# 16.1. Marine signature in West Antarctic climate as seen by AMPS

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## 1. Introduction

In East Antarctica, high interior elevations and steep coastal slopes usually confine ocean air masses to the immediate coastal regions. With relatively lower elevations, West Antarctica (WA) experiences a more ocean-influenced climate as offshore air masses more easily penetrate inland. In addition to this topographic feature, the portion of the Southern Ocean adjacent to WA exhibits intense meso- and synoptic-scale cyclonic activity (Carrasco et al., 2003; Simmonds et al.; 2003). Poleward-moving air associated with these depressions provides the primary mechanism for conveying ocean air properties over the ice sheet's interior.

This meridional transport of heat and moisture onto the Antarctic ice sheet has been studied with ECMWF reanalysis data (Genthon and Krinner, 1998; Tietäväinen and Vihma, 2008). In particular, Genthon and Krinner (1998) showed the 60°W-160°W longitude sector to be one of the main source region for energy and moisture south of latitude 70°S. Influx of moist ocean air affects the amount of precipitation and, ultimately, the mass input to the ice sheet. Due to their coarse resolution, existing reanalysis data sets do not allow the barrier effect of the steep coastal Antarctic topography for the atmospheric circulation to be well captured. High-resolution simulations of Antarctic climate using regional model have allowed more accurate investigation of the surface mass balance of the Antarctic ice sheet (e.g., Bromwich et al.; 2004; Van de Berg et al., 2005; Krinner et al., 2007). Using such a regional model, van de Berg et al. (2008) performed a comprehensive study of the heat budget of the Antarctic boundary layer, showing a distinctly positive heat budget over WA.

Since 2001, the Antarctic Mesoscale Prediction System (AMPS; Powers et al., 2003) project has provided twice-daily weather forecasts at a high spatial resolution over the entire Antarctic continent. Its forecasting performance has been evaluated and confirmed by various studies (e.g., Bromwich et al., 2005). Our objective here was to use this valuable data source to extract some climatological features of WA at a resolution not achieved so far by comparable works and characterize the influence of the ocean. The forecasting nature of the model used by AMPS does not allow consistent climatological studies over the full-length forecast archive because of regular configuration upgrades to the model. Our study investigated a two-year period, 2006-2007, so that the temporal representativeness of our “climatology” is necessarily limited. Characterization of the period of study with respect to a longer time period was addressed by use of a reanalysis data set.

## 2 Data

Our study uses the full time series of AMPS twice-daily weather forecasts from Jan. 2006 – Dec. 2007 covering the entire Antarctic continent and a large portion of the Southern Ocean. For the time period investigated here, AMPS employed Polar MM5, a version of the fifth-generation Pennsylvania State University-NCAR Mesoscale Model (MM5) with physics optimized for polar regions by the Polar Meteorology Group (PMG) of the Byrd Polar Research

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Center, 20-km horizontal resolution and 31 vertical σ-levels. This configuration remained unchanged between October 2005 and June 2008, which accounts for the time frame selected in this study.

In addition to the AMPS archive, we used the newly released reanalysis data set, ERA-Interim, produced by the European Centre for Medium-Range Weather Forecasts (ECMWF; Simmonds et al., 2007; Uppala et al., 2008). ERA-Interim is an ongoing experiment that should ultimately cover 1989-present. Yet, at the time of this study, only the 1989-2007 segment has been completed. This reanalysis data set is available at a nominal horizontal resolution of 1.5°. However, the original model run uses a reduced N128 Gaussian grid in order to minimize the effect of meridian convergence at the poles. Thus, the actual longitudinal resolution over Antarctica ranges 60-70 km (http://dss.ucar.edu/datasets/ds627.0). Evaluation of this recent reanalysis data set for high southern latitudes is currently under way at the PMG (Wang and Bromwich, 2009).

