The impacts of light-absorbing particles in snow (LAPS) on Tibetan Plateau surface temperature, ground hydrology, and East Asian S2S prediction

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Subseasonal to seasonal (S2S) prediction is scientifically challenging but has substantial societal impacts and economic consequences. The LS4P project aims to address the question of the impact of the initialization of large scale land surface/subsurface temperature (LST/SUBT) and snowpack in climate models on the S2S prediction over East Asia, where the high elevation Tibetan Plateau (TP) with large-scale snow cover is located. Initial modeling results suggest a significant relationship between the 2-meter temperature (T2m) bias in May over the TP and the precipitation bias in June over the south of the Yangtze River (Xue et al., 2018, 2019).

One important factor that affects snowpack and surface temperature is the presence of light-absorbing particles (LAPs, e.g., black carbon, brown carbon, and dust) in the atmosphere and in the snow layer. LAPs influence water and energy budgets of the atmosphere and snowpack in multiple ways (e.g., Twomey et al., 1984; Albrecht, 1989; Hansen et al., 1997; Ramanathan et al., 2001; Lau et al., 2006, Lau and Kim, 2006; Qian et al., 2009, 2011; Bond et al., 2013). In addition to their effects on atmospheric heating by absorption of solar radiation and interactions with clouds, LAPs in snow reduces snow albedo and increases absorption of solar radiation by the land surface, i.e., snow darkening effect (SDE), leading to accelerated snow aging processes and faster melting rate of snowpacks (Warren and Wiscombe, 1980; Hansen and Nazarenko, 2004; Ming et al., 2009; Xu et al., 2009). Modeling studies have suggested that SDEhas greater warming and snow-melting efficacy than any other anthropogenic agent (Jacobson, 2004; Hansen et al., 2005; Flanner et al., 2007; Qian et al., 2009), owing largely to a series of positive feedback mechanisms. LAPs in snow were identified as one of major forcing agents affecting climate change with high level of uncertainty in IPCC AR4 and AR5 (IPCC, 2007, 2013).

The TP is located close to densely populated regions in South and East Asia that possess the largest sources of BC in the world (Bond et al., 2006; Ramanathan et al., 2007, Menon et al., 2010). BC from industrial pollution, BC and organic carbon (OC) from wildfires and burning of agricultural wastes are plentiful in the Himalayas-Gangetic Plain (HGP). Although the Himalayas may inhibit horizontal transport from the Gangetic Plain to the TP, large quantities of BC and OC are transported via orographic uplifting, and up-slope winds along mountain valleys in the Himalayan foothills and deposited on snow in the Himalayas and TP. Himalayan ice core records indicate a significant increase in deposition of both BC and OC over the northern slope of the TP, especially since 1990 (Ming et al., 2008; Xu et al., 2009). Likewise, large quantities of desert dusts from the Middle East are transported by low-level monsoon southwesterly during the pre-monsoon and monsoon period, accumulate to great heights (~ 5 km) over the Himalayan foothills, and eventually deposit on the snow surface at higher elevations on the windward slopes and the top the TP (Lau and Kim 2018). Variability in LAPs in TP snow (LAPS) may trigger large spring LST anomalies there. Therefore, it is critical to quantify the LAPS impact in snow on the snowpack and surface temperature over TP, in order to improve the East Asian S2S prediction skill associated with the LST/SUBT over TP.

Under LS4P umbrella, we propose to coordinate a series of model simulations from several modeling groups so that we can compare the model simulated LAPs impact across different models and quantify the uncertainty of impact. We propose to do a set of experiments, with a control climate enabling full physics of snow-darkening (SDE) effects and another set of experiments, disabling the SDE effect, respectively, in a selected domain over the TP. Snowmelt in TP likely to be impacted by LAPs from both natural and anthropogenic sources. The hydroclimate in Eastern Asia is variously affected by SDE over TP on springtime snowmelt, leading to heatwave, extreme rainfall in nearby and downwind far field regions through atmospheric teleconnection (Lau et al., 2018, Lau and Kim, 2018).

We suggest the participating models could be either global model or regional model with sufficient large domain, to allow for atmospheric teleconnection effects between the TP LST/SUBT and Eastern Asia regional climate. Experiments will dovetail with the Phase-I predictability experiments proposed in LS4P. We could do either for one specific year, e.g. 2003 and/or multiple-year climatology simulations, with Phase I focusing on quantifying the impact of LAPs on LST/SUBT and snowpack over TP in May from different models. We will evaluate how much the model bias over TP will be reduced by including the SDE in the model. Other science questions to be addressed include such as how different SDE treatments, different model spatial resolutions, different aerosol schemes, and different meteorological fields simulated including wind and precipitation, will affect the springtime LST/SUBT and snowpack over TP.

At the Phase II, we will investigate the role of springtime LST/SUBT anomaly induced by SDE over TP in affecting large scale circulation in summer in East Asia. We need to better understand the physics and dynamics governing snowmelt, T2m temperature, land hydrology, and atmospheric dynamical feedback in leading to heatwaves or heavy rain through teleconnection.

This subproject can be included as part of LS4P, taking advantage of the organization structure that LS4P has established to move forward. So far the following groups have expressed interested in participating: U. Md/NASA GSFC (W. Lau/Kim), PNNL/DOE (Y. Qian/Wang), UCLA (Y. Xue/ Huang), CESM/NCAR/Scripps (Q. Zhang), MIT (Chien Wang), JPL (L. Wu/H. Su), ITPCAS/CAS (S. Kang), LLNL/DOE (Qi Tang.-), IAP/CAS (Zhaohui Lin), Tsinghua University (Yanluan Lin), UMD (Xin-Zhong Liang). Others potentially interested groups include: KIT/IMK, Germany (Anika Rohde), U. Michigan (Mark Flanner), U. Wyoming (X. Liu), NCAR (C. He), Sun Yat-Sen University (Zhenming Ji), and others.