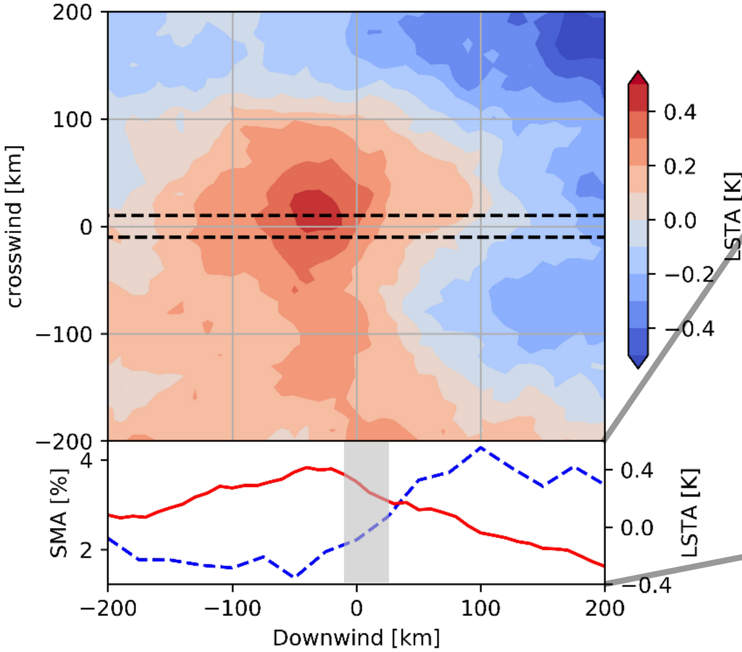
Observed Soil Moisture Impact on Strong Convection over Mountainous Tibetan Plateau

Strong convection over the TP is favoured over negative (positive) land surface temperature (soil moisture) gradients.

The signal is strongest for low topographic complexity, but still significant for over two thirds of cases.

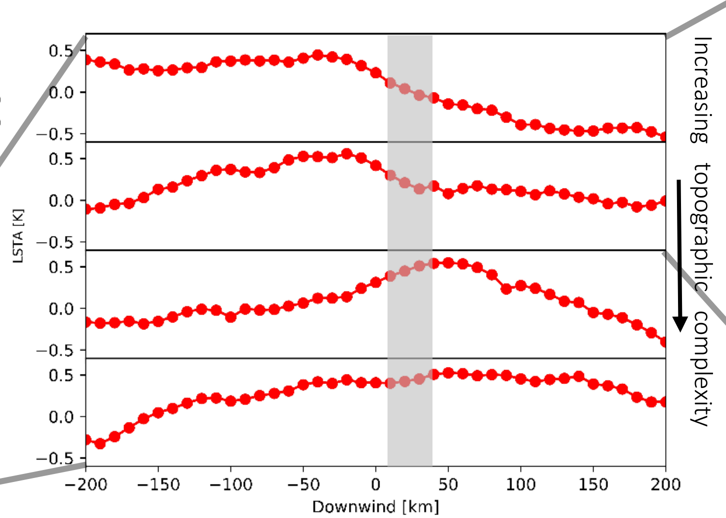
The atmosphere is only sensitive to local (30 km) soil moisture heterogeneity for lower wind speeds.



Mean surface conditions relative to initiation (0,0) of strong convection.

Upper – 2D Land Surface Temperature Anomaly (LSTA); Lower – 1D LSTA and Soil Moisture Anomaly (SMA).

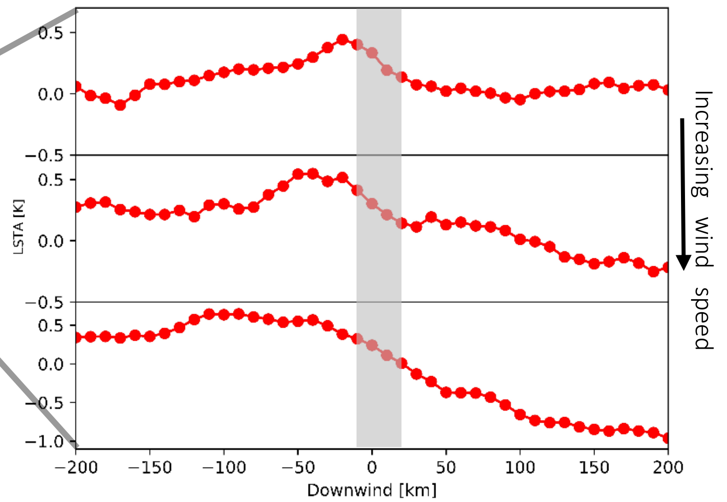
Significant negative downwind LSTA gradient anti-correlated with positive downwind SMA gradient.



