

IDC needs for atmospheric transport modelling and first experiences with the IDC Release 2.1 application software including HYSPLIT, OMEGA, and EDGE

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1. Possible ATM products

Atmospheric transport modelling (ATM) plays an important role in support of radionuclide monitoring to verify compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT) [1-3]. The goals of ATM related to the CTBT fall into two distinct categories. These are simulations to assess the performance of detector sites and the whole network on one hand side and the determination of possible source regions on the other hand side. Detection probability is the key quantity for station or network performance assessment. Source probability is a key quantity for source location. Regarding the scope of atmospheric transport modelling, one should carefully distinguish the fundamental differences between source probability and detection probability.

a) Detection probability

The objective of determining the detection probability is to assess the performance of a detector site or the whole network of stations. A quantity can be attached to each region and time that gives the probability to detect a release from there and then. As an assumption, the same source probability is used for each location and each point in time. The detection probability is fully determined by the minimum detectable concentration, the detector location, the collection period and the current meteorological data. A possible method to calculate the detection probability for a particular region is to calculate the percentage of particles arriving at the station and originating from a pseudo-release point that represents the respective area. One should be careful not to confuse the detection probability with the probability of a region to be the source location. Detection probability does not give an answer to the question for the region that has the highest probability to be the source of a detected relevant radionuclide. In fact, any region that has a non-zero detection probability carries the same probability to be the source. The region that has the highest probability for a release to be detected, does not necessarily have the highest probability to be the source region. Therefore, detection probability is misleading when applied for source location.

b) Source probability

The objective of determining the source probability is to localize the most likely location for a detected release of a relevant radionuclide. The quantity attached to a region and time is giving the probability that a detected release originated from there or that a release plume passed there. The underlying source assumption would be a single point source with a short release duration. The source probability can be partially determined by the same parameters as given above for detection probability but needs additional sample information (isotopic ratios, concentration). A method to calculate the source probability could be by weighting the transport time with an age probability distribution derived from isotopic ratios. The source probability can further be refined by positive indications from the possible source regions related to other detector sites where a radionuclide from the same source is measured as well as by negative indications from the possible source regions related to other detector sites where the radionuclide is not detected. A possible source strength can be derived from the measured concentration and by applying dispersion simulation.

With the difference of detection and source probability in mind, the possible products from atmospheric transport modelling (ATM) to support the CTBT verification can be outlined as follows and as put into perspective in Fig. 1.

1.1. ATM products for station or network performance (see Fig. 1, left column)

site(s) within a certain travel time. For each regional cell and for each time interval a logical value (true/false) can be determined by following air parcels or particles by the wind fields. This can be done by backward trajectories starting at the detector site or by forward trajectories from pseudo-release points. A regional cell that is reached by a backward trajectory within a certain travel time gets the value "true". Likewise, a region from which a forward trajectory reaches the station site within a given time gets a value "true" as well. If dispersion is accounted for, the hit function will take the simulated spread of the cloud into account.

The Detection Probability is a quantity that can be added to each region and time of the Station/Network Coverage product. It gives the probability to detect a standard release from a certain region. First summing all "hits" at the station originating from the pseudo-release point under consideration and then dividing it by the total number of pseudo-releases started from the same region is one way of calculating the detection probability. An improved approach takes the detection limit and plume dilution processes into account. A meaningful source strength that is related to a certain nuclear explosion release scenario may be used, e.g. 2.4 PBq for Ba-140, 0.13 PBq for Xe-133 on land, 13 PBq for Xe-133 on sea [4]. A refinement to the detection probability approach differentiates by possible source regions on sea and on land.

