Assessing Physical Relationships Between Atmospheric State and Fluxes and Boundary Layer Variability at McMurdo Station, Antarctica

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The self-organizing map (SOM) neural network, pattern sorting technique is used to to assess relationships between atmospheric conditions and boundary layer regimes near McMurdo Station, Antarctica, during the Department of Energy (DOE) ARM (Atmospheric Radiation Measurement) West Antarctic Radiation Experiment (AWARE), campaign from 23 November 2015 through 5 January 2017.

Objective:

-Understanding boundary layer stability (defined by the potential temperature profile) in Antarctica has important implications for the surface energy budget, momentum and moisture fluxes, as well as processes such as turbulence generation associated with different boundary layer stability regimes (e.g. Nigro et.al., 2017, Cheng and Brutsaert, 2004, Lawrence and Balsley, 2014).

-Use observations from the year long AWARE campaign to assess how near surface atmospheric characteristics vary with differing boundary layer stability regimes

-Define potential temperature profiles that span the range of boundary layer states in the AWARE radiosonde data using SOMs

-Identify relationships between the SOM-identified boundary layer regimes and atmospheric state and fluxes

Data and Methods:

- Data:
  - Radiosonde profiles of temperature, pressure, wind speed, and relative humidity taken from 30 November 2015 through 3 January 2017 at McMurdo Station, Antarctica (-77.85 °S, 166.66 °E, Map 1)
  - Radiation data of downwelling longwave radiation, upwelling longwave radiation, net longwave radiation, and net radiation taken from 24 November 2015 through 20 December 2016 were collected at an observation site several km away from McMurdo Station (-77.85 °S, 166.73 °S).
- Methods:
  - Interpolation
    - Radiosonde observations were interpolated to a normalized grid starting at 10.1 meters, every 5 meters up to 500 meters: in this range there will be clear indication of the boundary layer structure.
  - Self Organizing Maps (SOMs)
    - The SOM neural network pattern matching algorithm is used to identify 20 potential temperature anomaly profile patterns that span the range of profiles observed in the year-long AWARE radiosonde data.
    - Potential temperature anomaly was used to train the SOM because it will preserve the shape of the boundary layer profile while ignoring temporal changes in potential temperature across the entire study period.
    - Each individual radiosonde profile is mapped to a single SOM pattern such that the squared difference between the individual profile and the SOM pattern is minimized.
    - A list of profiles mapped to each profile is generated and can be used to composite other variables to the same SOM pattern to understand what conditions were like when those profiles occurred.

Map 1: Location of study, McMurdo Station, Antarctica, courtesy of Quantarctica.

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Acknowledgements and References:

