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SOME PECULIARITIES OF THE NEAR-SURFACE AIR TEMPERATURE CHANGE IN THE ANTARCTIC PENINSULA REGION

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Current climate in the Antarctic Peninsula (AP) region can be interpreted as a continued warming, still exceeding climatic norms but without significant rise on the Antarctic Peninsula stations. Assessments of trends in the near-air temperatures are made by applying homogeneity procedure and series of monthly SAT normalizing by amplitudes. The most intensive increase in surface air temperature at the end of XX - beginning XXI century recorded at Vernadsky and Rothera stations at the west coast of the Antarctic Peninsula. Most of inhomogeneities are observed in coldest decade, 1950s; current period is characterized by smoothening in the near-surface temperatures (SAT) ranges especially in comparison to 1950s because of changes in atmospheric circulation. Normalized SAT series is comparable between winter and summer seasons at west coast of AP, including Vernadsky and Rothera stations. Spatial and temporal characteristics of near surface temperatures are described, with significant seasonal and topography-dependant variability. Significant differences exist between stations at the west coast and those lying at Weddell Sea coast, especially in summer. By the Vernadsky data, summer warming is mainly responsible for the recession of glaciation. Modern regional warming is associated with growing influence of El Niño-Southern Oscillation, especially after well-known climatic shift in the 1970s due to increased surface temperature of the equatorial Pacific. On the background the overall warming trend some intradecadal SAT fluctuations are registered being associated with El Niño. On the basis of the recent SAT variability at other stations and multi-years' change in climate indexes it is concluded that no further warming can be expected in the near future.
Keywords: Antarctic Peninsula, climate change, warming, air temperature, inhomogeneity, correlation

Деякі особливості багаторічної зміни температури повітря на Антарктичному півострові
Тимофєєв В.Є.
Реферат. Поточний стан клімату в цьому районі можна інтерпретувати як триваюче потепління, при якому температура повітря ще перевищує кліматичні норми, але суттєво не підвищується на станціях Антарктичного півострова. Режим температури повітря характеризується згладжуванням коливань температури повітря, особливо порівняно з 1950-ми рр., через зміни в атмосферній циркуляції. Аналіз багаторічної тенденції змін у температурі повітря проведено з оцінкою статистичної однорідності рядів місячної температури повітря, а також нормованих характеристик. Найбільш інтенсивне підвищення температури приземного повітря в кінці XX – на початку XXI століття відзначено на станціях Академік Вернадський і Розера на західному узбережжі Антарктичного півострова. Оцінки багаторічних змін нормованих рядів температури повітря співставні між зимовим і літнім сезонами на західному узбережжі Антарктичного півострова, в тому числі станцій Академік Вернадський і Розера. Описано просторово-часові характеристики багаторічної тенденції температури повітря, зі значною сезонною мінливістю і залежністю від топографії. Існують значні відмінності між станціями західного узбережжя і тими, що розташовані на узбережжі моря Уедделла, особливо в літній сезон. За даними станції Вернадський, літнє потепління в основному відповідає за прискорення танення місцевого зледеніння. Сучасне регіональне потепління пов'язане зі зростаючим впливом Ель-Ніньйо-Південне коливання, особливо після кліматичного зрушення 1970 р. у зв'язку з підвищенням температури поверхні екваторіальній частині Тихого океану. На тлі загальної тенденції потепління деякі внутрідесятилітні коливання температури повітря пов'язані з явищем Ель-Ніньйо. На основі недавньої мінливості температури повітря на станціях регіону та багаторічних змін кліматичних індексів можна зробити висновок, що в найближчому майбутньому подальшого потепління в регіоні не очікується.

Некоторые особенности многолетнего изменения температуры воздуха на Антарктическом полуострове.
В.Е. Тимофеев
Реферат. Нынешнее состояние климата в этом районе можно интерпретировать как продолжающееся потепление, при котором температура воздуха еще превышает климатические нормы, но существенно не повышается на станциях Антарктического полуострова. Режим температуры воздуха характеризуется сглаживанием колебаний температуры воздуха, особенно в сравнении с 1950-ми гг., из-за изменений в атмосферной циркуляции. Анализ многолетней тенденции изменений в температуре воздуха проведен с оценкой статистической однородности рядов месячной температуры воздуха, а также нормированных характеристик. Наиболее интенсивное повышение температуры приземного воздуха в конце XX – начале XXI века отмечено на станциях Академик Вернадский и Розера на западном побережье Антарктического полуострова. Оценки многолетних изменений нормированных рядов температуры воздуха сопоставимы между зимним и летним сезонами на западном побережье Антарктического полуострова, в том числе станций Академик Вернадский и Розера. Описаны пространственные и временные характеристики многолетней тенденции температуры воздуха, со значительным сезонным различием и зависимостью от топографии. Существуют значительные различия между станциями западного побережья и теми, что расположены на побережье море Уэдделла, особенно в летнее время. По данным станции Вернадский, летнее потепление в основном ответственно за ускорение таяния местного оледенения. Нынешнее региональное потепление связано с растущим влиянием Эль-Ниньо-Южное колебание, особенно после климатической подвижки 1970 г. в связи с повышением температуры поверхности экваториальной части Тихого океана. На фоне общей тенденции потепления некоторые внутридесятидетние колебания температуры воздуха связаны с явлением Эль-Ниньо. На основе недавней изменчивости температуры воздуха на станциях региона и многолетних изменений климатических индексов сделан вывод, что в ближайшем будущем дальнейшего потепления в регионе не ожидается.

