# Planetary Boundary Layer Height over the Tibetan Plateau

## - climatology and connections with larger-scale climate

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# Background & research questions

As shown in previous studies, the Planetary Boundary Layer (PBL) at the Tibetan Plateau (TP) can reach very high [1].  It has also been found that the TP is a region of strong interactions with far reaching consequences - for example, thermal forcing exerted by the plateau contributes to the Indian and East Asian summer monsoons [2].

However, detailed knowledge is lacking about the characteristics of the PBL height (PBLH) across the TP, as well as its potential role in these interactions and its associations with other climate variables. Using the recently available reanalysis dataset ERA5 [3] spanning the four last decades, this study therefore aims to establish a climatology of TP PBLH and seek explanations for its spatial and temporal variations. The work is focused around the following questions:

- How has the PBLH over the TP varied during the last decades?
  - What are the seasonal variations?
  - What are the spatial patterns in means and trends across the TP?
  - Can differences be found in seasonal and diurnal cycles for different parts of the plateau?

- How is the PBLH related to other climate variables?

# Data and methods

- ERA5 reanalysis data for 1979-2018.
- PBLH readily available in the ERA5 output, calculation is based on the bulk Richardson number [4].
- Data were analysed for the TP (Figure 1).
  - Monthly data were analysed for the entire TP:  70-105 °E, 27-40 °N,  >3000m above sea level.
  - Hourly data were analysed for two sub-regions, selected on a basis of their PBLH trends.
    A: Monsoon season trend negative, stronger than 40 m/decade and significant at the 95 % level.
    B: Dry season trend positive and located east of 95 °E, south of 33 °N.
- Data were divided into a monsoon season (May-September) and a dry season (October-April).

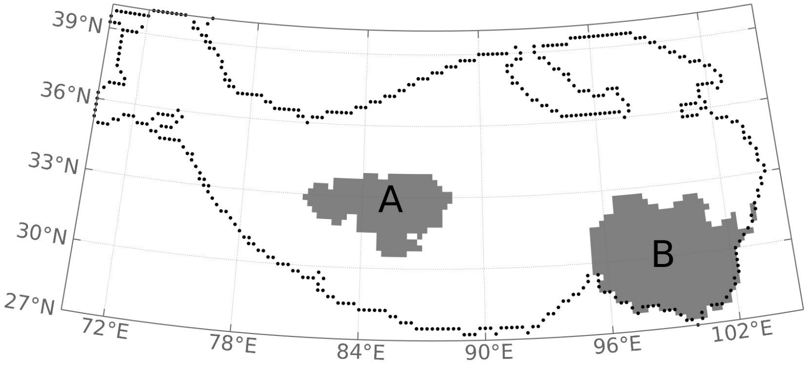
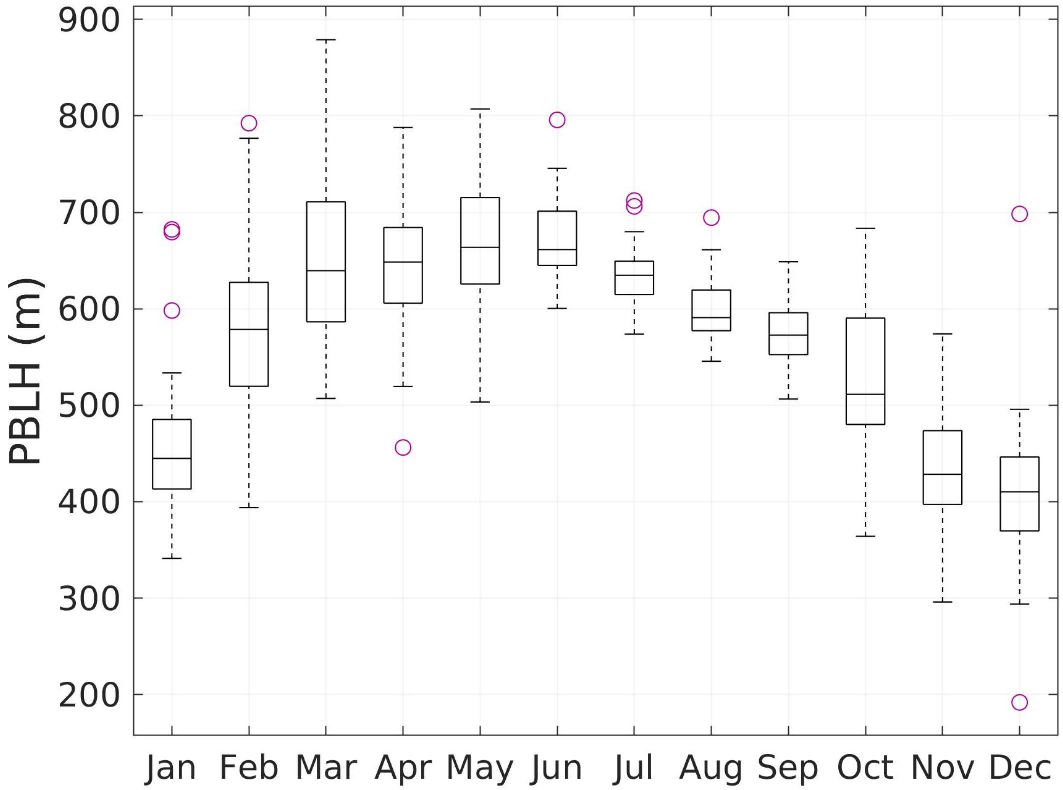



