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Atmospheric Profiles, Clouds and the Evolution of Sea Ice Cover in the Beaufort and Chukchi Seas

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LONG-TERM GOALS

This is a collaborative research project with the University of Washington (Axel Schweiger, PI). Its purpose is to examine the role of sea-ice and cloud interactions in the retreat of the seasonal ice zone (SIZ). As sea ice retreats further, changes in lower atmospheric temperature, humidity, winds, and clouds are likely to result from changed sea ice concentrations and ocean temperatures. These changes in turn will affect the evolution of the SIZ. An appropriate representation of this feedback loop in models is critical if we want to advance prediction skill in the SIZ. The overall project is an integrated observation and modeling program aimed at understanding the interplay of atmosphere, ice, and ocean in the SIZ of the Beaufort and Chukchi seas (BCSIZ). It will take advantage of routine Coast Guard C-130 domain awareness missions that take place at two-weekly intervals from March through November.

This portion of the overall project will contribute to technology development by adapting and deploying a new generation of truly expendable (<$700) micro-aerial vehicles (Data Hawk and SmartSonde) designed to obtain detailed high-vertical-resolution temperature, humidity and wind profiles and cloud layering information that cannot be obtained with traditional dropsondes. Our vision is that these vehicles will deliver new, inexpensive measurement capabilities for research and operational purposes in the data sparse region of the BCSIZ as well as other regions of the globe.

This project provides a unique and cost-effective opportunity to establish a fully integrated observation and modeling program that builds on existing experience and data in a region that is poorly understood and is undergoing rapid change. Improved prediction of the marine environment in this area may be critical for future Navy operations.

OBJECTIVES

The main objective of the University of Colorado portion of the project is to adapt an existing low cost, expendable small unmanned aircraft system (sUAS) called the DataHawk for air-deployment from a

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Coast Guard C-130 to measure temperature and humidity profiles and cloud top and base heights in the seasonal ice zone.

APPROACH

The approach builds on an existing low cost capability to measure in-situ atmospheric data, consisting of a small unmanned aircraft system (DataHawk) developed at the University of Colorado. The Data Hawk (Figure at right) is an electrically powered miniature UAV equipped with a thermodynamic sensor package measuring pressure, temperature, humidity, turbulence, and mean winds. The Data Hawk type of vehicle occupies a niche in between a drop or balloon sonde, which is low cost but cannot be guided, and a typical UAV, which provides guidance flexibility but uses costly avionics and commercial aerospace components. The Data Hawk vehicle and its avionics were designed with low cost and atmospheric sensing applications in mind. It uses a custom autopilot, developed by the investigators [*Pisano et al.,* 2007], using aerodynamics and control principles to minimize the flight control complexity, significantly reducing the size and cost of electronics and sensor components. It takes advantage of low cost components for the airframe and electric propulsion (from high-volume manufacturing for the radio control hobby industry). The flight control utilizes newly developed, robust, vector field guidance strategies [*Lawrence et al.*, 2008] to automate flight and simplify the ground station interface so that pilot training is not necessary to operate the vehicle. Currently, this vehicle and the flight control system are produced in small quantities at a unit cost of $700, more than an order of magnitude lower than other UAVs with similar capabilities, such as the folding wing BAE Coyote.

The sensing and avionics system on the DataHawk will be adapted to a folding-wing airframe that can be deployed from a Coast Guard C-130. This new vehicle, called the SmartSonde, will be expendible, similar to a dropsonde, but can be guided to regions of interest and can remain aloft, climbing and desceding, for approximately 1 hour to obtain high-resolution atmospheric measurements. New sensors will be developed to enable advanced wind and clould margin sensing from this platform. This work will be carried out at the University of Colorado by a graduate student in Aerospace Engineering Sciences, under the direction of PI Dale Lawrence and Co-I James Maslanik.

WORK COMPLETED IN FY 2014

Accomplishments toward the tasks outlined in the project proposal are detailed below.

- **Task 5: Design a tube launch canister and release mechanism for the SmartSonde**

The SmartSonde vehicle design was changed to use a twin-boom tail support, instead of the previous single boom. This eliminated undesirable tail rotation and made the design more rugged for tube launch. Figure 1 shows a prototype using the new design.