1. Introduction

Antarctic Peninsula (AP) is a region of a specific interest within Antarctica, which lies between cold Antarctic continent and warmer oceans, and showed one of the greatest rates of warming to the end of 20th century. Near-surface air temperature (SAT) growth during the recent decades in the region of AP and surrounding Subantarctic Islands exceeded global warming rates and caused numerous impacts to glaciation, sea-ice and regional live environment etc. (Vaughan, 2003, Smith at el., 2007) Much of observed retreat of ice-shelves has been related to lower-tropospheric warming and southward progression of a critical thermal boundary for ice shelf stability (Vaughan et al., 2003, Ingolfsson et al., 2008), the role of the atmospheric circulation is discussed in (Kononova**,** 2007).

Also the recent warming in AP region is closely corresponds in time to warming in different remote regions, including Alaska, AP's northern geographical counterpart, most of Europe including most parts of Russia, up to Central Siberia and high Arctic, Ukraine and south west Europe (Hinzmann et al., 2003, Rogers et al., 1995).

Centennial course of near-surface air temperatures (SAT) at Orcadas station, South Orkneys Islands is generally agreed with time frames of global changes, showing two-phase warming during the XX century, as well as agreed with variability of well-known PDO index (Tymofeyev, 2002) Climate in the Antarctic Peninsula (AP) region from mid-20 century has been characterized by several climate transitions, including outstanding warming episode in 1980s and 1990s, with highest rates in Southern Hemisphere.

The largest annual warming trend is found on the western coast of the Antarctic Peninsula, at Faraday/Vernadsky station (fig.1); the greatest seasonal warming is registered in winter, when the role of the sea-ice is the most important (Turner et al., 2005). On the other hand regional warming in the AP region contrasts to weak cooling in continental Antarctica (Turner et al., 2004, and 2009). Recent studies have suggested that significant variability has detected in the climate system the AP during latest decade (Martazinova et al., 2010).

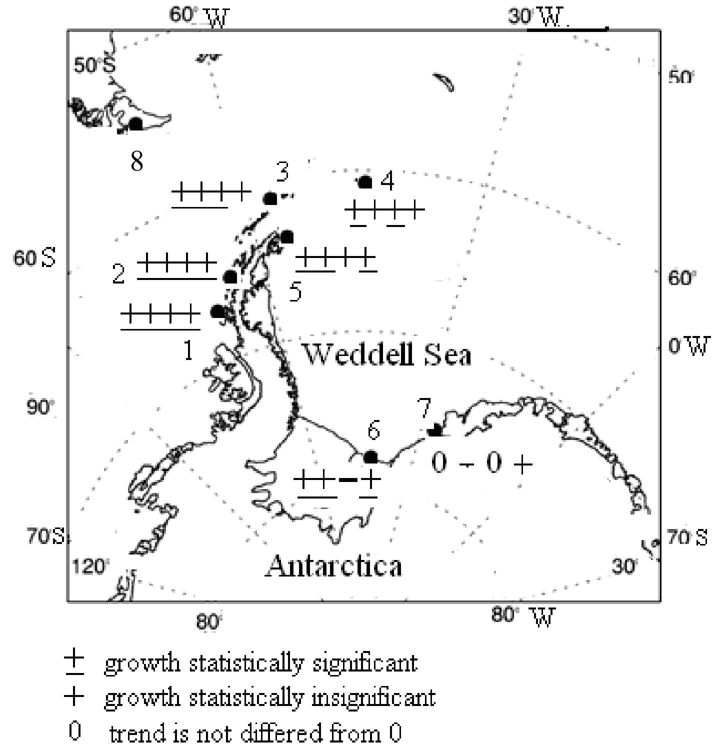

Fig. 1. Antarctic Peninsula and research stations with signs of multi-years' trends (1951–2010) in individual seasons (Summer, Autumn, Winter, Spring), 1 – Rothera, 2 – Vernadsky, 3 – Bellinsghausen, 4 – Orcadas, 5 – Esperanza; 6 – Belgrano, 7 – Halley, 8 – Punta-Arenas.

Atmospheric circulation is another important climate-making agent; indications of significant change during the recent episode of climate variability also have shown e.g., intensification of cyclonicity in the Southern ocean (Connoley, 1997), as well as shifts in blocking activity and storm-tracks in the Southern Hemisphere (Fyfe, 2003, Turner et al., 2002, Gruza et al., 2007).

Important conclusions were made on dependence of regional climates on El-Niño Southern Oscillation (ENSO) conditions (Turner, 2004), with alternative pressure anomalies in austral extratropics in years with different ENSO events. Much attention was paid to regional climate impacts of strengthening of the Southern Annular Mode (SAM) as hemispheric index of zonal air transport, or westerlies (van den Broeke et al., 2003, Marshall et al., 2011), however circulation mechanisms of recent climate change at AP region are still not completely studied. Our research showed intensification of cyclogenesis in the Bellingshausen Sea and eastward displacement of wedge of high pressure close to Antarctic Peninsula as a possible mechanism of winter warming (Martazinova et al., 2010). Other climatically important agent is the ozone hole that develops from September till early austral summer. It is recognized that strengthening of the westerlies within the circumpolar vortex was the dynamic background of the ozone hole, and on the other hand there are evidences of ENSO-SAM feedbacks, as well as ENSO - sea-ice dynamics and upper-tropospheric circulation (Turner et al., 2009).

This paper is devoted to detailing a multi-year changes in air temperature in the Antarctic Peninsula, re-assessing multi-years' trends in the region with significant interannual oscillations in SAT and specification of controlling factors. First, region of the Ukrainian Antarctic base Academic Vernadsky is in the focus of the research, as well as other stations in the Antarctic Peninsula.

