Pesquisa Antártica Brasileira (2012) 5: 217-221
(Brazilian Antarctic Research)
ISSN 0103-4049
http://vega.cnpq.br/pub/doc/proantar/

The annual cycle of the Atmosphere heat budget focusing on the southern hemisphere

MARCOS TONELLI, BRUNO FERRERO, ENVER GUTIERREZ and ILANA WAINER

Oceanographic Institute of the University of São Paulo, Praça do Oceanográfico, 191, 05508-120 São Paulo, Brazil

ABSTRACT

Based on NCEP/NCAR reanalysis and World Ocean Atlas 2005, the long-term variation of the Atmosphere heat budget has been investigated. The aim of this work was to evaluate the role of each component of the climate system on the planet energy balance, focusing on the atmospheric variability over the Southern Ocean and the Antarctic Continent. The calculation was performed according to the formulation used by Oort and Vonder Haar (1976). As expected, the ocean has shown a huge dominance on heat storage around the globe. A large seasonal variation on both oceanic and atmospheric systems was evident. Results show unusual atmospheric variability over the southern polar region. After removing the seasonal cycle, the atmospheric heat storage anomaly displays significant intraseasonal variability at high latitudes. EOF and Wavelets analysis show that the atmospheric heat storage changed from the beginning of the record with a distinct 2 months cycle, which is well defined between 60°S and 90°S. According to the EOF analysis it grew more intense from mid 20th to early 21st centuries, reflecting the warming trend.

Key words: heat budget, atmospheric heat storage, Antarctic energy balance.

INTRODUCTION

Since the mid 20th century it has been known that the ocean and the atmosphere together are the key elements in regulating the earth's heat budget (Gabites 1950, Fritz 1958). Therefore, many studies have been done to try to understand the dynamics associated with this energy balance. From Oort and Vonder Haar (1976) to Trenberth and Fasullo (2008), researchers have been trying to quantify the heat, moist and momentum fluxes in order to determine the role of each component in this balance.

In order to fully understand this complex energy balance one has to compute all the fluxes components between atmosphere-ocean and their energy transports (Trenberth 1997, Philander 1999). However, divergences among estimates of the absolute quantities associated to the global energy budget still hinder the numerical closure of the problem, both for observational and modeling fluxes computation (Trenberth et al. 1998, Neelin and Ning Zeng 2000, Fasullo and Trenberth 2008).

Since most of the previous studies have focused on the Northern Hemisphere, the aim of this work is to evaluate the annual variations of the heat storage in the Southern Hemisphere, specially over the Southern Ocean and the Antarctic Continent. The formulation described by Oort and Vonder Haar (1976) will be adopted. The question of how the ocean-atmosphere coupled system modulates the annual-seasonal cycle will be addressed. Data from two different sources will be employed: atmospheric data from the National Centers of Environmental Prediction/National Centre of Atmospheric Research – NCEP/NCAR reanalysis and oceanic

Correspondence to: Marcos Tonelli
E-mail: mtonelli@usp.br, brferrero@usp.br

data from World Ocean Atlas 2005 – WOA05 (Table I).

METHODOLOGY

DATA DESCRIPTION

The atmospheric data is obtained from the NCEP/NCAR reanalysis. It consists of a system of past data assimilation from 1948 to 2007. The variables used are monthly means of temperature, zonal and meridional velocity, geopotential height and relative moisture.

The ocean data are from the World Ocean Atlas 2005. This is a set of objectively analyzed (1° grid) climatological fields of *in situ* temperature, salinity, dissolved oxygen, Apparent Oxygen Utilization (AOU), percent oxygen saturation, phosphate, silicate and nitrate at standard depth levels for annual, seasonal and monthly compositing periods for the World Ocean. It also includes associated statistical fields of observed oceanographic profile, data interpolated to standard depth levels on both 1° and 5° grids.

Table I summarizes the data source, spacial and temporal resolution adopted in this study.

