

Applications of Aerosondes in the Arctic

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The U.S. Arctic remains one of the most difficult places on Earth for year-round scientific observations and research. Logistical support is very expensive, and scientists frequently face dangerous, cold sea-ice dynamics, aircraft icing—even polar bears. While satellites can obtain data in remote regions, their application to many arctic environmental problems is hampered by persistent cloudiness and the complexity of the underlying snow/ice surface.

One of the major recommendations of the 1997 report, “Logistics Recommendations for an Improved U.S. Arctic Research Capability” (www.arcus.org/logistics/index.html), was to increase use of robotic aircraft to meet the growing need for environmental observing in the region. Unmanned aerial vehicles (UAVs) excel in “dull, dirty, dangerous” missions.

Such UAVs, made by Aerosonde (www.aerosonde.com), were first flown in the Arctic (from a base in Barrow, Alaska) in April 1999 to obtain meteorological observations in support of the Department of Energy Atmospheric Radiation Measurement Program (ARM). However, after only 16 h of flying for this mission, the project lost two aircraft due to airframe icing and one aircraft due to carburetor icing. This mission clearly demonstrated the difficulties of flying the Aerosonde in the extreme arctic environment.

The National Science Foundation Office of Polar Programs soon followed these tests by funding a project to establish a facility in Barrow, Alaska, adapt the Aerosonde to extreme arctic conditions, adapt and integrate miniature instrumentation, and assimilate Aerosonde data into predictive models. Meanwhile,

the Office of Naval Research began supporting the development and integration of a variety of miniature research instruments for remote sensing of the sea ice surface, measurements of radiative fluxes, and in situ measurements of cloud and precipitation characteristics. Since the first Arctic flights, the Aerosonde has undergone a number of engineering modifications (see Table 1 for Aerosonde specifications). As a result, the Aerosonde project is overcoming the engineering and logistical challenges of operating in the polar environment.

ARCTIC-SPECIFIC TECHNOLOGY. The difficulty of addressing aircraft icing in the Arctic, where supercooled liquid water is abundant year-round, was compounded by a previous lack of research on icing amelioration for small airframes. Airframe icing (Fig. 1) has been addressed in several ways: prediction, detection, survival tactics, insulation or heating, and minimizing or removing icing. Testing (down to less

TABLE 1. Technical specifications for the Mark 3 Aerosonde.

SPECIFICATIONS	
WEIGHT	13.5 kg
WING SPAN	2.9 m
ENGINE	24 cc, fuel injected, premium unleaded petrol
NAVIGATION	GPS
PERFORMANCE	
SPEED/CLIMB	18 – 32 m s ⁻¹ /2.5 m s ⁻¹ (at sea level)
RANGE/ENDURANCE	>30 h/>3000 km
ALTITUDE RANGE	Up to 7 km (medium weight)
PAYLOAD	Maximum 2 kg with full fuel load

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FIG. 1. Ice on the leading edge of an Aerosonde together with an early icing device (the vertical tube) and the current piezoelectric device mounted on the leading edge of the wing (the device inside the circular opening above the fuselage).

than -20°C) has been conducted by Aerosonde in an industrial freezer and in an environmental chamber suitable for icing experiments on aircraft components at the University of Colorado.

All electronics bays have been insulated and the cables teflon-sheathed to mitigate cold-induced brittleness. The pitot-static system, which provides airspeed, is very prone to icing and failure. Icing of the pitot-static system has been solved by a heated tube that operates successfully even when considerable ice builds up on other forward-facing surfaces. Additionally, many instruments cannot operate effectively at the cold arctic temperatures, and appropriate insulation mechanisms have been implemented.

To eliminate carburetor icing, the Aerosonde engine has been converted to a fuel-injected system, which also allows the engine to be tuned for a much broader range of operating conditions. A redesigned lubrication system eliminates problems with cold engine oil and freezing condensation on the oil lines.