2. The data used and a brief description of the local topography

We used the data of mean monthly SAT at the stations with the longest monthly timeseries based on synoptic hours' measurements, Figure 1: Orcadas from 1904 (geographic coordinates 60.7°S, 44.7°W), Academic Vernadsky. (Faraday, UK before 1996, 65.4°S, 64.4°E), Bellingshausen (62,2°S, 58.9°W), for the period 1951–2010, Esperanza (63.4°S, 57° W), 1952–2010, Marambio, for the period for the period 1971–2010, and Rothera (67.5°S, 68.1°W (1975–2009), Belgrano, Halley (1957–2010) from database READER created by British Antarctic Survey (http://www.antarctica. ac.uk / met / READER /)._A timeseries of monthly and annual mean air temperature station at Bellingshausen (1968–2009) was complemented by the data of Deception base, 1951–1967, and timeseries at Rothera were complemented by the data of Adelaide Island, with the corresponding amendments, as recommended in the READER project. Missing data at selected years at Orcadas and Marambio stations were restored by linear approximation using spatial correlations with neighboring stations; correlations table are given below. Problem of climatological homogeneity is also discussed below.

Southern oscillation Index is taken from NOAA source http://www.esrl.noaa.gov/psd/data/climateindices/

Geographical environment of the study area is characterized by significant roughness of the surface, presence of mountainous terrain, numerous islands and deeply rugged coastline, as well as different types of glaciation and sea-ice. This causes frequent weather modifications and formation of the local climates. Bellingshausen and Orcadas are located at larger islands in ocean away from the mountain ranges and ice-shelves, so weather modifications here are restricted on the smaller scale, although larger-scale factors and sea-ice migrations are important. Vernadsky station is located at small island 8 km off the west coast of the Antarctic Peninsula, with maximum mountain range elevation 2000 m, and with frequent foehn winds. Esperanza is located at the northern tip of the Antarctic Peninsula, near the well-known oasis Hope Bay (the prevailing height of no more than 400–600 m), and proximity to Larsen ice-shelf and western Weddell Sea with abundant sea-ice, much more concentrated that in west coast. Synoptic conditions are also differed: warmer air is advected to the west AP coast from the Pacific; Weddell Sea' sea-ice is a source of colder air in comparison to west AP coast, with prevailing meridionality; resulting in colder climate.

3. Methods. Homogeneity of timeseries

Traditionally, to test homogeneity of timeseries we use Student's t-test, provided that the timeseries correspond to a normal distribution. There are alternatives to t-test for unequal variances in timeseries, which is typical for the regional stations in AP region. Furthermore, the size of the sample in some cases differs significantly, so a simplified formula of two-sample t-test has been applied:

$$t = \frac{|M_1 - M_2|}{\sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}}},$$

where M_1, M_2 – averages, σ_1, σ_2 – standard deviation, N_1, N_2 – length of the two timeseries. Number of degrees of freedom is calculated as $f = N_1 + N_2 - 2$.

The resulting value is compared to its critical value depending on the level of significance (90 or 95% significance level) and degrees of freedom. If $t < t_{cr}$. The null hypothesis H_0 of belonging to the same general population is not rejected.

Many indications have been made about large interannual variability of SAT in the AP region, which can reduce the significance of the linear trend approximation (Turner, 2005). Also, when SAT variability is differed between seasons or months, comparison of warming rates can be difficult.

Further study in the SAT time series involves the construction of a new series of mean monthly values of SAT, normalized to its amplitude accordingly to the formula:

$$X'(t) = \frac{X_i - X_{min}}{X_{max} - X_{min}}$$

Where X'(t) – transformed time series, X_i – the member of a raw timeseries, X_{min}, X_{max} – the minimum and maximum SAT at a given month, , X_{min} - X_{max} – the SAT amplitude.

A new timeseries X'(t) ranges from 0 to 1, making easier comparison of the trends coefficients in different months (seasons) or between different stations.

Homogeneity of timeseries. As mentioned before data of near-surface air temperatures at Antarctic Peninsula stations show great interannual variability, making estimation of trend significance difficult. It is well-known Academic Vernadsky station showed one of the greatest rates of warming (van den Broeke, 2003, Turner 2004, Martazinova et al., 2010), Table 1. We paid more attention to check Vernadsky data as it is longest uninterrupted in the Antarctic Peninsula made at unchanged observation site and frequently used as a reference timeseries.

Student t-test has been applied to identify homogeneity. The largest number of inhomogeneitites is identified during austral autumn and winter months, and the most noticeable – in April and May, in the first decade of observations, 1951–1960. Most of the inhomogeneites have been observed in consecutive months – from March to June 1953, June 1958 and April, May and July 1959 which are coldest years in the region. "Inhomogenoues years" being concentrated in one part of the timeseries could change the slope of the trend line. After exclusion of inhomogeneous values trends remain positive for all months; however its significance decreases from 5 to 10% in April and May.

After applying Homogeneity test for April timeseries a trend coefficient decreased from 0.34 to 0.60, and standard error of the coefficient has been lowered, improving the accuracy of the approximation from 0,18 °C to 0,14 °C, Table 1. Thus, exclusion of inhomogeneites does not change a positive trends in SAT implying that low-tropospheric warming is statistically significant in this region. Additionally, we are interested not only in a formal statistical procedure for testing the homogeneity of the timeseries, as to find a cause of the inhomogeneities. Zonal MSLP atmospheric pressure gradient has been calculated between 60 and 70 °S, in the sector of 270–300°E, i.e. immediately adjacent to the west coast of the Antarctic Peninsula. In Fig. 2 the gradient is presented along with the mean monthly SAT and calculated Student's t-test. In the years of inhomogeneity breaks (1953, 1959) Student's t-statistics exceeds the threshold corresponding to the adoption of the null hypothesis, and in addition, the zonal gradient is negative, implying easterly wind component. Hence eastern (south- east) transport was dominated in years with inhomogeneity, being attributed to strong cold spells from the Antarctic continent or the Weddell Sea sector.

