Variability of precipitable water content in the Atacama Desert

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Introduction

The Atacama Desert is a hyperarid area in the north of Chile that is considered by many to be the most arid desert in the world. Various mechanisms are understood to force this hyperaridity:

- The anticyclone in the southeast Pacific ocean forces southerly winds along the coast leading to upwelling of cold waters that cause a temperature inversion that prevents moisture transport to the high altitudes of the Atacama (Garreaud, 2010).
- The rainshadow effect of the Andes mountains to the east. Any precipitation or moisture that may come from the Amazon is forced to go over the mountains, where it is precipitated out before reaching the Atacama (Houston, 2003) (Fig 1).

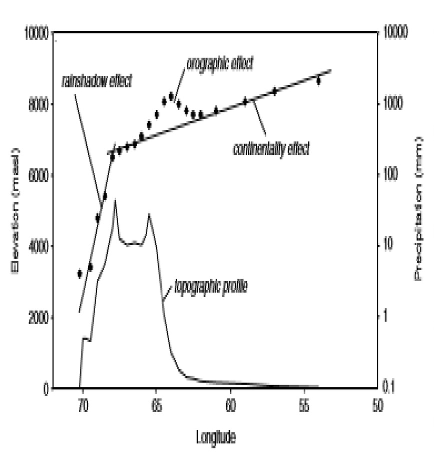

Figure 1: Cross section from Belem, Brazil to Iquique, Chile showing rainshadow effect (Houston, 2003).

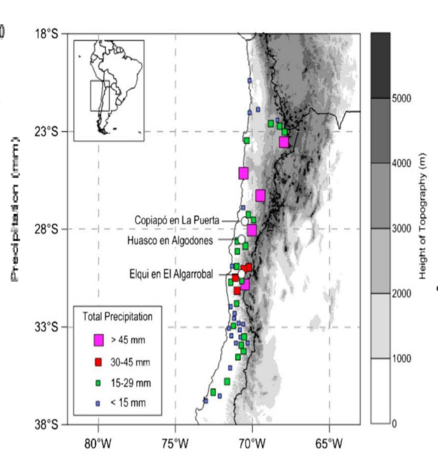

Figure 2: Extreme rainfall anomaly that occurred between 23 and 27 March 2015 (Barrett et all, 2016.)

Now, although this aridity is severe, there occur precipitation and flooding events that are catastrophic to the inhabitants of the area (Figure 2).

The physical mechanisms that drive these rainfall events remain partly unknown.

- What is known is that an increase in the amount of precipitable water vapor (PWV) is connected to these high precipitation flooding events
- Furthermore, the atmospheric transparency that results from such low precipitable water measurements is crucial for the many astronomical observations and data collection that occur throughout the region.
- The ALMA telescope, for example, can observe feasibly when PWV is below 5 mm. The Atacama satisfies this criterion most months of the year. (Marín and Barrett, 2017) (Fig 3).

