Applicability of RAMS for A Simulation of Wind and Temperature Fields in Bang Pakong Area, Thailand

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Abstract: - The Regional Atmospheric Modeling System (RAMS) was used to simulate historical wind and temperature fields in Bang Pakong area in order to support photochemical air quality modeling system during a summer and a winter time. High resolution datasets of Digital Elevation Model (DEM), global monthly Sea Surface Temperature (SST), and global reanalysis data from NCEP/NCAR were used as a part of the archived global analysis for preparation of geo-terrestrial process. The studied domain covered the Central and Eastern regions of Thailand. The model setup included one-way with nesting grid of Bang Pakong area using typical physical parameters. The configurations of each domain; time steps and grid resolution, were varied. The result showed that RAMS can be applied to simulate the historical meteorology (wind and temperature fields) of complex terrain and land/sea breeze. The statistical evaluation was tested in an average basis at the ground surface and found acceptable agreement between available observation and simulation results. Data assimilation by nudging analysis was then used with Thailand's weather information obtained from Thai Meteorological Department (TMD) to improve modeling simulations. These techniques showed an increase in modeling performance and a reduction on the deviation between meteorological observation and simulation. Data assimilation technique was found to be applicable in modeling improvement of wind speed, wind direction, and temperature.

Key-Words: - Meteorological model, RAMS, Evaluation, Modeling performance, Data assimilation

1 Introduction

Bang Pakong area is located in the Central and Eastern regions of Thailand over the Gulf of Thailand where exists a large number of industrial facilities and power plants (Fig. 1). This is an area of high pollution threat resulting from various emission sources and the complex of local wind and heat circulation (i.e., complex terrain and land/sea breeze). Pollution is found to be high in summer and winter time (around April and December, respectively). The Regional Atmospheric Modeling System (RAMS) [1] developed by the Colorado State University and the ASTER division of Mission Research Corporation was applied to simulate historical meteorology and atmospheric physics. Some key parameters (i.e., wind and temperature fields) are of interests for better understanding of the characteristics of local wind and temperature circulation. The good atmospheric model performance is needed in simulating meteorological fields. This will lead to acceptable input requirements for supporting photochemical air quality model [2].

RAMS is adopted for meteorology study. A comparison between meteorological simulation and available observation data was made. Performance evaluation by the comparison of two events was tested using typical statistical methods recommended for meteorological simulation. A nudging type of data assimilation with observation information enhanced the performance of RAMS. It is significant that the results of RAMS be acceptable before they are to be used in air quality model.

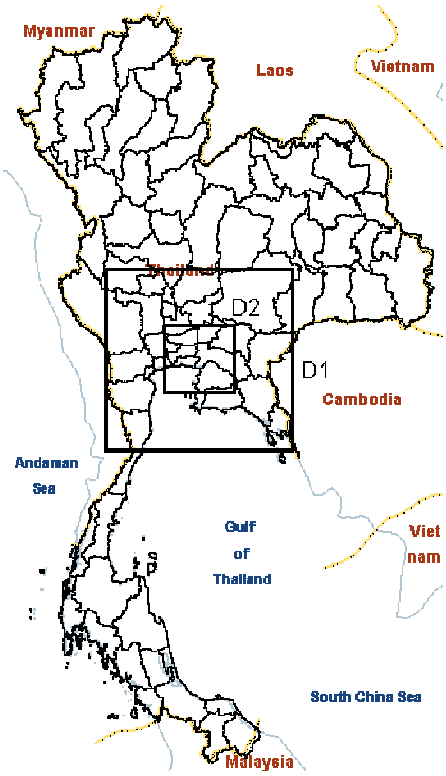

Figure 1. Area of study and analysis domain

As seen on Fig.1, it shows the domain of study and sub-region for analysis. Domain 1 (D1) covers Central and Eastern region of Thailand over the Gulf of Thailand and Domain 2 (D2) covers Bang Pakong area and surrounding areas

2 Methodology

The simulation was conducted with RAMS Version 4.4 using one-way nesting grid with a nesting ratio of 4:1 and 23 vertical layers with vertical grid stretch ratio of 1.20. Domain 1, the coarse (mother) domain, has a dimension of 400x400 km^2 and consists of 50x50 grid cells with a grid size of 4x4 km^2. Domains 2, the fine (child) domain consists of 150x150 grid cells with a grid size of 1x1 km, respectively. It is noted that Domain 1 covers all of the Central and Eastern regions of Thailand including the Gulf of Thailand while domain 2 locates in Bang Pakong area and the adjacent provincial land masses.