During flight, the first line of defense is an analysis of icing potential based on either meteorological analyses or the direct observations from the aircraft. The second line of defense is an icing-detection device specifically developed for the Aerosonde and installed on each aircraft. The icing sensor uses a piezoelectric element running at its natural resonance, which changes in a known fashion with temperature

and ice buildup. These sensors allow the operators to determine when the aircraft is in icing conditions, and also when ice has sublimated or melted, so that the aircraft can fly back into icing layers without having to land for visual inspection. To support research on aircraft icing, a small video ice-accretion camera (Swann SpyCam) is mounted on the wing to continuously monitor ice accretion on the airframe. Images from the camera are downloaded in real time via radio communications and used to calibrate the icing sensor and study where and how ice develops on the airframe.

The icing forecasting scheme and the icing detector help the aircraft avoid most icing conditions. However, sometimes flight through icing conditions is unavoidable or is desirable for research reasons. A Hyperpolish anti-icing coating on the wings and propeller helps inhibit ice formation, but is not sufficient to avoid ice development entirely.

The most promising approach to icing mitigation is to force the ice to break over the leading edge of the airfoil using an off-the-shelf servo and Mylar. Although this works in a wind tunnel, several issues remain to be addressed before successful implementation in the Aerosonde.

INSTRUMENTS. Instruments for the Aerosonde must fit the payload capacity of 7 kg, which includes fuel plus instruments. For each kilogram of payload, the range, which can exceed 3000 km, is reduced by 500 km. The space for instruments is $50 \times 125 \times 200$ mm, which can be modified for special shapes, and the aircraft provides 40 W of sustained power.

The harsh conditions have not prevented the Aerosonde from using instruments (Table 2) that are



FIG. 2. An Aerosonde being collected after landing on the NARL runway in Barrow.

TABLE 2. Aerosonde meteorological and environmental instruments.

PAYLOAD TYPE	MISSION	STATUS
Heitronics KT11 infrared pyrometer	Surface temperature	Operational
Still camera (Olympus)	Surface imaging	Operational
Video camera (Various)	Surface imaging	Operational
Sulfur and carbon compounds, NASA JPL	Volcanic plume and atmospheric chemistry	Instrument flight tested
Cloud particle image, NCAR	Cloud physics, icing	Unit complete and at integration stage
Micro Synthetic Aperture Radar, Brigham Young Univ.	Surface imaging	Unit complete and at integration stage

mostly purchased “off the shelf” from commercial vendors, with some modifications by Aerosonde. The two exceptions are among the more demanding but potentially valuable instruments: the micro-SAR (synthetic aperture radar) and cloud physics instrumentation, which are being designed specifically for the Aerosonde.

OPERATIONS. In some ways, the Aerosonde is well designed for Arctic operations. For instance, launches from a car roof rack, and belly landings, enable operations from a wide range of locations. In the Arctic, we use an old steel runway located at the disused Naval Arctic Research Laboratory (NARL), a few hundred feet from the coast of the Beaufort Sea (Fig. 2). It is difficult to keep the runway clear of snow, especially when the winds are high, which occurs frequently, especially during autumn. The logistics team is currently trying to get funding for snow-clearing equipment. During September 2002, a large number of polar bears stranded in the region posed yet another operational hazard.

In all missions, the aircraft is completely robotic, following a defined mission under the watchful eye of an Aerosonde commander. The recent installation of communications via low Earth-orbiting satellite (Iridium) enables operations and command to be located anywhere on Earth. The launch site at Barrow can command and monitor the aircraft in the vicin-

ity or on short endurance missions. For extended-range missions, however, we use a remote command center in Melbourne, Australia, which helps minimize the staff requirements in Alaska.

One ongoing problem for UAVs in the Arctic is the large number of small manned aircraft that rely on the “see and be seen” flight principle. To date, the Federal Aviation Administration (FAA) has limited us to operations beyond 12 n mi from shore, except for a single corridor from Barrow to the open ocean and over a small area near Point Barrow. The scientific missions would benefit greatly from expanding this area to include barrier islands such as Cooper Island, along the coast, over fast ice, and other land areas. The new Capstone Air Traffic Control System, which is currently being tested in Alaska, shows promise for helping to alleviate the “see and be seen” restraint on UAV operations.

