RECEPTOR ORIENTED ENSEMBLE DISPERSION MODELLING AS PERFORMED ON THE STANDARDISED SOURCE RECEPTOR SENSITIVITY FIELDS SHARED WITHIN THE CTBTO-WMO EMERGENCY RESPONSE SYSTEM FOR NUCLEAR EVENT LOCATION

Andreas Becker, Gerhard Wotawa and Lars-Erik De Geer

[1]Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization, (CTBTO), Vienna

INTRODUCTION

Under the provisions of the Comprehensive Nuclear-Test-Ban Treaty (CTBT), a global network measuring airborne radioactivity is currently in the built up phase. By end of 2004 32 of finally 80 highly sensitive particulate monitoring stations have commenced operations thus sending daily radionuclide (RN) samples spectra to be reviewed for CTBT relevant nuclides at the Vienna based Provisional Technical Secretariat (PTS) of the CTBT Organization (CTBTO). During the belonging screening process the RN samples are categorized into 5 Levels, whereby only the Levels 4 and 5 indicate the occurrence of at least one or more CTBT relevant nuclides. For a Level 5 categorization additional appearance of at least one fission product is required. A resume for the 8047 samples categorized in 2004 is given in Figure 1.

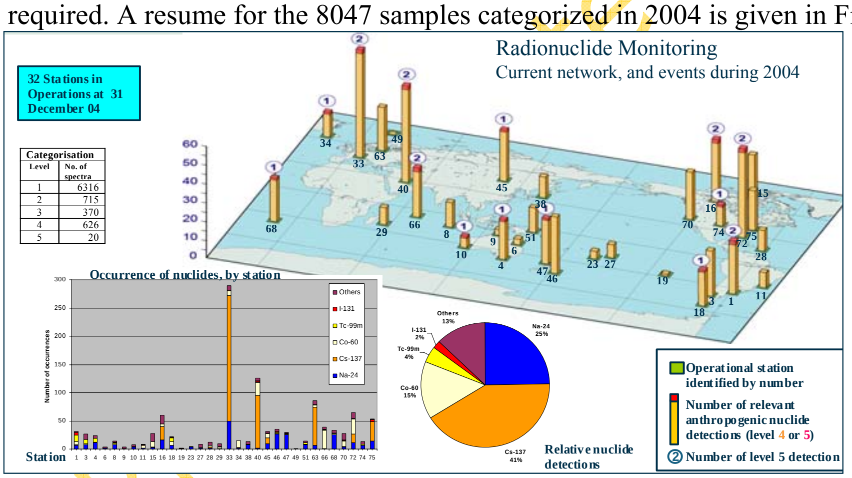


Fig.1; Global distribution of CTBT relevant nuclide occurrences as measured at the 32 in 2004 already operational RN stations of the CTBTO International Monitoring System (IMS).

As introduced during HARMO9 (Becker et al., 2004a) the International Data Centre (IDC) of the PTS maintains and permanently updates a source-receptor matrix (SRM) describing the global monitoring capability of this growing RN network in order to verify states signatories' compliance with the CTBT. This is done by means of receptor-oriented dispersion modelling (backward in time). In doing so roughly a quarter million of particles are released during the sampling period of each RN measurement daily performed in the IMS. The resulting particle plumes are then integrated 144 hours backward in time starting from the samples' collection stop times by means of the renowned Lagrangian Particle Dispersion Model (LPDM) FLEXPART (Stohl et al., 1998). Storing the surface level plume concentrations every three hours yields the so called sample specific source receptor sensitivity (SRS) fields. For the source region estimation those fields belonging to a scenario of RN measurements are combined to the SRM inverted to define the possible source region (PSR) of the RN detection scenario (Wotawa et al., 2003). For PSR definitions see Becker et al. (2004b, Annex II).

