Twenty-first century glacier slowdown driven by mass loss in High Mountain Asia

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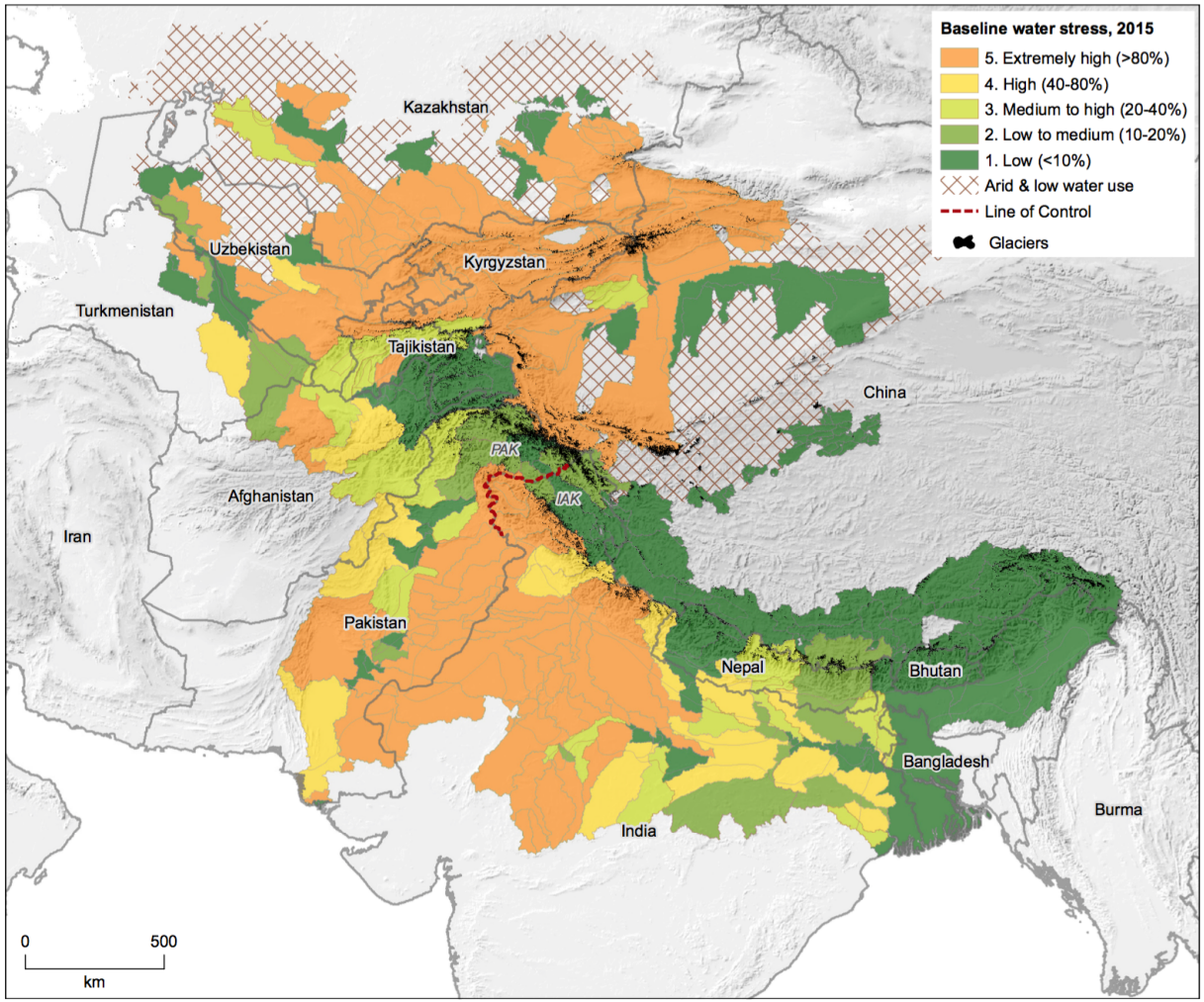
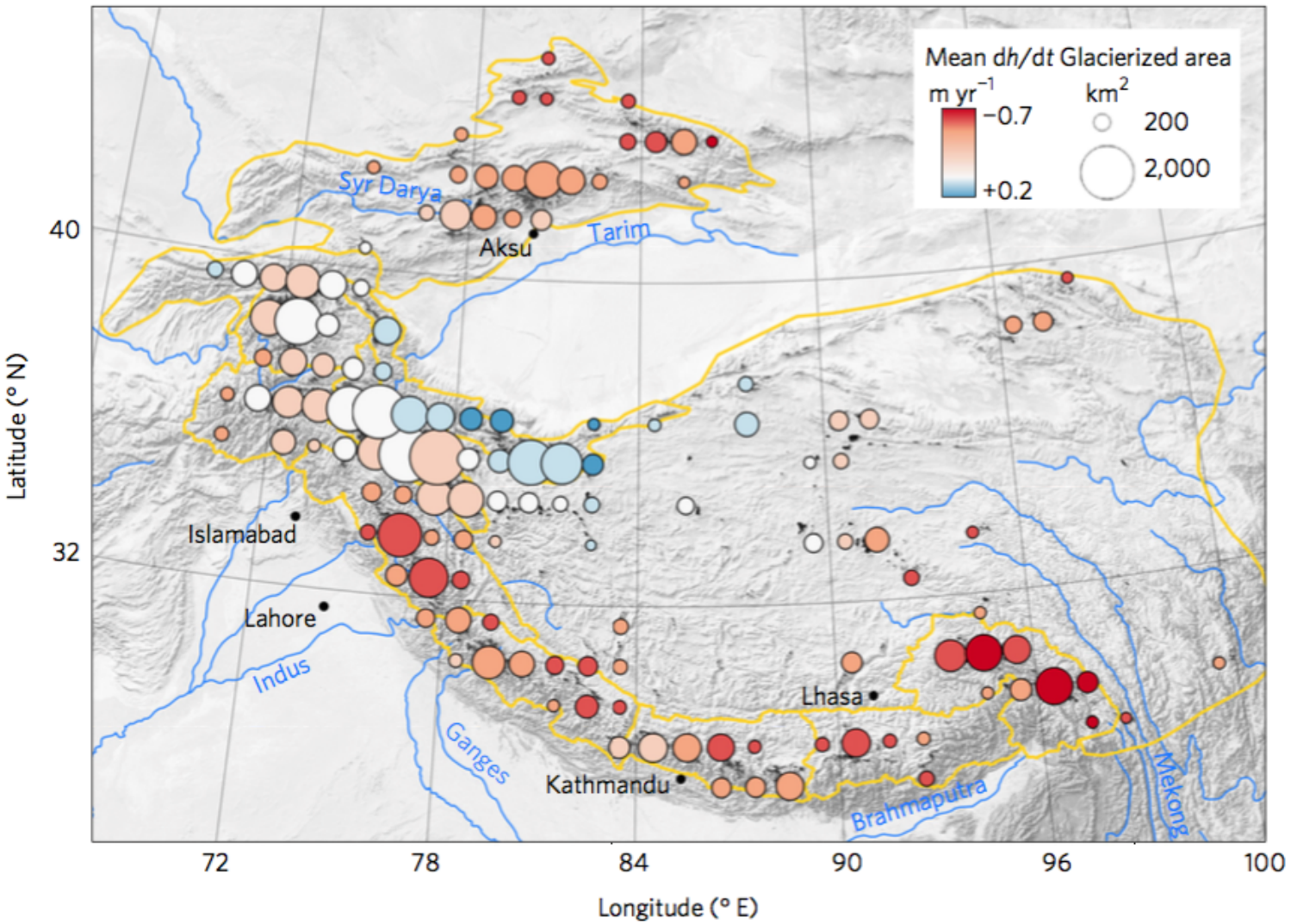
High Mountain Asia - The third pole

- Glaciers cover 118.200 km^2 (31 mm SLE) [Huss & Farinotti 2012]
- Water resources for >1.4 billion people [Immerzeel 2010]



Water stress 2015 [Pritchard 2017]

