# Visible and Thermal Imaging of Sea Ice and Open Water from Coast Guard Arctic Domain Awareness Flights

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## LONG-TERM GOALS

Our long-term goals are to better understand the interaction of sea ice with the regional and global climate and to improve the skill of predicting the evolution of the ice on daily to decadal time scales.

## OBJECTIVES

The overall objective of the proposed research is to collect detailed information about the thermal and physical state of the ice and ocean surface in the Beaufort and Chukchi seas in order to better understand the physical processes that control the melt, to better represent them in numerical models, and to better predict the seasonal evolution of the ice cover.

## APPROACH

The Coast Guard Arctic Domain Awareness (ADA) flights based out of Kodiak Alaska offer a tremendous opportunity to conduct repeated detailed surveys of the sea ice conditions in the Beaufort Sea. ADA flights are conducted twice per month from March through November and offer an especially valuable opportunity in the April-July and October-November periods for which model initialization and evaluation data is critically needed, and ship observations are typically not possible. Therefore, our group proposes to use the ADA flights for Seasonal Ice Zone (SIZ) Reconnaissance Surveys. From the Coast Guard C-130s, we will conduct atmosphere, ice, and ocean observations and buoy deployments from spring into fall in a coordinated experiment with multiple SIZRS observations proposed by various investigators in our team. There will be a set of core measurements needed to 1) make complete atmosphere-ice-ocean column measurements across the SIZ, 2) make a section of ice conditions across the SIZ, and 3) deploy drifting buoys to give time series of surface conditions. The overall SIZRS sampling strategy provides a mix of (i) fixed repeat sections and (ii) flexible sampling depending on ice and ocean conditions.

We propose to design and construct a package of high resolution infrared and visible cameras that can operate on the ADA flights and to then analyze the information obtained to determine the SST, the ice concentration, and the floe size distributions in order to better validate and initialize sea ice prediction models. The fully autonomous Visual-Infrared Package (VIRP) will consist of cameras and associated

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instrumentation and data recording equipment. This project will be integrated with the rest of the SIZRS effort and will provide critical measurements of the ice and ocean surface needed for other projects in the group. One goal of the SIZRS project is to create a holistic description of the annual changes of the ocean, ice, and atmosphere in the SIZ with the aim of enhancing predictive capabilities.

Our revised statement or work proposed that we would purchase a high-resolution infrared camera that would be integrated and installed on the CULPIS-X instrument package that is being designed and built by Dr. Mark Tschudi at the University of Colorado. This means that only one instrument package will need to obtain approval from the Coast Guard to be deployed on the aircraft. We would also acquire satellite remote sensing data (MODIS and SSMI) for flight planning before flights and during and after flights for inclusion in the SIZRS-DC database. The CULPIS-X package was to be deployed in one of the flare tubes at the rear of the aircraft.

Due to continued delays with the CULPIS-x instrument pod, still under review with the USCG Aircraft Configuration Control Board, we have are now using an alternate solution to gather thermal imagery of ocean water and sea ice by using a hand held thermal camera.

## WORK COMPLETED

This summer and fall we successfully deployed the thermal imaging camera system on board the US Coast Guard C130 ADA flights. The thermal camera, a VarioCam HD made by Jenoptik, is an uncooled, longwave microbolometer packaged in a hand-held enclosure. It has HD resolution (1024x768) and is paired with a visible camera that can be used to capture images simultaneously with the IR data. The camera can operate in two sampling modes, standalone and computer streaming. In standalone mode we can collect an IR and visible image approximately every 4-6 seconds, and the camera can operate without human intervention, except to change batteries. The sampling rate using computer recording is approximately 10 Hz from the IR camera, allowing for scene stitching to gather continuous IR image swaths. To replace the onboard visual camera in computer mode we use a GoPro camera mounted alongside to record wide field-of-view imagery. The camera deployment is pictured in Figure 1 showing the IR and GoPro (visual) cameras. We have also deployed a GPS to record plane position and altitude and auxiliary GoPro cameras looking out other plane windows to observe and record the sea surface and ice conditions.

