Regional Flash Flood Guidance

Konstantine Georgakakos, Director

Theresa Carpenter, Hydrologic Engineer

Jason Sperfslage, Software Engineer

Hydrologic Research Center

www.hrc-lab.org

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 w/ 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

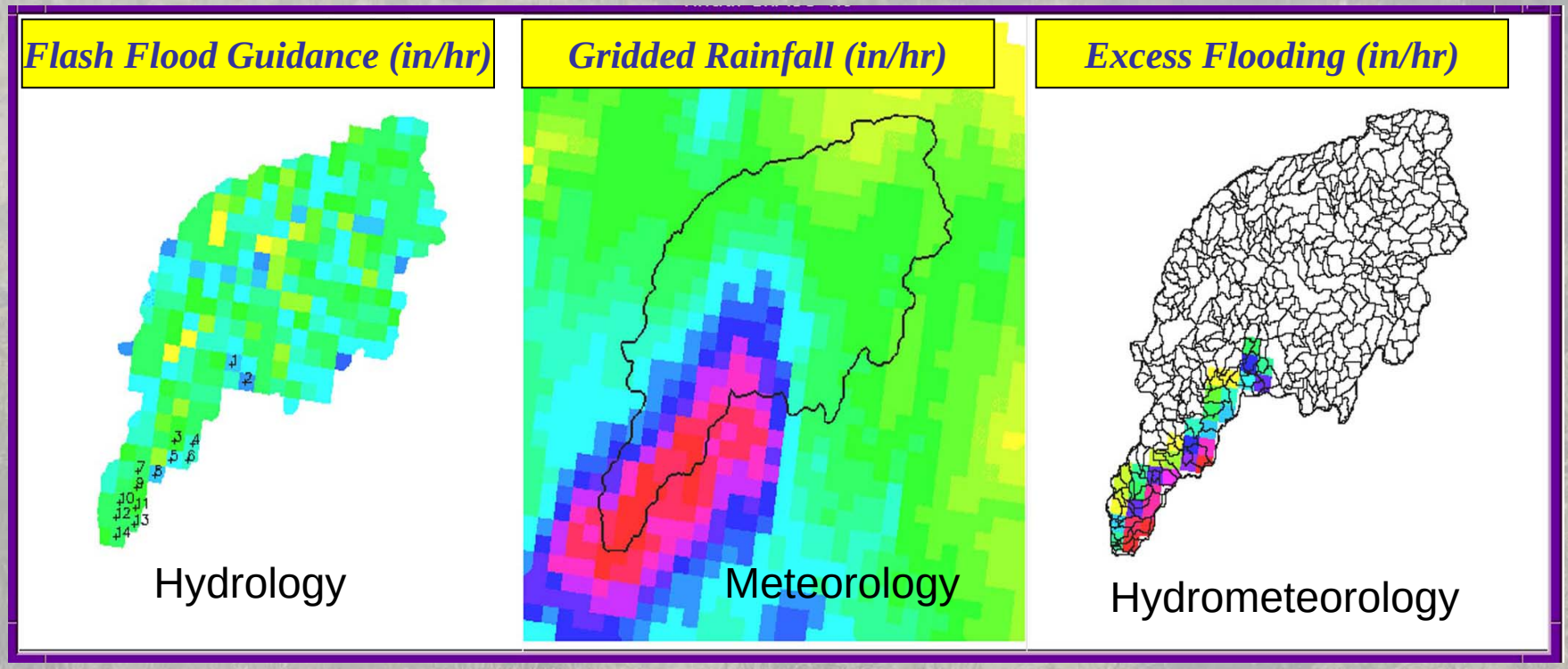
National Perspective

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



Flash Flood Guidance (FFG): The amount of rainfall of a given duration required to generate bankfull flows at the outlet of a basin.

DHM vs. FFG

DHM

- *Tool for short and long term forecasting of floods*
- *Produces entire hydrographs (w/ high uncertainty on small scales)*
- *Difficult to ingest local precipitation information after model cycle*
- *Awkward for local forecasters to make adjustments, needed for reliable flash flood warning*
- *Expensive to run in real time for very large areas with high resolution*

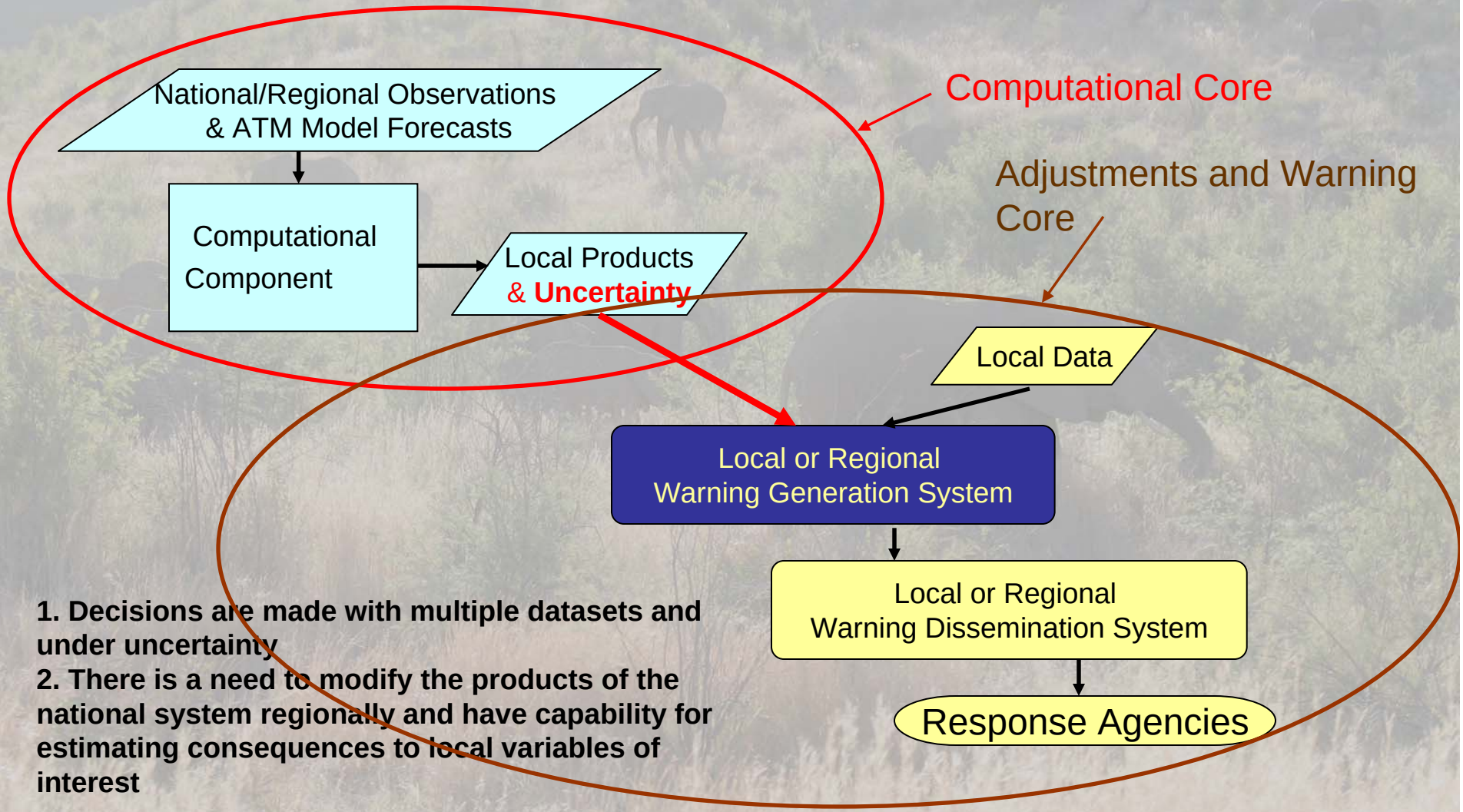
FFG

- *Diagnostic tool useful for quick flash flood occurrence diagnosis and short term prediction*
- *Concerns bankfull flows*
- *Readily ingests local precipitation information*
- *Local forecaster adjustments easy*
- *Promotes Close Collaboration of Hydrologists with Meteorologists*