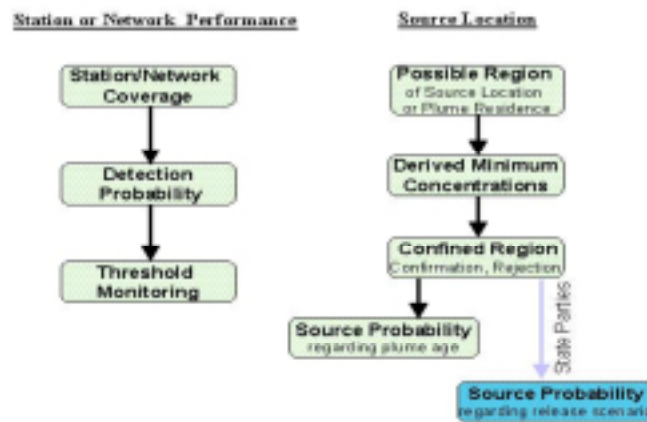


Fig. 1: Possible ATM products related radionuclide monitoring to verify the CTBT .

Threshold Monitoring is a concept developed to assess the performance of the seismic monitoring network. It provides the worst-case network detection capability indicated in magnitude for the analyzed hour and geographic region. It is proposed here to adopt this concept for the radionuclide monitoring network by estimating the minimum detectable release concentration for each analyzed time and geographic region. The minimum detectable release activity can be derived from the detection limit requirements for IMS radionuclide detectors (10-30 $\mu\text{Bq}/\text{m}^3$ for Ba-140, 1 mBq/m^3 for Xe-133) multiplied by the dilution factor. This dilution factor can be calculated by performing backward calculation with releasing a pseudo-tracer at the detector site. Correcting for radioactive decay in case of radionuclides that have a half-life in the order of the transport time is straightforward. Dispersion processes like turbulent diffusion can be taken into account by solving the adjoint tracer transport equation that uses the adjoint to the diffusion operator [5]. Reverse transport computations can be done with different algorithms. Using appropriate parameterisation, scavenging processes like wash-out could be considered as well. By doing reverse transport modelling, concentrations of a "retroplume" are calculated which provide the station visibility [6]. A refinement to threshold monitoring differentiates by possible source regions on sea and on land.

1.2. ATM products for source location (see Fig. 1, right column)

The Possible Source/Plume-Residence Region is equivalent to the Station/Network Coverage performance product (see first item in the previous list). It gives a logical value (true/false) for each regional cell and for each time interval to indicate where the detected plume may have resided a certain time before the collection period. If the release time is later than the earliest time included in this product, the source location may be included in the possible region product. The possible source/plume-residence area should be estimated with a reasonably high resolution in time and space.

The Derived Minimum Concentration can be calculated similar to the threshold monitoring performance product (see third item in the previous list). For each region and point in time the maximum release concentration value can be derived from the measured concentration at the detector site by accounting for diffusion and scavenging along the transport path with an ad-joint model and appropriate parameterisation.

The Rejected and Confirmed Possible Source/Plume-Residence Region results from a combined evaluation of measurements for more than one collection period and at different detector sites. The possible source/plume region can be confined by rejection and confirmation from the correlation with possible source/plume regions related to other samples. The confirmed region can be defined by the union of all geographic areas which are matching in travel time estimate for all sites that detect the same event (positive indication). The region can be further confined by cutting off those areas that have matching travel times and are related to samples in which the relevant radionuclide is not detected (negative indication). The method of choice for this kind of product is to solve the source-receptor matrix which contains the transfer functions between a number of possible regions for a radioactive release (sources) and a number of detector sites (receptors). The source-receptor matrix can be calculated by dispersion models in the forward or backward mode and then inverted with a least-square algorithm [7].

The Source Probability regarding plume age can be associated with the confined possible source/plume regions whenever an estimation of the event time is available. If isotopic ratios can be determined from the measured concentration of certain isotope pairs with suitable half-lives (e.g. Ba-140/La-140, Nb-95/Zr-95, Cs-134/Cs-137, Xe-133/Xe-131m, Xe-133m/Xe-133, Xe-135/Xe-133) the event time can be estimated. From the error associated with this estimate a plume age probability distribution can be derived. In combination with the travel times associated with the possible source regions a source probability can be assessed for each region.

