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Wavemill: Cryosphere Applications

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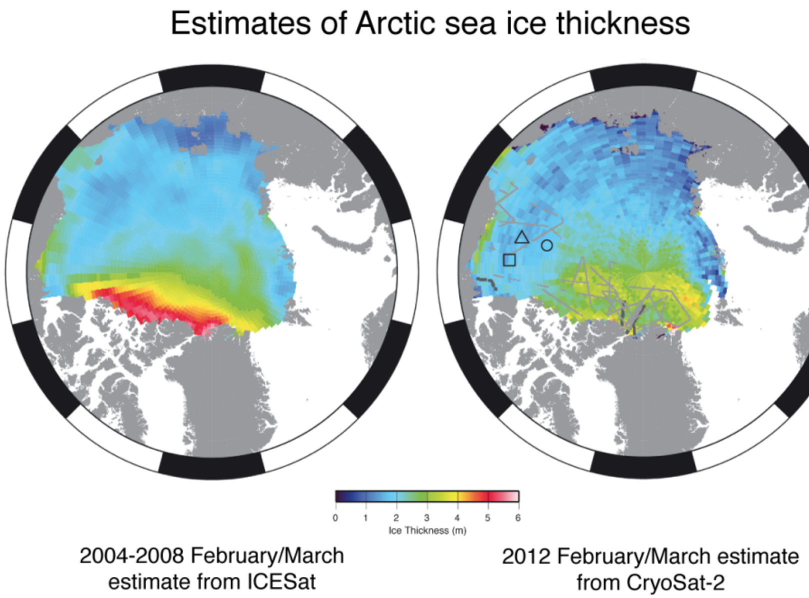
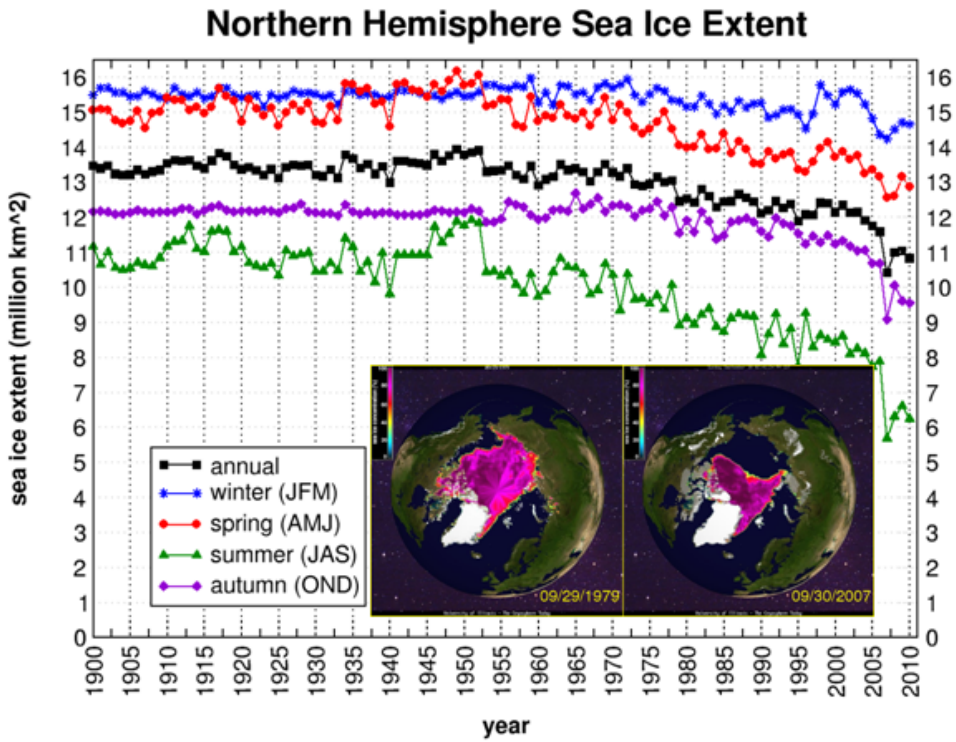
Key Drivers: Marine Cryosphere

Decline in sea ice thickness





Decline in sea ice extent (Arctic)

