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ATMOSPHERIC MOISTURE FLUXES OF THE NORTHERN HEMISPHERE

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1. Introduction

The atmospheric water balance couples up the moisture surface evaporation from the oceans and continents, moisture horizontal transport, moisture condensation and precipitation. The atmospheric moisture turnover influences Earth – atmosphere heat balance. The condensation heat modifies the incoming – outgoing radiation ratio and consequently atmospheric baroclinicity varies. In one's turn, it acts on the angular momentum, vorticity and kinetic energy. The papers on the atmospheric moisture cycle dates from second half the 20-th century, though the first publication on the planetary distribution of the precipitation appears as far back as the 1934 [1]. The most important results that related to the investigated problem is obtained in [2, 3, 4]. However, as denoted by Oort [5], these results have been exposed to errors, that associated with inadequate accuracy of the initial information.

Recently the papers appeared, in which moisture fluxes over the several geographic regions are investigated [6, 7]. Nevertheless, such researches that undoubtedly have science interest not allows to resolve a hydrological cycle problem that is set by Oort [5]. The errors that associated with an initial information insufficient accuracy can be reduced using the weather satellite data [8]. It is important to perform owing to both the spatial [9] and the temporal [10] large heterogeneity of the precipitation and evaporation fields.

2. Dataset and Methods

The GDAAC (Goddard Distributed Active Archive Centre) data are used in this study. It is specially oriented for the climate change and general circulation investigations. The 1998 year version of this dataset has a horizontal resolution of 2 × 2 degree on the 8 pressure level (1000, 950, 900, 850, 700, 500, 300 and 200 hPa) and its temporal coverage is March 1980 – November 1993.

The zonal mean values calculation procedure is came to following. Using monthly mean values of the dataset the season and year mean values of the precipitation and evaporation for aforementioned period are calculated. Then they are averaged onto latitudinal circles from 0° N to 90° N.

The water vapour flux magnitudes is defined with equation

$$\overline{W}_{\varphi} = \frac{1}{g}\int_0^{p_0}\left(\overline{q}\cdot\overline{v}\right)dp + \frac{1}{g}\int_0^{p_0}\overline{q^*\cdot v^*}\,dp\,, \qquad (1)$$

where $g = 9.8$ м с$^{-2}$ is the acceleration due to gravity, q is the air specific humidity, v is the meridional wind. Here an asterix denotes the deviation from the zonally averaged value for any variable x:

$$x^* = x - \overline{x}\,, \quad \text{where} \quad \overline{x} = \frac{1}{2\pi}\int_0^{2\pi} x d\lambda\,.$$

First term in Eq. (1) specifies the circulating moisture flux due to Hadley and Ferrel circulation cell. Second term in Eq. (2) is the vortex moisture flux that defined by the atmospheric eddies.

3. Results and analysis

3.1. Zonal mean distribution of the precipitation, evaporation and moisture fluxes

The values of precipitation and evaporation are shown in Fig. 1. It is seen, as a whole for year the evaporation magnitude is poleward scales down, to all appearances, due to radiation balance. All the same time there are two precipitation peaks: the first one is located over 10° N, i.e. in the zone of the Hadley cell ascending branch, and the second maximum sites in the middle latitudes and is conditioned by polar front.

The Northern Hemisphere dry zone is situated between 16° N and 48° N. Exactly in this latitudinal zone deserts sites (Mexico, Sugar, Saudi Arabia, Gobi etc.).

It is interestingly to compare the presented results (referred as D_1) and earlier obtained by Sellers [11] ones (referred as D_2). First, the precipitation values by D_1 over 10° N on 500 mm year $^{-1}$ is more than D_2 and over 50° N on 200 mm year $^{-1}$ is less than D_2. On the other hand, the precipitation minimum shifts from 24° N to 32° N. Due to this the dry zone expands on 10° northward in comparison with D_2.

