Modelling capabilities at ZAMG for the effects of an atmospheric nuclear explosion

Christian Maurer (ZAMG), Dèlia Arnold (ZAMG),

Gerhard Wotawa (ZAMG), Matthew McKinzie (NRDC)

ZAMG: Zentralanstalt für Meteorologie und Geodynamik, Vienna Austria
NRDC: Natural Resources Defense Council, Washington, DC, USA

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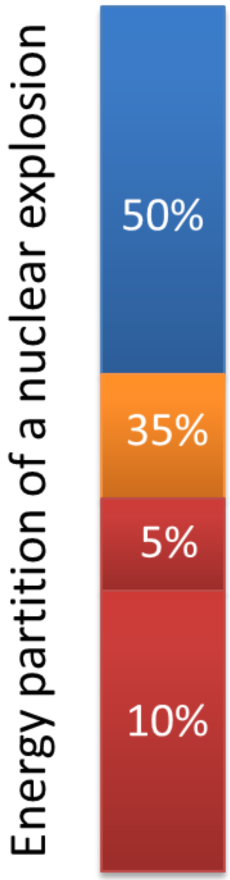
What are the effects of a nuclear explosion?



- Crater
- Blast Overpressure
- Blast Dynamic Pressure
- Thermal Radiation
- Initial Nuclear Radiation
- Local Fallout
- Global Fallout
- Electromagnetic Pulse

important effects in military planning

important widespread humanitarian effects

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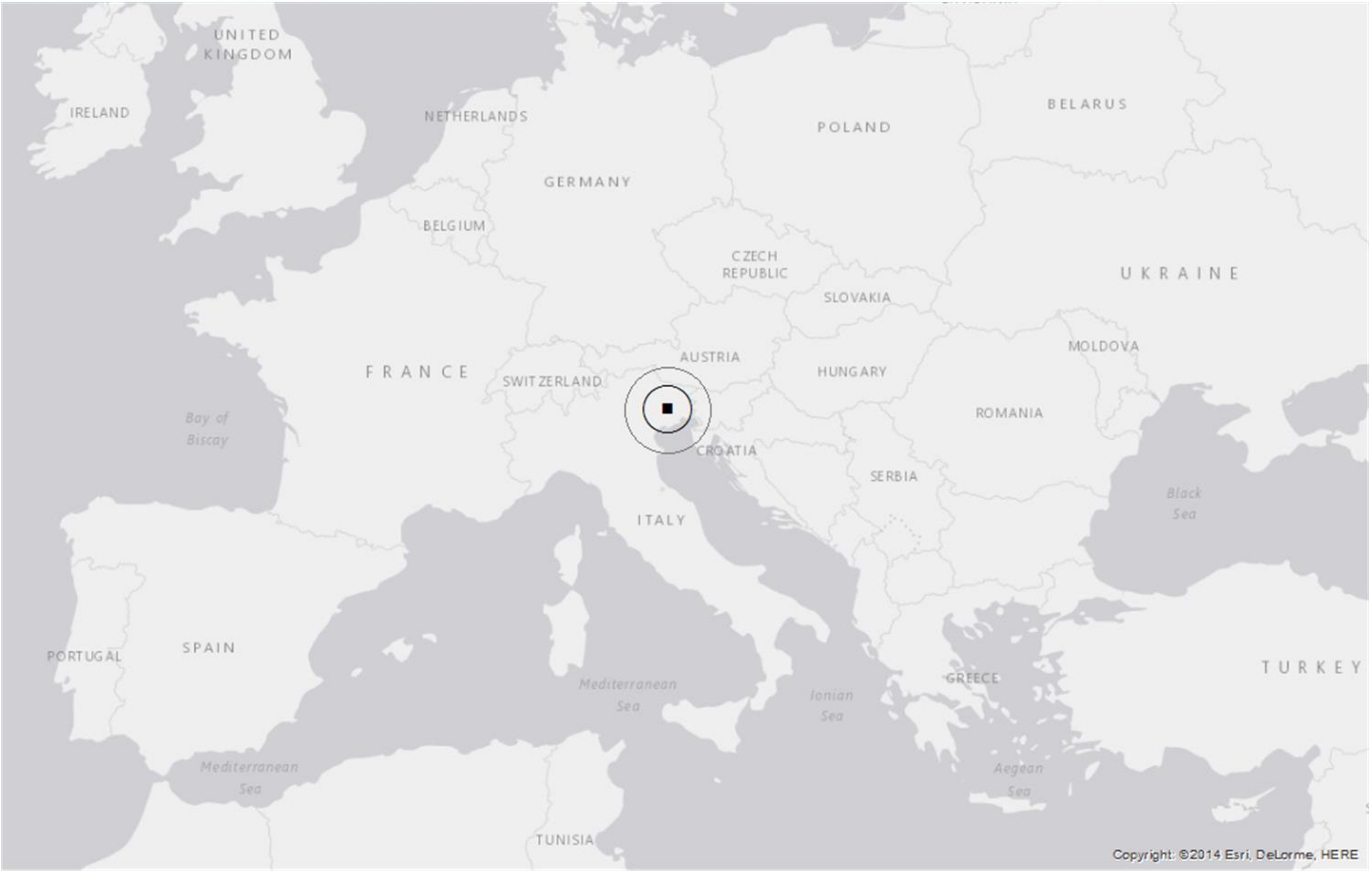
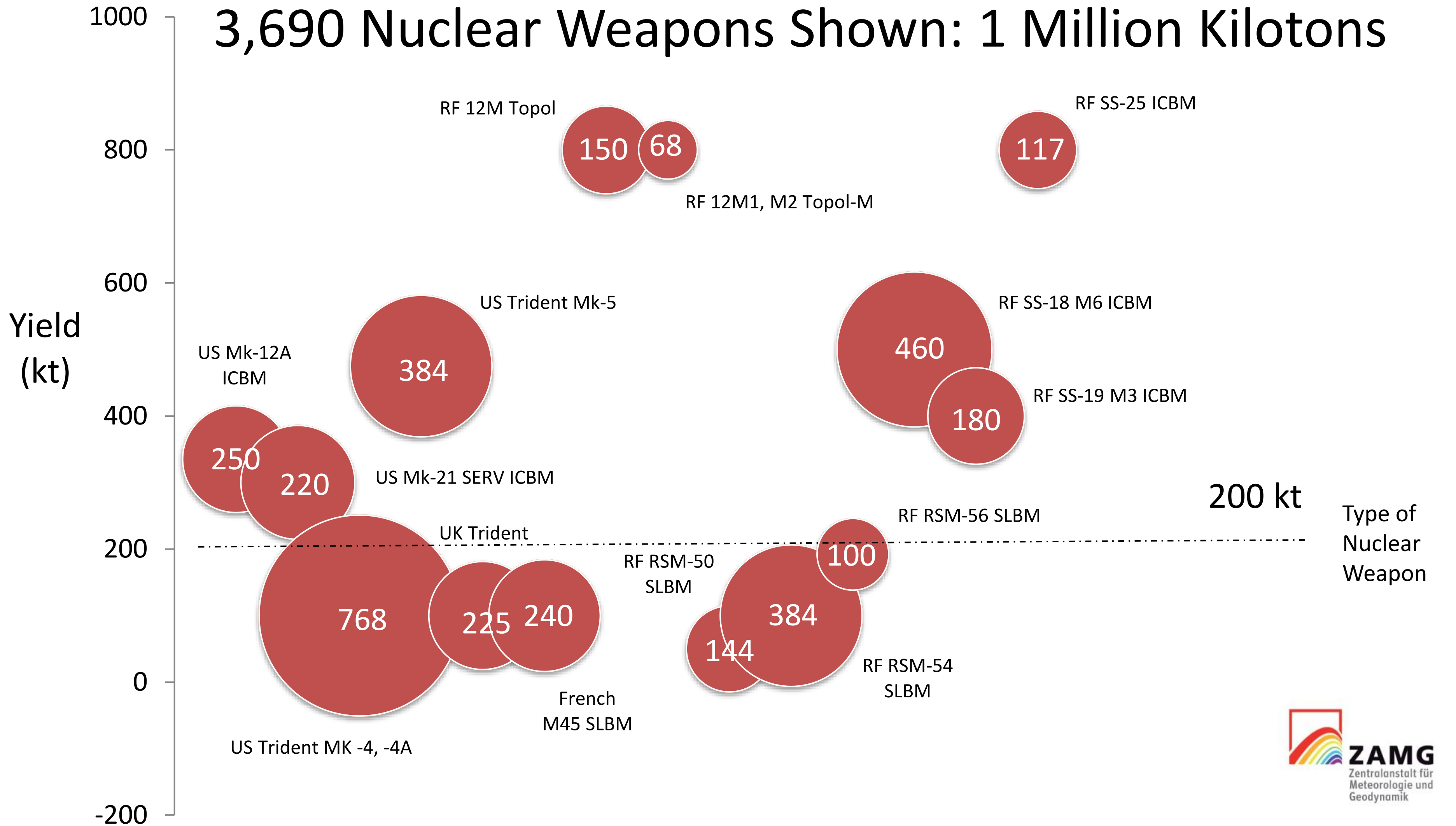
A hypothetical scenario: Attack on a military base



Choosing a nuclear yield

Data Source: Kristensen, Hans M., and Robert S. Norris. "Russian nuclear forces, 2014." *Bulletin of the Atomic Scientists* 70.2 (2014): 75-85; and "US nuclear forces, 2014." *Bulletin of the Atomic Scientists* 70.1 (2014): 85-93.



