IGARSS 2013
Melbourne, Australia
July 21 – 26

Continuous Sea Ice Thickness Estimation using a Joint MODIS/AMSR-E Guided Variational Model

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Motivation

- Sea ice thickness
  - Safe operations
  - Weather forecasts
- Manual measurement is unscable
- Use remote sensing for estimating ice thickness

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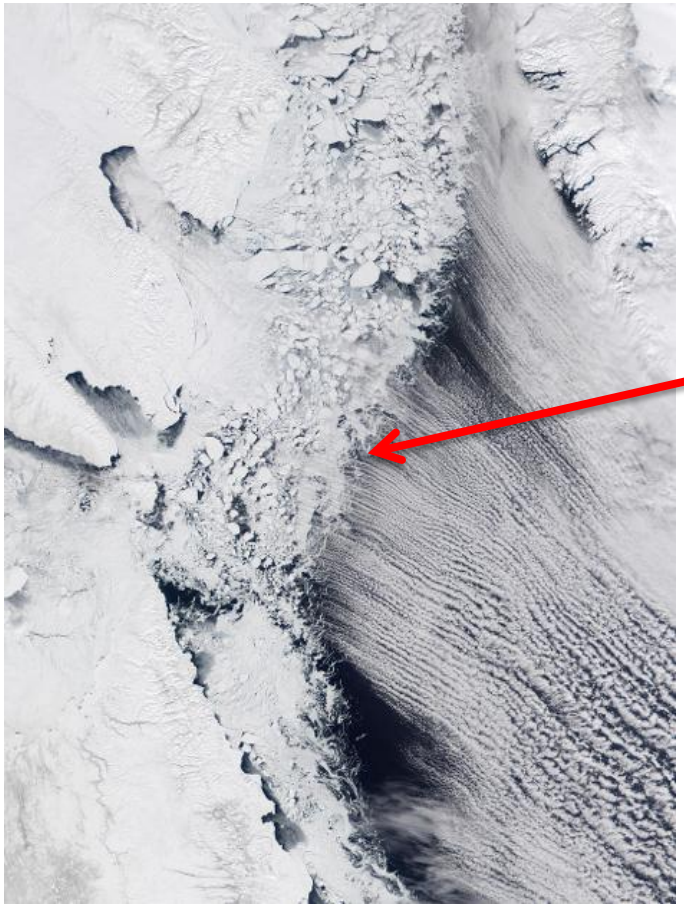
Problem with VIS/IR



Cloud or ice?

Source: Jacques Descloitres, MODIS Land Rapid Response Team

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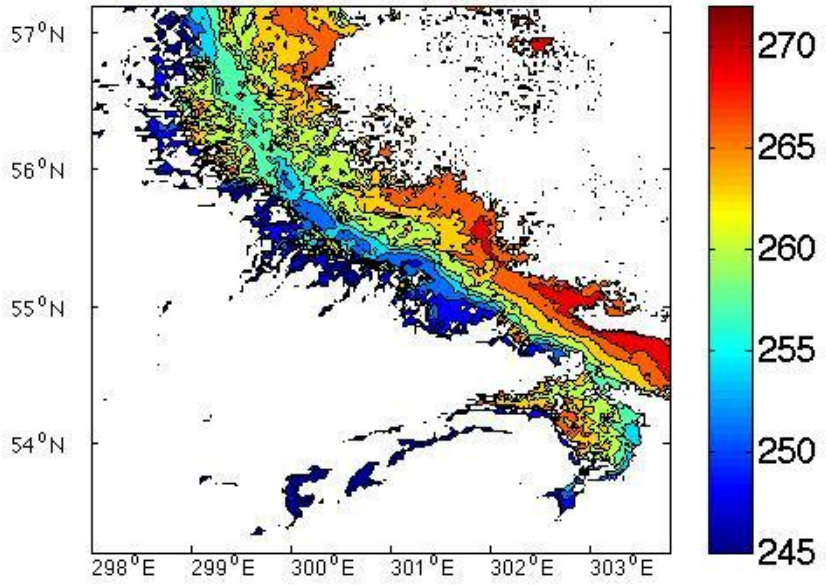
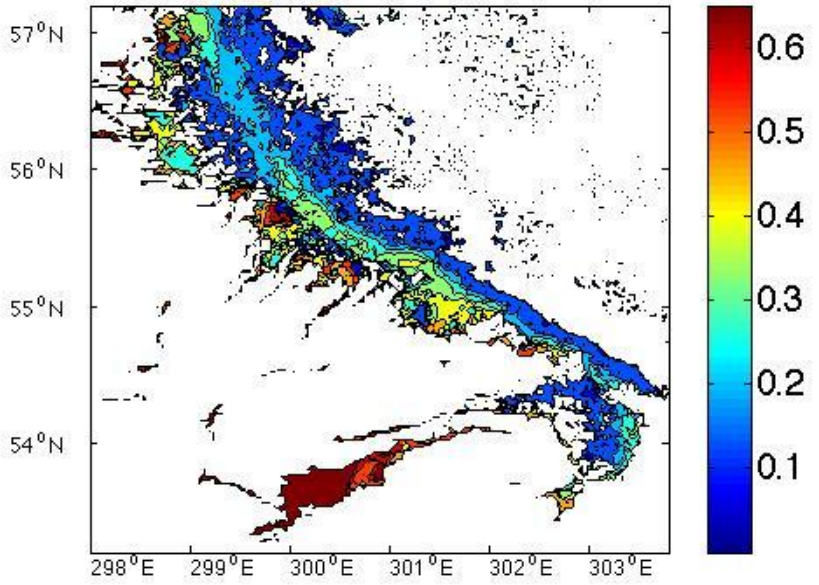
Motivation

