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Ocean Aerosol Measurements and Models in the Straits of Florida (The KEY-90 Experiment)

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ABSTRACT

The Navy Oceanic Vertical Aerosol Model (NOVAM) has been under development for some time. The model showed considerable promise in its first verification test during the First [International Satellite Cloud Climatology Project] (ISCCP) Regional Experiment (FIRE) in the eastern Pacific. Because much of the development work on NOVAM was done in this oceanic region, the model needed to be tested in very different environments to see just how universally it could be applied to other regions. KEY-90 was an experiment carried out in the tropical waters between the Florida Keys and Cuba in July 1990 to test the model. It included investigators from the U.S., U.K., and the Netherlands. The experiment included two lidars, two aircraft, a small boat, buoys, and several shore installations. The experiment provided an excellent data base not only to test the model for the tropical water scenario, but also to further investigate the convective marine boundary layer and to enhance further modeling schemes in this region. This paper describes the optical, IR, and meteorological measurements made during KEY-90 and shows the comparison between the NOVAM model predictions and measurement.

2. INTRODUCTION

The performance assessment of electro-optical (EO) device applications that involve vertical and slant paths through the marine atmosphere require a knowledge of the vertical variation of the optical properties of this atmosphere. It is usually assumed that the atmosphere is horizontally homogeneous, at least in the area of interest. This assumption may or may not be true depending on the weather situation. Electro-magnetic scattering and absorption by aerosol at wavelengths extending from the visible to the far infrared are two of the important properties needed for this assessment. Existing empirically derived expressions for the contributions of the aerosol to the EO propagation characteristics in the marine atmosphere were formulated for single levels. An example is the Navy Aerosol Model (NAM)[1,2] as found in LOWTRAN 6[3] and LOWTRAN 7[4]. To extend the extinction prediction to higher levels, a physical model is required to calculate the vertical distribution of the aerosol.

The NOVAM is being developed for this purpose[5,6,7,8,9]. NOVAM uses meteorological profile information to account for the physical processes that influence the vertical aerosol structure and are thought to be responsible for the observed variety of profiles. NOVAM has been designed to describe the non-uniform but also non-logarithmic aerosol distributions that are often observed throughout the marine atmospheric boundary layer (MABL). NOVAM is a mixture of empirical and dynamical models. NOVAM itself uses the NAM as a kernel and reverts to that model at the lowest levels of the marine boundary layer. NAM describes mathematically the aerosol size distribution at 10 meters above the sea surface. The specific distribution depends on input data of wind speed (both current wind speed and the 24-hour average), visibility and relative humidity. The model assumes that the atmospheric aerosol is composed of large sea-salt aerosol particles introduced into the marine atmosphere from the white water phenomenon at the air-sea interface and from smaller aerosol originating from other sources such as gas to particle conversion or man-made sources.

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3. DESCRIPTION OF NOVAM

The concentration of aerosols at any particular size interval will be dependent on the source strengths of the aerosol production and on the mixing process as it relates to scalar contaminants. On the other hand, the size of the hygroscopic sea salt aerosol will also be dependent on the relative humidity of the air parcel in which it finds itself immersed. As an hygroscopic aerosol picks up water vapor from the atmosphere and as it grows in size, it changes its chemical composition and therefore its index of refraction. In NOVAM, the NAM generated surface layer particle size distribution is mixed throughout the MABL by turbulent-controlled processes and is further modified by relative humidity effects. The physics describing these processes is determined by the MABL vertical structure. Various models describing the atmospheric vertical structure are included in NOVAM, such as a simple mixed-layer model[10], a shallow convection case[11], and a free convection model represented by exponential functions. The selection of the model is based on the input parameters describing the vertical stratification (thermal stability, the presence of an inversion, and the inversion height), cloud cover, cloud type, wind speed, and the requested wavelength for the extinction calculation.

The aerosol size distribution, dN/dr, is represented in NOVAM by a sum of log-normal functions as shown in equation 1. A similar equation is needed for each level of interest. Optical quantities are calculated from this size distribution using Mie theory since we assume that all of these aerosols are spherical in shape. In addition, the chemical composition of the aerosol must be known so that the index of refraction at any relative humidity can be estimated using the method of Hänel[12].

$$\frac{dN(z)}{dr}=\sum_{i=0}^{3}\frac{A_i(z)}{f_i(z)}\exp\{-C[\ln(r)-\ln(f_i(z)r_{io})]^2\} \qquad (1)$$

where
- z is the altitude in question.
- r_{io} is the mode radius of the i^{th} log-normal.
- i represents four classes of aerosol.
- C is a constant used for all classes of aerosol.
- $f_i(z)$ is the growth factor for each class.
- $A_i(z)$ is the log-normal amplitude of each class of aerosol.

