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METEOROLOGY FOR CALPUFF AT A SEASIDE INDUSTRIAL COMPLEX

Vanisa Surapipith[1], Naboon Riddhiraksa[1] and Pornpun Uttamung[2]

[1] Pollution Control Department, Bangkok 10400, Thailand
[2] Industrial Estate Authority of Thailand

Abstract: CALPUFF, a Lagrangian puff dispersion model approved by US EPA as a long-range transport regulatory model and a short-range model for complex terrain, was used to find the maximum ground level concentrations (a criterion used by the National Environmental Board of Thailand for decisions on the approval of new industrial facilities) of the two gaseous pollutants; sulfur dioxide and nitrogen dioxide. The study is crucial to the development of the Maptaphut industrial complex on the Eastern Seaboard of Thailand where the 334 point emissions sources were considered for their impacts on an array of community receptors set within a geographic domain characterized by gently rolling hills and 60 km of coastline. CALPUFF has a choice of using meteorological input data from, either its meteorological preprocessor, CALMET, or meteorological model like MM5 and WRF. This work discusses the pro/con of the two approaches, taking intensive campaign in September 2010. The study is supplied by the best available hourly emission input, and meteorology from 6 surface stations plus a Sodar/RASS for upper air profiles. This is due to the fact that the area is under public interest on how to specify a cap on total emission and a fair goal for emission trading to maintain the safe level of ambient air quality. It is also the unique opportunity to test the near-field application of the CALPUFF model in the tropical land-sea breeze circulation. The current results suggest that CALMET may not be optimal for simulating the meteorology in such the environment, and causes unusually high overestimation during the key episode. The complication raises a concern to regulators and industry on how to make the acceptable rules on the model application.

Key words: *CALPUFF, meteorology, Sodar/RASS, Thailand Eastern Seaboard*

INTRODUCTION

CALPUFF (Scire et al. 2000), a US EPA approved regulatory model, was used for finding the maximum ground level concentrations of the two gaseous pollutants; SO_2 and NO_x. The assessment was prescribed as the criterion used by the National Environmental Board, NEB, which is chaired by the Prime Minister of Thailand, for decision-making on the approval of new industrial facilities, in particular around the Thailand Eastern Seaboard area, so-called Maptaphut, in the Rayong province (Figure 1). The NEB at the Fourth meeting in 1998 has stated that the Industrial Estate Authority of Thailand (IEAT), the Office of Natural Resources and Environment (ONEP) and the Pollution Control Department (PCD) are responsible in studying the carrying capacity of the Maptaphut. The first phase of the study (2002 – 2004) established the infrastructure for the model application, following the recommendations of the U.S. EPA team of experts from EPA Region 7. In 2006, the conclusion of the first phase was reported to NEB, and a sub-committee was established to make technical investigation to the model validation. Following the report of the sub-committee, NEB requested IEAT to improve to the model performance, in particular, updating the emission database and upper air meteorology inputs. The decision was made based on the findings as described by Surapipith (2007).

Figure 1. The modelling domain in Thailand Eastern Seaboard

Upper-air meteorological profiles are important information required as input to atmospheric models, especially for application like air pollution. There is often a problem with shortage of good enough upper air data in developing countries where the measurement technology is not produced locally, and the cost of importing the equipments put constraint to the frequency of observations. In Thailand, contributing to WMO global weather prediction, the Thai Meteorological Department makes routine observation once a day at 00 GMT (07:00 hrs local time) at 5 fixed radiosonde stations (Bangkok, Chiang Mai, Ubon Ratchathani, Songkla and Phuket) across the country. The data is insufficient for atmospheric dispersion models, which require generally at least twice daily upper air data input. Also the upper air profiles over Bangkok, the nearest balloon site, do unlikely well represent the Atmospheric Boundary Layer (ABL) structure over the area of interest, which is located along the seaside around 200 kilometres further southeast away. During the first phase of the Maptaphut project, a Radar/RASS was installed for collecting upper-air profiles. At the end of the phase, the equipment was moved to a different site, and subsequently terminated due to its old age.

