1.2 The Use of High Resolution Numerical Fields for Regulatory Dispersion Modelling: An Analysis of RAMS and MC2 fields over Kamloops B.C.

Bryan McEwen *
Brendan Murphy

1.0 INTRODUCTION

Output fields from the Regional Atmospheric Modeling System (RAMS) and the Mesoscale Compressible Community (MC2) mesoscale models were obtained for the period of January 28 to February 10, 2003. The simulations cover a volume of space over the Thomson-Okanagan region of British Columbia (BC), and were produced during earlier work for the BC Ministry of Water, Land and Air Protection (MWLAP). The interval was representative of the brief periods during which high levels of particulate matter are measured in the area. Each model used Eta 90 km fields for initialization and nudging, with RAMS using 6-hourly analysis fields, and MC2 using 3-hourly forecast fields. RAMS used an innermost grid spacing of 1 km whereas MC2 used 2 km spacing. Output fields from the simulations were formatted for use with the CALPUFF meteorological processor (CALMET).

CALPUFF is a new generation regulatory dispersion model that requires 3-dimensional meteorological fields to determine the advection and dilution of air contaminants. Due to the relatively complex terrain of many British Columbian communities, several local meteorological stations are usually required to adequately characterise a region of interest. The station data is fed to the CALPUFF meteorological processor (CALMET), which constructs the fields in a deterministic manner. In areas where the necessary observation stations are not present, a considerable amount of time and money are required to establish them before an air quality study can commence. An alternative approach is to use the simulated meteorological fields from a prognostic mesoscale model. Such models are now able to simulate local temperature and winds at high resolution without the prohibitively large computer run times that until recently made their application unrealistic.

Previous mesoscale modelling studies have provided a measure of the statistical error in numerical meteorological fields in different situations. Predictions of temperature, wind, and other related variables can at times be significantly different than actual observations. However, regulatory dispersion modelling is generally used for predicting maximum

* Corresponding author address: Bryan McEwen, SENES Consultants Ltd., Vancouver BC. (604) 685-1612. E-mail: bmcewen@senesbc.ca

Predictions of temperature, wind, and other related variables can at times be significantly different than actual observations. However, regulatory dispersion modelling is generally used for predicting maximum and average pollutant concentrations over long periods of time (a year or more). For the purposes of regulatory modelling, a more important issue than hour-by-hour differences in modelled versus actual meteorology may be whether or not a prognostic model can generate the range, and frequency of atmospheric circulations experienced in an area.

Simulated meteorology has potential to replace the use of meteorological observations in regulatory dispersion modelling, particularly for areas with limited meteorological observations. However, there have been deficiencies noted in prognostic fields at certain times and meteorological conditions. Most notably, mesoscale models appear to have difficulty simulating boundary layer fields in regions of complex terrain, even when using relatively high horizontal and vertical grid spacing.

2.0 ASSESSMENT METHODOLOGY

Recent versions of CALMET (5.5 and higher) allow ‘no obs’ modeling with the exclusive use of prognostic meteorological fields. For this analysis, the RAMS and MC2 fields were used to drive CALMET without any modification from the ‘Diagnostic Wind Module’ within CALMET itself. To serve as a comparison, CALMET was also run using data from 5 available surface stations in the modeling domain, and an upper-air station approximately 100 km away in Kelowna. In this way, prognostic-derived and deterministic CALMET meteorological fields can be assessed within a common framework.

