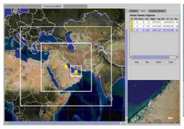
Evaluation of United Arab Emirates WRF two-way nested model on a series of thick coastal fog situations

Ghantoot pile-up caused by thick fog on March 11th, 2008

Recently, on 11 March early morning, a very thick fog occurred along the highway linking Dubai and Abu-Dhabi. At 06:00 local time (02:00 GMT), almost all the weather stations along the western U.A.E. coasts reported less than 100 meters visibility. Such a situation is usually happening at this period of the year, but this time, it caused a horrific traffic accident killing and injuring many people and burning more than 200 vehicles.

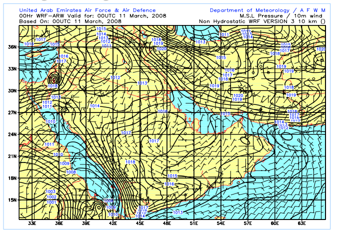
U.A.E. WRF model characteristics

WRF 2.2	Domain 'd01'	Domain 'd02'	Domain 'd03'		Domain 'd01'	Domain 'd02'	Domain 'd03'
Grid dimensions	40 km 158 x 126 x 38	13.33 km 256 x 226 x 38	4.44 km 172 x 136 x 38	Radiation	RRTM Dudhia schemes	RRTM Dudhia schemes	RRTM Dudhia schemes
Time step	225 s	75 s	25 s	PBL	YSU scheme	YSU scheme	YSU scheme
Micro-physics	Ferrier	Ferrier	Ferrier	Surface physics	Noah LSM	Noah LSM	Noah LSM
Cumulus scheme	Kain-Fritsch scheme	Kain-Fritsch scheme	Explicit.	Initial and Boundary Conditions.	3D-VAR GFS model for LBC	3D-VAR Two-way nest	3D-VAR Two-way nest

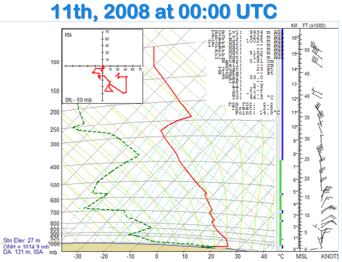


d01	Middle-East
d02	Arabian Peninsula
d03	United Arab Emirates
d04	Centered on Ghantoot introduced only for this study. 91 x 91 x 38 with 1.4 km
WRF-VAR with version 2.2	
UAE/WRF is operational at UAE Air Force & Air Defense since august 2006	

Fog situation of 11 March 2008 analyzed by UAE/WRF 3DVAR-FGAT



Abu-Dhabi actual RAOB for March 11th, 2008 at 00:00 UTC



Introduction

on 11 March, 2008, early morning, a very thick fog occurred along the highway linking Dubai and Abu-Dhabi. At 06:00 local time (02:00 GMT), almost all the weather stations along the western U.A.E. coasts reported less than 100 meters visibility. Such a situation is usually happening at this period of the year, but this time, it caused a horrific traffic accident killing and injuring many people and burning more than 200 vehicles.

This event, among multiple others, is denoting the great influence of weather phenomena in general and visibility drop as a particular most aggressive constraint for the economic and social activities in Emirates. The predictability of such phenomena is becoming among the first priorities.

The forecasts of fog occurrence, its extent, duration, and intensity are difficult in practical because fog is a boundary layer phenomenon which generally shows large variability in time and space. As the boundary layer is driven and initially set up by the synoptic scale behavior, the forecast of fog is, to a first approximation, determined by the general circulation. However, fog occurrence is often governed by mesoscale features as determined by regional characteristics of, and contributions from, the boundary layer. The diagnosis and prediction of these interactions are taken into account inside the current WRF version through a set of planetary boundary layer physics schemes. But, the interactions may be complicated by microphysical processes within and outside fog patterns.

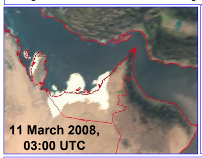
Every where in the world, fog prediction is a real challenge for any weather forecasting centre. The techniques used are generally depending on the local type of weather, climatology of the region, type of fog and geographical specificities. The experience of the local forecaster is generally central and beneficial when dealing with local and specific phenomena. But nowadays, scientific improvements in numerical weather prediction models made them very helpful in depicting even very small and delicate weather activities. These improvements are made especially at the levels of physics parameterizations, initialization methods and grid resolutions.

United Arab Emirates Weather Centre is relying on WRF model for almost all its forecasting tasks. The operational characteristics of such system are detailed in Ajjaji and Al-Katheri, 2007. U.A.E./WRF is making its own data assimilation based on the three dimensional variational analysis using the technique of First Guess at Appropriate Time (FGAT) and taking benefit of a large number of local observations not transiting through the GTS. FGAT is very helpful in dealing with fog prediction because it takes benefit of the information coming from frequently reported observations like METAR and RADAR. Observation nudging could also be turned on in conjunction with 3D-Var.