THE CTBTO-WMO RESPONSE SYSTEM TO SHARE SRS FIELDS

Within the CTBT environment it is important to quickly achieve decision-makers confidence in the SRM based backtracking products (PSR) issued by the PTS in cases when serious treaty relevant radionuclides are encountered within the IMS. Therefore the PTS has set up a robust and highly automated response system together with the Regional Specialized Meteorological Centres (RSMC) of the World Meteorological Organization (WMO) in the field of dispersion modelling as well as a few CTBT State Signatories National Data Centres (De Geer et al., 2004). The system is still in an experimental status. However, a growing level of automation and reliability has been achieved by means of three test campaigns, namely the 2003 (1st) and 2005 (2nd) CTBTO-WMO experiments on source region estimation and the 2005 1st so-called "System Wide Performance Test" of the PTS. The following basic rules apply:

- The PTS notifies WMO centres directly by sending standardised electronic mail messages triggered by consistent RN measurement scenarios or by each RN sample categorized to be Level 5. The messages contain all information required for the modelling, i.e. the geo-temporal references of those particulate filters (samples) that led to detection.
- The WMO Centres upload (via secured ftp) the requested SRS fields 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 and to perform uncertainty analyses.

In this paper we will focus on one of the experiments in order to study a scenario of RN measurements that would be consistent with one caused by a nuclear explosion. Fortunately we are lacking a real nuclear test in the past years, so suitable scenarios were generated numerical by means of the forward integration of the Version 3.2 of FLEXPART based on the analysis wind fields of the Global Data Analysis System (GDAS) provided on the public ftp server of the National Centers for Environmental Prediction (NCEP). The LPDM results showed for both experiments that a nuclear explosion sized equivalent to 1 kT in TNT with a yield of one Penta Bq in La-140 causes a global measurement scenario during a relatively long period (at least two weeks) after the explosion[6]. For the receptor oriented backward EDM of this paper we concentrate on the SRS data requested during the most recent 2005 CTBTO-WMO experiment where a 9 days scenario of 24 RN detections was simulated.

INTERCOMPARISON OF THE SRS DATA ENSEMBLE

Recognizing also the geo-temporal neighboured samples of the 24 RN detections 55 SRS fields have been requested in total from the 12 participants of the experiment. For each of these cases a model inter-comparison has been performed (Becker et al., 2005). In the absence of a true reference, each participant played for one time the observation that was compared to all other participants for all non-zero value pairs of identical geo-temporal grid reference.

Table 2: Score Matrix resulting from the LPDM inter-comparison for the 55 cases of backward EDM performed during the 2nd CTBTO-WMO experiment. Note that the 12 LPDMs

[6]For movies of the 1st and 2nd CTBTO-WMO experiments' nuclear event forward plume dispersion visit http://ctbto4.ctbto.org/atm/WMO-Cooperation/Reports/SourceScenario/scenarioreport.html and http://ctbto4.ctbto.org/atm/WMO-Cooperation/Reports/2005Scenario/scenarioreport.html

HARMO-10 Crete 2005

are only numbered in order to keep them anonymous. The 55 cases have been sorted according to the average agreement among all 12 LPDMs as listed in the second column together with the belonging standard deviation (3rd column). For each case the model that was in best agreement to the other 11 LPDM's is highlighted (solid bold). The overall agreement for the whole 2nd CTBTO-WMO experiment (resulting from the average of the second column) was 41.9%. In the final three rows the average agreement of each LPDM across all 55 cases of the 2nd experiment, it's belonging anomaly to the overall agreement and the belonging standard deviation is listed. The roman numbers give the final ranking of the LPDMs with regard to their distance to the centre of the complete ensemble of SRS fields shared. With regard to the Agreement value defined in equation (2) the model inter-comparison clearly spots LPDM No. 5 as the one best centred in the ensemble, which we thus call "median model" in analogy to the approach proposed by Galmarini et al. (2004a).

