The Ice Contamination Ratio Method: Accurately Retrieving Ocean Winds Closer to the Sea Ice Edge While Eliminating "Ice Winds"

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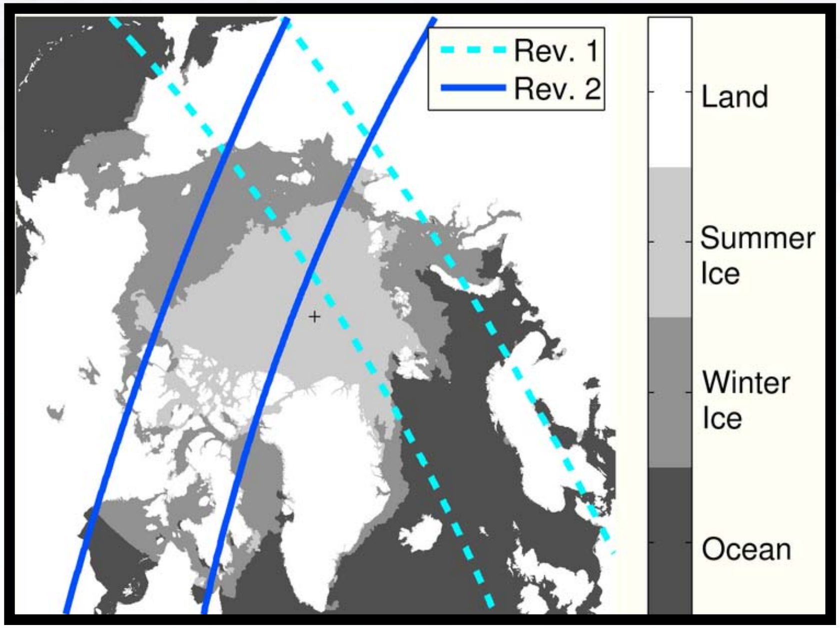
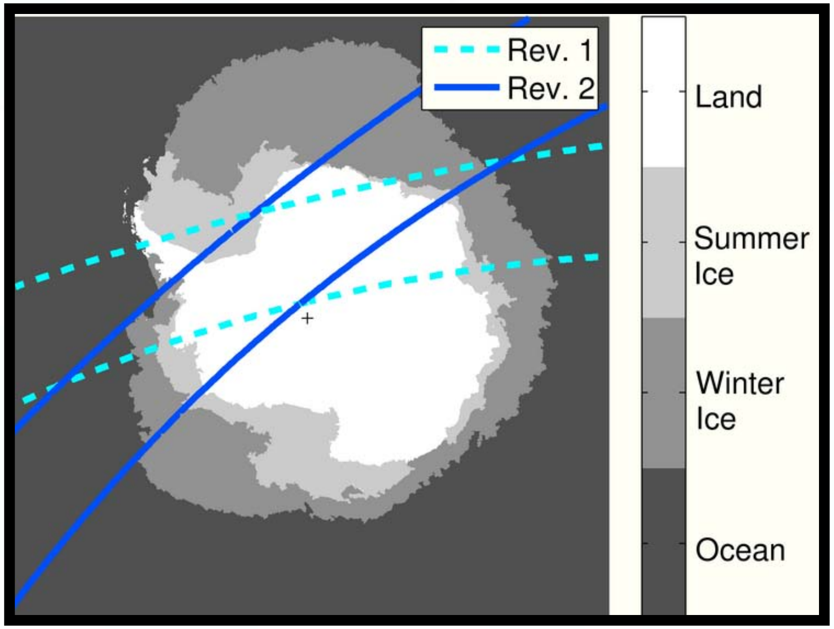
IOVWST Meeting

QuikSCAT Swath and Polar Ice



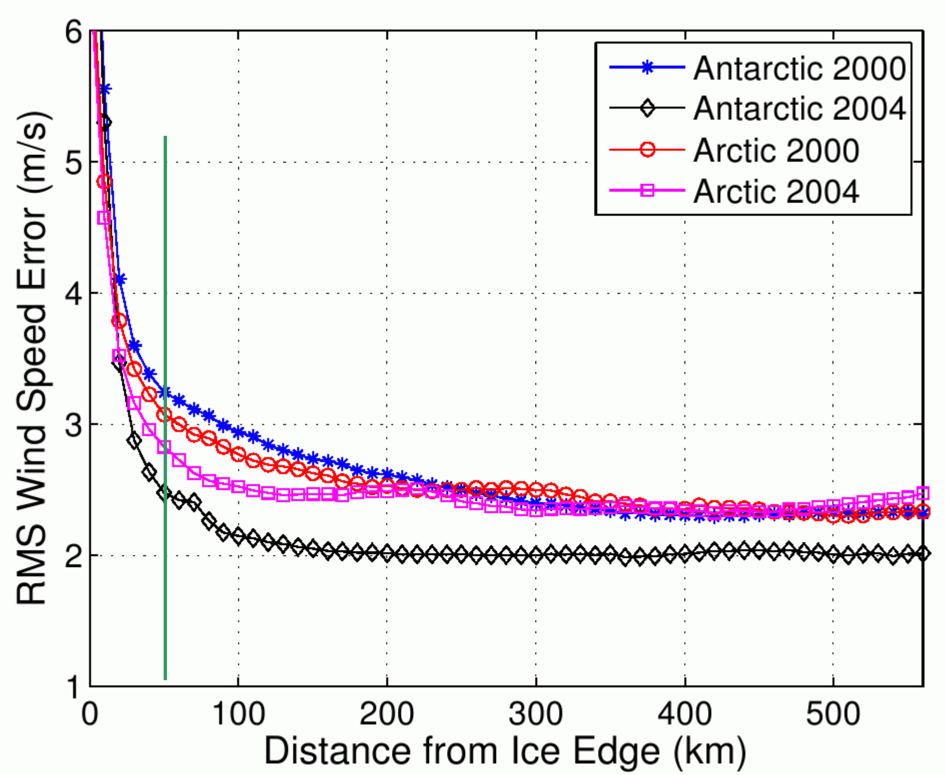
Arctic 2008



Antarctica 2008

Comparison to NCEP Winds

- Evidence of “Ice Winds” from RMS wind speed difference between NCEP (or ECMWF) and QuikSCAT.



8 million WVCs / year

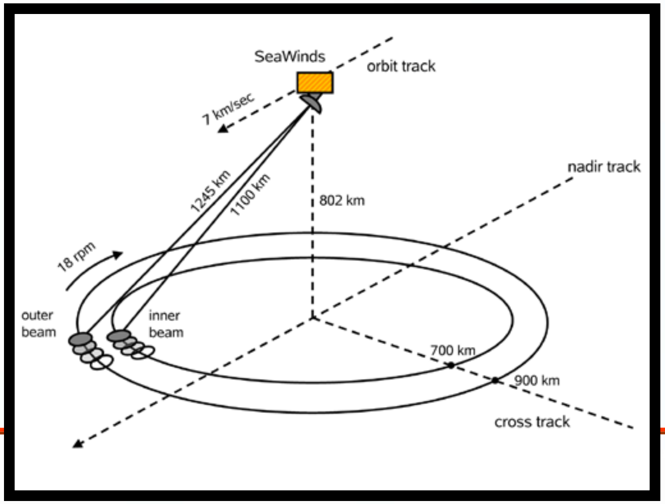
Problem and Motivation

- Satellite Scatterometers accurately measure ocean winds but can suffer from contamination from nearby sea ice
  - Sea ice backscatter is much brighter than ocean backscatter
  - Sea ice in the main lobe or nearby sidelobes biases the ocean backscatter measurements
  - Can result in erroneously high wind speeds -- “Ice Winds”
  - To avoid, processing within 50 km of ice edge discarded
    - Throws a lot of data away
    - Ice winds still occur due to fast moving ice
- Want to eliminate ice winds and estimate winds closer to sea ice edge
  - Adapt proven “land contamination ratio” approach for sea ice

SeaWinds on QuikSCAT

- SeaWinds is commonly referred to by its platform QuikSCAT
- Dual polarization, scanning pencil beam spaceborne scatterometer
- Transmits and receives at 13.4 GHz
  - VV at 54.1° incidence angle
  - HH at 46° incidence angle
- Measures normalized backscatter cross-section (σ^0) at (up to) four “looks”
  - Vpol fore
  - Vpol aft
  - Hpol fore
  - Hpol aft

  Inner/outer swaths
- High resolution images are created using the SIR algorithm



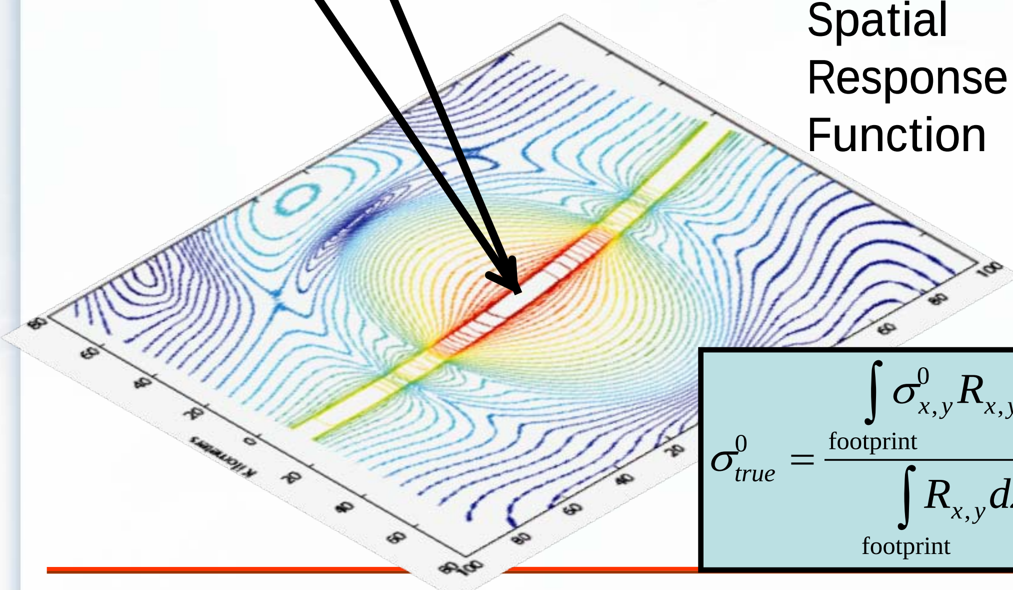
QuikScat Wind Overview
Conventional and UHR

$$\boldsymbol{\sigma}^{\mathbf{0}}_{Obs} = \boldsymbol{\sigma}^{\mathbf{0}}_{true}\left(1+\eta K_p\right)$$

