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

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ABSTRACT

United Arab Emirates (U.A.E.) is suffering almost all the year by the consequences of visibility reduction caused either by persistent dust and haze episodes or by the occurrence of thick fogs especially over marine and costal regions. Visibility drop due to fog usually happens during late night and early morning and could last several hours before dissipation. The U.A.E coastal fogs are generally advective caused by the north westerly surface flow draining huge amounts of moisture from the Arabian Gulf sea strait to the 600 km U.A.E western and southern coasts. The large contrast in temperature between land and sea especially during winter season accelerates the condensation process over land near the surface, and contributes to the formation of low stratiform clouds close to the surface since the very beginning of night time. The Weather Research and Forecasting model is among the tools used by the forecasters for fog prediction. It offers a large number of prognostic and diagnostic fog predictability parameters. However, UAE WRF is not always successful in predicting fog formation. Recently, during February and March 2008, among more than 10 thick fog situations, only 6 were correctly predicted. This study aims the scientific evaluation of multiple WRF fog ingredients like physical parameterizations schemes (microphysics, radiation, planetary boundary layer, surface, horizontal diffusion), horizontal and vertical resolution, assimilation techniques (3D-Var, Nudging), over a series of 2008 winter and spring fog situations. It has been found that the inner most nest with very fine resolution (1.4km), an adapted microphysics scheme (Lin et al.), an adequate planetary boundary scheme (Yonsei University) interfaced with Noah surface scheme and RRTM and Dudhia respectively long wave and short wave radiation schemes constitutes a satisfying scientific environment for WRF with respect to fog prediction. An improvement of fog patches location is noted also when 3D-Var warm initialization using the FGAT technique is used.

Key words: fog predictability, physical parameterization, mesoscale data assimilation

1. Introduction

Recently 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

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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.

This paper is subdivided into five sections. The next section is briefly explaining the technical design of the U.A.E./WRF system used in the experiments, and describes the environment of each experiment. The third section discusses the impact of the different possible physics parameterization combinations on the occurrence, position and intensity of the selected fog case; while the fourth and fifth sections analyze, respectively, the impact of horizontal and vertical model resolutions, and the role of assimilation options. And finally section 6 summarizes the obtained results and discusses some recommendations.

2. Experimental design

2.1. Brief description of the WRF and WRF 3D-Var used in the experiments.

All the conducted experiments (described below in details) are based on the last WRF version released on 04 April 2008. This version is still under test and validation at the U.A.E. Meteorological Department. UAE WRF model is running operationally (at the time of writing with version 2.2) since August 2006 over three two-way multi-nested domains with increasing horizontal resolutions of 40 km (domain d01), 13.3 km (d02) and 4.4 km (d03), centered on United Arab Emirates (24.5° N, 54.5° N) (Fig. 1). 38 hybrid sigma-pressure levels are considered on the vertical up to 50 hPa. The lateral boundary conditions for domain d01 are taken from the global NCEP GFS (0.5 × 0.5 degree) forecasts, at six hours frequency, up to 5 days. Ferrier microphysics scheme is chosen for all model domains, whereas Kain-Fritsch cumulus parameterization scheme is employed only for d01 and d02. For planetary boundary layer and surface physics, Yonsei University PBL and Noah LSM surface schemes are respectively used. Rapid Radiative Transfer Model (RRTM) long wave, and MM5 (Dudhia, 1993) shortwave radiation schemes are used. The model is run twice a day and produces forecasts up to 5 days with hourly post-processing

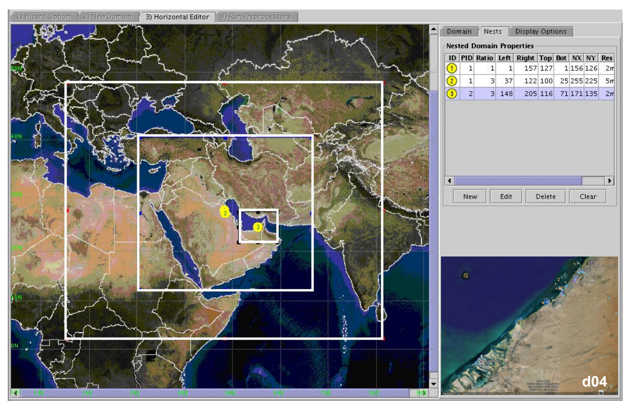

Figure 1 *UAE/WRF two-way nested operational model domains, d01, d02, d03 and d04.*

