MM5 Simulations over New Zealand - Application to the America's Cup Races

Alfred M. Klausmann[1], Benjamin de Foy, Jennifer Godfrey, and Joseph Scire

Earth Tech, Inc.

1. Introduction

Coastal New Zealand is well known to sailors for its complex wind patterns, which often result from terrain forced mesoscale wind systems. These conditions have important implications for sailing in the New Zealand coastal zone. During the America's Cup Challenger Series races, which took place from October 1999-February 2000, MM5 Version 2 was used to provide high resolution wind forecasts over the Hauraki Gulf for two of the American teams participating in the races.

This paper describes two commonly occurring mesoscale wind events that were predicted by MM5 Version 2 (MM5V2) during the operational runs, the North Island sea breeze and a meso-beta scale wind maximum over the southern Hauraki Gulf. A comparison of the cases with simulations using MM5 Version 3 (MM5V3) with high-resolution terrain and land use as well as a comparison with available observations are provided.

2. Data and Model Configuration

MM5 Version 2 was run with one-way triply nested grids with a nest ratio of 4:1 and 15 vertical layers. Simulations were also conducted with MM5 Version 3 using 23 vertical levels. Domain 1, the coarse "mother" domain, has a dimension of 2352x2352 kilometers and consists of 50x50 grid cells with a grid size of 48 km. Domains 2 and 3 consist of 57x57 grid cells with a grid size of 12 kilometers and 3 kilometers, respectively. Domain 2 covers all of the North Island of New Zealand while domain 3 includes the Hauraki Gulf and the adjacent land masses to the northwest, west and southwest as well as the Coromandel Peninsula. For domain 3, the MM5V2 runs used 9 km resolution terrain and 19 kilometer land use data, while for the MM5V3 runs 1 kilometer terrain and land use data was used.

Initial and lateral boundary conditions were provided by the twice daily "Aviation" run of the National Center for Environmental Prediction Global Spectral Model (AVN). These data were obtained from the World Area Forecast System (WAFS) files on the National Center for Environmental Prediction (NCEP) Office of Systems Operations server in Grib format with a resolution of 1.25 x 1.25 degrees. Sea surface temperature from the NCEP Global Data Assimilation System 1 degree x 1 degree files available once per day for the previous day were used. The AVN model data and the sea surface temperature were interpolated to the model grid using the REGRID preprocessor. The AVN model data is stored in 'thinned' grids consisting of 73 rows with 74 data points at the equator going down to 2 points at the poles. REGRID was expanded to read this format and interpolate it linearly to a 73x74 grid. For these simulations no enhancement of the gridded AVN data was performed with rawinsonde data. This was due to the difficulties in obtaining rawinsonde data in real time.

MM5 was configured with the explicit moisture scheme with simple ice phase processes, the Grell Cumulus parameterization scheme, and the 5 layer soil model was used with Blackadar Planetary Boundary Layer scheme (Grell et al., 1994).

3. Sea Breeze Flows

Figure 1 show an example of an MM5 wind field forecast during a sea breeze event on January 6, 2000 for domain 2. The synoptic conditions on this day were characterized by a broad weak surface anticyclone with a weak pressure gradient resulting in light south west flow over the North Island. The domain 2 predicted wind vectors show well-defined sea breeze flows on virtually the entire coastline. A well defined convergence zone resulting from opposing onshore flows from both the east and west coasts is evident north of Auckland extending to the northern tip of the island. A smaller but similar convergence zone is evident on the Coromandel Peninsula where sea breeze flows on both the eastern and western coasts are evident.

Figure 2a and 2b shows the predicted wind field for domain 3 for the Version 2 and Version 3 MM5 runs respectively. The predicted winds were generally consistent with those from domain 2 showing onshore flow on both the eastern and western coasts. Over the Hauraki Gulf along the immediate coast MM5V2 (Figure 2a) predicted an area of light winds, stronger northeast winds over the Gulf to the east, and southwest flow was predicted just inland from the Gulf extending southwestward into Auckland. The area of convergence and weak winds over the extreme eastern Gulf is the result of convergence of the two separate sea breeze flows. The MM5V3 predicted winds (Figure 2b) show that the onshore northeast

[1] Corresponding author address: Alfred M. Klausmann, Earth Tech, Inc., email: aklaus@src.com, Telephone: 978-371-4327, Fax: 978-371-2468

flow has penetrated just inland of the coast over the Northland Peninsula and is slightly weaker when compared to the MM5V2 predicted winds. The convergence zone is also better defined than in the MM5V2 predictions. Sea breeze flows of the type predicted by both MM5V2 and MM5V3 are well known in the region and have been depicted in earlier modeling studies (McKendry, 1989). The MM5 simulated winds are also in general agreement with those found in the observational study of McGill (1987) which showed similar sea breeze convergence zone patterns.

