# Meteorological evaluation of the New Plymouth region using MM5 and CALMET for the period January to June 2005

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*Submitted By:*
**Earth Tech, Inc.**
196 Baker Avenue
Concord, Massachusetts 01742
(978) 371-4000

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## ACKNOWLEDGEMENTS

The principal authors of this report are J. J. Godfrey, M. Phadnis and J. Scire of Earth Tech Inc., with contributions from G.W. Fisher and M. Sherman of Endpoint Ltd.

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# 1. INTRODUCTION

Earth Tech, Inc., on behalf of Endpoint Limited, has conducted an air quality analysis for the existing New Plymouth Power Station – a power generation facility located in the city of New Plymouth which is located on the west coast of the North Island of New Zealand. The work has been done to fulfill the obligations of New Zealand's FRST contract, 'Protecting New Zealand's Clean Air' (C01X0405) and is essentially a meteorological validation study of the CALPUFF modelling system based on peak $SO_2$ emissions from the New Plymouth Power Station.

This modelling analysis evaluates the local meteorological data with respect to the model's outputs and the monitored $SO_2$ data for 6 specific episodes during January – June 2005. The purpose of the modelling is to assess the meteorological conditions responsible for peak impacts of sulfur dioxide ($SO_2$).

The facility runs a duel fuel system, primarily on natural gas, but with the ability to use liquid fuels (diesel oil) under certain circumstances. The use of oil is restricted due to its sulphur content which may lead to elevated concentrations in the areas around the plant. During the early part of 2005, permission was granted by the Regional Council to allow the power station to use oil in order to meet national electricity demands. During these times the $SO_2$ emissions were non-zero, and the opportunity for assessing the meteorological effects of these arose. This is explored in this report.

## 1.1 Models Used

Since the power station is located at the coast a non-steady-state modelling approach that evaluates the effects of spatial changes in the meteorological and surface characteristics is necessary to properly evaluate the air quality impacts of the emission sources. Because of the lack of any upper air data in the region at all the modelling has had to use utilize prognostic MM5 data to provide hourly profiles of wind and temperature data. The U.S. Environmental Protection Agency (EPA) has adopted the CALPUFF modelling system as a Guideline Model for Class I impact assessments and other long-range transport applications or, on a case-by-case basis, for use in near-field applications involving complex flows (U.S. EPA, 2000). CALPUFF is recommended by both the Federal Land Managers Air Quality Workgroup (FLAG, 2000) and the Interagency Workgroup on Air Quality Modelling (IWAQM, 1998). CALPUFF is also accepted for use in New Zealand (MfE 1995. 1997) and has been used on several modelling analyses over the last few years.

CALMET is a diagnostic meteorological model that produces three-dimensional wind fields based on parameterized treatments of terrain effects such as slope flows, terrain blocking effects, and kinematic effects. Gridded data produced by the Penn State/NCAR Fifth Generation Mesoscale Model, MM5 were used by CALMET to help define the initial estimate of the wind fields for each of the six episodes considered here. Fine scale terrain effects were determined by the diagnostic wind module in CALMET.

CALPUFF is a non-steady-state puff dispersion model. It accounts for spatial changes in the CALMET-produced meteorological fields, variability in surface conditions (elevation, surface roughness, vegetation type, etc.), chemical transformation, wet removal due to rain and snow, dry deposition, and terrain influences on plume interaction with the surface. CALPUFF contains a module to compute visibility effects, based on a humidity-dependent relationship between particulate matter concentrations and light extinction, as well as wet and dry deposition fluxes. Meteorological and dispersion modelling simulations were conducted for nine episodes over the period January – June 2005. This is the period over which oil firing occurred at the station, and during which time $SO_2$ monitoring data from 2 sites were available.

## 1.2 Report Format

This report outlines the techniques, the data sources and the results of the modelling analyses.

**Section 2** gives a description of the site and background information.

**Section 3** provides a general description of the source configuration and stack emissions parameters, descriptions of the modelling domain, and the details of the meteorological, geophysical, and aerometric databases used in the analysis.

**Section 4** contains a description of the monitoring data and time series of the emissions.

**Section 5** gives an overview of the CALMET and CALPUFF models.

**Section 6** shows the key results.

**Section 7** contains some discussion and conclusions.

**Appendices** provide a detailed CALMET control files.

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# 2. SOURCE DESCRIPTION

## 2.1 Source Data

The New Plymouth Power Station has the potential to run at full load at 330 MW, with up to three oil-fired generating units each operating at 110 MW capacity. The station has a single 200m high stack (the largest such stack anywhere in New Zealand), illustrated in Figure 2.1.

Figure 2-1. The New Plymouth Power Station (view from the northeast).

Table 2-1 presents the source characteristics, although no specific source modelling has been undertaken for this study.

Table 2-1. Stack parameters.

| Source Description | LCC Coord East (km) | LCC Coord North (km) | Stack Height (m) | Base Elev (m) | Stack Diameter (m) | Fuel Oil Exit Velocity (m/s) | Fuel Oil Exit Temp (°K) |
|---|---|---|---|---|---|---|---|
| Main Stack | 0.00 | 0.00 | 200.00 | 0.0 | 3.35 | 18.8 | 448.00 |

Coordinates are in LCC (Reference latitude and longitude are = 39.0574ºS, 174.0277ºE; Standard parallels = 35ºS, 45ºS). Output is WGS84 datum. The tower was used as the reference point at 0, 0 km.

# 3. GEOPHYSICAL AND METEOROLOGICAL DATA

## 3.1 The New Plymouth Power Station Site

The New Plymouth Power Station is located right on the coast at the northwest end of Port Taranaki on the west coast of the North Island of New Zealand. The terrain rises steadily upward in a southerly direction to the summit of Mt Taranaki, a 2600 m high volcano, just 15 km away. Other mountain ranges directly southwest of the power station are the Pouakai and Kaitake mountain, some 20 km away. Close to the power station and just offshore are a number of small 10-15m high stacks, the tallest of which is Mt Paritutu (154m) which is located just a couple of hundred meters from the stack. The stack at 200m was built taller than Mt Paritutu to prevent an eddy occurring in the lee of the stack.

## 3.2 Modelling Domain and Terrain

Gridded terrain elevations for the modelling domain were derived from 3-second Shuttle RADAR Topographic Mission files. The terrain elevations are referenced on the geographic (latitude/longitude) coordinate system of the World Geodetic System 1984 Datum. Elevations are in meters relative to mean sea level, and the spacing of the elevations along each profile is 3-seconds, which corresponds to a spacing of approximately 90 m.

A 3-dimensional plot of the local region is shown in Figure 3-1. The location of the airport meteorological site and the power station are clearly marked. The complex terrain surrounding the power station is clearly visible. The CALMET domain is shown in Figure 3-2 and covers a region of 65 km x 65 km. A resolution of 250 m in the horizontal is used to resolve the variations of the terrain elevations in the area. The SRTM elevation records located within each grid cell in the computational domain are averaged to produce a mean elevation at each grid point. A 250 m resolution produces a workable number of grid cells (260 × 260) and allows adequate representation of the important terrain features.

The CALPUFF computational domain is the same as the CALMET domain. The domain extends 20 km or more beyond the region of interest in order to provide an adequate buffer zone at the boundaries to allow the effects of flow curvature and possible small-scale re-circulation to be evaluated.

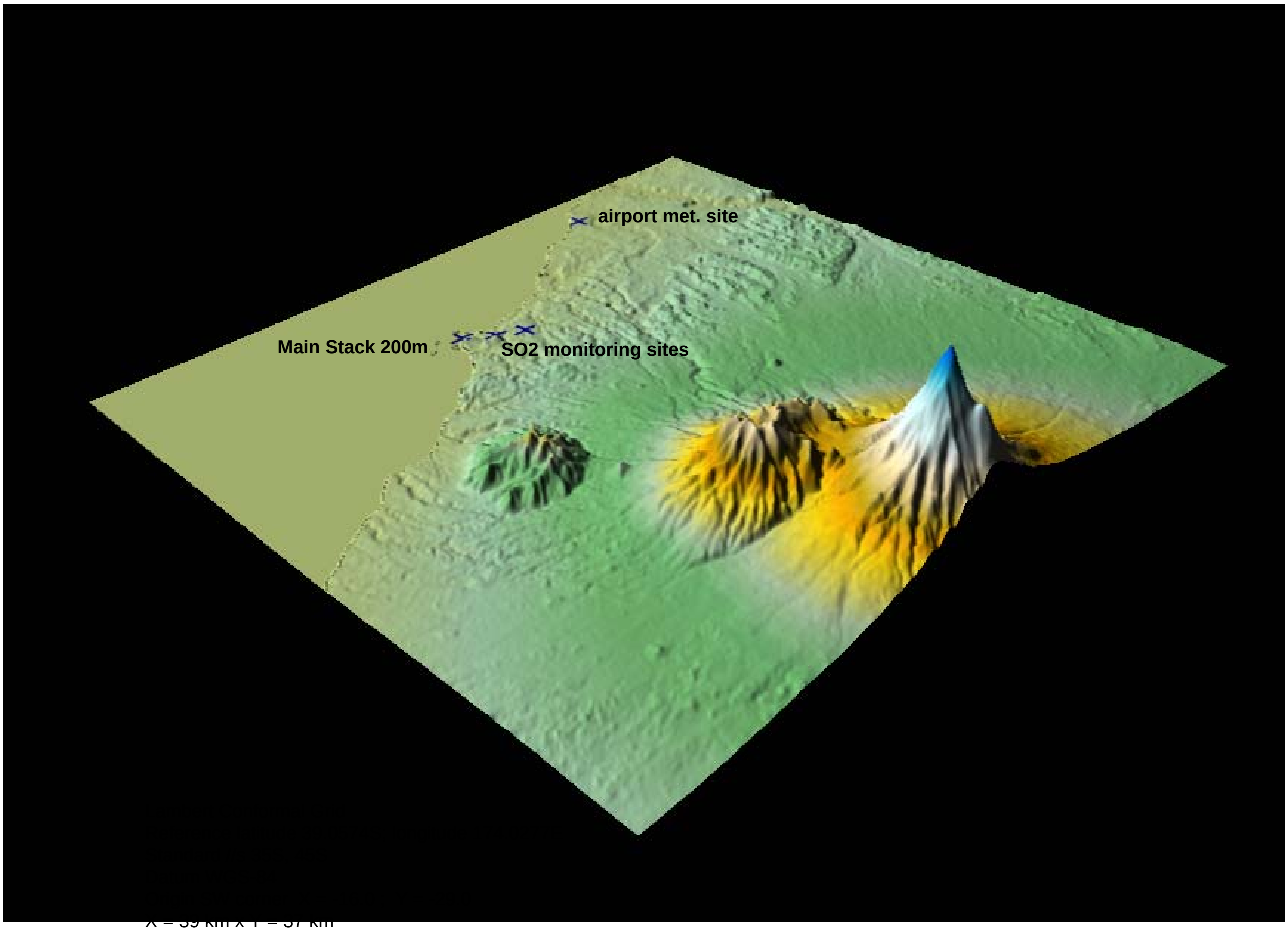



Figure 3-1. 3-Dimensional plot showing the complex topography around the power station. The Airport AWS station is clearly marked as is the power station and monitoring sites. (SRTM 90m terrain data + fine scale coastline - New Plymouth Power Station, New Zealand. 390 x 370 grid cells at 0.1 km resolution.)

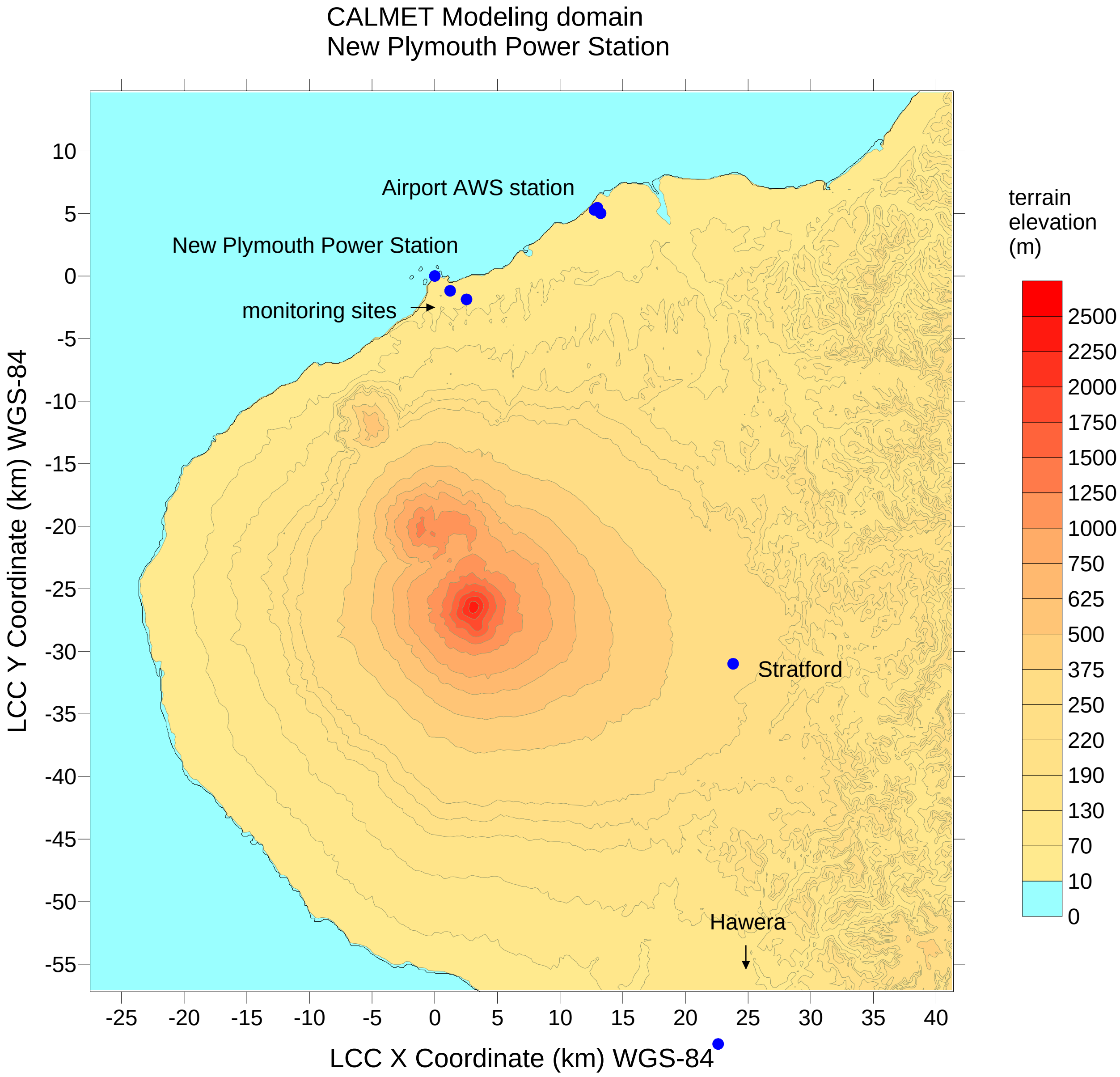



Figure 3-2. This plot shows the CALMET/CALPUFF modelling domain. The surface meteorological sites are also shown.

## 3.2 Land Use

The New Zealand LINZ Land Use data has been used to produce a gridded field of dominant land use categories. The NZ LINZ Land Use data has a vertical resolution of 5m and a horizontal resolution of 20m.

Land use data were processed to produce a 250 m resolution gridded field of land use categories over the modelling domain. The New Zealand LINZ land use data was mapped directly to CALMET's 14 Land use categories. Surface properties such as albedo, Bowen ratio, roughness length, and leaf area index were computed proportionally to the fractional land use. The New Zealand Land Use categories and their equivalent CALMET Land Use categories are described in Table 3-1. Table 3-2 displays the 14 CALMET land use categories and their associated geophysical parameters. Figure 3-3 shows the dominant land use categories for each CALMET grid cell in the modelling domain.

## 3.3 Meteorological Data Base

The CALMET model requires meteorological information from the surface and upper air as well as geophysical information about the Land Use and terrain heights. Specifically, CALMET requires surface observations of wind speed, wind direction, temperature, cloud cover, ceiling height, surface pressure, relative humidity, and precipitation type (e.g., snow, rain, etc.). These variables are routinely measured at the National Weather Service (AWS) surface stations. Gridded prognostic three-dimensional gridded data from the fifth generation MM5 model produced by State/NCAR (National Center for Atmospheric Research) is also used in the modelling. Table 3-3 lists the types of observational and modelled data available for the proposed modelling including available parameters.

As well as using gridded three-dimensional prognostic model data, CALMET also uses surface observations wherever possible. Table 3-4 lists those surface stations that were used in the modelling, either directly, or, to verify the prognostic model results.

Figures 3-4 shows the locations and spatial coverage of the two innermost MM5 grid points as well as the CALMET domain as was used in the modelling.

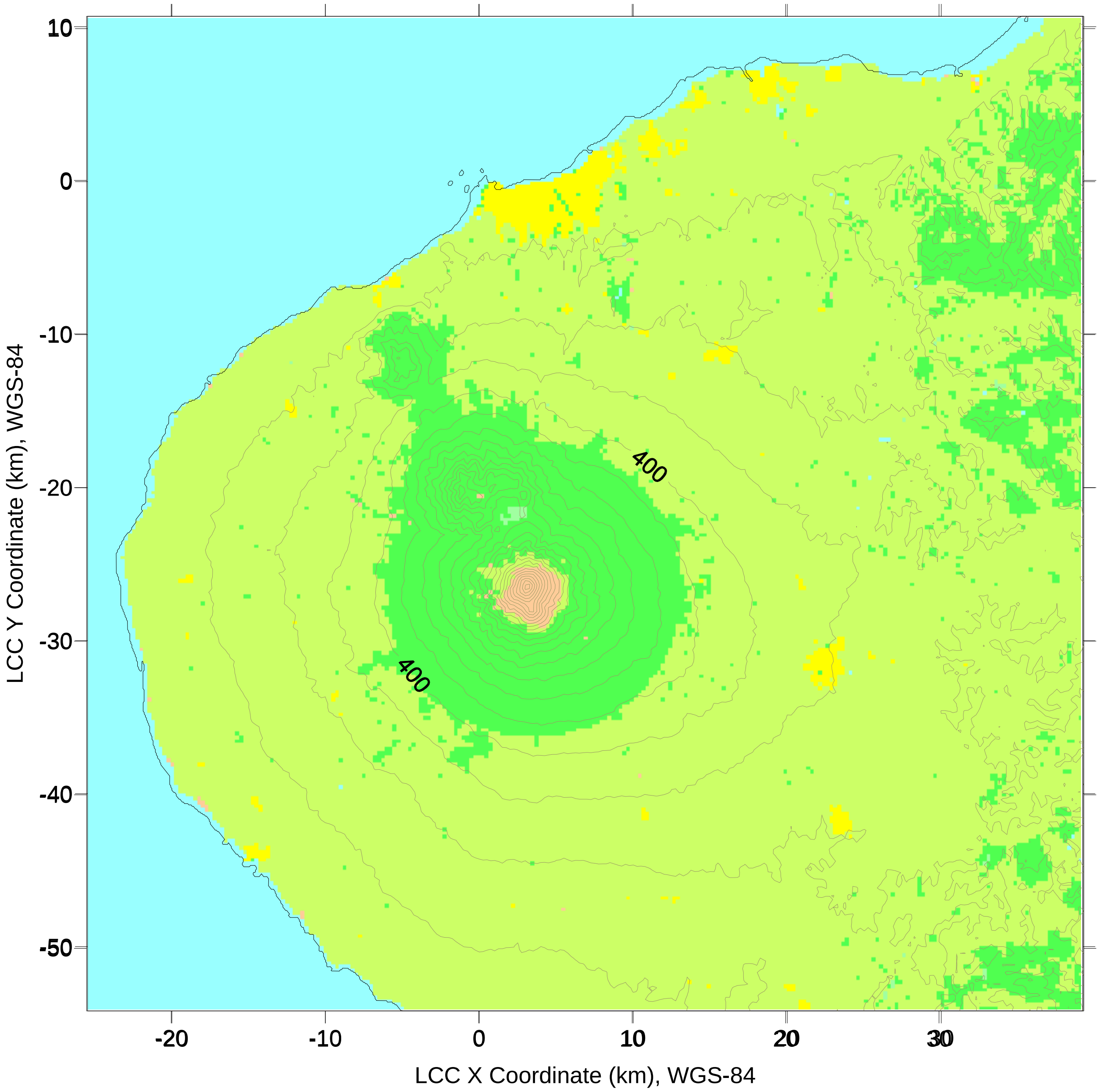



Figure 3-3. Land use for the CALMET/CALPUFF computational domain. The power station, nearby surface observational sites and the $SO_2$ monitoring sites are also shown.

Table 3-1. New Zealand LINZ Land Use and Land Cover Classification System as mapped to CALMET's 14 category system.

| New Zealand LU Category | New Zealand LU Category Definition | CALMET 14 category LU system |
|---|---|---|
| 1 | Built-up Area | 10 |
| 2 | Urban Parkland/ Open Space | 10 |
| 3 | Surface Mine | 10 |
| 4 | Dump | 10 |
| 5 | Transport Infrastructure | 10 |
| 10 | Coastal Sand and Gravel | 70 |
| 11 | River and Lakeshore Gravel and Rock | 70 |
| 12 | Landslide | 70 |
| 13 | Alpine Gravel and Rock | 70 |
| 14 | Permanent Snow and Ice | 90 |
| 15 | Alpine Grass-/Herbfield | 20 |
| 20 | Lake and Pond | 50 |
| 21 | River | 50 |
| 22 | Estuarine Open Water | 50 |
| 30 | Short-rotation Cropland | 20 |
| 31 | Vineyard | 20 |
| 32 | Orchard and Other Perennial Crops | 20 |
| 40 | High Producing Exotic Grassland | 20 |
| 41 | Low Producing Grassland | 20 |
| 43 | Tall Tussock Grassland | 20 |
| 44 | Depleted Tussock Grassland | 20 |
| 45 | Herbaceous Freshwater Vegetation | 30 |
| 46 | Herbaceous Saline Vegetation | 30 |
| 47 | Flaxland | 20 |
| 50 | Fernland | 20 |
| 51 | Gorse and Broom | 30 |
| 52 | Manuka and or Kanuka | 40 |
| 53 | Matagouri | 40 |
| 54 | Broadleaved Indigenous Hardwoods | 40 |
| 55 | Sub Alpine Shrubland | 40 |
| 56 | Mixed Exotic Shrubland | 40 |
| 57 | Grey Scrub | 40 |
| 61 | Major Shelterbelts | 40 |
| 62 | Afforestation (not imaged) | 40 |
| 63 | Afforestation (imaged post LCDB 1) | 40 |
| 64 | Forest Harvested | 40 |
| 65 | Pine Forest - Open Canopy | 40 |
| 66 | Pine Forest - Closed Canopy | 40 |
| 67 | Other Exotic Forest | 40 |
| 68 | Deciduous Hardwoods | 40 |
| 69 | Indigenous Forest | 40 |
| 70 | Mangrove | 60 |

Table 3-2. Default CALMET Land Use categories and associated geophysical parameters based on the U.S. Geological Survey Land Use classification system (14-category system).

| Land Use Type | Description | Surface Roughness (m) | Albedo | Bowen Ratio | Soil Heat Flux Parameter | Anthropogenic Heat Flux ($W/m^2$) | Leaf Area Index |
|---|---|---|---|---|---|---|---|
| 10 | Urban or Built-up Land | 1.0 | 0.18 | 1.5 | 0.25 | 0.0 | 0.2 |
| 20 | Agricultural Land – Unirrigated | 0.25 | 0.15 | 1.0 | 0.15 | 0.0 | 3.0 |
| -20* | Agricultural Land - Irrigated | 0.25 | 0.15 | 0.5 | 0.15 | 0.0 | 3.0 |
| 30 | Rangeland | 0.05 | 0.25 | 1.0 | 0.15 | 0.0 | 0.5 |
| 40 | Forest Land | 1.0 | 0.10 | 1.0 | 0.15 | 0.0 | 7.0 |
| 50 | Water | 0.001 | 0.10 | 0.0 | 1.0 | 0.0 | 0.0 |
| 54 | Small Water Body | 0.001 | 0.10 | 0.0 | 1.0 | 0.0 | 0.0 |
| 55 | Large Water Body | 0.001 | 0.10 | 0.0 | 1.0 | 0.0 | 0.0 |
| 60 | Wetland | 1.0 | 0.10 | 0.5 | 0.25 | 0.0 | 2.0 |
| 61 | Forested Wetland | 1.0 | 0.1 | 0.5 | 0.25 | 0.0 | 2.0 |
| 62 | Nonforested Wetland | 0.2 | 0.1 | 0.1 | 0.25 | 0.0 | 1.0 |
| 70 | Barren Land | 0.05 | 0.30 | 1.0 | 0.15 | 0.0 | 0.05 |
| 80 | Tundra | 0.20 | 0.30 | 0.5 | 0.15 | 0.0 | 0.0 |
| 90 | Perennial Snow or Ice | 0.05 | 0.70 | 0.5 | 0.15 | 0.0 | 0.0 |

*** Negative values indicate "irrigated" land use**

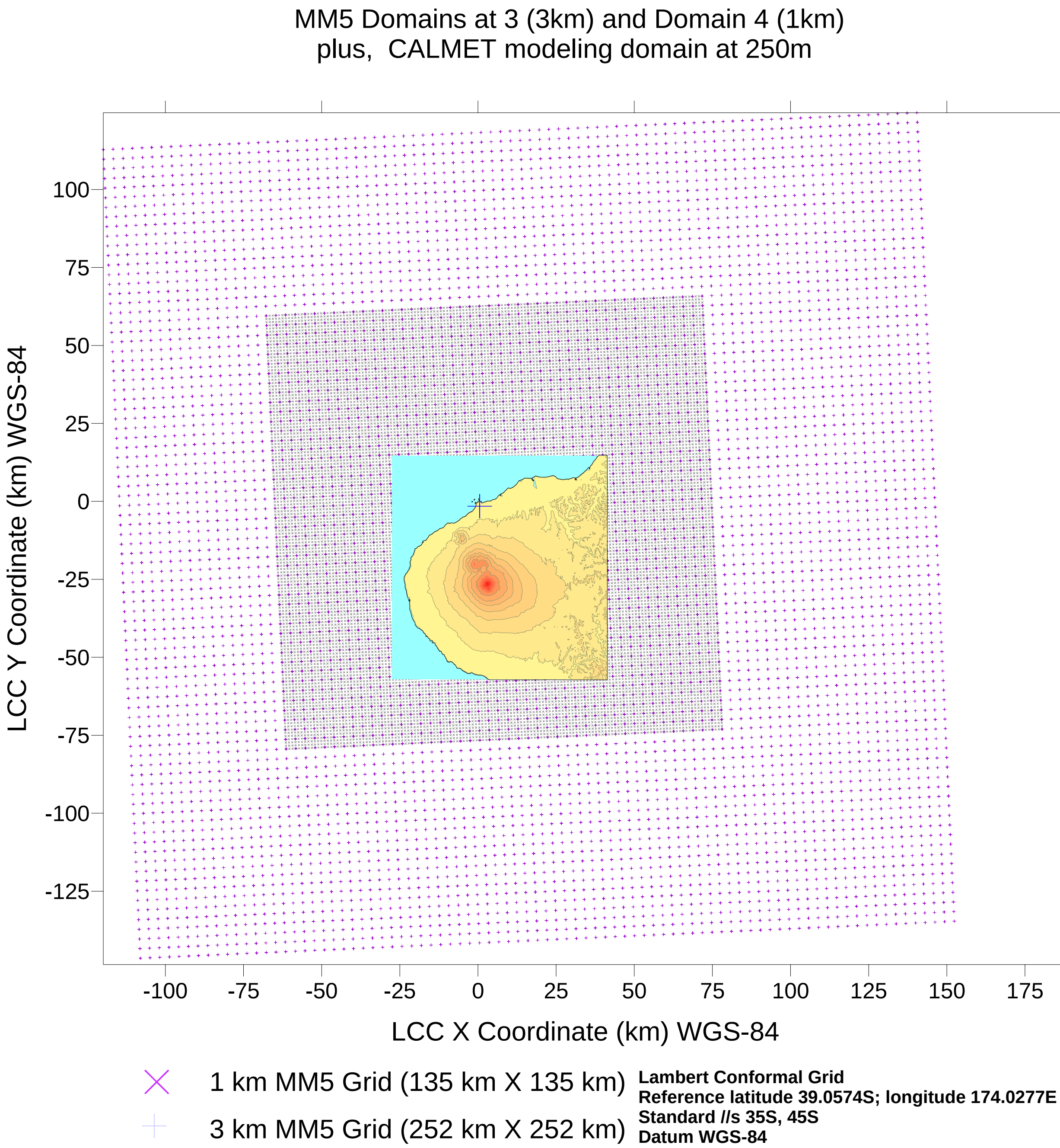



Figure 3-4. Locations of MM5 grid points for the two innermost nests, 3 km and 1 km. The CALMET modelling domain is also shown.