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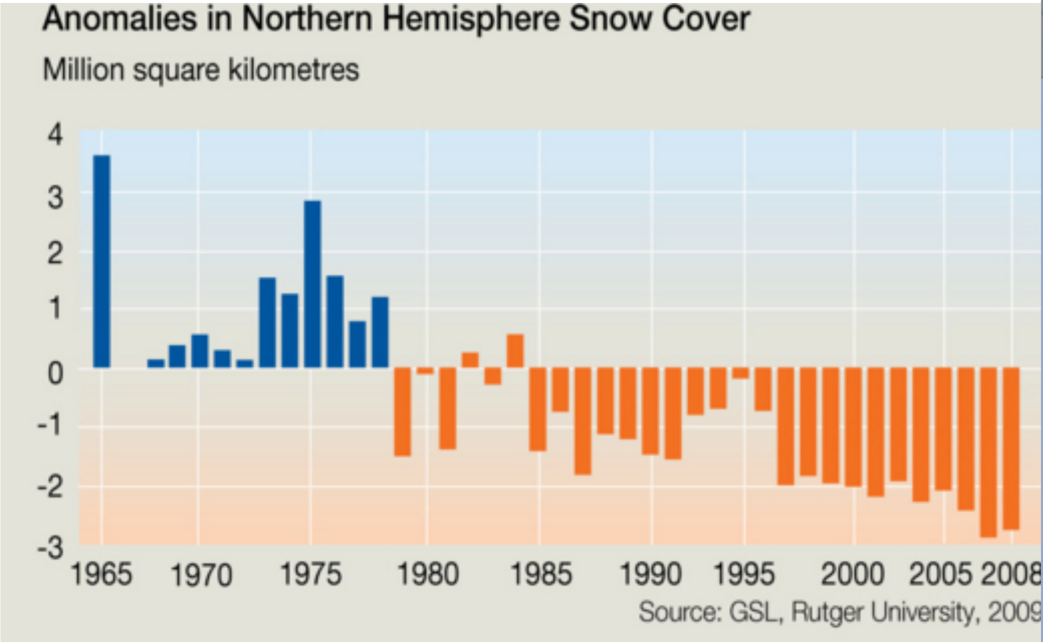
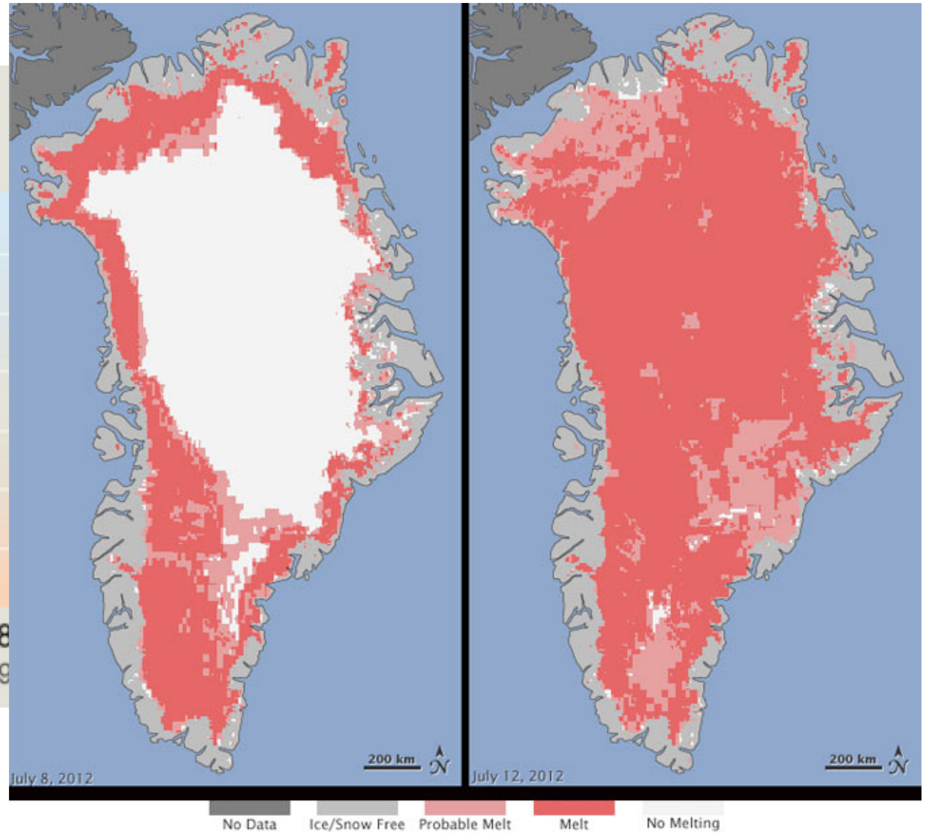
Key Drivers: Land Cryosphere

