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In coastal areas, the simplifying assumptions of horizontal homogeneity used in open ocean analysis are not always useable. Various human-generated aerosol sources such as towns and industrial centers can provide a complex portrait of merging plumes of non-natural aerosols which are advected out to the littoral zones. The extensive meteorological and aerosol measurements made during the Marine Aerosol Properties and Thermal Imager Performance (MAPTIP) experiment provided an ideal opportunity to view how these aerosol were advected from their sources to the littoral zone of the North Sea. MAPTIP was conducted along the Dutch coast in October/November 1993. The NCCOSC, RDT&E DIV (NRaD) instrumented Navajo aircraft flew two star pattern flights a day during the experiment at altitudes below 500 feet. During these flights, aerosol size distribution measurements along the flight path were being continuously recorded. These measurements were utilized for making aerosol concentration maps of the various sized aerosol groups. This paper shows the mesoscale effects of aerosol advection making the marine boundary layer in a littoral zone much more complicated than that of an open ocean.

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Aerosol characteristics in a coastal region (results from MAPTIP)

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ABSTRACT

In coastal areas, the simplifying assumptions of horizontal homogeneity used in open ocean analysis are not always useable. Various human-generated aerosol sources such as towns and industrial centers can provide a complex portrait of merging plumes of non-natural aerosols which are advected out to the littoral zones. The extensive meteorological and aerosol measurements made during the Marine Aerosol Properties and Thermal Imager Performance (MAPTIP) experiment[1] provided an ideal opportunity to view how these aerosol were advected from their sources to the littoral zone of the North Sea. MAPTIP was conducted along the Dutch coast in October/November 1993. The NCCOSC, RDT&E DIV (NRaD) instrumented Navajo aircraft flew two star pattern flights a day during the experiment at altitudes below 500 feet. During these flights, aerosol size distribution measurements along the flight path were being continuously recorded. These measurements were utilized for making aerosol concentration maps of the various sized aerosol groups. This paper shows the mesoscale effects of aerosol advection making the marine boundary layer in a littoral zone much more complicated than that of an open ocean.

Keywords: aerosol, marine, coastal, MAPTIP, electro-optic propagation

1. INTRODUCTION

The Navy Aerosol Model, (NAM)[2] and the Navy Oceanic Vertical Aerosol Model, (NOVAM)[3,4] (which uses NAM as its kernel) have not been shown to represent the coastal areas as accurately as marine or open ocean applications. This is because the data on which NAM was based came largely from the open ocean area.

It is known that in a coastal area where aerosol from industrial sources are advected out to a specific location, these aerosol may well overwhelm the numbers of the oceanic aerosol which are represented in the models. For this reason a coastal aerosol model needs to be developed. MAPTIP produced a good data base for this analysis since the operational period was divided into two distinct parts: an open ocean type of air mass and a continental air mass situation in which the air had been advected from over Europe.

2. COASTAL AND MARINE AEROSOL

The MAPTIP experiment offered an excellent set of measurements in which to investigate the differences between the coastal and the open ocean aerosol regimes. Gathman[5] has shown that during the experiment times of 18 October and 3 November 1993, both types of aerosol situations were experienced at the Meetpost Noordwijk (MPN), and occurred during different sub-periods of the experiment times.

The NAM/NOVAM set of models were developed for open ocean environments from open ocean data. Extension of these models to coastal regimes with very high air mass parameters has shown from time to time to cause excessive error in the models extinction predictions.[6] The NAM model is a three/four component log normal representation of the aerosol size distribution. It represents the dN/dr of the aerosol distribution by the expression in equation 1.

$$\frac{dN}{dr} = \sum_{i=0}^{3} k_i \cdot \frac{A_i}{f_i} \cdot \exp\left\{-1 \cdot \left[\log\left(\frac{r}{(r_{0i} \cdot f_i)}\right)\right]^2\right\} \tag{1}$$

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where the "f_i" parameters are the Gerber[7] growth factors which are functions of the ambient relative humidity, and the "k" parameters are normally unity but can be used for calibration and correction purposes. The mode radii parameters r_{oi} are: .03, 0.24 and 2.0 μm. Amplitudes A_i are determined by various meteorological parameters. Of particular interest is the parameterization of the A_0 and A_1 terms which are related to the air mass parameter. The original models were developed for the open ocean regime where the air mass parameters were of the order of 2 to 3. Provision was made for the model to represent the aerosol in a more continental air mass by allowing the air mass parameter to increase to larger values. This process works fairly well where the air mass is not totally "continental" in nature. In a truly continental region, the model is very sensitive to the air mass parameter as is shown in table I.

Table I: Sensitivity of NAM extinction predictions to 10% errors in the airmass parameter (a.m.p) for two wind speeds and two wave lengths.