Table 3-3. Meteorological data sources required for CALMET and parameters available

| Type of Dataset | Frequency | Source | Parameters |
|---|---|---|---|
| Surface | Hourly | New Plymouth Airport, Stratford and Hawera | Wind speed, wind direction, air temperature, ceiling height, cloud cover, relative humidity, surface pressure, precipitation type |
| Upper Air | Twice-daily | None available (all upper air data inferred from MM5 data) | Soundings of wind speed, wind direction, temperature. and pressure |
| Precipitation | Hourly | Precipitation was recorded from New Plymouth Airport site, but not treated explicitly | Hourly precipitation amounts |
| Overwater | Hourly | None provided | Hourly wind speed, direction and air-sea temperature difference |
| Modelled Profiles | Hourly | Produced by MM5 | Gridded fields of winds, temperature, pressure and humidity, rainfall, mixing ratios |

Table 3-4. Hourly surface stations, January – June 2005

| Station Name | Station ID | Latitude ° N | Longitude ° W | LCC X (km) | LCC Y (km) | Stn No. |
|---|---|---|---|---|---|---|
| New Plymouth Aiport | 02283 | 39.012 | 174.181 | 12.97174 | 5.45329 | 1 |
| Stratford | 23872 | | | 23.80752 | -30.99263 | 2 |
| Hawera | 25222 | | | 22.61185 | -61.37796 | 3 |

## 3.4 MM5 Description

The Fifth Generation Penn State/NCAR Mesoscale Model (MM5) is a three-dimensional numerical weather prediction model maintained at the National Center for Atmospheric Research (NCAR). MM5 can be run with multiple nested grids. It contains non-hydrostatic dynamics, a variety of physics options and the capability to perform Four Dimensional Data Assimilation (FDDA). MM5 is capable of simulating a variety of meteorological phenomena such as tropical cyclones, severe convective storms, sea-land breezes, and terrain forced flows such as mountain valley wind systems.

MM5 was used in this analysis to develop high-resolution three-dimensional meteorological fields through FDDA simulations to serve as an initial guess field for the CALMET Diagnostic Meteorological Model. The FDDA simulations involved running MM5 for the days corresponding to significant peaks in the monitoring data near the facility and then nudging the model solutions (i.e. predictions) toward a gridded analysis at regular intervals. This gridded analysis places a constraint on the model predictions so that the resulting meteorological fields are consistent with observational data for a given time interval and at the same time are dynamically balanced. This gridded analysis is developed using surface and upper air observations over the MM5 modelling domain and consists of both a full three dimensional meteorological analysis and a surface analysis. The result of the MM5 simulations with FDDA is a high resolution three dimensional gridded data set of meteorological fields (i.e. wind, temperature, pressure etc). A staggered grid cell configuration known as the Arakawa-Lamb B staggered grid is used by MM5. In this grid configuration scalars such as temperature or moisture variables are defined at the center of a grid cell known as the cross points. The vector quantities (e.g., u and v wind components) are defined at the corners of each grid cell known as the dot points.

Typically, meteorological analysis is performed on constant pressure levels instead of height. MM5 uses a terrain following vertical coordinate where the model vertical levels are defined by a dimensionless quantity σ. The σ coordinate is defined as:

$$\sigma = \frac{(P - P_t)}{(P_s - P_t)}$$

Where: P = Pressure, $P_t$ = Constant top pressure, $P_s$ = Surface pressure

The σ coordinate has a value of zero at the top of the model and a value of 1 at the surface.

### *3.4.1 MM5 Configuration*

MM5 data to drive the CALMET model was obtained from simulations that are described below. The MM5 modelling in this study includes in total three domains. Domains 1, 2, and 3 were all two-way nested. Geographical locations of the domains are presented in Figure 3-5. The center of the coarse domain (Domain 1) was located at 42$^{O}$S, 170$^{O}$E. The Lambert Conical Conformal (LCC) map projection was used in the model coordinates. The standard latitudes of the projection were 25$^{O}$S and 55$^{O}$S. This domain covers the southwestern Pacific Ocean the Tasman Sea with a total area of about $6x10^6$ $km^2$. The grid spacing was 27 km. The second-nesting domain (Domain 2) covers New Zealand with a grid size of 9 km. The third nesting-domain (Domains 3) was selected based on the needs of CALMET modelling and was centered on New Plymouth. The grid spacing of this domain was 3 km. Table 3-5 lists the details of configurations for the three domains. In the vertical direction, there were 32 sigma levels from the surface to 100 hPa, located at the sigma values of 1.00, 0.997, 0.994, 0.990, 0.985, 0.980, 0.975, 0.970, 0.960, 0.940, 0.920, 0.900, 0.870, 0.840, 0.810, 0.770, 0.710, 0.650, 0.600, 0.550, 0.500, 0.450, 0.400, 0.350, 0.300, 0.250, 0.200, 0.160, 0.120, 0.080, 0.050, 0.020, 0.000. More details of vertical levels are presented in Table 3-6.

The terrain elevation and land use category were from the 5-min, 2-min, 30-sec (~9 km, ~4 km, ~0.9 km, respectively) global data set for Domains 1 through 3.

The MM5 model was run in the non-hydrostatic mode. The mixed phase explicit moisture scheme that represents microphysics parameterizations (Reisner et. al., 1998) was used in all domains. The Grell cumulus parameterization scheme (Grell et. al., 1994) was used for convections in Domains 1 and 2, while explicit convection was carried out for Domain 3. The Grell scheme uses the updraft and down draft fluxes and the compensating flow to determine the heating and moisture vertical profiles. It is suitable for the grid resolution of 10-30 km. For domains with grid sizes less than 5 km, convection can be resolved explicitly in individual grid cells and therefore no cumulus parameterization needed. The planetary boundary layer module is from the NCEP Eta Model. Turbulent fluxes in the atmosphere and the turbulent fluxes between the atmosphere and the surface are parameterized using the 1.5 order turbulence closure parameterization. The cloud cover is predicted as a simple function of the grid box relative humidity, with the cloud liquid water path determined from the grid box temperature. Since there is significant exchange of heat and water during the Southern Hemisphere summer, we chose to use LSM in our modelling. The Noah LSM soil model was used for this purpose. The vertically resolved soil temperature profile allows rapid response to surface temperature changes. The SOILFAC parameter in the MM5 deck was increased to 1.5 in order to reduce the timestep in the soil model calculations. With larger timesteps, instability in numerical calculations significantly deteriorates the integration results. Physics options employed in the MM5 simulations are shown in Table 3-7.

MM5 was initialized using the large-scale analysis data from NCEP at NCAR. The NCEP Final Analysis (FNL) (http://dss.ucar.edu/datasets/ds083.2) data archived at NCAR exists every 6 hours at a spatial resolution of $1^o$ x $1^o$ at 21 standard pressure levels under 100 hPa: the surface, 1000, 975, 950, 925, 900, 850, 800, 750, 700, 650, 600, 550, 500, 450, 400, 350, 300, 250, 200, 150, and 100 hPa. The data include two-dimensional variables of snow cover, sea surface temperature, and sea level pressure, and three-dimensional variables of temperature, geopotential height, U and V components, and relative humidity. The Real Time Global SST (RTGSST) data ($0.5^o$x$0.5^o$) was used to constrain the lower boundary in modelling. MM5 now has an option to vary the lower boundary condition with respect to time. Hence we employed this option to provide a realistic representation of the time variation of the lower boundary condition. For the FNL dataset, the temporal resolution of the data being 6 hours, the lower boundary conditions were updates every 6 hours. Moreover, the SST data was interpolated to the three domain grids prior to the start of the simulation. This assures that the spatial lower boundary condition comes from the original RTGSST dataset. Alternatively, MM5 interpolates the lower boundary on the fly. In this case, the lower boundary values for domains 2 and 3 come from those integrated in domain 1 and may not be the original RTGSST values.

Since we are using MM5 for a post-analysis, we employed four dimensional data assimilation (FDDA) to force the model integration to the fields from the FNL data. Only three-dimensional FDDA was carried out since the surface observations were with a time resolution of 6 hours. We assume that the surface observations provided at NCAR are already incorporated in the FNL analysis and hence an additional analysis would not be required. In FDDA, only domain 1 (D1) was nudged toward the observations while the model integrated domains 2 and 3. Winds, temperature and moisture were nudged to the observed values every 6 hours. Further details about the runtime options and the nudging coefficients are given in Table 3-8.

The MM5 simulations were carried out on a 16 node, 32 processor Bewoulf Cluster running Linux. A parallel version of MM5 – the MM5 MPP was used for this purpose. The underlying model development of this version is the same as the original MM5. However this version of the model provides additional capabilities for the model to be run on distributed memory machines. Each MM5 simulation was 3 days long. Each 3 day simulation took ~18 wall clock hours on 4 processors.

Table 3-5. Configurations of MM5 domains for New Plymouth application.

| Domain # | Dimensions kmxkm | Map Projection | Grid size (km) | Vertical Levels | Grid numbers | Mother Domain | Mother Domain I/J | Terrain resolution (km) |
|---|---|---|---|---|---|---|---|---|
| Domain 1 | 2700x2214 | LCC | 27 | 32 | 101x83 | | | 9 |
| Domain 2 | 990x1152 | LCC | 9 | 32 | 111x129 | 1 | 38,19 | 4 |
| Domain 3 | 252x252 | LCC | 3 | 32 | 85x85 | 2 | 65,89 | 0.9 |

Table 3-6. Vertical levels used in the New Plymouth MM5 modelling.

| Level No. | ½ sigma | Ref P (mb) | Height (m) |
|---|---|---|---|
| 1 | 0.9985 | 1008.64 | 10.88 |
| 2 | 0.9955 | 1005.91 | 32.67 |
| 3 | 0.9920 | 1002.72 | 58.16 |
| 4 | 0.9875 | 998.63 | 91.03 |
| 5 | 0.9825 | 994.08 | 127.68 |
| 6 | 0.9775 | 989.53 | 164.47 |
| 7 | 0.9725 | 984.98 | 201.39 |
| 8 | 0.9650 | 978.15 | 257.04 |
| 9 | 0.9500 | 964.50 | 369.30 |
| 10 | 0.9300 | 946.30 | 521.02 |
| 11 | 0.9100 | 928.10 | 675.13 |
| 12 | 0.8850 | 905.35 | 871.28 |
| 13 | 0.8550 | 878.05 | 1112.03 |
| 14 | 0.8250 | 850.75 | 1358.95 |
| 15 | 0.7900 | 818.90 | 1655.29 |
| 16 | 0.7400 | 773.40 | 2095.28 |
| 17 | 0.6800 | 718.80 | 2651.80 |
| 18 | 0.6250 | 668.75 | 3192.74 |
| 19 | 0.5750 | 623.25 | 3713.51 |
| 20 | 0.5250 | 577.75 | 4265.66 |
| 21 | 0.4750 | 532.25 | 4853.66 |
| 22 | 0.4250 | 486.75 | 5483.04 |
| 23 | 0.3750 | 441.25 | 6160.77 |
| 24 | 0.3250 | 395.75 | 6895.85 |
| 25 | 0.2750 | 350.25 | 7700.17 |
| 26 | 0.2250 | 304.75 | 8589.99 |
| 27 | 0.1800 | 263.80 | 9482.79 |
| 28 | 0.1400 | 227.40 | 10369.65 |
| 29 | 0.1000 | 191.00 | 11370.36 |
| 30 | 0.0650 | 159.15 | 12369.28 |
| 31 | 0.0350 | 131.85 | 13348.71 |
| 32 | 0.0100 | 109.10 | 14282.17 |

Table 3-7. Physics options of New Plymouth MM5 domains.

| Domain # | Explicit Moisture Schemes (IMPHYS) | Cumulus Schemes (ICUPA) | PBL Scheme (IBLTYP) | Radiation Cooling of Atmosphere (FRAD) | Shallow Convection (ISHALLO) | Model (ISOIL) |
|---|---|---|---|---|---|---|
| Domain 1 | Mixed Phase | Grell | ETA-Yamada-Mellor | Radiation Cooling | None | Noah LSM |
| Domain 2 | Mixed Phase | Grell | ETA-Yamada-Mellor | Radiation Cooling | None | Noah LSM |
| Domain 3 | Mixed Phase | None | ETA-Yamada-Mellor | Radiation Cooling | None | Noah LSM |

Table 3-8. RUNTIME options used in MM5 modelling.

| 3D Data | SST Data | Time-varying SST | Update Frequency of SST | Space-varying SST | Runtime | Integration Timestep |
|---|---|---|---|---|---|---|
| FNL | RTGSST | Yes | 6 hours | Yes | 3 days | 81 sec |

| FDDA | Domains Nudged | Fields Nudged | Frequency of Nudging | Nudging Coefficients | | |
|---|---|---|---|---|---|---|
| | | | | Wind | Temperature | Moisture |
| 3D (analysis) | D1 | Winds, temperature, moisture | 6 hours | 2.5E-04 | 2.5E-04 | 1.0E-05 |

# 4 EMISSIONS AND MONITORING DATA

## 4.1 Ambient $SO_2$ Monitoring

Ambient $SO_2$ monitoring is conducted at two sites in the proximity of the power station, Blagdon Road and the Taranaki Base Hospital (see Figures 4-1 and 4-2). Both sites are located south-east of the power station. Further site information is given in Table 4-1. The closest meteorological site is located 14 km to the north east at New Plymouth Airport.

Table 4-1. Coordinates for New Plymouth monitoring sites. .

| Site | Latitude* | Longitude | Distance from stack | Direction from stack |
|---|---|---|---|---|
| Main Stack | 39.0574 | 174.0277 | NA | NA |
| Airport Met site | 39.0096 | 174.1754 | 14.0 km | ENE |
| Monitor 1 (Blagdon) | 39.0681 | 174.0419 | 1.7 km | SE |
| Monitor 2 (Hospital) | 39.0743 | 174.0571 | 2.9 km | SE |

*All co-ordinates WGS-84

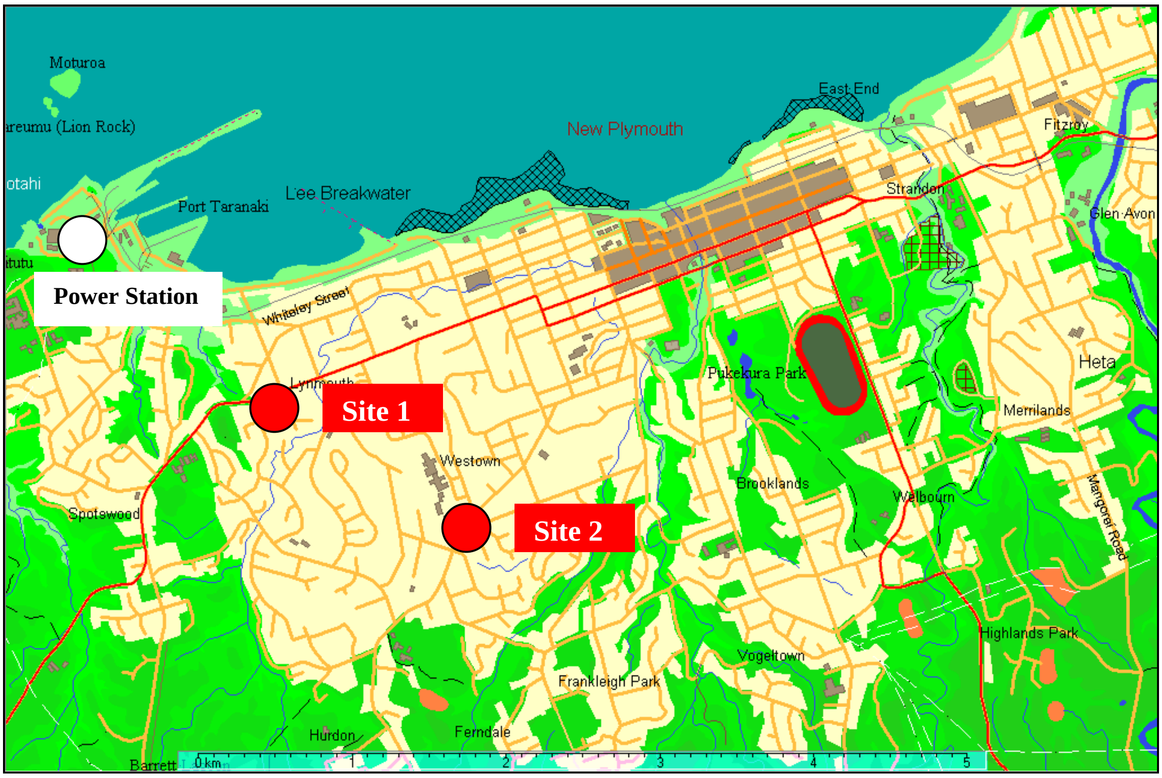



Figure 4-1. Map of New Plymouth showing the location of the monitoring sites and the power station. (Site 1=Blagdon Hill; Site 2 = Base Hospital).

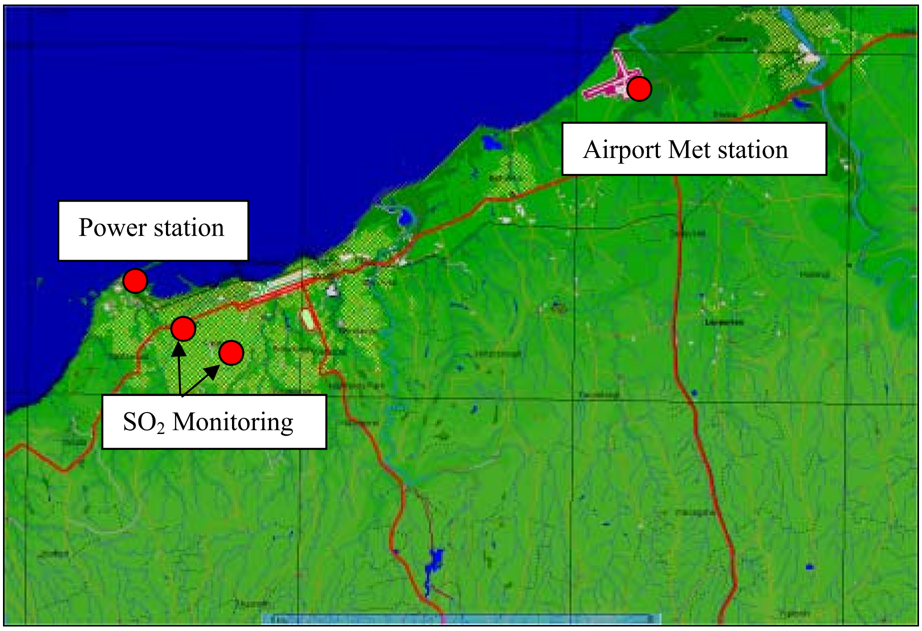



Figure 4-2. Map of New Plymouth and surrounding area.

Figure 4-3 displays the ambient hourly $SO_2$ concentrations for the period from May 2003 to August 2005. Both data sets show significant gaps where monitoring was interrupted. Figure 4-4 shows the period from February 2005 to August 2005. In general, the Blagdon monitoring site records higher concentration than the Base Hospital site. This is most likely due to the fact that the Blagdon site is closer to both the power station and other likely emissions sources (e.g. the port).

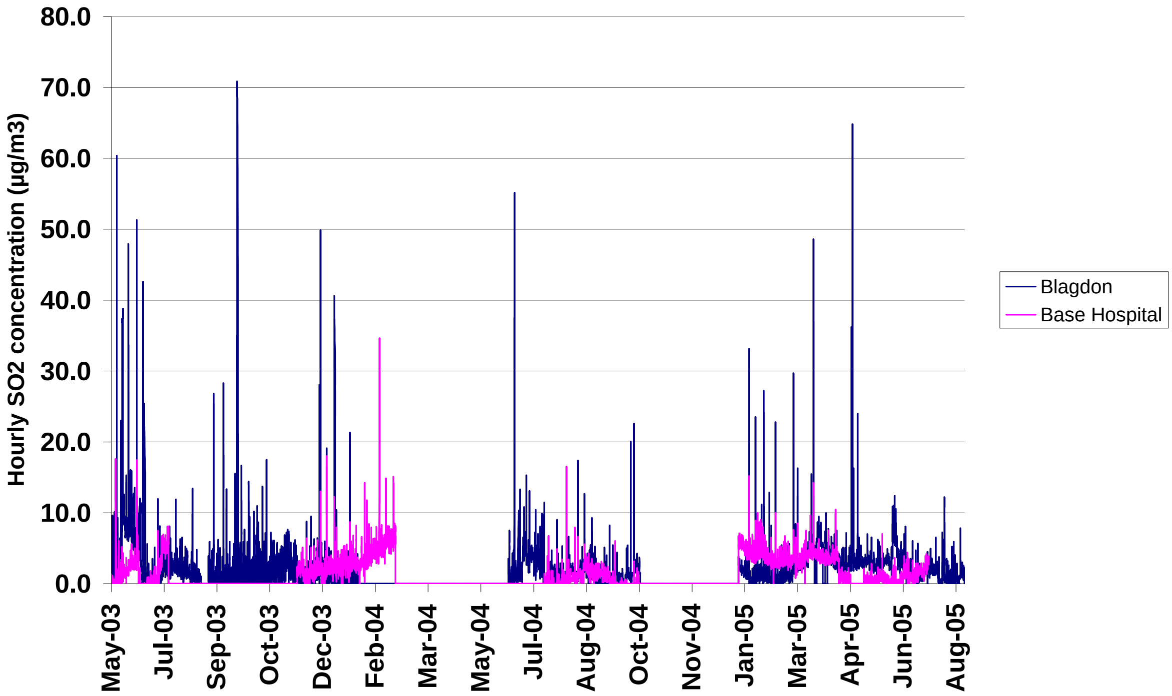



Figure 4-3. Ambient $SO_2$ monitoring (May 2003 to August 2005).

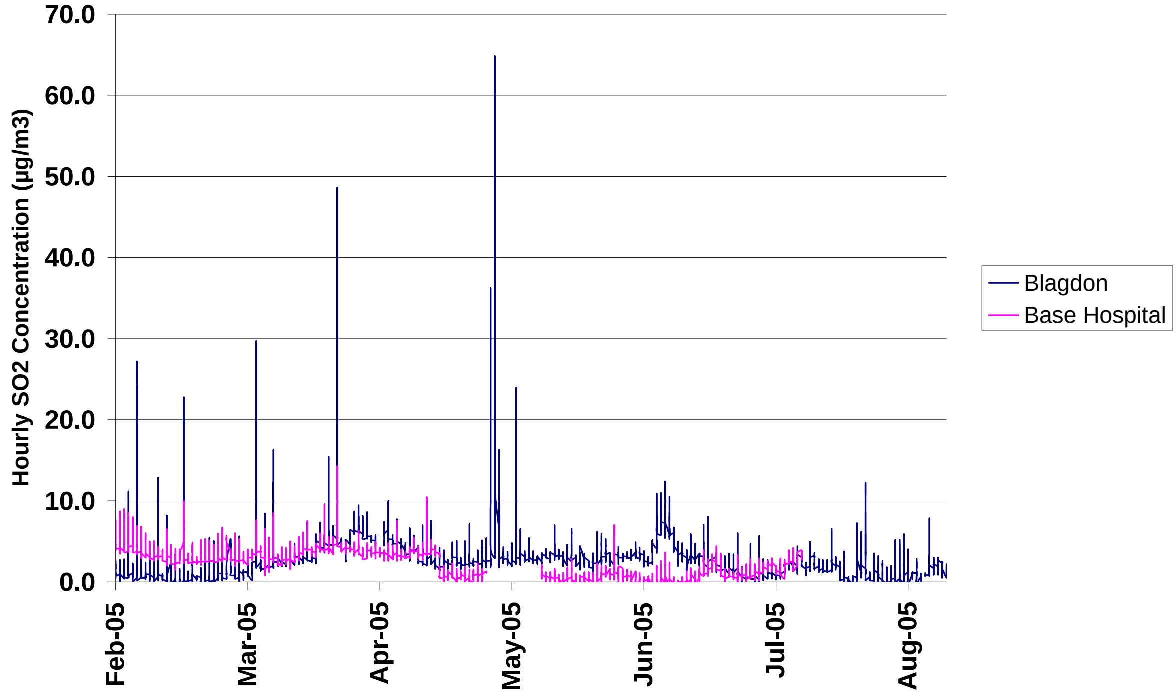



Figure 4-4. Ambient $SO_2$ monitoring (Feb 2005 to August 2005).

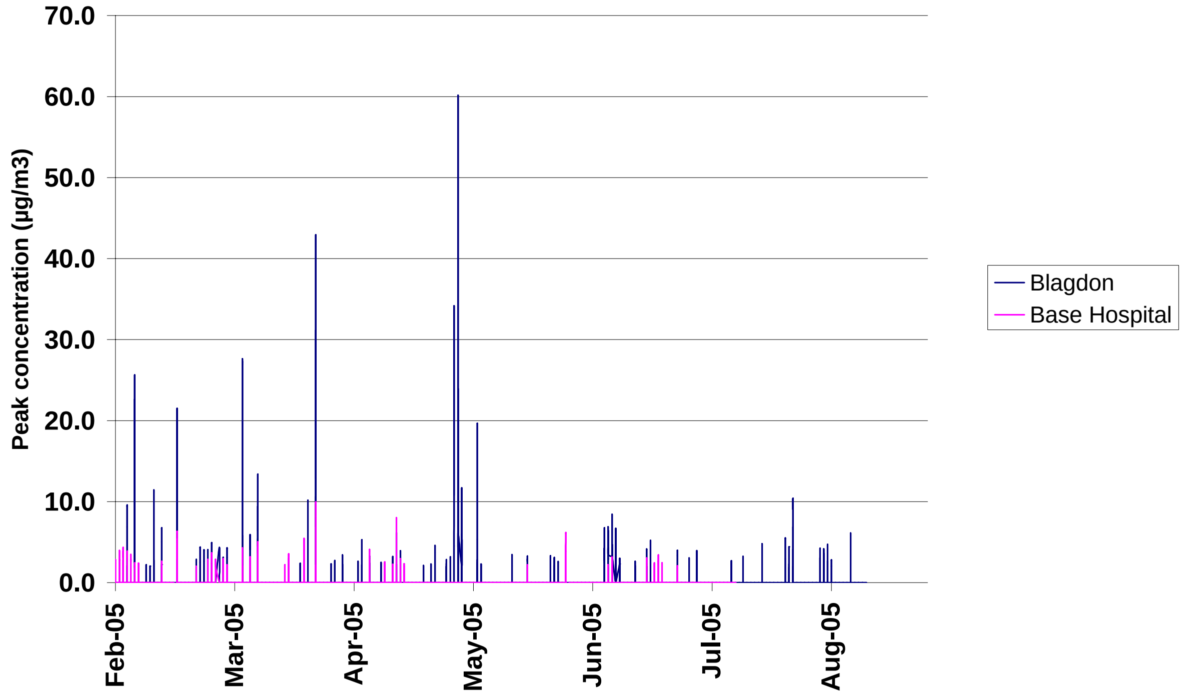



Figure 4-5. Peak $SO_2$ concentrations.

