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An update on the Karakoram Anomaly: Explaining the mechanisms through which regional atmospheric circulation variability drives summer temperatures and glacial melt in the western 3rd Pole

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This talk is primarily an overview of:

nature climate change

ARTICLES

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Karakoram temperature and glacial melt driven by regional atmospheric circulation variability

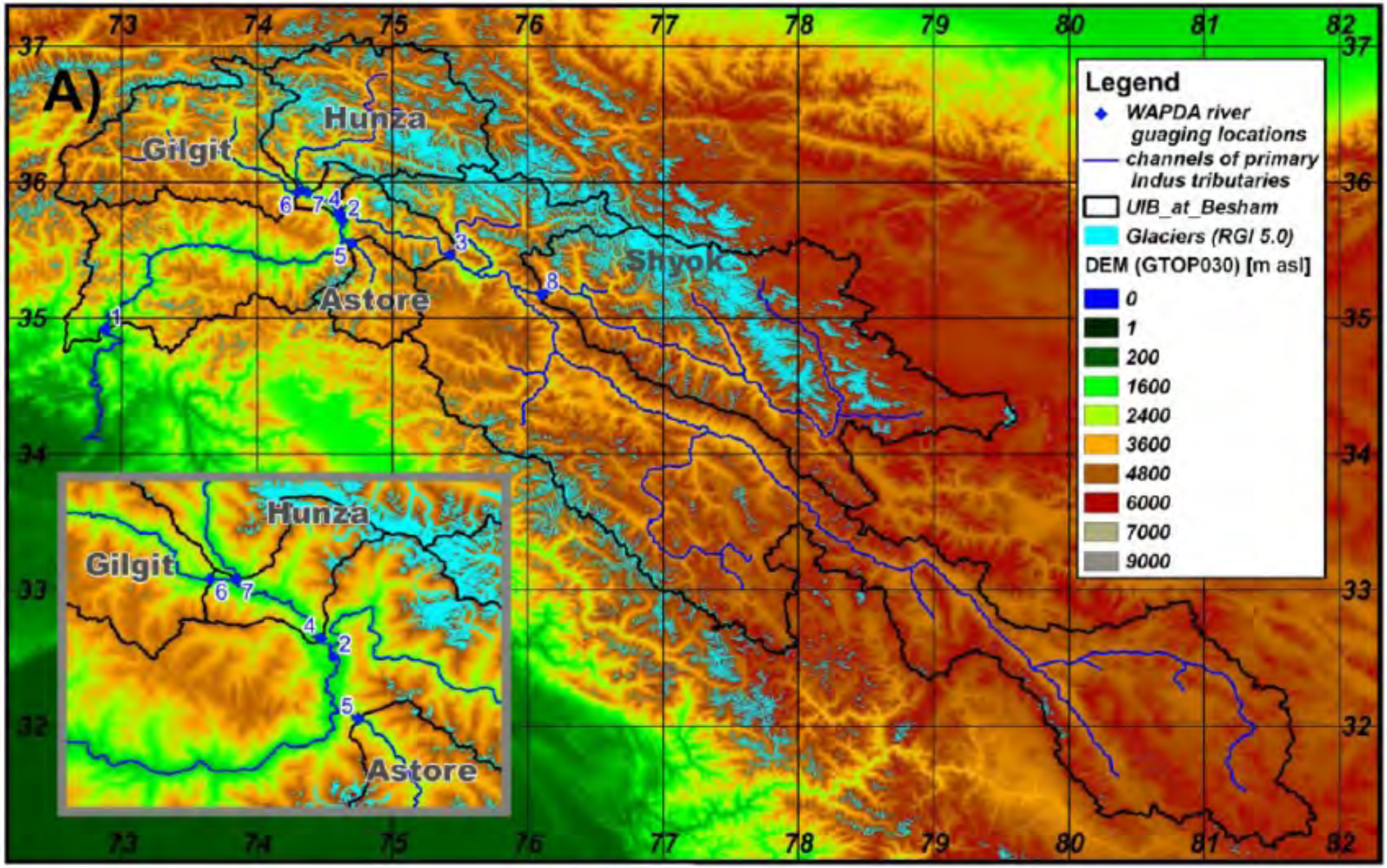
Nathan Forsythe*, Hayley J. Fowler, Xiao-Feng Li, Stephen Blenkinsop and David Pritchard

Identifying mechanisms driving spatially heterogeneous glacial mass-balance patterns in the Himalaya, including the 'Karakoram anomaly', is crucial for understanding regional water resource trajectories. Streamflows dependent on glacial meltwater are strongly positively correlated with Karakoram summer air temperatures, which show recent anomalous cooling. We explain these temperature and streamflow anomalies through a circulation system—the Karakoram vortex—identified using a regional circulation metric that quantifies the relative position and intensity of the westerly jet. Winter temperature responses to this metric are homogeneous across South Asia, but the Karakoram summer response diverges from the rest of the Himalaya. We show that this is due to seasonal contraction of the Karakoram vortex through its interaction with the South Asian monsoon. We conclude that interannual variability in the Karakoram vortex, quantified by our circulation metric, explains the variability in energy-constrained ablation manifested in river flows across the Himalaya, with important implications for Himalayan glaciers' futures.

Why understanding climate change impacts on the 3rd Pole is important

Bookhagen 2012

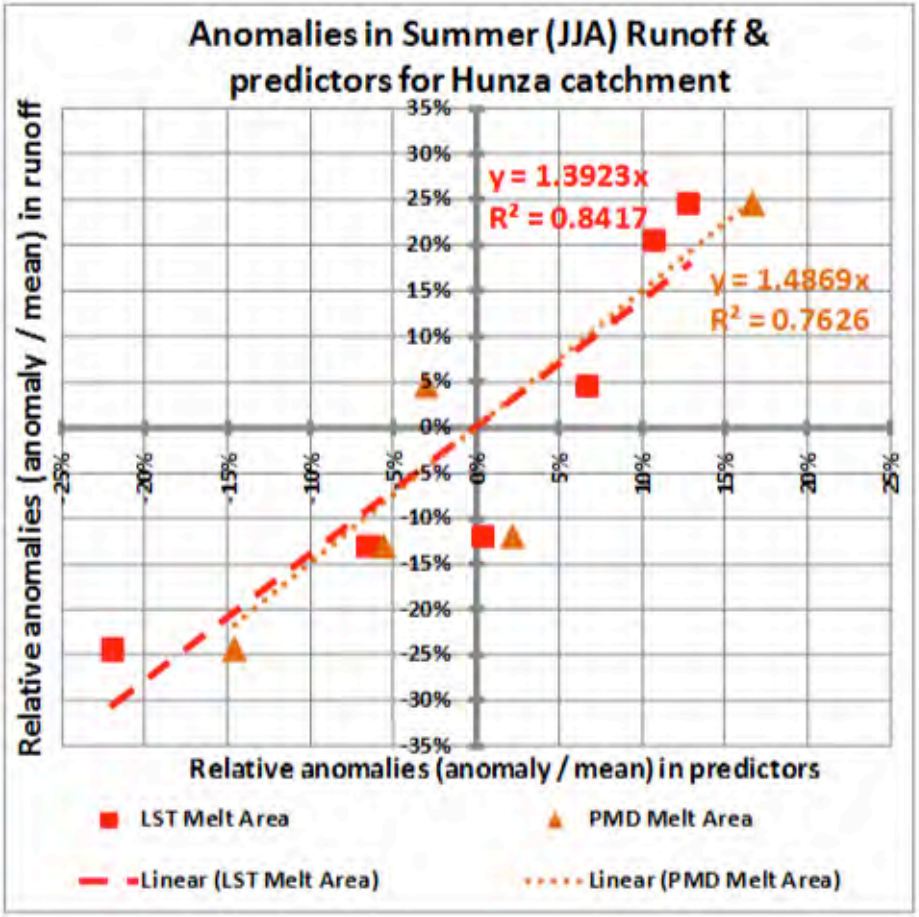
Western 3rd Pole hydroclimate relationships