The meteorology is introduced into NOVAM by determining the vertical distribution of $A_i(z)$ and $f_i(z)$. The amplitude function, A_i, is tied to NAM predictions at z=10 meters and the f_i growth terms are functions of chemical composition and relative humidity.

The size distribution of the aerosol in equation 1 requires a certain amount of input data for its calculation. NOVAM will use default input values if they are not available. In order to have the most accurate output, a complete set of quality input data is needed. The better the quantity and quality of these input data, the better the accuracy of the model's prediction.

The input files need to contain information on both the state of meteorological variability near the sea surface and of the MABL vertical structure. The latter information can be obtained from a radiosonde observation or an instrumented aircraft making ascents or descents. A default relative humidity profile, based on the surface observations, is generated[13] by NOVAM if the information on the vertical structure is not available. A prediction of extinction and absorption of optical energy due only to aerosol and available as a function of altitude for a wide number of wavelengths is the major NOVAM product.

4. MODEL EVALUATION

It is important to see how well a model will provide the needs for which it was developed. NAM[1] is based on data collected over the world's oceans. It has been evaluated by several users and has been updated from new experimental evidence[14,15]. The development of NOVAM, however, was based on a more limited set of data collected over the Pacific near the California coast. One method of testing NOVAM is to provide a simultaneous set of measurements of both the input and output of the model. From the input data, NOVAM will calculate its products and these can be compared with the independently measured set of data. In a perfect world the measurements and the predictions of the model would be identical. However, this does not usually happen. In fact, it is difficult to provide an accurate estimate of the measured extinction profile by which to compare the model performance. During the FIRE, the NOVAM was tested with data from a tethered balloon stationed at a series of altitudes above the sea surface which allowed good averages of extinction at each level to be obtained. A summary of the whole period of tests is shown in figure 1, in which a subjective grading system was devised in order to give an overall value to the model. The grade key indicates how close the model prediction came to an envelope of data describing all of the measurements[9].

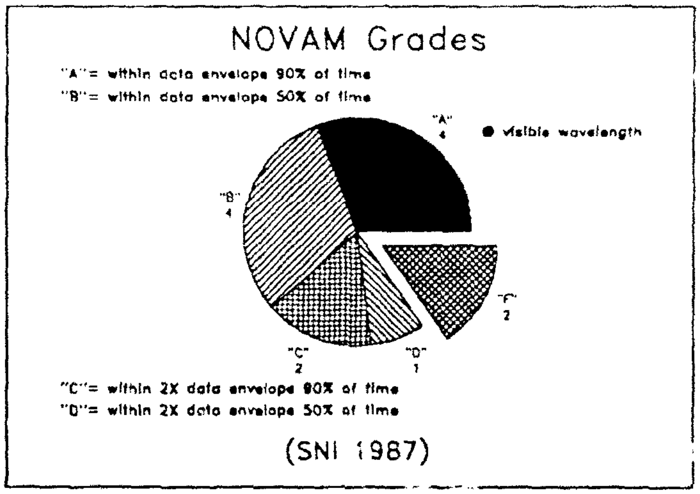

Figure 1: NOVAM evaluation at visible wavelength from the FIRE with a total sample of 13 experiment days.

The FIRE was done in the same Pacific coast area, where most of the model development data took place. Therefore, the initial NOVAM evaluation from the FIRE data was basically a limited test for the performance of NOVAM. Further evaluation is required in different geographical areas with different meteorological and oceanic conditions. Although several data sets are available which might be used for evaluation purposes, they were not designed for this purpose and often one or more input parameters are missing. Therefore the KEY-90 experiment was organized as the next step in the NOVAM validation process, in a tropical/trade wind situation, where the meteorology is strongly different from those in the atmosphere over the Pacific near San Nicolas Island (SNI).

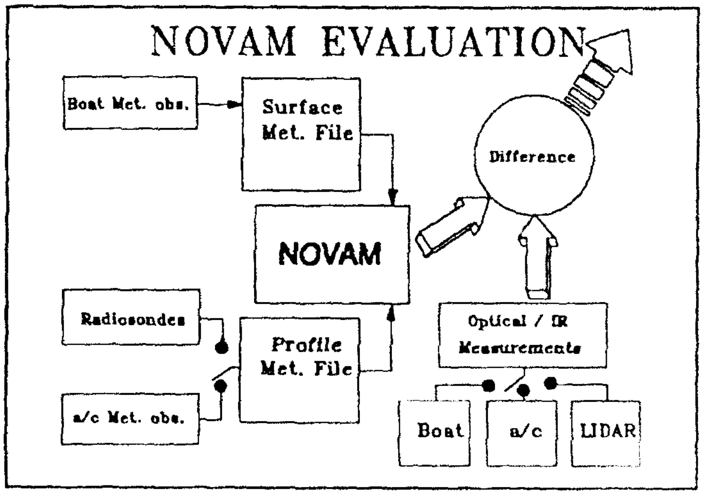

Figure 2: Schematic of general evaluation procedure as applied to the KEY-90 experiment.

