

Spatiotemporal variability of internal waves in the Caspian Sea

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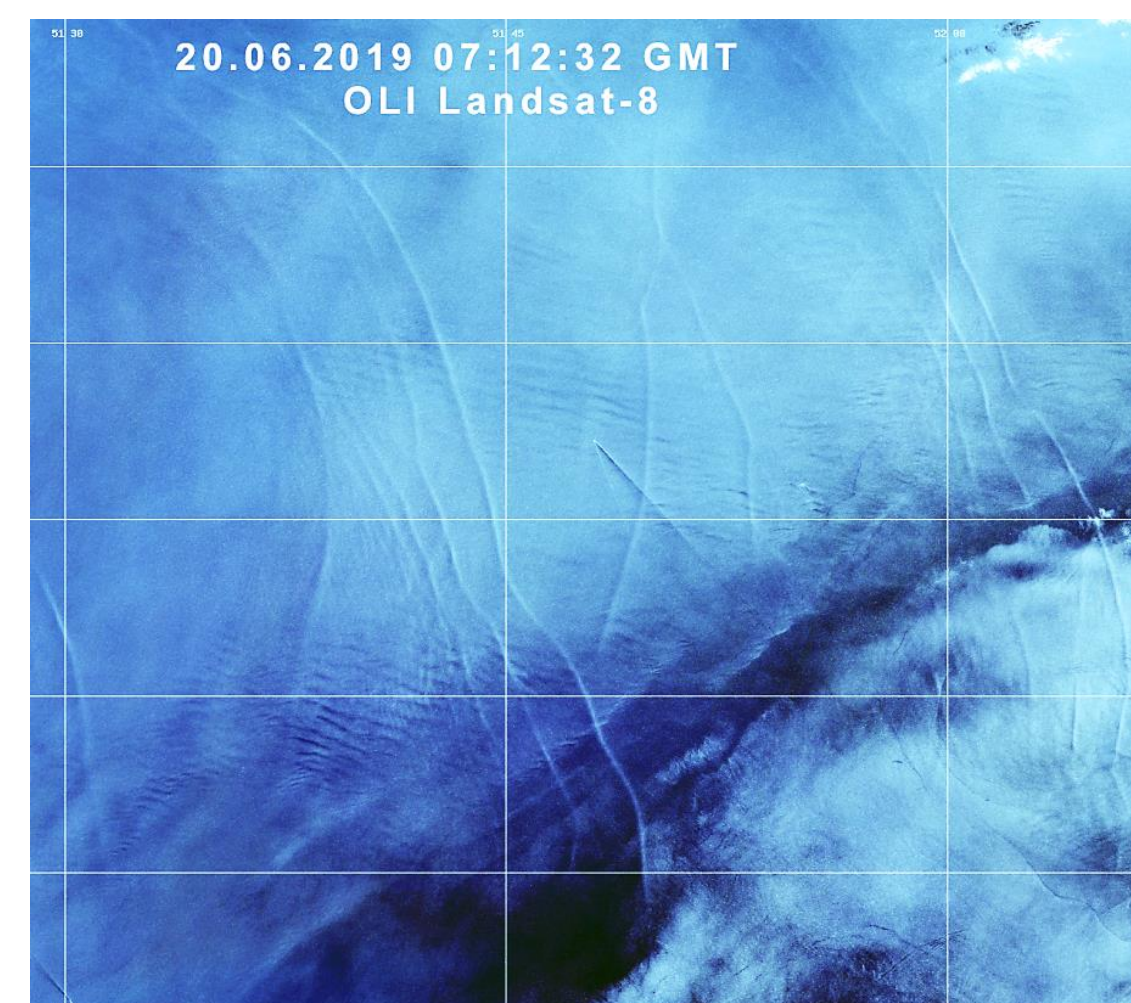
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Motivation