Decline in terrestrial snow cover





Summer 2012 melt over Greenland

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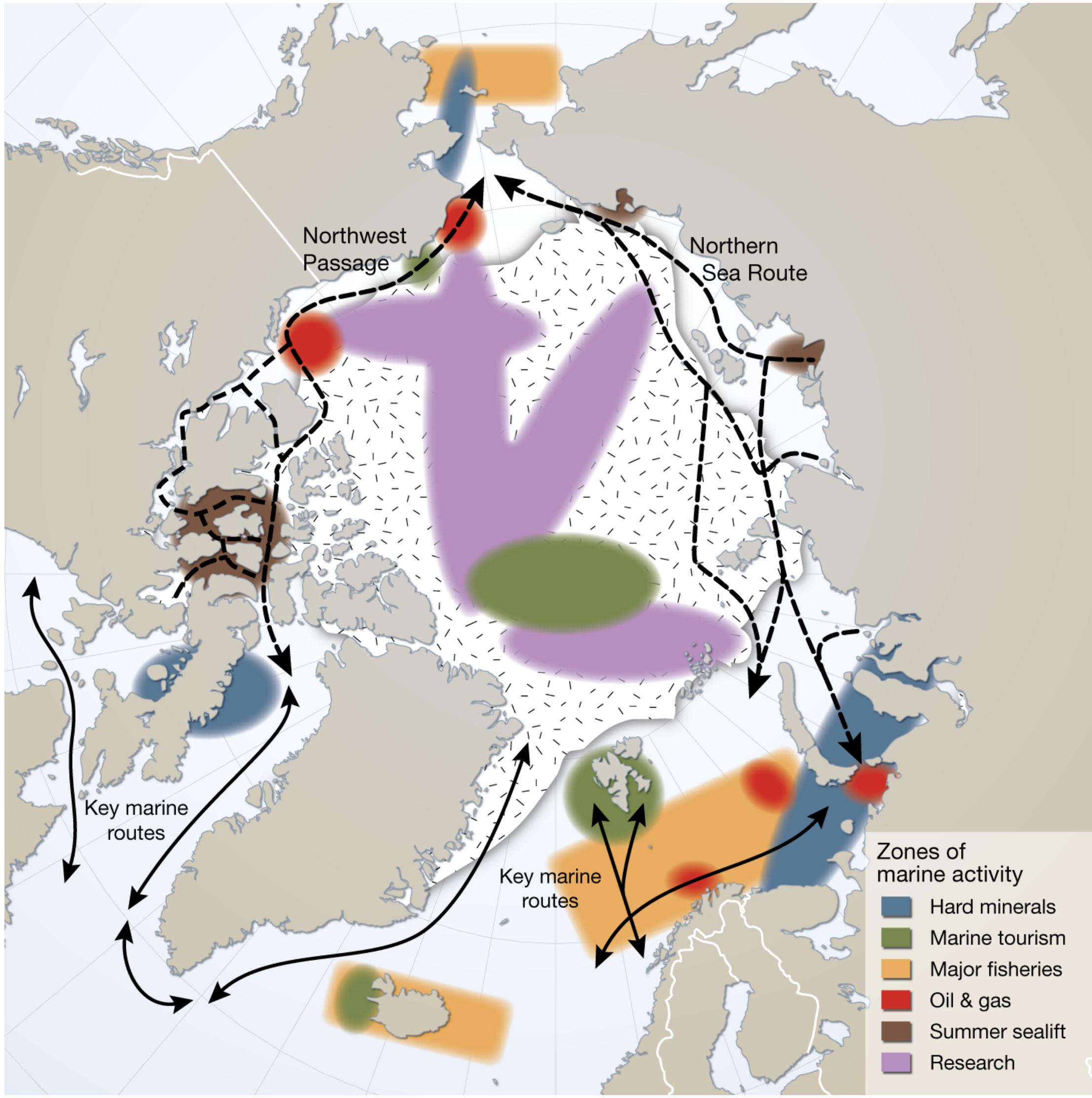
Key Drivers: Arctic Operations



