Remote Sensing in the Arctic Using Autonomous Sensors Developed under NASA's Airborne Science Program for the International Polar Year

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Abstract – In support of the International Polar Year (IPY), NASA's Airborne Science Program funded the development and demonstration of five autonomous sensor systems for unmanned aircraft systems (UAS) for Arctic remote sensing science. Following development, all five systems flew successful missions during 2009 and 2010. The missions were:

- "Sea Ice Roughness as an Indicator of Fundamental Changes in the Arctic Ice Cover: Observations, Monitoring, and Relationships to Environmental Factors." This research effort, led by the University of Colorado, combined satellite data analysis, modeling, and aircraft observations. The airborne experiment, "Characteristics of Arctic Sea Ice Experiment" (CASIE) flew from Svalbard, Norway on NASA's SIERRA UAS.

- "Microwave INSAR Properties of the Polar Ice Sheets." This research, led by Stanford University, flew JPL's UAVSAR L-band sensor system on NASA's G-III aircraft for ice topography measurements in Greenland.

- "An Interferometric Ka-band Synthetic Aperture Radar: A New Technique for Glacier and Ice-sheet Topography Mapping." This effort also made glacier measurements over Greenland using a Ka-band radar developed at JPL.

- "Lidar Measurement from a UAS in Support of IPY Activities." The NASA Goddard Cloud Physics Lidar (CPL) was modified for flight on NASA's Global Hawk UAS to measure polar vortex fragments during the recent GloPac mission.

- "UAV Microwave Temperature Profiling (MTP) For IPY." Temperature measurements were made throughout the GloPac mission, including at very high latitude and altitude.

Keywords: arctic, ice, polar, UAS

1. INTRODUCTION. NASA PROGRAM FOR DEVELOPING UAS AND UAS INSTRUMENTATION FOR CLIMATE SCIENCE

One of the most dramatic physical indications of global warming is the changing cryosphere, that is, changes in ice cover at the Earth's poles. Satellites, aircraft and UAS all have capabilities for monitoring the extent of ice and the dynamic changes with season. Somewhat more difficult are measurements of the thickness of the ice, the ice surface conditions, and other land cover such as permafrost, peak and vegetation. More complicated still are measurements of radiation and chemical composition of the atmosphere in polar regions. Sophisticated instruments and flight systems are required for these measurements that help scientists model and predict what's occurring at the poles. The International Polar Year (or IPY) was a collaborative, international effort researching the polar regions. The third IPY is currently in progress as of 2007 and will last into 2009. It is sponsored by the International Council for Science and the World Meteorological Organization. Unfortunately, the poles are expensive places to visit, because they are distant, cold and deserted; infrastructure is sparse and the terrain is rough in polar regions (often consisting of ice blocks with crevasses between them). Because satellite coverage at the poles is insufficient, and manned flights are so difficult, the opportunity to use UAS for research in these areas is enhanced. In 2007, through a Research Opportunities in Space and Earth Science (ROSES) solicitation, NASA awarded five research grants for the development of instrumentation for UAS and accompanying science related to IPY goals. The five projects are listed in Table 1.

Table 1. NASA grants awarded for UAS instrument development and test in conjunction with IPY.

PI	Instrument	Platform	Mission location	Mission schedule
James Maslanik, U. Colorado	Ice profilometer	SIERRA	Svalbard, Norway	Spring 09
Delwyn Moller, JPL	Ka-band SAR	G-III	Greenland	Spring 09
Howard Zebker, Stanford	L-band SAR	G-III	Greenland	Spring 09
McGill, GSFC	Cloud Physics Lidar	Global Hawk	Alaska	Spring 10
Mahoney, JPL	Microwave Temperature Profiler	Global Hawk	Alaska	Spring 10

For each of the five projects, a specific platform was identified. A specific instrument suitable for unattended flight on a UAS was flown, making a meaningful science measurement. NASA's Airborne Science Program funded the instrument development and integration onto the aircraft. NASA's Earth Science directorate funded the flights.

