The atmospheric boundary layer (ABL) represents the lowest portion of the atmosphere, which is in direct contact with the Earth’s surface and where most of the activities impacting human lives take place. Advances in computational resources and computing technologies have recently begun to enable a more routine application of atmospheric models at turbulence-resolving grid spacings. There are, however, different approaches depending on the model’s grid spacing, which in turn dictates the turbulence closure. Beyond the mesoscale limit, traditional weather prediction models are being exercised at fine grid spacings that fall into the so-called ‘gray-zone’ of turbulence parameterization (approximately 100 m $< \Delta < 1$ km). This range of grid spacings requires scale-aware parameterizations that account for the nature of partially resolved turbulence and horizontal heterogeneity (e.g., [1]). On the high wavenumber end of the energy spectrum, large-eddy simulation (LES) models ($\Delta < 10$ m) are used to explicitly represent production and part of the inertial range scales of three-dimensional turbulence. In this context, the application of the LES technique is no longer restricted to the classical idealized canonical scenarios and is experiencing a progressive transition toward large domain extents under heterogeneous forcing conditions that encompass part of the sub-meso and mesoscale spectrum.

As a result, these methods are enabling unprecedented insight into complex ABL phenomena in realistic environments, yet imposing new modeling challenges. With this Atmosphere Special Issue “Modeling of Atmospheric Boundary Layers at Turbulence-Resolving Grid Spacings”, we aimed to highlight recent progress in ABL modeling at turbulence-resolving scales, from new developments and methods to practical applications. The specific contents that were covered by the eight published papers can be organized into three topics: (1) using LES on idealized homogeneous scenarios to gain insight into the dynamics of ABLs and the role of grid spacing, (2) applications of LES to develop parameterizations, and (3) simulation of real-world ABLs downscaling from mesoscale to LES.

The first topic includes three studies by Park and Baik et al. [2], Park et al. [3] and Bopape et al. [4]. In [2], the authors investigated the characteristic of the decaying convective boundary layer (CBL) from LES results, after a sudden removal of surface heating is applied. After the cut-off, coherent convective circulations last about one convective time scale and then fade away. In the mixed layer, the decay time scale increases with height, indicating that nonlocal ABL-scale eddies decay slower than near-surface local eddies. In a follow up study, Park et al. [3] performed nine LESs to systematically investigate the role of wind shear in the decay on the CBL. The authors found that after the surface heat flux is stopped, the boundary-layer-averaged turbulent kinetic energy (TKE) stays constant for almost one convective time scale and then decreases following a power law. In the weak shear (buoyancy-dominated) cases turbulent structures are found to oscillate over time, while for strong-shear cases, mechanical turbulent eddies are generated, which transport heat downward in the lower boundary layers when convective turbulence decays significantly. In the last study on this topic section, Ref. [4] utilize different grid spacings to analyze grid-convergence aspects of the CBL as simulated by LES. It is found that for coarse grid spacings approaching the gray zone, the contribution to the heat flux from cold descending air is increased, and that from cold ascending air is reduced in the lower boundary layer. An interesting
experiment performed by the authors here is to increase subgrid-scale mixing for coarse grids within the LES regime, which results in overall improvements with respect to the control case at the same grid spacing. However, these improvements do not hold for grid spacings with the gray zone.

In the second topic that this Special Issue has contributed to, there are two articles [5,6]. One of them, by Durán et al. [5], employs LES data to develop a new length scale formulation that can be used by existing one-dimensional turbulence closures at gray zone grid spacings. The novelty of this length scale parameterization is that it is computed from the effective dissipation rate, derived from the LES results, and that takes into account the influence of the cross-scale transfer of TKE from the resolved to the sub-grid scales, which is non-zero in the gray zone of turbulence. The other study within this topic, by Barron et al. [6], utilizes LES output data to generate a transfer function between cloud size distributions (two-dimensional) and chord length retrieval methods (one-dimensional). The authors find that the cloud area distribution conditional on the chord length behaves like a gamma distribution with well-behaved parameters, in turn enabling an adjustment to the chord length distribution so it more closely matches the cloud area distribution.

