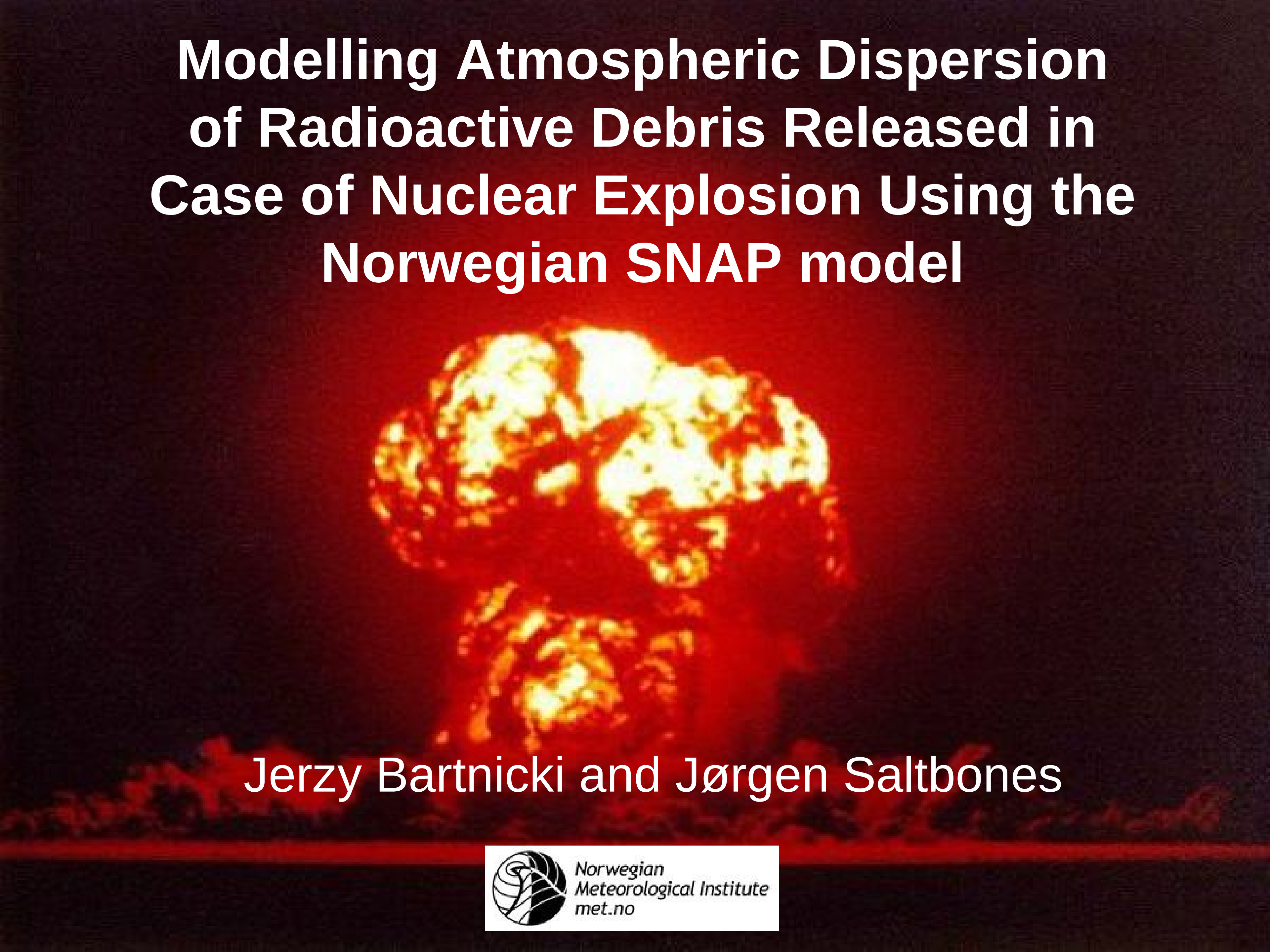
Modelling Atmospheric Dispersion of Radioactive Debris Released in Case of Nuclear Explosion Using the Norwegian SNAP model



Jerzy Bartnicki and Jørgen Saltbones

Norwegian
Meteorological Institute
met.no

Background

- Chernobyl accident in 1986
- Contamination of Norwegian territory
- Threats from other potential sources (e.g. Kola)
- Threat from potential terrorists attack
- Cooperation with Norwegian Radiation Protection Authority
- Cooperation with Nordic partners and EU

Main questions in case of nuclear accident or explosion outside Norway:

- Will the radioactive cloud reach Norway?
- If yes, when will the cloud reach Norway?
- What will be concentrations and depositions?

Tools to answer:

- Meteorological analysis e.g. trajectories
- **Norwegian operational dispersion model SNAP**
- Nordic cooperation (backup and uncertainty)
- ENSEMBLE (backup and uncertainty)

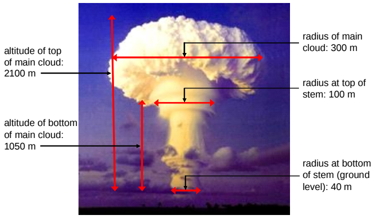
SNAP model - general

- Main ideas from UK NAME model
- Lagrangian particle model
- Gases, noble gases, particles of different size and density
- Advection and diffusion (Random Walk)
- Dry deposition (gravitational settling velocity for particles)
- Wet deposition (function of size and precipitation for particles)
- Meteorological input from HIRLAM 10 or 20 and from ECMWF

Applications

- Simulations of Chernobyl accident
- ETEX I and II
- Operational applications (met.no + NRPA)
- METNET project
- ENSEMBLE project
- BOMB version

- Historical simulations (Novaya Zemlya)



Bomb version – source term

Parameters for the cylinder, for the radioactive cloud shortly after the explosion and activities for explosive yield classes. Single cylinder cloud shape (from Person et al., 2000)