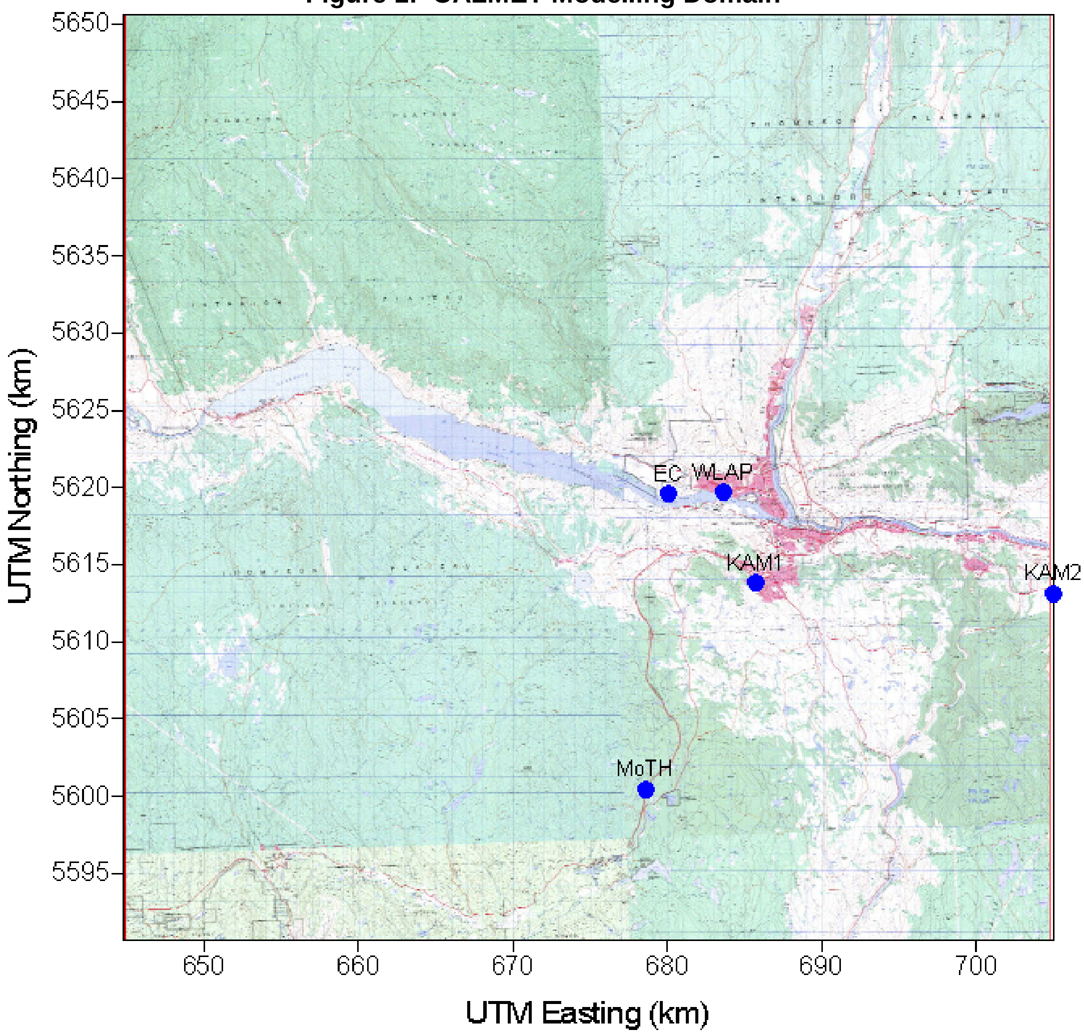
A series of CALMET ‘BENCHMARK’ deterministic runs were conducted by systematically removing one station from the initialization dataset. Each CALMET run was then used for a wind validation at the removed station location. In this way, identical validation was performed on the deterministic fields as on the prognostic-derived fields.

A Benchmark CALMET run was also conducted using all 5 surface stations. Temperature and stability-related parameters were compared between this 5-station deterministic Benchmark run and the prognostic-derived CALMET runs. These comparisons are not used to validate the prognostic-derived parameters, but instead provide an indication of how 'different' prognostic-derived meteorological fields are to deterministic fields. The surface stations used for wind validation, and for driving the CALMET deterministic runs are described in Table 1. Figure 1 shows the CALMET modeling domain, with the locations of the 5 surface stations.

Table 1: Surface Observation Station Locations

Surface Station	Location		
	Description	UTM E (km)	UTM N (km)
EC YKA (3780)	Kamloops Airport	680.072	5619.566
WLAP (Brocklehurst)	Kamloops city, 3.5 km E of Kamloops Airport	683.603	5619.689
MoTH (Walloper)	Coquihalla Highway, SSW of Kamloops	678.601	5600.482
Kam1	Pacific Way, southern edge of Kamloops	685.749	5613.792
Kam2	Barnhartvale Road, 15km E of Kamloops	704.993	5613.106

Figure 1: CALMET Modelling Domain



3.0 CALMET Modelling

The two-week period in winter, 2003 was dominated by a broad high-pressure system that persisted for most of the interval (Stull, 2003). As such, regional winds were generally light, and local terrain-induced circulation patterns were responsible for much of the variability in near-surface winds.