Key Utilisation Needs

Type	Key utilization need
Climate and Science	**1. Role of cryosphere in sea level rise**
	2. Sea ice mass balance and freshwater redistribution
	3. Sea ice model development and interactions
	4. Surface energy balances
Operations	**5. Design for infrastructure and operations**
	6. Ice charting (routine and custom)
	7. Hazards and tactical support (icebergs, avalanche risk, ice jams...)
	8. Water resources (agriculture, power, etc.)
Numerical weather prediction	**9. Global and regional-scale numerical forecasting**

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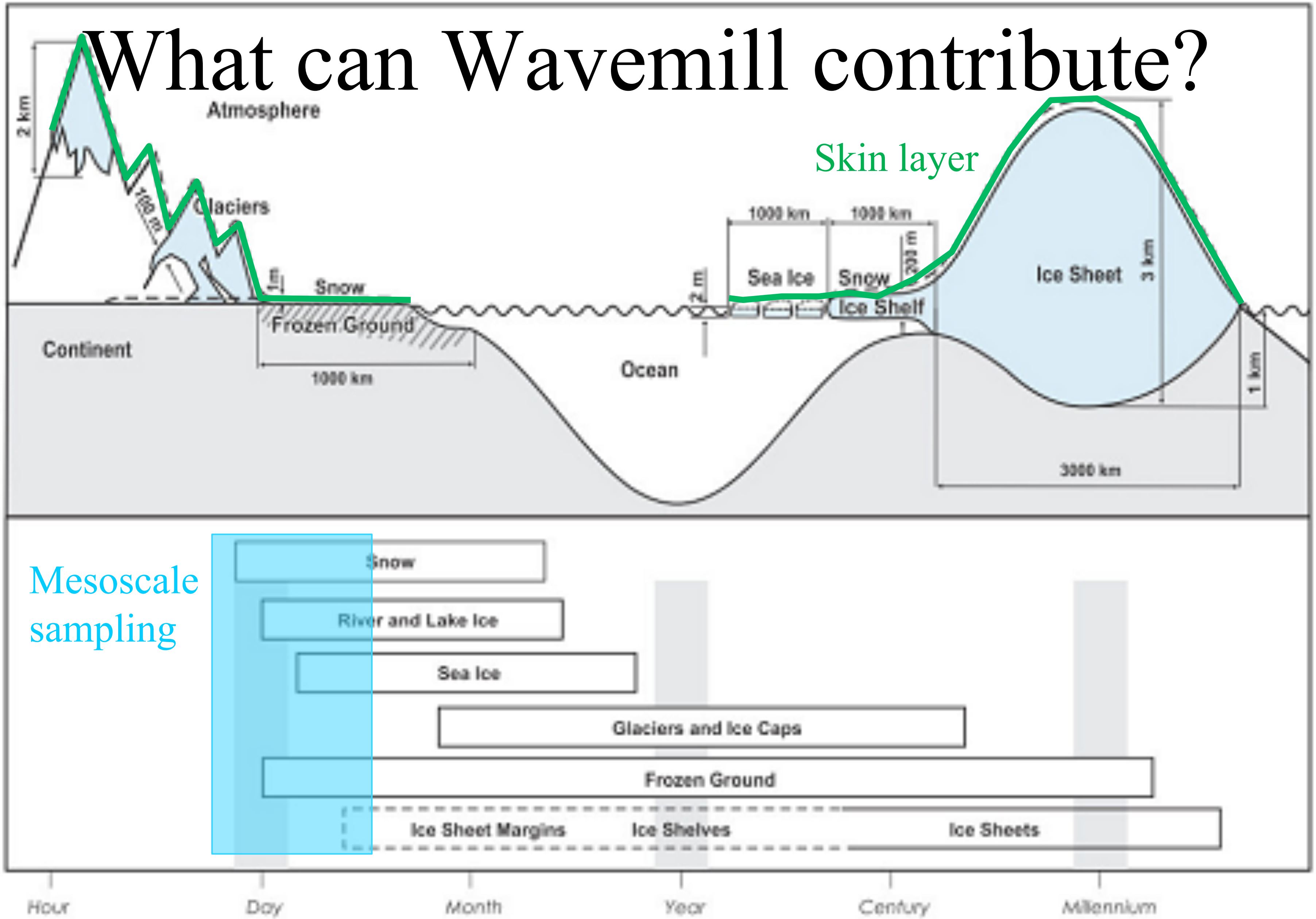
What can Wavemill contribute?