UAE WRF 3D-Var (version 2.2) became operational since September 2007, and the tunings of its different components are ongoing. It takes advantage of FGAT technique, multiple outer loops, use of unconventional satellite and Radar data, local background error statistics computed via the NMC method, adaptive tuning factors for the various observational data determined using Desroziers and Ivanov 2001, and Hollingsworth and Lonnberg, 1986, techniques. But, the current version of WRF 3D-Var suffers from the incapacity to assimilate raw radiances, the lack of an initialization procedure to filter the 3D-Var analyzed noisy fields (Wee and Kuo, 2004), and the absence of a surface analysis.

The same geometrical and geographical operational model setup is retained for the version WRF V3 used in the following experiments except the adding of a fourth domain, d04, centered on Ghantut (24.88°N, 54.85°E, ~

70 km to the south of Dubai) (Fig. 1) with a resolution of 1.4 km nested into domain d03.

2.2. Description of the conducted experiments

All the warm start experiments are using the GFS analysis of 10 March at 00:00 UTC, and perform 30 hours range forecasts covering the fog period which extended from late 10 March night at 21:00 UTC to early 11 March at 03:00 UTC. One has to add 4 hours corresponding to the U.A.E. gap to GMT time to retrieve the period extension in local time. Tables 1, 2 and 3 are summarizing the nomenclatures and configurations in the different experiments.

The evaluation of every experiment is performed by comparing some prognostic and diagnostic WRF outputs to the actual data given by surface observations (METAR, SYNOP) and to the composite low clouds MSG satellite images. The main model outputs used are the surface relative humidity, cloud water mixing ratio, low level cloud fraction, visibility calculated by Stoelinga and Warner method and visibility calculated by an FSL (Forecast System Laboratory) empirical formula.

The domain of evaluation is d04 which comprises five synoptic stations (Dubai 25.25°N – 55.33°E, Sharjah 25.33°N – 55.51°E, Abu-Dhabi 24.43°N – 54.65°E, Al-Minhad 25.03°N – 55.36°E and Al-Dhafra 24.30°N – 54.50°E). This domain of 110 km × 130 km extent was almost completely covered by the fog pattern on 11 March 2008 at 01:00 UTC as it could be seen on the satellite image (Fig. 2).

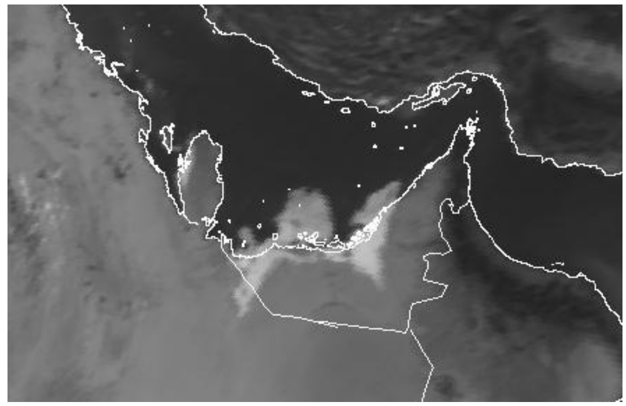

Figure 2 *Fog pattern seen on an infrared MSG satellite image on 11 March at 05:00 UTC (09:00 local time).*

Table 1	**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

Table 1 *Desscription of the WRF 30 hours range forecasts assessing the impact of microphysics (OPR, LIN, WSM6, GCE, TMS, MOR)*

Table 2	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

Table 2 *Description of the WRF 30 hours forecasts assessing the impact of planetary boundary layer physics (MYJ, MRF, PLEIM) and Radiation (GDR, CAM, GFDL)*

Table 3	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	Thermal Diffusion 5 layers	Thermal Diffusion 5 layers	Thermal Diffusion 5 layers	Thermal Diffusion 5 layers
Assimilation	FGAT	FGAT	FGAT	Nudging	FGAT	FGAT

Table 3 *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)*

Due to the great variability of fog in space and time, and to avoid the misleading which could be generated by this variability when comparing the model diagnostics to the actual, the evaluation consisted in determining the maximum humidity, mixing ratio and cloud fraction fields and the minimum visibility produced by the model inside domain d04, and comparing them to their actual counterparts.