2. LOW ALTITUDE SEA ICE SURFACE ROUGHNESS

The sea ice roughness project was carried out by Professor James Maslanik of the University of Colorado. (Crocker 2010) The airborne component, called Characterization of Sea Ice Experiment, or *CASIE*, made use of the NASA SIERRA UAS. The project was designed for the UAS to carry two laser profilometers at low altitude over sea ice to measure surface roughness from various optical properties. Other instruments were flown also, including a micro-SAR, microspectrometer and two tracking cameras. The total payload weight was less than 100 lbs. The airborne laser profiler ("UAV Laser Profiling System" or ULPS) is a combination laser profilometer and aircraft positioning system developed within the University of Colorado Research and Engineering Center for Unmanned Vehicles

The SIERRA UAS, shown in Figure 1, flew from Svalbard, Norway during summer 2009. This location, shown on the map in Figure 2, was selected to reach sea ice in the Arctic Ocean, and also because permission to fly in the Norwegian airspace was relatively easy to obtain.

Figure 1. SIERRA UAS on the ground at Ny-Alysund, Svalbard

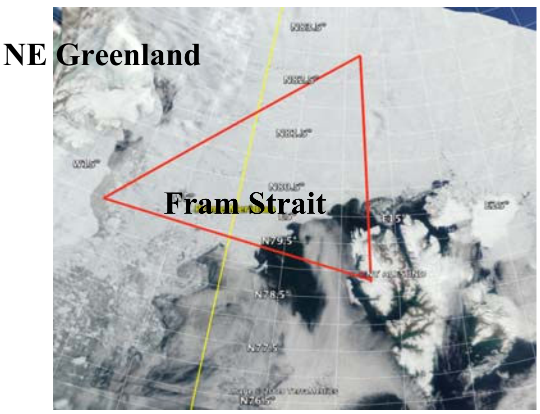

Figure 2. Flight domain approved by Norwegian authorities

Data obtained from this experiment have been successfully analyzed. Combinations of LIDAR profiling, optical imagery and radar imagery provide unique, highly detailed ice information revealing relationships between ice conditions and ice types, as shown in Figure 3 (Long 2010).

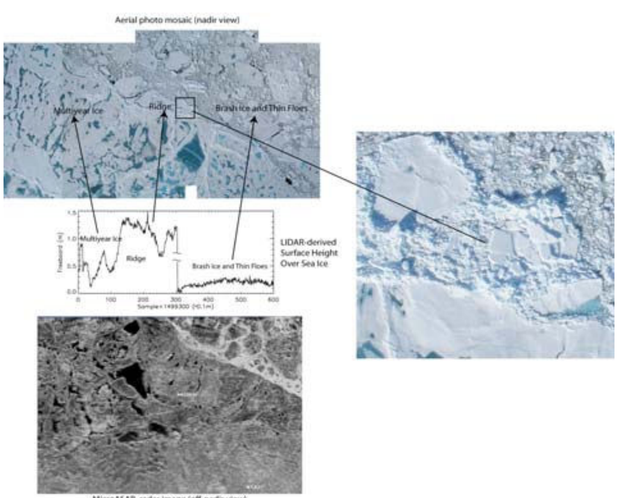

Figure 3. Ice data from the CASIE experiment

3. UAVSAR MISSIONS IN GREENLAND

NASA's "UAV SAR" program was initiated in 2006. Funded through the NASA Earth Science Technology Office, it included two major components: development of an L-band synthetic aperture radar (SAR) and development of flight controls for repeat-pass flight within a 10-m tube. The initial goal of the project was to provide an instrument system for making Earth surface imagery to map and detect fault lines using the technique of interferometry. Currently, the system flies on NASA's Gulfstream III aircraft. It has always been intended to transition to an unmanned system, and a duplicate system is under construction to fly on NASA's Global Hawk UAS. Even when flying on a manned aircraft, the precision flight controller establishes the flight parameters. The aircraft with SAR pod is shown in Figure 4 and the repeat-path trajectories in Figure 5.

As part of the UAS IPY program, two awards were granted to make use of the UAV-SAR on the Gulfstream III as a surrogate UAS. The aircraft flew to Greenland in spring 2009 to carry out the two projects, one carrying the L-band SAR, and the second carrying a new Ka-band SAR.

