

## USING ATMOSPHERIC $^{137}\text{Cs}$ MEASUREMENTS AND HYSPLIT TO CONFIRM CHERNOBYL AS A SOURCE OF $^{137}\text{Cs}$ IN EUROPE

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### **ABSTRACT**

The Chernobyl nuclear reactor accident released considerable amounts of radioactive material into the environment, including a large amount of  $^{137}\text{Cs}$ . A large fraction of the  $^{137}\text{Cs}$  was deposited on the ground in the surrounding areas. Two atmospheric monitoring stations that contribute data to the Prototype International Data Centre (PIDC), one in Stockholm, Sweden, and the other in Helsinki, Finland, routinely measure  $^{137}\text{Cs}$ . It is believed that the source of this  $^{137}\text{Cs}$  is the ground contaminated by the Chernobyl accident. The PIDC routinely uses HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) atmospheric modeling software to determine probable source locations of radionuclides detected during normal operations. In this paper, HYSPLIT was used in conjunction with the data from the PIDC to more firmly establish the link between Chernobyl and  $^{137}\text{Cs}$  measurements. The results indicate that an air mass containing  $^{137}\text{Cs}$  has a higher likelihood of having recently been in the Chernobyl area than an air mass that does not contain  $^{137}\text{Cs}$ . The inverse seems true also: an air mass that does not contain  $^{137}\text{Cs}$  is far less likely to have been in the vicinity of Chernobyl in the recent past. These results, while not definitive, are very encouraging. The results also improve the confidence in HYSPLIT.

**KEY WORDS:** Chernobyl, Cesium, PIDC

### **OBJECTIVE**

In 1986, the Chernobyl accident released large amounts of many different radionuclides into the atmosphere. Starting with its first sample in 1996, the Prototype International Data Centre (PIDC) has measured  $^{137}\text{Cs}$  at radionuclide monitoring stations in Europe. This paper attempts to link  $^{137}\text{Cs}$  re-suspension in the vicinity of Chernobyl to the  $^{137}\text{Cs}$  regularly measured by monitoring stations. To this end, HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) atmospheric modeling software was used in conjunction with radionuclide concentration measurements to show that the Chernobyl region is likely the source of  $^{137}\text{Cs}$ .

There are about 150,000 km<sup>2</sup> of land contaminated with  $^{137}\text{Cs}$  at greater than 37 kBq/m<sup>2</sup> (UNSCEAR, 2000). It is not surprising that conditions exist that re-suspend this  $^{137}\text{Cs}$ . One example is a forest fire in the Chernobyl area that re-suspended measurable amounts of  $^{137}\text{Cs}$ , that was detected by the PIDC in May, 2000. Once airborne, the  $^{137}\text{Cs}$  is transported considerable distances in the atmosphere. In particular, the  $^{137}\text{Cs}$  is transported to European atmospheric monitoring stations before the  $^{137}\text{Cs}$  concentration falls below the minimum detectable concentration.

There are four PIDC monitoring stations in Europe, all of which regularly measure  $^{137}\text{Cs}$ . Two of these, one in England and the other in Germany, sample air for seven days. For the purposes of this study, these measurements are too long to make reasonable predictions about the origin of the  $^{137}\text{Cs}$  re-suspension. Two other stations, one in Stockholm, Sweden, and the other in Helsinki, Finland, sample air for 24 hours. This shorter sampling time allows better estimation of an air mass's previous position. This study, therefore, only uses data from the Swedish and Finnish stations.

To model atmospheric transport, the PIDC runs HYSPLIT daily and generates a Field of Regard (FOR). The FORs show areas where it is most likely a parcel of air originated during a specified time period, and hence help



to indicate possible sources of radionuclides detected. These FORs were used to show a link between  $^{137}\text{Cs}$  measurements and Chernobyl. About 18 months of FOR data was used for this study.

### **RESEARCH ACCOMPLISHED**

This section begins by describing the data that was used from the PIDC. It then covers conditions that are favorable for transporting  $^{137}\text{Cs}$  from Chernobyl to the monitoring stations. It also describes how HYSPLIT was used to generate FOR data. Then the link between  $^{137}\text{Cs}$  measured at the monitoring stations and Chernobyl is established.

