Enabling a High-Resolution, Coupled Hydro-Meteorological System for Operational Forecasting of Severe Weather and Flooding Events in Rio de Janeiro

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

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

Rashmi Mittal, Vaibhav Saxena and Thomas George
IBM India Research Laboratory
Delhi, India

Other Presentations of Related Work

Conference on US 2012 Weather Impacts
- 2.4 Hindcast Analysis of the June 2012 Derecho and Its Impact on the Baltimore-Washington Metropolitan Area using High-resolution WRF-ARW

Symposium on the Coastal Environment:
- 8.3 Forecast Performance of an Operational Mesoscale Modeling System for Tropical Storm Irene in the New York City Metropolitan Region
- 2.2 High-resolution Simulations of a High-impact Rainfall Event for the Montpellier Region using WRF-ARW
- 2.3 December 2010 Northeast Blizzard: Event Analysis using High-resolution WRF for the New York City Metropolitan Area

Symposium on the Next Level of Predictions in Tropical Meteorology:
- 1.5 A Numerical Weather Prediction-Based Infrastructure for Tropical Meteorology Research and Operations in Brunei
- TJ36.3 The DOTSTAR Observations in Improving Tropical Cyclones Forecast using Ensemble-based Data Assimilation

Conference on Hydrology:
- 533 A Dynamic River Network Model for Regional-Scale Simulation

Conference on Climate Variability and Change:
- 551 Seasonal Climatology Studies for Tropical Region - Borneo Island Case Study

Conference on Weather, Climate, and the New Energy Economy:
- 10.1 Precision Wind Power Forecasting via Coupling of Turbulent-Scale Atmospheric Modeling with Machine Learning Methods
- 1.2 On-going Utilization and Evaluation of a Coupled Weather and Outage Prediction Service for Electric Distribution Operations
- 800 Utilization of a High Resolution Weather and Impact Model to Predict Hurricane Irene
- 409 Advanced Data Assimilation for Short-term Renewable Power Prediction: a Complex Terrain Case

Enabling a High-Resolution, Coupled Hydro-Meteorological System for Operational Forecasting of Severe Weather and Flooding Events in Rio de Janeiro

- 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)