The thriving scientific community in Barrow cannot exist without the support and cooperation of the broader North Slope community. While Aerosonde operations seem to have been received enthusiastically by most Barrow residents, some concerns have been raised about possible negative impact of the flights on local wildlife (notably bowhead whales and water fowl). Our response has included working on new ways to use the Aerosonde to help the Inuit, such as assisting with the ongoing bowhead whale census and other migratory animal surveys, aiding search and rescue operations, and helping assess coastal erosion. The Aerosonde team has also actively participated in local radio interviews and the local Spring Festival parade, demonstrated the aircraft at town meetings in Barrow, and helped enhance the science programs in local schools.

METEOROLOGICAL OBSERVATIONS. Icing and flight restrictions remain critical challenges, but the Aerosonde has been able to serve its original purpose in Barrow—to provide boundary advection for single-column model (SCM) experiments at the U.S. Department of Energy’s (DOE) Atmospheric Radiation Measurement (ARM) program site. For instance, during an SCM mission on 5–7 May 2002, three different Aerosondes provided continuous sampling for 48 h along a 30-km² box about 40 km north of Barrow (FAA restrictions prevented us from centering

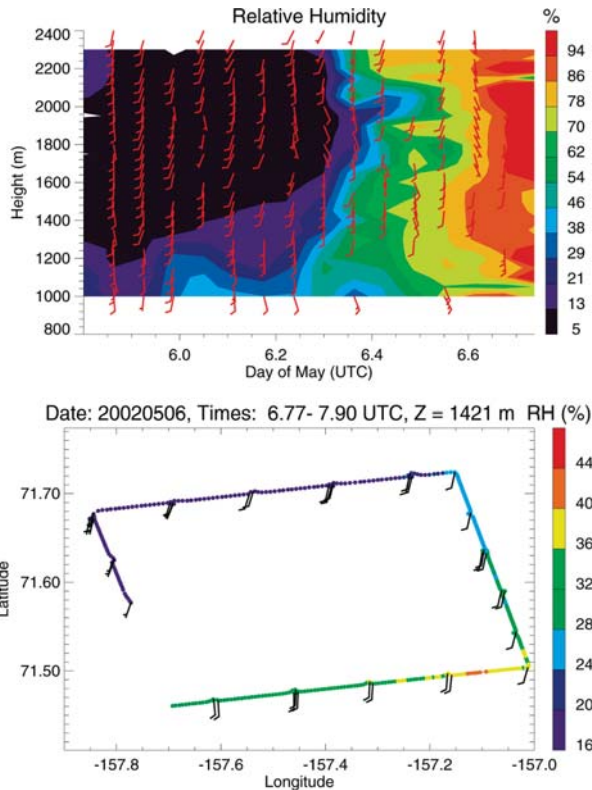


FIG. 3. Analysis of relative humidity obtained during single-column mission flown by multiple Aerosondes off the coast of Barrow on 5–6 May 2002. Time–height plot shown in the upper panel was generated using data from slant-descent/ascent by a single Aerosonde flown every 60–90 min. Horizontal variations in relative humidity shown in the lower panel were captured during (30-km) two-box pattern flown every 60–90 min.