Explosive yield (ktonnes)	**Base of the Cylinder (km)**	**Top of the cylinder (km)**	**Radius of the cylinder (km)**	**Activity (Bq)**
1	0.50	1.50	0.6	2×10^{19}
10	2.25	4.75	1.4	2×10^{20}
100	5.95	12.05	3.2	2×10^{21}
1000	10.00	25.00	8.5	2×10^{22}

Bomb version – source term

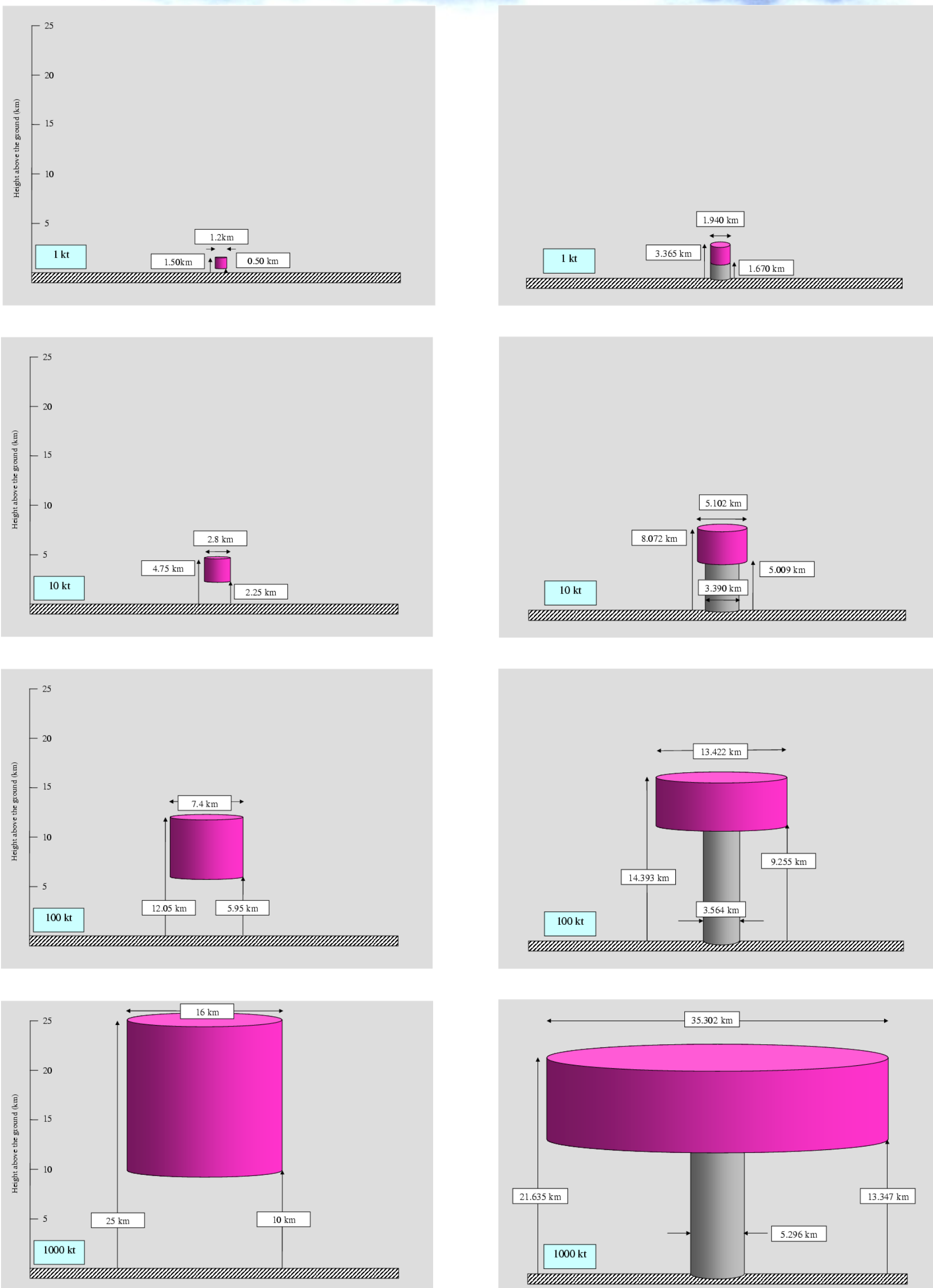
Parameters for two cylinders for the radioactive cloud shortly after explosion. **Mushroom** cloud shape. Activities are the same as in previous Table (from Sofiev et al., 2004)

Explosive yield (ktonnes)	Base of the upper cylinder (km)	Top of the upper cylinder (km)	Radius of the lower cylinder (km)	Radius of the upper cylinder (km
1	1.67	3.365	0.97	0.97
10	5.009	8.072	1.695	2.551
100	9.255	14.393	1.782	6.711
1000	13.347	21.635	2.648	17.651

Bomb version – source term

Particle size classes and corresponding parameters used in the SNAP model calculations. Note: we have assumed an equal share of the activity to each size class.

Class No.	Range of the particle radius (μm)	Activity share (%)	Gravitational settling velocity (cm/s)	Radius (μm) used for estimation of sedimentation velocity
1	0 - 3	10	0.2	2.2
2	3 -6.5	10	0.7	4.4
3	6.5 – 11.5	10	2.5	8.6
4	11.5 - 18.5	10	6.9	14.6
5	18.5 - 29	10	15.9	22.8
6	29 - 45	10	35.6	36.1
7	45 - 71	10	71.2	56.5
8	71 - 120	10	137.0	92.3
9	120 - 250	10	277.3	173.2
10	≥ 250	10	direct deposition	-



Bomb version – source term

Initial shapes of the radioactive cloud shortly after explosion for 1, 10, 100 and 1000 ktonnes yield. Cylinder type on the left, mushroom on the right.

