Features and Mechanisms of SAR Imaging of Shallow Water Topography of Subei Bank in the Southern Yellow Sea

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Contents

- Background
- Bathymetric Features of Subei Bank on SAR Images
- SAR Imaging Mechanisms
- Conclusions

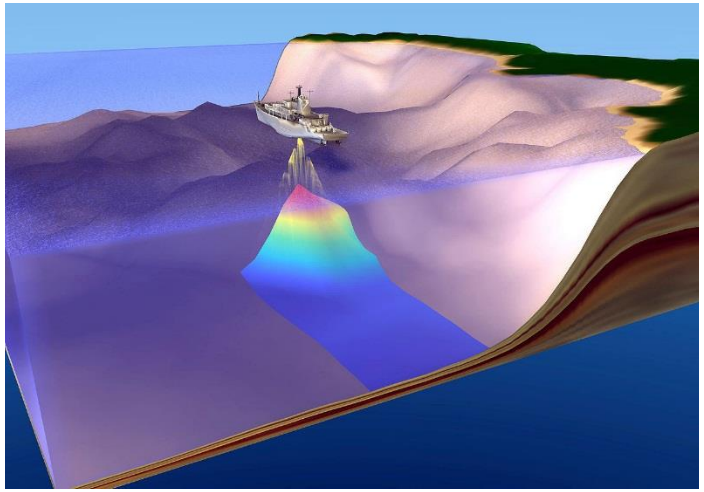
Background

- Fishery; Coastal engineering; Safe navigation; Development and utilization of resources in coastal zone…
- Coastal ocean dynamics; Accurate prediction of ocean current and waves…





