Using SAR to Examine Landfast Sea Ice Extent and Variability

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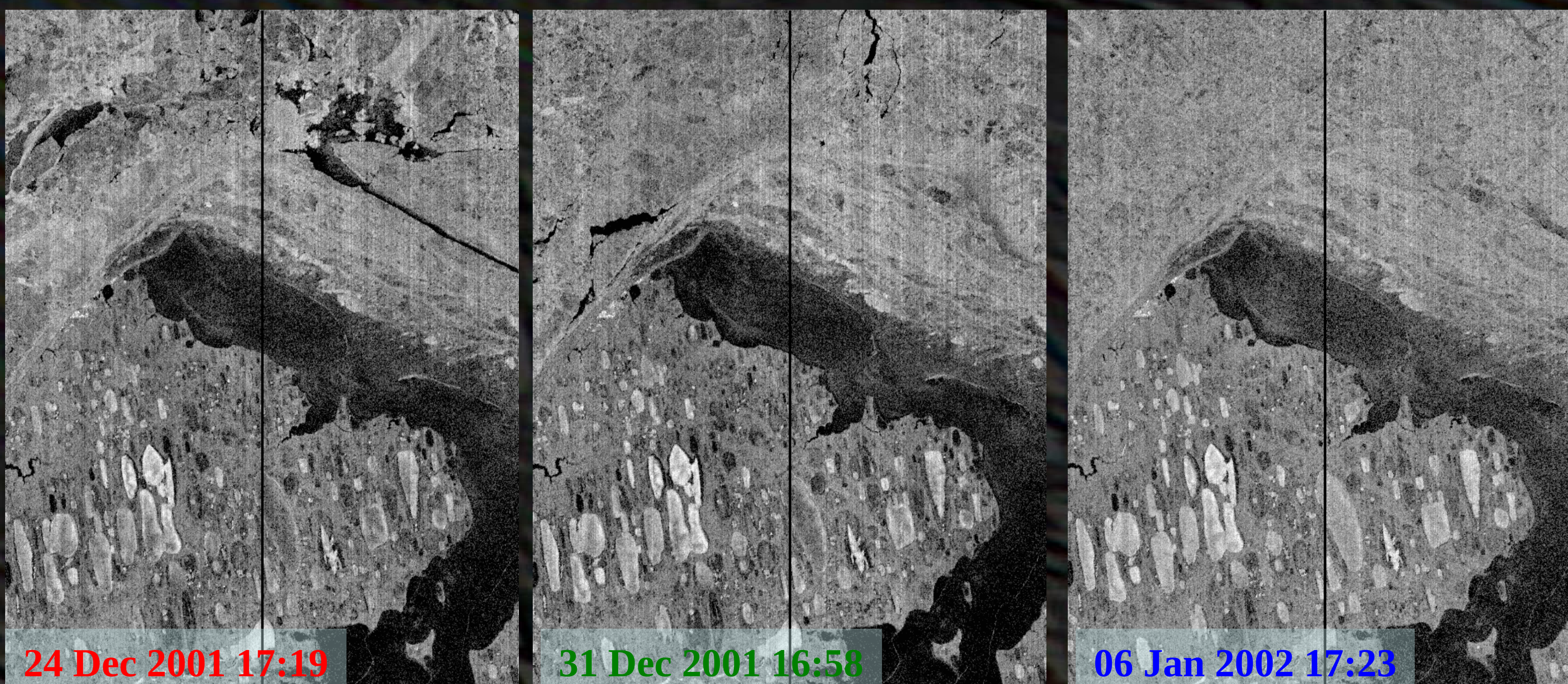

Acknowledgements

Project collaborators:

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Mineral Management Service

Thanks Alaska Satellite Facility!

especially Rudi Gens

Definition of Landfast Sea Ice

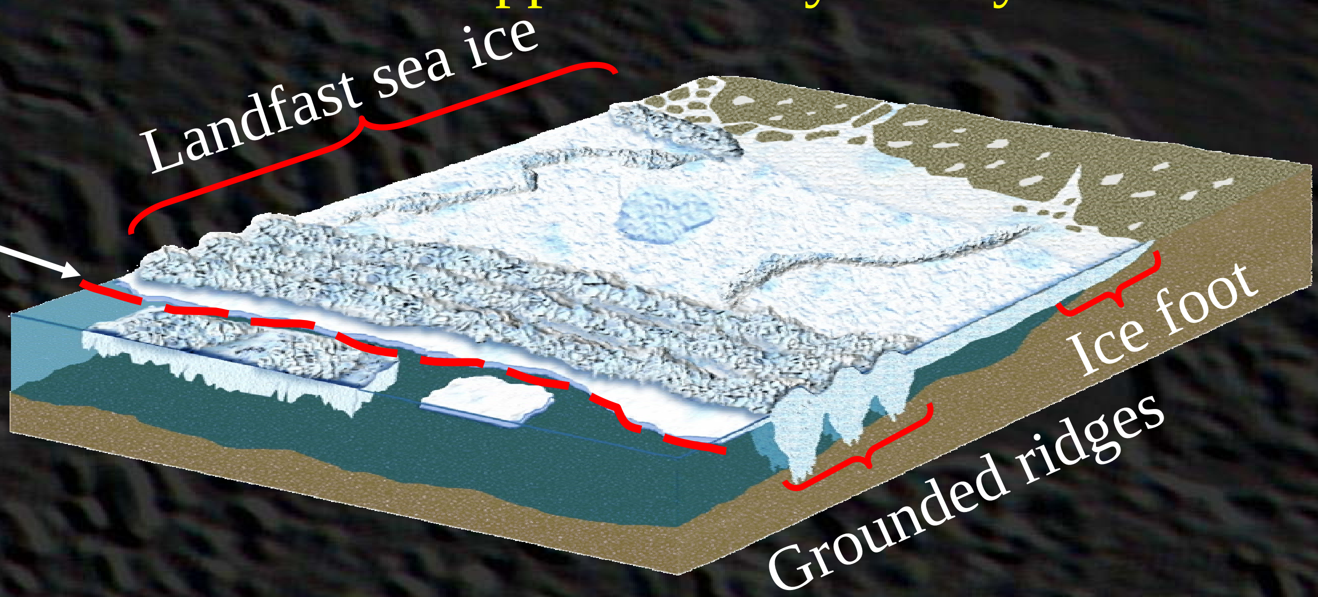
Various definitions in the literature

- "Sea ice that remains attached to the coast ..." (WMO, 1970)
- "Ice that is grounded or forms a continuous sheet which is bounded at the seaward edge by an intermittent or nearly continuous zone of grounded ice" (Barry et al., 1979)

