DTU Wind Energy
Department of Wind Energy

# WRF Sensitivity Analysis of Boundary Layer Clouds During the Cold Season

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Top-level Research Initiative

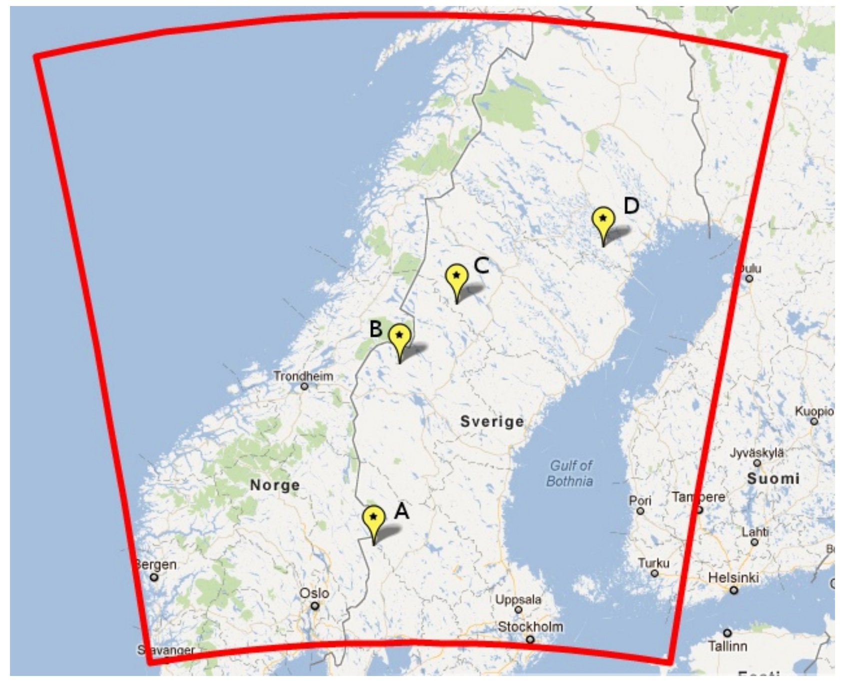


Figure 1: 10 km Modeling domain and sites of interest. Sites are approximate locations of wind parts found on Google Earth satellite photos & labeled alphabetically from south to north.

## Motivation

• Icing can be modeled based on output from NWP models such as WRF, but first models must be studied with regards to the properties important for turbine icing.

• Previous studies of microphysical schemes have focused on clouds outside of the boundary layer or fog, for turbine icing the intermediate levels are of greatest importance.

## Methodology

• WRF was run on 2 domains 30 km and 10 km with results coming from the 10 km domain (fig 1.)

• A total of 9 studies: 3 Planetary Boundary Layer (PBL) schemes coupled to 3 microphysical (mp) schemes

  • Mp Schemes: SUNY-Lin, Thompson, WSM5

  • PBL Schemes: MYNN2, MYJ, YSU

• Simulation ran 2010-12-31 - 2011-01-30 in 10 day chunks with 12 hours of spinup time

• Input and boundary conditions were from 1 degree FNL dataset, and 30 km domain was nudged using this data every 6 hours.

• 63 vertical levels were used with 10 levels in the rotor plane defined as between 35 and 125 m.

## Percentage of active icing hours

• At most sites differences in icing are dominated by microphysics.