2.5 km → UHR-AVE Algorithm

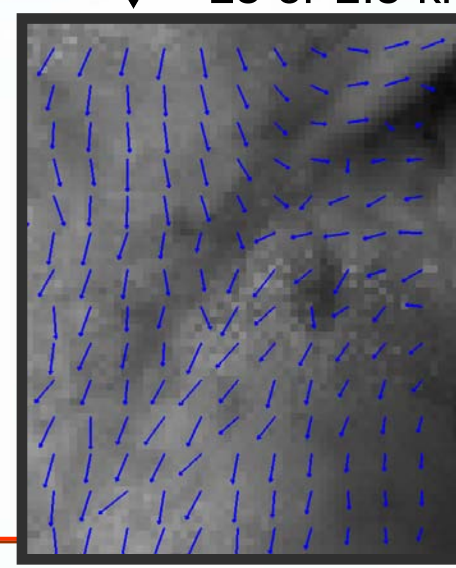
25 km → Wind Retrieval using GMF

Wind Vectors 25 or 2.5 km



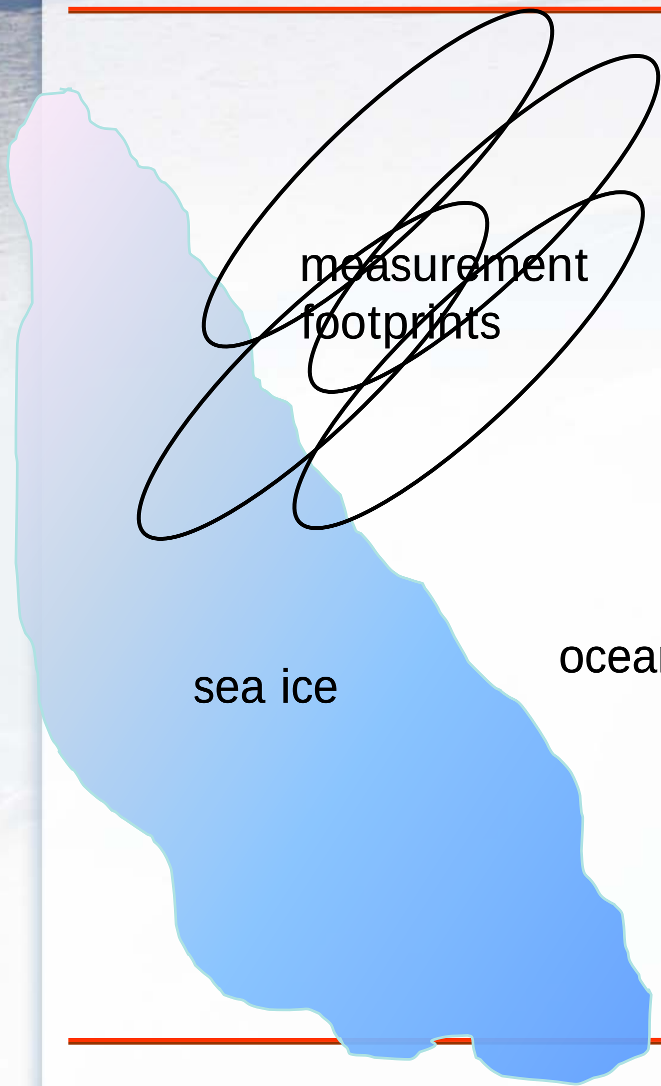
Spatial Response Function

$$\sigma^0_{true} = \frac{\int\limits_{\text{footprint}} \sigma^0_{x,y} R_{x,y}\,dxdy}{\int\limits_{\text{footprint}} R_{x,y}\,dxdy}$$

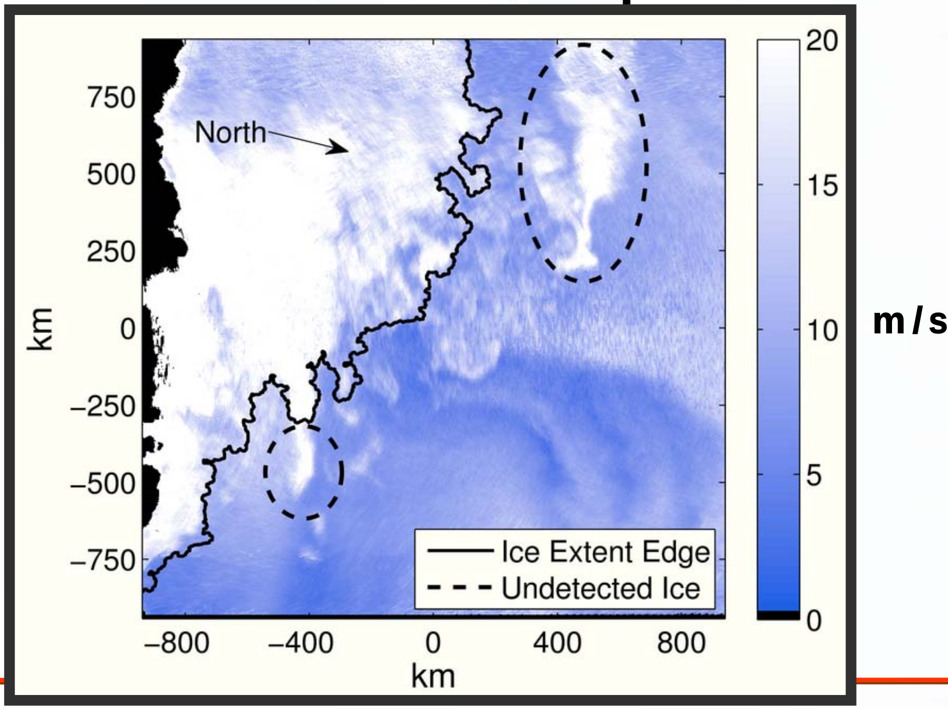


Ice Contaminated Winds

- Sea ice in/near mainlobe of response causes sigma-0 contamination
- Goal: detect and reject contaminated slices.



Contaminated Wind Speeds



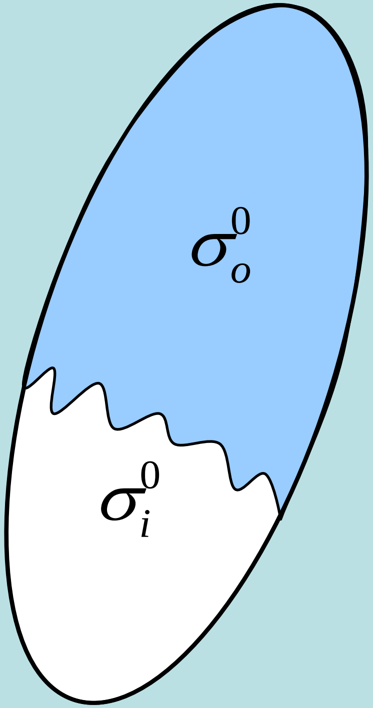
Ice Contribution Ratio

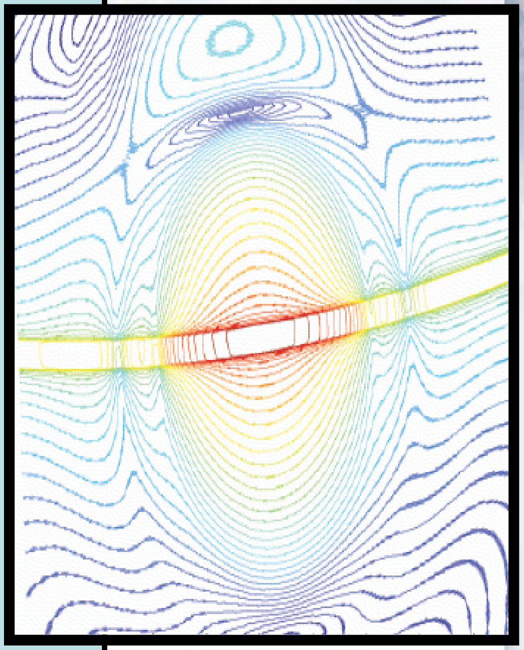
$$\sigma^0_{\text{true}} = \frac{\int_{\text{footprint}} \sigma^0_{x,y} R_{x,y}\,dxdy}{\int_{\text{footprint}} R_{x,y}\,dxdy}$$

$$= \frac{\sigma^0_i \int_{\text{Ice}} R_{x,y}\,dxdy}{\int_{\text{footprint}} R_{x,y}\,dxdy} + \frac{\sigma^0_o \int_{\text{Ocean}} R_{x,y}\,dxdy}{\int_{\text{footprint}} R_{x,y}\,dxdy}$$

$$= \sigma^0_i \text{ICR} + \sigma^0_o \left(1 - \text{ICR}\right)$$

where $\text{ICR} = \dfrac{\int_{\text{Ice}} R_{x,y}\,dxdy}{\int_{\text{footprint}} R_{x,y}\,dxdy}$

