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A review of the temporal and spatial variability of Arctic and Antarctic atmospheric circulation based upon ERA-40☆

David H. Bromwich [a,b,*], Sheng-Hung Wang [a]

[a] Polar Meteorology Group, Byrd Polar Research Center, The Ohio State University, Columbus, OH, United States
[b] Atmospheric Sciences Program, Department of Geography, The Ohio State University, Columbus, OH, United States

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Abstract

A survey of the spatial and temporal behavior of the atmospheric general circulation as it relates to both polar regions is presented. The review is based on the European Centre for Medium-Range Weather Forecasts (ECMWF) 40-year reanalysis (ERA-40), updated using ECMWF operational analyses. The analysis spans 1960–2005 in the Northern Hemisphere, but is restricted to 1979–2005 in the Southern Hemisphere because of difficulties experienced by ERA-40 prior to the modern satellite era.

The seasonal cycle of atmospheric circulation is illustrated by focusing on winter and summer. The huge circulation contrasts between the land-dominated Northern Hemisphere and the ocean-dominated Southern Hemisphere stand out. The intensification of the North Atlantic Oscillation/Northern Annular Mode and the Southern Annular Mode in DJF is highlighted and likely due to warming of the tropical Indian Ocean. The Arctic frontal zone during northern summer and the semi-annual oscillation throughout the year in the Southern Hemisphere are prominent features of the high latitude circulation in the respective hemispheres.

Rotated principal component analysis (RPCA) is used to describe the primary modes of temporal variability affecting both polar regions, especially the links with the tropical forcing. The North Atlantic Oscillation is a key modulator of the atmospheric circulation in the North Atlantic sector, especially in winter, and is the dominant control on the moisture transport into the Arctic Basin. The Pacific-South American teleconnection patterns are primary factors in the high southern latitude circulation variability throughout the year, especially in the Pacific sector of Antarctica where the majority of moisture transport into the continent occurs.

Keywords: General circulation; Polar meteorology; Arctic zone; Antarctic zone; Teleconnections; Moisture transfer

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* Corresponding author at: Polar Meteorology Group, Byrd Polar Research Center, The Ohio State University, 1090 Carmack Road, Columbus, OH 43210, United States. Tel.: +1 614 292 6692; fax: +1 614 292 4697.
E-mail address: bromwich@polarmet1.mps.ohio-state.edu (D.H. Bromwich).

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1. Introduction

As the result of unevenly distributed solar radiation, the atmosphere develops motions in an attempt to reach thermal equilibrium between sources and sinks of radiative heating. The atmospheric general circulation usually refers to atmospheric motion that has a relatively large horizontal scale (greater than several hundred kilometers) and persists for a few days to a few weeks (Monin, 1986; Grotjahn, 1993); examples are the Hadley and Ferrel cells (Lorenz, 1967).

The atmospheric circulation exhibits substantial variability. A teleconnection is a persistent, large-scale pattern of inter-correlated circulation anomalies within the atmosphere. Teleconnection patterns are preferred modes of low-frequency variability, typically lasting for weeks, months, or even years, and are associated with changes in the planetary-scale waves. Teleconnections are often associated with widespread and anomalous temperature and precipitation patterns, occurring in response to the anomalous pressure and wind fields. Temporally, the variability of teleconnection patterns reflects weather and circulation systems occurring on many time scales. Spatially, teleconnection patterns are regional in scale but can span entire ocean basins and continents (Wallace and Gutzler, 1981; Mo and Livezey, 1986; Barnston and Livezey, 1987; Bretherton et al., 1992). For example, changing circulation over the North Pacific basin can substantially influence climate over North America, central Europe, Eurasia and the Arctic region.

Enhancing our understanding of the spatial and temporal variability of atmospheric teleconnections is an important step toward improving climate forecasts. All teleconnections are naturally occurring aspects of the quasi-chaotic atmospheric system and are generally thought to result from internal atmospheric dynamics, although land masses, topography, sea surface temperatures and ocean circulation patterns are also central to the creation and persistence of teleconnections (Glantz, 1991). The tropics and subtropics, areas with high interannual and interdecadal variability, play key roles in the atmospheric circulation. The El Niño-Southern Oscillation (ENSO), which is associated with sea surface temperature (SST) changes in the central and eastern equatorial Pacific, has impacts on the climate at local (e.g., Kiladis and Diaz, 1989; Bell and Halpert, 1998; Bell et al., 1999), mid-latitude (e.g., Ropelewski and Halpert, 1986, 1989; van Loon and Shea, 1987; Hoerling et al., 2001, 2004), and high latitude (e.g., Cullather et al., 1996; Bromwich et al., 2000a; Genthon and Cosme, 2003; Fogt and Bromwich, 2006) regions on interannual and interdecadal timescales.

The concept of reanalysis has been described by Bengtsson and Shukla (1988), Trenberth (1995) and Kalnay et al. (1996). Reanalysis represents an effort to remove spurious trends in archived operational analyses that are associated with the evolving modeling and data assimilation system (Cullather et al., 2000). The primary goal of reanalysis is to provide global quality controlled data sets of analyzed and forecast fields for the research community. One recent and widely used reanalysis data set is the European Centre for Medium-Range Weather Forecasts (ECMWF) 40-year Reanalysis (ERA-40) (Simmons and Gibson, 2000; Uppala et al., 2005). The data set covers the period from September 1957 to August 2002, overlapping the earlier ECMWF 15-year reanalysis (ERA-15) (Gibson et al., 1999). Many variables from reanalyses are of high quality over regions with sufficiently abundant data (Uppala et al., 2005).

The outline of this paper based primarily on ERA-40 (see Section 2) is as follows. Geographic maps of the study regions are shown in Fig. 1. Section 3 reviews the general features of the atmospheric circulation at high latitudes. Original analysis is presented in Sections 4 and 5. The spatial and temporal variability (leading modes) during the December–January–February (DJF)