7.04 THE 2003 CTBTO-WMO EXPERIMENT ON SOURCE REGION ESTIMATION: AN EXAMPLE PROJECT FOR THE POTENTIAL OF STANDARDISED GLOBAL SOURCE-RECEPTOR FIELDS SHARED

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INTRODCUCTION

Among the different technologies applied to verify compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT), radionuclide monitoring by means of a 80 stations global network may be the only technology capable of detecting ambitiously disguised, or decoupled, nuclear explosion. In preparation for such a case the PTS performs since August 2002 source attribution by receptor oriented particle trajectory modelling to help determine the region from which suspicious radio nuclides may originate. In doing so a diagnostic 3D-transport model (FLEXPART, Stohl et al., 1998) is integrated backward in time based on global analysis wind fields yielding global fields of surface level adjoint concentrations stored in 3h frequency and at $1^0 \times 1^0$ horizontal resolution. This output constitutes the set of so-called source-receptor sensitivity (SRS) fields specific for each of the 80-radionuclide samples collected daily. The underlying methodology and efforts to explore its uncertainty shall be examined in the following.

THE SOURCE RECEPTOR SENSITIVITY (SRS) FIELDS CONCEPT

In principle source attribution is performed by the solution of the inversion problem formulated in the general source receptor relationship. For CTBT purposes it is feasible to regard only ground level sources (dynamic or extended venting from underground tests) thus we can define the source receptor sensitivity field to a certain measurement c_m as the 3-dimensional (2 horizontal, 1 temporal) dilution volume or factor field [m^{-3}] which translates any singular release S_l at a position *i, j* and time *n* into the measured activity concentration [Bq/m^3] according to equation (1)

$$c_m = \mathrm{M}_{ml} S_l = M_{mijn} S_{ijn} \tag{1}$$

Atmospheric transport model (ATM) simulations can estimate the values (dilution volumes) of the matrix elements $\mathbf{M}_{ml}$ or the SRS field M_{mijn}, respectively. In case that *m* (number of measurements/receptors) is higher than *l* (number of potential sources/events forward (prognostic) approaches resolving parts of the non-linear transport are recommended for the SRS field calculation (e.g. Becker et al., 2001). A typical example would be regional/local scale monitoring of a set of known sources.

For backtracking purposes, however, where the wind field is already available from analyses it can be shown that diagnostic ATM simulations can equally well be done backward in time (Flesch et al., 1995). This is fortunate for the global CTBT system with a very limited number of receptors, 80 sampling stations world-wide, but a large number, some 10 million[1], potential source cells. Hence instead of some 10 million forward mode computations we need only to process 80 backward mode ones. In the backward ATM mode a certain mass of an adjoint

[1] On a 1º × 1º × 3h space-time grid covering the Earth for two weeks there are 180 × 360 ×14 × 24/3 = 7.26 × 10 [6] source cells.

tracer is released at a constant rate at the station location between stop and start of the measurements and transported 6 days backward in time. The SRS field (of sensitivities in terms of inverse dilution volumes) results then from the adjoint tracer concentrations at position *i, j* and time step *n*, divided by the adjoint mass of the release concentrations stored in 3h frequency and at 1°×1° horizontal resolution.

SOURCE ATTRIBUTION PRODUCTS

A database of the SRS fields constitutes a very efficient repository of the atmospheric transport modelling information tailored to the monitoring network employed and the quantities measured. Based on this database source attribution analysis can be carried out specific for one measurement utilizing only its respective SRS fields yielding the so-called Field of Regard (FOR). However one can also test arbitrarily chosen source hypothesises (event scenarios) based on several SRS fields judged to provide information on the same event (Wotawa et al., 2003) yielding the so-called 'Possible Source Region' (PSR). Both source attribution products are calculated in a pure post-processing step. Hence it does not require the repetition of the dispersion-modelling step and is thus possible on currently sold PCs or Notebooks provided that access to the SRS fields is in place. A survey on the products, their definition including example visualisations is given in Becker et al. (2003, Annex I)

STRENGHTS AND PREREQUISITES OF THE SRS FIELD CONCEPT

The strength of the source-receptor approach lies in the clear distinction between the computational demanding (backward) modelling and the computational fast inversion, which is a pure post-processing step. The range of applications of the concept is scale independent provided that the following prerequisites are given:

1. For global scale applications it is important that the detector is highly sensitive in company with low background concentrations with regard to the trace substance actually measured.
2. For a quick source attribution a pre-defined source geometry has to be assumed.
3. The resolution of the SRS fields and the resolution of the wind-fields utilized during the diagnostic backward modelling are in the same order of magnitude.
4. The quality of the wind-field utilized has to be high to warrant high quality SRS fields.

