I Summer School - Surface-Atmosphere Interactions

Development of a Statistic Algorithm Applied to LES model

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Objective

1. The main objective of this work is to develop a statistical algorithm to process the data generated by the Large-Eddy-Simulation model (LES) in real time.
2. Use the LES model to characterize the Convective-PBL proprieties in order to validade the algorithm.

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Numerical Modeling Basis - A Short Review

Main Techniques

- Reynolds-Averaged Navier-Stokes - RANS
- Direct Numerical Simulation - DNS
- Large Eddy Simulation - LES

Modeling Basis Short Review - RANS and DNS

RANS & DNS

- RANS - Navier-Stokes statistics ensemble.
- RANS - Turbulent fluxes simplified solution.

Modeling Basis Short Review - RANS and DNS

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Modeling Basis Short Review - LES model

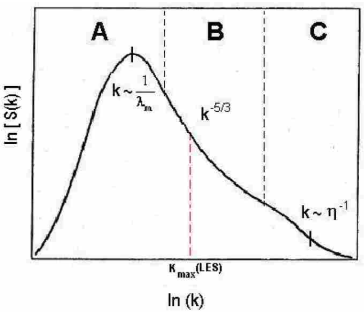

Figure: Energy Cascade; Three regions: (A) production, (B) Inertial Sub-interval and (C) dissipation. k is the wave number, λ_m the wavelenght associated with the most energetic eddy and η the Kolmogorov's microescale. The max wave number explicitelly resolved by the LES is represented by $k_{max}(LES)$.

Modeling Basis Short Review - The LES Model

LES main properties

- Using this kind of model is possible to understand the PBL most important behaviors like momentum, temperature and humidity turbulent fluxes
- The LES code used in this work was proposed by Moeng, 1984 and improved by Sullivan, 1994, mainly in the subgrid scheme.

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The LES Model - Some limitations

There's no free lunch...

- In the Surface Layer the grid “imposes” some limitations;
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LES in this work

- In this work we use a LES parallel version, modified by Moeng and Sullivan.
- The code was improved by Professor PhD. Umberto Rizza, *Istituto di Scienze dell'Atmosfera e del Clima* - (CNR-ISAC), Lecce - Italy and DSc. Edson Marques Filho, *UFRJ* (IGEO), RJ - Brazil.

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Simulation Description

NAMELIST			
Physics		**Numerical**	
Coriolis	$-1.0E-4s^{-1}$	Nr. Steps	28800
Z_0	$0.1m$	Δt	1s
$T_{profile}$	$298.0K$	Total Time	8 hours
$q_{profile}$	$8.0g/Kg$	Computational Time	12 hours
$\vec{V_g}$	$5\vec{i}+0\vec{j}+0\vec{k}m/s$	Grid	$10 \times 10 \times 2Km$
$\overline{w'\theta'}_0$	$0.1Km/s$	Spacing	96^3, $\approx 105 \times 105 \times 21m$
$\overline{w'q'}_0$	$0.04g/Kgm/s$		
$\frac{\partial\theta}{\partial z}$	$3.0K/Km$		
$\frac{\partial q}{\partial z}$	$0.0g/Km$		
$\frac{\partial\theta}{\partial t}$	$1.0K/h$		
$\frac{\partial q}{\partial t}$	$1.0g/Kg/h$		
T_0	$295.0K$		
q_0	$12.0g/Kg$		
Z_0^{CLP}	$850m$		

The LES Model - Some details

LES code

- Uses a pseudo-spectral method to resolve the momentum equations (horizontal components);
- Uses a FFT to the derivatives horizontally and a finite-difference method to the vertical one;

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Simulation Description

Temporal Scale	
time-step	dt
caracteristic velocity scale - surface layer	u_*
PBL Height	Z_i
Monin-Obukov Lenght	L
Stability parameter	$\zeta = \frac{Z}{L}$
Potential Temperature - Surface	θ_0
Specific humidity - Surface	q_0
Turbulent heat flux - Surface	$\overline{\theta' w_0'}$
Turbulent latent flux - Surface	$\overline{q' w_0'}$
$\theta_*^{MixedLayer}$	$\frac{<\theta' w'>}{w_*}$