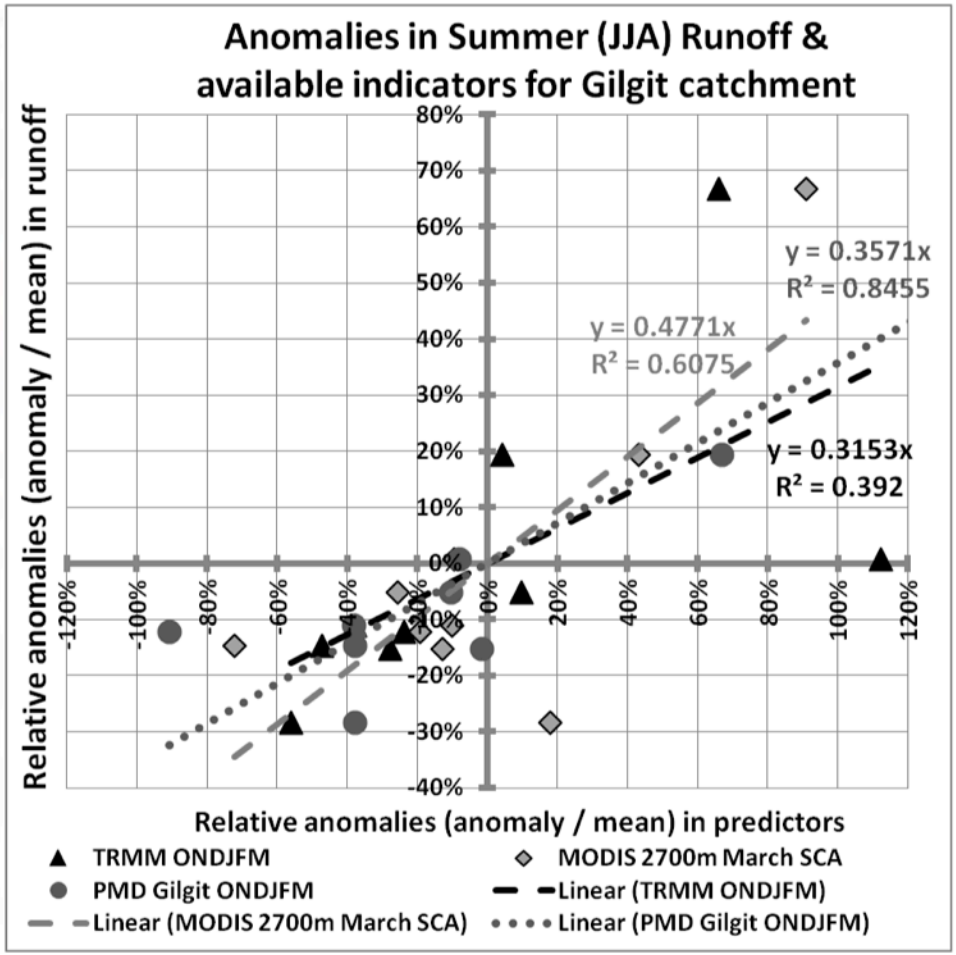
(figure) in Forsythe et al, 2017 (Supplementary Information)

Western 3rd Pole hydroclimate relationships

Glacial catchments



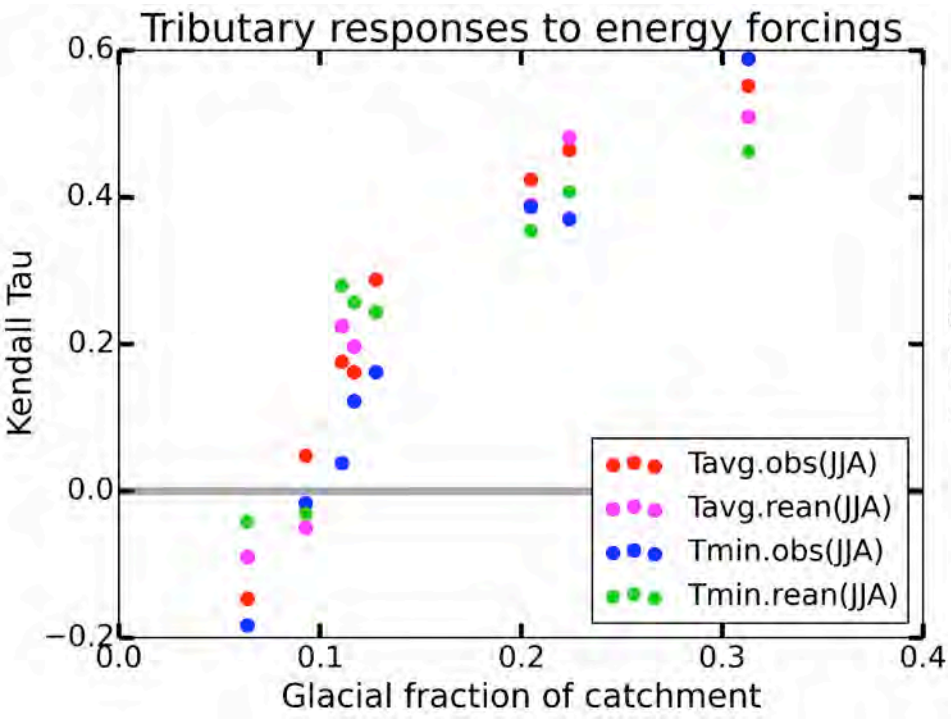
Nival catchments



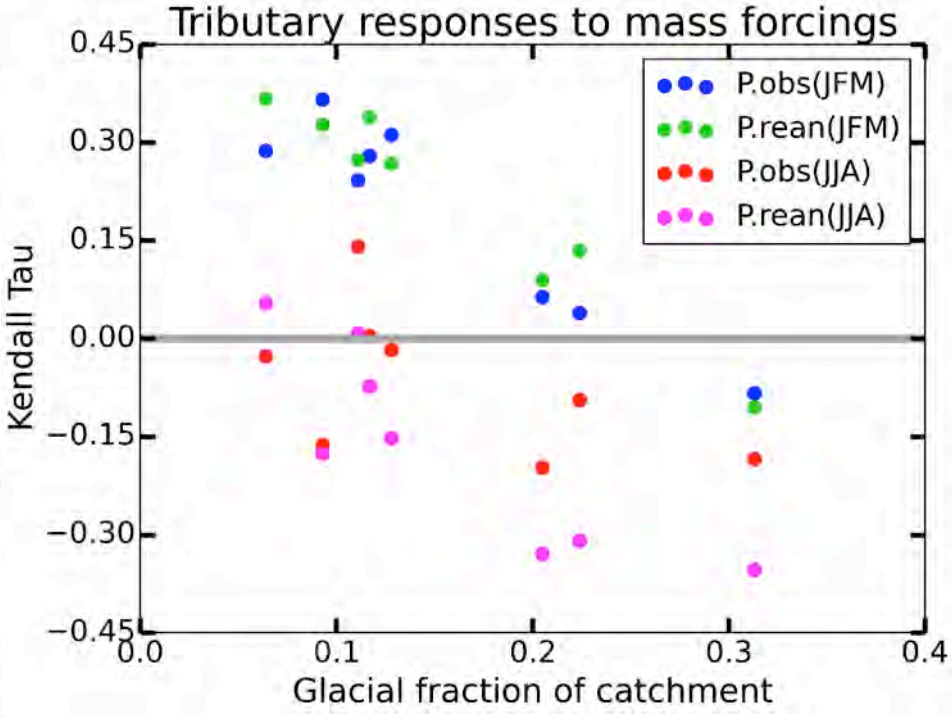
in Forsythe et al, 2012a … following Archer, 2003.

Western 3rd Pole hydroclimate relationships

Energy Forcings



Mass Forcings

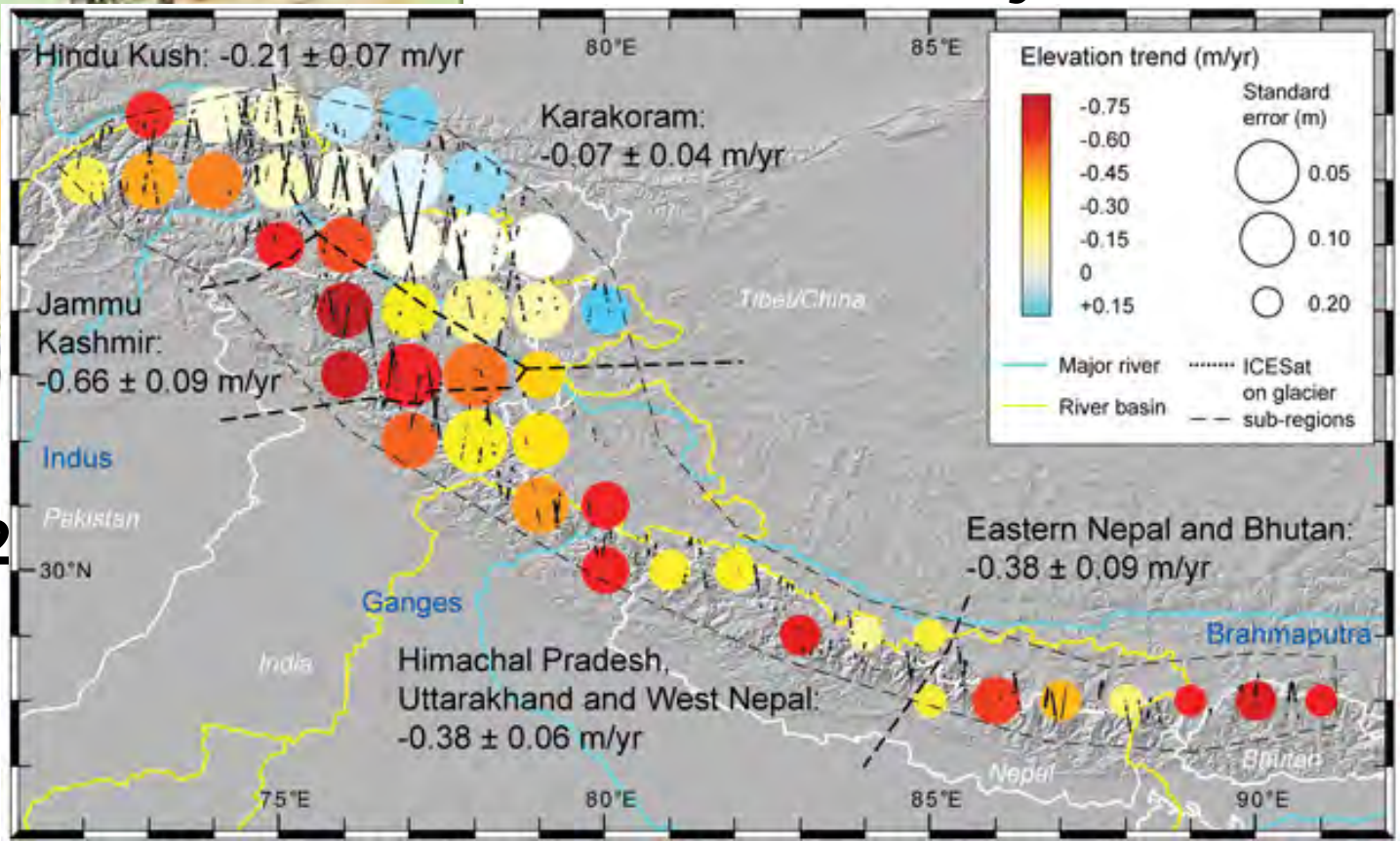


Forsythe et al, 2017 (Supplementary Information)