Figure 3 shows a time series plot of MM5V2 and MM5V3 predicted wind vectors compared with the observed winds at these three stations. The observations indicate a sea breeze had developed, although it was not as strong and didn't penetrate as far westward as the MM5 predictions suggest. MM5V3 winds show a stronger sea breeze than MM5V2 predicted. This appears to be a result of the poor representation of terrain and landuse for the MM5V2 simulations. The overestimation of the sea breeze flow by MM5V3 may be due to differences in soil moisture or cloudiness between MM5V3 and the actual environment.

4. Southern Hauraki Gulf Wind Maximum

Frequently during the Challenger Series races MM5V2 predicted a mesoscale wind maximum over the southern Hauraki Gulf region. This feature within the overall predicted wind field occurred during southwest flow conditions, originated over the Manakau Harbor and reached peak strength over the southern Hauraki Gulf. Occasionally the MM5 simulations predicted increased southwest winds into the central Hauraki Gulf, resulting in sharp gradients in wind speed and direction, particularly when a sea breeze was occurring over the Hauraki Gulf.

Figures 4a-b shows an example of such an event predicted by both MM5V2 and MM5V3 on February 4, 2000 as depicted by the domain 3 wind vectors and isotachs. At 13 hours into the simulation, a clear wind speed maximum with speeds greater than 20 knots was predicted by MM5V2 (Figure 4a) over the southern Hauraki Gulf. The band of light winds (< 2 knots) to the north is the result of a predicted sea breeze extending from the Hauraki Gulf northward along the eastern coast. The sea breeze coupled with the increasing southwest flow over the southern gulf results in a sharp wind speed gradient and confluent flow. This feature is evident in both the MM5V2 and MM5V3 predicted winds. The MM5V3 predicted wind field (Figure 4b) also depicts the wind maximum over the southern Hauraki Gulf although it is weaker, having peak speeds of about 15 knots only over a small area just between the Hunua Range and the Waiheke islands to the north.

Figure 5 shows a time series comparison of MM5V2 and MM5V3 predicted winds and observations taken at two stations within the southern Hauraki Gulf. The observations suggest that both MM5V2 and MM5V3 simulations are underestimating the surface winds over this area and possibly predicted the wind maximum to be located too far east.

It is hypothesized that this predicted mesoscale band of relatively strong winds over the southern Gulf region is the result of a synergistic interaction between the developing sea breeze flow off the Manakau Harbor, diurnally increasing southwest winds enhanced by a west coast sea breeze flow, reduced surface friction over the limited land mass between Manakau Harbor and the Hauraki Gulf and some channeling effects between the Hunua range south of the Gulf , terrain over the Waiheke Islands and the elevated terrain of the Waitekere Range northwest of Auckland.

5. Conclusions

Overall, MM5 has successfully predicted the onset and evolution of terrain forced mesoscale wind systems along the coast of Northern New Zealand and the Hauraki Gulf. Qualitatively, there was general agreement between the MM5 predicted wind fields and earlier modeling and observational studies. The MM5V3 simulations predicted the sea breeze flow off the Hauraki Gulf to be too strong and to penetrate too far west. Both MM5V2 and MM5V3 underestimated the strength of the southern Hauraki Gulf wind maximum.

A more in depth analysis is needed of these cases to identify the causes of the differences between MM5V2 and MM5V3. Further MM5V3 simulations to test the Land-Surface model is being considered.