## 3. Results

### *a. Singularities of 2006-2007*

The 19-year reanalysis data set is used to characterize the meteorological conditions prevailing over WA in 2006 and 2007 with respect to the 1989-2007 average. We examined the mean annual anomalies of sea-level pressure (SLP), precipitation and 2-meter temperature ($T_{2m}$) fields (Fig. 1).

The SLP field anomalies (Fig. 1a, 1b) show a characteristic wavenumber-3 distribution over the Southern Ocean for both years. In 2006, a center of positive anomalies is located north of the Ross Sea while high negative anomalies are found to the northwest of the Antarctic Peninsula. The anomalies are of opposite sign in 2007. These pressure pattern are indicative of an westward shift of the northerly mid-tropospheric air flow over the Amundsen/Bellingshausen Sea sector.

Consistent with the SPL anomalies, the mean annual precipitation anomalies (Fig. 1c, 1d)

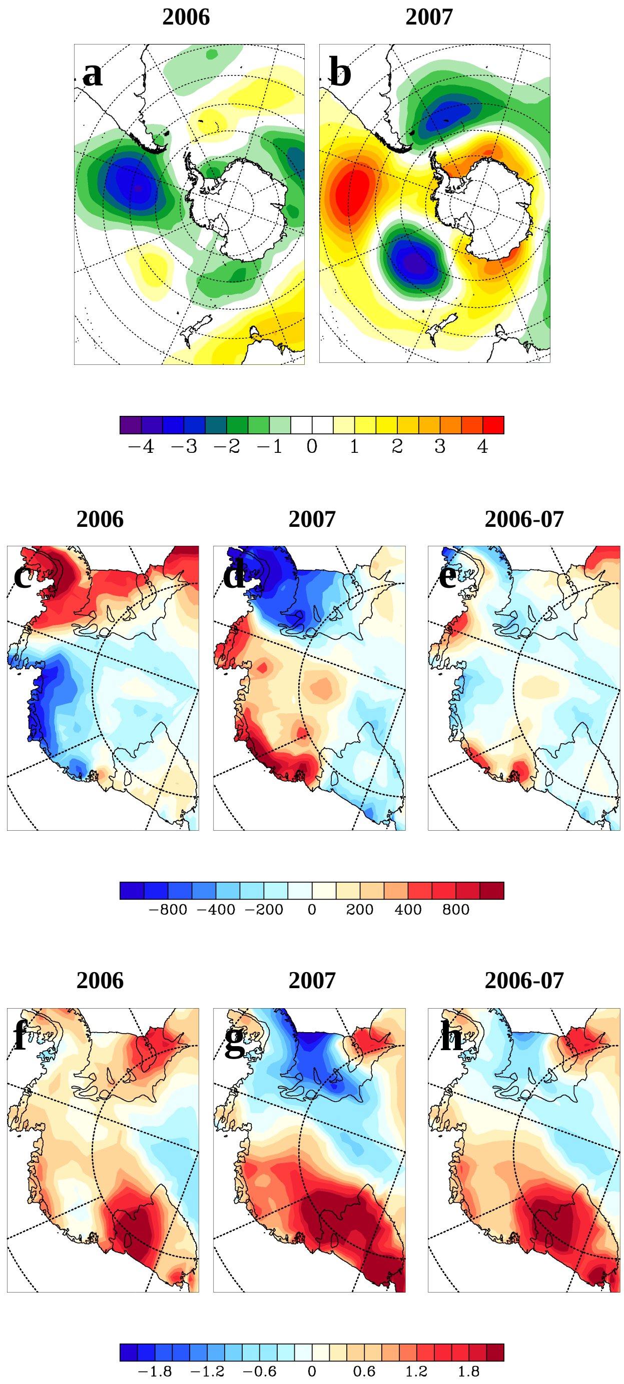

**Fig. 1**. Mean annual anomaly of sea-level pressure (a-b), precipitation (c-e) and 2-meter temperature (f-h) with respect to the 1989-2007 means for 2006 (left), 2007 (center) and 2006-07 combined (right) based on ERA-Interim data set. Units for pressure, precipitation and temperature are hPa, mm eq. water and °C respectively.