A 30-second elevation datasets of topography from the global USGS and vegetation data from USGS/GLCC were used in geo-processing step of RAMS. Initial and lateral boundary conditions were provided by the 4 times daily of the National Center for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR). Sea surface temperature from NCEP is at 1 degree of resolution. NCEP reanalysis and sea surface temperature data were analyzed and then interpolated to the model grid by RAMS/ISAN (ISentropic ANalysis package) [3] for the preparation of initial and lateral boundary region.

RAMS was configured using typical schemes; convective cumulus schemes [4], short and long wave radiation schemes with cloud effects [5], planetary boundary layer of turbulent mixing schemes [6], and land surface model [7]. For a better performance, nudging-type schemes of data assimilation [8] were integrated with the available observations from Thai Meteorology Department (TMD) where additional variables were included into RAMS. The model equation can be rewritten as:

$$\frac{\partial \phi}{\partial t} = \varepsilon \frac{\left(\phi_{obs} - \phi_{model}\right)}{\tau} \qquad (1)$$

where,

ϕ: prognostic variables for horizontal direction (i.e., wind and temperature).

τ: timescale controlling the strengths of nudging term and varies in three dimensions.

ε: weighting factor of a time scale in (*x, y, z*) direction

It is noted that the vertical direction is not necessary due to the possibility of divergence. The relation of timescale with coordinate can be expressed as:

$$\tau_{lat} = \tau_B \left[\frac{\left(x - x_I\right)^2}{\left(x_I - x_B\right)^2} \right] \qquad (2)$$

where,

τ_{lat}: nudging timescale of the lateral boundary region,

τ_B: timescale specified for the actual boundary point,

x_B: *x* coordinate of the boundary point, and

x_I: *x* coordinate of the interior point where the lateral boundary timescale goes to infinity

It is noted that this equation is applied only between x_B and x_I

Performance evaluation was initially tested by RAMS Evaluation and Visualization Utilities (REVU) [9] in order to interpolate and reformat RAMS user-specified output into graphical and plotting analysis files. Statistical tests were then used for the comparison of each parameter with observations. They are: (1) measurements of bias:

Mean Bias (*MB*), Gross Bias (*GB*), and Normalized Mean Bias (*NMB*) (2) measurements of error: Root Mean Square Error (*RMSE*), Normalized Mean Error (*NME*), and Index of Agreement (*IOA*) (3) measurements of points which model results are over a factor of 1.5, *F*(1.5), and factor of 2, *F*(2.0) of the observations. Mathematical formulation of *MB*, *GB*, *NMB*, *RMSE*, *NME*, *IOA*, *F*(1.5), and *F*(2.0) are expressed as follows (Eqs. 3-9) [10].

$$MB = \frac{1}{N}\sum_{1}^{N}(model - obs) \quad (3)$$

$$GB = \frac{1}{N}\sum_{1}^{N}|model - obs| \quad (4)$$

$$NMB = \left[\frac{\sum_{1}^{N}(model - obs)}{\sum_{1}^{N}(obs)}\right] \quad (5)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{1}^{N}(model - obs)^2} \quad (6)$$

$$NME = \left[\frac{\sum_{1}^{N}|model - obs|}{\sum_{1}^{N}(obs)}\right] \quad (7)$$

$$IOA = 1 - \left[\frac{\sum_{1}^{N}(model - obs)^2}{\sum_{1}^{N}\left(|model - \overline{obs}| + |obs - \overline{obs}|\right)^2}\right]$$

$$0 < IOA < 1 \quad (8)$$

$$F(1.5) \le \frac{obs}{model} \le F(2.0) \quad (9)$$

Statistical tests from other independent studies were taken as a standard baseline. These values were based upon the evaluation of variety sets of RAMS simulation to air quality applications [11, 12]. It should be noted that the purpose of these values was not an evaluation of a pass or a failure to any simulation of meteorological model. It only offers suggestions of acceptable and reliable results in the proper way. Another important consideration of statistics testing for an adequate meteorological performance to photochemical model was depended on how to develop and express an acceptable meteorological model of a given domain and selected episode of study. Unsatisfied statistical evaluation showed that the model required considering critically all related parameters and aspects of modeling parameters, inputs diagnostic, and process approaches.

3 Results and discussion

Figs. 2a-d shows results of a time series of wind and temperature fields, during the events on 21-23 April and 14-16 December, 2005 for domain 1 and 2, respectively. Domain 1 predicted wind field moving over the complex terrain at some boundary regions and sea breeze on the entire coastline. Domain 2 shows the synoptic conditions by land/sea breeze with a strong pressure gradient resulting in light south-west flowing over the land. Temperature field showed a well-defined convergence area from the sea (south and west) to the land opposing onshore.

Figs. 3a-b shows the comparison between predicted results of hourly wind speed, temperature, and wind vector plotting against time series and observations data. It is clearly indicated that RAMS can be used to reproduce the trend and magnitude of wind and temperature fields for historical runs at a certain level. With data assimilation (Figs. 3c-d), the modeling performance showed a better degree of deviation by 44.97 % of temperature, 52.71% of wind speed, and 50.55% of wind direction.