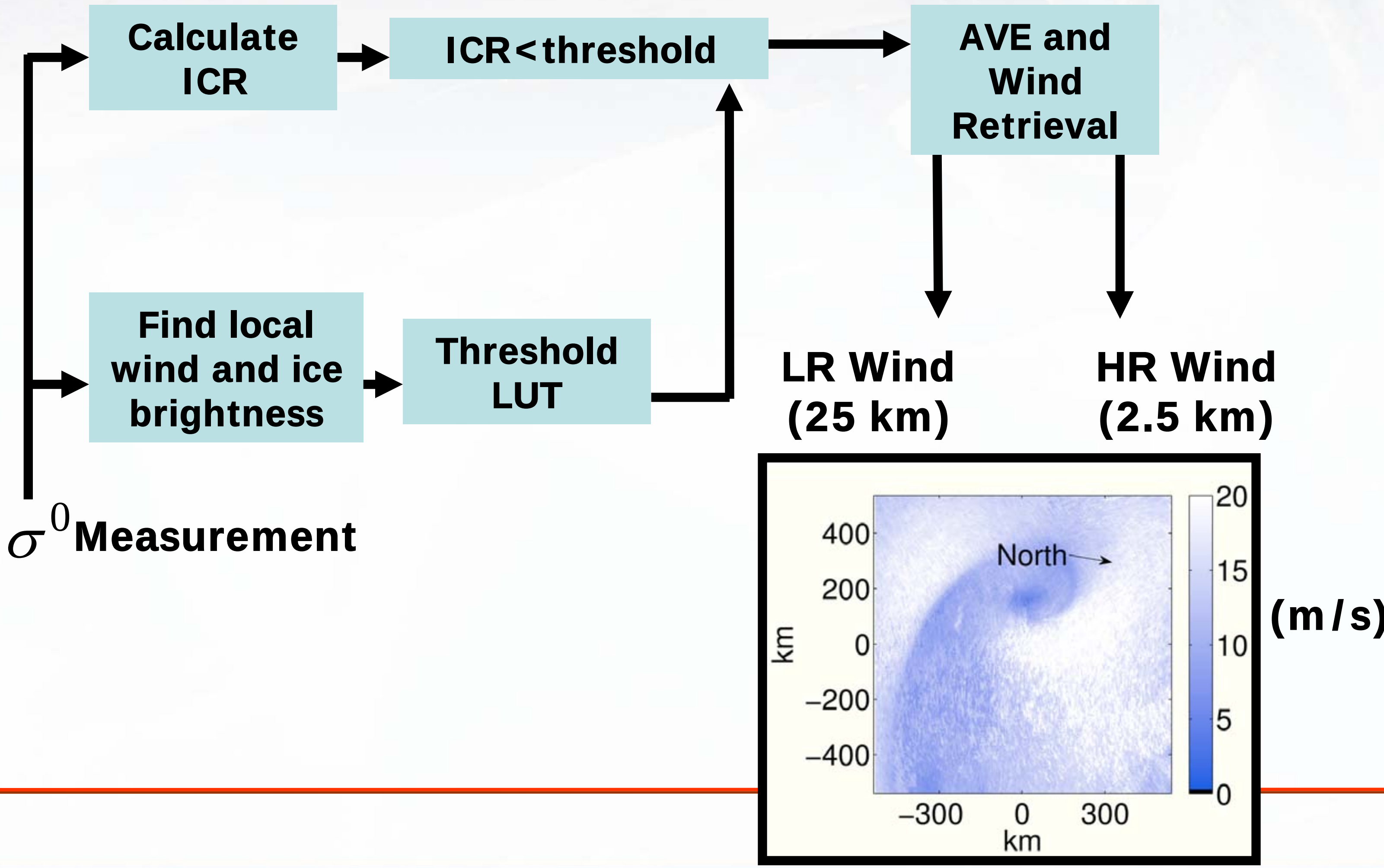




Assumption : $\sigma^0_{x,y}$ is constant over the ice within a footprint.

$\sigma^0_{x,y}$ is constant over the ocean within a footprint.

ICR Processing for Identifying and Discarding Ice Contaminated Measurements



ICR Estimation

$$\text{ICR} \approx \frac{\sum_{\text{Ice}} R[n]}{\sum_{\text{footprint}} R[n]} = \frac{\sum_{\text{footprint}} I[n]R[n]}{\sum_{\text{footprint}} R[n]} \quad \text{Random Sequence}$$

$$E[\text{ICR}] = \frac{\sum_{\text{footprint}} P_n\left(\text{ice}\middle|\boldsymbol{\sigma}^{\mathbf{0}}_{\mathbf{Obs}}\right)R[n]}{\sum_{\text{footprint}} R[n]}$$

$$\text{where } P_n\left(\text{ice}\middle|\boldsymbol{\sigma}^{\mathbf{0}}_{\mathbf{Obs}}\right) = \frac{P_n(\text{ice})P_n\left(\boldsymbol{\sigma}^{\mathbf{0}}_{\mathbf{Obs}}\middle|\text{ice}\right)}{P_n(\text{ice})P_n\left(\boldsymbol{\sigma}^{\mathbf{0}}_{\mathbf{Obs}}\middle|\text{ice}\right) + P_n(\text{ocean})P_n\left(\boldsymbol{\sigma}^{\mathbf{0}}_{\mathbf{Obs}}\middle|\text{ocean}\right)}$$

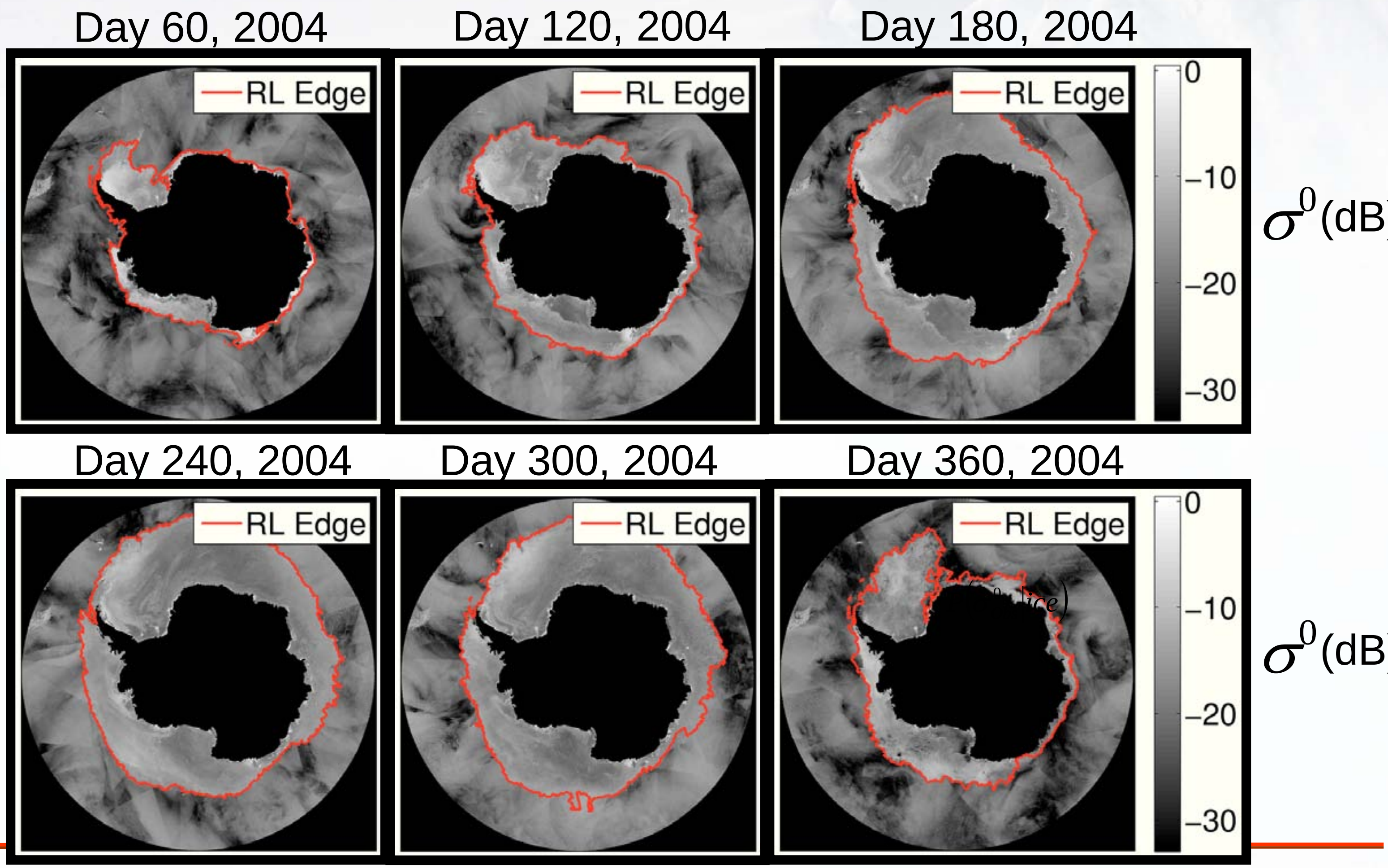
$P_n\left(\text{ice}\middle|\boldsymbol{\sigma}^{\mathbf{0}}_{\mathbf{Obs}}\right)$: posterior probability of ice

$P_n\left(\boldsymbol{\sigma}^{\mathbf{0}}_{\mathbf{Obs}}\middle|\text{ice}\right)$: observation probability

