Evaluation of the operational IDC ATM products by comparing HYSPLIT BA, FA and OMEGA FOR during Level 4 events in Scandinavia

Gerhard Wotawa, Martin B. Kalinowski

Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), Provisional Technical Secretariat (PTS)
International Data Centre (IDC), Monitoring Section, Fusion, Review and Services Unit
Vienna International Centre, P.O. Box 1200, A-1400 Vienna, AUSTRIA
gerhard.wotawa@ctbto.org, martin.kalinowski@ctbto.org

1. Introduction

With the Release 2 Software, the IDC got its first in-house capability of Atmospheric Transport Modeling (ATM) and the graphical representation of results to characterize possible source regions related to measured radionuclide spectra. To review its performance and identify possible shortcomings, this software was now tested in practical service. Measurements of Cs-137 in Europe are particularly suitable for model testing. First, Cs-137 has a long radioactive half-life and is transported over long distances. Second, sources of Cs-137 across Europe are sufficiently well known from prior scientific studies. The goals of this study are the following:

- To determine and discuss possible source regions for these events. Specifically, to test whether reasonable assumptions about the sources causing elevated Cs-137 activity in Europe can be gained with the existing IDC Release 2 ATM software.
- To review the Field of Regard (FOR) concept used at IDC and its current implementation to denote possible source regions connected with Level 4 (one anomalous anthropogenic radionuclide detected) and Level 5 events (detection of multiple anomalous anthropogenic radionuclides)

The stations in Stockholm (Sweden, SE001) and Helsinki (Finland, FI001) are the only daily reporting radionuclide stations in Europe currently contributing to the IDC database. The systems are equipped with High Purity Germanium (HPGe) detectors with a Cs-137 detection limit of better than 10 µBq/m^3. Seventeen Cs-137 related Level 4 events occurred at these two sites between July 1999 (start of Release 2 Software operation) and end of October 2000 (Fig. 1). This is 50% of all Cs−137 related events recorded, disregarding events in Kuwait City, where many Level 4 events were produced during the initial test phase due to the absence of a statistical upper limit setting. Besides the events classified with Level 4, there were also a number of episodes with similar concentration levels where the statistical upper limit setting procedure prevented Level 4 classifications.

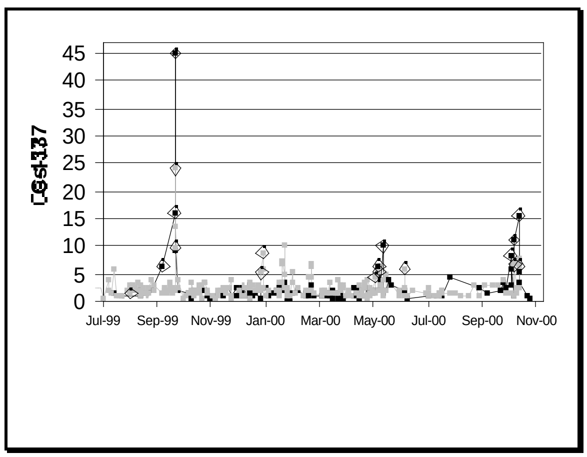


Figure 1: Time series of Cs-137 (µBq/m^3) measured at the stations SE001 (black line) and FI001 (grey line). Level 4 events are additionally marked with diamonds.

2. Transport models and FOR concept

Currently, the IDC produces Fields of Regard for radionuclide stations to denote possible source regions connected with Level 4 and Level 5 events. A Field of Regard (FOR) is defined as the geographical region from which the air that is sampled during the data collection period (24 hours) originates. FORs are computed for certain maximum transport times, for instance 72 hours. According to the definition, a 72 hours FOR would denote a region from which air is transported towards the station within 72 hours from the data collection stop.

Currently, the operational IDC FOR computations are based on the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model (Draxler and Hess, 1997) Version 3 fed with

National Centers for Environmental Prediction (NCEP). The input data resolution currently available at PTS/IDC is coarse in any respect (≈2°×2° horizontally; mandatory pressure levels vertically; one field every 12 hours). To obtain better resolutions for limited areas, FORs can also be calculated using the on-line dispersion code embedded into the limited-area weather prediction model OMEGA (Operational Multiscale Environment Model with Grid Adaptivity; Bacon et al., 2000). Within the IDC operational environment, FOR images are generally created applying the EDGE software package.