Attributes of FFG

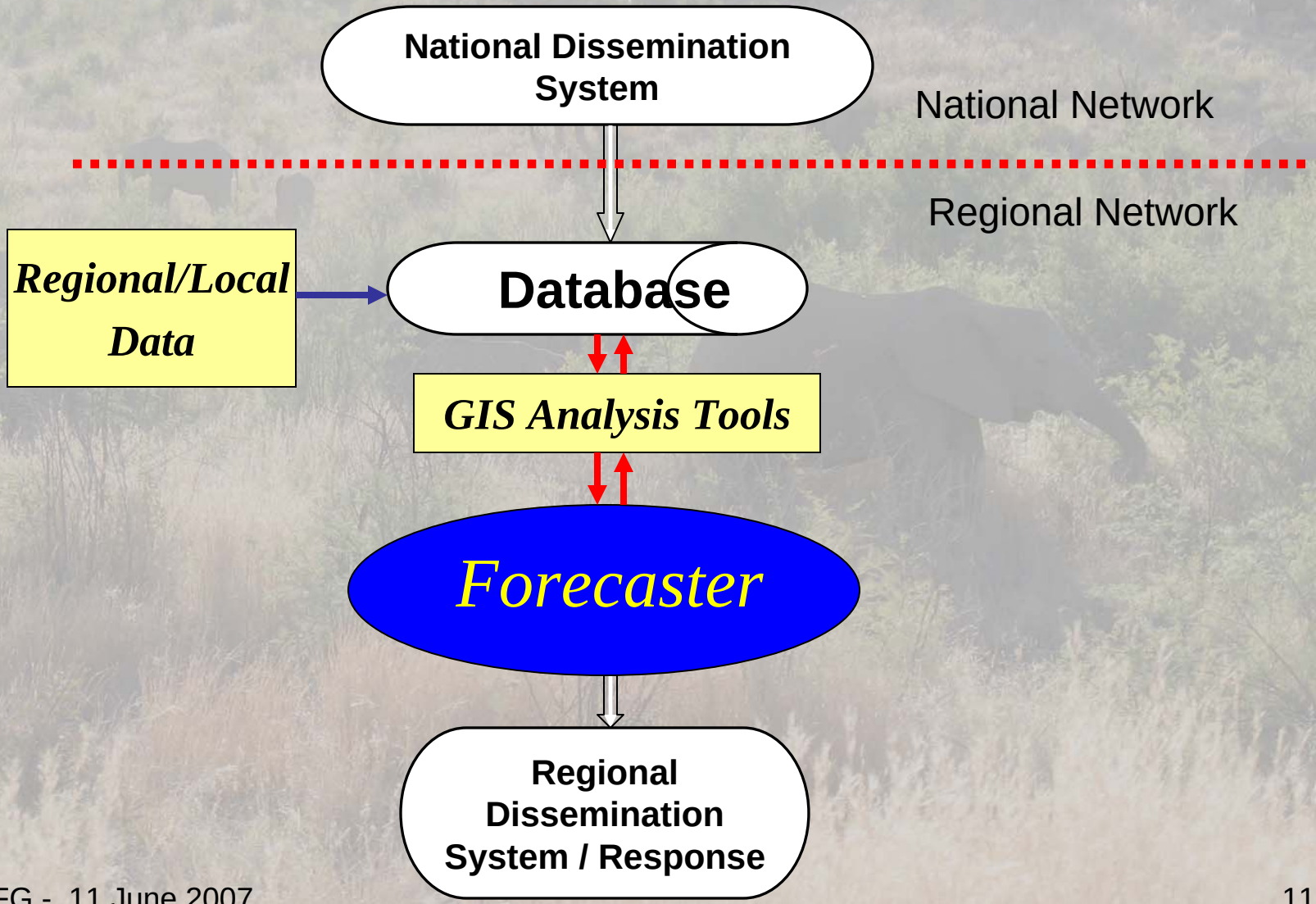
- ***Diagnostic tool useful for quick flash flood occurrence potential diagnosis in real time to alert local forecasters of an impending danger***
- ***Concerns bankfull flows***
- ***Readily ingests local precipitation information***
- ***Local forecaster adjustments easy***
- ***Promotes Close Collaboration of Hydrologists with Meteorologists***

From National Data to Regional Hydrometeorology to Local Data and Warnings



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



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.

