Implementation and preliminary tests of an air quality forecasting system based on WRF-Chem over Middle-East, Arabian Peninsula and United Arab Emirates.

INTRODUCTION

Air pollution has become an increasingly important environmental issue in the Middle East. High levels of suspended particulates have become a common parameter of many regions. Emissions of sulfur dioxide have been rising steadily as industrialization occurs. Nitrogen oxides have been increasing steadily in many localities

Air pollution management is usually developed from awareness, demands and realization of needs of the community and decision makers. Air pollution management requires capacity building, ground-based monitoring systems and networks for proper operation and strategic decision support. It also requires quality assurance and quality control, modeling tools and institutional capabilities for implementation.

However, detailed studies of the atmospheric environment in the Middle East have been limited. Since the end of 2000, a detailed study has been conducted regarding the atmospheric chemistry and microphysics over U.A.E. This orphan study characterized quite well the nature and spatial distribution of aerosols and trace gases over U.A.E.

Since two years, the meteorological department of the U.A.E. Air Force and Air Defense used routinely the WRF NWP model for its operational weather forecasts. And recently, with the maturity of the chemical component incorporated since 2004 into WRF library, extensive efforts are deployed with the objective of implementing an efficient operational air quality forecasting system based on WRF-Chem. Multiple constraints encountered this project; but the most arduous one was the lack of anthropogenic emissions inventories and data. To overcome this data shortage, it has been decided to use the following information sources:

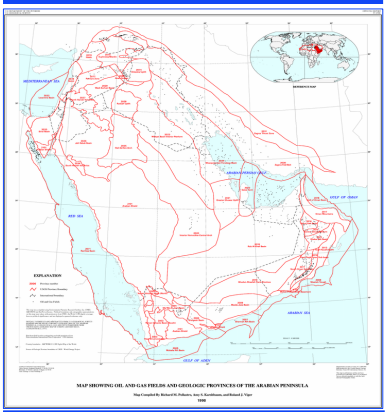
- ☐The known global area emission databases despite their poor resolution
- ☐Some of the recently collected data over U.A.E. by the governmental environment agencies.
- ☐Estimations of emissions contributed by the multitude oil fields operated in the region

Global Anthropogenic Emissions

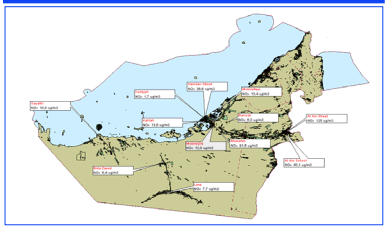
Inventory	categories	spatial resolution	temporal resolution
POET	anthropogenic biomass burning natural	1° × 1°	annual (anthropogenic) monthly (biomass burning) monthly (natural)
RETRO	anthropogenic biomass burning	0.5° × 0.5°	monthly
EDGAR 3.2FT2000	anthropogenic biomass burning	1° × 1°	annual
GFED v2	biomass burning	1° × 1°	monthly 8 day (available on GFED home site)
CO2 Andres et al.	anthropogenic	1° × 1°	annual
GEIA v.1	anthropogenic biomass burning natural	1° × 1°	annual + monthly for NOx, SO_2, and natural VOCs

The GEIA / ACCENT data portal is a cooperative effort providing surface emissions data for the main emission categories at global or regional scales, from several inventories (RETRO, POET, EDGARFT2000, GFEDv2, GEIA v1, etc)

Oil an Gas fields Emissions Inventory



U.A.E. Air Quality Monitoring



List of species offered by the international public databases associated with WRF-Chem inputs