3. FOR computation modes

A FOR can be computed in forward and backward mode. Computations in both modes can be based on meteorological analysis or meteorological forecast data. Backward mode means that the transport calculation is performed backward in time from the measurement location (e.g., HYSPLIT backward trajectories). This is computationally efficient especially if the number of stations is small compared with the number of potential release locations. As alternative to backward modeling, it is also possible to compute transport from a number of pseudo-release points forward in time, and to sample these particles (trajectories) at the receptor location. This concept is generally used for embedded dispersion calculations (transport modeling integrated into meteorological modeling). Forward Analysis (FA) FORs are implemented operationally at the IDC for single stations. However, a number of shortcomings of current implementation were identified. Issues include a lack of computational efficiency, the numerical instability (all particles can miss the station, resulting in a FOR with zero area as if the air came from nowhere) and the fact that FA FORs include particles that pass the receptor location high above ground. It is therefore assumed that, in the current installation, HYSPLIT Backward Analysis (BA) FORs are more accurate than FA FORs, a hypothesis further supported by the findings of this study.

4. Possible source regions for Level 4 events in Scandinavia

4.1 Methods

To determine the possible source regions for the Level 4 events in Scandinavia, HYSPLIT Backward Analysis (BA) FORs were calculated. For the subsequent analysis, a concentration-weighted average FOR was computed for all Level 4 events. To have a reference, this average FOR can be compared with an average FOR based on 32 arbitrarily selected cases, representing the climatological situation. The concentration weighting was done in respect to measured Cs-137 activity. Since no meteorological input data were available in two cases, only 15 out of 17 available Level 4 events could be utilized.

4.2 Results

The average FOR on arbitrarily selected days shows that transport from the West towards the stations SE001 and FI001 is the dominant process, while transport from Eastern or Southern Europe does occur infrequently (Fig. 2). The average FOR from all Level 4 events, on the contrary, covers a comparably small, obviously well defined, region (Fig. 3), indicating that such events coincide with specific transport situations. In particular, two typical situations could be identified: Two thirds of the events are associated with transport from Eastern Europe, they shall be referred to as Type 1 events in this study. One third of the events are associated with transport from the Northwest, they shall be referred to as Type 2 events. During the investigation period, type 2 events exclusively occurred in spring. Type 1 events, on the other hand, were spread all over the other seasons, but clearly dominated in fall (in 1999 as well as in 2000). In a second step, Type 1 and Type 2 events were investigated separately. The average 96 hours FOR of Type 1 events shows that possible source regions cover the area south of the stations down to the Southern Ukraine (Fig. 4). The average FOR remains relatively small and confined even after 96 hours of transport. For Type 2 events, on the other hand, the average 96 hours FOR covers Northwestern Scandinavia and the North Atlantic Region (Fig. 5). There is practically no overlap between the average FORs of Type 1 and Type 2 events in Scandinavia, indicating fundamentally different sources.

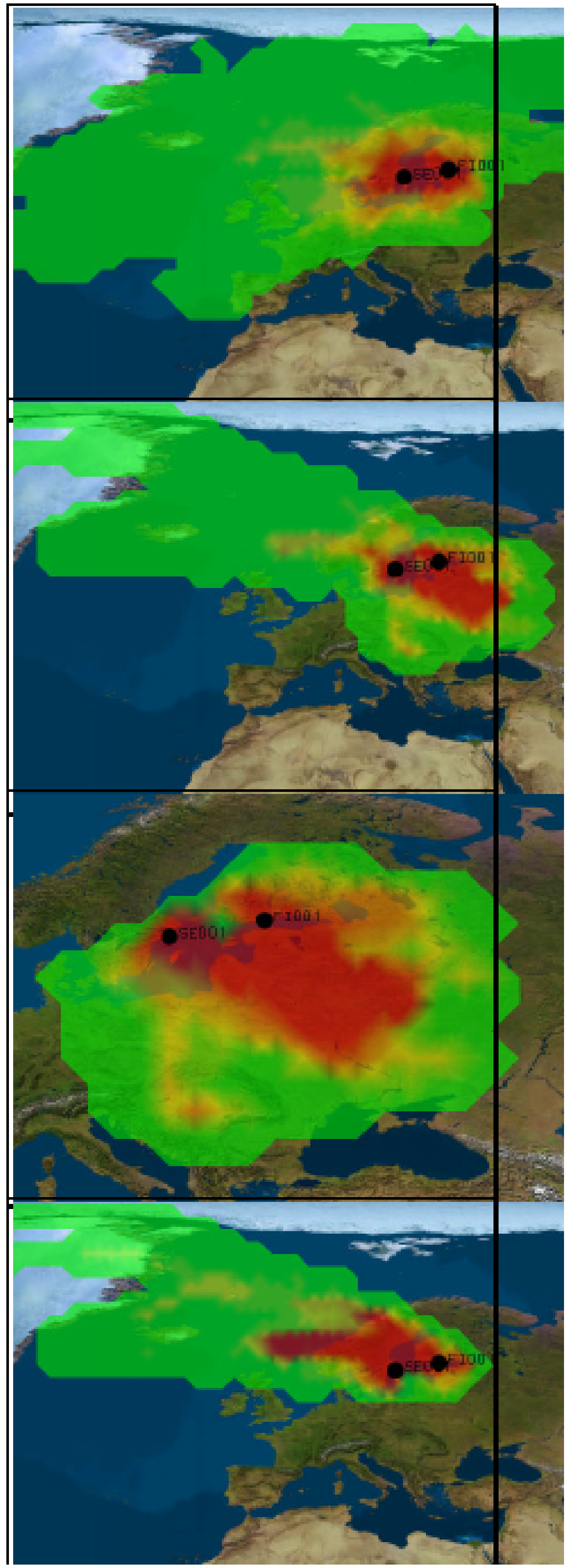
4.3 Conclusions and further investigations

