FINAL REPORT

Application of Radar Imagery as Input to a Rainfall-Runoff Model for the Kawela Watershed, Molokai, Hawaii

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Abstract

Spatial variability of rainfall is typically high and existing raingages usually are sparsely distributed on a watershed scale, which can lead to substantial over- and underestimation of total basin rainfall. Precipitation estimated from reflectivity measured by the NEXRAD radar promises spatially and temporally comprehensive coverage. Thus, hourly and daily radar rainfall was compared to raingage rainfall as potential input for a rainfall-runoff model in the Kawela watershed, Molokai, Hawaii. Rainfall rates from radar and raingages are log-normally distributed and correlate, although the relationship exhibits large scatter, especially at rainfall rates below 5 mm/day. Although radar rainfall is promising for the use in rainfall-runoff modeling, it is best to use radar rainfall to supplement areas without raingages or times without record as an addition to raingage data.

Introduction

Watershed-scale studies in Hawaii frequently require the integration of multiple aspects of basin-hydrology data including groundwater recharge, pollutant transport, sediment discharge, streambed erosion, and streamflow. Additionally the effects of rainfall variation or land-cover changes on any of these aspects may need to be assessed. As described by Field et al. (2007) for the Hanalei watershed, Kauai, multi-disciplinary analysis of terrestrial and marine ecosystems provides a broader understanding of the processes within a watershed. Multi-disciplinary analysis is particularly useful for watershed managers facing multiple concerns of improving coastal water quality, maintaining sustainable water supply, and restoring ecological integrity.

The primary factors controlling hydrologic processes in Hawaii watersheds are the temporal and spatial distribution of rainfall and runoff/infiltration characteristics. Existing watershed modeling studies in Hawaii include those on the Manoa-Palolo Stream, Oahu by Sahoo et al. (2006) and by El-Kadi and Yamashita (2007), on the Makaha Valley, Oahu (Mair et al. 2007), and on the Hanalei watershed, Kauai (Polyakov et al. 2007). Steep/mountainous terrain generates substantial and powerful runoff and streamflow is highly variable, often producing high peak flows in streams that have low base flows otherwise (Oki 2004). Rainfall in Hawaii is characterized by steep spatial gradients (Giambelluca et al. 2011). Existing networks of raingages are usually too sparse to reflect the full spatial variability of basin-scale areas. In this type of topography, time-series rainfall maps are generally more useful in identifying rainfall patterns than interpolation between the few existing raingages.

The National Weather Service's Weather Surveillance Radar-1988 Doppler Next Generation Weather Radar (NEXRAD) provides radar-inferred precipitation images (Smith and Krajewski 2002). Studies (e.g., Xie et al. 2006, Wang et al. 2008) have correlated these NEXRAD images with raingage data. The rainfall maps were made available in the form of

Geographic Information System-coverages (Gorokhovich and Villarini 2005, Xie et al. 2005). Such maps have been used as input for rainfall-runoff modeling in flat terrain (Peters and Easton 1997), complex mountainous terrain (Yates et al. 2000), and urban watersheds (Smith et al. 2007). Kalinga and Gan (2006) show that simulations with NEXRAD data accurately predict runoff hydrographs for convective storms but are less accurate for stratified storms. NEXRAD III images for Hawaii are available with a spatial resolution of ~1 km every 6 minutes from 2001 to the present day. However, the applicability of these images for Hawaii for use in hydrologic modeling has yet to be tested.

The Kawela watershed, a medium-size watershed on Molokai covering an area of 13.7 km^2, may provide a valuable and valid testing location. Average annual rainfall across the Kawela watershed is ca. 1,500 mm. Annual rainfall changes gradually from 3,300 mm at the top of the ridge to 330 mm at the coast (Giambelluca et al. 2011). Rainfall maps can be used to generate a rainfall-runoff model for the Kawela watershed to evaluate the accuracy of such a model for various climate and land-cover scenarios. The geographic/geologic/topographic patterns of the Kawela watershed are similar to those of many leeward Koolau watersheds on Oahu and similar areas on other Hawaiian islands. Therefore, a successful demonstration of this form of hydrologic modeling for the Kawela watershed would indicate applicability of this approach to other watersheds.

