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FINAL REPORT FROM THE UNIVERSITY OF WASHINGTON TO THE OFFICE OF NAVAL RESEARCH ON RESEARCH GRANT N00014-92-J-1191

PROJECT TITLE: "Airborne Studies of Ocean-Particle-Cloud-Interactions in the Arctic"

PRINCIPAL INVESTIGATOR: Professor Peter V. Hobbs
(Alan P. Waggoner was the chief scientist for the field project. Also, there were guest scientific investigators aboard the aircraft.)

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BACKGROUND

This research was part of the Office of Naval Research's (ONR) Lead Experiment ("LeadEx"), which was designed to clarify the effects of open water leads on the polar ocean and atmosphere.

The specific tasks of this grant were to operate the University of Washington's Convair C-131A research aircraft in the arctic in support of LeadEx, to analyze data collected aboard the aircraft, and to provide this data to other LeadEx investigators.

The Convair C-131A made 18 flights totalling 70 hours over the ice pack north of Deadhorse, Alaska, in April 1992. Data was collected on:

- particles and gases in the air
- the radiative properties of the ice surface, leads and ice crystal clouds

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- various methods for the remote detection of leads and surface temperatures
- heat fluxes from leads.

These data are still being analyzed, but brief summaries of some of the major conclusions to date are given below.

SUMMARY OF RESEARCH RESULTS

(a) **Particles and Gases in the Air**

Concentrations and emissions of dimethyl sulfide (DMS) from the ocean were low. We found concentrations of DMS to be 3 pptv or less (minimum detectable levels of DMS are about 1 pptv). Differences between DMS concentrations measured upwind and downwind of leads were in the noise level of our measurements. We occasionally measured 5-10 pptv of DMS, but only over areas with substantial open water (e.g., near Barrow late in April).

Methyl bromide ($CHBr_3$) concentrations were 8-15 pptv below 1,000 ft altitude; they decreased to approximately 5 pptv at 2,000 ft and to approximately 2 pptv at 30,000 ft. Our interpretation of this data is that the source of $CHBr_3$ is ice algae at the ice-water interface with emissions from open water leads. The mixing through the bottom thousand feet is retarded by strong surface inversions commonly found at this time of year. Concentration decreases slowly with altitude above the surface inversion as expected by photo dissociation. $CHBr_3$ is probably not responsible for any significant stratospheric ozone destruction because its relatively short lifetime in the troposphere minimizes transport into the stratosphere.

The concentrations of ice crystals in clear air were very low and were undetectable by our airborne replica sampling system or optical probes. Optical backscattering from the crystals was detectable on occasions by the lidar aboard the aircraft.

The concentration of arctic haze was low, as measured by an integrating nephelometer and filter sampling. We were able to detect the pollution plume from the industry concentrated near Deadhorse by elevated concentrations of condensation nuclei and of nitrogen dioxide. The Deadhorse plume was not detectable in optical scattering as measured by either the integrating nephelometer of the lidar. The low optical scattering of the plume was due to low emissions of particles larger than approximately 0.15 micrometers.

(b) **Radiative Properties of the Ice Surface, Leads and Ice Crystal Clouds**

Incident and reflected optical radiation fields were measured aboard the C-131A aircraft, in collaboration with Drs. Michael King and Si-Chee Tsay of NASA Goddard, using a scanning radiometer at thirteen narrowband spectral channels between 0.5 and 2.5 micrometers. Radiation measurements were obtained of:

- Surface bidirectional reflectance patterns under different atmospheric and surface conditions
- Spectral albedo at the nadir direction to imply the statistics of lead distributions within a particular domain (grid) area
- Angular distributions of scattered radiation deep within an optically thick ice crystal cloud.

Data from the first set of measurements have been analyzed and are discussed below. Data from the second and third items listed above await analysis.

Surface spectral reflectance in a major parameter of interest to the biospheric sciences, remote sensing, and global change communities. Detailed measurements of the bidirectional reflectance properties of natural surfaces are crucial to understanding and modeling their physical and radiative properties, as well as to aid in the remote sensing of aerosols and clouds above natural surfaces. The bidirectional reflectance was obtained by flying the aircraft (with ~20° roll and speed of ~80 m/sec.) in a clockwise circular orbit above the surface, resulting in a ground track approximately 3 km in diameter. At an altitude of ~600 meters, the pixel resolution at nadir is ~10 meters.

Two types of surface bidirectional reflectance patterns were measured in this manner: snow over tundra, and multi-year snow and sea ice. From these observations we have drawn the following conclusions:

- In the visible and near-infrared spectral range, the reflection function of multi-year snow and sea ice is greater than that of snow over tundra.
- The specular reflection and hot spot (direct backscattering or opposition effect) around the principal plane are clearly visible.
- Nearly isotropic scattering occurred at all viewing angles except near the forward and backward directions. However, multi-year snow and sea ice revealed larger variability due to higher spatial inhomogeneity associated with pressure ridges on the ice.

