Cloud microphysics and turbulence statistics of the nocturnal stratocumulus-capped boundary layer: New approaches to model evaluation based on ship-borne data

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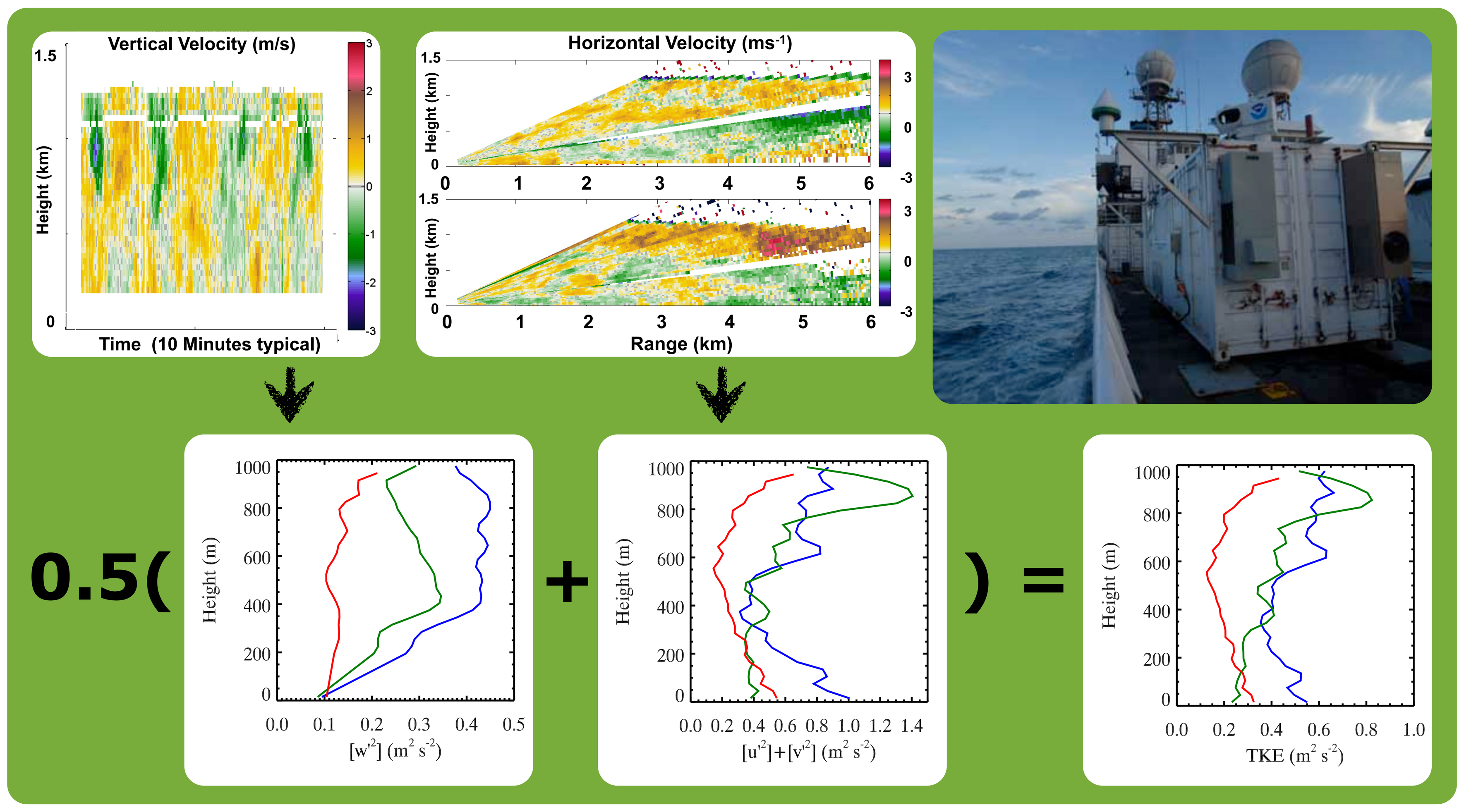
Goals