6. References

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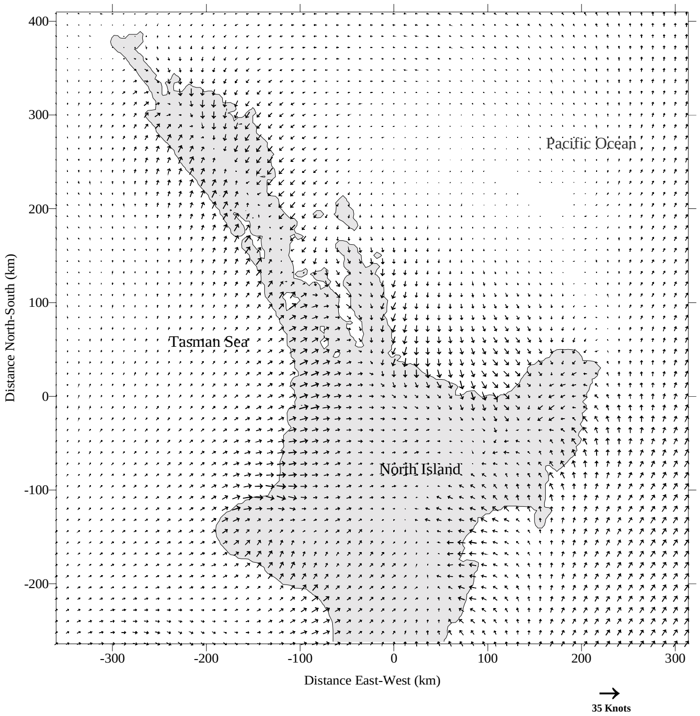

Figure 1. MM5V2 predicted wind vectors for domain 2 at 14 hours into the simulation. Valid time is 3:00 PM NZDT January 6, 2000

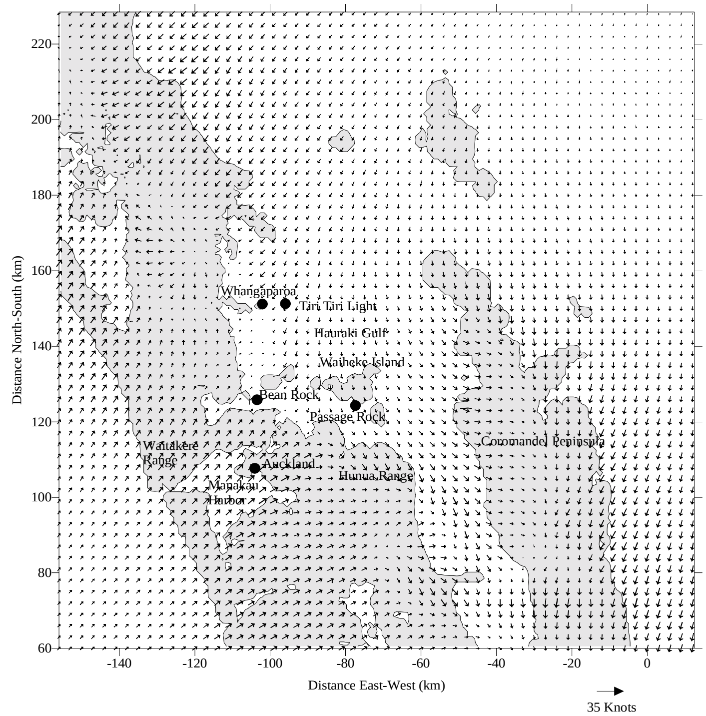

Figure 2a. MM5V2 predicted wind vectors for domain 3 at 14 hours into the simulation. Valid time is 3:00 PM NZDT January 6, 2000

