National Environmental Agency of Georgia

Simulation of Air Pollutant Distribution over the Caucasus on the bases of WRF-Chem model

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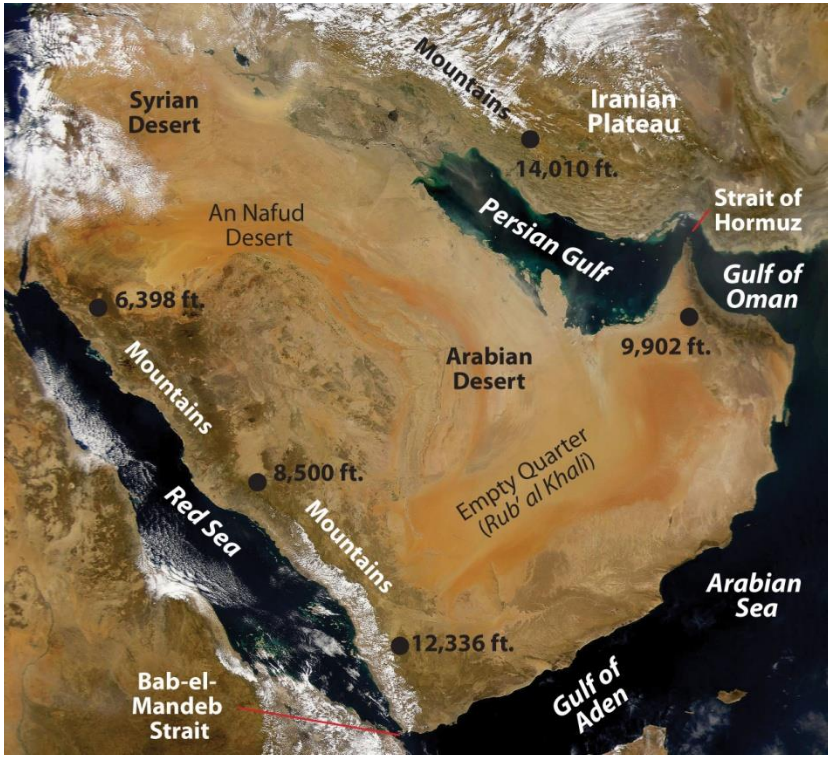
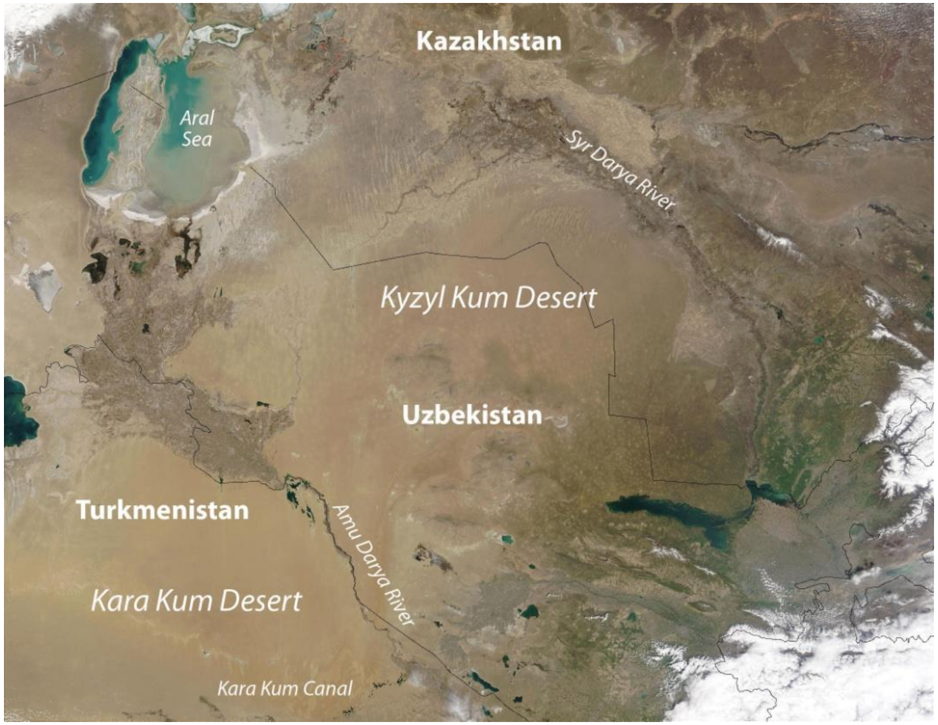
Pollutant agents

