Analyzing the extreme temperature and precipitation events in March 2015 in central and northern Chile

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Introduction

- During the second half of March 2015, extreme warm surface temperature anomalies were registered in central, southern, and austral Chile, even reaching to the Antarctic continent. Meanwhile, very heavy precipitation fell in the northern region of the country affecting the hyper-arid and semi-arid parts of the Atacama Desert, generating floods, alluviums, and destruction in several towns. In this paper, we analyze the synoptic-scale conditions present in Chile, South America, and upstream in the Southeast Pacific, from 18 to 27 March 2015, during which both events occurred.
- The primary goal of this study is to provide a synoptic-scale analysis of the physical forcing for these rare but hazardous events. By identifying the characteristics and forcing mechanisms for both the temperature and precipitation extremes, events which have important disaster-management implications. We also fill a gap in the current literature, as few studies prior to this one have examined extreme heat in Chile or connected it to extreme precipitation in the Chilean Atacama.
- These events were examined from a synoptic perspective with the goal of identifying forcing mechanisms and potential interaction between each.

Data & Methods

Several key data sets were used to understand the synoptic variability and physical forcing mechanisms for these two events (see Table 1 for a list of datasets, dates, and resolution). Surface temperature and precipitation, and upper-air temperature and dew point temperature observations, were provided by the Dirección de Meteorología de Chile.

Gridded observations of height, temperature, circulation, and precipitable water came from analyses of the GFS model and the ERA-interim reanalysis.

Table 1. Datasets, date ranges, and number of stations (or resolution) used in this study.

Variable	Dataset	Date ranges	Number of stations (or dataset horizontal resolution)
Daily maximum air temperature (at 2 m, in °C)	Dirección Meteorológica de Chile (DMC)	18-27 March 2015	16 surface stations
Exceedence probability, daily maximum air temperature	Dirección Meteorológica de Chile (DMC)	15-31 March, 1950-2015 (1952-2015 for La Serena)	9 surface stations
Air temperature forecasts	GFS predictions, 3-hourly out to 172 h	Forecasts initialized every 6 h between 0000 UTC 17 March 2015 and 1800 UTC 22 March 2015	0.5 degree horizontal resolution
Height (500 hPa; in m), wind (500 hPa, 850 hPa; in m s^{-1}), sea level pressure (in hPa), temperature (850 hPa; in °C), precipitable water (in mm)	GFS analyses	Analyses at 1200 UTC daily between 19 March 2015 and 26 March 2015	0.5 degree horizontal resolution
Upper-air temperature and dew point temperature (both in °C), height (in m), and wind speed and direction (in m s^{-1})	Integrated Global Radiosonde Archive (IGRA), from NOAA National Centers for Environmental Information (NCEI)	1200 UTC (0900 Local), 19-26 March 2015	4 upper-air stations
Precipitation (in mm)	Dirección Meteorológica de Chile (DMC), Dirección de Aguas (DGA), and Sistema de Red Agroclima	23-27 March 2015	46 surface stations
Infrared brightness temperatures	GOES East	Daily at 1700 UTC (1400 Local) between 21 and 26 March	4 km horizontal resolution
Precipitation accumulated (in mm)	ERA Interim reanalysis	20-27 March 2015	0.5 degree horizontal resolution
Streamflow and rainfall	Dirección General de Aguas (DGA)	3-hourly observations between 19-27 March 2015	3 stations

