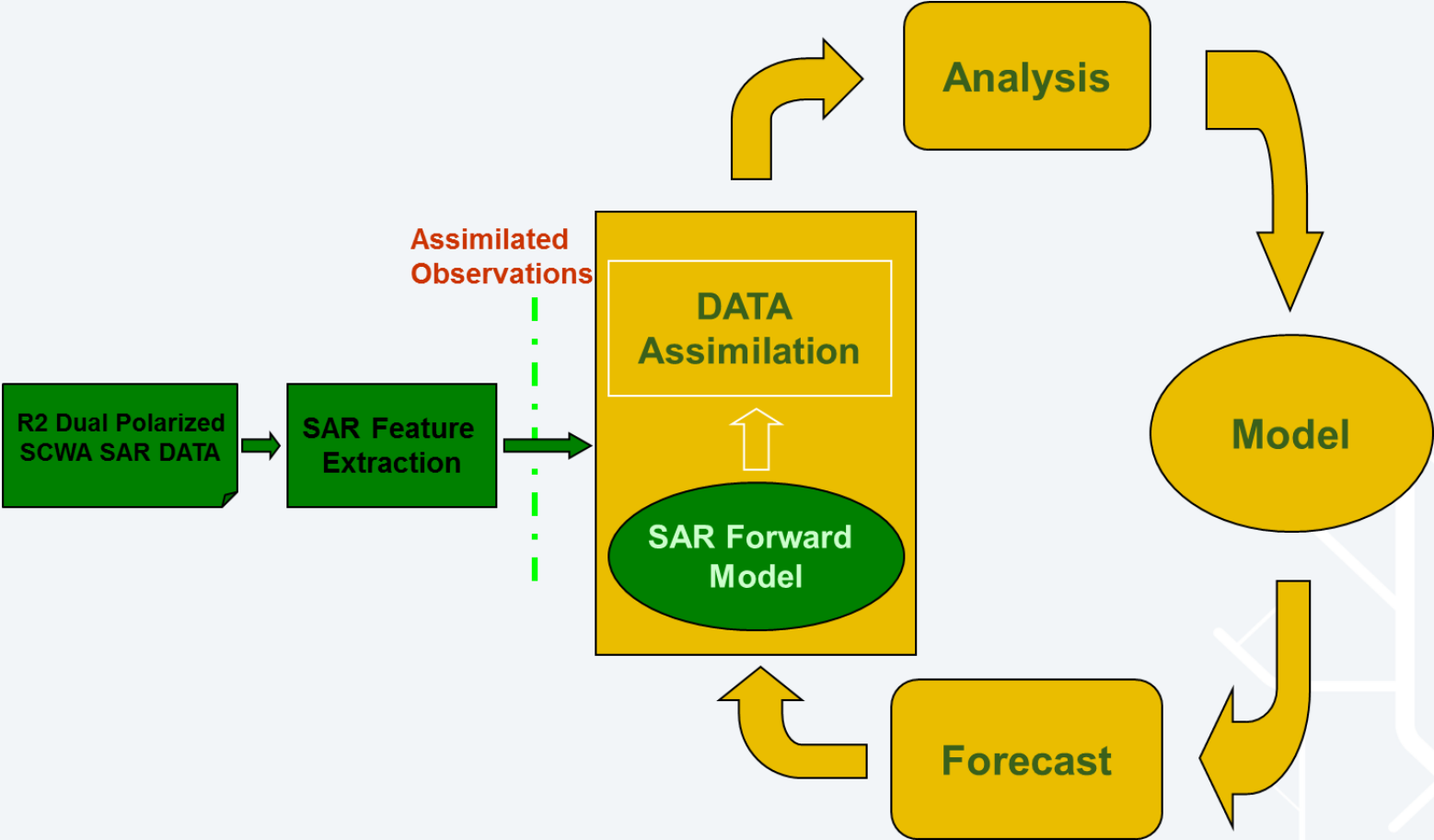




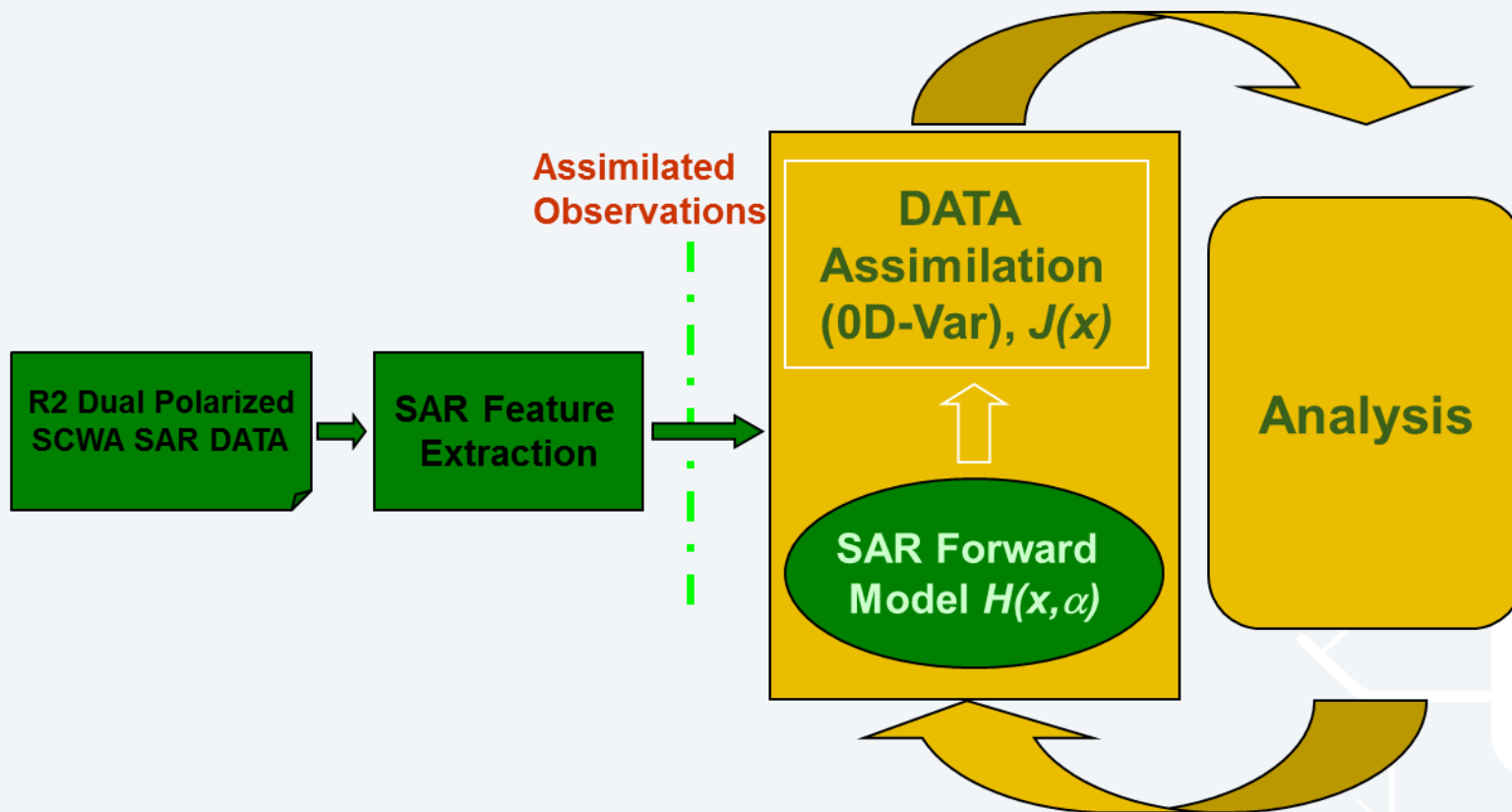
Sea Ice Concentration Retrievals by Using Composite ScanSAR Features in a SAR Data Assimilation Process

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SAR Data Assimilation



SAR Data Assimilation



Data Assimilation Formulation

$$J(x) = \frac{1}{2} \underbrace{(y - H(x, \alpha))^T R^{-1} (y - H(x, \alpha))}_{J_{\text{obs}}} + \frac{1}{2} \underbrace{(x - x^b)^T B^{-1} (x - x^b)}_{J_b}$$

- y : the observed SAR features
- H : the forward model, $H(x, \alpha)$ is the predicted SAR feature
- x : ice concentration
- α : incidence angle
- R : observation error covariance matrix
- B : background error covariance matrix



RadarSAT-2 ScanSAR data

- RadarSAT-2 SCWA Dual-polarized data
 - C Band, 5.6 GHz
 - HH and HV channels
 - 500 km swath width
 - 100 m pixel spacing