To date, the camera was flown on four missions in 2014, June 17, July 22-23, August 14 and September 23-24. A final mission for this year is planned for October 14. On each mission, data is collected from the IR camera only when the rear cargo door is open for instrument drops (ocean buoys, expendable CTD and current meters, dropsondes) which can last 10-20 minutes per drop for and there are usually 6-10 total drops in a flight. This mode of operation is not ideal as it doesn't provide continuous coverage, however we cannot fly the full duration with the cargo door open due to. For each drop period we record IR and visual imagery and GRP data. Finally, the camera can report image brightness temperatures we have been trying to test methods to get better calibrations than the internal reference embedded in the camera.

## RESULTS

Processing and analysis of the image data have only just begun due to the recent collection of the data. Our analysis will focus on the extracting basic metrics from the IR and visual imagery including sea and ice temperature, melt pond temperature, percentage ice coverage, and ice flow and melt pond size distributions. We are also collaborating within APL (Schweiger) to estimate cloud top temperatures when viewed during dropsonde launches. Our current results cover a basic survey of the ice and sea conditions recorded from the IR and visual imagery.

***Figure 1. Picture of the camera mounted in the tail section of a C130, ready to view the ocean and ice surface through the rear cargo door.***

Ice conditions varied significantly over the course of the summer and into the start of the fall. In general we can see the progression from the ice breakup, to melt erosion, and finally the reformation of new ice with old ice. Figure 2 shows an IR and visual image pair of pack ice on 17 June at approximately 73°N, 150°W. The imagery shows a lead in the ice and reveals that the ice surface is warmer than the surrounding ocean by 2-3C. Due to the low angle of the sun it is also possible to see waves in most of the open water of the lead (lower part of the visible image), as it appears lighter than other areas of open water, such as the at the top of the visual image.

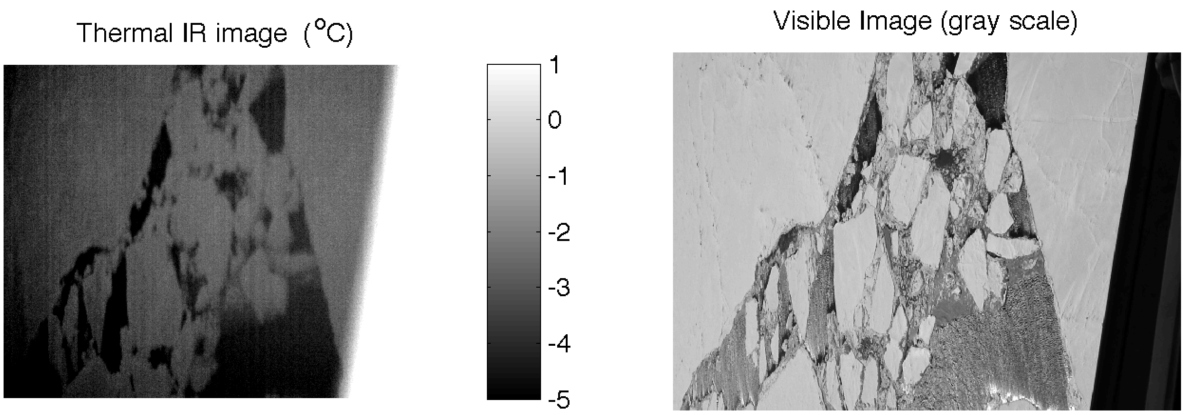


***Figure 2. (left) thermal IR image (right) visual band image from 300' altitude at 73° N taken on 17 June 2014. The thermal image shows that the water surface is approximately 2-3C cooler than the ice surface. The triangular sections on the right side of each image are where the side of the plane is visible (warm in IR and dark in visible).***

The ice conditions a little more than a month later, on July 23, are starkly different. Numerous melt ponds and channels characterized the ice at this time. Figure 3 shows an IR and visible image pair from approximately 72.5°N, 150°W. The melt ponds on the ice flows in this example vary in temperature from warmer than the surrounding ice to as cold as the ocean water in the lead. Cold ponds are interpreted as having melted trough to the ocean below as seen by their dark color in the visible image. The warmer ponds are likely heated above the ice temperature by solar insolation. The melting of the ice is observable through the streaming of warm water flowing into the lead from the larger ice flow near the top of the image. The draining process is not diffuse as seen by the specific locations where warm water is draining into the lead.

