Dispersion modelling of radioactive pollutants: application of the DETRACT code system at the “Hanford scenario”

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The "Hanford scenario" (Scenario H)

- Acute accidental release of radioactive ^{131}I from the stack of the Hanford (Washington, USA) Purex Chemical Separations Plant
- Release duration: 2 – 5 September 1963
- Scenario prepared during VAMP (Validation of Environmental Model Predictions) program of IAEA
- Used by the Dose Reconstruction Working Group of BIOMASS (Biosphere Modelling and Assessment Methods), in 1999 , as the initial test exercise

Details of the release

- Stack height: 60.5 m
- Stack radius: 1.067 m
- Geographical coordinates: 46.549 N, 119.517 W
- Stack flow: 56.63 m^3/s
- Effluent temperature: 25 C
- 100% molecular iodine (I_2) released, quickly partitioned into particulate (25%), reactive gas (40%) and organic (35%)

Scenario H: Challenging and interesting case

- For the evaluation of modelling systems:
  - Atmospheric dispersion
  - Deposition
  - Passage of radioactive pollutants to food chain
- Complex case:
  - Irregular topography
  - Time-variation of source
  - Long duration of release: 3½ consecutive days, with changing meteorological conditions (variation of wind speed and direction + day/night stability variations)

Aspects treated in this paper

- We focus on atmospheric dispersion and deposition (no passage to food chain modelled)
- Evaluation of the modelling system:
  - Meteorological pre-processor (FILMAKER)
  - Atmospheric dispersion model (DIPCOT – Lagrangian particles)
- Measured data used for the evaluation: air concentrations of ^{131}I at the 21 sampling points around the Plant
  - Daily averaged values
  - Time integrated values over the entire release duration

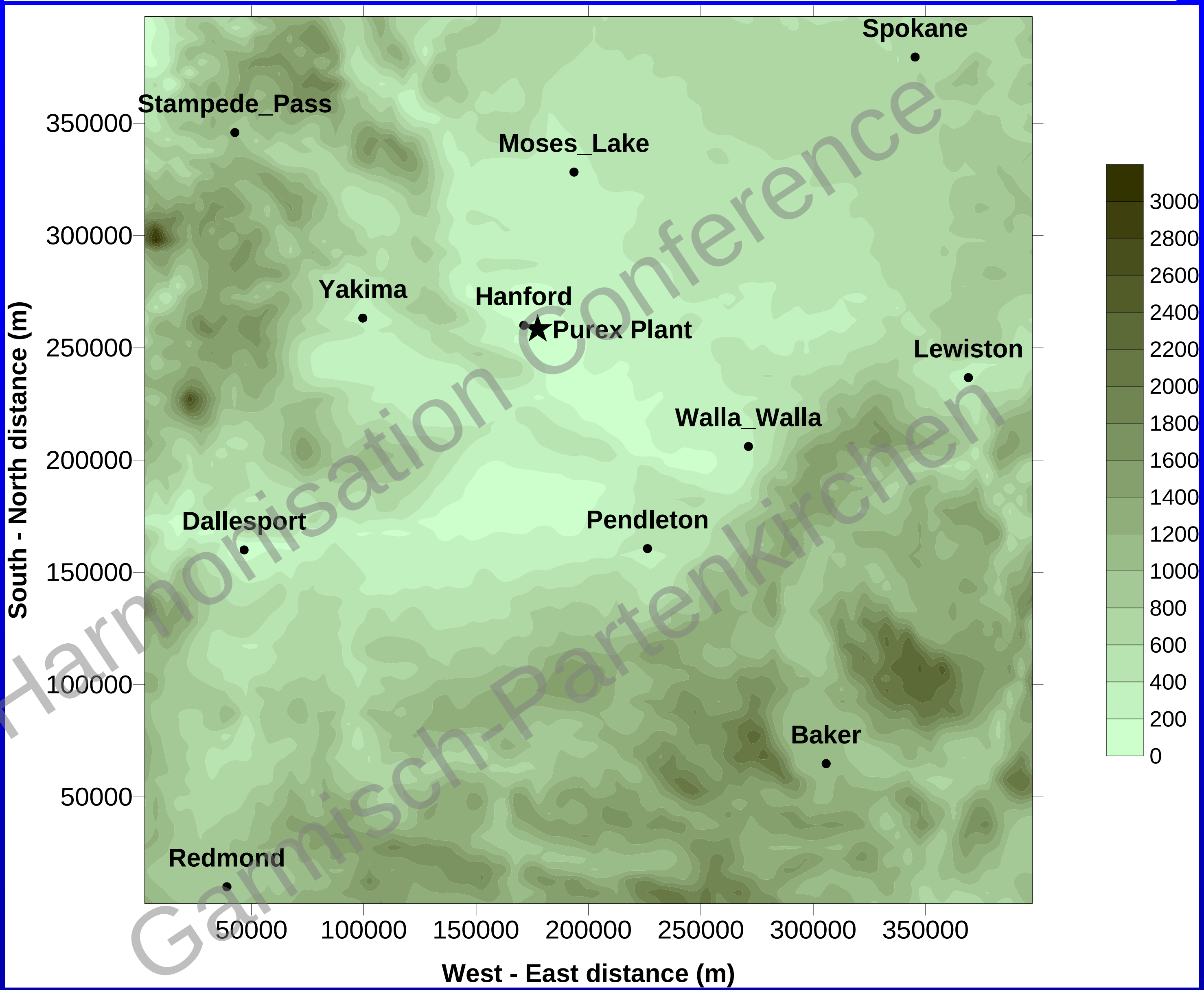
Components of the modelling system (1)