We use two criteria for remotely sensed data:

1. the ice is contiguous with the land
2. the ice lacks detectable motion for approximately 20 days

Seaward Landfast Ice Edge (SLIE)



Methodology

Study area and dataset

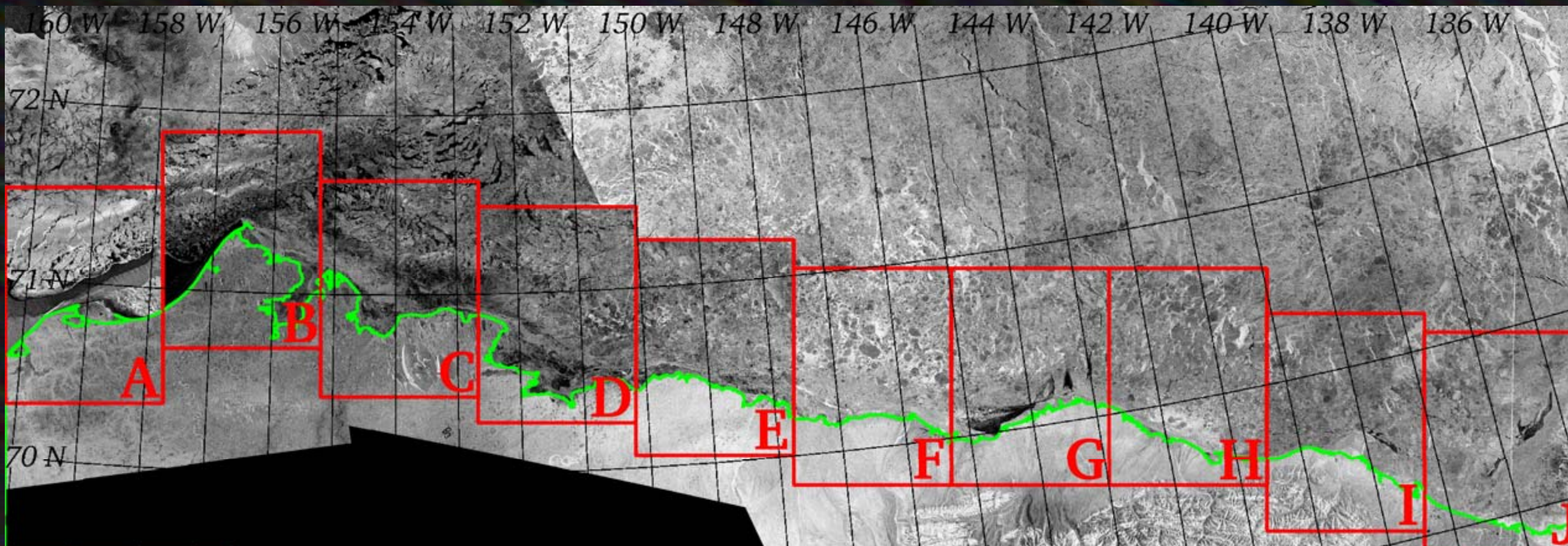


Table 1: Summary of Radarsat imagery used in this study

Ice season	# parent scenes acquired	# mosaics generated	Mean period spanned by mosaic (days)	Mean period between 3 consecutive mosaics (days)
1996-97	134	29	2.7	20.2
1997-98	126	28	2.5	19.9
1999-99	111	30	2.5	19.9
1999-00	113	28	2.6	19.0
2000-01	91	30	2.4	20.6
2001-02	152	35	2.5	16.7
2002-03	123	29	2.6	20.8
2003-04	109	29	2.1	21.0
All years	*959*	*238*	*2.5*	*19.8*

Applying our definition of landfast ice to SAR data

1) **The ice is contiguous with the coast**
2) **The ice lacks detectable motion for approximately 20 days**

Requirements:

a time interval to determine motion / lack thereof

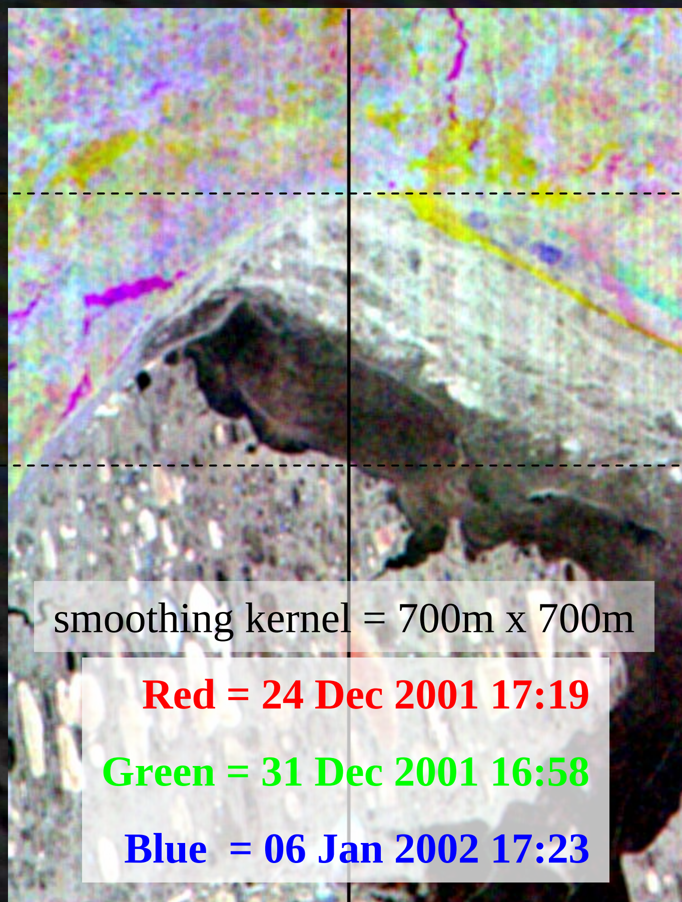
- a single image is not sufficient
- we use 3 consecutive colocated mosaics $\Rightarrow$ ~20 days