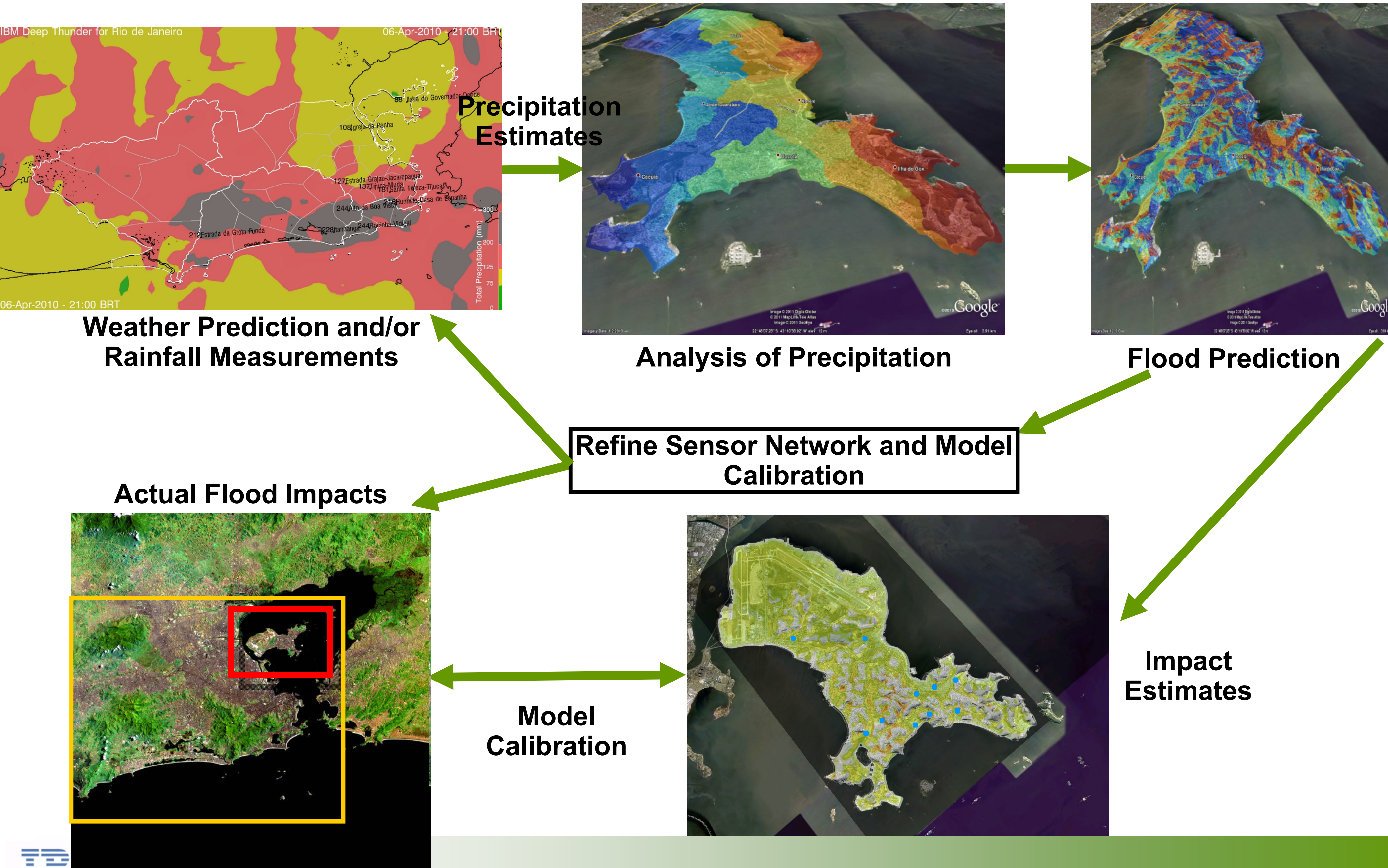
Approach

- **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

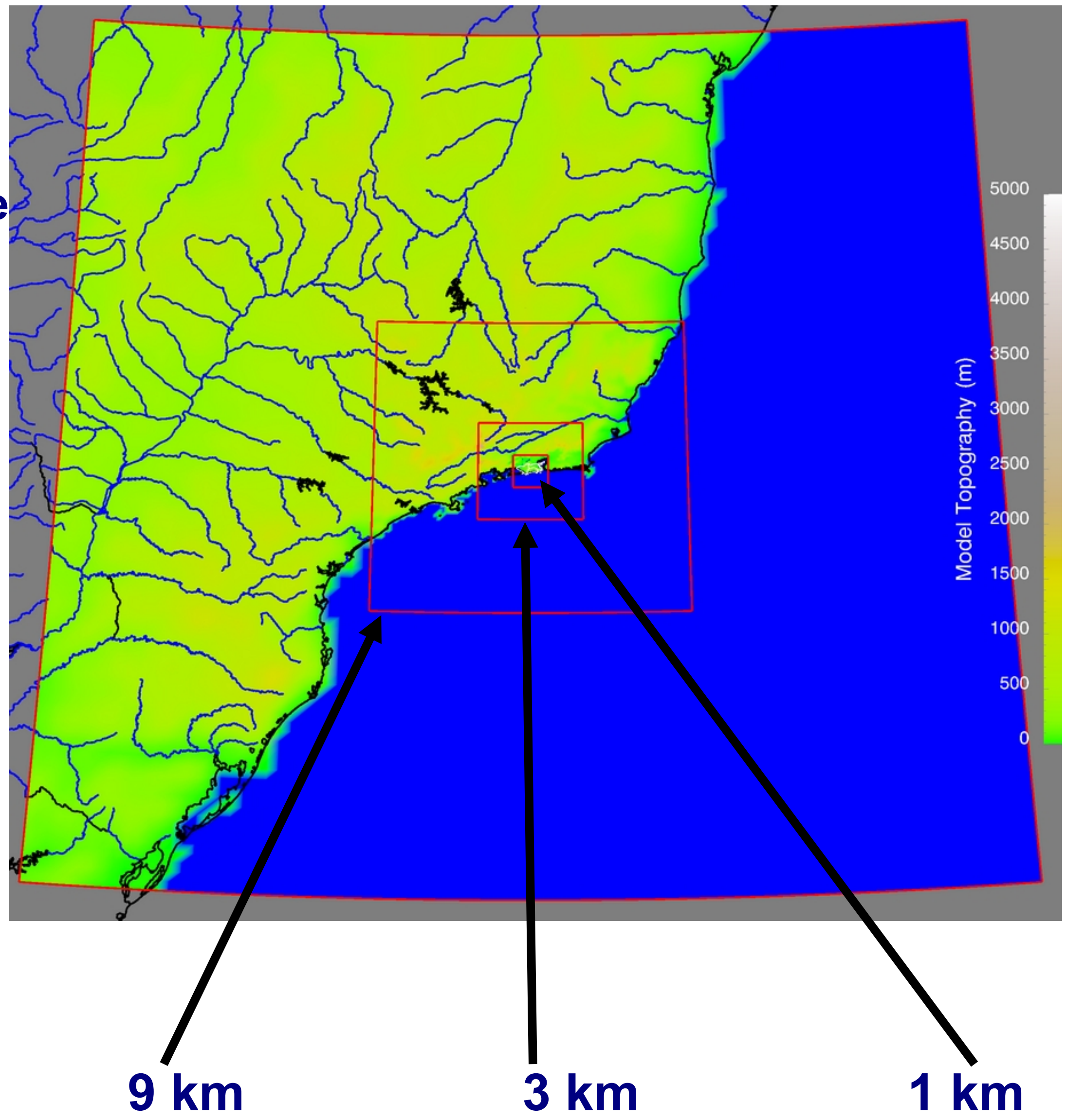


Status

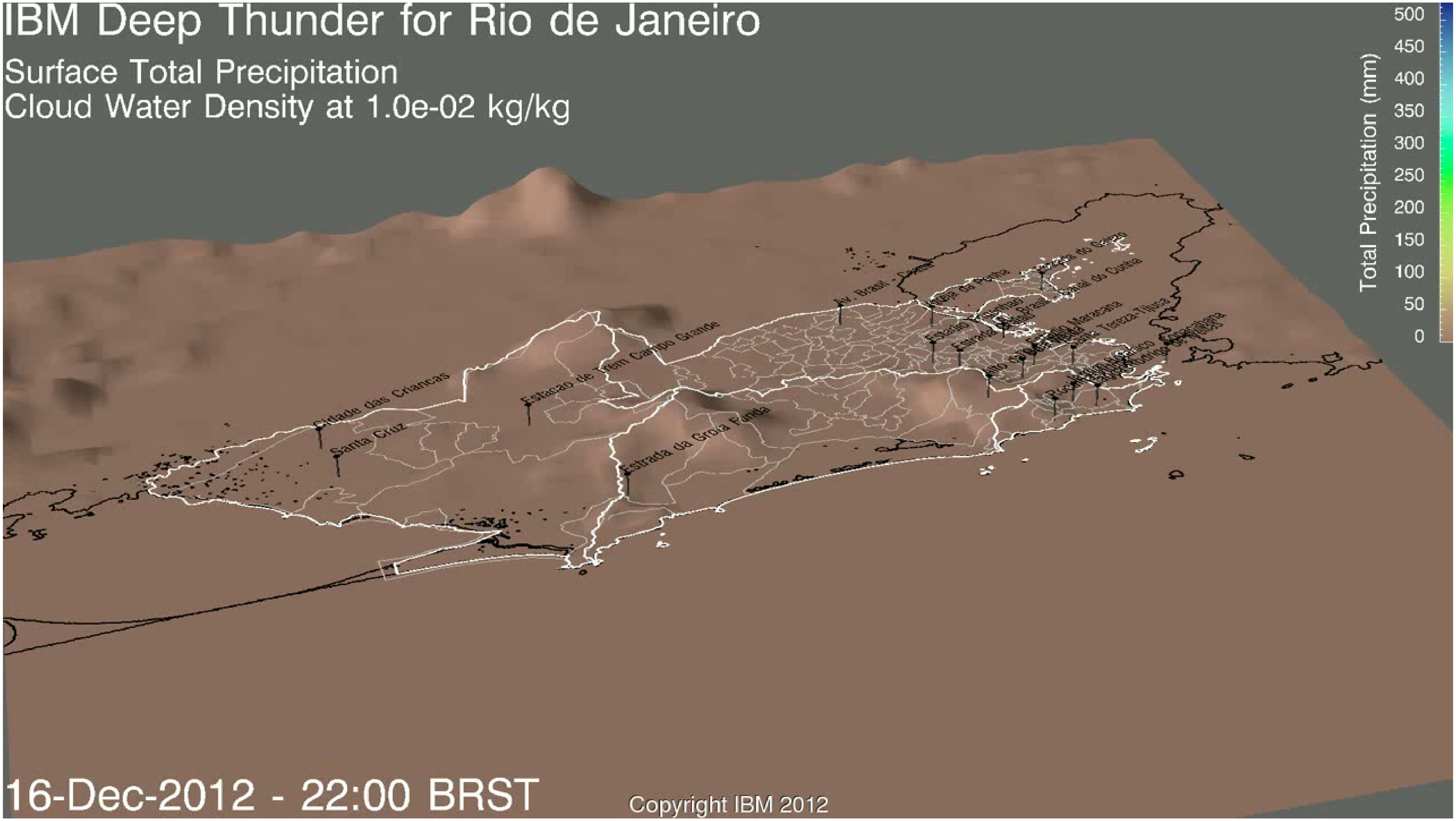
- R&D enabled high-resolution operational weather forecasting starting in May 2011
  - 48-hour forecast updated every twelve hours, produced at IBM Research in New York
  - Disseminated via a web portal ("Previsão Meteorológica de Alta Resolução" or PMAR [High-Resolution Weather Forecast]) at the client 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
  - 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
  - Data assimilation is not feasible given the lack of real-time observing system

