FOEHN EVENT TRIGGERED BY AN ATMOSPHERIC RIVER UNDERLIES RECORD TEMPERATURE ALONG CONTINENTAL ANTARCTICA*

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1. OVERVIEW

West Antarctica, particularly the Antarctic Peninsula (AP), has recently been a site of remarkable temperature change, with a long-term warming trend in near-surface temperature observed over the last 50 years (Marshall et al., 2006; Turner et al., 2016). Recent changes in large-scale circulation patterns (e.g., Southern Annular Mode) and associated strengthening of westerly marine air advection are thought to be the main drivers of the long-term warming trend in the Antarctic Peninsula (e.g., Kushner et al., 2001; Marshall et al., 2006). In addition to large-scale forcing, warm air masses can be episodically advected eastward over the orographic barrier of the peninsula, causing warm and dry downslope winds. This foehn event largely amplifies the background large-scale farming, especially over the eastern part of the peninsula.

Here we document an extreme event of such warming amplification. A record-setting temperature of 17.5°C occurred on 24 March 2015 at the Esperanza station located near the northern tip of the AP. The objective of this study is to describe the record high-temperature event in detail and to discuss how large-scale forcing played a key role in triggering the foehn winds during the event. We also aim to disentangle the role of the large-scale forcing versus local dynamics by removing the surface topography in the northern part of the AP in a regional climate model simulation.

2. DATA AND APPROACH

We studied the event using surface station data, satellite imagery, reanalysis data and numerical simulations. Satellite imagery of the Larsen B Ice Shelf was obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) Antarctic Ice Shelf Image Archive (Scambos et al., 1996), provided by the National Snow and Ice Data Center. We used two satellite images before and after the record high-temperature event (22 and 25 March 2015, respectively) in order to illustrate the impact of the foehn event and to thus evaluate short-term effects on the cryospheric processes. To illustrate the large-scale cloudiness and water vapor conditions over the AP during the event, we obtained Antarctic composite infrared and water vapor imagery data for 24 March 2015 at 4 km spatial resolution, from the University of Wisconsin-Madison Antarctic Meteorological Research Center repository. The atmospheric circulation during the event was analyzed using the

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European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis (ERA-Interim, hereafter ERAINT) (Dee et al., 2011).

We conducted two numerical simulations using the RegCM4 regional atmospheric model at a 10 km spatial resolution, with and without topography (CTR and NOTOPO, respectively) in the northern AP. The model realistically reproduces the main synoptic fields and extreme conditions before and during the event. Despite this reasonable agreement in large-scale forcing, the model illustrates the difficulty in reproducing the steep SAT increase at foehn onset. Similar difficulties persist even with a relatively higher spatial resolution (6 and 2 km) in the numerical experiment carried out with the WRF model.

3. RESULTS

On 24 March 2015, the higher temperatures were recorded at the Esperanza and Marambio stations (17.5ºC and 17.4ºC, respectively) on the leeward side of the northern tip of the AP (Figure 1a). Positive temperature anomalies are not only confined to northern parts of the AP but also evident in the center and southern parts of the AP, with warm temperature anomalies ranging between +6 and +16ºC based on the Era-Interim reanalysis (Figure 1b).

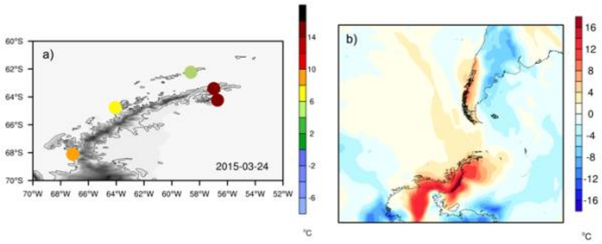

Figure 1. (a) Daily maximum near-surface air temperature distribution over the northern part of the Antarctic Peninsula on 24 March 2015. (b) Spatial distribution of daily maximum temperature anomaly on 24 March 2015 with respect to the long-term daily maximum temperature climatological mean (24 March, 1979–2014) ERA-Interim reanalysis.

An atmospheric river (AR) event resulted in warm and moist air advection toward the peninsula before the record-setting temperature event, eventually triggering a foehn episode on the leeward side of the central and northern Antarctic Peninsula on 24 March 2015. The MODIS Antarctic Ice Shelf Image Archive of Larsen B provides clear evidence for disintegration and advection of sea ice, as well as the formation of melt ponds on ice sheet surface at the base of the Antarctic Peninsula mountain range (Figure 2). The satellite images clearly illustrate that a single, short-lived but extreme foehn warming can have a significant impact on the surface cryosphere by largely amplifying the warming signal produced by the large-scale warm advection.

