

Prince George Air Quality Emissions and Modelling: Appendix B

Meteorological Model (CALMET) Setup and Evaluation

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Final Version: 2020-10-20

1. Executive Summary

This appendix serves as supplementary material for the main *Prince George Air Quality Emissions and Modelling* report. The Prince George modelling system consists of four primary pieces: the micro-emission inventory (MEI), the meteorological model (CALMET), the dispersion model (CALPUFF), and the web-based analysis and simulation tool (AirQuest). Each section is explored in detail in individual appendices. This appendix will detail the setup and evaluation process for the CALMET meteorological model for the Prince George airshed.

CALMET simulates a diagnostic wind field for the Prince George airshed in three dimensions, primarily based on hourly surface observations, twice-daily vertical atmospheric profiles (upper air observations), and surface land use and terrain values (Scire et. al. 2011). The model first produces an initial-guess wind field based on the airshed terrain (slope flows and terrain blocking) which is then adjusted based on the observation data. This process is applied for each hour over a three-year period (2014 – 2016), producing three-dimensional wind fields for the Prince George airshed. These can then be used in the CALPUFF model to drive the dispersion of air pollutants.

In the recent updates, several changes were made to the Stantec (2010) CALMET modelling system for Prince George. The hourly surface meteorological observations from ten surface stations were included in the 2014 – 2016 period – three more stations than the Stantec (2010) modelling system. The twice-daily upper air observations were also updated for the single upper air station within the airshed. In addition, changes were made to how far CALMET ‘looks’ for downwind terrain which may steer the wind. In the previous system, a distance of 20 km was used – quite large relative to the spatial extent of the airshed of 40 km by 40 km. Reducing this distance to 1 km was more realistic for the airshed and resulted in a better fit to the observed winds. In addition, an issue of the influence (or lack thereof) of the observation data on the model wind field was identified in the previous modelling system. First, model outputs at observation stations which had another station in close proximity were being influenced perhaps too much by the nearby station. This issue is most pronounced for stations which are geographically close but are influenced differently by the terrain – such as those in the valley bottom versus on the plateau. These influences were limited for two stations in the valley using CALMET’s surface interpolation barriers – additional work is required in order to completely separate the valley and plateau observations. Counter to this, it was also noted that the model did not consider station observations much in areas away from the station – in these areas only the upper air observations were considered. As the hourly surface observations are more representative than a single, twice-daily observation upper air station, the radius of influence for observation stations was increased in the current updates.

The CALMET model tended to underpredict the wind speeds at observation station locations within the airshed. While a portion of the observed winds were considered to be calm due to instrument error at low wind speeds ($< 0.5 \text{ m s}^{-1}$), modelled winds were never calm as there was always ‘some’ wind produced in the interpolation process. Wind directions at these locations

were predicted well, however, as eluded to previously stations in close proximity to each other tended to have poorer performance in the model. The model winds were modelled best during the Spring months, with minor reductions in performance as the seasons progressed. When leaving out a single observation station in the model inputs the model performed worse at that station (as expected), however, the performance was determined to be adequate for use in the dispersion model.

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3. Acknowledgements

We would like to thank C. Corbel, D. Fudge, A. Veira, and J. Spagnol for their previous work on the project. Funding for this project was provided by the City of Prince George, the Prince George Air Improvement Roundtable (PGAIR), and Northern Health.

4. CALMET Meteorological Model

CALMET is the meteorological model that produces the three-dimensional wind, temperature and humidity fields (among others) that are needed for CALPUFF, the dispersion model. Full documentation of the CALMET model can be found in Scire et. al. (2011). The version of CALMET (v6.334) was not updated from earlier phases in the project, and previous input settings and geophysical data were used where applicable. The CALMET model is ran separately with varying geophysical inputs for each season. A copy of the CALMET input file is included at the end of this report, detailing the settings and flags implemented in the model. The Prince George airshed was defined as a 40 km x 40 km grid at a 1 km resolution with 12 vertical levels. The surface level is at 10 m above the ground and the remaining levels scale up non-linearly to a top height of 2500 m. There are 4 main input sections for CALMET: geophysical data, surface observations, precipitation observations, and upper air observations.

4.1. Geophysical Data

The previous geophysical data files developed during the original phase of the project were used, as the parameters are unlikely to have changed significantly since 2005. The geophysical data files were split by seasons to account for parameters that have seasonal variation such as surface albedo. Terrain and land use data are kept static across all seasons. The MAKEGEO processor was used to estimate the remaining geophysical parameters (surface roughness, albedo, Bowen ratio, heat fluxes and Leaf-area index) over the Prince George airshed using the predefined land use data.

The TERREL processor was used to process surface elevations over the Prince George airshed during a previous phase of the project. Terrain heights were extracted from the Shuttle Radar Topography Mission 3 (SRTM3) data available through the U.S. Geological Survey (USGS). This dataset had a base resolution of 90 metres and was converted to a resolution of 1 kilometre over the Prince George airshed (Figure 1). Tabor mountain is to the southeast, and a 'y' shaped valley is formed as a result of the confluence of two major rivers (the Fraser and the Nechako).

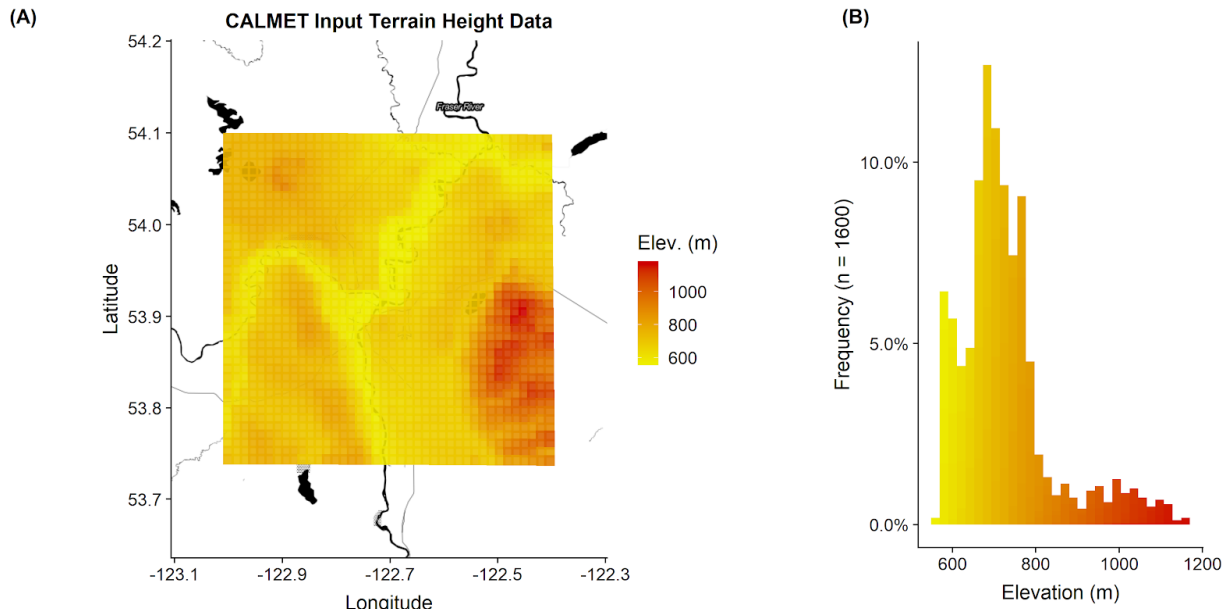


Figure 1. Spatial (A) and total (B) distribution of CALMET input terrain height data for the Prince George airshed. The airshed is defined at the surface as a 40 x 40 grid with a 1 km resolution, and elevations are derived from the 90 m resolution Shuttle Radar Topography Mission 3 (SRTM3) terrain data.

In a previous phase of the project, land use information was extracted from the BC government's ArcMap system and manually converted to CALMET's 14 category land use system (based on the USGS Land Use and Land Cover Classification System). These values were then revised using local land use information and additional information available on the City of Prince George's "PGMap" system (Figure 2). The airshed is primarily forested land (>60%) and, in lesser amounts, agriculture (~20%) and urban (~10%). The remaining < 10% of land use is range land, water, wetland, or barren ground. The rivers are not large enough in most locations to be resolved by the airshed resolution of 1 km. Land use categories were assigned values for every geophysical parameter, with differing values for each season.

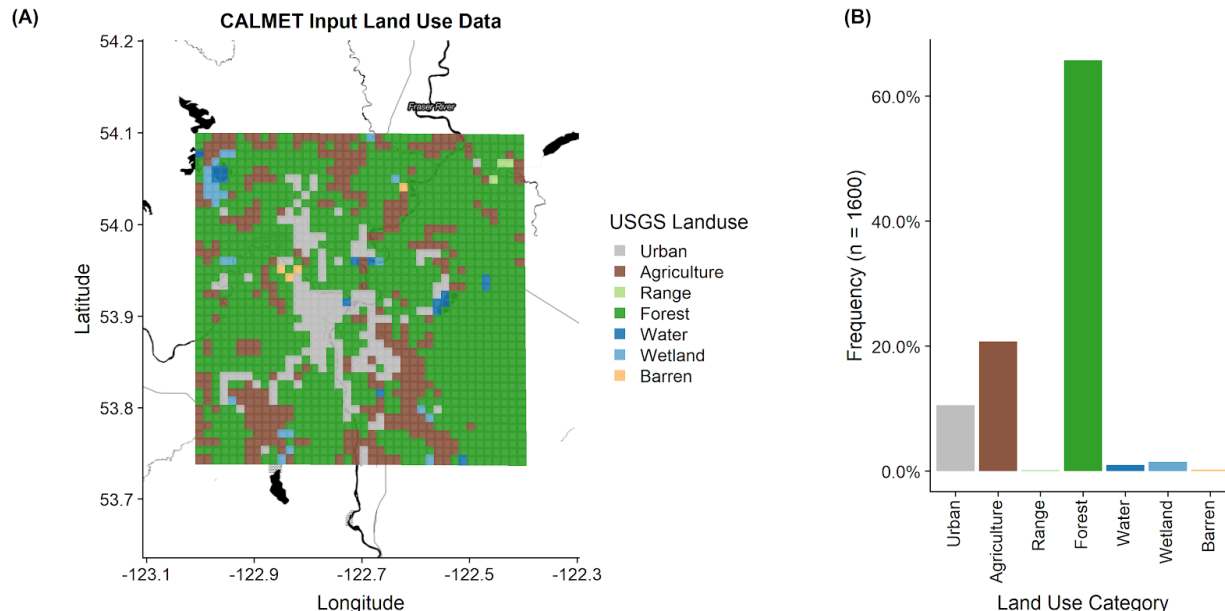


Figure 2. Spatial (A) and total (B) distribution of the CALMET input land use data for the Prince George airshed. Land use data from the previous modelling study were used, valid for the year 2005. The modelled airshed consists of a 40 x 40 grid with a 1 km resolution, utilizing land use data extracted from the BC government's ArcMap system and manually converted to CALMET's 14 category land use system. CALMET's system is based on the USGS Land Use and Land Cover Classification System. The gridded land use values were then revised based on local land use information and additional information available on The City of Prince George's "PGMap" system.

4.2. Surface Observations

CALMET requires hourly observations of wind speed, wind direction, temperature, cloud cover, ceiling height, surface pressure, relative humidity, and precipitation type code. While missing values are allowed, CALMET requires one observation of each variable from at least one station for every hour. During the modelling period there were nine viable surface observation stations located within the Prince George airshed (

Table 1). A map displaying these observations station locations is shown in Figure 3. Two stations (AIRP and MASS) were operated by Environment and Climate Change Canada (ECCC); three stations (GLEN, PLAZ, and PULP) were operated by the British Columbia Ministry of Environment (BCMoE); three stations (MSLX, EXPL, and GLAD) were operated by the Prince George Monitoring Working Group (PG MWG) and one station (UNBC) was operated by the University of Northern British Columbia. Reported winds with speeds less than or equal to 0.5 m s^{-1} were considered to be calm, and had their speed and direction set to 0.