Simulation Description

Resolved and sub-grid spatial scales	
Velocities components variances	$< u'^2 >, < v'^2 >, < w'^2 >$
θ and q variances	$< \theta'^2 >, < q'^2 >$
Vertical flux - Sensible heat	$< w' \theta' >$
Vertical flux - Latent heat	$< w' q' >$
Zonal flux - Sensible heat	$< u' \theta' >$
Zonal flux - Latent heat	$< u' q' >$
Meridional Flux - Sensible heat	$< v' \theta' >$
Meridional Flux - Latent heat	$< v' q' >$
Mean Zonal Velocity	$< u >$
Mean Meridional Velocity	$< v >$
Momentum Flux Variance	$< u' w' >$
Momentum Flux Variance	$< v' w' >$
Momentum Flux Variance	$< u' v' >$
Shear Production	$-\overline{u' w'} \frac{\partial \bar{u}}{\partial z} - \overline{v' w'} \frac{\partial \bar{v}}{\partial z}$
Thermal Production	$\frac{g}{\theta} \overline{w' \theta'}$
Transport	$\frac{\partial}{\partial z} \left(\overline{e' w'} + \frac{\overline{w' p'}}{\rho_0} \right)$
Dissipation	ϵ

The SGS Model

SGS

- The SGS model proposed by Sullivan considers that the turbulence can be splited in a isotropic and non-homogeneous part.

$$\tau_{ij} = -2\nu_t \gamma S_{ij} - 2\nu_T \langle S_{ij} \rangle$$

$$S_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)$$

$$\tau_{\theta i} = -2\nu_\theta \frac{\partial \theta}{\partial x_i}$$

γ is the isotropy factor. This factor is responsible by the transition between the resolved and SGS scale.

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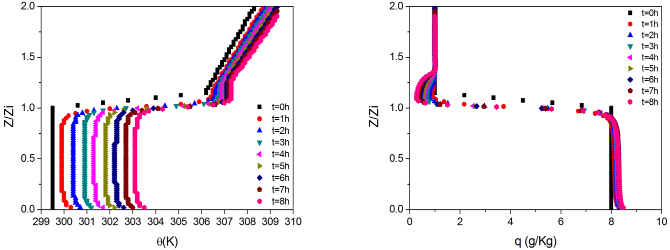
Vertical and Temporal profiles

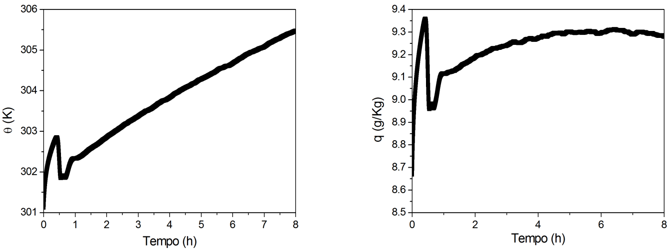


(a) Potential temperature **(b) Specific Humidity**

Figure: Vertical Evolutions

The vertical profiles present the expected results fors a Convective-PBL. In the surface layer, the temperature and humidity present a reduction with the height. The properties homogeneity is observed in the mixed-layer. The PBL top is defined when $Z/Zi = 1$.

Vertical and Temporal profiles



(a) Potential temperature **(b) Specific Humidity**

Figure: Temporal Evolutions

The intial instability can be visualized. In this case, the sensible and latent heat fluxes are constant during the simulation, generating the profiles above. However, the fluxes can be modified forcing the temperature and/or humidity.

Vertical and Temporal profiles

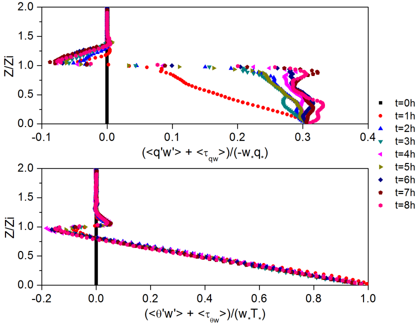


Figure: Vertical transport of temperature and humidity

The humidity and temperature present the expected profiles for a convective-PBL. The subgrid effect is very important in both cases.

The subgrid importance

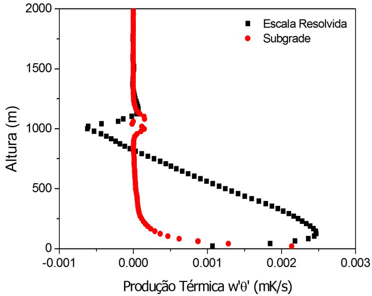
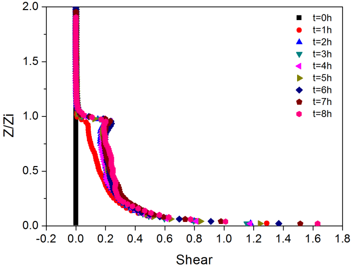


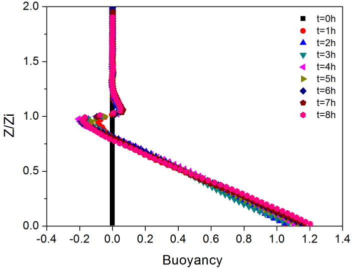
Figure: Thermal Production

The SGS thermal production presents a major importance in the surface and in the PBL top. Therefore, is critically necessary to develop good parametrizations to simulate the subgrid phenomena.

