High Resolution Integrated Weather-Flood Modelling Framework

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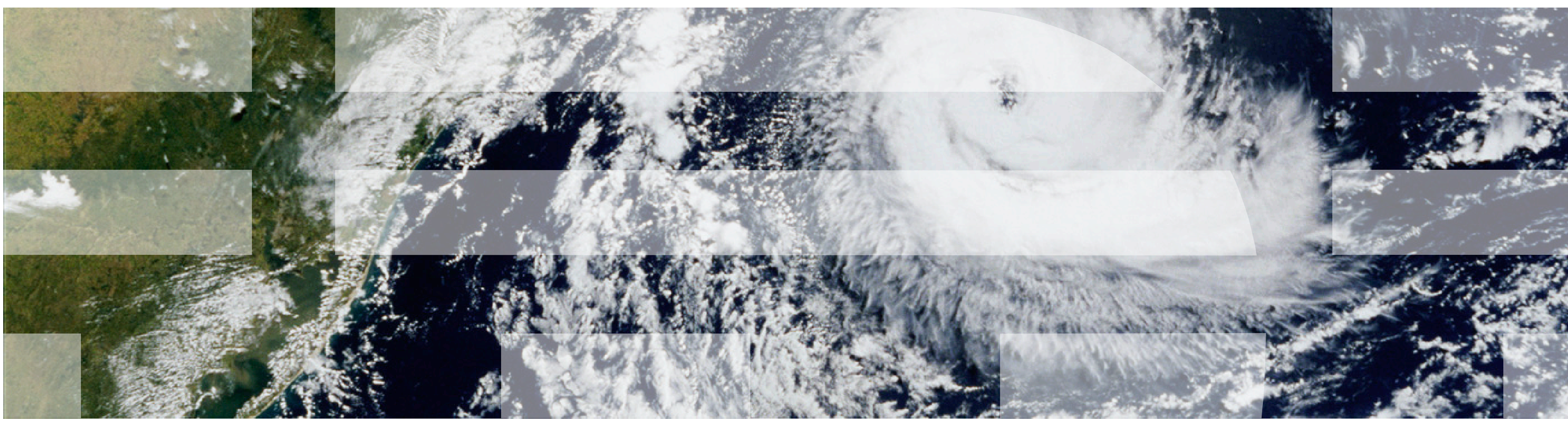

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Flooding is a common challenge over the world

- **Flooding is the most common of all environmental hazards and it regularly claims over 20,000 lives per year and adversely affects around 75 million people world-wide**

$7B in Damage!

Motivation: 5-6 April 2010 Flooding Event in Rio

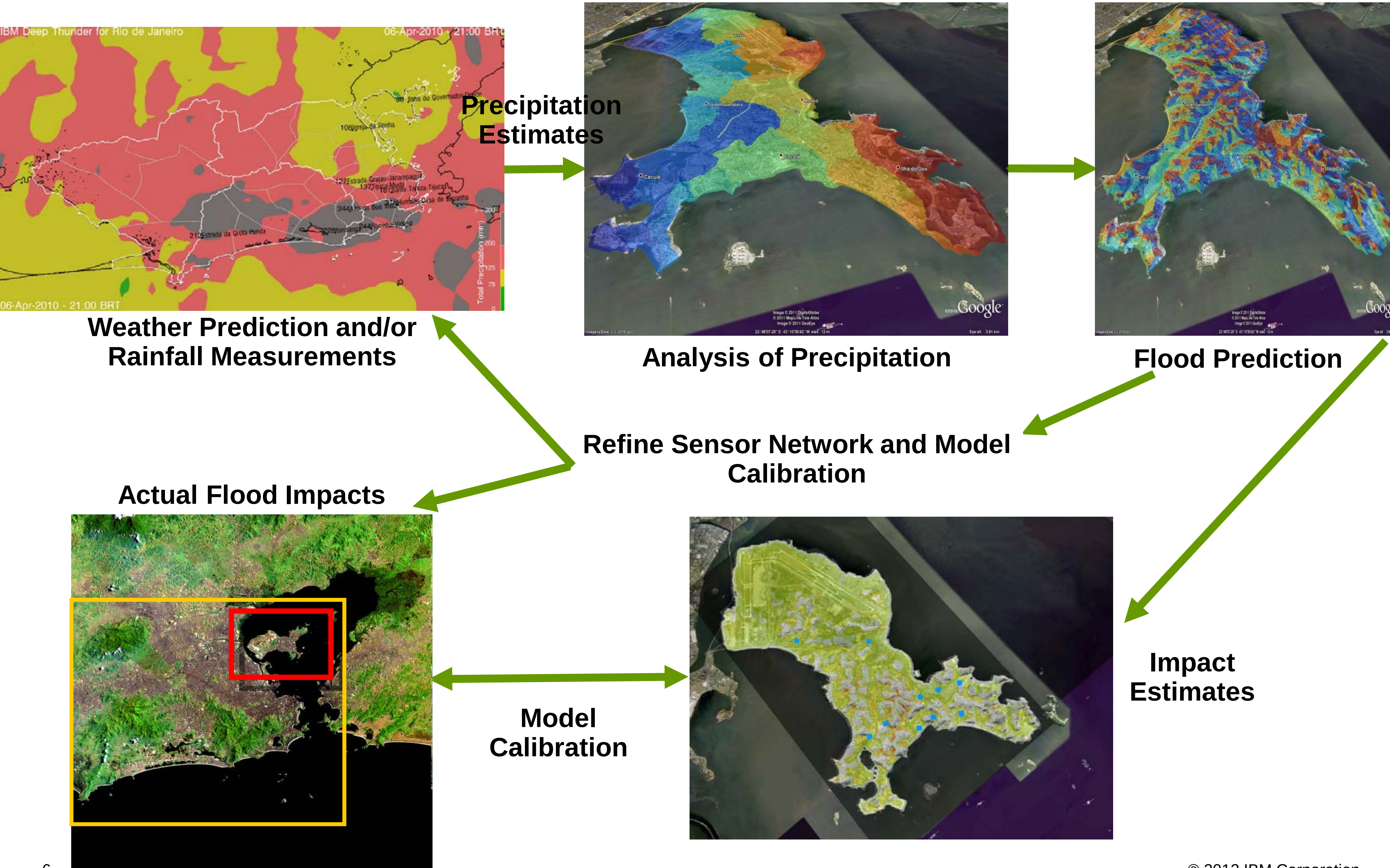
- Coastal storm with heavy rains (up to 284mm in 24 hours) starting at about 1700 BRT on 5 April 2010 – heaviest recorded compared to the previous 48 years
- One of the most significant global weather events of 2010
- Local flooding leading to mudslides, killed over 100 people in Rio and left thousands homeless
- Widespread disruption of transportation systems (e.g., road closures, airport and rail delays)
- Rio de Janeiro mayor admitted that the flooding of April 2010 uncovered significant gaps in the city's preparedness to respond to major emergencies/crises….."