Bolch et al., 2012

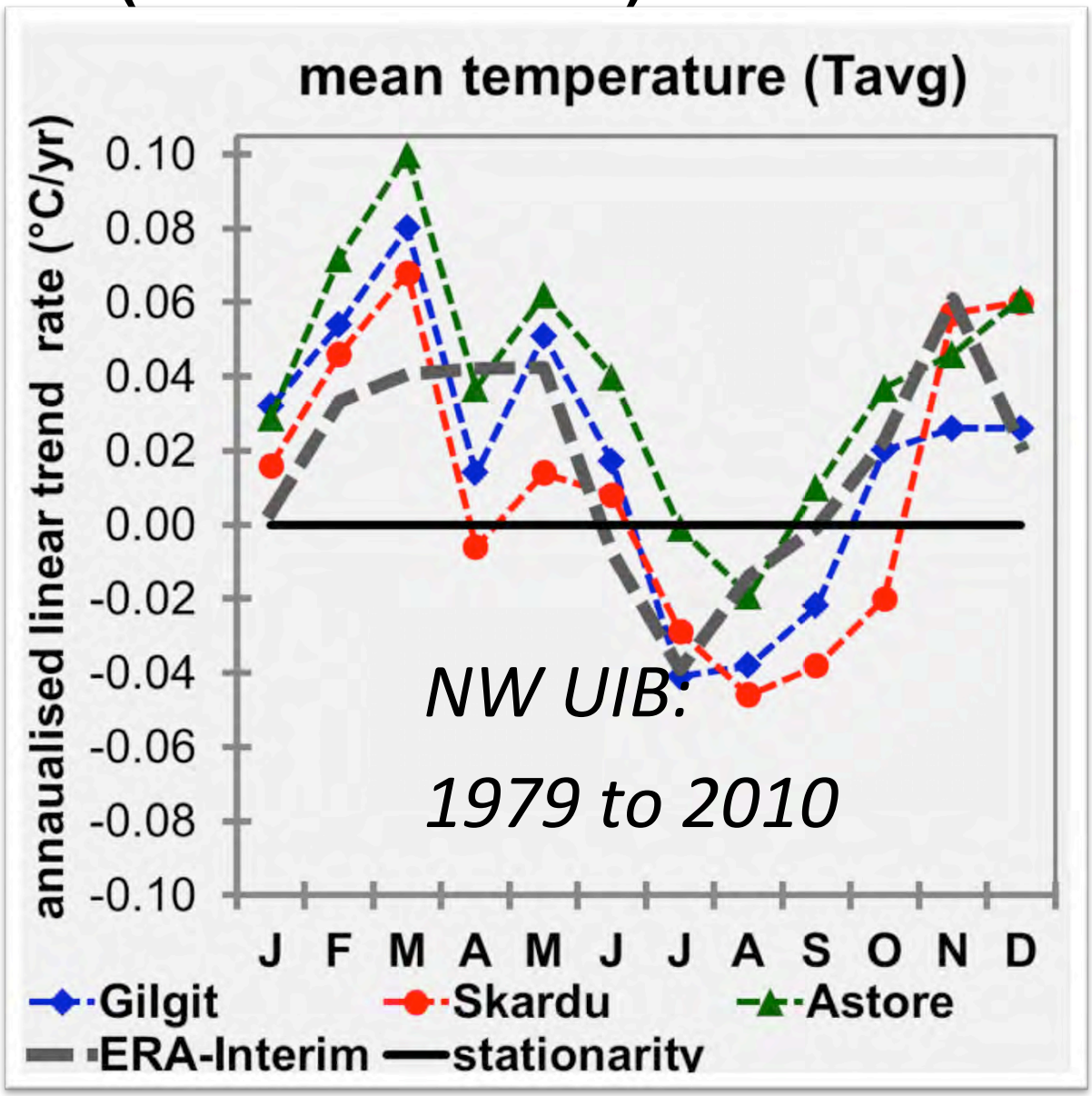
Glaciers of the 3rd Pole are shrinking in the east and growing/stable in the west, hence the "***Karakoram Anomaly***."

Kaab et al., 2012



How is climate changing in the western 3rd Pole (Karakoram)?

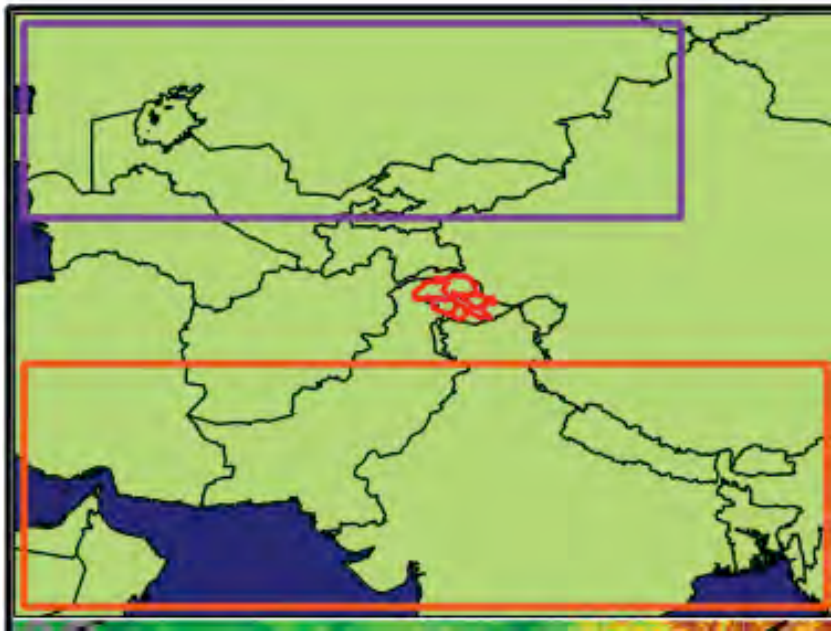
- Seasonally asymmetrical temperature trends in the Hindu Kush-Karakoram (Fowler and Archer 2006)
- Summer cooling logically associated with the "***Karakoram Anomaly***" via glacial melt (runoff).
- Conflicting trends (sign & magnitude) between sub-regions of the 3rd Pole.
- Increase in winter and summer precipitation since 1960s at some stations (Archer & Fowler 2004)



What might be the climatic drivers of the cooling trend in summer temperatures in the Karakoram?

Defining an indicator of driving atmospheric circulation

1) Tested influence on Karakoram station-observed 2m air temperature of atmospheric circulation & surface variables from reanalyses with methods used by Yadav (2009) for precipitation.
2) Identified two areas of strong correlation, but opposing influence, for (westerly) zonal wind at 200-hPa and 500-hPa; pressure levels that roughly bound the westerly jet –difference these north-south to give the **Karakoram Zonal Shear (KZS)**.
3) The **KZS** is the north-south shear of zonal wind, denoting the latitudinal position and change in intensity of the westerly jet upstream of the Karakoram.

