Acquisition of Ice Thickness and Ice Surface Characteristics In the Seasonal Ice Zone by CULPIS-X During the US Coast Guard's Arctic Domain Awareness Program

PI: Mark A. Tschudi
University of Colorado
CCAR, 431UCB
Boulder, CO 80309 USA
phone: (303) 492-8274 fax: (303) 492-2825 email: mark.tschudi@colorado.edu

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LONG-TERM GOALS

- Teaming with the Seasonal Ice Zone Reconnaissance Surveys (SIZRS) campaign (J. Morrison, Univ. Washington; PI) to:
  - o Investigate new technologies, e.g., sensors, platforms and communications, for sustained operation and observation in the challenging Arctic environment
  - o Improve understanding of the physical environment and processes in the Arctic Ocean

OBJECTIVES

- *What is the volume of sea ice in the Beaufort Sea Seasonal Ice Zone (SIZ) and how does this evolve during summer as the ice edge retreats*? Recent observations suggest that the remaining ice in the Beaufort Sea is younger and thinner in recent years in part because even the oldest ice advected into the region does not survive the summer melt.
- *How does ice thickness relate to ice surface conditions, such as reflectance and ice surface temperature?* During summer, melting ice is covered extensively by melt ponds, which exhibit a reflectance considerably lower than the surrounding ice. Recent analyses have indicated that ponds on thinner ice are often darker, accelerating the ice-albedo feedback over thin ice in summer. During winter, leads and very thin ice are centers for ocean-atmosphere heat flux, so their fractional coverage and contribution to the surface-to-atmosphere heat flux need to be quantified.

APPROACH

The CULPIS-X (CU Laser Profiler InStrument – eXtended) package is designed to take advantage of the US Coast Guard's (USCG) Arctic Domain Awareness (ADA) Program. Under this program, the USCG has deployed a C-130 Hercules aircraft to fly once a month during summer and early fall (typically June-October) each year. The ADA C-130 flights originate in Kodiak, Alaska and overfly, among other areas, the Beaufort Sea, providing a unique opportunity to provide extensive, repeated observations of sea ice and the ocean in and near the SIZ.

CULPIS-X has been designed and built by a University of Colorado-Boulder student team, led by PI M. Tschudi, to fit into a USCG C-130 flare tube and operate in an autonomous mode. The package contains a laser altimeter/profiler, skin-temperature pyrometer, nadir-viewing spectrometer, digital camera, aircraft inertial measurement unit, a differential-capable GPS receiver, and a payload control and processing board. The CULPIS-X lidar and camera were previously deployed in the Arctic as a package called CULPIS [*Crocker et al.,* 2012]. The CULPIS-X instruments are designed to acquire:

- Distance to surface measured at 400 observations per second (CULPIS lidar)
- Surface reflectance (hyperspectral radiometer)
- Surface temperature (Everest infrared thermometer)
- Digital camera snapshots
- Aircraft pitch, roll, yaw and rates of motion
- GPS position (basic position fix and carrier phase data)

The CULPIS-X package has undergone an extensive safety review by the USCG. This review process entailed Computational Fluid Dynamics (CFD) simulations by the US Navy's Naval Air Systems Command (NAVAIR) to evaluate the effect of air flow around CULPIS-X at nominal C-130 flight speeds. The output of these simulations was input into a Finite Element Design (FED) model, developed here at CU-Boulder by P. Coffin, a PhD student (advisor Prof. K. Maute) in the Dept. of Mechanical Engineering. The results from the FED analysis, along with a computer-aided design (CAD) model, were forwarded to the USCG Aviation Logistics Center (ALC) in mid-2014 for review. The review could not be scheduled for 2014 and was deferred until 2015. An Aircraft Configuration Control Board (ACCB) request was re-initiated in early 2015 with the USCG ALC by our POC in Kodiak, AK, LT. William Coombs. The CFD and FED data were analyzed by the Engineering group at ALC, and **approval was granted to fly CULPIS-X on the USCG C-130** in late August 2015.

Matthew Tooth, a graduate student in M. Tschudi's department (Aerospace Engineering, Colorado Center for Astrodynamics Reseach (CCAR)), joined the CULPIS-X team during Fall 2014, replacing W. Tandy and K. Williamson. Matt has worked on developing documentation and hardware upgrades for CULPIS-X. In addition, John Stark, a recent Ph.D. graduate from CU-Boulder's Aerospace Engineering Department, has returned on a contract basis for software upgrades in the CULPIS-X control board.

WORK COMPLETED

"SOFT Test" – Kodiak, Alaska

On May 13 2015, CULPIS-X was shipped to Kodiak, AK to perform a "SOFT test." This ground-based test is run to ensure no electromagenetic interference occurs with on-board C-130 equipment when CULPIS-X is in operation. M. Tschudi and M. Tooth traveled to Kodiak to unpack and install CULPIS-X into a USCG C-130 flare tube (Figures 1,2). The first-ever installation of CULPIS-X into a C-130 flare tube was successful, and the aircraft was towed a few hundred feet from the hangar to perform the SOFT test. CULPIS-X was then powered on, and the SOFT test was performed by USCG Kodiak technicians by evaluating the performance of communications and other electrical equipment on the aircraft. CULPIS-X passed the SOFT test, and it was then shut down, removed from the flare tube, packed and returned to CU-Boulder.