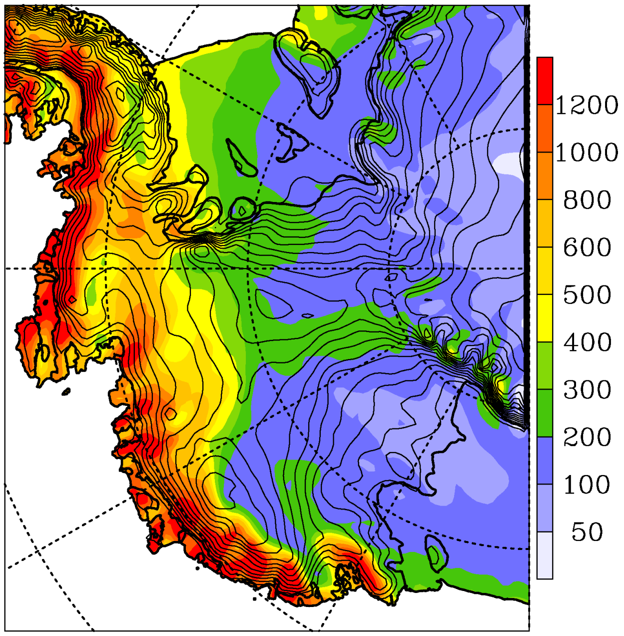

**Fig. 2**. 2006-2007 mean annual total precipitation (in mm eq. water) from AMPS archived forecasts. Black contours represent the 20-km resolution model terrain.

show almost reversed patterns over WA between 2006 and 2007, with values of opposite signs on either side of longitude 90°W approximately. Thus, the annual precipitation distribution averaged over 2006-2007 exhibits only low deviation from the 1989-2007 average overall (Fig. 1e), except over some limited coastal zones. The 2-year time period is expected to be fairly representative of the mean annual precipitation distribution for the last two decades.

The mean annual $T_{2m}$ anomalies (Fig. 1e, 1f) exhibit a longitudinal contrast only for 2007, the year 2006 being warmer than average over most of WA. The resulting 2-year mean anomaly (Fig. 1h) yields significantly warmer temperature over the Ross Ice Shelf area and, to a lesser extent, over western WA. Thus, temperatures in these regions may be overestimated in our "climatology" based on AMPS archive.

### b. Climatological features of West Antarctica

In the following, we successively present the 2006-2007 annual means for precipitation, 2-meter potential temperature ($\theta_{2m}$) and cloud fraction obtained with the AMPS archive.

*Precipitation*. The mean annual precipitation for 2006-2007 is shown on Figure 2. Beside high orographically-induced precipitation in the vicinity of the coast, the Amundsen/Bellingshausen (A/B) sector of WA, most exposed to northerly flows, exhibits higher values than the Weddell and Ross Sea sectors. Although precipitation decreases sharply away from the coast, relatively high values are still observed over the interior of WA compared to what is measured over the East Antarctic Plateau.

A distinctive feature on Figure 2 is the tongue-shaped band of higher values that approximately follows the topographic ridge between the Ronne Ice Shelf and the Ross Ice Shelf drainage systems. This elongated signature is most apparent in autumn (MAM) and winter (JJA) seasons (not shown), which is concurrent with the annual precipitation maximum. This band does not follow a strictly meridional direction but shows a southwestward curvature. The series of high-elevated mountain ranges stretching in a northeast-southwest direction between the Antarctic Peninsula and the Transantarctic Mountains may account for this deviation as they represent an important constraint for northerly flows. This curvature may further result from the cyclonically rotating motion of air masses penetrating over WA.

Areas of lower precipitation are visible on the lee side of coastal mountain ranges with respect to the prevailing wind (Pine Island Glacier, interior of Marie Byrd Land) and indicate local "shadow effects" due to topography.

