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Causes of the Antarctic region record high temperature at Signy Island, 30th January 1982

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Abstract

On 30th January 1982, the research station on Signy Island (South Orkney Islands) reported a daily maximum temperature of 19.8 °C. This is a record maximum for any station south of 60°S. We use surface observations, atmospheric reanalyses and high-resolution atmospheric model simulations to investigate the drivers of this extreme event. At the time of the record temperature exceptionally warm air was being advected southwards towards the South Orkney Islands from the subtropical South Atlantic. This air mass cooled significantly at levels below 1 km during its long track over the cold Southern Ocean but remained relatively warm above this level. Atmospheric model simulations show that warm air from upper levels was brought down towards the surface over Signy Island in a föhn wind generated by northerly flow over Coronation Island, a mountainous island just to the north of Signy Island. Modelled temperatures over Signy Island are in good agreement with observations and thus support the hypothesis that the record temperature was caused by a combination of exceptional warm advection with conditions suitable for the generation of föhn. Since conditions conducive to föhn occur relatively frequently, föhn warming may have a significant influence on the local climate and ecology of Signy Island.

Keywords: observational data analysis; regional and mesoscale modelling; mesoscale; mountain; polar; föhn wind

1. Introduction

On 30th January 1982, the British Antarctic Survey research station at Signy Island (Figure 1) reported a daily maximum surface air temperature of 19.8 °C. The World Meteorological Organisation (WMO) has recently recognised this as a record high temperature for the Antarctic region, defined as all land and ice shelves lying south of 60°S (de los Milagros Skansi *et al.*, 2017). To put this record into a regional context, we note that the absolute maximum temperature for the Antarctic continent (17.5 °C on 24th March 2015) was measured at Esperanza station on the Antarctic Peninsula, 660 km southwest of Signy Island. By contrast, Grytviken station on the subantarctic island of South Georgia, 900 km to the northeast of Signy Island, recorded a station record maximum temperature of 22.9 °C on 31st January 1982. While it is not surprising that a station at the northern limit of the Antarctic region should hold the regional temperature record, the observed temperature was exceptional even for Signy, exceeding the second highest ranked temperature in the record by 1.8 °C. Only 1% of monthly maximum temperatures in the Signy record exceed 15 °C.

de los Milagros Skansi *et al.* (2017) considered possible causes of this extreme event and suggested that it was driven by a combination of exceptional warm advection together with a local föhn effect. In this article, we examine these mechanisms in greater detail. We use global atmospheric reanalyses to investigate the large-scale atmospheric circulation associated with the event. In addition, we carry out very high-resolution simulations with a regional atmospheric model to investigate how interaction of the large-scale flow with local orography contributed to the extreme conditions observed. We discuss how both regional circulation and local processes contributed to the record event and consider the importance of both for controlling local climate.

2. Data and methods

2.1. Meteorological observations

We make use of surface meteorological data from the two research stations in the South Orkney Islands that were operating in January 1982. Signy Research Station (60°43′S, 45°36′W, elevation 7 m, WMO station number 88925) is situated on the eastern shore of Signy Island, one of the smaller islands of the group (Figure 1). To the north lies the larger Coronation Island, which rises to over 1200 m elevation. The station was established by the UK in 1947 and operated as a year-round station until 1996, since when it has been occupied only during austral summer. Further east in the South Orkney Islands is Laurie Island, where Orcadas station (60°44′S, 44°44′W, elevation 4 m, WMO station number 88968) is located. Established in 1903 by