  • SUNY-Lin consistently lowest, with Thompson consistently highest

• Amount of icing decreases up to 10% or 72 hours with mean vs max

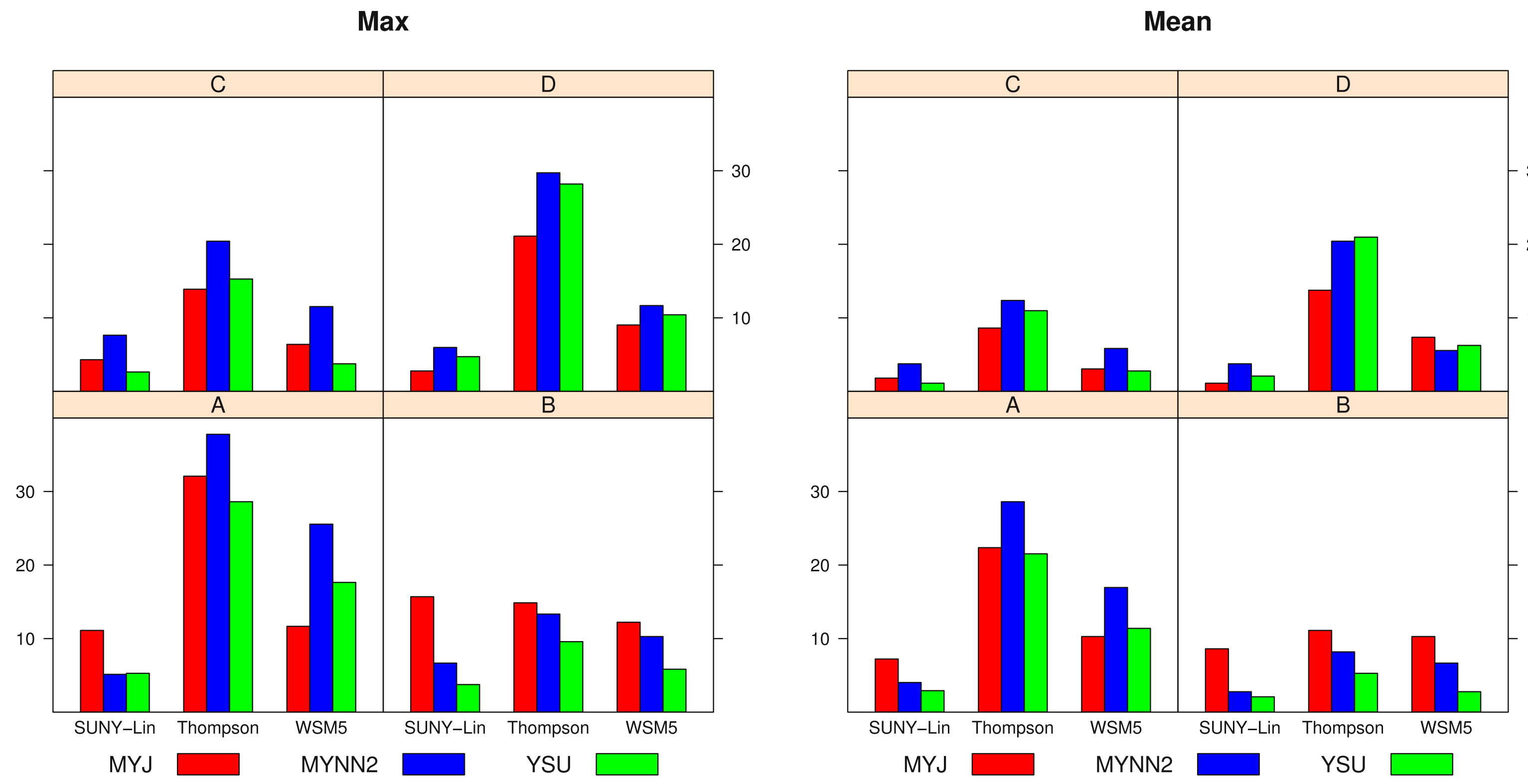


Figure 2: Percentage of period which has had icing. Max indicates at least one level in the rotor plan had icing conditions. The mean graph shows locations where the average values across the rotor plane met the criteria. Groups show different mp schemes, while colors indicate different PBL schemes.

## Temperature vs icing

• WSM5 and SUNY-Lin both show warmer temperature distributions when icing is occuring.

