

# **Radar Imaging of Current Features: A Synergy of Backscatter Power and Doppler Shift**

## *Формирование РЛ изображений морских течений: Совместный анализ доплеровского сдвига и мощности обратного рассеяния*

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*(5) Geophysical Institute, University of Bergen, Norway*

*(6) BOOST Technologies, Brest, France*

## ***MOTIVATION***

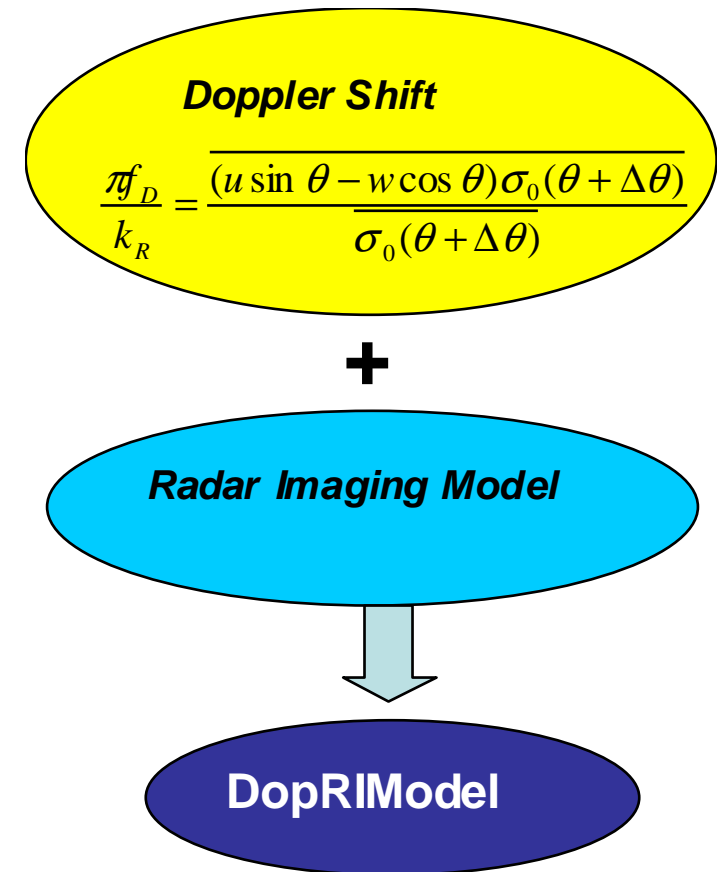
Doppler centroid anomaly will be soon a product routinely producing from space-born SAR. Synergetic analysis of SAR NRCS and Doppler shift could significantly improve quality of the ocean current monitoring from the space

## ***OBJECTIVE***

Develop SAR imaging model which should consistently reproduce observed modulations of NRSC and Doppler shifts related to ocean current features, fronts, and other phenomena (e.g. oil spills)

## ***APPROACH***

Recently two new methods for quantitative studies of SAR imaging of current features were published in J.Geophys.Res. (Ocean). They are the Doppler shift approach (Chapron et al. 2005), and the radar imaging model (RIM), (Kudryavtsev et al. 2005; Johannessen et al. 2005). This study combines these two approaches in a unified DopRim model.

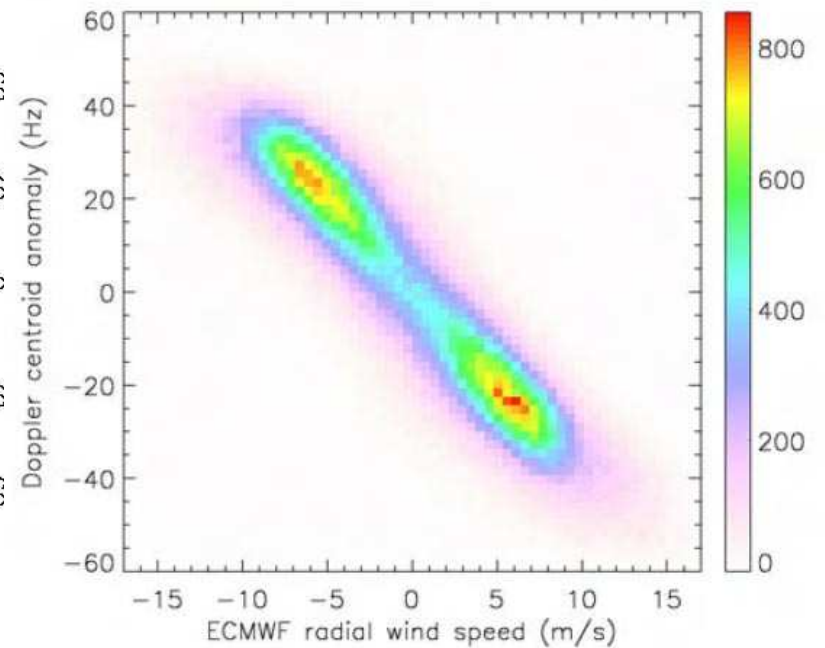
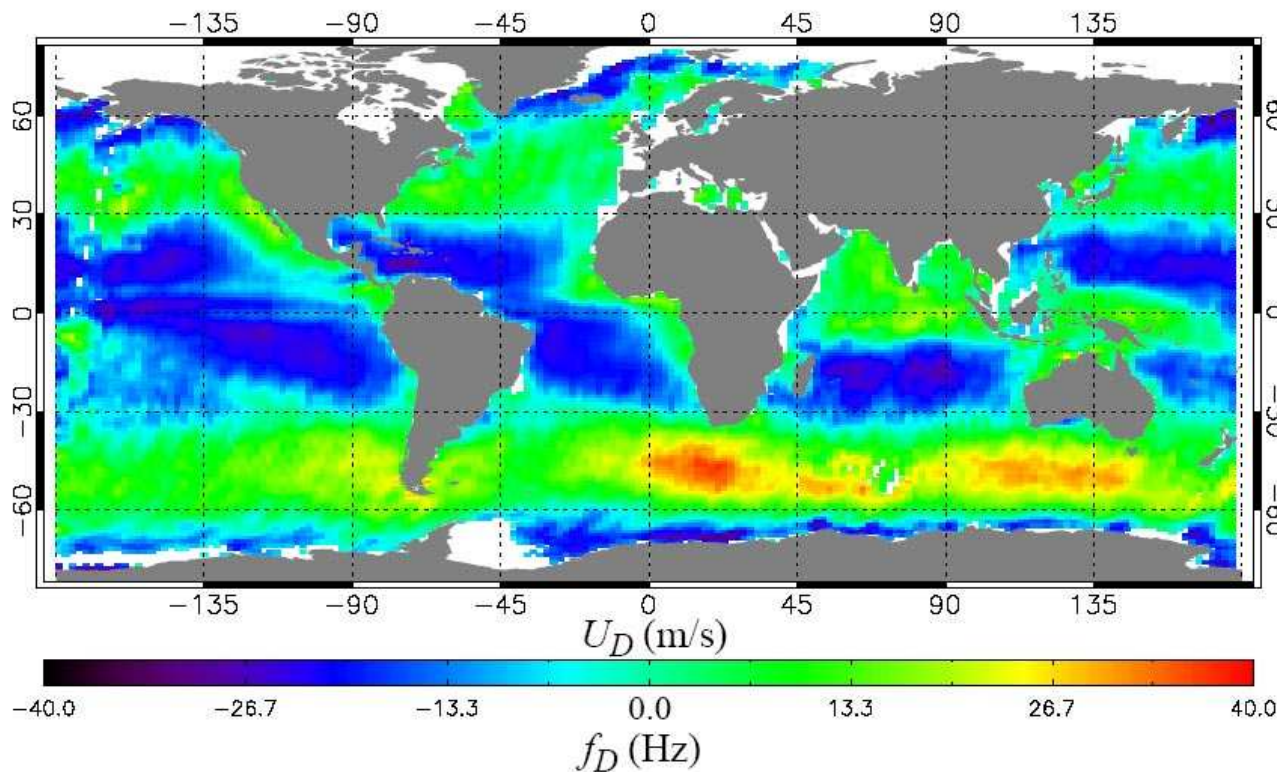


# Doppler centroid anomaly by SAR: Some Results

## Некоторые результаты по измерению доплеровского сдвига с использованием PCA

Chapron B., F. Collard, and F. Ardhum, 2005,  
*Direct measurements of ocean surface velocity from space: Interpretation and validation,*  
*J.Geoph.Res.*, 110, C07008, 2005

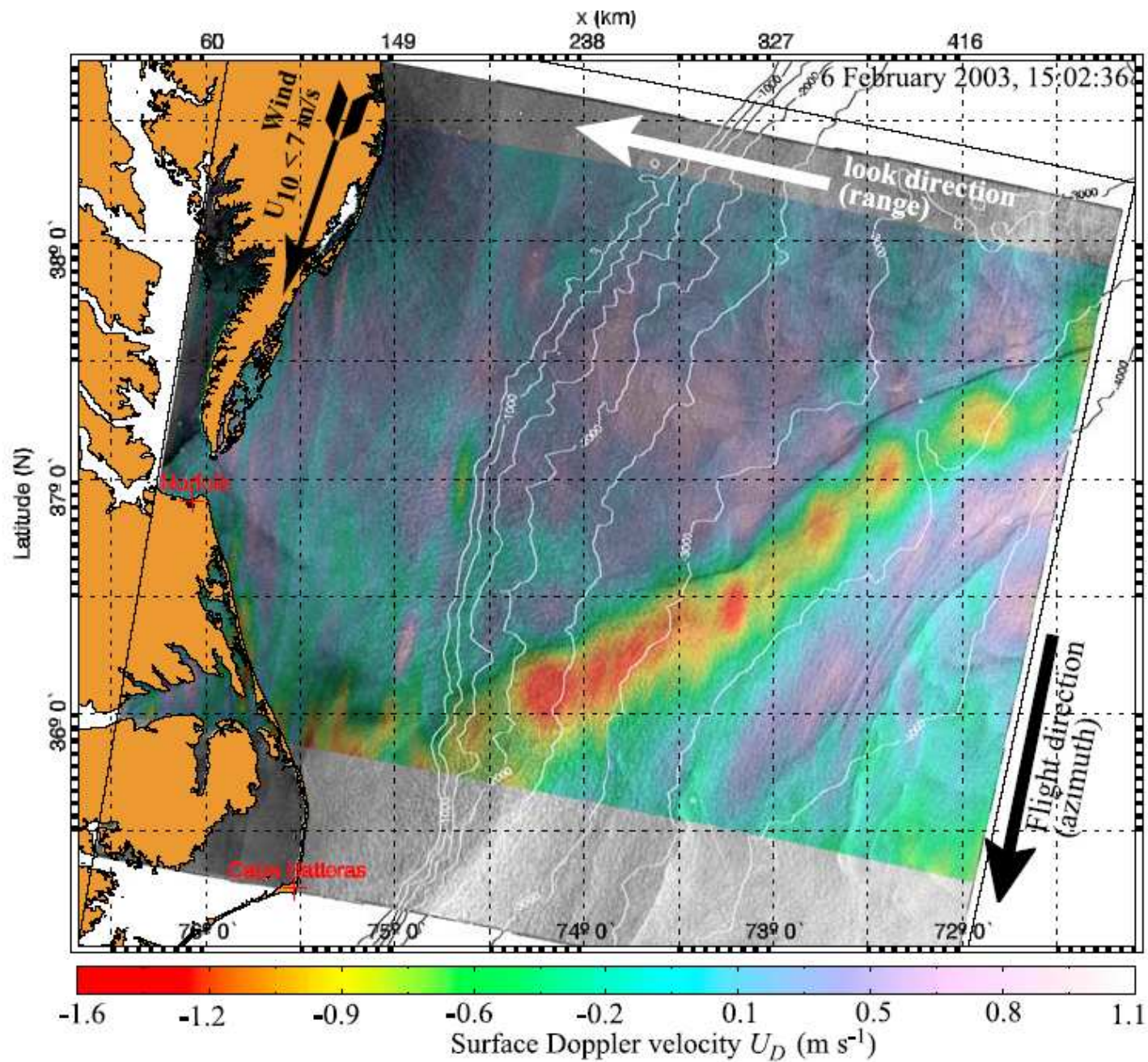
### ASAR ENVISAT Global Observations



For C-band 1m/s surface current  
Corresponds to Doppler shift  
 $F=15-20$  Hz at 20-30 deg incidence

# ASAR ENVISAT Observation of the Gulf Stream

## Наблюдения Гольфстрима с помощью РСА ENVISAT



# Doppler Shift: Governing Equations

## Доплеровский сдвиг: Основные уравнения

$$\frac{\pi f_D}{k_R} = \frac{\overline{(u \sin \theta - w \cos \theta) \sigma_0(\theta + \Delta \theta)}}{\overline{\sigma_0(\theta + \Delta \theta)}}$$

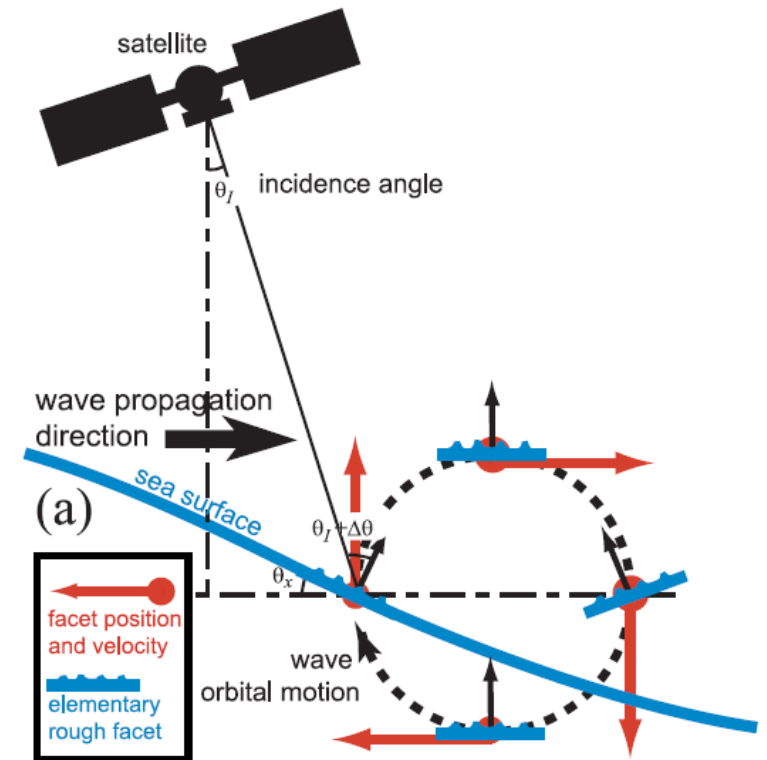
$$V_D = \pi f_D / k_R \sin \theta = \bar{c} + u_S - \frac{1}{\tan \theta} \cdot \frac{\overline{\tilde{w} \tilde{\sigma}_0}}{\bar{\sigma}_0} + \frac{\overline{\tilde{u} \tilde{\sigma}_0}}{\bar{\sigma}_0}$$

$$V_D = u_S + \bar{c} - \frac{1}{\tan \theta} \frac{1}{\sigma_0} \frac{\partial \sigma_0}{\partial \theta} \iint_{k < k_d} \cos(\varphi_R - \varphi) c B(\mathbf{k}) d \ln k d \varphi + \iint_{k < k_d} \cos(\varphi_R - \varphi) c B(\mathbf{k}) M d \ln k d \varphi$$