The Source Probability regarding release scenario can be associated with the confined possible source/plume regions, if an assumption about the source strength probability distribution is available. This may be estimated by State Parties from general assumptions and if possible with additional information about a suspected event and associated release scenario. For each region and time the derived minimum release concentrations can be weighted by the estimated source strength probability distribution.

It should be noted that a lot of work has been done on performance products described in the first list, especially in network design studies during the CTBT negotiations undertaken to determine the optimum network. In more recent times, these approaches were followed to assess the impact of proposed station relocations [1-4]. Additional procedures for applying meteorological data are important with respect to the IMS for assessing the detection performance of single stations and for the whole network. These include for example special studies on coupling and de-coupling of ground-based stations from air masses in higher altitudes, especially above the boundary layer.

In the following section this paper puts a focus on atmospheric transport modelling related to the IDC products. These are mainly based on the second list above. Much less experience has been gained in generating ATM products for source location. At three informal meetings, the meteorological community discussed issues related to CTBT verification [1-3]. The approach needed here is somewhat similar to the tools developed for environmental emergency response systems [8]. However, the problem is inverse in time, since in general information about releases are not available and the ATM activity will be triggered by a detection of a relevant anthropogenic radionuclide.

2. IDC mandate for atmospheric transport modelling

The mission of the International Data Centre (IDC) is to support the verification responsibilities of

These products shall be provided “without prejudice to the final judgements with regard to the nature of any event, which shall remain the responsibility of States Parties” [Protocol to the CTBT, Part I, Section F, paragraph 18]. One important and restrictive implication of this mission on ATM products is that these should not be based on any assumption about possible sources which could result in a prejudice.

The CTBT and its Protocol provide little explicit guidance with regard to atmospheric transport modelling as part of International Data Centre (IDC) products and services. There is one clearly ATM related requirement defined by one of the IDC services to States Parties:

“Assisting individual States Parties, at their request and at no cost for reasonable efforts, with expert technical analysis of International Monitoring System data and other relevant data provided by the requesting State Party, in order to help the State Party concerned to identify the source of specific events.” [Protocol to the CTBT, Part I, Section F, paragraph 20.c)]

The appendix to the Resolution establishing the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Organization gives an indicative list of verification tasks. This is meant to be illustrative of the verification-related tasks the Preparatory Commission might need to undertake in implementing the relevant provisions of the Treaty and the resolution establishing it. Accordingly, the Operational Manual for Radionuclide Monitoring will require the Preparatory Commission to develop, among others, “Procedures for the integration of relevant meteorological data if appropriate” [part I, paragraph 9, of the Protocol to the Treaty]. The reference points at the relevant section on radionuclide monitoring in the Protocol. Therefore, the Preparatory Commission has a clear mandate to include procedures on atmospheric transport modelling related to radionuclide monitoring into the Operational Manual.

At the beginning of the year 2001, the framework for related activities and products is still under discussion in the Preparatory Commission and will be set in the Operational Manuals for the International Monitoring System (IMS) and for the IDC. Many questions regarding atmospheric transport modelling for the IMS and the IDC remain open. However, some reasonable elements for ATM products have been drafted and related software has been developed. These are described in the following section.

The IDC will not be left alone with this task. It has been decided that it will cooperate with the World Meteorological Organization. In 1997, the WMO set up a task group on WMO/CTBTO matters to explore areas of possible future collaboration. Its findings were presented in a final report [9]. A framework agreement between the CTBTO PrepCom and the WMO was proposed in 2000 and is supposed to be signed in 2001.

With Release 2.1 application software, the IDC got the first in-house capabilities for atmospheric transport modelling (HYSPLIT [10] and OMEGA [11]) and with interfaces to a commercial visualization tool (EDGE). From the first experiences with these tools, procedural needs and software enhancement proposals can be formulated.

3. First experience with atmospheric transport modelling at the IDC

3.1. HYSPLIT network performance assessment

With Release 2.1 software, a first approximation to the radionuclide network performance can be estimated on a daily basis by the union of all HYSPLIT Fields of Regard (FORs) for all station sites. Accordingly, $(84 \pm 1)\%$ of the globe is covered by the 79 defined Treaty sites after 14 days travel time as averaged over combined FORs for 19 different periods in 1999 and 2000.