Internal waves (IWs) are an intrinsic feature of all density stratified water bodies: oceans, seas, lakes and reservoirs. IWs occur due to various causes. Among them are tides and inertial motions, variations in atmospheric pressure and wind, underwater earthquakes, water flows over bottom topography, anthropogenic factors, etc. In coastal areas of oceans and tidal seas, IWs induced by tidal currents over shelf edge predominate. Such IWs are well-studied in multiple field, laboratory and numerical experiments. However, the data on IWs in non-tidal seas, such as the Black, Baltic and Caspian Seas, are scarce. Meanwhile, our multi-year satellite observations prove IWs to be quite a characteristic hydrophysical phenomenon of the Caspian Sea. The sea is considered non-tidal because tide height does not exceed 12 cm at the coastline. And yet surface manifestations of IWs are regularly observed in satellite data, both radar and visible. The goal of our study was to reveal spatial, seasonal and interannual variability of IW surface manifestations in the Caspian Sea in the periods of 1999-2012 and 2018-2019 from the analysis of satellite data.

Surface manifestation of internal waves



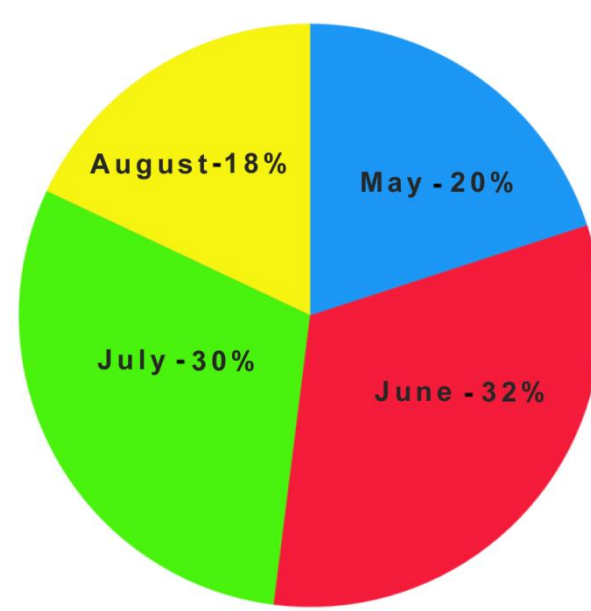
Manifestation of internal wave trains on the True Color image of OLI Landsat-8 (4-3-2 spectral channels)



Manifestation of internal wave trains on radar image of SAR-C Sentinel-1A (VV-polarization)

Seasonal variability

Surface manifestations of internal waves were observed from early May to mid-September. In some years, depending on hydrometeorological conditions — water heating, wind situation, etc., internal waves did not have surface manifestations in May or September.