In situ measurement



Small coverage

Short period

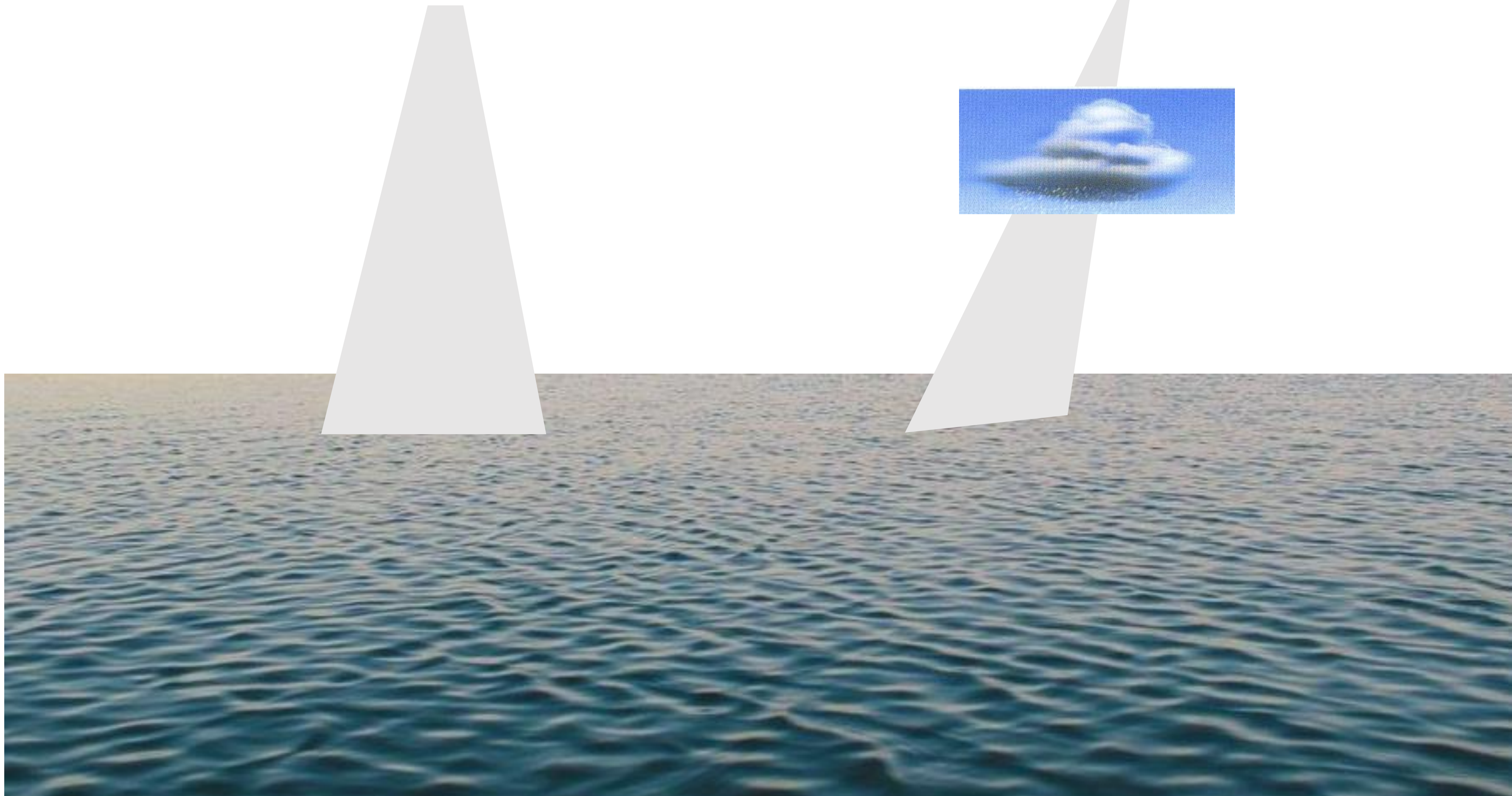
Huge costs

Limited by weather and ocean states

Satellite remote sensing

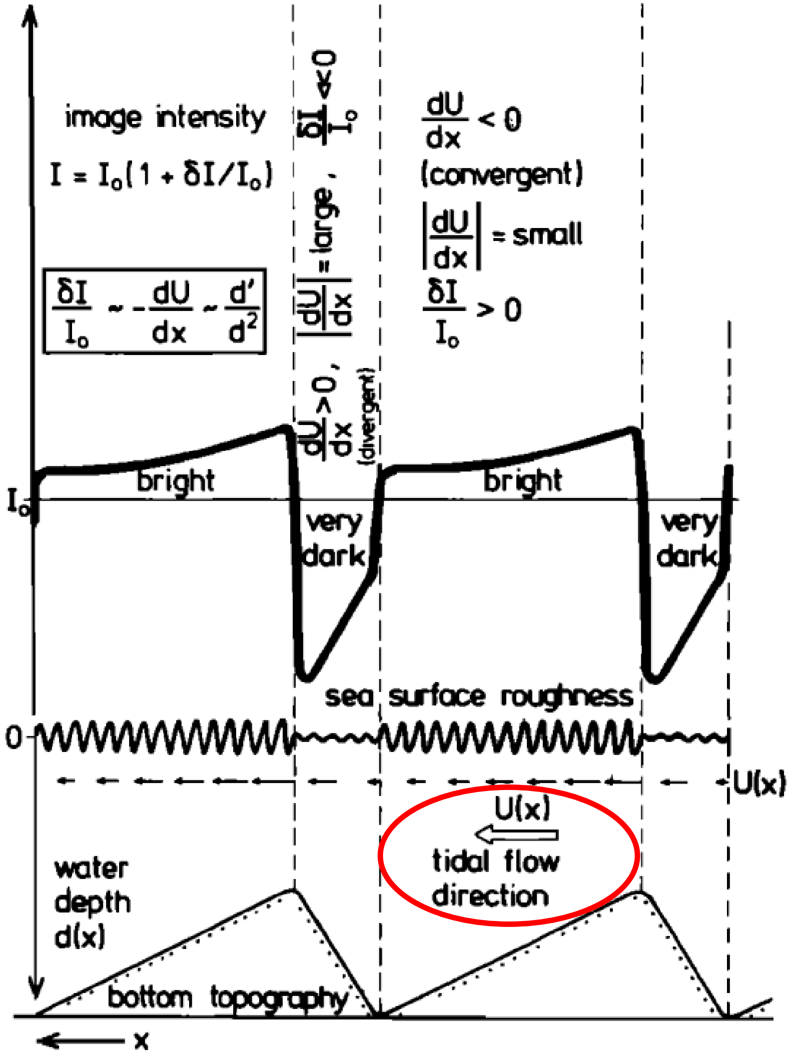
Optical sensor

SAR

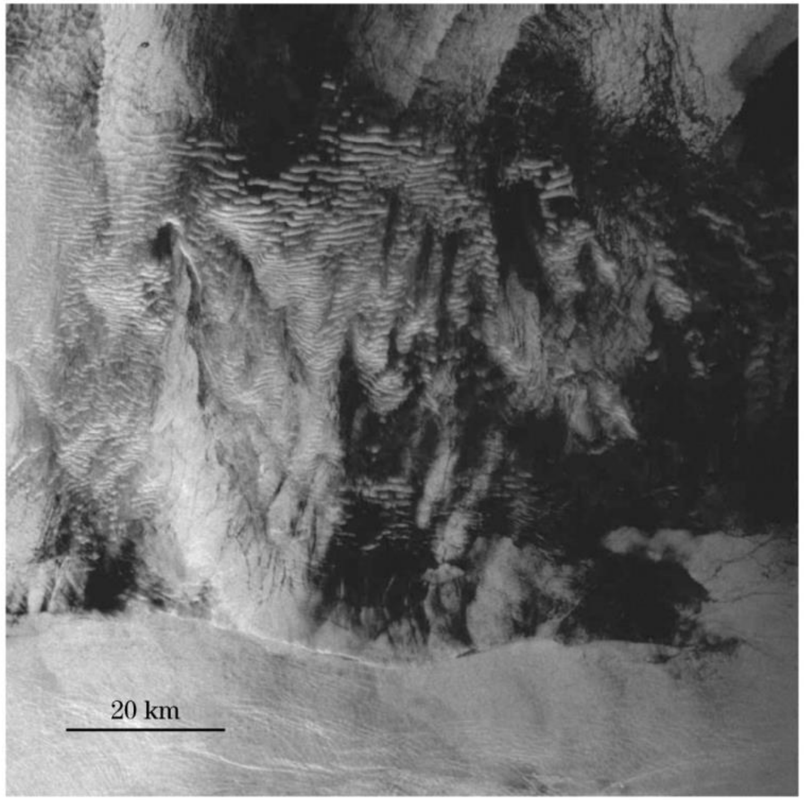


Previous studies: when tidal current is perpendicular to topographic features (e.g., sand ridge), the underwater topography can be imaged by SAR

SAR image of the southern North Sea (Alpers and Hennings, 1984)

