Deliverable Number
DA04/4.3

Deliverable Name:
Operational DUST entrainment model, on-line implementation

DDr. Kurt Fedra
Environmental Software & Services GmbH
A-2352 Gumpoldskirchen, Austria

Due Date: PM 12, December 31, 2011

<table>
<thead>
<tr>
<th>Dissemination Level</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PU</td>
<td>Public</td>
</tr>
<tr>
<td>PP</td>
<td>Restricted to other program participants (including the Commission Services)</td>
</tr>
<tr>
<td>CO</td>
<td>Confidential, only for members of the Consortium (including Commission Services)</td>
</tr>
</tbody>
</table>
• **Introduction**

This Deliverable relates to Action/task A04/4.3, DUST entrainment model, which provides input to the CAMx (fate and transport) model.

The Deliverable has developed, implemented and tested a dynamic, distributed model for wind erosion of soils (dust entrainment). The deliverable was due December 2011, was started ahead of schedule in February 2011 with literature research and completed with the on-line availability of the DUST entrainment model by June 2011.

The DUST model is available both in a stand alone implementation for calibration and sensitivity analysis, as well as a module of the integrated model system, for both scenario analysis (validation runs) and the daily forecasts. The DUST model generates an hourly emission matrix that provides input to the 3D nested grid transport model CAMx, where it can be simulated either as a conservative species, or part of the photochemical aerosol modelling. The on-line manual pages for the DUST entrainment model can be found at [http://80.120.147.34/MANUALS/AIRWARE/dustent.html](http://80.120.147.34/MANUALS/AIRWARE/dustent.html)

• **Technical aspects of the deliverable**

All results and associated interactive model and analysis tools are accessible from the PM3 model home page: [http://www.ess.co.at/LIFE](http://www.ess.co.at/LIFE)

The DUST entrainment model uses the following principles, input data and parameters:

- Model basics: the entrainment model is a non-linear threshold model of wind speed acting on a source area of a given (dynamic) erodibility, that depends on soil, soil moisture, and land cover.
- Main input is dynamic (hourly) wind speed field, derived from the 1 km (diagnostic interpolation) of the 3 km hourly estimates from any dynamic, 3D prognostic model such as MM5 or WRF; the estimated average wind speed is converted into a distribution around the mean using a Weibull function (for a critical evaluation, see Celik et al., 2010); number of bins, shape parameter, and a cutoff level (expressed as a multiple of the mean) can be defined;
- Spatially distributed input data (at a 1 km resolution grid) include:
  - land use/land cover with an associated erodibility parameter, or NDVI data, normalized into the same range from 0 to 10.
  - soil type (default data derived from the FAO global soil data set); from the soil data, three fraction (coarse, medium, and heavy (fine) are derived, each with their own wind speed threshold, see below;
  - soil moisture, expressed as the fraction of water in the upper layer of the soil, computed by the prognostic meteorological model.
  - Slope and aspect (relative to the prevailing wind direction in each cell).
Model parameters also include

- soil moisture threshold (can be made soil type and fraction specific, depending e.g., on loam and clay fractions or soil organic content)
- wind speed thresholds for each of the three soil fractions;
- an exponent for the wind erosion speed dependency;
- linear scaling parameters for wind speed (input) and soil moisture;
- a linear calibration coefficient to correct overall bias.

**Detailed DUST model description**

The dust entrainment model is a distributed, (arbitrary resolution) dynamic (hourly time step) model to predict the wind erosion and entrainment of particles from natural surfaces. It produces dynamic emission matrices, that together with any anthropogenic emission data for point, line and area sources, provide input to the respective transport, dispersion, and deposition model used. In addition to the threshold friction velocity approach (e.g., Draxler et al. 2001) that uses geomorphology and soil properties, is also considers vegetation coverage and soil moisture as estimated by the MM5 prognostic meteorological model used to forecast wind velocities, and a Weibull function to generate distributed wind speeds around the predicted hourly mean. The dust entrainment model estimates non-pyrogenic dust emission from natural surfaces as a function of primarily wind speed, land cover/vegetation, soil characteristics, and soil moisture.