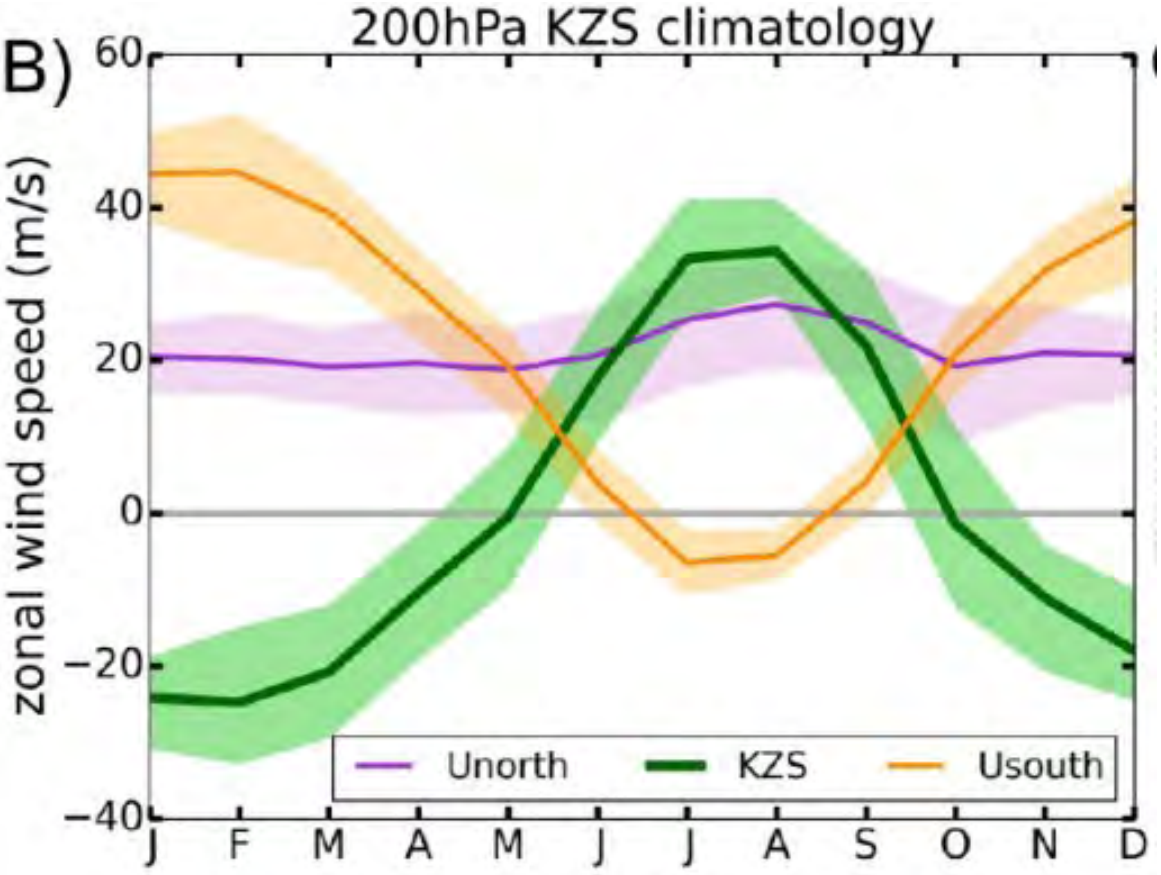


Forsythe et al., 2017

Climatology of the KZS/KZI

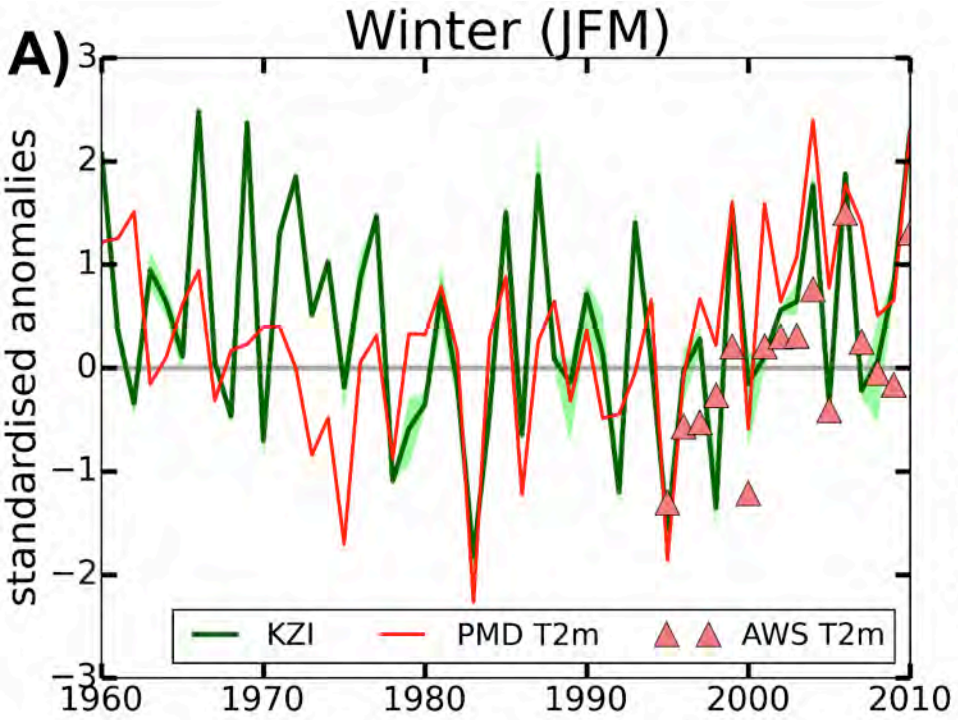
In order to work in ‘anomaly space’, we also produce a dimensionless metric, the “**Karakoram Zonal Index**” (**KZI**) by standardising the KZS.

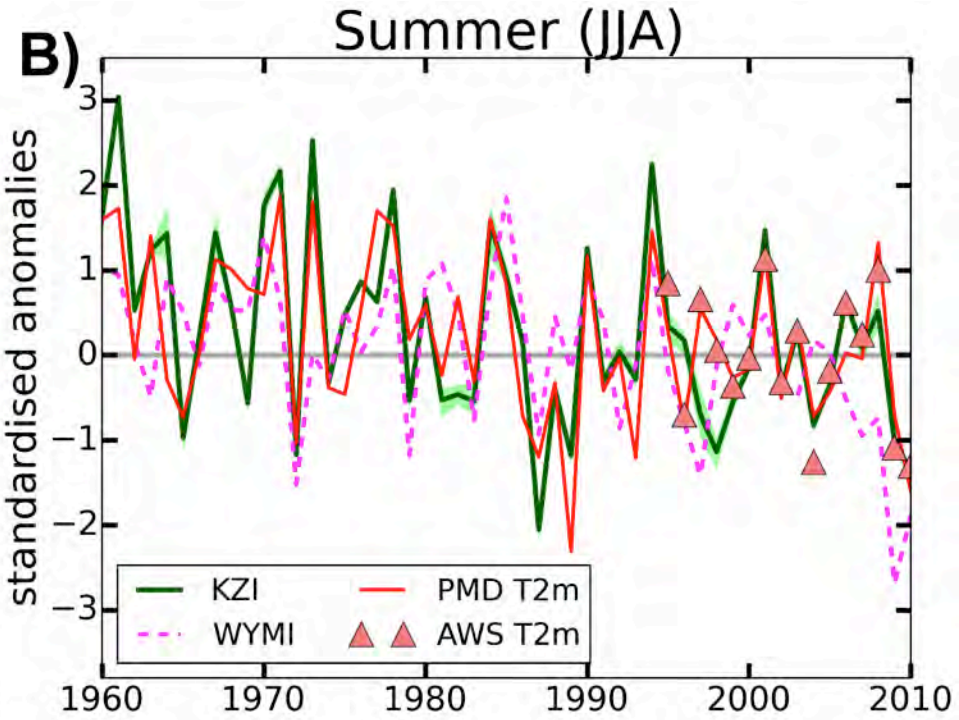
- A positive (negative) **KZI** state indicates an anomalous northward (southward) shift in the ‘intensity-position’ moment of the westerly jet relative to the climatological mean.



