Numerical Simulations of Two Local thunderstorms over Central Oahu during the Warm Season

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Introduction

Over Hawaii, trade winds are persistent during the warm season with mid-tropospheric subsidence and a trade-wind inversion (~ 2 km). Under **typical trade-wind conditions** over Hawaii **during the warm season**, **warm rain showers are frequent** as the trade-wind cumuli/showers drift inland and interact with the island terrain. In addition to warm rain showers, **thunderstorm events occur during the warm season**. During the warm season of 2000−2015, based on the Storm Event Database, National Center for Environmental Information (NCEI) data, **an averaged of 2.1 daytime (1000-1800 Hawaiian Standard Time) thunderstorm events occurred over Oahu**. However, comprehensive studies of this type of events over Oahu are lacking. In this study, **two unusual warm season (May-October) afternoon local thunderstorm cases (June 7, 2003 and October 13, 2013) over Oahu are first time investigated**. For both events, heavy showers produced small stream and drainage ditch floodings. **The first event also recorded an F0 tornado**. **For the second event, a funnel cloud with small hails were reported**. The high-resolution (~ 1.5 km) simulations are conducted to study the island-induced airflow and weather for these two events.

Synoptic Analyses from CFSR

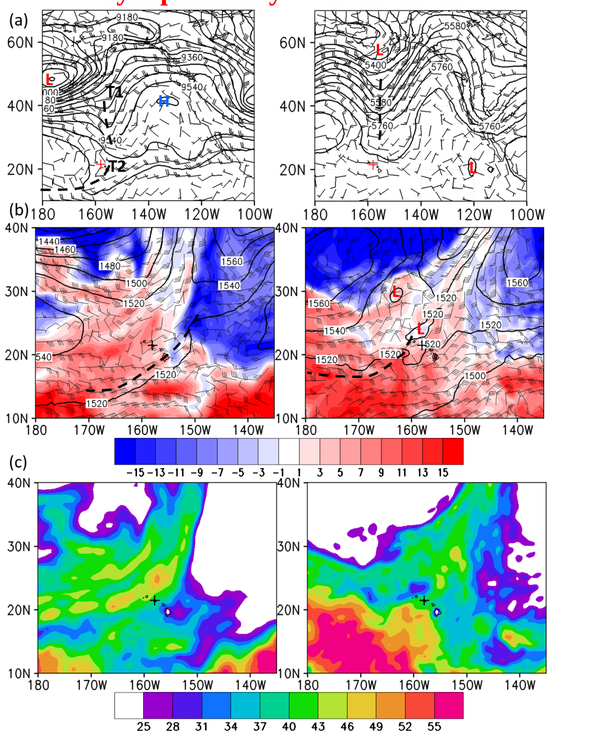

Fig 1. (a) The geopotential height (gpm, contour) and wind barb at the 300-hPa level. (b) The geopotential height (gpm, contour), wind barb, and equilibrium potential temperature anomaly (K, shaded) at the 850-hPa level. (c) The total precipitable water (kg m^{-2}, shaded). All plots are based on CFSR at 1400 HST 7 June, 2003 (left) and at 1400 HST 13 October, 2013 (right). The plus signs (+) indicate the island of Oahu.

Both events initiated over central Oahu during the afternoon hours under a favorable synoptic environment, including the present of **an upper-level trough** with **a low-level weak wind shear line northwest of Hawaii** and **a moist tongue with high (> 40 mm) total precipitable water (TPW)**.

Observational Analyses

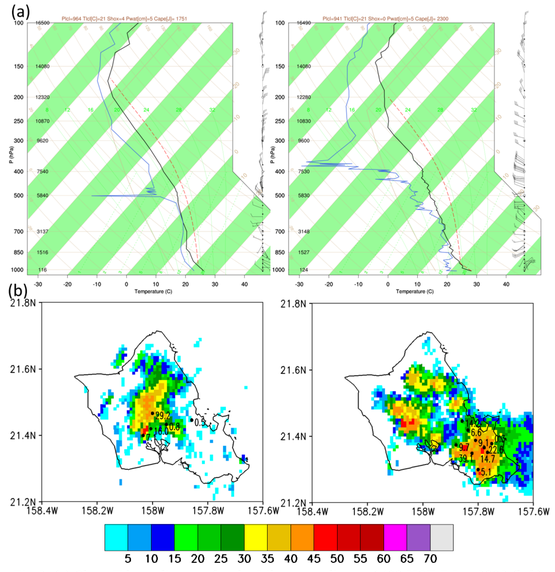

Fig 2. (a) Skew T-logp diagram for the Lihue sounding at 1400 HST 7 Jun 2003 (left) and at 1400 HST 13 October, 2013 (right). (b) The composite reflectivities (dBz, shaded) from Molokai radar and hourly rainfall accumulation from the Hawaii hydronet data (mm, black text) at 1500 HST 7 June 2003 (left) and at 1400 HST 13 October, 2013 (right).