	% error: 0.55 ext.		% error: 10.6 ext.	
a.m.p.	ws=5	ws=10	ws=5	ws=10
2	7	3	1	0
8	17	12	6	3
16	19	18	13	9
32	33	20	20	17

Here several cases were calculated using NAM in which a 10 percent error in the determination of the air mass parameter was assumed. The table shows the percentage error in the visible and far infrared (IR) aerosol extinctions from a 10% uncertainty in the air mass parameter. In the open ocean conditions, when the a.m.p. term is small, the IR determination of aerosol extinction is not really affected by the errors in the a.m.p. Even errors in the visible wavelengths are of the same order of magnitude as the errors in the a.m.p. for low wind regimes. However, when we approach the situations which occur near the coast areas, the aerosol extinction errors increase considerably for the assumed 10% error in the determination of the a.m.p. It is for this and other reasons a coastal aerosol model needs to be developed which will specifically address the description of coastal aerosols.

Determination of the coastal and open ocean regimes during MAPTIP was determined following the technique of Gathman.[5] The extinction data shown in figures 1 and 2 were obtained using the measured aerosol size distribution from a Particle Measurement Systems (PMS) ASSP-100 device located on the MPN. The histogram for the visible wavelength extinction showed two distinct modes with the means separated by an order of magnitude (figure 1).

A time series of this set of data (figure 2) shows clearly how the extinction values at 0.55 μm transition rapidly from the low "open ocean" values during the first part of MAPTIP to an order of magnitude higher during the second period, when air was continental in origin.

It is informative to see if other measurements of visual extinction show the same sort of two mode behavior. The data shown in figures 3 and 4 were obtained from the Canadian participants in MAPTIP[1], the Defense Research Establishment Valcartier (DREV). They operated an HSS Model VF-500-110 Visibility Sensor located near the NRaD ASSP aerosol spectrometer during the experiment. The data in these two figures are expressed in terms of extinction for easy comparison with the extinction calculation obtained from the aerosol measurements. Figure 3 is a histogram of the extinction data showing the same two modes as does the NRaD data. Although the figure here shows relatively more data in the "open" ocean regime than in the "coastal" regime, this can be explained by the amount of times the two different instruments were in operation. The ASSP device was used sparingly during the first half of MAPTIP because of a need to time-share power with other investigators. During the last half of the MAPTIP, however, the instrument was allowed to operate in a more or less continuous mode. The means of the two groups are very close, however.

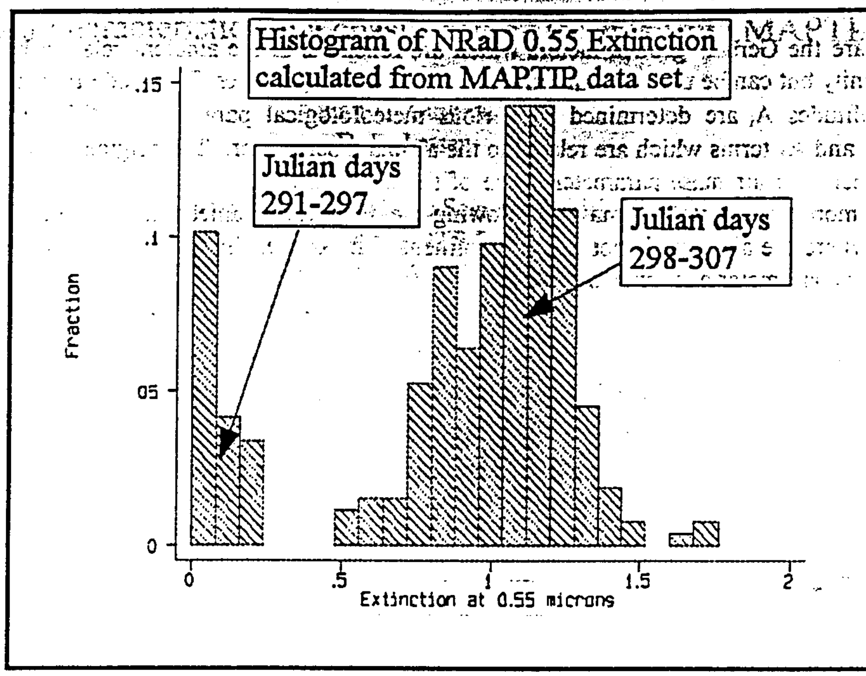

Figure 1: Reproduction of the histogram plot obtained by Gathman[5] from the 0.55 micron extinction calculations made from the ASSP data on the MPN tower by NRaD. This plot shows two distinct groups of aerosols which differ by at least an order of magnitude from each other.

