Calibration and Validation of the CryoSat Radar Altimeter

Devon Ice Cap – Spring/Fall 2004

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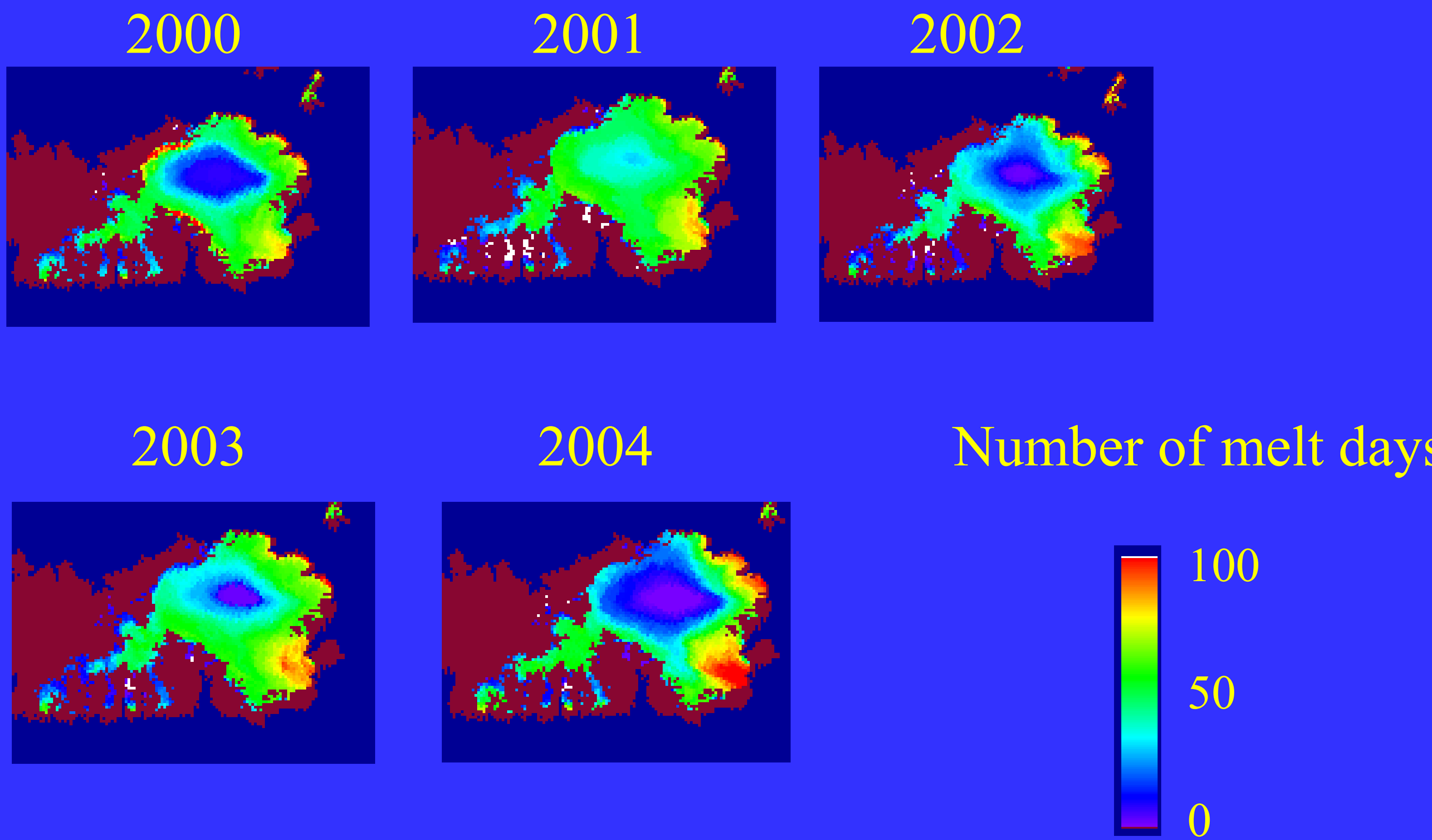
Objectives

• Challenges faced by CryoSat radar altimeter in detecting long term changes in ice thickness over small ice caps

