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Wave attenuation in the Agulhas Current.

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Abstract: Describes satellite observations of wave height reduction in the Agulhas Current in South Africa. Occurrence when waves are aligned with the flow; Decrease in wave height; Prevalence in the northern parts of the Agulhas Current.

The enlargement of surface wave height in the Agulhas Current, caused by waves propagating in the opposite direction to the current, is well known for its danger to large vessels traversing the Cape route. Occurrence characteristics of the phenomenon have recently been determined. This paper reports novel satellite observations of wave height reduction in the Agulhas Current, occurring when waves are more or less aligned with the flow. The reduction takes the form of a small but noticeable decrease in wave height; the maximum recorded reduction amounted to about one half of the undisturbed wave height. The phenomenon seems more prevalent in the northern parts of the Agulhas Current where the frequency of north-easterly swell is higher than in the south.

The Agulhas Current, flowing in a south-westerly direction along the eastern and southern coasts of South Africa,[1] is exposed to waves approaching from the south-west Indian Ocean and the Southern Ocean. Waves propagating from the south-west are generated by wind fields associated with low-pressure weather patterns passing eastwards south of the continent,[2] and generally oppose the direction of the Agulhas Current flowing to the southwest. The ensuing wave-current interaction causes amplification of the wave heights through refraction and reflection[3-7] and these so called 'giant waves' become a hazard to shipping and cause vessels to be damaged or lost.[8-10] A recent investigation[11] empirically confirmed the existence of wave enhancement in the Agulhas Current and found that for about 16% of the time waves were amplified by more than 40%, while amplifications of greater than 100%, double the unaffected wave height, were also found on occasion.

On the other hand, waves approaching the Agulhas Current from the east or north-east are more or less aligned with the current, and the wave-current interaction causes the wave energy to diverge and the wave heights to decrease.[3] Apart from theoretical treatment of this phenomenon,[3-5,6,10] wave attenuation in the Agulhas Current (and, for that matter, elsewhere in the world) has not been observed directly, so Geosat wave data were inspected primarily to verify the existence of this phenomenon. The study was engendered when observed decreases in significant wave height could not be fully explained by the effect of the bottom topography as the waves Propagated onto the continental shelf[11] (depths less than 200 m).

Data and methods

Data for the present investigation, collected by the Geosat satellite,[12] covered the period November 1986 to February 1989. During this time the satellite orbital pattern repeated exactly with tracks about 140 km apart in the target area (Fig. 1). A global grid, comprising ascending and descending tracks, was executed every 17.05 days between 1986 and 1990. This means that 17.05 days passed before a particular track was revisited, but other tracks in the vicinity were covered within that period. The Geosat altimeter emitted high-frequency radar pulses vertically downward, and the significant wave height (SWH, a representative measure of wave height) was determined from the signature of the returned echo[13,14] with an accuracy of about 0.4 m.[15,16] The footprint of the beam (area illuminated) varied between 2 and 8 km (depending on the sea state[13]), and the SWHs averaged over one second were centred about 7 km apart along the tracks. The regularity of the satellite coverage, and the imperviousness of radar to cloud cover, makes altimetry well suited for studies of this kind.[11,17]

The satellite did not record wave direction, but the latter was equated to the wind direction portrayed on weather charts. No distinction was made between locally generated surface waves and remotely generated swell.

Infrared satellite imagery was used to verify the position of the Agulhas Current during cases of enhancement or attenuation. Although the images were not corrected for geometric distortion, the current was mostly close inshore in the relevant areas so that any positional uncertainty was limited. However, the images do not provide insight into the speed distribution within the current. The time delay between the observation of the wave amplification/attenuation and the infrared satellite image was normally less than one day, and this was not considered further.

Results

To illustrate the contrast between wave amplification and attenuation along the South African east coast, one example of each was selected along two satellite lines (A229 and A100, Fig. 2a). The cases of enlargement coincided with the presence of frontal low pressures south or south-east of the continent, and south-westerly wind along the coast (derived from synoptic weather charts). It was therefore assumed that the waves were moving against the Agulhas Current. The cases of attenuation coincided with the presence of atmospheric highs south-east of the continent, and easterly or north-easterly coastal wind; it was similarly inferred that the waves were moving with the current. This crude assumption (equating the wave directions to the wind direction indicated on the synoptic charts) did not allow the maturity of the wave field, nor any other effects that may have influenced the characteristics of the wave field, to be taken into account. The amplification/attenuation is not very distinct, considering the multitude of other fine structure in the SWH profiles, but becomes more noticeable when two wave profiles are compared along the same satellite line. The profiles along the satellite line A100 (Fig. 2a) are virtually inverted, suggesting that the current field was very similar in both cases, only the wind was reversed.

