Interdecadal changes of tropospheric circulation in Southern extratropics during the recent warming in the Antarctic Peninsula

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Summary An analysis of changes of atmospheric circulation in the Southern Hemisphere in relation to recent warming at the Antarctic Peninsula in last thirty years is presented. The sea level pressure and geopotential fields change in 1960-2000 are considered. It was shown that large-scale baric formations of the Southern Hemisphere had displaced to the west about 15-20^{o} during this period. It resulted in the warm winters in last years at the Antarctic Peninsula region. The approach to the classification of meteorological fields based on the method of analogs of synoptic processes (etalon-field method) is briefly described and applied to extra tropical sector of Southern Hemisphere that includes Antarctic. The most informative 'etalon' weather patterns were set off for each decade 1960-2000. Predominant weather pattern in 1990s shows more intensive cyclonicity, with series of cyclones west of the Antarctic Peninsula, and depression at the Bellingshausen Sea in the place of the ridge in 1960s.

Citation: Martazinova V., Tymofeyev V. (2007), Recent warming at the Antarctic Peninsula as viewed against changes in atmospheric circulation,in Antarctica: A Keystone in a Changing World – Online Proceedings of the 10th ISAES X, edited by A. K. Cooper and C. R. Raymond et al., USGS Open-File Report 2007-1047, Extended Abstract 067, 4 p.

Introduction

One of the greatest rates of growth in near-surface air temperatures (SAT) in the Southern Hemisphere is registered in the region of Antarctic Peninsula (AP) and surrounding Subantarctic Islands. Collapse of the Larsen B ice shelf in 2002 is the best example; other climatically induced changes were found in land glaciation, sea-ice, ecosystems etc. Regional warming contrasts to weak cooling in continental Antarctic (Turner et al., 2007), however, closely corresponds in time to global changes, as well as to the SAT growth in the Northern Hemisphere extratropics and polar regions. The reasons of recent climate change in AP region are still not completely studied and the aim of this paper is the analysis of the climate variability of the Antarctic Peninsula as viewed against decadal large-scale atmospheric circulation change.

Data and method

Mean sea level pressure (MSLP) and geopotential fields archive of World Data Center for Meteorology, Obninsk and atmospheric reanalysis data from ERA-40 as well as climatology of Antarctic Peninsula stations with longest uninterrupted records are used. The ERA-40 were used only for interpolation observation data in areas with rare number of stations because of known problems of reanalysis in Southern Hemisphere (Marshall, 2003).

A powerful tool for synoptic climatology is classification of synoptic processes on a small number of categories.. Several methods of classification using EOFs, cluster analysis, CCA and PCA were developed in the climate studies. Recently, the self-organised maps (SOM) were applied for the classification purposes in the Antarctic (Uotila et al., 2006). In this study we use method of etalon-fields (Martazinova, 2005) that is based on the method of analogs of synoptic processes. Let us briefly consider algorithm of this method in application to the SLP fields. Archive of SLP fields was presented as a matrix **P** with elements p_{ij}, which correspond to the values of pressure in the point *j* of a regular grid of field *i* of archive:

$$\mathbf{P}=\begin{vmatrix} p_{11} & p_{12} & \cdots & p_{1j} & \cdots & p_{1n\text{-}1} & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2j} & \cdots & p_{1n\text{-}1} & p_{1n} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ p_{N1} & p_{N2} & \cdots & p_{Nj} & \cdots & p_{Nn\text{-}1} & p_{Nn} \end{vmatrix}, \quad \text{if} \quad \overline{p_i} = \frac{1}{n}\sum_{j=1}^{n} p_{ij}, \text{ then} \quad \mathbf{P}=\begin{vmatrix} p_{11} & p_{12} & \cdots & p_{1j} & \cdots & p_{1n\text{-}1} & p_{1n} & \overline{p_1} \\ p_{21} & p_{22} & \cdots & p_{2j} & \cdots & p_{1n\text{-}1} & p_{1n} & \overline{p_2} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots\ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots\ldots \\ p_{N1} & p_{N2} & \cdots & p_{Nj} & \cdots & p_{Nn\text{-}1} & p_{Nn} & \overline{p_N} \end{vmatrix},$$

where $i = 1,...,N,\ j = 1,...,n$. If each value of field *i* is subtracted from $\overline{p_i}$, then matrix **P** is transformed as