Ice temperature (K)



Ice thickness (m)



Labrador Coast, January 10, 2009

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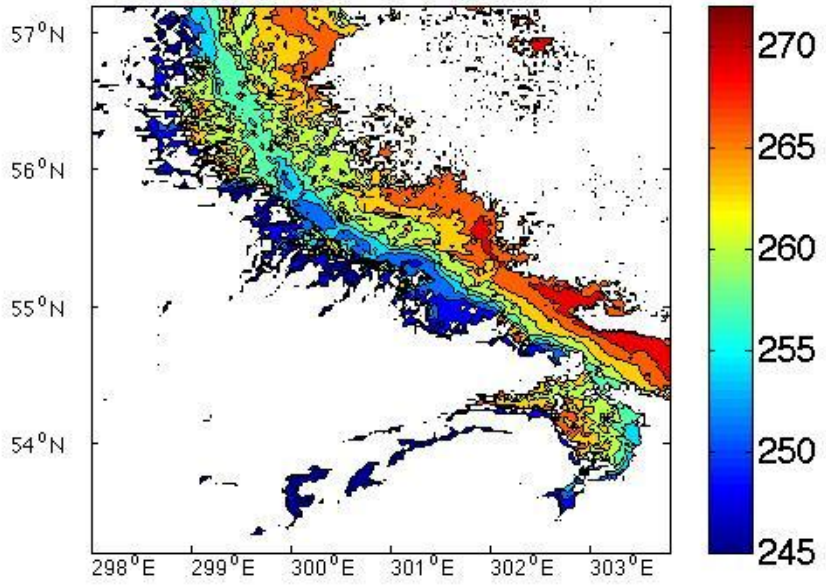
Motivation

Ice temperature (K)



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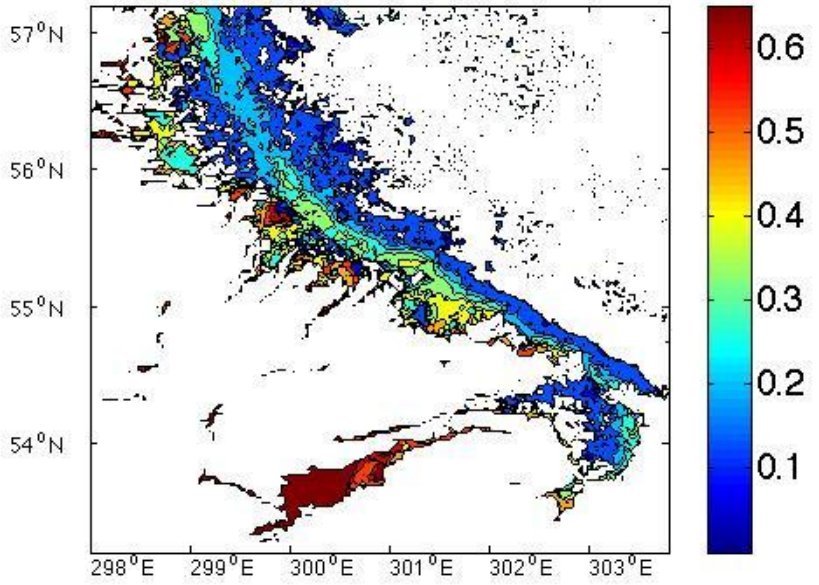

(Inverse) correlation!

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Outline

- Image data
- Proposed Method
  1. Temperature generation
  2. Ice thickness estimate
- Results
- Conclusions & Future Work

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Data

- Aqua satellite
  - AMSR-E (passive microwave)
    - 12.5km, sea ice concentration product
    - Lowest 3 bands (6.9, 10.8, 18.7 GHz)
  - MODIS (VIS/IR)
    - MOD29: 1km, ice temperature product (240—271K)
- Imagery
  - Jan 1 2007 – Feb 28 2007 (daily)
  - Baffin Island, Labrador Coast (Canada)

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High-Level Rationale

- 2 data types are very complementary

	Affected by Cloud?	Resolution
Passive Microwave (AMSR-E)	No	Coarse
VIS/IR (MODIS)	Yes	Fine

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High-Level Rationale

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Method Overview

1. **Generation**: Generate continuous surface temperature map.
2. **Estimation**: Estimate ice thickness from surface temperature.