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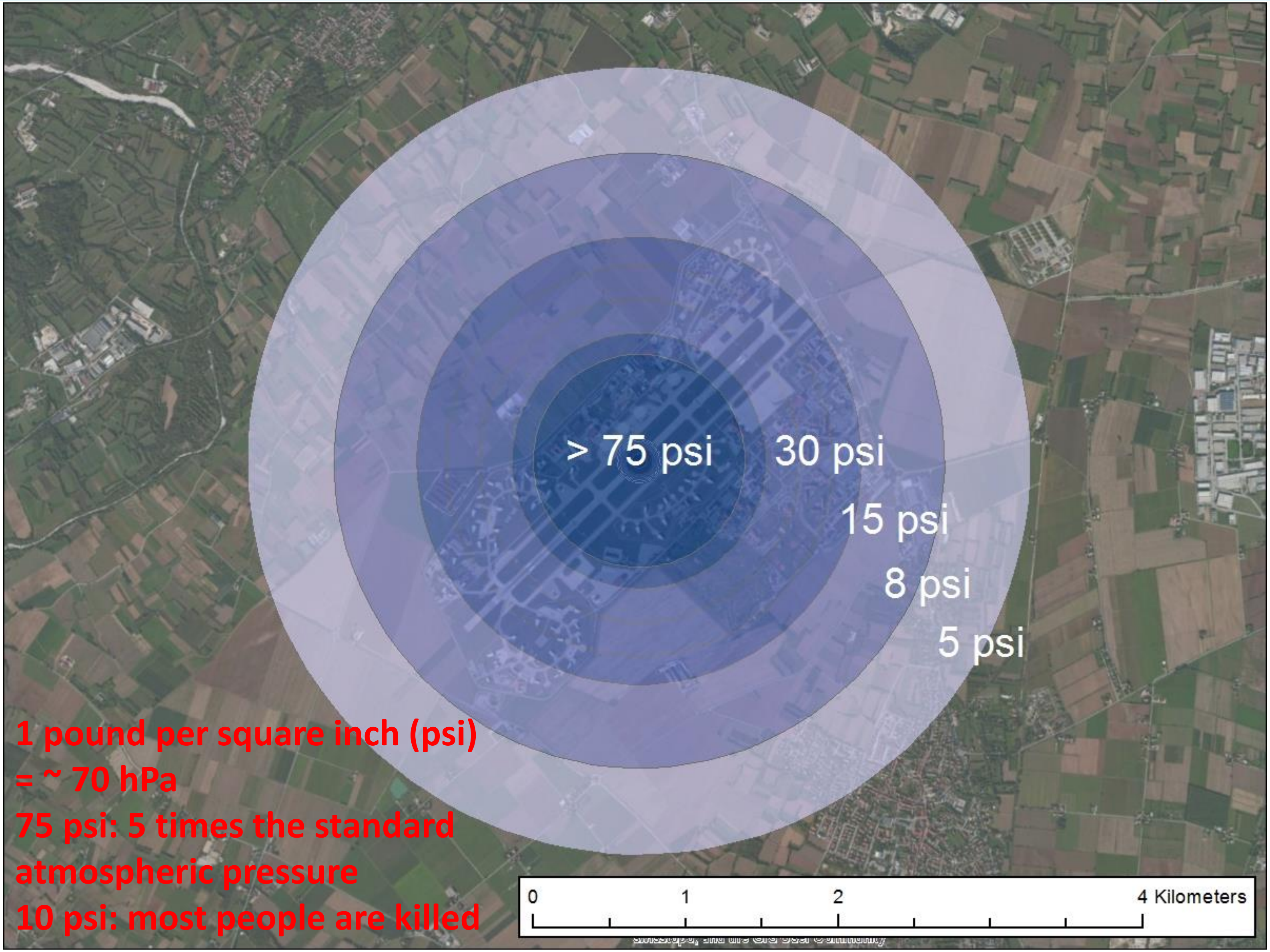
Blast



1 pound per square inch (psi)
= ~ 70 hPa
75 psi: 5 times the standard atmospheric pressure
10 psi: most people are killed

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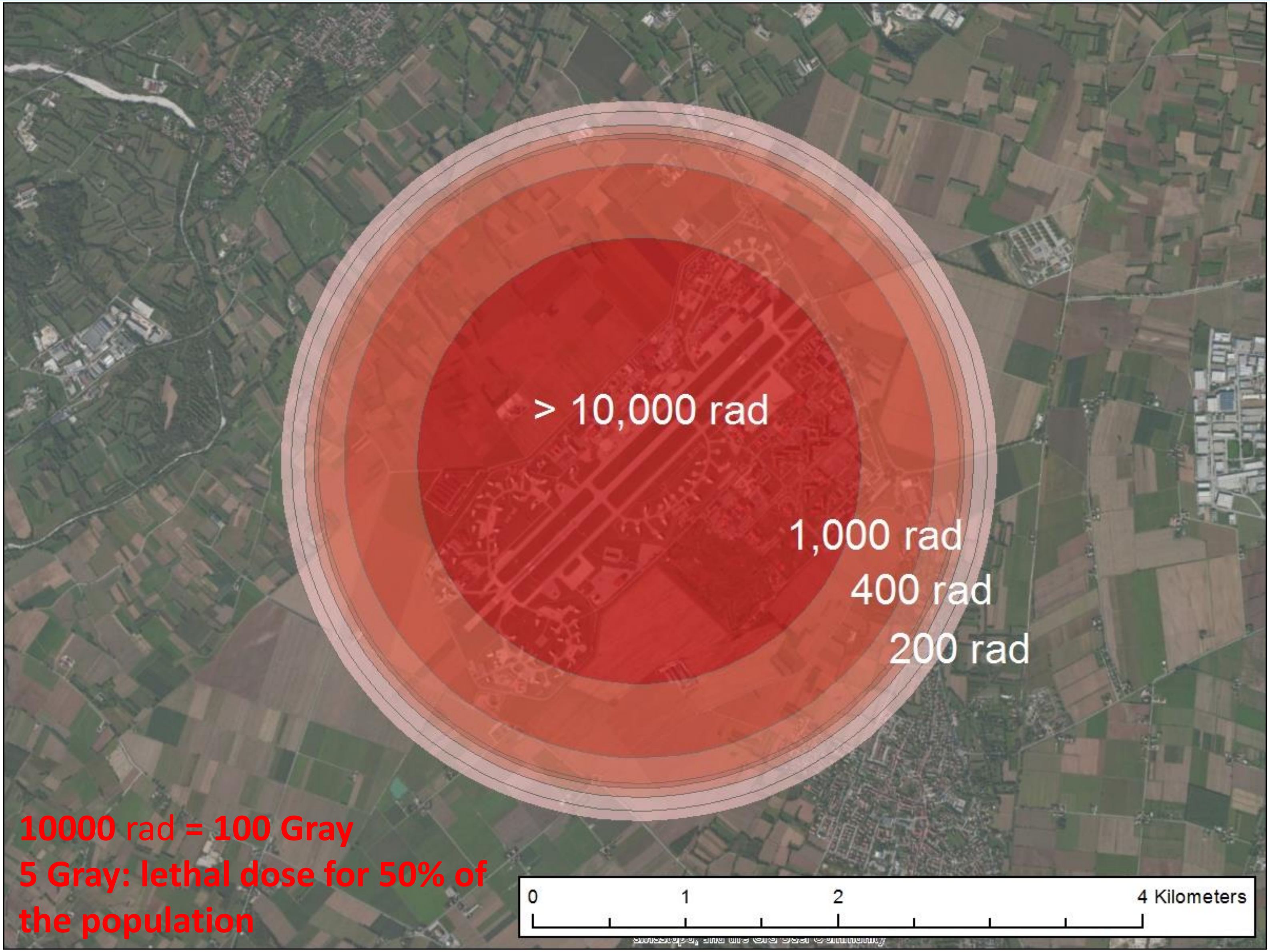
Initial radiation



