Foehn event triggered by an atmospheric river underlies record-setting temperature along continental Antarctica *

Deniz Bozkurt[1], **Roberto Rondanelli**[1,2], Julio C. Marín[3] and René Garreaud[1,2]

[1]Center for Climate and Resilience Research, University of Chile, Santiago, Chile
[2]Department of Geophysics, University of Chile, Santiago, Chile
[3]Department of Meteorology, University of Valparaiso, Valparaiso, Chile

*Bozkurt, D., Rondanelli, R., Marín, J., Garreaud, R., 2018. Foehn event triggered by an atmospheric river underlies record-setting temperature along continental Antarctica. *Journal of Geophysical Research-Atmospheres*, 123(8):3871-3892, doi:10.1002/2017JD027796

2018 International Atmospheric Rivers conference, Scripps Institution of Oceanography, 25-28 June

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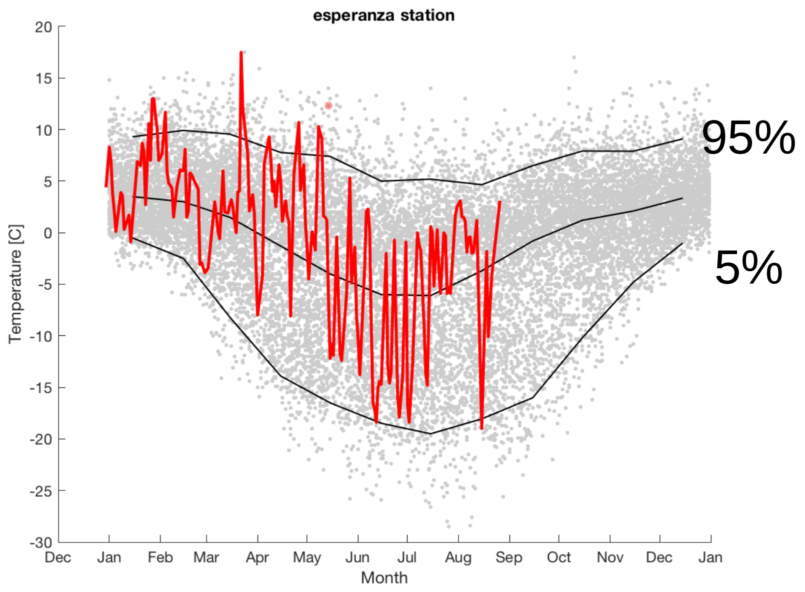
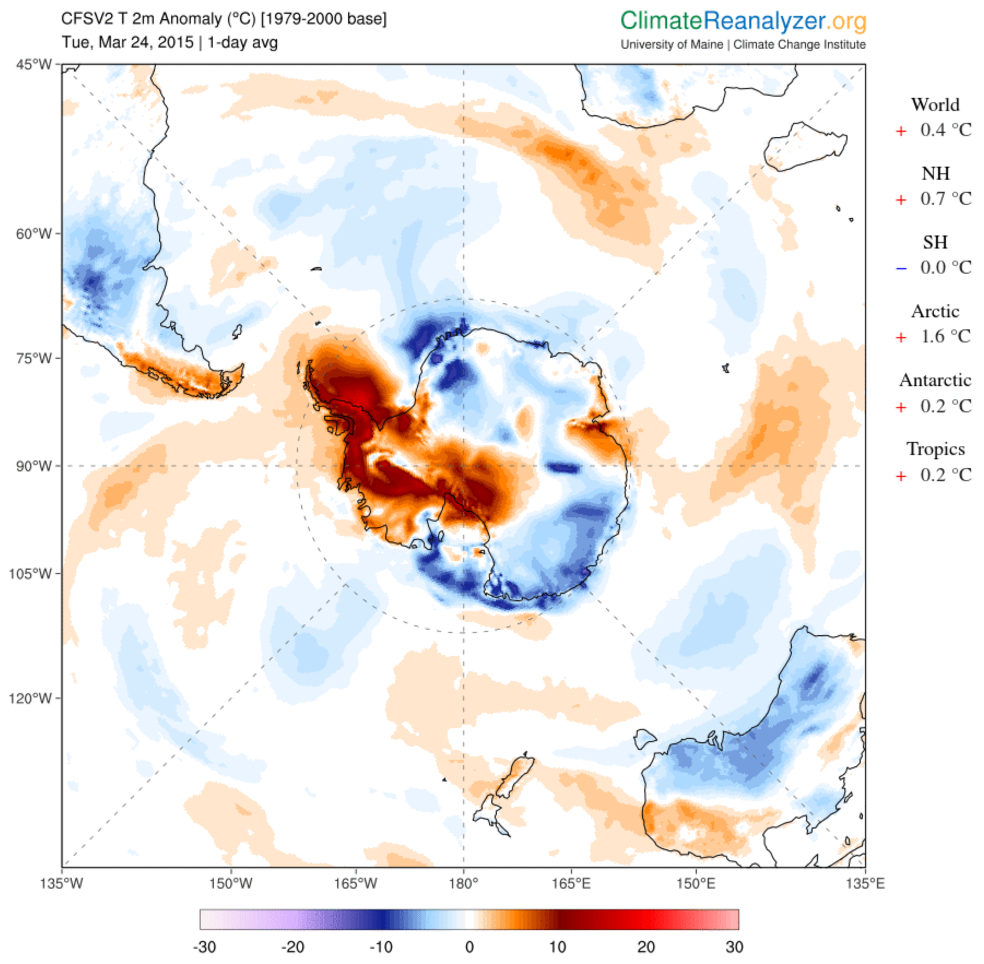
24 March 2015: The highest temperature on the Antarctic continent

Highest Temperature on the Continent: 17.5°C, Esperanza Research Base, 24 March 2015 (March LTM: 0.5°C)

Skansi, M. d. L. M., et al. (2017), Evaluating highest-temperature extremes in the Antarctic, *Eos, 98,* https://doi.org/10.1029/2017EO068325.





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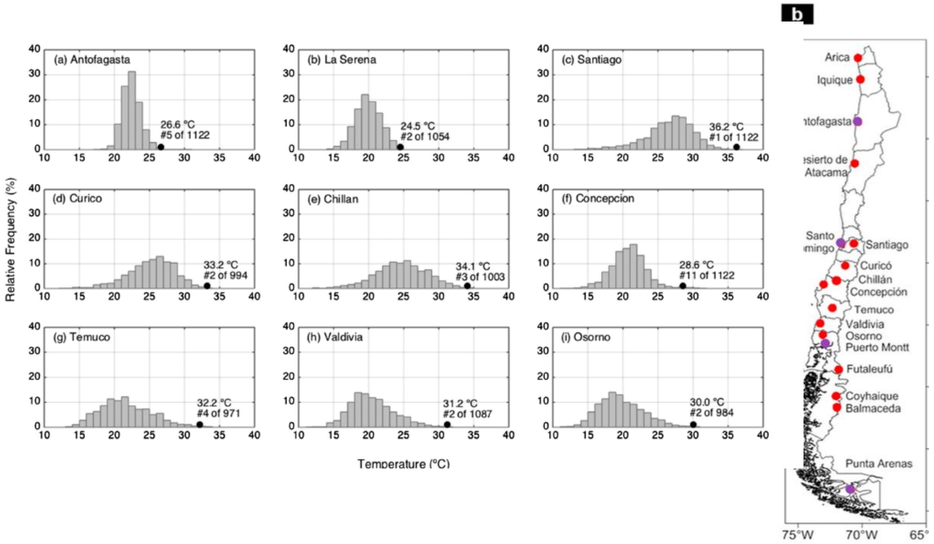
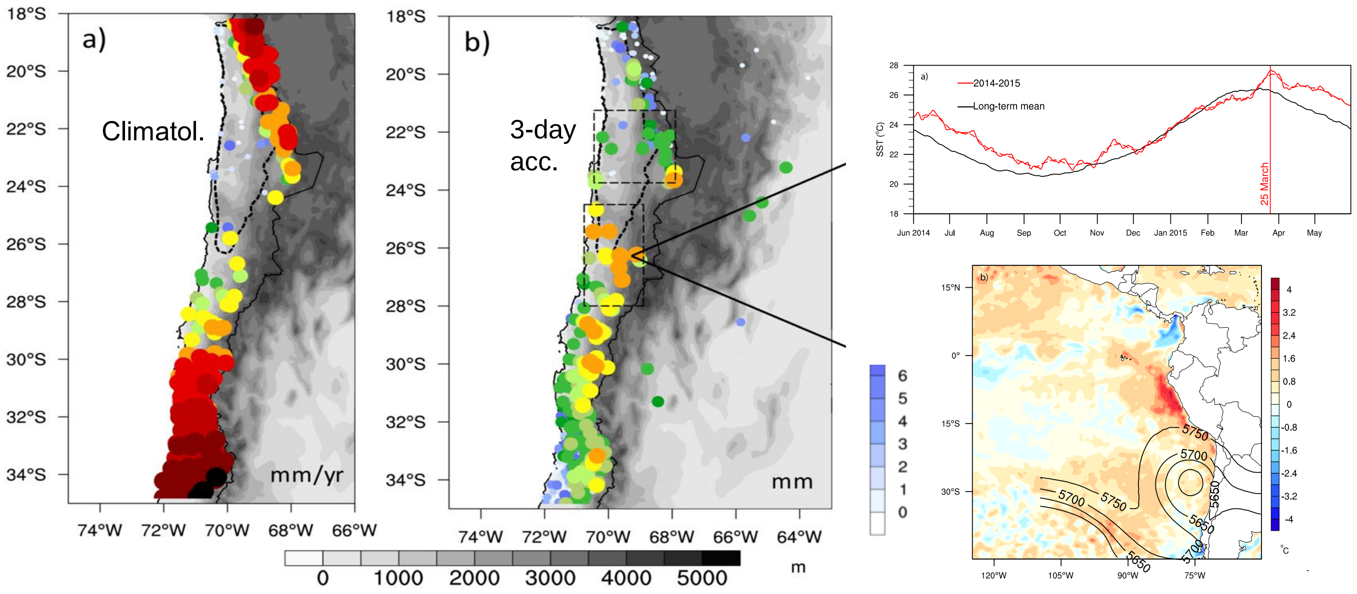
The event occurred just at the onset of the strong 2015-2016 El Niño event (between 18-27 March 2015), at the same time that the west coast of South America (northern, central, and southern Chile) was experiencing a series of extreme hydrometeorological events

Extreme temperature events in Chile



Barrett et al., (2016), Extreme temperature and precipitation events in March 2015 in central and northern Chile, J. Geophys. Res., doi: 10.1002/2016JD024835

The March 2015 Atacama Flood



Bozkurt et al., (2016), Impact of warmer eastern tropical Pacific SST on the March 2015 Atacama floods, Mon. Wea. Rev., DOI:10.1175/MWR-D-16-0041.1