If one suggests that long waves are narrow, then

$$V_D = \bar{c} + u_S - \frac{\varepsilon^2 C}{2 \tan \theta} \frac{1}{\sigma_0} \frac{\partial \sigma_0}{\partial \theta} + \frac{\varepsilon^2 C}{2} |M_H^P|$$

as proposed in Chapron et al, JGR, 2005

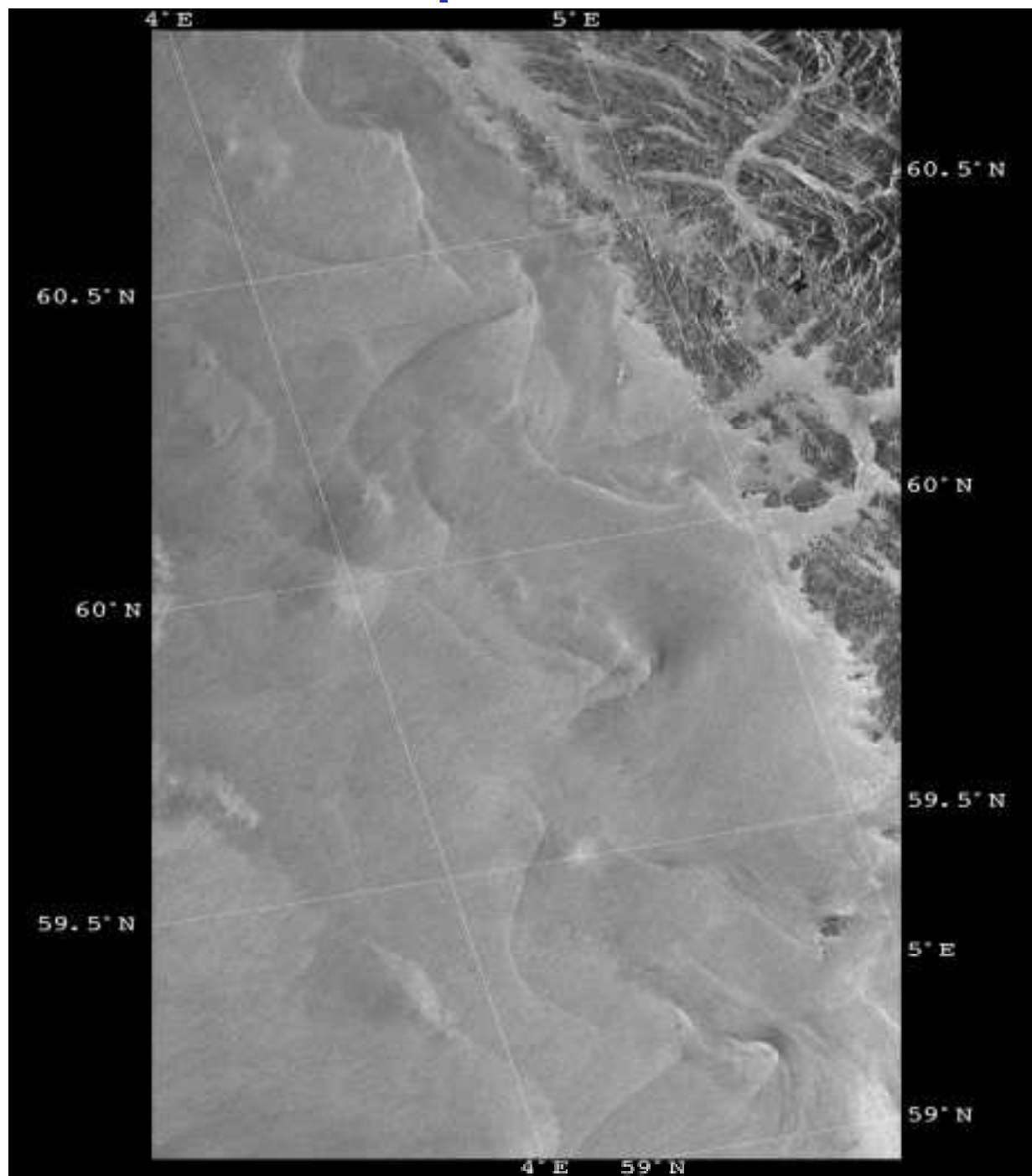


# SAR Signature of Sea Surface Currents

## Проявления течений в РСА изображениях

Model approach developed by

*Kudryavtsev V., D.Akimov,  
A.Johannessen, and B. Chapron,  
On radar imaging of current features.  
Part 1: Model and comparison with  
observations,  
J.Geoph.Res., VOL. 110, C07016,  
doi:10.1029/2004JC002505, 2005*



## RADAR IMAGING MODEL (RIM)

### *Модель формирования РЛ проявлений изменчивости морской среды*

1. Total NRCS is a sum of radar backscatter from “regular” surface ( $\sigma_{0R}^p$ ) and wave breaking ( $\sigma_{0WB}$ )

$$\sigma_0^p = \sigma_{0R}^p (1 - q) + \sigma_{0WB} q$$

“Regular surface” NRCS is composite model combining specular reflection and 2-scale Bragg model. NRCS  $\sigma_{0WB}$  results from specular reflections from wave breaking patterns.

2. Statistical properties of the sea surface are defined through wave spectrum  $B(\mathbf{k})$  based on solution of energy balance equation.

3. Response of wind waves to surface disturbances defines from solution of the same energy balance equation:

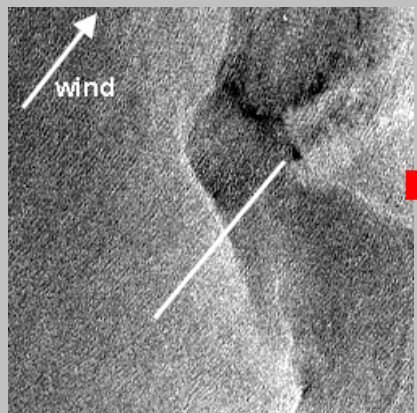
$$B(\mathbf{k}, \mathbf{x}) = B_0(\mathbf{k}) \left[ 1 + \int T(\mathbf{k}, \mathbf{K}) e^{i(\mathbf{K} \cdot \mathbf{x} - \Omega t)} d\mathbf{K} \right]$$

$T(\mathbf{k}, \mathbf{K})$  is spectral MTF accounting for impact of different mechanisms:

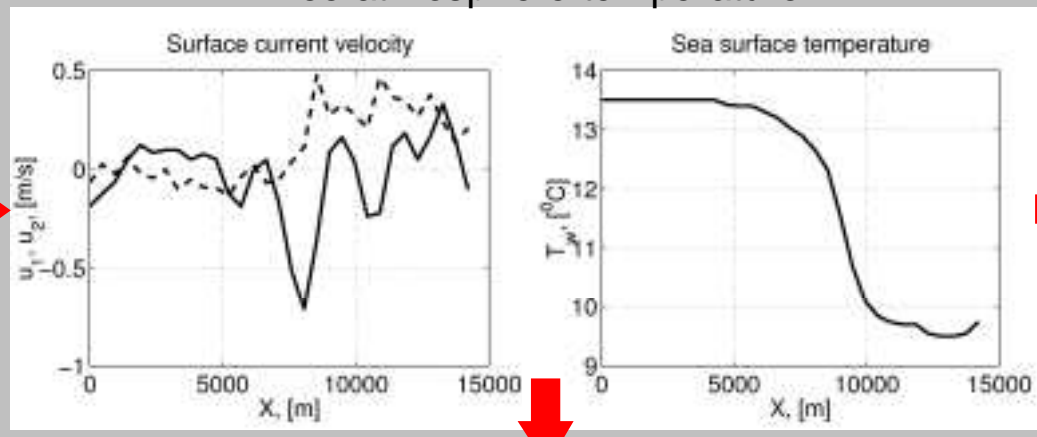
$$T(\mathbf{k}, \mathbf{K}) = \frac{\tau}{1 + i \cdot r} \left[ \omega^{-1} m_k^{ij} u_{i,j} + \tilde{\beta} + \tilde{I}_{WB} \right]$$

1- current, 2-varying wind stress, 3-wave breaking, 4-surfactants (included in  $B_0(\mathbf{k})$ )

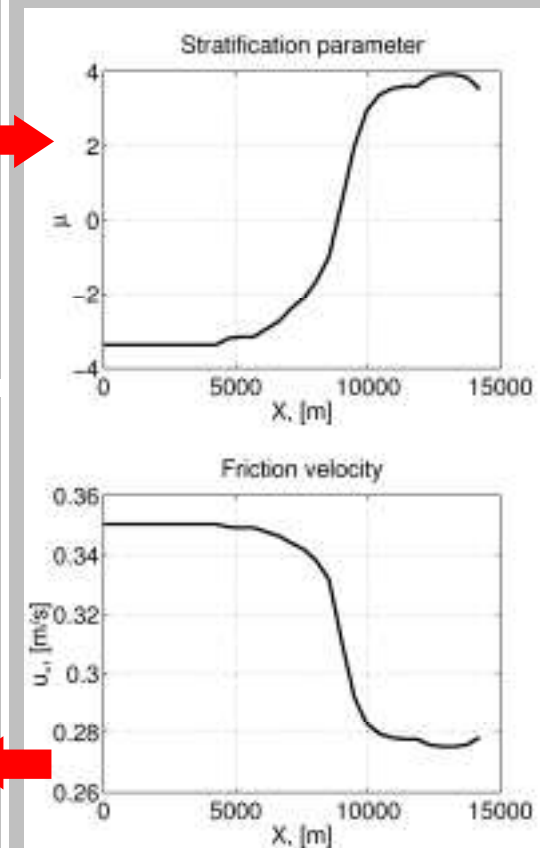
Observed frontal feature



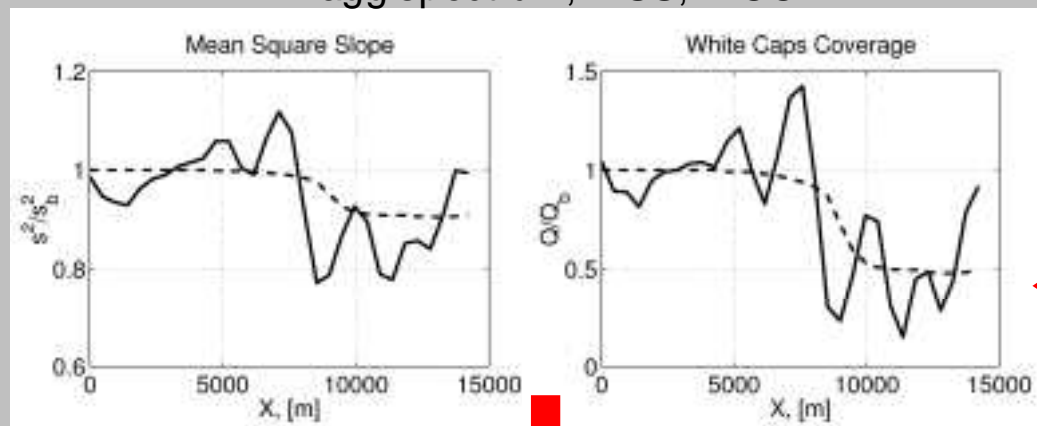
Input: current velocity, SST, geostrophic wind and free atmosphere temperature



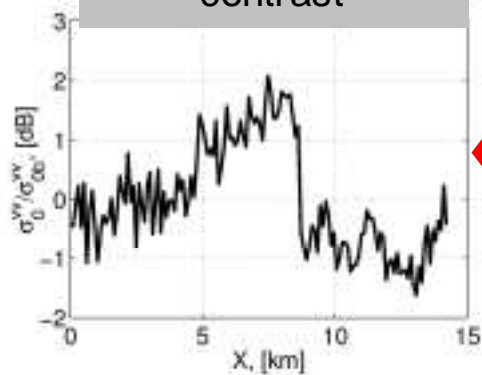
Atmospheric Boundary Layer model output



Wave spectrum transformation model output: Bragg spectrum, MSS, WCC

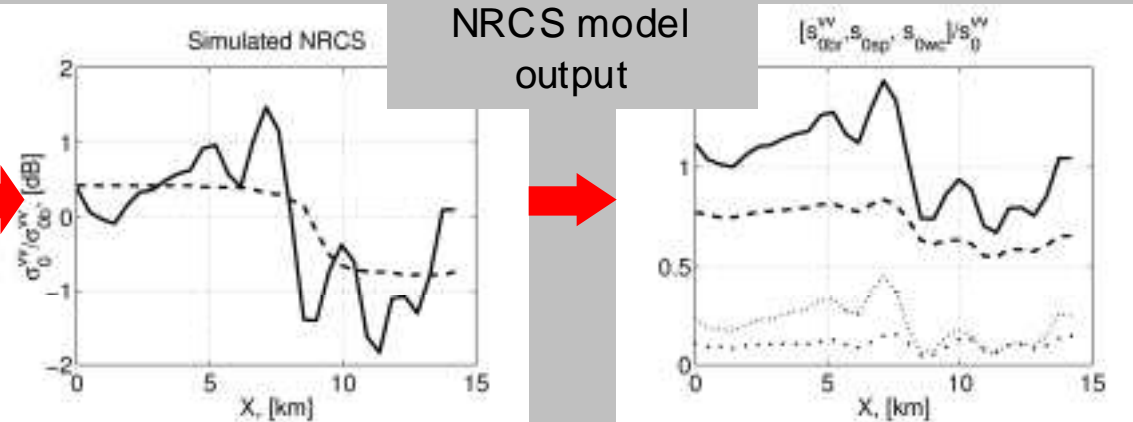


Measured NRCS contrast



comparison

NRCS model output



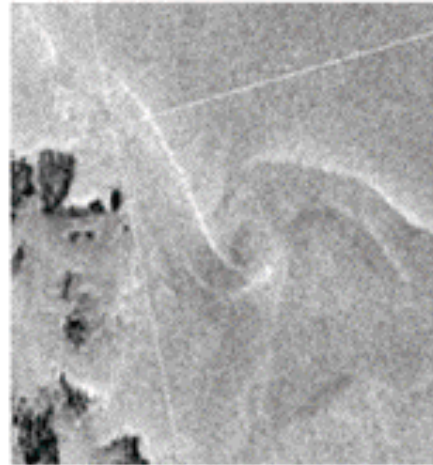
Radar Imaging Model



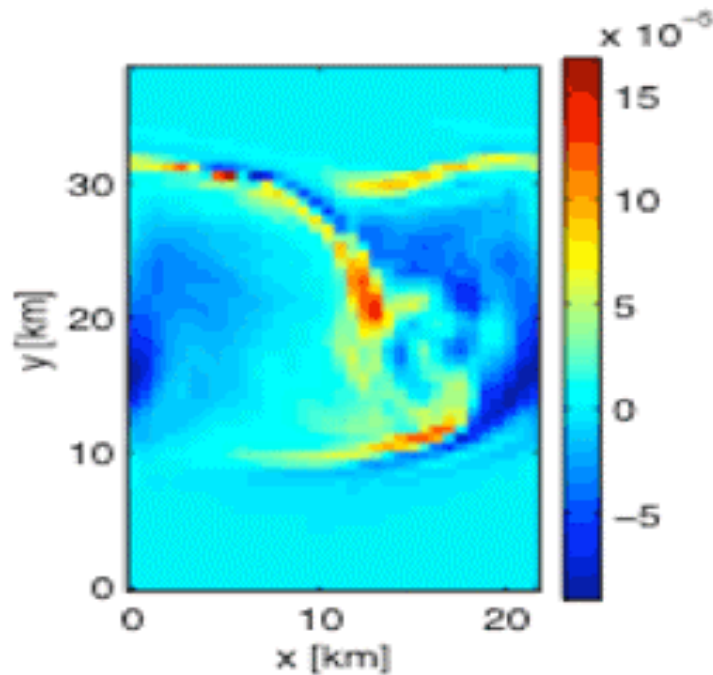
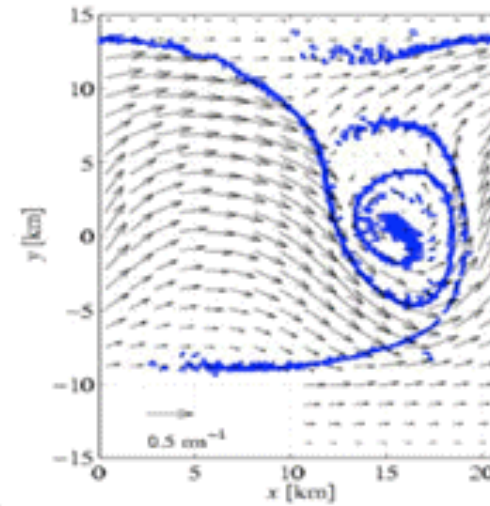
# Comparison with Observations: Modeled frontal eddy

