Enabling An Advanced Numerical Weather Prediction Model for Operational Forecasting in Rio de Janeiro

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Other Presentations of Related Work

Conference on Hydrology:

- 4.5 Flooding Forecasting in the City of Rio de Janeiro Using Historical Data

Conference on Interactive Information Processing Systems:

- 3B.2 Creating a Numerical Weather Prediction-Based Infrastructure for Research and Operations in Brunei
- 10A.4 Implementation and Operation of Mesoscale Numerical Weather Prediction Modeling Systems

Conference on Weather, Climate, and the New Energy Economy:

- 3.2 Methodology for Analyzing and Comparing Weather Forecasts for Use in Business Applications
- 571 On-Going Utilization and Evaluation of a Coupled Weather and Outage Prediction for Electric Distribution Operations

Enabling An Advanced Numerical Weather Prediction Model for Operational Forecasting in Rio de Janeiro

- Motivation and background
- Approach
- Status
- Examples
- Validation
- Next Steps

5-6 April 2010 Flooding Event

- 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 200 people and left 15000 homeless
- Widespread disruption of transportation systems (e.g., road closures, airport and rail delays)

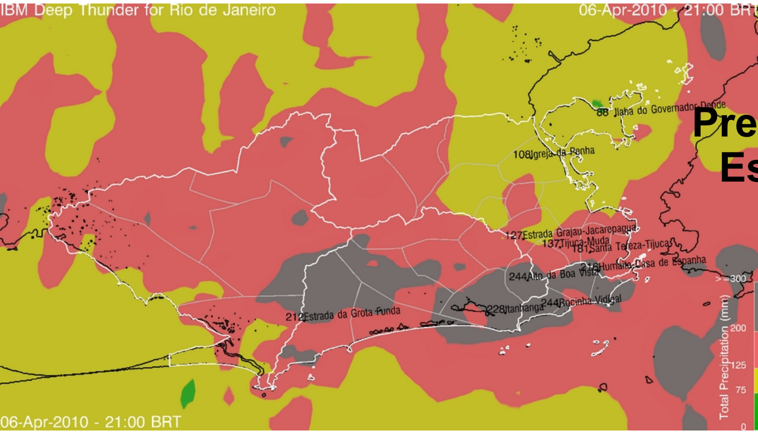
Approach

- **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

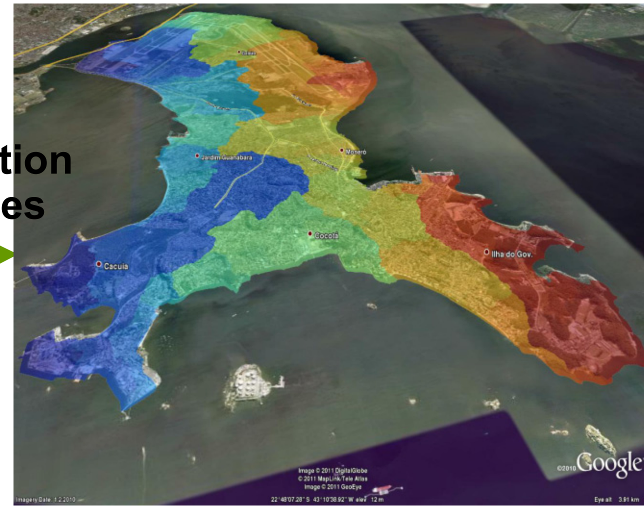
- **Retrospective analysis of key, historical events**
  - Many numerical experiments to enable effective model configuration for research and operations, addressing computational and physics issues as well as verifiable hindcasts
- **Considerations**
  - TRMM-based climatology suggests a broad stratiform 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

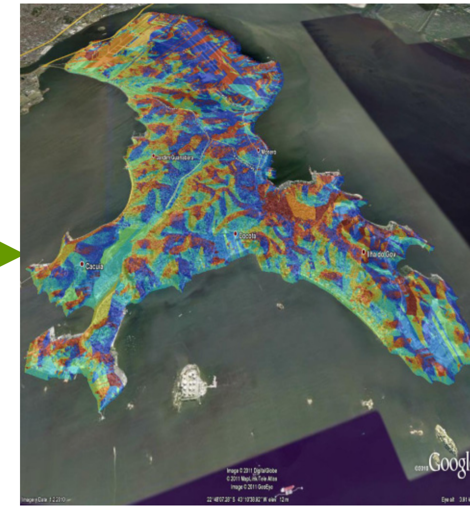


Weather Prediction and/or Rainfall Measurements

Precipitation Estimates



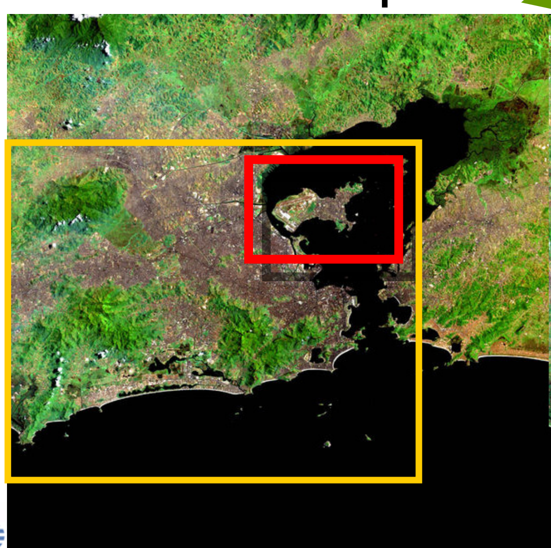
Analysis of Precipitation



Flood Prediction

Refine Sensor Network and Model Calibration

Actual Flood Impacts



Model Calibration

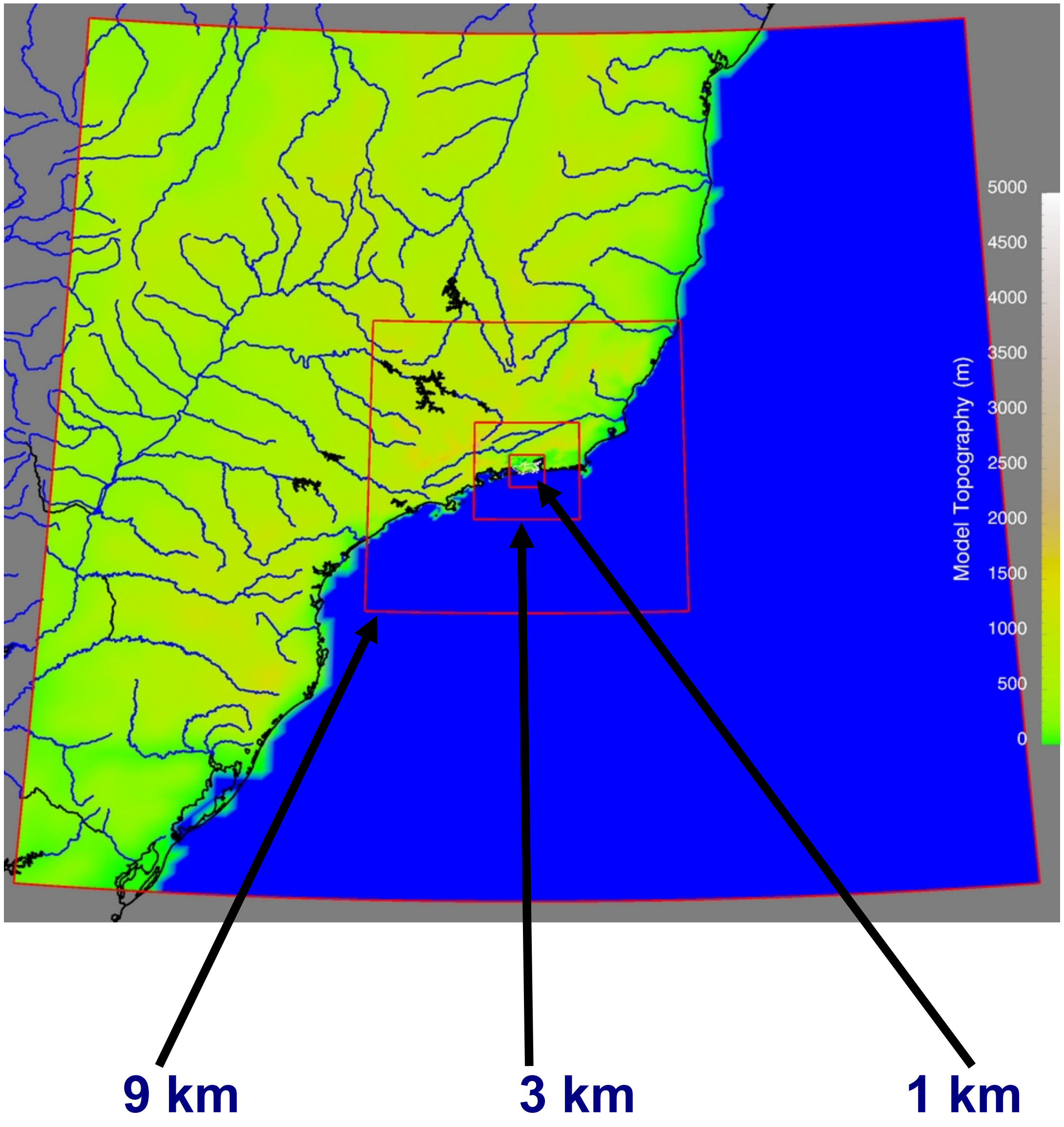
Impact Estimates

Status

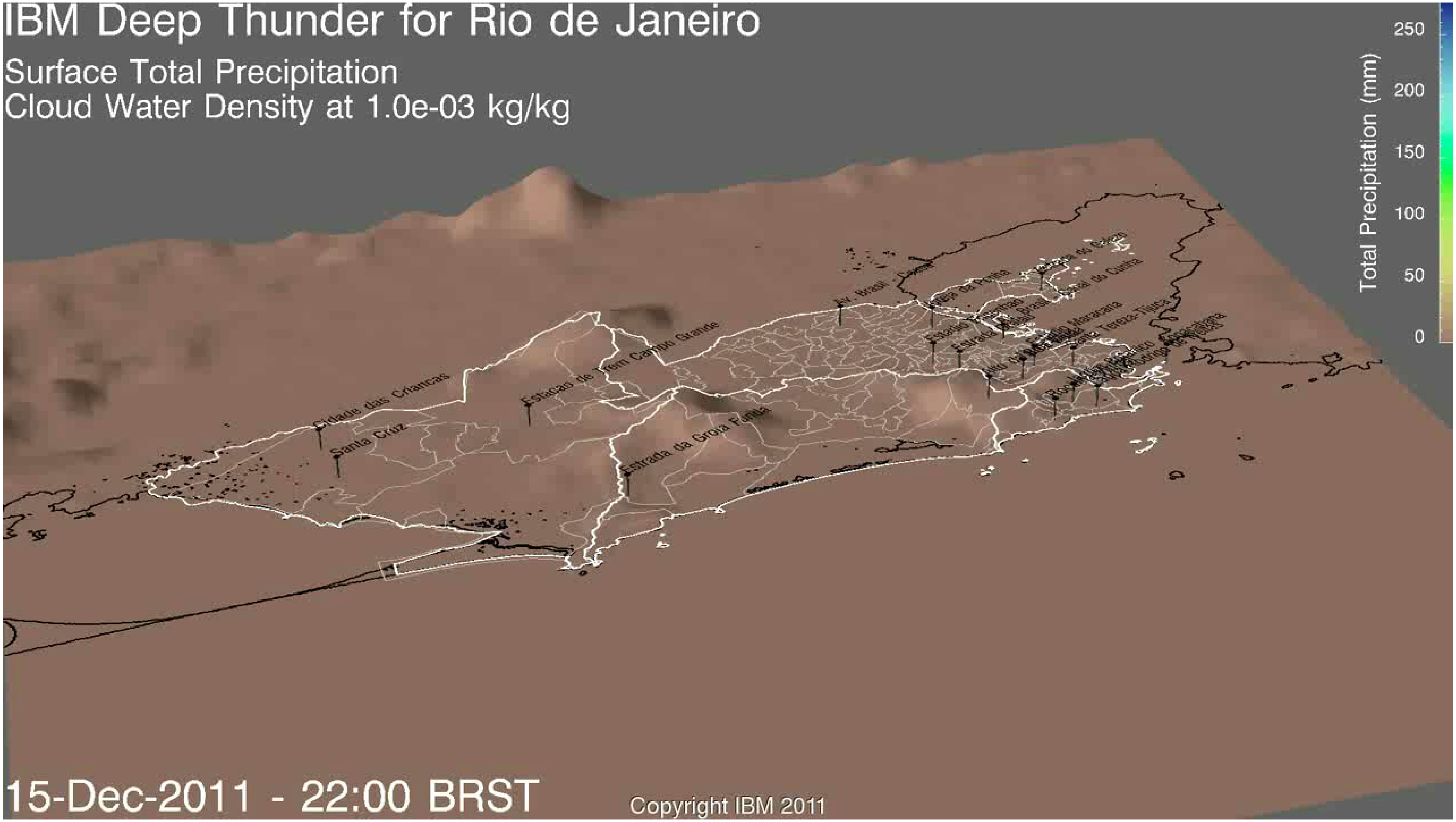
- R&D enabled high-resolution operational weather forecasting starting in May 2011
  - 48-hour forecast updated every twelve hours, generated at IBM Yorktown
  - Disseminated via a web portal ("Previsão Meteorológica de Alta Resolução" or PMAR [High-Resolution Weather Forecast]) at the client site through 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 (Hydrology 4.5)
  - 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