TABLE I

Data	Spacial Resolution	Time Resolution
NCEP/NCAR	2.5° × 2.5° × 17	1979-2005
WOA05	1° × 1° × 33	climatology

The problem formulation can be written as:

$$\frac{\partial E}{\partial t} = S_{atm} + S_{ocn} + S_{land} + S_{ice} \qquad (1)$$

where E is the system's total energy and S_{atm}, S_{ocn}, S_{land}, S_{ice} are the terms representing atmosphere, ocean, land and cryosphere storage (respectively). The atmosphere and ocean components are dominant terms. S_{land} and S_{ice} were not considered in our calculations. Each term of Equation (1) is given by:

$$S_{ocn} = \frac{\partial}{\partial t}\int_{B_o}^{T_o} \rho C_o T dz \qquad (2)$$

$$S_{atm} = \frac{\partial}{\partial t}\int_{Ba}^{Ta} \rho + C_A T + gZ + L_e q + dz \qquad (3)$$

ρ is the air density (1 kg/m^3),
C_A is the specific heat at constant volume for atmosphere (1004.4 J/(kg K)),
T is the air temperature,
gZ is the geopotential height,
L_e latent heat of air evaporation (2.5×10^6 J/kg) and
q is specific humidity of air.
C_o is the specific heat at constant volume for the ocean ($C_o = 3996$ J/(kg K), $\rho_o = 1000$ kg/m^3) and T in Equation (2) is the potential temperature of the ocean. The terms considered in the formulation were obtained from the climatological average. For the atmospheric heat storage (Sa) field EOF and Wavelets analysis were performed.

RESULTS AND DISCUSSION

Figure 1 shows the zonally averaged oceanic heat storage rate (So) calculated according to equation (2) as a function of time and latitude. The first thing to notice is the difference between hemispheres, where seasonal oscillation is evident; the ocean stores heat during the summer and releases it to atmosphere during the winter. Secondly, the amount of exchanged heat deserves attention due to its wide range, from over 200 W/m^2 stored during summer to 175 W/m^2 given back during the winter months in each hemisphere. This pattern is consistent with the variability of the energy flow from Atmosphere to Earth shown on Figure 2, where hemispheric differences and seasonal oscillation are again evident. These results are consistent with those presented by previous studies such as Oort and Vonder Haar (1976) and Trenberth and Fasullo (2008).

The zonally averaged atmospheric heat storage rate (Sa) can be seen on Figure 3. The first panel (Figure 3a) displays the mean for the 1979-2005 period, while panels 3b and 3c show the mean anomaly for the first and last 5 years, respectively. As expected, the seasonal cycle is the remarkable feature in the first panel and the amount of heat storage is way smaller than the oceanic component, as previously shown by Fasullo and Trenberth

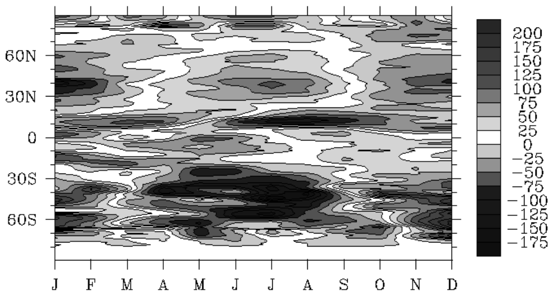

Fig. 1 – Climatological zonally averaged rate of heat storage in the Ocean (W/m^2).

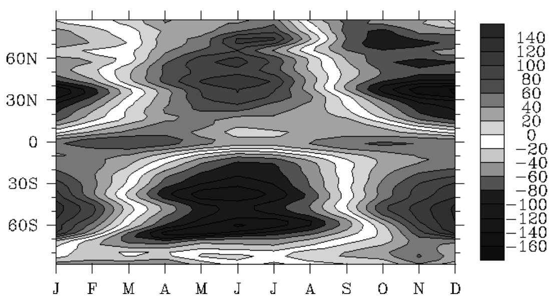

Fig. 2 – Climatological zonally averaged energy flow from Atmosphere to Earth (W/m^2).