2.3. Synoptic situation analysis

The synoptic situation of 11 March 2008 (Figure 3) over U.A.E. was characterized by the persistence of a high pressure extended from Saudi Arabia generating a northerly to north easterly flow over the south-western U.A.E. coasts associated in the upper air (500 hPa) with a westerly anticyclonic zonal cold advection supporting the subsidence of cold air over the whole Arabian Gulf sea. This situation contributed to two major fog occurrence prerequisites; the surface anticyclone generated a well developed surface inversion while the subsidence over the sea contributed to the formation of abundant moisture offshore the western coasts. The northerly and north westerly circulation affected the whole boundary layer and contributed to a net decrease in the temperature field.

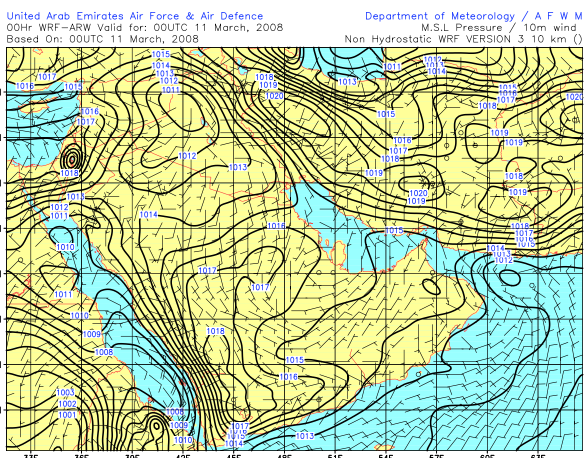

Figure 3 *Synoptic situation of 11 March 2008 analyzed by UAE/WRF 3DVAR-FGAT at 00:00 UTC.*

This particular fog synoptic environment is, in fact, not the prevailing one. 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.

3. Impact of physical parameterizations

WRF model offers several choices for physical parameterizations. Some are adequate at large scales and should be turned on in models with coarse grids; others are adapted for mesoscale models. Currently, several physics components have been included in WRF: microphysics, cumulus parameterization, long wave radiation, short wave radiation, boundary layer turbulence (PBL), surface layer, land-surface parameterization, and sub-grid scale diffusion.

The fog phenomenon could mainly be depicted by microphysics, solar radiation, PBL and surface layer parameterizations. The experiments described in tables 1, 2 and 3, are trying all the possible combinations between these schemes and evaluate their impact on fog occurrence, location and intensity.

3.1. Impact of microphysics.

The tested micro-physics schemes are Purdue Lin scheme (Lin et al, 1983 and Rutledge and Hobbs, 1984), WRF Single-Moment 3, 5, and 6 class (WSM3, WSM5 and WSM6) (Hong et al.), Eta Grid-scale Cloud and Precipitation known as Eta Ferrier scheme, Thompson et al., 2004 microphysical scheme and Two-moment microphysics scheme of Morrison et al., 2005.

The maximum surface relative humidity calculated by the model for domain d04 as well as visibility calculated as the minimum of visibilities determined using respectively Stoelinga-warner (1999) and FSL methods, when each option of the microphysics choices is enabled, are shown in figures 4.a and 4.b.

From these figures we can notice that all the microphysics schemes are satisfactory in predicting the amount of surface humidity (more than 95 %) along the fog period. The discrepancy between actual and model between 18:00 and 22:00 is due to the fact that the humidity values reported by this figure correspond to the maximum over the whole d04 domain, and before 22:00 most of the fog pattern was located over the sea, whereas the actual data are provided by land stations only.

