EXERCISE 5
The Ru-106 event in autumn 2017

Aims:

1. Work with a complex real case scenario with an unknown source
2. Understand the Probable Source Regions (PSR)
3. Poor man’s inversion

Questions? Write christian.maurer@zamg.ac.at

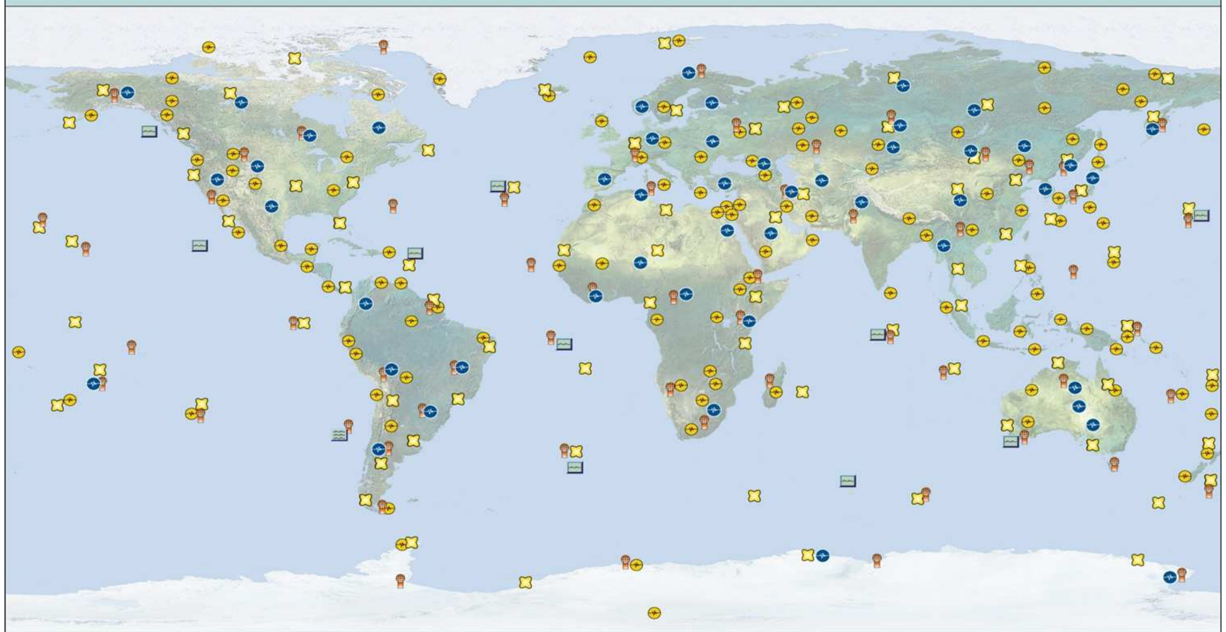
ARTICLE I - BASIC OBLIGATIONS
Each State Party undertakes ***not to carry out any nuclear weapon test explosion or any other nuclear explosion****, and to prohibit and prevent any such nuclear explosion at any place under its jurisdiction or control.*

Entry into force: As soon as 44 countries which operate nuclear reactors have ratified the Treaty (not just signed).

The **International Monitoring System (IMS)**

80 radionuclide stations foreseen, whereof **40** will be equipped with **noble gas** measuring devices

>80 % of the network currently installed



Primary seismic stations | Auxiliary seismic stations | Radionuclide stations | Hydroacustic stations | Infrasound stations

Ru-106 real scenario: Set-up the FLEXPART run

- Specifications:
  - COMMAND FILE:
    - Backward run: 25 September 2017 00 UTC to 3 October 2017 09 UTC
    - Output every 3 hours
    - Convection
    - Residence times output
    - No nested output
    - No adaptation to TL
  - OUTGRID FILE:
    - Resolution 1.0 degree
    - LLC: 0.0° N, -179.0° E
    - 90x360 grid cells
    - 1 output layer, 150 m a.g.l.

Which of the first two samples (release ends on 1 and 2 October) could be related to the nuclear facilities of Dimitrovgrad or Majak in Russia at around Sep., 25th, 21 UTC, to 26th, 03 UTC ?

- RELEASES FILE:
  - Point source at CTBTO IMS station Stockholm (SEP63): 59.41° N, 17.95° E, 0-10 m a.g.l.
  - 1st release:
    1. Release start: 30 September 2017, 09 UTC
    2. Release end: 1 October 2017, 09 UTC
    3. Total mass: 1 Bq of Ru-106 (species nr. 18)
    4. Particles released: 100000
    5. COMMENT = "RELEASE_SEP63_1
  - 2nd and 3rd release:
    1. Release start: 1 and 2 October 2017, 09 UTC
    2. Release end 2 and 3 October 2017, 09 UTC
    3. Total mass, particles released and appropriate comments as for 1st release

Ru-106 real scenario: Source term estimate

Assuming a release between Sep., 26th, 00 UTC, and 03 UTC, and a measurement of 1 mBq/m3 at SEP63 between 1 Oct., 9 UTC, and 2 Oct., 9 UTC, what is your source term estimate? *„Poor man's inversion"*

$$m[Bq/m^3] = M[s] * s[Bq/s*m^3] \rightarrow$$

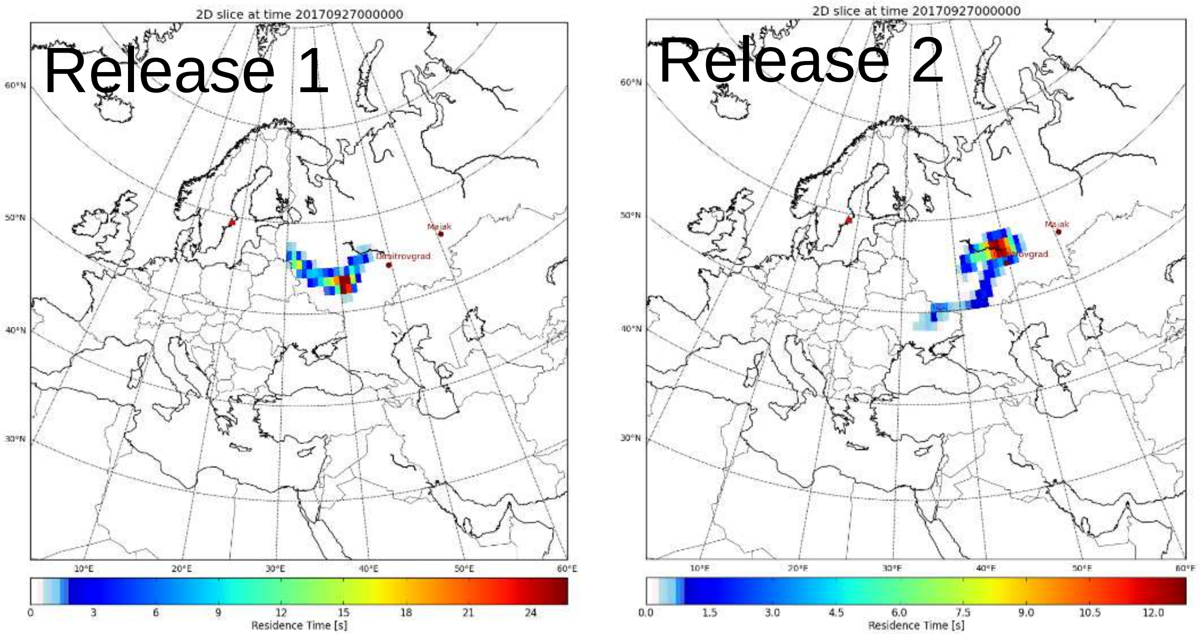
$$S[Bq]=m[Bq/m^3]/M[s]*3*3600[s]*100000*100000*150[m^3]$$

m = measurement

M = transfer coeffcient matrix (aka source receptor sensitivity, footprint ...)