A series of sensitivity experiments based on this system are conducted in this study to assess the quality of UAE/WRF when dealing with fog and visibility drop predictions. This excludes visibility drop due to dust load which is another common feature of U.A.E. weather and whose prediction is performed actually using a dust model based on Nickovic et al.

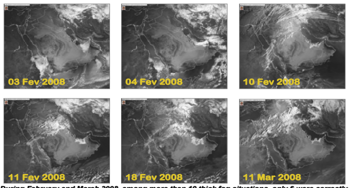
The experiments are measuring the impact of each ingredient among the existing options in the WRF version 3 package related to physics parameterizations (Nine microphysics schemes, four shortwave and long wave radiation schemes, three planetary boundary layer schemes and four land-surface models), horizontal resolution (nested 40 km, 13.3 km, 4.4 km and 1.4 km), vertical resolution (38, 45 and 60 Eta hybrid levels), assimilation techniques (cold start using GFS analysis, warm start using FGAT, cold start with nudging). Some new WRF options, which were released with the recent version 3, are also tested like Pleim and Xiu physics options; dynamic time stepping and digital filter initialization.

The experiments are concerning only one fog situation having occurred on early 11 March 2008. But, the best combination found for the above mentioned configurations is tested on six other fog cases.



Generally fog occurs when southerly hot air masses affect UAE and Gulf Sea during all the day time and cause huge amount of humidity close to the sea surface due to evaporation, and with the inversion of the flow to cold and light north westerly generated by sea breeze during the early afternoon time, these huge quantity of water vapor condensate close to the surface over the marine and coastal areas.

Main February – March 2008 fog situations



During February and March 2008, among more than 10 thick fog situations, only 6 were correctly predicted by U.A.E. WRF model

Experimental Design

	OPR	LIN	WSM6	GCE	TMS	MOR
Start Time	10-03-2008 00:00	10-03-2008 00:00	10-03-2008 00:00	10-03-2008 00:00	10-03-2008 00:00	10-03-2008 00:00
Forecast range	30	30	30	30	30	30
Initial state	ARW 3D-VAR	ARW 3D-VAR	ARW 3D-VAR	ARW 3D-VAR	ARW 3D-VAR	ARW 3D-VAR
Nesting	Two-way	Two-way	Two-way	Two-way	Two-way	Two-way
Vertical Resolution	38	38	38	38	38	38
Micro-physics	Ferrier	Lin et al.	WSM 6-class graupel scheme	Goddard GCE scheme	Thompson	Morrison
Shortwave Radiation	Dudhia	Dudhia	Dudhia	Dudhia	Dudhia	Dudhia
Longwave Radiation	RRTM	RRTM	RRTM	RRTM	RRTM	RRTM
Planetary Boundary Layer	Yonsei University	Yonsei University	Yonsei University	Yonsei University	Yonsei University	Yonsei University
Surface Scheme	Noah LSM 4 layers	Noah LSM 4 layers	Noah LSM 4 layers	Noah LSM 4 layers	Noah LSM 4 layers	Noah LSM 4 layers
Assimilation	FGAT	FGAT	FGAT	FGAT	FGAT	FGAT

Description of the WRF 30 hours range forecasts assessing the impact of microphysics (OPR, LIN, WSM6, GCE, TMS, MOR)

	GDR	CAM	GFDL	MYJ	MRF	PLEIM
Start Time	10-03-2008 00:00	10-03-2008 00:00	10-03-2008 00:00	10-03-2008 00:00	10-03-2008 00:00	10-03-2008 00:00
Forecast range	30	30	30	30	30	30
Initial state	ARW 3D-VAR	ARW 3D-VAR	ARW 3D-VAR	ARW 3D-VAR	ARW 3D-VAR	ARW 3D-VAR
Nesting	Two-way	Two-way	Two-way	Two-way	Two-way	Two-way
Ver. Resolution	38	38	38	38	38	38
Micro-physics	Lin et al.	Lin et al.	Lin et al.	Lin et al.	Lin et al.	Lin et al.
Shortwave Rad.	Goddard	CAM	GFDL	Dudhia	Dudhia	Dudhia
Longwave Radiation	RRTM	CAM	GFDL	RRTM	RRTM	RRTM
Planetary Boundary Layer	Yonsei University	Yonsei University	Yonsei University	Mellor Yamada Janjic	MRF	ACM2/Pleim
Surface Scheme	Noah LSM 4 layers	Noah LSM 4 layers	Noah LSM 4 layers	Noah LSM 4 layers	Noah LSM 4 layers	Noah LSM 4 layers
Assimilation	FGAT	FGAT	FGAT	FGAT	FGAT	FGAT

