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VERIFICATION OF THE NAVAL OCEANIC VERTICAL AEROSOL MODEL DURING FIRE

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1. INTRODUCTION

The Naval Oceanic Vertical Aerosol Model (NOVAM) has been formulated to estimate the vertical structure of the optical and infrared extinction coefficients in the marine atmospheric boundary layer (MABL), for wavelengths between 0.2 and 40 μm[1]. NOVAM was designed to predict, utilizing a set of routinely available meteorological data, the non-uniform and non-logarithmic extinction profiles which are often observed. NOVAM is based on a combination of empirical and physical models for the processes that determine the aerosol dynamical behaviour. The extinction properties are calculated from the aerosol profiles using Mie theory.

NOVAM is restricted to the marine atmosphere. The differences between NOVAM and land-based models are the marine type of scaling used for the turbulent controlled processes near the sea surface, and the determination of the surface concentrations with the Navy Aerosol Model (NAM).[2] NAM has been extensively updated from the original. It produces a particle size distribution at a height of 10 m above the surface from the input data of wind speed, visibility and relative humidity. This NAM-generated surface-layer particle size distribution is mixed throughout the MABL by turbulent-controlled processes, further modified by relative-humidity effects. Various models describing these processes are included in NOVAM, such as a simple mixed-layer model[3] and a shallow convection case.[4] Provision has been made to include other models such as for deep convection. The selection of the model is based on the vertical stratification, cloud cover, cloud type, wind speed, and the requested wavelength for the extinction calculation. If the information on the vertical structure is not available a default relative humidity profile, based on the surface observations, is generated.[5] This default profile is also used when the required input parameters do not satisfy the presently supported models. For the calculation of extinction for wavelengths between 1 and 11 μm below marine stratus clouds an empirical model[6] is used. This stratus model applies only to wind speeds less than 5 m/s.

For the initial evaluation of NOVAM, data from the July 1987 FIRE experiment was used. Aerosol particle size distributions, aerosol scattering and required meteorological parameters throughout the MABL were obtained from both airborne and surface based platforms. The aerosol-derived extinction properties throughout the MABL are compared with the NOVAM estimates.

2. THE FIRE/EOMET EXPERIMENTS

The Navy's EOMET (Electro-Optics METeorology program) participation in FIRE was both to be supportive of FIRE and to build a quality data base from which NOVAM could be evaluated. Measurements were made from an aircraft, a balloon and a ship. An overview of the measurements made by the EOMET group is presented in table 1.

The R/V Point Sur, operated for the National Science Foundation by the California State University System for the Naval Postgraduate School (NPS), made continuous (24 hour/day) measurements for the period 7-16 July, 1987. The R/V Point Sur was generally located 30-40 km upwind (Northwest) of San Nicolas Island (SNI).

The Naval Ocean Systems Center (NOSC) airborne platform was utilized to characterize the low level structure of the marine boundary layer. Flights were made on 15, 19, 23 and 24 July, 1987. The prescribed flight pattern for the NOSC aircraft consisted of spiral profiles taken near the Naval Research Laboratories (NRL) ground facility at SNI and upwind of SNI near the R/V Point Sur. Each flight was scheduled to occur simultaneously with the NOAA-9 satellite overpass.

The NRL balloon facility[7] was located at the northwest tip of SNI approximately 17 m above sea level. The NRL aerostat system consisted of a 538 m^3 balloon, with a lifting capacity of 227 kg and a flat bed trailer which serves as a "mobile" mooring system. The instrument package hangs 35 meters below the balloon and the power source to eliminate exhaust contamination near the sensitive aerosol sensing devices. The platform is aligned with the wind by an aerodynamic mechanism. During FIRE, 13 aerosol profiles were measured on 16, 18, 19, 20, 22, 23, 24 and 25 July, 1987.

Extinction profiles were obtained in three independent ways:
- NOVAM calculations utilizing measured meteorological parameters,
- Mie calculations utilizing aerosol size distributions,
- Direct measurements of extinction (molecular and aerosol) at one wavelength by means of a spherical nephelometer.

3. SYNOPTIC SITUATION AND SURFACE MEASUREMENTS ON THE R/V POINT SUR, 14-16 JULY

The meteorological synoptic scale situation during the 14-16 July period was controlled by two pressure systems. A stationary 1032-1036 mb closed surface high pressure system was located west of Washington State and British Columbia, Canada. A well-defined thermal low was located over Southern California. These two systems caused west to northwest winds in the vicinity of SNI due to the outflow from the high located to the northwest.

The time series of surface-layer parameters obtained from the R/V Point Sur for 14-16 July are presented in Figure 1. Features of interest are the steadily decreasing wind speeds and the diurnal variation of both the wind speed and direction. The steady decrease in wind speed was associated with the thermal low which was moving northeast (more inland) from the Baja of California on 14 July to the California-Nevada border on 16 July. The eastern Pacific surface high pressure systems remained nearly stationary during this period. Steadily decreasing wind speeds are important to the production of marine aerosols.