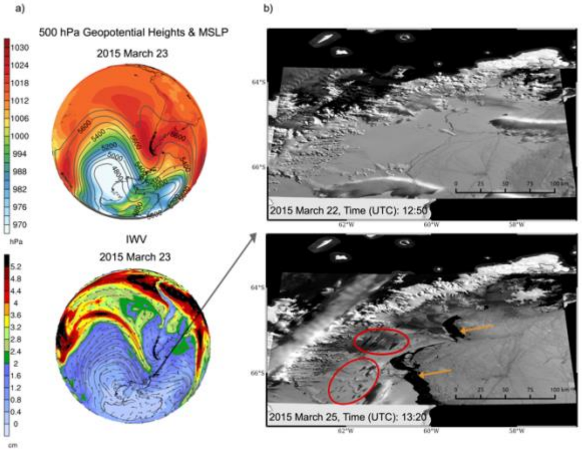

Figure 2. (a) The 23 March 2015 mean sea level pressure (hPa; shaded) and 500 hPa geopotential heights (m; contour lines at 100 m intervals) from ERA-Interim (top). Also shown is 23 March 2015 integrated water vapor (cm; shaded) and 850 hPa wind vectors from ERA-Interim (bottom). (b) MODIS images of Larsen B and Larsen A embayments before (22 March 2015, 12:50 UTC) (top) and after (25 March 2015, 13:20 UTC) (bottom) the record high-temperature event. Orange arrows indicate areas of sea ice disintegration and offshore advection. Red circles contain dark patches on the fast ice and glacier surface (melt ponds)

The modeling experiment illustrates that almost all of the precipitation occurs due to the orographic enhancement (e.g., >95% on the windward side of the AP) (Figure 3). CTR-NOTOPO shows the existence of local topographically induced warming along the eastern coast of the AP. For instance, a marked warming (>8ºC) with respect to NOTOPO occurs on the leeward side of the central AP (around 64ºS) on 24 March.

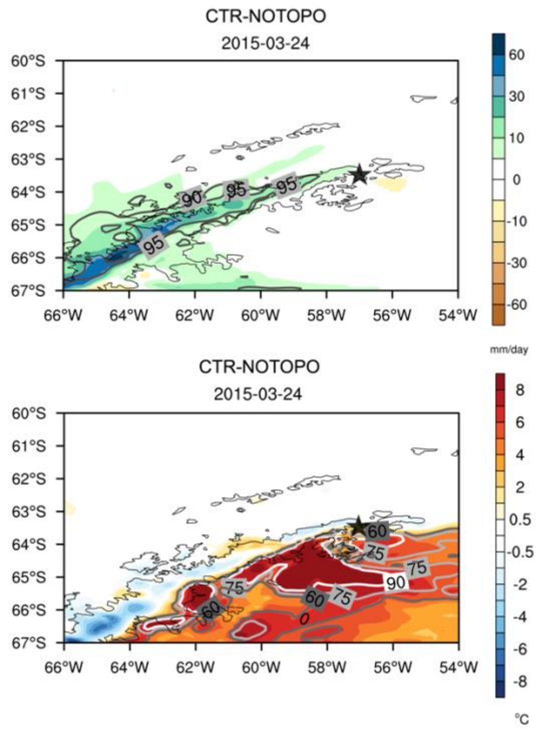

Figure 3. Precipitation (mm d^{-1}) and temperature (ºC) differences between the CTR and NOTOPO experiments on 24 March 2015. Black stars show the location of the Esperanza station. Precipitation difference contours correspond to the relative precipitation changes (%) between the CTR and NOTOPO experiments. Temperature difference contours indicate the ratio (*100) of differences in maximum near-surface air temperature between the CTR and NOTOPO experiments to the ERAINT maximum near-surface air temperature anomalies on 24 March with respect to 1979–2014 climatology (white contours >90%, light gray contours >75%, and dark gray contours >60%).

As the northern tip of the AP is located away from the main AP mountain range, topographically induced warming on its leeward side is relatively smaller than that in the central AP. A ratio of Δ*SAT* to Era-Interim SAT anomalies on 24 March indicates that more than 90% of the warming can be attributed to the foehn effect on the leeward side of central AP, whereas ~60% of the warming can be attributed to the foehn effect over the northern tip of the eastern AP (very close to the Esperanza station) (Figure 3).

4. CONCLUSIONS

We suggest a link between local-scale forcing (i.e., foehn effect warming) and large-scale forcing (i.e., AR) in explaining the record-setting temperature occurring on 24 March 2015 at the Esperanza research base. The synoptic-scale analysis based on the ERA-Interim re-analysis data shows a deep low-pressure center over the Amundsen-Bellingshausen Sea and a blocking ridge over the southeast Pacific which provided favorable conditions for the development of an AR with a northwest-southeast orientation, directing warm and moist air toward the AP and triggering a widespread foehn episode. The water vapor reaching the windward side of the peninsula due to the AR was instrumental to the orographic precipitation enhancement and latent heat release on the windward side, suggesting that the main foehn mechanism was at work during this episode. It can be argued that an anomalous source of water vapor enhancing the moisture transport toward the AP through ARs may play a crucial role in the occurrence of foehn events, as well as in determining the extremity of these events. Furthermore, moisture transport is also critical in understanding temperature effects on the surface cryosphere, given the large warming amplification that occurs with this particular event. We have refrained here from dwelling on the origin of the AR and its associated atmospheric teleconnection forcing. Therefore, further research is needed to better clarify the mechanisms at both hemispheric and local scales which control the occurrence of extreme temperature events on the AP.

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