Motivation: Brunei Natural Disaster Events

- 1962: Major flood
- 1980s: Fires in water village
- 1987: Rasau gas blow-out in Belait District
- 1991: Poor air quality resulting from Mount Pinatubo eruption in the Philippines
- 1998: Regional haze
- 1999: Flash flood during La Niña
- 2008: Temburong flash flood
- 2009: Extensive flash flood in Muara, Tutong an Belait districts

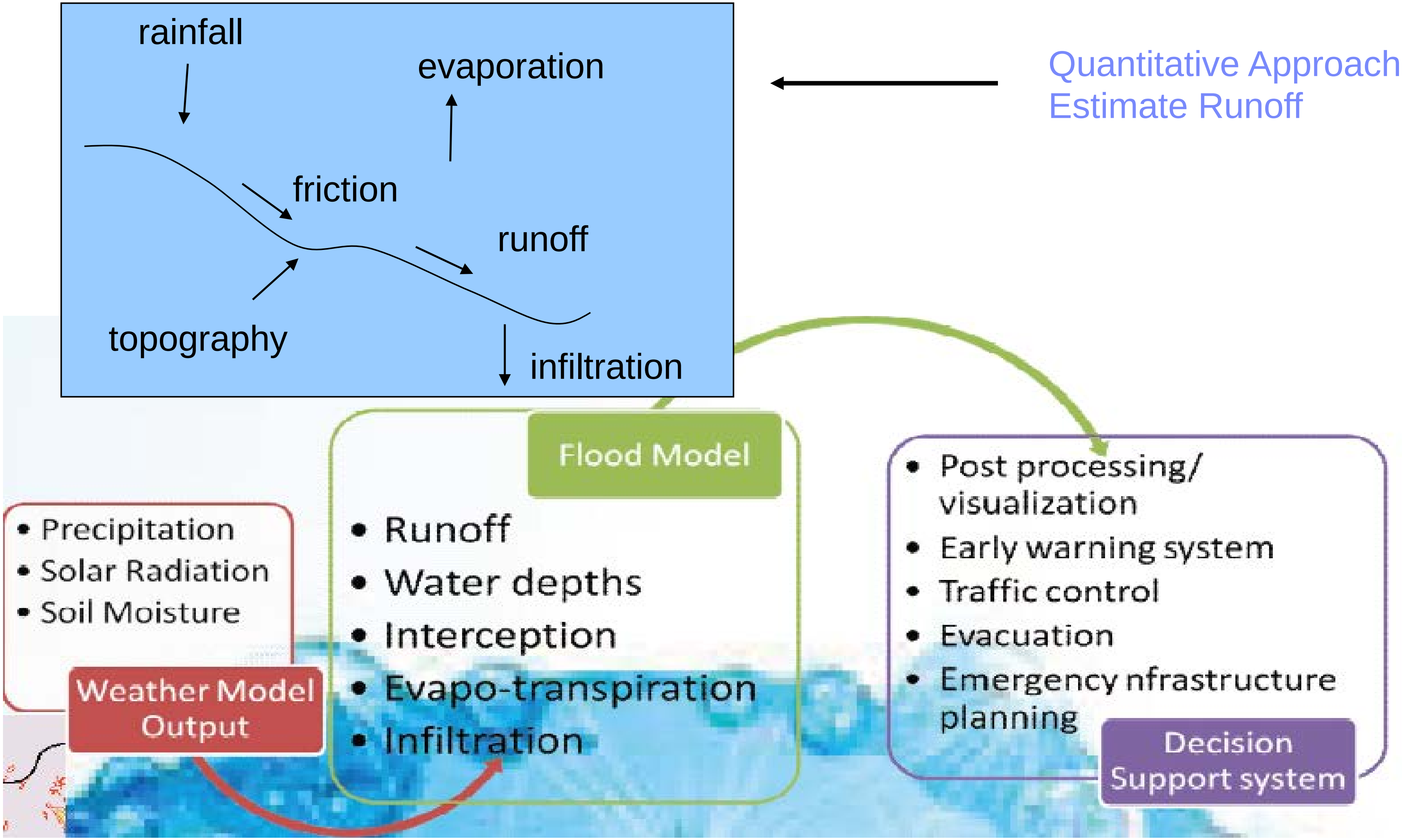
- 20 January 2009 Flash Flood in Brunei
- Heavy rainfall for 4 to 5 hours with a record 145.8mm in 24 hours.
- Widespread disruption of electric distribution, transportation and communications systems