(2008). In the Southern Hemisphere there is a gain of heat for seven months (January to July) with the maximum absolute value of 20 W/m^2 in April and loss of heat during the remaining five months, with the minimum absolute value of 33 W/m^2 in November. In contrast, the Northern Hemisphere gains heat between August and December (absolute maximum of 25 W/m^2 in September) and loses heat from January to July (absolute minimum value of 30 W/m^2 in April). This indicates the role of the oceanic processes as a mechanism of northward inter-hemispheric exchange of heat storage.

As a way of synthesizing the analyzed period and to assess whether the differences discussed may correspond to a regime change, EOF analysis is performed. Figures 4 and 5 show the first and second EOF modes. This method is used to examine the evolution of the mean state in annual (Figure 4) and intraseasonal (Figure 5) scales. The spacial structure of EOF 1 describes 53.7% of the explained variance and presents an evident hemispheric difference along with a strong seasonal signal. The associated

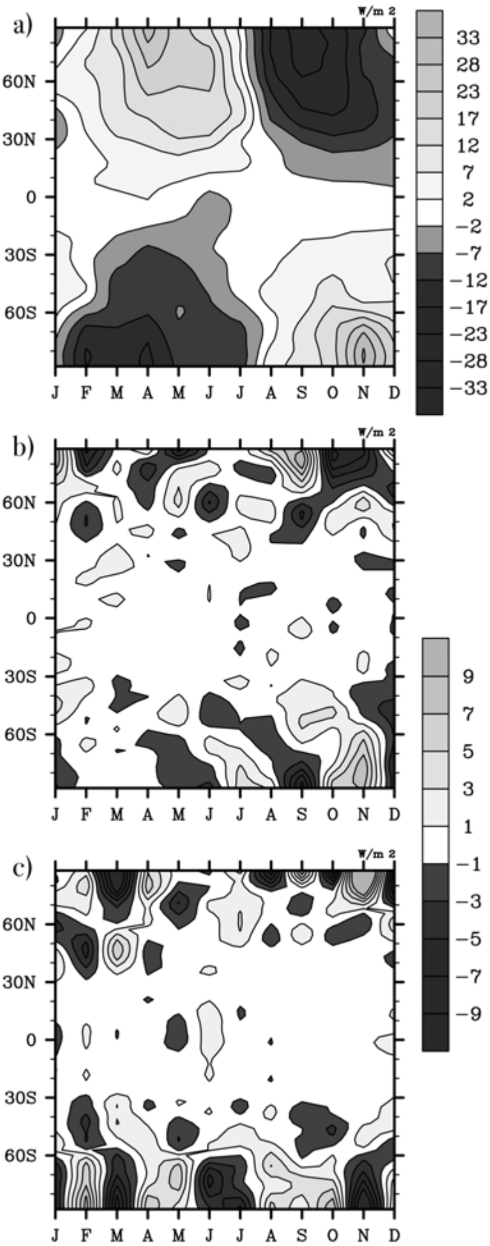

Fig. 3 – a) Zonally averaged rate of heat storage in the Atmosphere (W/m^2); b) anomaly of the first 5 years (W/m^2); c) anomaly of the last 5 years (W/m^2).

time series shows a weakening of the amplitude of the annual signal and also a negative trend of this signal. This suggest that the atmosphere is storing less heat in the last 27 years. The second mode, which explains only 5.3% of the remaining variance, consists of an intraseasonal mode, and display

