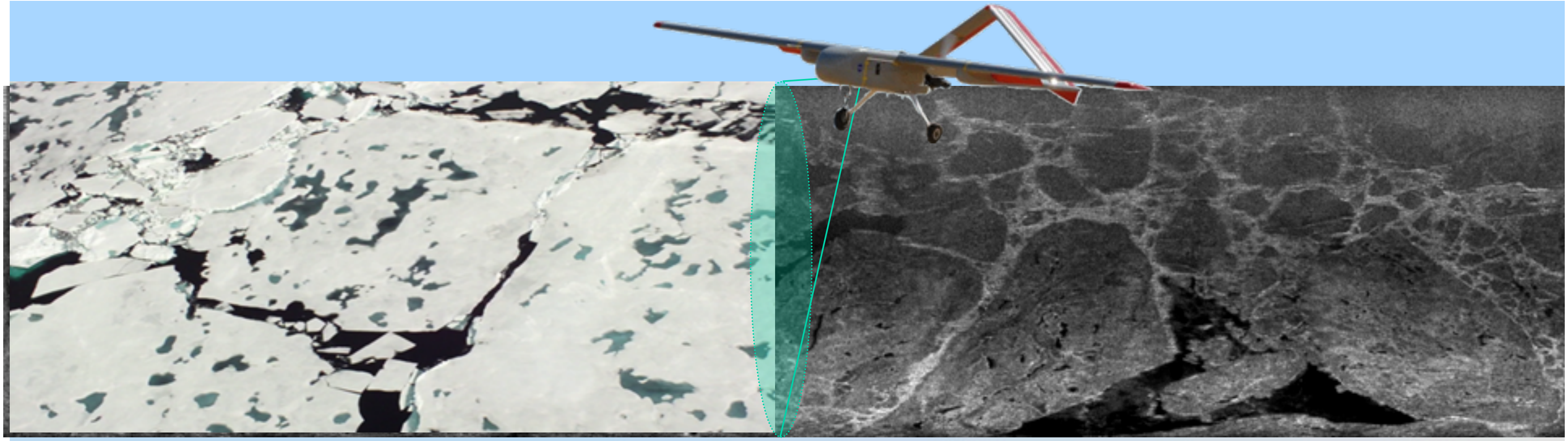

Environmental Science Combining Data from a Small SAR on an Unmanned Aircraft with Satellite Observations: The microASAR on the NASA SIERRA UAS for the Characterization of Arctic Sea Ice Experiment (CASIE)

17 November 2009

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Matthew Fladeland, Richard Kolyer – NASA Ames

Ian Crocker, James Maslanik, Ute Herzfeld – University of Colorado

MicroASAR – SIERRA – CASIE

Introduction: Using SAR on a Small UAS

- **Synthetic aperture radar (SAR) is useful for surveillance and remote sensing applications**
  - The microASAR is a complete, self-contained SAR system
  - Designed to be small and lightweight while still being robust and capable
  - Ideal for use on unmanned aircraft systems (UAS) and other small aircraft

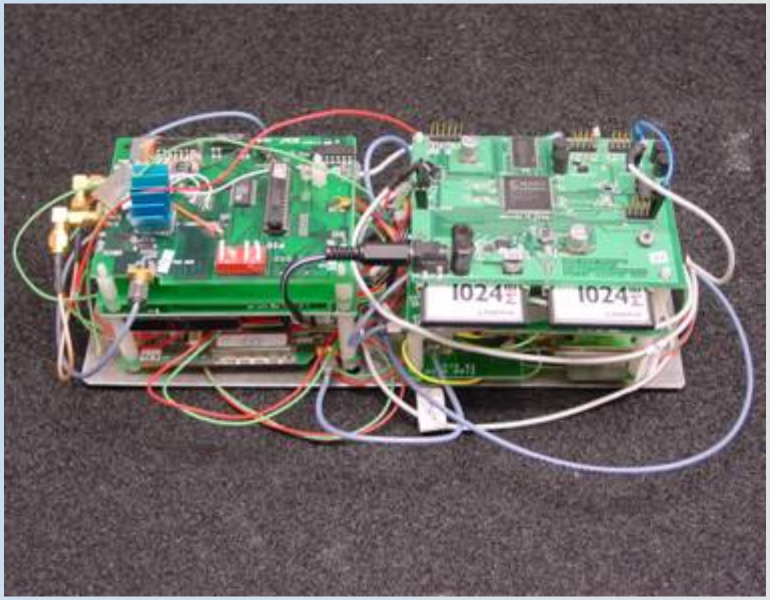
- **The NASA SIERRA UAS is a medium unmanned aircraft**
  - Ideal for deployment in remote areas where manned flight is dangerous.
  - Capacity to carry multiple payloads
  - Suitable for a variety of missions.

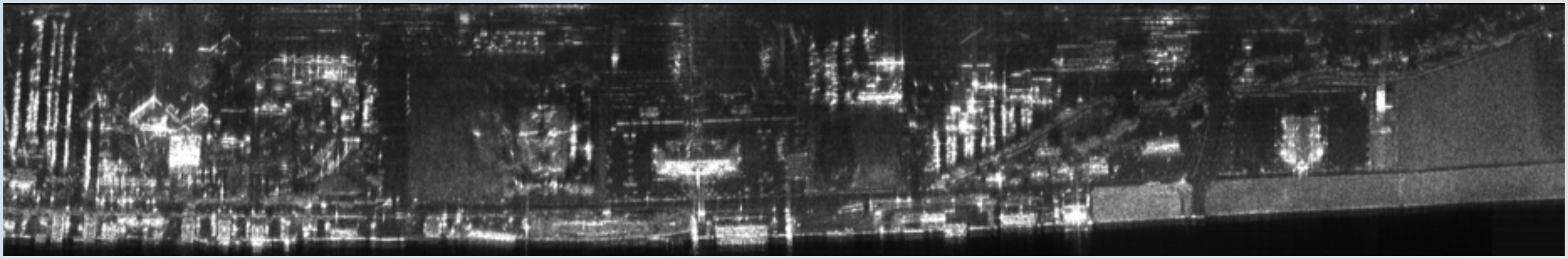
- **The Characterization of Arctic Sea Ice Experiment 2009 (CASIE-09)**
  - Combines the use of a variety of remote sensing methods
    - satellite observations
    - UAS sensors
  - Provides fundamental new insights into ice roughness on the scale of meters to tens of meters in the context of larger-scale environmental forcing
  - A technological and operational testbed to demonstrate the value of autonomous vehicles for long-range, long-duration remote sensing science.

MicroASAR – SIERRA – CASIE

Legacy of the BYU µSAR

- µSAR designed and built entirely by students at BYU
- Small, lightweight, low-power stripmap SAR system
- Successfully used to gather data on several different platforms
- Not very reliable



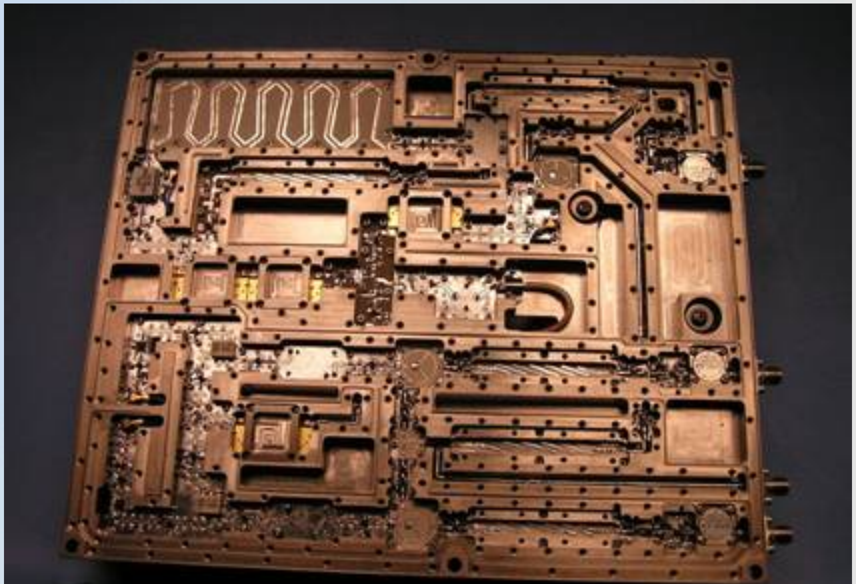


Nice proof of concept, but we need something better to deploy in the Arctic

MicroASAR – SIERRA – CASIE

MicroASAR

- **Uses many of the successful μSAR design traits**
  - A continuous wave (CW) SAR system
    - High SNR transmitting much less peak power
  - Analog de-chirp on receive reduces the sampling requirements to keep the data rate low
  - Low power
- **Introduces significant design improvements**
  - Flight-grade RF hardware
  - Aluminum enclosure
  - Improved removal of feedthrough between antennas
  - Increased capabilities (swath width, altitude, etc.)