Urban Flood Forecasting Framework



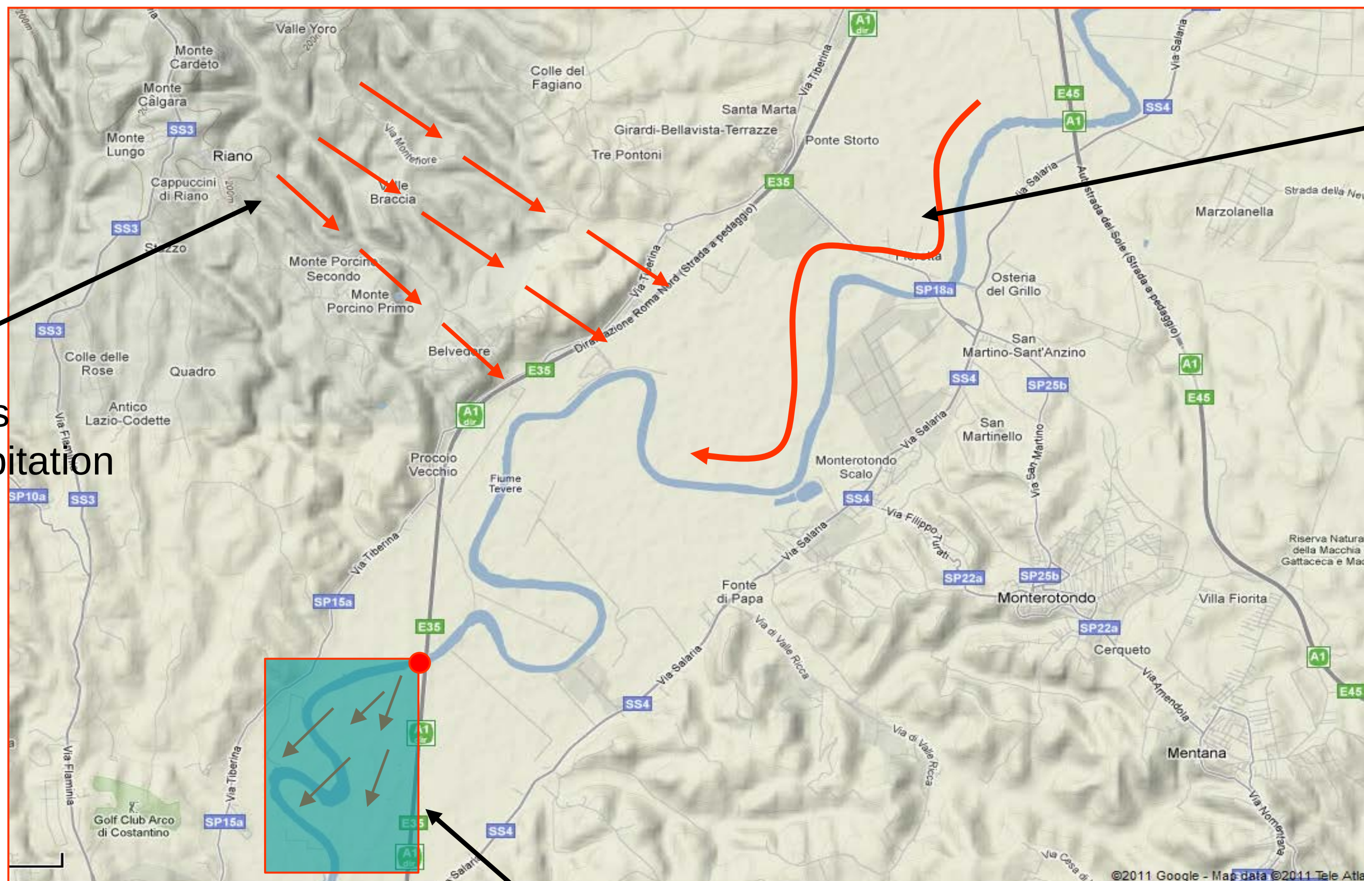
Main Elements of Modelling framework

Quantitative Approach to Estimate Runoff



Flood Analytics

- Modelling of the water transport on the land surface and within river channel can be done by physical models
- Efficient and large scale modelling of the water transport is the basic building block of many different flood related applications



