River ice mapping from TerraSAR-X images

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SAPHIR

Background

- Ice cover affects stream flow, modifies the ecosystem, causes flooding, restricts navigation, influences hydropower generation
- Frazil ice could cause jam and then flooding

Background

- Ice cover affects stream flow, modifies the ecosystem, causes flooding, restricts navigation, influences hydropower generation
- Frazil ice could cause jam and then flooding

Ice jam potential areas must be discriminated

Purpose

To develop a tool which allows the classification of different river ice types

1. Existing approaches

2. Study site and data

3. Results

4. Conclusion

Existing approaches

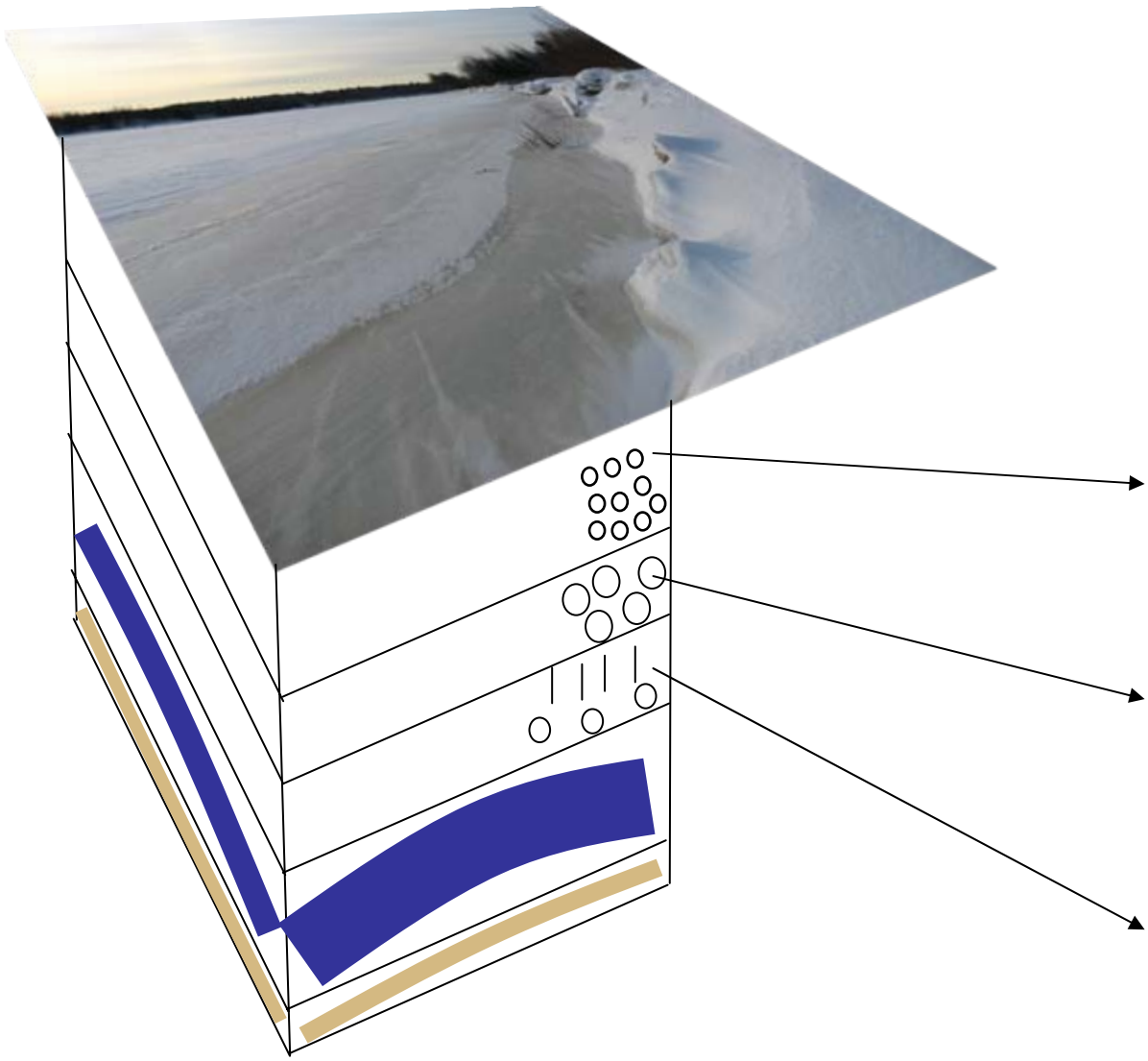
- Few studies based on **multi-polarized** and **multi-frequency** data *(Melloh and Gatto, 1990)*

- Polarization diversity & theoretical modeling significantly increase estimation accuracy *(Kwok et al, 1995; Nghiem and Bertoia, 2001)*

- **Sparse in-situ measurements** *(Weber et al, 2003)*

- Problems of **generalization** (adaptation to other test sites) *(Drouin, 2007)*

River ice types



Cons. ice

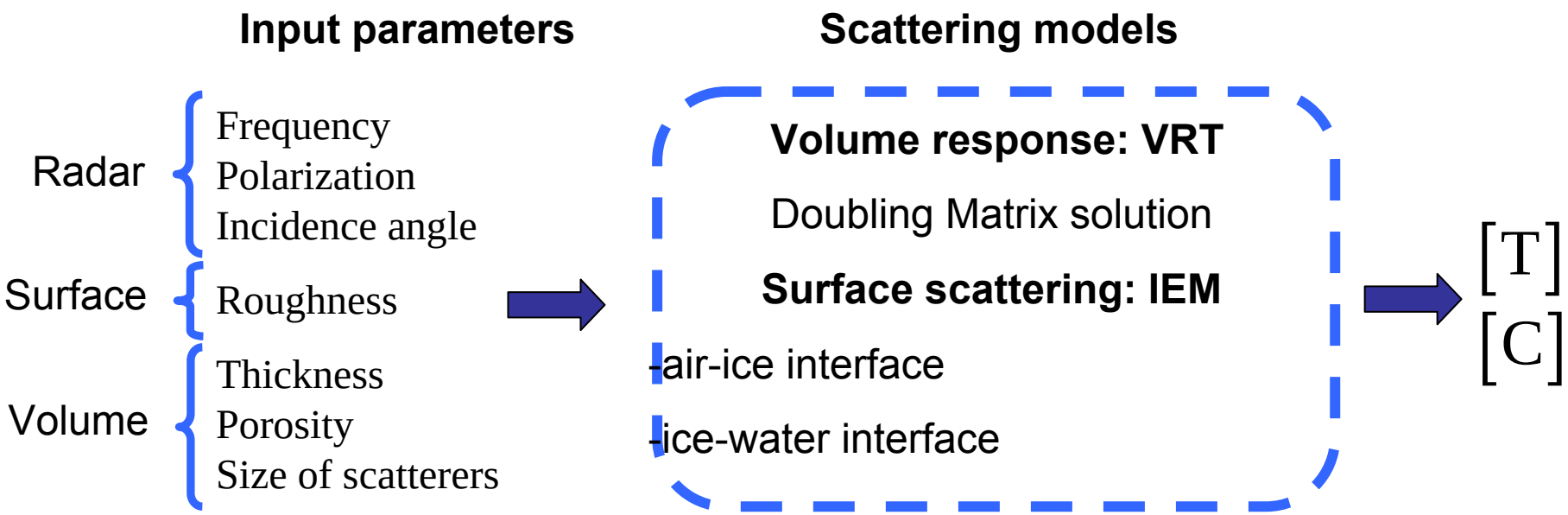
Snow ice

Frazil ice

Thermal ice

Electromagnetic model

- Based on the **radiative transfer** theory
- Inputs defined from laboratory ice core measurements
- Outputs: backscattering coefficients
- **Extension to the polarimetric case** → $[T]$ as output



1. Existing approaches

2. Study site and data

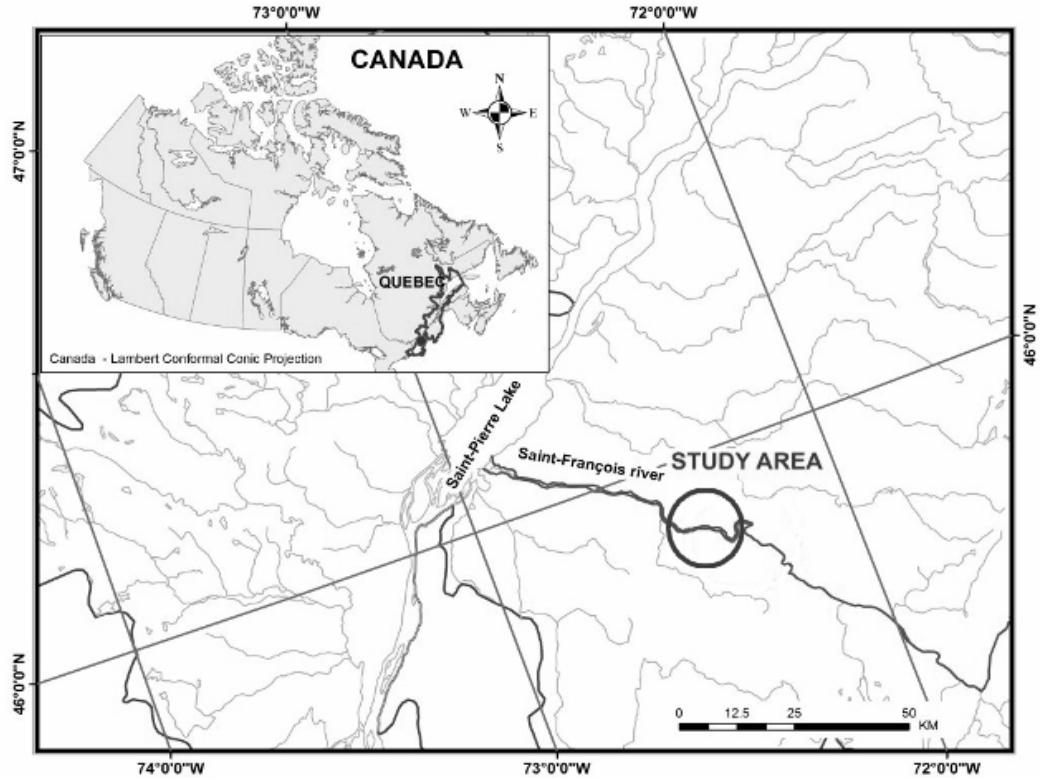
- Study site
- Radar data
- Field data

3. Results

4. Conclusion

Study site

The Saint-François river



Study site

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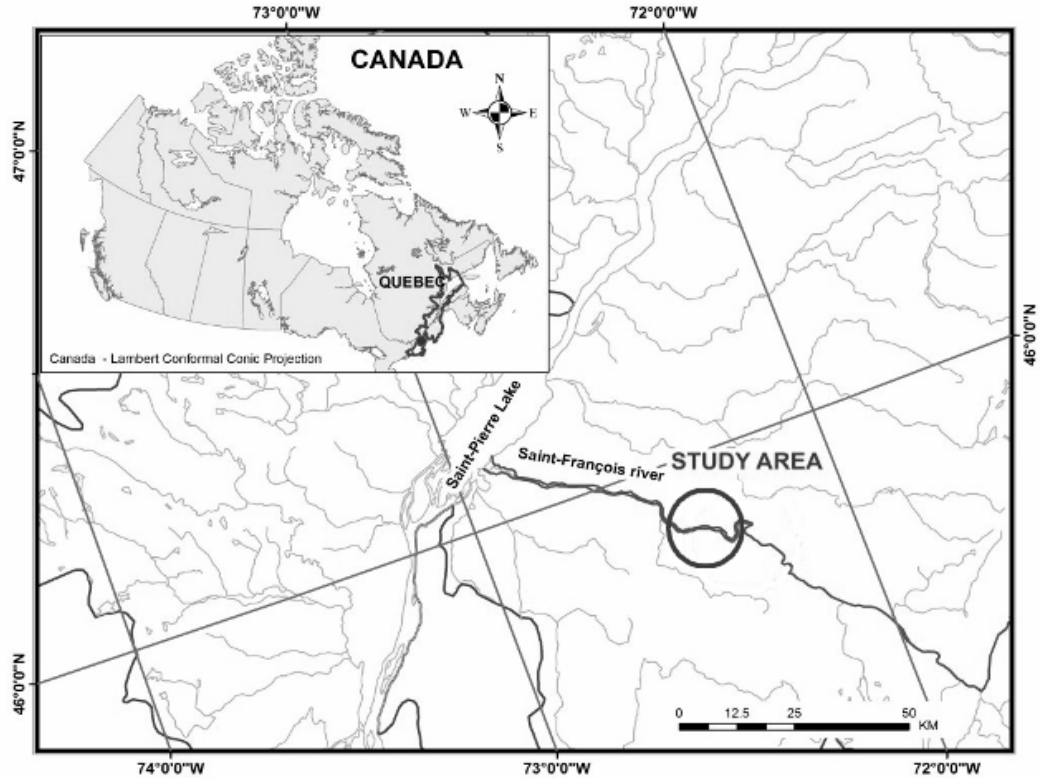


- Ice jams occur every year
- Monitored since 2001
- Close to Quebec city

Radar data

TERRASAR-X
9.65 Ghz

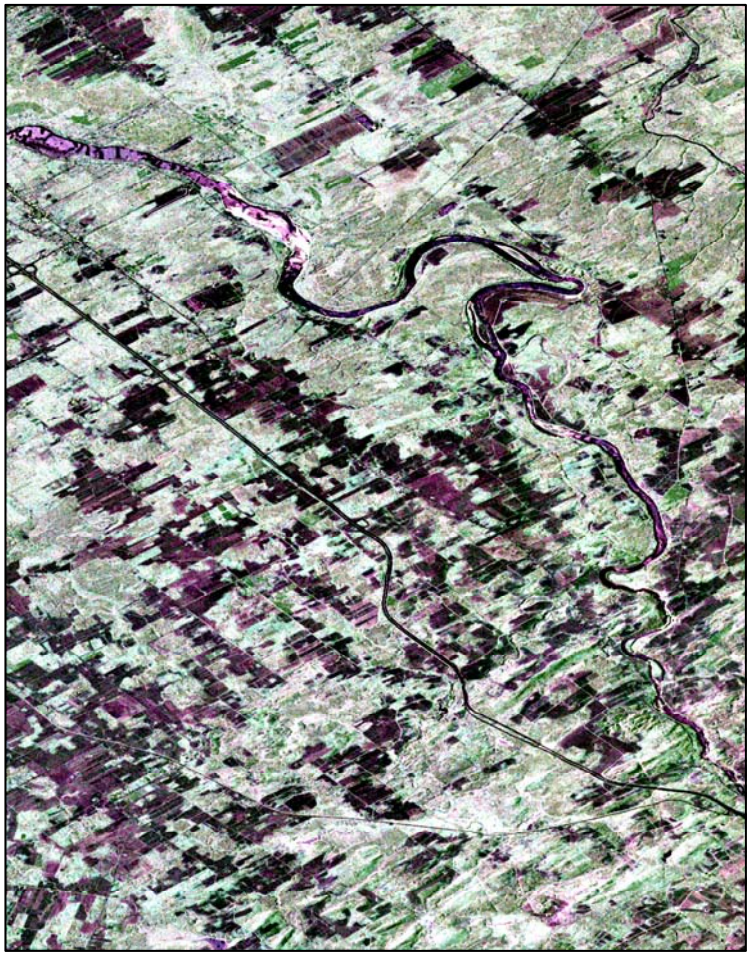
Acquisition date	17 Feb 08	10 Mar 08
Platform	Spaceborne	Spaceborne
Sensor	TerraSAR	TerraSAR
Band	X	X
Polarization	HH-VV	HH-VV
Range Resolution	6m	6m
Incidence angle	35º	35º