• Temperature differences could impact type of ice formed

• Little difference in between different sites (not shown)

• PBL schemes don't make a large difference in the average temperature distribution across the rotor plane, but changes are larger for icing hours

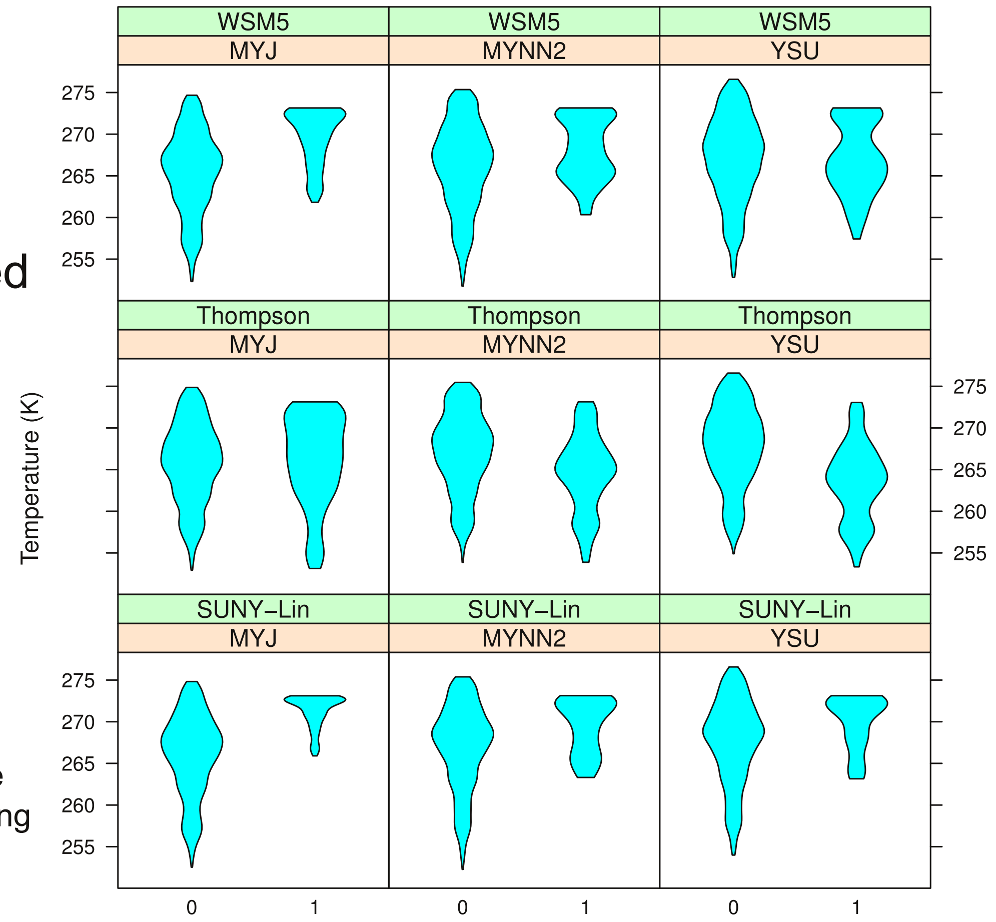


Figure 3: Violin plot of mean temperature across rotor plane for icing (1) and no icing (0) conditions across all four sites.

## Wind speed vs icing

• All schemes show lower wind speed distributions at sites other than B.

• Large differences between the sites, especially for icing conditions with B, when using the MYJ & MYNN2 PBl scheme. This combination shows higher wind speed distributions for icing cases than no-icing cases, only example as such.

• SUNY-Lin mp scheme shows very low wind speeds during icing events at C & D.

• Very large dependece on the PBL scheme used compared to icing frequency and temperature plots.