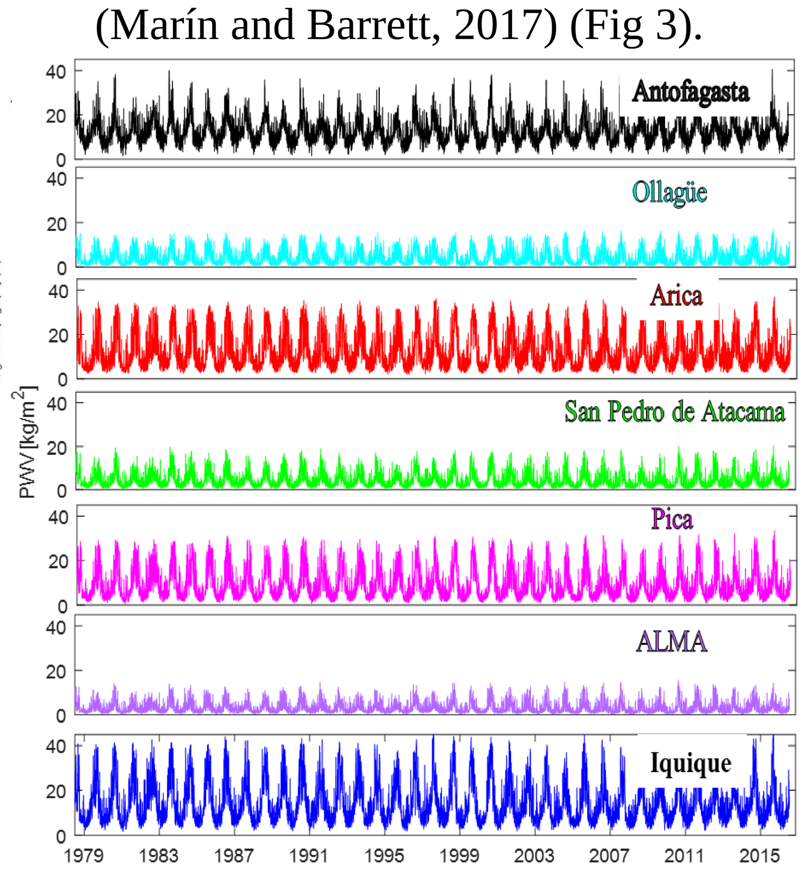

Figure 3: Daily variations in Precipitable Water Vapor Content Across seven stations throughout Atacama from 1979 to 2016.

Data and Methods

- Daily Total Column Water Vapor (PWV) data was taken from the ERA-Interim Reanalysis from the European Centre for Medium-Range Weather Forecasts (ECMWF) at seven distinct locations in the Chilean Atacama Desert (Fig 4)
- Monthly Means of Daily Values (also from ERA-Interim) were divided into the seasons (DJF and JJA) and correlated with the means of 14 variables from 1979 to 2016 across a large portion of the Southern Hemisphere.