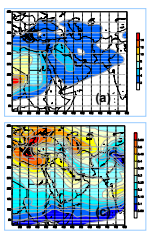
Fields	Used database	RADM2 Super-Category	Units
Carbon Monoxide	RETRO	E_CO	ST'/ h
Nitrogen Oxides	RETRO	E_NO	ST ' / h
Sulfur Dioxide	EDGAR	E_SO3	ST ' / h
Ammonia	FAO	E_NH3	ST ' / h
Methane	EDGAR	E_CH4	Mol / h
Ethane	RETRO	E_ETH	Mol / h
Alkane1 (primarily Ethane)	RETRO	E_HC3	Mol / h
Alkane2 (excluding C3H8,C2H2,organic acids)	RETRO	E_HC3	Mol / h
Alkane3 (excluding butanes)	RETRO	E_HC5	Mol / h
Alkane4 (excluding pentanes)	RETRO	E_HC8	Mol / h
Ethylene	RETRO	E_OL2	Mol / h
Olefin1 (excluding propylene)	POET	E_OLT	Mol / h
Olefin2 (excluding dienes and styrene)	POET	E_OLI	Mol / h
Isoprene	POET	E_ISO	Mol / h
Aromatic 1 (excluding benzene and toluene)	RETRO	E_TOL	Mol / h
Aromatic 2 (excluding Xylene)	RETRO	E_XYL	Mol / h
Formaldehyde (methanal)	RETRO	E_HCHO	Mol / h
Acetaldehyde	RETRO	E_ALD	Mol / h
Higher Aldehydes	RETRO	E_ALD	Mol / h
Benzaldehyde	RETRO	E_ALD	Mol / h
Acetone	RETRO	E_KET	Mol / h
Methyl-Ethyl Ketone	POET	E_KET	Mol / h
Methanol	RETRO	E_HC3	Mol / h
Glyoxal	RETRO	E_ALD	Mol / h
Methylglyoxal	RETRO	E_ALD	Mol / h
Biacetyl	RETRO	E_ALD	Mol / h
Phenols	RETRO	E_CSL	Mol / h
Cresols	RETRO	E_CSL	Mol / h
Methacrolein	RETRO	E_ALD	Mol / h
Methylvinyl ketone	RETRO	E_KET	Mol / h
Propylene	RETRO	E_OLT	Mol / h
Acetylene	RETRO	E_HC3	Mol / h
Benzene	RETRO	E_TOL	Mol / h
Butanes	RETRO	E_HC3	Mol / h
Pentanes	RETRO	E_HC5	Mol / h
Toluene	RETRO	E_TOL	Mol / h
Xylenes	RETRO	E_XYL	Mol / h
Propane	RETRO	E_HC3	Mol / h
Dienes	RETRO	E_OLI	Mol / h
Styrene	RETRO	E_OLT	Mol / h
Organic Acids	RETRO	E_ORA2	Mol / h
PMFINE - unspeciated primary PM2.5	GOCART	E_PM25	ST ' / h
PSO4 - PM2.5 sulfate	GOCART	E_SO4	ST ' / h
PNO_3 - PM2.5 nitrate	--	E_NO3	ST ' / h
POA - PM2.5 organic aerosol	GOCART	E_ORG	ST ' / h
PEC - PM2.5 elemental carbon	GOCART	E_EC	ST ' / h
PM10-PRI – unspeciated primary PM10	GOCART	E_PM10	ST ' / h

The global inventories are provided in area emissions mode with horizontal resolutions of 0.5°×0.5° or 1°×1°. Generally, the provided emissions concern the precursor gases CO, NOx, NMVOC (Non Methane Volatile Organic Compounds) and SO2, the acidifying gases NH3, NOx and SO2, and Ozone Depleting Gases.

RETRO database hold by a European project coordinated by Max Planck Institute for Meteorology, Hamburg, is the most complete. It offers global emissions on 0.5°×0.5° for a large variety of pollutants categories and sub-categories especially for NMVOCs.

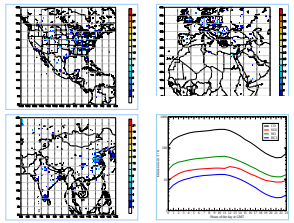
Almost all the data managed by the ACCENT project are monthly averaged and gridded in ASCII and NetCDF formats. The units of almost all the compounds are Kg/m2/s, and RETRO files contain also the information about the grid boxes areas. The fluxes per cells of 0.5°×0.5° of any specie could then, very easily, be deduced.

Gocart Aerosols Climatology



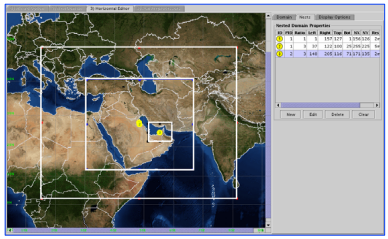
Aerosols emissions in Tones / hour per grid cell of 0.5°×0.5°, deduced from the GOCART model climatological three-dimensional concentrations for April for (a) PM-10, (b) PM-25, (c) Sulfate (PM-25 sub-category), (d) Organic PM-25.

The conversion to hourly emissions is inspired from EPA hourly database. International Time Zone is respected



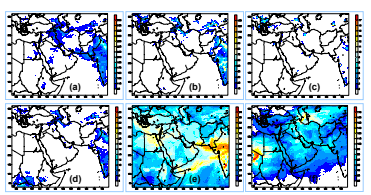
Sulfur Dioxide emissions over USA (a), Europe (b) and eastern Asia (c). One can notice that the emissions in Europe are twice bigger than those emitted over eastern Asia at 17:00 UTC. It is day time in Europe and night in Asia. Emissions are in Tones / hour per grid cell of 0.5°×0.5°. Panel (d) illustrates the diurnal variation functions.

