Testing the HBG model under strong stabilities of GABLS4

A SCM inter-comparison study using CCAM

Jing Huang¹ | Marcus Thatcher¹ | Elie Bou-Zeid²
24 June 2016, Salt Lake City
The 22nd Symposium on Boundary Layers and Turbulence, AMS
Outline

• The Huang-Bou-Zeid-Golaz (HBG) model (Huang et al., JAS, 2013)
  • GABLS
  • Local Richardson number similarity
  • The HBG model
• GABLS4 inter-comparison
  • GABLS4
  • Single column model (CCAM) and available schemes for SABL
  • Land surface model (CABLE)
• Results
  • Surface temperature
  • Surface sensible heat flux
  • Temperature at 42 m
  • Wind speed profile
• Conclusions
GABLS and LES runs

- Initial conditions
  - Geostrophic wind: $U_g=8.0$ m/s, $V_g=0.0$ m/s
  - Potential temperature: 265K up to 100m, then it increases at a rate of 0.01 K/m

- Boundary conditions
  - MOST wall model at surface and no stress and no penetration at the simulation domain top
  - Prescribed surface temperature with a constant decreasing rate of 0.25 K/h
  - Roughness length $z_{0m} = z_{0h} = 0.1$ m

- Higher stabilities
  - Increasing the surface cooling rate from 0.25K/h
  - We also test much higher stabilities than GABLS, going up to 2.5K/h (Case A-F)

- LES setup
  - Simulation domain
    - 162X162X160 grid points
    - 800X800X400 m³
  - Courant-Friedrichs-Lewy (CFL) number is around 0.1
  - Total physical run time: 10 hours
  - Statistics were obtained with the results of the last three hour
With increasing stability:

- Stronger wind speed peak, and vertical gradient of mean temperature
- Lower low-level jet, and shallower boundary-layer
- Decrease in surface momentum and increase in temperature flux

Table 1. Mean boundary layer characteristics for stable ABL simulations with steady surface cooling rates.

<table>
<thead>
<tr>
<th>Case</th>
<th>Cooling rate (K h⁻¹)</th>
<th>h (m)</th>
<th>(u_\ast) (m s⁻¹)</th>
<th>(\theta_\ast) (K)</th>
<th>(L_{MO}(z = 0)) (m)</th>
<th>(L_{OZ}) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.25</td>
<td>158</td>
<td>0.247</td>
<td>0.0392</td>
<td>104</td>
<td>14.4</td>
</tr>
<tr>
<td>B</td>
<td>0.5</td>
<td>128</td>
<td>0.226</td>
<td>0.0653</td>
<td>51.9</td>
<td>8.15</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>106</td>
<td>0.208</td>
<td>0.114</td>
<td>24.8</td>
<td>4.31</td>
</tr>
<tr>
<td>D</td>
<td>1.5</td>
<td>94.5</td>
<td>0.198</td>
<td>0.158</td>
<td>15.9</td>
<td>2.88</td>
</tr>
<tr>
<td>E</td>
<td>2</td>
<td>86.9</td>
<td>0.190</td>
<td>0.199</td>
<td>11.5</td>
<td>2.11</td>
</tr>
<tr>
<td>F</td>
<td>2.5</td>
<td>81.5</td>
<td>0.184</td>
<td>0.237</td>
<td>8.93</td>
<td>1.65</td>
</tr>
</tbody>
</table>

[Absolution: Testing the HBG model under strong stabilities | Jing Huang]
Local scaling theory

- Dimensionless combinations of variables should be functions of $z/\Lambda$ (Nieuwstadt 1984).

**However...**

- Eddy diffusivities are $z$-less under strongly stable conditions.

$$
\phi_{K_m} = K_m \Lambda^{-1} \tau^{-1/2}
$$
$$
\phi_{K_h} = K_h \Lambda^{-1} \tau^{-1/2}
$$
$$
\Lambda = -\tau^{3/2} \Theta (\kappa g q)^{-1}
$$

[Huang and Bou-Zeid, JAS, 2013]
Local Richardson number similarity

\[ K_m = l_m^2 \left| \frac{\partial U}{\partial z} \right|, \]
\[ l_m = l_N f_m^{1/2}(R_i_g), \]
\[ \frac{1}{l_N} = \frac{1}{Kz} + \frac{1}{l_\infty}, \]

**SHARP:**
\[ f_m(R_i_g) = \begin{cases} 
(1 - 5R_i_g)^2 & 0 < R_i_g \leq 0.1 \\
(20R_i_g)^{-2} & R_i_g > 0.1
\end{cases} \]