## 4.2 Correlations

In Figure 4-5 the hourly $SO_2$ concentrations have been presented by reducing the 'noise' and disregarding lower value concentrations. The result enables a comparison of 'peak' concentration for both the Blagdon and the Base Hospital monitoring sites. The figure illustrates that peaks at Blagdon quite often coincide with peaks at the Hospital.

## 4.3 Ship $SO_2$ Emissions

Port Taranaki, located just east of the power station, experienced an average of 3.1 ship movements per day during the period from 1 February 2005 to 31 August 2005. The maximum daily number of ship movements experienced during this time was eight, and on a few occasions there were no ship movements. A comparison of Figure 4-5 and Figure 4-6 reveals that, while it is not always the case, often the peaks in $SO_2$ concentrations generally coincide with times when ship movements are occurring. It is likely that the correlation only occurs during certain wind conditions.

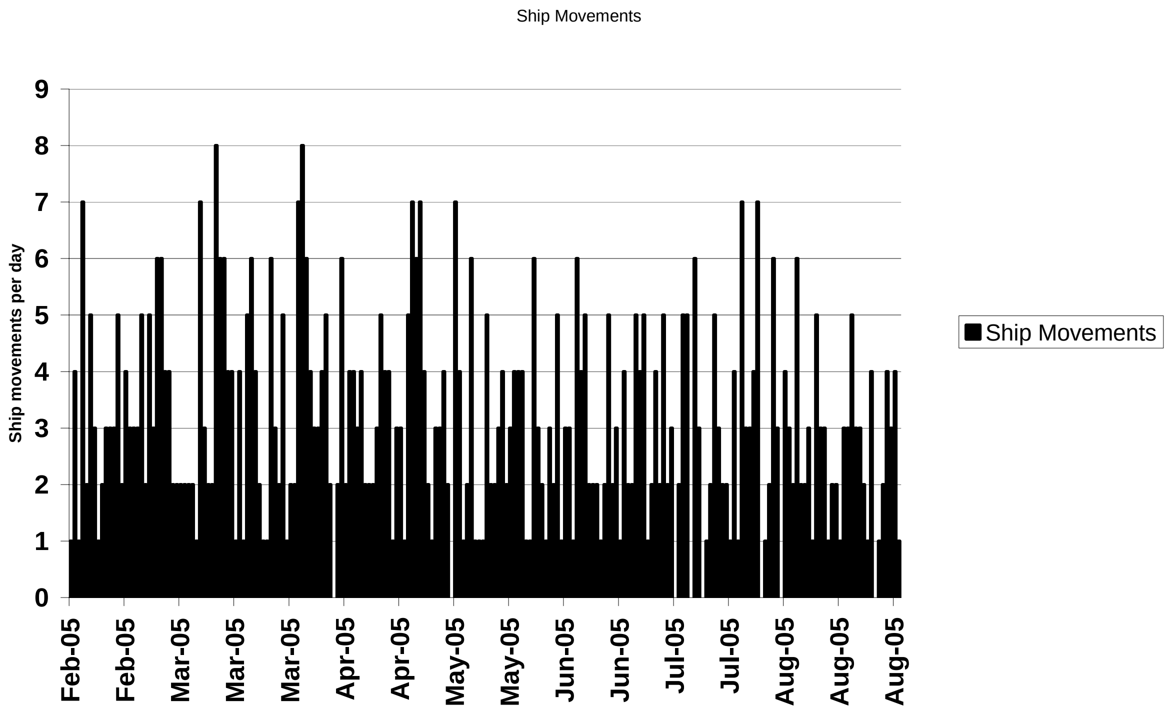



Figure 4-6. Daily ship activity indicating potential $SO_2$ emissions.

## 4.4 Power Station $SO_2$ Emissions

Power station emissions of $SO_2$ have not explicitly been measured, however fuel use data is known. Figure 4-7 shows the tonnes of fuel oil used during the period from 17 February 2005 to 30 May 2005.

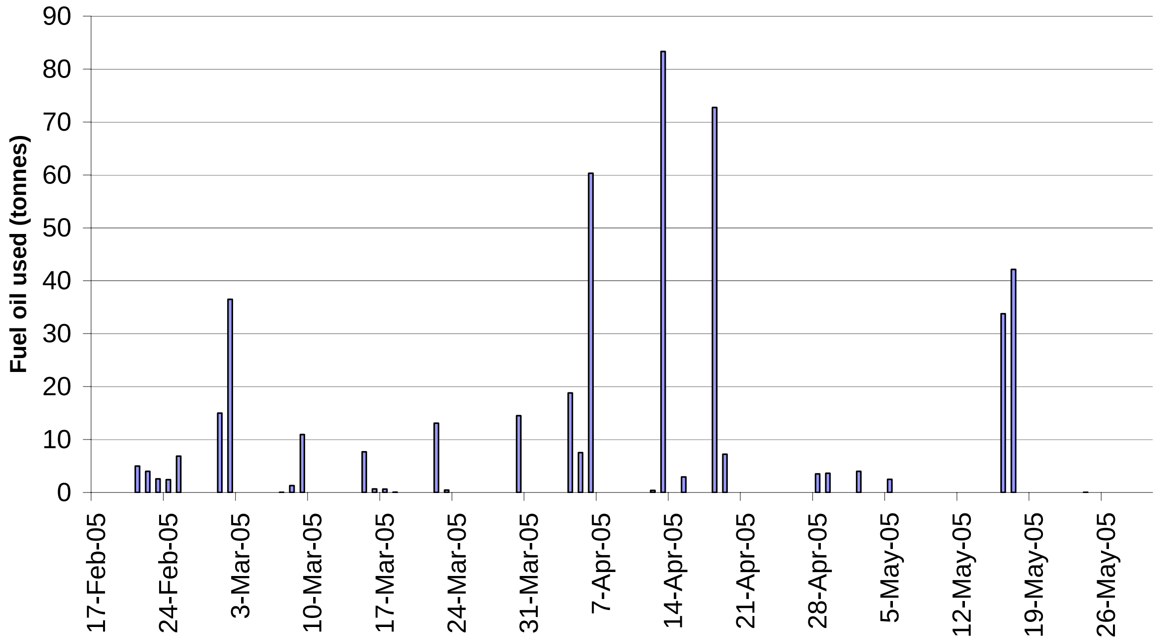



Figure 4-7. Fuel oil use for New Plymouth power station.

The fuel use data in Figure 4-7 is not an absolute indicator of $SO_2$ discharged, since data on the sulphur content of the fuel has not been analysed. The data only gives an indication of the days when $SO_2$ emissions occurred, and a crude indication of the amount.

## 4.5 Conclusion

The data presented in this section show qualitatively the relationship between the $SO_2$ monitoring results and the potential sources. It is clear that the power station emissions are not a significant contributor to the $SO_2$ concentrations at the monitoring sites over the six-month study period. A full analysis of the emissions from ships has not been undertaken, since accurate information on the amount of $SO_2$ discharged, and the exact position of the ships is not known. However it is clear that the ship emissions are potentially a significant source for the minor $SO_2$ peaks in the New Plymouth city area.

# 5. MODELLING METHODOLOGY

## 5.1 Model Selection

The CALPUFF modelling system (Scire et al., 2000 a, b) was used in the modelling analysis. CALPUFF and its meteorological model CALMET are designed to handle the complexities posed by the complex terrain, the long source receptor distances, chemical transformation and deposition. CALMET is a diagnostic meteorological model that is used to drive the CALPUFF dispersion model. It produces three-dimensional wind and temperature fields and two-dimensional fields of mixing heights and other meteorological fields. It contains slope flow effects, terrain channeling, and kinematic effects of terrain. CALPUFF is a non-steady-state Gaussian puff model that includes algorithms for building downwash effects as well as chemical transformation, wet deposition, and dry deposition. One capability of CALPUFF not found in many specialized models such as CTDMPLUS is the ability to treat the combined effects of multiple processes (e.g., building downwash effects in complex terrain; dry deposition and over water dispersion, etc.). A complete summary of the capabilities and features of CALMET and CALPUFF is provided in Appendix 1.

Other regulatory models such as the Industrial Source Complex Short Term (ISCST3) and Ausplume models have several important limitations for this type of application. One critical limitation is that ISCST3, Ausplume and Aermod are steady-state, straight line plume models that cannot respond to the terrain-induced spatial variability in the wind fields or to changes in dispersion conditions resulting from changes in surface characteristics. ISCST3 uses spatially invariant wind fields based on single-station wind observations. Also, the steady-state formulation does not account for causality effects (i.e. the transport time required for pollutants to reach receptors), which can be important for source-receptor distances greater than a few kilometers.

## 5.2 Modelling Domain Configuration

The CALMET/CALPUFF computational domain consists of a uniform horizontal grid with a grid cell size of 250 m in order to properly resolve spatial changes in flow fields and surface characteristics. In the vertical, a stretched grid was used with a fine resolution in the lower layers in order to resolve the mixed layer and a somewhat coarser resolution aloft. The ten vertical levels are centered at: 10, 30, 60, 120, 190, 330, 560, 900, 1400, and 2950 meters.

## 5.3 Meteorological Modelling

MM5 meteorological data was used to define the initial guess field for the CALMET simulations, with the addition of surface wherever possible. The diagnostic wind module in CALMET produced winds with a grid spacing of 0.25 km at 260 × 260 grid cells. The MM5 data was available at a resolution of 3 km for all episodes and at 1 km for episodes, 6 February, 17 February and March 10. 1 km nested grids could not be done for episodes due to the length of time required for each simulation.

**Step 1 Field: Terrain Effects**

In developing the Step 1 wind field, CALMET adjusts the initial guess field to reflect kinematic effects of the terrain, slope flows and blocking effects. Slope flows are a function of the local slope and altitude of the nearest crest. The crest is defined as the highest peak within a radius TERRAD around each grid point. The value of TERRAD was set to 15km based on an analysis of the scale of the terrain. The Step 1 field produces a flow field consistent with the fine-scale CALMET terrain resolution (250m).

**Step 2 Field: Objective Analysis**

In Step 2, observations are incorporated into the Step 1 wind field to produce a final wind field. Each observation site influences the final wind field within a radius of influence (parameters RMAX1 at the surface and RMAX2 aloft). Observations and Step 1 field are weighted by means of parameters R1 at the surface and R2 aloft: at a distance R1 from an observation site, the Step 1 wind field and the surface observations are weighted equally. In this application, when the surface stations were included in the modelling were given a weight of 5-8 km. On this domain a R1 value of 5-8km still gives significant weight to the Step 1 wind field.

## 5.4 CALPUFF Computational Domain

No dispersion modelling was conducted for this part of the analysis.

# 6. RESULTS

## 6.1 Episodes Examined

Six episodes showing $SO_2$ peaks have been individually evaluated in this analysis. They are;

*23 January, 6 February, 17 February, 6 March, 25 March, 30 April/1 May.*

Because of the length of time required to run the prognostic meteorological model, MM5, a continuous record of prognostic data could not be possible in the time given for this evaluation study. Instead MM5 was run for the day when the peak $SO_2$ occurred and for one-day prior to the episode.

## 6.2 Analysis of Meteorological Observations

The first series of results shows how the meteorological model results compare with the site observations. Figures 6.1 to 6.4 show the wind roses from the meteorological stations at New Plymouth Airport, Stratford and Hawera, for each of the four times of day – morning, afternoon, evening and night.

These are later referenced to the outputs from the meteorological models.

One of the key features shown here is the very strong influence of Mt Taranaki on the wind fields throughout the day. Although on-shore sea breezes are a key component of the flow during the day, all of those considered in the analyses here failed to show any clearly defined return flow aloft. The true reasons for this are not clear, and more analysis work needs to be done, but it is possible that the up-slope mountain flows prevent the formation of the return sea breeze aloft.

Another clear feature is the substantially different wind climatologies at different times of day at each of the sites which are directly influenced by the mountain and the shape of the coastline. Onshore sea breeze type flow predominates at all stations between 12h and 17h each day. Onshore flow is west at New Plymouth and Hawera and north and south at Stratford. Offshore drainage off the mountain predominates during the night from 18h to 05h each morning and is still a strong factor in the flow during the morning 06h – 11h prior to onset of the sea breeze.

A uniform wind vector scale length has been used for all figures and case studies in order that figures may be compared against one another. The vector scale length used is,

0.05 inches = 1 m/s to 0.30 inches = 15 m/s

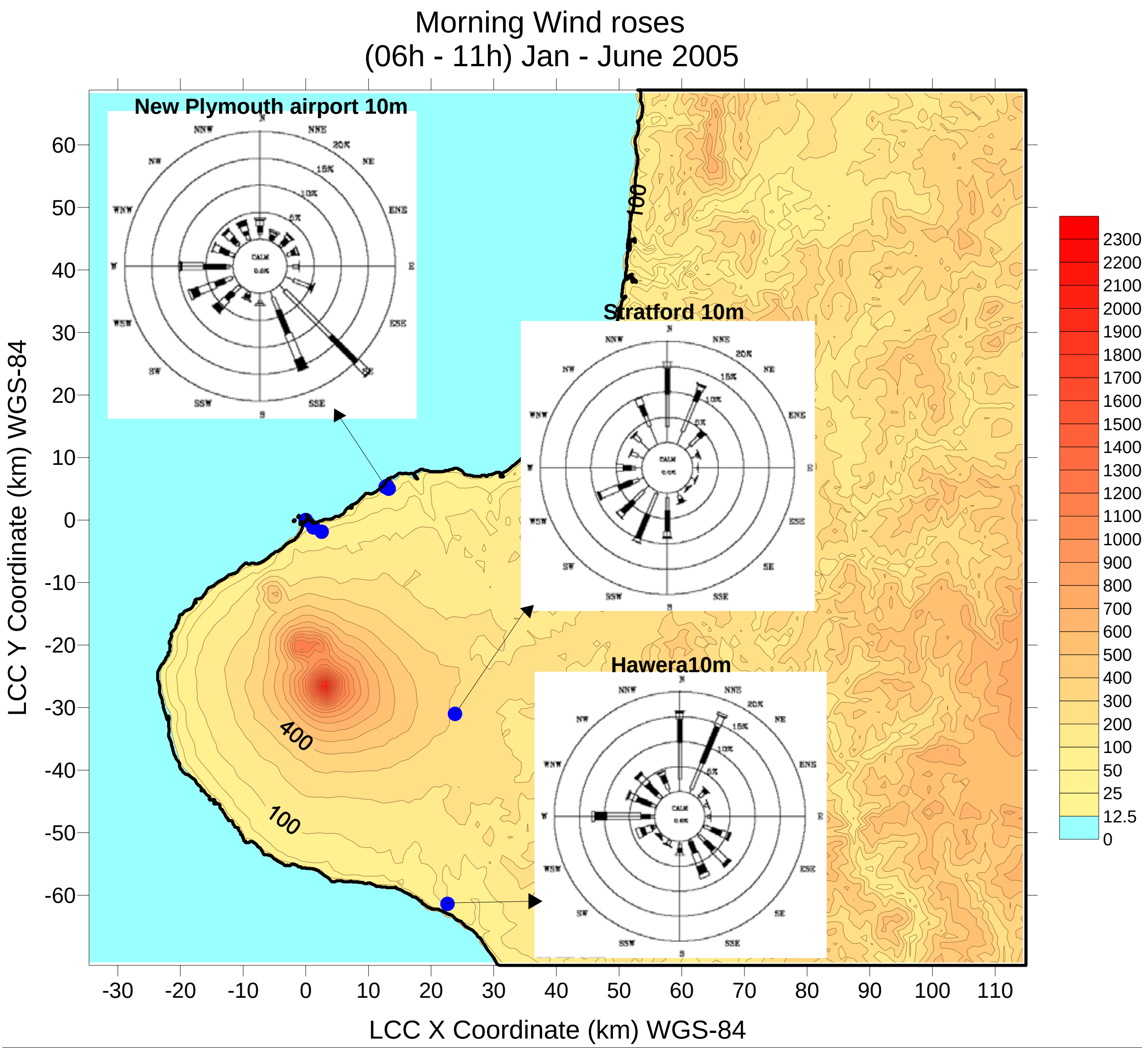



Figure 6-1. This figure shows the morning wind roses at the Airport, Hawera and Stratford from 1 January 2005 – 30 June 2005.

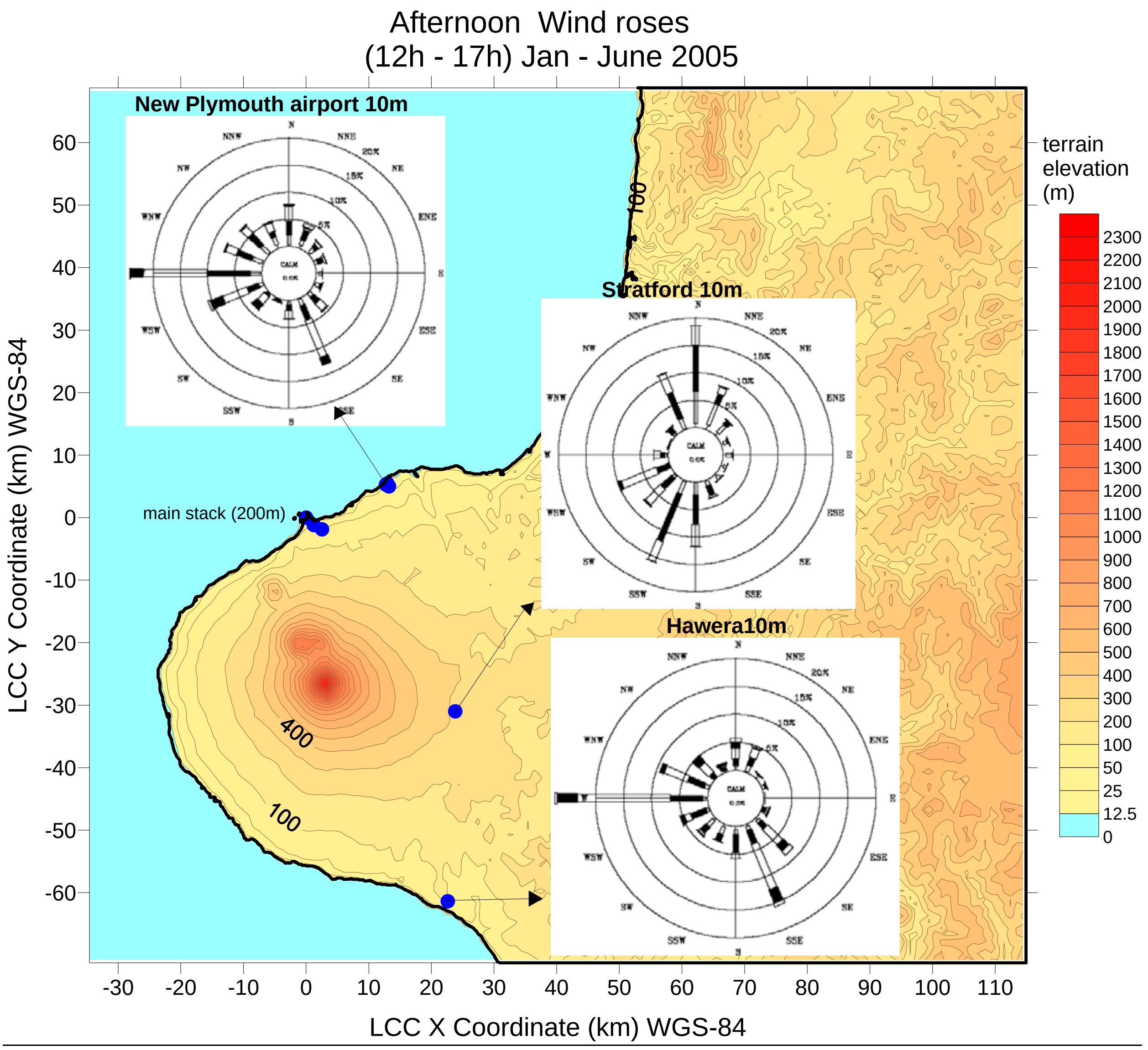



Figure 6-2. This figure shows the afternoon wind roses at the Airport, Hawera and Stratford from 1 January 2005 – 30 June 2005.

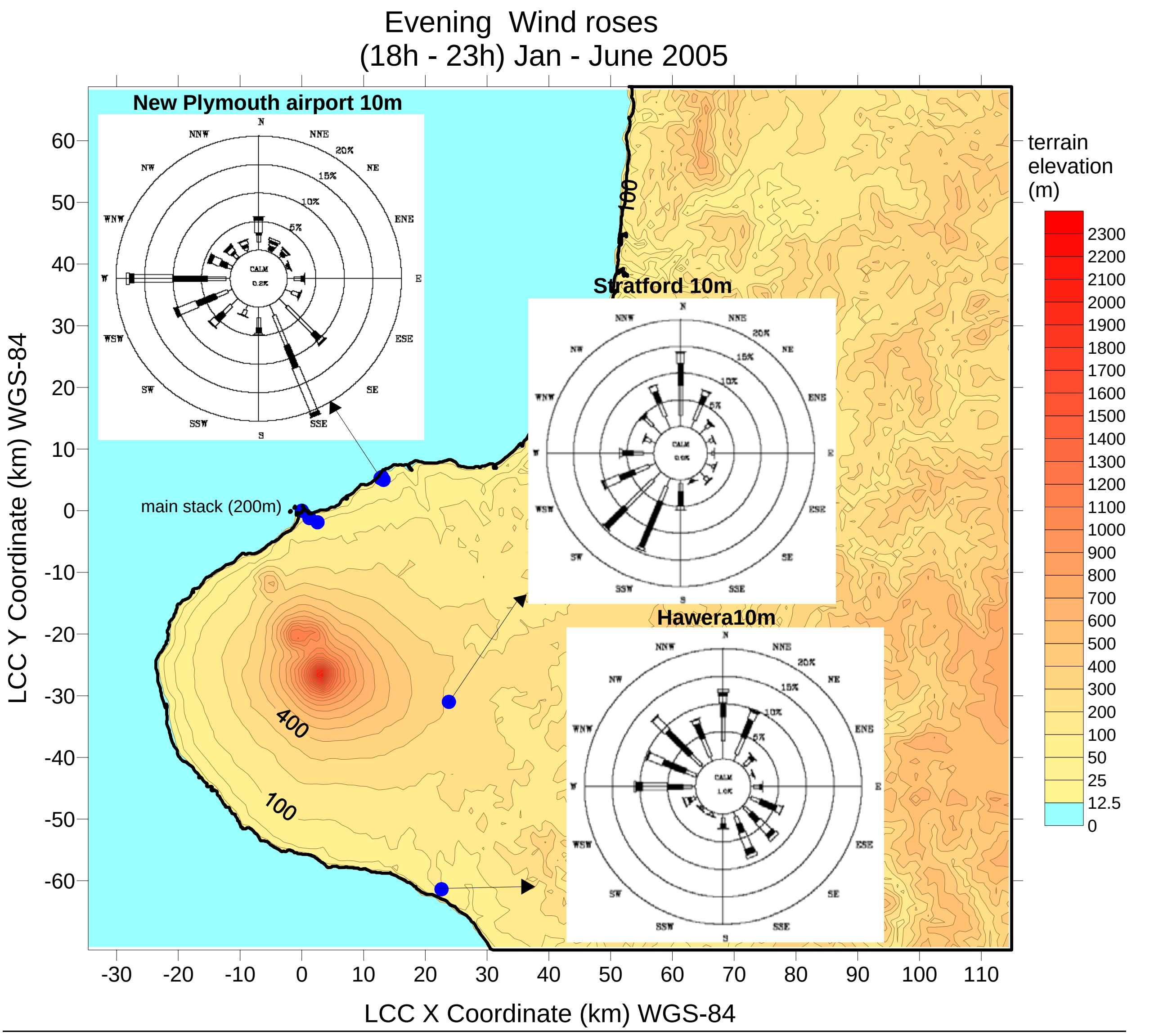



Figure 6-3. This figure shows the evening wind roses at the Airport, Hawera and Stratford from 1 January 2005 – 30 June 2005.

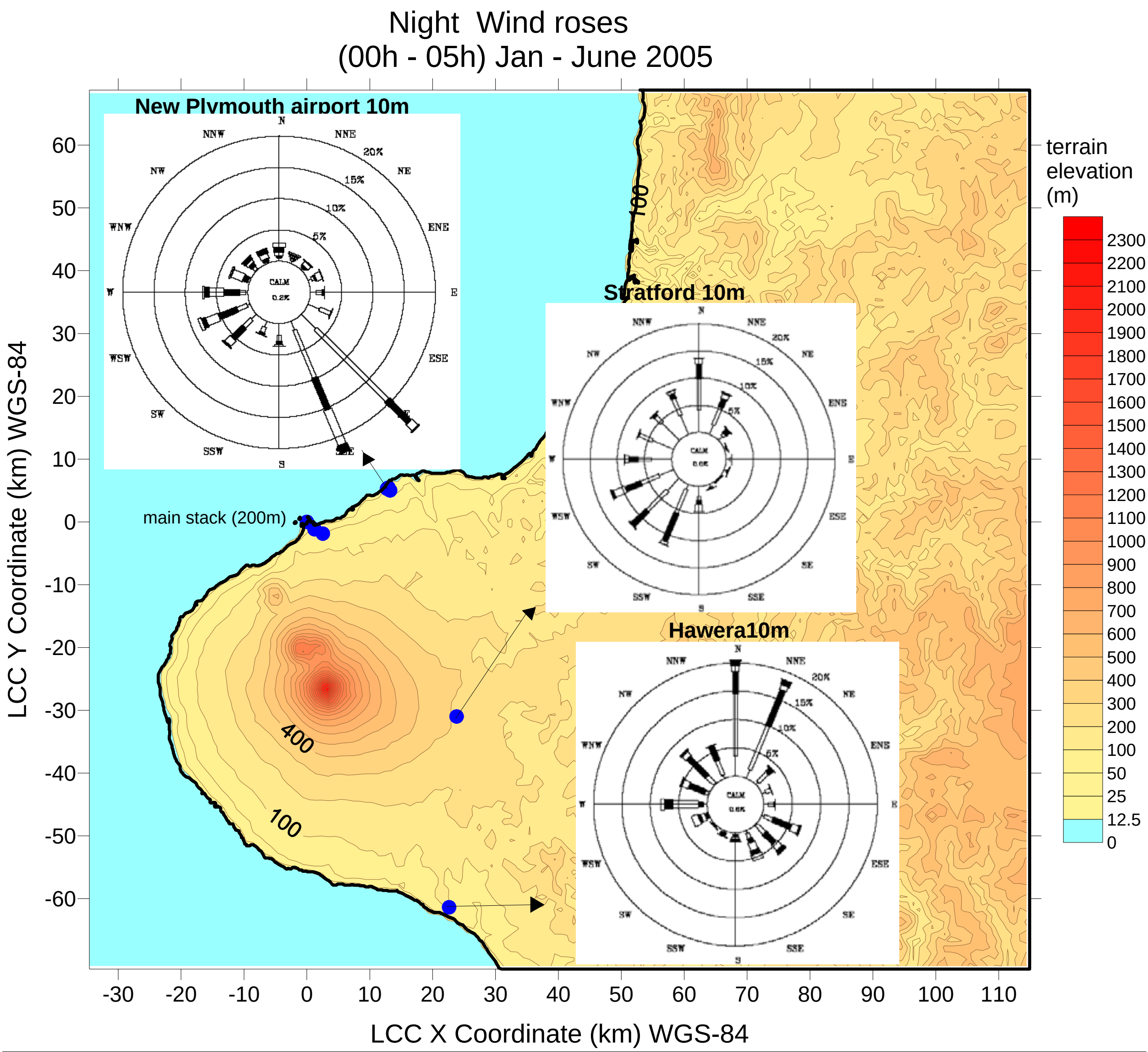



Figure 6-4. This figure shows the afternoon nighttime wind roses at the Airport, Hawera and Stratford from 1 January 2005 – 30 June 2005.