	AV	σ	1	2	3	4	5	6	7	8	9	10	11	12	AV	σ
rankNZP46_2005012600:Agreem.	50.90	6.70	53.26	55.53	49.37	56.04	51.55	**59.60**	49.90	53.87	38.22	47.58	38.92	56.98		
rankRN007_2005012100:Agreem.	50.13	5.30	51.52	**55.85**	41.03	54.98	55.64	52.92	53.25	52.31	42.95	44.27	44.98	51.87		
rankNZP46_2005012400:Agreem.	47.75	6.29	51.08	50.39	48.31	49.76	**54.52**	48.00	47.74	51.77	32.35	39.61	45.28	54.18		
rankNZP46_2005012200:Agreem.	47.65	6.23	49.34	46.60	46.93	51.07	**55.53**	51.26	51.58	50.44	35.66	38.04	41.53	53.83		
rankNZP46_2005012300:Agreem.	47.16	6.35	48.92	48.88	49.22	47.45	**54.97**	53.64	46.81	47.74	32.52	37.95	45.40	52.45		
rankNZP47_2005012221:Agreem.	46.75	7.18	52.19	51.49	48.99	50.98	**53.66**	51.87	31.45	45.57	38.09	44.64	38.87	53.17		
rankNZP47_2005012321:Agreem.	46.20	6.29	49.38	45.86	50.28	46.62	**55.58**	49.67	34.85	48.86	38.14	41.53	39.38	53.12		
rankCLP18_2005012715:Agreem.	45.18	5.23	46.69	50.22	37.66	47.74	**50.81**	50.47	41.71	47.93	37.89	37.65	43.77	49.62		
rankGBP68_2005012718:Agreem.	45.06	5.17	44.36	48.67	39.71	50.50	**52.66**	45.74	39.44	47.96	36.48	43.54	41.04	50.64		
rankCLP18_2005012815:Agreem.	44.64	4.65	46.20	47.35	35.79	43.51	**53.17**	48.31	42.57	46.56	38.57	46.41	41.12	46.12		
rankNZP46_2005012100:Agreem.	44.63	5.30	49.19	45.45	41.76	47.91	49.75	48.90	46.01	44.19	33.87	42.91	35.96	**50.57**		
rankBRP11_2005012615:Agreem.	44.16	6.02	44.83	**51.52**	40.63	48.00	51.00	47.01	43.06	45.11	33.90	32.74	43.12	47.98		
rankRN067_2005012700:Agreem.	44.08	5.39	46.19	41.87	40.91	49.71	46.96	48.22	46.42	46.22	35.70	42.64	33.34	**50.80**		
rankRN007_2005012200:Agreem.	44.00	4.30	43.80	43.49	43.33	44.23	**50.76**	45.04	47.67	45.93	33.71	46.57	38.94	44.50		
rankCLP19_2005012518:Agreem.	43.86	8.39	49.34	46.07	27.77	52.10	**53.35**	52.32	37.84	46.54	34.32	45.74	33.80	47.17		
rankNZP47_2005012121:Agreem.	43.69	7.26	50.31	48.88	38.65	45.29	**54.75**	49.93	33.41	43.99	35.72	41.81	32.74	48.86		
rankCKP23_2005012321:Agreem.	43.05	7.26	45.77	49.66	33.29	48.85	50.68	**51.54**	40.15	47.90	35.46	31.97	35.67	46.30		
rankRN002_2005012800:Agreem.	42.93	8.90	43.33	51.84	41.58	47.59	**52.22**	50.99	42.49	40.58	39.76	20.35	35.50	48.91		
rankCLP18_2005012615:Agreem.	42.76	5.67	36.20	47.85	35.46	43.09	**50.81**	47.40	39.43	46.75	35.34	40.05	40.83	49.92		
rankCKP23_2005012521:Agreem.	42.60	7.42	49.49	39.71	35.11	48.44	**51.22**	49.73	37.71	46.34	37.04	31.82	33.66	50.97		
rankFRP27_2005012318:Agreem.	42.41	5.83	40.19	46.96	41.13	47.24	**50.20**	48.72	38.77	46.44	33.81	34.32	35.61	45.42		
rankBRP11_2005012715:Agreem.	42.38	7.78	48.15	46.93	45.21	44.91	**51.68**	44.03	38.45	44.40	37.90	25.17	31.73	50.03		
rankFJP26_2005012100:Agreem.	42.37	7.63	47.71	38.39	41.34	36.87	**51.31**	48.26	48.84	49.26	26.57	36.59	35.35	47.80		
rankCKP23_2005012221:Agreem.	42.30	6.25	43.53	46.68	38.86	45.25	**50.84**	47.10	38.38	46.58	33.37	29.68	40.78	46.47		
rankBRP11_2005012915:Agreem.	42.27	7.10	49.85	44.14	42.64	42.51	**51.12**	49.05	38.77	43.59	35.58	29.55	31.84	48.62		
rankARP01_2005012918:Agreem.	42.16	7.91	41.92	46.03	46.12	47.74	48.87	49.10	36.70	43.49	39.06	24.14	32.26	**50.47**		
rankARP01_2005012718:Agreem.	42.15	7.88	46.26	46.07	41.50	43.25	51.19	49.66	36.31	43.46	39.86	28.81	27.86	**51.54**		
rankARP03_2005012412:Agreem.	42.09	4.02	44.36	40.92	34.81	38.48	**49.69**	44.49	41.26	44.50	42.21	41.15	37.51	45.72		
rankBRP11_2005012815:Agreem.	42.00	6.57	48.05	44.26	43.09	44.07	**49.71**	47.53	38.38	43.12	35.27	31.94	30.27	48.29		