Table 1. Surface observation stations within the Prince George airshed for the years 2014 to 2016. The first two stations (AIRP and MASS) were operated by Environment and Climate Change Canada (ECCC); the following six stations (EXPL, GLAD, GLEN, MSLX, PLAZ, and PULP) were operated by the British Columbia Ministry of Environment (BCMoE); and the final station (UNBC) was operated by the University of Northern British Columbia (UNBC). Many stations names have had 'Prince George' replaced with 'P.G.' for display purposes. Note that 'PG Marsulex' (MSLX) has not been altered.

| Station | Station Name | Latitude | Longitude | ASL (m) | Anemometer Height (m) | Anemometer ASL (m) |
|---------|------------------------|----------|-----------|---------|-----------------------|--------------------|
| AIRP | P.G. Airport Auto BC | -122.670 | 53.889 | 680 | 14 | 694 |
| MASS | P.G. Massey Auto BC | -122.790 | 53.899 | 601 | 14 | 615 |
| EXPL | P.G. Exploration Place | -122.734 | 53.904 | 570 | 14 | 584 |
| GLAD | P.G. Gladstone School | -122.762 | 53.857 | 583 | 14 | 597 |
| GLEN | P.G. Glenview School | -122.776 | 53.995 | 750 | 17.8 | 767.8 |
| MSLX | PG Marsulex | -122.734 | 53.844 | 535 | 15 | 550 |
| PLAZ | P.G. Plaza 400 | -122.742 | 53.914 | 588 | 27 | 615 |
| PULP | P.G. Pulp | -122.686 | 53.923 | 600 | 22 | 622 |
| UNBC | UNBC Rooftop | -122.814 | 53.892 | 784 | 30 | 814 |

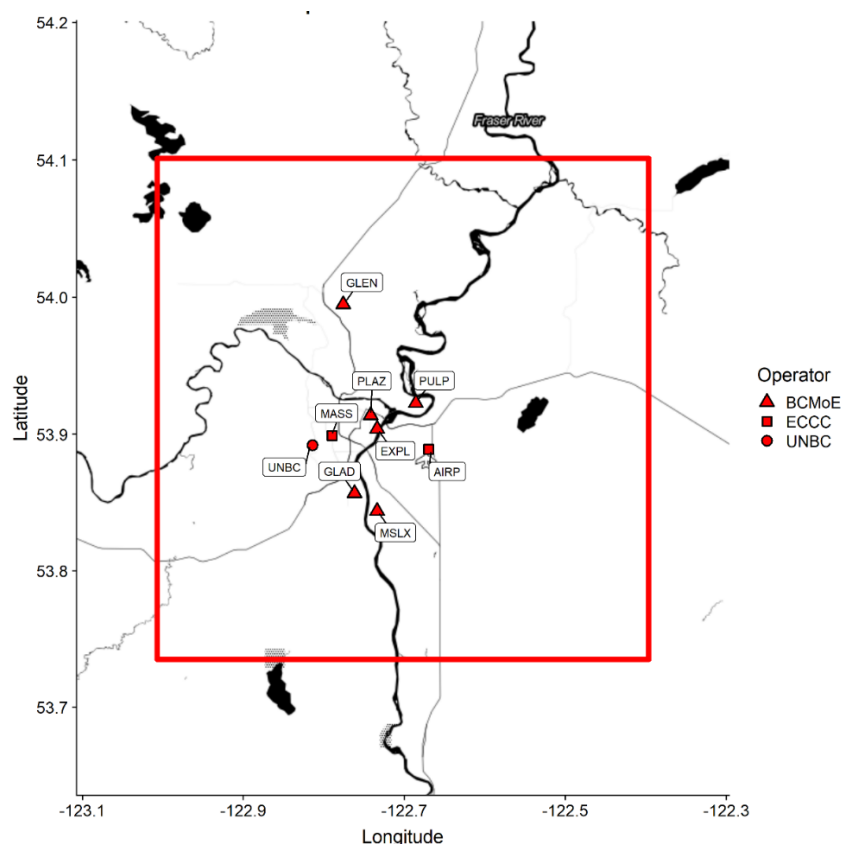


Figure 3. Meteorological observation stations within the Prince George airshed between 2014 – 2016. Five stations were operated by the British Columbia Ministry of Environment (BCMoE), two were operated by Environment and Climate Change Canada (ECCC), and one was operated by the University of Northern British Columbia (UNBC). PLAZ, GLAD, and MSLX were also ambient air pollutant monitoring sites.

Wind roses summarising the hourly input wind observations for each station are shown in Figure 4. GLAD, GLEN, EXPL, PLAZ, PULP, and UNBC display similar wind patterns, however, PLAZ, PULP, and UNBC wind speeds are higher due to their higher relative elevations. PULP winds have a higher frequency of north winds due to the surrounding valley flow, while PLAZ and EXPL show a higher frequency of easterly and northeasterly winds, respectively. AIRP has a strong north/south flow pattern and has the highest mean wind speed. MSLX also shows this strong north/south flow along with a high frequency of southeasterly winds resulting from the surrounding topography. MASS wind speeds are the lowest of all stations on average and have a higher frequency of northeasterly winds.

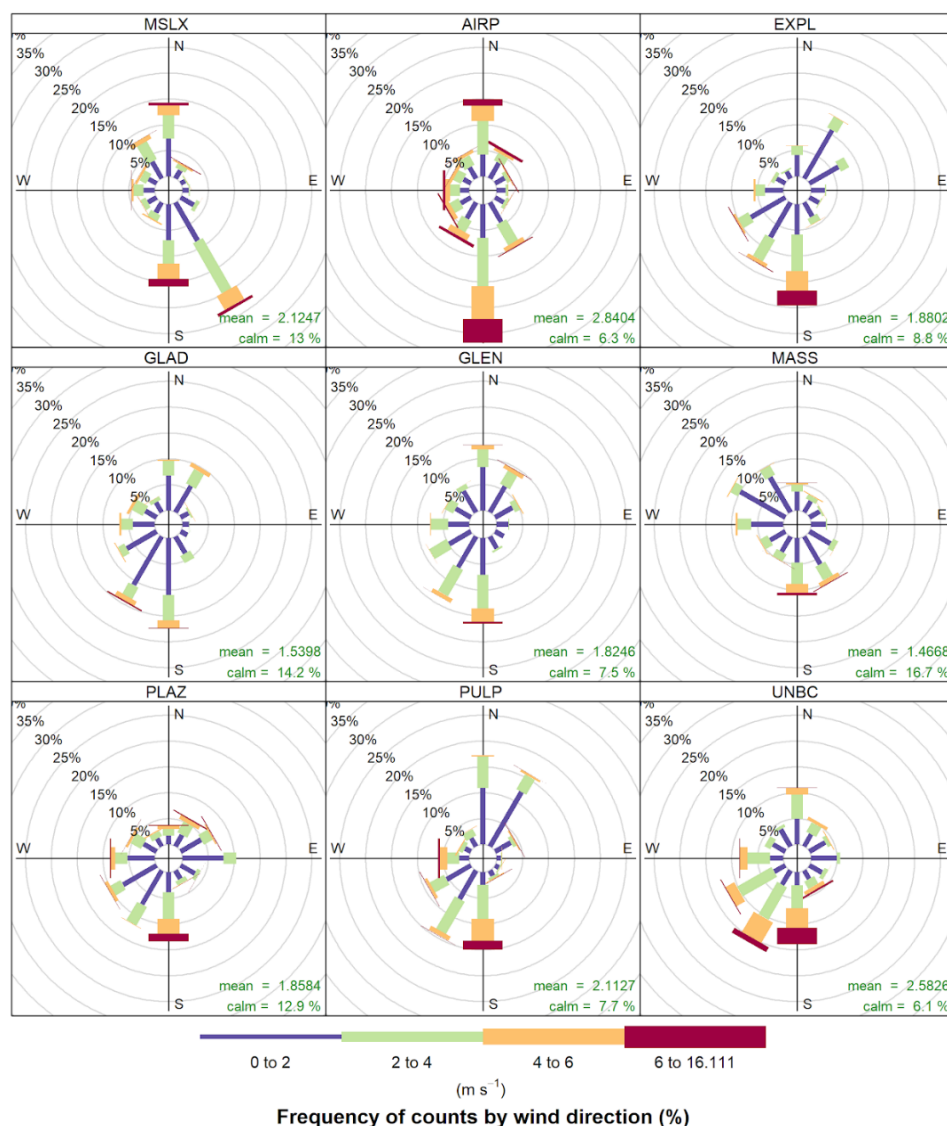


Figure 4. Wind roses of hourly observed winds over three years at the nine observation stations located in the Prince George airshed between 2014 – 2016. Displays frequency of counts for four wind speed ($m s^{-1}$) 'bins' by wind direction. Frequencies are displayed in the northwest quadrant, radiating from the center. Mean wind speed over the 3 years is displayed in the bottom right for each station along with the percent frequency of calm winds (those $< 0.5 m s^{-1}$).

The variation in time of the observed hourly wind speeds from all observation stations is displayed in Figure 5. Each station's observations were grouped by hour-of-day (Figure 5A), by month-of-year (Figure 5B), and by day-of-week (Figure 5C). Then the mean and 95% confidence interval in the mean were calculated, with the uncertainty intervals calculated through bootstrap resampling. All stations except the UNBC station follow a similar diurnal pattern for wind speed, peaking in the afternoon, while the UNBC station has a second peak near midnight and does not vary as much through the day. There is little variation between days of the week, however there is a seasonal cycle (peak mean wind speeds in March and November). The AIRP station typically has the highest wind speeds of all the stations, while the MASS station typically has the lowest.

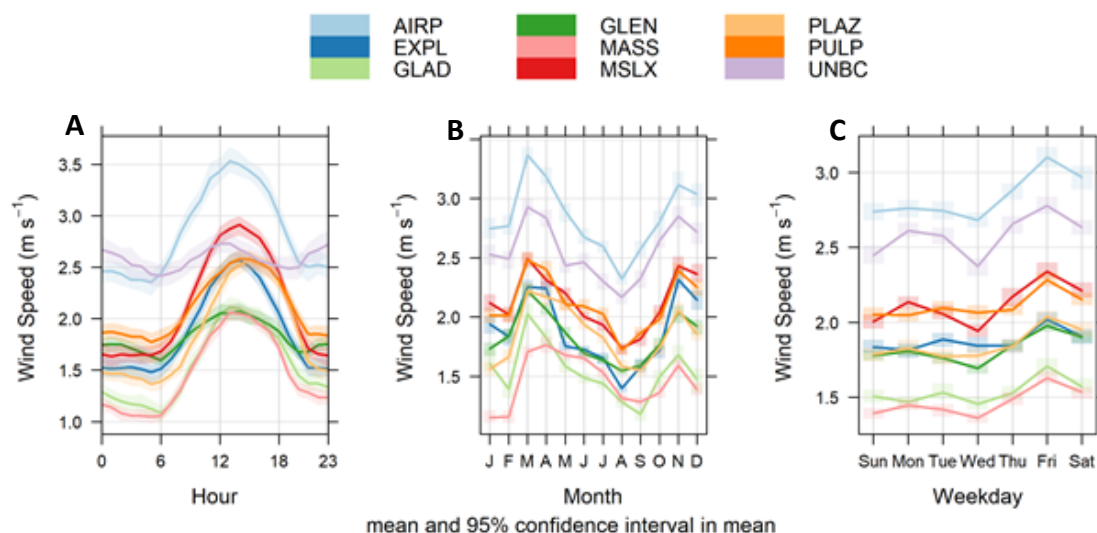


Figure 5. The variation with time of the observed hourly wind speeds from all observation stations. Each station's observations were grouped by hour-of-day (A), by month of the year (B), and by day-of-week (C). Then the mean and 95% confidence interval in the mean were calculated for each group, with the uncertainty intervals determined using bootstrap resampling. Wind speeds less than or equal to 0.5 m s^{-1} were considered calm and were set to 0 m s^{-1} .

CALMET requires hourly observations of precipitation type code, ceiling height, and cloud coverage alongside its surface observation inputs. The precipitation codes were developed using the input precipitation data (See Section 4.3) following the rules defined in the United States Federal Meteorological Handbook (Table 2). Ceiling height and cloud coverage were determined based on the hourly Meteorological Terminal Aviation Routine (METAR) reports from CYXS (same location as AIRP). If two or more cloud levels are identified, the first (lowest) level was used for both ceiling height and cloud coverage. The upper bounds of the METAR cloud coverage categories were used (in eighths of the sky) and were rounded up following conversion to tenths of the sky, as required by CALMET.

Table 2. Precipitation type codes utilized for the CALMET surface observations. Categories are based on the United States Federal Meteorological Handbook, considering precipitation amount over the past hour and whether the air temperature was above or below freezing

| Precipitation Code | Precipitation Amount (mm) | Ambient Temperature (°C) |
|--------------------|---------------------------|--------------------------|
| 0 | 0 | Any |
| 1 | < 2.5 | > 0 |
| 2 | 2.5 - 7.6 | |
| 3 | > 7.6 | |
| 19 | < 2.5 | ≤ 0 |
| 20 | 2.5 - 7.6 | |
| 21 | > 7.6 | |

There were 26,304 hourly entries (total) from the observation stations located in the Prince George airshed from 2014 - 2016. The GLAD station was missing data from November 12, 2015 onwards while the remaining stations had near complete coverage of the model period (Table 3). A period of consistent 0 m s⁻¹ wind speeds was removed from the UNBC station between 2015-05-29 16:00:00 PST and 2015-10-08 15:00:00 PST. There were 262 missing ceiling height entries and 1103 missing cloud coverage entries, both of which were linearly interpolated to infill missing data. Air temperatures were linearly interpolated to fill any missing values prior to developing the precipitation type codes. The precipitation data used to develop the precipitation type codes already handled missing entries handled.