Dry deposition

In the model equations we have assumed that model particles located above the mixing height level are not affected by the dry deposition process. Reduction of activity *A*, for each model particle located within the mixing height, due to dry deposition after time Δ*t* can be calculated as:

$$A(t+\Delta t) = A(t) \cdot e^{-k_d \cdot \Delta t}$$

$$k_d = \frac{v_d}{h}$$

Percent of activity remaining in the model particle after one model time step (min.) with dry deposition only, for each of 10 particle size classes.

Wet deposition (1)

$$A(t+\Delta t) = A(t)\cdot e^{-k_w \cdot \Delta t}$$

The coefficient of wet deposition k_w is a function of the particle radius r and the precipitation intensity q (Baklanov and Sørensen, 2001):

$r \le 1.4\mu m$	$k_w = a_0 \cdot q^{0.79}$
$1.4\mu m < r \le 10\mu m$	$k_w = (b_0 + b_1 \cdot r + b_2 \cdot r^2 + b_3 \cdot r^3)\cdot f(q)$
$r \ge 10\mu m$	$k_w = f(q)$

$$f(q) = a_1 \cdot q + a_2 \cdot q^2$$

$$a_0 = 8.4 \cdot 10^{-5}$$

$$a_1 = 2.7 \cdot 10^{-4}$$

$$a_2 = -3.618 \cdot 10^{-6}$$

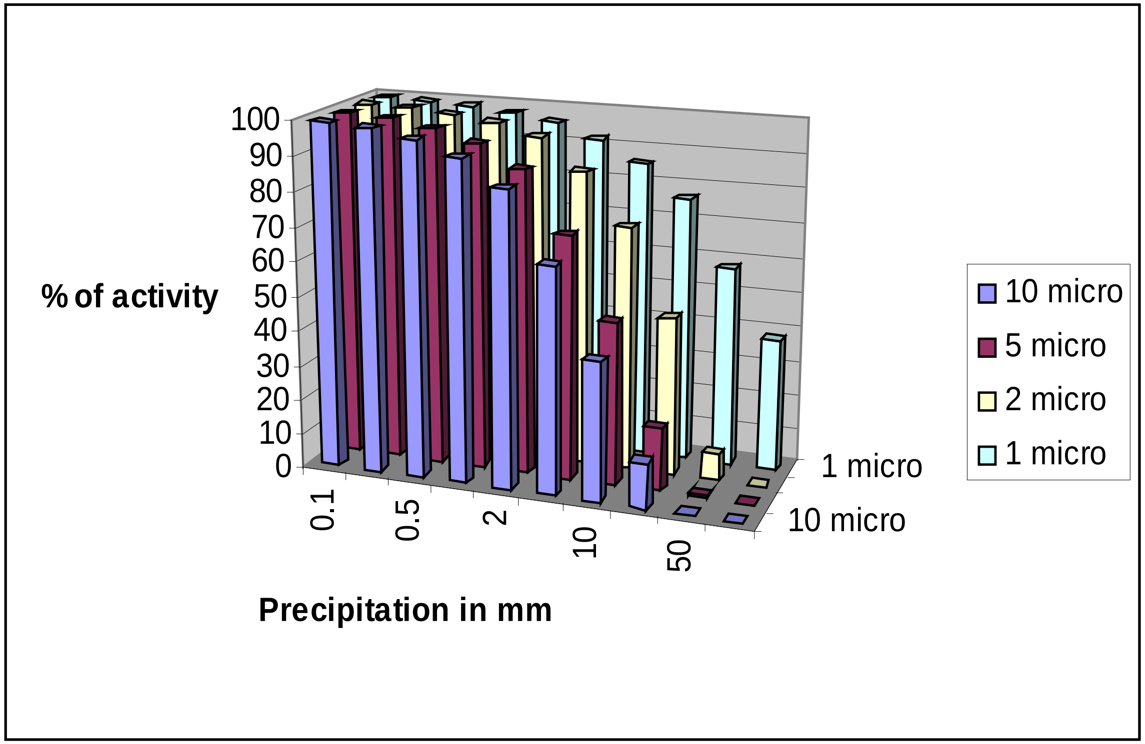
$$b_0 = -0.1483$$

$$b_1 = -3.220133$$

$$b_2 = -3.0062 \cdot 10^{-2}$$

$$b_3 = 9.34458 \cdot 10^{-4}$$

Wet deposition (2)



Percent of activity remaining in the particle after one model time step with wet deposition only, for four particle classes.

Simulations

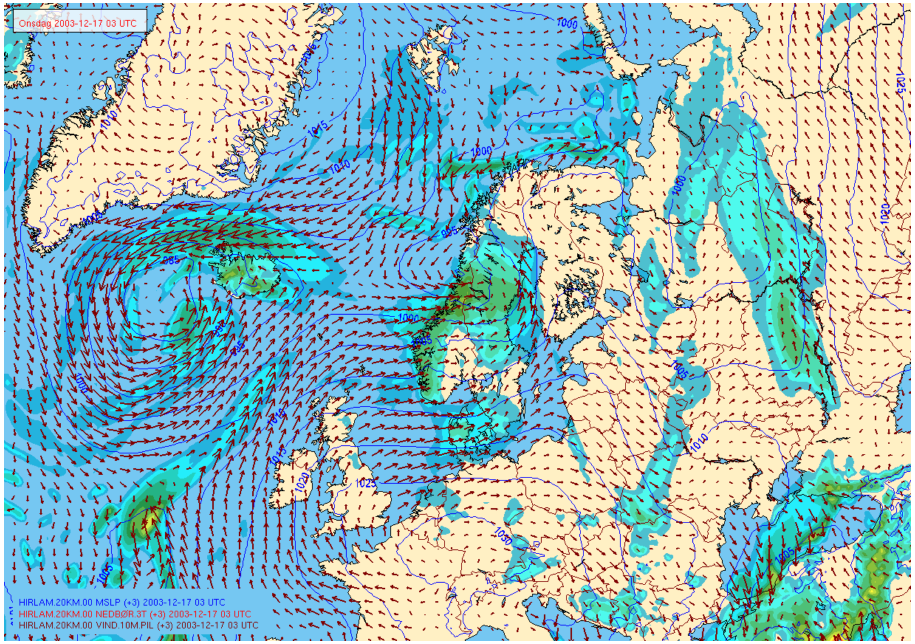
(1) In the first example, the SNAP model has been used to simulate a hypothetical nuclear explosion north of Scotland on 17 December 2003 at 00 UTC. Forecasted meteorological situation (wind, MSLP and precipitation) indicated transport of radioactive debris to the east passing southern Norway