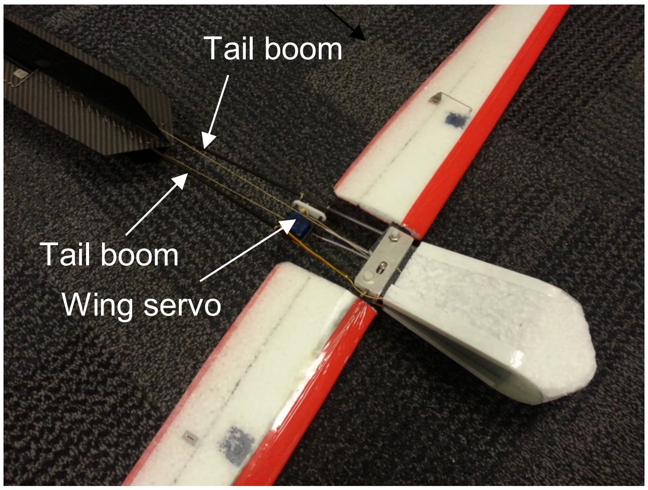

Figure 1: Improved SmartSonde tail boom and wing deployment servo.

The wing unfolding mechanism was changed from a stored-energy approach, to a slower and more controlled constant-velocity approach, using a servo motor instead of an extension spring. This actually proved to be lighter weight and lower cost, and was much more reliable in overcoming the increased resistance torque of the wing latch mechanism near the wings-open position. This is also shown in Figure 1.

A new autopilot was designed and constructed to provide more reliable flight characteristics in dense clouds. This design uses new low-cost inertial sensors instead of thermopiles to sense vehicle atttiude for flight control and wind measurement. It also provides much improved memory and computational speed compared to the older CUPIC design, yet is only about 15 percent larger. See Figure 2. Drivers for the new sensor suite have been written and tested. The flight control code is now in the process of being ported from the CUPIC to the new hardware platform.

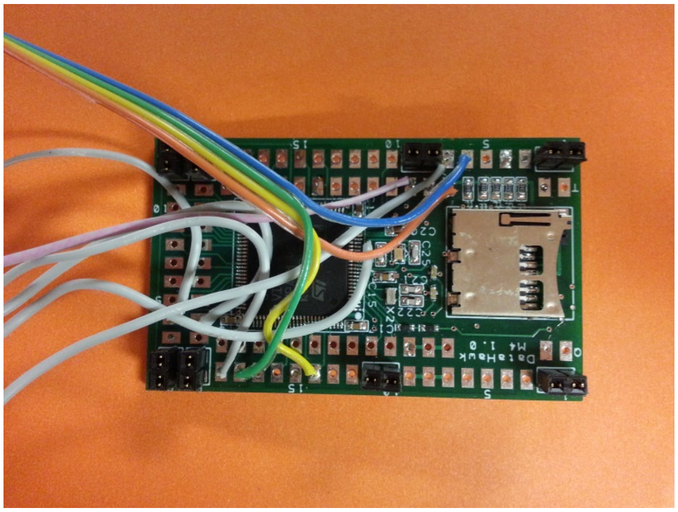

Figure 2: New autopilot prototype for SmartSonde flight control and wind/cloud

Approval from the Coast Guard to launch the SmartSonde from a C-130 was pursued. This initial application was not successful, due to its low priority in the Coast Guard mission set, resulting in no resources to investigate the safety concerns. Instead, it was suggested to eliminate the concerns by removing the motor from the SmartSonde, making it a GliderSonde. This would make it impossible for the GliderSonde to ascend above the release altitude, enabling assured deconfliction with the C-130. A second application was submitted along these lines, and is currently under evaluation by the Coast Guard.

- **Task 10: Validate cloud base sensing methodology using SmartSonde in restricted airspace**
  Two approaches were pursued to validate the IR sensing system. An existing DataHawk vehicle with this sensing system was flown in conjunction with a commercial ceilometer (Vaisala CL31) into a low cloud deck at Oliktok Pt. Alaska in R-2204 restricted airspace (as a measurement of opportunity during the recent MIZOPEX field campaign). An alternative approach was developed by incorporating the proposed IR sensors and ground-sky temperature difference algorithm into a tethered balloon borne payload (Figure 3).This approach allows the balloon to repeatedly ascend and descend through the cloud base under quiescent sensor attitude conditions. The same ceilometer was used to provide a cloud base reference measurement, as well as visual markings of altitudes where the balloon and its payload disappeared into the cloud base.