Shear and buoyancy



(a) Shear



(b) Buoyancy

Figure: Vertical Evolutions

Shear and Buoyancy are normalized.

TKE

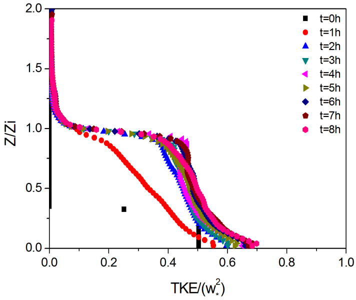


Figure: Turbulent Kinetic Energy vertical profile

More intense in the surface layer.

Momentum fluxes

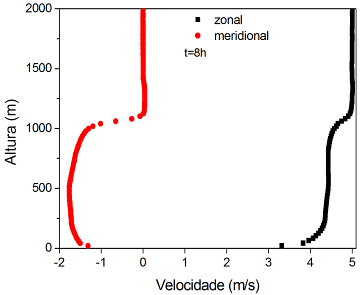


Figure: Zonal and meridional wind components vertical profiles

All the velocity components converges to the geostrophic values.

Momentum fluxes

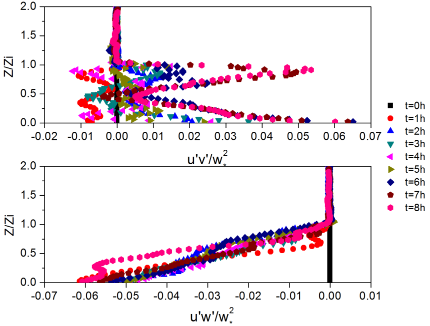
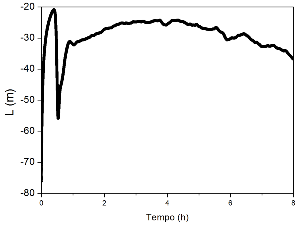


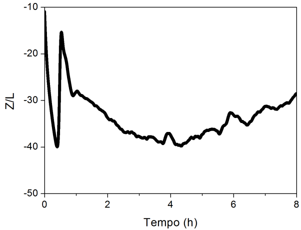
Figure: Vertical and horizontal second order statistical momentum

All results are normalized by the characteristical mixed-layer velocity scale. For the horizontal momentum occurs an intensification, started in the end of the simulation.

Flow properties



(a) L

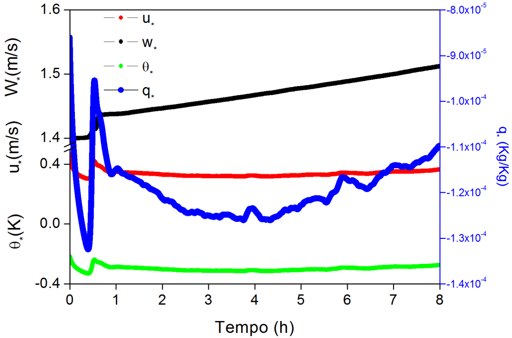


(b) ζ

Figure: Temporal Evolutions

The theoretical atmosphere simulated in this work presents a instable condition with moderate winds. The Monin-Obukov lenght and the stability parameter give a good idea about the (in)stability.

Characteristic scales



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PBL Height

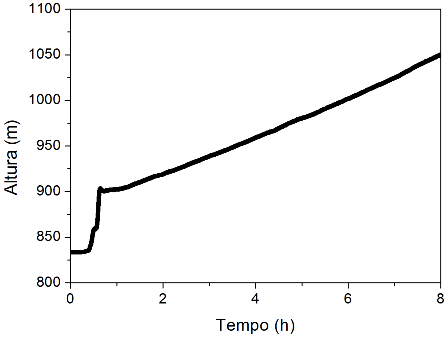

Figure: PBL Height

A typical evolution for a PBL can be observed in the figure.

Summary

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- The statistic analysis was successfully implemented and validated for a known case;
- The second order fluxes were implemented;
- The main convective-PBL properties were simmulated using the LES model;
- The post-processing was eliminated;
- The results presented here indicate that the algorithm is ready to be applied to other cases, e.g. SBL.