In summer the precipitation values are remained in that geographical belt as for whole year. However, the underlying surface drying is observed between 32 and 69° N that testify about the precipitation failure over continents under the large evaporation conditions. However it is possible to note the sharp increase of the precipitation near 52° N and same decrease near 66° N. Such distribution testifies about the polar front presence.

In winter the sharp decrease of the evaporation is observed above 40° N owing to, most probably, frontal cloudiness and, as results of this, the underlying surface is saturated with moisture. Also in addition to precipitation maximum in the tropics the sharp increase of pre-

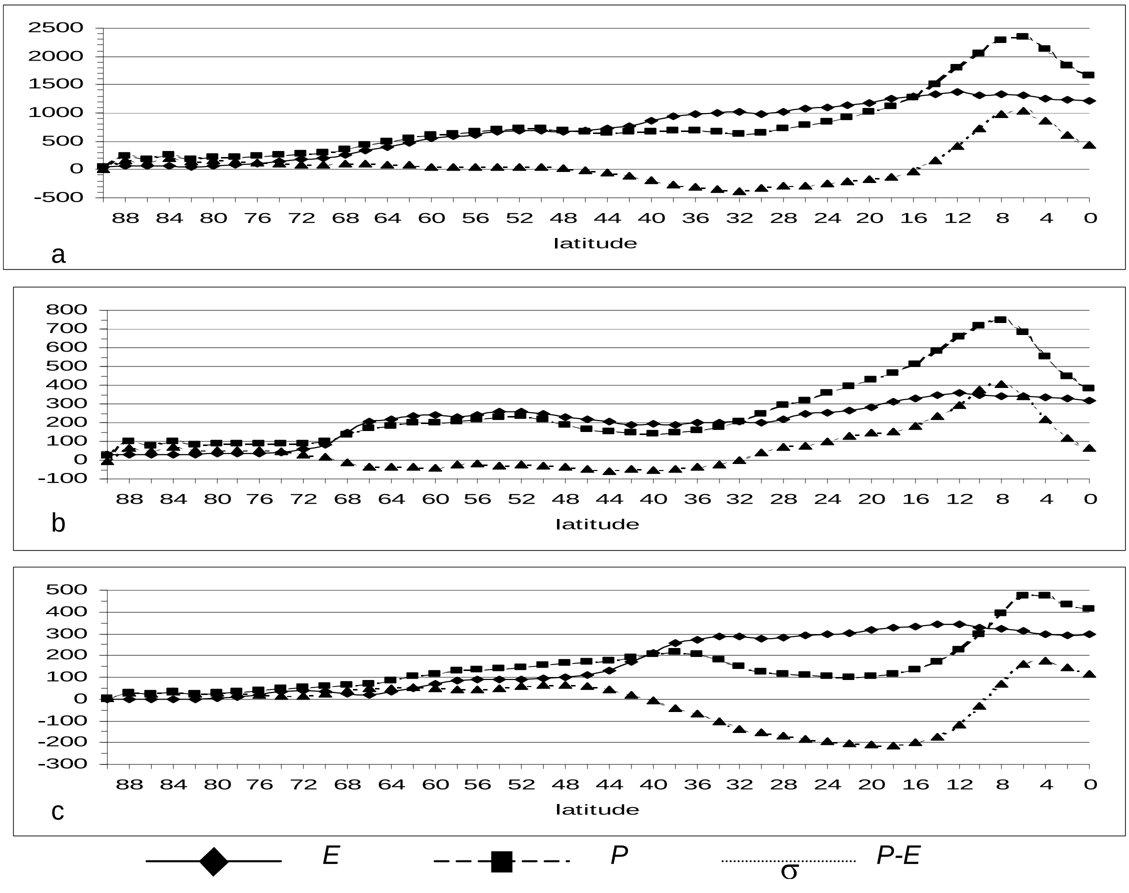

Figure 1. – Zonal mean distribution for year (a), summer (b) and winter (c) of evaporation, precipitation and difference (a –mm year $^{-1}$; b,c – mm season^{-1}).

cipitation is registered over 38° N. If this pattern to compare to the summer distribution the southward polar front shift and the polar front zone extension can see. The southward displacement of the Hadley cell and the half as less again precipitation decrease in its zone is observed in comparison with summer. At the same time in the polar front zone the precipitation is equal both in winter and in summer. Also there are the sharp increase of the precipitation before the polar front and the evaporation decrease at the expense of a frontal cloudiness.