Although the instruments applied in this study need further refinement, the following conclusions can be drawn. First, there are two different, distinct source regions for Cs-137 measured in Stockholm and Helsinki. One source region is in Eastern Europe (Type 1 events), the other in Northwestern Scandinavia (under the plausible assumption that the Cs-137 neither comes from North America nor from the Atlantic Ocean).

As far as Type 1 events are concerned, our model results are well in line with what is already known from the literature. Large-scale Cs-137 deposition took place during the 1986 nuclear accident in Chernobyl (NEA, 1995). The areas with the highest contamination after the accident are all within the average FOR area with the highest detection probability (red-filled area in Fig. 4). So it is likely that the Cs-137 measured in Scandinavia was re-suspended from the surface of these areas.

As far as Type 2 events are concerned, we have to consider two aspects. First, large coniferous forests are within the red filled area of the average FOR of these events (Fig. 5). Second, these events exclusively occurred during springtime. Thus, we can formulate the hypothesis that Type 2 events are caused by pollen of trees growing on soils contaminated with Cs-137. Forests are known to efficiently filter out radionuclides from the air, and they show enhanced retention (NEA, 1995). The pollens are released during the spring and can be transported towards the sites. Two additional arguments are in favor of this hypothesis. First, the large-scale wind speeds during these events were high, which would facilitate long-distance transport of such pollen. Second, the time between the first and the last of these events was approximately one month, similar to the pollen release period.

Generally, these results show that the ATM software currently in place at the IDC is a suitable starting point. By applying the FOR concept in the backward analysis mode, reasonable assumptions about the sources causing elevated Cs-137 activity in Europe were obtained. An improved specification of Cs-137 sources in Europe, however, would offer the IDC the opportunity to test and possibly calibrate its models. To better clarify the sources, a Cs-137 source inventory should be numerically reconstructed from measurements and transport calculations. For that purpose, the data period can be extended back to 1998 (start of IDC Release 1 Software). Not only the Level 4 events, but also all other measurements



should be included into the analysis. There are basically two possible approaches to reconstruct a source inventory.

First, simple backward air trajectories could be calculated for the measurement stations. These trajectories together with the measurements can be evaluated on a regular grid. Statistical trajectory source analyses (sometimes called trajectory statistics) have been extensively described in literature (Stohl, 1998). One method developed some years ago (Stohl, 1996) has, for example, been successfully applied to reconstruct a summertime source inventory for carbon monoxide (CO) in North America to clarify the contribution of forest fires to air pollution (Wotawa and Trainer, 2000).

As second approach, source receptor matrices could be calculated from the measurements applying a transport model. The formal inversion of such a matrix would yield a source inventory. Due to under-determination, source receptor matrices tend to be ill conditioned, so additional constraints need to be applied. Such methods were recently presented in literature (e.g., Seibert, 2000).