Description of the WRF 30 hours forecasts assessing the impact of planetary boundary layer physics (MYJ, MRF, PLEIM) and Radiation (GDR, CAM, GFDL)

	THD	RUC	GFSI	NDGI	LEV45	LEV60
Start Time	10-03-2008 00:00	10-03-2008 00:00	10-03-2008 12:00	10-03-2008 12:00	10-03-2008 00:00	10-03-2008 00:00
Forecast range	30	30	30	30	30	30
Initial state	ARW 3D-VAR	ARW 3D-VAR	GFS cold start	ARW 3D-VAR	ARW 3D-VAR	ARW 3D-VAR
Nesting	Two-way	Two-way	Two-way	Two-way	Two-way	Two-way
Ver. Resolution	38	38	38	38	45	60
Micro-physics	Lin et al.	Lin et al.	Lin et al.	Lin et al.	Lin et al.	Lin et al.
Shortwave Radiation	Dudhia	Dudhia	Dudhia	Dudhia	Dudhia	Dudhia
Longwave Radiation	RRTM	RRTM	RRTM	RRTM	RRTM	RRTM
Planetary Boundary Layer	Yonsei University	Yonsei University	Yonsei University	Yonsei University	Yonsei University	Yonsei University
Surface Scheme	Thermal Diffusion 5 layers	RUC 6 layers	Noah LSM 4 layers	Noah LSM 4 layers	Noah LSM 4 layers	Noah LSM 4 layers
Assimilation	FGAT	FGAT	FGAT	Nudging	FGAT	FGAT

Description of the WRF 30 hours forecasts assessing the impact of land surface models (THD and RUC), initialization methods (GFSI, NDGI), and vertical resolution (LEV45, LEV60)

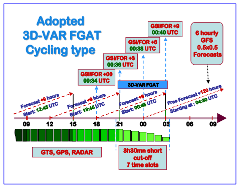
Micro-physics hydrometeors	Extinction coefficient
Cloud liquid water (CLW)	$\beta_{cw} = 144.7C^{0.88}$
Rain water (RW)	$\beta_{rw} = 1.1C^{0.75}$
Cloud ice (CI)	$\beta_{ci} = 163.9C^{1.00}$
Snow (SN)	$\beta_{sn} = 10.4C^{0.78}$
Stoelinga and Warner Visibility	$VIS(meter) = \frac{-\ln(0.02)}{\beta_c}$, $\beta_c = \beta_{cw} + \beta_{rw} + \beta_{ci} + \beta_{sn}$

Relationship between the mass concentration (C, gm^{-3}) and the extinction coefficients (β, km^{-1})

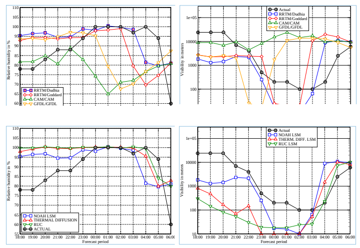
NOAA / FSL Visibility	$VIS(mile) = 6000\frac{T - T_d}{RH^{1.75}}$

Visibility is an empirical function of Temperature, dew point temperature and relative humidity

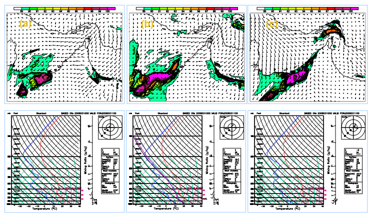
Adopted 3D-VAR FGAT Cycling type



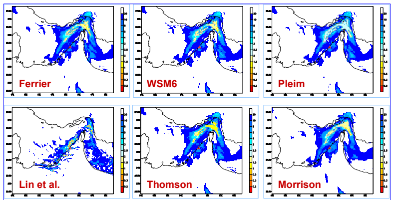
Results



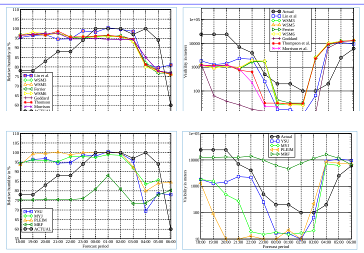
The panels on the left give the maximum surface relative humidity calculated by the experiments dealing with radiation (top) and land surface models (bottom) in domain d04. The panels on the right give the minimum visibility.



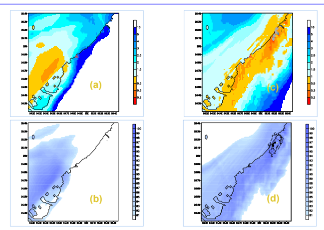
Surface relative humidity predicted by WRF model at 01:00 UTC when using a) GFS analysis, b) GFS analysis with 3 hours nudging, 3DVAR-FGAT in warm start, with the corresponding Predicted Tephigrams at Ghantoot (24.88° N, 54.85° E) on 00:00 UTC.