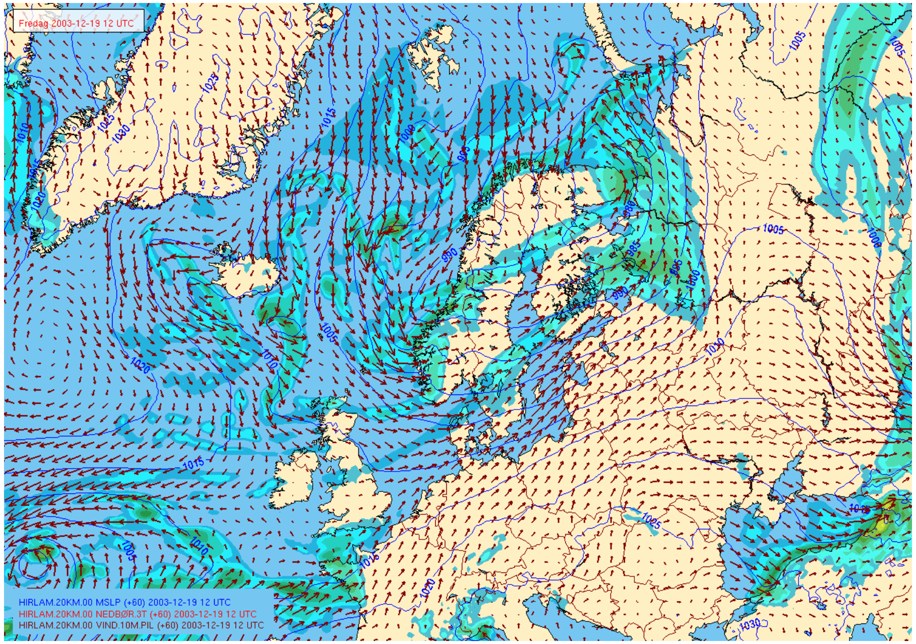
(2) In the second example of simulation, the SNAP model has been used to simulate a hypothetical nuclear explosion, taking place near Jan Mayen. The main goal of this simulation was a comparison of the results for two different initial shapes of the radioactive cloud: cylinder and a mushroom shape.