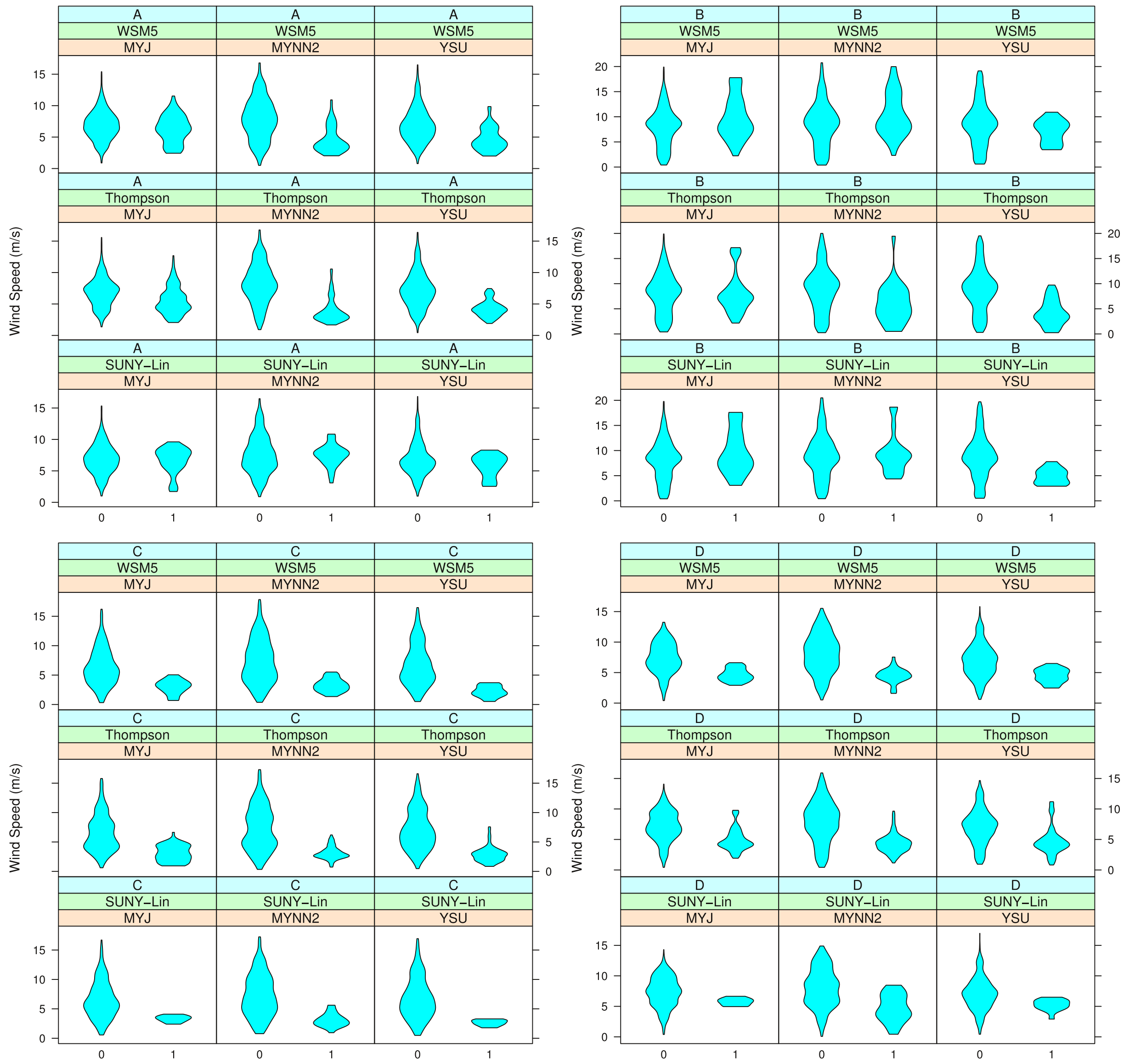

Figure 4: Violin plot of mean wind speed across rotor plane for icing (1) and no icing (0) conditions for each site.