$P_n(\text{ice})$: prior probability of ice

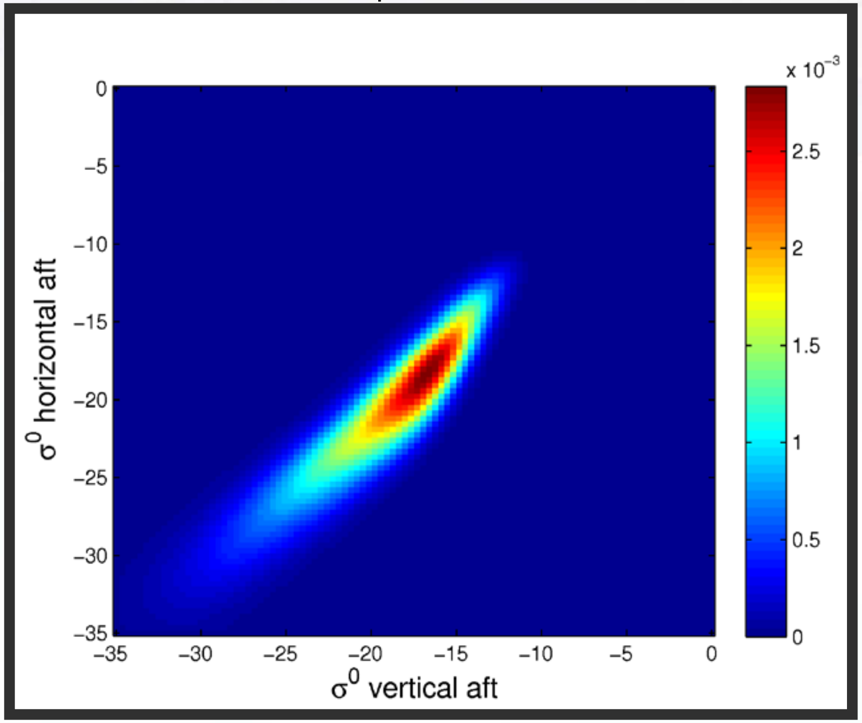
Constructing Observational PMFs

$$P\left(\sigma^0_{Obs}\middle|ice\right) \text{ and } P\left(\sigma^0_{Obs}\middle|ocean\right)$$

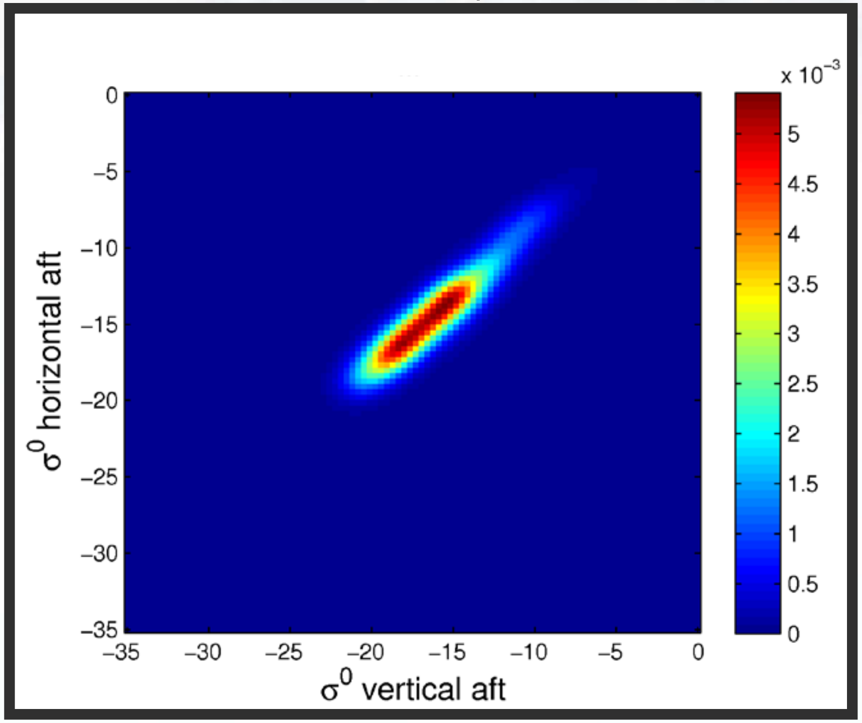


Observation Probabilities

$$P\left(\sigma^0_{Obs} \middle| ocean\right)$$



$$P\left(\sigma^0_{Obs} \middle| ice\right)$$

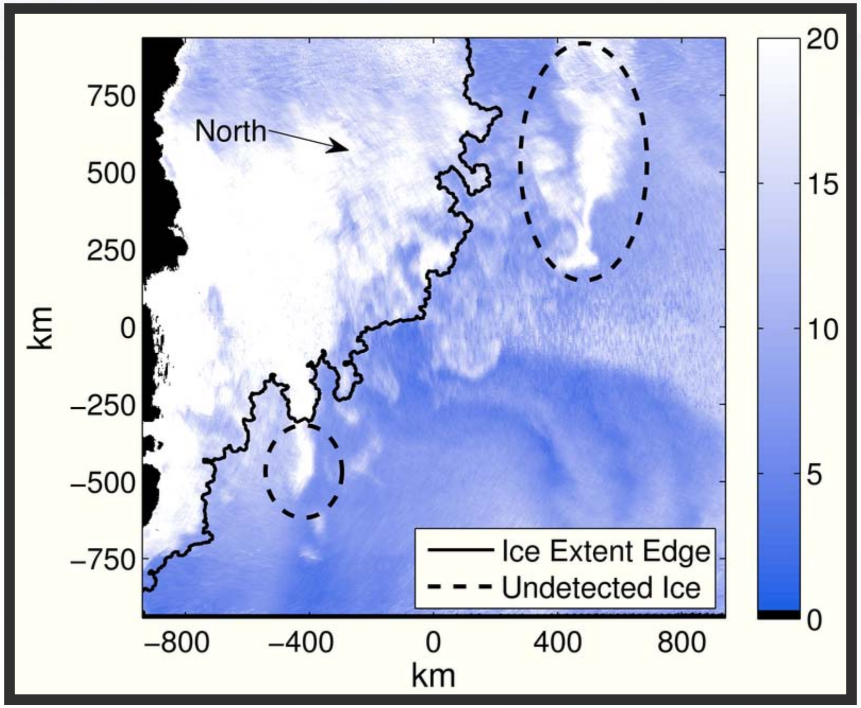


Note: Example PMF from DOY 228-243, 2004 UHR sigma-0 (avewr) data
Actual PMF's generated in the four dimensional measurement space

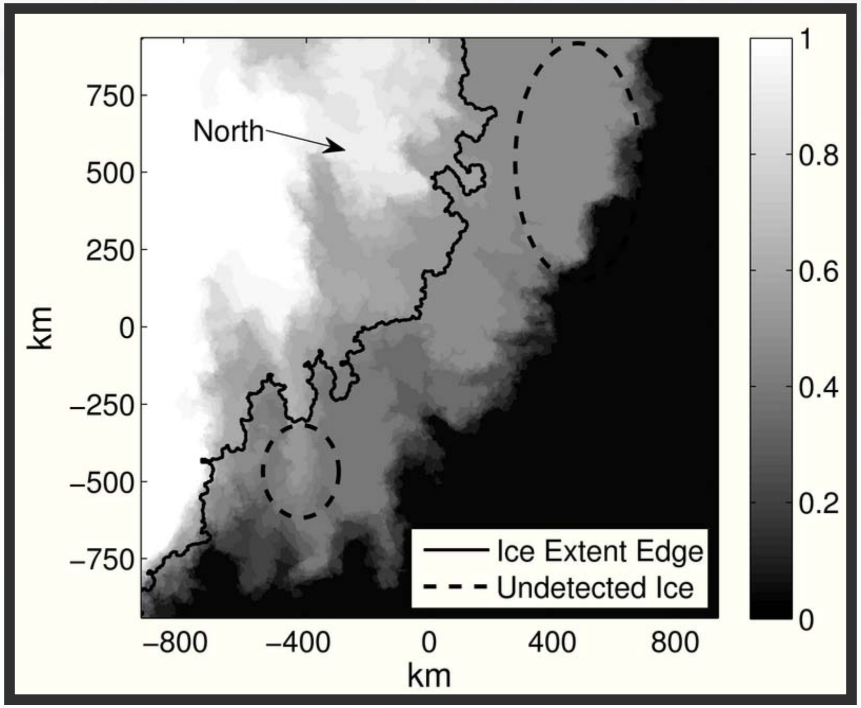
Ice Prior Generation

$$P(ice)$$

Wind Speed (m/s)