Figure 1: CULPIS-X, installed into a USCG C-130 flare tube on May 13, 2015. Inside of aircraft with flare tube door open. Visible is battery (black) and command and control box (white). Photo by M. Tooth.

Figure 2: CULPIS-X installed into flare tube, on tarmac at USCG Air Station Kodiak, AK on May 13, 2015

Documentation

M. Tooth wrote a CULPIS-X Assembly manual and an Operations Manual for use by the USCG. These documents were requested by our USCG Kodiak contact, LT. William Coombs. These documents will be helpful in the event that USCG technicians operate or need to install or remove the package from the aircraft.

CULPIS-X Maintenance

M. Tooth has tested and performed minor upgrades to CULPIS-X (Figures 3, 4), to ensure that the system continues to operate, with all instruments acquiring data and writing the data to SD cards. One challenge for our project is that the long wait for flight approval resulted in components aging and developing issues. Matt has updated worn wiring and has recently built and integrated a new digital camera snapshot timer. He also strengthened the instrument sled by adding an aluminum plate to further increase flex tolerance.

J. Stark was re-hired as a temporary consultant to work on some required control board programming updates. John had previously upgraded the control board architecture to use a GPS time steered pulse per second (PPS) signal to drive the events occurring on each microcontroller. The advantages of this methodology include better compatibility with the new sensor package and improved field reliability. He also previously wrote drivers for the GPS board, the Ocean Optics spectrometer, Everest IR temperature, ULS Lidar, and the data logging system to support the upgraded architecture. John is currently working on updating the GPS timing software.

Figure 3: CULPIS-X instrument package. Sensor package on right, data acquisition box in middle, battery on left. Aluminum sled, sitting on table, fits into the C-130 flare tube, box protrudes out flare tube.

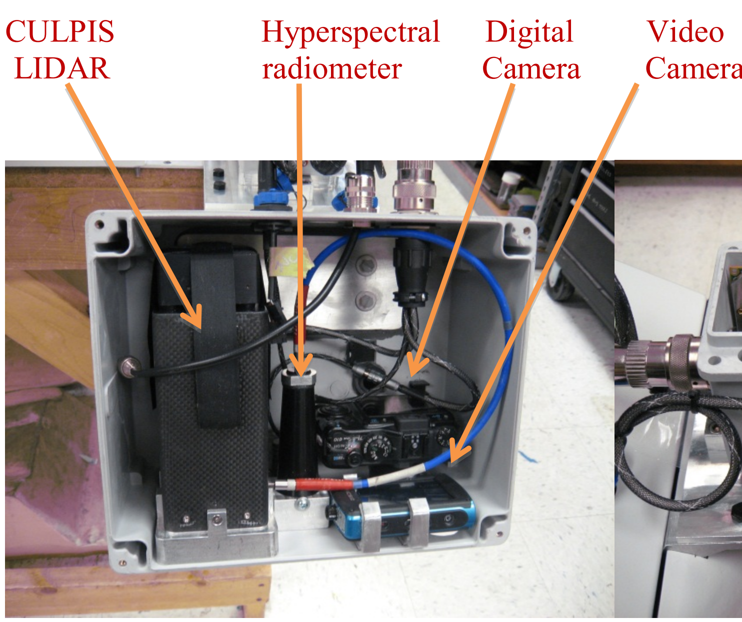

Figure 4a: CULPIS-X sensor package. Not Shown: IR thermometer.