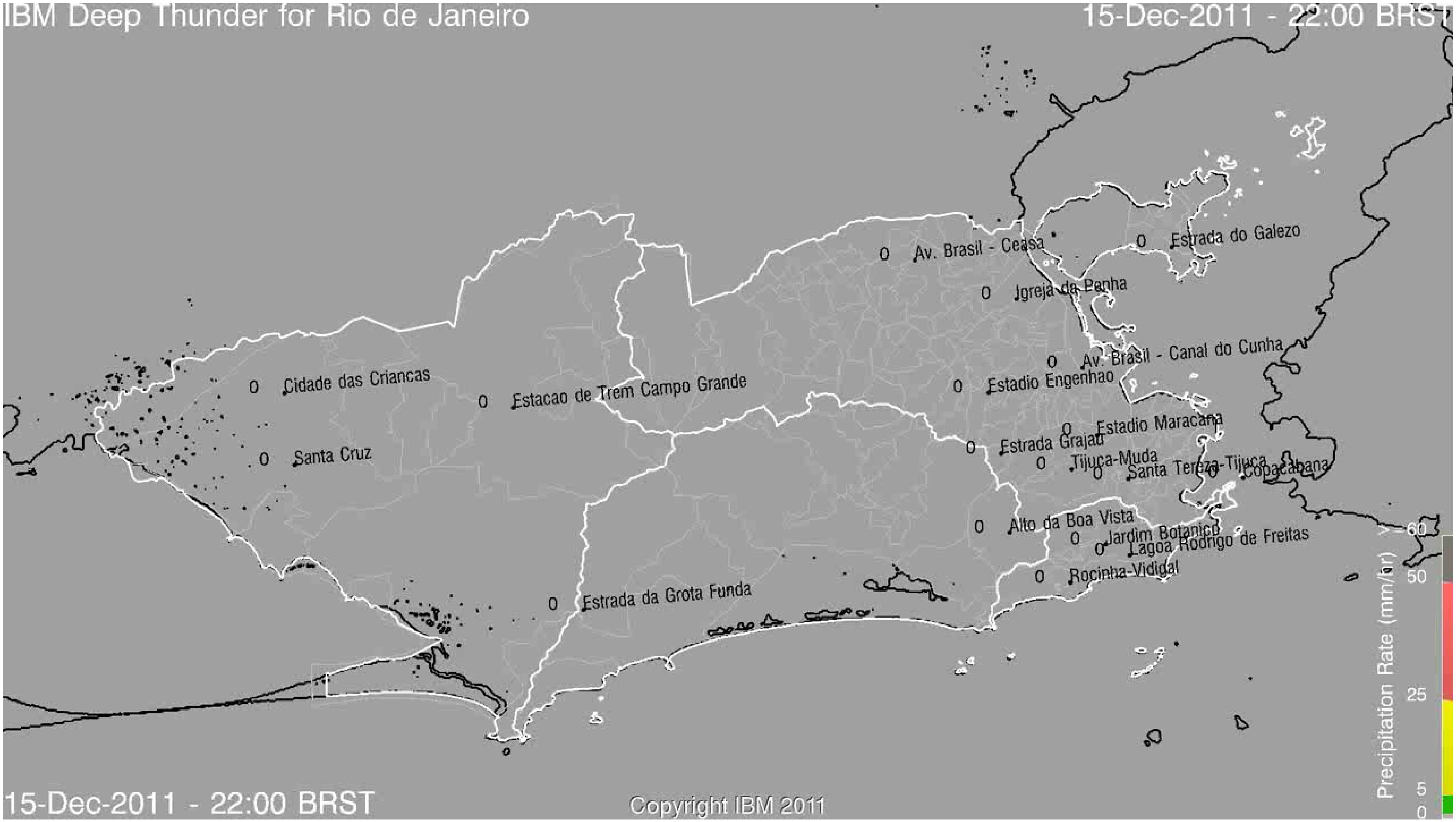


Operational Forecast of 16-17 December 2011 Rainfall Event



Animation of three-dimensional forecasted clouds with terrain surface and precipitation

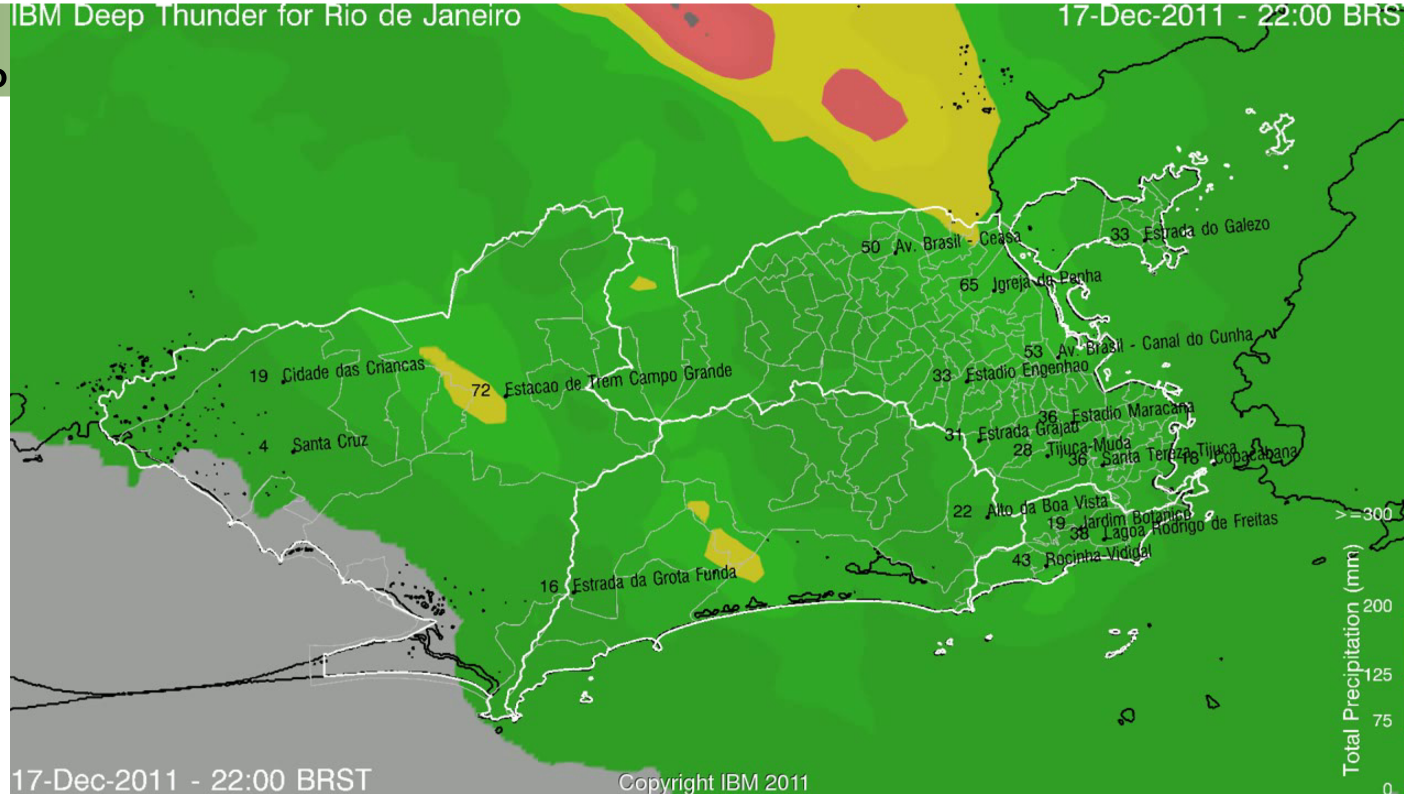
Operational Forecast of 16-17 December 2011 Rainfall Event

