Enabling High-Resolution Hydro-Meteorological Modelling for Operational Short-Term Forecasting in Rio De Janeiro

Lloyd Treinish, Anthony Praino and James Cipriani
IBM Thomas J. Watson Research Center
Yorktown Heights, NY, USA

Ulisses Mello, Kiran Mantripragada, Lucas Villa Real and Paula Sesini
IBM Brazil Research Laboratory
São Paulo, Brazil

Vaibhav Saxena, Thomas George and Rashmi Mittal
IBM India Research Laboratory
Delhi, India
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- Motivation and background
- Approach
- Status
- Examples
- Validation
- Next Steps
5-6 April 2010 Flooding Event

- Coastal storm with heavy rains (over 300mm in less than 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 200 people and left 15000 homeless
- Widespread disruption of transportation systems (e.g., road closures, airport and rail delays)
Approach

- Create a targeted NWP-based forecasting system focused on Rio de Janeiro
  - End-to-end process (user to meteorology) tailored to business needs, leveraging “Deep Thunder” work at IBM Research
  - Operational infrastructure and automation with focus on HPC, visualization, and system and user integration
  - 48-hour forecasts at 1km horizontal resolution with up to 40 hours of lead time
  - Coupled business applications (analytics and visualization) with actual end users to address usability and effectiveness
  - Accessible within the integrated city command center to enable effective planning and response to emergencies and special events as well as more efficient routine operations
Approach

- Retrospective analysis of key, historical events
  - Many numerical experiments to enable effective model configuration for research and operations, addressing computational and physics issues as well as verifiable hindcasts

- Considerations
  - TRMM-based climatology suggests a broad stratiform region
  - In addition to its near-tropical setting along the coast of the Atlantic Ocean and the western portion of Guanabara Bay, there are regions where the terrain has a high aspect ratio, related to the Sierra do Mar mountains
  - Although sea breezes moderate the temperatures along the coast, especially during the summer, cold fronts from the Antarctic can lead to rapid changes in local weather
Approach to Urban Flood Forecasting

Weather Prediction and/or Rainfall Measurements

Precipitation Estimates

Analysis of Precipitation

Model Calibration

Refine Sensor Network and Model Calibration

Flood Prediction

Impact Estimates

Actual Flood Impacts
Status

- R&D enabled high-resolution operational weather forecasting starting in May 2011
  - 48-hour forecast updated every twelve hours, generated at IBM Yorktown
  - Disseminated via a web portal (“Previsão Meteorológica de Alta Resolução” or PMAR [High-Resolution Weather Forecast]) at the client site through specialized visualizations

- Operational evaluation on-going validated against data from weather stations operated by the city

- R&D to enable direct flood prediction, driven by the meteorology
  - Flooding model implemented in July 2011, using limited historical data and high-resolution (1m) lidar-based terrain data as well as maps of soil type, land occupation, and city structure (see companion talk by L. V. Real)
  - Disseminated via the PMAR web portal at the client site through specialized visualizations
Weather Model Configuration

- **WRF-ARW Community Model (v3.2.1)**
  - Four 2-way nests at 27, 9, 3 and 1 km horizontal resolution focused on Rio de Janeiro (90x90)
  - 65 vertical levels with ~15 in the planetary boundary layer to ensure capturing of orographic effects
  - 48 hour runs twice daily (initialized at 0 and 12 UTC)
  - NOAA GFS for background and lateral boundary conditions
  - SRTM-based model orography
  - 1/12-degree SSTs
  - Thompson double-moment 6-class microphysics, RRTM long wave radiation, GSFC short wave radiation, YSU PBL, NOAH LSM, Kain-Fritsch cumulus
Operational Forecast of 16-17 December 2011 Rainfall Event

IBM Deep Thunder for Rio de Janeiro
Surface Total Precipitation
Cloud Water Density at 1.0e-03 kg/kg

Animation of three-dimensional forecasted clouds with terrain surface and precipitation
Operational Forecast of 16-17 December 2011 Rainfall Event

Animation of forecasted precipitation rate
Operational Forecast of 16-17 December 2011 Rainfall Event

Rainfall Totals

Runoff Totals
Operational Forecast of 16-17 December 2011 Rainfall Event

Site-specific forecast at the location of a rain gauge in Rio de Janeiro
Precipitation Forecast Validation

Focus on amount of precipitation connected to the process of using the forecasts for issuing warnings, etc.