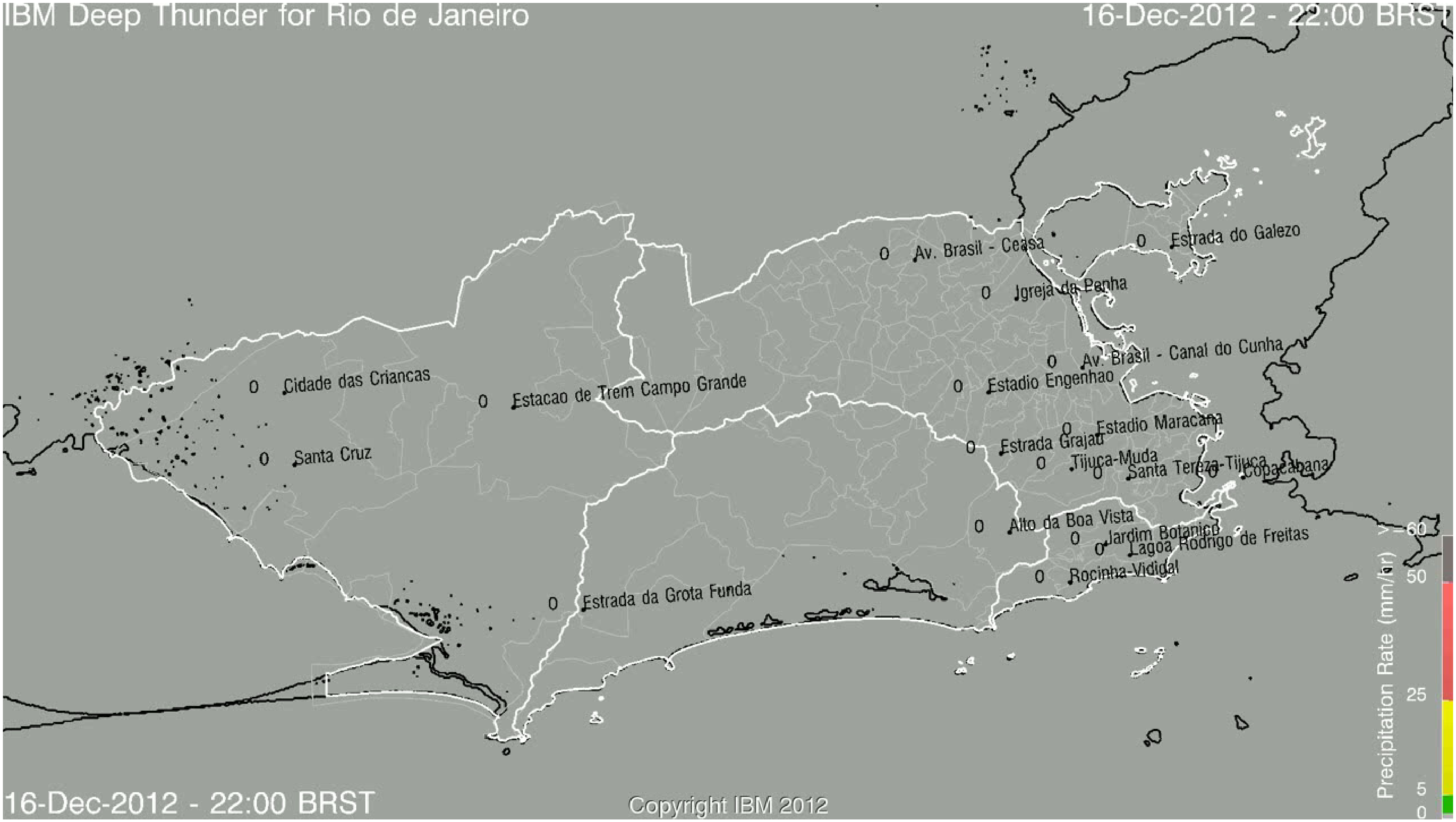


Operational Forecast of 17 December 2012 Rainfall Event



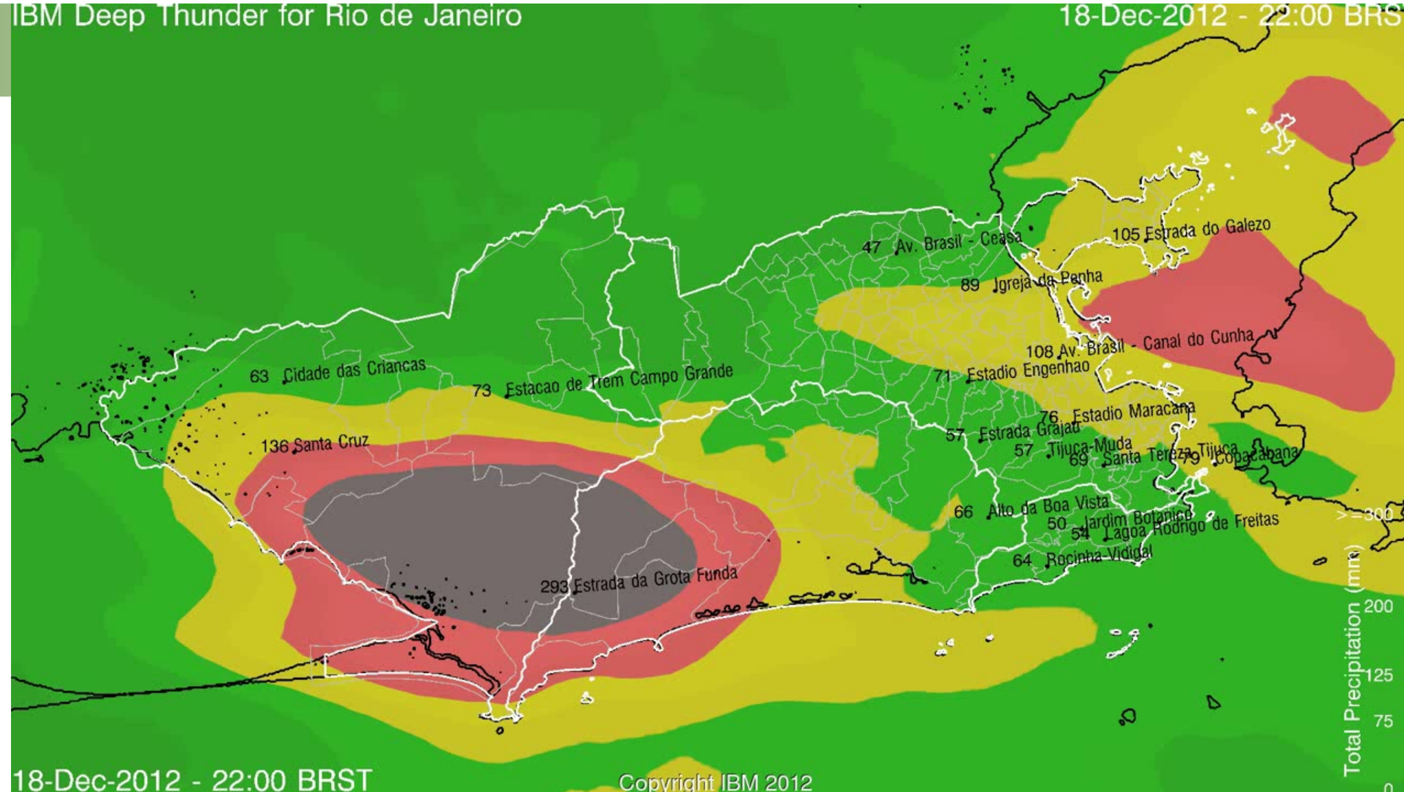
Animation of three-dimensional forecasted clouds with terrain surface and precipitation