At 1500 HST 7 June, the sounding data from Lihue indicate **weak and variable winds speed** (< 5 m s^{-1}) at low levels with **a weak inversion** at the 550-hPa level (Fig. 2a left). The temperature profile is close to pseudo-adiabatic curve below the 200-hPa level with relatively **high (~ 1751 J kg^{-1}) convective available potential energy (CAPE)** indicating that the rising air parcel would be positive buoyant after reaches the level of free convection (LFC) (~ 915 hPa). The **unusual deep moist layer** (from surface to 550 hPa), **relatively large K index** (~ 32), and **a weak inversion** indicate the environment is **favorable for the development for heavy precipitation**. The observed radar echoes from the Molokai radar show that the storm forms **over central Oahu with maximum radar reflectivities ~ 50 dBZ** at 1500 HST (Fig. 2b left). Figure 2b left shows the hourly rainfall during 1401−1500 HST over Oahu. Note that only stations that recorded precipitation were included in the figure. **Radar reflectivities and rain gauges over central Oahu indicate that this thunderstorm event is localized in nature with the maximum hourly rainfall ~ 29 mm h^{-1}** (Fig. 2b left).

At 1400 HST 13 October, the Lihue sounding (Fig. 2a right) shows less than 10 knots surface winds, **absence of TWI**, **high K index** value (36), **large CAPE** (~ 2300 J kg^{-1}) with LFC ~ 862 hPa, and a deep (950−650 hPa) moist layer. With abundant moisture and conditionally unstable atmosphere, the conditions are favorable for the development of localized thunderstorms. The observed radar reflectivities show two major convective areas: one over the eastern slopes of Waianae Mountain Range; the other over the southeastern corner of Oahu (Fig. 2b right). **Southeastern Oahu recorded an hourly rainfall maximum of 39 mm ending at 1400 HST** (Fig. 2b right). Note that the rain gauge data over central Oahu are unavailable during the period.

Results from the Two Case Study

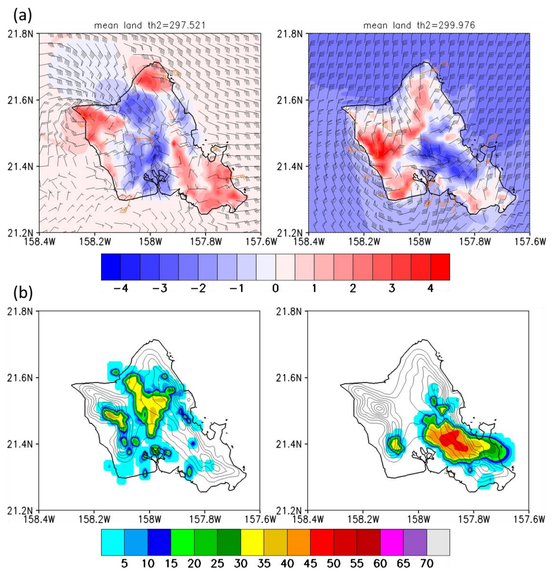

Fig 3. (a) The simulated 10-m wind barb (black), observed surface wind barb (orange): one pennant is 5 m s^{-1}, full barb is 1 m s^{-1}, and half barb is 0.5 m s^{-1}, and the simulated 2-m potential temperature anomaly (K, shaded) at 1500 HST 7 June, 2003 (left) and 1400 HST 13 October, 2013 (right). (b) The simulated radar reflectivities (dBz, shaded) and terrain height (contours in 100 m-intervals) at 1500 HST 7 June, 2003 (left) and at 1400 HST 13 October, 2013 (right).