- The correlations were made between PWV and sea surface temperature, mean sea level pressure, 2 meter temperature, the *u* and *v* components of 10 meter winds, and the *u* and *v* components and geopotential heights for 300-hPa, 500-hPa, and 700-hPa using the Pearson Product-Moment correlation coefficient.
  - ➢ Coefficients $|r| \geq 0.19$ are statistically significant at the 95% confidence level.

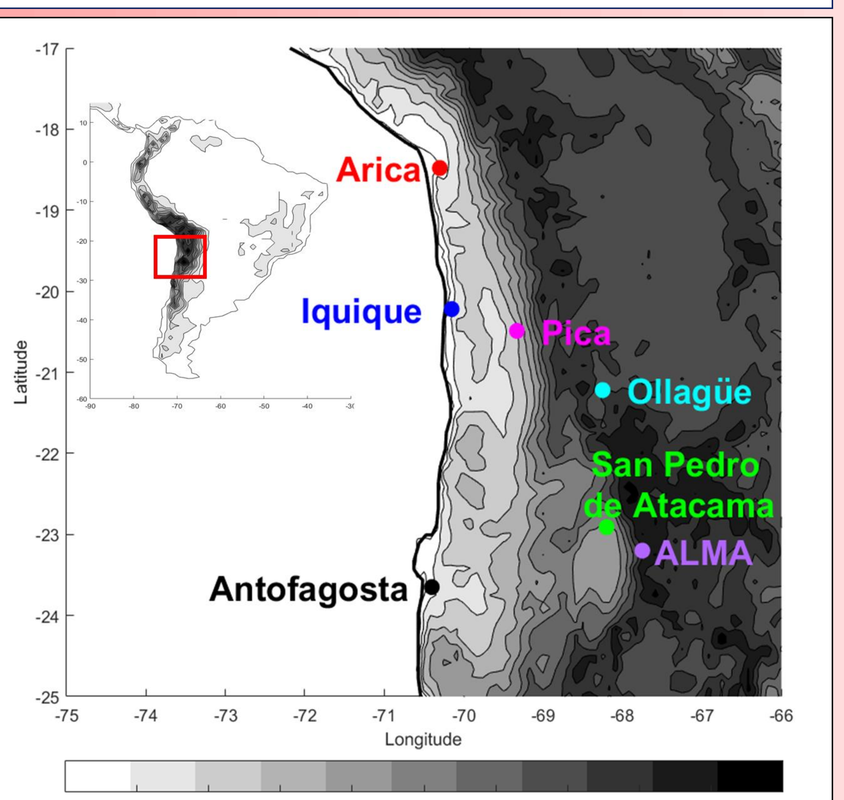

Figure 4: Seven locations color coded to match Figure 2 in the Atacama Region that will be investigated and their relative locations and elevations.