Figure 3: Tethered balloon-borne IR sensing payload

RESULTS FROM FY 2014

- A second flight of the tethered balloon-borne IR cloud margin sensor was conducted in Colorado on an overcast day with a particularly low cloud deck. This provided much better data than the previous attempt, providing several penetrations of the cloud base. Two different IR sensors were utilized, having different temperature signal gains, along with coincident measurements from a commercial ceilometer (Vaisala CL-31). Figure 4 shows the ceilometer backscatter power plots (black lines) at 10 second intervals during one of the balloon ascents (dashed blue line). Higher backscatter power is indicated by a shift to the right. This clearly shows a cloud margin beginning at about 240m altitude, with a peak in return power at about 280 m. Above that, the power decreases, and no higher returns were present, indicating that the

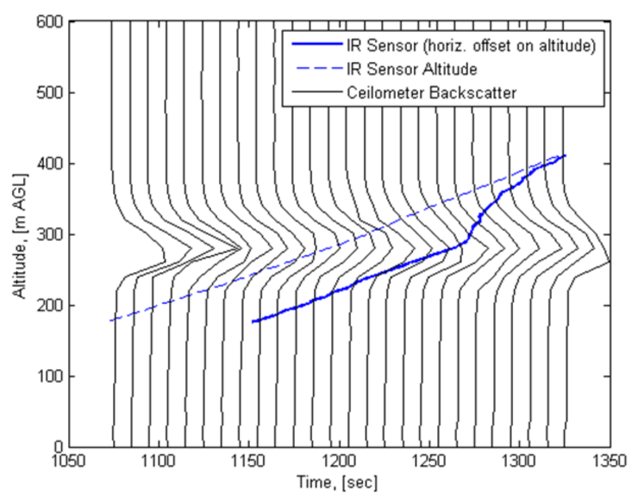

Figure 4: First successful flight validation of the IR cloud margin sensor on a tethered balloon.

laser return is extinguished above about 340m, presumably due to a dense, thick cloud layer. The margin of the layer is rather diffuse, extending over an optical extinction length of about 100m. The high gain IR sensor reading is provided on the same plot (thick blue line), by an offset to the right from the corresponding sensor altitude (dashed blue line). This signal is proportional to the temperature difference between a 45deg downward-looking thermopile and a 45deg upward-looking thermopile. Below the cloud layer the temperature difference is large, indicated by the large offset to the right of the blue line from the dashed line. As the sensor enters the cloud margin, the relatively higher ground temperature is obscured by the thickening cloud, and the temperature difference begins to reduce rapidly, essentially coincident with the peak in ceilometer backscatter power. Above this altitude, the IR sensor signal continues to decrease, consistent with a dense, thick cloud layer, which should completely remove any ground-sky temperature difference once sufficiently inside the cloud margin. This sensor's optical extinction depth is also about 100m, beginning at the altitude of maximum ceilometer return. This data indicates that the new IR cloud margin signal (taken at the abrupt inflection point in its optical temperature difference reading) agrees with the ceilometer cloud margin reading (taken at the peak in backscatter power) to within about 30m in altitude.

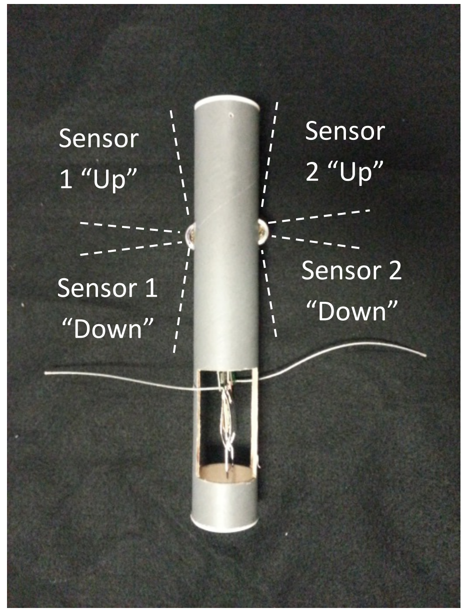

Figure 5: Two IR cloud margin sensors integrated into a MetroModem drop sonde.