### **PIDC Data**

The PIDC receives data from a global system of atmospheric monitoring stations. The Swedish and Finish systems are two of these stations. The stations send High Purity Germanium (HPGe) gamma-ray spectra to the PIDC on a regular basis, usually daily. The spectra are analyzed to determine which radionuclides are present and what their concentrations are. This includes concentrations for  $^{137}\text{Cs}$ . The Swedish and Finish stations have been providing the PIDC with this data since 1996.

The PIDC uses atmospheric data and atmospheric modeling software to estimate previous locations of air that was sampled by a monitoring station. The model is run daily. This allows the PIDC to estimate the source of any unusual radionuclides that are observed at a station. The modeling software results were available from May 1999 to September 2000, which are the dates included in this study.

### **$^{137}\text{Cs}$ Transport**

In order for  $^{137}\text{Cs}$  to travel from Chernobyl to a European monitoring station located over 1000 kilometers away it must first be re-suspended in the air. Then atmospheric conditions must be such that the  $^{137}\text{Cs}$  is transported to the monitoring station. Some possible mechanisms for re-suspension include high winds stirring up contaminated soil (Gillette and Porch, 1978), burning of contaminated vegetation (Garger et al, 1998), or perhaps a disturbance in the sarcophagus surrounding the reactor. Atmospheric conditions consist mostly of prevailing winds blowing in the correct direction. This study did not attempt to look at processes that could re-suspend the  $^{137}\text{Cs}$ . Hence discrepancies could result where HYSPLIT indicates air transport in the correct direction but no  $^{137}\text{Cs}$  was detected. On the other hand, if  $^{137}\text{Cs}$  from the Chernobyl region was measured, then both of the above conditions must have been met.

### **HYSPLIT**

The PIDC uses HYSPLIT atmospheric modeling software to simulate particle trajectories in the atmosphere. These trajectories are then used to create FORs as follows. Simulated particles were released every hour from a  $2^\circ \times 2^\circ$  grid formed from points located at the intersection of even lines of latitude with even lines of longitude. HYSPLIT used measured atmospheric data to simulate the trajectories real particles would follow if released under the same conditions. If a particle passed near a station in the simulation, its point of origin was noted as having a particle reach the detector. The simulations were run for 24, 48, and 72 hours. After a run was complete, the number of particles that reached the detector was totaled, and the grid point tallies were normalized so that the sum of all grid point values in an FOR is one.

A few remarks are in order. First, the  $2^\circ \times 2^\circ$  grid square is somewhat coarse, resulting in coarse resolution. Second, the model was only run for 72 hours. The distance between Chernobyl and the monitoring stations is large enough that it could easily take more than 72 hours for an air mass to travel between the two. Therefore, some  $^{137}\text{Cs}$  measurements were possibly not associated with Chernobyl because the air mass took longer than 72 hours to reach the station. Also remember that the atmosphere is a complex system and no model is perfect.

### **Combining HYSPLIT and $^{137}\text{Cs}$ Concentrations with Atmospheric Transport**

Because FORs are normalized, combining them is accomplished by simply adding them together. The figures that follow were created with three different objectives in mind. Figure 1 is an average of all FORs that were



available for the Swedish station. It serves as a baseline and allows any unusual features to be seen. Figure 2 only includes FORs for days when the concentration of  $^{137}\text{Cs}$  was above  $4 \mu\text{Bq/m}^3$ , which indicates likely origins of high  $^{137}\text{Cs}$  concentrations. Figure 3 only includes FORs for days when  $^{137}\text{Cs}$  was not measured, indicating where  $^{137}\text{Cs}$  does not originate. The FORs are drawn as contour plots. Figures 4 through 6 are corresponding FORs for the Finnish station.

The figures show that when  $^{137}\text{Cs}$  was measured, air was much more likely to have come from Chernobyl. In figures 2 and 5, high likelihood regions are near the stations and Chernobyl. There are other regions where the air might have originated, but they have smaller associated probabilities. Since the stations sample air for 24 hours, it is possible for more than one air mass to pass over a station and be included in a sample. Also, air in transit for more than 72 hours is not included in the FORs. Data from both stations indicate Chernobyl as being the most likely source for  $^{137}\text{Cs}$ .