Thus, in a first approximation, we show that it is unique atmospheric circulation that has been responsible for the frequent inhomogeneity in this region in the 1950s representing statistical sort of inhomogeneity. Note that in the latest decades with climate warming no inhomogeneous were identified; only one of the last years showed some colder anomaly, like in 2009, accompanied by negative MSLP gradient, but not significant as in the first decades of observations.

So in addition to traditional homogeneity tests, we've made analysis into the atmospheric circulation that is important for the region with significant distance between stations. Main homogeneity has been observed during the colder climate in the mid-20th century, current warming period is characterized by greater homogeneity especially during the winter season.

Additionally inhomogeneous outliers were checked against neighboring stations. The closest for Vernadsky Bellinshgausen and Deception stations are located (northward), and Rothera, (southward, so simplest method to check data is scatter diagram. For April, and May 1952, 1953, 1958 и 1959 all outliers at Vernadsky are coincided with those at Deception being caused by strong cold spells. So we conclude that these inhomogeneities have been caused by specific meteorological and synoptic regime which is unusual for current climate, as such extreme weather

Table 1

Coefficients of the linear trends (°C/ decade) of the mean monthly air temperature, $\bar{T}$, minimum T_{min} and maximum T_{Max}, and monthly mean standard deviation $\bar{\sigma}$, along with coefficients of the linear trends, b, Vernadsky Station, 1951–2010

Air temperature index	Months					
	1	2	3	4	5	6
$\bar{T}$	0.27**	0.28*	0.30* (0,13*)	0,60* (0,34**)	0.63* (0,37*)	0.93* (0,76*)
T_{max}	0,24**	0,11	-0,04	0,25	0,64*	0,16
T_{Min}	0,65*	0,83*	0,90*	1,30*	2,10*	2,84*
($\bar{\sigma}$, b)	1,15 -0,03	1,84 -0, 04	2,45 -0,06	2,80 -0,08**	3,12 -0,10*	3,85 -0,10*
Air temperature index	Months					
	7	8	9	10	11	12
$\bar{T}$	1.03* (0,81*)	0.98* (0.82*)	0.44*	0.34** (0.31**)	0.12	0.13 (0.16)
T_{max}	-0,11	-0,27**	-0,12	-0,64*	-0,10	0,05
T_{Min}	2,80*	2,30*	1,76*	1,46*	1,20*	0,62*
($\bar{\sigma}$, b)	4,37 -0,12*	3,67 -0,14*	3,18 -0,08**	1,95 -0,08**	1,08 -0,10*	0,62 -0,06

Note. For $\bar{T}$ in brackets trends coefficients of homogeneous series are given for individual months where inhomogeneity has been revealed and excluded Level of statistical significance is represented Along with the trends coefficients, by asterisks: * – coefficient is significant at 95 % significance level, ** – 90 % significance level.

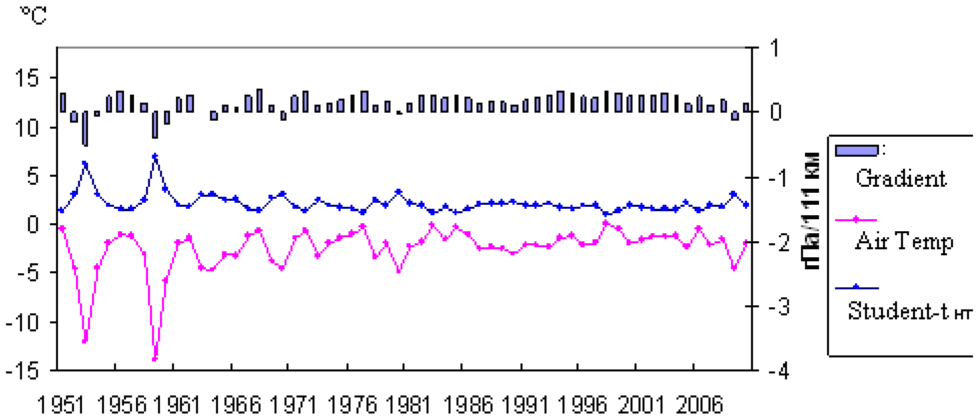

Fig. 2. The original timeseries of monthly mean air temperature (°C), Vernadsky Station, Student's t-criterion, zonal circulation index (hPa/111 km), April.

has not been observed during the recent climate warming. And final step in explaining inhomogenity is atmospheric circulation analysis, applying specific etalons of the atmospheric circulation types obtained early (Martazinova et al., 2012). This study is a bit aside from this topic, however we indicate that the most significant variability in near-surface temperatures is observed during the autumn and winter seasons being a result of cold air intrusion within Antarctic ridge of high pressure. Smaller SAT variability during Warmer seasons is attributed to cyclones' series in much more smoothed zonal flow that is characteristic for the period of the recent warming.

4. Details of near-surface warming at Academician Vernadsky and other stations

At Vernadsky Station, the most common feature of warming is the growth in the minimum air temperature in all seasons, against less pronounced increase or even a negative trend (from June to November) in the maximum temperature (Table I). The most impressive increase in the minimum temperature is seen during the winter months, with coefficients of the linear trends greater than 1°C per decade May-July. In conditions of current warming, probability of severe and prolonged cold spells in winter is significantly decreased, compared to the mid-20 century.

Smallest warming rate is registered in November and December, 0.12 and 0.13°C/decade, January, central summer month has been warmed at a rate 0.27°C/decade. Trends coefficients in minimum air temperatures exceed those for maximum ones, however in contrast to winter, maximum temperatures also increased, in January and February, 0.24, and 0,11°C/decade.