Simulation (1) – meteorology

3 hrs after explosion

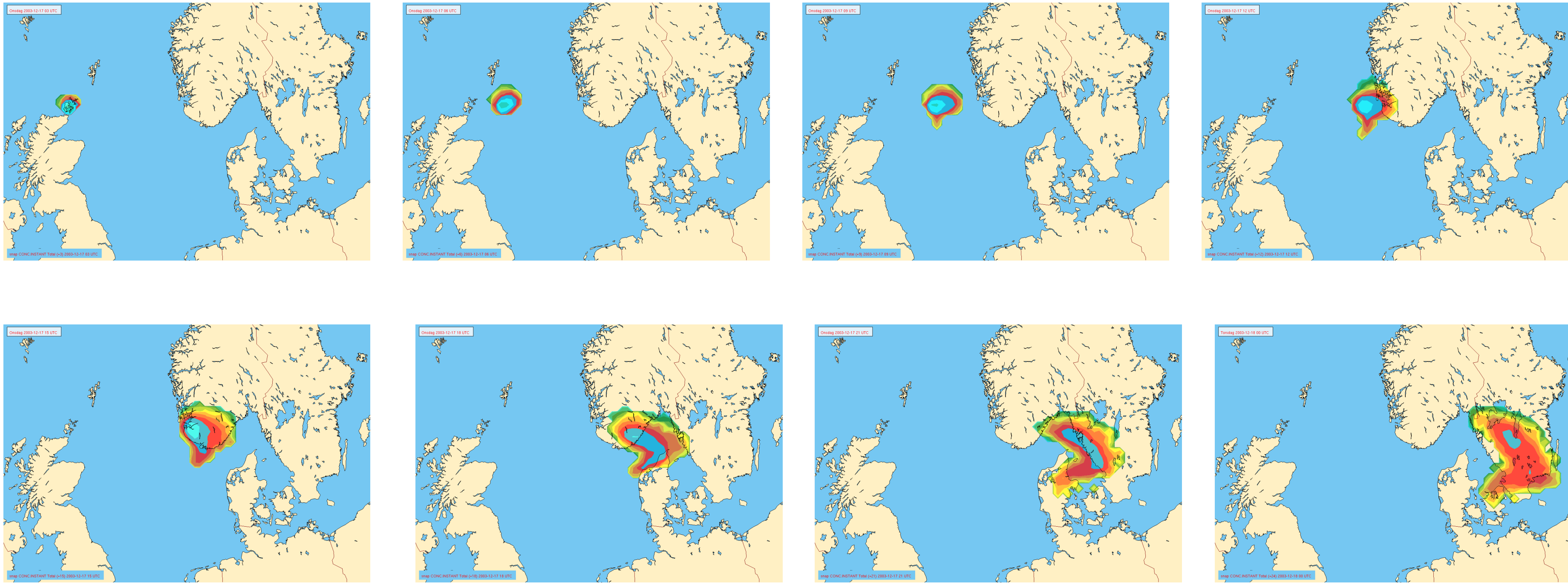
60 hrs after explosion





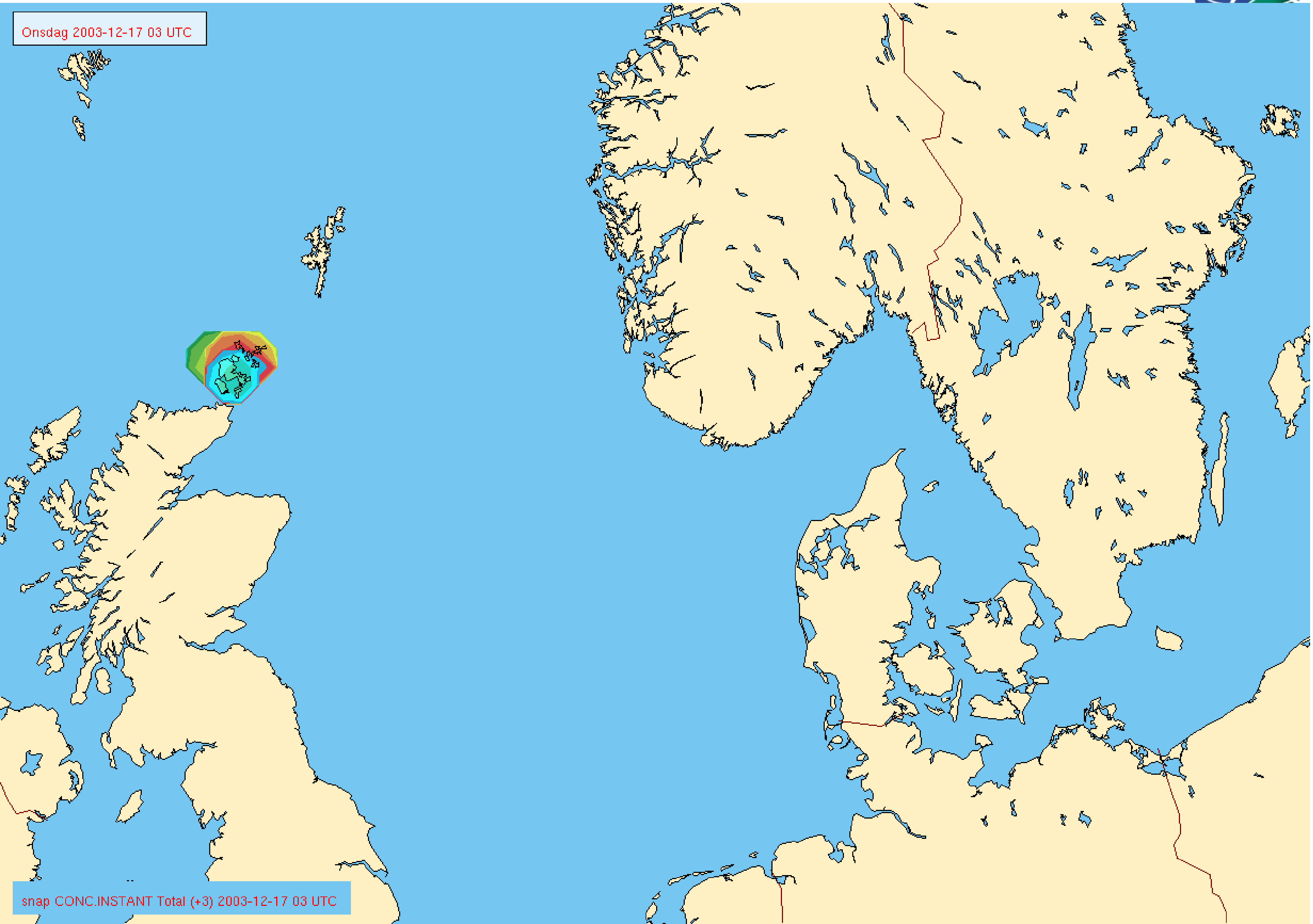
Meteorological situation, 3 hrs and 60 hrs after explosion. MSLP, wind at 10m level and precipitation are shown

Simulation (1) – results



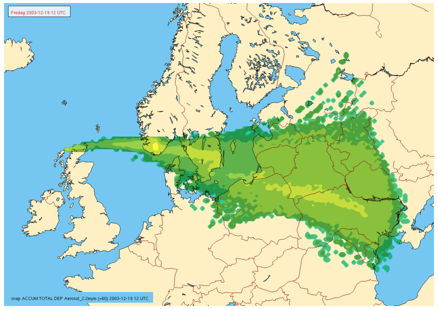
Movement of the radioactive cloud (instantaneous activity at the ground) up to 60 hours after explosion with 3 hours interval. Maximum of the activity – 106 Bq m^{-2} near the detonation site