CALMET modeling was performed with a horizontal grid spacing of 250m, with topographical heights and landuse categories determined from high resolution (90m) datasets. Although the CALMET runs were at a higher resolution than the mesoscale simulations, a quick comparison of RAMS surface winds with RAMS-derived CALMET surface winds showed little difference in circulation patterns.

Surface wind validation was not performed at the EC YKA and Kam2 station locations, due to Kam2 being at the edge of the modeling domain, and EC YKA having a high percentage of zero wind speeds recorded (due to a relatively high instrument threshold). In addition, both the EC and the WLAP station winds were removed from the BENCHMARK input file for validation of surface winds at WLAP station, due to the close proximity of these two surface stations.

4.0 RESULTS

4.1 Surface Wind

A great degree of variability in surface wind direction was noted in both the station observation data, and the prognostic simulations. The stagnant conditions modeled in this study are very challenging for any meteorological model to represent. In addition, the standard deviation of observed wind direction increases during low wind speeds, and the ability of a single monitoring location to represent a large volume of space is suspect. Therefore, it was expected that there would be significant differences between observed and modeled surface winds.

Surface wind comparisons are provided in Tables 2 to 4 for the WALLOPER, WLAP and KAM1 stations. Two-week mean wind speed and scalar wind direction, in addition to Root Mean Square Error (RMSE) scores are shown. The RMSE values of each CALMET run are similar to those determined from previous mesoscale model validation studies, with the exception of the RMSE direction scores, which are higher than the 50 – 60 ^{o} commonly found in the literature (e.g., Hanna and Yang, 2001). The very light winds of the modeling period may be responsible for this difference. Each of the three CALMET modeling scenarios achieved similar RMSE scores, although the deterministic runs have higher RMSE direction scores overall. As modeled wind direction is particularly important for a dispersion analysis, the frequency of modeled wind direction within 45^{o} of the observed wind direction was also determined, to provide a rough indication of how often a CALMET run produced the 'correct' wind direction.

The RAMS-derived CALMET run was clearly the most successful at modeling surface winds at the WLAP station, which is situated in an east-west oriented valley, at low elevation. At the higher elevation stations, the MC2-derived CALMET run was the most successful of the three CALMET modeling strategies. This indicates that the MC2 innermost grid spacing of 2 km may not have been adequate to capture the influence of the valley on the regional winds.

Wind rose (WR) diagrams were constructed for the three station locations to assess how well each CALMET modeling scenario reproduced the surface wind patterns, regardless of time. Figures 2, 3 and 4 show the two-week WR diagrams for the observed, deterministic (BENCHMARK), RAMS-derived and MC2-derived surface winds. The only close match between observed and modeled WR diagrams occurs with the RAMS-derived CALMET run at the WLAP station location (in the valley). At the other two locations, the MC2-derived WR diagrams are significantly different than observed diagrams, but provide the best representation of surface winds over the two weeks. The BENCHMARK WR diagrams are not a good match to observations at any station location.

4.2 Temperature

CALMET BENCHMARK temperatures were compared against predicted temperatures from the prognostic-derived CALMET runs, both in the form of average surface temperatures and average vertical temperature gradients through Layer1 to Layer 4 (surface to 150m height). In addition, CALMET mixing heights and Pasquill-Gifford stability classes were compared, due to the strong influence these parameters can have in dispersion modelling. The temperature and stability comparisons were conducted at the WLAP station location, since there is greater interest (and difficulty) simulating boundary layer structure in valley locations. Table 5 shows the temperature comparisons at WLAP station.

Table 2: Surface Wind Comparison at WALLOPER station

	Mean For Two-Week Period		Root Mean Square Error (n = 328)			Frequency of modelled wind direction within 45^o of observed
	Speed (m/s)	Wind Direction (^{o})	Vector (m/s)	Speed (m/s)	Direction (^{o})	
OBSERVED DATA	**2.0**	**245**	-	-	-	-
BENCHMARK	1.2	185	2.5	2.0	74	29%
RAMS	2.3	260	2.9	1.7	77	24%
MC2	1.8	269	2.4	1.7	50	54%

Table 3: Surface Wind Comparison at WLAP station

	Mean For Two-Week Period		Root Mean Square Error (n=328)			Frequency of modelled wind direction within 45^o of observed
	Speed (m/s)	Wind Direction (^{o})	Vector (m/s)	Speed (m/s)	Direction (^{o})	
OBSERVED DATA	**2.2**	**152**	-	**-**	**-**	**-**
BENCHMARK	1.3	192	2.4	1.5	88	30%
RAMS	1.7	149	2.4	1.2	75	49%
MC2	0.9	162	2.6	1.6	98	14%

