# Airborne Infrared Measurements for CBLAST-LOW

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## LONG-TERM GOALS

The long-term goal is to understand the mechanisms that produce spatial variability over a wide range of scales in ocean surface skin temperature under low wind conditions.

## OBJECTIVES

The first objective is to use an airborne infrared imager to produce both overview maps and high resolution time series of thermal variability over the CBLAST study area. The second objective is to combine these data with measurements by other investigators to determine the extent to which horizontal variability in surface temperature is related to atmospheric and sub-surface phenomena.

## APPROACH

The approach is to make airborne measurements of horizontal variability of ocean surface skin temperature during the CBLAST experiment using two complimentary infrared (IR) sensors. An IR imaging system will provide high spatial and temporal resolution while a narrow field-of-view (FOV) radiometer system will provide calibrated surface temperature. The IR imager system will use up- and down-looking cameras in order to discriminate between real skin temperature variations and apparent variations caused by reflection from clouds. The high spatial coverage and fine spatial and temperature resolution of our systems will allow us to examine spatial scales in skin temperature from processes that span the atmospheric boundary layer of *O*(1km) down to wave-related processes *O*(1m). We will produce thermal maps at higher altitudes to compare with the fine-scale structures observed at lower altitude. We will transect between the tower and the offshore array at the nominal altitude of less than 100 m with occasional flights at altitudes of 300 m to 1000 m. This will provide the opportunity to utilize the tower and offshore array data sets as well as directly compare sea-surface signatures with the oceanic and atmospheric boundary layer processes and fluxes. For the pilot experiment, we made sea surface measurements with a single Amber Radiance HS imager (256 x 256 pixels), a Pulnix digital video camera, and a Heimann KT-15 radiometer. The dual IR camera system is being purchased under a DURIP award and will be use in the main experiment next year.

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14. ABSTRACT

**The first objective is to use an airborne infrared imager to produce both overview maps and high resolution time series of thermal variability over the CBLAST study area. The second objective is to combine these data with measurements by other investigators to determine the extent to which horizontal variability in surface temperature is related to atmospheric and sub-surface phenomena.**

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The technique for obtaining high spatial resolution and low noise temperature measurements is to operate the imager at a fast frame rate and then obtain a point measurement by taking the average of each image. The high frame rate provides closely spaced samples and averaging the 64K pixels in each image can reduce the noise to less than 0.1 °C. For a nominal speed of 50 m/s, the aircraft moves roughly 1.7 m in the time that one frame is taken. At an altitude of 10 m, the image size is approximately 6.3 m. This technique provides much lower noise measurements than can be obtained using infrared radiometers, which typically have noise equivalent temperatures of 0.5 °C when operated at a frequency of 30 Hz. However, radiometers can provide a more accurate measurement than imagers, so we also deploy a radiometer with which to calibrate the imager measurements.

## WORK COMPLETED

We participated in the CBLAST pilot experiment in July and August of 2001 by mounting our instruments on the LongEZ aircraft. Prior to the experiment, the primary effort was the development of a data acquisition system that would meet the stringent weight and space limitations of the LongEZ. The data have been cataloged and we are beginning to survey it for interesting features.

## RESULTS

The imager used in the pilot experiment operates in the short wavelength infrared band and therefore is susceptible to solar reflection during the daytime. Furthermore, we found that there was significant reflection from the LongEZ fuselage and wings when flying at an altitude of 10 m, which is used when making flux measurements. Therefore, we have focussed out initial inspection of the measurements on flights made before or after sunset and at high altitude.

