19th International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
3-6 June 2019, Bruges, Belgium

MODELLING THE HANFORD SITE RADIOLOGICAL SCAPE EPISODE AND EVALUATION WITH FIELD MEASUREMENTS

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Abstract: Radioactive accidents may occur in nuclear power plants, producing radioactive material leaks that usually is dispersed around the exhaust area. Tools development to manage this kind of accidental or deliberate contaminant emission has become a major challenge. To study the model response in nuclear accidents, the Hanford Site case has been analyzed. Hanford Site was a nuclear production complex located by the Columbia River, in the south-eastern state of Washington. This installation is operated by the US Federal Government, and it was the first full-scale plutonium production reactor in the world. On the 2nd and 3rd of September 1963, under very stable meteorological conditions, an unanticipated emission of 60 Ci of I^{131} happened when conducting nuclear tests. Nowadays, the Hanford Site is considered the most polluted area in the United States. Meteorological simulations have been performed using the WRF-ARW model (Weather Research and Forecasting - Advanced Research). WRF-ARW has been run for a 30-year period (1980-2010) and validate with values from the local meteorological stations, in order to select the year with more similar meteorological conditions to 1963, because no data are available for this year. Also, HYSPLIT model (HYbrid Single Particle Lagrangian Integrated Trajectory) and RASCAL tool (Radiological Assessment System for Consequence AnaLysis), have been used to carry out nuclear analyses of this study case. Some scenarios with different rate emission were launched and evaluated with air samples collected in the Hanford Site (Soldat, 1964). Despite both models overestimate the field measurements, results show a similar trend, and HYSPLIT gets a better estimation of the measured values.

Key words: *WRF, HYSPLIT, emergency response model, RASCAL, Hanford Site*

INTRODUCTION

In the United States, at the secret military enclosure of Hanford Site (State of Washington), nine nuclear reactors moderated by graphite and cooled by light water, whose energy dissipates in the atmosphere, were constructed (Chernobyl-type). One of Hanford Site reactors was a dual-use reactor to produce military plutonium for nuclear bombs and electric power. This reactor was used during the Second World War to produce military plutonium for nuclear warheads, and then dismantled gradually between 1964 and 1987. Nowadays, the Hanford Site is considered the most polluted area in the United States and is being cleaned by the Environmental Protection Agency (Velarde, 2013).

On the 2nd and 3rd of September 1963, an unanticipated emission of 60 Ci of I^{131} was measured in this enclosure during nuclear tests. According to the analyses carried out by Soldat (1964) at the plant, most of the I^{131} was released on the night from the 2nd to the 3th of September under very stable meteorological conditions. Measurements were made in the air, grass, milk and thyroid gland of possible affected people. That study concluded that no person examined was exposed to a dose higher than that allowed for the population as established at that time.

In this work, air measurements reported by Soldat (1964) are compared with HYSPLIT and RASCAL simulations. As will be explained in the methodology, because of the lack of meteorological data needed to drive HYSPLIT for that specific period, meteorology from another year (September 2008) has been used. The choice of this specific year will be justified.

METHODOLOGY

Hanford Site is the studied area, located in the south-eastern Washington State, within a semiarid region in the Columbia Plateau and on the confluence of the Snake, Yakima and Columbia Rivers. Hanford Site is surrounded by Rattlesnake Mountain, Yakima Ridge, Umtanum Ridge and Saddle Mountains. The climate of the Hanford Site is defined by the presence of these mountain barriers and its rain shadow effect (Hoitink et al., 2005). Its geographical position and topography define a semiarid climate. The episode analysed in this work corresponds to the month of September, with mean monthly temperatures about 19ºC, accumulated precipitation about 8mm, average wind speed around $3ms^{-1}$, and WNW winds.

Meteorological modelling approach

Authors have extensive experience on meteorological modelling and have developed an own methodology to select the optimum meteorological modelling configuration for every region an application (Arasa et al., 2016). This methodology has been considered to configure the meteorological modelling approach.

Meteorological simulations have been performed using the Weather Research and Forecasting - Advanced Research (WRF-ARW) version 3.7.1 (Skamarock et al., 2008), developed by the National Center of Atmospheric Research (NCAR). It is a universally used community mesoscale model and a state-of-the-art atmospheric modelling system that is applicable for meteorological research, climate scenarios and numerical weather prediction. WRF is a fully compressible and non-hydrostatic model with terrain-following hydrostatic pressure coordinate. The initial and boundary conditions for WRF modelling have been supplied by the NCEP/NCAR Climate Forecast System Reanalysis (CFSR) (Saha et al., 2010) with 0.5º of spatial resolution and 6 h of temporal sampling. Meteorological simulations have been run from 1^{st} to 30^{th} September for a 30 year period (1980-2010), and validate with values from the local meteorological stations, to select the year with more similar meteorological conditions to 1963. This will solve the non-existence of meteorological data for 1963.

In Figure 1, modelling domains used for the simulations over the Hanford Site are shown. Modelling is built over a mother domain (called d01) with 27 km spatial resolution, centred at 46.55ºN 119.5ºW; inner nested domains (d02, d03 and d04) have 9-3-1 km as horizontal resolution.