Therefore, in May 2008, the Sodar/RASS system was installed, and has been collecting data over the Maptaphut area since then. The Sodar/RASS model PA5, manufactured by REMTECH Inc., France, is set to measure wind and temperature vertically every 100 m, starting from 150 m above the ground, up to the heights of 3050 and 1550 m, respectively, and report the data to the modeling team as hourly averages.

Despite that the Sodar/RASS started commissioning in May 2008, it has not collected data continuously due to a number of problems. First, the instrument was damaged by an electrical insurgent during a thunderstorm in July 2008, and the damaged parts were sent back to France to be fixed, which took a couple of weeks. Then in early 2009, the instrument started to perform poorly with more than 70% data missing. The manufacturer has again requested for the instrument to be fixed in France after identifying that the high humidity could have contributed to some instrumental failure.

After the instrumental problem was fixed, the temperature data records were identified as potentially giving off higher than actual temperatures. This was found through comparison with temperature profiles observed by the Bureau of Royal Rainmaking, who already launches the routine radiosonde observation balloons in the Eastern Seaboard to provide the necessary upper air information to the rainmaking operation during the dry season. Rankin formula, taking relative humidity into account, was recommended by the manufacturer to use for correcting the readings, until March 2010, when the Sodar/RASS was then fine tuned to finally perform suitable to the local condition.

With the better upper air data, the CALPUFF modelling study of the Second Phase was resumed with the observation only option in CALMET. The data from 6 surface stations and the upper air station (the Sodar/RASS), during the evaluation period which was planned for 7 days, 6 – 12 September 2010. The SO2 and NOx hourly emissions from the Continuous Emission Monitoring system (CEMs) were used for 90% of the emission loading. The hourly input included exit gas temperatures and velocities. For the cases where flow rate was not available, the hourly production rate was used for the calculation of hourly emissions according to fuel used.

The 291 point emissions sources were considered for their impacts on an array of community receptors set within a geographic domain characterized by gently rolling hills and 25 km of coastline. The CALPUFF model was run at PCD computing centre. The activity is taken as one of the key factors affecting the development of the Maptaphut industrial complex on the Eastern Seaboard of Thailand.

METHODOLOGY

The CALMET setting for the model validation:

(1) Land use and Digital Elevation Model (DEM) from the Land Department was extracted using ArcGIS for the current 60x60 km^2 domain (Figure 1) with 250 m x 250 m horizontal resolution

(2) Surface meteorology for CALMET comprises hourly temperature, humidity, pressure, wind speed and direction at 10m height from the stations showed in Figure 2.

(3) Upper Air meteorology for CALMET: using Sodar/RASS' temperature with following modifications:

3.1 Selected profiles at 7.00 AM and 7.00 PM and discard the rest. We also tried 24- hours per day, but that did not produce better results.

3.2 Modified temperatures as suggested by the Sodar/RASS manufacture, i.e. using virtual humidity in the Rankin formula, for the time period before that was fixed.

3.3 From the altitudes where the RASS data were unavailable (about 1700 m onward, except on the 8th, 10th and 12th at 7.00 AM, the data were missing from 0 m onward), we used sounding temperatures obtained from the website above.

3.4 Sounding temperatures were modified to fit with the Sodar/RASS data, with the assumptions that the temperature profile should be linear around the connecting point and converge to an original sounding temperature at 12 km. We found that the sounding temperatures were lower than the Sodar/RASS at the same altitudes.

3.5 For the Wind speed and Wind direction, using Sodar/RASS data as available, and from the altitudes where the RASS data were unavailable, using sounding data without modification.

The CALPUFF setting for the model validation:

Since the CALPUFF was applied in the near field, in this case, the vertical distribution used was then taken as Gaussian. The ISC-type of terrain adjustment was used as the terrain adjustment method. There is either no subgrid-scale complex terrain, nor elongated slugs for the near-field puffs modeled. Transitional plume rise was modeled with stack tip downwash. No vertical wind shear modeled above stack top, and puff splitting was not allowed. In the model, chemical transformation rates were compute internally using MESOPUFF II scheme. Although the aqueous phase transformatiom mechanism could be modeled in CALPUFF, it was not taken in this case, while the wet removal and dry deposition processes were modeled.