- Meteorological pre-processor FILMAKER
  - Purpose: calculation of gridded meteorological data (horizontal grid: Cartesian, non-equidistant; vertical grid: terrain-following, non equidistant)
  - Input: observations from random stations + data from Numerical Weather Prediction models
  - Output: all meteorological data required by Atmospheric Dispersion Models
  - Method of calculations: $1/r^2$ interpolations horizontally; semi-empirical relations; linear, power-law, logarithmic, exponential interpolations vertically, according to variable; divergence minimisation for wind velocity horizontally
  - Operational use of FILMAKER: in RODOS (Real-time On-line DecisiOn Support system for nuclear emergencies in Europe)

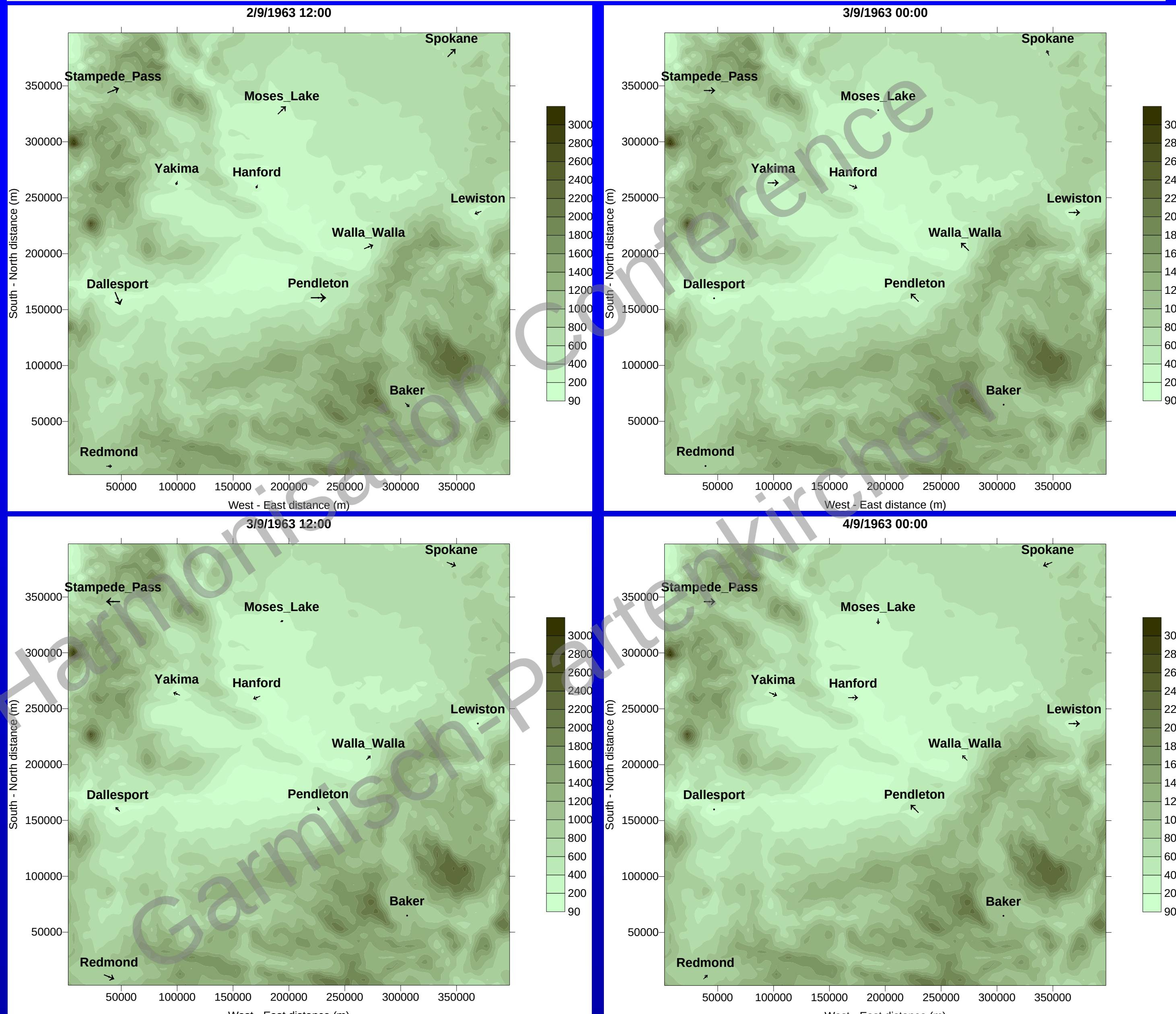
Components of the modelling system (2)

- Atmospheric dispersion model DIPCOT
  - Lagrangian particles model
  - Particles are assumed to follow the wind flow $x_i^{n+1} = x_i^{n} + \left(\overline{u_i} + u_i'\right)\Delta t$
  - Turbulent velocity fluctuations are based on the assumption that turbulent diffusion can be modelled as a Markov process, using Langevin equation $$du_i' = a_i dt + b_i dW_i(t)$$
  - α_i, b_i are, in general, functions of time, space and velocity. The coefficient b_i is obtained through consistency with the Kolmogorov's similarity theory while α_i is determined by consistency between the Lagrangian and the Eulerian statistics, according to the "well-mixed criterion" (Thomson, 1987)
  - Concentration calculations: Gaussian-shaped density kernel