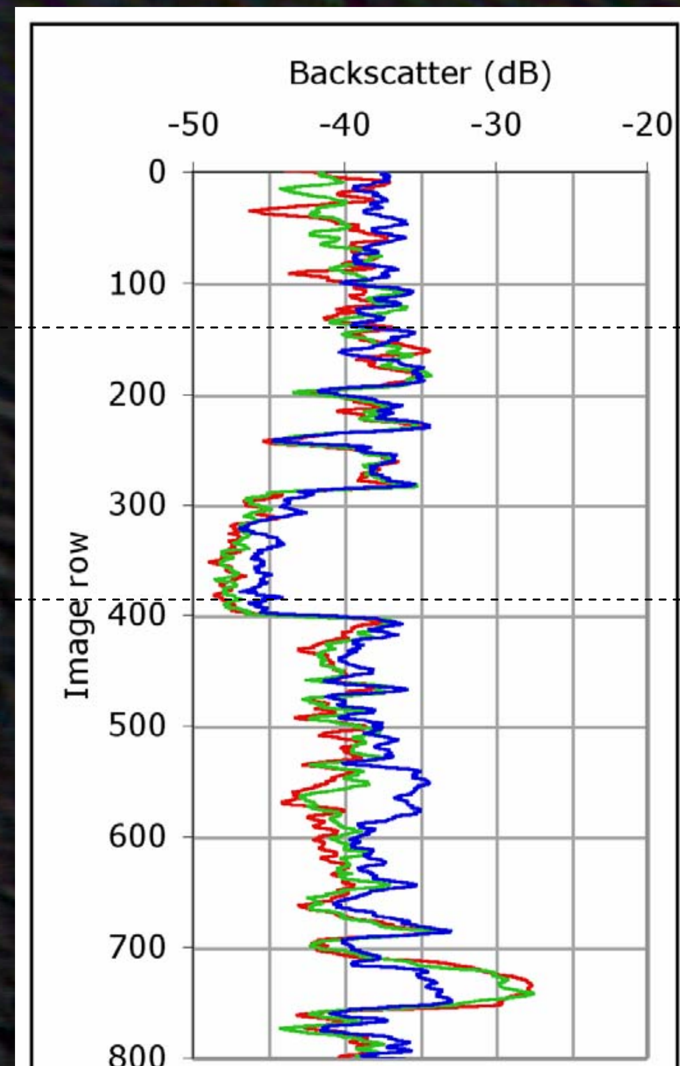
high quality data

- ScanSAR calibrated geotiffs - 100m resolution
- accurate georeferencing - co-location error < 500m

Towards an automated SLIE detection algorithm

The backscatter signature of landfast ice should remain constant over consecutive images





Spatial gradient fields

The gradient of an image is a **vector field** with two components defined by:

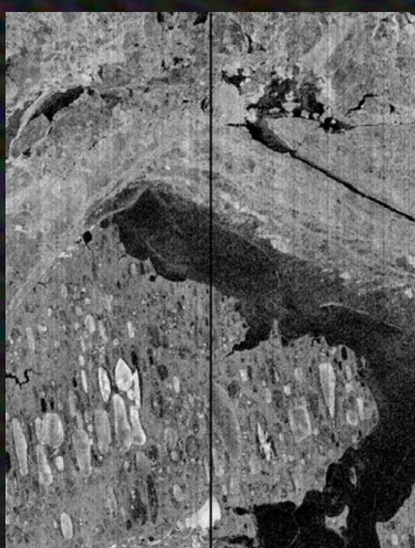
$$\nabla\Phi = \frac{\partial\Phi}{\partial x}\underline{i} + \frac{\partial\Phi}{\partial y}\underline{j}$$

where i and j are the unit horizontal and vertical vectors respectively

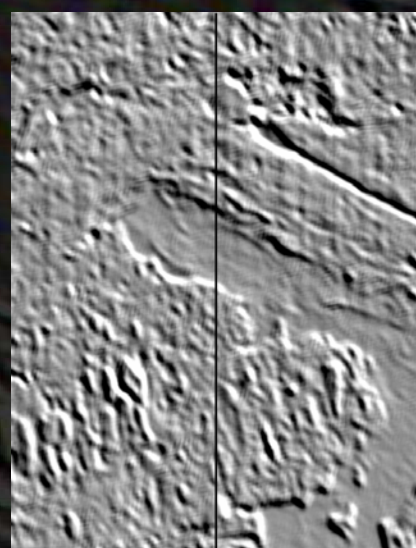
In discrete form, it is approximated by:

$$\left(\frac{\partial\Phi}{\partial x}\right)_{i,j} \approx \frac{\Phi_{i-d,j} - \Phi_{i+d,j}}{d}, \left(\frac{\partial\Phi}{\partial y}\right)_{i,j} \approx \frac{\Phi_{i,j-d} - \Phi_{i,j+d}}{d}$$

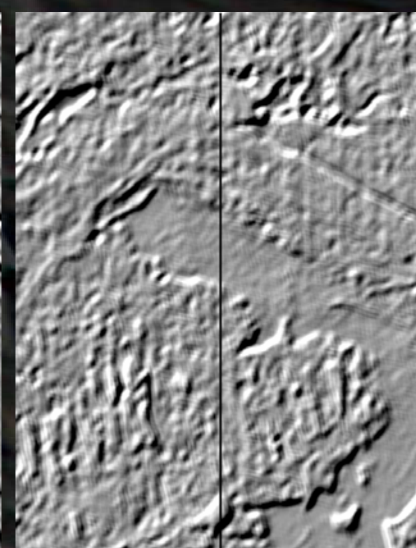
(d = 3)



