ESA–MOST China Dragon 4 Cooperation

→ ADVANCED TRAINING COURSE IN OCEAN AND COASTAL REMOTE SENSING

Applications of SAR Data for Coastal Marine Activity Monitoring

Zhang Xi (张晰) xi.zhang@fio.org.cn

The First Institute of Oceanography, Ministry of Natural Resources, China

12 to 17 November 2018 | Shenzhen University | P.R. China

Hosted by

Importance of Coastal Zone

- A coastal zone is the interface between the land and water.
- Coastal plays an important role in the economy of coastal nations.
  - Rich resources: fishery, petroleum, natural gas.
  - Lots of beautiful natural attractions: tourism and real estate.
- A majority zones of the population inhabit and human activities.
  - More than 70% of the world's megacities.
  - More than one billion people rely on the source in the zones.




Importance of Marine Activity Safety Monitoring

- Shipping accounts for more than half of the total marine activity.
- With the belt and road initiative, role of coastal shipping in China is accentuated.
- Need for means of monitoring vessel activity and provide navigation security.

Advantage of SAR

- Weather independent
- Day-and-night ability
- High resolution imaging
- Wide swath

Part I. Ship detection

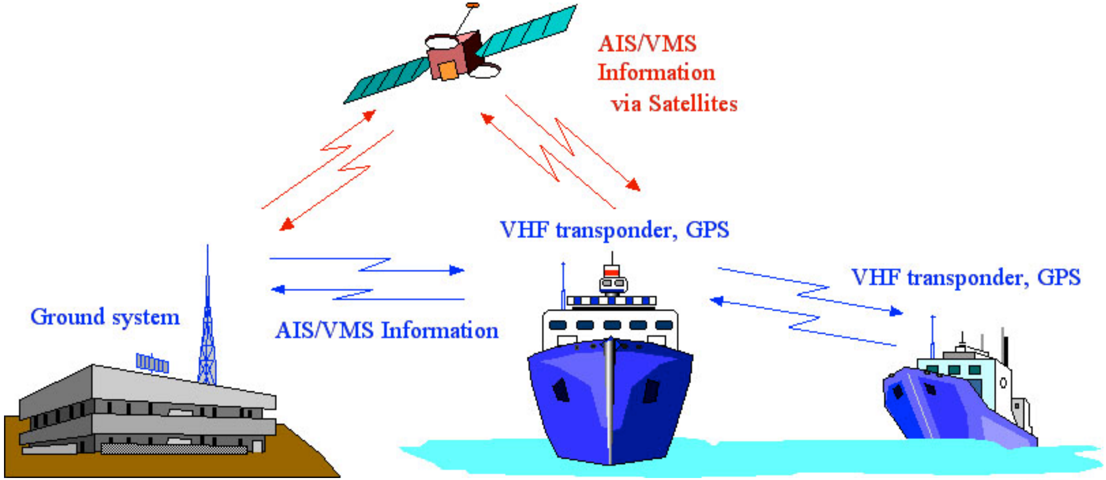
Marine human activity monitoring

Part II. Sea ice detection

Marine activity security monitoring

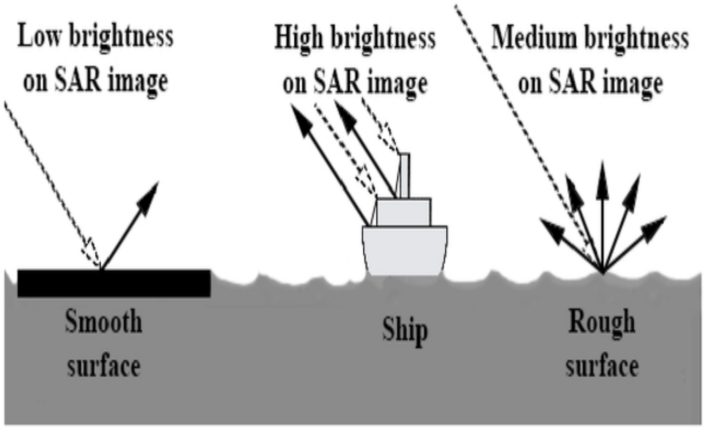
Part I. Ship detection by SAR

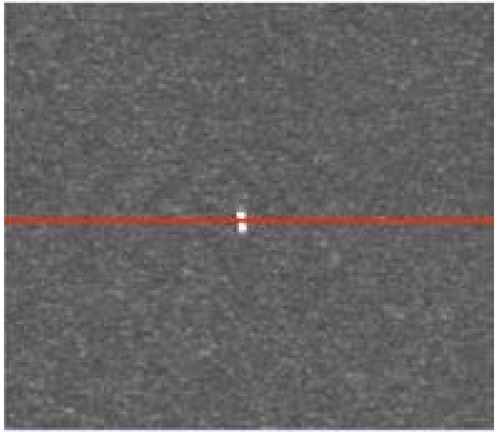
- Most of ship installed Automatic Identification System (AIS) which provides the real time static and dynamic information of ship.
- Problem of ships without AIS signals: illegal ship, poaching boat, smuggler.
- Need for vessel monitoring systems from space with SAR.

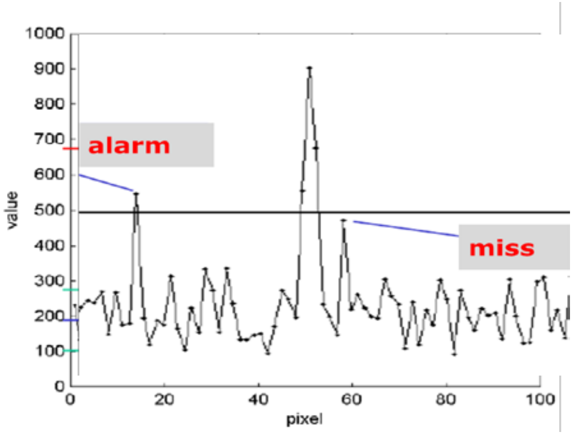


(1) Threshold method

- Ship target returns significant backscattering, because it contains corner-shaped structures.
- The value of target pixel is compared with the statistical values (mean, standard deviation) of background.
- Threshold is unreliable, and doesn't work in most situations.

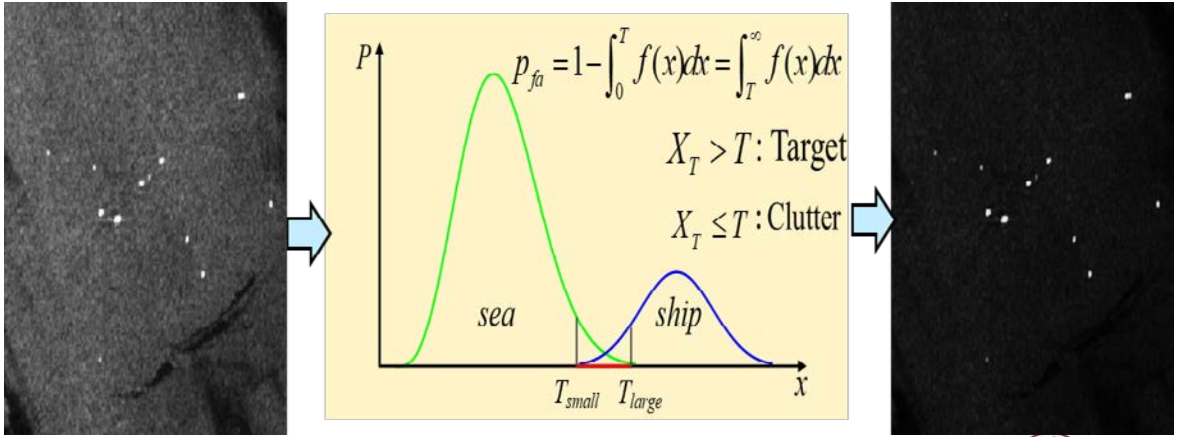






(2) Constant false alarm rate (CFAR)

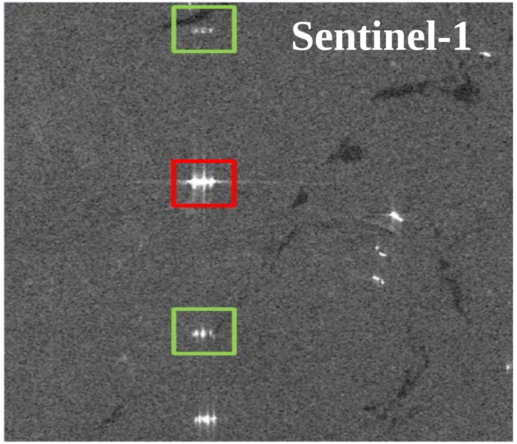
- Get a property of threshold that maintain an approximately constant rate of false target detections when the clutter are variable.
- Requirements: accurate fitting the clutter scenario.
- Performance: suitable for most situations, accuracy≥80%.



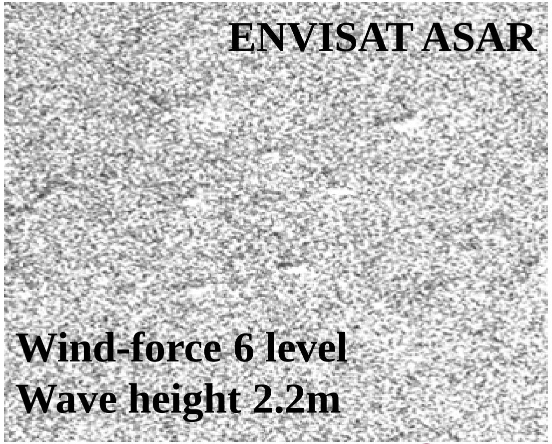
Model	PDF
WBL	$f_A(x) = \frac{\gamma}{\sigma^{\gamma}}(x)^{\gamma-1}\exp[-(\frac{x}{\sigma})^{\gamma}], x, \gamma, \sigma > 0$
LGN	$f_A(x) = \frac{1}{\sqrt{2\pi}\sigma x}\exp[-\frac{(\ln x - m)^2}{2\sigma^2}], \sigma > 0, m \in R$
G⁰	$f_A(x) = \frac{2L^L(L-\alpha)}{\Gamma^{\alpha}\Gamma(L)\Gamma(-\alpha)}\frac{x^{2L-1}}{(\gamma + Lx^2)^{L-\alpha}}, x, L, \gamma > 0, \alpha < 0$
K-root	$f_A(x) = \frac{4}{\Gamma(L)\Gamma(\gamma)}(\frac{L\gamma}{\mu})^{\frac{L+\gamma}{2}} x^{L+\gamma-1} K_{\lambda-L}(2x\sqrt{\frac{L\gamma}{\mu}}), x > 0$
GΓD	$f_A(x) = \frac{\lvert\gamma\rvert \kappa^{\kappa}}{\sigma\Gamma(\kappa)}(\frac{x}{\sigma})^{\kappa\gamma-1}\exp[-\kappa(\frac{x}{\sigma})^{\gamma}], x \in R^+$

Disadvantages of CFAR

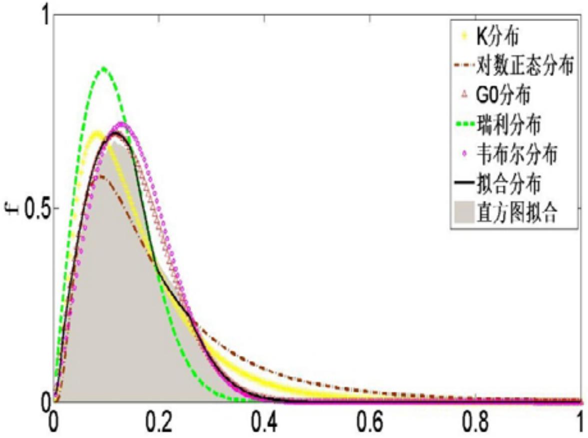
- False alarms which have high scattering: azimuth ambiguity.
- Loss targets which have low RCS: especially high sea state in which clutter can submergence vessel targets.
- Depended on the accuracy of sea clutter fitting.