Сопоставление с данными наблюдений: модельный фронтальный вихрь

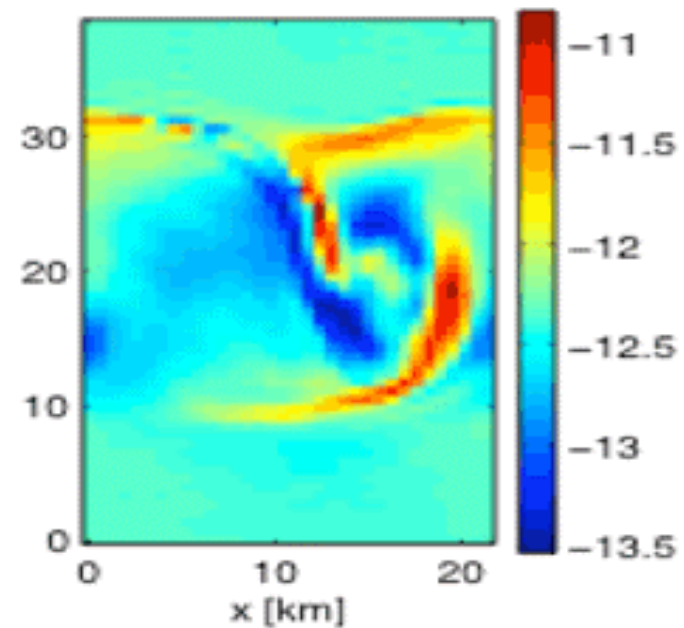
**a**



**b**



**c**



**d**

# Merger of RIM and Doppler models.

## Объединение модели RIM с моделью доплеровского сдвига

### RIM NRCS

$$\sigma_0^P = \sigma_{0R}^P(1-q) + \sigma_{0b}^P q$$

### Velocity of Facets

$$\bar{c}^P = P_{br}^P c_{br} + P_{sp}^P \bar{c}_{sl} + P_{wb}^P \bar{c}_b$$

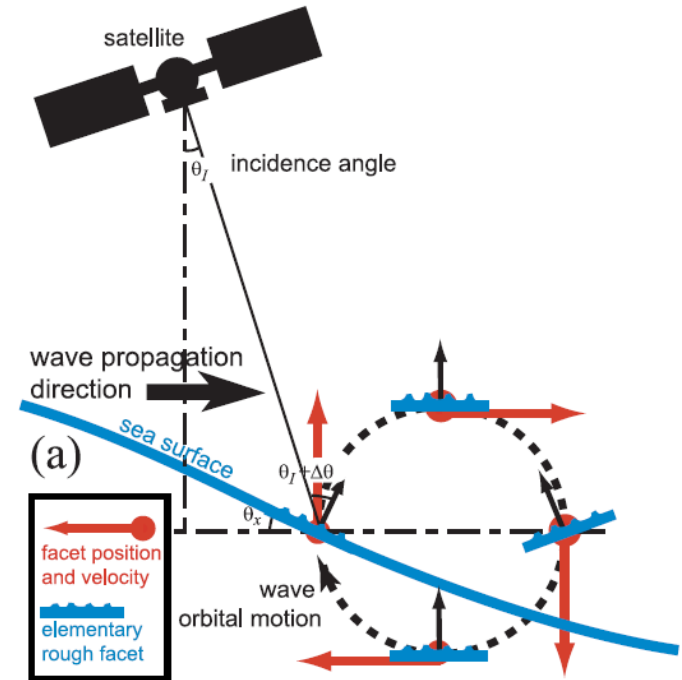
$$\bar{c}_{sl} = \frac{\iint_{k < k_d} \cos(\varphi_R - \varphi) c B(\mathbf{k}) d \ln k d \varphi}{\iint_{k < k_d} \cos(\varphi_R - \varphi) B(\mathbf{k}) d \ln k d \varphi}$$

$$\bar{c}_{wb} = \frac{\iint_{k < k_{wb}} \cos(\varphi_R - \varphi) c \beta(\mathbf{k}) B(\mathbf{k}) d \ln k d \varphi}{\iint_{k < k_{wb}} \cos(\varphi_R - \varphi) \beta(\mathbf{k}) B(\mathbf{k}) d \ln k d \varphi}$$

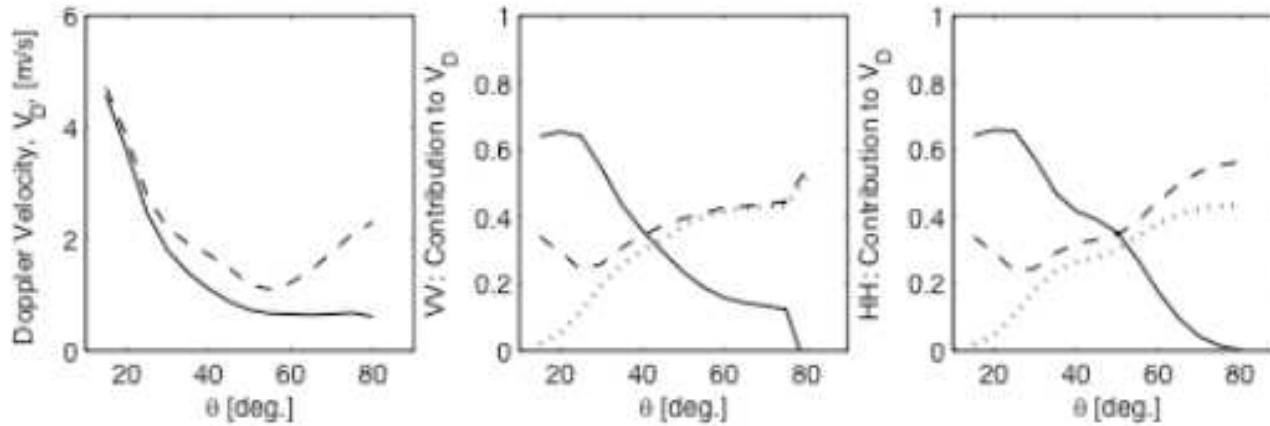
$$V_D = u_S + \bar{c} - \frac{1}{\tan \theta} \frac{1}{\sigma_0} \frac{\partial \sigma_0}{\partial \theta} \iint_{k < k_d} \cos(\varphi_R - \varphi) c B(\mathbf{k}) d \ln k d \varphi + \iint_{k < k_d} \cos(\varphi_R - \varphi) c B(\mathbf{k}) M d \ln k d \varphi$$

### Hydrodynamic MTF

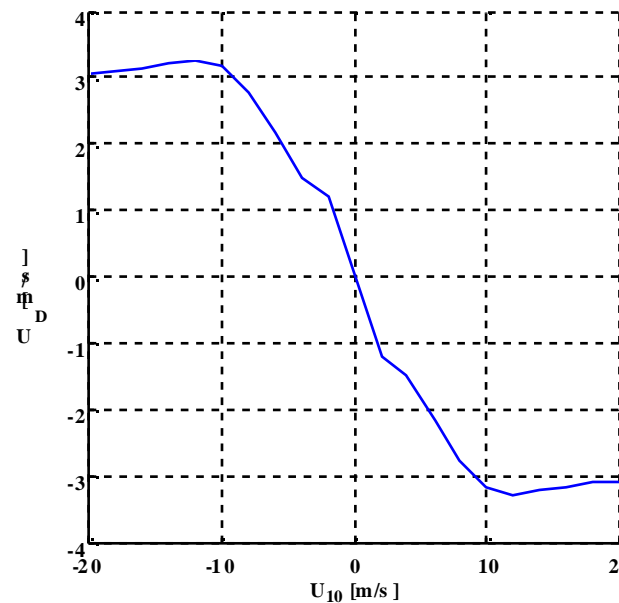
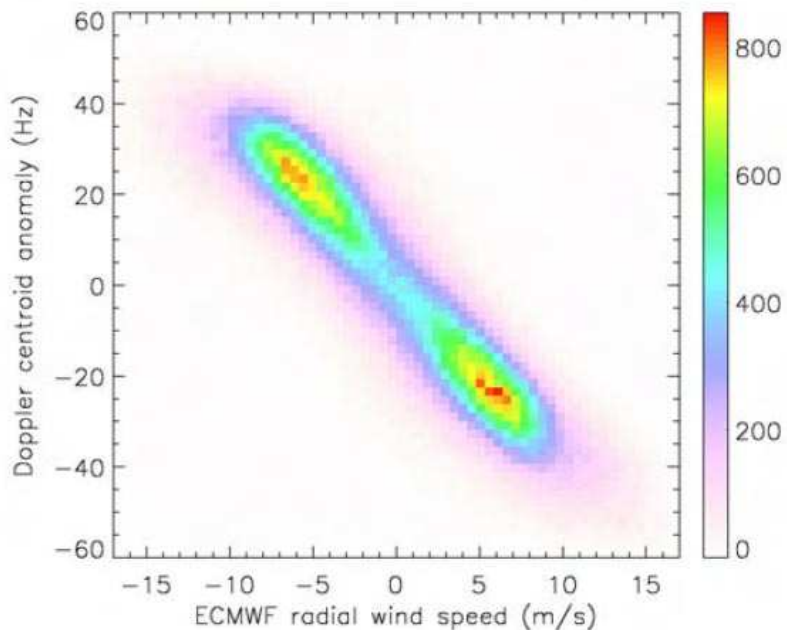
$$M = P_{br}^P \left( M_B + \frac{s_i^2}{\sigma_{br}^P} \frac{\partial \sigma_{br}^P}{\partial s_i^2} M_{S_i} \right) + P_{sp}^P \left( \frac{s_i^2}{\sigma_{sp}^P} \frac{\partial \sigma_{sp}^P}{\partial s_i^2} \right) M_{S_i} + P_{wb}^P M_q$$



# Some background features: Некоторые фоновые характеристики



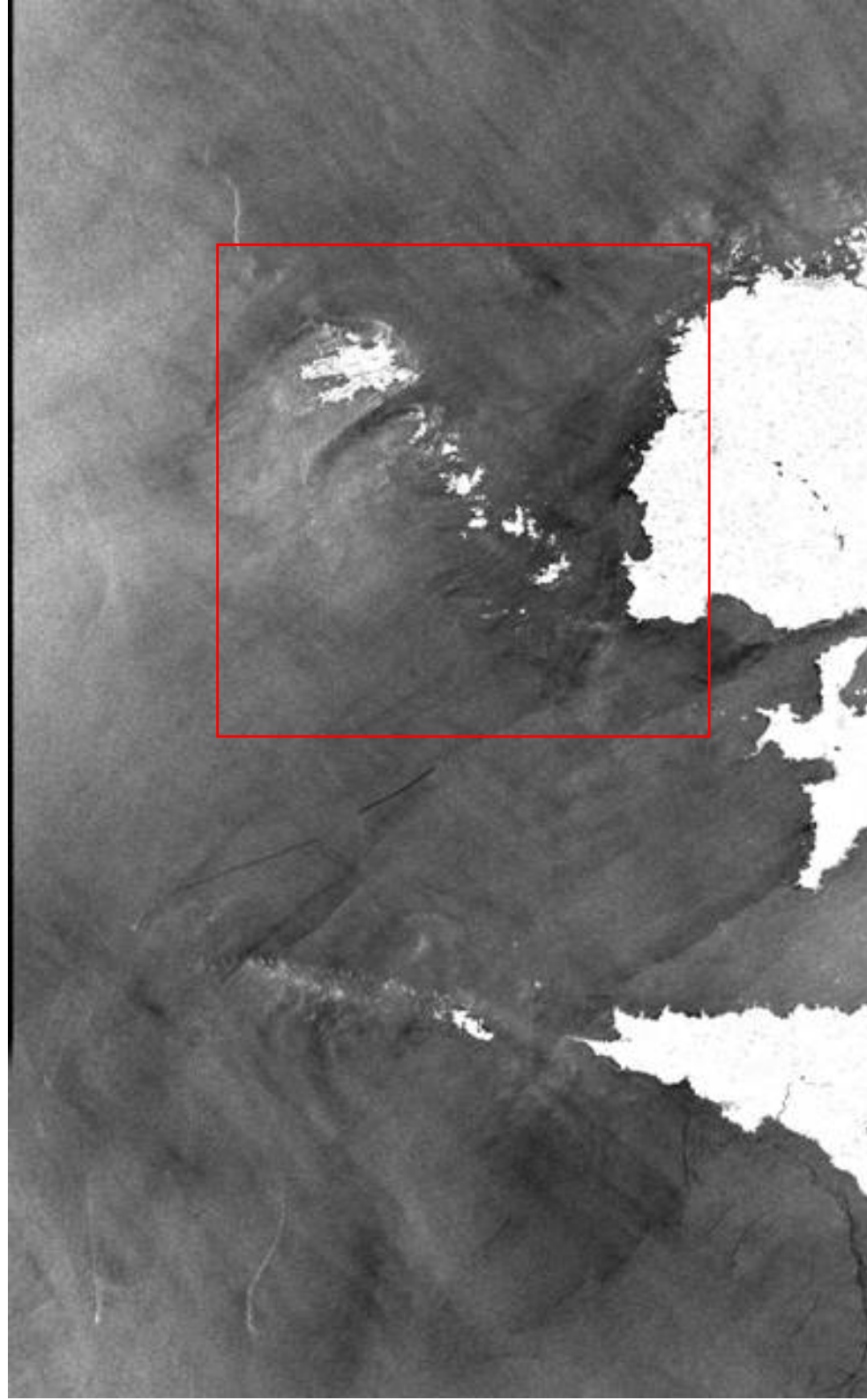
**Figure 1.** Up-wind Doppler velocity for C-band VV (solid line) and HH (dashed line) versus incidence angle at a wind speed of 10 m/s (left). Relative contributions to the Doppler velocity from the motion of the scattering facets (dashed line), the tilt of the longer waves (solid line), and the hydrodynamic modulations (dotted line) for VV polarizations versus incidence angles at a wind speed of 10 m/s (middle). The same presentation as in the middle plot, but for HH polarization (right).