To improve this method, it is proposed here to calculate the minimum detectable release activity for each possible release area. This can be derived from the detection limit requirements ($10\text{--}30 \mu\text{Bq/m}^3$ for Ba-140, 1 mBq/m^3 for Xe-133) and by simulating dispersion and scavenging. The result would be equivalent to threshold monitoring for seismic events. This should be differentiated by the particulate (80 sites) and gas (40 of these sites) network as well as by source regions on sea and land.

3.2. HYSPLIT and OMEGA FOR comparison

Daily HYSPLIT FORs are attached to the RRR (old name: ARMR). For Level 4/5 events, OMEGA FORs will be published in the SSREB (old name: FPEB). Therefore, it is of interest to understand how

An initial study compared 83 FOR pairs for the same radionuclide station and for the same day, i.e. for the same meteorological input data. The size of the geographical area represented by the HYSPLIT FORs is in most cases (70%) larger than that computed by OMEGA. The distance of the FOR center from the station is larger for HYSPLIT in more than half of all cases (56%). The wind directions, reflected by the positions of the FORs relative to the

radionuclide station, agree only in less than half (42%) of the comparisons. As a result, the degree of overlap between both model's FOR results appears to be poor (see Fig. 2). In three quarters of all cases, OMEGA and HYSPLIT FORs overlap less than 50%. In one third of all cases, OMEGA and HYSPLIT FORs do not overlap at all.

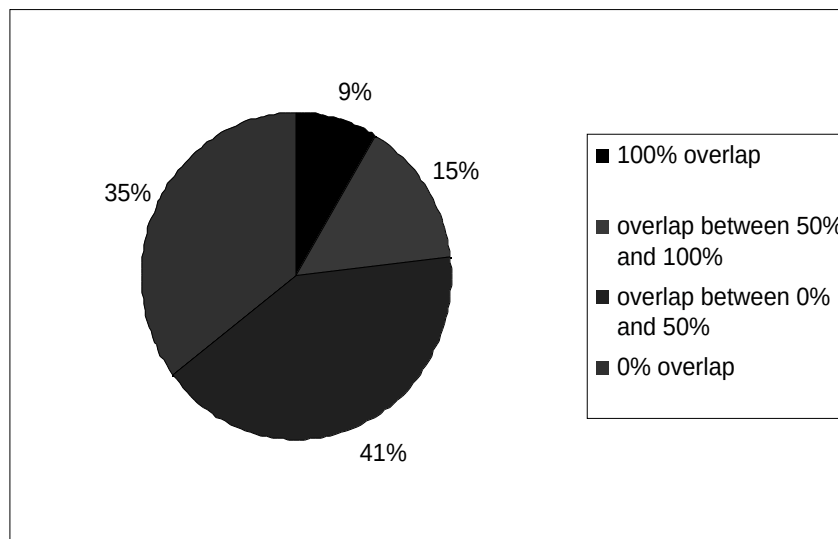
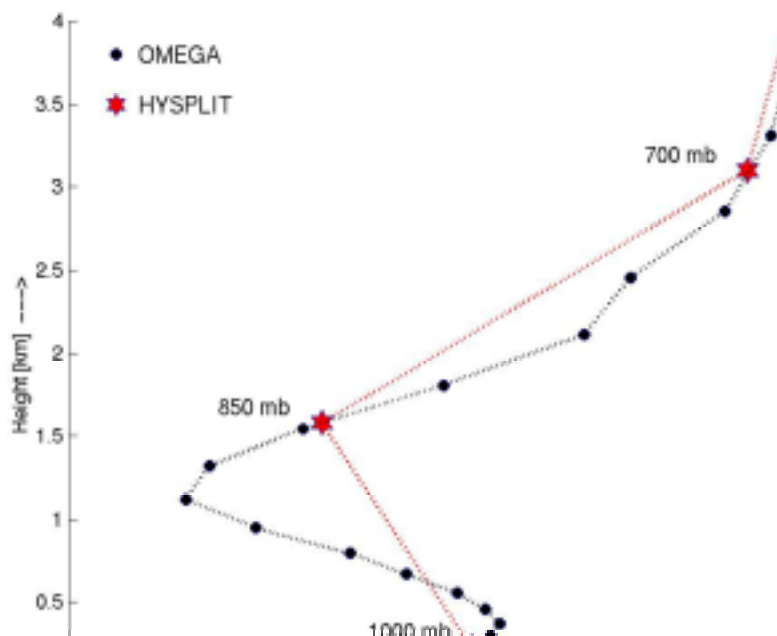


