ADVANCES IN ATMOSPHERIC SCIENCES, VOL. 40, FEBRUARY 2023, 187–193

• News & Views •

Earth Summit Mission 2022: Scientific Expedition and Research on Mt. Qomolangma Helps Reveal the Synergy between Westerly Winds and Monsoon and the Resulting Climatic and Environmental Effects

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(Received 16 June 2022; revised 6 August 2022; accepted 8 August 2022)

ABSTRACT

"Earth summit mission 2022" is one of the landmark scientific research activities of the Second Tibetan Plateau Scientific Expedition and Research (STEP). This scientific expedition firstly used advanced technology and methods to detect vertical meteorological elements and produce forecasts for mountain climbing. The "Earth summit mission 2022" Qomolangma scientific expedition exceeded an altitude of over 8000 meters for the first time and carried out a comprehensive scientific investigation mission on the summit of Mt. Qomolangma. Among the participants, the westerly–monsoon synergy and influence team stationed in the Mt. Qomolangma region had two tasks: 1) detecting the vertical structure of the atmosphere for parameters such as wind, temperature, humidity, and pressure with advanced instruments for high-altitude detection at the Mt. Qomolangma base camp; and 2) observing extreme weather processes to ensure that members of the mountaineering team could successfully reach the top. Through this scientific expedition, a better understanding of the vertical structure and weather characteristics of the complex area of Mt. Qomolangma is gained.

Citation: Ma, Y. M., and Coauthors, 2023: Earth summit mission 2022: Scientific expedition and research on Mt. Qomolangma helps reveal the synergy between westerly winds and monsoon and the resulting climatic and environmental effects. *Adv. Atmos. Sci.*, **40**(2), 187−193, https://doi.org/10.1007/s00376-022-2166-3.

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1. Introduction

Chinese scientists have overcome many difficulties to continue to carry out many scientific studies in the Mt. Qomolangma area in the past years. However, the research conducted in previous studies has been limited by observational quality and short study periods and, therefore, cannot provide a full understanding of the climatic and environmental change processes over the Mt. Qomolangma area (Ma, 2007; Ma et al., 2021). During "Earth summit mission 2022: Scientific Expedition and Research on Mt. Qomolangma", new advanced technologies, methods, and means were applied to jointly investigate and study the vertical change characteristics and interaction mechanisms of the six spheres in the Mt. Qomolangma area. The expedition focused on major scientific issues such as the synergy between the westerly winds and monsoon, the changes of Asian water tower, ecosystem and biodiversity, and human activities, and the environmental law changes in the extremely high-altitude area of Mt. Qomolangma under the background of climate warming. New scientific researches and breakthroughs regarding changes in greenhouse gas concentrations, the carbon sink function of the ecosystem, and human adaptation to extreme environments have led to innovative ideas for preserving the environment on Mt. Qomolangma in order to responsibly advance civilization in the highlands of the Tibetan Plateau through the Third Pole Environmental protection plan and green development. This "Earth summit mission 2022" scientific research expedition on Mt. Qomolangma exceeded an altitude of 8000 meters for the first time and included a comprehensive scientific investigation mission on the top, which is a challenging feat for human beings due to the very high altitude of the Qomolangma area.

The westerly–monsoon synergy and influence unit of the "Earth summit mission 2022" scientific research expedition on Mt. Qomolangma had two important tasks, which are outlined in the following subsections:

1.1. *Atmospheric vertical structure detection*

Instruments such as a high-altitude radio sounder, wind radar, microwave radiometer, EC (Eddy Covariance) system, and high-altitude automatic weather station (AWS) are used at the base camp of Mt. Qomolangma to obtain the vertical structure information of wind, temperature, humidity, and pressure in the Mt. Qomolangma area. National Observation and Research Station for Qomolongma Special Atmospheric Processes and Environmental Changes, located in Tibet, China (28°21'54"N, 86°56'53"E, asl (above sea level) 4276 m, Qomolangma Station, QOMS) provides regular observations. This research mission used observations from instruments such as an atmospheric boundary layer tower, EC system, AWS, X-band radar, Wind Profiler and RASS (Radio acoustic sounding system), radio sounder, microwave radiometer, etc.