Table 3. Percent data capture for surface observation variables required by CALMET for each observation station.

| Station | Wind Speed | Wind Dir. | Ambient Temp. | Cloud Cover | Ceiling Height | Surface Pres. | RH | Precip. Code |
|--------------|--------------|--------------|---------------|--------------|----------------|---------------|--------------|--------------|
| AIRP | 99.6% | 99.6% | 99.5% | 100% | 100% | 99.6% | 99.6% | 100% |
| MASS | 99.6% | 99.6% | 99.6% | 0% | 0% | 99.6% | 99.2% | 0% |
| EXPL | 98.6% | 98.6% | 99.3% | 0% | 0% | 0% | 99.3% | 0% |
| GLAD | 61.0% | 61.0% | 62.0% | 0% | 0% | 0% | 61.9% | 0% |
| GLEN | 95.6% | 95.7% | 95.9% | 0% | 0% | 0% | 0% | 0% |
| MSLX | 99.7% | 99.7% | 99.9% | 0% | 0% | 0% | 99.9% | 0% |
| PLAZ | 99.5% | 99.5% | 97.4% | 0% | 0% | 0% | 97.4% | 0% |
| PULP | 99.2% | 99.2% | 99.3% | 0% | 0% | 0% | 0% | 0% |
| UNBC | 84.6% | 84.6% | 96.6% | 0% | 0% | 96.6% | 96.6% | 0% |
| Total | 93.0% | 93.0% | 94.4% | 11.1% | 11.1% | 32.9% | 72.7% | 11.1% |

4.3. Precipitation Observations

Hourly observations of precipitation amount from at least one observation station are required by CALMET for every hour. During the modelling period there were 2 viable precipitation stations located within the Prince George airshed - the Prince George Airport Auto (AIRP) and the Prince George Massey Auto (MASS) station (See Section 4.2). Both stations were operated by Environment and Climate Change Canada (ECCC). The AIRP station was selected as the primary precipitation station. Missing observations from the AIRP station were first replaced with values from the MASS if present, then the remaining missing values were linearly interpolated. The AIRP station had a total of 161 missing hourly entries, 116 of which were filled with valid entries from the MASS station, leaving the remaining 45 to be linearly interpolated. On average precipitation amounts are highest in June and October, slightly higher in the mornings, and do not vary significantly between days of the week (Figure 6).

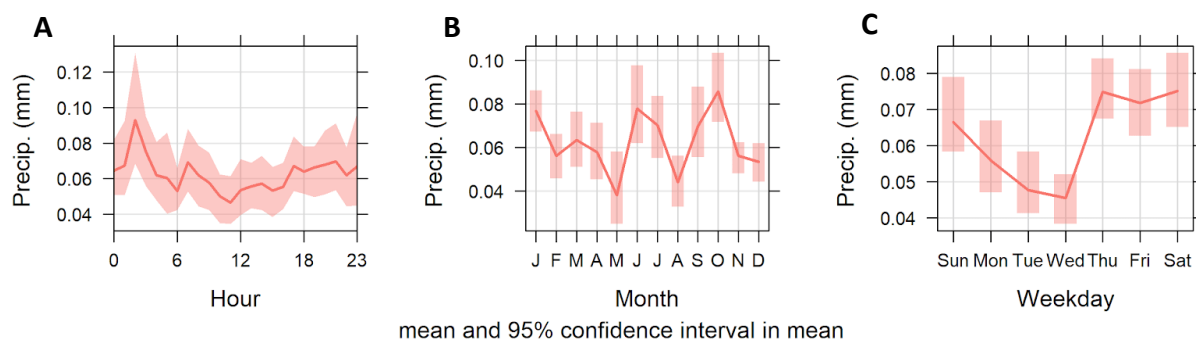


Figure 6. Mean hourly precipitation amount (mm) and 95% confidence intervals in the mean for the 2014 – 2016 period by (A) hour-of-day (B) month and (C) day-of-week. Data sourced primarily from the Prince George Airport Auto (AIRP) observation station - 116 missing observations were filled with data from the Prince George Massey Auto (MASS) observation station, and the remaining 45 missing values were linearly interpolated.

4.4. Upper Air Observations

CALMET requires twice-daily vertical profiles of wind speed, wind direction, temperature, pressure, and elevation, with at least a 00:00 UTC (00Z) and 12:00 UTC (12Z) sounding for each day. Missing soundings are not allowed by CALMET and are required to be infilled prior to running the model. If the upper air wind speed and direction, or air temperature are missing CALMET will linearly interpolate the missing values as long as the surface and top levels are not missing. Within the airshed, the Prince George Massey Auto BC (MASS) station was the only station with regular soundings.

Of the 2192 total required soundings, the MASS station had 48 invalid soundings and 6 missing soundings. Invalid sounding dates are displayed in Figure 7. Invalid soundings were those without complete records for the surface and/or top level, required by CALMET for interpolating data at other vertical layers. The missing soundings occurred on the following days: November 6th, 2014; December 10th, 2014; March 13th, 2015; April 14th, 2015 (x2); and April 23rd, 2015. The invalid and missing soundings were replaced with the mean of the soundings on either side, 24 hours apart, such that the mean of two 00Z soundings replaced a missing/invalid 00Z

sounding. If either of these soundings was missing or invalid, the next sounding 24 hours away was used; if that was also unavailable only the nearest sounding was used instead of the mean of two soundings.

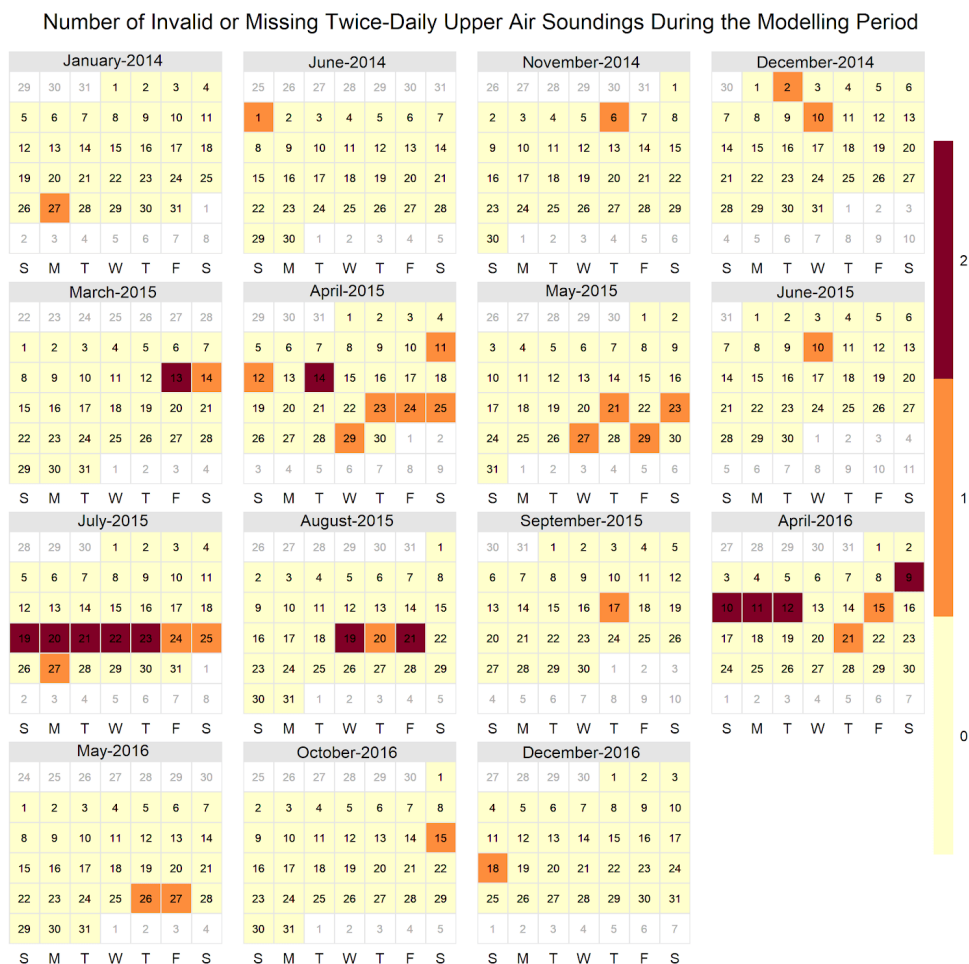


Figure 7. Number of invalid or missing upper air soundings at the Prince George Massey Auto BC (MASS) station for the years 2014 to 2016. Months with no invalid or missing soundings are not shown. Of the 2192 total required soundings (2 per day), the MASS station had 48 invalid soundings and was missing 6 soundings. The missing soundings occurred on the following days: November 6th, 2014; December 10th, 2014; March 13th, 2015; April 14th, 2015 (x2); and April 23rd, 2015.

5. Changes to the Modelling System

While many of CALMET input settings did not change from previous work, further analysis identified several beneficial changes. Previously, the CALMET input file had a TERRAD setting of 20 km, much larger than the recommended 5 - 10 km (based on the airshed resolution of 1 km). This setting controls the distance which CALMET ‘looks’ downwind for terrain which acts to steer the wind. As the airshed is modelled is only 40 km by 40 km, a TERRAD setting of 20 km would not properly capture the terrain steering effects in this airshed. Monthly wind vector correlations between modelled and observed winds at each station were calculated, following

methods outlined in Crosby et. al. (1993), for various TERRAD settings (Figure 8). This correlation method allows for the comparison of both wind speed and direction, rather than comparing them individually. A vector correlation equal to 2 indicates a perfect correlation between the model and observed wind vectors. Wind vector correlations at each observation station tended to improve as the TERRAD values were lowered. A TERRAD setting of 20 km or 15 km did markedly worse at most stations, and there appears to be only a slight improvement when setting TERRAD lower than 5 km. A TERRAD setting of 1 km was selected as it was determined to have the highest wind vector correlation at all observation stations.

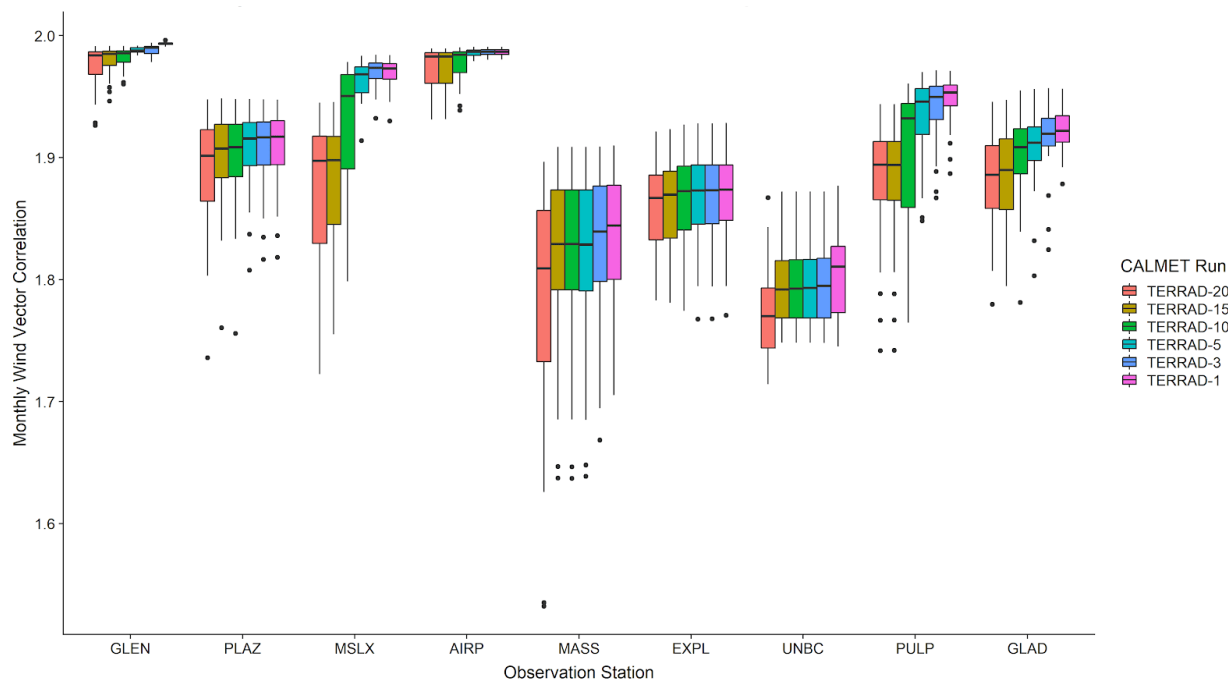


Figure 8. Boxplots of monthly wind vector correlations comparing wind speed and direction concurrently for CALMET model outputs and station observations from the same location for multiple CALMET 'TERRAD' settings for the 2014 – 2016 period. 'TERRAD' determines the distance downwind CALMET 'looks' when determining the terrain influence on wind patterns. A monthly wind vector correlation equal to 2 indicates the CALMET winds correlate perfectly with the observed winds at that location for that month (based on hourly data). Comparison locations are indicated on the x-axis, and each location has 5 individual boxplots – one for each TERRAD setting. The 'TERRAD' settings get smaller as you move from left to right for an observation location.

