GISMO: Arctic '07
Flight Planning Document

April 12, 2007

1.0 Introduction

GISMO is a concept for a spaceborne radar system designed to measure the surface and basal topography of terrestrial ice sheets and to determine the physical properties of the glacier bed. Our primary objective is to develop this new technology for obtaining spaceborne estimates of the mass of the polar ice sheets with an ultimate goal of providing essential information to modelers estimating the mass balance of the polar ice sheets and estimating the response of ice sheets to changing climate. Our technology concept employs VHF and P-band interferometric radars using a novel clutter rejection technique for measuring the surface and bottom topographies of polar ice sheets. Our approach will enable us to reduce signal contamination from surface clutter, measure the topography of the glacier bed, and paint a picture of variations in bed characteristics. The technology will also have applications for planetary exploration including studies of the Martian ice caps and the icy moons of the outer solar system. We have recently shown that it is possible to image a small portion of the base of the polar ice sheets using a SAR approach. Through the concept developed here, *we believe that, for the first time, we can image the base and map the 3-dimenional basal topography beneath an ice sheet at up to 5 km depth.*.

1.1 Overview

During Arctic '07, we plan to conduct airborne observations using the NASA P-3 aircraft over Greenland. The planned flight lines are shown in figure 1. We will validate the following GISMO objectives

1) relative backscatter strength at 150 and 450 MHz
2) determine maximum swath width for interferometry
3) demonstrate clutter rejection approaches (InSAR, tomography, multiaperture beam formation)
4) investigate mosaic formation over areas suspected to have a wet bed
5) acquire data over thick and thin ice
6) acquire calibration data over the ocean
7) acquire data over all snow zones.

1.2 General Flight Parameters

Flights at 150 MHz
Flights at 450 MHz
Speed 270 Knots
Flight elevation 26,000 ft above sea level (one leg of Sonde flight at 1500 ft above ice sheet surface)
Special targets should be located 400 left or right of the nadir track
Digital Camera Photography over select areas.

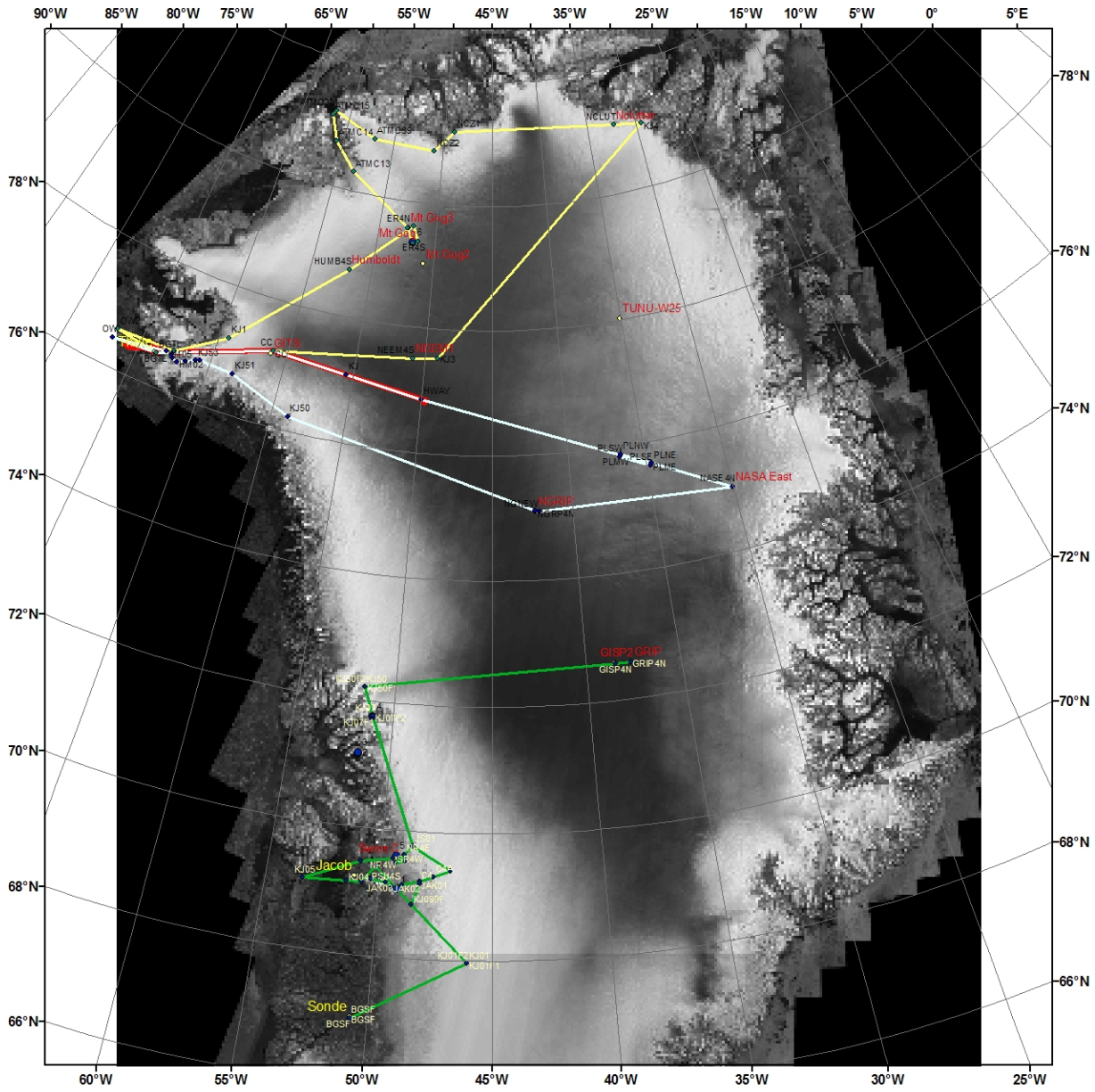


Figure 1. GISMO flight lines for Arctic ‘07

2.0 GISMO: Sondrestrom Flight

Overview

Objectives: Observations at two frequencies; Observations from thin to thick ice; Observations of Clutter zones and moulins; calibration site; all glacier facies.

Parameters

1 Sonde Flight at 150 MHz
1 Sonde Flight at 450 MHz
Speed 270 Knots
Outbound elevation 26,000 ft above sea level
Inbound elevation 1500 ft above ice sheet surface
Inbound flight line offset 100 m from outbound flight line
Special targets(Swiss Camp, GRIP, GISP) should be located 400 left or right of the nadir track

Events

Start at Sonde and climb to 26000 ft
leg across ablation, wet and percolation facies
Traverse across Jacobshavn Clutter zone
Pass over Disko Bay for Calibration
Swiss Camp Race Track – 4-6 legs, 25 m spacing - not accurately represented on shape file (opportunity to dump data during turns)
Northern Clutter Targets
Dry Snow Zones and on to GISP/GRIP
Outbound leg can end before GISP/GRIP if time is short.

Descend to 1500 ft above surface

Return leg at lower elevation (1500 ft)
Eliminate race track and extensive ocean calibration
Return leg deviates from Outbound leg by including flight segments down and then back up the Jacobshavn Channel and over PSU sites.

Way-point list

Long	Lat	Name
309.3	67	BGSF
309.3	67	BGSF
309.3	67	BGSF
313.9465	67.95465	KJ01
309.7974	69.40807	KJ02
309.2225	69.15037	KJ03
308.5632	69.13953	KJ04

306.6419	69.09326	KJ05
309.1128	69.47167	FIORD
310.5411	69.55282	NR1W
311.0259	69.61438	NR1E
311.1129	69.52979	SR1E
310.6299	69.46824	SR1W
310.5413	69.55261	NR2W
311.0262	69.61417	NR2E
311.1131	69.52958	SR2E
310.6302	69.46803	SR2W
310.5415	69.5524	NR3W
311.0264	69.61396	NR3E
311.1133	69.52937	SR3E
310.6304	69.46781	SR3W
310.5418	69.55219	NR4W
311.0266	69.61375	NR4E
311.1135	69.52916	SR4E
310.6306	69.4676	SR4W
311.4171	69.75886	JS01
308.9572	71.75833	KJ07
308.3894	72.20556	KJ50
321.5356	72.58109	GISP4N
322.3626	72.58161	GRIP4N
322.3626	72.58071	GRIP4NF
321.5358	72.58019	GISP4NF
308.3896	72.20467	KJ50F1
308.3921	72.20589	KJ50F2
308.9599	71.75867	KJ07F1
308.9599	71.75868	KJ07F2
311.4194	69.75921	JS1F1
313.1318	69.39667	C4B
312.4069	69.29411	C4A
311.7932	69.22072	JAK01
310.5811	69.10772	JAK02
310.3009	69.17171	JAK03
309.6568	69.20253	JAK04
310.3009	69.17171	JAK03
310.5811	69.10772	JAK02
311.0258	69.15135	PSU4S
311.7932	69.22072	JAK01
311.8029	69.18056	C4
311.5004	68.84767	KJ099F
313.9481	67.95529	KJ01F1
313.9476	67.95385	KJ01F2
309.3011	66.9992	BGSFF

Photography (following the way point list above) (See Camera Parameters Section)
Can be done on either the 450 or 150 MHz flight depending on cloud. Only one observation is needed.