Radar data

TERRASAR-X Dual-polar HH-VV

17 Feb 2008

10 March 2008

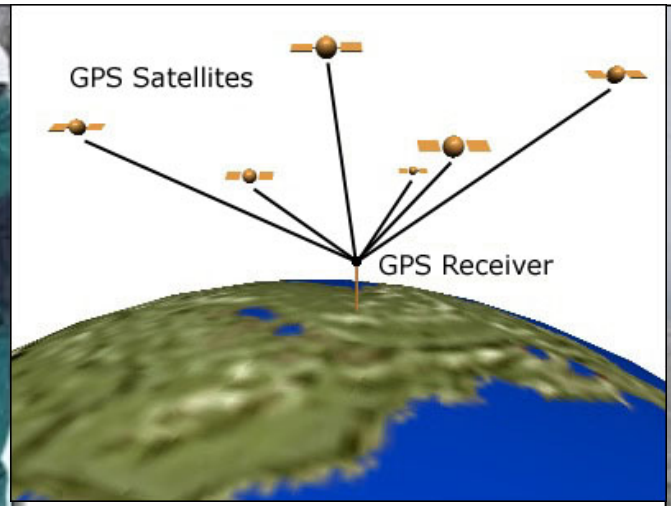


$|HH|^2$ $|HH + 2R(HHVV) + VV|^2$ $|VV|^2$

Field data

Ice core measurement

GPS

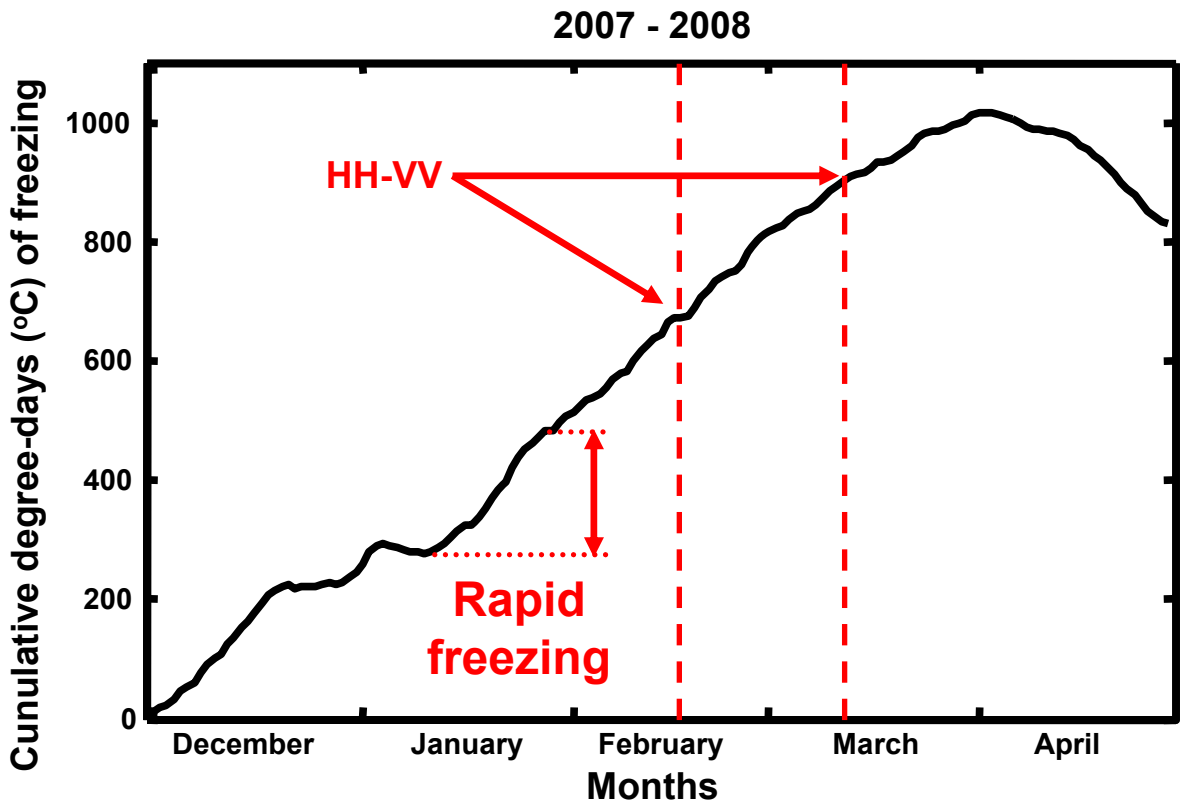


Georadar

Freq: 900Mhz

Weather conditions

$$CDDF = -\sum_{Days}\left(\frac{T_{MAX} + T_{MIN}}{2}\right)$$



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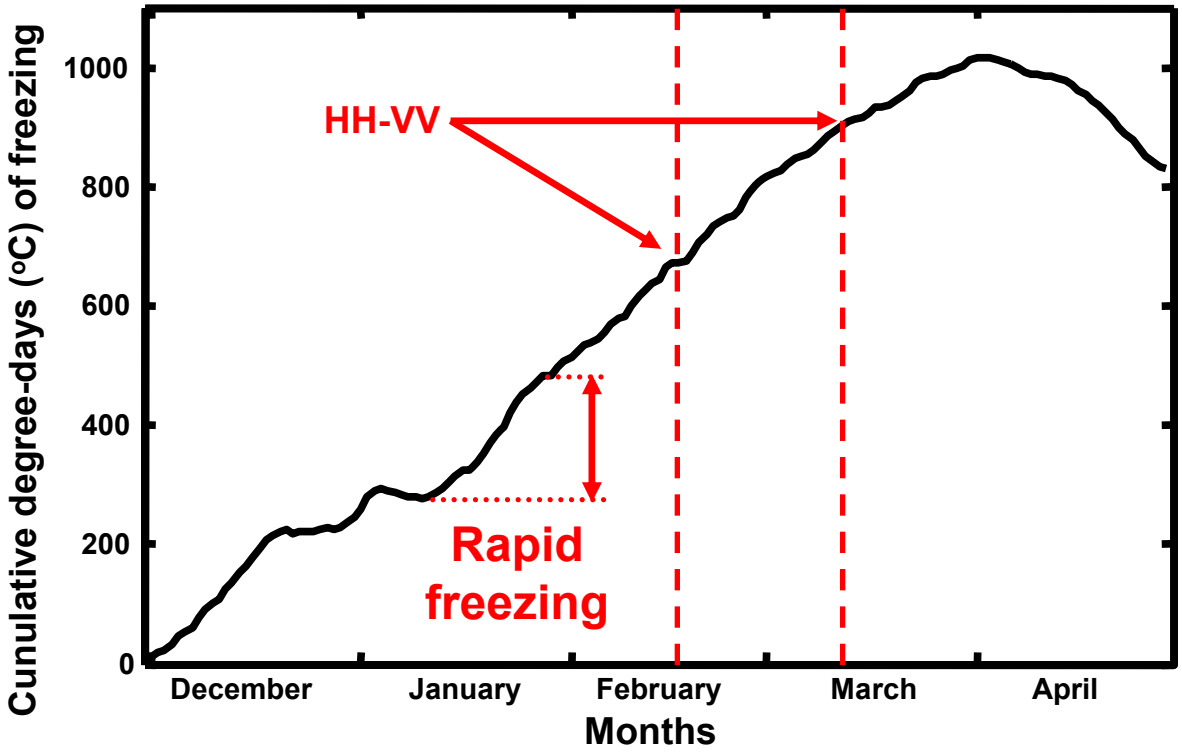
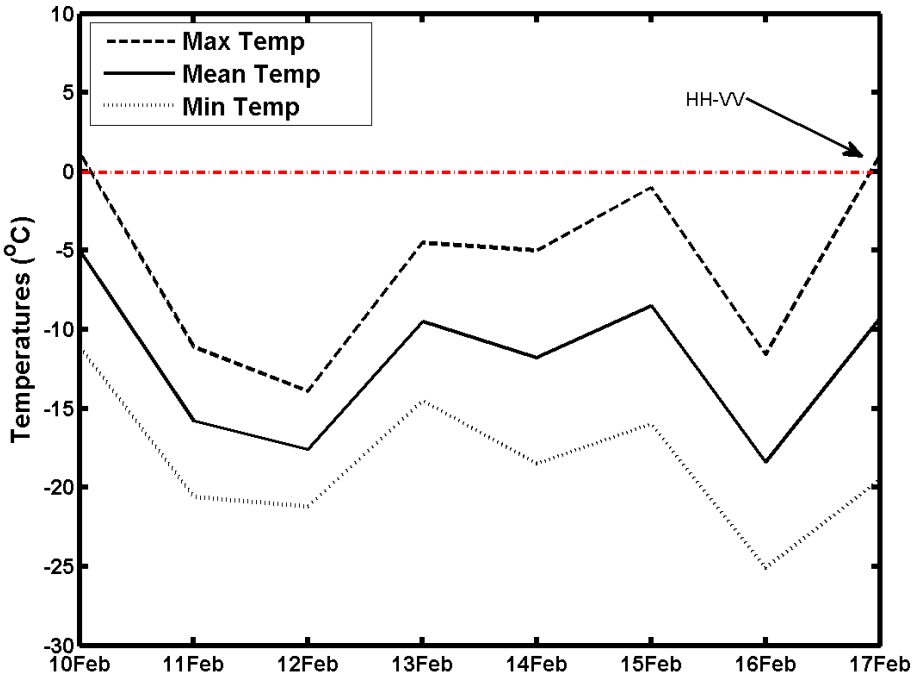
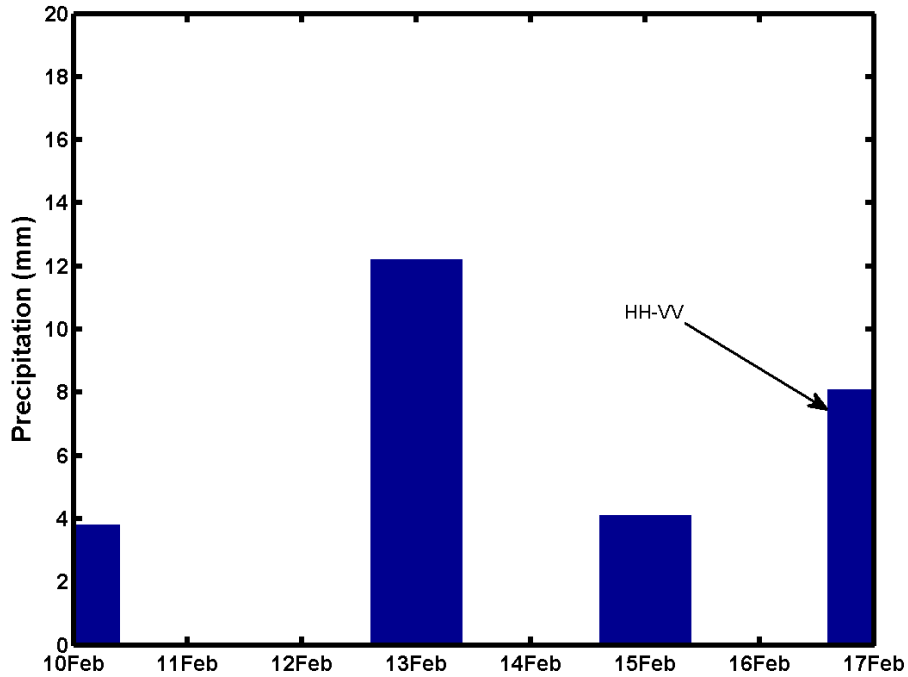


- Presence of frazil
- Great quantity of air trapped within the ice cover
- Inclusions with large diameters

Weather conditions

17 February 2008

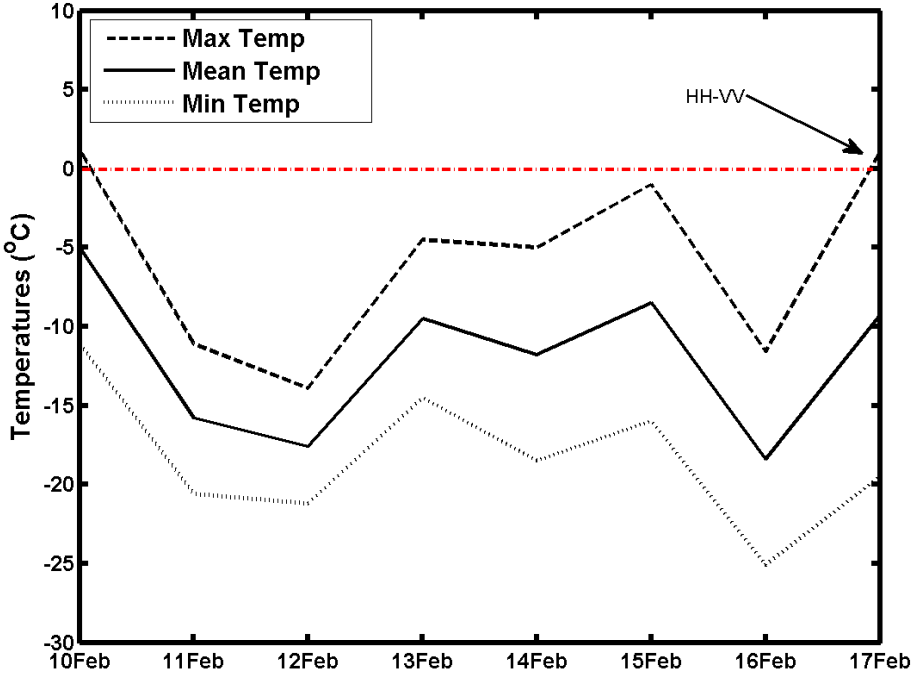


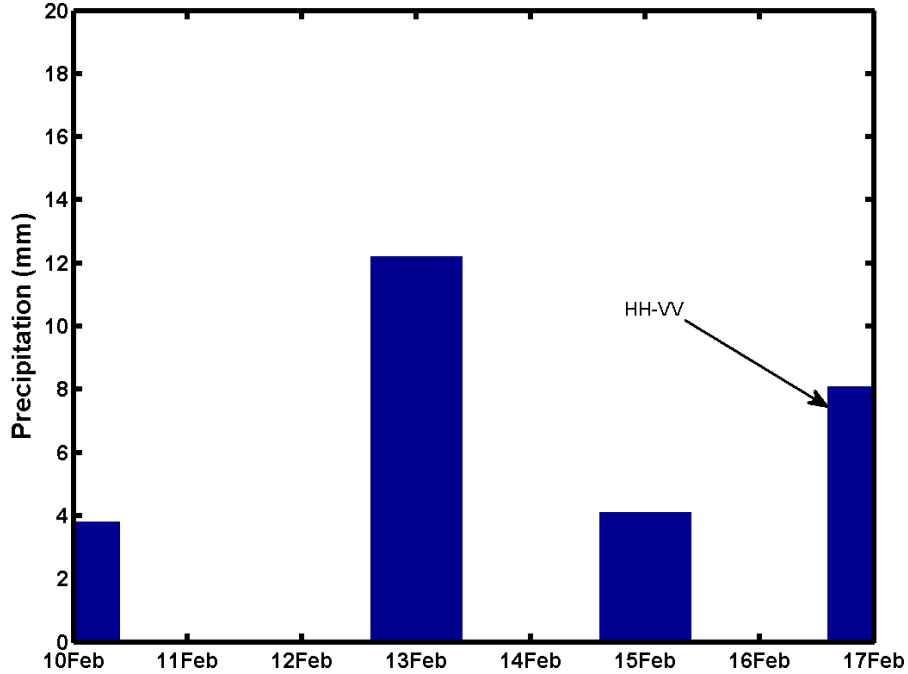


Weather conditions

17 February 2008

Negative temperatures





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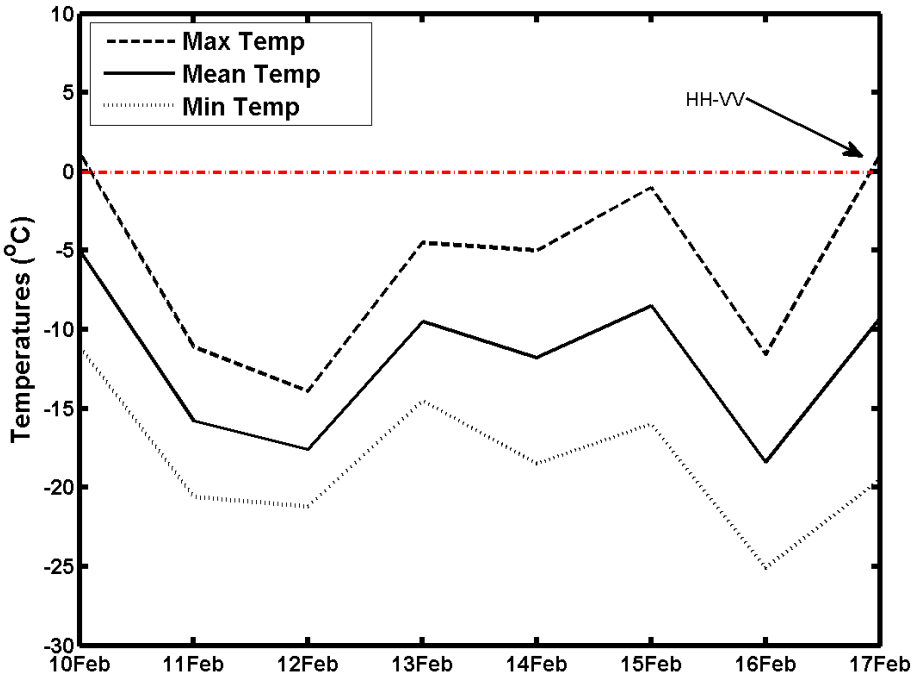
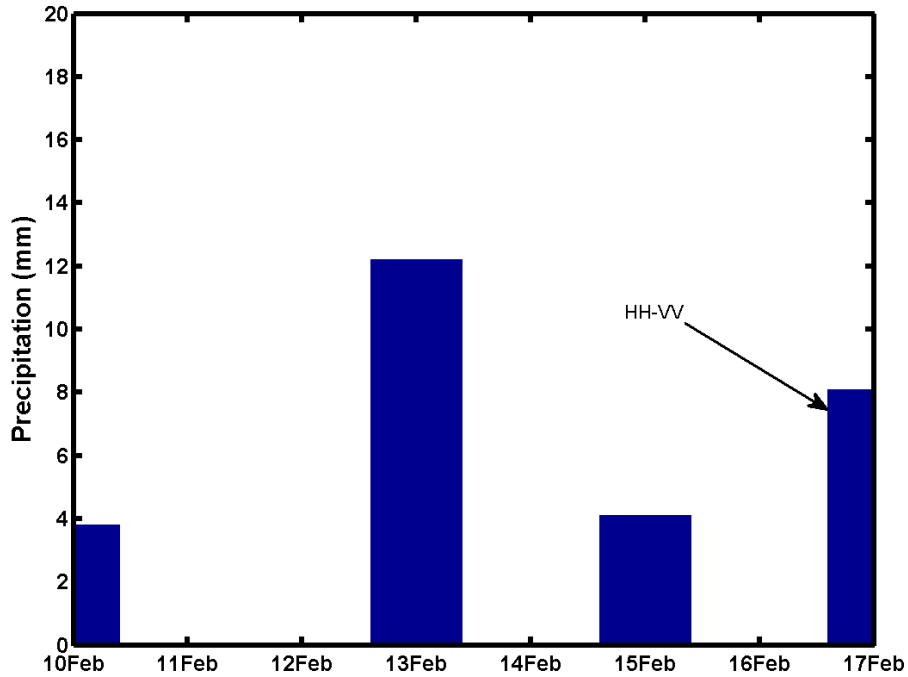