Azimuth ambiguity

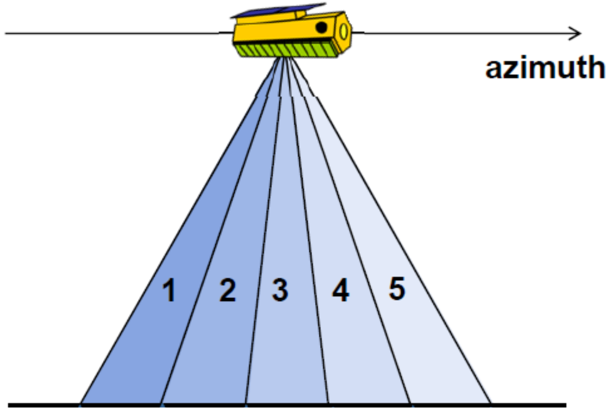


High sea state

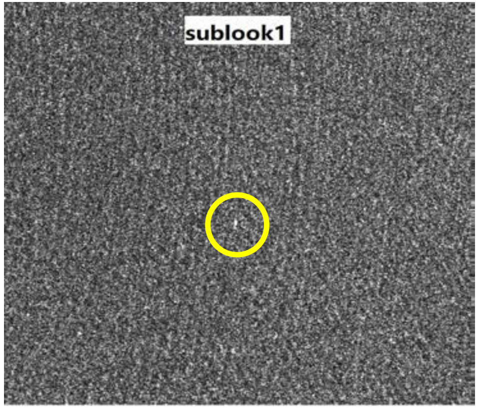


(3) Multi-Look Cross Correlation (MLCC)

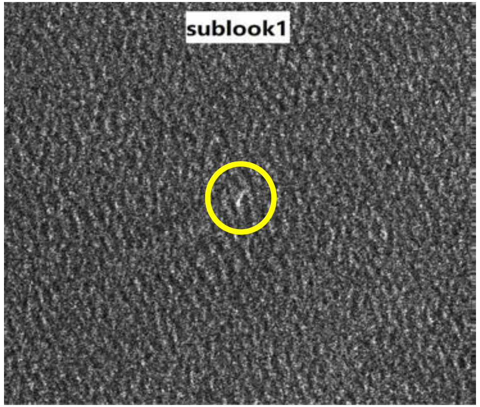
- For realizing high resolution in azimuth direction, SAR needs illuminating a zone in an integration time.
- Splitting the illuminating beam into two or more sub-beams, so that center time of each look is difference.
- Ships are deterministic targets, so their inter-look sub-images possess higher coherence than the uncorrelated random images of the sea surface and azimuth ambiguity.



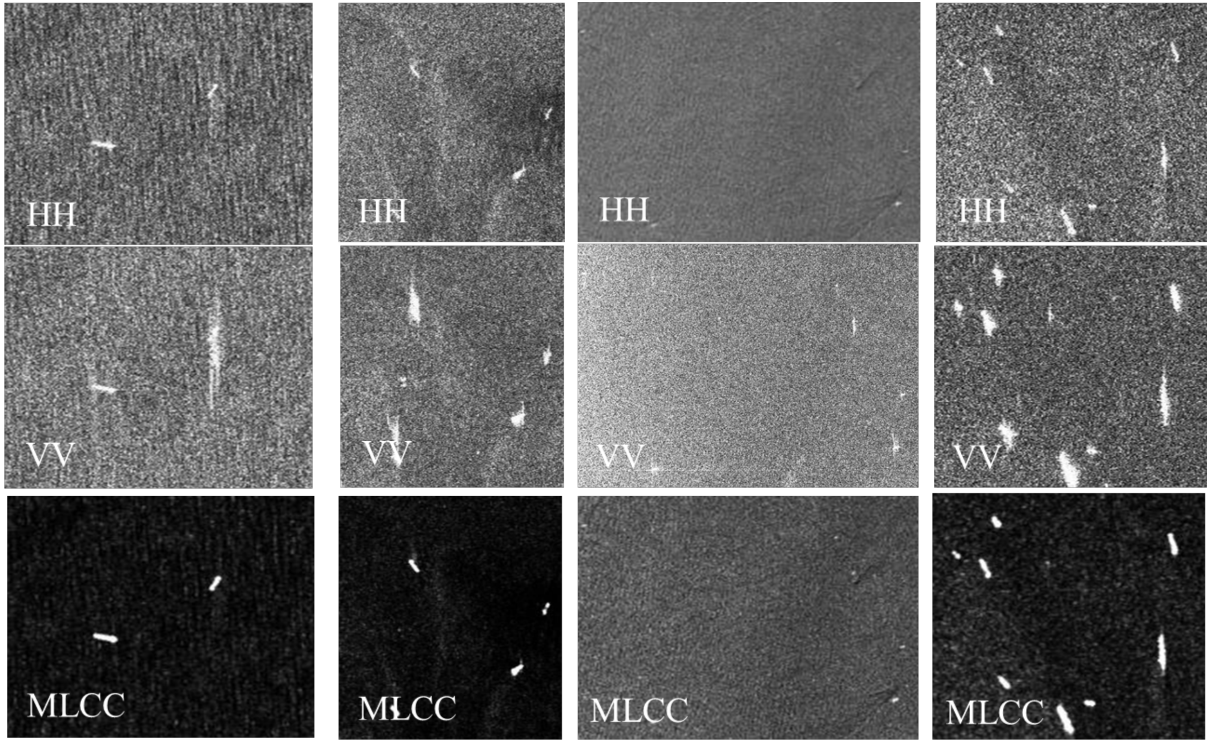
SAR imaging and sub-look



Azimuth ambiguity and dynamic sea surface

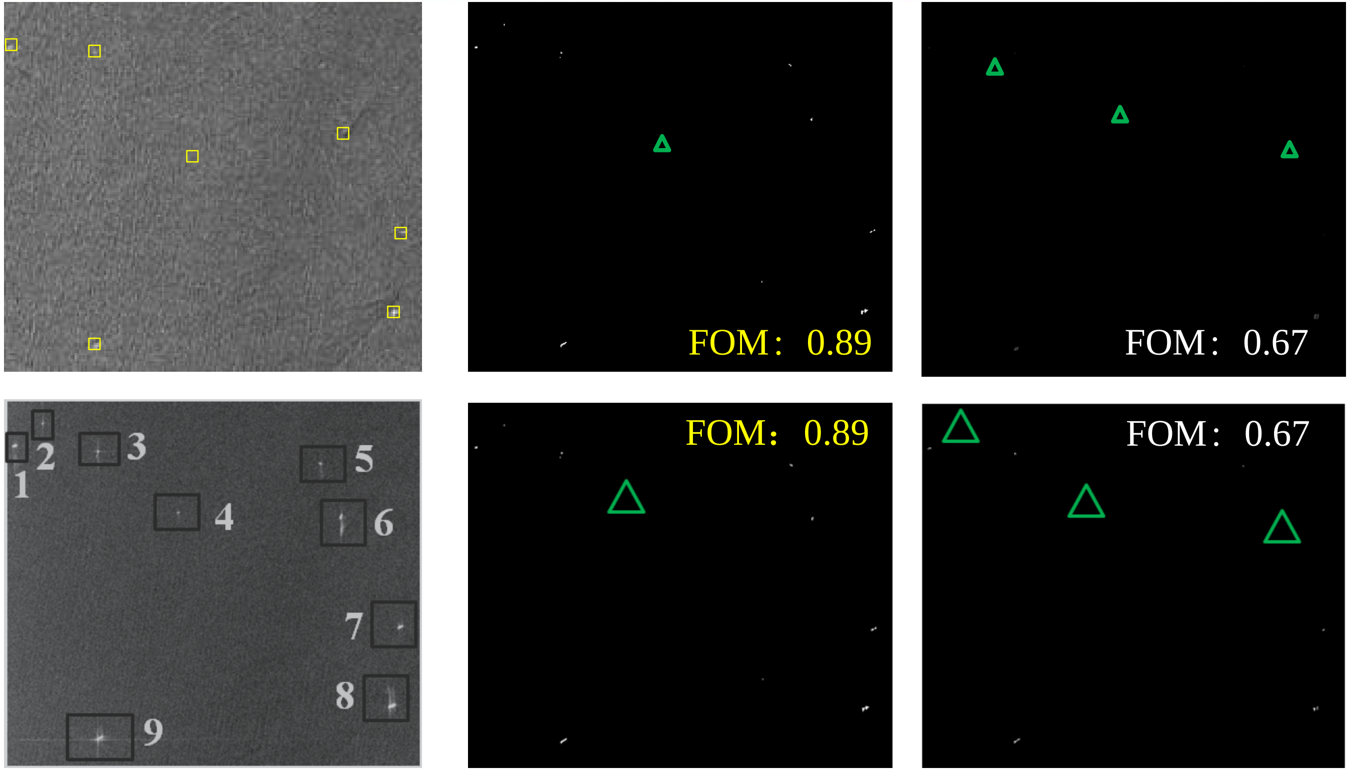


Ship target and dynamic sea surface



	SCR（dB）			
	1#	2#	3#	4#
MLCC	**40.84**	**38.96**	**29.31**	**31.81**
VV	12.19	11.45	8.10	7.63
HH	13.45	16.02	16.51	15.94

MLCC can dramatically improve SCR, compared with HH, SCRs increase 27, 22, 13, 16dB.



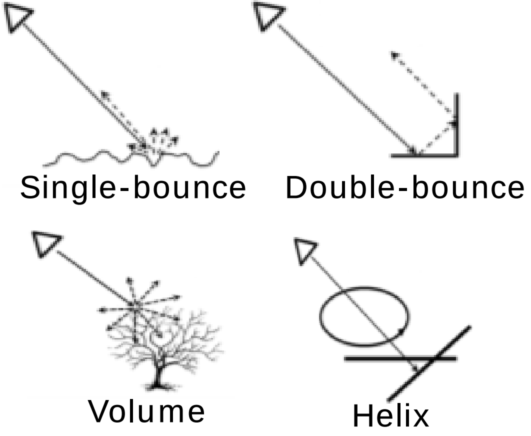
Sentinel-1 HH MLCC CFAR

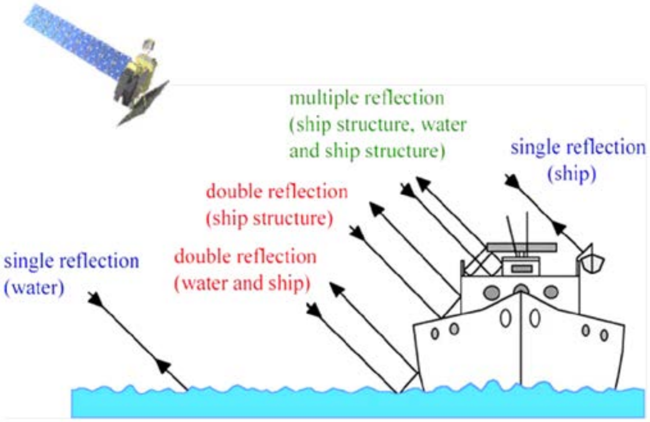
△ Loss ○ false

$$FOM = \frac{N_{tt}}{N_{fa} + N_{gt}}$$

(4) Polarimetric filter

- Polarimetric SAR provides more information than single-polarization data.
- Scattering components can be decomposed from PolSAR returns.
- Ship consists of single-bounced, double-bounced and multi-bounced reflection.
- In the case of sea surface, single-bounced is the mainly scattering component.



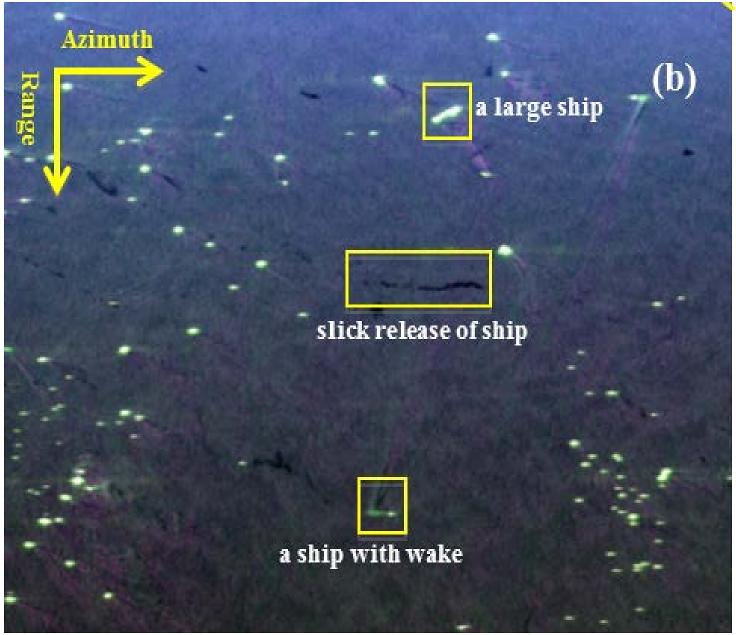


A simply filter can be used to distinguish ships from sea background.