TABLE 1. Meteorological Measurements by the EOMET Group during FIRE.

Measurement	Instrument	Frequency
I. NPS: R/V Point Sur		
Mean Surface Layer:		
Radiation(short,total)	radiometers	continuous
Vector wind	propeller/vane	continuous
Temperatures:		
Air	resistance therm.	continuous
Dew point	cooled mirror	continuous
Sea surface	floating thermistor	continuous
Waves	bridge observation	1 per hour
Turbulence		
Wind	hot-film anemometer	continuous
Humidity	Lyman-alpha Sensor	continuous
Aerosol and Radon		
.08 to 1.5 μm radius	PMS ASASP	continuous
0.5 to 12 μm radius	PMS CSASP	continuous
Radon concentration	HV filter	1 per hour
Mixed Layer and above:		
Vector wind	rawinsonde	6 per day
Temperature	rawinsonde	6 per day
Humidity	rawinsonde	6 per day
Inversion height and strength	rawinsonde/sodar	6 per day/ continuous
Turbulence	sodar	continuous
II. NRL Aerostat, SNI		
Air temperature	dry bulb thermometer	5 Hz
Relative humidity	dry/wet bulb psychrometer	5 Hz
	saturation hygrometer	5 Hz
Liq. water conc.	forward scatt. meter	5 Hz
Wind vector	bivane anemometer/ inclinometers/compasses	5 Hz
Visual scattering	nephelometer	1 Hz
Altitude	altimeter	1 Hz
Aerosol, 0.5-16 μm radius	PMS CSASP	1 Hz
Videorecordings	video recorder	continuous
III. NOSC AIRBORNE PLATFORM		
Temperatures:		
Air	Rosemont	continuous
Dew point	EG&G cooled mirror	continuous
Sea surface	Barnes IR	continuous
Cloud top	Barnes IR	continuous
Aerosol, 0.25-15 μm radius	PMS ASSP	continuous
15-150 μm radius	PMS OAP	continuous
Altitude	Rosemont	continuous

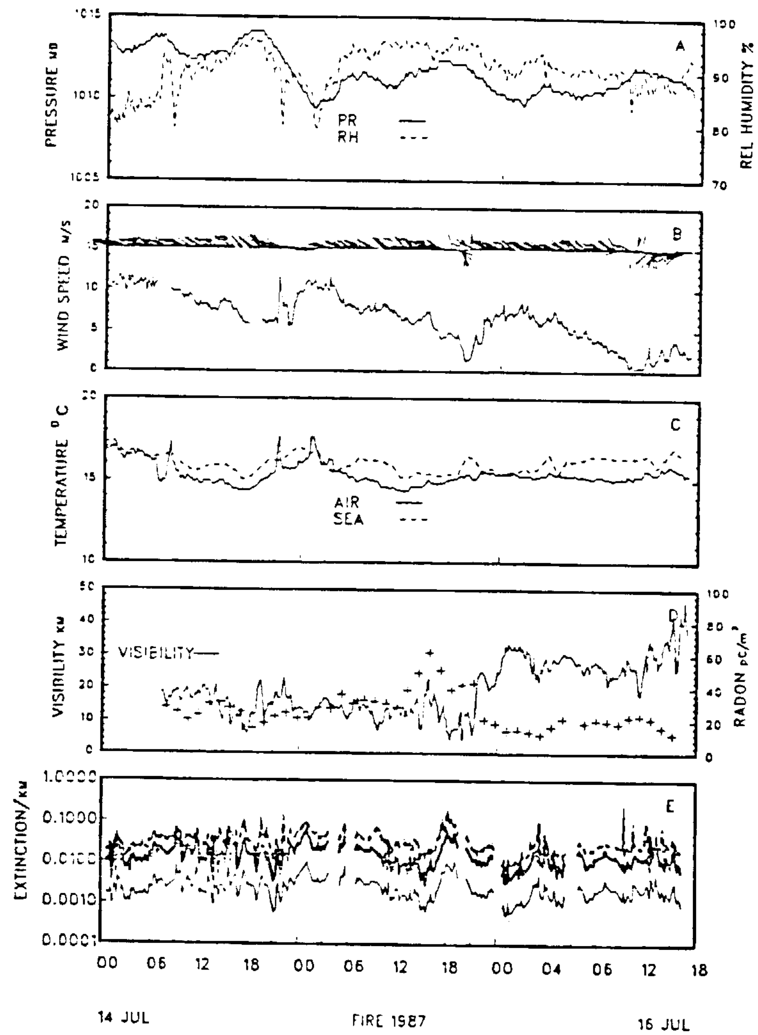

Figure 1. Time series of R/V Point Sur surface observations, July 14-16, 1987:
a. atmospheric pressure and relative humidity
b. wind speed and wind direction
c. air temperature and sea surface temperature
d. visibility and Radon concentrations (+)
e. extinction coefficients calculated from the aerosol particle size distributions for wavelengths of 0.55, 0.63, 0.69, 1.06 and 10.6 μm (top to bottom traces).
Note that the time is UT, i.e. 7 hours ahead of local time (PDT).