$$\mathbf{\Delta P}=\begin{vmatrix} \Delta p_{11} & \Delta p_{12} & \cdots & \Delta p_{1j} & \cdots & \Delta p_{1n\text{-}1} & \Delta p_{1n} \\ \Delta p_{21} & \Delta p_{22} & \cdots & \Delta p_{2j} & \cdots & \Delta p_{1n\text{-}1} & \Delta p_{1n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \Delta p_{N1} & \Delta p_{N2} & \cdots & \Delta p_{Nj} & \cdots & \Delta p_{Nn\text{-}1} & \Delta p_{Nn} \end{vmatrix}, \quad \text{where} \quad \Delta p_{ij} = (p_{ij} - \overline{p_i}).$$

Two criteria were used to find field-analogs of fields corresponding to matrix **P**. First one that allows identifying geometrical similarity of fields is the criterion of similarity based on the sign of anomaly of two fields:

$$\rho = \frac{n_+ - n_-}{n}, \qquad -1 \ge \rho \ge 1 \ ,$$

where n is the total number of points of a regular grid, n_+ is the number of points in which the sign of Δp_{ij} coincides, n_- is the number of points in which the sign of Δp_{ij} is opposite. Note, that unlike standard criterion ρ , in which values of SLP in the points of a regular grid were subtracted from the climatic values of pressure in points of the grid, we subtract pressure from average value of each field. Such approach allows preserving individuality of every field of SLP.

The rectangular symmetric matrix **R** represents values of criterion similarity ρ of synoptic patterns as

$$\mathbf{R}=\begin{vmatrix} 1 & \rho_{12} & \cdots & \rho_{1j} & \cdots & \rho_{1N} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \rho_{i1} & \rho_{i2} & \cdots & \rho_{ij} & \cdots & \rho_{iN} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \rho_{N1} & \rho_{N2} & \cdots & \rho_{Nj} & \cdots & 1 \end{vmatrix},$$

where diagonal elements ρ_{ii} = 1 show the relationship between fields i and itself whereas others ρ_{ij} show relationship between fields i and j. We assume that synoptic pattern "1" is analogous to "j"pattern when $\rho_{1j} \ge 0.3$ that corresponds to the geometrical similarity of the pressure troughs and depressions in fields "1" and "j at the >65% of given area. These patterns are class of synoptic patterns of first field of matrix **P**. Another class of synoptic patterns of the first field of matrix **P** is distinguished when $\rho_{1j} < -0.3$ that corresponds to the geometrical similarity of the pressure troughs and depression in fields "1" and "j at the 65% of given area. Residuary intermediary values $-0.3 < \rho_{1j} < 0.3$ correspond to other classes. Procedure of calculation of analogous synoptic patterns should be repeated for residuary synoptically patterns as long as all situation will be distributed between classes. To refine the selected class of synoptic patterns we applied second criterion: criterion of mean square distance between two fields η as

$$\eta^2 = \frac{1}{n}\sum_{j=1}^{n}(x_{ij} - x_{kj})^2 ,$$

where $\eta > 0$, x_{ij} and x_{kj} are values of pressure in j point of a regular grid of two fields i and k. The synoptic patterns are analogs in the given class when $\rho \ge 0.3$ and $\eta \le 1$. The class with the largest sample is the most probable class of fields of SLP. The class with the least sample is the least probable class of fields SLP that represents rare synoptic patterns. The variety of fields belongs to the class, so, we should distinguish one most informative field. To determine most informative field in every class we again use criteria ρ and η. Add the column of the average values $\overline{\rho_i}$ in the matrix **R**:

$$\mathbf{R}^{(1)} = \begin{vmatrix} 1 & \rho_{12} & \cdots & \rho_{1j} & \cdots & \rho_{1N} & \overline{\rho}_1 \\ \cdots & \cdots & \cdots & \cdots & \cdots & & \cdots \\ \rho_{i1} & \rho_{i2} & \cdots & \rho_{ij} & \cdots & \rho_{iN} & \overline{\rho}_i \\ \cdots & \cdots & \cdots & \cdots & \cdots & & \cdots \\ \rho_{N1} & \rho_{N2} & \cdots & \rho_{Nj} & \cdots & 1 & \overline{\rho}_N \end{vmatrix}, \text{ where } \quad \overline{\rho}_i = \frac{1}{N}\sum_{j=1}^{N}\rho_{ij} .$$

The largest value of $\overline{\rho}_i$ of i-th field in the every class with $\overline{\eta}_i$ is "etalon-field" for given class of synoptic patterns. The revealed etalon-field have best similarity (according criterion $\rho > 0.3$) among the fields at 500 hPa. The most probable etalon (>65%) represents predominant circulation.