It is also interesting to note where the air originates when no  $^{137}\text{Cs}$  is detected (Figures 3 and 6). Air appears to come from similar places as the average (Figures 1 and 4) but with lower probabilities of originating near the Chernobyl region. This is what would be expected if Chernobyl were the source of  $^{137}\text{Cs}$ . Since none of the other places where air normally reaches the stations from are a source of high  $^{137}\text{Cs}$  concentrations, Chernobyl must be the source of the elevated measurements.

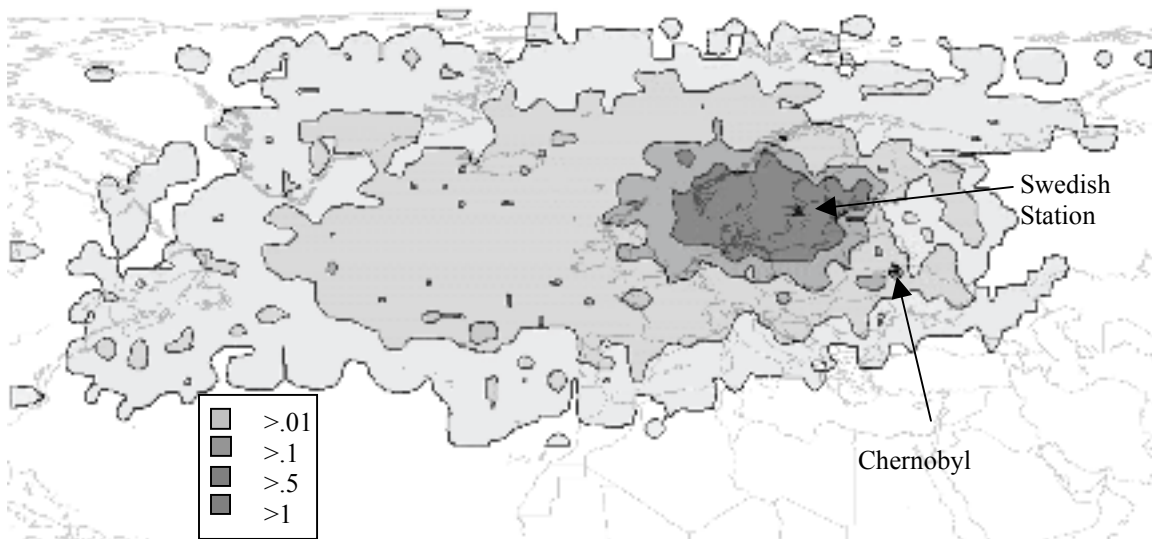
Instead of selecting FORs based on whether or not  $^{137}\text{Cs}$  was measured, they can be selected based on having a high probability of air reaching a radionuclide monitoring station from the Chernobyl area. This was done using four grid points near Chernobyl. For Sweden,  $^{137}\text{Cs}$  was seen 11 out of 13 times when one of these four points had a probability of greater than .05. For Finland the same analysis yields 6 of 9 times. The days with higher likelihood also include the highest measurements of  $^{137}\text{Cs}$  made at both stations. Table 1 contains a list of probabilities and  $^{137}\text{Cs}$  concentrations.

For several particularly high concentrations of  $^{137}\text{Cs}$ , HYSPLIT trajectory models were run. Figure 7 shows the result for one of these runs. It can clearly be seen this day (which was the highest concentration measured to date at the Swedish station) that the air mass goes almost directly from the Chernobyl region to Stockholm.