Simulation (1) – results

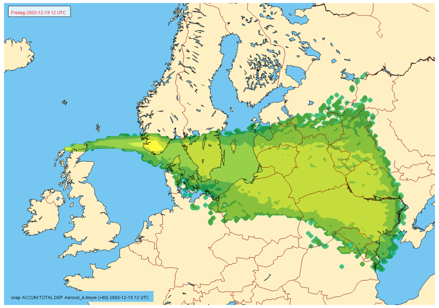


Simulation (1) – results

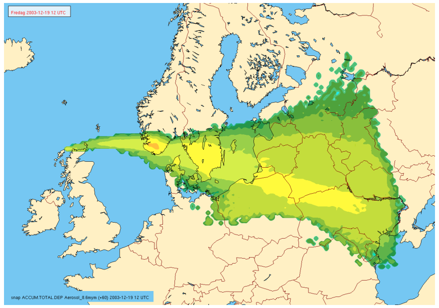
Class 1: Particle radius 2.2 µm



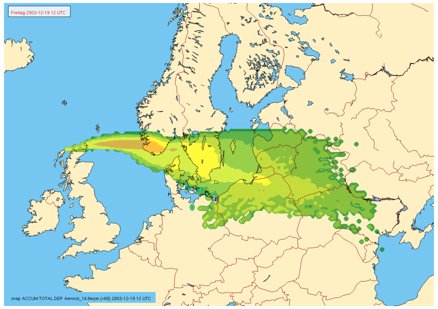
Class 2: Particle radius 4.4 µm



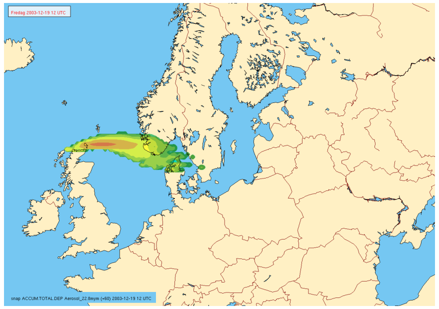
Class 3: Particle radius 8.6 µm



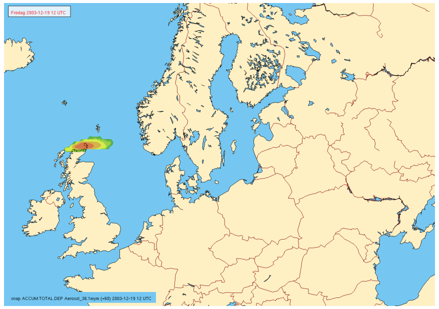
Class 4: Particle radius 14.6 µm



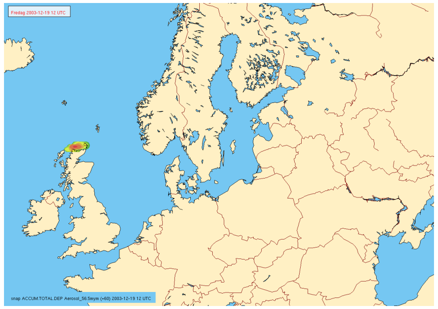
Class 5: Particle radius 22.8 µm



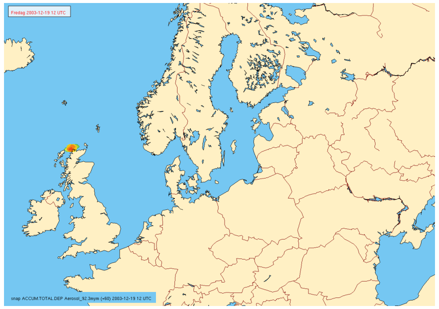
Class 6: Particle radius 36.1 µm



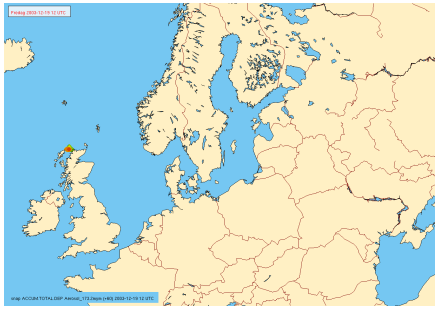
Class 7: Particle radius 56.5 µm



Class 8: Particle radius 92.3 µm



Class 9: Particle radius 173.2 µm

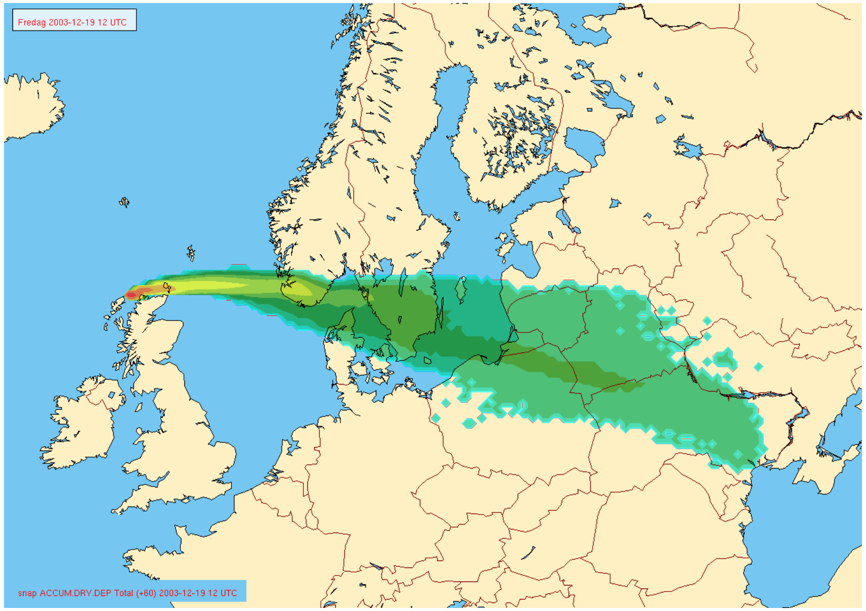


Accumulated total deposition for different classes particles, 60 hours after explosion

