Tidally driven system around the Shantar Islands (the Sea of Okhotsk).

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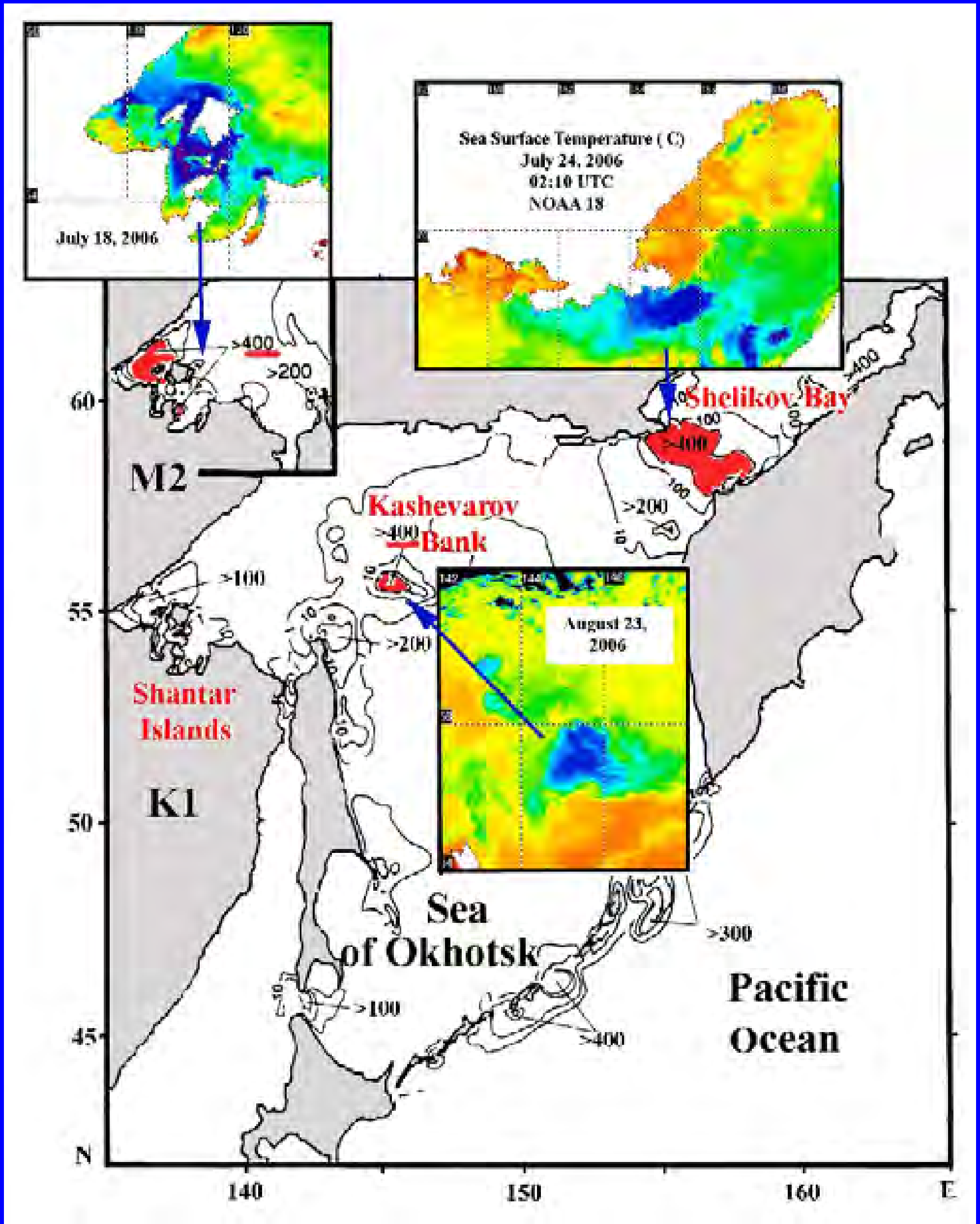
The Shantar Islands are located in the southwestern part of the Sea of Okhotsk (Russia, Khabarovsk Region).

The Shantar Islands National Park

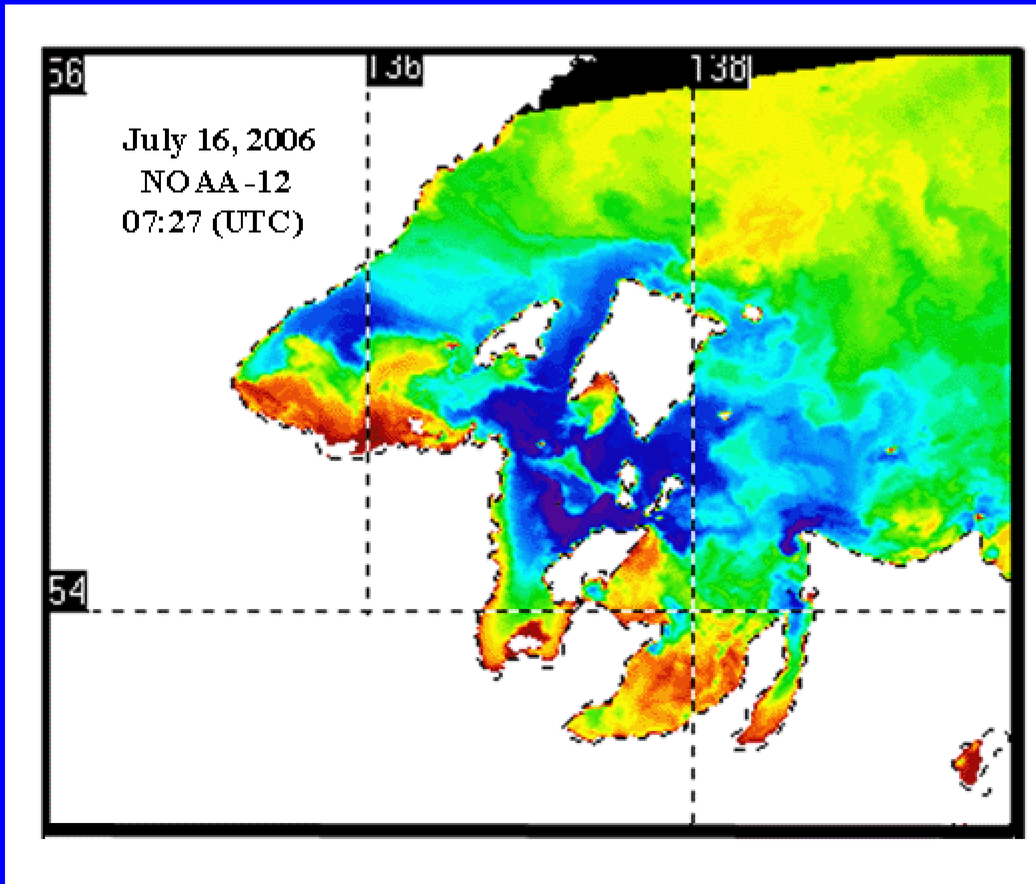
The Shantar Islands area is a unique marine ecosystem that features complex oceanographic processes maintains a high biological diversity of marine life

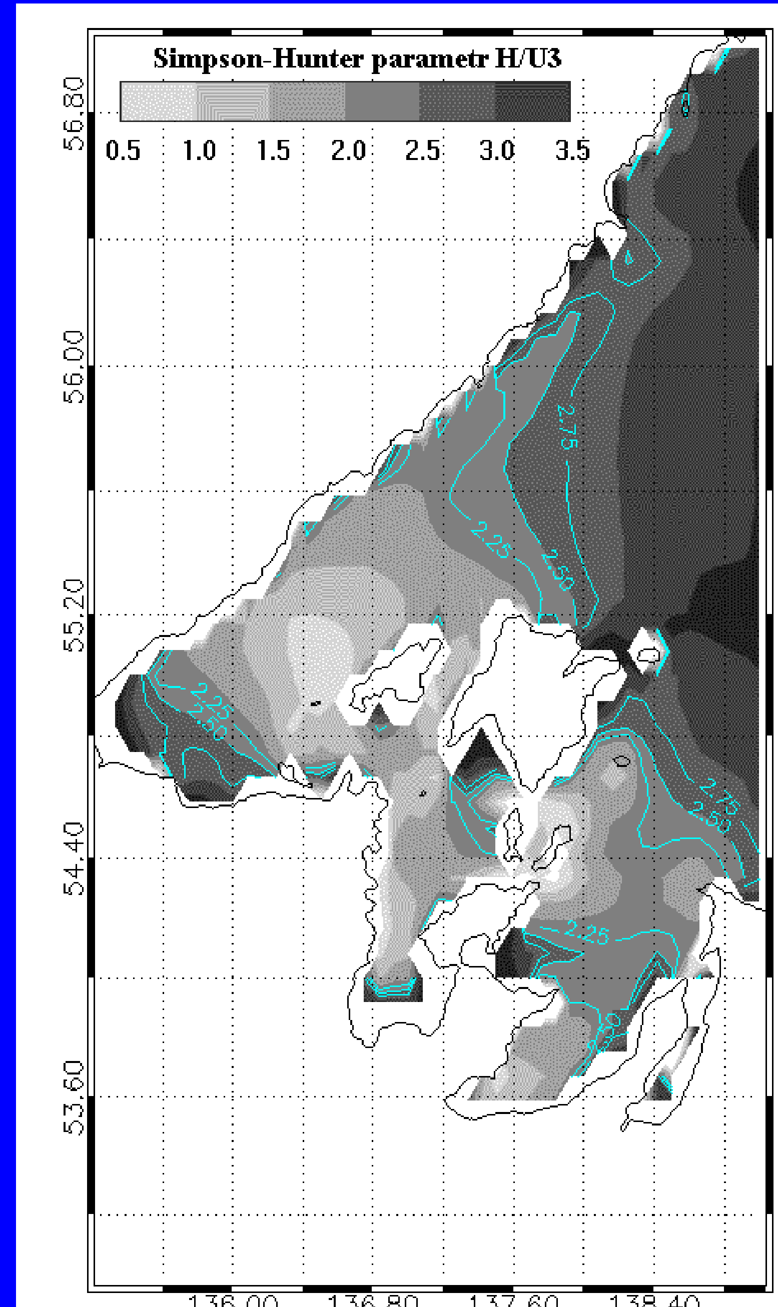


The rate of energy dissipation per unit surface in the Okhotsk Sea (erg s^{-1} cm^{-2}) due to the K1 and M2 tidal components from Kowalik and Polyakov, 1998.