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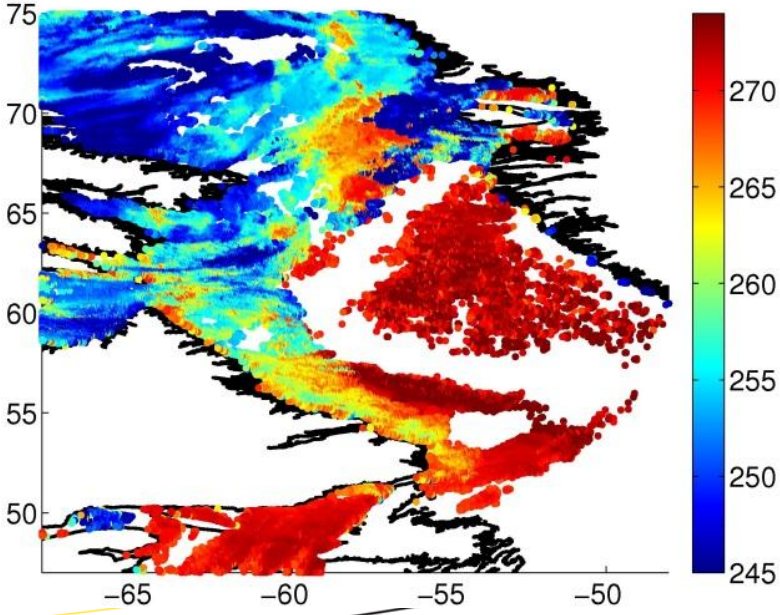
Step 1: Generation

- **Goal**: continuous surface temperature map
- **Idea**: regard cloud-cover pixels as noise
- Multi-modality Guided Variational (MGV) model
  - Total variation
  - Polarization ratio (AMSR-E)



Aside: Total Variation

- Consider least-squares
  - Infinite number of solutions: how to interpolate missing data?
  - $\hat{s} = \text{argmin} \, ||\hat{s} - s||_2$
  - But s is incomplete!
- Total variation assumes piecewise smoothness
  - Realistic assumption for ice transitions
  - $\hat{s} = \text{argmin} \, \alpha||\hat{s} - s||_2 + \beta \sum_i |\hat{s}_i - \hat{s}_{i+1}|$

Aside: Polarization Ratio

- Normalized difference between polarization brightness temperatures:

$$PR(v) = \frac{B_V(v) - B_H(v)}{B_V(v) + B_H(v)}$$

- Related to ice thickness

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Step 1: Generation

- Represent sparse info as sampled from a continuous map:

$$\begin{bmatrix}\mathbf{m_0}\\ \mathbf{m_1}\\ \mathbf{m_2}\\ \mathbf{m_3}\end{bmatrix} = \begin{bmatrix}C_0\\ C_1\\ C_2\\ C_3\end{bmatrix}\begin{bmatrix}\mathbf{z_0}\\ \mathbf{z_1}\\ \mathbf{z_2}\\ \mathbf{z_3}\end{bmatrix}$$

MODIS

AMSR-E

$\mathbf{m_0}$ – sparse MODIS surface temperature

$\mathbf{z_0}$ – continuous surface temperature

$\mathbf{m_{1,2,3}}$ – PR for lowest 3 AMSR-E frequencies

$\mathbf{z_{1,2,3}}$ – continuous PR

C_i – observation matrix

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Step 1: Generation

- Use MGV to find $\mathbf{z_0}$
  - Fit temperature map with least-squares
  - Use spatial variability of AMSR-E PRs

$$\hat{z}_o = \operatorname{argmin}\left[\alpha \left\| m_o - C_o \hat{z}_o \right\|_2 + \beta \sum_j \sum_{k \in N(j)} \exp\left(-\lambda_s \left\| j-k \right\|_2\right) \underbrace{\sum_{i=0}^{3} \exp\left(-\lambda_i \left\| z_i(j) - z_i(k) \right\|\right)}_{AMSR-E data} \left| \hat{z}_o(j) - \hat{z}_o(k) \right| \right]$$

  - Sum over 3 lowest AMSR-E frequencies

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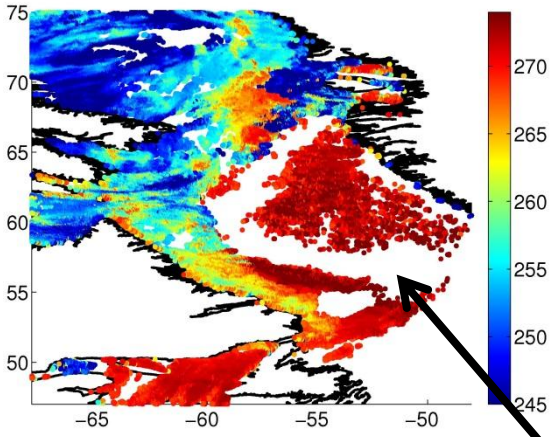
Step 1: Generation



Swath data
(MODIS)

