Regional Flash Flood Guidance

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Flash Floods

WORLD METEOROLOGICAL ORGANIZATION (WMO):
“ A flood of short duration with a relatively high peak discharge ”

AMERICAN METEOROLOGICAL SOCIETY (AMS):
“ A flood that rises and falls quite rapidly with little or no advance warning, usually as the result of intense rainfall over a relatively small area ”

A local hydrometeorological phenomenon that requires:
1. BOTH Hydrological and Meteorological expertise for real time forecasting/warning
2. Knowledge of local up to the hour information for effective warning (24 - 7 operation)

For this effort: response time is 6 hours or less
Large River Flooding vs. Flash Flooding

**LRV**
- Catchment response affords long lead times
- Entire hydrographs can be produced with low uncertainty with good quality data
- Local information less valuable
- A hydrologic forecasting problem primarily
- Affords time for coordination of flood response and damage mitigation

**FF**
- Catchment response is very fast and allows very short lead times (<12hrs)
- Prediction of occurrence is of interest
- Local information is very valuable
- A truly hydro-meteorological forecasting problem
- Coordination of forecasting and response is challenging over short times
The Need

**Flash Floods** are very significant disasters globally …

- Highest number of deaths per people affected

… **BUT** there are no discernible trends for loss reduction

- No flash flood warnings for vast populated areas of the world
- Lack of local expertise and of regional cooperation
- Little in situ data in small regions
- Large-river flood-warning strategies ineffective for flash floods
The Regional Vision

Implement regional flash flood warning systems with high resolution that allow local forecaster timely updates in order to improve response by governments, international organizations, NGOs, the private sector, and the public to occurrences of flash floods worldwide.
National Perspective

System with national and regional components

National Level: Real-time national retrieval and operations maintenance
Powerful computing environment
Meteorological and Hydrological expertise
Communications

Regional Level: Meteorological and Hydrological expertise
Communications
Local information and processing
Forecasting and warning
Link to response agencies
Flash Flood Guidance (FFG): The amount of rainfall of a given duration required to generate bankfull flows at the outlet of a basin.
<table>
<thead>
<tr>
<th><strong>DHM</strong></th>
<th><strong>FFG</strong></th>
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<tr>
<td>- Tool for short and long term forecasting of floods</td>
<td>- Diagnostic tool useful for quick flash flood occurrence diagnosis and short term prediction</td>
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<tr>
<td>- Produces entire hydrographs (w/ high uncertainty on small scales)</td>
<td>- Concerns bankfull flows</td>
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<tr>
<td>- Difficult to ingest local precipitation information after model cycle</td>
<td>- Readily ingests local precipitation information</td>
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<tr>
<td>- Awkward for local forecasters to make adjustments, needed for reliable flash flood warning</td>
<td>- Local forecaster adjustments easy</td>
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<tr>
<td>- Expensive to run in real time for very large areas with high resolution</td>
<td>- Promotes Close Collaboration of Hydrologists with Meteorologists</td>
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Attributes of FFG

- Diagnostic tool useful for quick flash flood occurrence potential diagnosis in real time to alert local forecasters of an impending danger

- Concerns bankfull flows

- Readily ingests local precipitation information

- Local forecaster adjustments easy

- Promotes Close Collaboration of Hydrologists with Meteorologists
From National Data to Regional Hydrometeorology to Local Data and Warnings

Computational Core

National/Regional Observations & ATM Model Forecasts

Computational Component

Local Products & Uncertainty

Local Data

Local or Regional Warning Generation System

Local or Regional Warning Dissemination System

Response Agencies

1. Decisions are made with multiple datasets and under uncertainty.
2. There is a need to modify the products of the national system regionally and have capability for estimating consequences to local variables of interest.
Regional Component for Warnings

National Dissemination System

National Network

Regional Network

Regional/Local Data

Database

GIS Analysis Tools

Forecaster

Regional Dissemination System / Response
Dealing with Forecast Uncertainty is Important

Forecasts are inherently uncertain.

Decisions to issue warnings and take response measures are made under uncertainty.

