**Motivation**

- Parameterization of the stably-stratified atmospheric boundary-layer is of crucial importance to large-scale atmospheric models, especially in Polar Regions.
- However, the performance of most available parameterization schemes are very stability-sensitive such that operational climate models have to impose excessive turbulence mixing to prevent decoupling of the atmospheric component from the land component under strong stability.
- We develop and test a general turbulence mixing model of the stable boundary-layer that works well under varying stabilities using large-eddy simulations (LES) and a Single-Column Model (SCM).

**Study Cases**

We study cases based on the one used by the Global Energy and Water Cycle Experiment Atmospheric Boundary-Layer Study (GABLS) (Beare et al. 2006; Cuxart et al. 2006). A horizontally homogeneous land surface and a constant geostrophic wind is assumed. Six cases with steady surface cooling rates and two cases with unsteady surface cooling rates are used:

<table>
<thead>
<tr>
<th>Case</th>
<th>Cooling rate (K h⁻¹)</th>
<th>h (m)</th>
<th>u₀ (m s⁻¹)</th>
<th>θ (K)</th>
<th>L (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.25</td>
<td>173</td>
<td>0.253</td>
<td>0.0406</td>
<td>105</td>
</tr>
<tr>
<td>B</td>
<td>0.5</td>
<td>149</td>
<td>0.234</td>
<td>0.0699</td>
<td>52.1</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>126</td>
<td>0.217</td>
<td>0.123</td>
<td>25.0</td>
</tr>
<tr>
<td>D</td>
<td>1.5</td>
<td>113</td>
<td>0.207</td>
<td>0.169</td>
<td>16.1</td>
</tr>
<tr>
<td>E</td>
<td>2</td>
<td>103</td>
<td>0.198</td>
<td>0.211</td>
<td>11.7</td>
</tr>
<tr>
<td>F</td>
<td>2.5</td>
<td>96.2</td>
<td>0.191</td>
<td>0.249</td>
<td>9.03</td>
</tr>
</tbody>
</table>

Table 1. Statistics for cases with steady surface forcings: Case A - F.

**Model Formulation**

Traditionally the mixing length under stable conditions has been formulated as:

\[ l_m = l_N f_\text{m}^{1/2} \left( R_i \right) \]

where \( l_N \) is the mixing length under neutral conditions, \( R_i \) is the gradient Richardson number and \( f_\text{m} \) is an empirical correction function. We show in Figure 2 that \( f_\text{m} \) is not a universal function of \( R_i \). We propose instead the following form of \( l_m \) and the comparison between the LES computed mixing length and the one given by this model is shown in in Figure 3.

\[ \frac{1}{l_m} = \frac{1}{l_N} + \frac{R_i}{\lambda} \]

**Results**

For cases with steady forcings:
- The HBG model reproduces the near-surface temperature that is closes to LES.
- For \( u_0 \), the HBG model converges to the LES results, while the other two do not.

For cases with unsteady forcings:
- All three models perform well for Case A.
- Only the HBG model works well for B-F.

**Conclusion**

We developed a new first-order turbulence mixing model for the stable atmospheric boundary-layer. This model was tested using the GFDL single-column model by comparing to fine resolution large-eddy simulations. Using test cases with both steady and unsteady surface cooling rates, we found that:
- The traditional parameterizations based on the concept of a stability correction function do not work under strong stabilities.
- Instead, the performance of our new model (HBG) is rather stability-insensitive (tested till \( R_i \) of \( \approx 1 \)).
- The HBG model also performs better when stability forcings are unsteady.
- With increasing instability: 1) angle between stress and strain decreases, 2) turbulent structures become more pancake-like, 3) buoyant destruction becomes ~ viscous dissipation.

**References**


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