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Atmospheric circulation and its variability over the Antarctica and Southern Oceans

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The climatological-mean circulation in the atmosphere and ocean in the mid- and high latitudes is much more uniform in the zonal direction over the Southern Hemisphere than over the Northern Hemisphere. The stronger uniformity arises from the much smaller fraction of land area and the particular configuration of the Antarctica. The Antarctic Circumpolar Current (ACC) over the Southern Ocean is the sole major current system that is circumpolar (as atmospheric jet streams). Along the ACC, a prominent oceanic frontal zone (Antarctic Polar Frontal Zone) forms around 45S with strong sea-surface temperature (SST) gradient, which is favorable for the development of migratory cyclones and anticyclones. Developing baroclinically, these atmospheric eddies transport heat poleward to relax the meridional air temperature gradient. Through the thermal wind adjustment to this heat transport, the westerly momentum is transferred downward to accelerate the surface westerly winds along the oceanic frontal zone. Characterized by stormy westerly winds, this maritime region has therefore been known as "roaring forties" and "furious fifties" since the Age of Discovery. After the passage of a cyclone, relaxed air-temperature gradient enhances cross-frontal differential heat supply from the ocean, which can restore the temperature gradient efficiently. With this "oceanic baroclinic adjustment", cyclones and anticyclones can develop recurrently along the oceanic frontal zone to form a storm-track.
Wavy cyclonic and anticyclonic disturbances that develop baroclinically propagate into the subtropics in the upper troposphere, while transporting westerly momentum to mid-latitudes. With this transport, a polar-front jet (PFJ) forms, a deep westerly jet stream with strong surface westerlies. The annular mode, which is the dominant mode of variability in the extratropical atmosphere, is manifested as vacillations of a PFJ. In the austral spring the annular mode tends to exhibit deep structure that represents joint vacillations between the PFJ and stratospheric polar-night jet (PNJ). It has been suggested that the cooling in the polar stratosphere since the mid-1980 s may have led to the strengthening of the surface westerlies over the Southern Ocean via the annular mode variability.
The Southern Ocean is the sole region where a direct comparison is meaningful between the observed atmospheric circulation and its counterpart that is simulated through an "aqua-planet experiment", in which zonally uniform SST distribution is prescribed globally as the lower-boundary condition of an atmospheric genera circulation model. A pair of aqua-planet experiments, one with a realistic SST profile including frontal gradient around 45S and the other with the corresponding profile without frontal gradient, has confirmed the critical importance of the frontal SST gradient in simulating a storm-track, PFJ and annular mode in a realistic manner.
It should be noted that troposphere-stratosphere coupled variability around the Antarctica occurs not only through the annular mode but also through planetary-scale Rossby waves. In some occasions, a stationary anticyclonic anomaly associated with a Rossby wave train amplifies locally to form a blocking high through interaction with migratory cyclones and anticyclones. If a waveguide forms vertically to connect the PFJ with the stratospheric PNJ, accumulated wave energy in the blocking anticyclone can propagate upward as a Rossby wave packet, which may lead to the deceleration of PNJ. In fact, the breakdown of the polar vortex and associated ozone

hole in late September 2002 was caused by a Rossby wave packet that emanated upward from a prominent blocking anticyclone over the South Atlantic. The particular anticyclone formed at the leading edge of a tropospheric Rossby wave train that had been forced by extremely active cumulus convection in the subtropical southwestern Pacific.

Keywords: storm track, oceanic frontal zone, polar-front jet, polar-night jet, Rossby waves, annular mode