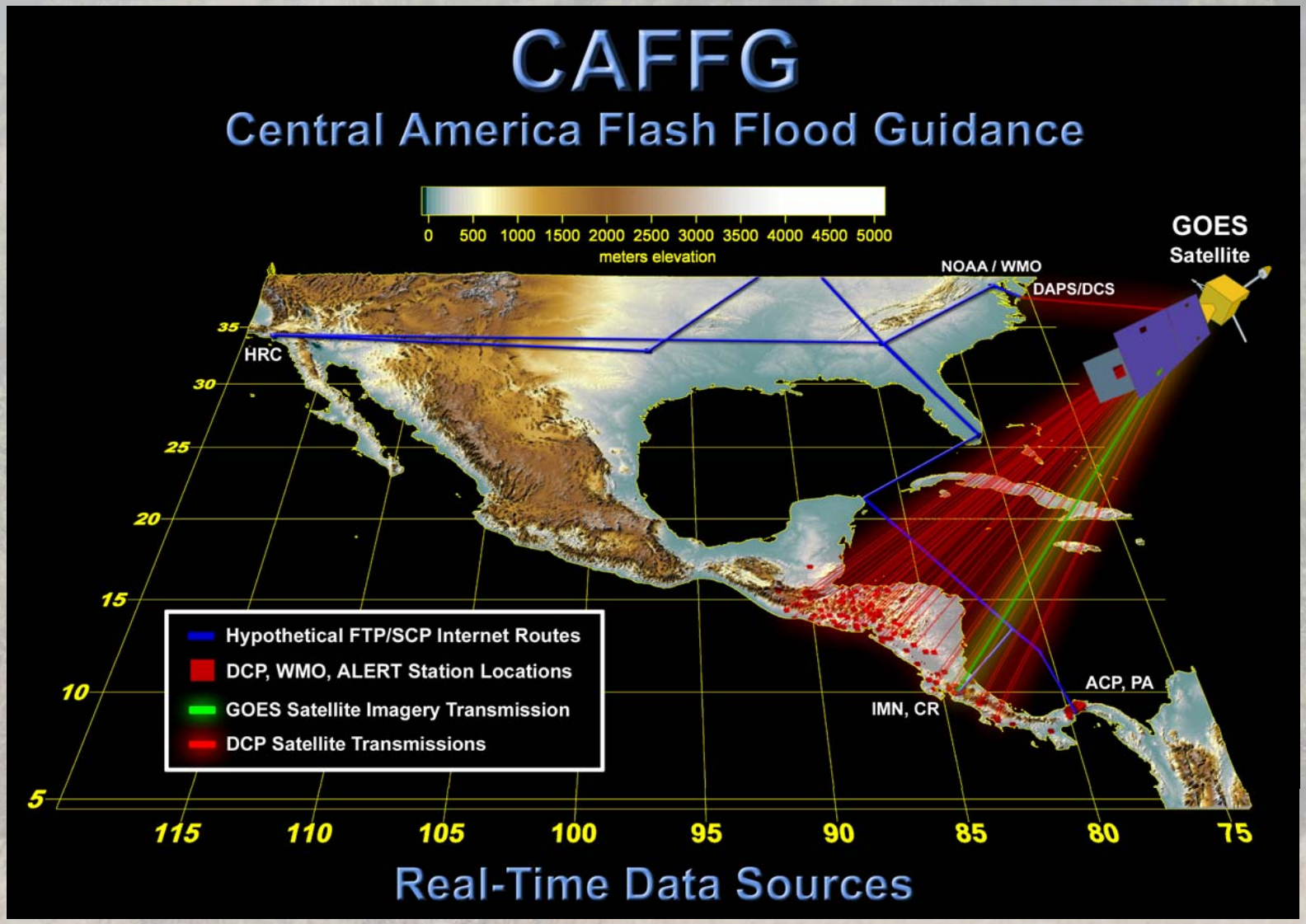
Research and Development History

- **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

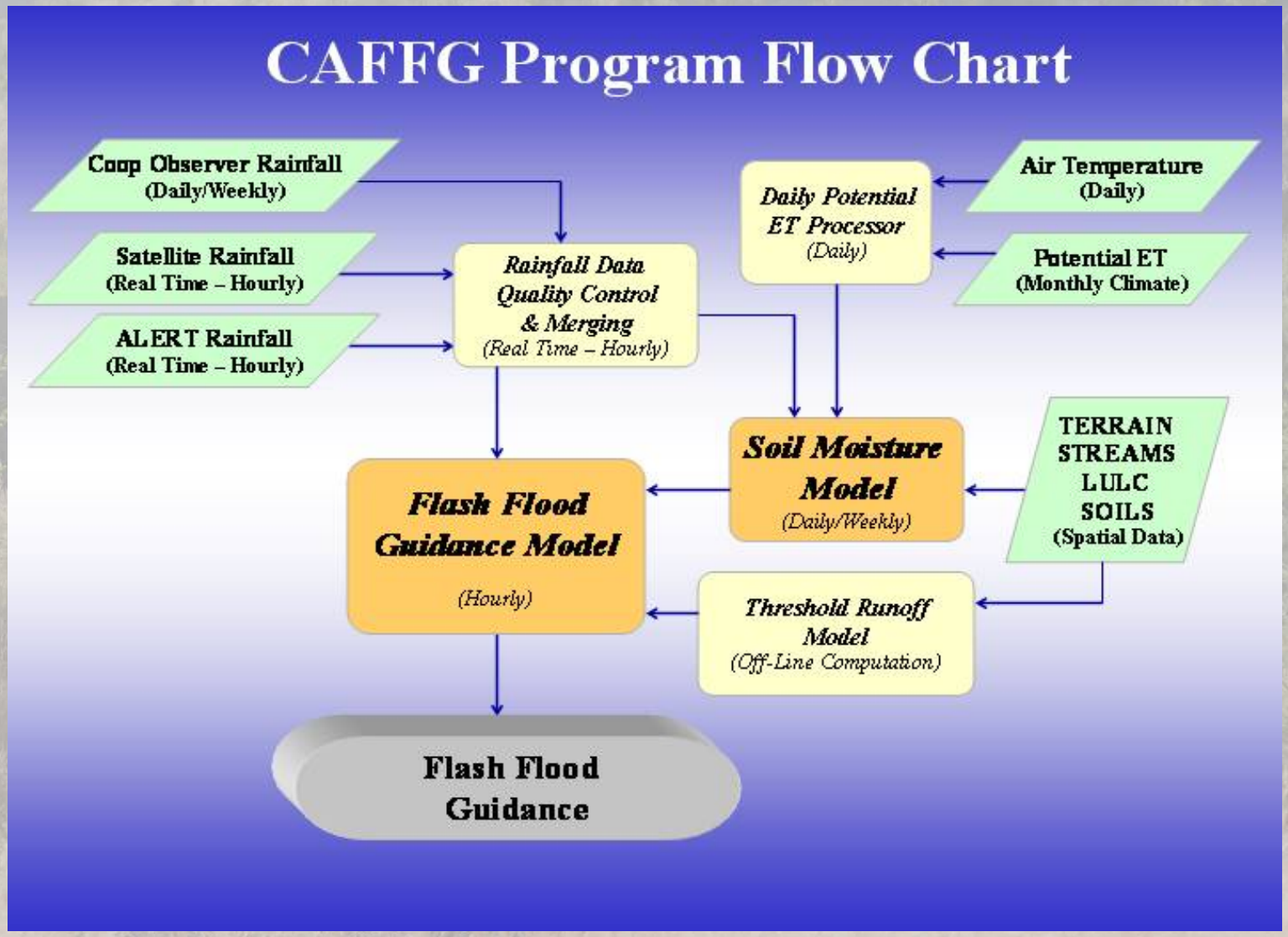
Key In-depth **References** (out of a total of 41 reports and papers):

Carpenter, T.M., et al. (1999) *Journal of Hydrology* **224**, 21-44. – Threshold Runoff
Georgakakos, K.P. (2005) *Journal of Hydrology* **317**, 81-103. – Soil Moisture/FFG
Ntelekos, A.A., et al. (2006), *J. Hydrometeorology*, **7**(5), 896-915. – Uncertainty in FFG
Georgakakos, K.P. (2005/2007) *ACTIF Norway 05 Conf. Proc. & Journal of Hydrometeorology (in review)*
Sperfslage, J.A., et al. (2004) *HRC Limited Distribution Report* – Operational System Implementation