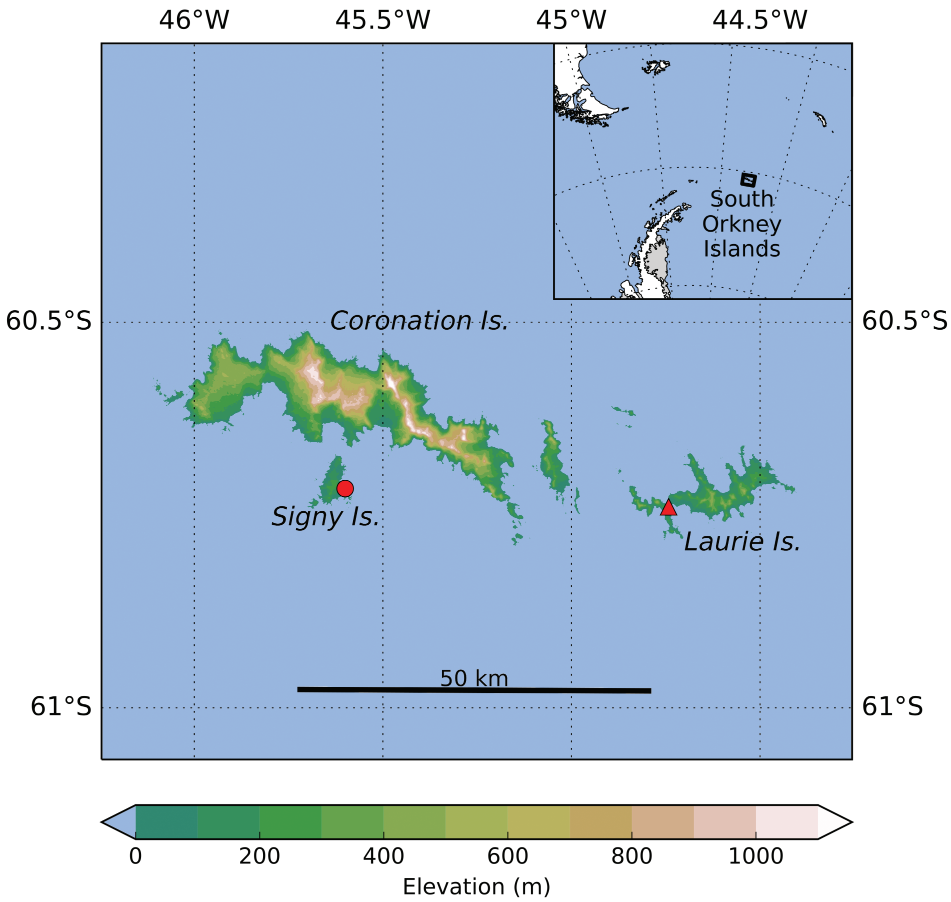

Figure 1. Location and topography of the South Orkney Islands, showing Signy (red circle) and Orcadas (red triangle) research stations.

the Scottish National Antarctic Expedition and operated by Argentina since 1904, Orcadas provides the longest unbroken series of meteorological observations for any station of 60°S (Zitto *et al.,* 2016).

The South Orkney Islands lie to the south of the main polar front in the Southern Ocean and thus experience a climate typical of the maritime Antarctic. Monthly mean temperatures at Signy and Orcadas range from around +1 °C in January to around −10 °C in July, with large interannual variability. The islands lie within the path of the southern ocean storm track and are frequently subject to eastward-moving cyclonic weather systems that bring strong winds, low cloud and precipitation. In this location, the islands can experience the advection of both cold air masses from the Weddell Sea sector of the Antarctic and much warmer air from mid-latitudes.

In 1982, Signy station was operating a very basic climatological observing programme. A full manual synoptic observation was carried out at 0900 local time (1200 UTC) every day. In addition, maximum and minimum thermometers were read at 0900 and 2100 local time (1200 and 0000 UTC). Continuous measurements of temperature, humidity and wind speed were recorded on paper charts by electromechanical autographic instruments. At Orcadas station, synoptic observations were made at 6-hourly intervals.

2.2. Atmospheric reanalysis data

In order to put the local observations into a broader synoptic context, we use data from the European Centre for Medium-Range Weather Forecasts Interim Reanalysis (ERA-interim, Dee *et al.,* 2011). While limited *in situ* observations are available over the high-latitude South Atlantic sector, assimilation of satellite sounder data from 1979 onwards provides a strong constraint on the reanalysis. After 1979, reanalysis fields therefore provide a reliable representation of broad-scale atmospheric conditions at high southern latitudes (Bromwich and Fogt, 2004).