**GFDL model:**
\[ f_m(R_i_g) = \begin{cases} 
(1 - 5R_i_g)^2 & 0 < R_i_g \leq 1/7 \\
(1 - 0.1R_i_g)^2 & 1/7 < R_i_g \leq 10 \\
0 & R_i_g > 10
\end{cases} \]

**Long-tails:**
\[ f_m(R_i_g) = (1 + 10R_i_g)^{-1} \quad R_i_g > 0 \]

[Huang et al., JAS, 2013]
The new model (HBG)

SHARP:

\[
\frac{1}{l_m} = \frac{1}{l_N} + \frac{Ri_g}{\lambda} = \frac{1}{\kappa z} + \frac{1}{l_\infty} + \frac{Ri_g}{\lambda}
\]

[Huang et al., JAS, 2013]
GABLS4 SCM/LSM inter-comparison

• Based on a real case on 11 Dec. 2009 under strong stability (Ri>1) at DomeC Antarctica
  • Stage 1b – Coupling of SCM with LSM, prescribed initial surface and soil conditions and atmospheric forcing
  • Stage 2 – Same as Stage 1b BUT the surface temperature is given
  • Stage 3 – idealized case: no radiation, no moisture, no prescribed atmospheric forcing, only prescribed surface temperature and constant geostrophic wind speed

From O. Traullé (left) and E. Brun (right)
Single column model - CCAM

- CCAM: Cubic-Conformal Atmospheric Model developed by CSIRO
- Support a variable-resolution global grid using Schmidt transformation
- Three SABL schemes:
  - The HBG model
    \[
    \frac{1}{l_m} = \frac{1}{\kappa z} + \frac{1}{l_\infty} + \frac{Ri_g}{\lambda}
    \]
    \[
    l_\infty = 9 \text{ m}, \quad \lambda = 0.45 \text{ m}
    \]
  - The Louis (1979) model (a long-tail type)
    \[
    f_m(Ri_g) = (1 + 4.7Ri_g)^{-2}
    \]
    \[
    l_\infty = 100 \text{ m}
    \]
  - A standard prognostic k-eps model
  - A modified Louis (1979) model
    \[
    f_m(Ri_g) = (1 + 4.7Ri_g)^{-2}
    \]
    \[
    l_\infty = 9 \text{ m}
    \]
Land surface model CABLE: Community Atmosphere Biosphere Land Exchange model developed by CSIRO and BOM

- Biophysical component
  - Surface radiation transfer
  - Canopy turbulence

- Biogeochemical component
  - Land use and land use change

- Two-leaf turbulence
- Six soil and three snow layers

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Surface temperature

- K-eps scheme collapses during night
  - Low surface temperature
  - Shallow SABL

HPBL

- Louis scheme
  - Overestimate surface temperature
  - Give spurious deep SABL
  - HBG and Louis 9m perform similarly
  - Slightly shallower SABL for HBG

Stage 1b

\[ hpbl = h_{\tau=0.05\tau_s} / 0.95 \]
Surface sensible heat flux

- Observation flux is actually at $z = 7m$ – k-eps produces too little flux
- Louis scheme leads to more flux during night
- HBG and Louis 9m still perform similarly
Temperature at 42 m

- Louis scheme overestimates temperature at 42m
- K-eps scheme
  - Best result for Stage 1 & 2
  - Constant temperature during night at Stage 3 as a result of a shallow SABL and no prescribed atmospheric forcing
- HBG and Louis 9m still perform similarly
Louis scheme leads to fast wind speed increase at surface
- Relative to HBG, Louis 9m scheme causes a longer mixing length under strong stabilities
  - HBG produces a low-level jet while Louis 9m does not
  - Still needs investigation on the elevated low-level jet and wind speed near surface
- K-eps gives right LLJ but wrong shear at the top of SABL
Conclusions

• The HBG scheme has been tested under strong stabilities (Ri>1) using CSIRO-developed SCM (CCAM) and LSM (CABLE).

• The HBG scheme gives
  • The best overall result
  • Elevated LLJ

• The original Louis (1979) scheme leads to
  • Overestimated surface temperature
  • Spurious deep SABL

• The k-eps scheme could collapse under strong stabilities
  • Underestimated surface temperature
  • Too shallow SABL
  • Right LLJ

• Louis 9m
  • Similar to HBG
  • No LLJ simulated
Thank you

CSIRO Oceans and Atmosphere
Dr Jing Huang
Research Scientist

+61 2 6281 8253
Jing.R.Huang@csiro.au
www.weru.csiro.au