We can notice also that WSM 3, 5 and 6 are very similar. This could be explained by the fact that the concept of these schemes is almost the same. The differences come from the number of hydrometeors taken into account in every one. But since in our U.A.E region ice and graupel and even rain do not accompany fog patterns, only cloud water is processed by all these schemes. And this is reducing the performances of WSM6 and WSM5 to those of WSM3.

Among these entire microphysics schemes, the most realistic one seems to be Lin et al. This could be seen on the concordance of the predicted relative humidity with the actual form 00:00 UTC to 03:00 UTC which correspond to the thickest fog period.

All the schemes are successful in predicting the visibility drop, but since the actual visibility measurements are generally performed by rough estimations, it is very hard to tell which scheme is the best. Lin et al. seem fitting in a satisfactory way the shape of the actual visibility while all the other schemes dissipate the fog very early except Morrison scheme which is very pessimistic and drops the visibility to less than 10 meters since 18:00 UTC.

3.2. Impact of planetary boundary layer physics.

In the following experiments we retain and keep the microphysics scheme based on Lin et al and we modify the available PBL schemes.

Planetary boundary layer is the region where low clouds and fog forms. But PBL is also responsible of eddy transports in the whole atmosphere column, not just in the boundary layer. Therefore, the influence of PBL schemes is crucial in governing fog occurrence, location and intensity. The corresponding schemes offered by WRF are: MRF described by Hong and Pan 1996, Yonsei University (YSU) which is an advanced generation of MRF, Mellor Yamada Janjic (MYJ) (Janjic, 1996, 2002) and Asymmetric Convective Model version 2 (ACM2; Pleim,. 2007a,b)

In term of maximum predicted surface relative humidity over domain d04 (Fig. 4.c), all the schemes seem realistic. However, MYJ and PLEIM seem closer to the actual humidity shape. In term of visibility (Fig 4.d) linked directly to the lowest cloud fraction (Stoelinga and warner), YSU and MYJ seem coherent with respect to the actual visibility, whereas PLEIM predicts the fog patterns always over the sea (not shown) and MRF is very dry.

3.3. Impact of shortwave and longwave radiation physics

The following experiments are using Lin et al. as microphysics and YSU as planetary boundary layer physics.

The radiation schemes provide atmospheric heating due to radiative flux divergence and surface downward longwave and shortwave radiation for the ground heat budget. Within the atmosphere the radiation responds to model-predicted cloud and water vapor distributions, as well as specified carbon dioxide, ozone, trace gas and particulate matter concentrations.

The schemes tested in this study are Rapid Radiative Transfer Model (RRTM) (Mlawer et al, 1997) longwave combined with MM5 Dudhia (Dudhia, 1989) and Goddard (Chou and Suarez, 1994) shortwave, CAM longwave combined with CAM shortwave and Eta Geophysical Fluid Dynamics Laboratory (GFDL) longwave combined with GFDL shortwave.

It is possible to imagine combinations between radiation schemes from different longwave and shortwave options, but then, these experiments will be numerous and most probably will lead to the same result. We preferred not to play a lot with these possibilities.

From figures 4.e and 4.f, it turns out that RRTM/Dudhia and RRTM/Goddard are the most realistic with a slight advantage of RRTM/Dudhia, whereas GFDL/GFDL and CAM/CAM do not depict correctly the fog pattern. The failure of GFDL and CAM could be attributed to their eventual incapacity to deal with mesoscale phenomena, because they are conceived for global models.

3.4. Impact of Land surface physics

In the following experiments, Lin et al. is used for microphysics, YSU for PBL and RRTM/Dudhia for longwave and shortwave radiation.

The land-surface schemes (LSM) use atmospheric information from the surface layer, Radiative forcing from the radiation scheme, and precipitation forcing from the microphysics and convective schemes, together with internal information on the land's state variables and land-surface properties, to provide heat and moisture fluxes to the PBL scheme.

WRF model offers four options for land surface physics, thermal diffusion LSM with 5 soil layers, Unified Noah LSM with 4 soil layers, Rapid Update Cycle (RUC) LSM with 6 layers and Pleim-Xiu LSM with 2 layers. We were not able to test the latter scheme because the corresponding WRF run was unstable. At the time of writing, we guess probably some source code bugs since this scheme is not yet well tested in WRF version 3.

