

2005 ENGAGEMENT GRANT RECIPIENT
Numerical Simulations of Airflow and Weather over the Island of Oahu
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Motivation: The trade-wind belt has a minimum in the global distribution of rainfall. However, local trade-wind showers are frequent over the Hawaiian Islands because of terrain and local winds. Besides orographic lifting on the windward slopes, the mountain also acts as a barrier to the approaching airflow and as a heat source (sink) during the day (night) (Chen and Nash 1994). With different sizes (< 140 km), shapes and mountain heights (500 m - 4,100 m), and large variations in local microclimate ranging from humid tropical conditions on the windward side to dry conditions on the lee side and some areas with semi-arid terrain covered by lava rocks, the Hawaiian Islands are ideal to study the island flow response under different flow regimes and heterogeneous surface properties.

In this research, we would like to address the following questions: With adequate depiction of the terrain and surface properties in the model, to what extent can the effects of terrain and diurnal heating cycle on island-scale weather over Oahu be simulated by the NCAR/PSU (National Center for Atmospheric Research/Penn State University) MM5 model (Mesoscale Model version 5) coupled with an advanced land surface model (LSM) (F. Chen and Duhia 2001); and what are the effects of trade-wind conditions, e.g., strong and weak trades, on the island-scale airflow and weather over Oahu?

Methods: Four nested domains are employed in the model with a two-way nesting approach. The four nesting domains have horizontal resolutions of 40.5 km, 13.5 km, 4.5 km, and 1.5 km, and horizontal dimensions of 82 x 82, 70 x 70, 79 x 88, 52 x 64 with 28 vertical levels. The innermost nested domain with a 1.5-km resolution covers the entire island of Oahu. The vegetation covers and soil properties compiled by Zhang et al. (2005) for Oahu are used. The observed data collected during July-August 2005 are used to validate the model results. During this two-month period, the daily model run is initialized by the output of Global Forecast System (GFS) with a horizontal resolution of about 100 km provided by NCEP (National Centers for Environmental Prediction). Statistical analyses of model performance of the 1.5-km Oahu model during this two-month period are evaluated at each station including the absolute errors, root mean square errors of simulated surface air temperature, moisture and winds.

During the summer months, trades are persistent. To study the effects of terrain and diurnal heating cycle on island-airflow and weather, the mean diurnal variations of meteorological variables at each grid point are constructed from model simulations for this two-month period and compared with station observations. To investigate the effects of trade-wind conditions on island-scale airflow and weather, the model simulations and observations for two groups of strong and weak trade-wind categories are separately averaged and analyzed.

Use of HPC resources: The coupled MM5/LSM used in this research has a distributed-memory parallel option. With the option, the model can be run on distributed-memory computer system. However, the integrated processes of a set of full non-hydrostatic equations on all 28 levels of four nested grids (613312 grid points) still require huge computer resources. High-performance computing (HPC) resources are crucially required factors for this research. The squall system at MHPCC was used to run the model with distributed-memory parallel option.

Results and future work: At night, both the observations and simulations show weak winds over central Oahu with westerly mountain winds on the eastern slopes of the Waianae Mountains (Fig. 1a). In the early afternoon, easterly trades are observed and simulated over the island interior with almost uniform wind direction except along the western lee-side coast (Fig. 1b). Furthermore, the incoming trade-wind flow decelerates as it approaches the island because of island blocking and land-sea differential surface friction with relatively strong winds off the northwestern and southeastern coasts. The westerly winds at night on

the eastern slopes of the Waianae Mountains at night and the sea breezes (or westerly) winds along the western coast in the afternoon are caused by nighttime land surface cooling and daytime land surface heating, respectively. Under strong trade-wind days, the thermally driven diurnal winds (e.g., the nighttime mountain winds on the eastern slopes of the Waianae coast and the daytime sea breezes along the lee-side coast) are less significant than those of the weak trade-wind days.

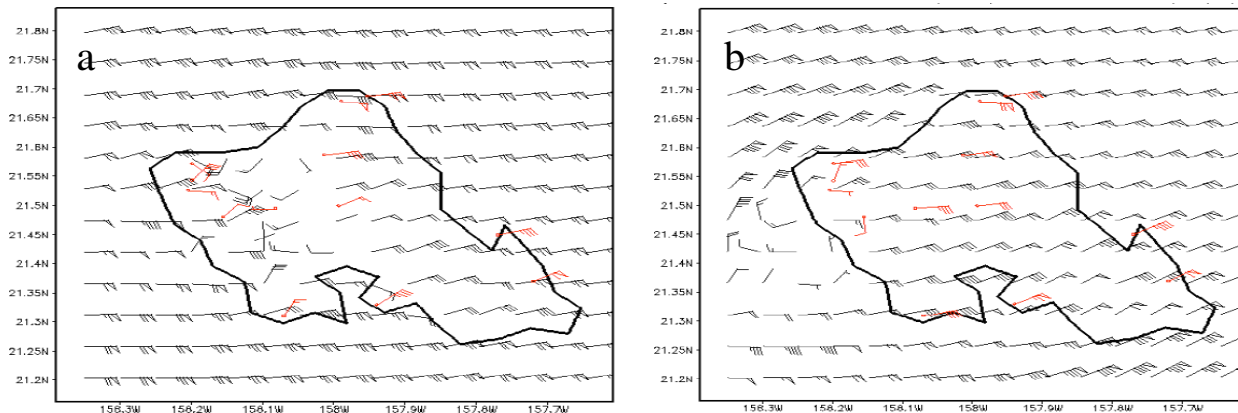


Figure 1. Mean simulated winds (back barb) and mean observed wind at 13 hourly weather stations (red barb) at (a) 05 HST and (b) 14 HST for July and August 2005. One pennant: 5 m s^{-1} , one full barb: 1 m s^{-1} .

Simulated rainfall accumulation for the two summer months shows a maximum rainfall over the Ko'olau Mountains, a small secondary maximum on lee-side slopes of the Waianae Mountain range and a minimum over central Oahu in agreement with observations (Nguyen 2006). The simulated rainfall on the windward side and over the Ko'olau Mountains shows an afternoon minimum; along the lee-side Waianae coast, it has a weak afternoon maximum under weak trade-wind conditions. The simulated rainfall amount over the Ko'olau Mountains and on the windward side is higher when trades are stronger. These results are in agreement with observations.

On the windward coast, relatively cool and moist conditions are simulated. The minima in relative humidity are simulated in the lee sides of both the Ko'olau Mountains and the Waianae Mountains. The warmest temperatures in the afternoon are simulated in the lee-side urban areas including Honolulu and the Ewa plain.

In the near future, we would like to use the newly developed WRF (Weather Research and Forecast) model, developed at the National Center for Atmospheric Research, to conduct high-resolution simulations of heavy rainfall events over the Hawaiian Islands, especially the recent record breaking prolonged wet period during February 19 – April 2, 2006.

References

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