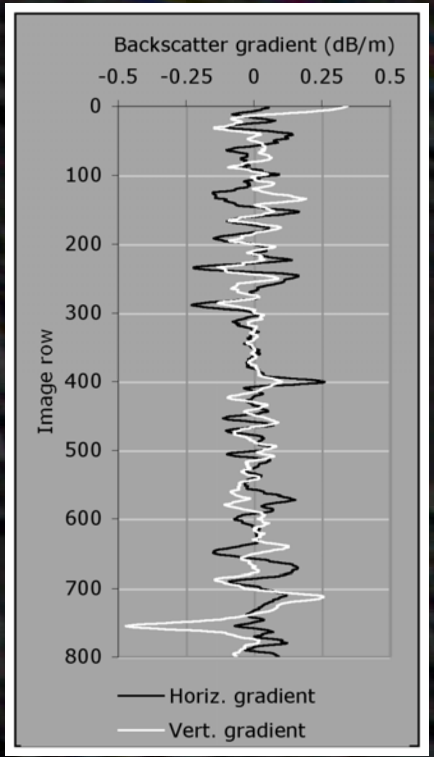
24 Dec 2001 17:19



$$\frac{\partial\Phi}{\partial x}$$



$$\frac{\partial\Phi}{\partial y}$$



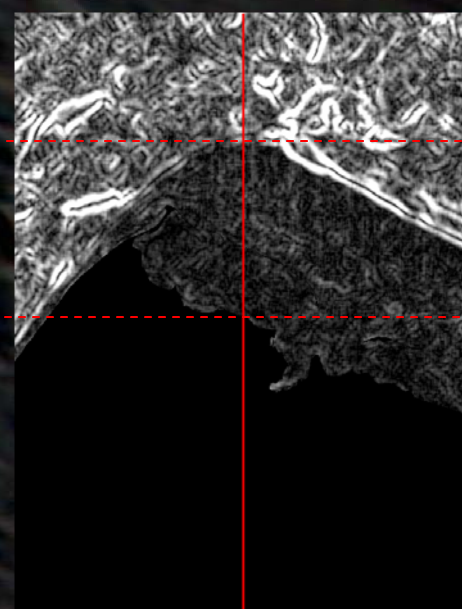
Gradient field differences

$$\Delta_{horiz}(\nabla\Phi) = \sum_{m=1,2}\sum_{n=2,3}\left|\frac{\partial\Phi_m}{\partial x} - \frac{\partial\Phi_n}{\partial x}\right|$$

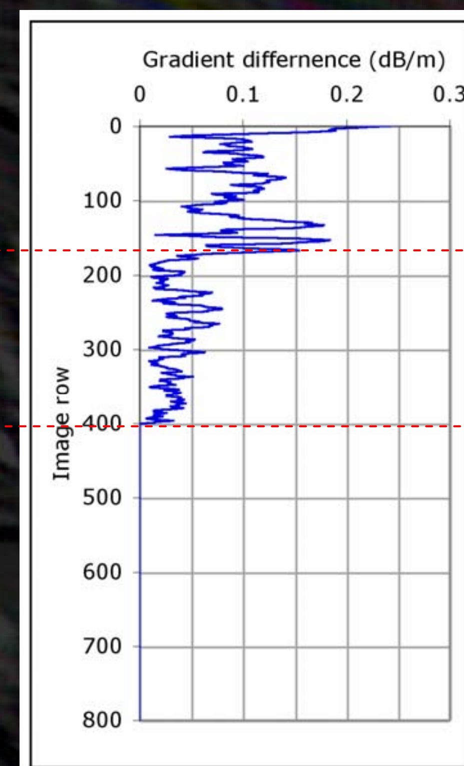
$$\Delta_{vert}(\nabla\Phi) = \sum_{m=1,2}\sum_{n=2,3}\left|\frac{\partial\Phi_m}{\partial y} - \frac{\partial\Phi_n}{\partial y}\right|$$

$$\Delta(\nabla\Phi) = \sqrt{\left(\Delta_{horiz}(\nabla\Phi)\right)^2 + \left(\Delta_{vert}(\nabla\Phi)\right)^2}$$

- Each gradient component of each SAR image is differenced separately to preserve directionality
- Landfast ice exhibits a low gradient difference magnitude