Thermal Diffusion and Noah are similar with respect to fog forecasting with a slight advantage of the former scheme (Fig. 4.g and 4.h). However, over U.A.E. and Arabian Gulf region, this scheme seems to lead to overestimated excessive surface humidity. The routinely operational scores of U.A.E. WRF when this scheme is enabled show always a systematic positive bias (of about 8 %) for relative humidity on the surface. Thus, it constitutes a pessimistic model with respect of fog forecast. We should certainly expect more false alarms while using this surface model. As a consequence we prefer to retain Noah LSM instead.

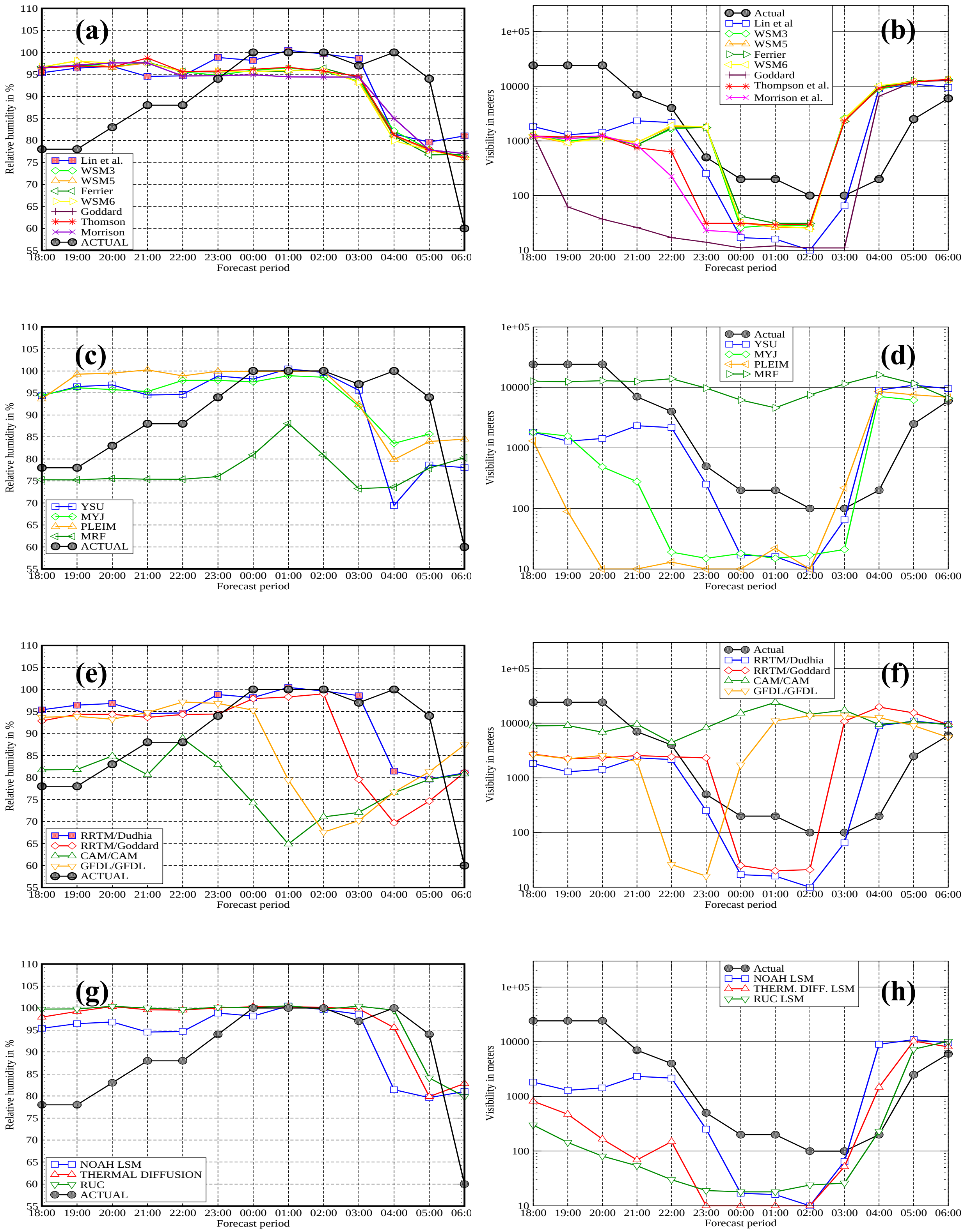

Figure 4 *The panels on the left give the maximum surface relative humidity calculated by the different above descried experiments in domain d04, the panels on the right give the minimum visibility. The actual humidity and visibility is given by the black curve in each panel*