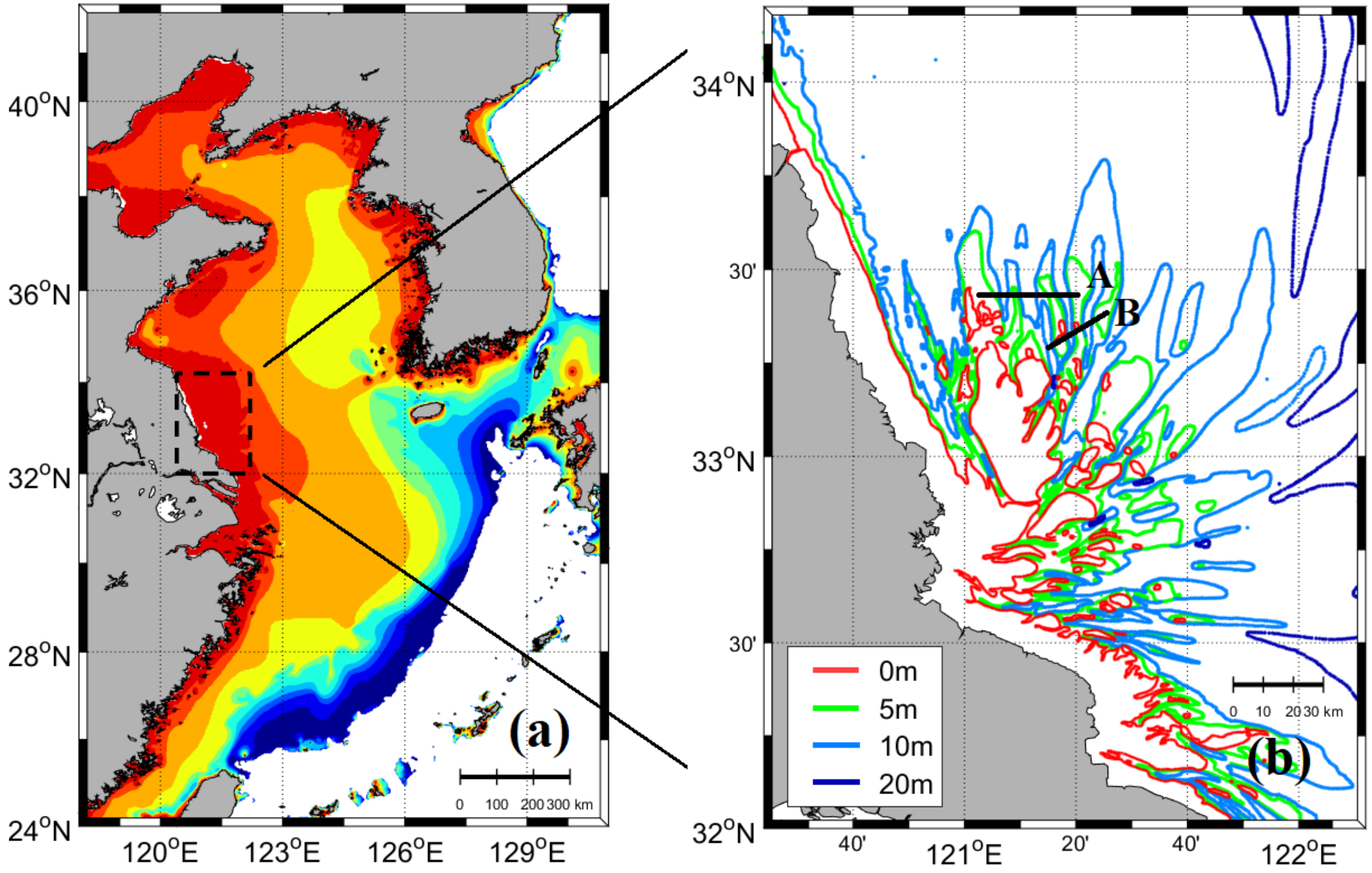


Schematic of SAR imaging of shallow water topography (Alpers and Hennings, 1984)



SAR image of the Taiwan shoal (Zheng et al., 2006)

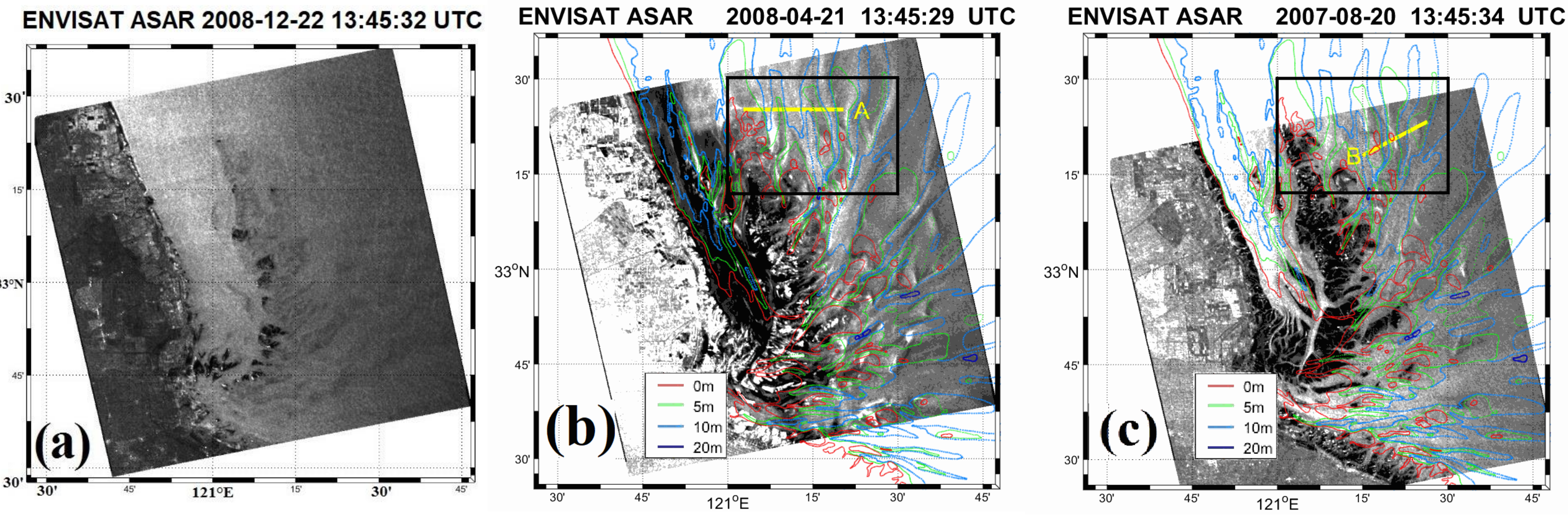
Recent observations show: when tidal current is parallel to topographic feature, the underwater topography can also be imaged by SAR



Subei Bank consists of 70 sand ridges and tidal channels. Water depth is between 0~25m and the topography is complex and changeable.

Bathymetric Features of Subei Bank on SAR Images

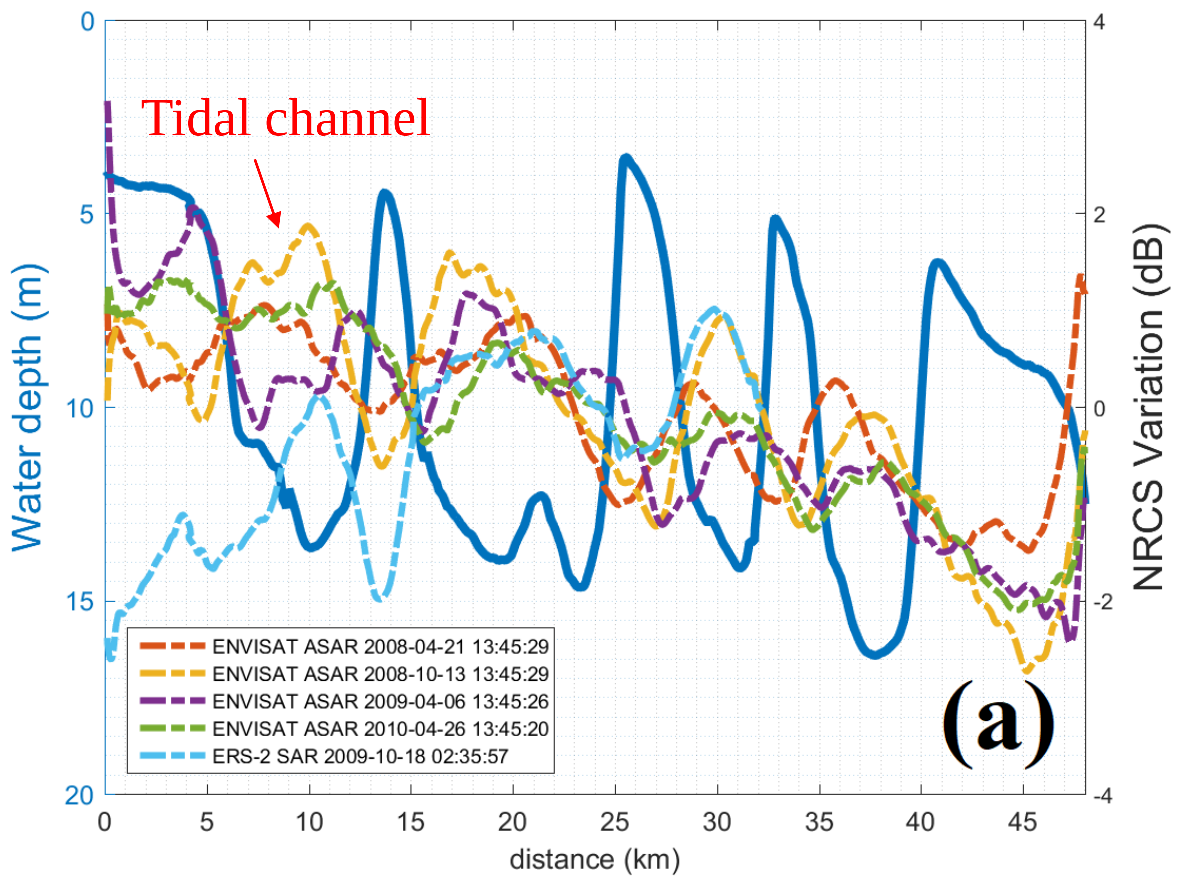
- What underwater topography do the wide or narrow bright stripes correspond to ?
- Why does the same sea area show different radar backscatter features?