As minimum temperatures have been growing faster than maximum, monthly amplitude of air temperature is declining. Multi-years' decrease in monthly SAT oscillation is also accompanied with decrease in the standard deviation, table 1. Standard deviations in winter months exceed those for summer months at least by factor of 3. This is mainly caused by increasing contrast between the oceanic and continental air masses in winter. Additionally, long-term course shows decrease in standard deviation in all months, with a maximum trend -0,14°C/decade in August.

The increase in the monthly SAT during the summer season, despite the lowest seasonal rate, is the most important factor for the assessment for the state of regional glaciation, because of extension of the ablation period (days with an average temperature above zero). Monthly mean SAT and the minimum SAT at the period of ablation has a statistically significant trend (coefficient of 0.72°C /decade at 95% level of significance), and the maximum temperature varies slightly (factor of 0,32 °C / decade). The course of the average temperature of the ablation period shows several transitions through the freezing level, being mostly negative until the end of the 1960s, and during a short period of 1976–1980, and positive in 1971–1975, as well as during the era of the recent warming episode since the early 1980s. Since the mid-1990s all three summer months on the average warmer than the freezing point.

Normalization of the timeseries as described above will allow for a comparison of long-term course of air temperature between the different months and seasons with significantly differing amplitudes of SAT. The trends coefficients of the normalized timeseries of mean monthly SAT are shown in Fig. 3 along with those for original timeseries.

Analysis of trends coefficients in the new normalized timeseries, in contrast to the original, show a seasonal variation of warming on Vernadsky and Rothera Stations, with peaks in the main seasons (January-February), and minima in the transition seasons (March, April, October). Thus, the magnitude of warming in summer and winter seasons in relation to the monthly amplitudes are comparable. At Bellingshausen station normalized warming is more seasonally-variable and shows minima in October-January, and has peaks at the end of a cold season (August-September), and in February-March. Station Orcadas, the most remote from the continents, and Esperanza, located close to glaciers at the northeast AP coast shows less intensive annual warming than at first two stations, and the greatest increase in the normalized temperature in the summer months. Minimum warming rates are observed in Autumn, in general agreement to (Turner, 2004), however trends shows intra-seasonal differentiation. Orcadas has almost no warming in September, least significant warming trend is observed in Esperanza in October and July, and in Bellingshausen in October. Much more variable seasonal variation of warming rates on north-east stations is related to local topography, as well as to greater degree of meridionality in the lower troposphere (van den Broeke, 2003). Accordingly to our previous conclusions the persistence of the low-pressure in the Bellingshausen Sea is mainly responsible for warming at west coast; Esperanza and Orcadas stations are under influence of tropospheric ridge or rear part of Weddell Sea low (Turner, 2005). The role of the larger-scale atmospheric circulation to the regional climate change, as well as El Niño, is emphasized in (Wenju et al., 2007, Turner et al., 2009).

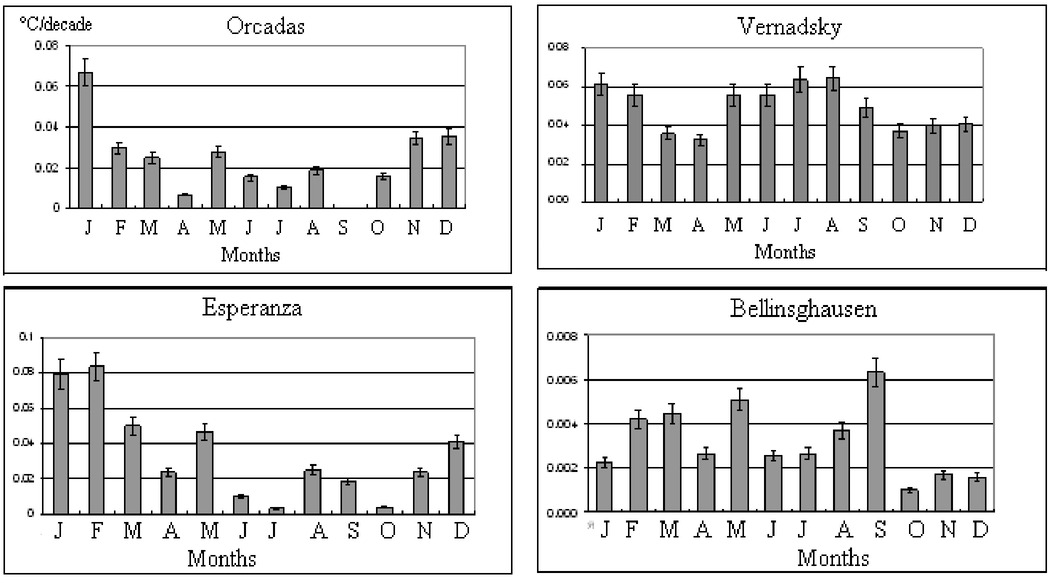

Fig. 3. Coefficients of linear trends (°C/decade) of mean monthly near-surface air temperature, normalized to the amplitude in the given month, Vernadsky and Orcadas, Esperanza, Bellinsghausen, 1951–2010 (5% confidence interval is shown).

Further consider how accumulated anomalies of the annual mean air temperature at the stations on the Antarctic Peninsula have been changing, by five-year periods. It is well-known that this period closely corresponding to the typical El Niño cycle [Turner, 2004]. Accumulated anomalies annual mean SAT also occurs discontinuously from 1951, (Fig. 4), with several periods of increase between 1956–1960 and 1961–1965, 1976–1980 and 1981–1985, and between 1991–1995 and 1996– 2000. Thus, five-year period 1996–2000 was the warmest in the region; after 2000, the warming trend has almost stopped at Vernadsky and has slightly changed the sign at the rest stations.