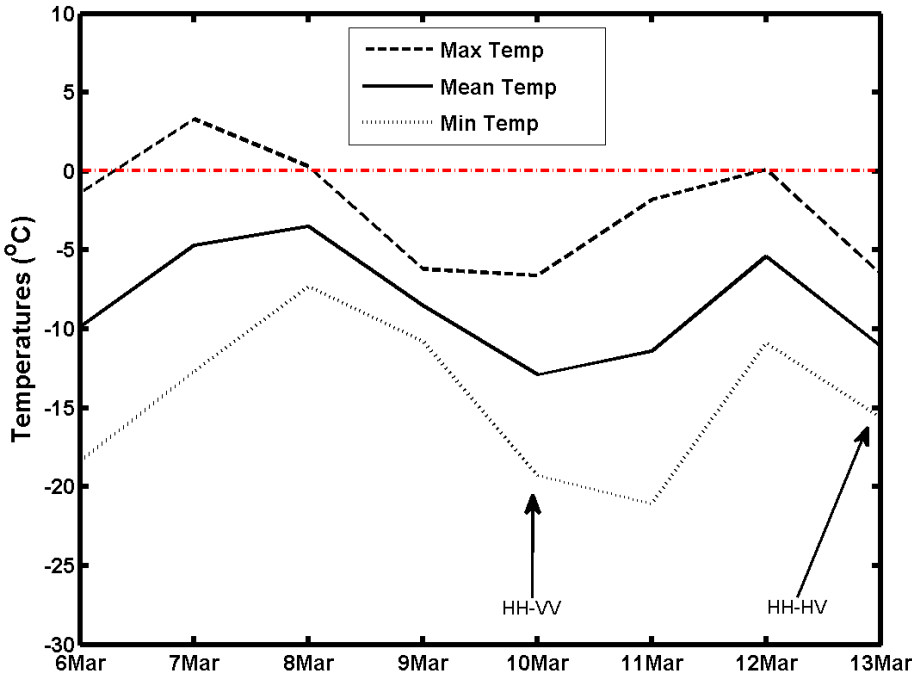
Snowfall

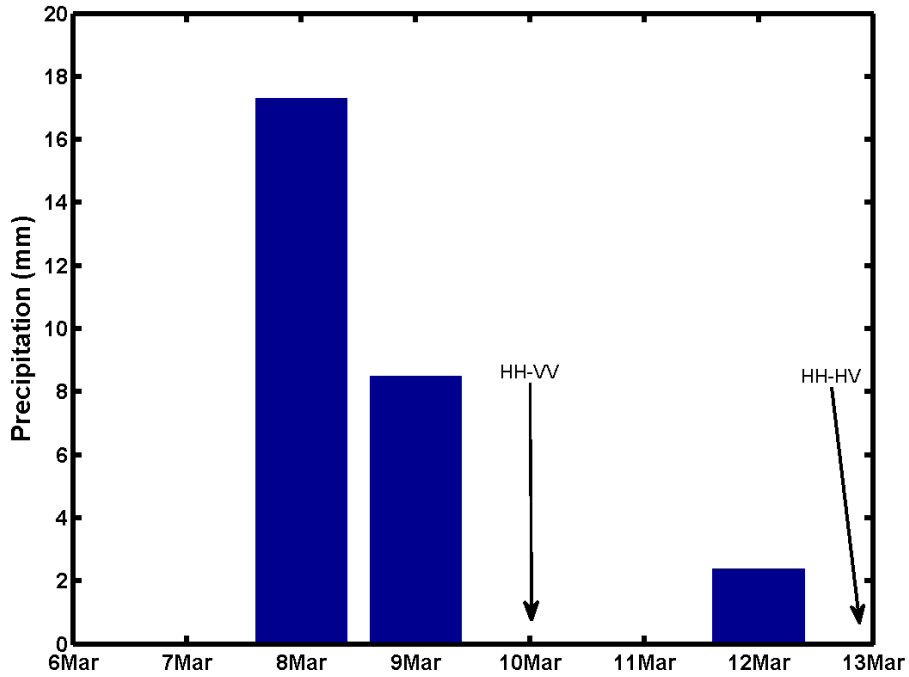


- Dry snow cover

Weather conditions

10 March 2008

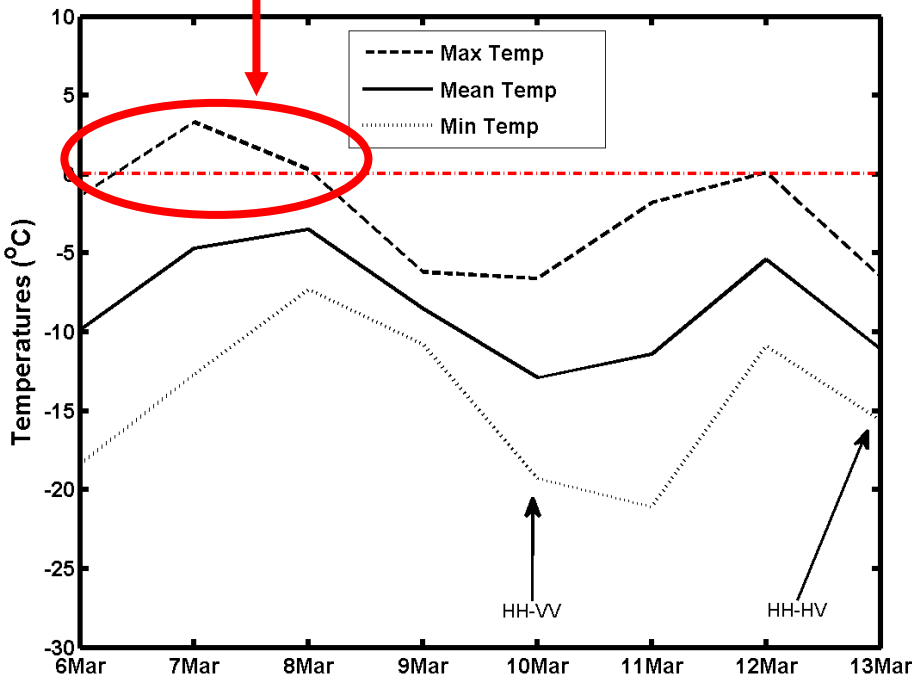


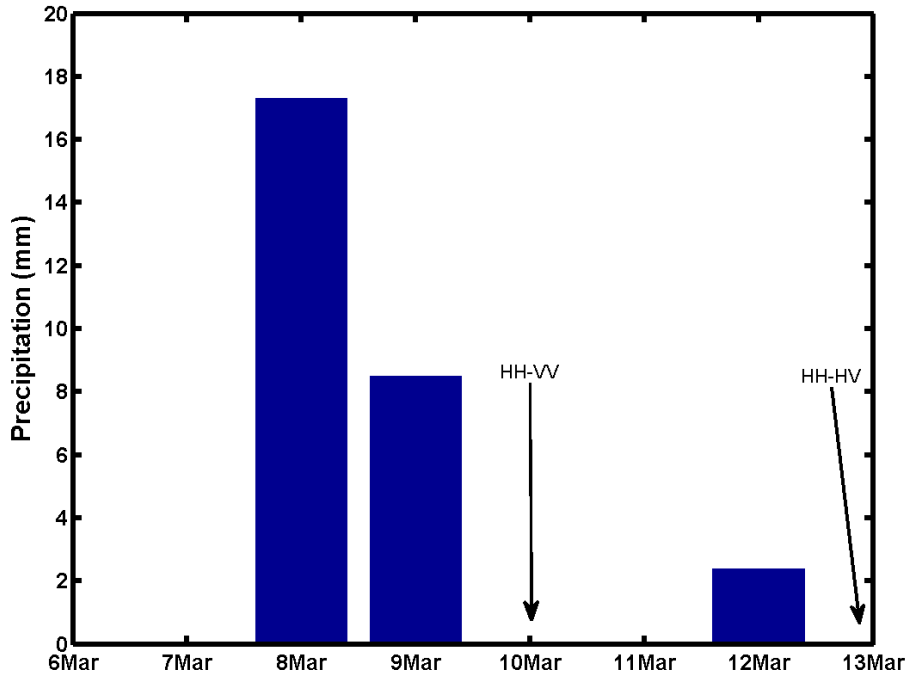


Weather conditions

10 March 2008

Positive temperatures





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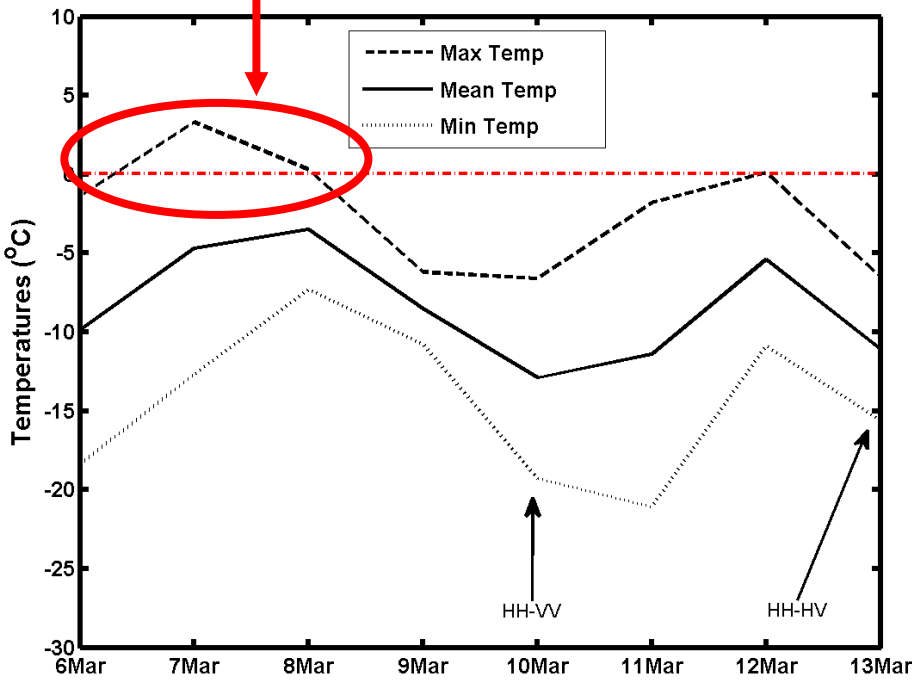
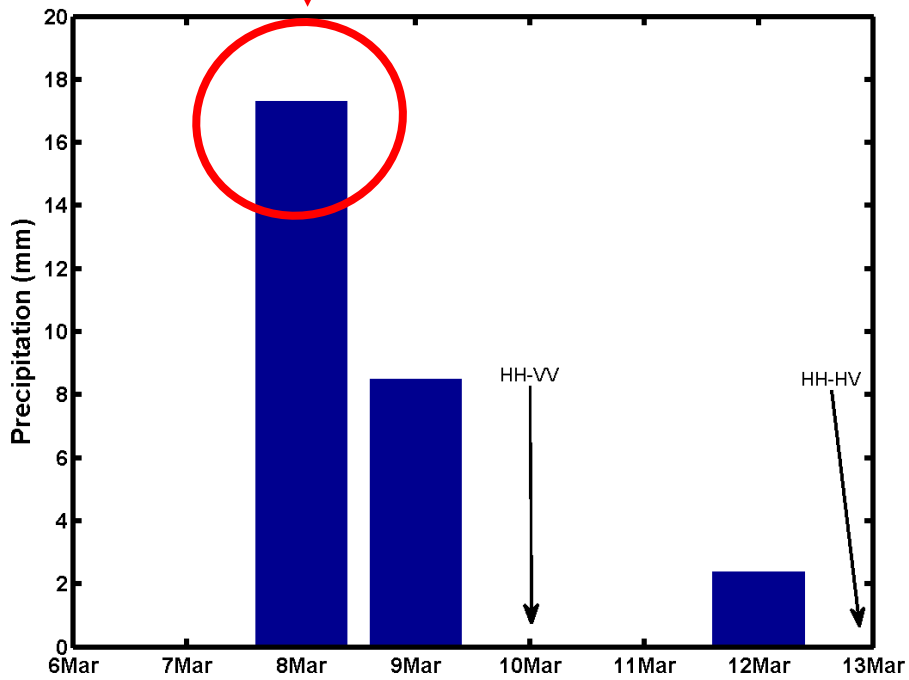


Snowfall and rainfall



Weather conditions

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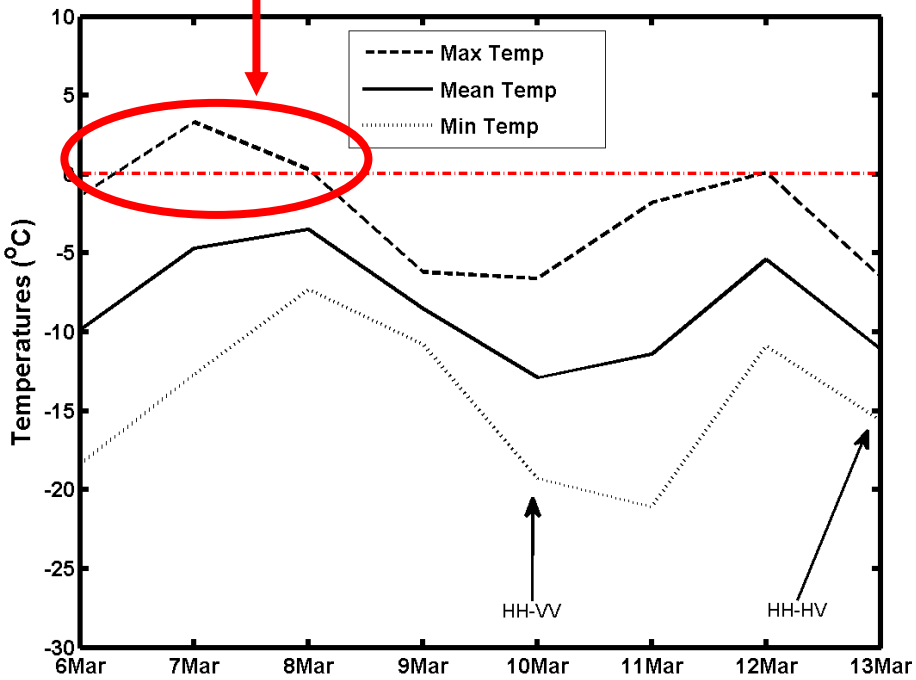

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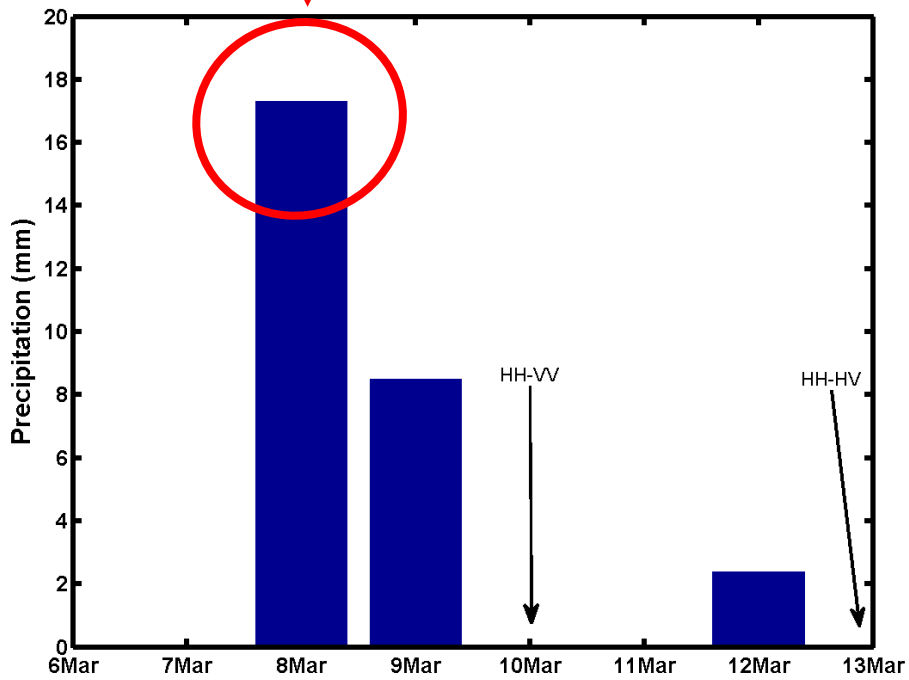

- **Wet snow cover**

1. Existing approaches

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Full-polar with reflexion symmetry

$$T_{\text{FULL}} = \frac{1}{2}\begin{pmatrix} \langle S_{HH}+S_{VV}\rangle\langle S_{HH}+S_{VV}\rangle^{*} & \langle S_{HH}+S_{VV}\rangle\langle S_{HH}-S_{VV}\rangle^{*} & 0 \\ \langle S_{HH}-S_{VV}\rangle\langle S_{HH}+S_{VV}\rangle^{*} & \langle S_{HH}-S_{VV}\rangle\langle S_{HH}-S_{VV}\rangle^{*} & 0 \\ 0 & 0 & 4\langle S_{HV}\rangle\langle S_{HV}\rangle^{*} \end{pmatrix}$$

Dual-polar HH-VV

$$T_{DUAL} = \frac{1}{2}\begin{pmatrix} \langle S_{HH}+S_{VV}\rangle\langle S_{HH}+S_{VV}\rangle^{*} & \langle S_{HH}+S_{VV}\rangle\langle S_{HH}-S_{VV}\rangle^{*} \\ \langle S_{HH}-S_{VV}\rangle\langle S_{HH}+S_{VV}\rangle^{*} & \langle S_{HH}-S_{VV}\rangle\langle S_{HH}-S_{VV}\rangle^{*} \end{pmatrix}$$

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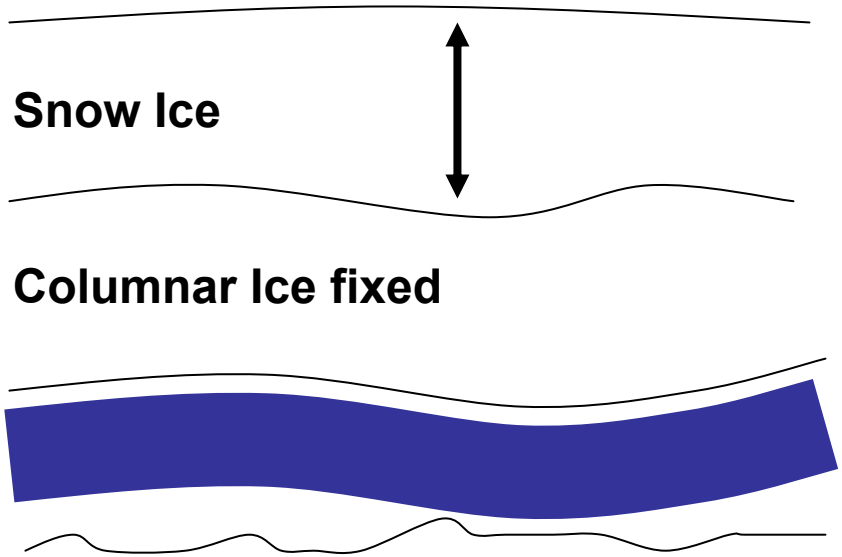
$$\lambda_{1-DUAL} = \lambda_{1-FULL} = \frac{1}{2}\left(\sigma_{HHHH} + \sigma_{VVVV} + \sqrt{\left(\sigma_{HHHH} - \sigma_{VVVV}\right)^2 + 4\sigma_{HHVV}\sigma_{HHVV}^{*}} \right)$$