Meteorological calculations domain: topography, meteorological surface stations, release location ("Purex Plant")



Measured wind vectors at different times



Remarks based on the meteorological measurements

- Strong wind variations between the stations
- The terrain features have a strong influence on the wind:
  - Local drainage flows towards the valleys, and channeled flows
- At the Hanford site, the wind speed is in general low with dominant directions from the west and north west
- Temperature inversions occurred during night, which broke during the days resulting unstable conditions
- No precipitation occurred during the release period

Specifications for meteorological calculations

- Domain horizontal dimensions: 400 × 400 km^2 (to include most of the available monitoring stations)
- Discretizations:
  - Horizontal: 80 × 80 cells with dimensions 5 × 5 km^2
  - Vertical: 29 cells with dimensions 50 to 500 m up to 10 km
- Measurement data used by the meteorological pre-processor:
  - Hourly data of wind velocity, temperature, pressure and atmospheric stability from the ground stations
  - Hourly profiles of wind and temperature from the meteo-tower at Hanford (up to 400m height)

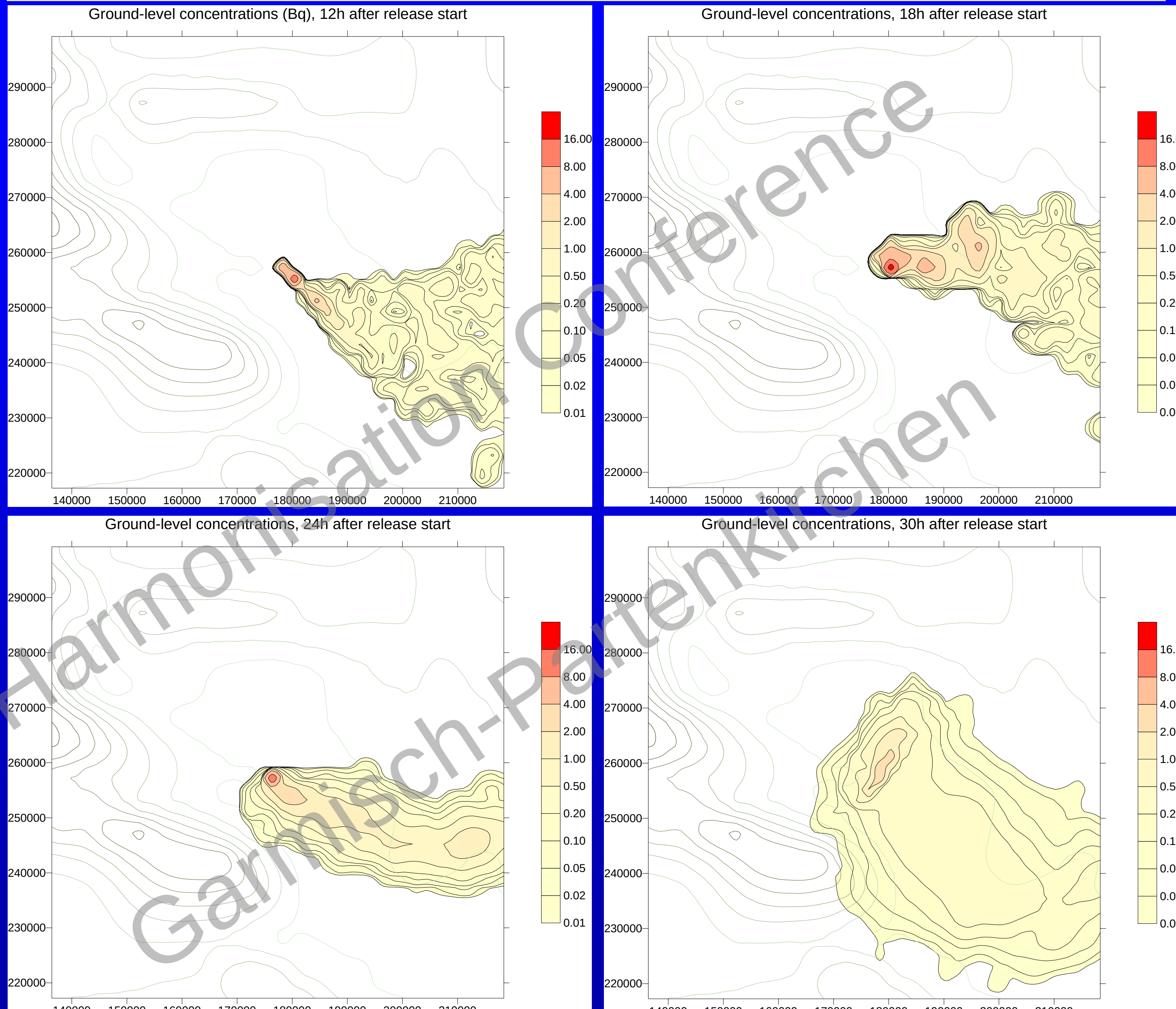
Specifications for meteorological calculations (2)

- Spatial interpolation to calculate 3-D meteorological fields from measurements:
  - $1/r^2$ horizontally
  - Logarithmic or power-law vertically
- The required variables that were not included in the observations (e.g., mixing layer height) are calculated by semi-empirical relations
- Time period simulated: duration of the release, from 12:00 of 2/9 to 23:00 of 5/9 local time
- Output data calculated on hourly basis: wind, temperature, stability, mixing layer height, humidity, pressure, precipitation, heat flux, etc.

