niña period (December 1998: **Top**) and an El Niño period (December 1997: **Bottom**). Saturation Mixing Ratio (SMR) shown in colors (in ppmv).

lation (ENSO). The importance of convection that overshoots its level of neutral buoyancy is highly uncertain. Some convection gets to the tropopause level and into the stratosphere (*e.g.*, Danielsen, 1982), such as the example shown in **Figure 24**. But just how much convection overshoots the tropopause is still uncertain. Recent work with active satellite sensors (Pan and Munchak, 2011; Yang *et al.*, 2010; Liu and Zipser, 2005) indicates that overshooting occurs only a small fraction of the time. The impact of this convection on air mass fluxes and particularly the hydration or dehydration of the lower stratosphere is not well constrained. Large-scale transport and convection are a focus of several projects, including SEAC4Rs, ATTREX-CAST-CONTRAST, SOWER and StratoClim.

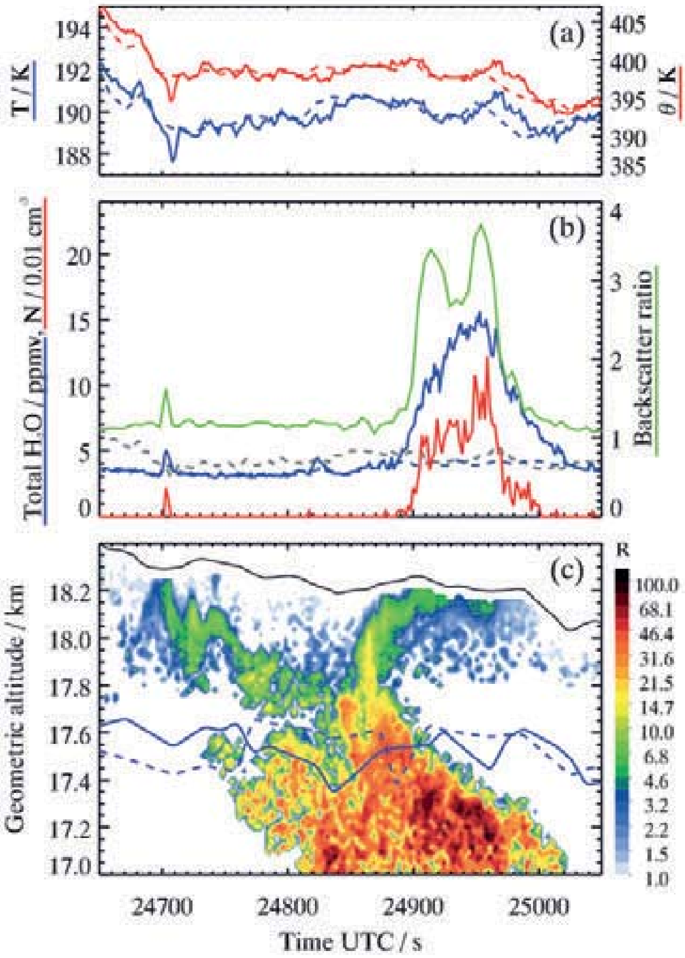

Figure 24: Overshooting convection near Darwin Australia from the SCOUT campaign. **Top**: Temperature. **Middle**: Backscatter Ratio (green), Total water (blue) and particle number concentration (red). **Bottom**: lidar backscatter (contours), tropopause altitude (blue) and aircraft altitude (black). From Corti *et al.*, 2008, Figure 3.