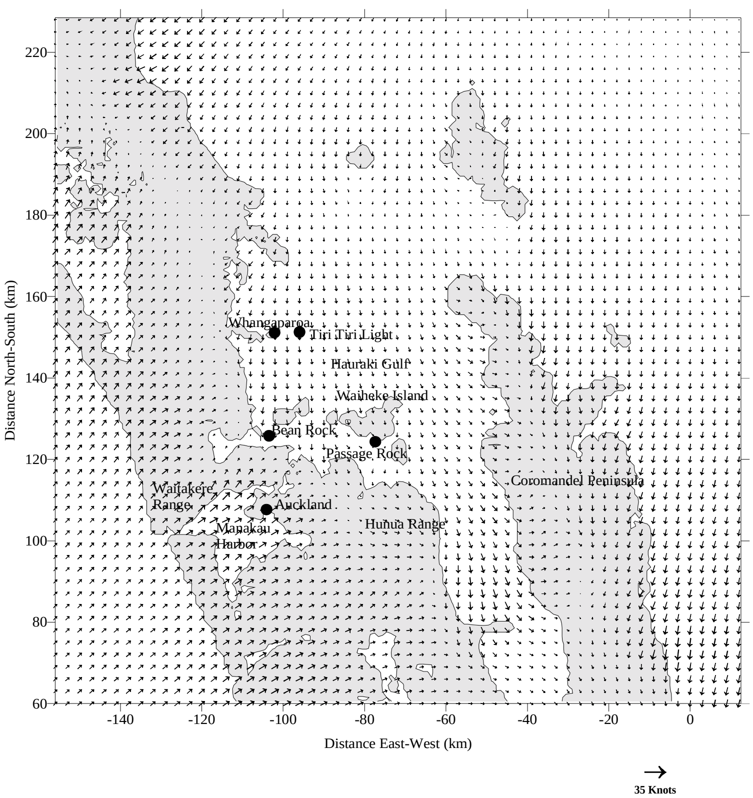

Figure 2b. MM5V3 predicted wind vectors in domain 3 at 14 hours into the simulation. Black circles denote meteorological monitoring sites. The vaid time is 3:00 PM NZDT January 6, 2000

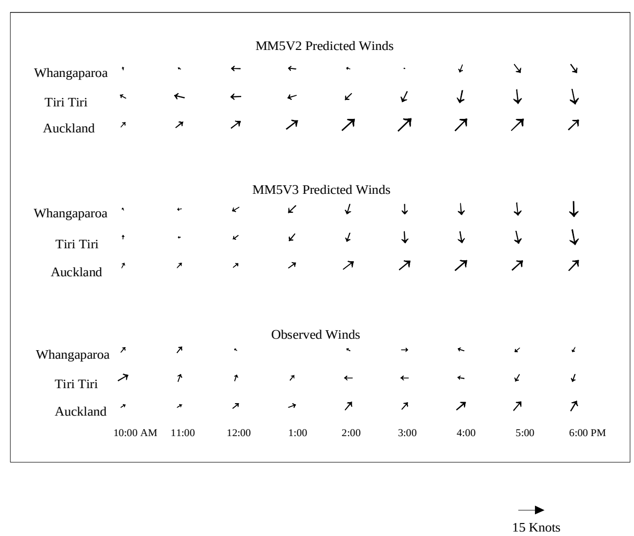

Figure 3. Time series plot of predicted and observed wind vectors for January 6, 2000 for three meteorological monitoring sites.