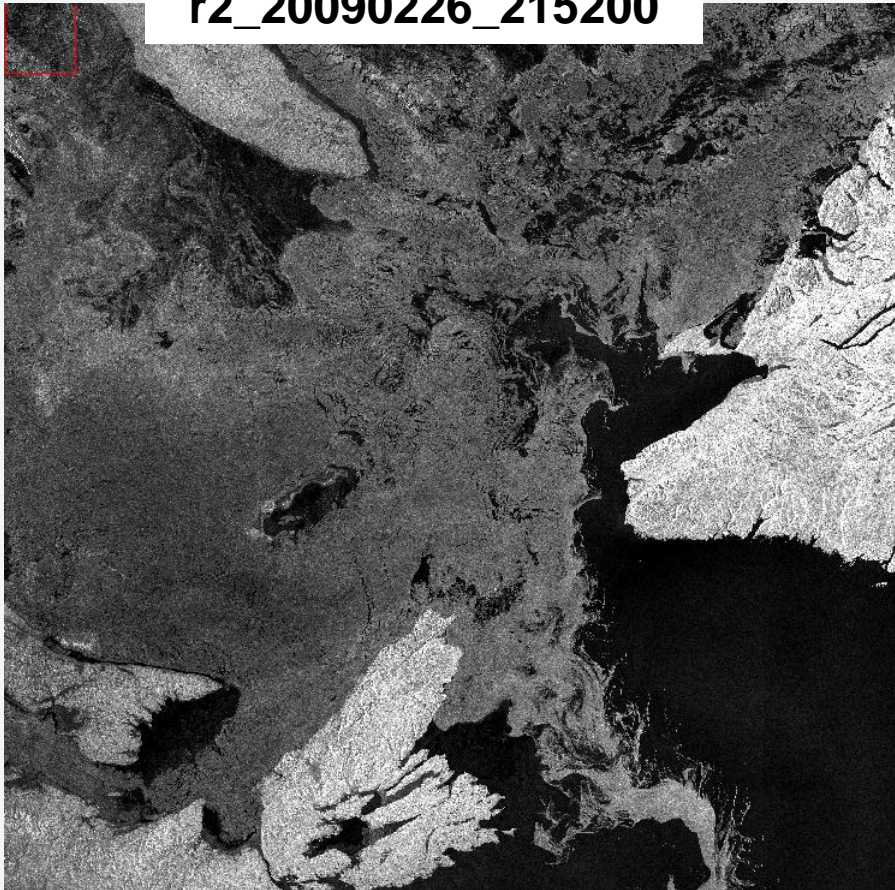


SAR Features

- RadarSAT-2 SCWA SGF Product – HH channel



r2_20090226_215200



r2_20090301_220402



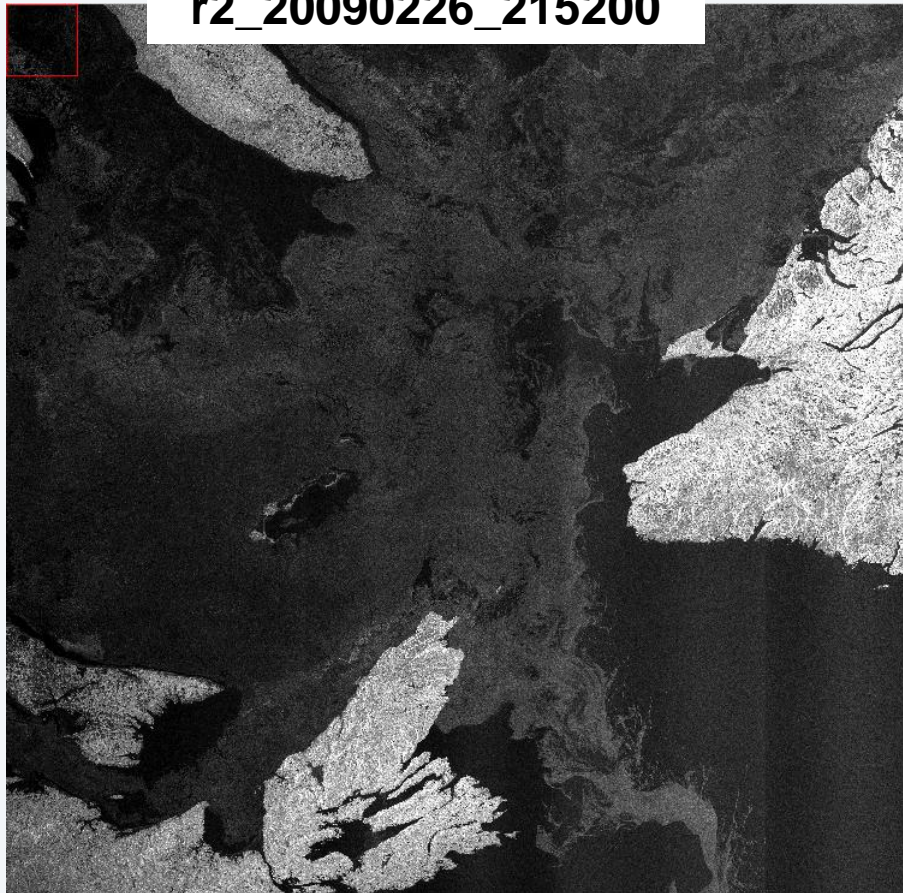
RadarSAT-2 Data and Products © MacDonald, Dettwiler and Associates Ltd. (2009) - All Rights Reserved.

SAR Features

- RadarSAT-2 SCWA SGF Product – HV channel



r2_20090226_215200



r2_20090301_220402



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SAR Features

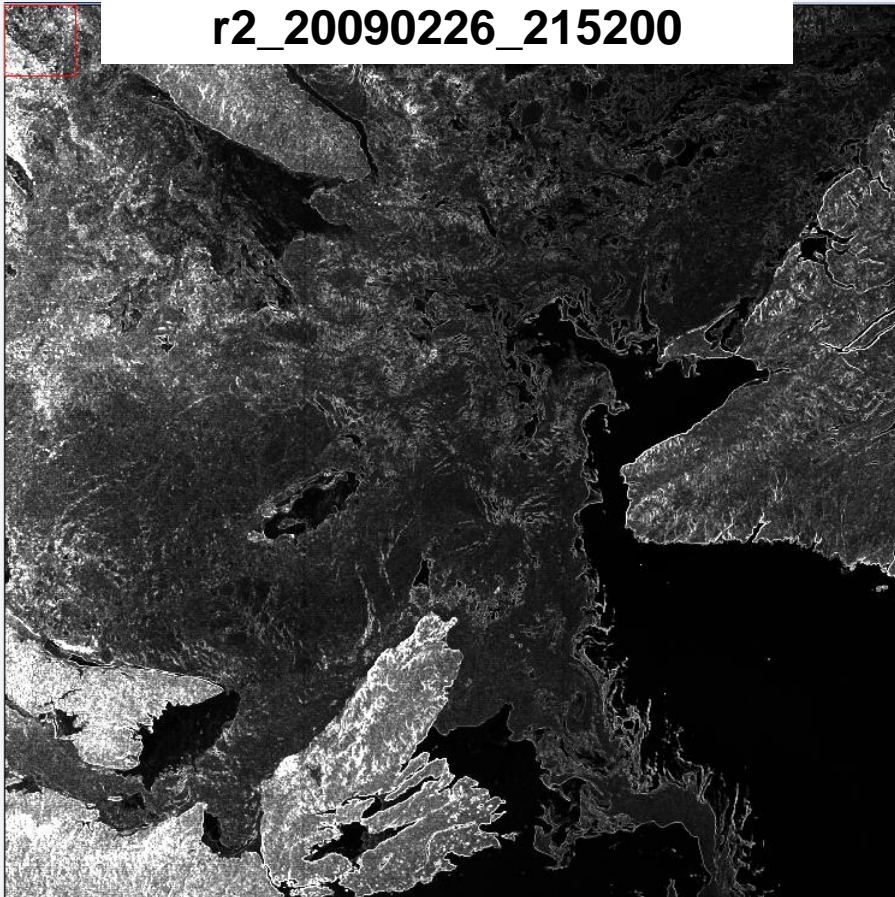
F. ID	SAR Texture	Polarization	Description	
0	Amplitude Sigma Nought	HH	Sigma Nought	
1			Lee Filtered Image	
2			Mean	
3			Variance	
4			Homogeneity	
5			Contrast	
6			Dissimilarity	
7			Entropy	
8			Second Moment	
9			Correlation	
10			Data-Range	
11		Mean Euclidean Distance		
12		HV	HV	Sigma Nought
13				Lee Filtered Image
14				Mean
15				Variance
16				Homogeneity
17				Contrast
18				Dissimilarity
19				Entropy
20				Second Moment
21				Correlation
22				Data-Range
23	Mean Euclidean Distance			
24	Sigma Nought Power	Combination of Polarizations	HH/HV	
25		HH-HV		
26	Sigma Nought Power (dB)	HH	Sigma Nought	
27		HV	Sigma Nought	
28	Sigma Nought Power (dB)	HH	Sigma Nought (dB)	
29		HV	Sigma Nought (dB)	



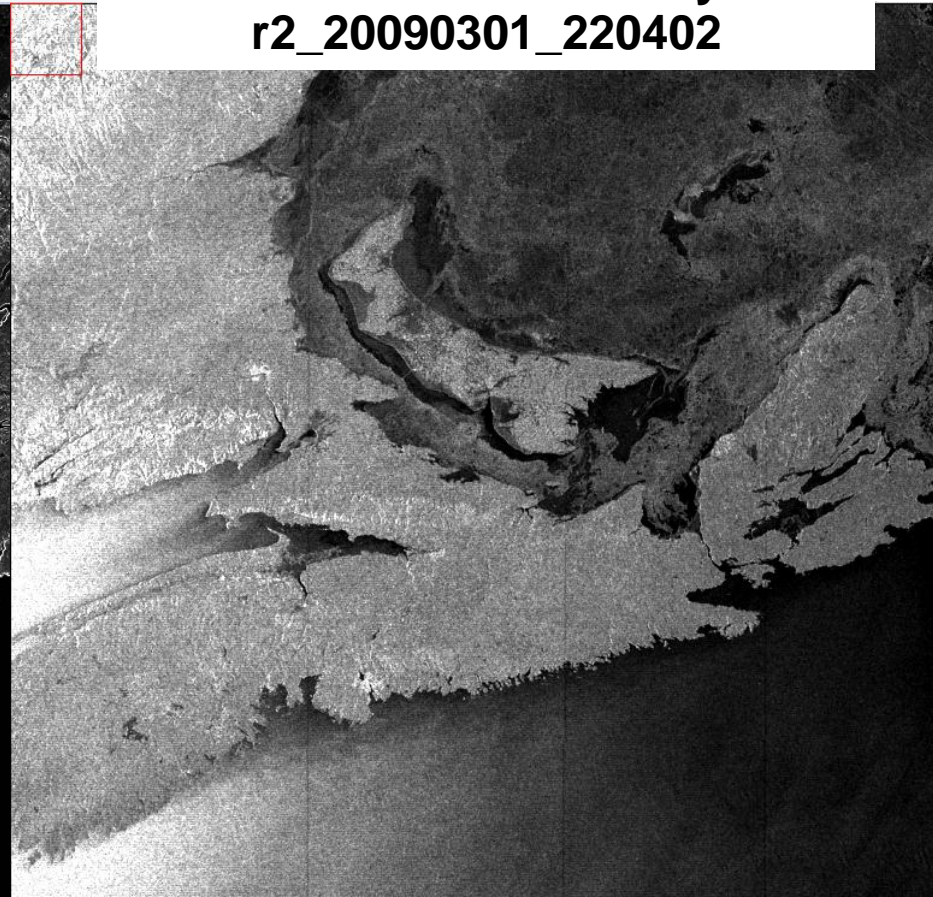
SAR Features

- Texture Feature Examples

Observed HH-Variance from
r2_20090226_215200



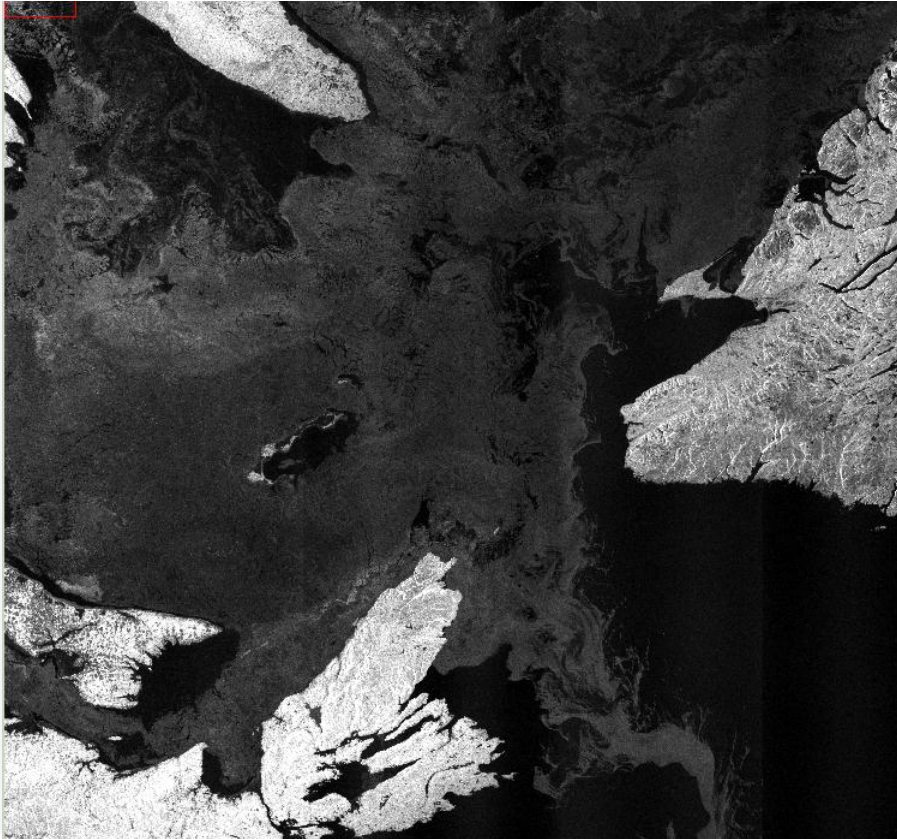
Observed HH-Dissimilarity from
r2_20090301_220402