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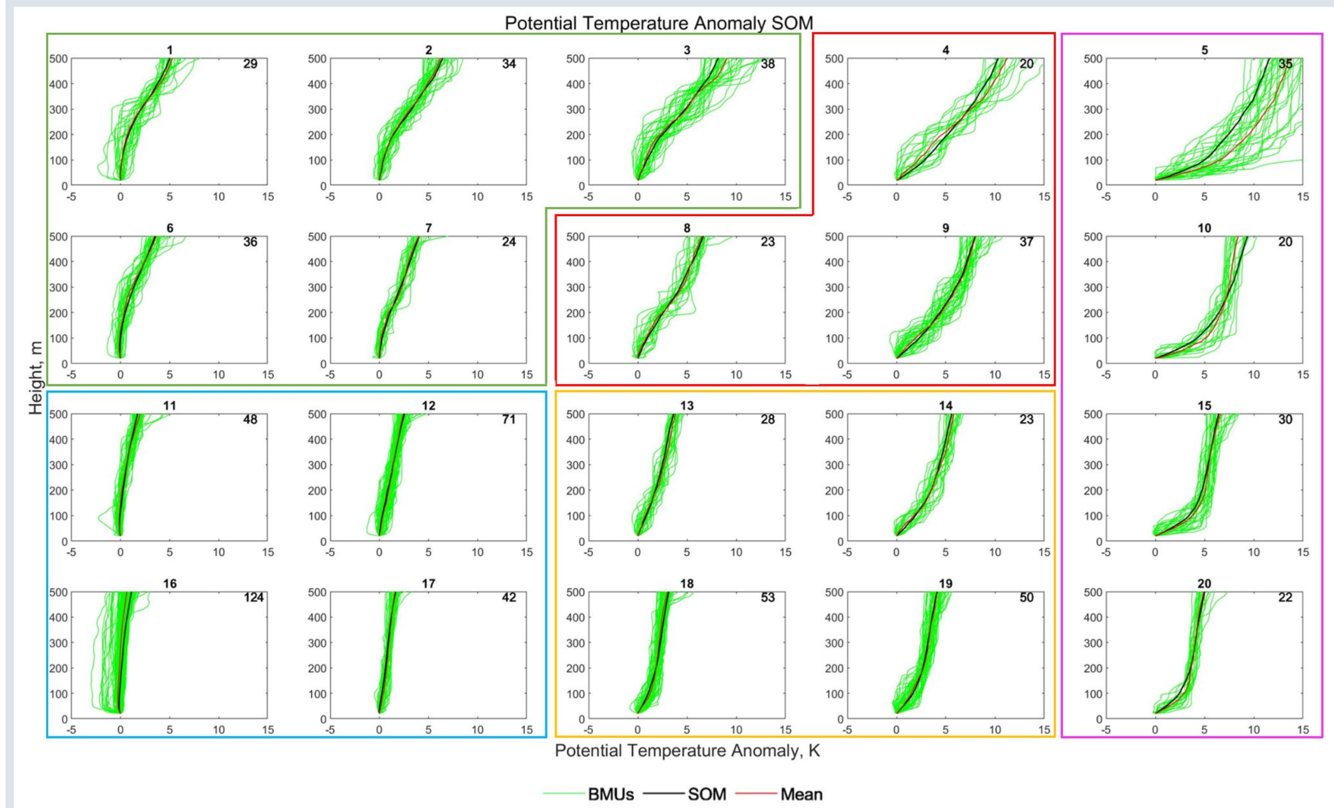

Figure 1: SOM showing different boundary layer stability regimes observed (refer to Table 1) on an annual basis. The black line shows the trained SOM profiles, the green lines are the radiosonde profiles that mapped to each pattern (Best Matching Units, BMUs), and the red line is an average of these profiles. The colored boxes indicated the organization of each pattern to a specific regime, explained in Table 1.

Stability Regime	Figure 2 Color Code	Pattern Numbers	Description
WS	Green	11, 12, 16, and 17	Weak stability throughout the depth of the profile
WSEA	Orange	1, 2, 3, 6, and 7	Weak stability at the surface with enhanced stability aloft
MSWA	Blue	13, 14, 18, and 19	Moderate stability at the surface with weak stability aloft
MS	Red	4, 8 and 9	Moderate stability throughout the depth of the profile
SS	Pink	5, 10, 15, and 20	Strong stability at the surface

Table 1: Stability regimes observed in SOM (Figure 1),where pattern number is seen at the top center of each pattern in Figure 1.