2.3. Regional atmospheric model

We have carried out a high-resolution simulation of atmospheric flow around the South Orkney Islands during the record high temperature event using Polar-WRF, a polar-optimized version of the Advanced Research Weather Research and Forecasting model (WRF-ARW) version 3.5.1. Details of the underlying model formulation can be found in the WRF-ARW technical notes (Skamarock *et al.,* 2008), while the polar optimizations are described by Hines and Bromwich (2008). These include important modifications to key regional physical processes, including fractional sea ice, an optimized surface energy balance over the snowpack and sea ice, and an enhanced treatment of cloud microphysics and radiative processes. In what follows, we refer to the polar-optimized model simply as WRF.

The simulations were run on a series of four nested domains, with one-way forcing between domains. The three outermost domains each had 100×100 grid points at horizontal resolutions of 27 km, 9 km, and 3 km, respectively. Domain 4, 121×100 grid points at a horizontal resolution of 1 km, was centred over the South Orkney Islands and covered the area shown in Figure 1. All four domains had 50 vertical levels between the surface and the model top at 50 hPa. The topography of the South Orkney Islands was derived from the 50 m resolution Advanced Spaceborne Thermal Emission and Reflection Radiometer-Global Digital Elevation Model (ASTER GDEM). Missing data points were filled using contours from the Scientific Committee for Antarctic Research Antarctic Digital Database (SCAR ADD, http://www.add.scar.org/) matched to satellite imagery (P. Fretwell, 2017, pers. comm.). Permanent snow cover and glaciers in this region are not well captured in the default United States Geological Survey land use data available in WRF. Therefore, the glacier mask in all domains was updated using land type data from the SCAR ADD.

The model was initialized on 23rd January 1982 0000 UTC and was run forward to 1st February 1982 0000 UTC. Initial and lateral boundary conditions were derived from ERA-interim, with the lateral boundary conditions and surface fields (sea ice and sea surface temperatures) updated every 6 hours. Model data were saved at hourly intervals.

3. Results

3.1. The record high temperature event of January 1982

Between the 25th and the 27th January 1982, Signy temperatures recorded at 1200 UTC remained just above freezing but started to rise from the 28th (Figure 2). On the 30th January, the 1200 UTC temperature was reported as +9.6 °C, and the maximum thermometer reading (covering the period 30th January 0000 UTC−1200 UTC) was recorded as +19.8 °C. The thermograph chart indicates a maximum temperature of 68 °F (20.0 °C) at around 0300 UTC on the 30th, in good agreement with the maximum thermometer reading. Temperatures remained high through the 31st (1200 UTC observation +13.6 °C) but returned to near-freezing values from 1st February onwards. Over the entire period, temperatures recorded at Orcadas station were much less variable, ranging between +4.0 and −0.7 °C (Figure 2).

The Signy anemograph chart (not shown) indicates light ($< 2.5\,\mathrm{m\,s^{-1}}$) winds between 2100 UTC on the 29th and 0130 UTC on the 30th, at which time there was a sudden change to very gusty conditions, with peak wind speeds of around $10\,\mathrm{m\,s^{-1}}$ around the time that the record temperature was observed. The corresponding hygrograph chart (not shown) indicates fairly constant relative humidity of around 80% until around 1200 UTC on the 29th, followed by a rapid fall to a minimum of around 55% at around 1700 UTC. After this time, relative humidity started to rise slowly but then showed two further rapid falls, the first at around 0000 UTC on the 30th and the second, to 55%, around the time of the record temperature observation (0300 UTC).

3.2. Synoptic forcing

At 0000 UTC on 27th January the South Orkney Islands were under the influence of a relatively cool southeasterly airstream. At the same time, an extensive low-pressure system was developing over the eastern Pacific sector of the Southern Ocean. Over the next 2 days this system moved eastwards towards the Drake Passage and, by 0000 UTC on 30th January, had extended meridionally into a trough lying between the west coast of the Antarctic Peninsula and southern Chile. Meanwhile, a ridge developed in the western South Atlantic around 45°W and extended southwards towards Antarctica (Figure 3(a)). Between these two features, a large geopotential height gradient drove strong northwesterly winds in the lower troposphere over the South Orkney Islands. However, this situation did not persist for long. Over the following 48 h, the trough-ridge system moved rapidly eastwards and winds over the South Orkney Islands consequently weakened and moved round to the west.