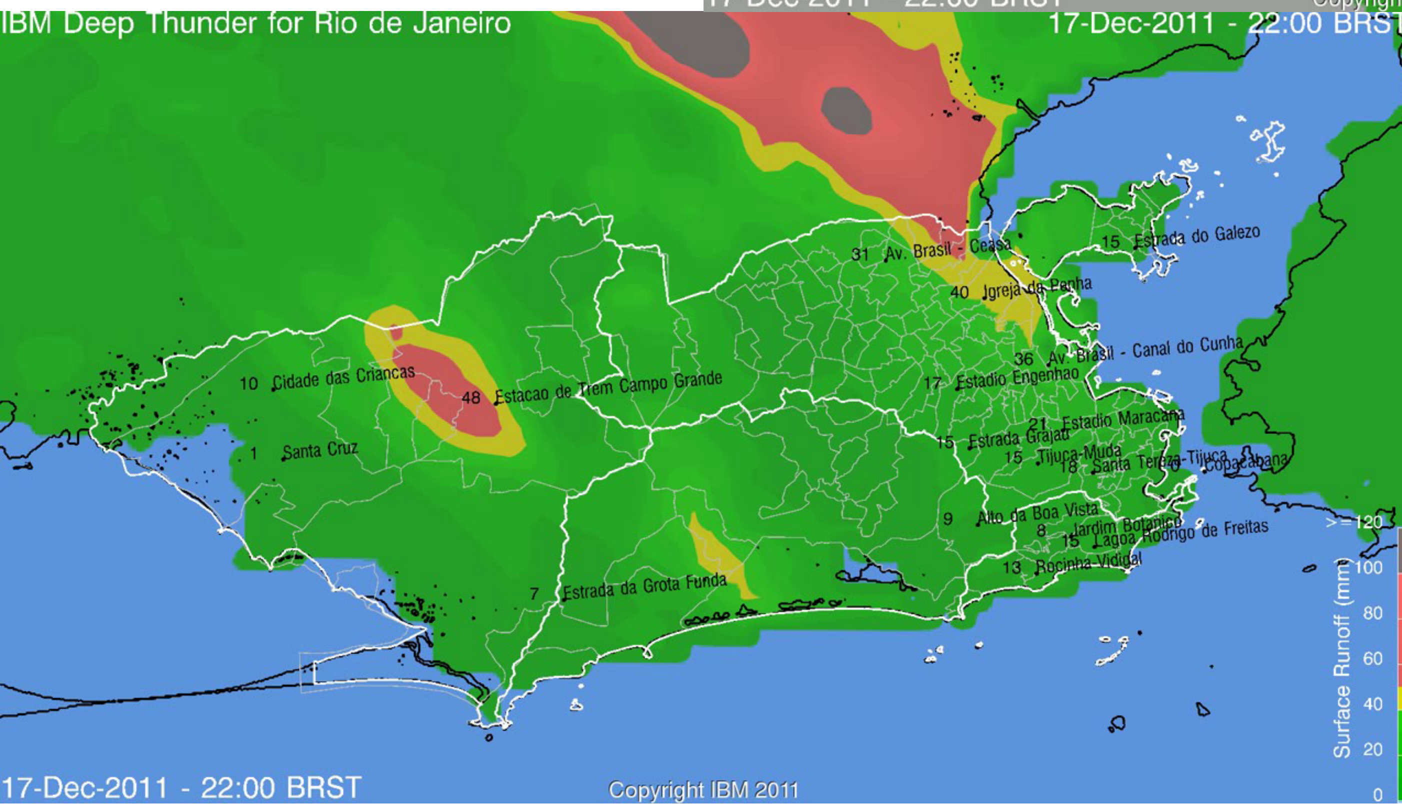


Animation of forecasted precipitation rate

Conference o

Operational Forecast of 16-17 December 2011 Rainfall Event

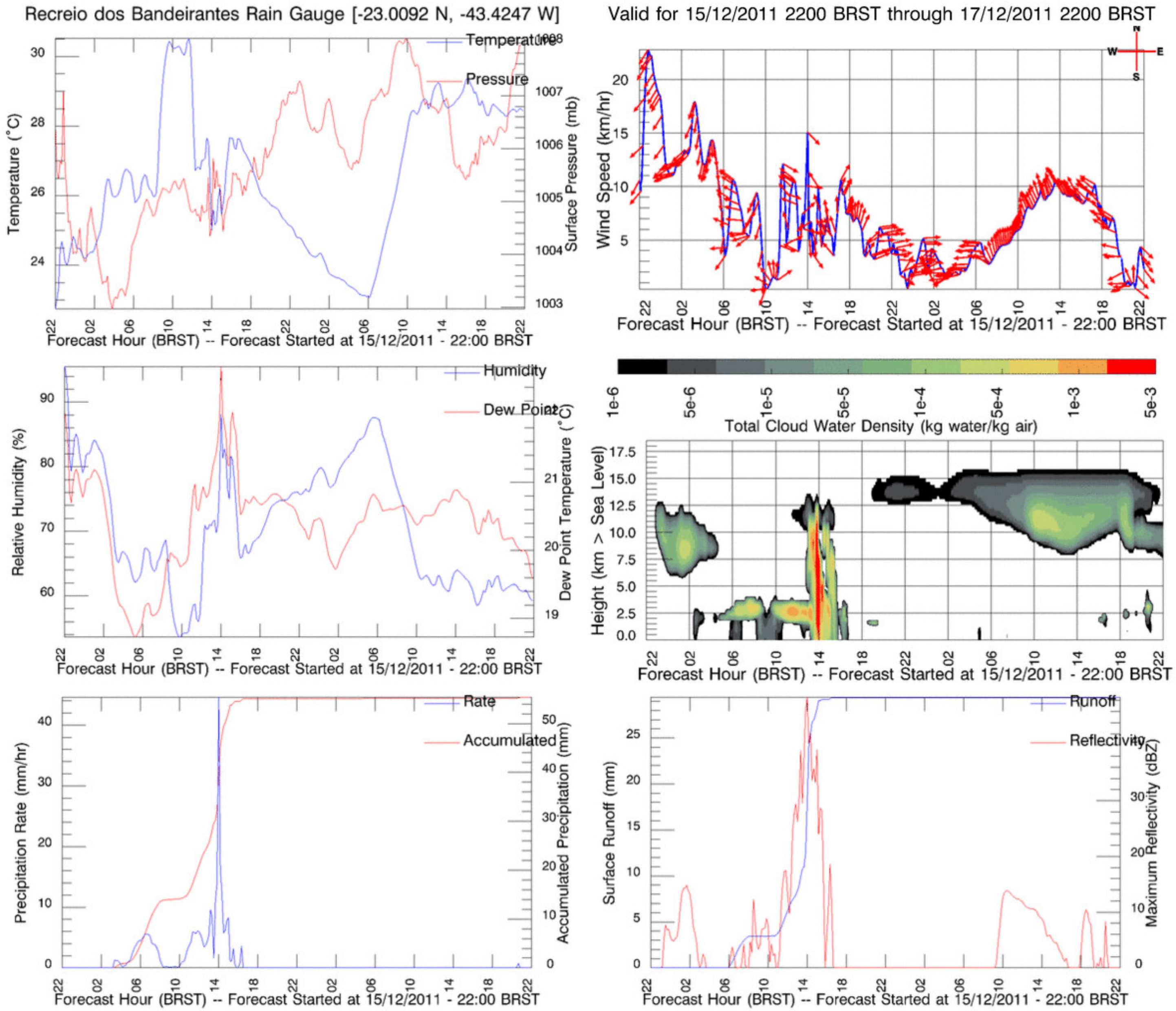




Rainfall Totals

Runoff Totals

Operational Forecast of 16-17 December 2011 Rainfall Event



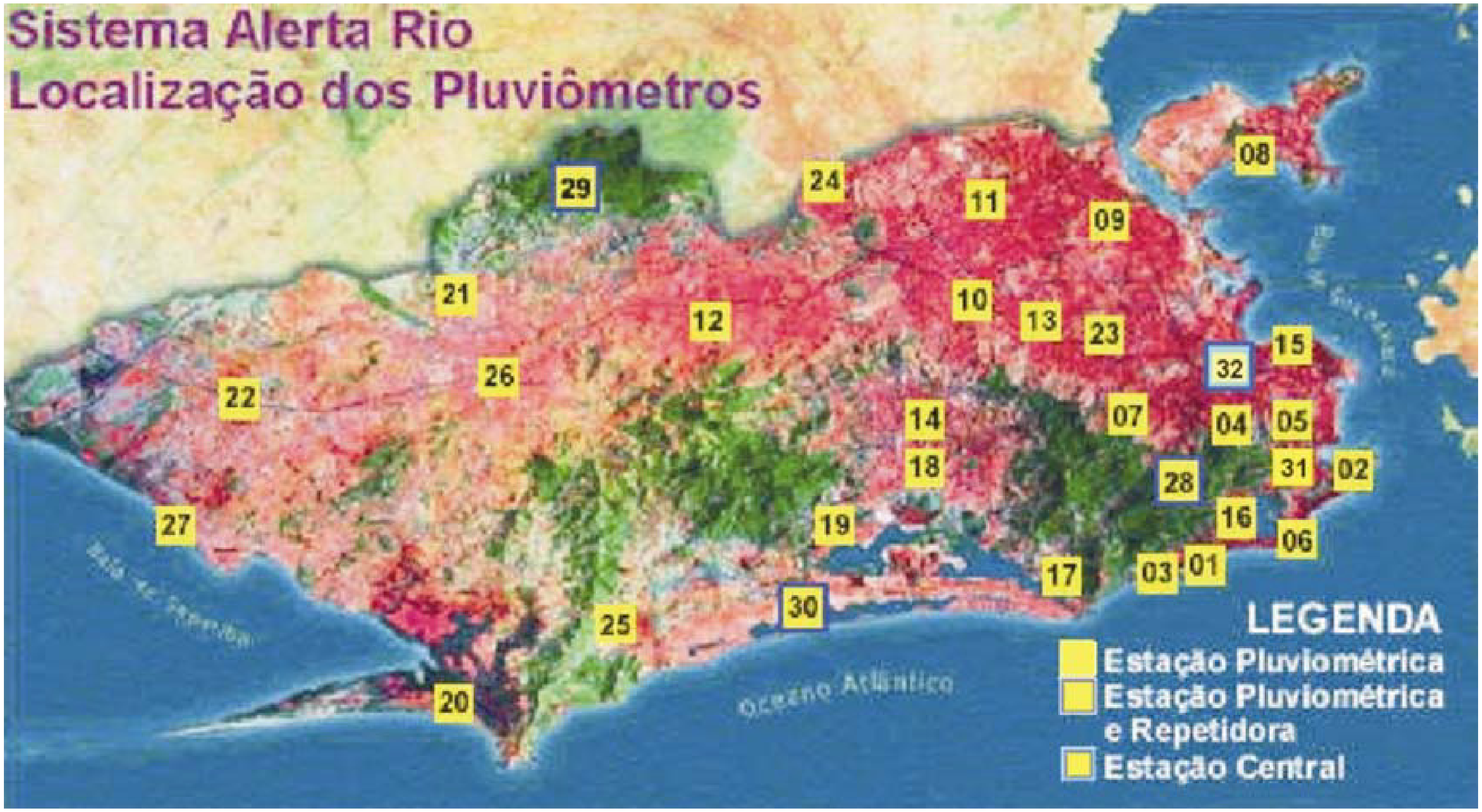
Site-specific forecast at the location of a rain gauge in Rio de Janeiro

Precipitation Forecast Validation

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

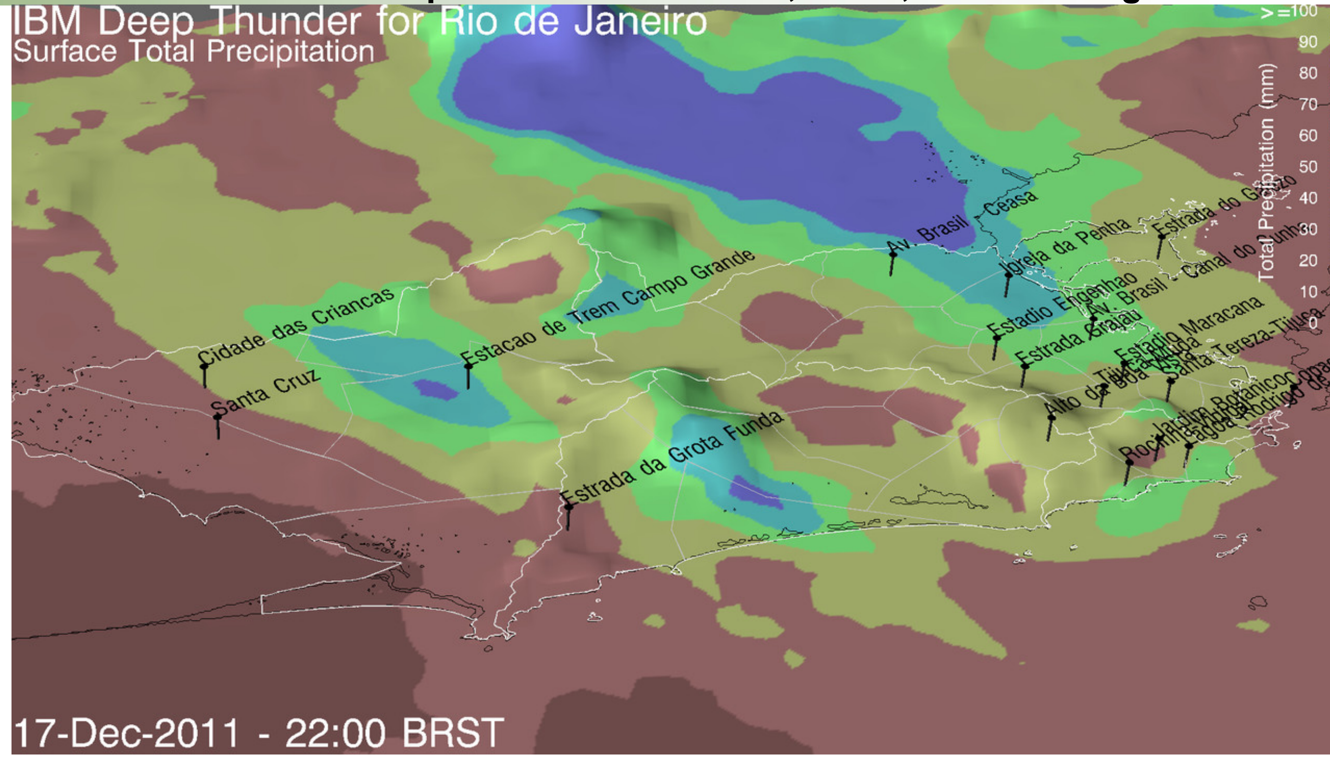
- Analyze the amount of rainfall reported hourly at each of the 33 rain gauges within every 12-hour period
  - Given length and update rate of forecasts, implies 13 values to compare every 12 hours for each rain gauge
- Categorize the rainfall measurements and forecasts based upon the response to rainfall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