## 6.3 Analysis of Meteorological Modelled Results vs. Monitoring Data

In this section each individual $SO_2$ episode is analysed. Model results are compared independently against actual observations measured at each of three meteorological stations.

### *6.3.1 Case 1- 23 January 2005*

An $SO_2$ peak occurred at 16h on January 23, 2005. The cause of the peak was a decrease in wind speed and a distinct change in the wind direction from north northwest to northwest. There was no true sea breeze recorded on this day, although the onshore flow can be described as a sea breeze there was no return flow aloft. Figure 6-7 for the January 23, 00h – 23h shows the time series plot. Prior to the peak at 16h and after the peak at 16h, the $SO_2$ values were negligible. The synoptic conditions in the 12 hours leading up to this episode were dominated by northerly winds at the surface and northwesterly winds aloft. The peak $SO_2$ occurred with a drop off in wind speed. Drainage flow off Mt Taranaki occurs during the night of the 22nd January as can be seen in Figure 6-5. Figure 6-6 shows the flow at 16h when the peak $SO_2$ value occurred. During the daytime the flows on the northern flank of Mt Taranaki are subject to up-mountain flow assisted by the overriding synoptic conditions. The figure shows how the northerly flow is forced to split around Mt Taranaki creating an area of increased flow along its western and eastern flanks and a region of calm in the lee of the mountain. The results shown in Figure 6-6 are the results of the CALMET/MM5 model run which does not include any observations. The observations recorded at the Airport, Hawera and Stratford are marked in red.

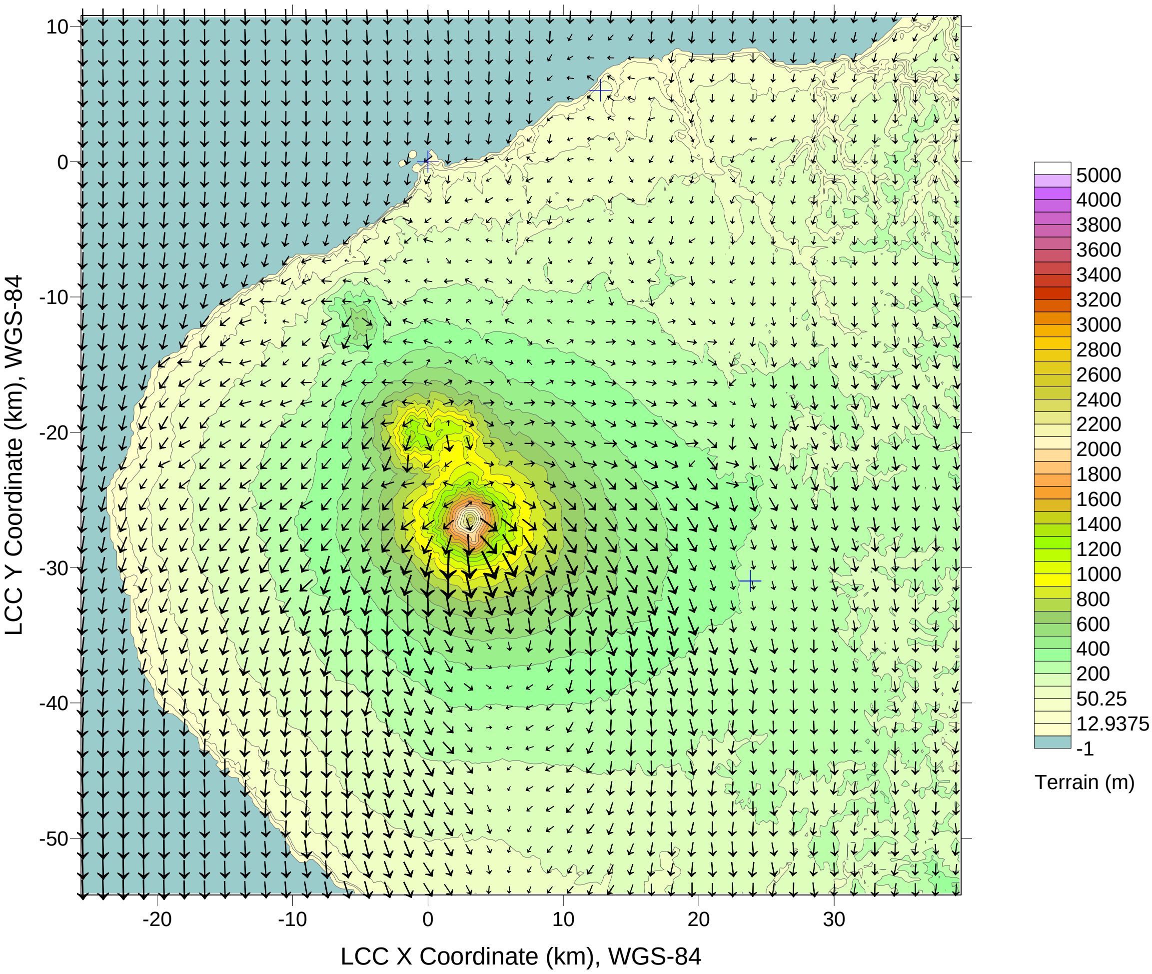



Figure 6-5. Even though the synoptic flow is northerly, nocturnal drainage from Mt Taranaki at 00h on 23 January 2005 is a strongly dominant feature of the meteorological environment. Note how the flow at the airport is quite distinctly different to that around the power station which is affected by the low buttresses in the region.

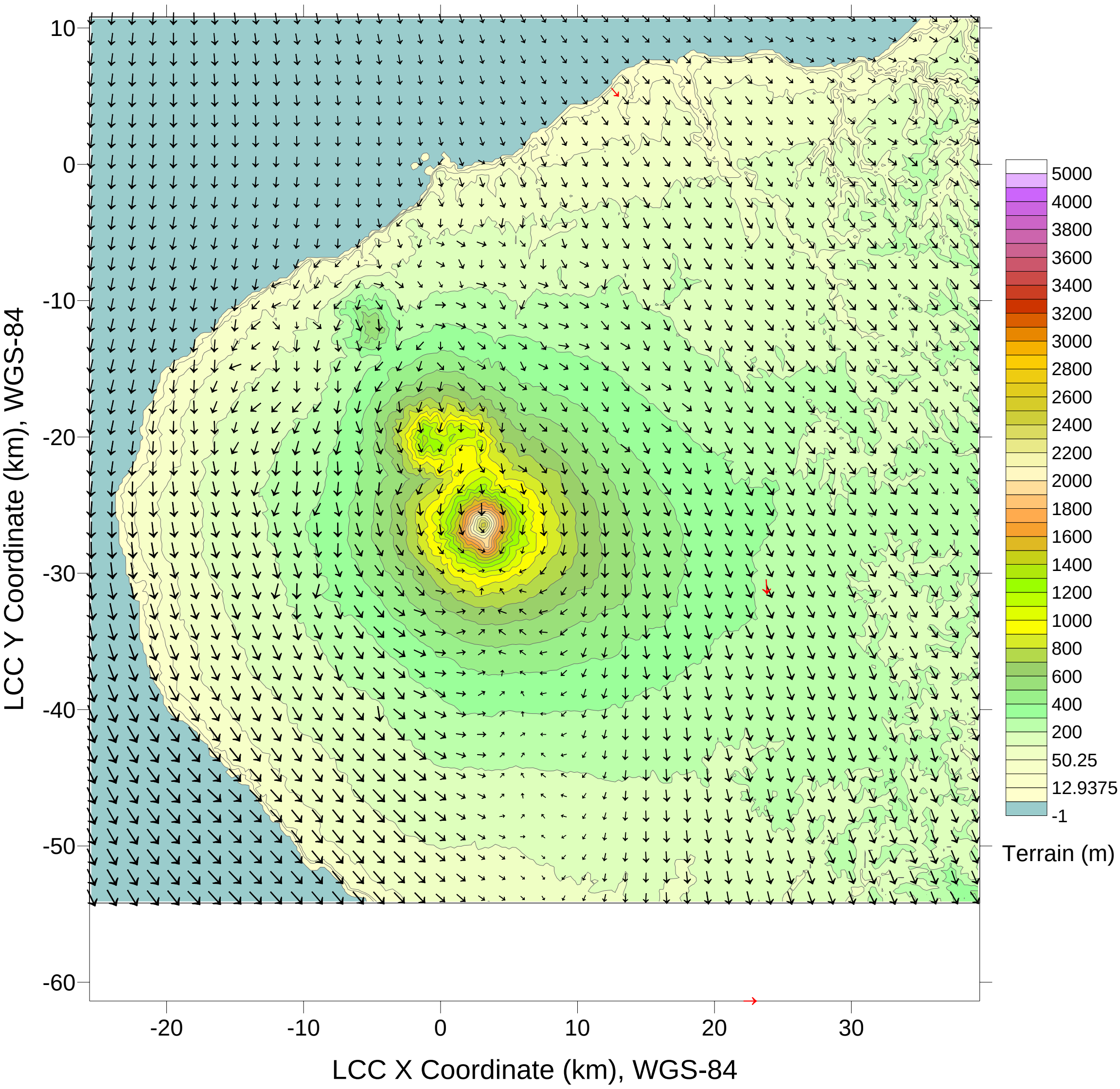



Figure 6-6. This figure shows how the modelled wind field compares to the actual observations measured at Hawera, Stratford and the Airport. The wind field is applicable to hour 16h on the 23 January, 2005. No surface or upper air observations were used in the modelling.

Figure 6-8 compares the CALMET/MM5 modelled results vs. the actual observations at 10m for 23 January hr 16 – the time of the $SO_2$ peak. Even without observations, the models correctly predict a drop in wind speed during the course of the day as seen at both Stratford and the Airport, and is therefore in good agreement with the observations from midday onwards. During the morning hours, the model and the observations are less in agreement, as reflected in the wind direction. The models predict more easterly flow during the morning hours swinging to northerly and then northwesterly during the afternoon, whereas the observations show the flow to be predominantly from the north northwest during the entire period. The reasons for this are unclear, it is possible that MM5 is responding too strongly to the diurnal forcing caused by Mt Taranaki. By midday, however, the models have corrected themselves and are consistent with the observations for the remainder of the day. Even though the sources responsible for causing the $SO_2$ peak are not known, the meteorological event triggering the peak is known, i.e., a rapid decrease in wind speed under an onshore flow.

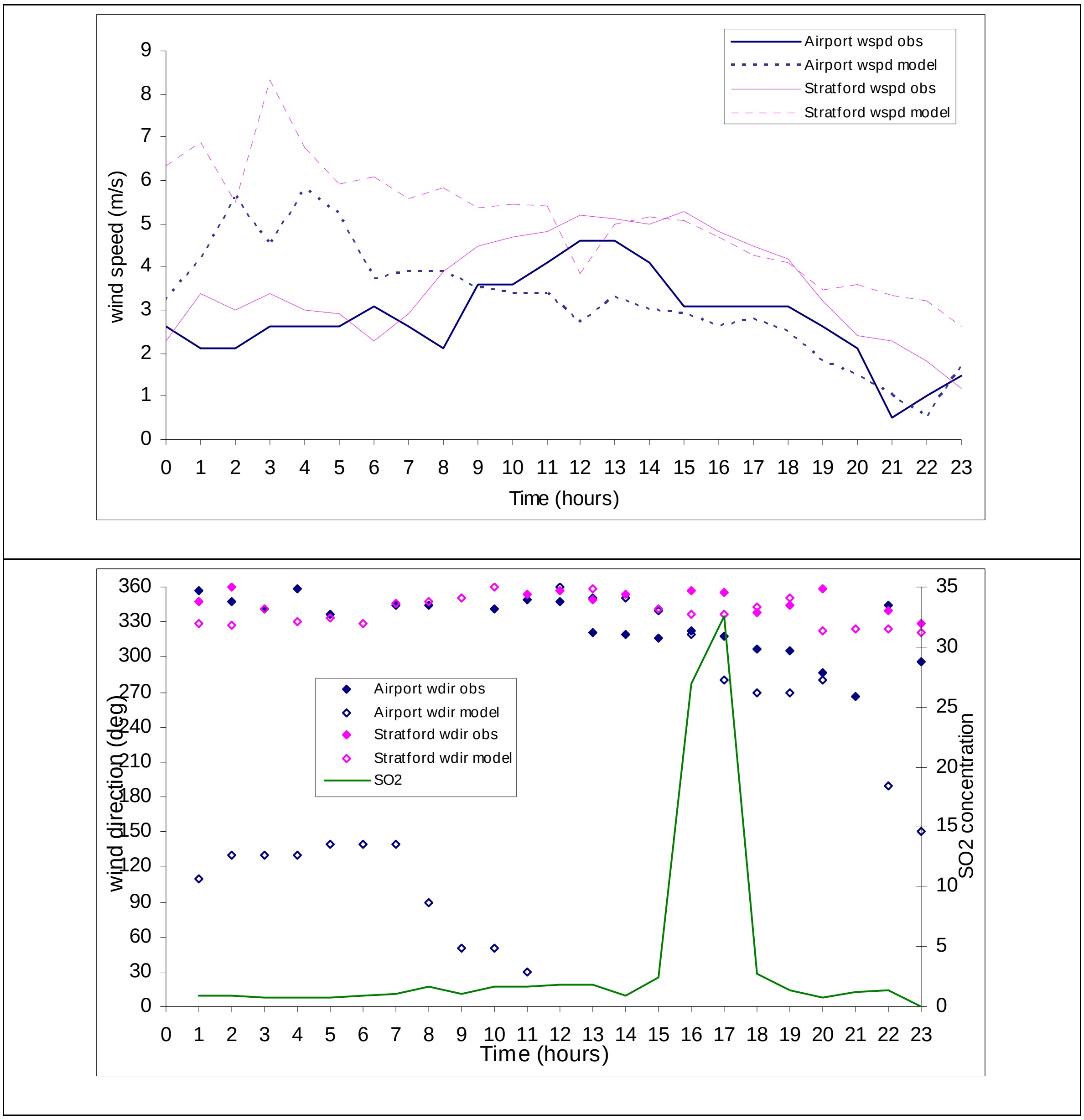



Figure 6-7. Time series through 23 January 2005. Top graph shows the wind speed from the Airport and Stratford meteorological stations vs. that produced by CALMET/MM5. The lower diagram shows wind direction at the observational sites vs. wind direction produced by the model. $SO_2$ concentrations as measured at the monitoring site are also shown.

Note. These comparisons compare the CALMET/MM5 modelled results vs. the actual observations at 10m. The model correctly predicts a drop in wind speed during the course of the day as seen at both Stratford and the Airport, and is therefore in good agreement with the observations from midday onwards. But, during the morning hours the model and the observations are less in agreement, which is reflected in the wind direction. The models predict more easterly flow during the morning hours swinging to northerly and then northwesterly during the afternoon, whereas the observations show the flow to be predominantly from the north northwest during the entire period.

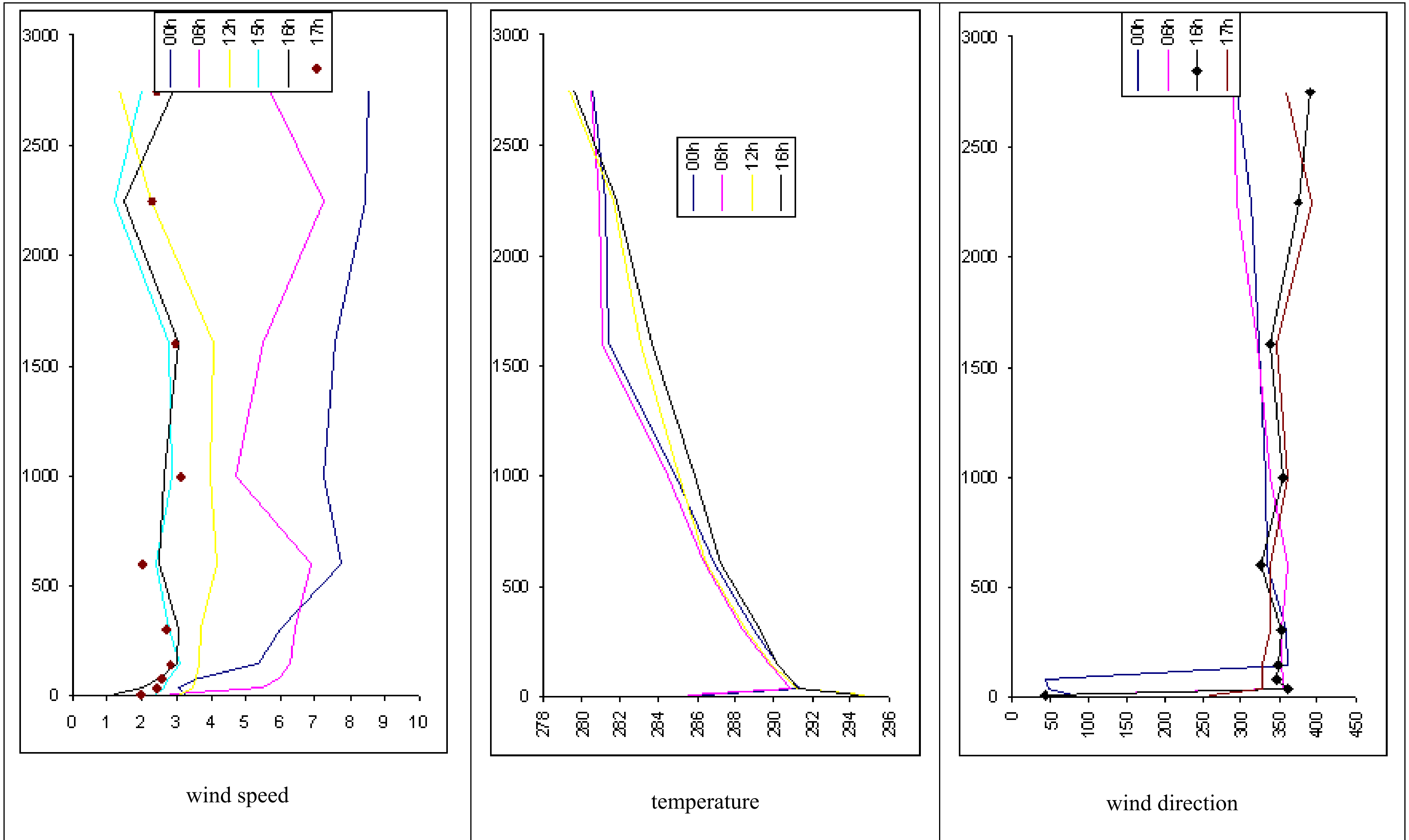



Figure 6-8. Vertical profiles through 23 January 2005 at various times of the day on the 23[rd.] The diagram show from the left, vertical profiles of wind speed, temperature and wind direction at the power station. The decrease in speed leading up to the peak $SO_2$ episode at 16h is clear. The temperature profile shows a rapid decrease in temperature close to the surface around 16h and the wind direction profile shows a big direction change close to the surface at 16h.

### *6.3.2 Case 2 - 6 February 2005*

A series of $SO_2$ peaks occurred between 13h and 22h on 6 February, 2005. Similarly, to the first case, the cause of the peaks were due to a rapid decline in the wind speed with a gradual swing in the wind from northeasterly through northerly to northwesterly. Because of the light wind speeds the flow became highly variable across the modelling region. Similarly, to other cases no true sea breeze is seen to occur during the day as the return flow of the sea breeze is suppressed due to the up-mountain flow. The synoptic conditions in the 12 hours leading up to this episode were dominated by north easterly winds throughout the profile (as determined from MM5 output). As expected drainage flow off Mt Taranaki occurs during the night of the 5th February as can be seen in Figure 6-9.

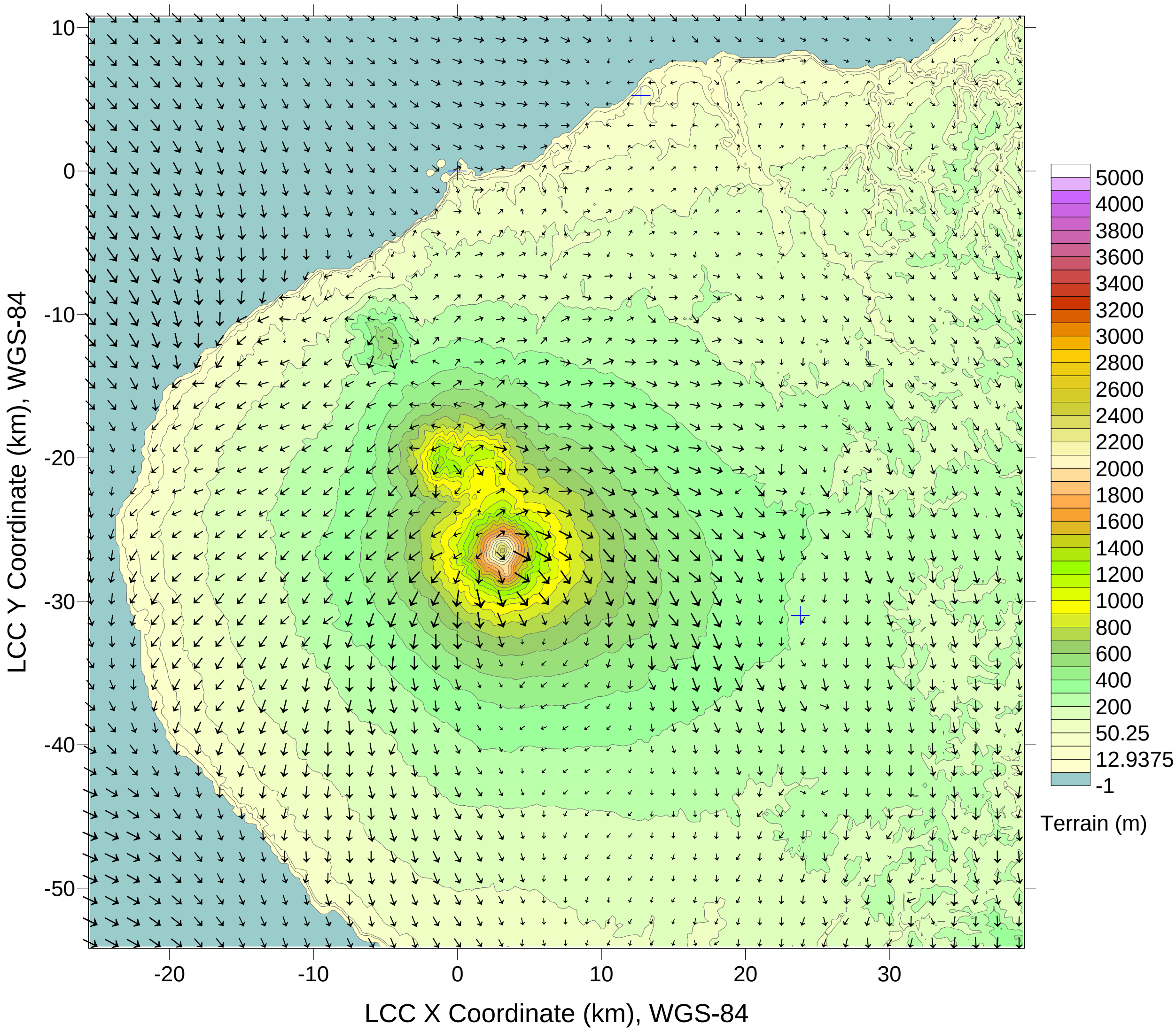



Figure 6-9. Even though the synoptic flow is northerly, nocturnal drainage from Mt Taranaki at 00h on 6 February 2005 is a strongly dominant feature of the meteorological environment. Note how the flow at the airport is quite distinctly different to that around the power station which is affected by the low buttresses in the region. Note that the wind speed vector length has been kept constant throughout the case studies, this allows cases to be compared against one another.

Figure 6-10 (directly below), shows time series of the wind speed (top) and wind direction (below) throughout the day of the 6th February. The model (at the airport) agrees well with the airport observations throughout the time series. The sharp decline in wind speed around 16h is distinct at both the power station and the airport.

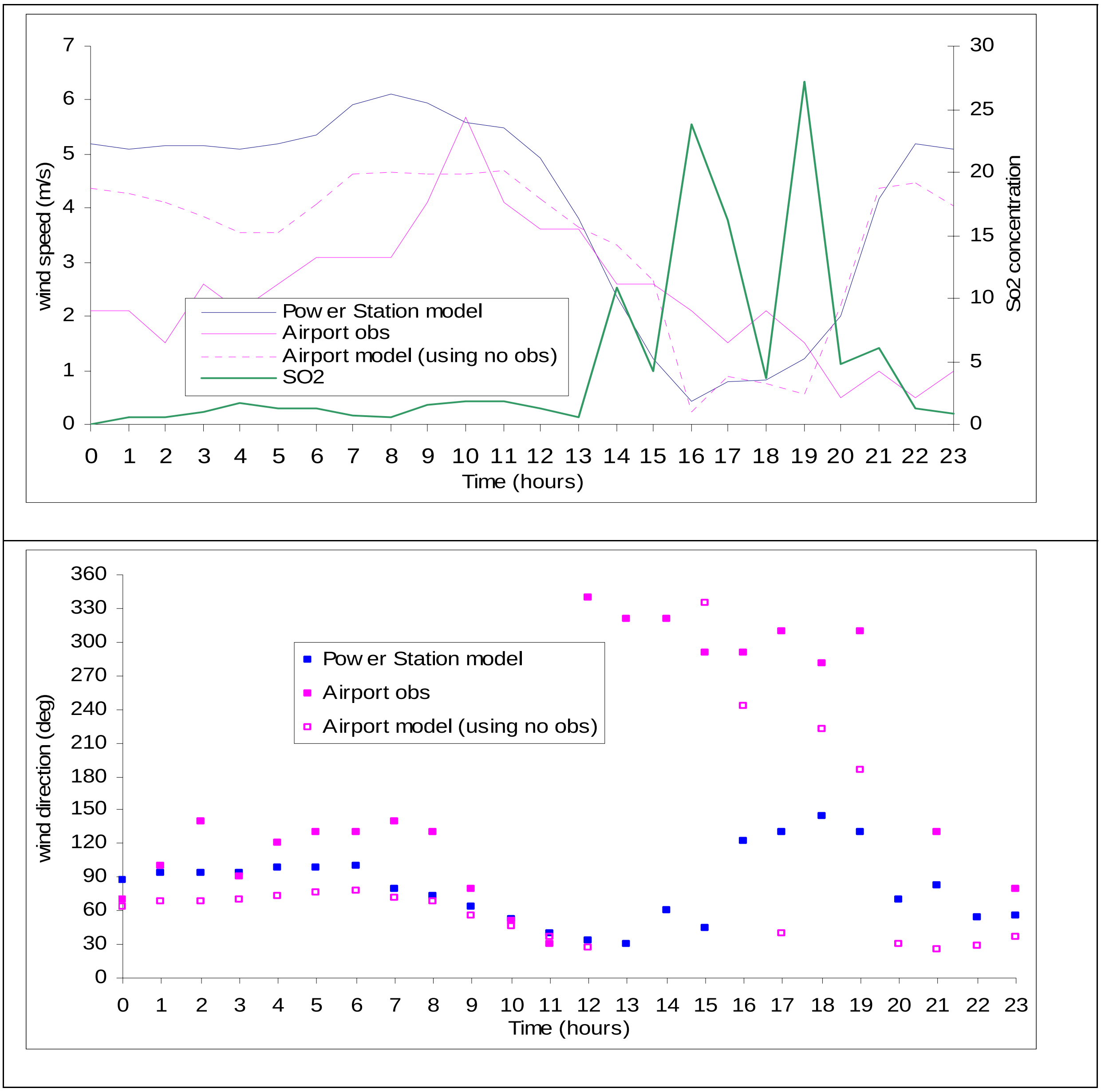



Figure 6-10. Wind speed (top) and direction (bottom) time series of the 6th February 2005. The pink solid line marks the observation while the pink dashed line shows the results of the CALMET/MM5 model run using no observations to drive the model at all.