Outbound 26000 ft Elevation
Sensor length set to 15 mm
F = 18 mm
Interval = 31 sec

Camera On for Segments Connecting:
BGSF to NR1W
NR1W to NR1 E
NR1E to SR1 E
SR1E to SR1 W
SR1 W to NR2W
Camera off

Camera on
SR4W to KJ50
Camera off

Return flight 1500 ft elevation above surface
Sensor Length set to 15 mm
F = 18 mm
Interval = 2.5 sec

Camera on
KJ50 to KJ07 (+20 km)
Camera off

Camera on
C4b to C4
Camera off

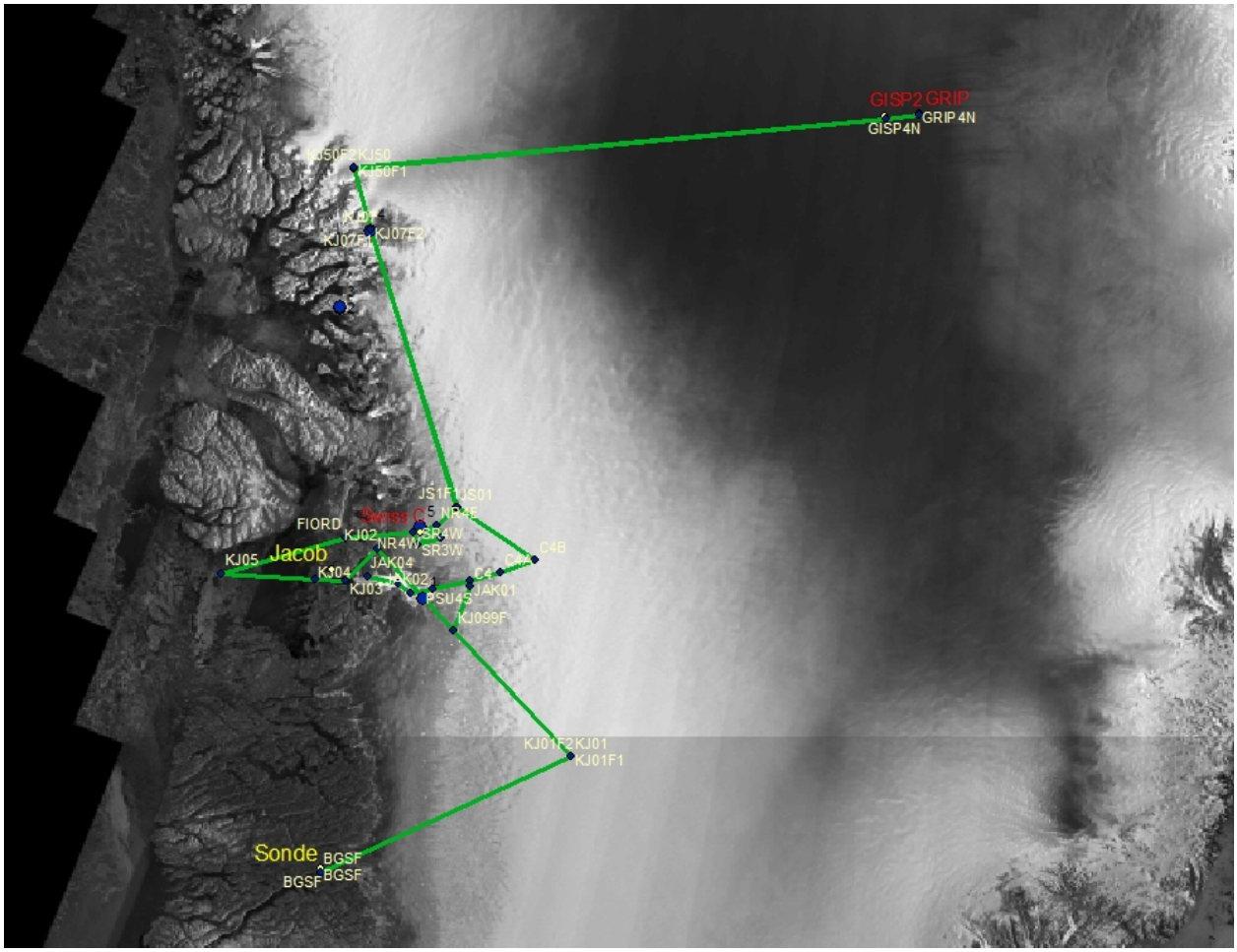


Figure 1. Sonde outbound yellow dots: cities; red dots: field camps; Blue dots: places where Prasad has identified clutter