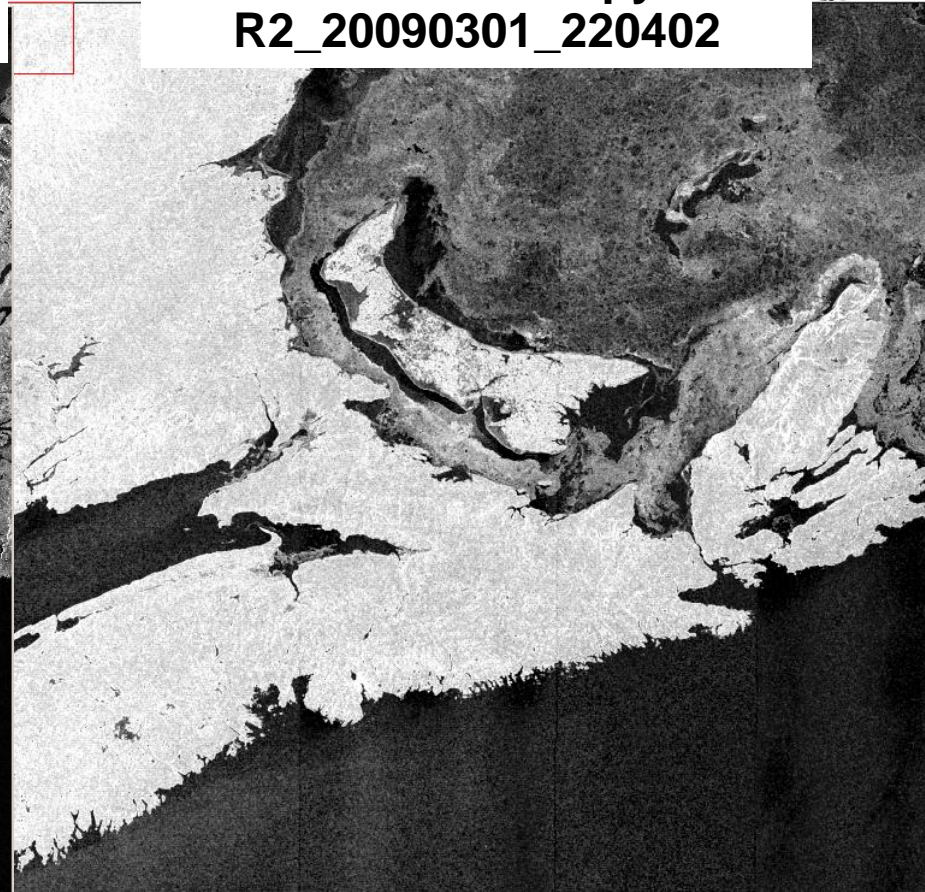
SAR Features

- Texture Feature Examples

Observed HV-Lee Filtered Image from
R2_20090226_215200



Observed HV-Entropy from
R2_20090301_220402



Forward Model



$$\text{SAR feature} = IC \cdot \{a_9 \alpha + a_8 ITh + a_7 ITh \cdot \alpha + a_6 SD + a_5 SAT + a_4 SD \cdot SAT\} + (1 - IC) \cdot \{a_3 WS \cdot \alpha \cdot \cos 2\phi\} + a_2 IC + a_1 \alpha + a_0$$

ITh = ice thickness (from CIS image analysis chart)

IC = ice concentration (from CIS image analysis chart)

α = incidence angle (know)

SAT = surface air temperature (from GEM)

SD = snow depth (from GEM)

WS = wind speed (from GEM)

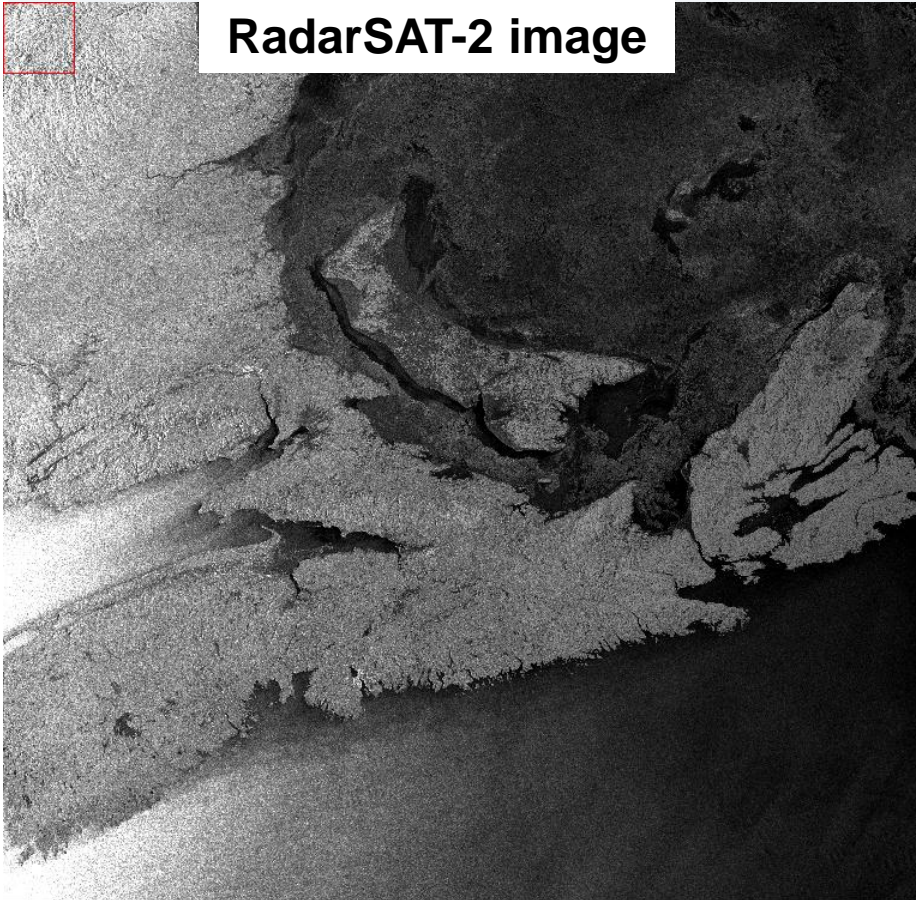
ϕ = angle between instrument angle (know) and wind direction (from GEM)

α_i = “optimal” model coefficients estimated from “training data”