Fully dynamic 1D model for efficient within-river modeling

2D run-off models connecting precipitation to river channel

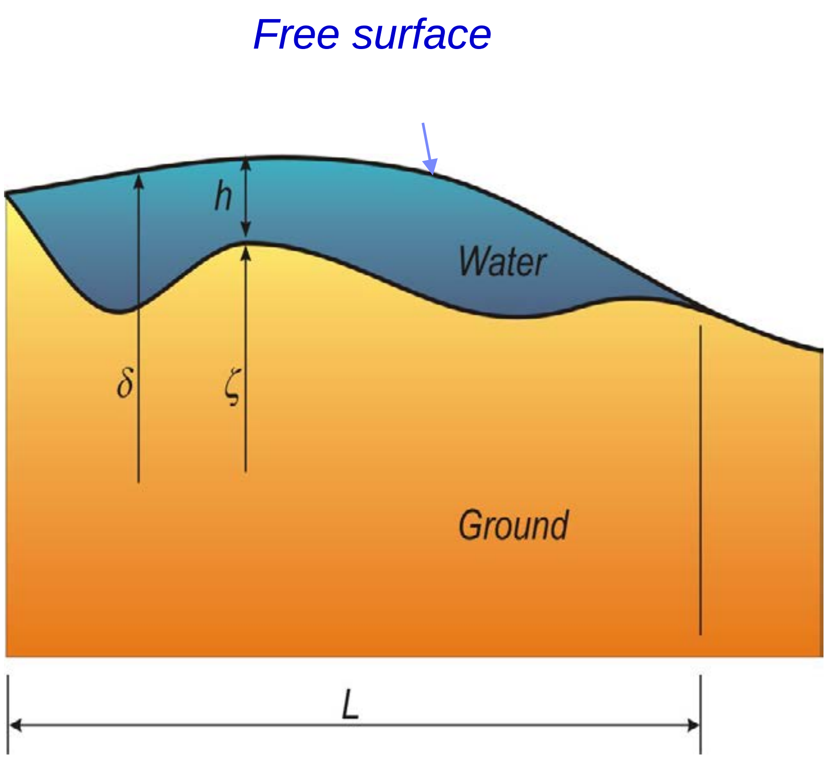
Detailed 2D routing model for accurate flood plain estimate at selected high-risk urban locations

Hydraulic 2D : Surface Runoff Model Assumptions

Surface runoff problems have usually the following characteristics:

- The average depth of the layer of fluid is very small in relation to its other dimensions.
- The vertical velocity is usually smaller than the horizontal ones.
- The hydrostatic balance is a good approximation in the vertical direction :

$$\frac{\partial p}{\partial z} = \rho g$$



Complete Shallow Water Model (Including Friction)

$$\left\{\begin{aligned}
&\frac{\partial h}{\partial t}+\frac{\partial(\bar{u}h)}{\partial x}+\frac{\partial(\bar{v}h)}{\partial y}=\overset{\text{rainfall}}{R}-\overset{\text{infiltration}}{I}-\overset{\text{evaporation}}{E}\pm\overset{\text{canals}}{C}\\
&\frac{\partial(\bar{u}h)}{\partial t}+\frac{\partial(\bar{u}h\bar{u})}{\partial x}+\frac{\partial(\bar{v}h\bar{u})}{\partial y}=\tau_x^w-\frac{n_x^2 g\sqrt{u^2+v^2}}{h^{1/3}}\bar{u}-gh\left(\frac{\partial h}{\partial x}+\frac{\partial \varsigma}{\partial x}\right)\\
&\frac{\partial(\bar{v}h)}{\partial t}+\frac{\partial(\bar{u}h\bar{v})}{\partial x}+\frac{\partial(\bar{v}h\bar{v})}{\partial y}=\tau_y^w-\frac{n_y^2 g\sqrt{u^2+v^2}}{h^{1/3}}\bar{v}-gh\left(\frac{\partial h}{\partial y}+\frac{\partial \varsigma}{\partial y}\right)
\end{aligned}\right.$$

+ Initial condition: *topography, water depth and velocities known*

+ Boundary conditions: *Prescription of values or derivatives of unknowns at the boundary*

Diffusive Wave Approximation of Complete Shallow Water Model

$$\frac{\partial h}{\partial t}+\frac{\partial\left(\overline{u}h\right)}{\partial x}+\frac{\partial\left(\overline{v}h\right)}{\partial y}=R-I-E\pm C$$

elimination of the inertial terms

$$\frac{\partial\left(\overline{u}h\right)}{\partial t}+\frac{\partial\left(\overline{u}h\overline{u}\right)}{\partial x}+\frac{\partial\left(\overline{v}h\overline{u}\right)}{\partial y}=\tau_x^w-\frac{n_x^2 g\sqrt{u^2+v^2}}{h^{1/3}}\overline{u}-gh\left(\frac{\partial h}{\partial x}+\frac{\partial \varsigma}{\partial x}\right)$$

≈ 0

$$\frac{\partial\left(\overline{v}h\right)}{\partial t}+\frac{\partial\left(\overline{u}h\overline{v}\right)}{\partial x}+\frac{\partial\left(\overline{v}h\overline{v}\right)}{\partial y}=\tau_y^w-\frac{n_y^2 g\sqrt{u^2+v^2}}{h^{1/3}}\overline{v}-gh\left(\frac{\partial h}{\partial y}+\frac{\partial \varsigma}{\partial y}\right)$$

≈ 0

Diffusive wave Approximation → inertia term is taken negligible

Diffusion Model for the Shallow Water

$$
\begin{cases}
\dfrac{\partial h}{\partial t} + \dfrac{\partial\left(\overline{u}h\right)}{\partial x} + \dfrac{\partial\left(\overline{v}h\right)}{\partial y} = R - I - E \pm C & (1) \\[2ex]
\overline{u} = -\dfrac{h^{2/3}}{n_x \left|\partial H / \partial s\right|^{1/2}} \left(\dfrac{\partial (h + \varsigma)}{\partial x} \right) \qquad \overline{v} = -\dfrac{h^{2/3}}{n_y \left|\partial H / \partial s\right|^{1/2}} \left(\dfrac{\partial (h + \varsigma)}{\partial y} \right) & (2)
\end{cases}
$$

where the wind stresses were neglected for the sake of simplicity.