A concern over the influence that nearby stations have on each other, especially PLAZ and EXPL, arose when comparing the CALMET and original station wind rose diagrams. It seemed that the model winds at PLAZ were more an average of the two stations instead of being primarily influenced by the PLAZ observations as expected. To attempt to limit this influence, a surface interpolation barrier was implemented in CALMET between PLAZ and EXPL. The model will not utilize observations on the other side of one of these barriers in the interpolation process, limiting the effect stations have on specified areas. In the process of this testing, rather low radii of influence parameters ($R1 = 0.75$ km, $R2 = 1$ km) were noted in the CALMET input file. While this would reduce the influence nearby stations had on each other, it would also limit

the influence observations had on grid cells greater than R1 away. These cells would instead be interpolated from the twice-daily vertical soundings. R1, the radius of influence for the surface level, was increased to 5 km and R2, that for the second vertical level, was increased to 7km. This allows for the UNBC station, for example, to have a greater influence on most of the west-central domain, when previously it only influenced the neighbouring grid cells. Implementing the surface interpolation barrier and increased R parameters showed an improvement in monthly wind vector correlations at most stations, however UNBC and GLEN were not significantly affected (Figure 9).

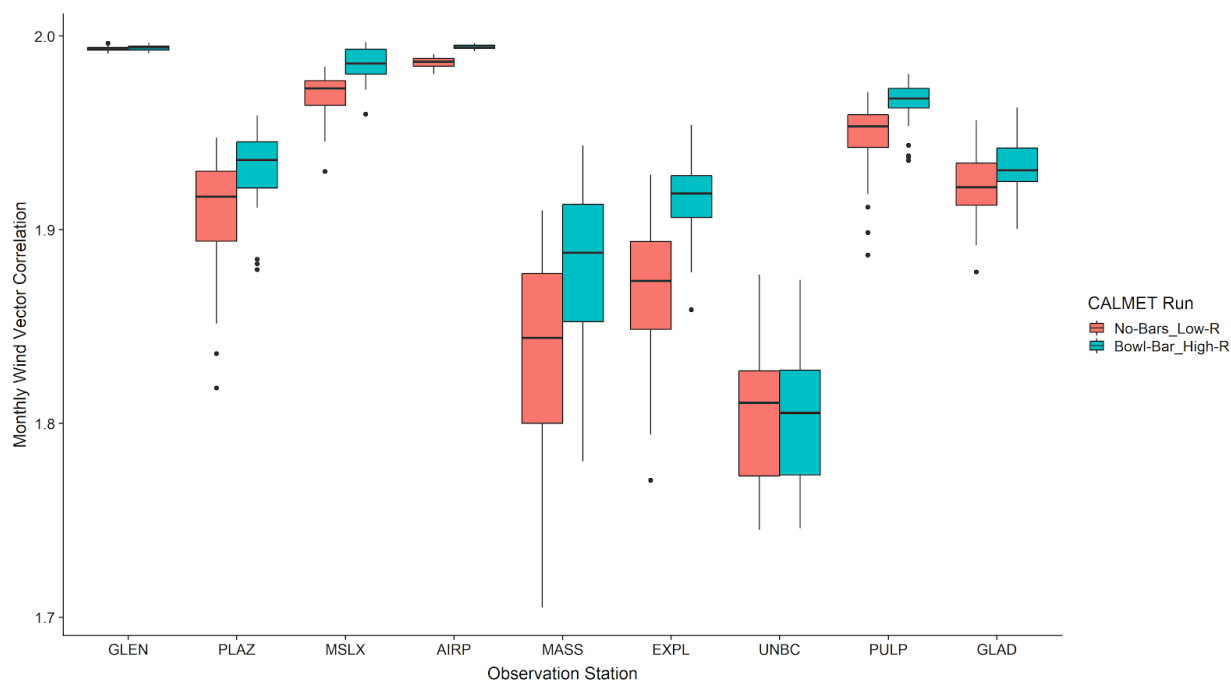


Figure 9. Boxplots of monthly wind vector correlations comparing wind speed and direction concurrently for CALMET model outputs and station observations from the same location for the 2014 – 2016 period. A monthly wind vector correlation equal to 2 indicates the CALMET winds correlate perfectly with the observed winds at that location for that month (based on hourly data). There are two boxplots for each observation station. The first is using the original CALMET model settings with no surface interpolation barriers ('No-Bars') implemented and relatively low radii of influence ('Low-R') for observation stations. The second boxplot (the 'improved' model) has a surface interpolation barrier implemented between the PLAZ and EXPL station ('Bowl-Bar') and higher radii of influence ('High-R').

6. Evaluation of CALMET

The evaluation of the CALMET outputs involves the comparison of these outputs at the same locations as the ten observation stations with the respective observations at that location. This allows us to infer how well the model preforms at these locations. It is important to note that these observations are directly used to interpolate the model results – as a result it is expected for the model to preform less well at other locations. To try and understand this effect, a leave-one-out analysis was performed where a select station was not included in the model inputs, allowing for comparisons to be made at that location without the observations themselves influencing the

results. The model's performance at this location should give an indication of the accuracy at locations which do not have observations normally.

Modelled wind speeds are biased lower than the observations at all stations, however, the frequencies of wind directions are almost matching for most stations (Figure 10). Winds are never calm in the model; however, observation winds range from 3.5% to 14.2% calm by station. All observed winds lower than 0.5 m s^{-1} were considered calm due to anemometer limitations in measuring very low wind speeds. Even with the surface interpolation barrier discussed previously in place, the model still performs worse at EXPL and PLAZ. This effect is also observed between MASS and UNBC and to a lesser extent between GLAD and MSLX, however, due to data limitations and time constraints an additional surface barrier between these stations was not implemented. The modelled EXPL winds appear to be influenced by the observed easterly mode at PLAZ, and vice versa for the observed northeasterly mode at EXPL. The same can be said for MASS and UNBC with their southerly to northeasterly winds. Modelled winds at GLAD appear to be influenced by the observations from the nearby MSLX station, shifting the wind distributions counterclockwise and increasing the frequency of northerly and southerly winds.

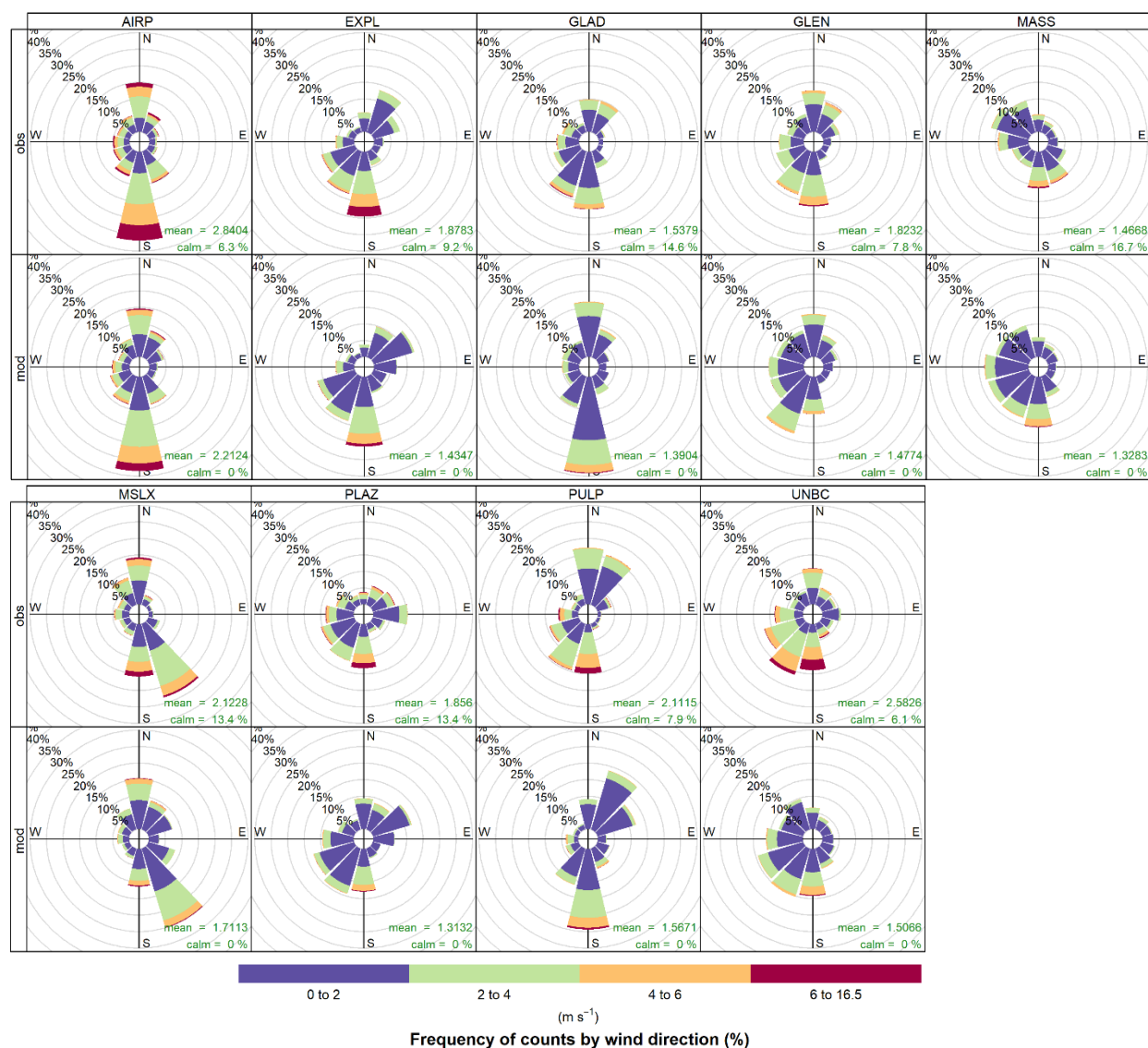


Figure 10. Wind roses of hourly observed and CALMET modelled winds over three years at the nine observation stations located in the Prince George airshed between 2014 – 2016. Displays frequency of counts for four wind speed (m s^{-1}) 'bins' by wind direction. wind speed over the 3 years is displayed in the bottom right for each station along with the percent frequency of calm winds (those $< 0.5 \text{ m s}^{-1}$). CALMET model winds are never calm due to the interpolation method used by CALMET (there is always 'some' wind) and CALMET does not need to be limited to $< 0.5 \text{ m s}^{-1}$ (a concern which arises in observations due to wind direction inaccuracies at low speeds).

Following methods outlined in Crosby et. al. (1993) wind vector correlations were calculated between model outputs and observations, with a value of 2 being a perfect correlation (Figure 11). As stated previously, these vector correlations allow for the comparison of both wind speed and direction at the same time. Wind vector correlations range from 1.7 to 2 at all stations, with Winter having the worst vector correlations and Spring having the best. PLAZ, MASS, EXPL and UNBC perform the worst, likely due to the influence from nearby stations. PULP and GLAD are better, but do not perform as well as GLEN and AIRP. This could be resulting from

CALMET not sufficiently modelling the valley flows at this spatial scale. GLEN and AIRP would not be as influenced by these valley flows, which may explain their higher and more seasonally consistent monthly wind vector correlation.