**Figure 1.** The TP and two sub-regions for which hourly PBLH was analysed.

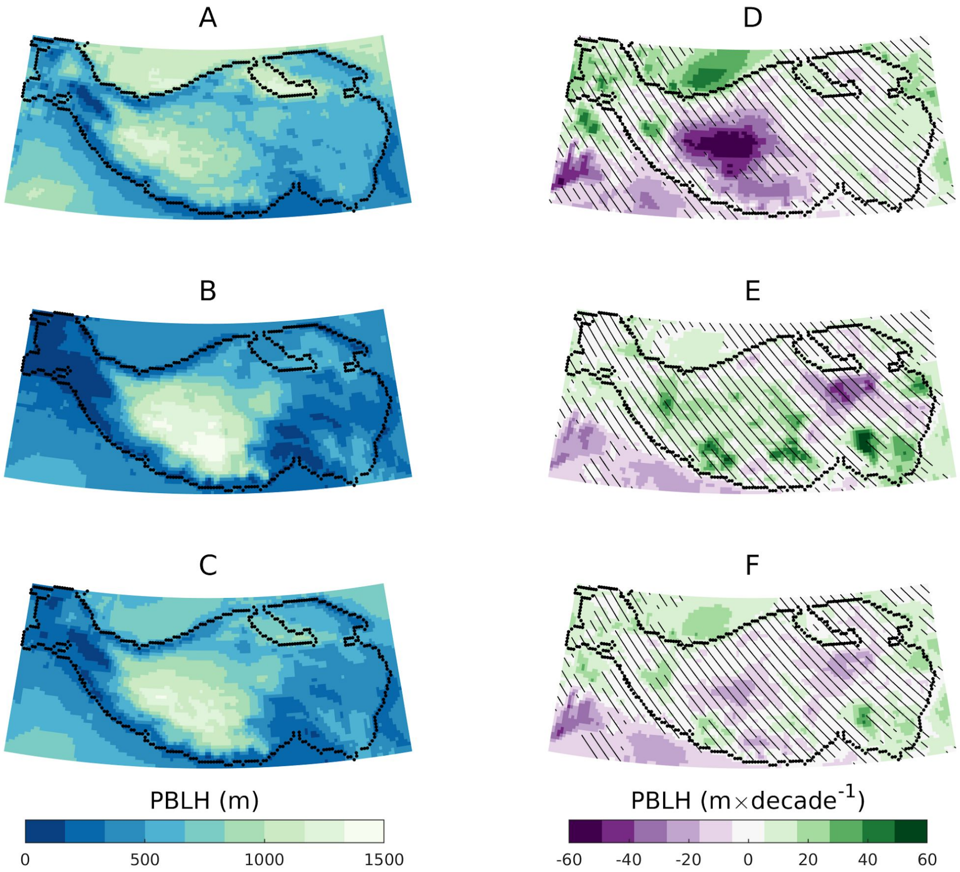
# PBLH Climatology: TP-average seasonal cycle




