LETTER
ATMOSPHERIC PHYSICS

Earth and Planetary Physics
3: 87–92, 2019
doi: 10.26464/epp2019017

A multi-location joint field observation of the stratosphere and troposphere over the Tibetan Plateau

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Abstract: The unique geographical location and high altitude of the Tibetan Plateau can greatly influence regional weather and climate. In particular, the Asian summer monsoon (ASM) anticyclone circulation system over the Tibetan Plateau is recognized to be a significant transport pathway for water vapor and pollutants to enter the stratosphere. To improve understanding of these physical processes, a multi-location joint atmospheric experiment was performed over the Tibetan Plateau from late July to August in 2018, funded by the five-year (2018–2022) STEAM (stratosphere and troposphere exchange experiment during ASM) project, during which multiple platforms/instruments—including long-duration stratospheric balloons, dropsondes, unmanned aerial vehicles, special sounding systems, and ground-based and satellite-borne instruments—will be deployed. These complementary methods of data acquisition are expected to provide comprehensive atmospheric parameters (aerosol, ozone, water vapor, CO_2, CH_4, CO, temperature, pressure, turbulence, radiation, lightning and wind); the richness of this approach is expected to advance our comprehension of key mechanisms associated with thermal, dynamical, radiative, and chemical transports over the Tibetan Plateau during ASM activity.

Keywords: Tibetan Plateau; Asian summer monsoon; stratosphere and troposphere exchange

Citation: Zhang, J. Q., Liu, Y., Chen, H. B., Cai, Z. N., Bai, Z. X., Ran, L. K., Luo, T., Yang, J., Wang, Y. N., … Lu, D. R. (2019). A multi-location joint field observation of the stratosphere and troposphere over the Tibetan Plateau. *Earth Planet. Phys.*, *3*(2), 87–92. http://doi.org/10.26464/epp2019017

1. Introduction

The Tibetan Plateau, an area of about 2.5 × 10^6 km^2, is the highest plateau in the world, its average elevation exceeding 4 km above sea level. Its atmospheric circulation patterns are influenced by westerlies, the Indian monsoon, and the Asian monsoon (Yao T et al., 2012). Because of its high altitude and unique geographical location, thermodynamic processes over the Tibetan Plateau can strongly influence Asian precipitation and the Asian monsoon, and regional climates of the Northern Hemisphere (Zhou XJ et al., 2009). In view of the Plateau's significant impact on climate and weather, exploration of thermal and dynamical patterns over the Tibetan Plateau has become an active area of research (Wu GX et al., 2007).

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Received 03 NOV 2018; Accepted 04 JAN 2019.
Accepted article online 17 JAN 2019.

In particular, the Asian summer monsoon (ASM) anticyclone circulation system over the Tibetan Plateau has been recognized to be a significant transport pathway for water vapor and pollutants to enter the stratosphere (Zhou XJ et al., 1995; Gettelman et al., 2004; Li QB et al., 2005; Fu R et al., 2006; Park et al., 2007; Randel et al., 2010; Bian JC et al., 2011; Chen B et al., 2012; Bergman et al., 2013). These compositions, suspended in the stratosphere, are thought to affect global climate and environment via microphysical, chemical, and radiative processes (Solomon et al., 2011; Vernier et al., 2015; Yu P et al., 2017). However, observational evidence supporting the above theories are largely based on data retrieved from satellite observations (Bian JC et al., 2012). To improve our understanding of physical processes above the Tibetan Plateau, comprehensive measurements derived from collocated ground-based and *in-situ* instruments are absolutely needed. Therefore, a multi-location joint atmospheric experiment funded by the STEAM (stratosphere and troposphere exchange experiment over the Asian summer monsoon) project was performed over the Tibetan Plateau from late July to August in 2018, which is presented as follows.

2. STEAM Project

STEAM is a five-year (2018–2022) field campaign project sponsored by the Chinese Academy of Science (CAS) to improve understanding of the chemical and dynamical processes in the upper troposphere and lower stratosphere (UTLS) over the Tibetan Plateau. As shown by the abridged general view in Figure 1, multiple ground-based and satellite-borne instruments and special sounding systems, deployed via such platforms as long-duration stratospheric balloons, dropsondes, and unmanned aerial vehicles, will collect data during the execution period of the project. Comprehensive atmospheric parameters in terms of aerosol, ozone, water vapor, CO_2, CH_4, CO, temperature, pressure, turbulence, radiation, lightning, and wind can thus be collected and analyzed to help us gain deeper comprehension of key processes associated with the thermal, dynamical, radiative, and chemical transports in the UTSL over the Tibetan Plateau during the ASM. The variety of data from remote sensing and *in-situ* measurements will be combined with model simulations (climate model, chemical model, and trajectory model) to investigate the mechanisms of stratosphere and troposphere exchange and the effects of that exchange on regional climates. The project's comprehensive dataset can also be applied to validate previous measurements from satellites, such as TanSat, TropOMI, OCO-2 and GOSAT-2.