Although there are a number of possible ways of evaluating the performance of a model, the general idea behind the comparison remains the same. This general evaluation scheme is shown in figure 2 where model predictions and measurements are compared. Presented earlier was a quick overall view of the performance of NOVAM in the visible range in the vicinity of San Nicolas Island, California. An exact duplication of the SNI experiment in the Florida KEYs was impossible for a number of reasons. Therefore a slightly different evaluation procedure was used for the KEY-90 experiment. This evaluation process can be used to see how NOVAM might work in the very best of circumstances as well as the worst of cases. When the best case is examined, the maximum potential of the model to actually predict important parameters is evaluated.

The general objective of the KEY-90 experiment was to provide an environment in which enough quality measurement data could be obtained so as to verify the operation of NAM and NOVAM in a tropical ocean scenario. This was accomplished by simultaneously obtaining the meteorological parameters necessary to exercise NOVAM in its full capability and at the same time providing a "ground" truth measurement of optical properties at various wavelengths. The measured extinction profile provided one standard by which to judge the model extinction profile predictions.

NOVAM requires as an input two files which contain information on the meteorological state of the atmosphere. The first describes the meteorological environment at the sea surface while the second contains a preset preamble containing certain characteristics of the sounding data and the listing of the sounding data itself. This file describes for the model the meteorological state of the column of air where the vertical structure of the optical/IR parameters is desired.

The preamble to the profile data file can be obtained in several ways. Some of the sub-models adapted into NOVAM were designed originally to simply have an "expert" examine the radiosonde recording and to subjectively determine these parameters. In the user-friendly personal computer version of NOVAM, a manual input technique was kept to accommodate this type of use. Of course there is a semi-automatic method of obtaining these parameters which utilizes a computer - human interface.

In this evaluation experiment, where properties of the atmosphere are being modeled and measured, one is always confronted by the variation constantly taking place in the atmosphere. There are questions that need to be asked, such as, by what data standards should the model predictions be judged and how accurate is the set of input data used by the model? A particular measurement used in the evaluation must have a known accuracy. This accuracy will depend on a number of factors such as:

a- Sampling procedure (remote sensing or in situ).
b- Assumptions in horizontal homogeneity of the atmosphere.
c- Sampling statistics (are there enough particles to determine a statistically significant number?).
d- Instrumentation error.
e- Data algorithm error (e.g. determining extinction from lidar returns).

Redundancy is a method to reduce the uncertainty in a particular measurement. Since the atmosphere is a complex entity which contains many variations in both space and time, it is sometimes quite difficult to obtain an adequate measurement which precisely represents the quantity desired. One of the features of KEY-90 was that several measurements of the important data were obtained simultaneously by the use of several different instruments operating independently. This redundancy was useful not only to insure against instrument failure during a critical experiment, but also was used to determine data quality. Thus, when several of the instruments gave readings which converged, it is quite certain that differences in calibration and sampling were minimized. On the other hand, when a set of measurements were taken and one of the instruments indicated data that was consistently outside the envelope of data from the other comparable instruments, then it was assumed that there was some sort of problem with that instrument, its calibration, or its sampling method.

5. OPERATIONAL PROCEDURES

The KEY-90 experiment took place near the Florida Keys from July 2 to July 19, 1990, in the Straits of Florida in the area southeast of Marathon, Florida. An overview of the location of the KEY-90 experiment area is shown in figure 3. This location, in combination with the ability to make boat and aircraft measurements, offered the opportunity to be away from land influences and major continental effects on the aerosol data while at the same time being in a "tropical" trade wind regime at a minimum of cost. The base of operations of the experiments was Marathon, Florida (about 81 06 W, 24 40 N), the home base of a small boat called *Renegade*. The boat was instrumented and used for surface measurements of aerosol and meteorological parameters, as well as for radiosonde launches. The measurements aboard the boat were made by personnel from the University of Manchester Institute of Science and Technology (UMIST); The Naval Research Laboratory (NRL); The Naval Postgraduate School (NPS); and The Physics and Electronics Laboratory of TNO, (FEL-TNO). Other kinds of data were collected ashore in Marathon. Data on the vertical structure of extinction and backscatter from aerosol were obtained from both the shore-based lidar operated by FEL-TNO and from the airborne aureole lidar operated from the NRL aircraft[16,17,18]. The NRaD aircraft[19] provided both meteorological profiles and aerosol size distribution measurements from which aerosol extinction could be calculated. The local airport provided landing facilities for the NRaD aircraft. The NRL P3 aircraft which carried the downward looking lidar was based at nearby Key West Naval Air Station. Radiosondes were launched by NPS, both from the boat and ashore in Marathon.