Replacing Eqs. (2) in (1), we obtain the following equation:

Numerical Scheme

- Finite Volume Method
- Forward time stepping
- Locally and globally conservative
- 2^{nd} order accurate in space and time
- Structured Cartesian Mesh

Finite volume principle

Continuity equation in flux form:

$$\frac{\partial h}{\partial t} + \vec{\nabla} \bullet \left(h\vec{v} \right) = Q$$

Integrate over one time step Δt and the 2D finite volume Ω with area A:

$$\int_{t_n}^{t_{n+1}} \int_{\Omega} \frac{\partial h}{\partial t} d\Omega dt + \int_{\Omega} \int_{t_n}^{t_{n+1}} \vec{\nabla} \bullet \left(h\vec{v} \right) dt d\Omega = \int_{t_n}^{t_{n+1}} \int_{\Omega} Q dt$$

Apply the Gauss divergence theorem:

$$\int_{t_n}^{t_{n+1}} \frac{dh}{dt} dt + \frac{1}{A_\Omega} \oint_{\partial\Omega} \vec{F} \bullet \hat{n} dl = \int_{t_n}^{t_{n+1}} Q dt$$

$\hat{n}$: Unit normal vector

$\vec{F}$: Time-averaged numerical flux

h : Cell-averaged pressure thickness

Discrete Form : Orthogonal fluxes across cell interfaces

Flux form ensures mass conservation

$$\int_{t_n}^{t_{n+1}} \frac{dh}{dt} dt + \frac{\Delta t}{A_\Omega} \oint_{\partial\Omega} \vec{F} \bullet \hat{n} dl = 0$$

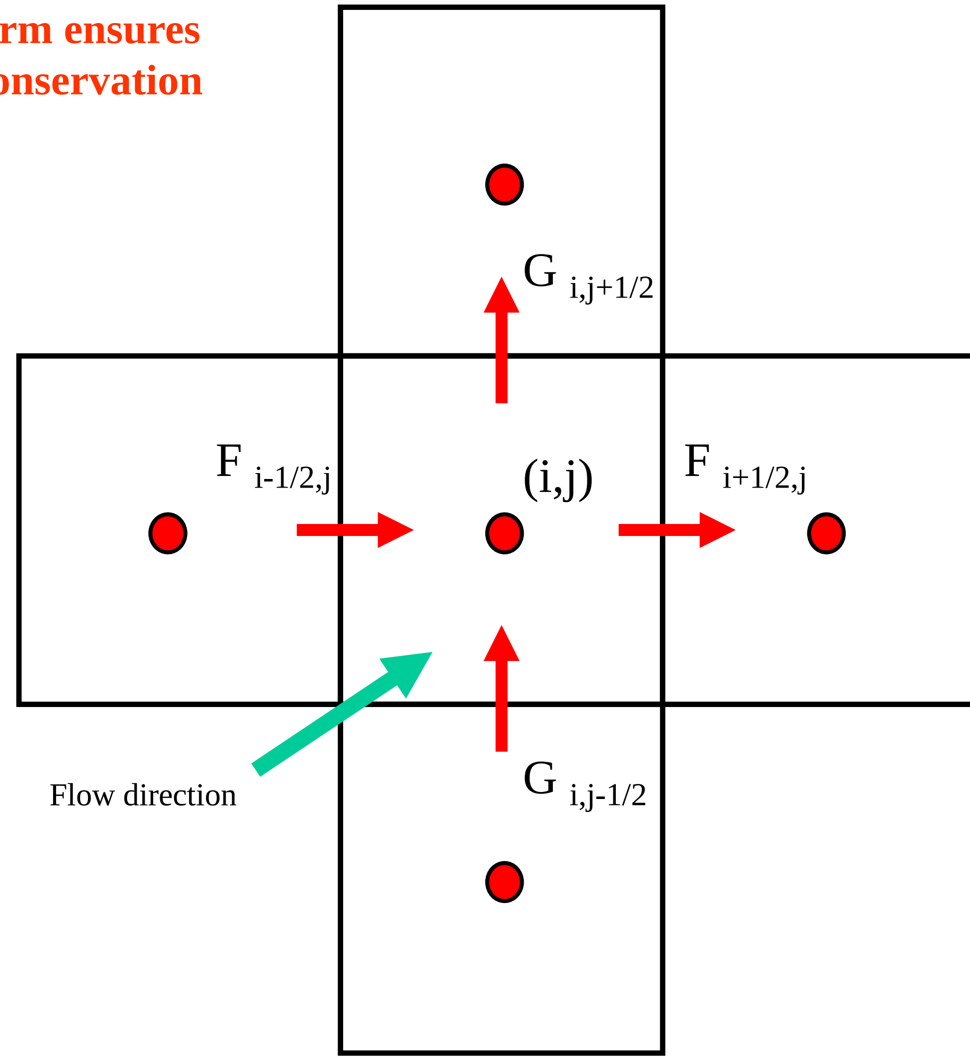
$$h^{n+1} = h^n - \frac{\Delta t}{A_\Omega} \sum_{i=1}^{4} \vec{F}_i \bullet \hat{n}_i l_i$$

Upwind-biased Finite volume method

$$h_{i,j}^{n+1} = h_{i,j}^{n} - \frac{\Delta t}{A_{i,j}} \left(\Delta y_{i+\frac{1}{2},j} F_{i+\frac{1}{2},j} - \Delta y_{i-\frac{1}{2},j} F_{i-\frac{1}{2},j} \right)$$

$$- \frac{\Delta t}{A_{i,j}} \left(\Delta x_{i,j+\frac{1}{2}} G_{i,j+\frac{1}{2}} - \Delta x_{i,j-\frac{1}{2}} G_{i,j-\frac{1}{2}} \right)$$