S = source

ECMWF:

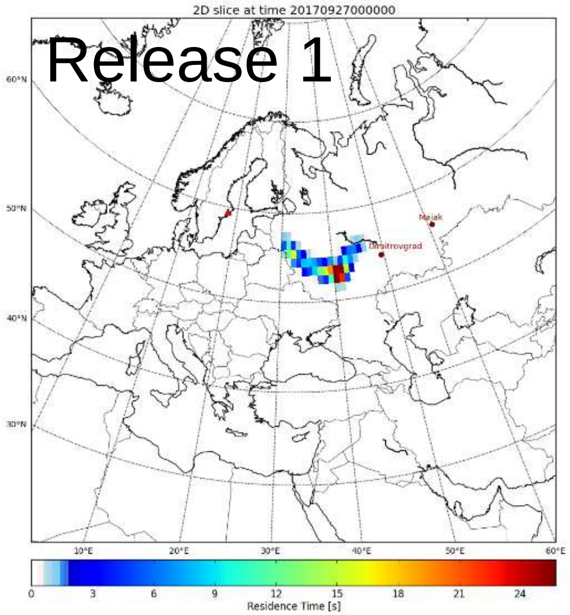


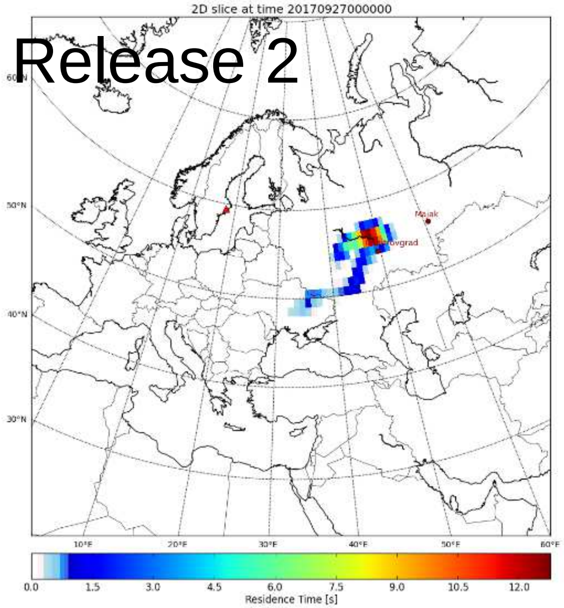
./plot_FLEX_binary.py ./output_ECMWF[NCEP]/ False nuc1 0 0 [1] alldates lcc False 0,65,30,75 mesh True

Ru-106 real scenario: Source term estimate

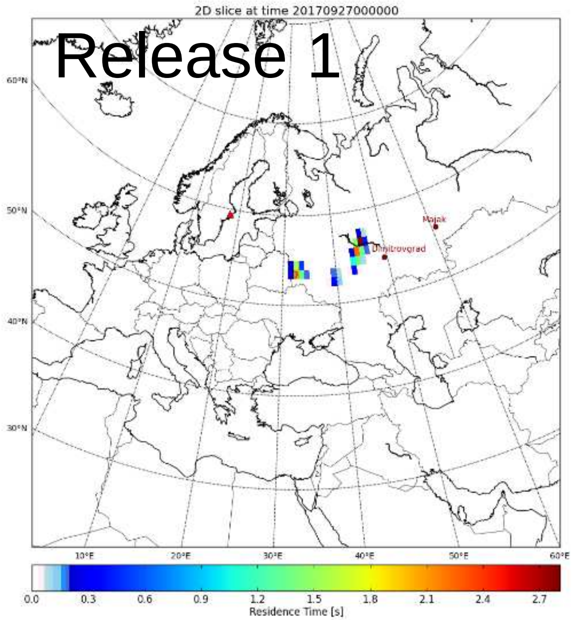
$$m[Bq/m^3] = M[s] * s[Bq/s*m^3] \longrightarrow s[Bq]=m[Bq/m^3]/M[s]*3*3600[s]*100000*100000*150[m^3]$$

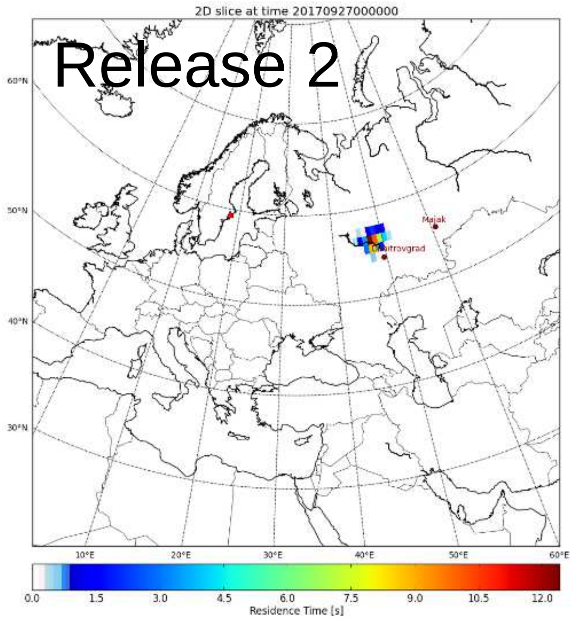
ECMWF:





NCEP:





Ru-106 real scenario: The concept of SRS fields

SRS file: An ASCII file consisting of a header line with all the metadata information and four columns afterward with the loaction and time of non-zero FLEXPART concentrations for just one vertical level:

```
17.950  59.410 20170930 09 20171001 09 0.10E+01   153  3  3 1.000 1.000 "Ru-106" -179.0000   0.0000  360   90
 58.000    17.000     1  0.2222537E-05
```

Source location longitude
Source location latitude
Collection start time
Collection stop time
Released mass
Output simulation time length
Output time interval
Output time interval (place holder)
Horizontal resolution in longitude direction (degrees)
Horizontal resolution in latitude direction (degrees)
Species Name
Lower left corner longitude of OUTGRID in degrees
Lower left corner latitude of OUTGRID in degrees
Number of grid cells in longitude direction
Number of grid cells in latitude direction

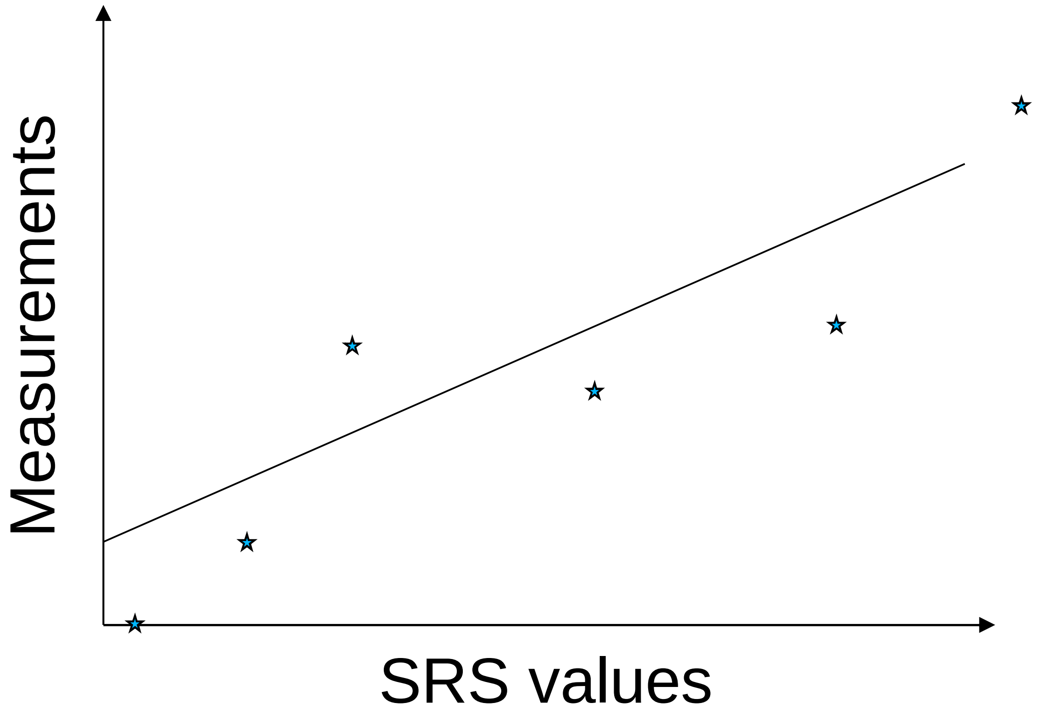
```
58.000    17.000     1  0.2222537E-05
59.000    17.000     1  0.1206449E+03
58.000    18.000     1  0.1381382E+02
.
.
```

Lower left corner latitude of respective grid box
Lower lef corner longitude of respective grid box
Time step (positive if bwd)
Non-zero concentration

Very intiutive way of depicting FLEXPART output for one level and all time steps, standard FLEXPART output format of CTBTO

Ru-106 real scenario: The concept of PSR fields

For every grid cell and time step: Determine *how well measurements fit a release*. Assumption of ~ puff release. Also „non-detections“ can be helpful for constraining the source region.