Results

Extreme temperatures

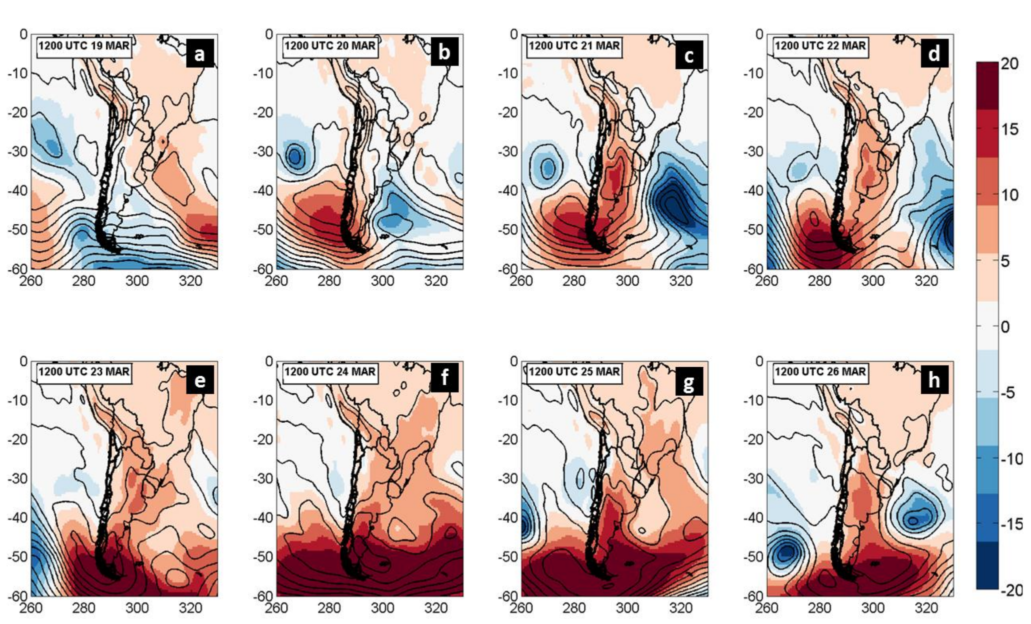

Figure 1. Sea-level pressure (SLP; black curves) and anomalies (shading) Both values in hPa, and anomalies based on 1981-2010 March mean

Sea level pressures and anomalies during this 8-day period (Fig 1) resembled 500-hPa height field and anomalies (not shown). Over central and northern Chile, subtle surface ridging (anomalies up to +5 hPa) was seen. By 20 March 2015, significant surface ridging was seen over southern Chile (SLP anomalies up to +15 hPa), and subtle surface troughing (anomalies up to -2 hPa) was seen along the coast of central and northern Chile, with ridging still seen over the northern Chilean Andes and the Bolivian altiplano. The coastal trough amplified by 21 March 2015, the day after the highest temperatures were recorded, with SLP anomalies of -5 hPa seen centered near 35ºS. For the next 5 days, sea level pressures continued to resemble coastal troughing, and on 25 March 2015 (Fig. 1g), the coastal trough was seen to have merged with the cutoff low that slowly approached from the west. Along with the approach of the cutoff low, SLP anomalies in southern Chile and the straight between South America and Antarctica increased significantly, peaking on 24 March 2015 (Fig. 1f) nearly +30 hPa above March monthly normal.

Significant positive surface temperature anomalies were recorded throughout central and southern Chile (Fig. 2a).Interestingly, highest surface temperature anomalies (generally +4°C to +8°C) were seen in central Chile (30°S to 38°S; Fig. 1) from 18 to 22 March 2015. Then, highest temperature anomalies (generally +8°C to +11.5°C) were seen in south-central and southern Chile (38°S to 48°S) from 21 to 27 March. The absolute highest temperature anomaly (+11.2°C) was recorded in Valdivia (39.8°S 73.2°W) on 26 March. In the capital Santiago, at Quinta Normal (station 330020), an all-time record maximum temperature of 36.2°C was recorded on 20 March 2015 at 16:23 (local time).