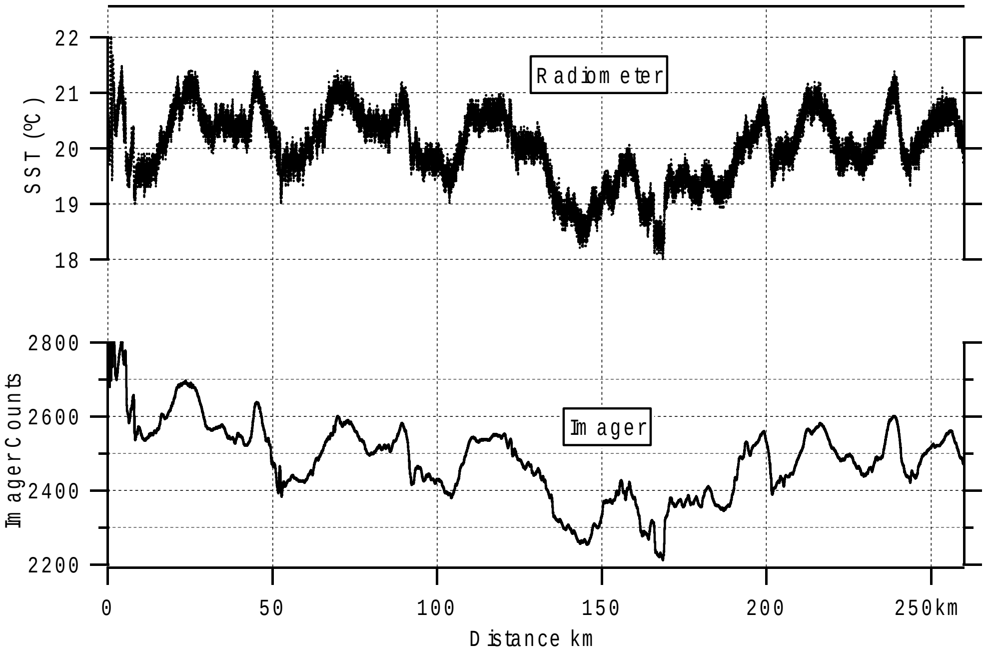
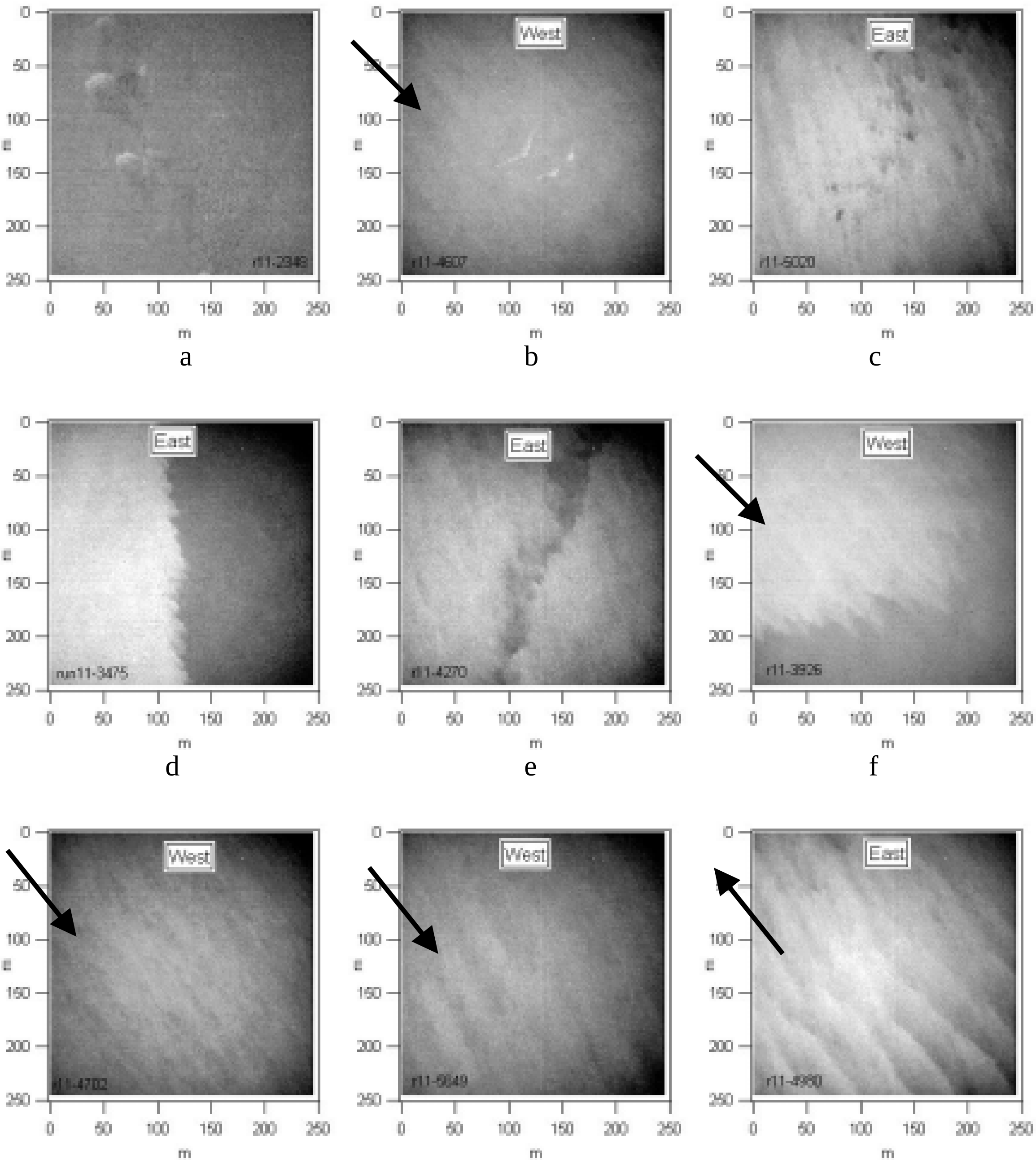