The Sea of Okhotsk is a region of strong tidal currents. According to Kowalik and Polyakov (1998) the major energy sink for diurnal tides is Shelikhov Bay. The major portion of semidiurnal tide energy is dissipated in the southwestern region (Shantar Islands area). The tidal current enhanced over Kashevarov Bank. Vertical stirring assosiated with strong tidal currents is sufficient in some area to mix downward the seasonal buoyancy input and prevent or partly destroy the summer stratification. The boundary between the mixed and stratified waters is delineated by a well defined fronts with sharp change in SST and another properties.

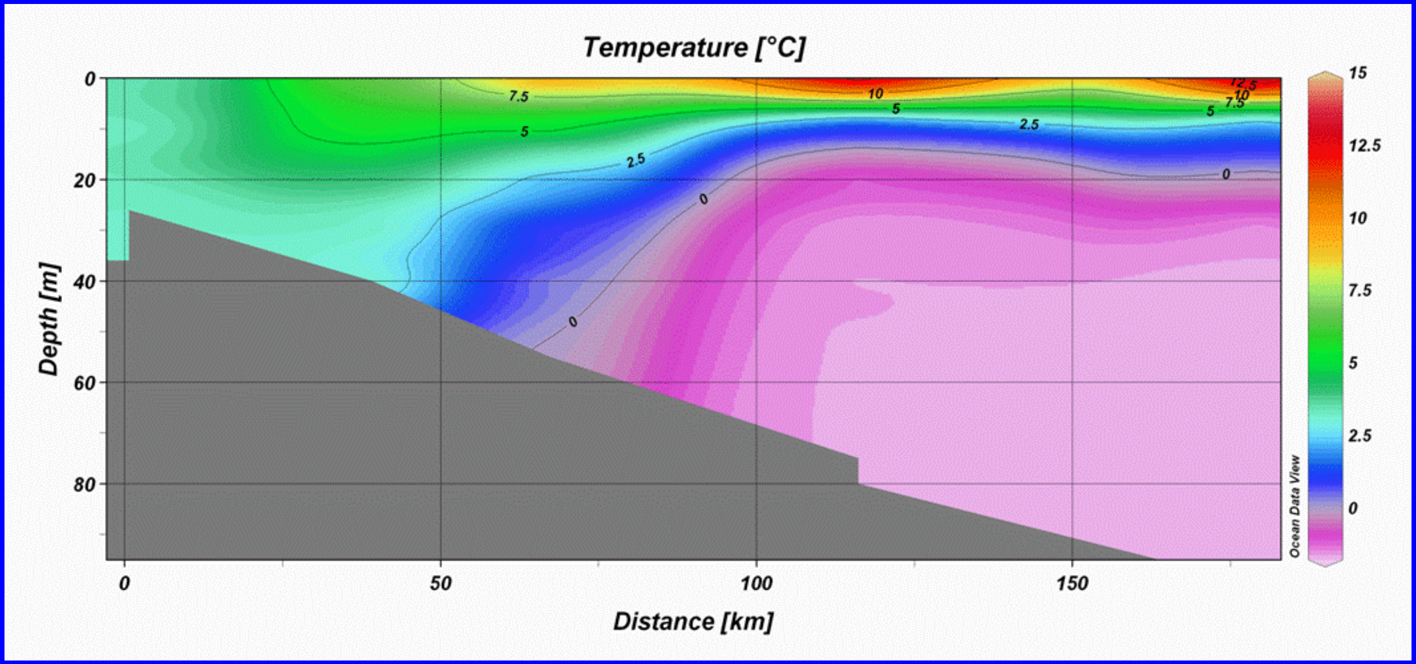
The Shantar tidal mixing front

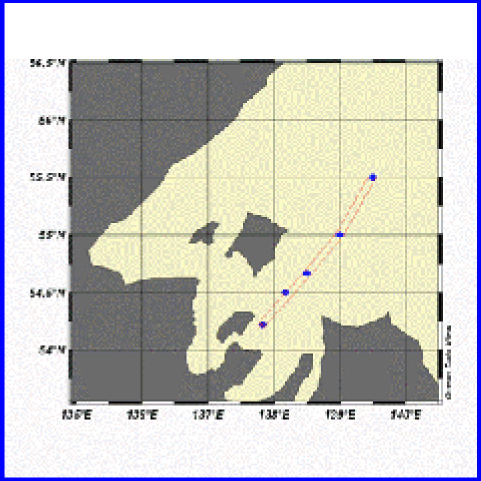


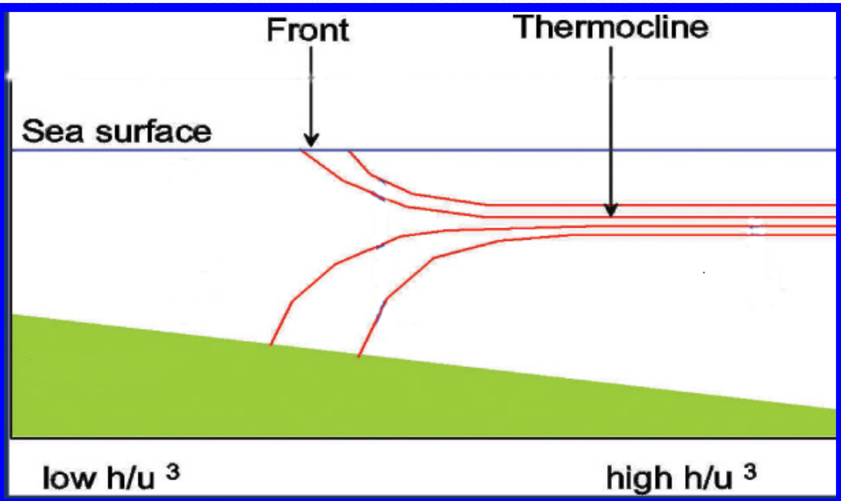


The location and seasonal variability of the tidal mixing front (TMF) around the Shantar Islands were studied using satellite and hydrographic data. The Shantar TMF is the dominant feature of the summer hydrographic structure of the southwestern shelf of the Sea of Okhotsk . The mean positions of TMF are compared to the distribution of Simpson and Hunter's (1974) tidal mixing parameter. SH showed by using a simply potential energy balance that fronts should be along the line of the critical value of the parameter log H/U3. The critical value log H/U3=2.5.

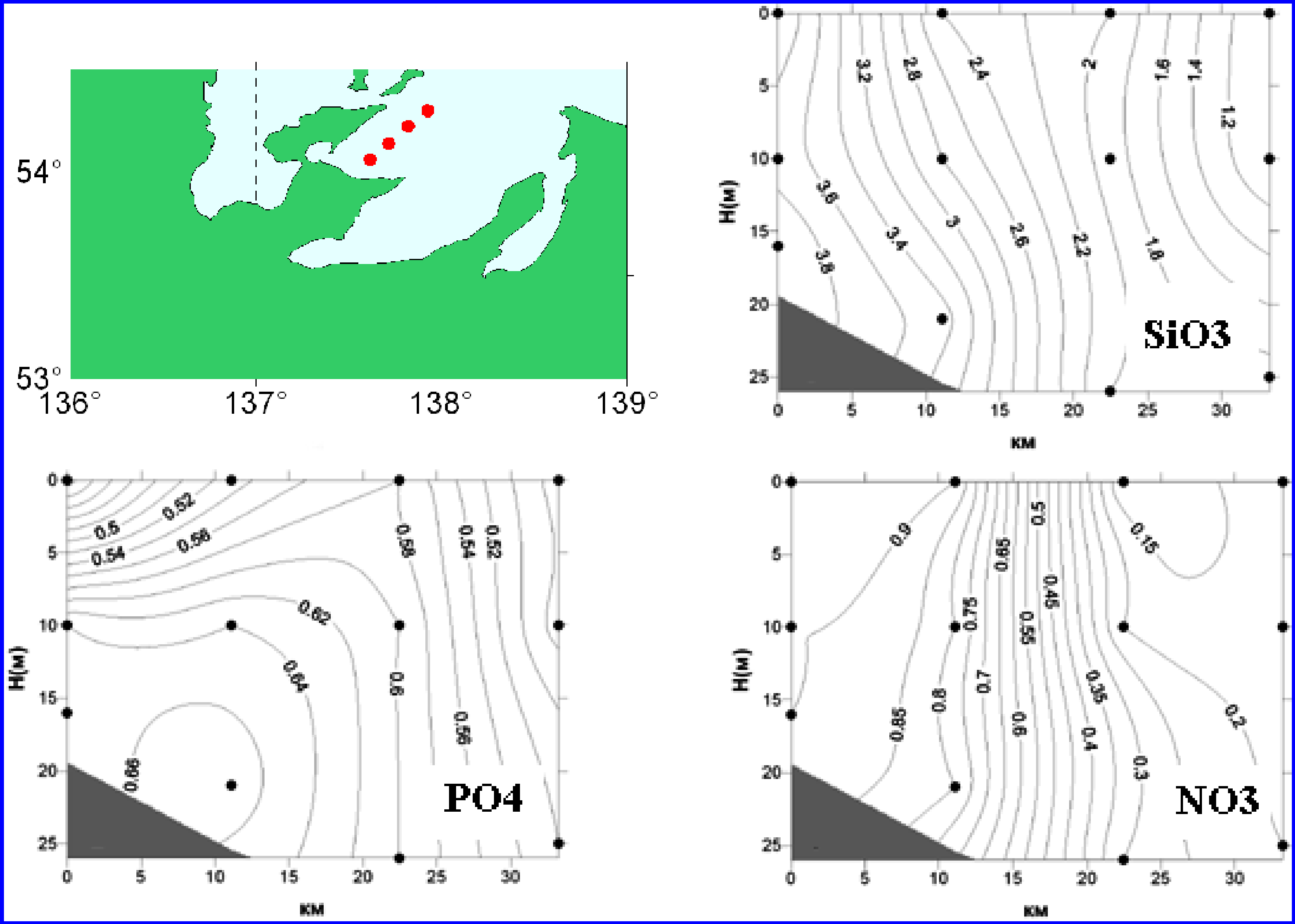
Thermohaline structure of the Shantar tidal mixing front