Dependence on local topographic variability (standard deviation (SD)).

Top – SD < 200m; Upper Middle – 200 > SD > 300m; Lower Middle – 300 > SD > 400m; Bottom – SD > 400m.

Significant negative downwind LSTA gradients only for the two subsets with relatively modest topographic variability (SD < 300m), corresponding to ~70% of total dataset.



Sensitivity to background wind speed (s).

Top – s < 1.5ms^{-1}; Middle – 1.5ms^{-1} < s < 2.5ms^{-1}; Bottom – s > 2.5ms^{-1}.

Significant negative downwind LSTA gradients for all subsets. However a local signal is only evident for lower wind speeds (s < 2.5 ms^{-1}).

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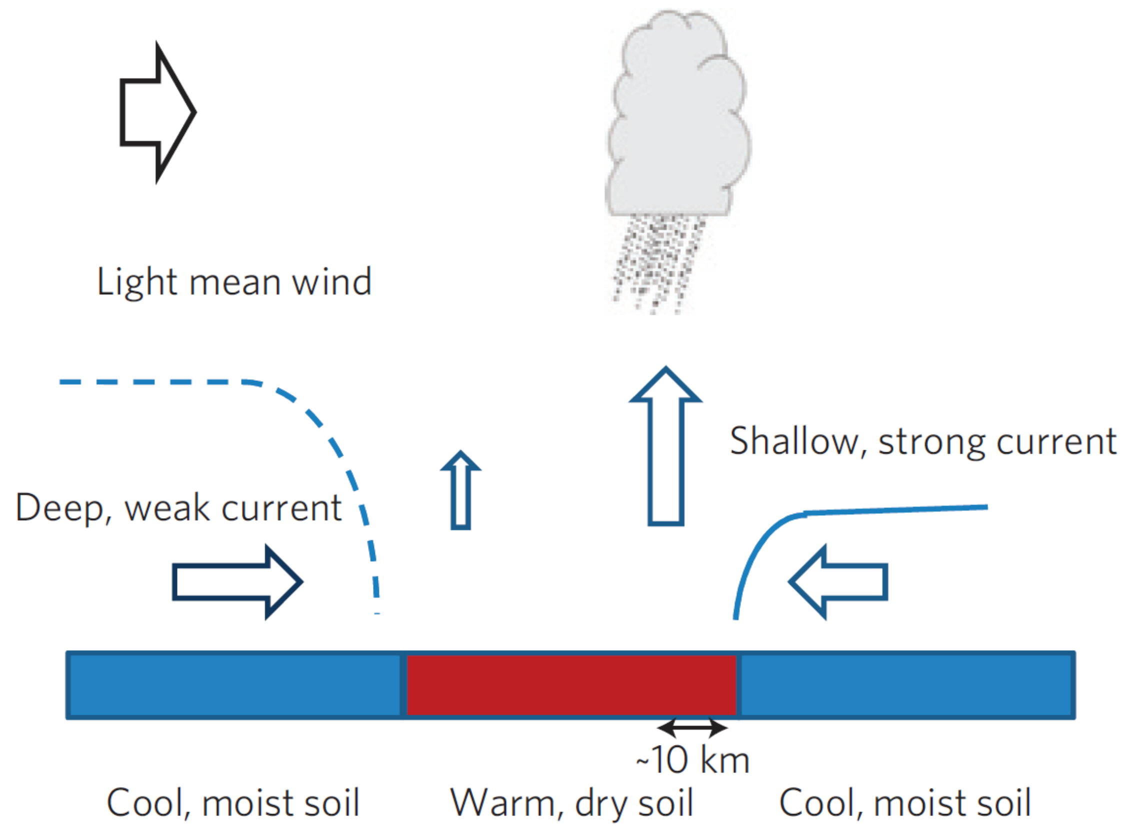

Schematic depicting impact of soil moisture heterogeneity on convective initiation. Taylor et al. (2011).