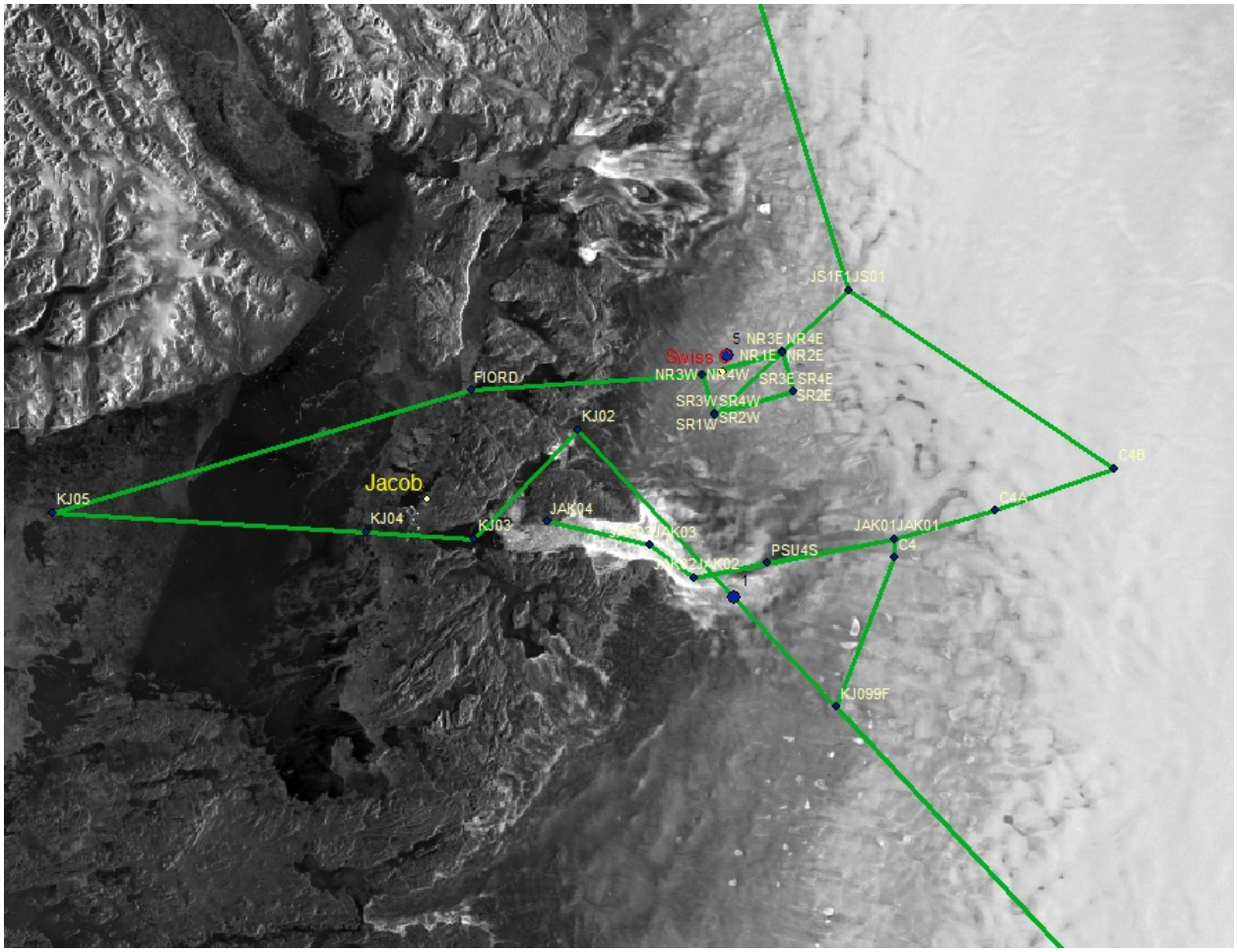


Figure 2. Sonde flight details around Jacobshavn

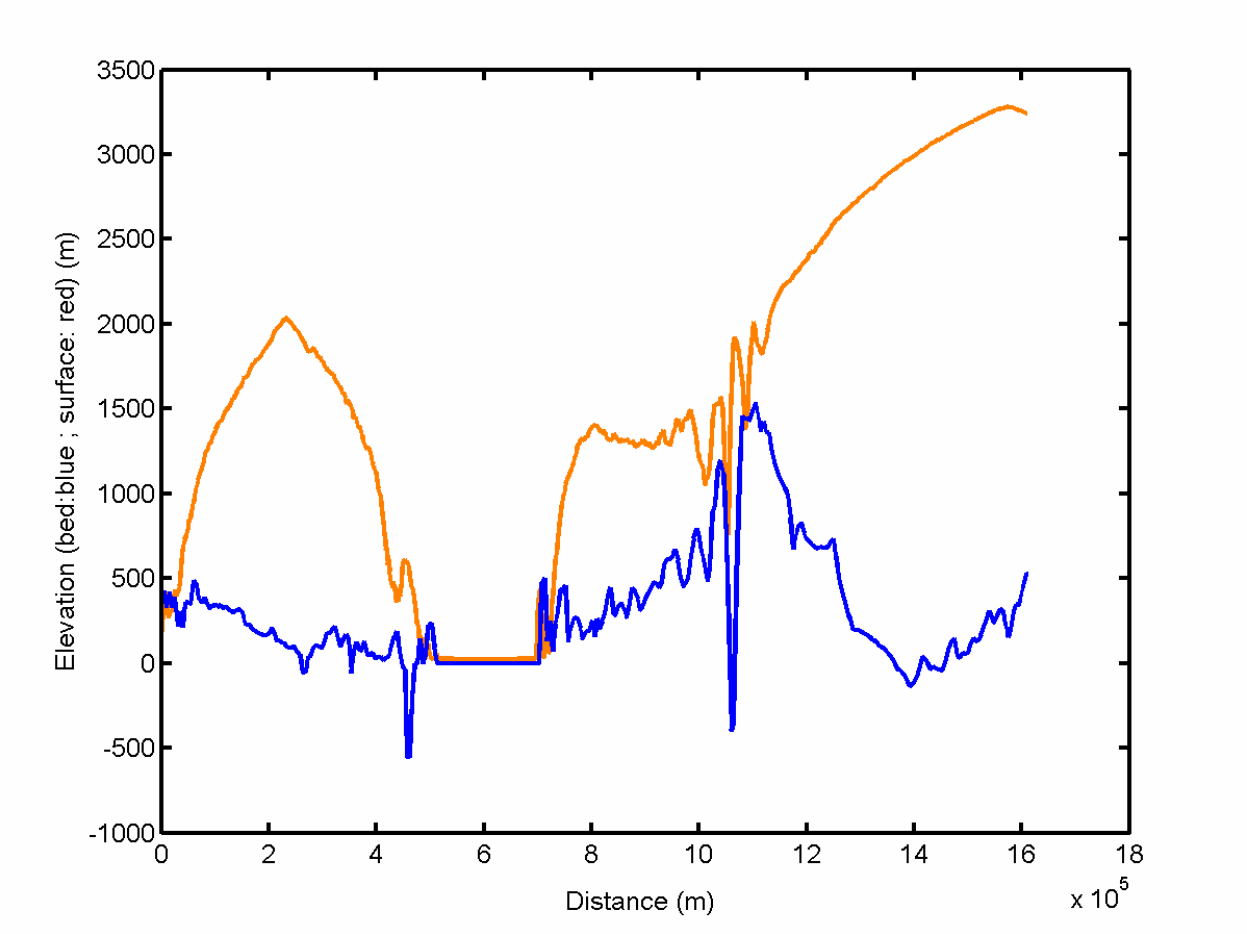


Figure 3. Surface and bottom topography along the flight line (wgs-84)

3.0 GISMO: Thule Flight 1

Overview

Objectives: Observations at two frequencies; Repeat May 06 flight line; Observations from thin to thick ice; Open water calibration; Image NGRIP site; Subglacial water zones; mosaic images over North East Ice Stream all snow facies

Parameters

1 Flight at 150 MHz
1 Flight at 450 MHz
Speed 270 Knots
Flight elevation 26,000 ft
Special targets(NGRIP, NASA East) should be located 400 left or right of the nadir track
Flight includes a minimum of 3 parallel lines, separated by 2 km an passing over the North East Ice Stream.

Events

Begin at Thule and climb to 26000 ft
Proceed Towards GITS along the May 06 Route towards
Proceed towards North East Ice Stream; execute 3 parallel lines starting between coordinates (opportunity to dump data during turns)
Continue on to NASA East
Turn Towards NGRIP
Pass Over NGRIP

Return along outlet glaciers starting at
Fly down outlet Harold Moltke glacier (pending flight clearance)
Return towards Thule
Open Water Cal

Options: If time is short, turn towards NGRIP before reaching NASA East. If time is available add more mosaicking lines across the North East Ice Stream

Long	Lat	Name
291.3	76.53	BGTL
291.3	76.53	BGTL
291.3	76.53	BGTL
299	77.19	CC
304.5167	77.0833	KJ
310.0163	76.85713	HWAY
323.4138	75.85639	PLMW

325.2996	75.64067	PLME
325.2688	75.62438	PLSE
323.3826	75.8401	PLSW
323.445	75.87268	PLNW
325.3303	75.65695	PLNE
330.0053	75.00333	NASE4N
317.9411	75.08861	NGNEW
317.7004	75.1036	NGRP4N
301.1447	76.23083	KJ50
296.7031	76.644	KJ51
294.2619	76.66867	KJ52
294.0215	76.64921	KJ53
293.3394	76.57861	HM01
292.8222	76.51732	HM02
292.4753	76.55894	HM03
292.3002	76.59096	HM04
291.8601	76.61913	HM05
288.1344	76.45833	OW
291.3	76.53	BGTL

Photography (following the way point list above) (can be done on either the 150 or 450 MHz flight depending on cloud)
26000 Ft
Sensor length set to 15 mm
F = 18 mm
Interval = 31 sec

Camera on
BGTL to CC
Camera off

Camera on
PLMW to PLME
Camera off

Camera On
KJ50 to BGTL
Camera off

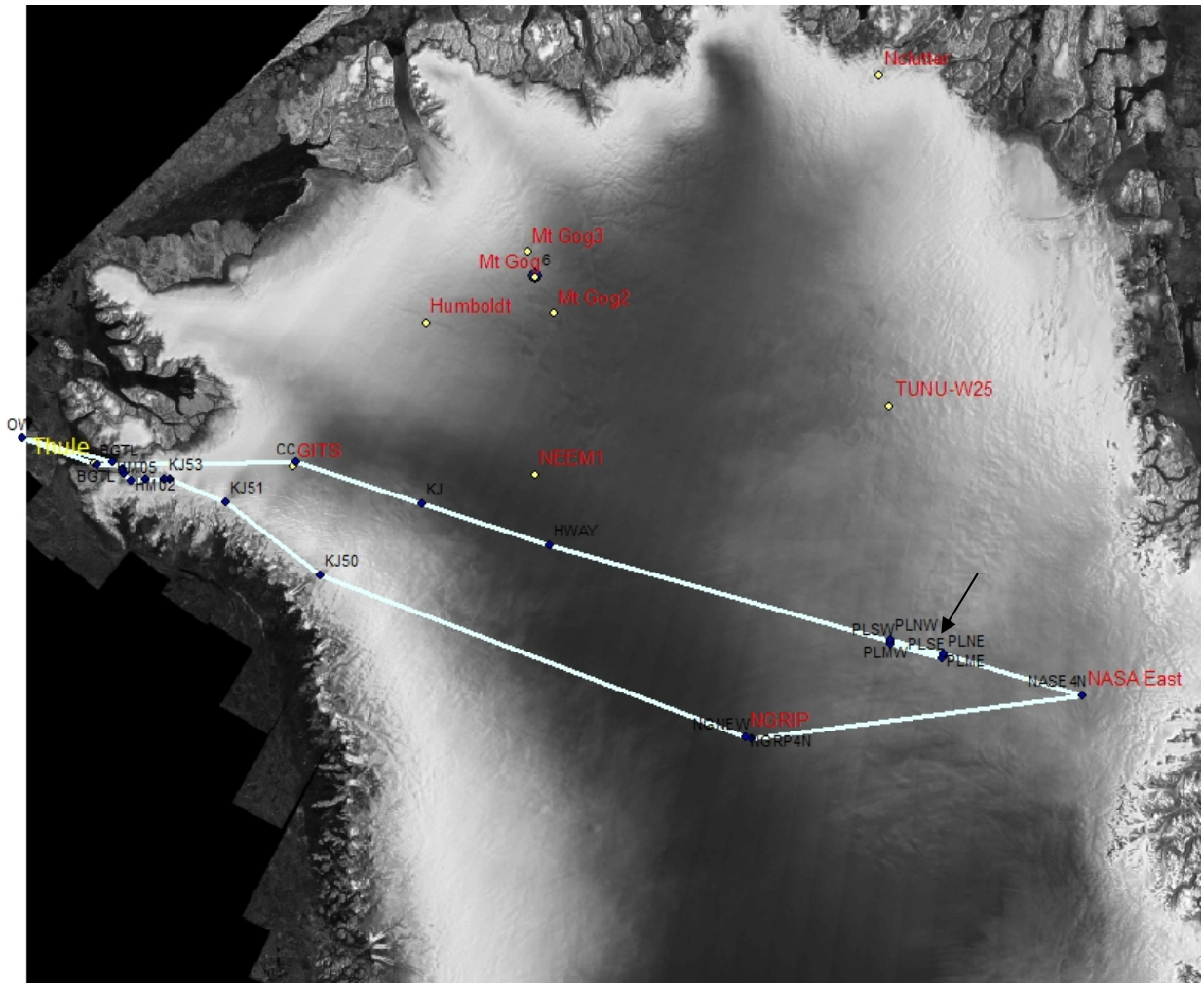


Figure 1. Thule Flight 1. Red line is the May 06 route. Yellow dots: cities; red dots: field camps and clutter. Three lines, spaced 2 km apart will be used to mosaic scenes over the North East Ice Stream (arrow)