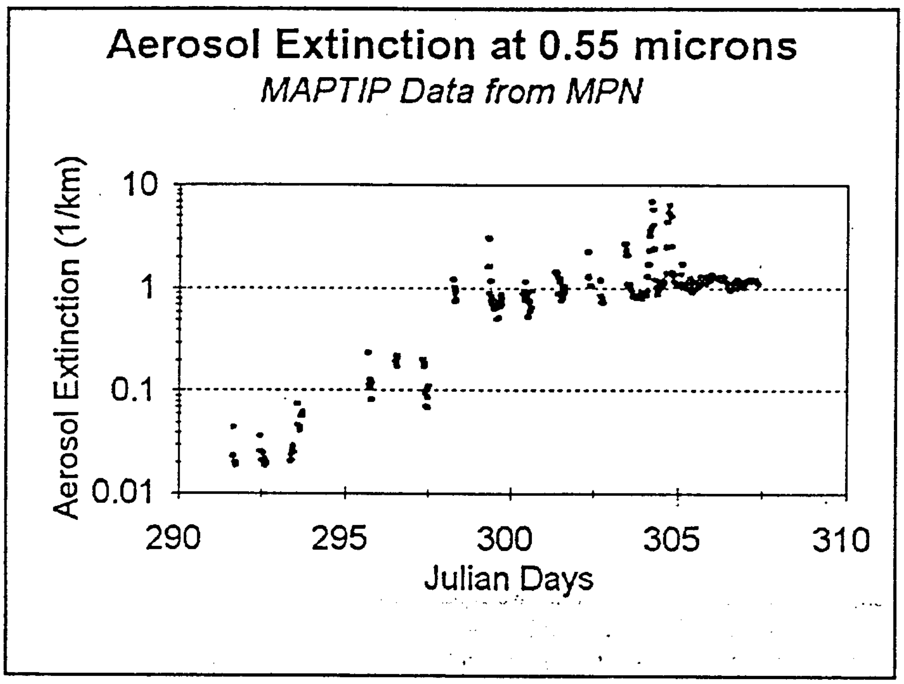

Figure 2: Time series of the calculated 0.55 micron extinction made from the 1/2 hour averages of the aerosol size distribution made by the PMS ASSP aerosol spectrometer on the MPN tower during MAPTIP 1993.

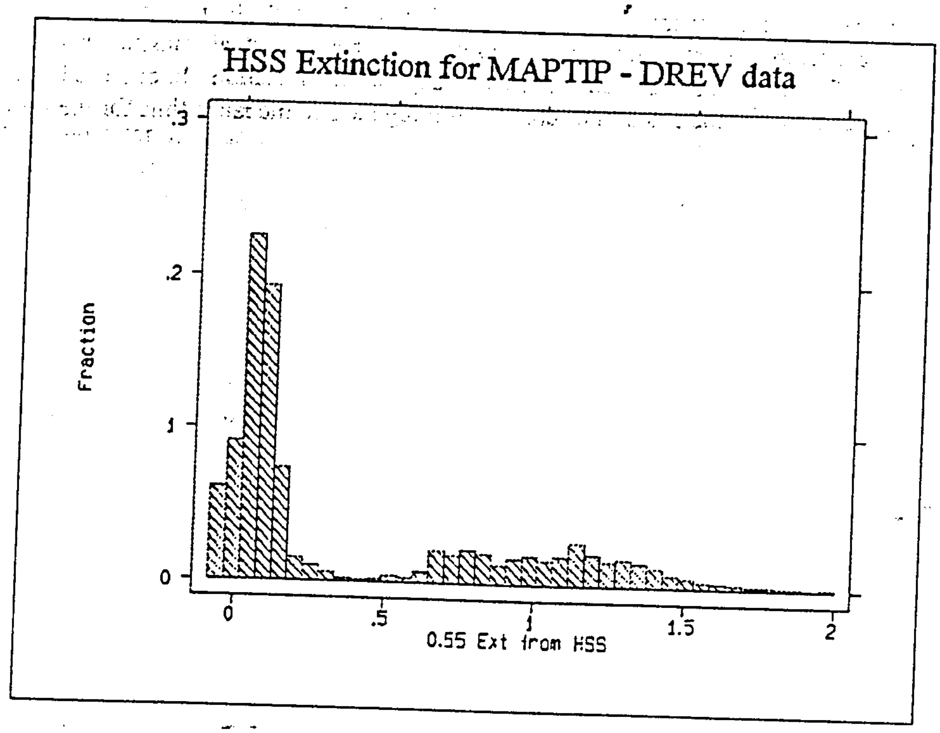

Figure 3: There are two distinct groups in the HSS data as well as in the ASSP extinction data.