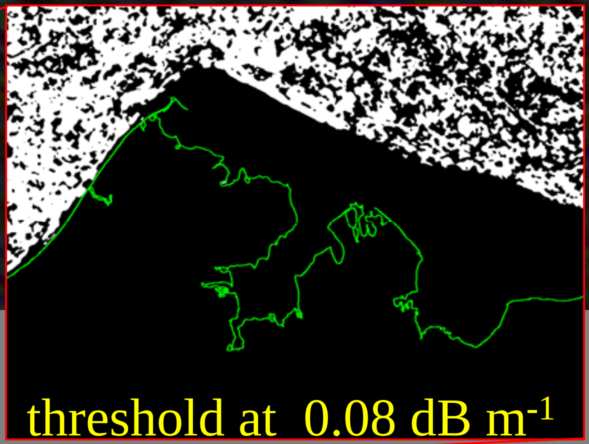


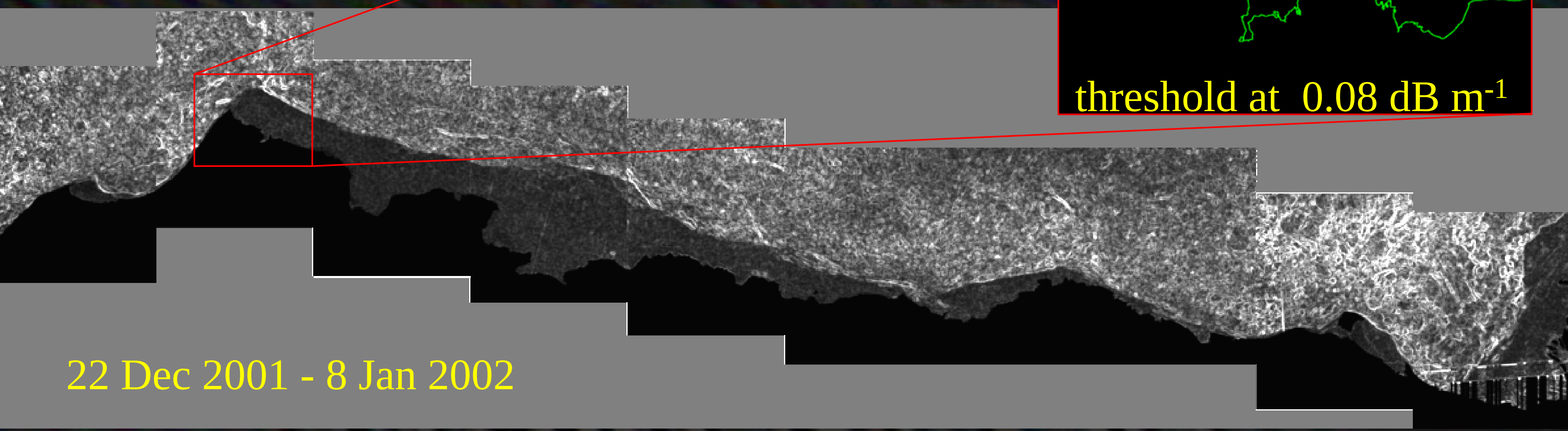
24 Dec 2001 - 6 Jan 2001



Gradient difference mosaic - midwinter

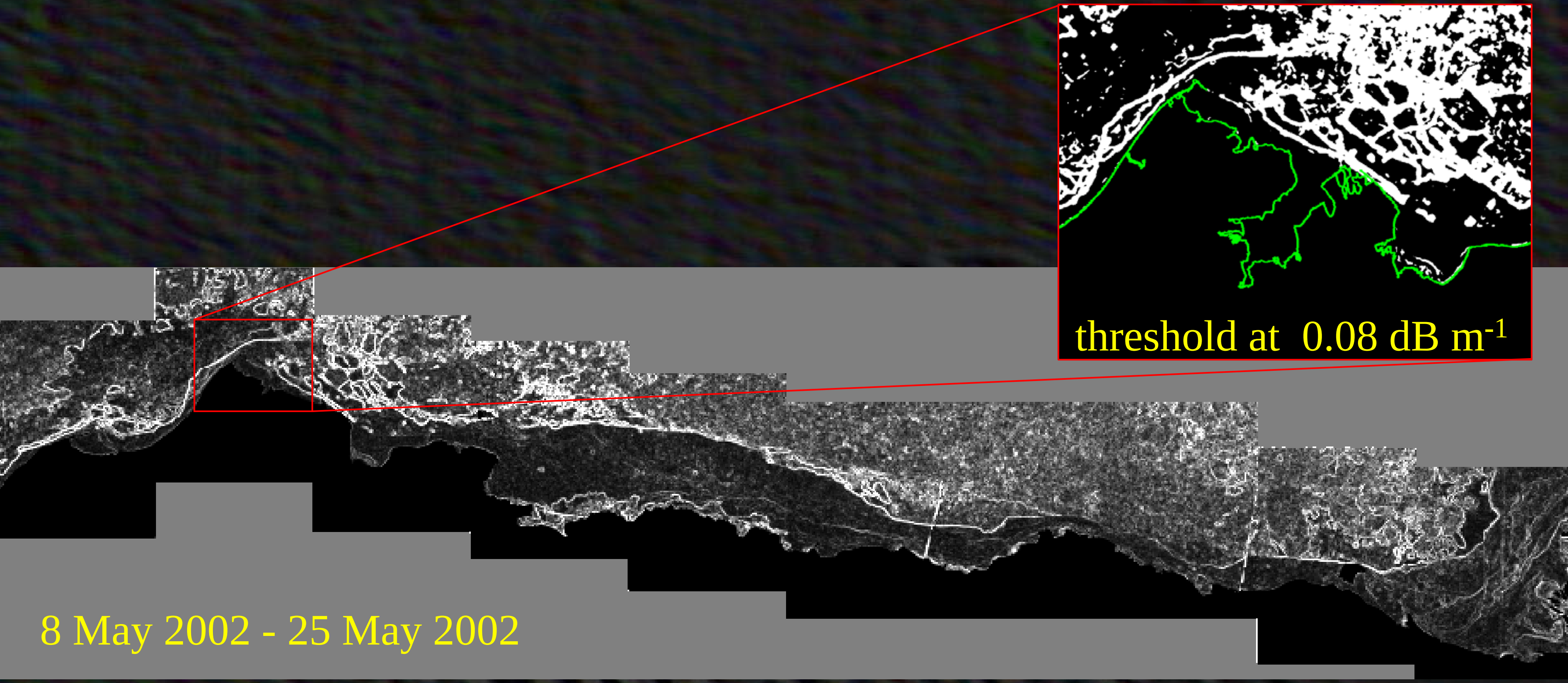
Mosaic all the gradient difference sub-region images together





- Threshold values typically between ~0.05 and 0.1 dB m^{-1}
- SLIE is clearly visible but disconntinuous

Gradient difference mosaic - spring

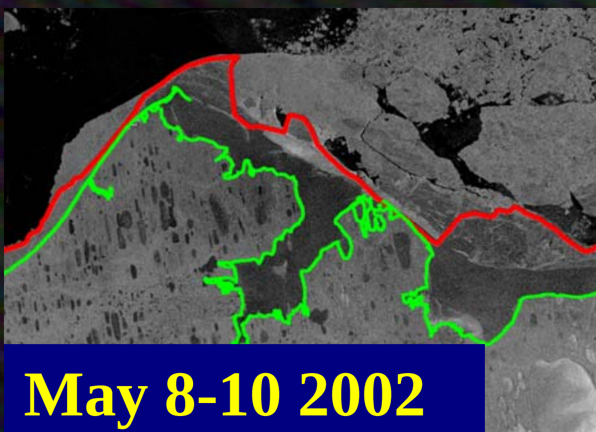


- Surface melt and flooding introduce difficulties
- No unique threshholding value for all regions of all images
- Automated delineation technique remains elusive