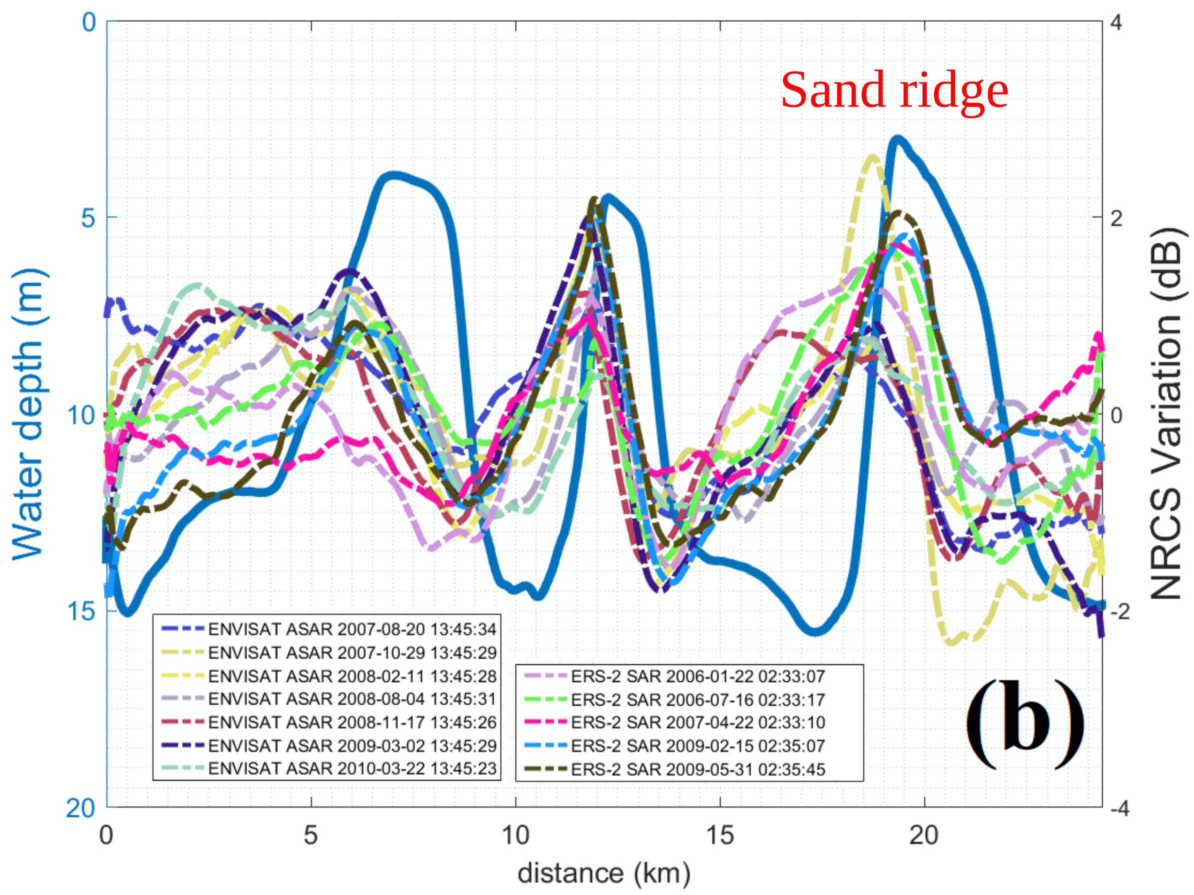


SAR images: ENVISAT ASAR + ERS-2 SAR（2006~2010, VV-polarization）

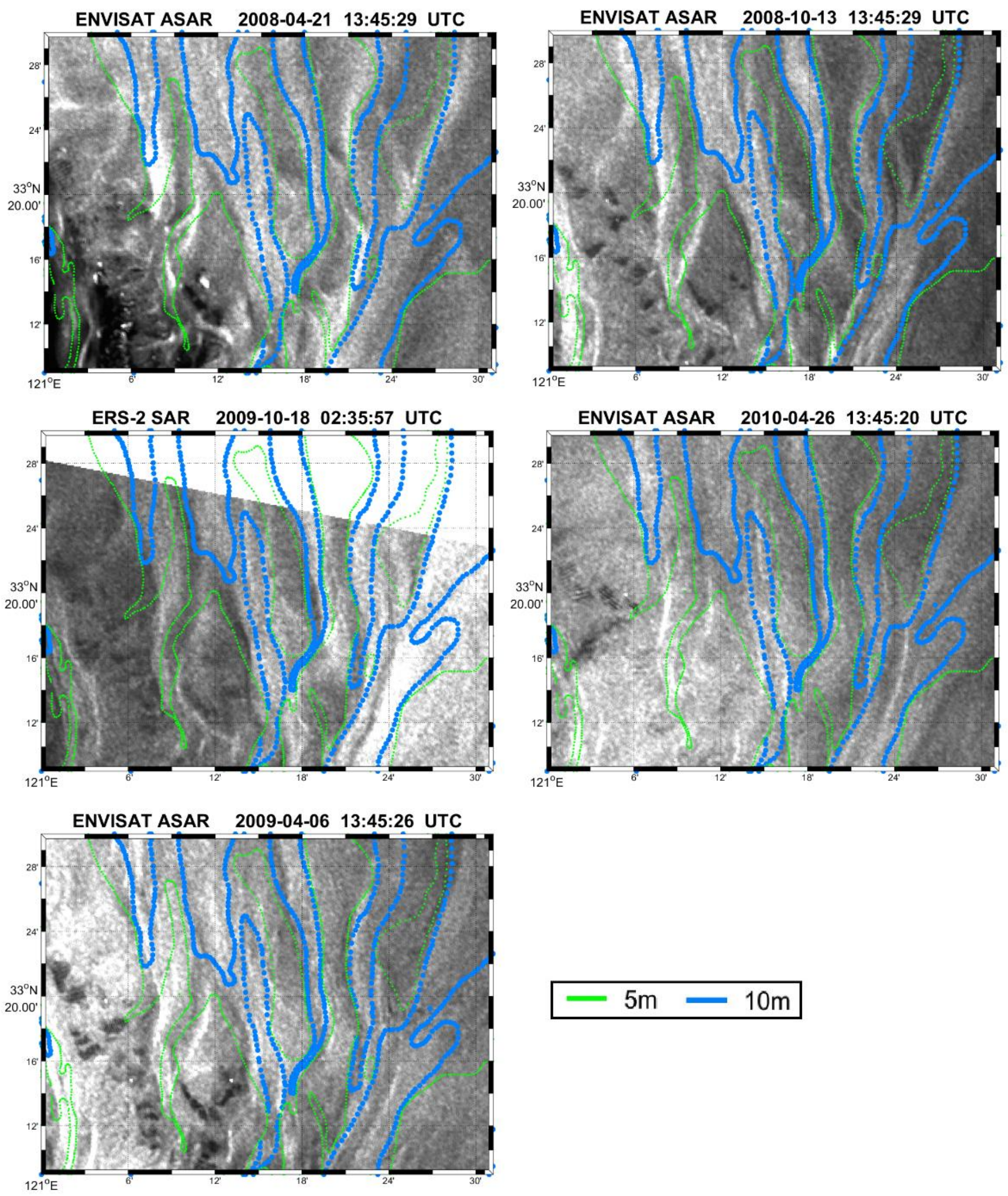
Two typical bathymetric features

- wide bright stripes correspond to tidal channels
- narrow bright stripes correspond to submarine sand ridges





◆(1) wide bright stripes ~ tidal channels

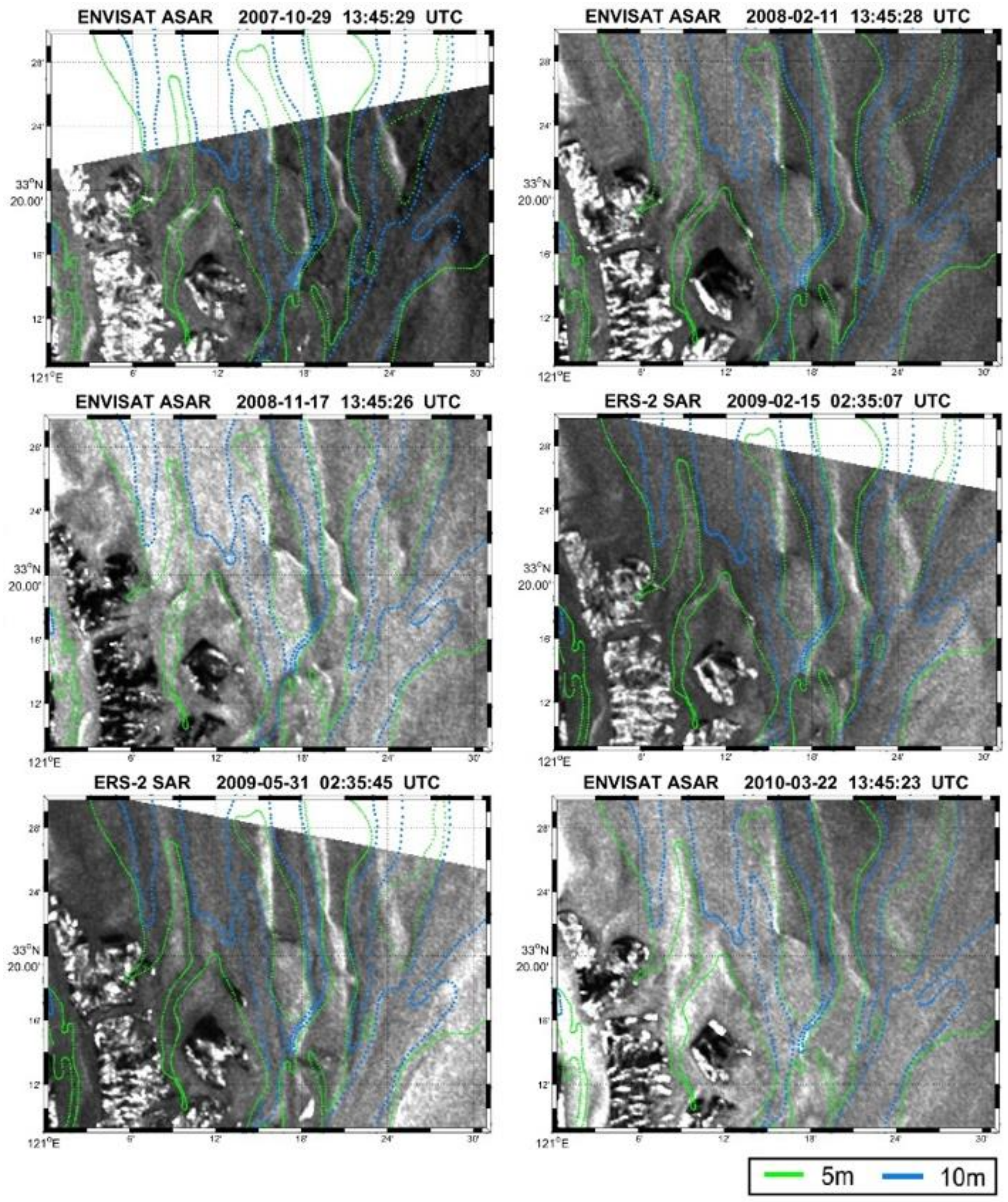


- ✓ All images were acquired at flood tidal phase
- ✓ High tidal level
- ✓ Southerly and weak wind (2~6 m/s)

No.	Satellite	Acquisition Date (yy-mm-dd)	Acquisition Time (UTC)	Tidal phase	Water level (m)	Wind direction*	Wind speed (m/s)
1	ENVISAT	2008-04-21	13:45:29	flood	0.20	105	6.3
2	ENVISAT	2008-10-13	13:45:29	flood	1.10	174	4.8
3	ENVISAT	2009-04-06	13:45:26	flood	1.25	172	2.0
4	ERS-2	2009-10-18	02:35:57	flood	1.30	195	5.6
5	ENVISAT	2010-04-26	13:45:20	flood	1.20	210	2.7

