Uncertainty quantification of atmospheric transport and dispersion backtracking using an ensemble approach

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Introduction

Atmospheric transport and dispersion backtracking is important for the verification regime of the Comprehensive Nuclear Test-Ban-Treaty, which bans nuclear explosions worldwide. Knowledge of the uncertainty on atmospheric transport and dispersion backtracking gives more confidence in the analysis of nuclear test explosion signals picked-up by the International Monitoring System (IMS). Here we present an ensemble approach to quantify uncertainty and apply the technique on recent radioxenon measurements taken by the IMS.

Methods

On the 6th of January 2016, the Democratic People's Republic of Korea have announced a nuclear bomb test at the Punggye-ri Nuclear Test Site (see Fig. 2 for the location). Seismic wave signals were quickly picked up by the IMS. From analyses (CTBTO, 2016), the location and time of the event have been determined to be near the Punggye-ri Nuclear Test Site, on the 6th of January 2016 at 01:30 UTC. However, radionuclide observations are necessary to discriminate between conventional and nuclear explosions. Since the nuclear test took place underground, only a fraction of certain radionuclides can seep to the atmosphere. Radioxenon is most likely to seep through the rocks.

We consider six ^{133}Xe samples taken by the IMS (Table 1; see Fig. 2 for the location of the stations). Using the FLEXPART model (Stohl et al., 2005) in backward mode (Seibert and Frank, 2004), we have backtracked each radioxenon sample. FLEXPART is driven by numerical weather data: we have used 50 perturbed members and the control forecast of the Ensemble Data Assimilation of the European Centre for Medium-Range Weather Forecasts (ECMWF).

FLEXPART outputs Source-Receptor-Sensitivity fields (SRS; *M*), which can be folded with a source term field (*S*) to obtain simulated concentrations at the IMS stations:

$$c_{sim} = \sum_{i,j,n} M_{ijn} . S_{ijn}$$

where (*i,j*) are spatial indices and *n* denotes the time index.

Since S_{ijn} is fixed for each (*i,j,n*), we can calculate the correlation between the observed concentrations $c_{obs,k}$ and the corresponding simulated concentrations $c_{sim,k}$ (Becker et al, 2007):

$$correlation = \frac{cov(c_{obs,k}; c_{sim,k})}{var(c_{obs,k}).var(c_{sim,k})}$$

Table 1: ^{133}Xe samples showing anomalously high radioxenon activity concentrations.

Station name	Collection start	Collection stop	Activity concentration (mBq/m^3)
RN38	2035 UTC 16-02-16	0835 UTC 17-02-16	1.72
RN38	0835 UTC 17-02-16	2035 UTC 17-02-16	1.79
RN38	2035 UTC 17-02-16	0835 UTC 18-02-16	1.41
RN38	0835 UTC 18-02-16	2035 UTC 18-02-16	1.28
RN38	2035 UTC 18-02-16	0835 UTC 19-02-16	0.68
RN77	1800 UTC 22-02-16	0600 UTC 23-02-16	0.21

Results

Fig. 2 shows spatial maps of the correlation between the SRS and the observed concentrations for different times. At all selected times, the correlation reaches high values for certain regions. The correlation exhibits a peculiar shape due to the complex terrain of the Korean Peninsula. By looking at the percentage of ensemble members that have a correlation above 0.75, we can narrow down the possible source regions (Fig. 2, bottom row). The backtracking calculations link possible source locations with possible release times. However, since a priori we do know neither the source location nor the release time of the observed ^{133}Xe, we do not know which couple of source location versus release time is true. Results show that, amongst other locations, the Punggye-ri Nuclear Test Site can be considered as a possible source location, showing a high correlation with the observations.