The transformation of SLP fields in the Southern Hemisphere in 1960-2000

Whereas in Northern hemisphere the three-vortex system of planetary atmospheric circulation exists, an atmospheric circulation in the Southern hemisphere is a four-vortex system (fig. 1). Every pair of center of action (CA) of the four-vortices systems (maximum and minimum of the pressure) takes area of about 100^{o} of the longitude. The placed at about 200^{o} of the longitude climatic CA - depression dominates the rest.

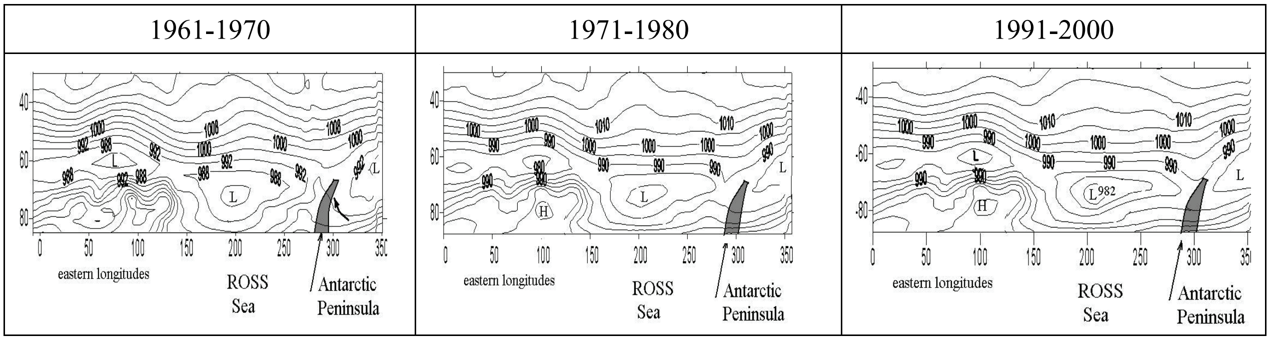

Figure 1. Mean sea level pressure fields in January averaged over decades.

In 1960-2000 the state of CA in the Southern Hemisphere was essentially changed (fig.1). The sea level pressure fields of the last two decades (fig.1) show the change of atmospheric circulation in troposphere in the Southern Hemisphere during the period of global warming 1970-2000. The displacement of the large-scale baric patterns in the Southern Hemisphere to the west on about 15-20^{o} was occurred at past decades (Tymofeev and Martazinova, 2006). The cyclone over the Ross Sea expanded and shifted in the end 20th century to the Antarctic Peninsula. It was resulted in the warm winters in last years in the AP area (fig.2). We expect that CA-depression will be displaced to the AP and they will change significantly the climatic conditions at the station Vernadsky in the next decade.

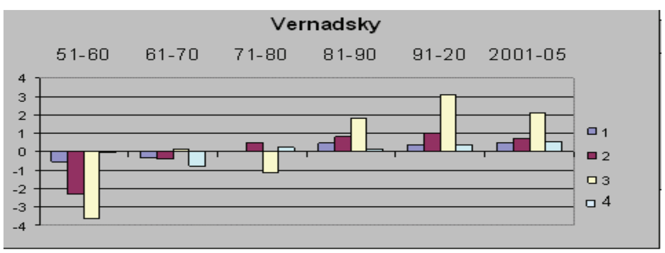

Figure 2. Decadal change of the temperature on the station Vernadsky, Ukraine (65°14'S, 64°15'W), formerly known as Faraday, UK. 1- January, 2 –April, 3 – July, 4 – October.

The change of local climate and etalon of the synoptic pattern at the Antarctic Peninsula in the recent warming

Seasonal warming is much more inhomogeneous on east coast AP stations, where air temperatures are colder and topography is more complicated. The most significant warming is observed at Vernadsky station and Bellinsghausen Sea (King-George Island), with rates exceeding 2°C over the last 30 years. Winter months’ warming is mainly contributed to annual growth of SAT and is accompanied by decrease of annual, seasonal and daily ranges of surface air temperatures and significant increase in minimum ones. Summer warming being much smaller by magnitude (0.65˚C/30 years) is potentially of greater significance for ablation, with increasing melting rates when daily averages exceed zero point and probability of rains is increased. Total period of days with average temperatures exceeding freezing is expanded for about a month between 1960s and 1990s. The temperature records in last years showed weakening of the air temperature growth on the most AP stations although they still significantly bigger than in South Hemisphere.