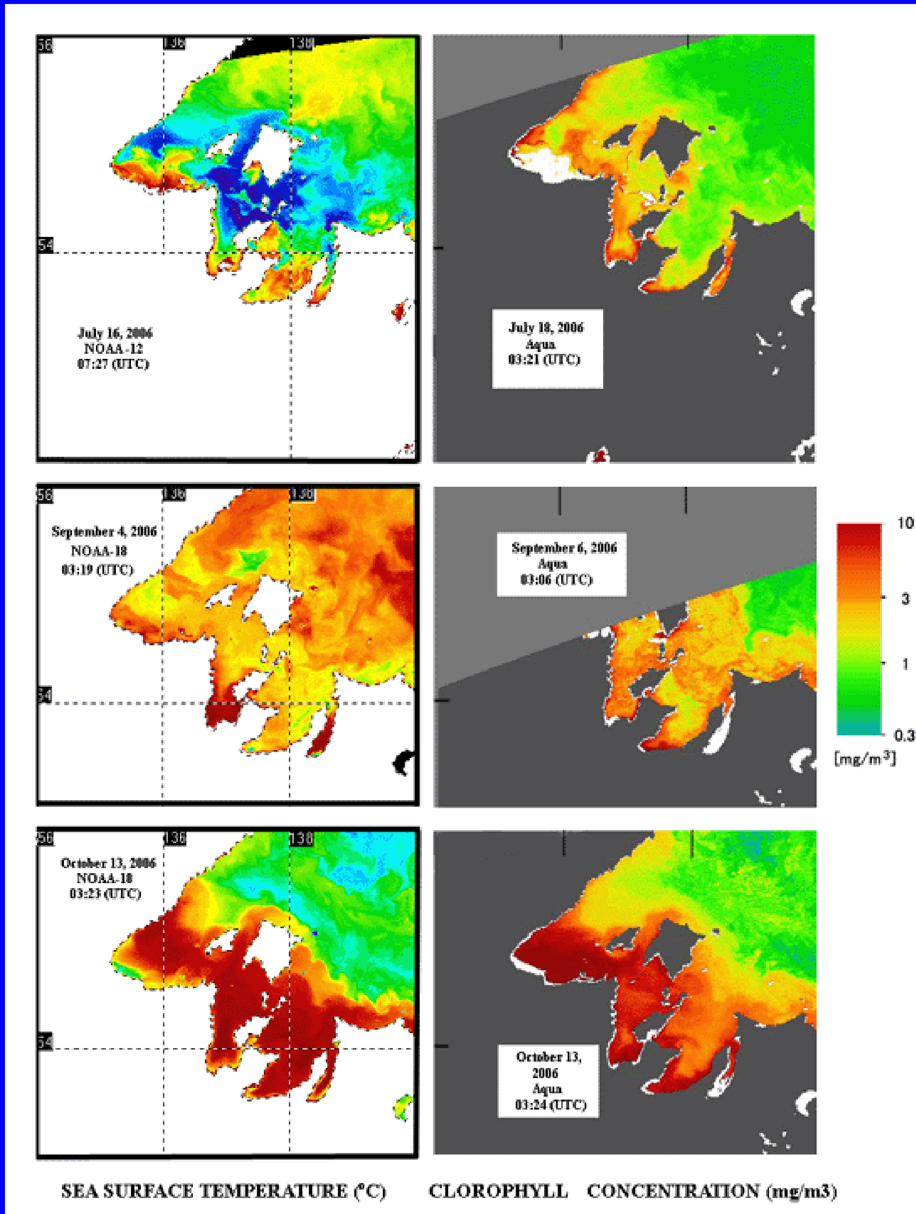




- The Shantar tidal mixing front separates tidally mixed coastal waters from stratified open shelf waters.



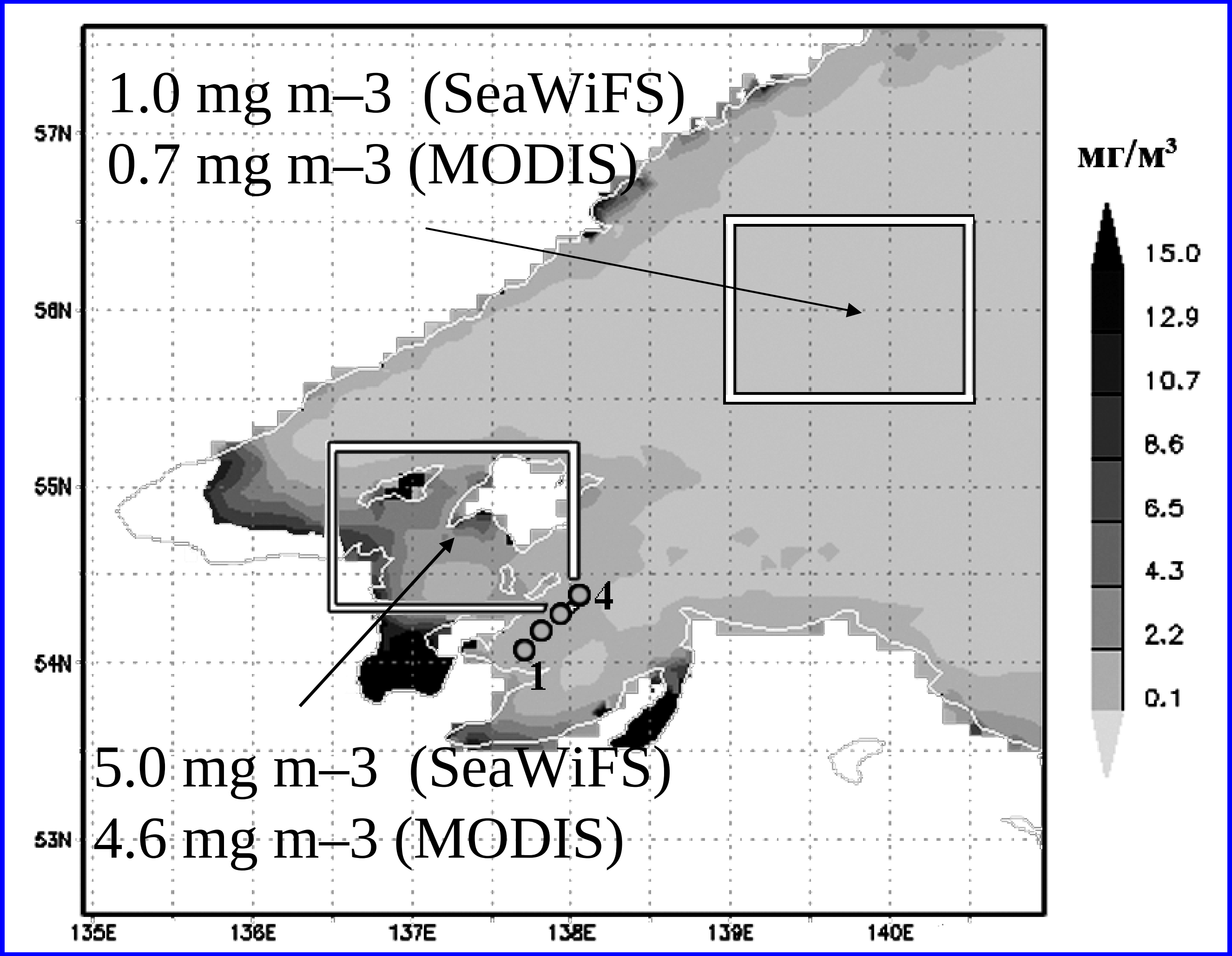
Vertical distributions of nutrients (mkM) in the Shantar Islands area (July 2003). High levels of dissolved nutrients are observed within the tidal mixing region.



AVHRR IR images of SST and MODIS images of ocean color obtained during 2006. Warm temperatures are represented by the warm colours (red), cool temperatures are represented by the cool colours (blue).