For C-band 1m/s surface current corresponds to Doppler shift  $F=15-20$  Hz at 20-30 deg incidence

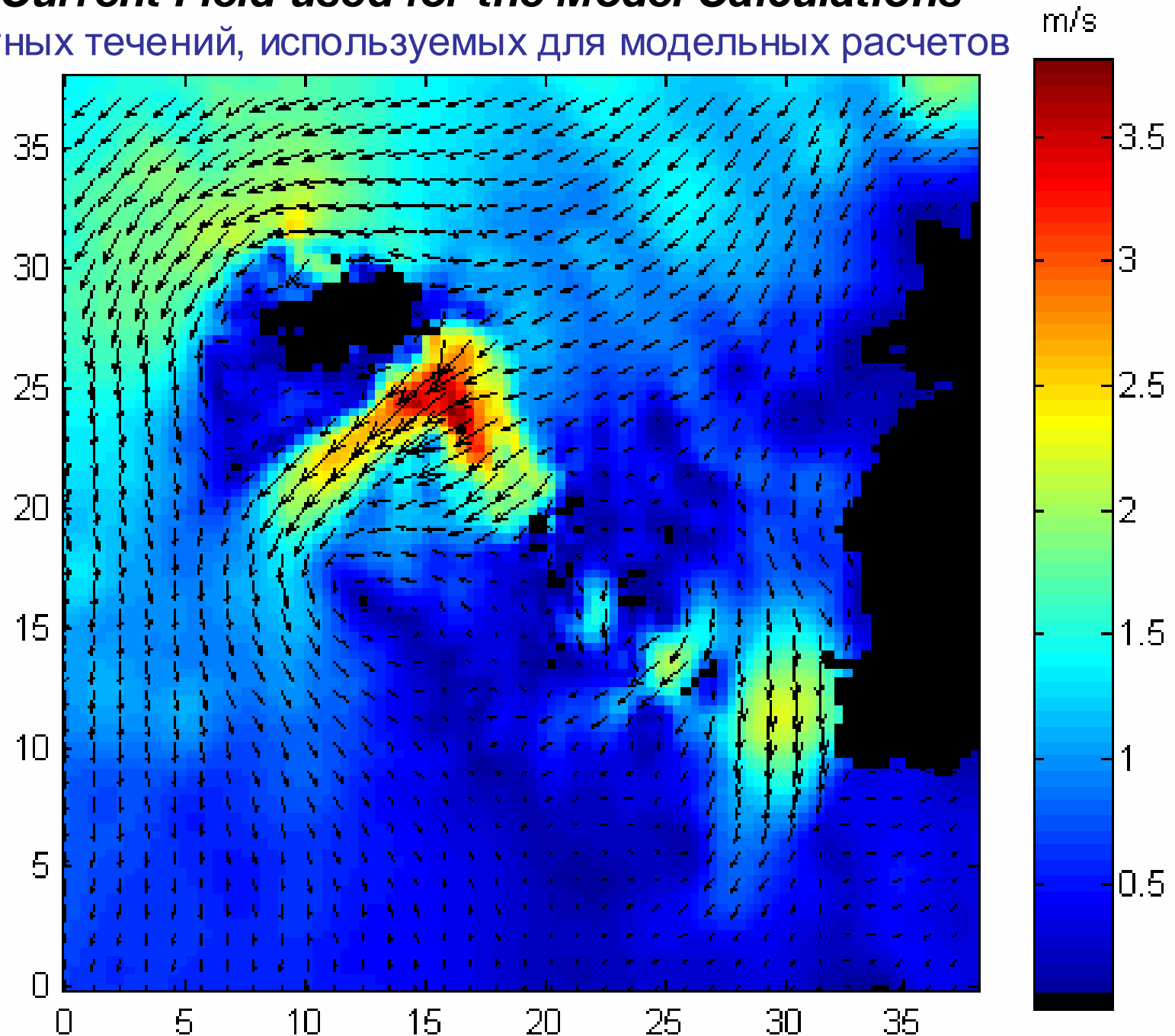
***ENVISAT ASAR***  
***Brest Coast***

**РСА изображение  
прибрежной зоны  
Франции**



# ***Model Surface Current Field used for the Model Calculations***

Поле поверхностных течений, используемых для модельных расчетов

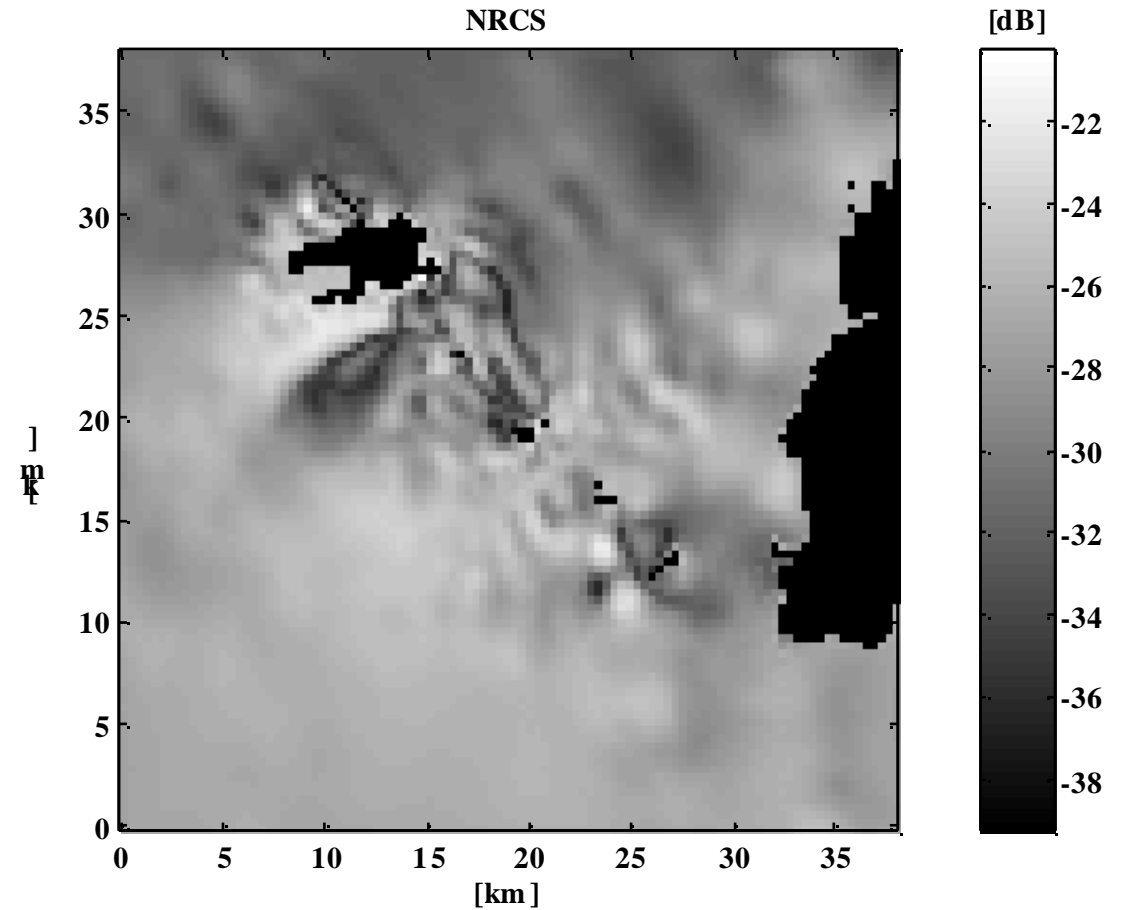


# RIM simulation of SAR signature of tidal current near Atlantic coast of France

*Модельные расчеты РСА проявлений приливных течений в прибрежной зоне Франции*

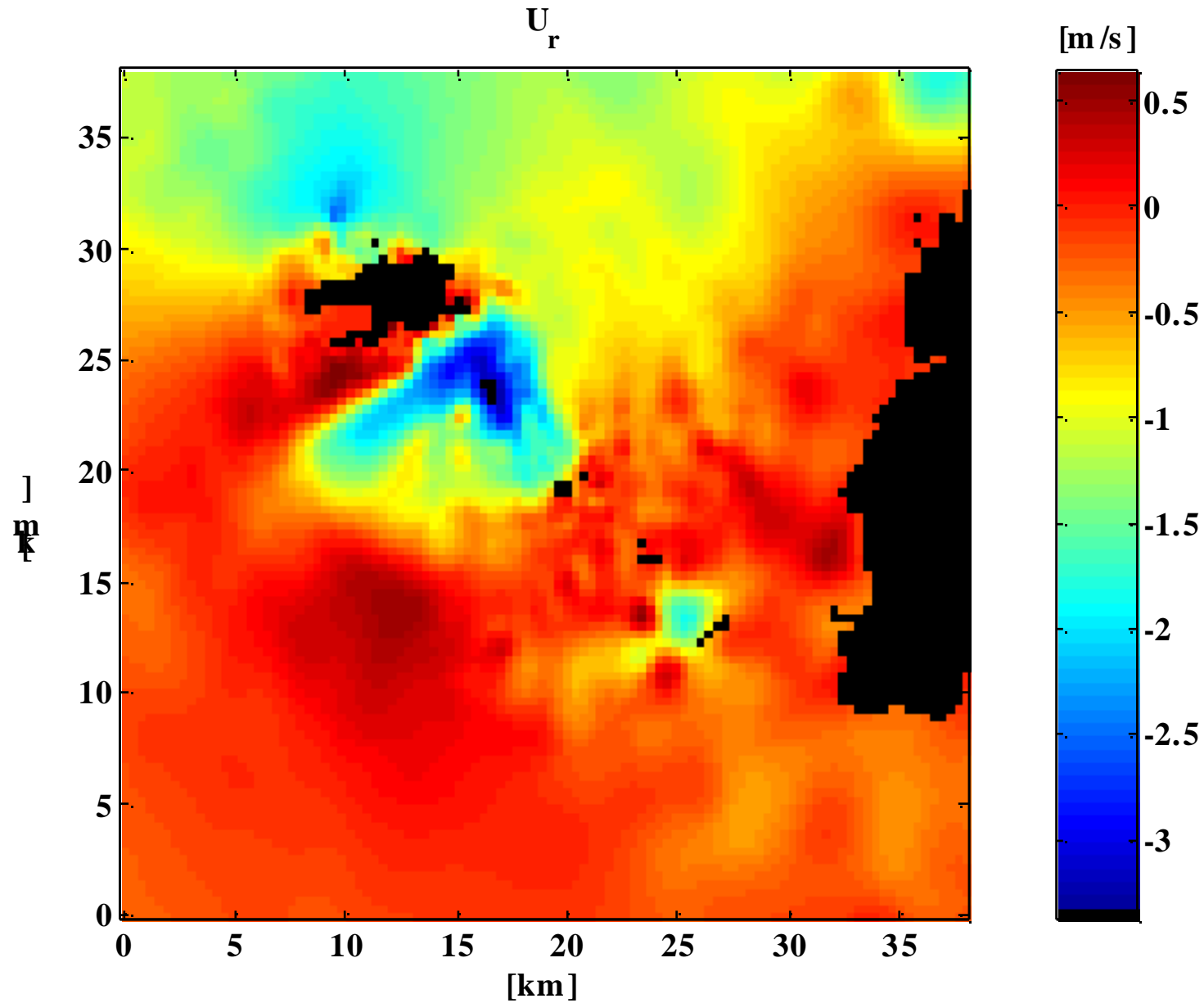


ENVISAT ASAR image with strong manifestations of tidal current



RIM simulation of the SAR image

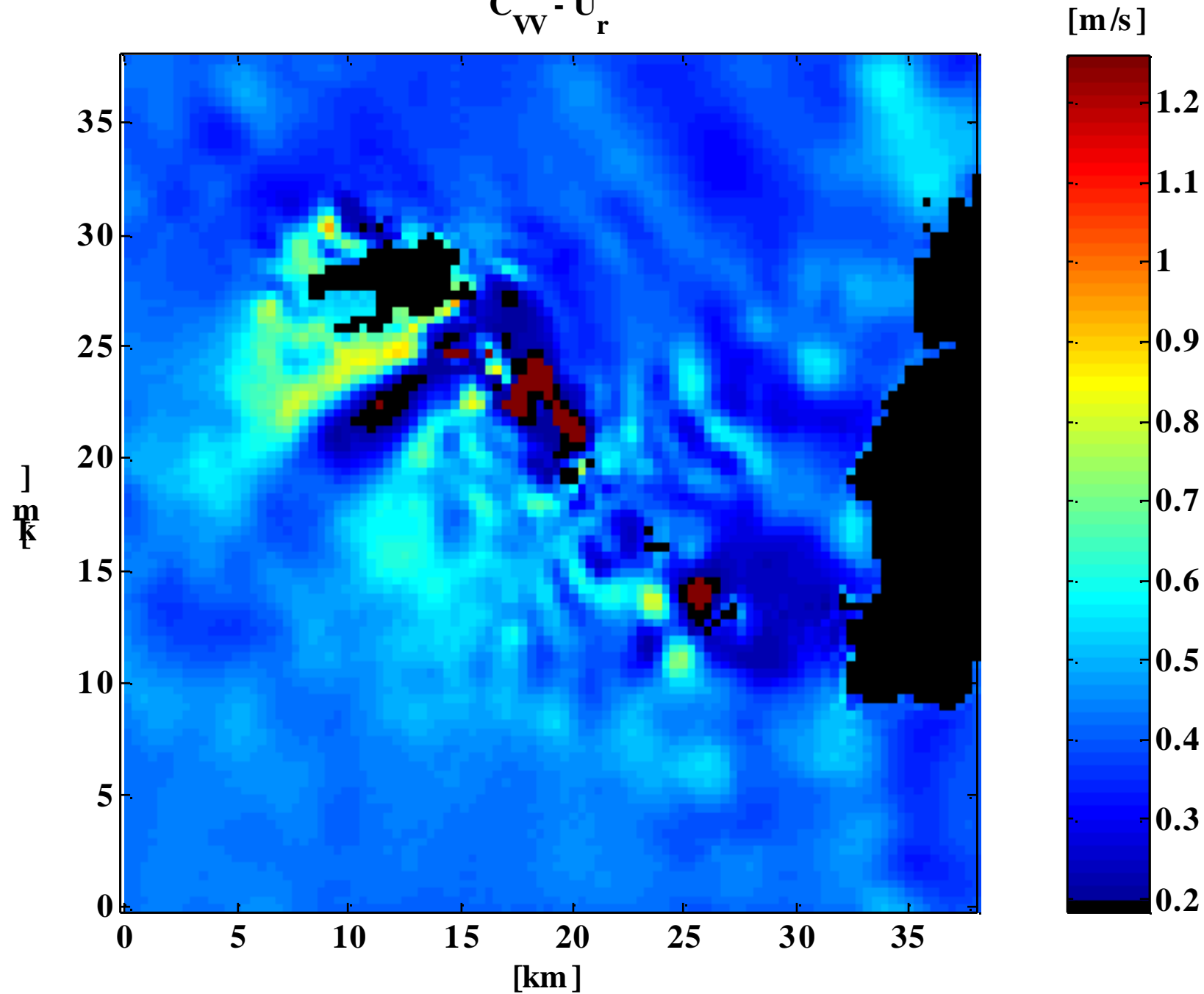
***Projection of Current Velocity on Radar Look Direction***  
***Проекция вектора скорости течения на РЛ азимут***