Problem and Research Objectives

The objective of this study is to compile available radar-rainfall and raingage data for Molokai, Hawaii, compare radar-inferred rainfall with observed rainfall from raingages, and provide radar- and gage-rainfall as input to a rainfall-runoff model for the Kawela watershed, Molokai. The rainfall-runoff modeling part is dropped from the scope in agreement with the U.S Geological Survey, because it is developed in a subsequent study by the U.S Geological Survey to evaluate the accuracy of such a model for various climate and land-cover scenarios on streamflow and groundwater recharge.

Methodology

The project was addressed in three phases: 1) compile available radar-rainfall and raingage data for Molokai, 2) compare radar-inferred rainfall with observed rainfall from raingages, and 3) provide radar- and gage-rainfall as input to a rainfall-runoff model for the Kawela watershed, Molokai.

1a) Data compilation of radar rainfall—The PHMO NEXRAD station on Molokai is located on top of West Molokai Mountain at an elevation of 415 m above sea level (Figure 1).

Radar rainfall is a function of radar reflectivity and rainfall rate. 1-hr accumulated precipitation (N1P) images for the period 5/5/2001–4/25/2010 were downloaded at http://www.ncdc.noaa.gov/nexradinv/chooseday.jsp?id=phmo. While the radar provides an image of 1-hr rainfall totals for every 5 to 6 min in irregular intervals, only the files at the full hour ±3 min were considered. The binary radar image files were clipped to the geographic extend Molokai and converted to ESRI ASCII raster files with a rectangular grid-cell size of 70 m using the National Oceanic and Atmospheric Administration's (NOAA) Weather and Climate Toolkit, version 2.4.2 (upgraded version available at http://www.ncdc.noaa.gov/oa/wct/index.php). The pixel (rainfall) values of the grid cell's centroid closest to each raingage were extracted as 1-hr time series for the comparison with the gages. The 1-hr time series were also transferred as a cumulative function to daily rainfall values.

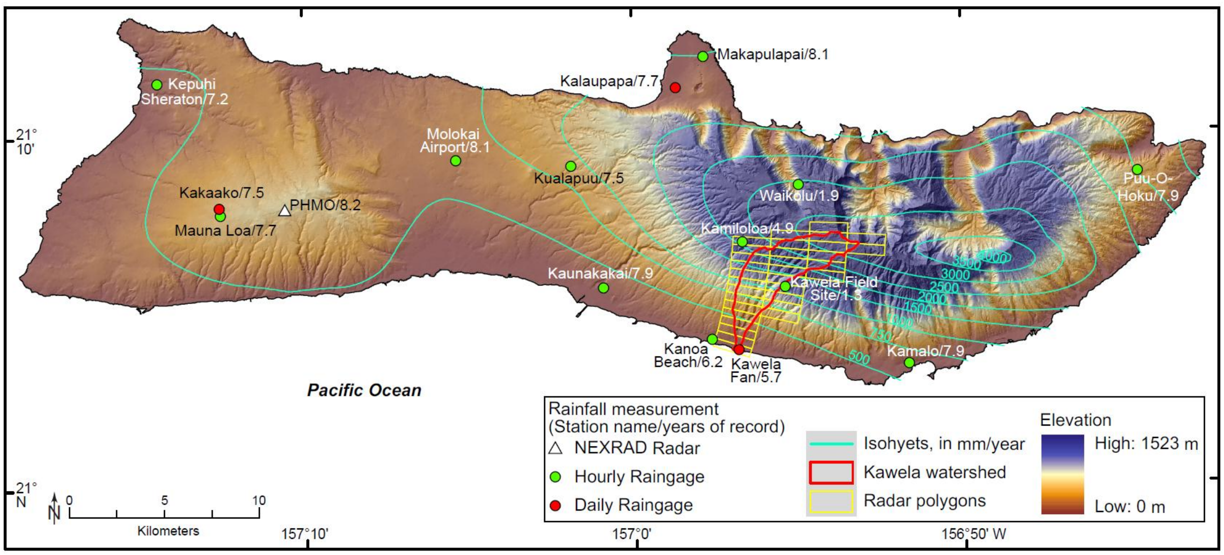

Figure 1. Map of elevation, isohyets (Giambelluca et al. 2011), location of radar and raingages, sampling interval, length of record available, and radar polygons intersecting Kawela watershed, Molokai, Hawaii.