-99.90 -99.90 20171003 09 20171003 09 0.10E+01 201 3 3 1.00 1.00 -179.0 0.0 360 89 "CORRELATION MAP“

Header very similar to that of SRS files. However, no station coordinates are given as there could be much more than just one station involved.

1
17.95 59.41

Number and coordinates of all involved sampling stations (blue stars in figure above)

51.00 14.00 16 0.6077475E-08 0.3692852E-08 0.4999775E-03

Lower left corner latitude of respective grid box, lower left corner longitude of respective grid box, time step, explained variance (R^2), slope of regression and offset of regression

Ru-106 real scenario: Create srs files

Create ASCII-srs files (one level, all time steps) from binary FLEXPART output (one time step, all levels):

- ln -s /exercise_material_ru106/flexout2srsmnetcdf.out
- mkdir outputsrs_ECMWF[NCEP], outputsrs_ECMWF[NCEP]/20171001/, outputsrs_ECMWF[NCEP]/20171002/ and outputsrs_ECMWF[NCEP]/20171003/
- Create CONTROL file:

```
./output_ECMWF[NCEP]/
./summed_binary/ ! path for summed binary - NOT needed for current application
=================================
1 ! Number of FLEXPART level to start at
1 ! Number of FLEXPART level to stop at
1.0 ! Multiplication factor to get s
fp ! Model name stamp in file name
f10 ! Version stamp in file name
1 ! species to start with
1 ! species to end with
1 [2,3] ! selected release - VERY IMPORTANT for current application
1900010100 ! selected start date-time
2100010100 ! selected stop date-time
.false.  ! indication, whether summed binary should be produced
001 ! file suffix for summed binary - NOT needed for current application
part-sum   ! summed species name for summed binary - NOT needed for current application
.false.  ! indication, whether simple file name should be used
.false.  ! indication, whether decay should be applied a posteriori
```

- ./flexout2srsmnetcdf.out
- Gzip and move *conc_RELEASE_SEP63_1_Ru-106.fp.2017100109.f10.1.srm*, *conc_RELEASE_SEP63_2_Ru-106.fp.2017100209.f10.1.srm and conc_RELEASE_SEP63_3_Ru-106.fp.2017100309.f10.1.srm* to outputsrs_ECMWF[NCEP]/20171001/, outputsrs_ECMWF[NCEP]/20171002/ and outputsrs_ECMWF[NCEP]/20171003/

Create Probable Source Region (PSR) fields:

- ln -s /exercise_material_ru106/locate_multi
- Create CONTROL file:

```
# SRS File archive
./outputsrs_ECMWF[NCEP]/

#
# Species measured
#
1                    ! number of species
Ru-106      0.0         ! half-life [s]
#
# Scenario/Measurements
#
1E-18                ! background concentration, used only for FOI approach
3                    ! number of measurements
conc_RELEASE_SEP63 20171001 09  0.0E-3   ! station | collection stop | concentration above MDC
conc_RELEASE_SEP63 20171002 09  1.0E-3
conc_RELEASE_SEP63 20171003 09  0.5E-3

FALSE  ! indication, whether srs-files are in CTBTO format (corner longitudes and latitudes of global field not given)
FALSE  ! indication, whether time integration should be applied
10.75 ! days to start time integration before last collection stop
++++++++++++++++++++++++++++
```

Assume consecutive samples of 0, 1 and 0.5 mBq/m3 (1 mBq/m3 = 1E-3 Bq/m3))

- ./locate_multi: yields output correlation.txt (Please ignore the source estimate given by locate_multi in the last but one line of the screen output! Using this information requires a non-standard FLEXPART output in bwd mode!).

Plot PSR fields:

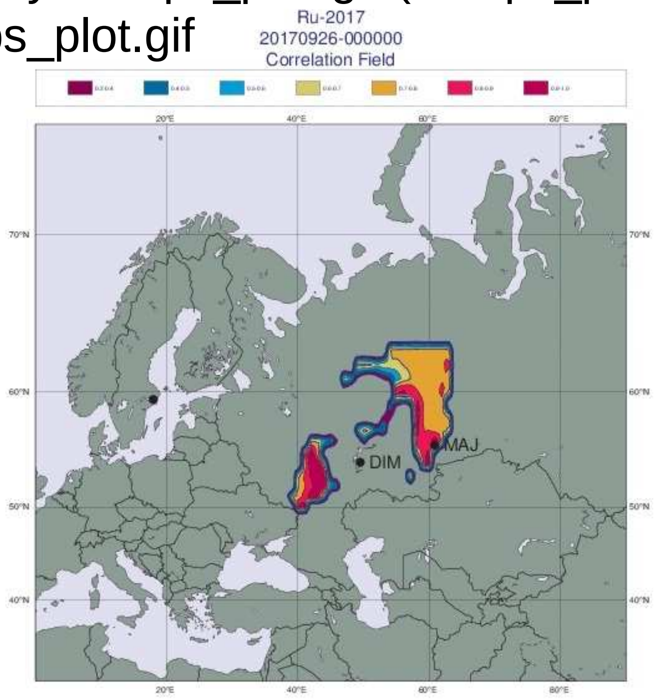
- Change the bashrc (or unload and load modules manually; Magics is needed):
  mv $HOME/.bashrc $HOME/.bashrc_normal
  mv $HOME/.bashrc_Ru $HOME/.bashrc
  source $HOME/.bashrc
- ln -s /exercise_material_ru106/corelplot
- **Create CONTROL file**

CONTROL file:

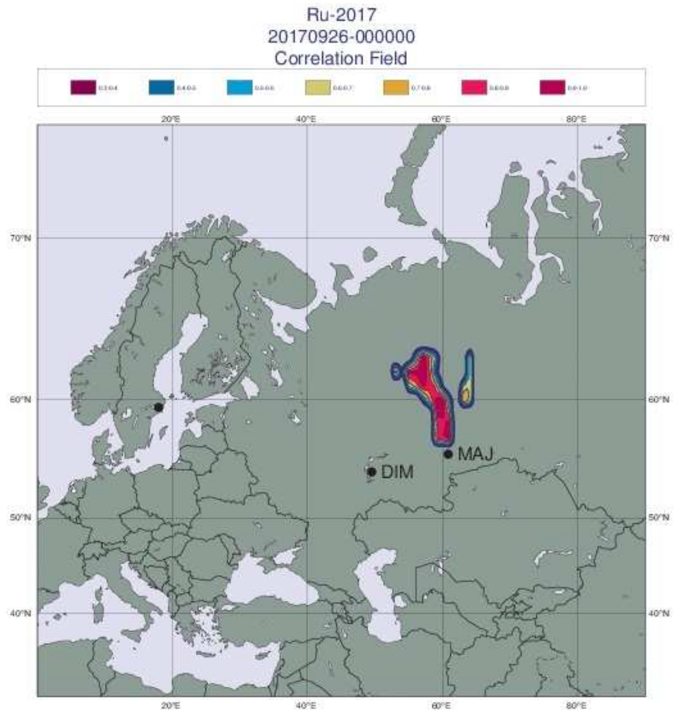
```
./correlation_ECMWF[NCEP].txt
Ru-2017
210 ! Duration of plot (hours forward or backward)
211 2            ! Projection (1 Cylindrical, 2 Mercator)
1             ! Plot Stations (1 - yes)
gard.dat
1             ! Manual Domain (0 - no; 1 - yes)
10.0 5.0 5.0       ! Domain Dilution, Expansion (LON), Expansion (LAT)
0 90 30 75         ! LON1 LON2 LAT1 LAT2 (if manual domain option equal 1)
```