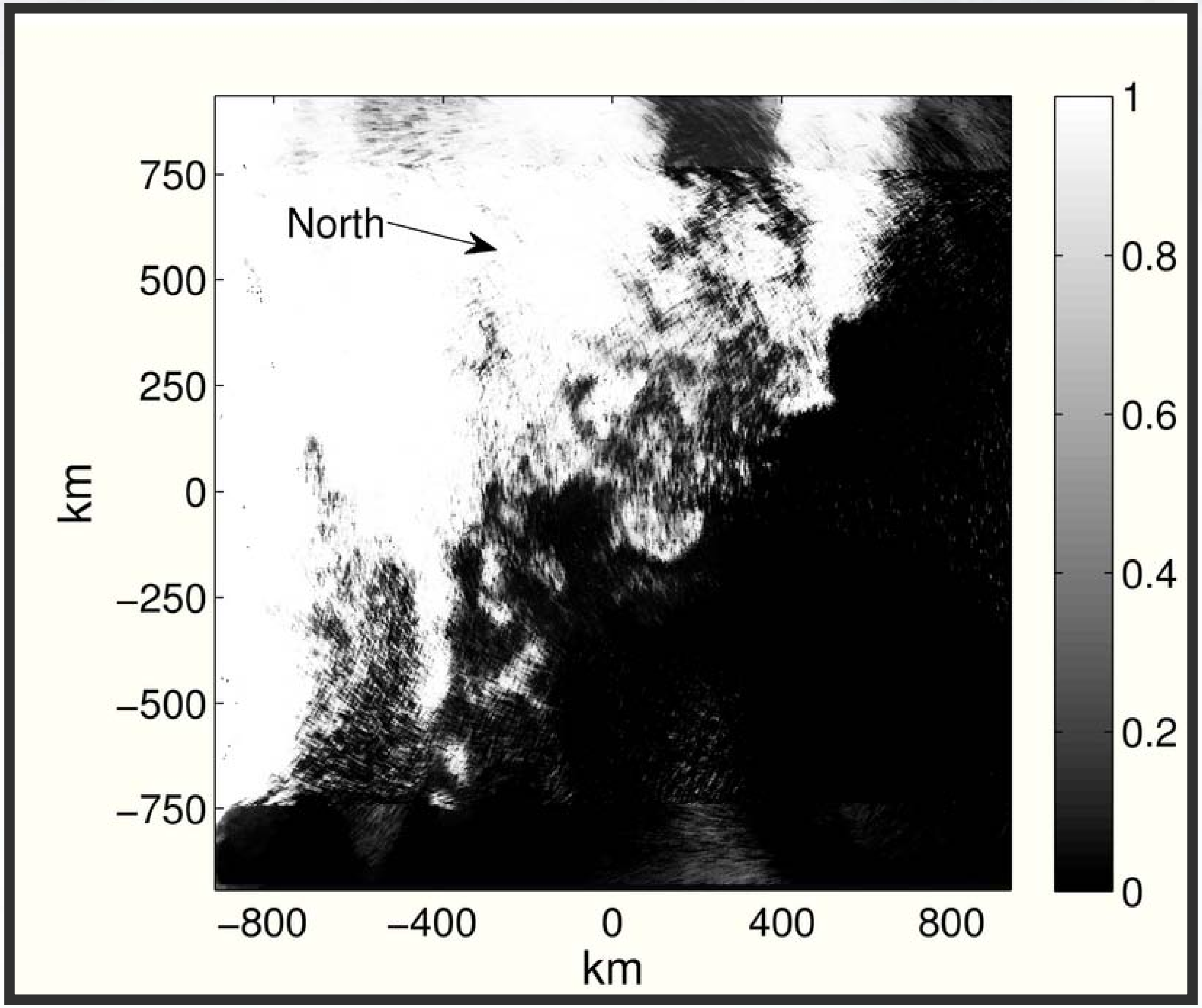


Prior Probability

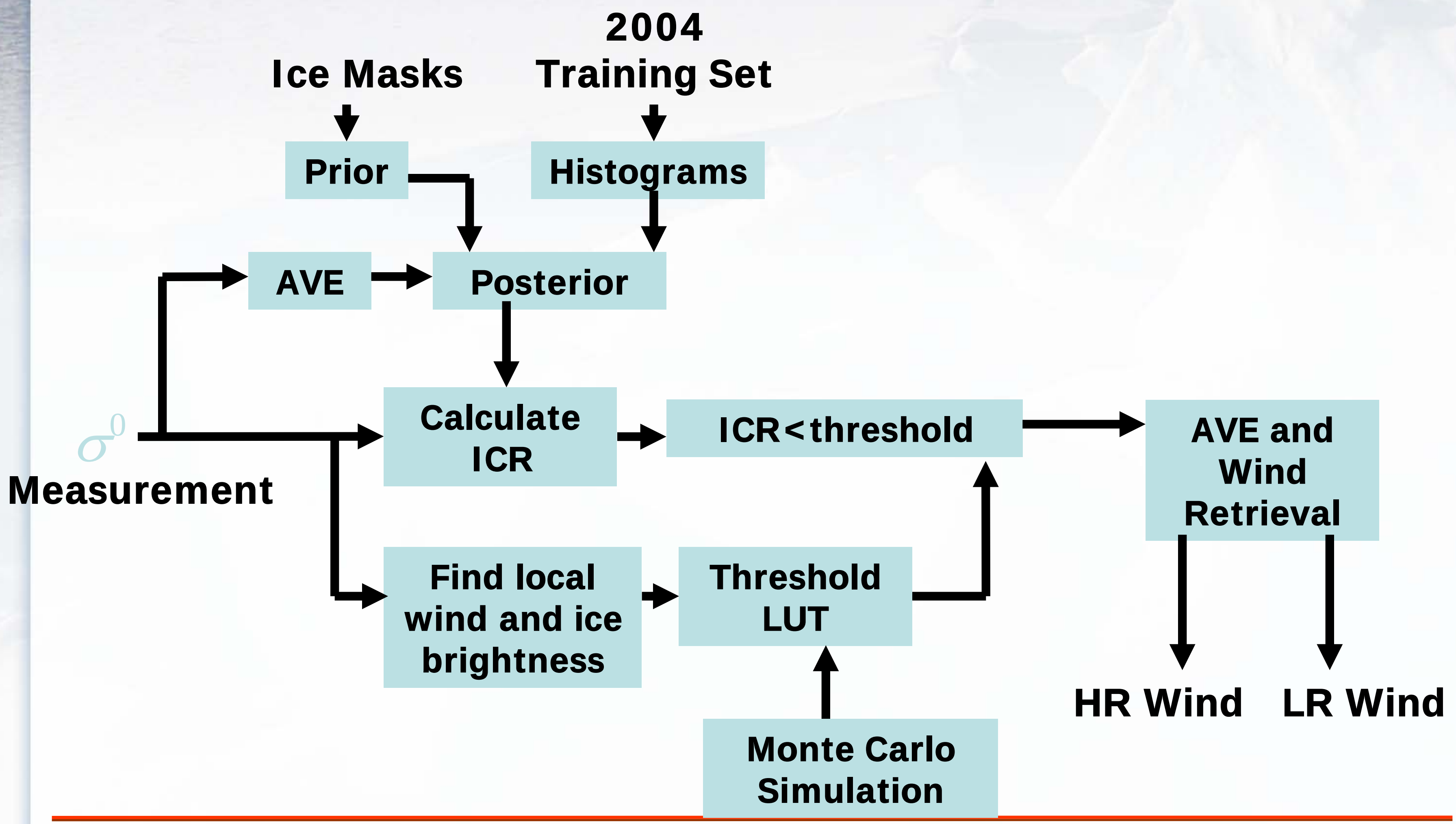


- Ice prior is generated by averaging operational QuikSCAT ice masks within a local sliding time window. Window length of 23 days is used here.

Computed Posterior Probability $P\left(ice \middle| \sigma^0_{Obs}\right)$



ICR Algorithm
(tests individual sigma-0 for sea ice contamination)



Monte Carlo Simulation

Choose

$\mathbf{w} \rightarrow \boxed{\mathrm{GMF}_w} \rightarrow \boldsymbol{\sigma}^0_{\text{ocean}}$

ICR

$\boldsymbol{\sigma}^0_{\text{ice}}$

Incidence/azimuth angles from cross-track location

$$\boldsymbol{\sigma}^0_{\text{Sim}} = \left[\mathrm{ICR}\,\boldsymbol{\sigma}^0_{\text{ice}} + (1-\mathrm{ICR})\,\boldsymbol{\sigma}^0_{\text{ocean}}\right]\left(1+\eta K_p\right)$$

$\eta \sim N(0,1) \longrightarrow$ 1500 Realizations

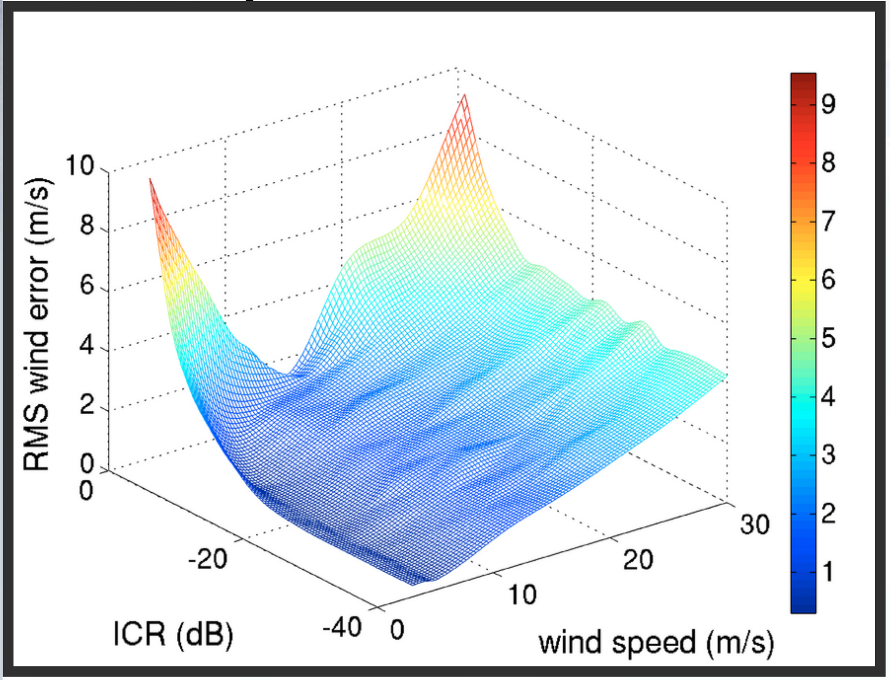
$$\boldsymbol{\sigma}^0_{\text{Sim}} \rightarrow \boxed{\mathrm{GMF}_w^{-1}} \rightarrow \hat{\mathbf{w}}_{\text{Sim}}$$

$$\varepsilon_{\text{RMS}} = \sqrt{\frac{\sum_{i=1}^{1500}\left(\|\mathbf{w}\| - \|\hat{\mathbf{w}}_{\text{Sim},i}\|\right)^2}{1500}}$$