10000 rad **= 100 Gray**
5 Gray: lethal dose for 50% of the population

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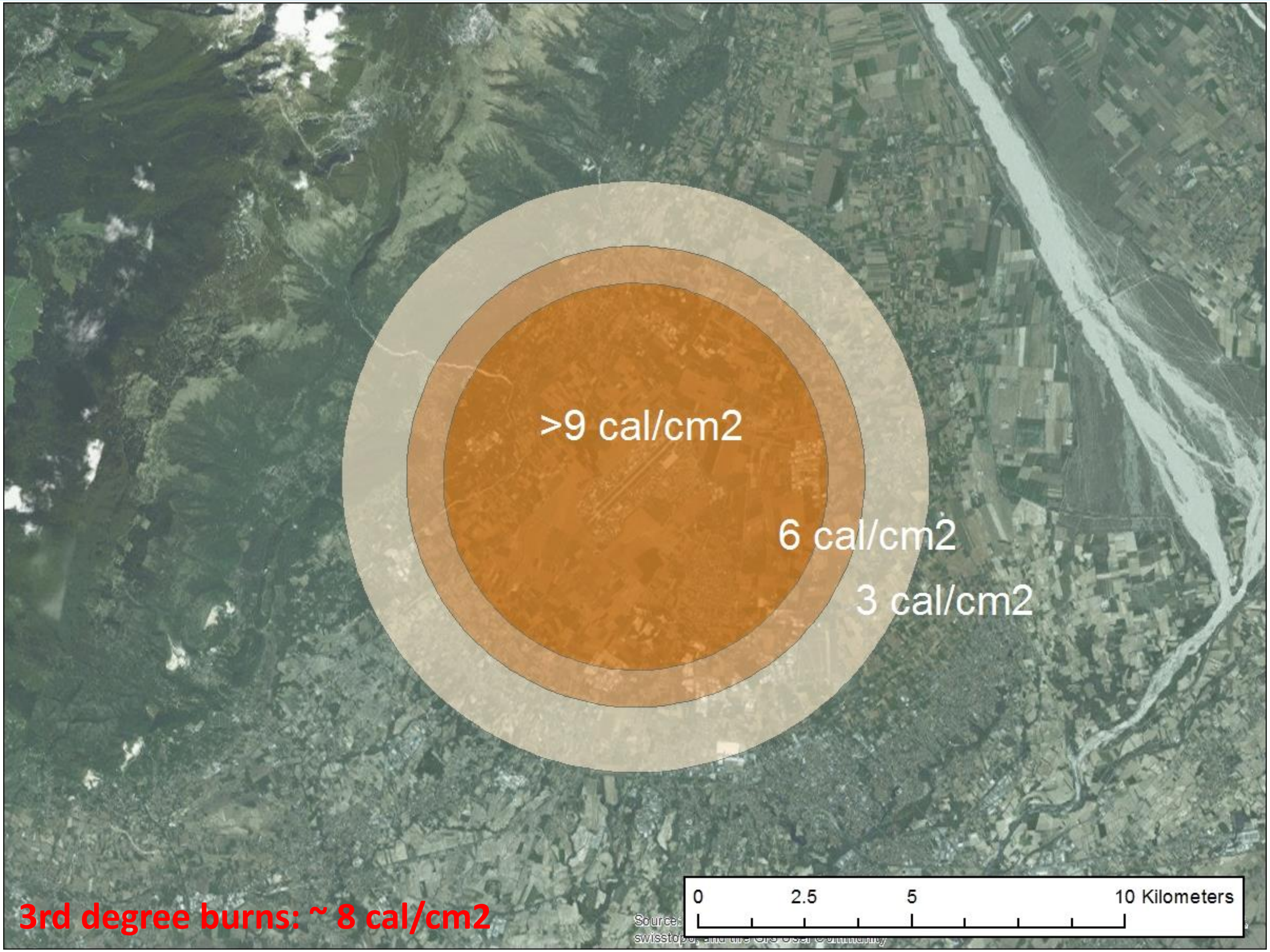
Thermal radiation



3rd degree burns: ~ 8 cal/cm2

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United States Department of Defense HPAC: Casualty tables

For an Unsheltered Population:

	Best Estimate		
	Prompt	Fallout	Total
Fatalities	16,901	69,740	86,641
Injuries	6,304	150,559	156,863
Total Casualties	23,205	220,299	243,504

For a Sheltered Population:

	Best Estimate		
	Prompt	Fallout	Total
Fatalities	10,169	16,208	26,377
Injuries	16,737	39,280	56,017
Total Casualties	26,906	55,488	82,394

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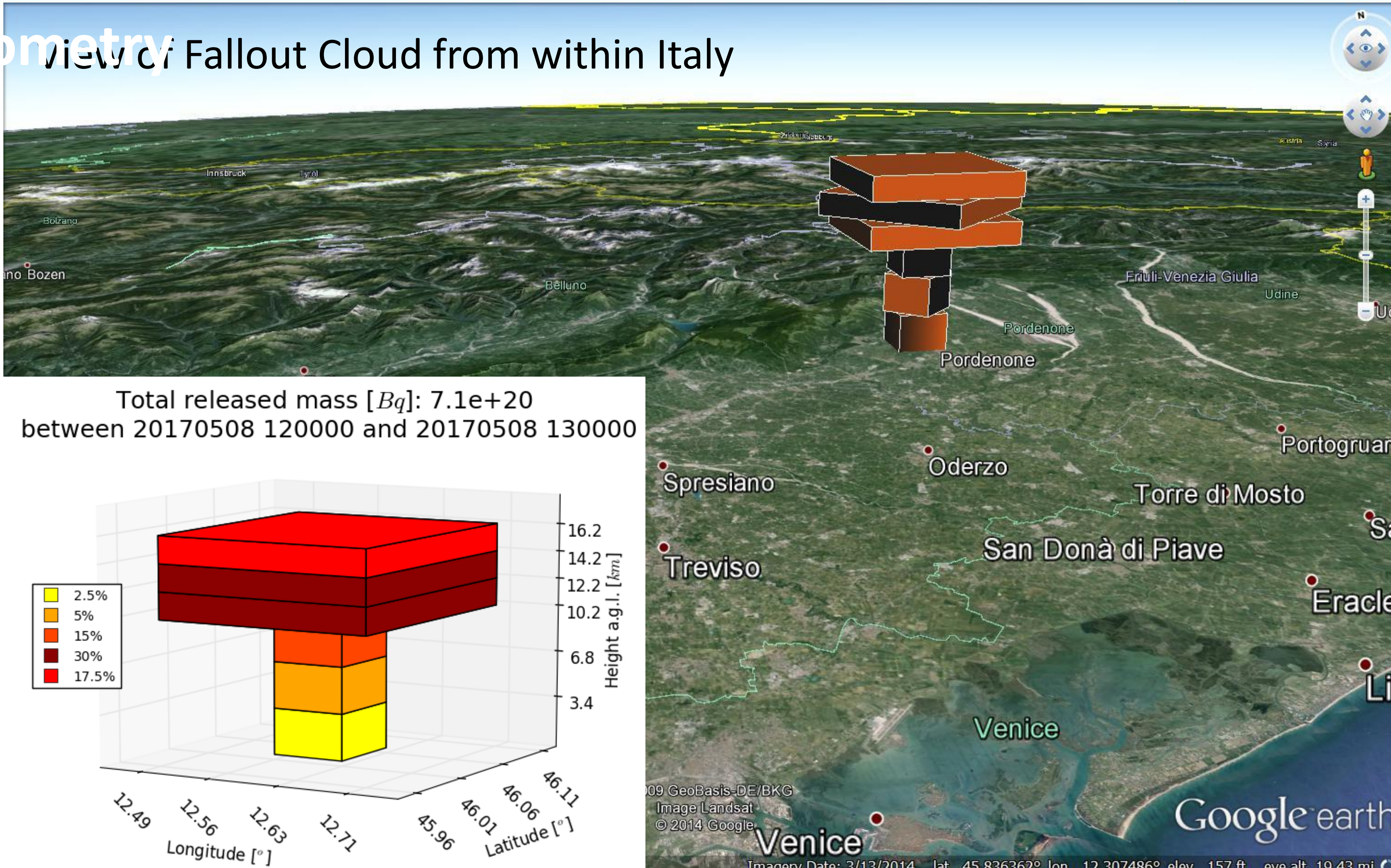
First steps: Developing a prototype single-isotope source term for FLEXPART: Fallout Cloud ometry



Diameters:

