Flash Floods in Hawaii

- The Flash Flood Problem
- Flood Ingredients
  - Weather Patterns
  - Terrain effects
  - Soil moisture
- Past Events
- Detection and Forecasting Tools
- NWS Advisories

The Flash Flood Problem in Hawaii

- 322 events in 40-year period
- 8.3 per year
- Causes most of the direct wx-related fatalities
- November is the worst month for storms (1-2 flash floods)
- June has the best weather
Factors that Contribute to Flood Challenge

1. **Small watersheds:** Steep slopes and shallow soils make the time between peak rain and peak discharge small, as little as 15 minutes. Half of the State is within 5 miles of the shore, therefore lead time for a response time is very short.

2. **Terrain influences:** The typical Hawaiian flood occurs when a convective cloud becomes anchored to mountains.

3. **Precipitation processes:** Clouds may be deep cumulonimbus or "shallow" warm rain clouds. Scale of convective clouds is relatively small.

**Ingredients for Heavy Rain**

- **Moisture – lots of water vapor**
  - Large amounts of low level moisture results in unstable air and more rainfall
  - Large amounts of mid-level moisture helps preserve parcel buoyancy

- **Large upward motion**
  - Low level convergence & upper level divergence needed for heavy rainfall.

- **Slow storm motion (i.e. long duration)**
  - Increases total rainfall over basin

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**Rainfall vs Water Vapor**

**Hurricanes Possess Lots of Water Vapor**

- Blue line – Water vapor in column
- Red line – Sea level pressure

**Hurricane Georges, September 1998**

Enhanced IR image during peak rainfall period of the Nov. 2000 Big Island flood event.
Four Heavy Rain Patterns:
Provide Moisture and Upward Motion

1. Cold front passage
2. Kona low
   • Slow moving
   • Ample upward motion
   • Advects moisture from deep tropics
3. Upper-level low or trough
   • over tropical system or its remnants is very dangerous.
     e.g., Nov 2000 Flood
4. Tropical Cyclone
   • tropical storm
   • hurricane

Kona Lows
Cause more flash floods in Hawaii than any other storm system

Mesoscale or Island Scale Features

- Terrain forcing
  • Ideal lifting mechanism for prolonged heavy rains
  • Rain maxima often over slopes exposed to low level flow
- Lee-side convergence zones (a.k.a. “plumes”)
  • Enhanced low level convergence.
  • Southeasterly or southerly flow can cause “plume” to drift over downstream islands

Kona Low
A non-frontal subtropical cyclone that initially forms aloft.
Hana Flood

Big Island Plume and Terrain Anchoring

Rainfall Distribution: New Year’s Storm

24-hour rainfall in inches. Distribution determined by the terrain.

Contours for a 100-yr rainfall event with overlay of 20” rainfall contour.

Contributing Factors

- Soil moisture content from previous rains
- Previous Rainfall: Rate, duration, pattern
- Soil type, depth and stratification: determines infiltration rate & flow type

Paauau Stream overtopping Belt Highway at Pahala during Nov. 2000 Big Island flood event.
Contributing Factors

- Land use affects basin response
  - Agriculture
  - Natural forest
  - Urbanized
- Basin slope & size
  - Small, steep: < 1 hr response time
- Channel condition
  - Debris dams?

Geographic Aspects: Development of flash floods occurs in valleys and on unstable hillsides. Islands with narrow coastal transportation corridors can have large sections isolated by debris flows. This occurred on Oahu on New Year's Eve, 1987 when all transport to East Oahu was severed.

Notable Events

- November 2000
  - SE and E Big Island
  - $70 Mil.
  - 37 inches/24-hrs (22 in./6-hr)
- Dec 1991 Anahola Flood
  - East Kauai
  - $5 Mil. & 4 fatalities
- Dec 1987/Jan 1988 “New Years Flood”
  - East Oahu
  - 22 inches/24-hrs
  - $34 Mil.
- Nov 1996 “Election Day Storm”
  - S. & Cen. Oahu
  - 14 inches/12-hrs
  - $13 Mil.

Hilo Flood 1-2 November 2000

24-hour rainfall (solid) and 100-year flood rainfall (dashed).
Hilo Flood 1-2 November

24-hr rainfall (solid) and 100-yr flood rainfall (dashed).

Figure 1 Hourly rainfall rate (inches per hour) for Hilo for the period 1 to 2 November 2000.

Upper Level Divergence of Winds

Analysis for 1200 UTC 25 January 1996 of 250 mb streamlines and isotachs (every 5 m/s).
Low Level Convergence of Winds


January 1996 Flood Case

Display of radar reflectivity (dBZ) of storms located over O'ahu at 1258 UTC 25 January 1996. (a) PPI and (b) RHI located along black line in a). White numbers in a) denote locations of LARC rain gages.