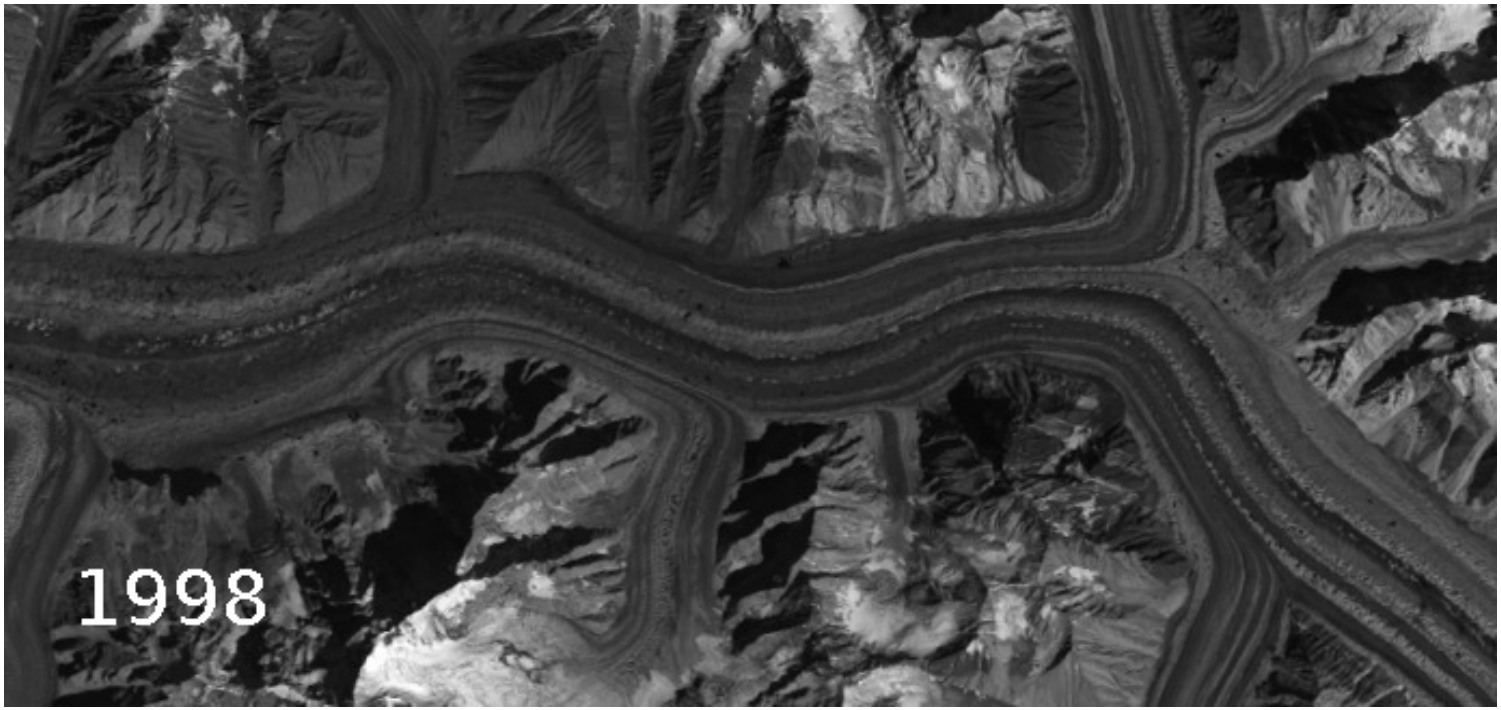
High Mountain Asia - Glacier evolution



Elevation change trends 2000-2016 [Brun et al., 2017]

Objectives

What is the dynamic response of glaciers to the climate forcing ?



⇒ Generate ice flow velocities from feature-tracking at the scale of the High Mountain Asia from optical satellite images (Landsat).
⇒ Investigate link between mass changes and ice flow.

Automated observation of ice flow velocities

Inputs

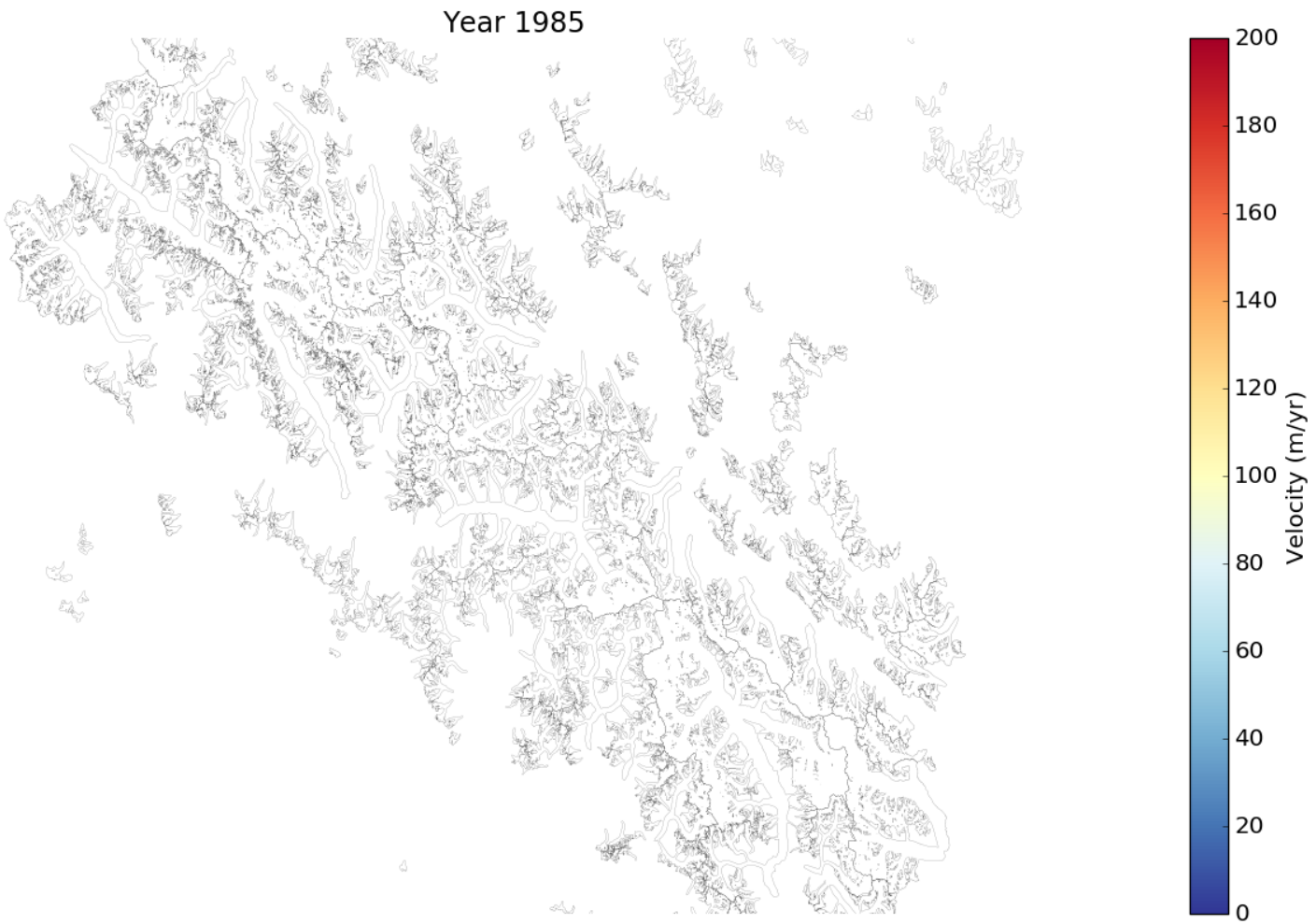
- Landsat 8 panchromatic (15 m) - 2013-
- Landsat 7 panchromatic, incl. SLC-off (15 m) - 1999-
- Landsat 4/5 PCA of B1, B2, B3, B4 (30 m) - 1985-2010

Overview

- JPL autonomous Repeat Image Feature Tracking [*Gardner et al.*, 2017]
- Normalized-cross correlation
- Pre-processing : Wallis filter, Fourier filtering (along-track banding)
- Automatically detect variable search distance
- Progressive template size [16, 32, 64, or 128 pix]

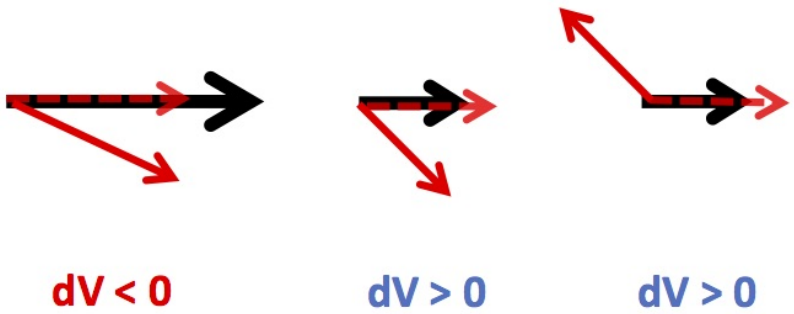
16 days to $\sim$1 year pairs $\Rightarrow$ **>2 million image pairs over HMA !**

Annual time series - 1985-2017 - Karakoram

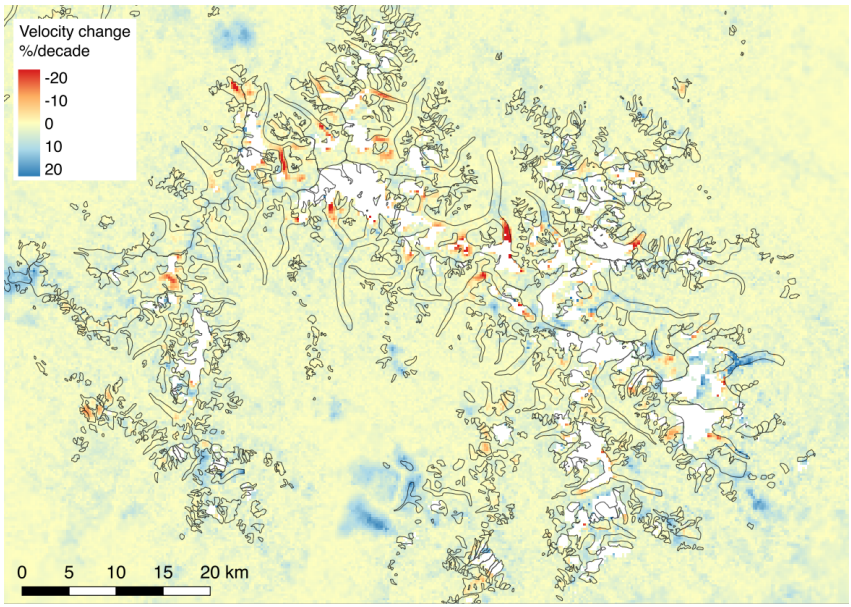


How to quantify a change in velocity ?