The northwesterly airstream advected very warm subtropical air southwards towards the South Orkney Islands. Temperatures at 875 hPa (approximately 1 km altitude) from the ERA-interim reanalysis in the vicinity of the South Orkney Islands are shown on Figure 2. On 27th January, the temperature at this level was around −10 °C but steadily increased from early on 28th January as the warm advection set in, reaching a peak of 17.4 °C at 0000 UTC on 30th January. This is the highest temperature found at this location and altitude in the ERA-interim reanalysis between 1979 and 2015, indicating the truly exceptional nature of this warm air advection event. Subsequently, temperatures at 875 hPa decreased slowly as the warm air stream moved away from the South Orkney Islands.

Figure 3(b) shows the vertical temperature profile at 0000 UTC on 30th January. The profile suggests that the warm air mass cooled substantially below 1 km during the course of its long track across the cold Southern Ocean (sea surface temperature was around +1 °C in the vicinity of the South Orkney Islands) while air at levels above around 1 km was relatively unmodified and remained very warm, leading to very stable stratification below 1 km. If air from the 875 hPa level were brought adiabatically to sea level it would reach a temperature of 28.9 °C, i.e. significantly in excess of the maximum temperature measured at Signy. In the following section, we use the WRF simulations to explore how air with a high potential temperature might have

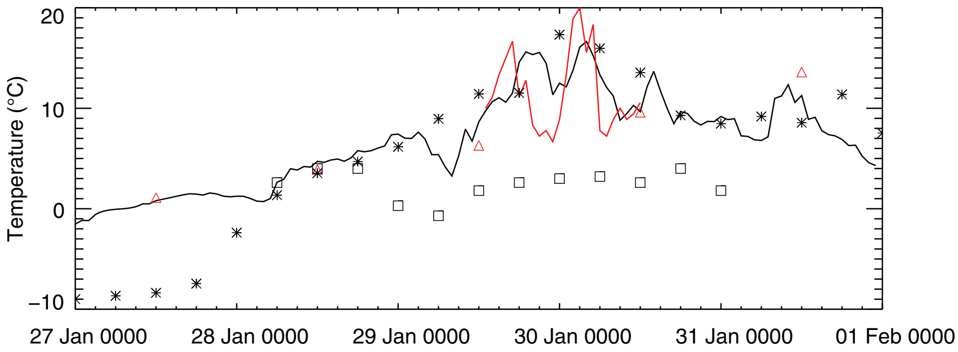

Figure 2. Temperatures during the record event. Red triangles – Signy 1200 UTC temperature readings, squares – Orcadas 6-hourly temperature readings, asterisks – 875 hPa temperatures from ERA-interim reanalysis, red line – Signy hourly temperatures read from the thermograph chart, black line – 2 m temperatures simulated by WRF at the grid point closest to Signy Research Station.

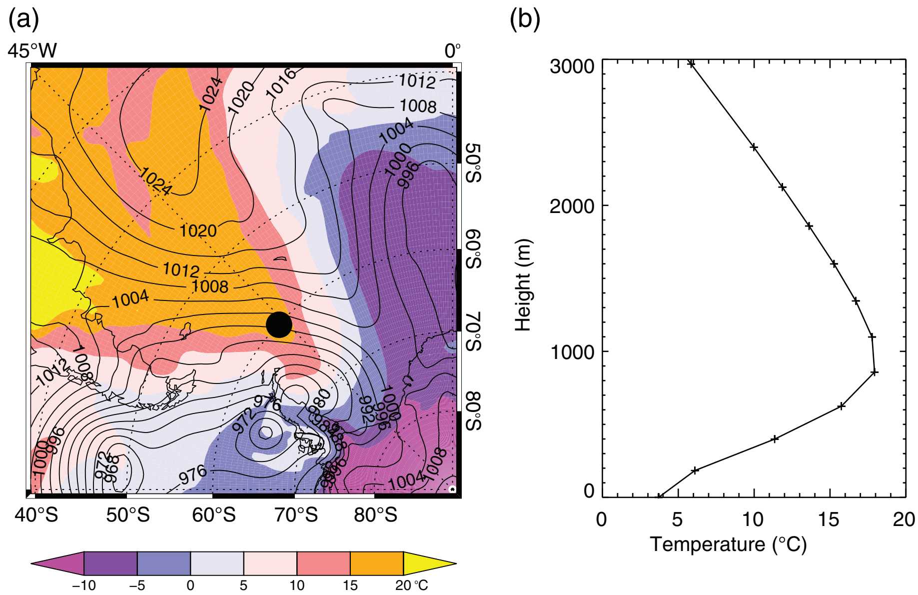

Figure 3. (a) Mean sea-level pressure (contours) and 875 hPa temperature (colour shading) from the ERA-interim reanalysis at 0000 UTC on 30th January 1982. The filled circle indicates the location of the South Orkney Islands, (b) Vertical temperature profile from the ERA-interim reanalysis at 0000 UTC on 30th January 1982 at this location.