The VOCALS field experiment yielded a rich data set on cloudy boundary layer dynamics and the opportunity to evaluate numerical models against observations. Here we

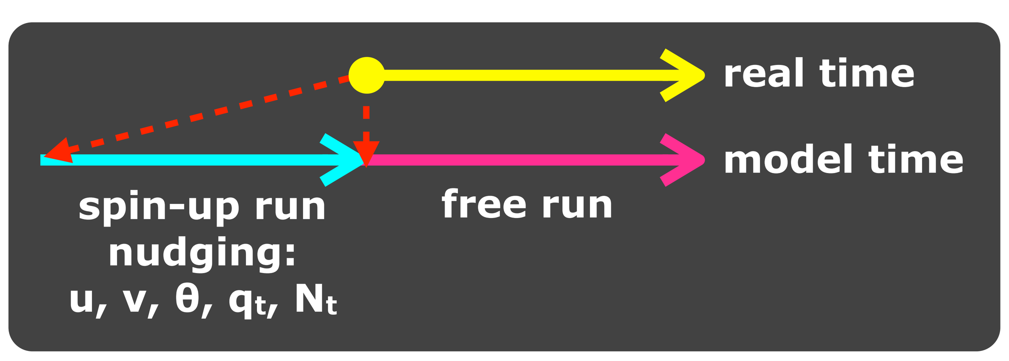
- evaluate the ability of the Weather Research and Forecasting (WRF) model to represent turbulence in the cloudy marine boundary layer compared to measurements by a high resolution Doppler lidar on board the R. H. Brown
- identify ways to improve the model.



Above: The bottom panels are a product from the Doppler lidar. These profiles represent time evolution over one hour.

Simulation strategy for evaluation with Lidar data

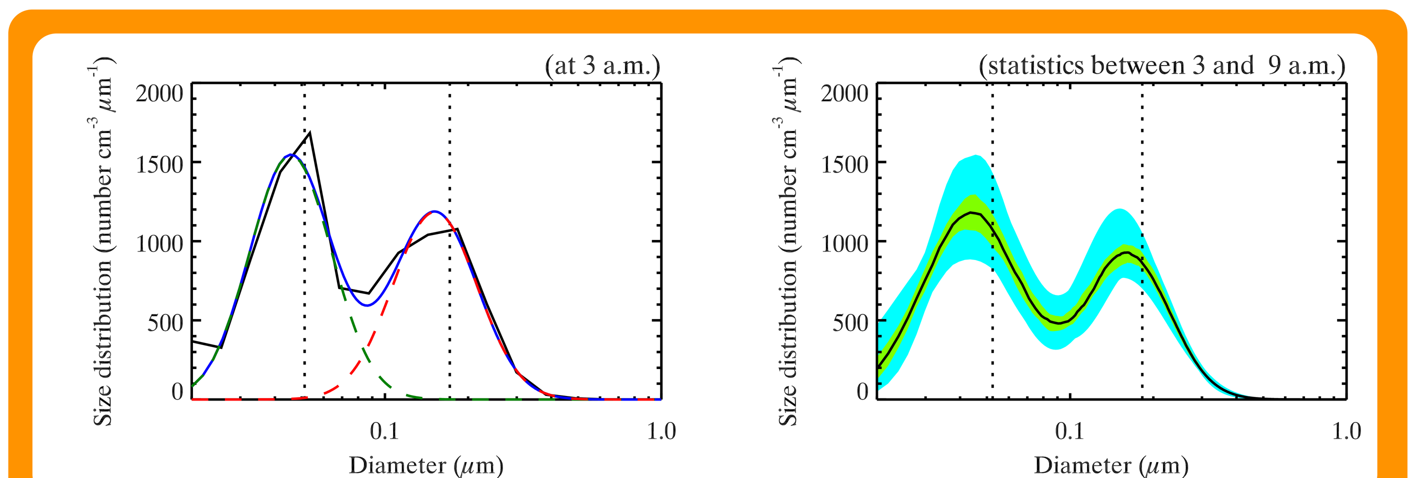
Clouds and turbulence are inextricably linked. However, this linkage is missing at the initial model time. In order to compare with the observed turbulence, establishing the turbulence associated with the initial cloud field is crucial. We use a nudging technique to maintain the horizontal mean fields while turbulence is allowed to freely develop (spin-up run). This produces the required adjustment of turbulence and cloud for subsequent simulation (free run).