rankCKP23_2005012921:Agreem.	41.91	6.11	42.94	41.77	36.07	**49.22**	48.59	48.67	35.15	45.10	36.12	32.36	38.63	48.28		
rankCKP23_2005012421:Agreem.	41.84	7.07	45.07	40.01	31.44	49.46	49.62	**50.96**	38.73	47.43	35.73	33.64	34.36	47.61		
rankCKP23_2005012821:Agreem.	41.63	7.32	45.02	43.60	33.33	44.74	48.45	**50.36**	36.95	47.15	36.25	27.58	36.37	49.79		
rankFJP26_2005012200:Agreem.	41.63	5.93	40.25	41.28	39.81	40.88	**47.80**	44.10	47.11	47.66	27.21	38.38	37.73	47.60		
rankARP01_2005012818:Agreem.	41.54	8.62	43.06	44.90	43.82	44.90	**50.81**	48.04	35.28	48.94	38.22	23.50	28.22	48.74		
rankCLP19_2005012618:Agreem.	41.40	6.75	**48.92**	43.89	33.74	46.42	48.31	46.61	36.07	42.26	27.98	44.98	34.36	44.23		
rankCLP19_2005012318:Agreem.	41.39	7.02	47.44	47.38	28.35	48.33	**49.06**	43.04	34.61	43.60	36.15	32.96	38.58	47.16		
rankRN073_2005012900:Agreem.	41.02	5.67	39.72	40.82	31.17	33.57	46.12	42.56	**47.32**	46.54	32.46	44.53	43.58	43.90		
rankARP01_2005012418:Agreem.	40.56	6.47	38.99	44.70	30.40	46.39	**47.66**	47.12	35.32	46.06	38.13	32.01	33.92	46.02		
rankFJP26_2005012300:Agreem.	40.26	6.27	34.33	45.12	39.08	43.11	46.24	40.03	45.02	44.43	25.86	34.37	39.18	**46.52**		
rankCKP23_2005012121:Agreem.	40.15	5.12	40.23	42.00	33.80	40.36	**46.22**	45.50	35.54	44.03	29.58	38.17	41.07	45.22		
rankARP03_2005012812:Agreem.	40.06	4.18	36.21	40.54	36.96	34.98	44.47	**46.84**	40.20	44.56	34.18	43.55	37.23	41.30		
rankARP03_2005012512:Agreem.	39.96	6.74	41.54	45.47	27.92	44.98	**49.26**	43.23	42.01	43.41	37.50	30.62	30.95	42.66		
rankARP01_2005012618:Agreem.	39.75	6.70	41.72	45.17	31.16	43.45	47.11	**48.16**	33.02	44.70	35.96	30.09	32.45	44.00		
rankFRP27_2005012218:Agreem.	39.58	8.06	37.29	46.01	38.01	44.51	48.29	**49.40**	36.40	41.93	21.24	30.47	43.69	36.75		
rankARP01_2005012518:Agreem.	39.23	6.39	43.22	44.82	30.33	44.57	**47.60**	45.09	35.49	40.09	32.20	38.45	28.18	39.69		
rankCLP18_2005012915:Agreem.	38.86	5.85	34.18	44.06	32.27	44.11	**47.23**	40.40	40.60	42.61	26.04	39.07	38.51	37.22		
rankRN002_2005012900:Agreem.	38.85	7.94	40.73	45.71	35.95	34.36	47.50	**48.17**	41.87	38.34	32.93	19.52	36.79	44.25		
rankCLP19_2005012418:Agreem.	38.55	6.44	43.85	37.54	28.87	42.84	**46.82**	44.63	34.66	43.26	32.67	29.94	33.15	44.42		
rankNZP46_2005012500:Agreem.	38.28	12.49	42.79	45.42	2.04	41.28	**46.89**	45.80	42.45	42.50	27.87	38.34	38.74	45.28		
rankCLP18_2005012515:Agreem.	37.75	7.32	38.46	44.71	18.83	**45.01**	44.20	42.69	35.72	40.87	31.12	38.34	35.82	37.07		
rankFRP27_2005012118:Agreem.	36.80	7.95	32.05	42.87	32.71	41.64	44.60	**46.67**	32.22	42.14	19.30	28.53	39.01	39.84		
rankCLP18_2005012415:Agreem.	35.96	5.74	30.86	42.73	24.58	**43.93**	38.53	38.47	38.88	41.32	30.13	34.00	34.03	29.70		
rankARP03_2005012712:Agreem.	34.35	4.48	30.50	35.05	31.23	32.71	**43.34**	39.81	35.44	37.82	30.84	28.77	29.91	36.73		
rankRN073_2005012800:Agreem.	32.88	7.36	26.81	35.18	24.79	39.02	34.90	35.96	**40.10**	39.08	28.80	38.21	35.95	15.60		
rankARP03_2005012612:Agreem.	32.85	4.10	33.35	34.53	26.88	32.68	**39.25**	37.97	32.91	37.08	32.40	28.03	26.93	32.38	AV	σ
LPDM's Agreement across 2nd Experiment			43.36	44.95	36.45	44.76	49.11	47.09	39.97	45.02	33.95	35.60	36.63	45.91	41.90	5.12
Anomaly against overall Agreement of 41.90			1.46	3.05	-5.45	2.86	7.21	5.19	-1.93	3.12	-7.95	-6.30	-5.27	4.01	0.00	5.12
σ of LPDM's Agreement across Experiment			5.90	4.49	8.50	5.16	4.23	4.25	5.26	3.48	4.78	7.03	4.68	6.81		
			VII	V	X	VI	I	II	VIII	IV	XII	XI	IX	III		