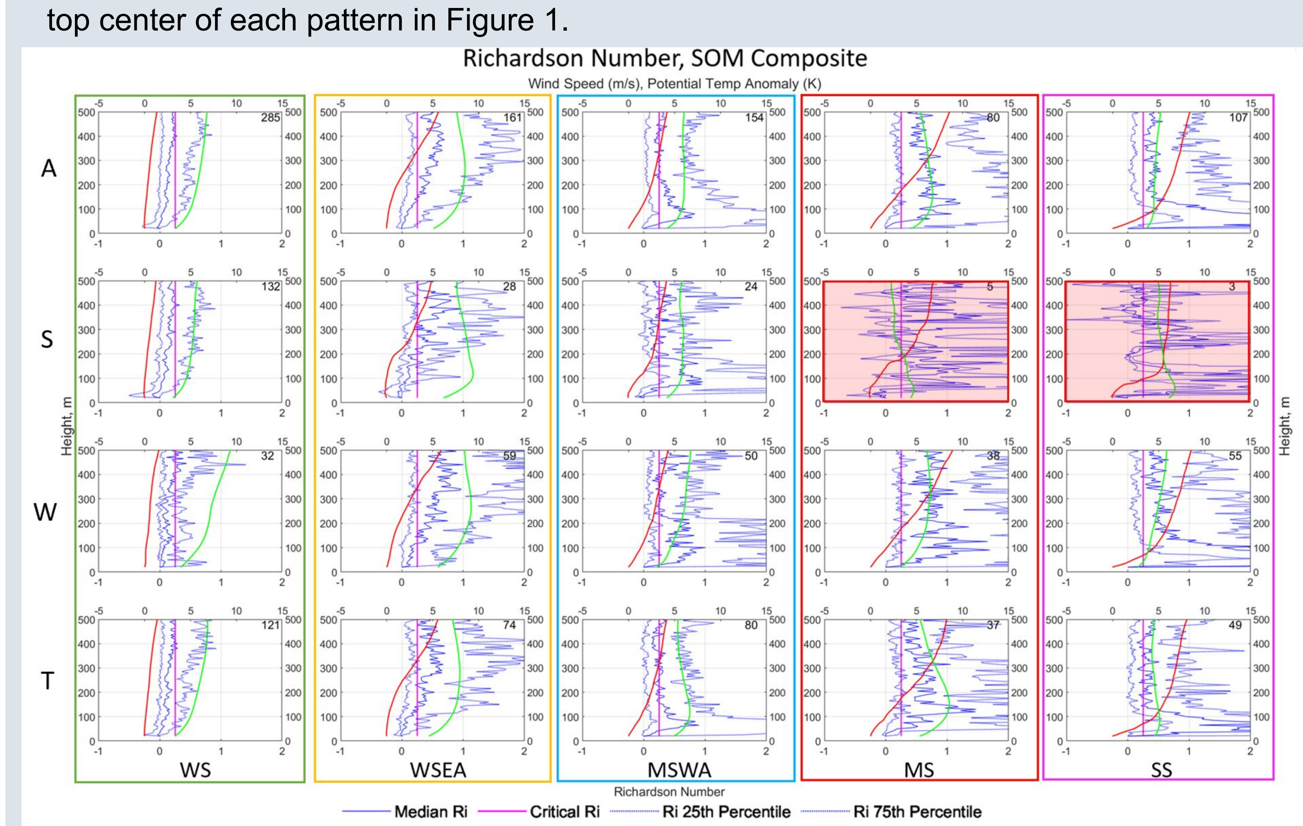

Figure 2: The median Richardson number for each regime in each season (solid blue line) and 25th and 75th Richardson number percentiles (dashed blue lines). The mean wind speed profile (green line) and mean potential temperature anomaly profile (red line) for each regime in each season is also shown. The solid pink line indicates the critical Richardson number of 0.25. The red shading in the summer season MS and SS regime indicates a low number of observations (5 and 3, respectively).

Results:

- Potential temperature anomaly SOM:
  - 20 patterns of the master SOM (Figure 1) were sorted according to stability type into five regimes from weakly stable (bottom left of SOM) to strongly stable (right column of SOM) (Table 1).
  - The frequency of occurrence of each regime in each season can be seen in Table 2.
    - The weak stability (WS) regime dominates in summer, occurring almost 70% of the time.
    - Moderate and strong stability regimes (MSWA, MS and SS) occur the majority of the time in winter but weak stability regimes (WS and WSEA) occur almost 40% of the time.
- Wind Speed:
  - In the winter, weaker median winds in the MSWA, MS and SS regimes result in weaker mechanical mixing which allows for the development of enhanced stability near the surface. This is in contrast to the transition seasons where wind speed shows less variability across the different stability regimes (Figure 3).
  - The WS regime is characterized by fairly consistent surface wind speeds across all seasons. This is in contrast to the MS and SS regimes where there is more variability between seasons (Figure 3).
- Radiation:
  - A decrease is seen in winter in median downwelling longwave radiation from the WS to SS regimes, consistent with reduced surface radiative warming from the atmosphere leading to the development of a surface inversion and enhanced near surface stability. This can also be seen in the transition seasons, although not as clearly as in the winter. In the summer there are not enough MS and SS cases to identify a robust pattern across stability regimes of downwelling longwave radiation (Figure 4).
  - Generally the median surface net radiation decreases from the WS to the SS boundary layer regime (Figure 5), which is consistent with more stable regimes being partially driven by less energy at the surface.
  - In summer, the surface net radiation is positive and much larger than in other seasons (Figure 5), which corresponds to the dominance of the WS boundary layer regime this time of year (Table 2).
  - The net radiation in winter is negative, which allows for more stably stratified boundary layer regimes to dominate this time of year (Table 2), but even the WS and WSEA regimes in winter have negative surface net radiation, which indicates that processes other than radiative heating and cooling control the boundary layer stability regimes.
- Richardson Number:
  - The Richardson number quantifies the role of static stability and wind shear in generating or suppressing turbulence.
  - A negative bulk Richardson number indicates buoyancy-driven turbulence and unstable conditions, and a positive bulk Richardson number indicates mechanically-driven turbulence and stable conditions. A higher positive bulk Richardson number indicates strong stability and/or weak wind shear, whereas a smaller positive bulk Richardson number indicates weak stability and/or large wind shear.
  - The critical Richardson number of 0.25 is used to separate turbulent (<0.25) from non-turbulent (>0.25) conditions .
  - Some of the maximum bulk Richardson numbers in the SS regime mirror the strength of the inversion, which is much stronger than the wind shear in these cases, and too strong for turbulence to be generated. In the WS regime, it can be seen that the bulk Richardson numbers are much closer to, or even below, the critical value of 0.25, and thus turbulence is much more likely in these profiles.