The final topic, dealing with LES in the context of mesoscale-to-microscale downscaling for ABL modeling includes three publications [7–9]. Doubrawa and Muñoz-Esparza [7] perform coupled mesoscale-LES simulations of five daytime periods down to a grid spacing of \( \Delta = 25 \) m, used to evaluate available gray-zone parameterizations at \( \Delta = 333 \) m. Their results reveal that users should refrain from coarse LES and favor the scale-aware, Shin-Hong parameterization [10] over traditional one-dimensional schemes, with coarse LES overestimating turbulent energy across scales and YSU underestimating it and failing to reproduce its horizontal structure. Despite yielding the best results, the Shin-Hong scheme overestimates the effect of grid dependence on turbulent transport, highlighting the outstanding need for improved solutions to seamlessly parameterize turbulence across scales. Another contribution to this topic was made by Udina et al. [8]. In this study, a 25-day long nested mesoscale-LES experiment was performed, reaching a grid spacing of 111 m in the innermost domain, and with the purpose of exploring the ability of the model to reproduce the turbulence magnitudes within the first tens of meters of the boundary layer. The authors found that only LES is able to reproduce the energy of eddies with lifetimes shorter than a few hours (nonexistent in the mesoscale simulation). However, TKE is generally underestimated in their simulations compared to sonic anemometer observations, mainly due to a low standard deviation of the vertical velocity component (likely attributed to insufficient vertical grid spacing and probably due to the inaccuracy of the sub-grid scheme for coarse-LES grids). Finally, the study from Arthur et al. [9], which in fact was the first manuscript opening this Special Issue, takes the mesoscale-LES downscaling methodology to the next level by modeling wind turbine effects at their innermost LES domain (\( \Delta = 10 \) m). The authors simulated the wind farm response to a frontal passage, demonstrating the adequacy of the meso-LES coupling strategy in capturing both the dynamics of the frontal passage and the turbine response. An interesting aspect of this study was to show that use of the cell perturbation method to generate inflow turbulence in the nested LES domain [11,12], and also employed by the other studies on this topic, improves the representation of turbulence structures within the region of interest.

The articles collected in this Special Issue demonstrate the value of the large-eddy simulation technique in order to advance our understanding and predictive modeling capabilities of ABL phenomena. These contributions provide illustrative examples of the benefit of LES as a tool to: (i) improve our understanding of ABL dynamics, (ii) support the development of parameterizations, and (iii) provide realistic representation of ABL phenomena under real-world mesoscale-driven forcing conditions.

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References
1. Honnert, R.; Efstathiou, G.A.; Beare, R.J.; Ito, J.; Lock, A.; Neggers, R.; Plant, R.S.; Shin, H.H.; Tomassini, L.; Zhou, B. The Atmospheric Boundary Layer and the “Gray Zone” of Turbulence: A critical review. *J. Geophys. Res. Atmos.* **2020**, *125*, e2019JD030317. [CrossRef]
2. Park, S.B.; Baik, J.J. Characteristics of Decaying Convective Boundary Layers Revealed by Large-Eddy Simulations. *Atmosphere* **2020**, *11*, 434. [CrossRef]
3. Park, S.B.; Baik, J.J.; Han, B.S. Role of Wind Shear in the Decay of Convective Boundary Layers. *Atmosphere* **2020**, *11*, 622. [CrossRef]
4. Bopape, M.J.M.; Plant, R.S.; Coceal, O. Resolution Dependence of Turbulent Structures in Convective Boundary Layer Simulations. *Atmosphere* **2020**, *11*, 986. [CrossRef]
5. Ődén, I.B.; Schmidli, J.; Bhattacharya, R. A Budget-Based Turbulence Length Scale Diagnostic. *Atmosphere* **2020**, *11*, 425. [CrossRef]
6. Barron, N.R.; Ryan, S.D.; Heus, T. Reconciling Chord Length Distributions and Area Distributions for Fields of Fractal Cumulus Clouds. *Atmosphere* **2020**, *11*, 824. [CrossRef]
7. Doubrawa, P.; Muñoz-Esparza, D. Simulating Real Atmospheric Boundary Layers at Gray-Zone Resolutions: How Do Currently Available Turbulence Parameterizations Perform? *Atmosphere* **2020**, *11*, 345. [CrossRef]
8. Udina, M.; Montornès, A.; Casso, P.; Kosović, B.; Bech, J. WRF-LES Simulation of the Boundary Layer Turbulent Processes during the BLLAST Campaign. *Atmosphere* **2020**, *11*, 1149. [CrossRef]
9. Arthur, R.S.; Mirocha, J.D.; Marjanovic, N.; Hirth, B.D.; Schroeder, J.L.; Wharton, S.; Chow, F.K. Multi-scale simulation of wind farm performance during a frontal passage. *Atmosphere* **2020**, *11*, 245. [CrossRef]
10. Shin, H.H.; Hong, S.Y. Representation of the subgrid-scale turbulent transport in convective boundary layers at gray-zone resolutions. *Mon. Weather Rev.* **2015**, *143*, 250–271. [CrossRef]
11. Muñoz-Esparza, D.; Kosović, B.; Mirocha, J.; van Beeck, J. Bridging the transition from mesoscale to microscale turbulence in numerical weather prediction models. *Bound. Layer Meteorol.* **2014**, *153*, 409–440. [CrossRef]
12. Muñoz-Esparza, D.; Kosović, B.; Van Beeck, J.; Mirocha, J. A stochastic perturbation method to generate inflow turbulence in large-eddy simulation models: Application to neutrally stratified atmospheric boundary layers. *Phys. Fluids* **2015**, *27*, 035102. [CrossRef]

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