The entire MicroASAR

MicroASAR – SIERRA – CASIE

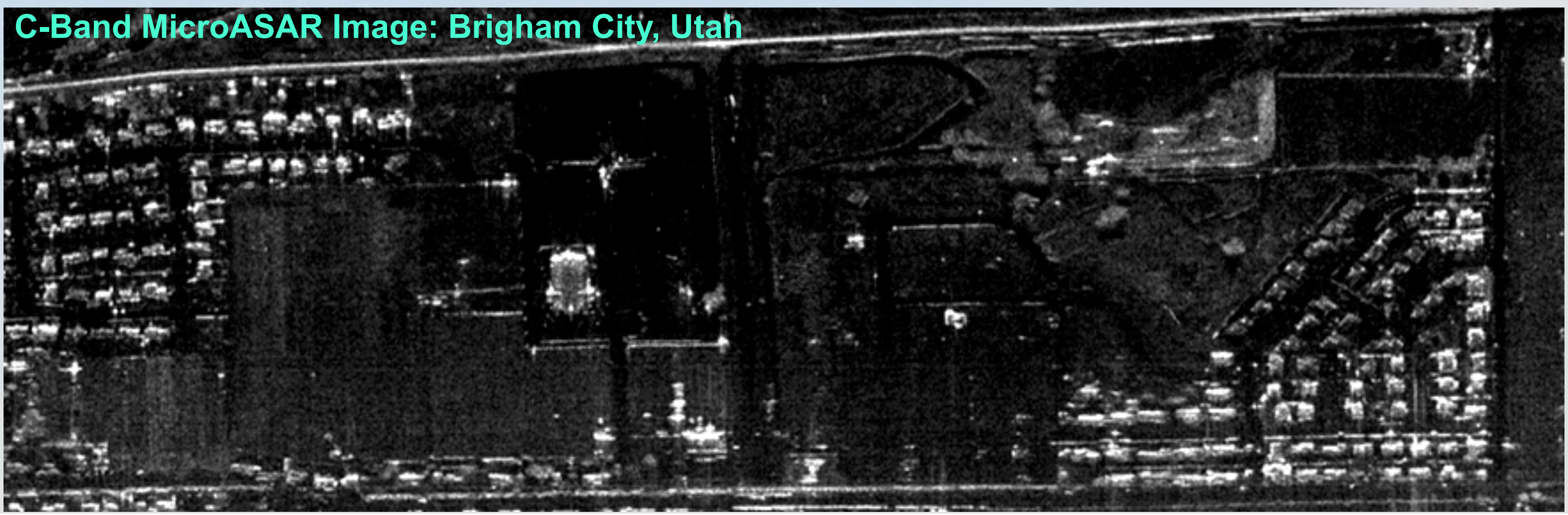
MicroASAR Specifications

Physical Specifications	
Transmit Power	30 dBm (~1 W)
Supply Power	< 35 W
Supply Voltage	+16 to +32 VDC
Dimensions	22.1 x 18.5 x 4.6 cm
Weight	2.2 kg

Radar Operating Specifications	
Theoretical Resolution	0.75 m (@ 200 MHz BW)
Operating Altitude	500 - 4000 ft
Maximum Swath Width	500 – 2500 m
Operating Velocity	10 - 150 m/s
Collection Time (for 10 GB)	30 – 60 min (PRF dependent)

Radar Parameters	
Modulation Type	LFM-CW
Frequency Band	C-band
Center Frequency	5428.76 MHz
Signal Bandwidth	80 - 200 MHz (variable)
PRF	7 – 14 kHz

Antennas (2 Required)	
Type	2 x 8 Patch Array
Gain	15.5 dB
Beamwidth	8.5º x 50º
Size	35 x 12 x 0.25 cm


C-Band MicroASAR Image: Brigham City, Utah

MicroASAR – SIERRA – CASIE

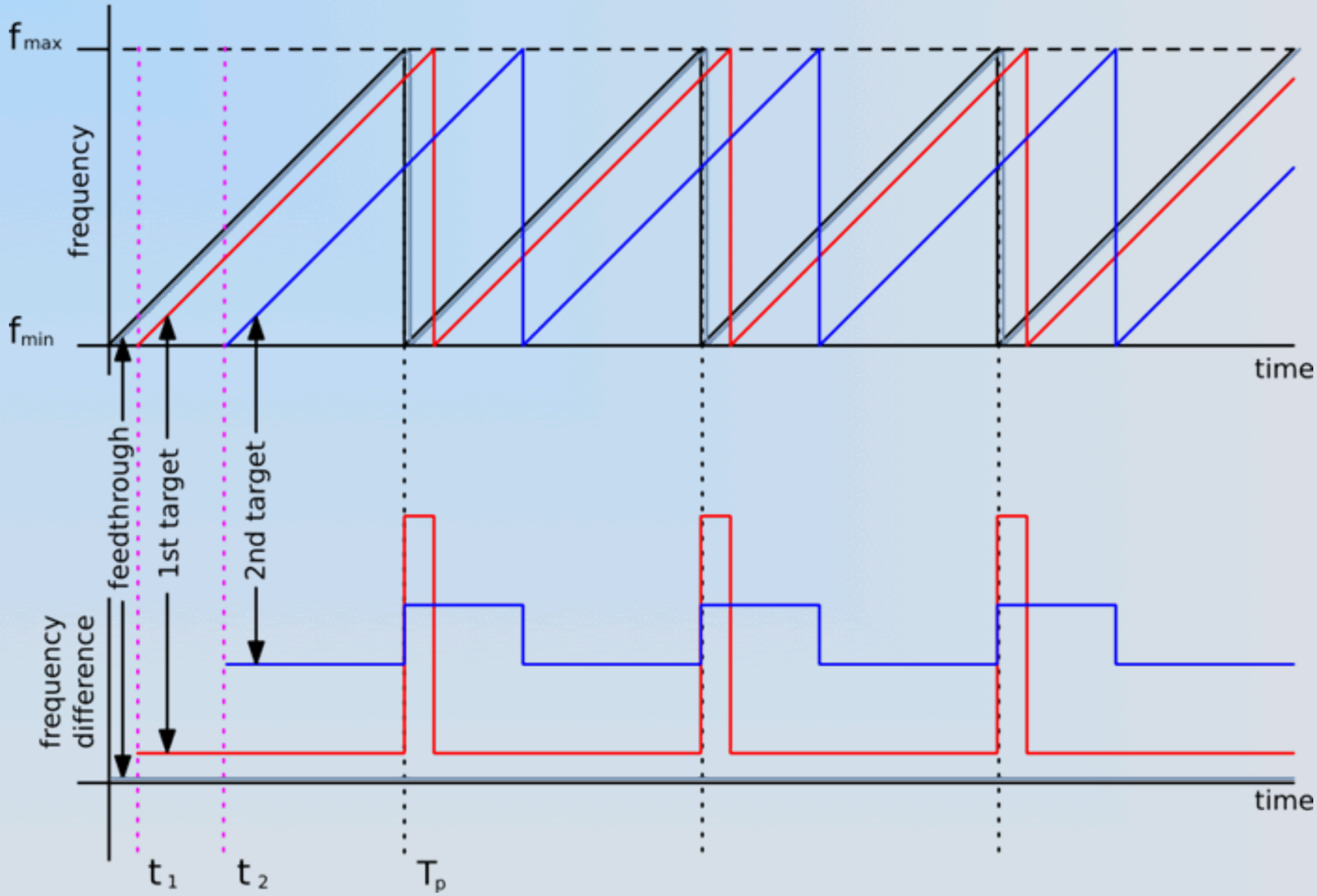
LFM-CW Operation

- **Benefits**
  - Facilitates compact design
  - Maximizes length of transmitted pulse
    - Improved SNR
    - Lower peak transmit power
  - Allows for analog dechirping
    - Range compression is reduced to single FFT
    - Reduced sampling bandwidth