- **Umbrella: ~ 8.4 km**
- **Stem: ~2.8 km**

Yield: 200 kt

Following the work of *Rolph et al. (2014)*

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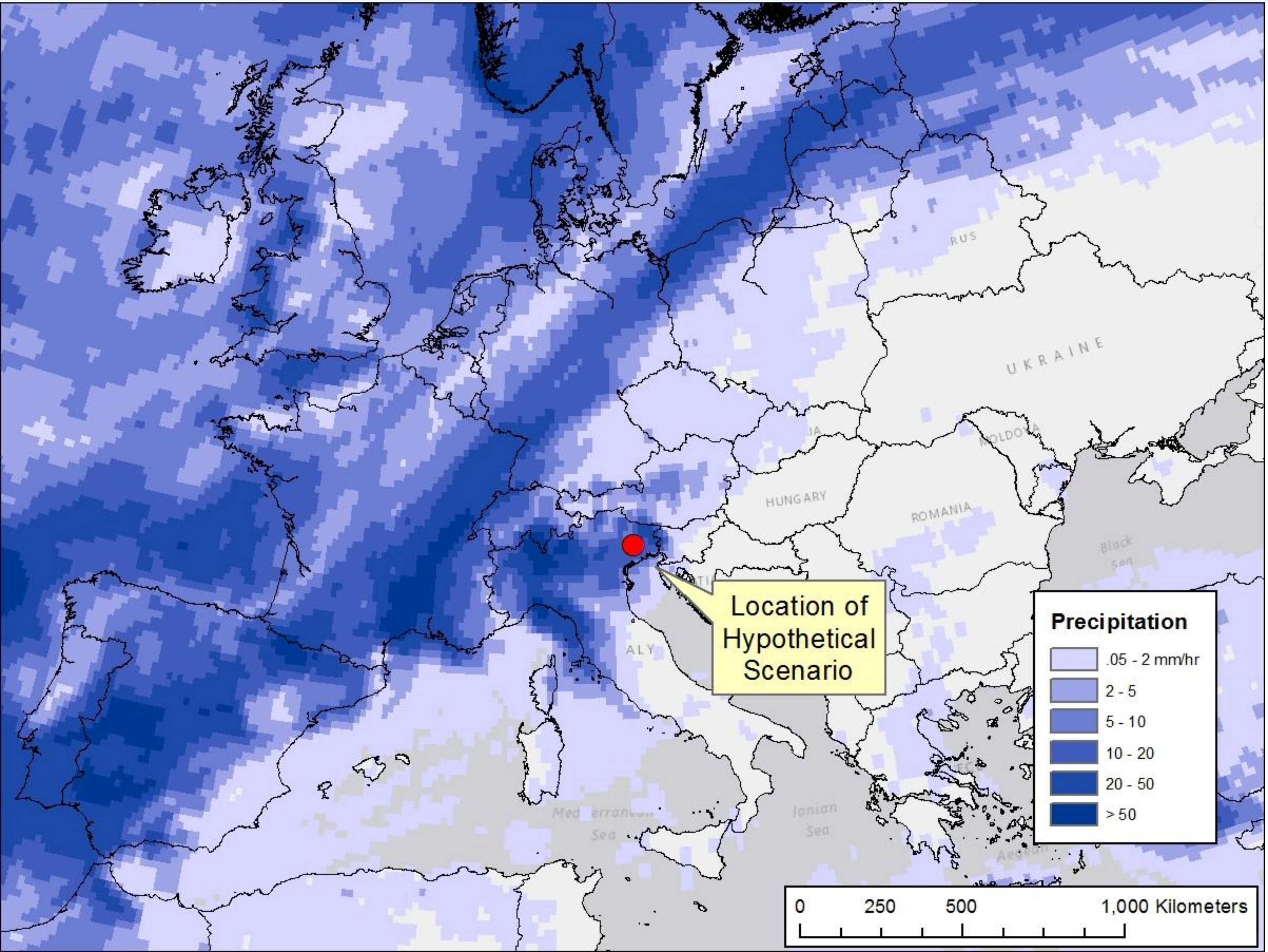
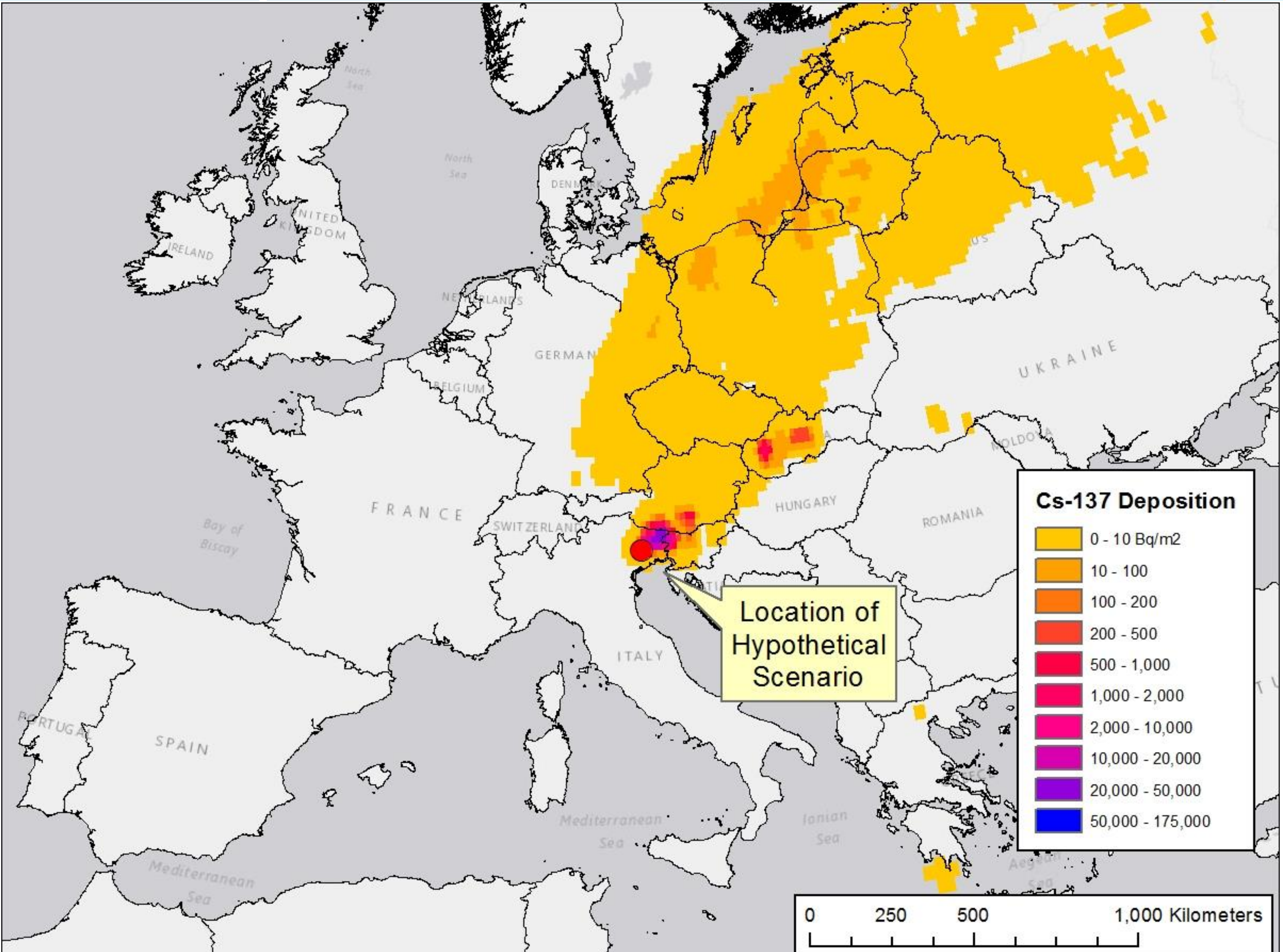
1st scenario: October 2014, 2 days accumulated precipitation



1st scenario: October 2014, 2 days accumulated Cs-137 deposition



> 550 kBq/m² (red or violet): resettlement zone

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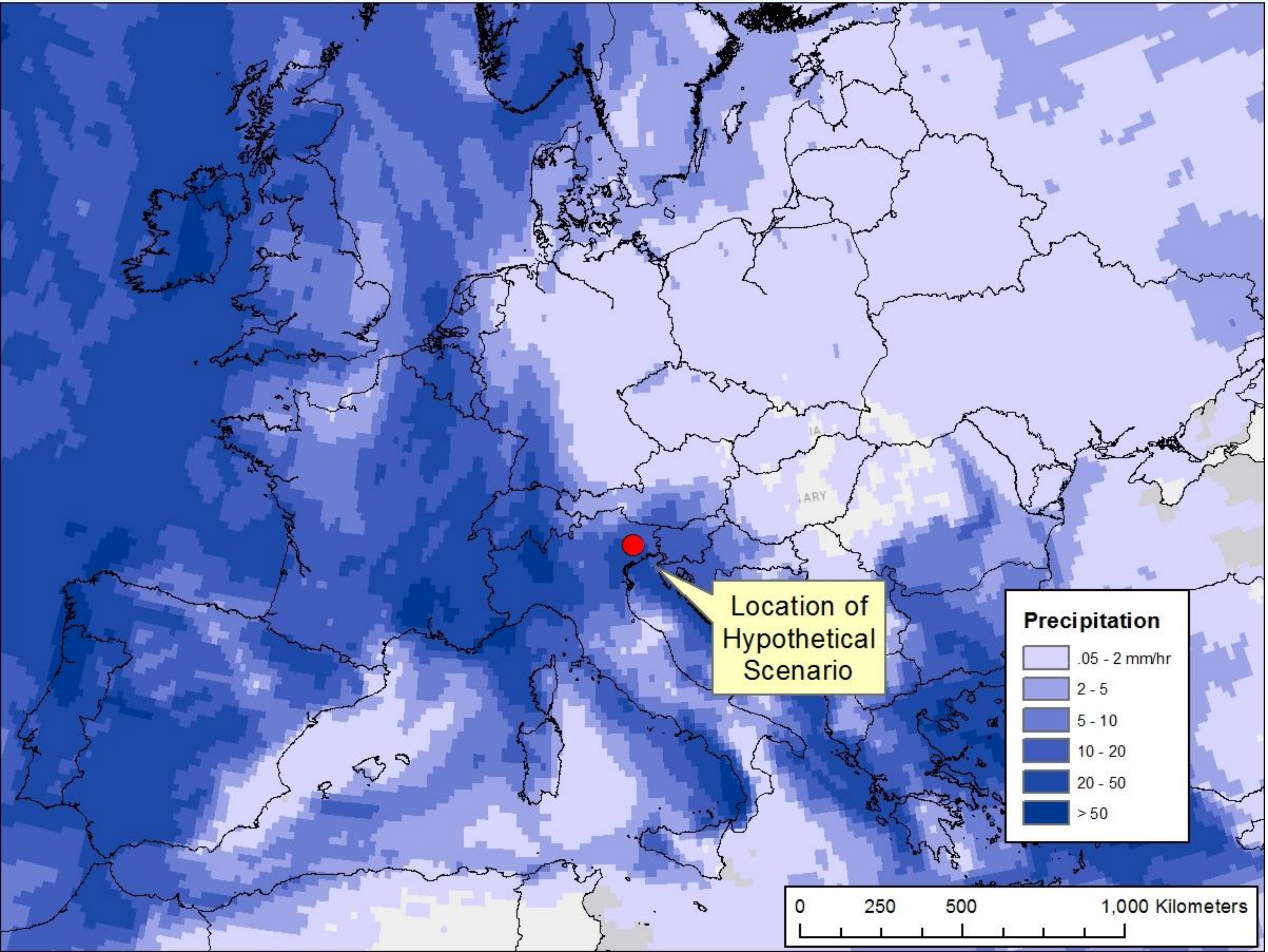
2nd scenario: November 2014, 2 days accumulated precipitation