Finally, Long-term Changes in the TTL are not well understood, and critical uncertainties remain. Due to changes in the radiative balance with increasing greenhouse gases in the UTLS region (tropical TTL warming and cooling of the extra-tropical lower stratosphere), thermal wind balance is expected to result in an increase in the sub-tropical jet speed and poleward movement of the jet (*e.g.*, Polvani and Kushner, 2002), but how this impacts the details of the TTL radiative balance is not well understood. The large-scale thermal structure of the TTL and the cold point tropopause temperature is highly correlated with interannual variability of water vapour (Fueglistaler and Haynes, 2005). This is nicely illustrated in **Figure 25**, showing that large-scale cold point temperature variability along trajectories (the 'Lagrangian Cold Point') dominates interannual variability of stratospheric water vapour (though cirrus processes and transport set the exact level). However, the long-term (decadal) variability of tropical tropopause temperature is not well characterised or simulated. How changes in the TTL (specifically TTL water vapour and cirrus clouds) impact tropospheric climate (*e.g.*, through cloud radiative effects) and stratospheric chemistry (through changes in ozone chemistry and H_2O entry into the stratosphere) is uncertain. These topics cannot be directly addressed through campaigns, but ongoing projects such as GRUAN, SHADOZ, NOAA long term monitoring and global reanalyses will help reveal the nature of long-term climate variations in the TTL.

Campaign Description

Planned campaigns in the TTL are listed in **Table 1**. Most of these campaigns are scheduled in the Asia/Pacific region over the next several years, or are ongoing projects. During the workshop there was much discussion regarding these projects and campaigns. Details are provided in the table, but we chronologically summarise some of the key features of the campaigns here, and also highlight some of the coordinated activities that were discussed at the workshop. This information is also being distributed via interactive Google Maps layers that are

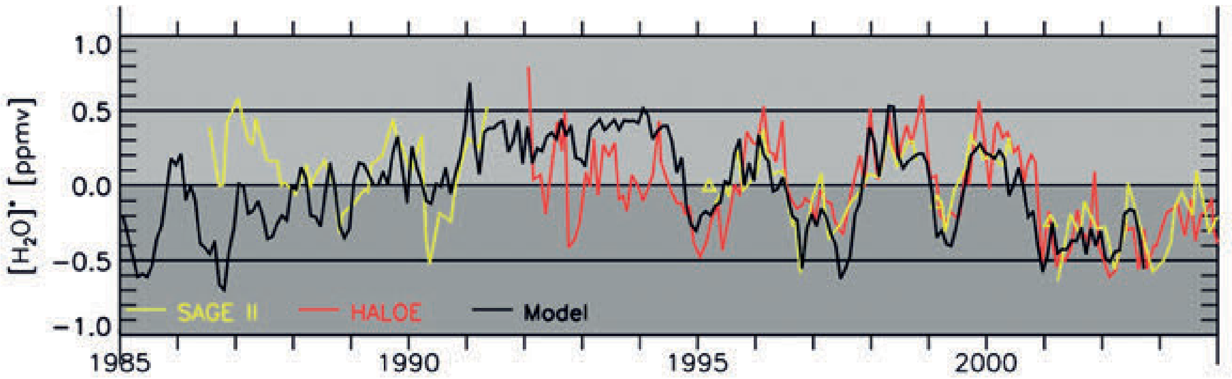

Figure 25: From Fueglistaler and Haynes 2005, Figure 2a: Interannual variability in tropical lower stratospheric water vapour and temperatures. Lower stratospheric (at 400K potential temperature) tropical (30°S to 30°N) monthly mean water vapour mixing ratio ([H_2O]T400) anomalies. Yellow, SAGE II; red, HALOE; black, model predictions.

available to the community, and available for sharing information, as detailed below.

Starting in January 2013, there will be several projects in the TTL, along with ongoing projects that currently operate continuously. The Soundings of Ozone and Water Vapor in the Equatorial Region (SOWER) campaign will launch radiosondes from Biak, Indonesia, and Hanoi, Vietnam. In addition, the Southern Hemisphere Additional OZonesonde (SHADOZ) project will continue their launches from several sites, as will the Ticosonde project in Costa Rica. The GCOS Upper Air Reference Network (GRUAN) will continue its launches of ozone and water vapour soundings, but mostly not in the TTL, and there will be monthly NOAA Frost Point (FP) soundings from Hilo, Hawaii, at the edge of the tropics (19°N). There will be additional Radiosondes launched from Palau (7°N, 134°E), and the Airborne Tropical Tropopause Experiment (ATTREX) will be flying a NASA Global Hawk over the central and eastern Pacifi from southern California.