Location	Latitude [°S]	Longitude [°W]	Elevation [m]	Era-Interim Invariant Geopotential[m]
Antofagasta	23.65	70.4	40	548
APEX	23.0	67.75	5100	3966

Table 1: Describes the locations and elevations of the seven stations.

Result 1: precipitable water and the large scale atmosphere

In summer, when PWV is highest (Marín and Barrett 2017), five of the 14 analyzed variables exhibit synoptic-scale patterns of correlation with PWV at ALMA (Fig. 5).

- High 500-hPa heights over the southern cone of S. America (20°-40°S, 80°-40°W), and lower 500-hPa heights over the tropical eastern Pacific and western Atlantic(Fig 5a)
- Easterly 300-hPa zonal wind over a belt from 10°-40°S over much of the southeast Pacific Ocean and South America (Fig 5b)
- Northerly 10-m winds over the southeast Pacific, adjacent to northern Chile from 10°N-30°S, and southerly 10-m winds over the Atacama itself (25°-30°S along 75°W) (Fig 5c)
- Warm sea surface temperatures over the entire southeastern Pacific Ocean and western south Atlantic Ocean (Fig 5d)
- Low surface pressure along the Pacific coastline from 70°-110°W and 5°-45°S (Fig 5e)

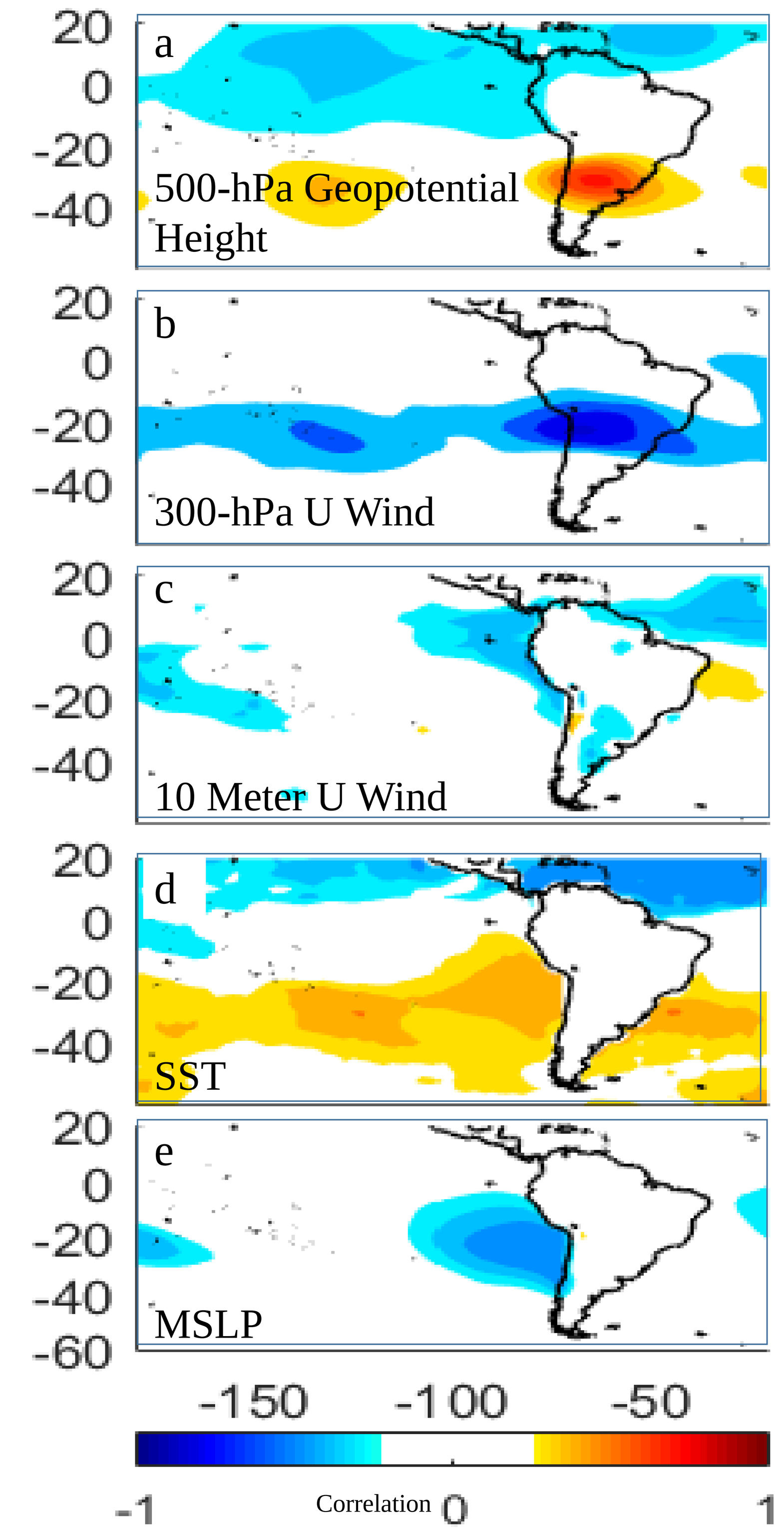

Figure 5: Five of the 14 investigated variable correlations with PWV in December, January, and February.

Result 2: Altitude Differences

Most stations have similar patterns of variability, which indicate that the controls on PWV over the Atacama Region are both synoptic scale and uniform from the coast inland, independent of altitude.

- However, the patterns of correlation for three variables (mean sea level pressure and the *u* and *v* components of 10 meter wind) suggest that they affect PWV at high altitudes differently than at low altitudes