Stability Regime	Annual	Summer	Winter	Transition Seasons
WS	36.2%	68.8%	13.6%	33.5%
WSEA	20.4%	14.6%	25.3%	20.5%
MSWA	19.6%	12.5%	21.3%	22.0%
MS	10.1%	2.6%	16.2%	10.2%
SS	13.5%	1.5%	23.5%	13.5%

Table 2: Frequency of occurrence for each stability regime in each season. The numbers in the upper right corners of each pattern in Figures 1 and 2 is the number of occurrences for each pattern, likewise of the numbers above each box plot in Figures 3, 4, and 5.

Future Work:

- Future work will include evaluation of the performance of the Antarctic Mesoscale Prediction System to predict boundary layer conditions.
- Use of the DataHawk II Unmanned aerial Vehicle (UAV) to sample the boundary layer conditions in West Antarctica.

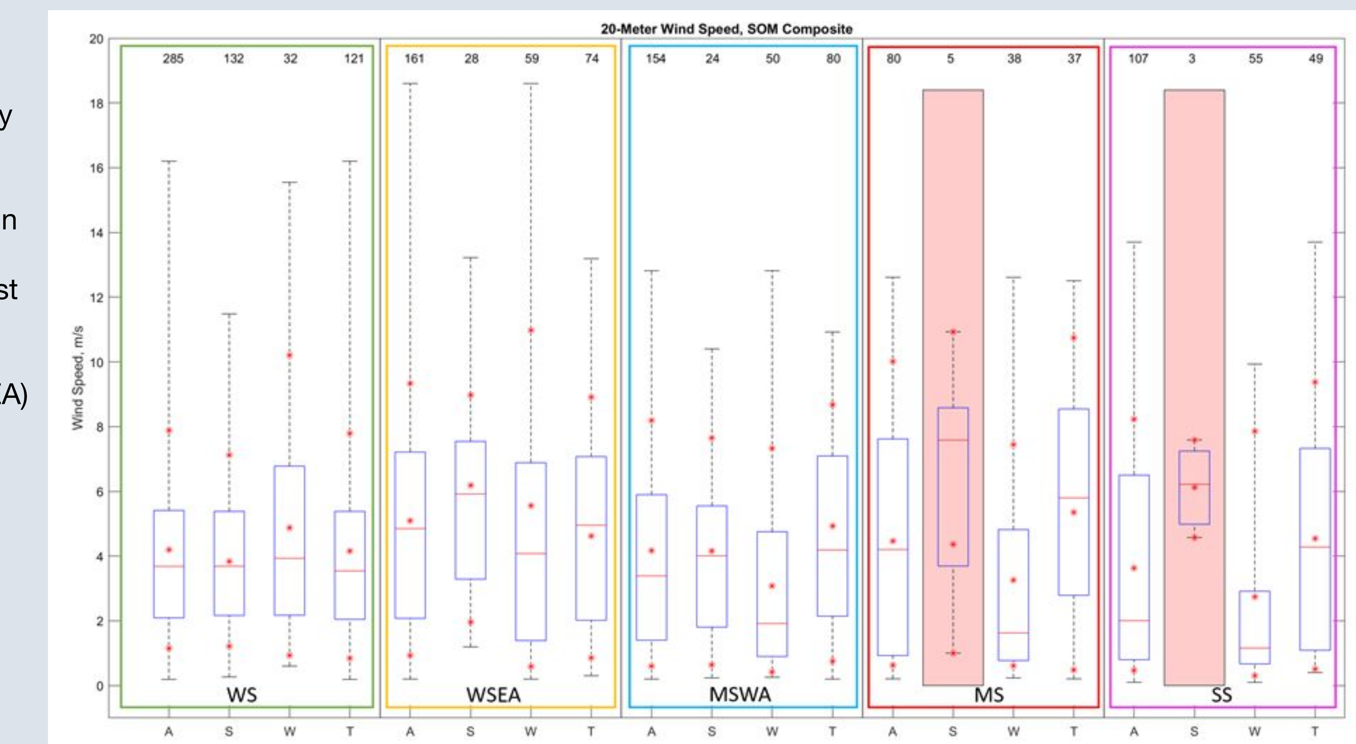