The first two prerequisites are given for CTBT verification problems:

- For a key isotope ^{140}Ba the minimum detectable concentration of the γ-ray detectors utilized is 30μBq. Together with the yield of a 1-kT detonation (2.4 Penta-Bq) a threshold dilution volume of approximately $10^{20}m^3$ with regard to the relevant SRS field values is achieved.
- Given the above detailed resolution a point source (3h puff or continuous) is a realistic nuclear event scenario with a simple geometry.

The dispersion modeller can control the third prerequisite. The fourth prerequisite, however, requires continued attention as discussed in the next paragraph.

THE JOINT CTBTO-WMO EXPERIMENT

In order to address the uncertainties of SRS fields associated with the dynamics of the atmosphere the PTS cooperates with the World Meteorological Organisation (WMO) and its Regional Specialised Meteorological Centres (RSMCs) in the field of dispersion modelling (CTBTO Preparatory Commission, 2004). The overall objective of this cooperation is to create a robust and quick CTBTO-WMO response system providing PTS with a diversified view of world experts on source region estimation. During a joint CTBTO-WMO numerical experiment the SRS fields have proven to be a suitable standard which was easily followed by 7 RSMCs and three other governmental national data centres within timelines typical for emergency response modelling systems. The experiment showed for the first time the feasibility of a standardised and fully automated (and electronic) exchange of data suitable for source attribution in near real-time for a global measurement network. In the experiments set up the SRS fields provider can bring in his full meteorological expertise without the need to know all details about the sources and the measurements despite the time information with regard to the samples raised. This should be of interest for anyone running a network to monitor atmospheric parameters as well as for purposes in the fields of nuclear disaster management and estimation of pollution hazards

Main features of the CTBTO-WMO response system

On an experimental basis the PTS and the WMO centres have agreed upon the following procedures:

- The PTS notifies WMO centres directly by sending standardised electronic mail messages. The messages contain all information required for the modelling.
- The WMO Centres upload standardised SRS fields as requested in an agreed format to a PTS server within 24 hours.
- As a measurement scenario evolves, the PTS may notify WMO Centres not only on one day, but also on a number of consecutive days.
- The PTS uses the standardised source-receptor information supplied by the co-operating WMO centres to create specific products like Fields of Regard (FOR) and Possible Source Region (PSR) estimates.
- The system can fully rely on digital, electronic means of communication. Telephone calls or facsimile messages are not needed.

SRS fields uncertainty and model inter comparison

PTS conducted a centralized post-processing of the 23 SRS fields shared during the experiment (Figure 1) including multivariate statistics to elucidate and quantify the integral uncertainty, related to different wind fields and models utilised.