1.2. *Extreme weather process observation and forecasting*

All the scientific research and observation data from the Base Camp of Mt. Qomolangma and the Qomolangma Station are combined with the the data collected by the meteorological support vehicle to help inform forecasts of extreme weather processes. Successful data collection and forecasts ensure that the members of the mountaineering team can climb the summit safely, contributing to the successful completion of the "Earth summit mission 2022" Scientific Research expedition in the Mt. Qomolangma area.

2. Study area and key scientific infrastructures during the "Earth summit mission 2022" Scientific Research expedition on Mt. Qomolangma

The Qomolangma Station is maintained by the Institute of Tibetan Plateau Research, CAS (ITPCAS) and is located in the core area of the Qomolangma Nature Reserve (Fig. 1) with a heterogeneous landscape, including high mountains, the Gobi Desert, and a pebble river beach. Available observational data range from single physical parameters measured by basic meteorological instruments to comprehensive observations measured by complex geoscience systems; and these types of observations are becoming more abundant (Ma, 2007; Ma et al., 2021).

The base camp of Mt. Qomolangma is 5200 meters above sea level. It is another key observation site for this scientific research expedition. The instruments utilized for this expedition include a high altitude radiosonde, wind radar, microwave radiometer, AWS, and EC system. An additional AWS is placed at 7028 meters (Fig. 1).

All the instruments and the parameters they measured at Qomolangma Station and Mt. Qomolangma Base Camp are shown in Table 1.

3. Preliminary observation results and discussion

Based on the observations from the base camp and Qomolangma Station, we found that during the scientific research period (especially during the summit period) the best time to rush to the summit was around 4 May. The atmospheric circulation over the Mt. Qomolangma area was relatively stable, which was suitable for scientific research team members to climb the top. In order to verify the mountaineering weather forecast, we mainly analyzed the observation data before and after 4 May. The specific observation results are as follows:

3.1. *Vertical change of wind field observed by lidar*

We find that northerly wind prevailed from night to morning from 4 to 6 May, and the wind speed was relatively low, which was the result of a mutual offset between southerly glacial wind and northerly valley wind. In the afternoon, when the sun heats the surface, a downdraft is generated on the glacier of Mt. Qomolangma in the south, causing a local circulation and downhill wind; at the same time, the mountain in the north is also heated by the sun, causing a local circulation of valley wind and uphill wind, strengthening the southerly wind. In addition, the vertical momentum exchange between large-scale