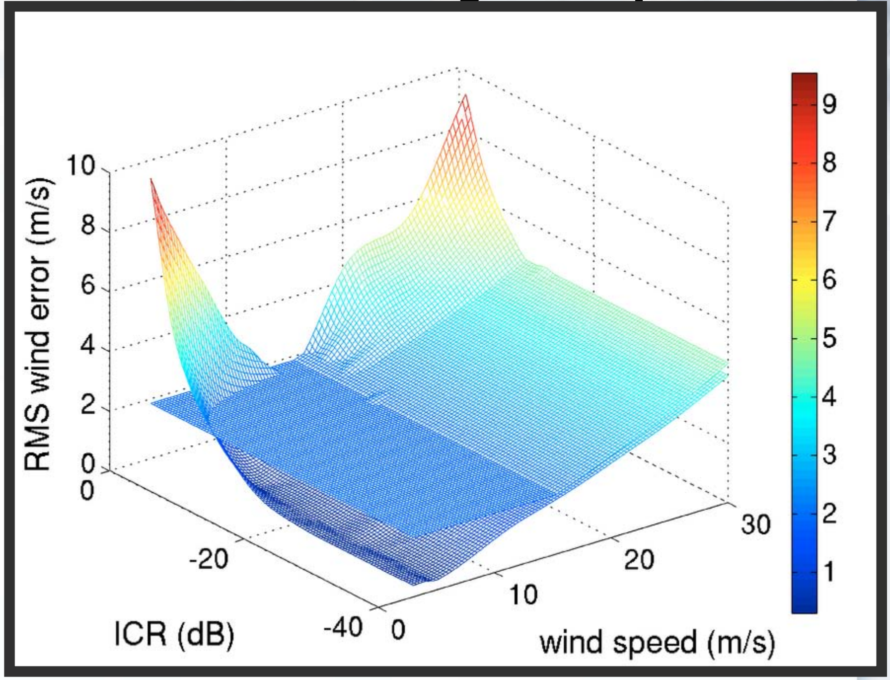
- Simulation parameters:
  - ICR
  - wind
  - ice backscatter
  - cross track location
- 1500 simulated winds for each parameter set
- RMS error computed

Thresholding

Example Simulation Results



Thresholding Example



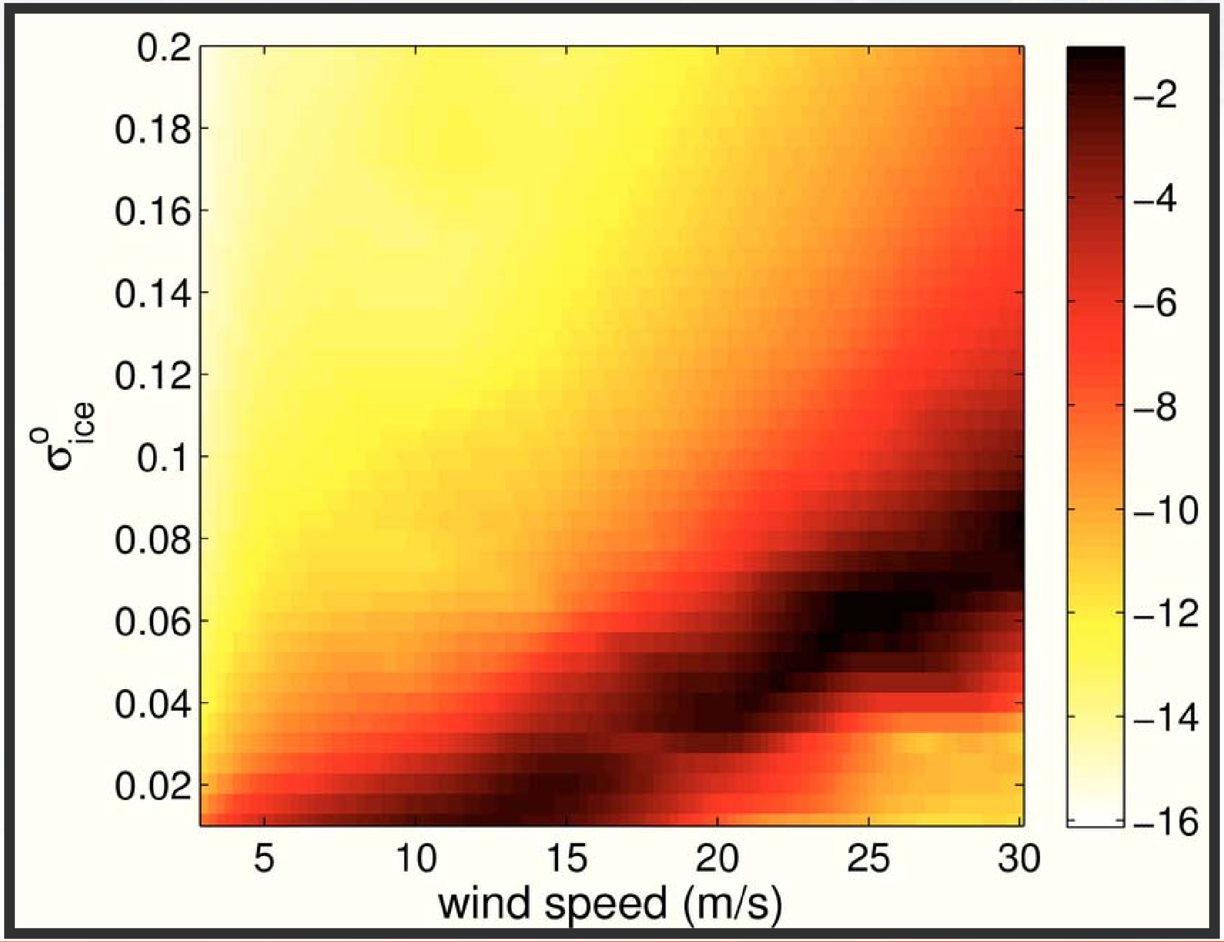
Cross track 7
Ice brightness 0.0375

$$\varepsilon_{\text{rel}} = \frac{\varepsilon_{\text{Ice}} - \varepsilon_{\text{Ice Free}}}{\varepsilon_{\text{Ice Free}}}$$

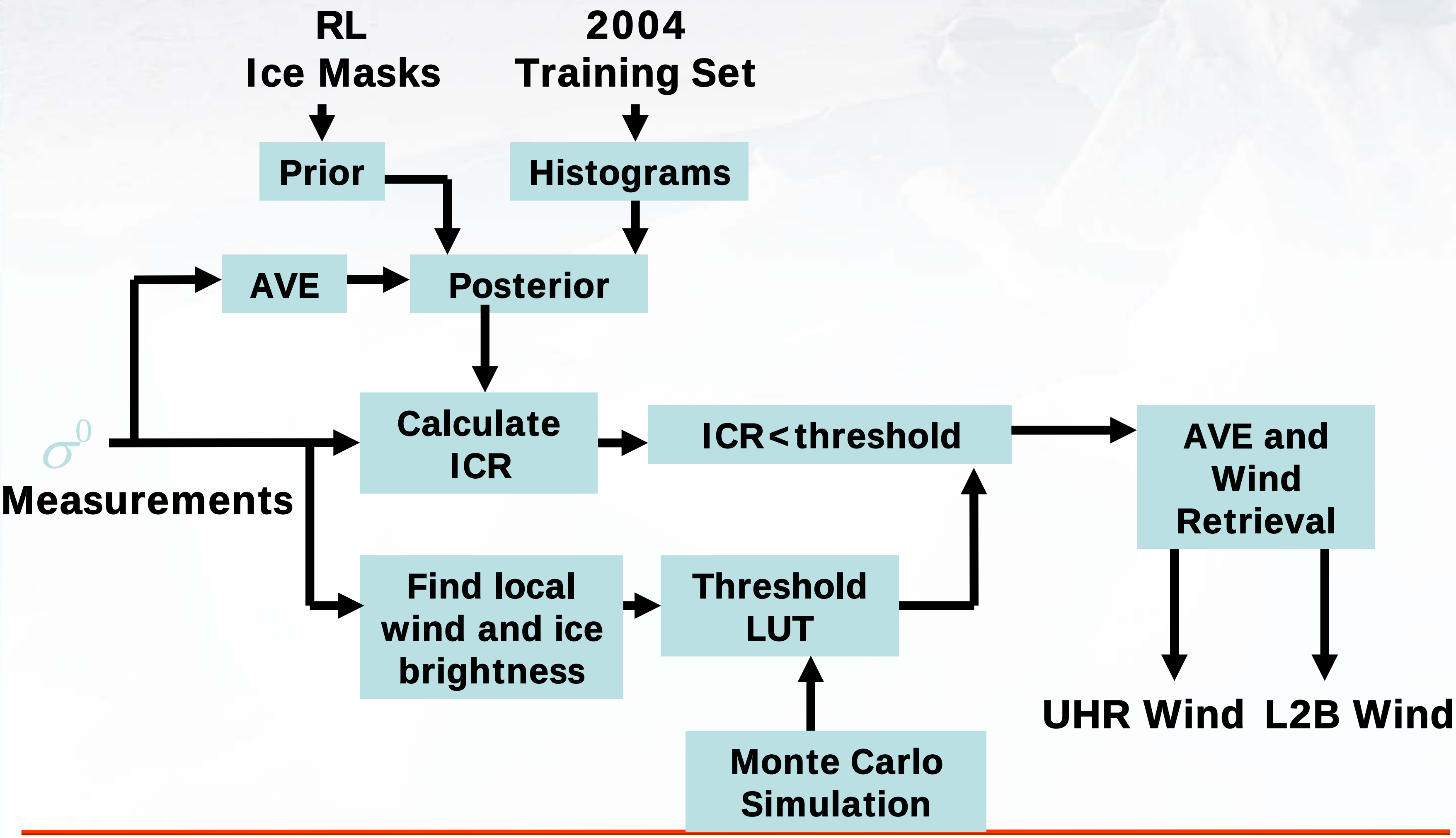
10 %
Relative Error Threshold

Simulation Results

Simulated ICR Thresholds (dB)