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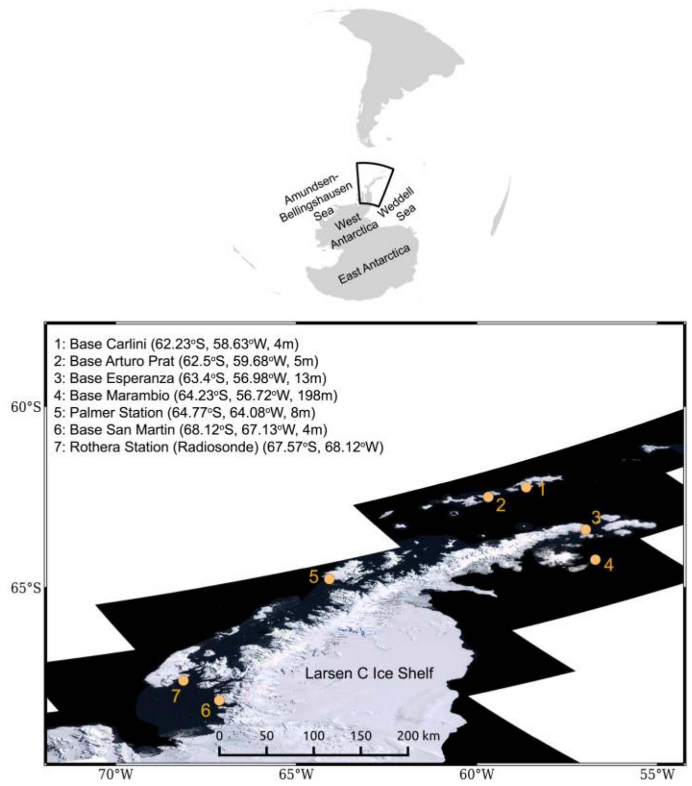
Data and methodology

Meteorological stations



Satellite imagery

- MODIS Antarctic Ice Shelf Image Archive
- Antarctic composite infrared and water vapor imagery data

Reanalysis

ERA-Interim (daily MSLP, geopotential heights, wind vectors, specific humidity)

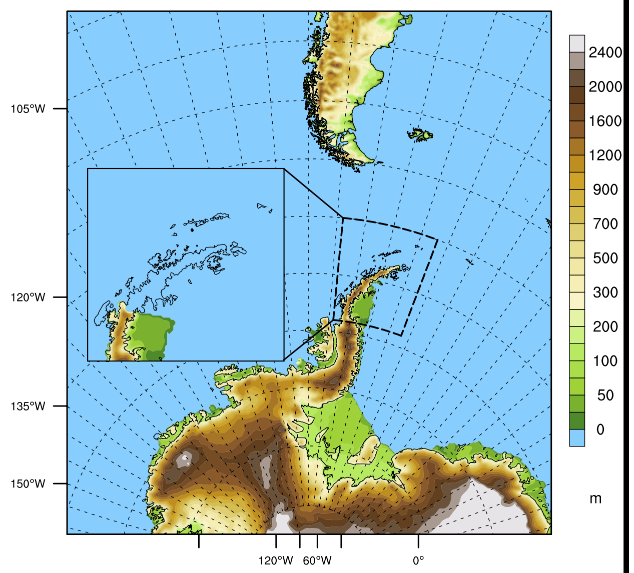
Integrated water vapor

$$IWV = \frac{1}{g}\int_{1000}^{300} q dp$$

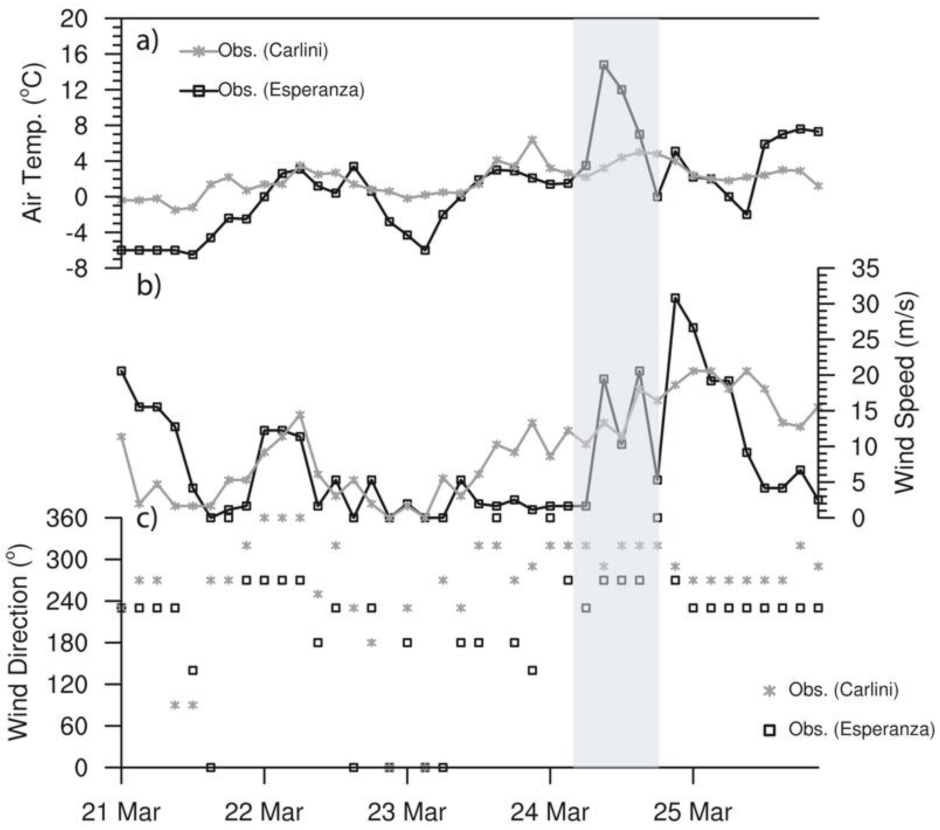
Integrated vapor transport

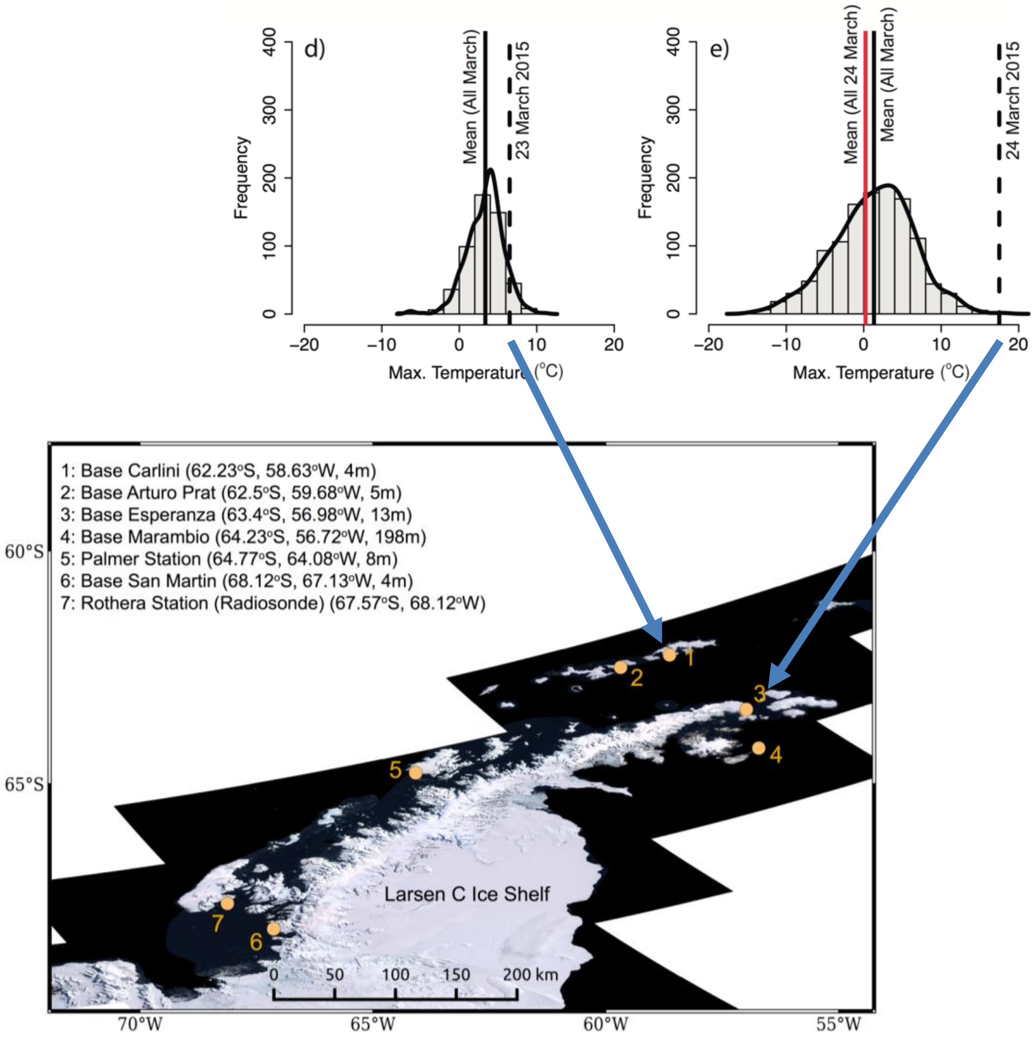
$$IVT = \sqrt{(\frac{1}{g}\int_{1000}^{300} qu dp)^2 + (\frac{1}{g}\int_{1000}^{300} qv dp)^2}$$

Numerical simulations



Observation of the event: Local conditions





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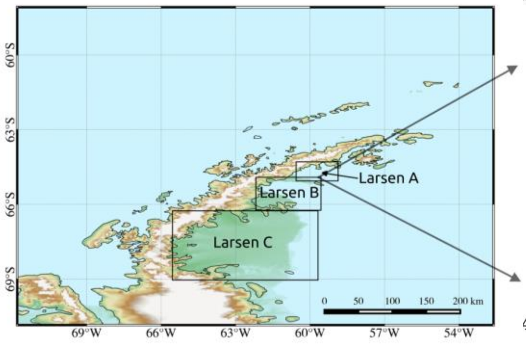
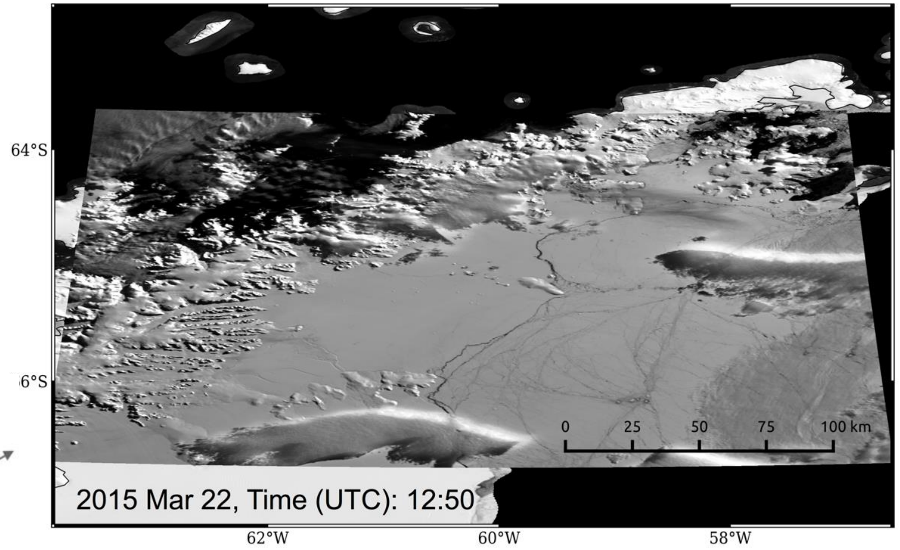
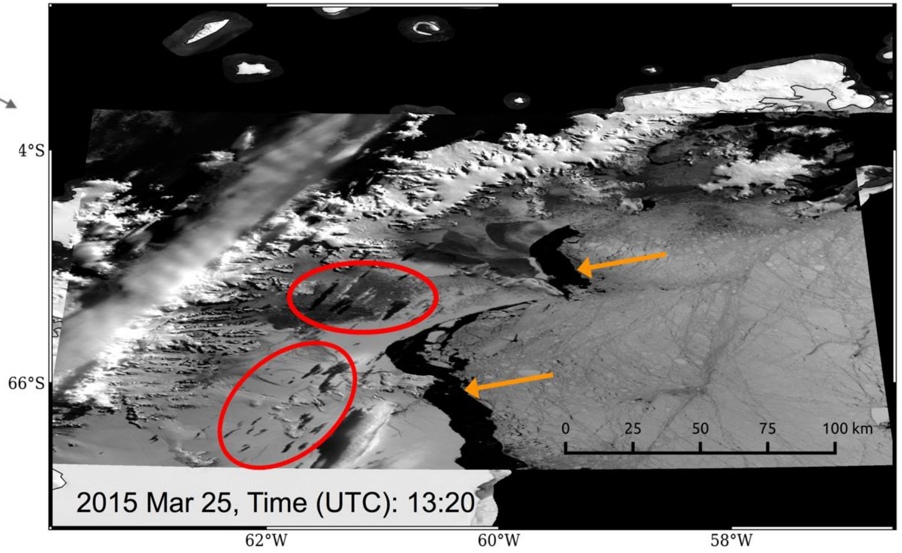
Observation of the event: Local conditions







MODIS Antarctic Ice Shelf Image Archive

- There is evidence of sea ice disintegration and dark patches on the fast ice and glacier surface (melt ponds) on land-fast ice in the Larsen A and Larsen B embayments, consistent with the impact of foehn winds on the surface cryosphere

- 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.