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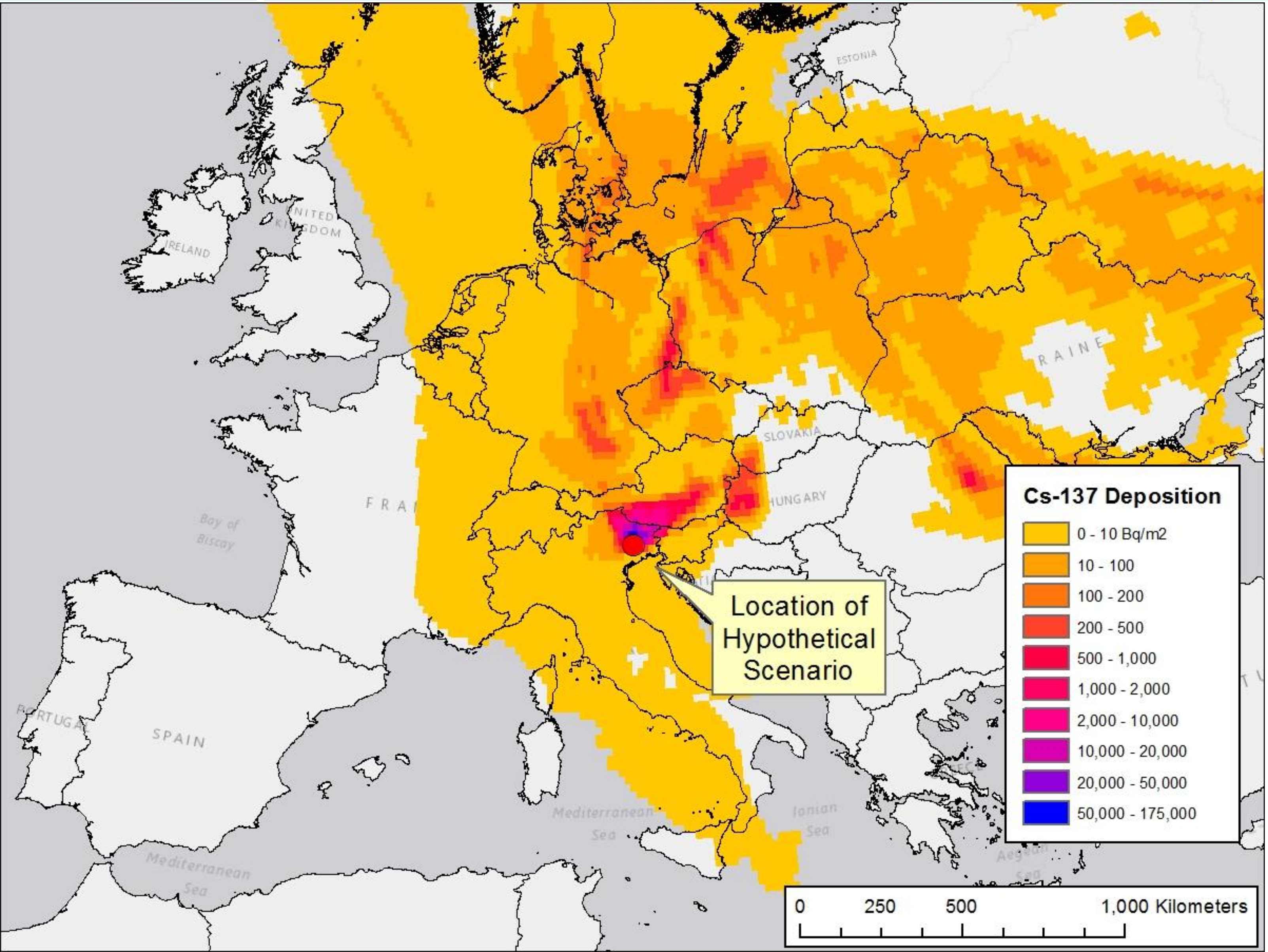
2nd scenario: October 2014, 2 days accumulated Cs-137 deposition



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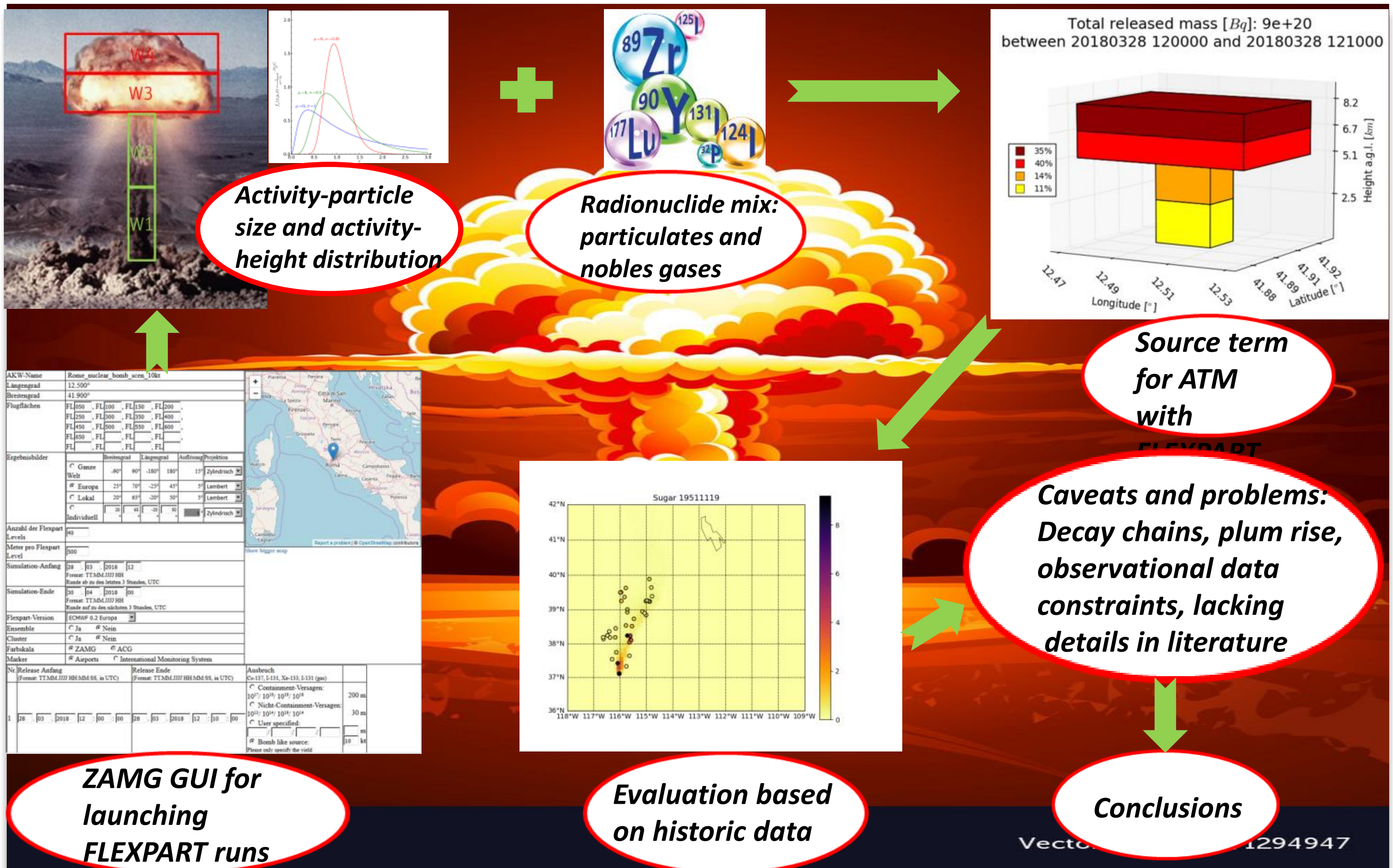
FFG-FORTE-Projekt „ABC-Maus“ (2019-2021): Overview of tackled topics



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The source term: Assumptions for the radionuclide mix

Radionuclide mix provided by the *Radiation and Nuclear Safety Authority of Finland* STUK (based partly on *Kraus and Foster, 2013* & *2014*) – assumptions:

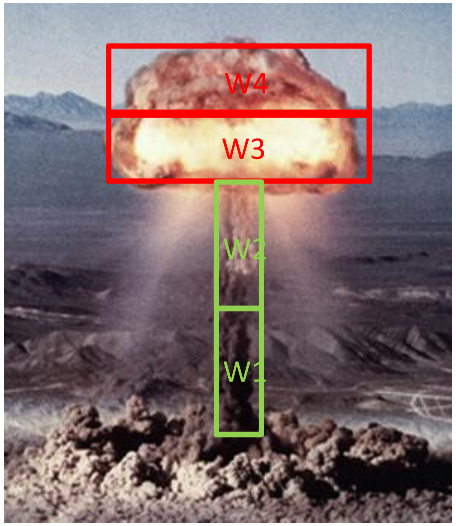
- **Uranium**-fuelled **or Plutonium**-fuelled **gun-type**: 25kg (eqiv. to 10 kt yield), 94% U-235, 6% U-238
- **Pure-fission weapon** (yield < 300 kt), no fusion
- **Surface burst** (‣ stem + umbrella cloud)
- Underlying surface: Concrete and asphalt mix
- Internal cladding material (bomb structure): Stainless steel
- Activation products (also included) compared to fission products are hardly relevant ‣ surrounding of site has minor impact
- *Glasstone and Dolan (1977)*: 1 kt = 1.45E+23 fissions
- Nuclide specific **cumulative or independent U-235, U-238 and Pu-239 fission product yields** based on *England and Rider (1993a, 1993b)* multiplied with the number of fissions and decay constants give specific activities at t=0.