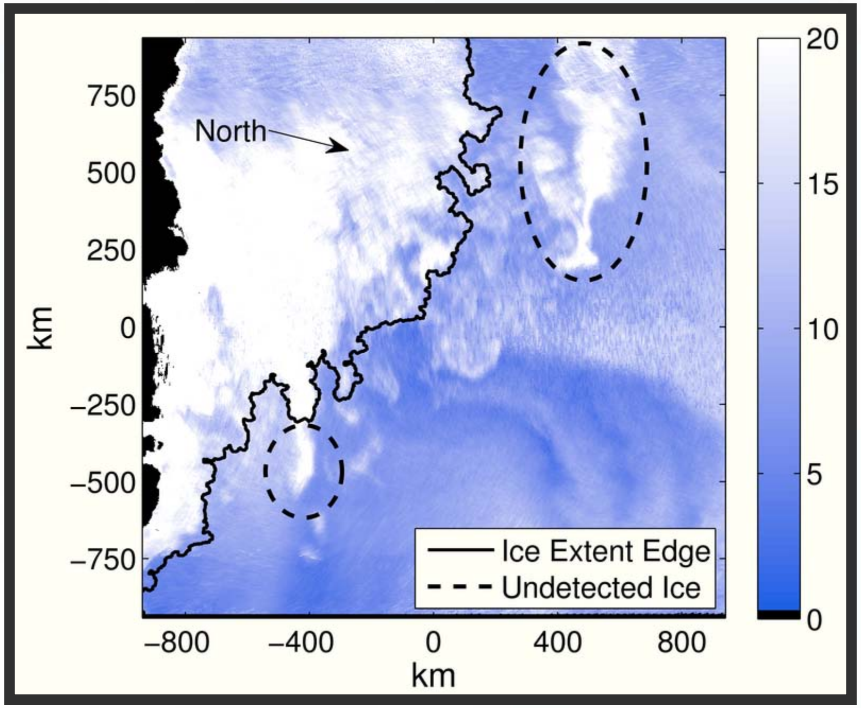
ICR Algorithm



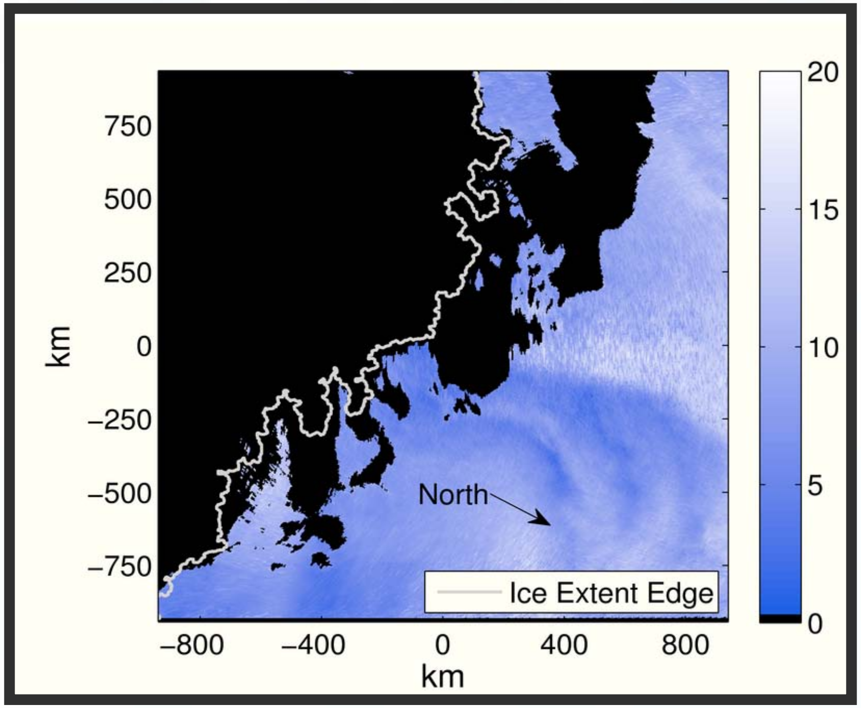
Case Study
December 15, 2004

Location: South of Africa

Contaminated HR Wind Speed (m/s)



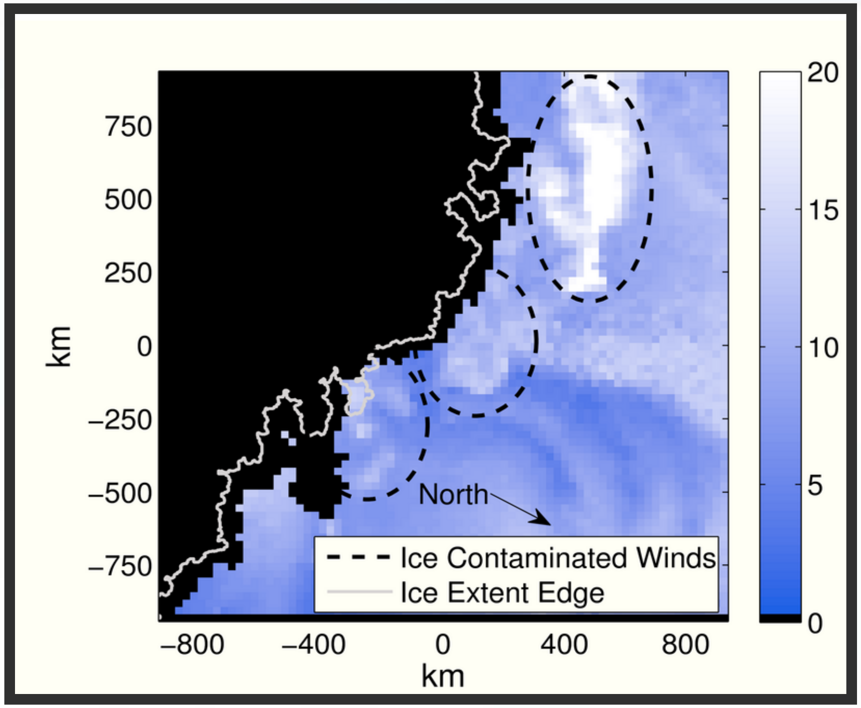
ICR Processed HR Wind Speed (m/s)



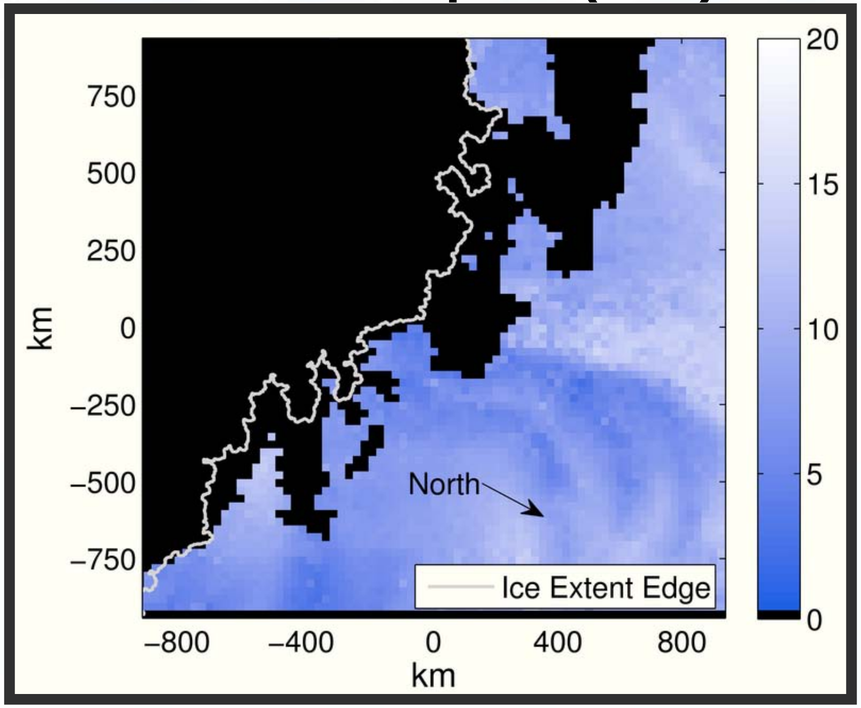
Case Study

Location: South of Africa

L2B Wind Speed (m/s)



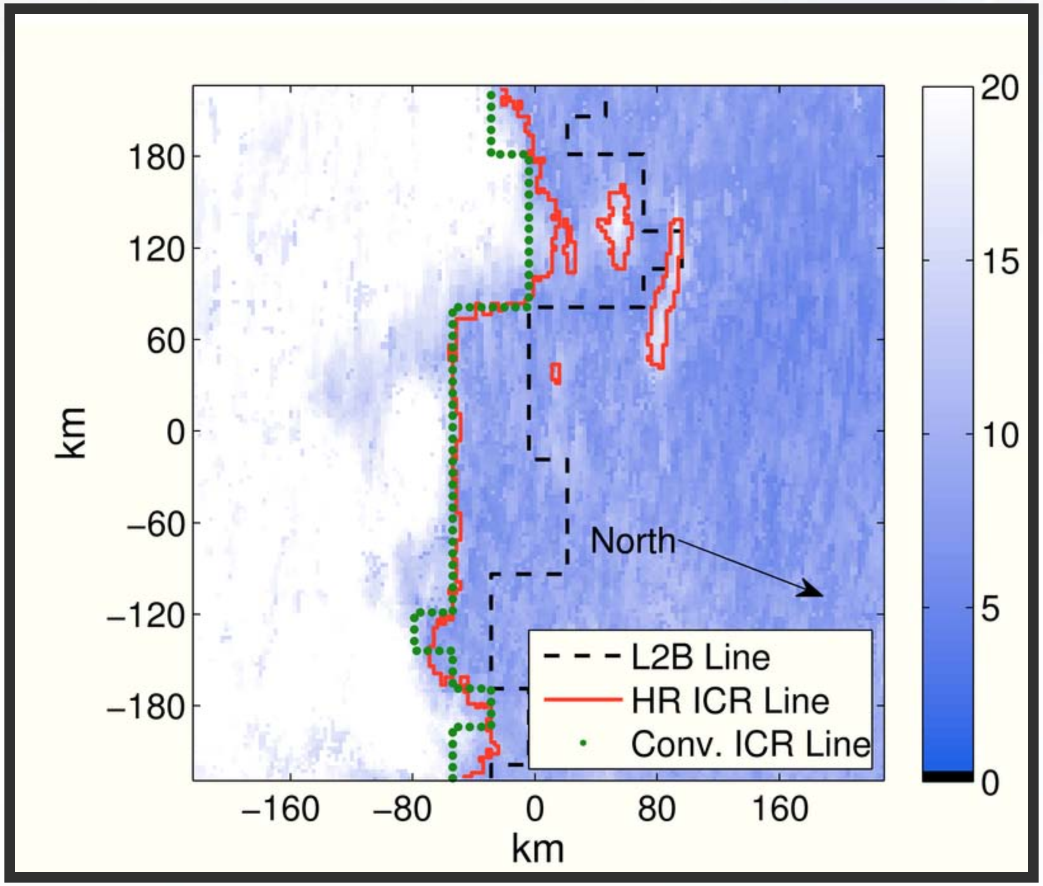
ICR Processed LR Wind Speed (m/s)