1) Retrieval of surface heights from radar backscatter
   - radar echo influenced by both surface and subsurface properties of the ice cap
   - Complicates retrieval of surface elevation across different glacier facies throughout different times of the year

2) Need to discriminate between long term thickness changes and short term fluctuations caused by:
   - Snowpack compaction
   - Firn densification

Extent of Melting on the Devon Ice Cap Derived from Quickscat Imagery (2000 – 2004)



Imagery provided by Libo Wang (2005)

Calibration Studies on the Devon Ice Cap

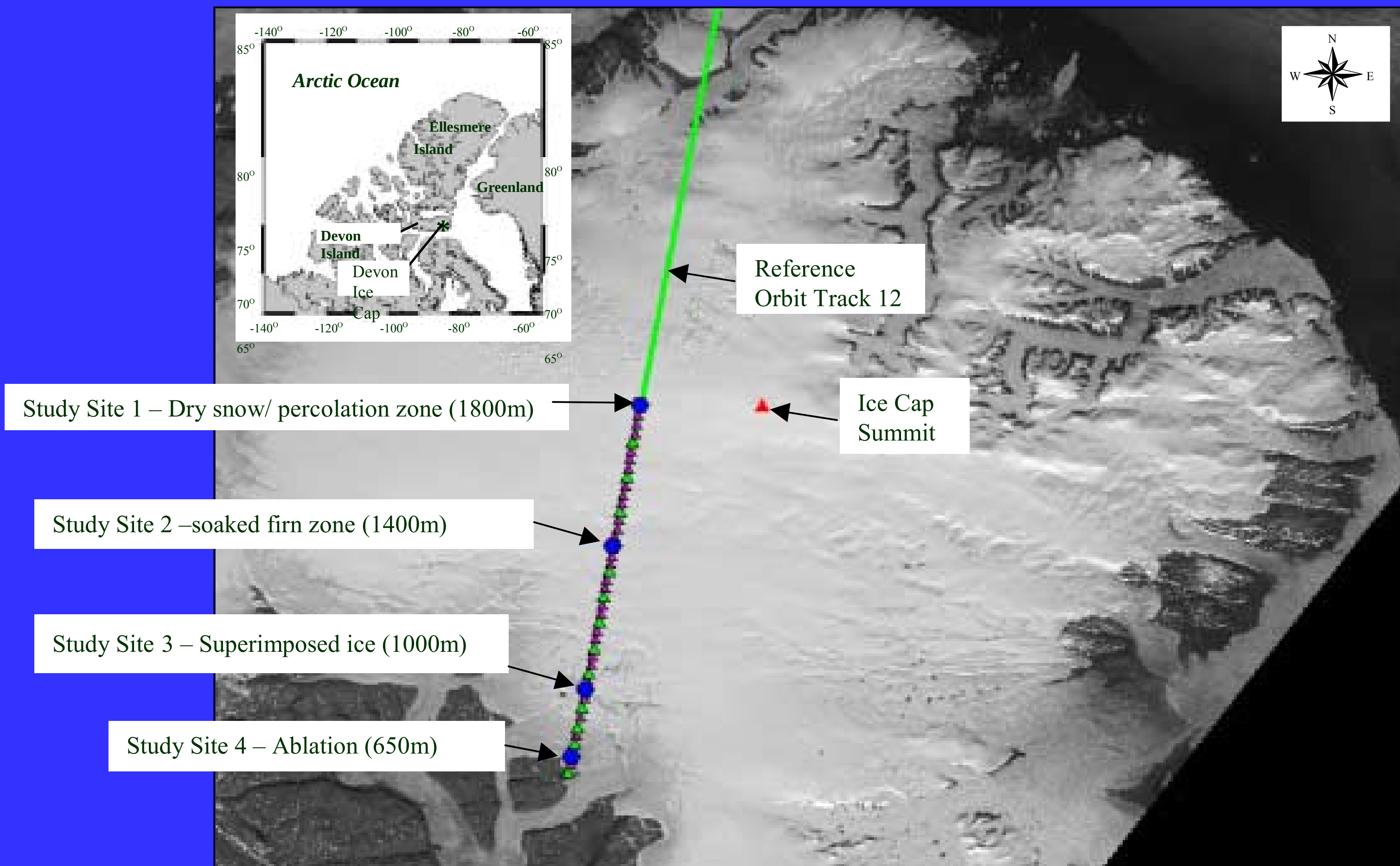
- Synchronize field campaigns with airborne overflights performed by the Alfred Wegener Institute, Germany
  - ASIRAS - 13GHz radar altimeter
  - Laser scanner