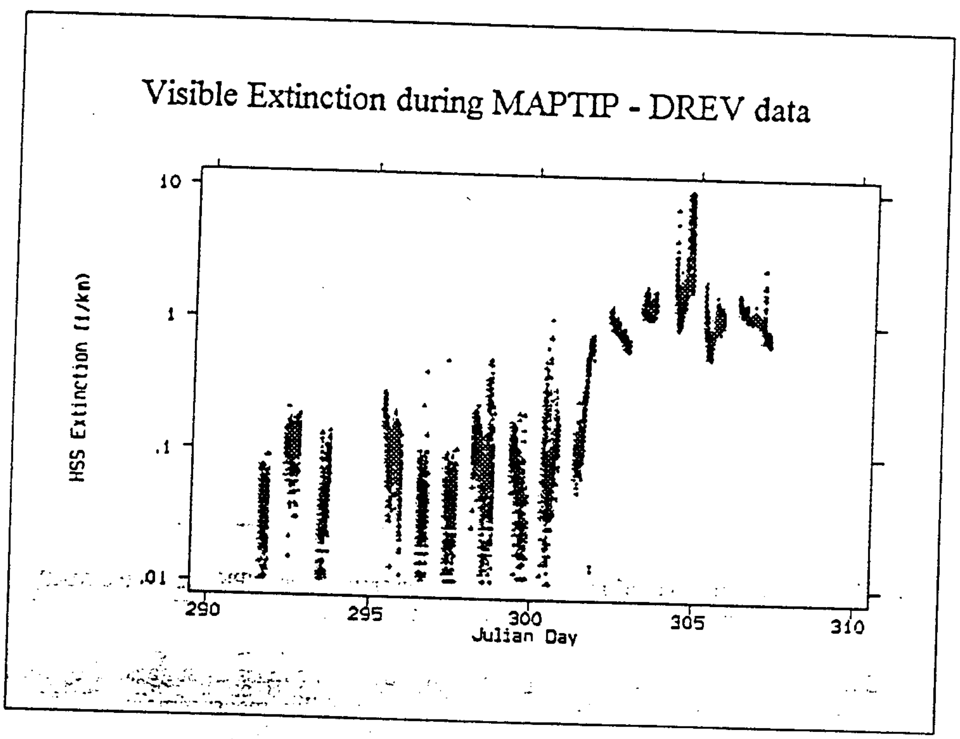

Figure 4: A time series plot of the 0.55 micron extinction as measured by DREV's HSS visiometer during MAPTIP 1993.

Figure 4 shows a time series of the Canadian HSS data taken during MAPTIP. It show the same general shape as did the NRaD data except there is a discrepancy between the two data sets as to when the actual transition between "open" ocean to "coastal" regime took place. There is a time difference of about 1 day for this transition. In order to be on the safe side, we will we will define the earliest time for the end of the "open" ocean regime and the latest time for the start of the "continental" regime.

3. OTHER INDICATORS OF AIR MASS

3.1 Radon

One of the measurable parameters used in the calculation of the a.m.p. in NAM is the radon concentration. The technique of using radon as a tracer of how long an air mass was over water was originally suggested by Larson and Bressan[8]. The reasoning is that radon 222 is only produced over land areas and has a half life of several days. Thus if the air is relatively free from this trace gas, then we know that the air mass has been at sea for several days. It can then be assumed that the various processes in operation to "clean" the air from its original "continental" aerosol state to a more pure "marine" state would be related to the radon concentration. This technique has been hampered by a lack of off - the - shelf reliable measurement systems. (The sensitivity of these devices is about 3 orders of magnitude higher than that needed for routine radon measurements in homes.) Littfin[9] has assembled a reliable automatic radon monitoring device for this purpose. This device was mounted on MPN and produced data throughout the MAPTIP experiment. Shown in figure 5 is a time series of the radon concentration. Here we see that the radon counts change over time from a low during Julian day 301 to a rather rapidly increasing high toward the end of the experiment.

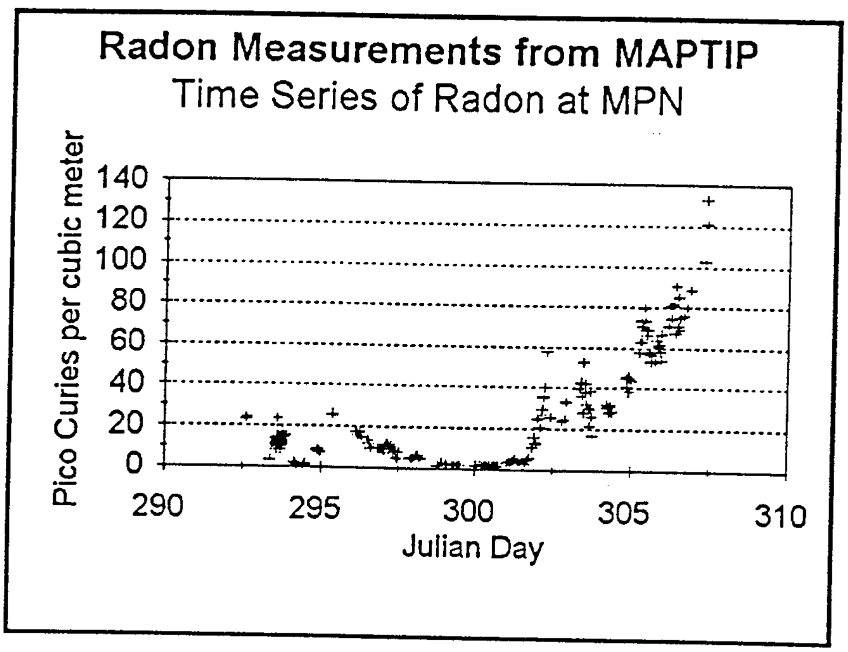

Figure 5: A time series plot of measured Radon concentration at MPN during the MAPTIP experiment. Radon gas is used as a tracer of continental air in NAM and NOVAM.

The radon measurements during MAPTIP thus show the two regimes of the air mass as suggested by the aerosol and visibility measurements. The transition time between the regimes agrees with the visibility measurements.

3.2 Wind Direction

The wind direction at the tower is an indicator of where the air mass is coming from. Wind direction in and of itself, however, is not a good indicator because of the non-linear nature of the wind direction. For short term indicators it is helpful in determining that the air mass is coming from a certain sector, but slight curvature to the streamlines of wind cause larger uncertainties as distances increase. Wind direction is thus only a short term indicator of the history of the air mass.