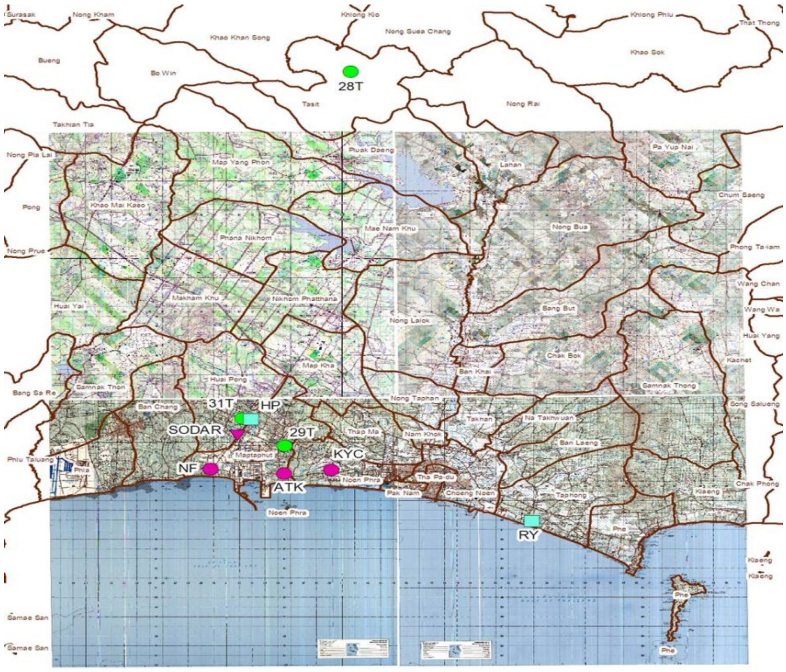

Figure 2. The location of meteorological stations of which the data were used as input to the CALMET/CALPUFF

RESULTS AND DISCUSSION

The CALPUFF result for the model evaluation period is showed in Figure 3. Here, “Sum108sodar+cloud” is the sum of SO2 hourly concentration contribution from plant no.108 as predicted by Calpuff run with precip.dat (4 stations: 28T, 29T, TMD's Rayong, TMD’s Hoi Pong) plus higher resolution of Sodar profiles, and cloud observation at Hoi Pong. “sum108p2” is the sum of SO2 hourly concentration contribution from plant no.108 as predicted by Calpuff run with precip.dat (4 stations: 28T, 29T, TMD's Rayong, TMD’s Hoi Pong). “station” is the hourly observed SO2 concentration at PCD's 29T. “rain (PCD)” is the hourly observed rainfall at PCD's 29T. “rain (TMD)” is the hourly observed rainfall at TMD's Rayong Station. “rain (Hoi Pong)” is the hourly observed rainfall at TMD's Agromet Station (located at Hoi Pong, near 31T). It is found that there was unusually high over-estimation.

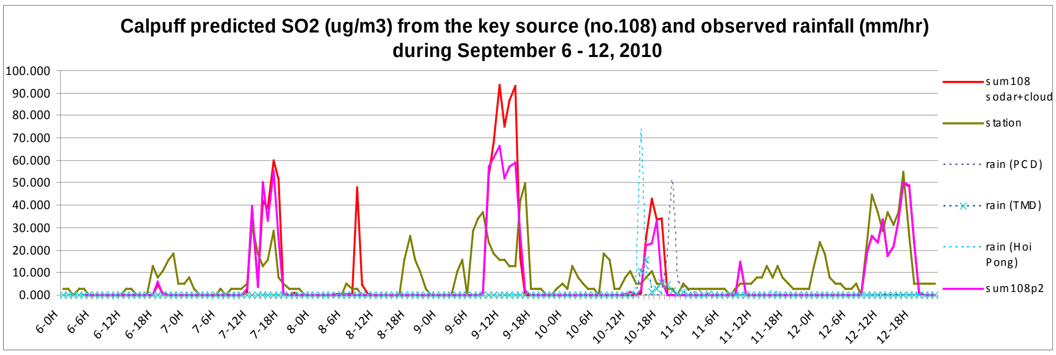

Figure 3. CALPUFF result for the model evaluation period

There are several points in CALMET that were identified as potential problems affecting to the CALPUFF result. Firstly, the maximum radius of influence for Upper Air Station (RMAX2 variable) could be too small. The current RMAX2 value was set to 25-km, which does not extend all of the way across the 60-km x 60-km domain. Since RMAX2 does not extend across the entire domain, CALMET must rely upon similarity theory to extrapolate winds aloft from surface stations for areas outside of the maximum radius of influence.