The diurnal variations in wind speed and direction, during the 24-hour periods, were concluded to be due to the intensification of the thermal low, east of the area, during the local afternoon. This could imply a local circulation influenced by the land-sea proximity.

Evidence that there was a land-sea influence associated with the diurnal variation appears in the diurnal variation of the Radon concentration. Whether the Radon was advected horizontally or arrived in the mixed layer due to entrainment is unknown. The increase in temperature and decrease in humidity on the diurnal scale could be associated with entrainment of warm dry air from above the inversion. The entrainment of overlying air with continental aerosol is as important to NOVAM's performance as the horizontal advection of continental air.

The continental influence is obvious in the afternoon of 15 July, when the Radon concentrations peaked to 60 pCi/m^3. The increased Radon concentrations, a clear indication of continental influences, are followed by an increase in the extinction coefficients. The increase in the extinction coefficients is observed at all wavelengths from the visible to the far IR.

4. SIMULTANEOUS AIRCRAFT AND BALLOON FLIGHTS DURING THE STRATUS CASE OF 15 JULY 1987

Evaluation of the NOVAM stratus model utilized the aircraft- and balloon-derived meteorological profiles and surface-based observations for the stratus conditions of 15 July 1987, 1500-1700 (PDT). A uniform stratus layer (100% cover) existed at and upwind of SNI with a base around 400 m and tops at 700 m. Winds were northwesterly at 5 m/s. Cloud base at SNI was determined at 320 m from the balloon liquid-water measurements. Drizzle was observed at the ground. Extinction coefficients fluctuated from 80 km^{-1} in the cloud, to low values (0.01 km^{-1}) above the cloud layer. The balloon RH instrument was pegged at 100% throughout the whole boundary layer. Upwind, however, the relative humidity below the clouds varied in the vertical between 95% and 100%, as determined from the aircraft data. The surface relative humidity at the R/V Point Sur, approximately 30 NM upwind from SNI, was 92% (Figure 1). This is a classic case of a stratus deck in which warm dry conditions existed above the moist marine stratus layer.

Extinction profiles for this situation are shown in Figure 2. Figure 2a shows the AMP sensitivity of NOVAM for the visible wavelengths. Note that NOVAM selected the mixed-layer model for these calculations because the sub-stratus model does not apply to wavelengths smaller than 1 μm. The fluctuations in the extinction coefficients determined from all sources are generally contained within the AMP limits. In the regions around 120 m and those above 320 m, where the extinction coefficients are outside the NOVAM bounds, the aircraft-observed relative humidities approached 100% - a region where NOVAM is not applicable. The problem here is that the hygroscopic aerosol (like sea salt droplets in the MABL) can be activated when relative humidities go slightly over 100%. The activated aerosols grow in size very fast and behave as cloud droplets[8] and cannot be described by equations that apply to subsaturated aerosol. This puts them into the arena of fog or cloud physics, and outside of the realm of aerosol modeling - including the capabilities of NOVAM. Figure 2d shows the liquid water concentration profile and Figure 2e the measured size distributions associated with this supersaturation phenomenon.

Figures 2b and 2c show the 1.06 μm and 10.6 μm extinction profiles. The sub-stratus model is not as sensitive to the AMP as the mixed-layer model.

Differences between the measured extinction coefficients and NOVAM estimates are in the high-humidity regions just described. The peak in the size distributions shown in Figure 2e affects the far IR more than the near IR.

5. CONCLUDING REMARKS

We have illustrated the value of NOVAM for estimating the non-uniform and non-logarithmic extinction profiles, based on a severe test involving conditions close to and beyond the limits of applicability of NOVAM. A more comprehensive evaluation of NOVAM from the FIRE data is presented in ref. 9, which includes a clear-air case. For further evaluation more data are required on the vertical structure of the extinction in the MABL, preferably for different meteorological conditions and in different geographic areas (e.g. ASTEX).