Figure 3: Median (red horizontal line), mean (middle red star), 10th and 90th percentiles (outside red stars), 25th and 75th percentiles (limits of blue box) and minimum and maximum (whiskers) 20-meter wind speed for each regime and each season (A=annual, S=summer, W=winter, T=transition season). The red shading in the summer season MS and SS regime indicates a low number of observations (5 and 3, respectively).

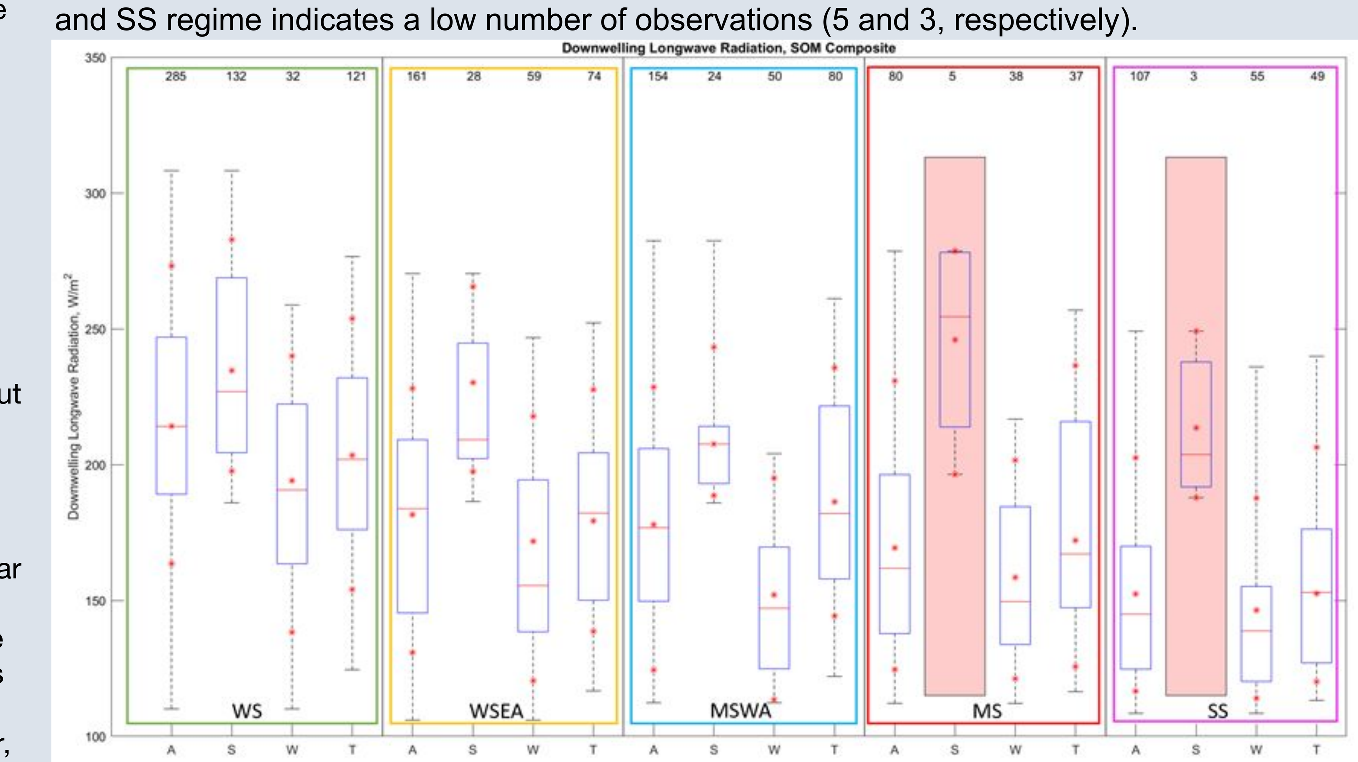

Figure 4: Median (red horizontal line), mean (middle red star), 10th and 90th percentiles (outside red stars), 25th and 75th percentiles (limits of blue box) and minimum and maximum (whiskers) downwelling longwave radiation for each regime and each season (A=annual, S=summer, W=winter, T=transition season). The red shading in the summer season MS and SS regime indicates a low number of observations (5 and 3, respectively).