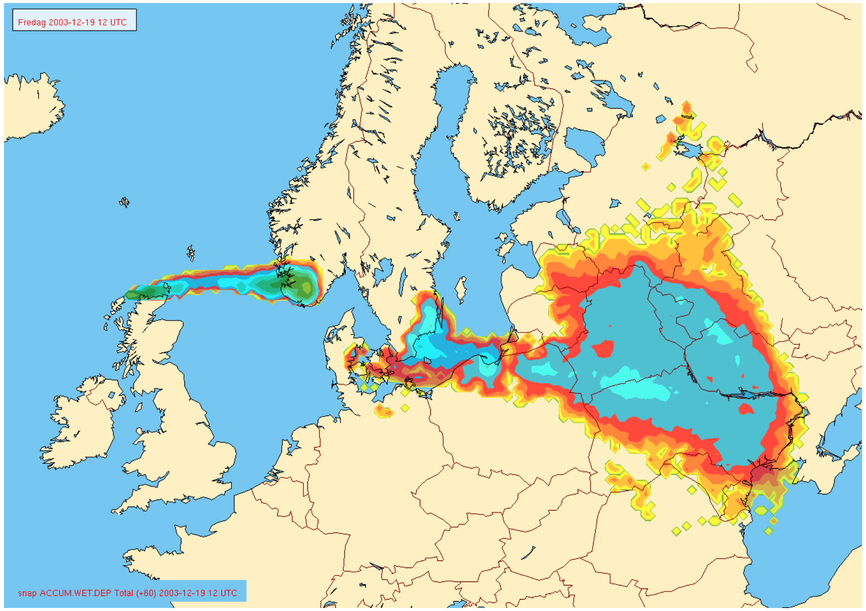
Simulation (1) – results

Accumulated total dry and total wet deposition 60 hours after explosion. Maximum of dry deposition – 1010 Bq m-2 close to the detonation site. Maximum of wet deposition – 108 Bq m-2 occurs in the south of Norway.