Table 4: Surface Wind Comparison at Kam1 Station

	Mean For Two-Week Period		Root Mean Square Error (n=328)			Frequency of modelled wind direction within 45^o of observed
	Speed (m/s)	Wind Direction (^{o})	Vector (m/s)	Speed (m/s)	Direction (^{o})	
OBSERVED DATA	**1.4**	**187**	-	-	-	-
BENCHMARK	2.0	163	2.1	1.3	86	30%
RAMS	2.3	187	2.4	1.6	78	34%
MC2	0.9	220	1.5	0.9	75	39%

Table 5: Temperature Comparisons at WLAP Station

	MORNING (4 A.M.)			AFTERNOON (4 P.M.)		
	Mean Surface Temperature (K) (n=14)	Mean Vertical Temperature Gradient Near Surface (^{o}C/100m)	Max Vertical Temperature Gradient Near Surface (^{o}C/100m)	Mean Surface Temperature (K) (n=14)	Mean Vertical Temperature Gradient Near Surface (^{o}C/100m)	Minimum Vertical Temperature Gradient Near Surface (^{o}C/100m)
BENCHMARK	**272.0**	**+1.1**	**+2.5**	**276.6**	**-0.8**	**-1.1**
RAMS	273.1	-0.4	0.0	279.5	-0.4	-0.8
MC2	265.9	+1.8	+2.8	267.0	+1.6	+0.3

The BENCHMARK surface temperatures are determined in CALMET from surface station temperature data and therefore are a near-perfect match to observations at this location. The vertical temperature gradients are determined from the radiosonde profile from the Kelowna station. The Kelowna station is located in a valley oriented north-south and is almost 100m higher in elevation than the Kamloops (WLAP) station. However, due to the synoptic high pressure pattern that existed for most of the period, the Kelowna profiles are likely representative of conditions experienced at Kamloops.

On average, RAMS-derived surface temperatures are reasonably close to BENCHMARK, but greater afternoon warming is evident. The MC2-derived surface temperatures are consistently lower than observed, with lesser diurnal variation. Vertical temperature gradients near the surface are weaker in the case of RAMS (particularly at 4 A.M.) and stronger in the case of MC2 (particularly in the afternoon) than BENCHMARK. The tendency for RAMS to produce neutral-type temperature profiles during evenings with stable conditions has been found in previous studies (e.g., Lyons, 1995).

4.3 Stability

Comparisons of both Pasquill-Gifford (PG) stability classes and mixing heights were completed to give an indication of differences in stability-related parameters in deterministic versus prognostic-derived CALMET fields. Figure 3 shows the distribution of PG classes, and Figure 4 shows a comparison of mean mixing heights from the three different CALMET scenarios for the duration of the two-week period.

Determination of CALMET PG classes is based on cloud cover, surface wind speed, and time of day. Evening mixing heights in the CALMET model are largely dependent on surface temperatures and cloud cover. Daytime mixing heights are proportional to both the surface heat flux (which in turn depends on cloud cover, surface temperature and wind speed) and the vertical temperature profile in the layer above the previous hours' mixing height (Scire, 2000). The BENCHMARK CALMET run uses cloud cover from the EC YKA surface station. Currently, CALMET 'no obs' modeling has the option of either using an externally generated cloud-cover input file, or allowing the model to calculate cloud amounts based on the prognostic relative humidity field at 850 mb. As cloud-cover was not available in the MC2 fields, the latter selection was used.

Figure 3 shows a dramatic difference in the frequency of PG class 6 (unstable) and class 4 (neutral) between the deterministic and prognostic-derived CALMET runs. As all three CALMET runs produced low wind speeds, these results are almost certainly a result of differences in cloud cover. To illustrate the point, Table 6 shows observed EC YKA cloud cover fractions and cloud fractions extracted directly from the RAMS fields at approximately the same location (although the RAMS CALMET run did not use these cloud fractions).

Table 6 shows that Kamloops experienced complete cloud cover a surprising 33% of the time. This is likely due to low-level cloud that commonly develops in the valley communities of the Thomson-Okanagan during the winter, which is not experienced at higher elevations. The RAMS cloud fractions over the valley are more representative of mesoscale cloud, which was generally sparse. Since the local valley cloud develops below 850 mb, the CALMET algorithm for determining cloud fractions would also tend not to represent it. The MC2-derived run also has category 2 (moderately stable) occurring over twice as often as BENCHMARK. This is due in part to the very low wind speeds developed by MC2 in the valley.