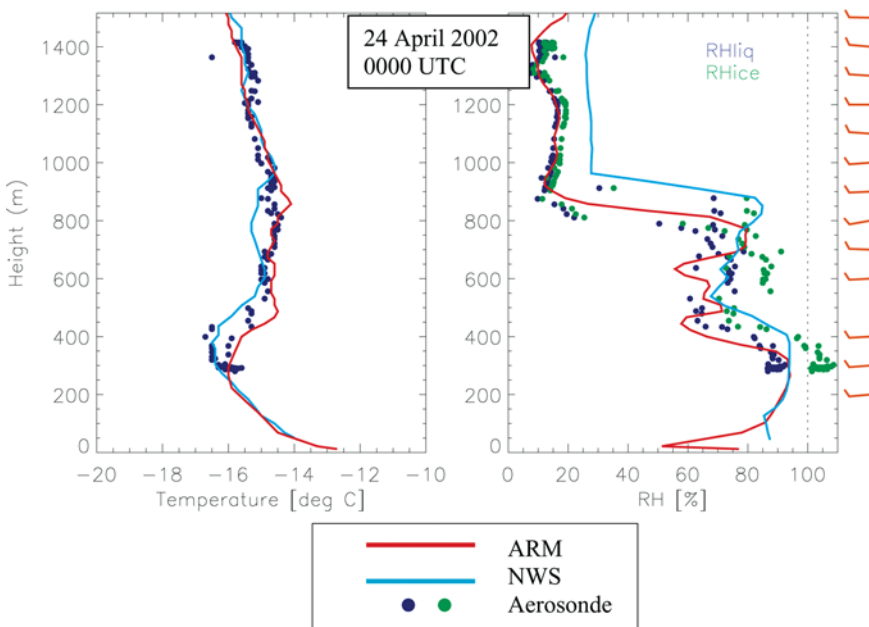


FIG. 4. Sounding data obtained around 0000 UTC on 24 April 2002 at three separate locations in the Barrow vicinity. Aerosonde data shown are from an up-down profile obtained at Point Barrow between 2330 and 0007 UTC. Wind barbs in the right margin are also from the Aerosonde. NWS data were provided by the JOSS at 6-s time resolution. ARM data have a 1-s time resolution.

observations over the ARM site). An attempt was made to fly each side of the box at constant altitude and then perform a profile during the fifth leg. This pattern had to be adjusted when icing conditions developed. Nonetheless, profiles from the Aerosonde indicated a rapid moistening between 1 and 2 km as relative humidities in this layer increased from 5% to over 90% in association with the passage of a warm front and associated strong southerly flow (Fig. 3).

A number of Aerosonde missions have also been flown to evaluate the accuracy and representativeness of the local operational soundings by the NWS near Post Rogers Memorial Airport and at the DOE ARM facility. To date, approximately 20 Aerosonde profiles flown at Point Barrow have coincided with NWS soundings.

In the example profiles in Fig. 4, the NWS VIZ B2 sonde tends to be more moist than the ARM and Aerosonde RS80 15H radiosondes, particularly in an extremely dry layer above 900 m. The ARM and Aerosonde relative humidity values agree fairly well. The greatest variability between the three soundings occurs between 300 and 900 m, where the NWS sounding is 1°–2°C cooler than that obtained at the ARM site and by the Aerosonde at Point Barrow. The boundary-layer depth (topped by an inversion) also varies by about 75 m between the NWS and ARM sondes. The differences in the soundings may arise from a combination of different sonde instruments used by Aerosonde, ARM, and NWS, and slight differences in locations of the soundings that can give quite different results in a coastal environment.

Owing to the lack of in situ sounding measurements and difficulties with satellite-retrieved profiles in the region, large NWP errors in