Let's analyze the water vapor fluxes across the latitudinal circle (Fig. 2).

Since the negative values v (southward) in a lower troposphere and the positive ones (northward) in a upper troposphere are approximately equal for the Northern Hemisphere Hadley cell, an integral circulating flux is determined of the magnitudes difference. At the same time the magnitudes of q are maximal in a planetary boundary layer, therefore the lower-troposphere southward circulating flux is determinative in the tropics.

Examining the annual fluxes distribution let's see that the Southern Hemisphere Hadley cell influence affects to the 8° N. Also the vortex moisture flux is antifase to the circulating one and it is positive almost in whole hemisphere having the maximum in a tropics.

The subtropical moisture outflow causes the precipitation deficit in this region and, as result of this, the underlying surface dehydration is observed.

In summer the Southern Hemisphere Hadley cell extends approximately to 20° N and this is verified by water vapour circulating flux distribution. Also the northward subtropical vortex flux is more than circulating one. It is necessary to note here that the summer Hadley cell have less intensity. All this causes the total flux positive values almost in whole hemisphere. The negative values of the mid-latitude vortex flux, probably, are accounted for the cold-air surges.

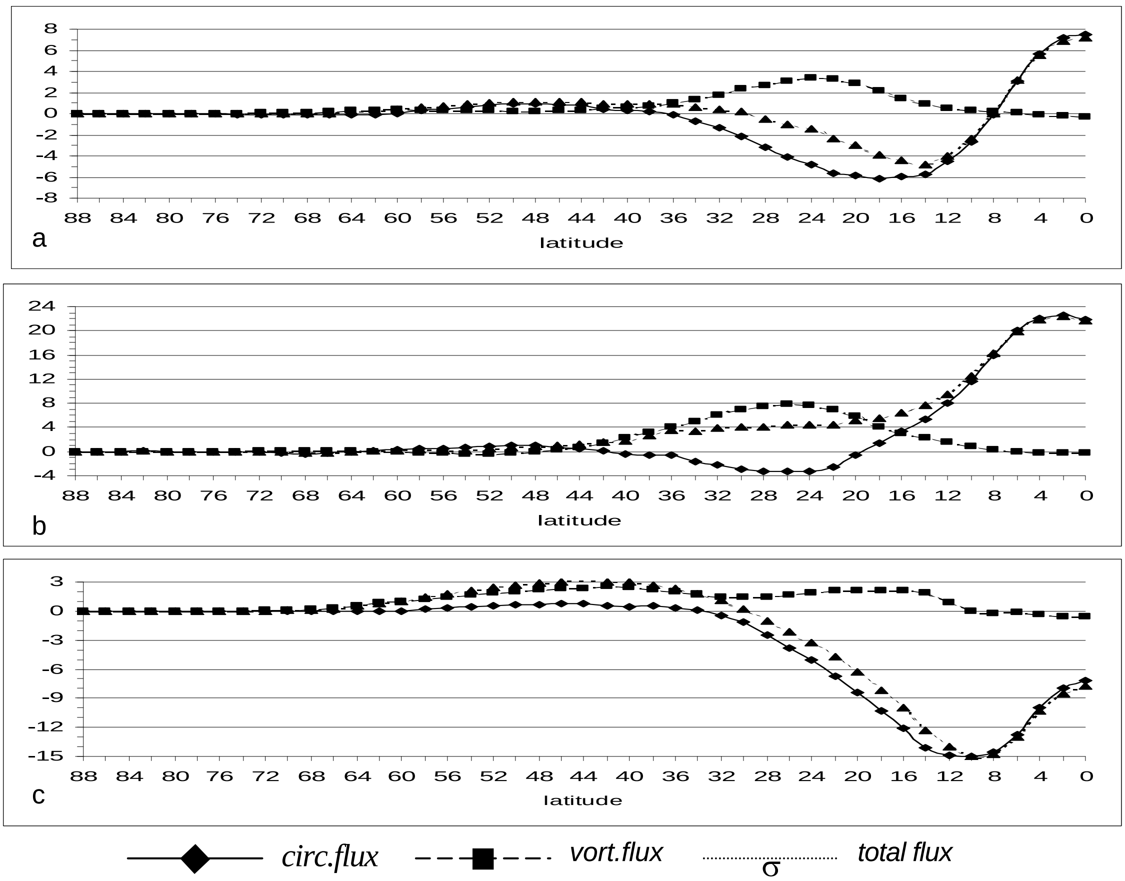

Figure 2. – Integral values of moisture fluxes across latitudinal circles ($\times 10^8$ kg c^{-1}) averaged for year (a), summer (b) and winter (c).

The summer water vapour inflow is observed in whole hemisphere, so that the described above mid-latitude underlying surface dehydration is defined by excessive evaporation not insufficient precipitation.