Forsythe et al., 2017

High correlation between KZI and summer T_{2m} in the Upper Indus

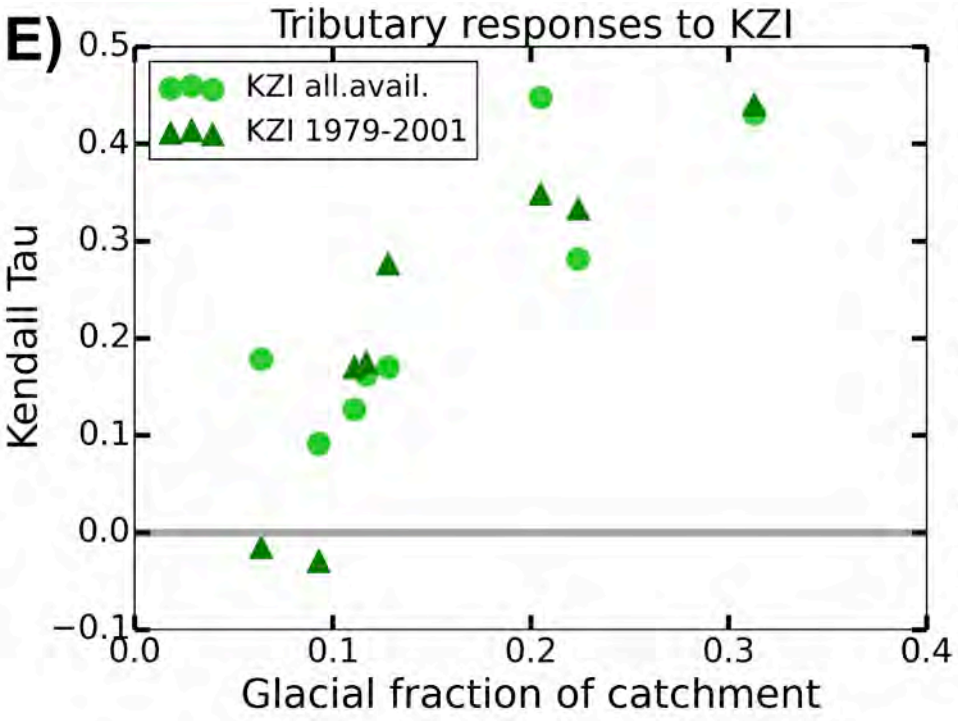


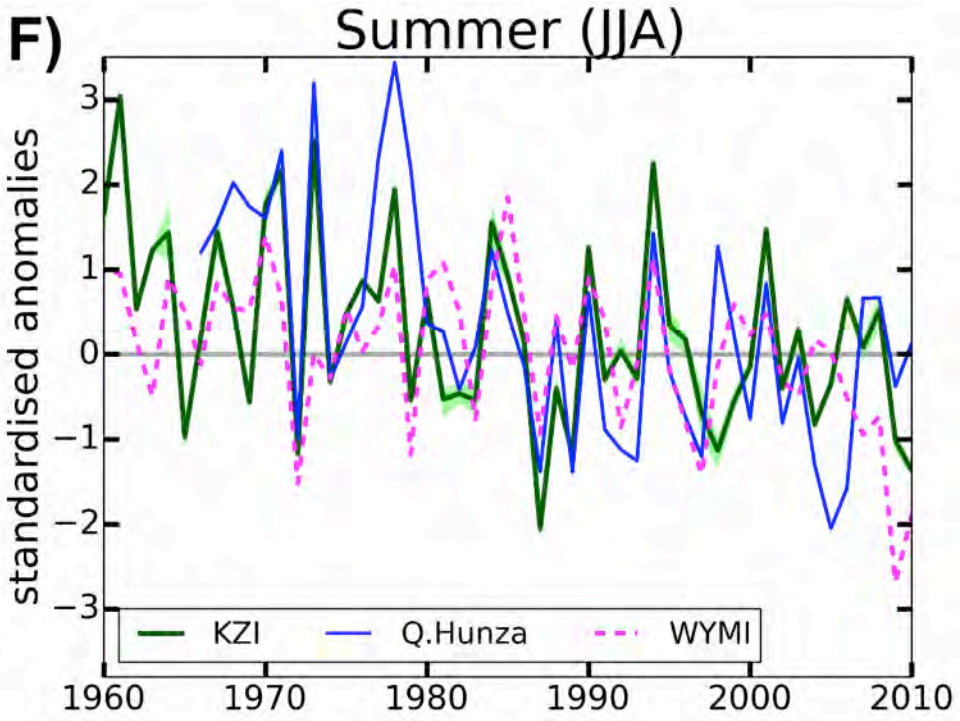


One positive (negative) standard deviation of KZI yields a Karakoram T_{2m} increase (decrease) of **0.59°C** (+/-0.19°C, R^2=0.32, p=0.005) in winter and **0.74°C** (+/-0.14°C, R^2=0.57, p<0.001) in summer.

Forsythe et al, 2017

High correlation between KZI and summer streamflow in the Upper Indus



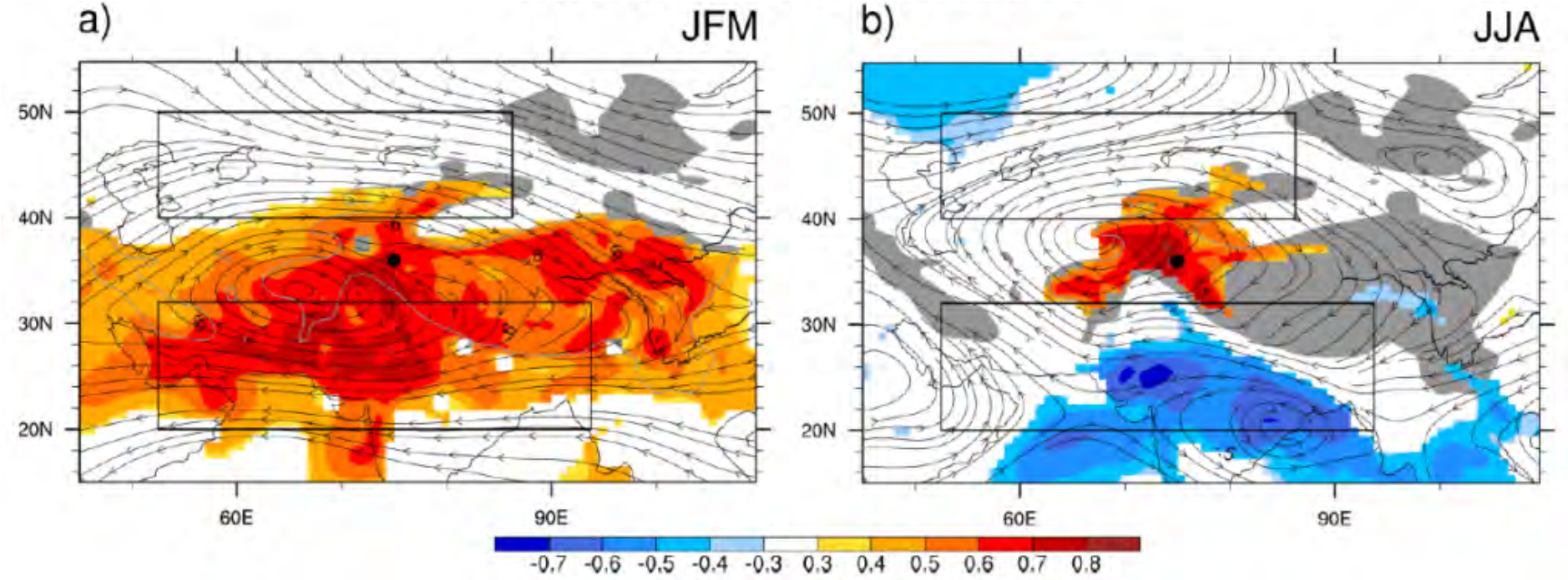


Summer streamflow from the "glacial-regime" Hunza tributary of the Indus **increases (decreases) by 13.6%** (+/-2.4%, R^2=0.405, p<0.001) **for one positive (negative) standard deviation of KZI.**

Forsythe et al, 2017

Warm High/Cold Low T_{2m} response to circulation state characterised by persistent anomalous regional vortex system – the "Karakoram Vortex" …

which could also be called the Western Tibetan Vortex



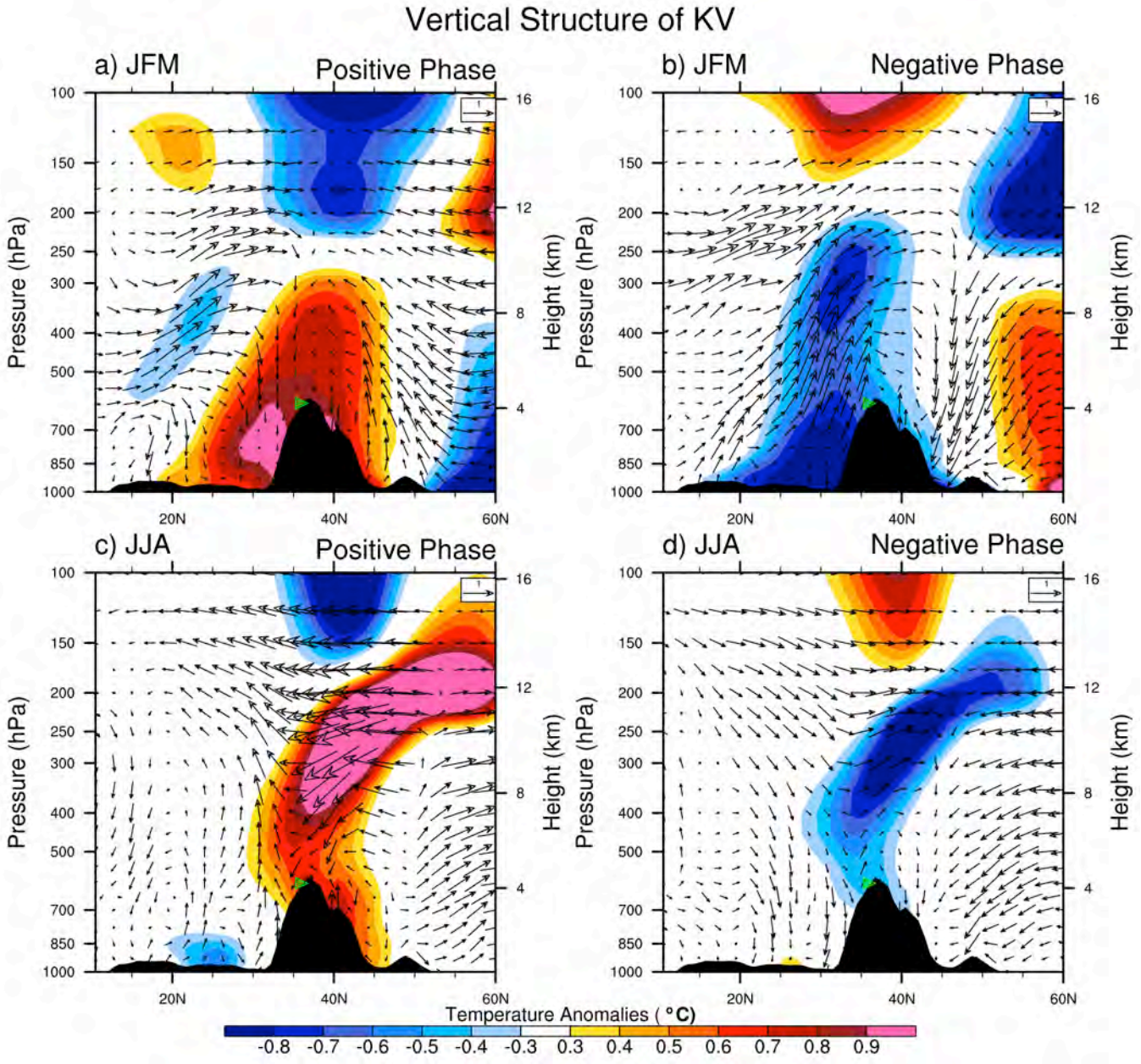
(1) Areas of positive (negative) correlation between KZI and T_{2m} correspond to anticyclonic (cyclonic) anomalies in winter (JFM) and summer (JJA).