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Potential role of Wavemill

PARAMETER	Operations: goal (threshold)				Climate: goal (threshold)			
	Spatial resolution	Temporal resolution	Accuracy	Comments	Spatial resolution	Temporal resolution	Accuracy	Comments
SEA ICE								
Ice extent / ice edge	0.1km (10km)	<1d	0.1km (10km)		1-5km (10km)	1d	5km (10km)	GCOS 2011 specifies 7d revisit
ice concentration					10km (15km)	1d	5% (10%)	Some sources specify down to 1km spatial
ice classification					10km (15km)	1d	5% (10%)	
ice thickness	0.5km	1d	10%	Up to 20km spatial resolution cited (SA Sea Ice CCD URD 2012)	25km	1d	0.1m	5km cited by SA Sea Ice
leads / polynyas	0.1km	1d	0.1km^2	25m cited for operations (IICWG)	10km	1d	5%	
meltponds (% area)				10% cited (IICWG, NWP and operations)	0.5km	1d	1-5%	
ridge height							1m (2m)	
ice motion	0.1km (25km)	1d	0.5km/d (3km/d)		1km (25km)	1d	1km/d (3km/d)	6hrs (regional NWP) to 7d (GCOS-2011) cited
snow depth on ice					5km (10km)	1d	2cm (5cm)	
melt onset					10km (15km)	1d	1d (2d)	
ICEBERGS								
size					0.001km (0.01km)	1hr (1day)	30%	
position								
draft								
velocity								
FRESHWATER ICE								
river ice edge location								
river ice concentration	30m	1d	5%		30m	1d	5%	
river / lake ice concentration								
river / lake ice thickness								
LAND ICE AND SNOW								
Topography					30m (100m)	1yr (5yr)	1m (5m)	
topographic change					1km (5km)	1yr (5yr)	5cm (10cm)	
surface velocity					20m (100m)	30d (1yr)	10m/yr (5%)	
snow accumulation					1km (25km)	180d (1yr)	1cm/yr	
snow mass on land					100m (500m)	1d (6d)	10% (20kgm^{-2})	
permafrost topography					30m (100m)	1yr (5yr)	1m (5m)	
freeze/thaw cycle of soil					0.1km (1km)	0.5d (6d)		

Particular Wavemill capabilities

Wavemill compliant spatial resolution

Wavemill compliant temporal resolution

Uncertain

GCOS observation requirements 2007

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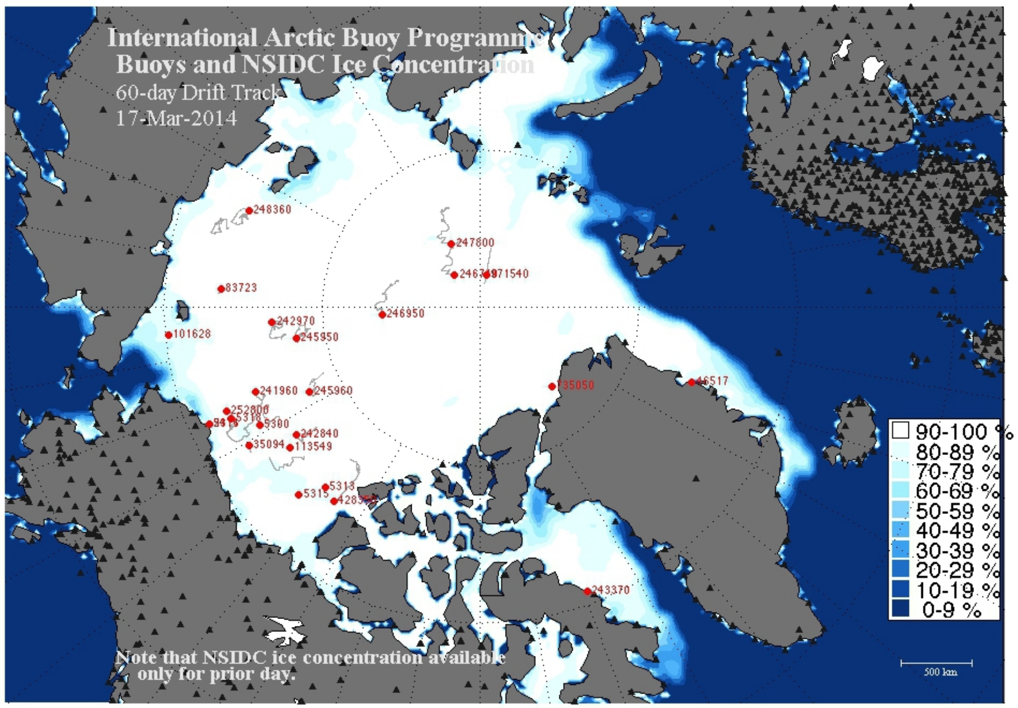
Sea ice motion