Secondly, the vertical extrapolation setting could be the other problem. In conjunction with the RMAX2 setting, when the maximum radius of influence for the upper air data is not large enough to cover the entire domain and exercising CALMET in default configuration, CALMET will use similarity theory to vertically extrapolate winds (IEXTRP = 4). It is important to recall that many of the diagnostic model features of CALMET were designed for the development of three-dimensional wind fields over larger modeling domains with relatively sparse observations, especially for upper air observations. In such situations, it may be appropriate to consider using similarity theory to extrapolate vertical temperature and winds, but in a case when the modeling domain is only 60-km by 60-km with upper air observations provided through an on-site Sodar/RASS system, using similarity theory to vertically extrapolate temperature and winds is not necessarily the best approach.

The wind roses in Figure 4 indicate some divergence between the CALMET predicted layer 2 winds and observations from the 100-m tower operated by the PCD. Manual inspection of the UP.DAT file provided by the PCD indicates that the first several layers above the surface have a persistent westerly direction, at least during certain periods of the 6 – 12 September 2010 base case period. This would correspond to the greater westerly values predicted by the model at layer 2

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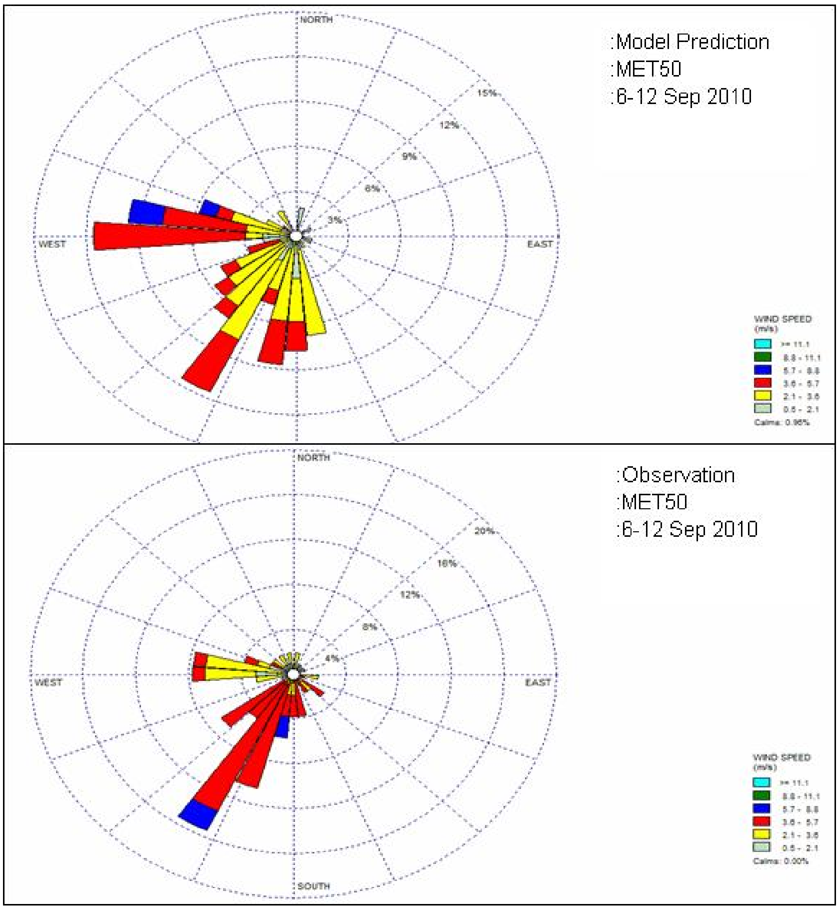

Figure 4. Wind roses comparison between the CALMET predicted layer 2 winds and observations from the 100-m tower

The divergence between the observed and predicted directions will inevitably have an impact on plume transport, especially for elevated point sources such as the BLCP facility. Under the current CALMET configuration, similarity theory is used to vertically extrapolate winds above layer 1 in the model. The similarity theory option within CALMET is based upon the study published by van Ulden and Holtslag (1985). This uses similarity theory and observed wind data to extend the influence of the surface wind speed and direction into the layers aloft. Wind speed and direction are altered in each layer aloft up to 200-m above the surface or to the level of the mixing height, whichever is greater. Once the wind direction is altered, the wind direction and speed are converted back to u and v components for use in interpolation routines.