In boreal summer of 2013, several other activities are planned. In addition to ongoing NOAA FP, GRUAN, SHADOZ and Ticosonde launches, there will be a coordinated aircraft campaign, the Southeast Asia Composition Cloud and Climate Coupling – Regional Study (SEAC4RS) with two aircraft (NASA DC8 and ER2). The plans for SEAC4RS are currently being finalised and NASA is currently considering Singapore as its base of operations. SEAC4RS also has a sounding compliment at several sites in south east Asia: SEAC4RS Intensive Ozonesonde Network Study (SEACIONS). The Sounding of Water Vapour Ozone and Particles (SWOP) campaign of soundings will also occur at this time in Lhasa, China.

From December 2013 - February 2014, several more campaigns are planned in the Asia-Pacific region. These campaigns are documented in **Figure 26**, showing an example of the Google Maps layers. Soundings from the ongoing projects (SHADOZ, GRUAN, NOAA-FP, Ticosonde) are indicated in blue and red. SOWER launches are also indicated in blue. There will be campaigns with aircraft at Guam (13°N, 144°E) and Chuuk (7°N, 152°E). Guam is expected to host the ATTREX Global Hawk, the UK National Environmental Research Council (NERC) BAe-146 in the Coordinated Airborne Studies in the Tropics (CAST) project, and the US National Science Foundation (NSF) Gulfstream 5 for the Convective Transport of Active Species in the Tropics (CONTRAST) project. CONTRAST is still subject to final approval. Chuuk will also feature soundings as part of CAST. A sounding complement to ATTREX, the Balloon Tropical Tropopause Experiment (BATTREX) is planned for Manus, Papua New Guinea (2°S, 147°E), shown in green on Figure 26.

Finally, there are campaigns planned for the boreal summer of 2014 and beyond. ATTREX is expected to fly from north Australia, and BATTREX is also planning on operating from Manus Island. Beyond this, the StratoClim project (recently proposed) would continue observational soundings and ground-based observations in the Pacific in 2014 or 2015, with an aircraft campaign in 2015.

Google Maps layers for Figure 26, and the other seasons, are available on the workshop web page (**http://physics.valpo.edu/ttlworkshop/maps.html**). These layers represent an interesting opportunity to work together, and share information on an open source platform. These maps are useful for information sharing, and presentations. They can be displayed in Google Maps or Google Earth, and exported into

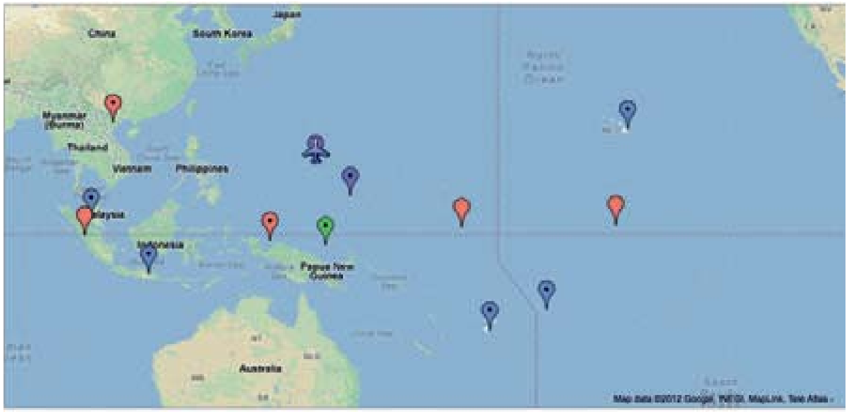

Figure 26: Global TTL campaigns in DJF 2013-2014 from a shared Google maps layer. Blue indicates 'operational' sounding stations from SOWER and SHADOZ (**http://croc.gsfc.nasa.gov**; Thompson *et al.*, 2011). Aircraft location indicates CONTRAST, ATTREX and CAST in Guam. Purple are CAST soundings, Green is BATTREX location (Manus Island). The inactive sites have balloons without dots in them. The active sites show balloons with dots. See workshop web page for a link to the interactive map.

the Google Earth standard Keyhole Markup Language (KML). In addition, there is the ability to link with other pieces of information. Geo-tagged twitter messages for example, can be made to display on the map, to share information (such as times and locations of sounding launches). Flight tracks of aircraft (in KML format, for example) can also be displayed. Some of the common flight planning software being used for managing aircraft campaigns can work with this information for input and export. Those who are interested in participating, and even contributing, should visit the workshop website for access to the maps, and for instructions on how to post information to the maps.