Velocity magnitude difference



dV < 0 dV > 0 dV > 0



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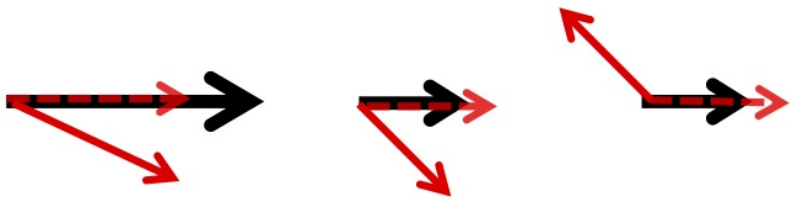
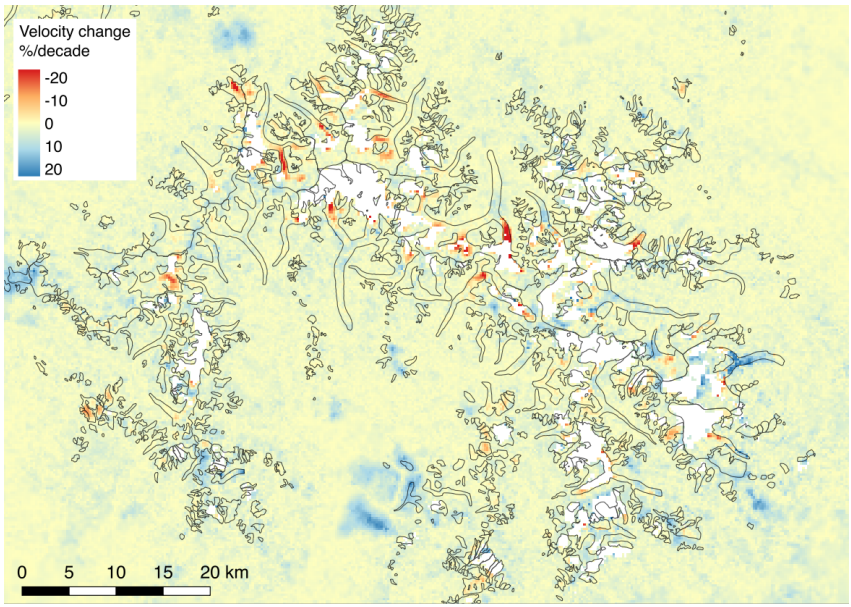
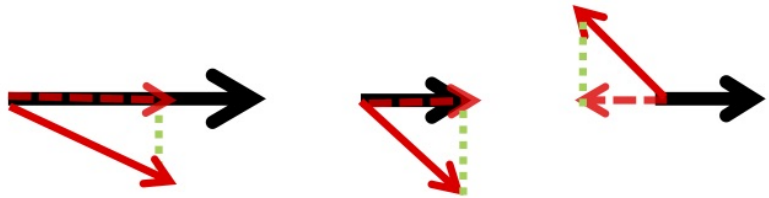


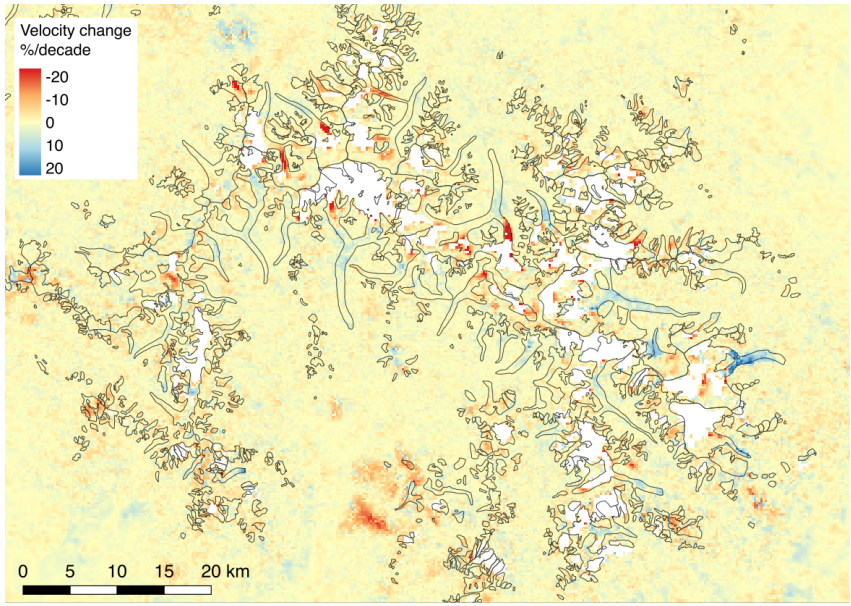
dV < 0 dV > 0 dV > 0



"Velocity anomaly"

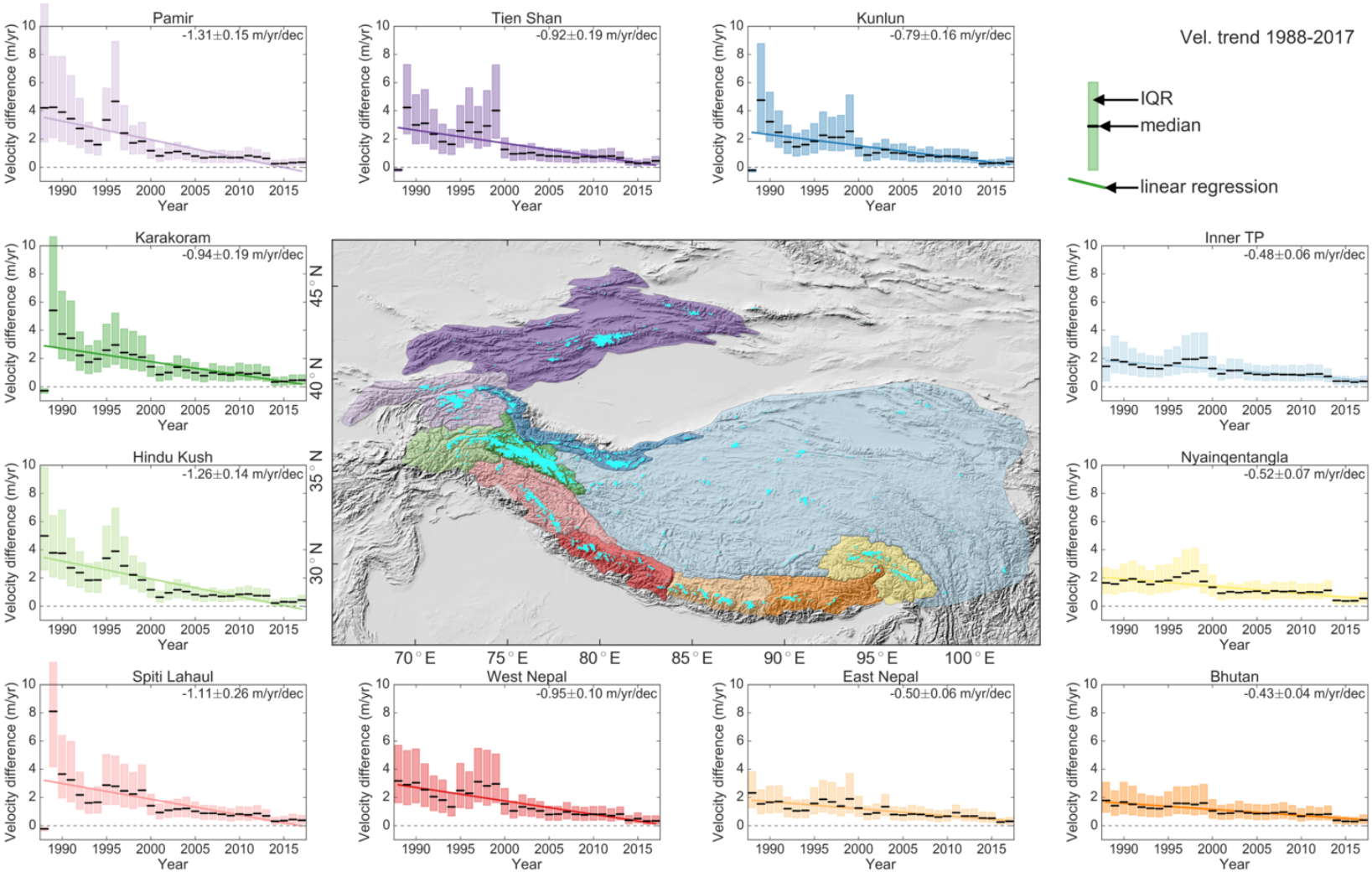


dV < 0 dV > 0 dV < 0



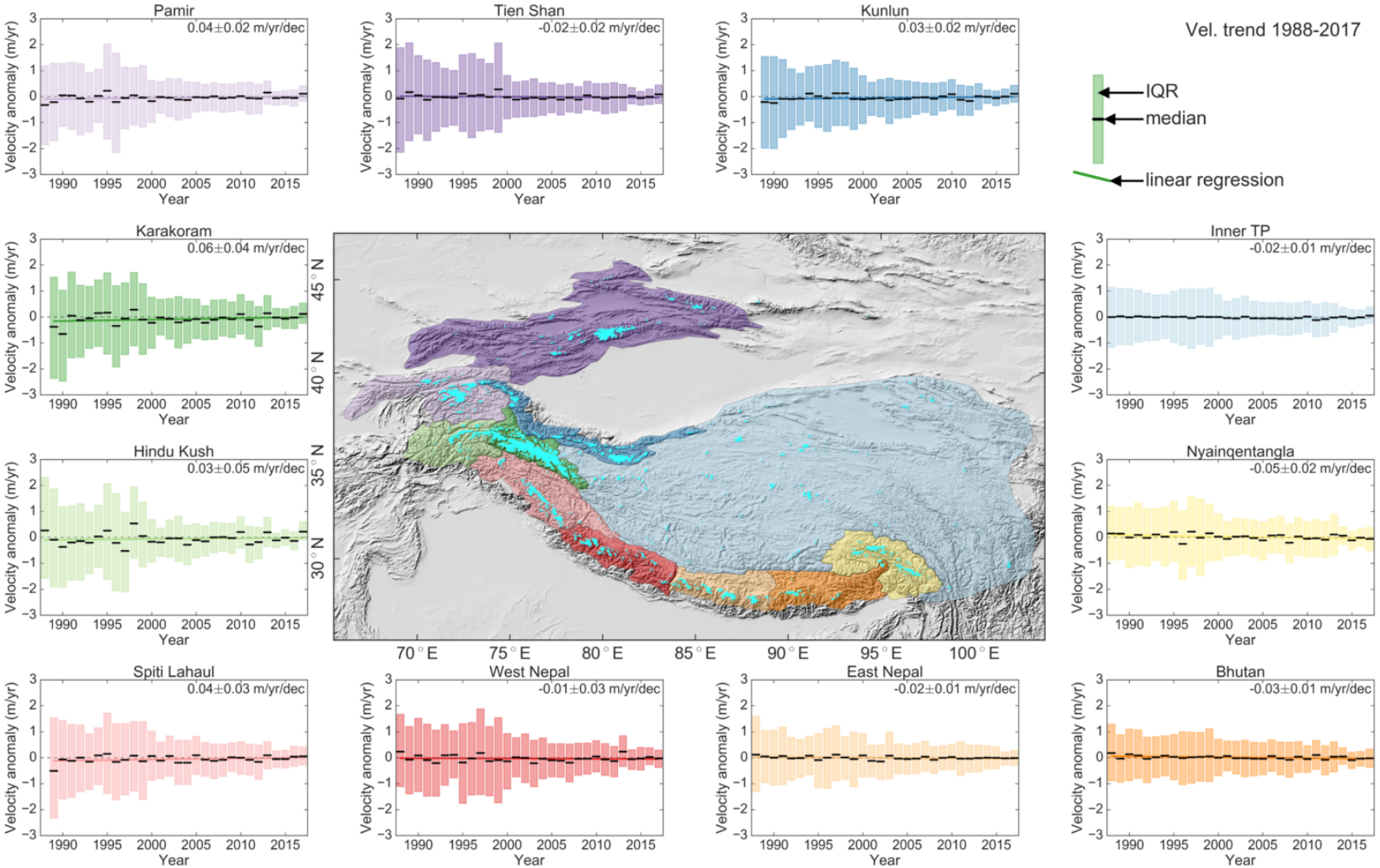
How to quantify a change in velocity ? - Off ice