Operational Forecast of 17 December 2012 Rainfall Event

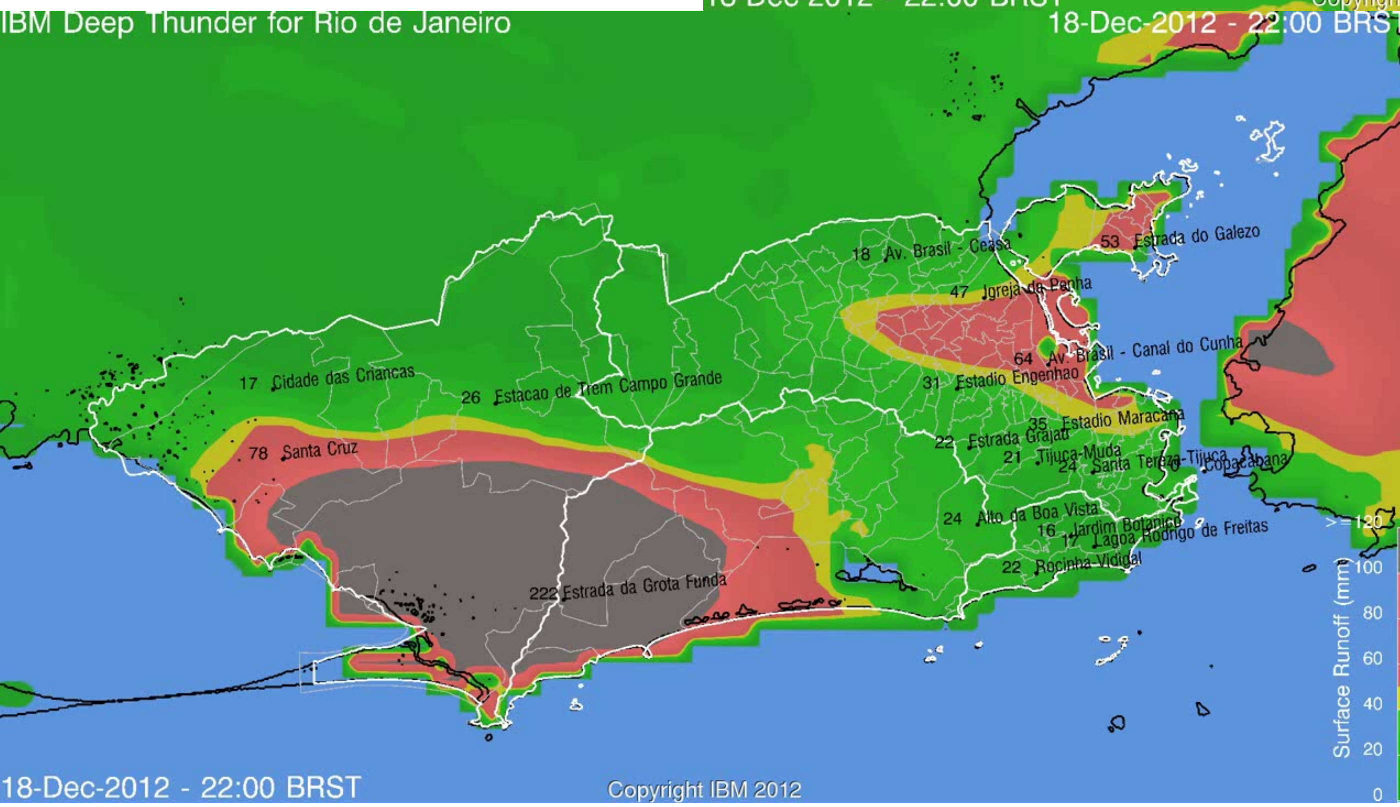


Animation of forecasted precipitation rate

Operational Forecast of 17 December 2012 Rainfall Event