The maps, for example, can be used to help share information about sounding launches and aircraft flight tracks. This information can be used for Lagrangian studies of air parcels: trying to sample the same air parcel from an aircraft, and later a balloon sounding, linked using trajectory information, often called a 'match' of air parcels (Hasebe *et al.*, 2007). Trajectory model runs from sounding locations and aircraft flight tracks are planned as part of these campaigns to assist with this information.

Finally, the wealth of campaign information can also hopefully be supplemented by high-resolution sounding information from existing sites. Much of the information from Radiosondes is not archived or transmitted, and there was a commitment on the part of the participants to try to work to improve the reliability of operational sounding networks, and collect high-resolution information from regular soundings. This exchange may take a number of forms, but making the exchange sustainable will be a challenge.

There is thus wonderful potential to make all these campaigns work together to add to their individual reach, and to enable further progress to be made. The bilateral TTL workshop was a start, by beginning coordinated planning, and improving communication. The ultimate goal is to obtain better data to make progress on understanding the key questions noted above.

Expected Progress

The campaigns described represent an exceptional opportunity for *in situ* observations of the TTL. Several aircraft campaigns in different seasons (SEAC4RS, ATTREX, CAST, CONTRAST, StratoClim) will provide a wealth of data, combined with numerous balloon campaigns (CAST, SOWER, BATTREX, SWOP). Ongoing projects (GRUAN, SHADOZ, SOWER, NOAA, Ticosonde) with new instrumentation will add to this campaign data. The next three years will be a prime time for making progress in many areas.

The hope for progress stems from new instrumentation and new platforms. In particular, there is a focus on observing cirrus cloud microphysics, ice supersaturation, and ice nucleation. New instrumentation is available that provides better constraints on ice crystal number, and more confidence has been built up in water vapour observations at cold temperatures and high supersaturations (see Figure 21). In addition, simultaneous measurements of humidity (with frost point instruments), temperature, ozone and ice particles (with small optical measurements) from balloons are providing a wealth of new data. All this will enable us to make progress on these questions.

Furthermore, the unprecedented suite of aircraft, many flying in formation (as in CAST, ATTREX, CONTRAST, and SEAC4Rs) will be important for understanding convective transport and TTL composition. This will occur both in the boreal summer near the Asian monsoon (SEAC4Rs), as well as in boreal winter in the Western Pacific (CAST-ATTREX-CONTRAST). These campaigns will probe many tracers, both at convective inflow in the lower atmosphere, and outflow in the TTL. The scope of these campaigns will be extended by a network of sounding stations (SOWER, BATTREX, SWOP), and several ground sites with significan instrumentation. The TTL workshop made great progress in discussions among these groups about how to use innovative coordination strategies to expand the reach of different projects and to share data. These projects are backed up by several ongoing and mature reanalysis efforts, geosynchronous and polar-orbiting satellite information on TTL humidity and clouds, as well as active lidar and radar sensors from space that may still be available.

Several of the science questions are more difficult to address on a campaign basis. While individual convective events can be sampled, understanding the roles of convective transport, TTL circulation and stratospheric wave-driven mean circulation is difficult. Understanding the climatological TTL radiative balance is also difficult on a campaign basis. These campaigns can be linked together and to existing data records with satellites, global models and reanalysis systems. In turn, these campaigns, and particularly the high density of campaigns and observations, are important for validation of satellite measurements and understanding TTL processes represented in models. Understanding potential long-term (interannual) changes in the TTL cannot be accomplished in a single campaign. Several campaigns over a few years will help, but critically the campaigns need to be linked with continual long-term measurements in the TTL, and with satellites, global models and reanalysis systems.