Figure 4. UAVSAR in pod carried by NASA G-III

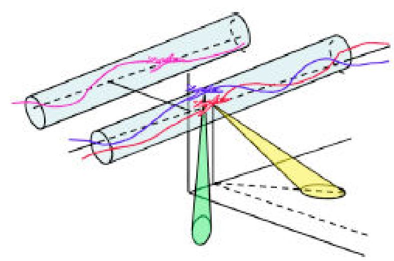

Figure 5. Precision path flying for interferometric measurements

The first project, *Multiwavelength InSAR Properties of the Polar Ice Sheets*, was led by Professor Zebker of Stanford University. Because remote sensing is a critical technology for study of the Earth's polar ice sheets, and poor accessibility, harsh environmental conditions, and the vast size of the ice sheets make satellite observations especially useful, it is important that the signals obtained from space be well calibrated and validated. Radar methods in particular have proven very helpful in observing and constraining ice velocities, dynamics, discharge and accumulation processes. The goal of this project was to acquire and analyze data at various radar wavelengths to be useful in algorithm development for future observations. L, C, and X band (24, 6, and 3 cm) measurements need to be made over the ice sheets and to determine the mechanisms at each wavelength for microwave interaction with the ice. The team used the UAVSAR instrument now being developed at JPL to collect L-band data. Flight tracks of and preliminary data are shown Fig. 6.

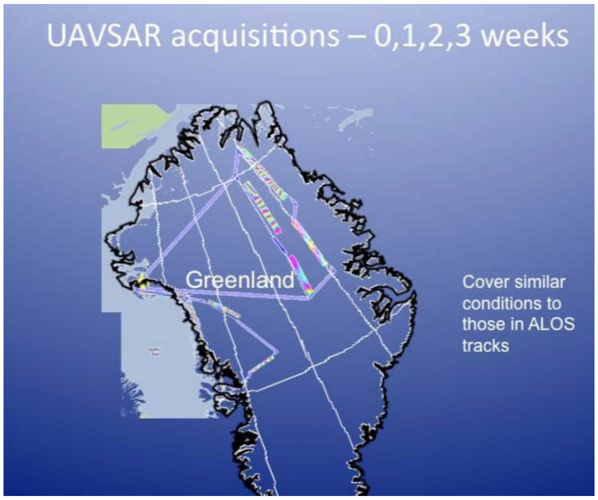

Figure 6. Map of Greenland indicating flight locations. Thule AFB is located at the northwest tip and the Jakobshaven glacier mid-way on the west coast.

A specific sample is shown in Figure 7. This L-band SAR experiment produced repeat pass tracks about 52 km in length from the west coast of Greenland just north of Jakobshavn Glacier. This scene consists primarily of ice, with increase in elevation of 800 m from the coast to the interior part of the track.


Figure 7. Sample Interferometric data from UAVSAR

The second mission carried out on the Gulfstream III was *An Interferometric Ka-band Synthetic Aperture Radar:*, led by Delwyn Moller of Remote Sensing Solutions. For this mission, the project team built a second pod for the aircraft and installed a Ka-band SAR to make ice thickness measurements in the region near the Jakobshaven glacier. The Ka-band pod is shown in Figure 8. To measure ice thickness, the Ka-band wavelength is more effective than L-band. This has been demonstrated using the Glacier and Land Ice Surface Topography Interferometer (GLISTIN), a novel Ka-band digitally beam-formed interferometer developed at JPL.

The Ka-band experiment in Greenland was highly successful, resulting in the first ever application of millimeter-wave single pass interferometry for measurements of glacier elevation changes (Moller 2010). Some results from the experiment are shown in Figure 9. The system is now being duplicated to support other airborne and satellite missions.


Figure 8. Pod carrying Ka-band antennas on lower surface.

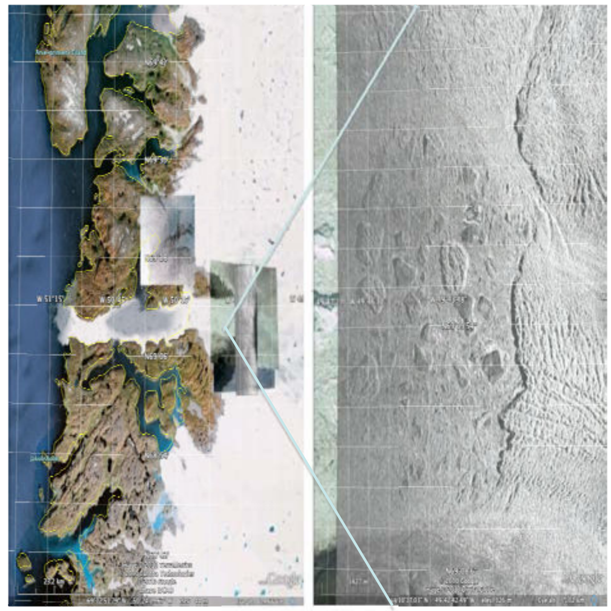
Figure 9. Ka-band Quick look of Jakobsholm pass

4. GLOBAL HAWK PACIFIC (GLOPAC) MISSION

The NASA Global Hawk, shown in Figure 10, is a large, high altitude, long-endurance UAS with payload capability of several thousand pounds. The GloPac mission, which flew in April 2010, carried eleven instruments, as shown in Figure 11. GloPac was an AURA Validation Experiment, in which measurements made from the aircraft were used to corroborate measurements from NASA's AURA satellite. Two awards were granted for instrument development in conjunction with IPY objectives.