- Analyze the amount of rainfall reported hourly at each of the 33 rain gauges within every 12-hour period
  - Given length and update rate of forecasts, implies 13 values to compare every 12 hours for each rain gauge

- Categorize the rainfall measurements and forecasts based upon the response to rainfall events of different magnitudes
  - Weak: < 5 mm
  - Moderate: 5 – 25mm
  - Strong: 25 – 50mm
  - Very strong: > 50mm

- Given the four categories, use a 4x4 contingency table for statistics
Rain Gauge Network in Rio de Janeiro

Precipitation measurements used for model validation
Summary of Forecast Validation Results

- Accuracy averaged over all rain events from 26 May 2011 through 08 January 2012 by 12-hour periods for all categories:
  - Hour 00-12: 93.6%
  - Hour 12-24: 91.8%
  - Hour 24-36: 93.1%
  - Hour 36-48: 92.8%

- Accuracy averaged over rain events from 26 May 2011 through 08 January 2012 by 12-hour periods for all categories, assuming a +/- 5mm tolerance at each category threshold:
  - Hour 00-12: 97.1%
  - Hour 12-24: 95.6%
  - Hour 24-36: 96.2%
  - Hour 36-48: 95.8%
A Second Approach to Validation of Precipitation Forecasts

- A different categorization was developed based upon client request, which still has excellent forecasting skill
  - Forecasts and measurements for accumulation every six hours are calculated and compared in timing and location for each of the rain gauges
  - A tolerance of +/-20% of the accumulation is considered when comparing the forecasts and measurements
  - If the measurement is less than 25mm, a minimum tolerance of +/-5mm is used
  - The same tolerance range is applied to handle no-rain forecasts and false positives
  - A 2x2 contingency table is used to calculate the score, which is the number of elements in the diagonal of the contingency table
  - Forecast accuracy = (hits + correct negatives)/total

- The accuracy should be calculated using all available accurate rain gauge data and reported at an aggregate level over all rain gauges
- The accuracy should be calculated and reported for each 6-hour range contained in a forecast simulation of 48 hours

- Weekly reports of forecast performance of the last seven and 30 days
- GeoRio data are used along with measurements from INMET

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<tr>
<td>Misses</td>
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<td>Correct Negatives</td>
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Deep Thunder Weekly Average Accuracy Based on 6-hour Accumulated Precipitation for Rio de Janeiro
Prototype Flood Model

- Given available data developed a simplified high-resolution analytical model for flood prediction
  - Detailed (1km resolution) precipitation and runoff forecasts from Deep Thunder
  - 1m LiDAR Digital Terrain Models (DTMs)
  - GIS maps of soil type, land occupation, and city structure (streets, lakes, rivers, etc)
  - Limited digital drainage data was available
  - Very good historical flooding data was available (catalogued at least 232 recurrent locations)

- Determine if a site, which is historically prone to flooding, could receive a surface runoff flow leading to a flooding event
Flood Model Example – April 2010 Event Hindcast

IBM Deep Thunder for Rio de Janeiro

- Final frame of an animation that depicts hourly changes of the flooding through 48 hours
- The gravity-driven terrain channeling is shown clearly
Yellow shows areas flooded during the April 2010 event in a relatively small portion of the city (left and right)

Predicted flood areas for the April 2010 event (overlaid on the right)
Next Steps

- **Continue operational evaluation**
  - Refine verification metrics and incorporate additional observations, where feasible

- **Enhance meteorological model and delivery**
  - Based upon the verification results, adjust model physics and configuration
  - Incorporate additional local data to improve surface representation