Cloud cover

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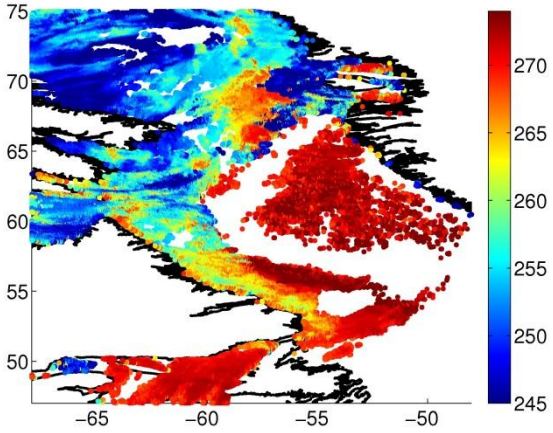
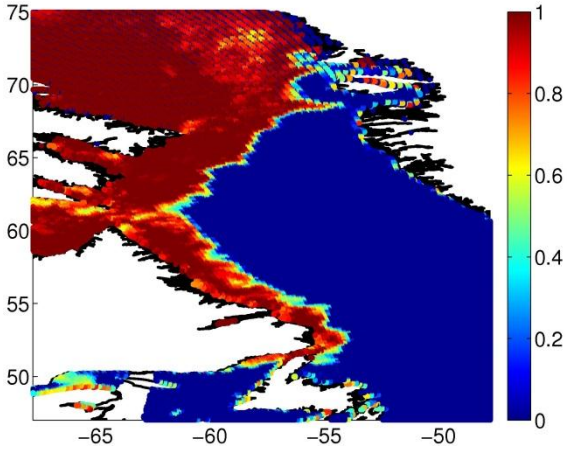
Step 1: Generation



Swath data (MODIS)



Ice concentration (IC) from AMSR-E

$$T_s = 265 * IC + 274 * (1 - IC)$$

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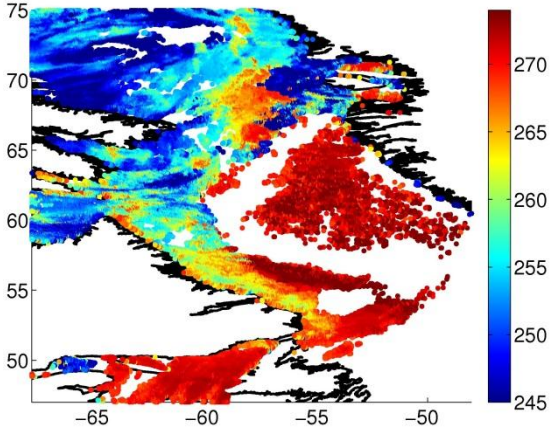
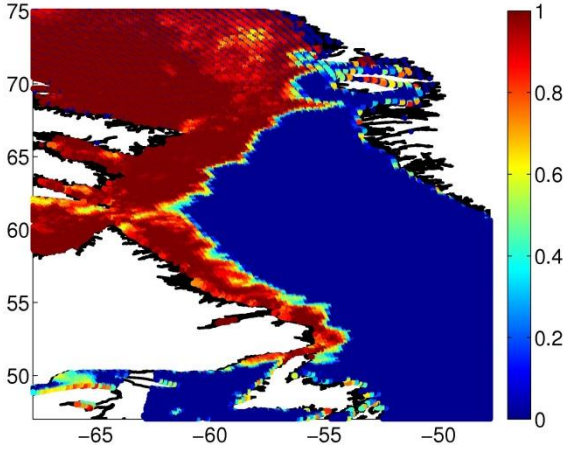
Step 1: Generation



Swath data (MODIS)



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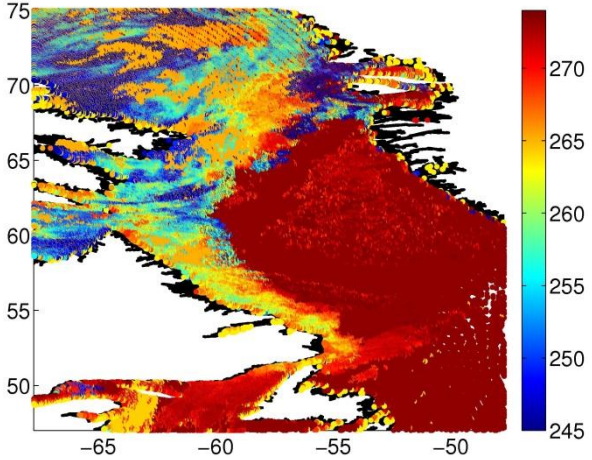