F: fluxes in x direction
G: fluxes in y direction

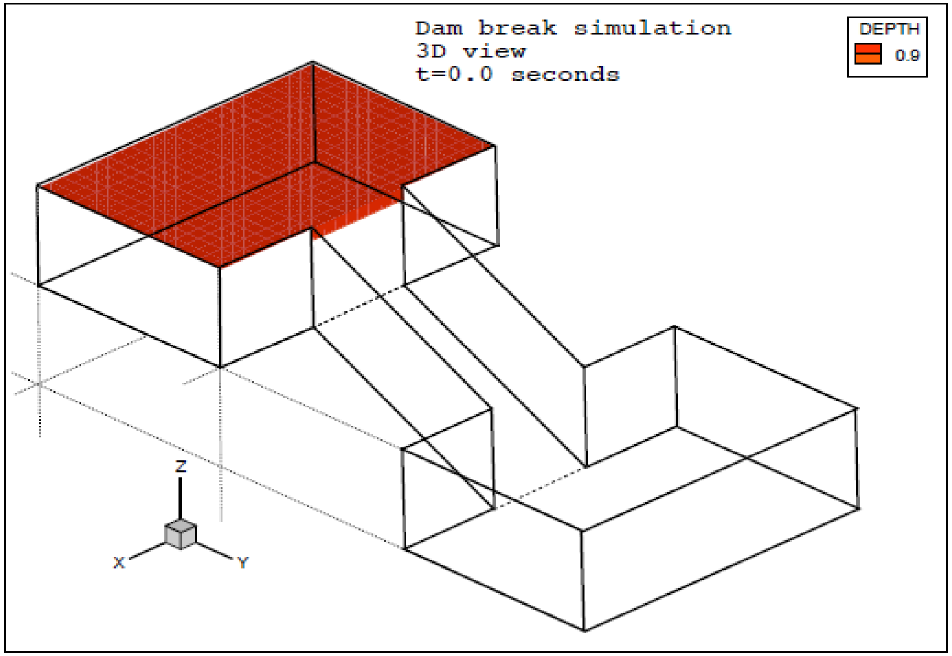


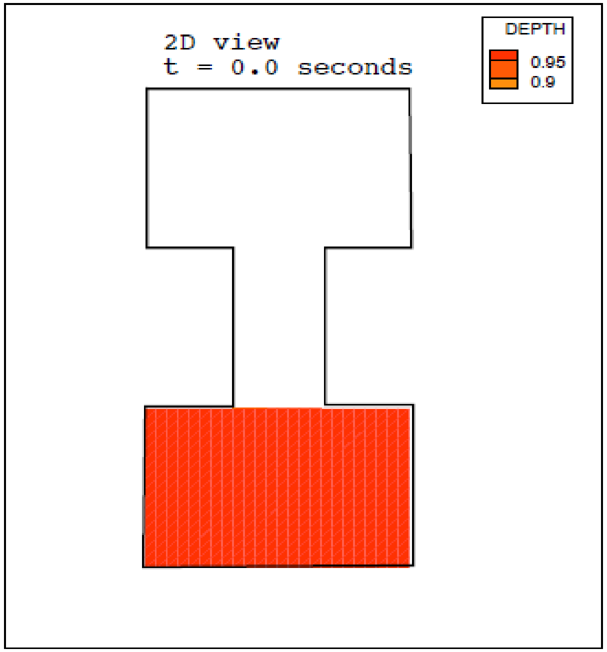
Test Case : Ideal Dam Break Problem

Test Case Description:

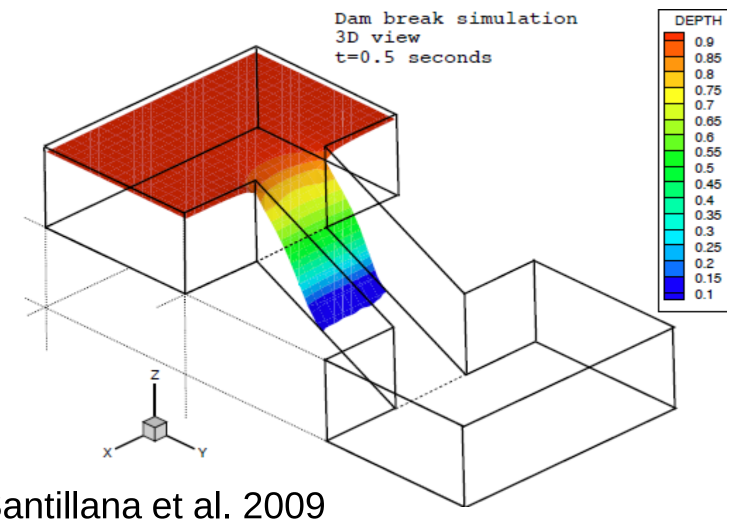
A channel was designed to connect two reservoirs,
up hill- completely filled with water, downhill- completely empty