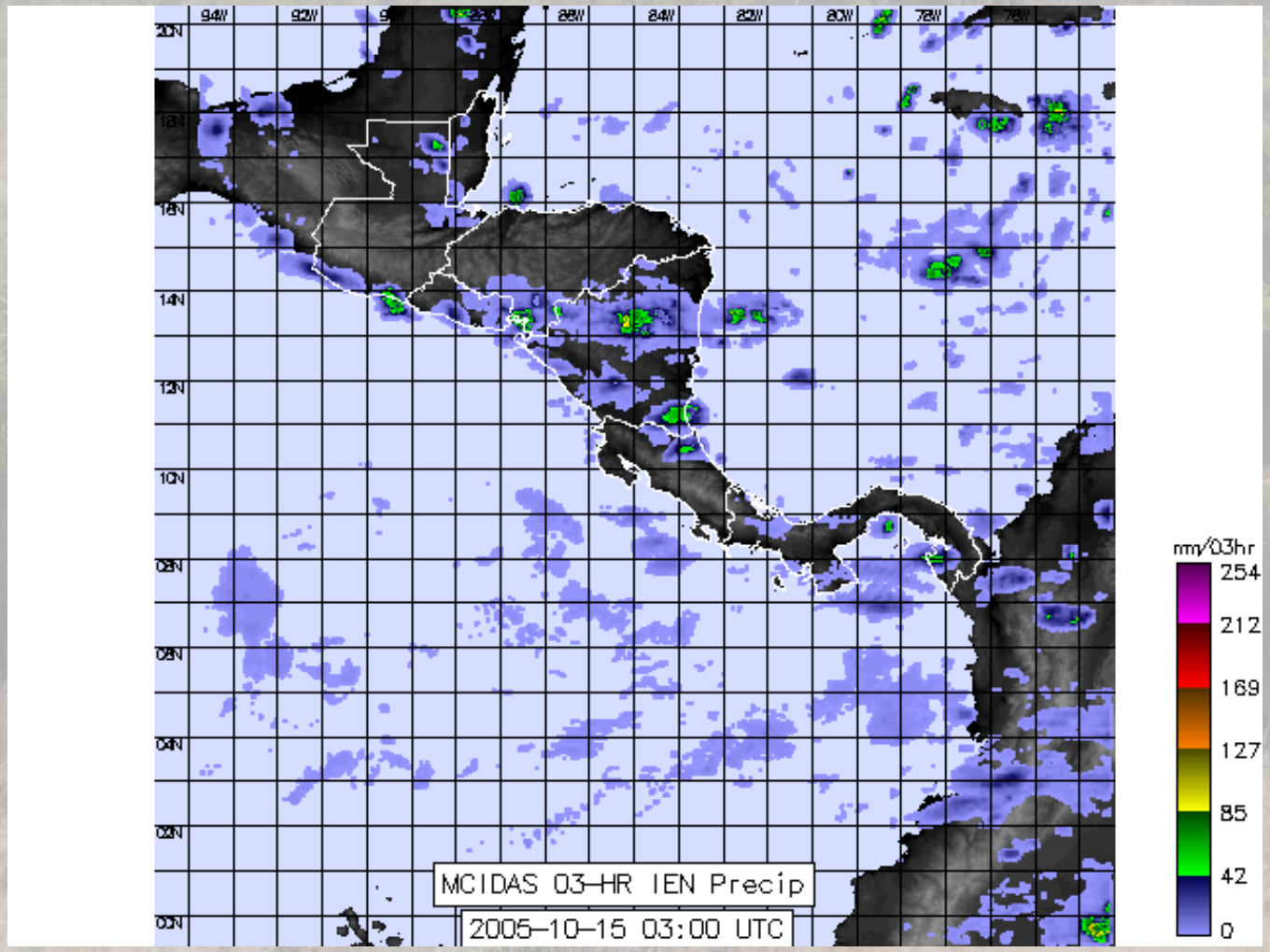
Regional Warning System



Central America Flash Flood Guidance



Satellite Rainfall - Hydroestimator



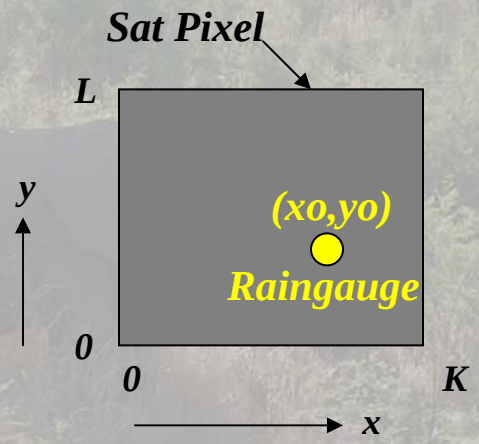
- IR based
- Short latency
- CR Regional node

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*

$$R_{SAT} = \frac{1}{KL} \iint_{0-L,0-K} f(x,y)\,dx\,dy$$

$$R_G = f(x_o, y_o)$$



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

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

Regional Bias

Random Error

Transformation for Normality

Bias Adjustment Basics

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

$$\beta_{t+1} = \beta_t + w_{t+1}$$

$$z_{t+1} = \beta_{t+1} + v_{t+1}$$

Kalman Filter
Stochastic Approximations

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

Bias (B)

Kalman Filter for Tracking the Errors

Stochastic Approximations Algorithm

Prediction:

$$\hat{\beta}_{t+1}^{-} = \hat{\beta}_{t}^{+}$$

$$P_{t+1}^{-} = P_{t}^{+} + Q_{t+1}$$

Updating:

$$\hat{\beta}_{t+1}^{+} = \hat{\beta}_{t+1}^{-} + K_{t+1}\left(z_{t+1} - \hat{\beta}_{t+1}^{-}\right)$$

$$P_{t+1}^{+} = (1 - K_{t+1})P_{t+1}^{-}$$

$$K_{t+1} = P_{t+1}^{-}(P_{t+1}^{-} + R_{t+1})^{-1}$$

Stochastic Approximations Algorithm for Model Error Variance

Enforces compliance between predicted residual variance and theoretical residual variance

$$\hat{Q}_{t+1} = \hat{Q}_t + \frac{\left(\frac{\partial P^-_{t+1}}{\partial Q}\right) \cdot S_t}{\left(\frac{\partial P^-_{t+1}}{\partial Q}\right)^2 S_t + \sigma^2_{t+1}} \cdot \left((r^-_{t+1})^2 - P^-_{t+1} - R_{t+1} \right)$$