- Instantaneous motion vs mean field
- Precision 2.5 cm/s
- Mean field from conventional SAR
- Instantaneous motion ~3 per day required
- Augment buoy observations



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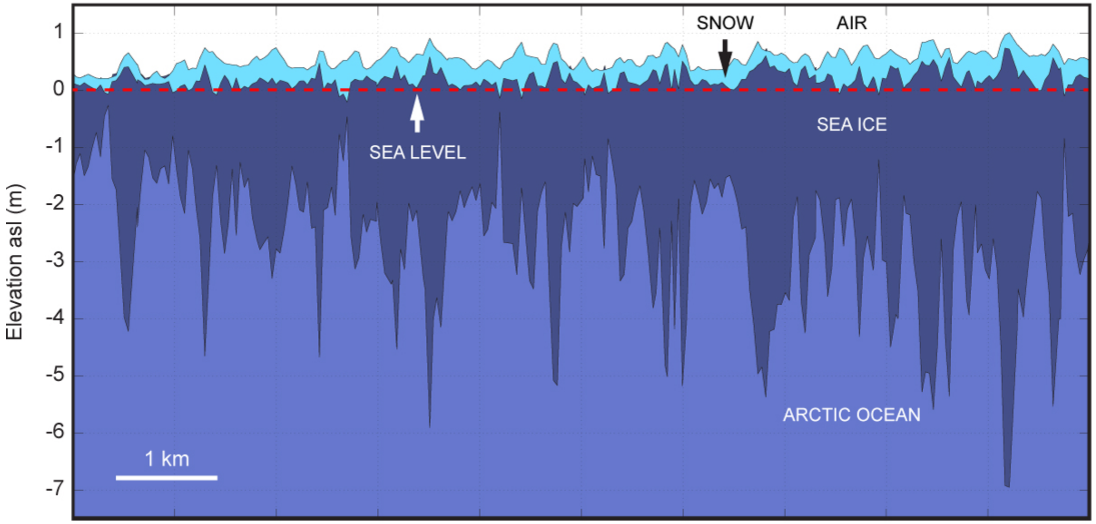
Terrestrial snow water equivalent

- Good supporting analysis including field observations from CORE-H2O
- Sensitivity – to 1cm SWE
- Good range – to 2m snow depth
- Sampling adequate
- Topographic influence – direct mitigation from INSAR?