Convection over the Tibetan Plateau (TP) has been linked to extreme weather downstream (e.g. Zhao et al. 2019).

The TP is semi-arid and plateau-scale longitudinal soil moisture gradients have been shown to influence storm genesis (Sugimoto & Ueno, 2010).

Previous work in semi-arid Sahel (Taylor et al. 2011; hereafter T11) found enhancement of convective initiation over mesoscale soil moisture gradients. This smaller scale feedback has yet to be investigated for the TP.

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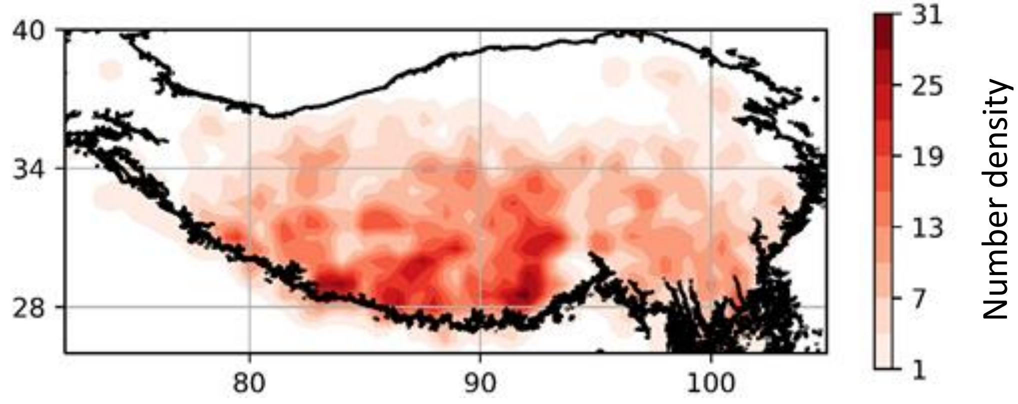
Identification of strong convection

Strong convection in June – September (JJAS) for 2013 - 2019 is identified using the 5 km hourly Fengyun-2 Cloud Top Temperature (CTT) product.

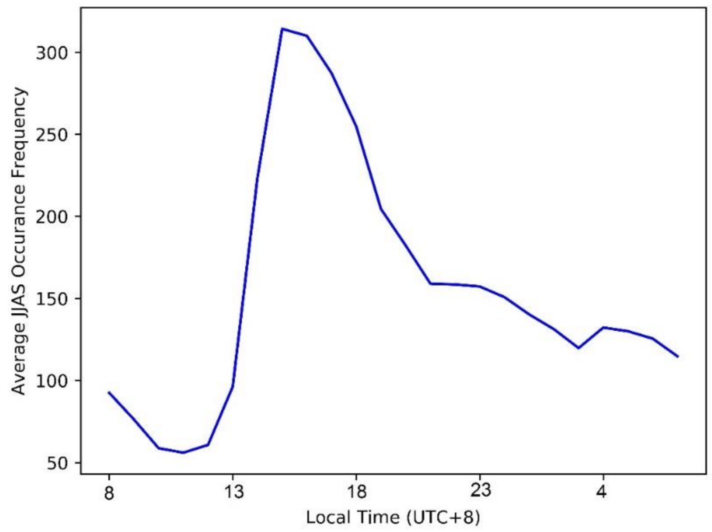
Initiation is defined as a new, rapidly cooling (dT/dt < -10 degrees hr^{-1}) cloud area less than 30 km across with CTT less than -54°C. The coordinate of the coldest pixel within the cloud area (corrected for parallax) is taken as the initiation point.

Cases are filtered for proximity to lakes. We perform an additional analysis to assess the impact of topography (see page 6).

Our analysis focuses on late afternoon strong convective initiation (1700 – 2000 LT). This is to ensure we are sampling initiations that triggered after our observations of surface conditions (see next page).



7-year average spatial distribution of strong convective initiation cases.



7-year average diurnal cycle of strong convective initiation cases.

Characterization of pre-storm surface wetness

Data

Pre-storm surface wetness is characterized from complementary satellite observation of Land Surface Temperature (LST) and Soil Moisture (SM).

We use early afternoon (1330 LT) AMSR2 satellite LST and mid-morning (1030 LT) ASCAT satellite SM.