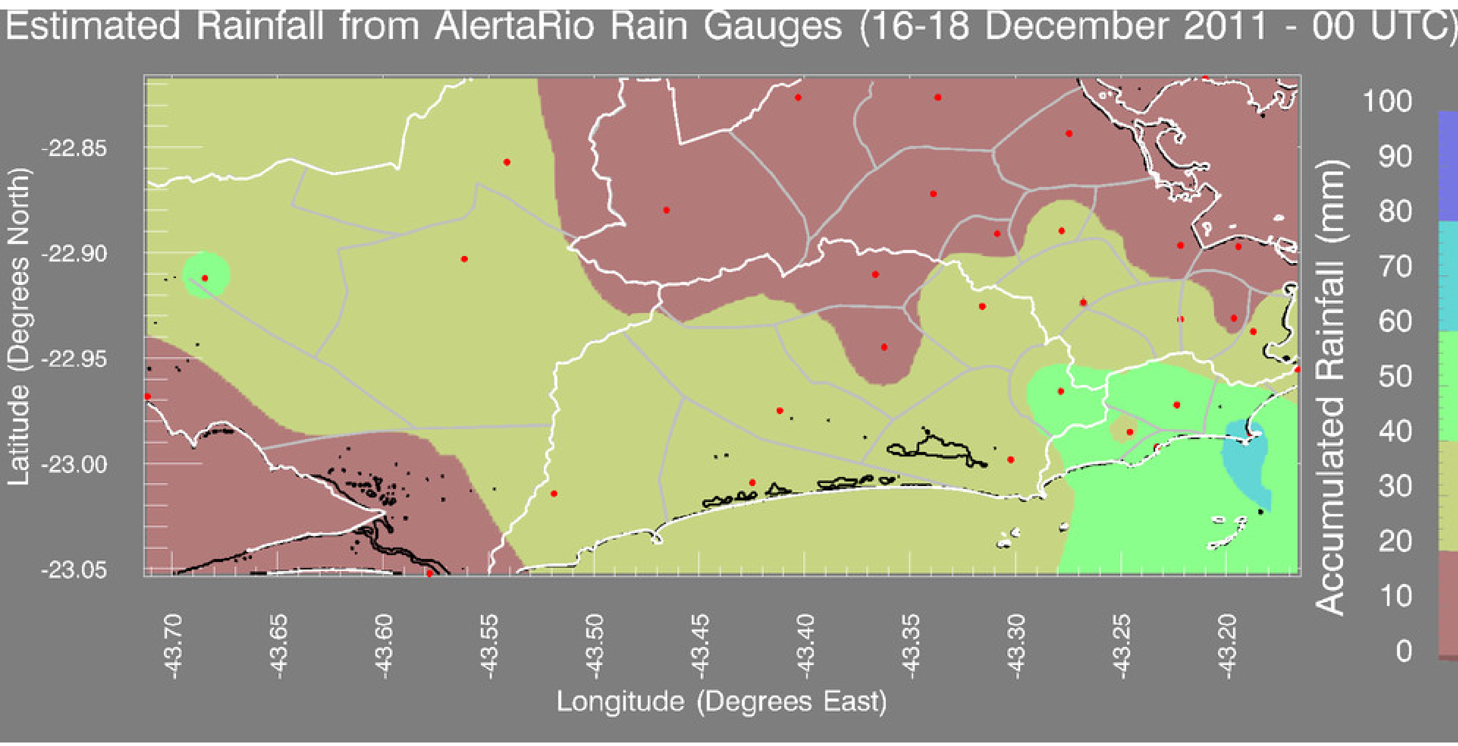
Rain Gauge Network in Rio de Janeiro



Precipitation measurements used for model validation

Rainfall Forecast vs. Observations: 16-17 December 2011



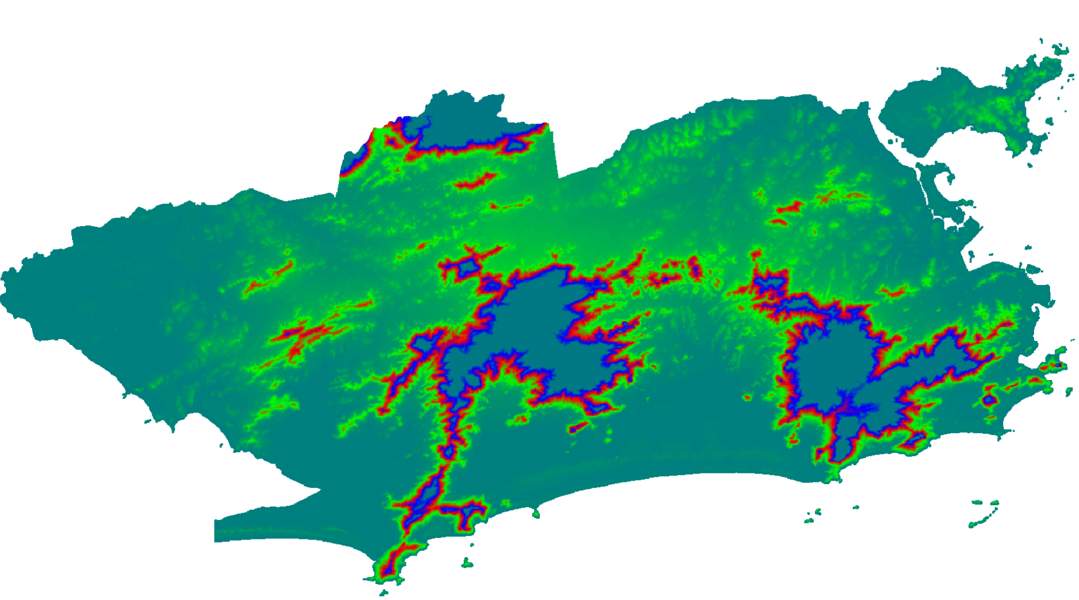


Forecast Accuracy based upon the four categories = 0.947

Summary of Forecast Validation Results

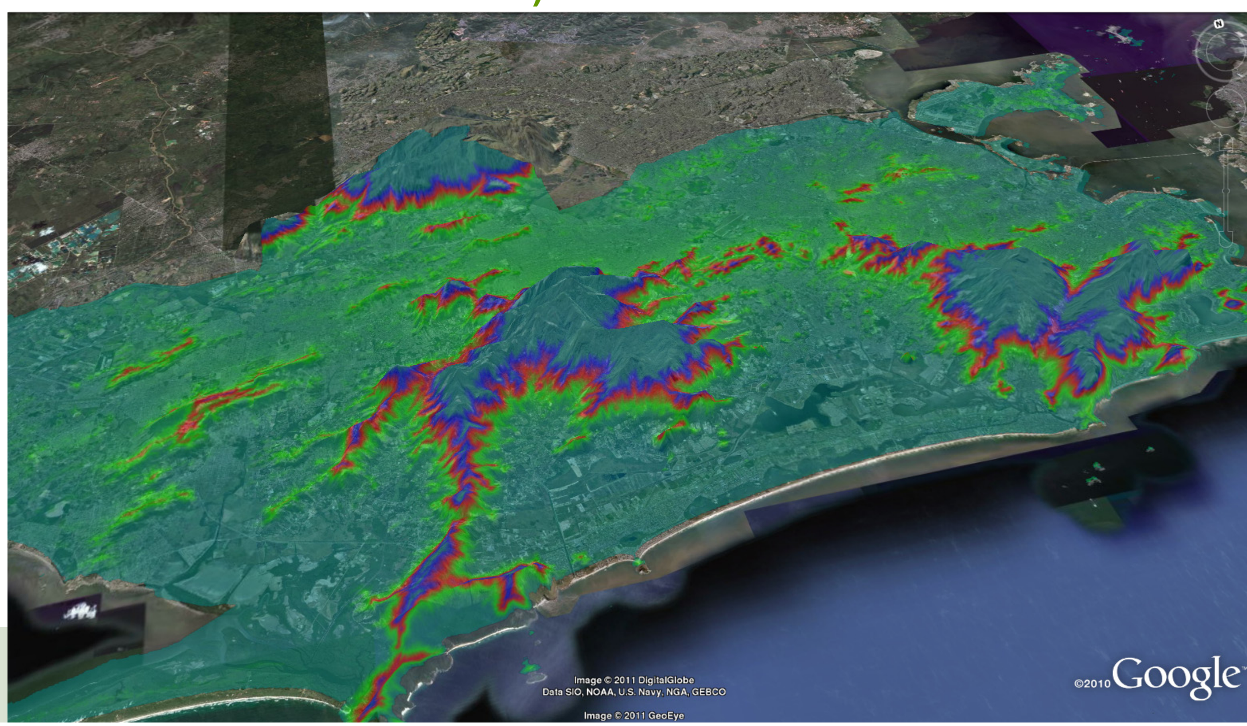
- **Accuracy averaged over all rain events from 26 May 2011 through 08 January 2012 by 12-hour periods for all categories**
  - **Hour 00-12: 93.6%**
  - **Hour 12-24: 91.8%**
  - **Hour 24-36: 93.1%**
  - **Hour 36-48: 92.8%**
- **Accuracy averaged over rain events from 26 May 2011 through 08 January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

Flooding Model

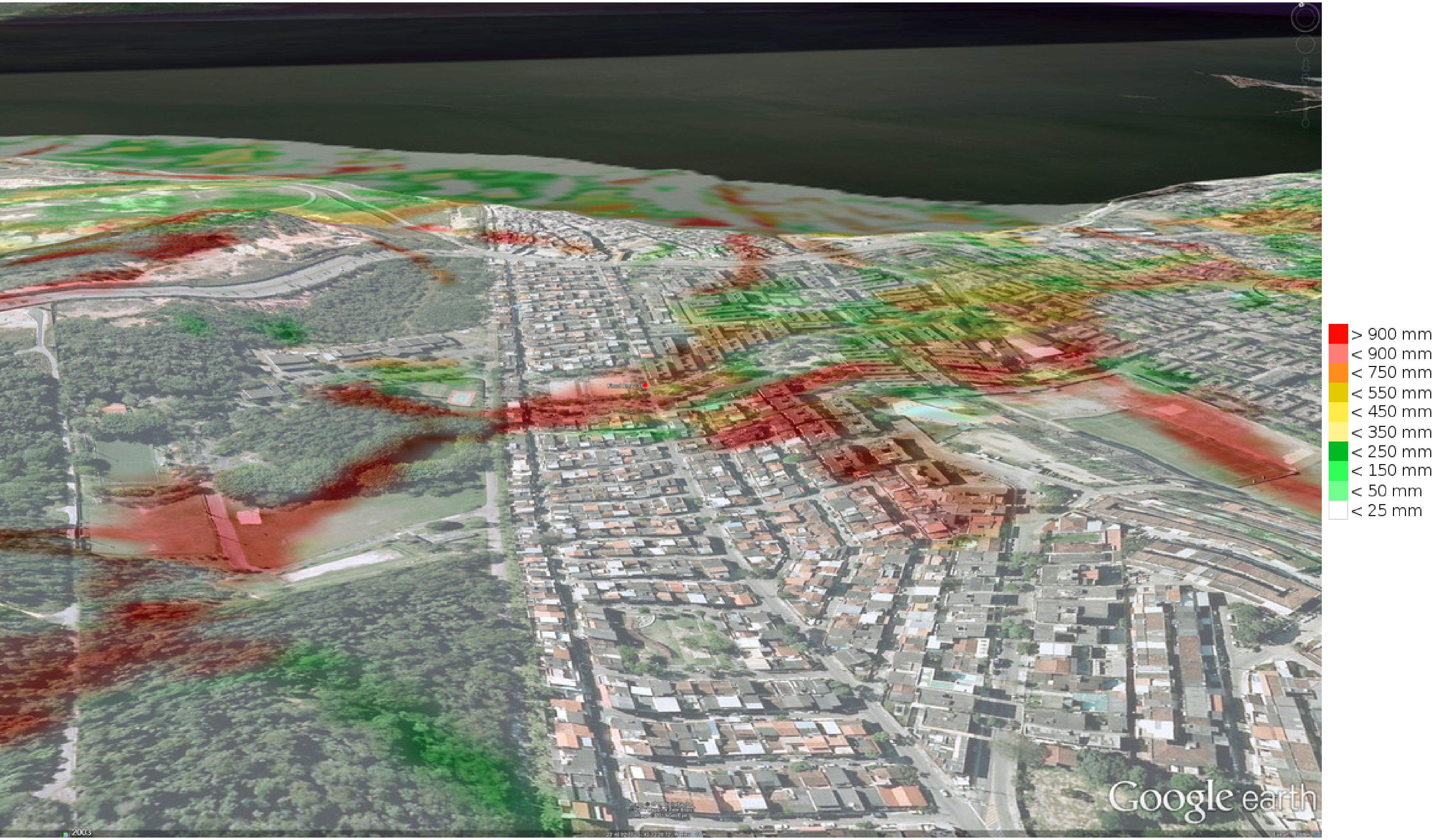


- Given available data developed a simplified high-resolution analytical model for flood prediction
  - Detailed (1km resolution) precipitation and runoff forecasts from Deep Thunder
  - 1m LiDAR Digital Terrain Models (DTMs)
  - GIS maps of soil type, land occupation, and city structure (streets, lakes, 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
- Hydrology 4.5: “Flooding Forecasting in the City of Rio De Janeiro Using Historical Data”