- Highest values reached in spring and early summer
- Spread larger in the dry season than in the monsoon season

**Figure 2.** For each month, summary statistics of the monthly mean PBLH are displayed. Each box gives the median (central line in each box), the 25th percentile (bottom of each box), the75th percentile (top of each box), the most extreme values not considered outliers (the ”whiskers”, i.e. black lines above and below boxes) and possible outliers (pink circles. Outliers are values more than 1.5 times the interquartile range away from the top or bottom of the box).

# PBLH Climatology: Spatial patterns in means and trends

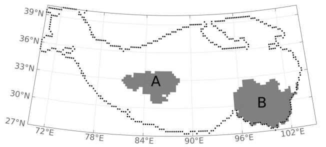


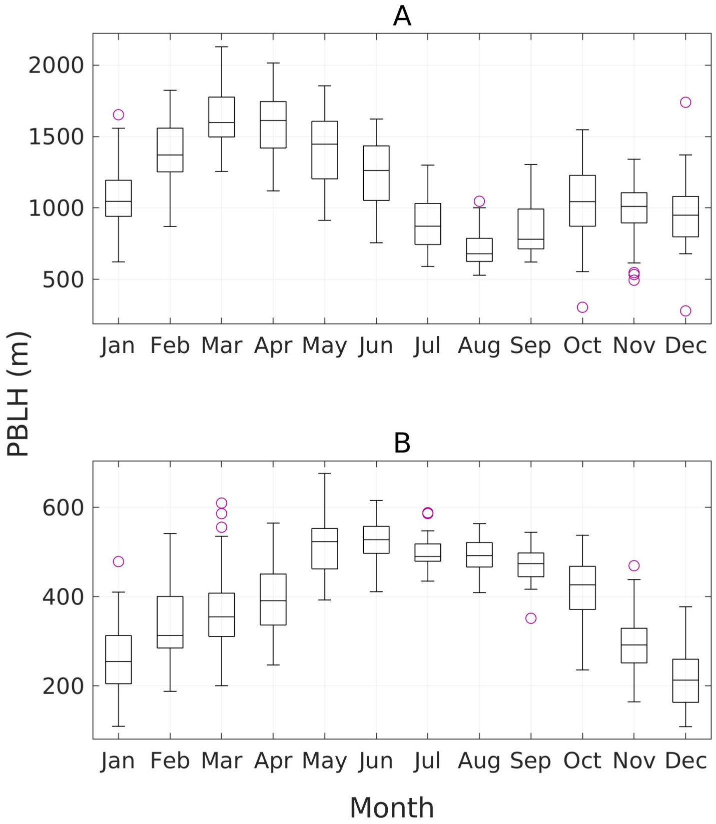

- Spatial patterns in mean seasonal PBLH are relatively similar for both seasons, with higher values in central TP and lower toward its rims.
- The highest values are found in south-central TP in the dry season (Figure 3 B).
- The most striking feature of the trends is a large region of statistically significant decreasing PBLH in the central TP in the monsoon season (Figure 3 D).

**Figure 3.** Left column: Mean PBLH for the monsoon season (A), the dry season (B) and the full year (C). Right column: Linear trend in PBLH for the monsoon season (D), dry season (E) and annual (F) means. Black lines are drawn over regions were the trend is NOT statistically significant at the 95 % level.

# PBLH Climatology:

## Seasonal cycles of two regions with different PBLH characteristics



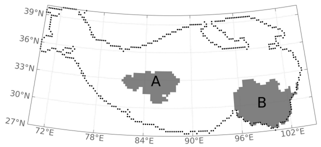




- PBLH in region A is higher than PBLH in region B in all months.
- The PBLH in region A reaches its greatest heights in late winter and spring and thereafter declines to reach its yearly minimum in August. In contrast, PBLH in region B peaks during late spring and summer.