Figure 3: Distribution of CALMET PG Classes

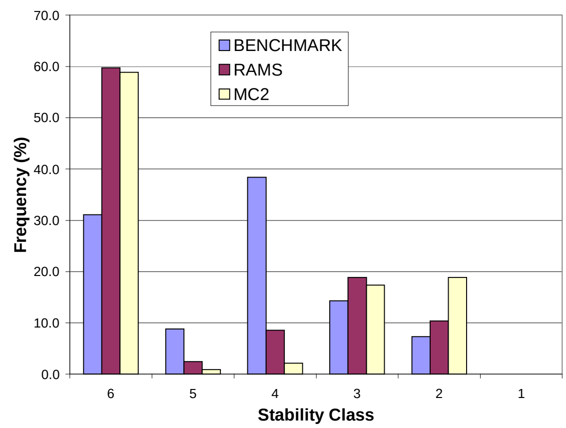


Figure 4: Mean CALMET Mixing Heights by Hour of Day

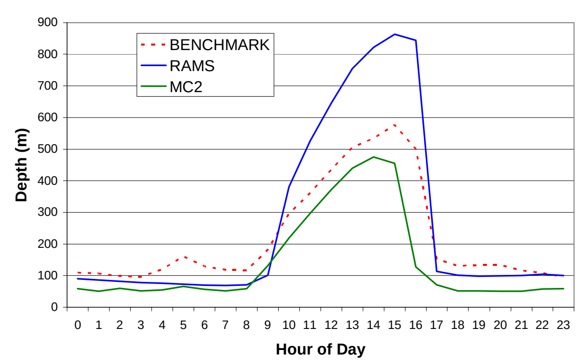


Table 6: Distribution of Observed vs. RAMS Cloud Fractions at EC YKA Station Location During the Modelling Period

Cloud Fraction (tenths)	RAMS (%)	EC YKA (%)
0	52	10
1	14	4
2	18	12
3	6	8
4	7	7
5	2	8
6	0	4
7	0	7
8	0	6
9	0	12
10	0	33

The RAMS-derived mixing heights are both lower in the morning and higher in the afternoon than those in the BENCHMARK run. The cause is at least partly due to a combination of lower cloud fraction amounts and higher afternoon surface temperatures. The RAMS-derived neutral-type temperature profiles near the surface during the evening and early morning hours (while radiosonde data shows stronger stability) evidently do not have a large impact on CALMET determination of mixing height.

The MC2 run has mean hourly mixing heights lower than BENCHMARK at all hours of the day. Similar to the RAMS runs, lower cloud fractions may be partly responsible for the low evening heights, further decreased due to the cooler MC2 surface temperatures. The low afternoon mixing heights are likely due to lower MC2 surface temperatures and surface wind speeds, and stronger modelled vertical temperature gradients than those produced in the BENCHMARK run. Although the difference between MC2 and BENCHMARK mixing heights are greater than for the RAMS values in the evening and early morning, the MC2 values are closer on average in the afternoon.

5.0 CONCLUSION

Modelling of the stagnant conditions experienced during the interval considered in this study was challenging for both the deterministic and the prognostic-derived CALMET runs. During such conditions, the use of RAMS or MC2 fields with CALMET, without the support of local observations, produced superior surface wind fields to CALMET when using 1 upper-air station and 3 or 4 surface stations. The MC2 winds were a closer match to station observations outside of the valley, compared to RAMS, but were not a good match in the valley, where RAMS winds were clearly much better. The finer horizontal spacing of RAMS inner grid likely is partly responsible for this difference, although other differences between the RAMS and MC2 models, or modeling options, may have had a contributing role.

There were large differences between deterministic and prognostic-derived temperature and stability related parameters in the valley. Of particular significance, surface temperature and cloud cover fractions were found to have a large effect on CALMET's determination of PG classes and mixing heights. The CALMET scheme to calculate cloud cover amounts based on relative humidity at 850 mb does not capture the existence of low level cloud, which was likely experienced in the valley setting of Kamloops during the modeling period. However, it was noted that cloud cover fractions in the RAMS fields were not a good match to observations in the valley, suggesting that, for RAMS at least, the CALMET cloud cover algorithm may have represented actual RAMS cloud cover reasonably well. Further investigation of this issue is needed.