- There were no numerical models, which calculated air pollution (with the prognostic aims) on the regular basis (every day) to the beginning of 2016, when we started modeling air pollution distribution in Georgia. We chose mineral dust to investigate air pollutant distribution over Georgia (Caucasus Region more general).
- This parameter was chosen for the many reasons. Mineral dust produced by wind erosion is an important factor in the earth-atmosphere ocean system. It directly affects the earth’s energy budget by scattering and absorbing radiation; it indirectly affects the energy budget by modifying the microphysics of the clouds. Additionally, dust has substantial impacts on the hydrological cycle and many biogeochemical cycles by providing reaction sites and carrying many condensed and absorbed species.
- Also, there was no air pollutant’s distribution study in Georgia on the regular basis (every day), to use it as sources of pollutant agents in numerical models and we had no access to the similar studies outside of Georgia. What about mineral dust, there are quite enough sources around the Caucasus, for example Caspian Sea beach deserts in Central Asia (Kazakhstan, Turkmenistan and Uzbekistan) and Syrian Desert. Using mineral dust as pollutant agent was preferable by the reason that, its sources are pretty good investigated and has detailed description in many global numerical models.

The nearest pollution sources around the Caucasus

south of the Caucasus





east of the Caucasus

Dust storms

- When a gust front or other strong wind blows loose sand and dirt from a dry surface fine particles are transported by saltation and suspension. As the force of wind passing over loosely held particles increases, particles of sand first start to vibrate, then to jump up and down ("leaps"). When value of the wind velocity significantly grows up, it causes a dust storm. The process moves soil from one place and deposits it in another. The distance may be several hundred, even thousand km-s.

Consequences of dust storms

- When the dust particles moved by wind come in to the low pressure area with high humidity, they become condensation centers, which in turn lead to formation of rains.
- The raindrops have a yellow color; such colored raindrops are observed very seldom in Georgia.
- Dust storms cause soil loss from the dry lands, and worse, they preferentially remove organic matter and the nutrient-rich lightest particles, thereby reducing agricultural productivity. Also the abrasive effect of the storm damages young crop plants. Dust storms also reduce visibility affecting aircraft and road transportation. In addition dust storms also create problems due to complications of breathing in dust.

Choosing of the model

- Therefore we decided to select a numerical model, which was capable to correctly calculate dust particle distribution over Caucasus region. Such model was WRF-Chem, the one of the main preferences was the following feature of the model: it was totally free.
- We have many years experience of using WRF (both ARW and NMM cores) as numerical weather prediction model. Thousands of runs of the model with the various parameterization schemes over the Georgia (Caucasus region).
- When we started, we used v3.7, at the Jun 2016 we upgraded model to v3.8. Now we use v3.9.1.
- Model was created and maintenance by NOAA(National Oceanic and Atmospheric Administration) and NCAR(National Center for Atmospheric Research).