Flood Model Example: Hindcast for 5-6 April 2010 Event



Next Steps

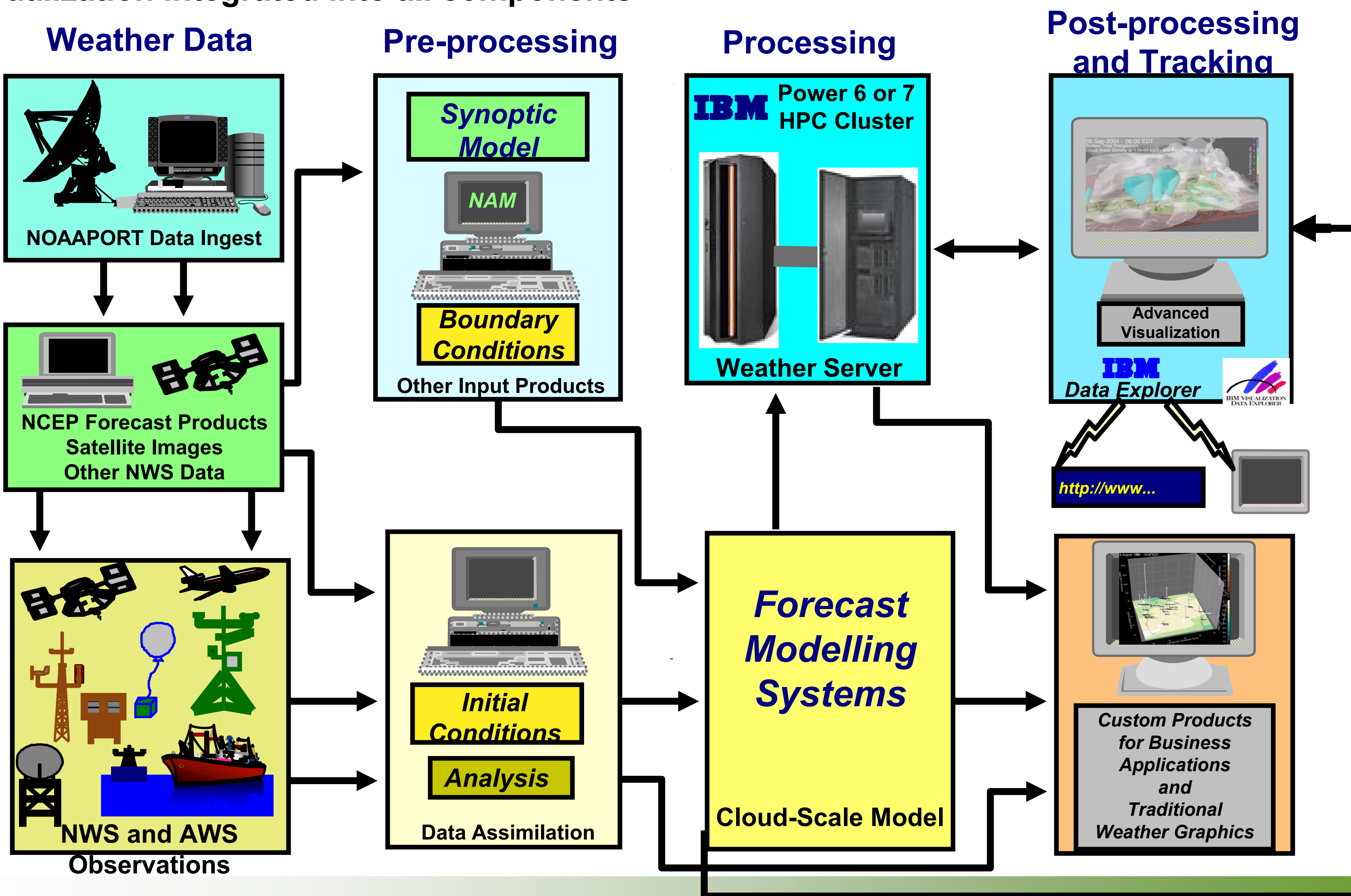
- **Continue operational evaluation**
  - Refine verification metrics and incorporate additional observations, where feasible
- **Enhance meteorological model and delivery**
  - Based upon the verification results, adjust model physics and configuration
  - Incorporate additional local data to improve surface representation
- **Enhance hydrological model and delivery**
  - Operational implementation of more comprehensive hydrological model for flood and impact forecasting

Backup

Slides

Deep Thunder Implementation and Architecture

- User-driven not data-driven (start with user needs and work backwards)
- Sufficiently fast (>10x real-time), robust, reliable and affordable
- Ability to provide usable products in a timely manner
- Visualization integrated into all components



Simplified *Deep Thunder* Processing Data Flow for Rio

NOAA (NCEP)

- **<u>Global Forecasting System</u>**: T574L64, 8 days
- Ensemble model, 4x/day, various products and resolutions
- Spectral, spherical solution

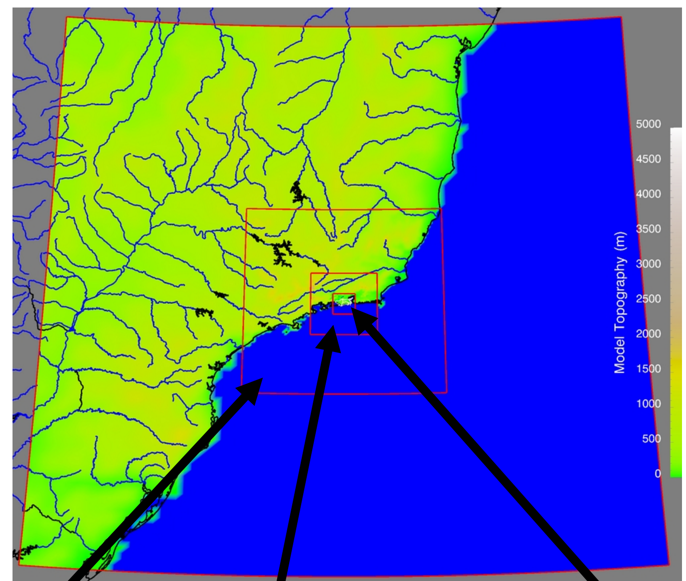
Observations

Surface Observations and Local Radar

Data Used to Generate

- **Boundary conditions**
- **Initial conditions**
- **Forecast verification**
- **Calibration of model and observations**

IBM *Deep Thunder*



9 km **3 km** **1 km**

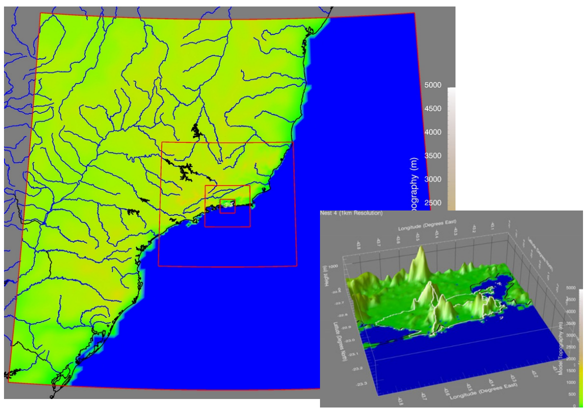
Uses of Weather and Flood Prediction in Rio de Janeiro

Alerta Rio
(Landslides Monitoring and Alert System)

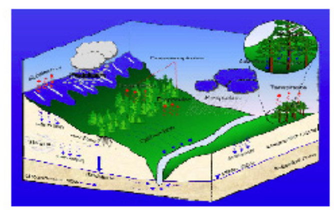
SMAC
(Environment, Air Monitoring)

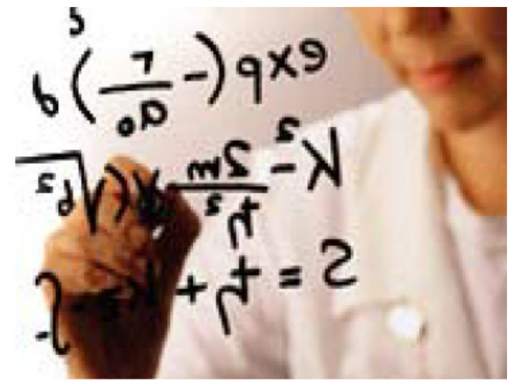
Rio Águas
(Water Levels, Lakes, Hydrographic Basins, Ocean)

IPP
Instituto Pereira Passos
(Geography, cartography, topography, vegetation, urban occupancy and soil usage)



