Dust Storm Simulation with the Regional Air Quality Forecast Model EURAD

*Hristo Chervenkov [1], **Hermann Jakobs[2]***

[1] *National Institute of Meteorology and Hydrology – Bulgarian Academy of Sciences, Russki blvd. 139, 4000 Plovdiv, Bulgaria*

hristo.tchervenkov@meteo.bg

[2] ***Rhenish Institute for Environmental Research (RIU)***

Aachener Str. 209, 50931 Köln, Germany

Hermann.Jakobs@eurad.uni-koeln.de

Overview

- **Description of the dust storm event**
  - **Comparison: forecast ↔ observation**
  - **high measurements of PM10 values in Central Europe**
  - **Satellite measurements indicate dust storm**

- **Numerical treatment of dust emission for the EURAD model**

- **Results of different szenarios**

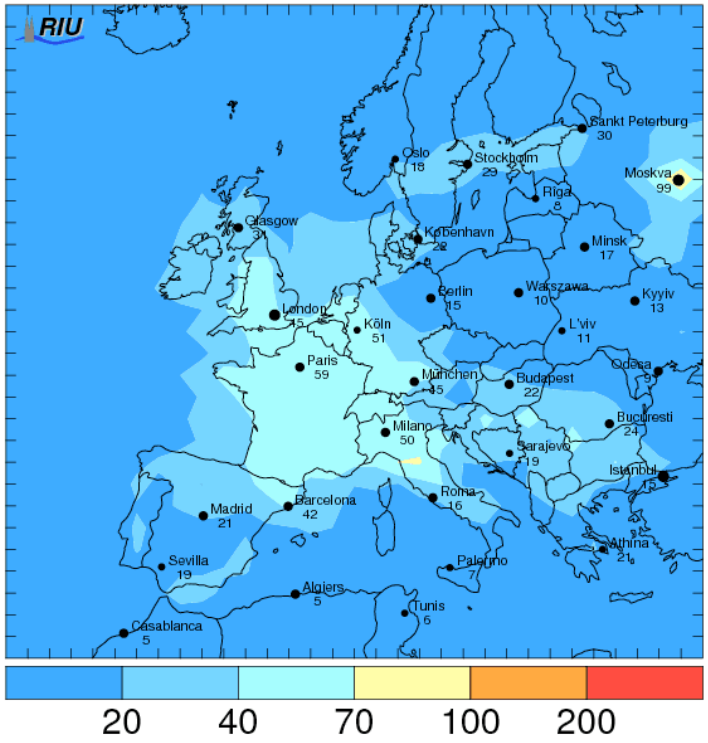
cost

http://www.chemicalweather.eu/

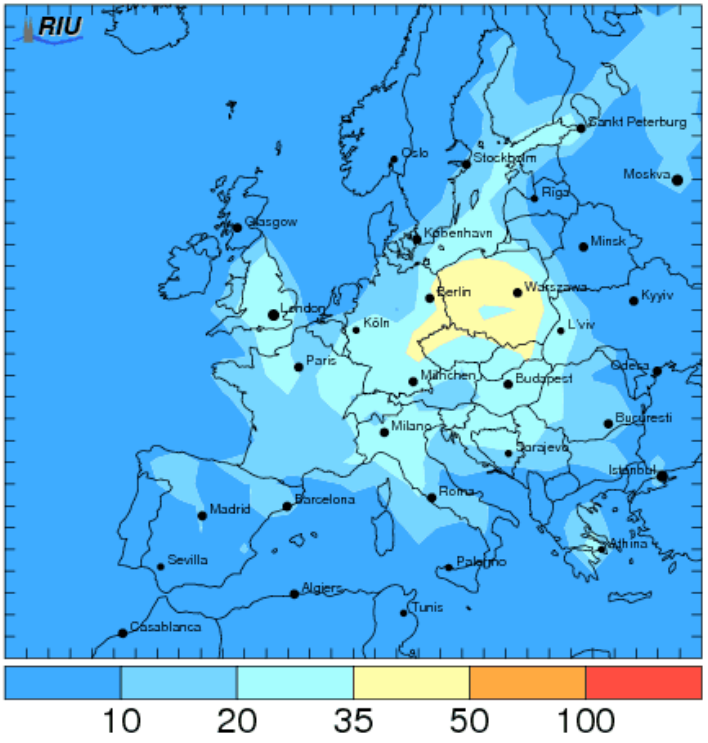
Description of the dust event March 23-25, 2007

Forecast: PM10 (daily Max., animated 24h mean)

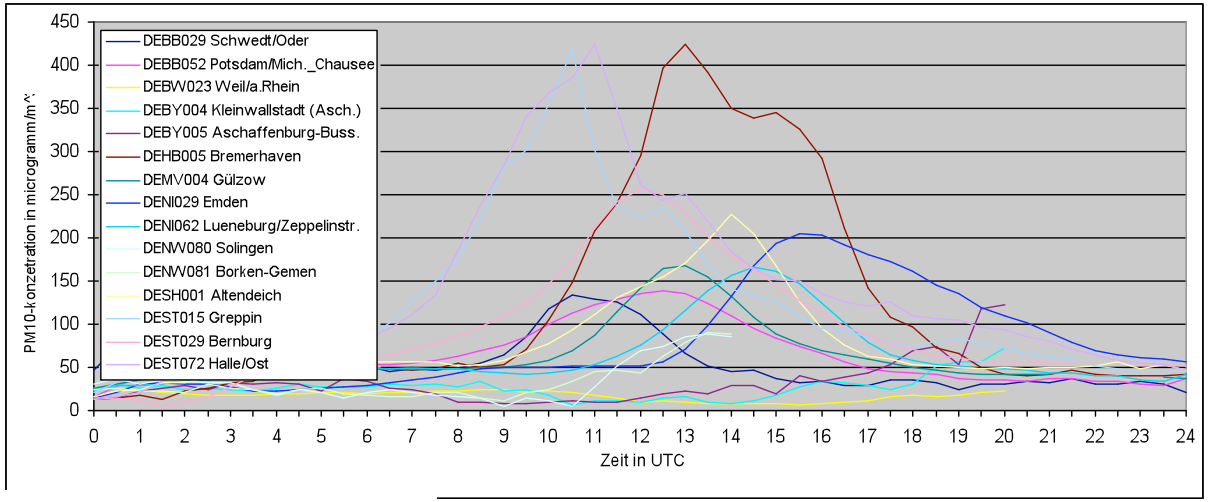
PM10 µg/m³ Level 1 24.03.2007 Daily Maximum