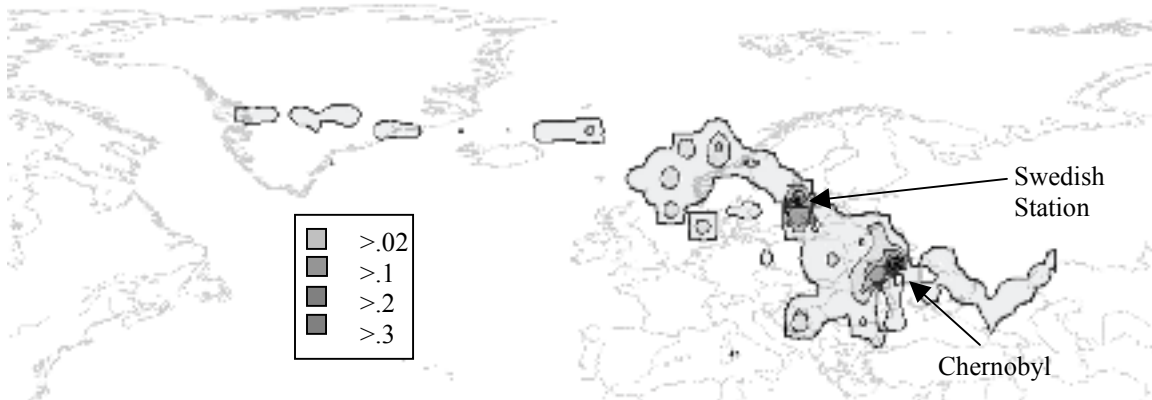
**Table 1.** Probabilities of air originating at a grid point near Chernobyl and  $^{137}\text{Cs}$  concentrations actually measured.

Sweden		Finland	
Probability	Concentration ( $\mu\text{Bq/m}^3$ )	Probability	Concentration ( $\mu\text{Bq/m}^3$ )
0.053	0.59	0.065	Not Detected
0.053	0.58	0.071	0.86
0.055	Not Detected	0.071	0.86
0.065	1.9	0.14	5.7
0.065	1.9	0.17	3.3
0.067	1.8	0.17	3.3
0.069	6.4	0.19	Not Detected
0.069	6.4	0.21	5.7
0.11	45	0.22	Not Detected
0.17	16		
0.19	Not Detected		
0.32	45		
0.39	16		

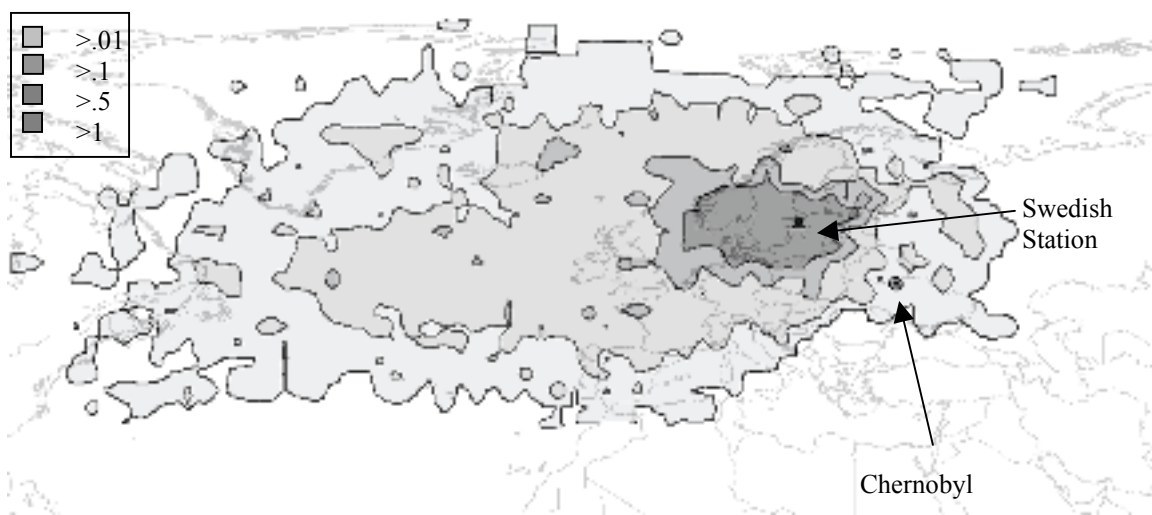




**Figure 1.** Average of all available FORs for the Swedish station.



**Figure 2.** FORs for the Swedish station when the concentration of  $^{137}\text{Cs}$  was greater than  $4 \mu\text{Bq/m}^3$ .