MPN is only 9 km off the Dutch coast. When the wind is from the east, European aerosol should be evident. When the wind is from the general north northeast directions, it should be more representative of an open sea situation. This is evident in the data shown in figure 6.

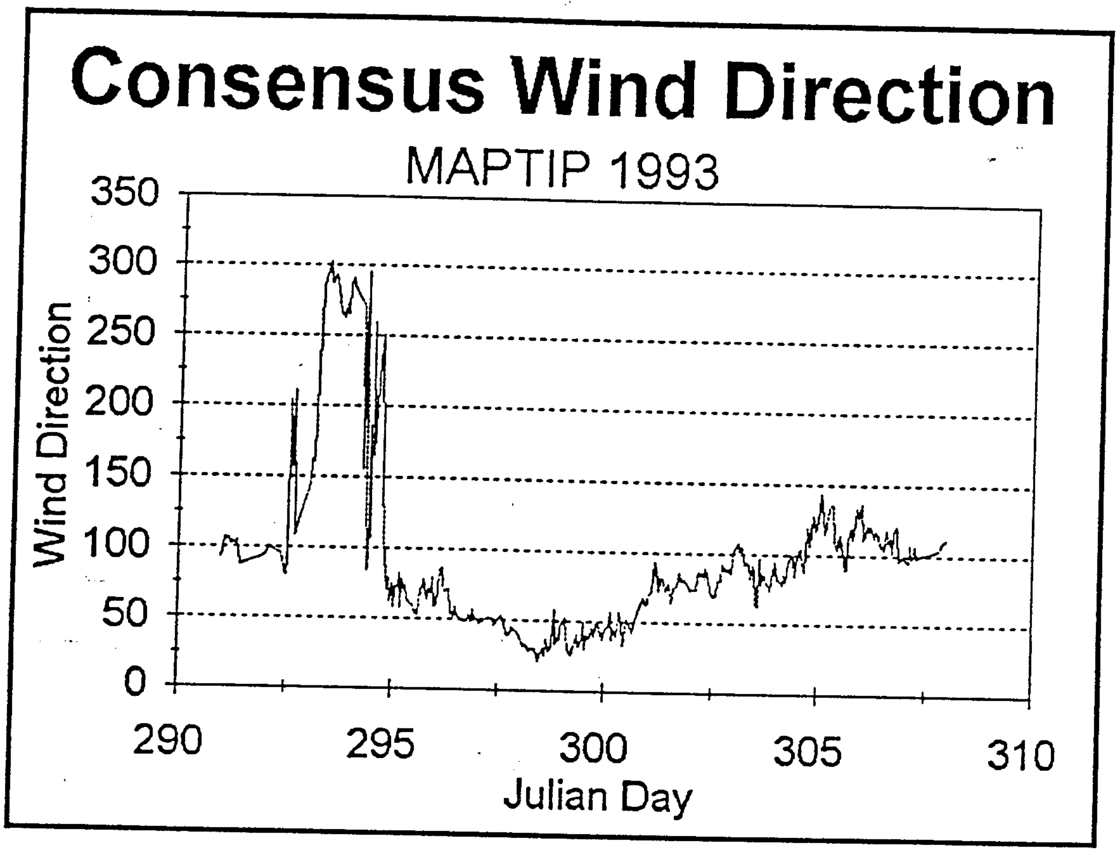

Figure 6: A time series plot of the consensus wind direction measurements made during the MAPTIP experiment. Note the "pulse" on day 293 and 294 showing directions from 250 to 300 degrees, which is really from the northwest.

3.3 Air Mass Trajectories

Air mass trajectories are very important in understanding the history of the air mass and its changes as it traverses the earth. The Meteorological Office at de Bilt, the Netherlands, produced a series of air trajectories during the MAPTIP experiment. Shown in figure 7 are the trajectories at the lowest altitudes for the experiment.

The square at the hub of the spokes is the MAPTIP operational area of interest. The plot shows again the twofold nature of the air masses during MAPTIP, i.e., air coming from the North Sea at the beginning of the measurements and from the central continent of Europe toward the end of the experiment.

Some of the changes in the radon concentration can be related to how long the air mass has been over land. For instance, on Julian day 300, it is indicated that the air has come almost directly from the east. Even though directly east from MPN is industrial Europe, the air spent time over the Baltic Sea and did not pick up additional radon gas. This is confirmed in the time series of radon gas measurements on MPN. Contrast this to the air on Julian Days 302 and 307 where the air was from over central Europe. The radon concentration for this case is very high. This is of course also confirmed by radon 222 measurements (figure 5). This shows the shortcoming of the assumptions made in relating the "continental" aspects of the air mass with its radon content.

