# Modelling Sea-Ice System Adjustments pertaining to Marginal Ice Zone Development as a result of Ocean waves

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The polar oceans are evolving rapidly, particularly at the surface where air, sea and ice exchange heat and momentum, and especially in the Arctic basin. Compared with earlier decades, Arctic sea-ice cover has thinned, adjusted from predominantly perennial ice to seasonal ice and reduced in extent to nearly 30% less at the end of a longer summer melt period when it now resembles a marginal ice zone (MIZ). There is also more deformed sea-ice, increased primary productivity and ecosystem shifts, and swings in atmospheric circulation and Northern Hemisphere weather patterns. The depleted ice cover is associated with greater storm activity, such as arose during the great cyclone in August 2012. Severe events now occur more often and the combination of fiercer winds and increased accumulated open water fetches produces larger waves throughout the region, which then nourish ice albedo-temperature feedback by breaking up the sea-ice and bringing warm water into contact with ice floes.

In contrast to the Arctic, Antarctica is a continent with 98% of its land blanketed by ice, surrounded by an ocean which has most of its surface covered by seasonal sea-ice that forms in salt water during the winter and almost entirely melts again in the summer. While Antarctic terrestrial ice decreases at an accelerating rate – an average rate of 70 Gt/year, Antarctic sea-ice is increasing in extent despite the Southern Ocean warming faster than the rest of the world's oceans (0.17°C per decade as opposed to 0.1°C). Although the causes are complex, one probable candidate is increased rain, snowfall and continental freshwater runoff, which freshens and stabilizes the surface waters so that mixing is undermined and less heat is transported upwards from the warmer deeper ocean to melt the sea-ice. Pervasive Southern Ocean waves supplement ice growth as well, by breaking floes up so that they are more mobile and additional areas of open water can freeze over. Notwithstanding, the observed Antarctic sea-ice expansion is expected to moderate and reverse as climate warming continues.

It is therefore apparent that, on account of global climate change, ocean waves now exert a much greater contribution in all of the polar seas than ever before. Yet their impact is absent in contemporary ice/ocean models and general circulation models, just as sea-ice parameterization is deficient in wave forecasting models such as Wavewatch III®.

In this talk I will explain why waves have recently become so important for both the summer Arctic and the Southern Ocean, by reason of their pivotal influence in MIZs where they break up, pummel and redistribute ice floes to produce the floe size distribution and alter concentration. In doing so, waves create and sustain the aggregate morphology of the MIZ, the part of the ice cover that is close enough to the open ocean boundary to be affected by its presence. In compact, i.e. quasi-continuous, interior pack ice, wave vectors can propagate substantial distances — they suffer attenuation as a consequence of cumulative encounters with pressure ridges, cracks and leads that reflect some wave energy back, and because of the inelasticity of the sea-ice, but they can be modelled effectively using a 1D methodology. In the MIZ, on the other hand, the penetrating ocean waves are immediately scattered radially by individual ice floes in the MIZ mélange, so a 2D model is needed. I will show results from an ice/ocean model of the Fram Strait in the Greenland Sea, with *sectorized* 1D ocean wave trains embedded to approximate incoming directional seas that selectively alter floe size distribution. I will also give details of a novel 2D wave-ice scattering model, applicable to both the Arctic and Southern Ocean ice fields, which advects a directional spectrum into the sea ice where it is scattered into multiple circular wave fronts that are compounded and repeatedly reconfigured as an amended directional spectrum which systematically advances further into the ice. Attenuation, spreading and breakage can be found at any point, so wave advection and modification of polar sea ice attributes and upper surface water structure can be ascertained to refine existing conjectures about ice extent. While the 2D scattering model has not yet been incorporated into an ice/ocean model or a general circulation model, its computational efficiency indicates that this will be possible.