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Investigação da camada limite superficial na região Antártica. Parte II: fluxos verticais turbulentos de calor e horizontal momentum

Surface boundary layer investigation in Antarctic region. Part II: vertical turbulent fluxes of heat and horizontal momentum

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Resumo

A região antártica é um dos lugares mais intocáveis pela sociedade humana e ao mesmo tempo, susceptível às variações climáticas. Modelos numéricos de previsão do tempo e clima requerem informações sobre as condições atmosféricas desta região como dado de entrada para parametrizações, as quais ajudam a descrever e prognosticar o tempo em qualquer região do planeta. Este trabalho propõe estudar os fluxos turbulentos verticais de calor e momento horizontal na Estação Antártica Brasileira, localizada na Ilha Rei George. O principal objetivo é obter indiretamente os fluxos turbulentos utilizando a Teoria de Similaridade de Monin-Obukhov a partir de dados in situ de Janeiro de 2014. Os resultados mostraram uma variação diurna dos fluxos de calor (latente e sensível), com valores predominantemente positivos para o mês, caracterizados pelo parâmetro de estabilidade como um período instável. A maioria dos valores de fluxo de calor sensível e latente foram em torno de 0 – 50 Wm^{-2}. O fluxo de momento ficou concentrado em valores entre 0 – 0,1 Nm^{-2}, com picos de 1 Nm^{-2} associados a ventos intensos na região, devido à passagem de ciclones.

Palavras-chave: *Fluxo turbulento de calor sensível, fluxo turbulento de calor latente, fluxo de momento, Teoria de Similaridade de Monin-Obukhov, região Antártica.*

Abstract

The Antarctic region is one of the untouchable places by the human society and, at the same time, susceptible to the climatic variations. Global numerical weather prediction and climate models require information about atmospheric conditions in this region to be used as input on these models through parameterizations, which help to describe the weather in that region and predict the weather in other regions on the planet. This work proposes to study the vertical turbulent fluxes of heat and horizontal momentum in the Antarctica Brazilian Station, located in King George Island. The main objective is to obtain indirectly the vertical turbulent fluxes of heat and horizontal momentum utilizing the Monin-Obukhov Similarity Theory using in situ data from January 2014. The results showed the diurnal variation of turbulent heat fluxes (latent and sensible), with positive values during this month characterized predominantly by the stability parameter as an unstable period. Most of sensible and latent heat flux values were around 0-50 Wm^{-2}, respectively. The momentum flux presented most of the values between 0-0.1 Nm^{-2} and the peaks around 1 Nm^{-2} were associated to intense winds due to cyclone passage over the region.

Keywords: *Turbulent sensible heat flux, turbulent latent heat flux, momentum flux, Monin-Obukhov similarity theory, Antarctic region.*

1 Introduction

The Antarctica region is one of the most preserved and most vulnerable place on the planet to environmental changes. Therefore, alterations in this environment, natural or anthropogenic, have a potential to biologic and socioeconomic impacts, which may affect the Earth system as a whole (Laws, 1990). The atmospheric system monitoring is essential to evaluate these changes, which means collecting continuously environmental data, with quality and for a long period, contributing in assessment of future implications, subsidizing decision-making.

A way of assessing the atmospheric conditions in Antarctica is through the study of the Planetary Boundary Layer (PBL) in the region. The surface boundary layer (SBL) is the lowest part of the PBL, typically the bottom 10%, adjacent to the surface where the turbulent fluxes are considered as non-divergent and approximately constant (Monin and Obukhov 1954; Dyer 1974).

The SBL has its origin linked to the exchanges of energy, momentum, and mass between the atmosphere and the surface, modulated by the turbulence on time scale of around one hour. In this time scale, the sensible and latent heat vertical turbulent fluxes determine the vertical mean structure of temperature and moisture in the PBL, while the vertical turbulent flux of horizontal momentum gives condition to the dynamic mean structure of the PBL, both on continental and oceanic regions in high and lower latitudes (Stull 1988; Arya 2005).

An alternative way of estimating the surface layer fluxes is indirectly, through observations of air specific humidity, air temperature and horizontal wind velocity by the Monin-Obukhov Similarity Theory (MOST). This indirect method requires observation of these properties at least three level of height and time average values of the variable of ten minutes to one hour (Stull 1988).