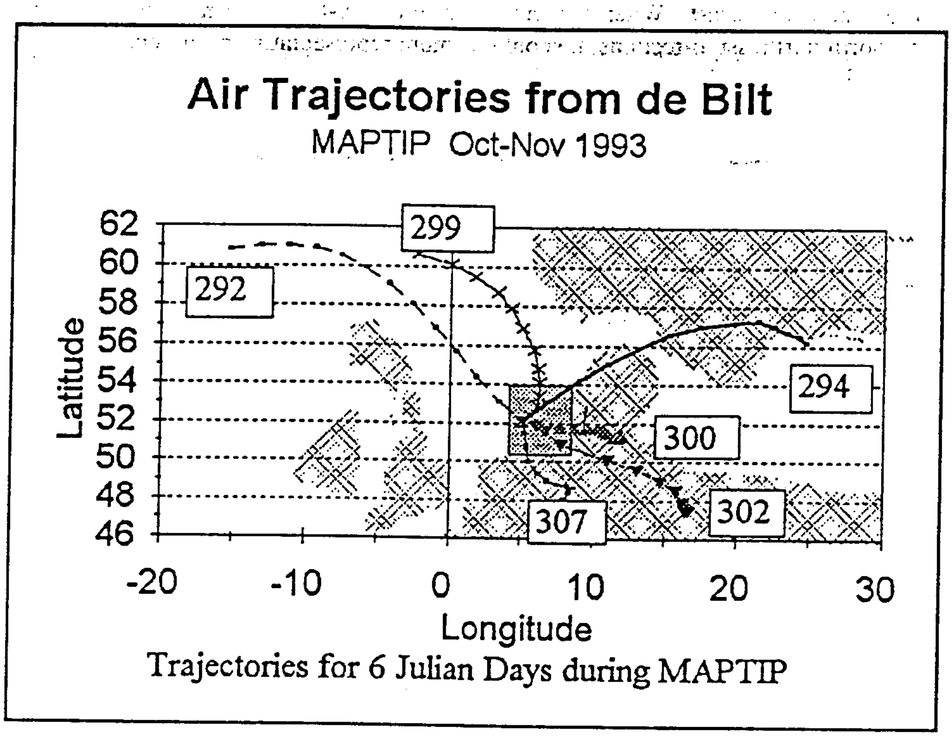

Figure 7: A plot of six air trajectories as calculated by the Met Office at de Bilt for the period of MAPTIP superimposed on a sketch of the land masses in the area.

4. DISCUSSION

The various indicators as to the origin of the air mass during MAPTIP, as determined by the various methods available to the MAPTIP experiment, all agree as to an "open" sea and a "continental " type of air mass being advected into the area by meso scale mechanisms. The techniques discussed above all determine to some degree the type of aerosol at a point. This type of information is essential for determining the air mass type at a point. It is interesting to note the comparison of the radon measurements at MPN to the airmass trajectories. The highest radon concentrations come from the air that had been over the central parts of the continent for a long period of time and the lowest where the air came toward the tower directly over the North Sea.

In summary, the plot shows again the twofold nature of the air masses coming to the MAPTIP area. Air came from the North Sea at the beginning of the measurements and from the central continent of Europe toward the end of the experiment.

5. AEROSOL MAPS

In the coastal areas, many sources of aerosol exist. During times when offshore winds are blowing, one would expect that the aerosol content just off shore would not be particularly well mixed in the horizontal directions and various structures would no doubt exist. For instance, there might be plumes of aerosol from several different factories, which, as they are advected offshore would be distinct from each other for several kilometers before they blended together into a single continental air mass. This complex structure can best be viewed by mapping the coastal aerosol. Several techniques might potentially be used for this purpose. For instance, there were aerosol measurements made aboard H.M.S. Tydeman as it traversed the area throughout the experiment. The speed of the ship, however, limits its usefulness as the structure of the atmosphere can change rapidly with time. Continuous measurements of aerosol were made on the MPN tower and at the shore station as well as on the ship, but this is, at best, only three points on which to base the map. The NRaD aircraft, however, does offer an opportunity to produce such a map because of its speed and the flight path used during MAPTIP.

5.1 Aircraft Measurements during MAPTIP

The NRaD aircraft was used for multiple applications, from being an IR target to providing profiles of aerosol and sea surface temperature measurements throughout the experimental region. There were two different flight patterns used during the experiment. One was a vertical spiral made over the MPN tower to make a sounding of the aerosol and the meteorological parameters at the site. The other mode of operation was to fly in a starlike pattern at a relatively low altitude (below 500 feet) (figure 8).