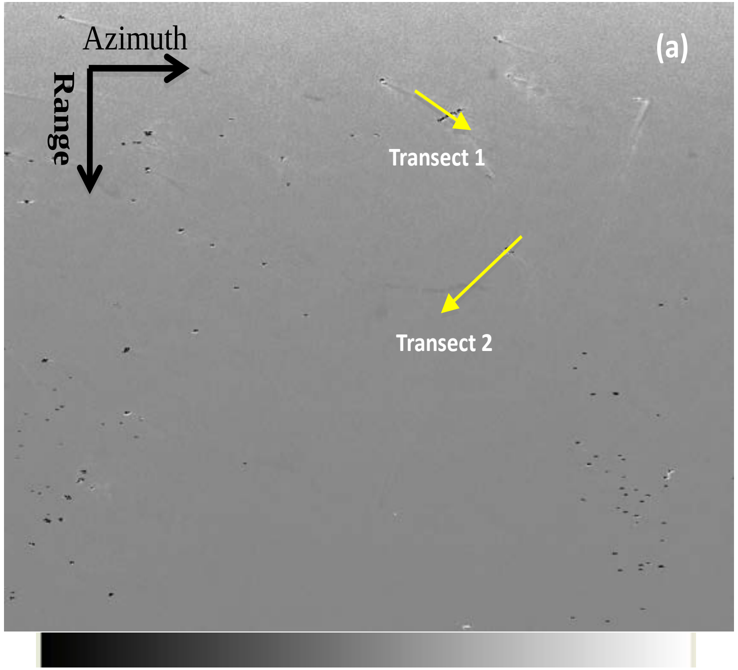
Don't need clutter fitting!

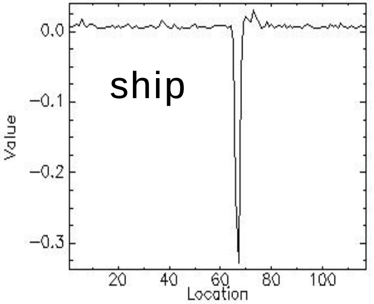
$$\begin{cases} \mathrm{Re}\left(\left\langle s_{hh} s_{vv}^{*} \right\rangle\right) < 0: & \text{ship target} \\ \mathrm{Re}\left(\left\langle s_{hh} s_{vv}^{*} \right\rangle\right) \geq 0: & \text{sea surface} \end{cases}$$

conjugate product of co-polarization (CPC)

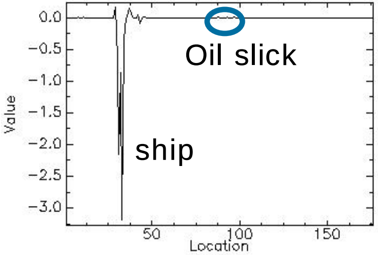


UAV-SAR



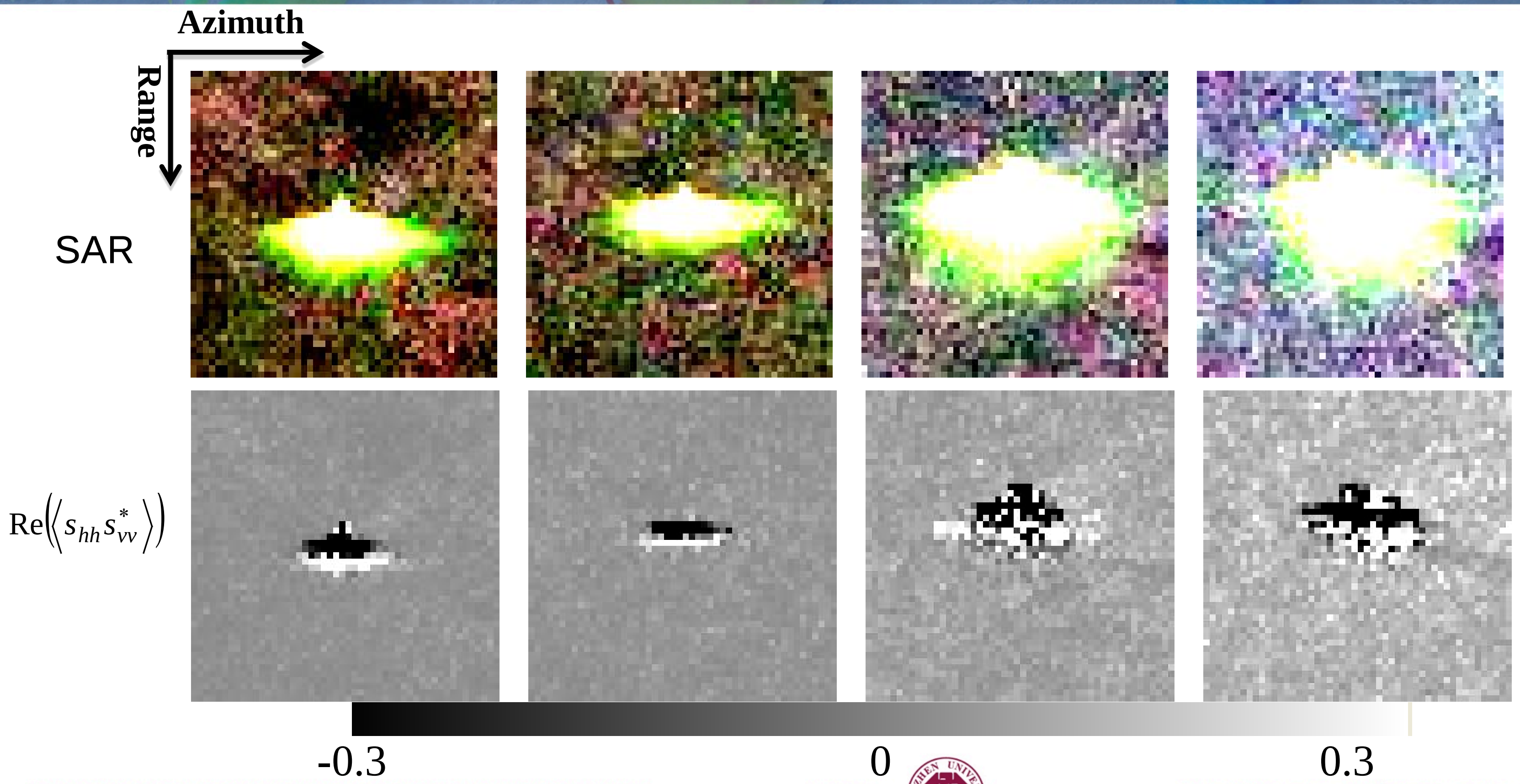


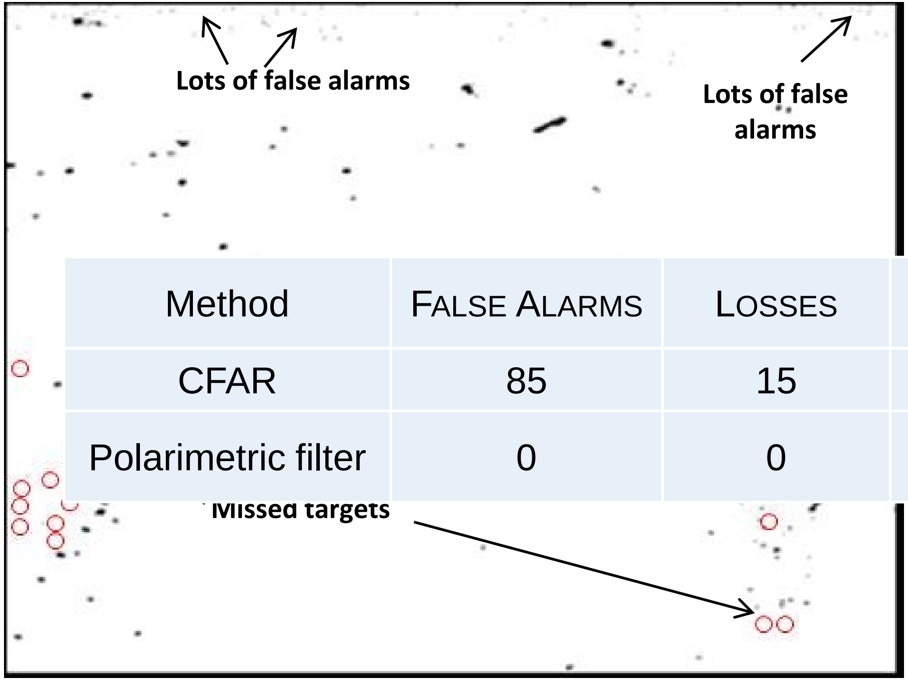
(b) Transect 1



(c) Transect 2

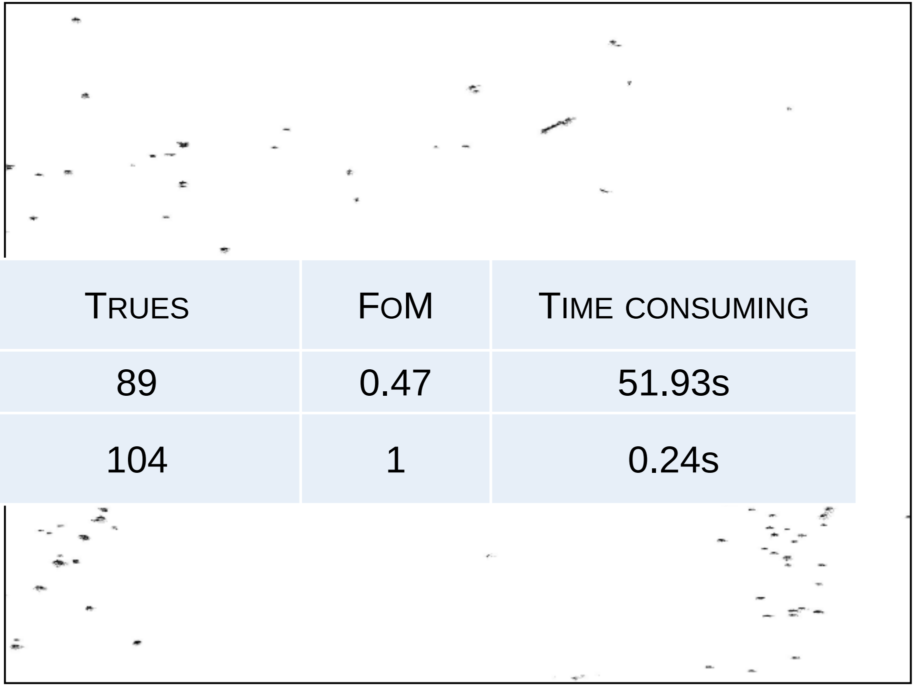
$$\mathrm{Re}\left(\left\langle s_{hh} s_{vv}^{*} \right\rangle\right)$$


Azimuth
Range
SAR
$\mathrm{Re}\left(\left\langle s_{hh} s_{vv}^{*} \right\rangle\right)$
-0.3
0
0.3



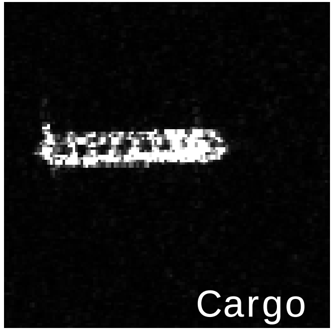
Method	False Alarms	Losses	Trues	FoM	Time consuming
CFAR	85	15	89	0.47	51.93s
Polarimetric filter	0	0	104	1	0.24s