Ideal dam removed. Water flows completely to the empty one

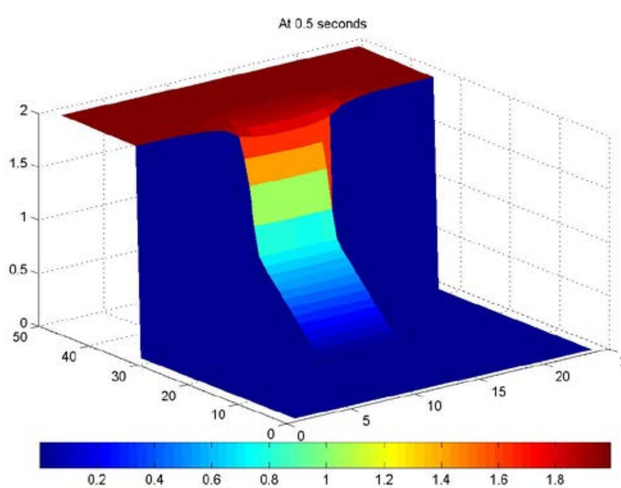




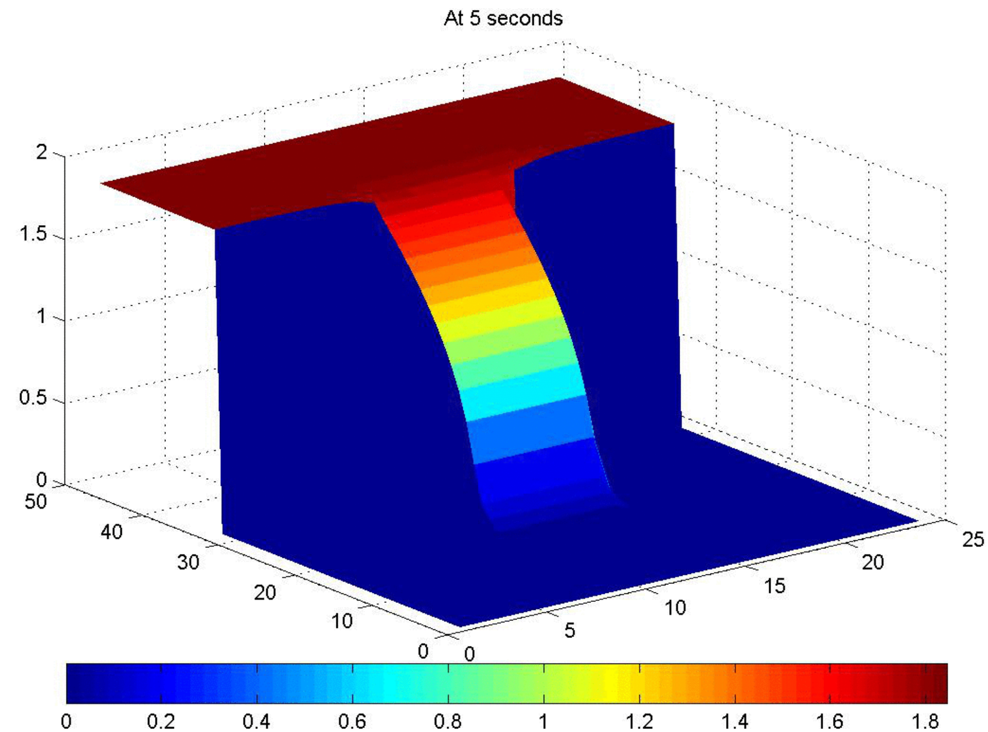
Result : Dam Break Problem



Santillana et al. 2009



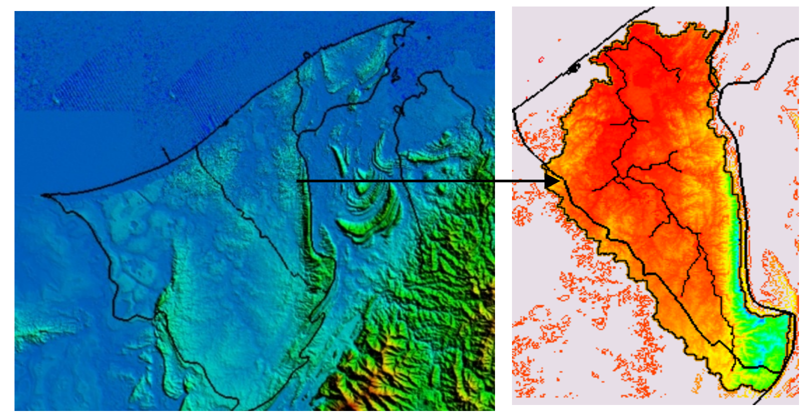
IBM model

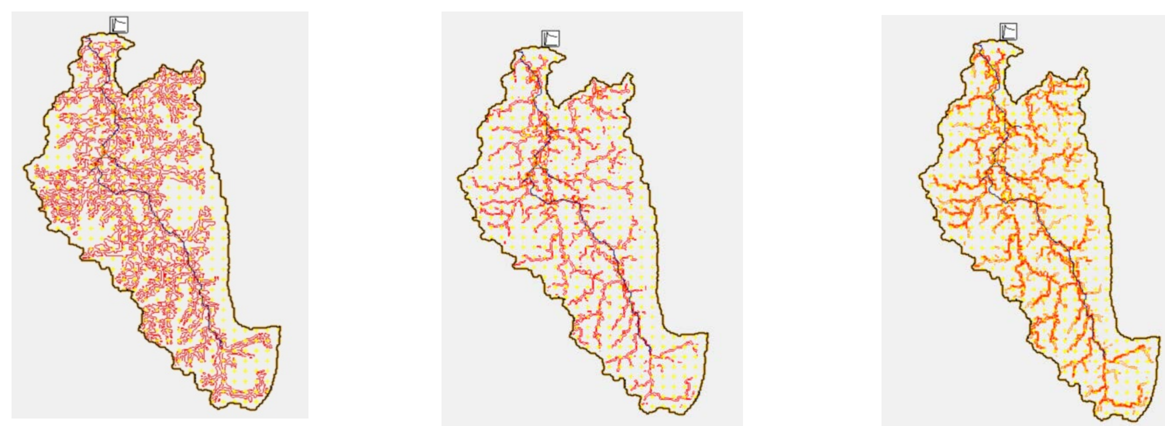


Test case Simulation for 100 seconds of simulation

GSSHA Simulations

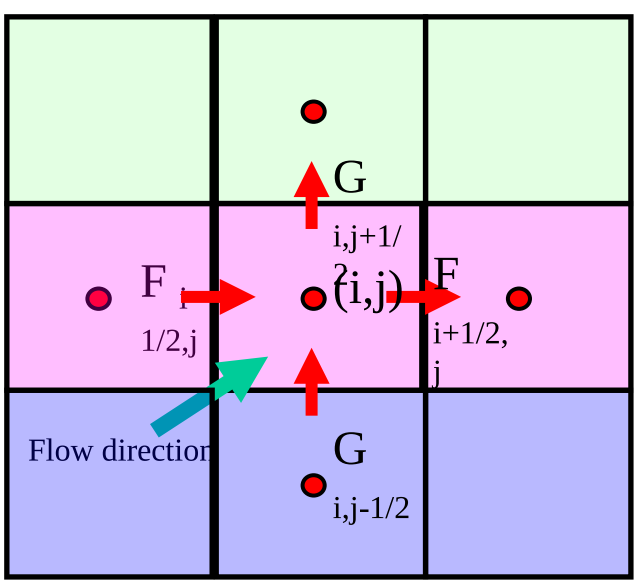
- DEM- SRTM
- Watershed Delineation
- Grid creation
- Land use, soil, vegetation etc.
- Precipitation
- flow model run

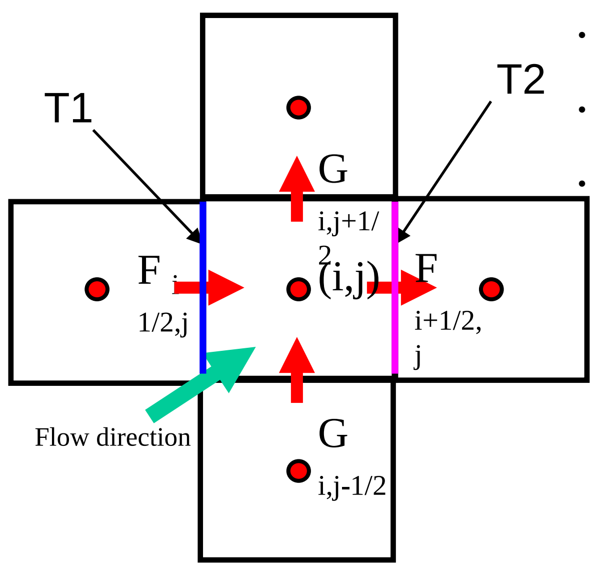




Work in Progress

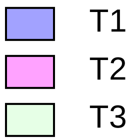
- Code parallelization : OpenMP + MPI
- Real World Case Studies
- Parameterizations : infiltration , evapotraspiration etc





Code Parallelization:

- Shared Memory parallelization using OpenMP
- Parallel computations for X and Y edges
- Parallel computations for grid cells



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Universiti Brunei Darussalam (UBD), in collaboration with International Business Machines (IBM), is establishing a UBD | IBM Centre on Regional Climate-Weather Modelling and Impacts on Rainforests, Renewable Energy, Crops & Flooding at Universiti Brunei Darussalam (UBD). The Centre will focus on collaborative research on these cutting-edge Smarter Planet modelling topics using high performance computing facilities to be installed at UBD. The partnership will include new personnel hires at UBD and deep collaboration with IBM Research Labs at India, NY/USA (Watson) and Brazil.