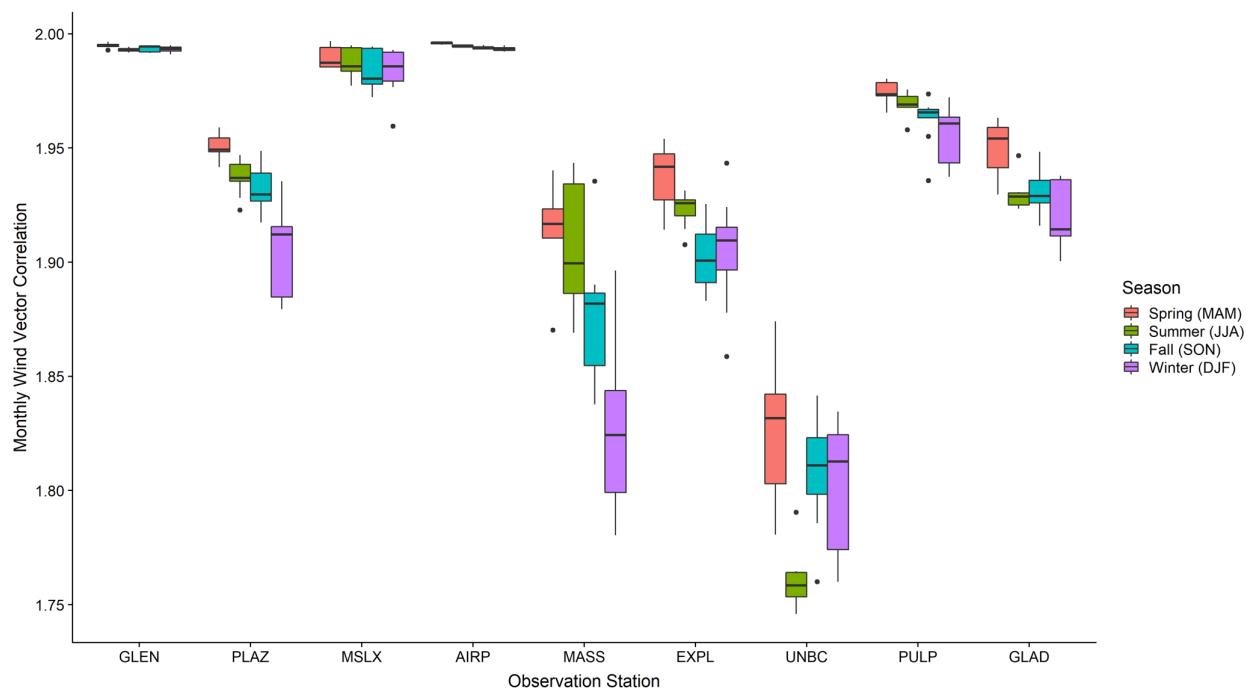


Figure 11. Boxplots of monthly wind vector correlations comparing wind speed and direction concurrently for CALMET model outputs and station observations from the same location by season for the 2014 – 2016 period. ‘TERRAD’ determines the distance downwind CALMET ‘looks’ when determining the terrain influence on wind patterns. A monthly wind vector correlation equal to 2 indicates the CALMET winds correlate perfectly with the observed winds at that location for that month (based on hourly data). Comparison locations are indicated on the x-axis, and each location has 4 individual boxplots – one for each season (Spring – Winter).

As discussed previously, comparing the CALMET model results with those produced with one observation station left out (‘leave-one-out’ analysis) allows for the estimation of the model’s performance in areas without direct influence from the observation stations. CALMET was ran with the Gladstone Elementary (GLAD) observation station left out - a comparison of monthly wind vector correlations from those and the ‘all stations’ model outputs is shown in Figure 12. Most stations are not affected by the removal of the GLAD station from the CALMET model inputs. The MSLX station, GLAD’s nearest neighbour, shows a slight improvement when GLAD is left out. As expected, leaving out GLAD leads to a significant increase in the variability and an overall reduction in the monthly wind vector correlations at the GLAD observation station.

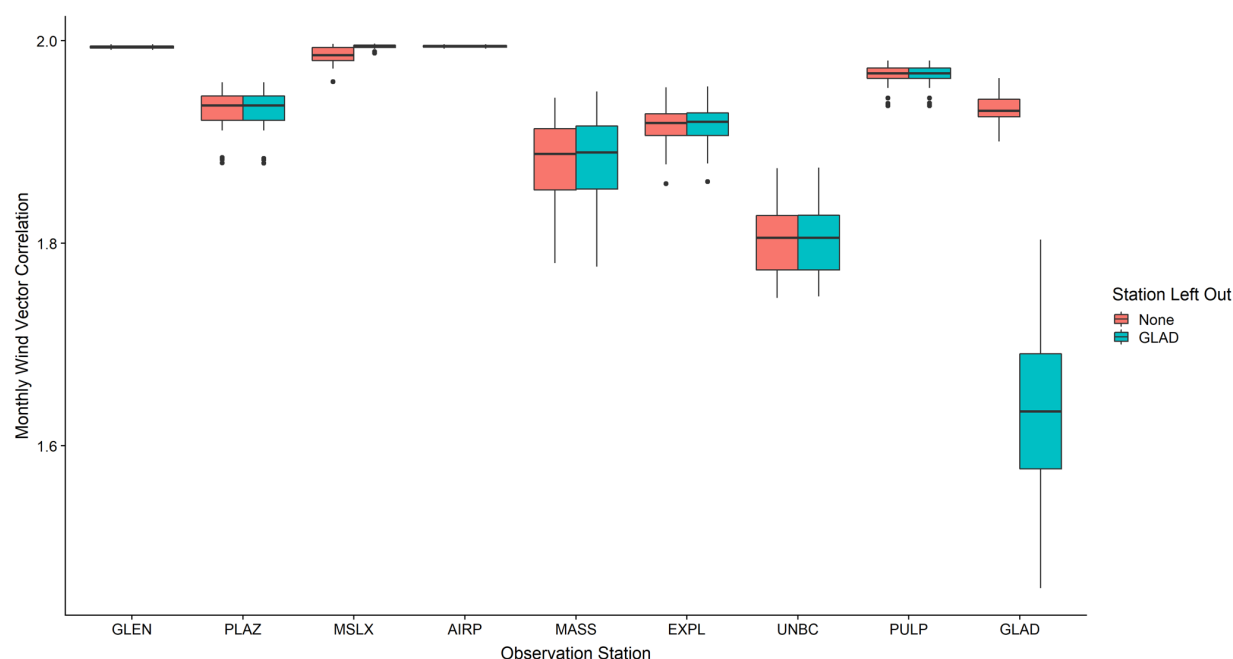


Figure 12. Boxplots of monthly wind vector correlations comparing wind speed and direction concurrently for CALMET model outputs and station observations from the same location for the 2014 – 2016 period. There are two plots per station - the left (red) are the results from the original CALMET model run, and the right (blue) are those with the GLAD station not included in the model inputs. A monthly wind vector correlation equal to 2 indicates the CALMET winds correlate perfectly with the observed winds at that location for that month (based on hourly data).

7. Conclusions: Limitations, Future Work and Recommendations

Generally, CALMET was judged to perform adequately, and is improved considerably over previous renditions of the modelling system. Due to technical and time limitations not every imagined improvement could be made to the Prince George CALMET meteorological modelling system. The new work primarily involved the updating of observation data for the period as well as several changes to the model run settings. Further analysis of outputted dispersion model results, created using the updated micro-emission inventory (MEI) and CALMET outputs, point to some possible issues. While many of these issues can be attributed to inadequacies in the MEI, the CALMET system forms the basis for the dispersion of pollutants in the CALPUFF model and as a result it has a strong influence on the resulting modelled concentrations. If the CALMET system is not properly modelling the hourly winds in the airshed, then the ability of the CALPUFF model to disperse these pollutants realistically is significantly hampered.

8. References

- Crosby, DS, Breaker LC, and Gemmill WH. (1993). A Proposed Definition for Vector Correlation in Geophysics: Theory and Application. *Journal of Atmospheric and Oceanic Technology*. 10, 355-367. DOI: 10.1175/1520-0426(1993)010%3C0355:APDFVC%3E2.0.CO;2
- Scire, JS, Strimaitis DG, and Yamartino RJ. (2011). A User's Guide for the CALPUFF Dispersion Model (Version 6). Earth Tech, Inc. Accessed September 22nd, 2019 from: http://www.src.com/calpuff/download/CALPUFF_Version6_UserInstructions.pdf
- Stantec (2010): Prince George Air Quality Dispersion Modelling Study – A Revision. Final Report, Ministry of Environment Environmental Protection Division, Prince George, BC.
- Veira A, Jackson PL, Ainslie B, and Fudge D. (2013). Assessment of background particulate matter concentrations in small cities and rural locations – Prince George, Canada. *Journal of the Air and Waste Management Association*. 63(7), 773-787. DOI: 10.1080/10962247.2013.789091

9. CALMET Input File

CALMET.INP 2.1 Hour Start and End Times with Seconds
 Met Data XXBYRXX
 Spring Conditions

----- Run title (3 lines) -----

CALMET MODEL CONTROL FILE

INPUT GROUP: 0 -- Input and Output File Names

Subgroup (a)

| Default Name | Type | File Name |
|--------------|--------|-----------------------------------|
| GEO.DAT | input | ! GEODAT=GEO.DAT ! |
| SURF.DAT | input | ! SRFDAT=S-MOD.DAT ! |
| CLOUD.DAT | input | * CLDDAT= * |
| PRECIP.DAT | input | ! PRCDAT=PRECIP.DAT ! |
| WT.DAT | input | * WTDAT= * |
| CALMET.LST | output | ! METLST=METXXBYRXX.LST ! |
| CALMET.DAT | output | ! METDAT=METXXBYRXX_XXSEAXX.DAT ! |
| PACOUT.DAT | output | * PACDAT= * |

UNBC Netcdf output file

| Default Name | Type | File Name |
|--------------|--------|---------------------------------|
| NETCDF.NCF | output | !NETCDF=CALMET_FALL_XXBYRXX.nc! |

All file names will be converted to lower case if LCFILES = T
 Otherwise, if LCFILES = F, file names will be converted to UPPER CASE
 T = lower case ! LCFILES = F !
 F = UPPER CASE

NUMBER OF UPPER AIR & OVERWATER STATIONS:

| | | |
|---|------------|----------------|
| Number of upper air stations (NUSTA) | No default | ! NUSTA = 1 ! |
| Number of overwater met stations (NOWSTA) | No default | ! NOWSTA = 0 ! |

NUMBER OF PROGNOSTIC and IGF-CALMET FILES:

| | | |
|---------------------------------------|------------|--------------|
| Number of MM4/MM5/3D.DAT files (NM3D) | No default | ! NM3D = 0 ! |
| Number of IGF-CALMET.DAT files (NIGF) | No default | ! NIGF = 0 ! |

!END!

Subgroup (b)

Upper air files (one per station)

| Default Name | Type | File Name |
|--------------|-------|-------------------------|
| UP1.DAT | input | 1 ! UPDAT=UP.DAT! !END! |

Subgroup (c)

```

-----
Overwater station files (one per station)
-----
Default Name  Type      File Name
-----
SEA1.DAT      input     1 * SEADAT=SEA_449.DAT * *END*
-----

Subgroup (d)
-----
MM4/MM5/3D.DAT files (consecutive or overlapping)
-----
Default Name  Type      File Name
-----
MM51.DAT      input     1 * M3DDAT=LSPXXBYRXX.DAT * *END*
-----

Subgroup (e)
-----
IGF-CALMET.DAT files (consecutive or overlapping)
-----
Default Name  Type      File Name
-----
IGFn.DAT      input     1 * IGFDAT=CALMET0.DAT * *END*
-----

Subgroup (f)
-----
Other file names
-----
Default Name  Type      File Name
-----
DIAG.DAT      input     * DIADAT=                *
PROG.DAT      input     * PRGDAT=                *

TEST.PRT      output    * TSTPRT=                *
TEST.OUT      output    * TSTOUT=                *
TEST.KIN      output    * TSTKIN=                *
TEST.FRD      output    * TSTFRD=                *
TEST.SLP      output    * TSTSLP=                *
DCST.GRD      output    * DCSTGD=                *

-----
NOTES: (1) File/path names can be up to 70 characters in length
      (2) Subgroups (a) and (f) must have ONE 'END' (surrounded by
          delimiters) at the end of the group
      (3) Subgroups (b) through (e) are included ONLY if the corresponding
          number of files (NUSTA, NOWSTA, NM3D, NIGF) is not 0, and each must have
          an 'END' (surround by delimiters) at the end of EACH LINE

          !END!

-----

INPUT GROUP: 1 -- General run control parameters
-----
Starting date:  Year   (IBYR)  --   No default  ! IBYR = XXBYRXX !
                Month   (IBMO)  --   No default  ! IBMO = XXBMOXX !
                Day     (IBDY)  --   No default  ! IBDY = XXBDYXX !
Starting time:  Hour    (IBHR)  --   No default  ! IBHR = XXBHRXX !
                Second  (IBSEC) --   No default  ! IBSEC = XXBSCXX !

Ending date:   Year    (IEYR)  --   No default  ! IEYR = XXEYRXX !
                Month   (IEMO)  --   No default  ! IEMO = XXEMOXX !
                Day     (IEDY)  --   No default  ! IEDY = XXEDYXX !
Ending time:   Hour    (IEHR)  --   No default  ! IEHR = XXEHRXX !
                Second  (IESEC) --   No default  ! IESEC = XXESCXX !