3. Multi-Location Joint Atmospheric Experiment in 2018

3.1 Site

In July–August 2018, a multi-location joint atmospheric experiment, funded by the STEAM project, was conducted at three sites (as shown in Figure 1): (1) Golmud (GLM; 36.48°N, 94.93°E; 2760 m MSL); (2) Lhasa (LSA; 29.66°N, 91.14°E; 3650 m MSL); and (3) Yangbajain (YBJ; 30.21°N, 90.43°E; 4300 m MSL). GLM is a field site where a stratospheric balloon bore payloads to provide measurements. The LSA site is the WMO station with the number 55591. Special sounding systems focused on the vertical profiles of water vapor, ozone, aerosol, spectrum, and intensity of thermal turbulence was installed at the site. The YBJ site is located in the International Cosmic Ray Observatory, which is about 90 km northwest of the city of LSA. A ground-based lidar system—APSOS (Atmospheric Profiling Synthetic Observation System)—has been deployed at YBJ since October 2017 (Lu DR et al., 2018).

3.2 Key Instruments and Measurements at Three Sites

3.2.1 GLM

The GLM field campaign has been under preparation since August 7 2018. The stratospheric balloon with payloads aboard was launched at 6:10 LST 16 August 2018 when near surface weather conditions favored balloon release. The launch process and flight path of the balloon are shown in Figure 2. The stratospheric balloon generally flew to the northeast during its ascent period, and then floated to the southwest after taking its place in the stratosphere. About 2.5 hours later, the stratospheric balloon was at risk of floating over the Kunlun Mountains, which threatened to make payload recovery difficult. Therefore the balloon was cut down at 8:55 and the payloads were successfully recovered.

The *in-situ* measurements made by instruments borne by the bal-

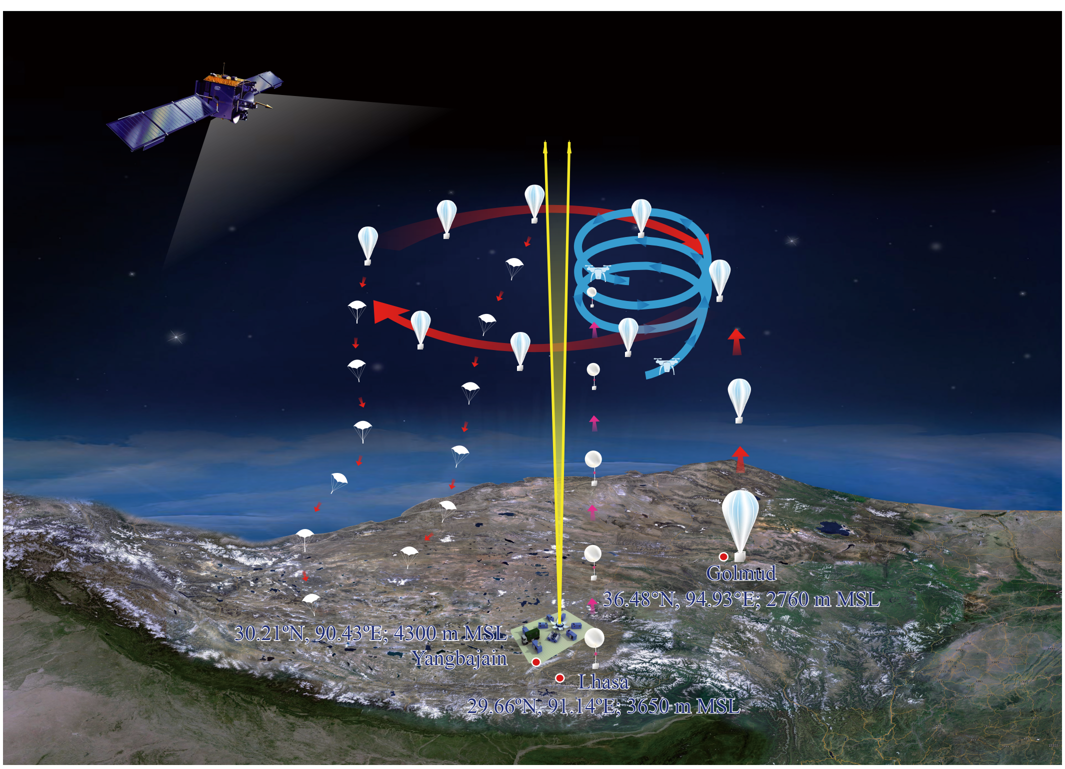

Figure 1. Abridged general view of the platforms/instruments deployed by the STEAM project, including long-duration stratospheric balloon, dropsonde, unmanned aerial vehicle, special sounding system, ground-based and satellite-borne facilities.