Hydrometeorological forecasts for smaller regions based on national data carry considerable uncertainty.

Uncertainty comes in a variety of forms, from biases to a variety of distributions of forecast residuals, and it is time dependent. So it must be considered by the system in a non-trivial quantitative manner.
Research and Development History

- **1970-1988**: US NWS Produces FFG statistically for each River Forecast Center. Also, research in adaptive site specific FF prediction systems.
- **1988-1993**: IIHR/HRC develop physically consistent FFG formulations based on GIS and create the first operational codes for US NWS
- **1993-2005**: HRC continues research in various aspects of the FFG process and system (sparsely gauged basins and uncertainty issues, forcing and models). The development of prototype regional systems using FFG are proposed and accepted in work plan of WMO CHy Working Group on Applications (2002-2003)
- **2004**: The Central America Flash Flood Guidance System becomes operational (serves 7 countries in CA)
- **2006**: Additional systems are under development or considered for deployment in Korea, Romania and Southeast Asia

Key In-depth References (out of a total of 41 reports and papers):

Regional Warning System

CAFFG
Central America Flash Flood Guidance

Real-Time Data Sources

GOES Satellite
NOAA / WMO
DAPS/DCS

HRC
IMN, CR
ACP, PA

Hypothetical FTP/SCP Internet Routes
DCP, WMO, ALERT Station Locations
GOES Satellite Imagery Transmission
DCP Satellite Transmissions

SAFFG - 11 June 2007
Central America Flash Flood Guidance

CAFFG Program Flow Chart

- Coop Observer Rainfall (Daily/Weekly)
- Satellite Rainfall (Real Time – Hourly)
- ALERT Rainfall (Real Time – Hourly)
- Rainfall Data Quality Control & Merging (Real Time – Hourly)
- Daily Potential ET Processor (Daily)
- Air Temperature (Daily)
- Potential ET (Monthly Climate)
- Soil Moisture Model (Daily/Weekly)
- TERRAIN STREAMS LULC SOILS (Spatial Data)
- Threshold Runoff Model (Off-Line Computation)

Flash Flood Guidance Model (Hourly)

Flash Flood Guidance
Satellite Rainfall - Hydroestimator

- IR based
- Short latency
- CR Regional node
Satellite Rainfall Adjustment and Merging

- Vastly different scales of satellite pixel and rain gauge area
- Orography organizes surface rainfall according to prevailing winds
- Satellite IR returns do not directly measure rainfall
- There may be significant misregistration errors in satellite data

\[ R_{SAT} = \frac{1}{KL} \int_{0}^{L} \int_{0}^{K} f(x, y) \, dx \, dy \]

\[ R_G = f(x_o, y_o) \]

\( f(x,y) \): Rainfall volume field over a time interval \( T \)

\[ R_{SAT}, R_G \geq R_0; \quad g(R_{SAT}) = \alpha g(R_G) + B + \varepsilon \]

Transformation for Normality

Regional Bias

Random Error
Bias Adjustment Basics

Kalman Filter
Stochastic Approximations

- N pairs of consecutive values
- At least 20% raingauges with rain
- Conditional Mean > Threshold (mm/h) (satellite and gauge)

\[ \beta_t = \ell n \left( \sum_{j=1}^{N_g} R_g(t, j) \right) \]

\[ \beta_{t+1} = \beta_t + w_{t+1} \]

\[ z_{t+1} = \beta_{t+1} + v_{t+1} \]
Kalman Filter for Tracking the Errors

**Prediction:**
\[ \hat{\beta}_{t+1}^- = \hat{\beta}_t^+ \]
\[ P_{t+1}^- = P_t^+ + Q_{t+1} \]

**Updating:**
\[ \hat{\beta}_{t+1}^+ = \hat{\beta}_{t+1}^- + K_{t+1} \left( z_{t+1} - \hat{\beta}_{t+1}^- \right) \]
\[ P_{t+1}^+ = (1 - K_{t+1}) P_{t+1}^- \]
\[ K_{t+1} = P_{t+1}^- \left( P_{t+1}^- + R_{t+1} \right)^{-1} \]
Stochastic Approximations
Algorithm for Model Error Variance

