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A coupled decadal-scale air-sea interaction theory: the NAT-NAO-AMO-AMOC coupled mode and its global impacts

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Observational analysis shows that the North Atlantic Oscillation (NAO) leads the oceanic Atlantic Multidecadal Oscillation (AMO) by 15–20 years and the latter also leads the former by around 15 years. The Community Climate System Model (CCSM) version 4 is employed to investigate the relevant mechanism in the linkage between the NAO and AMO. The results show that the positive North Atlantic Oscillation (NAO) forces the strengthening of the Atlantic meridional overturning circulation (AMOC) and induces a basin-wide uniform sea surface temperature (SST) warming that corresponds to the Atlantic multidecadal oscillation (AMO). The SST field exhibits a delayed response to the preceding enhanced AMOC, and shows a pattern similar to the North Atlantic tripole (NAT), with SST warming in the northern North Atlantic and cooling in the southern part. This SST pattern (negative NAT phase) may lead to an atmospheric response that resembles the negative NAO phase, and subsequently the oscillation proceeds, but in the opposite sense. This implies a NAO-AMO-AMOC coupled mode in decadal scale. Based on these mechanisms, a simple delayed oscillator model is established to explain the quasi-periodic multidecadal variability of the NAO. The magnitude of the NAO forcing of the AMOC/AMO and the time delay of the AMOC/AMO feedback are two key parameters of the delayed oscillator. For a given set of parameters, the quasi 60-year cycle of the NAO can be well predicted. This delayed oscillator model is useful for understanding of the oscillatory mechanism of the NAO, which has significant potential for decadal predictions as well as the interpretation of proxy data records.

The NAT-NAO-AMO-AMOC coupled mode has important influences on global and regional climate. The twentieth century Northern Hemisphere mean surface temperature (NHT) is characterized by a multidecadal warming-cooling-warming pattern followed by a flat trend since about 2000 (recent warming hiatus). Here we demonstrate that the multidcadal variability in NHT including the recent warming hiatus is tied to the NAT-NAO-AMO-AMOC coupled mode and the NAO is implicated as a useful predictor of NHT multidecadal variability. An NAO-based linear model is therefore established to predict the NHT, which gives an excellent hindcast for NHT in 1971–2011 with the recent flat trend well predicted. NHT in 2012–2027 is predicted to fall slightly over the next decades, due to the recent NAO decadal weakening that temporarily offsets the anthropogenically induced warming.

The subtropical eastern Australian rainfall (SEAR) shows evident fluctuations over decadal to multidecadal time scales and is connected to the NAO over decadal time scales, with the NAO leading by around 15 yr. The decadal-scale variability of SEAR is associated with the NAT-NAO-AMO-AMOC coupled mode which can have a delayed impact on SST fluctuations in the subpolar Southern Ocean (SO), and these SST changes could in turn contribute to the decadal variability in SEAR through their impacts on the Southern Hemisphere atmospheric circulation. A linear model for SEAR decadal variability was developed by combination of the NAO and Pacific decadal oscillation (PDO). The observed SEAR decadal variability is considerably well simulated by the linear model, and the relationship between the simulation and observation is stable. SEAR over the coming decade may increase slightly, because of the recent NAO weakening and the return of negative PDO phase.