Velocity magnitude difference

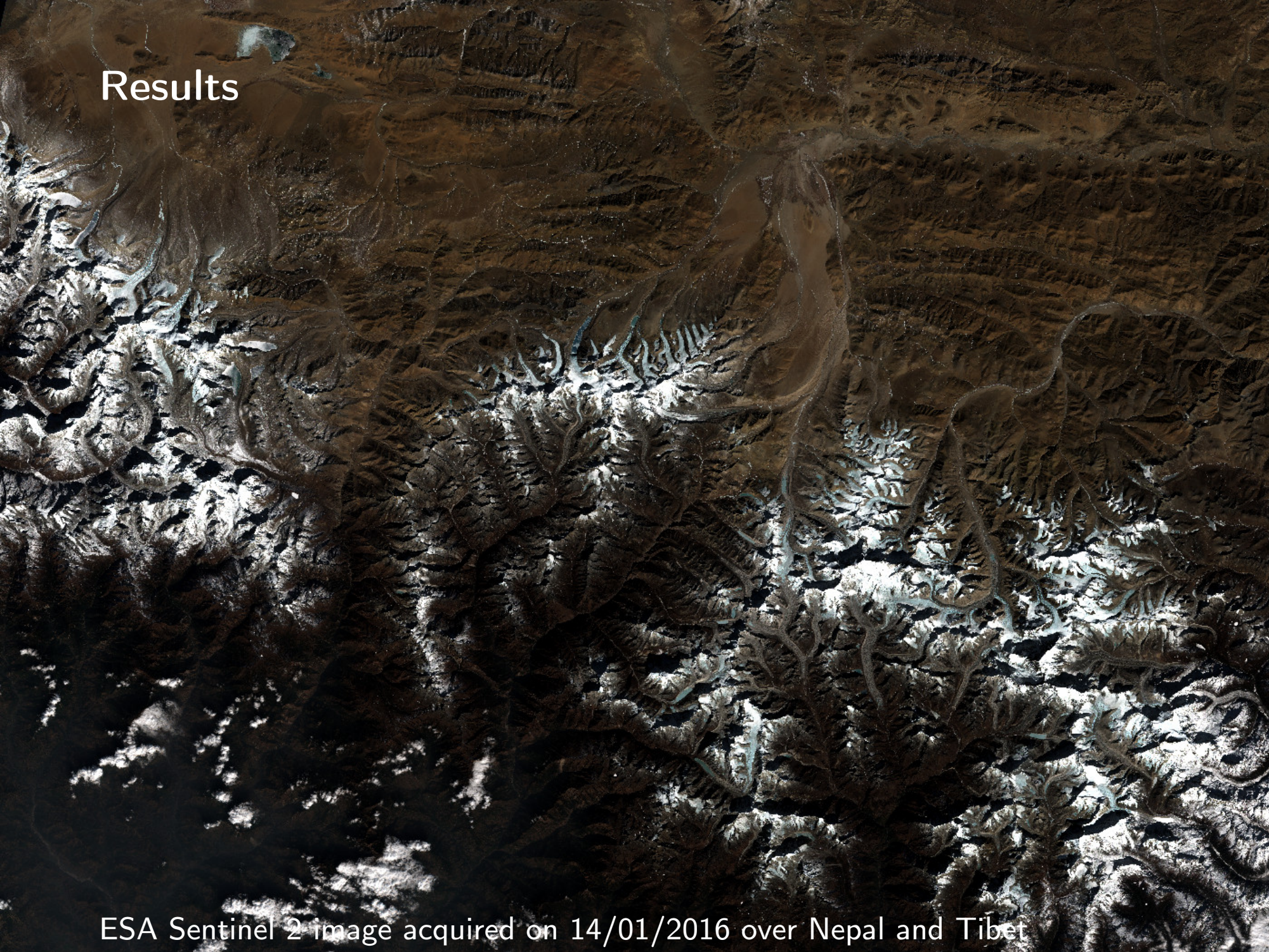


How to quantify a change in velocity ? - Off ice

Velocity anomaly

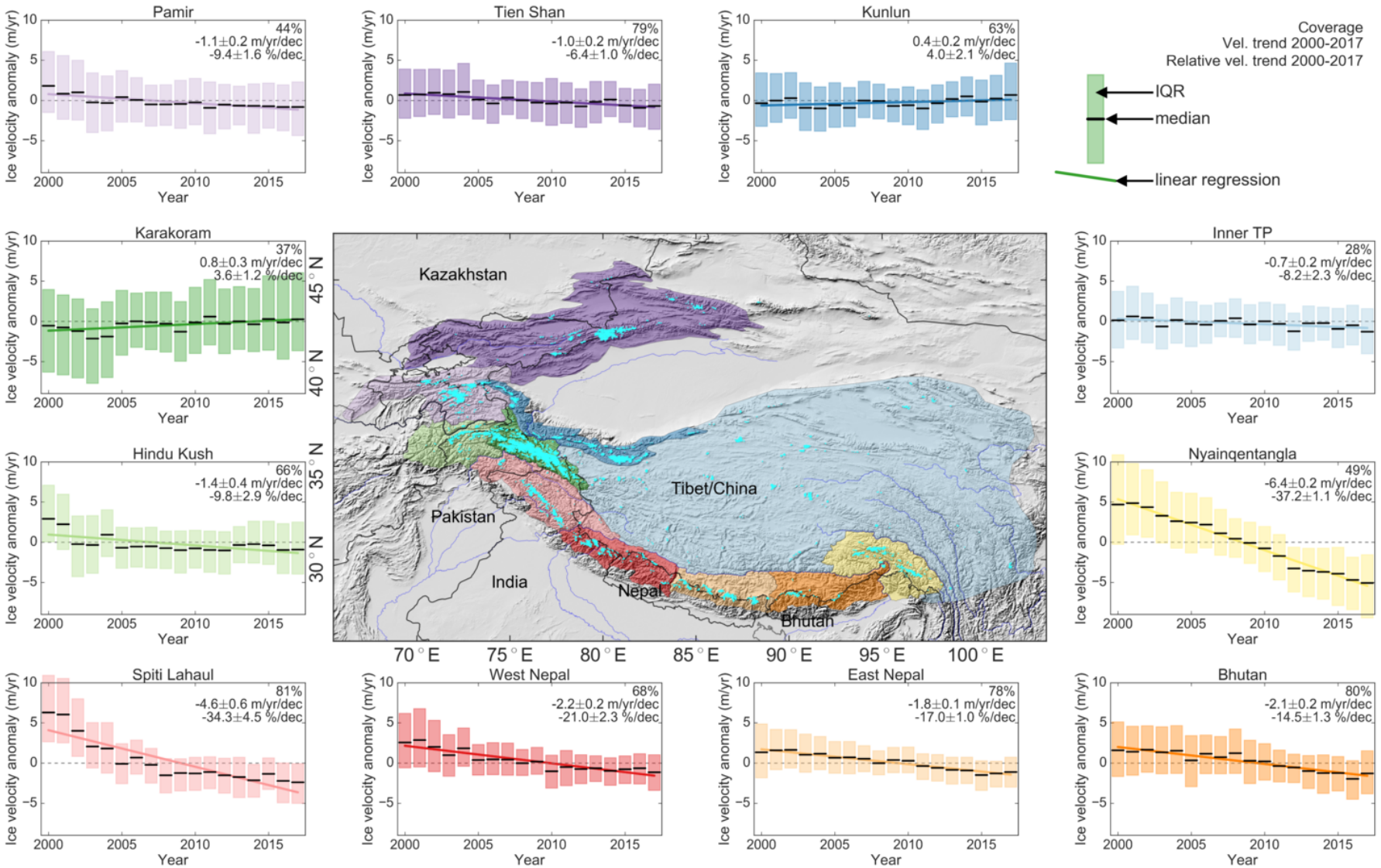


Results



ESA Sentinel 2 image acquired on 14/01/2016 over Nepal and Tibet

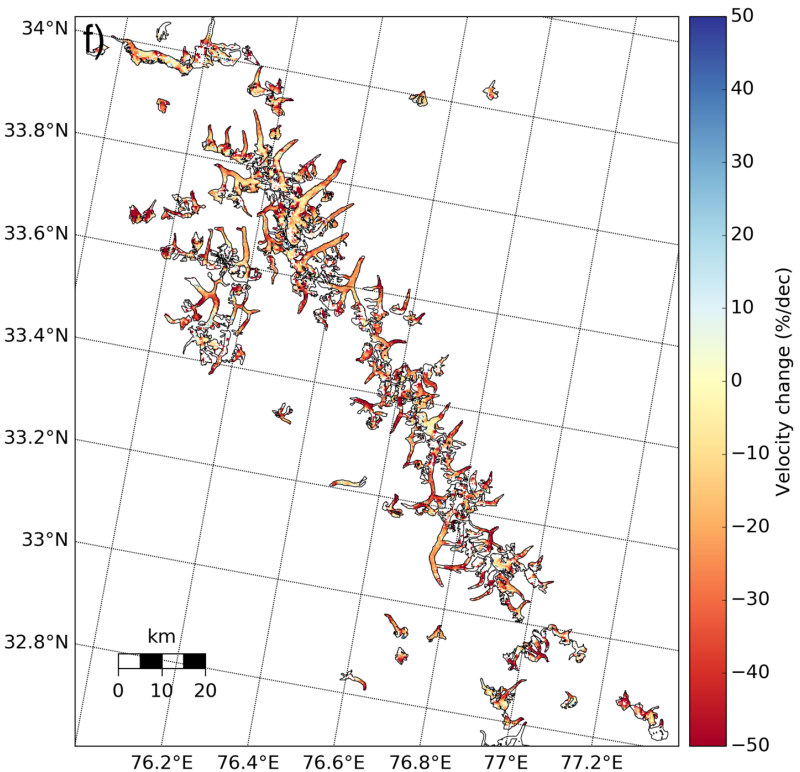
Velocity anomaly time series 2000-2017



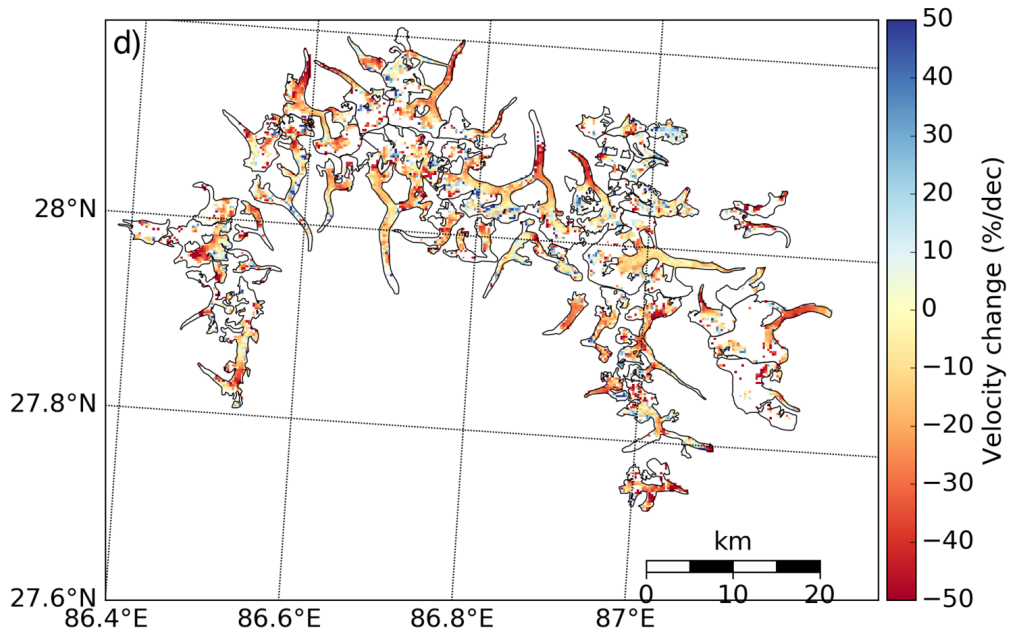
- Most glaciers slowing down, concomitant with ice thinning
- Break in trends in the western regions