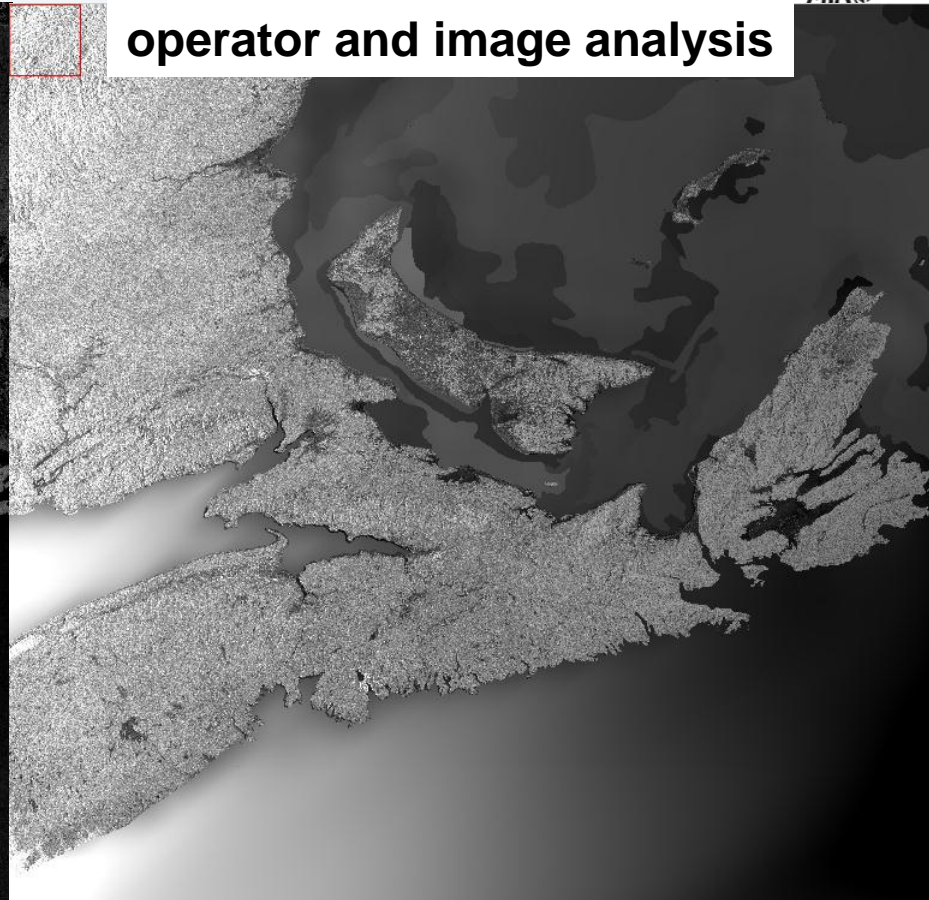
Simulated SAR Features

- r2_20090301_220402

Observed HH from
RadarSAT-2 image



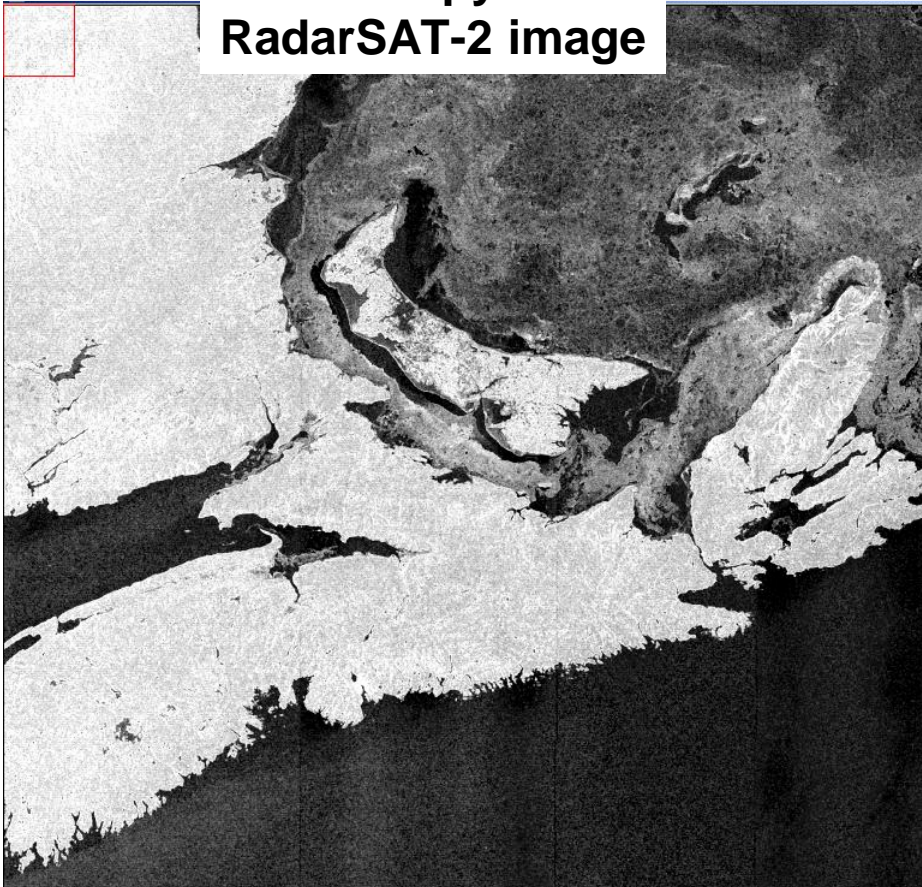
Predicted HH from obs
operator and image analysis