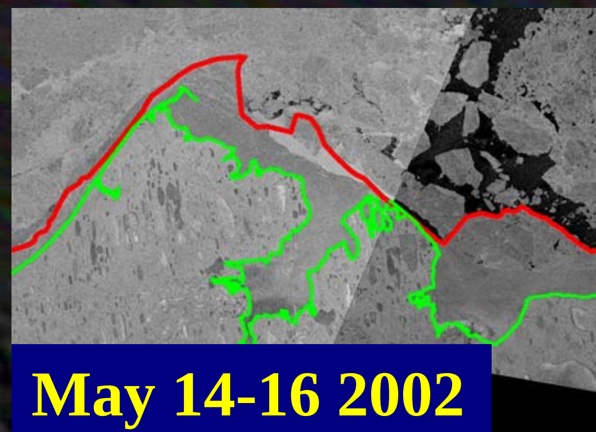
Delineation of the SLIE

SLIEs are manually delineated from

- **3 consecutive mosaics**
- **the corresponding gradient difference mosaic**



May 8-10 2002



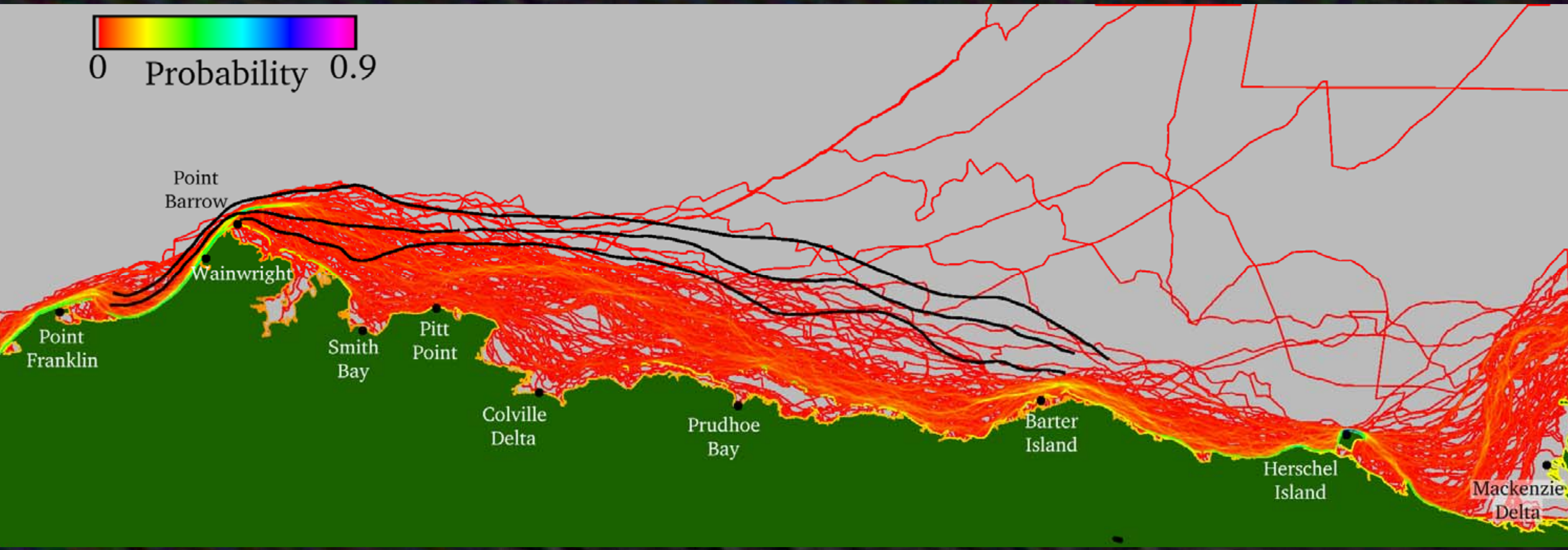
May 14-16 2002

May 22-25 2002

May 8-25 2002

Results

Stacked SLIE delineations



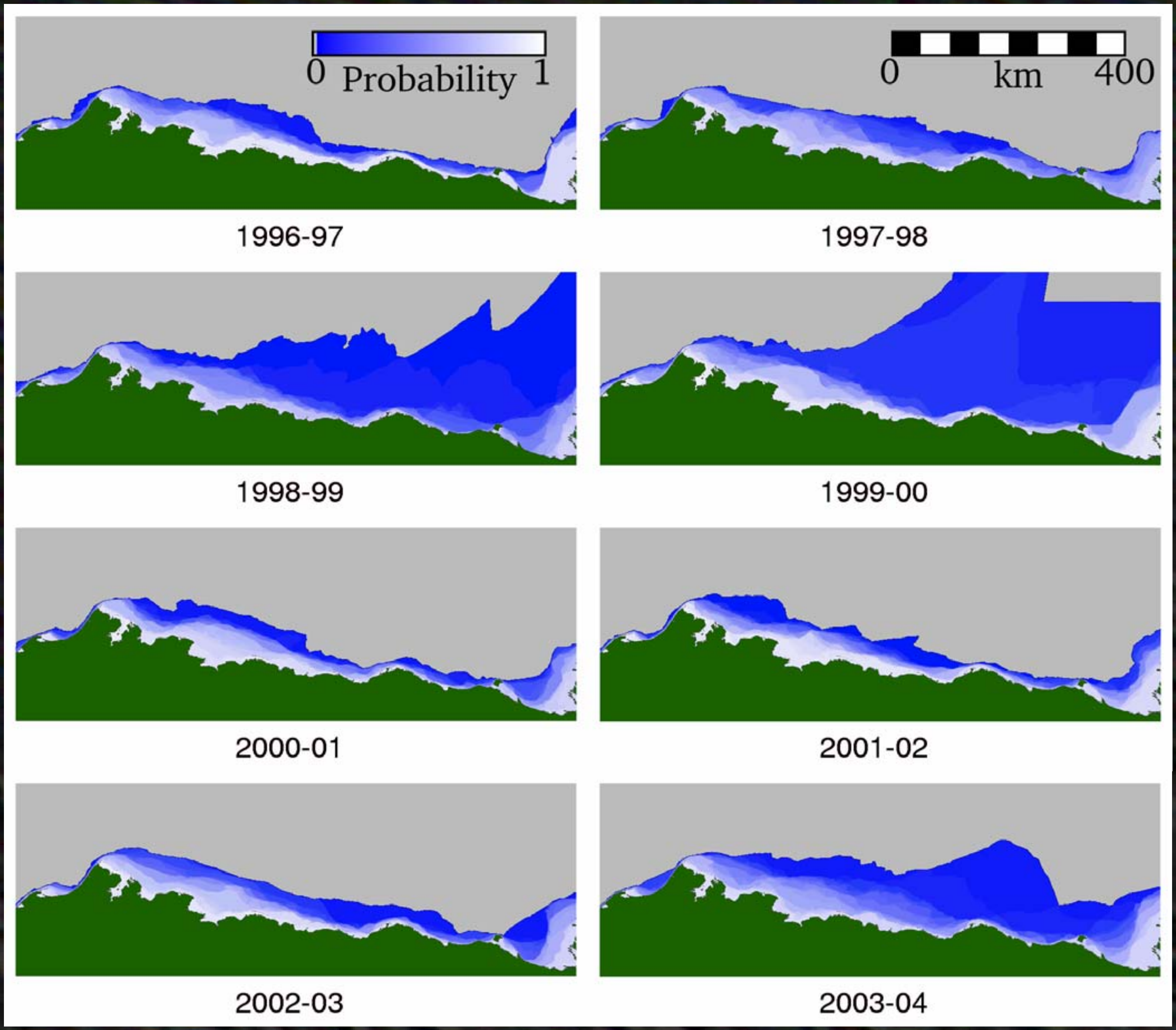
222 SLIEs from 1996-2004 stacked on top of each other