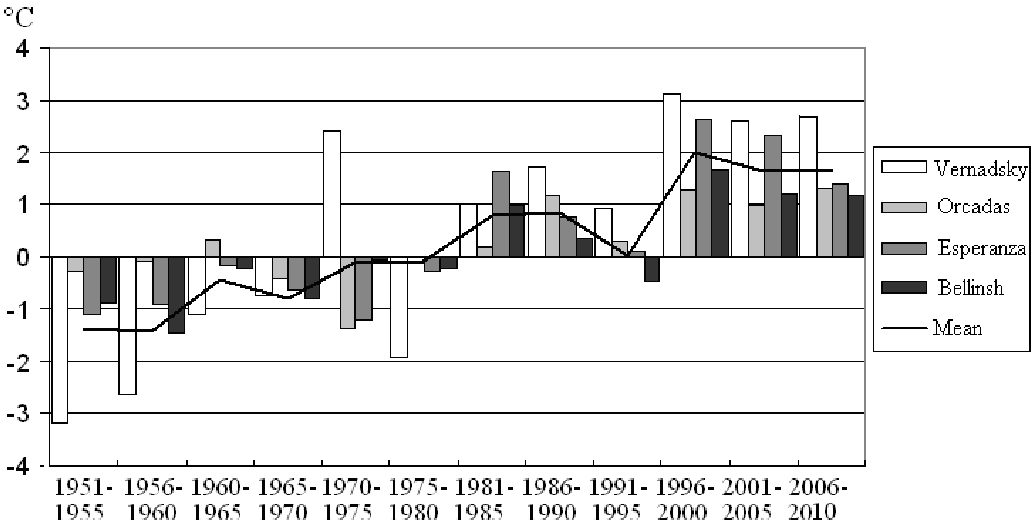

Fig. 4. Accumulated anomalies of annual mean SAT (°C) by 5-years periods, Vernadsky, Bellinshgausen, Esperanza, Orcadas, and total mean, 1951–2010.

Spatial correlations of SAT. Spatial correlation is expected to improve our understanding of peculiarities of the regional warming by seasons and also can help to find reference stations for climatological issues. The best correlation between stations is detected in winter season (table 2). As to Vernadsky station, the best correlation extends in the quasi-meridional direction, i.e. along AP west coast with a maximum correlation of 0.92 with Rothera (300 km south). Bellingshausen station, north off 500 km, also shows statistically significant correlation coefficient, 0.78. Summer months' correlation coefficients are much smaller, and rarely reach statistically significance. For Vernadsky, the largest coefficient for summer SAT is detected with Rothera SAT, 0,71. In both seasons, the largest decrease in spatial correlation from Vernadsky is noted in the north-east direction, i.e. across Peninsula, between Esperanza and Marambio, down to small negative correlation coefficients in summer.

Table 2

Correlation matrix of monthly mean SAT between stations at Antarctic Peninsula (right part: numerator – July, denominator – January; left part-numerator – October, dominator – April), 1971–2010

Station	Vernadsky	Bellinshgausen	Esperanza	Orcadas	Rothera	Marambio
Vernadsky	1,0 1,0	0,78 0,16	0,56 -0,08	0,60 0,17	0,92 0,71	0,45 0,03
Bellinshgausen	0,58 0,46	1,0 1,0	0,85 0,10	0,73 0,20	0,83 0,30	0,76 0,29
Esperanza	0,33 0,23	0,45 0,37	1,00 1,00	0,68 0,58	0,68 0,15	0,93 0,63
Orcadas	0,46 0,37	0,63 0,47	0,48 0,38	1,0 1,0	0,70 0,22	0,60 0,51
Rothera	0,82 0,76	0,53 0,34	0,38 0,17	0,34 0,27	1,00 1,00	0,58 0,11
Marambio	0,26 0,23	0,36 0,25	0,83 0,61	0,36 0,34	0,37 0,25	1,00 1,00

Note. For Marambio station period of calculation 1971– 2002 so significance level for Correlation coefficients is differed than for other stations.

On the other hand, a significant correlation exists between summer SAT at Vernasdky and Bellingshausen, Bellingshausen and Marambio, however between Vernadsky and Marambio it is weaker! One can say that Bellingshausen is located in the "boundary correlation" area, so given reference station not at all times can be used to check inhomogeneity in the region.

Further analysis has been made to check whether correlations remain stable for shorter periods of time, on decadal timescale, implying major climate transition in mid-1970s. A sliding correlation of monthly mean SAT between 2 pairs of stations has been calculated for the time window 11 years, with a shift of 1 year. Correlation coefficient is greatest between SAT at Rothera and Vernadsky being statistically significant even for shorter periods of time, on decadal timescale, Fig. 5. Correlation between SAT at Vernadsky and Bellinshgausen is more variable, being maximum 0.9 in 1951–1970, and then decreasing to 0.6 by the end of the 1980s. Then it increases again in 1991–2000, and in the recent decade, the correlation goes down again and such oscillations must be taken into account when processing the data.

Like winter, the best correlation of SAT between Vernadsky and Rozera is in summer, however it is more variable, and periods with minimum coefficients between these stations coincides with the periods with maximum correlation between Vernadsky and Bellinsgauzen. During the period of the recent warming correlation coefficient of Vernadsky monthly SAT with that at Rothera is statistically significant, and with Bellingshausen is slightly negative (-0.1, -0.2) and statistically insignificant. It is obvious the influence of external factors (atmospheric circulation) is mainly contributing to these changes.