Seasonal variability of the Shantar tidal mixing front

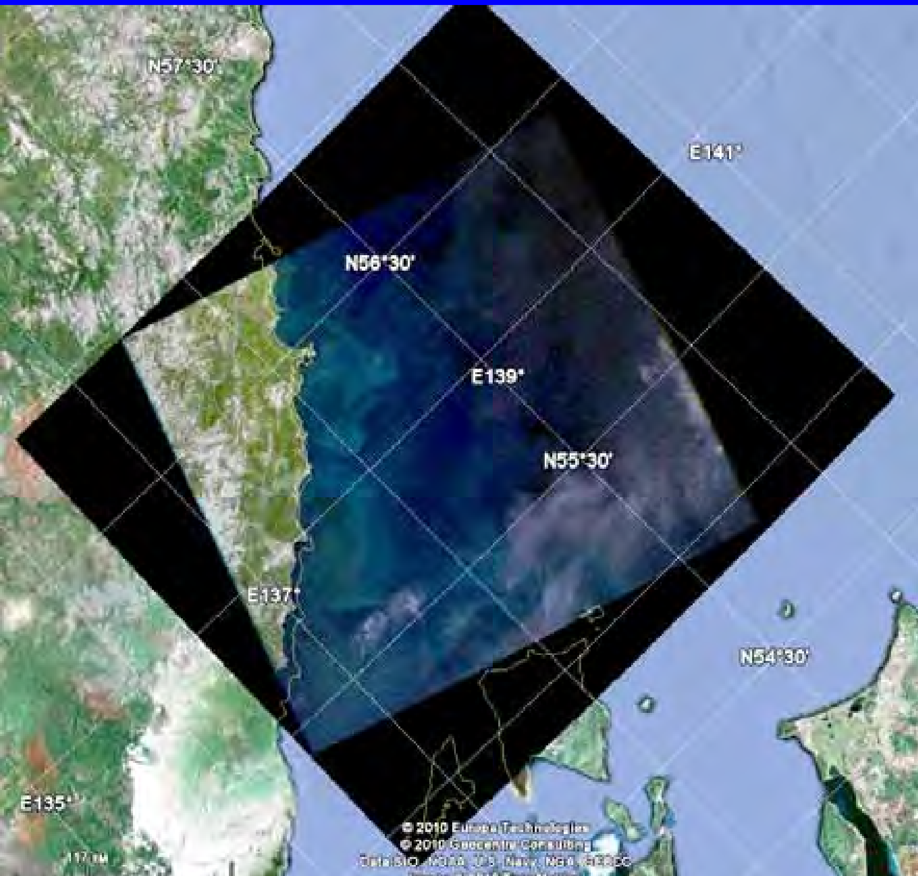
The Shantar front forms in July after ice melting and persist through summer until the late October. The front remains in relatively constant position. Seasonal variation of a surface heat flux leads to a frontal temperature gradient of the opposite sign. The net heat flux into the sea in summer is greater on the mixing side of front then on the stratified side. During the cooling greater heat content of mixed water lead to the higher SSTs. The thermal TMF around the Shantar Islands also is consistent with satellite derived chlorophyll-a front detected by MODIS. As the front developed, higher chlorophyll a concentrations appeared in the coastal well-mixed water, in contrast to the seasonally-stratified water.



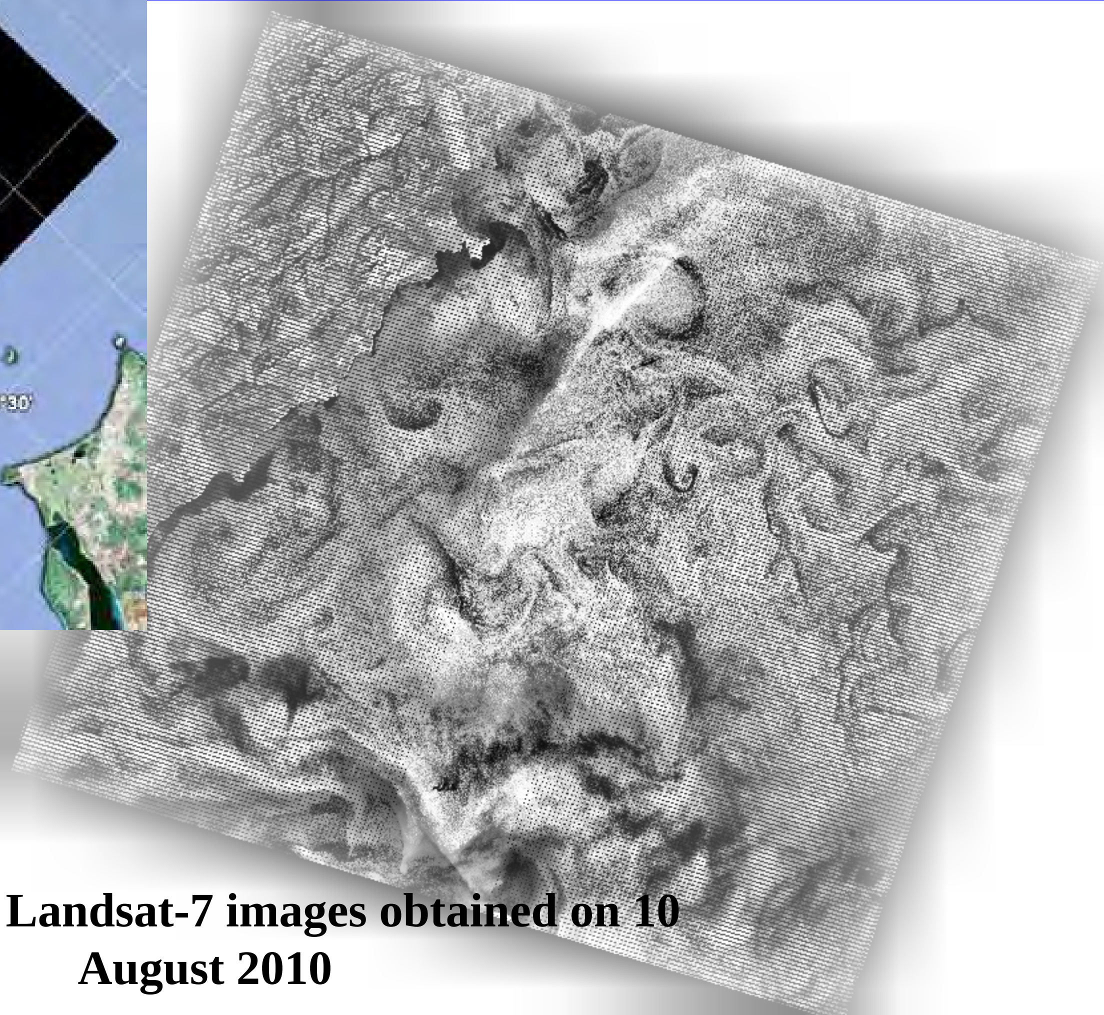
Mean satellite derived (MODIS Aqua) surface chl-a concentration (mg m–3) in July- October 2007

The tidal mixing region around the Shantar Islands was an area of prolonged production during the summer after spring bloom. We analyzed multiyear (2002-2007) averages of seasonal (July-October) chlorophyll composites derived from SeaWiFS and MODIS for two boxes. Chlorophyll around the Shantar Islands up to 5 times higher compared to the middle shelf region.

Submesoscale activity over the nortwestern Okhotsk shelf

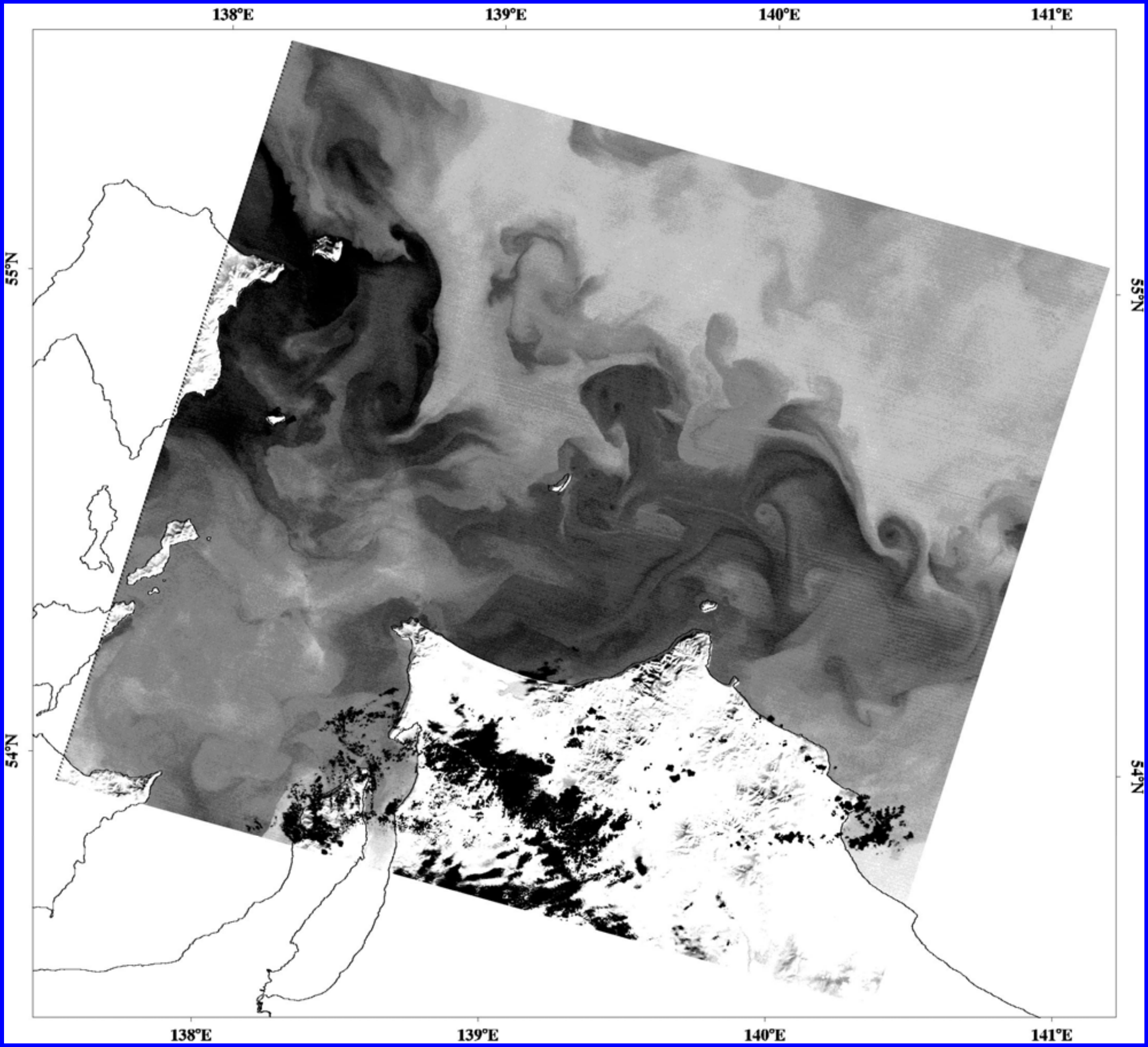


Ocean colour (left panel) and SST (right panel) images from the Landsat-7 ETM+ remote instrument show that submesoscale eddies are common features over the continental shelf off the Shantar Islands



Landsat-7 images obtained on 10 August 2010

Where is the submesoscale eddies form ?