Complete temperature image

$$T_s = 265 * IC + 274 * (1 - IC)$$

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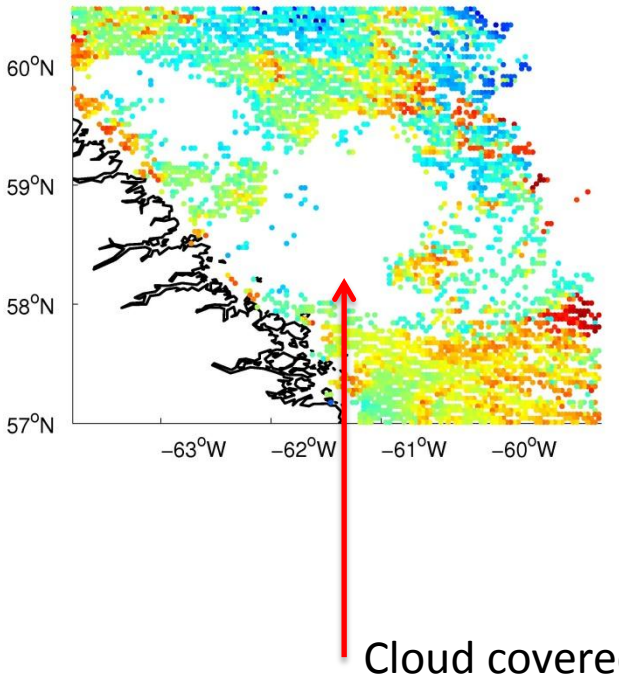
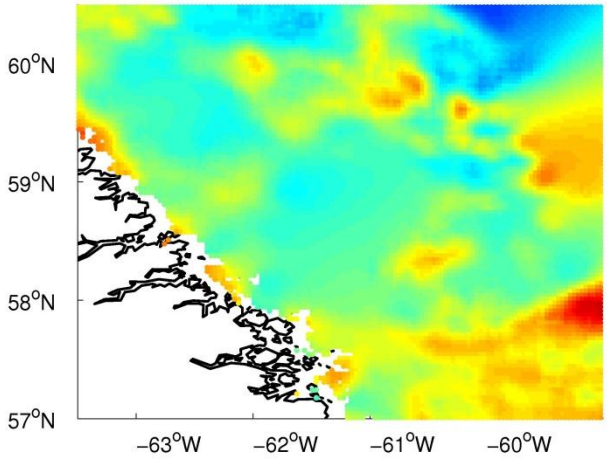
Example: Surface Temperature

MODIS Swath data

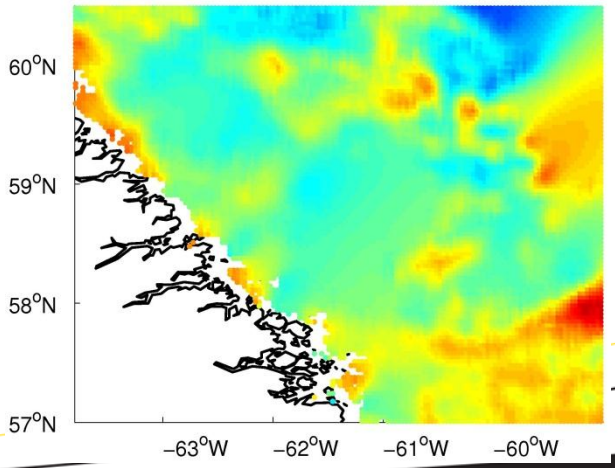


Cloud covered pixels!

TV (MODIS only)



MGV (MODIS+AMSR-E)



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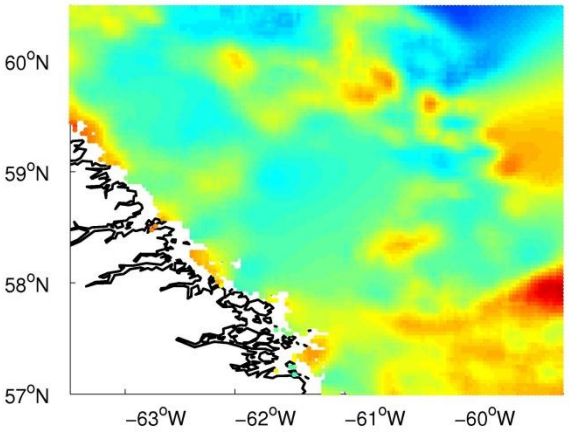
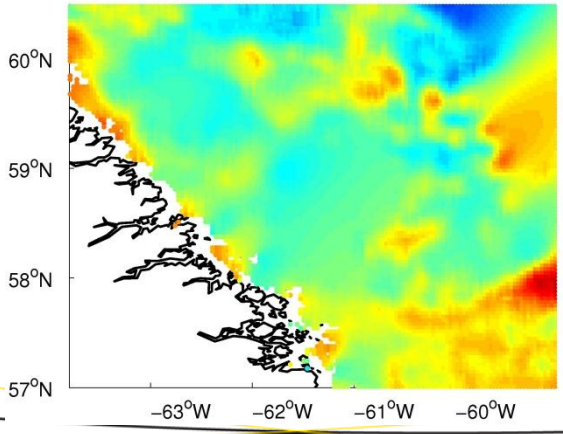
Example: Surface Temperature