# Contribution of Surface Roughness Modulation to the Doppler Velocity

## Вклад модуляции ветрового волнения в доплеровскую скорость

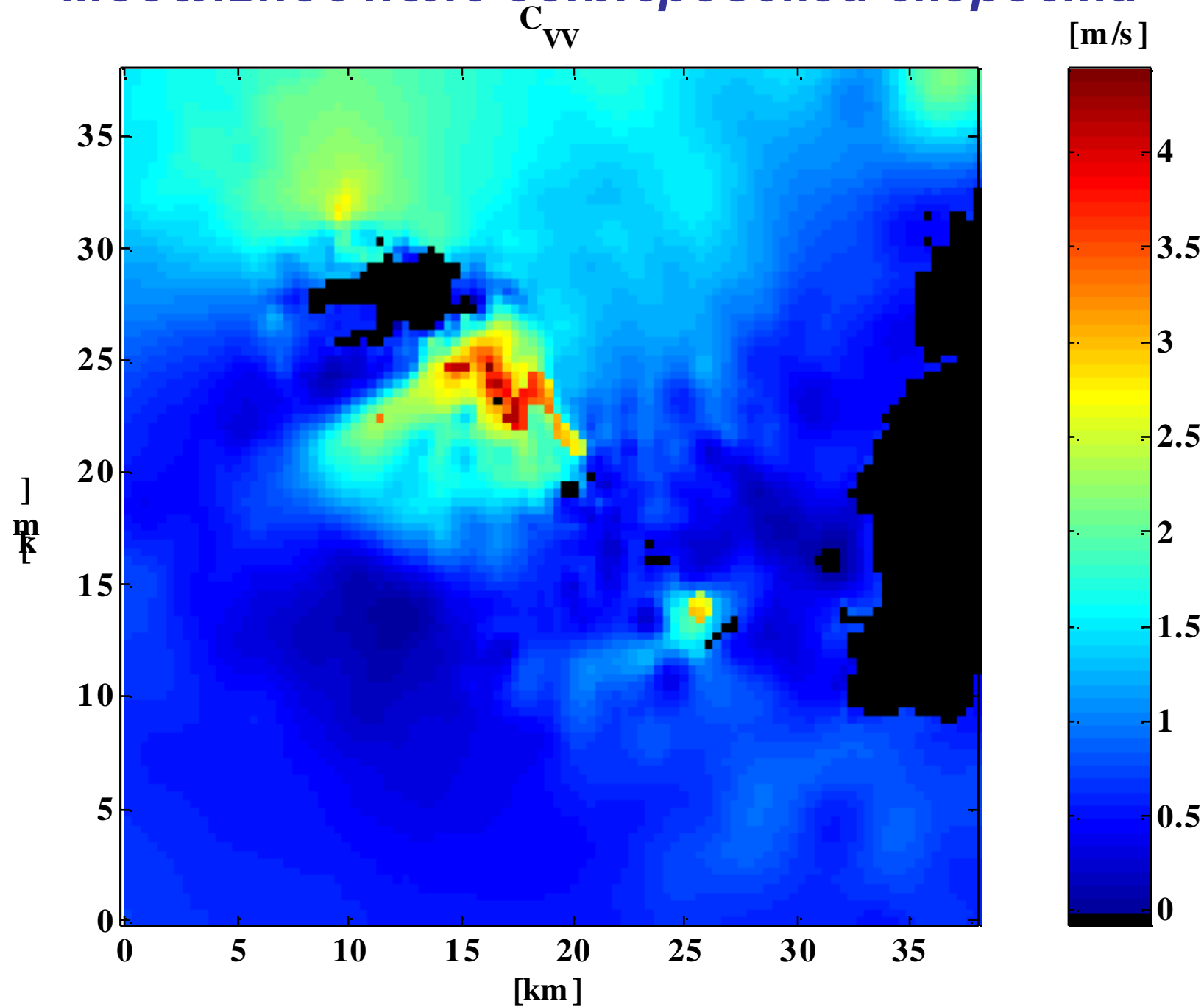
$$C_{\text{WV}} - U_r$$



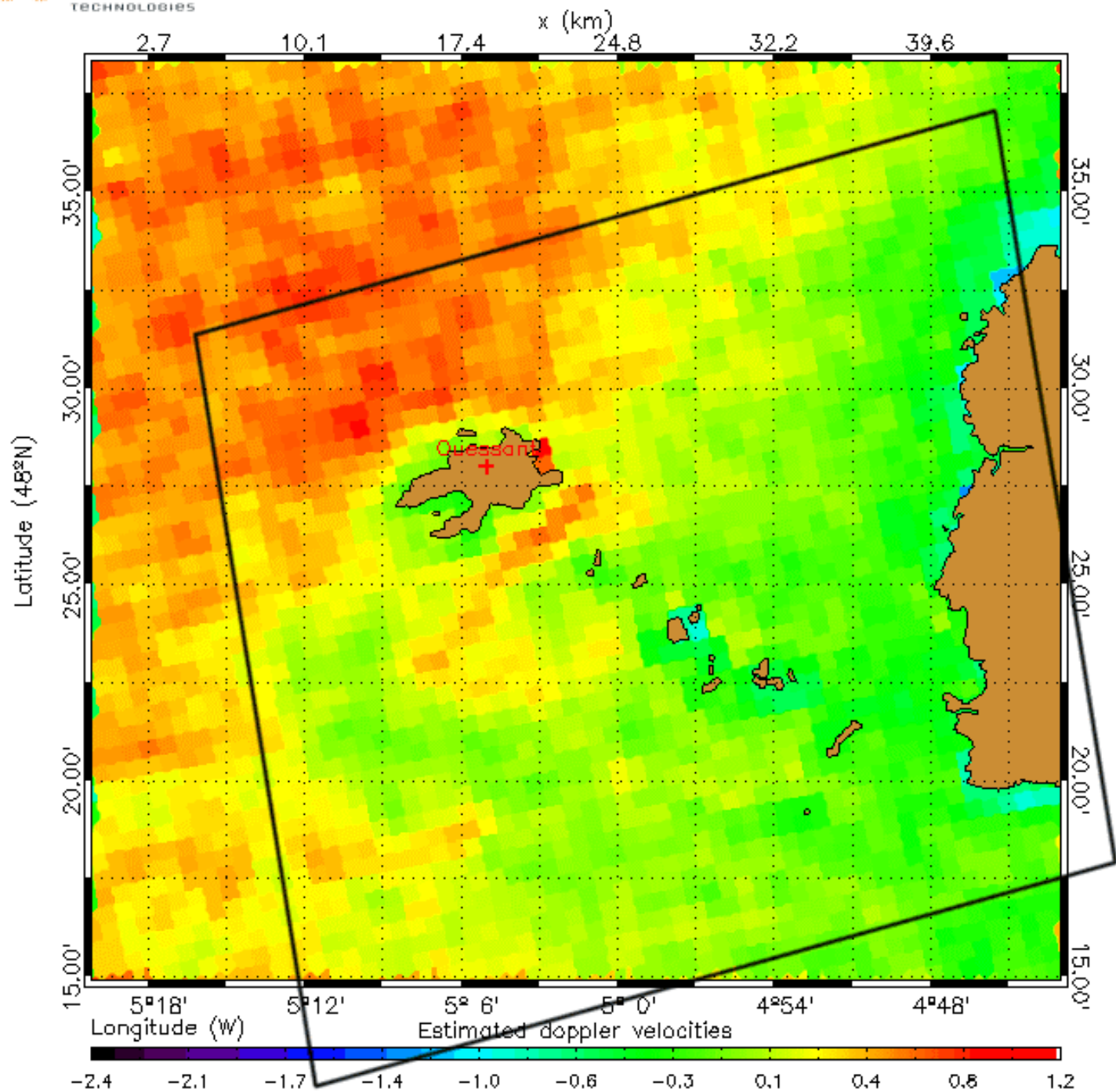


# *The DopRim model Doppler Velocity*

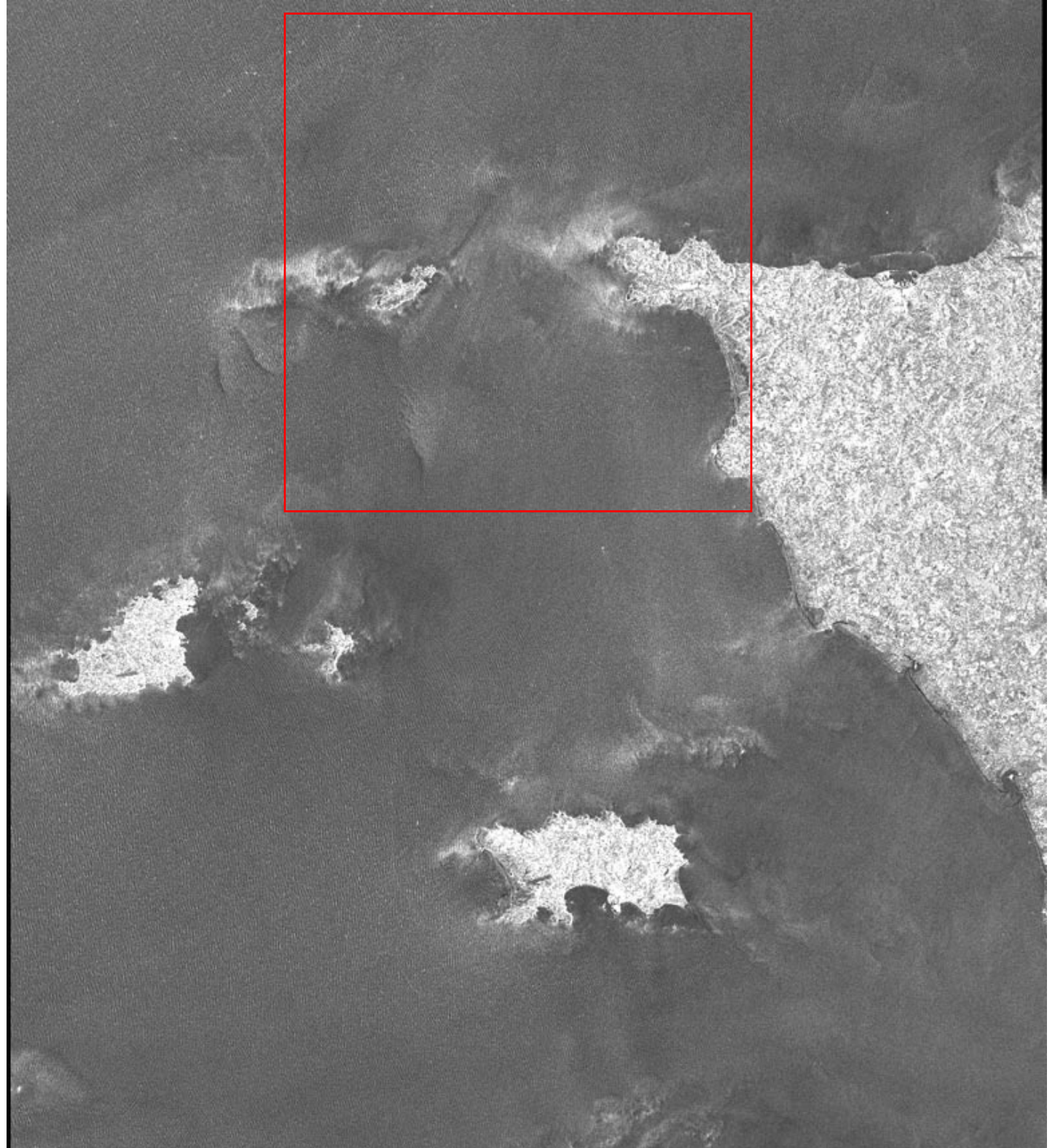
## *Модельное поле доплеровской скорости*