Tab. 1 shows the statistical summary of RAMS simulation and available observations with recommended values. Modeling evaluation was taken place by the method of various statistical tests. Most of the tests are showing in the satisfactory level. With data assimilation technique, it was found to increase the reliability of RAMS for use as results in photochemical air quality model.

4 Conclusion and recommendation

RAMS has successfully applied to predict the historical episodes during a summer and winter time. The evolution of complex terrain was found to influence on mesoscale wind and temperature fields along the coastline of the Gulf of Thailand and mountainous areas. Like many studies [13-16], Modeling performance was found to give a good agreement from statistical tests on wind and temperature fields (see Table. 2).

Data assimilation can be used to support the increase of modeling performance to assure reliability. More observational data should be included in the prognostic model for better improving nudging type of data assimilation.

Updating the inputs is another way to enhance the performance by the integration of the local data into the model (i.e., soil or land use), which is expected to draw a better representative of geo-terrestrial information. For an in-depth analysis, sensitivity tests of RAMS by the consideration of microphysics, physical schemes, and parameterizations should be further investigated.

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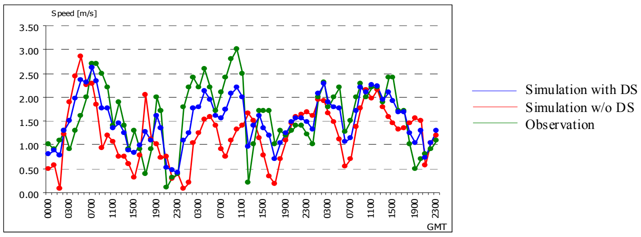

Figure 2a. Wind speed during summer time

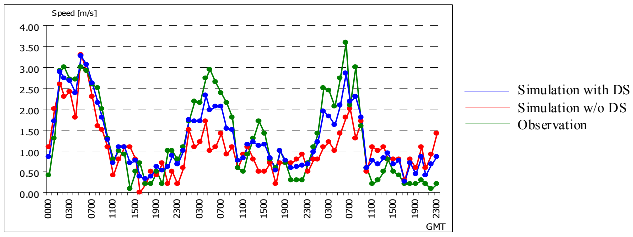

Figure 2b. Wind speed during winter time

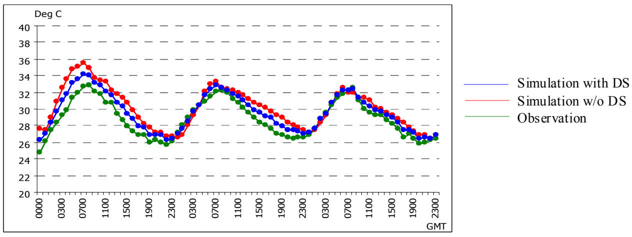

Figure 2c. Temperature during summer time

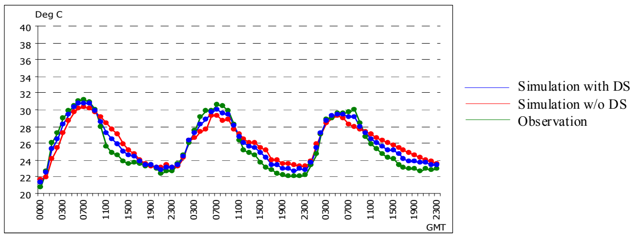

Figure 2d. Temperature during winter time

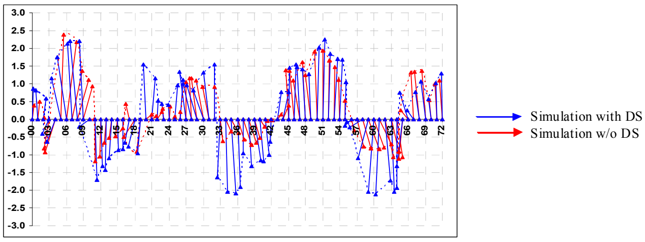

Figure 3a. Wind vector during summer time
(simulation and observation)

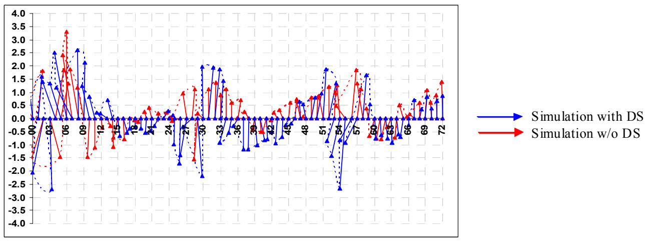

Figure 3b. Wind vector during winter time
(simulation and observation)

