



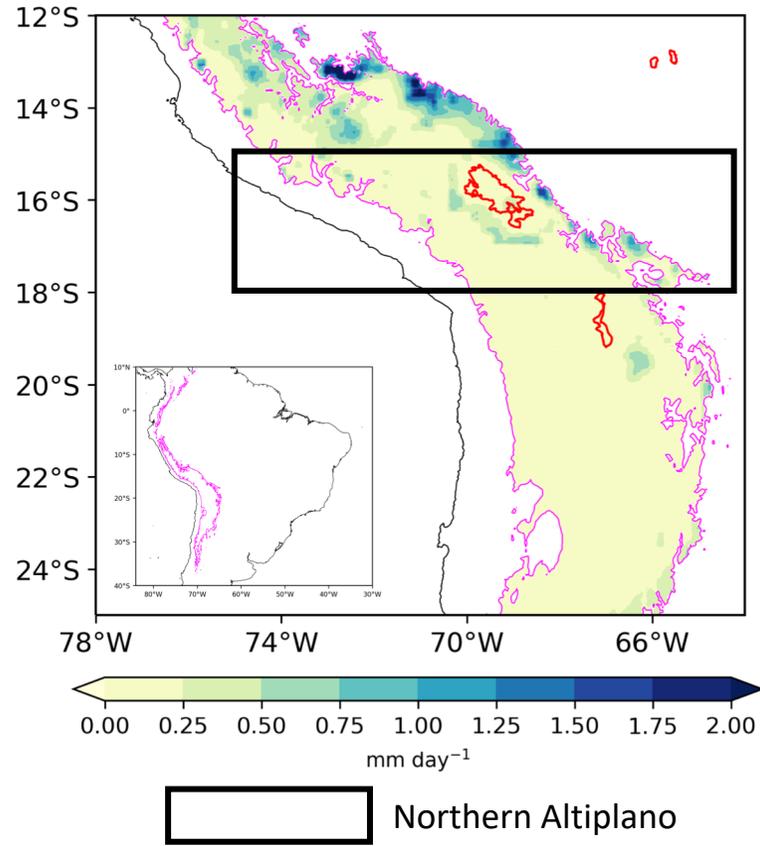
Atmospheric mechanisms controlling extreme winter precipitation events in the northern Altiplano

H. Segura, J.C. Espinoza, C. Junquas, T. Lebel, M. Vuille, J-E. Sicart, T. Condom



Extreme precipitation events in the northern Altiplano during June-August

June-August precipitation (1982-2018; CHIRPS)



June-August precipitation over **the northern Altiplano** is small; however, extreme precipitation events in this season cause serious damage to socio-economic activities in this Andean region, and they are responsible for the loss of human lives.



Fuente: Infobae



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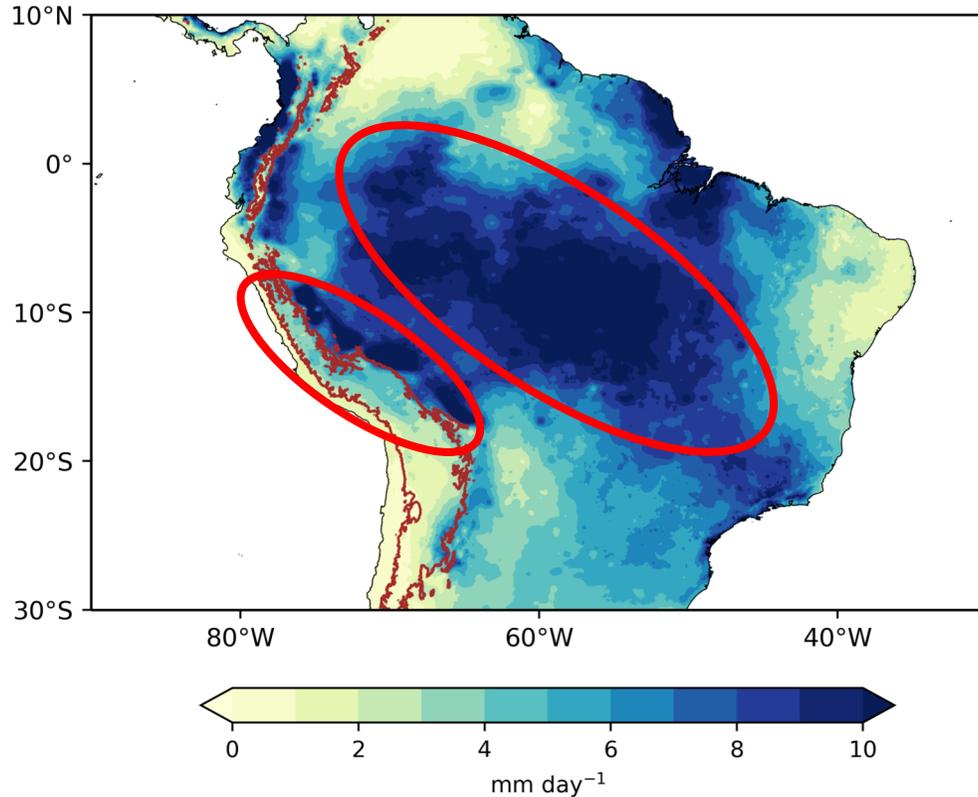
<https://www.infobae.com/2013/09/02/1505879-la-ola-frio-peru-y-bolivia-mato-al-menos-30000-animales/>

<https://diariocorreo.pe/edicion/puno/advierten-temporal-de-nieve-y-granizo-en-la-region-puno-831012/>

<https://publimetro.pe/actualidad/muerto-y-mas-5-mil-damnificados-intensas-nevadas-puno-16259-noticia/>

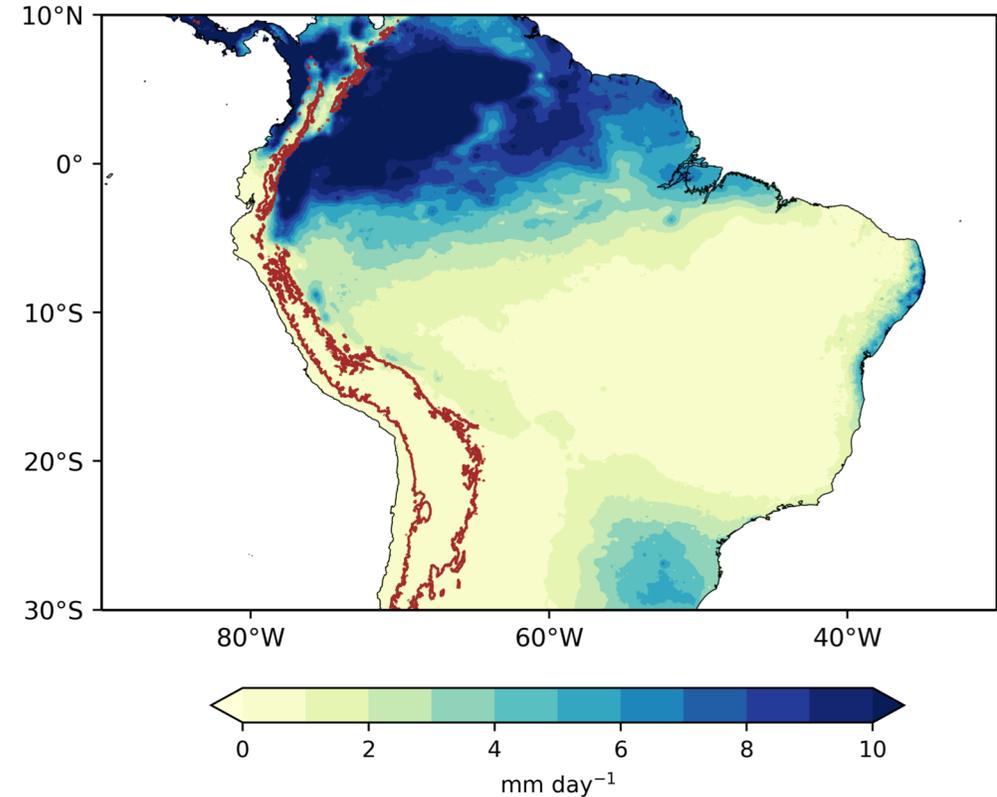
Introduction: Precipitation climatology of South America

December-February (1982-2018)



- Development of the South American Monsoon System (SAMS).
- Precipitation over southern tropical South America (SA): central and southern Amazon, and the southern tropical Andes.