* Wind direction is 0 for northerly wind, positive clockwise

◆ (2) narrow bright stripes ~ sand ridges



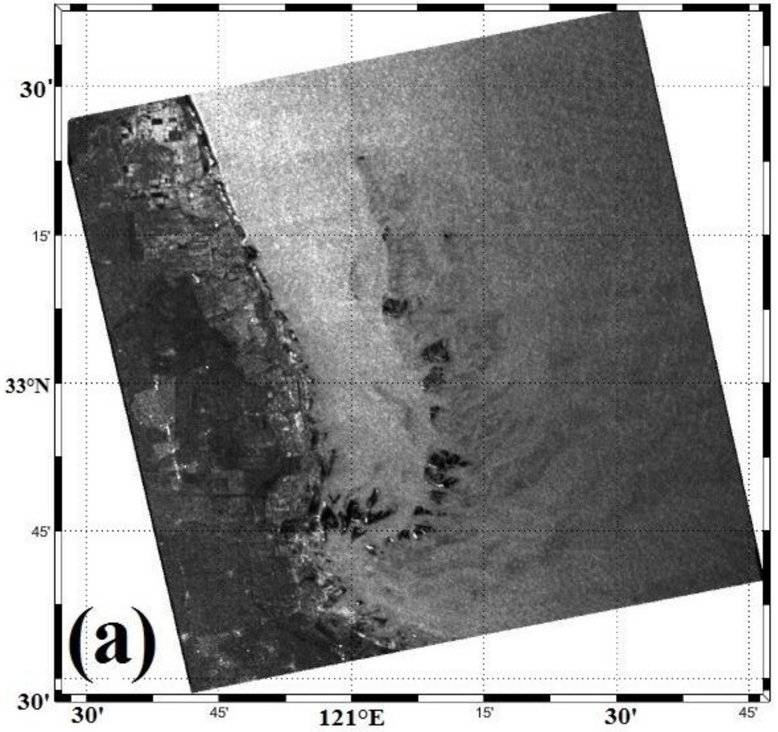
- ✓ Most at flood tidal phase
- ✓ Low tidal level
- ✓ Strong wind (5~11 m/s), different direction

No.	Sensor	Acquired Date[1] (yy-mm-dd)	Acquired Time[1] (hh:mm:ss)	Bathymetric features type	Tidal phase[2]	Water level[2] (m)	Wind direction[3]	Wind speed (m/s)
6	ERS-2	2006-01-22	02:33:07	narrow	ebb	-1.00	351	6.0
7	ERS-2	2006-07-16	02:33:17	narrow	flood	-1.20	158	10.5
8	ERS-2	2007-04-22	02:33:10	narrow	flood	-1.00	20	9.8
9	ENVISAT	2007-08-20	13:45:34	narrow	ebb	-1.20	125	9.8
10	ENVISAT	2007-10-29	13:45:29	narrow	flood	-1.00	24	6.6
11	ENVISAT	2008-02-11	13:45:28	narrow	flood	-1.60	355	7.4
12	ENVISAT	2008-08-04	13:45:31	narrow	flood	-1.00	132	5.9
13	ENVISAT	2008-11-17	13:45:26	narrow	flood	-1.60	351	11.4
14	ERS-2	2009-02-15	02:35:07	narrow	flood	-1.00	17	6.5
15	ENVISAT	2009-03-02	13:45:29	narrow	flood	-1.30	28	6.9
16	ERS-2	2009-05-31	02:35:45	narrow	flood	-1.30	200	5.4
17	ENVISAT	2010-03-22	13:45:23	narrow	ebb	-0.90	149	5.6

◆(3) no bathymetric features

- ✓ Most at ebb tidal phase
- ✓ Medium water level
- ✓ Strong wind, different direction

ENVISAT ASAR 2008-12-22 13:45:32 UTC



No.	Sensor	Acquired Date (yy-mm-dd)	Acquired Time (hh:mm:ss)	Tidal phase	Water level (m)	Wind direction	Wind speed (m/s)
1	ERS-2	2006-02-26	02:33:02	flood	1.10	355	12.0
2	ENVISAT	2006-09-04	13:45:32	ebb	0.70	45	8.0
3	ENVISAT	2008-03-17	13:45:32	ebb	0.90	124	5.9
4	ENVISAT	2008-12-22	13:45:29	ebb	0.40	300	7.6
5	ERS-2	2009-03-22	02:35:23	ebb	0.30	342	9.2
6	ERS-2	2009-09-13	02:35:57	ebb	-0.40	162	3.3
7	ENVISAT	2009-09-28	13:45:23	ebb	-0.20	156	6.7
8	ENVISAT	2010-01-11	13:45:24	ebb	0.90	346	10.8

A summary

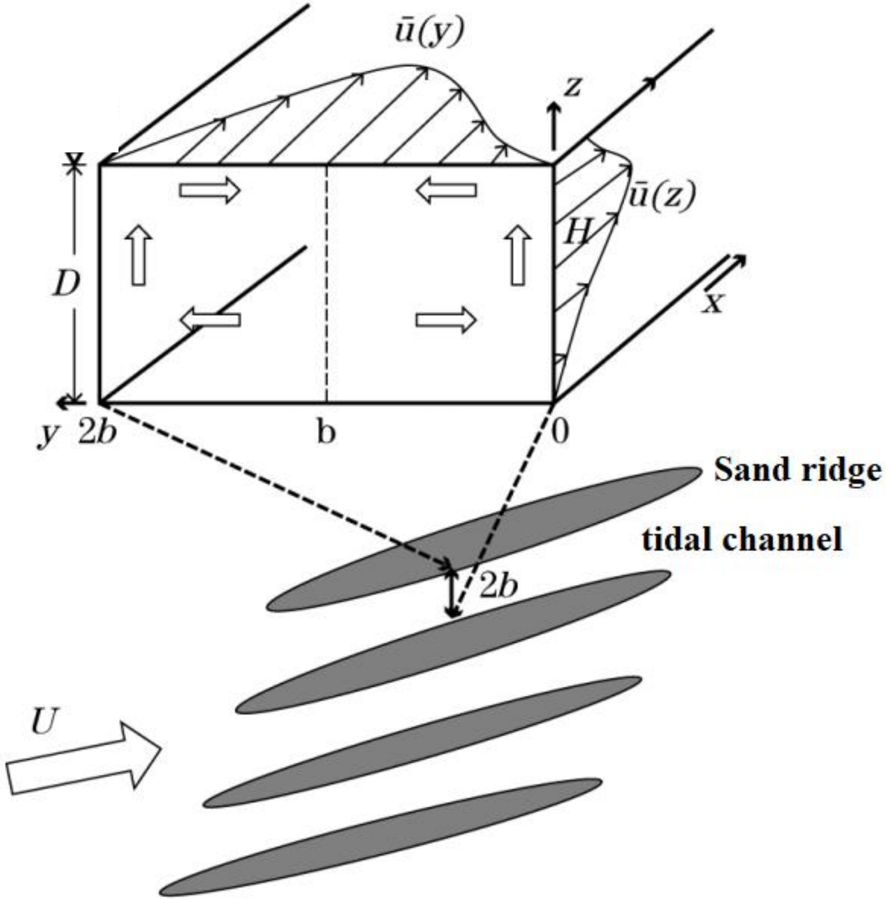
Conditions of SAR imaging of shallow water topography of Subei Bank：

- Flood tide is favorable for SAR imaging of topography
- Except for tidal current, wind and tidal level also play an important role

Imaging Mechanisms ?