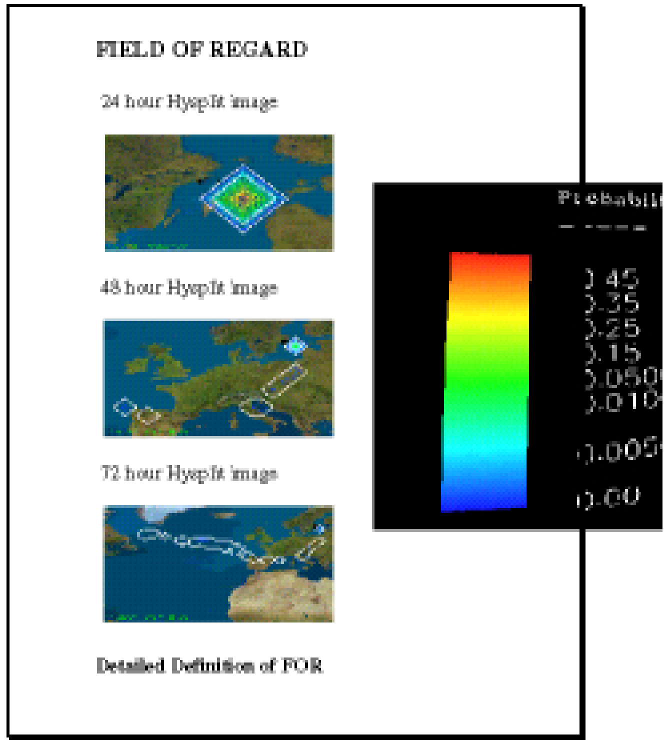


Figure 6: 24, 48 and 72 hr FORs related to a Level 4 event (SE001, October 13, 2000).

5. Review of the FOR concept and its implementation at IDC

Besides a first, tentative determination of possible source regions, the Level 4 cases were also used to review the ATM and visualization software in place at the IDC.

5.1 Single case study of operational FA FOR computation

Shortcomings of the operational HYSPLIT FOR computation in the Forward Analysis (FA) mode have already been mentioned. One of the biggest issues, namely the considering of trajectories even if they pass the stations high above the ground and its practical consequences shall be investigated in a case study.

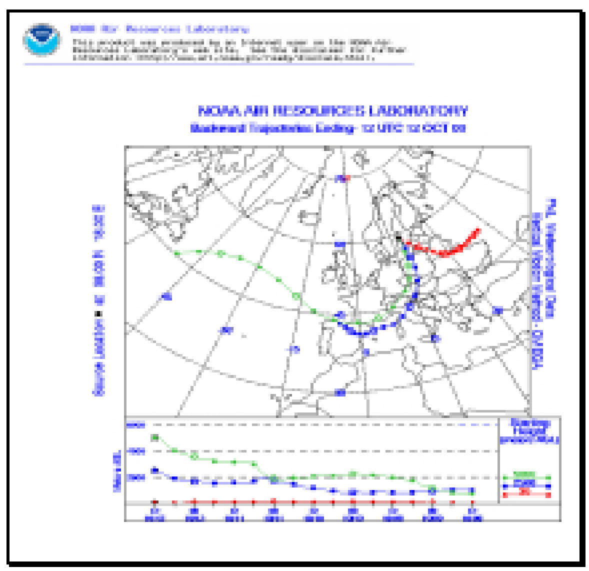


Figure 7: NOAA ARL/HYSPLIT backward trajectories related to the Level 4 event at SE001 on October 13, 2000. Trajectories were started in three different altitudes above the station (30 m, 2500 m, 5000m). After 4 days of transport, all trajectories end near the surface.

On October 13th, 2000, a Level 4 event occurred at the station SE001 (Cs-137 above statistical average). Therefore, HYSPLIT FA Field of Regard images (24, 48, 72 hours backward) were attached to the Atmospheric Radionuclide Measurement Report (Fig. 6). The 48 hour FOR image indicates transport from Southwestern Europe. For 72 hours, transport from the remote North Atlantic is indicated. This, however, is in contradiction with HYSPLIT BA FORs, which show transport from a relatively small area in Eastern Europe, indicating a Type 1 event (re-suspension of Cs-137). The question is whether the deviations of thousands of kilometers reflect normal uncertainty in transport computations, or whether one result is right and the other is wrong from a meteorological point of view.