- ./corelplot: yields ps_plot.gif (and ps_plot.ps)
- animate ps_plot.gif

ECMWF:



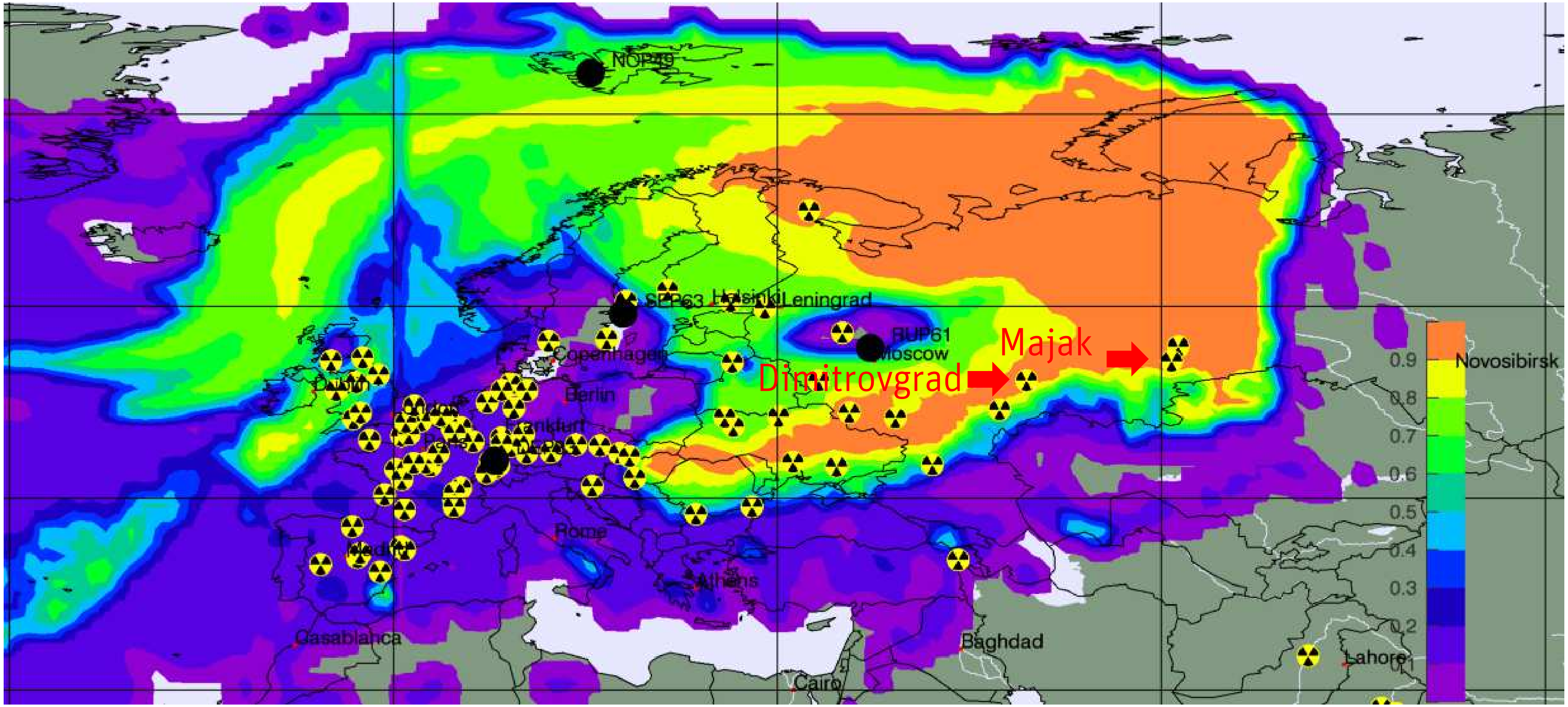
NCEP:



Ru-106 scenario: First radionuclide analysis

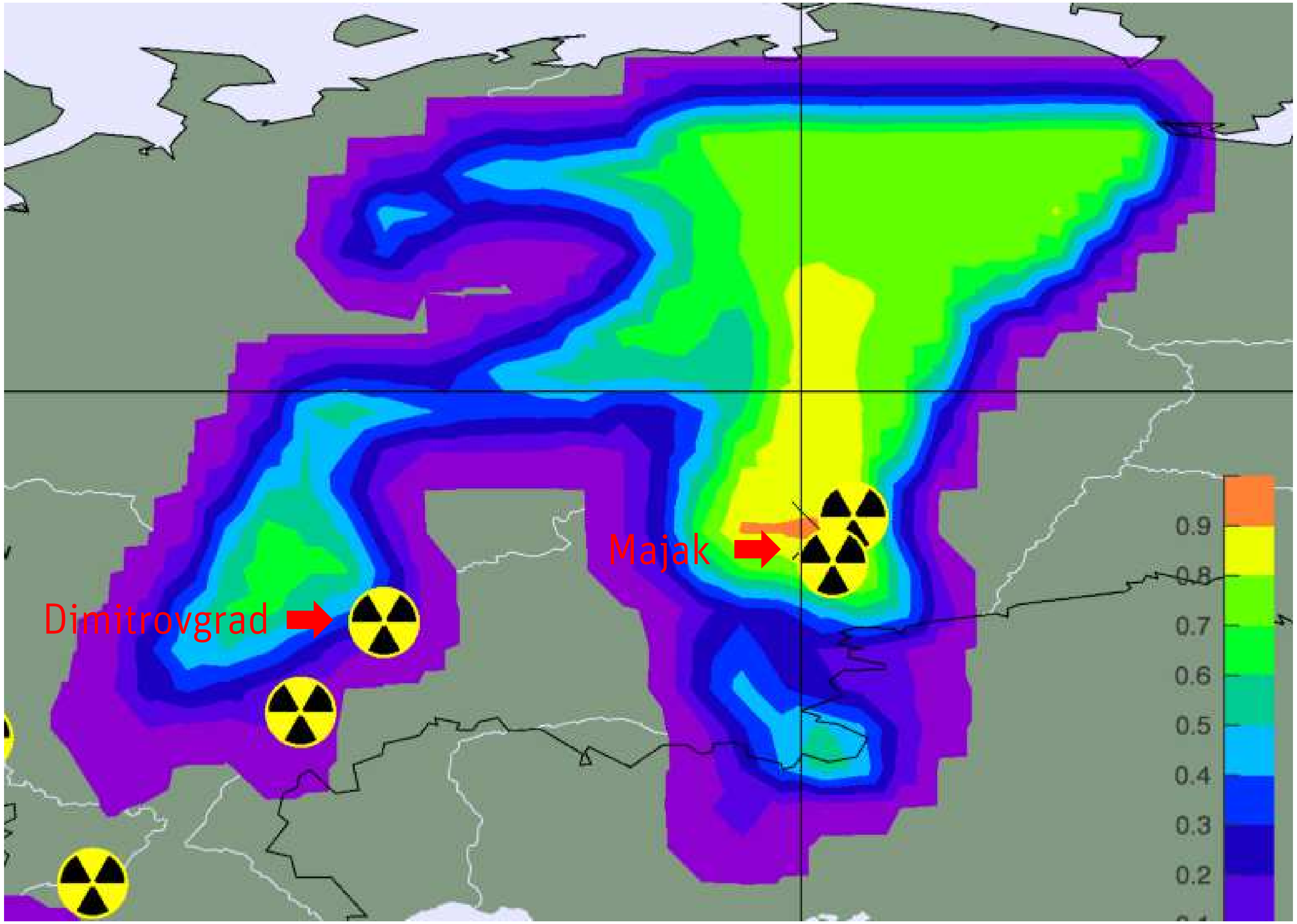
- **Elevated Ru-106 (and Ru-103) measurements all over Europe** (national stations and CTBTO station in Stockholm) **end of September/beginning of October 2017**, with an exceedance of 175 mBq/m³ in southeastern Europe.
- **No other nuclides (e.g., Xenons, Barium, Lantan, Caesium or Iodine) found in the spectra (of CTBTO station Stockholm): Atmospheric and underground nuclear explosions as well as an accident in a nuclear power plant can be ruled out as source of the Ruthenium**
- According to the ratio of Ru-106 to Ru-103 the radionuclides were produced 400 days before being released
- **Conclusion: Incident or accident in a re-processing or isotope production**