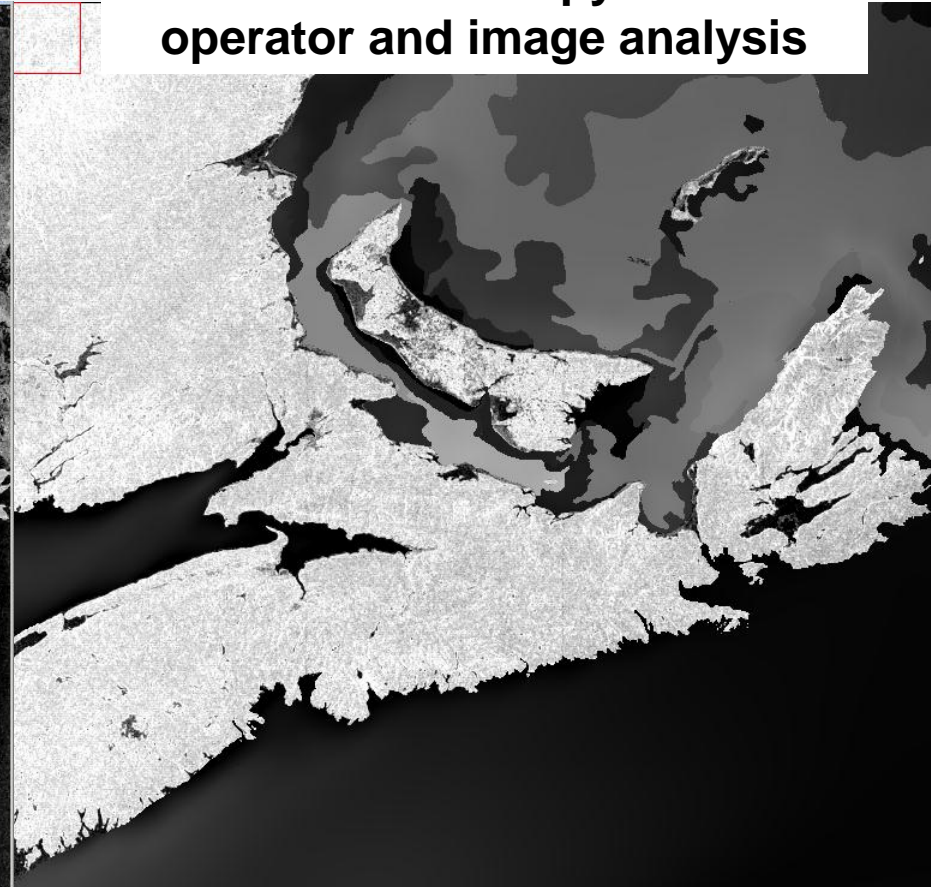
Simulated SAR Features

- r2_20090301_220402

HV-Entropy from
RadarSAT-2 image

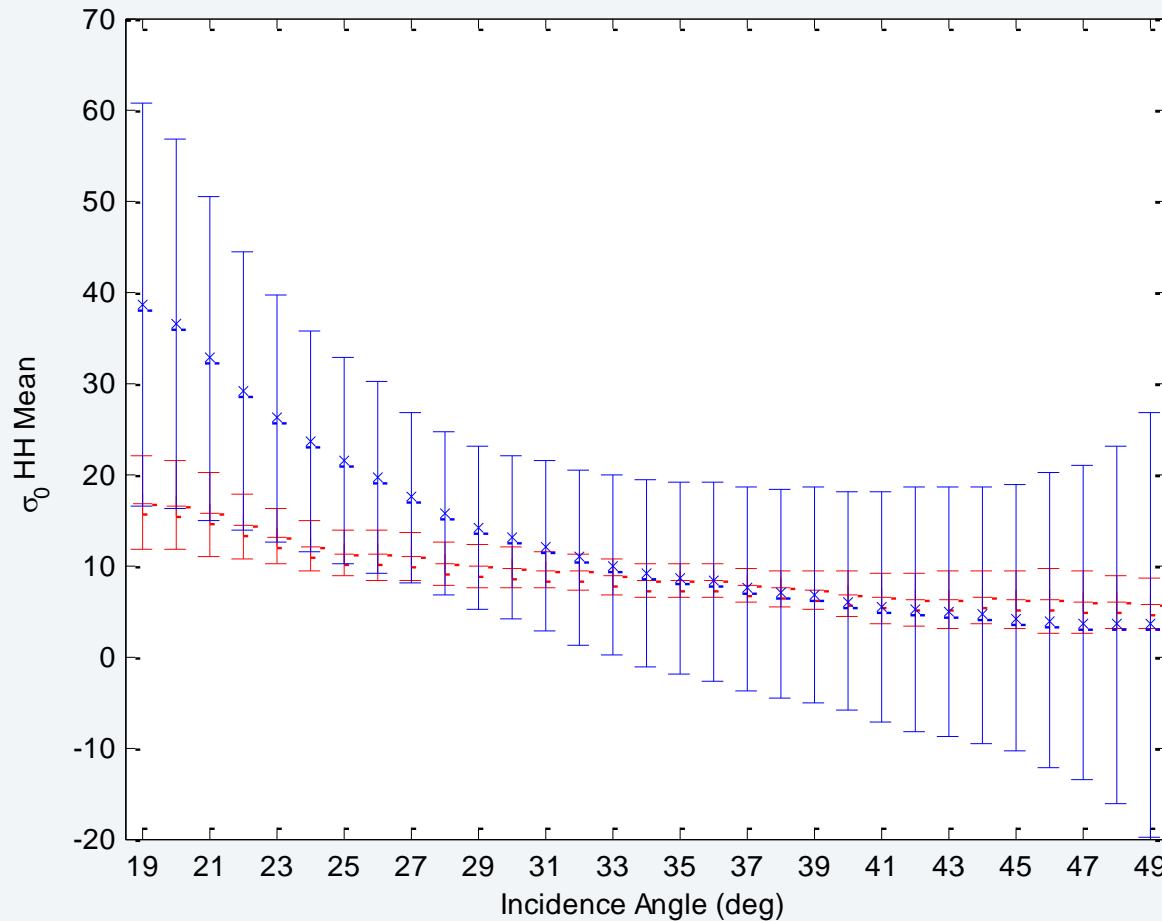


Predicted HV-Entropy from obs
operator and image analysis



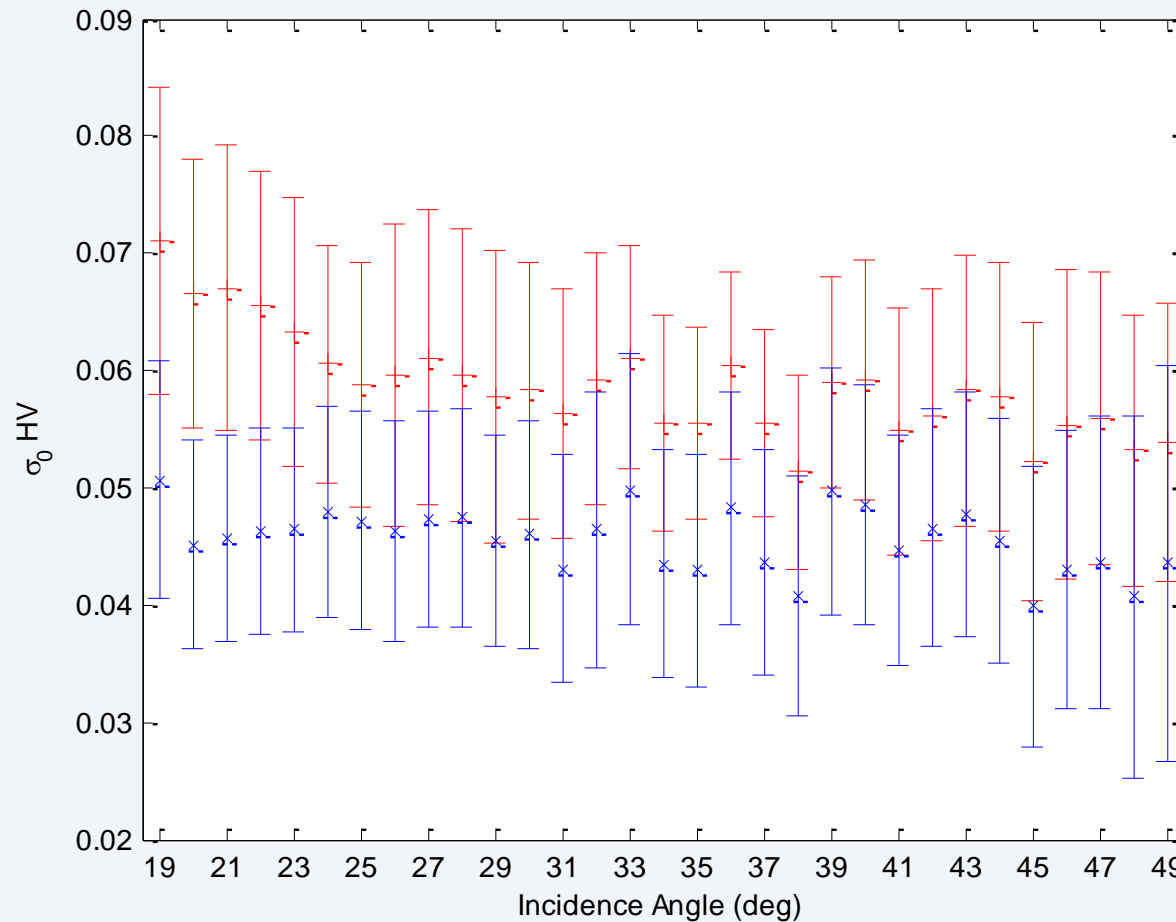
Sea-Ice Open Water Discrimination

Mean and Standard deviation of SAR feature (σ_0 HH Mean) for **Sea ice (Red)** with $IC > 95\%$ and **Open Water (Blue)** versus incidence Angle



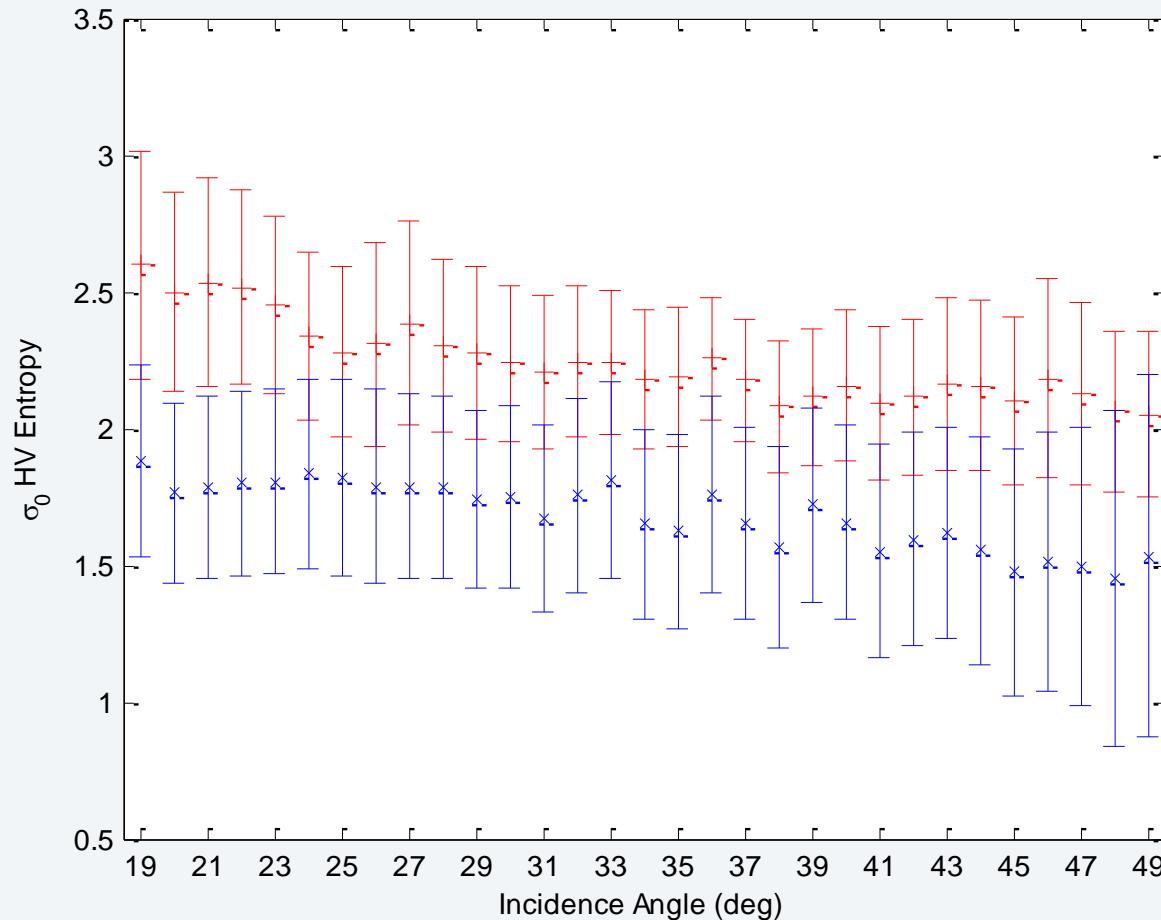
Sea-Ice Open Water Discrimination

Mean and Standard deviation of SAR feature (σ_0 HV) for **Sea ice (Red)** with $IC > \%95$ and **Open Water (Blue)** versus incidence Angle



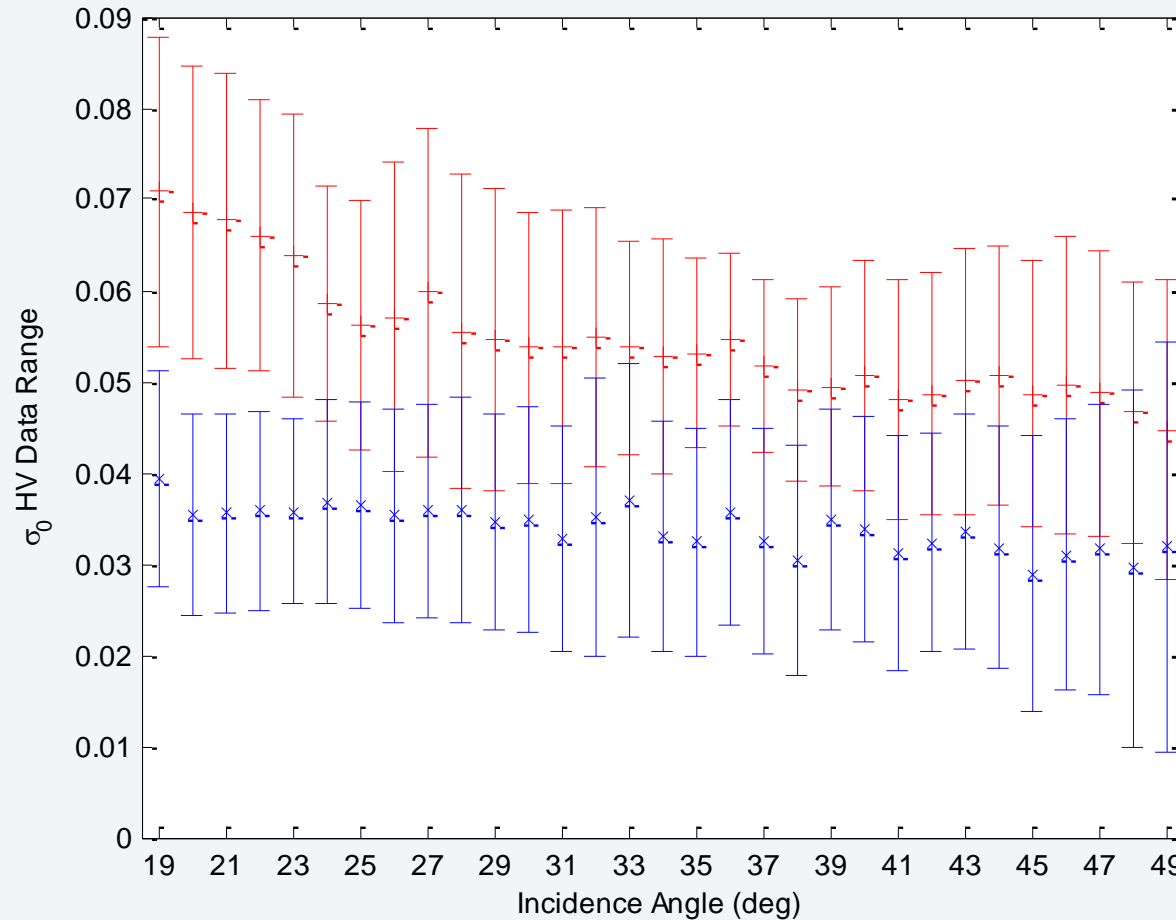
Sea-Ice Open Water Discrimination