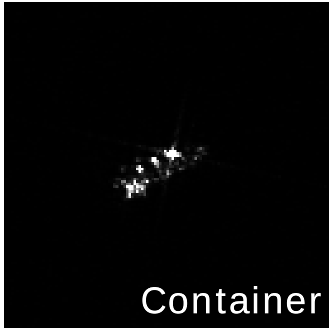
Result of CFAR

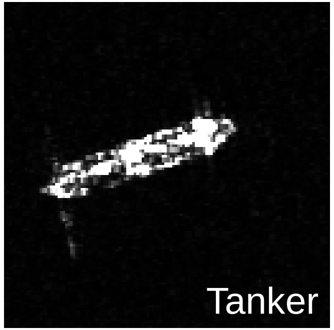


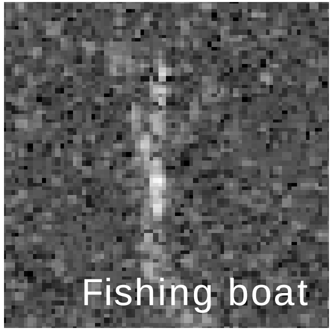
Result of Polarimetric filter

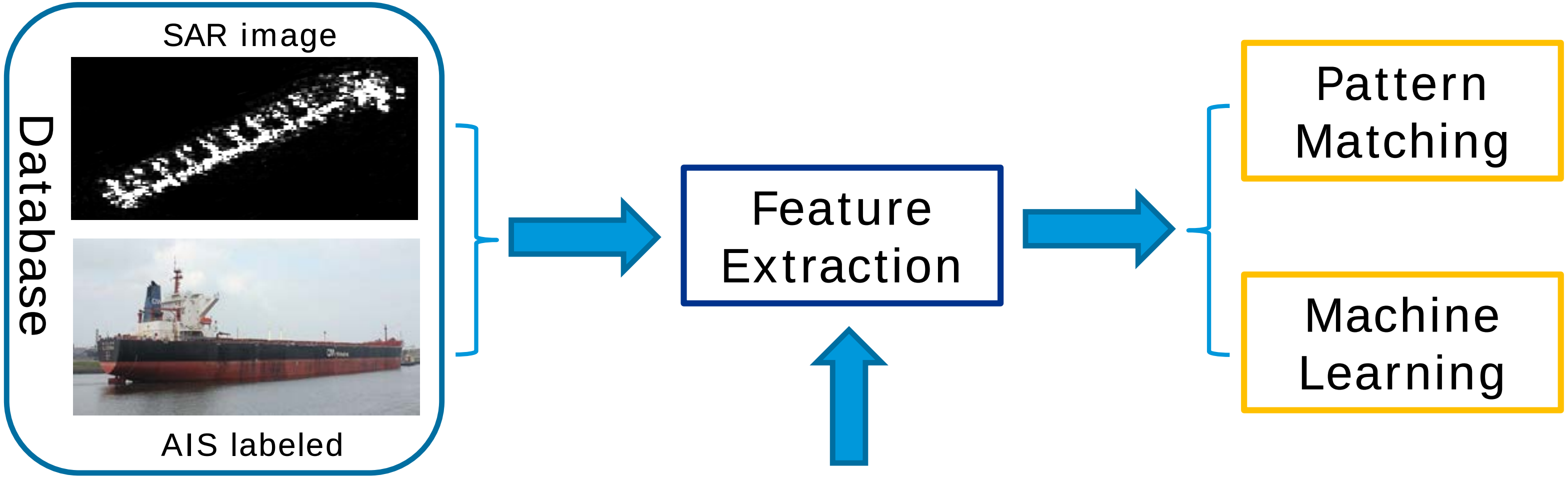
2. Ship Classification Algorithms









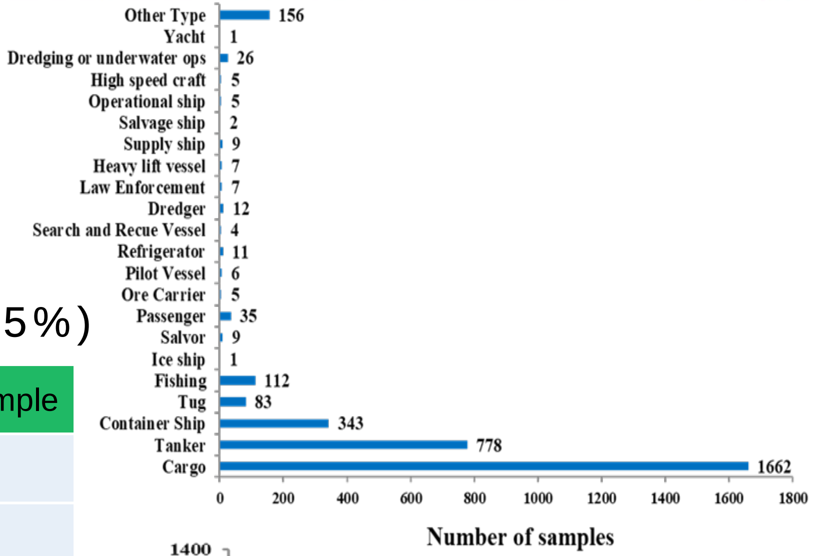


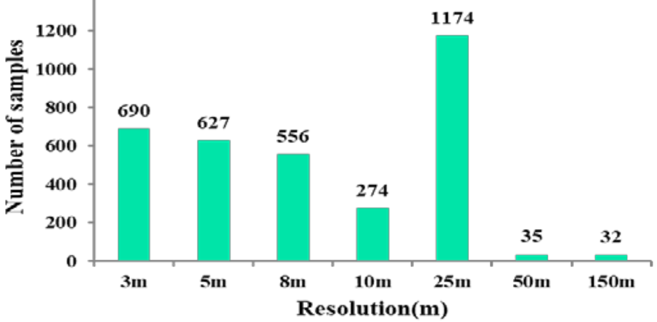
Possible features:

- Length, width, contour
- Moments of inertia
- Fractal measures
- Intensity of pixels
- Polarimetric parameters
- Attributed Scattering Center

(1) Ship samples database

- 101 SAR images; 3388 samples;
- More than 20 categories;
- Three bands; multi-polarization;
- 1873 samples’ resolution higher than 8m (55%)





Satellite	Polarization	Incident angle	No. SAR	No. Sample
RADARSAT-2	HH/HV/VV/VH	22—43	27	967
TerraSAR-X	HH/HV/VV	29—45	7	116
ENVISAT ASAR	VV	20—34	1	32
UAVSAR	HH/HV/VV/VH	60—80	6	51
GF-3	HH/HV/VV/VH	20—50	59	1798
Sentinel-1	VV/VH	35—45	3	424

(2) Ship classification by moderate-resolution SAR

Although from moderate-resolution SAR (30~50m) we can’t see much more details of ship, the swath is large compared with high resolution SAR.

3 ship categories

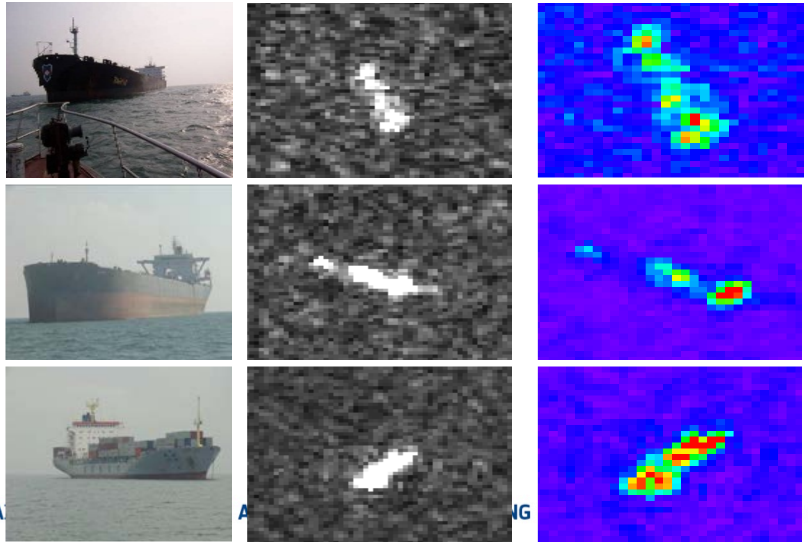
ENVISAT ASAR 30m

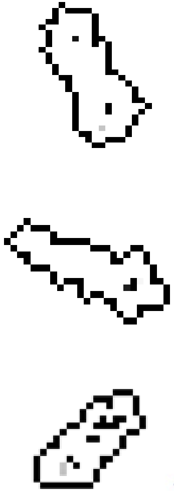
Scattering Center + Pattern Matching

Cargo

Tanker

Container ship





100 ships with AIS

	Cargo	Tanker	Container	Accuracy
Cargo	41	27	2	58.57%
Tanker	7	14	1	63.64%
Container	0	1	7	85.7%
Accuracy				62%

(3) Ship classification by high-resolution SAR

- Selecting discriminate features and constructing an appropriate classifier are two essential factors for HR SAR ship classification.
- According to our comprehensive analysis, we find an optimal combination of features and classifier which has the highest ship classification accuracy in SAR-AIS matched samples.

Nonredundant complementary feature subset in all 21 features

- ship length
- ship perimeter
- mean of RCS
- mean/std of RCS

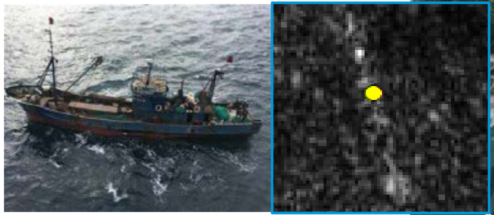
Optimal classifier for selected features

- Naive Bayes
- Minimum distance
- Decision tree
- KNN
- SVM

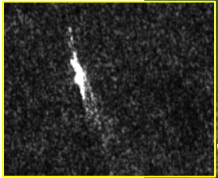
For cargo, tanker, container ship classification accuracy ~90%

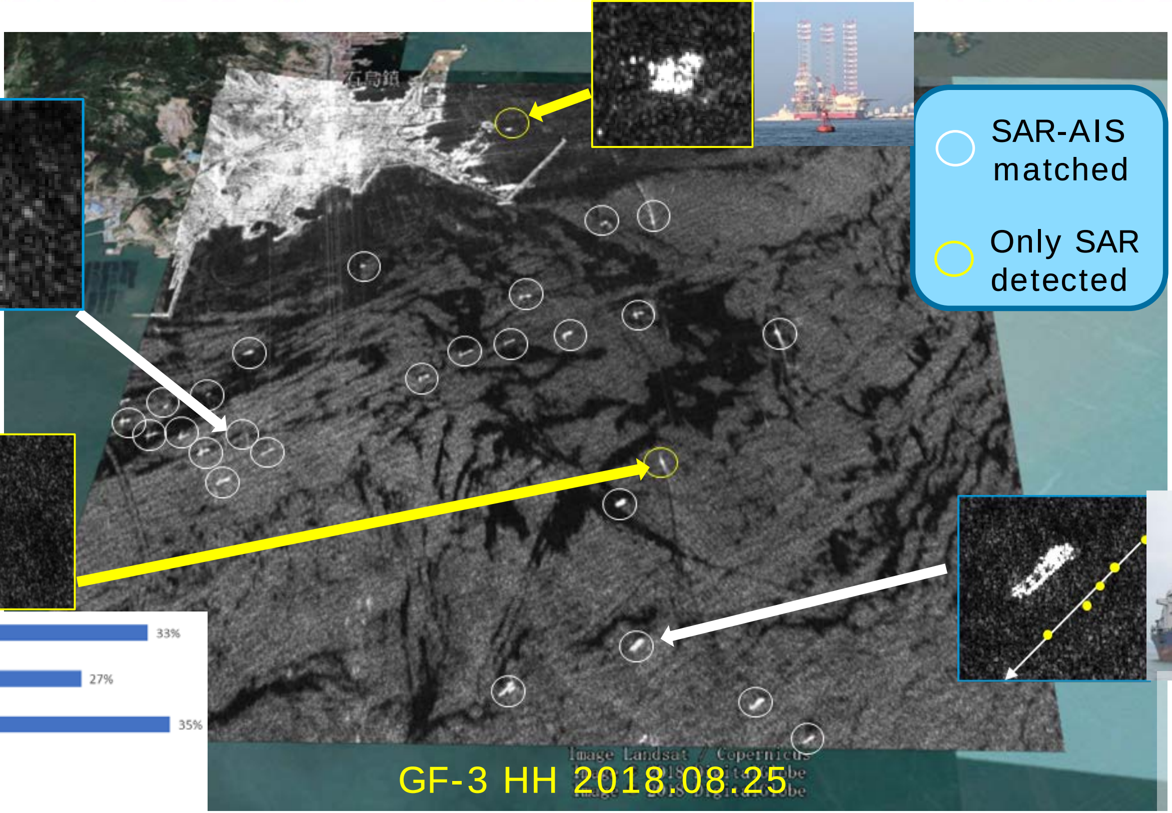
Accuracy depends on the number and types of categories!!!