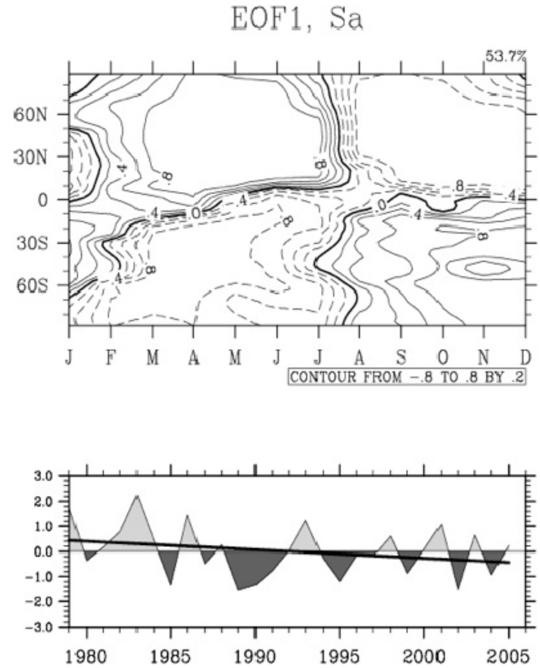

Fig. 4 – First EOF mode of atmospheric heat storage (Sa) and associated principal component time series.

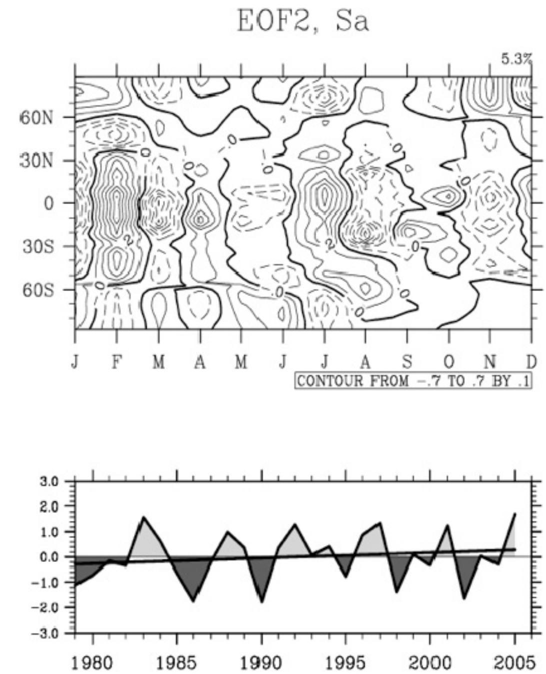

Fig. 5 – Second EOF mode of atmospheric heat storage (Sa) and associated principal component time series.

a positive trend for the last 27 years (0.3 W^2/m^4), suggesting an intensification of this variability. Finally, the wavelets analysis applied to the Sa (Figure 6) shows that indeed the interannual variability has diminished during the last 27 years, and that the intraseasonal variability increased during the same period.

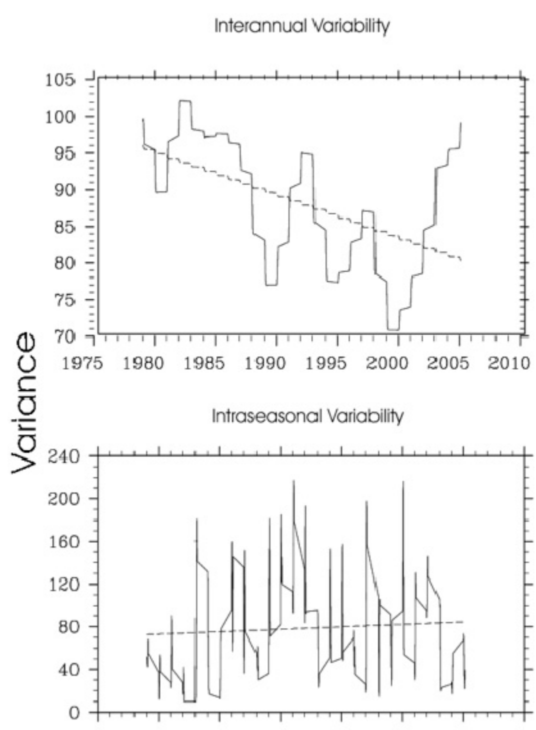

Fig. 6 – Atmospheric heat storage (Sa) wavelets variance time series.

CONCLUSION

Adopting the formulation presented by Oort and Vonder Haar (1976) it has been possible to calculate Earth's heat budget with data from NCEP/NCAR reanalysis and World Ocean Atlas 2005, focusing on the atmospheric heat storage rate (Sa) over the Southern Hemisphere and over Antarctica.