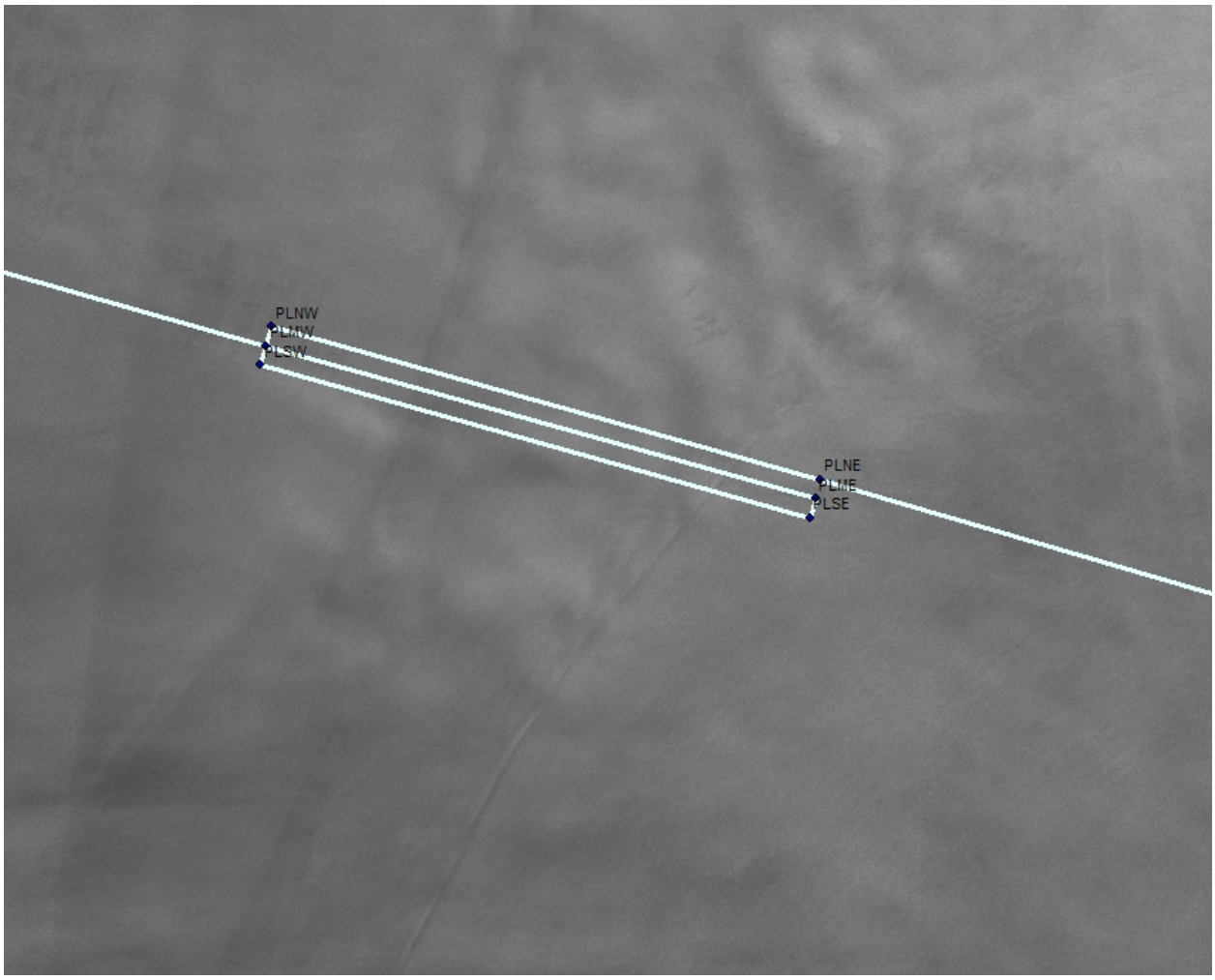


Figure 2. Lines for image mosaic over Northeast Ice Stream.

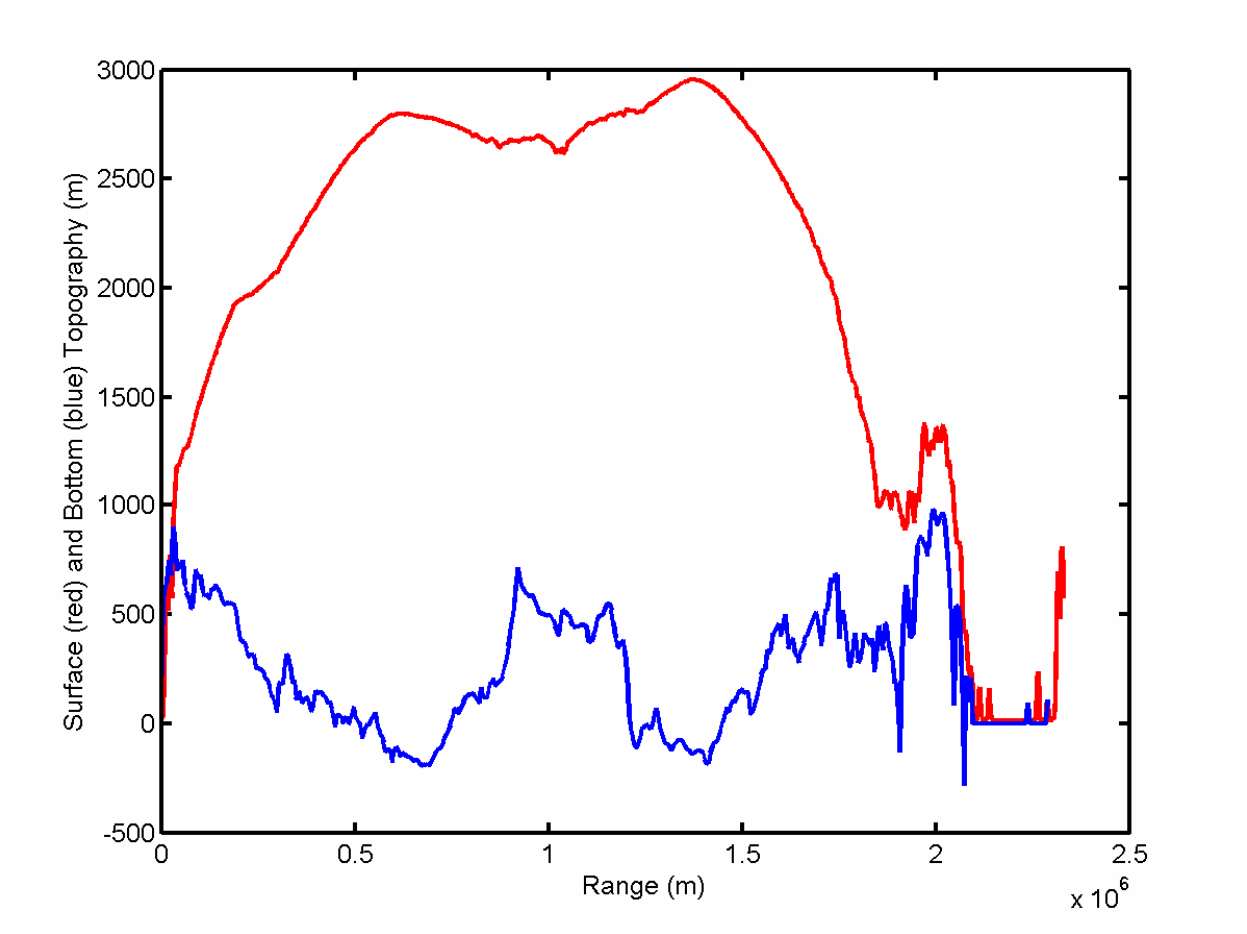


Figure 3. Surface and bottom topography

4.0 GISMO: Thule Flight 2

Overview

Objectives: Observations at two frequencies; Observations from thin to thick ice; Open water calibration; Race Track over Mt. Gogineni; Clutter Sites; Peterman Glacier and Ice Shelf; Subglacial water zones; all snow facies

Parameters

1 Flight at 150 MHz
1 Flight at 450 MHz
Speed 270 Knots
Flight elevation 26,000 ft
Special targets(GITS, NEEM, Mt. Gogineni, Humboldt) should be located 400 left or right of the nadir track

Events

Begin at Thule and climb to 26000 ft
Proceed over GITS
Proceed over NEEM
Turn Northeast and then on to North Clutter Site
Cross Northern Crevasse Zone
Pass down Petermain Glacier

Excecute Mt. Gogineni Race Track, 25 m spacing, 4 passes minimum. One leg offset 400 m from these points
Parallel leg should be located to the East of these points. Opportunity to dump data during turns.

Pass over Humboldt Camp
Return towards Thule

Open Water Cal

Options: Increase number of legs in Mt Gogineni race track if time permits. If time is short, head northeast from Neem to a point west of Nclutter to decrease total distance.

291.3	76.53	BGTL
291.3	76.53	BGTL
291.3	76.53	BGTL
299	77.19	CC
309.1023	77.49644	NEEM4S
310.984	77.52594	KJ3
330.5673	81.02071	KJ4
327.777	81.101	NCLUT
311.0761	81.18278	NCZ1
309.135	80.84722	NCZ2
303.0334	80.90015	ATMC39
298.486	81.18356	ATMC38
298.154	81.1187	ATMC15
299.27	80.7199	ATMC14
301.66	80.3038	ATMC13
307.5307	79.56843	WR1N
308.0907	79.33823	WR1S
308.5424	79.37452	ER1S
307.9804	79.60471	ER1N
307.5296	79.56833	WR2N
308.0896	79.33814	WR2S
308.5412	79.37443	ER2S
307.9793	79.60462	ER2N
307.5285	79.56824	WR3N
308.0885	79.33805	WR3S
308.5401	79.37433	ER3S
307.9782	79.60453	ER3N
307.5273	79.56815	WR4N
308.0873	79.33796	WR4S
308.539	79.37424	ER4S
307.9771	79.60444	ER4N
303.1825	78.74836	HUMB4S
295.6888	77.17829	KJ1
292.4058	76.66162	KJ2
288.2217	76.60778	OW2
291.3	76.53	BGTL

Photography (following the way point list above) (can be done on either the 150 or 450 MHz flight depending on cloud)
26000 Ft
Sensor length set to 15 mm
F = 18 mm
Interval = 31 sec

Camera On
NEEM (+- 20 km)
Camera off

Camera on
KJ4 to ATMC13
Camera off
Camera on (once around the raceway)
WR2N to WR2S to ER2S to ER2N
Camera off