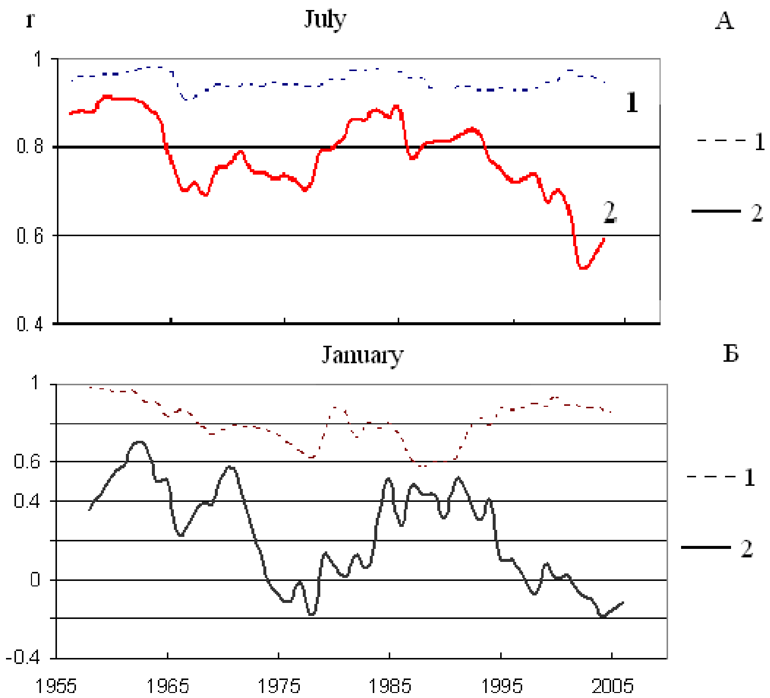

Fig. 5. Correlation coefficients of monthly mean SAT between Vernadsky and Rothera, Vernadsky and Bellinshgausen stations calculated for the time window 11 years, with a shift of 1 year, for the period 1951–2010, July.

Such correlation oscillations must be taken into account when processing the data for climatological purposes, including checking inhomogeneity. E. g., Bellinshgausen data cannot be reference point for Vernadsky in all seasons in current climatic period, Rothera is preferable. Another conclusion is that spatial correlations are higher in colder climate in AP region; during current warming only correlation southward Vernadsky remains statistically significant.

Interpretation of Orcadas centennial data. Most research into the effects of ENSO has been concerned with tropical and mid-latitude areas, where there are long in situ meteorological records and high-quality atmospheric analyses extending back into the early part of the 20th century or earlier. Statistically significant relationships between ENSO and climatic parameters are much more difficult to detect in the Antarctic because of the relatively short length of the in situ meteorological records, about 60 years at best. The only station with 100y timeseries in the region of interest is Orcadas. Such a long record increase the possibility of finding statistically significant relationships between ENSO and other climatic parameters in remote location, to detect teleconnections (Mo and White, 1985). Additionally, centennial timeseries allow us making analysis on the part of timeseries, to detect periods of stationarity. Correlation coefficient for the whole centennial timeseries is not statistically significant, 0.18, but correlations calculated with a running window of 31 years show growing correlations to the Southern oscillation index, greater than 0.36, being statistically significant during 1990s – decade of peaking warming in the region, Fig. 6.

So influence of El-Niño has been growing to the end of the 20th century. Negative correlations with SOI in the beginning of the 20rs century shows that first phase of warming have obviously not been caused by ENSO.

Climate change on centennial time scale is clearly seen in the space of the first and second components (PCA) of annual mean SAT by the Orcadas more than 100y-long data, Fig. 7. The most significant shift in climate regime occurred between 1960s and 1970s, when the PCA moved

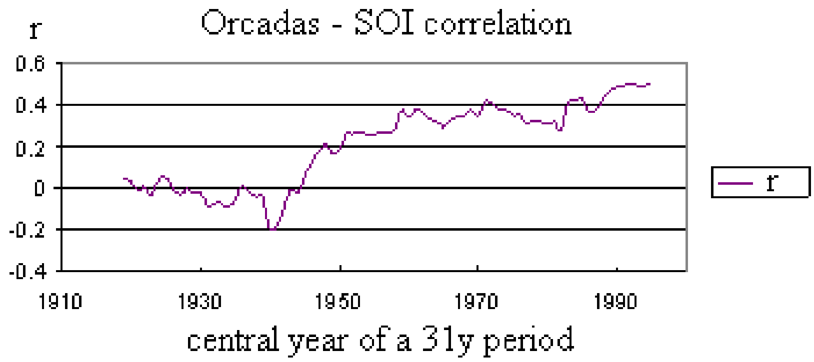

Fig. 6. Sliding correlation coefficient of Orcadas annual mean SAT and Southern oscillation Index, obtained for the running time window of 31 years, with a one year-shift, beginning from the decade 1919–1948, up to 1981–2010.

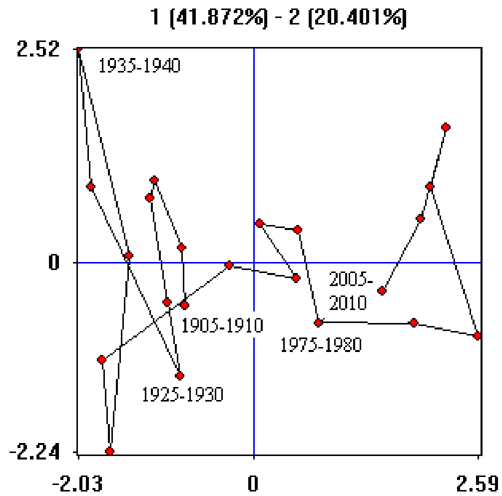

Fig. 7. Changing climate regime in the space of the first and second principal components of the annual mean SAT at Orcadas (°C), decimated after 5 years.

from the negative into the positive quadrant. Period of current warming is different from that in the early twentieth century, with first component above zero. There is a tendency to returning to the conditions of the 1980s in the latest 5years, i.e. to the initial period of modern warming. With some caution it can be concluded that one can expect a period of continued warming in the region for a closest decade.