```

```

UTC time zone          (ABTZ) -- No default          ! ABTZ= UTC-0800 !
(character*8)
PST = UTC-0800, MST = UTC-0700 , GMT = UTC-0000
CST = UTC-0600, EST = UTC-0500

Length of modeling time-step (seconds)
Must divide evenly into 3600 (1 hour)
(NSECDT)                Default:3600          ! NSECDT = 3600 !
                        Units: seconds

Run type                (IRTYPE) -- Default: 1          ! IRTYPE= 1 !

0 = Computes wind fields only
1 = Computes wind fields and micrometeorological variables
  (u*, w*, L, zi, etc.)
  (IRTYPE must be 1 to run CALPUFF or CALGRID)

Compute special data fields required
by CALGRID (i.e., 3-D fields of W wind
components and temperature)
in additional to regular          Default: T          ! LCALGRD = T !
fields ? (LCALGRD)
(LCALGRD must be T to run CALGRID)

Flag to stop run after
SETUP phase (ITEST)          Default: 2          ! ITEST= 2 !
(Used to allow checking
of the model inputs, files, etc.)
ITEST = 1 - STOPS program after SETUP phase
ITEST = 2 - Continues with execution of
              COMPUTATIONAL phase after SETUP

Test options specified to see if
they conform to regulatory
values? (MREG)                No Default          ! MREG = 0 !

0 = NO checks are made
1 = Technical options must conform to USEPA guidance
    IMIXH   -1      Maul-Carson convective mixing height
                   over land; OCD mixing height overwater
    ICOARE   0      OCD deltaT method for overwater fluxes
    THRESHL  0.0    Threshold buoyancy flux over land needed
                   to sustain convective mixing height growth
    ISURFT   > 0    in OBS mode (pick one representative station)
                   -2    in NOOBS mode (itprog=2) (average all
                   surface prognostic temperatures to get
                   a single representative sf. temp)
    IUPT     > 0    in OBS mode (pick one representative station)
                   -2    in NOOBS mode (ITPROG>0) (average all surface
                   prognostic temperatures to get a single
                   representative sf. temp)
    IZICRLX  1      Do NOT use convective mixing height relaxation
                   to equilibrium value
                   Dennis FUDGE (MoE) modification and extra comment (Oct 2012):
                   "Allow relaxation of convective mixing height to equilibrium
value when 0<QH< THRESHL.
                   Use convective mixing height relaxation to equilibrium value"

!END!

-----

INPUT GROUP: 2 -- Map Projection and Grid control parameters
-----

Projection for all (X,Y):
-----

```

```

Map projection
(PMAP)                      Default: UTM      ! PMAP = UTM  !

    UTM : Universal Transverse Mercator
    TTM : Tangential Transverse Mercator
    LCC : Lambert Conformal Conic
    PS  : Polar Stereographic
    EM  : Equatorial Mercator
    LAZA : Lambert Azimuthal Equal Area

False Easting and Northing (km) at the projection origin
(Used only if PMAP= TTM, LCC, or LAZA)
(FEAST)                      Default=0.0      ! FEAST  = 0.000  !
(FNORTH)                     Default=0.0      ! FNORTH = 0.000  !

UTM zone (1 to 60)
(Used only if PMAP=UTM)
(IUTMZN)                     No Default      ! IUTMZN = 10    !

Hemisphere for UTM projection?
(Used only if PMAP=UTM)
(UTMHEN)                     Default: N      ! UTMHEM = N    !
    N  : Northern hemisphere projection
    S  : Southern hemisphere projection

Latitude and Longitude (decimal degrees) of projection origin
(Used only if PMAP= TTM, LCC, PS, EM, or LAZA)
(RLAT0)                      No Default      ! RLAT0 = 0N    !
(RLON0)                      No Default      ! RLON0 = 0E    !

    TTM : RLON0 identifies central (true N/S) meridian of projection
           RLAT0 selected for convenience
    LCC : RLON0 identifies central (true N/S) meridian of projection
           RLAT0 selected for convenience
    PS  : RLON0 identifies central (grid N/S) meridian of projection
           RLAT0 selected for convenience
    EM  : RLON0 identifies central meridian of projection
           RLAT0 is REPLACED by 0.0N (Equator)
    LAZA: RLON0 identifies longitude of tangent-point of mapping plane
           RLAT0 identifies latitude of tangent-point of mapping plane

Matching parallel(s) of latitude (decimal degrees) for projection
(Used only if PMAP= LCC or PS)
(XLAT1)                      No Default      ! XLAT1 = 0N    !
(XLAT2)                      No Default      ! XLAT2 = 0N    !

    LCC : Projection cone slices through Earth's surface at XLAT1 and XLAT2
    PS  : Projection plane slices through Earth at XLAT1
           (XLAT2 is not used)

-----
Note:  Latitudes and longitudes should be positive, and include a
       letter N,S,E, or W indicating north or south latitude, and
       east or west longitude.  For example,
       35.9 N Latitude  = 35.9N
       118.7 E Longitude = 118.7E

```

Datum-region

The Datum-Region for the coordinates is identified by a character string. Many mapping products currently available use the model of the Earth known as the World Geodetic System 1984 (WGS-84). Other local models may be in use, and their selection in CALMET will make its output consistent with local mapping products. The list of Datum-Regions with official transformation parameters is provided by the National Imagery and

Mapping Agency (NIMA).

NIMA Datum - Regions(Examples)

```
-----
WGS-84      WGS-84 Reference Ellipsoid and Geoid, Global coverage (WGS84)
NAS-C       NORTH AMERICAN 1927 Clarke 1866 Spheroid, MEAN FOR CONUS (NAD27)
NAR-C       NORTH AMERICAN 1983 GRS 80 Spheroid, MEAN FOR CONUS (NAD83)
NWS-84      NWS 6370KM Radius, Sphere
ESR-S       ESRI REFERENCE 6371KM Radius, Sphere
```

Datum-region for output coordinates

```
(DATUM)                      Default: WGS-84      ! DATUM = WGS-84  !
```

Horizontal grid definition:

```
-----
Rectangular grid defined for projection PMAP,
with X the Easting and Y the Northing coordinate
```

```

      No. X grid cells (NX)      No default      ! NX =   40  !
      No. Y grid cells (NY)      No default      ! NY =   40  !

Grid spacing (DGRIDKM)          No default      ! DGRIDKM = 1.  !
                                Units: km
```

Reference grid coordinate of

SOUTHWEST corner of grid cell (1,1)

```

      X coordinate (XORIGKM)      No default      ! XORIGKM = 500.000 !
      Y coordinate (YORIGKM)      No default      ! YORIGKM = 5955.000 !
                                Units: km
```

Vertical grid definition:

```
-----
      No. of vertical layers (NZ)  No default      ! NZ =   12  !

Cell face heights in arbitrary
vertical grid (ZFACE(NZ+1))      No defaults
                                Units: m
      ! ZFACE = 0.,20.,50.,80.,110.,150.,200.,300.,400.,800.,1400.,2000.,3000.  !
```

!END!

```
-----
INPUT GROUP: 3 -- Output Options
-----
```

DISK OUTPUT OPTION

```

Save met. fields in an unformatted
output file ?                (LSAVE) Default: T      ! LSAVE = T !
(F = Do not save, T = Save)
```

Type of unformatted output file:

```
(IFORMO)                      Default: 1      ! IFORMO = 1  !
```

```

      1 = CALPUFF/CALGRID type file (CALMET.DAT)
      2 = MESOPUFF-II type file     (PACOUT.DAT)
```

LINE PRINTER OUTPUT OPTIONS:

```

Print met. fields ? (LPRINT)          Default: F      ! LPRINT = T !
(F = Do not print, T = Print)
(NOTE: parameters below control which
      met. variables are printed)

Print interval
(IPRINF) in hours                    Default: 1      ! IPRINF = 728 !
(Meteorological fields are printed
 every 728 hours)

Specify which layers of U, V wind component
to print (IUROUT(NZ)) -- NOTE: NZ values must be entered
(0=Do not print, 1=Print)
(used only if LPRINT=T)              Defaults: NZ*0
! IUROUT = 1 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 !
-----

```

```

Specify which levels of the W wind component to print
(NOTE: W defined at TOP cell face -- 12 values)
(IWOUT(NZ)) -- NOTE: NZ values must be entered
(0=Do not print, 1=Print)
(used only if LPRINT=T & LCALGRD=T)
-----
                                  Defaults: NZ*0
! IWOUT = 1 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 !

```

```

Specify which levels of the 3-D temperature field to print
(ITOUT(NZ)) -- NOTE: NZ values must be entered
(0=Do not print, 1=Print)
(used only if LPRINT=T & LCALGRD=T)
-----
                                  Defaults: NZ*0
! ITOUT = 1 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 !

```

```

Specify which meteorological fields
to print
(used only if LPRINT=T)              Defaults: 0 (all variables)
-----

```

| Variable | Print ? | |
|---------------|----------------------------------|-------------------------------|
| ----- | (0 = do not print, 1 = print) | ----- |
| ! STABILITY = | 1 | ! - PGT stability class |
| ! USTAR = | 1 | ! - Friction velocity |
| ! MONIN = | 1 | ! - Monin-Obukhov length |
| ! MIXHT = | 1 | ! - Mixing height |
| ! WSTAR = | 1 | ! - Convective velocity scale |
| ! PRECIP = | 1 | ! - Precipitation rate |
| ! SENSHEAT = | 1 | ! - Sensible heat flux |
| ! CONVZI = | 1 | ! - Convective mixing ht. |

Testing and debug print options for micrometeorological module

```

Print input meteorological data and
internal variables (LDB)          Default: F      ! LDB = F !
(F = Do not print, T = print)
(NOTE: this option produces large amounts of output)

```

```

First time step for which debug data
are printed (NN1)                Default: 1      ! NN1 = 1 !

```

```

Last time step for which debug data
are printed (NN2)                Default: 1          ! NN2 = 1  !

Print distance to land
internal variables (LDBCST)       Default: F          ! LDBCST = F !
(F = Do not print, T = print)
(Output in .GRD file DCST.GRD, defined in input group 0)

Testing and debug print options for wind field module
(all of the following print options control output to
wind field module's output files: TEST.PRT, TEST.OUT,
TEST.KIN, TEST.FRD, and TEST.SLP)

Control variable for writing the test/debug
wind fields to disk files (IOUTD)
(0=Do not write, 1=write)        Default: 0          ! IOUTD = 0  !

Number of levels, starting at the surface,
to print (NZPRN2)                Default: 1          ! NZPRN2 = 1  !

Print the INTERPOLATED wind components ?
(IPR0) (0=no, 1=yes)            Default: 0          ! IPR0 = 0  !

Print the TERRAIN ADJUSTED surface wind
components ?
(IPR1) (0=no, 1=yes)            Default: 0          ! IPR1 = 0  !

Print the SMOOTHED wind components and
the INITIAL DIVERGENCE fields ?
(IPR2) (0=no, 1=yes)            Default: 0          ! IPR2 = 0  !

Print the FINAL wind speed and direction
fields ?
(IPR3) (0=no, 1=yes)            Default: 0          ! IPR3 = 0  !

Print the FINAL DIVERGENCE fields ?
(IPR4) (0=no, 1=yes)            Default: 0          ! IPR4 = 0  !

Print the winds after KINEMATIC effects
are added ?
(IPR5) (0=no, 1=yes)            Default: 0          ! IPR5 = 0  !

Print the winds after the FROUDE NUMBER
adjustment is made ?
(IPR6) (0=no, 1=yes)            Default: 0          ! IPR6 = 0  !

Print the winds after SLOPE FLOWS
are added ?
(IPR7) (0=no, 1=yes)            Default: 0          ! IPR7 = 0  !

Print the FINAL wind field components ?
(IPR8) (0=no, 1=yes)            Default: 0          ! IPR8 = 0  !

!END!