- **Drawbacks**
  - Necessitates separate TX/RX antennas for isolation
  - Feedthrough between antennas is inevitable
  - Limited Range

MicroASAR – SIERRA – CASIE

LFM Dechirping



The received signal is mixed with the transmit signal, resulting the difference between the signal frequencies. Near range targets have a lower frequency than far range targets.

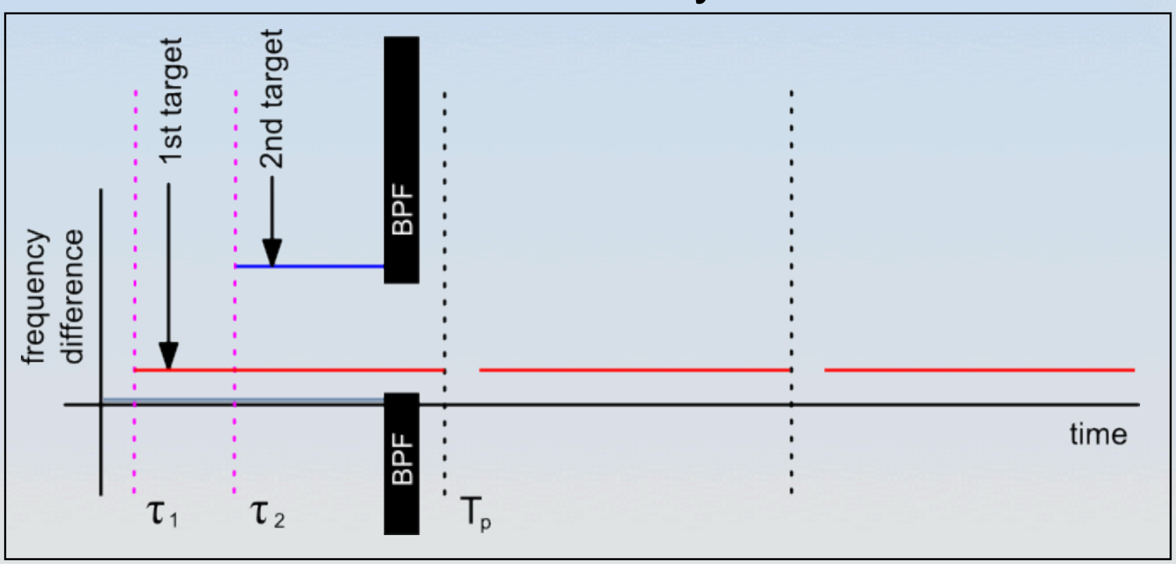
MicroASAR – SIERRA – CASIE

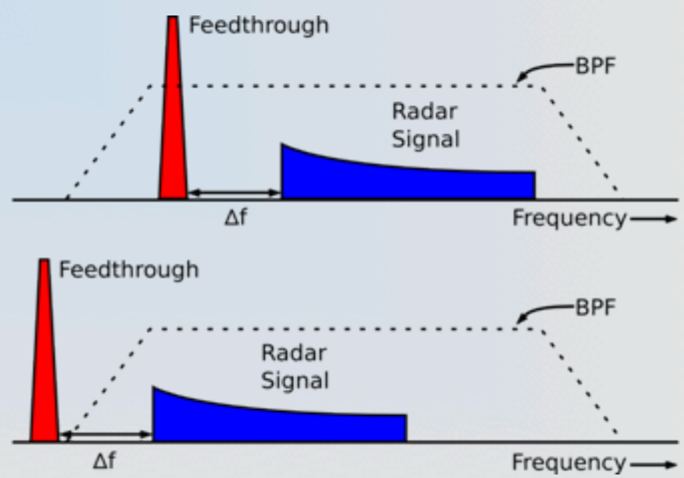
Feedthrough Removal

- **μSAR removes feedthrough at baseband using a HPF with very low cutoff frequency**
  - HPF has very long impulse response which causes smearing and degradation in filtered signal

- **microASAR utilizes SAW BPF at receiver IF**
  - TCXO is set so that feedthrough component is mixed down to null in BPF
  - Δf is influenced by altitude and PRF

$$\Delta f = \frac{2Bf_p}{c_0}\left(R_n - \beta\right)$$

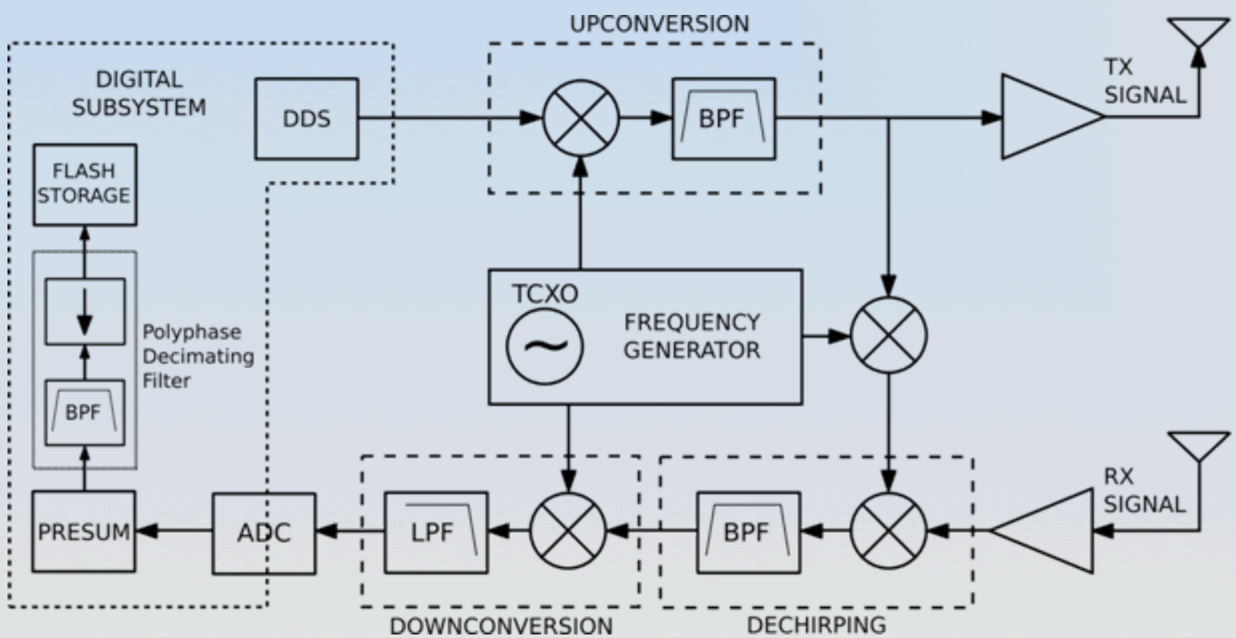




MicroASAR – SIERRA – CASIE

microASAR Hardware

- All signals derived from single LO to ensure phase coherence
- FPGA controls digital portion and system parameters
- DDS's generate SAR signal
- Up-converted to C-band
- Amplified and transmitted
- Receive signal is amplified
- The received signal is mixed with the transmit chirp, offset in frequency, which de-chirps the signal at an intermediate frequency
- A SAW band-pass filter with large out-of-band rejection removes the antenna feed-through and signal returns from outside the target swath
- The reduced bandwidth signal is mixed-down and digitized
- The digital signal is stored on Compact Flash cards or streamed over Ethernet
- Range-Doppler, Frequency-Scaling, and Backprojection algorithms have been developed for processing the data
- The Backprojection algorithm allows for non-linear flight paths (i.e. circular)