4. Impacts of horizontal and vertical resolution.

The impact of horizontal resolution was easily quantified by looking to the comparison results of the same model outputs over the four two-way nested domains d04 (1.4 km), d03 (4.4 km), d02 (13.3 km) and d01 (40 km). As each nest is greatly governed and guided by its parent, and since the type of fog treated in this case study is caused by the synoptic environment, no major differences were depicted from coarse resolution to fine resolution in term of fog occurrence. However, the fog location and intensity shows large improvements when going from coarse to fine meshes.

But an amazing result was reported when vertical resolution is increased from 38 levels to 45 and 60: the fog pattern almost completely disappeared from domains d03 and d04 (4.4 and 1.4) km which is denoting a deterioration effect of vertical resolution increase. This could be attributed eventually to the following argument: All the radiation schemes in WRF are column (one-dimensional) schemes, so each column is treated independently, and the fluxes correspond to those in infinite horizontally uniform planes, which is a good approximation if the vertical thickness of the model layers is much less than the horizontal grid length. This assumption would become less accurate at high horizontal resolution.

5. Impact of model initial state.

WRF model could be initialized through multiple procedures. The commonly and widely used initialization is the dynamical adaptation mechanism which consists in interpolating the analyses of other regional or global models. The interpolation is performed by sophisticated packages like WPS (WRF Pre-processing System) or WRFSI (WRF System Initialization) and takes into account the target resolution topography, soil types, vegetation, land sea mask, local albedo, soil moisture and temperature, …etc. The problem of this initialization procedure resides in the inadequacy of coarse meteorological fields with the targeted high resolution: the fields interpolated do not contain any mesoscale information and the interpolation is unable to create any mesoscale signal. The models initialized by this procedure generally take long time before creating their own mesoscale trace, and during the period of adjustment, the forecast could be unusable. To alleviate this problem, observation nudging could constitute a very good and efficient solution, but it is also possible to operate a data assimilation scheme for the mesoscale model itself. This will create a mesoscale initial state if the observations used in the process of assimilation are adequate and dense enough. As a consequence, the forecast model will develop the mesoscale features since its early time steps.

U.A.E. WRF is running its own data assimilation based on WRF 3D-Var, with an analysis window of 6 hours. It uses for this purpose all the observations available in its domain either conventional or not. But it still uses the version WRFVAR 2.2 which is not yet able to assimilate some remote sensed data. First Guess at Appropriate Time is also adopted in order to take into account all the frequently reported observations like METARS, AIREP, AMDAR and Atmospheric Motion Vectors, and then be able of following the rapidly evolving phenomena.

With FGAT we consider that nudging is useless, because the information which should be brought by observation nudging is already taken into account by an FGAT of 6 hours centered on the short cut-off analysis time.

The following experiments compare the impacts of using FGAT data assimilation, GFS cold initialization and Nudging procedure applied on GFS initial state.

The model physics environment is based on Lin et al, YSU PBL, RRTM/Dudhia radiation and Noah LSM surface scheme, but operated by WRF V2.2 which is operational and interfaced with WRFVAR 2.2.

The forecasts emitted from these initial state starts 6 hours before fog occurrence; they are based on 10 March 2008 at 12:00 UTC.

From figure 5, we can notice the large similarity between GFSI and NDGI despite a little improvement in NDGI. At 01:00 UTC, the main core of the fog pattern affected only the western U.A.E more than 150 km away from Ghantut. In NDGI this pattern succeeded in reaching the coasts of Abu-Dhabi but didn’t go so far. FGAT presents a completely different shape more realistic and showing clear mesoscale signals. The pattern is covering the coasts from Dubai in the north to Ruways in the south-west and showing thick fogs between Dubai and Abu-Dhabi along the highway. This is, in our belief, proving the superiority of 3DVAR FGAT in this kind of situations.