6.0 ACKNOWLEDGEMENTS

This study was funded by the British Columbia Ministry of Water, Land and Air Protection.

7.0 REFERENCES

Scire, J.S., F.R. Robe, M.E. Fernau, and R.J. Yamartino, 2000: A User's Guid for the CALMET Meteorological Model (Version 5). Earth Tech Inc., Concord, MA.

Lyons, W.A., C.J. Tremback, and R.A. Pielke, 1995: Applications of the Regional Atmospheric Modeling System (RAMS) to Provide Input to the Photochemical Grid Models for the Lake Michigan Ozone Study (LMOS). J. Appl. Met, **34**, 1762-1786.

Stull, R., 2003: South Central B.C. Air Quality Ensemble Forecast Research, A Final Grant Report to the BC Ministry of Water, Land and Air Protection (WLAP).

Hanna, S.R., and R. Yang, 2001: Evaluation of Mesoscale Models' Simulations of Near-Surface Winds, Temperature Gradients and Mixing Depths. J. Appl. Met., **40**, 1095-1104.

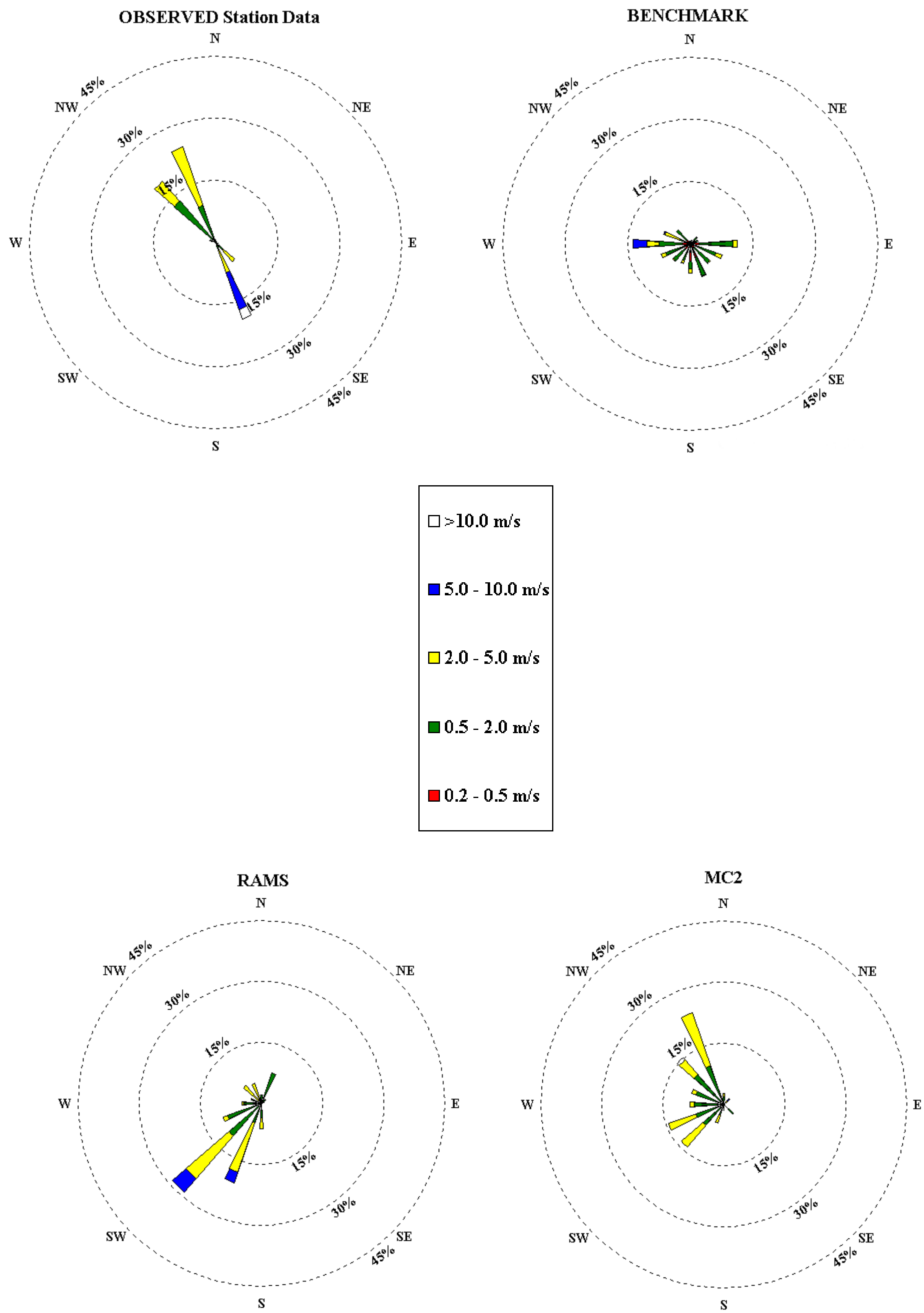


Figure 2: WR Diagrams at WALLOPER Surface Station

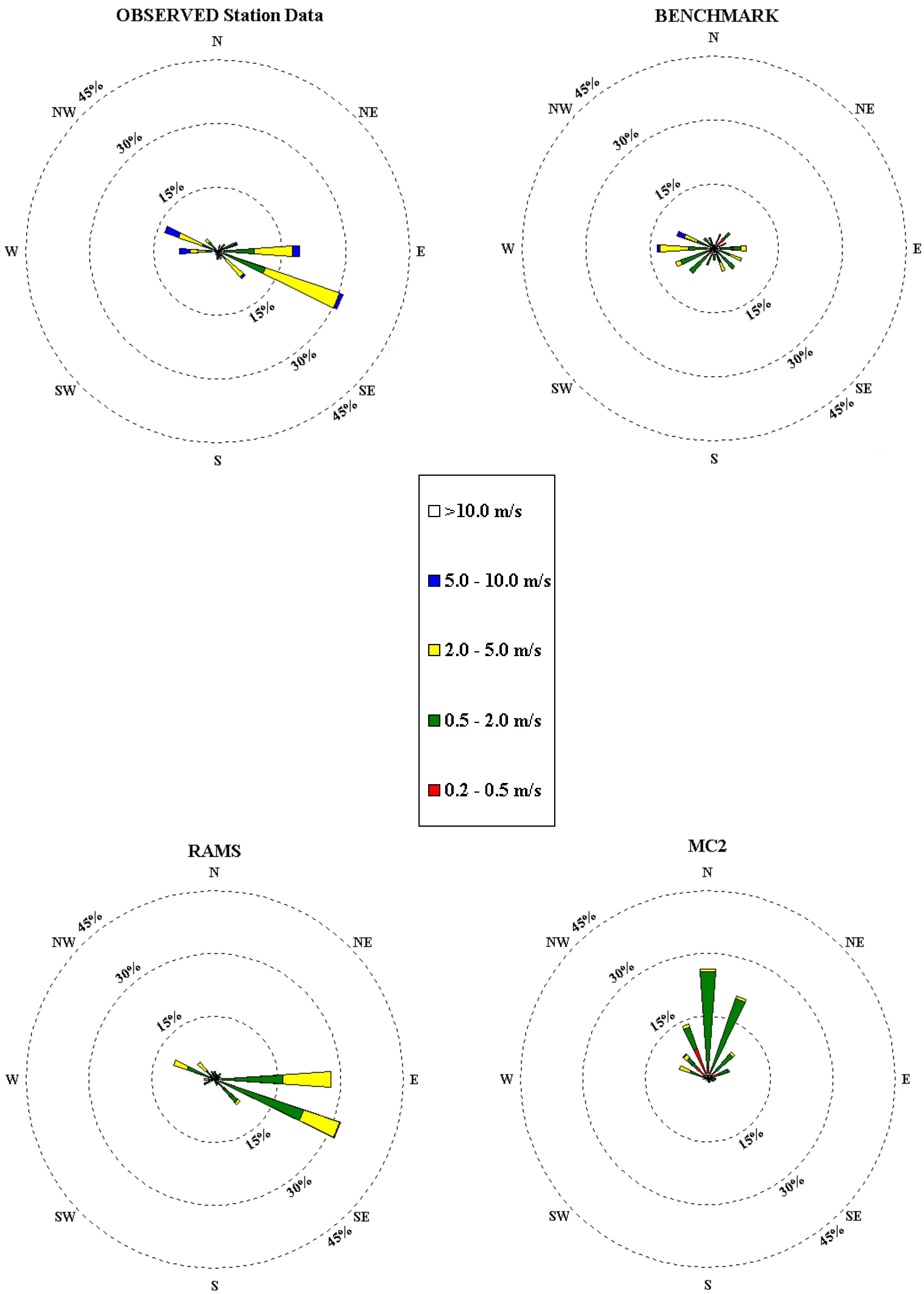


Figure 3: WR Diagrams at WLAP Surface Station

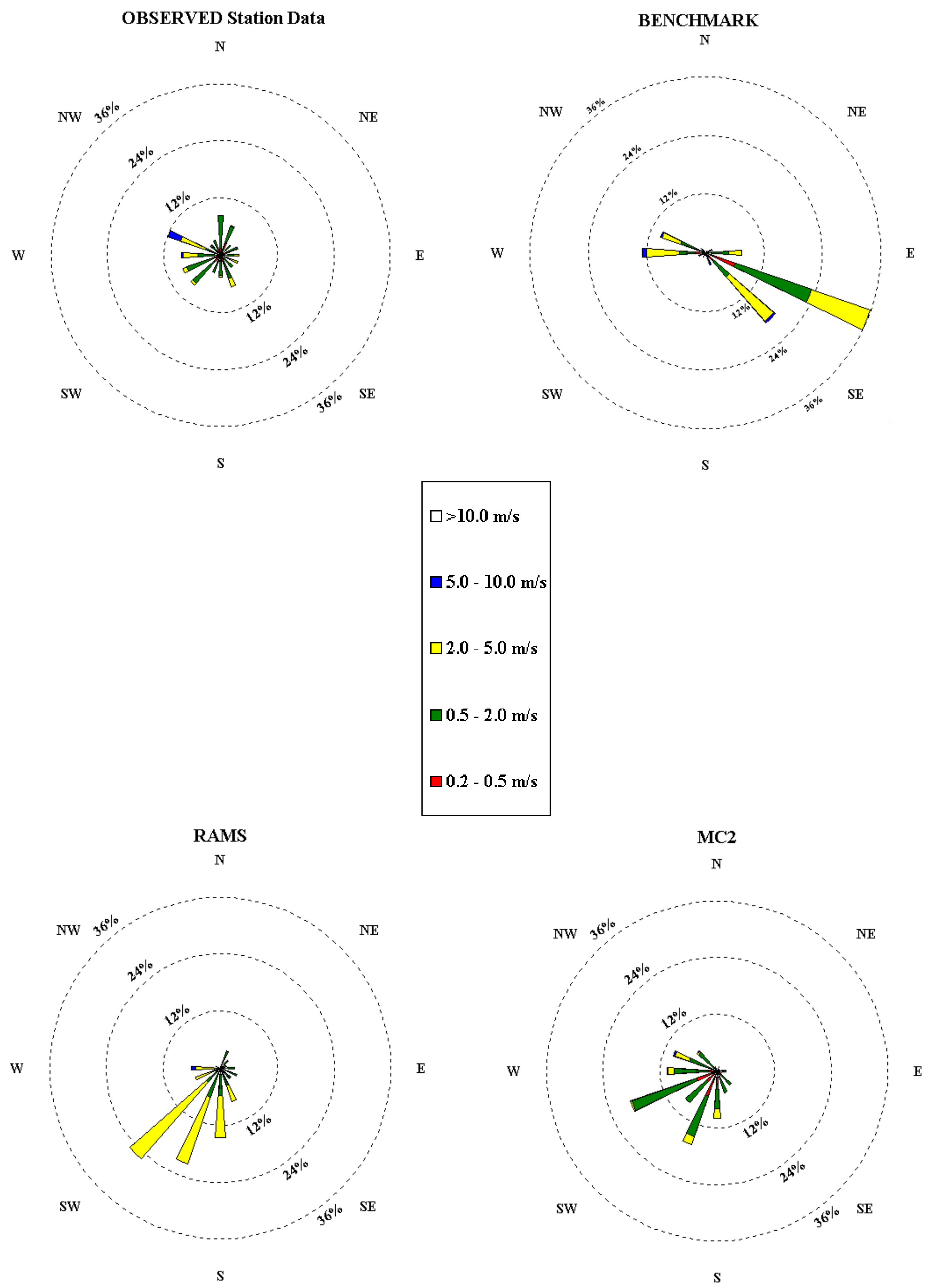


Figure 4: WR Diagrams at Kam1 Surface Station