Critical Needs

The workshop participants recognised some critical needs beyond the observations to be carried ou over the next few years. With respect to the campaign observations themselves, it is critical to have additional balloon measurements in the Western Pacific and Asian region to provide high vertical and spatial resolution views of the larger picture around the campaigns, and to help evaluate satellites and reanalysis systems in the region. Innovative strategies for observing similar air masses through ‘Match’ observations (Hasebe *et al.*, 2007) will allow these campaigns to be linked in space.

In the long term, in order to make continued progress, two key steps are necessary. The first is critical support of ground-based monitoring programs based in the tropics that observe the TTL with balloons and ground-based remote sensing. These include the Network for the Detection of Atmospheric Composition Change (NDACC), SHADOZ, GRUAN, and individual country efforts such as work conducted by the US Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility program. Regular radiosonde stations could also save higher resolution data to archives at little or no cost. Sustaining regular measurements is low cost and critical for climate records.

The second step is continuation of high quality satellite observations. The last five years or so have been a very good time for satellite observations of the TTL. The combination of active satellite sensors for precipitation (TRMM), thick clouds (CloudSat) and thin cirrus (CALIPSO) from active sensors, combined with water vapour, ozone and other tracers from multiple platforms (MLS, HIRDLS, ACE, SMILES and the European satellites) has enabled progress on several fronts. This continues a long tradition of observations in the TTL, particularly of water vapour and ozone. The history of many of the satellite sensors in the TTL is illustrated in **Figure 27**. While the majority of the space-borne measurements shown in Figure 27 that were current in early 2012 are continuing as of this writing (November 2012), although the loss of ENVISAT in spring 2012 was a big loss. Many of the satellite systems that are currently operational have already or will soon have exceeded their expected operational lifetimes, and the science community should expect to lose one or more of the A-Train[1] satellites in the next five years or so

The end-of-life of the current generation of sensors may endanger future progress on TTL science and will create gaps in climate records if satellite measurements of TTL ozone and water vapour, in particular, are not maintained. With regard to ozone, the outlook for data continuity is good, with the successful launch of the NPOESS Preparatory Project (NPP) satellite in October 2011 (now rechristened Suomi NPP in honour of Vern Suomi). On board NPP is the Ozone Mapper Profiler Suite, OMPS. OMPS will be supplemented by the launch of the Dutch TROPOMI instrument in 2014. Middle-to-upper tropospheric water vapour coverage is also in relatively good shape, with the AIRS instrument on Aqua and the IASI instrument on the MetOp satellites providing unprecedented coverage for operational data assimilation, along with the recent addition of the CrIS-ATMS system

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[1] Among those shown in Figure 27, the NASA EOS Aqua and Aura satellites, CloudSat, and Calipso are all part of the “A-train”.