Thirdly, upper air data and CALMET model top were subjected in relation to default maximum mixing height. CALMET requires winds and temperature at all model levels. The current approach caps the CALMET model top at 2500-m, reflecting guidance of the terrain following coordinates that would require the upper air data to be higher over the hills in the northern part of the domain, where elevation would be higher than where the Sodar/RASS located. The prepared UP.DAT files have provided the twice daily soundings through the 300-mb level, which is approximately at 9700-m elevation, although the Sodar/RASS data is available through approximately 3050-m altitude. The additional levels are substituted from radiosonde data collected by the TMD, south Bangkok site. Sounding temperatures were modified to fit with the Sodar/RASS data, with the assumptions that the temperature profile should be linear around the connecting point and converge to an original sounding temperature at 12 km. It was found that the sounding temperatures were lower than the Sodar/RASS at the same altitudes, with approximately a -5º C from radiosonde compared to RASS.

With all the points noticed, it is realized that adjusting and tailoring CALMET wind fields requires expertise both in mesoscale and microscale meteorological effects within the features of the CALMET diagnostic model. This process is an iterative process which inherently relies upon the ability to visualize the results of the CALMET simulation to determine if the adjustments to the model control options induced the desired meteorological features. Currently, a number of options exist for graphically displaying CALMET wind fields, with advantages and disadvantages of each option. The most common method for displaying CALMET wind field data is through producing vector plots from the CALPOST package and displaying static vector plots in commercial packages such as Golden Software's SURFER package. This has the distinct advantage of the ease of use and the wide spread use of SURFER in the air quality modeling community. However, it is largely impractical for very large data sets because individual plots of hourly winds must be generated in the SURFER package. In recent distributions of the CALPUFF graphical user interface (GUI), another package called CALVIEW has been implemented to read SURFER files generated from CALPOST to provide a seamless time series view of winds.

Finally, the Base Case evaluation period (6 – 12 September 2010) has found to be the insufficient time period for model performance evaluation in relation to typical U.S. EPA recommendations. U.S. EPA recommends a minimum of one month of hourly values for performance evaluation. Additionally, the 1-week period of September 2010 is from a time from which shows primary seasonal dominance, and does not show much evidence of diurnal modulation of wind due to land/sea breeze. Tuning the air quality model for a specific condition is problematic because concentrations occur under a variety of meteorological conditions.

CONCLUSION AND RECOMMENDATION

The development of a high resolution prognostic meteorological dataset based upon MM5 or WRF should be the options to provide meteorology for air quality modelling in the area. While the CALMET diagnostic meteorological model maximizes the ability to incorporate the observations in the data rich environment of the modeling domain, it is important to recognize the inherent limitations of such a modeling system. CALMET is a diagnostic model, which relies upon observations to construct the three-dimensional wind and temperature fields with limited diagnostic adjustments. For the simulation of a land/sea breeze, CALMET does not have a sea breeze module that can operate in the absence of overwater meteorological observations. Therefore, CALMET as used in this work is limited by horizontally and vertically by the density of surface and upper air observations to adequately simulate the full three-dimensional structure of the land/sea breeze.

In the future work, visualization tool will be necessary to improve the meteorological simulation of CALMET. It is learned that the USEPA has adapted programs developed by the US Forest Service for their BlueSky smoke dispersion forecasting system. Software has been developed to convert CALMET output into either MODELS3 IOAPI format. MODELS3 IOAPI format data can be readily displayed in programs such as the Visualization Environment for Data Rich Interpretation (VERDI)

The application of CALPUFF for the Maptaphut Seaside Industrial Complex is reasonable, given the complex nature of the winds and the availability of ample measurement data. The recommended actions mostly address the modeled meteorology and will enhance the models ability to simulate dispersion from the Industrial Estates sources. These improvements should be carried out before the model can be fully applied for regulatory purposes in the region.

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