```

```

-----
INPUT GROUP: 4 -- Meteorological data options
-----

```

```

NO OBSERVATION MODE              (NOOBS) Default: 0      ! NOOBS = 0  !
0 = Use surface, overwater, and upper air stations
1 = Use surface and overwater stations (no upper air observations)
   Use MM4/MM5/3D.DAT for upper air data
2 = No surface, overwater, or upper air observations
   Use MM4/MM5/3D.DAT for surface, overwater, and upper air data

```

NUMBER OF SURFACE & PRECIP. METEOROLOGICAL STATIONS

Number of surface stations (NSSTA) No default ! NSSTA = 9 !
 Number of precipitation stations
 (NPSTA=-1: flag for use of MM5/3D.DAT precip data)
 (NPSTA) No default ! NPSTA = 1 !

CLOUD DATA OPTIONS

Gridded cloud fields:
 (ICLOUD) Default: 0 ! ICLOUD = 0 !
 ICLOUD = 0 - Gridded clouds not used
 ICLOUD = 1 - Gridded CLOUD.DAT generated as OUTPUT
 ICLOUD = 2 - Gridded CLOUD.DAT read as INPUT
 ICLOUD = 3 - Gridded cloud cover from Prognostic Rel. Humidity
 at 850mb (Teixera)
 ICLOUD = 4 - Gridded cloud cover from Prognostic Rel. Humidity
 at all levels (MM5toGrads algorithm)

FILE FORMATS

Surface meteorological data file format
 (IFORMS) Default: 2 ! IFORMS = 2 !
 (1 = unformatted (e.g., SMERGE output))
 (2 = formatted (free-formatted user input))
 Precipitation data file format
 (IFORMP) Default: 2 ! IFORMP = 2 !
 (1 = unformatted (e.g., PMERGE output))
 (2 = formatted (free-formatted user input))
 Cloud data file format
 (IFORMC) Default: 2 ! IFORMC = 2 !
 (1 = unformatted - CALMET unformatted output)
 (2 = formatted - free-formatted CALMET output or user input)

!END!

 INPUT GROUP: 5 -- Wind Field Options and Parameters

WIND FIELD MODEL OPTIONS

Model selection variable (IWFCOD) Default: 1 ! IWFCOD = 1 !
 0 = Objective analysis only
 1 = Diagnostic wind module
 Compute Froude number adjustment
 effects ? (IFRADJ) Default: 1 ! IFRADJ = 1 !
 (0 = NO, 1 = YES)
 Compute kinematic effects ? (IKINE) Default: 0 ! IKINE = 0 !
 (0 = NO, 1 = YES)
 Use O'Brien procedure for adjustment
 of the vertical velocity ? (IOBR) Default: 0 ! IOBR = 0 !
 (0 = NO, 1 = YES)
 Compute slope flow effects ? (ISLOPE) Default: 1 ! ISLOPE = 1 !
 (0 = NO, 1 = YES)
 Extrapolate surface wind observations
 to upper layers ? (IEXTRP) Default: -4 ! IEXTRP = -4 !
 (1 = no extrapolation is done,
 2 = power law extrapolation used,

```

3 = user input multiplicative factors
    for layers 2 - NZ used (see FEXTRP array)
4 = similarity theory used
-1, -2, -3, -4 = same as above except layer 1 data
    at upper air stations are ignored

Extrapolate surface winds even
if calm? (ICALM)                Default: 0      ! ICALM = 1 !
(0 = NO, 1 = YES)

Layer-dependent biases modifying the weights of
surface and upper air stations (BIAS(NZ))
-1<=BIAS<=1
Negative BIAS reduces the weight of upper air stations
(e.g. BIAS=-0.1 reduces the weight of upper air stations
by 10%; BIAS= -1, reduces their weight by 100 %)
Positive BIAS reduces the weight of surface stations
(e.g. BIAS= 0.2 reduces the weight of surface stations
by 20%; BIAS=1 reduces their weight by 100%)
Zero BIAS leaves weights unchanged (1/R**2 interpolation)
Default: NZ*0
                                ! BIAS = -1 , -.9 , -.8 , -.7 , -.6 , -.5 , -.3 , -.1 , .1 , .4
, .8 , 1 !

Minimum distance from nearest upper air station
to surface station for which extrapolation
of surface winds at surface station will be allowed
(RMIN2: Set to -1 for IEXTRP = 4 or other situations
where all surface stations should be extrapolated)
                                Default: 4.      ! RMIN2 = -1.0 !

Use gridded prognostic wind field model
output fields as input to the diagnostic
wind field model (IPROG)        Default: 0      ! IPROG = 0 !
(0 = No, [IWFCOD = 0 or 1])
1 = Yes, use CSUMM prog. winds as Step 1 field, [IWFCOD = 0]
2 = Yes, use CSUMM prog. winds as initial guess field [IWFCOD = 1]
3 = Yes, use winds from MM4.DAT file as Step 1 field [IWFCOD = 0]
4 = Yes, use winds from MM4.DAT file as initial guess field [IWFCOD = 1]
5 = Yes, use winds from MM4.DAT file as observations [IWFCOD = 1]
13 = Yes, use winds from MM5/3D.DAT file as Step 1 field [IWFCOD = 0]
14 = Yes, use winds from MM5/3D.DAT file as initial guess field [IWFCOD = 1]
15 = Yes, use winds from MM5/3D.DAT file as observations [IWFCOD = 1]

Timestep (seconds) of the prognostic
model input data (ISTEPPGS)      Default: 3600   ! ISTEPPGS = 3600 !

Use coarse CALMET fields as initial guess fields (IGFMET)
(overwrites IGF based on prognostic wind fields if any)
                                Default: 0      ! IGFMET = 0 !

RADIUS OF INFLUENCE PARAMETERS

Use varying radius of influence    Default: F      ! LVARY = T!
(if no stations are found within RMAX1,RMAX2,
or RMAX3, then the closest station will be used)
Dennis FUDGE (MoE) modification and extra comment (Oct 2012):
"Generally used due to typical station density in B.C.
However do not select if stations outside of RMAX1 are definitely not wanted"

Maximum radius of influence over land
in the surface layer (RMAX1)       No default    ! RMAX1 = 5. !
                                   Units: km

Maximum radius of influence over land
aloft (RMAX2)                     No default    ! RMAX2 = 10. !
                                   Units: km

Maximum radius of influence over water
(RMAX3)                           No default    ! RMAX3 = 20. !

```

Units: km

OTHER WIND FIELD INPUT PARAMETERS

Minimum radius of influence used in the wind field interpolation (RMIN) Default: 0.1 ! RMIN = 0.1 !
Units: km

Radius of influence of terrain features (TERRAD) No default ! TERRAD = 1 !
Units: km

Relative weighting of the first guess field and observations in the SURFACE layer (R1) No default ! R1 = 0.75 !
(R1 is the distance from an observational station at which the observation and first guess field are equally weighted) Units: km

Relative weighting of the first guess field and observations in the layers ALOFT (R2) No default ! R2 = 1.00 !
(R2 is applied in the upper layers in the same manner as R1 is used in the surface layer). Units: km

Dennis FUDGE (MoE) modification and extra comment (Oct 2012):
"Should not be greater than RMAX2"

Relative weighting parameter of the prognostic wind field data (RPROG) No default ! RPROG = 0. !
(Used only if IPROG = 1) Units: km

Maximum acceptable divergence in the divergence minimization procedure (DIVLIM) Default: 5.E-6 ! DIVLIM= 5.0E-06 !

Maximum number of iterations in the divergence min. procedure (NITER) Default: 50 ! NITER = 50 !

Number of passes in the smoothing procedure (NSMTH(NZ))
NOTE: NZ values must be entered
Default: 2,(mxnz-1)*4 ! NSMTH =
2 , 4 , 4 , 4 , 4 , 4 , 4 , 4 , 4 , 4 , 4 , 4 , 4 , 4 !

Maximum number of stations used in each layer for the interpolation of data to a grid point (NINTR2(NZ))
NOTE: NZ values must be entered Default: 99. ! NINTR2 =
99 , 99 , 99 , 99 , 99 , 99 , 99 , 99 , 99 , 99 , 99 , 99 !

Critical Froude number (CRITFN) Default: 1.0 ! CRITFN = 1. !

Empirical factor controlling the influence of kinematic effects (ALPHA) Default: 0.1 ! ALPHA = 0.01 !
Dennis FUDGE (MoE) modification and extra comment (Oct 2012):
"Empirical factor controlling the influence of kinematic effects.
Not used since IKINE = 0."

Multiplicative scaling factor for extrapolation of surface observations to upper layers (FEXTR2(NZ)) Default: NZ*0.0
! FEXTR2 = 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0. !
(Used only if IEXTRP = 3 or -3)

BARRIER INFORMATION

Number of barriers to interpolation
of the wind fields (NBAR) Default: 0 ! NBAR = 8 !

Level (1 to NZ) up to which barriers
apply (KBAR) Default: NZ ! KBAR = 1 !

THE FOLLOWING 4 VARIABLES ARE INCLUDED
ONLY IF NBAR > 0

NOTE: NBAR values must be entered No defaults
for each variable Units: km

X coordinate of BEGINNING
of each barrier (XBBAR(NBAR)) ! XBBAR = 0. !
517.5, 515.5, 517.5, 522.5, 517.5, 511.5, 517.5, 511.5 !
Y coordinate of BEGINNING
of each barrier (YBBAR(NBAR)) ! YBBAR =
5970.5, 5972.5, 5977.5, 5973.5, 5977.5, 5976.5, 5970.5, 5976.5 !
X coordinate of ENDING
of each barrier (XEBAR(NBAR)) ! XEBAR =
522.5, 518.5, 500.5, 531.5, 525.5, 500.5, 522.5, 517.5 !
Y coordinate of ENDING
of each barrier (YEBAR(NBAR)) ! YEBAR =
5973.5, 5974.5, 5987.5, 5994.5, 5994.5, 5982.5, 5955.5, 5955.5 !

DIAGNOSTIC MODULE DATA INPUT OPTIONS

Surface temperature (IDIOPT1) Default: 0 ! IDIOPT1 = 0 !
0 = Compute internally from
hourly surface observations or prognostic fields
1 = Read preprocessed values from
a data file (DIAG.DAT)

Surface met. station to use for
the surface temperature (ISURFT) Default: -1 ! ISURFT = 1 !
(Must be a value from 1 to NSSTA,
or -1 to use 2-D spatially varying
surface temperatures,
or -2 to use a domain-average prognostic
surface temperatures (only with ITPROG=2))
(Used only if IDIOPT1 = 0)

Temperature lapse rate used in the Default: 0 ! IDIOPT2 = 0 !
computation of terrain-induced
circulations (IDIOPT2)
0 = Compute internally from (at least) twice-daily
upper air observations or prognostic fields
1 = Read hourly preprocessed values
from a data file (DIAG.DAT)

Upper air station to use for
the domain-scale lapse rate (IUPT) Default: -1 ! IUPT = 1 !
(Must be a value from 1 to NUSTA,
or -1 to use 2-D spatially varying lapse rate,
or -2 to use a domain-average prognostic
lapse rate (only with ITPROG>0))
(Used only if IDIOPT2 = 0)

Depth through which the domain-scale
lapse rate is computed (ZUPT) Default: 200. ! ZUPT = 200. !
(Used only if IDIOPT2 = 0) Units: meters

Initial Guess Field Winds

```

(IDIOPT3)                                Default: 0      ! IDIOPT3 = 0  !
0 = Compute internally from
  observations or prognostic wind fields
1 = Read hourly preprocessed domain-average wind values
  from a data file (DIAG.DAT)

Upper air station to use for
the initial guess winds (IUPWND)  Default: -1      ! IUPWND = -1  !
(Must be a value from -1 to NUSTA, with
-1 indicating 3-D initial guess fields,
and IUPWND>1 domain-scaled (i.e. constant) IGF)
(Used only if IDIOPT3 = 0 and noobs=0)
-----

Bottom and top of layer through
which the domain-scale winds
are computed
(ZUPWND(1), ZUPWND(2))      Defaults: 1., 1000. ! ZUPWND= 1., 1000. !
(Used only if IDIOPT3 = 0, NOOBS>0 and IUPWND>0)  Units: meters
-----

Observed surface wind components
for wind field module (IDIOPT4) Default: 0      ! IDIOPT4 = 0  !
0 = Read WS, WD from a surface
  data file (SURF.DAT)
1 = Read hourly preprocessed U, V from
  a data file (DIAG.DAT)

Observed upper air wind components
for wind field module (IDIOPT5) Default: 0      ! IDIOPT5 = 0  !
0 = Read WS, WD from an upper
  air data file (UP1.DAT, UP2.DAT, etc.)
1 = Read hourly preprocessed U, V from
  a data file (DIAG.DAT)

LAKE BREEZE INFORMATION

Use Lake Breeze Module  (LLBREZE)
                        Default: F      ! LLBREZE = F  !

Number of lake breeze regions (NBOX)      ! NBOX = 0  !

X Grid line 1 defining the region of interest      ! XG1 = 0.  !
X Grid line 2 defining the region of interest      ! XG2 = 0.  !
Y Grid line 1 defining the region of interest      ! YG1 = 0.  !
Y Grid line 2 defining the region of interest      ! YG2 = 0.  !

X Point defining the coastline (Straight line)
(XBCST) (KM)  Default: none      ! XBCST = 0.  !

Y Point defining the coastline (Straight line)
(YBCST) (KM)  Default: none      ! YBCST = 0.  !

X Point defining the coastline (Straight line)
(XECST) (KM)  Default: none      ! XECST = 0.  !

Y Point defining the coastline (Straight line)
(YECST) (KM)  Default: none      ! YECST = 0.  !

Number of stations in the region      Default: none ! NLB = 0  !
(Surface stations + upper air stations)

Station ID's  in the region  (METBXID(NLB))