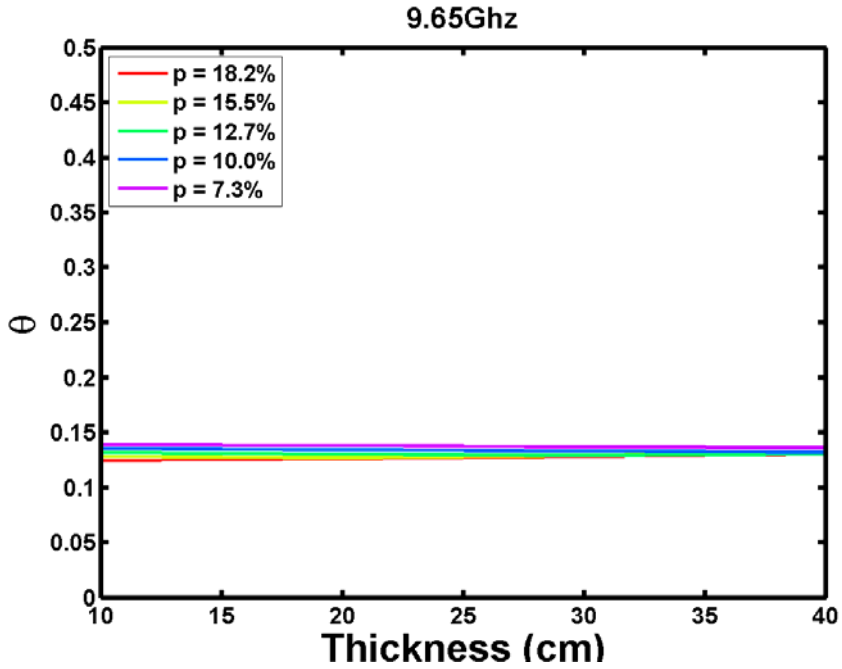
$$\lambda_{2-DUAL} = \lambda_{2-FULL} = \frac{1}{2}\left(\sigma_{HHHH} + \sigma_{VVVV} - \sqrt{\left(\sigma_{HHHH} - \sigma_{VVVV}\right)^2 + 4\sigma_{HHVV}\sigma_{HHVV}^{*}} \right)$$

$$\theta = -\frac{\lambda_1}{\lambda_1 + \lambda_2}\log_2\frac{\lambda_1}{\lambda_1 + \lambda_2} - \frac{\lambda_2}{\lambda_1 + \lambda_2}\log_2\frac{\lambda_2}{\lambda_1 + \lambda_2}$$

Simulation results

Effect of Snow ice



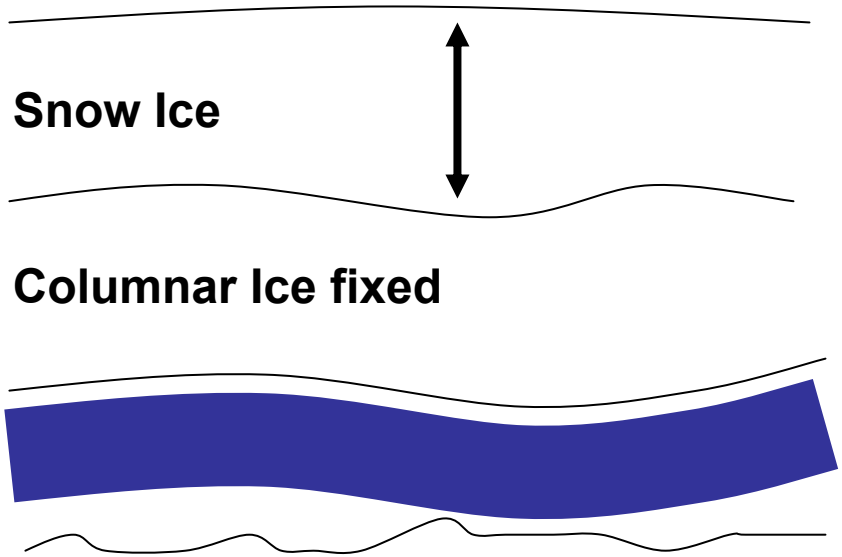


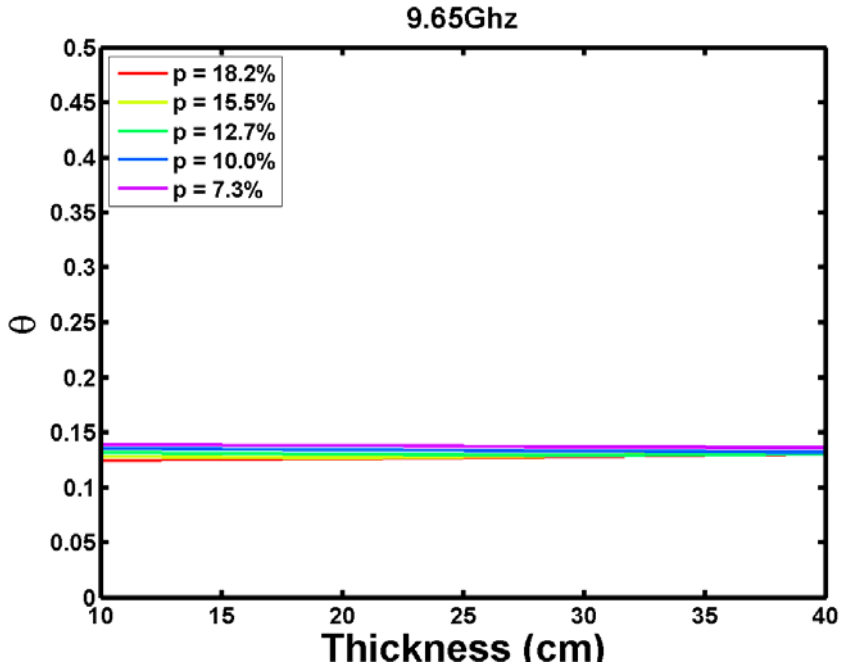
Columnar Ice :
- Thickness = 30cm
- Air bubble size : 0.05cm
- Porosity = 7.3%

(kσ,kL) for both air-ice and ice-water boundaries is (0.25,1)

Simulation results

Effect of Snow ice





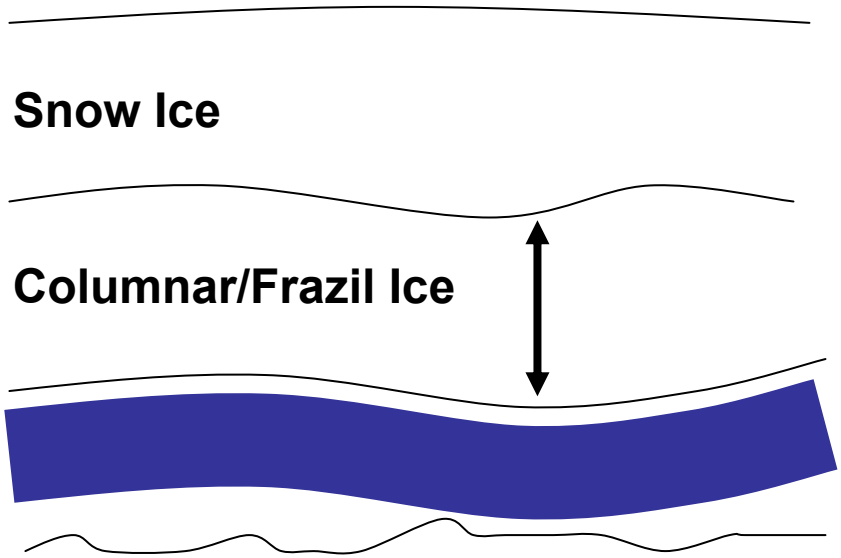
Columnar Ice :
- Thickness = 30cm
- Air bubble size : 0.05cm
- Porosity = 7.3%

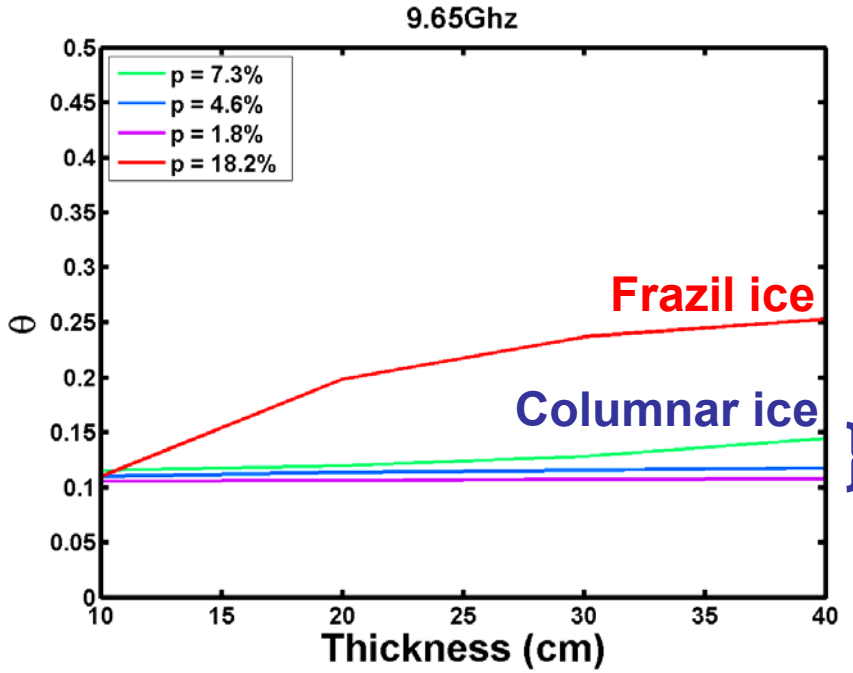
Snow ice do not affect θ

(kσ,kL) for both air-ice and ice-water boundaries is (0.25,1)

Simulation results

Effect of Columnar and frazil ice



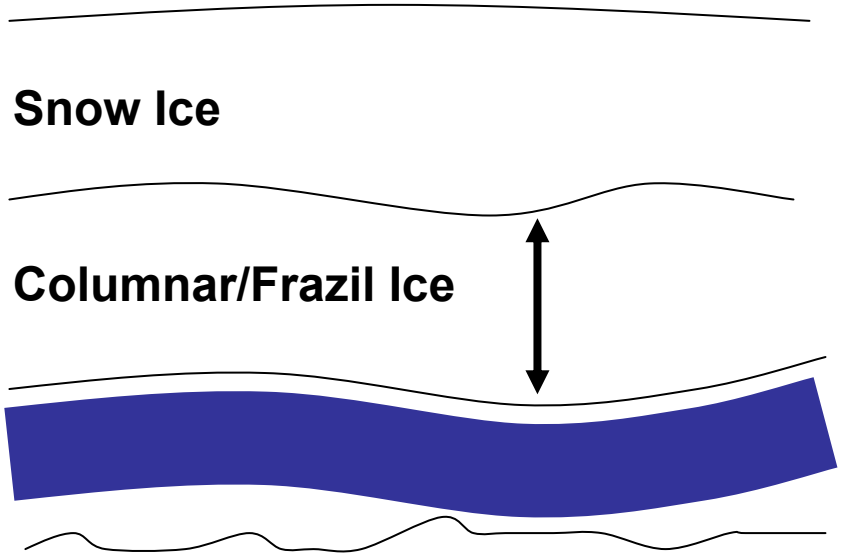


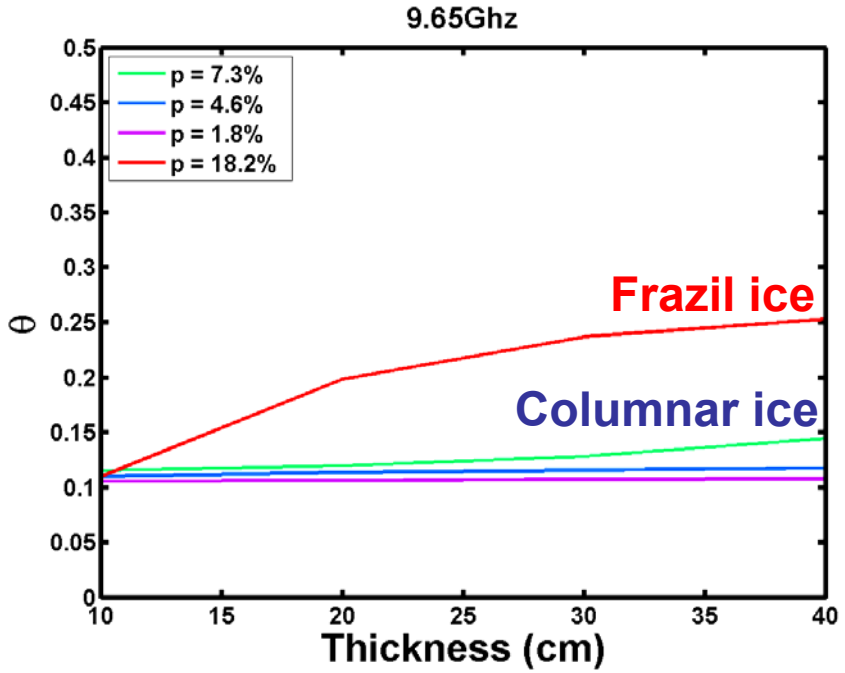
Snow Ice :
- Thickness = 30cm
- Air bubble size : 0.05cm
- Porosity = 18.2%

(kσ,kL) for both air-ice and ice-water boundaries is (0.25,1)

Simulation results

Effect of Columnar and frazil ice





Snow Ice :
- Thickness = 30cm
- Air bubble size : 0.05cm
- Porosity = 18.2%

Columnar and Frazil ice affects θ

(kσ,kL) for both air-ice and ice-water boundaries is (0.25,1)

3 classifications

- **Hierarchical**
- **Wishart**
- **SVM**

} *Statistical*

OW : Open Water

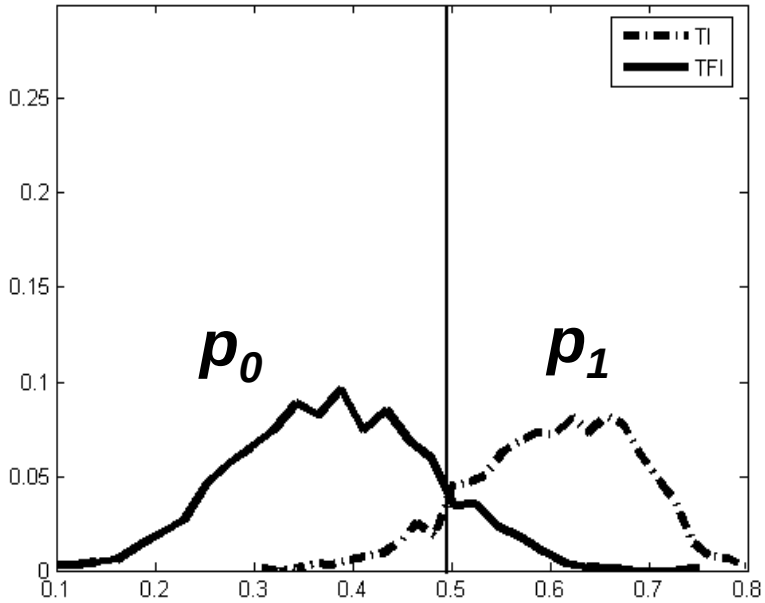
CI 1 : Heavily consolidated ice

CI 2 : Consolidated ice

TFI : Thermal with/without frazil ice

FI : Frazil ice

Choice of parameters



$$\begin{cases} \text{Bhattacharrya}(p_0, p_1) = -\log \sum_x \sqrt{p_0(x)\, p_1(x)} \\ \text{Chi}^2(p_0, p_1) = \sum_x \dfrac{\left(p_0(x) - p_1(x)\right)^2}{\left(p_0(x) + p_1(x)\right)} \end{cases}$$

Choice of parameters for discriminating the i^{th} class:

$$\text{Param} = \arg\min \left[\frac{1}{N_c - i} \sum_{j=i+1}^{N_c} Chi^2\left(p_i, p_j\right) \right]$$

With N_c *the number of classes*

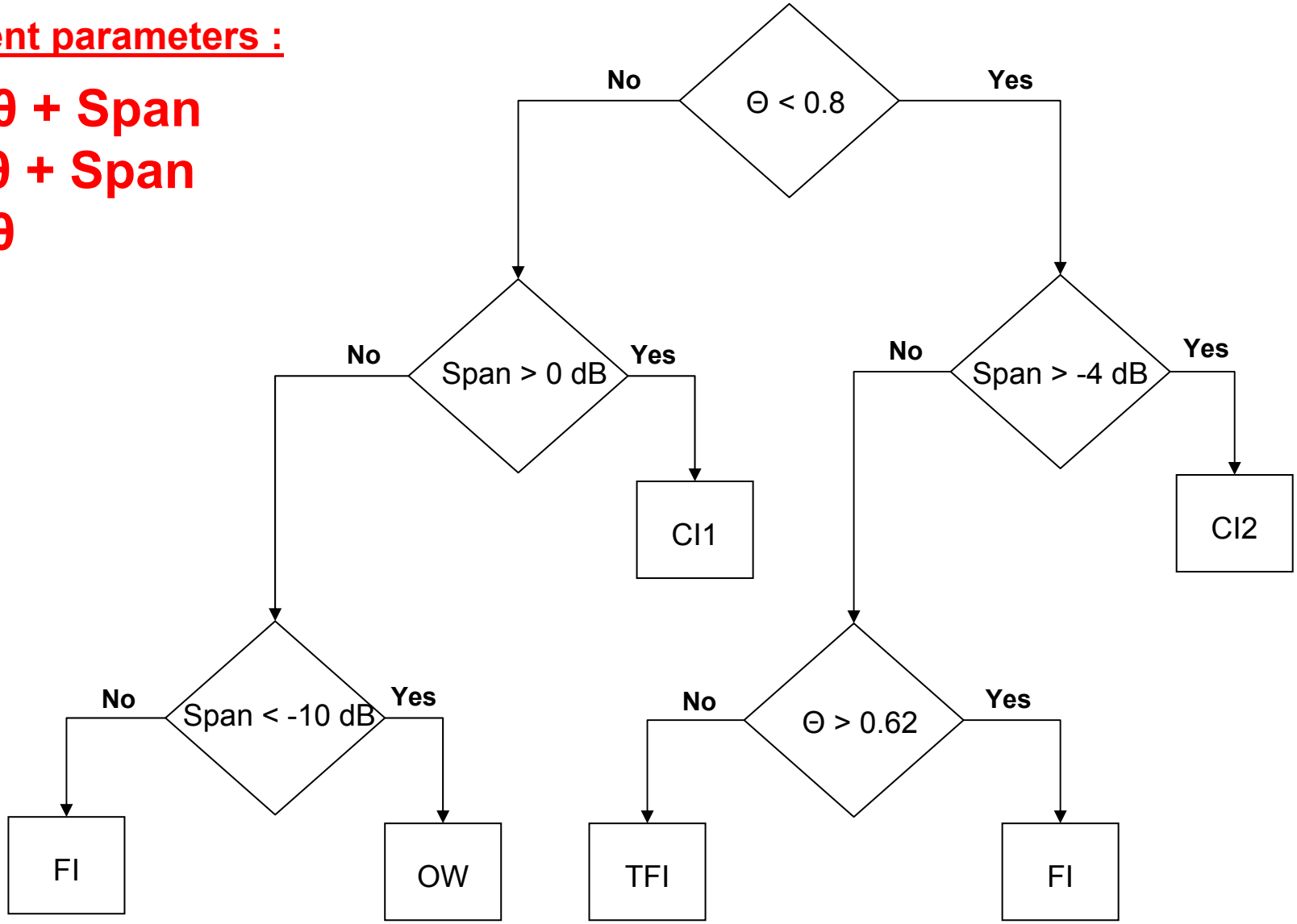
Hierarchical classification

The pertinent parameters :

