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 four 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 methodology for land surface temperature/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). Finding 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.

(5) Discovering a strong linkage between the TP spring LST/SUBT and summer precipitation over North America; and ***a Tibetan Plateau-Rocky Mountain Circumglobal (TRC) wave train*** *from the TP through northeast Asia and the Bering Strait to the western part of North America.*

(6) 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.

(7) Identifying 6 regions in the world where June precipitation is significantly related to the global SST anomalies based on the LS4P-I experiment.

Based on (6) and (7), it is found that *the TP LST/SUBT is a first order source of the S2S predictability, which is comparable to the ocean conditions.*

(8) Assessing the current status of regional climate model simulations over East Asia and the TP, including TP land temperature and regional S2S prediction.

(9) 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; Saha et al., 2023; 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-I ensemble mean fails to produce such a 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 coastal West Africa 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. In Phase I, a close link between the TP and the Rocky Mountains land temperature and precipitation in East Asia and N. America has been founded. It is imperative to explore the effect of the Rocky Mountains land temperature on the Northern Hemisphere precipitation anomalies. Meanwhile, the pilot study on the LST/SUBT effect of the Southern Hemisphere mountains will start for a possible LS4P-III.

(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 done in Zhang et al. (2019) and Liu et al. (2020).

(6) Thus far, the LS4P research is mainly focusing on late spring – early summer (or at the monsoon onset stage). The year 2022's 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) There is a need to further study the combined remote and local (due to soil moisture, vegetation, etc.) effect. Furthermore, the possible effect of snow and aerosols in snow have been listed in the LS4P White paper but have not been investigated to date.

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 located 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 of and uncertainties in the LST/SUBT processes versus in SST effects in S2S prediction? How do they synergistically affect global S2S predictability?

The LS4P project plans to have volunteer groups among the LS4P-II participants to further improve the LST/SUBT initialization and transfer to operational applications.

3. Linkages with Other International Programs

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 GEWEX Regional Hydroclimate Project over the CONUS (US-RHP; part of the GEWEX Hydroclimatology Panel). The US-RHP's goal is to understand and characterize the water, energy, and carbon cycles over the CONUS in the Anthropocene, out to climate time scales. The US-

RHP will collaborate with the LS4P in regional modeling and relevant U.S. climate and hydrological data sharing. The LS4P will also collaborate with the US-RHP to develop the RCM's experimental protocol (RCMip-North America) over North America based on the US-RHP's experiment design.

Third Pole Environment (TPE) has been closely collaborated with the LS4P-I and provided strong various supports during the LS4P-I. The LS4P objectives are consistent with one of the TPE research goals in understanding the TP's terrestrial land environments on the regional and global climate through global and regional modeling. The joint LS4P-TPE RCMip-East Asia has produced interesting results. The TPE will continue to collaborate with the LS4P to further the study of regional feedbacks and global teleconnections.

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 GLASS will further collaborate with the LS4P through the Soil Parameter Model Intercomparison Project (SP-MIP).

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 of these project groups when developing 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 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 monsoon. 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 had a kickoff workshop in Chicago on the Sunday before the 2022 AGU Fall Meeting. It consisted of a general overview of current status of relevant (meaning with potential links to LS4P) projects, a summary of LS4P Phase-I achievements, discussions on the most challenging issues, and the scope and approach of LS4P-II. Some results from the pilot experiments for LS4P phase II were also presented. A set of seasonal experiments was proposed and finalized during the workshop to examine the effect of LST/SUBT initialization in western U.S. on S2S drought/flood prediction. A summary of the workshop discussion will be reported in the GEWEX Newsletter (2023, Vol. 1, 7-10).

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) with a cold spring in the western U.S. and severe flooding in the Yangtze River Basin with a warm spring in the TP. 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 plus one optional experiment using global models **(Table 1).**

Task 1 (Case CTL) will consist of 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. For the LST/SUBT initial conditions, please see Table 1. The Observed April-August 1998 daily SST will be specified as the boundary condition for the AMIP-type integrations. At least 6 ensemble members are required.

Task 2 (Case RMI) will impose an LST/SUBT mask for the western U.S. in order to reproduce the observed cold May T2m there to examine its impact on N. America and global precipitation, especially the drought in the Southern Great Plains and the flooding in the Yangtze River Basin.

Task 3 (Case TPI) will impose an LST/SUBT mask for the TP to reproduce the observed very warm May T2m there to examine its impact on global precipitation, especially the severe drought and flooding. *Please note, due to the model deficiency in keeping the observed land temperature anomaly, some models may need separated Case CTLs for Case RMI and Case TPI.*

Task 4 (Case SST) will replace the 1998 SST by the climatological SST to test the SST effect on the global flood/drought.

Task 5 (Case RMI+TPI, optional). In addition, an experiment with combined Tasks 2 and 3 will be conducted as optional tasks for voluntary groups. The difference between Case RMI+TPI and Case CTL and the difference between Case RMI+TPI and Case SST will show the combined effects of RMI and TPI and combined effects of Case RMI, Case TPI and Case SST, respectively.

The LS4P-II experimental design is listed in Table 1. The requirement of the model outputs will be the same as LS4P-I as presented in Xue et al. (2021).

Table 1 LS4P-II Global Model Experimental Design

Experiment	**Description**
Case CTL	Ocean boundary conditions for AMIP-type run: Observed May-August 1998 daily SST and sea-ice. Atmospheric and land initial conditions, such as soil moisture, snow from reanalysis for the year 1998. The initial LST/SUBT over the Western U.S and TP will be based on a reference, such as your model's normal S2S run as did in LS4P-I, climatology, or imposing a mask, such as $-\Delta T$ or $+\Delta T$.
Case RMI	Same as Case CTL, except for an initial LST/SUBT mask will be imposed over the Western U.S. based on observed T2m anomaly and model bias over the Western U.S.
Case TPI	Same as Case CTL, except for an initial LST/SUBT mask imposed over the TP based on the observed T2m anomaly and model bias over the TP
Case SST	Same as Case CTL, except that climatological SST will be applied (instead of 1998 SST)

Case RMI+TPI*	Same as Case CTL, except for an initial LST/SUBT mask imposed over both the TP and the Western U.S. based on each's observed T2m anomaly and local model bias

Note: 1). Integration period: late April 1998 through August 1998 (i.e., till 31 August) with a minimum 6 members

2) Model output requirements: Same as LS4P I (Xue et al., 2021, GMD)

3). Case with "*" is optional. The group who finishes the case is encouraged to write a paper for this case.

d) 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 of the global model results will also be considered.

e) The LS4P-II group activity will focus on the challenging issues (1)-(4) listed in Section 1. We will carry out experiments with volunteer groups during Phase II to tackle the challenging issues (5)-(7).

f) 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, as well as relevant studies. 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 the 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.

High-resolution (4 km) hydroclimate data (water year 1980 through water year 2021) over the CONUS will be available from the NCAR Research Data Archive.

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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