Source term geometry

- **Mushroom with stem and hat** according to *Harvey et al. (1992)* **for surface burst:** Top of hat top_{Hat} and stem top_{Stem} as function of yield [kt]. Differences in empirical formulae for top_{Hat} and top_{Stem} according to yield thresholds 2 and 20 kt. Radii of hat r_{hat} and stem r_{stem} are also a function of yield.

- **Detonation height [a.g.l.]**: If **critical height** (also a function of yield) is **exceeded**: **Stem is omitted,** W3 and W4 are combined (like in the Swedish MATCH model). **Surface burst ▸ Air burst.**

- **However: Vertical structure** (i.e., a mushroom cloud with stem and hat) **as well the horizontal extension** seem to **have a negligible impact** according to literature. **What counts** are the **total explosion column height** as well as the **activity-particle size and activity-height distribution.**



Stabilized Mushroom Cloud (~5 to 10 minutes after a surface detonation)
(https://physics.stackexchange.com/questions/276999/nuclear-explosion-confined-by-gravity)

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The number-particle size and activity-particle size distribution

- **Activity should not be distributed according to number-particle size distribution(s)** ▸ large particles would be under-represented. Rather **it should be distributed according to activity-particle size distribution(s) (i.e., (an) upper moment(s) of the number-particle size distribution(s)).**

- Using an **overlap of two log-normal activity-particle size distributions** (*Harvey et al., 1992*; *Baker et al., 1987*; *Ledger, 2015,* MATCH model) seems to be ***state of the art.***

- In order to **cover dispersion and deposition over a wide range of distances** a **wide range of particle sizes occurring in a nuclear explosion is needed to be covered.** The particle range follows from the following considerations:

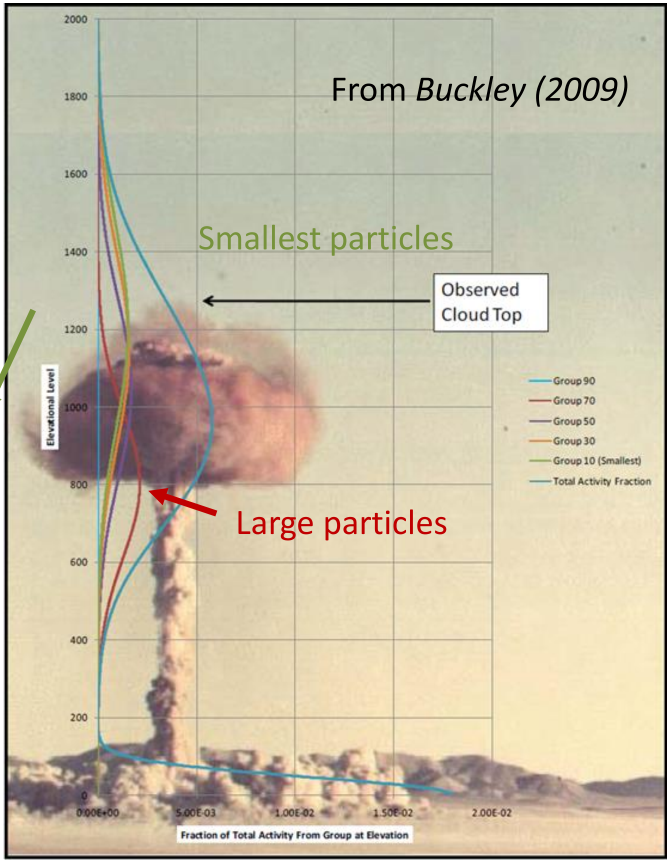
  Particles > ~ 250 µm fall out in the immediate vicinity of the explosion site (*Bartnicki und Saltbones, 2003*).

  Particles > ~ 20 µm (as, e.g., predominately used in *Rolph et al., 2014*) **fall out within the first 24 hours and within some 100 km** (*Baker, 1987*) ▸ ABC-IS should cover also longer forecast lead times and distances!

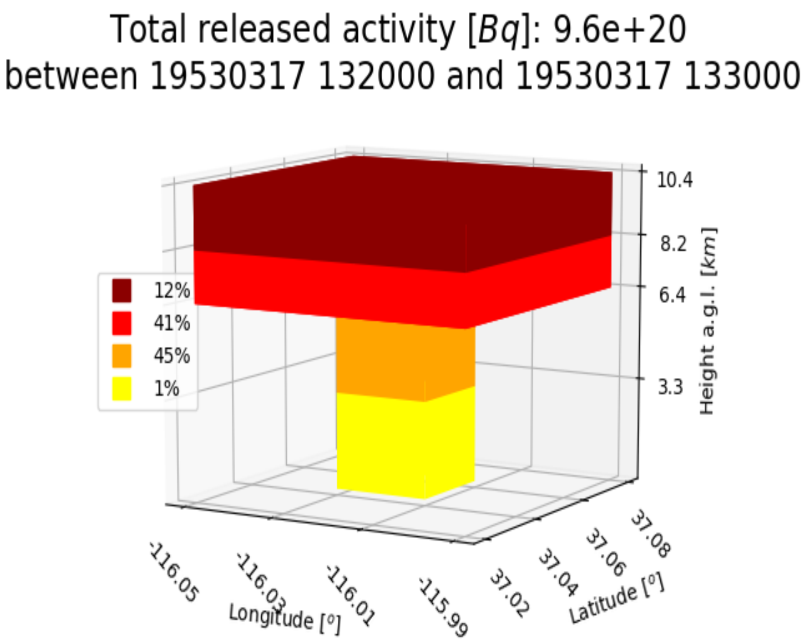
  Particles < ~5 µm will remain aloft even for periods longer than one week (*Baker, 1987*). They are not relevant for fallout in surface emergency response, but for military aviation purposes it may be important to have estimated activity concentrations in the atmosphere.

Vertical distribution of activity

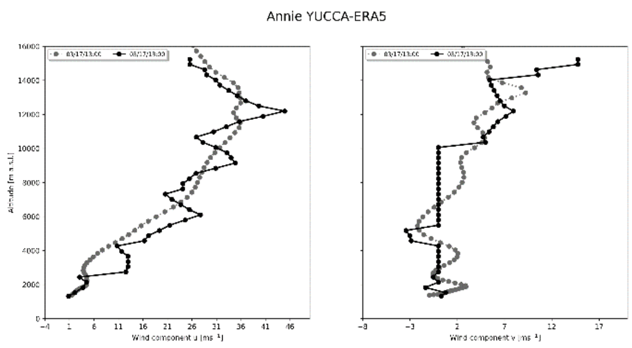
- According to *Buckley (2009):* Calculate **central particle group stabilization heights** and corresponding **standard deviations** based on empirical relations **connected to the Cloud Rise Module (CRM) of DELFIC** as nonlinear function of ln(yield[kt]) ▸
- Calculate **vertical Gaussian activity distribution** and integrate it over the wafer segments, **adapt cloud top and** (for air bursts) **bottom heights (±3σ) for consideration of the invisible part of the cloud.**
- **Highest activities** should be found **in the last but one uppermost wafer and for the smallest particle size due to toroidal motion during cloud stabilization.**
- **Generic noble gas is distributed equally over all wafers.**



Example source term



Nevada test Annie (16 kt, Tower burst detonated at 91 m a.g.l.)



ECMWF-ERA5-re-analysis profils (grey) and historic profiles (black) for u- und v-components of wind [m/s]. ERA5 is used for driving FLEXPART.