Geophysical Research Letters

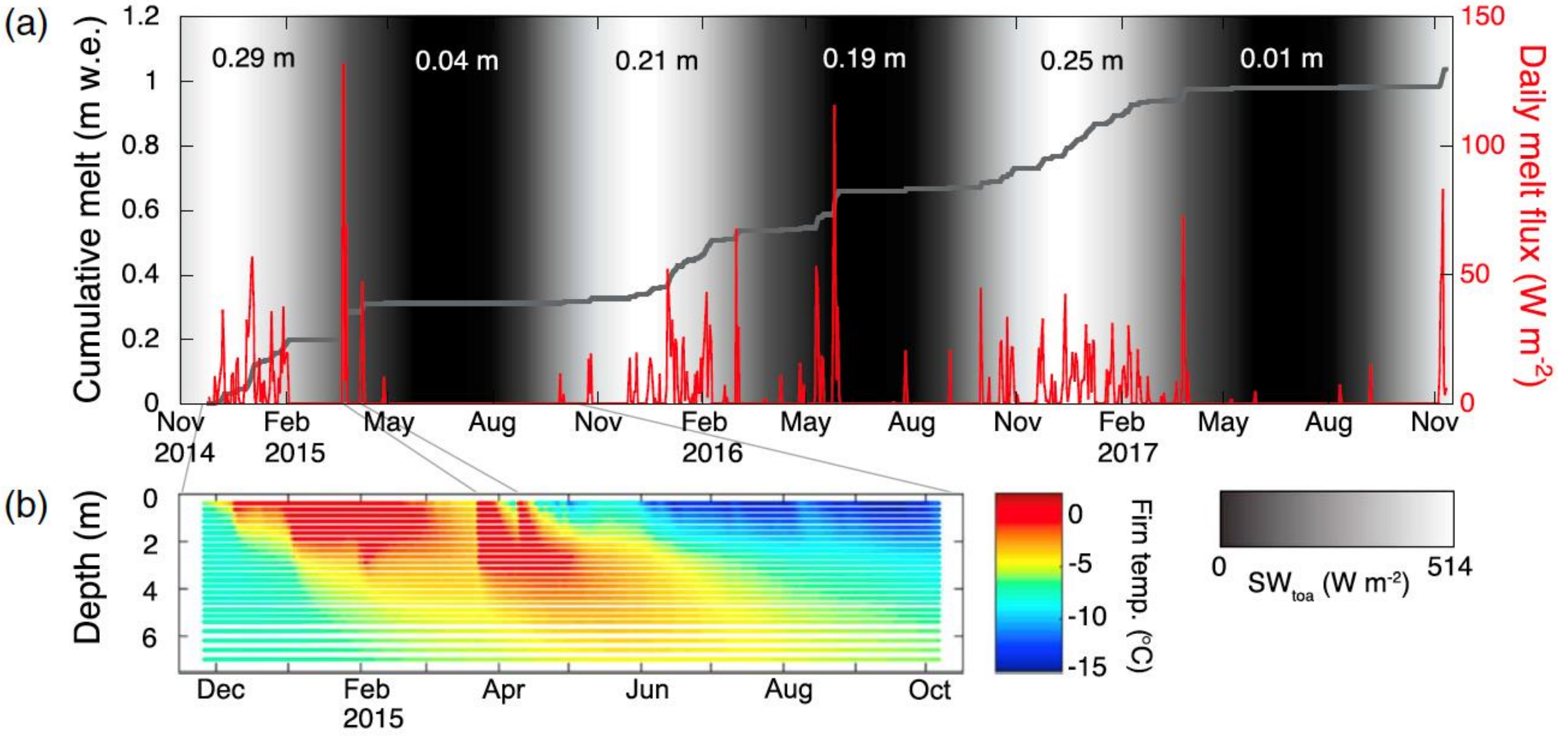
RESEARCH LETTER
10.1029/2018GL077899

Intense Winter Surface Melt on an Antarctic Ice Shelf

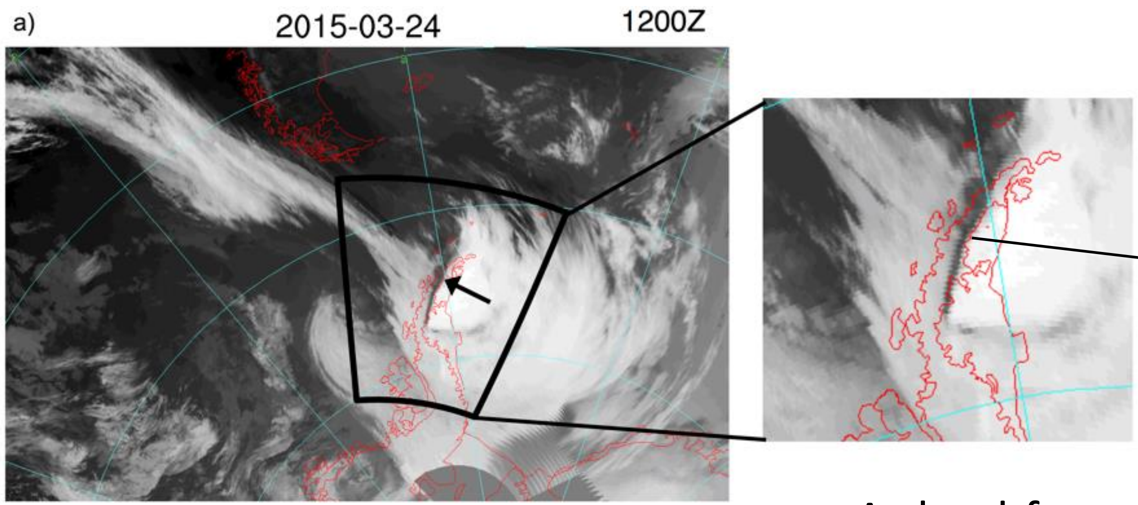
P. Kuipers Munneke[1], A. J. Luckman[2], S. L. Bevan[2], C. J. P. P. Smeets[1], E. Gilbert[3,4], M. R. van den Broeke[1], W. Wang[5], C. Zender[5], B. Hubbard[6], D. Ashmore[7], A. Orr[3], J. C. King[3], and B. Kulessa[2]

[1]Institute for Marine and Atmospheric research Utrecht, Utrecht University, Utrecht, Netherlands, [2]Department of Geography, Swansea University, Swansea, UK, [3]British Antarctic Survey, Natural Environment Research Council, Cambridge, UK, [4]School of Environmental Sciences, University of East Anglia, Norwich, UK, [5]Department of Earth System Science, University of California, Irvine, CA, USA, [6]Centre for Glaciology, Department of Geography and Earth Sciences, Aberystwyth University, Aberystwyth, UK, [7]School of Environmental Sciences, University of Liverpool, Liverpool, UK

Key Points:
- Wintertime surface melt occurs frequently in the Antarctic Peninsula
- Winter melt heats the firn to a depth of about 3 m, retarding or reversing winter cooling
- Increased greenhouse gas concentrations could increase the occurrence of winter surface melt

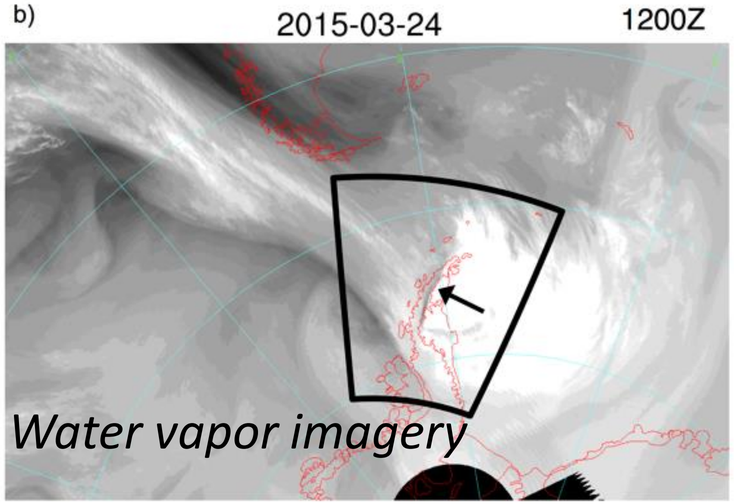


Observation of the event: Local conditions



Antarctic composite infrared imagery data

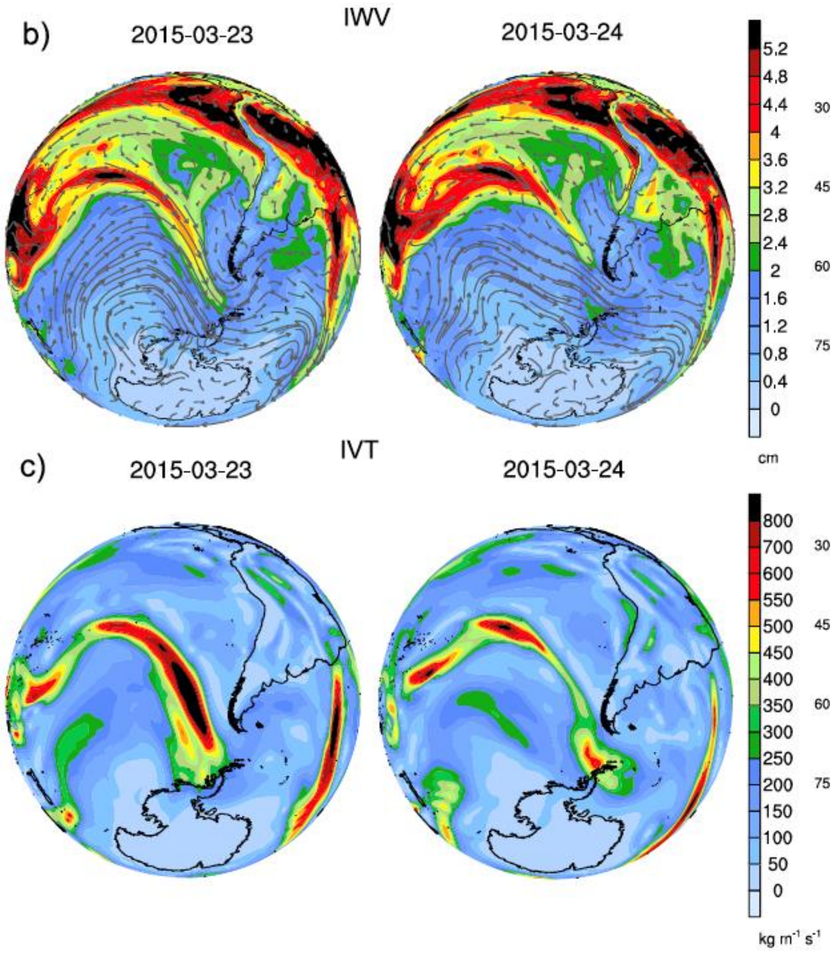
~ 350 km in length, with a width of 20-60 km