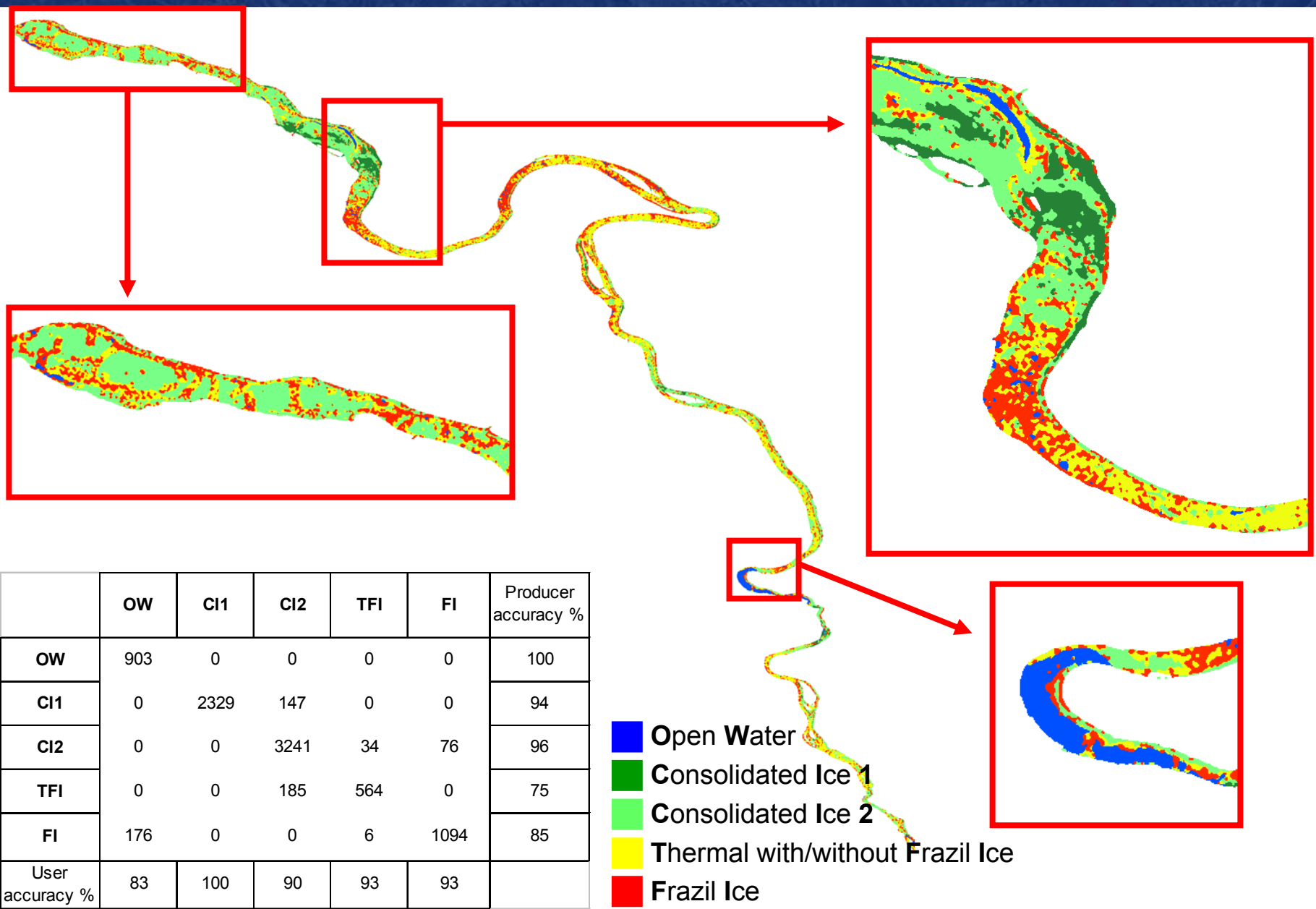
OW vs all : **θ + Span**

CI vs all : **θ + Span**

CoI vs FI : **θ**

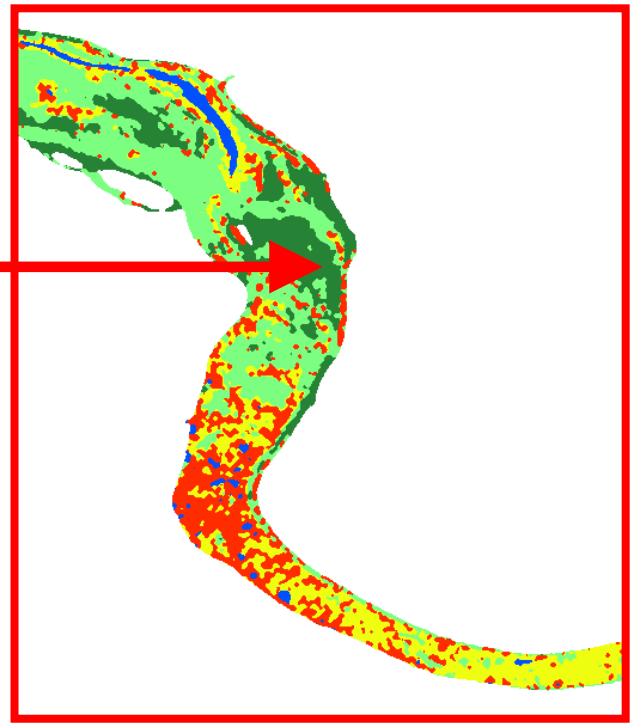


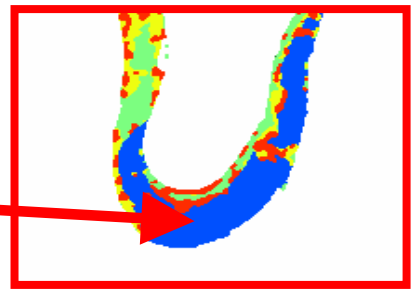
Hierarchical classification



	OW	CI1	CI2	TFI	FI	Producer accuracy %
OW	903	0	0	0	0	100
CI1	0	2329	147	0	0	94
CI2	0	0	3241	34	76	96
TFI	0	0	185	564	0	75
FI	176	0	0	6	1094	85
User accuracy %	83	100	90	93	93	

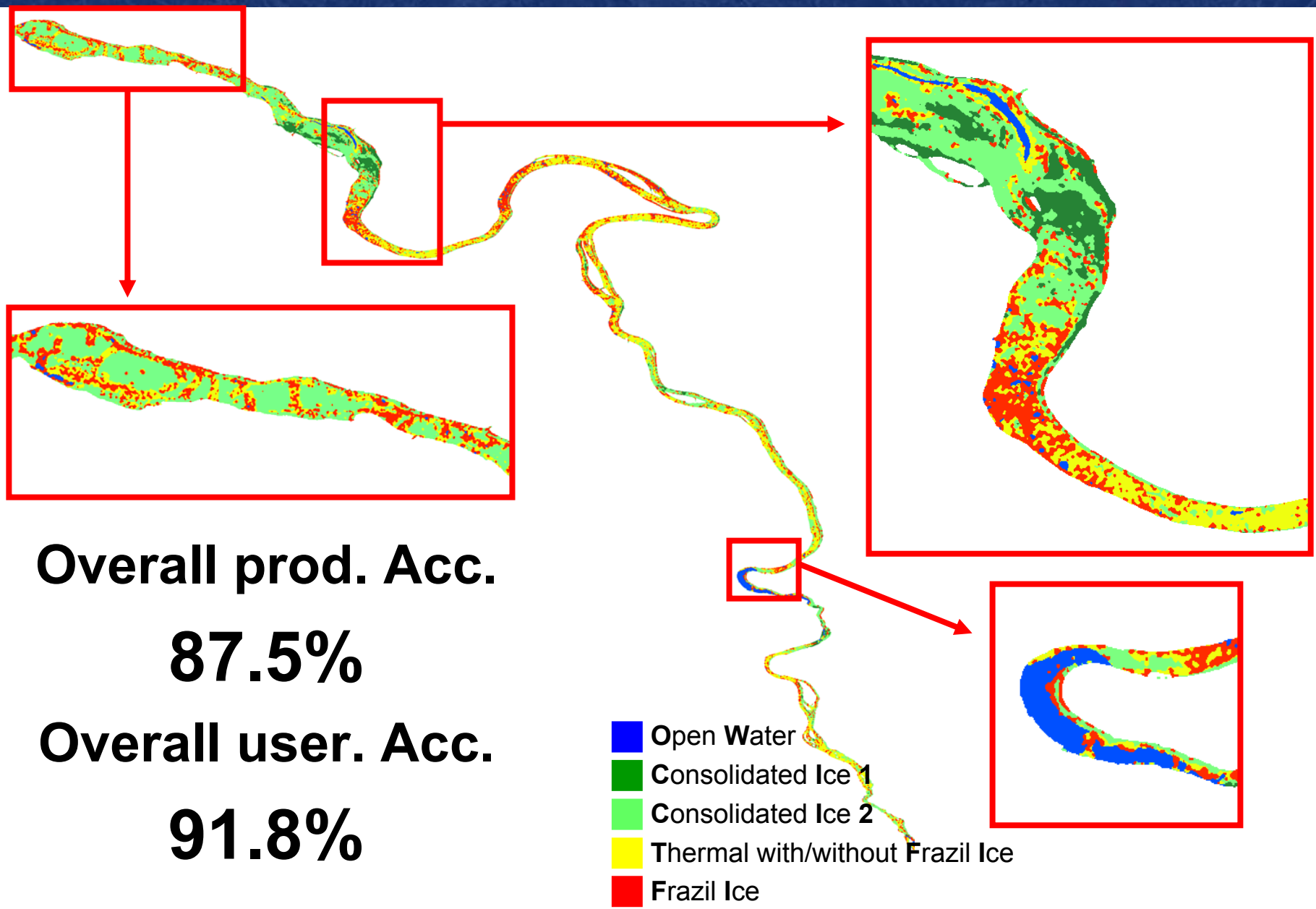
Hierarchical classification





Open **W**ater
Consolidated **I**ce **1**
Consolidated **I**ce **2**
Thermal with/without **F**razil **I**ce
Frazil **I**ce

Hierarchical classification



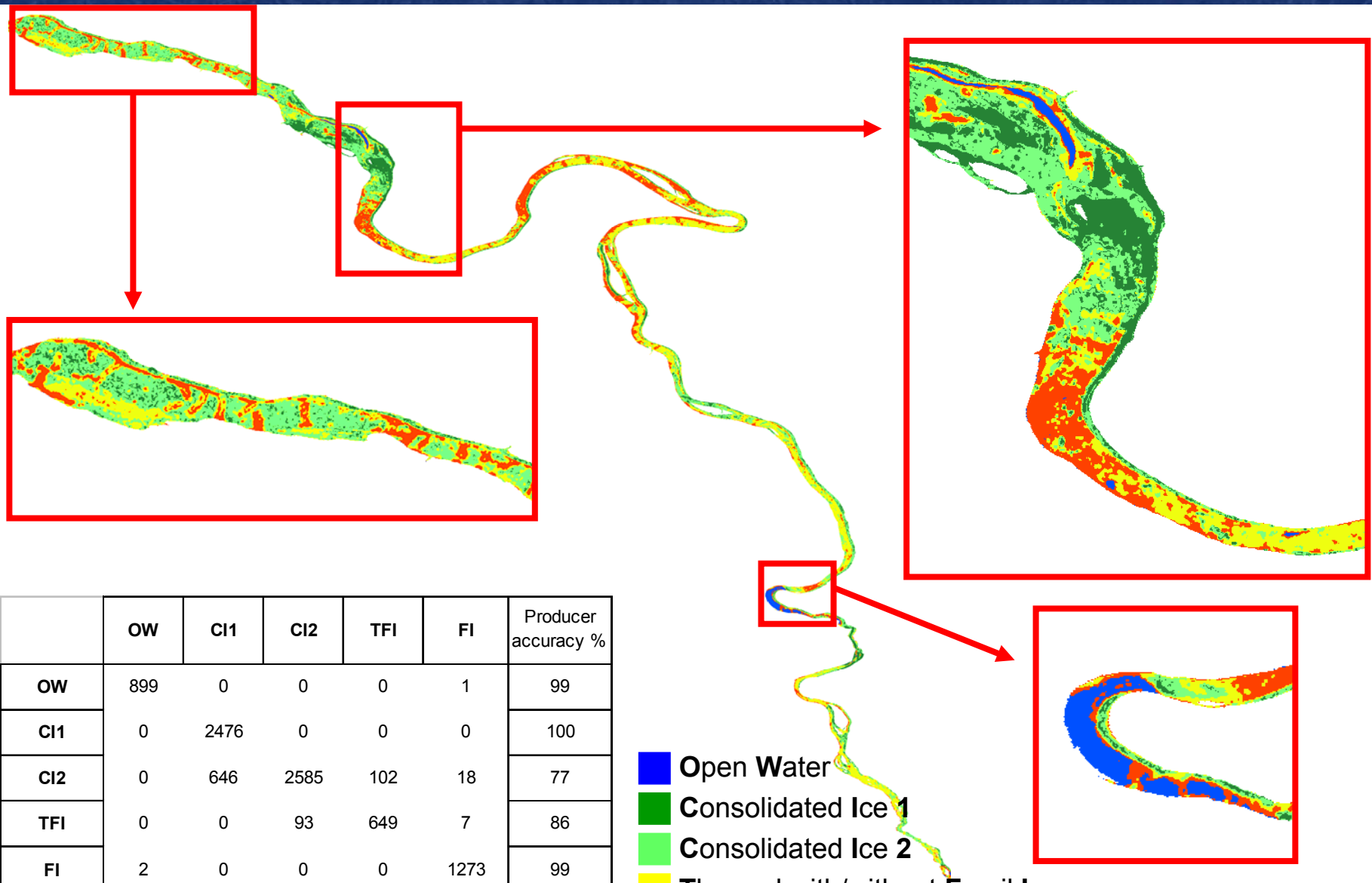
Overall prod. Acc.

87.5%

Overall user. Acc.