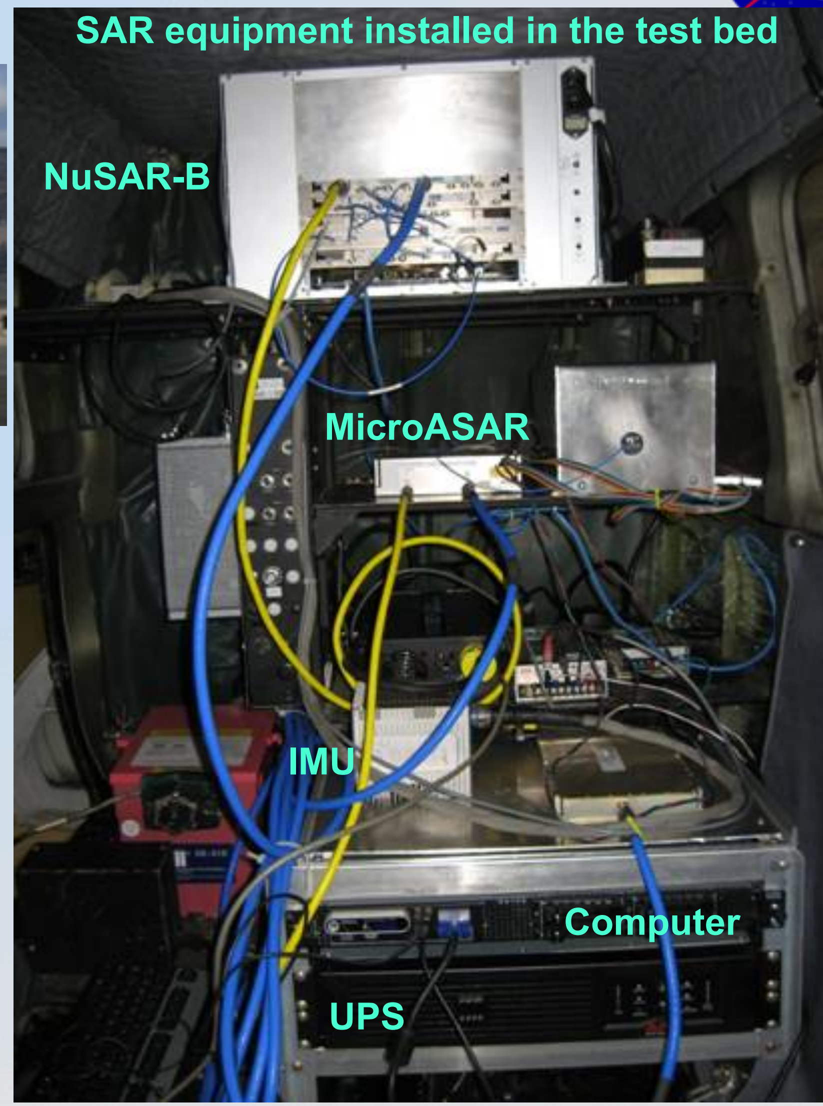
MicroASAR – SIERRA – CASIE

System Testing

A Cessna O-2 Skymaster, our test bed aircraft
"Surf Angel" on the runway at Brigham City, Utah

Antennas mounted under the belly of the test bed

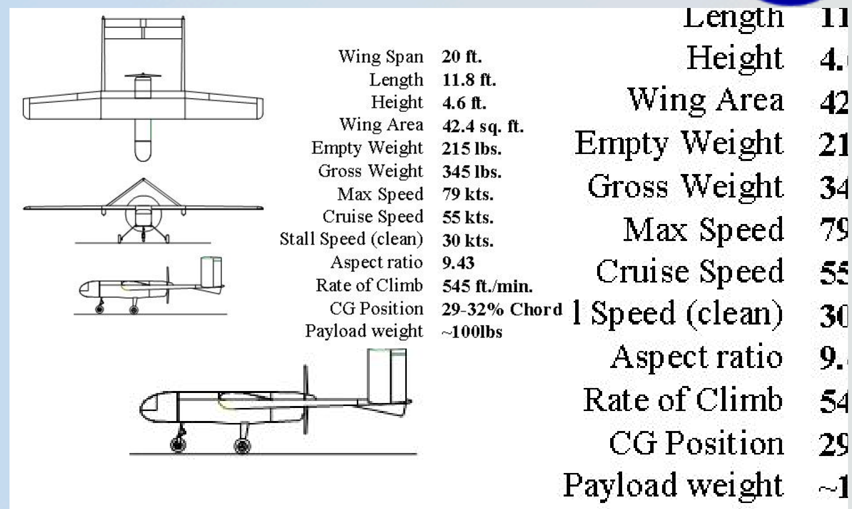
SAR equipment installed in the test bed



MicroASAR – SIERRA – CASIE

The NASA SIERRA UAS

Sensor
Integrated
Environmental
Remote
Research
Aircraft



A medium class, medium duration aircraft designed by the Navel Research Laboratory to test new instruments and support NASA earth science flight experiments.

First flights in October 2007 at Fort Hunter Liggett, CA

Fladeland, M. M., Berthold, R., Monforton, L., Kolyer, R., Lobitz, B., & Sumich, M., "The NASA SIERRA UAV: A new unmanned aircraft for earth science investigations", American Geophysical Union, Fall Meeting 2008, abstract B41A-0365.

MicroASAR – SIERRA – CASIE

The NASA SIERRA UAS

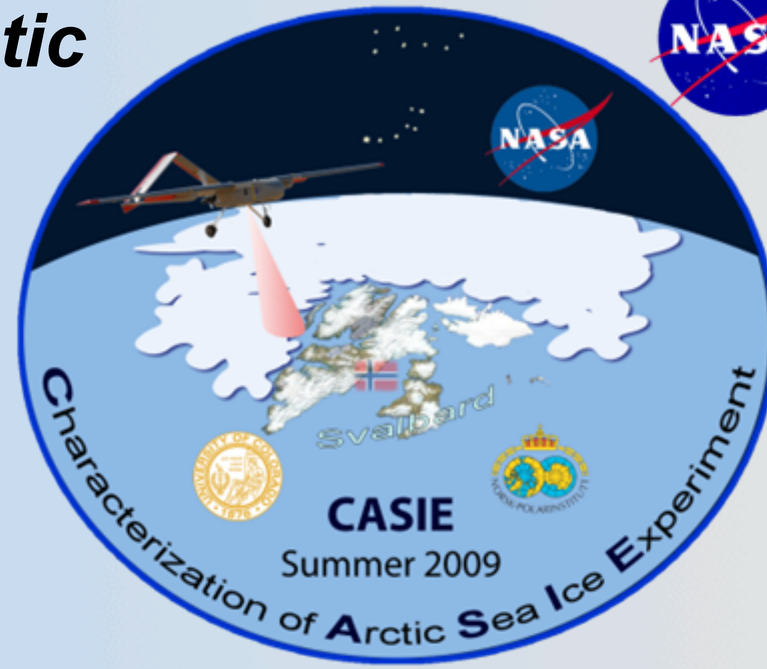
System Description

- **Engine** – Herbrandson Dyad 290B
- **Airframe** – NRL Design; R&R Products fabrication
- **Electrical System** – Designed and built by NASA and L-3/Vertex; reviewed by Ames Flight Management Team
- **Fuel System** – ATL foam filled bladder
- **Avionics** – Piccolo II autopilot system
- **Data Systems** – RCATS; custom PC-104
- **Actuators** – (1) Hitec 805 servo for throttle control, (10) CK Design Techonologies Linear Actuators
- **Command, Communications, and Control** – Specktrum 2.4 GHz transmit and receive for RC control; Piccolo Cloudcap II autopilot (900 MHz ground control station w/ waypoint navigation or manual control); 421 MHz radio for LOS data telemetry; IRIDIUM satellite modem for beyond line-of-site operations

The SIERRA UAS is of particular value when long duration flights preclude a human pilot, or where remoteness and harshness of the environment puts pilots and manned aircraft at risk.