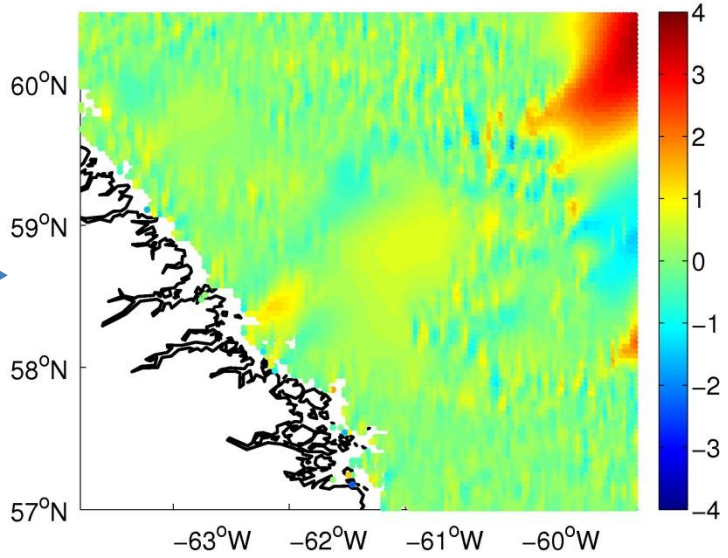
TV (MODIS only)



MGV (MODIS+AMSRE)



MGV − TV



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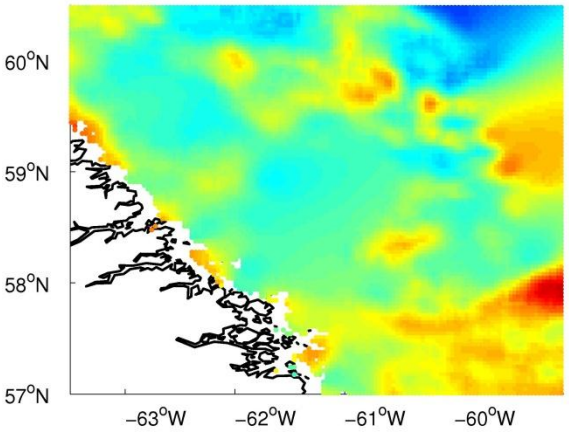
Example: Surface Temperature

TV (MODIS only)



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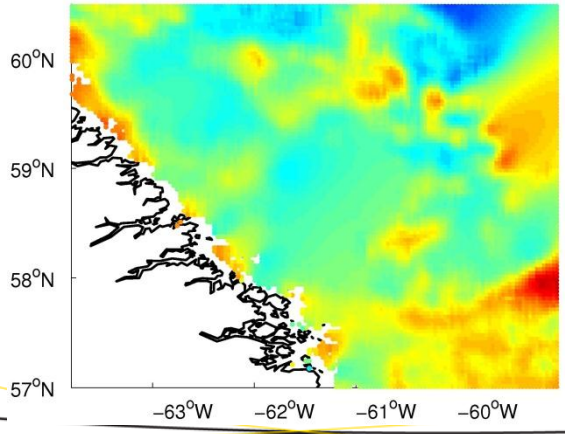
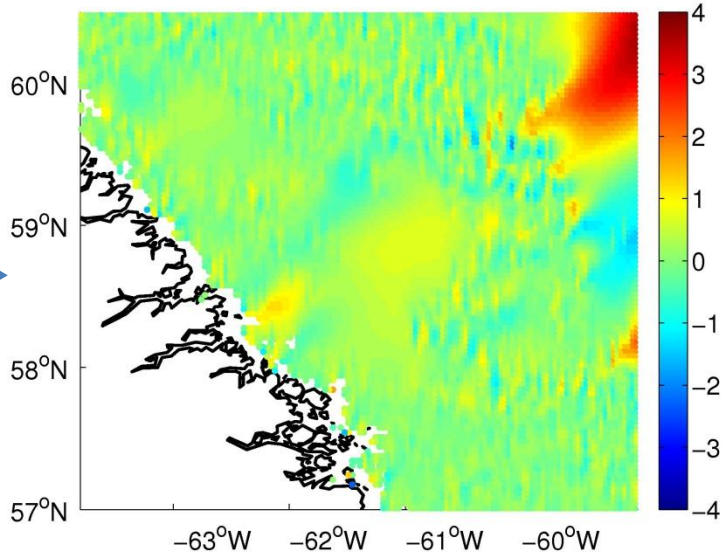


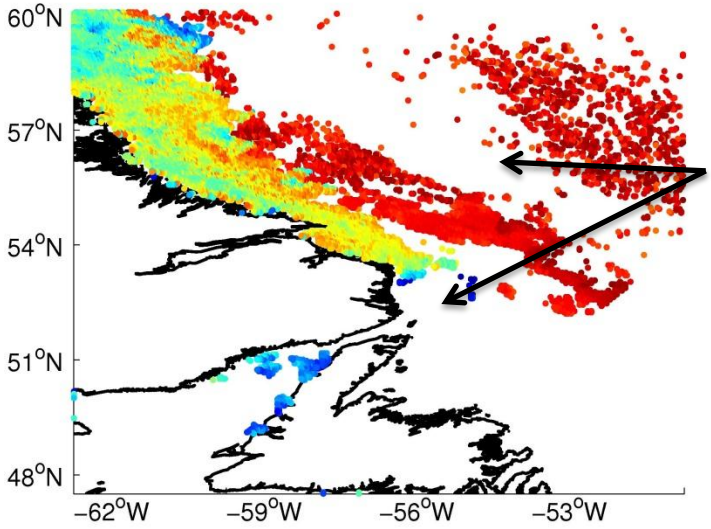
$2^\circ \approx 10cm$ [Wang et al. 2010]