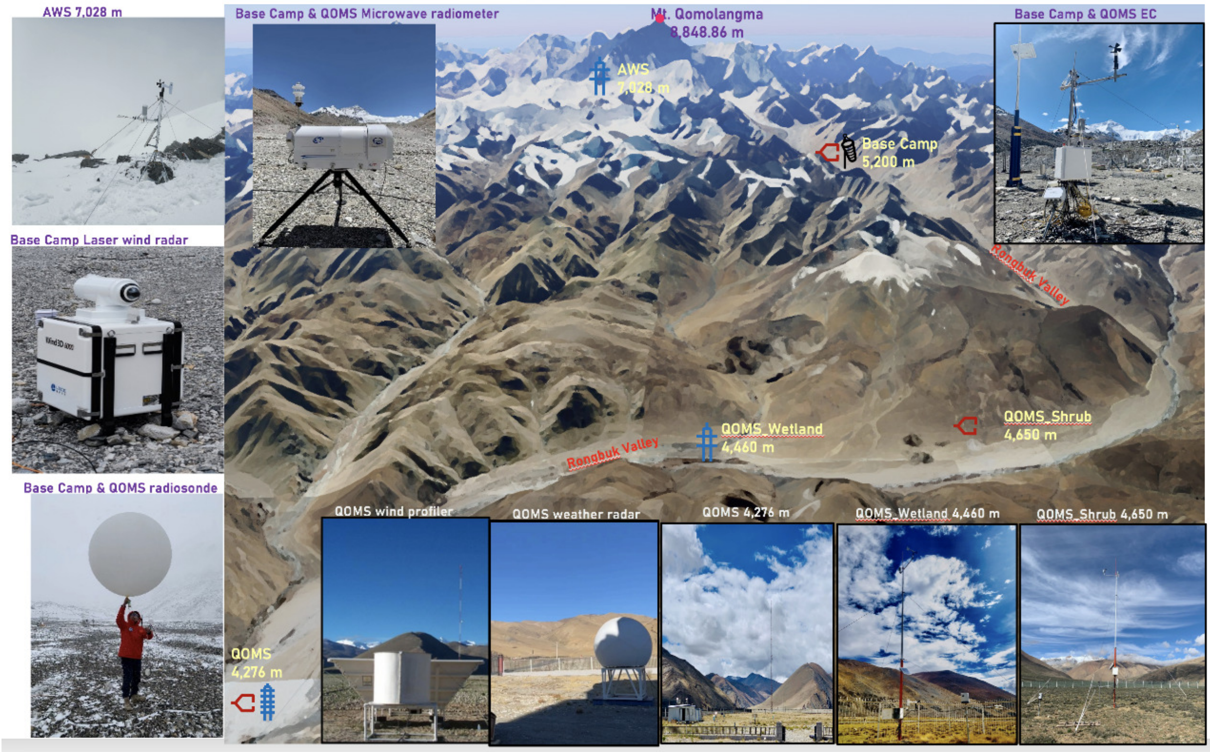
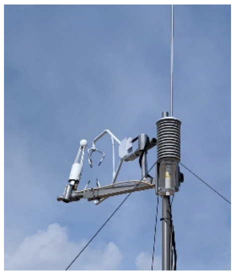
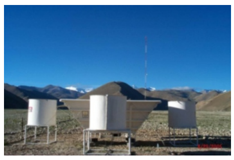
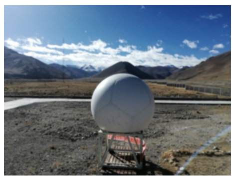


Fig. 1. The instruments utilized at Qomolangma Station and Mt. Qomolangma Base Camp.

Table 1. The instruments and parameters they measured at Qomolangma Station and Mt. Qomolangma Base Camp.

Instrument	Model	Purpose	Photo
Laser wind radar	3D 6000	Continuous observation of wind direction and speed in vertical direction	
Vaisala radiosonde	RS41	Observed vertical atmospheric elements: temperature, pressure, humidity, and wind	

Table 1. (Continued.)

Instrument	Model	Purpose	Photo
Microwave radiometer	MWP967KV	Continuous observation of vertical atmospheric temperature and humidity	
Atmospheric boundary layer tower observation system	MILOS520	Determination of various meteorological elements in the lower atmosphere	
EC system	CSAT3 (3D ultrasonic wind speed) Li-7500 (CO_2/H_2O gas analyzer)	Measure energy flux (sensible heat, latent heat, momentum flux) and material flux (CO_2, H_2O), some aerodynamic parameters	
Wind Profiler and RASS	LAP3000, Vaisala	Profile of air temperature, and wind speed and direction	
X-band radar	PR11-D	Wind speed, rainstorm, hail, precipitation	

westerlies and the boundary layer increases the low-level wind speed. However, on 3 May, there was a northerly wind throughout lower to upper levels all day. It manifests as the westerly trough. The base camp was upstream of the trough, and the weather was satisfactory. On 4 May, at the top of Mt. Qomolangma, the horizontal wind speed was low, with a maximum of 15 m s^{-1} (Fig. 2).

3.2. *Vertical change of air temperature and relative humidity observed by radiosonde system*

As seen in Fig. 3, the height of the convective boundary layer at the Qomolangma Base Camp reached about 3000 meters on 3 May, the stable boundary layer lasted from the night of 3 May to the morning of 4 May, and the convective