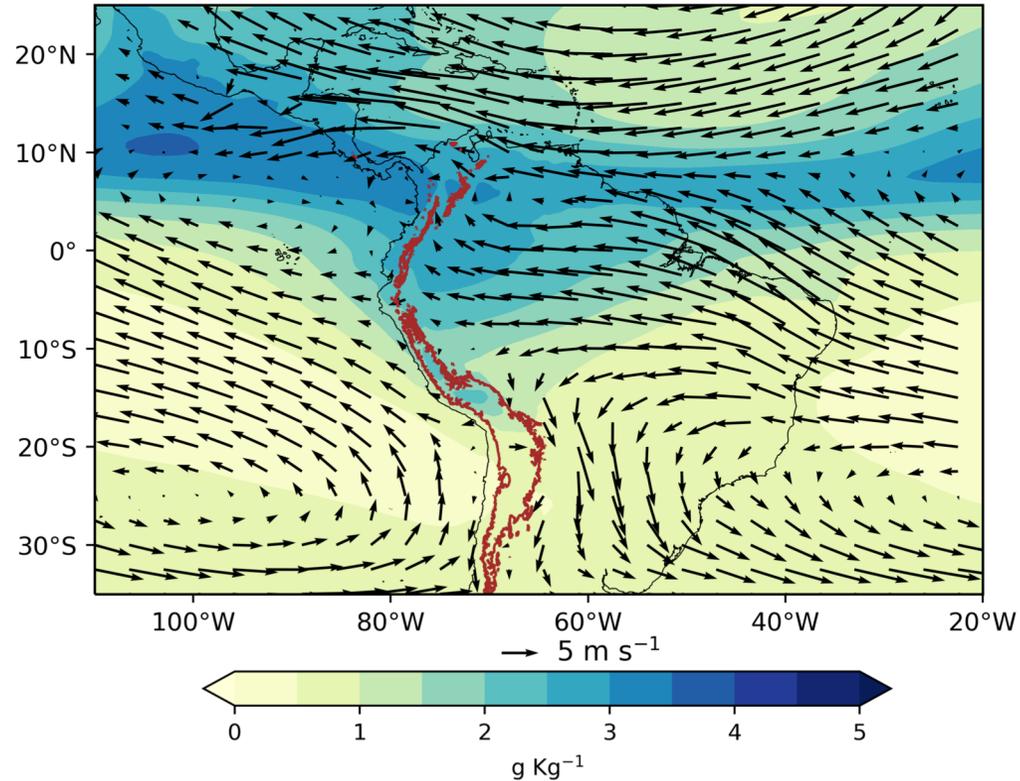
June-August (1982-2018)



- |The weakening of the SAMS.
- Precipitation over northern tropical SA. Dry season in the central and southern Amazon, and the southern tropical Andes (20S-8S).

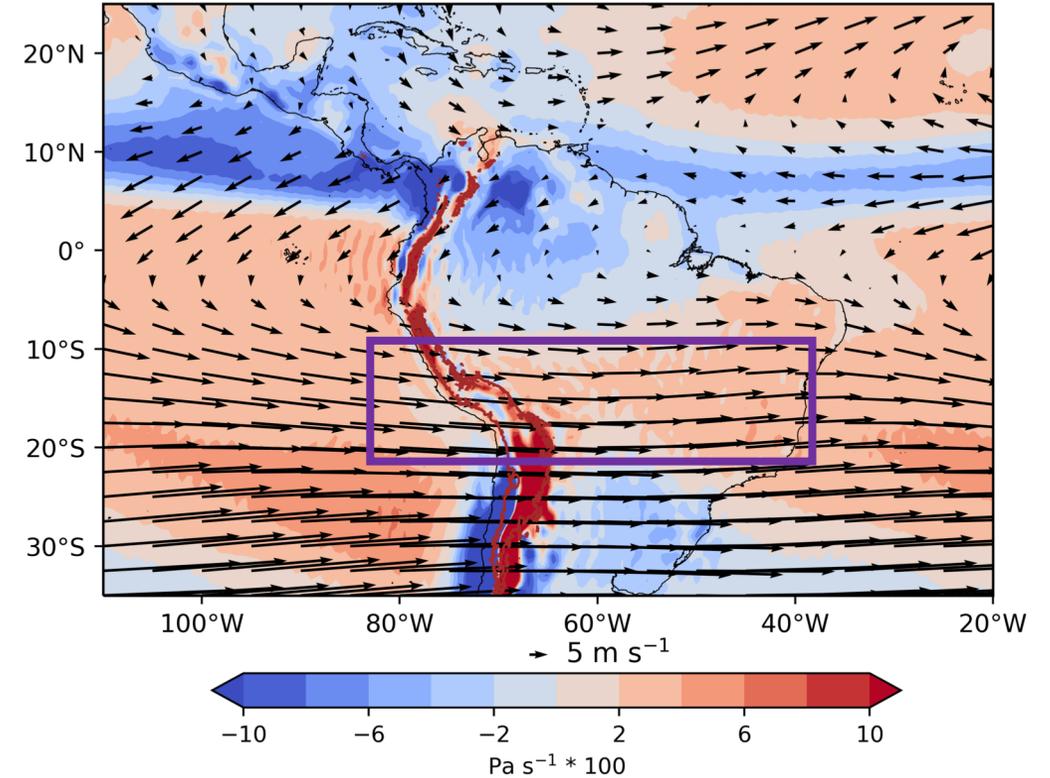
Introduction: June-August Climatology (1979-2018)

Zonal and meridional wind (vector) at 850 hPa;
Specific humidity (color) at 500 hPa.



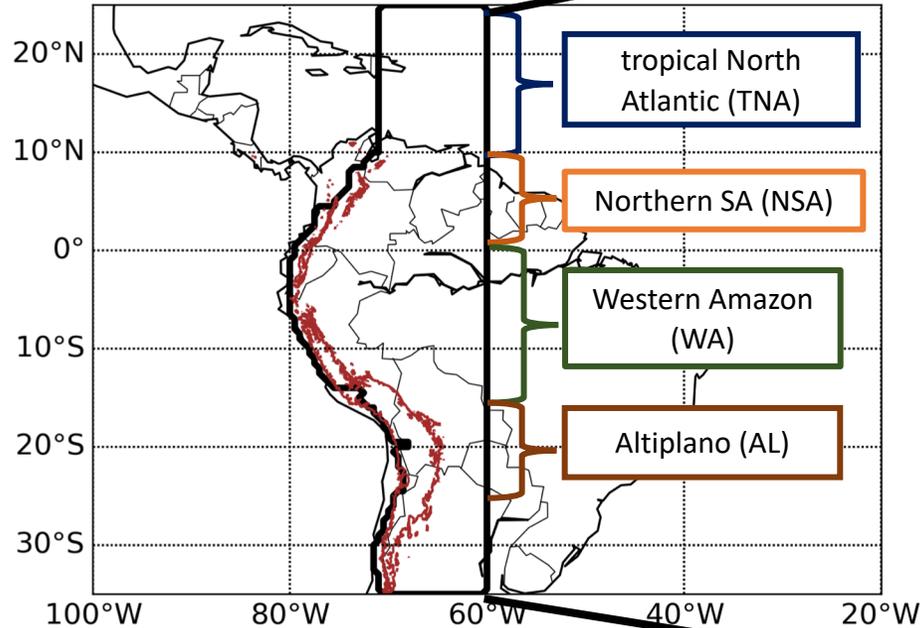
- Low-level easterlies over tropical South America (SA).
- Lack of cross-equatorial winds: the weakening of the SAMS

Zonal and meridional wind (vector) at 200 hPa;
Vertical velocity (color) at 500 hPa.