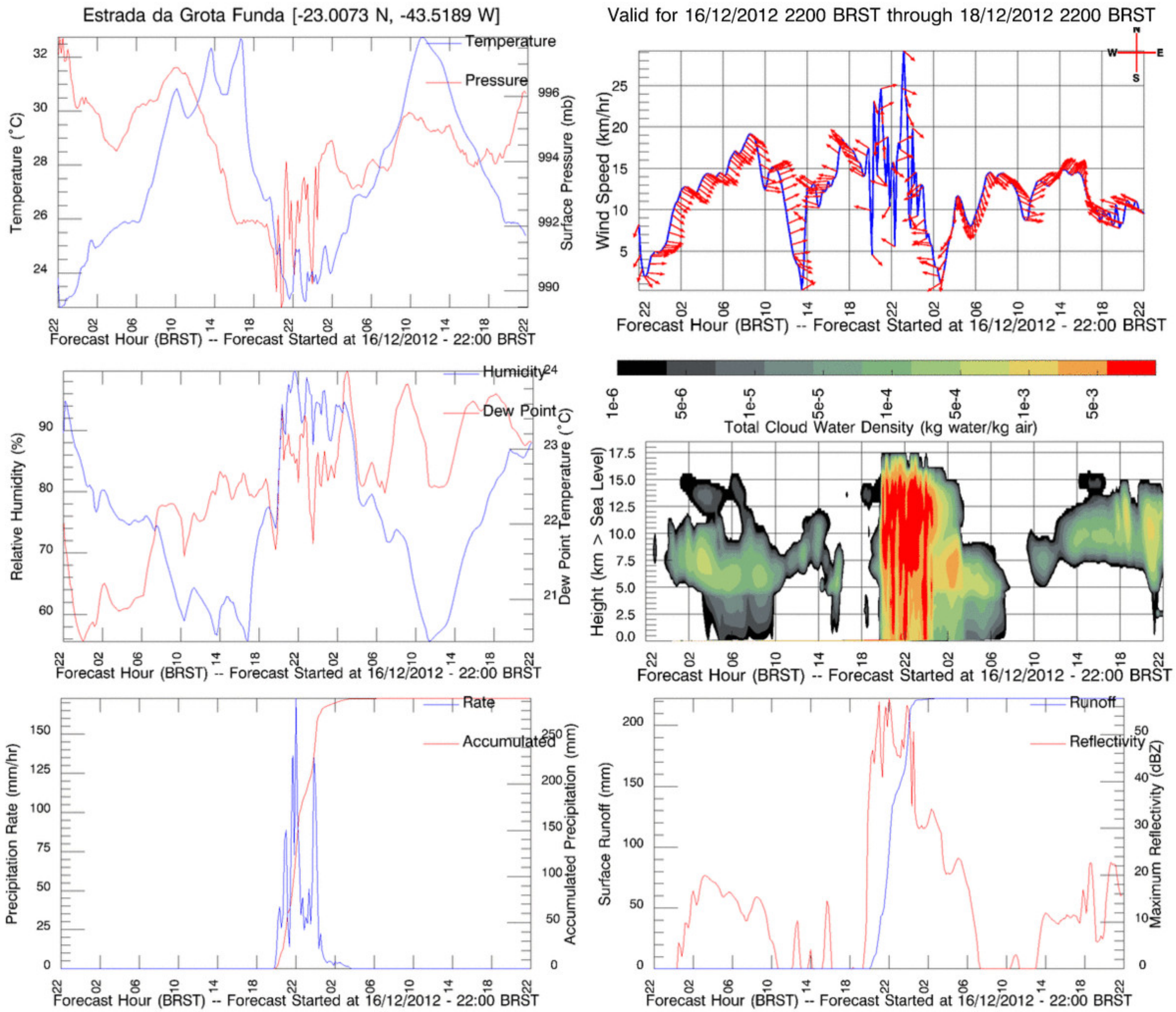


Rainfall Totals



Runoff Totals

Operational Forecast of 17 December 2012 Rainfall Event



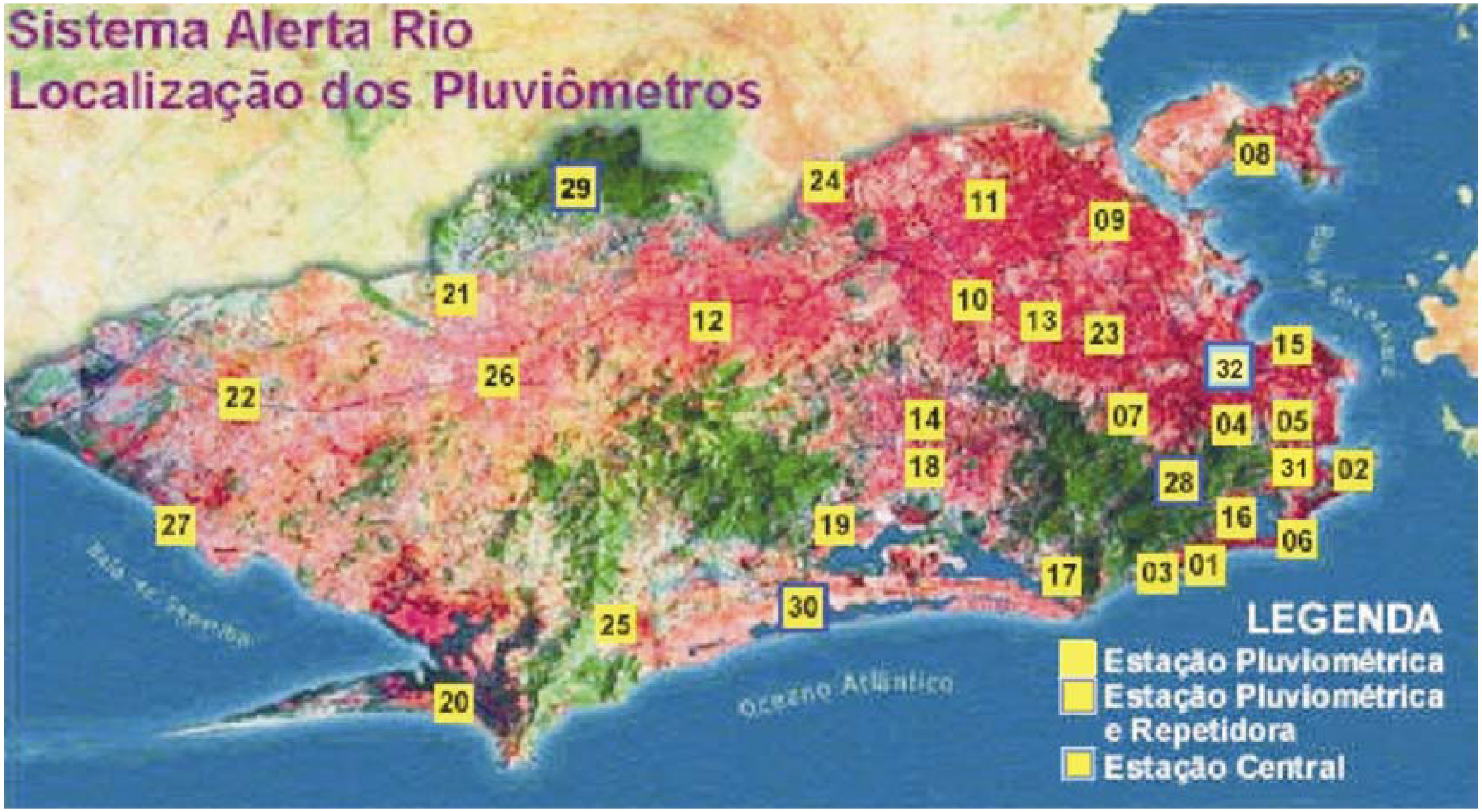
Site-specific forecast in Rio de Janeiro