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

$$\sigma^2_{t+1} = 2\left(P^-_{t+1} + R_{t+1}\right)^2$$

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

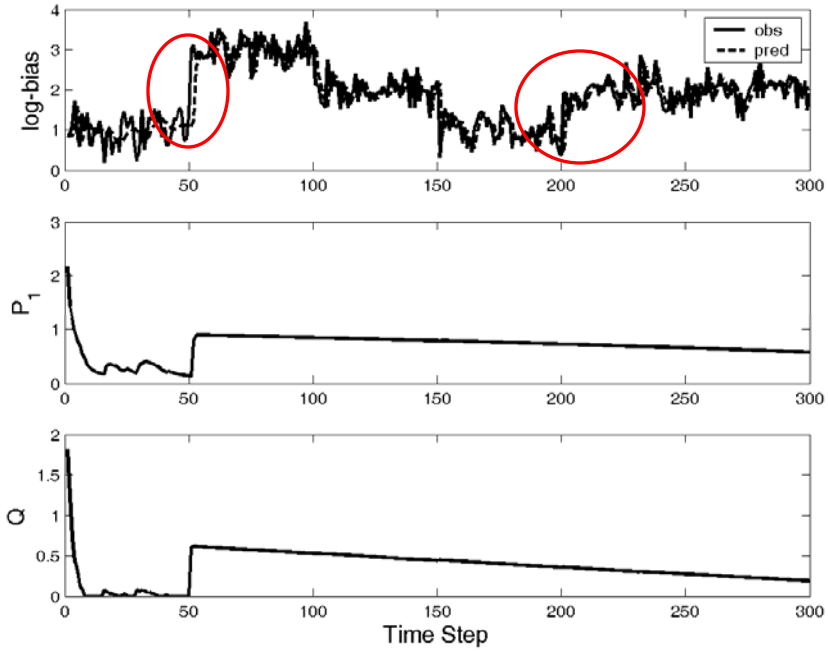
$$\hat{Q}_1 = \frac{P_o^2}{P_o + R_o}$$

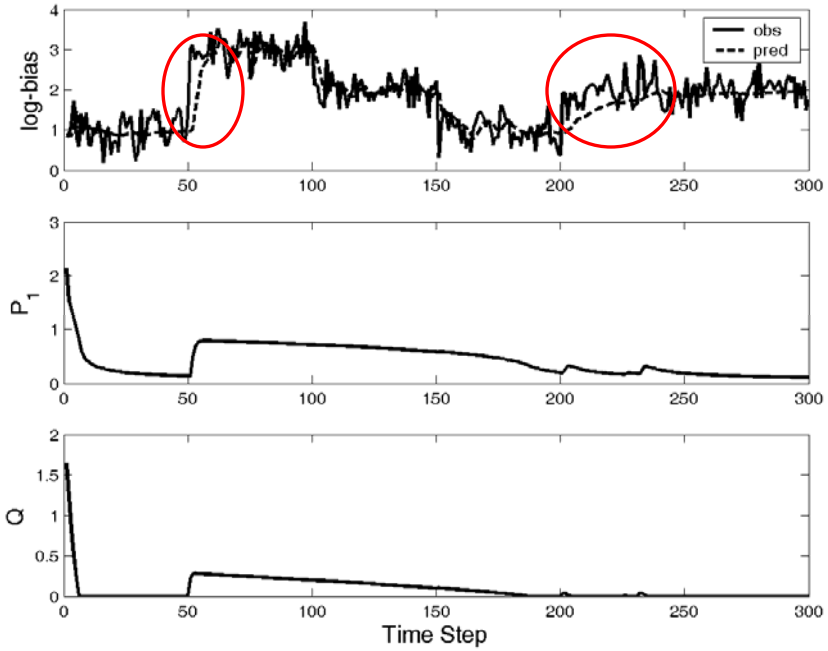
$$S_1 = \left(0.9\ \hat{Q}_1\right)^2$$

$$\frac{\partial P_1^-}{\partial Q} = 1$$

Restarts due to gauge data errors

Synthetic Data Tests