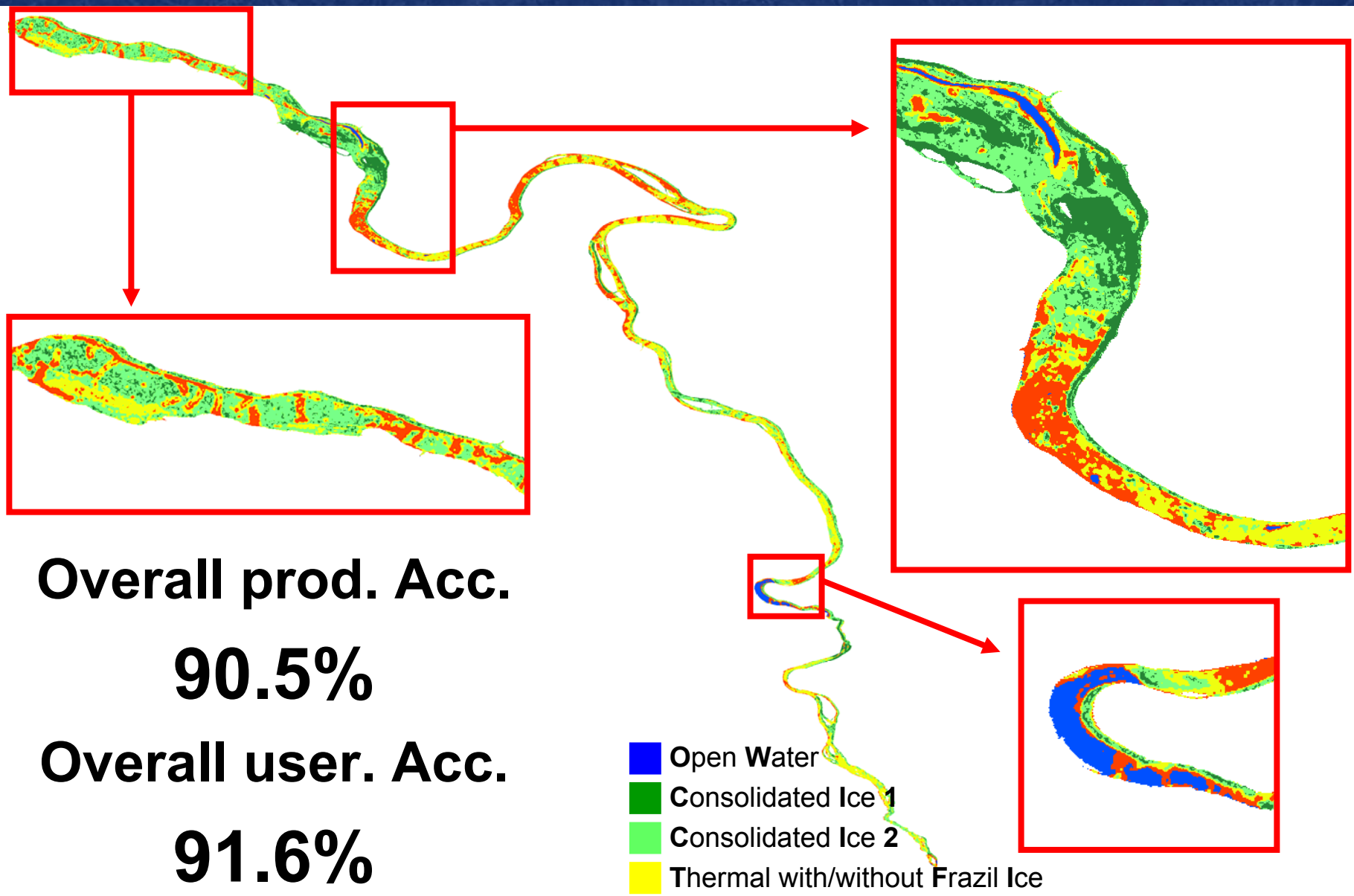
91.8%

Wishart Classification



	OW	CI1	CI2	TFI	FI	Producer accuracy %
OW	899	0	0	0	1	99
CI1	0	2476	0	0	0	100
CI2	0	646	2585	102	18	77
TFI	0	0	93	649	7	86
FI	2	0	0	0	1273	99
User accuracy %	99	79	96	86	98	

Wishart Classification



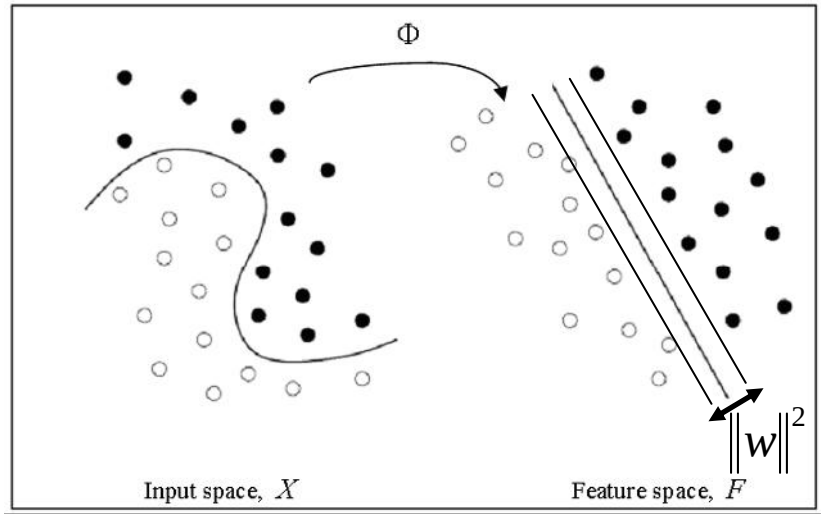
Overall prod. Acc.

90.5%

Overall user. Acc.

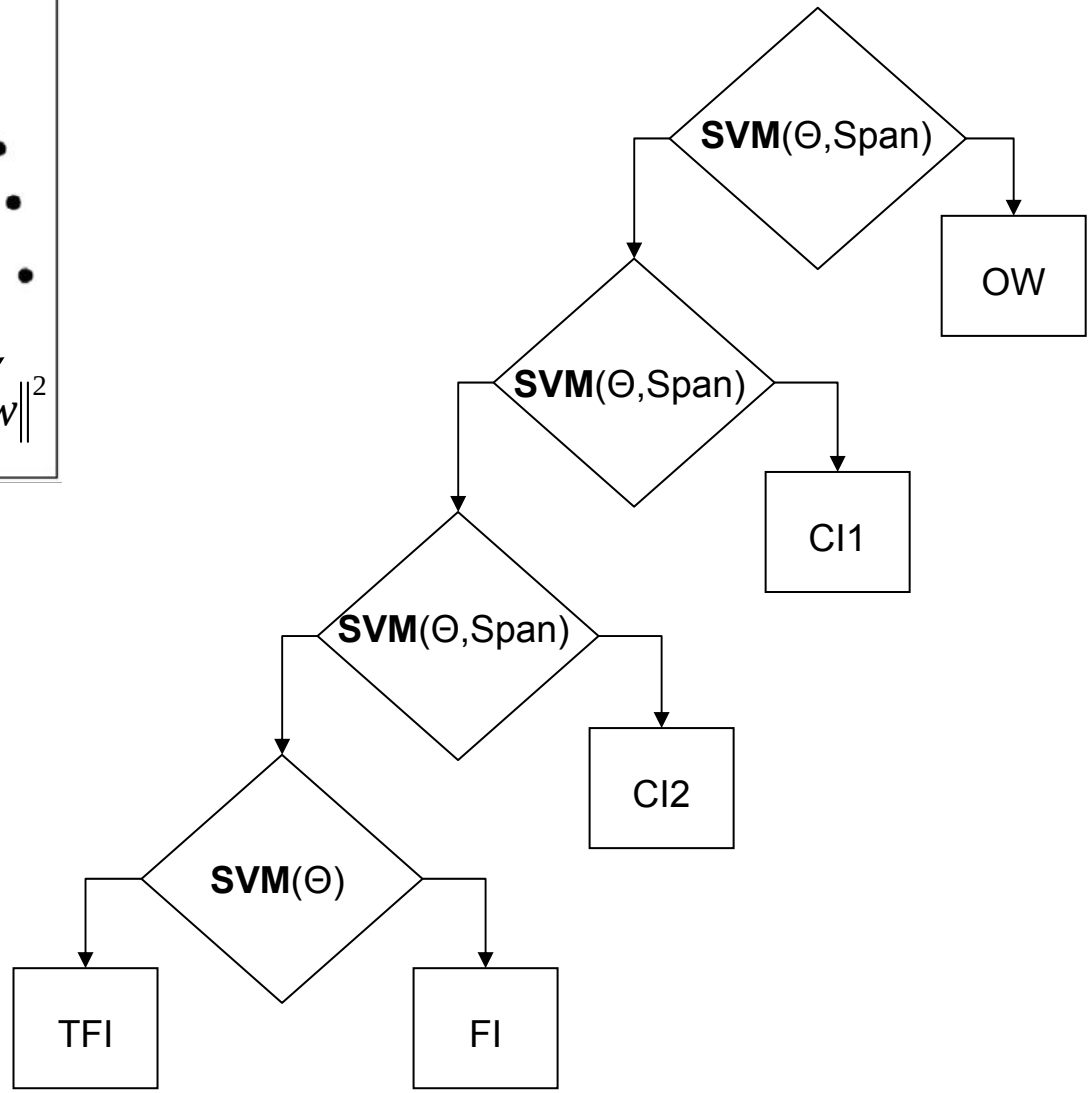
91.6%

SVM classification

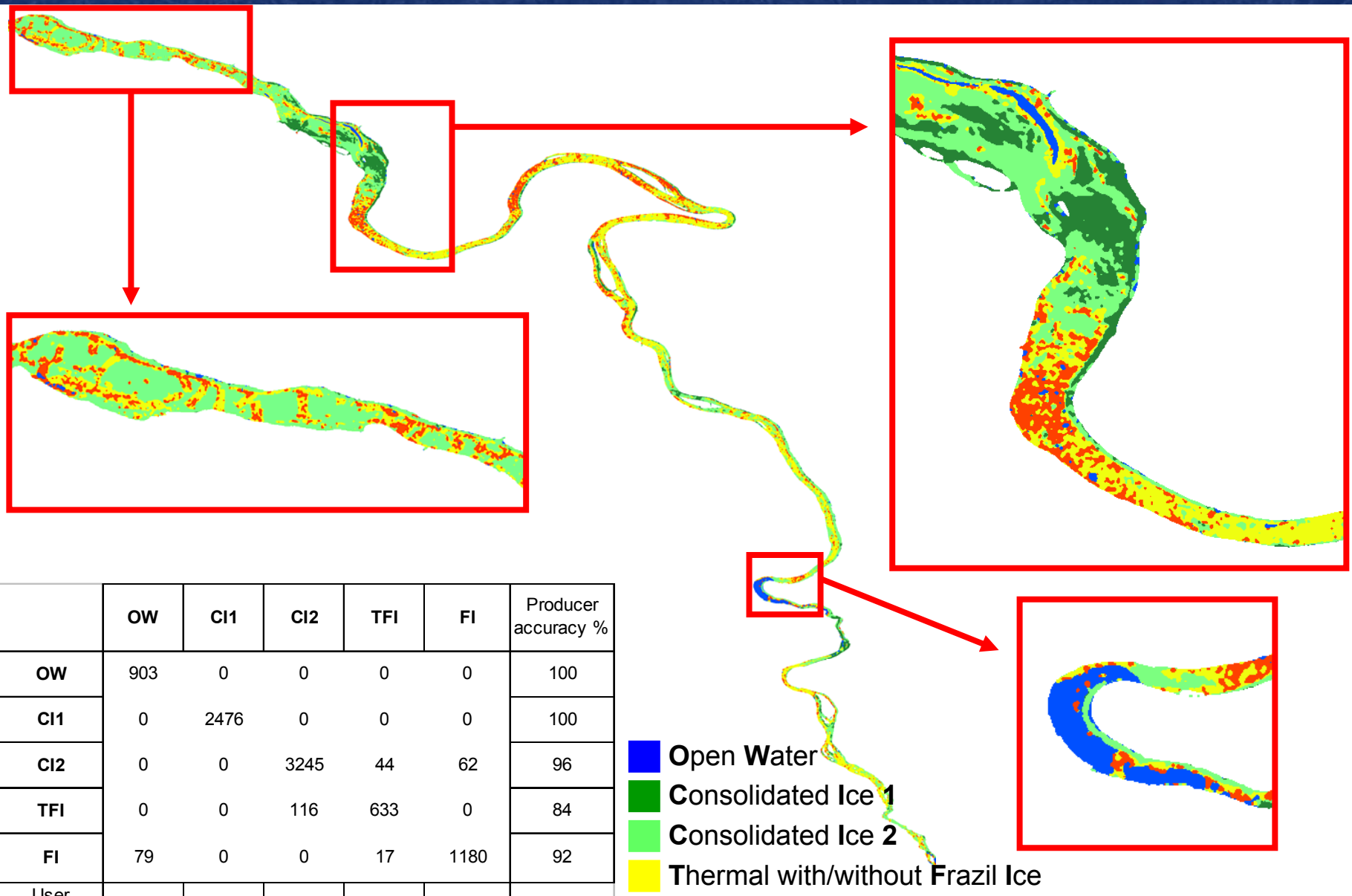


$$\min_{w,b} \quad \frac{1}{2}\|w\|^2$$

$$s.t \quad \begin{aligned} w.x_i &\geq b+1 \quad y_i \in Class1 \\ w.x_i &\leq b-1 \quad y_i \in Class-1 \end{aligned}$$

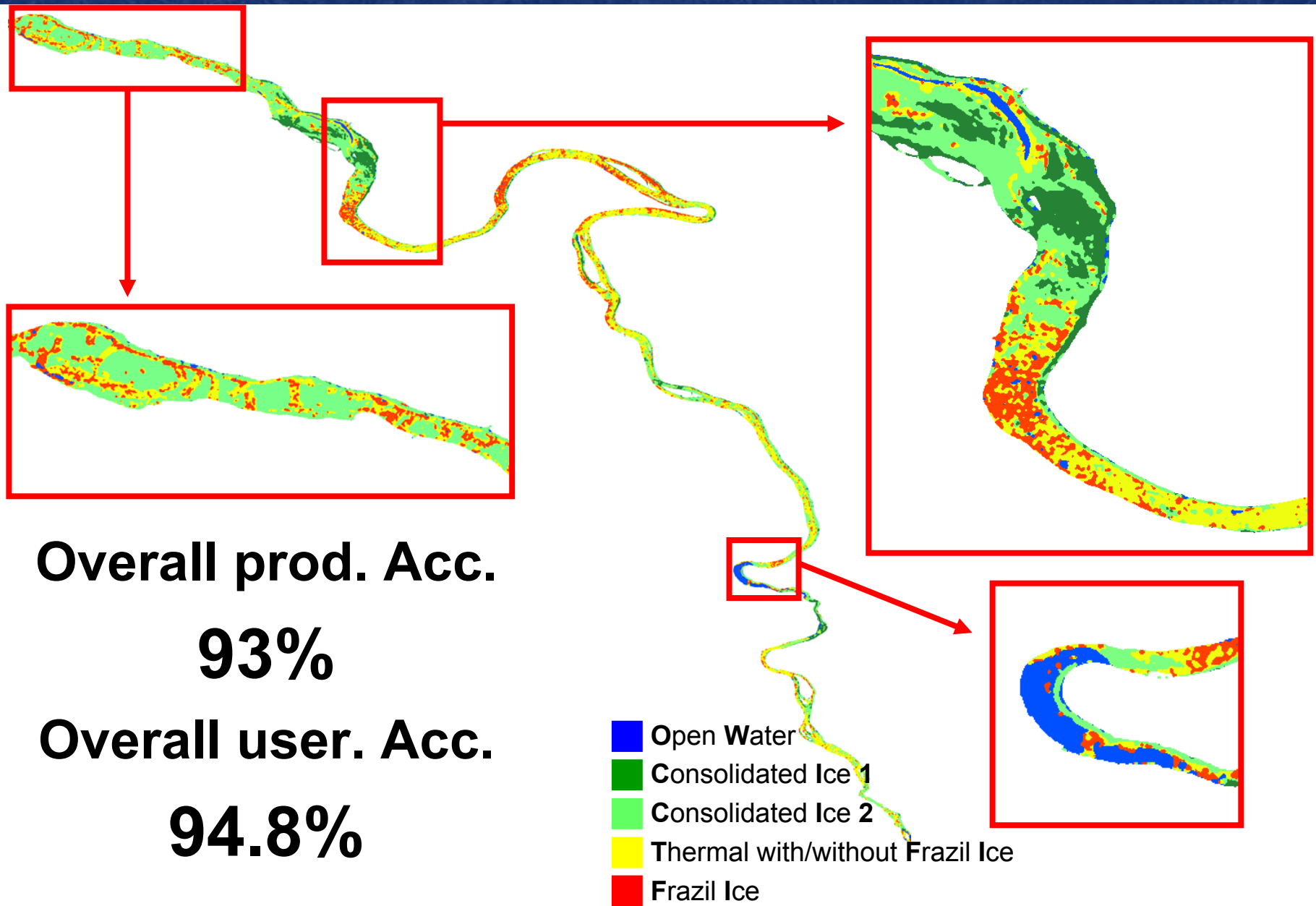


SVM classification



	OW	CI1	CI2	TFI	FI	Producer accuracy %
OW	903	0	0	0	0	100
CI1	0	2476	0	0	0	100
CI2	0	0	3245	44	62	96
TFI	0	0	116	633	0	84
FI	79	0	0	17	1180	92
User accuracy %	92	100	96	91	95	

SVM classification



Overall prod. Acc.

93%

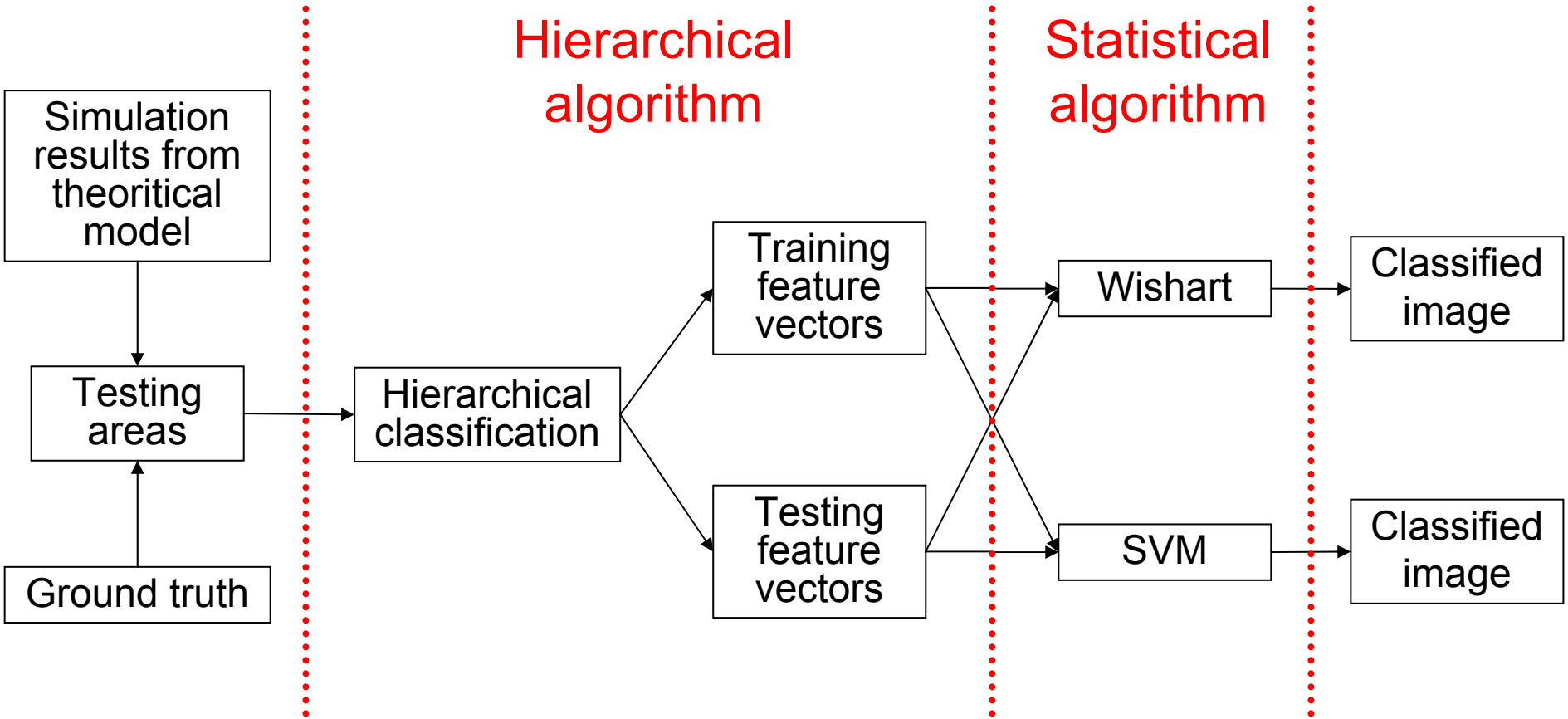
Overall user. Acc.