Storm Total Rainfall


Oahu New Year’s Eve Flood

Contours for a 100-yr rainfall event with overlay of 20” rainfall contour from the New Year’s Eve Storm.

Detection & Forecasting Tools

- Balloon and Aircraft Soundings
- Satellite Imagery and products
- Radar Imagery and products
- Rain gage data
- Stream gage data
- Numerical models
- Spotters
- Experience

Satellite Products

- Visible: Hi-res views of circulations and low level boundaries
- IR provides cloud top temperature
- WV: Useful for tracking upper-level motion
  - Jets, cyclonic circulations, short waves

Soundings

Balloon and Aircraft soundings provide information on moisture content and stability of air.

Satellite Products

A growing number of derived products
- GOES products
  - Total Water Vapor
  - Stability
  - Winds
  - Low tracking
- Polar orbiter products
  - Water vapor
  - Rate rate
  - Surface winds

Water vapor image just prior to onset of Nov. 2000 Big Island flood event

Lihue sounding just prior to heavy rains from Dec. 1991 Anahola flood event

Manoa Valley flood Halloween 2004

850 mb low tracking product
Additional Forecast Tools

- Radar data
  - Short term forecast tool
  - Look for signs of heavy rain initiation
    - Pre-existing lines of showers or outflow boundaries can intensify over mountainous terrain

- Surface data
  - Watch for changes in wind speed/direction, dew point, and 24-hr pressure trend

- Experience
  - Years of looking at numerical and observational data improves skill in most cases

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Flash Flood Detection – Rain Gages

- Automated system provides alarm for intense rain.
- “Ground truth” on actual rainfall…but
  - Wind bias
  - Intense rainfall low bias
  - Spatial coverage limitations
- Provides some lead time
- 2 to 4 inches per hour significant

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Anahola Flood 13-14 December 1991

Hourly rainfall from gage at Anahola during the 1991 Anahola flood.

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Doppler Radar

Doppler radar measures rainfall rates, wind speeds.
Radar Data & Derived Products

- Provides good spatial and temporal resolution
  - 1 deg x 1 km
  - Update every 5 to 6 minutes
- Excellent for cell motion
- Cells with reflectivity cores >= 50 dBZ bear close monitoring
  - Slow moving?
  - Terrain anchored?
- Cross-sections for vertical structure
- Rainfall estimates
  - 1-hr, Storm total, User defined
- Vert. Integrated Liquid (VIL)
  - >=25 kg/m² significant

**Storm total rainfall from Molokai WSR-88D covering December 1999 flood event.**

Basin Areal-Mean Estimated Rainfall

- Derived from reflectivity data
- Radar “bins” assigned to stream basins
  - Basins delineated using digital elevation model data
- Reflectivity converted to rain intensity
- Intensity values for each volume scan averaged over all bins in basin
- Basin accumulations determined
- Basin rainfall data compared to stream data to determine flash flood threshold rainfall

**3-hr basin accumulation from January 1996 flood event.**

Stream Gages

- Real-time capability on growing number of sites
- 1- to 4-hour routine transmission interval
- Emergency broadcast capability available if flood threshold known
- Excellent “ground truth” of flood conditions
- Limited lead time for operations
- Data used for rainfall threshold calibration (AMBER)

**USGS stream gage at Kahana Stream.**

Other Tools

- **Spotters**
  - “Eyes and ears” of NWS in the field
  - Trained volunteers
  - Law enforcement and emergency management officials
- **Experience**
  - Years of working flood events improves skill in most cases
Weather Modeling
1. Input all available observations.
2. Interpolate data to points on an even grid.
3. Apply laws of physics, including parameterization of surface and cloud processes too small for the model to directly include - integrate equations forward in time.
4. Output resulting forecast as contoured maps for interpretation.

Challenges in modeling heavy precipitation in Hawaii
1. Convective clouds are relatively small.
2. Terrain impacts occur on small scale.
3. Lack of data over the ocean.

Numerical Models
- **Global models**
  - Guidance up to 16 days
  - Identify weather patterns and ingredients favorable for heavy rains
  - Precipitation forecast is poor, but can be useful in qualitative sense
- **Regional models**
  - Guidance up to 3 days
  - Provides better details on spatial distribution
  - Rainfall forecasts are better than global models, but still relatively poor and used mainly in qualitative sense.

NWS Flash Flood Advisories
1. Flood Potential Outlook (36 hr in advance)
   - event is possible within 36 hr
2. Flood Watch (36 hr in advance)
   - event is likely within 36 hr
3. Flash Flood Warning (updated every 3 hr)
   - threat to life and property is imminent or occurring

Questions?