Figure 6-11 shows the spatial wind field of the CALMET/MM5 model run which does not include any observations. The actual observations recorded at the Airport, Hawera and Stratford are marked in red and overlay the plot. Note in this case the model shows light northerly flow at Stratford whilst the actual observation is showing light southwesterly flow, although the models and observations appear to be consistent at both Hawera and the airport. To the east of Mt Taranaki, the models predict distinct northerly flow which has been further enhanced by the eastern flank of Mt Taranaki. The light variable flow to the north, east and south of the model domain is clearly evident and consistent with the observations during this time. With the lack of any upper air data to verify the conditions through the boundary layer, it is not clear why MM5 produces the northerly flow along the eastern side of the model domain.

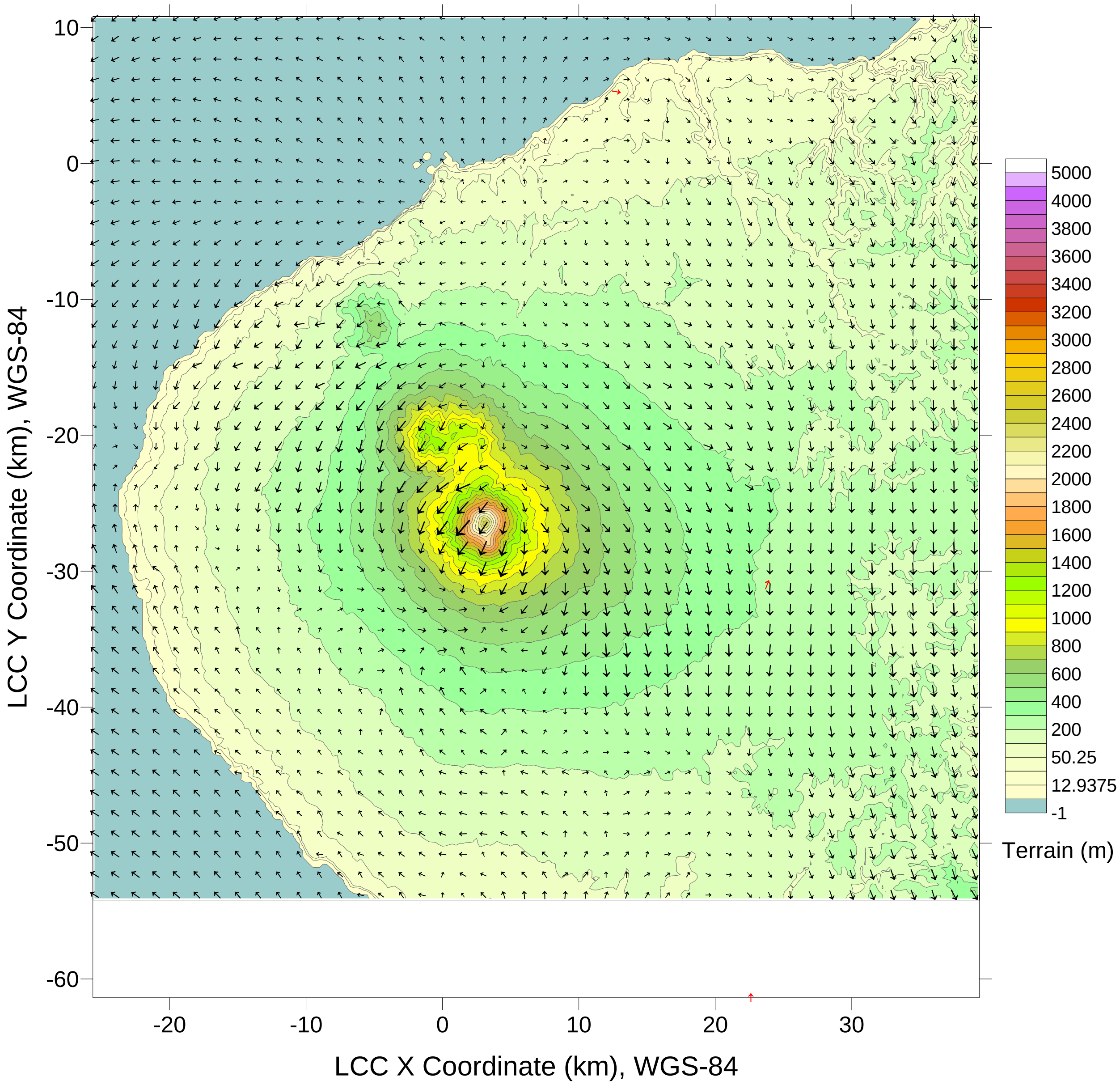



Figure 6-11. This plot shows the spatial wind field of the CALMET/MM5 model run which does not include any observations for 6 February hr 18, the time that peak $SO_2$ concentrations were measured. The actual observations recorded at the Airport, Hawera and Stratford are marked in red.

These comparisons compare the CALMET/MM5 modelled results vs. the actual observations at 10m. The model correctly predicts a drop in wind speed during the course of the day as seen at both Stratford and the Airport. From about 15h as the winds get lighter the model tends to deviate from the observations which is to be expected in light variable conditions.

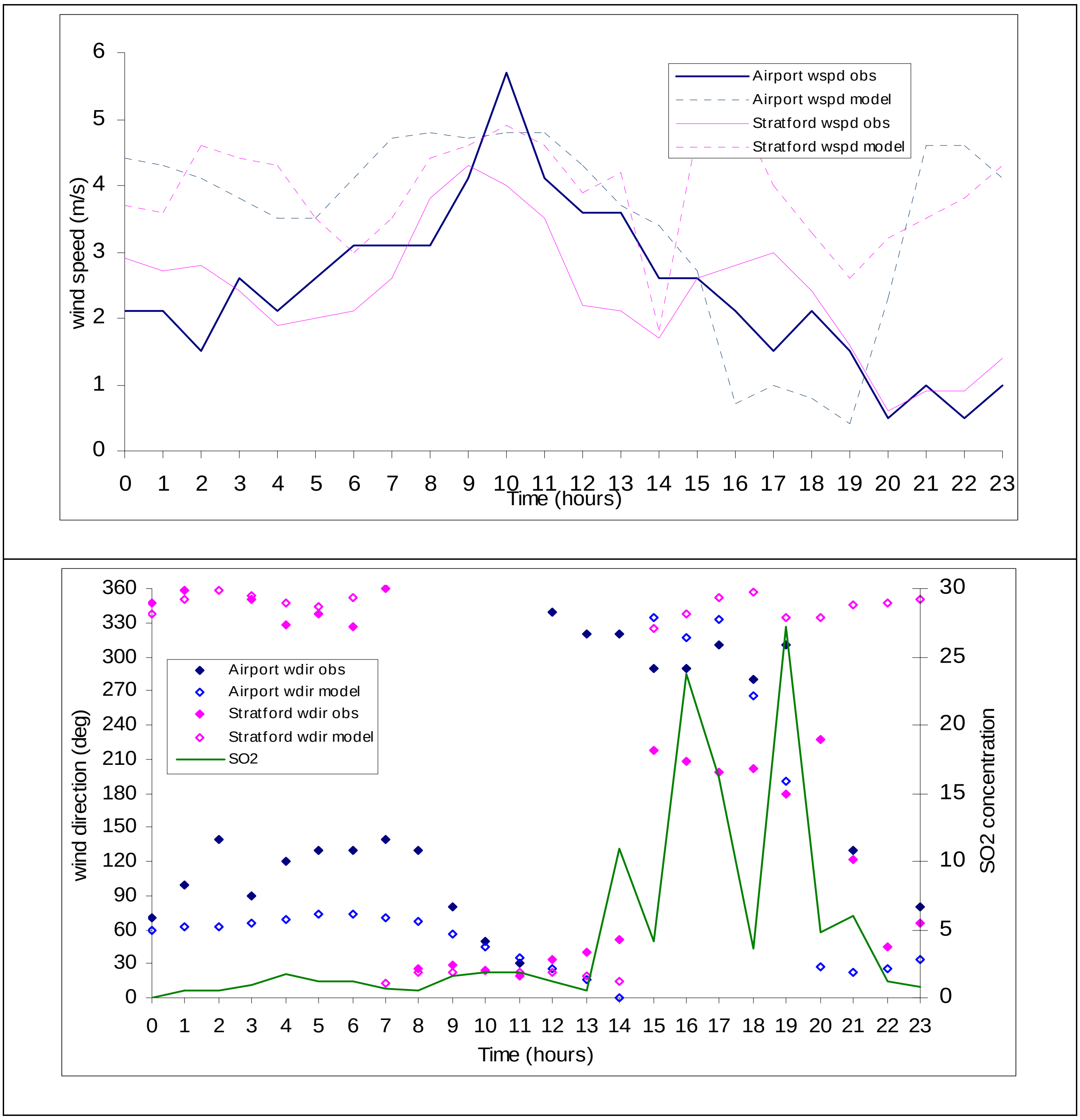



Figure 6-12. Time series of wind speed and direction through 6 February 2005. Top graph shows the wind speed from the Airport and Stratford meteorological stations vs. that produced by CALMET/MM5. The lower diagram shows wind direction at the observational sites vs. wind direction produced by the model. $SO_2$ concentrations as measured at the monitoring site are also shown.

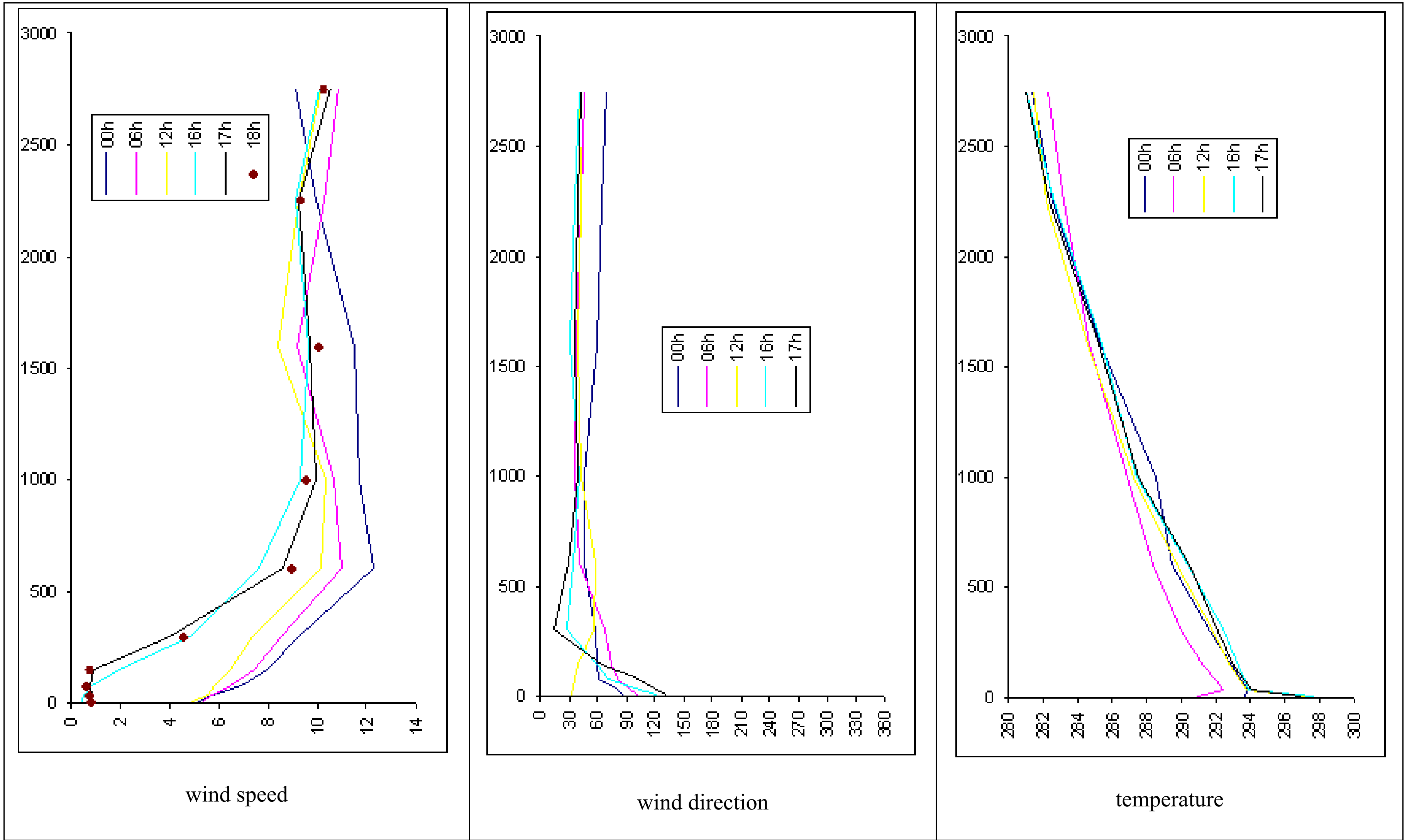
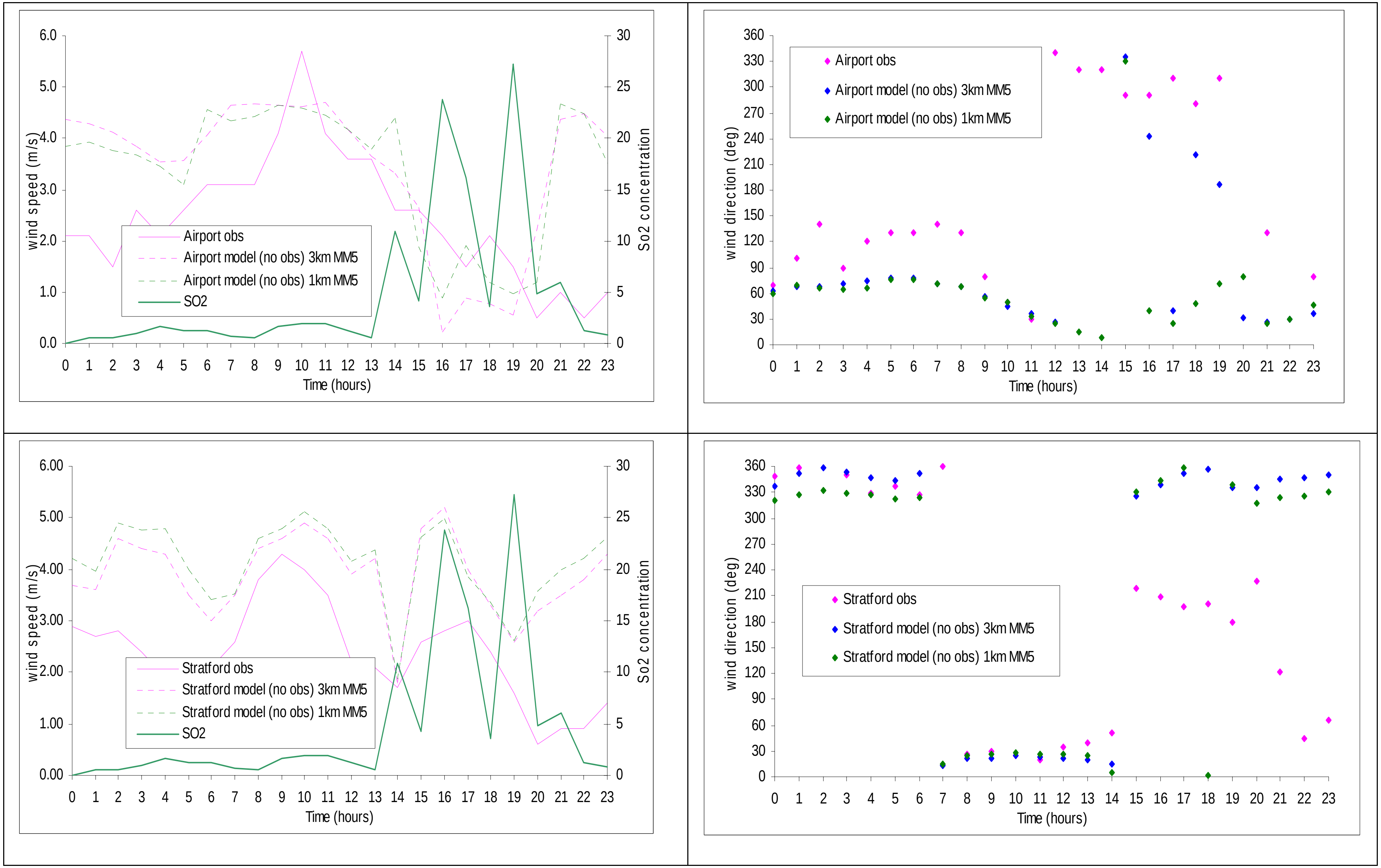



Figure 6-13. Modelled vertical profiles through 6 February (using MM5 3km domain) 2005 at various times of the day on the 23rd. The diagram show from the left, vertical profiles of wind speed, temperature and wind direction at the power station. The decrease in speed leading up to the peak $SO_2$ episode at 16h is clear. The temperature profile shows a rapid decrease in temperature close to the surface around 16h and the wind direction profile shows a big direction change close to the surface at 16h.

Figure 6-14 shows the results of the MM5 3km domain when used as the initial guess wind into CALMET which has a resolution of 250m versus the 1km MM5 domain at the three locations where there is available observation data; the Airport, Stratford and Hawera. In these model runs, no observations were included into the models at all. But for the sake of comparisons the observations are shown alongside the MM5 3km and 1km results. The reason for this comparison is to compare whether the 1km MM5 data is better than the 3km MM5 data. The 3km MM5 data has a data point at every 3km and employs the terrain and Land Use data at 3km resolution. The 1km MM5 data has a data point at every 1km and employs the terrain and Land Use data at a 1km resolution. Over Mt Taranaki the difference in terrain elevation is more than 1000 m between the two different data sets. Unexpectedly, the results of this comparison show little difference between the 3km and 1km MM5 data sets at the three observation sites, with the 1km and 3km MM5 data following similar patterns (which are very similar to the actual observations). These results imply either, that the 3km MM5 data adequately captures the same fine scale 3D effects of the 1km MM5 data, or, that CALMET with its finely resolved terrain and Land Use data is able to correct the less well defined 3km MM5 data. Depending on what data is given it CALMET can sometimes correct a poorly resolved prognostic wind field by virtue of the fine resolution terrain and Land Use data, plus its employment of mesoscale slope flow affects. However, this is not always the case and depends on the quality of the prognostic model data.

An interesting comparison to this study would be to compare the results of MM5 with CSIRO's TAPM model vs. observations and MM5/CALMET vs. TAPM/CALMET vs. observations. To see how;

(1) TAPM does alone (as compared to MM5).
(2) How TAPM does when run through CALMET (as compared with MM5)
(3) The TAPM wind field compares to the MM5 wind field and, the TAPM/CALMET wind field compares to the MM5/CALMET wind field.



wind speed (m/s)
So2 concentration
Time (hours)
Airport obs
Airport model (no obs) 3km MM5
Airport model (no obs) 1km MM5
SO2
wind direction (deg)
Time (hours)
Airport obs
Airport model (no obs) 3km MM5
Airport model (no obs) 1km MM5
wind speed (m/s)
So2 concentration
Time (hours)
Stratford obs
Stratford model (no obs) 3km MM5
Stratford model (no obs) 1km MM5
SO2
wind direction (deg)
Time (hours)
Stratford obs
Stratford model (no obs) 3km MM5
Stratford model (no obs) 1km MM5

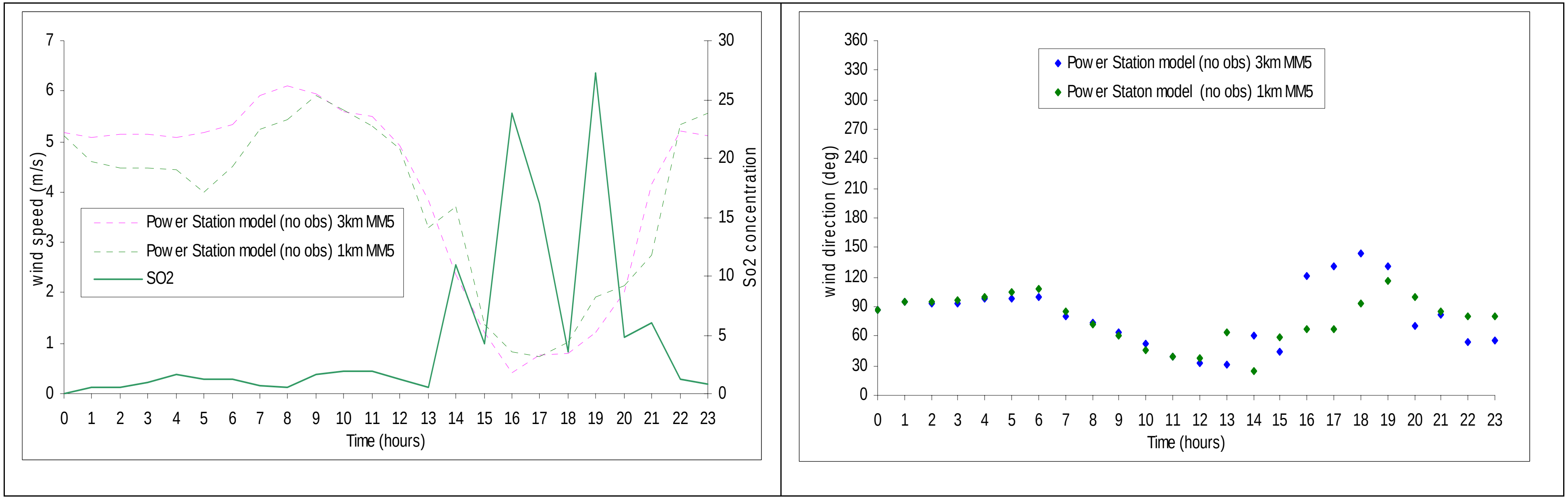



Figure 6-14. Time series plots through the 6 February 2005 from 00h to 23h. The peak $SO_2$ periods occurred at ~16h and 19h. The plots show the results of the MM5/CALMET model runs using the 3km MM5 data as the initial guess wind field vs. the 1km MM5 data as the initial guess wind. No observations were included in the model runs at all.

### 6.3.3 *Case 3 – 17 February 2005*

$SO_2$ peaks occurred at 05h and again around 11h on 17 February 2005. The meteorological situation before the episodes was dominated by northwesterly flow in the range 4 – 8 m/s which is stronger than during the other episodes studied. As a consequence of the stronger winds the $SO_2$ peaks are not as high as those recorded for the other cases. Prior to the two $SO_2$ peaks and after them all other $SO_2$ values were negligible. Like the other case studies drainage flow is a dominant nighttime feature from Mt Taranaki, persisting through to the morning hours, see Figure 6-15.

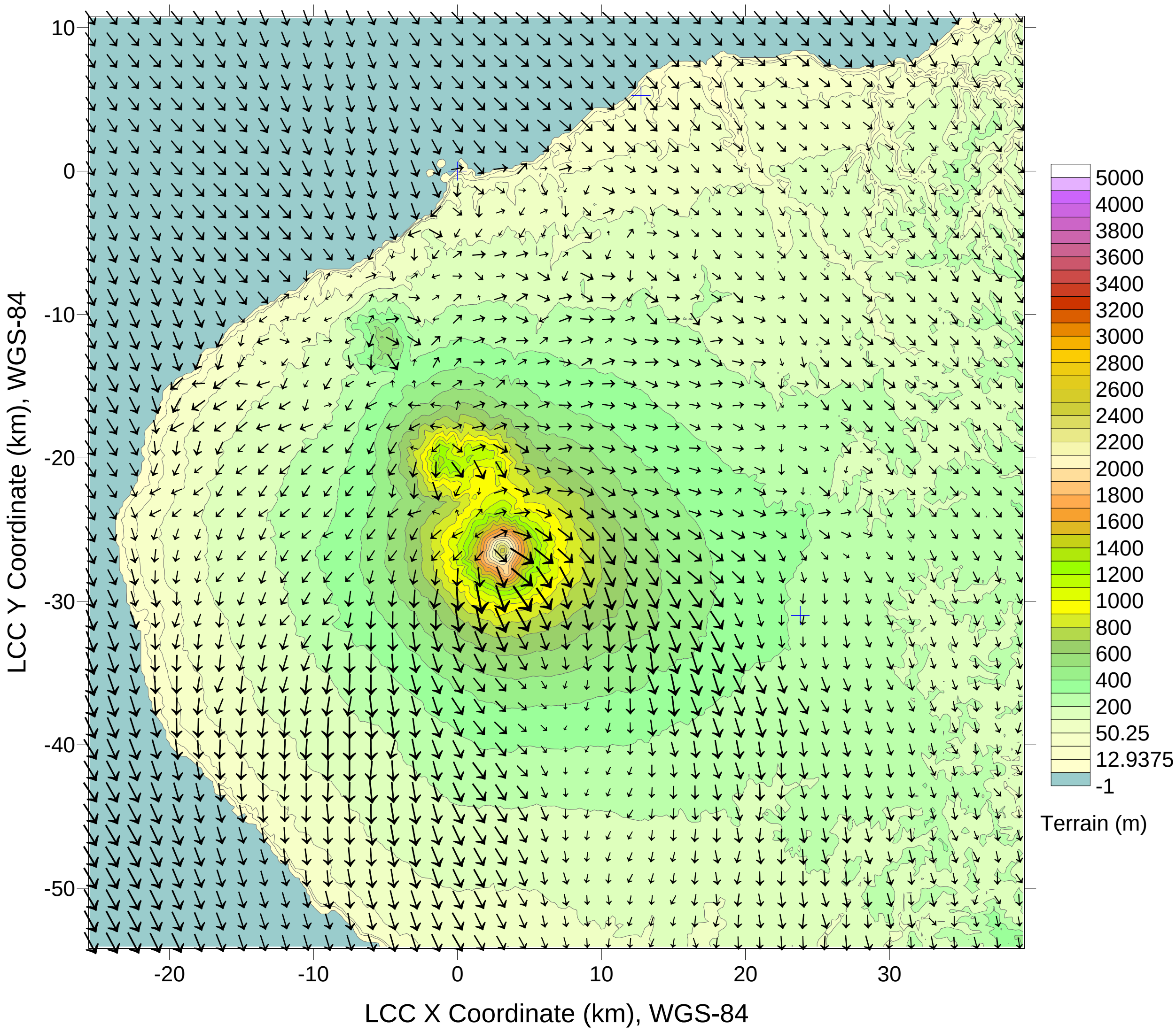



Figure 6-15. Under moderate synoptic flow nocturnal drainage remains a dominant feature of the New Plymouth region throughout the night and early morning. This plot is representative of hour 00h on the 17 February 2005. Note how Mt Paritutu, the sugar loafs and the cliffs along the shore immediately affect the onshore flow.