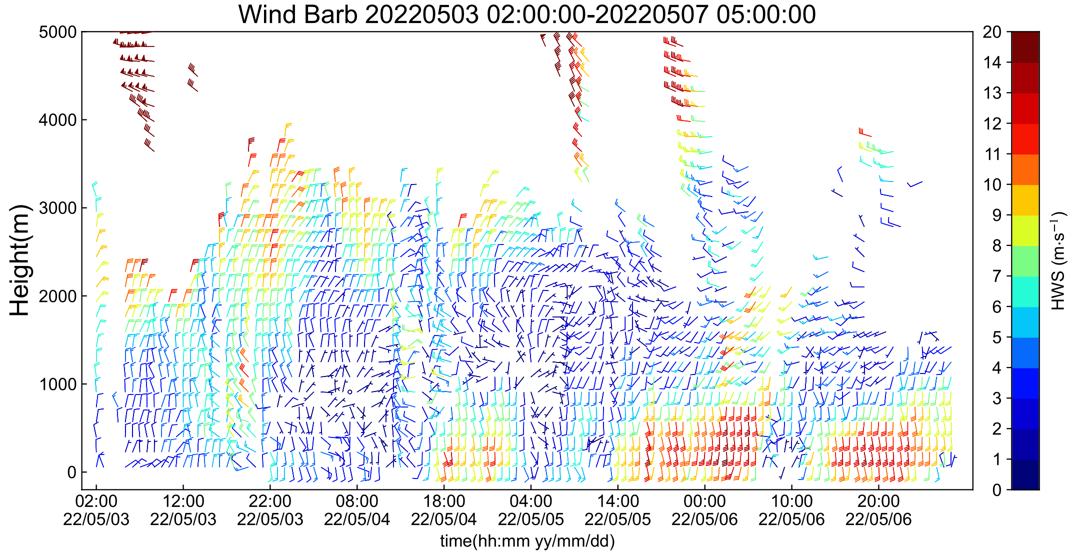


Fig. 2. Vertical variation of wind field observed by lidar.