The measurements were made during different periods throughout the 24 hour day in order to prevent the observations from all being made in a similar meteorological/diurnal situation. The limiting time for the experiment was the amount of time it took for the *Renegade* to get from the shore base to the rendezvous point and to return each day. Manual and automatic measurements were made continuously from the time the boat left the harbor until it returned. However, while sailing to the rendezvous point, instruments aboard the boat were checked and logs were kept. Upon arrival at the point, the boat was stopped and the FEL-TNO rotorod buoy put over the side of the boat and a radiosonde was launched. The rotorod device is an instrument to measure large aerosol close to the sea surface and is described in more detail in chapter 4 of the FEL-TNO report[20]. Usually, two rotorod profiles were measured at each location. In between these two profile measurements, the boat was pointed upwind for the UMIST aerosol measurements with the PMS optical particle counters and moving only fast enough to keep steerage. At the same time, some rotorod measurements were made beside the UMIST equipment for comparison purposes and for NAM validation. While the boat was at the operational area, an aircraft profile was made with the NRaD aircraft. In all, eighteen flights were made in conjunction with the NOVAM evaluation in the vicinity of Marathon, Florida. From these flights, a total of forty-two vertical profiles were made.

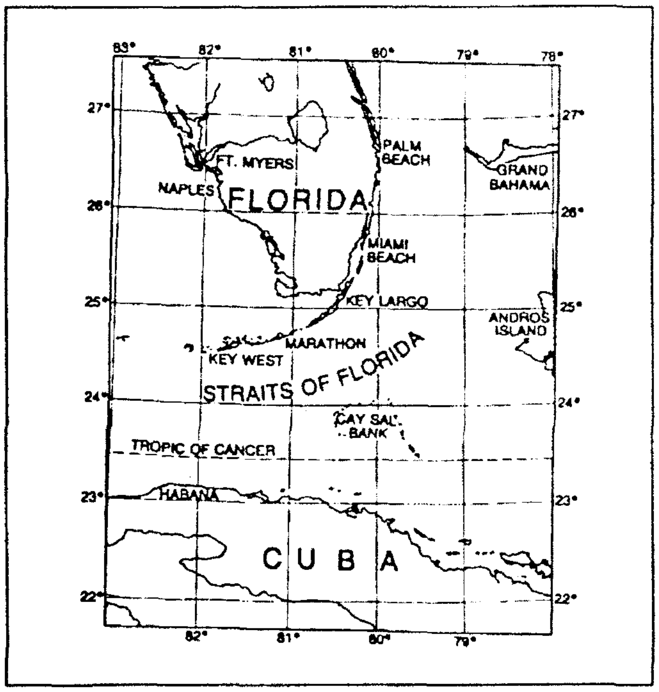

Figure 3: Map of the operation of KEY-90.

Before an experiment, the NRL aircraft aureole laser and telescope were aligned; the detectors and amplifiers were calibrated using a ground target that provided a constant signal and a neutral density filter that reduced a signal by a fixed amount. During the flights, a series of racetrack circuits were flown over the boat. The northern turn took place south-west of the Florida Keys. The southern turn took place north of the Cay Sal Bank islands. Each leg was approximately 65 km long and the entire circuit took approximately 20 minutes. Some of the lidar profiles coincided with the in situ data taken from the boat and the NRaD aircraft while the others provided background information on the horizontal homogeneity of the surrounding atmosphere.

6. RESULTS FROM KEY-90

In preparation for the evaluation of NOVAM in the Keys, all of the available data were gathered together by 'experiment day' for detailed analysis. In this report, the date of 14 July 1990 was chosen as the day at which to present a more detailed look.

TABLE I

SURFACE OBSERVATION FILE FOR 14 JULY 1990

Sea Surface Temperature (C)	29.7
Air Temperature (C)	28.2
Relative Humidity (%)	82.6
Optical Visibility (km)	26
Current real wind speed (m/s)	5.4
Averaged wind speed [24 hours] (m/s)	5.1
Air Mass Parameter [1..30]	1.6
Cloud cover (tenths)	0.3
Cloud type [0..10]	8
Surface IR ext. (1/km) @10.6	0.044
Present weather in standard code[0-99]	3
Height of lowest cloud (m)	250
Zonal/seasonal category (1..6)	2

The surface observation file was obtained for each date by extensive statistical analysis of each of the needed parameters. All available sources for a particular parameter were utilized and weighted. Values which, for some reason, were outside of the main band of observations were excluded from the average used in the input file. The range of time over which the average was taken included only the time when the boat was at the observation point. The complete set of these analyzed data is referred to as the consensus surface observation data file for KEY-90. The particular set of data for the day in question is shown above in table I. The surface IR extinction in this case was determined from a Mie calculation on the average aerosol size distribution made on the boat.