Figure 6-16 shows the MM5/CALMET spatial wind field across the model domain. The resulting wind field contains no observational data and is purely model results. For interest the actual observations recorded at the same time and at the same vector length scale are overlain in red for the airport, Stratford and Hawera.

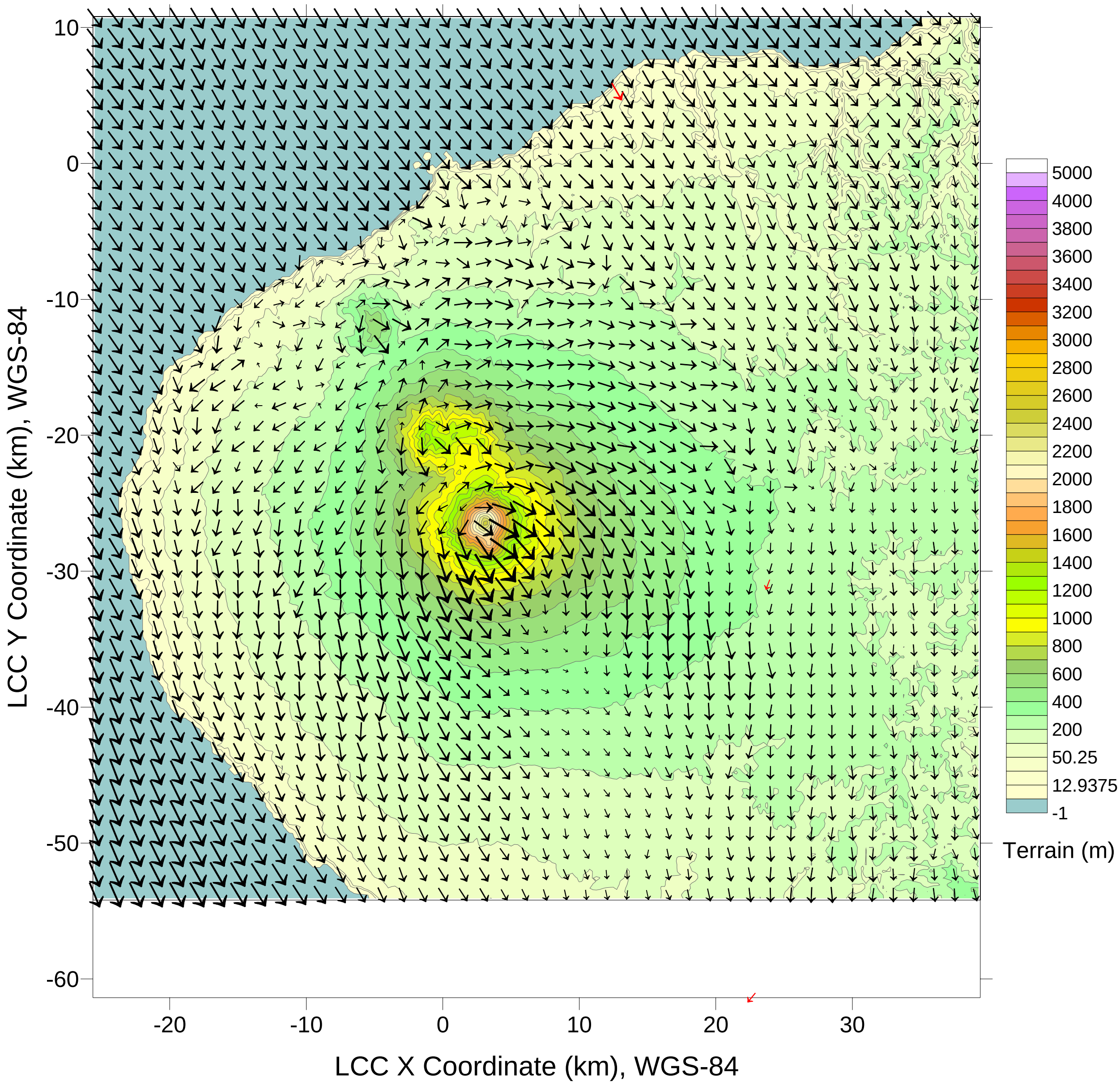



Figure 6-16. This figure shows how the modelled wind field compares to the actual observations measured at Hawera, Stratford and the Airport. The wind field is applicable to hour 11h on the 17 February, 2005, i.e. at the time of one of the $SO_2$ peaks. No surface or upper air observations were used in the modelling.

Note. These comparisons compare the CALMET/MM5 modelled results vs. the actual observations at 10m. In this case the model does very well against the observations throughout the entire day. This case is unlike the others as the peak $SO_2$ periods occur under increasing wind speed as opposed to a decreasing speed. Figure 6-16 is particularly interesting in that it shows the significant downwind effect of Mt Paritutu and the sugar loafs on the surface (10m) flow. Directly downwind of the power station light variable wind persists in the lee of Mt Paritutu which is not seen anywhere else along the coast.

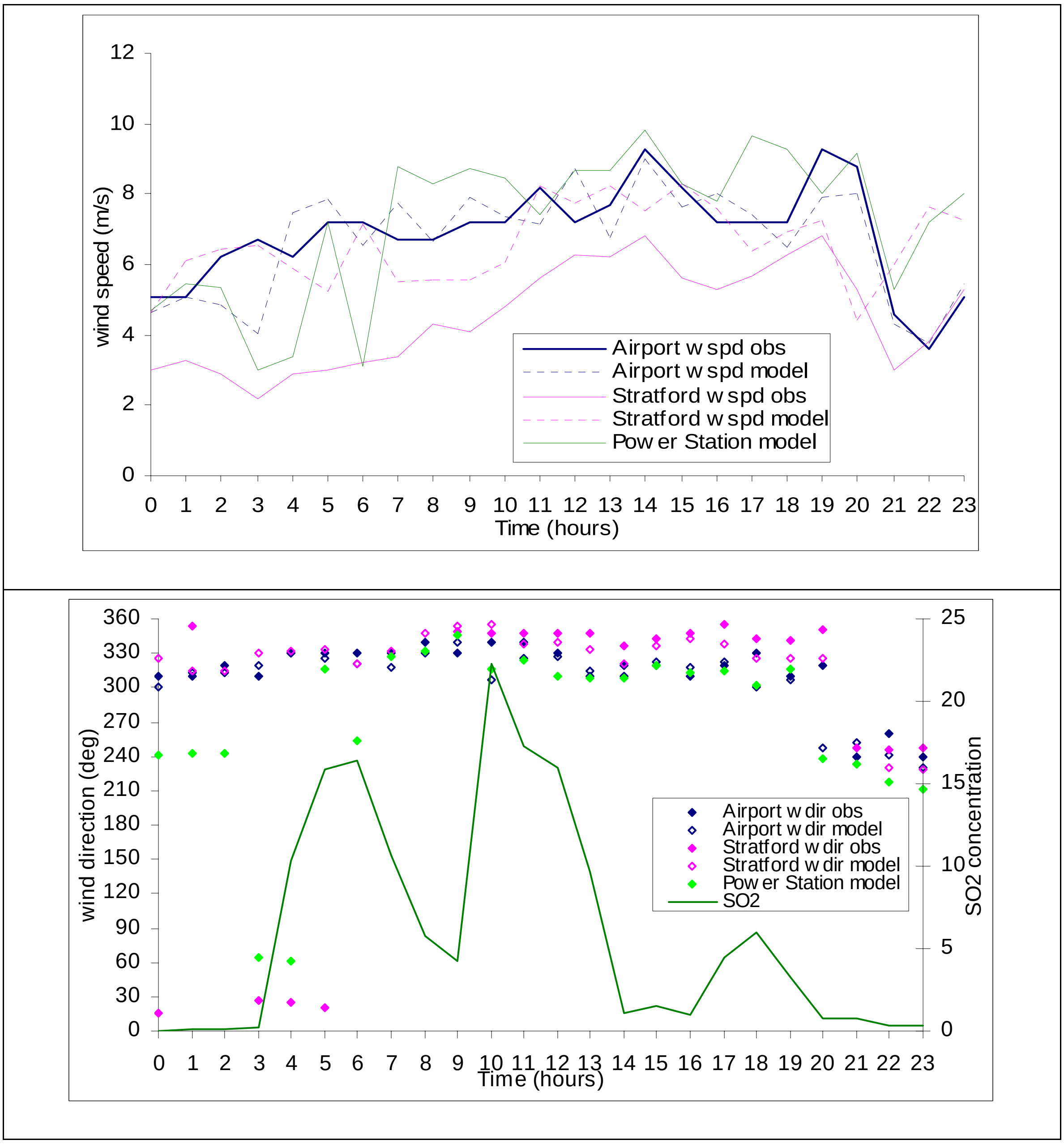



Figure 6-17. Time series through 17 February 2005. Top graph shows the wind speed from the Airport and Stratford meteorological stations vs. that produced by CALMET/MM5. The lower diagram shows wind direction at the observational sites vs. wind direction produced by the model. $SO_2$ concentrations as measured at the monitoring site are also shown.

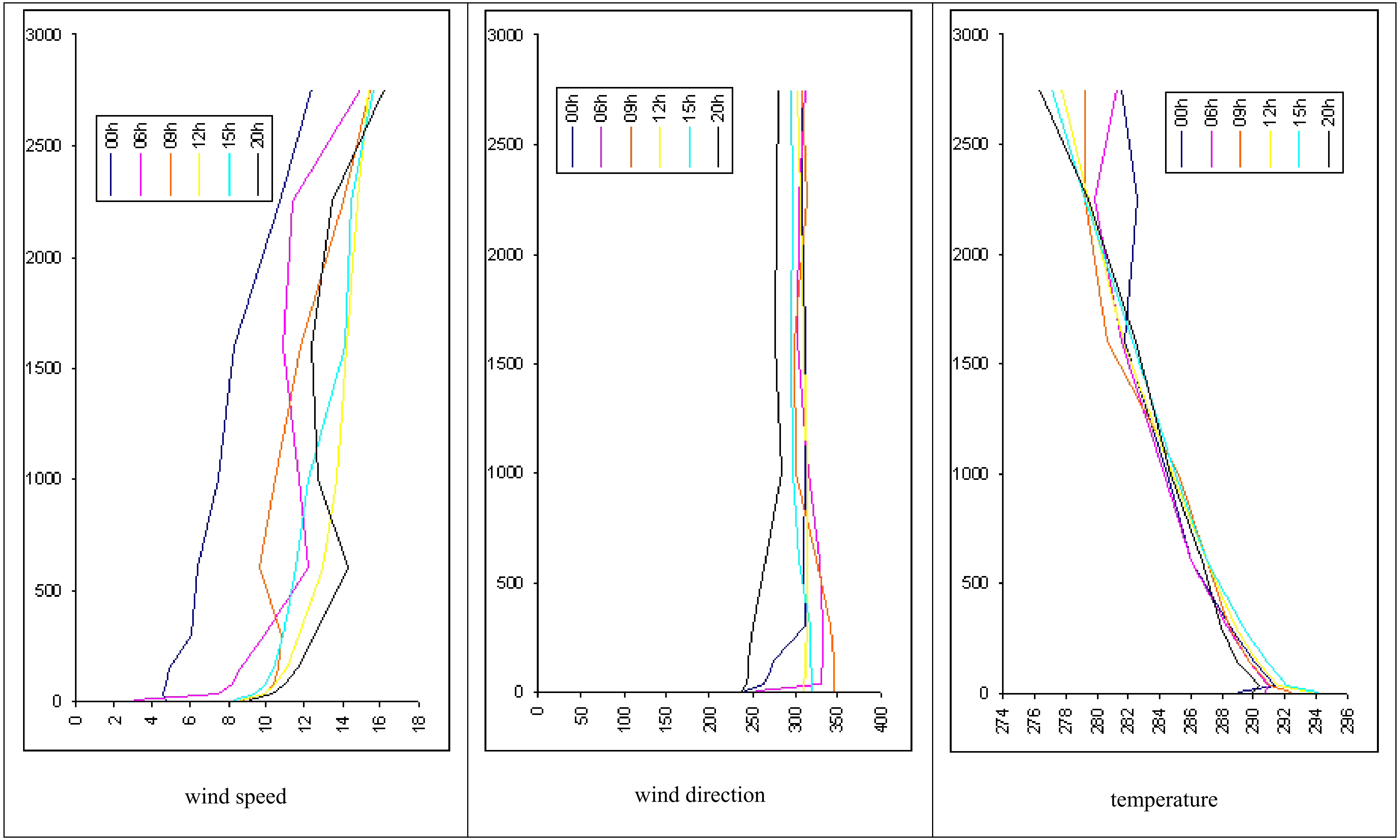



Figure 6-18. Modelled vertical profiles through 17 February 2005 at various times of the day. Nothing unusual is seen to occur. This case shows the wind speed increasing through the day at the surface where it starts out as a westerly wind becoming more northerly orientated during the course of the day. The temperature curves show a normal adiabatic lapse rate with early morning inversions close above the surface.

#### *6.3.4 Case 4 - 6 March 2005*

$SO_2$ peaks occurred at 10h and 17h on 6 March, 2005. Similar to the other episodes discussed here, the dominant synoptic flow was from a northwesterly direction. During the early morning hours the flow was light < 1.5 m/s but strengthened throughout the course of the day to > 8 m/s. Nocturnal drainage flow occurs throughout the night and early morning hours. This case is similar to that of the 17 February where $SO_2$ peaks occurred under an increasing wind speed as opposed to the other cases were the wind speed decreased. The figure below Figure 6-19 shows offshore drainage from the mountain and an onshore northwest flow. Around the city of New Plymouth and stretching northeast toward the airport the flow is light and variable.

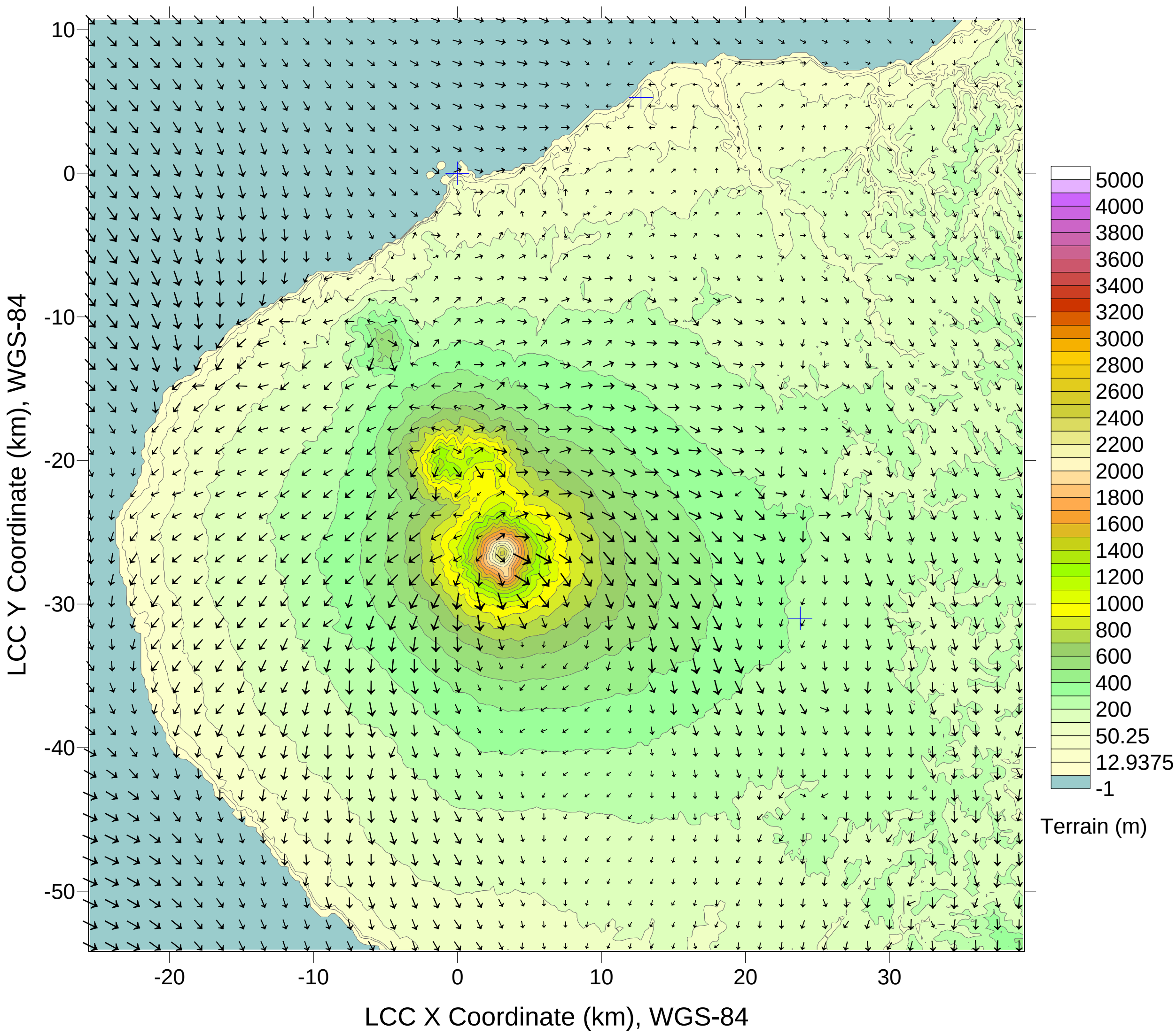



Figure 6-19. CALMET/MM5 spatial wind field applicable to 00h on 6 March 2005. Surface observations were used in this modelling.

The results shown in Figure 6-20 (below) are the results of the CALMET/MM5 model run which does not include any observations.. The actual observations recorded at the Airport, Hawera and Stratford are marked in red and overlay the plot. It is obvious from Figure 6-20 that the wind speed at the time of the second $SO_2$ peak, at 16h is much stronger than that recorded in Figure 6-19. The wind speed and direction as recorded at the three observations sites are in very good agreement at 16h with the model's predictions.

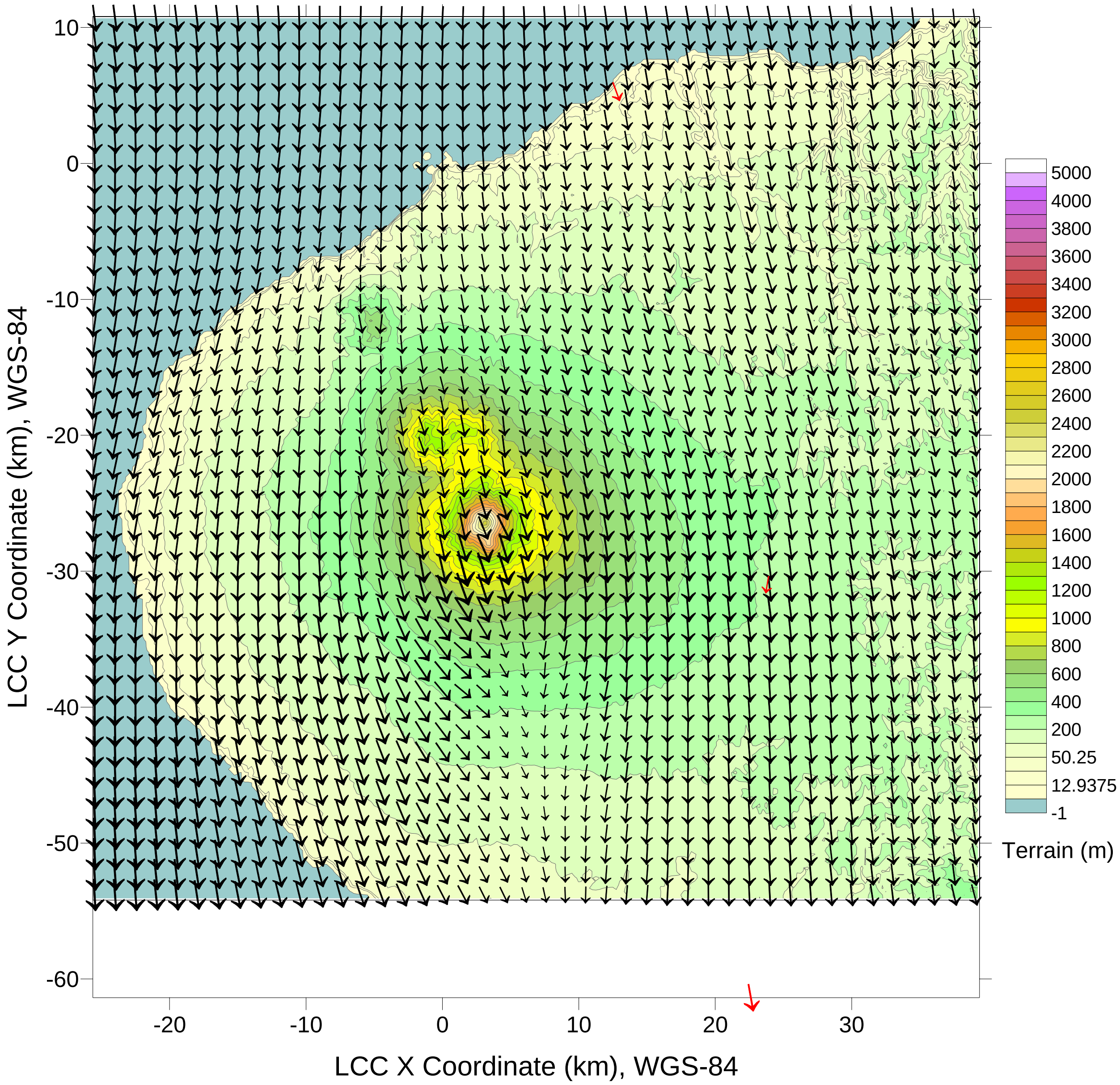



Figure 6-20. This figure shows how the modelled wind field compares to the actual observations measured at Hawera, Stratford and the Airport. The wind field is applicable to hour 16h on the 6 March, 2005, i.e. at the time of the second $SO_2$ peak. No surface or upper air observations were used in the modelling.

Figure 6-21 below shows the model results vs. the actual observations at Stratford and the airport over the course of the day on 6 March 2005. Similarly to the previous case, the model's predictions at the two sites vs. the observations are in very good agreement. With respect to wind direction there is least agreement between the models and observations at the airport during the early morning hours when the wind speed is light. However, by 08h the model and observations are in full agreement. The $SO_2$ time series is inconsistent with the meteorological time series which shows a consistent onshore flow with little variation in direction. The two $SO_2$ peaks occur 3 hours apart which are an indication that the plume travels intermittently across the monitoring site. An arc of monitoring stations would give a much clearer picture of the temporal and spatial extent of the $SO_2$ plumes.

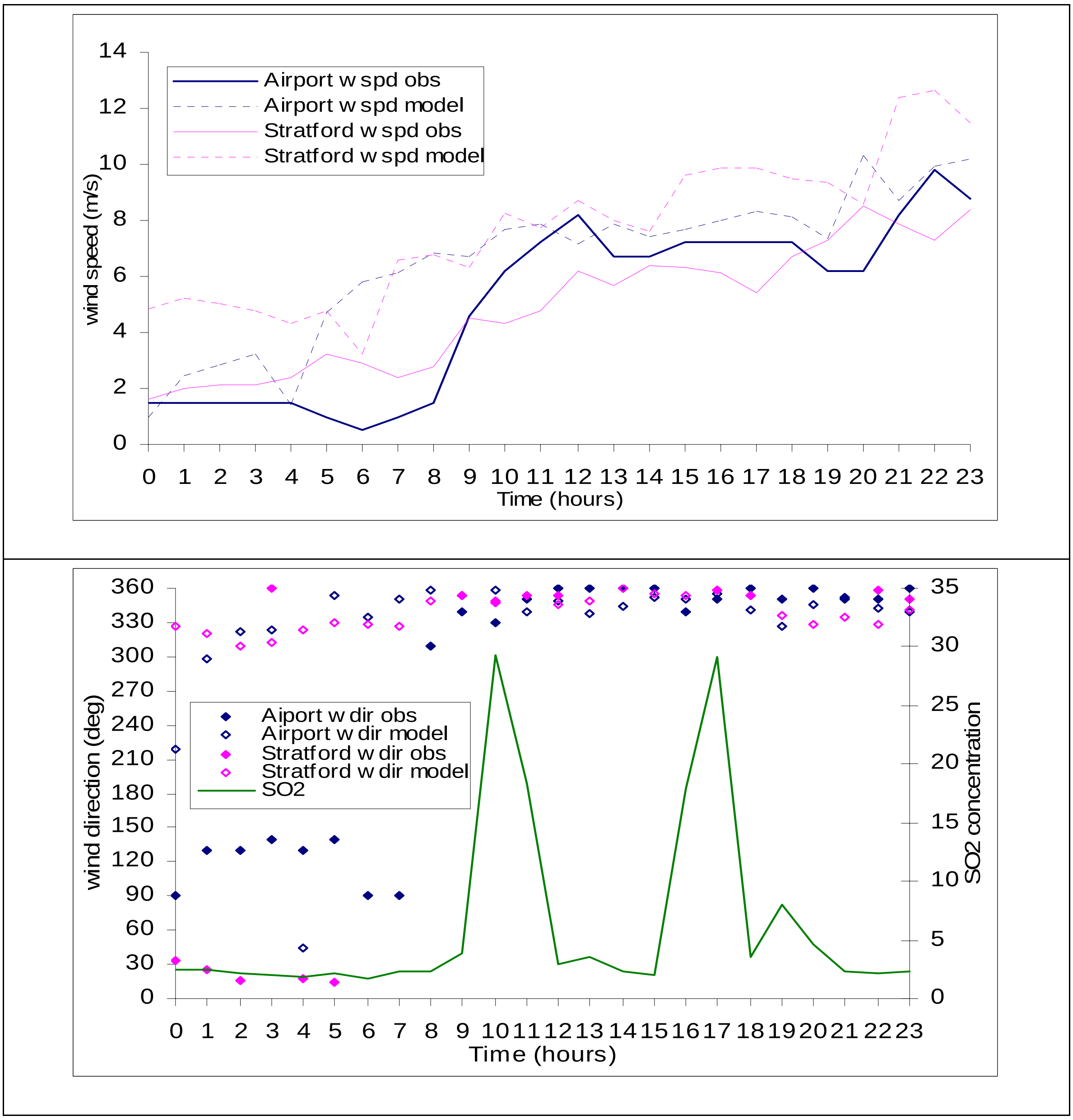



Figure 6-21. Time series through 6 March 2005. Top graph shows the wind speed from the Airport and Stratford meteorological stations vs. that produced by CALMET/MM5. The lower diagram shows wind direction at the observational sites vs. wind direction produced by the model. $SO_2$ concentrations as measured at the monitoring site are also shown.