The latest imagery shows the reformation of the ice pack since the height of the summer. Figure 4 shows a visual and IR image pair from 26 September from approximately 71°N, 143°W. The ice at this time has completely changed from the melt conditions and appears to be mostly new ice that is visibly darker in character than the previous flights. The melt ponds are absent here and the few patches of open water are warmer than the ice by 1.5 C, revealed in the IR imagery. The ice itself is distinctly variable in temperature with some patches up to 0.5 C cooler than surrounding ice and corresponds to visibly brighter ice. We interpret this as older ice with newer, warmer ice around it.

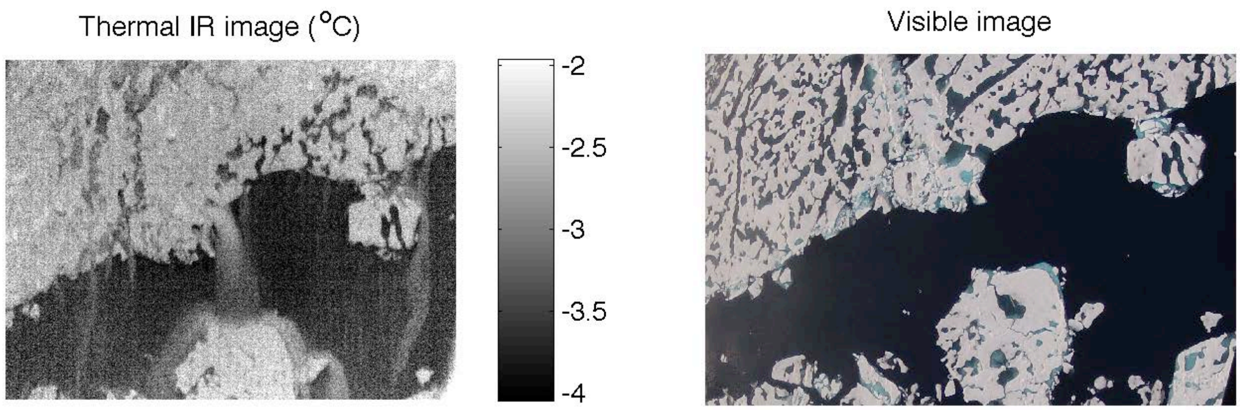


***Figure 3. (left) thermal IR image (right) visual band image from 300' altitude at 72.5° N taken on 23 July 2014. The lead in the center of the images is surrounded by rotten ice pocked with numerous melt ponds and channels. The IR image shows warm water draining from the surface and flowing into cooler ocean water in the lead. Melt pond temperature is variable, some are cooler and some are warmer than the surrounding ice.***

## IMPACTS/APPLICATIONS

This information will allow for a detailed characterization of sea ice that can be used in process studies, for model evaluation, calibration of satellite remote sensing products, and initialization of sea ice prediction schemes. Very-high-spatial and fine-temperature resolution airborne measurements may lead to new discoveries about the structure and physical processes important for sea ice and the local open ocean environment that are not possible from satellite- or ship-based measurements.

## RELATED PROJECTS

This project is part of a broad collaboration of investigators concentrating on using the ADA flights to observe the seasonal ice zone and to investigate the marginal ice zone (where ice and open ocean interact). Table 1 lists these projects.