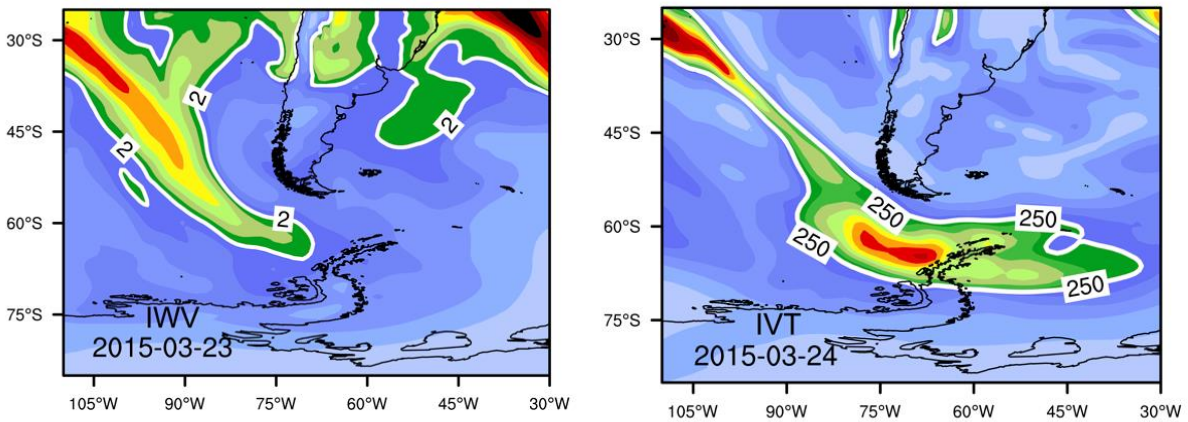
Water vapor imagery

- A cloud-free zone or "foehn-gap" oriented north-south, just on the leeward side of northern AP
- Downstream clouds are brighter and colder than clouds upstream from the gap
- The foehn gap is also evident in the water vapor image which also confirms that water vapor is being transported from the mid-latitudes

Observation of the event: Synoptic conditions and AR event



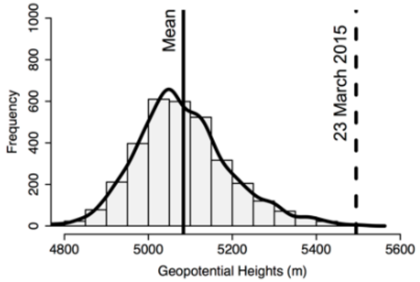
- A deep low-pressure center over the Amundsen-Bellingshausen Sea and a blocking ridge over the southeast Pacific which provided favorable conditions for the development of an atmospheric river with a northwest-southeast orientation, directing warm and moist air towards the AP



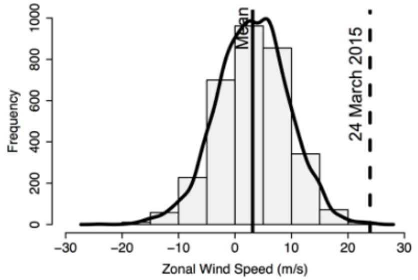
IVT and IWV values confirm and satisfy the AR conditions during 23-24 March.

Synoptic conditions in upstream of AP

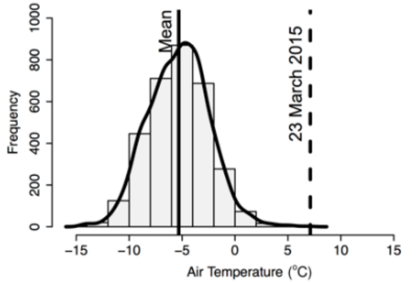
H500



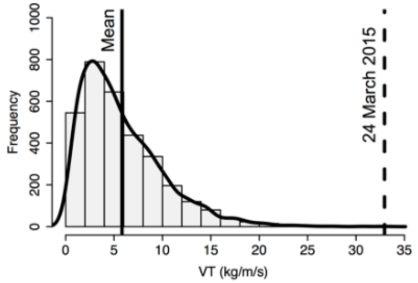
u850



T850



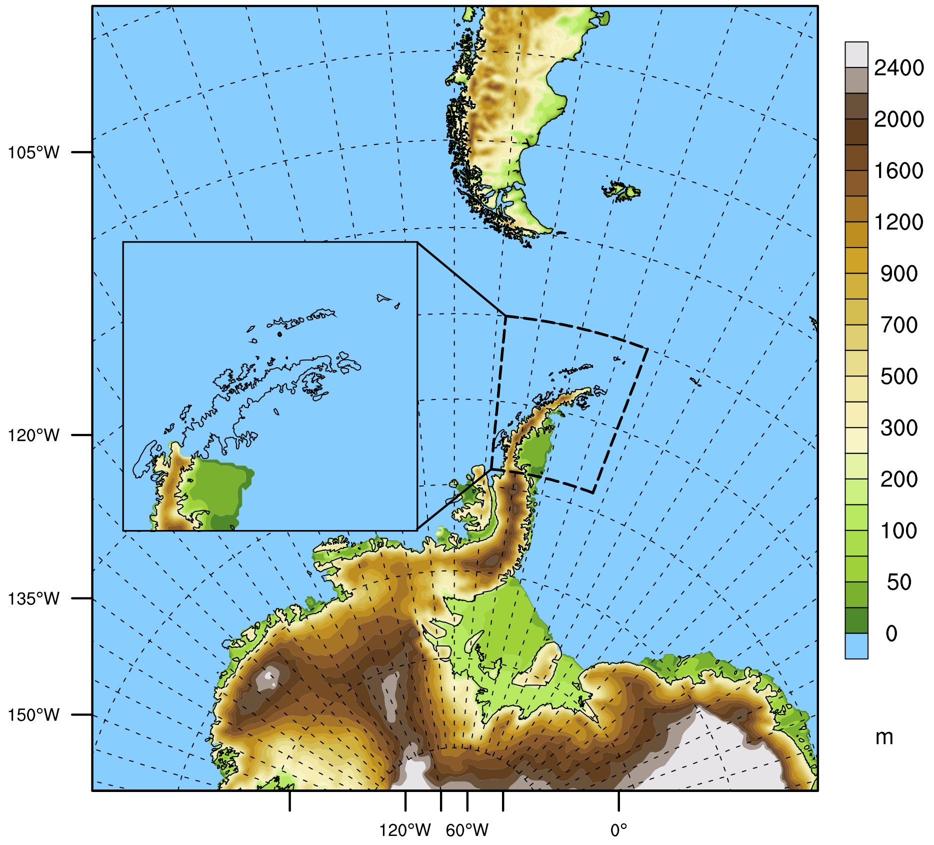
VT 850

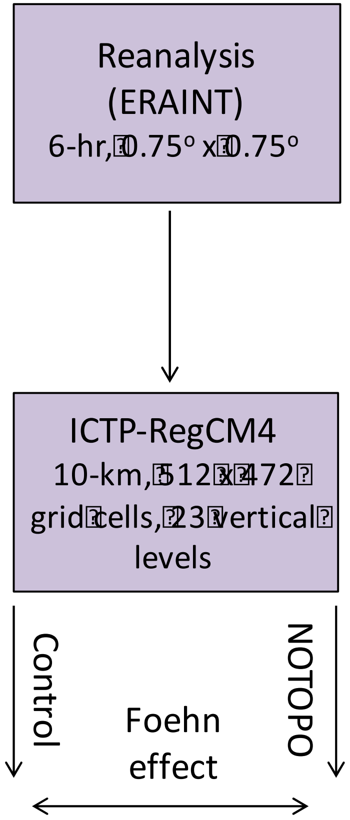


- **In the context of 35 years of reanalysis data**, the **record temperature** event on the windward side of the AP is characterized by similarly **extreme circulation features** (up to ~ 24 m/s wind speeds at 850 hPa and 5500 m geopotential heights at 500 hPa) **and thermodynamic conditions** (~ 12ºC air temperature anomalies and more than 30 kg m-1 s-1 vapor transport at 850 hPa) during late summer-early fall (January-February-March) period.

Numerical simulations

RegCM4 10-km



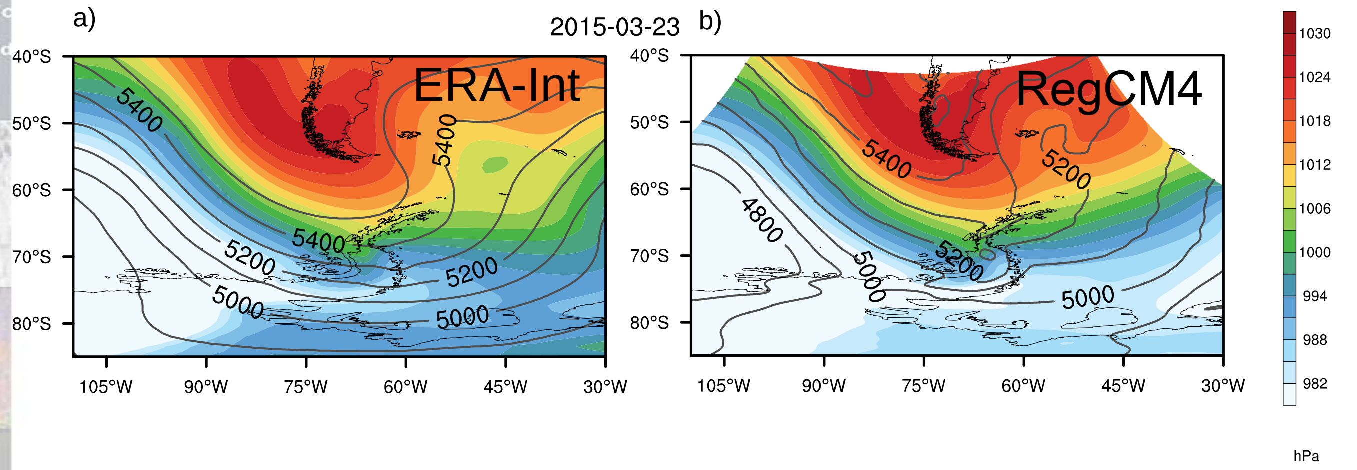


Experiemental setup	
Number of grids and simulation period	*512x472 15-31 March 2015*
Spatial and vertical resolution	*10km and 23 pressure levels*
Radiation and convective scheme	*NCAR-CCSM3, Grell+Emanuel*
Land surface	*BATS*
Initial and boundary conditions	
Pressure levels	*ERA-Interim (0.75ºx0.75º, 37 level., 6hr)*
SST& Ice concentration	NOAA OISST.V2 (*1ºx1º)*
Land use and vegatation	*GLCC (30-sec)*

