Air-sea interaction in tropical atmosphere: influence of ocean mixing on atmospheric processes

Dariusz Bartłomiej Baranowski

Abstract

Changes in activity of deep convective clouds, developing over warm waters of tropical oceans, are dominant mode of diurnal to intraseasonal variability of the atmospheric circulation in the tropics. One the major factors determining the development and evolution of atmospheric convection are the sea surface temperature. Thus, the variability of the upper ocean stratification, which impacts the sea surface temperature, is an important factor in the variability of the atmospheric convection in the tropics. In this thesis, the two way interactions between atmospheric convection and upper ocean are investigated on the basis of the in-situ measurements, satellite data and numerical simulations.

The results show that state of atmospheric convection impacts the diurnal distribution of thermal energy in the upper ocean. Under calm and clear sky conditions, with daily mean wind speed below 6 ms^{-1} and daily mean solar radiation flux above 80 Wm^2, a shallow warm layer of several meters depth develops on the surface of the ocean. This warm layer may be interpreted as a diurnal sea surface temperature anomaly which often reaches amplitude of 0.8 ^{0}C and drives an anomalous flux of 4 Wm^2 from the ocean to the atmosphere. Based on these results a predictive model of sea surface temperature anomaly, as a function of surface insolation and wind speed, is developed. The derived sea surface temperature anomaly and surface fluxes are used in analysis of the development and evolution of atmospheric convection organized in equatorial convectively coupled Kelvin waves.

A novel Kelvin wave trajectory database based on satellite data is introduced in this study. The investigation of surface fluxes and remote sensing data, augmented by the numerical modeling, shows that substantial fraction of Kelvin waves is initiated as a result of interaction with another Kelvin wave. Two distinct categories are defined and analyzed independently. The first one accounts for two- and multiple Kelvin wave initiations which occur when diurnal sea surface anomaly is high. The second category is a “spin off” initiation which occurs when a Kelvin wave initiates over the area through which another Kelvin wave passed within a few days. Results show that primary forcing of such waves are increased wind speed and latent heat flux at the ocean surface.

In the following Chapter investigation of interactions between Kelvin wave and upper ocean is presented. Variability of the ocean surface and subsurface along Kelvin wave trajectories over Indian Ocean is investigated. It is shown that fast propagating Kelvin waves impact diurnal variability of the sea surface temperature, surface wind speed and latent heat flux. Composites of all the Kelvin waves show that changes in wind speed, latent heat, and sea surface temperature anomaly have similar signature. Wind speed and latent heat flux increase and a sea surface temperature anomaly decreases during Kelvin wave passage. Such changes depend on the phase of the Madden-Julian Oscillation in which Kelvin wave propagates.

In the next Chapter the properties of convectively coupled Kelvin waves in the Indian Ocean and their propagation over the Maritime Continent are studied. It is shown that Kelvin waves are longitude-diurnal cycle phase locked over the Africa, Indian Ocean and Maritime Continent. This means that they tend to propagate over definite areas during specific times of the day. Over the Maritime Continent, longitude-diurnal cycle phase locking is such that it agrees with mean, local diurnal cycle of convection in the atmosphere. The strength of the longitude-diurnal cycle phase locking differs between non-blocked Kelvin waves, which make successful transition over the Maritime Continent, and blocked waves that terminate within it. It is shown that a specific combination of Kelvin wave phase speeds and time of the day at which a wave approaches the Maritime Continent influences the chance of a successful transition into the Western Pacific. Kelvin wave that maintains phase speed of 10 to 11 degrees per day over the central-eastern Indian Ocean and arrive at 90E between 9UTC and 18UTC has the highest chance of being non-blocked by the Maritime Continent. The distance between the islands of Sumatra and Borneo agrees with the distance travelled by an average convectively coupled Kelvin wave in one day. This suggests that the Maritime Continent may act as a “filter” for Kelvin waves, favoring successful propagation of those waves which are in phase with the local diurnal cycle of convection. The AmPm index, a simple measure of local diurnal cycle for propagating systems, is introduced and shown to be a useful metric depicting key characteristics of the convection associated with propagating Kelvin waves.

Thus, the main message of this thesis is that interaction between atmospheric convection and upper ocean are characterized by two-way feedbacks. Mature atmospheric convection influences the distribution of the energy in the upper ocean affecting the sea surface temperature. On the other hand, changes in the sea surface temperature impact the organization of the atmospheric convection in equatorial convectively coupled Kelvin waves.