probability = fraction of SLIEs occuring at same location

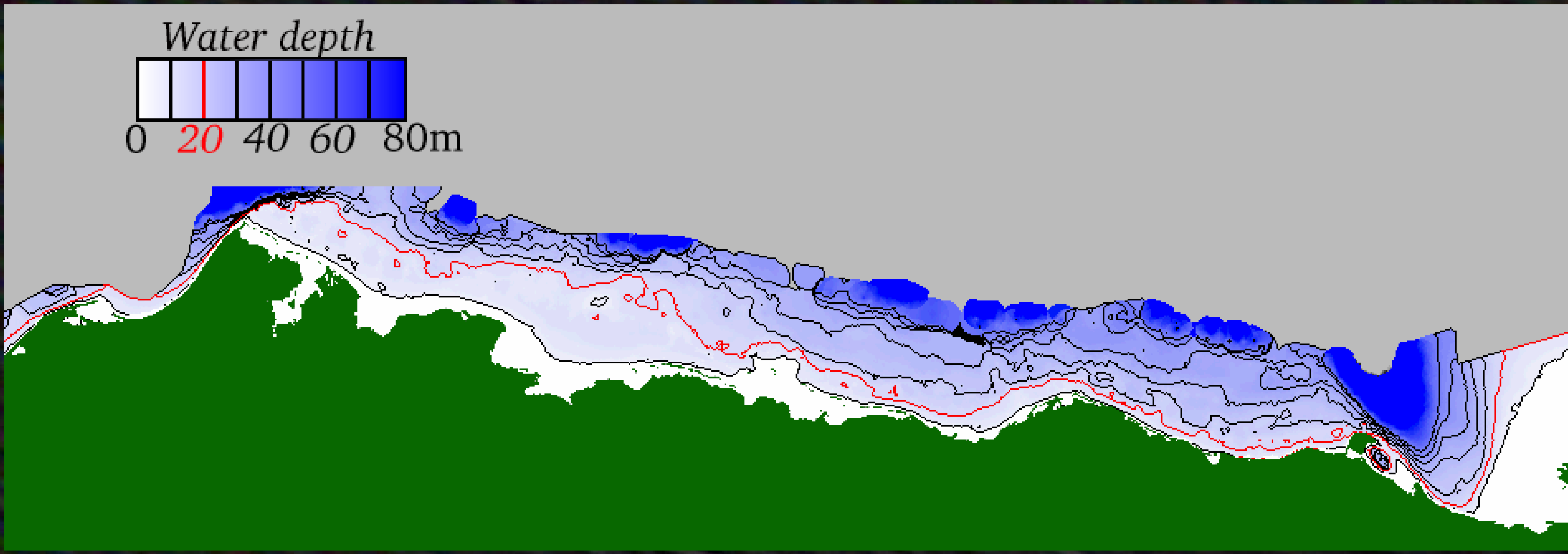
zones of preferred location indicated by orange-green colors

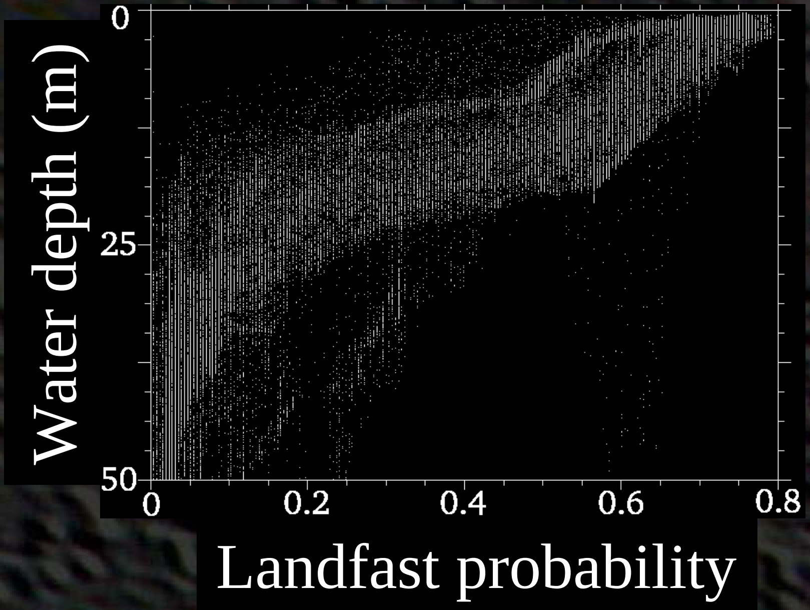
discrete nodes of higher probability within this zone