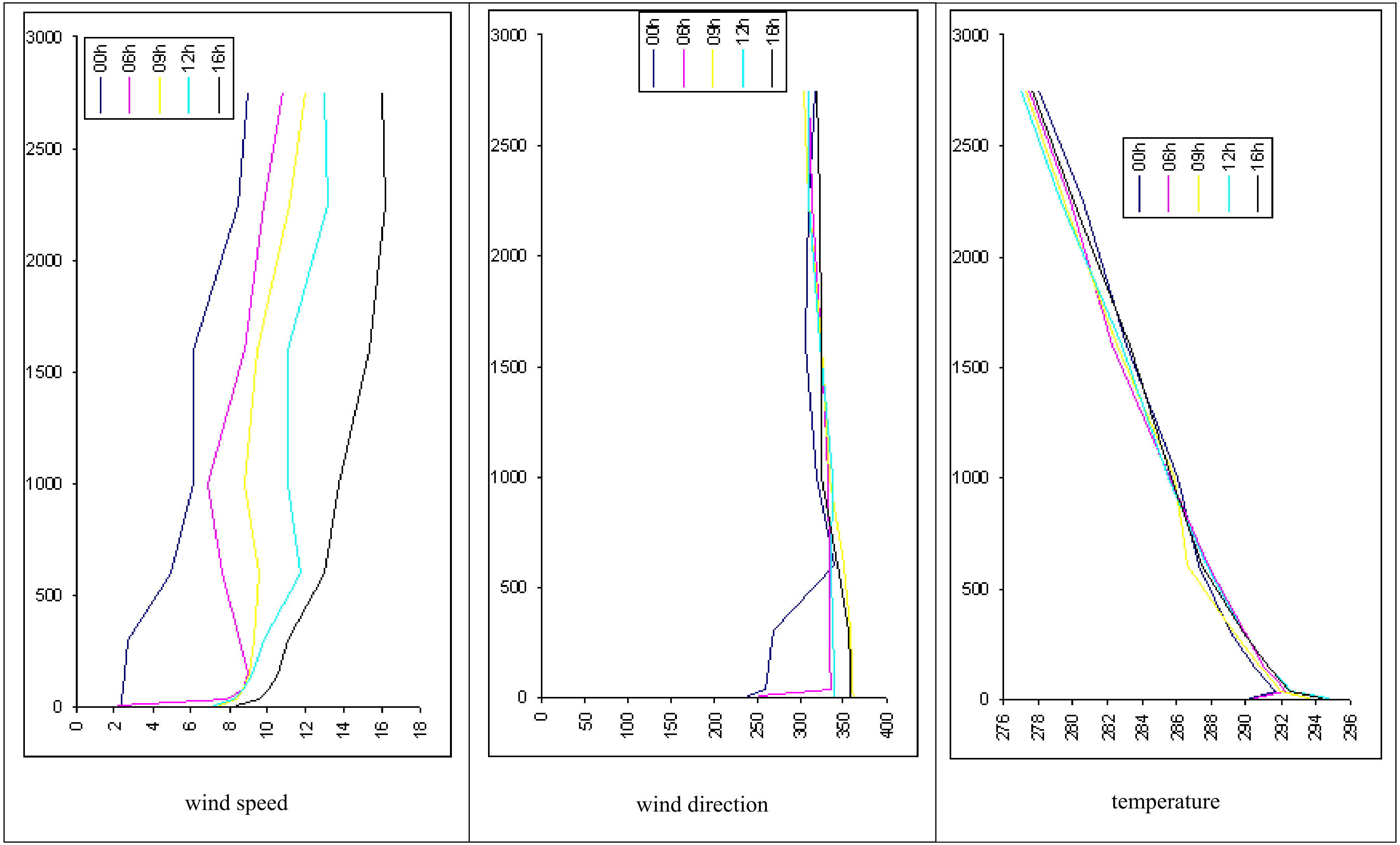



Figure 6-22. Modelled vertical profiles through 6 March 2005 at various times of the day. The diagram show from the left, vertical profiles of wind speed, temperature and wind direction at the power station. The wind shows a distinct increase in speed from around 2 m/s at 00h increasing to around 6 – 8 m/s by the middle of the day. The wind direction profile shows the wind shifting from a northwest direction to a northerly direction throughout the day. The temperature profile shows a slight small inversion during the morning hours.

### 6.3.5 *Case 5 - 25 March 2005*

Two $SO_2$ peaks occurred at 12h and 17h on 25 March, 2005 which is a reflection of either an intermittent plume, or, a meandering plume which drifts over the monitoring station every couple of hours under specific meteorological conditions. Unlike some of the other cases where the wind speed is either decreasing in strength or, increasing in strength (like the latter two cases), this case shows moderate to strong wind flow throughout the day of the 25th March. The flow starts out from the northeast and gradually swings through north to a north northwesterly direction. As a result of the stronger wind field the flow is much more homogeneous with little variability occurring between the power station and the airport – a distance of some 12 km. The overriding synoptic flow appears to swamp out the diurnal off shore flow on the northern side of the mountain causing the flow to split and speed up around its flanks.

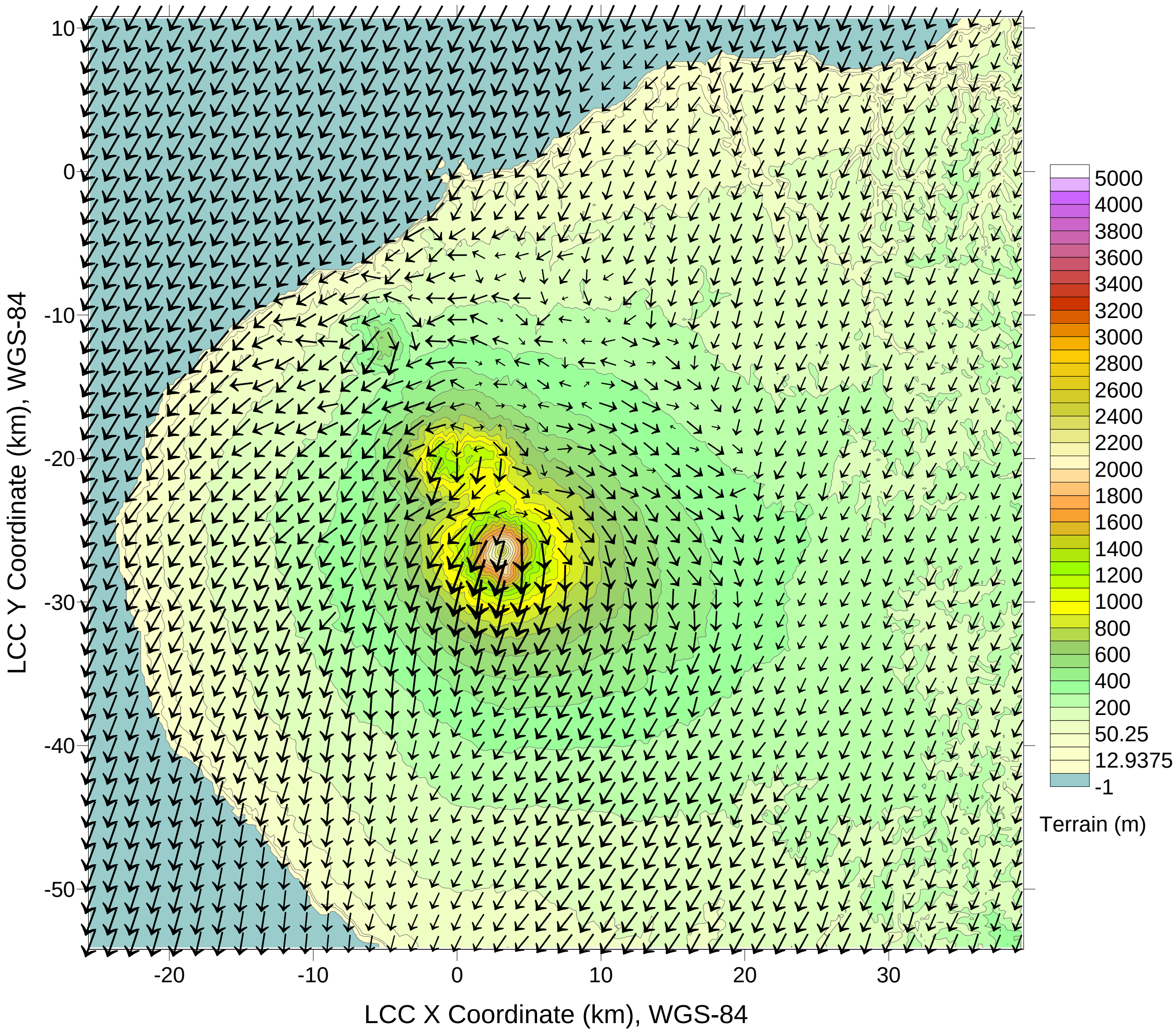



Figure 6-23. CALMET/MM5 spatial wind field for the 25 March 2005 at 00h.

Similarly to the last case, which also showed stronger wind conditions the models are in very good agreement with the observations for this case (See Figure 6-24) Figure 6-26 shows the time series plots which shows the model vs. the observations at the airport and at Stratford. And Figure 6-25, (below) shows the CALMET/MM5 wind field applicable to one of the $SO_2$ peaks, i.e. 12h on the 25 March 2005. The results shown in Figure 6-25 are the results of the

CALMET/MM5 model run which does not include observations at all. The actual observations recorded at the Airport, Hawera and Stratford are marked in red.

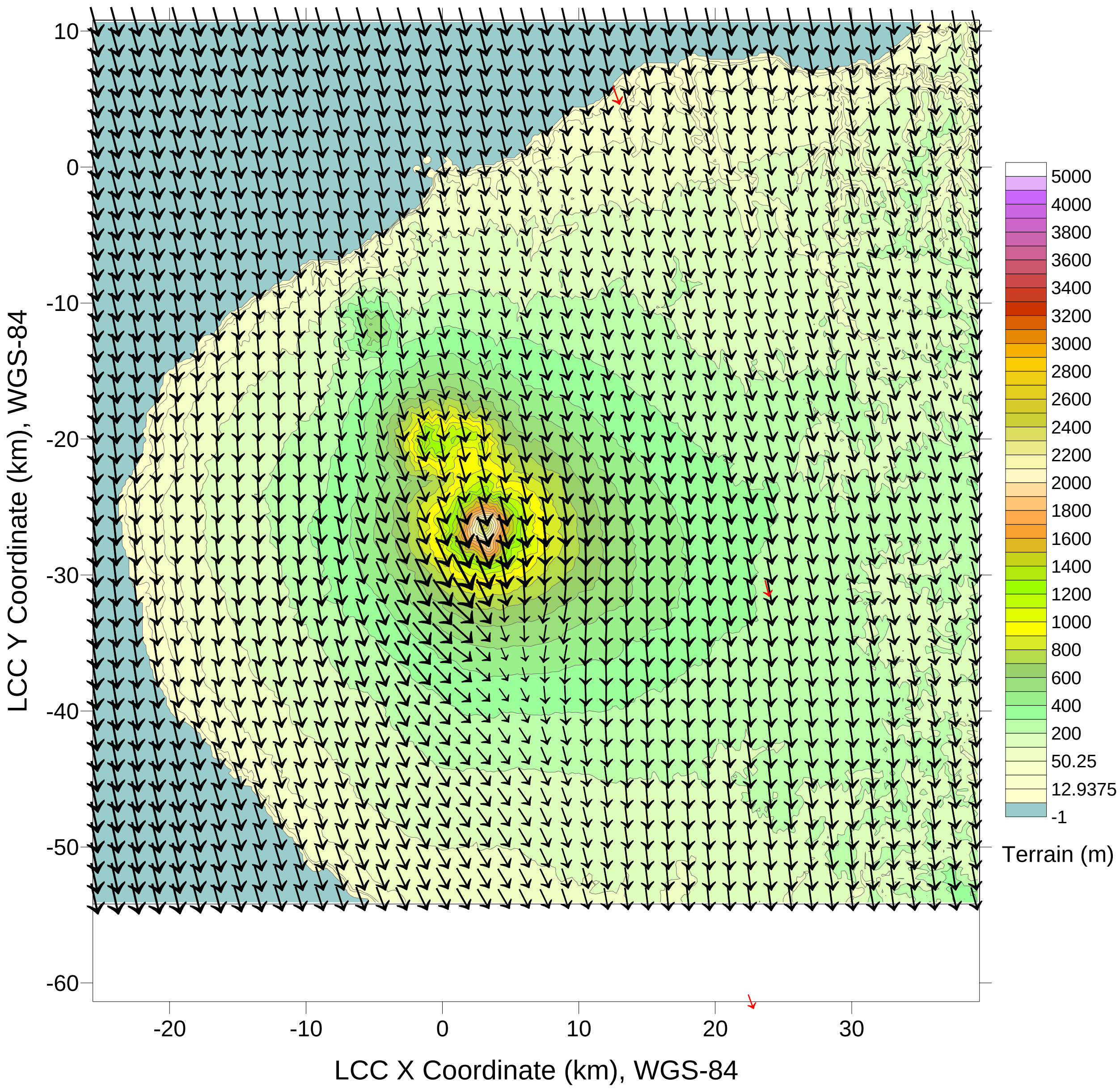



Figure 6-24. This figure shows how the modelled wind field compares to the actual observations measured at Hawera, Stratford and the Airport. The wind field is applicable to hour 12h on the 25 March, 2005, i.e., the time when one of the $SO_2$ peaks occurred. No surface or upper air observations were used in the modelling.

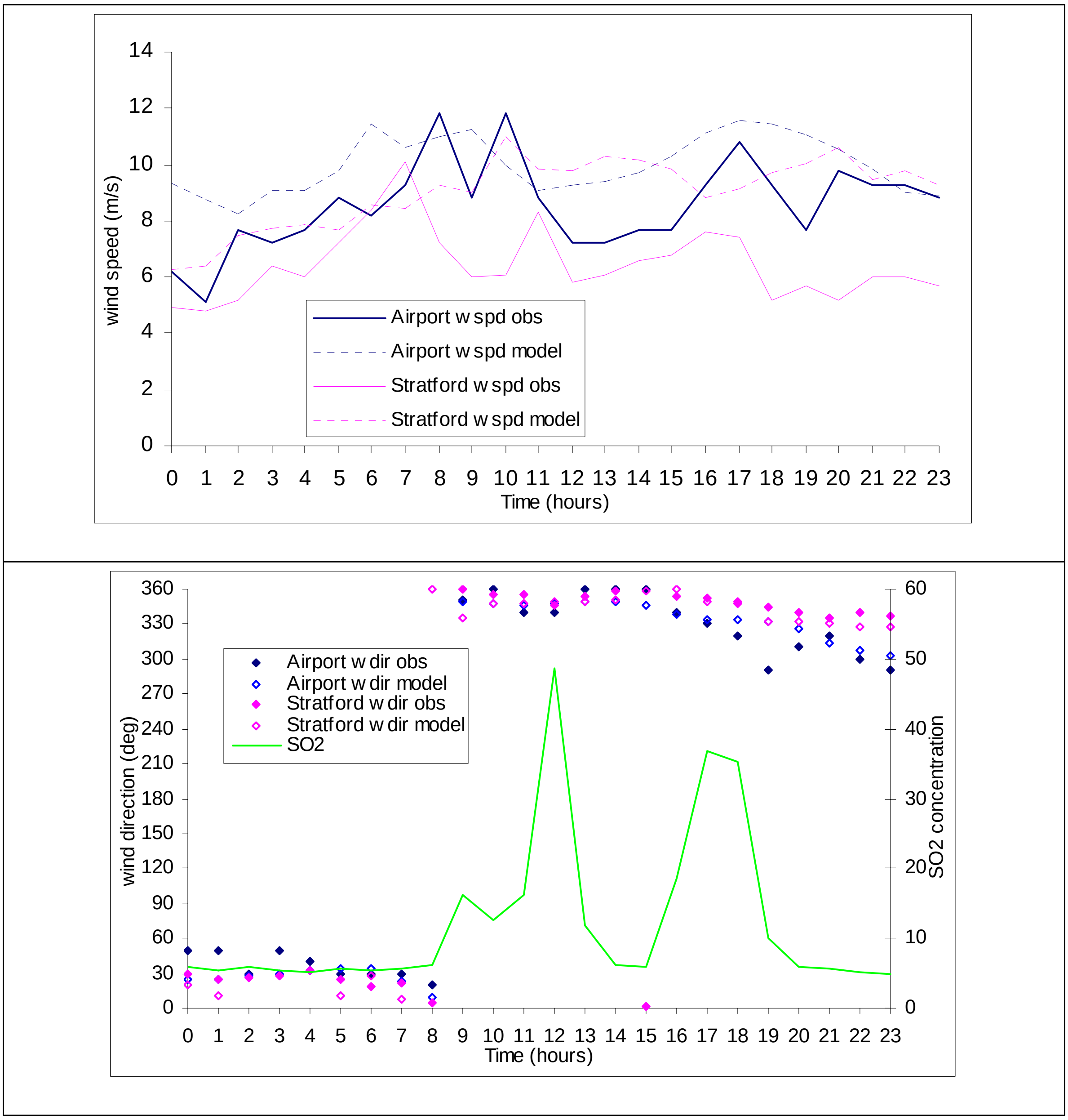



Figure 6-25. Time series through 25 March 2005. Top graph shows the wind speed from the Airport and Stratford meteorological stations vs. that produced by CALMET/MM5. The lower diagram shows wind direction at the observational sites vs. wind direction produced by the model. $SO_2$ concentrations as measured at the monitoring site are also shown.

Note. The model and observations are in very good agreement for this entire time series.

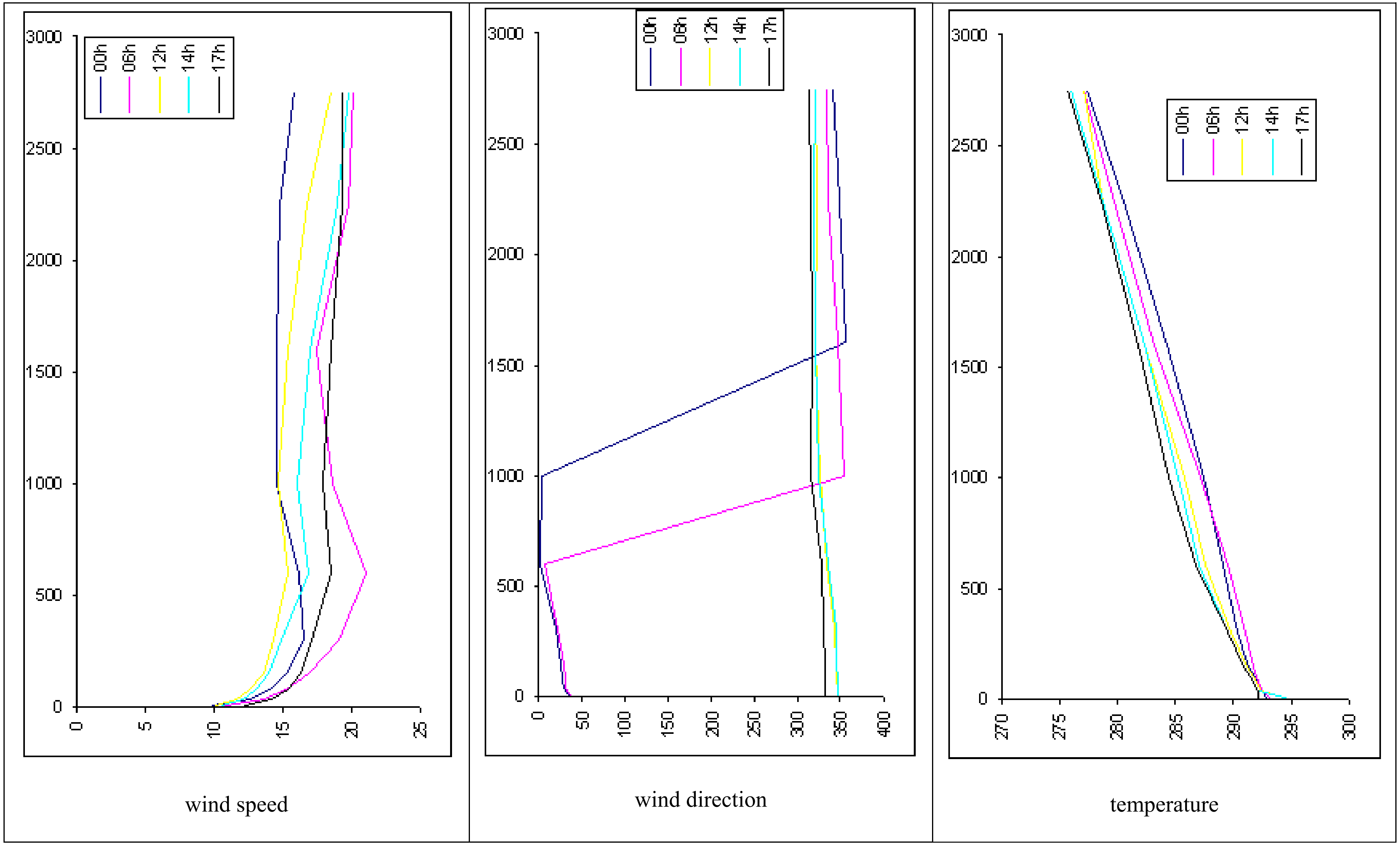



Figure 6-26. Vertical profiles of 25 March 2005 at various times of the day. From the left, vertical profiles of wind speed, temperature and wind direction at the power station. The wind speed profiles show the strength of the wind at the power station at different times of the day. At no stage does the wind speed decrease, remaining at >10m/s the entire day. The wind direction starts as north northeasterly flow then swings over to a northwesterly direction. The temperature profile is as expected with the stronger winds and no surface inversions are visible.

#### *6.3.6 Case 6 - 30 April to 1 May 2005*

$SO_2$ peaks occurred at 22h on 30 April 2005 and on 1 May at 09h, and 12h. The wind flow is predominantly from the northwest at 301° and remains at this direction throughout the entire episode. Figure 6-27 shows the spatial wind field at 00h over the CALMET domain. Note how because of the terrain around the power station the northwesterly flow at 10m is deflected to be west, whilst the airport has predominantly northwest flow.

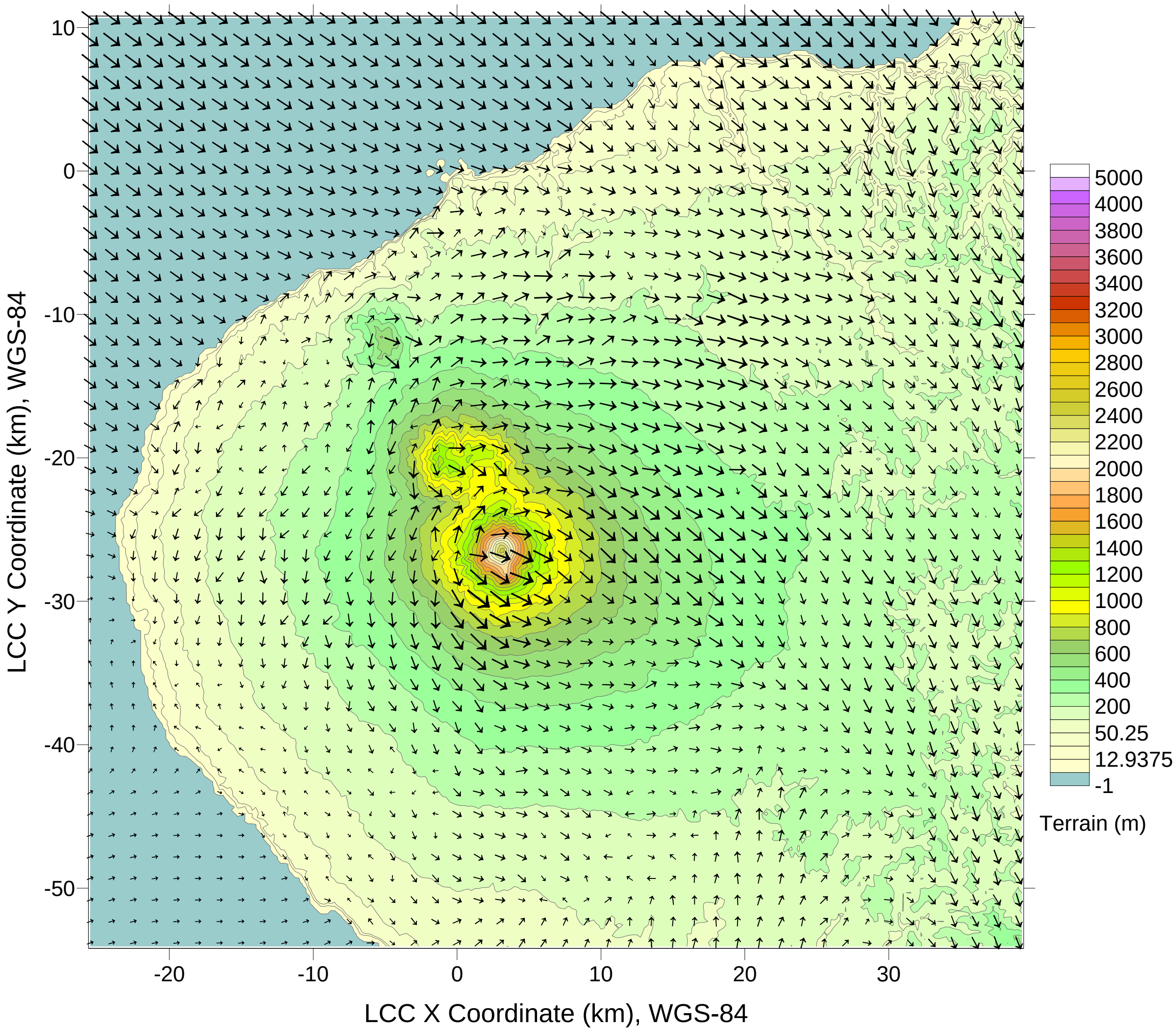



Figure 6-27. CALMET/MM5 spatial wind field applicable to 00h on 1 May 2005.

Figure 6-28 shows the results of the CALMET/MM5 model run which does not include observations at all. The actual observations recorded at the Airport, Hawera and Stratford are marked in red.

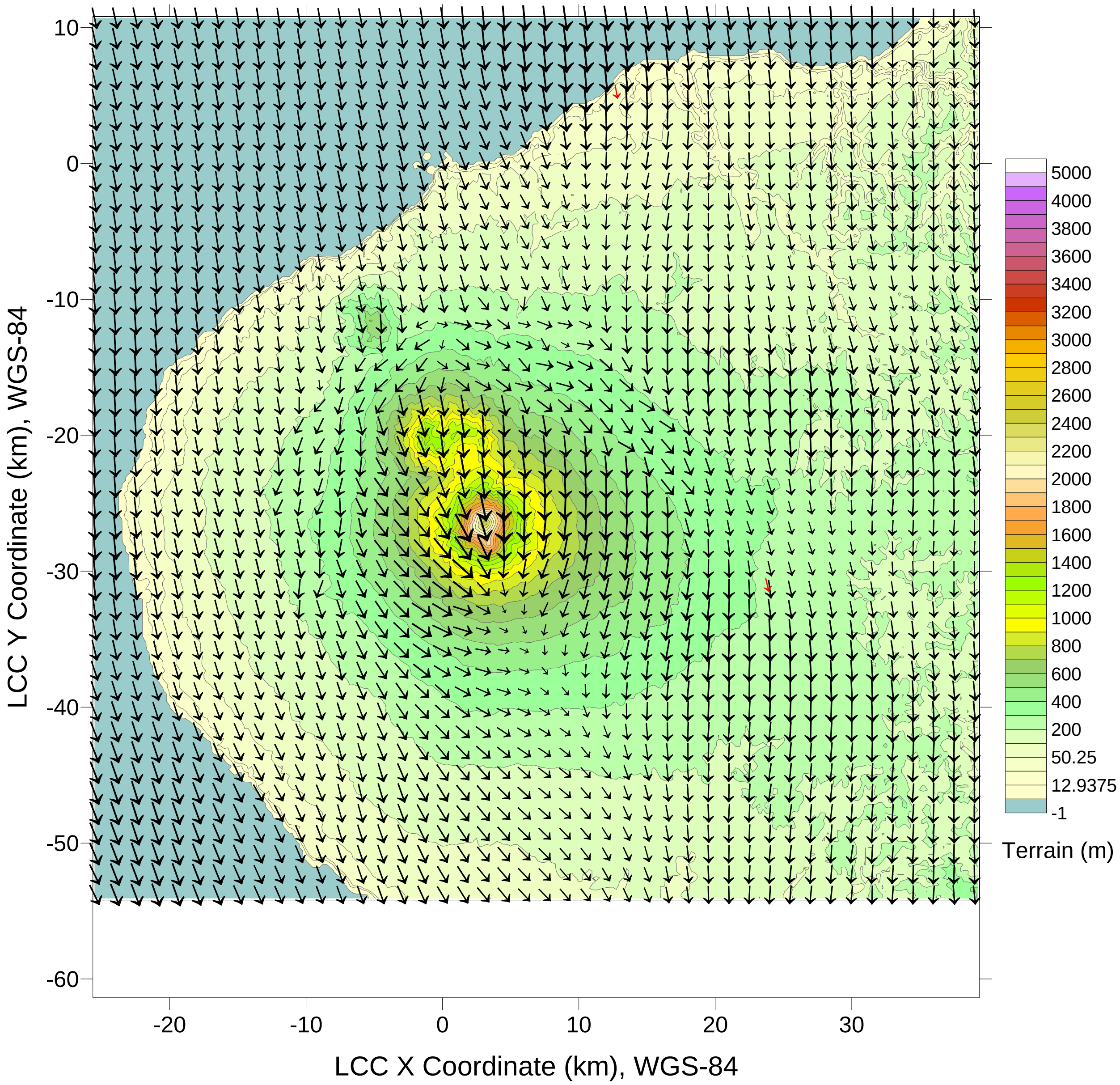



Figure 6-28. This figure shows how the modelled wind field compares to the actual observations measured at Hawera, Stratford and the Airport. The wind field is applicable to hour 12h on the 1 May, 2005. No surface or upper air observations were used in the modelling.