*2-meter potential temperature.* Figure 3 shows the mean annual $\theta_{2m}$. This variable removes the adiabatic cooling due to elevation and reflects the mean heat budget at the surface of the ice sheet, with contribution from heat transport and from diabatic processes related to phase changes of water. A distribution comparable to that of precipitation is observed, with higher potential temperature found on the A/B sector of WA and a tongue-shaped band stretching over the central topographic ridge.

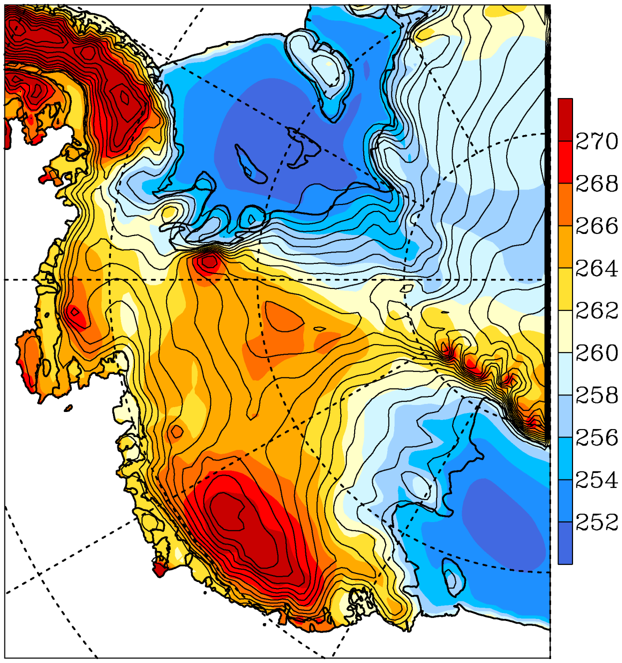

**Fig. 3**. 2006-2007 mean annual 2-meter potential temperature, $\theta_{2m}$ (in K), from AMPS archived forecasts.

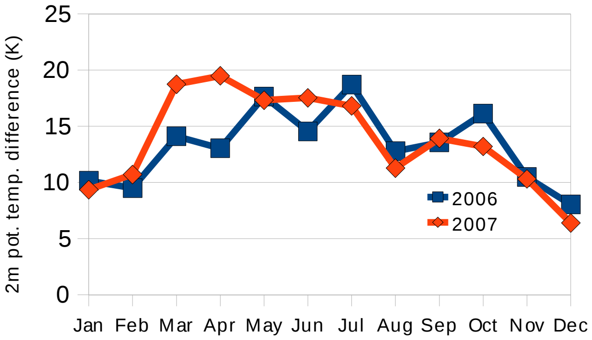

**Fig. 4**. Monthly mean 2-meter potential temperature difference between Byrd AWS (80.0°S, 119.4°W; 1530 m) and Gill AWS (80.0°S, 178.6°W; 30 m) for 2006-2007 as simulated by AMPS.

Interestingly, high-elevated areas in central WA show significantly warmer potential temperatures than those observed on the flat, low-elevated ice shelves. For example, $\theta_{2m}$ at Byrd AWS (80.0°S, 119.4°W; 1530 m), close to the ice divide, generally exceeds that at Gill AWS (80.0°S, 178.6°W; 30 m) over the Ross Ice Shelf by more than 10 K (Fig. 4, showing only temperatures simulated by AMPS). The minimum difference is found to occur in the summer. Actual monthly temperatures recorded by both AWS can be obtained from the Antarctic Data for Environmental Research (READER) website (http://www.antarctica.ac.uk/met/READER/). However, discontinuities in Byrd and Gill temperature records make consistent comparison difficult so that it was decided not to include them in Figure 4.

The possible signature of a Föhn effect can be seen over the interior of western Marie Byrd Land where high potential temperatures are associated with low annual precipitation and cloud fraction.