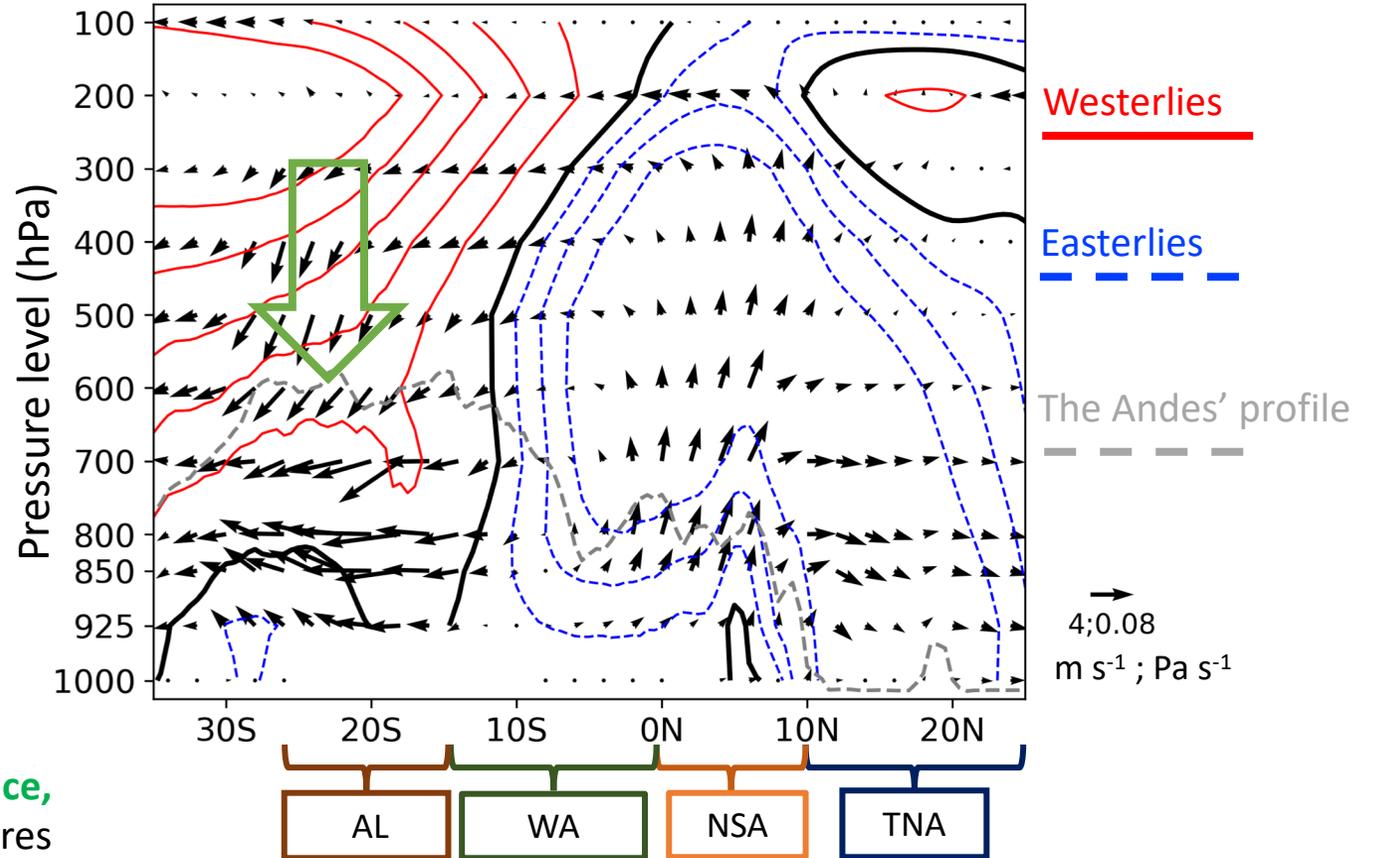


- Convection (**subsidence**) is observed over northern (southern) tropical SA
- Upper-level westerlies dominate southern tropical SA: the western and the southern Amazon, and the southern tropical Andes.

Meridional circulation over western tropical South America – June-August



Zonal mean of vertical motion and meridional winds (vectors);
Zonal winds (contours)

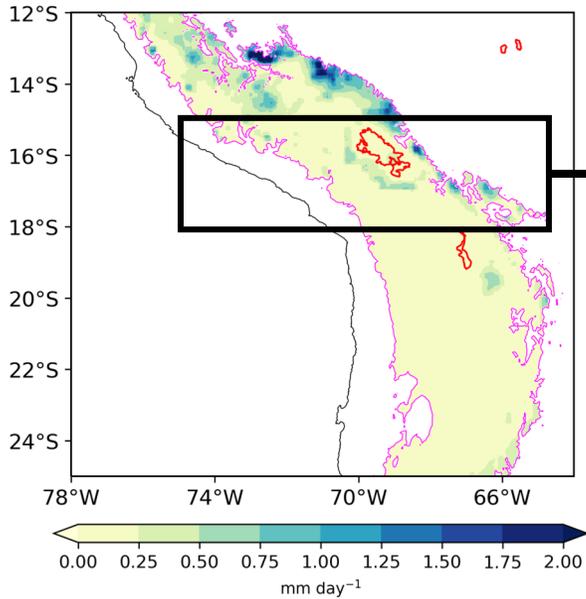


Mid- and upper-level westerlies, as well as **strong subsidence**, predominate over the Altiplano. These climatic features indicate that convection rarely occurs over the Altiplano during June-August season.

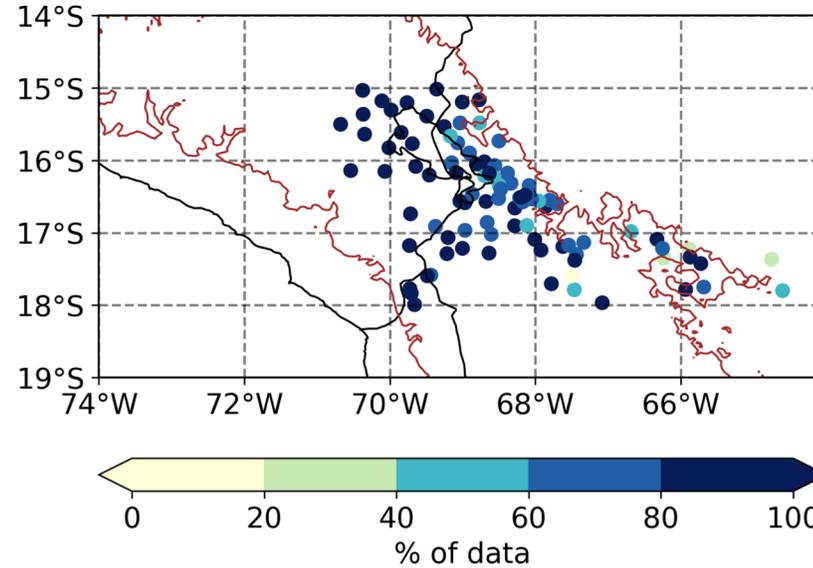
What are the mechanisms associated with extreme precipitation events in the Altiplano in JJA?

In-situ precipitation over the northern Altiplano (June-August; JJA)

JJA precipitation (1982-2018; CHIRPS)



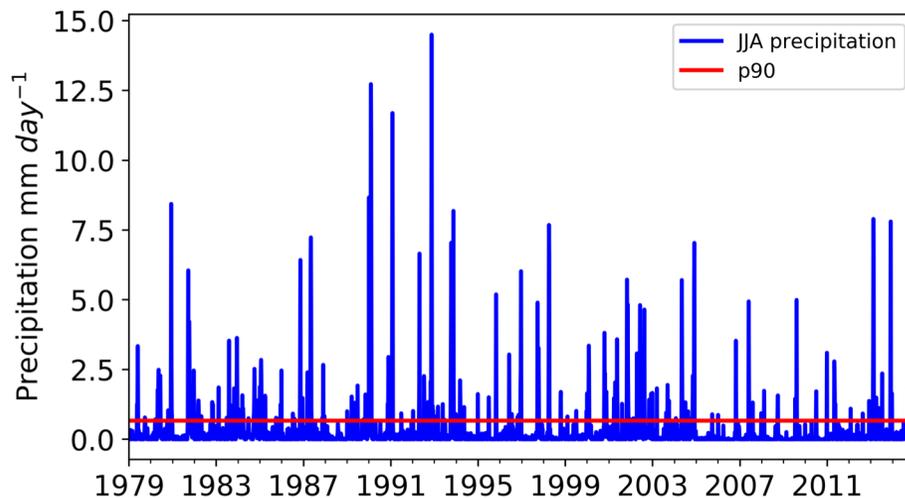
Percentage of days with available precipitation data



-We worked with **101 stations between 18S-15S above 3000 m.a.s.l.** from the “Data on climate and Extreme weather from the Central Andes” (DECADE; Hunziker et al., 2017).