been brought down from upper levels towards the surface through interaction of the broad-scale atmospheric flow with the local orography.

3.3. The impact of local orography

Figure 4(a) shows modelled 10 m winds and 2 m air temperatures across the inner WRF model domain at 0300 UTC on 30th January. At this time, modelled 10 m winds upwind of the islands are from the north, while winds at mountain summit level (around 1 km) are northwesterly. Reduced wind speeds immediately north (upwind) of Coronation Island are indicative of blocking of the strongly stratified incident flow by the island's steep orography. Over the southern (lee) slopes of Coronation Island, the low-level winds are strongly accelerated and 2 m temperatures are generally 10–15 °C higher than on the upwind side of the island. The region of accelerated winds and raised temperatures extends southwards from Coronation Island to Signy Island and beyond. A time series of modelled 2 m temperature at the grid point closest to Signy research station is shown on Figure 2. Modelled temperatures follow those observed quite well [mean bias = +1.0 °C, root mean square (RMS) error = 4.0 °C, $r = 0.3$, $p < 0.1$], but the maximum modelled temperature at this location is 16.6 °C, i.e. over 2 °C below than that observed. However, one grid point (1 km) further north, the modelled 2 m temperature reached 19.8 °C at 0300 UTC, in perfect agreement with the Signy observation.

Figure 4(b) shows a cross-section of potential temperature along a north–south line across Coronation Island and Signy Island. Southward flow of the stably stratified air at levels below the crest of Coronation Island is blocked while, downwind of the crest, air of relatively high potential temperature is forced downwards from levels above the crest and descends the lee slope, warming adiabatically and accelerating to form a warm föhn wind. The model simulation shows that the föhn flow reaches the southern coast of Coronation Island