SAR Imaging Mechanisms of Subei Bank

◆ (1) wide bright stripes ~ tidal channels



The mean flow is parallel to the tidal channels

Secondary Circulation Theory

(Zheng et al., 2012)

Assuming mean flow has horizontal and vertical velocity shears:

$$\bar{u}(y) = -\frac{y}{\mu}\frac{dP_0}{dx}\left(b - \frac{y}{2}\right)$$

$$\bar{u}(z) = sin\frac{\pi z}{2H}, 0 \ll z \ll D$$ (with an apex at H)

$$\bar{u}(y,z) = -\frac{y}{\mu}\frac{dP_0}{dx}\left(b - \frac{y}{2}\right) sin\frac{\pi z}{2H}, 0 \ll y \ll 2b, 0 \ll z \ll D$$

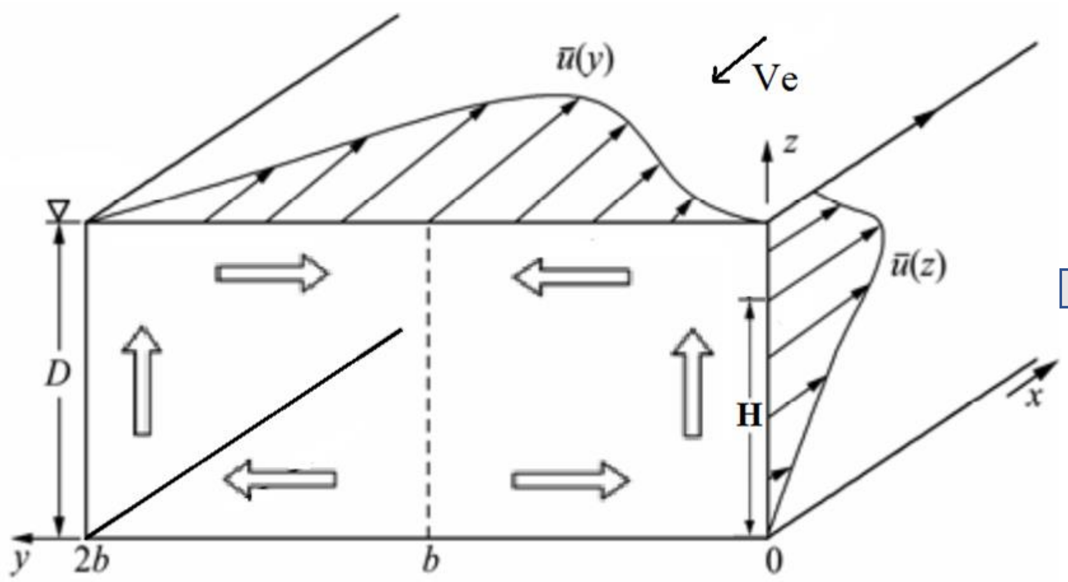
⇩ solve the governing equations

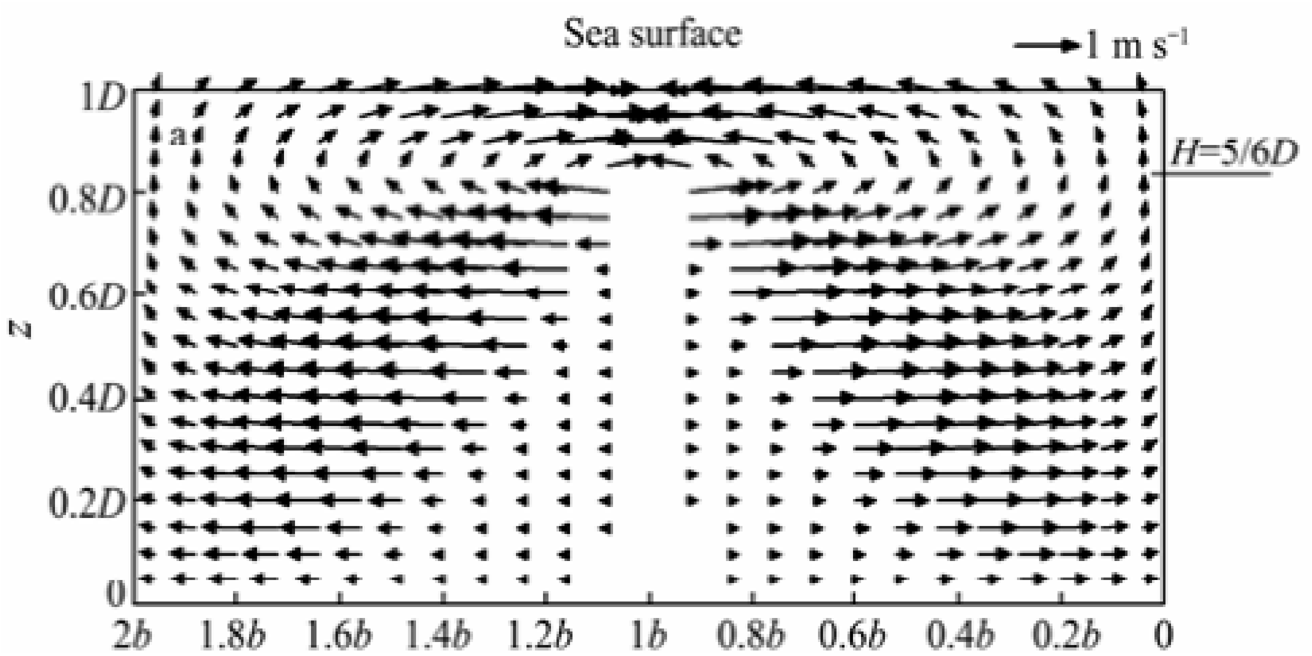
$$w(y,z) = w_0\left(sin\frac{\pi z}{2H}\right)^{\left[1+\frac{y(2b-y)}{2(b-y)^2}\right]}$$