October 8, 2000 Case Study

Location: East of the Drake Passage

Wind Speed (m/s)



Validation Metrics

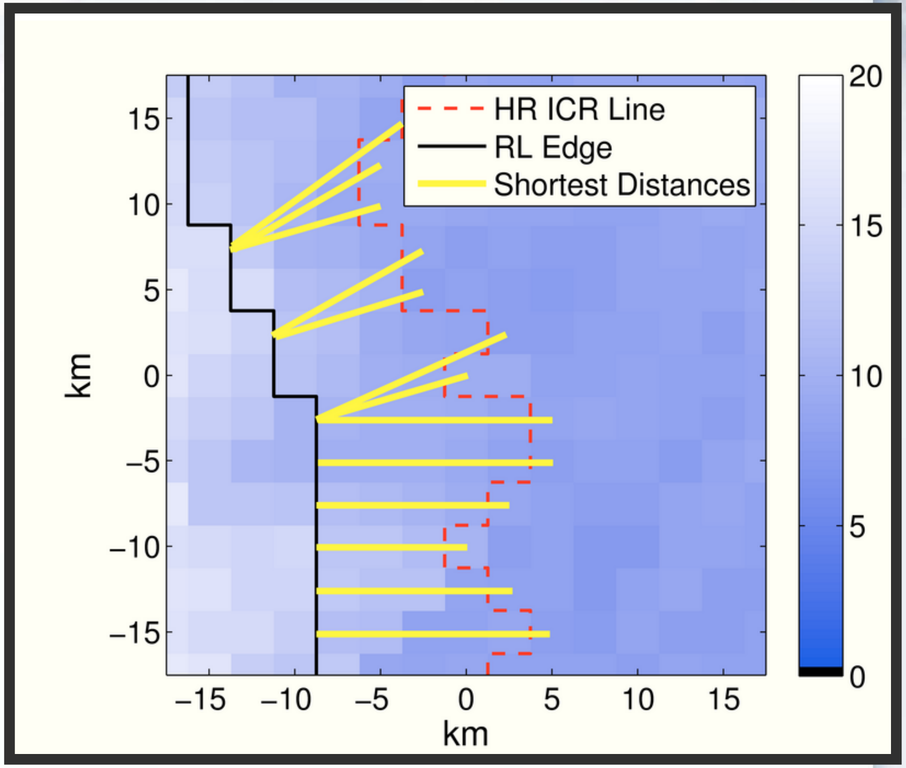
1) Stand-off Distance (SOD)

$$\mathrm{SOD} = \mathrm{mean}(d_1, d_2, \ldots, d_N)$$

2) Relative Error – Compares against National Center for Environmental Prediction (NCEP)

$$\varepsilon_{\mathrm{rel}} = \frac{\varepsilon_{\mathrm{ICR}} - \varepsilon_{\mathrm{Ice\ Free}}}{\varepsilon_{\mathrm{Ice\ Free}}}$$

Wind Speed (m/s)



2000/2004 Metric Validation

Metric	Set	UHR	25 km	L2B
SOD (km)	Antarctic 2000	22.7	22.8	57.9
	Antarctic 2004	22.9	23.1	64.7
	Arctic 2000	22.1	22.2	38.7
	Arctic 2004	22.0	21.8	37.2
ϵ_{rel} (%)	Antarctic 2000	21.7	18.1	31.6
	Antarctic 2004	30.4	27.3	34.3
	Arctic 2000	16.5	20.6	31.2
	Arctic 2004	21.9	26.7	40.0

100,000 wvcs for 25 km & L2B, 1 million wvcs for UHR

2008 Wind Distributions

1) ICR winds, L2B agree
(Ice-free)

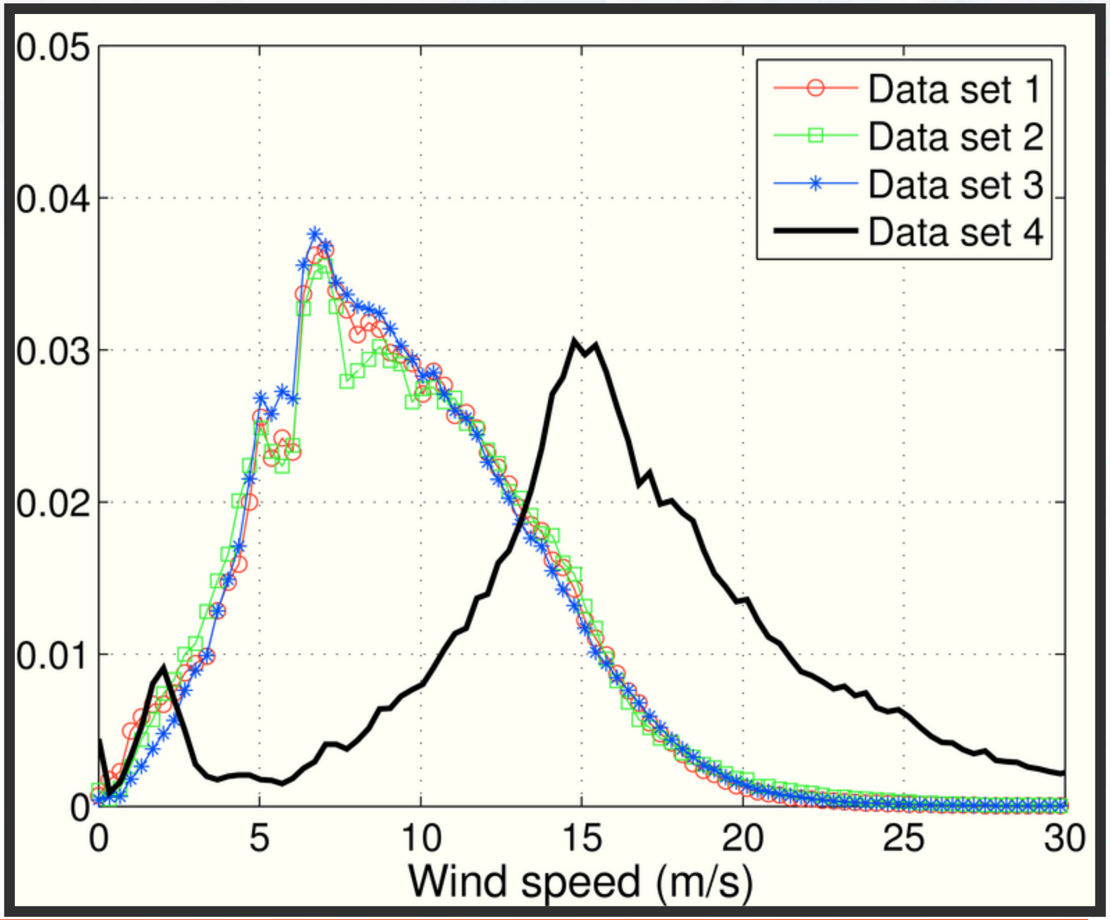
2) L2B winds, ICR agree
(Ice-free)

3) ICR winds, L2B disagree
(Ice-free)

4) L2B winds, ICR disagree
("Ice winds")

5133 revs, 4 million wvcs

Antarctic Wind Probability Distributions



Conclusion

- New ICR processing retrieves wind an average of 22.5 km (Antarctic) 15.9 km (Arctic) from sea-ice edge
  - Improvement from original 50 km ice-edge masked winds
- ICR processing improves wind estimate integrity in regions of possible sea ice
  - Eliminates so-called "Ice Winds"
- ICR processing applied to Arctic and Antarctic regions
  - Augmented L2B product (only near-ice regions modified)
  - UHR near-ice product (new)
- Plan to apply to ASCAT and OSCAT in near future
- Journal paper currently in review:

  W.J. Hullinger and D.G. Long, "Mitigation of Sea Ice Contamination in QuikSCAT Wind Retrieval", *IEEE Transactions on Geoscience and Remote Sensing*, in review, 2012

Backup Slides

Overview

- Brief review of QuikSCAT wind retrieval
- Ice Contribution Ratio (ICR) Measurement Model
- ICR Calculation
- ICR Threshold Determination
- Case Studies
- Performance Analysis
- Conclusion

Metrics using Various Priors

Stand-off Distance (m)

Res.	Set	5 day	11 day	17 day	23 day	L2B
2.5 km	Antarctic 2000	20.1	21.5	22.3	22.7	-
	Antarctic 2004	19.7	21.1	22.3	22.9	-
	Arctic 2000	19.6	21.0	21.6	22.1	-
	Arctic 2004	20.1	21.0	21.8	22.0	-
25 km	Antarctic 2000	20.5	21.9	22.6	22.8	57.9
	Antarctic 2004	20.4	21.5	22.7	23.1	64.7
	Arctic 2000	19.9	21.1	21.6	22.2	38.7
	Arctic 2004	19.9	20.9	21.7	21.8	37.2

Relative Error (%)

Res.	Set	5 day	11 day	17 day	23 day	L2B
2.5 km	Antarctic 2000	27.1	26.0	24.7	23.7	-
	Antarctic 2004	36.9	34.0	31.4	30.4	-
	Arctic 2000	15.1	15.3	15.6	16.5	-
	Arctic 2004	21.7	22.6	21.8	21.9	-
25 km	Antarctic 2000	19.7	18.1	18.4	18.1	31.6
	Antarctic 2004	30.0	30.0	27.5	27.3	34.3
	Arctic 2000	17.3	17.3	19.0	20.6	31.2
	Arctic 2004	24.6	24.8	25.2	26.7	40.0

Effect of Ocean Prior

ICR Processed Winds (m/s)