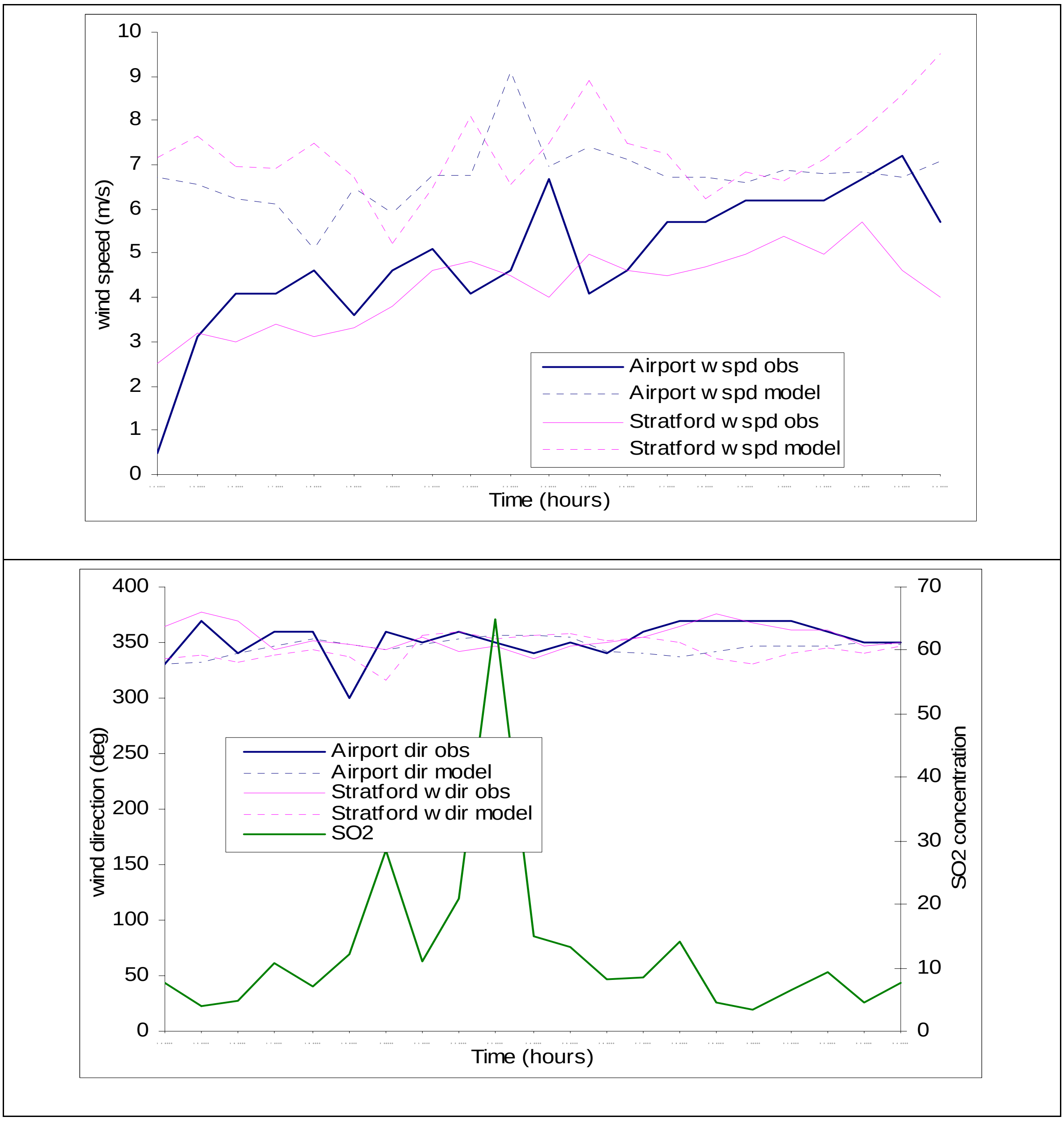



Figure 6-29. Time series through 30 April hr 14 through to 23h on 1 May 2005. Top graph shows the wind speed from the Airport and Stratford meteorological stations vs. that produced by CALMET/MM5. The lower diagram shows wind direction at the observational sites vs. wind direction produced by the model. $SO_2$ concentrations as measured at the monitoring site are also shown.

Note. It is interesting to see that the model predicts higher wind speeds than the observations for this episode, one of the only ones where there is a distinct discrepancy in the wind speeds. The direction predicted by the model vs. observations are very good.

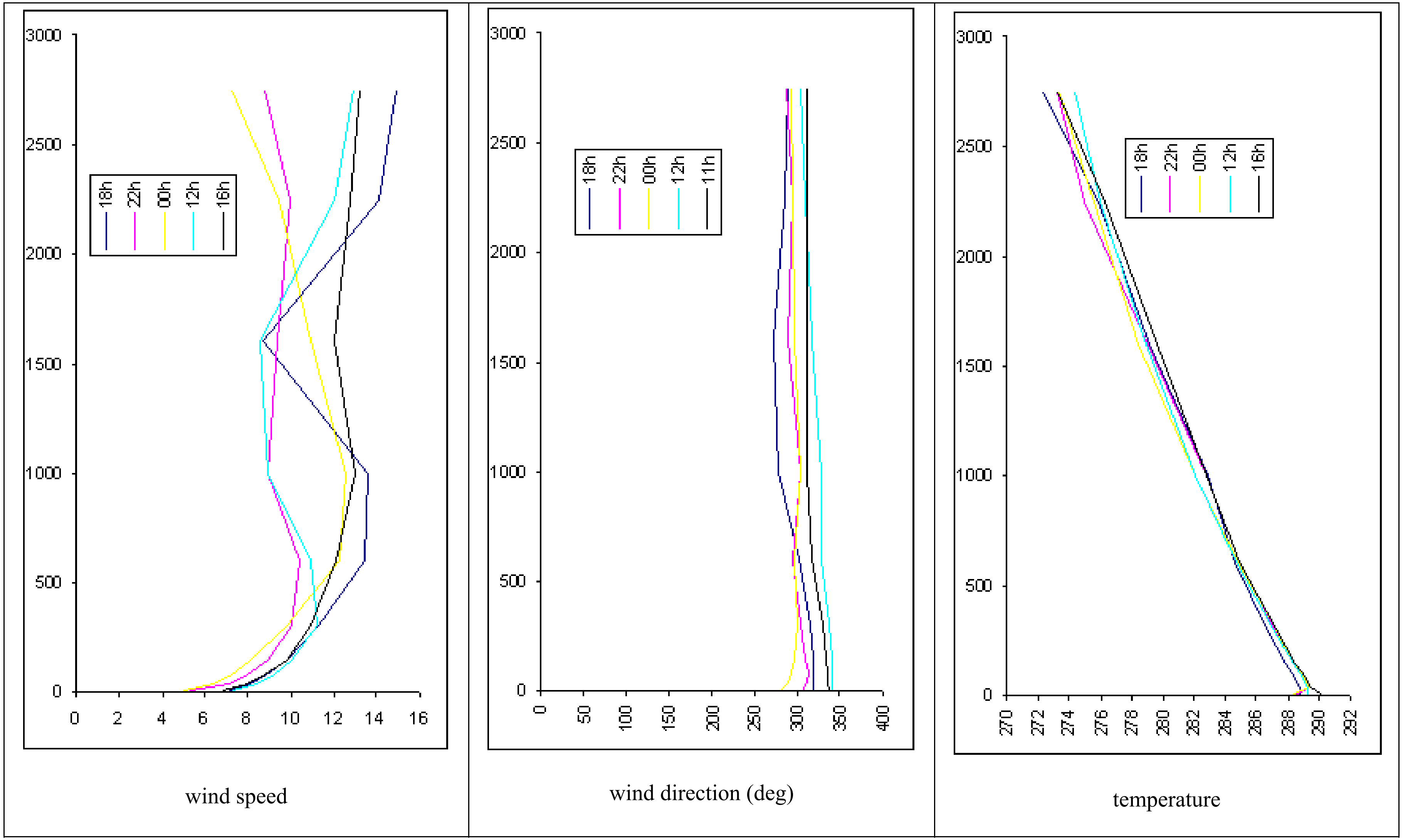



Figure 6-30. Vertical profiles through 30 April hour 18h through to 1 May 16h. The diagram show from the left, vertical profiles of wind speed, temperature and wind direction at the power station. The wind profiles show a distinct increase through the lower boundary layer to a height of around 500m before leveling off. The wind direction is consistent throughout the boundary layer from a northwesterly direction. The strongly declining temperature profile is also expected under the windy conditions.

# 7. DISCUSSION AND CONCLUSIONS

Chapter 6 shows the results of the meteorological evaluation of various $SO_2$ peak episodes which occurred at monitoring sites in New Plymouth, between January 2005 and June 2005. Initially the aim of this study was to compare the predicted modelled $SO_2$ from the power station emissions with those recorded at the monitoring sites, however, after a period of time an analysis showed that the $SO_2$ monitoring site did not reflect the power station emissions and that peaks could be from any number of sources in the region. Since there was no suitably detailed emissions inventory for the New Plymouth region, the dispersion modelling component of this study could not be conducted and hence this study has evolved into an evaluation of the meteorological models, MM5 and CALMET vs. observations.

A second problem with the monitoring data is that the recorded $SO_2$ peaks during the study period of January to June 2005, show intermittent peaks as the plume passes backwards and forwards across the monitoring site. This means that the true $SO_2$ peaks are most likely not being measured at the monitoring sites, nor is the $SO_2$ time series likely to be a true representation of the dispersing plume's footprint. A true evaluation of plume dispersion would require an arc of monitoring sites which would give a more realistic picture of the dispersing plume, its true peak concentrations and the direction from whence it originated.

The results described below provide the details of what the meteorological conditions were at the time of the $SO_2$ peaks and the reasons why the peaks probably occurred. More importantly though this study provides an evaluation of the CALMET modelling system with observations where it is seen to perform particularly well. This study highlights the need for careful meteorological modelling in complex environments, typical of most of New Zealand. Further this study serves as a base for further model intercomparisons of the other commonly used model in New Zealand, TAPM, a prognostic model developed by CSIRO. An examination of MM5 vs. TAPM vs. observations would be useful as would a comparison of MM5/CALMET and TAPM/CALMET vs. observations.

The 6 meteorological events that have been individually evaluated in this analysis are;

*23 January, 6 February, 17 February, 6 March, 25 March, 30 April/1 May.*

Because of the length of time required to run the prognostic meteorological model, MM5, a continuous record of prognostic data could not be possible in the time given for this evaluation study. Instead MM5 was run for the day when the peak $SO_2$ occurred and for one-day prior to the episode. The MM5 in this modelling includes 3 nested grids. Domains 1, 2, and 3 were all two-way nested with grid spacings of 27km, 9km and 3km for the innermost nest, respectively. A fourth nest at 1km resolution was conducted on just two runs in order that comparisons could be made between the 3km and 1km grids.

The key findings of this study are:-

- One of the key features identified in this study is the very strong influence of Mt Taranaki on the wind fields at the airport, Stratford and Hawera throughout the day. The Stratford wind rose shows a strong bias to north-south orientated flows, which reflects its location to the east of the massif. Hawera is dominated by flows from the north, i.e. flow off the massif and westerly on-shore flows, and, the airport is strongly biased to southeast flow directly from Mt Taranaki. Further this study highlights the fact that the meteorological conditions in the vicinity of the power station are quite different to that at New Plymouth Airport. In previous studies it has always been assumed that the airport is representative of New Plymouth.

- Sea breezes are a key component of the flow during any summer day, but, unlike a typical sea breeze which has a surface on-shore component and an off-shore component, aloft, none of the sea breeze days studied failed to show the return flow aloft. The exact reasons for this are not clear, but the summer day up-slope mountain flows appear to prevent the formation of the return sea breeze aloft.

- Another clear feature is the very strong diurnal cycle at each of the sites which are directly influenced by the mountain and the shape of the coastline. Onshore sea breeze type flow predominates at all stations between 12h and 17h each day. Onshore flow is west at New Plymouth and Hawera and north and south at Stratford. Offshore drainage off the mountain predominates during the night from 18h to 05h each morning and is still a strong factor in the flow during the morning 06h – 11h prior to onset of the sea breeze.

- Two of the cases studied produced $SO_2$ peaks during periods of decreasing wind speeds, 23 January and 6 February. Both these cases showed distinct similarities. Early in the day the flow was either northerly or north northeasterly which during the course of the day swung through north to end up as a northwesterly. In both cases the peaks coincided with a decrease in wind speed and a change in wind direction. In each of these light wind cases the models struggled initially to get the initial flow direction correct where both times the model predicted more easterly flow than what was actually recorded. But during the course of the day as the flow swung around to north then northwest and the speed dropped the models and observations were in full agreement. Under extremely light wind conditions the models and observations deviate which is to be expected as the wind direction swings about with a high degree of variability.

- The remainder of the cases (17 February, 6 March, 25 March and 30 April) all produced $SO_2$ peaks during periods of either increasing wind speeds or under moderate to strong flow. Similarly to the light wind cases above these cases showed strong similarities. Like the light wind cases the flow began initially as either a northeast or northerly flow which during the course of the morning swung through north to end up as either a northerly flow or a northwest flow. The models and observations were more in agreement with one another in the stronger wind cases.

Independently of the $SO_2$ monitoring data this study has also shown that;

- The influence of Mt Taranaki on the region's air quality dispersion is profound. Any model not able to show the full diurnal and 3 dimensional affects of the mountain is not going to represent the air dispersion correctly. As the results show, the combination of MM5's non-hydrostatic ability and its fine scale resolution (3km) with 32 vertical levels coupled with CALMET's even finer grid resolution (250m), slope flow algorithms and, the ability to directly add observational sites makes this combination an attractive modelling tool for all complex regions in New Zealand.

- The MM5 3km domain did as well as the MM5 1km domain when used as the initial guess wind field into CALMET which was run at a fine resolution of 250m. These results imply either, that the 3km MM5 data adequately captured the same fine scale 3D effects of the 1km MM5 data, or, that CALMET with its finely resolved terrain and land use data is able to correct the less well defined 3km MM5 data. Depending on what data is given it CALMET can sometimes correct a poorly resolved prognostic wind field by virtue of the fine resolution terrain and land use data, plus its employment of mesoscale slope flow affects. However, this is not always the case and depends on the quality of the prognostic model data.

The results of this study show that the hybrid approach of coupling the non-hydrostatic MM5 model with a fine scale diagnostic model like CALMET is able to produce realistic modelling results and is a necessary precursor for realistic dispersion modelling in the region.

Finally, in relation to the analysis of $SO_2$ monitoring data:-

- During the periods when the power station was operating on oil, and thus emitting $SO_2$, there were no clear events where this was detected in either of the two $SO_2$ monitoring sites.

- Indeed all of the 'spikes' in the $SO_2$ monitoring over the six-month period examined occurs when (a) the power station was not operating on oil, or (b) the winds were from another quarter. This leads to the conclusion that practically all of the $SO_2$ measured in New Plymouth over the periods of oil burning were from other sources. Emissions from ships in the port have been identified as a likely source (although there may be others as well).

Further research may be undertaken on (a) additional time periods when the station operates on oil (some testing during September 2005 may be suitable), (b) explicitly modelling other sources (although this may not be possible as data on ship emissions is not detailed), (c) modelling the dispersion of power station $SO_2$ and determining that it did indeed end up at places other than the monitoring sites.

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# APPENDIX A

**CALMET INPUT FILE**

New Plymouth Power Station on Gas
Case Study - 5 - 6 February 2005
No upper air, surface plus MM5 simulation
--------------- 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=D:\DATA\NEWPLY~1\CASEST~1\6FEB\260GEO.DAT !
SURF.DAT input ! SRFDAT=D:\DATA\NEWPLY~1\CASEST~1\6FEB\SURF.DAT !
CLOUD.DAT input * CLDDAT= *
PRECIP.DAT input * PRCDAT= *
MM4.DAT input ! MM4DAT=D:\DATA\NEWPLY~1\CASEST~1\6FEB\05020506.DAT !
WT.DAT input * WTDAT= *

CALMET.LST output ! METLST=WCALMET.LST !
CALMET.DAT output ! METDAT=WCALMET.DAT !
PACOUT.DAT output * PACDAT= *

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 = 0 !
Number of overwater met stations
(NOWSTA) No default ! NOWSTA = 0 !
!END!
-------------------------------------------------------------------------------
Subgroup (b)
---------------------------------
Upper air files (one per station)
---------------------------------
Default Name Type File Name
------------ ---- ---------
-------------------------------------------------------------------------------
Subgroup (c)
-----------------------------------------
Overwater station files (one per station)
-----------------------------------------
Default Name Type File Name
------------ ---- ---------
-------------------------------------------------------------------------------
Subgroup (d)
----------------
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= *
-------------------------------------------------------------------------------
NOTES: (1) File/path names can be up to 70 characters in length
(2) Subgroups (a) and (d) must have ONE 'END' (surround by
delimiters) at the end of the group
(3) Subgroups (b) and (c) 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= 2005 !
Month (IBMO) -- No default ! IBMO= 2 !
Day (IBDY) -- No default ! IBDY= 6 !
Hour (IBHR) -- No default ! IBHR= 0 !
Base time zone (IBTZ) -- No default ! IBTZ= -12 !
PST = 08, MST = 07
CST = 06, EST = 05
Length of run (hours) (IRLG) -- No default ! IRLG= 24 !
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
!END!
------------------------------------------------------------------------------
INPUT GROUP: 2 -- Map Projection and Grid control parameters
--------------

Projection for all (X,Y):
------------------------
Map projection (PMAP) Default: UTM ! PMAP = LCC !

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 = -999 !

Hemisphere for UTM projection?
(Used only if PMAP=UTM)
(UTMHEM) 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 = 39.0574S !
(RLON0) No Default ! RLON0 = 174.0277E !

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 = 35S !
(XLAT2) No Default ! XLAT2 = 45S !

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 withofficial 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 = 260 !
No. Y grid cells (NY) No default ! NY = 260 !
Grid spacing (DGRIDKM) No default ! DGRIDKM = 0.25 !
Units: km
Reference grid coordinate of
SOUTHWEST corner of grid cell (1,1)

X coordinate (XORIGKM) No default ! XORIGKM = -25.624 !
Y coordinate (YORIGKM) No default ! YORIGKM = -54.197 !
Units: km
Vertical grid definition:
------------------------
No. of vertical layers (NZ) No default ! NZ = 10 !
Cell face heights in arbitrary
vertical grid (ZFACE(NZ+1)) No defaults
Units: m
! ZFACE = 0.,20.,50.,100.,200.,400.,800.,1200.,2000.,2500.,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 = F ! (F = Do not print, T = Print)

(NOTE: parameters below control which met. variables are printed)

Print interval (IPRINF) in hours Default: 1 ! IPRINF = 1 !

(Meteorological fields are printed every 1 hours)

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

! IUVOUT = 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 -- 10 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 = 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 = 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 = 0 ! - PGT stability class
! USTAR = 0 ! - Friction velocity
! MONIN = 0 ! - Monin-Obukhov length
! MIXHT = 0 ! - Mixing height
! WSTAR = 0 ! - Convective velocity scale
! PRECIP = 0 ! - Precipitation rate
! SENSHEAT = 0 ! - Sensible heat flux
! CONVZI = 0 ! - 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 = 2 !

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 = 1 !

0 = Use surface, overwater, and upper air stations

1 = Use surface and overwater stations (no upper air observations)

Use MM4/MM5/M3D for upper air data

2 = No surface, overwater, or upper air observations

Use MM4/MM5/M3D for surface, overwater, and upper air data

NUMBER OF SURFACE & PRECIP. METEOROLOGICAL STATIONS

Number of surface stations (NSSTA) No default ! NSSTA = 3 !

Number of precipitation stations

(NPSTA=-1: flag for use of MM5/M3D precip data)

(NPSTA) No default ! NPSTA = 0 !

CLOUD DATA OPTIONS

Gridded cloud fields:
(ICLOUD) Default: 0 ! ICLOUD = 3 !
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

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 = 0 !
(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 = 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 , 0 !

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 = 4.0 !
Use gridded prognostic wind field model output fields as input to the diagnostic wind field model (IPROG) Default: 0 ! IPROG = 14 !
(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/M3D.DAT file as Step 1 field [IWFCOD = 0]
14 = Yes, use winds from MM5/M3D.DAT file as initial guess field [IWFCOD = 1]
15 = Yes, use winds from MM5/M3D.DAT file as observations [IWFCOD = 1]

Timestep (hours) of the prognostic
model input data (ISTEPPG) Default: 1 ! ISTEPPG = 1 !

RADIUS OF INFLUENCE PARAMETERS

Use varying radius of influence Default: F ! LVARY = F!
(if no stations are found within RMAX1,RMAX2,
or RMAX3, then the closest station will be used)

Maximum radius of influence over land in the surface layer (RMAX1) No default ! RMAX1 = 5. !
Units: km
Maximum radius of influence over landaloft (RMAX2) No default ! RMAX2 = 6. !
Units: km
Maximum radius of influence over water (RMAX3) No default ! RMAX3 = 10. !
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 = 15. !
Units: km

Relative weighting of the first guess field and observations in the SURFACE layer (R1) No default ! R1 = 4. !
(R1 is the distance from an Units: km observational station at which the observation and first guess field are equally weighted)

Relative weighting of the first guess field and observations in the layers ALOFT (R2) No default ! R2 = 5. !
(R2 is applied in the upper layers Units: km in the same manner as R1 is used in the surface layer).

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 !

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 !

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

Empirical factor controlling the influence of kinematic effects
(ALPHA) Default: 0.1 ! ALPHA = 0.1 !

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. !
(Used only if IEXTRP = 3 or -3)

BARRIER INFORMATION

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

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. !
Y coordinate of BEGINNING
of each barrier (YBBAR(NBAR)) ! YBBAR = 0. !

X coordinate of ENDING
of each barrier (XEBAR(NBAR)) ! XEBAR = 0. !
Y coordinate of ENDING
of each barrier (YEBAR(NBAR)) ! YEBAR = 0. !

DIAGNOSTIC MODULE DATA INPUT OPTIONS

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

Surface met. station to use for the surface temperature (ISURFT) No default ! ISURFT = 1 !
(Must be a value from 1 to NSSTA)
(Used only if IDIOPT1 = 0)
--------------------------

Domain-averaged temperature lapse rate (IDIOPT2) Default: 0 ! IDIOPT2 = 0 !
0 = Compute internally from twice-daily upper air observations
1 = Read hourly preprocessed values
from a data file (DIAG.DAT)

Upper air station to use for the domain-scale lapse rate (IUPT) No default ! IUPT = 0 !
(Must be a value from 1 to NUSTA)
(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
--------------------------

Domain-averaged wind components
(IDIOPT3) Default: 0 ! IDIOPT3 = 0 !
0 = Compute internally from twice-daily upper air observations
1 = Read hourly preprocessed values a data file (DIAG.DAT)

Upper air station to use for
the domain-scale winds (IUPWND) Default: -1 ! IUPWND = -1 !
(Must be a value from -1 to NUSTA)
(Used only if IDIOPT3 = 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) 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 (FCORIOL) Default: 1.E-4 ! FCORIOL = 1.0E-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)

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 Default: 200. ! DZZI = 200. !rate is computed (DZZI) 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 Units: meters
overwater mixing hts. are used)
Maximum overwater mixing height Default: 3000. ! ZIMAXW = 3000. !
(ZIMAXW) -- (Not used if observed Units: meters
overwater mixing hts. are used)

TEMPERATURE PARAMETERS

3D temperature from observations or
from prognostic data? (ITPROG) Default:0 !ITPROG = 1 !

0 = Use Surface and upper air stations (only if NOOBS = 0)
1 = Use Surface stations (no upper air observations) Use MM5/M3D for upper air data
(only if NOOBS = 0,1)
2 = No surface or upper air observations Use MM5/M3D 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 temperatureinterpolation (TRADKM) Default: 500. ! TRADKM = 500. !
Units: km

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

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

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

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

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

PRECIP INTERPOLATION PARAMETERS

Method of interpolation (NFLAGP) Default = 2 ! NFLAGP = 2 !
(1=1/R,2=1/R**2,3=EXP/R**2)
Radius of Influence (km) (SIGMAP) Default = 100.0 ! SIGMAP = 100. !
(0.0 => use half dist. Btwn nearest stns w & w/out precip when NFLAGP = 3)
Minimum Precip. Rate Cutoff (mm/hr) Default = 0.01 ! CUTP = 0.01 !
(values < CUTP = 0.0 mm/hr)
!END!
------------------------------------------------------------------------------
INPUT GROUP: 7 -- Surface meteorological station parameters
--------------
SURFACE STATION VARIABLES
(One record per station -- 3 records in all)

```
       1     2
     Name   ID          X coord.   Y coord.   Time   Anem.
                          (km)       (km)     zone   Ht.(m)
    ----------------------------------------------------------
! SS1  ='HAWE'   25222      22.612     -61.378   -12    10  !
! SS2  ='STRA'   23872      23.808     -30.993   -12    10  !
! SS3  ='AIRP'    2283      12.747       5.277   -12    10  !
-------------------
```

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

2
Six digit integer for station ID
!END!
------------------------------------------------------------------------------
INPUT GROUP: 8 -- Upper air meteorological station parameters
--------------
UPPER AIR STATION VARIABLES
(One record per station -- 0 records in all)

```
       1     2
     Name    ID     X coord.   Y coord.  Time zone
                      (km)       (km)
```

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

2
Five digit integer for station ID

!END!
------------------------------------------------------------------------------
INPUT GROUP: 9 -- Precipitation station parameters
--------------
PRECIPITATION STATION VARIABLES (One record per station -- 0 records in all)
(NOT INCLUDED IF NPSTA = 0)

```
       1        2
     Name   Station    X coord.  Y coord.
              Code       (km)      (km)
     ------------------------------------
-------------------
```

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)

!END