-We made use of daily precipitation data for June-August seasons for the 1979-2014 period, which give a total of **3312 days**.

We computed a **daily precipitation time – series (blue line)** by calculating, for each day, the mean of precipitation using the available data from the **101 rain-gauge stations**.



-We identified 333 days or individual events in which precipitation surpassed the **percentile 90** of the **daily time-series (p90=0.67 mm; red line)**.

-If the time-breach span between these individual events is less or equal to 5 days, we joined them as a single event

-As a result, we ended up with **129 winter extreme precipitation events in the northern Altiplano (WEPEs)**.

Winter extreme precipitation events in the northern Altiplano (WEPEs)

Lifetime (days)	Total Events	Total PP (mm)	Max PP (mm day ⁻¹)	Min PP (mm day ⁻¹)	Mean PP (mm day ⁻¹)
1	56	65.9	3.0	0.7	1.2
2	28	82.3	5.0	0.7	1.5
3	9	71.9	11.7	0.7	2.7
4	7	67.0	7.7	0.6	2.4
5	11	124.0	8.4	0.1	2.3
6	4	29.9	3.6	0.2	1.3
7	4	56.9	7.9	0.1	2.0
8	5	57.7	7.8	0.2	1.4
9	2	45.1	7.0	0.5	2.5
10	0	0.0	0.0	0.0	0.0
11	1	34.5	14.5	0.3	3.1
12	2	78.6	12.7	0.1	3.3
Total	129.0	713.9			

Events lasting one day

Events lasting two days

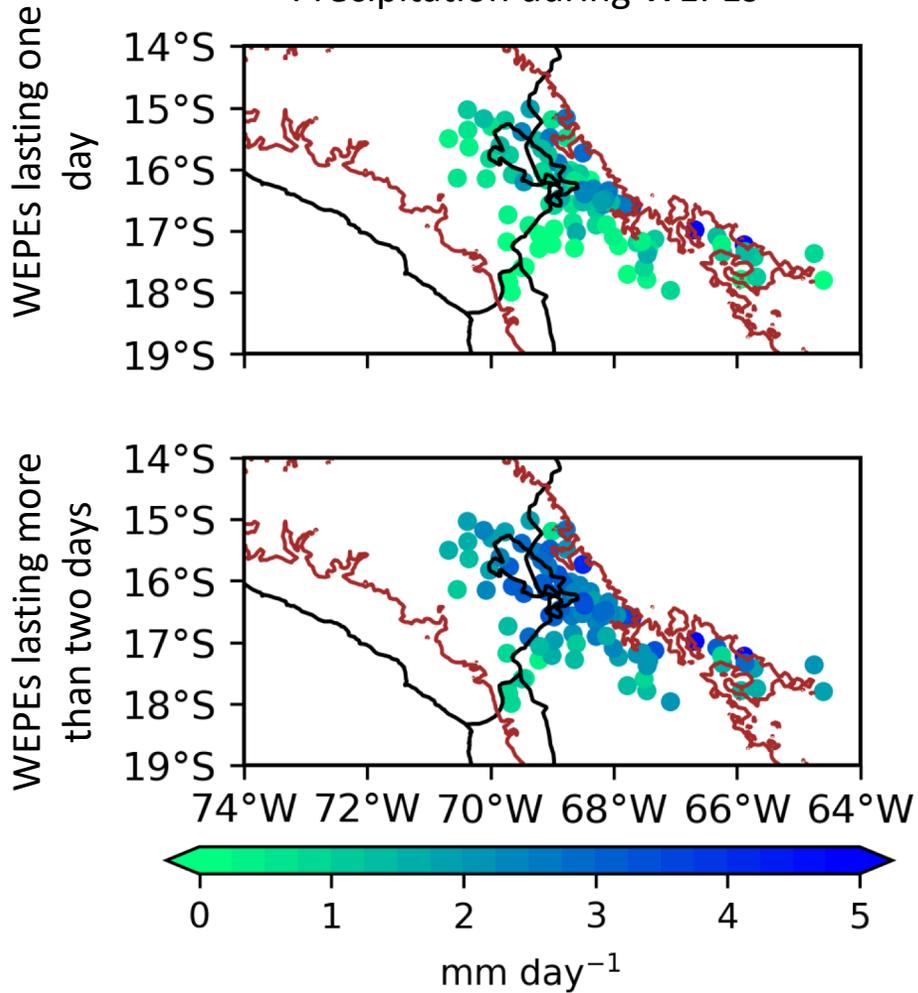
Events lasting more than two days

The 129 WEPEs represent 11% of total days during JJA for the 1979-2014 period, but they contribute to 73% of total precipitation in JJA seasons.

What is the atmospheric circulation associated with these extreme events? Cold surges or upper-level troughs?

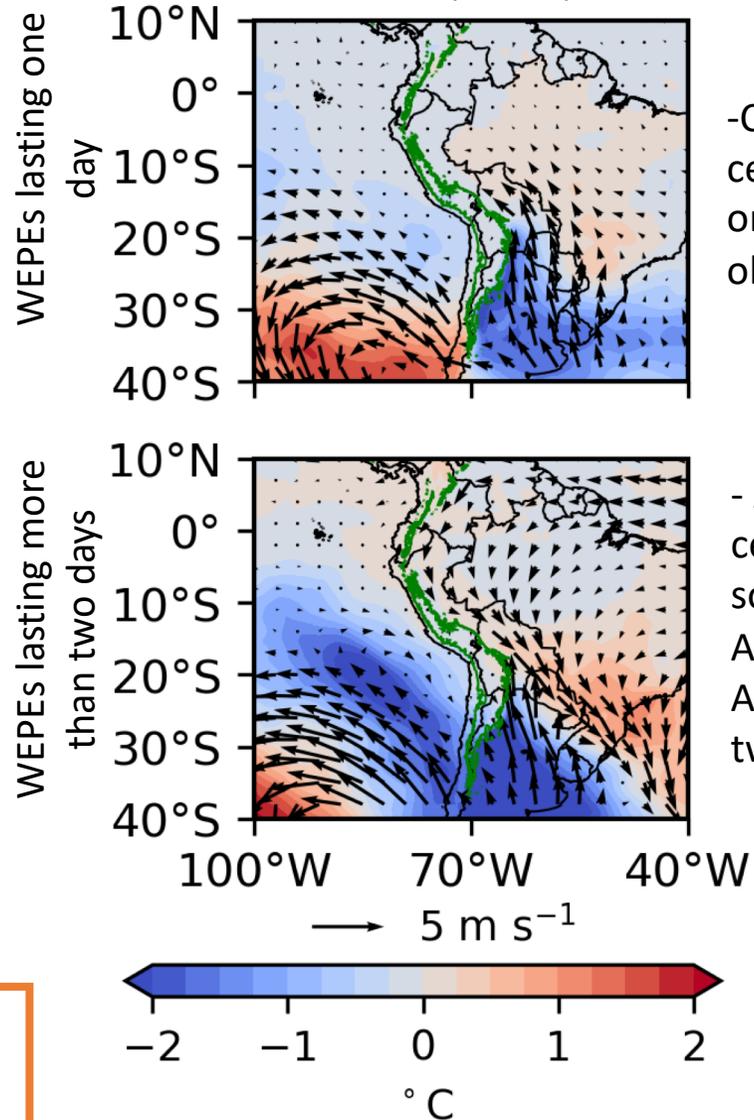
Atmospheric circulation associated with WEPEs

Precipitation during WEPEs



-WEPEs lasting more than two days present more regional precipitation than WEPEs lasting one and two days.