MicroASAR – SIERRA – CASIE

Characterization of Arctic Sea Ice Experiment 2009 (CASIE-09)



Conducted under the auspices of the International Polar Year (IPY)

The principal investigator, Dr. James Maslanik was awarded a competitively selected grant by the NASA Science Mission Directorate, under the 2006 Research Opportunities in Space and Earth Sciences (ROSES).

The mission has three science goals:

Determine the degree to which ice-roughness monitoring via remote sensing can detect basic changes in ice conditions such as ice thickness and ice age.

Investigate relationships between ice roughness and factors affecting the loss or maintenance of the perennial ice cover.

Determine how roughness varies as a function of different kinematic conditions and ice properties.

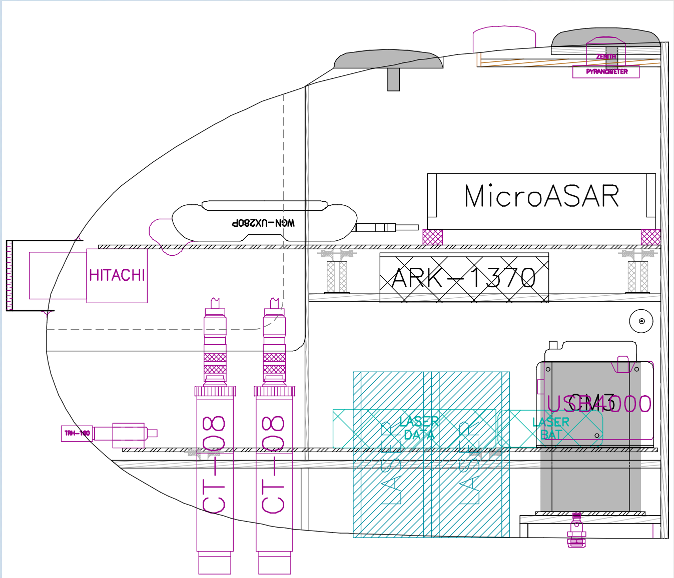
NASA deployed the SIERRA with the microASAR onboard, along with a ground control station, a science team, and an operation and logistics team to collect science data in and around the Svalbard archipelago of Norway in July 2009.

MicroASAR – SIERRA – CASIE

SIERRA Payload

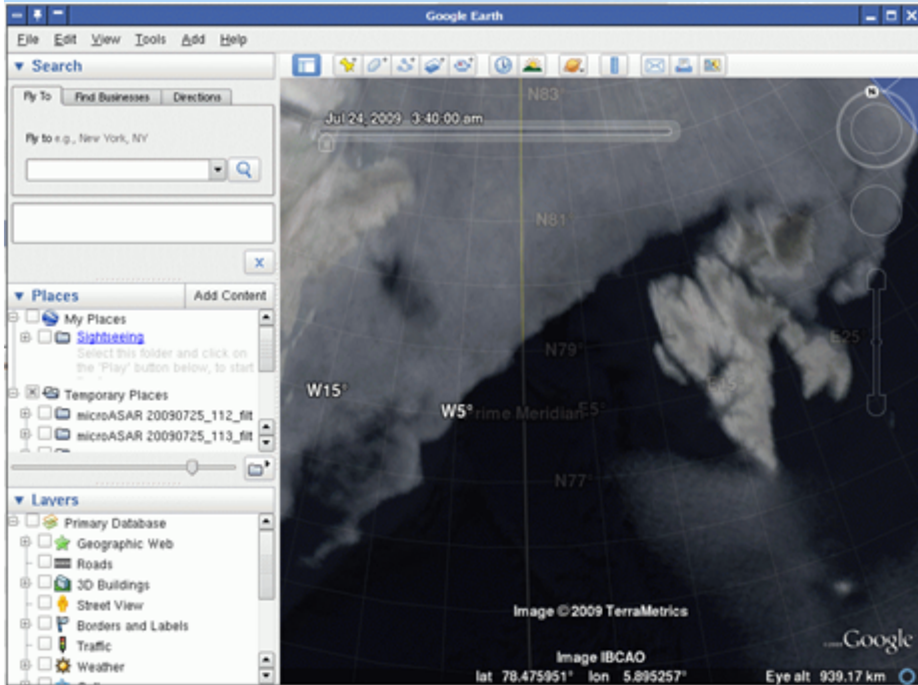
For the CASIE mission, the SIERRA payload consisted of:

- Laser altimeter/surface height profiler (non-scanning) system consisting of two lasers acquiring simultaneous but laterally offset laser tracks, GPS, inertial measurement unit, and payload computer
- Imaging synthetic aperture radar (the microASAR) with video camera
- Three digital cameras
- Up- and down-looking broadband shortwave radiation pyranometers
- Up- and down-looking shortwave spectrometers
- Down-looking temperature sensors (pyrometers)
- Temperature/Rh Sensors