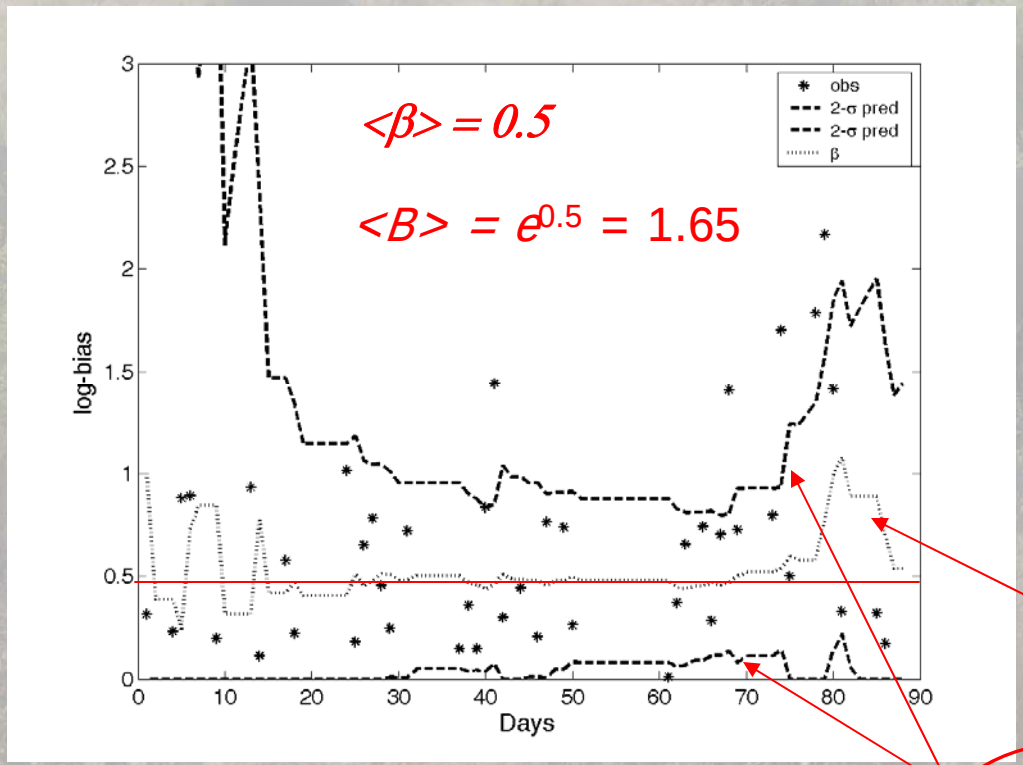


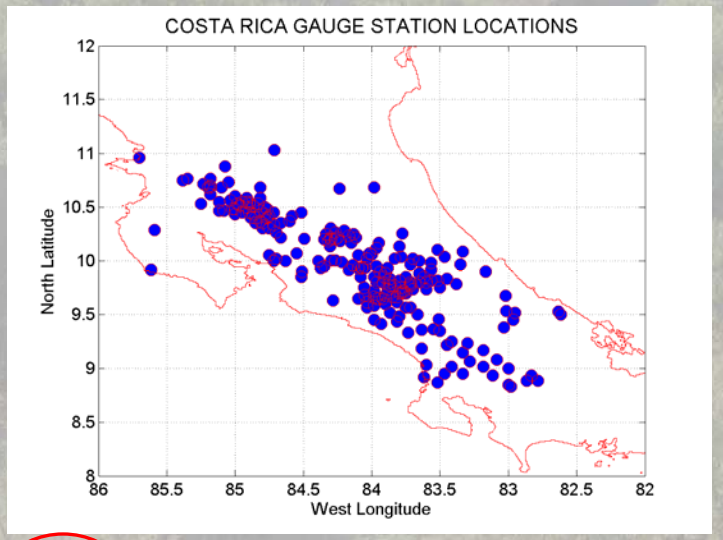


Medium Observation Error

Large Observation Error

Costa Rica Data Tests

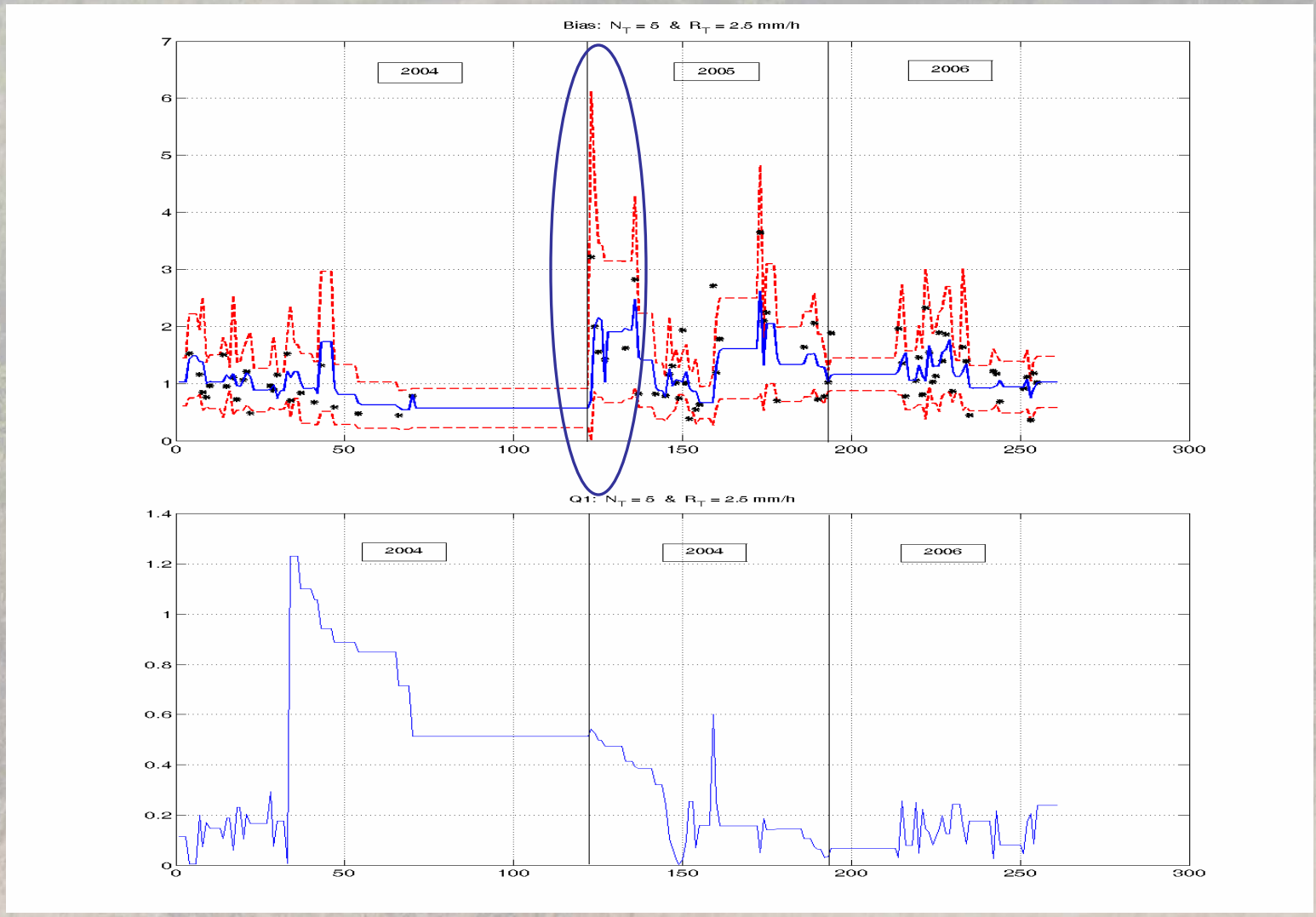




$$\hat{B}_{t+1}^{-} = \exp\left\{ \hat{\beta}_{t+1}^{-} + 0.5 P_{t+1}^{-} \right\}$$

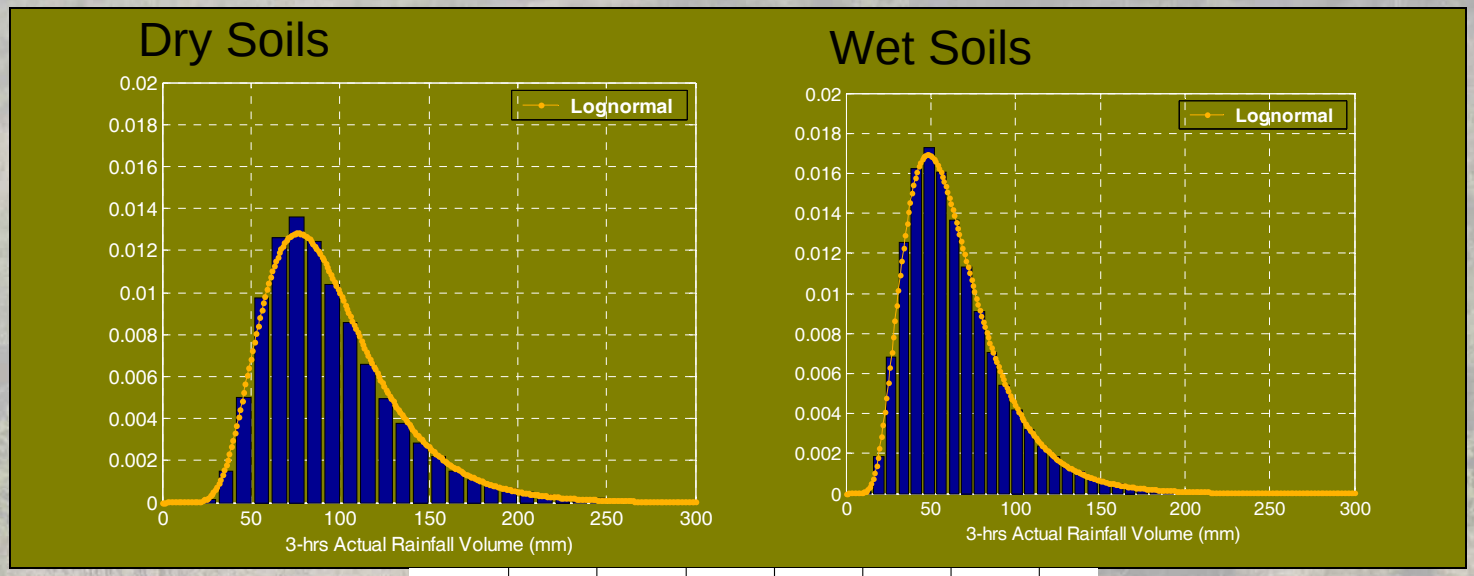
$$2x\sqrt{\sum}_{t+1}^{-} = \left(\hat{B}_{t+1}^{-}\right)^2 \left(\exp\left\{P_{t+1}^{-}\right\} - 1\right)$$

