Dominant role of vertical air flows in the unprecedented warming on the Antarctic Peninsula in February 2020

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Near-surface air temperature at Esperanza station on the northern tip of the Antarctic Peninsula reached 18.3°C on 6 February 2020, which is the highest temperature ever recorded on the entire Antarctic continent.

News:

- The Antarctic Peninsula is setting heat records. They won’t stand long.
- Antarctic heat wave melted 20 percent of an island’s snow cover in days, caused melt ponds to proliferate.
Near-surface air temperature at Esperanza station on the northern tip of the Antarctic Peninsula reached 18.3°C on 6 February 2020, which is the highest temperature ever recorded on the entire Antarctic continent.

The Antarctic Peninsula (AP) has experienced dramatic warming in recent decades, affecting the mass balance of the ice shelves. Detecting mechanisms of the extreme temperature is conducive to interpreting the variability of weather and climate in the AP and assessing its connections with the cryosphere.
Data and Methods

Data
• **Obversions**: Integrated Surface Database three-hourly
• **Reanalysis**: ERA5 hourly \(0.25° \times 0.25°\)

Methods
• Thermodynamic equation:
  \[
  \frac{\partial T}{\partial t} = -V \cdot \nabla T + \left( \frac{RT}{cp} - \frac{\partial T}{\partial p} \right) \omega + \frac{J}{cp}
  \]
  1. Horizontal advection: \(-V \cdot \nabla T = -[u(\partial T/\partial x) + v(\partial T/\partial y)]\)
  2. Vertical motion: adiabatic heating \((\omega \frac{RT}{cp})\) & vertical advection \((-\omega \frac{\partial T}{\partial p})\)
  3. Diabatic heating: Shortwave and longwave radiation, Latent heat & Sensible heat

• **HYSPLIT** (Hybrid Single-Particle Lagrangian Integrated Trajectory) model:
  1. Heat budget analysis
  2. Trajectory cluster analysis

2m temperature and 10m wind components
mean sea level pressure
500 hPa geopotential height and wind components
850 hPa temperature and geopotential height
975 hPa and 925 hPa vertical velocity
surface pressure and geopotential
3 Results

I. Observations and relevant atmospheric circulation

II. Contributions of thermodynamic processes

III. Climatological analyses of extreme warm events
Observations and relevant atmospheric circulation

- Time series and spatial distribution

Fig. 1 Time series of three-hourly surface observations
The temperature increased with the wind speed increasing and the humidity decreasing.

Fig. 2 Spatial distribution of 2 m temperature anomaly.
The large positive anomalies cover more area on the east side.
Observations and relevant atmospheric circulation

Atmospheric circulation evolution in near-surface layers

- A high-pressure ridge moved eastward from the southeastern Pacific Ocean;
- A low-pressure trough over southern South America;
- Near surface, high pressure over the southeast to South America and low pressure over the southeastern Pacific Ocean; 500hPa, a blocking high over the Drake Passage;
- A north-south oriented ridge.

Fig. 3 Sea level pressure and 10m wind on 2, 4, 6 and 8 February.
Observations and relevant atmospheric circulation

Atmospheric circulation evolution in mid-troposphere

- A high-pressure ridge moved eastward from the southeastern Pacific Ocean;
- A low-pressure trough over southern South America;
- Near surface, high pressure over the southeast to South America and low pressure over the southeastern Pacific Ocean; 500hPa, a blocking high over the Drake Passage;
- A north-south oriented ridge.

Fig. 4 500 hPa geopotential height and wind on 2, 4, 6 and 8 February.
Contributions of thermodynamic processes

- Quantify the local temperature variations

Fig. 5 Time series of temperature changes from three terms.

- The vertical motion was the main contribution.
- The warming rate from vertical term around the station was fast.
- On the lee side, the potential temperature contour indicates an isentropic drawdown.

Fig. 6 Spatial distribution of vertical terms and vertical cross section of the wind speed and potential temperature at 63.5°S.
Contributions of thermodynamic processes

Quantify the heat budget of foehn warming

- The contribution of isentropic drawdown was small.
- The dominant contribution was sensible and radiative heating.
- The contributions of latent heating and pressure gradient were negative.
Contributions of thermodynamic processes

- Atmospheric River is marked by the integrated water vapor transport (IVT):

\[
IVT = \sqrt{\left( \frac{1}{g} \int_{1000\,hPa}^{300\,hPa} qudp \right)^2 + \left( \frac{1}{g} \int_{1000\,hPa}^{300\,hPa} qvpd \right)^2}
\]

- An atmospheric river weakened when approaching the AP. This foehn warming was not linked to the precipitation and latent heating on the windward side.

- The dynamical factor was more important in shaping the IVT.

Fig. 8 The distribution of integrated vapour transport and timeseries of IVT and 10m wind speed.
Climatological analyses of extreme warm events

- Trajectory cluster analysis and composite analysis

Fig. 9 Average 10-day backward trajectories and boxplot of the extreme temperatures for six clusters.

- Most air masses (89%) originated over the Pacific Ocean
- Cluster 5 includes the event of February 2020. Its origin is closest to the station among the trajectories from the west.

Fig. 10 Composite of 500 hPa geopotential height anomaly of Cluster 5.

The high pressure anomaly is the typical large-scale circulation characteristic.
Anomalous 500 hPa geopotential height and wind averaged during 6 to 8 February in 2020

### Trajectory cluster analysis and composite analysis

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Conclusions

• The high-pressure ridge favored the transport of warm air masses to the northern AP.
• The vertical air flows (Foehn) made a larger contribution to the abrupt warming.
• The dominant contribution to the foehn warming was sensible and radiative heating.
• Extreme high temperatures in summer are associated with air masses over the Pacific Ocean.
Prospect:

- Large-scale moisture transport and warm air advection
- Local-scale located on the leeward side of a mountain

Similar high temperatures may be recorded in the future. Higher-resolution numerical simulations are needed to better resolve all mechanisms affecting meteorological variables and their interaction with the ocean and cryosphere in the complex AP environment.

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Thank you!