Hydrological Model





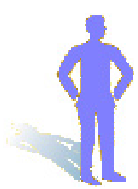
Center of Operations

CET-RIO

Mayor's Office

Rio Águas

Alerta Rio

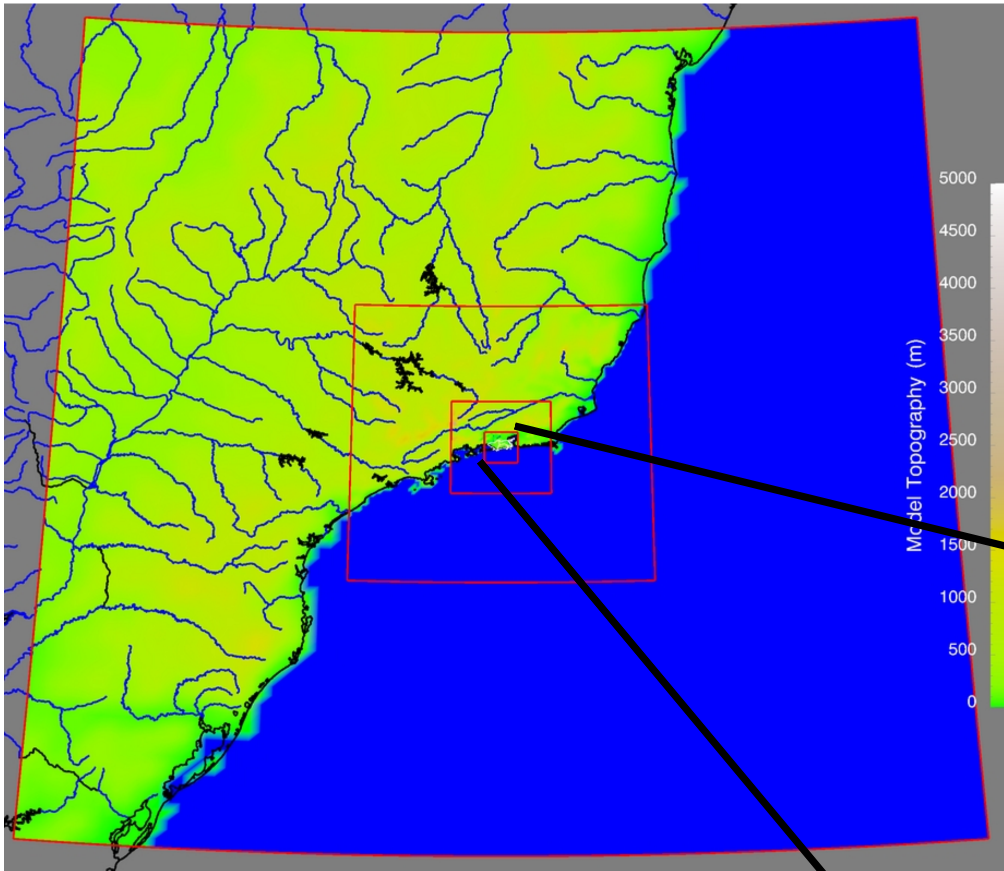


User

Command Center for Rio de Janeiro

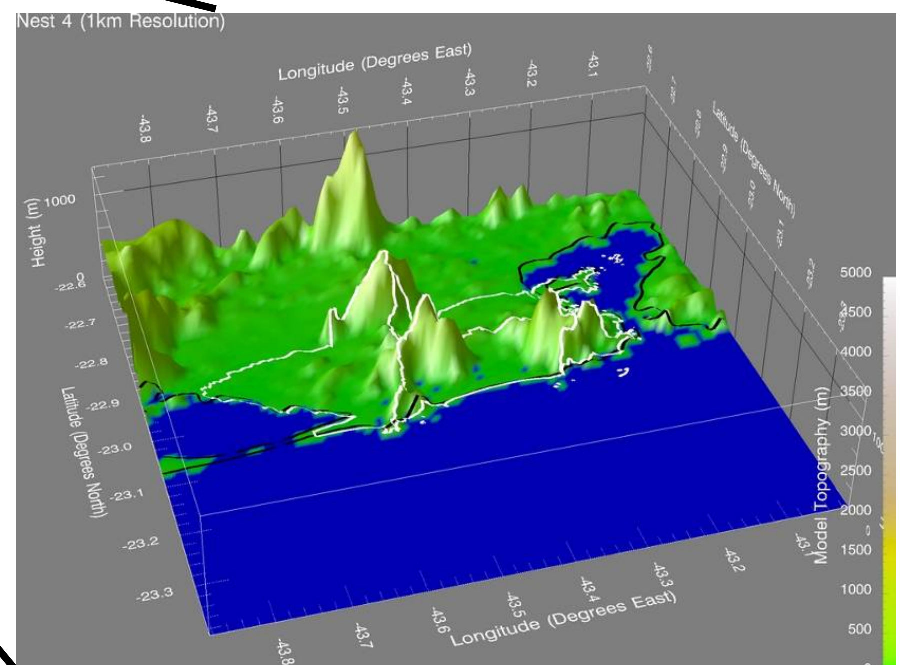
IBM

Weather Model Configuration

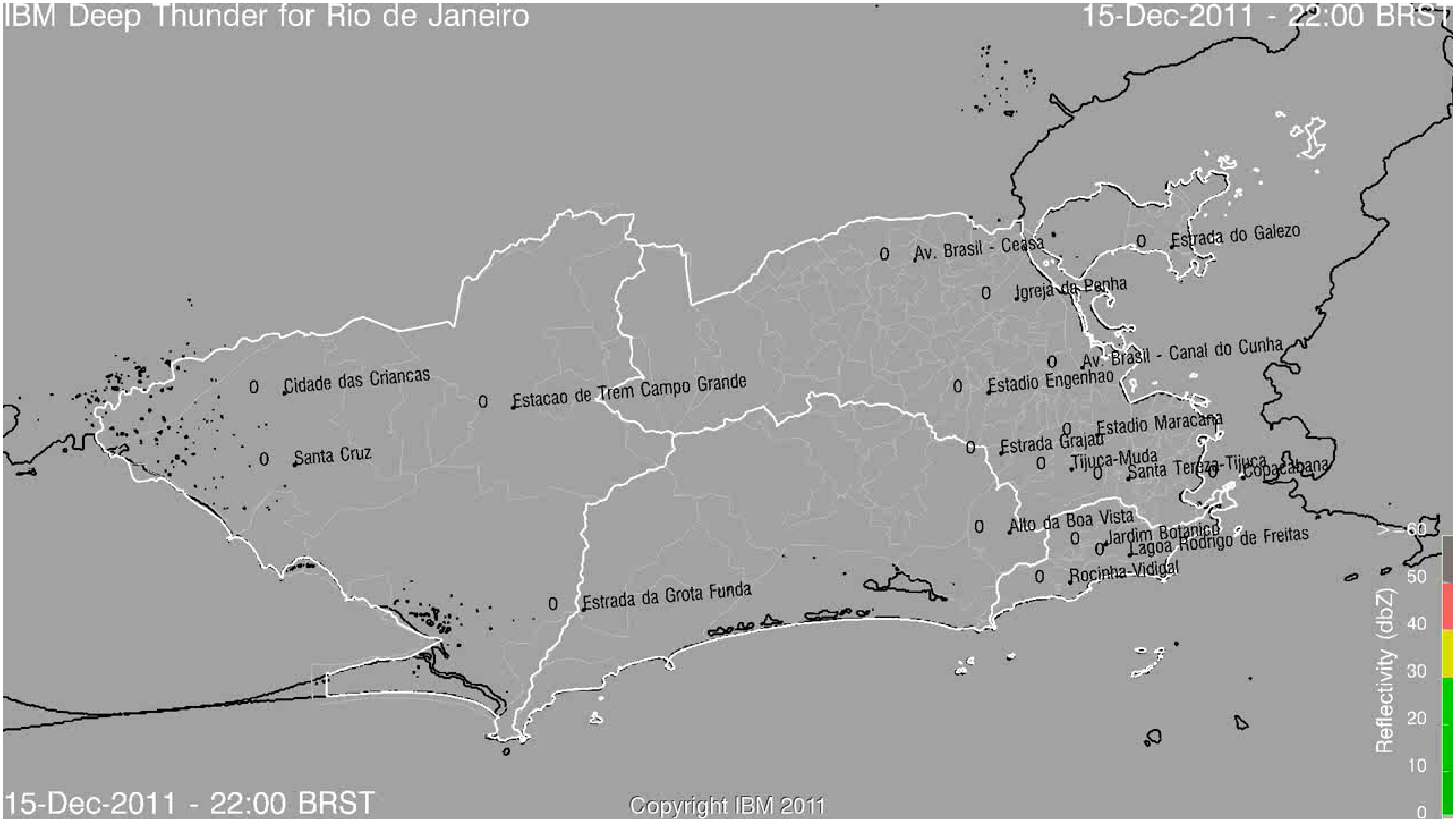


Four 2-way telescoping nests at 27, 9, 3 and 1 km horizontal resolution focused on Rio de Janeiro

