SENSITIVITY OF WRF MODEL TO SIMULATE GRAVITY WAVES

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13TH ANNUAL WRF USERS’ WORKSHOP
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Motivation

- Observational study of internal gravity waves (IGWs) generated at the top of a drainage flow (gravity current)
- Tower measurements SABLES 2006 campaign
- Oscillations in pressure, vertical velocity and temperature

From Viana et al. 2010
Objectives

1. Introduction

- Study the capability of the WRF model to capture the gravity waves
- Analyze the sensitivity of two planetary boundary layer (PBLs) schemes → MYJ and YSU
- Understand the origin of the IGWs
- Analyze the characteristics of the gravity waves generated by the gravity current applying wavelet transform to WRF model data
Overview

1. Introduction
2. Model setup
3. PBL and surface layer description
4. Results
   I. Description of the studied night
   II. Model experiments evaluation
   III. Overview on mesoscale fields
   IV. Oscillation features
5. Conclusions
Gravity or density currents are flows created by differences in the density of two adjacent fluids.

They can be originated by cold fronts, sea-breeze fronts, squalls, etc.

Irruption of these flows may result in vertical displacement of air parcels from their equilibrium position → source of IGWs

IGWs can transport energy and momentum, and can be a source of turbulence

Mesoscale models are useful to study mesoscale disturbances
Model setup

- **WRF-ARW v3.1.1**
- 3 domains 2-way nesting $\rightarrow$ 4th domain 1-way nesting
- 27 – 9 – 3 – 1 km
- 48 sigma vertical levels $\rightarrow$ 20 levels within first 250 m

<table>
<thead>
<tr>
<th></th>
<th>Domain 1</th>
<th>Domain 2</th>
<th>Domain 3</th>
<th>Domain 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal grid</td>
<td>27 km</td>
<td>9 km</td>
<td>3 km</td>
<td>1 km</td>
</tr>
<tr>
<td>Dimensions (x, y, z)</td>
<td>65, 60, 48</td>
<td>88, 82, 48</td>
<td>139, 130, 48</td>
<td>154, 100, 48</td>
</tr>
<tr>
<td>Ini. &amp; bound cond.</td>
<td>NCEP CFSR 0.5° $\times$ 0.5° every 6h</td>
<td></td>
<td>WRF domain (D3)</td>
<td></td>
</tr>
<tr>
<td>Simulated period</td>
<td>22-06-2006 to 24-06-2006</td>
<td></td>
<td>Night 22-23</td>
<td></td>
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</tbody>
</table>
2. Model setup

- 2 experiments
- Common physics
  - Radiation: Dudhia scheme for short wave radiation, RRTM for long wave radiation
  - Land surface: NOAH Land-Surface Model (4 subsoil layers)
  - Microphysics: New Thompson et al. scheme
  - Convection: Grell 3D scheme
- Different PBL and surface layer schemes
  - Exp. 1 YSU: Yonsei University scheme, MM5 similarity
  - Exp. 2 MYJ: Mellor-Yamada Janjic, Eta surface layer
PBL description

3. PBL description

- Exp. 1 Yonsei University scheme (YSU) (Hong et al., 2006)
  - First order scheme, non-local closure turbulence, with a counter-gradient term
  - MRF modification
  - It considers the nonlocal fluxes implicitly through a parameterized nonlocal term

  - 1.5-order (level 2.5), local turbulence closure model of Mellor and Yamada (1982)
  - It determines eddy-diffusion coefficients from prognostically calculated turbulent kinetic energy (TKE)
Surface layer

Calculates surface exchange coefficients to compute sensible, latent and momentum fluxes. It provides the lower boundary condition for the vertical transport in PBL scheme, important for temperature and moisture.

- Exp. 1 Similarity theory (MM5)
  - Coupled with YSU PBL scheme

- Exp. 2 Similarity theory (ETA)
  - Coupled with MYJ PBL scheme
  - Based on similarity theory (Monin and Obukhov, 1954)
  - Includes parameterizations of viscous sub-layer
Results

- Overview of the studied night
- Overview on mesoscale fields
- Model experiments evaluation
  - Vertical structure of the density current
- Oscillations features
Description of the night case

- SABLES 2006 campaign
- Night 22-23 June 2006, high pressure area, weak horizontal pressure gradient
- Values recorded at different levels of the mast show weak NW wind and a shift at 2130 UTC, sudden intrusion of an eastern current of moderate speed.
- Temperature drops and thermal inversion is reduced
- Specific humidity rises with the current arrival
- Vertical heat flux reveals displacement of parcels due to the outbreak
Mesoscale overview