Wave height attenuation was observed all along the South African east coast (Fig. 2b). Only those cases of attenuation which occurred offshore of the continental shelf edge (thus excluding any possible effect of bottom topography on waves[11]) are presented. The effect of the Agulhas is quite clearly shown in the profile along line A14 (Fig. 2b): in that profile the attenuation of wave height was embedded in a region of generally larger waves due to a local storm (showing that, occasionally, it can be calmer inside the current than outside!). The following points were noteworthy:

- The number of attenuation events in the northerly parts of the survey area exceeded those in the south, which agrees with the prevalence of noah-easterly swell in the northern part of the Agulhas Current (Fig. 3b) and its relative absence in the southern parts (Fig. 3a).
- In contrast to the 25 cases of wave amplification that were studied, only eight cases of wave attenuation were found (Figs 2 and 4), signifying the relative infrequency of attenuation. This is supported by the occurrence characteristics of swell in the vicinity of the Agulhas Current (Fig. 3), which shows that north-easterly swell (associated with attenuation) is generally far less common than south-westerly swell (associated with amplification).

Comparison between these observations and existing theories was largely unsatisfactory. This may be ascribed, on the one hand, to a number of uncertainties in the data, including inaccuracy in the estimates of the wave direction, possible time lapses between the determination of the satellite wave height, wind direction and position of the current, wave refractive effects in the current, and the absence of any knowledge of the in situ current speed and wave period.

On the other hand, limitations in the applicability of the present theoretical treatments also contribute to the difference between theory and observations. One approach[18,19] underestimated the observed amplification and attenuation (see Fig, 4, where a current velocity of 1.5 m s^{-1} in the core of the Aguihas Current[20,21] was accepted). The enhancement is strongly dependent on the wave period (an unknown), and if the observed swell was of local rather than remote origin the wave periods would be generally shorter than conventionally assumed (possibly below 10 s) and the agreement between theory and observations better. It is unfortunate that a more sophisticated theoretical treatment of wave-current interaction[4,5] requires considerably more in situ supporting data than is generally available (e.g. the curvature of the current, the spatial velocity field inside the current, the exact location of the observed enhancement within this current field). For that reason it was not employed here to simulate the enhancement or attenuation.

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DIAGRAM: Fig. 1. Ascending ground tracks of the Geosat satellite off the east coast of South Africa, orientated diagonally across the Agulhas Current. Also indicated are the north-easterly and south-westerly wave directions.

GRAPH: Fig. 2. a, Profiles of satellite-derived significant wave height (SWH) against latitude along two tracks, to contrast events of wave amplification (peaks) and wave attenuation (troughs) (see arrows). Profile numbers refer to the tracks in Fig. 1. b, Profiles of SWH at various locations along the South African east coast (see Fig. 1 for location of the tracks). The attenuation (arrows) in the SWH profiles is indicated.

DIAGRAM: Fig. 3. Swell roses, based on 32 years' observations by voluntary observing ships, indicate occurrence frequency of different swell heights and directions (direction from which the swell comes), in a, the southern (35-37degreesS, 20-22 degrees E) and b, the northern (29-31degrees S, 31-33 degrees E) parts of the area of investigation. The thickness of each part of the rose is related to the height (see height scale) and the length to the frequency of occurrence (see frequency scale).

GRAPH: Fig. 4. Relative magnitude ($H1H_0$ dots) of wave heights inside the Agulhas Current (H) relative to the height outside the current (H_0), as a function of the angle between waves and current direction (see inset). Values larger than one indicate amplification; those less than one indicate attenuation. Orientation angles between 0 degrees and 90 degrees indicate waves propagating more or Mess in the same direction as the current, angles between 90 degrees and 180 degrees indicate waves opposing the current. Curves represent theoretical amplification or attenuation[18,19] for waves with 5-s and 15-s periods in a current of 1.5 m s^{-1}.

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