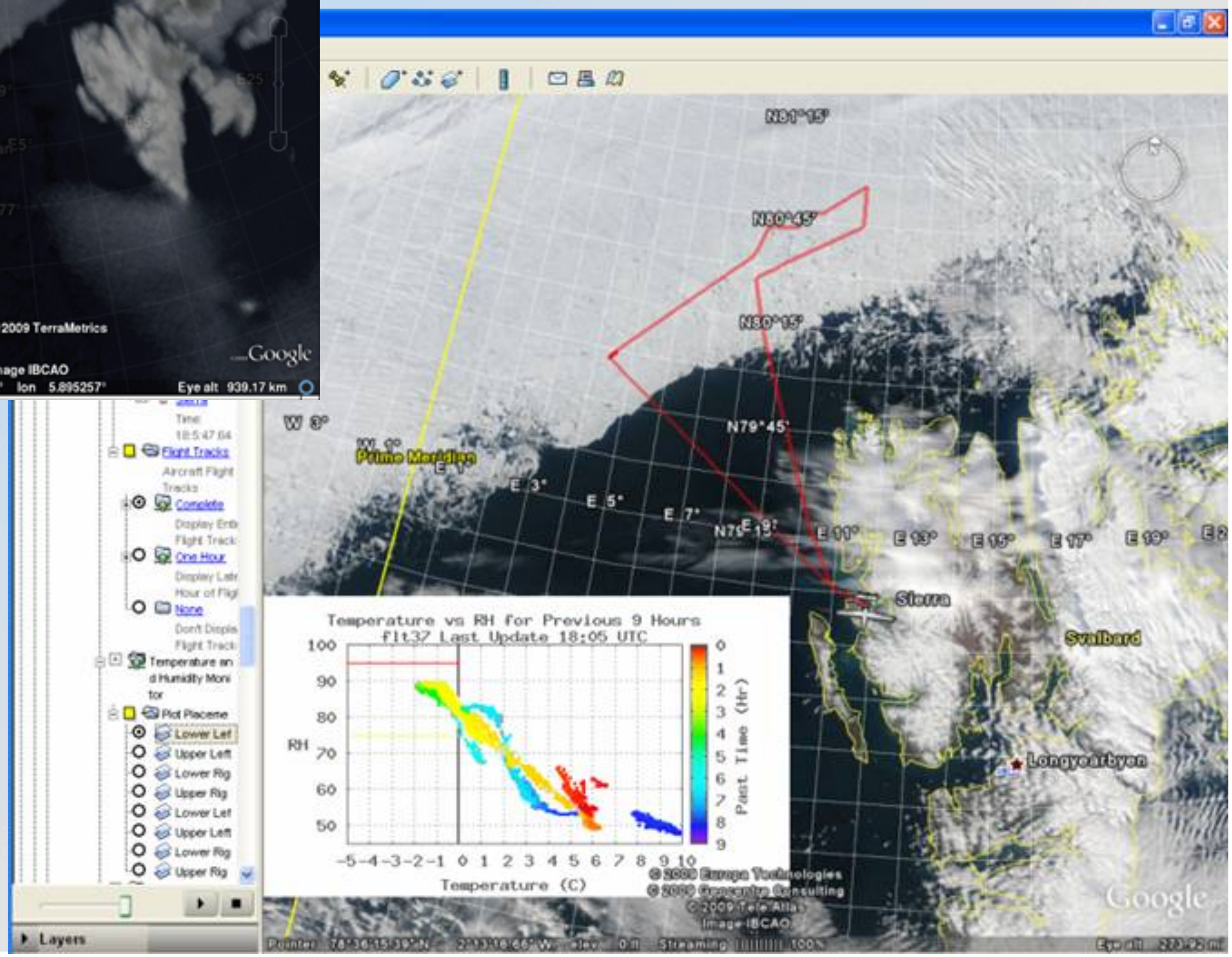


The MicroASAR antennas mounted on the side of the SIERRA

MicroASAR – SIERRA – CASIE



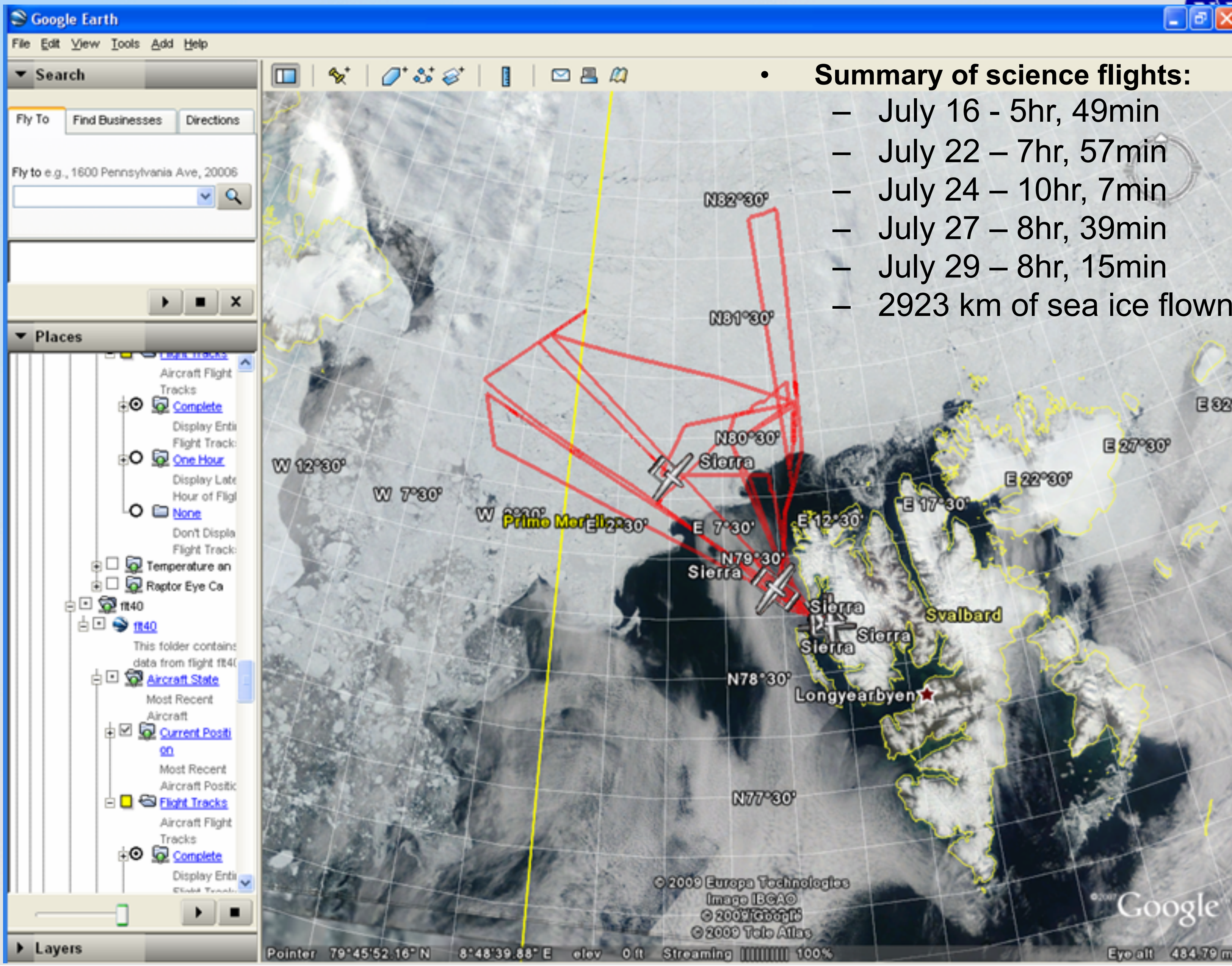
Screenshot of customized mission planner used for planning missions using satellite and weather data as well as tracking icing conditions



QuikScat Image – satellite scatterometer data provided by BYU in near real time for tracking ice edge when optical imagery is obscured by clouds

MicroASAR – SIERRA – CASIE

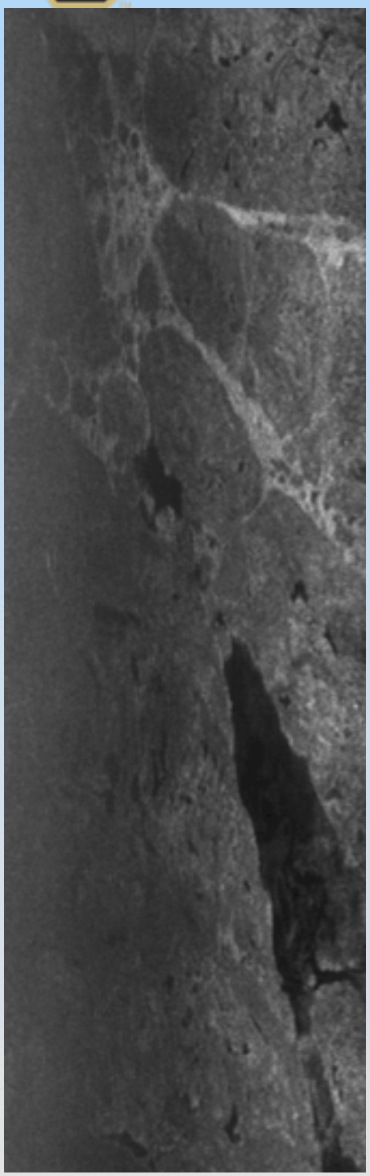
Flight tracks from CASIE science flights