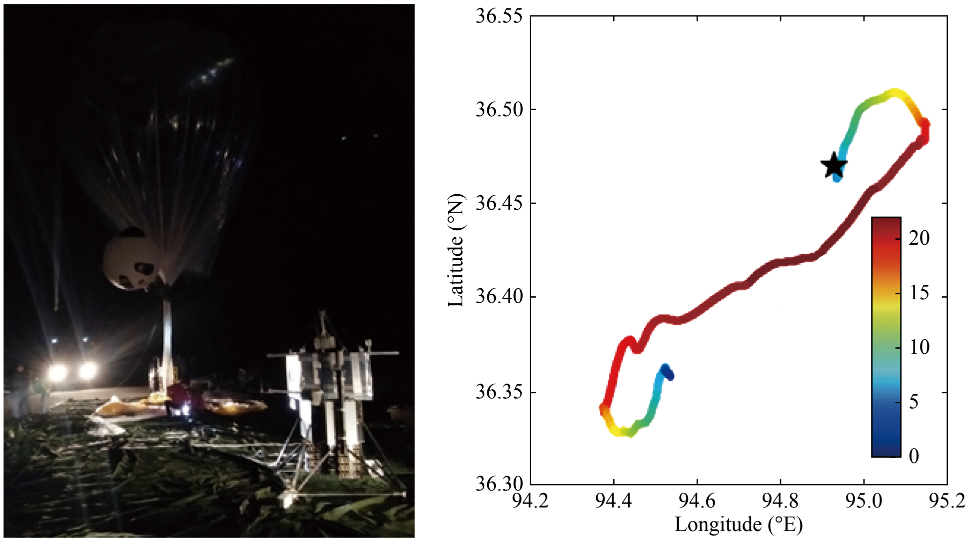

Figure 2. Stratospheric balloon launch (left panel) and its flight path (right panel) in the multi-location joint atmospheric experiment in 2018. The color bar in right panel represents the flight altitude above sea level, units in km; the black asterisk denotes the launch site at GLM.

loon included atmospheric temperature (*T*), relative humidity (*RH*), pressure (*P*), radiation (shortwave, longwave and UV), aerosol (aerosol particle number density and size distribution in the 140- to 3000-nm diameter range), and transient luminous events. Evidence of a robust enhanced aerosol layer near the tropopause was revealed recently by Yu P et al. (2017), based on *in-situ* measurements from the Portable Optical Particle Counter (POPS) at Kunming. We observed a similar feature in the GLM experiment at the edge of ASM anticyclone circulation system. Further studies are needed to explore the sources of this enhanced aerosol layer and its climate and environment impact.

In addition to *in-situ* instruments, eight dropsondes were aboard the platform and released during the flight, to provide a vertical profile of atmospheric *T, RH, P,* wind speed, and direction along the balloon's flight path. The dropsonde system, including the dropsondes, their dropping control device, and its data transmission and receiver modules, was developed ourselves. Figure 3 shows as an example, the vertical profile of temperature and *RH* from the dropsonde released at 07:37:58 LST 16 August 2018 over GLM. It can be seen that the detailed structures of both atmospheric parameters were well captured by our instrument. The ground-based sounding system was also deployed at GLM between August 7 and 16 to provide vertical atmospheric measurements from surface upward to ~30 km. An automatic weather station was employed at the site's surface to collect ground weather conditions (i.e., *T*, *RH*, *P*, wind speed and direction) during the entire campaign period.