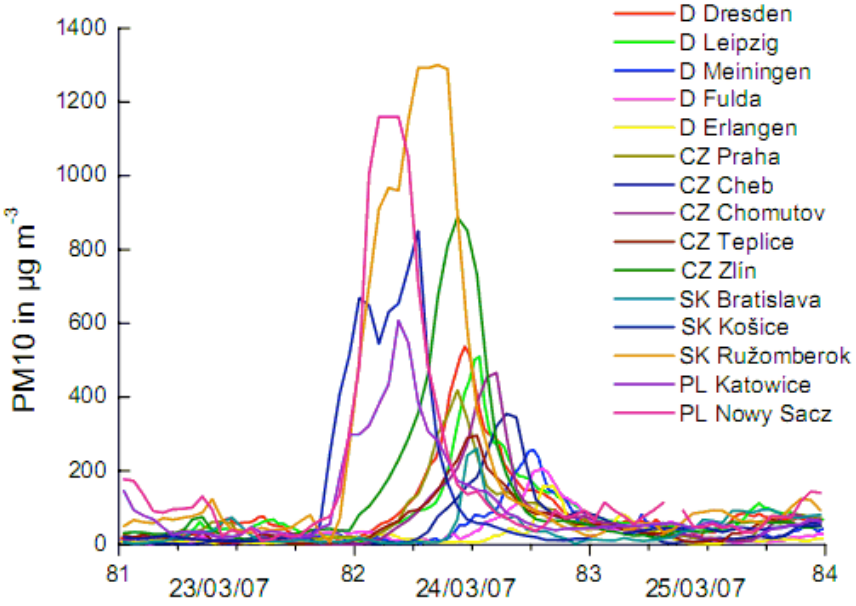


PM10 µg/m³ Level 1 23.03.2007 Daily Mean



Description of the dust event March 23-25, 2007



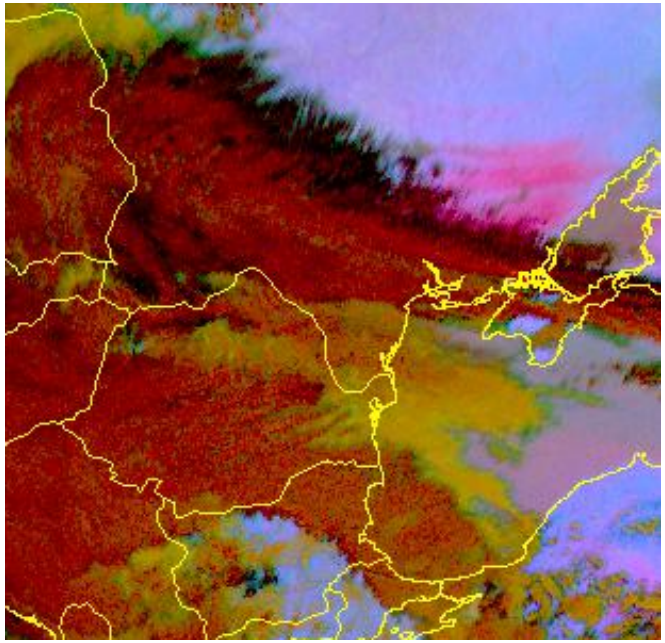


Above: PM10 concentration for some German stations at 24 March 2007
Left: measurements in DE, CZ, SK and PL (after Birmili et al., 2008)
Note: values higher than 1000 µg/m³

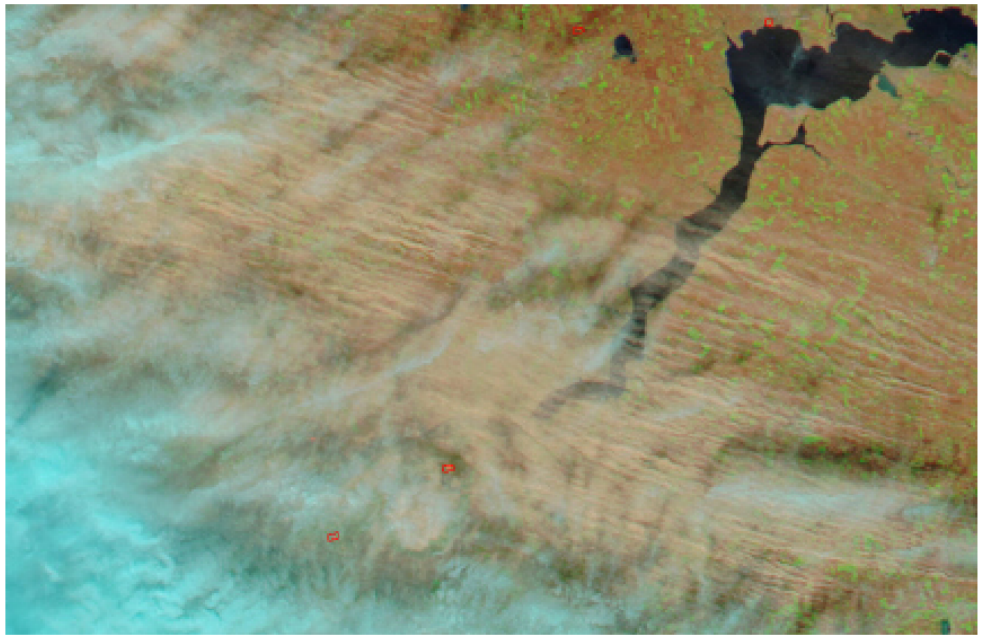
www.riu.uni-koeln.de

Description of the dust event March 23-25, 2007

Satellite images:



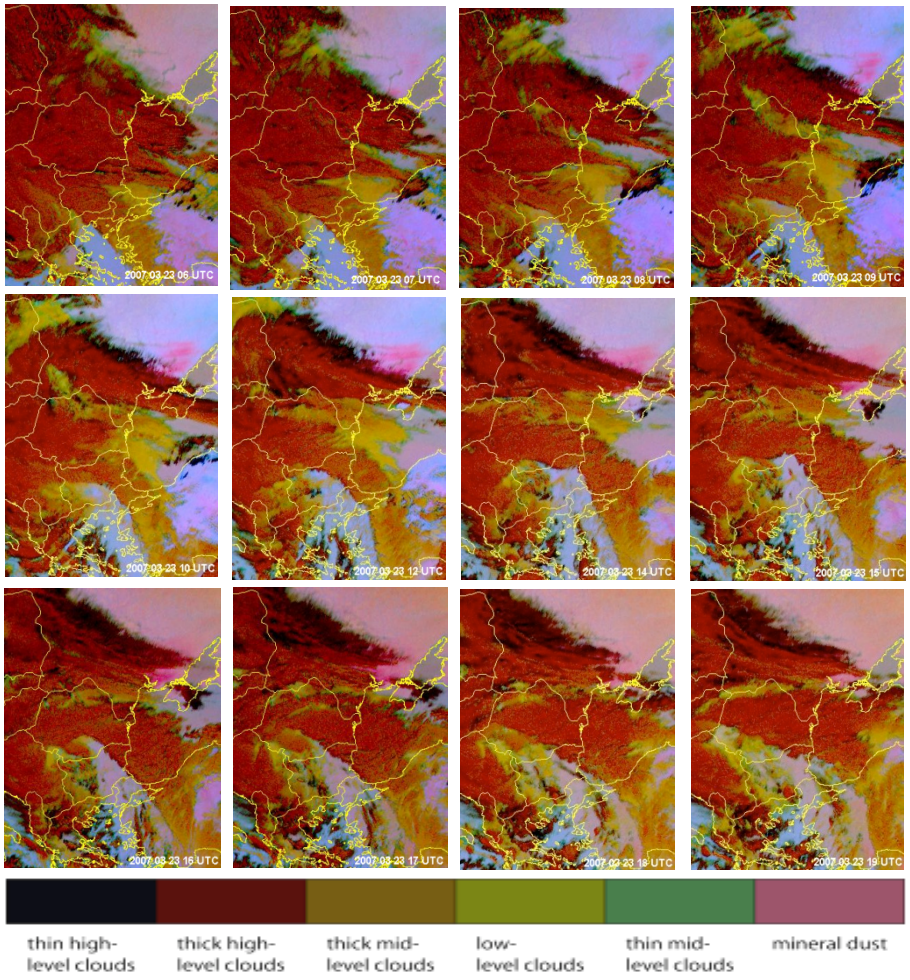
EUMETSAT“dust RGB” image one hour after the dust source activation (23.03.2007 12 UTC).



