Abstract Dragon 1 Symposium, July 2021 (max: 1000 words):

Cryosphere-hydrosphere-biosphere interactions of the Asian water towers: using remote sensing to drive hyper-resolution ecohydrological modelling

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High Mountain Asia cryosphere and water resources remain still largely unconstrained, despite very substantial advances in modelling and remote sensing. In this project, we leverage the opportunity offered d by ESA and NRSCC *to exploit new remotely sensed datasets to advance our understanding of blue and green water interactions in high elevation catchments in the first truly inter-comparative study across HMA.* I will provide an update of the main project objectives, methods and modelling approaches, and present preliminary results in both modelling and remote sensing.

Our main overall aim is to *understand how green water processes affect the availability of blue water from glaciers, snow and precipitation across High Mountain Asia.* To achieve this goal, we are working with our Chinese partners in a very close collaboration and have designed three main objectives. The first objective is to advance our understanding of cryospheric, vegetation and land surface changes from remote sensing observations at benchmark sites; the second objective is to generate glacier-specific altitudinal surface mass balance profiles to investigate patterns of changes and validate the glacier component of the land surface model; and the third one ist o quantify the water cycle of select HMA water towers using a novel hyper-resolution land surface model to examine variability, seasonality and long term changes, with emphasis on the feedback between blue and green water.

Use of a hyper-resolution ecohydrological model, fed by Earth System Observations, is very novel. We will bridge the modelling gap between snow and glaciers, which generate the runoff that ultimately feeds major rivers, and downstream water cycle components such as vegetation, which buffer, delay or amplify that runoff. We will focus on blue (runoff) and green (evapotranspiration) water interactions in HMA, which are often examined separately. We will integrate water supply changes due to a vanishing cryosphere with the effect of vegetation to dampen or amplify those changes, especially in periods of droughts. The new model will be applied to 10 *benchmark* catchments representative of the climatic differences of HMA. Its application and validation will be based on remote sensing data: high-resolution satellite data of land-cover, surface albedo, snow, vegetation phenology, surface water, glacier velocities, surface lowering and mass balance will guide model developments and support model calibration and validation in a systematic manner to ensure comparability across case studies. The 10 glacierized sites span a variety of climates, glacier conditions and mass balance regimes. For each catchment, field measurements of glacier melt, mass balance, runoff and meteorological variables are also available and will complement the remote sensing data.

To present, we have advanced on all three main objectives. We have developed a method to derive snow cover and snow line elevation from satellite images and applied to the entire HMA, providing both a novel understanding of snow cover patterns across this very broad scale and validation data for the modelling at the 10 catchments. We have devised a new method to retrieve glacier albedo from remote sensing that has been applied also to the entire HMA region, and is being refined now to understand catchment-scale patterns and variability. For the second objective, we have developed a new method to retrieve altitudinally resolved surface mass balance from satellite derived elevation differences, have applied it to all glaciers in HMA and are now refining it to provide the validation datasets for the 10 catchments. I will present results from its application to the Langtang benchmark catchment in Nepal. Towards objective 3, we have setup the new land surface model in the same Langtang catchment, for the two data-rich years of 2017-2019, and are analysing the first simulations now. The model setup entailed a number of major challenges, from the spatial redistribution of the meteorological forcing from station data to the characterisation of the parameters controlling the vegetation response. It is the first time that a physically-based model that calculates all energy and mass fluxes in a distributed manner is applied to a HMA catchment: the energy balance calculations require knowledge of wind, radiation fluxes, relative humidity fields in addition to the temperature and precipitation forcing commonly used in more empirical glacio-hydrological models, and parameters need to be defined in space and time. I'll present the application of the model to the Langtang catchment, its validation with remote sensing data and highlight the advantages that this new modelling perspective offers over more traditional modelling results.

Finally, I'll present the project next steps and the planning towards the achievement of our goals. At the end of the project, our multidisciplinary team of European and Chinese scientists will: i) provide an advanced characterisation of the main glacier and hydrological processes from remote sensing observations in the high elevation catchments of HMA; ii) resolve the altitudinal surface mass balance for all study glaciers and determine patterns and drivers of surface mass balance; iii) use a novel hyper-resolution earth-surface model to simulate the complexity of the high mountain water budget, understand blue-green water fluxes and quantify changes in past and future streamflow.