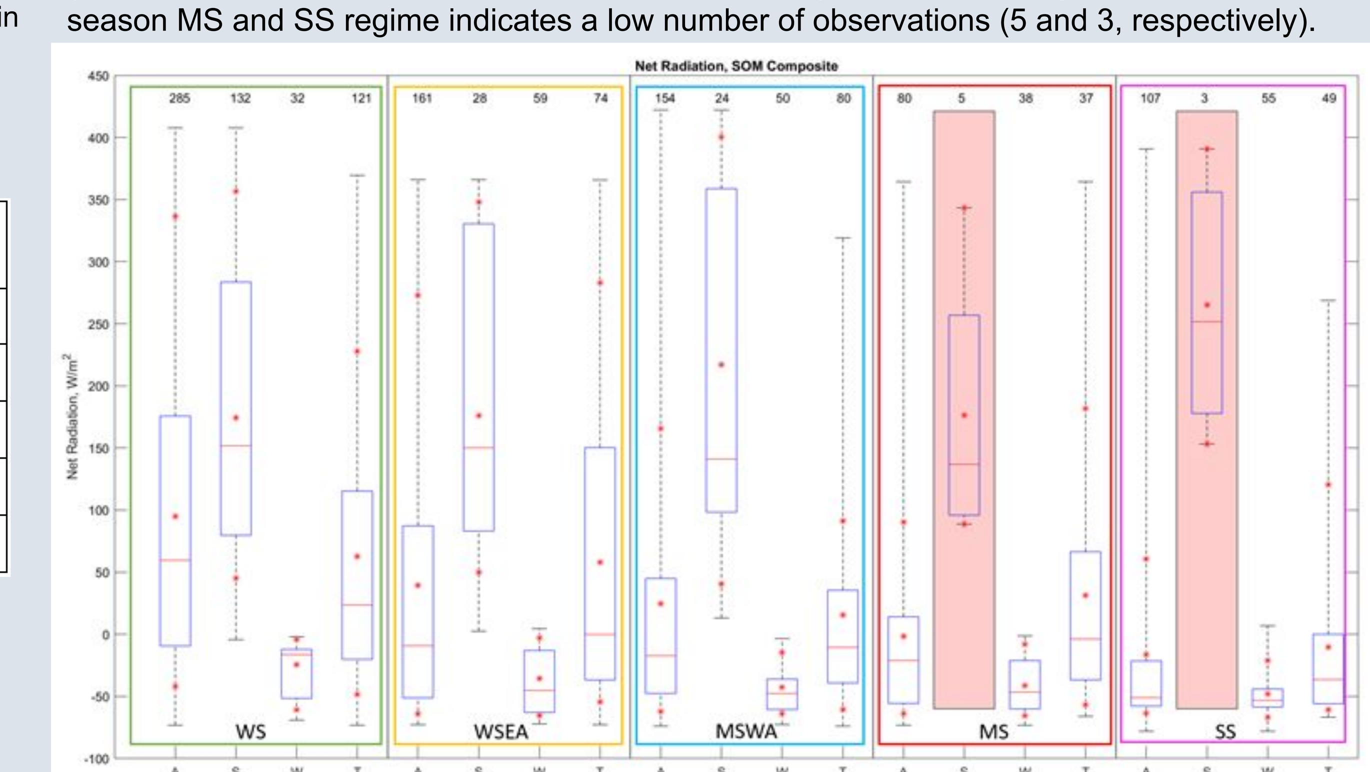

Figure 5: Median (red horizontal line), mean (middle red star), 10th and 90th percentiles (outside red stars), 25th and 75th percentiles (limits of blue box) and minimum and maximum (whiskers) net radiation for each regime and each season (A=annual, S=summer, W=winter, T=transition season). The red shading in the summer season MS and SS regime indicates a low number of observations (5 and 3, respectively).