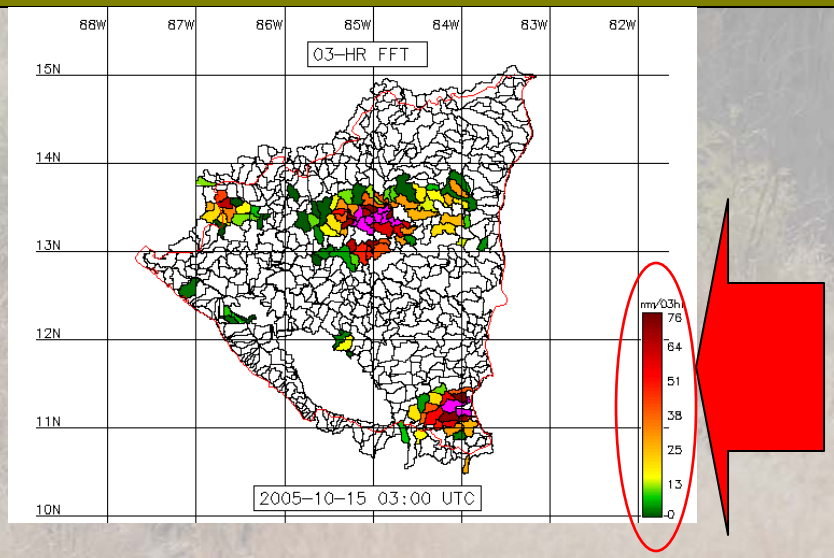
CAFFG Operational Results



Uncertainty Estimation

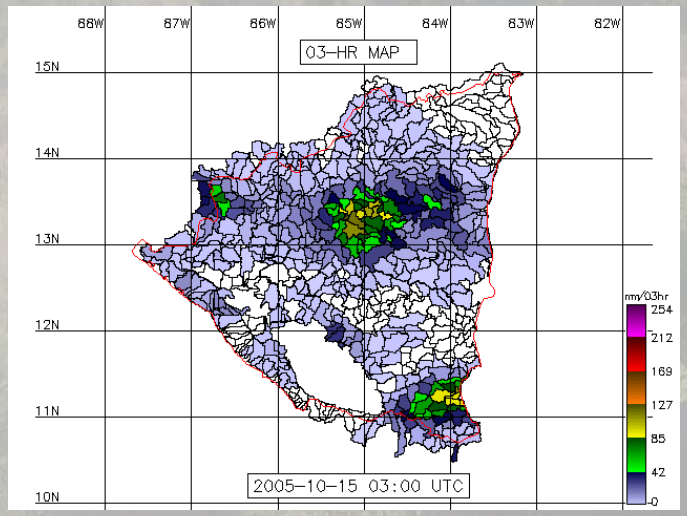
3-hr Flash Flood Guidance Probability Density Function