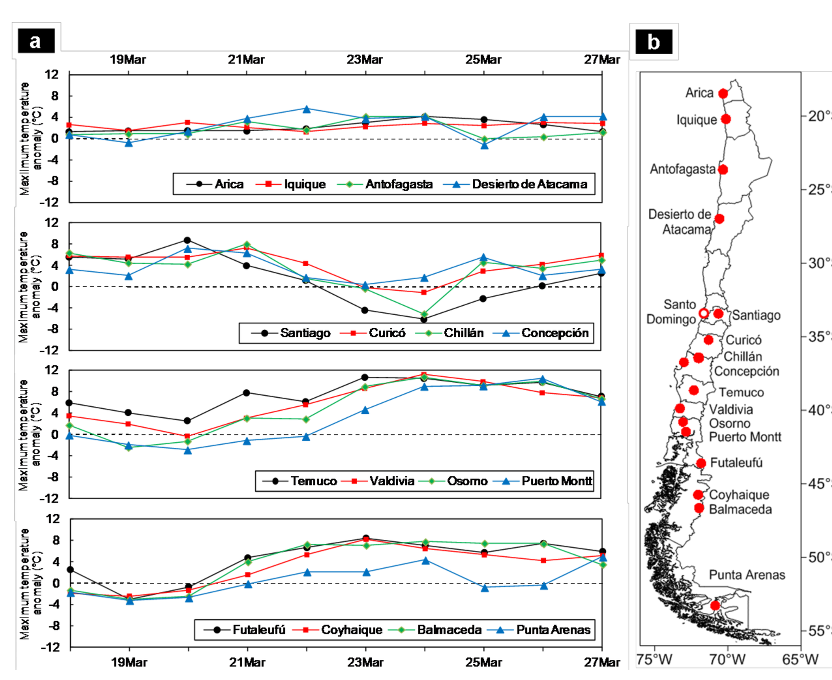

Figure 2. Daily anomalies of maximum temperature (in °C), from 18-27 March 2015 (panel a). Anomalies calculated with respect to the 1981-2010 March mean. Locations of the temperature and upper-air stations used in the analysis (panel b). An open red circle was used to indicate the radiosonde station at Santo Domingo station, referenced in Figure 3.

Although the highest surface air temperatures were recorded in central Chile, the largest low- and mid-troposphere height anomalies were observed in southern Chile. This anomaly pattern was confirmed in analysis of heights at 925, 850, and 500 hPa at the four radiosonde upper-air sites in Chile. Between 23 and 25 March, Punta Arenas recorded anomalies over 2 standard deviations above normal in the lower and middle troposphere (anomalies were based on the Punta Arenas radiosonde record from 1994-2015). The observed 500-hPa height observed at 1200 UTC on 24 March 2015, 5820 m, was the highest since upper-air observations began there in 1994. These record heights confirmed the presence of a strong, deep blocking anticyclone that prevented the cutoff low from gaining latitude as it progressed east into northern Chile.