Our analysis focuses on LST due to the higher quality (lower uncertainties, less missing data) of LST observations compared to SM.

Temporal LST anomalies (LSTAs) are a well-used proxy for soil moisture conditions (e.g. T11, Taylor 2015).

Daily LSTAs and SM anomalies (SMAs) are computed with respect to a seven year monthly climatology.

Method

Following T11, LSTA and SMA fields are rotated with respect to background wind (using 10 m wind vectors from ERA5) then computed as a function of location (±200 km) relative to each initiation. Individual cases are averaged to produce composite mean surface fields.

To minimize sampling issues due to missing data (particularly for soil moisture), only cases with at least 70% valid AMSR2/ASCAT pixels go forward for the analysis. Our resulting sample size is 1717 (213) strong convection initiation cases for LSTA (SMA).

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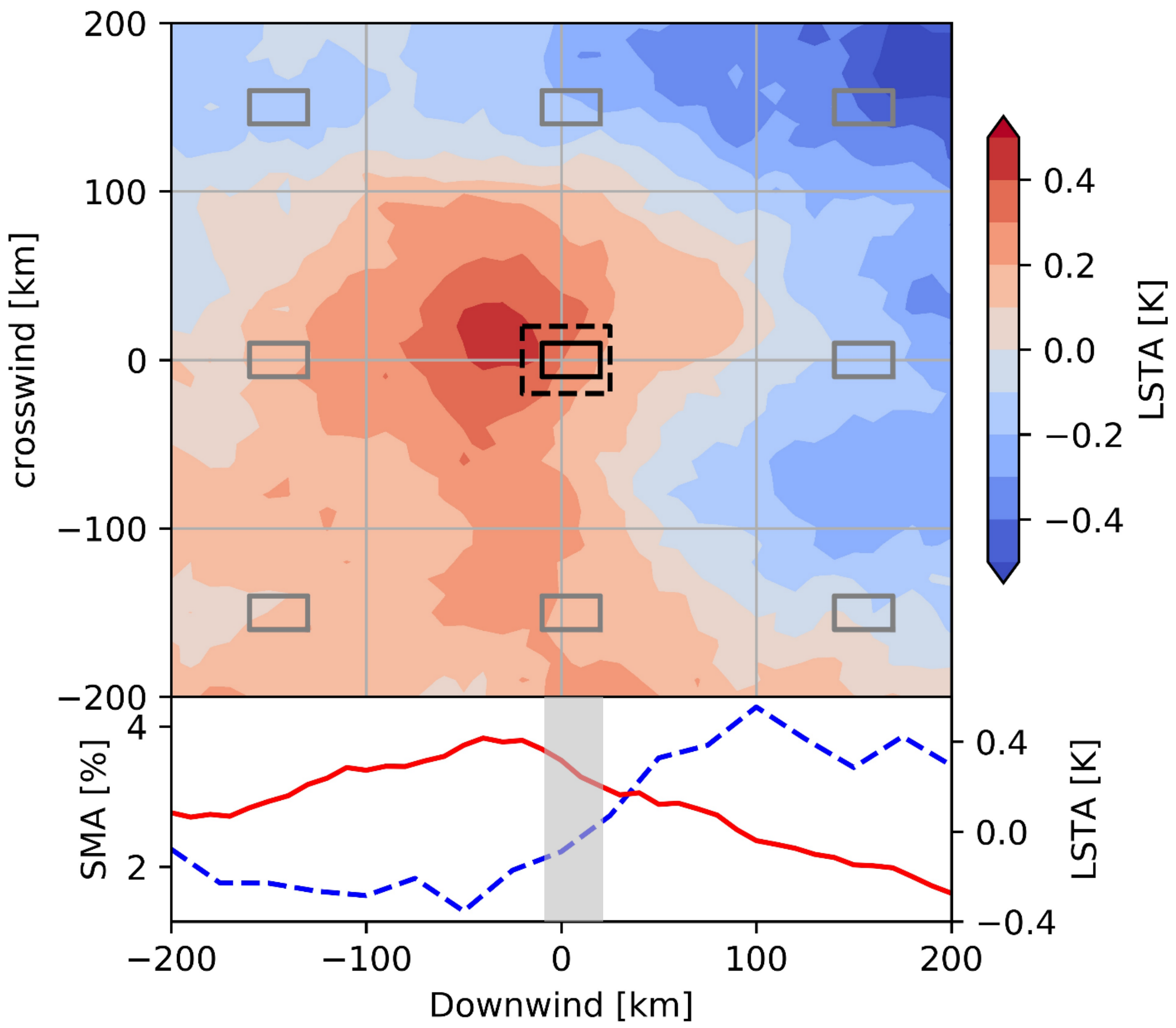
Results: Mean Conditions



Upper: Black dashed box represents 40x40 km area over which topographic variability (standard deviation) is calculated (see next page).