Field of highest integrated correlations (= Probable Source Region – PSR) in the time frame Sep., 20th-30th, 2017, largely confined to Russia!



Based on FLEXPART-9 and ECMWF 1.0° data; SRS fields from SEP63, DEP33, NOP49 and RUP61 as well as on CTBTO/IDC software WEBGRAPE (*Web-connected graphics Engine*)

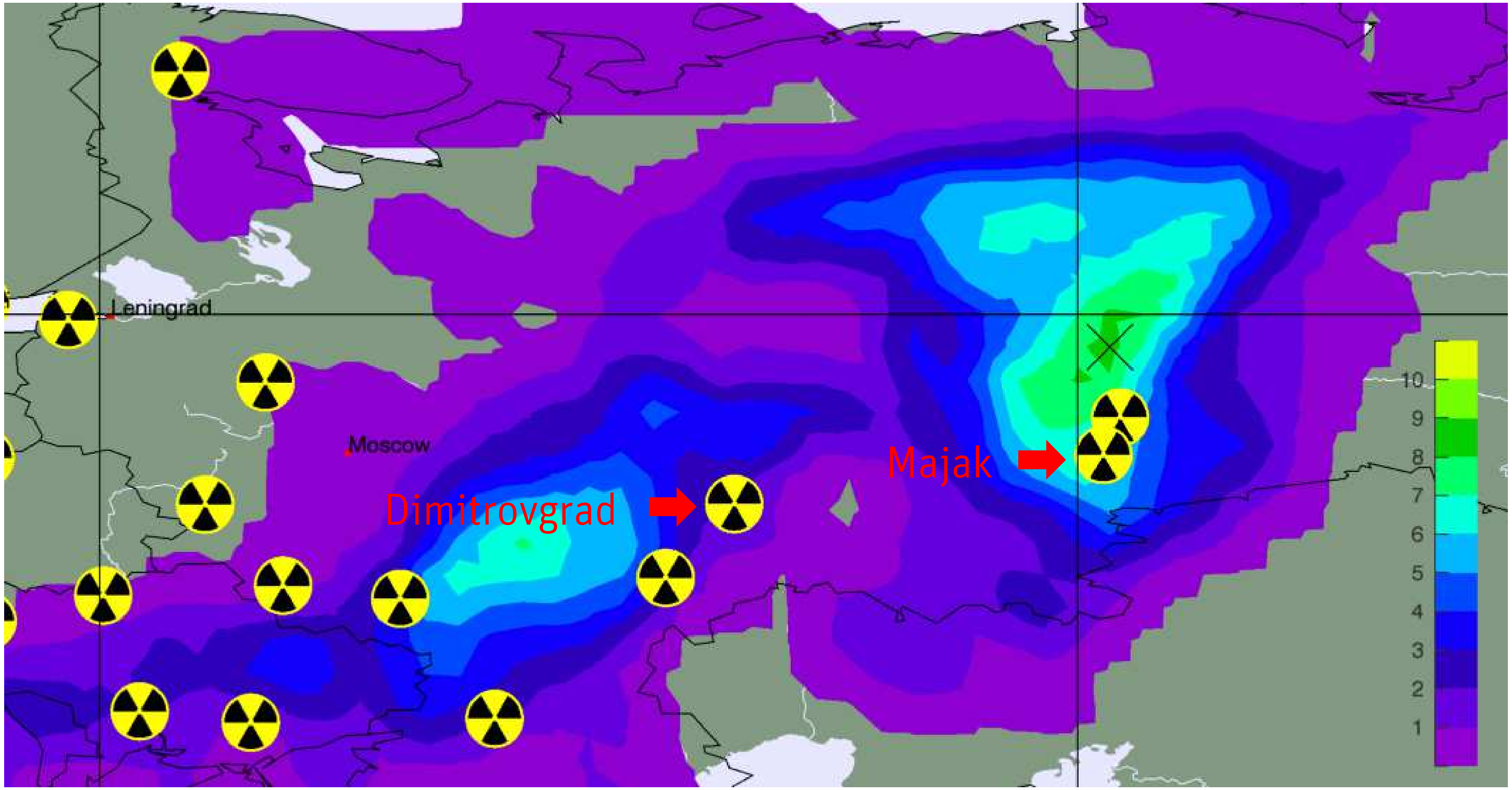
Single model for time slot Sep., 25th, 15-18 UTC



Based on FLEXPART-9 and ECMWF 1.0° data

Multi-Model overlap for time slot Sep., 25th, 21-00 UTC

Overlap of PSR fields (in total 11) showing at least a correlation of 0.5

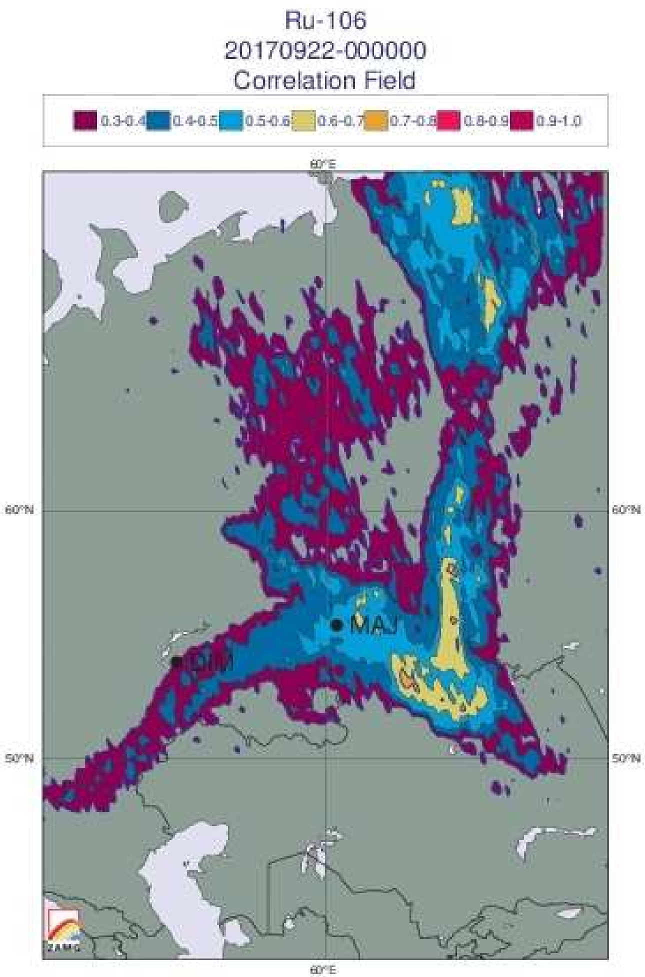


Based on WMO *Regional Specialized Meteorological Centers* (RSMC) dispersion model outputs. ZAMG is one of the backtracking RSMCs.