3. Ship monitoring application

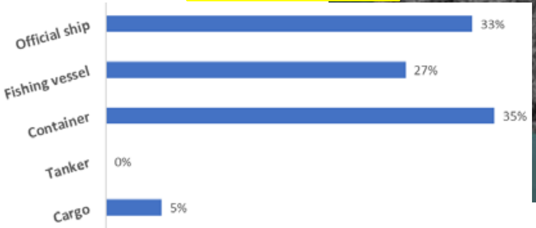


Name : Ivrongyuyun
Type : Fishing boat
Length : 26m
Width : 6m





Name : Ronghai1
Type : Cargo
Length : 149m
Width : 21m



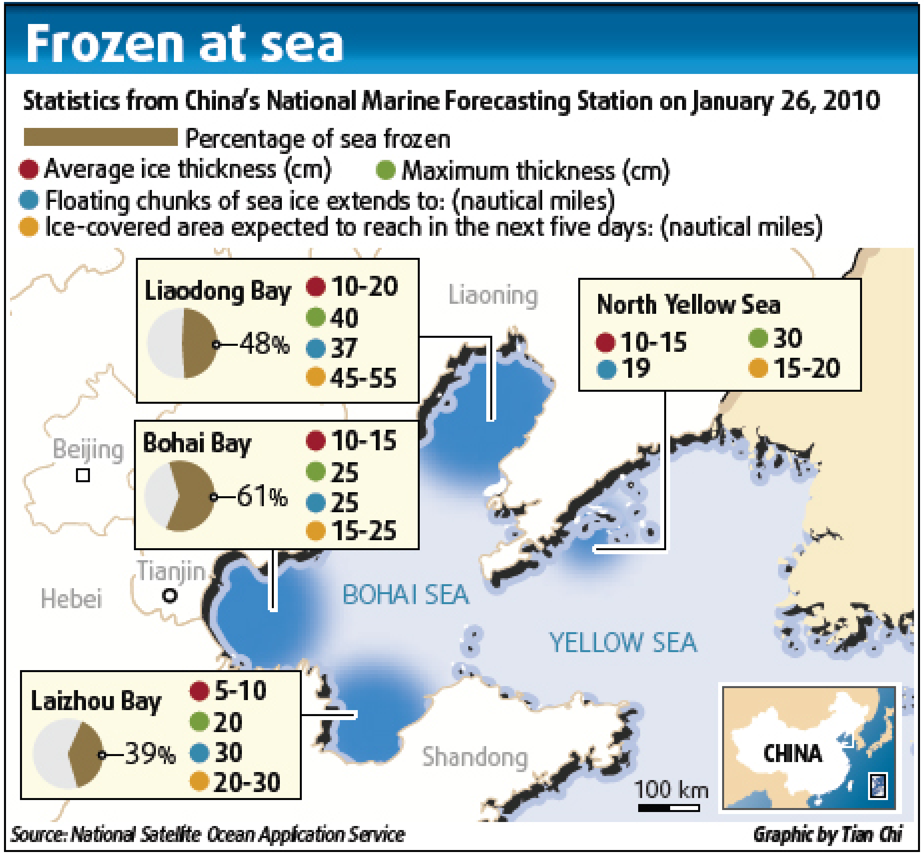
Part II. Sea ice monitoring by SAR

Motivation of sea ice monitoring

- The region surrounding the Bohai Sea accounts for about 23% of China’s GDP.
- Most of ships in the Bohai Sea have not ice breaking capabilities.
- Sea ice seriously threatens marine navigation and engineering safety.

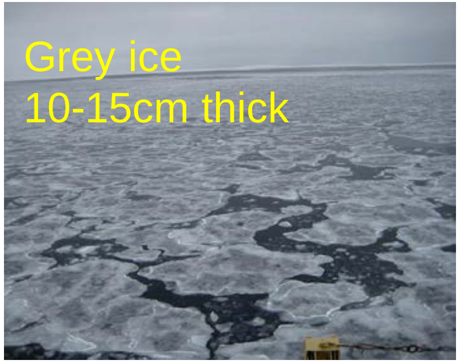
Ice information requirements

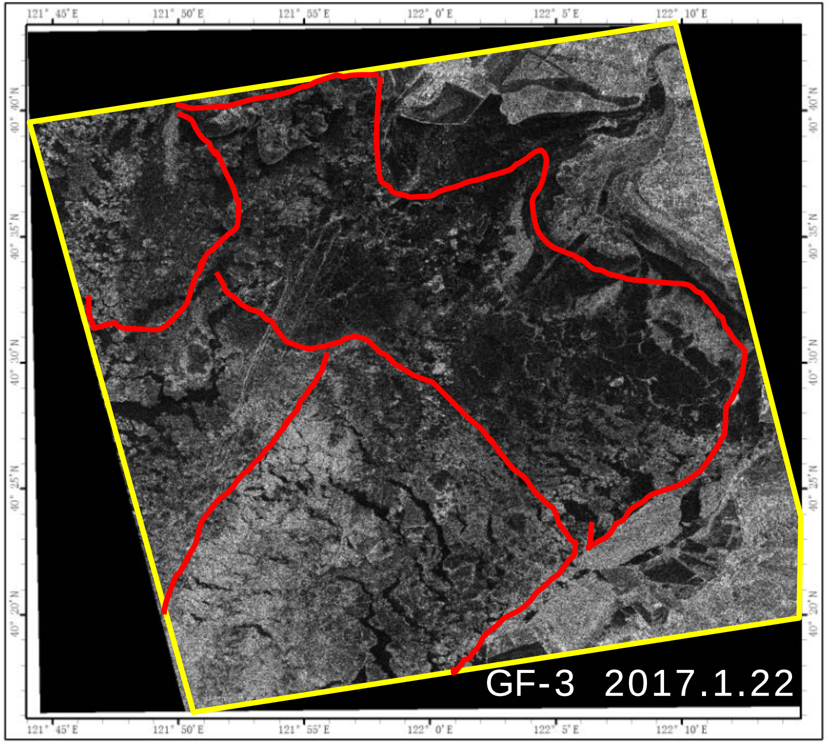
- Ice type (charting)
- Ice thickness
- Ice velocity



1. Sea ice classification and charting

(1) Sea ice characteristic in the Bohai sea



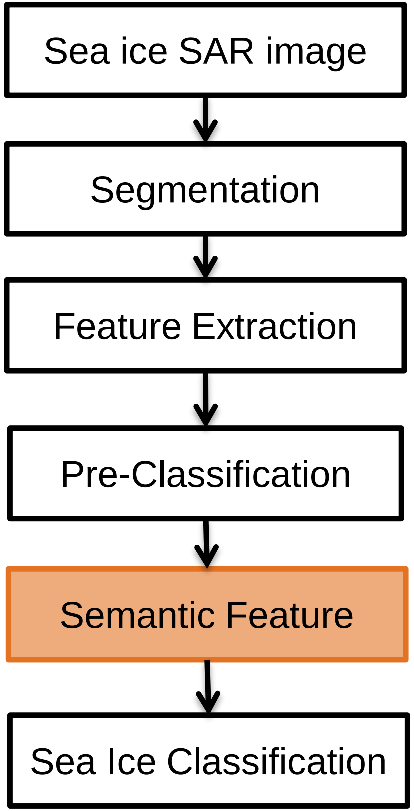


(2) Sematic feature

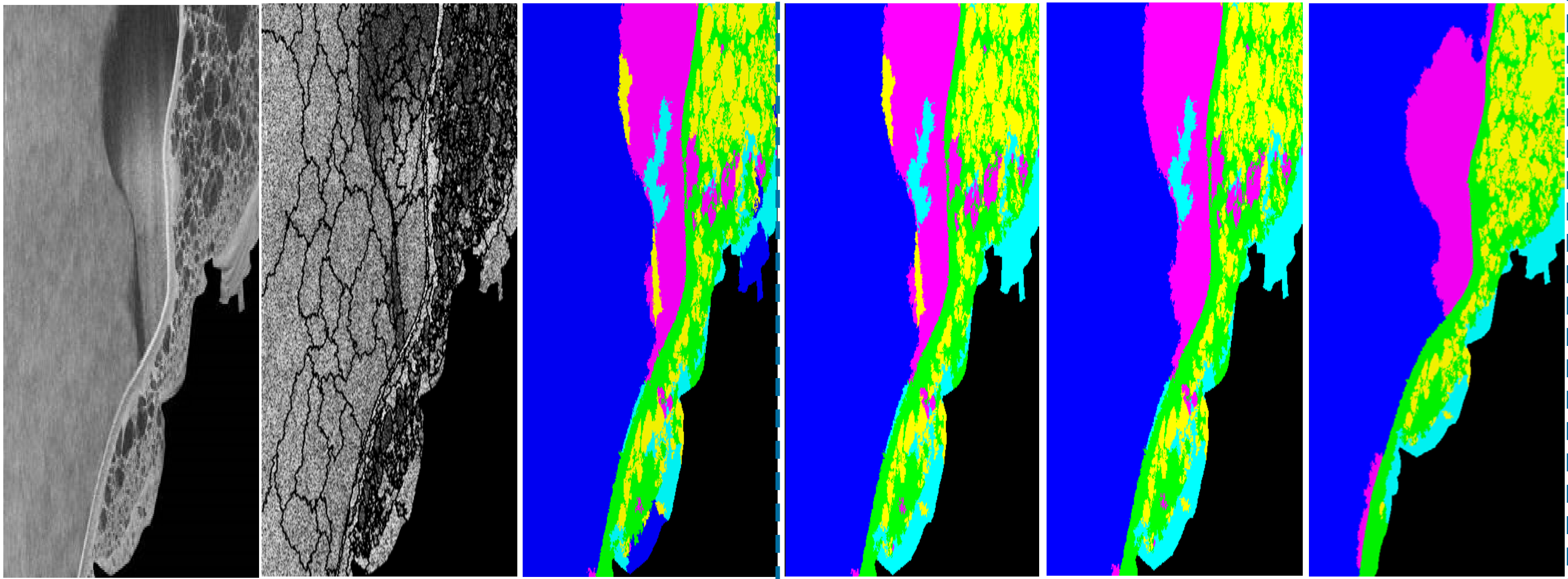
- Geometry characterization:
  - Grey ice is rounded
  - New ice more rectangular
  - ....
- Spatial relationship characterization:
  - Grey ice symbiotic with grey-white ice
  - Land fast ice is adjacent to land
  - ......

伴生关系	应用对象		对应伴生关系的描述	
	误判类别	应属类别		
固定冰与陆地相接	初生冰、初期冰、一年冰	固定冰	固定冰与陆地的邻接距离为0，而初生冰、灰冰和灰白冰等类型与陆地的邻接距离大于零，由此可将误判斑块归为固定冰。	设初生冰、灰冰和灰白冰等类型斑块到陆地的距离为d，则：当$d = 0$时，斑块类型修正为固定冰。
海水和初生冰相接	固定冰	初生冰	海水与初生冰的邻接距离为0，固定冰与海水的邻接距离大于零，由此可将误判斑块归为初生冰。	设固定冰斑块到海水的距离为d，则：当$d = 0$时，斑块类型修正为初生冰。
海水和初生冰的包围度	海水	初生冰	如果误判海水斑块完全被初生冰包围，面积小于一定阈值，则可被修正为初生冰。	设B_{ij}中i代表海水，j代表初生冰，若海水斑块面积为S_i，则：当$B_{ij} \geq 0.9$，且$S_i \leq S_t$时，斑块类型修正为初生冰。
海水和初生冰的包围度	初生冰	海水	如果误判初生冰斑块完全被海水包围，且面积小于一定阈值，则可被修正为海水。	设B_{ij}中i代表初生冰，j代表海水，若初生冰斑块面积为S_i，则：当$B_{ij} \geq 0.9$，且$S_i \leq S_t$时，斑块类型修正为海水。