MODIS composite image over South Ukraine 23.03.2007 10:50 UTC

Description of the dust event March 23-25, 2007

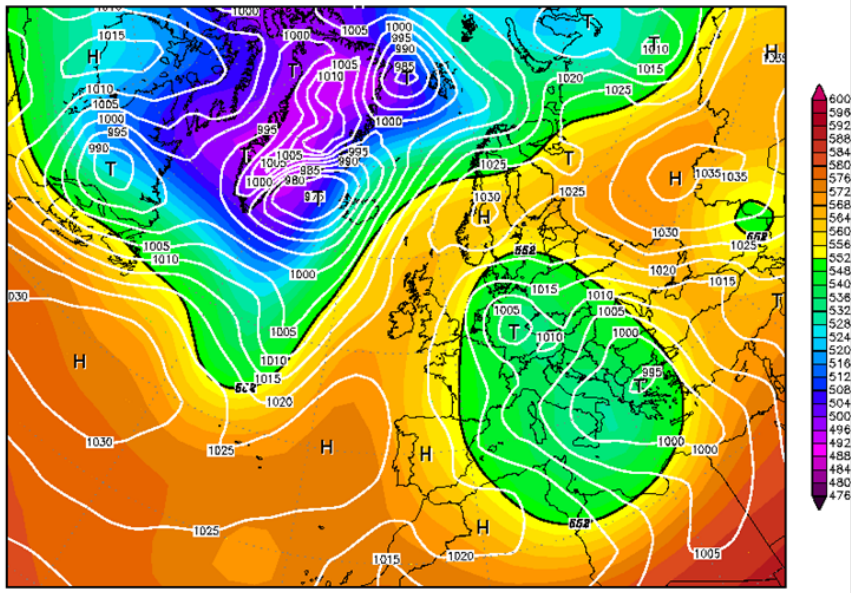
Satellite images:



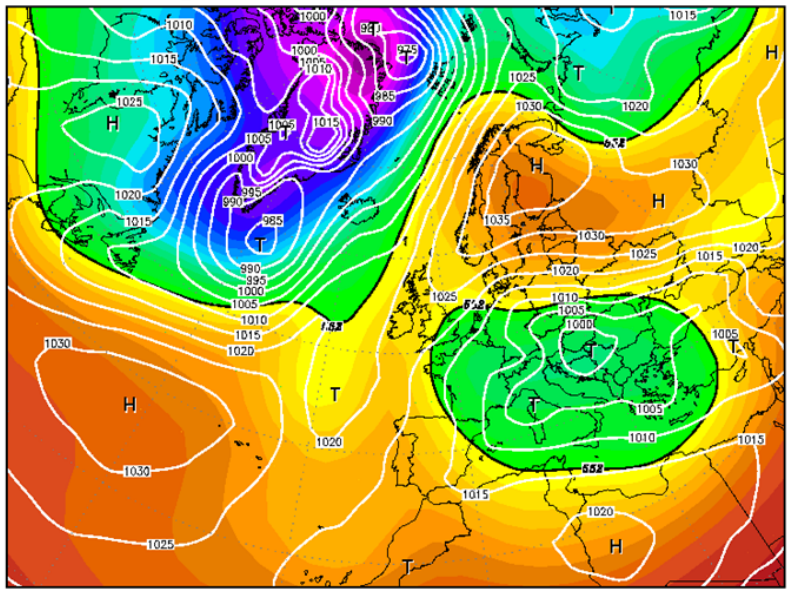
EUMETSAT‘s “Dust-RGB“ (R: IR 12.0-IR10.8; G:IR10.8-IR8.7; B: IR 10.8) figures at 23.03.2007 from 6 UTC to 19 UTC (NIMH-BAS Archive)