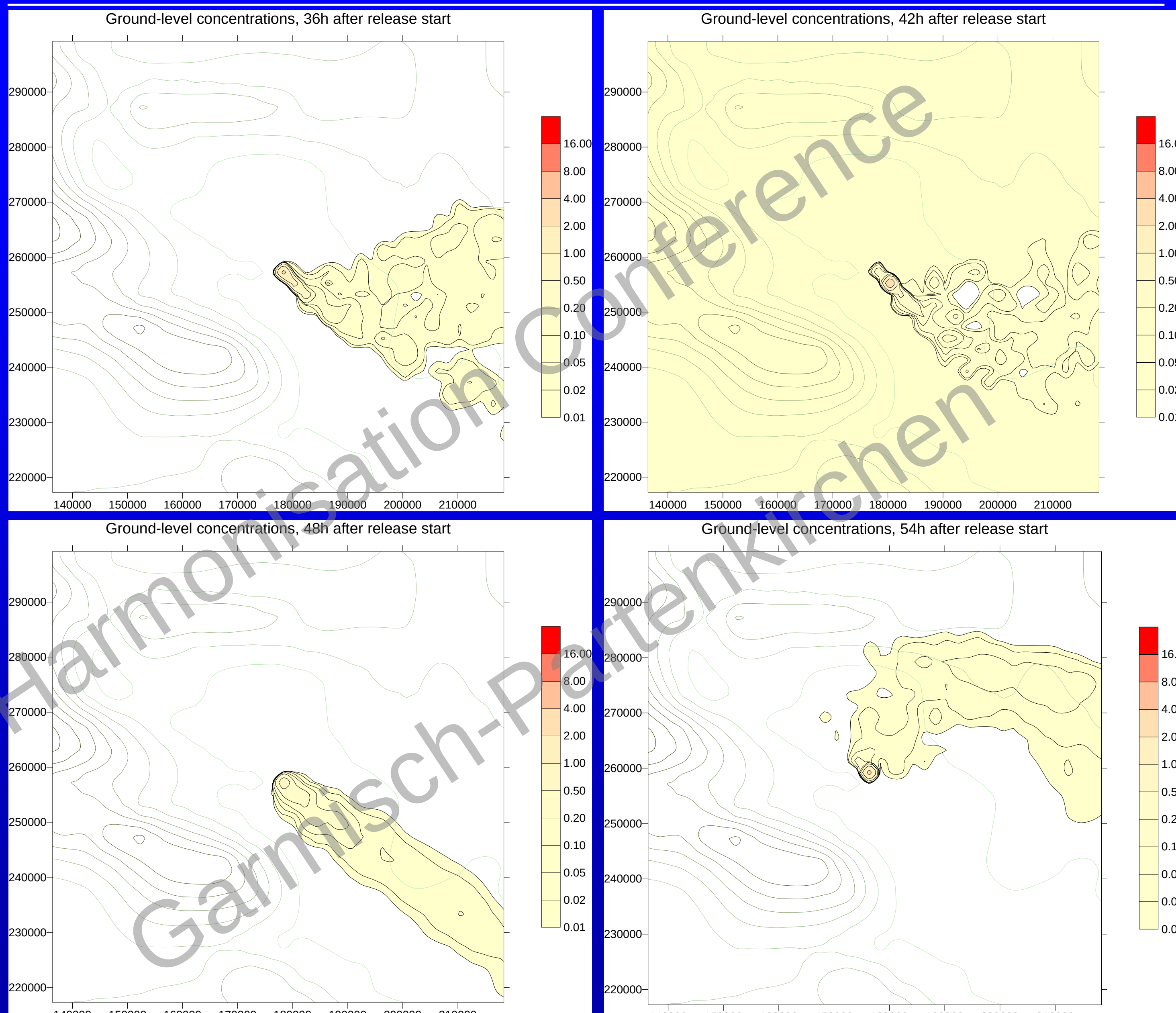
Atmospheric dispersion calculations

- Actual time-variation of the release
- Release quantity was reduced by 35% to account for organic forms of iodine, which was not captured by the samplers
- The modelled released activity has been distributed to 9270 particles (1 particle emitted every 33 s)
- The lagrangian model calculated the particles displacement based on random velocities added to the mean wind velocity
- The concentrations have been calculated both on a regular grid (42×42 cells of 2×2 km2) and at the sampling locations at 1-hour intervals
- Dry deposition of iodine has been taken into consideration
- The dispersion calculations lasted the entire period of the release (12:30 of 2/9 to 23:00 of 5/9 local time)