- Data from the first field deployment of the IR cloud margin sensor was also obtained during the September SIZRS campaign in Alaska. Working with the manufacturer of the MetroModem drop sonde, additional telemetry channels were added, with an analog interface for two IR cloud margin sensors on each sonde (Figure 5). As in the tethered balloon test in Colorado, the two sensors had different signal gains, so the optimum setting could be determined for the cloud margin sensing in the high latitude environment, where ground/sky temperature differences were not expected to be as large as at lower latitudes. Figure 6 shows the two sensor readings (in counts) versus the sonde pressure altitude (in hPa), along with the RH data from the same sonde. Note the abrupt change in IR sensor readings at about 900 hPa, indicating passage from a clear region at high altitudes, where the optical sky temperature is lower than that of the cloud deck below, into the upper margin of the cloud where

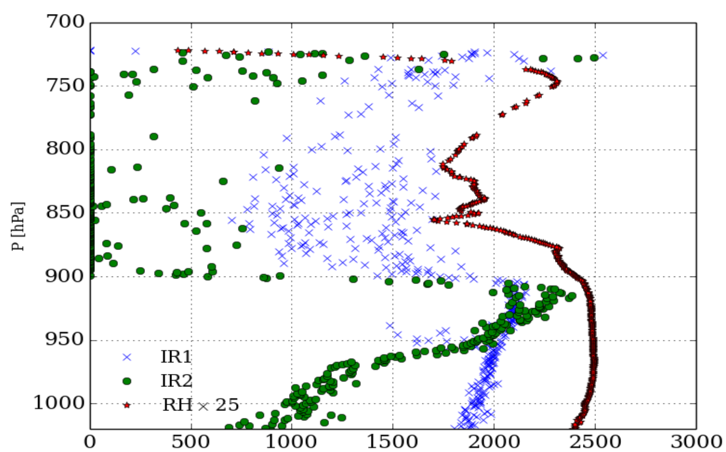

Figure 6: First field measurements from the IR cloud margin sensor on a drop sonde.

the up vs. down optical temperature difference vanishes (at about 2000 counts for both sensors) since both the up and down thermopiles in each sensor see only the local cloud temperature. At about 950 hPa an up-down temperature difference emerges relatively slowly, presumably due to a diffuse cloud base providing a gradually clearing view of the relatively warmer ground. These initial results are very encouraging in that cloud margins seem to be sensitively visible in the IR sensor data.

- An alternative to the vertical optical cloud base sensing approach was investigated, that may be able to provide a more precise cloud margin measurement. This avoids the uncertainty caused by the vertical optical extinction depth in a cloud margin by looking *horizontally* for IR backscatter, which could vary much more abruptly when cloud margins are distinct and uniform laterally, compared to the laser ceilometer or the up vs. down optical temperature difference. This requires an airborne IR backscatter system that can look horizontally as it enters the cloud margin.

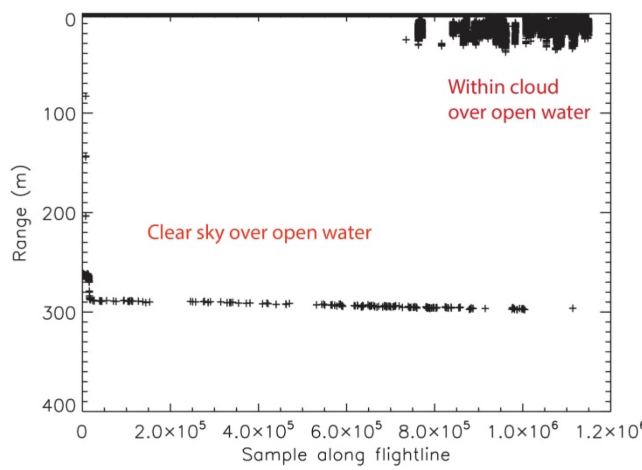

Figure 7: Response of CULPIS airborne infrared laser altimeter to presence of liquid water cloud.

Previous work by our group using airborne laser altimeters oriented vertically and operating in the near infrared portion of the spectrum (approximately 900 nm) has shown that this class of laser rangefinder is sensitive to reflection from cloud water droplets. For example, Figures 7 and 8 show laser altimeter range data and aerial photographs obtained by the NASA SIERRA UAS using the CU Lidar Profling and Imaging System (CULPIS), during a transition from operation in clear sky over open water at an altitude of about 290m to flying within cloud. As seen in the right-hand side of the plot, scattering from water droplets limits the penetration depth of the laser to about 30m.