Meteorological Situation March 23-25, 2007

NCEP Reanalysis 500 hPa Geopotential and surface pressure



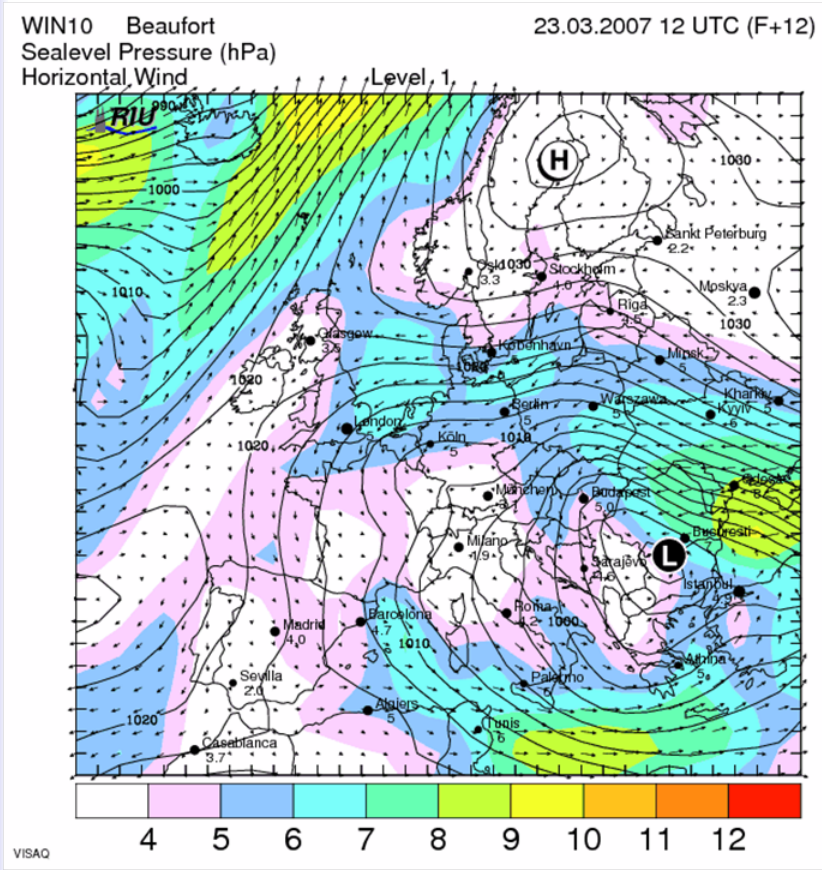
23 March 2007 00 UTC



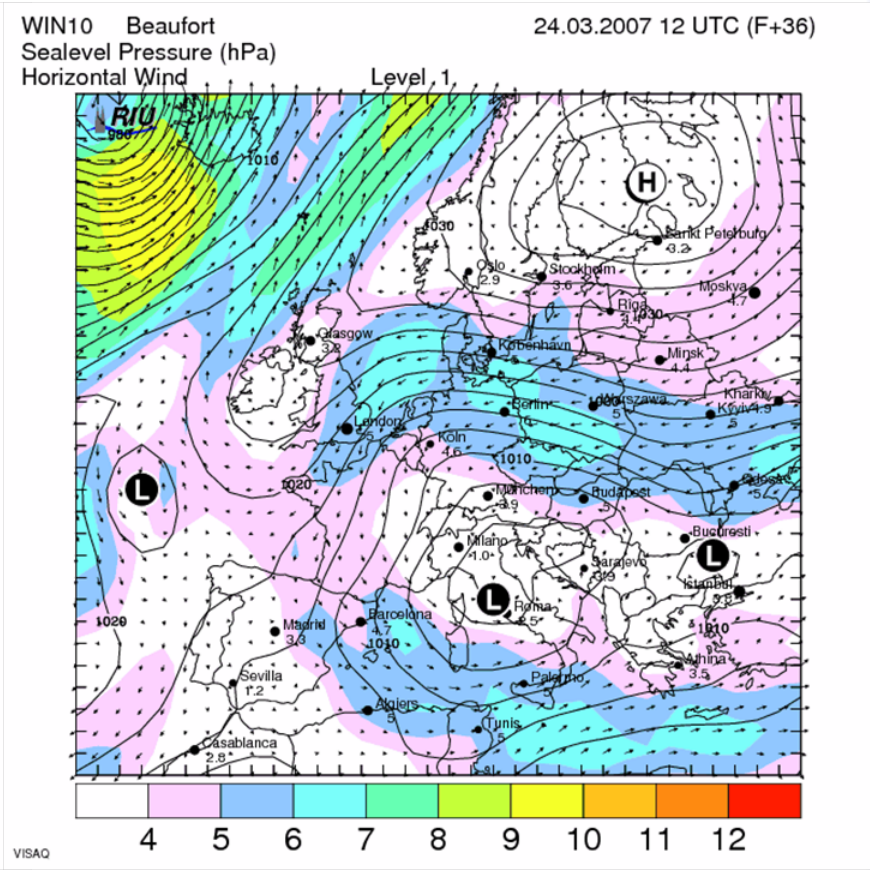
24 March 2007 00 UTC

Meteorological Situation March 23-25, 2007

EURAD MM5 forecast: 10m Wind and seal level pressure



23 March 2007 12 UTC

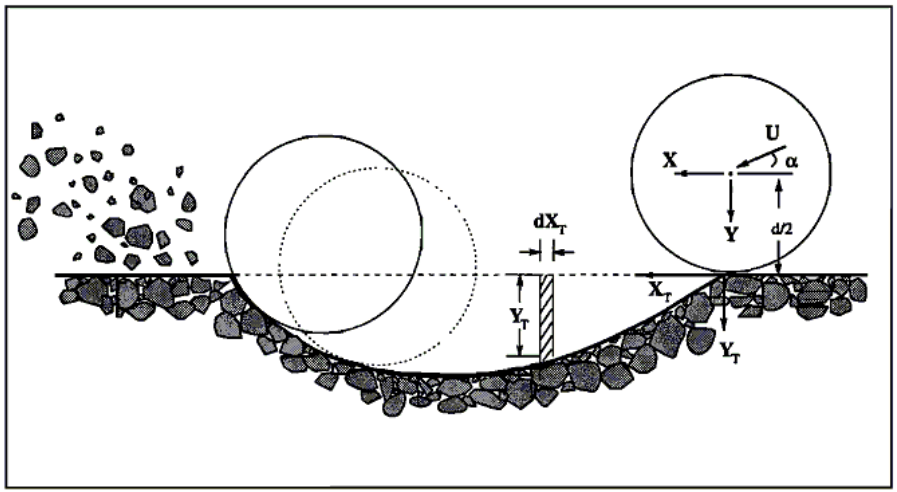


24 March 2007 12 UTC

Dust Emission parameterization

Shao, 2001; Shao et a., 2007

- **Process of saltation**
  - where relatively big (mainly sand) particles that are easily lifted from the surface impact on the ground
  - The release of kinetic energy breaks the binding of finer soil particles like clay



An illustration of volume removal process by saltation bombardment. A saltating particle ploughes through the soil, creates a small crater, and ejects particles into the air. (from Y.Shao "*A model for mineral dust emission*"JGR, VOL. 106, NO. D17, pp. 20,239-20,254, SEPT. 16, 2001)

Dust Emission parameterization

The main mechanism for dust emission is widely consider to be saltation bombardment and aggregates desintegration. Dust emission schemes based on this assumption has the following form

$$\tilde{F}(d_i, d_s) = \alpha(d_i, d_s) Q(d_s)$$

$\tilde{F}$ is dust emission rate for the *ith* particle group of size d_i generated by the saltation of particles of size d_s,

α is a coefficient depending both on and . Empirical expressions based on wind tunnel experiments have been proposed and the order of magnitude of α is 10^{-5} m^{-1}.

$Q(d_s)$ is the so-called (streamwise) saltation flux – a quantity, proportional to the intensity of the saltation bombardment.

Dust Emission parameterization

$$\tilde{F}(d_i, d_s) = c_y \eta_{fi}[(1-\gamma)+\gamma\sigma_p](1+\sigma_m)\frac{gQ(d_s)}{u_*^2}$$

where c_y is a dimensionless coefficient and γ is a function specified as $\gamma = \exp[-(u_* - u_{*t})^3]$;

g is acceleration due to gravity and u_* is friction velocity

σ_m is the ratio between m (mass of impacting particle) and m_Ω (mass ejected by bombardment), which can be interpreted as bombardment efficiency. σ_p is the ratio of free dust to aggregated dust ratio, i.e.

$$\sigma_p = \frac{\eta_{mi}}{\eta_{fi}} = \frac{p_m(d_i)}{p_f(d_i)},$$

Here $p_m(d_i)$ and $p_f(d_i)$ are the minimally disturbed soil particle-size distribution and the fully disturbed soil particle-size distribution for a given soil.

Dust Emission parameterization

The Owen's formula is used for the calculation of the saltation flux:

$$Q(d_s) = \begin{cases} c_0 \sigma \frac{\rho_a}{g} u_*^3 \left(1 - \frac{u_{*t}^2}{u_*^2}\right) & u_* \geq u_{*t} \\ 0 & u_* \prec u_{*t} \end{cases},$$

where σ is the fraction of erodible area, ρ_a is the air density and c_0 is dimensionless coefficient (~1).
With threshold friction velocity u_{*t}

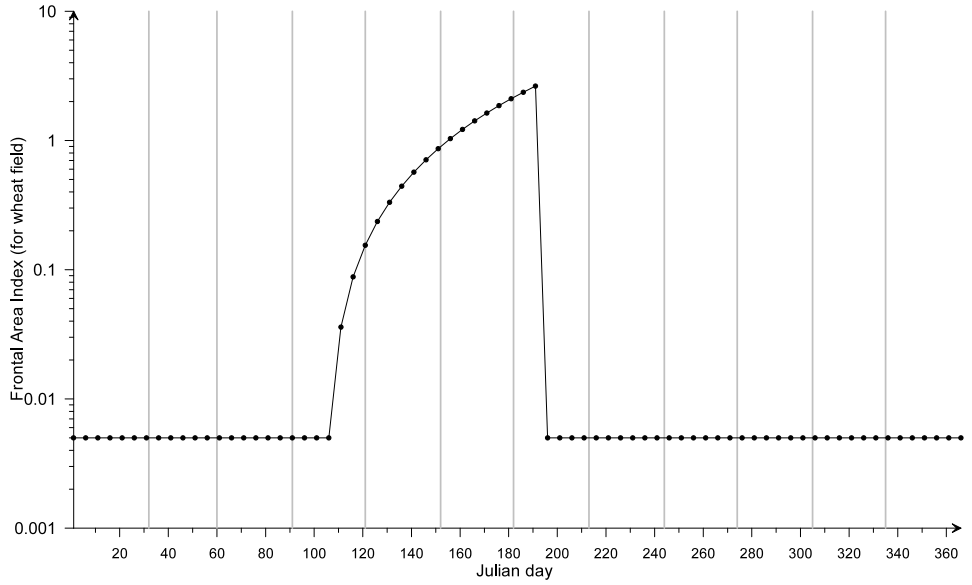
$$u_{*t}(d_s; \lambda, \theta, sl, c_r) = u_{*t}(d_s) f_\lambda(\lambda) f_w(\theta) f_{sc}(sl) f_{cr}(cr)...,$$

The terms f_λ, f_w, f_{sc} and f_{cr} are the correction functions for surface-roughness elements, soil moisture, salt concentration and surface crust, respectively. The frontal area index (FAI) λ is the area projected into the flow by the roughness elements per unit ground area, also known as the roughness density.

