Impact of initialized land temperature and snowpack on sub-seasonal to seasonal prediction (LS4P) Phase II Protocol

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1). Background Information

Since the inception in 2018 of the Global Energy and Water Exchanges (GEWEX) program initiative - the "Impact of Initialized Land Temperature and Snowpack on Sub-seasonal to Seasonal Prediction" (LS4P, https://ls4p.geog.ucla.edu), it has completed its first phase experiment (LS4P-I) in which more than 40 institutions worldwide have participated. LS4P-I has organized three international workshops, published a number of papers, and been working on a special issue in *Climate Dynamics*. The LS4P-I has made achievements in the following aspects (Xue et al., 2021, 2022):

1) Identifying large biases for every LS4P model in producing observed surface 2-meter temperature (T2m) over the Tibetan Plateau (TP)
2) Developing an initialization scheme for land surface/subsurface temperatures (LST/SUBT) to improve the TP surface temperature simulation.
3) Presenting the observed evidence of land memory and persistence of the T2m anomaly in high mountains and analyzing the lag relationship between June global precipitation anomalies and the May TP T2m anomaly.
4) Identifying 8 hot spot regions in the world where June precipitation is related in a statistically significant manner to anomalies of TP May T2m and LST/SUBT based on the LS4P-I numerical experiments and analyses of observational data, as well as investigating related mechanisms.
5) Discovering a strong linkage between the TP spring LST/SUBT and summer precipitation over North America; a correlation of -0.44 with $p < 0.01$ between the May Tibetan Plateau Index (TPI) and May Rocky Mountain Index (RMI) from 1981 to 2015, and a wave train from the TP through the Bering Strait to the western part of North America.
6) Identifying 6 hot spot regions in the world where June precipitation is significantly related to the global SST anomalies based on the LS4P-I experiment.
7) Assessing the current status of regional climate simulations over East Asia and the TP, and TP land temperature and regional S2S prediction.
8) Publishing a number of papers on the S2S predictability and LST/SUBT effect (Diallo et al., 2022; Qi et al., 2022; Qiu et al., 2022; Sugimoto et al., 2022; Xu et al., 2022; Xue et al., 2021, 2022; Yang et al., 2022).

As a new development, the LS4P-I also identified the following issues that need to be further addressed:

1) With the improved initialization, the LS4P-I ensemble mean is still unable to fully produce the observed TP T2m anomaly. It is imperative to further improve the initialization procedure/methodology of LST/SUBT and develop the methodology for transition to operational applications.

2) In some regions, such as in the Eurasian continent and India, the statistical analysis revealed lag correlation between precipitation there and the TP T2m, but the LS4P ensemble mean fails to produce such relationship. This issue(s) deserves further investigation.

3) In some regions, the TP LST/SUBT anomaly of the LS4P-I ensemble mean produced significant June precipitation anomalies, such as in western Australia and western Europe, but with the opposite sign compared to the observation. It is unclear whether this is a model deficiency, or if some other processes involved are more dominant than the TP LST/SUBT effect.

4) In addition to the TP, other high mountain regions' roles in S2S prediction and their corresponding hot spot regions need to be investigated.

5) The causes of the LST/SUBT anomaly are unclear. Possible roles of snow, aerosol in snow, winter Arctic circulation, and other factors in producing the LST/SUBT anomaly in the high mountain regions need further investigation as did in Zhang et al. (2019) and Liu et al. (2020).

6) Thus far, the LS4P research is mainly focusing on later spring – early summer (or at the monsoon onset stage). This year's (2022) severe anomalies occurred in middle and late summer (or at the late monsoon stage). Some pilot studies using data analyses and prototype numerical experiments are desirable.

7) The possible effect of snow and aerosols in snow have been listed in the LS4P White paper but have not been investigated.

The achievements and unsolved issues discussed above provide the basis for the LS4P phase II (LS4P-II) activity.

2. Project Goals

This project (LS4P-II) intends to address two questions:

- Where are the hot spot regions of the surface temperature anomaly in the western U.S. , mainly in the Rocky Mountain region, in the S2S prediction? How do the Rocky Mountain Index (RMI) and Tibetan Plateau Index (TPI) synergistically affect global S2S predictability.
- What is the relative role and uncertainties in the LST/SUBT processes versus in SST in S2S prediction? How do they synergistically affect global S2S predictability?
- The improvement of the LST/SUBT initialization and transition to operational applications will also be a task during the LS4P-II project.

3. Linkages with Other International Program – *to be finalized after the LS4P-II kickoff workshop*

The role of the LST/SUBT anomaly over the Western U.S., mainly the Rocky Mountains, and Tibetan Plateau in S2S prediction will be the focus of LS4P-II. The LS4P-II will collaborate with the Third Pole Experiment (TPE) and Regional Hydroclimate Project over the CONUS. The TPE will provide the data and a database to support this project.