```



```

(Surface stations first, then upper air stations)
! METBXID = 0 !

!END!

-----

INPUT GROUP: 6 -- Mixing Height, Temperature and Precipitation Parameters
-----

EMPIRICAL MIXING HEIGHT CONSTANTS

Neutral, mechanical equation
(CONSTB)                                Default: 1.41    ! CONSTB = 1.41 !
Convective mixing ht. equation
(CONSTE)                                Default: 0.15    ! CONSTE = 0.15 !
Stable mixing ht. equation
(CONSTN)                                Default: 2400.   ! CONSTN = 2400.!
Overwater mixing ht. equation
(CONSTW)                                Default: 0.16    ! CONSTW = 0.16 !
Absolute value of Coriolis
parameter (FCORIO)                       Default: 1.E-4   ! FCORIO = 1.2E-04!
Units: (1/s)

SPATIAL AVERAGING OF MIXING HEIGHTS

Conduct spatial averaging
(IAVEZI) (0=no, 1=yes)                   Default: 1        ! IAVEZI = 1 !

Max. search radius in averaging
process (MNMDAV)                           Default: 1        ! MNMDAV = 1 !
Units: Grid
      cells

Half-angle of upwind looking cone
for averaging (HAFANG)                     Default: 30.      ! HAFANG = 30. !
Units: deg.

Layer of winds used in upwind
averaging (ILEVZI)                         Default: 1        ! ILEVZI = 1 !
(must be between 1 and NZ)

CONVECTIVE MIXING HEIGHT OPTIONS:
Method to compute the convective
mixing height (IMIXH)                       Default: 1        ! IMIXH = 1 !
  1: Maul-Carson for land and water cells
  -1: Maul-Carson for land cells only -
      OCD mixing height overwater
  2: Batchvarova and Gryning for land and water cells
  -2: Batchvarova and Gryning for land cells only
      OCD mixing height overwater

Threshold buoyancy flux required to
sustain convective mixing height growth
overland (THRESHL)                         Default: 0.0      ! THRESHL = 0.05 !
(expressed as a heat flux                    units: W/m3
per meter of boundary layer)

Threshold buoyancy flux required to
sustain convective mixing height growth
overwater (THRESHW)                       Default: 0.05     ! THRESHW = 0.05 !
(expressed as a heat flux                    units: W/m3
per meter of boundary layer)

Option for overwater lapse rates used
in convective mixing height growth

```

```

(ITWPROG)                                Default: 0      ! ITWPROG = 0  !
0 : use SEA.DAT lapse rates and deltaT (or assume neutral
    conditions if missing)
1 : use prognostic lapse rates (only if IPROG>2)
    and SEA.DAT deltaT (or neutral if missing)
2 : use prognostic lapse rates and prognostic delta T
    (only if iprog>12 and 3D.DAT version# 2.0 or higher)

Land Use category ocean in 3D.DAT datasets
(ILUOC3D)                                Default: 16      ! ILUOC3D = 16  !
Note: if 3D.DAT from MM5 version 3.0, iluoc3d = 16
      if MM4.DAT,                typically iluoc3d = 7

```

OTHER MIXING HEIGHT VARIABLES

```

Minimum potential temperature lapse
rate in the stable layer above the
current convective mixing ht.          Default: 0.001 ! DPTMIN = 0.001 !
(DPTMIN)                               Units: deg. K/m
Depth of layer above current conv.
mixing height through which lapse
rate is computed (DZZI)                Default: 200.  ! DZZI = 200.  !
                                         Units: meters

Minimum overland mixing height          Default: 50.   ! ZIMIN = 50.   !
(ZIMIN)                               Units: meters
Maximum overland mixing height          Default: 3000. ! ZIMAX = 3000. !
(ZIMAX)                               Units: meters
Minimum overwater mixing height         Default: 50.   ! ZIMINW = 50.   !
(ZIMINW) -- (Not used if observed
overwater mixing hts. are used)         Units: meters
Maximum overwater mixing height         Default: 3000. ! ZIMAXW = 3000. !
(ZIMAXW) -- (Not used if observed
overwater mixing hts. are used)         Units: meters

```

OVERWATER SURFACE FLUXES METHOD and PARAMETERS

```

(ICOARE)                                Default: 10      ! ICOARE = 10  !
0: original deltaT method (OCD)
10: COARE with no wave parameterization (jwave=0, Charnock)
11: COARE with wave option jwave=1 (Oost et al.)
    and default wave properties
-11: COARE with wave option jwave=1 (Oost et al.)
    and observed wave properties (must be in SEA.DAT files)
12: COARE with wave option 2 (Taylor and Yelland)
    and default wave properties
-12: COARE with wave option 2 (Taylor and Yelland)
    and observed wave properties (must be in SEA.DAT files)

```

Note: When ICOARE=0, similarity wind profile stability PSI functions based on Van Ulden and Holtslag (1985) are substituted for later formulations used with the COARE module, and temperatures used for surface layer parameters are obtained from either the nearest surface station temperature or prognostic model 2D temperatures (if ITPROG=2).

```

Coastal/Shallow water length scale (DSHELF)
(for modified z0 in shallow water)
( COARE fluxes only)

```

```

                                Default : 0.      ! DSHELF = 0.  !
                                units: km

```

```

COARE warm layer computation (IWARM)          ! IWARM = 0  !
1: on - 0: off (must be off if SST measured with
IR radiometer)                                Default: 0

```

```

COARE cool skin layer computation (ICOOL)      ! ICOOL = 0  !

```

1: on - 0: off (must be off if SST measured with
IR radiometer) Default: 0

RELATIVE HUMIDITY PARAMETERS

3D relative humidity from observations or
from prognostic data? (IRHPRG) Default: 0 ! IRHPRG = 0 !

0 = Use RH from SURF.DAT file
(only if NOOBS = 0,1)
1 = Use prognostic RH
(only if NOOBS = 0,1,2)

TEMPERATURE PARAMETERS

3D temperature from observations or
from prognostic data? (ITPROG) Default: 0 ! ITPROG = 0 !

0 = Use Surface and upper air stations
(only if NOOBS = 0)
1 = Use Surface stations (no upper air observations)
Use MM5/3D.DAT for upper air data
(only if NOOBS = 0,1)
2 = No surface or upper air observations
Use MM5/3D.DAT for surface and upper air data
(only if NOOBS = 0,1,2)

Interpolation type
(1 = 1/R ; 2 = 1/R**2) Default: 1 ! IRAD = 1 !

Radius of influence for temperature
interpolation (TRADKM) Default: 500. ! TRADKM = 30. !
Units: km

Maximum Number of stations to include
in temperature interpolation (NUMTS) Default: 5 ! NUMTS = 3 !

Conduct spatial averaging of temp-
eratures (IAVET) (0=no, 1=yes) Default: 1 ! IAVET = 1 !
(will use mixing ht MNMDAV, HAFANG
so make sure they are correct)

Default temperature gradient
below the mixing height over
water (TGDEFB) Default: -.0098 ! TGDEFB = -0.0098 !
Units: K/m

Default temperature gradient
above the mixing height over
water (TGDEFA) Default: -.0045 ! TGDEFA = -0.0045 !
Units: K/m

Beginning (JWAT1) and ending (JWAT2)
land use categories for temperature
interpolation over water -- Make ! JWAT1 = 999 !
bigger than largest land use to disable ! JWAT2 = 999 !

PRECIP INTERPOLATION PARAMETERS

Method of interpolation (NFLAGP) Default: 2 ! NFLAGP = 1 !
(1=1/R, 2=1/R**2, 3=EXP/R**2)

Radius of Influence (SIGMAP) Default: 100.0 ! SIGMAP = 40. !
Units: km
(0.0 => use half dist. btwn
nearest stns w & w/out
precip when NFLAGP = 3)

Minimum Precip. Rate Cutoff (CUTP) Default: 0.01 ! CUTP = 0.01 !
Units: mm/hr
(values < CUTP = 0.0 mm/hr)

!END!

 INPUT GROUP: 7 -- Surface meteorological station parameters

SURFACE STATION VARIABLES

(One record per station -- 10 records in all)

| | 1 | 2 | | | | |
|-------|--------|----|------------------|------------------|--------------|------------------|
| | Name | ID | X coord. (km) | Y coord. (km) | Time zone | Anem. Ht. (m) |
| ! SS1 | 'MSLX' | 1 | 517.504 | 5966.328 | 8 | 15.2 ! |
| ! SS2 | 'AIRP' | 2 | 521.688 | 5971.334 | 8 | 14 ! |
| ! SS3 | 'EXPL' | 3 | 517.476 | 5973.000 | 8 | 14 ! |
| ! SS4 | 'GLAD' | 4 | 515.686 | 5967.725 | 8 | 15 ! |
| ! SS5 | 'GLEN' | 5 | 514.684 | 5983.050 | 8 | 17.8 ! |
| ! SS6 | 'MASS' | 6 | 513.798 | 5972.416 | 8 | 15 ! |
| ! SS7 | 'PLAZ' | 7 | 516.946 | 5974.064 | 8 | 27 ! |
| ! SS8 | 'PULP' | 8 | 520.620 | 5975.156 | 8 | 22 ! |
| ! SS9 | 'UNBC' | 9 | 512.193 | 5971.669 | 8 | 30 ! |

 1
 Four character string for station name
 (MUST START IN COLUMN 9)

2
 Six digit integer for station ID

*

Dennis FUDGE (MoE) modification and extra comment (Oct 2012):
 "These are the new coordinates for the meteorological data.
 Even though the distances are off by as much as 540 metres,
 I don't think these new coordinates will change Calmet much.
 But, if we are re-running Calmet it may be best to used the correct locations just to be
 on the safe side.
 Difference in locations (metres):
 ='PLAZ' 157 m
 ='NORT' 109 m
 ='PULP' 128 m
 ='AIRP' 372 m
 ='GLEN' 30 m
 ='UNBC'
 "

!END!

 INPUT GROUP: 8 -- Upper air meteorological station parameters

UPPER AIR STATION VARIABLES

(One record per station -- 1 records in all)

| | 1 | 2 | | | |
|-------|--------|----|------------------|------------------|-----------|
| | Name | ID | X coord. (km) | Y coord. (km) | Time zone |
| ! US1 | 'MASS' | 1 | 513.141 | 5972.414 | 0 ! |

 1
 Four character string for station name
 (MUST START IN COLUMN 9)

2

```

    Five digit integer for station ID

*
Dennis FUDGE (MoE) modification and extra comment (Oct 2012):
"These are the new coordinates for the meteorological data.
Even though the distances are off by as much as 540 metres,
I don't think these new coordinates will change Calmet much.
But, if we are re-running Calmet it may be best to used the correct locations just to be
on the safe side.
    Difference in locations 538 metres
"

!END!

-----

INPUT GROUP: 9 -- Precipitation station parameters
-----

PRECIPITATION STATION VARIABLES
(One record per station -- 1 records in all)
(NOT INCLUDED IF NPSTA = 0)

      1          2
Name   Station   X coord. Y coord.
      Code      (km)    (km)
-----
! PS1  ='YXS'      1    521.198   5970.682      !

-----

1
Four character string for station name
(MUST START IN COLUMN 9)

2
Six digit station code composed of state
code (first 2 digits) and station ID (last
4 digits)

*
Dennis FUDGE (MoE) modification and extra comment (Oct 2012):
"These are the new coordinates for the meteorological data.
Even though the distances are off by as much as 540 metres,
I don't think these new coordinates will change Calmet much.
But, if we are re-running Calmet it may be best to used the correct locations just to be
on the safe side.
    Difference in locations 372 metres
"

!END!

```