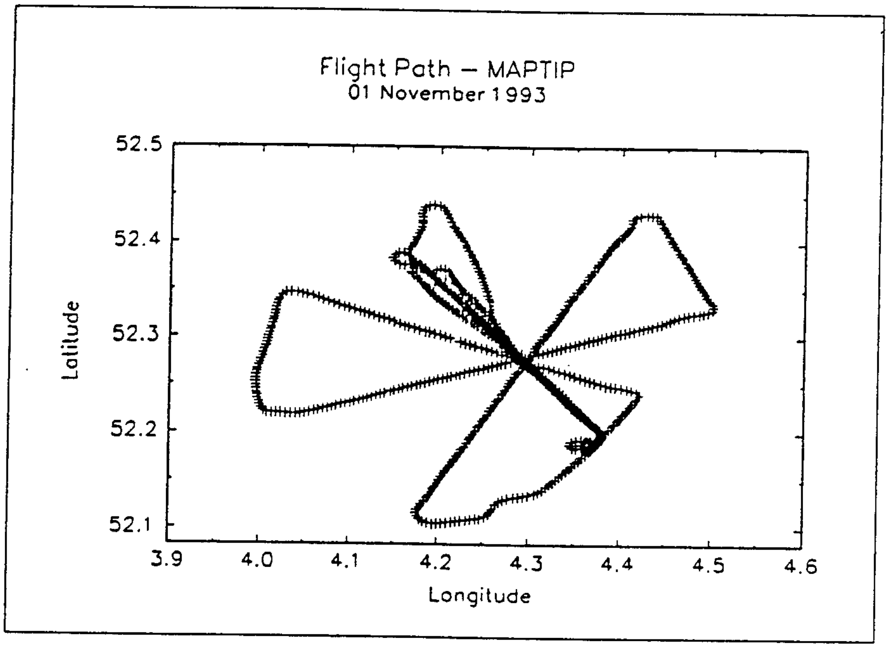

Figure 8: The flight path of the NRaD aircraft during the constant altitude phase of the 01 November 1993 MAPTIP experiment. The total flight takes about two hours, so parts of the structure that might change in this time scale would be lost in this technique. The hub of the wheel shape is the MPN tower at 52.2739 degrees North and 4.2961 degrees East.

The position of the aircraft was accurately recorded by a GPS satellite system from Trimble Navigation (model TNL-2000 GPS). It also contained an FSSP_100 (0.5-47μm) and an OAP_200 (30-300 μm) aerosol spectrometer both from Particle Measurement Systems Inc.. These instruments allow us to make some inference as to the aerosol structure in the MAPTIP area of interest.

The speed of the aircraft has both a good and a bad aspect for getting an accurate aerosol map of the area. First of all, the speed is absolutely necessary if the sampling area is to be of reasonable size. A slow moving sensor would take many hours to cover the same area as the aircraft, and the structure of the aerosol may well change during this period of time. However, it is difficult to make statistically significant samples of the larger aerosol when the sample time is on the order of 1 second. Of course, longer sample times would no longer be a point sample. Some sort of compromise must be made in using the aircraft measurements to map the aerosol structure. In this paper we chose to look at the aerosol concentration in the smallest size bin of the PMS system (mean size of 0.375 microns diameter and a width of 0.25 microns). This size range usually has counts of 100 or more every second so that we feel that the counts used in our mapping procedure will be statistically significant. It does not however address the more interesting geographical structure of the larger aerosol, which will affect IR transmission the most. However, these small particles will provide a map by which we can see something of the structure of the aerosol during the various phases of MAPTIP.

5.2 Aerosol Maps

In the process of carrying out the MAPTIP experiment, the NRaD aircraft made a number of "star" pattern flights each day. These flights were carried out at a relatively low altitude and were interspersed with vertical spirals. These low constant altitude flights obtained a considerable amount of information on the concentration of aerosol in a widely diverse spatial array.

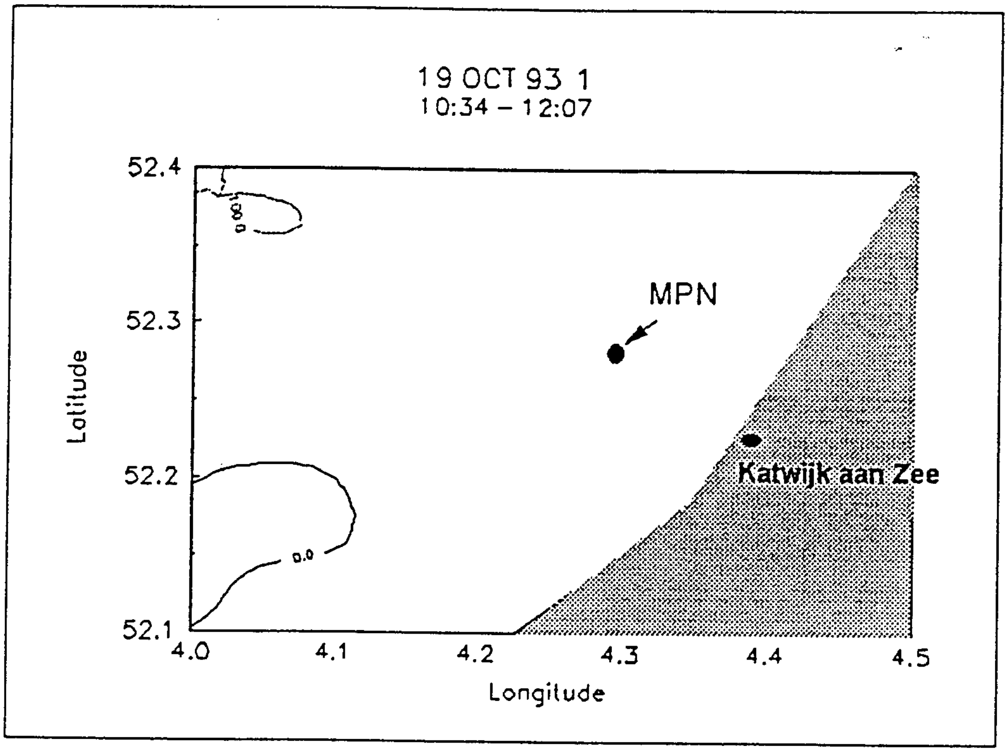

Figure 9: An aerosol concentration map made during 19 Oct. in which measurements at the MPN tower indicated an essentially "open" ocean aerosol environment. The pockets of aerosol seen here may or may not be from ships traversing the region but it is felt that they could indeed be from noise sources either in the data itself or from the interpolation needed in the contouring of irregular data.