NOVAM also needs a radiosonde profile which describes the altitude variation of temperature and humiditv. These data were available from both the NRaD aircraft meteorological profiles and from the series of radiosonde soundings. This resulted in several sets of these profiles for each experiment day but fortunately, they agree quite well with each other. Because these values are so close to each other, the model seems insensitive to which set of input profiles are used in the evaluation process. The data for 14 July 1990 are shown in figure 4 as the heavy line. This curve is rather typical for all of the soundings taken during KEY-90. It is characterized by the singular lack of an inversion of any kind. In order to contrast this lack of inversion to other types of atmospheric conditions, a temperature plot taken with the same instrumentation during the FIRE (SNI-87) is shown as a thin line in the figure. Note the extremely strong temperature inversion at 700 meters. Penetration through this region into the upper atmosphere by air from the marine boundary layer is highly improbable whereas in the case of KEY-90, there is no inversion

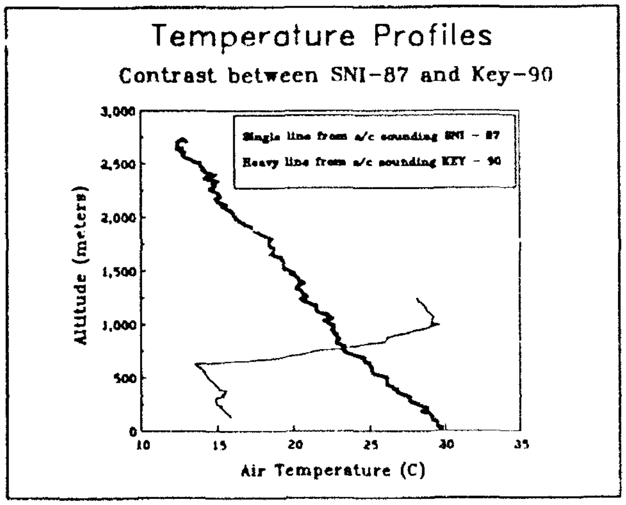

Figure 4: Typical temperature profiles showing contrast between SNI-87 and KEY-90.

stopping plumes of air from the surface going to any altitude. The FIRE (SNI-87) data shown in figure 4 is characterized by a single strong inversion and should be classified by the users of NOVAM as an "almost well mixed" boundary layer. Since there are no inversions in the KEY-90 profiles, the user of NOVAM should not report any inversion in the preamble in this case and the model will consequently use the exponential decay mode of describing the altitude dependence of the aerosol with respect to the altitude.

Figure 5 is a plot of the mixing ratio profiles for the two cases which had their potential temperature profiles shown in figure 4. The mixing ratio also shows a very dry layer of air above the moist ocean layer in the SNI-87 case, where as in the KEY-90 case, the moisture at the surface is very high and drops off with altitude in a monotonic fashion.

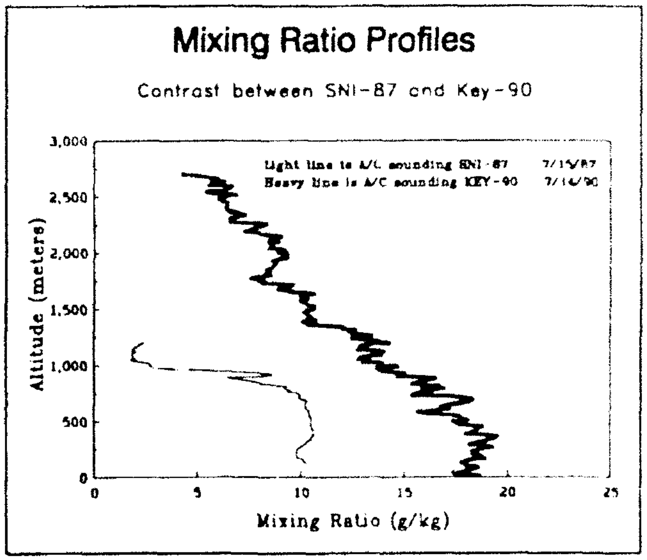

Figure 5: Typical mixing ratio profiles showing contrasts between SNI-87 and KEY-90.

Figure 6 shows a plot of several sets of extinction data obtained from different instruments at the wavelength of 1.06μ from the KEY-90 experiment on that day. This plot shows the extinction calculated from the NRL downward-looking lidar, the extinction calculated from the NRaD aircraft aerosol measurements, the NOVAM estimate of extinction based on radiosonde data, and the value of extinction at the surface obtained from calculations on the surface aerosol size distribution. Although the location of all of these observations are within a few kilometers, the time scales of the data on which they are based differ quite widely from each other. First of all, the lidar return was done in a single shot of the lidar. The time required for the aerosol sampling aircraft to make the ascent from the surface to 3000 meters is on the order of 20 minutes and of course different parts of the profile were measured in different parts of the atmosphere as it circled. The surface aerosol size distribution is considered the most reliable in terms of a long term average since it was obtained by averaging particle data for a period of greater than an hour. The NOVAM plot used information from the surface as well as from the best of the meteorological profile made from the aircraft sounding.