Lower: SMA = blue dashed line; LSTA = solid red line.

Following T11 downwind LSTA gradients are computed over a distance of 30 km.

Initiation (solid black rectangle) and up to eight non-initiation (grey rectangles) gradients are sampled for each case with sufficient local LSTA data.

We derive a mean initiation gradient of −5.8 mK km^{-1} compared with a mean non-initiation gradient of−0.2 mK km^{-1} from n_i = 1376 initiation and n_{ni} = 4640 non-initiation samples.

To assess the significance of the difference between these mean gradients, we use the same statistical test as T11. A pooled set of initiation plus non-initiation gradients is created. From this, random combinations of n_i and n_{ni} gradients are drawn without replacement, with their respective means found. This process is repeated 100,000 times.

We find the mean initiation gradient to be statistically significant (p value of 0.03).

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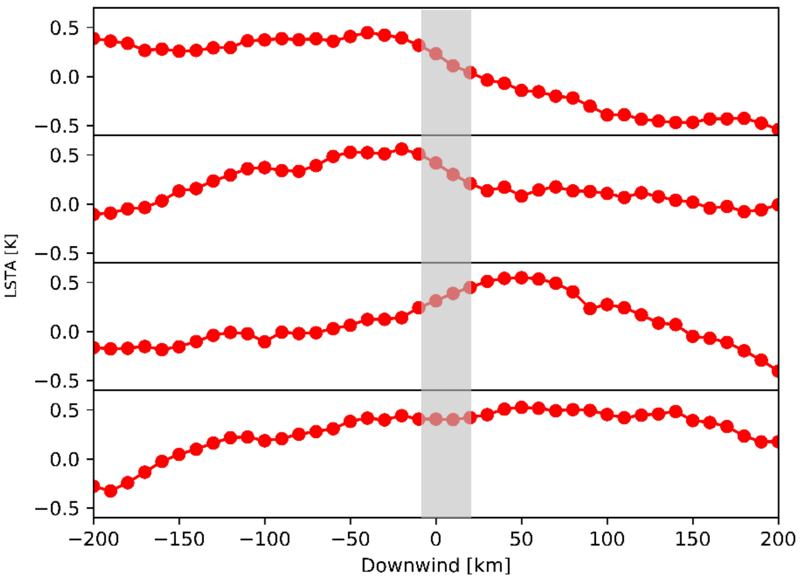
Results: Subset Analysis

Dependence on topographic complexity

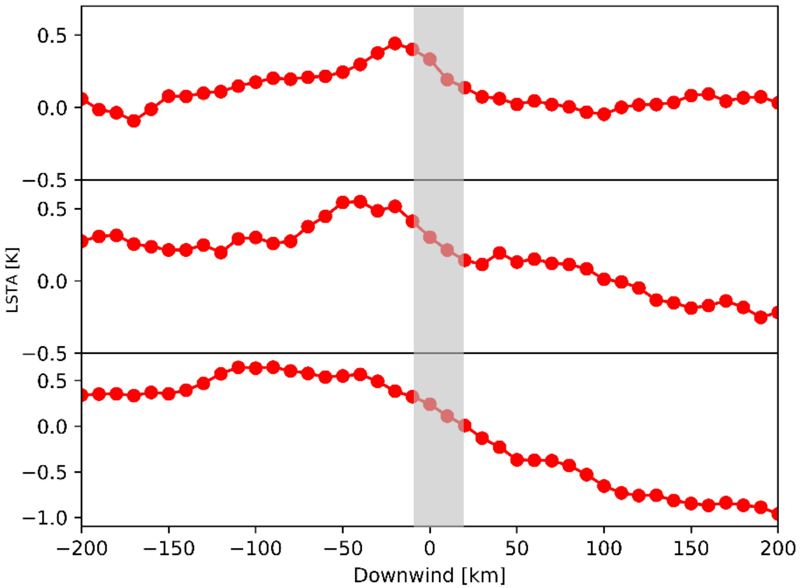


Topographic Variability	N cases	Gradient	P value
< 200m	788	-9.2 mK km^{-1}	0.009
200 – 300m	393	-10.0 mK km^{-1}	0.04
300 – 400m	234	+6.9 mK km^{-1}	0.06
> 400m	302	+0.5 mK km^{-1}	0.3