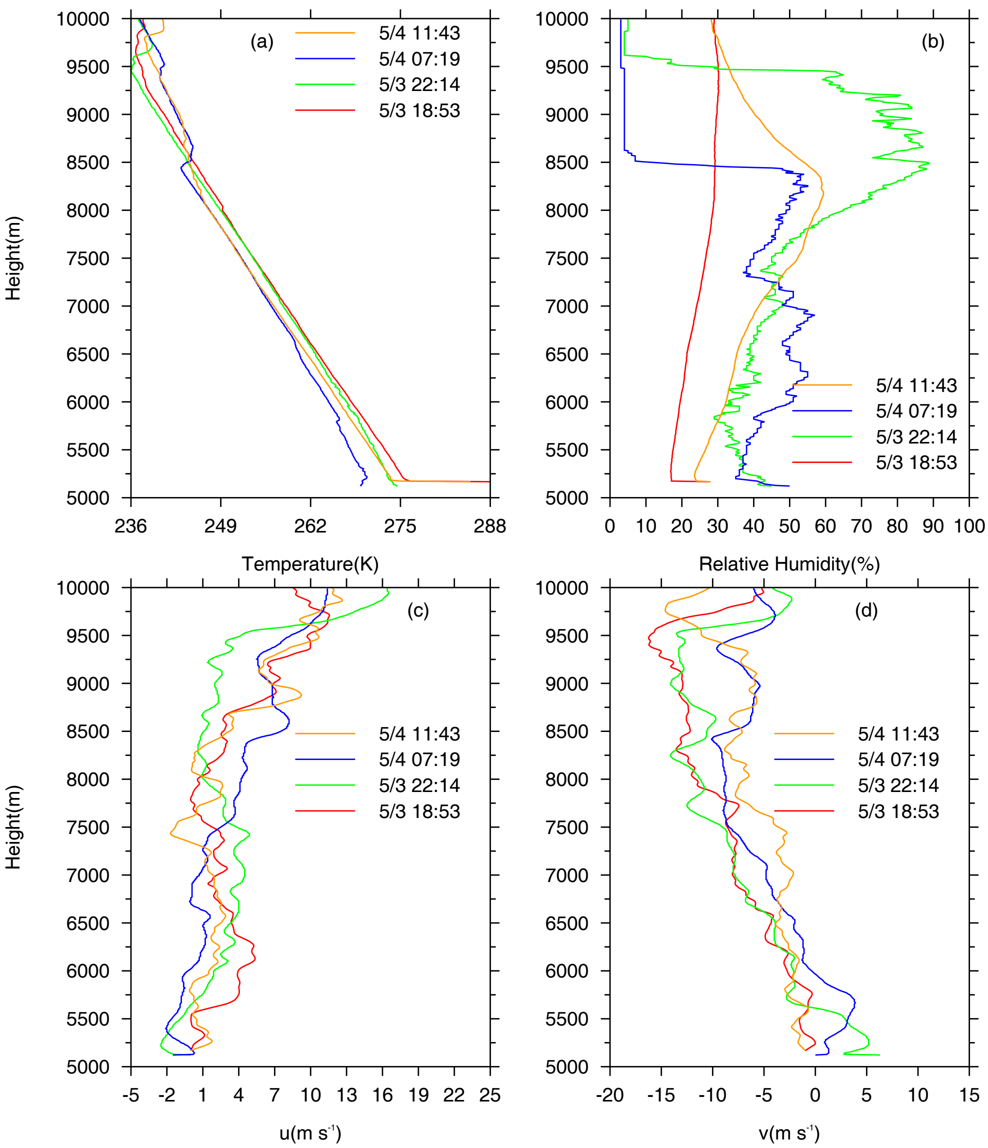


Fig. 3. Vertical change in air temperature and relative humidity from 3 to 4 May.

boundary layer reached 3000 meters again at 0000 local standard time (LST; LST = UTC+ 8 h) on 4 May. During the morning of 4 May, the relative humidity at the top of Mt. Qomolangma was less than 40%, which was conducive to the continuation of sunny weather, and the horizontal wind speed was less than 10 m s^{-1}, which was satisfactory for climbing the summit (Fig. 3).

3.3. *Vertical change of air temperature and relative humidity observed by microwave radiometer*

The temperature shows a single peak diurnal variation at the surface, with the maximum value at 1330 LST and the minimum value at 0800 LST. The diurnal variation of temperature below 2 km was relatively obvious (Fig. 5).

The surface heating process drives the changes in the boundary layer height (Fig. 4, Fig. 5). The boundary layer height begins to increase at 1100 LST, reaches its maximum at about 1300 LST, remains elevated until about 1900 LST, then decreases and remains stable at night.

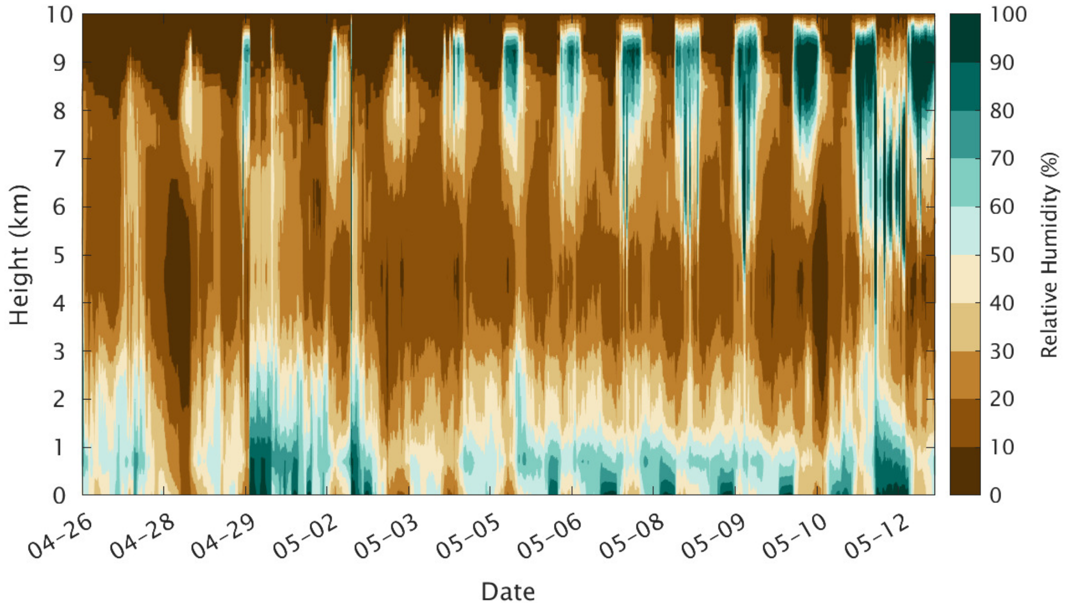


Fig. 4. Relative humidity observed by microwave radiometer.