Velocity trend 2000-2016

1. Calculate a linear trend in velocity in each 240m x 240m pixel



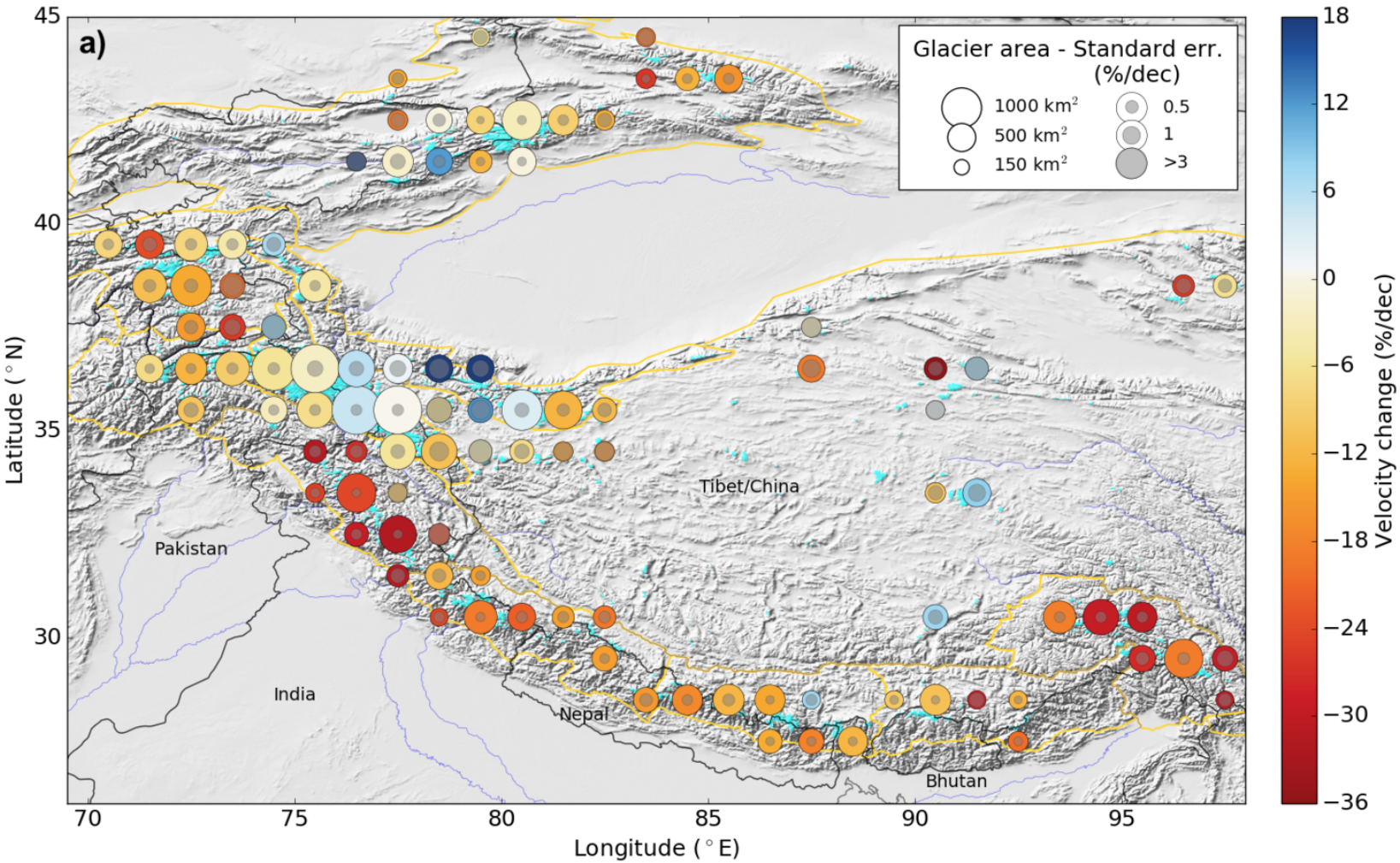
Spiti Lahaul



Everest

Regional trends 2000-2016

2. Regional average on a 1 x 1 degree grid



⇒ Velocity trends mirror elevation change

Regional trends 2000-2016

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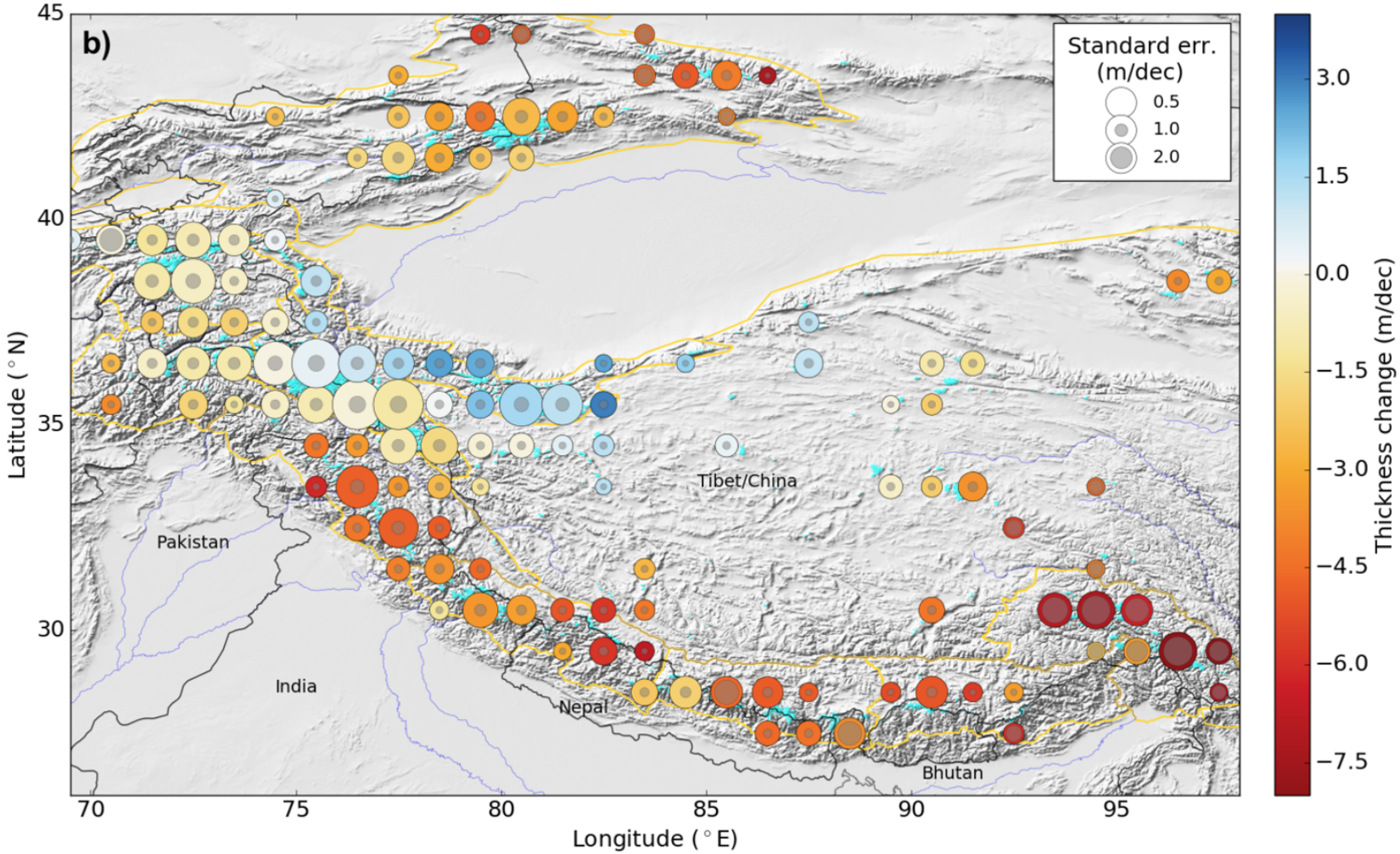