65 vertical levels with 10 to 20 in the planetary boundary layer

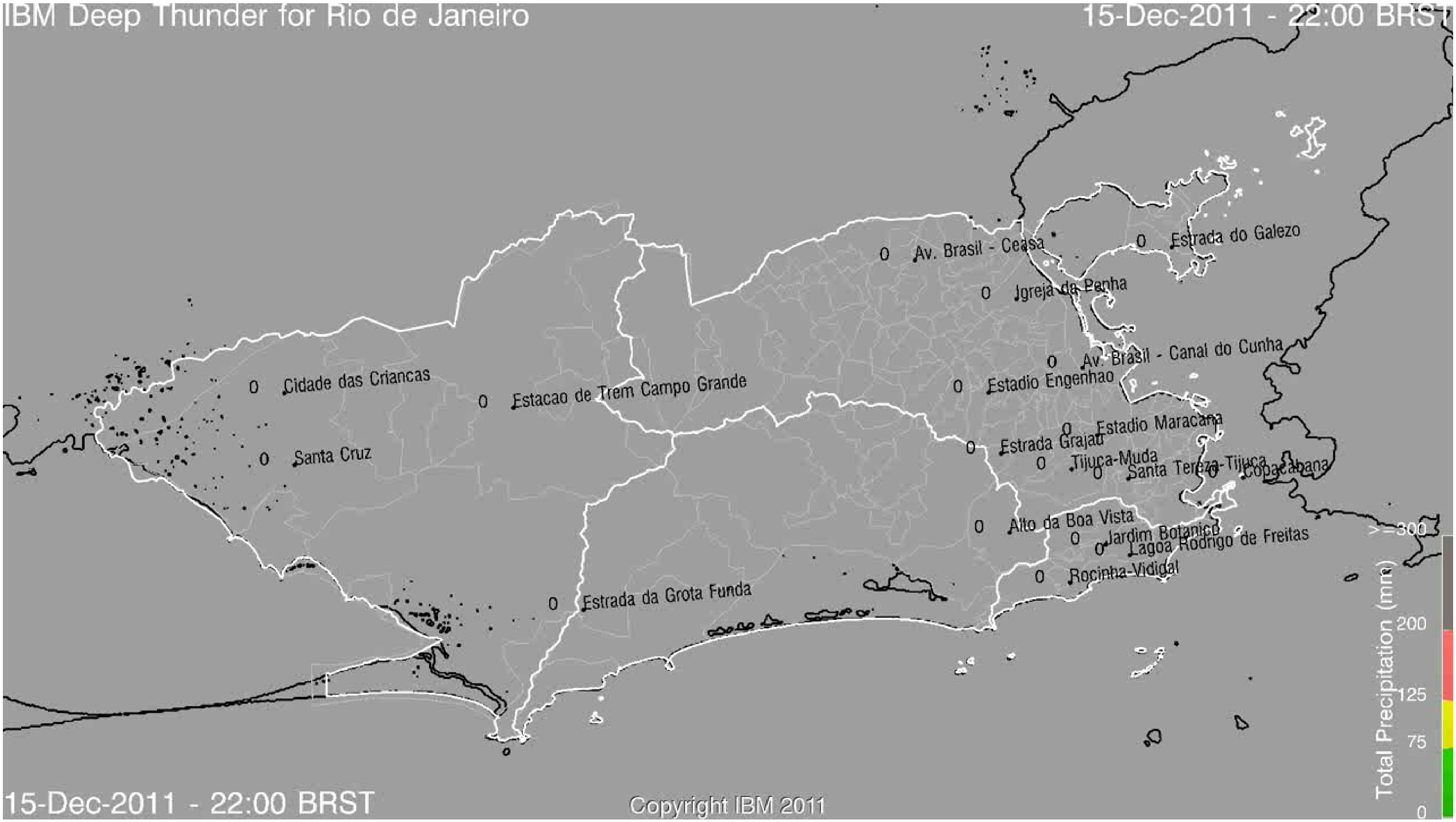


Operational Forecast of 16-17 December 2011 Rainfall Event



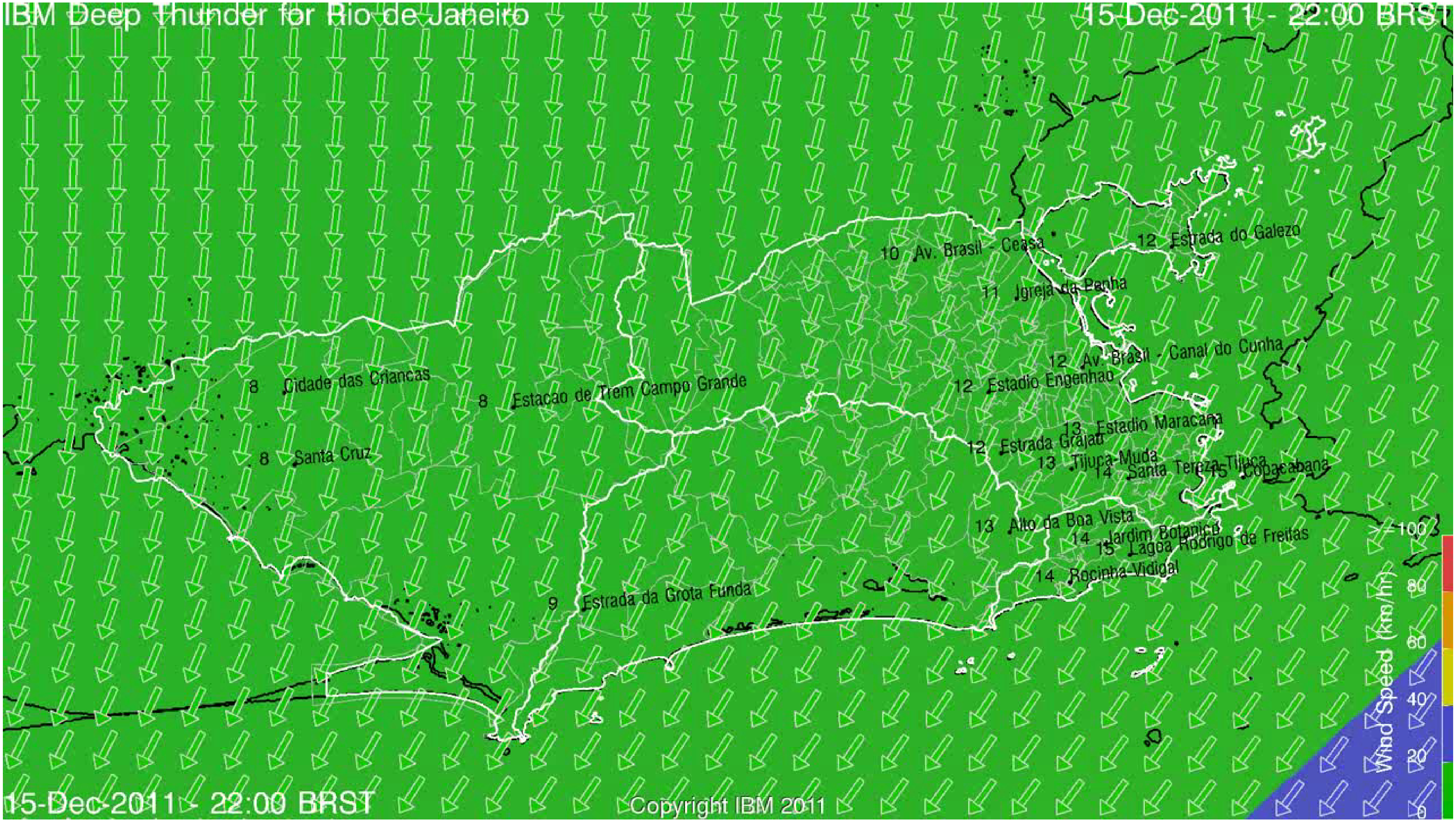
Animation of storm intensity

Operational Forecast of 16-17 December 2011 Rainfall Event



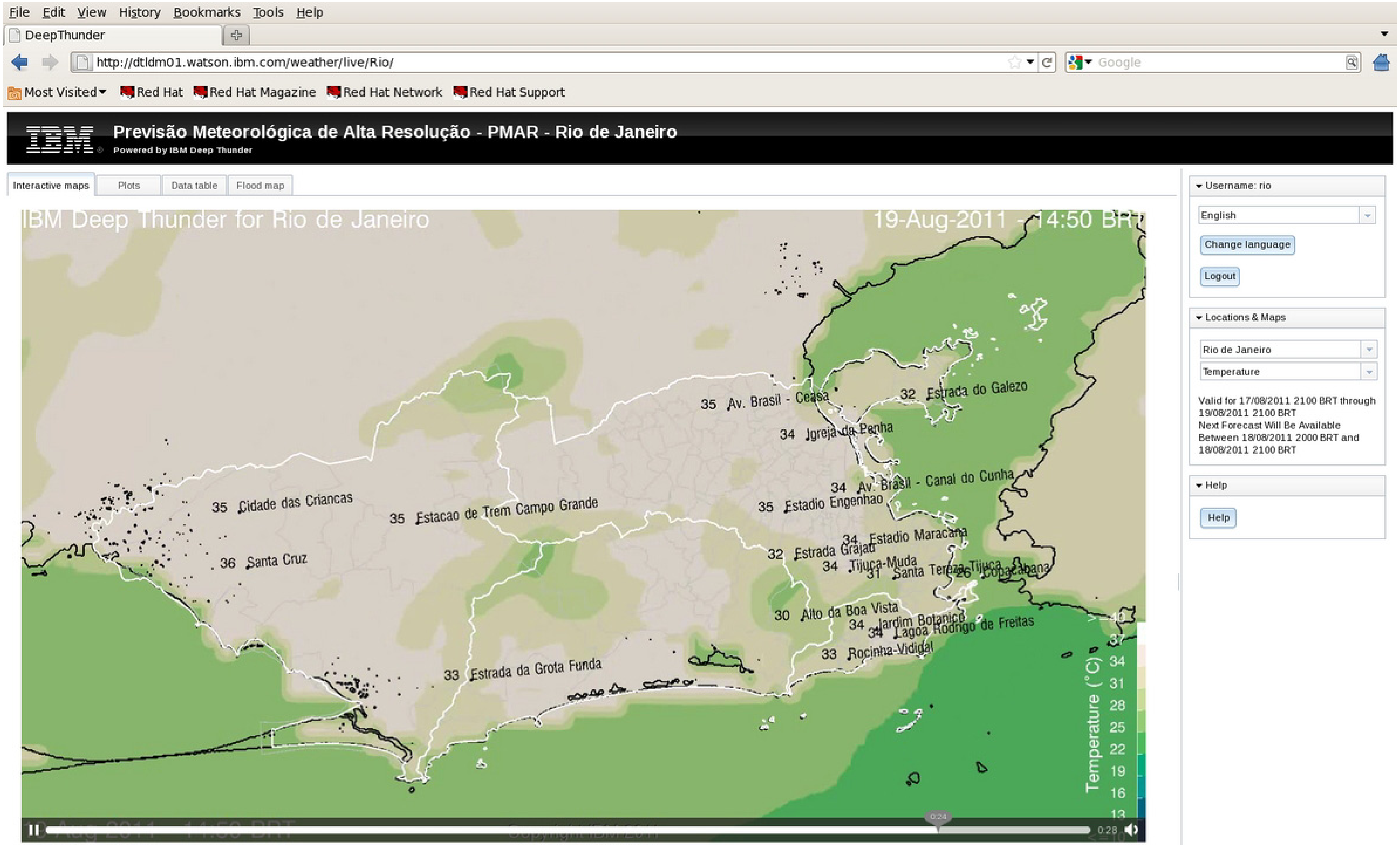
Animation of forecasted precipitation

Operational Forecast of 16-17 December 2011 Rainfall Event

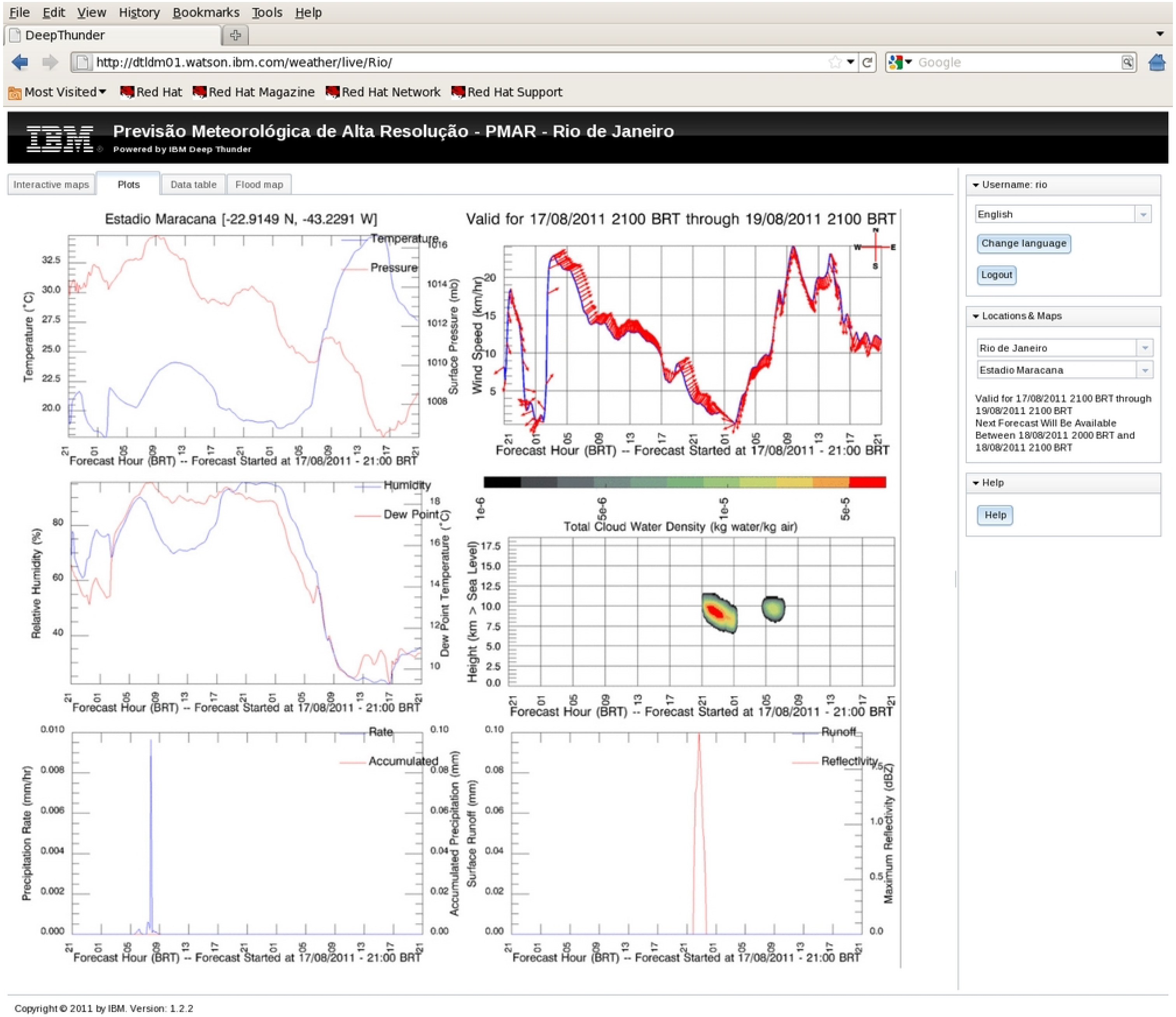


Animation of forecasted winds

Web-Based Forecast Dissemination at the Command Center



Web-Based Forecast Dissemination at the Command Center



Web-Based Forecast Dissemination at the Command Center

File Edit View History Bookmarks Tools Help

DeepThunder

http://dtldm01.watson.ibm.com/weather/live/Rio/

Most Visited Red Hat Red Hat Magazine Red Hat Network Red Hat Support

Previsão Meteorológica de Alta Resolução - PMAR - Rio de Janeiro

Powered by IBM Deep Thunder

Interactive maps | Plots | Data table | Flood map

Date	Time	Time Zone	Temperature (C)	Humidity (%)	Precipitation (mm)	Precipitation Rate (mm/hr)	Pressure (mb)	Wind Speed (km/hr)	Wind Direction (Degrees)	Dew Poir
17/08/2011	21:00	BRT	21.1	68.2	0	0	1014.7	8.2	53.9	15.1
17/08/2011	21:10	BRT	17.8	82.4	0	0	1013.7	6.3	19	14.6
17/08/2011	21:20	BRT	18.5	77	0	0	1014.1	10	7.4	14.2
17/08/2011	21:30	BRT	20.5	65.3	0	0	1014.1	15	11.3	13.6
17/08/2011	21:40	BRT	21.5	61.8	0	0	1014.4	20.1	9.7	13.7
17/08/2011	21:50	BRT	21.6	61.9	0	0	1014.3	22.7	6.3	13.9
17/08/2011	22:00	BRT	22	59.9	0	0	1013.7	22.9	3	13.7
17/08/2011	22:10	BRT	22.2	59	0	0	1014.2	21.7	2.3	13.7
17/08/2011	22:20	BRT	22.3	57.7	0	0	1013.7	20.2	1.3	13.4
17/08/2011	22:30	BRT	22.3	57	0	0	1014.1	19.5	3.8	13.3
17/08/2011	22:40	BRT	22	57.6	0	0	1013.9	18	3.2	13.1
17/08/2011	22:50	BRT	21.3	58.6	0	0	1014	15.6	359.1	12.7
17/08/2011	23:00	BRT	20.4	59.8	0	0	1014.1	12.2	353.7	12.3
17/08/2011	23:10	BRT	19.2	65.3	0	0	1014.4	5.8	310.1	12.5
17/08/2011	23:20	BRT	18.4	73.5	0	0	1014.2	6.4	233.4	13.5
17/08/2011	23:30	BRT	18.2	77.8	0	0	1014.2	5.6	212.8	14.2
17/08/2011	23:40	BRT	18.2	77.8	0	0	1014.6	4.3	205.5	14.2
17/08/2011	23:50	BRT	18.2	78.1	0	0	1014.8	3.3	195.5	14.2