Anomalies of zonal and meridional winds (vector) and air temperature (colors) at 850 hPa at the onset (day0) of WEPEs



-Cold surge to the east of the eastern central Andes is observed in WEPEs lasting one. The same atmospheric circulation is observed in WEPE lasting two days

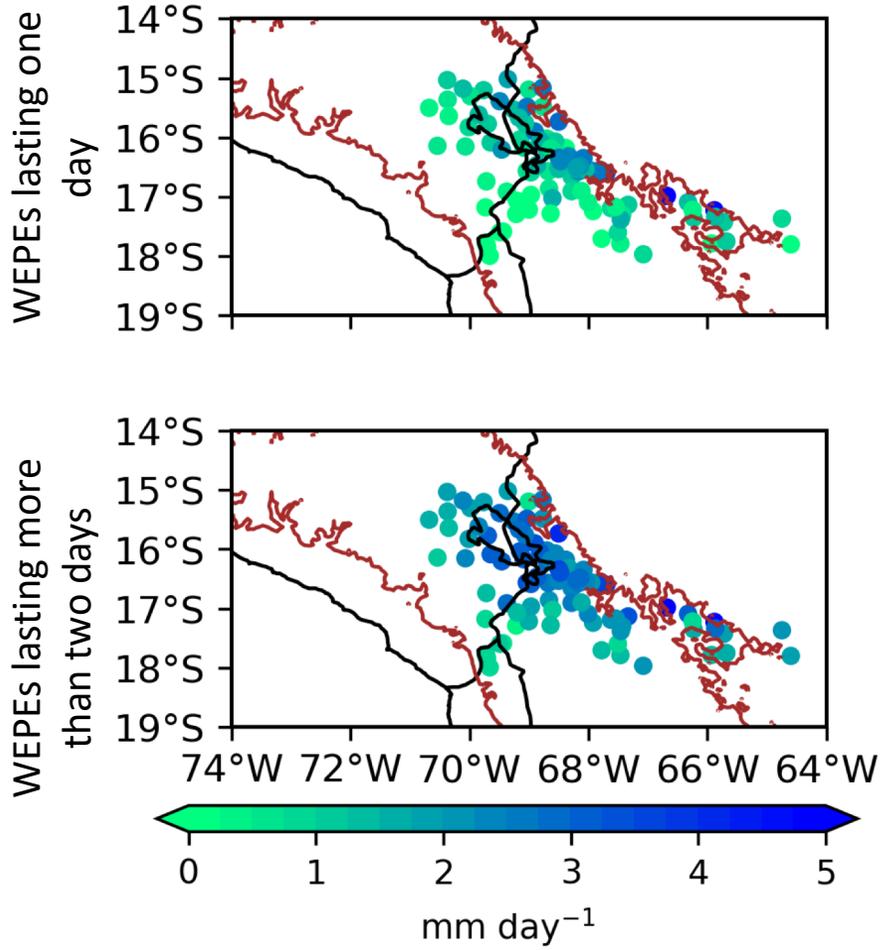
- Apart of the cold surge to the east of the central Andes, there is an anomalous southward moisture transport from the Amazon toward the southeastern South America region in WEPEs lasting more than two days.

Cold surge to the east of the Central Andes is associated with WEPEs

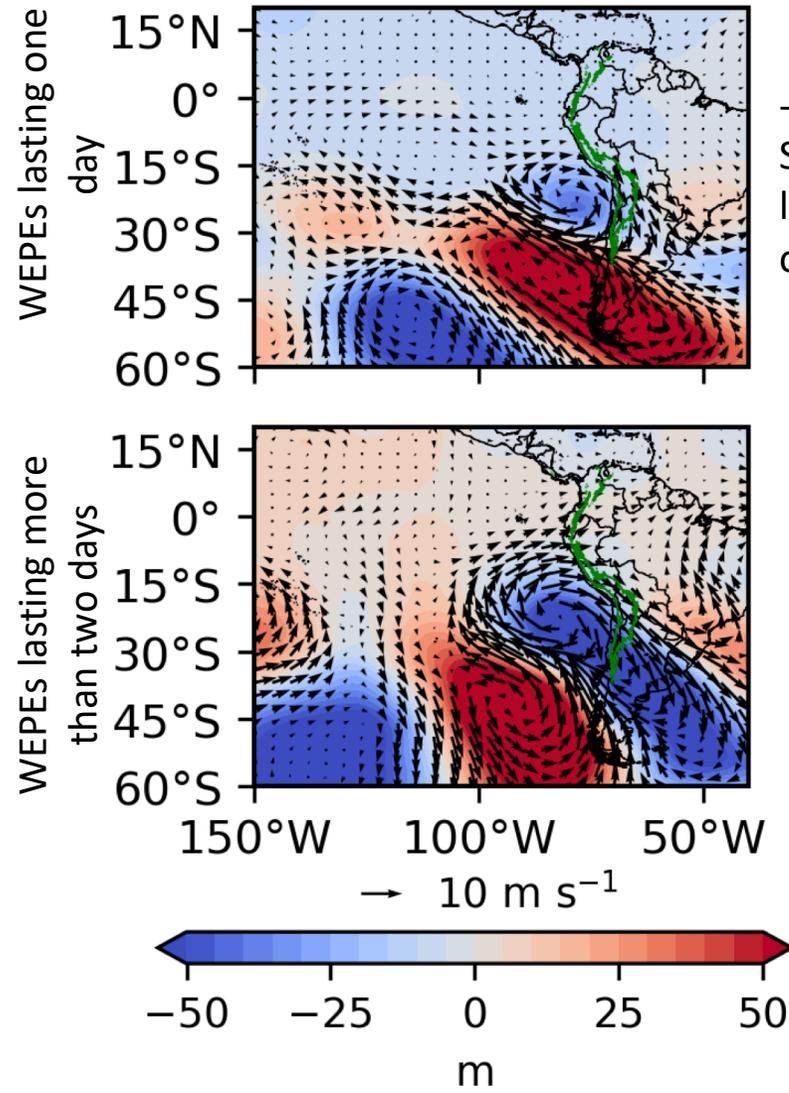
What about at 500 hPa?

Atmospheric circulation associated with WEPEs

Precipitation during WEPEs



Anomalies of zonal and meridional winds (vector) and geopotential height (colors) at 500 hPa at the onset (day0) of WEPEs



- **Wave train** emanating from the Southern Pacific is observed in WEPEs lasting one day at day0. This is also observed in WEPEs lasting two days

- Intensified anomalies of geopotential height and horizontal winds intensify are observed in WEPEs lasting more than 2 days.

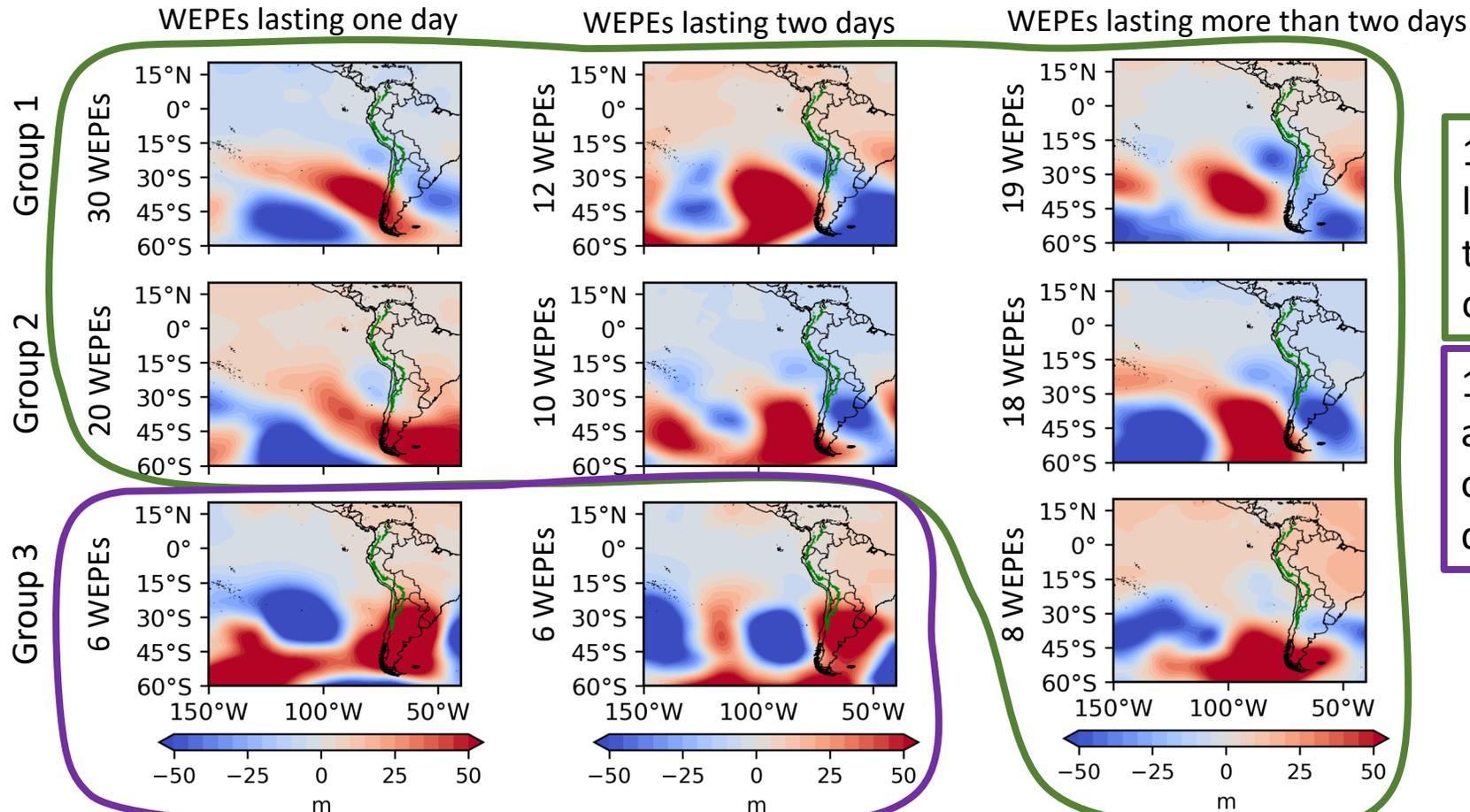
WEPEs are associated an upper-level trough over the