Hence for each of the 55 backward EDM cases a cross-comparison matrix was calculated in terms of the fractional bias (FB), Pearsson Correlation Coefficient (R^2) and the Figure of Merit in Space (FMS also known as Overlap). Based on these three individual measures, the final **rank** (RNK) value is computed with

$$RNK = R^2 + (1 - |FB/2|) + FMS/100 \qquad (1)$$

The maximum achievable RNK value, indicating identical SRS field values, is 3. For the calculation of the so-called "Agreement" of the observation model *k* (column 3+*k* in Table 2) with all others (playing the prediction) we preferred to give the percentage of the maximum RNK value while excluding of course the trivial auto-correlation result as follows

$$Agreement_k = \frac{100}{3(n-1)}\left(\sum_{i=1}^{n-1} \varepsilon_{ik} RNK_i - 3\right) \qquad (2)$$

with $n=12$ and $\varepsilon_{ik} = 1$ for i≠k and 0 for i=k

For each of the 55 backward EDM cases the average agreement of each LPDM with all other 11 ones can be listed row by row yielding the score table of Table 2. There we sorted the 55 cases according to the overall agreement achieved among the 12 participants (second column titled 'AV') that obviously is ranging widely from above 50% in the best case down to less than 33% in the worst case. Comparing this case to case variability of the agreement with the participants' variability in agreement for one case (retrieved from each row in Table 2) it becomes obvious that this is in the same scale which can also be read from the belonging σ values (3rd column for case specific variance across participants, bottom row for participants' case to case variance). Moreover it is interesting to notice that those cases with a relatively high overall agreement (top rows in Table 2) are NOT necessarily accompanied by relatively low case specific across participants' variance in model agreement.