伴生关系	应用对象		对应伴生关系的描述	
	误判类别	应属类别		
海水和灰冰的包围度	海水	灰冰	如果误判海水斑块被灰冰的包围程度大于一定阈值，则可被修正为灰冰。	设B_{ij}中i代表海水，j代表灰冰，则：当$B_{ij} \geq B_t$时，斑块类型修正为灰冰。一般情况下，B_t在0.6~0.7之间。
初生冰和灰冰的包围度	灰冰	初生冰	如果误判灰冰斑块被初生冰包围程度大于一定阈值，可被修正为初生冰。	设B_{ij}中i代表灰冰，j代表初生冰，则：当$B_{ij} \geq B_t$时，斑块类型修正为初生冰。一般情况下，B_t在0.7~0.9之间。
灰冰和固定冰的包围度	固定冰	灰冰	如果误判固定冰斑块被灰冰包围程度超过一定阈值，可被修正为灰冰。	设B_{ij}中i代表固定冰，j代表灰冰，则：当$B_{ij} \geq B_t$时，斑块类型修正为灰冰。一般情况下，$B_t > 0.6$。
灰冰和灰白冰斑块的面积和紧致度	初生冰	灰冰或灰白冰	通过对误判初生冰斑块面积和紧致度的计算和比较，分别设定面积和紧致度的阈值，大于阈值的是灰冰，反之是灰白冰。	若初生冰斑块面积为S_i，紧致度C_i，则：当$C_i \geq C_t$，且$S_i \geq S_t$时，斑块类型修正为灰冰 当$C_i \leq C_t$，且$S_i \leq S_t$时，斑块类型修正为灰白冰。



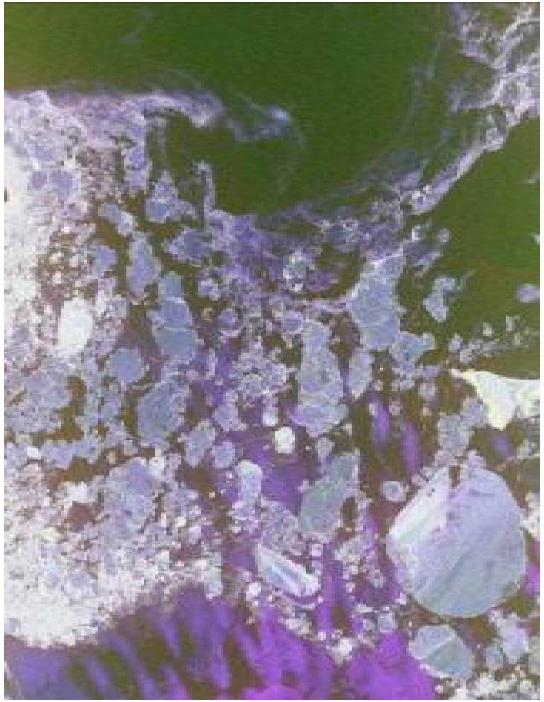
(3) Demonstration   Radarsat-2   2009.1.14



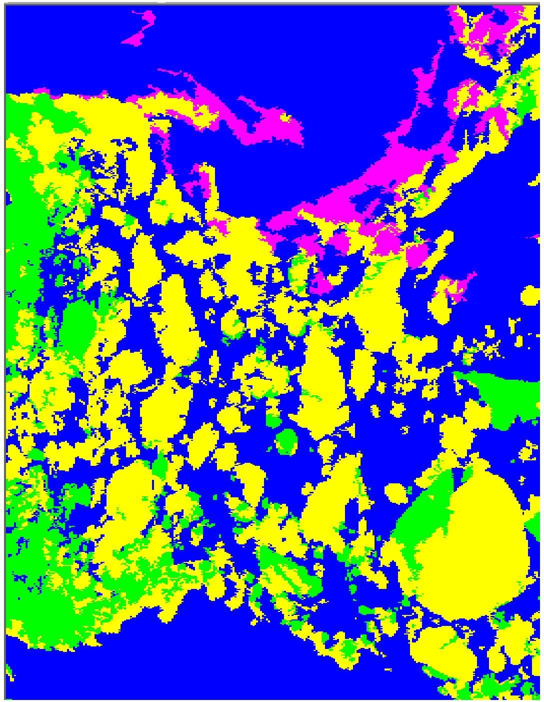
SAR   Segmentation   Pre-Classification   Semantic knowledge-based modification

Open water **New ice** **Grey ice** **Grey-white ice** **Land fast ice**

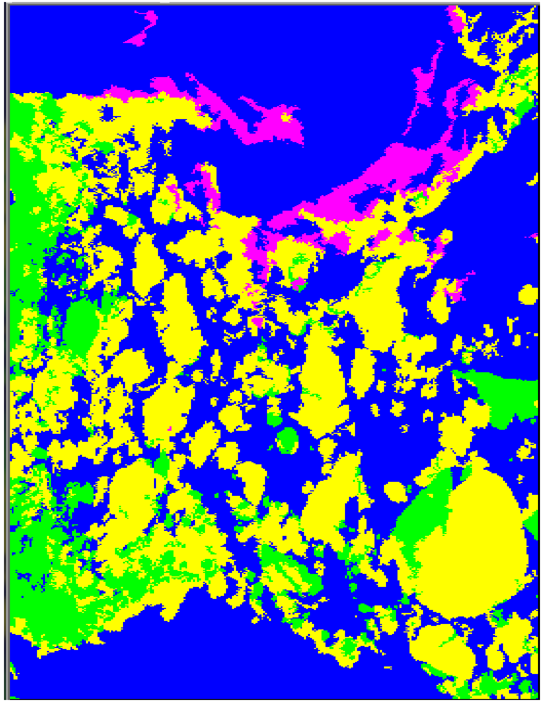
SAR image



Visual interpret



Results

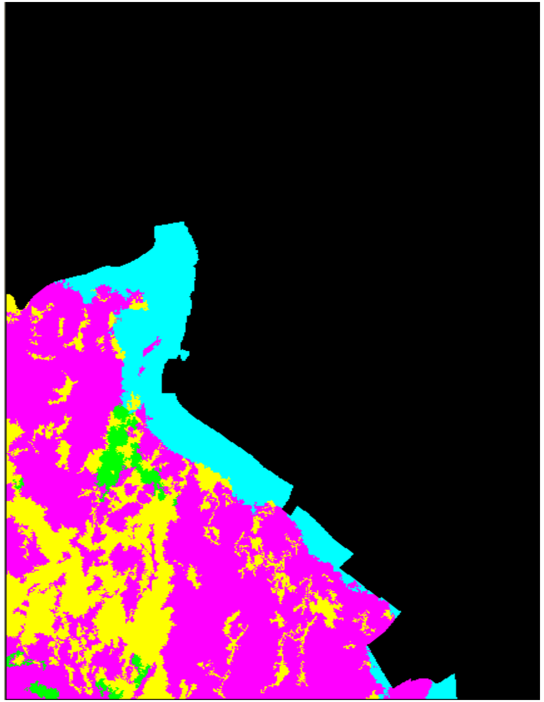


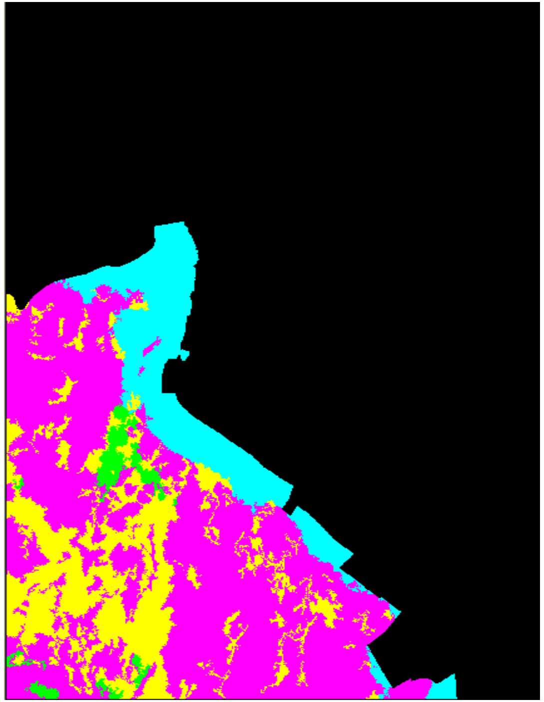
Open water | Grey ice | New ice | Grey-white ice

$\kappa = 0.90$; Accuracy:93.4%

Radarsat-2 2010-2-8

SAR image | **Field work interpret** | **Results**





Landfast Ice   New Ice   Grey Ice   Grey-white Ice

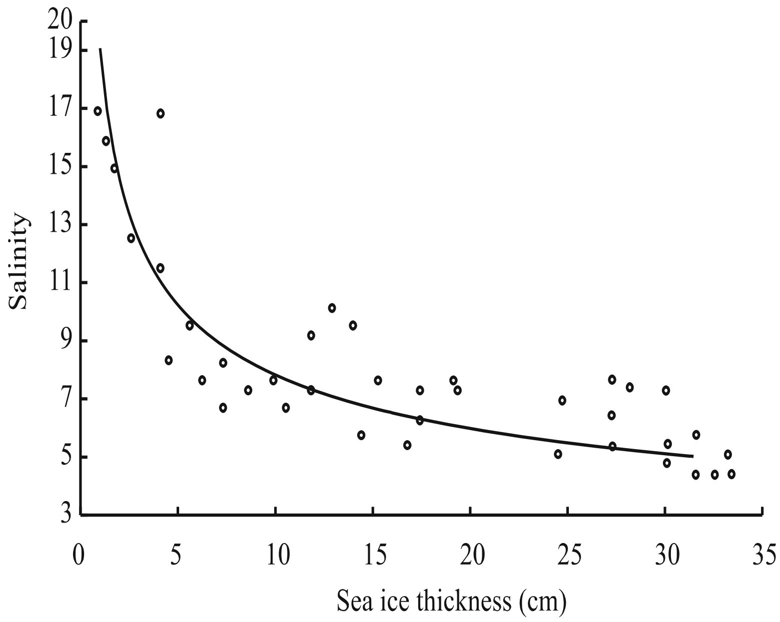
κ = 0.92; Accuracy:94.5%

Radarsat-2   2014-1-18

2. Sea ice thickness retrieval

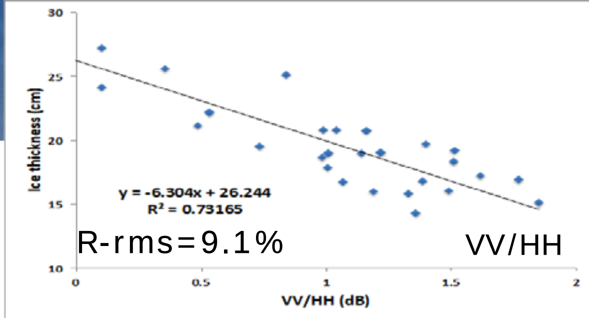
- Sea ice in the Bohai Sea is first-year ice, which has large dielectric constant due to high salinity content;
- The growth of sea ice is linked to a desalination process. Ice salinity decreases as ice becomes thicker.
- Polarization ratios have strong correlation with dielectric constant when standard deviations of sea ice surface slope are small (level surface ice, @X-Bragg)

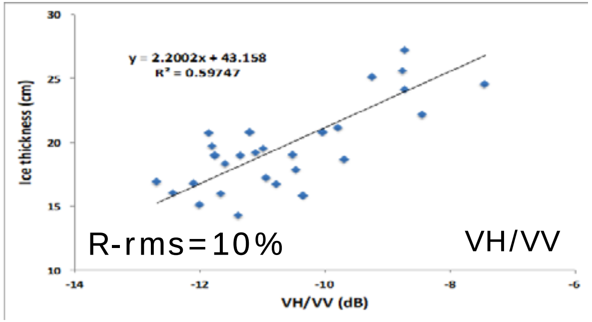
Ice thickness → Dielectric ← Pol-ratio

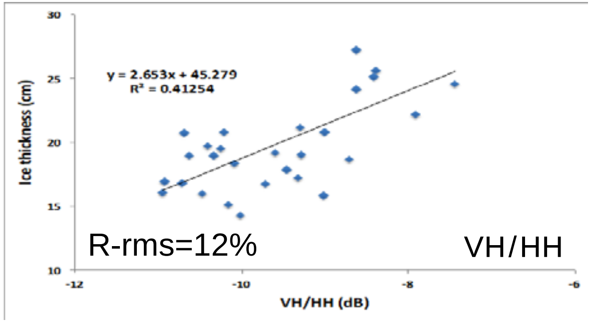


$$\frac{\sigma^0_{VV}}{\sigma^0_{HH}} \quad \frac{\sigma^0_{VH}}{\sigma^0_{VV}} \quad \frac{\sigma^0_{VH}}{\sigma^0_{HH}}$$

$$\frac{\sigma^0_{VV}}{\sigma^0_{HH}} > \frac{\sigma^0_{VH}}{\sigma^0_{VV}} > \frac{\sigma^0_{VH}}{\sigma^0_{HH}}$$