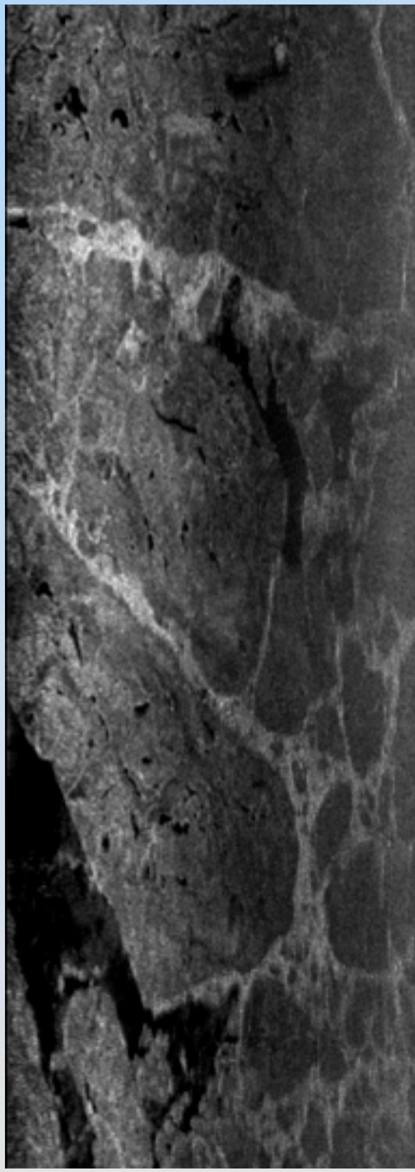


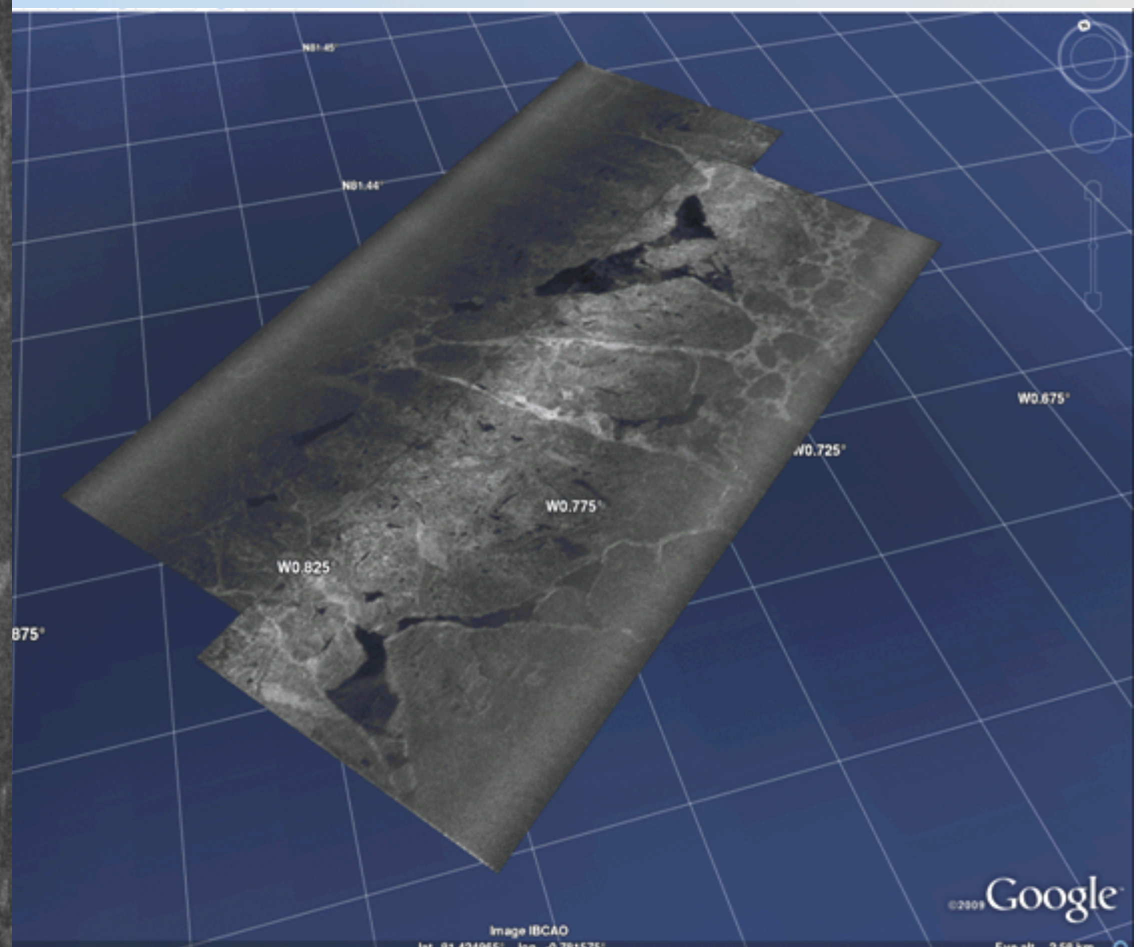
- **Summary of science flights:**
  - July 16 - 5hr, 49min
  - July 22 – 7hr, 57min
  - July 24 – 10hr, 7min
  - July 27 – 8hr, 39min
  - July 29 – 8hr, 15min
  - 2923 km of sea ice flown