Ru-106 real scenario: Conclusions I

- **Material was released either around the re-processing plant of Majak** (60.8° E Lon. and 55.69 ° N Lat.) **or the radiopharmaceutical facility of Dimitrovgrad** (49.48° E Lon. and 54.19° N Lat.)
- **Source strength: ≤1 Petabequerel = 1000 Terabequerel**
- **Most probable release time** (according to maximum correlations) **between Sep., 25th and 26th**
- **ZAMG‘s results are in agreement with those of the French Institute for Radiation Protection and Nuclear Safety (IRSN) and the German Bundesamt für Strahlenschutz BFS**

Time-integrated Probable Source Region based on 38 backward fields originating from Romania (observations officially received from the National Environment Protection Agency in Romania)

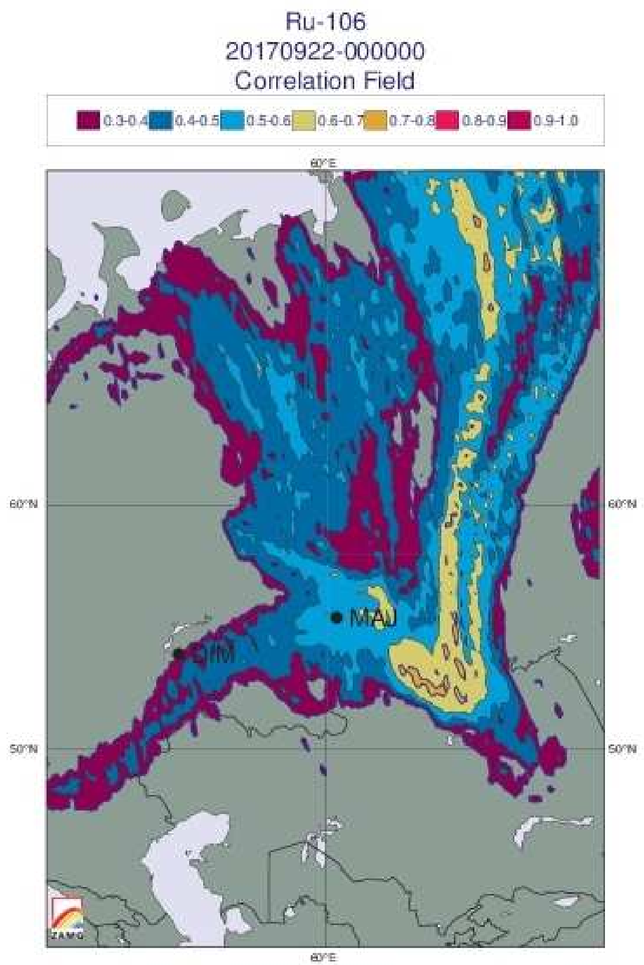


Based on 0-100 m a.g.l.

Majak is not located within the area of maximum correlation!

Even more tricky: if overlap of backward fields in the PRS calculation is enforced (=*hypothesis of one single source location at a single time*) PSRs collapse!

Caveats: <u>Model errors</u> (NWP and/or ATM) and <u>wrong measurement metadata</u> can easily be the source of mismatch!



Based on 0-1000 m a.g.l

ADDITIONAL MATERIAL

Going beyond atmospheric transport modelling

Ru-106 real scenario: Light phenomenon

Austrian pilot report received by ZAMG: "*I am a pilot working for a Luxembourgian carrier and was flying back from Novosibirsk to Europe in the night from 25th to 26th of September, local departure time 22:30 (i.e., 17:30 UTC). South of Yekaterinburg we saw a big, slightly greenish, luminous phenomenon in the night sky. The shape of the phenomenon reminded us on a cat's eye, the color was similar to that one of an aurora borealis. The local aviation authority led the phenomenon back to a probable rocket launch. They had already received some notifications about the phenomenon….During the next half hour the phenomenon disappeared…..*"

Artificial light phenomenon observed over Yekaterinburg, night 25th-26th of September 2017
http://media.englishrussia.com/newpictures/Fishing_in_the_North//104321/102527/2001_50_56_full.jpg

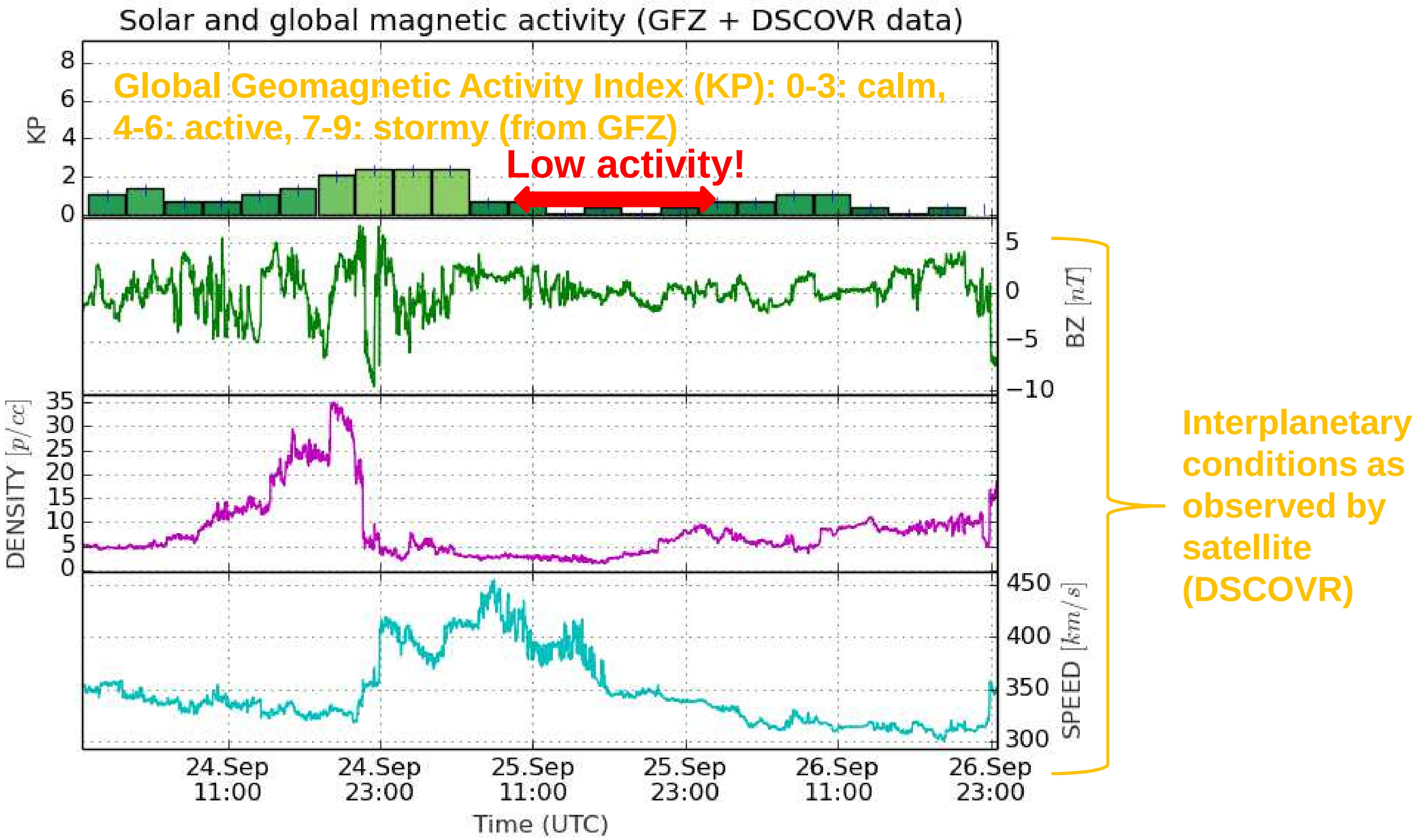
Ru-106 real scenario: Collecting further evidence