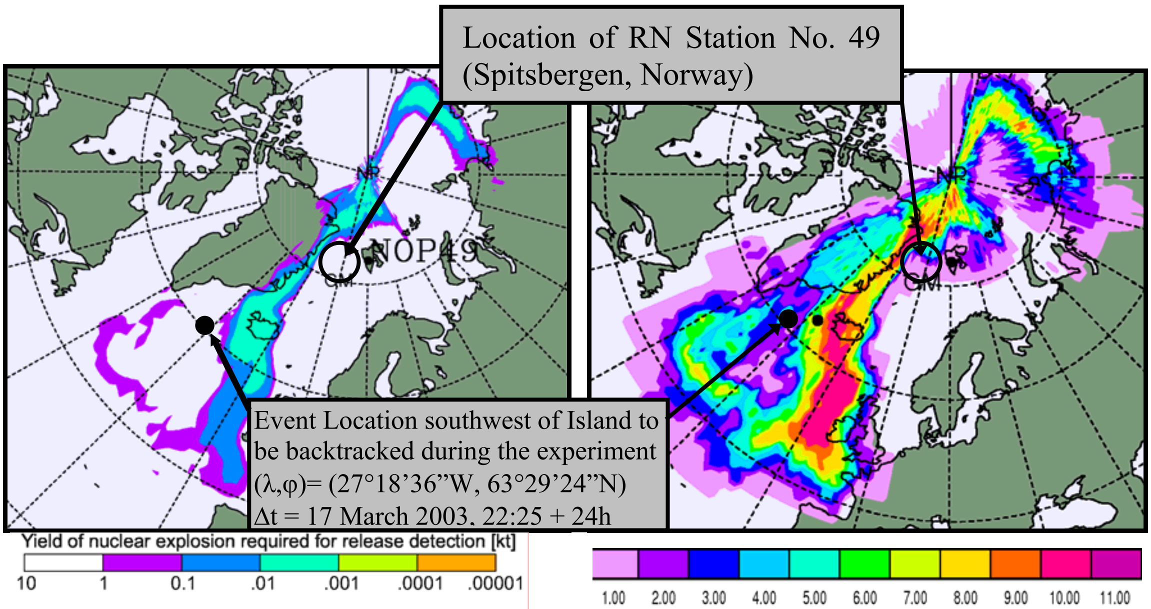

Figure 1. Quantitative so-called "Field of Regard" as calculated by PTS (left) and overlaid binary „Fields-of-Regard" (right) identified by the 11 participants to the 2003 CTBTO-WMO Experiment. The colours on the right plot indicate how many participants agreed on regions where hypothetical radio nuclides were sufficiently sensed during a virtual 24-hour radioactivity measurement at station RN 49 (Spitsbergen, sampling stop at 22 March 2003, 9 UTC). In the left plot the colour-coded areas indicate where a nuclear explosion of a certain yield would be consistent with this virtual measurement. Both plots refer to the same 3h-time period where the virtual event actually took place during the experiment.