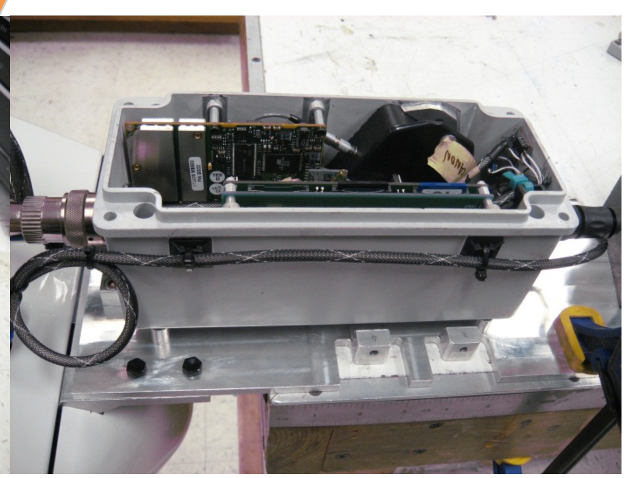

Figure 4b: CULPIS-X data acquisition box

RESULTS

A USCG ADA flight was planned for Oct 6, 2015. The mission was to perform air sampling with another SIZRS instrument over Central Alaska, then land at Fairbanks, AK to refuel, before flying direct to Deadhorse, AK and continuing up the 150W longitude line to the sea ice edge, near 77.5N, then descend to low-level (~500ft.) for CULPIS-X data acquistion. The C-130 would then return back along the 150W line to Deadhorse, then fly direct to Kodiak. M. Tschudi and M. Tooth traveled to Kodiak and unpacked the CULPIS-X crate, pre-assembling it to mount into the flare tube the night before the planned flight. On the morning of the proposed flight, we learned that the C-130 designated for our mission would not be available. This was due to maintenance issues on other C-130s, and the need for one aircraft to be in readiness for any emergency search and rescue operation. Our ADA flight to the Arctic was therefore canceled, and no backup day was available. CULPIS-X was then packed and returned to Boulder.

A possible test flight in the Kodiak area will be requested for early December 2015, as an additional C-130 will be in Kodiak at that time, increasing the chance of aircraft readiness for a local mission. To prepare for a future CULPIS-X test flight, we are re-testing instruments in our lab. The ULS laser in this package was tested by M. Tooth by powering on the laser and pointing it at our lab wall, then changing the distance to the wall by moving towards and away from the wall at various distances. The data from the laser (Figure 5) confirm that it is acquiring distance measurements with a low amount of noise.

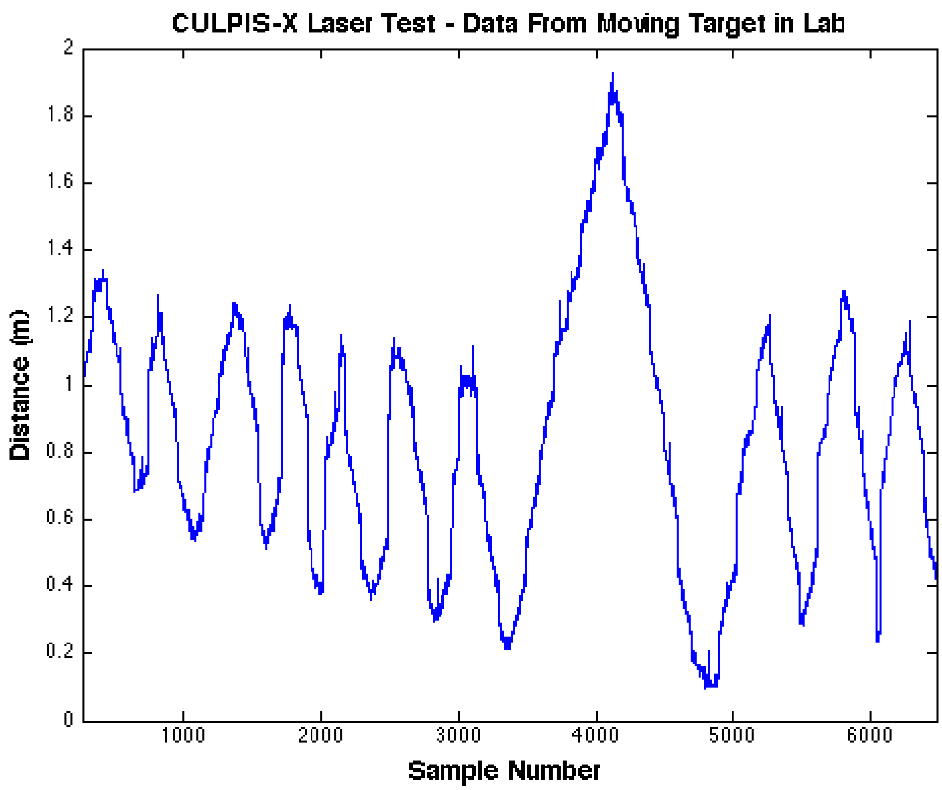

Figure 5: ULS Lidar data from CULPIS-X, acquired recently during lab testing. Distance was varied to target to sucessfully test the lidar response.

IMPACT/APPLICATIONS

Due to the cancellation of the final (October) USCG ADA flight for 2015, we were unable to deploy CULPIS-X in the Arctic as planned. We will request a test flight in the Kodiak area for early December, 2015. In the event this cannot occur, a backup test flight date in Spring 2016 will be requested. This test flight will ensure that we are ready to deploy CULPIS-X on ADA flights in 2016.

RELATED PROJECTS

SIZRS (J. Morrison, Univ. Washington; PI)

REFERENCES

Crocker, R. Ian, James A. Maslanik, John J. Adler, Scott E. Palo, Ute C. Herzfeld, and William J. Emery, 2012: A Sensor Package for Ice Surface Observations Using Small Unmanned Aircraft Systems. *IEEE Trans. Geoscience and Rem. Sens*., Vol. 50, No. 4, APRIL 2012.