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Better Operational Forecasting for Contemporary Arctic via Ocean Wave Integration

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Whether configured for operational purposes or for research, current coupled ice-ocean models and oceanic global circulation models lack sophistication in regard to core aspects of sea ice behavior, notably the determinative contribution that ocean waves make in evolving the sea ice canopy and hastening its annihilation. Considerably enhanced climate- resolving accuracy and reliability can potentially be achieved by incorporating naturally pervasive ocean wave / sea ice interactivity into a state-of-the-art polar ocean modeling framework originally developed and hosted by NERSC in Norway. This paper focuses on how to do this, recognizing the benefits that will flow from the research through better model parameterization and forecasting precision—especially with reference to contemporary adverse global warming effects.

INTRODUCTION

Recently, a sequence of publications has appeared that focuses on how natural ocean waves interact with polar sea ice in its several forms: quasi-continuous sheets, broken-up pack ice characteristic of the MIZ[1] and pancake ice slurries (Weber, 1987; Liu and Mollo-Christensen, 1988; Melsom, 1992; Shen and Squire, 1998; Squire et al., 1995; Squire, 2007). Considerable work has been done to understand scattering from various sea ice irregularities, e.g. cracks, open or refrozen leads, floe edges, changes in material property or thickness, pressure ridges, etc. (Bennetts and Squire, 2012b; Vaughan and Squire, 2007; Vaughan et al., 2007; Williams and Squire, 2004, 2006, 2007) and on ocean wave propagation through open ice fields such as MIZ (Bennetts et al., 2010; Bennetts and Squire, 2009, 2010; Bennetts and Williams, 2010). In addition, these elemental studies have been brought together to replicate how waves travel through large swathes of quasi-continuous natural sea ice that include an authentic distribution of leads and a representative empirical topography (Mahoney et al., 2007) found by submarine upward-looking sonar (Squire et al., 2009; Vaughan et al., 2009). Comparable progress has been made in the MIZ too (Bennetts et al., 2010; Bennetts and Squire, 2012b; Kohout and Meylan, 2008), where the FSD[2] is caused primarily by ocean waves. As waves penetrate the ice pack they are scattered by the floes, losing energy with distance traveled. On entry, they are powerful enough to fracture and at times pulverize local ice into slurry, a little further in they usually break up floes, but deeper in still the waves have become sufficiently emaciated that they no longer regulate floe size (Squire and Moore, 1980; Toyota et al., 2006, 2011; Wadhams et al., 1987). Beyond the fractured zone (Vaughan and Squire, 2011) the ice is quasi-continuous—ice floes are customarily larger though still punctuated by cracks, pressure ridges and leads. Scattering continues to take place at these heterogeneities, but because they are less abundant, other mechanisms such as sea ice inelasticity, turbulence, viscous damping in the water and collisions between floes can dominate. An alternation prevails, where the sea ice influences the incoming ocean waves and swells and the waves reshape the undergirding structure of the MIZ by regulating floe diameter through fracture.

Despite the patently intimate relationship between ocean waves and sea ice, their effect is not yet built into operational ice-ocean forecasting models and OGCM[3]. This is of major importance to every maritime endeavor in each polar or subpolar sea, notably in regard to the safety of ships engaged in fisheries, tourism and geophysical or hydrographical prospecting, and Arctic offshore enterprises allied to hydrocarbon exploration. Vital operational forecasts to support these activities are currently deficient, as they neglect a fundamental physical process that profoundly affects the sea ice cover. Moreover, the well-documented reductions in ice thickness, extent and concentration in the summer Arctic Ocean (Holland et al., 2006; Kwok and Rothrock, 2009; Serreze et al., 2007; Wadhams and Davis, 2000), which have caused the ice to become more like a MIZ, and the redistribution of sea ice morphology in the Southern Ocean, indicate that ocean waves will now exert a much greater influence than hitherto. This change will be fueled by the heightened and more extreme meteorological events that we continue to experience due to climate change, leading to higher waves being created at distant storm centers that then advance into the ice cover. But it will also be affected by the greater fraction of open sea within ice fields, which will promote the generation of waves in situ by increasing fetch. The

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[1]Marginal ice zone, the 10s–100s km-wide outer part of the pack ice cover that interacts with the open ocean, comprising a mélange of dispersed floes and cakes a few meters across near the ice edge but increasing in size with penetration

[2]Floe size distribution

[3]Oceanic global circulation models