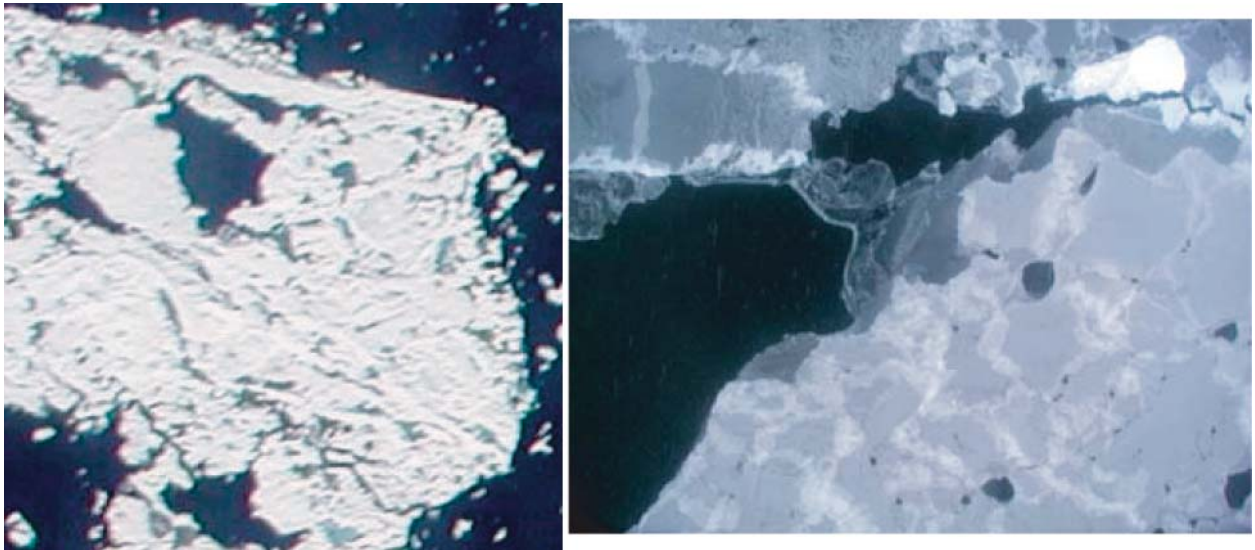
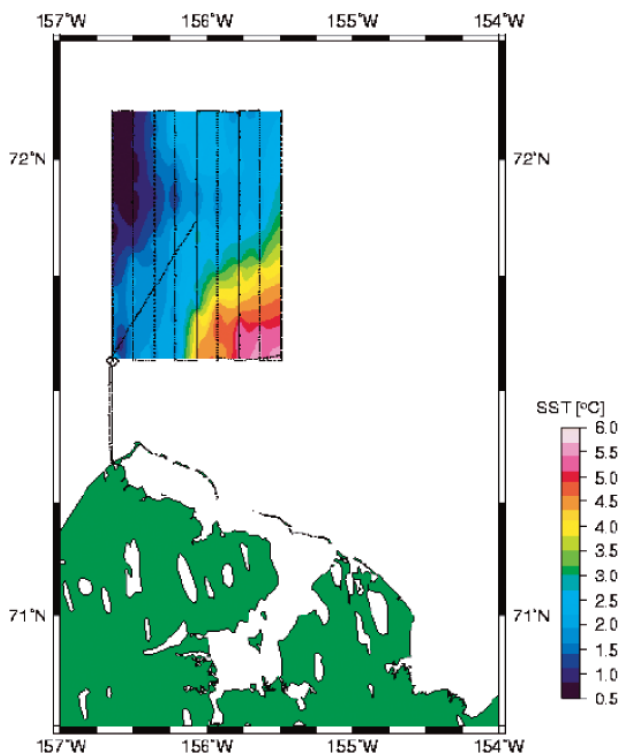


FIG. 5. (left) Summer sea-ice conditions showing melt ponds on the surface of a multiyear floe approximately 100 km north of Barrow in August 2000, recorded from an aircraft altitude of 1500 m. (right) Nilas, new, and young ice in a refreezing lead in April 2002, observed from an altitude of 200 m.

the Arctic are not uncommon. An eventual goal is to use the Aerosondes in targeted (or adaptive) observational strategies to provide input to the operational NWP models. Data from Aerosonde flights have been

used by both the National Center for Environmental Predictions and the European Centre for Medium-Range Weather Forecasting in their operational analyses. We have also been working with the NWS in Alaska to disseminate sounding data from the Aerosonde in real time.

SST (17 Sep. 2002)



SURFACE REMOTE SENSING. We have used the KT-11 infrared pyrometer to measure surface temperature and a camera to image the ice surface (Fig. 5). To date, sea-ice investigations using Aerosondes have focused on basic ice reconnaissance; mapping of ice concentration, melt-pond fraction, and refreezing lead conditions; studies of ice and surface temperatures within the marginal ice zone; and sampling of atmospheric conditions over sea-ice leads.

During September 2002, a large region of open water spanned much of the Beaufort Sea region. Surface temperature mapping revealed a large plume of anomalously warm waters that persisted for at least two weeks (Fig. 6). The warm plume appeared to originate east of Point Barrow. It is believed that the strong gradients in SST observed by the Aerosonde were created by outflow from the MacKenzie River.

FIG. 6. Ocean surface temperatures from raster-grid pattern flown by an Aerosonde on 17 September 2002. The surface skin temperature is obtained with a downward-looking KT-11 radiometer (figure courtesy of J. Inoue).