MicroASAR – SIERRA – CASIE

Overlapping microASAR images from adjacent flight tracks



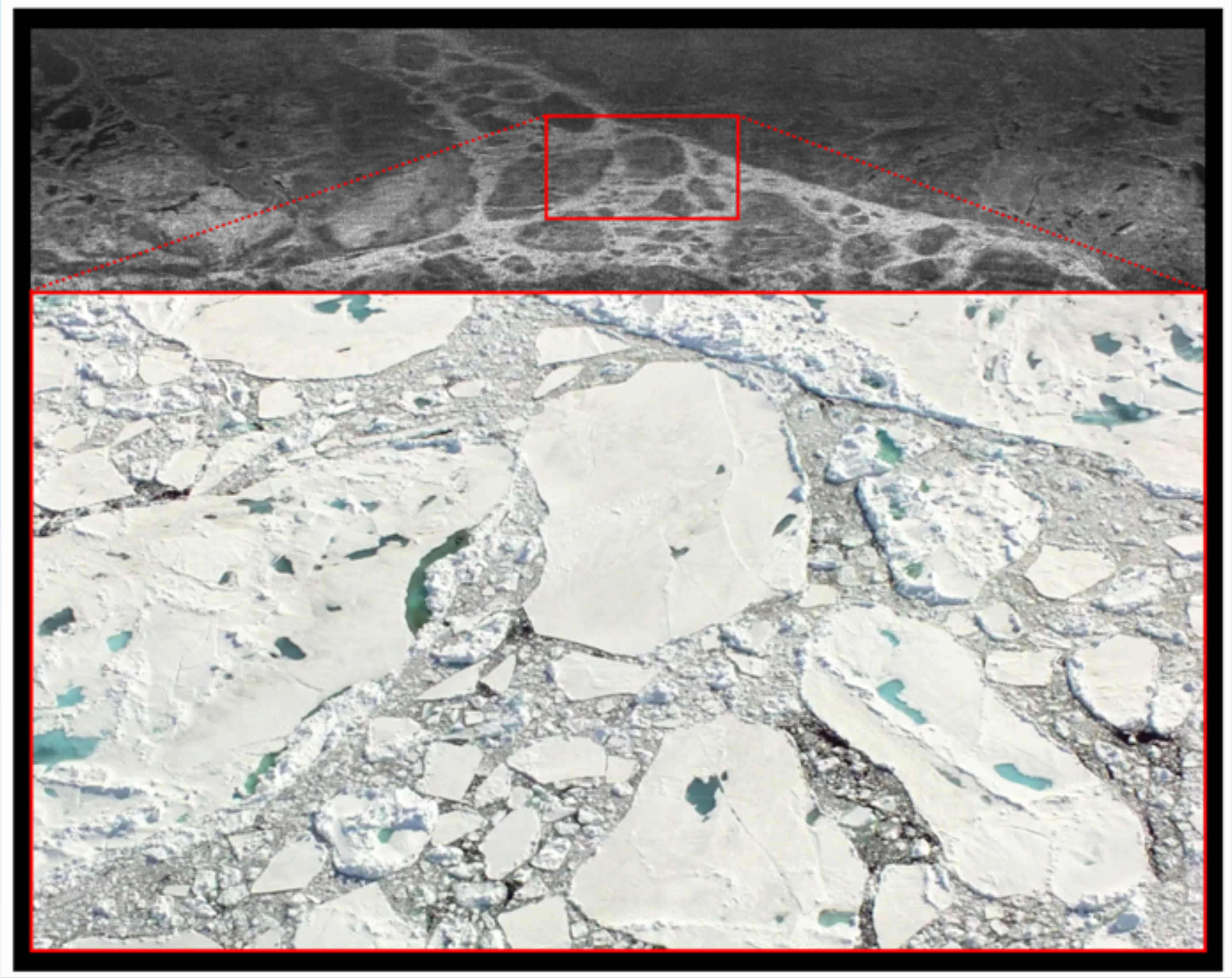




As displayed in GoogleEarth

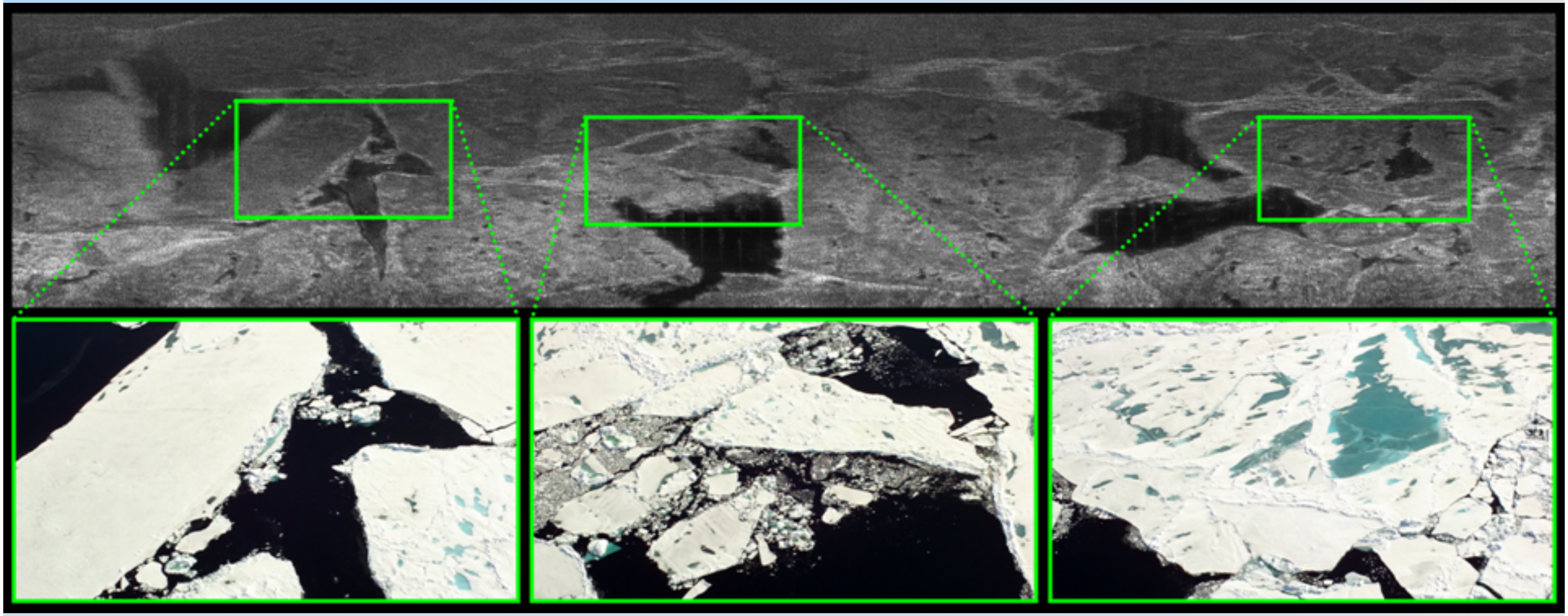
MicroASAR – SIERRA – CASIE

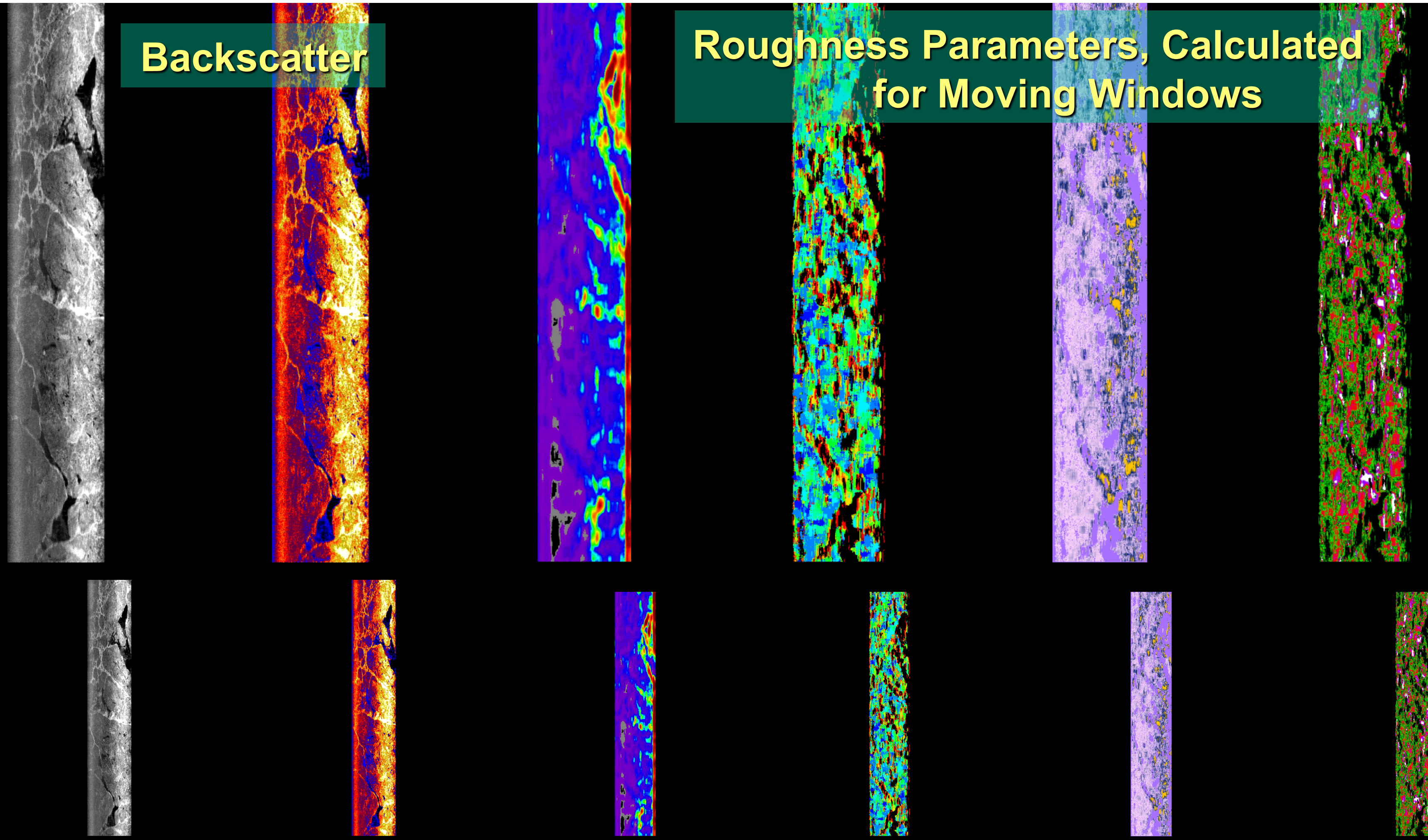
MicroASAR / Optical Comparison



MicroASAR – SIERRA – CASIE

MicroASAR / Optical Comparision





Provided by Ute Herzfeld, University of Colorado

MicroASAR – SIERRA – CASIE

Conclusion

- **Successful collection of science data shows the value of a UAS operated small synthetic aperture radar**
- **The compact, flexible design of the microASAR made it ideal for this mission**
- **Many applications for a small SAR on a UAS are available**
  - Demonstrated as a real possibility
- **The ongoing study of the collected data aims to**
  - Develop classification methods
  - Compare with satellite SAR data
  - Characterize sea ice roughness and sea ice type
  - All in support of the CASIE mission objectives