Enforces compliance between predicted residual variance and theoretical residual variance

\[ \hat{Q}_{t+1} = \hat{Q}_t + \left( \frac{\partial P_{t+1}^-}{\partial Q} \right) \cdot S_t \cdot \left( \left( \frac{\partial P_{t+1}^-}{\partial Q} \right)^2 S_t + \sigma_{t+1}^2 \right) \]

\[ S_{t+1} = \left[ \left( \frac{\partial P_{t+1}^-}{\partial Q} \right)^2 + \frac{1}{S_t} \right]^{-1} \]

\[ \sigma_{t+1}^2 = 2 \left( P_{t+1}^- + R_{t+1} \right)^2 \]

Applied each time step
Bias Adjustment Algorithm

Application

- Once a day for the past 24 hrs
- Bias estimated from at least 25 pairs
- Gauges and satellite grids included if rainfall greater than 1 mm/h

Important issue:
Gauge data quality control

Initial Conditions

\[ \hat{Q}_1 = \frac{P_o^2}{P_o + R_o} \]

\[ S_1 = \left( 0.9 \hat{Q}_1 \right)^2 \]

\[ \frac{\partial P_1^-}{\partial Q} = 1 \]

Restarts due to gauge data errors
Synthetic Data Tests

Medium Observation Error

Large Observation Error
Costa Rica Data Tests

\( \langle \beta \rangle = 0.5 \)

\( \langle B \rangle = e^{0.5} = 1.65 \)

\[
\hat{B}_{t+1} = \exp \left\{ \hat{\beta}_{t+1} + 0.5 P_{t+1} \right\}
\]

\[
2x \sqrt{\sum_{t+1} \left( \hat{B}_{t+1} \right)^2 \left( \exp \{ P_{t+1} \} - 1 \right)}
\]
CAFFG Operational Results
Uncertainty Estimation
3-hr Flash Flood Guidance Probability Density Function

Dry Soils

Wet Soils

+ User input
CAFFG NMHS PRODUCTS
Central America Flash Flood Guidance System
6-Hourly Soil Moisture - Date: 15 May 2004 0000Z

6-HOUR SOIL SATURATION RATIO

- 0 - 0.33
- 0.33 - 0.5
- 0.5 - 0.64
- 0.64 - 0.77
- 0.77 - 0.88
- 0.88 - 1
Training and Cooperation

**Training:**

- System Technical Basis
- Maintenance
- Interpretation of Guidance Products

  Hands-on training of personnel who will operate the system
  Workshops for NMHS and Response Agency personnel

**Cooperation:**

- Assist NHMSs to develop protocol for issuing warnings based on flash flood guidance

- Assist NMHSs and Response Agencies to develop protocol for dissemination, receipt and interpretation of warning information to appropriate users within countries

- Assist NMHSs and Response Agencies to develop evaluation plans for system utility
CAFFG Initial Validation

System operators from Costa Rica and El Salvador were in daily communication with Country Agencies to receive community information regarding local flooding.

Flooding in the Panama Canal verified by local TV news. Flooding time at the airport was reported at approximately 9 p.m. local time.

3-Hourly FF Threat (*adjst*):
- **Hits**: 57% (63 – 100%)
- **False**: 30% (0 - 21%)
- **Misses**: 13% (0 - 16%)
Disaster Risk Reduction Component

**Objective:**
Ensure effective integration of the flash flood guidance information in disaster risk reduction

**Aim:**
Effective utilization of flash flood warnings for protection of lives, livelihoods and property.

**Means:**
- Strengthen cooperation among the technical and civil protection agencies
- Develop joint training programs
- Develop validation programs and information
- Assist in developing public outreach and awareness programs (regional to local)
CAFFG Funding Agencies

U. S. Agency for International Development (USAID)
- Office of U. S. Foreign Disaster Assistance (OFDA)

U. S. National Oceanic and Atmospheric Administration (NOAA)
- Office of Hydrologic Development/ National Weather Service
- International Activities Office/ National Weather Service
- Climate Program Office
Thank You