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Diurnal Variation of Near-Surface Wind Speed Probability Distribution under Clear and Cloudy Sky

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1 Observations

Land surface wind speed (SWS) distributions at 3734 global weather stations are characterized by the Weibull-like PDF during the day and by a nighttime PDF with a consistently greater skewness as shown in Figure 1 (He, et al. 2010). Recent 10-year wind tower observations at Cabauw indicate that this large nighttime skewness is a shallow feature in the stable boundary layer (Monahan, et al, 2011; He et al., 2012). Current state of art RCMs fail to capture this observed diurnal variation of near surface wind speed PDF (He et al, 2010).

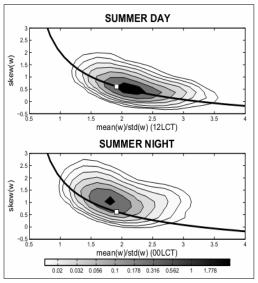

Fig.1. Kernel density estimates of the joint PDFs of mean(w)/std(w) and skew(w) for (top) daytime and (bottom) nighttime weather station data over global land in the summer season during 1979–99. The contour intervals are logarithmically spaced. The solid line is the theoretical curve for a Weibull variable, and the white square corresponds to a Rayleigh variable.

Here, we extend and continue our previous studies by addressing the following questions:

- Does diurnal variation of the SWS PDF share the same features under clear-sky and cloudy skies;
- Can we simulate the observed diurnal variation of SWS PDF in a single-column model (SCM) with a comprehensive physical parameterization package and potentially new parameterizations?
- How is the diurnal cycle of SWS PDF influenced by the diurnal cycle of the background geostrophic winds?

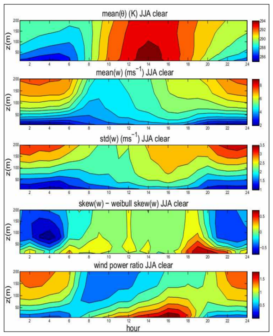

Fig. 2. The observed diurnal variation of potential temperature; mean, standard deviation, and skewness excess of boundary layer wind speed, and diurnal ratio of wind power density under clear-sky in JJA at the Caubauw site during the period from 2007 to 2011. The skewness excess is defined as the difference between the observed skewness and that of a best-fit Weibull variable. The nighttime wind extreme is contained within the shallow nocturnal boundary layer under clear-skies.

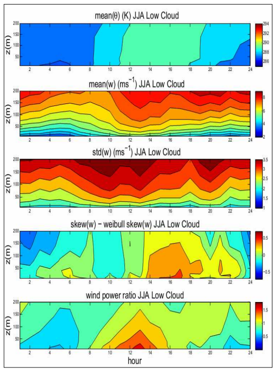

Fig. 3 As in Fig. 2 but under cloudy-sky conditions. The large SWS skewness excess contained in the shallow stable boundary layer under clear-skies is not found under cloudy conditions.

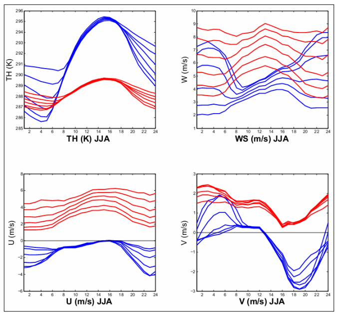

Fig. 4 Composite diurnal cycles of mean potential temperature, wind speed, and U,V components at six vertical levels (10m, 20m, 40m, 80m, 140m, 200m) under clear-sky (blue line) and cloudy-sky (red line) in JJA from 2007 to 2011 at Cabauw.

Both the thermal structure and wind shear undergo significantly different diurnal variations under clear-sky and cloudy skies. In the case of clear skies, much stronger temperature inversion is developed at the top of nocturnal boundary layer and near surface winds becomes well mixed within daytime unstable PBL; while under cloudy-sky conditions, the diurnal cycle of potential temperature is very weak and both day-time and night-time wind shear is large from the surface to 200 m.

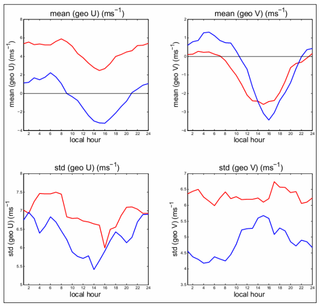

Fig.5 Diurnal cycles of mean and standard deviation of surface geostrophic wind in U (left) and V (right) under clear-sky (blue line) and cloudy-sky (red line) conditions in JJA during 2007 to 2011 at Cabauw. A sea-breeze circulation is evident under clear-sky conditions; while under cloudy skies, surface geostrophic winds is mainly from northwest (ocean to land) throughout the day.