The high resolution Landsat thermal image clearly show that the Shantar tidal mixing front may be baroclinically instable causing them to meander and shed submesoscale eddies.

LANDSAT-5 TM high resolution thermal image of the Shantar frontal region collected on 20 September 2007.

- The measured parameters of shelf waters' stratification allowed us to estimate the baroclinic Rossby deformation radius:

$$Rd = (g'h_e)^{0.5} / f = 3.5 \text{ km},$$

where $g' = g(\rho_2-\rho_1)/\rho_2$ is reduced gravity,

$\rho_2-\rho_1 = 2$ kg m–3

is the density difference

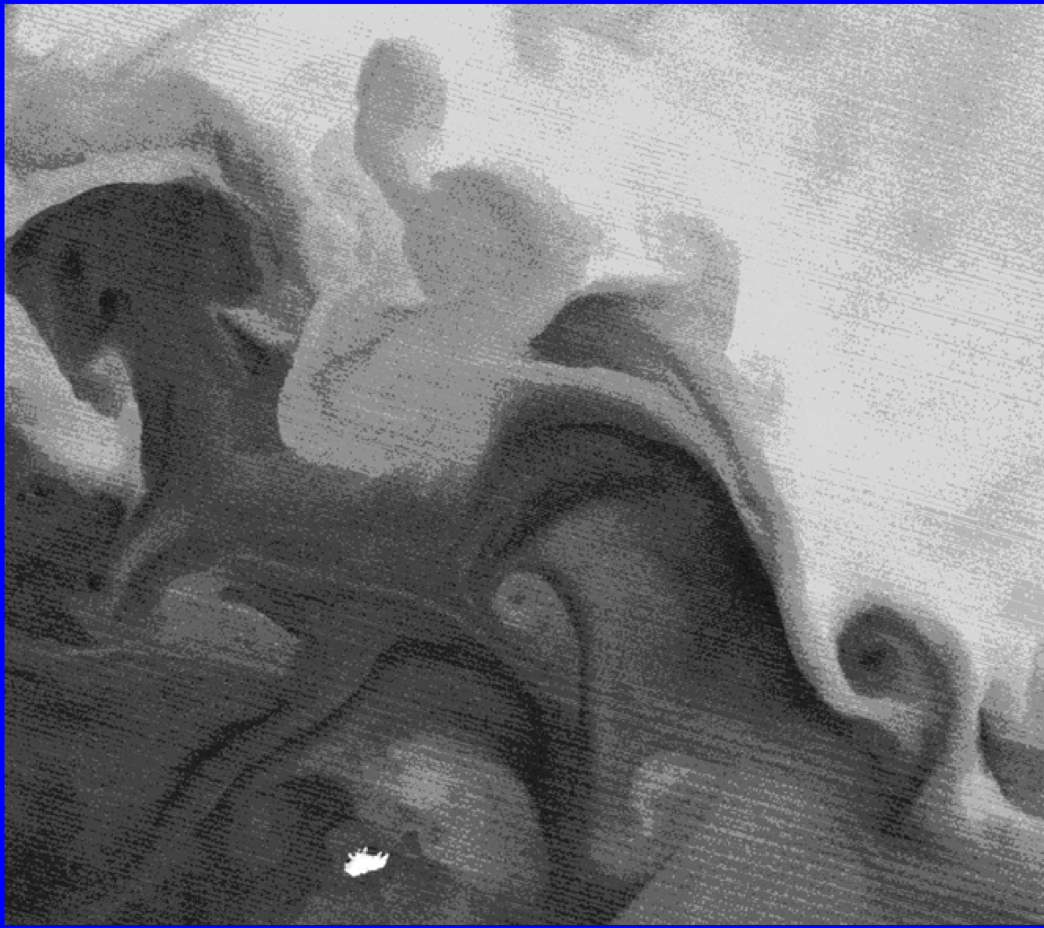
between the upper and lower layers,

$h_e = h_1h_2/h_1+h_2$ (h_1=10 и h_2

= 50 m is the upper and lower layers thickness),

and $f = 1.15*10^{-4}$ s^{-1}

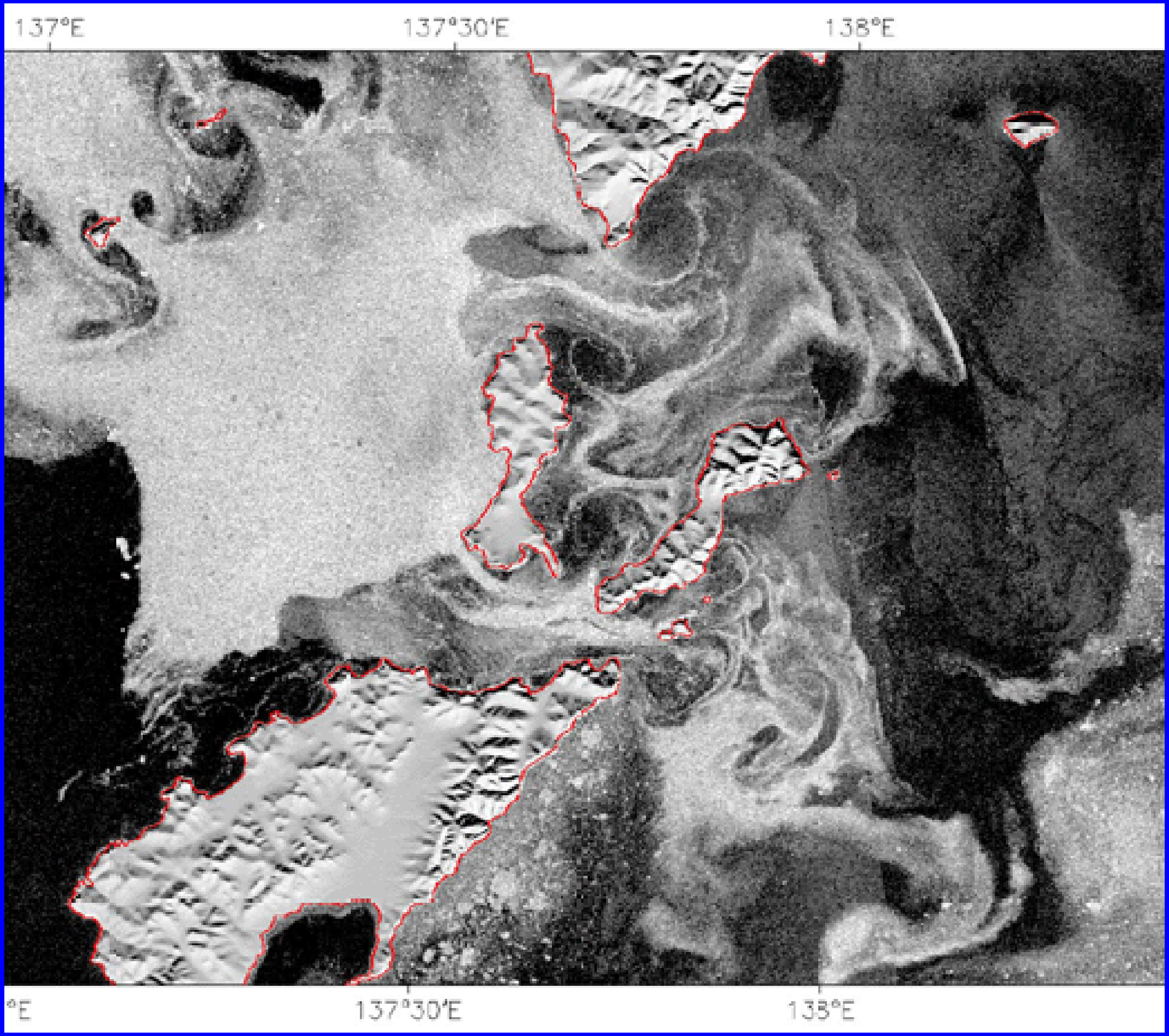
is the Coriolis parameter.



Direct evidence of submesoscale structures that might be assosiated with frontally generated baroclinic eddies.The length scale of this eddies (5 km) is consistent with that expected as the Rossby deformation radius is about 3.5 km.