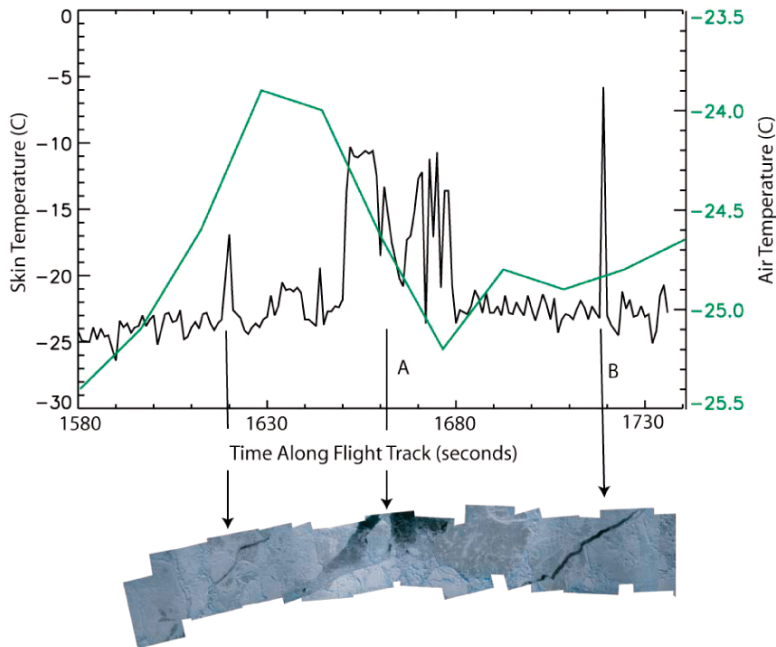


FIG. 7. Surface temperatures (black line), air temperatures (at 200-m altitude; green line) and aerial photographs acquired along a flight-track segment within pack ice on 16 March 2003. Winds were from the east, with the aircraft flying from west to east (left to right along the x-axis). Increases in surface temperature correspond to leads visible in the photo mosaic. New and young ice in leads, as indicated at locations A and B, are associated with the darker areas in the image mosaic.

During March–April 2003, several missions focused on extensive mapping of skin temperatures in conjunction with aerial photographs of ice conditions. These data are proving useful for mapping the fraction of the ice cover consisting of leads and young ice, as well as studying possible effects of leads on atmospheric conditions. The temperature contrast between leads and thick ice permits estimation of the fraction of lead area within the pack: new ice is estimated as ice warmer than -10°C and young ice as warmer than -20°C , with a mean temperature of thick ice of -24°C . As suggested by data from the flight on 16 March (Fig. 7), an increase and oscillation of air temperatures downwind of the lead may be indicative of the effects of a convective plume of warm air generated by the lead.

FUTURE DEVELOPMENTS. Instruments under development for the Aerosonde (Table 3) offer considerable potential for further investigations of sea-ice conditions. For example, using a combination of laser altimeter and infrared thermometer, the

Aerosonde has the potential for determining sea-ice thickness, surface roughness, and surface temperature over ice, water, and land. Such capability on the Aerosonde would be substantially less expensive than alternatives involving manned aircraft and submarines. Other potential applications using the planned sensors include detailed radar mapping of surface conditions, retrieval of spectral albedo of land surfaces, and monitoring of coastal erosion.

The new instrumentation also should help the Aerosonde make more sophisticated remote observations of the surface and to measure cloud particles and gaseous constituents in the atmosphere, such as ozone. These instruments could serve applications beyond scientific research. For instance, the addition of the infrared camera might assist in the search and rescue of stranded hunters, fisherman, and pilots. The aircraft could monitor coastal sea-ice hazards, pipelines, and shipping routes; perhaps survey birds, whales, and seals; or track caribou herds with radio collars.

With over 1000 h of operation in the Arctic, the Aerosonde has provided valuable meteorological observations as well as remote observations of the ocean

TABLE 3. Instrumentation under consideration for the Aerosonde.

PAYLOAD TYPE	MISSION
Laser altimeter	Environmental surveillance, ice mapping, ocean waves, enable low-altitude flights
Microwave radiometer	Ice and snow age, cloud water content
Short- and long-wave radiometers (down and up)	Energy balance and albedo
Infrared camera	Ice conditions at night, biological, and search and rescue

and sea-ice surface. Additional instruments could extend the range of applications considerably. These instruments, as well as completion of a catapult launch system and implementation of the active airframe deicing system, should extend the range of polar operational capabilities, particularly if FAA clearance can be obtained for flight over land and takeoff under low ceiling conditions.

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FOR FURTHER READING

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