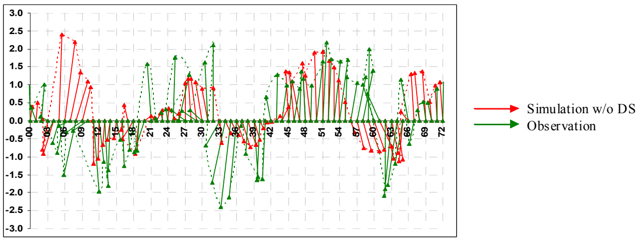

Figure 3c. Wind vector during summer time
(simulation with data assimilation and observation)

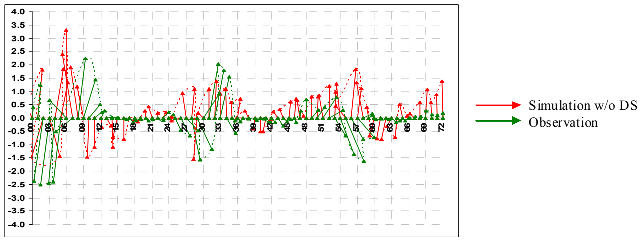

Figure 3b. Wind vector during winter time
(simulation with data assimilation and observation)

Table 1. Modeling evaluation using statistical tests between simulation and observation

SUMMERTIME (21-23 Apr 2005)	BIAS			ERROR			FACTOR	
	MB	GB	NMB	RMSE	NME	IOA	1.50	2.00
TEMP w/o DS	1.26	1.40	0.04	1.65	0.05	0.88	100.00%	100.00%
TEMP with DS	0.75	0.79	0.03	0.92	0.03	0.96	100.00%	100.00%
WS w/o DS	-0.36	0.70	-0.23	0.87	0.44	0.52	86.30%	91.78%
WS with DS	-0.09	0.32	-0.06	0.40	0.20	0.88	89.04%	94.52%
WD w/o DS	10.20	84.36	0.06	109.89	0.52	0.65	75.34%	87.67%
WD with DS	6.91	40.96	0.04	53.92	0.25	0.88	87.67%	93.15%

WINTERTIME (14-16 Dec 2005)	BIAS			ERROR			FACTOR	
	MB	GB	NMB	RMSE	NME	IOA	1.50	2.00
TEMP w/o DS	0.41	1.16	0.02	1.33	0.05	0.94	100.00%	100.00%
TEMP with DS	0.33	0.62	0.01	0.72	0.02	0.98	100.00%	100.00%
WS w/o DS	-0.24	0.61	-0.18	0.76	0.46	0.77	69.86%	78.08%
WS with DS	-0.02	0.29	-0.02	0.36	0.23	0.96	72.60%	83.56%
WD w/o DS	-61.26	145.95	-0.29	169.01	0.69	0.49	67.12%	71.23%
WD with DS	-30.10	72.78	-0.14	84.24	0.34	0.87	71.23%	79.45%

Table 2. Comparison of this work and other RAMS independent researches

	RAMS STUDIES	BIAS	ERROR	RSME
TEMPERATURE	Emery et al. (2001)	±0.50	2.00	-
	Rao et al. (2001)	1.38	2.29	3.03
	Zhong and Fast (2003)[a]	-0.74	-	2.50
	Zhong and Fast (2003)[b]	-1.78	-	2.62
	Castelli et al. (2004)	-	-	3.40
	Hanna and Yang (2001)	-	-	-
	This study w/o DS[c]	**0.84**	**1.28**	**1.49**
	This study with DS[d]	**0.54**	**0.70**	**0.82**
WIND SPEED	Emery et al. (2001)	-	-	2.00
	Rao et al. (2001)	0.61	1.41	1.80
	Zhong and Fast (2003)[a]	0.66	-	1.63
	Zhong and Fast (2003)[b]	0.35	-	2.00
	Castelli et al. (2004)	-	-	1.57
	Hanna and Yang (2001)	-0.10	-	1.60
	This study w/o DS[c]	**-0.30**	**0.65**	**0.81**
	This study with DS[d]	**-0.06**	**0.31**	**0.38**
WIND DIRECTION	Emery et al. (2001)	-	-	20.00
	Rao et al. (2001)	-	-	-
	Zhong and Fast (2003)[a]	-0.43	-	68.37
	Zhong and Fast (2003)[b]	-1.11	-	64.58
	Castelli et al. (2004)	-	-	-
	Hanna and Yang (2001)	-12.00	-	76.00
	This study w/o DS[c]	**-25.53**	**115.15**	**139.45**
	This study with DS[d]	**-11.59**	**56.87**	**69.08**

[a] simulation cases with light wind
[b] simulation cases with strong wind
[c] simulation cases during summer and wintertime
[d] simulation cases during summer and wintertime using available observation stations for data assimilation