3.2.2 LSA

Coincident *in-situ* measurements collected by instruments borne by sounding balloons were conducted in LSA from 25 July to 25 August. The vertical profiles included water vapor—from a Cryogenic Frostpoint Hygrometer (CFH; Vömel et al., 2007), ozone concentration—from an electrochemical concentration cell (ECC) ozonesonde (Komhyr, 1969), cirrus clouds and aerosols—from a

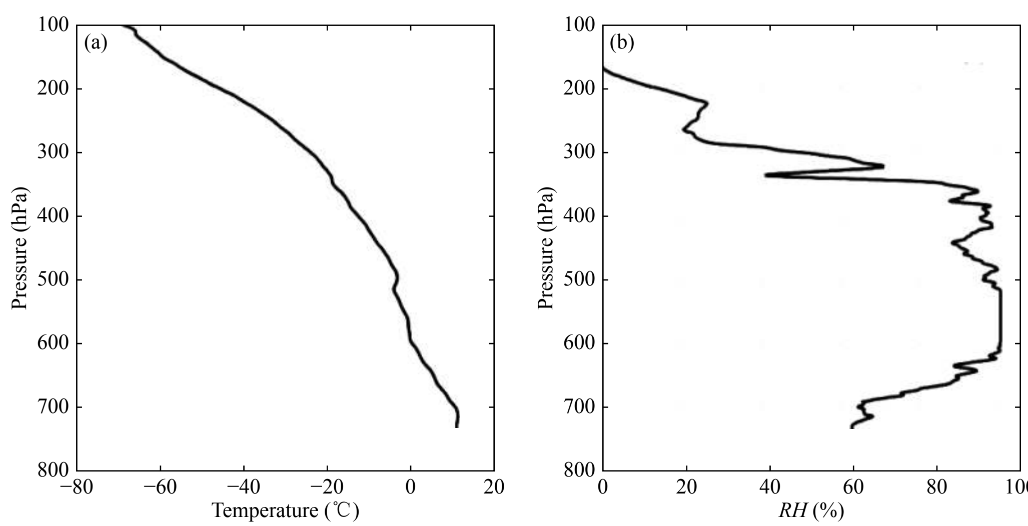

Figure 3. Vertical profile of temperature (a) and *RH* (b) provided by the dropsonde released at 07:37:58 LST 16 August 2018 over GLM.

Compact Optical Backscatter Aerosol Detector (COBALD; Rosen and Kjome, 1991), and meteorological variables—from an Imet radiosonde. A total of 15 vertical profiles were provided by the four coincident sondes, of which one profile was launched with a POPS to detect the aerosol particle number density and size distribution (Gao RS et al., 2016). A ground-based POPS was deployed at the site for more than 20 days to obtain surface aerosol properties.

Figure 4 shows the vertical profile of the water vapor mixing ratio from CFH and the ozone mixing ratio from an ECC launched at 23:58:00 LST 13 August 2018 at LSA. Compared to the general structure of the vertical profile presented in Bian JC et al. (2012), the case presented here tended to detect lower water vapor mixing ratios (<100 ppmv) and relatively higher ozone mixing ratios in the middle troposphere, which might be associated with a mid-latitudes intrusion of a filament of stratosphere (Bian JC et al., 2012; Li D et al., 2018). Further study will perform a detailed analysis of this case.

The followed three facilities were also deployed at LSA: (1) A mobile atmospheric system to measure near-surface *T, RH*, and turbulence intensity (Wu XQ et al., 2015; Qing C et al., 2016a); (2) A Micro-Pulse Lidar to monitor evaluations of the boundary layer structure and boundary layer clouds throughout the day (Zhu WY et al., 2013); and, (3) A micro-thermometer radio-sounding system released by the sounding balloon to measure the vertical structure of the spectrum and intensity of thermal turbulence (Qing C et al., 2016b), resulting in a total of 15 observational profiles during the campaign.

3.2.3 YBJ

The Atmosphere Profiling Synthetic Observation System (APSOS) was deployed in YBJ in October 2017. A brief description of APSOS is presented here for completeness; a more detailed introduction can be found in the literature of Lu DR et al. (2018).

APSOS is the first ground-based facility for profiling atmospheric variables and multiple constituents in the whole (neutral) atmosphere from the surface upward to the lower thermosphere. It enables simultaneous observations and extensive studies of the atmosphere's vertical structure and constituent transport. The system consists primarily of five lidars (devoted to measurements of the vertical structures of atmospheric *T*, wind, water vapor, ozone, CO_2, SO_2, NO_2, aerosol, cloud, and the sodium layer), a W-band dual polarization cloud radar, a superconducting terahertz radiometer, and an integrated telescope.

4. Summary and Future Plans

A multi-location joint stratosphere and troposphere experiment was performed over the Tibetan Plateau in 2018. Three main types of platforms, i.e. stratospheric balloon, special sounding system, and ground-based remote sensing facility, were deployed at, respectively, GLM, LSA and YBJ during the 2018 campaign. The campaign resulted in a comprehensive observational dataset, as summarized in Table 1.

More data will be accumulated continuously during the five-year execution period of the project (2018–2022). The current letter introduces the field project and its five-year schedule of measurements. The observational data collected in 2018 are now in the process of quality control and analysis. Relevant specific results are expected in future research articles.