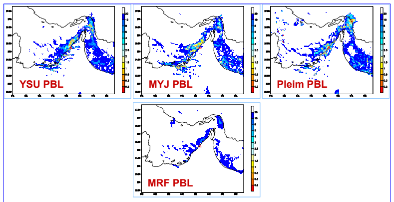
Diagnosed visibility in the fog situation of 03 March 2008. Domain d03 (4.4 km), Yonsei University as PBL, Noah as LSM, RRTM/Dudhia as longwave and shortwave radiation, 38 vertical levels



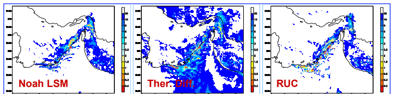
The panels on the left give the maximum surface relative humidity calculated by the experiments dealing with micro-physics (top) and planetary boundary layer (bottom) in domain d04. The panels on the right give the minimum visibility.



Cloud fraction (contoured) and visibility (shaded) calculated by FSL method in a) the operational run and c) by the modified run. Surface relative humidity (shaded) and cloud water mixing ratio (contoured) predicted by b) the operational run, and d) the modified run. The red triangle shows Ghantoot location.



Diagnosed visibility in the fog situation of 03 March 2008. Domain d03 (4.4 km), Lin et al as micro-physics, Noah as LSM, RRTM/Dudhia as longwave and shortwave radiation, 38 vertical levels



Diagnosed visibility in the fog situation of 03 March 2008. Domain d03 (4.4 km), Lin et al as micro-physics, Yonsei University as PBL, RRTM/Dudhia as longwave and shortwave radiation, 38 vertical levels

WRF ingredient tested	Best choices
Micro-Physics (WSM3, WSM5, WSM6, Lin et al., Pleim, Goddard, Thomson, Morrison)	Lin et al., WSM6
Shortwave Radiation and Longwave Radiation RRTM/Dudhia, RRTM/Goddard, CAM/CAM, GFDL/GFDL)	RRTM/Dudhia, RRTM/Goddard
Planetary Boundary Layer (Yonsei University, Mellor Yamada Janjic, Pleim, MRF)	YSU, MYJ, Pleim
Surface Land Model (Noah, Thermal diffusion, RUC)	Noah, THD
Horizontal resolutions (40 km, 13.33 km, 4.44 km, 1.4 km)	4.44 km, 1.4 km
Vertical resolution (38, 45, 60 levels)	38 levels
Initial State (GFS cold start, GFS + Nudging, WRF-3DVAR-FGAT)	WRF-3DVAR-FGAT

Summary

This study tested a series of scientific options offered by WRF version 3 having an influence on fog predictability. These options comprise the entire physics alternatives especially at the levels of microphysics, planetary boundary layer, shortwave and longwave radiation, surface layer model. The impact of different vertical and horizontal resolutions was also fetched. Different initialization methods using cold start, cold start with nudging and warm start with first guess at appropriate time, were examined.

The series of experiments conducted are dealing with a thick fog case study which took place on late night of 10 March 2008 and early morning of 11 March 2008 and covered the major south western coastal parts of U.A.E.

The main results obtained are summarized as it follows:

1. Planetary boundary layer physics and land surface models play a key role in fog depiction. The most reliable options in the context of U.A.E. region are Yonsei University for PBL and Noah for LSM.
2. Shortwave and longwave radiation affect also the fog occurrence. Rapid Radiative Transfer Model as longwave and Dudhia as shortwave are the best. Goddard shortwave lead also to good results.
3. Almost all the microphysics schemes are valid, but Lin et al. scheme presents more satisfactory fog predictability potentiality.
4. Horizontal resolution does not affect fog occurrence but finer resolution lead to better fog location and intensity predictions. Vertical resolution should be taken with care since some assumptions in some physics components necessitate a certain link between horizontal and vertical layers depths.
5. Using GFS analyses as initial states for the model give bad results if the spinup period is short. When using a GFS initial state, the local phenomena like fog occurrence are well predicted in the ranges beginning from 24 hours and ahead. Ranges less than 24 hours are affected by the spinup/spindown problem. Observational nudging has a limited impact when applied on a GFS initial state, its efficiency depend on the frequency and relevance of the observations used in the nudging, as well as on the cut-off nudging period. 3DVAR-FGAT with a warm start mode is beneficial, it includes the advantages of nudging, but it incorporates the different sources of information in a more complicated and coherent way permitting the creation of small scales features inside the analysis. These small scales are crucial in positioning subsequently the fog patterns accurately and orienting the forecast model for well predicting their intensity.

AKNOWLEDGMENT

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