The goal of this study is to provide an estimative of the surface layer fluxes by the indirect form in the Antarctic Brazilian Station – Estação Antártica Comandante Ferraz (EACF), located in King George Island. The data used in this work was obtained by the ETA Project.

2 Methodology

The Antarctic Brazilian Station is located in Keller Peninsula, into the Bay Admiralty, King George Island, in South Shetland Islands, in Antarctic Peninsula (62°05′07″ S, 58°23′33″ W, 20 m about mean sea level). The islands are situated 130 km of the Antarctic continent and 849 km of the southernmost point of the South American continent – Cape Horn.

The data presented in this study was obtained by the ETA Project during January of 2014, in the EACF with *in situ* observations. Details of the data and instrumentation can be obtained in Alves et al. (2015).

Here, the estimative of the vertical turbulent fluxes was performed using the indirect method (MOST). A Fortran 90 algorithmic of the Micrometeorology Group of the IAG/USP (Oliveira et al., 2013) was used to obtain the turbulent fluxes in the SBL.

The flux-profile relationship in the SBL might be estimate by the MOST considering the surface layer as horizontally homogeneous and stationary, which is useful when direct method of turbulent fluxes are not available (Arya 2001). The theory proposes local similarity functions (universal functions) for momentum and heat/humidity, which are unique for each type of atmospheric conditions.

For atmospheric neutral and unstable conditions, the functions have shown good results when compared with the direct method (Businger et al. 1971; Hicks 1976; Högström 1988). For a stable atmosphere, especially over weak winds condition (strong stratification); the comparison with the direct method has not provided good agreement (Lee 1997, Sharan et al. 2003). The restrictions are due to weak and intermittent turbulence, presence of internal waves, Kelvin-Helmholtz instabilities, etc (Finnigan et al. 1984; Mahrt 1989, 1998;; Mahrt et al. 1998; Cuxart et al. 2000;). Therefore, different researchers have proposed improvements to the method (Zilitinkevich and Chailikov 1968; Webb

1970; Businger et al. 1971; Dyer 1974; Hicks 1976; Högström 1996, Zilitinkevich et al. 2007, Zilitinkevich and Esau 2007).

The flux-profile method was described by Dyer (1965 1974), Businger et al. (1971), Yagüe et al. (2006), Kramm et al. (2013) among others. The method is iterative and introduces dimensionless gradients of the average variables of horizontal wind velocity, air potential temperature and air specific humidity into universal functions related to the stability parameter (ζ = (z-d)/L), which is a ratio between the height of measurement (z) less the displacement height (d), and Obukhov length (L) at the reference level (Monin and Obukhov 1954). The |L| means the height above the ground where the buoyancy and shear production of turbulent kinetic energy are of equal magnitude; below this height shear dominates and above it, buoyancy dominates. In unstable stratification, the parameter is negative and positive for stable stratification. Values around zero mean neutral stratification.

The method initially assumes neutral condition ($\zeta^0 = \zeta_0^0 = 0$) for the atmosphere. After this consideration, a straight-line equation ($y = \alpha + \beta x$) is adjusted to the measurement levels (three levels of observation) by the method of least squares. The first scale characteristics of wind velocity, air potential temperature and specific humidity (u_*, θ_*, and q_*) are found by the angular coefficient of the straight-line equation and then the universal functions can be estimated.

Given the characteristic scales, the vertical of sensible (H) and latent (LE) turbulent heat fluxes and momentum (τ) can be expressed as (Fairall et al. 1996):

$$H = -\rho_0 c_p u_* \theta_* \qquad (1)$$

$$LE = -\rho_0 L_V u_* q_* \qquad (2)$$

$$\tau = \rho_0 (u_*)^2 \qquad (3)$$

where ρ_0 is the air density (1.15 kgm^{-3}), c_p is the specific heat of dry air at constant pressure (1004 J K^{-1}kg^{-1}) and L_V is the latent heat of vaporization (2,500 Jg^{-1}).

The energy balance components are considered here positive when the fluxes are from surface toward the atmosphere.

3 Results and discussion

Characteristic scales (u_*, θ_*, and q_*) (Fig. 1) have agreed with theory, which suggest that these scales are the measure of the mean vertical gradient (here estimated by the method of least square) corrected by the stability parameter (Businger et al. 1971).