**Figure 4.** Seasonal cycles of PBLH in regions A and B. (Box plot statistics calculated as for Figure 2).

# PBLH Climatology:

## Diurnal cycles of two regions with different PBLH characteristics




- In the central TP region (A), the mean PBLH (thick lines in Figure 5) is higher during the dry season than during the monsoon season for most hours while the opposite is true for the southeastern TP region (B).
- Region A features extremely high maximum afternoon PBLH in both seasons (thin lines in Figure 5 A).

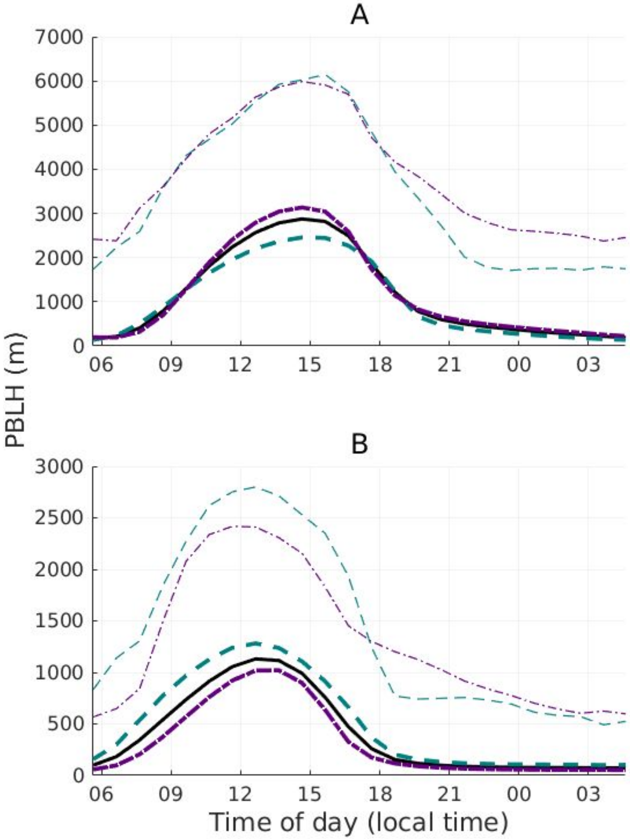



**Figure 5.** Diurnal cycles of PBLH in region A and B. Thick lines: Mean diurnal cycles for the monsoon season (blue-green dashed), the dry season (purple dash-dot) and annual (solid black) means. Thin lines: The maximum value of the entire 1979-2018 period is shown for each hour. The time on the x axis shows local time (calculated for the middle of each region, respectively).

# Why was the monsoon season PBLH in central TP significantly decreasing?

## Correlations between PBLH and selected climate variables over the TP

- Extremely strong positive correlations with surface sensible heat flux across the plateau (Figure 6 A).
- Mainly negative correlations with precipitation, especially in central TP (Figure 6 B).
- Mainly positive correlations with wind speed at 500 hPa, although negative correlations are present along the rims of the plateau and in the west and east (Figure 6 C).

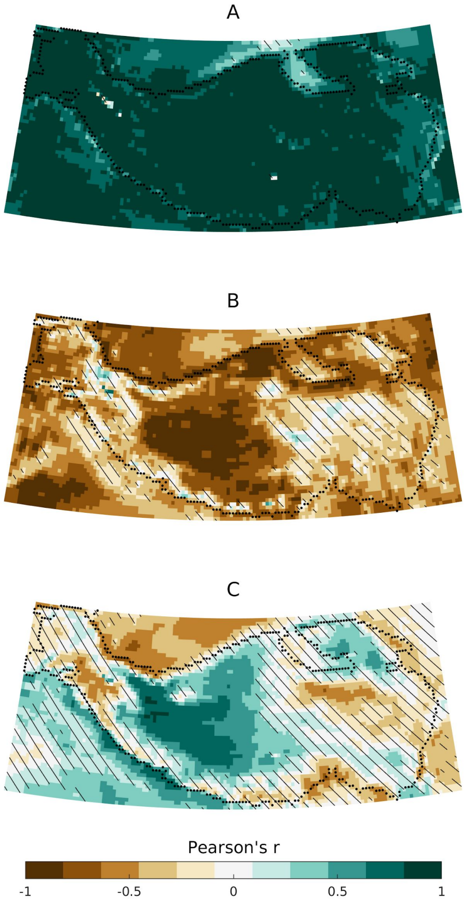



**Figure 6.** Monsoon season correlations with surface sensible heat flux, (positive upwards; A), precipitation (B) and wind speed at the 500 hPa level (C). Black lines are drawn over regions where the correlation was NOT significant at the 95% level.

