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A possible scenario of a drastic change in Antarctic coastal polynyas associated with ice sheet loss

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Coastal polynyas, which are newly-forming sea-ice areas surrounded by pack ice, are formed by divergent ice motion driven by winds and/or ocean currents. Antarctic coastal polynyas are very high sea-ice production areas, because the heat insulation effect of sea ice is reduced significantly in the case of thin ice and accordingly huge heat loss to the atmosphere occurs. The resultant large amount of brine rejection leads to dense water formation. The dense water is a major source of Antarctic Bottom Water (AABW), which is a key player in the global climate system as a significant sink for heat and possibly carbon dioxide. Coastal polynyas are also sites of biological ”hot spots”, because of much-enhanced primary productivity.

Very recent studies have suggested that landfast sea ice, which is stationary sea ice attached to coastal features such as grounded icebergs and glacier tongues play an important role in the formation of some coastal polynyas by blocking ice advection to cause divergence. Key examples are the Cape Darnley Polynya and Mertz Polynya, both of which are major source areas of AABW.

In this study, we present the first combined circumpolar mapping of Antarctic coastal polynyas and fast ice, based on satellite observation to examine and quantify the linkage between coastal polynyas and fast ice. The map reveals that most coastal polynyas are formed on the western side of fast ice, suggesting that fast ice is an essential element for the formation of most coastal polynyas. Furthermore, we demonstrate that a drastic change in fast ice extent, which is particularly vulnerable to climate change, causes dramatic changes in associated polynyas and possibly AABW formation that can potentially contribute to further climate change.

The map presented in this study reveals that many of the coastal polynyas are formed along the East Antarctic coast where fast ice dominates. In the West Antarctic sector, it was suggested that intrusion of relatively warm Circumpolar Deep Water (CDW) onto the continental shelf causes the basal melting of ice shelves, possibly leading to acceleration of iceberg calving. Future climate change might precipitate a similar situation also in the East Antarctic sector where the location of CDW is relatively close to the continent. This possibly causes drastic changes of fast ice extent directly by melting, or indirectly by acceleration of iceberg calving. The drastic change in fast ice extent is expected to cause a dramatic change in the polynya area and sea-ice production. Further, a huge tabular iceberg can directly affect the polynya area by covering over as shown in the Ross Sea Polynyas area in 2000 and 2002; giant icebergs B-15 and C-19, calved from the Ross Ice Shelf, causing a significant reduction of the polynya area and sea-ice production. The results of this study suggest that fast ice and precise polynya processes should be addressed by next-generation models to reproduce the formation and variability of sea-ice production, dense water, and AABW properly. The mapping presented in this study would give the boundary/validation data of fast ice and sea-ice production for such models.

Keywords: Coastal polynya, Landfast sea ice, Antarctic Bottom Water, Iceberg, Ice sheet