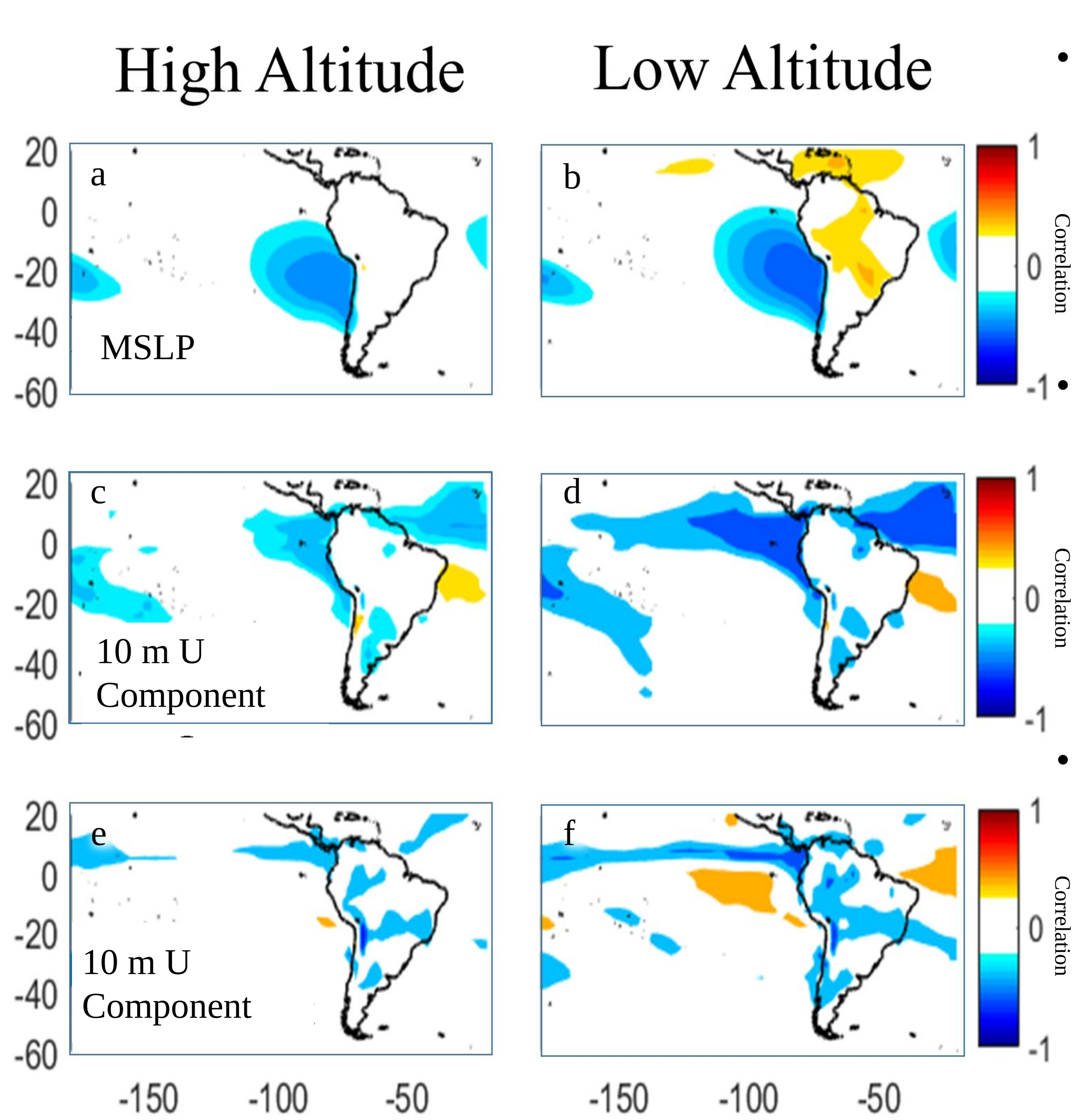

Figure 6 High altitude correlation patterns compared with low altitude patterns for mean sea level pressure, and the *u* and *v* components at 10 meters

- Positive correlations between PWV and MSLP over the Amazon are only seen for low-altitude stations (Figs 6a,b)
- Positive correlations between PWV and 10-m Meridional wind over the Atacama are only seen for high-altitude stations (Figs 6c,d)
- Positive correlations between 10-m zonal wind and PWV (120°-90 °W, 0 °-20 °S) are only seen for low altitude stations (Figs 6e,f).

Result 3: seasonal variations independent of altitude

In addition to different correlation patterns between low and high altitude stations, seasonal (summer vs winter) differences also appear in correlation patterns independent of altitude.

- At both Antofagasta and ALMA, DJF (summer) correlations between 500-hPa and PWV in JJA (Winter)(Figs 7a,b and 8 a,b). However, both stations reverse similarly, indicating little influence by station altitude.
- The correlation pattern between 700-hPa *u* and PWV are very similar: a seasonal reversal that does not depend strongly on altitude