MGV − TV



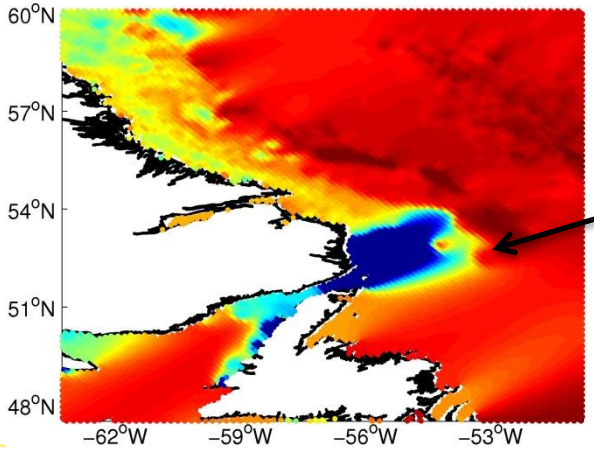
Example: Surface Temperature

Swath data



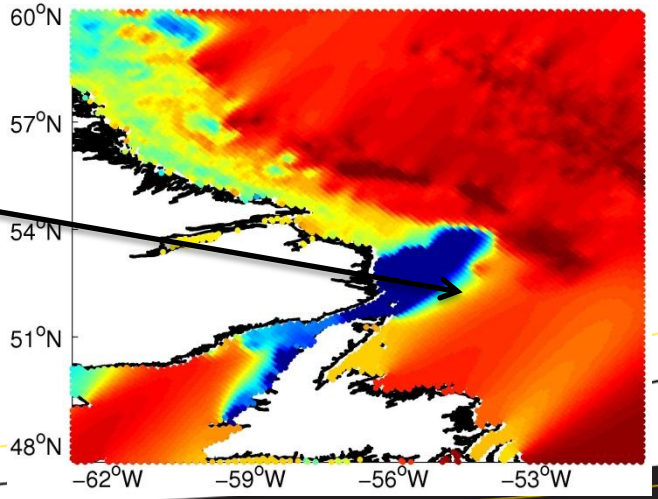
Cloud covered pixels!

TV (MODIS only)



MGV more realistic

MGV (MODIS+AMSR-E)



Step 2: Estimation

- Given surface temperature, solve heat balance equation:

$$F_{long}^{ß} - F_{long}^{Ý} + F_{sens} + F_{lat} + F_{c} = 0$$

Longwave radiation

Sensible heat flux
(ΔT air & ice)

Latent heat flux
(Δvapour over ice)

Conduction
(transfer through ice)

X.Wang, J.R. Key, and Y. Liu, "A thermodynamic model for estimating sea and lake ice thickness with optical satellite data," Journal of Geophysical Research, vol. 115, pp. C12035, 2010.

Step 2: Estimation

- Given surface temperature, solve heat balance equation:

$$F_{long}^{ß} - F_{long}^{Ý} + F_{sens} + F_{lat} + F_c = 0$$

- Most are functions of surface temperature ($\mathbf{z_0}$)
- $F_c = \frac{k(T_s - T_w)}{h}$, where is h ice thickness
  - Given surface temperature, solve for h!

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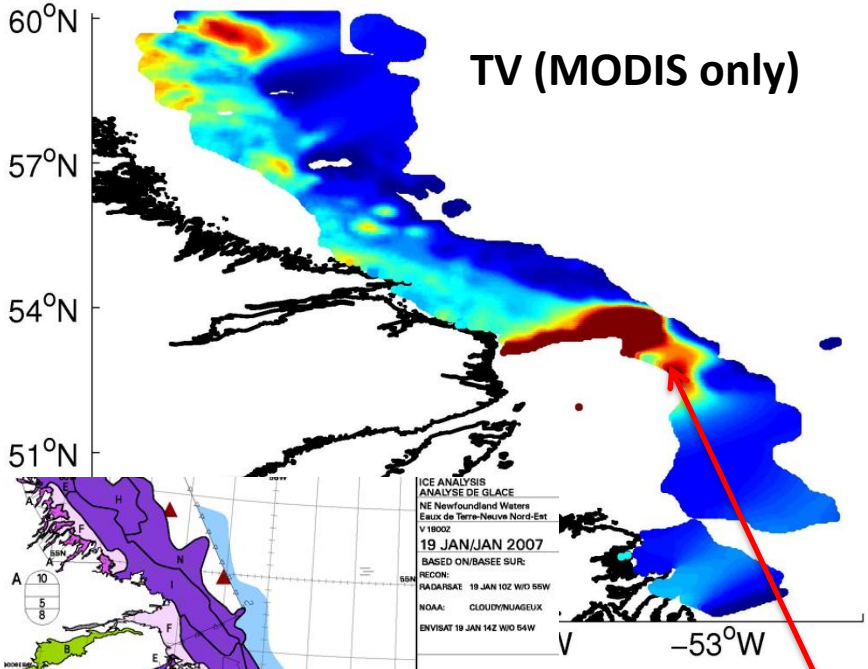
Results