亚洲水塔的冰冻圈-水圈-生物圈相互作用：利用遥感技术驱动高分辨率的生态水文模拟

尽管在模型模拟和遥感应用方面取得了重大进展，但高亚洲地区（High Mountain Asia）冰冻圈和水资源的研究仍然具有诸多限制。本项目凭借 ESA 和 NRSCC 提供的合作机会生产了新的遥感数据集，并首次完成了该地区流域中蓝水和绿水相互作用的比较研究。本此汇报总结了项目的主要目标、研究方案和模拟方法方面的最新进展，并对模型模拟和遥感方面的初步结果加以介绍。

本研究的总体目标是了解绿水如何影响高亚洲地区冰川、雪和降水生成的蓝水的可利用性。为了实现这一目标，我们正在与来自于中国的合作伙伴紧密合作，并设置了三个主要目标：1）通过典型站点的遥感观测增加对冰冻圈、植被和陆地表面过程的理解；2）生成特定冰川的表面物质平衡产品，用以研究冰川物质平衡的变化模式及对陆地表面模型中冰川的模拟结果加以验证；3）使用新一代高分辨率的陆地表面模型来量化高亚洲水塔的水循环过程，以探究其空间变异性，季节性和长期的趋势变化，重点研究蓝水和绿色水之间的反馈作用。

本研究最为突出的创新点是将对地遥感观测应用到高分辨率的生态水文模型中，从而耦合积雪和冰川模型，后者产生的径流会补给河流、湖泊及下游水循环组分（如植被）的用水，进而可能会缓冲、延迟或增加下游的整体径流量。本研究将主要关注高亚洲地区通常单独研究的蓝水（径流）和绿水（蒸散）间的相互作用，探究长期（特别是干旱时期）冰冻圈及植被对该地区水资源变化的影响。模型将对代表高亚洲地区气候差异的 10 个典型冰川流域进行模拟和研究。土地覆盖，地表反照率，雪，植被物候，地表水，冰川速度，地表沉降和物质平衡的高分辨率卫星数据将用于指导模型开发并对模型进行校准和验证，以确保各流域的研究之间具有可比性。本研究选取的 10 个典型冰川流域涵盖不同的气候类型，冰川位置和物质平衡模式，各流域中对于冰川物质平衡、径流和气象因子的实地观测可对遥感数据加以补充。

现阶段，本研究在三个主要目标上均已取得了可喜成果。针对以第一个目标，首先发展了一种从卫星影像中提取积雪和雪线高度的方法，并已将其应用到整个高亚洲地区，既增加了对于大区域内积雪模式的理解，又为本研究 10 个流域的模型模拟提供了验证数据；其次提出了一种从遥感数据中反演冰川反照率的新算法，该方法现已应用于整个高亚洲区域，目前正在完善以了解流域尺度上冰川反照率的分布模式及其空间差异。对于第二个目标，建立了一种从卫星数据估算的冰川高程变化中获取高分辨率的冰川表面物质量平衡的新方法，已将其应用于高亚洲地区的所有冰川，现阶段正对其加以完善，用以作为 10 个流域的验证数据集。同时，本汇报将介绍将该方法应用于尼泊尔 Langtang 流域的最新进展。针对第三个目标，本项目已于 2017–2019 的两个数据较为丰富的年份，在 Langtang 流域发展了新的陆地表面模型。构建该模型的重大挑战之一是将站点观测的气象数据应用到到控制植被响应的参数化方案中。本研究是首次将基于物理机理的模型以分布式方式计算高亚洲流域内的所有能量和物质通量。与现有大多数的冰川水文模型通常使用降水及在时空上定义各个参数的方法不同，该模型中的能量平衡计算除了需要温度和降水以外，还需要有关风，辐射通量，相对湿度的知识，因而具有更为可靠的模拟结果。同时本研究将介绍该模型在Langtang流域的应用，并通过遥感数据对其进行验证，并重点介绍这种新的模拟方法相对于传统模拟结果所具有的优势。

最后，将介绍该项目的后续安排以及为实现既定目标而制定的具体计划。项目结束时，由欧洲和中国科学家组成的跨学科团队将：1）基于高亚洲地区的遥感观测，对主要冰川和水文过程加以深入探究； 2）获取各流域冰川表面物质平衡，并确定其分布模式和驱动因素；3）利用新一代高分辨率陆地表面模型来模拟高海拔复杂山区水资源的变化情况，了解蓝水和绿水的，并最终量化过去和将来该地区水资源的变化。