Dust Emission parameterization

Dust emission is effective (summary)

- strong winds: $u_* > u_{*t}$
- particle density
- dry soil
- soil roughness



Implementation of dust emission within EURAD

- Simulation with some known geographical data about the dust event (a posteriori – “case 1”)
- Simulation without any known data about the dust event (a priori – “case 2”)
- Simulation (sensitivity study) with higher soil moisture (“case 3”)

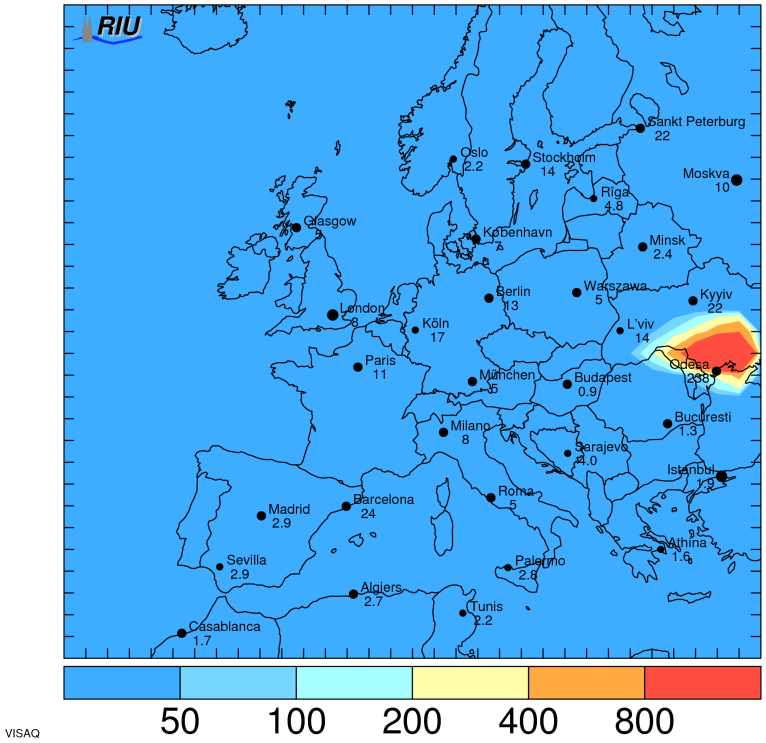
Within Domain N0 (Europe)

International Workshop on Air Quality Forecasting Research

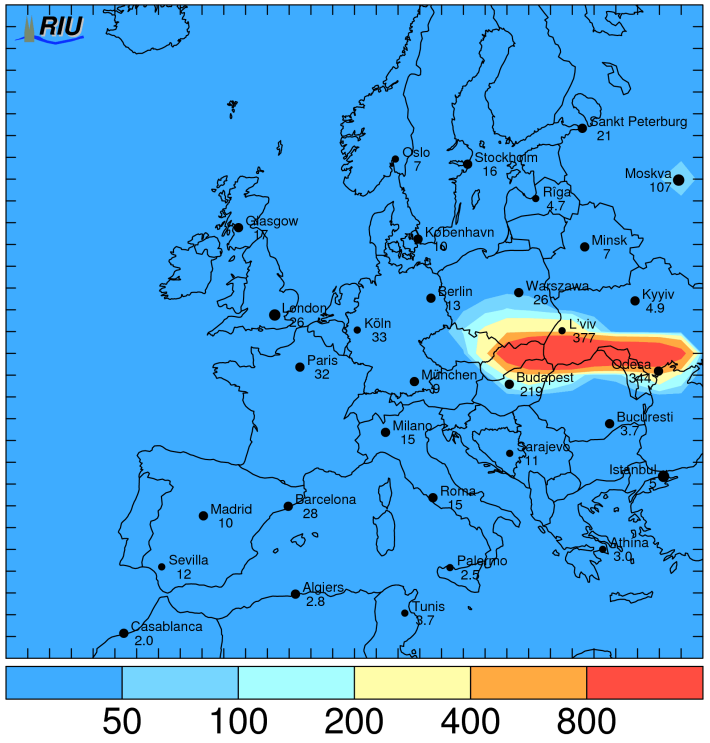
Implementation of dust emission within EURAD

Case 1, Europe

PM10 µg/m³ Level 1 23.03.2007 12 UTC (F+12)

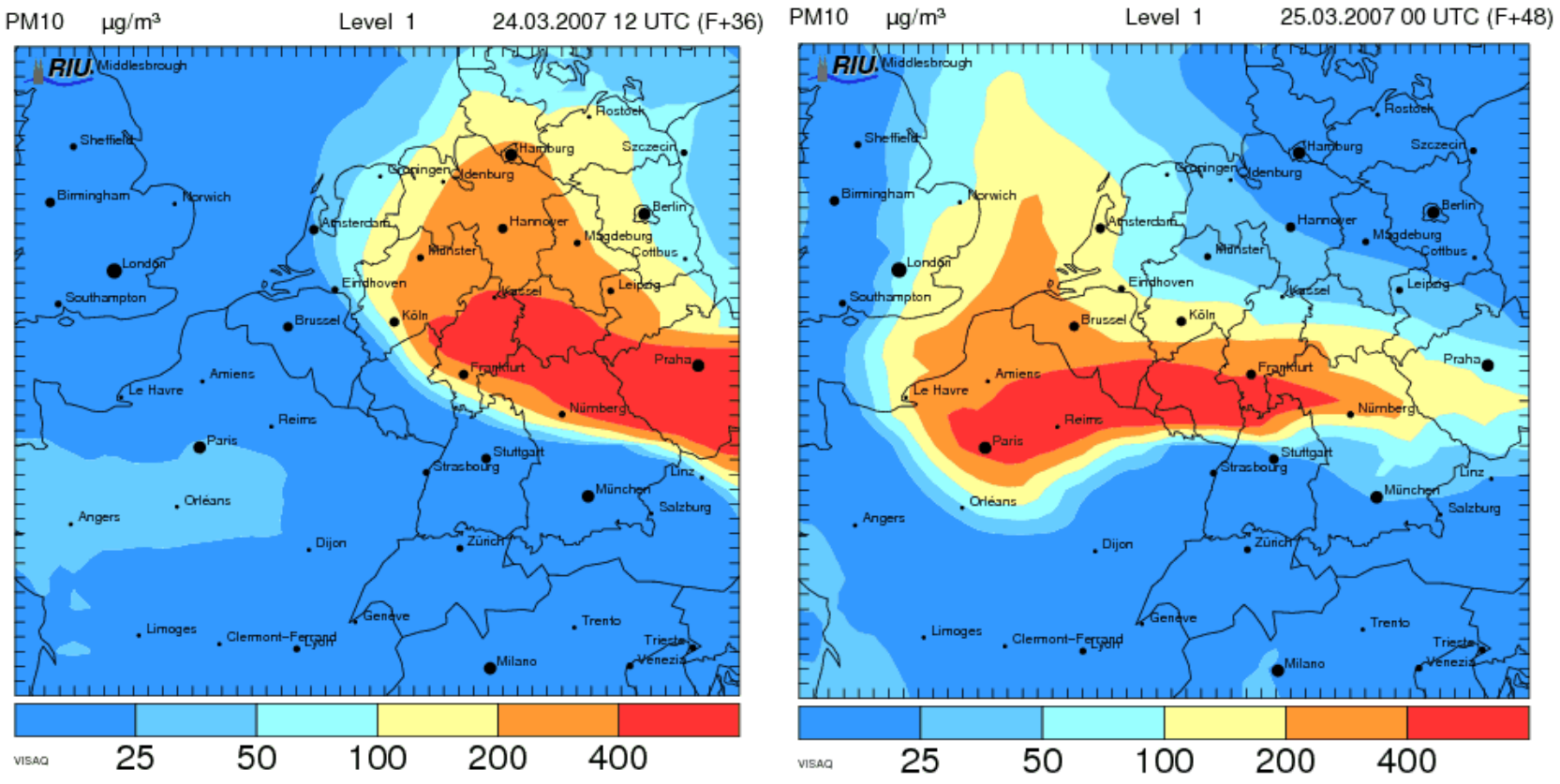


PM10 µg/m³ Level 1 24.03.2007 00 UTC (F+24)