18/08/2011	00:00	BRT	18	79.2	0	0	1014.7	2.1	159.8	14.3
18/08/2011	00:10	BRT	17.9	80.2	0	0	1014.8	2.2	100.2	14.3
18/08/2011	00:20	BRT	17.8	80.9	0	0	1015.1	2.6	87.6	14.4
18/08/2011	00:30	BRT	17.6	82.1	0	0	1015.2	2.8	74.2	14.4
18/08/2011	00:40	BRT	17.4	83.3	0	0	1015.2	3.5	57.5	14.4
18/08/2011	00:50	BRT	17.4	83.2	0	0	1015.1	3.8	51.3	14.4
18/08/2011	01:00	BRT	17.4	82.3	0	0	1015.1	3.4	47.6	14.3
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18/08/2011	01:30	BRT	17.3	80.4	0	0	1014.8	2.2	79.3	13.8
18/08/2011	01:40	BRT	17.3	80.1	0	0	1014.6	2.4	101.3	13.7
18/08/2011	01:50	BRT	17.3	78.5	0	0	1014.5	1.8	119.1	13.4
18/08/2011	02:00	BRT	17.9	72.9	0	0	1014.4	3.3	259.7	12.9
18/08/2011	02:10	BRT	20.5	63.9	0	0	1014.5	16.3	259	13.3
18/08/2011	02:20	BRT	22.2	63.7	0	0	1014.4	25.7	257.3	14.9
18/08/2011	02:30	BRT	21.9	69.9	0	0	1014.1	27.4	258.1	16
18/08/2011	02:40	BRT	21.6	74.3	0	0	1014.3	27.5	259	16.7
18/08/2011	02:50	BRT	21.4	77	0	0	1014.4	27.2	259	17.1
18/08/2011	03:00	BRT	21.2	78.9	0	0	1014.5	26.7	259	17.3
18/08/2011	03:10	BRT	21.1	80.2	0	0	1014.5	26.2	259.1	17.4
18/08/2011	03:20	BRT	21	81.2	0	0	1014.6	25.7	259.1	17.5
18/08/2011	03:30	BRT	20.9	82.2	0	0	1014.7	25.2	258.7	17.6
18/08/2011	03:40	BRT	20.8	83	0	0	1014.8	24.8	258.2	17.7
18/08/2011	03:50	BRT	20.7	83.6	0	0	1014.9	24.6	257.7	17.7
18/08/2011	04:00	BRT	20.6	84.2	0	0	1014.9	24.5	257.5	17.8
18/08/2011	04:10	BRT	20.6	84.8	0	0	1015	24.2	257.4	17.8
18/08/2011	04:20	BRT	20.5	85.5	0	0	1015.2	23.9	257.8	17.9
18/08/2011	04:30	BRT	20.4	86.4	0	0	1015.3	23.6	258.3	18
18/08/2011	04:40	BRT	20.4	87.3	0	0	1015.4	23.4	258.6	18.1
18/08/2011	04:50	BRT	20.3	88.3	0	0	1015.5	23.2	258.8	18.2

Username: rio

English

Change language

Logout

Locations & Maps

Rio de Janeiro

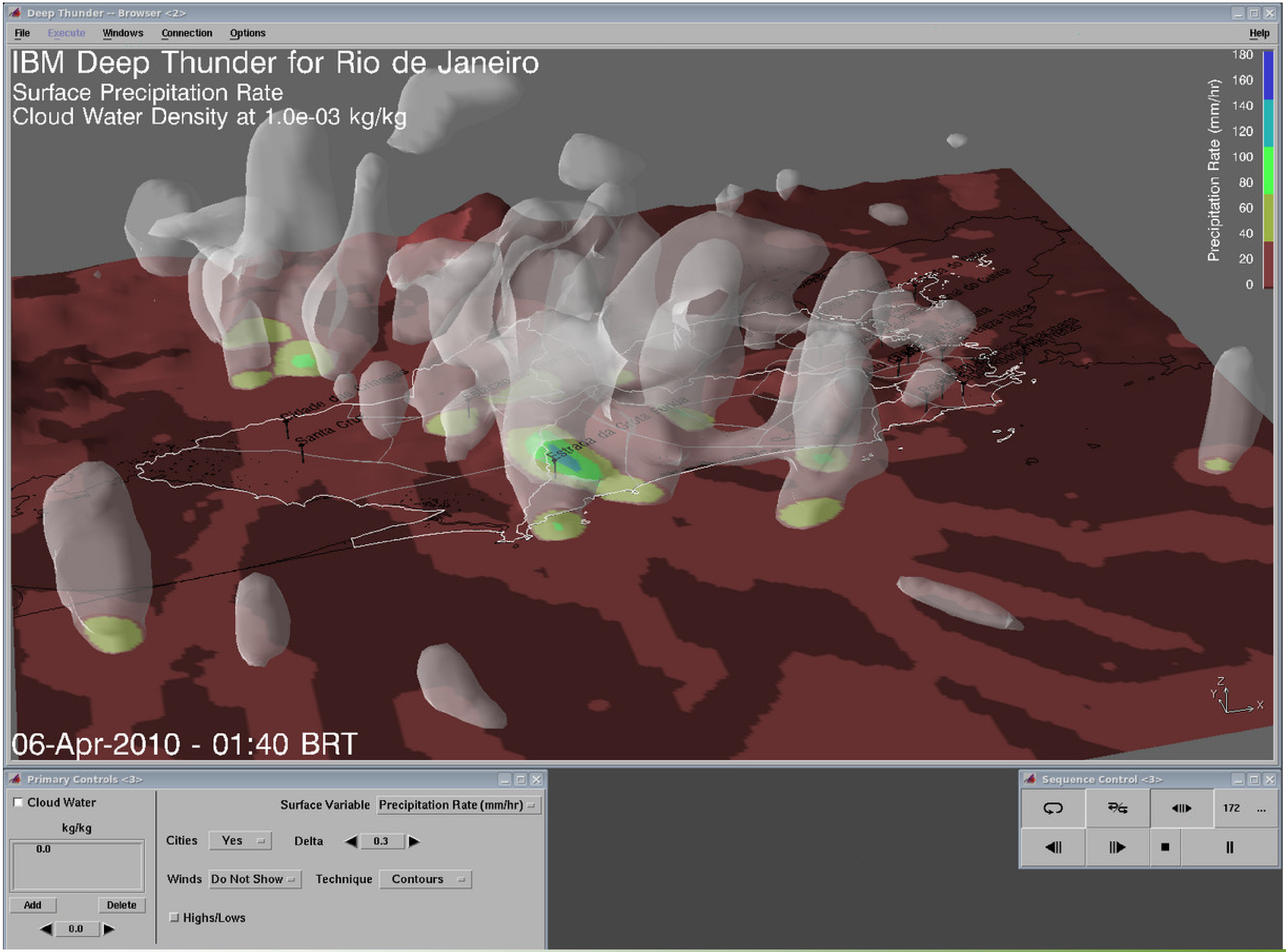
Alto da Boa Vista

Valid for 17/08/2011 2100 BRT through 19/08/2011 2100 BRT
Next Forecast Will Be Available Between 18/08/2011 2000 BRT and 18/08/2011 2100 BRT

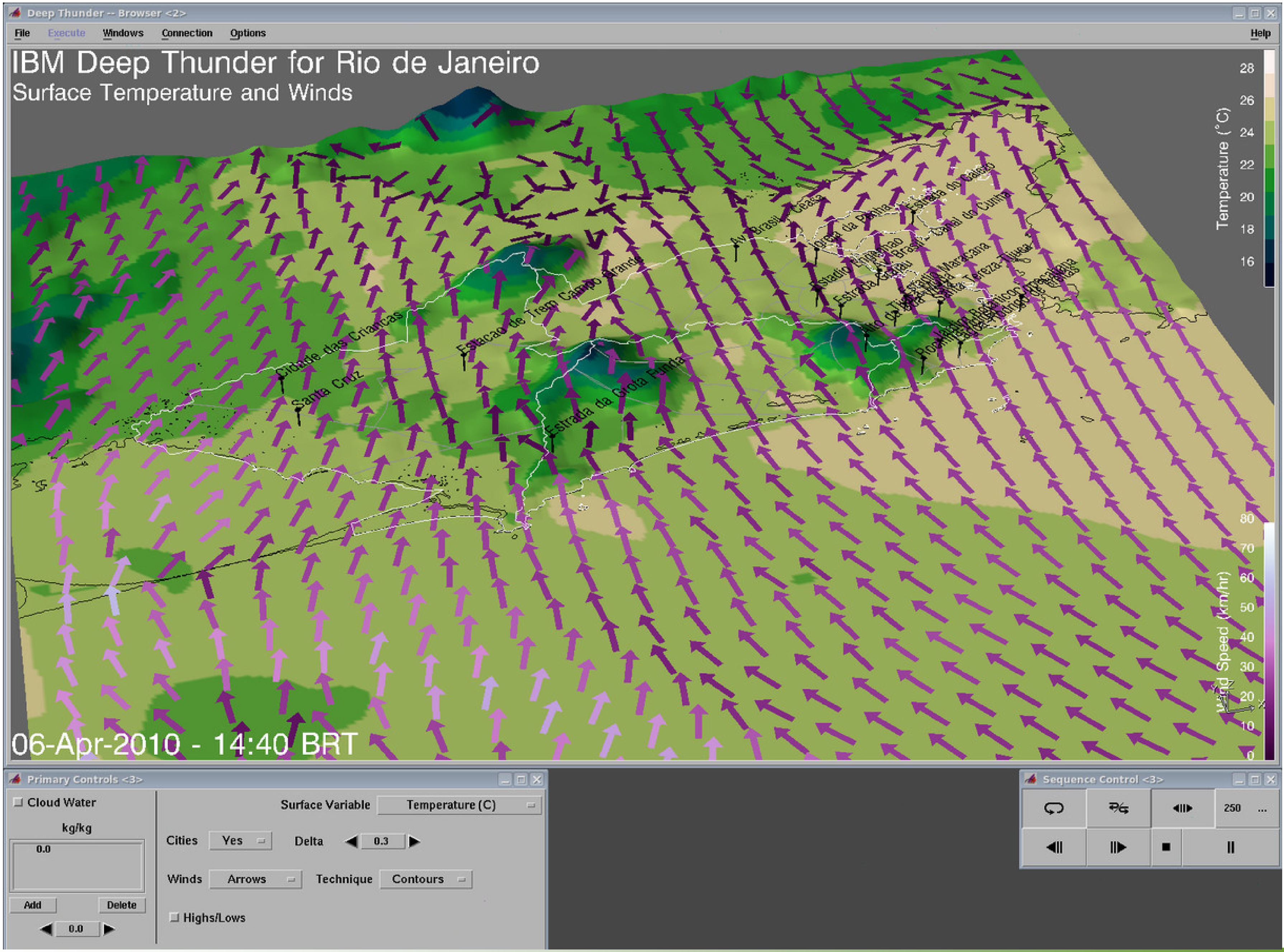
Help

Help

Interactive 3d Visualization Application



Interactive 3d Visualization Application



Web-Based Forecast Dissemination at the Command Center