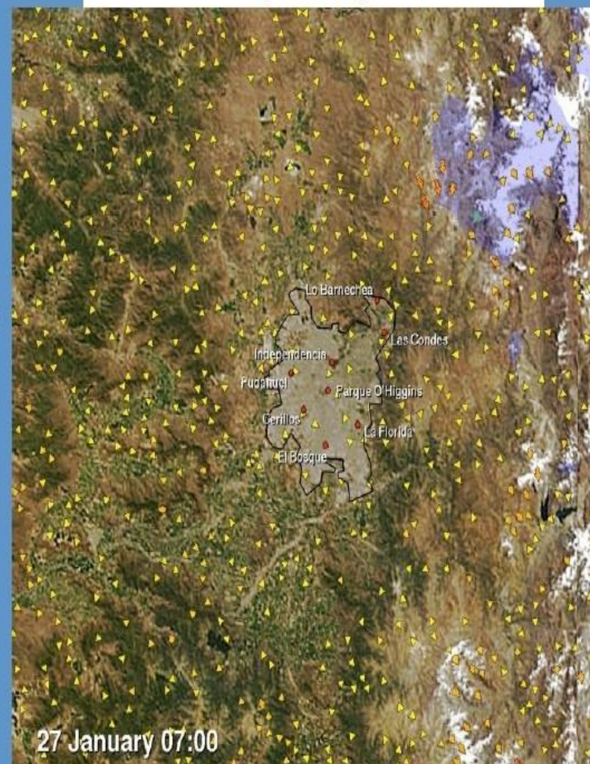
WRF-Chem

- WRF-Chem is the Weather Research and Forecasting (WRF) model coupled with Chemistry. The model simulates the emission, transport, mixing, and chemical transformation of trace gases and aerosols simultaneously with the meteorology. The model is used for investigation of regional-scale air quality, field program analysis, and cloud-scale interactions between clouds and chemistry. It is a state-of-the-art system for simulation and prediction of weather, climate, air quality and dispersion of pollutants.
- Current version of WRF-Chem (3.9.1) contains multiple parameterizations to simulate greenhouse gases, dust, fires, volcanoes, gas and aerosol chemistry (ranging from simple to more complex schemes), meteorology-chemistry interactions and so on.

WRF-Chem: Online coupling of modeling systems

Weather Data Analysis & Assimilation & Emissions

Simultaneous forecasts of weather and air quality



Chemistry, Aerosols, radiation, clouds, temperature, winds

Weather and AQ-Forecast

WRF-Chem: Download code

- For the setup of WRF-Chem one needs to download both WRF and chemistry codes from WRF web page: http://www2.mmm.ucar.edu/wrf/users/download/get_sources.html.
- Also the following libraries: NetCDF/HDF5, Jasper and PNG have to be installed. They are needed to work with specific types of files: NetCDF (v3 or v4) and GRIB (v1 or v2). All meteorological parameters, required for the model run are stored in that types of files.

WRF-Chem: Compile code

- Set environmental variables:

  Define which model core to build (use ARW only) - setenv EM_CORE 1 / export EM_CORE=1

  Include Chemistry code in WRF model - setenv WRF_CHEM 1 / export WRF_CHEM=1

  Use/(not use) Kinetic Pre-Processor (KPP) - setenv WRF_KPP 1(use) or setenv WRF_KPP 0 (no KPP)

  setenv FLEX_LIB_DIR /usr/lib Or export FLEX_LIB_DIR=/usr/lib

  setenv YACC ‘/usr/bin/yacc –d’ Or export YACC= ‘/usr/bin/yacc –d’