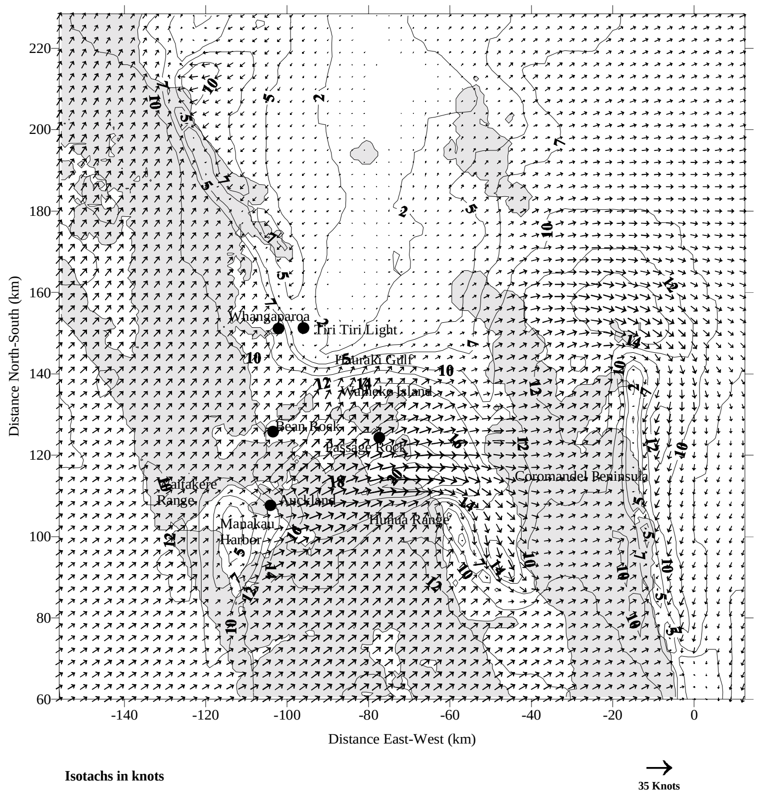

Figure 4a. MM5V2 predicted wind vectors in domain 3 at 13 hours into the simulation. Black circles denote meteorological monitoring sites. Valid time is 2:00 PM NZDT February 4, 1000

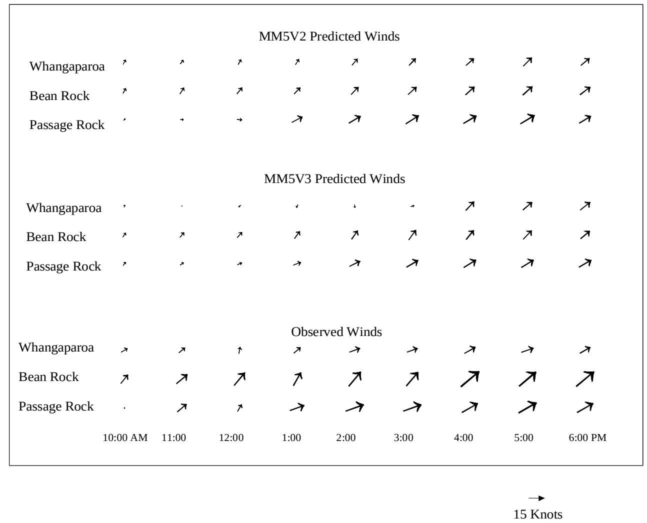

Figure 5. Time series plot of predicted and observed wind vectors for February 4, 2000 for three meteorological monitoring sites.

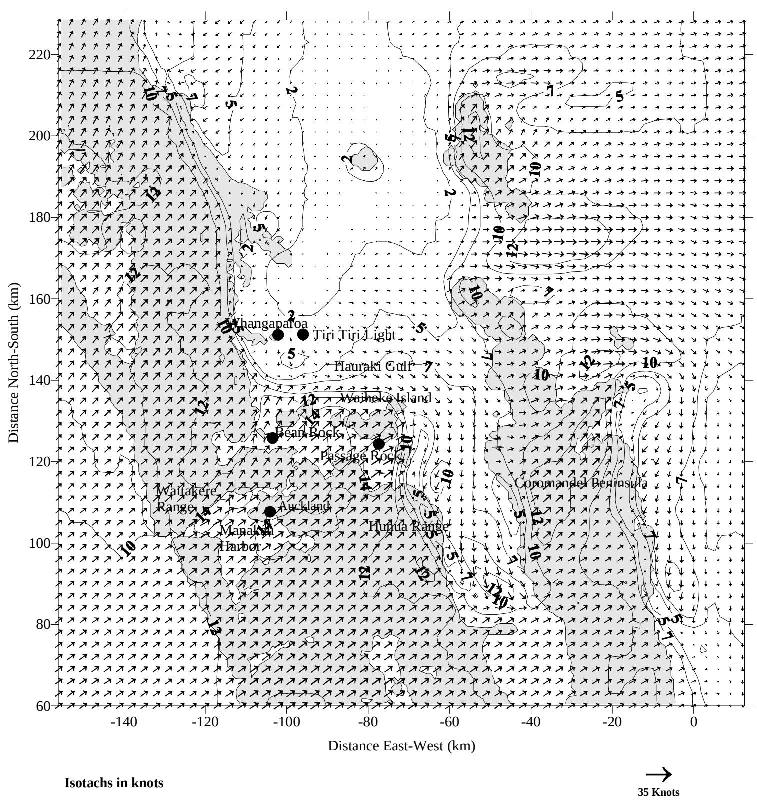

Figure 4b. MM5V3 predicted wind vectors in domain 3 at 13 hours into the simulation. Black circles denote meteorological monitoring sites. The valid time is 2:00 PM NZDT February 4, 2000.