Interannual variability



Comparison with bathymetry

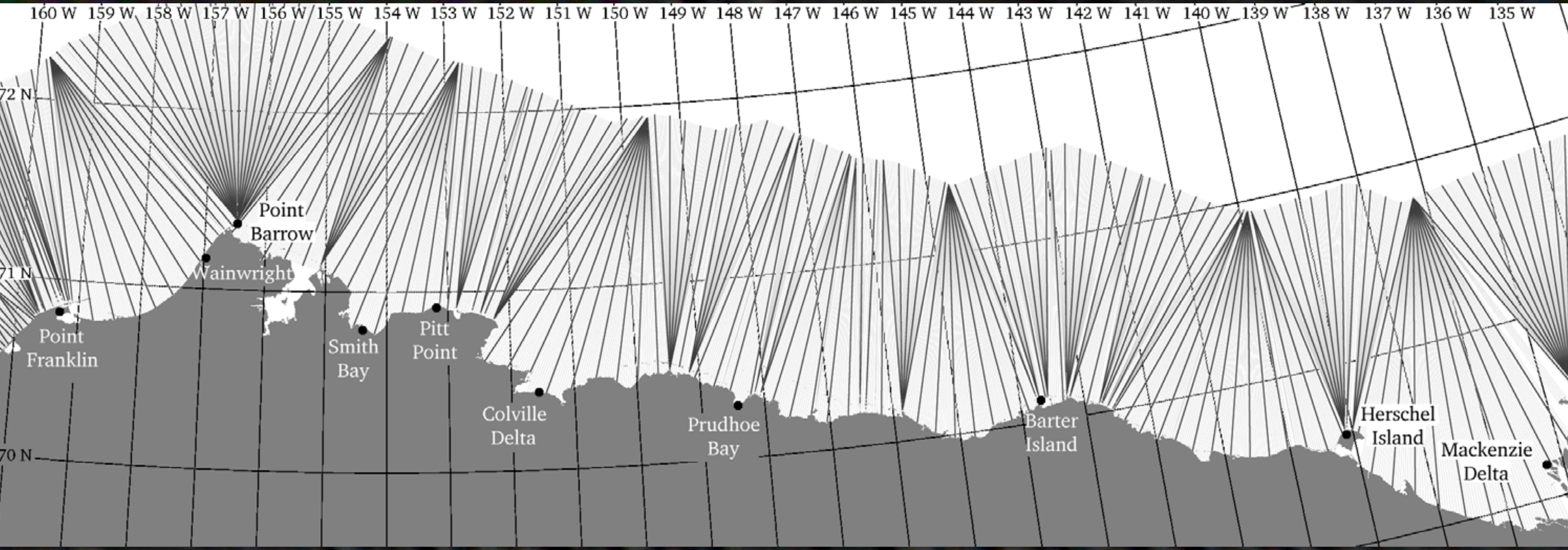




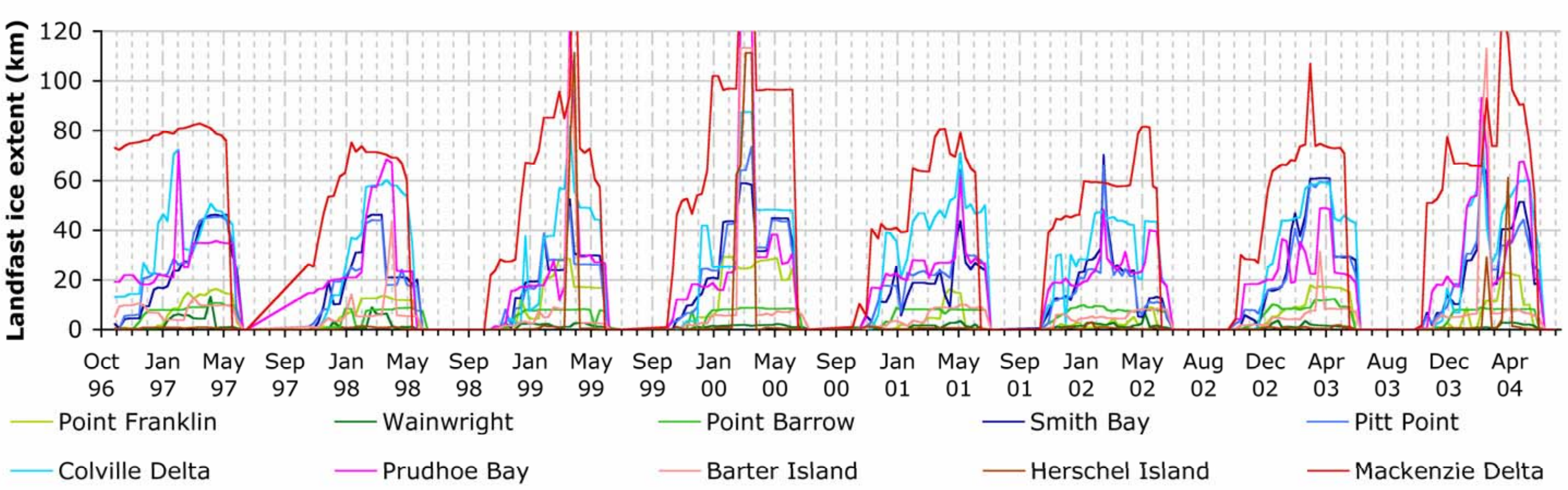
Measuring Landfast Ice Width

Landfast ice width is measured along profiles ~normal to the coast

- ~ 2000 transects performed
- 200 average landfast ice widths calculated
- non-linear co-ordinate axis



Landfast Ice Development



Overall development appears asymmetric

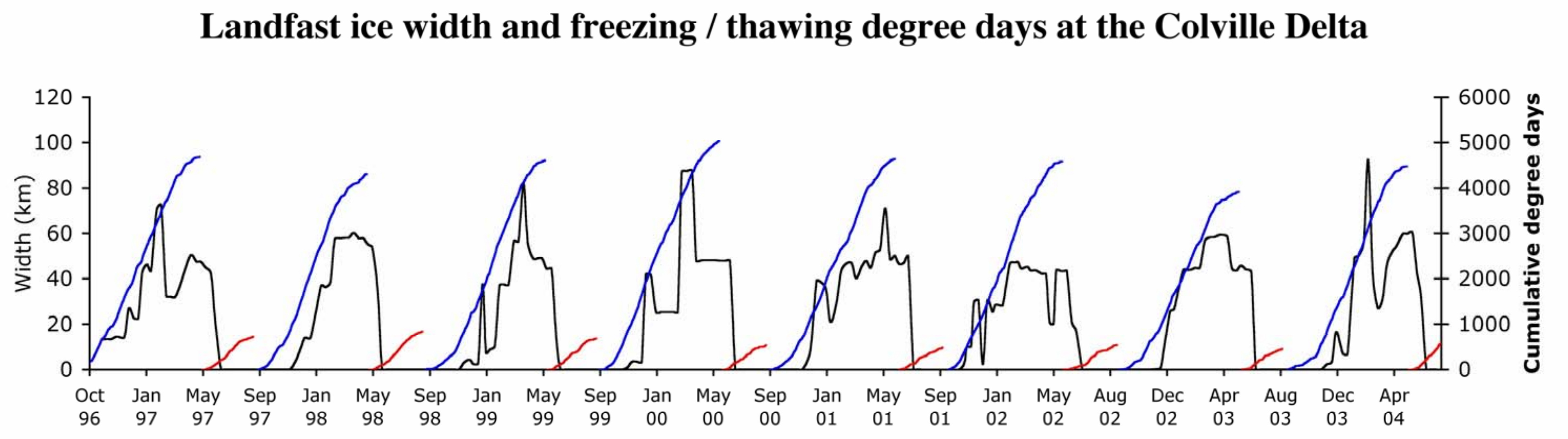
- slow advance in winter
- rapid break-up in spring

Peak extent does not coincide everywhere in study area

Temporary extensions can be seen

- landfast ice advances then retreats to previous position

Freezing / thawing degree days



Retreat of landfast ice preceded by onset of thaw

- accumulated thawing degree days at break-up appears constant

Little correlation with freezing degree days

Conclusions

Colocated SAR works!

- automated technique remains elusive

SLIEs have a preferred location zone

- landfast probability correlates with water depth
- discrete nodes suggest SLIE is discontinuously grounded

Timeseries of landfast ice captures episodic events

- high spatial and temporal resolution
- allows detailed comparison with climate data