Extreme precipitation

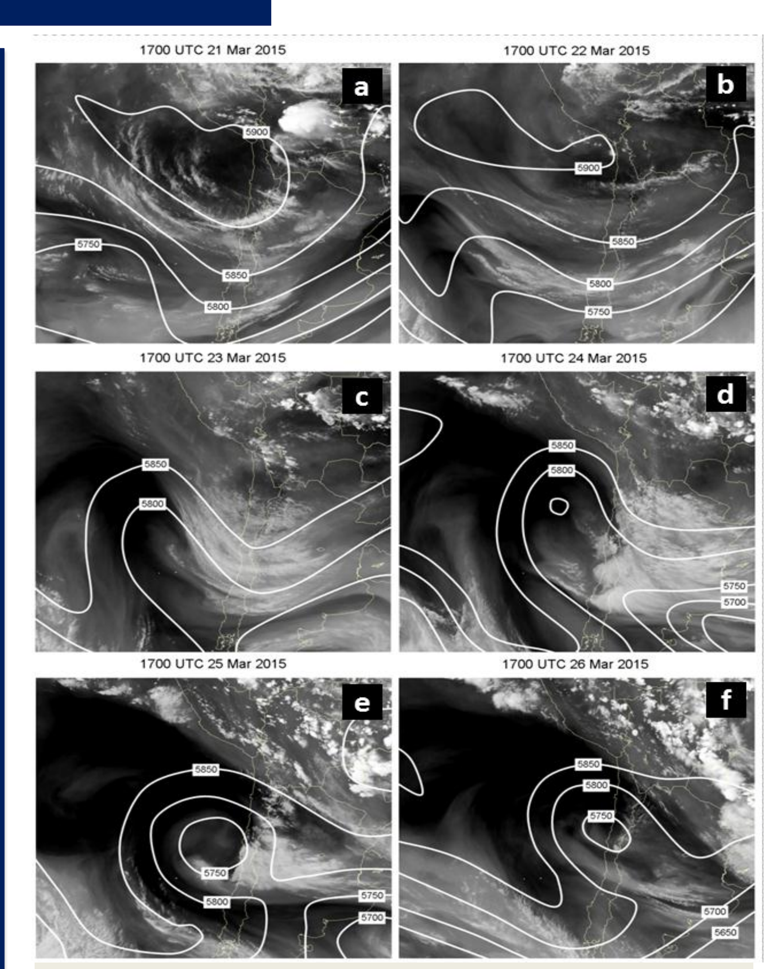

Figure 3. Infrared satellite images from GOES East (GOES 13), daily at 1700 UTC (1400 Local), from 21 March 2015 (panel a) to 26 March 2015 (panel f). White curves indicate 500 hPa height (in m) from GFS analyses.

From 20 to 23 March, in the days leading up to the heavy precipitation event, scattered convective precipitation was seen in the Peruvian and Bolivian altiplanos, over the Chilean Andes, and east in the plains of Argentina (Fig. 3 a-b and Fig. 5 a-d). The 24-h period ending 1200 UTC 24 March 2015 saw significant precipitation (over 100 mm) over the central Chilean Andes (Fig. 6e), indicative of the approach of the cutoff low and reduction in static stability. The heavy precipitation event itself began in the afternoon of 24 March (seen as cold cloud tops in infrared imagery; Fig. 3d) and lasted through 27 March (Fig. 5 f-h). Heaviest precipitation over the Atacama was centered between 28°S and 24°S.

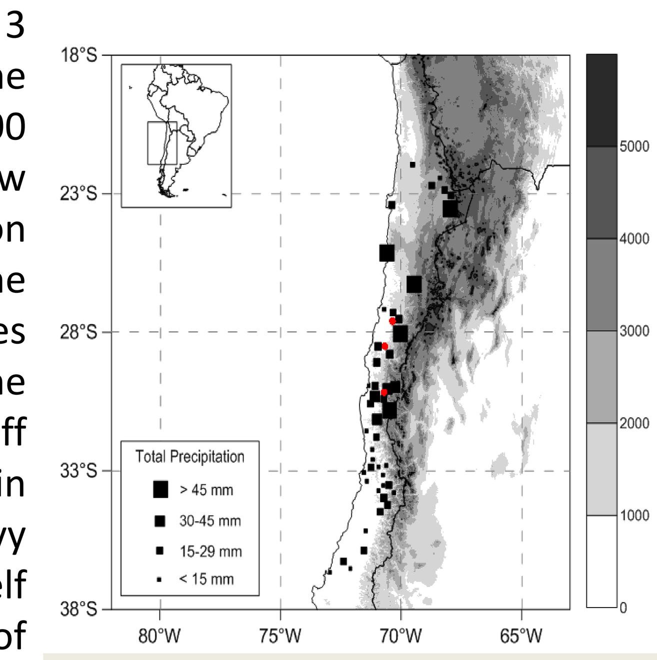

Figure 4. Accumulated precipitation (black squares; size indicates precipitation total in mm) from 23 to 27 March 2015.

El Salvador station, 26.2°S 69.6°W at 2240 m elevation, recorded 87.0 mm, the maximum observed during of this event (Fig. 4). Indeed, from 32°S-38°S, most stations recorded fewer than 15 mm, while from 29°S-32°S, mean station precipitation was between 15 and 45 mm. North of 29°S, several stations recorded greater than 45 mm.

The primary forcing for this heavy precipitation event came during the approach of an upper-troposphere cutoff low. However, as noted by Garreaud and Fuenzalida (2007), cutofflows in March do not always produce precipitation in the Atacama. The unusual northward position of the cutoff low for a late-summer or early-autumn event contributed to the northward expansion of precipitation. However, another likely significant contributor to both the northward expansion and the heavy nature of the precipitation was the very high precipitable water anomalies observed over the Arica bight and adjacent coastal zones (Fig. 6). This precipitable water was advected by anomalous northerly winds. They also advected warmer than normal air in the lower troposphere. The high precipitable water values were likely the result of anomalously warm sea-surface temperatures off the coast of Perú as a result of the developing 2015 El Niño.