6. ACKNOWLEDGEMENTS

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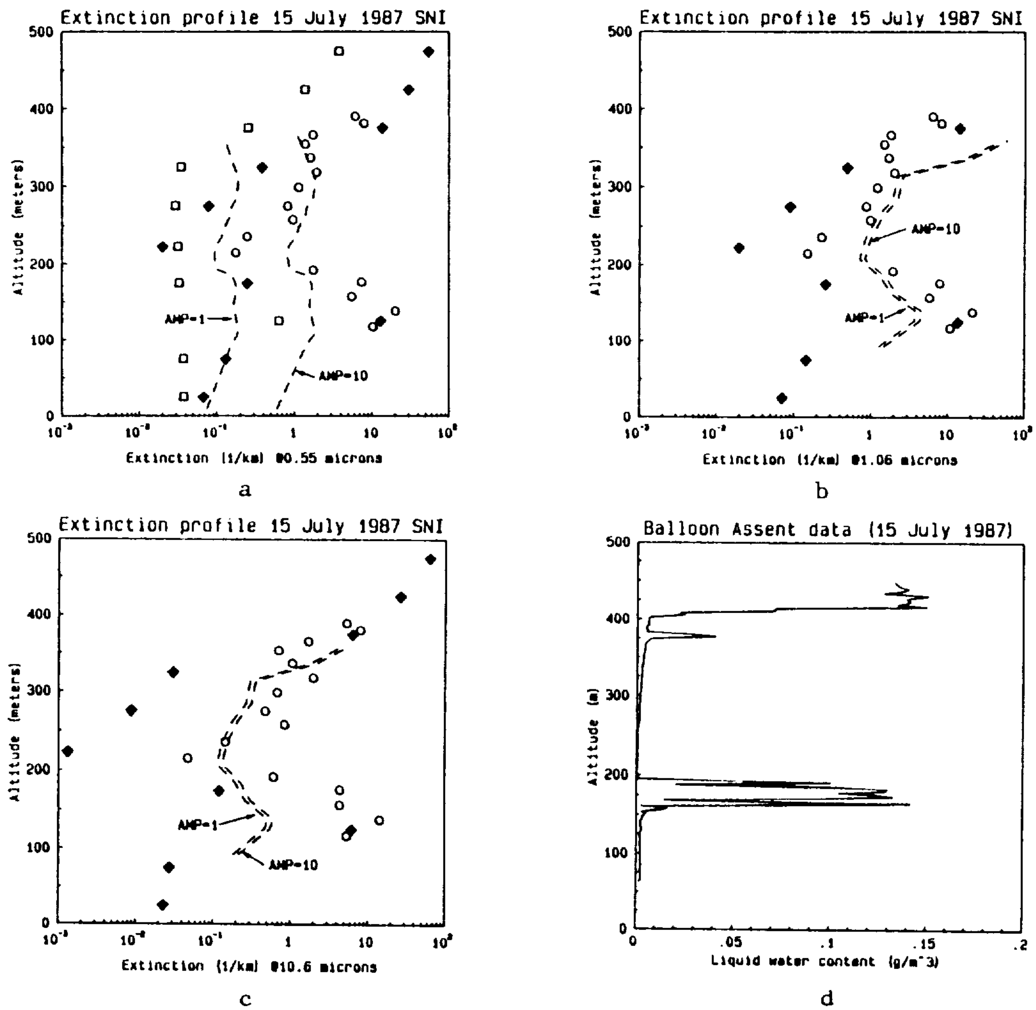

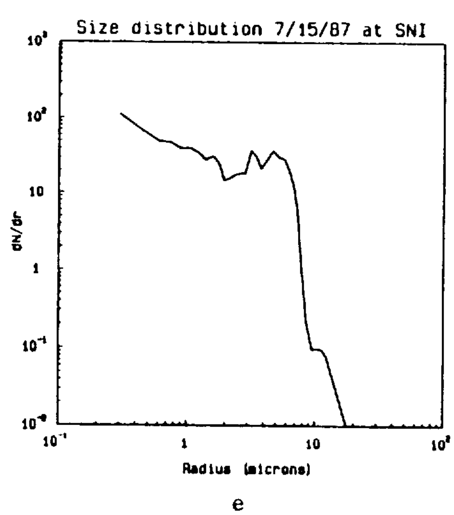

Figure 2. Stratus case for 15 July:
a. extinction profiles for 0.53 μm, derived from the balloon (◆) and aircraft (o) aerosol measurements, the balloon nephelometer measurements (□) and estimated with NOVAM for AMP's of 1 and 10. The NOVAM profile is estimated utilizing the mixed-layer model because the sub-stratus model does not apply to wavelengths smaller than 1 μm. The curves are further explained in the text.
b. extinction profiles for 1.06 μm wavelength, derived from the balloon (◆) and aircraft (o) aerosol measurements and estimated with NOVAM (sub-stratus model) for AMP's of 1 and 10.
c. as figure b, but for 10.6 μm wavelength.
d. liquid water content profiles measured from the balloon[7].
e. aerosol size distribution measured at a level of 125 m from the balloon. The pronounced peak in the spectrum is due to the growth of activated aerosols in supersaturated conditions (relative humidity slightly higher than 100%).