***Figure* 1 Plots of sea surface temperature measurements from the radiometer (top) in degrees Celsius and in digital counts by the imager (bottom) versus distance along the ocean surface. The record is roughly 250 km long and the traces are correlated, showing that they measured the same features. The features range in scale from a few kilometers to tens of kilometers. The temperature range of the radiometer data is from 18 to 21 °C.**

Figure 1 show a comparison between the measurements made by the radiometer (top) in degrees Celsius and the imager (bottom) in digital counts. These data were taken at night on 8-3-01 from about 0100 - 0300 hours UTC (8-2-01, 2100 – 2300 local) from an altitude of 390 m. At this altitude, the spatial resolution in an image is 1 m and the diameter of the surface spot viewed by the narrow FOV radiometer is 43 m. The wind speed ranged from 6 to 10 m $s^{-1}$ and the direction was from the SW. The figure shows that the noise level for the radiometer is greater than 0.5 °C, while that of the imager is less than 10 counts. Although the imager data have not been calibrated, the range of the imager data in counts compared to that of the radiometer in degrees Celsius indicates that the imager noise level was less than 0.1 °C. These preliminary results indicate that our technique to obtain high resolution, low noise temperature measurements using an airborne imager will yield the desired result. This example shows a range of spatial scales of variability, from 10's of kilometers down to a few 100 meters.

The images in Figure 2 show a variety of features observed during the same flight as the data shown in Figure 1. Lighter shades of gray are warmer temperatures and the dynamic range of the grayscale used in each image is roughly 1 °C. Each image is roughly 245 m x 245 m, the axis scales correspond to the spatial scale in meters, and the wind direction is indicated by a black arrow. The white crescent shapes in Figures 2a and 2b are whitecaps propagating in roughly the same direction as the wind. Figure 2a shows dark patches behind the whitecaps, which may correspond to cooling foam. Figure 2c shows cool blotches of unknown origin distributed over a warm streaky background. The middle row, Figures 2d-f, shows a variety of frontal features. Note that the streakiness of the frontal feature in Figure 2f is aligned with the wind direction.