Mean and Standard deviation of SAR feature (σ_0 HV Entropy) for **Sea ice (Red)** with IC>%95 and **Open Water (Blue)** versus incidence Angle



Sea-Ice Open Water Discrimination

Mean and Standard deviation of SAR feature (σ_0 HV Data Range) for **Sea ice (Red)** with $IC > \%95$ and **Open Water (Blue)** versus incidence Angle



Simple Forward Model

$$H(IC, \alpha_o) = SAR_{feature} = tp_{ice}(\alpha_o) \cdot IC + tp_{ow}(\alpha_o) \cdot (1 - IC)$$

H : Observation operator (forward model operator)

IC : Ice Concentration

α_i : Incidence Angle

$\alpha_o = \text{floor}(\alpha_i)$

α_o : Rounded Incidence Angle

$\alpha_o = 19, 20, \dots, 49$ for SCWA

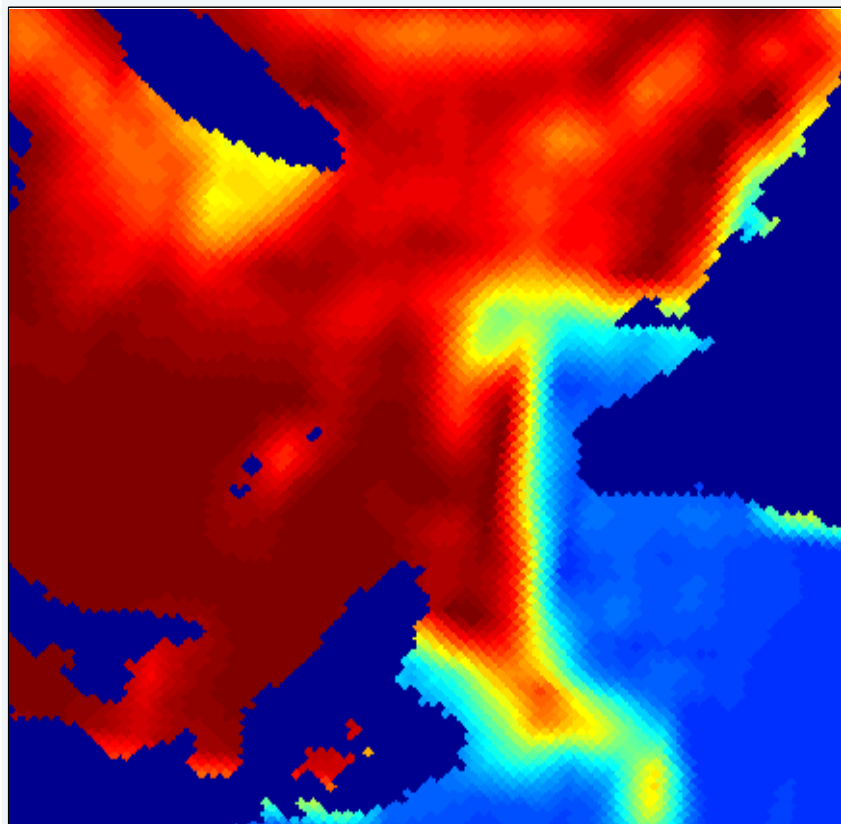
Number of Incidence Angle quantization level: 31