WEPEs are associated with only cold surge or upper-level trough or both of them?

K-means clustering of geopotential height at 500 hPa during the onset of WEPs

We made use of the K-mean clustering method in the anomalies of geopotential height at 500 hPa at the day0 of WEPs. We decided to apply this clustering technique separately in WEPs lasting one, two, and more than two days. Using the silhouette method we decided to get three clusters for each group.

Anomalies of geopotential height at 500 hPa



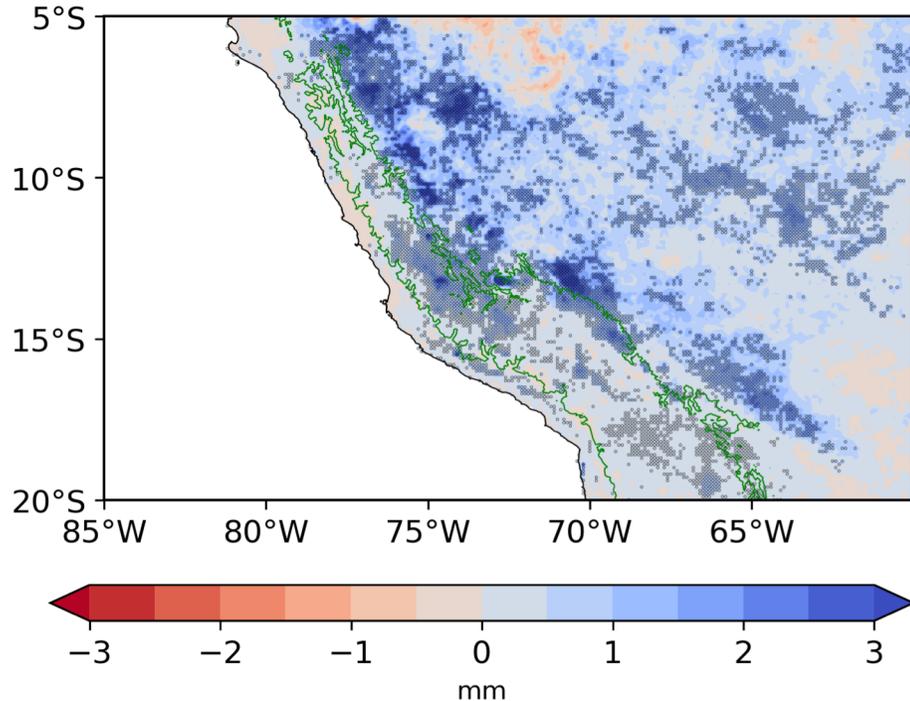
117 WEPs show an anomalous low-pressure system (upper-level trough) over the Peruvian-Chilean coast at day zero (0) of the event.

12 WEPs are characterized by an anomalous high-pressure system over subtropical South America at day zero (0) of the event.

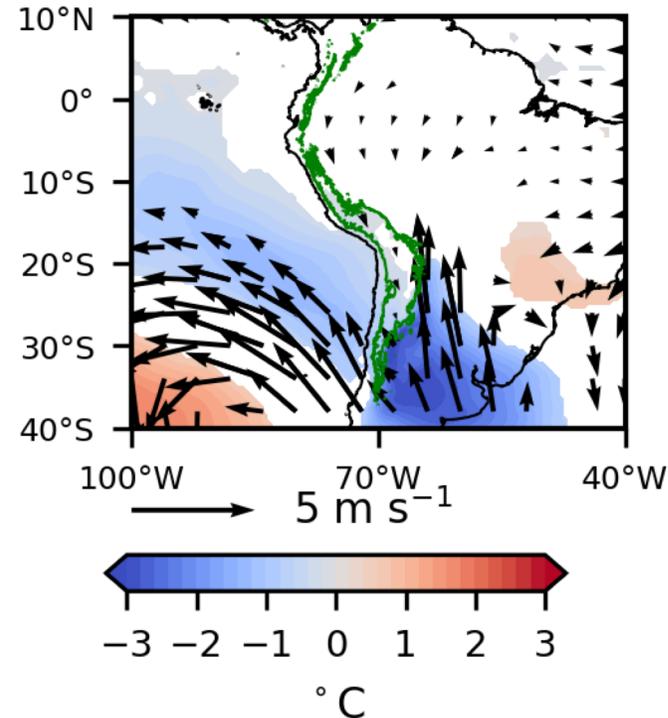
What is the type of atmospheric circulation associated with the 117 WEPs?

WEPEs associated with an upper-level trough over the Peruvian-Chilean coast

Anomalies of precipitation (colors)