- **Enhance hydrological model and delivery**
  - Operational implementation of more comprehensive hydrological model for flood and impact forecasting
Backup

Slides
Global Forecasting System:
T574L64, 8 days
Ensemble model, 4x/day, various products and resolutions
Spectral, spherical solution

Data Used to Generate
- Boundary conditions
- Initial conditions
- Forecast verification
- Calibration of model and observations

IBM Deep Thunder

Surface Observations and Local Radar

Data Flow for Rio
Uses of Weather and Flood Prediction in Rio de Janeiro

- **Alerta Rio**
  - Landslides Monitoring and Alert System

- **SMAC**
  - Environment, Air Monitoring

- **Rio Águas**
  - Water Levels, Lakes, Hydrographic Basins, Ocean

- **IPP**
  - Instituto Pereira Passos
  - Geography, cartography, topography, vegetation, urban occupancy and soil usage

- **User**

- **Hydrological Model**

- **Center of Operations**

- **Mayor's Office**

- **Alerta Rio**

- **CET-RIO**

- **Rio Águas**
Command Center for Rio de Janeiro
Weather Model Configuration

Four 2-way telescoping nests at 27, 9, 3 and 1 km horizontal resolution focused on Rio de Janeiro.

65 vertical levels with 10 to 20 in the planetary boundary layer.
Web-Based Forecast Dissemination at the Command Center
Web-Based Forecast Dissemination at the Command Center
### Web-Based Forecast Dissemination at the Command Center

#### Previsão Meteorológica de Alta Resolução - PMAR - Rio de Janeiro

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<th>Precipitation (mm)</th>
<th>Precipitation Rate (mm/hr)</th>
<th>Pressure (mb)</th>
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**Note:** The data is valid for 1/08/2011 00:00 BRT through 1/08/2011 23:00 BRT and updated every 60 minutes after 1/08/2011 23:00 BRT.
Interactive 3d Visualization Application

IBM Deep Thunder for Rio de Janeiro
Surface Precipitation Rate
Cloud Water Density at 1.0e-03 kg/kg

06-Apr-2010 - 01:40 BRT
Interactive 3d Visualization Application
Hindcast of the Severe Rainfall Event of 5-6 April 2010 at 1 km Resolution

Animation of three-dimensional forecasted clouds with terrain surface and precipitation
Hindcast of the Severe Rainfall Event of 5-6 April 2010 at 1 km Resolution

Animation of forecasted winds
Hindcast of the Severe Rainfall Event of 5-6 April 2010 at 1 km Resolution

Animation of storm intensity
Hindcast of the Severe Rainfall Event of 5-6 April 2010 at 1 km Resolution
Hindcast of the Severe Rainfall Event of 5-6 April 2010 at 1 km Resolution

Site-specific forecast at the location of a rain gauge in Rio de Janeiro
Forecast Validation Assumptions

Focus on amount of precipitation connected to the process of using the forecasts for issuing warnings, etc.

- Analyze the amount of rainfall reported hourly at each of the 33 GeoRio rain gauges within every 12-hour period
  - Given length and update rate of forecasts, implies 13 values to compare every 12 hours for each rain gauge

- Compare measurements at each rain gauge with each 48-hour forecast at that location derived from 8100 points on the computational grid

- Categorize the rainfall measurements and forecasts as follows, based upon the response to rainfall events of different magnitudes
  - Weak: < 5 mm
  - Moderate: 5 – 25mm
  - Strong: 25 – 50mm
  - Very strong: > 50mm

- Assume that each rain gauge measures rainfall accurately
  - Tipping buckets may under report amounts for strong and very strong events
Forecast Validation Approach

- Rainfall measurements are categorical (i.e., did it rain or not, by defined criteria)
  - Given the four categories, use a 4x4 contingency table with forecasts shown by row and measurements by columns

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<td>Very Strong</td>
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- Forecast accuracy is based upon the percentage correct on the diagonal (i.e., the forecast has the amount of rainfall in the same category as observed during the 12-hour period)
Web-Based Forecast Dissemination at the Command Center