Precipitation Uncertainty Hampers the Understanding of Glacier Response To Climate in High Mountain Asia

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The Precipitation Problem

- Accurate quantification of precipitation is critical for understanding **glacier and cryospheric health**.
- Precipitation observations, especially in mountain environments, are lacking, **spatially/altitudinally biased** and/or experience temporal paucity (e.g. Pamir/Karakoram).
- **Large under-catch**, particularly for solid precipitation!
- Satellite estimates convert available information (e.g. cloud top temperatures) to rainfall rates based upon statistical relationships, constrained by observations.
- Reanalysis and modelled precipitation is often represented on **very coarse grids** (10's to 100's km) and convection (among other things) must be parameterised.
- High Mountain Asia contains several of the **world's most critical largest water towers**!
- Improved understanding of precipitation in all forms is critical. But to date, limited attention paid to the effect of different estimates on glacier health.

How much do precipitation estimates disagree?

In magnitudes? Annual precipitation can range from **-70 to +400%** compared to observations at a range of elevations.

In seasonality? The westerly extent of summer (JJAS) precipitation fraction is highly variable, particularly for W. Himalaya and Karakoram glaciers.

In tendency? There are sub-regional disagreements in direction and magnitude of decadal precipitation change.

- **PERSIANN-CCS-CDR (5 km)**
- **ERA5-Land (9 km)**
- **CHIRPSv2 (4 km)**
- **IMERG (10 km)**
- **HARv2 (10 km)**
- **NHM (5 km)**
- **WRF (9 km)**