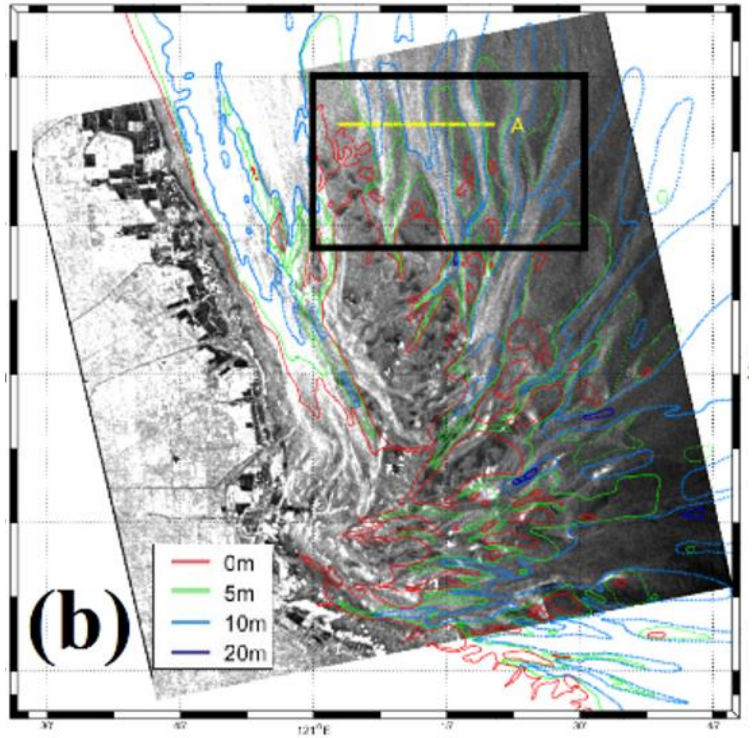
$$v(y,z) = -v_0\left[\frac{y(2b-y)}{2(b-y)}\right]\left(sin\frac{\pi z}{2H}\right)^{\frac{y(2b-y)}{2(b-y)^2}} cos\frac{\pi z}{2H}$$

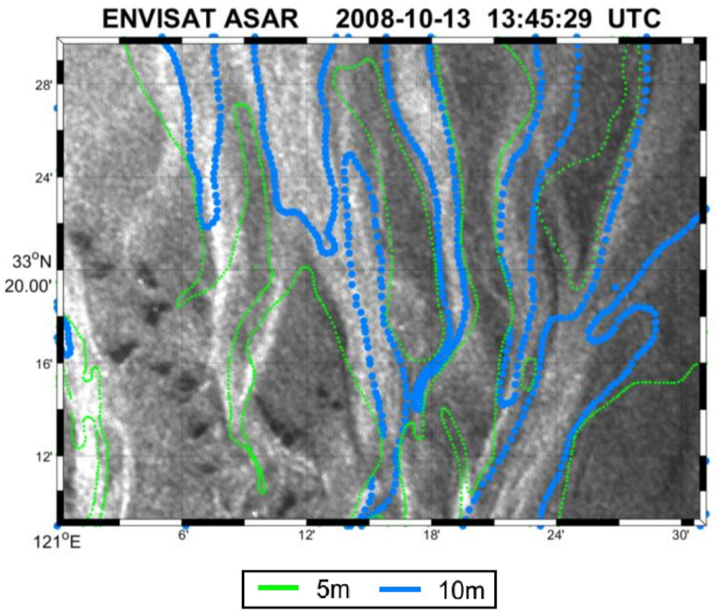
- If the wind-induced upper Ekman current is in the opposite direction of the mean flow (H<D)

Current convergence occurs over tidal channel

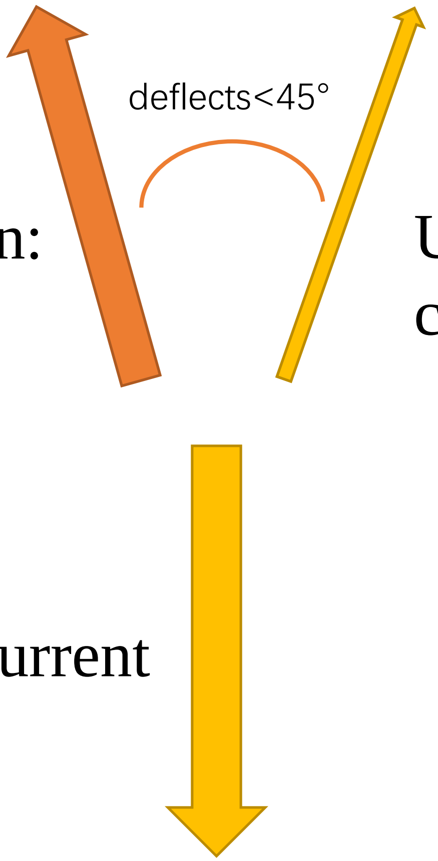








Wind direction:



Upper Ekman current direction

Flood tidal current direction

For all tidal channel images, the direction of upper Ekman current is opposite to tidal current
→ Surface current convergence occurs over tidal channels, leading to bright stripes on SAR imagery

◆(2) narrow bright stripes ~ sand ridges

Low tidal level at imaging time → Wave breaking ? → increased roughness over sand ridges

- Relationship of wave breaking (Nelson and Gonsalvas, 1992):

$$\gamma_b = 0.55 + \exp(-0.012\cot(m))$$

where γ_b is the rate of breaking height to breaking depth, m is the seafloor slope

Average slope of sand ridges: m=0.004 → γ_b =0.6 ⇒ **Wave breaking depth~ 3 m**

- For the fully developed sea heights (Hubert, 1957):

$$H = \frac{0.3}{g}U^2$$

Average wind speed at SAR imaging time: 7.7m/s

→ Wave height ~ 1.8 m

Sand ridges depth ~ 4 m

Average Tidal level ~ -1.2 m

Instantaneous Water depth < **Wave breaking depth**

Conclusions

- Under different wind and ocean conditions, SAR images show different bathymetric features, with tidal channels imprinted as wide bright stripes and sand ridges imprinted as narrow bright stripes.
- Possible mechanisms：
  - ✓ During the high tidal level, when the direction of upper Ekman current is opposite to tidal current, the shears of horizontal flow will generate the secondary circulation and induce a convergence at the sea surface over the tidal channel.
  - ✓ During the low tidal level, waves from deep water will break down when propagating over the sand ridges, leading to increased sea surface roughness.

Thank you！