Implementation of dust emission within EURAD

Case 1, Central Europe

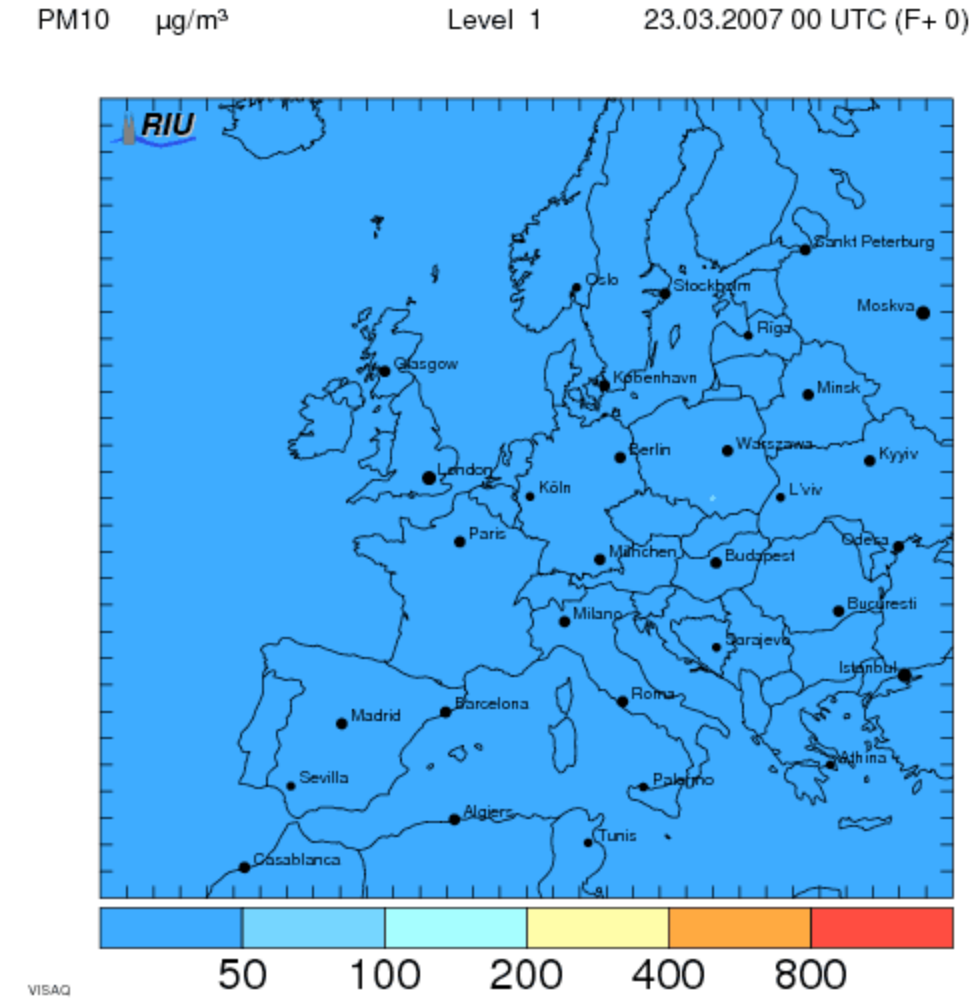


Implementation of dust emission within EURAD

Case 1, Europe

Animation

23.03.2007

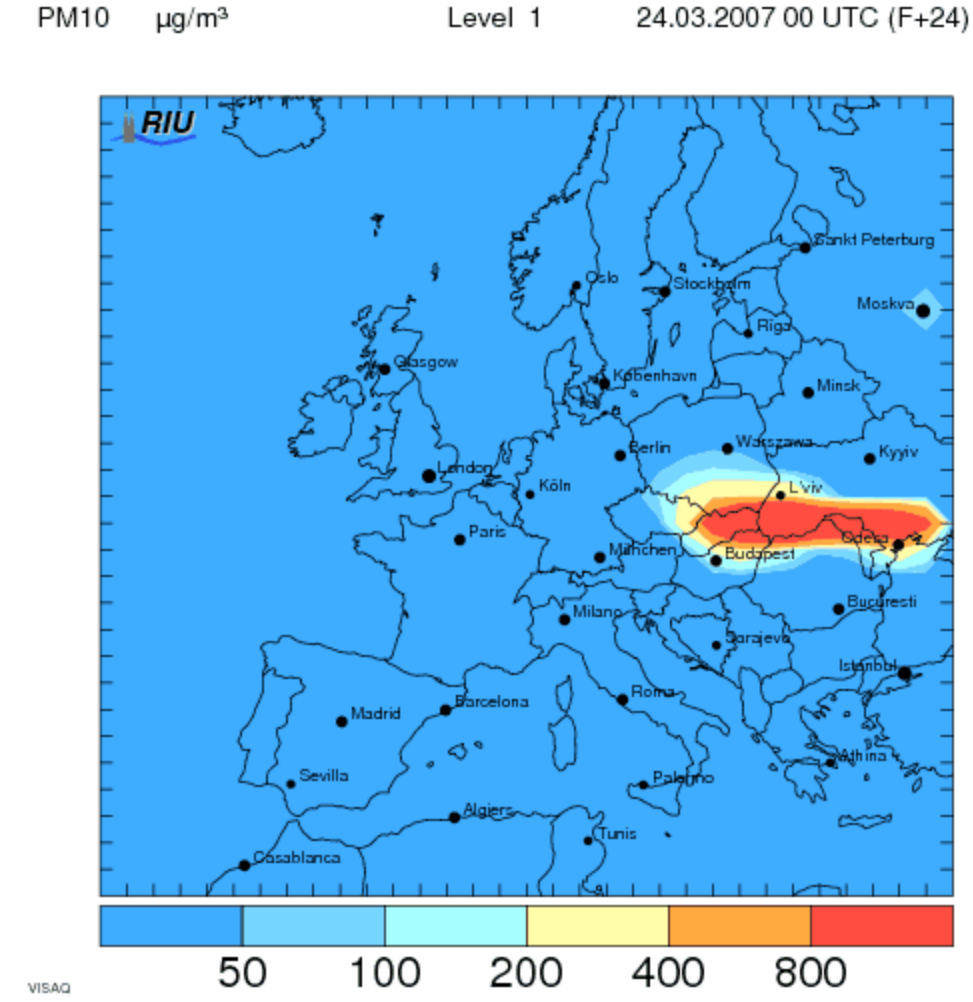


Implementation of dust emission within EURAD

Case 1, Europe

Animation

24.03.2007

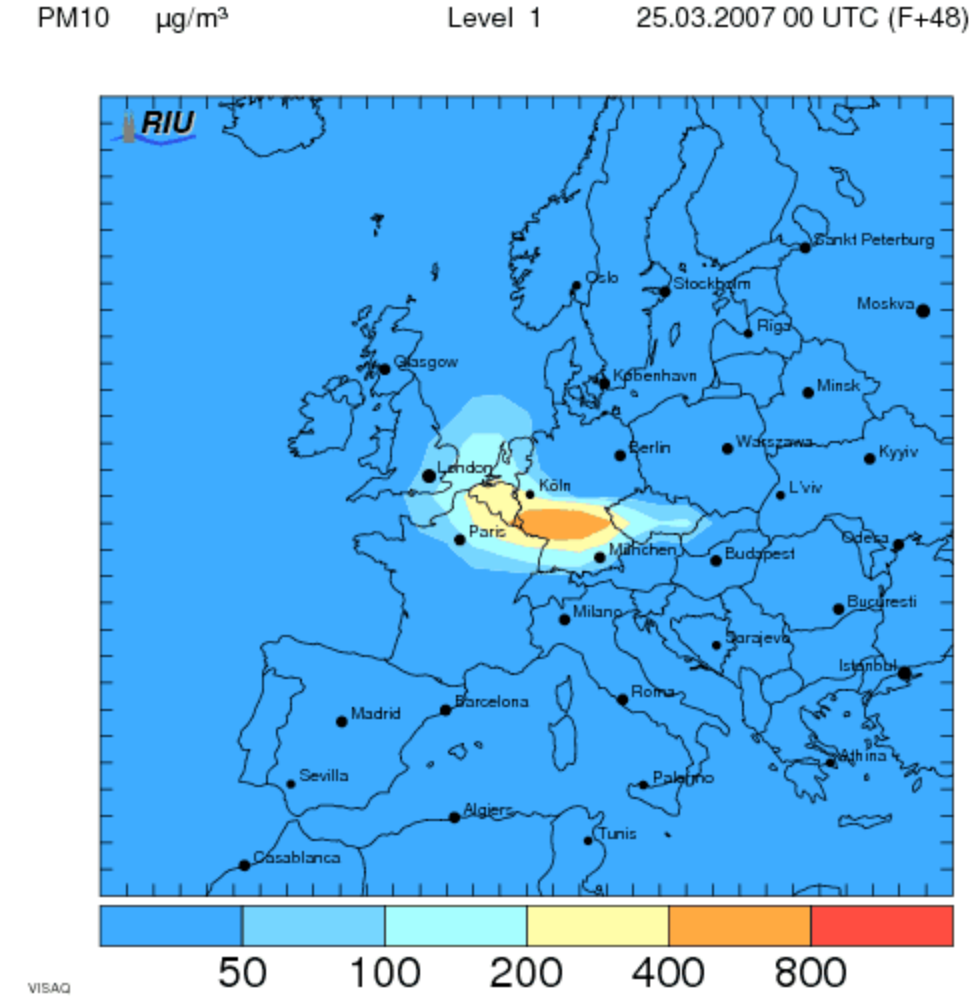


Implementation of dust emission within EURAD