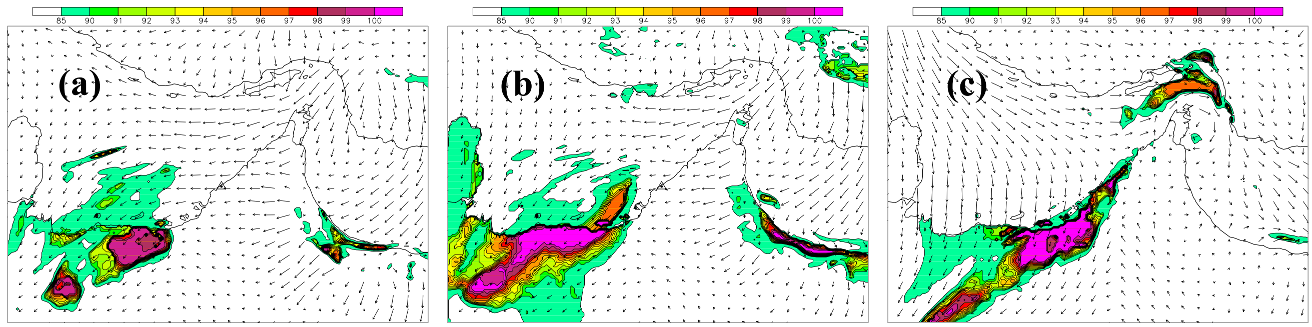

Figure 5 Surface relative humidity predicted by WRF model at 01:00 UTC when using a) GFS analysis, b) GFS analysis with 3 hours nudging, 3DVAR-FGAT in warm start.

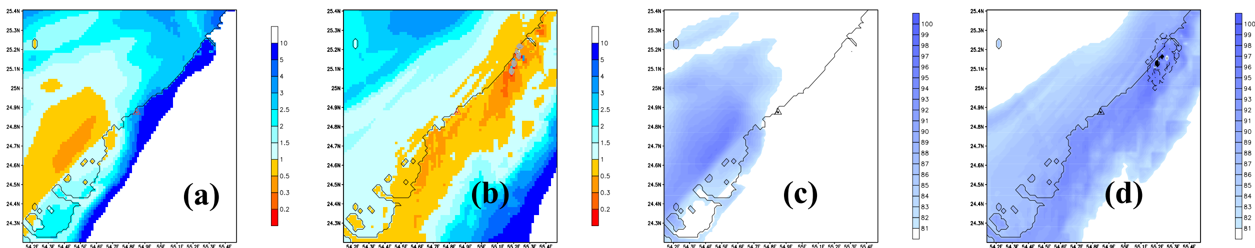

Figure 6 *Cloud fraction (contoured) and visibility (shaded) calculated by FSL method in a) the operational run and c) by the modified run. Surface relative humidity (shaded) and cloud water mixing ratio (contoured) predicted by b) the operational run, and d) the modified run. The red triangle shows Ghantut location.*

On figure 6, low level cloud fraction , cloud water mixing ratio, surface relative humidity and visibility are shown at 01:00 UTC for the operational run OPR (Fig 6.a and 6.c) and for the modified WRF environment taking into account the best above determined options (Fig 6.b and 6.d). One can notice the improvements brought by the modified run.

6. Discussion and conclusion.

This study tested a set of scientific options, offered by WRF version 3, having an influence on fog predictability. These options comprise the entire physics alternatives 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 assessed. 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:

- 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.
- 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 satisfactory results.
- Almost all the microphysics schemes are valid, but Lin et al. scheme presents better fog predictability potentiality.
- 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 dependency between horizontal and vertical layers depths.
- Using GFS analyses as initial states for the model give bad results if the analysis time is close to the fog period. 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, and 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.

The configuration incorporating all the above cited best options is applied on 6 other fog cases. The results are examined using the eyeball verification and seem to be satisfactory.

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