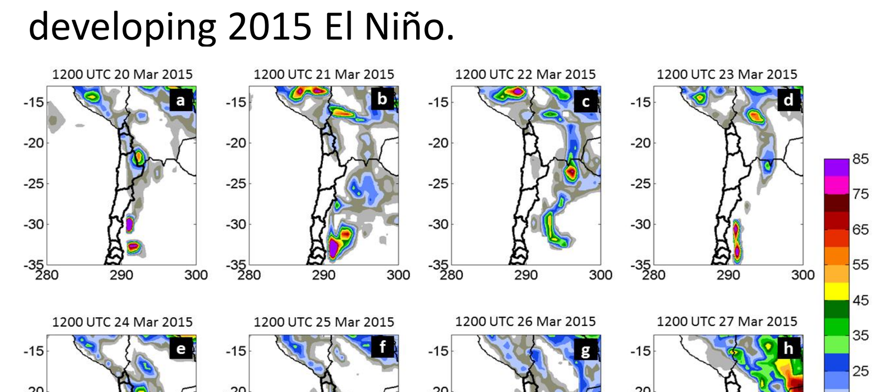

Figure 5. Accumulated precipitation from ERA-Interim reanalysis (in mm) for 24-h periods from 1200 UTC (0900 Local) 20 March 2015 (panel a) to 1200 UTC 27 March 2015 (panel h), with accumulations ending on the dates and times indicated on each panel.

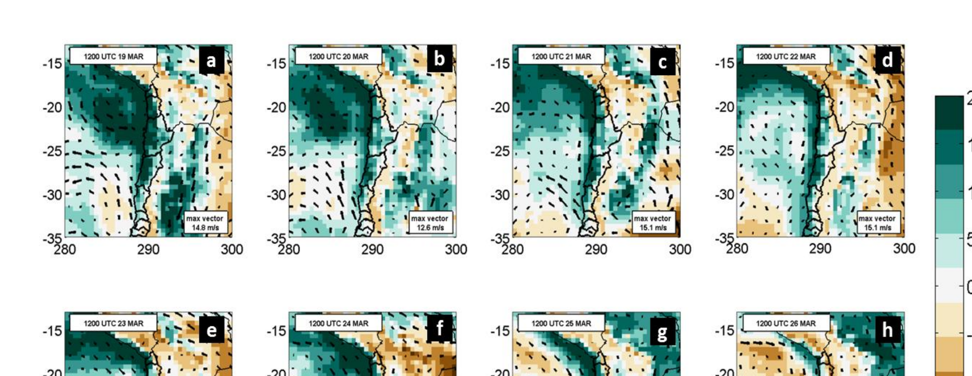

Figure 6. Precipitable water content anomalies (in mm) and 850 hPa winds (in m s-1). Anomalies of precipitable water are with respect to 1981-2010 March mean.

Major Conclusions

The extreme precipitation in northern Chile occurred immediately after an extreme heat event in central Chile and concurrent with an extreme heat event in south-central and southern Chile. Evolution of 500-hPa height and wind fields, 850-hPa temperature and wind fields, and SLP fields suggests that the events occurred during an amplified and partially blocked flow pattern.

This expansive and strong upper-level ridge provided at least three important physical forcing mechanisms for the extreme events of the week:

1) As it approached Chile from 19-20 March 2015, it generated the subsidence and anomalous easterly flow needed to support the strong insolation and warm boundary layer conditions that produced the extreme heat in Santiago.

2) By amplifying and expanding throughout the rest of the period, it caused the upper low, originally connected to a trough over the Drake Passage on 19 March 2015, to become cut off from equatorward flow and thus progress only slowly eastward, at approximately 5 m s^{-1}. By the date of the landfall of the cutoff low in northern Chile, height anomalies over 200 m above normal extended along 60ºS from 110ºW to 30ºW, nearly a 5000 km expanse.

3) This southern blocking ridge (e.g., Trenberth and Mo 1985; Marques and Rao 1999; Damião and Albuquerque 2014) provided subsidence and insolation needed for the strong positive surface temperature anomalies observed in south-central and southern Chile.

Acknowledgements

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