(2) Winter correlations between the KZI and T_{2m} almost uniformly positive across HMA.

(3) In summer, positive correlations are restricted to the Karakoram and western tail of the Tibetan Plateau, while negative correlations cover the Indo-Gangetic Plains

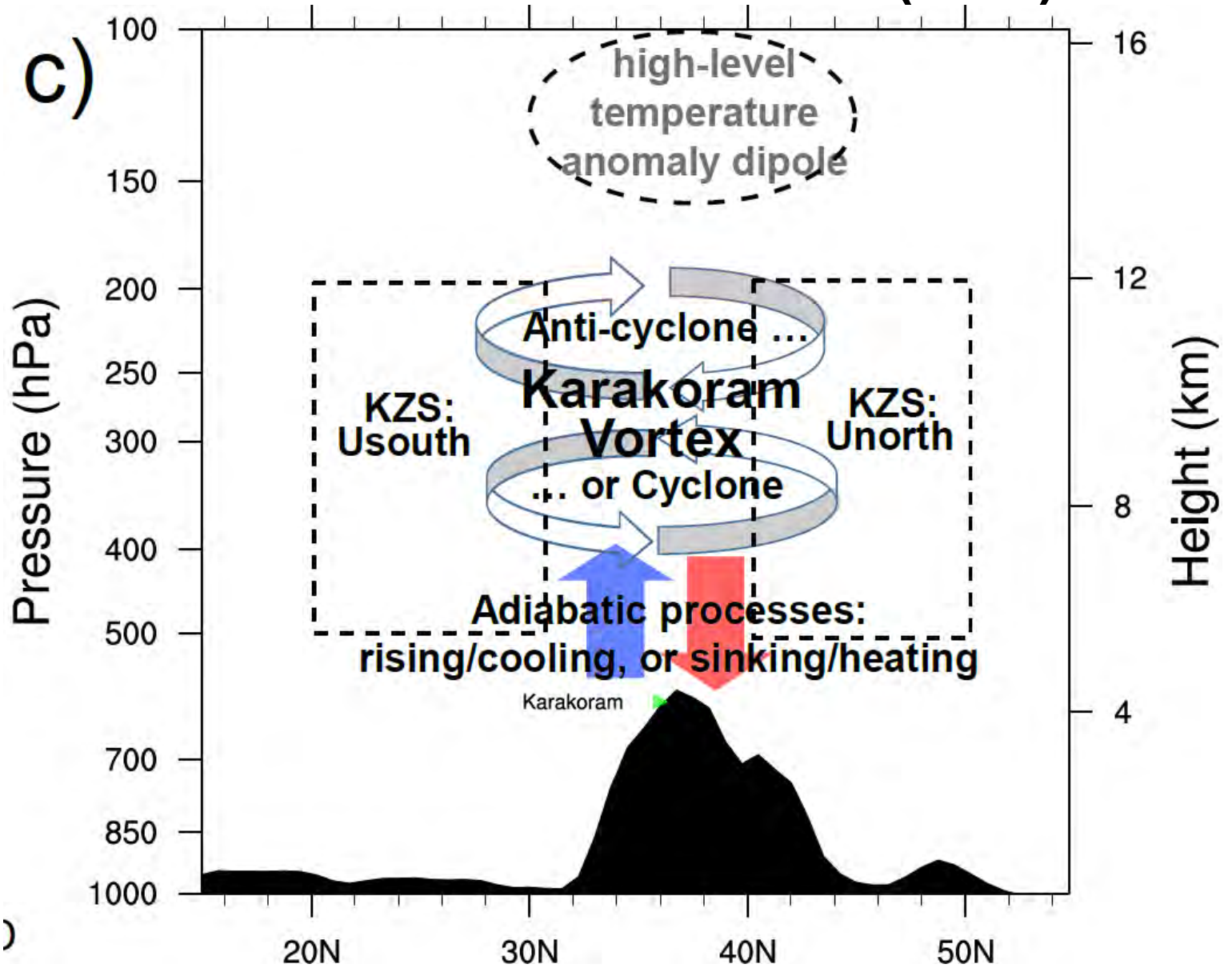
Forsythe et al., 2017

Vertical Structure of the Karakoram Vortex

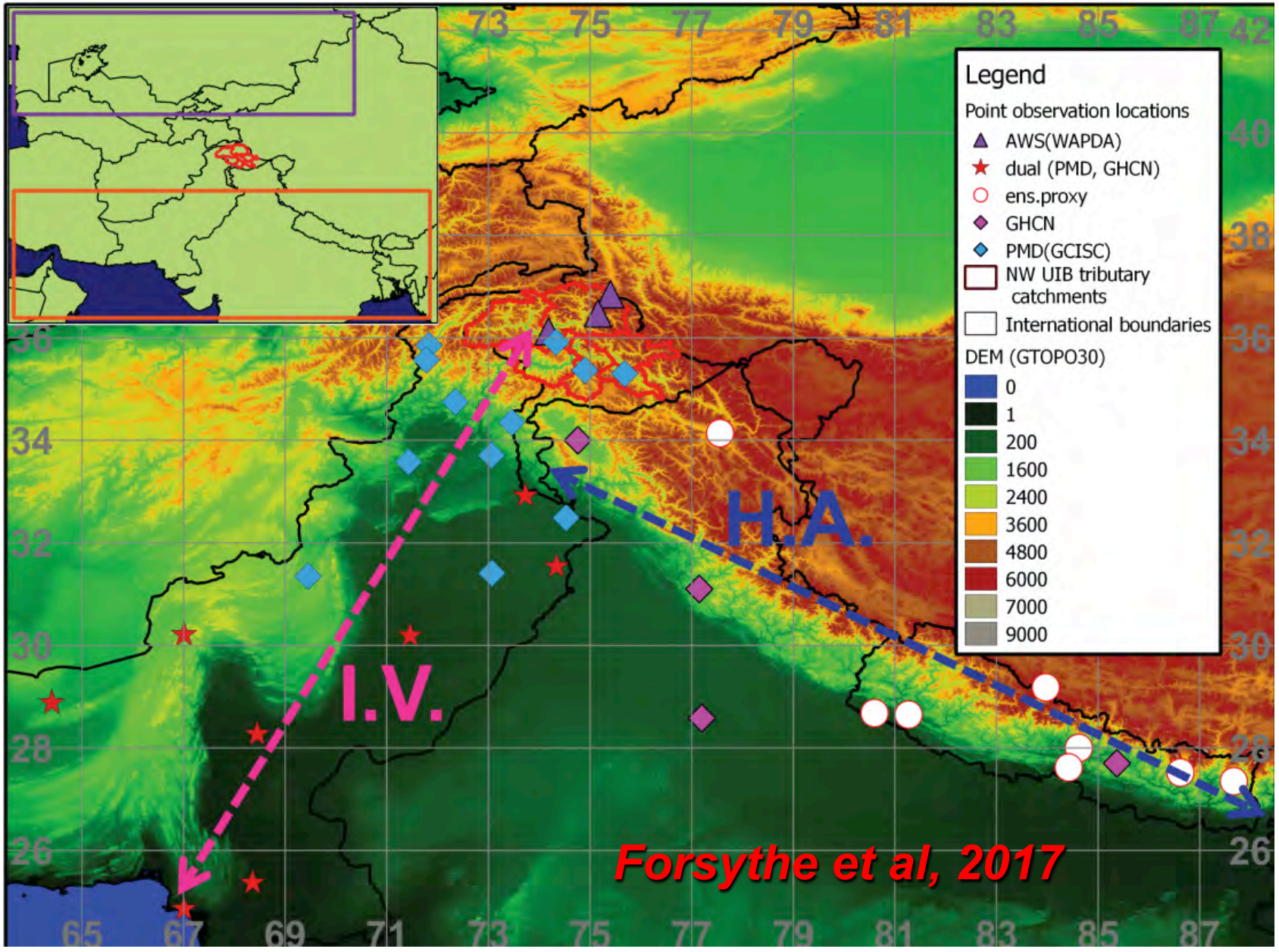


Forsythe et al., 2017

Conceptual explanation of the Karakoram Vortex (KV)