The images in the third row, Figures 2g-2i show distinctive streaks of various scales that are aligned with the wind. To our knowledge, these are the first infrared images of this type of streaky feature accompanied by high quality wind data to confirm that they are aligned with the wind. These streaks are likely a manifestation of Langmuir circulation cells.



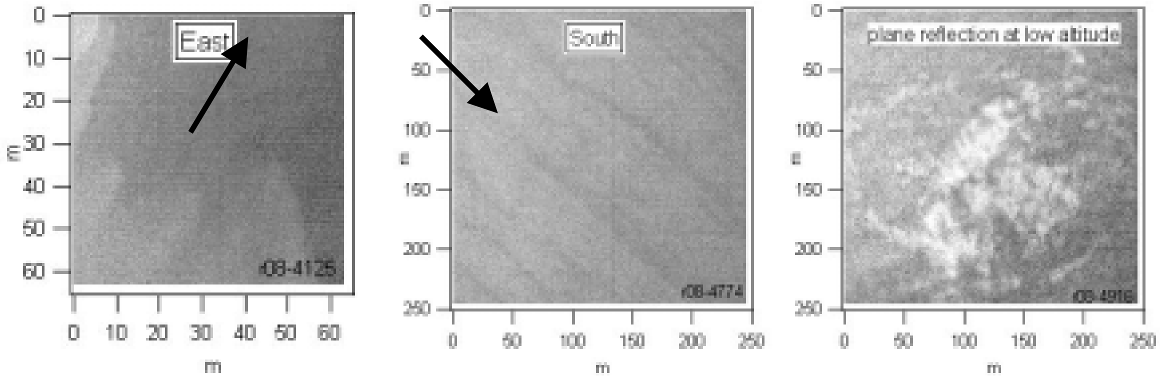
a b c

d e f

g h I

*Figure 2. Infrared images showing variety of features observed on 8-3-01. The look direction is noted at the top of the image and the black arrow shows the wind direction. See text for detailed descriptions of features and their interpretation.*

We also observed similar streaky features under low wind speed conditions. Figure 3 shows images taken before sunrise on 8-1-01 when the wind speed ranged from calm to 6 m $s^{-1}$ from the NW. The first image, Figure 3a, shows a temperature front with tongue-like features that are aligned with the wind. Figure 3a was taken at an altitude of 100 m and the image size is roughly 65 m x 65 m. The image in Figure 3b is the same size as those in Figure 2 and shows streaks aligned with the wind. Note that although the spacing of the streaks in Figure 3b is comparable to that in Figures 2g and 2h, the dark parts of the streaks under the lower wind speed conditions of Figure 3b appear significantly narrower than under high winds.



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a b c

*Figure 3. Sample images for low wind speed conditions (calm to 6 m $s^{-1}$) taken on 8-1-01. Wind and look-directions as in Figure 2. (a) Tongue-like features aligned with the wind along a temperature front, (b) Streaks aligned with the wind, and (c) contamination of image due to reflection from the plane at low atltitude.*

The incidence angle for the imager was set to 15 ° in an attempt to reduce the contaminating effect of reflection from the plane when flying at low altitude. Nonetheless, we found that the effect corrupted the image when the plane was flying at or below an altitude of 25 m, as shown in Figure 3c. This example implies that care must be taken when interpreting all infrared sea surface temperature measurements made from low flying aircraft.

## IMPACT/APPLICATIONS

The encouraging results of our first airborne measurements under the CBLAST DRI imply that we will be able to provide sea surface temperature measurements during the main CBLAST experiment with high spatial resolution and accuracy. If we can show that the streaky features aligned with the wind are indeed a thermal manifestation of Langmuir cells, the impact will be the development of a remote sensing technique to quickly characterize the scale of extent of this important secondary circulation mechanism.

## TRANSITIONS

None

## RELATIONSHIP TO OTHER PROGRAMS OR PROJECTS

This project is in collaboration with A.T. Jessup of the Applied Physics Laboratory at the University of Washington and Jerry Crescenti and Tim Crawford of NOAA.