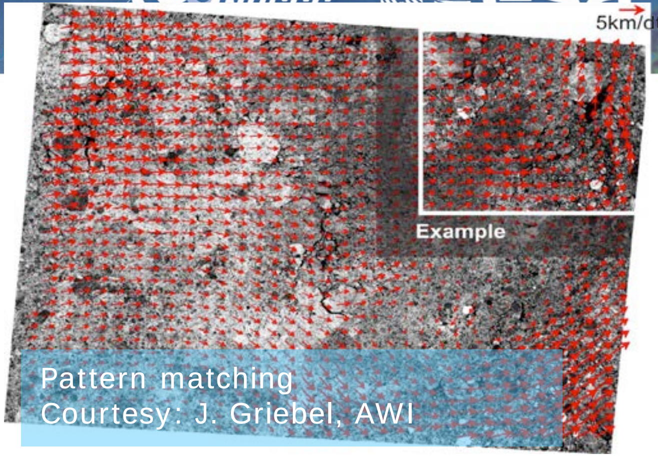




3. Sea ice velocity estimation

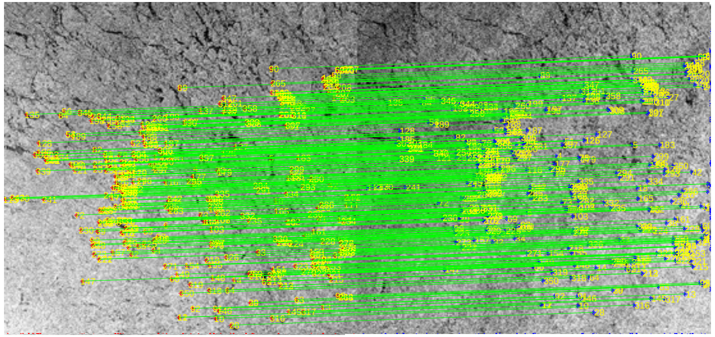
Pattern matching

- Block-wise correlations in spatial or frequency domain
- About 10-20 × image resolution, regular grid
- Time consuming, negligible rotation



Feature tracking

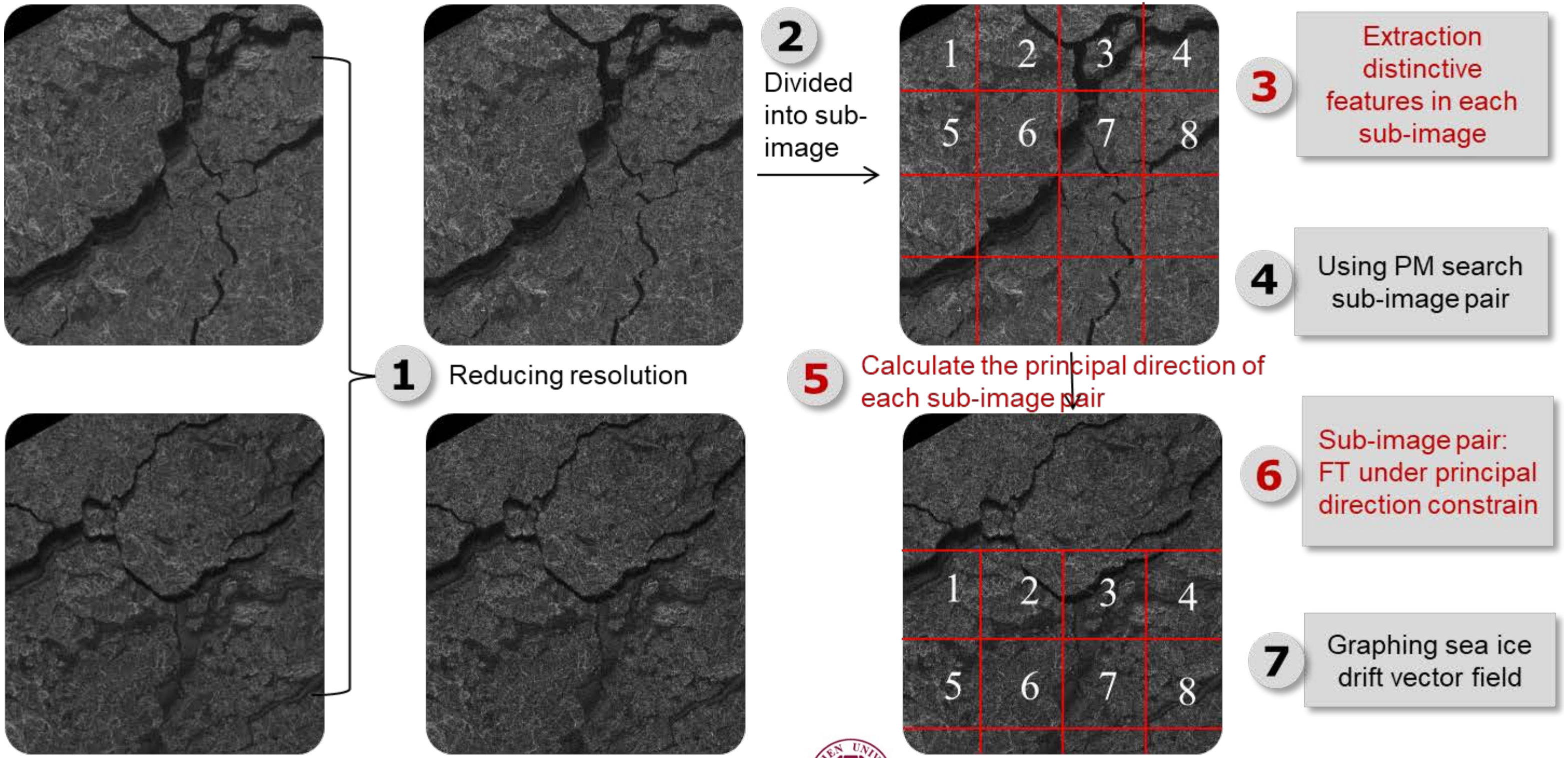
- Identification & tracking of stable structures
- Includes rotational, preferable for marginal ice zone
- Fast computation speed
- Irregular grid, much false matches



Filter false matched key points: 358

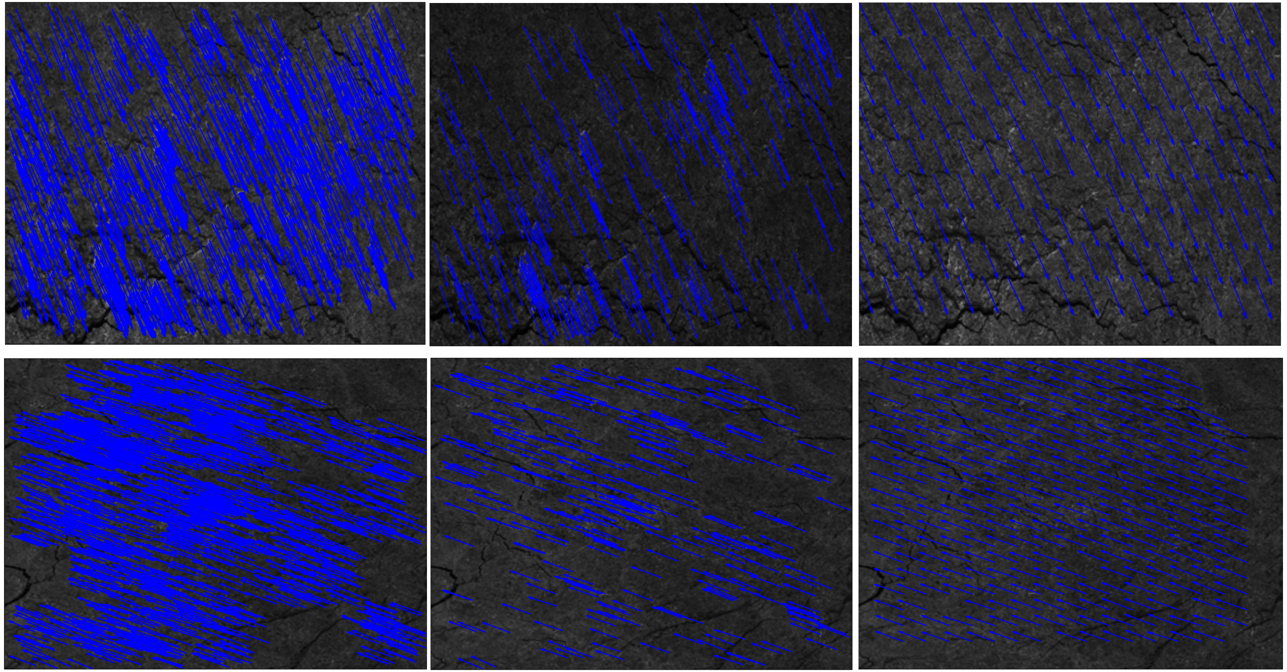
Multi-scale sea ice drift estimation based on principal direction constraint

Pattern matching
+
Feature tracking



Fully automatic!

Sentinel-1 SAR Application



Proposed method | Feature tracking | Pattern matching

	Prop.	FT	PM
Matched	2088	5762	170
Corrected	1834	476	145
Percent	87.8%	8.3%	85.3%
Time/s	342	545	8128

	Prop.	FT	PM
Matched	1462	4521	342
Corrected	1254	362	269
Percent	85.8%	8.0%	78.7%
Time/s	163	237	1888

(4) Sea ice hazard risk assessment

For marine transportation, I_1 =Ice concentration × thickness

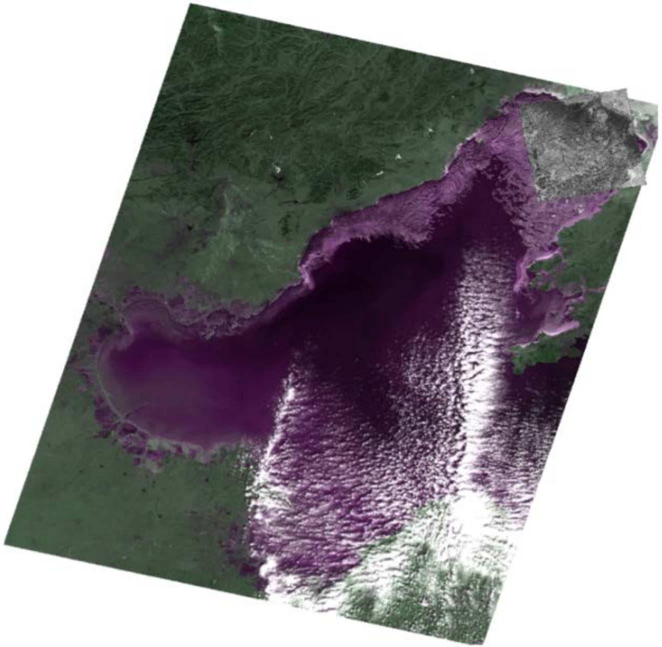
For offshore construction, $I_2 = I_1$ +Ice concentration × thickness × velocity

- Ice concentration (%): 0-15, 15-50, 50-80, 80-100
- Ice thickness (cm): 0-10, 10-20, 20-30, >30
- Ice velocity (m/s): 0-0.2, 0.2-0.4, 0.4-0.6, >0.6

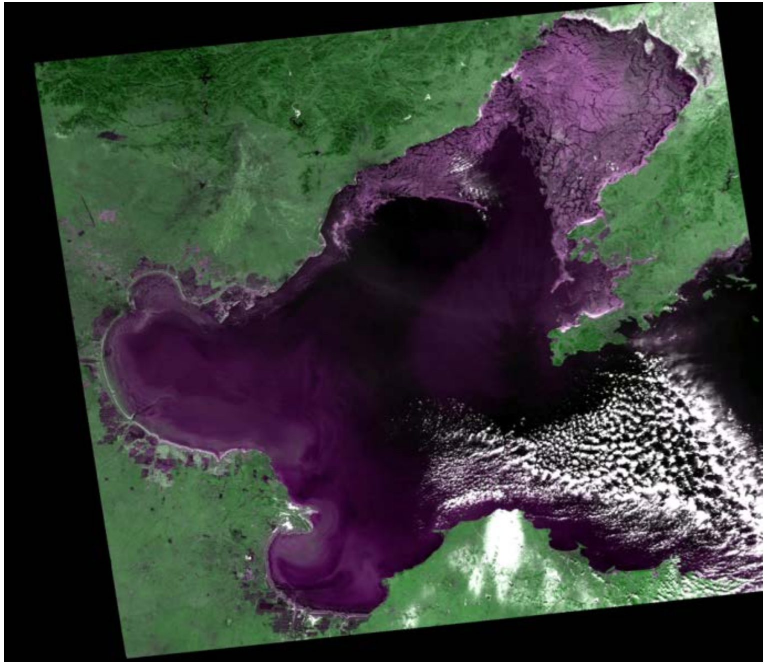
- I_1 for marine transportation
  - No hazard: 0~1.5
  - Low hazard: 1.5~10
  - Median hazard: 10~24
  - Severe hazard: >24