Base case

- Non-precipitating, nocturnal stratocumulus
- Initial conditions based on 3:36 a.m. UTC 2008/11/18
- Domain: 6.4 x 6.4 x 2 km
- Grid spacing: $\Delta x = \Delta y = 100$ m, $\Delta z \sim 10$ m (200 levels)
- Time step: 0.2 seconds (physical mode), 8 acoustic substeps (for acoustic and gravity waves)
- Duration: 4-hour spin-up run, 6-hour free run
- 5th-order horizontal and 3rd-order vertical advection scheme (Wicker and Skamarock 2002)
- Prognostic 1.5-order SGS TKE closure
- Two-moment microphysics (Feingold et al. 1998)
- RRTMG longwave radiation (updated every 30 seconds)
- Subsidence estimated from ECMWF operational data
- 1-hour nudging time scale

Aerosol distribution



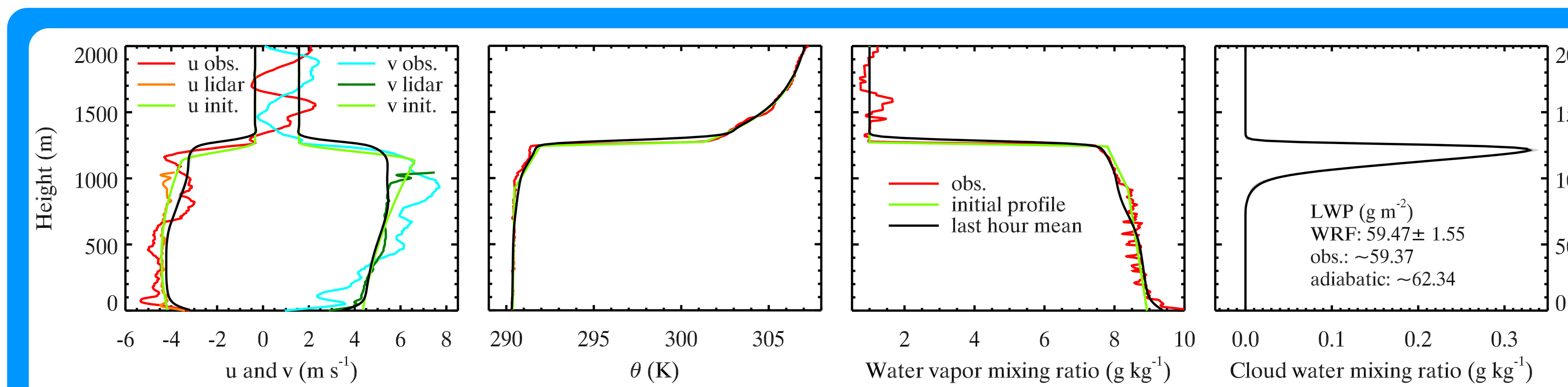
The observed aerosol size distribution is bimodal, and is approximated by a bimodal lognormal distribution with modes at 0.05 microns and 0.18 microns. This aerosol concentration produces very little drizzle.