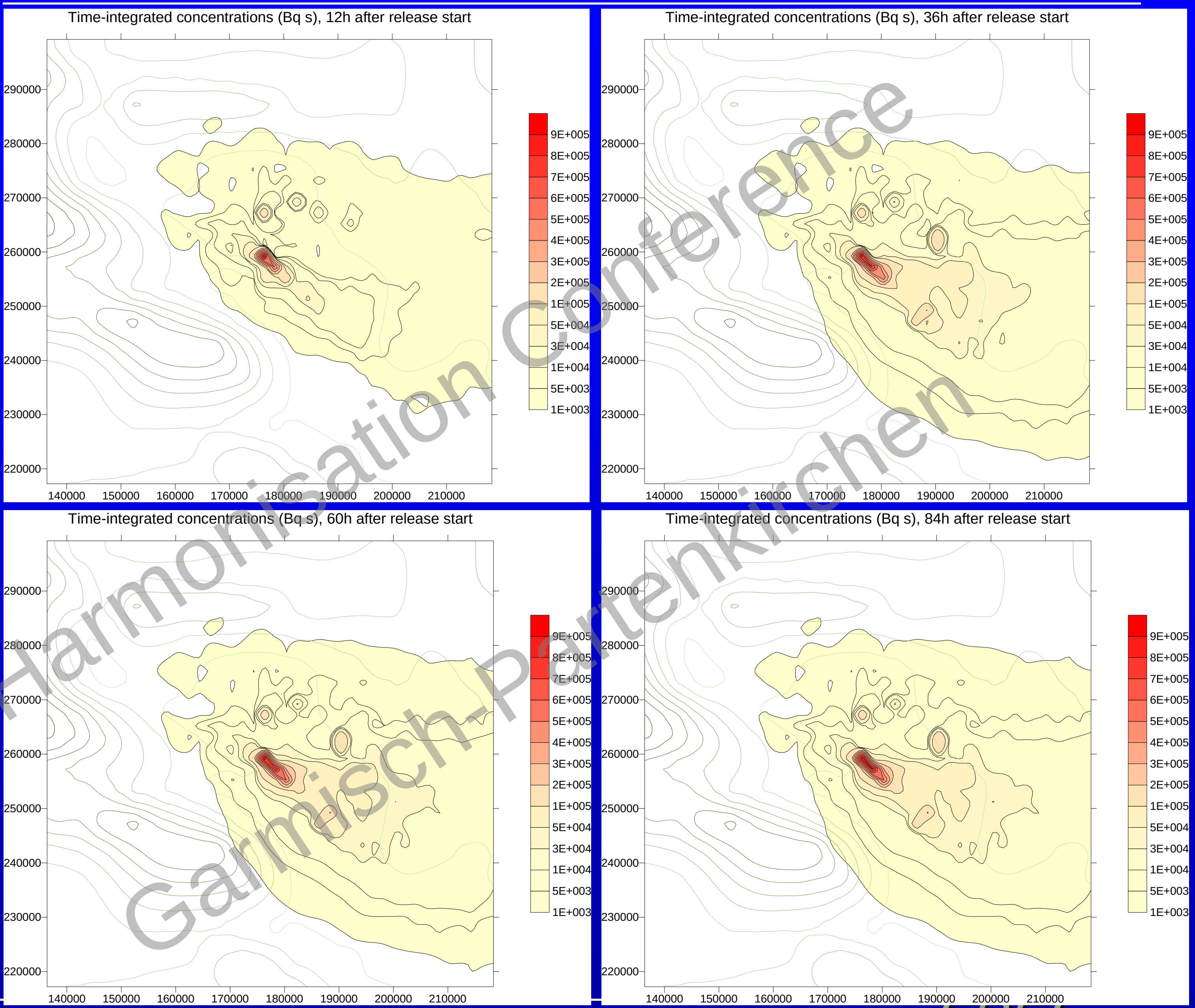
Ground-level concentrations, at 12, 18, 24, 30 h after release start



Ground-level concentrations, at 36, 42, 48, 54 h after release start



Time-integrated concentrations (Bq s), 12, 36, 60, 84 h after release start



Remarks for the dispersion calculation results

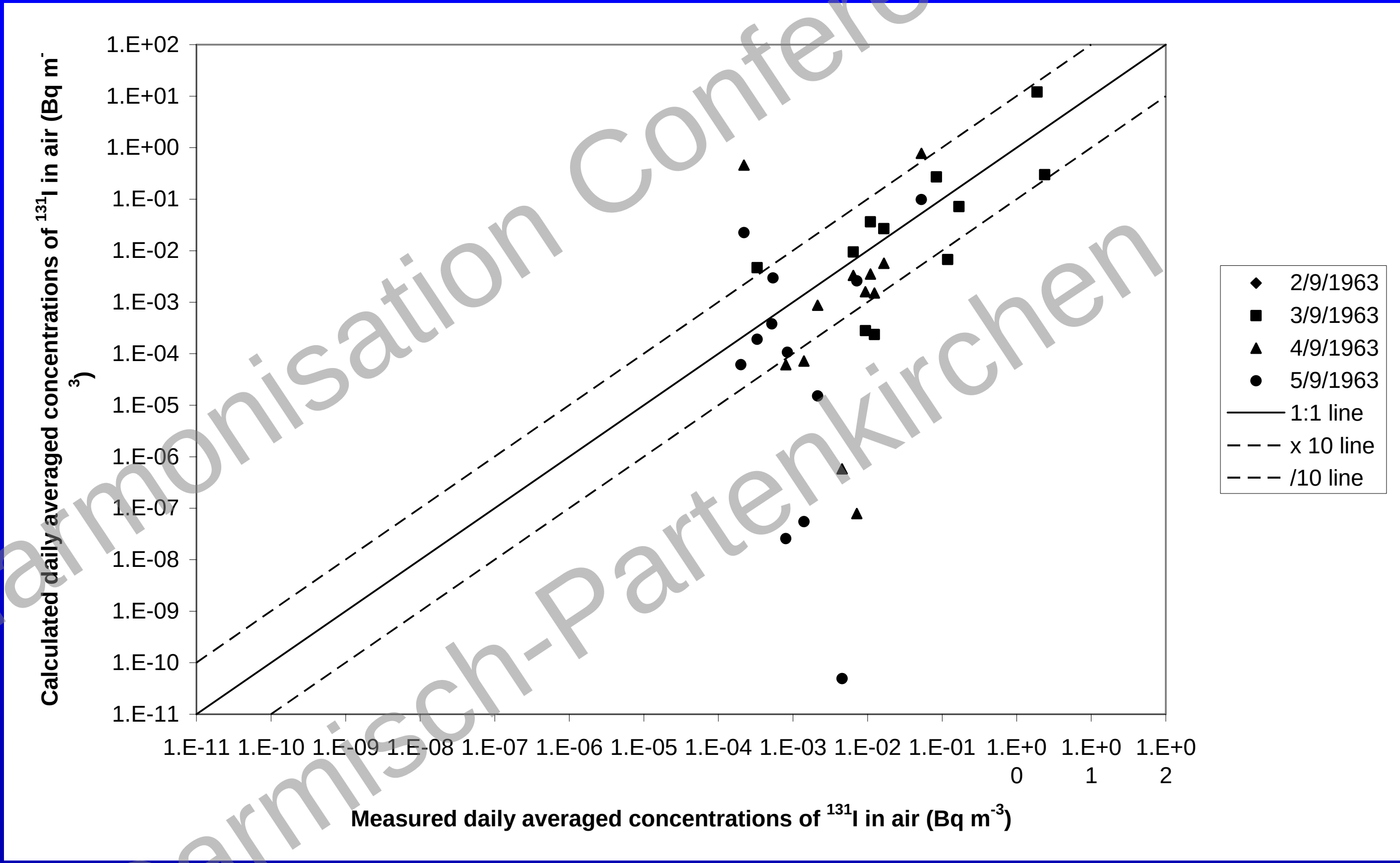
- The dispersion occurred mainly in the direction from north-west to south-east:
  - Due to the topography, the prevailing winds are north-west to west
- The most affected area was the sector east to south-east of the source
- However, due to the wind variability and the extended duration of the release, a large area has been covered by the plume