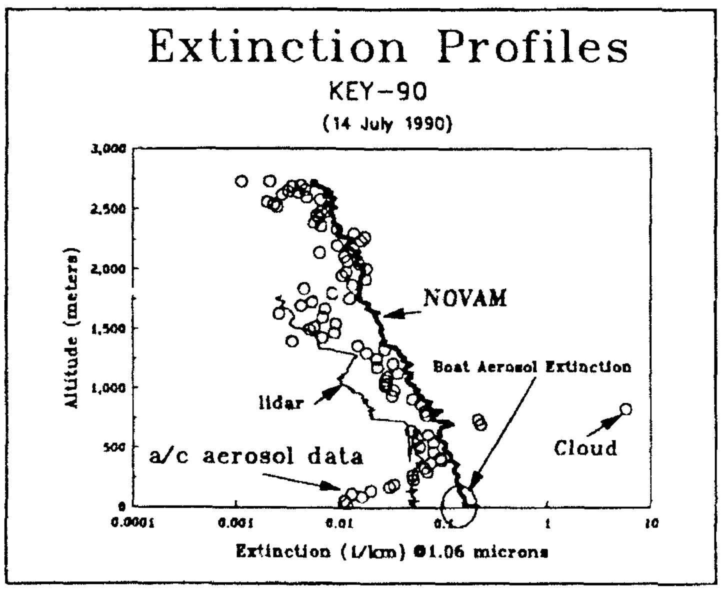

Figure 6: Comparison of measured and predicted extinction values.

One odd feature of the aircraft aerosol profile is the apparent drop off of extinction near the surface. Most of the profiles during the experiment showed this characteristic. Relative humidity data (which could cause such a feature) do not indicate that particle growth is the reason for this curve. In order to investigate this phenomenon, the aerosol size distribution was looked at in more detail.

The NRaD aircraft is not able to visually determine if it is sampling within horizontally homogeneous air. It could very well be flying between the upward and downward flowing convective columns as it makes a profile over a period of time. In addition, there has to be a compromise between the length of time spent at each altitude (in order to obtain enough aerosol particles to statistically give a reasonable value) and the length of time and/or distance to fly before a different air mass is being measured. Figure 7 shows the aerosol size distribution near the sea surface from three sets of real data and from the NOVAM determined distribution. In this figure we are only looking at levels close to the sea surface and thus the vertical structure of NOVAM model is not tested. Here we see that the size distribution at the bottom of the aircraft extinction profile (solid heavy line) did not see any particles larger than 1μ radius. Also available at a time and place somewhat near where all of these data were taken is an average of 10 miles of level flight where extinction average could be determined near the sea's surface (circles). This shows that particles out to 10μ radius were observed, and this data agrees well with the boat values which are averages obtained over about 1 hour. Model results (thin solid line) show a slight over-estimation in dN/dr at radii below about 2 or 3μ radius and an underestimation at radii larger than these values.

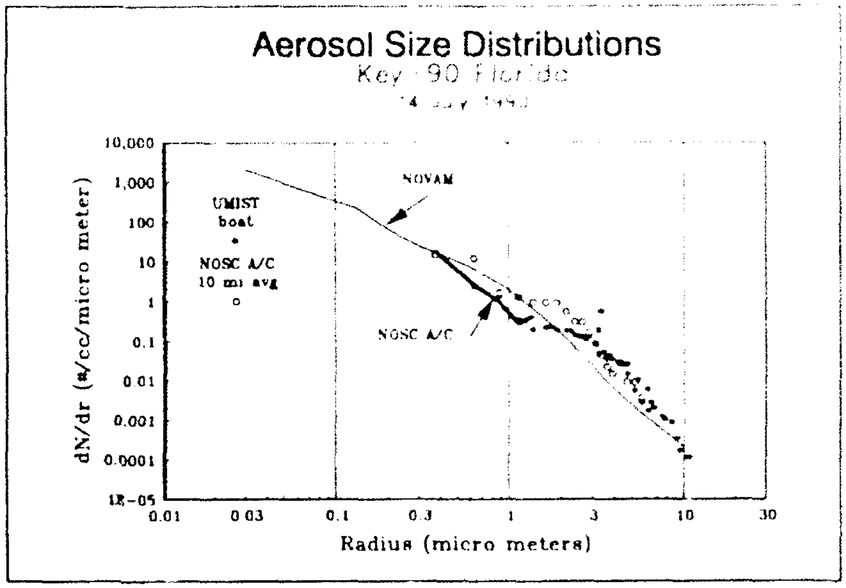

Figure 7: Aerosol size distributions, on 14 July 1990 within 100 meters of the sea.