- Analyze ground / airborne measurements → insight into dominant factors that influence radar backscatter

- Field campaigns → spring/fall, 2004 and 2006
  - Seasonal/interannual variability
  - Discriminate between short term fluctuations and long term trends

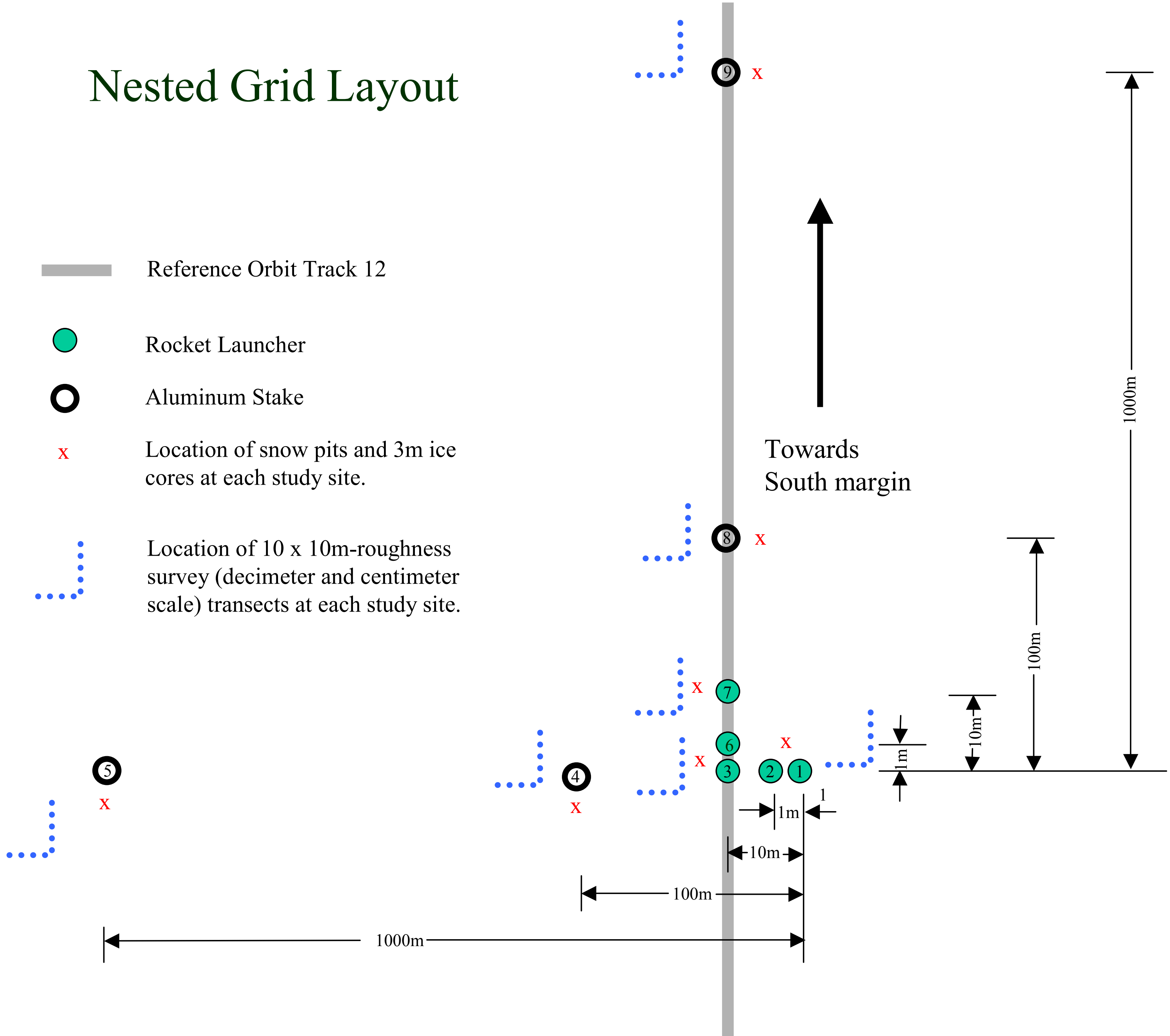
CryoSat Land Ice Calibration Sites in the Northern Hemisphere (2004-2006)