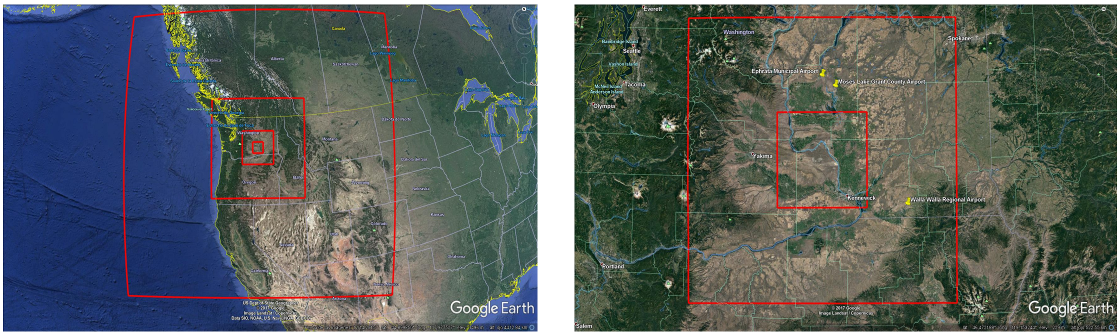

Figure 1. Modelling domains for simulations d01, d02, d03 and d04 (left), and d03 and d04 and measurement stations considered for the numerical evaluation (right). [Images generated using Google Earth]

To validate meteorology results, WRF model was run each September for every year included in the period 1980-2010. Modelled and observed values from local meteorological stations are compared using different statistics. Considered stations correspond to the stations of Ephrata Municipal Airport (47.3078ºN, 119.5154ºW, 382 m a.s.l), Moses Lake Grant County Airport (47.20778ºN, 119.31917ºW, 365 m a.s.l) and Walla Walla Regional Airport (46.09472ºN, 118.28694ºW, 355 m a.s.l). Measurement data information has been obtained using Climate Data Online Access (www.ncdc.noaa.gov/cdo-web).

To evaluate the model performance, four statistics have been selected among the large amount of methodologies that can be applied: the Mean Bias (MB), the Mean Absolute Gross Error (MAGE), the Root-Mean-Square Error (RMSE) and the Index of Agreement (IOA). These statistics provide information on how uncertain a model is, regarding to the observations (Denby et al., (2008) and according to them a benchmark is given following Emery et al. (2001) and Tesche et al. (2002) suggestions. In the case of wind direction, a modification of the traditional formula of MB and MAGE has been applied (Jiménez-Guerrero et al., 2008; Soler et al., 2011; Reboredo et al., 2015). Wind statistics are calculated for wind speeds higher than $0.5ms^{-1}$ to avoid calms.

The evaluation performed is focused on d03 which covers geographical locations corresponding to the measurement stations, and on the wind variable, because is the most important meteorological parameter for the dispersion model. Results of the numerical evaluation are showed in Table 1. Results obtained for all measurement stations show that the model accomplishes the recommendations for RMSE and IOA wind speed, and for MB wind direction. For wind direction, MAGE is higher than the recommended value. In any case, the benchmark value of 30º is a valid reference value for meteorologically simple areas (locations with low topography complexity and/or land use variance and which meteorology depends on the synoptic scale). Model tends to slightly underestimate wind speed.

Table 1. Comparison between modelled and observed values from WRF simulations and meteorological local stations. *Calculating statistics considering all the stations together.

Meteorological parameter (reference height)	Statistic (Recommendation)	Ephrata Airport	GrantCounty Airport	WallaWalla Airport	All stations*
Wind speed (10 m)	MB (<±$0.5ms^{-1}$)	-0.53 ms^{-1}	-0.20 ms^{-1}	-1.02 ms^{-1}	-0.60 ms^{-1}
	RMSE (<$2.0ms^{-1}$)	2.22 ms^{-1}	1.93 ms^{-1}	1.84 ms^{-1}	2.00 ms^{-1}
	IOA (≥0.60)	0.67	0.67	0.67	0.67
Wind direction (10 m)	MB (<±10°)	0º	15º	17º	10º
	MAGE (<30°)	47º	47º	43º	46º

Numerical evaluation of WRF model was used to select the most representative year in the whole period 1980-2010. Statistic values for wind speed and wind direction are compared year by year for the three stations. 2008 was the year selected, because meteorological wind conditions are the most similar to 1963 observed values, and the model evaluation for the year 2008 gave good results.

Dispersion modelling

HYSPLIT model (HYbrid Single Particle Lagrangian Integrated Trajectory) and RASCAL tool (Radiological Assessment System for Consequence AnaLysis) have been used to carry out nuclear analyses of this study case. HYSPLIT is used to determine the emission, transport, dispersion and deposition of particles (Draxler and Hess 1998). It has been developed by the Bureau of Meteorology of Australia and the ARL (Air Resources Laboratory) of the NOAA (National Oceanic and Atmospheric Administration) in the United States. The model calculation method is a hybrid between Eulerian and Lagrangian approaches. Advection and diffusion calculations are made in a Lagrangian framework while concentrations are calculated on a fixed grid (Draxler and Hess 1998). HYSPLIT is one of the ATDM considered for emergency management by the World Meteorological Organization (WMO). On the other hand, RASCAL tool was developed for the U.S. Nuclear Regulatory Commission and is used for emergency preparation purposes amongst nuclear operators and regulators; his code is based on a straight-line Gaussian model.