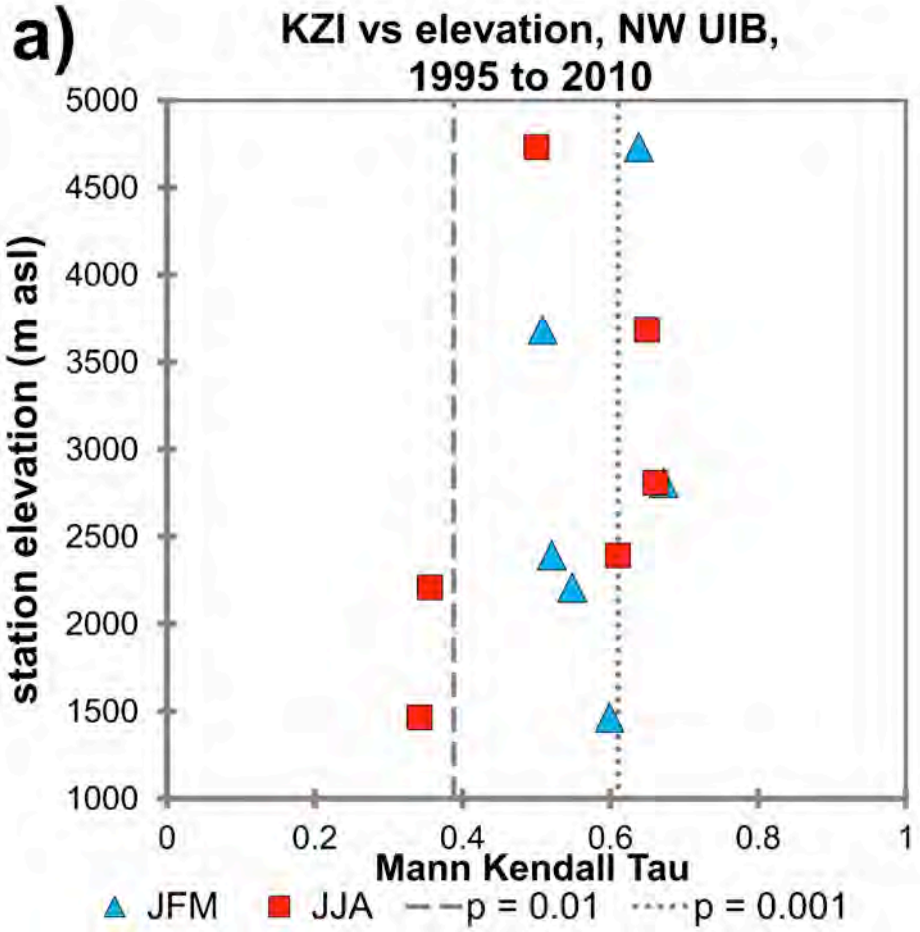


Spatial dimensions of KZI vs T_{2m}

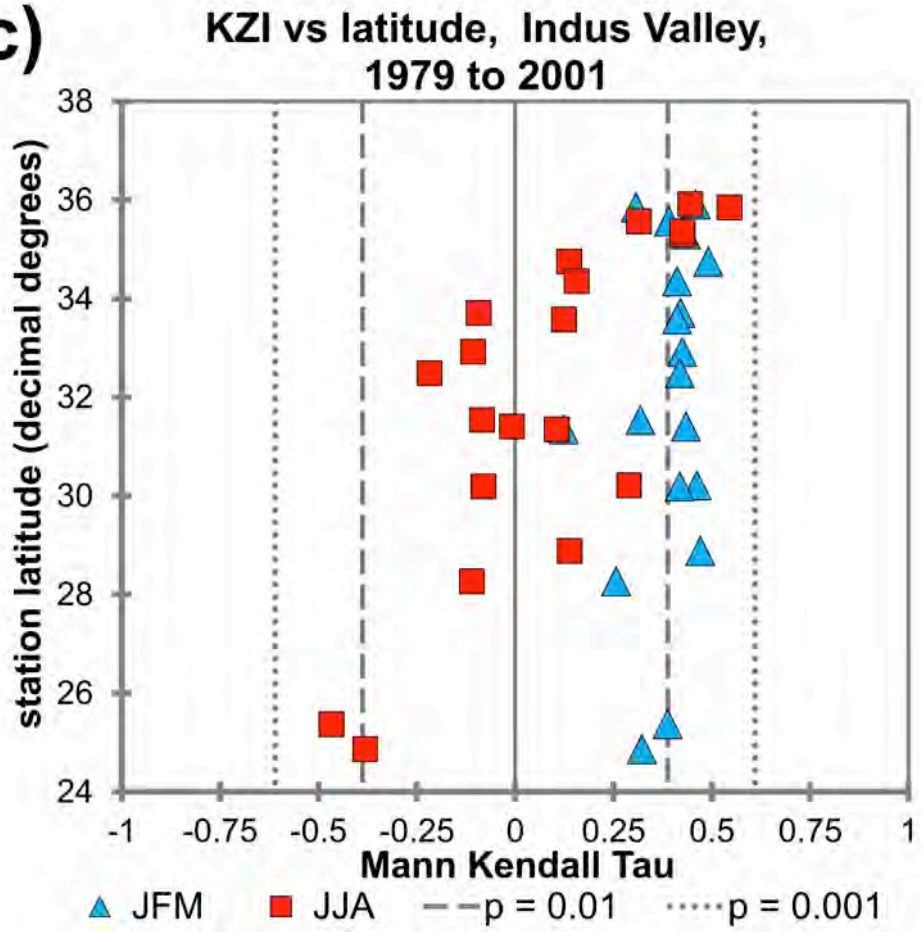


Spatial dimensions of KZI vs T_{2m}

Elevation dependence

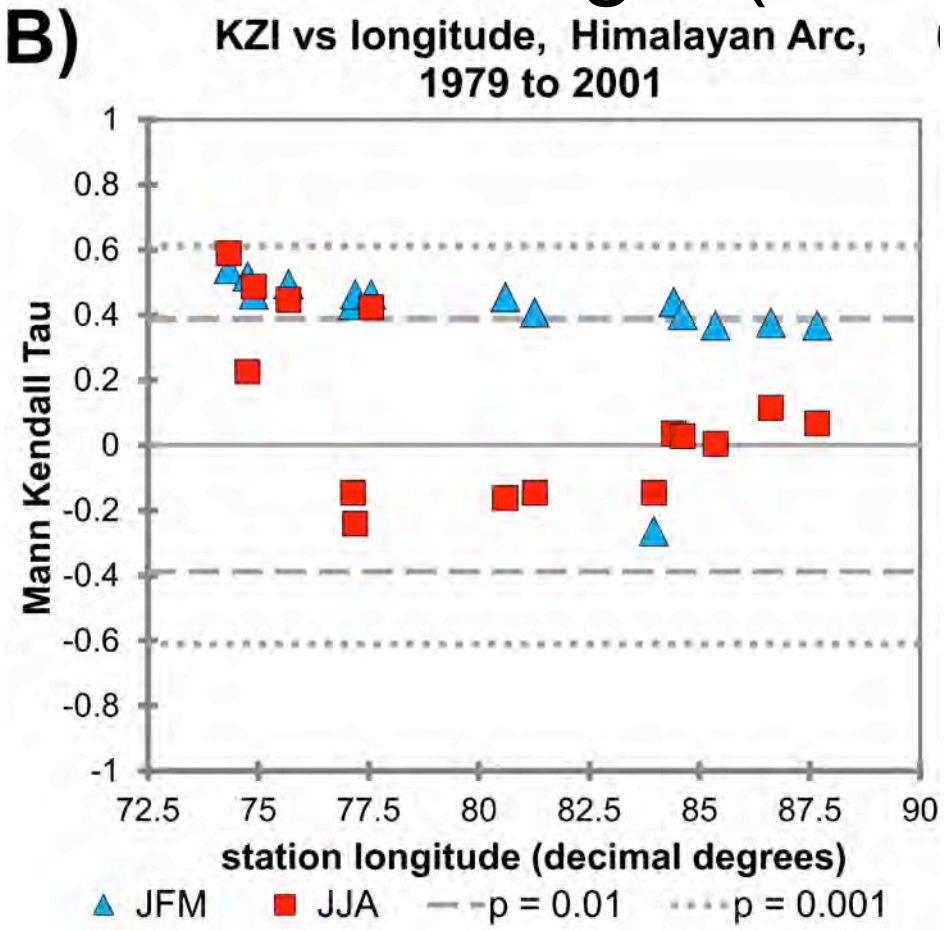


Latitudinal dependence



Forsythe et al., 2017

Spatial dimensions of KZI vs T_{2m}: longitudinal-dependency along the 3rd Pole's southern margin (Karakoram-Himalaya)