# Why was the monsoon season PBLH in central TP significantly decreasing?

## Trends in selected climate variables

- In the central TP, the pattern of negative trend in monsoon season sensible heat flux (Figure 7 A) is almost identical to that of PBLH (Figure 3 D).
- The precipitation (Figure  7 B) in contrast has an increasing monsoon season trend in this region.
- For wind speed at 500 hPa the trend in this region predominantly negative except for the southern parts. The trends lack statistical significance except in the north (Figure 7 C).

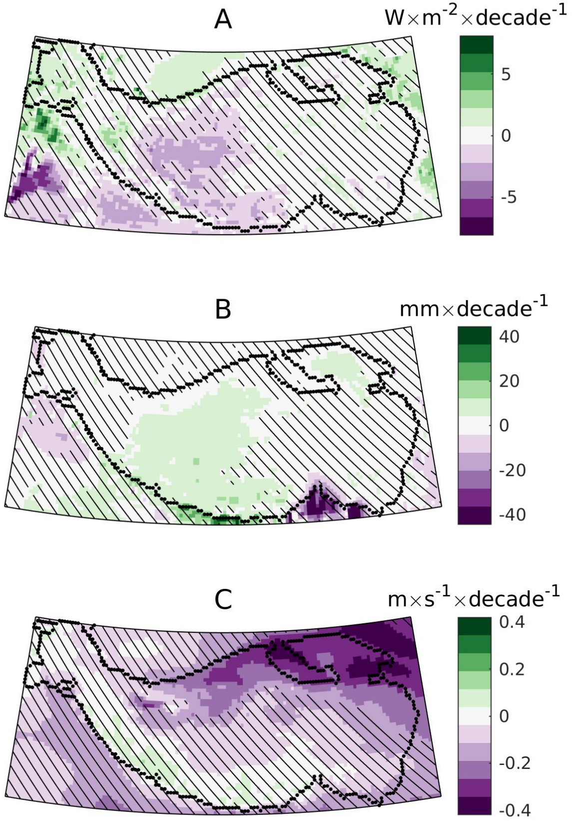
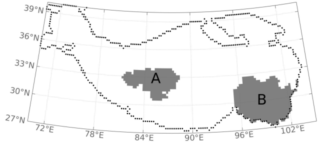



**Figure 7.** Linear trends in monsoon season sensible heat flux, (positive upwards; A), precipitation (B) and wind speed at the 500 hPa level (C). Black lines are drawn where the trend was NOT significant at the 95% level.

# Summary & discussion




**Seasonal cycles**

- TP-average PBLH is highest in spring and summer, with the highest medians in May and June and the highest extreme in March. In the central TP region (A) the PBLH peaks in March-April and thereafter declines to reach its minimum in August, while southeastern TP region (B) has its highest PBLs in May-September.
- Given its strong negative correlation with precipitation and positive correlation wind speed in region A, the PBLH may decrease in response to the increased precipitation and decreased wind speed as the monsoon season arrives, in line with previous findings of seasonal PBLH variations in monsoon regions [5]. However, the surface sensible heat flux, which is one of the most crucial factors behind the high TP PBL [6], is somewhat larger during the monsoon season than during the dry season (not shown). It is possible that low atmospheric stability in the dry season, partly associated with the jet stream position, may help winter and spring PBLs to grow high [1,7] in this region in spite of the slightly smaller sensible heat flux.
- As for region B, its location suggests that it should be influenced by both the Indian Monsoon and the East Asian Monsoon [8]. It is therefore not clear why this region, in contrast to region A, has its highest PBLs during the monsoon season.