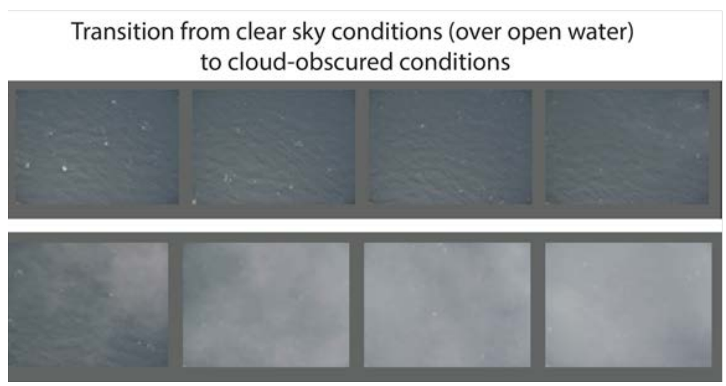

Figure 8: SIERRA UAV aerial photographs showing surface and sky conditions along the transition from clear sky to presence of clouds (corresponding to the laser altimeter range data in Figure 7). Moisture observed on the SIERRA's camera as well as humidity measurements and the range data themselves indicate t that the UAV was flying within cloud rather than in clear conditions over cloud.

Due to size and power requirements, laser systems such as CULPIS are unsuitable for smaller UAS such as the SmartSonde. We therefore considered other sensor options, including a small, inexpensive infrared rangefinder (Sharp GP2Y0A710K0F, \$25) and a relatively short-range laser rangefinder (Lightware SF02, $275). The experimental approach involved exposing the rangefinders to clear air and to steam to simulate the presence of cloud moisture. As depicted in Figures 9 and 10, this involved alternately allowing steam to rise into the view path of the sensors vs. blocking the steam to yield a clear path. An Arduino Uno was used to log voltage output from the sensors, with voltage output correlating to range. While this is a simple and relatively crude test arrangement, we consider it sufficient to address the basic question of whether these small, low-cost sensors are affected by presence of water droplets. The results show that both instruments are sensitive to the presence of water droplets in the form of steam within the view path (Figures 11 and 12). The responses are substantial, suggesting that simple thresholding of the data could be used to detect presence of cloud water droplets within the view path. Based on these results, we are

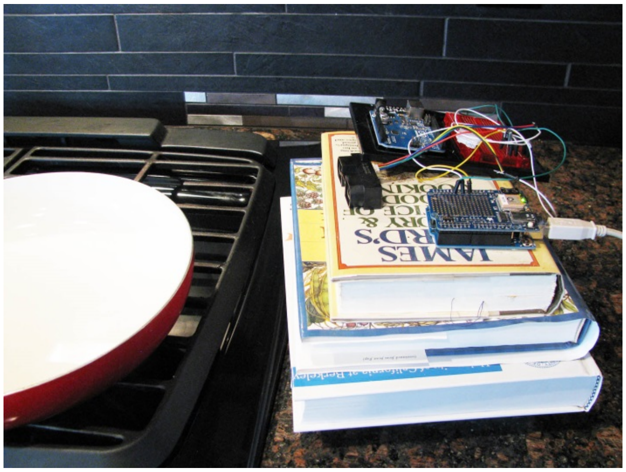

Figure 9: Experiment arrangement with the Sharp rangefinder, alternating between viewing clear air and steam produced by

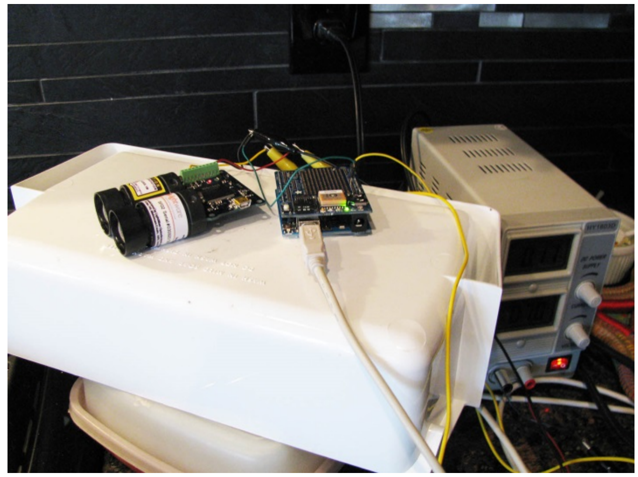

Figure 10: Experiment arrangement with the larger Lightware rangefinder.