*Cloud fraction*. The cloud cover can be used to trace moist air masses that flow over the ice sheet without necessarily generating precipitation. Figure 5 shows the mean annual cloud fraction (ranging 0-1) over WA, whose distribution is found to be very similar to that of precipitation. No distinction has been made here between lower and upper clouds. The presence of the elongation of higher cloud fraction over the central topographic ridge has been detected by satellite-born lidar in a study conducted by

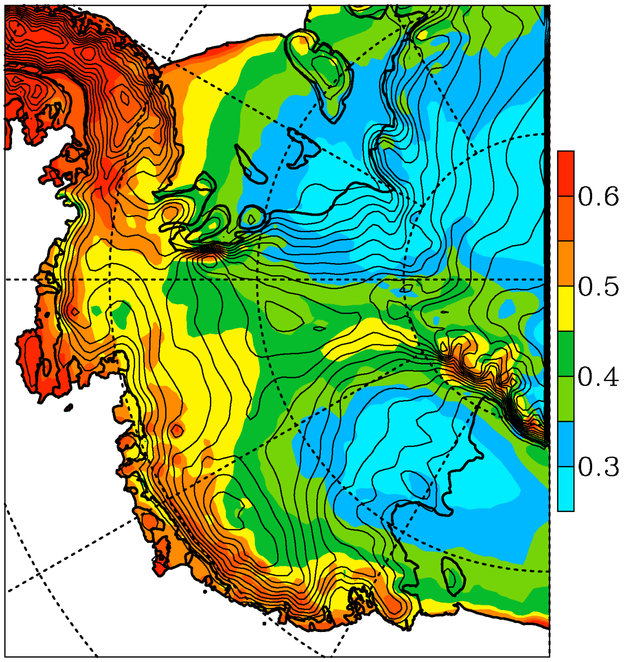

**Fig. 5**. 2006-2007 mean annual cloud fraction (ranging 0-1) from AMPS archived forecasts.

Spirnhirne et al. (2005) for October 2003. This suggests that the tongue-shaped pattern of moist air is well captured by the model and is potentially a robust feature of West Antarctic climate.

*c. Spatial correlations*.

The influence of marine air masses has been further explored by computing time correlations between the daily precipitation time series at four sites and: 1/ the full daily precipitation field (Fig. 6); 2/ the full daily 500-mb geopotential height field (Z500; Fig. 7). Analysis of the Z500 field allows identification of the prevailing upper-level flow associated with precipitation. The selected sites are located on either side of the topographic ridge (Fig. 6a, 6c and Fig. 7a, 7c), upslope of the Transantarctic Mountains (Fig. 6b and 7b) and near the Ross Ice Shelf (Fig. 6d and 7d), respectively. Only the zero-lag correlation is shown here, i.e. correlations are computed for precipitation or Z500 variations occurring on the same day.

Fig 6a and 6b show how air masses originating from the coast can potentially penetrate deep into the interior of WA and reach beyond the Transantarctic Mountains. As shown on Fig. 7a and 7b, these far-reaching flows mainly originate from the Bellingshausen Sea and are accompanied by precipitation over the eastern part of WA (east of the topographic ridge). On the other hand, Fig. 7c and 7d show a climatologically distinct region in western WA where precipitation is constrained by the central topographic ridge and the Transantarctic Mountains further west. In this case, correlations with the Z500 field indicate air flowing mainly from the Amundsen and the Ross Seas.

## Conclusion and perspectives

This study is a tentative high-resolution climatology of West Antarctica (WA) based on the AMPS forecast archive from 2006-2007. We specifically investigated how the intrusion of offshore air masses can be traced into the climate