Because of airspace restrictions during the first STEAM experiment of 2018, the stratospheric balloon was launched at the edge of the ASM anticyclone circulation system over the Tibetan Plateau and flew only for ~4 hours. The STEAM plan calls for a similar experiment mode 1–2 times every year from 2019 to 2022. More instruments/platforms, such as AirCore systems (Karion et al., 2010), ground-based spectrometers, and unmanned aerial vehicles, will be deployed on schedule. Meanwhile, by applying for larger airspace, we expect to be able to release the stratospheric balloon in the core region of the ASM anticyclone circulation system and fly it throughout one day or even several days over the Tibetan Plateau. Studies based on these comprehensive

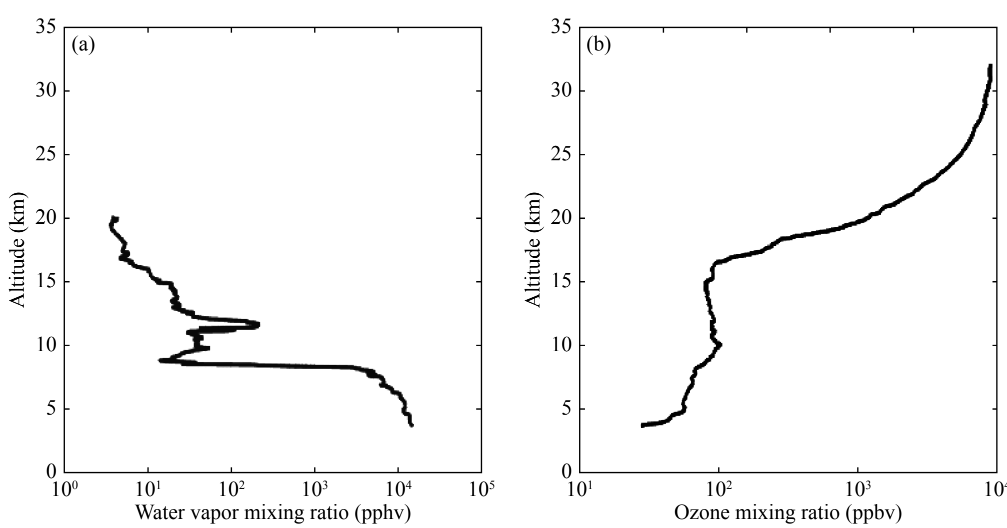

Figure 4. Vertical profile of water vapor mixing ratio (a) and ozone mixing ratio (b) from the sondes launched at 23:58:00 LST 13 August 2018 at LSA.

Table 1. Summary of multi-location joint STEAM experiment in 2018

Sites	Platforms/instruments	Measurements
GLM	Stratospheric balloon borne *in-situ* payload	Vertical (Horizontal) profile of atmospheric *T, RH, P*, radiation, aerosol, and transient luminous events during lifting (floating) period
	Stratospheric balloon borne dropsonde	Vertical profile of atmospheric *T, RH, P*, and wind along the dropping path of the dropsonde
	Ground-based sounding system	Vertical profile of atmospheric *T, RH, P*, and wind from surface upward to ~30 km
	Surface automatic weather station	Ground *T, RH, P*, and wind
LSA	Special sounding systems	Vertical profile of water vapor, ozone, cirrus cloud, aerosol, spectrum and intensity of thermal turbulence
	Surface facility	Aerosol, *T, RH*, turbulence intensity, boundary layer structure and boundary layer cloud
YBJ	Ground-based remote sensing system	Vertical structure of atmospheric *T*, wind, water vapor, ozone, CO_2, SO_2, NO_2, aerosol, cloud, and the sodium layer

observational data are likely to greatly improve understanding of key processes associated with thermal, dynamical, radiative, and chemical transports in the UTSL over the Tibetan Plateau during the ASM. These measurements can also be combined with model simulations to investigate the mechanisms of stratosphere and troposphere exchange over the Tibetan Plateau, knowledge that may help reduce uncertainties in our understanding of regional climates and improve weather predictions.

Acknowledgments

The authors would like to acknowledge all STEAM members for their contributions to the 2018 multi-location joint atmospheric experiment. Special thanks are extended to the Academy of Opto-Electronics, Chinese Academy of Sciences, for providing and releasing the stratospheric balloon at the Golmud site. This work is supported by the Strategic Priority Research Program of the Chinese Academy of Sciences (Grant Nos. XDA17010101, XDA17010102, XDA17010103, XDA17010104 and XDA17010105).

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