(c) Remote Sensing of Leads and Surface Temperatures

An IR radiative thermometer (Heinman KT-19) aboard the aircraft appeared to be superior to lidar in detecting and characterizing leads. Ice-surface temperatures were warmer downwind than they were upwind from a refrozen lead. Surface temperatures measured with the IR thermometer were compared to those measured by the AVHRR satellite (channel 4, 10.5 micrometers) on two days with minimal visual presence of diamond dust to one day with visually evident diamond dust. Without diamond dust, the AVHRR temperature was lower by 1-2° C. With diamond dust the AVHRR temperature was higher than that given by the IR thermometer by 1-2° C. On all three days, the standard deviation of the difference between the IR and AVHRR measured surface temperatures was about 0.6° C.

Y. Yu, D. Rothrock and R. Lindsay (UW/APL) have selected flight data collected on 14 April 1992 as an example to estimate the effect of ice crystal precipitation on surface temperatures measured by AVHRR. Using flight measurements taken only at an altitude below 120 m, with the downward solar radiation larger than 300 W m^{-2} and the airplane roll less than 2°, they compared surface temperatures measured with the IR thermometer and the AVHRR. Assuming a snow emissivity of 0.9985 at 14° of satellite scan angle, and using 105 comparison pairs of data points, they found that the AVHRR temperature was warmer than the airborne measurements by 3 ± 0.9°C. The bias in the AVHRR measured temperature appears to be related to a strong temperature inversion on that day (about 10° C temperature difference) up to about 700 m. Future work will involve study of the spatial spectra of variations in ice temperature measured by the IR thermometer, and implications for sensible heat fluxes from the surface.

Jennifer Francis (UW/APL) is also using data from the KT-19 infrared thermometer aboard the Convair C-131A to validate surface temperatures derived from the TOVS and AVHRR satellites. The KT-19 data are particularly suited to this purpose because transects can be averaged over the footprint of the satellite pixel, providing values that are representative of area-averaged surface temperatures. This method overcomes a serious problem that plagues comparisons of satellite retrievals with ground-based measurements from point sources. Results indicate that the effects of low-level, clear-air precipitation (diamond dust) are significant, particularly when the surface-based inversion is strong. Satellite-derived surface temperature estimates can be 2 to 4° C too warm owing to the effects of diamond dust. Research is presently underway to determine the conditions under which diamond dust occurs, and to estimate its effect on infrared radiation fluxes. Aircraft-derived temperature profiles (as well as radiosondes from the ice camp) are also used to validate temperature profiles and low-level stratification retrieved from TOVS radiances. Errors in satellite-derived temperature profiles during the LeadEx period are on the order of 2 and 3° K above and below 800 mb, respectively.

(d) Heat Fluxes from Leads

We found that the heat flux from a single lead determined from a surface drag approach was about 40 W m^{-2}. The heat flux was also calculated from the measured change in the temperature versus altitude over time for the lowest few hundred meters, by applying the thermodynamic energy equation assuming, that radiative flux divergence was small. The result of this calculation was 30 W m^{-2}.

(e) Aircraft Data

A written summary of data recorded aboard the University's Convair research aircraft during LeadEx was provided to Dr. Robert Fett for inclusion in the LeadEx aircraft data archive. This summary included winds aloft data and aircraft flight tracks, as well as lapse rate as a function of time and location.

PUBLICATIONS

1. Sheridan, P. J., R. C. Schnell, T. J. Conway and R. J. Ferek. 1992: Aerosol Chemistry Measurements over the Beaufort Sea During AGASP-IV/LEADEX, April 1992, Proceedings of the Fifth International Conference on Arctic Air Chemistry, ed. by N. Z. Heidam, 7-10 September 1992, Copenhagen, Denmark.
2. Contributions to "The LeadEx Experiment", EOS, 74, 393–397 (1993).
3. Ferek, R. J., P. V. Hobbs and L. F. Radke: Dimethyl Sulfide in the Arctic Atmosphere. J. Geophys. Res. (To be submitted).
4. Tsay, S. C. and M. D. King: Observational and Theoretical Studies of Various Types of Surface Bidirectional Reflectivity. J. Atmos. Sci. (In preparation).

5. Yu, Y., D. A. Rothrock and R. W. Lindsay: Validation of AVHRR Sea Ice Surface Temperature with *in situ* and Aircraft Data. (In preparation).

PRESENTATIONS

1. Waggoner, A. P.: University of Washington Atmospheric Sciences LeadEx Flight Program, Presented at the LeadEx Workshop, Applied Physics Laboratory, University of Washington, Seattle, October 5–7, 1992.
2. Waggoner, A. P.: An Early Look at LeadEx, Presented at Atmospheric Sciences Colloquium, University of Washington, Seattle, February 19, 1993.
3. Tsay, S. C., and M. D. King: Measurements of Bidirectional Reflectivity over Snow, Ice and Other Types of Surfaces. Presented at AGU Spring Meeting, Baltimore, May 24–28, 1993.