Dispersion model evaluation

- The calculation results have been compared with the observations:
  - daily averages (due to availability of such measurement data)
  - time-integrated values for the period of the release (due to their close relationship with the radiation doses that the population is exposed to)
- The observed air concentration values during the days previous to the release start have been considered as background values for each station

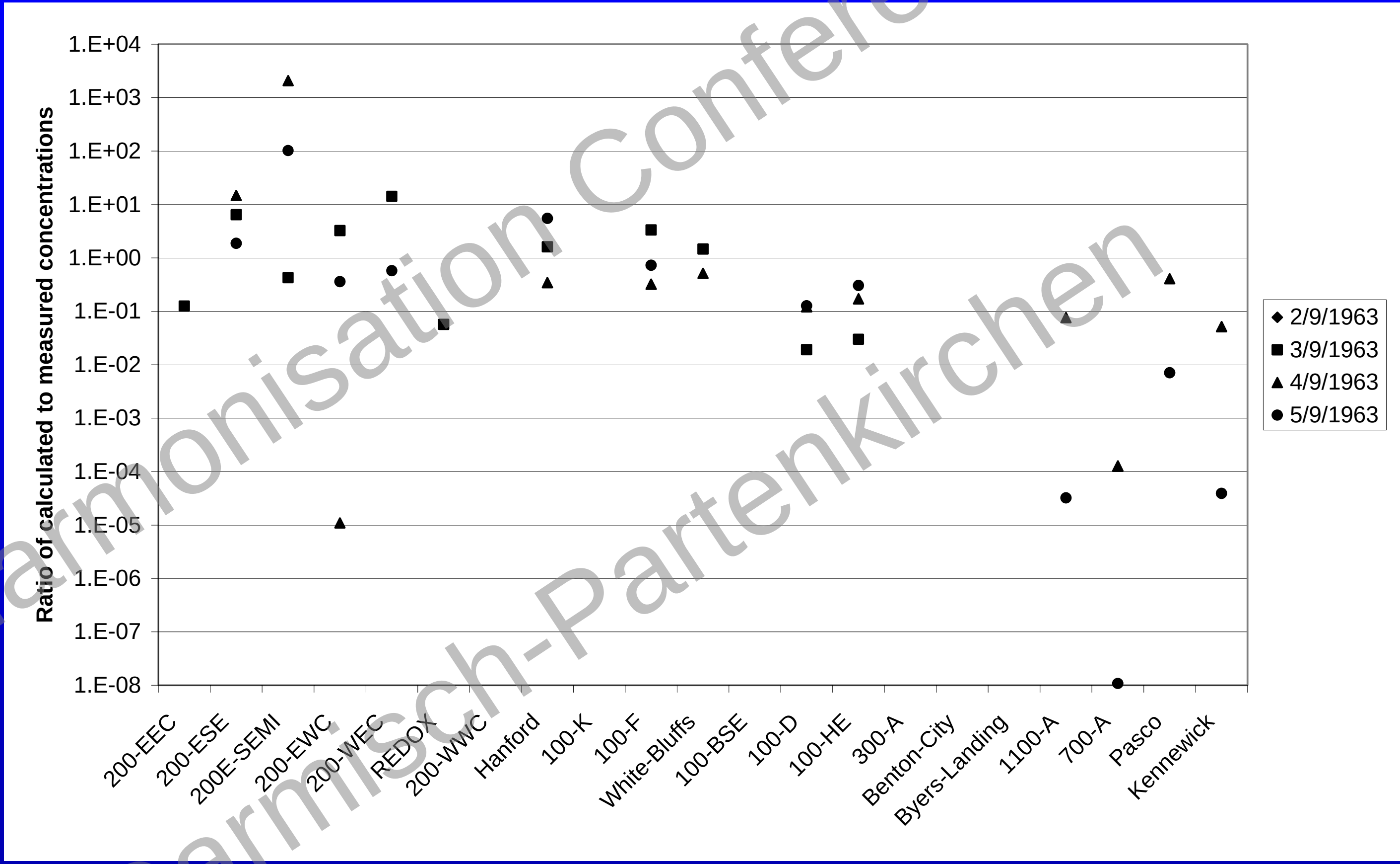