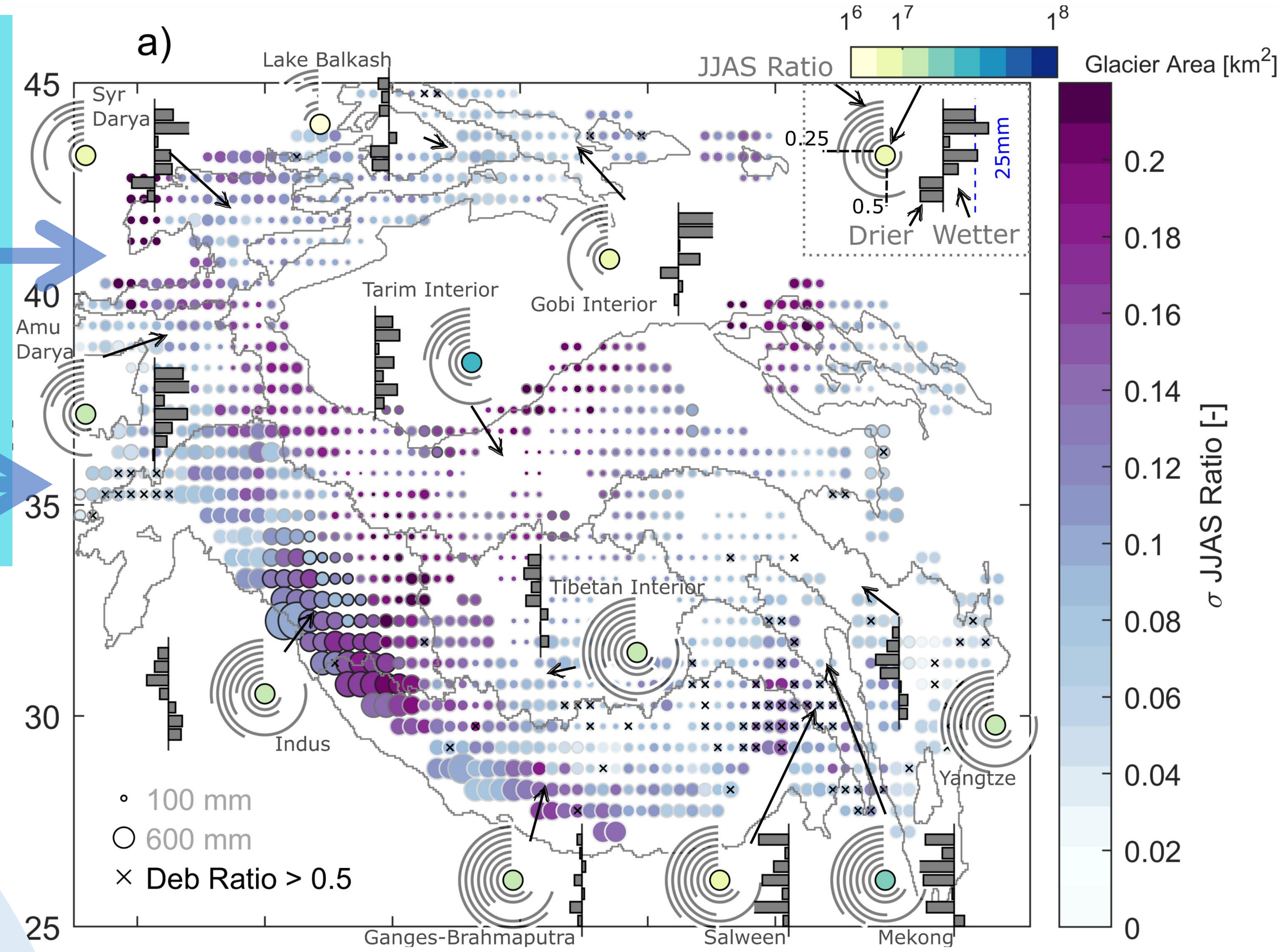

Figure 1: *The standard deviation of the JJAS precipitation ratio (colour scale) and standard deviation of decadal period absolute differences (circle scale) and relative differences (circle edge tone) in mean annual precipitation for HMA glaciers per 0.5° grid. Grids with a mean debris ratio > 0.5 are marked with crosses.*

Complex Topography

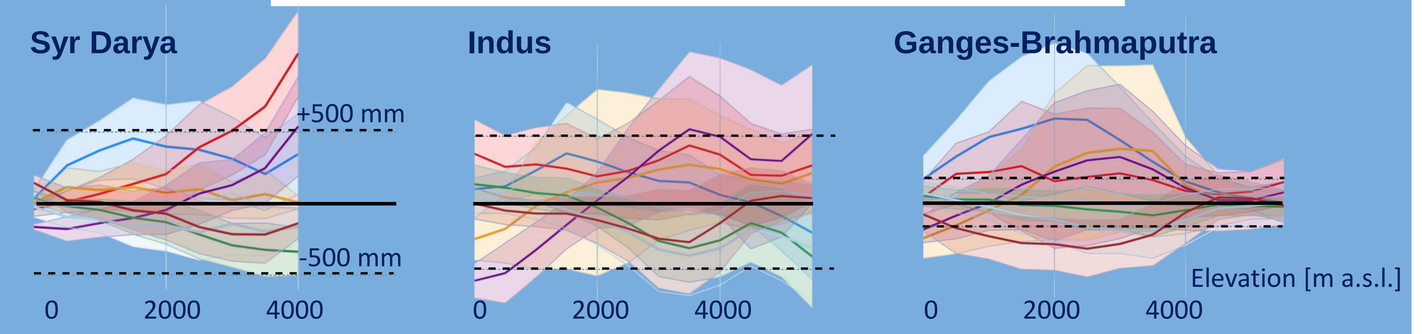

Figure 2: *Anomalies of mean absolute annual precipitation per dataset rel. to the mean of all vs. elevation.*

- Anomalies of mean absolute annual precipitation are largest ~3000-4000 m a.s.l. (compared on 0.1° grid).
- Large discrepancy in windward side of Himalayan chain:
  - Topographic complexity
  - Sub-grid variability
  - Representation of convection?
  - Lack of assimilation of datasets near glaciers?
- An order of magnitude difference between datasets in the windward side of the Langtang catchment, Nepal.
- What seasonal variability?
- What control on snowfall?
- What impact on glacier mass balance?

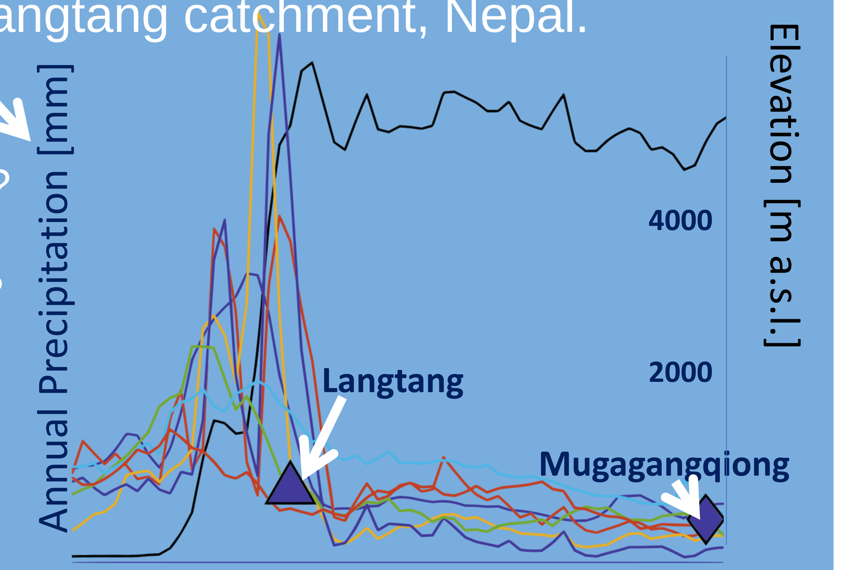

Figure 3: *2018-2019 total precipitation along a transect of Fig. 1. Observations shown by the shapes.*

Outlook

Major discrepancies of precipitation magnitude, tendencies, seasonality and timing (seasonal and sub-daily).