In winter, when the Hadley cell intensity is maximal, circulating flux and the determinate by it total flux are southward directed to 30° N. The vortex flux is positive to the north of 10° N and is as much than circulating one to the north of 30° N.

The water vapor inflow is observed till 10° N and above 44° N. Accordingly, if to compare with (P - E) value, can conclude that in this case the tropical underlying surface dehydration take place as result of the precipitation deficit.

3.1. Oceanic and continental distribution of moisture fluxes

If to assume that year mean values of the specific humidity (q) over the ocean and land along latitudinal circles are approximately equal, the water vapour fluxes differences are defined by the meridional wind differences.

From the aforesaid and analysing Fig. 3 can conclude following. Although in the low latitudes the continental area twice is less than oceanic one, over the land the Hadley cell intensity is more. At the same time Ferrel cell locating on the middle latitudes is developed only over the oceans. Also, over continents in contrast to water surface southward wind take place.

If also to assume the low-latitude moisture content is more than mid-latitude one, over oceans the year mean Ferrel cell intensity is more in comparison with the Hadley cell (Fig. 4). Above all it is applied to the warm half-year when over the oceans the south circulation is extremely poorly developed, whereas over the continents the situation is the inverse (Fig. 3). To all appearances this is a cause of the observed zonal mean evaporation and precipitation distributions over the continents in summer.

In winter the Hadley cell intensities over oceans and continents are approximately equal