- The location of the phenomenon roughly agrees in location with the Majak re-processing plant around 120 km south of Yekaterinburg
- The time frame matches very well.
- **Thus, the following hypotheses possibly explaining the phenomenon were looked at:**

  1. **Magnetic storm**
  2. **(Forest)-fire activity (also in relation to a fire at Majak)**
  3. **Artificial aurora**

Ru-106 real scenario: Solar and global magnetic activity

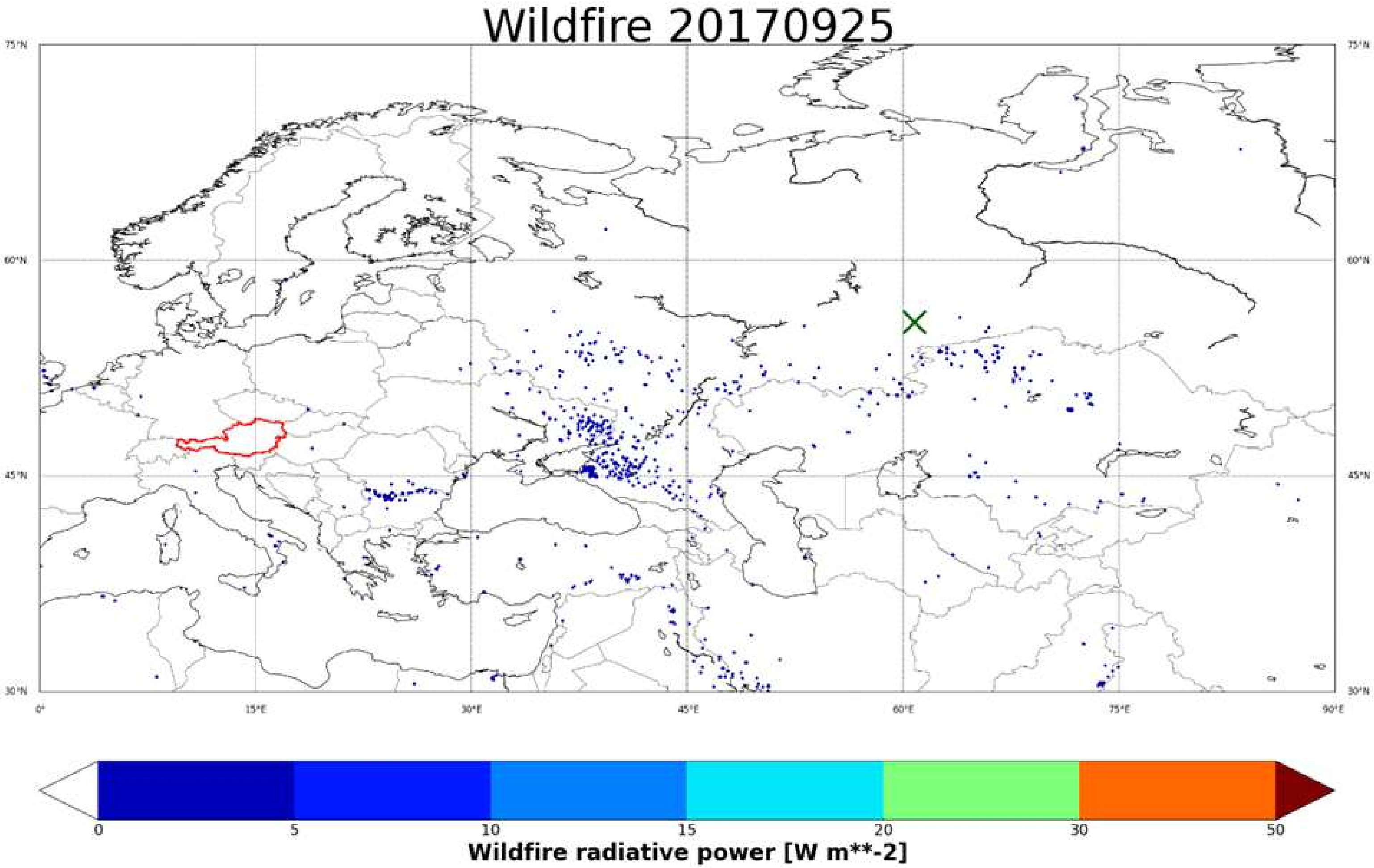
In the night when the pilot made his observation the situation was totally calm. It is therefore highly unlikely that this particular observation



Measured solar and magnetic activity in the time period 24th to 26th of September

Ru-106 real scenario:Fire radiative power areal density

No fire was detected on Sep., 25th and 26th, at or around Majak



Average of observed fire radiative power areal density [Watt per meter square] on Sep., 25th, 2017. Blue dots: fires with radiative power areal density below 5 W/m^2. Green cross: Majak re-processing plant. Data from *Copernicus Atmosphere Monitoring Service* (CAMS) *Global Fire Assimilation System* (GFAS)

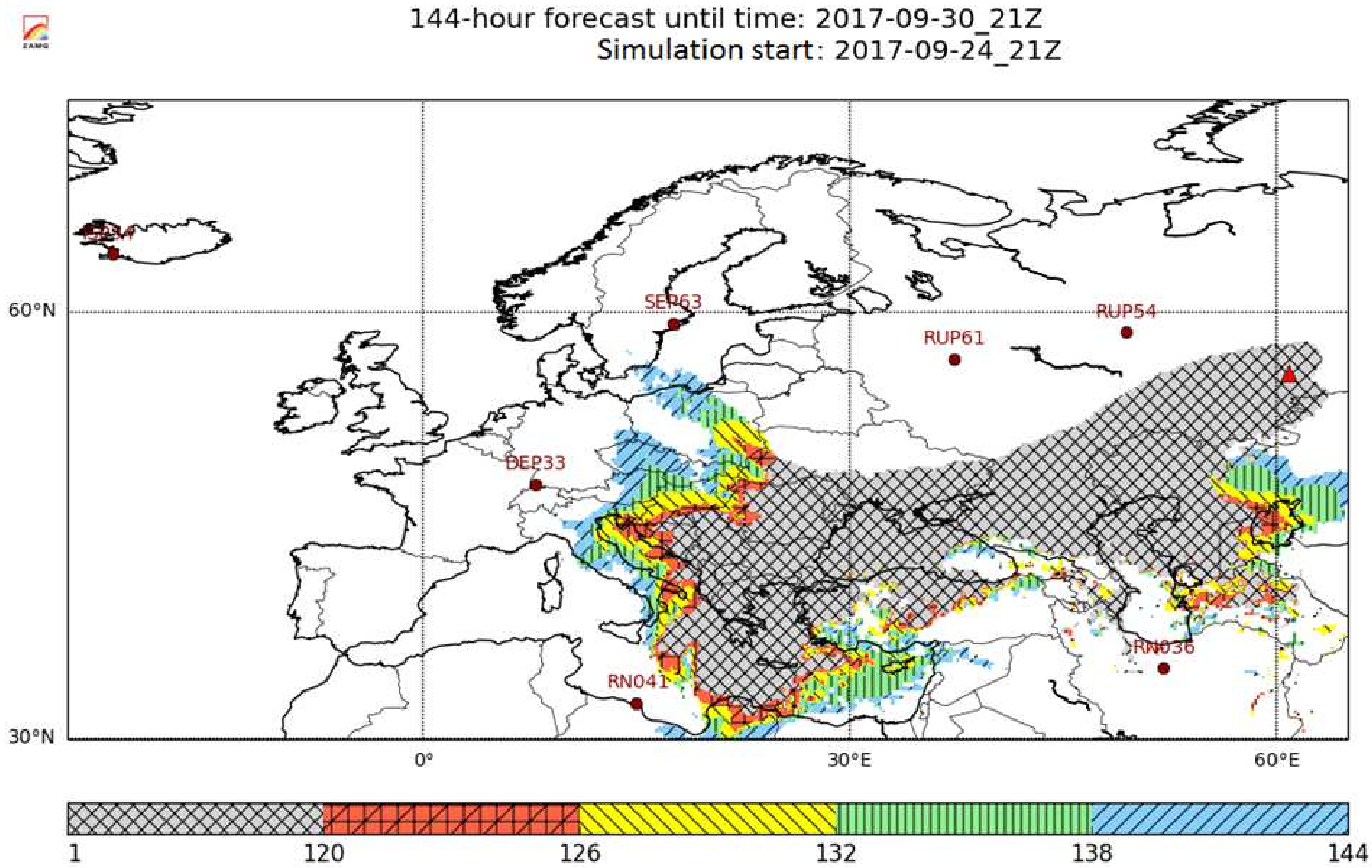
Ru-106 real case: Artificial aurora due to radioactivity

