A MODELING STUDY OF THE ATMOSPHERIC RESPONSE TO A MIDLATITUDE SST FRONT

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAIʻI AT MĀNOA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

OCEANOGRAPHY

AUGUST 2013

By

Thomas Kilpatrick

Dissertation Committee:

Niklas Schneider, Chairperson
Bo Qiu
Eric Firing
Peter Müller
Gary Barnes

Keywords: Marine atmospheric boundary layer, air–sea interaction, SST front, Ekman pumping

ABSTRACT

Recent studies indicate that midlatitude sea surface temperature (SST) fronts' influence extends through the marine atmospheric boundary layer (MABL) into the free atmosphere, with implications for climate variability. To better understand the mechanisms of this ocean-to-atmosphere influence, SST-induced MABL convergence is explored here with the Weather Research and Forecasting (WRF) regional atmospheric model in an idealized, dry, two-dimensional configuration, for the two archetypes of a prescribed geostrophic wind blowing across an SST front and along an SST front.

First, strong cross-front background winds $\overline{U}$ are considered. A "strong" wind is defined here as a wind that results in an $O(1)$ cross-front Rossby number $\epsilon = U/fL$, where U is the cross-front component of the MABL wind and L is the length scale of the SST front. Since $\epsilon = O(1)$, advection dominates and the MABL cannot maintain an Ekman momentum balance as the friction and pressure gradient terms are altered by the air–sea heat flux. Nonrotating, internal boundary layer-like physics prevail directly above the SST front and leave a clear signal in the cross-front surface stress and wind stress divergence.

The SST-induced MABL convergence results in vertical motion that excites a weak stationary internal gravity wave in the free atmosphere, analogous to a mountain wave. For $\overline{U}$=15 m s^{-1}, the gravity wave forced by an SST increase of 3°C over 200 km is comparable to that forced by an 80 m change in topography.

Second, an along-front background wind $\overline{V}$ is considered. MABL convergence and divergence spin up a quasigeostrophic jet in the free atmosphere, on a time scale of a few days. The jet strength is critically dependent on the background wind strength $\overline{V}$.

Friction and rotation generate a cross-front wind within the MABL. For $\overline{V}$=15 m s^{-1}, the MABL approximates an Ekman momentum balance, though advection is significant ($\epsilon \approx 0.2$–0.3). The MABL vorticity budget is consistent with nonlinear Ekman pumping wherein geostrophic vorticity is imprinted by the air–sea heat flux and advected by the Ekman transport. The Ekman pumping attenuates over time, indicative of stratified spindown.