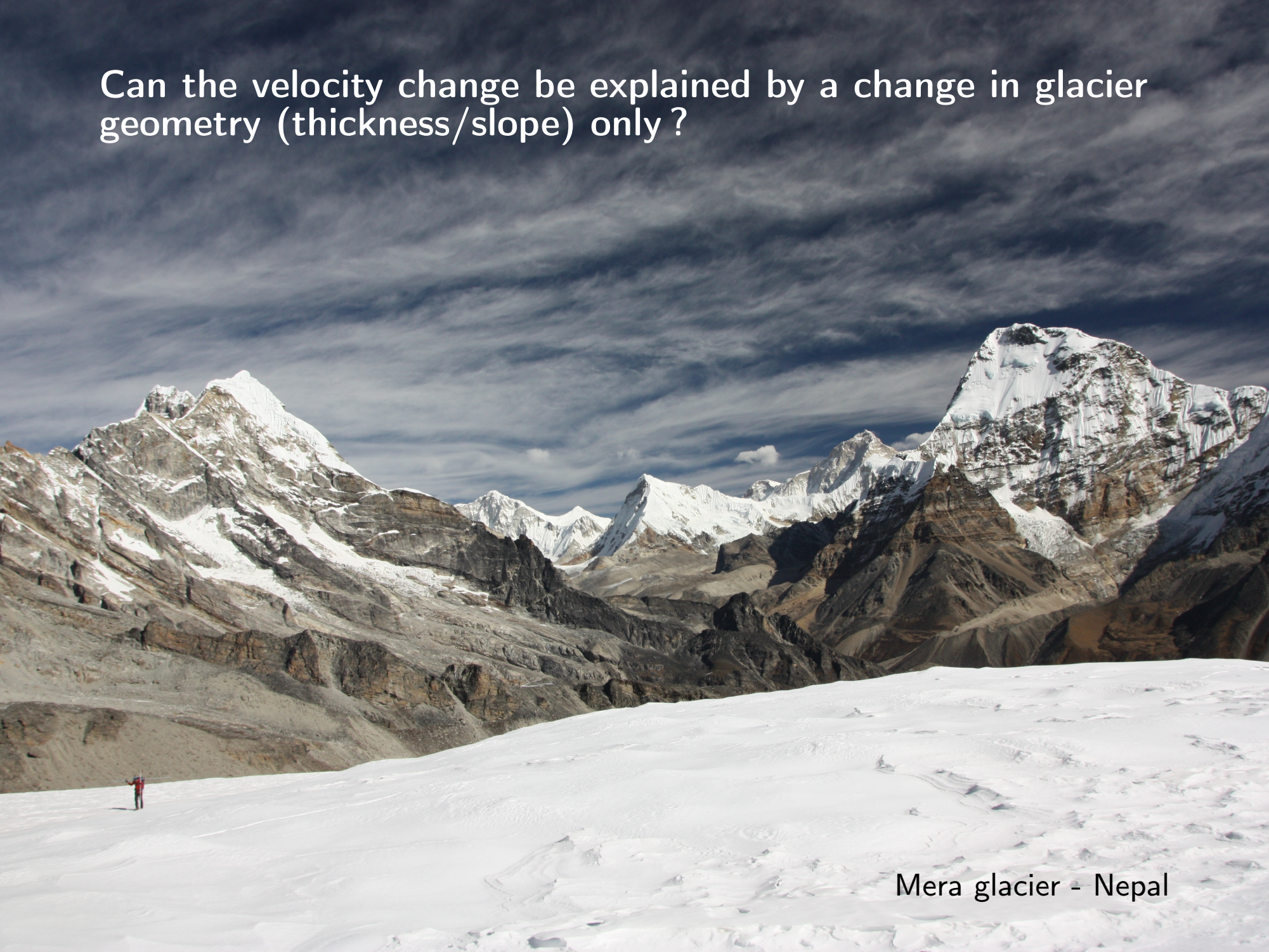


⇒ Velocity trends mirror elevation change

Can the velocity change be explained by a change in glacier geometry (thickness/slope) only ?



Mera glacier - Nepal

Relationship thickness vs velocity change

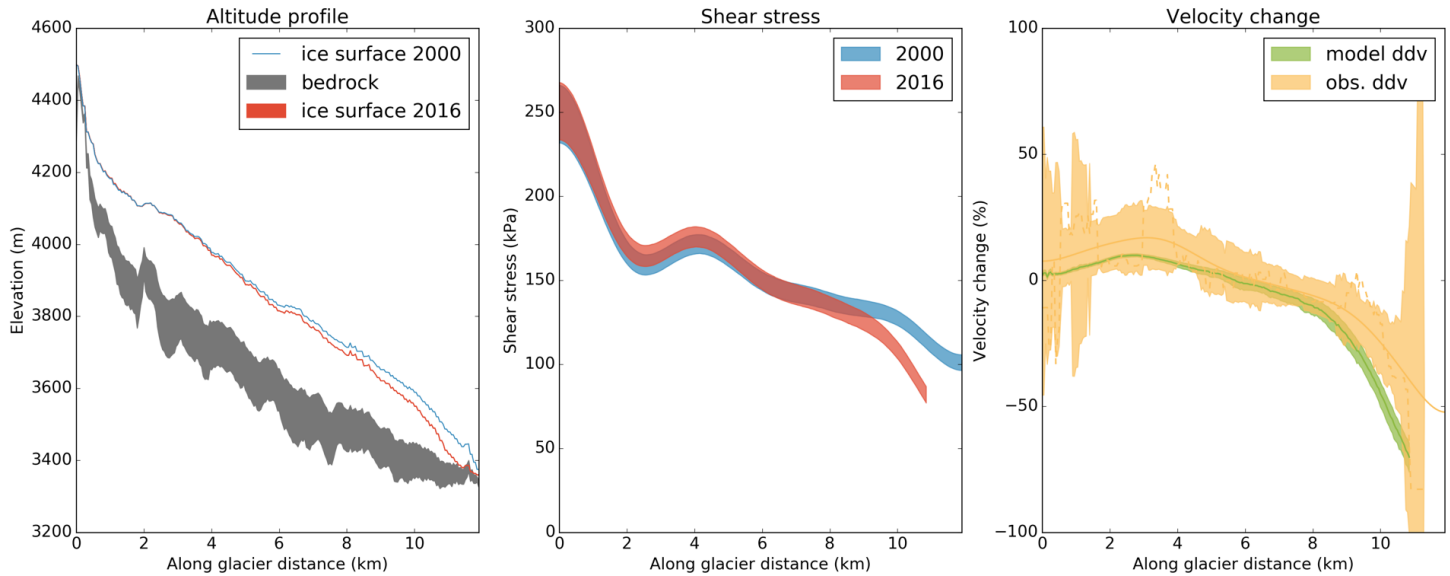
Driving stress (we know)

$$\tau(x) = \rho g H(x) \frac{\partial S}{\partial x}(x) \quad (1)$$

Surface velocity (we hypothesize)