RASCAL is one of the models currently used to evaluate radiological cases, but it has a lot of limitations (meteorology input must be introduced via user interface and it can only be provided by stations, there are inconsistences with calm winds, domains always centered in the release point, simulations can not be longer than 48 hours, etc.). This study was focused in HYSPLIT model, and it was configured to solve these RASCAL limitations. It was coupled with WRF meteorological data and it was set for three scenarios with different rate emission, in order to compare with RASCAL results and with air samples collected in the Hanford Site. These samples were collected in the area following the accident of 2nd – 3rd September 1963 (Soldat, 1964). 23 stations were reported by the study were measurements of the maximum concentration of I^{131} in the air were registered.

Three different scenarios were defined for the Hanford Site case (Table 2). *Scenario 1* was executed with HYSPLIT, coupled with WRF meteorological data, for the whole month of September, with I^{131} maximum rate measured in Soldat (1964); *Scenario 2* was also set in HYSPLIT model for every day of September, and it was launched with an average rate (calculated between 09/02 and 09/30 from Soldat results); *Scenario 3* was carried out by RASCAL model, with I^{131} with 36 meteorological hourly data from 36 stations, since 09/02 00:00 to 09/08 00:00, because this model can not handle a full month of data; this third scenario was also executed with HYSPLIT (for the whole September) in order to compare results under the same conditions.

Table 2. Emissions considered in the three scenarios defined for the Hanford Site case.

Release period	Scenario 1	Scenario 2	Scenario 3		
Start (UTC)	09/02 12:25	09/03 0:00	09/02 19:25	09/02 23:25	09/03 6:30
Stop (UTC)	09/02 23:30	09/03 24:00	09/02 23:25	09/03 6:30	09/03 10:10
Rate (Ci/h)	**2.61**	**0.49**	**1.38**	**2.61**	**2.31**

RESULTS AND DISCUSSION

Figure 2 shows a comparison between all the scenarios launched with HYSPLIT and the measurements from Soldat (1964). Despite both models overestimate the field measurements, results show a similar trend, and HYSPLIT gets a better estimation of the measured values. Scenario 2, the one with the lower source term, has the best fit with observations, especially for the stations located near the source where higher values where measured.

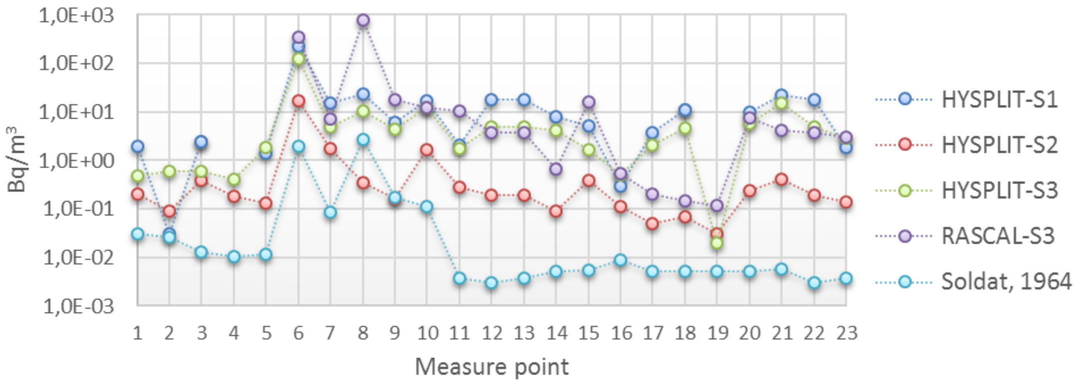

Figure 2. Comparison of I^{131} results for the three scenarios and air samples collected after the release of September 1963 (Soldat, 1964). X axis represents each station where samples were collected.

Statistical values for all the scenarios for HYSPLIT model are presented in Table 3. RMSE was calculated for the release day, and for the average of the whole month of September. Average RMSE for all the scenarios are much lower than one day RMSE. Hence, it is not convenient to work with only one day of data. Again, Scenario 2 has the best statistical results, with a RMSE value much lower in both Average and Release day conditions.

Table 3. Statistical values calculated for the three HYSPLIT scenarios.

HYSPLIT Scenario	RMSE – Release day	RMSE – Average
1	45,6	11,5
2	12,7	0,6
3	33,4	7,6

Using HYSPLIT model instead of RASCAL give to scientific community a lot of added values to study radiological cases. HYSPLIT is coupled with the most used meteorological model worldwide (WRF), and because of that, the meteorological uncertainty of this kind of systems is reduced. The model can be configured to reproduce specific meteorological conditions of any part of the world doing a specific calibration.

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