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Statistical analysis of submesoscale eddies of the Baltic, Black and Caspian seas

- Submesoscale eddies eddies (in water!) with a diameter less then *baroclinic Rossby radius of deformation* typical for the basin (< *ca.20 km in diameter*)
- The study is aimed to retrieve some general statistical information about submesoscale eddies in the Baltic, Black and Caspian seas using satellite SAR data for two years (2009-2010)
- Spiral eddies on sea surface were first seen in 1968 on the Apollo Mission. There are still lots of uncertainties concerning this type of eddies such as their 3D structure, typical lifetime, mechanisms of generation, etc.

Object, aims and motivation of the study

Regions of interest







Data description



Table. 2009/2010

Sea \ Data	Envisat WSM	Envisat IMM	ERS-2 IMM	Total
Baltic	261/506	7/15	E2/179	221/640
Daille	201/500	//15	55/120	521/049
Black	97/124	156/130	76/101	329/355
Caspian	147/194	14/28	-/-	161/222
Total	505/824	177/173	129/229	811/1226

Baltic Sea coverage with SAR images



Interannual variability



Seasonal variability



Black Sea coverage with SAR images





Interannual variability

Seasonal variability





Caspian Sea





Seasonal variability



Eddy manifestation: "black" eddies



At moderate wind speeds eddies usually appear in the SAR images due to the presence on the sea surface of natural films. Such surfactants alter sea surface tension by smoothing the ripples and thus diminishing backscatter cross-section. Surfactant films get involved in the orbital motion of eddies, in such a way imprinting them in radar images.

Eddy manifestation: "black" eddies



(a) ERS-2 SAR on 21.06.2009 at 09:47 UTC (b) Envisat ASAR on 25.04.2009 at 09:09 UTC



Eddy manifestation: "white" eddies

At higher wind speeds eddies appear in SAR imagery as a result of wave/current interactions and look like curved current shear.

24 km (b)

12

18 km (*a*)

(a)Envisat ASAR image on 14.04.2010 at 20:10 UTC (b)ERS-2 SAR image on 12.03.2010 at 08:14 UTC

12

Frequency of eddy manifestation



 (a) Share of images with eddies detected in the total number of images analyzed
 (b) Mean number of eddies per image (with eddies detected)

Wind speed seasonal variability



Total number of eddies



- totally ca. 14.000 eddies
- ■71% "black" eddies
- **29%** "white" eddies
- **98%** cyclonic eddies

Seasonality in eddy manifestation



Characteristic eddy size

Table 1. Sample statistics of the mean eddy size

Eddy type	N	Observed parameters				
		Data	Mode	Median	Mean	Stand
		range				dev
Baltic "black"	2826	1.2-48	4	5-3	6.4	4.0
Baltic "white"	1114	2.3-32	7	7.6	8.5	3.8
Black "black"	1329	1.1-66	6	6.2	7.4	5.4
Black "white"	621	1.5-32	10	8.4	9.3	4.0
Caspian "black"	1456	1.2-38	4	6.8	7.9	4.6
Caspian "white"	461	2.8-33	6	9.0	9.7	3.6

Table 2. Values of the baroclinic Rossby radius of deformation

Baltic Sea	Black Sea	Caspian Sea	
1-10	15-20	17-22	
	(12 in shelf area)	(3-8 in shelf area)	

Histograms of eddy diameter



The Baltic Sea



Seasonality of eddies in the Baltic Sea



The Black Sea



Seasonality of "black" eddies in the Black Sea



Seasonality of "white" eddies in the Black Sea

«White» eddies





Seasonality of eddies in the Caspian Sea



Conclusions

- In average about 39% of all the images analyzed contained some manifestations of vortical structures.
 In the warm season share of images with eddies detected was higher than in the cold season. Mean number of eddies per image was detected to be higher in spring. summer, and autumn than in winter.
- Surfactant films provide about 71% of eddy occurrences in SAR images ("black" eddies). The rest part
 of eddy manifestations was accounted for by wave/current interactions ("white" eddies). "Black"
 eddies were detected mainly in summer, spring and autumn seasons. "White" eddies were distributed
 rather evenly during all the seasons.
- Totally about ca. 14.000 vortical structures were detected. 98% of them had cyclonic rotation.
 Numbers of eddies detected in different seas were proportional to numbers of images analyzed.
- For the most perfectly shaped ca. 8.500 eddies their spatial scale was defined. Eddy diameter varied from 1 to 75 km, while 99% of eddies were within a range of 1-20 km. Characteristic size of "black" eddies in all the basins was less than that of "white" eddies. Characteristic eddy size for the Baltic, Black and Caspian seas proved to be proportional to the baroclinic radius Rossby of deformation typical for these basins.
- Though none of the distributions Gaussian, Rayleigh, Poisson, and FRED perfectly repeated a histogram shape, the Poisson distribution demonstrated better conformity with the data observed.
- Analysis of spatial eddy distribution showed that "black" eddies were distributed rather evenly through the basins and did not demonstrate significant connection with basin- and meso-scale surface circulation. "White" eddies seem to generate (manifest) in the regions with highest wind speeds with resulting intense drift currents.

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