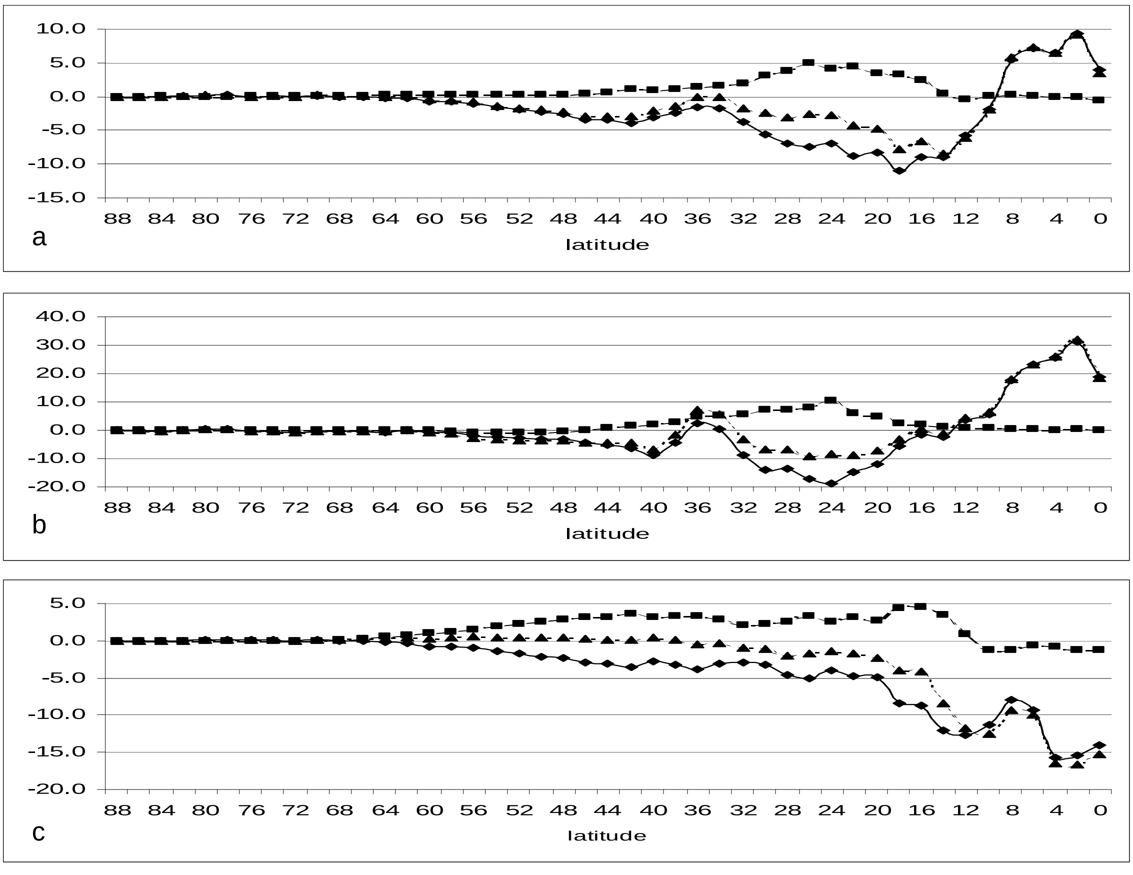

Figure 3. – Integral values of moisture fluxes across latitudinal circles over continents ($\times 10^8$ kg c^{-1}) averaged for year (a), summer (b) and winter (c). Definitions as on Fig.2.

(Figures 3 and 4), but Ferrel cell take place only over the oceans.

So, the aforesaid distribution features of the dry zones and polar front can be interpreted: a) by the intensive continental Hadley cell in summer b) by the presence of the oceanic mid-latitude circulating cell in winter.

As a whole in the 40 – 65° N latitudinal zone over the oceans the northward circulating water vapour flux dominates, but over the land in this belt the circulating flux, as a rule, have the southward.

Also can talk about the mid-latitude vortex water vapour flux comes to nothing both for the warm half-year and for whole year, whereas in winter the vortex flux neutralise the circulating one. Due to this in winter the continental mid-latitude flux practically is not observed. On the other hand over oceans both in winter end in summer the mid-latitude northward moisture flux is registered, in winter it twice is more than in summer.

It is necessary to distinguish the continental water vapour outflow in the 45 - 60° N belt and the oceanic inflow to the north of 50° N are observed both in winter and in summer. However continental dry zone is observed only in summer. Most probably the moisture is transported by zonal wind from the oceans to the land. Nevertheless in summer even this "additional" atmospheric moisture is insufficient for the gross evaporation compensation.

4. Conclusion

In this work the zonal distributions of the precipitation, evaporation and moisture fluxes as an atmospheric part hydrological cycle are investigated. Main conclusions of this work are following:

- for the second half of the 20-th century the summer drought shifted 10° northward reaching 48°;