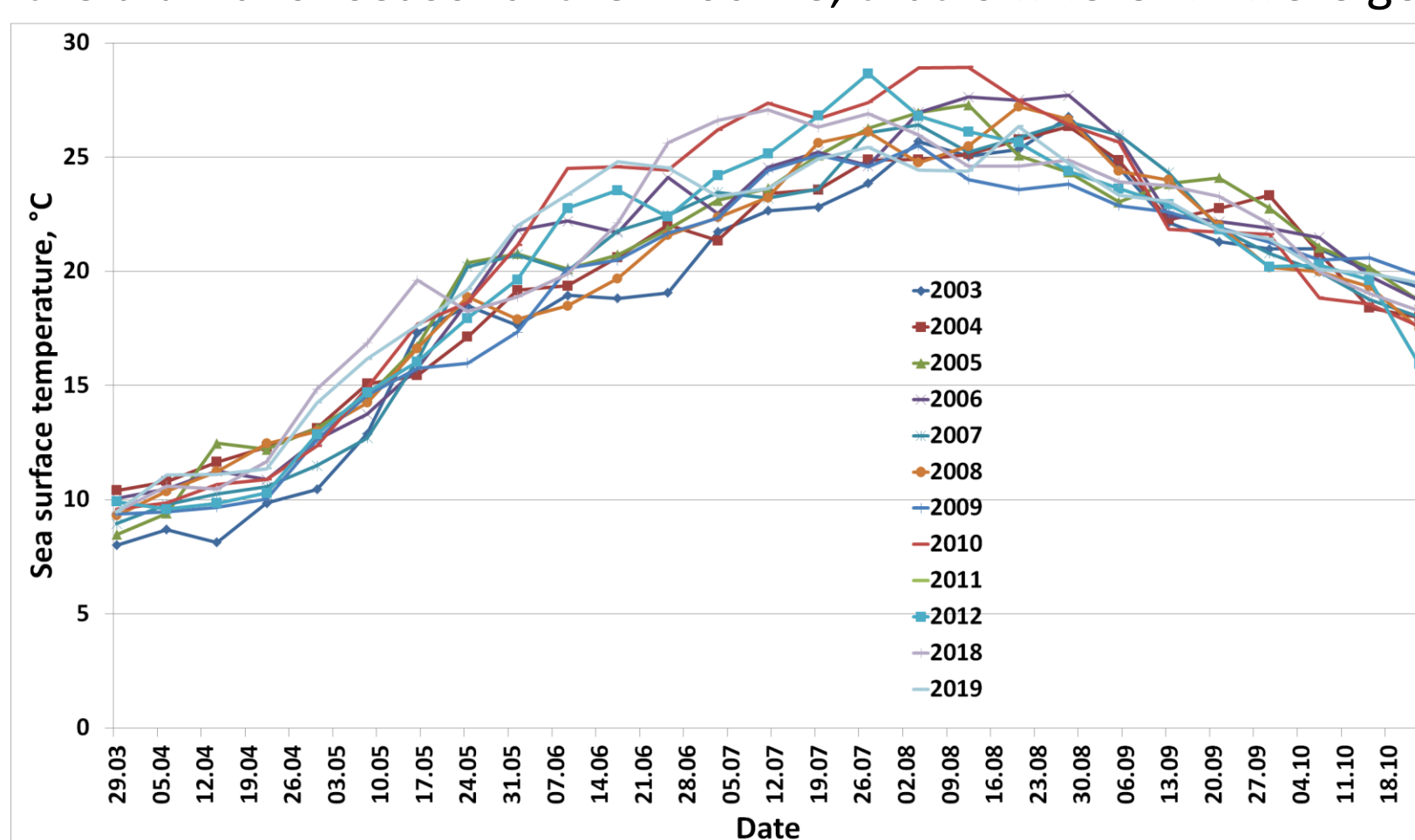
The diagram shows the percentage distribution of radar images containing the manifestations of internal waves by months in 2019, when the amount of data in each month was constant.

Spatial variability

Surface manifestations of internal waves are regularly observed in the eastern part of the Middle Caspian and the northeastern part of the South Caspian. In the Northern Caspian due to its shallow water and the absence of pronounced stratification, internal waves are not formed, or do not have surface manifestations in satellite images. In the western part of the Caspian Sea, internal waves are rarely observed and, as a rule, at the beginning of the summer season. Packets of internal waves propagate to the shore, and their generation sites are located mainly above the depths of 50 - 200 m.

Interannual variability

It is difficult to trace and evaluate interannual variability for 1999-2002, because for these years we did not have radar data. However, according to the available data for the entire period, we can conclude that in different years the dates of the first manifestations of internal waves vary significantly. For example, in 1999 and 2000, internal waves were first observed in July. And in 2004, internal waves were observed until mid-September. Since no in situ measurements were conducted in the sites of regular IW manifestations, an attempt was made to establish the dependence of IW occurrence frequency on seasonal and interannual variations of sea surface temperature, an indirect indicator of the depth of the diurnal or seasonal thermocline, that is where IW were generated.



Sea surface temperature (SST) was estimated from MODIS Aqua data, from Giovanni NASA Open Data Portal. The results of a joint analysis of SST and manifestations of internal waves showed that in 2010 the temperature in July was higher than in other years, and there are more manifestations of internal waves. But the problem requires further research.

Mapping of internal waves

Mapping of surface manifestations of internal waves was carried out in the “See the Sea” information system using the “Work with Polygons” tool. Manifestations of each confirmed packet of internal waves were outlined and stored in the database “internal waves”



A composite map of surface manifestations of internal waves, compiled on the basis of satellite radar data (red) and Ocean Color data (green) for 1999-2012 and 2018-2019

In the Caspian Sea, surface manifestations of internal waves (SMIWs) have distinct seasonal variability. In the end of May and in the first half of June, SMIWs can be found only in the western part of South Caspian; in the second part of June and in July, all SMIWs are observed on the east, near the Absheron Sill; and, in August, they appear northeast of the Absheron Peninsula.

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