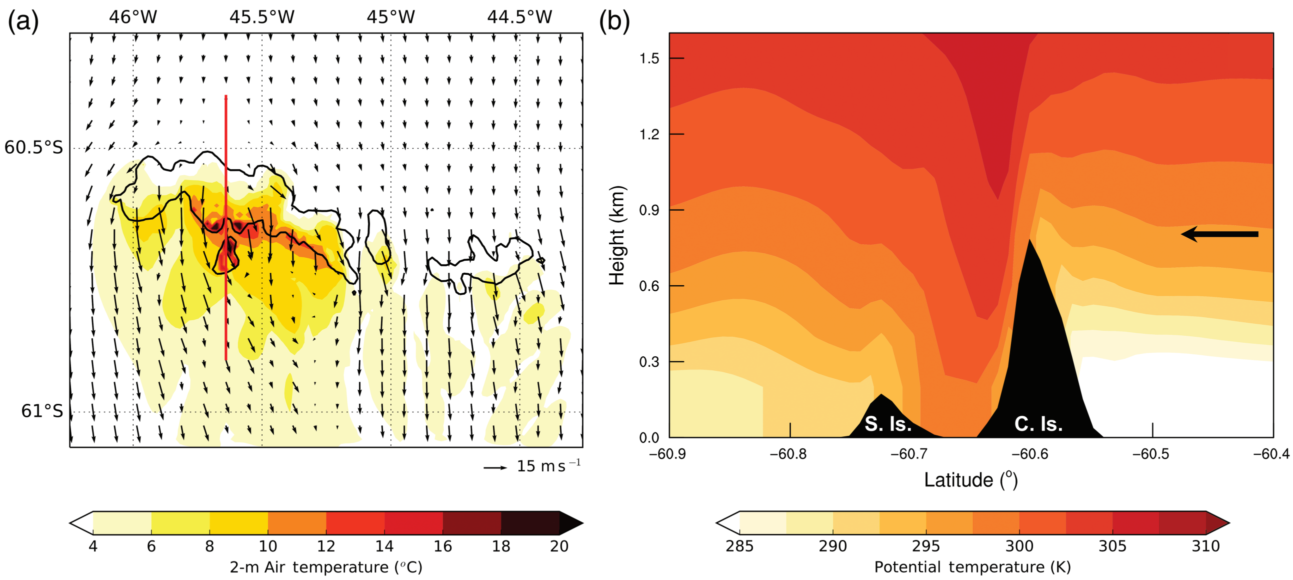

Figure 4. (a) 10 m wind vectors (arrows) and 2 m temperatures (shading) simulated by WRF at 0300 UTC on 30th January 1982. (b) A cross-section of WRF potential temperature along the red line shown on (a) at this time. C. Is. = Coronation Island, S. Is. = Signy Island. The large arrow on (b) indicates the general direction of the wind along this section.

and continues southward onto Signy Island. A hydraulic jump-like feature is visible over Signy Island, where the warm air reascends steeply to higher levels, creating a large north–south gradient in near-surface temperature across Signy Island (Figure 4(a)). The modelled 10 m wind speed reproduces the main features observed in the Signy anemograph record (not shown) quite accurately (mean bias = +3.8 m s^{-1}, RMS error = 5.8 m s^{-1}, $r = 0.6$, $p < 0.01$).

4. Discussion

The present study confirms the suggestion (de los Milagros Skansi *et al.*, 2017) that the record high temperature at Signy Research Station on 30th January 1982 was caused by a combination of exceptional warm air advection together with additional warming resulting from a local föhn effect. Situated immediately downwind of the Coronation Island mountain chain, Signy Island was directly in the path of adiabatically warmed air descending from around summit level. The high temperatures measured at Signy Island were not experienced at Orcadas. Situated on a low-lying isthmus joining parts of Laurie Island that themselves do not exceed 250 m elevation, the latter station did not experience a significant föhn effect and associated lee-side warming.

Elvidge and Renfrew (2016) discuss the different mechanisms that can give rise to föhn warming in the lee of a mountain barrier, including those that they term ‘isentropic drawdown’ and ‘latent heating and precipitation’. For the event studied here, it would appear that the first of these is the major contribution to lee-side warming. ‘Plunging’ isentropes, associated with upstream blocking of the flow, are clearly seen in Figure 4(b). It is possible that there is a minor additional contribution to warming from the second mechanism. The WRF simulation shows some precipitation falling on the upwind side of Coronation Island but this is mostly confined the extreme west of the island and precipitation rates do not exceed 10 mm day^{-1}.

Föhn warming has been shown to be an important factor in controlling local climate at a number of locations at high southern latitudes, including the island of South Georgia (Bannister and King, 2015), the Antarctic Peninsula (Cape *et al.*, 2015) and the McMurdo Dry Valleys (Speirs *et al.*, 2013). The proximity of Signy Island to the mountains of Coronation Island makes it likely that föhn may also be a significant influence on the former’s microclimate. Signy is directly downwind of topography of elevation 500 m or greater for winds in the sector 328°–070°. The ERA-interim analysis indicates 875 hPa winds within this sector and with a speed of 5 m s^{-1} or greater for about 10% of the time so conditions conducive to föhn over Signy Island will not be uncommon. We have estimated the potential impact of föhn on Signy Island’s microclimate by comparing monthly mean temperatures at Signy with those at nearby Orcadas which, as discussed above, is less likely to be influenced by föhn. Monthly mean temperatures based on four observations per day are available for both stations for the period 1956–1969 (Turner *et al.*, 2004). Over this period, Signy temperatures exceed those at Orcadas by a mean of 0.2 °C (statistically significant at better than 0.1%). While other factors may contribute to this difference, it is consistent with the hypothesis that föhn exerts a small warming influence on Signy Island’s microclimate. Signy Island is known to support a terrestrial ecosystem that is both richer and more biodiverse than those seen at comparable maritime Antarctic sites (Smith, 1990). Extended studies are required to determine whether föhn warming helps to maintain a favourable microclimate that enables this ecosystem to flourish.

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