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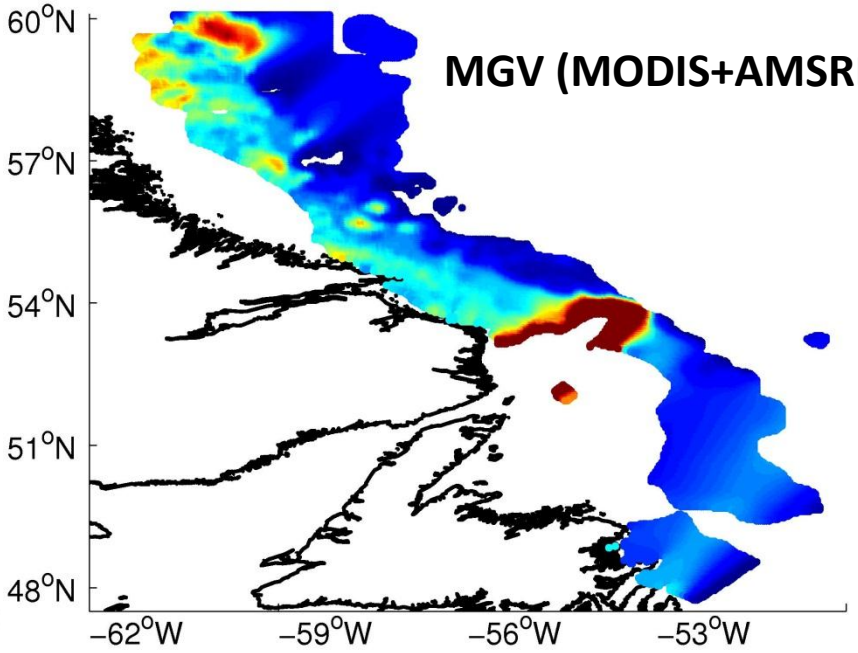
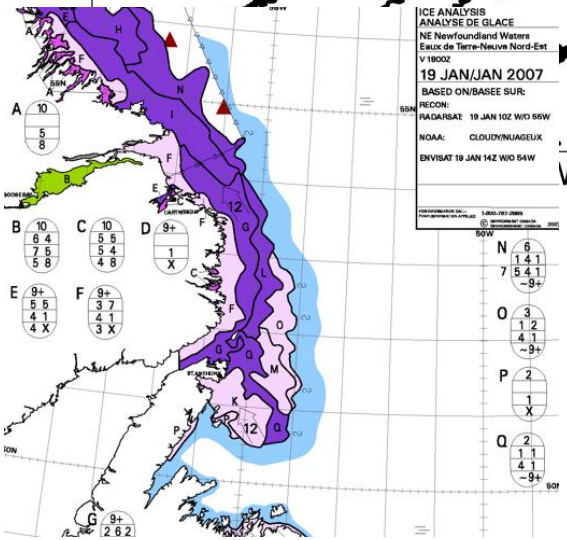


MGV (MODIS+AMSRE)



Ice thickness from ice chart

Cloud contaminated points lead to erroneously high values of sea ice thickness

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Comparison with Ice Charts

- Surface temperature and ice thickness calculated for each day from Jan 1 2007 – Feb 28 2007

	Absolute difference in [m]		
Ice chart Thickness (m)	**Swath data**	**MODIS TV**	**MODIS+AMSR-E MGV**
0-0.1	0.1274	0.1225	0.1198
0.1-0.15	0.0820	0.0764	0.0774
0.15-0.30	0.1019	0.1029	0.1029
> 0.30	0.2130	0.2115	0.2094
Number of points	5242	6753	6711

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Conclusions

- MGV produced realistic surface temperature estimates in regions with cloud cover.
- However, method can also spread the influence of a cloud contaminated pixels.
- MGV accuracy in cloud covered pixels attains base accuracy of visible pixels.

Future Work

- Limit the spread of information in a local region to avoid unrealistic results.
- Automatic parameter selection

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Acknowledgements

- Data Sources:
  - Ice charts provide by the Canadian Ice Service
  - MODIS data – MOD product NSIDC
  - AMSR-E brightness temperatures – NSIDC
  - AMSR-E sea ice concentration – NSIDC
- Funding provided by the National Science and Engineering Research Council of Canada

Download these slides!

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Thank You!

Comments/Questions/Feedback:

ramelard@uwaterloo.ca

http://vip.uwaterloo.ca

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Comparison with Ice Chart – QC

Ice chart Thickness (m)	Swath data	MODIS TVD	MODIS+AMSR-E MGV
0-0.1	0.0469	0.0456	0.0444
0.1-0.15	0.0622	0.0559	0.0558
0.15-0.30	0.0718	0.0710	0.0726
> 0.30	0.1248	0.1248	0.1232
Number of points	3119	4146	4086