At 1500 HST 7 June, the simulated 10-m winds and 2-m potential temperature (θ) anomaly (Fig 3a, left) indicate the **development of onshore flows over the Oahu coasts** resulted from **daytime land surface heating**. **The simulated afternoon onshore flows at the surface is consistent with observations** (orange wind barb in Fig. 3a, left). The surface cool pool with more than **3 K temperature deficit** caused by **rain evaporative cooling** results in divergent airflow over central Oahu. The simulated reflectivities show a **maximum ~ 40 dBZ over central Oahu**, whereas the observed radar reflectivities show more concentrated convective activities over **central Oahu with maximum reflectivities ~ 50 dBZ** (Fig. 3b, left).

At 1400 HST 13 October, the simulated island-scale airflow is **influenced by the orography and thermal effect with the onshore flows** around the Oahu coasts (Fig. 3a right). **The simulated onshore flows over the eastern and southern coasts are consistent with the observed surface winds**. There are some discrepancies, however. The simulated onshore flow over the western coast (~ 5 m s^{-1}) is stronger than observations (~ 3 m s^{-1}). With the simulated surface cool pool, the northwesterly offshore flow (easterly wind) is simulated over southeastern Oahu (central Oahu). **The simulated reflectivities are mainly over southeastern Oahu** with maximum ~ 50 dBZ at 21.4°N, 157.9°W, **resulting from the convergence between the incoming northerlies from the northern coast and the southerly onshore flow from the southern coast**. A relatively weak reflectivity area (20−10 dBZ) extends southeastward from the maximum simulated reflectivities (Fig. 3b, right).

Impacts of Island Circulations on Local Thunderstorms

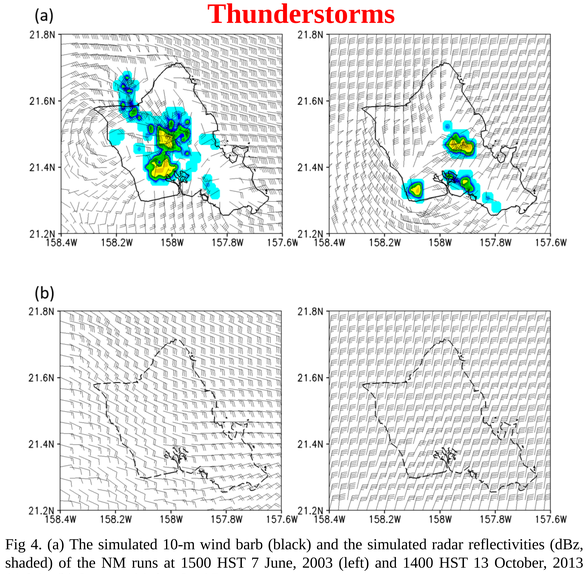

Fig 4. (a) The simulated 10-m wind barb (black) and the simulated radar reflectivities (dBz, shaded) of the NM runs at 1500 HST 7 June, 2003 (left) and 1400 HST 13 October, 2013 (right). (b) Same as (a), but for AD runs.

To investigate the **impact of orographic effects**, a model sensitivity test is performed by **reducing model terrain heights by 95% (No Mountain, NM)**. To assess the **impact of land surface heating** on the afternoon thunderstorms, another model sensitivity test is conducted with **the island of Oahu completely removed with the surface covered by ocean water (Aqua Domain; AD)**.

Without orographic effects (the NM runs), the **convergence zone** over central Oahu from afternoon onshore flows along the coasts and the development of the **heavy showers** over land are still **simulated** (Fig. 4a).

When the terrain is removed with the area covered by water (the AD runs), **no convective cells** are simulated in the area **even though large-scale conditions are favorable** (Fig. 4b).

Conclusion

- Both thunderstorms are associated with an upper-level trough with a low-level weak shear line northwest of Hawaii under weak surface winds.
- The storm environment is characterized by a deep moist layer with high TPW and absent of TWI in a conditional unstable atmosphere.
- Both events occurred under pronounced afternoon sea-breeze circulations.
- Numerical simulations show that the high-resolution (~ 1.5 km) models are capable of predicting these short-live local thunderstorms over Oahu.
- Examples of how island-scale circulation can effect afternoon thunderstorm.
- Without land surface heating, no convective cloud formed.
- Under disturbed weak wind conditions, land surface forcing is critical to the development of localized afternoon thunderstorms during the warm season.

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