Submesoscale eddies and fronts in the tidal mixing region around the Shantar Islands

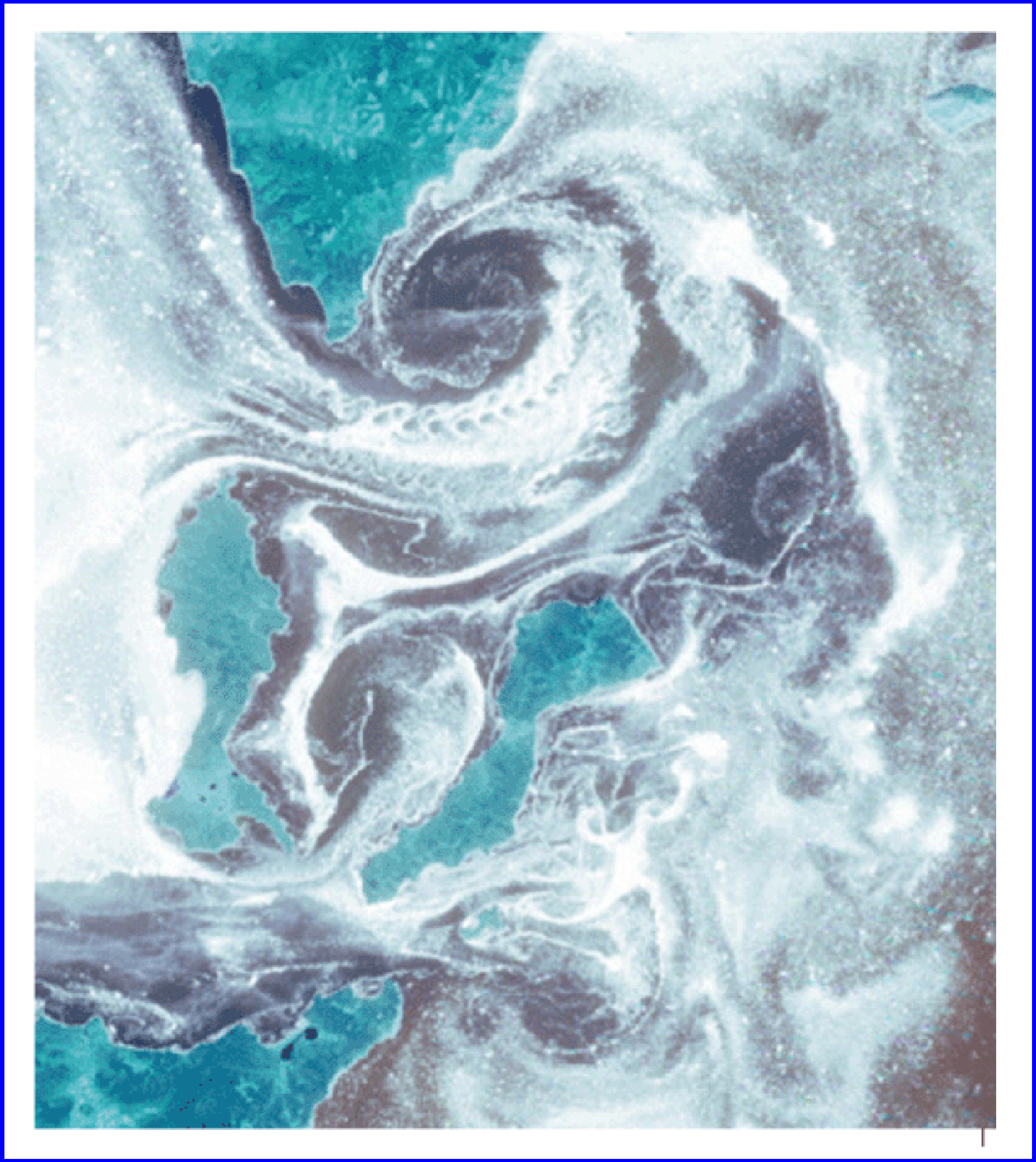
- Convergent fronts and eddies have consequences for ecosystem structure and function that span life-form scales ranging from the phytoplancton to the largest marine mammals.
- The finding recurrent pattern is a key step toward advancing the understanding and prediction of ecosystem variability. Although the ecological significance of marine fronts is well established, the complex processes forcing marine ecology at the relatively small scales are quite challenging to resolve.
- High –resolution Landsat and ASAR Envisat images can identify the narrow zones in which convergence and associated biological activity may be particularly energetic.



In coastal waters the interaction of topography with the tidal current results in complex dynamic structures. Eddies are formed downstream of headlands and islands

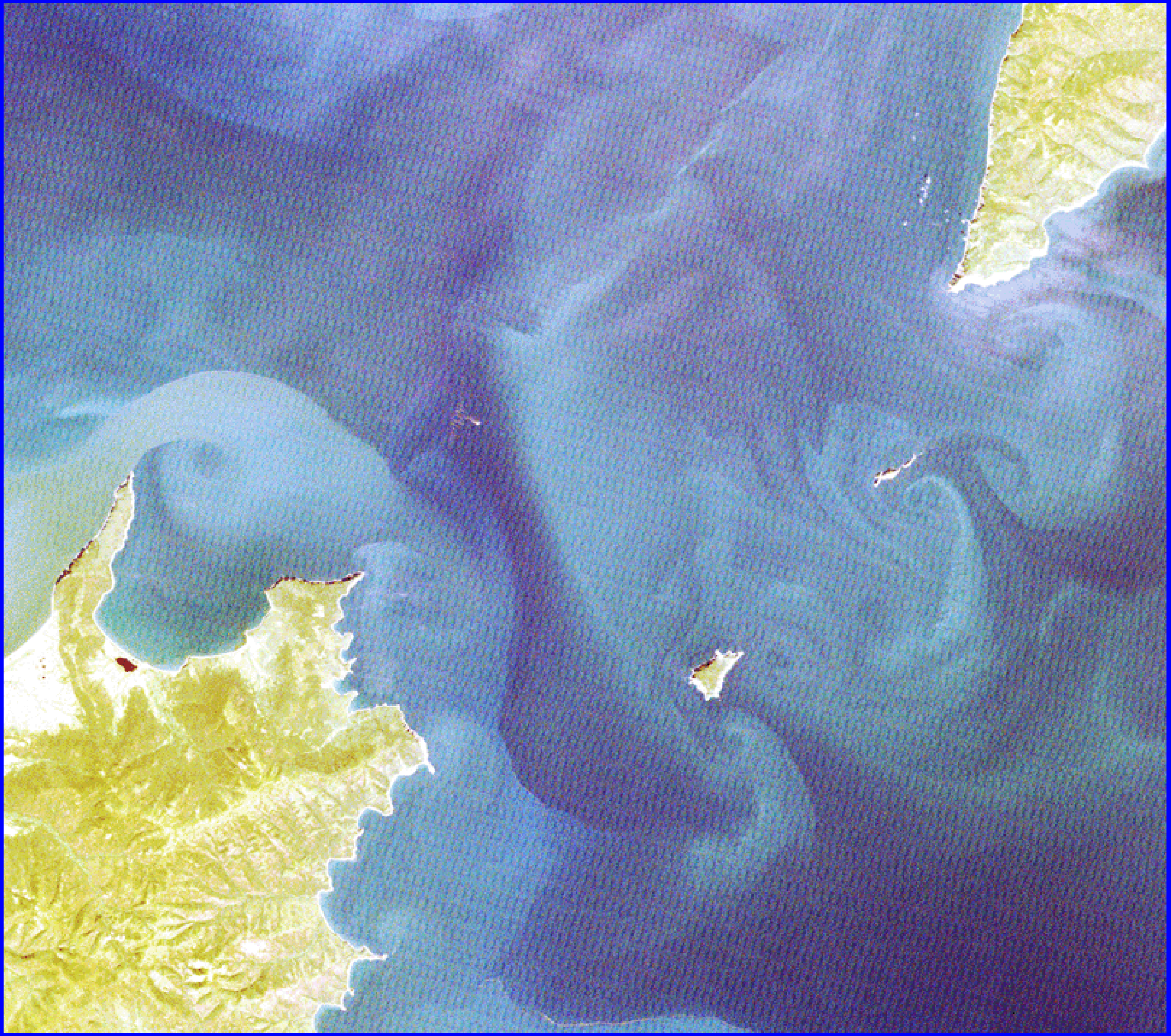
Submesoscale fronts and eddies on the SAR images obtained on 23 June 2008. Features are recognized due to melting ice.

The SAR image was provided by the ESA.



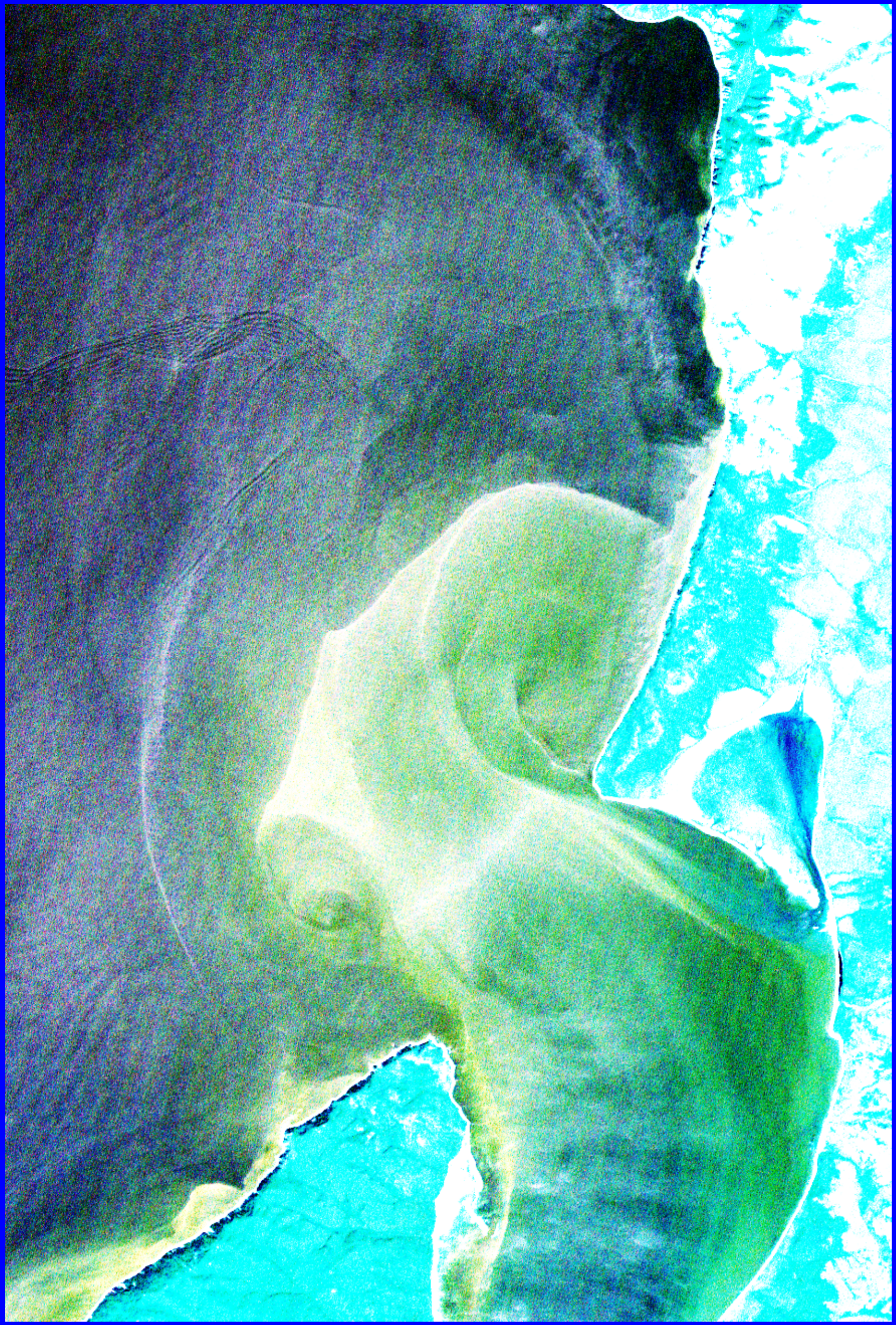
Landsat-7 ETM+ RGB image acquired on 7 July 2005

The Landsat image show the formation of headland eddy.