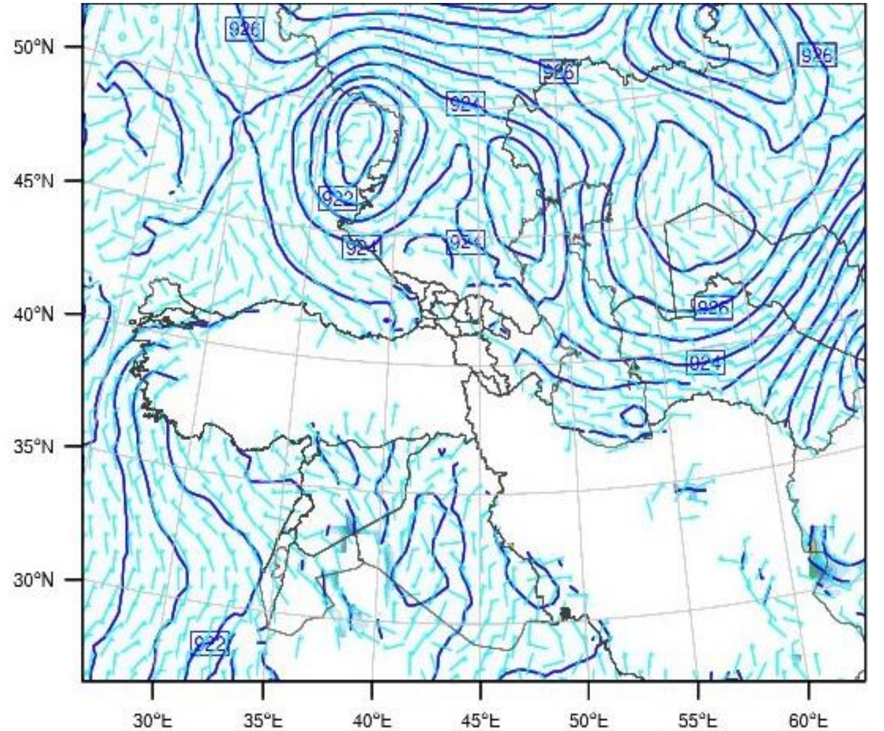
- Go to the WRV3 directory; configure and issue “compile em_real” command.
- Check if “real.exe and wrf.exe” files are created in WRFV3/main directory.
- Go to the WPS directory; configure and compile Preprocessing files: mainly “geogrid.exe, ungrib.exe and metgrid.exe”. For our purpose these 3 files are quite enough.

WRF-Chem: Run

- WRF-Chem modeling system follows the same structure as the WRF model by consisting of these major programs:
  - — The WRF Pre-Processing System (WPS)
  - — WRF-Var data assimilation system
  - — WRF solver (ARW core only) including chemistry
  - — Post-processing and visualization tools

Domain configuration

- One needs domains correct configuration to run WRF-Chem successfully.
- We use the following domains:
- Main domain: 26.90°E - 62.60°E with 100 grid points, 26.20°N - 51.60°N with 81 grid points, 40 vertical layers and horizontal resolution 37.2 km, Nested domain: with 14.2 km resolution, We chose such big domain to include in the domain all nearest dust sources (Central Asian and Syrian deserts). Especially Central Asian deserts are very important because of very frequent occurrences of the dust storms - more than 140 days in year (Orlovsky et al., 2005). Also to include that regions where the atmospheric processes formation (which are critical for Caucasus Region) take place.



Parameterization scheme

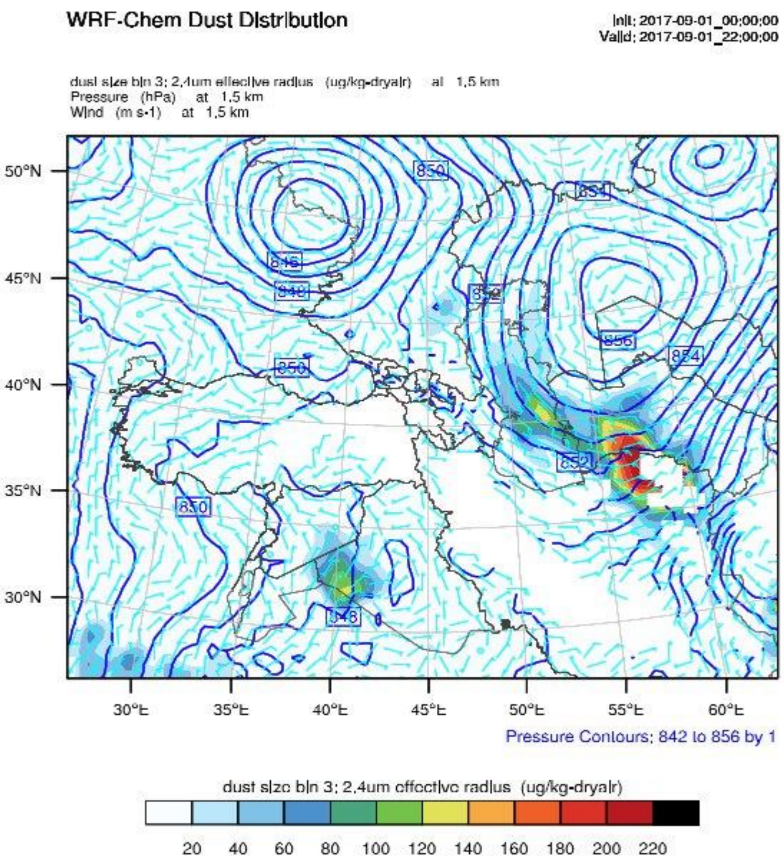
- We use the following parameterization scheme:
  - Lin microphysics scheme
  - RRTMG scheme for longwave and shortwave radiation transfer within the atmosphere and the surface
  - Eta similarity surface layer
  - RUC (pressure level data and hybrid coordinate data) land surface model
  - New Grell (G3) cumulus parameterization scheme
  - Eta operational (Mellor-Yamada-Janjic) scheme for planetary boundary layer
- Prognostic period is 48 hours.
- Chemistry parameters use Dust only value (chem_opt = 401).
- WRF-Chem model use GOCART (Ginoux et al., 2001) scheme to estimate dust sources. It calculates the dust emission flux online in the model by using the following expression:

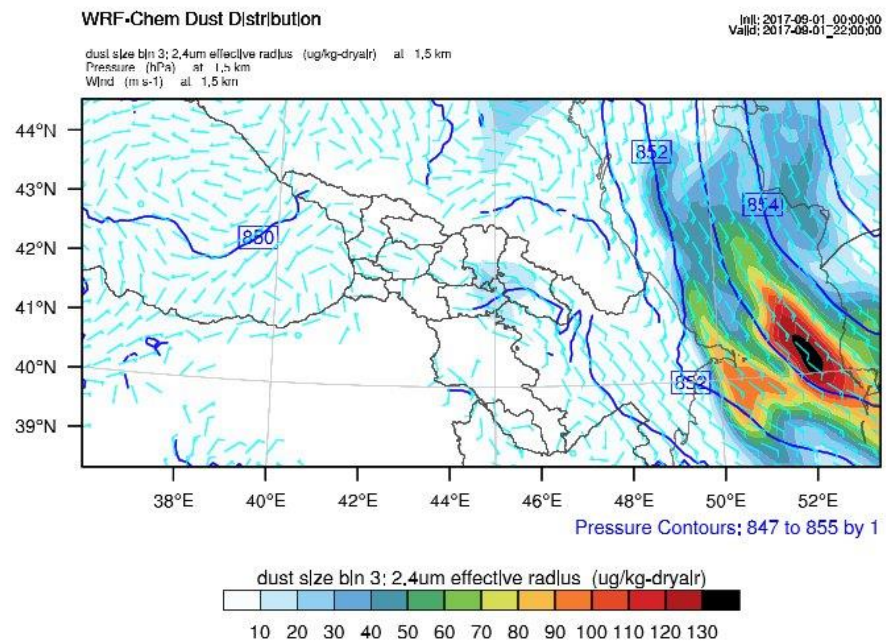
$$F_p = \begin{cases} CSs_p u_{10m}^2 (u_{10m} - u_t) & \text{if } u_{10m} > u_t \\ 0 & \text{otherwise} \end{cases}$$

- Where F_p(kg m^{-2} s^{-1}) represents the emission flux for size bin p, C is an empirical proportionality constant (kg m^{-5} s^2), S is the source function representing the fraction of alluvium available for wind erosion, s_p is the fraction of each size class of dust in the emission, u_{10m}(m s^{-1}) is the horizontal wind speed at 10m above the surface, and u_t is the threshold velocity (m s^{-1}) below which dust emission does not occur and is a function of particle size, air density and surface moisture. The value of C is proposed as 0.4–0.65×10^{-9} kg m^{-5} s^2 and u_t has value 5-10 (m s^{-1}) for the Central Asian Deserts.

WRF-Chem postprocessing

- Model results are used for the creation of prognostic maps of dust distribution.
- We use NCL (NCARG Command Language) for this purpose.





Acknowledgment and References

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- ***References***

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