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1. Research Fellow in Hydrology

UBD | IBM Centre is inviting applications for a Research Fellow in the area of hydrology and soil/water management as part of the Centre. A Ph.D. in relevant areas of engineering or sciences is preferred, though Masters degree holders with strong relevant expertise and experience can be considered. Topics of research performed by the Research Fellow will be at the intersection of hydrological modeling, flood forecasting, and soil/water/forestry management. As part of the UBD | IBM Centre, IBM Research invites Research Fellows for collaboration on-site at IBM Research Labs in India, NY/USA (Watson) and Brazil.

Contact rajks@in.ibm.com for more information

Interested candidates can send their applications to:

Deputy Director, UBD|IBM Centre, Universiti Brunei Darussalam (saiful.husain@ubd.edu.bn)

Tungku Link Road, Gadong, BE 1410

Brunei Darussalam

Tel: 673 2463001 Ext 1345, Fax: 673 2461502

Thanks!!

Hydraulic models

- GSSHA
  - http://chl.erdc.usace.army.mil/gssha
  - CHL, USACE
- CCHE2D
  - http://www.ncche.olemiss.edu/sw_download
  - NCCHE, Mississippi university, USDA
- MIKE SHE
  - http://mikebydhi.com/
  - DHI
- ISIS 2D
  - http://www.halcrow.com/isis/isis2d.asp
- Infoworks ICM
  - http://www.innovyze.com/products/infoworks_icm/

Two Approaches

- Hydrologic modelling
  - Physics of the process is unknown
  - Conceptual models
  - Derived from experience and data statistics
- Hydraulic Modelling
  - Physics based equations
  - Involves Partial differential equations
  - Need numerical methods to solve