Zonally averaged means show a strong signal from the annual cycle, which was expected due to the seasonality of Sun-Earth system. As a first attempt to remove the annual cycle, first and last 5 years anomalies were computed, revealing a 2 months oscillation-like signal for Sa over high latitudes.

EOF analysis performed to assess the dominant patterns of Sa revealed the dominance of the annual variability in the spacial structure of the first EOF mode. Intraseasonal oscillations, although weakly represented, could be an important signal over the Antarctic continent with period of 2 months. EOF and Wavelets analysis time series show a weakening trend for the annual cycle (0.4 W^2/m^4 in 27 years). Along with this negative trend, the time series from the second EOF mode and Wavelets analysis show a strengthening trend, associated with the increase of intraseasonal behavior (0.3 W^2/m^4 in 27 years).

So the question remains whether the changes observed in the variability of Sa could be a response to the global warming trend and what could be the impacts on the Antarctic environment.

RESUMO

Utilizando dados da re-análise NCEP/NCAR e do World Ocean Atlas 2005, foi investigada a variação de longo termo do balaço de calor da atmosfera. O objetivo deste trabalho foi avaliar o papel de cada componente do sistema climático no balanço de energia do planeta, especialmente a variabilidade atmosférica sobre o Hemisfério Sul e o continente antártico. Foi adotada a formulação proposta por Oort and Vonder Haar (1976). Como esperado, o oceano apresentou grande dominância em termos do armazenamento do calor no âmbito global. A variabilidade sazonal ficou evidente tanto para o oceano quanto para atmosfera. Foi observada uma variabilidade incomum no termo atmosférico sobre a região polar sul. Removendo o ciclo sazonal, a anomalia do armazenamento de calor pela atmosfera mostra uma variabilidade em escala intrasazonal em altas latitudes. Análises de EOF e Wavelets mostram que o armazenamento de calor pela atmosfera alterou-se entre o início e o fim do período analisado, evidenciando uma oscilação com período de 2 meses muito bem marcada entre as latitudes de 60°S e 90°S. De acordo com a EOF, esse modo de variabilidade intensificou-se entre meados do século XX e início do século XXI, refletindo a tendência de aquecimento.

Palavras-chave: balança de calor, armazenamento do calor atmosférico, balanço de energia na Antártica.

REFERENCES

Fasullo JT and Trenberth KE. 2008. The annual cycle of the energy budget: Global mean and land-ocean exchanges, J Clim 21(10): 2297–2313.

Fritz S. 1958. Seasonal heat storage in the ocean and heating of atmosphere. Arch Meteor Geophis Bioklim A10: 291–300.

Gabites JF. 1950. Seasonal variations in the atmospheric heat balance. Sc. D. Thesis, MIT.

Lau K-M, Sheu P-J and Kang I-S. 1994. Multiscale low-frequency circulation modes in the global atmosphere. J Atmos Sci 51: 1169–1193.

Lorenz EN. 1963. Deterministic nonperiodic flow. J Atmos Sci 20: 130–141.

Neelin JD and Ning Zeng. 2000. A Quasi-Equilibrium Tropical Circulation Model-Formulation. J.A.S., 1741–1766.

Oort AH and Vonder Haar TH. 1976. On the Observed Annual Cycle in the Ocean-Atmosphere Heat Balance Over the Northern Hemisphere. J Phys Oceanogr 6: 781–800.

Philander SG. 1999. El Niño, La Niña and the Southern Oscillation. Academic Press, 1990, 293 pp.

Tenberth KE. 1997. Using Atmospheric Budgets as a Constraint on Surface Fluxes. J Climate 10: 2796–2809.

Trenberth KE, Branstator GW, Karoly D, Kumar A, Lau N-C and Ropelewski C. 1998. Progress during TOGA in understanding and modeling global teleconnections associated with tropical sea surface temperatures. J. G. R., 14291–14324.

Trenberth KE and Fasullo JT. 2008. An Observational Estimate of Inferred Ocean Energy Divergence. J Phys Oceanogr 38: 984–999.