RNK-Col.-AV-List	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	*ROW-AV*	*STDEV*
NOP49_2003032009	1.24	1.49	1.27	1.44	1.30		0.93	1.37	1.02	1.19	1.52	1.28	*0.19*
ISP34_2003032012	1.61	1.82	1.24	1.68	1.72		1.38	1.77	1.37	1.25	1.73	1.56	*0.22*
RN015_2003032000	1.26	1.17	0.86	1.23	1.12	1.17	0.29	1.03	0.90	0.90	1.21	1.01	*0.28*
DEP33_200302006	1.63	1.83	1.52	1.50	1.72		1.72	1.79	1.36	1.44	1.78	1.63	*0.16*
RN055_2003032000	1.37	1.52	1.12	1.54	1.37	1.53	1.57	1.58	1.08	1.04	1.58	1.39	*0.21*
RN061_2003032000	1.68	1.84	1.53	1.57	1.89	1.77	1.81	1.74	1.43	1.26	1.83	1.67	*0.20*
SEP63_2003032009	1.50	1.60	1.51	1.56	1.79		1.29	1.65	1.28	1.45	1.77	1.54	*0.17*
NOP49_2003032109	1.37	1.44	1.00	1.42	1.32		1.12	1.31	1.19	1.31	1.47	1.29	*0.15*
ISP34_2003032112	1.68	1.76	1.30	1.69	1.83		1.42	1.69	0.96	1.34	1.78	1.55	*0.28*
RN015_2003032100	1.23	1.30	0.79	1.23	1.13	1.28	0.30	0.97	0.86	0.90	1.19	1.02	*0.30*
DEP33_200302106	1.47	1.79	1.48	1.44	1.76		1.54	1.79	1.27	1.35	1.76	1.57	*0.20*
RN055_2003032100	1.62	1.79	1.29	1.65	1.68	1.68	1.71	1.79	1.27	1.08	1.83	1.58	*0.25*
RN061_2003032100	1.49	1.76	1.50	1.61	1.81	1.65	1.66	1.66	0.78	1.34	1.79	1.55	*0.29*
SEP63_2003032109	1.52	1.67	1.17	1.56	1.67		1.26	1.58	1.26	1.12	1.67	1.45	*0.22*
NOP49_2003032209	1.29	1.35	0.99	1.46	1.43		1.21	1.36	1.19	0.91	1.45	1.26	*0.19*
ISP34_2003032212	1.64	1.71	1.38	1.71	1.73		1.37	1.70	1.28	1.41	1.74	1.57	*0.18*
RN015_2003032200	1.26	1.44	0.82	1.39	1.26	1.37	0.31	1.09	1.04	0.97	1.41	1.12	*0.34*
DEP33_200302206	1.36	1.51	1.33	1.34	1.45		1.19	1.53	1.14	1.14	1.49	1.35	*0.15*
RN055_2003032200	1.41	1.36	1.18	1.56	1.56	1.58	1.46	1.56	0.94	1.01	1.65	1.39	*0.24*
RN061_2003032200	1.43	1.24	1.09	1.49	1.57	1.44	1.37	1.55	0.87	1.20	1.49	1.34	*0.22*
SEP63_2003032209	1.60	1.64	1.45	1.68	1.81		1.41	1.66	1.17	1.31	1.81	1.56	*0.21*
RN041_2003032200	1.41	1.37	1.30	1.41	1.64	1.43	1.43	1.67	0.98	1.28	1.62	1.41	*0.20*
RN054_2003032200	1.59	1.72	1.36	1.63	1.65	1.52	1.64	1.60	0.92	1.26	1.68	1.50	*0.24*
Column-Average	*1.46*	*1.57*	*1.24*	*1.51*	*1.57*	*1.49*	*1.28*	*1.54*	*1.11*	*1.19*	*1.62*	***1.42***	**0.18**
Percentage of Max.	***48.8***	***52.4***	***41.3***	***50.4***	***52.5***	***49.8***	***42.6***	***51.4***	***37.0***	***39.8***	***54.0***	***47.3***	*5.93*
σ	*5.0*	*6.9*	*7.6*	*4.6*	*7.7*	*5.9*	*14.7*	*8.1*	*6.3*	*5.8*	*6.2*	*7.2*	
Perc. without No.6	***50.2***	***54.9***	***43.4***	***52.0***	***54.8***		***44.4***	***53.6***	***40.5***	***42.7***	***56.0***	***49.2***	*5.89*
	1	**2**	**3**	**PTS**	**5**	**6**	**7**	**8**	**9**	**10**	**11**		

Figure 2. Score Table with regard to the rank values (RNK) resulting from the statistics applied on each of the 23 SRS fields. The column (participant) average of each participant is listed below with its standard deviation (σ). Results from participant No.6 could only be considered in 11 cases, therefore the bottom lines of each table show results for the 12 cases without No.6 contribution). The most right columns show the averages of the rows (ROW-AV across 23 station samples) and its standard deviation (STDEV), describing the agreement among all participants on a case-by-case basis. The three cases with highest (light grey) and lowest (dark grey) agreements are highlighted.

In doing so the statistical measures, Fractional Bias (FB), Pearson Cross-Correlation and Figure of Merit in Space (FMS or Overlap) as introduced by Graziani et al. (1998) have been aggregated to a rank value (RNK) as proposed by Draxler et al. (2001). For a detailed methodology see Becker et al. (2003, Annex II).

The statistics have been done on all 23 SRS fields separately and afterwards aggregated to a final score table (Figure 2) comprising the whole experiment. This table actually can be examined from different perspectives, namely either from the viewpoint of a model intercomparison one or from the viewpoint of comparing different cases (events) regarding uncertainty.

From the first perspective the degree of congruence of one model compared to the overall one (see bordered boxes in score table) is regarded, providing important information mainly to the modellers themselves. From the second perspective the rank values specific for the SRS field shared are compared in a case by case way (row by row in the score table). This gives valuable information about the models agreement in certain meteorological situations and the related impact on the reliability of the source attribution. To provide an example the three least (dark grey) and the three most (light grey) congruent cases (SRS fields) are highlighted Figure 2 providing all participants information about the to be expected quality of the dispersion modelling with regard to the meteorological situation on a case by case basis. Such information provides added value to decision-makers since it can be made available in near-real-time mode.

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