# Поле доплеровской скорости определенное по РСА

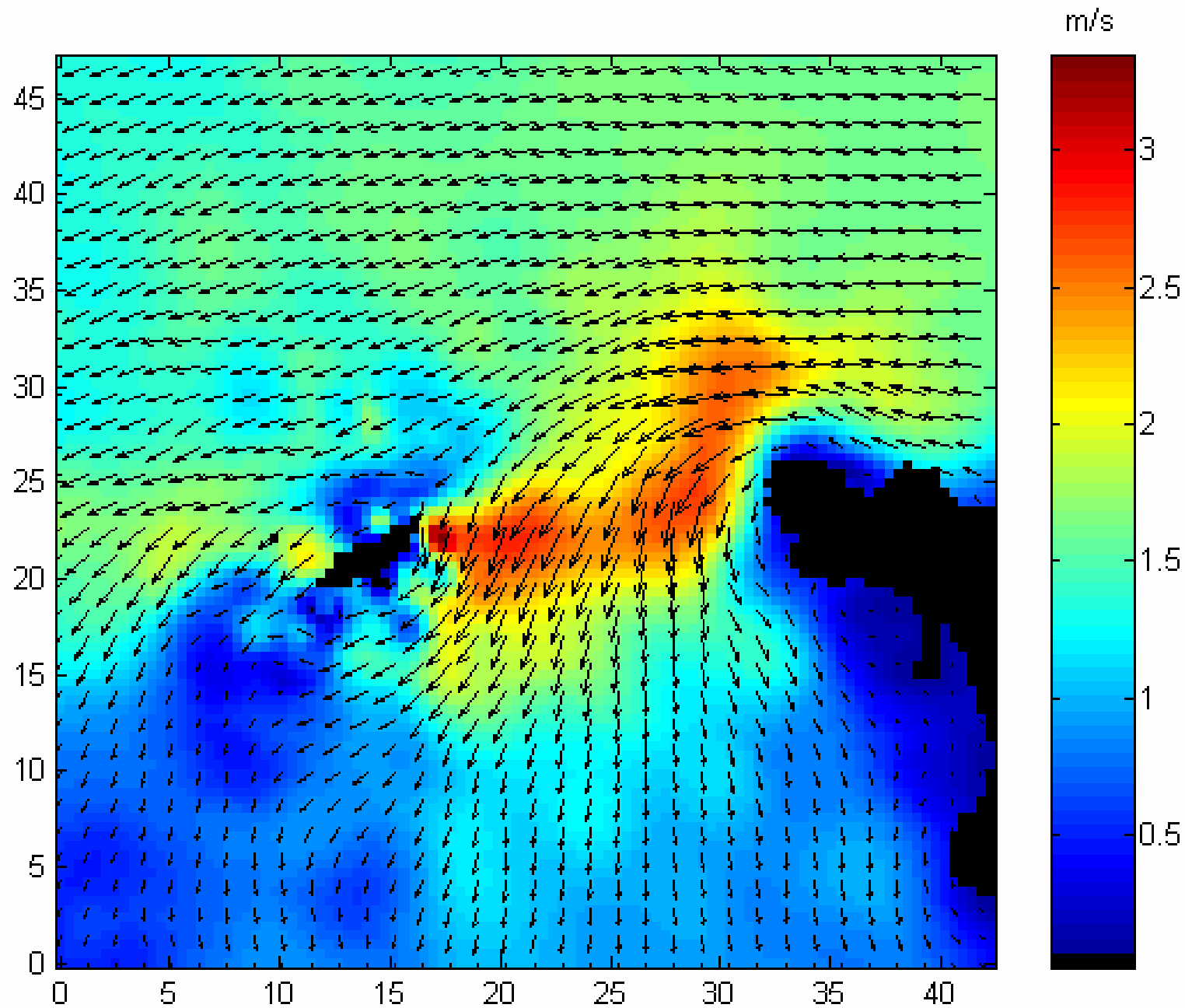


***ENVISAT ASAR  
English Channel  
(Cherbourg)***



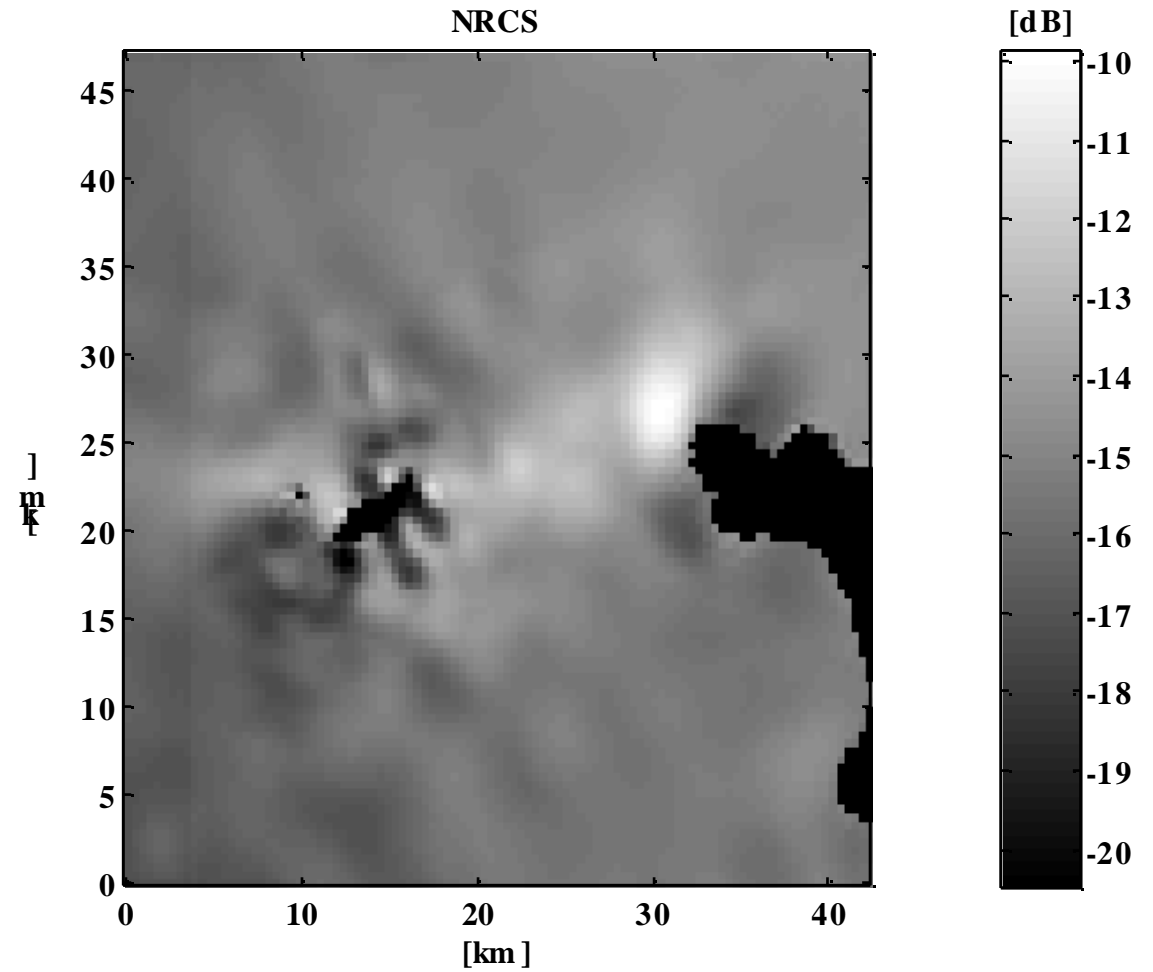
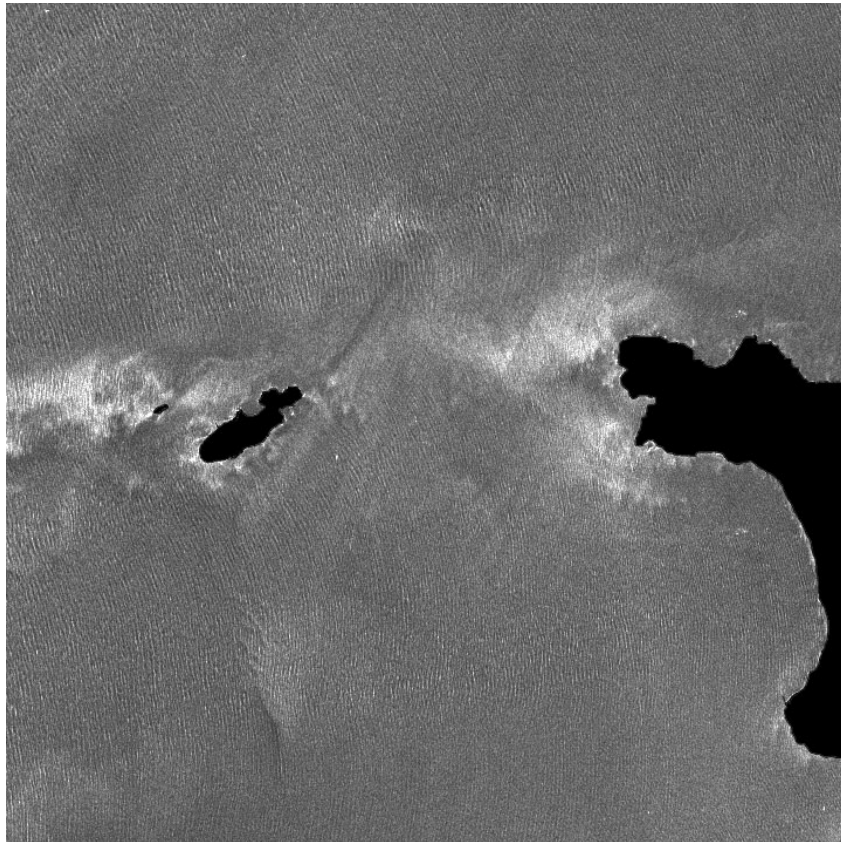
# Model Surface Current Field used for the Model Calculations

Поле поверхностных течений, используемых для модельных расчетов



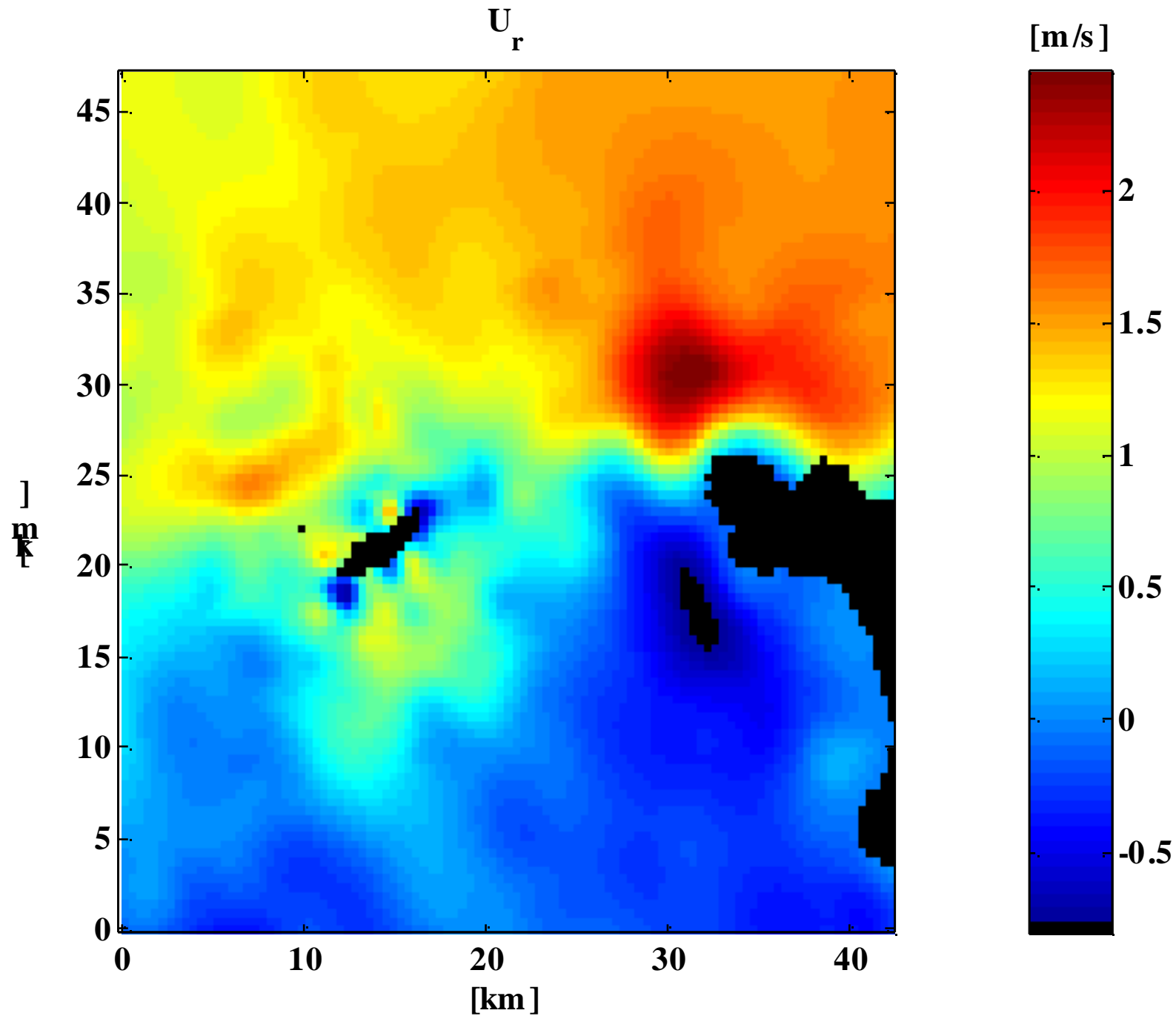
# RIM simulation of SAR signature of tidal current: English Channel (Cherbourg)

Модельные расчеты РСА проявлений приливных течений



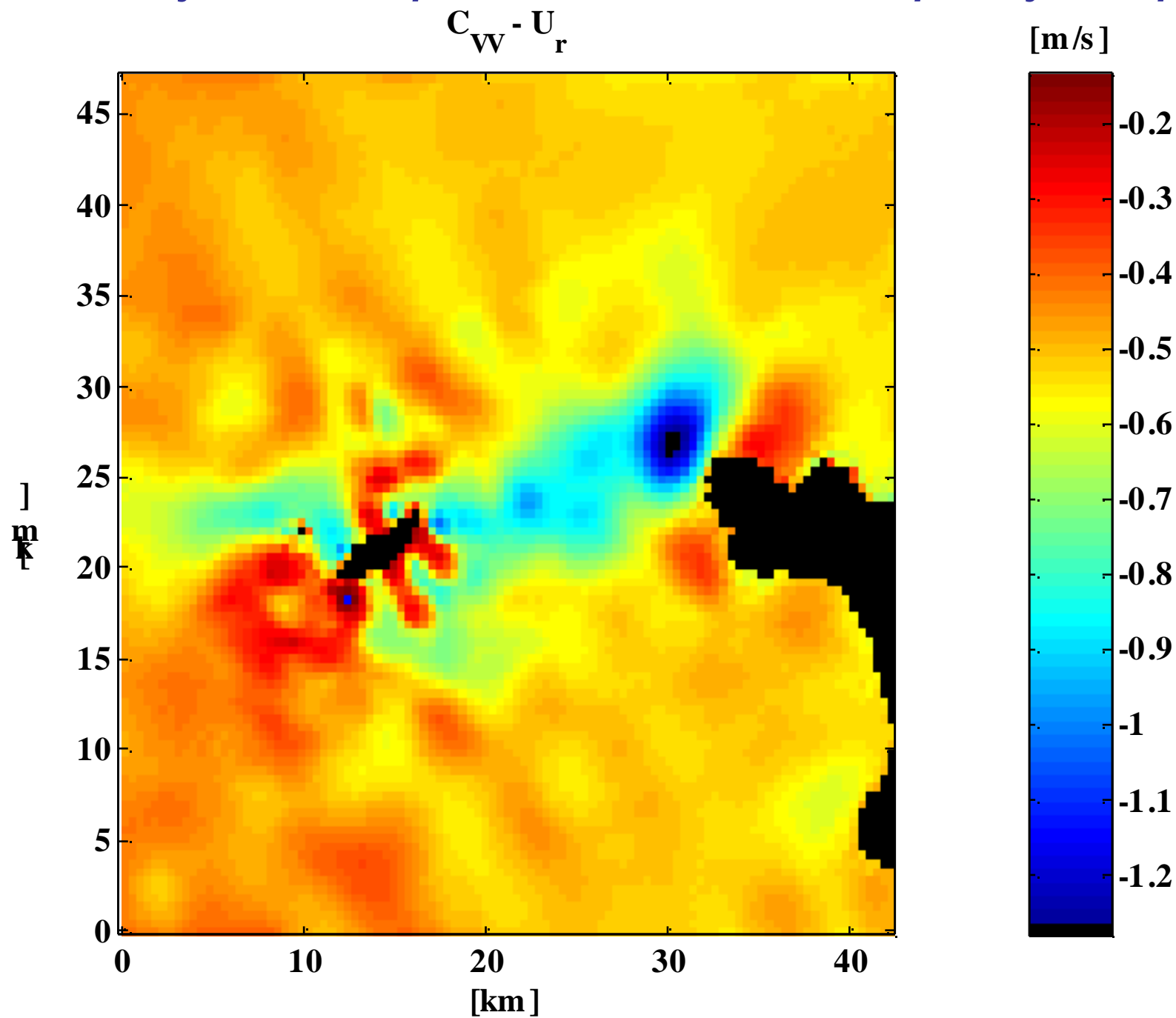
# Projection of Current Velocity on Radar Look Direction

Проекция вектора скорости течения на РЛ азимут



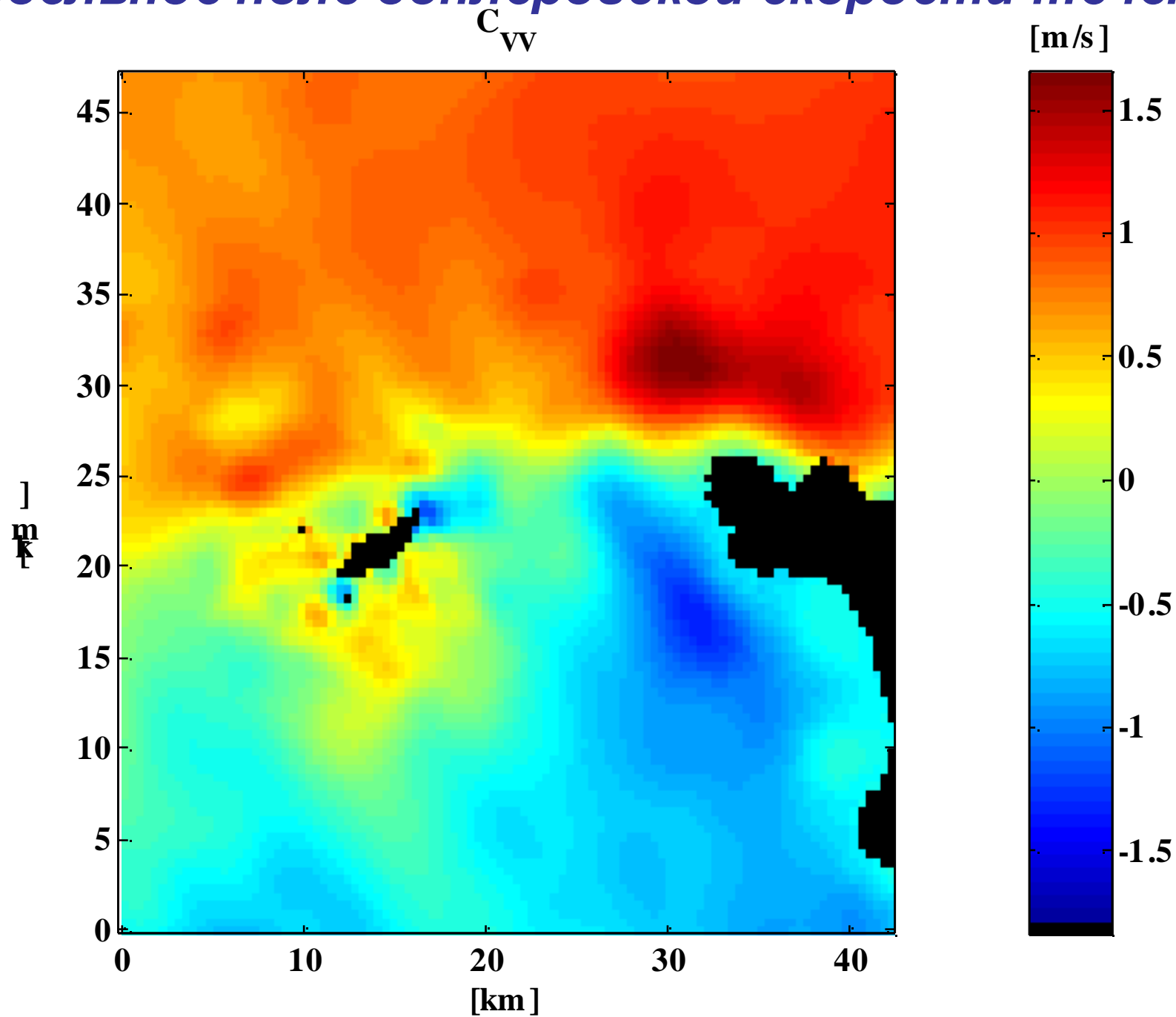
# Contribution of Surface Roughness Modulation to the Doppler Velocity