0D-Var Analysis Results

F_ID: 3_4_7_8_9_11_13_23

X_b : Background State; PM data only



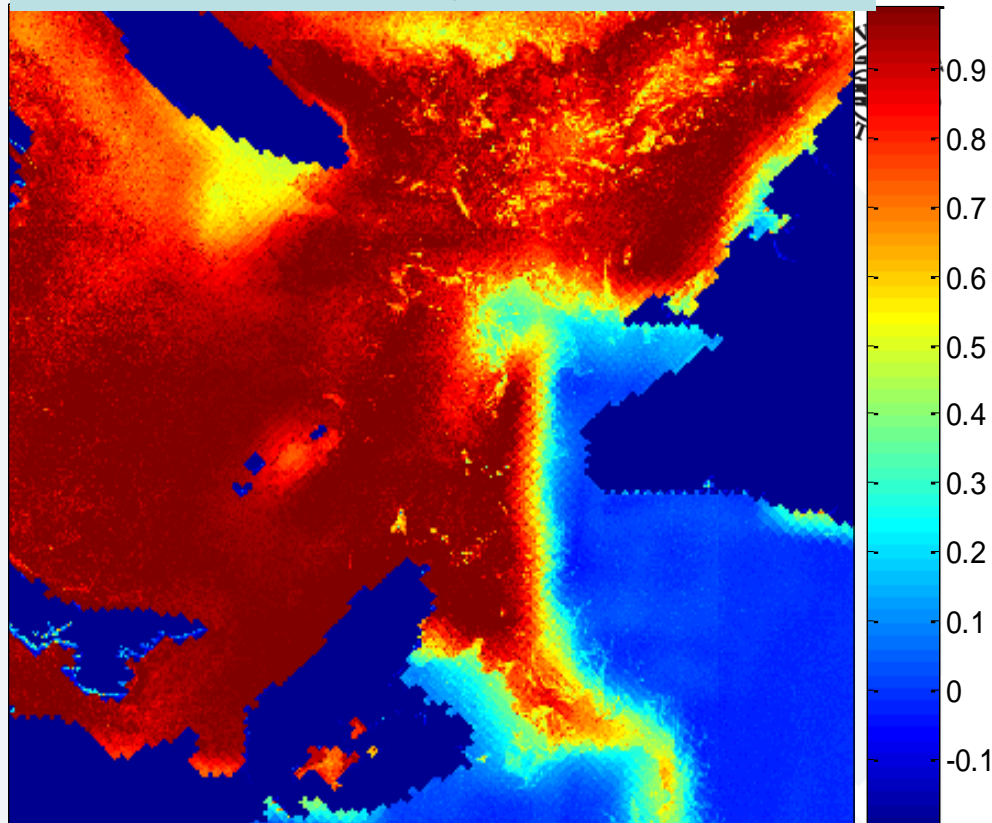
Background_Bias

-0.0744

Background_Std

0.199

$X_a = X_b + \Delta x$
0D-Var Analysis Result



Analysis_Bias

-0.0667

Analysis_std

0.194

0D-Var Analysis Results

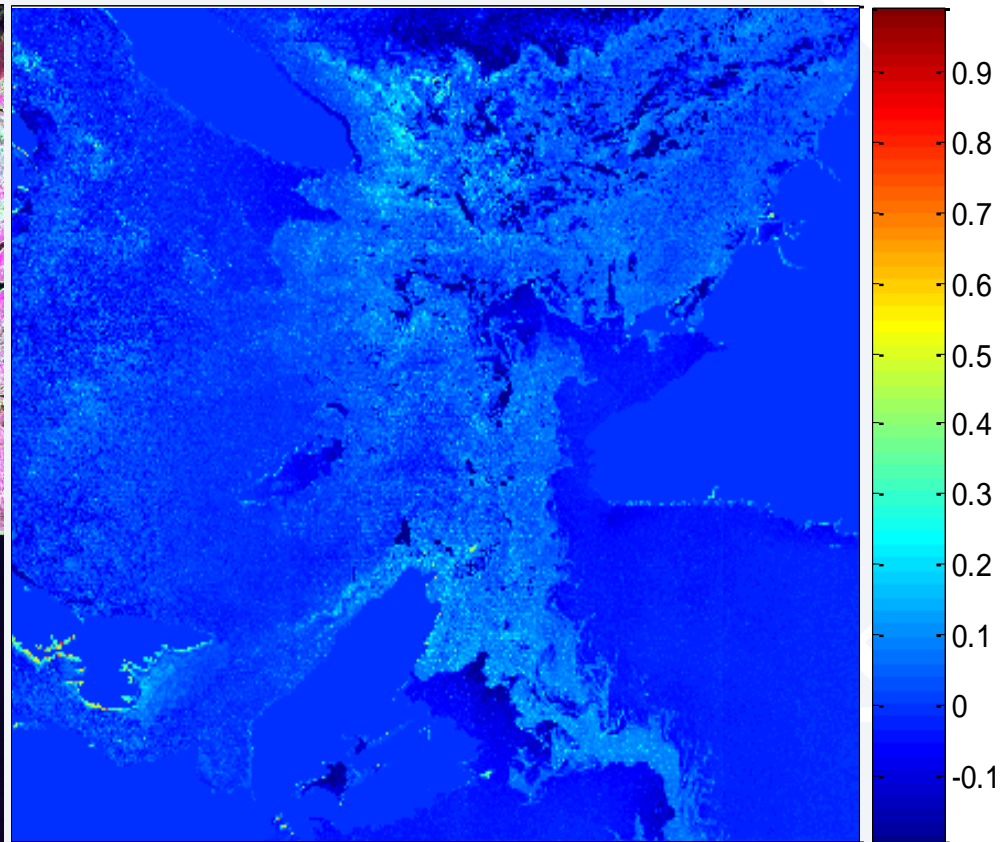
R: HH Lee-Filtered Image

G: HH Variance

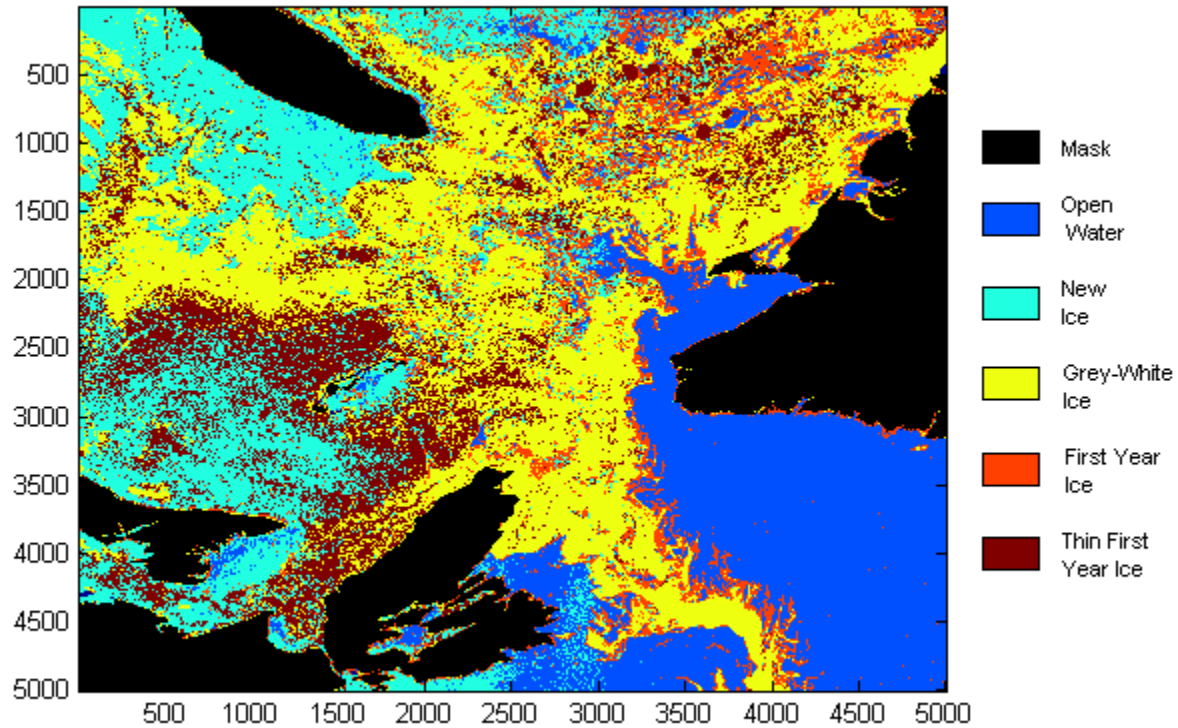
B: HV Mean

R2_20090226_215200

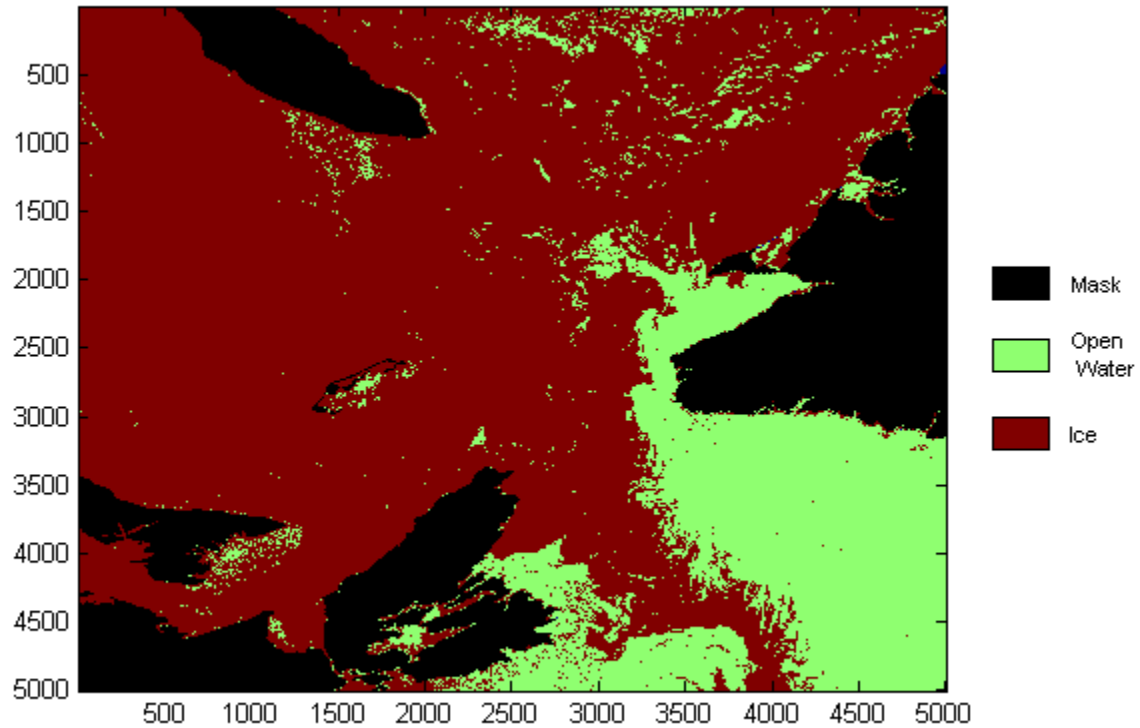
Analysis Increment: Δx



RBF-SVM, $c=5$

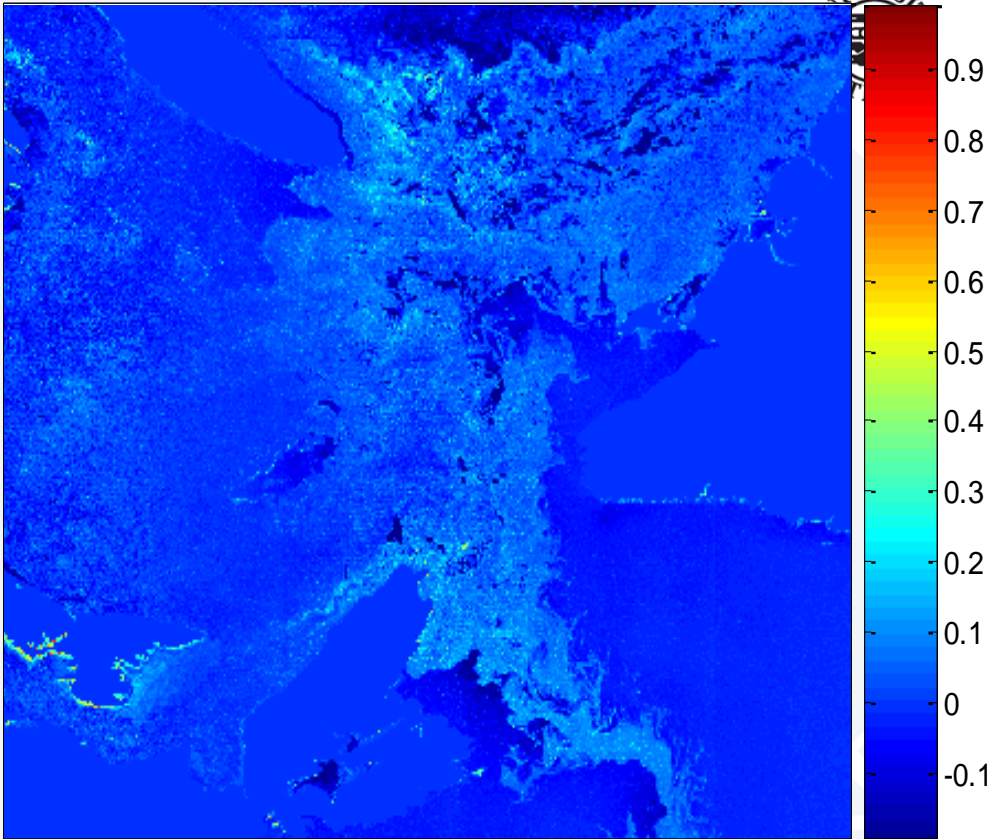
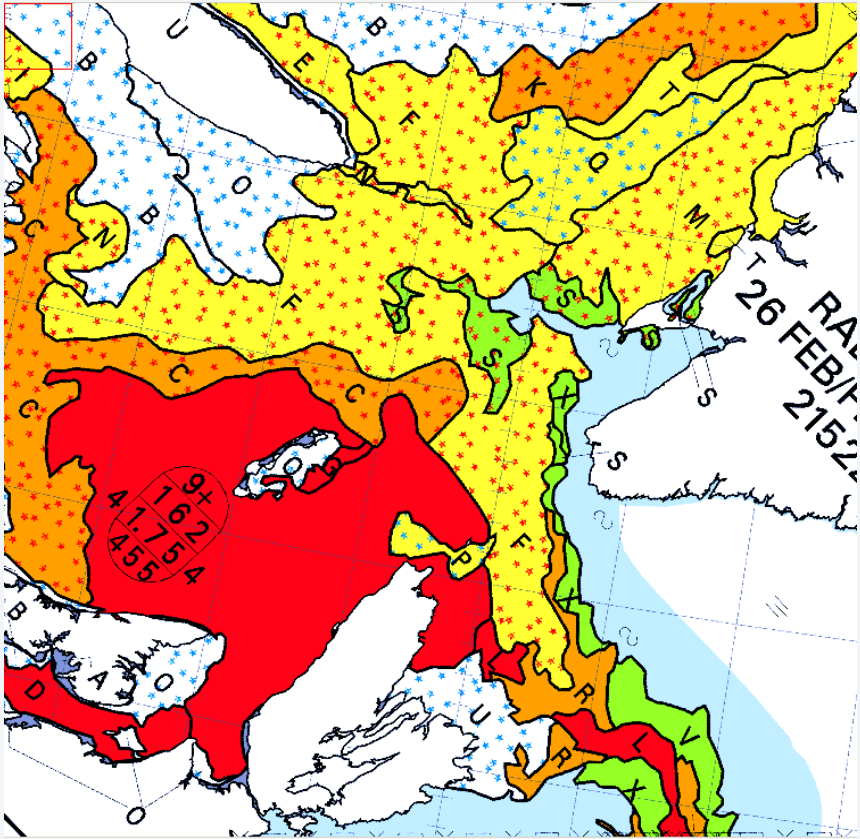