CryoSat Transect and Study Sites on the Devon Ice Cap



•Provides insight into along track variability throughout all 4 glaciological zones across the ice cap

Nested Grid Layout



Field Measurements

1. Independent measures of surface elevation
   - Match laser altimetry
   - Check on radar altimetry

2. Long term (40yr) measures of surface elevation change
   - Compare with short term (2004-2006) estimate derived from airborne altimetry

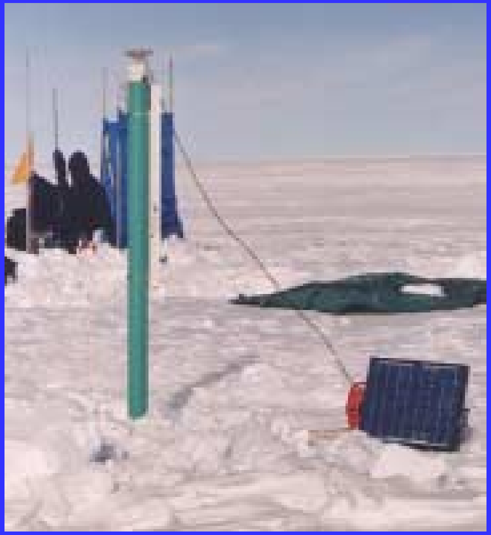
3. Quantify rates of firn densification
   - Magnitude of firn compaction throughout major glaciological zones / seasonal basis

4. Surface roughness and subsurface characteristics
   - insight into effects of surface and volume scattering on the radar backscatter between glaciological zones and over time

5. Record meteorological conditions
   - Quantify relationship between temp → firn / snowpack compaction rates
   - Wind direction / intensity → surface roughness

1) Independent Measures of Surface Elevation

- Static GPS
  - acquired at each pole within each nested grid (±1.5cm x-y ±3cm z)
  - Along transect poles (± 4 cm x-y, ±6 cm z)



- Kinematic GPS
  - Along the entire transect
  - 100m x 100m grids at each study site
  - accuracy ±3cm horizon. ±5cm vertical

2) Independent measures of long term elevation change

$$\partial H/\partial t_{strain} = b - F\,(H\,(\varepsilon_x + \varepsilon_y) + u_{\mathrm{xy}}(\partial H/\partial x))$$

(***Physics of Glaciers***, Paterson, 1994; pg 257)

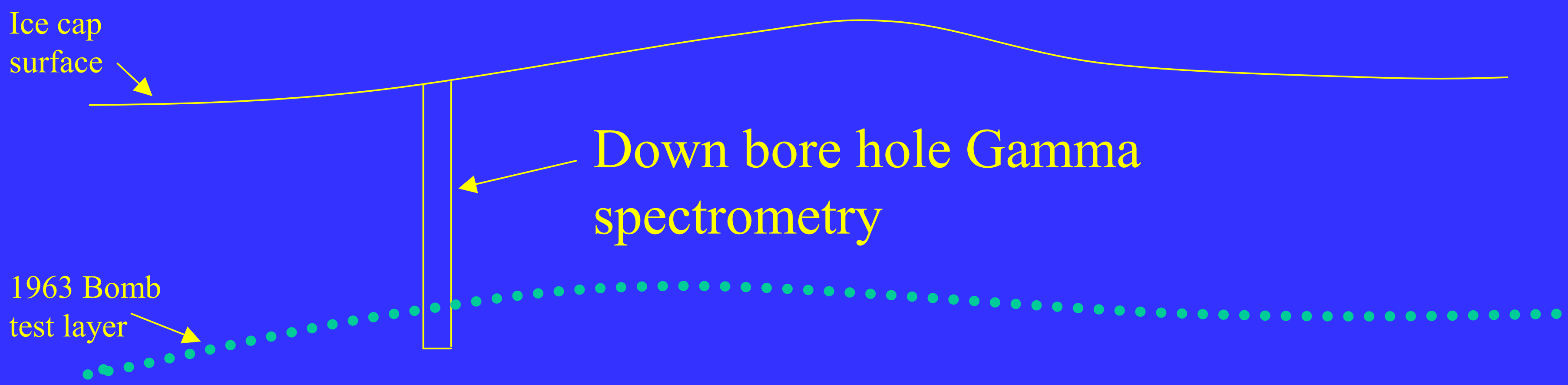
$u_{\mathrm{xy}}(\partial H/\partial x)$ = ice thickness gradient*