*Вклад модуляции ветрового волнения в доплеровскую скорость*



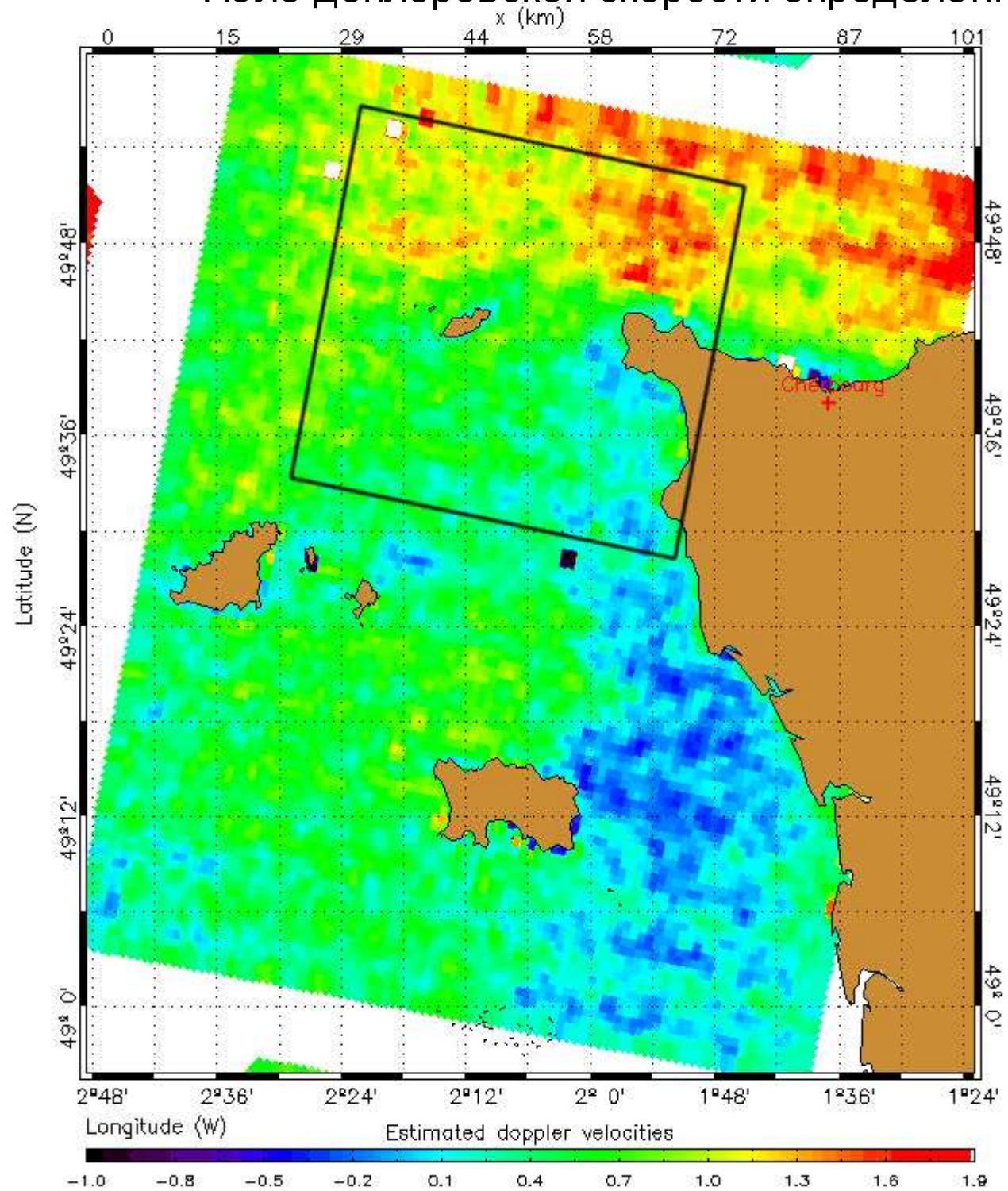
# The DopRim model Doppler Velocity

Модельное поле доплеровской скорости течения





# Поле доплеровской скорости определенное по РСА



## Does Doppler velocity inevitably corresponds to “real” surface velocity?

The answer is

- ***YES when modulations of surface roughness by current is weak, and***
- ***NO when modulations are strong.***

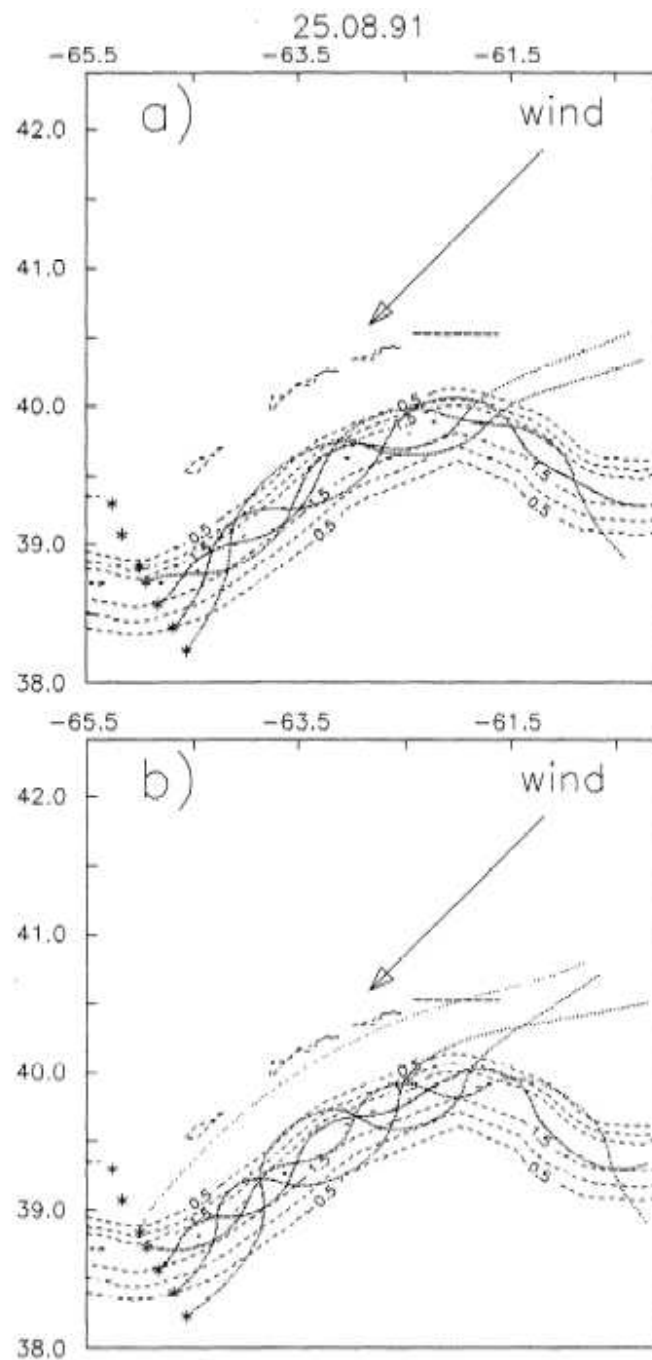
In order to illustrate this case we consider the ocean surface wave field in the Gulf Stream zone at a special conditions when wind blows opposite to the current. At such conditions effect of the trapping of surface waves by jet-current with strong enhancement of wave energy may take place. This phenomenon had been observed and investigated in field experiments by Kudryavtsev et al. JGR, 100, C10, 1995.

**Соответствует ли поле доплеровской скорости полю реальных течений?**

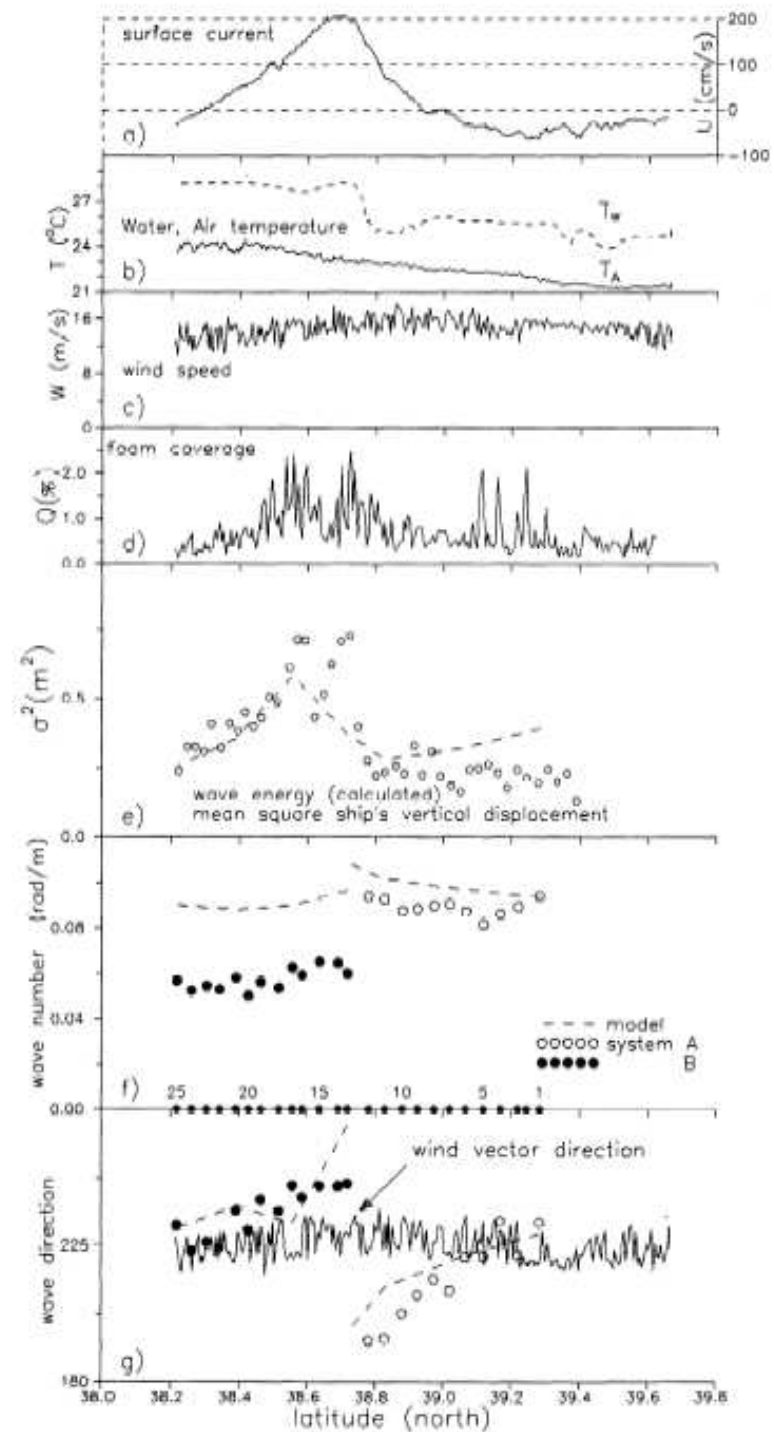
**-Да, если модуляции ветрового волнения этими течениями малы**

**- Нет, если эти модуляции велики**

Для иллюстрации, рассмотрим поле волн на Гольфстриме, когда ветер в среднем направлен навстречу течению. В этих условиях возможно образование системы захваченных волн с резким увеличением энергии (это явление наблюдалось в экспериментах Kudryavtsev et al. JGR, 100, C10, 1995)