Fig. 2: Degree of overlap between HYSPLIT FORs and OMEGA FORs for the same date and same site.

HYSPLIT and OMEGA seem to indicate contradicting FORs. These differences can in part be understood by the higher resolution of OMEGA and by the different use of the MRF (Medium Range Forecast) meteorological input data (HYSPLIT interpolates, OMEGA uses them as initial and boundary conditions). A more significant reason is the 5% probability threshold of the standard EGDE macro. It cuts off the low probability source regions and, hence, does not display the full area from which air arrived at the detector. A proper EDGE macro should be used that covers all areas with non-zero probability. However, the main reason probably is the difference in vertical model structures.

HYSPLIT and OMEGA are not contradictory, but different. A major difference lies in the vertical model structures with implications on the simulated wind speed (see Fig. 3). With MRF input, HYSPLIT has only 2 pressure levels below 2 km, where OMEGA has about 17. Conversion layers within the planetary boundary layer are much better resolved in OMEGA. Linear interpolation in HYSPLIT can miss low and high wind speed levels. Both models assume a surface release (10 m), where OMEGA typically has appropriately low wind speeds, whereas HYSPLIT may use wind speeds that are valid at several hundred meters. Typically, these are higher and, therefore, HYSPLIT FORs can reach larger distances. Also, shearing winds are not well resolved in HYSPLIT and FOR directions can be different to OMEGA FORs. Comparison of simulated pseudo-plumes with volcano ash plumes are used to demonstrate these differences in the vertical structure.

The differences in FORs as computed with HYSPLIT and OMEGA need to be understood and explained to the State Signatories. The concept of the FOR and the method for its computation need further evaluation. One point of concern is the resolution in space and time. Experience shows that in general the OMEGA standard $15^\circ \times 15^\circ$ grid is too small to cover the full source region after 48 hours transport time. The need to increase the grid size compromises the resolution advantage of the OMEGA pseudo-release points, unless there is an option to use more than 15×15 pseudo-release points and accept a longer simulation run time.



3.3. The initial WMO/IDC exercise

In May 2000, an informal test between the IDC and WMO Regional Specialized Meteorological Centers (RSMCs) took place. The communication worked in a timely manner. Response times were quick, ranging from less than one up to 16 hours. The large amount of information needs to be reduced for State Parties. In this case, there were 112 image files filling a total of 30 MBytes. For the future cooperation, goals and procedures for attempting a scientific consensus, for addressing the uncertainties in localisation under the particular weather conditions, and for conveying divergent views should be drafted and tested. RSMCs may issue joint statements. The IDC may draft and apply a template for Expert Technical Analysis on source location.

This informal test provides an opportunity to compare HYSPLIT and OMEGA FORs with results of other models and meteorological input data for locating a possible source region. Most results are quite comparable. The IDC output that compares best with the RSMC results is generated by the HYSPLIT backward analysis mode. Possibly, the backward mode should be used for generating the standard FOR product that is attached to the RRR instead of the currently applied HYSPLIT forward analysis mode. For more on this hypothesis see [12].

4. Conclusion

There is a variety of possible ATM products which can either serve station and network performance assessment or identification of possible source regions. Methods for source location are in a process of dynamic research and development and there is still room for improvement on implementing high-quality models in the operational environment of the International Data Centre (IDC).

The views expressed herein are those of the author and do not necessarily reflect the views of the CTBTO Preparatory Commission.

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