Anomalies of horizontal winds (vectors) and air temperature (contour) at 850 hPa

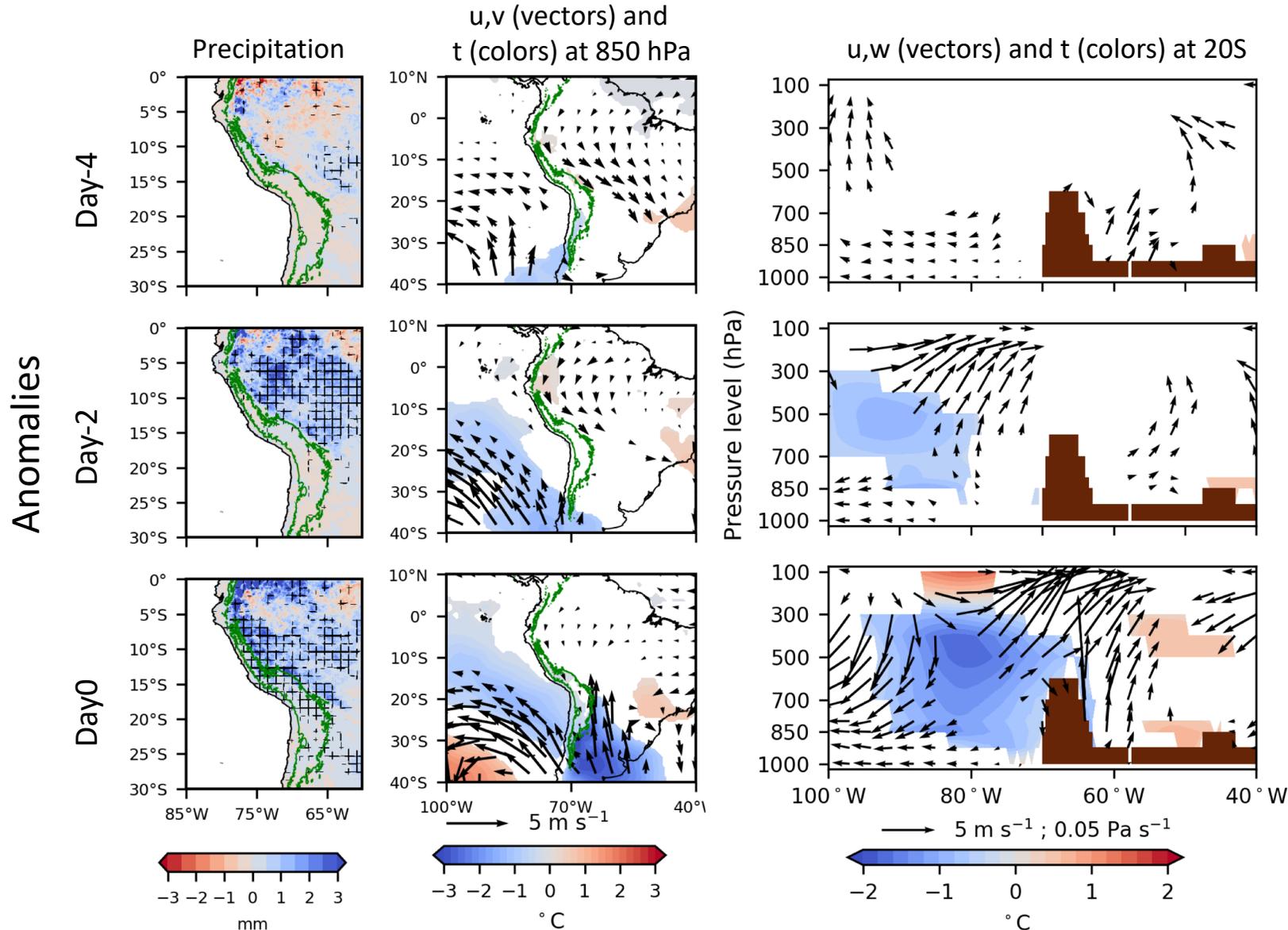


117 WEPEs associated with upper-level trough over the Peruvian-Chilean coast, are also related to cold surge along the eastern Central Andes.

How is the atmospheric circulation associated with these 117 WEPEs prior to the onset?

- Significantly increased precipitation is observed over the western Amazon and the southern tropical Andes at Day0 of the WEPEs.
- Low-level southerly anomalies are observed at the eastern Central Andes, accompanied by cold air temperature anomalies.
- Northerly anomalies over the equatorial region indicate a role in the moisture transport from the Amazon.

WEPEs associated with an upper-level trough over the Peruvian-Chilean coast

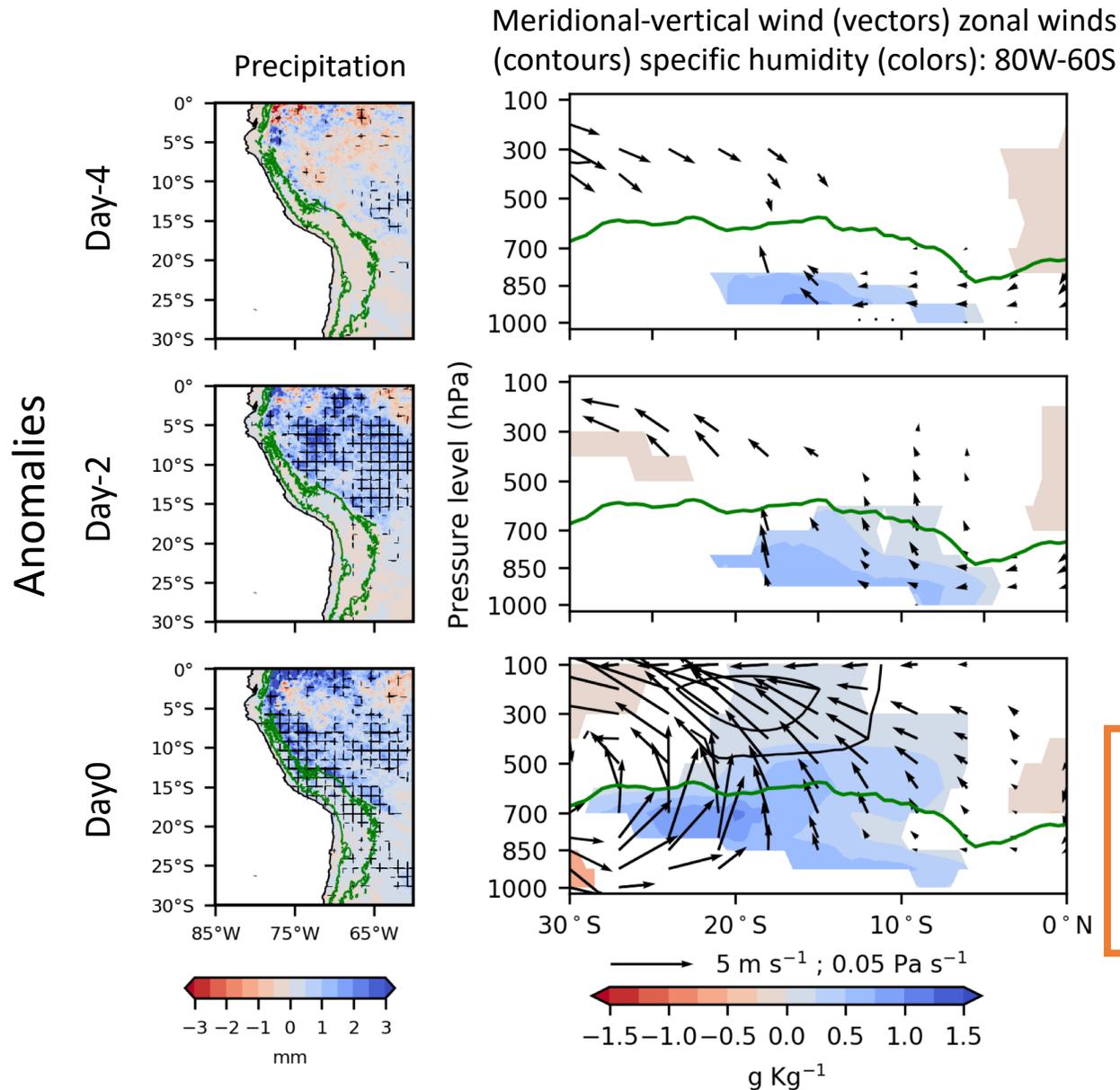


At Day-4, the southward moisture transport from the Amazon toward the SESA region is intensified.

At Day-2, enhanced convection is observed over the western Amazon. It is associated with a weakening of low-level northerly anomalies over the western Amazon, and the arrival of the upper-level trough over the Peruvian-Chilean coast.

117 WEPEs in the northern Altiplano are explained by the convection triggered by the **cold surge** along the eastern Central Andes and the **upper-level trough** over the Peruvian-Chilean coast.

WEPEs associated an upper-level trough over the Peruvian-Chilean coast



The days prior to the development of WEPEs in the northern Altiplano, low-level northerly anomalies **moisten the lower troposphere over the western Amazon.**

Convection and precipitation over the western Amazon, prior to the development of WEPEs, intensify the transport of moisture from the lower to the mid-troposphere over the western Amazon.

At Day0, the tropospheric moistening over the western Amazon and the Altiplano is associated with the development of deep convection over those regions. It is also observed a **connection between the upper-level trough and cold surge.**

The association between cold surge and upper-level trough enhances convection over the Altiplano and the western Amazon, as well as it intensifies the moisture transport from the Amazon toward the Andes.

Conclusions

- The onset of 117 WEPEs lasting from one to 12 days is strongly associated with: i) a prior mid-tropospheric moistening over the western Amazon, ii) cold surge along the eastern central Andes, and iii) upper-level trough over the Peruvian-Chilean coast.
- The association between cold surge and upper-level trough enhances deep convection over the Altiplano and the western Amazon. Besides, the cold air temperature advection by the cold surge to the upper-level trough could help in developing long-lasting events.
- 12 winter extreme precipitation events in the Altiplano (WEPEs) lasting one and two days are associated with low-level southerlies along the eastern tropical Andes crossing the equator.
- The meridional circulation triggered by this southerly regime transports moisture from the equatorial region toward the Altiplano. This moisture transport in association with easterly anomalies over this Andean region explains the development of convection and precipitation over the northern Altiplano.