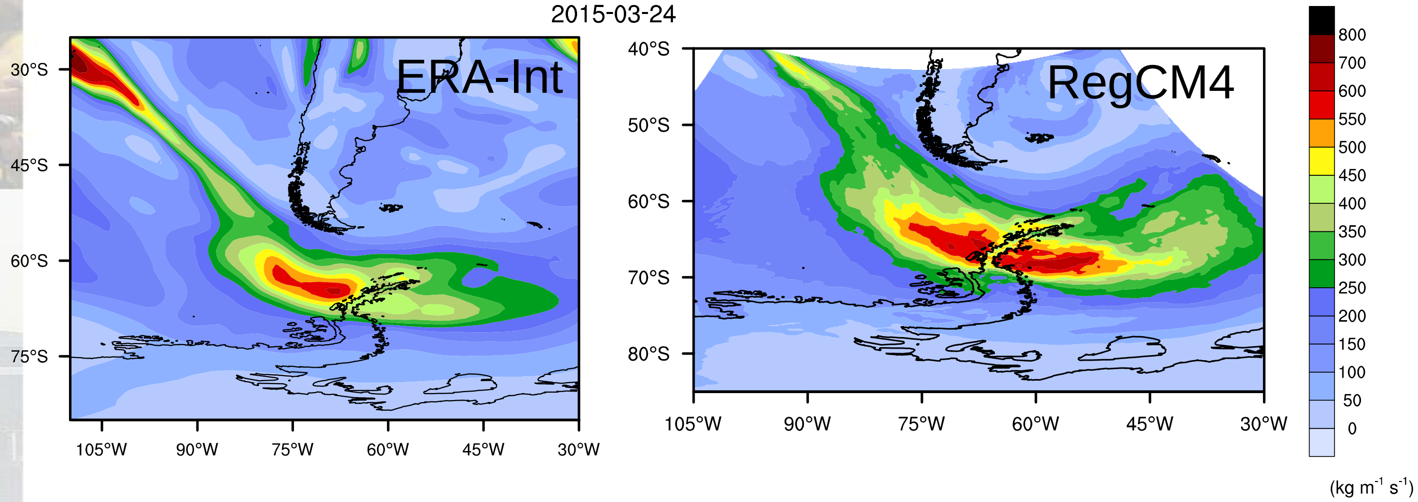
- To disentangle the role of the large-scale warm air advection versus the local topographically-induced warming
- No-topo experiment was run to gauge the foehn wind contribution to the warming

Model validation (RegCM4)

500 hPa geopotential heights & MSLP

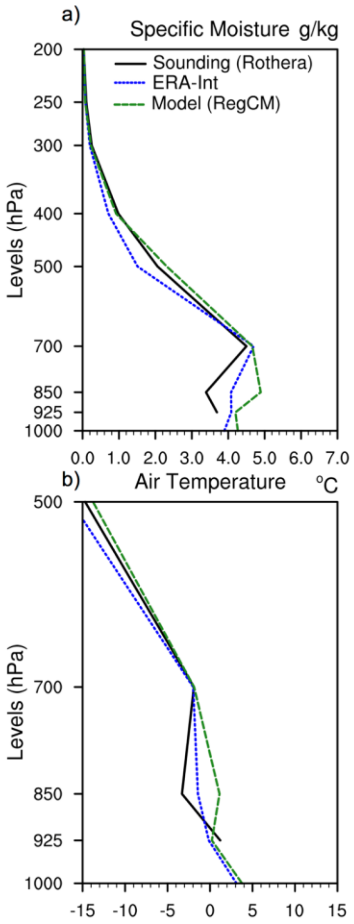


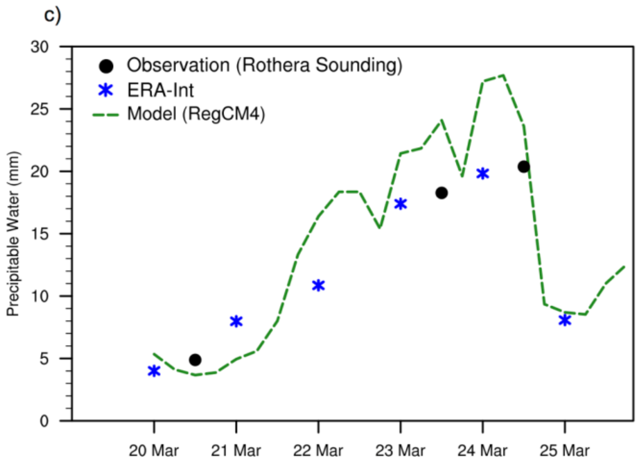
IVT

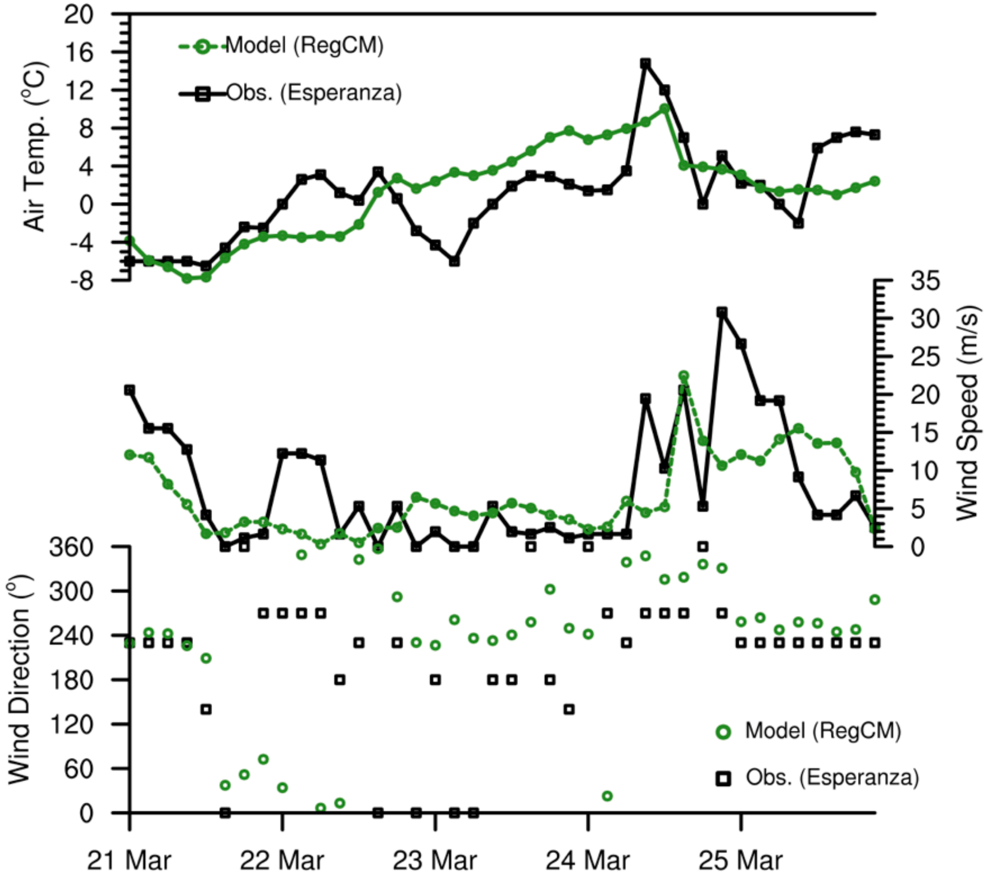


- A reasonable agreement on large-scale forcing and the model realistically reproduces the main synoptic fields and extreme dynamical and thermodynamical conditions before and during the event

Model validation (RegCM4)