Dispersion model evaluation

Scatter plot of calculated vs. observed ^{131}I concentrations in air, for each day during the release and for all sensors with non-zero values. Factor-of-10 and 1:1 lines are also drawn



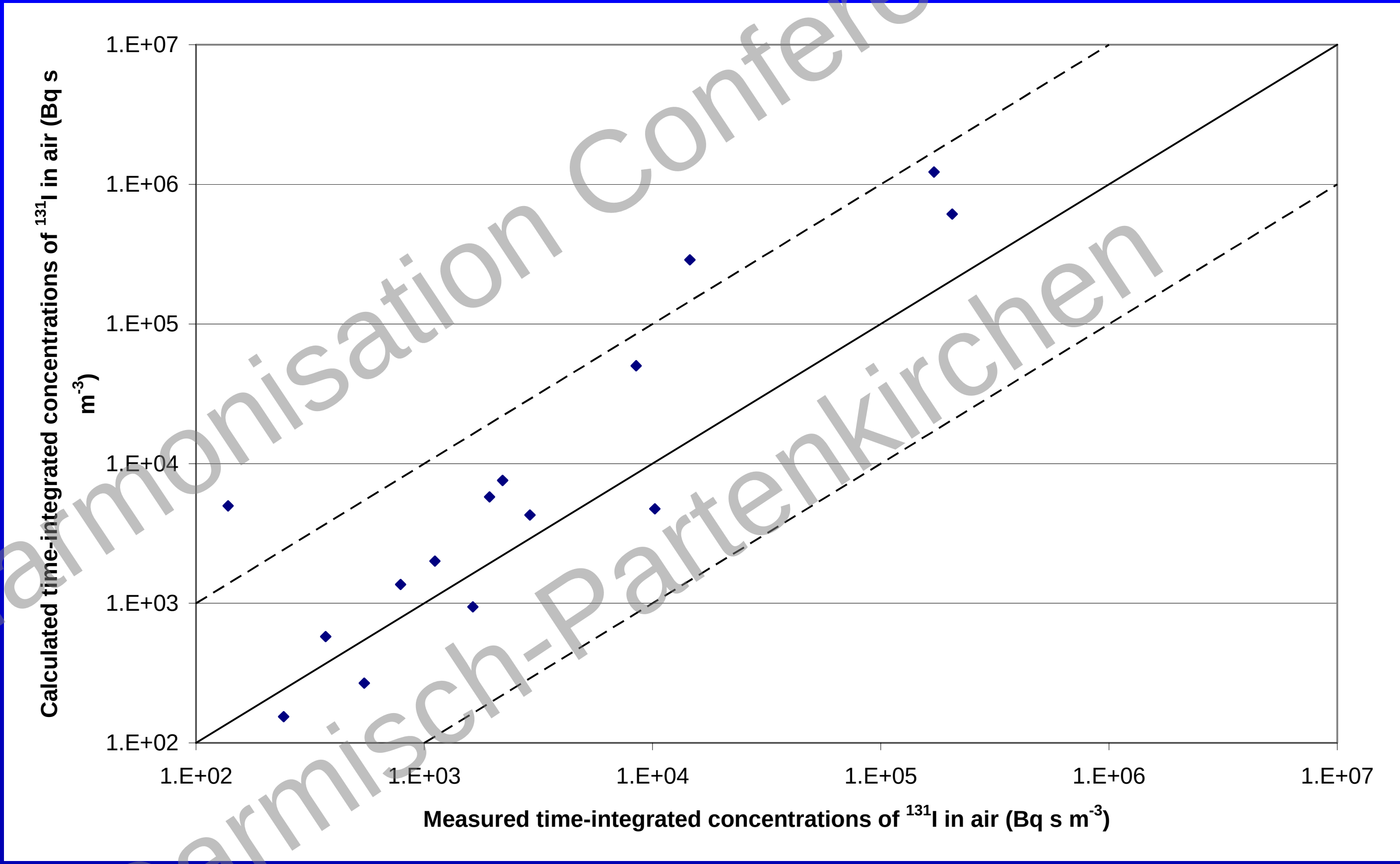
Dispersion model evaluation

Ratio of calculated to observed daily averaged concentrations for all days of the release and for all sensors with non-zero values (ordered by increasing distance from the release point)