4 Spin-up runs

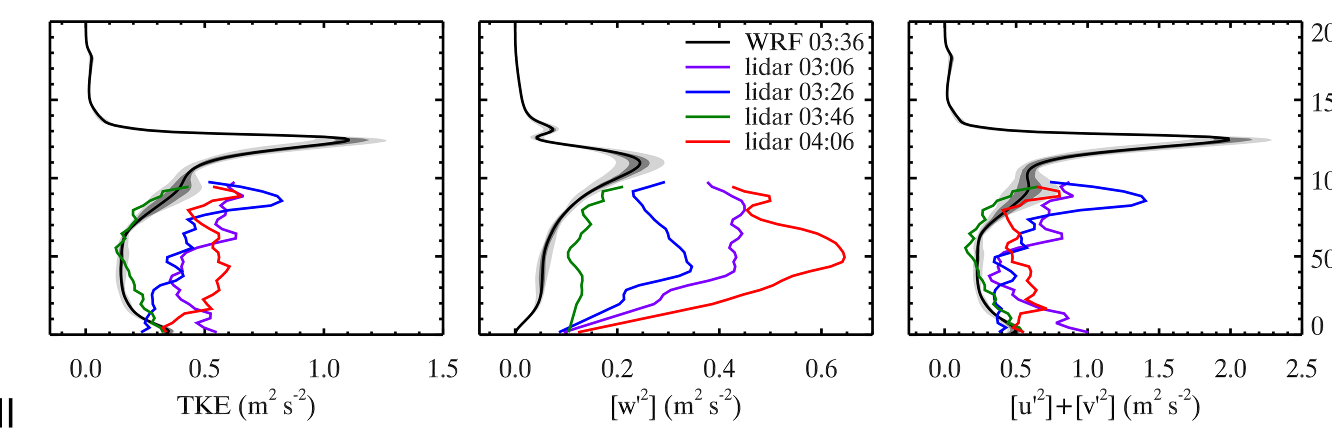
In order to investigate the effect of domain size and resolution for both spin-up and free runs, we performed 4 spin-up simulations. The first case is the base case.