$$U_s = C\tau^m \quad (2)$$

1. We calculate the change in driving stress along glaciers centre flow lines

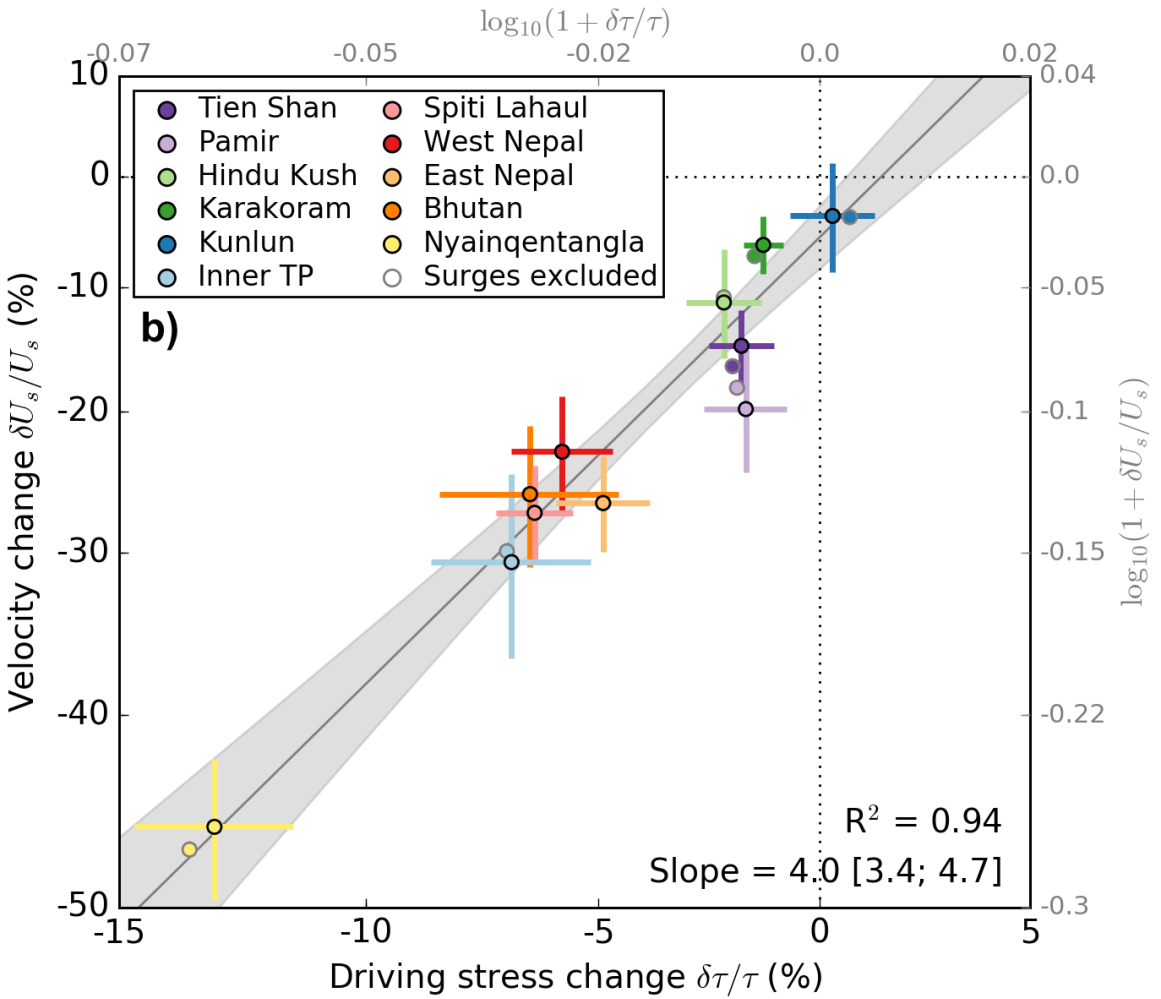


Inputs :

- Modelled bed topography [Huss & Farinotti 2012]
- Observed elevation changes [Brun et al., 2017]

Relationship thickness vs velocity change

2. We compare regional averages of driving stress change vs velocity change



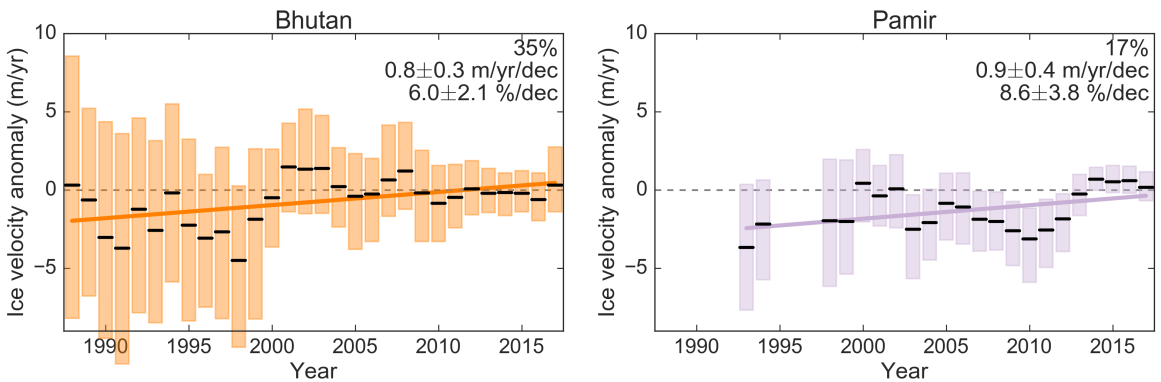
⇒ The change in driving stress (thickness + slope) explains 94% of the inter-regional variability in velocity change !

Conclusions

- Main trend is slow-down of glaciers over 2000-2017.
- Velocity change mirrors thickness change ⇒ Climate-driven
- Velocity change largely explained by changes in driving stress, and primarily thickness :
  ⇒ Changes in basal conditions do not matter at regional/decadal scales
  ⇒ Changes in glacier flow can be modelled from surface observations only

Methodological aspects : <u>be aware of biases !</u>

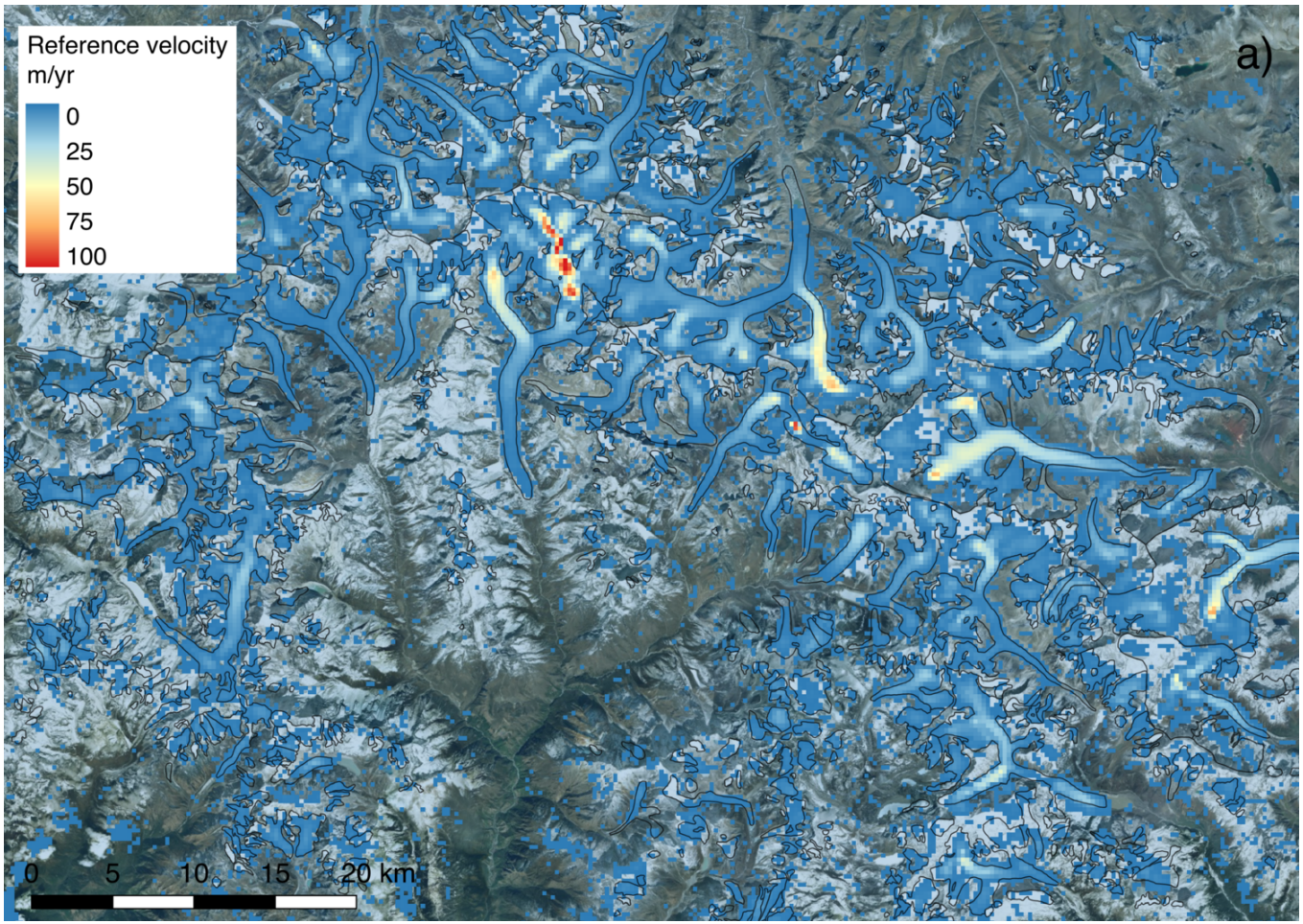
- Use of "velocity anomaly" recommended when SNR low
- Biases exist between velocity obtained from different Landsat missions