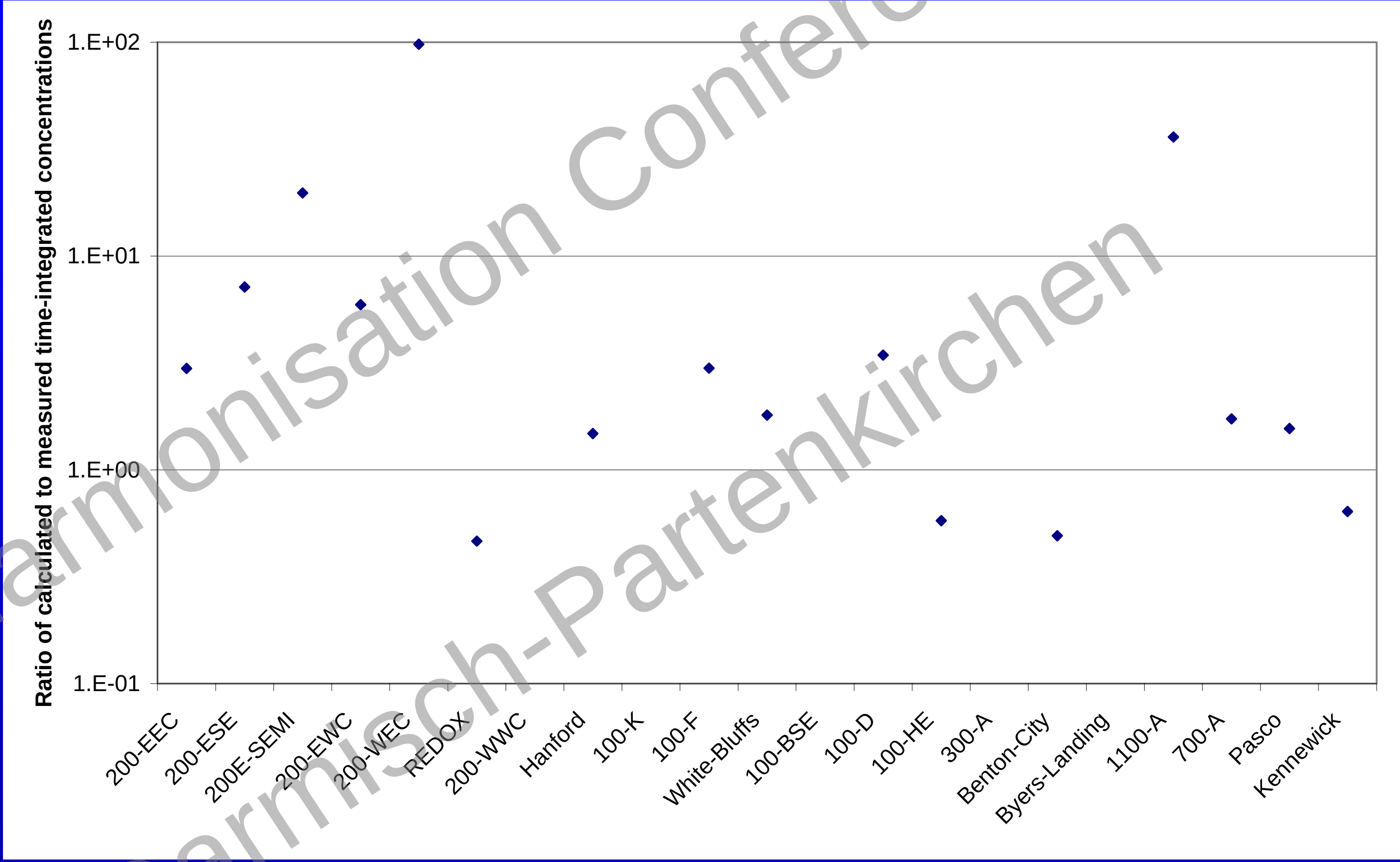
Dispersion model evaluation

Scatter plot of calculated vs. observed tme-integrated ^{131}I concentrations in air, for each day during the release and for all sensors with non-zero values. Factor-of-10 and 1:1 lines are also drawn



Dispersion model evaluation

Ratio of calculated to observed time-integrated concentrations for the period of the release and for all sensors with non-zero values (ordered by increasing distance from the release point)



Dispersion model evaluation

	Factor-of-2	Factor-of-5	Factor-of-10
Daily averaged concentrations	17%	40%	57%
Time-integrated concentrations	37.5%	68.8%	85.7%

Conclusions (1)

- The Hanford scenario is an interesting and challenging case for dispersion modelling because of:
  - Complex topography
  - Long duration of release
  - Variable source
  - Variable meteorological conditions
  - Radioactive pollutant, with passage to food chain
- The influence of the terrain on the wind field is strong: local variations between the monitoring stations
- Variations of meteorological (stability) conditions between night and day (inversions – unstable conditions)

Conclusions (2)

- The prevailing winds are west to north west
- No precipitation occurred
- In this paper we focused on the dispersion modelling (not passage of radioactive pollutant into food chain studied)
- The modelling system used (DETRACT) consisted of a meteorological pre-processor (FILMAKER) and a lagrangian atmospheric dispersion model (DIPCOT)
- The dispersion modelling results showed that due to the wind variations, the plume covered an extended area during the 3½ days of the release, however extending mostly east to south east of the source

Conclusions (3)

- From the dispersion model evaluation procedure:
  - Daily averaged concentrations:
    - slightly better agreement between model results and observations for higher concentrations close to the source
    - The scatter increases for smaller concentrations as we move away from the source
  - Time integrated concentrations:
    - No apparent trend with distance from the source
    - Good level of agreement

Conclusions (4)

- The high values the statistical indices for the level of agreement concerning in particular the time-integrated concentrations, indicate that DETRACT is a tool suitable to be used within computing systems evaluating the environmental impact of accidental releases to the atmosphere, and designed to evaluate the radiation doses to which the population is exposed due to atmospheric dispersion of radio-nuclides