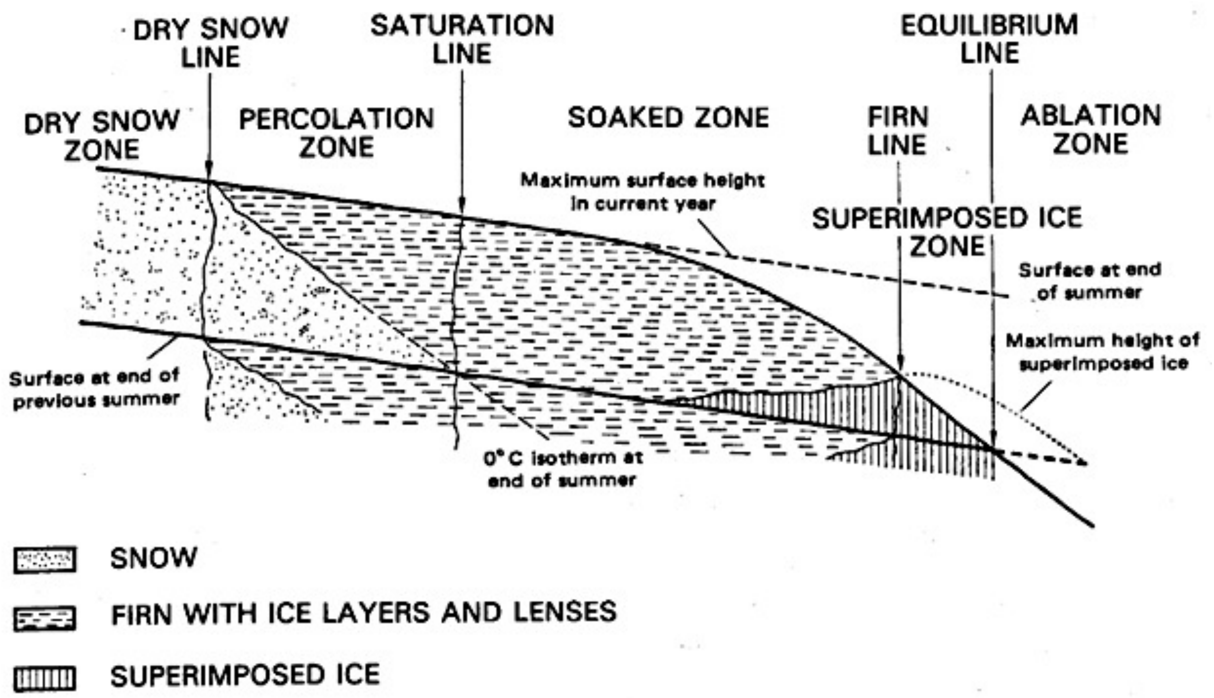
Sea ice snow depth

- Lower range of snow depth sensitivity than terrestrial snow – cms rather than tens cms?
- Lack of field data
- Important for altimetry



Ice sheet snow accumulation

- "Current" snow accumulation (decadal vs millenial)
- Separation of surface vs internal (snow accumulation factors)
- Important for mass balance



Key parameters

- Incidence angle 20° vs 30°
  - Mixed, depends on product
  - No evidence of show stopper for any application
- Dual polarisation
  - Useful in some cases at 30°
  - Not so useful at 20°
- Wide swath
  - Useful to augment sampling

Conclusions

- Novel estimation of high frequency sea ice motion, currently not sampled by any spaceborne sensors;
- Sampling of the thin surface layer of the cryosphere facilitated by the high operating frequency (Ku band), in particular snow cover, which is inadequately sampled by existing spaceborne sensors.
- Observations of poorly sampled dynamic processes, particularly in regard to the marginal sea-ice zone and terrestrial snow cover;
- Complementary observation capabilities to many existing and planned satellite missions, including altimeters and SARs, that would enhance the interpretation of observations from those sensors.
- The ability to observe currents and other oceanographic parameters in polar waters, in polynyas and larger leads, providing insight into ocean-ice interactions within pack ice.
- Speculatively, some interesting possibilities regarding the synergistic use of multiple parameters from Wavemill that could result in innovative products, for example in relation to retrieval of SWE using local slope.

Key Issues

- Further exploration of how observations would be converted to products
  - Basic for algorithms
  - Statistical sampling issues
  - Biases
- Some good observations at Ku band over terrestrial surfaces (Core-H2O), less so over the marine environment.
- Recommend some firm analysis once Wavemill design is fixed with operations scenarios, in terms of:
  - Temporal-spatial sampling in key cryospheric regions
  - Sensitivity/precision
  - Synergies with other planned missions – key for cryosphere
  - Etc