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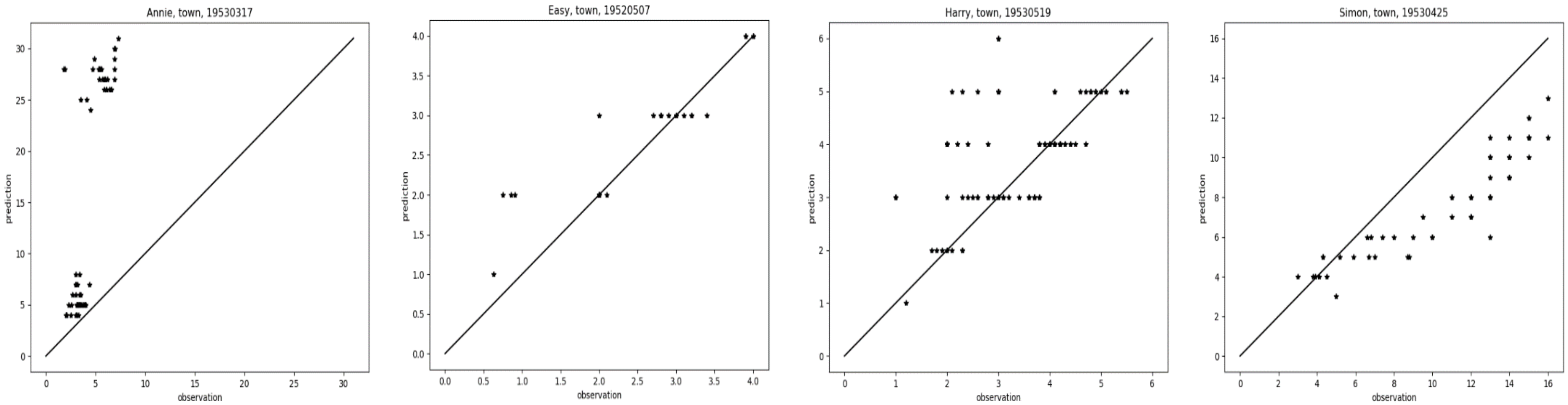
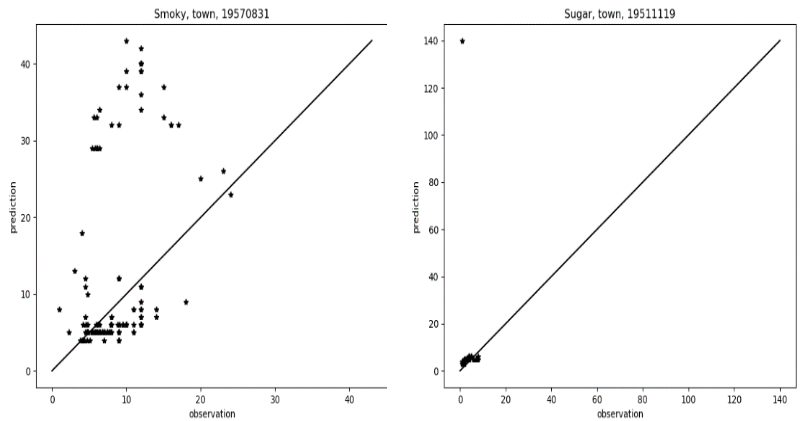
Evaluation for six historic Nevada US-tests I: Arrival times [h]





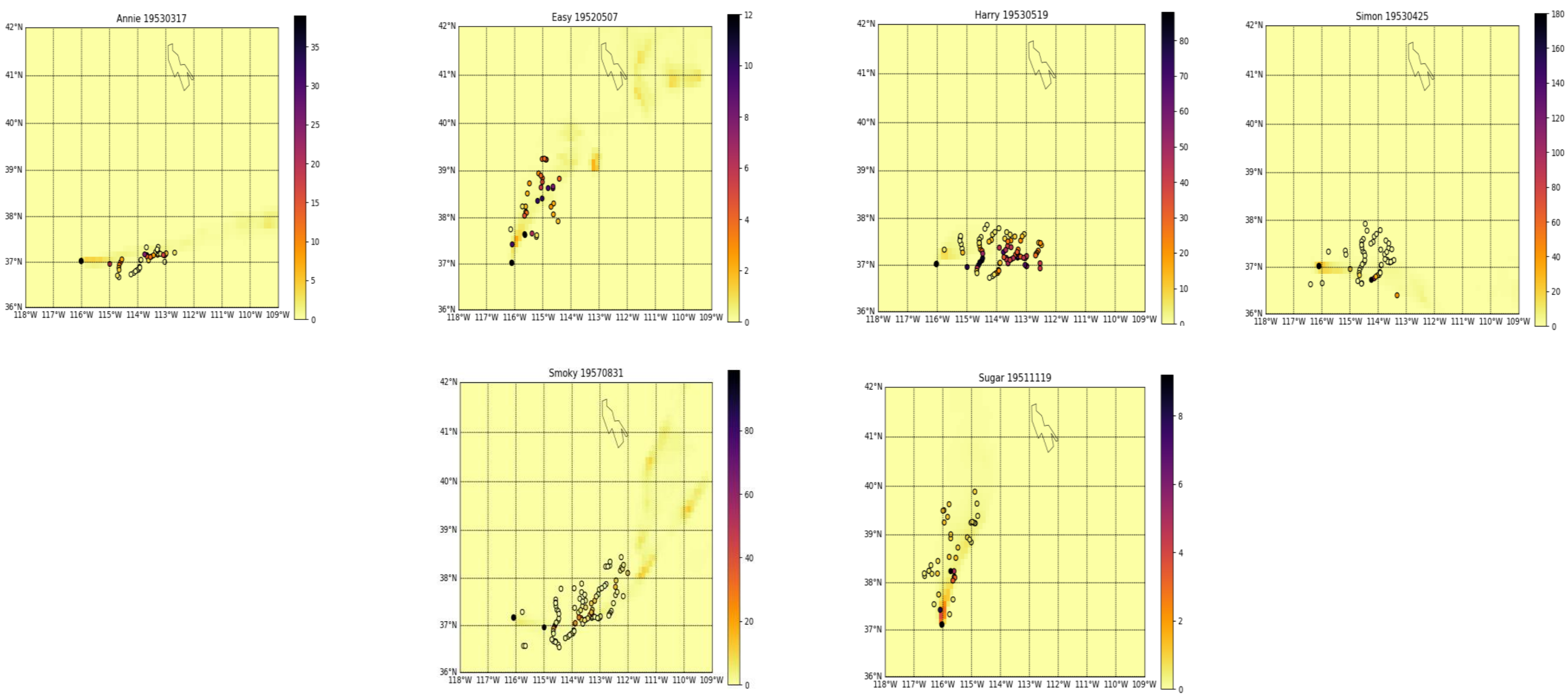
Same six tests as evaluated by *Rolph et al. (2014)* based on their source term module for HSYPLIT.

<u>Observational data:</u> US Department of Energy's (DOE's) <u>Town Data base</u>.

Evaluation for six historic Nevada US-tests II: Ground shine dose rates [mR/h] at T+12

Case: Figure of Merit in Space Fractional Bias Normalized Mean Square Error 95. perc. observations 95. perc. model

Annie: 72.22 -1.81 55.94 25.45 1.170 **Easy:** 61.76 -1.81 27.74 10.7 0.866 **Harry:** 82.35 -1.92 84.06 75.6 1.343



Simon: 92.45 -1.52 81.45 33.7 3.136 **Smoky:** 73.56 -1.80 113.2 26.3 1.353 **Sugar:** 62.5 -1.41 11.88 4.87 0.509

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Early Detection

Early Detection of a nuclear blast can be performed based on data from the International Monitoring System (IMS) of CTBTO/Vienna