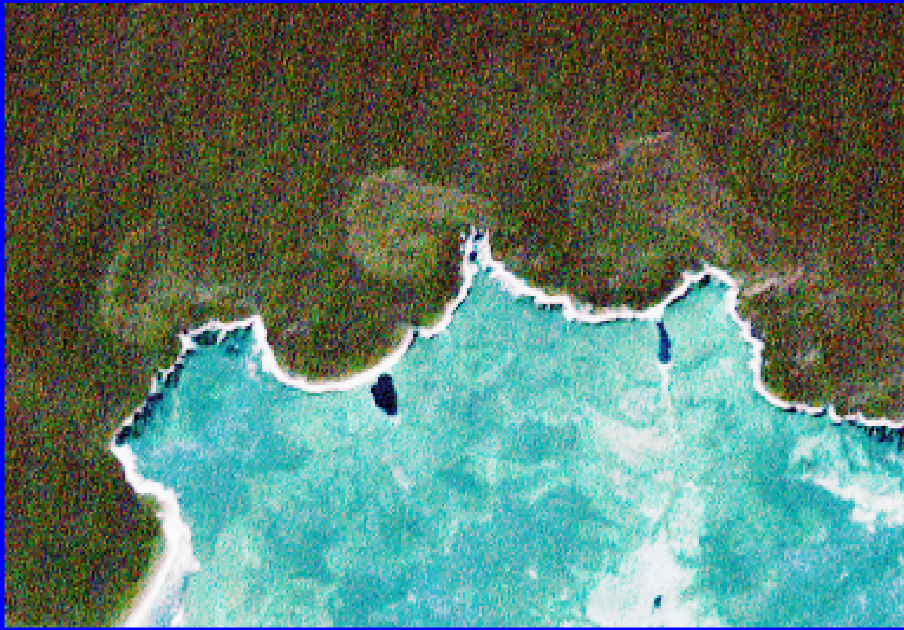
Landsat-5 TM RGB image acquired on 10 August 2010.

The headland eddy system is complicated by the presence of an islands offshore, which generates an additional island wake eddy system



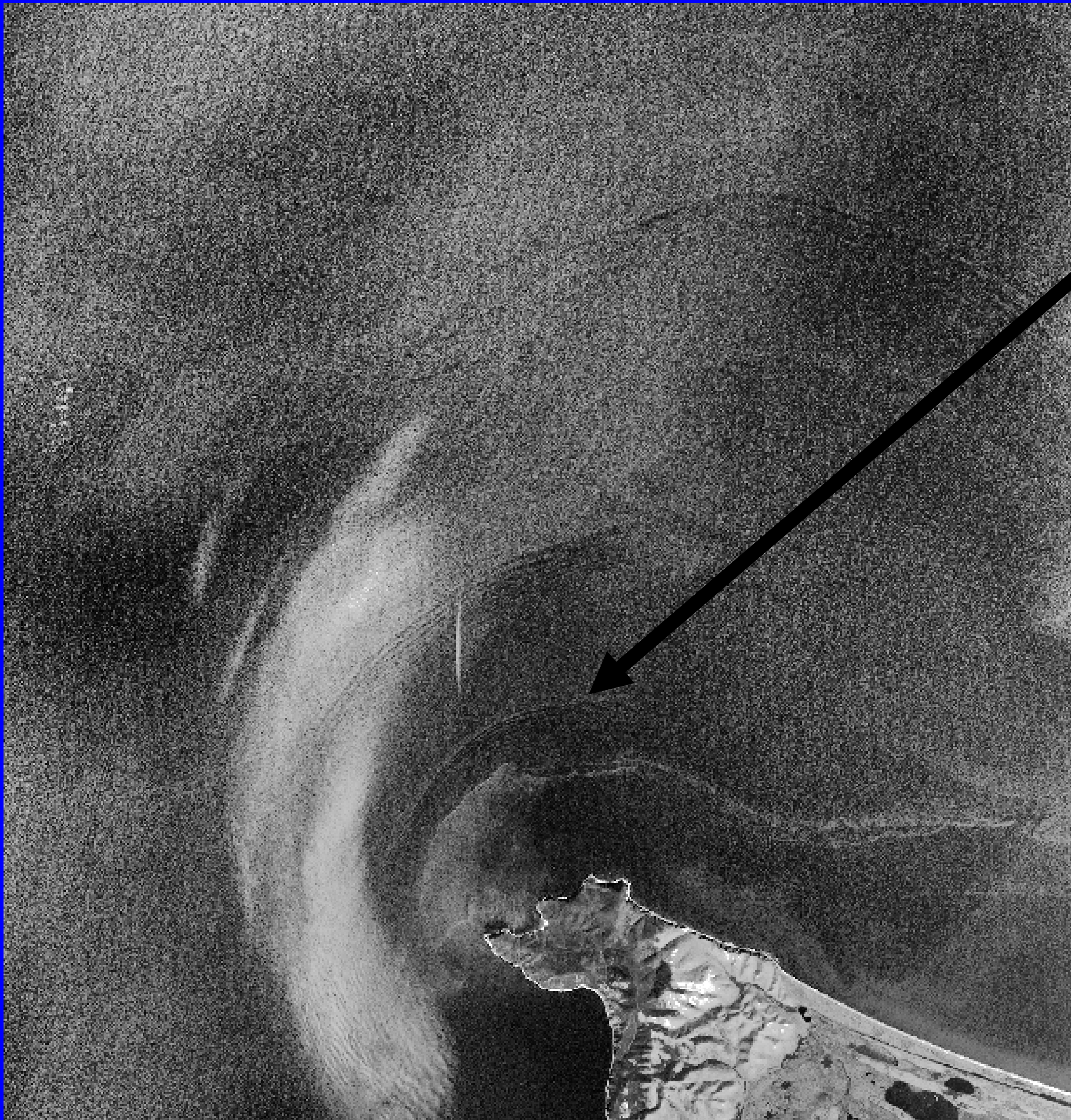
The fragment of Landsat-7 ETM+ RGB image collected on 12 October 1999 show jet-type system in a St.

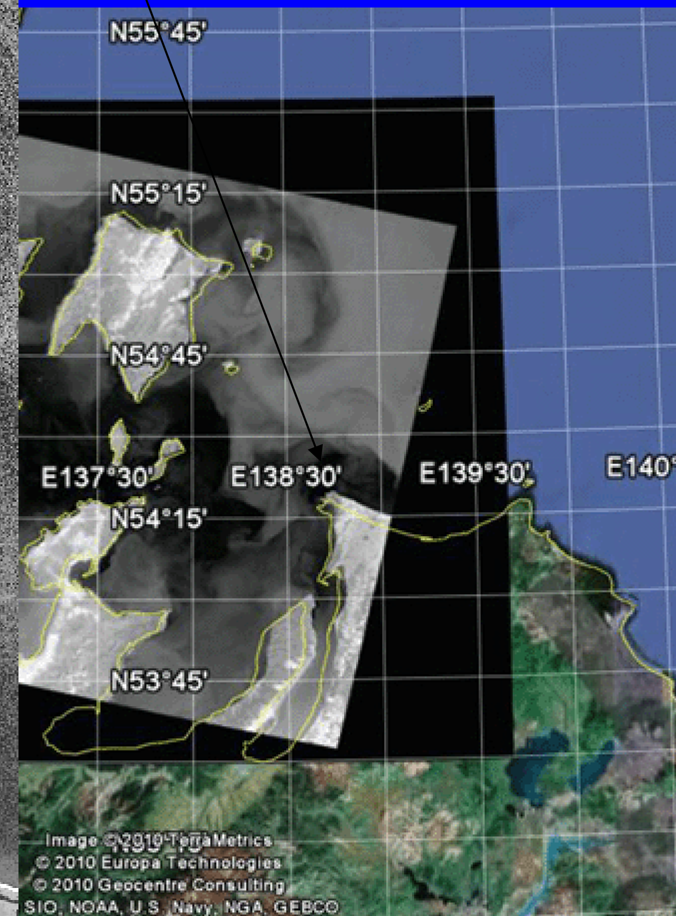
Nikolai bay.



The development of the headland eddies are identified on this satellite image.