The objective of the KEY-90 experiment was to see if the NOVAM model could be used in the case of a "tropical" ocean in which there are no strongly defined capping inversions and which is characterized as a convective type of atmosphere. The current model of NOVAM selects the set of exponential functions for cases in which no inversions are detected. The question that was asked is "Is this model good enough in the case of convection and how does it compare with the strong inversion cases found off of the coast of California?" As shown in the single day, 14 July 1990, the NOVAM model did a reasonable job in providing the extinction profile if the no inversion mode were used. In fact, the variations in measured data allow enough uncertainity that most of the model predictions fall within the data envelope of the measured data.

7. CONCLUSIONS

All of the data for KEY-90 were evaluated for wavelengths of 0.55, 1.06, 3.5 and 10.6 μ in a manner in which the data envelope of extinction profile was compared with the plot of the NOVAM-generated extinction profile using the same criterion that was used in figure 1. Figure 8 shows pie charts of the grades of the NOVAM performance of this data. The performance is comparable to that found during the SNI-87 FIRE. The atmospheres from the California experiment all contained one or two strong inversions whereas the KEY-90 experiment consisted exclusively of an inversion-free atmosphere.

The experiment at KEY-90 was very useful in determining how well the exponential sub-model of NOVAM worked with this free convection environment. The FIRE (SNI-87) data set, on the other hand, contains meteorological cases which exercised the inversion sub-models of NOVAM. There are, no doubt, many cases existing in the marine atmosphere in which the dividing line between these cases cannot be so easily determined. Only continued exercise of the model in many types of atmospheric conditions will fill in these gaps. The question of whether or not the model is good enough for a particular application will depend on the requirements for the application. Clearly, the state of the art in making the required atmospheric measurements has still not reached its ultimate perfection and probably never will. The chief value in a model like NOVAM is that if the meteorological data are known for a particular application either from an historic data base or some other method, then the more elusive aerosol properties of the atmosphere can also be determined.

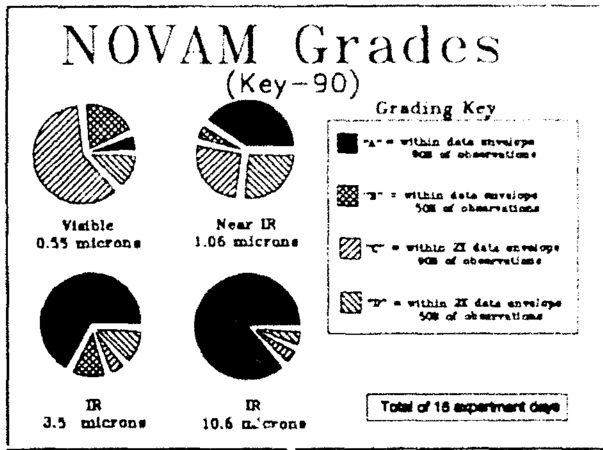

Figure 8: Grades for NOVAM performance during Key-90.

The criterion by which the model was graded is shown in the grading key in a box in figure 8. The data envelope in these cases was obtained by manually enclosing the area occupied by the circles in the log-linear plot such as in figure 6. This results in two curves where the distance between them represents a variance-like value of the measurements at each level. Likewise, an envelope was drawn which was twice the size of the original one also drawn on the log-linear plot and centered about the same median line. The grading for each case then depended on where the NOVAM profile was with respect to the data envelope and the 2X data envelope. Clearly if the model would always be contained within the data envelope, it would be working as well as could be ascertained from the data measurements and we would give this a grade of "A".

The problem with this system of grading is that as the variance in the measurement decreases, then the grades would tend to decrease. Clearly if a measurement gave a very thin line that had no variance, then the possibility of exactly matching this data with a model prediction would be small indeed. This process is shown in figure 8 where the progression of NOVAM's grades to better and better values as the wavelength goes from visible to the far IR. This is because of the decreasing aerosol concentration that exists at any level for increasing radius. This causes the variance in the measured aerosol derived extinction data to become larger at the longer wavelengths as larger particles become more important in the Mie calculation in these wavelengths.