The profile data was processed using only the constant altitude data. Latitude, longitude and aerosol concentration from range 1 were used as an input to an irregular data contour plotting package called *Axum*, from TriMetrix, Inc. The flight pattern was not ideal for use in a contour plot but by increasing the grid sizes for the irregular data, a reasonable plot could be obtained. Figure 9 shows a typical "open" ocean situation in which our point measurements at MPN indicated a non coastal aerosol regime. We see that there are few aerosol and there is no indication of plumes leaving the shore. On the other hand, the data shown in figure 10 is for the period where our platform measurement indicated that we were indeed in a coastal aerosol regime. This plot shows the evidence of aerosol plumes leaving the coast and overtaking the tower.

6. CONCLUSIONS

The maps shown in figures 9 and 10 indicate that there is considerable structure in the concentration of the smallest measured sizes of coastal aerosol during MAPTIP. Differences in the plumes from various land based sources can well cause differences in identical measurements made at the same time but in physically separated places. The maps show that trying to model the coastal aerosol will be a difficult job if detailed structures are to be included.

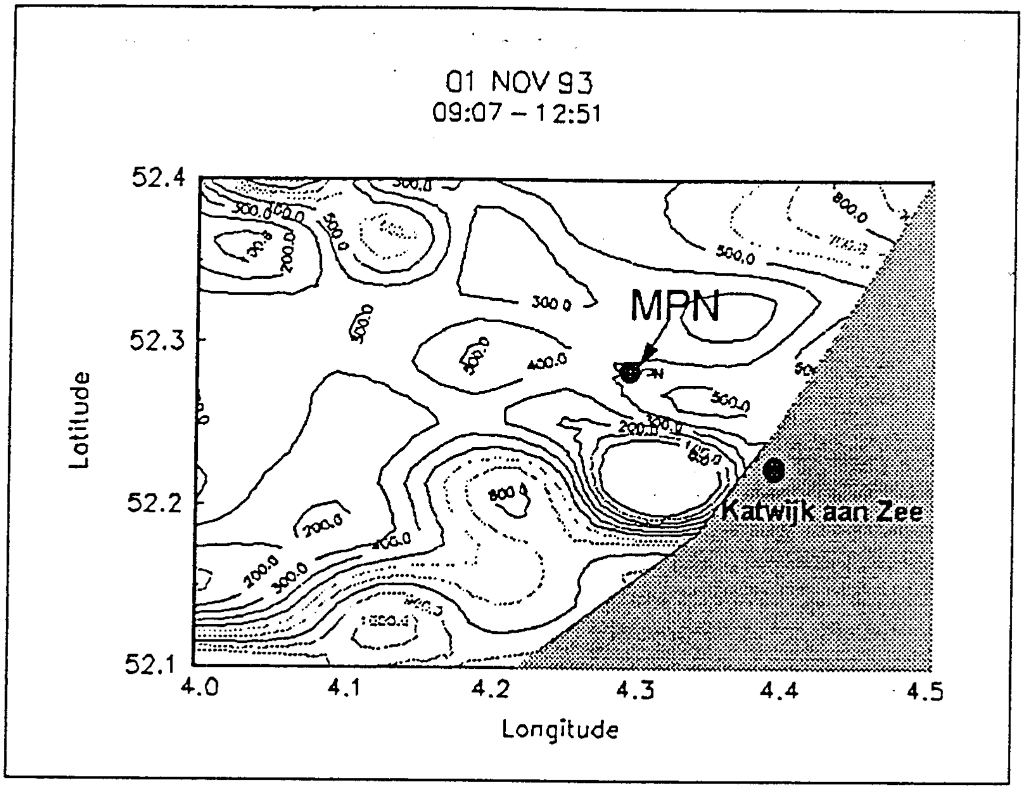

Figure 10: This is a map of the MAPTIP area during the period when the measurements at MPN indicated that there were indeed coastal aerosols in the region.

Although the flight path shown in figure 8 was not designed for contouring purposes, an adequate map could be produced which shows the main structures in the experiment area. However, by carefully adjusting the flight path to improve the contouring effort, more detailed structures could be obtained.

The complex nature of the coastal aerosol and its non-uniform horizontal distributions show why a simple model such as NAM, designed for the "open" ocean environment where horizontal homogeneity is the norm, can not be adequately applied to coastal aerosol. Because of the importance of these waters to the modern Navy, an extensive effort should be expended to provide a meso scale coastal aerosol model which can adequately take into account the complex structures of a coastal environment.

7. ACKNOWLEDGMENTS

We wish to thank the MAPTIP scientific committee and especially our Dutch colleagues for their provisions in making this experiment possible. We wish to thank ONR code 322 for the support of this project.

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