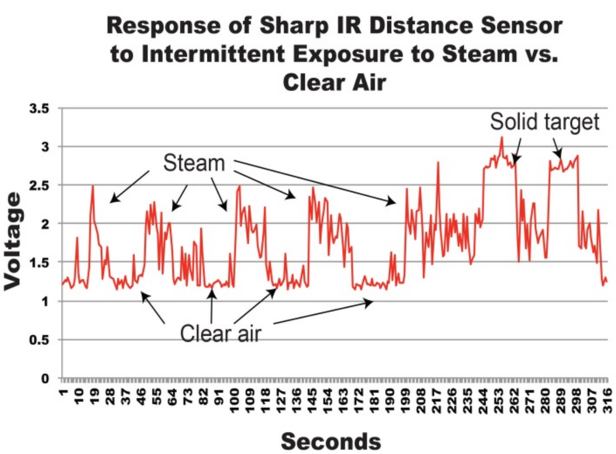

Figure 11: Response of the Sharp rangefinder to intermittent presence of steam along the view path of the instrument. In the particular setup used, an increase in voltage corresponds to shorter distance (i.e., the sensor was receiving returns from water droplets).

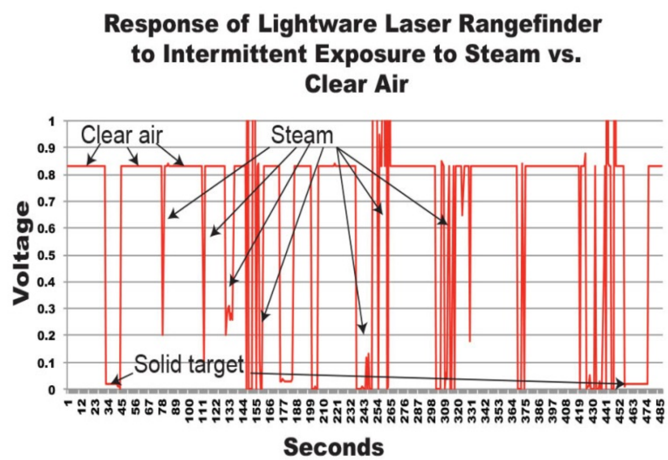

Figure 12: Response of the Lightware SF02 laser rangefinder to intermittent presence of steam along the view path of the instrument. In the particular setup used, a decrease in voltage corresponds to shorter distance (i.e., the sensor was receiving returns from water droplets).

considering additional testing that would include: (1) smaller, lower-cost and shorter-range Sharp-type infrared rangefinders; (2) reducing the sensor approach to simply an infrared LED and infrared sensor to test effects of obscuration by water droplets; and (3) exposure to actual cloud/fog conditions.

IMPACT/APPLICATIONS

The new SmartSonde folding wing design enables the slow flying sUAS to be deployed in a variety of ways from much higher speed delivery vehicles, including 1) sonobuoy tube ejection, 2) hand dropping from the rear ramp (e.g. for the C-130), 3) release from wing pods, and 4) release from fuselage stores pods or bays. It also enables ground or water launch from bungee or air gun launchers. This provides a flexible ability to deliver the sensing system from a variety of carriers, expanding the ability to take atmospheric measurements at low cost over wide areas.

RELATED PROJECTS

The Marginal Ice Zone Process Experiment (MIZOPEX) seeks to explore the use of unmanned aircraft systems (UAS) to provide a complementary ability to make surface and sub-surface measurements in the Arctic marginal ice zone. The DataHawk vehicles that were precursors to the SmartSonde in this project are being re-purposed in MIZOPEX as one-way self-deploying surface sondes (SDSS) to land in the ocean in and near the ice margins to measure surface and subsurface sea temperatures over a ten day period. See http://ccar.colorado.edu/mizopex/index.html for more information.

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