Potential impacts of pronounced decadal-scale variations in sea surface temperature (SST) in the North Pacific subarctic frontal zone (SAFZ) upon seasonally-varying atmospheric states are investigated, using 48-year long observational data and a 120-year simulation with an ocean-atmosphere coupled general circulation model (CGCM). SST fields based on in-situ observations and the ocean component of the CGCM have minimal horizontal resolutions to resolve frontal SST gradient across SAFZ. Both the observations and CGCM simulation provide a consistent picture between SST anomalies in SAFZ (yielded by its decadal-scale meridional displacement) and their association with atmospheric anomalies. Correlated significantly with SST anomalies persistent in SAFZ from fall to winter, a coherent decadal-scale signal in the wintertime atmospheric circulation over the North Pacific emerges in October and develops into an equivalent barotropic anomaly pattern similar to the Pacific/North American (PNA) pattern. The PNA-like signal with the weakened (enhanced) surface Aleutian low in correlation with positive (negative) SST anomalies in SAFZ becomes strongest and most robust in January, sustained by effective feedback forcing from synoptic-scale disturbances migrating along the Pacific storm-track that shifts northward (southward) in accord with the oceanic SAFZ. This PNA-like signal, however, breaks down in February, suggestive of particular sensitivity of that anomaly pattern to subtle differences in the background climatological-mean state. Despite its collapse in February, the PNA-like signal recurs in next January. This sub-seasonal evolution of the signal suggests that the PNA-like anomaly pattern may develop as a response to the persistent SST anomalies that are maintained by ocean dynamics.