Case 1, Europe

Animation

25.03.2007

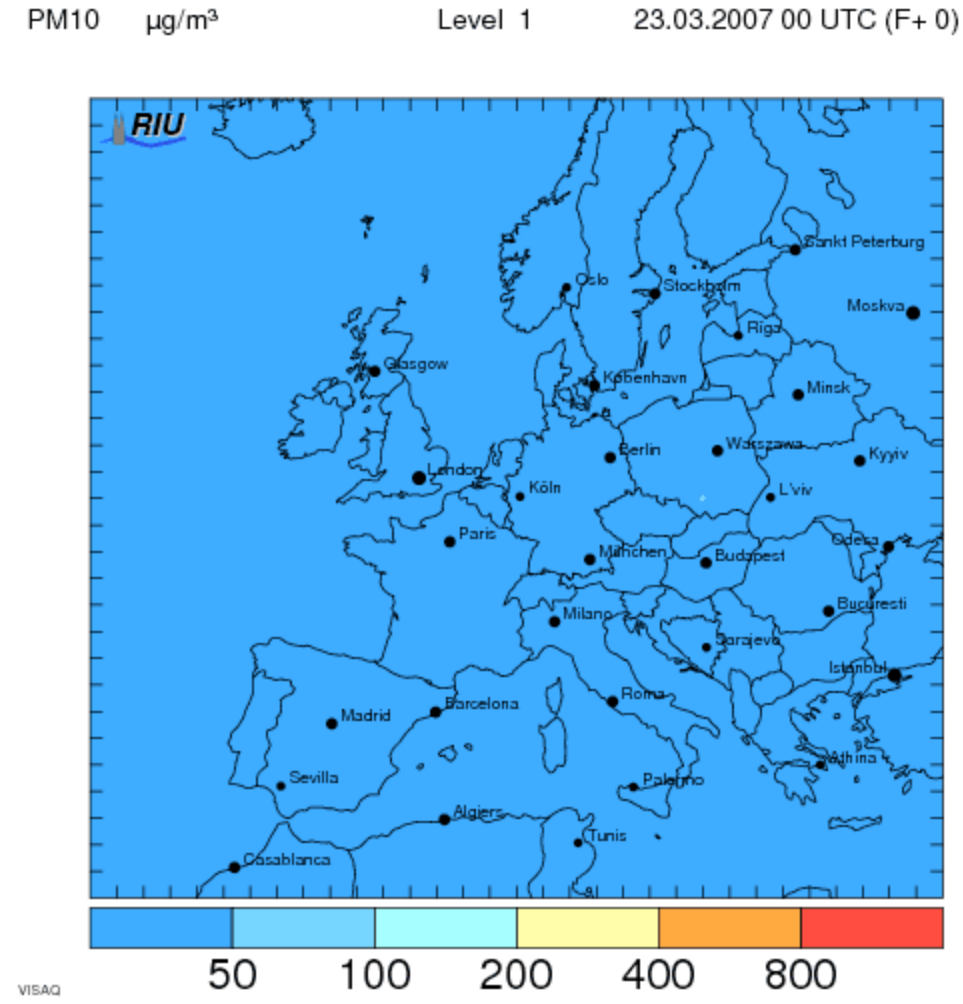


Implementation of dust emission within EURAD

Case 2, Europe

Animation

23.03.2007

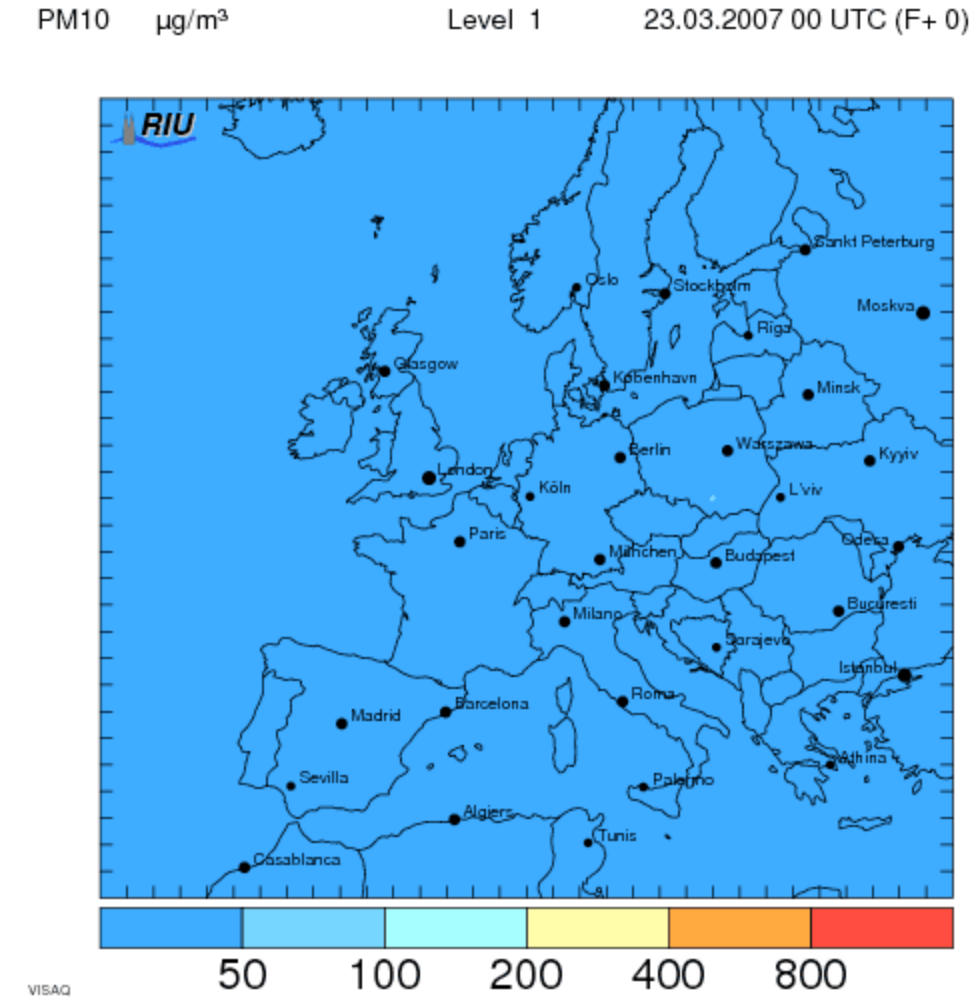


Implementation of dust emission within EURAD

Case 3, Europe

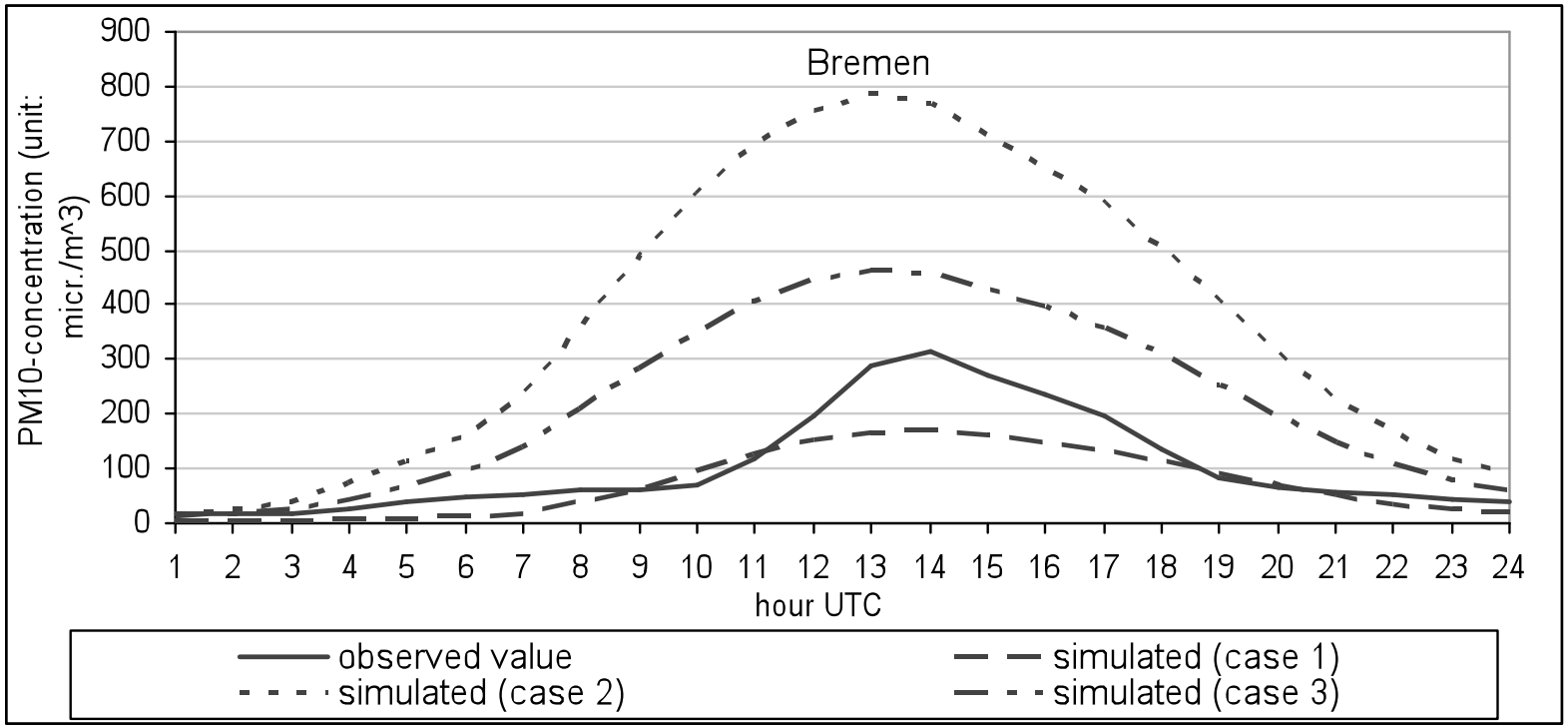
Animation

23.03.2007



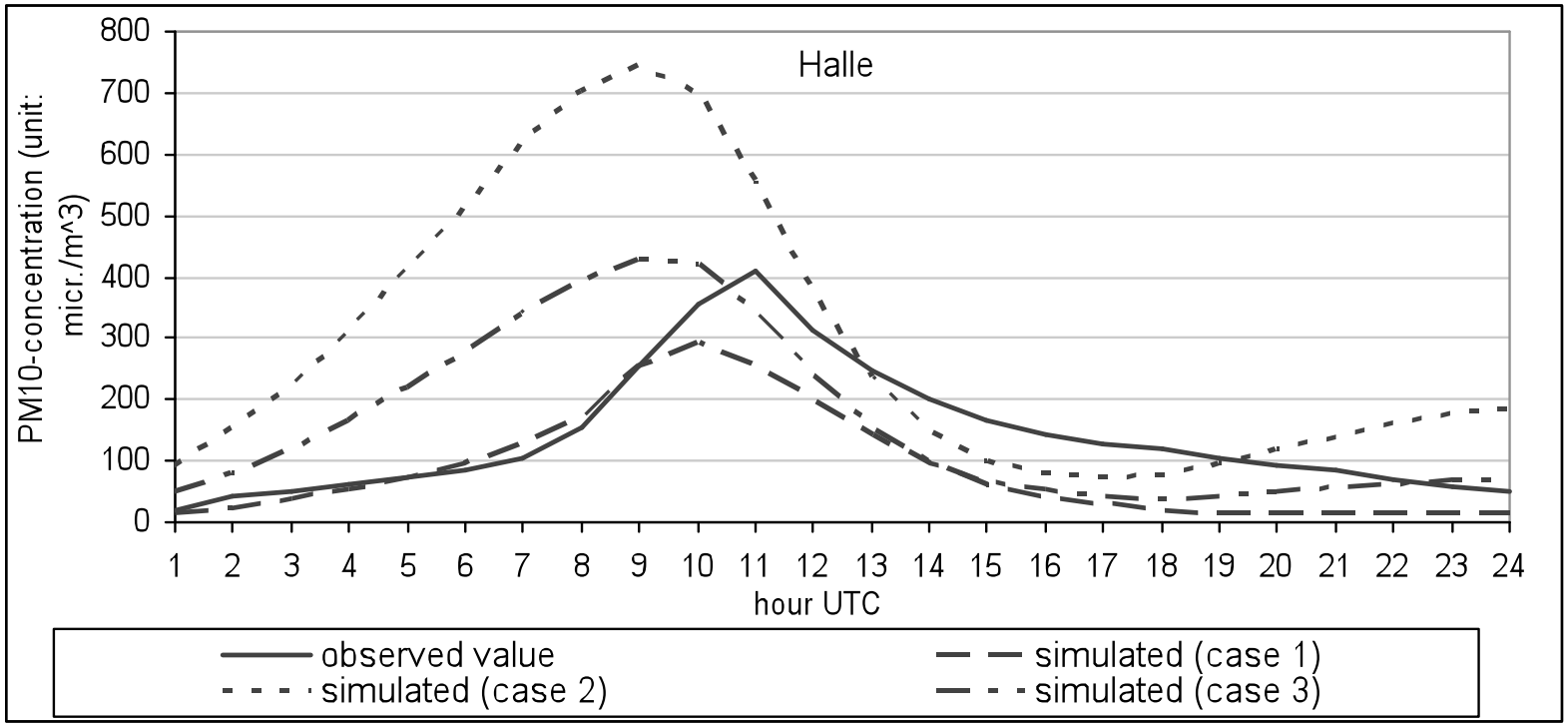
Implementation of dust emission within EURAD

Comparison of the cases: Bremen



Implementation of dust emission within EURAD

Comparison of the cases: Halle



Summary

- Observation of a heavy dust transport over Europe
- Use of dust emission parameterization
- Implementation within the EURAD model
- Reasonable good performance within the forecast mode of the EURAD model
- Use for future dust events