Camera on
KJ1 to BGTL

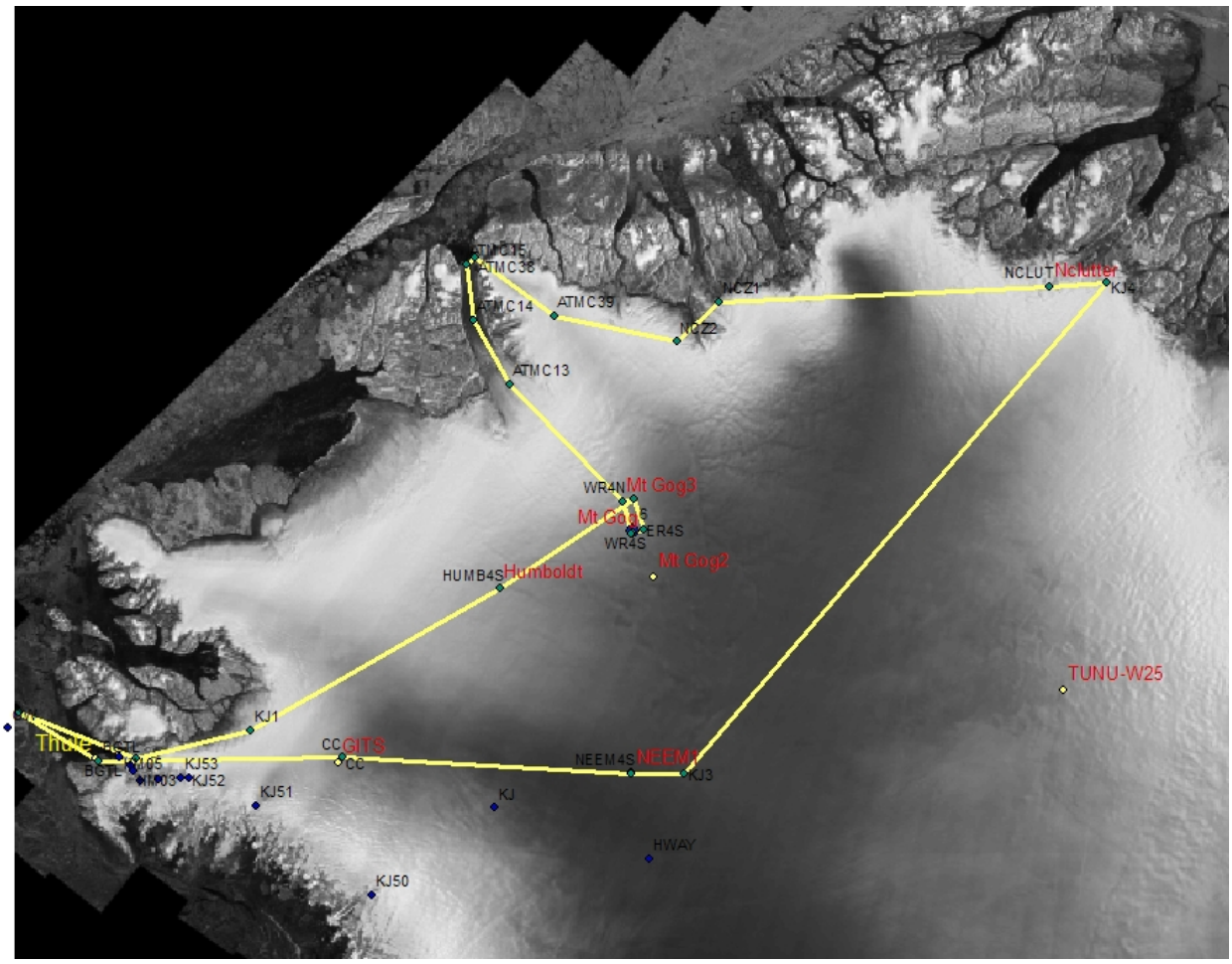


Figure 1. Thule Flight 2. Yellow dots: cities; red dots: field camps and clutter. Mt Gogineni Race track location is also shown.

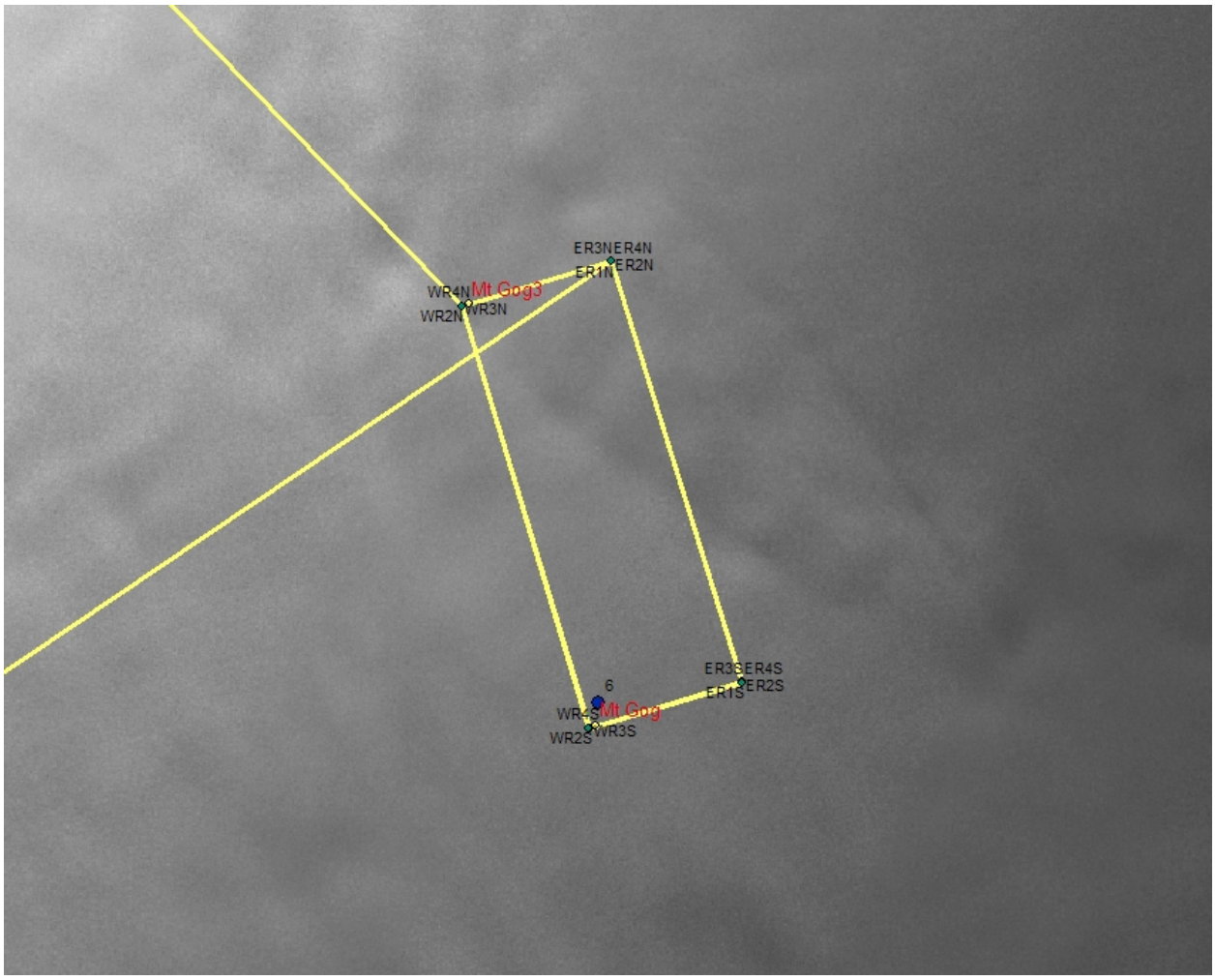


Figure 2. Race Track near Mt. Gogineni.

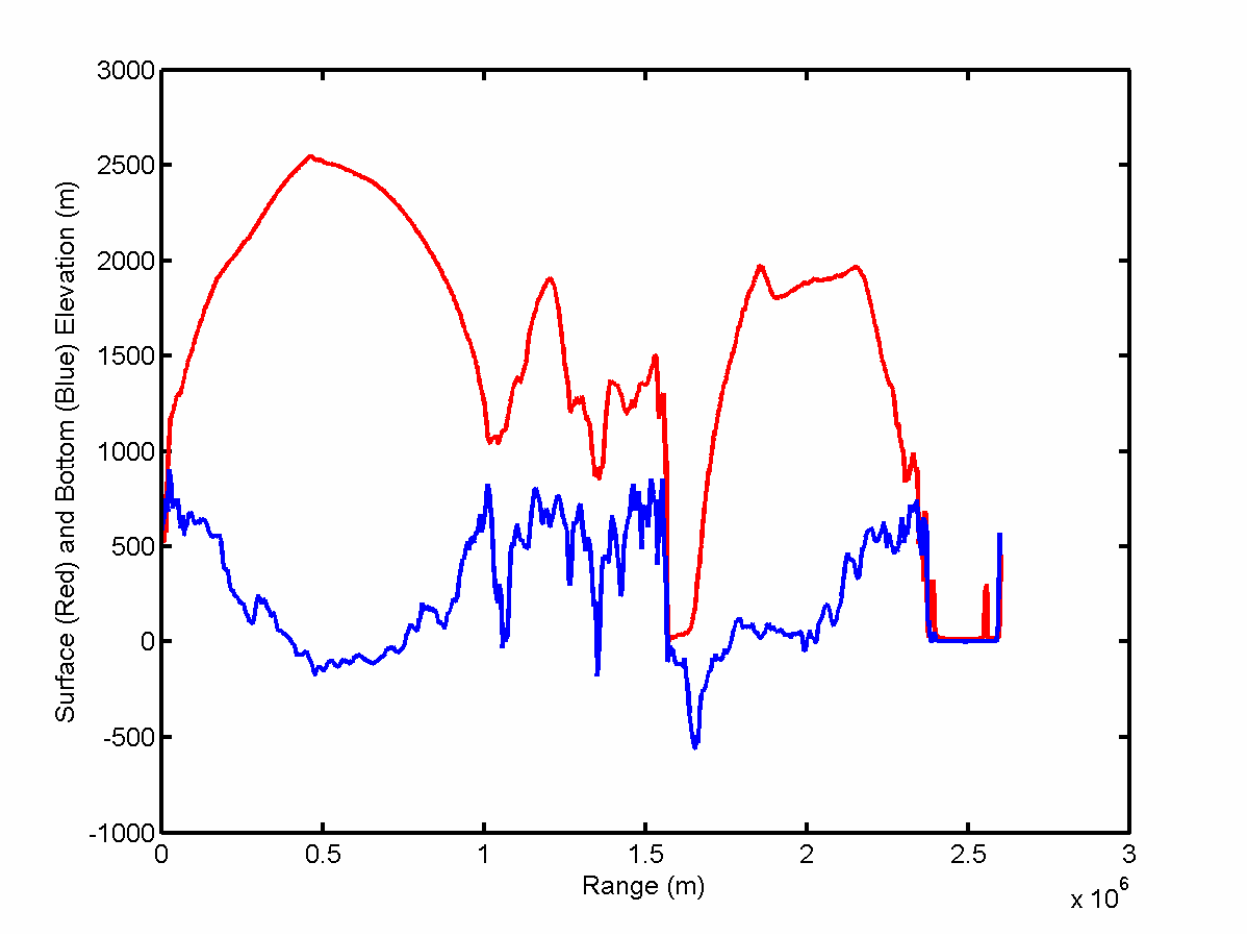


Figure 3. Surface and bottom topography along the flight line (wgs-84)