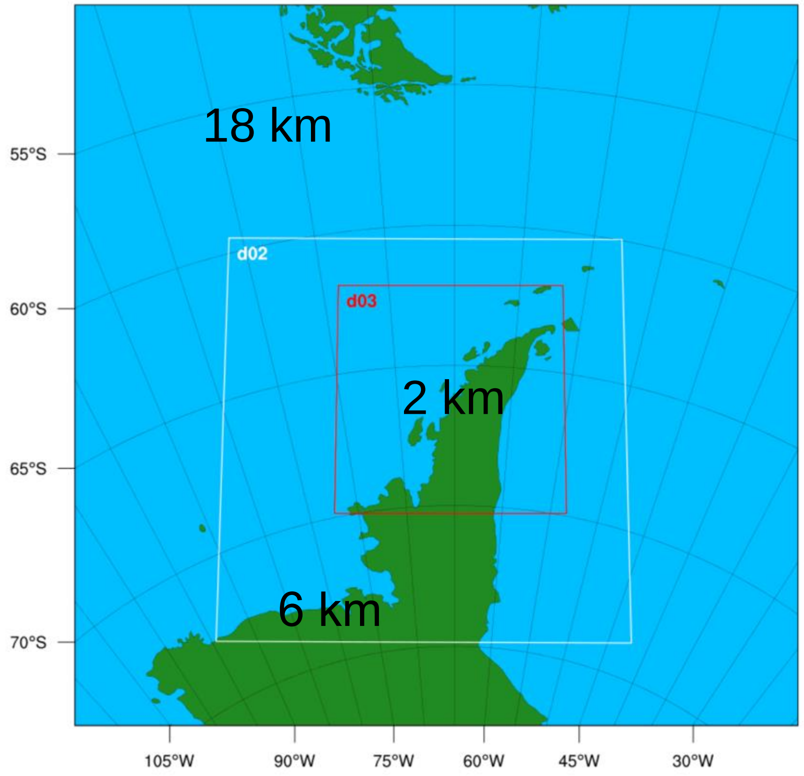


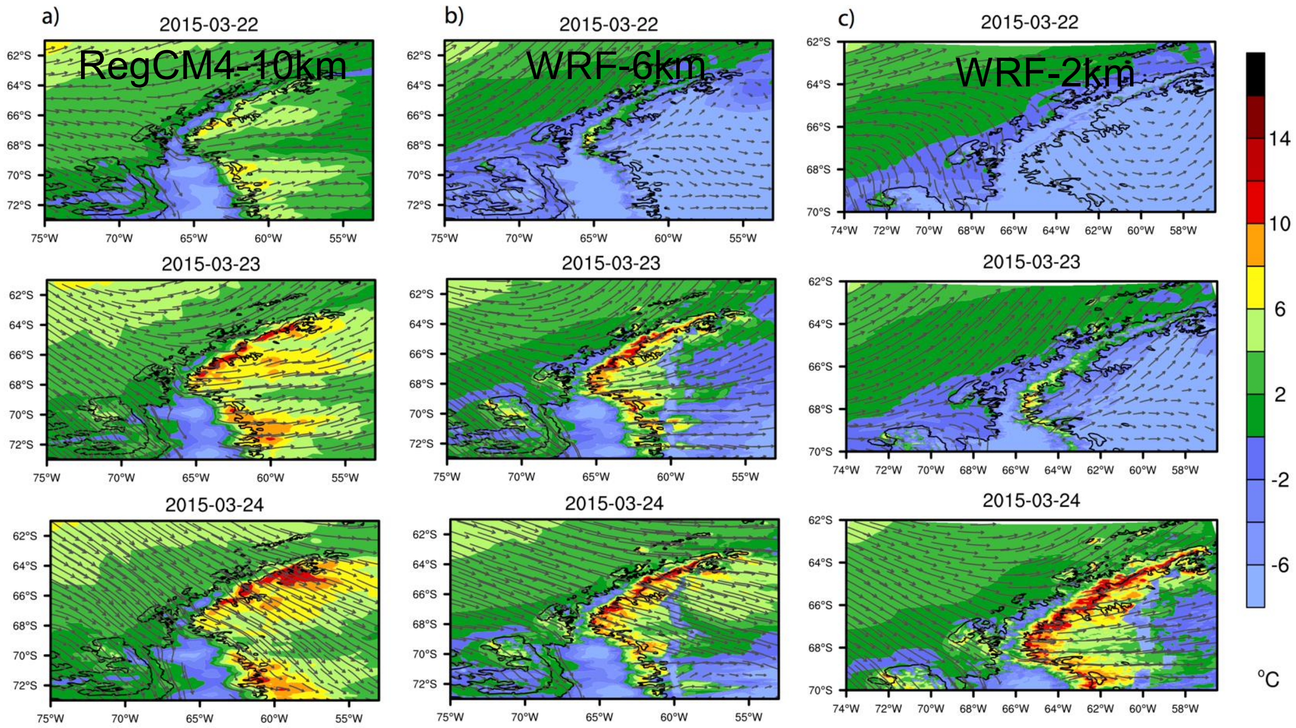


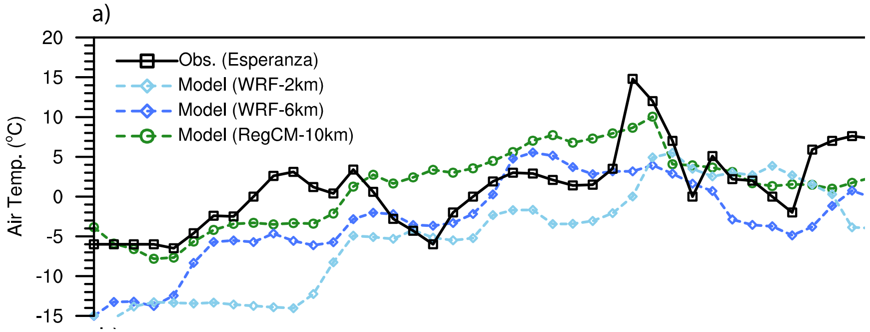
- A reasonable agreement on thermodynamic conditions in upstream of AP
- Control run captures the temperature increase and fohen wind but not as sharp as in reality

Non-hydrostatic numerical simulations

WRF





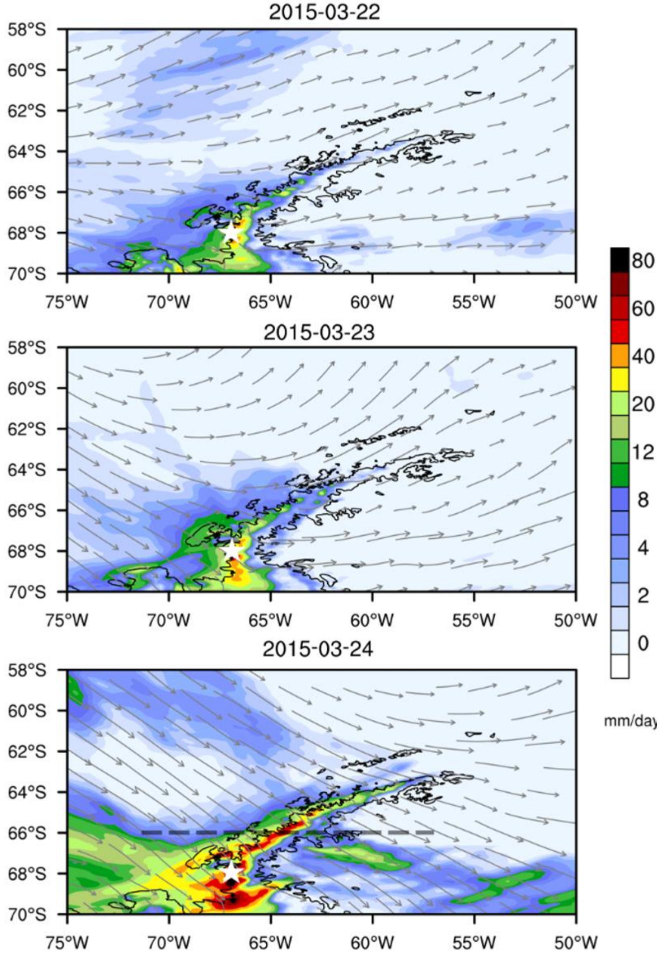


Similar difficulties in reproducing the steep temperature increase persist even with a relatively higher spatial resolution (6- and 2-km) in the numerical experiment carried out with the WRF model.

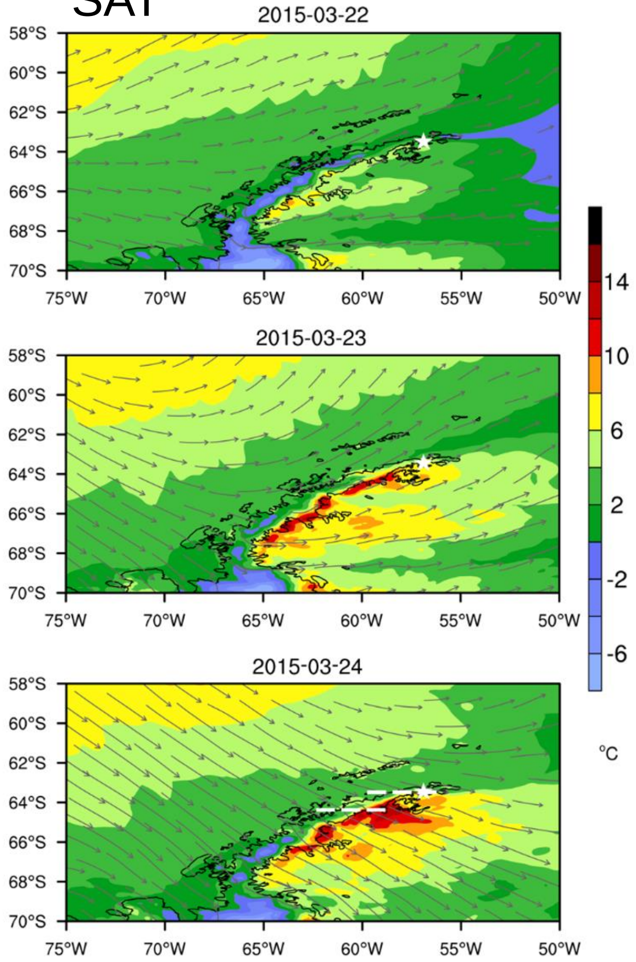
RegCM4 10-km

Simulation results: foehn characteristics

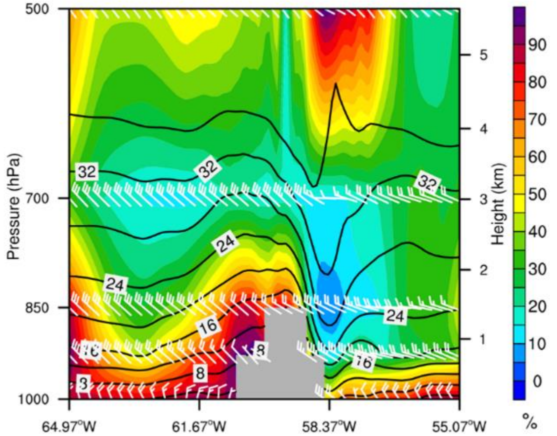
a) Rainfall



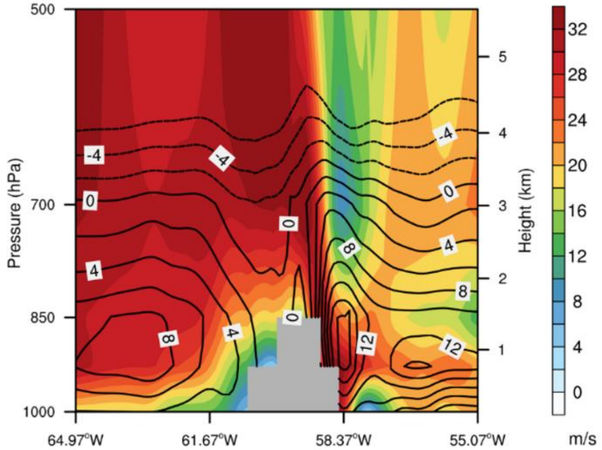
SAT



RH, Theta, wind



Ta, wind speed



a low-level blocking upstream and mountain wave activity, with warm and dry air aloft being advected downward to the surface on the leeward side

Elevated near-surface wind velocities (~ 30 m s−1) with marked warm air temperatures (>12◦C) along the lee slope highlight the impact of foehn-induced warming

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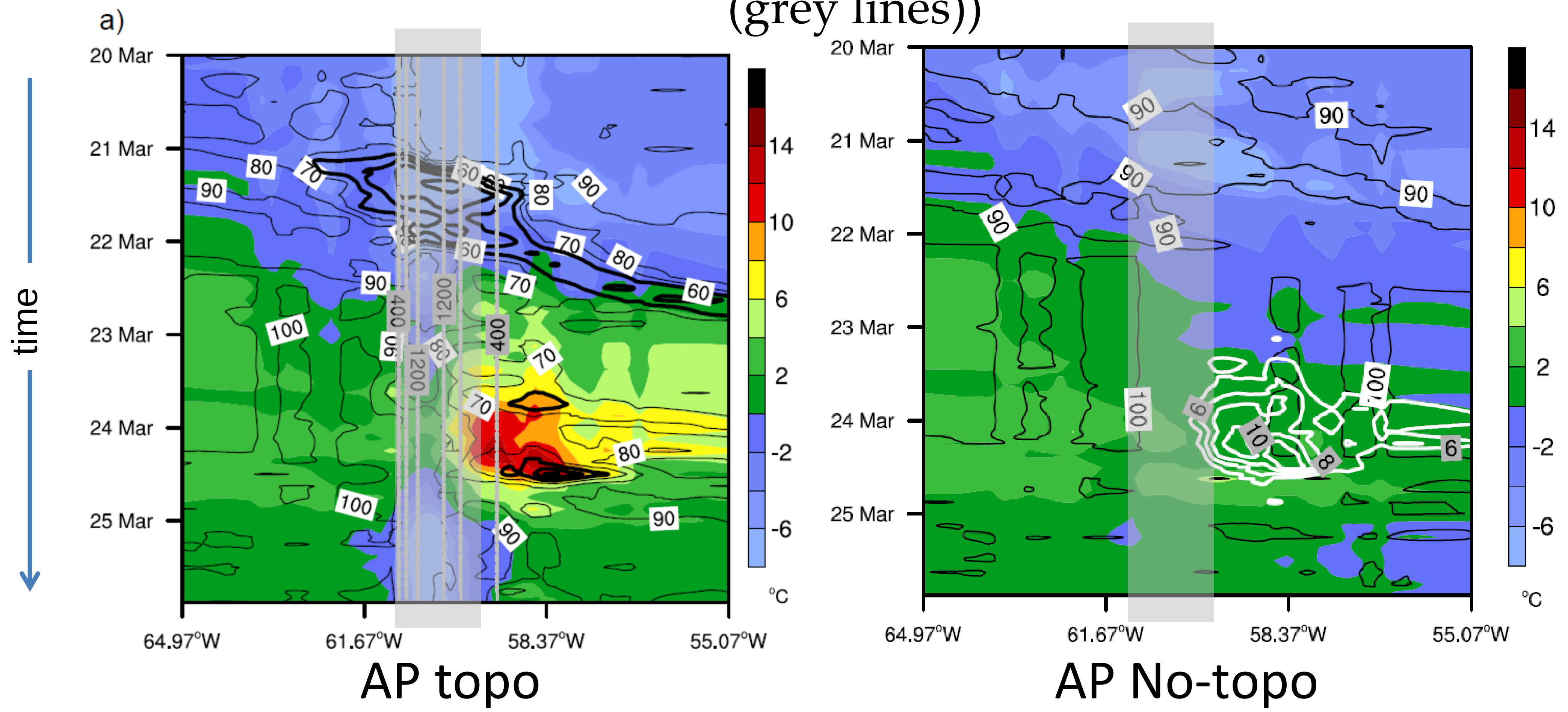
RegCM4 10-km