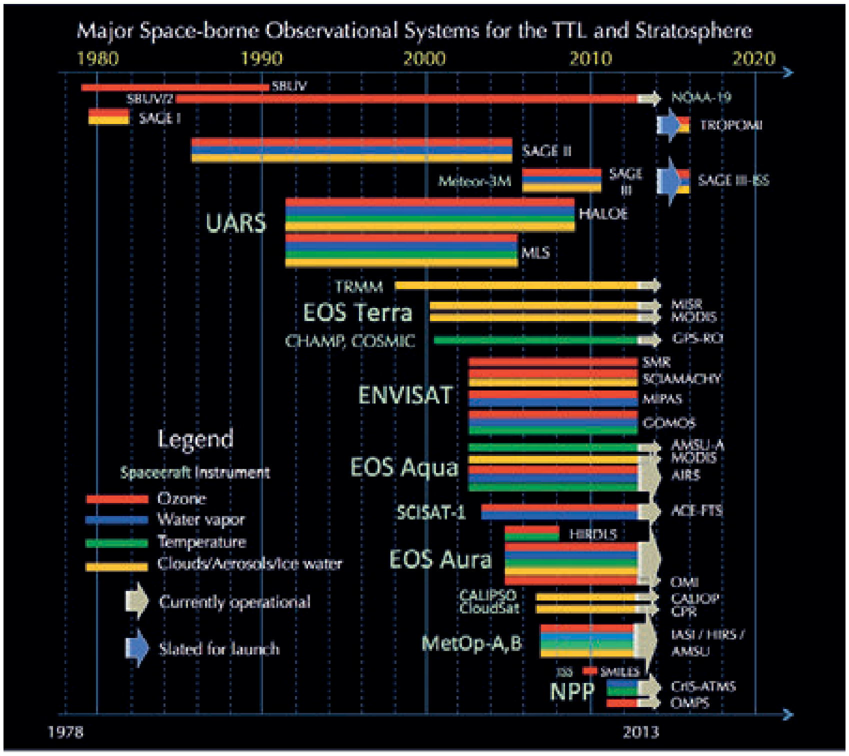

Figure 27: Timeline of TTL Satellite Measurements. Original by Sakazaki, for the TTL Workshop.

on board Suomi NPP. However, for stratospheric water vapour, the long run of the combined HALOE/MLS record is threatened, and we can only hope that SAGE III-ISS, also set for launch in 2014, will operate long enough to provide overlap between both MLS and whatever may succeed it.

This highlights the critical importance of the few proposed satellite missions that will take measurements in the TTL. Among these is the ESA Process Exploration through Measurements of Infra-red and Millimeter-wave Emitted Radiation, PREMIER, mission. PREMIER is currently undergoing a feasibility study and will launch no earlier than 2016. Such missions are a critical part of scientific progress and maintaining long-term climate records.

Of equal importance is the continuing allocation of the rather modest resources for maintaining ground-based records, in particular soundings of water vapour. In addition to NOAA's Boulder soundings, which now encompass a more than 30-year record of mid-latitude water vapour, tropical water vapour has been measured regularly in Costa Rica since 2005 by the Ticosonde program. More recently, NOAA has established a program at Hilo, a key site located at the margins of the tropics.

Summary and further activities

The TTL workshop finished with extensive discussion of coordination among field projects. The group intends to launch a collaborative page to share information on projects in the TTL during the next few years, and link to the tutorial materials presented during the workshop. As part of the workshop coordination activities, we are developing Google Maps layers for observations in the next few years. An example is shown in Figure 26, with locations for some of the projects already on the map. These maps will be continually updated and publicly accessible. URLs are available at the workshop web pages. It is hoped that some of these open source collaboration tools can be used in real time to better share information among participants.

The workshop ended on a positive note. The next few years represent a 'Golden Age' for TTL observations with a rise of observation campaigns in the critical regions of south and east Asia and the western Pacific. The community attending the workshop represented a confluence of international projects that are attempting to better understand this critical region. The funded projects form the current core of efforts in the TTL, and will be carried out in both boreal summer and winter. Other projects currently being planned will provide critical synergies.

Perhaps the Hindu term 'Satya Yuga' (Golden age, or age of Truth) is appropriate to describe the wealth of knowledge we will gain about the TTL during these 'Several Accentuated Tropical Years for Analysis' (SATYA), a new 'golden age' for TTL observations. Like a Hindu age, it is hoped that the impact may last for a long time, and this would be particularly true if the observations can be used by many researchers and integrated within long-term projects to understand the evolving climate of the TTL. The participants in the workshop are committed to sharing knowledge amongst themselves and the community, and urge support for continued observations. For those interested in the TTL, please see the workshop web pages for tutorial archives, and updated maps and links to upcoming campaigns.

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At the 20**th** SPARC Scientific Steering Group meeting held in Buenos Aires, Argentina, November 2012, the results from the blog on "Should SPARC change its name?" were presented. The overwhelming majority within the SPARC community agreed to keep the acronym "SPARC" but change its meaning to "Stratosphere-troposphere Processes And their Role in Climate". The WCRP Joint Scientific Committee endorsed SPARC's decision. In order to depict the project's new, extended mandate and to demonstrate that SPARC is making a serious effort to achieve this mandate, the decision was made to create a new logo.

We are inviting the SPARC community to join in the discussions on how the new logo should look. More at www.sparc-climate.org.

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