- I_2 for offshore construction
  - No hazard: 0~1.8
  - Low hazard: 1.8~14
  - Median hazard: 14~38.4
  - Severe hazard: >38.4

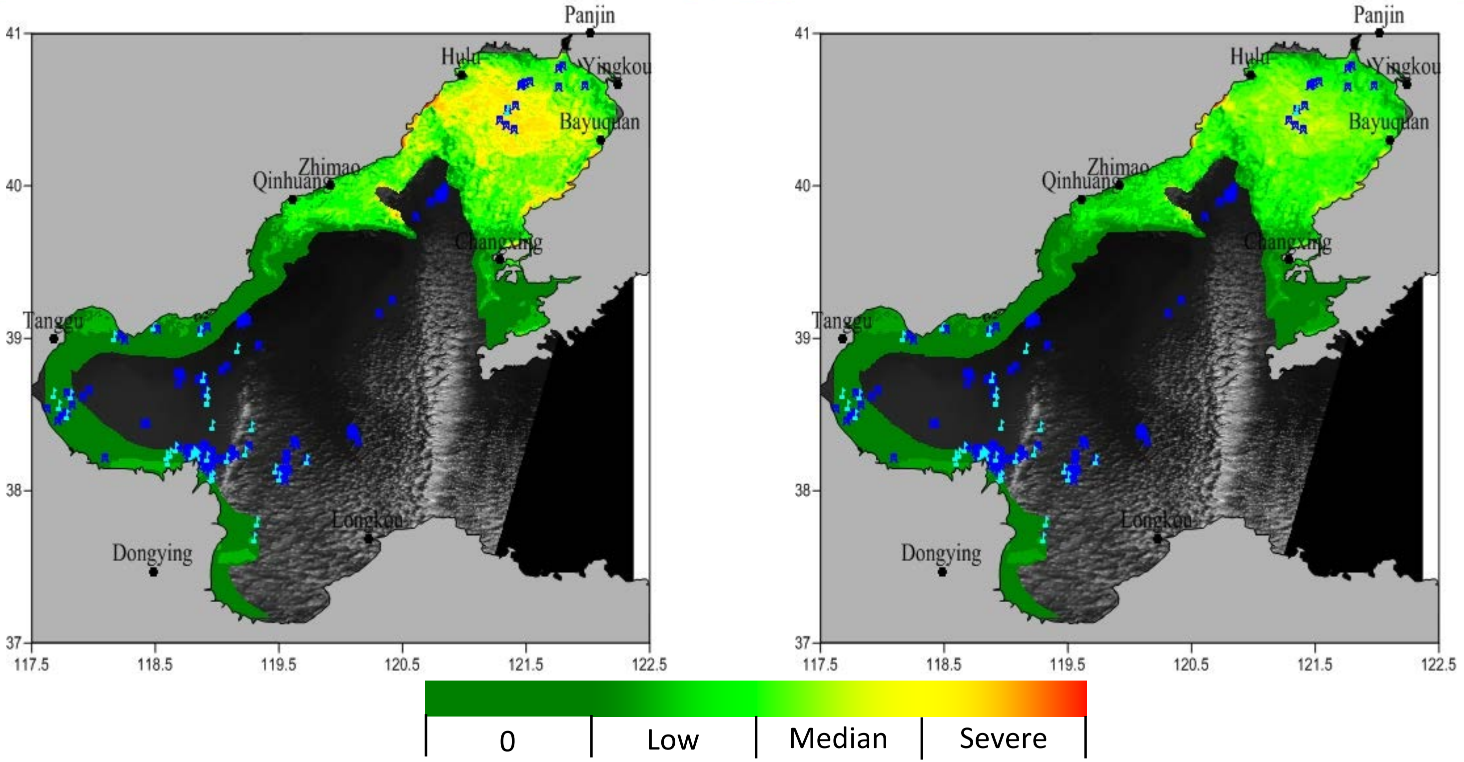
Example 1. A normal ice year



2006.2.3-10:13 (ASAR)
2006.2.3-11:00 (MODIS)



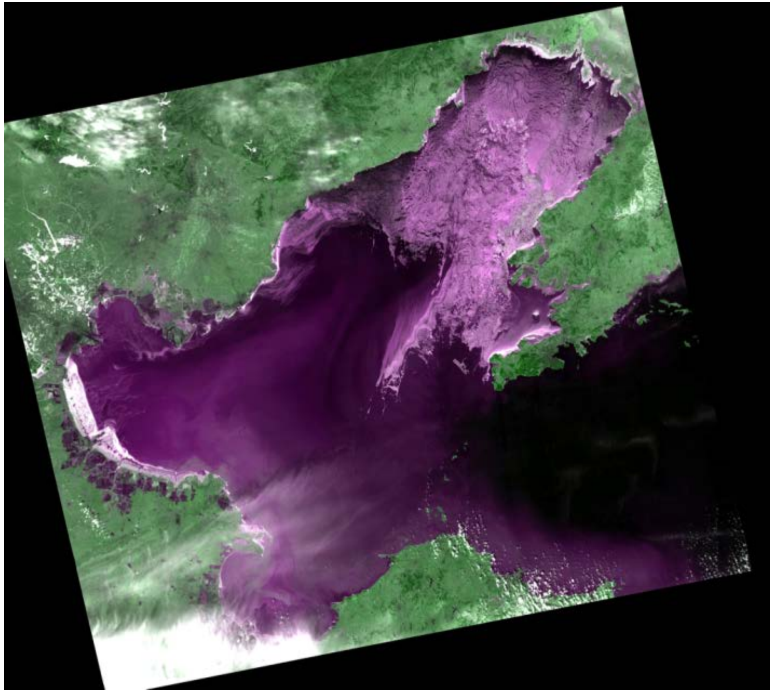
2006.2.4-13:20 (MODIS)



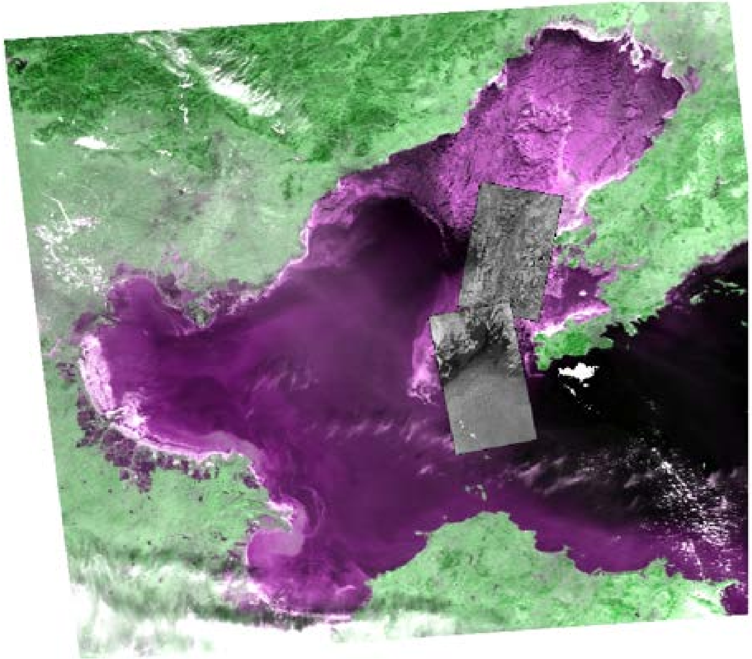
I_1 for marine transportation

I_2 for offshore construction

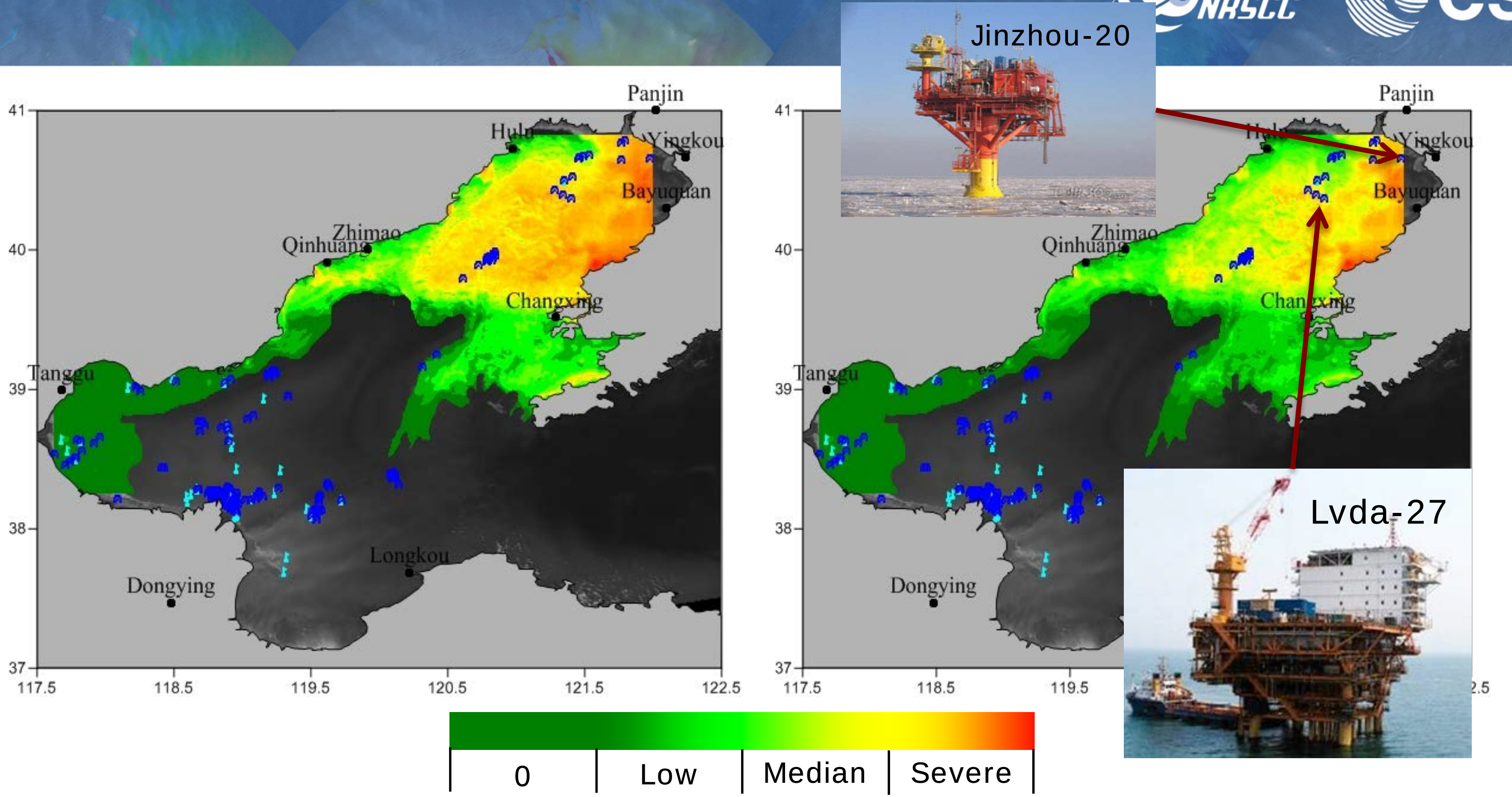
Example 2. A heavy ice year



2010.2.12-12:55 (MODIS)



2010.2.13-09:50 (ASAR)
2010.2.13-10:20 (MODIS)



I_1 for marine transportation

I_2 for offshore construction

Thanks for your attention!