Broadly problematic across High Mountain Asia, but **Indus basin a key focus point** for both observations and model development.

Local bias-correction critical (or optimisation against observed mass balance), but **timing remains a key challenge** for future high resolution atmospheric models.

Modelled Impact

- Non-corrected precipitation amounts create >7 m w.e. divergence of modelled mass balance in a single hydrological year (2018-2019).
- Bias-correction (EQM) against local pluviometer captures seasonal pattern of mass balance, but still with up to 3 m w.e. range of estimates.
- Timing of precipitation events are critical for a summer-accumulation type catchment. Adding biases of datasets to observed timing gives better results ('inverse-corrected').
- High elevation, clean ice areas are most impacted.

Zoom in

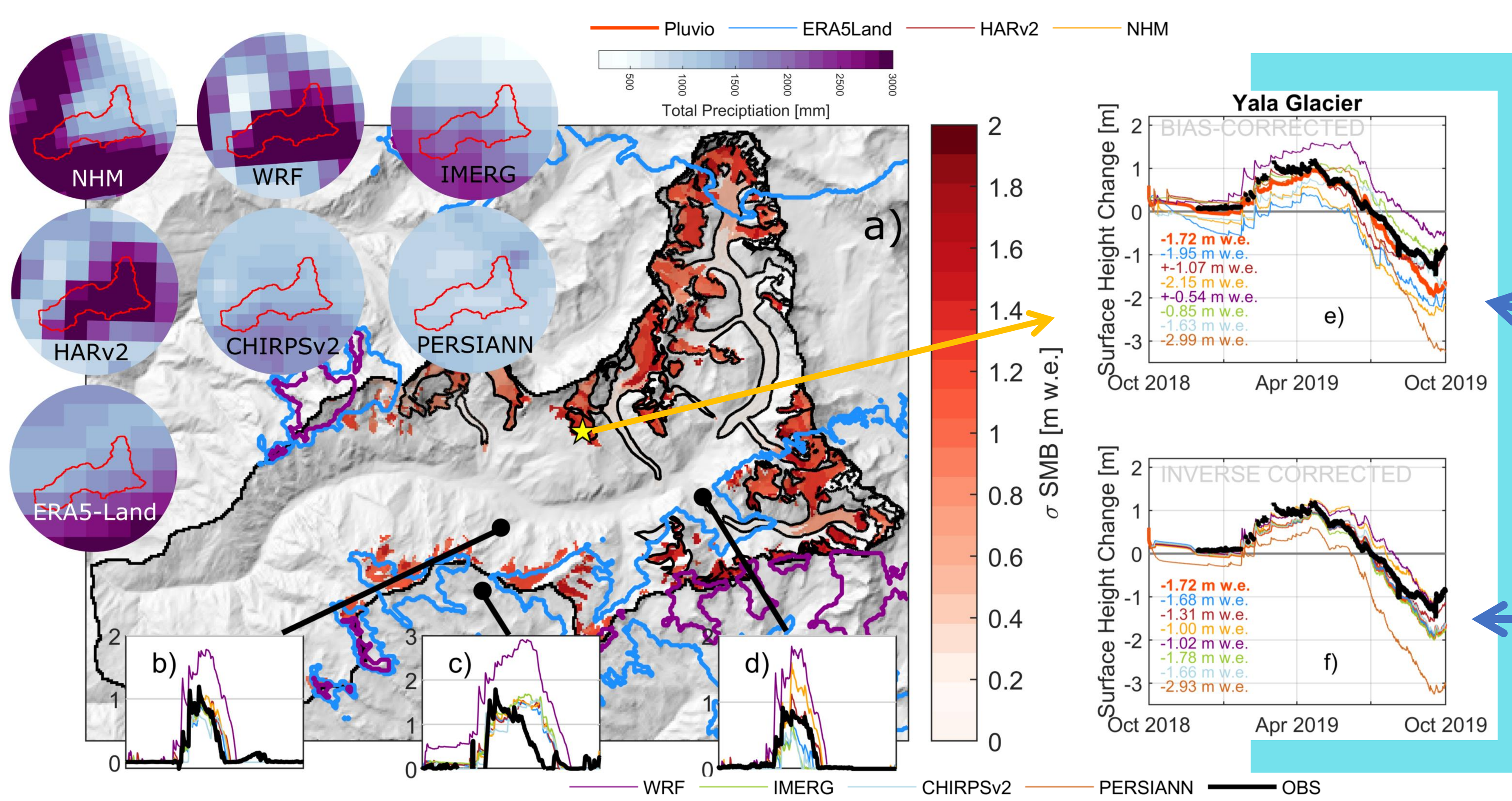

Figure 4: *2018-2019 total precipitation amounts (top left) and results of std. dev. of modelled mass balance (red scale) using datasets after bias-correction. Model results from Yala Glacier AWS are shown (right) after bias-correction (top right) and considering an 'inverse-correction' (bottom right).*

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