## Future Work - Icing Frequency

• More advanced icing model based on Brakel et al (2007)

• Introduction of sublimation and melting

• Use of CFD modeling to help better determine droplet flow around turbine blade

• Higher resolution WRF modeling

• Evaluation of icing periods against observations

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## Hydrometeor Classes

- droplet - Small liquid phase cloud particle
- rain - Large liquid phase cloud particle
- ice - Small solid phase cloud particle
- snow - Large solid phase cloud particle

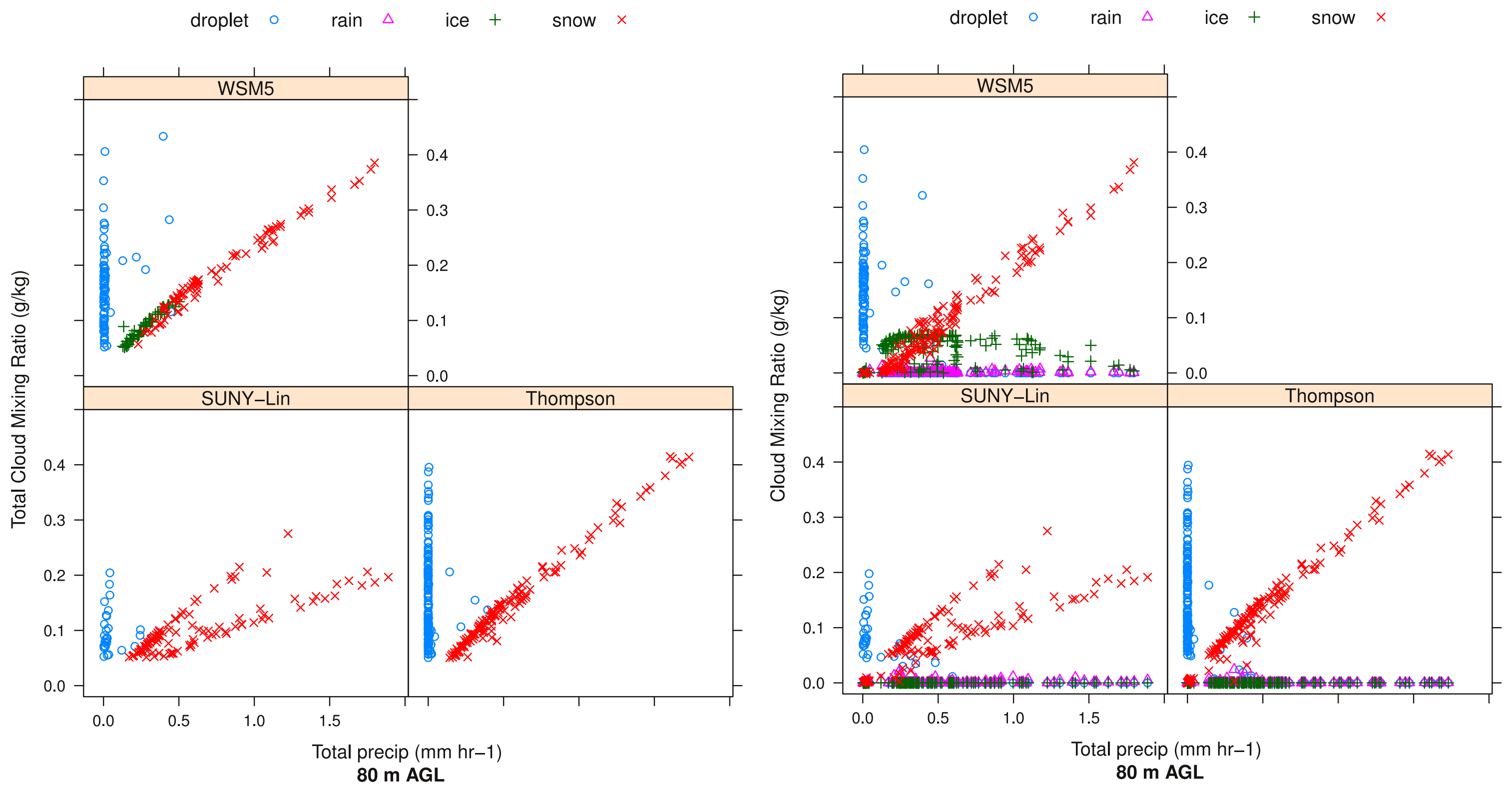


Figure 5: Scatter plot showing cloud mixing ratio vs precipiation rate for icing conditions based on the sum of all hydrometeor types at hub height (80 m) using the MYNN2 PBL scheme at site A. Left figure shows total cloud mixing ratio, with the dominant category represented by different colors and shapes. Right figure shows individual hydrometeor groups.

## Should precipitation be included in icing model?

- Snow is the dominant hydrometeor class during precip
- WSM5 is the only mp scheme with significant cloud ice
- Rain hydrometeor is a non-factor for all mp schemes
- Total hydrometeor amount increases linearly with precipiation rates for Thompson and WSM5
- SUNY-Lin scheme has two linear growth rates
- Most droplet dominated clouds produce little precip