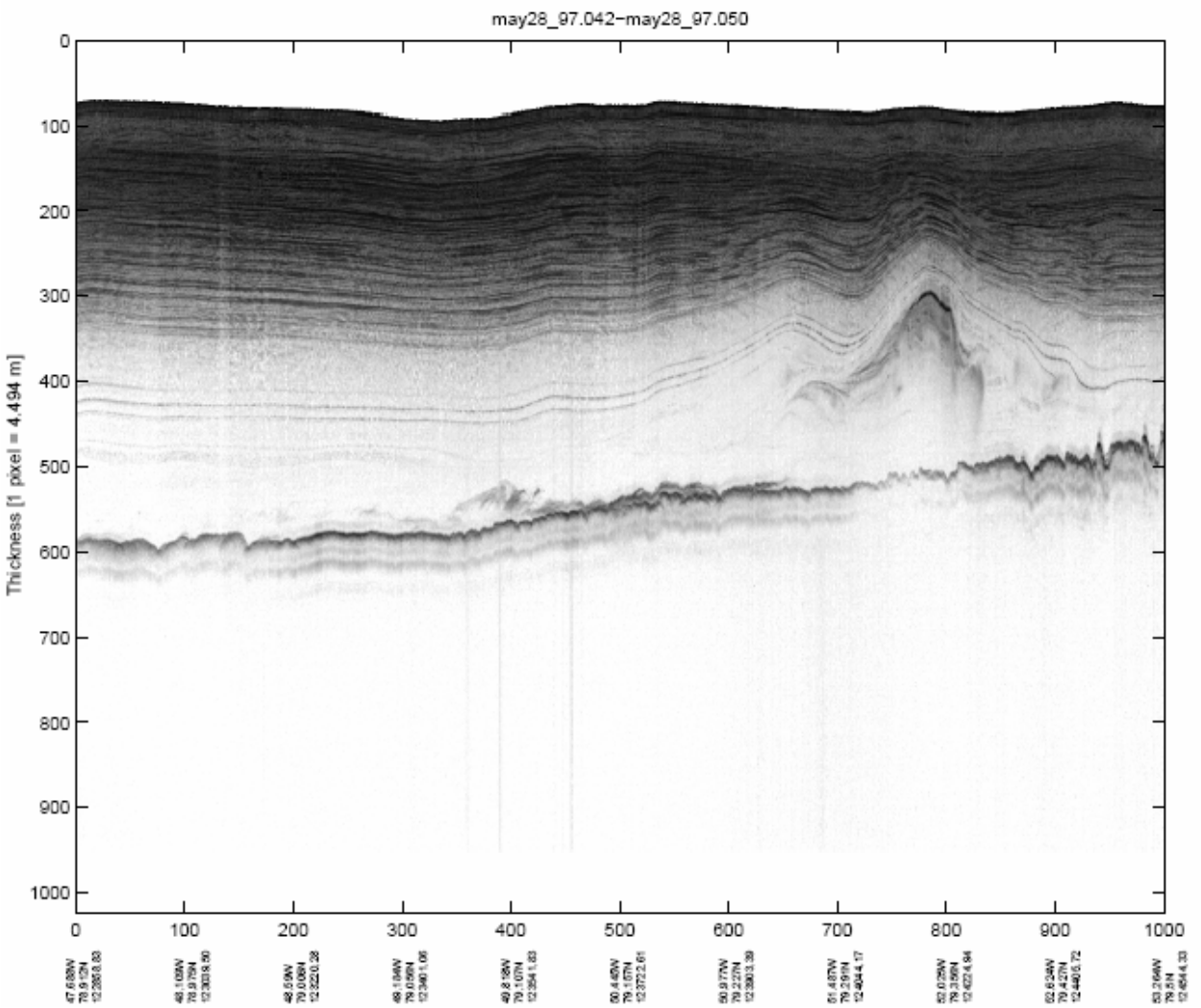


Figure 4. Mount Gogineni

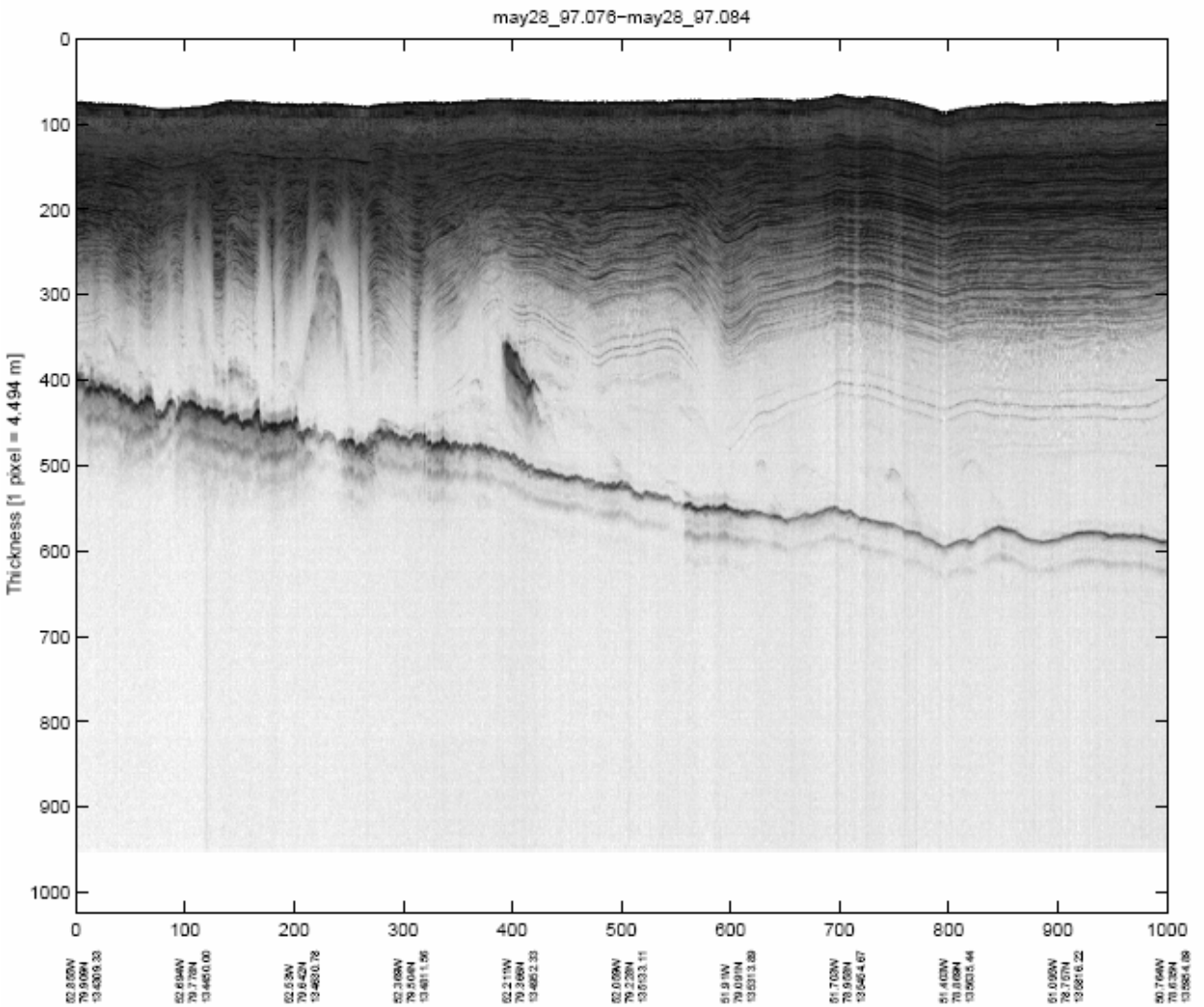


Figure 5. Mount Gogineni 3

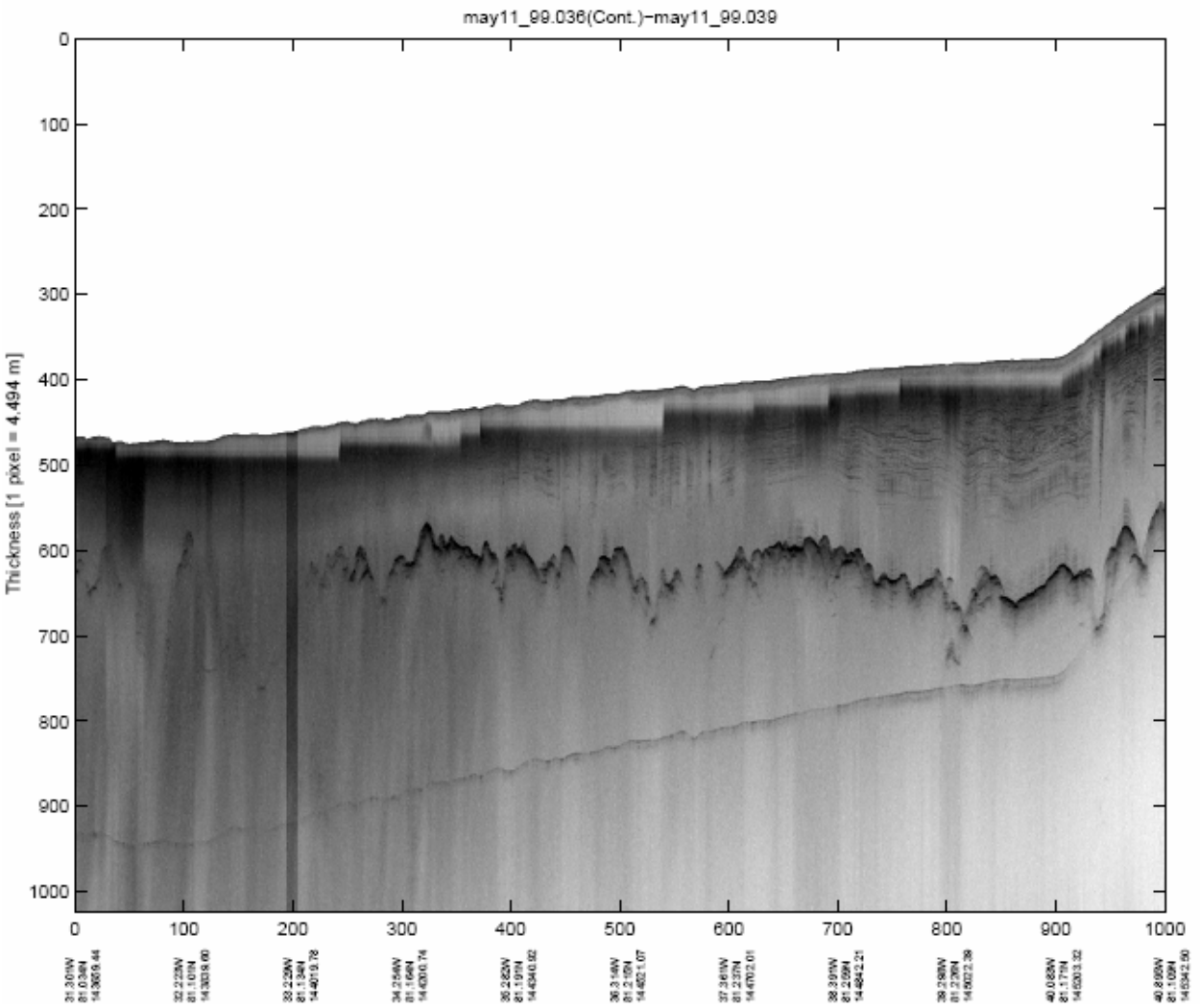


Figure 6. Northern Clutter

5.0 GISMO Experiment Check List

Complete preflight briefing with pilots
Antennas properly configured
Pre flight Calibration completed (see calibration procedures sheet)
Radar Parameters Checked (see Parameters list)
GPS System Working and Recording Data
Inflight data validation via A-scope inspection and InSAR processing
Open Water Calibration data acquired
Post-flight calibration
Data downloaded and backed up.
Post flight data analysis via InSAR processing
Copy all data logs
Identify successful photo runs and identify regions for repeat try

6.0 Calibration during installation, and before and after each mission

During Installation:

We need to perform four types of calibrations:

1) Inject transmitter signal into each receiver through a known length of delay line and attenuation, and measure each receiver response.
2) Measure chirp waveform and record it.
3) Measure time delay from the rack to each antenna using a network analyzer.
4) Measure system response by flying over the ocean.

During a mission:

1) Record transmitter chirp waveform at the start and end of each mission, and during the mission on a disc with an oscilloscope.
   This would probably require a directional coupler with 60-dB coupling coefficient with the coupled-port connected to an oscilloscope. The trigger to generate the chirp must be used to trigger the oscilloscope and data are recorded by the operator on disc. This task can be handled by the new RF engineer.

2) Fly over the ocean to collect data over a distance of 10-20 km before and after each mission.

7.0 Testing Results for ΔΣ Power Amps

The two power amplifiers for the 450 MHz band of the GISMO radar were tested by applying a pulsed RF signal at the input of each module, and recording the corresponding output on a spectrum analyzer. The pulsed (TTL) gating signal was set to 2 kHz with a duty cycle of 20% (pulse width 100us). These are testing parameters suggested by the manufacturer. The RF input tone was supplied by an HP8648D generator operating at a frequency of 450 MHz. The output power was monitored with the spectrum analyzer triggered by the same 2 kHz TTL gating signal.