ESA Sentinel 2 image acquired on 14/01/2016 over Mount Everest

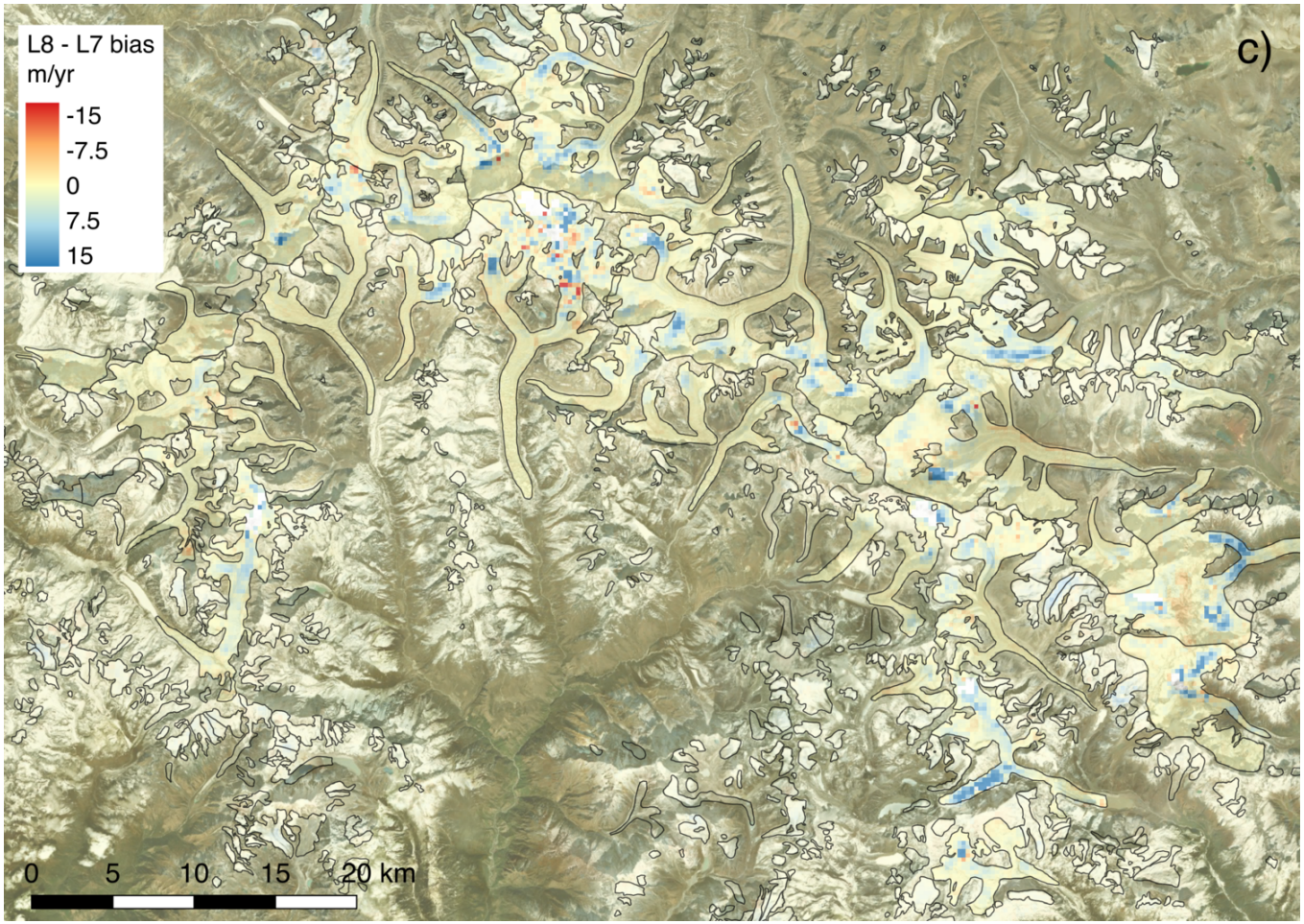
Velocity time series - Sensor bias

Mean velocity 1985-2017



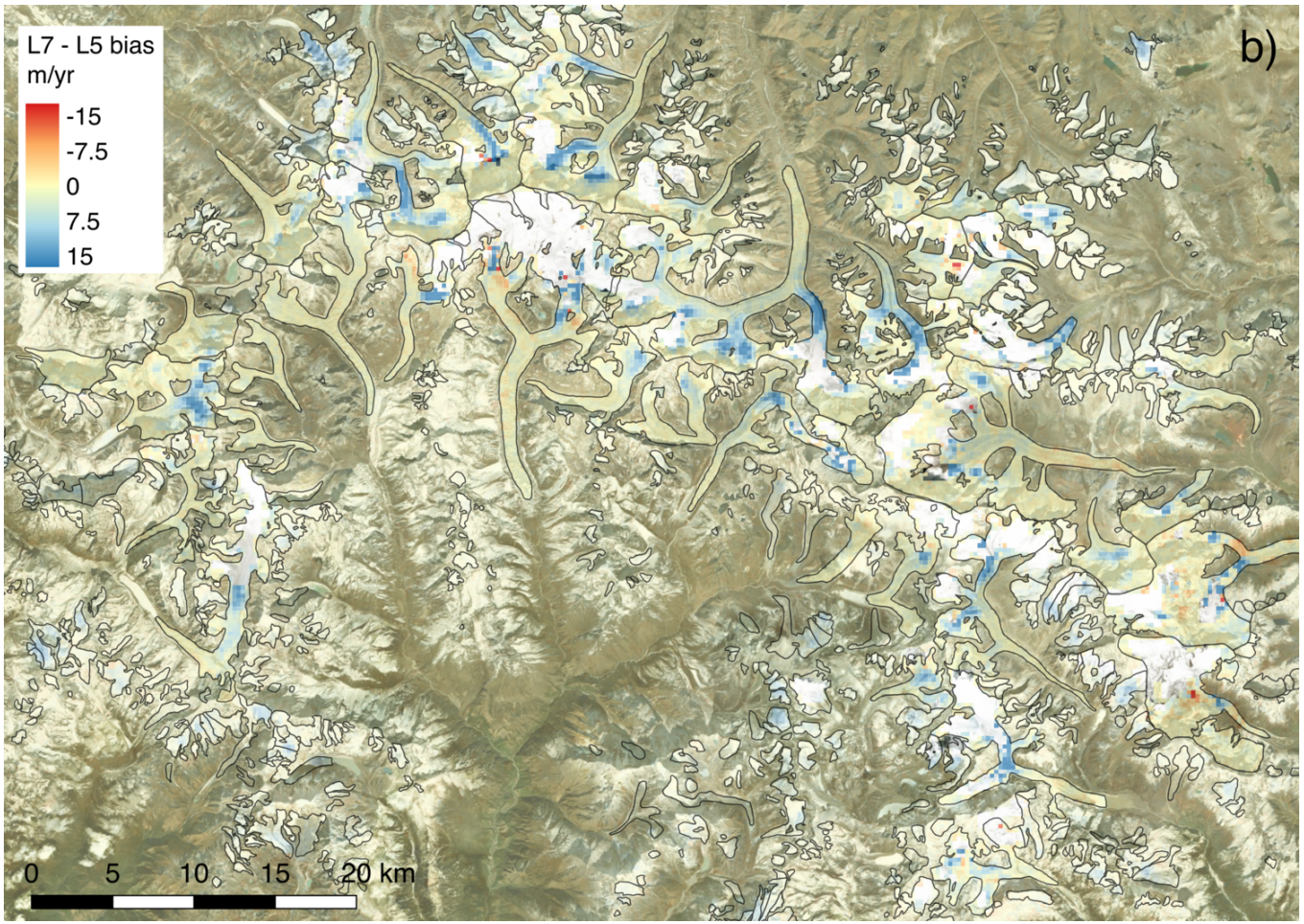
Velocity time series - Sensor bias

Difference L8 - L7 velocities over 2013-2017



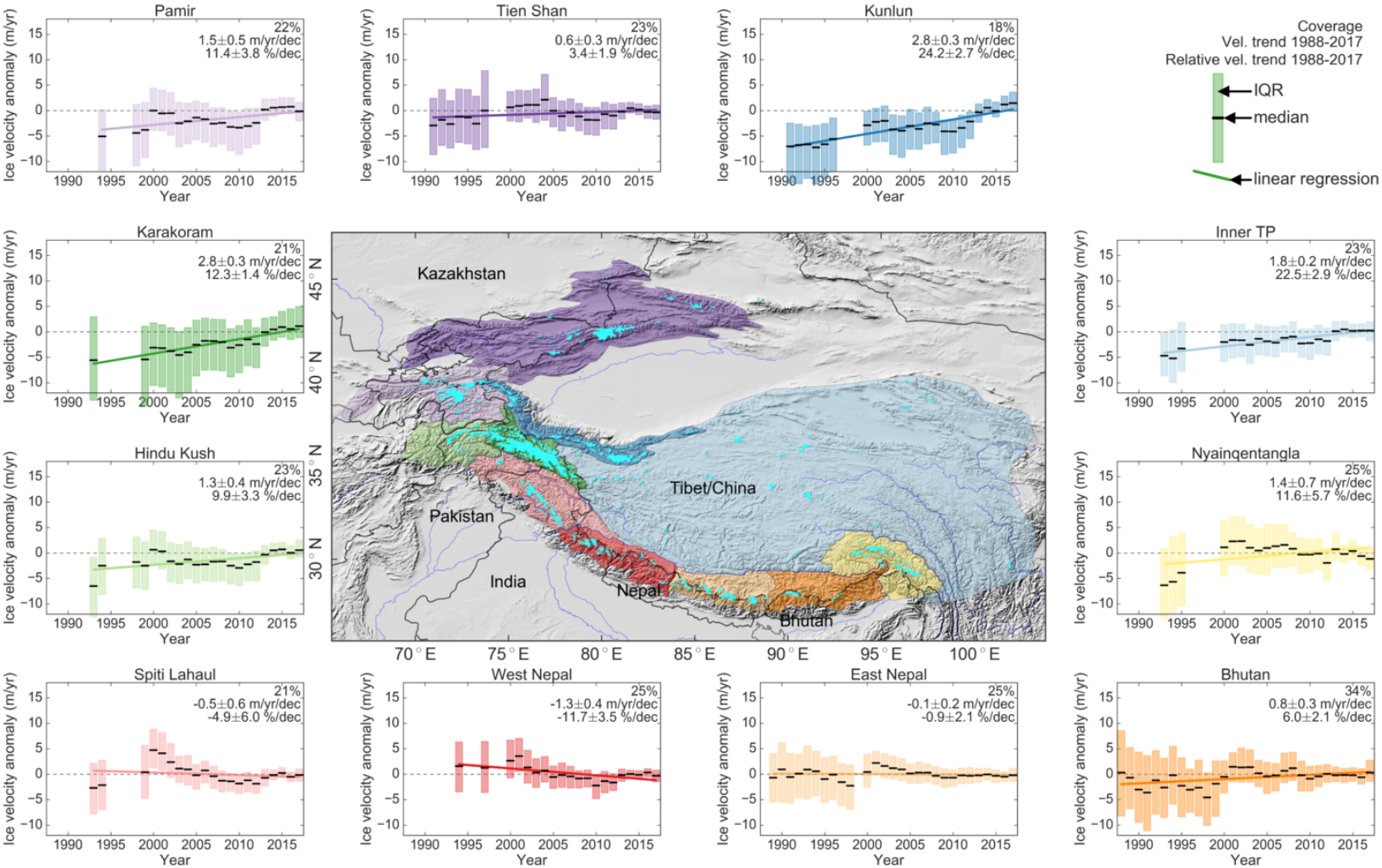
Velocity time series - Sensor bias

Difference L7 - L5 velocities over 1999-2010



Velocity time series - 1985-2017

Before correction



Velocity time series - 1985-2017

After correction