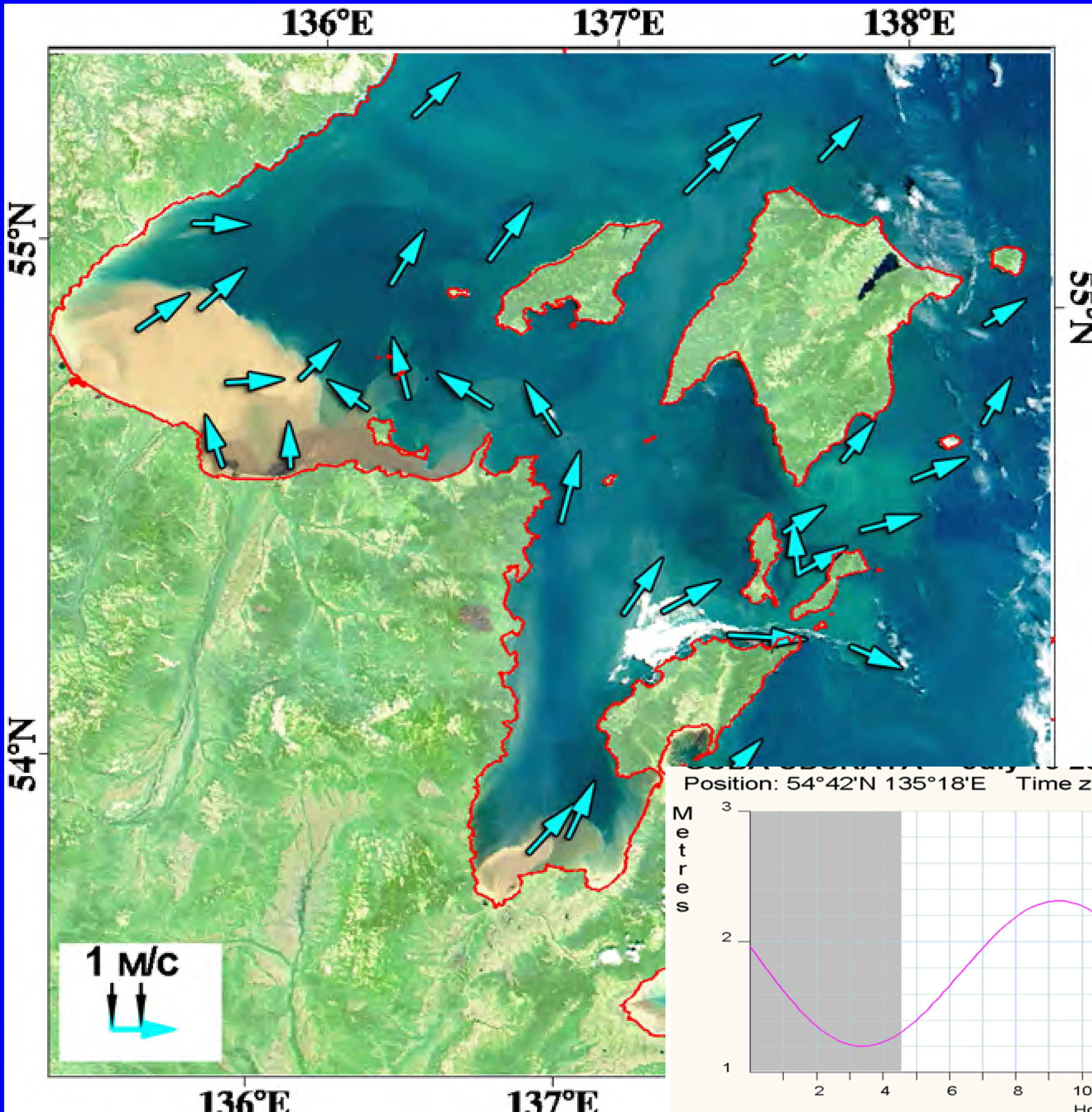
Headland front



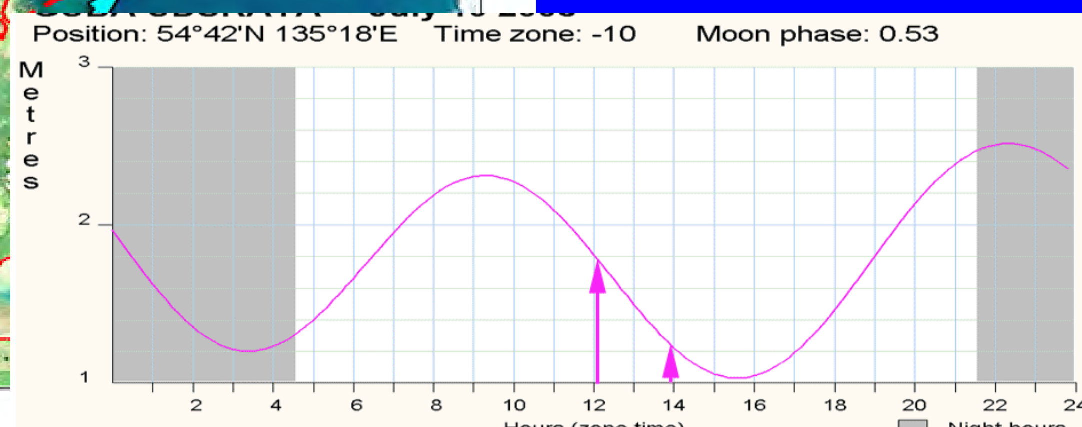


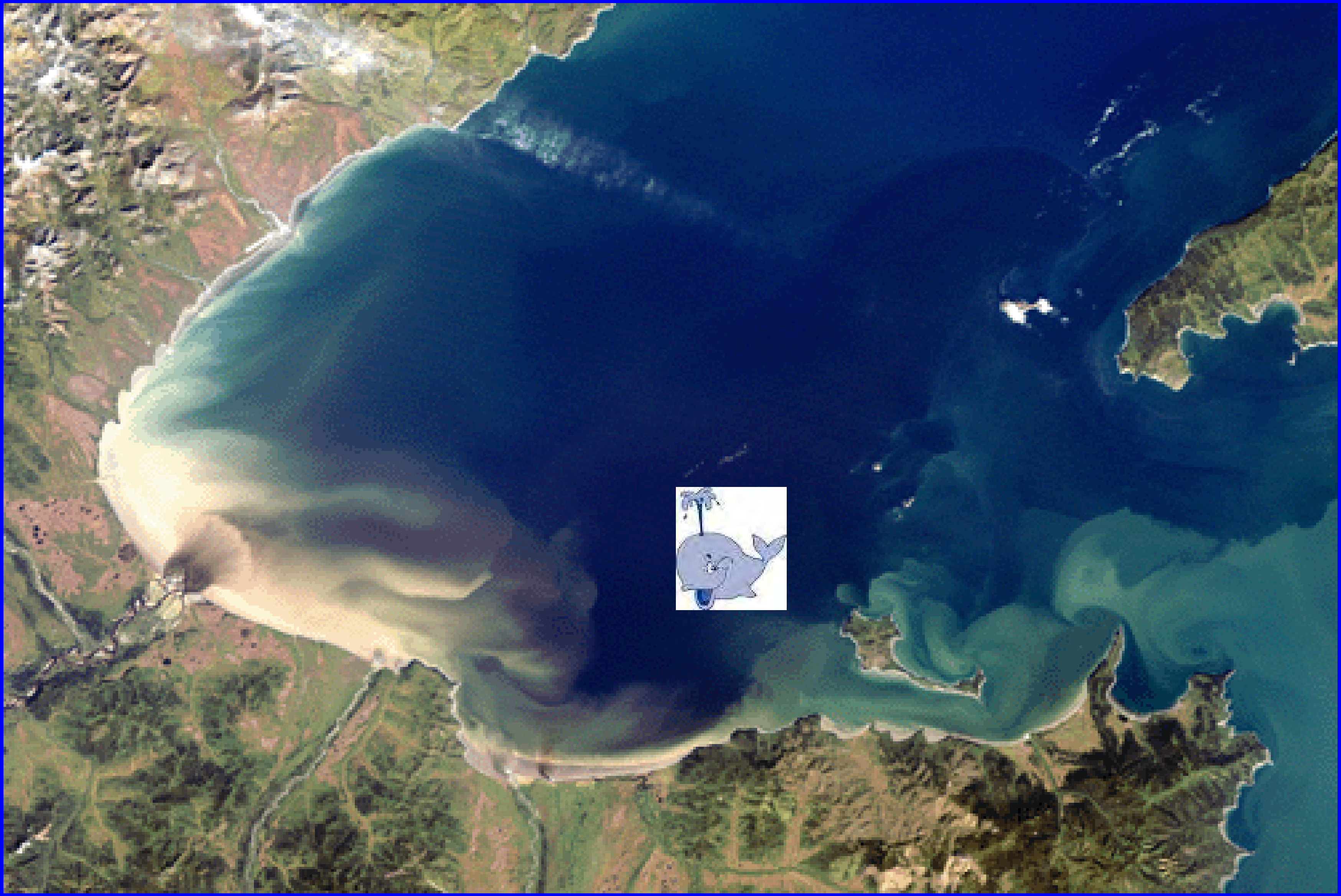
Landsat-5 TM RGB image acquired on 17 August 2001

River plume fronts in the Shantar Islands region



- Aqua MODIS RGB image acquired on 10 July 2008. The currents are shown during ebb tide. The seaward flank of the plume is marked by a sharp front





Landsat-5 TM RGB image acquired on 22 September 2009 show how prevailing northwesterly winds and coastal topography can strongly influence river plume behavior.

SUMMARY

- The Shantar tidal mixing front is generated in the transition zone between the vertical mixed water and the stratified water. The location of front is controled by the variation in tidal mixing caused by spatial changes in M2 tidal current amplitide U and the depth H. The critical value of the Simpson-Hunter parameter $\log(H/U^3)=2.5$.
- The Shantar tidal mixing front may be baroclinically instable causing them to meander and shed eddies on the scale of internal Rossby radius.
- The phytoplankton ecology is influenced by tidal current in a variety of ways, including enrichment of growth conditions and aggregation at the fronts.

The SAR images were provided by the ESA under project "The study of submesoscale processes in the North Pacific marginal seas".
MODIS images courtesy of MODIS Rapid Response Project at NASA/GSFC.
AVHRR images were provided by the Center for Regional Satellite Monitoring of Environment FEB RAS