94.8%

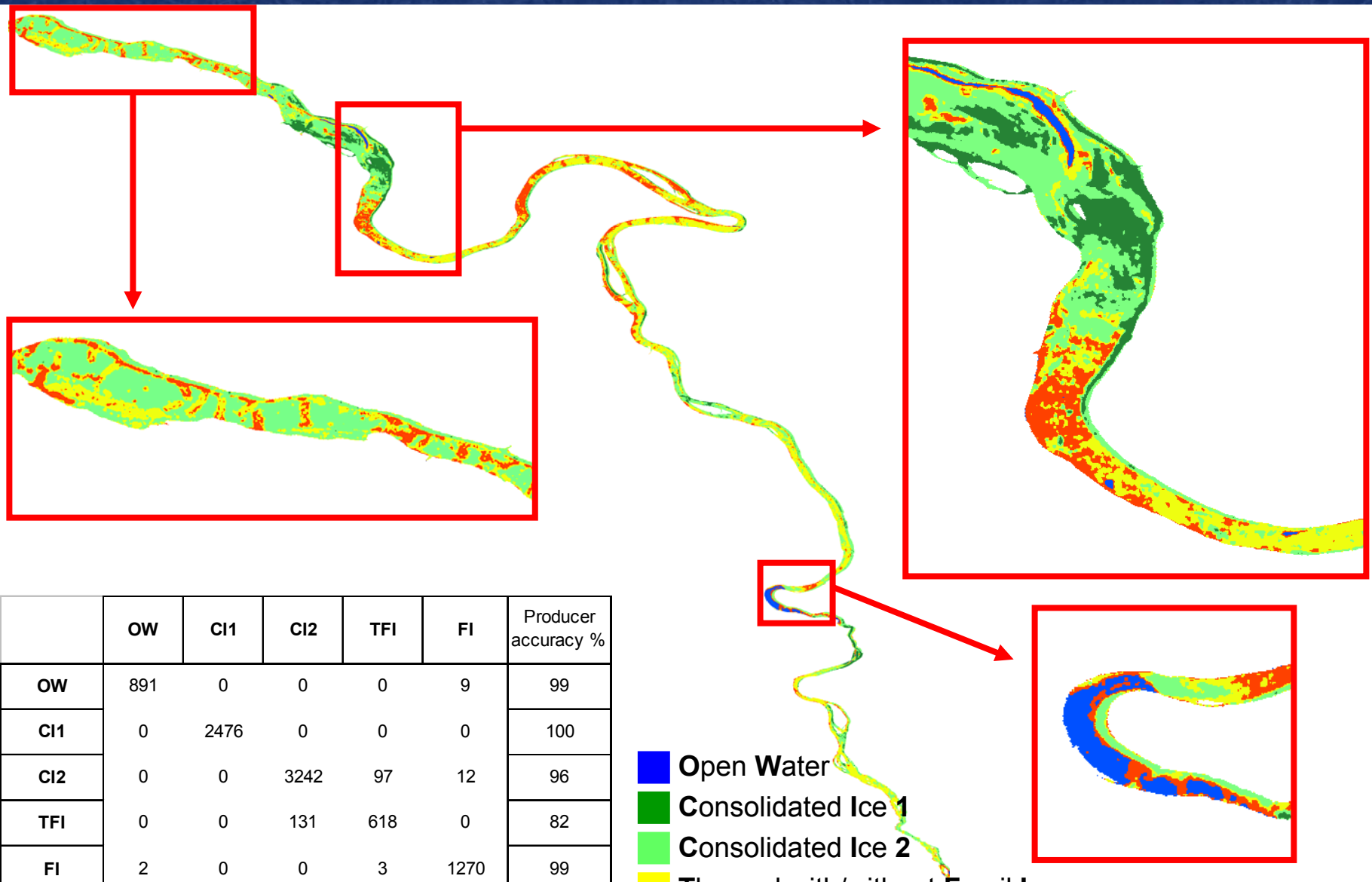
2 hybrid classifications

- Hierarchical + Wishart
- Hierarchical + SVM

Hybrid classifications

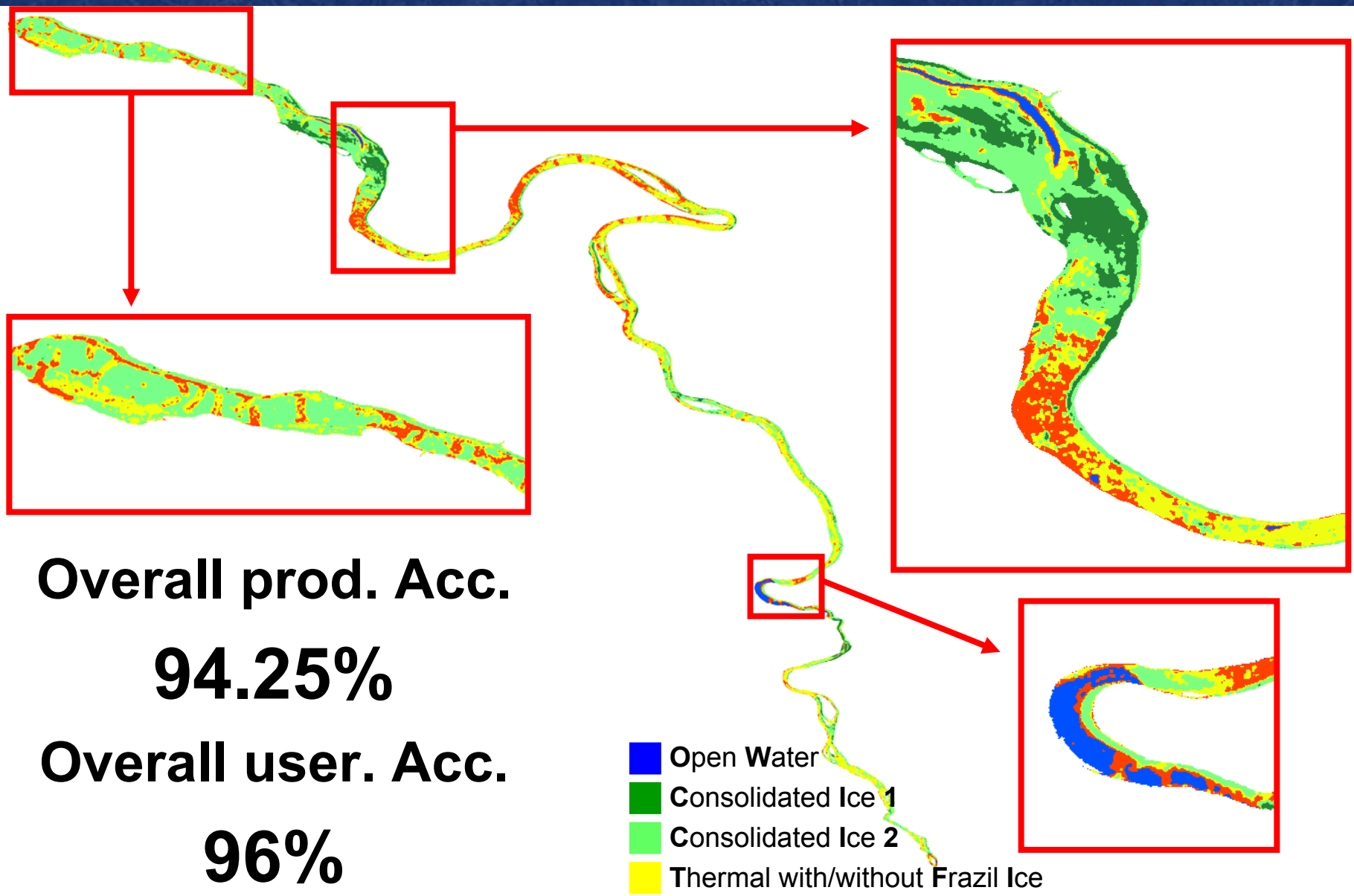


Hiera + Wishart classification



	OW	CI1	CI2	TFI	FI	Producer accuracy %
OW	891	0	0	0	9	99
CI1	0	2476	0	0	0	100
CI2	0	0	3242	97	12	96
TFI	0	0	131	618	0	82
FI	2	0	0	3	1270	99
User accuracy %	100	100	96	86	98	

Hiera + Wishart classification



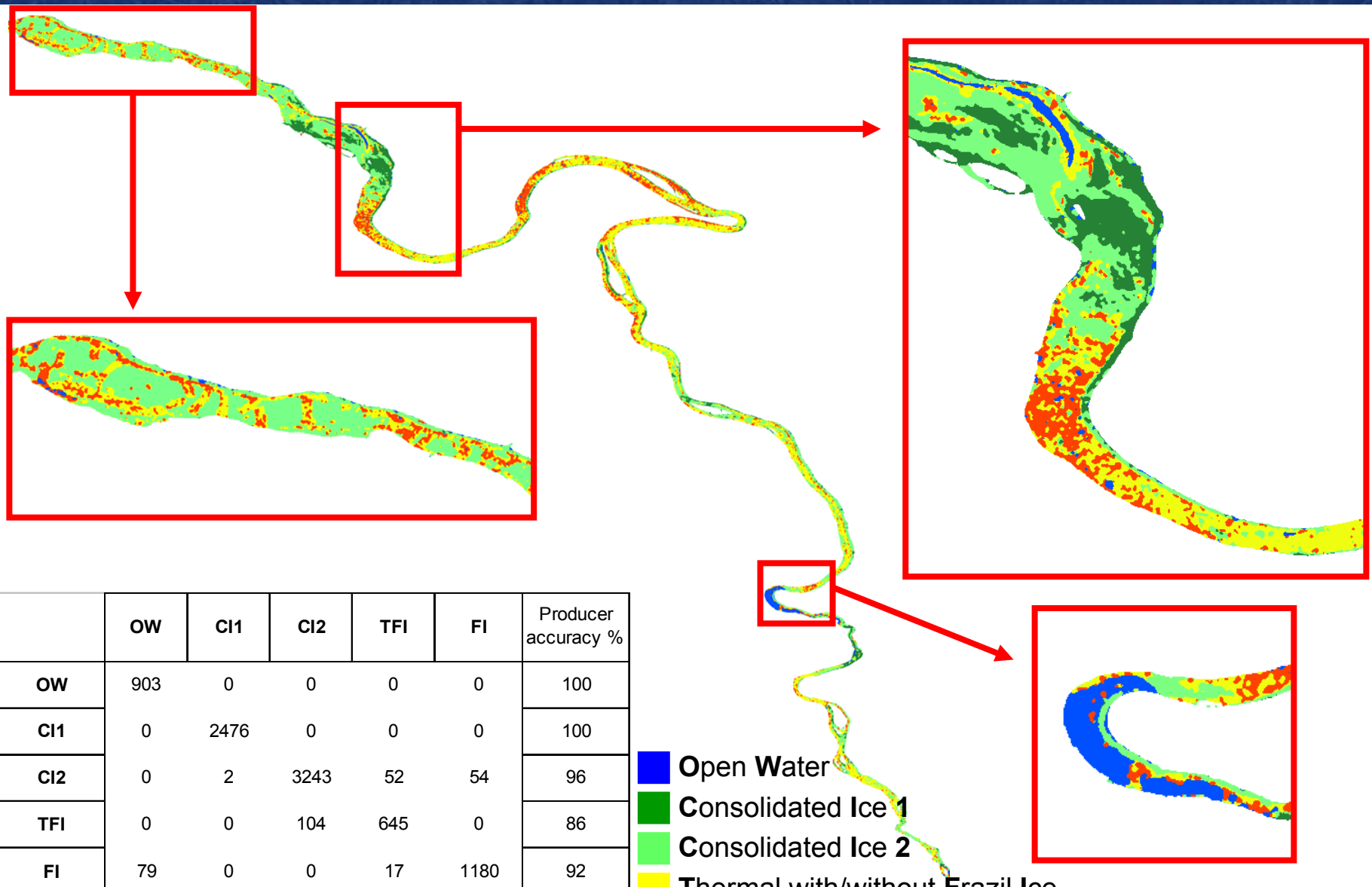
Overall prod. Acc.

94.25%

Overall user. Acc.

96%

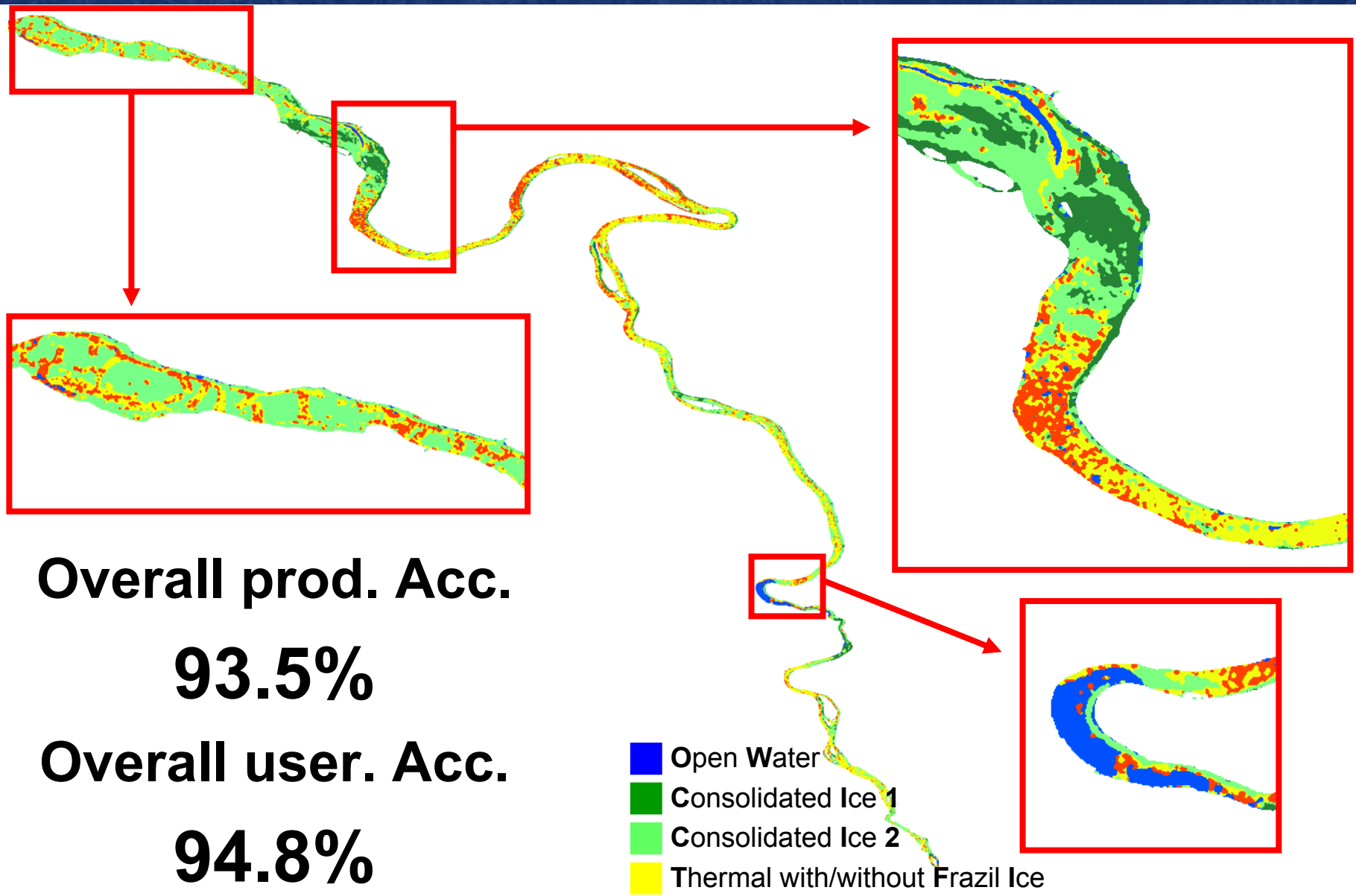
Hiera + SVM classification



	OW	CI1	CI2	TFI	FI	Producer accuracy %
OW	903	0	0	0	0	100
CI1	0	2476	0	0	0	100
CI2	0	2	3243	52	54	96
TFI	0	0	104	645	0	86
FI	79	0	0	17	1180	92
User accuracy %	92	100	96	91	95	

Open **W**ater
Consolidated **I**ce **1**
Consolidated **I**ce **2**
Thermal with/without **F**razil **I**ce
Frazil **I**ce

Hiera + SVM classification



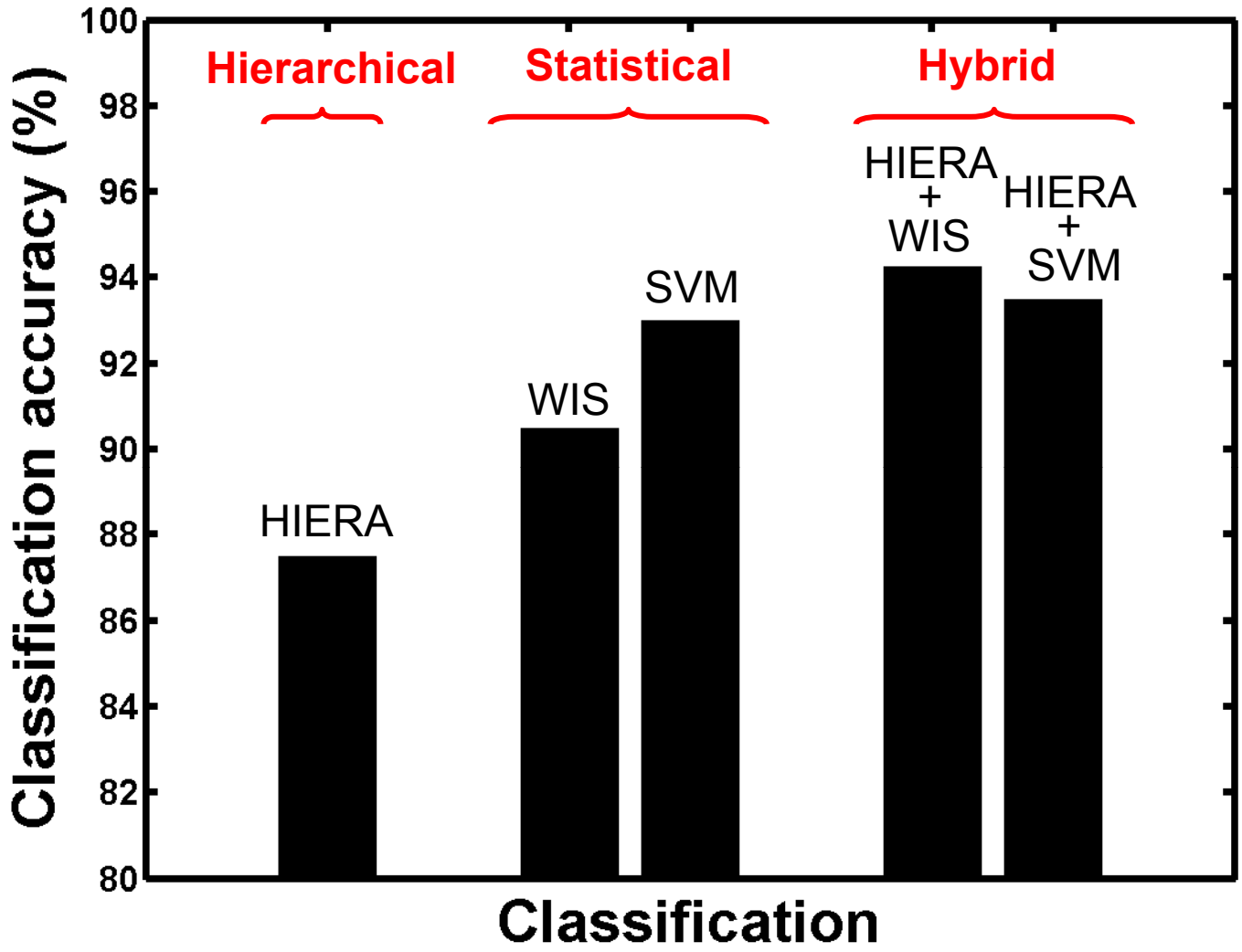
Overall prod. Acc.