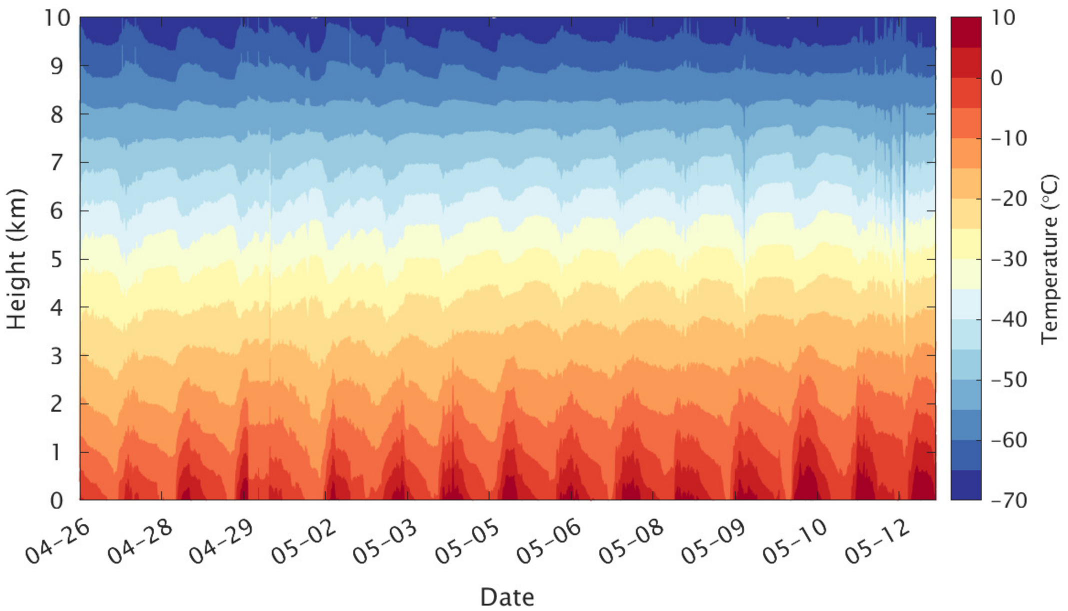


Fig. 5. Air temperature observed by microwave radiometer.

4. Outlook

Through this scientific research, we can better understand the vertical structure and weather characteristics of the complex area of Mt. Qomolangma. In the future, we will focus on vertical atmospheric detection and extreme weather observation and prediction, continue to carry out corresponding scientific research in the Qomolangma area, and further support various findings. Together, this research and future studies will contribute to the landmark scientific research activity of STEP.

In the next stage, a comprehensive three-dimensional observation system of "Earth–atmosphere–cloud–precipitation" will be built by combining the observational system used in this paper with the six AWSs (at 5400 m, 5800 m, 6500 m, 7790 m, 8300 m, and 8830 m – the highest altitude AWS in the world) and the ozone and airborne sounding detection system, etc, that were constructed during the "Earth summit mission 2022: Scientific Expedition and Research on Mt. Qomolangma". It will be a great advancement for understanding the earth–atmosphere interaction processes, atmospheric boundary layer processes, physical characteristics of cloud precipitation, and the propagation of atmospheric pollutants in the Himalayas and the entire Tibetan Plateau. It will also be beneficial for furthering our understanding of the impact of the Tibetan Plateau on weather, climate, and atmospheric environmental processes, and it will help promote our knowledge of earth system science on the Tibetan Plateau.

Acknowledgements. This research was funded by the Second Tibetan Plateau Scientific Expedition and Research Program (STEP) (Grant No. 2019QZKK0103), the Strategic Priority Research Program of Chinese Academy of Sciences (XDA20060101), and the National Natural Science Foundation of China (Grant Nos. 91837208 and 41830650).

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