Domain 3 (3km grid)

2 m temp + wind 10m  1200-2300 UTC

YSU

MYJ

Surface Temperature (°C)
Wind (m/s)

Surface Temperature Contours: 4 to 30 by 2

 Longitude

8 10 12 14 16 18 20 22 24 26 28 30 32 34

Surface Temperature (°C)
A density current coming from the NE

Wind at 100 m  1200-2300 UTC

YSU

MYJ
Mesoscale overview

Cross section NE-SW (Domain 3)
4. Results

Cross section NE-SW: Projected horizontal wind 1200-2300 UTC

Mesoscale overview

Projected horizontal wind (m s⁻¹)

-10 -8 -6 -4 -2 0 2 4 6

2006-06-22 12:00:00

2006-06-22 12:00:00
Mesoscale overview

Cross section NE-SW: Potential temperature 1200-2300 UTC

YSU

MYJ

Potential temperature (K)

284 288 292 296 300 304 308 312 316

13th Annual WRF Users' Workshop
Model experiments evaluation at CIBA site

1 km (D4) model outputs

At the top of the tower (~100 m):

- Wind speed increases
- Wind turns from north to east in both schemes
- Temperature drops 5 C
- Specific humidity rises

Observation (CIBA tower)  
WRF-MYJ experiment  
WRF-YSU experiment
Vertical structure of the gravity current

Wind speed time-height diagram at CIBA site

RASS-SODAR

WRF-YSU

WRF-MYJ
4. Results

Temperature time-height diagram at ClBA site

RASS-SODAR

WRF-YSU

WRF-MYJ
Oscillations features

Mean magnitudes $\rightarrow$ 12-minute model outputs / Spectral analysis $\rightarrow$ 1-minute model outputs

YSU scheme
No oscillations

MYJ scheme
Oscillations
Oscillations features

YSU scheme
No oscillations

MYJ scheme
Oscillations

4. Results
Oscillations features

Wavelet transform method (Terradellas et al., 2005) applied to 1 minute model outputs of potential temperature at 167 m

<table>
<thead>
<tr>
<th>WRF- MYJ (167 m)</th>
<th>Observed (Viana et al., 2010) (50-100 m)</th>
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<tbody>
<tr>
<td>f (outputs) = 0.016 Hz</td>
<td>f (data) = 2 Hz</td>
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<tr>
<td>T = 20-22 min</td>
<td>T = 9.2 min</td>
</tr>
<tr>
<td>c = 6-9 m s(^{-1})</td>
<td>c = 6.2 m s(^{-1})</td>
</tr>
<tr>
<td>Dir = 240-260°</td>
<td>Dir = 20°</td>
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<tr>
<td>λ = 8-10 km</td>
<td>λ = 3.5 km</td>
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- Modeled waves are seen between 130 and 300 m / Observed waves are seen below 100 m
- Higher periods and wavelengths in modeled waves

Energy wavelet density (K\(^2\) s\(^{-1}\))

Inside the cone of influence there is a signal of \(\sim\)20 minutes period.
WRF model is a good tool to study the origin and development of a density current and the generation of IGWs.

MYJ experiment represents better the main features of the density current and is capable to detect oscillations with the entrance of the current at a given point.

YSU experiment captures the arrival of the current on time but does not reproduce the gravity waves.
The origin: a cold air mass coming from the Cantabric sea, modulated by the topography

The intrusion of the density current pushes upwards the ambient air (acting as a cold front) forming a warmer layer at the top of the current where oscillations developed

Waves in the model are produced at higher altitudes than the observed ones

Modeled waves have longer periods and wavelengths than observed
Discrepancies may be due to:

- The modelled wave may arrive as a damped and smoothed perturbation
- Wavelet transform technique is applied to different magnitudes with different frequencies (model / observations)
- 1 km resolution could be too coarse to solve a wave of 3.5 km
Conclusions (IV)

Results to be published in the Quarterly Journal of the Royal Meteorological Society

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<th>Quarterly Journal of the Royal Meteorological Society</th>
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<td>Model simulation of gravity waves triggered by a density current</td>
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Keywords: mesoscale disturbances, numerical simulation, PBL schemes, WRF model
Future work

- Understand better the influence of the surface-layer schemes coupled with PBL schemes
- Perform further studies to clarify the capacity of the models to simulate IGWs
- Increase the resolution (< 1 km)
- Perform further studies with WRF-LES
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THANK YOU!!

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