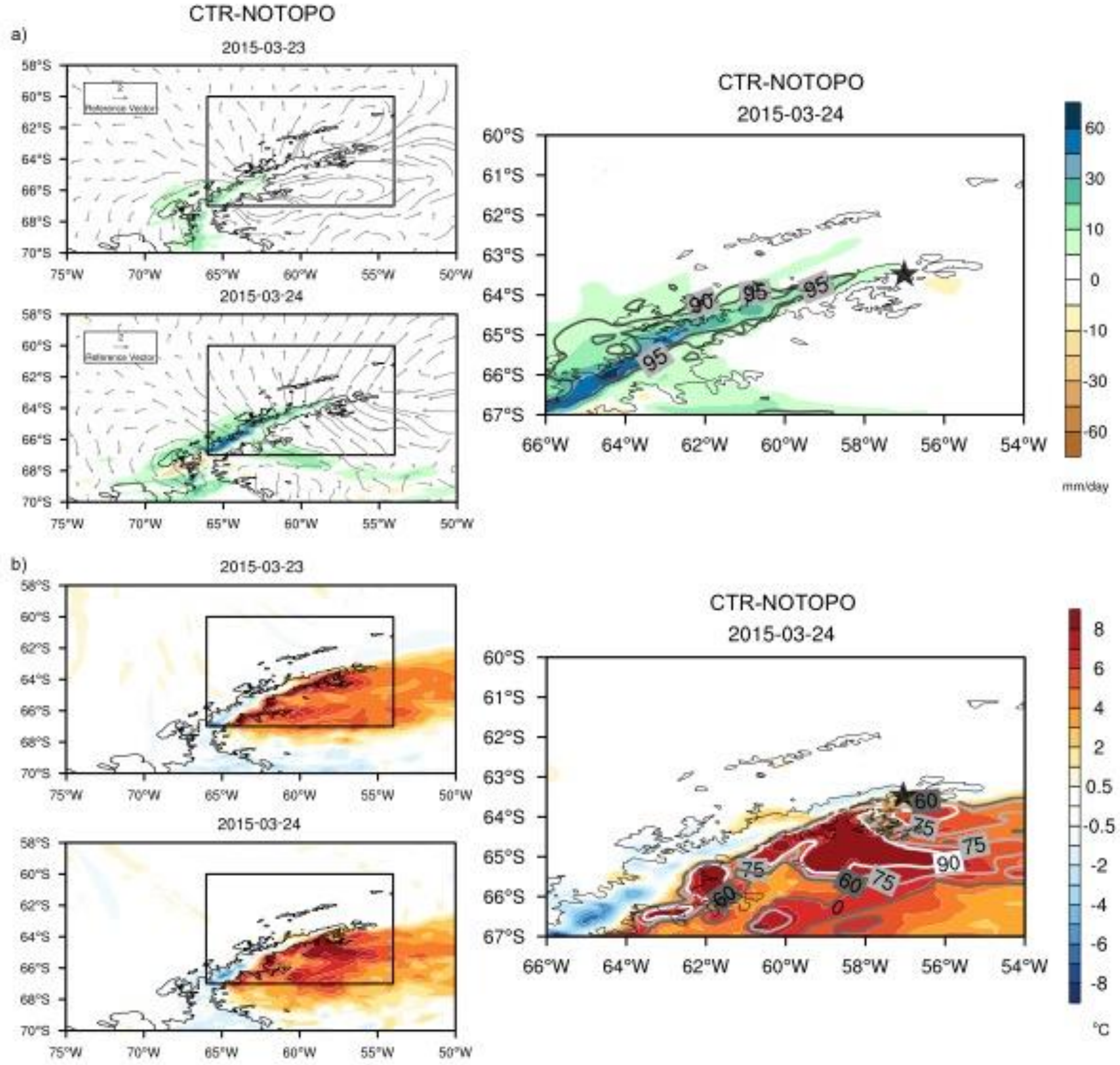
Control-versus-No topo simulations

SAT Time-longitude cross sections at 66ºS (Surface temperature (colors), RH (contours), Elevation (grey lines))



Control-versus-No topo simulations: Precipitation and temperature differences

RegCM4-10km



The CTR- NOTOPO illustrates that almost all of the precipitation occurs due to the orographic enhancement (e.g., >95% on the windward side of the AP)

CTR-NOTOPO shows the existence of local topographically-induced warming along the eastern coast of the AP

A ratio of Δ*SAT (CTR-NOTOPO)* to ERAINT 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 eastern AP (very close to the Esperanza)

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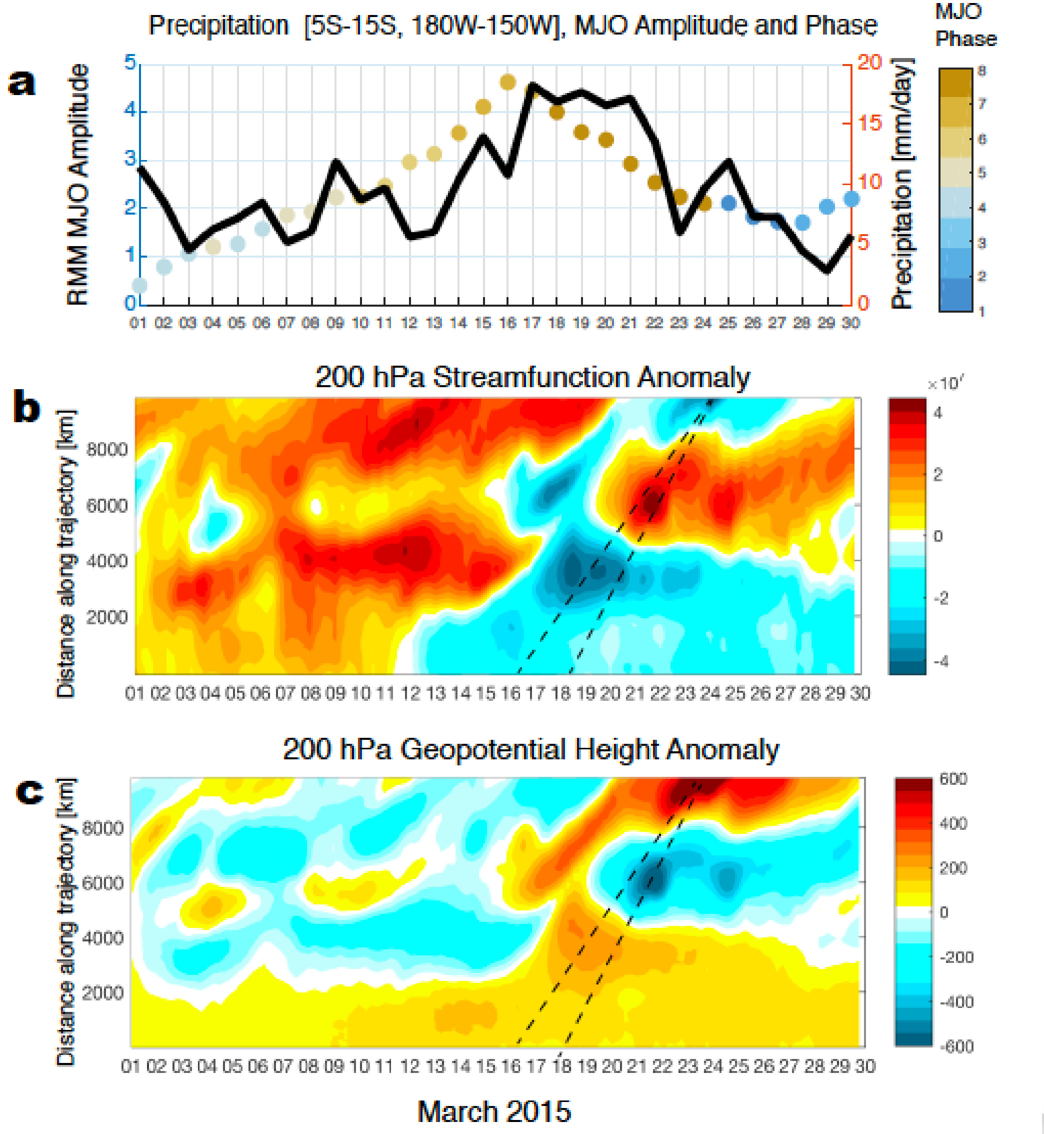
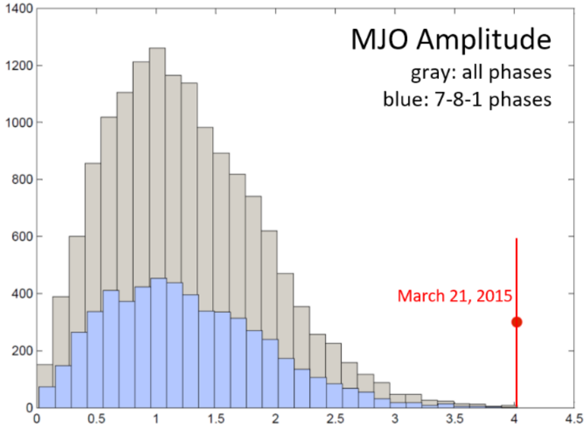
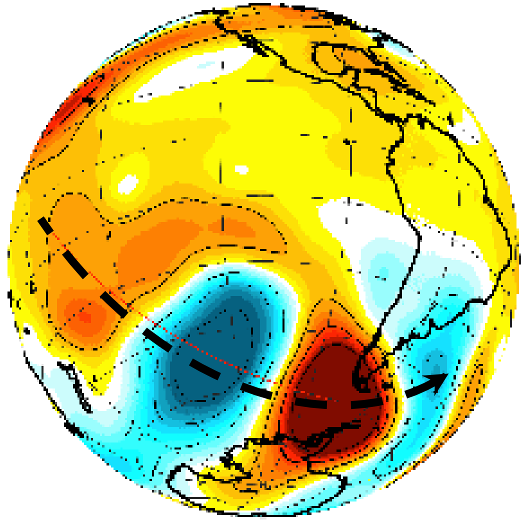
Largest MJO on record