5. Discussion

In comparison to previous studies, trends in near-surface air temperatures re-assessed by new data from regional stations till 2010, as well as spatial correlations are specified by seasons and time periods. The largest annual warming trends are found on the western coast of the Antarctic Peninsula, with the greatest seasonal warming in winter, confirming previous works (van den Broeke, 2003, Turner et al., 2004)

Current period of continued warming is characterized by smaller variability in SAT especially during the winter season. Smoothing in the SAT ranges implies greater homogeneity in climatological sense and greater confidence to the data (provided measuring technique remains the same).

Most manifestations of statistical inhomogeneity in the air temperature in the Antarctic Peninsula are associated with coldest years in the mid-20th century due to the unique conditions in the atmospheric circulation. Exception of inhomogeneous values does not change the positive trend in air temperature, confirming statistically significant warming in the study area.

Warming rate at other stations extended to the ocean is smaller, with weaker variability. Significantly variable seasonal trends are registered for other stations located in the North-east Antarctic Peninsula in complex topography. Some seasons showed slight cooling or change in the trend sign In general this is in agreement with (Turner et al., 2005), but trend coefficients became smaller at Orcadas and Esperanza, on extended timeseries up to 2010.

By the Vernadsky data, summer warming is mainly responsible for the recession of glaciation, ice-shelves and island small glaciers, because of expansion of ablation period (Ingolfsson, 2002). Further changing net balance from accumulation to ablation is expected in the near future in keeping the current anomalies above the climatic norm.

Spatial correlation of seasonal SAT between regional stations showed seasonal-dependent difference, reasoning by topography and tropospheric circulation, and found to be variable in time, showing difference between colder and warmer decades. Significant differences exist between stations at the west coast and those lying at Weddell Sea coast, especially in summer. This research helped us to justify search reference stations for climatological applications.

El-Niño-Southern Oscillation shows greater influence to the regional climate from climate shift in mid-1970s. It is well-known from the literature that the pressure decrease in the Antarctica intensifies westerly flow as a consequence of predominance of the warm El Niño episodes from mid-1970s to early 21st century, as well as Southern Annular Mode intensification, due to ozone hole deepening (Wenju et al., 2007,Stammerjohn et al., 2008, Turner et al., 2009, Marshall et al., 2011).

Analysis of a regional climate change and SAM conditions in Antarctica showed that Antarctic Peninsula (and Weddell Sea sector) is one of the most sensitive regions, and regional warming is attributed to the increase in positive SAM (van den Broeke et al., 2003, Marshall, 2011). Turner (2004) showed composite anomalies in MSLP fields for individual ENSO events; he also found correlation coefficient 0.30 between annual SOI and Vernadsky SAT. We presented here more significant monthly correlations and correlations calculated by part of timeseries, showing increase of correlations using time lags.

In the last decade 2001–2010 and some recent years most stations in the region showed a tendency to deceleration in mean annual air temperatures; some individual months became somewhat colder than in the previous decade. This is related to transition of ENSO to colder phase, no further growth in SAM, stabilization of the ozone hole, some new features in the atmospheric circulation, namely greater time residence in anticyclones in the south-east Pacific.

6. Results

Current climate can be interpreted as a continued warming, still exceeding climatic norms of near-surface air temperature, but remaining more or less stable at stations in the Antarctic Peninsula region during the last decade.

The most intensive increase in surface air temperature at the end of XX - beginning XX1 century recorded at the west coast of the Antarctic Peninsula, according to Vernadsky and Rothera stations data. Warming period is characterized by smoothening in the near-surface air temperatures ranges especially in comparison to 1950s because of changes in atmospheric circulation. In the last decade or so most stations in the region showed a tendency to deceleration in mean annual air temperatures; some individual months became somewhat colder than in the previous decade. The regional warming is caused by sustained change in one or more climate-making factors; one of them is atmospheric circulation.

Multi-years' growth of near surface temperatures occurred differently by seasons on stations with various topography at north-east Graham Land. Warming has seasonal features, with mainly summer warming at Orcadas and Esperanza and year-round warming at Vernadsky, Bellinshgausen and Rothea (transition seasons are warmed less). Monthly and seasonal amplitude of SAT was found different between main seasons, so trends of normalized series of SAT is comparable between winter and summer seasons at west coast of AP, including Vernadsky and Rothera stations.

Spatial correlation in seasonal SAT between regional stations showed seasonal-dependent difference. Significant differences exist between stations at the west coast and those lying at Weddell Sea coast, especially in summer. By the Vernadsky data, summer warming is mainly responsible for the recession of glaciation, as length of period with SAT above freezing became longer. A significant difference of winter warming rates between the west and east coast of the Antarctic Peninsula arise from different topography and the difference in the atmospheric circulation.

Analysis of climate change on centennial time scale has been carried out by the data of Orcadas station by means of first principal components of SAT, and juxtaposing with the recent SAT variability at other stations and multi-years' change in climate indexes we conclude that no further warming can be expected in the near future.

Modern regional warming is associated with growing influence of El Niño-Southern Oscillation, especially after well-known climatic shift in the 1970s due to increased sea surface temperature of the equatorial Pacific. On the background the overall warming trend some intradecadal SAT fluctuations are registered being associated with El Niño.

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