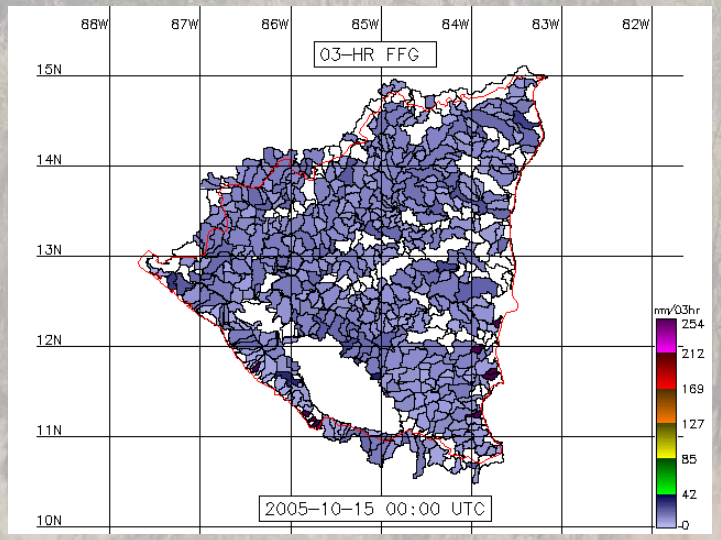


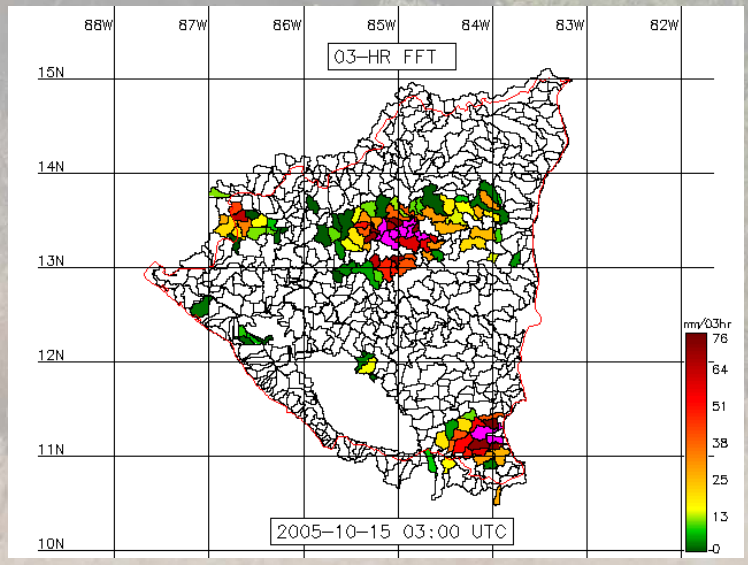


+ User input

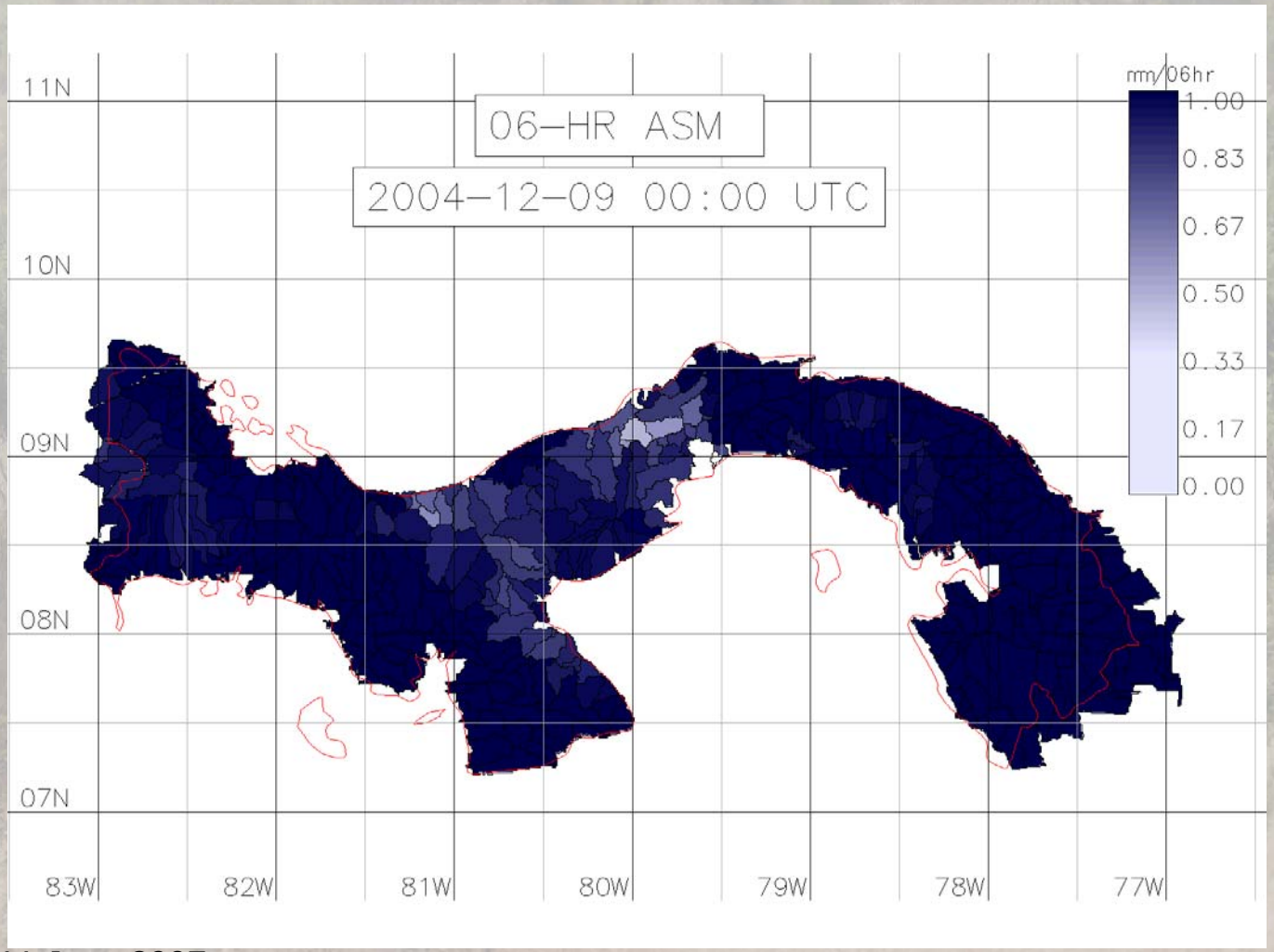
CAFFG NMHS PRODUCTS





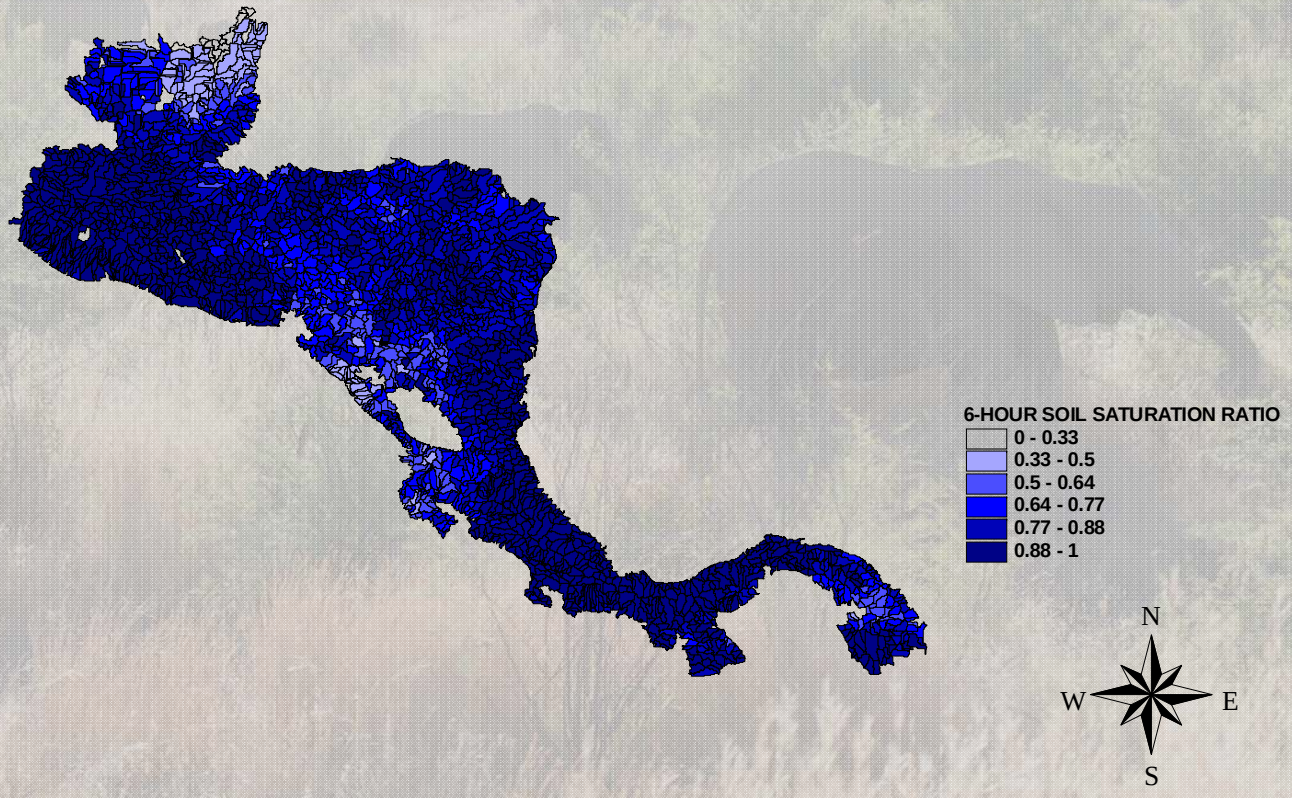


CAFFG Soil Moisture Product



CAFFG Regional Soil Moisture Product

Central America Flash Flood Guidance System
6-Hourly Soil Moisture - Date: 15 May 2004 0000Z



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:

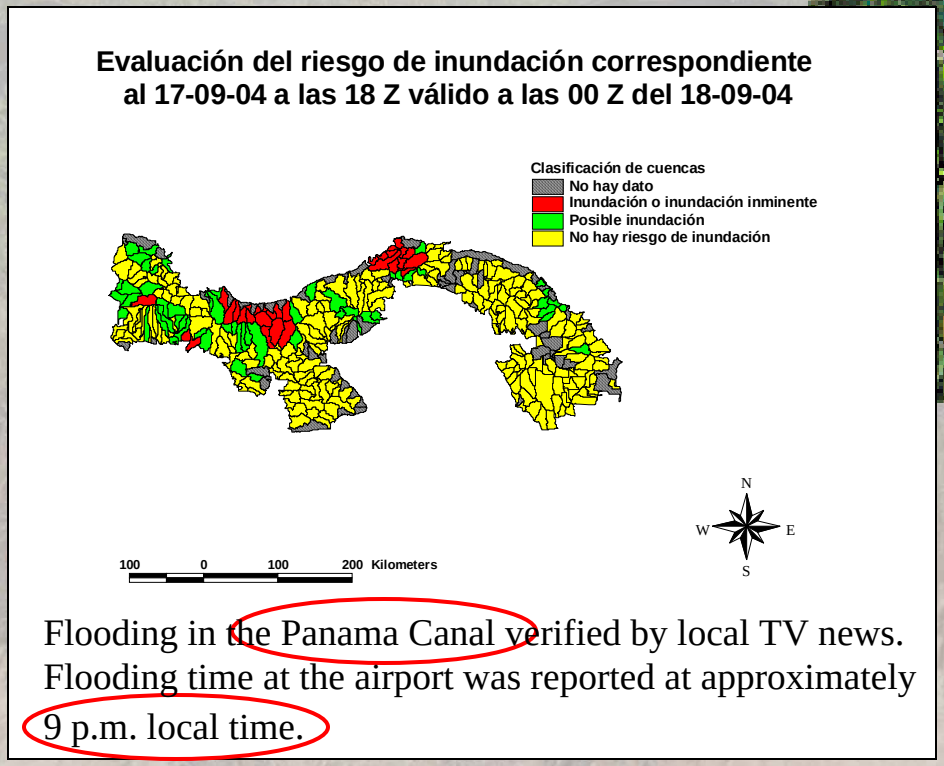
Assist NHMSs to develop protocol for issuing warnings based on flash flood guidance

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