$F\,(H\,(\varepsilon_x + \varepsilon_y))$ = depth average thickness change derived from horizontal strain

b = 40 year mass balance

*obtained from radio echo sounding data – J. Dowdeswell, Cambridge University, U.K.

Estimate of 40 year mass balance (*b*)



$$b = \frac{\text{ice density (kg m}^{-3}\text{) x depth to bomb layer(m)}}{\text{40years}}$$

2) Independent measures of long term elevation change

Coffee Can technique (Hamilton and Whillans, 2000)

$$\partial H/\partial t_{cc} = b\,/\,\rho + z + u\,v$$

b = 40 year mass balance

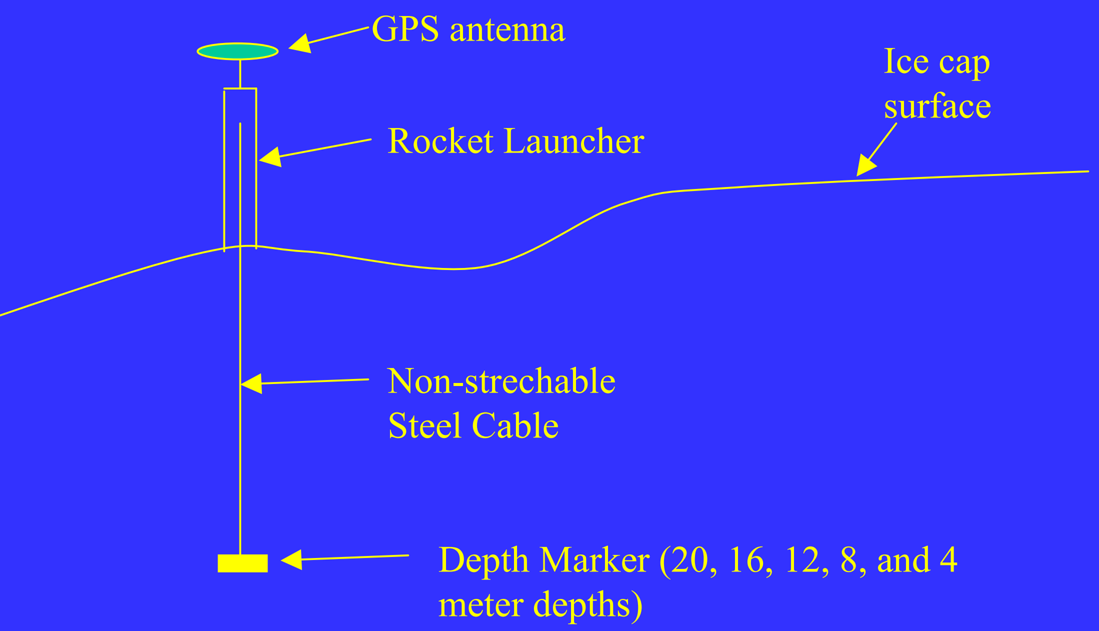
ρ = firn density at marker

u = horizontal velocity

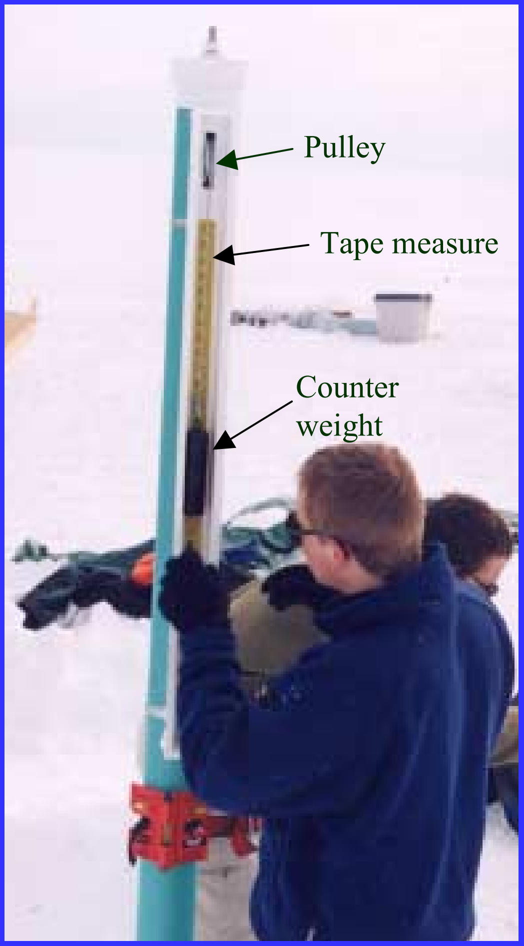
v = surface slope

z = vertical velocity

Coffee Can Technique - Vertical Velocity (z)



Rocket Launcher Setup



Results – Firn Compaction

Site	Average density throughout upper 20m of firn (kg m^3)	Firn Compaction Values: April – August, 2004 (cm)				
		20m	16m	12m	8m	4m
1	568	-6.7	-6.6	-4.9	-4.4	-1.4
2	728	-1.5	-1.1	-1.7	-1.1	0
3	917	n/a	n/a	+1.6	+1.0	+0.9

Results – Thickness Change Measurements

Site #	Coffee Can $\partial H/\partial t_{cc}$ (m a^{-1})	Vertical Strain Equation $\partial H/\partial t_{strain}$ (m a^{-1})
1	-0.13 ± 0.03	N/A
2	-0.31 ± 0.05	-0.18 ± 0.05
3	-0.14 ± 0.06	-0.35 ± 0.07
4	-0.57[1] ± 0.06	-0.35[1] ± 0.05

[1]Mass balance determined from winter 2003/2004 acc. and summer 2004 abl.

- Thickness changes are consistent with basin wide estimates of accumulation zone thinning of -0.12 ± 0.12 m a^{-1} derived in Burgess and Sharp, in prep.

3) Subsurface Properties

- Snow pits - Stratigraphy, density, grain size, grain type, temperature, and moisture