Figure 10. NASA's Global Hawk flying GloPac.

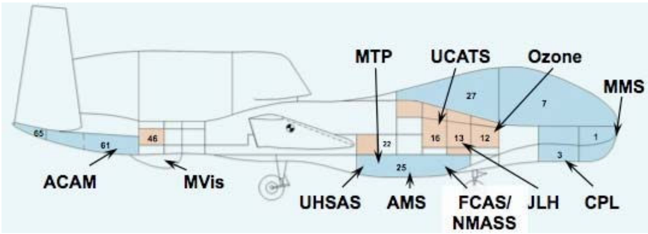

Figure 11. Instruments flown on the Global Hawk during GloPac include the CPL and MTP

A map of the April 23-24, 2010 flight lines for the GloPac mission are shown in Figure 12. The flight track heads specifically toward the North Pole. Note that in this 30-hour mission, the Global Hawk has sufficient range to fly from Edwards AFB all the way above 85 degrees north latitude, a journey of 10,000 km, in which artic atmosphere was sampled by many instruments. The objective of this particular science flight was sample the polar vortex and Asian dust.

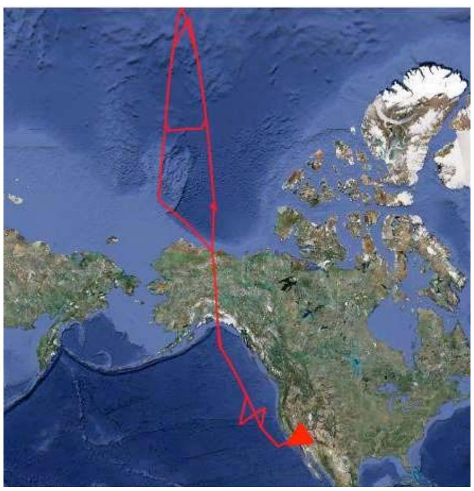

Figure 12. Highest latitude reach of Global Hawk during GloPac.

The first IPY-funded project involved the use of NASA Goddard's Cloud Physics Lidar (CPL). The CPL system, operated by Dr. Matthew McGill of NASA GSFC, is a proven instrument for measuring aerosols in the atmosphere. It has flown routinely at high altitude on NASA's ER-2 research aircraft. Under the IPY program, the instrument was modified to fly entirely unattended on the Global Hawk. The CPL was located in the nose, as shown in Figure 13. The CPL successfully recorded dust and aerosol densities during GloPac.

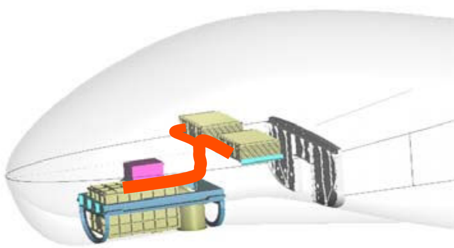

Figure 13. NASA Goddard CPL located on Global Hawk UAS.

The second funded project was to repackage JPL's Microwave Temperature Profiler MTP) for routine use on the Global Hawk. This instrument also has significant history on manned aircraft, having flown at high altitude on NASA's ER-2 and WB-57. A temperature profile above and below flight level provides important meteorological context for measurements made by other *in situ* and remote sensing instruments of trace gases, aerosols and hyrdrometeors aboard such an aircraft. The new UAS MTP instrument, shown in Figure 14, also operated successfully during GloPac. Temperature measurements were compared with coincidental measurements made by NOAA.

Figure 14. JPL Microwave Temperature Profiler located on the Global Hawk

5. FUTURE PLANS

Both low-altitude and high-altitude platforms are needed for polar missions, with long endurance in both cases. The UAS must operate in a harsh physical environment and a challenging communications environment. The UAS-IPY missions have proven that platforms and automated payloads can be utilized for these important climate missions. Future missions to increase the frequency of observations and to correlate with satellite observations are being planned. In particular, the Global Hawk is being readied for missions to Antarctica as part of Operation Ice Bridge in the next few years.

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