Thanks!

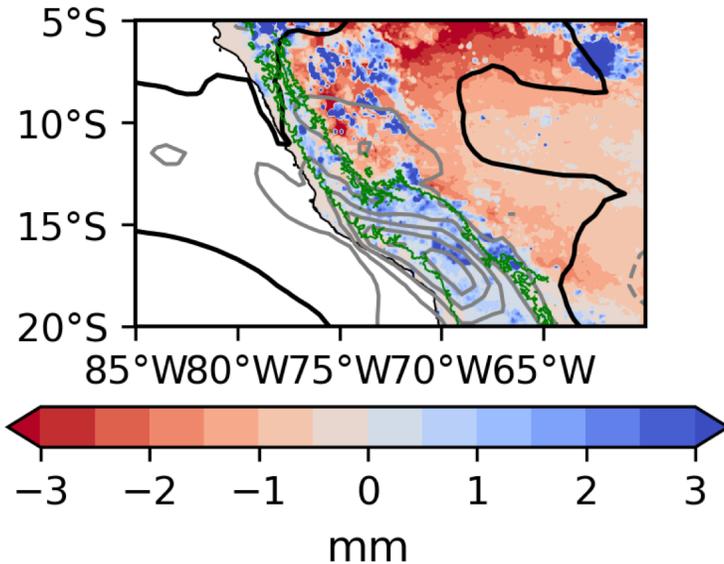
Email: hans.msc90@gmail.com

Supplementary Materials

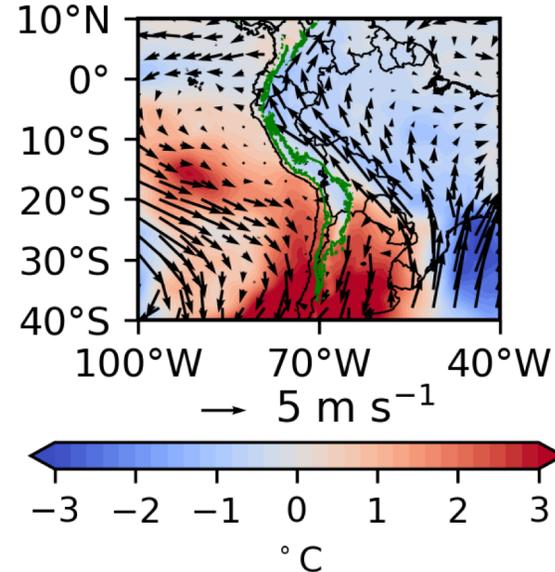
WEPEs associated with a mid-level High-pressure system over subtropical South America

Mean WEPEs lasting one day (Group3)

Anomalies of precipitation (colors) and;
specific humidity (contour) at 500 hPa



Anomalies of horizontal winds (vectors) and
air temperature (contour) at 850 hPa



12 winter extreme precipitation events in the northern Altiplano (WEPEs) are associated with a southerly regime crossing the equator to the east of the Andes.

This southerly regime at the equator is only associated with WEPEs lasting one and two days

-While positive precipitation and mid-level moisture anomalies are observed over the northern Altiplano and the southern tropical Andes, the western Amazon region presents negative anomalies.

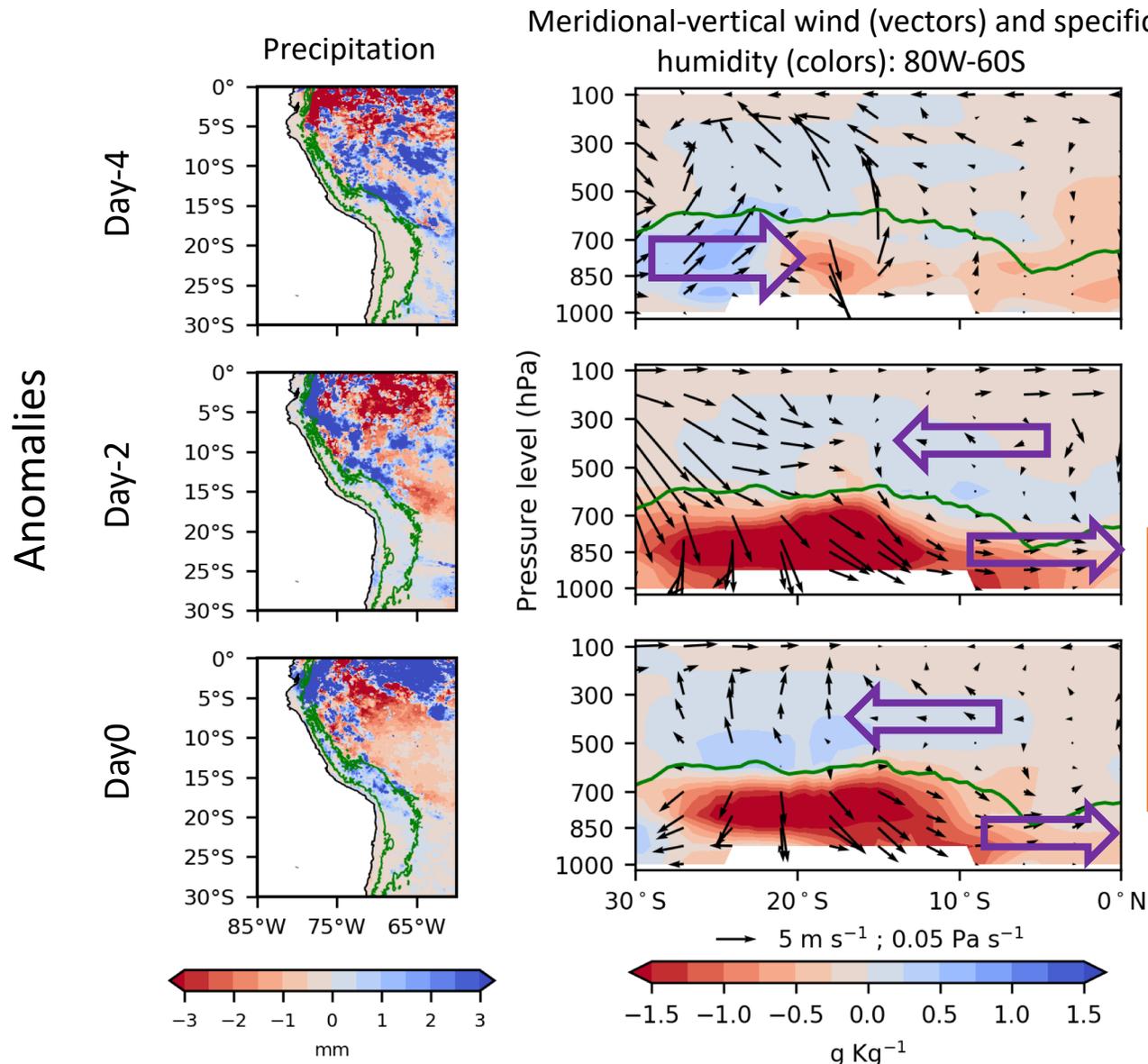
-Low-level southerly anomalies dominates over western tropical South America. Cold air temperature anomalies are observed over the same region.

-Similar atmospheric circulation and precipitation anomalies are observed in WEPEs lasting two days associated with a mid-level High over the subtropical South America (6 WEPEs).

But how does moisture arrives over the northern Altiplano if western Amazon convection is inhibited?

WEPEs associated with a mid-level High-pressure system over subtropical South America

Mean of WEPEs lasting one day (Group3)



At Day-4, we observe strong convection at 15S as a result of low-level southerly anomalies entering the tropical region. Precipitation is observed over the western Amazon.

At Day-2, anomalous subsidence over the southern Amazon and the Altiplano helps low-level southerly anomalies to cross the equatorial region (advection of anticyclonic vorticity anomalies). A mid-level southward transport is observed over the western Amazon.

At Day0, the association between mid-level southward moisture transport arriving to the northern Altiplano, easterly anomalies and cold air temperature anomalies over the Altiplano could trigger heavy precipitation events over this Andean region.

What are the atmospheric mechanisms associated with the others 117 WEPEs in the northern Altiplano?