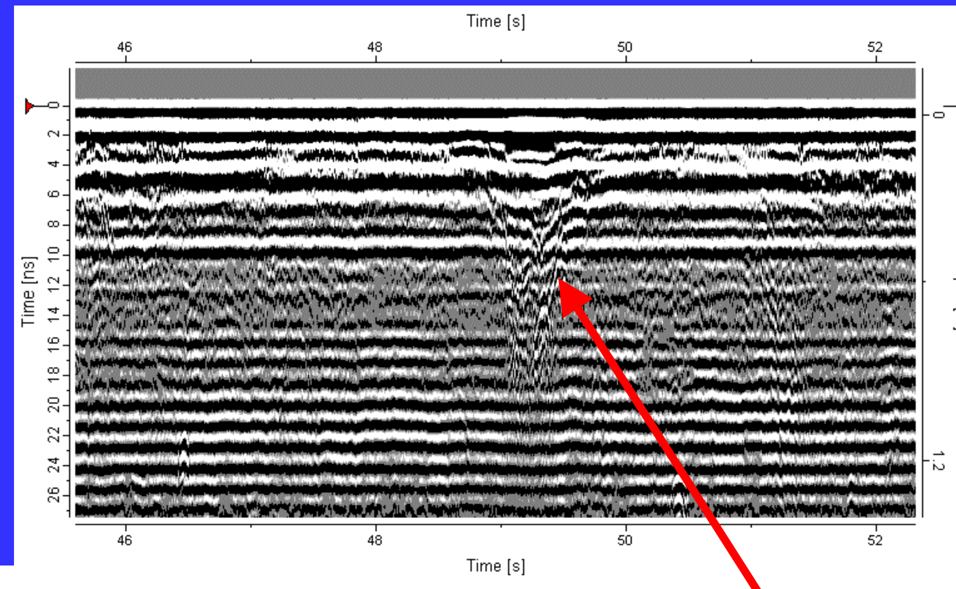
3) Subsurface Properties

- Density and stratigraphy of 3-meter ice cores at each study site

- Density and stratigraphy of 1-meter ice cores from the bottom of snow pits at along transect poles

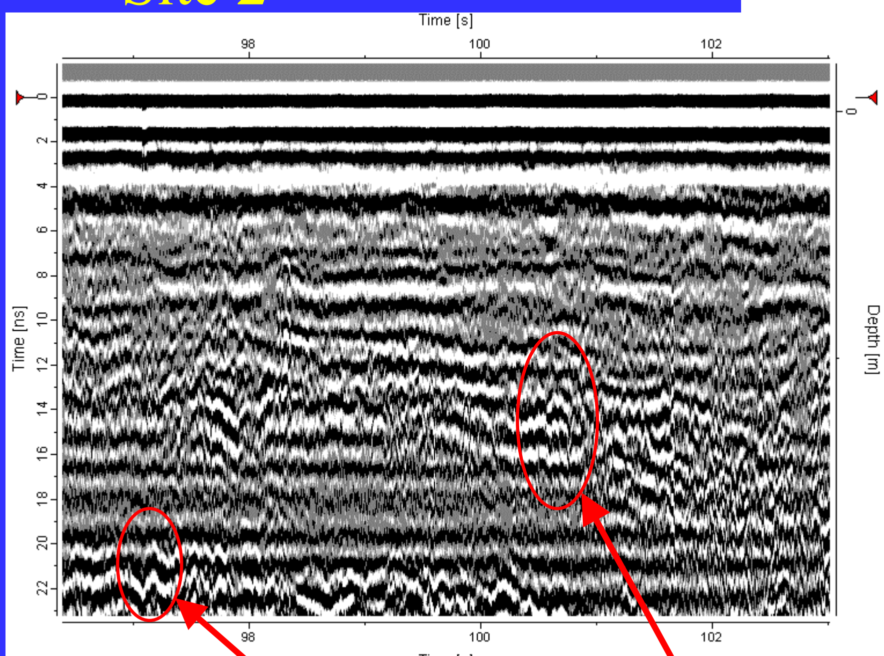
1GHz Ground Penetrating Radar Profile Results

Site 3



Crevasse?

Site 2



Folding

Faults

- Penetrates 1 – 3m below surface
- Tracks continuity of dominate ice lenses between snowpits/ice cores