Statistically significant ($p < 0.05$) negative downwind LSTA gradients are found for the two subsets with relatively modest topographic variability (SD < 300m), corresponding to 69% of the total dataset.

For the remaining sub-samples, there is no consistent relationship with local LSTA gradients.

Sensitivity to background wind speed



Wind Speed	N cases	Gradient	P value
< 1.5 ms^{-1}	399	-8.8 mK km^{-1}	0.02
1.5 – 2.5 ms^{-1}	388	-8.9 mK km^{-1}	0.04
> 2.5 ms^{-1}	394	-10.5 mK km^{-1}	0.02

For cases where SD < 300m only.

Statistically significant ($p < 0.05$) negative downwind LSTA gradients are found for all subsets.

A local (30km) signal is only apparent for lower wind speeds ($s < 2.5 ms^{-1}$).

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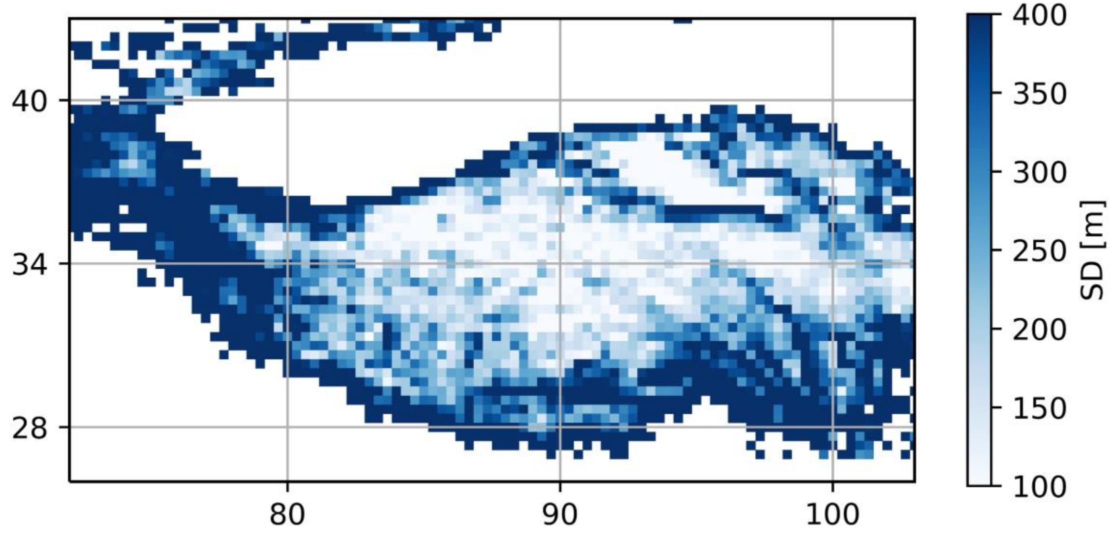
Summary

As found in the Sahel, strong convection over the TP is favored over negative (positive) land surface temperature (soil moisture) gradients.

We observe a weakening of the soil moisture signal with increasing topographic complexity. This is consistent with observations over East Mongolia (Teramura et al. 2019) and results from idealized model experiments (Imamovic et al. 2017).

Strong wind speeds appear to play an important role in suppressing the impact of small scale (~30 km) heterogeneity on convective initiation, but may emphasize larger-scale gradients.

Our results demonstrate that, even in the complex TP environment, mesoscale variations in soil moisture still play an important role in storm development. Models will not only need to capture the soil moisture – convection feedback, but also its dependence on the highly varying TP surface and synoptic conditions.



Topographic variability over the TP. Standard deviation (SD) calculated on 40x40 km grid.

Further details and results will be presented in our paper. Please direct any questions to Dr Emma J Barton emmbar@ceh.ac.uk.

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