Slight cooling is registered in some seasons on Esperanza and Orcadas in 2001-2005; this is accompanied with dominant winter snow accumulation in recent years on snow field polygon near Vernadsky station. Winds are intensified in mid- and lower troposphere during the recent warming episode, with predominant west-north-waterlines. The predominant weather patterns were calculated by etalon field method for last three decades. The greatest difference was found for predominant patterns calculated for winter seasons of 1960s and 1990s (fig. 3). Well-developed subtropical high in the East Pacific with wedge extended towards the Bellinsghausen Sea is a most

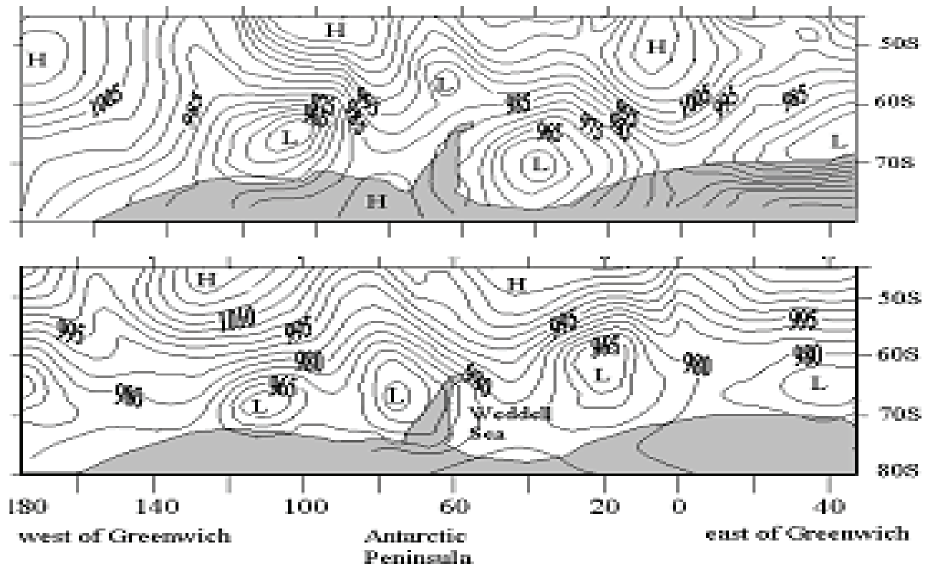

Figure 3. Etalon MSLP fields for July-August, 1960s and 1990s, extratropical sector of Southern Hemisphere. Contour of Antarctic continent is shaded.

important feature of the dominant weather pattern for 1960s; it has created significant meridionality and south air inflows towards AP region. On the other hand, east coast of AP is under influence of rear (cold) part of depression over the Weddell Sea. Predominant weather pattern in 1990s shows more intensive cyclonicity, with series of cyclones west of AP, and depression at Bellinsghausen Sea in the place of the wedge in 1960s. It has displaced eastward between decades and is positioned over the central Weddell Sea. Such weather pattern prevents intrusions of cold air to AP region from the interior of Antarctic continent and could be considered as a circulation background for the recent climate warming in the Antarctic Peninsula region. Stronger pressure gradients over Graham Land with dominant north-west winds are also responsible for frequent regional weather modifications with the formation of regional wind circulations, e.g. foehnes and other like-katabatic winds of regional scale. Such winds were obviously favorable to the collapse of marginal parts of Larsen ices shelf in 2002.

Summary

The atmospheric circulation changes from decade to decade during the warming period at the Antarctic Peninsula (AP) region were studied. Dominant weather pattern in the 1990s was found to be more stable between individual seasons and years (probability of 76% against 55% in the 1960s). Maximum probability of 88% was registered in one of the warmest winters of 1998, when the weather pattern was presented by series of deep and strong cyclones. Even though the ridge near AP in average MSLP fields is seen only as weak ridge between two climatic depressions over seas of Bellingshausen and Weddell, the procedure of distinguishing the dominant weather patterns allowed us to highlight positions of this ridge.

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