4) Surface Roughness Measurements

Stadia Rod

Laser level pointer

Decimetre Scale

Centimetre scale

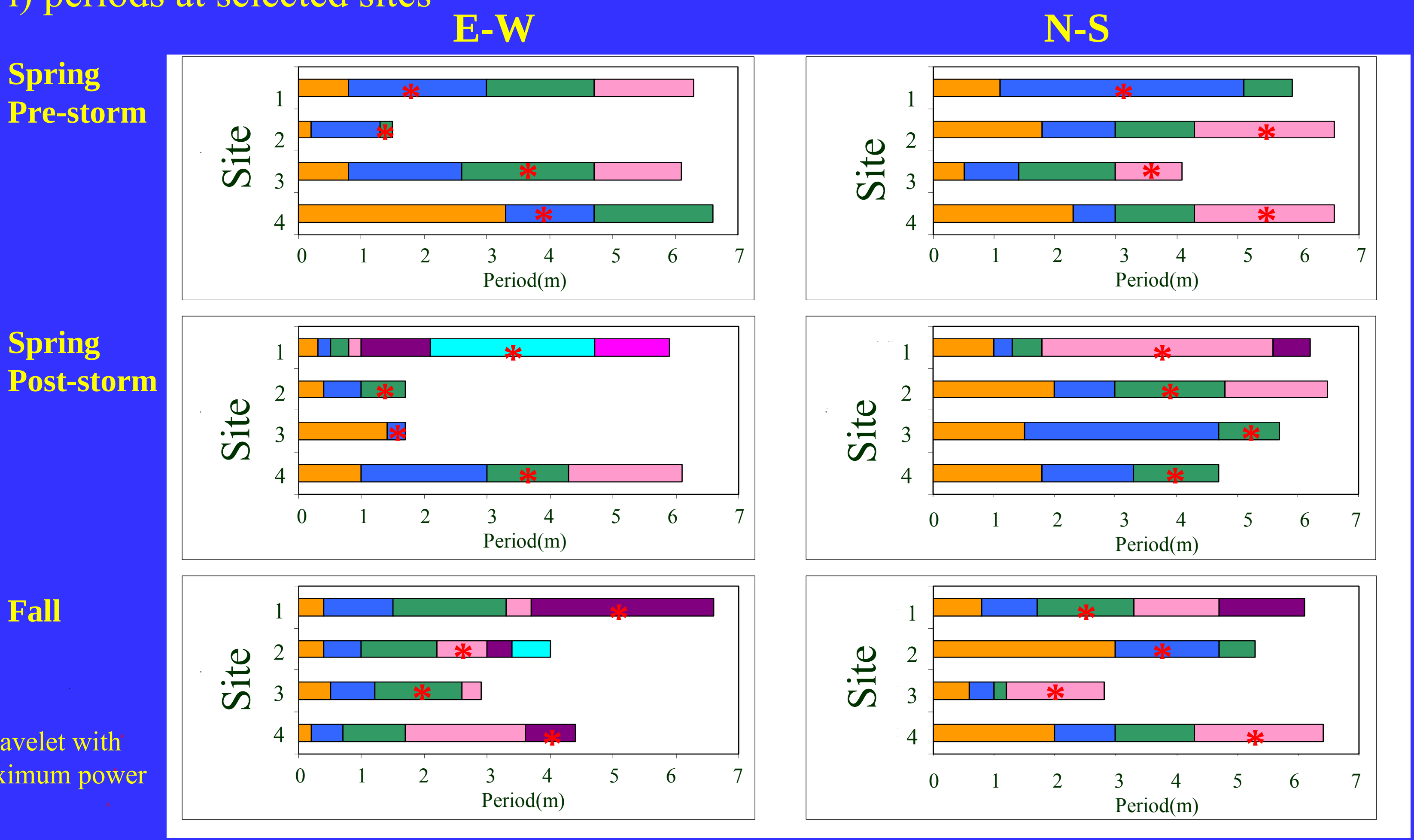
4) Surface Roughness Measurements

Meter Scale

Oblique - qualitative

Decimetre scale roughness – wavelet analysis

i) periods at selected sites



* wavelet with maximum power

Analysis by Fiona Cawkwell, University of Alberta, Canada

6) Meteorological Data

Weather stations at sites 1, 2, and 3

•15 HOBO™ temp loggers mounted on mass balance poles along the transect.

Results – Meteorological Data

- 13 out of 15 HOBO™ temperature data loggers
  - Spans the full elevational range of the transect
- AWS data from 2 of 3 weather stations (sites 1 and 2) retrieved
  - May be able to download data from Site 3 in Spring 2005

Meteorological Data

- Spatial covariance between air temps.
- Quantify relationship between temperature and densification rates of snowpack and firn
- Determine effects of wind/precipitation on snow grain size and surface roughness

Next steps …

- Data sharing (field data and airborne laser / radar altimetry) with ESA in order to determine the predominant factors that influence radar signal

- Characterize distinct zones along transect based on field / airborne radar data
  - Improve interpretation of radar signal over other ice covered regions

- 2006 Spring / Fall field campaigns should coincide with both airborne and spaceborne measurements
  - Effects of atmosphere on satellite signal
  - Interannual / seasonal variability on ice cap

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