A plot of the output power (Pout) as a function of input power (Pin) for the amplifiers appears in Fig. 1. The effect of the attenuator chain placed at the output of the amps, as well as cable losses were calibrated out of the measurement. Both units (designated PA1 and PA2, respectively) are linear up to about 8 dBm of input power, after which saturation effects are noticeable. Dr. Allen pointed that this is acceptable as long as the units are able to produce Pout=2kW. The measured values of Pout for an input power of +17dBm are 63.7 dBm and 63.3 dBm for PA1 and PA2, respectively. These figures agree with the settings reported by ΔΣ (slightly larger than 63 dBm for both units).

Both units were left ON for about 1 hr, with Pin= 17 dBm. No significant power change was visible at the output.

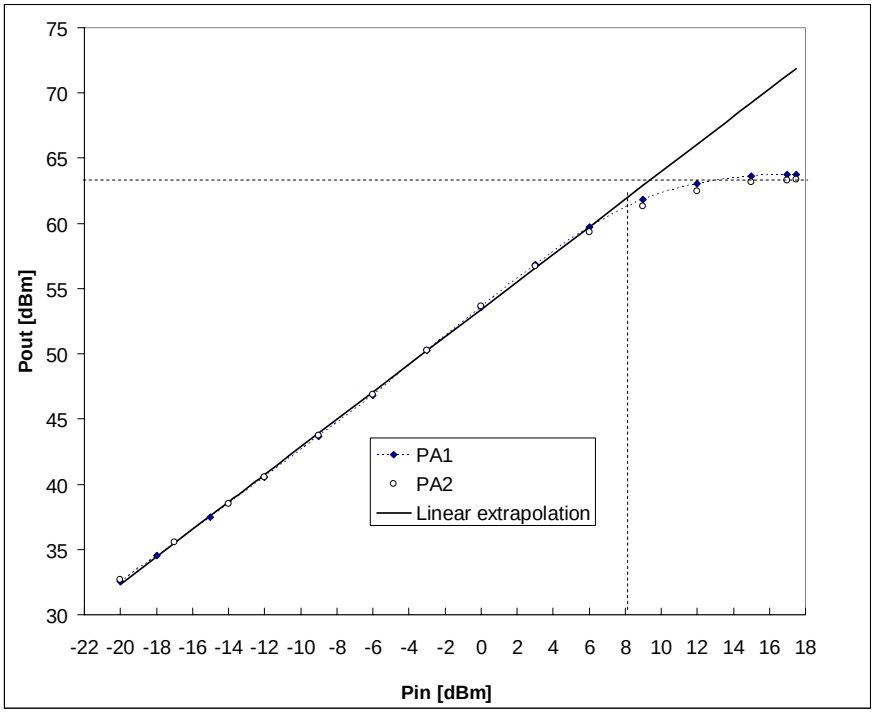


Fig. 1. Recorded output power as a function of input power for the 450 MHz ΔΣ power amps.

8.0 Parameter List

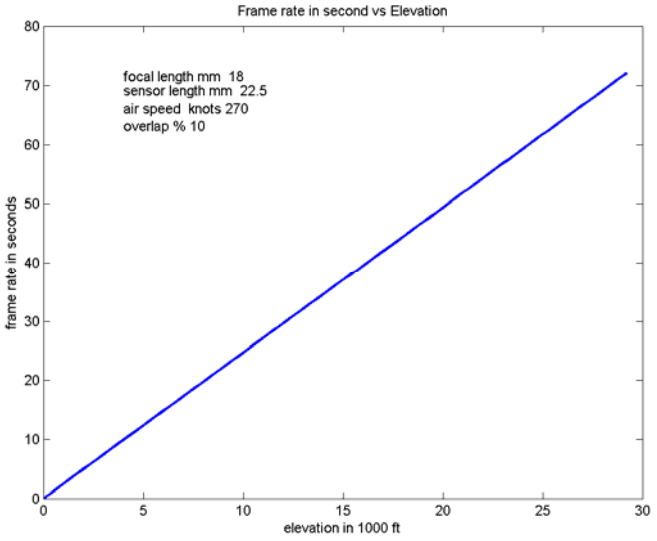
Parameters	**May 2006 150 MHz**	**April 2007 150 MHz**	**April 2007 450 MHz**
Carrier frequency	150 MHz	150 MHz	450
Sampling frequency	120 MHz	120 MHz	
Chirp_start_freq (IF)	20 MHz	20 MHz	
Chirp_Stop_freq (IF)	40 MHz	40 MHz	
Pulse_duration	3 us	10 us	
PRF	14992.5 Hz	10000 Hz	
Range_samples	4672	4672	
Echo_delay	3.5 us / 14 us	1.5 us	
Number of waveforms	4	1	
Number of transmit channels	2	1	
Number of receive channels	6	5	
Trasmit Power (high elevation)		1 kW (2 kW max)	1 kw (2 kW max)
Transmit Power (low elevation		200 W	200 W

9.0 Flight Hour Summary

Flight line	total time (hours)	data collection time (hours)
Thule 2	6.6	5.4
Thule 1	5.1	4.8
Sonde	7.4	6.6
2 flights per line	38.2	33.6

10 Camera Parameters

	Sensor length = 22.5 m			Sensor Length = 15 mm		
	Distance (km)	Spacing (km)	Interval (sec)	Distance (km)	Spacing (km)	Interval (sec)
H=26000						
F=18 mm	7.25	6.53	47	4.83	4.35	31
F=55 mm	2.37	2.14	15	1.58	1.42	10
H=1500						
F=18 mm	0.57	0.57	3.7	0.38	0.35	2.5
F=55 mm	0.19	0.17	1.2	0.13	0.11	0.8