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Marine Cryosphere

Measurement need	Possible Wavemill products	Synergies with other sensors	Preferred configuration						Wavemill Challenges	Potential role of Wavemill
			Polarisation		Incidence angle		Sampling[1]			
			HH or VV	HH+VV	20°	30°	Dual swath 200km (assumed resolution)	Wide swath >>200km (assumed resolution)		
Ice edge and concentration	Ice / open water	Other sensors to help resolve ambiguities and enhance spatial-temporal sampling	✓	✓✓	✓✓	✓	✓ (100m)	✓✓ (<1km)	Open water ambiguities for particular wind speeds; ambiguities in summer and in marginal ice zone	Supporting mission
Leads and polynyas							✓✓ (100m)	✓ (<1km)		
Ice type classification	First-year / multi-year ice	Augment lower frequency SAR sensors	✓	✓✓	✓	✓✓	✓ (100m)	✓✓ (<1km)	Sensitivity to surface roughness; sensitivity to overlying snow cover	Supporting mission
	Thin and young ice detection	All	✓	✓✓	?		✓✓ (100m)	✓ (<1km)	Thin ice is transient; temporal revisit may limit utility	Experimental
Ice motion	Mean motion field	Passive microwave, scatterometry, SAR, radiometry	✓	✓	✓	✓	✓✓ (1km)	✓ (<25km)	Achieving temporal and spatial resolution	Supporting mission
	Near instantaneous ice motion field	Buoys	✓	✓	?		✓✓ (1km)	✓ (<25km)	Number of revisits per day; directional precision	Experimental
Ice thickness	Sea ice freeboard converted to thickness	Altimeters for mean sea surface elevation in leads; passive microwave or Wavemill for snow cover	✓	✓	✓✓	✓	✓✓ (15km)	✓ (<25km)	Sufficient vertical precision over 25km; influence of snow cover	Topographic mode no longer planned
Snow water equivalent	Snow depth	Passive microwave for independent estimates of snow depth	✓	✓✓	✓✓	✓	✓ (1km)	✓✓ (<5km)	Sensitivity to the range of snow depths; influence of underlying ice	Possible primary mission
Melt onset and duration	Melt onset date; ablation state	Other SAR data	✓	✓✓	?		✓ (1km)	✓✓ (<10km)	Ablation state is speculative	Supporting mission
Icebergs	Iceberg freeboard and thickness	Altimetry	✓	✓✓	✓✓	✓	x (15km)	x (>15km)	Spatial resolution rules out all but largest bergs	Topographic mode no longer planned
	Iceberg detection and motion	Other SARs to track major icebergs	✓	✓✓	✓	✓✓	✓ (1km)	x (>>1km)		Supporting mission

[1] Assumed 100m ≥ 4 looks for image products

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Land Cryosphere

Measurement need	Possible Wavemill products	Synergies with other sensors	Preferred configuration						Wavemill Challenges	Potential role of Wavemill
			Polarisation		Incidence angle		Sampling[1]			
			HH or VV	HH+VV	20°	30°	Dual swath 200km (assumed resolution)	Wide swath >>200km (assumed resolution)		
Precise surface topography (changes) of ice sheets, mountain glaciers, ice caps, and outlet glaciers of ice sheets	Surface elevation Surface elevation change	Radar altimetry, laser altimetry, INSAR	✓	✓	?		x (15km)	x (>15km)	Adequate spatial resolution	Topographic mode no longer planned
Surface velocity fields of glaciers and ice streams	Surface velocity	InSAR, SAR feature tracking	✓	✓✓	?		x (1km)	x (>1km)	Adequate spatial resolution	Supporting mission
Snow accumulation on ice sheets	Snow accumulation in relation to contemporary (decadal) conditions	Scatterometry and passive microwave can be used for longer term accumulation rates	✓	✓✓	✓✓	✓	✓✓ (1km)	✓ (>1km)	Surface-volume scatter ambiguity; definition of depth (~time period) sampling; algorithms for dry zone vs percolation zone	Possible primary mission
Terrestrial snow cover	Snow depth SWE	X band SAR for thicker snow cover; scatterometers and passive microwave for coarser resolution	✓	✓✓	✓	✓✓	✓✓ (100m)	✓ (<500m)	Temporal resolution; vegetation, snow melt, slope impact, covering range of snow depths	Possible primary mission
Permafrost changes	Surface elevation change	Other INSAR missions	✓	✓✓	?		x (1km)	x (>1km)	Insufficient spatial resolution	Topographic mode no longer planned
Freeze/thaw cycle of soil	Surface changes in relation to freeze/thaw	Other SAR missions; optical sensors sensitive to vegetation (NIR)	✓	✓✓	?		✓✓ (100m)	✓ (<500m)	Unproven	Experimental
Snow and ice facies distribution (diagenetic zones)	Snow and ice facies distribution (ice sheets)	Multi-frequency SAR observations may be useful for different depth sampling	✓	✓✓	✓✓	✓	✓✓ (100m)	✓ (<500m)	Insensitive to buried percolation features	Supporting mission

[1] Assumed 100m ≥ 4 looks