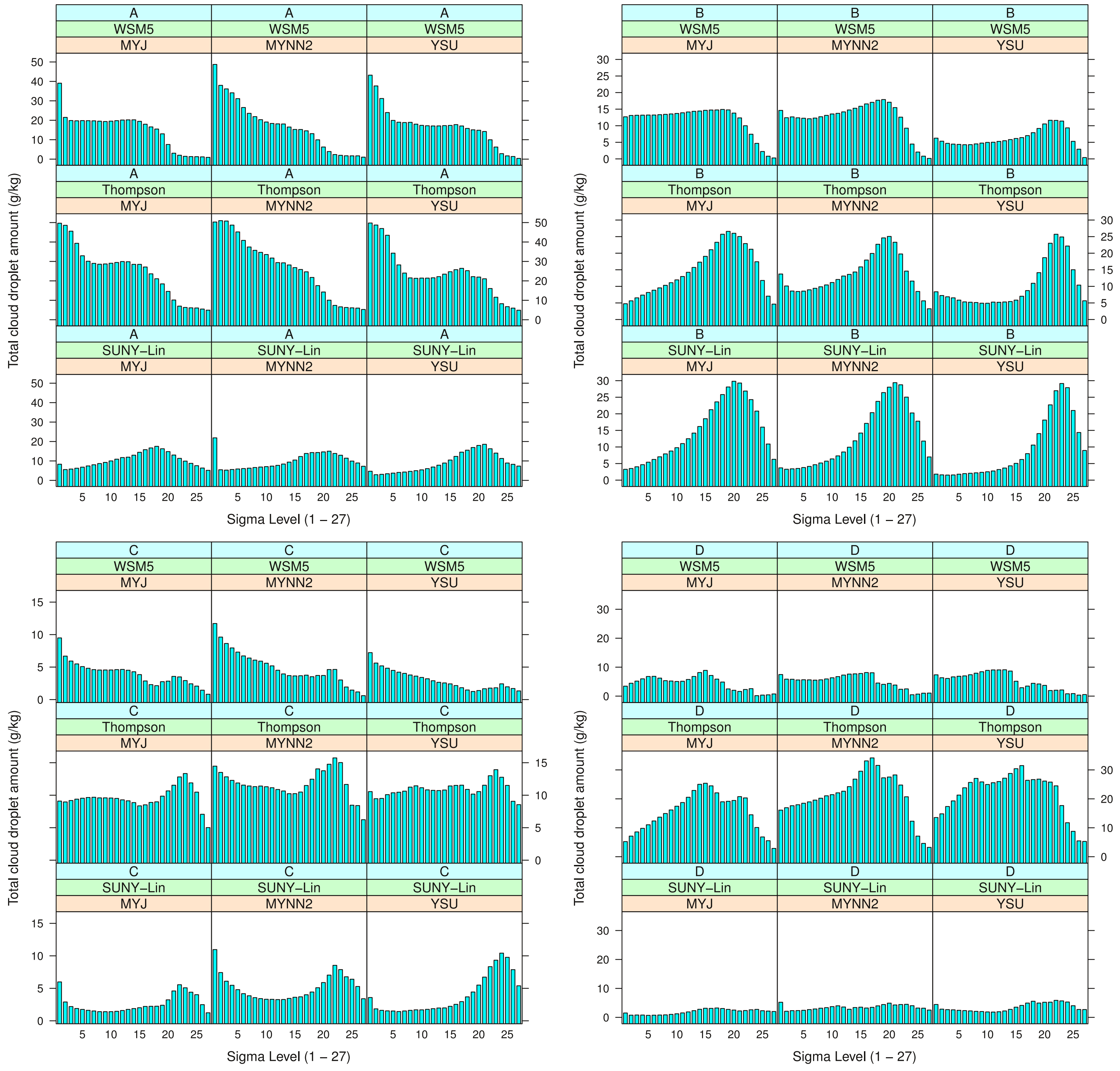


Figure 6: Barchart showing the total cloud droplet mixing ratio for sigma levels from 1-27 (0-1000m agl) at each station & for each model sensitivity for the entire modeling period.

## Cloud Droplet Mixing Ratio (qc) with Height

- All stations have approximately same height for each sigma level (not shown)
- Height of maximum qc varies greatly with station
  - Site B shows peak of qc at highest altitude
  - At all sites except B SUNY-Lin shows flattest profiles
  - Most sites show reduced qc at top and bottom of selected heights
  - Both WSM & Thompson show large amounts of qc at the surface for site A, most likely fog in the model. Site C Shows a similar trend for WSM5.
- PBL does not show a large impact on the location of qc amounts in the vertical
- Distributions inside the rotor plane ~ sigma 3-13 generally show flat profiles or profiles which increase slightly with height.

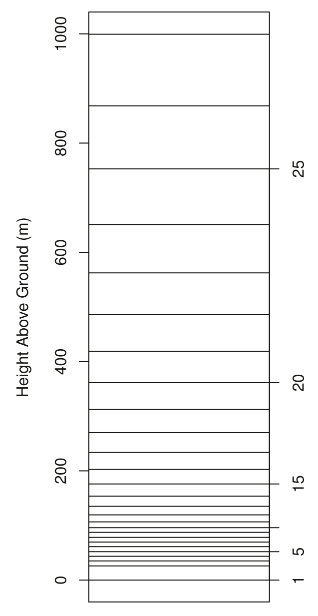


Figure 7: Mean height above ground of each sigma level

## Conclusions

- Selection of MP scheme has large impact on cloud particle amount and type
- PBL scheme is of lesser importance, but still can make significant differences, especially in the related wind profile
- Site location is key in types of interactions between schemes
- Thompson consistently shows most liquid cloud in the PBL
- SUNY-Lin consistently shows least liquid cloud
- WSM5 only scheme with significant ice particles in PBL
- Cloud particles scale with rate of precip, so precip need not be included in turbine icing models
- Interaction between PBL and mp schemes largely affects wind speed & temperature profiles during icing conditions

## Future Work Boundary Layer Clouds

- Evaluate findings against observations at similar locations
- Examine mixed phase clouds in the model
- Expand height based evaluation to include mixed and solid phase clouds
- Examine diurnal variation in cloud parameters

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References:
Brakel, T. W., J. P. F. Charpin, and T. G. Myers, 2007: One-dimensional ice growth due to incoming supercooled droplets impacting on a thin conducting substrate. International Journal of Heat and Mass Transfer, 50, 1694–1705, doi:10.1016/j.ijheatmasstransfer.2006.10.014.