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%**

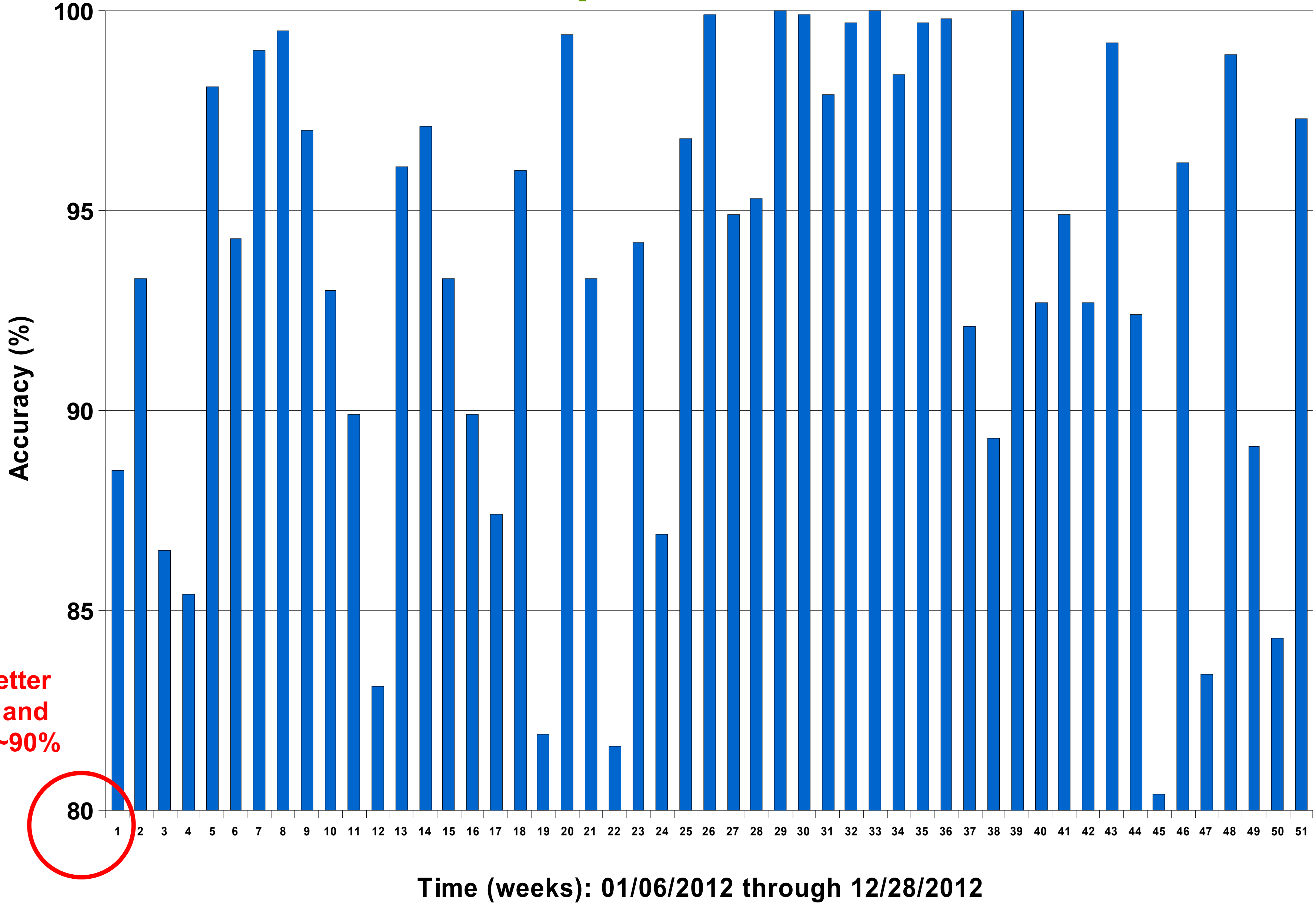
A Second Approach to Validation of Precipitation Forecasts