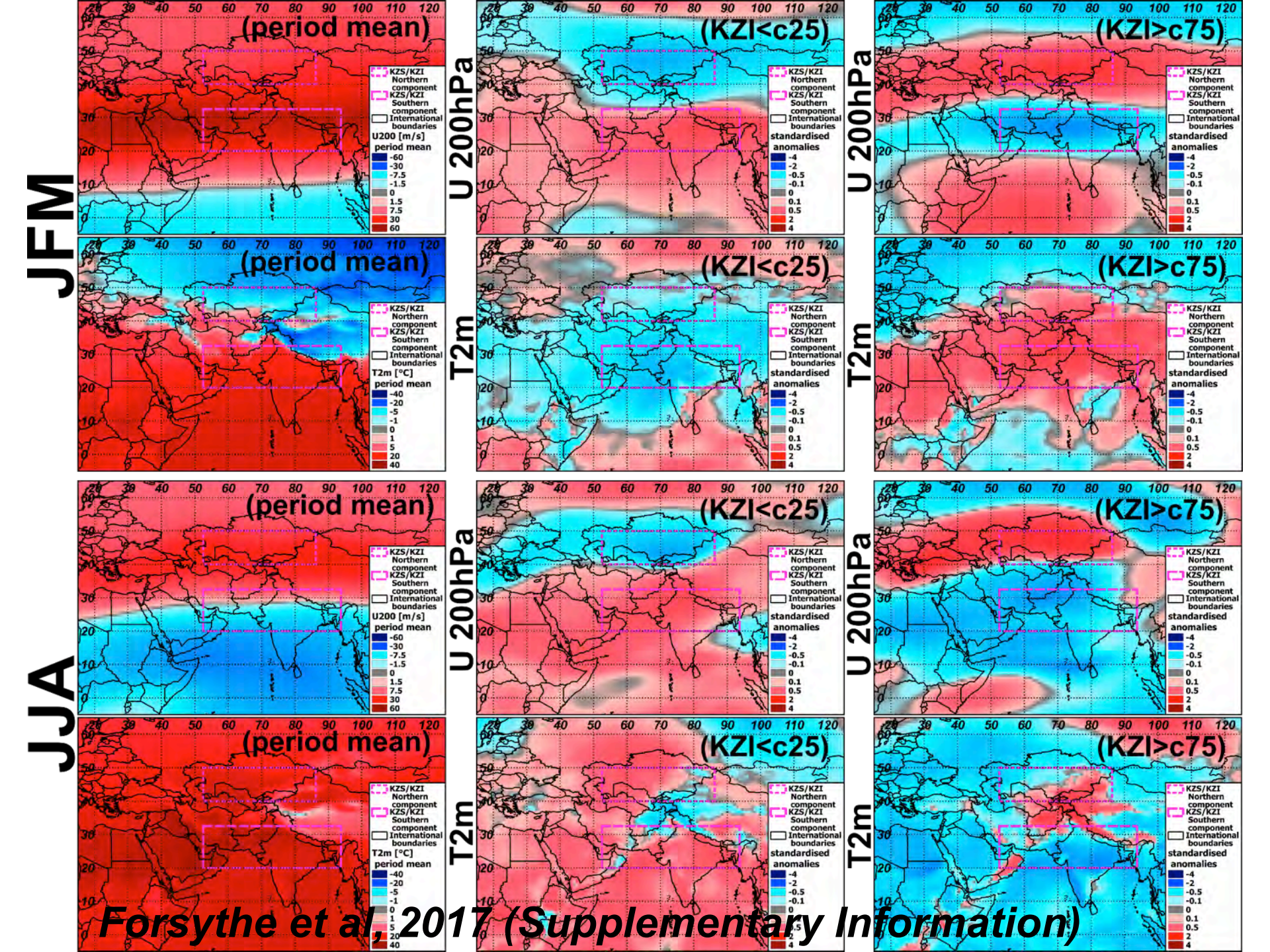


=> Regionally consistent strong positive correlations in late winter (JFM)

=> Sharp break in Summer (JJA) correlations between Leh (positive) and Shimla (negative) at ~77.5°E

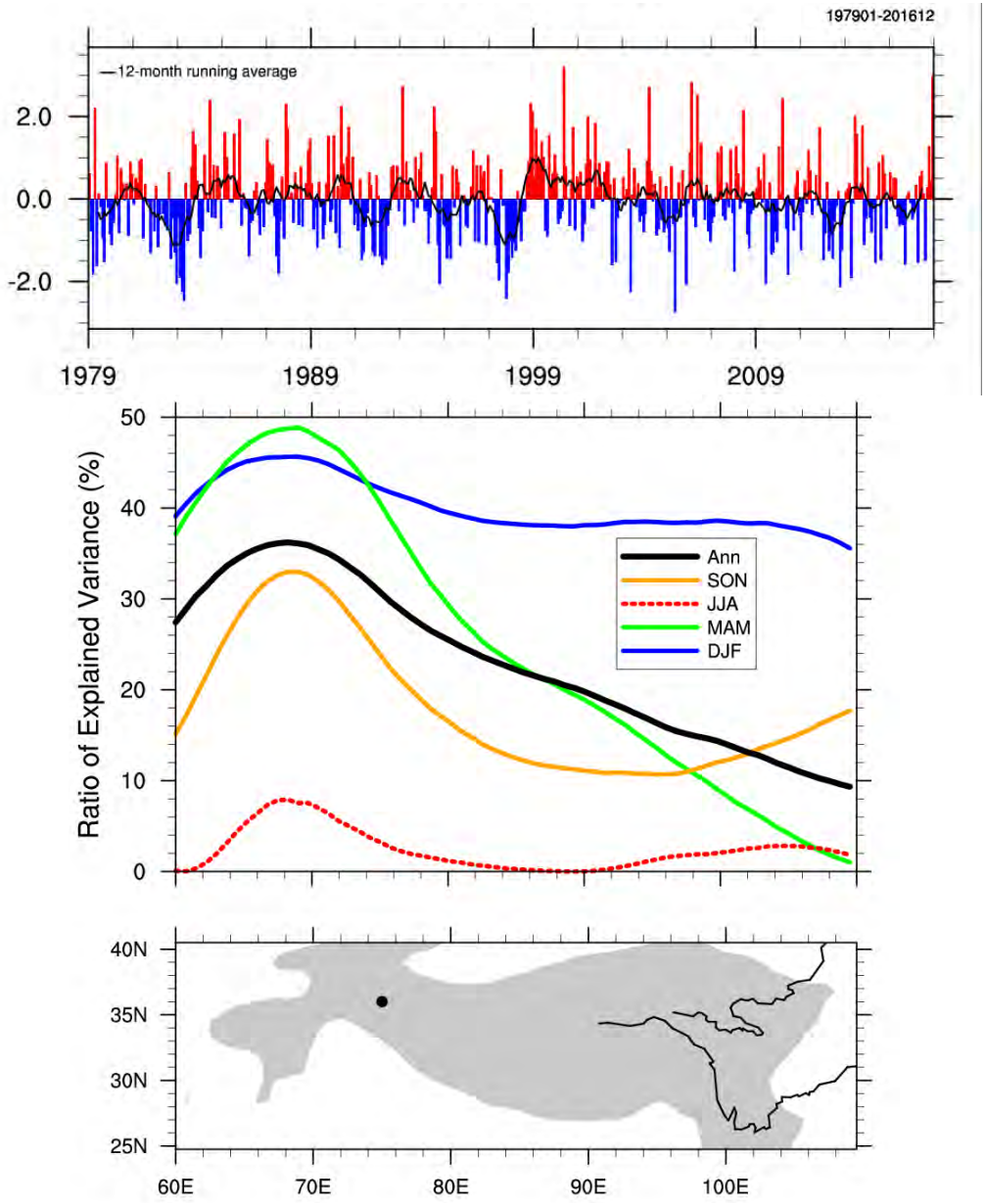
Forsythe et al, 2017

Differentiated JJA response provides a possible physical mechanism for "Karakoram Anomaly"



Forsythe et al, 2017 (Supplementary Information)

On-going & future KZI/KV-related work



While initial KZI-research focused on key, contrasting seasons (JFM vs JJA), current and future work will examine the **complete annual cycle**.

Substantial research is underway and/or planned to investigate:

a) the seasonal variability of KZI influence over the **entire 3rd Pole** (longitudinal) domain;

b) **thermodynamic processes** linked to the Karakoram Vortex;

c) **multi-decadal/20th century variability** of KZI/KV and its links to sub-regional climate;

d) Representation of **KZI/KV in GCMs**.

examples from Li et al, in review in Climate Dynamics

Summary

1. A regional circulation index, the **"Karakoram Zonal Index"**, (**KZI**) quantifies the **latitudinal position-intensity moment** of the **"westerly jet"** upstream of the western 3rd Pole.

2. The **KZI** **explains a substantial portion** of Karakoram **variance** in seasonal T_{2m} and streamflows from heavily glaciated Upper Indus tributary catchments in recent decades.

3. The Karkoram Vortex provides a **physical mechanism** for the response of Karakoram seasonal T_{2m} to the **KZI** (warm high/cold low systems with strong vertical motion/adiabatic effects).

3. Sub-regional **differences** in **JJA KZI-T_{2m} response** constitute a **climatic mechanism** to at least partly explain the **"Karakoram Anomaly"** through glacial melt (runoff).

4. Global reanalyses reproduce KZI influence on T_{2m} suggesting **skilled** GCMs should be **capable of reproducing KZI** characteristics.

5. On-going and future work will add insight into the atmospheric processes linked to the Karakoram Vortex (quantified by **KZI**).


Thank you for your time!
Your questions & comments
are most welcome !