The total Dust PM10 emission [g/s/ha or km²] is calculated as the product of

1. WindFactor,
2. ErosionFactor (erodibility)

The **Wind factor**

is computed from average hourly (monitored or generated by MM5) ground level wind speed (m/s) using a Weibull function to generate a distribution of wind speeds and their relative frequency around that mean, as follows:

\[
\begin{align*}
\text{for } v > TR: f(v) &= (v - TR)^{**\text{EXP}} \\
\text{for } v < TR: f(v) &= 0 \\
\text{where } TR \text{ is the (user-defined) Wind Threshold,} \\
\text{and EXP is the (user-defined) Exponent} \\
\text{windFactor} &= \text{sum over all frequency classes of } ( f(v) \times \text{frequency}(v) ) \\
\text{frequency}(v) &= (k/c) \times \text{pow((v/c), (k-1))} \times \text{exp(-pow((v/c), k))} \\
\text{where } v \text{ is the wind speed, } k \text{ is the shape parameter, } c \text{ is the scale parameter of the Weibull distribution. The Weibull distribution is a continuous probability distribution, named after Waloddi Weibull, who described it in detail in 1951. The shape parameter } k \text{ is used defined s part of the model calibration. A user defined multiplier can be used to scale the original, hourly average wind speed.}
\end{align*}
\]
The Erosion factor

The erosion factor (erodibility) depends on:

- Vegetation index (NDVI), directly obtained from remote sensing data or land cover/land use (e.g., CORINE or USGS classification (see: http://edc2.usgs.gov/glcc/afdoc2_0.php#olso (chapter 4.2), with an NDVI range and default value associated with every land cover class); the NDVI estimates can be derived from MODIS satellite data (500 m resolution, 32 day average reflectance data). An alternative is a global data set from the Global Land Cover Facility (www.landcover.org) that covers the percentage of woody vegetation, herbaceous vegetation, and a bare ground percentage (source: http://glcf.umd.edu/data/vcf).

  The Vegetation Continuous Fields collection contains proportional estimates for vegetative cover types: woody vegetation, herbaceous vegetation, and bare ground. The product is derived from all seven bands of the MODerate-resolution Imaging Spectroradiometer (MODIS) sensor onboard NASA’s Terra satellite. GLCF editions of MODIS products differ from DAAC editions by coming in GeoTIFF format, geographic coordinates, WGS84 datum, and a tiling system designed to fit well with Landsat imagery. The continuous classification scheme of the VCF product may depict areas of heterogeneous land cover better than traditional discrete classification schemes. While traditional classification schemes indicate where land cover types are concentrated, this VCF product is great for showing how much of a land cover such as "forest" or "grassland" exists anywhere on a land surface.

- FAO soil type (that defines the fractions of coarse (sand) medium (silt) and fine (loam) soil components,

- slope, orientation (aspect),

- soil moisture for the top layer (computed by the prognostic meteorological model used e.g., MM5 or WRF), and in conjunction with drying/recently dried soils, saltation as a mechanical process to break up the crust and thus increase erodibility.

- Erodibility at soil moisture above the threshold is zero, below the threshold (drier soils) it increases according to:

  \[
  \begin{align*}
  \text{soil moisture} > \text{SMT} \% \Rightarrow \text{sm}\_\text{factor} &= 0 \\
  \text{soil moisture} < \text{SMT} \% \Rightarrow \text{sm}\_\text{factor} &= (\text{SMT} - \text{soil}\_\text{moisture}) \times \text{SMM}
  \end{align*}
  \]

  where

  \[
  \begin{align*}
  \text{SMT} &= \text{soil moisture threshold} \\
  \text{SMM} &= \text{soil moisture multiplier}
  \end{align*}
  \]
Model input data

Input data generated from MM5, hourly, 1 km resolution are

- average ground level (10m) wind speed, generated by dynamic downscaling from NCEP GFS global forecasting data or FNL re-analysis data sets for historical events or scenarios;

- hourly soil moisture (m3/m3) in the topmost soil layer used by MM5.
• **Land use or Land cover, NDVI, Soils**

  several alternative data layers can be used for the estimation of the erodibility factor (see above). This include land cover classification such as CORINE or the global USGS data set, where for each land cover or land use class, a range of landuse coefficient value is defined, within which the user can select a specific value for a scenario.

  Soil fractions are taken from the global FAO soil data base (HWSD, Harmonized World Soil Data Base); three fractions (coarse, medium, fine (heavy) are used, each with their own friction velocity threshold.

  The HWSD is a 30 arc-second raster database with over 16000 different soil mapping units that combines existing regional and national updates of soil information worldwide (SOTER, ESD, Soil Map of China, WISE) with the information contained within the 1:5 000 000 scale FAO-UNESCO Soil Map of the World (FAO, 1971-1981).