FLL, $c=2$



0D-Var Analysis Results

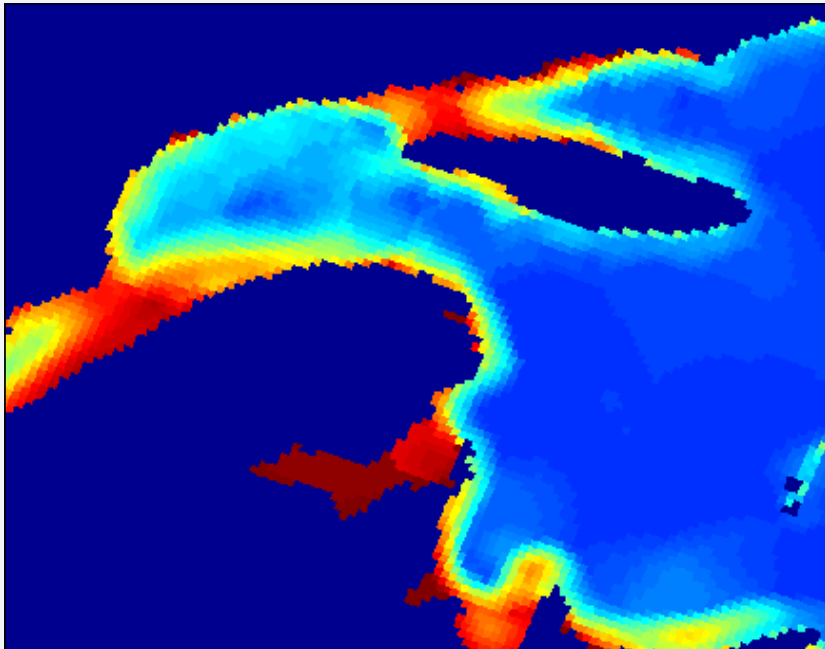
Analysis Increment: Δx



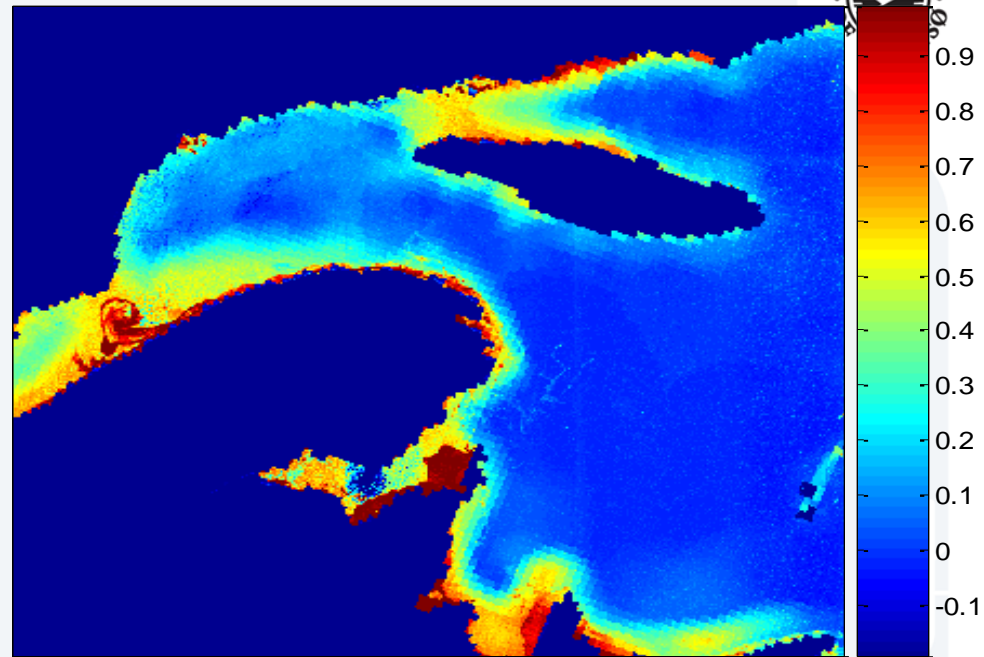
0D-Var Analysis Results

R2_20100221_103028

X_b : Background State; PM data only



$$X_a = X_b + \Delta x$$



Background_Bias

0.1471

Background_Std

0.3057

Analysis_Bias

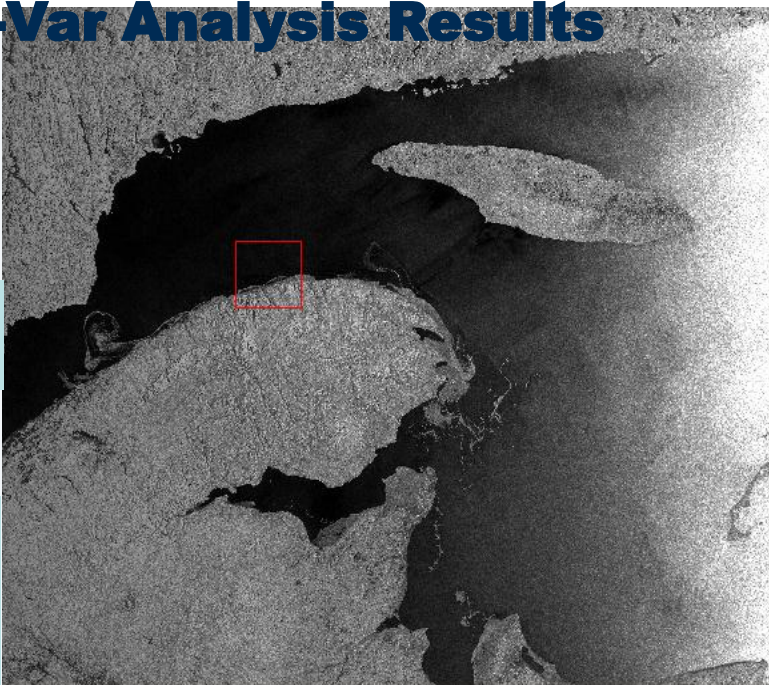
0.0889

Analysis_std

0.2645

OD-Var Analysis Results

HH

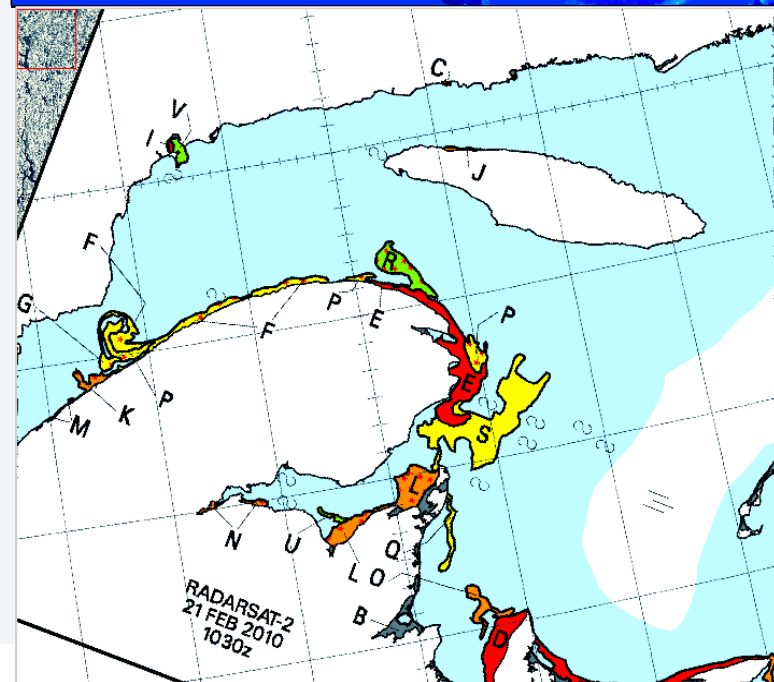
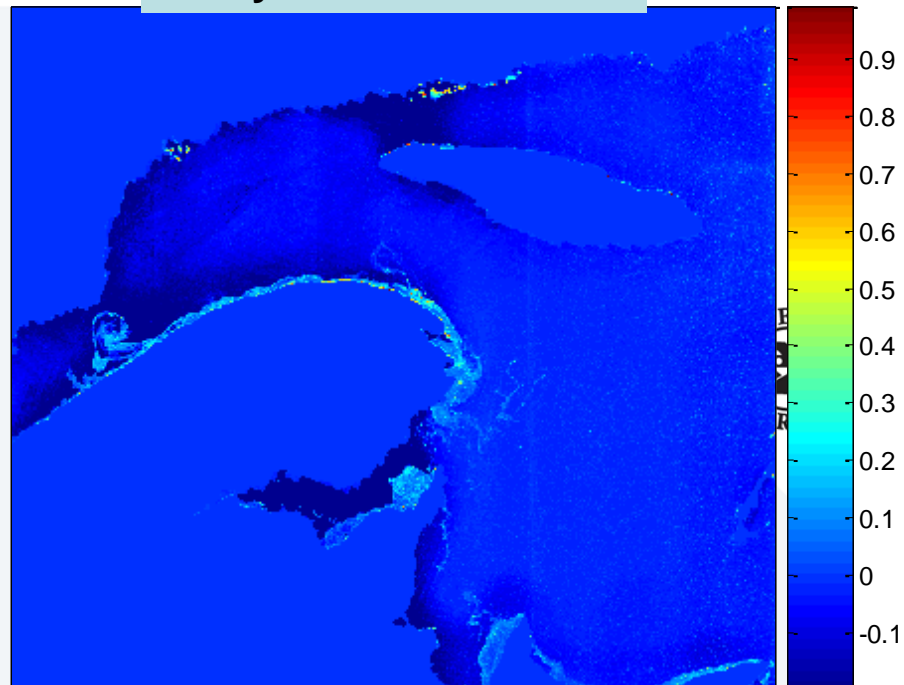


R2_20100221_103028

HV



Analysis Increment: Δx



OD-Var Analysis Results



SAR and Passive Microwave Data Analysis Fusion			
Data	Criterion	Bias	Standard Deviation
R2_20090226_215200	Background State	-0.0744	0.1986
	Analysis	-0.0609	0.1934
R2_20090301_220402	Background State	-0.0308	0.1534
	Analysis	-0.0033	0.1552
R2_20090301_220517	Background State	-0.1185	0.2352
	Analysis	-0.0857	0.2046
R2_20100221_103028	Background State	-0.1471	0.3057
	Analysis	-0.0889	0.2645

Separability Measures and Discrimination Analysis



$$S_w(k) = \sum_{i=1}^k \sum_{x \in C_i} (x - \mu_i)(x - \mu_i)^T \quad S_B(k) = \sum_{i=1}^k n_i (\mu_i - \mu)(\mu_i - \mu)^T$$

$$\Rightarrow d_1 = \text{tr}(S_w S_b)^{-1} \quad \Rightarrow d_2 = \frac{\text{tr}(S_b)}{\text{tr}(S_w)}$$

$$\Rightarrow d_3 = d_{ij} = \frac{1}{2} \text{Tr} \left\{ (\Sigma_i - \Sigma_j) (\Sigma_j^{-1} - \Sigma_i^{-1}) \right\} + \frac{1}{2} \text{Tr} \left\{ (\Sigma_i^{-1} + \Sigma_j^{-1}) (m_i - m_j)(m_i - m_j)^T \right\}$$

$$\Rightarrow d_4 = d_{ij}^T = 2(1 - e^{-d_{ij}/8})$$

$$\Rightarrow BD = \frac{1}{8} (m_i - m_j)^T \left[\frac{\Sigma_i + \Sigma_j}{2} \right]^{-1} (m_i - m_j) + \frac{1}{2} \ln \left[\frac{\left| \frac{\Sigma_i + \Sigma_j}{2} \right|}{\sqrt{|\Sigma_i| |\Sigma_j|}} \right]$$

$$\Rightarrow JM = J_{ij} = 2(1 - e^{-BD})$$

SAR Feature Selection

F. ID	Pol.	Feature Description	Seperability Measure d_i	Analysis Bias
0	HH	Sigma nought	0.03985	-0.02602
1		Lee Filtered Image	0.04259	-0.02595
2		Mean	0.04298	-0.02588
3		Variance	0.00903	-0.02634
4		Homogeneity	0.00151	-0.02663
5		Contrast	0.03068	-0.02573
6		Dissimilarity	0.01053	-0.02608
7		Entropy	0.02460	-0.02690
8		Second Moment	0.03213	-0.02710
9		Correlation	0.00062	-0.02685
10		Data Range	0.00017	-0.02640
11		Mean Euclidean Dist.	0.07743	-0.02797
12	HV	Sigma nought	0.18698	-0.02693
13		Lee Filtered Image	0.28383	-0.02720
14		Mean	0.15418	-0.02738
15		Variance	0.06867	-0.02651
16		Homogeneity	0.27563	-0.02782
17		Contrast	0.15037	-0.02682
18		Dissimilarity	0.26211	-0.02740
19		Entropy	0.39735	-0.02755
20		Second Moment	0.26033	-0.02734
21		Correlation	0.03721	-0.02683
22		Data Range	0.32366	-0.02661
23		Mean Euclidean Dis.	0.17128	-0.02662
24	-	HH/HV	0.02290	-0.02632
25	-	HH-HV	0.05640	-0.02584
26	HH	Sigma nought Pow.	0.04772	-0.02572
27	HV	Sigma nought Pow.	0.13750	-0.02665
28	HH	Sigma nought Pow. dB	0.02122	-0.02629
29	HV	Sigma nought Pow. dB	0.00616	0.34266

➤ Analysis Bias as a selection criteria



Best SAR feature combination selection

➤ Top-Down & Bottom-Up Strategies

➤ Feature Selection for Incidence Angle Intervals

Feature Selection for Incidence Angle Intervals

Incidence Angle Intervals	F ID	Selected SAR Feature
$19^\circ \leq \alpha < 28^\circ$	2	HH Mean
$28^\circ \leq \alpha < 35^\circ$	22	HV Data range
$35^\circ \leq \alpha < 42^\circ$	7	HH Entropy
$42^\circ \leq \alpha$	8	HH Second Moment

Dataset	Background Bias	Analysis Bias
r2_20090226_215200	-0.07439	-0.0738
r2_20090301_220402	-0.03076	-0.0179
r2_20090301_220517	-0.1185	-0.1154
r2_20090305_102559	-0.0764	-0.0663
r2_20090305_102713	-0.1274	-0.1072
r2_20100201_101317	-0.1029	-0.0990
r2_20100201_101431	-0.0306	-0.0303
r2_20100204_102550	-0.2261	-0.2230
r2_20100208_100900	0.05917	0.05681
r2_20100208_101015	-0.0127	-0.0109
r2_20100214_103447	0.1549	0.1367
r2_20100221_103028	0.1471	0.1247
r2_20100221_103142	0.0439	0.04387



Acknowledgements

- **Canadian Ice Service (CIS)**





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Thank you for your attention!

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