93.5%

Overall user. Acc.

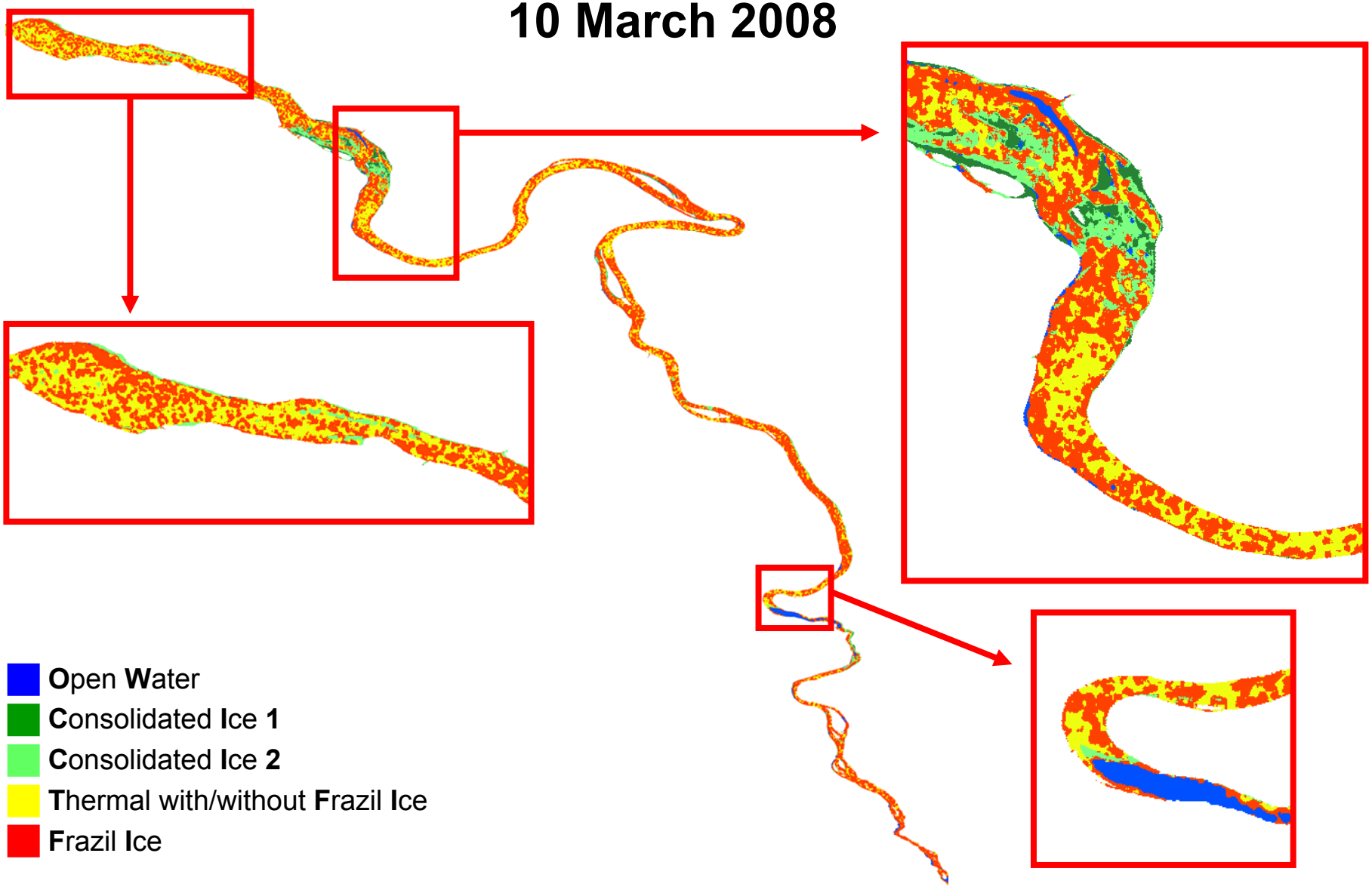
94.8%

Classification results

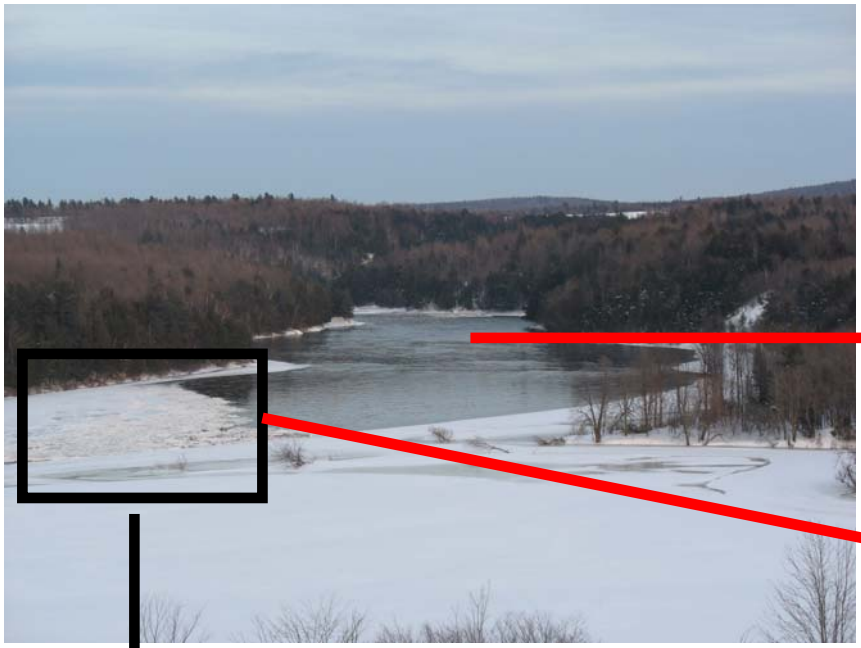


SVM test

10 March 2008

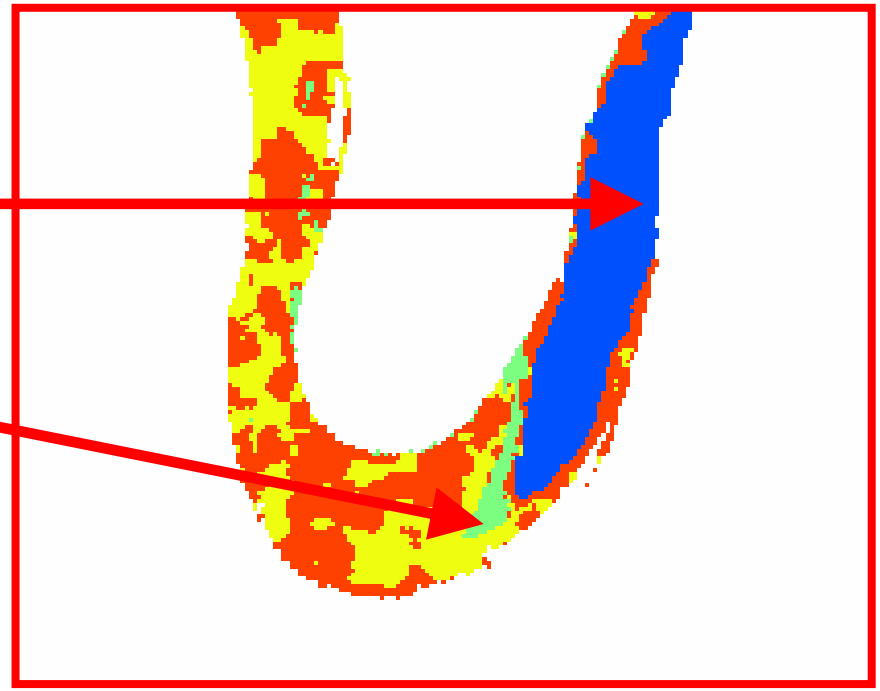


SVM test



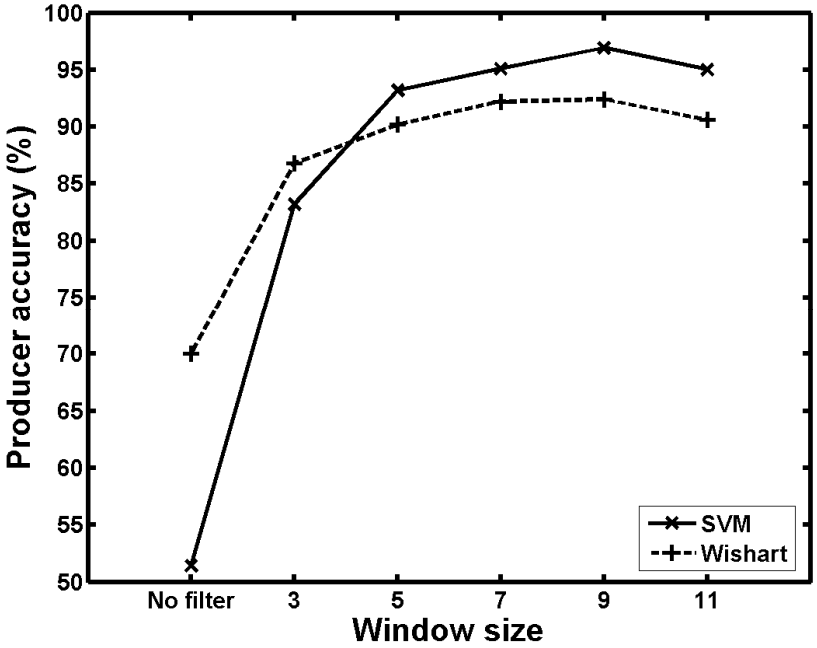
Zoom

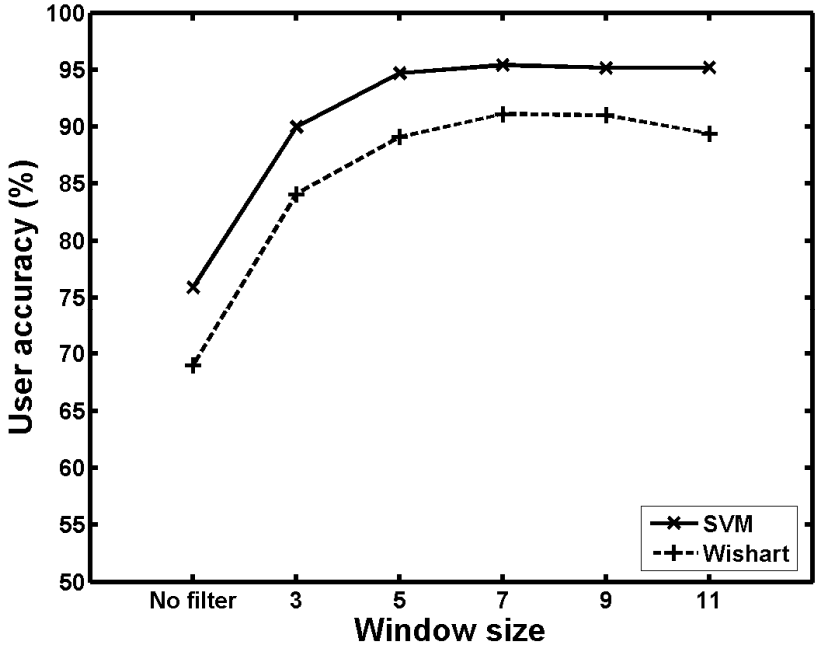
10 March 2008



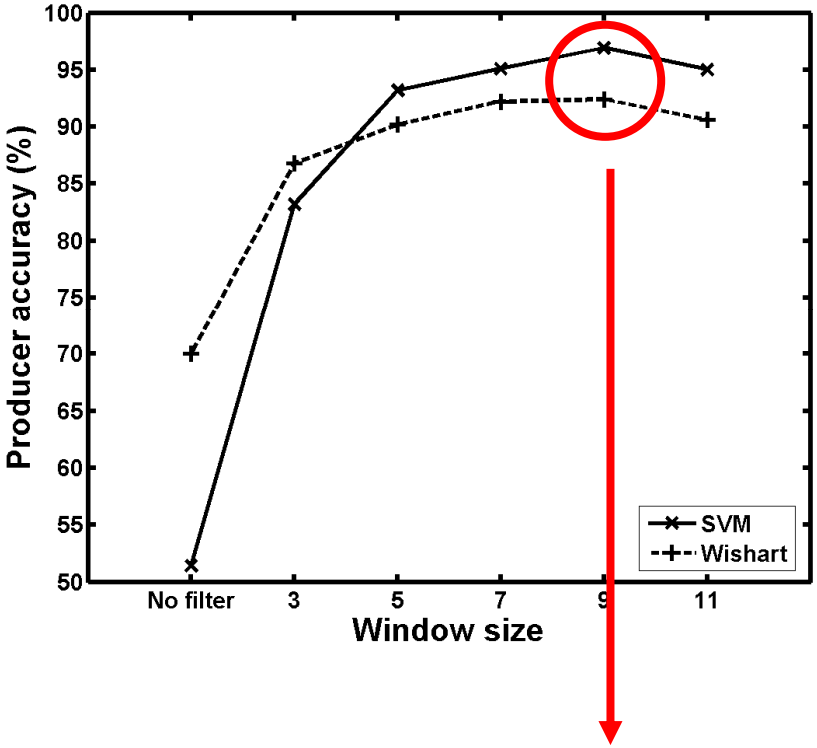
- **O**pen **W**ater
- **C**onsolidated **I**ce **1**
- **C**onsolidated **I**ce **2**
- **T**hermal with/without **F**razil **I**ce
- **F**razil **I**ce

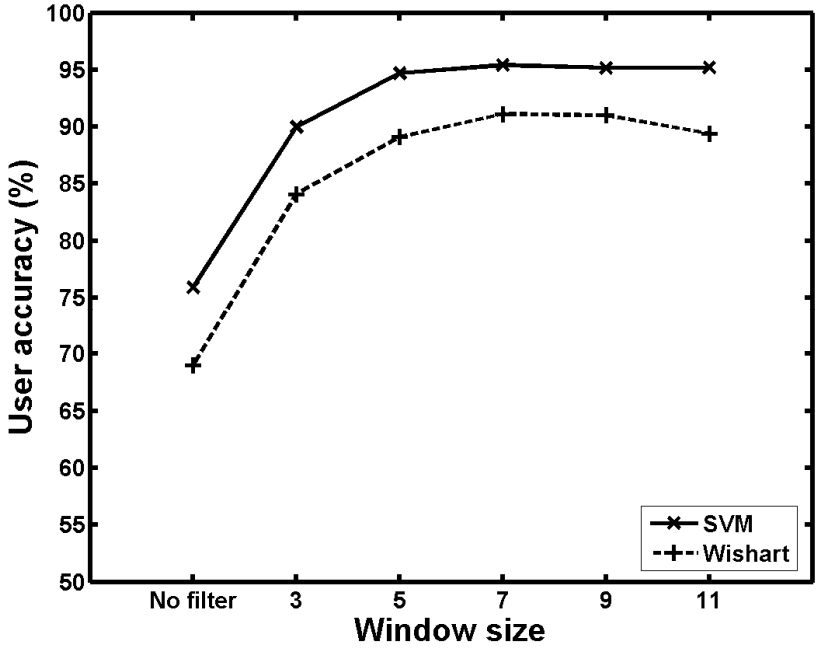
Classification optimization





Classification optimization





- Best statistical classification = **SVM**
- Best Lee speckle filter window size = **9**

1. Existing approaches

2. Study site and data

3. Results

4. Conclusion

Conclusions

The goal of this work:

To develop a tool which allows the segmentation of different river ice types

We proposed:

- Using **multi-polarized data**
- Using an electromagnetic river ice **model**

Results:

- No ambiguities between water and ice discrimination
- River ice types well detected at X-band
- Powerful hybrid classifications
- SVM more adaptable to other data than hierarchical classification

Outlook:

- Multi-frequency analysis (Radarsat-2 – Terrasar-X)
- Estimate physical parameters (thickness, density)