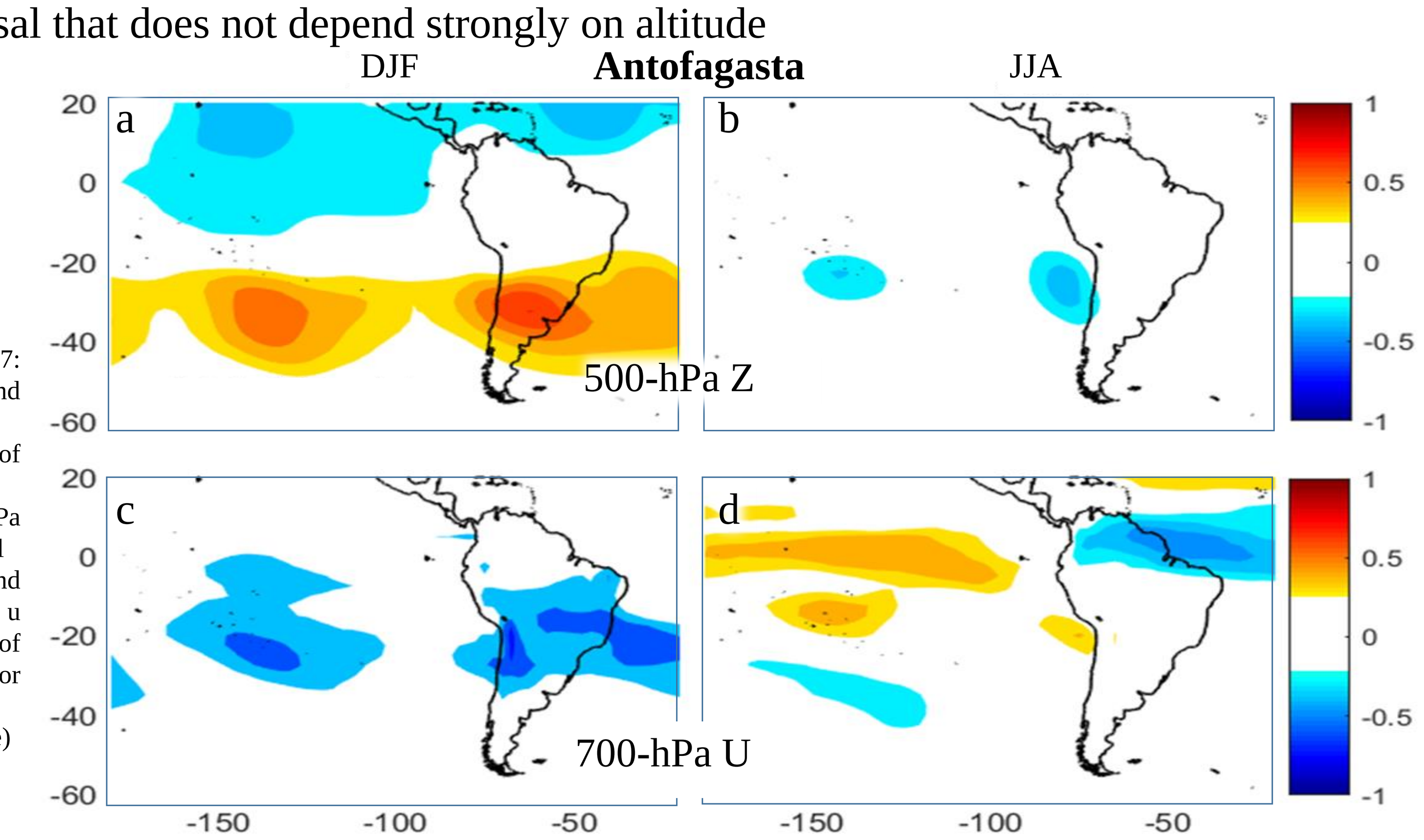

Figure 7: Summer and Winter patterns of correlation with 500 hPa Geopotential height and 700 hPa u component of the wind for Antofagasta (low altitude)