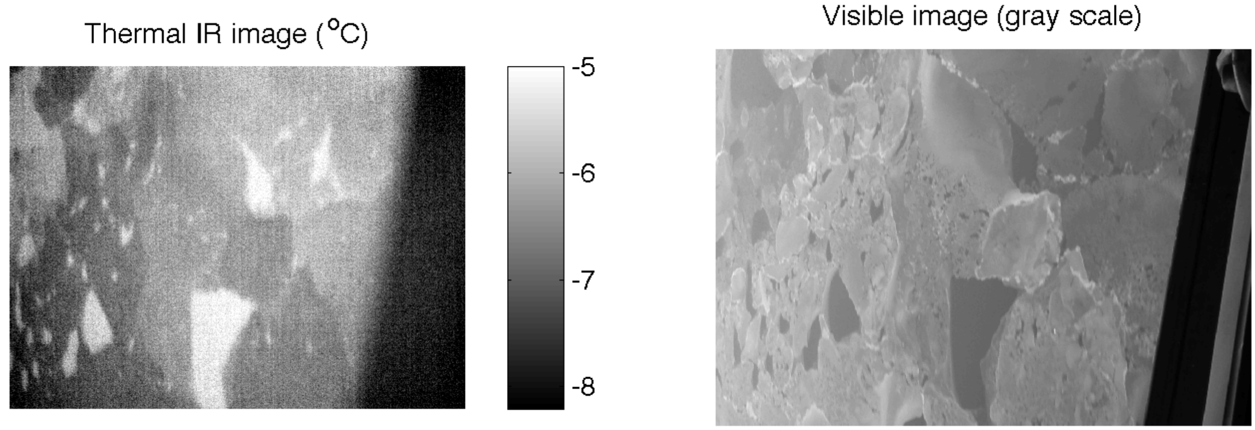


***Figure 4. (left) thermal IR image (right) visual band image from 6500' altitude at 71° N taken on 26 September 2014. Both image data show a very heterogeneous surface composed of small patches of warm open water (visibly dark on the right image). The ice surface is visibly mottled in character and correlates with variable temperate. The triangular sections on the right side of each image are where the side of the plane is visible (cool in IR and dark in visible).***

***Table 1: Core and Collaborating Projects of the SIZ Reconnaissance Survey Flights***

| Project | PI | Co-PIs | Observations/Activity on C-130 Flights |
|---|---|---|---|
| *Ocean Profile Measurements During the SIZRS* | ***Morison*** | | Ocean expendable probes AXCTD & AXCP for T, S, V, internal waves/mixing |
| *Clouds and the Evolution of the SIZ in Beaufort and Chukchi Seas* | ***Schweiger*** | ***Lindsay, Zhang, Maslanik, Lawrence*** | Atmospheric profiles (dropsondes, micro-aircraft), cloud top/base heights |
| *Arctic Ocean Surface Temperature project* | ***Steele*** | | Buoy drops for SLP, SST, SSS, & surface velocity |
| *Visible and Thermal Images of the SIZ from the Coast Guard Arctic Domain Awareness Flights* | ***Lindsay*** | ***Chickadel*** | Vis and IR profiles (VIRP) for SST, FSD across SIZ |
| Ice thickness and character ….. using CULPIS-X | ***Tschudi*** (UColorado) | ***Maslanik,*** | CULPIS-X Laser profiler for ice thickness, reflectance, skin temperature, Vis imagery |
| MIZMAS: Modeling the Evolution of Ice Thickness and Floe Size Distributions (FSD….. | Zhang | Schweiger, Steele | SIZRS observations (SAR/LDIP/MODIS/Landsat) for FSD. Integrate SIZRS observations & model |
| International Arctic Buoy Program | Rigor | Clemente-Colón & Vancas (NIC) | Drop buoys for SLP, temperature and surface velocity |
| Waves & Fetch in the MIZ | Thompson | | SWIFTS buoys measuring wave energy/dissipation |
| Assessment of Sea Ice Conditions ….. | Rigor | Nghiem (JPL), Clemente-Colón (NIC), Wensnahan | SIZRS ground truth for sea ice assessment |
| Linkage of Sea Ice …..Winds | Overland (PMEL) | | Comparisons of SIZRS dropsonde data with ship launched balloons and 2014 P-3 |

AXCTD= Air Expendable CTD, AXCP= Air Expendable Current Profiler, SLP= Sea Level atmospheric Pressure, SST= Seas Surface Temperature, A/C= aircraft, FSD= Floe Size Distribution, SIC=Sea Ice Concentration