BACKWARD EDM TO IMPROVE SOURCE ATTRIBUTION ACCURACY

Moreover to the pure model inter comparison, the SRM data shared during the 2005 experiment has been post-processed using the backward analogue to the EDM technique No. 5 introduced by Galmarini et al, (2004a). They have shown for the ETEX case that the aggregated ensemble dispersion prediction is more accurate than any single model prediction in forward mode (Galmarini et al., 2004b).

We chose the distance of the location of the maximum correlation coefficient value of the PSR field (white box in Table 3 plots) to the actual source location (white dot in Table 3 plots) as the metric for the source attribution accuracy. According to our preliminary results our source attribution technique validated for the first ETEX release by Wotawa et al. (2005) yields a superior behaviour of the 2005 experiments' "median model" (see caption of Table 2) towards any other single model result if the exact time of the singular 3 hourly source release is already known (Table 3, second row). However, in the more realistic case that neither the location nor the time of the nuclear event release is known, it turns out that the simple non-weighted across participants' average of the inversion results (PSR fields in terms of correlation coefficients) yields the best backtracking results, with the maximum correlation closest to the real source location (Table 3, bottom row).

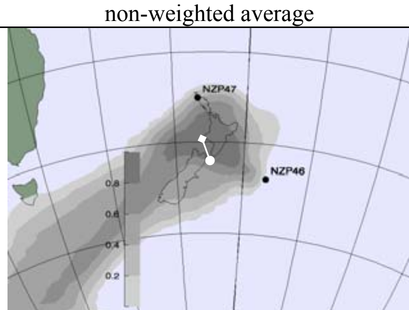
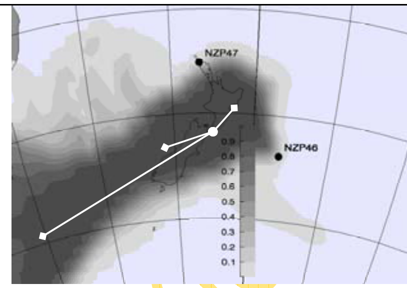
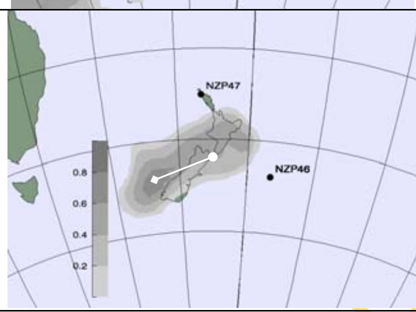
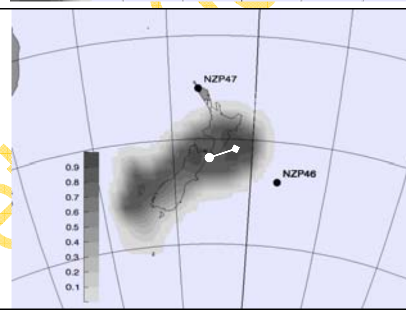
Hence if we take the LPDM's capability to backtrack the correct source location of a nuclear event's RN measurement scenario as an indicator of backward mode EDM, it is evident that the EDM results have the potential to be superior against any single LPDM backtracking calculation. Therefore ensemble dispersion modelling approaches can also improve the accuracy of backtracking products. This has implications for the design of any kind of emergency response system relying on these products. However, there is still a lot of investigation needed about the most suitable EDM methodology in backward mode, and the above proposed "non-weighted average" method or Galmarini et al's "median model" approach should rather be seen as first milestones towards a more generalized and also theoretically justified methodology.

Table 3: Backtracking of the nuclear event's geo-temporal source location[7](see white dot) by two different backward EDM approaches: (second column): Non-weighted average of all participants PSR fields and (third column) single "median model" based PSR field. Note that

□ Τυεσδαψ ϑανυαρψ 18, 2005 ατ 16:12 ΥΤΧ ωιτη χο–ορδινατεσ λ=174.86ºΕ, φ=41.89ºS

HARMO-10 Crete 2005

in the first plot row the cases were no precise temporal source assumption was made are illustrated. In the bottom row the same results are shown for a source assumption that is already precise in time. In each plot the source attributions accuracy is depicted by the distance between the actual source location (white dot) and the maximum in the PSR field (white box) which is not well defined in the upper row “Median Model” PSR field.