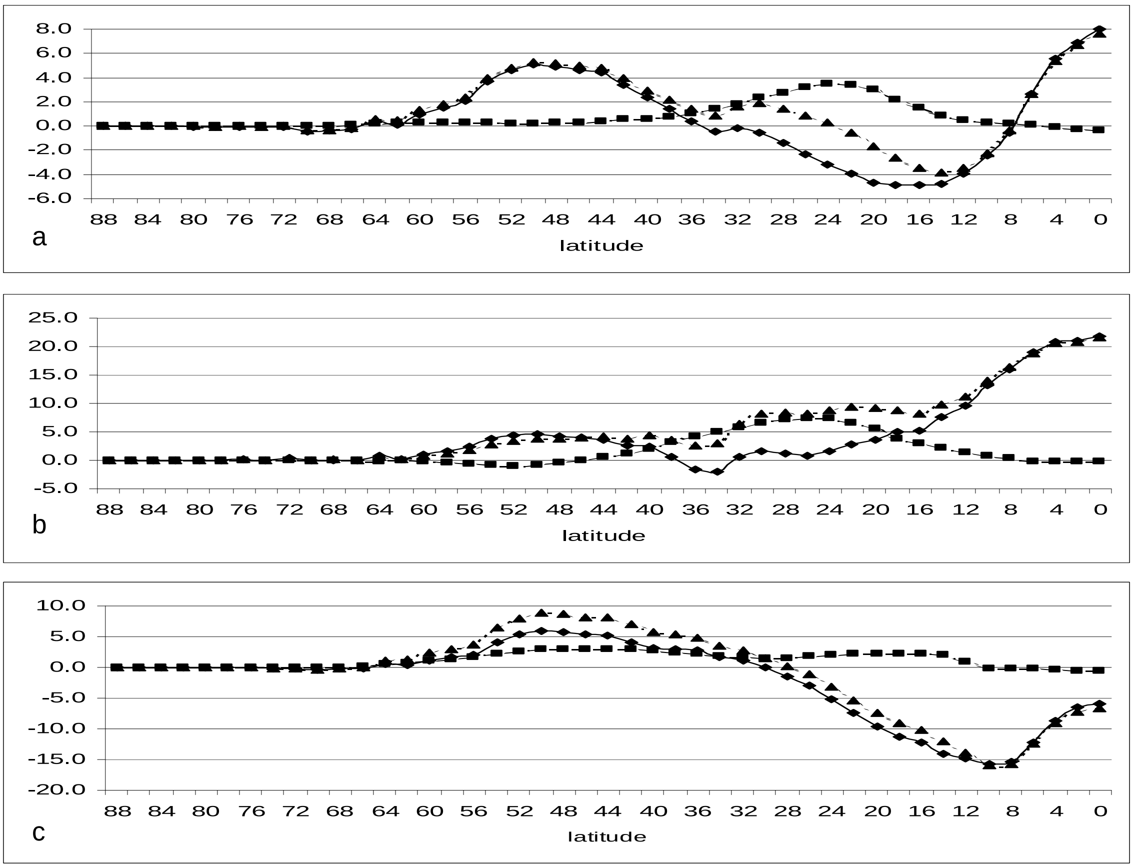

Figure 4. – Integral values of moisture fluxes across latitudinal circles over oceans ($\times 10^8$ kg c^{-1}) averaged for year (a), summer (b) and winter (c). Definitions as on Fig. 2.

- the zonal mean distribution of precipitation is well correlated with the seasonal position of the polar front;

- the location of the dry zones is dominated by the circulation conditions above the oceans in winter and above continents in summer. The explanation is an intensive Hadley cell circulation above continents in summer and the presence of a mid-latitude circulation cell above oceans in winter.

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В статье на основе данных GDAAC исследуются параметры, влияющие на влагооборот атмосферы, такие как осадки, испарение и потоки влаги. Найдено, что среднеширотное распределение осадков хорошо коррелируется с сезонными положениями климатического полярного фронта. Также, определено, что за вторую половину 20-го века зона «засушливости» распространилась на 10° к северу и достигла 48° с.ш. Закономерности относительно расположения зон «засушливости» и климатического фронта зимой определяются циркуляционными условиями над океанами, а летом – над материками. Причем это можно объяснить интенсивной циркуляцией Гадлея над материками летом и наличием циркуляционной ячейки умеренных широт над океанами зимой.