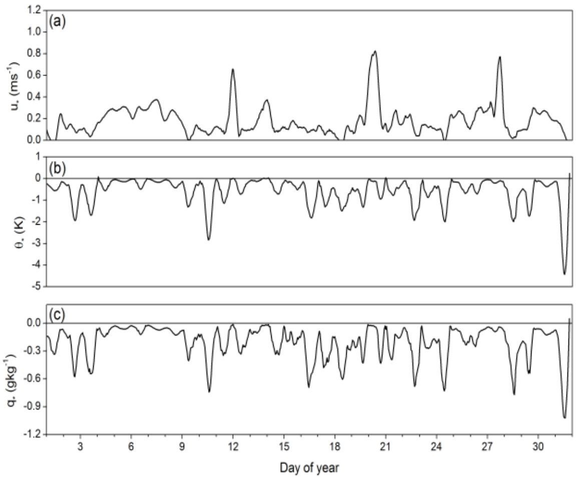

Figure 01. Temporal variation of the hourly averaged values of scale characteristics of (a) velocity, (b) air temperature and (c) air specific humidity during January 2014 (horizontal straight line indicates 0 value).

Most of the characteristic scale of velocity values are between 0 and 0.3 ms^{-1} (Fig.2a) in agreement with Stull (1988), and peaks with maximum value above 1.0 ms^{-1} (Fig.2a). These peaks were observed particularly during the night over intense winds coming from N and E, influenced in large scale by low-pressure centres, during transition periods (Fig.3a).

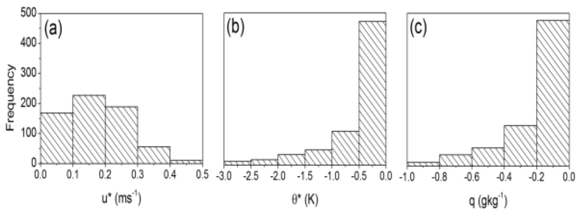

Figure 02. Histogram of the hourly averaged characteristic scales of (a) velocity, (b) potential temperature (θ_*), and (c) humidity for January 2014.

Characteristic scales of potential temperature and humidity show a diurnal variation with values higher during the day (Fig. 1b, c), related to diurnal heating of surface, responsible for larger vertical gradient of these variables. During January, most of the values of θ_* varied between 0 and -0.5 K, and q_* varied between 0 and -0.2 gkg^{-1}. From day 04 to 09 is noted small variation of these scales with negative values around zero, influenced by the advection of a cold and dry air mass originated of a high-pressure centre located over the Antarctic Peninsula and Weddell Sea (east of Antarctic Peninsula) with winds from E. This air mass has favoured the vertical homogenization of thermodynamic properties in the measurement level.

During the investigated period, the Obukhov length (L) mostly indicates an unstable atmosphere (Fig.3). Stable periods were observed in a few days, especially at night, agreeing with negative values of H (Fig.4a).

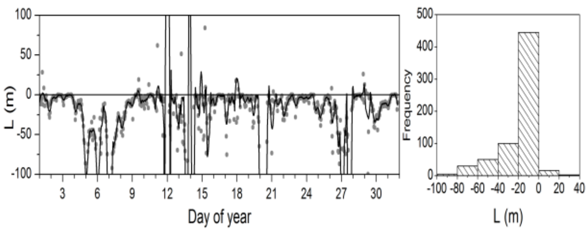

Figure 03. Temporal variation of the hourly averaged values of (a) Obukhov length (L) (horizontal straight line indicates 0 value and black line is the curve fitting) and (b) histogram of L during January 2014.

The H presented a diurnal cycle (Fig. 4a), with higher values during the day and lower at night. H is 75% comprehended in a range of 0 - 100 Wm^{-2}, with most of values smaller than 50 Wm^{-2} (Fig. 5a), which may be related to the time of sunlight (approximately 18h30min of sunlight) and consequently to a larger heating of the surface. The negative values of H correspond to less than 10% of the data.