- **Artificial auroras have been observed** in the past, for example, **in the context of atmospheric nuclear tests** several decades ago (*Glasstone and Dolan, 1977*).
- **Many substances can emit light in the visible range if stimulated by ionizing radiation from radioactive material.**
- **If activities in the 100-1000 TBq range are set free, light releases (artificial auroras) are not unlikely** (Steinhauser, personal communication).
- As there seems to have occurred no magnetic storm or fire activity, **the phenomenon the pilot observed could have indeed been triggered by nuclear activity released at Majak.**

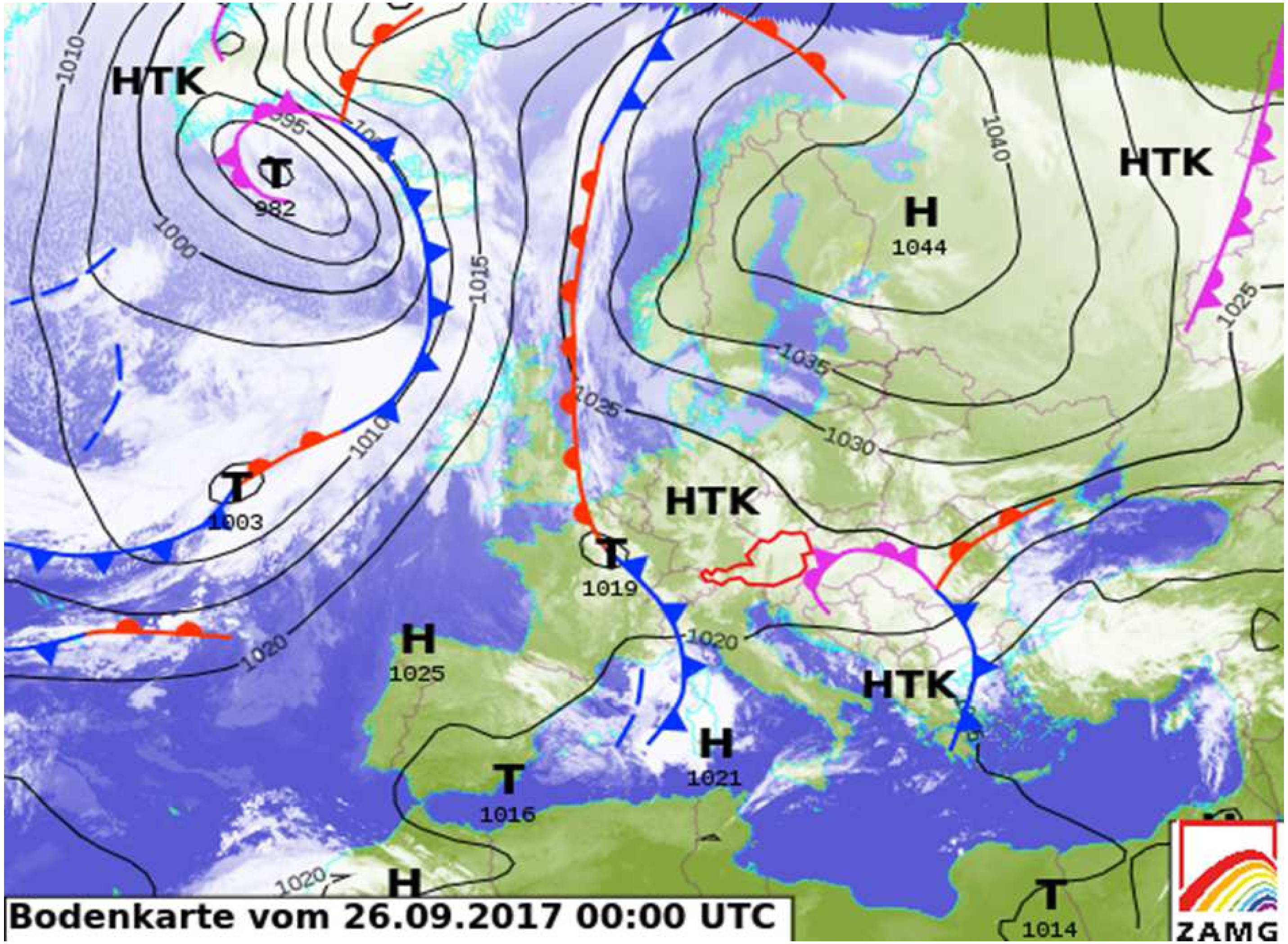
Ru-106 real sceario: ZAMG forward simulations

- Model: FLEXPART-8.2.3
- Meteorological fields: 1.0° ECMWF data with 0.2° nest covering also the Ural
- Assumed source location: Majak
- Assumed release amount: 10^{15} Bq = 1000 TBq
- 13 consecutive 3-hourly release intervals starting at 20170924 21:00 UTC
- Goal: Estimate the most likely release interval and to compare modelled station activity concentrations from all releases with measurements.

Ru-106 real scenario: Plume arrival times



Arrival times (in hours) relative to simulation start. Red triangle: Majak re-processing plant. Dark red dots: CTBTO IMS stations. Hypothetical plume release at Majak on 25th of September between 18 and 21 UTC



ZAMG's surface pressure chart and front analysis for Sep., 26th, 00:00 UTC.

Anticyclonic transport straight in western and south-western direction by a persisting high

Ru-106 real scenario: Summary

- **Observed Ru-106 levels in Europe in early autumn of 2017 were quite unusual.** Up to 176 mBq/m³ were measured in Eastern Europe (usually CTBTO uses the unit µBq/m³ for particulates!).
- **There is high evidence that the source of the Ru-106 is located in Russia (or Kazakshstan) and that a major nuclear accident occurred in a nuclear waste re-processing plant or during transport of material generated there.**
- **A release in the re-processing plant of Majak due to a loss in cooling of a radioactive solution is a likely scenario. Botched fabrication of a Cerium-144 source needed in the search for sterile neutrinos at the Gran Sasso National Laboratory in L'Aquila, Italy, is an option** (*Cartlidge, 2018*).

THANK YOU FOR YOUR ATTENTION!

References:

- S. Glasstone and P. J. Dolan, 1977: The Effects of Nuclear Weapons. 3rd edition, United States Department of Defense and the United States Department of Energy, 653 pp.
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- A. Trapeznikov, A. Aarkrog, V. Pozolotina, S. P. Nielsen, G. Polikarpov, I. Molchanova, E. Karavaeva, P. Yushkov, V. Trapeznikova, N. Kulikova, 1994: Radioactive pollution of the Ob river system from Urals nuclear enterprise 'MAJAK', *Journal of Environmental Radioactivity,* **25** (1-2), doi: 10.1016/0265-931X(94)90009-4.
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- Prof. Dr. Petra Seibert, 2018: Ruthenium-106 event in Europe, Autumn 2017. http://homepage.univie.ac.at/petra.seibert/ru106.html
- E. Cartlidge, 2018: Isotope cloud linked to failed neutrino source. *Science*, **359** (6377), 729, doi: 10.1126/science.359.6377.729.