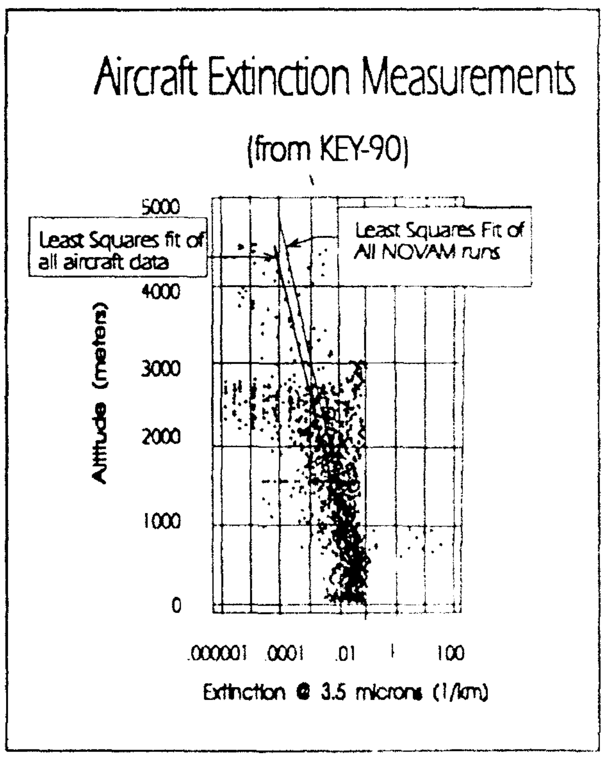

Figure 9: All KEY-90 3.5μ extinction data plotted on the same graph.

The real problem in evaluating the performance of a model like NOVAM is that of finding a suitable standard by which to judge the result. The error bars in the model prediction can only be based on the quality of the measurements made to evaluate the model's performance. In KEY-90 all of the meteorology of the experiment days were very similar to each other. Consequently, only one type of atmospheric model was used by NOVAM and a more statistical approach can be made in comparing model with measurement. Figure 9 shows a plot of all of the 3.5μ extinction measurements used in the analysis of figure 8 but plotted all together. It is seen in this plot that although there is a large scatter in individual points, the points tend to cluster about a profile which could be represented by a segmented straight line on the log-linear plot. The lower drop off of extinction between the ocean surface and 400 meters shows up on the plot but this feature will be ignored because of the explanation given above. A least squares fit was made of all of these data (including the drop off at the surface) and is shown by the labeled line in the figure. From similar data obtained from NOVAM for all of these cases, a similar least squares fit of predicted values was made to a line and it is shown plotted on the same curve as the measurements. It is seen that the agreement between model and measurement for a large amount of data is quite good. Perhaps the model's scale heights of the extinction profiles should, in this case, be adjusted by a small amount to minimize even this difference. The data in figure 9 shows that the extinction at any particular time and place may be very different (by orders of magnitude) from that at the same place but at a different time even though the atmospheric conditions are quite similar. A model such as NOVAM can not hope to predict this detail in the measurements. The best that can be hoped for is that on the average, NOVAM will predict the average profile of extinction.

In table II, we see a portion of the statistics obtained in regression analysis used in determining the least squares fit of both the aircraft data and the NOVAM predicted data. The table shows some of the analysis of variance statistics from this study. In the table the M.S. columns represent the mean square of the data as it spreads out from the regression line. The units of measure here are logs of extinction so that the spread in the data is directly represented in the log-linear plot of figure 9 where the value of 1 refers to an order of magnitude in M.S. of the residual of the regression. A distinct increase in M.S. of the data from the aircraft as the wavelength increases is seen in the table. This is the result of the lack of aerosols available for the measurement at the larger aerosol sizes which are needed for the Mie calculation at the longer wavelengths. This is the cause of the apparent increase in grades shown in figure 8.

TABLE II

Wavelength (μ)	M.S. of aircraft *measurements [log of ext.]*	M.S. of NOVAM data [log of ext.]
0.55	1.612	0.450
1.06	1.966	0.406
3.5	3.706	0.401
10.6	3.983	0.477

The same set of statistical data used in the regression study shows that the slope of the regression line for the NOVAM data test differs from the regression line slope of the aircraft data by about 20% over all of the wavelengths. The slope here is again expressed in terms of the change in altitude (meters) per change in the log of extinction. There appears to be a slight increase in slope magnitude with increasing wavelength in the measured data indicating that the scale height of the larger particles is less than that of the smaller particles.

This experiment has concentrated on what happens to the atmospheric aerosol in this tropical ocean environment. The effects of meteorological processes in the transport of aerosols has been the only topic of study. All effects of extinction due to the interaction of the electro-magnetic energy with atmospheric molecules have been intentionally overlooked so that the aerosol aspect of the problem could be examined in detail. This was done because the interaction with molecules is relatively well understood. We must not, however, lose sight of the practical fact in looking for these aerosol details that the total extinction is a combination of both molecular and aerosol effects. Because of the very high water vapor content of the KEY-90 environment, the molecular extinctions at the 3.5μ and 10.6μ wavelengths will dominate the extinction in these cases and all small differences between model and measurement shown in figure 9 are in reality irrelevant.

NOVAM has shown itself to be reasonably successful in two divergently different atmospheric conditions. It will continue to undergo further testing in its performance at other geographic locations on a lower priority basis. A user-friendly PC version will be made available to the scientific community in the near future.

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