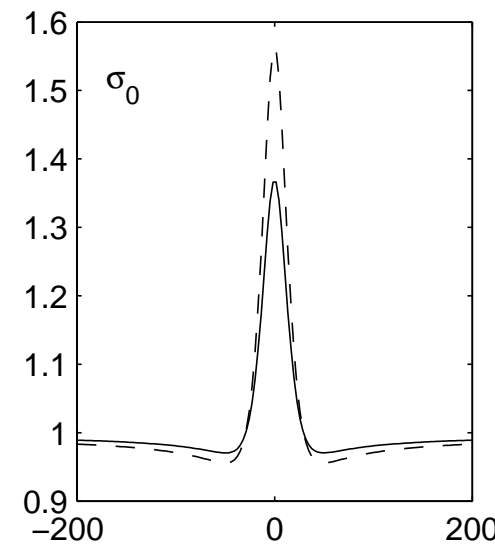
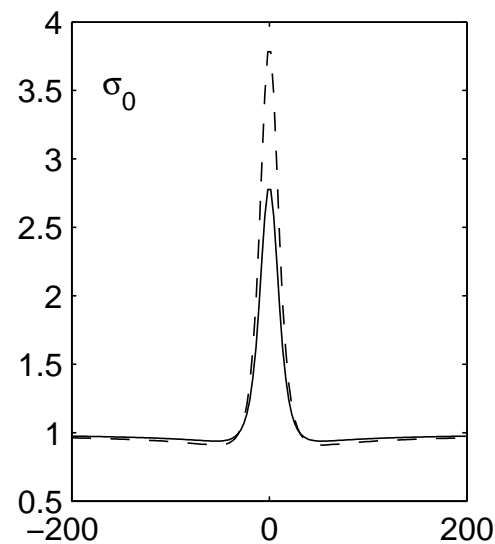
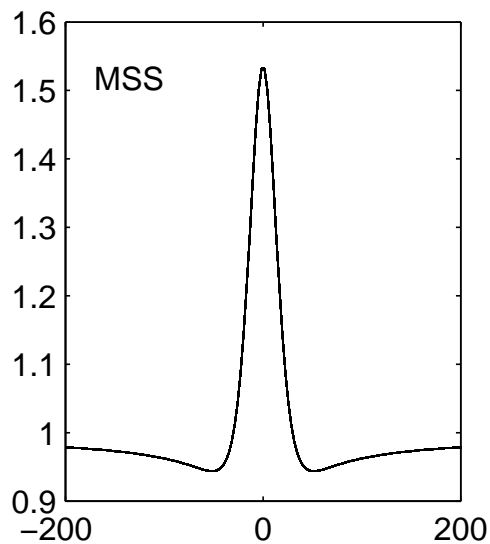
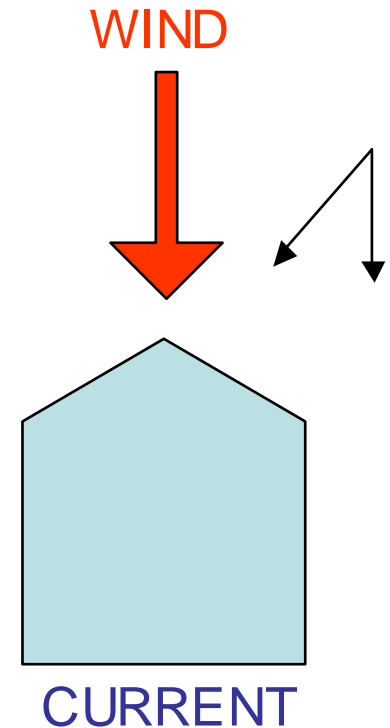
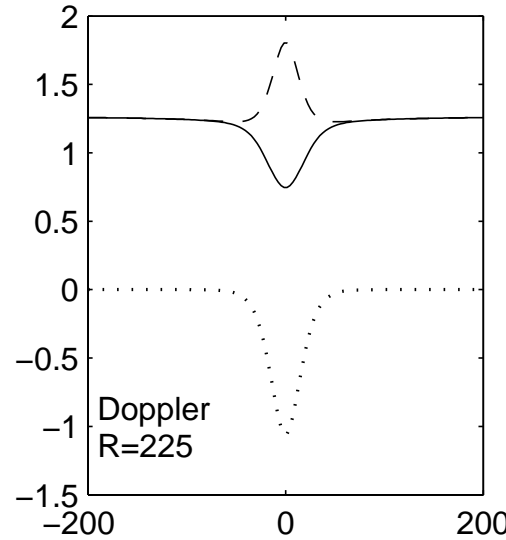
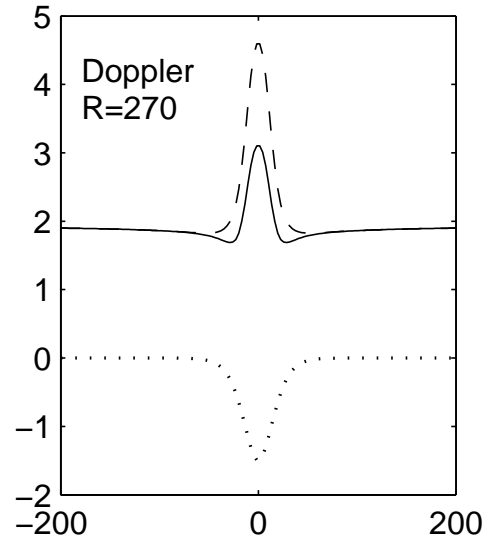
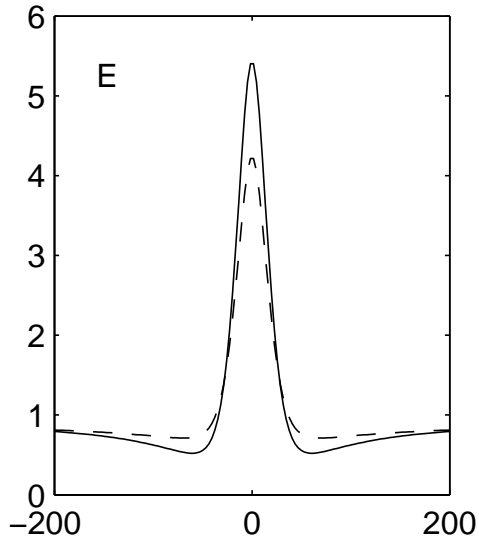
**Figure 8.** The same as in Figure 4. Experiment 13. Wind vector arrows show mean wind direction and have a length equal to dimensional fetch of the background waves.



**Figure 9.** The same as in Figure 5. Experiment 13.

# Jet-Like Current (wind waves and swell)

5 m/s Wind and Swell are Opposite to Jet-Current (Wdir=270; CUdir=90)



**Conditions:**

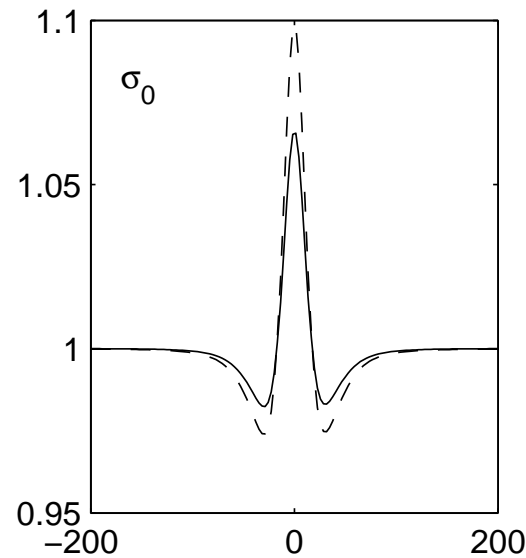
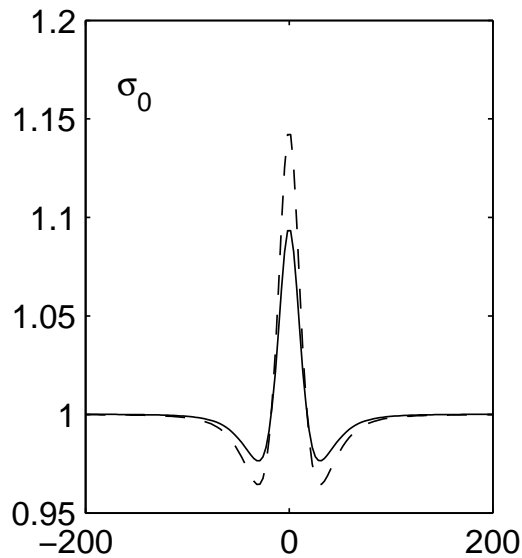
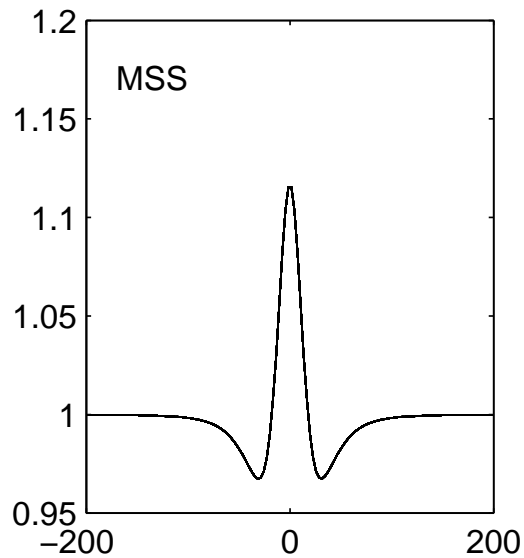
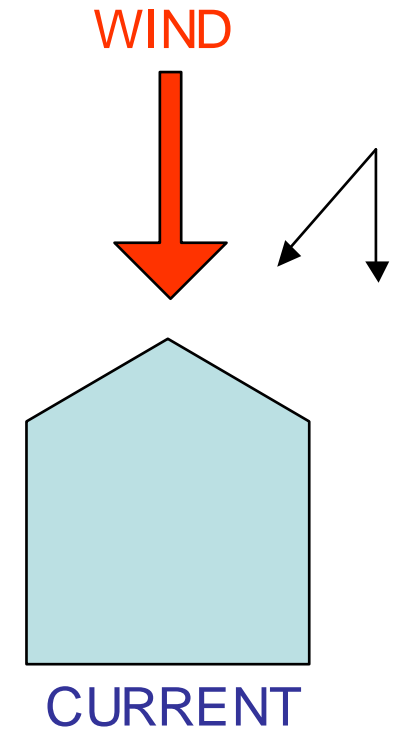
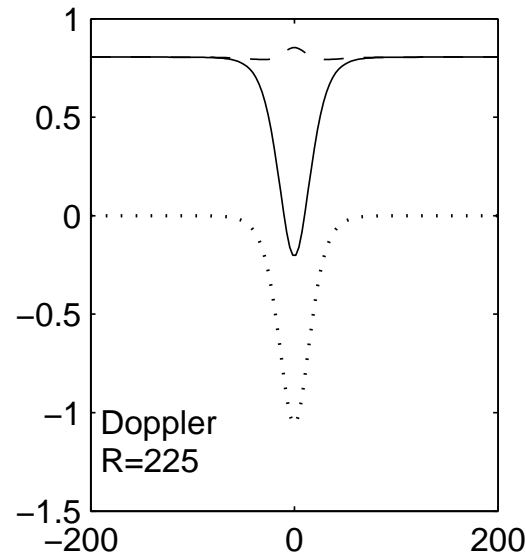
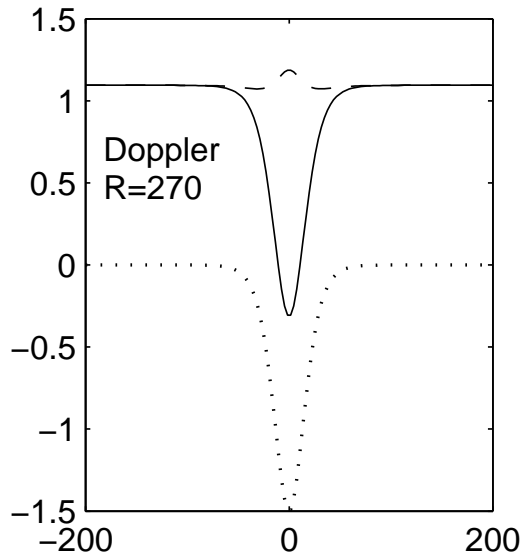
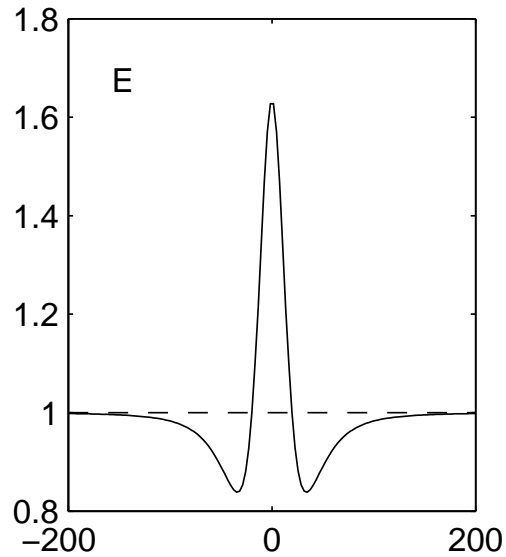
Wind 5 m/s opposite to jet;  
 Jet width is 80 km,  
 Velocity is 1.5 m/s;  
 Swell: KA=0.05, L=200m

**Radar observations:**

C-band, VV;  
 Incidence angle 30 deg.;  
 Radar look:  
 a) down-wind and  
 b) 45 deg clockwise  
 off wind direction

# Let-Like Current (wind waves only)

5 m/s Wind (NO Swell) is Opposite to Jet-Current (Wdir=270; CUdir=90)



## Conditions:

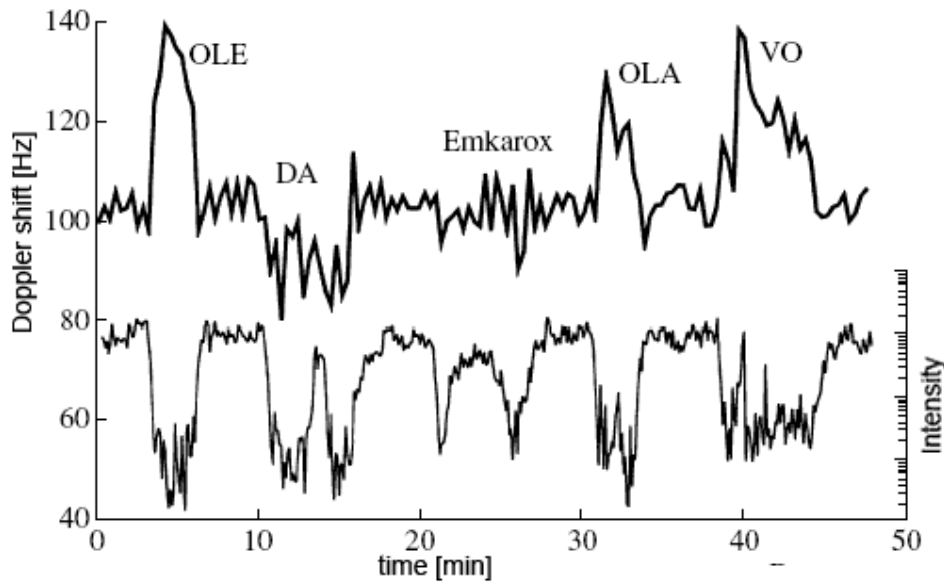
Wind 5 m/s opposite to jet;  
 Jet width is 80 km,  
 Velocity is 1.5 m/s;  
 No swell

## Radar observations:

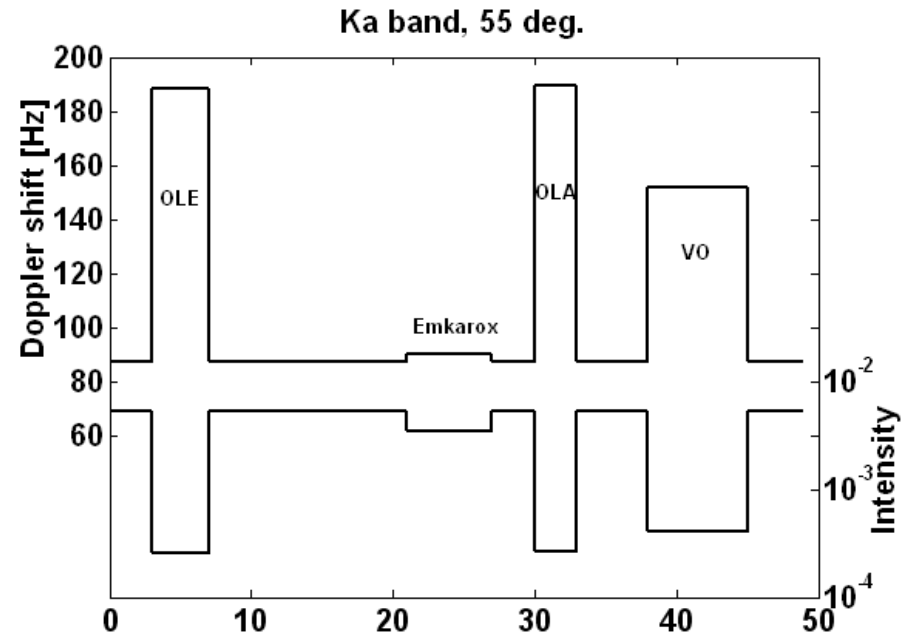
C-band, VV;  
 Incidence angle 30 deg.;  
 Radar look:  
 a) down-wind and  
 b) 45 deg clockwise  
 off wind direction

# Radar Imaging of Oil Spills - DopRim Approach

Modulation of radar return and Doppler shift by slicks:  
Ka-band, VV. Wind speed 7m/s



***Experiment by Ermakov et al. 2002  
(Dokl. RAS, 388)***



***Model Simulation***

## Заключение

Доплеровские сдвиги становятся «стандартным» продуктом обработки РСА изображений получаемых из космоса.

Доплеровские сдвиги совместно с «обычной УЭПР» могут служить важным Источником информации для определения поля поверхностных течений.

Ветровые волны дают существенный вклад в доплеровскую скорость, приводя к тому, что в фоновых условиях она составляет 30% скорости ветра

Соответственно, модуляции ветрового волнения на течениях могут приводить к значимым отклонениям поля доплеровской скорости от реального поля.

Предложена модель, которая согласованно описывает вариации мощности обратного рассеяния и доплеровского сдвига вызванные течениями и/или иными поверхностными неоднородностями

Предварительные результаты сопоставления модельных расчетов с данными измерений – вполне обнадеживающие, однако необходимость дальнейших шагов в развитии и улучшения модели очевидна.