**Figure 3.** FORs for the Swedish station when no  $^{137}\text{Cs}$  was measured.



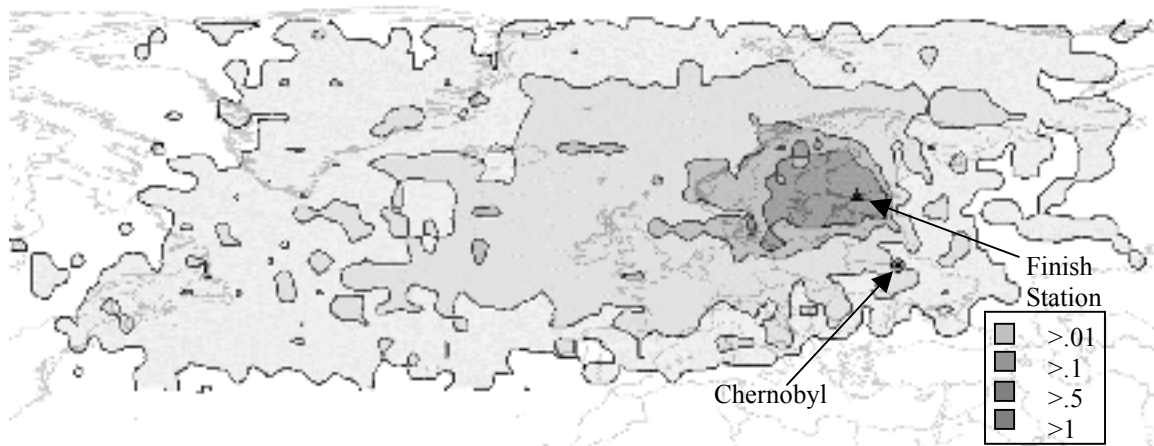


Figure 4. Average of all available FORs for the Finish station.

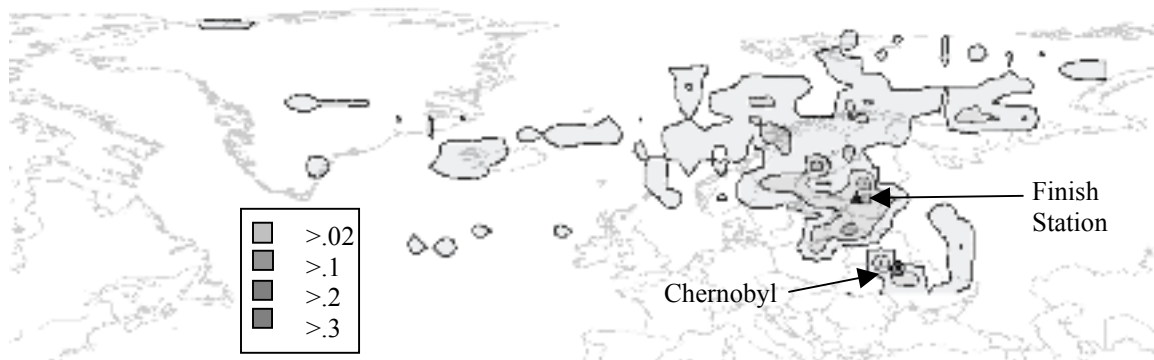
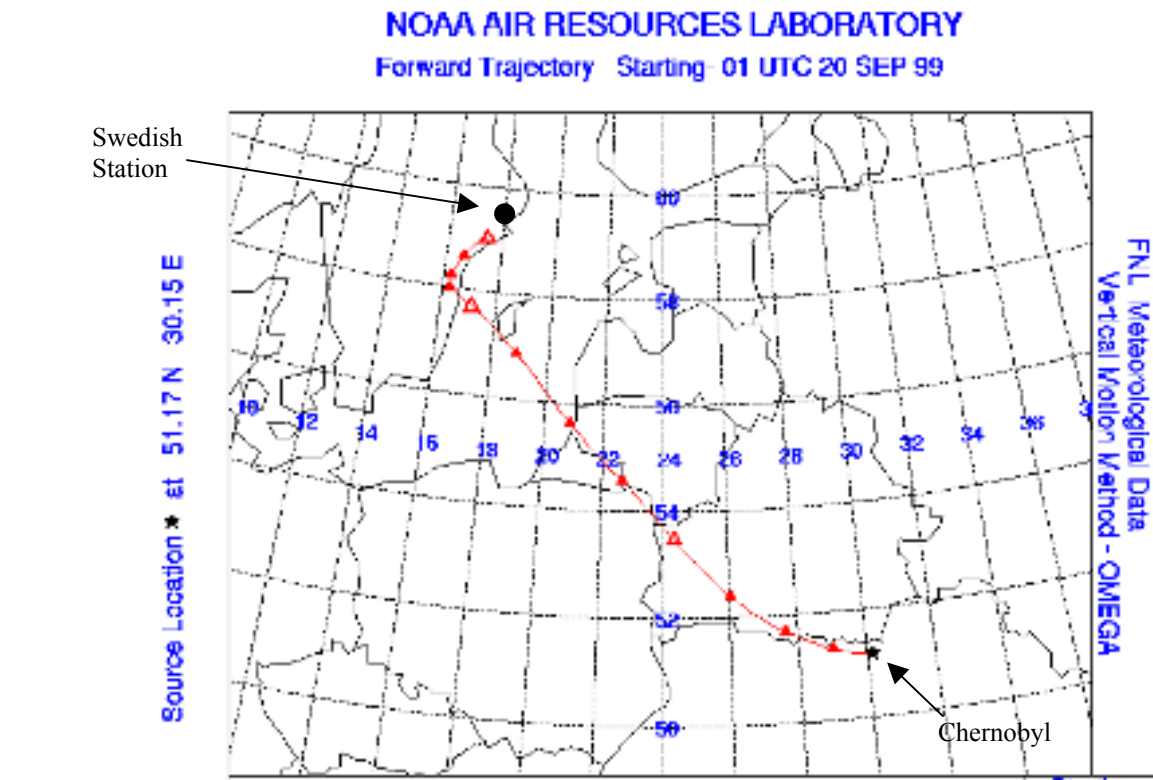