<table>
<tr><td>Assumed source period in 2005</td><td>EDM Method
non-weighted average</td><td>EDM Method
“Median Model”</td></tr>
<tr><td>All 6 days backward from 21st January 0 UTC</td><td>
</td><td>
</td></tr>
<tr><td>Exact the three hours during source release (3 hours backward from 18th January 18 UTC)</td><td>
</td><td>
</td></tr>
</table>

REFERENCES

Becker, A., G. Wotawa and L.-E. De Geer, 2004a: The 2003 CTBTO-WMO Experiment on source region estimation: An example project for the potential of standardized global source-receptor fields shared. *Proceedings 9th Int. Conf. on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes*, **2**, 351-355.

Becker, A., G. Wotawa and L.-E. De Geer, 2004b: Review on New PTS modeling capabilities supporting the emerging CTBTO-WMO response system including a proposal for standardized model intercomparison. WMO, WWW, CBS/ERA-CG/INF.1/Doc.8(3). http://www.wmo.ch/web/www/ERA/Meetings/ERACG-Geneva2004/Doc8-3.doc.

Becker, A., G. Wotawa and L.-E. De Geer, 2005: On the CTBTO-WMO response System set up for Ensemble Calculation of standardised Source-Receptor Relationship Information for the Purpose of Source Attribution of airborne Radioactivity Measurements raised within the CTBTO International Monitoring System. *Geophysical Research Abstracts,* **7**, *06316, SRef-ID: 1607-7962/gra/EGU05-A-06316*

De Geer, L.-E., Wotawa G. and A. Becker, 2004: Towards a formal and automated CTBTO-WMO response system WMO, WWW, CBS/ERA-CG/INF.1/Doc.8(1). http://www.wmo.ch/web/www/ERA/Meetings/ERACG-Geneva2004/Doc8-1.doc.

Galmarini S., R. Bianconi, W. Klug, T. Mikkelsen, R. Addis, S. Andronopoulos, P. Astrup, A. Baklanov, J. Bartniki, J.C. Bartzis, R. Bellasio, F. Bompay, R. Buckley, G.T. Geertsema, H. Glaab, M. Kollax, M. Ilvonen, A. Manning, U. Pechinger, C. Perssnon, E. Polreich, S. Potemski, M. Prodanova, J. Saltbones, H. Slaper, M.A. Sofiev, D. Syrakov, J.H. Sørensen, L. Van der Auwera, I. Valkama and R. Zelazny, 2004a: Ensemble dispersion forecasting – Part I: concept, approach and indicators. *Atmos. Env.* **38**, 4607-4617.

Galmarini S., R. Bianconi, R. Addis, S. Andronopoulos, P. Astrup, J.C. Bartzis, R. Bellasio, R. Buckley, H. Champion, M. Chino, R. D'Amours, E. Davakis, H. Eleveld, H. Glaab, A. Manning, T. Mikkelsen, U. Pechinger, E. Polreich, M. Prodanova, H. Slaper, D. Syrakov, H. Terada and L. Van der Auwera 2004b: Ensemble prediction forecasting-Part II: application and evaluation. *Atmos. Env.* ***38**, 4619-4632.*

Stohl, A., Hittenberger, M. and G. Wotawa, 1998: Validation of the Lagrangian Particle Dispersion Model FLEXPART against large-scale tracer experiment data. *Atmos. Env.* **32**, 4245-4264.

Wotawa, G., L.-E. De Geer, P. Denier, M. Kalinowski, H. Toivonen, R. D'Amours, F.Desiato, J.-P. Issartel, M. Langer, P. Seibert, A. Frank, C. Sloan and H. Yamazawa, 2003: Atmospheric transport modelling in support of CTBT verification – Overview and basic concepts. *Atmos Env.* **37**, 2529-2537.

Wotawa, G., A. Becker and L.-E. De Geer, 2005: Near-real-time computation and post-processing of source-receptor sensitivity information for a global monitoring network of airborne radioactivity *Geophysical Research Abstracts,* **7**, *03308, 2005, SRef-ID: 1607-7962/gra/EGU05-A-0330*