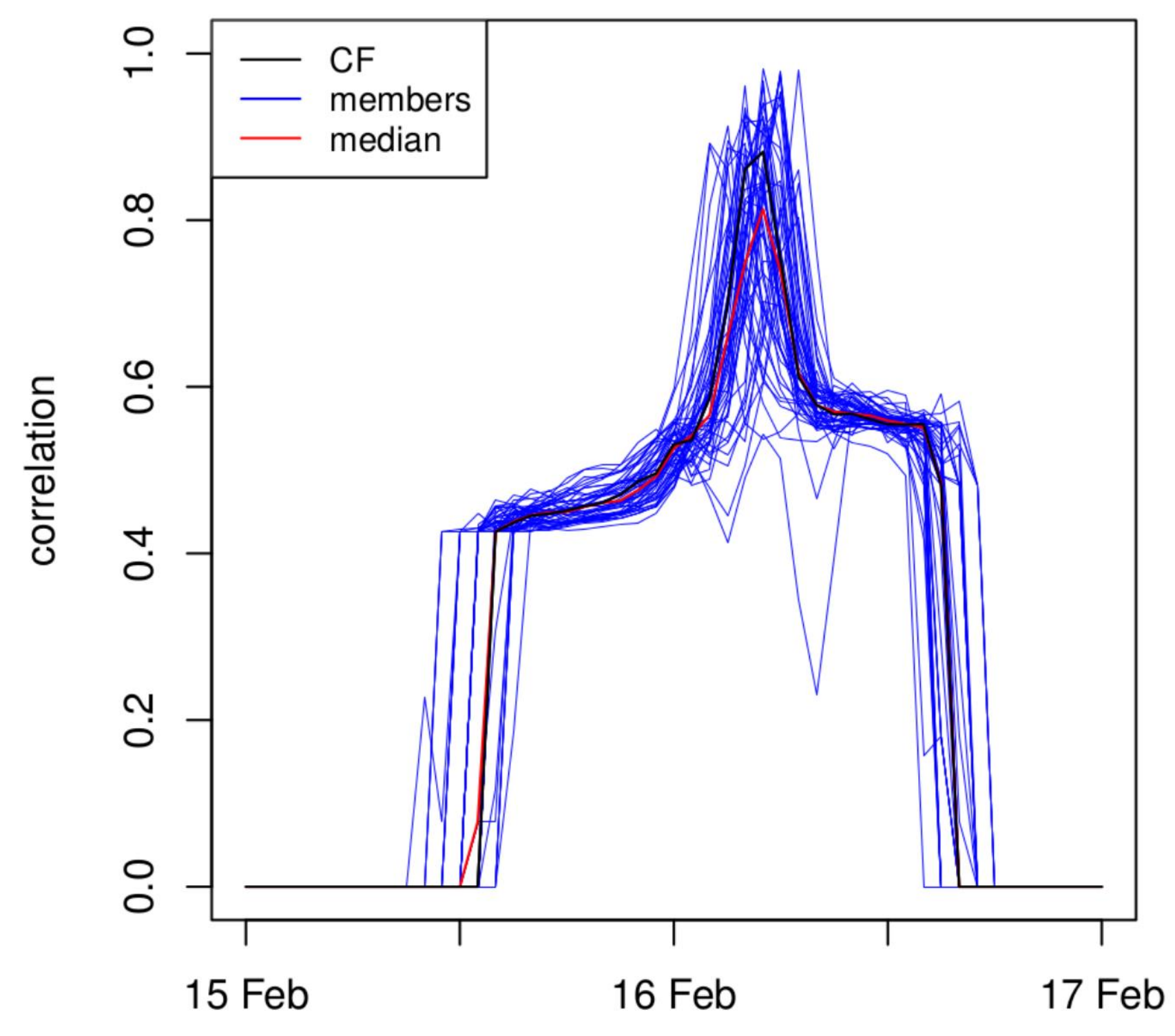

Fig. 1: Time series of the correlation between the SRS and the observed concentrations at the Punggye-ri Nuclear Test Site.