2. Clear-sky SCM simulations

The clear-sky near surface wind speed PDF is simulated using the SCM version of the Canadian Centre for Climate Modelling and Analysis (CCCma) fourth-generation AGCM (CanAM4), with a new semi-empirical diagnostic turbulent kinetic energy scheme, a stochastic parameterization of intermittent mixing at the boundary layer inversion, and a red noise process for the background geostrophic winds with a 2-day autocorrelation. Temperature and humidity profiles were relaxed to specified (very dry) profiles.

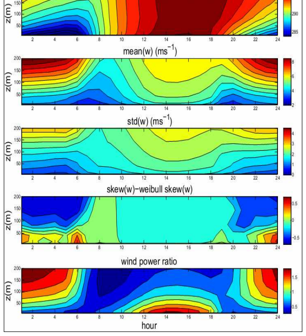

Fig. 6 Simulated diurnal cycle of potential temperature and wind speed PDF from surface to 200m with the fixed diurnal varying incoming solar radiation at TOA and an imposed geostrophic wind using the observed diurnal variation of mean and standard deviation shown in Fig.5. Intermittent mixing is parameterized within the boundary layer inversion.

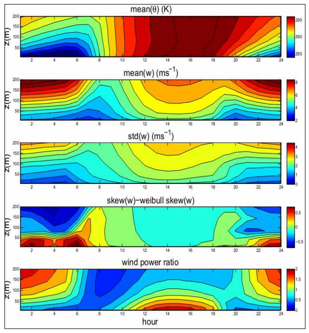

Fig. 7 As in Fig. 6 but with an imposed geostrophic wind was modelled as a red noise process with a constant mean (3,0) m/s and standard deviation (6,6) m/s. Comparing with Fig. 6, when diurnal variations of surface geostrophic winds are turned off, the SCM simulates an unrealistically large SWS skewness within the shallow nocturnal PBL in the early morning.

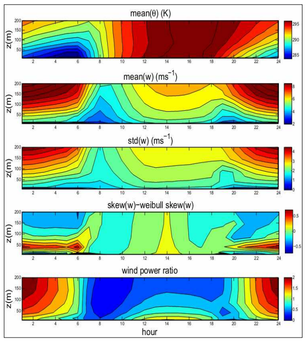

Fig. 8 As in Fig. 7 but stochastic process of intermittent mixing is turned off within the boundary layer inversion. All wind structures change, particularly diurnal variations of SWS skewness and wind power ratio are poorly represented under clear-sky conditions. The utility of stochastic parameterization of intermittent mixing in successfully simulating SWS PDF is further addressed in Monahan et al., 2011 and He et al., 2012.

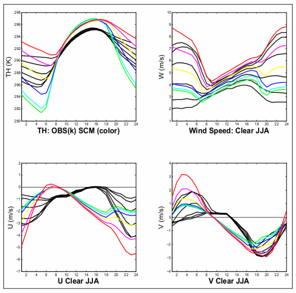

Fig. 9 Comparison between JJA observations at Cabauw (black) and SCM simulation (color) at six levels shown in Fig. 4 for mean potential temperature, wind speed, and vector wind components.

This comparison suggests that the SCM with a new semi-empirical diagnostic TKE scheme and a stochastic parameterization for intermittent mixing does a reasonable work in simulating the correct vertical structure of mean potential temperature and mean wind shear in both the nocturnal stable PBL and the daytime unstable PBL under clear-sky conditions.

3. Conclusions

- The observed near surface SWS PDF is significantly different between clear-sky and cloudy-sky conditions;
- Intermittent mixing in the stable stratification is necessary for realistic simulating the clear-sky diurnal variation of the SWS PDF;
- The SCM can better simulate the observed JJA clear sky SWS PDF when diurnal variations of geostrophic winds are accounted for;
- Simulations were improved by adding a simple stochastic parameterization for intermittent mixing in the stable boundary layer;
- A natural future step is to understand and better simulate cloudy-sky SWS PDF using current SCM potentially with improved representation s of moist processes.

References

He et al., JGR-Atmos, 2010;
Monahan, et al., J. Climate, 2011;
He, et al., J. Climate, 2012.