Total: 337 Facilities

Primary Seismic stations:50

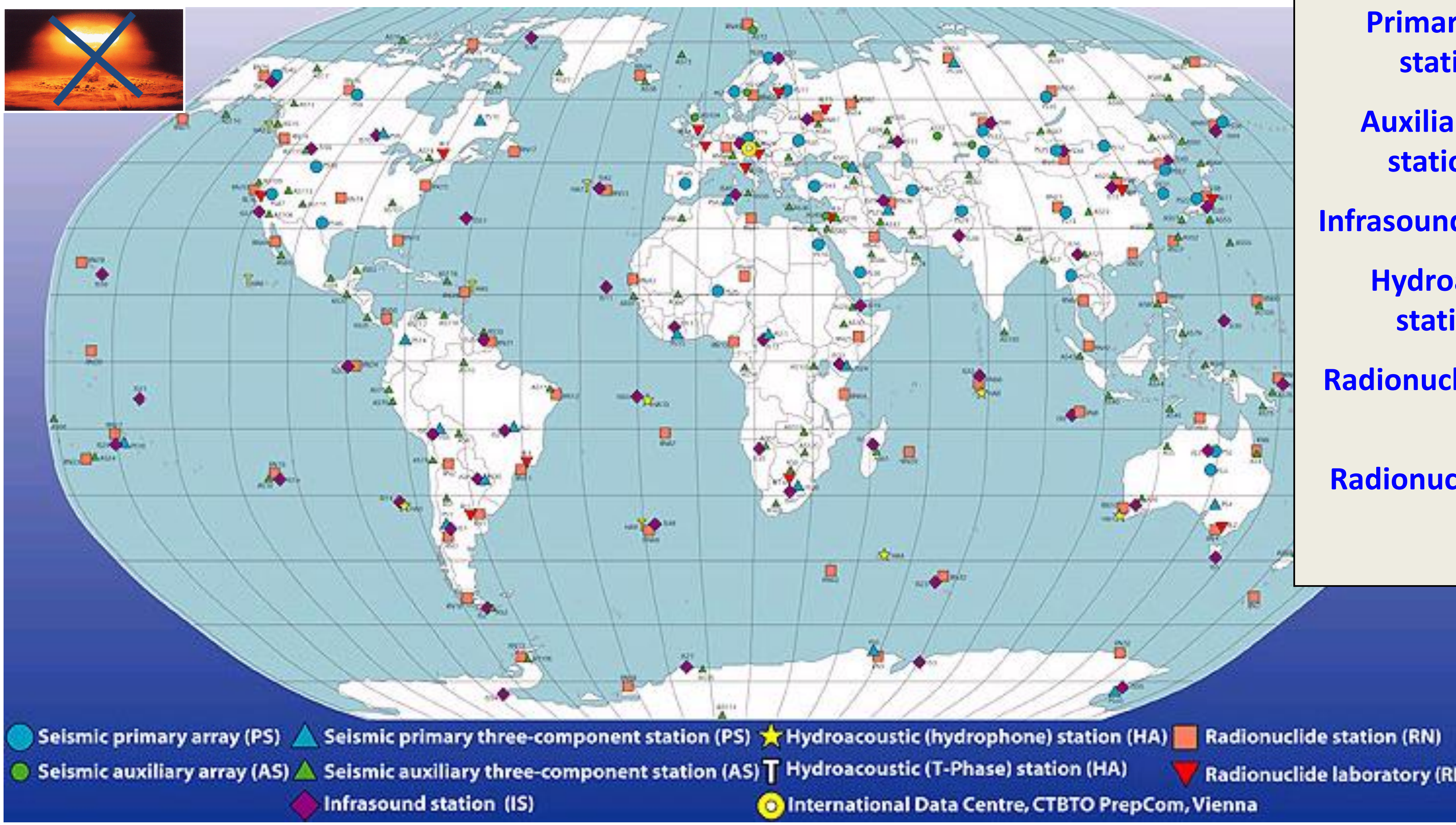
Auxiliary seismic stations: 120

Infrasound stations: 60

Hydroaccoustic stations: 11

Radionuclide stations: 80

Radionuclide labs: 16



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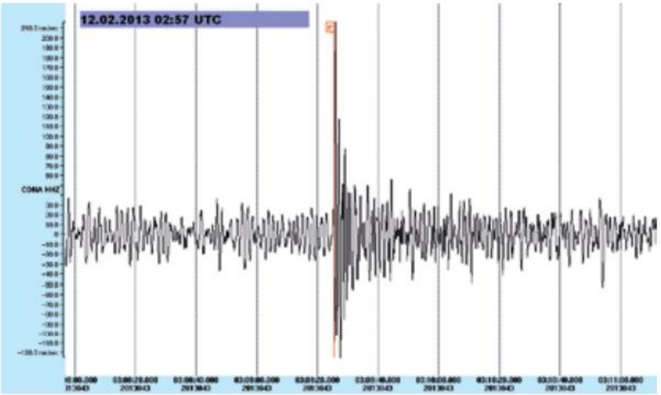
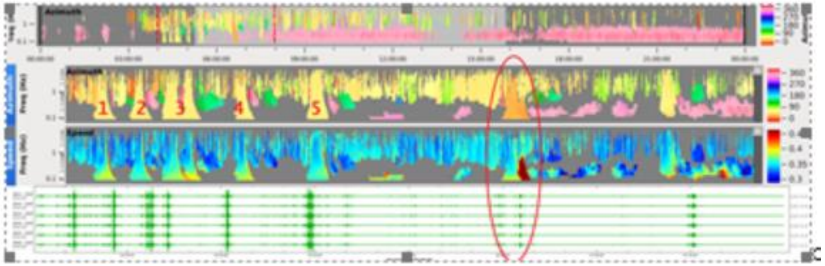
Early Detection (2)

- **Seismic signals –ground motion caused by explosion (for underground or near-surface)**



Seismogram of the announced nuclear test in North Korea in 2013. The signal was recorded not only at the Conrad Observatory, but also at all other seismic broadband stations in Austria.

- **Infrasound signals – atmospheric explosions**



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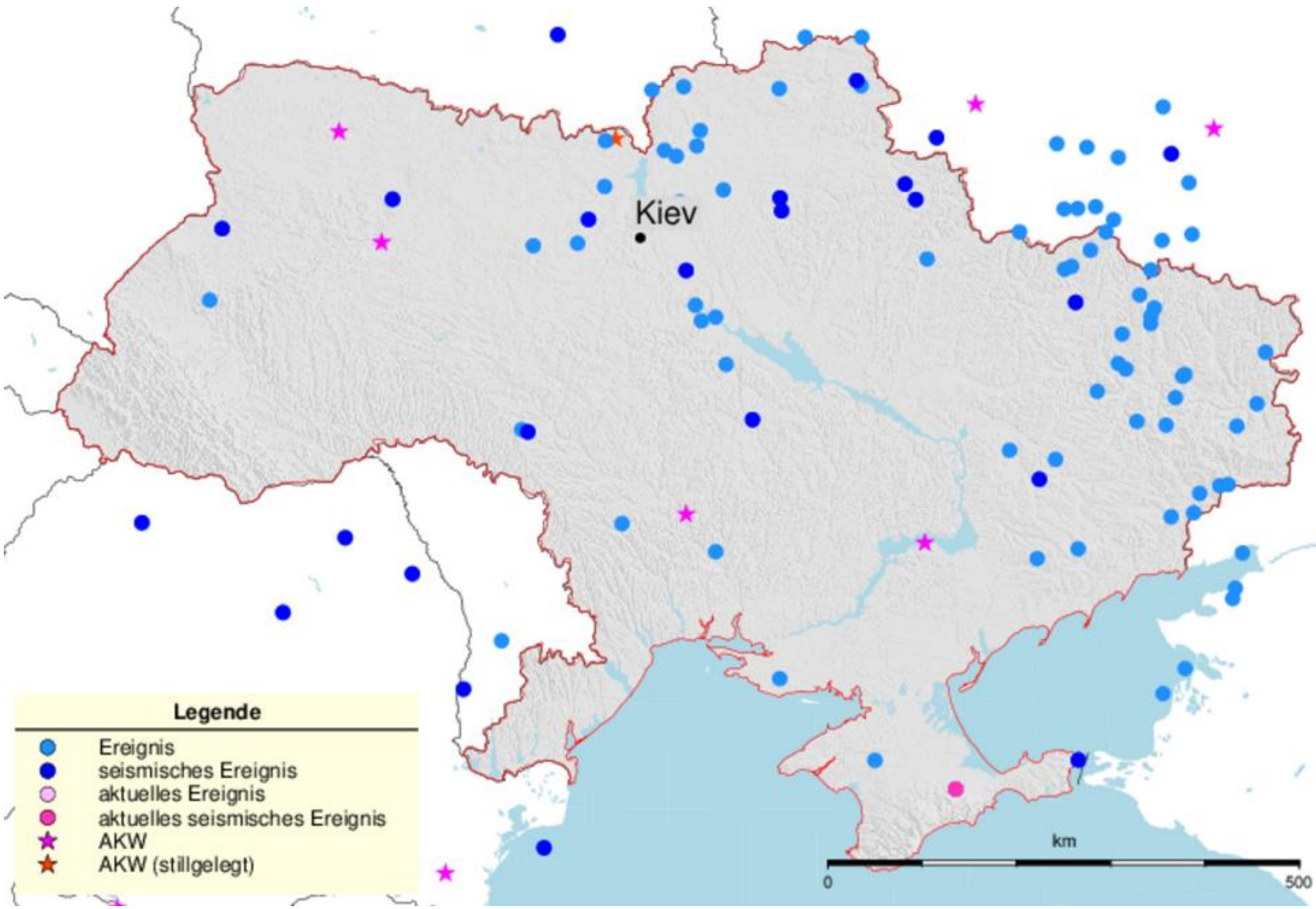
Early Detection (3)

Seismic Signals detected in Ukraine – Belarus – Russia Region



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Specific conclusions

- Based on existing publicly-available literature a default **nuclear explosion source term to be fed into FLEXPART atmospheric transport and dispersion calculations was developed** in the frame of the project ABC-Maus.

- It is **based on a bimodal log-normal activity particle-size distribution** and a **normal activity distribution in the vertical around central particle group altitudes. Local to global fallout is considered (particles of 2.2 to 173.2 µm).**

- An **evaluation was performed for the near field** based on six historic US Nevada tests. **Arrival times** are **satisfactorily modelled** (results are similar to *Rolph et al. (2014)*), **dose rates due to ground shine are considerably underestimated**. The nuclide mix might need to be revisited.

- Source terms of other organizations show deficiencies as well for the Nevada tests , e.g., SMHI-MATCH.

Overall conclusions

- Open-source information can be used to calculate the **effects of a nuclear explosion in terms of crater, blast, thermal, initial radiation and fallout effects**.
- **Military targeting requirements** for destruction of hardened objects **involves surface or near-surface bursts, maximizing fallout**.
- For a 200 kt nuclear explosion, the **prompt nuclear weapons effects are far more localized than the fallout effects, which were shown to extend across international boundaries** for a hypothetical scenario.
- **Variations of fallout patterns with weather conditions** are a motivation for non-nuclear weapon states to develop a capability to **model nuclear explosive effects to mitigate humanitarian impacts of a nuclear conflict**.
- **Humanitarian impacts of nuclear war continue to be relevant to our societies**, given the large nuclear arsenals retained decades after the end of the Cold War, and new nuclear weapons development in some states.
- **ZAMG is prepared** for early detection as well as estimating plume dispersion after an atmospheric nuclear explosion.

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