1b) Data compilation of raingages—For the period of existing radar data, 15 raingages on Molokai have precipitation records available. Of these raingages, 12 have hourly or smaller temporal sample intervals (Figure 1). Data from Kamiloloa and Makapulapai were downloaded through the RAWS network of the Western Regional Climate Center, available at http://www.raws.dri.edu/wraws/hiF.html. Rainfall data at Molokai Airport was available from the NOAA National Climatic Data Center at http://cdo.ncdc.noaa.gov/qclcd/QCLCD?prior=N. Data from Kaunakakai and Kamalo were downloaded through the NOAA Hydronet, available at http://www.prh.noaa.gov/hnl/hydro/hydronet/hydronet-data.php. Precipitation data at Puu-O-Hoku, Kualapuu, Kepuhi Sheraton, Mauna Loa, and Kalaupapa are available at the NOAA National Climatic Data Center http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnsNear~20023492~25. Rainfall data at Kakaako and Waikolu was collected by the USGS, available at http://waterdata.usgs.gov/nwis/. Rainfall data from the

Kawela Field Site was provided by Jonathan Stock, precipitation at the Kanoa Beach was collected by Dough Macmillan, and rainfall at Kawela Fan was recorded by Bill Feeter. Rainfall time series sampled at shorter intervals than 1 hour were aggregated as a cumulative function to 1-hr rainfall values and time series sampled at shorter intervals than 1 day were aggregated to daily rainfall values.

2) Radar-gage comparison— Distribution of rainfall data is tested for normal and log-normal distribution by plotting the data on a probability scale. The raingage rainfall was compared to the radar-inferred rainfall for hourly and daily records for every non-zero data pair to identify applicability of radar rainfall for Molokai.

3) Gage- and radar-rainfall time series for Kawela—Data files containing the hourly and daily rainfall rate at each raingage were provided to the U.S Geological Survey. The Kawela watershed intersects 33 radar polygons of ca. 2 x 0.5 km containing the averaged radar rainfall over that area (Figure 1). The coordinates and the pixel (rainfall) values at the radar-rainfall polygon's centroid intersecting the Kawela watershed are exported to hourly and daily radar-rainfall time series and provided to the U.S Geological Survey. A subsequent study by the U.S Geological Survey will utilize both rainfall products as input to a rainfall-runoff model for the Kawela watershed, Molokai.

Results

Plotting hourly and daily rainfall rates from radar and raingages on a probability scale indicates that both data sets are log-normally distributed (Figure 2). Thus, the comparison of radar rainfall and raingage rainfall data is performed through logarithmic transformation.

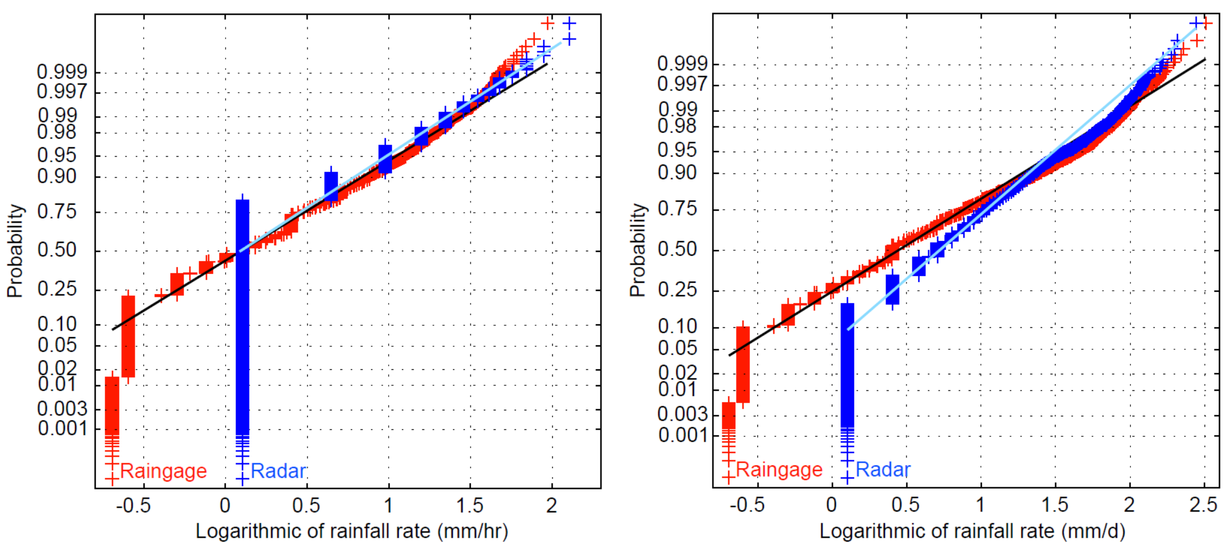

Figure 2. Normal probability plot of hourly and daily radar- and raingage rainfall 5/2001–4/2010 for Molokai.