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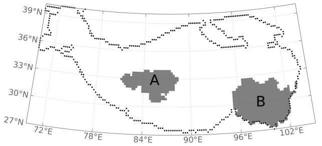
# Summary & discussion




## TP PBLs get high

- As found by previous studies [1,7], TP PBLs may reach extremely high. Especially, **the central TP stands out, with dry season mean PBLH of up to ~1500 meters and maximum hourly PBLH of ~6000 meters** in both seasons. This may be attributed to the relatively dry conditions and large sensible heat fluxes at the central plateau (not shown).

## Diverging trends

- PBLH trends differ between seasons and regions. The dry season is dominated by (mostly non-significant) increasing trends, whose pattern closely resembles those of the dry season surface sensible heat flux trends. In the southeastern TP region (B) the sensible heat flux has increasing trends whose spatial distribution is very similar to increasing near-surface air-temperature trends. In addition, precipitation is decreasing in parts of this region (not shown). Increasing temperatures and declining precipitation may therefore have resulted in positive sensible heat flux trends and thus increasing PBLH in this region. The monsoon season in contrast is dominated by decreasing PBLH trends in the central plateau, as will be discussed on the next slide.

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# Summary & discussion

**Decreasing monsoon season PBLH in central TP**

- The monsoon season PBLH has a declining trend of ~60 m/decade in central TP.
- The spatial patterns of the declining surface sensible heat flux trend is almost identical to that of PBLH, indicating that the trend is dominated by declining surface sensible heat flux.
- Monsoon season precipitation is strongly anticorrelated with PBLH in central TP and has an increasing trend.
- **Taken together, the above could be seen as an indication that the increasing monsoon season precipitation acts to reduce the surface sensible heat flux and thereby the PBLH. This reduction may be brought about by alterations to the surface energy budget.** Such alterations could result from the increased precipitation (more of the available energy partitioned into latent heat flux as conditions become more moist) as well as cloudiness associated with the precipitation increase (clouds can block incoming solar radiation).
- In addition, PBLH is positively correlated with wind speed at 500 hPa in this region. Although not statistically significant, the slightly decreasing wind speed in most of the region may play some role for the sensible heat flux decrease.

# References

[1] Chen X, Añel JA, Su Z, de la Torre L, Kelder H, van Peet J, et al. (2013) The Deep Atmospheric Boundary Layer and Its Significance to the Stratosphere and Troposphere Exchange over the Tibetan Plateau. *PLoS ONE 8*(2): e56909. https://doi.org/10.1371/journal.pone.0056909

[2] Wu, G., Liu, Y., He, B. *et al.* Thermal Controls on the Asian Summer Monsoon. *Sci Rep* **2,** 404 (2012). https://doi.org/10.1038/srep00404

[3] Copernicus Climate Change Service (C3S) (2017): ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global climate . Copernicus Climate Change Service Climate Data Store (CDS), accessed 2019/2020. https://cds.climate.copernicus.eu/cdsapp#!/home

[4] ECMWF. (2017). Part iv: Physical processes. In IFS Documentation CY43R3. ECMWF. Retrieved from https://www.ecmwf.int/node/17736

[5]Chan, K. M., & Wood, R. (2013). The seasonal cycle of planetary boundary layer depth determined using COSMIC radio occultation data. *Journal of Geophysical Research: Atmospheres*, *118*(22), 12-422.

[6] Yang, K., Koike, T., Fujii, H., Tamura, T., Xu, X., Bian, L., & Zhou, M. (2004). The daytime evolution of the atmospheric boundary layer and convection over the Tibetan Plateau: observations and simulations. *Journal of the Meteorological Society of Japan.Ser. II,82*(6), 1777–1792

[7] Chen, X.,ˇSkerlak, B., Rotach, M. W., A ̃nel, J. A., Su, Z., Ma, Y., & Li, M. (2016). Reason for the extremely high-ranging planetary boundary layer over the western Tibetan Plateau in winter. *Journal of the atmospheric sciences,73*(5), 2021–2038

[8] Yao, T., Thompson, L., Yang, W., Yu, W., Gao, Y., Guo, X., ... & Pu, J. (2012). Different glacier status with atmospheric circulations in Tibetan Plateau and surroundings. *Nature climate change*, *2*(9), 663-667.