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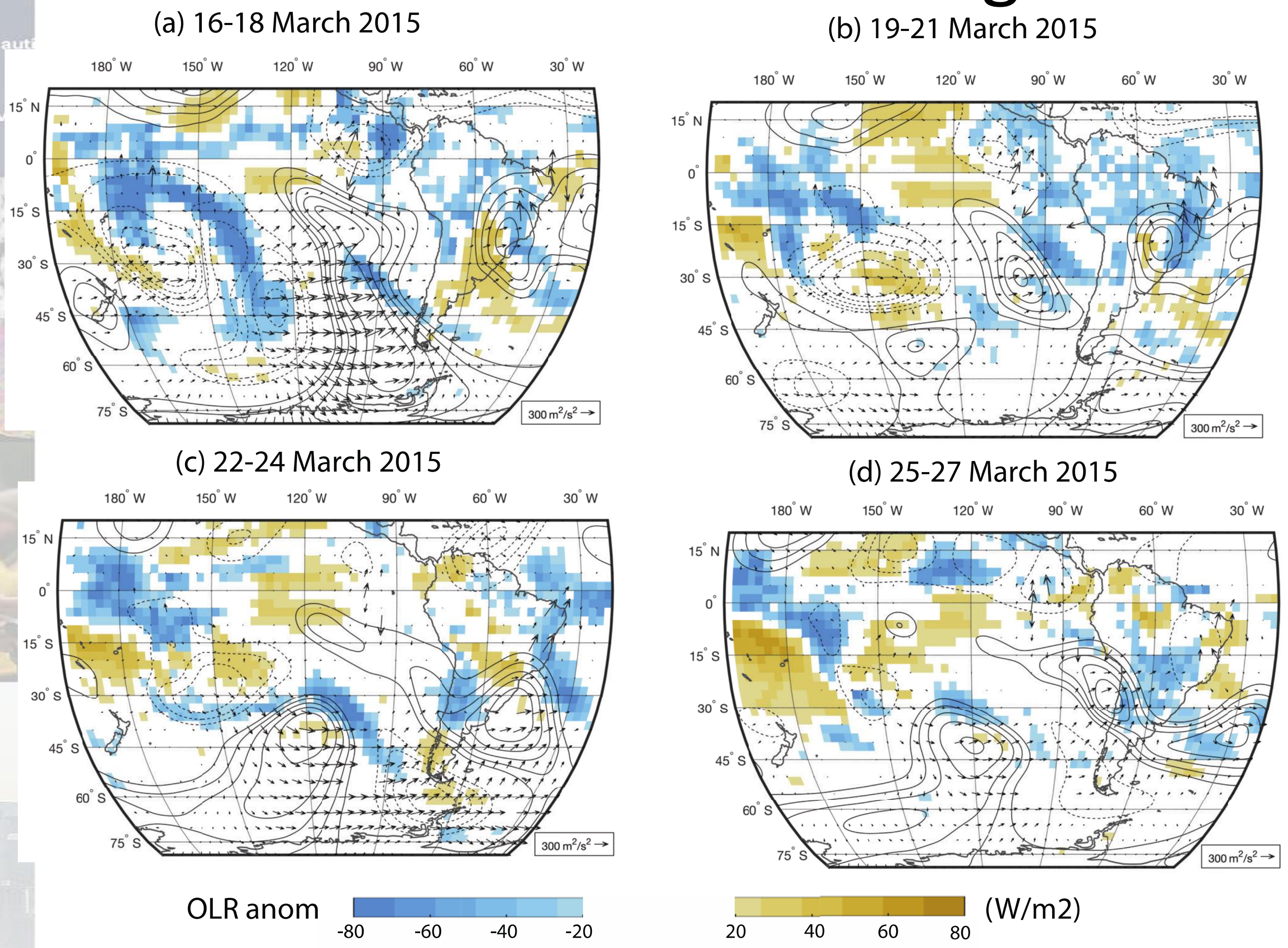
Outlook: Large scale context



OLR anomaly (colors)

W vector, wave activity flux at 200 hPa

Streamfunction anomalies at 200 hPa
(Solid contours: cyclonic anomalies
Dashed contours: anticyclonic anomalies)

$$\mathbf{W} = \frac{1}{2|\mathbf{U}|}\begin{bmatrix} U(\psi_x^2 - \psi\psi_{xx}) + V(\psi_x\psi_y - \psi\psi_{xy}) \\ U(\psi_x\psi_y - \psi\psi_{xy}) + V(\psi_y^2 - \psi\psi_{yy}) \end{bmatrix}$$

W vectors are approximately parallel to the group velocity of an stationary Rossby wave.

Rondanelli et al., 2018 (in preparation)

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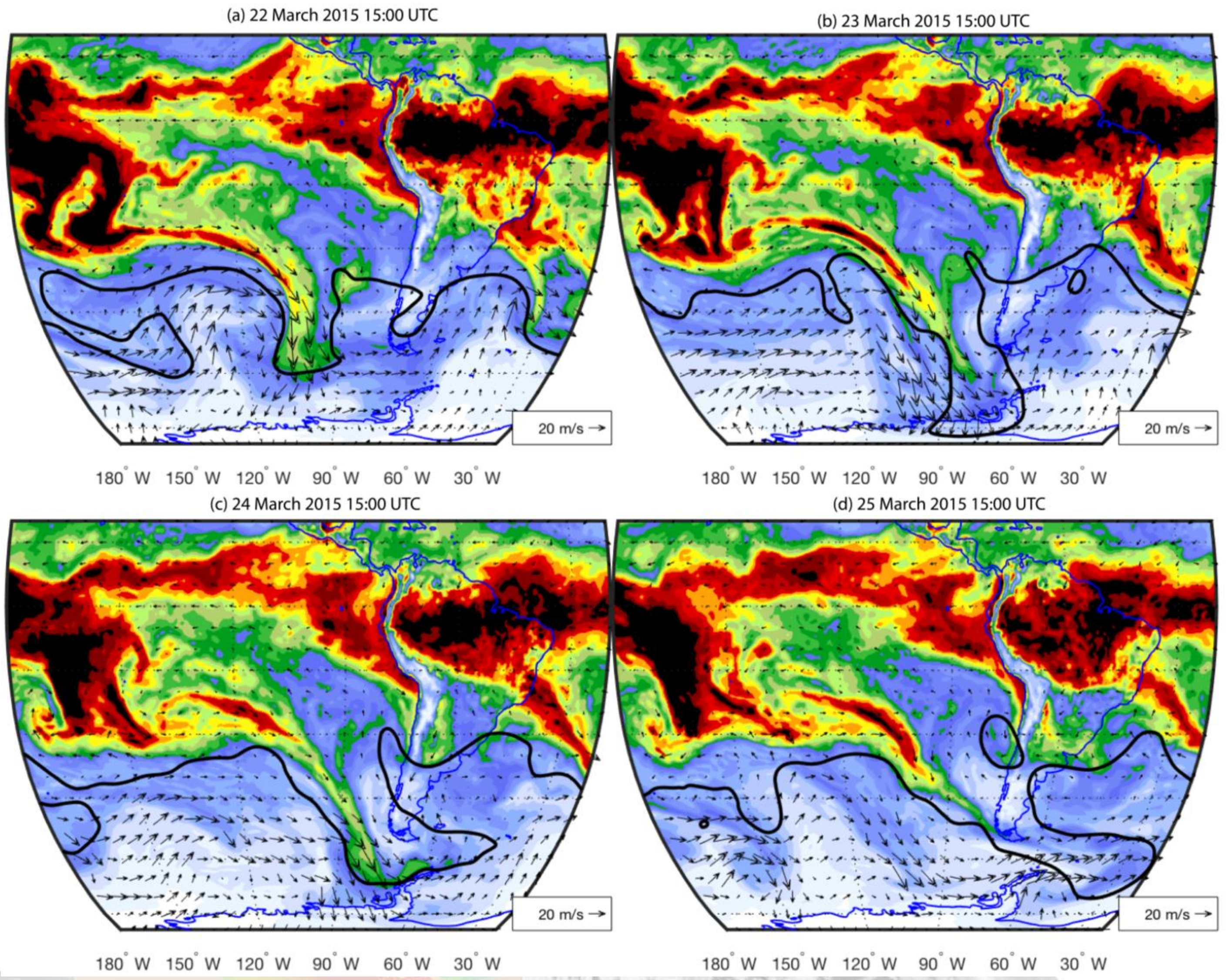
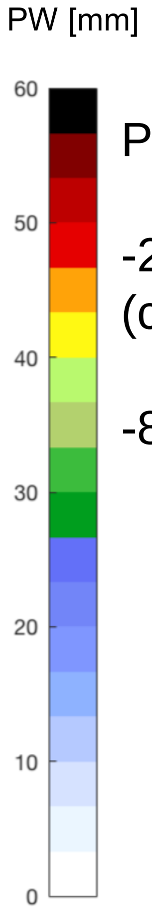
Rossby Wave breaking





Precipitable Water (color)

-2PVU at 330 K isentropic surface (contour)

-850 hPa wind vectors.

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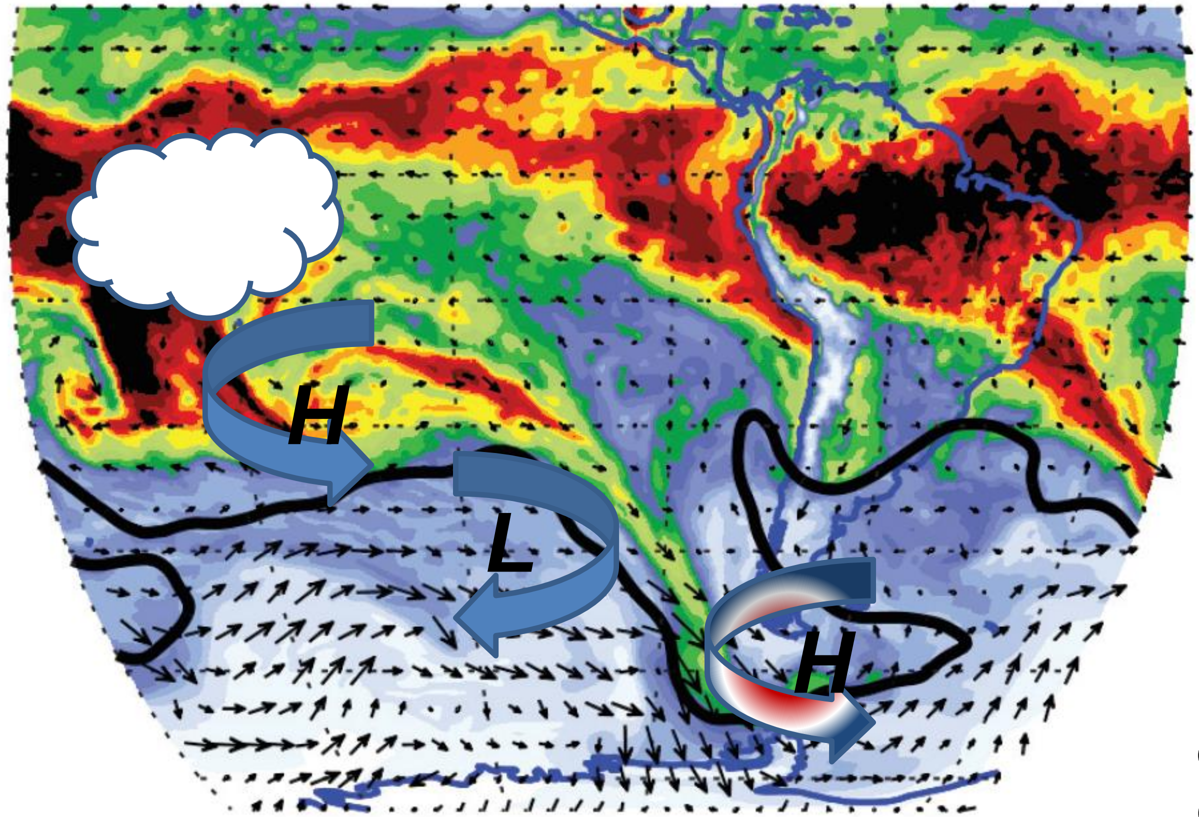
Conclusions



- Results presented here 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 occurred on 24 March 2015 at the Esperanza research base
- A key finding in our results is that the water vapor reaching the windward side of the AP due to the AR was instrumental to the orographic precipitation enhancement and latent heat release on the windward side
- We attribute ~ 60% of the warming at Esperanza station directly to the foehn effect, the rest to the advection of warm air from mid-latitudes
- Propagation of a Rossby wave pulse driven by tropical convection (largest MJO on record) is identified as the origin of the circulation that produces the extreme AR event.