This question, however, could easily be resolved by a backtracking of air parcels released in different heights above the receptor location (SE001) in the middle of the data collection period (October 12th, 12 UTC; Fig. 7). The air trajectory subsequently arriving at SE001 near ground level comes, as indicated by the BA FOR images, from Eastern Europe with low mean transport speed. Back trajectories passing the station in 2.5 km height originate in south western Europe, while trajectories passing at 5 km above the station originate over the North Atlantic. Both elevated trajectories originate near ground level and strongly ascend while being transported towards Scandinavia. This shows that air originating near the ground within the FA FOR region as indicated in the official product would pass the station SE001, but not near the surface but in the mid troposphere. Thus, these air parcels would be irrelevant for the measurements, unless, for example, precipitation events during the sampling time could bring the material down. On the other hand, the relevant regions of regard, namely those in Eastern Europe, are not indicated at all. This example shows that these deviations are no sign of transport uncertainty, but that the FA method as used in the IDC products potentially produces erroneous results in the sense of indicating potentially irrelevant regions and missing the relevant ones.

5.2 Comparison of average HYSPLIT FA/FF FORs with HYSPLIT BA FORs and with average OMEGA FF FORs

Average HYSPLIT FA FORs during Level 4 cases of Type 1 and Type 2 were computed to allow for a comparison with the already presented average HYSPLIT BA FORs. These computations showed that even average FA FORs are noisy and discontinuous. Due to problems as referred to in the preceding section, FA FORs did not give such a clear picture in the sense that the region indicated, especially for type 1 events, was considerably larger. All in all, though, the separation between transport from Eastern Europe (Type 1) and transport from the Atlantic (Type 2) worked out similar.

Unlike the huge differences encountered between backward and forward mode, the average FORs in analysis and forecast mode proved to be qualitatively very similar. This indicates that the meteorological forecast error, compared with the other shortcomings involved in the FOR computation in forward mode, seems to be of secondary importance, at least for forecast periods of 48-72 hours.

For special analyses with higher spatial and temporal resolution connected with Level 4 and Level 5 Events, FORs based on the OMEGA model can be computed on a selectable limited area grid. OMEGA FORs can only be computed in the forward mode (Forward Forecast, FF). By comparing average OMEGA FORs for type 1 and 2 events on two grids with different resolution (one covering Europe and the Atlantic, the other only Europe), we could show that OMEGA FF FORs exhibit similar problems like HYSPLIT FORs computed in the forward mode. One problem is again that the FOR calculation method seems to consider particles passing the measurement location high above the ground. The fields were noisy and discontinuous. The noisiness was somehow reduced on the finer grid, indicating that some of the computational problems are an issue of the horizontal resolution of pseudo release points.

5.3 Conclusions

The HYSPLIT FA FORs as used within some IDC products for the location of possible source regions in ICD Release 2 software can produce erroneous results. They sometimes indicate regions not relevant for the surface measurements, and miss regions that would be of relevance. To avoid such problems, it would be preferable to use HYSPLIT BA FORs within the products. This approach would also significantly improve the computational efficiency, and would avoid empty FOR images. In the current installation, HYSPLIT BA FORs, however, are also potentially problematic, because they are computed disregarding diffusion. However, huge differences (on the order of 5000 km) in FOR regions with identical underlying meteorological model data (MRF model) could be explained just with the problems in the applied technical concepts of FOR computation. This finding applies not only to HYSPLIT/MRF FORs, but also to OMEGA FORs, which can only be computed in the forward mode.

6. Summary and conclusions

In this study, Cs-137 measurements at Northern European radionuclide stations were investigated to determine and discuss possible Cs-137 sources applying the existing IDC Release 2 Atmospheric Transport Modeling (ATM) software and to review the Field of Regard (FOR) concept and its implementation. Besides all limitations, the current software proved to be useful in specifying Cs-137 sources. Two different possible sources were identified, one probably in connection with Cs-137 re-suspension from the soil in Eastern Europe (Type 1 events), and one possibly in connection with Cs−137 transported with pollen from coniferous trees in Scandinavia (Type 2 events). As far as FOR computations are concerned, the current installation at IDC proved to be dissatisfactory. The computational concept in place is inaccurate and produces potentially erroneous results. Cases were identified where FOR images denoted regions that were meaningless for the radionuclide surface measurements, while important regions were not identified. These shortcomings apply to HYSPLIT/MRF as well as to OMEGA FOR computations and thus affect the whole IDC ATM system. The computation of FORs in the backward analysis mode generally proved to be more reliable and more accurate. This mode, however, also shows its drawbacks (no diffusion considered; computation method makes sure that trajectories end at station altitude, but it is not guaranteed that they start near ground level).

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