Figure 5. FORs for the Finish station when the concentration of  $^{137}\text{Cs}$  was greater than  $4 \mu\text{Bq/m}^3$ .



Figure 6. FORs for the Finish station when no  $^{137}\text{Cs}$  was measured.





**Figure 7.** Trajectory for the day the highest concentration of  $^{137}\text{Cs}$  was measured in Stockholm.

## **CONCLUSIONS AND RECOMMENDATIONS**

A link was established between  $^{137}\text{Cs}$  re-suspended in the Chernobyl region and  $^{137}\text{Cs}$  measured by two European monitoring stations in several ways. First, it was shown that when  $^{137}\text{Cs}$  was measured, it was more likely for the air that was sampled to have come from the Chernobyl region. Secondly, when no  $^{137}\text{Cs}$  was measured the sampled air was much less likely to have been in the Chernobyl region. Likewise, if air did not come from the Chernobyl region,  $^{137}\text{Cs}$  wasn't seen. It was also shown that if air did move from the Chernobyl region to a monitoring station, it was likely to contain detectable concentrations of  $^{137}\text{Cs}$ . While these results are qualitative in nature, the evidence strongly suggests that a correlation exists.

Another benefit of this study is an increased confidence in the tools used and the manner in which they are used. Data analysis using two different stations yielded equivalent results. These results agree with what common sense dictates, namely that re-suspension of  $^{137}\text{Cs}$  in the Chernobyl region is the source of  $^{137}\text{Cs}$  in Sweden and Finland. One can thus conclude that using radionuclide concentrations obtained with currently fielded systems in conjunction with HYSPLIT produces good results.

If more conclusive evidence of the link between  $^{137}\text{Cs}$  re-suspension near Chernobyl and high  $^{137}\text{Cs}$  concentrations is desired, there are a couple of investigations that could be performed. First,  $^{134}\text{Cs}$  was also released during the accident. In fact, several of the earlier samples measured by the PIDC contain both  $^{137}\text{Cs}$  and  $^{134}\text{Cs}$ . Due to its 2-year half life, almost all of the  $^{134}\text{Cs}$  will have decayed. But it might be possible, using a detection methodology with reduced minimum detectable concentrations, to measure the ratio of  $^{137}\text{Cs}$  to  $^{134}\text{Cs}$  in both soil in the Chernobyl region and in the samples from the monitoring stations. If the ratios match, this would be strong evidence for one causing the other. Also, determining conditions good for the re-suspension of  $^{137}\text{Cs}$  into the atmosphere could help to improve the data used in this study.



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