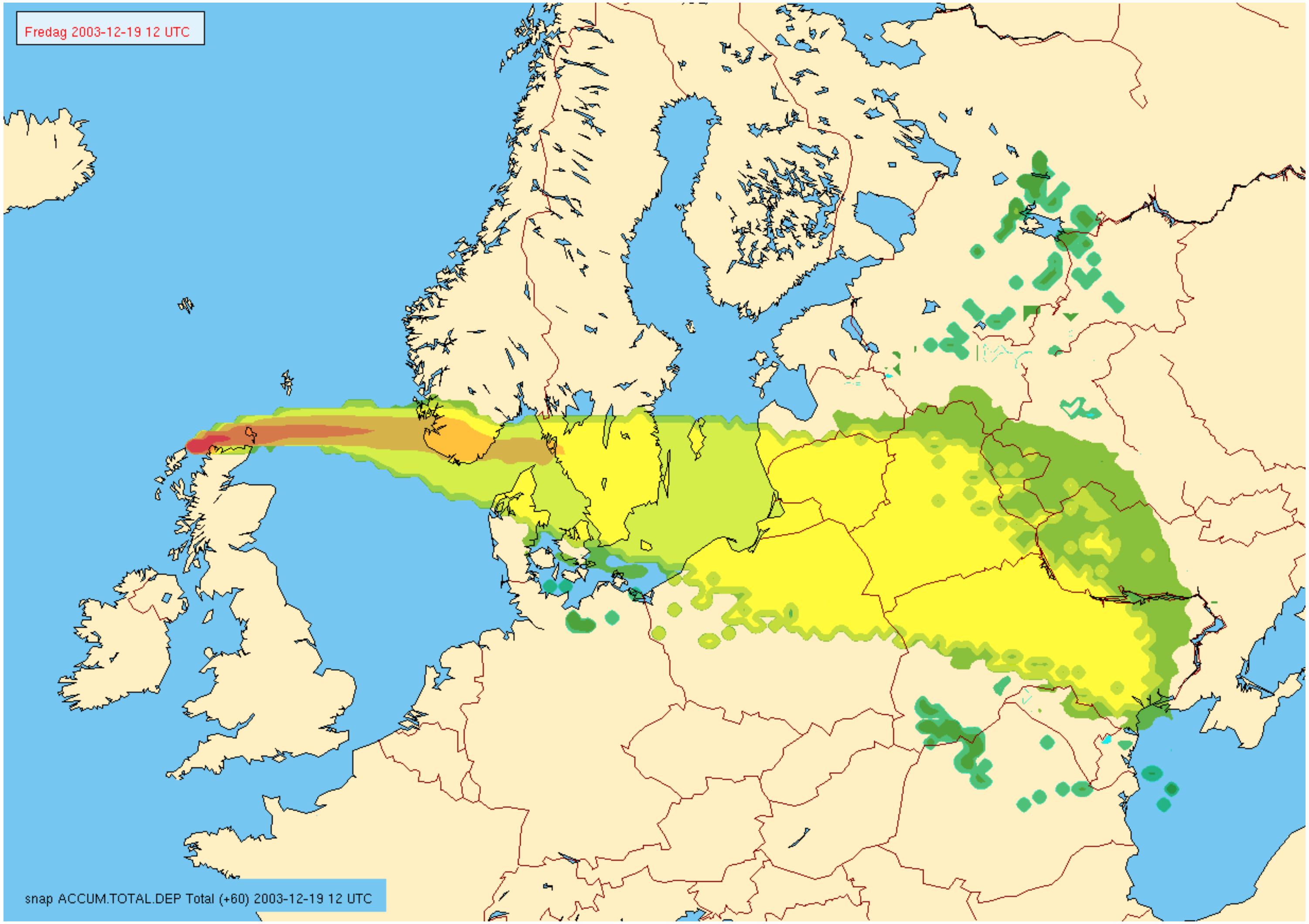
Dry



Wet



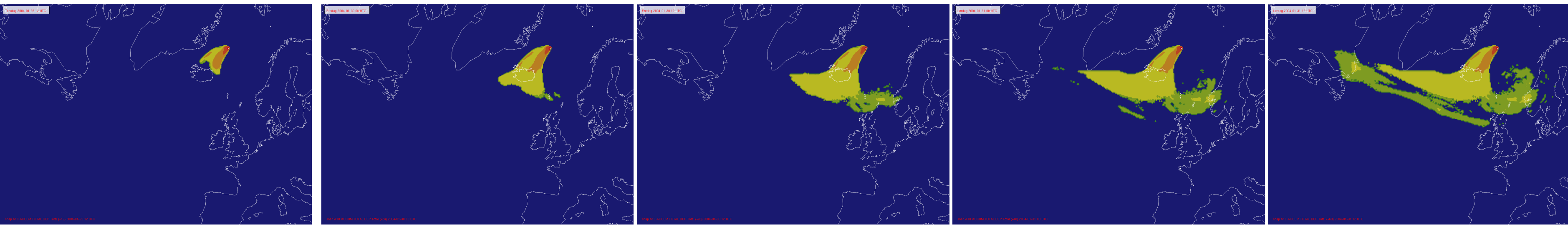
Simulation (1) – results



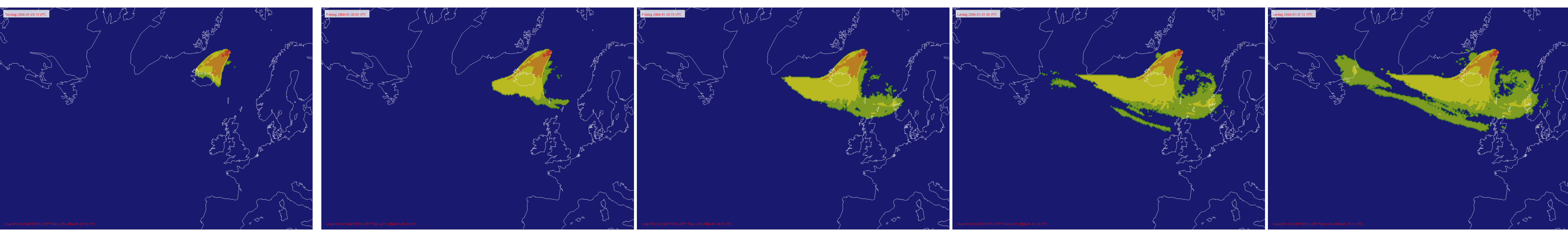
Accumulated total deposition (sum from all particle classes) 60 hours after explosion.

Simulation (2) – results

Cylinder



12 24 36 48 60

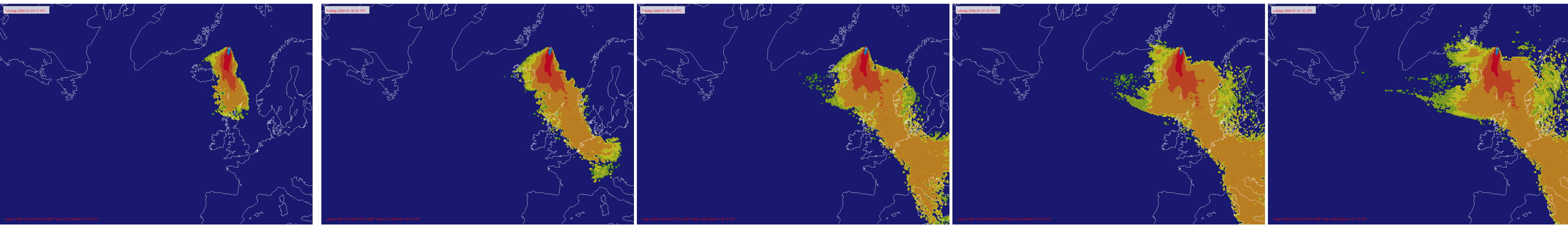


Mushroom

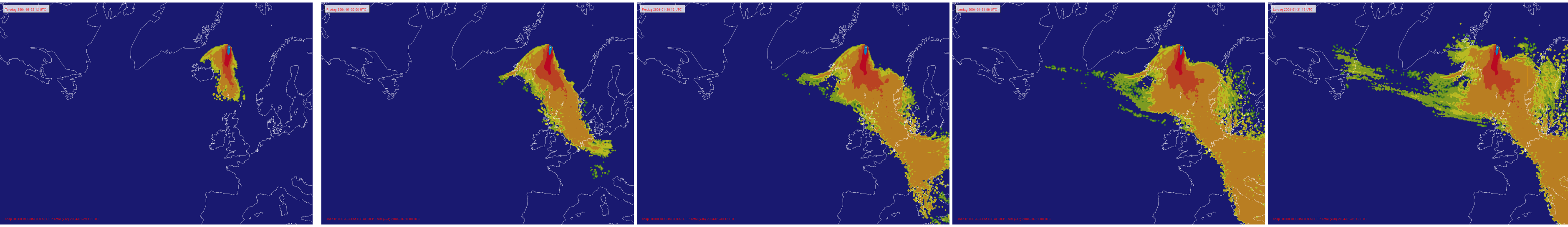
Comparison of accumulated total deposition for cylinder and mushroom initial shapes for the radioactive cloud: 12, 24, 36, 48 and 60 hrs after the explosion. The location of explosion is Jan Mayen and the yield is 10 ktonnes. .

Simulation (2) – results

Cylinder



12 24 36 48 60



Mushroom

Comparison of accumulated total deposition for cylinder and mushroom initial shapes for the radioactive cloud: 12, 24, 36, 48 and 60 hrs after the explosion. The location of explosion is Jan Mayen and the yield is 1000 ktonnes. .

Conclusions

- Bomb version of the SNAP model is fully operational at the Norwegian Meteorological Institute
- Only particles with radius smaller than 20 µm are reaching Norway
- Regular pattern of accumulated dry deposition but irregular pattern of wet deposition
- Initial cloud shape not important for LRT
- Explosive yield important for LRT

Thank you for your attention

We hope that in the future the SNAP model will never be used for such task in real situation