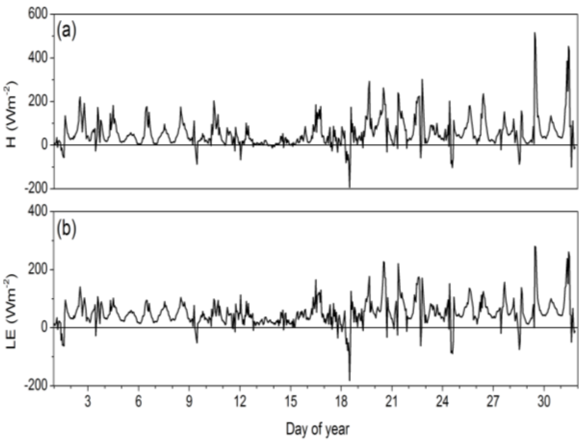

Figure 04. Temporal variation of the hourly averaged (a) sensible (H) and (b) latent (LE) heat fluxes during January 2014 (horizontal straight line indicates 0 Wm^{-2}).

The LE also presented a diurnal cycle similar to H (Fig. 4b). LE has 85% of its values between 0 and 100 Wm^{-2} with most of the values smaller than 50 Wm^{-2} (Fig. 5b). This is a period of high intensity of the incoming solar radiation (austral summer) and the prevalent positive values of LE may be related to the melting ice sheet that occurs in the region.

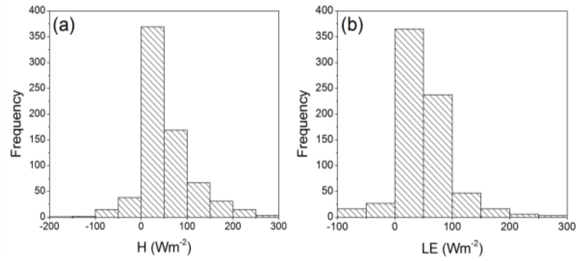

Figure 05. Histogram of hourly averaged (a) sensible (H), (b) latent (LE) heat fluxes for January 2014.

The results showed here for heat fluxes agree partially with the study realized by Choi et al. (2008). The authors have studied the net radiation and the turbulent energy exchanges in a non-glaciated coastal area, in King George Island (Sejong Station, located on the north-west edge of the Barton Peninsula), in December 2002 (austral summer). They used the direct method - eddy covariance system - for the estimative of the turbulent fluxes, adopting the same signal convention used here.

The H monthly average was 64 Wm^{-2} with a large variability due to the snow/ice presence over the surface. The LE values were relatively constant and between 15 and 20 Wm^{-2}. The sum of H and LE reached approximately 80 Wm^{-2}, which was one order of magnitude larger than that obtained by Bintanja (1995) at the glaciated areas on the Peninsula Antarctica (-34.8 to 5.6 Wm^{-2}). However, the turbulent fluxes over non-glaciated areas are more intense than over glaciated area.

Most of the momentum flux has exhibited predominant magnitude of 10^{-1} Nm^{-2} with approximately 90% of its values smaller than 0.1 Nm^{-2} (Fig. 6), agreeing with Stull (1988).

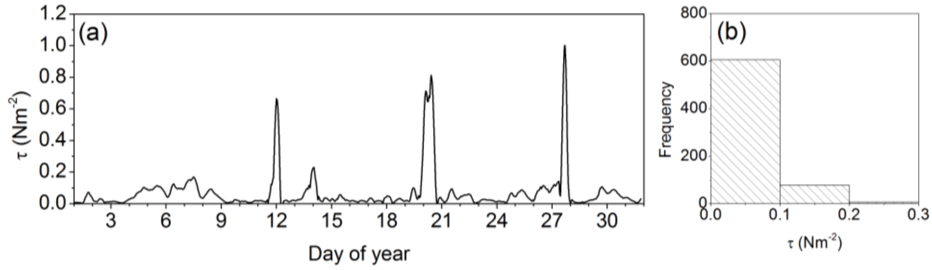

Figure 06. Temporal variation of hourly averaged (a) momentum flux (τ) and (b) histogram of hourly averaged τ during January 2014.

4. Conclusions

The estimative of the vertical turbulent fluxes of heat and horizontal momentum have shown good agreements with the main atmospheric systems that occurred in the region, contributing with diurnal variation of the estimated fluxes. In addition, vertical turbulent fluxes of sensible and latent heat were primarily positive and smaller than 50 Wm^{-2}, which agree with previous study made at the same island.

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