Large scatter characterizes the relationship between radar-and gage-precipitation rates with better agreement at larger rainfall rates (Figure 3). Reasons for the disparity include the size of radar polygons, the binning of radar-inferred precipitation, and uncertainty in radar- and raingage rainfall. The radar polygons represent averaged rainfall over ca. 1 km^2, which might be too large to capture spatial differences. Further, the 1-hr radar-inferred rainfall is binned in 16 data levels with variable increments (0/2.5/6.4/12.7/19.1/25.4/32/38/45/51/64/75/100/150/200 mm), which might be too coarse to capture differences in rainfall. This is substantial at the light-rain level, indicated by the larger scatter below 5 mm of raingage rainfall (Figure 3).

Uncertainty in the estimated rainfall from the radar reflectivity is supplemented by uncertainty in the measured value at the raingage. Tipping buckets may miss heavy-rain events simply because the possible tip frequency is too low and water flushes through the gage without being quantified. Additional uncertainty stems from reporting errors; not all agencies collecting data impose the same quality assurance/quality control procedure on the rainfall measurements. Finally, the main purpose of radar rainfall is its use for flash-flood forecasting and it is not designed as a replacement of physical rainfall measurements in gages.

Correlation coefficients of the log-transformed values are 0.56 and 0.59 for the hourly and daily rainfall, respectively. Overall, the fit between radar rainfall and raingages is reasonable with higher confidence at larger rainfall rates. Although radar rainfall is promising for the use in rainfall-runoff modeling, it is best to use radar rainfall to supplement areas without raingages or times without record as an addition to raingage data.

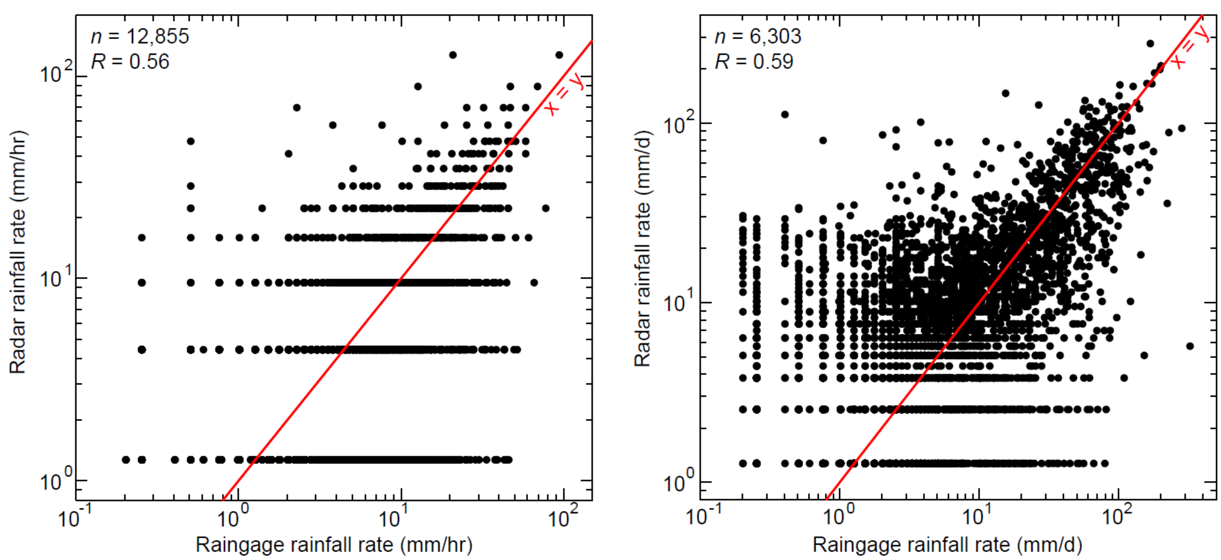

Figure 3. Comparison of hourly and daily radar- and raingage rainfall 5/2001–4/2010 for Molokai, *n* denotes the number of non-zero data pairs and *R* the correlation coefficient.

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