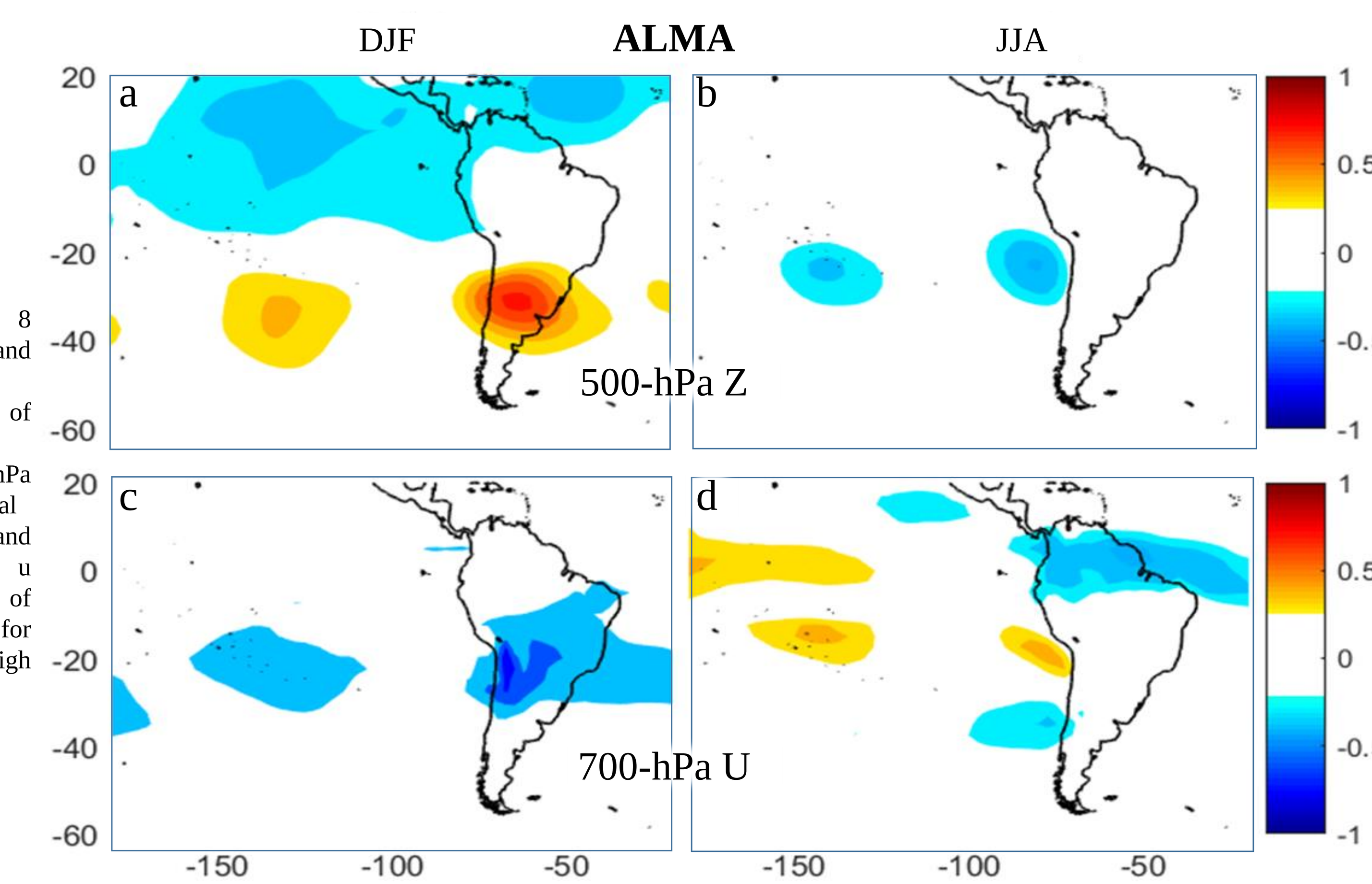

Figure 8 Summer and Winter patterns of correlation with 500 hPa Geopotential height and 700 hPa u component of the wind for ALMA (high altitude)

Conclusions

The variation in precipitable water vapor in the Atacama Desert in northern Chile is correlated with other atmospheric variables. These correlations have different patterns across the continent of South America and the South Pacific.

- In summer, precipitable water vapor displays synoptic-scale correlation patterns with 500-hPa geopotential height, 300-hPa *u* wind, 10 meter *v* wind, sea surface temperature, and mean sea level pressure.
- Seven stations were considered for this study, including three at relatively high altitudes that are further inland and 4 at lower altitudes along the coast. Those along the coast displayed different correlation patterns than those further inland.
- This altitude differences, however, didn't impact the variability that exists between austral summer and austral winter. Both at high altitude and low altitude, the correlation patterns remain the same: 500-hPa geopotential height and 700-hPa *u* component of wind exhibit different correlation patterns and areas from DJF to JJA

Works Cited

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