Frame rate in second vs Elevation
focal length mm 18
sensor length mm 22.5
air speed knots 270
overlap % 10
frame rate in seconds
elevation in 1000 ft
0
10
20
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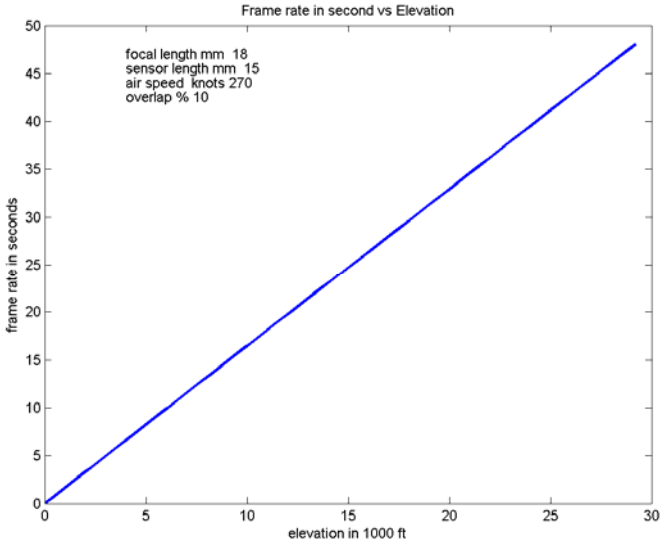
40
50
60
70
80
0
5
10
15
20
25
30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sensor length mm 15
air speed knots 270
overlap % 10
frame rate in seconds
elevation in 1000 ft
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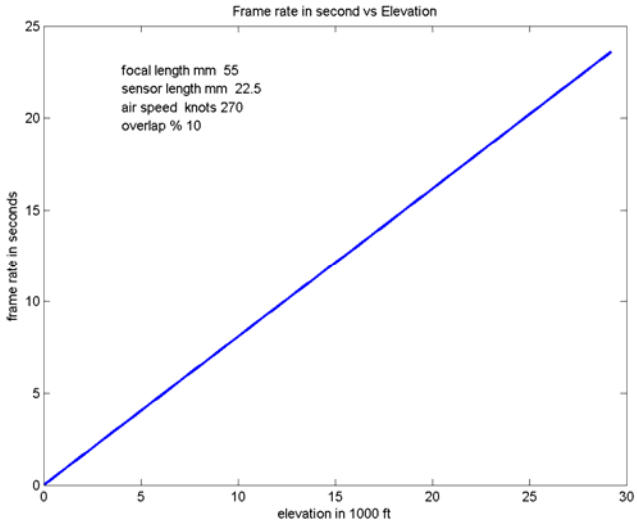
40
45
50
0
5
10
15
20
25
30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air speed knots 270
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frame rate in seconds
elevation in 1000 ft
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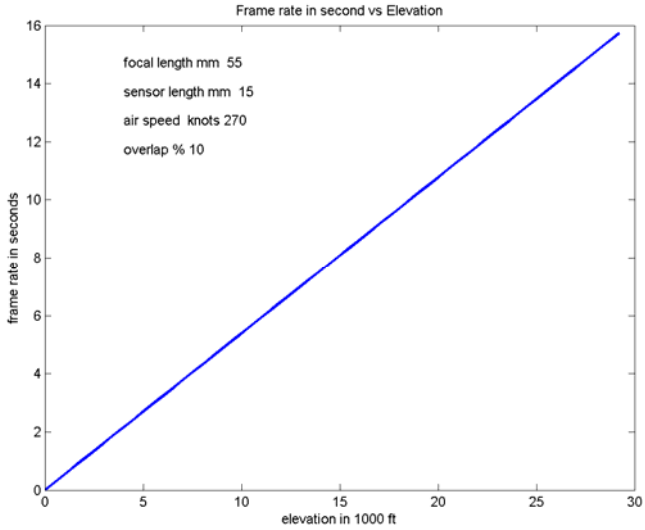
10
15
20
25
0
5
10
15
20
25
30


Frame rate in second vs Elevation
focal length mm 55
sensor length mm 15
air speed knots 270
overlap % 10
frame rate in seconds
elevation in 1000 ft
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2
4
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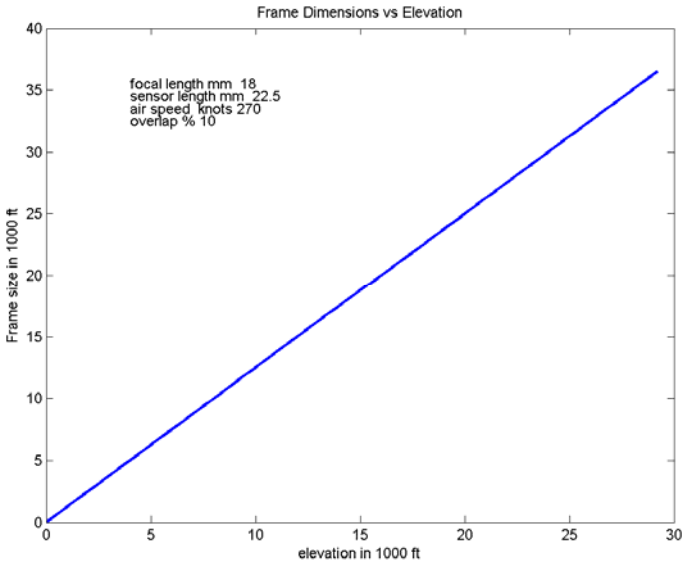
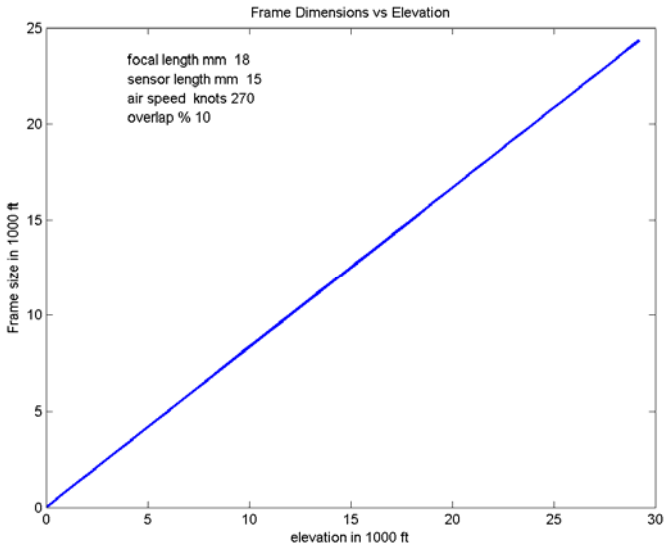
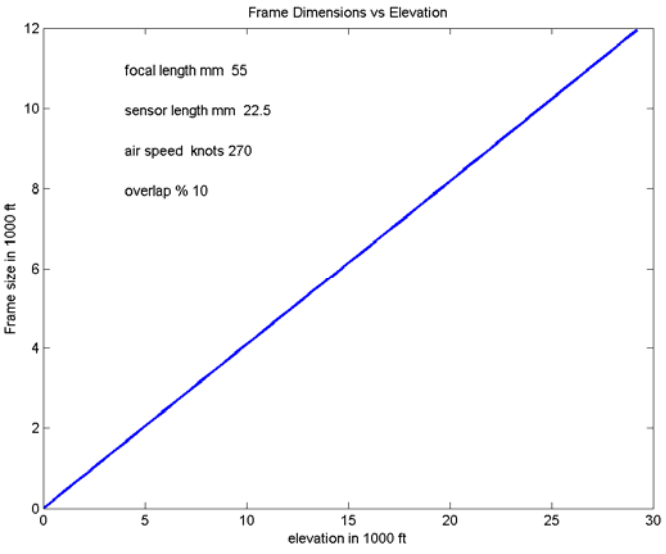
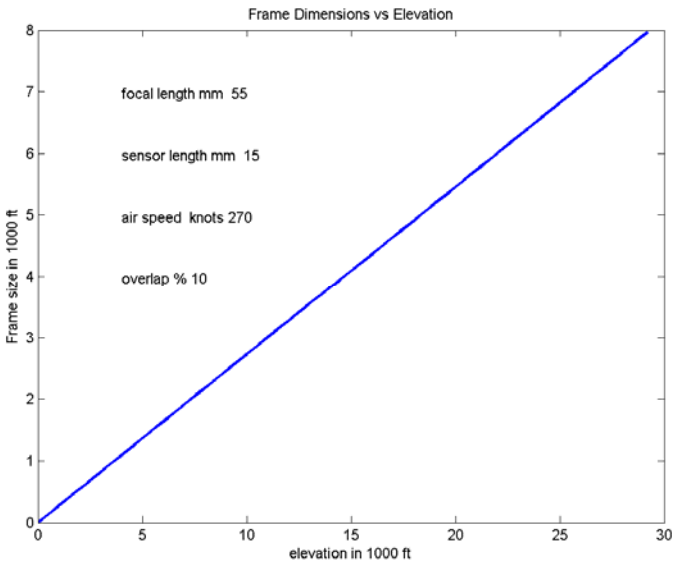
12
14
16
0
5
10
15
20
25
30


Frame Dimensions vs Elevation
focal length mm 18
sensor length mm 22.5
air speed knots 270
overlap % 10
Frame size in 1000 ft
elevation in 1000 ft
0
5
10
15
20
25
30
35
40


Frame Dimensions vs Elevation
focal length mm 18
sensor length mm 15
air speed knots 270
overlap % 10
Frame size in 1000 ft
elevation in 1000 ft
0
5
10
15
20
25
30


Frame Dimensions vs Elevation
focal length mm 55
sensor length mm 22.5
air speed knots 270
overlap % 10
Frame size in 1000 ft
elevation in 1000 ft
0
2
4
6
8
10
12
0
5
10
15
20
25
30


Frame Dimensions vs Elevation
focal length mm 55
sensor length mm 15
air speed knots 270
overlap % 10
Frame size in 1000 ft
elevation in 1000 ft
0
1
2
3
4
5
6
7
8
0
5
10
15
20
25
30