Δx (m)	Δz (m)	X (km)
100	10	6.4
100	10	12.8
100	10	25.6
50	5	6.4

Spin-up run

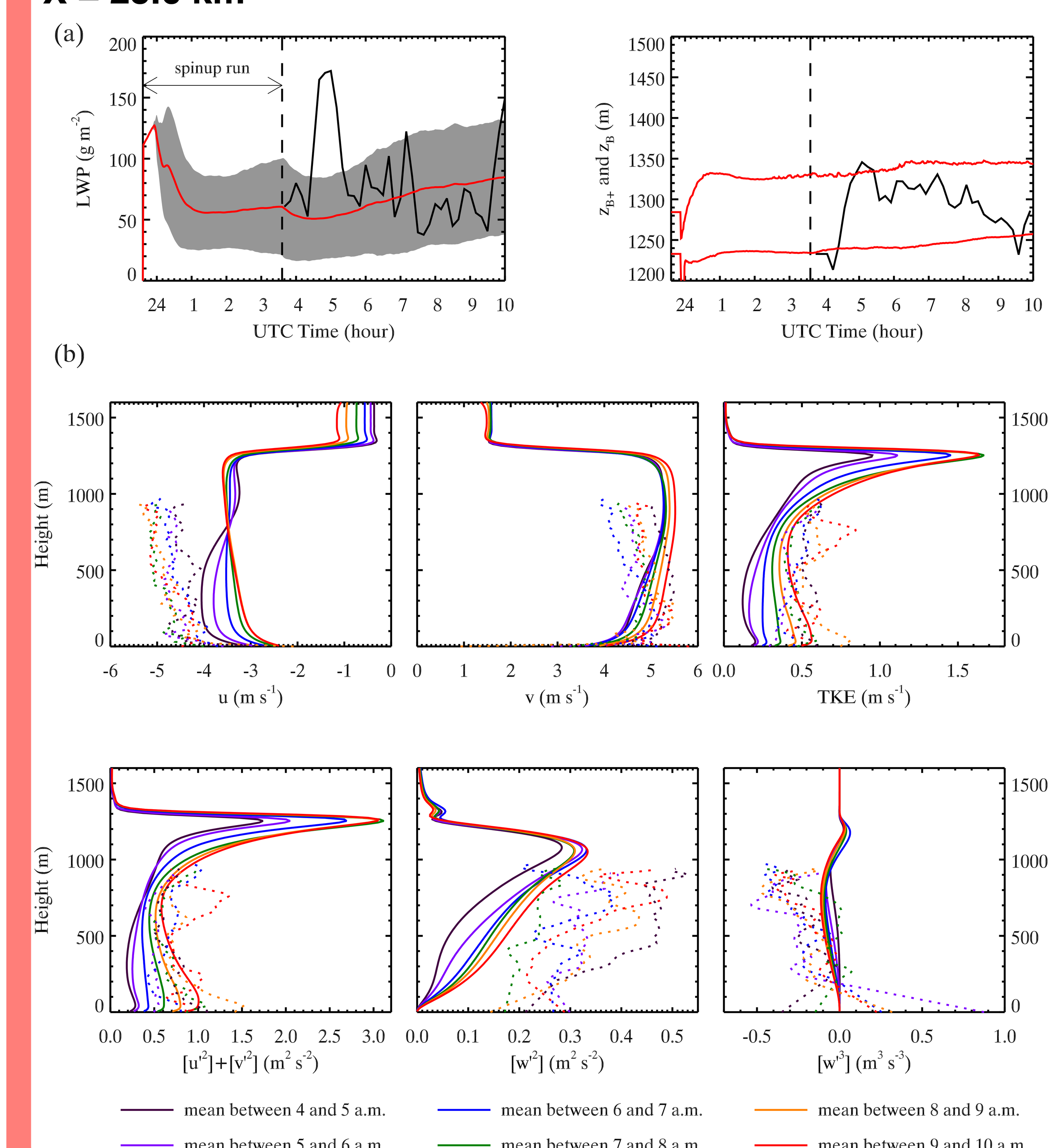


Spin-up results for the base case. A Tukey box plot is used for the last hour of WRF. Narrow variability suggests that the turbulence is in balance with the mean profiles. **The TKE is underestimated, especially the [w'²].** All other cases produce similar results.



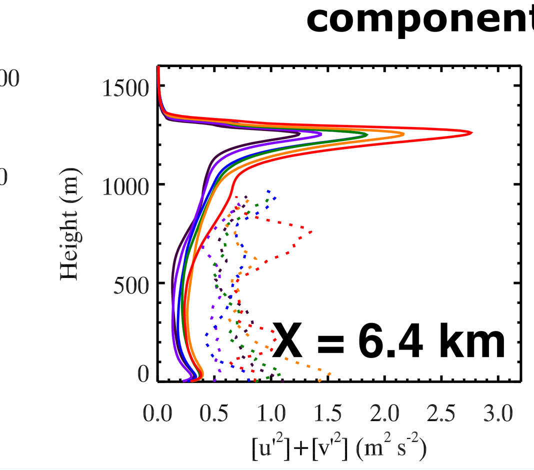
Free run

X = 25.6 km



The best free run among the cases simulated. The following modification has been made: 1) stronger divergence to match the observed PBL top, 2) **interactive surface flux calculation, which produces weaker forcing than that based on observed fluxes, and results in more radiatively driven turbulence.**

Our simulations suggest that the domain size has more effect than the resolution. As the domain becomes larger, the PBL becomes more turbulent, especially in the horizontal component.



Diffusion

Turning off the SGS diffusion produces stronger turbulence, as expected, and provides a better match to the lidar measurements. This suggests that either the SGS scheme is not adequate or the model's numerical diffusion is too large. Further research involving numerical diffusion (e.g., advection scheme) is required to address this point.