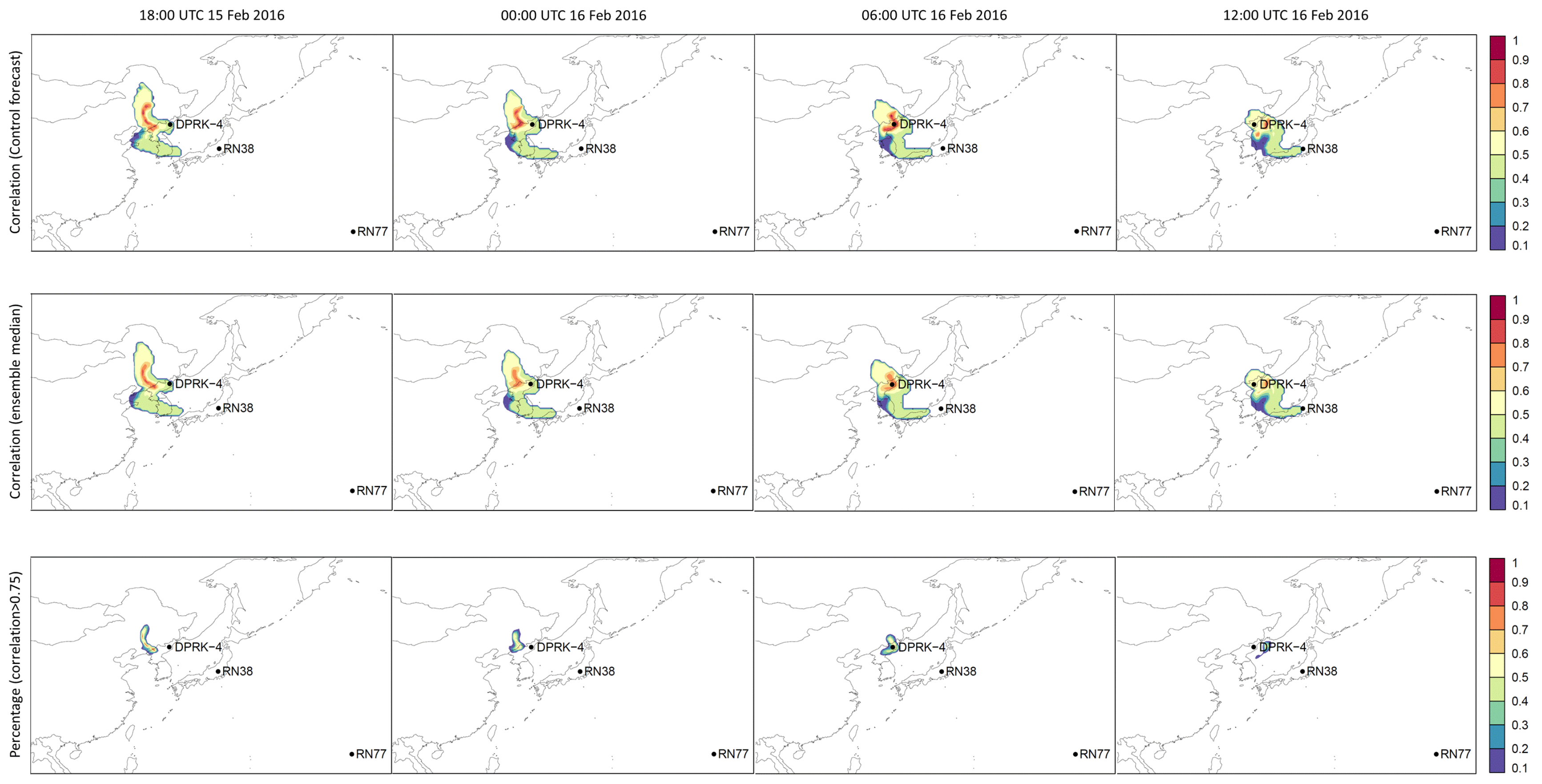

Fig. 2: Spatial maps with the correlation between SRS and observed concentrations (top: for the control forecast; middle: ensemble median) and percentage of members having a correlation > 0.75 (bottom) at different times. DPRK-4 denotes the location of the Punggye-ri Nuclear Test Site where the test took place. RN38 and RN77 denote the location of the IMS stations where the radioxenon samples were taken.

Conclusions

Six ^{133}Xe radioxenon activity concentrations have been measured recently at two IMS stations (Table 1). Using FLEXPART and the 50+1 member Ensemble Data Assimilation of ECMWF, we have backtracked the samples to their possible sources. Results show that the ensemble approach can be useful in support of the Comprehensive Nuclear Test-Ban-Treaty verification regime by providing an uncertainty quantification.

References:

- Becker, A., Wotawa, G., De Geer, L. E., Seibert, P., Draxler, R. R., Sloan, C., ... & Grillon, Y. (2007). Global backtracking of anthropogenic radionuclides by means of a receptor oriented ensemble dispersion modelling system in support of Nuclear-Test-Ban Treaty verification. *Atmospheric Environment*, *41*(21), 4520-4534.
- CTBTO (2016). Technical findings on the DPRK event as of 7 January. Available on *newsroom.ctbto.org*.
- Seibert, P., & Frank, A. (2004). Source-receptor matrix calculation with a Lagrangian particle dispersion model in backward mode. *Atmospheric Chemistry and Physics*, *4*(1), 51-63.
- Stohl, A., Forster, C., Frank, A., Seibert, P., & Wotawa, G. (2005). Technical note: The Lagrangian particle dispersion model FLEXPART version 6.2. *Atmospheric Chemistry and Physics*, *5*(9), 2461-2474.