10 days chemistry Simulation with WRF-Chem over Middle-East, Arabian Peninsula and United Arab Emirates



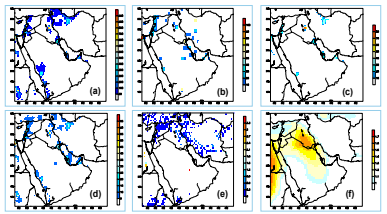
WRF-Chem version	Version 3 released on 4 April 2008 with latest bug fixes of 16 May 2008
Domains horizontal resolutions	40 km for d01 13.333 km for d02 4.444 km for d03
Domains horizontal grids dimensions	156×126 for d01 256×226 for d02 171×136 for d03
Number of vertical levels	38 for every domain
Lateral boundary conditions	GFS FNL analyses
Initial conditions	WRF 3D-Var warm start
Longwave radiation	RRTM
Shortwave radiation	Dudhia
Surface layer	Monin-Obukhov
Land-surface model	Noah LSM 4 layers
Planetary boundary layer scheme	Yonsei University
Microphysics	Lin et al
Cumulus parameterization	Kain-Fritsch
Chemical mechanism	RADM2 (Chang et al)
Aerosols mechanism	Modal Aerosol Dynamics Model for Europe (MADE : Akermann et al 1998) Secondary ORGanic Aerosol Model (SORGAM : Schell et al., 2001)
Photolysis	Madronich, 1987
Dry deposition	Weseley, 1989
Biogenic Emissions	Online using the Simpson, et al. 1995 and Guenther et al. 1994
Anthropogenic emissions	Prepared as in section 2
Dust option as coded in WRF-Chem V3	Not active
Sea salt as coded in WRF-Chem V3	Not active
Dimethyl Sulfide as coded in WRF-Chem V3	Not active
Emissions input frequency	60 minutes

horizontal fields and Time series

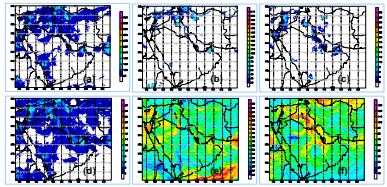


Predicted concentrations of CO (panel a), NOX (panel b), SO2 (panel c), aggregated VOCs (panel d), Ozone (panel e) and PM25 (panel f), at 09 April 2007 at 12:00 UTC over domain d01 (40 km). Units are in ppbv in (a), (b), (c), (d), (e) and in µg/kg in (f).

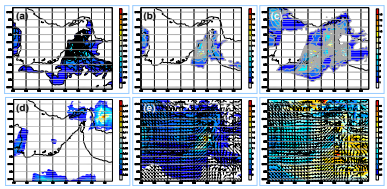
Input Emissions on WRF Grid d02



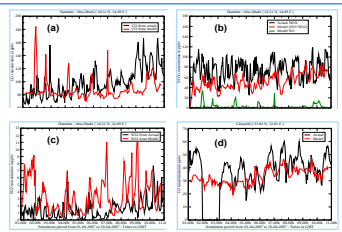
April Emissions of CO (panel a), SO_2 (panel b), NO (panel c), aggregated VOCs (panel d), and NH_3 (panel e) compiled for domain d02 and valid at 12:00 UTC. Units are in Moles per square kilometer per hour. Panel (f) illustrates emissions of PM25 in $\mu g/m^3 m/s$.



Predicted concentrations of CO (panel a), NOX (panel b), SO2 (panel c), aggregated VOCs (panel d), Ozone (panel e) and PM25 (panel f), at 08 April 2007 at 18:00 UTC over domain d02 (13.3 km). Units are in ppbv in (a), (b), (c), (d), (e) and in µg/kg in (f).



Predicted concentrations of CO (panel a), NOX (panel b), SO2 (panel c), Isoprene (panel d), aggregated VOCs (panel e) and Ozone (panel f) at 01 April 2007 at 17:00 UTC over domain d03 (4.4 km). Units are in ppbv.



Time series of CO, NOX, SO2 and O3 concentrations recorded (black lines) and predicted (red lines) at Abu-Dhabi (Hamdan Street) and Ghayathi (western U.A.E.). CO actual concentrations are scaled by a factor of 0.2 in order to correspond to their model counterparts.

Summary and Conclusion

The preliminary obtained results seem not far from the actual recorded by the United Arab Emirates operated air quality stations. The interpretation of the different horizontal fields concentrations showed that U.A.E. is endangered by pollution generated thousands of miles away, especially over Iraq, Kuwait, Saudi Arabia and Qatar due to U.A.E. specific climatological characteristics governed by prevailing north westerly winds associated with air masses subsiding just at the vertical of U.A.E.

Despite the promising results obtained with WRF-Chem, the problem of huge computation capacities needed by this model when running at high resolution with sophisticated chemical mechanisms constitutes a challenge for any operational use.

AKNOWLEDGMENT

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Radi AJJAJI, Ahmad Awad Al-Katheri, Abdullah Dhanhani, United Arab Emirates Air Force and air Defense Meteorological Department, 2008.