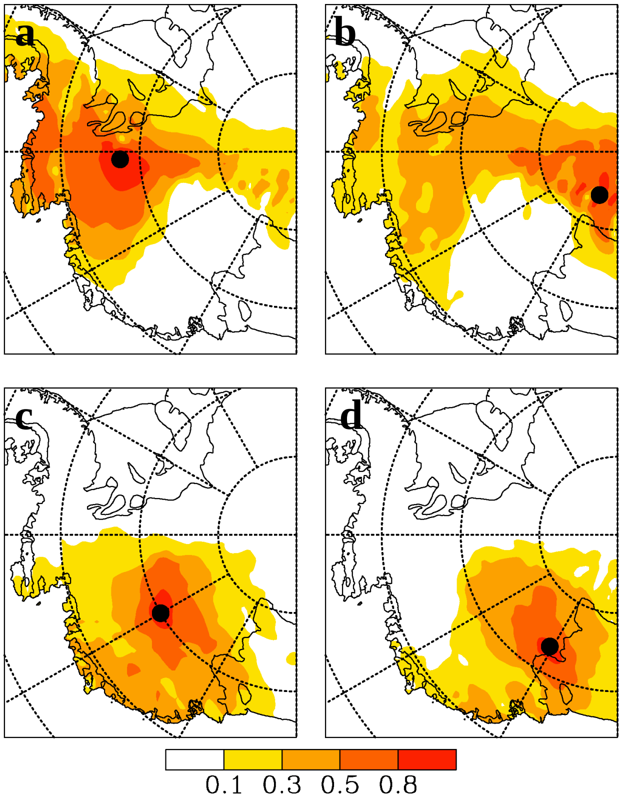

**Fig. 6**. Zero-lag time correlation between the full daily precipitation field and daily precipitation time series at: (a) Ellsworth Mountains; (b) upper Queen Maud Mountains; (c) Byrd Station; (d) Siple Dome. These sites are denoted by the black dots.

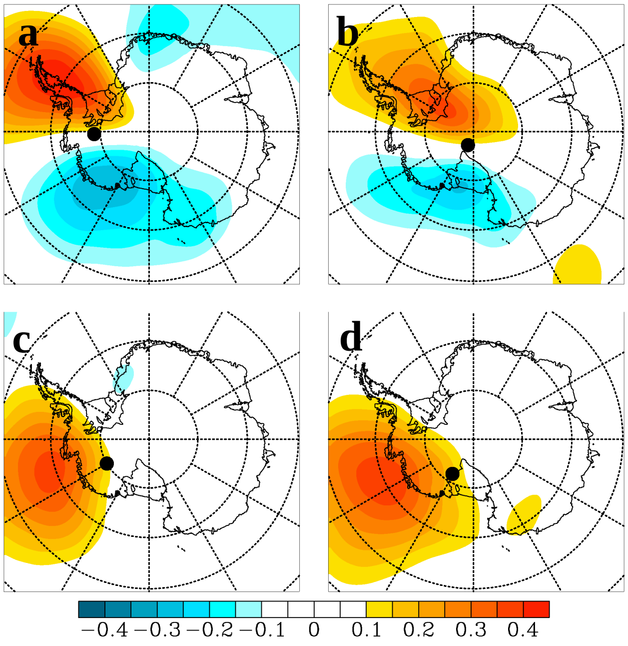

**Fig. 7**. Zero-lag time correlation between the 500-mb geopotential height field and the precipitation time series for the same four sites as in Fig. 6.

of this ice sheet. This ocean influence is primarily manifested by higher surface potential temperature, precipitation and cloud fraction, most apparent on the Amundsen/Bellingshausen sector. The ocean signature also appears clearly as a tongue-shaped pattern of relatively warm and moist air across central WA, suggesting frequent transport of marine air as far as onto the Transantarctic Mountain range.

In East Antarctica, higher elevation and a steeper coastal topography act to reduce the ocean influence over the Polar Plateau. By contrast, the climate of WA is more greatly dependent on the cyclonic activity over the adjacent Southern Ocean. In this respect, recent studies indicating significant surface and tropospheric warming in WA (Bromwich et al., 2008; Steig et al., 2009) raise the issue of possible changes in the atmospheric circulation in this region. This may have resulted in spatial and temporal changes of the ocean influence over WA. This issue should be addressed in an upcoming study.

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