  The resulting raster database consists of 21600 rows and 43200 columns, which are linked to harmonized soil property data. The use of a standardized structure allows for the linkage of the attribute data with the raster map to display or query the composition in terms of soil units and the characterization of selected soil parameters (organic Carbon, pH, water storage capacity, soil depth, cation exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class and granulometry). Reliability of the information contained in the database is variable: the parts of the database that still make use of the Soil Map of the World such as North America, Australia, West Africa and South Asia are considered less reliable, while most of the areas covered by SOTER databases are considered to have the highest reliability.

For the vegetation index, we use the [see above, http://glcf.umd.edu/data/vcf, http://www.landcover.org] The Vegetation Continuous Fields collection contains proportional estimates for vegetative cover types: woody vegetation, herbaceous vegetation, and bare ground. The product is derived from all seven bands of the MODerate-resolution Imaging Spectroradiometer (MODIS) sensor onboard NASA's Terra satellite. The continuous classification scheme of the VCF product may depict areas of heterogeneous land cover better than traditional discrete classification schemes. While traditional classification schemes indicate where land cover types are concentrated, this VCF product is great for showing how much of a land cover such as "forest" or "grassland" exists anywhere on a land surface.

The blue color (no or very little bare ground) for the sea and the Northern part of the domain (Southern Europe) is segregated by a land-sea mask derived from the land cover data sets.
Alternative color coding and the use of the log of the index make the (numerical) differences of Southern Europe more visible; however, the extreme differences in bare (unvegetated) soils between the Northern and Southern parts of the domain and thus the different source characteristics are very obvious.

Compared to several alternative models described in the literature, DUST is certainly one of the most complex (number of inputs and processes) with the highest temporal resolution, but also sensitivity to the parameters (high level of non-linearity due to the multiple thresholds on time variable inputs.)
References and Selected Bibliography


Eolian Suspension Above the Saltation Layer, the Concentration Profile. Journal of Sedimentary Research, v74/2 pp 176-183

Hagen, L.J. (1998)

Hansen, M., R. DeFries, J.R. Townshend, M. Carroll, C. Dimiceli, and R. Sohliberg (2003),
Vegetation Continuous Fields MOD44B, 2001 Percent Tree Cover, Collection 3, University of Maryland, College Park, Maryland, 2001.

"Global Percent Tree Cover at a Spatial Resolution of 500 Meters: First Results of the MODIS Vegetation Continuous Fields Algorithm", Earth Interactions, Vol 7, No 10, pp 1-15.


Evidence of direct suspension of loessial soils on the Columbia Plateau. USDA ARS.

Marticorena, B., and Bergametti, G. (1995)

Stewart, D.A., and Essenwanger, O.M. (1978)
Frequency Distribution of Wind Speed Near the Surface. American Meteorological Society, 0021-8932/78/pp 1633-1642,

Stout, J. (1990)
Wind erosion within a simple field. Trans. Amer. Soc. Agric. Engin. 33(5) pp 1597-1600

**Tatarko, J. and Wagner, L. (2007)**

**Wagner, L.E. (1996)**
An Overview of the Wind Erosion Prediction System. Contribution from USDA-ARS in cooperation with Kansas Ag. Exp. Station, Contribution No.96-205 A.


**Woodruff, N.P. and Siddoway, F.H. (1965)**


Proof of deliverable

All components of the dust model, emission matrices, Weibull function, sensitivity analysis, and the integration in both scenario analysis (validation runs) and regular forecast runs are accessible on-line, linked from http://www.ess.co.ar/LIFE

Weibull distribution and the resulting entrainment values for different soil fractions

Vegetation index in the 4,800 km domain
medium soil texture

General Properties
- Name: Life - 4889 R 29.08.04
- Start date: 29.08.04
- Start time: 

Matrix Properties
- Cell size: 1000
- Components: 4
- Rows: 4000
- Columns: 4000

Matrix Statistics - Average over all timespans
- Average: 21
- Min: 11
- Total cumulative value: 2723782.6

Temporal Pattern (Averages)
- 

Data

soil type distribution: medium grained soils

heavy soil texture

General Properties
- Name: Life - 4889 R 29.08.04
- Start date: 29.08.04
- Start time: 

Matrix Properties
- Cell size: 1000
- Components: 4
- Rows: 4000
- Columns: 4000

Matrix Statistics - Average over all timespans
- Average: 2.0
- Max: 4.0
- Total cumulative value: 1272732.0

Temporal Pattern (Averages)
- 

Data

soil type distribution: fined grained (heavy) soils
Entrainment estimate for Cyprus (exaggerated for demonstrations to compensate high soil moisture values in March; larger emissions are only expected in summer with high temperatures and longer periods without precipitation).
Entrainment components (dust) in the overall emission scenario (example from the calibration runs)