This initiative is relevant to the GEWEX Global Land Atmosphere System Study (GLASS) panel because estimating the contribution of memory in the land to atmospheric predictability from convective to seasonal timescales is one of its main themes. This requires an understanding of the key physical interactions between the land and the atmosphere and how the associated feedbacks can change the subsequent evolution of both the atmosphere and the land states. The focus of LS4P on soil temperature also complements the primary focus on soil moisture of GLASS so far.

The LS4P activities are closely related to the WWRP/WCRP S2S project, in which land initialization and configuration is one of its major activities. The LS4P will also tackle two challenges: High-Impact Weather and Water, which have been listed in the WWRP Implemental Plan 2016-2023 (WWRP, 2016). The LS4P research activities to address these scientific challenges will be developed and executed along the lines of the WWRP/WCRP S2S project. At the same time, LS4P model experiments (including model setup) will complement, rather than duplicate, ongoing activities of the WWRP/WCRP S2S project through coordination.

With the collaborations from these programs, the LS4P will interact with all these project groups and develop the experiments, which will support and complement their planned research sub-projects. We will also coordinate with these projects to develop skill metrics/predictands to better measure impact against observation.

4. Major Tasks of and Preliminary Timeline for the LS4P-II

The LS4P project consists of several phases. Phase-II will focus on the western U.S. (mainly the Rocky Mountains area), and effect of its land temperature on precipitation over North and Central America and other regions, especially its interaction with East Asian precipitation and TP surface temperature. The Phase II experiments will start in early 2023 and last for about two years. We expect Phase II will be completed by the end of 2024 or early 2025. Phase III will focus on the high elevation areas along the Andes mountains.

a. We plan to have a kickoff workshop in Chicago on the Sunday before the 2022 AGU Fall Meeting. It will consist in a general overview of current status of relevant projects, summary of LS4P Phase-I achievements, and discussions on the most challenging issues and the scope and approach of LS4P-II. Some results from the pilot experiments for LS4P phase II will also be presented. A set of seasonal experiments will be proposed and finalized during the workshop to examine the effect of LST/SUBT initialization in western U.S. on S2S drought/flood prediction.
b. For LS4P Phase II, we will select the year 1998, when the summer had severe drought in Texas and Oklahoma (Hong and Kalnay, 2002) and severe flooding in the Yangtze River Basin. In addition, the year 1998 was a strong El Nino year. A strong SST effect is expected and will be compared with that due to the high elevation LSTs. The pilot experiments for the 1998 case have shown promising and encouraging results.

c. The LS4P-II will consist of four experiments using global models. Task 1 will consist in the control run from late April 1998 through August 1998 with each group's normal setting for a S2S prediction for initial conditions and land/ocean surface conditions. Observed April, May, and June
d. 1998 daily SST will be specified as the boundary condition for the AMIP-type integrations. At least 6 ensemble members are required. Task 2 will impose an LST/SUBT mask for the western U.S. in order to reproduce the observed cold May T2m there to exam its impact on N. America and global precipitation, especially the drought in Southern Great Plains and flood in the Yangtze River Basin. Task 3 will impose an LST/SUBT mask for the TP to reproduce the observed very warm May T2m there to exam its impact on global precipitation, especially the severe drought and flood. Task 4 will replace the 1998 SST by the climatological SST to test the SST effect on the global flood/drought. In addition, an experiment with combined Tasks 2 and 3 will be conducted as an optional task for voluntary groups. The requirement of the model outputs will be the same as LS4P-I as presented in Xue et al. (2021).
e. The regional climate modeling group will conduct experiments to test the impact of anomalies of the land surface temperature, snow cover and soil moisture on the regional climate, e.g., continental U.S. and East Asia. Downscaling the global model results will also be considered.
f. The LS4P-II group activity will focus on challenging issues (1)-(4) in Section 1. We will carry out experiments with volunteer groups during Phase II to tackle the challenging issues (5)-(7).
g. A project session in the 2023 AGU Fall Meeting will be organized to report the results from Phases I and II and *Climate Dynamics* Special Issue. A workshop before the 2023 AGU meeting will also be considered to discuss the progress, preliminary results, and problems to be resolved, as well as future plans.

5. Data

The model output data will be stored in the Lawrence Livermore National Laboratory and Third Pole Environment (TPE) database.

The field campaign data from the TPE - the Third Atmospheric Scientific Experiment for Understanding the Earth-Atmosphere Coupled System over the Tibetan Plateau, and Zeng et al. (2018) snow data, and other available data, such as reanalysis data, will be used for this project.

6. Major Participants

More than 40 institutions from North America, Asia, Europe, South America, and Africa have confirmed to participate in this effort (See attachment). Organizers of this project include: Yongkang Xue (UCLA); Aaron Boone (Météo France-CNRM, CNRS), and Tandong Yao (ITPR, CAS).

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