- **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

Hits	False Alarms
Misses	Correct Negatives

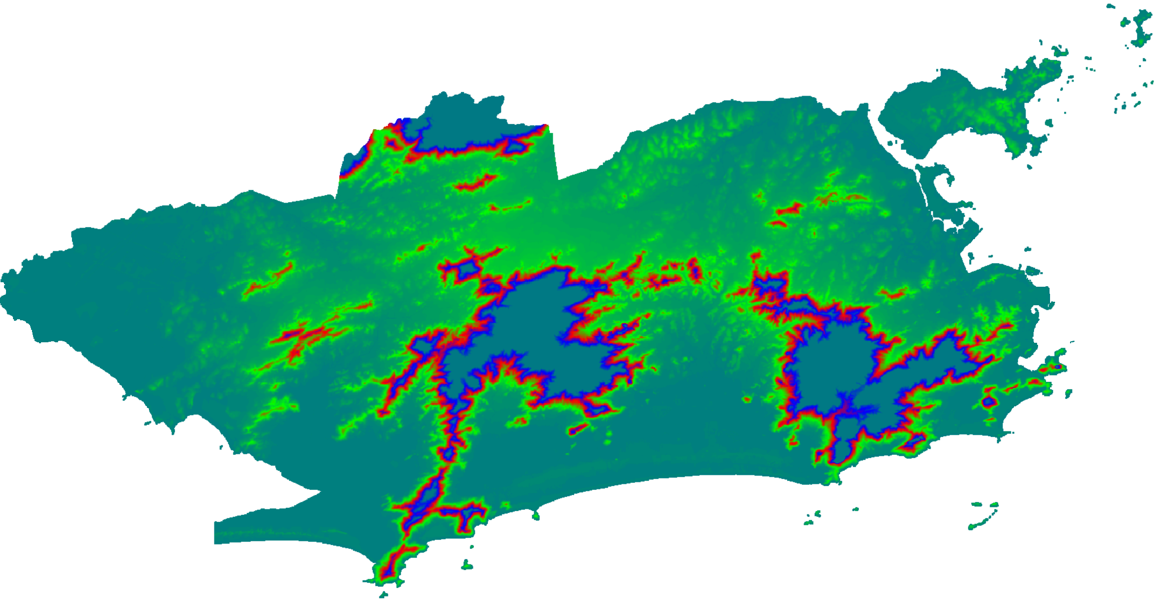
  - The accuracy should be calculated using all available accurate rain gauge data and reported at an aggregate level over all rain gauges
  - The accuracy should be calculated and reported for each 6-hour range contained in a forecast simulation of 48 hours
- **Weekly reports of forecast performance of the last seven and 30 days**
- **GeoRio data are used along with measurements from INMET**

Deep Thunder Weekly Average Accuracy Based on 6-Hour Accumulated Precipitation for Rio de Janeiro



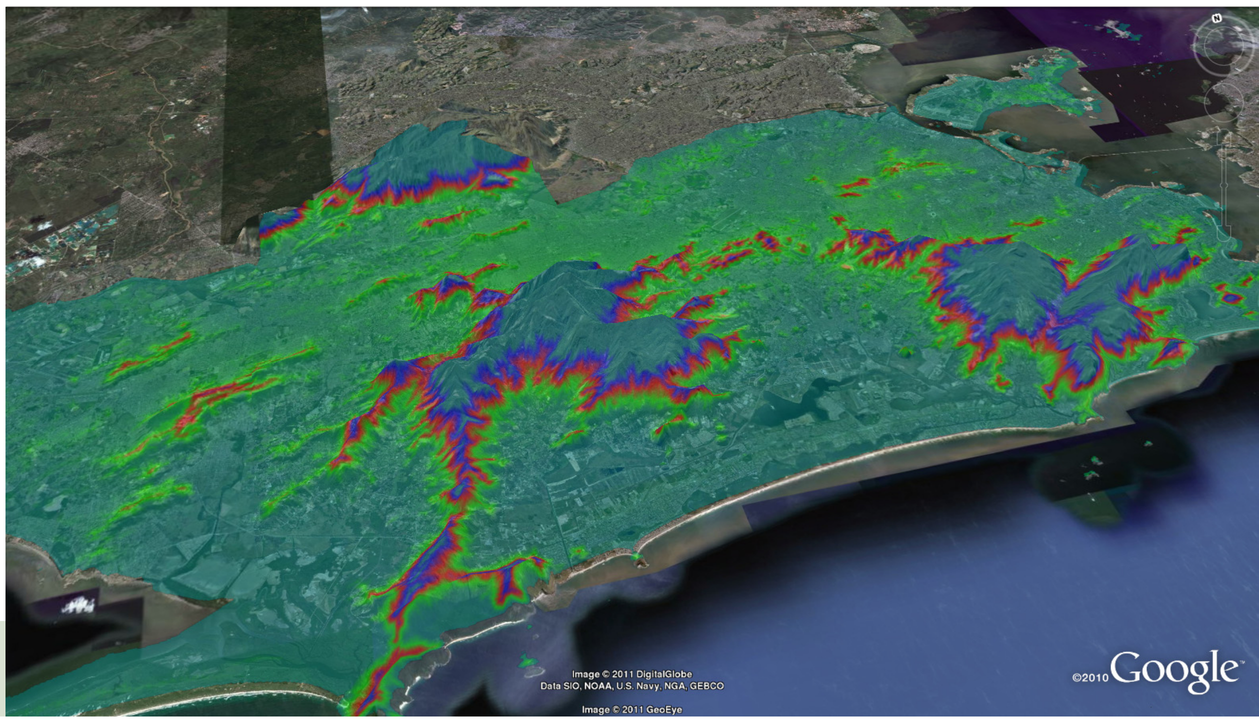
Always Better than 80% and Averages ~90%

Flood Model

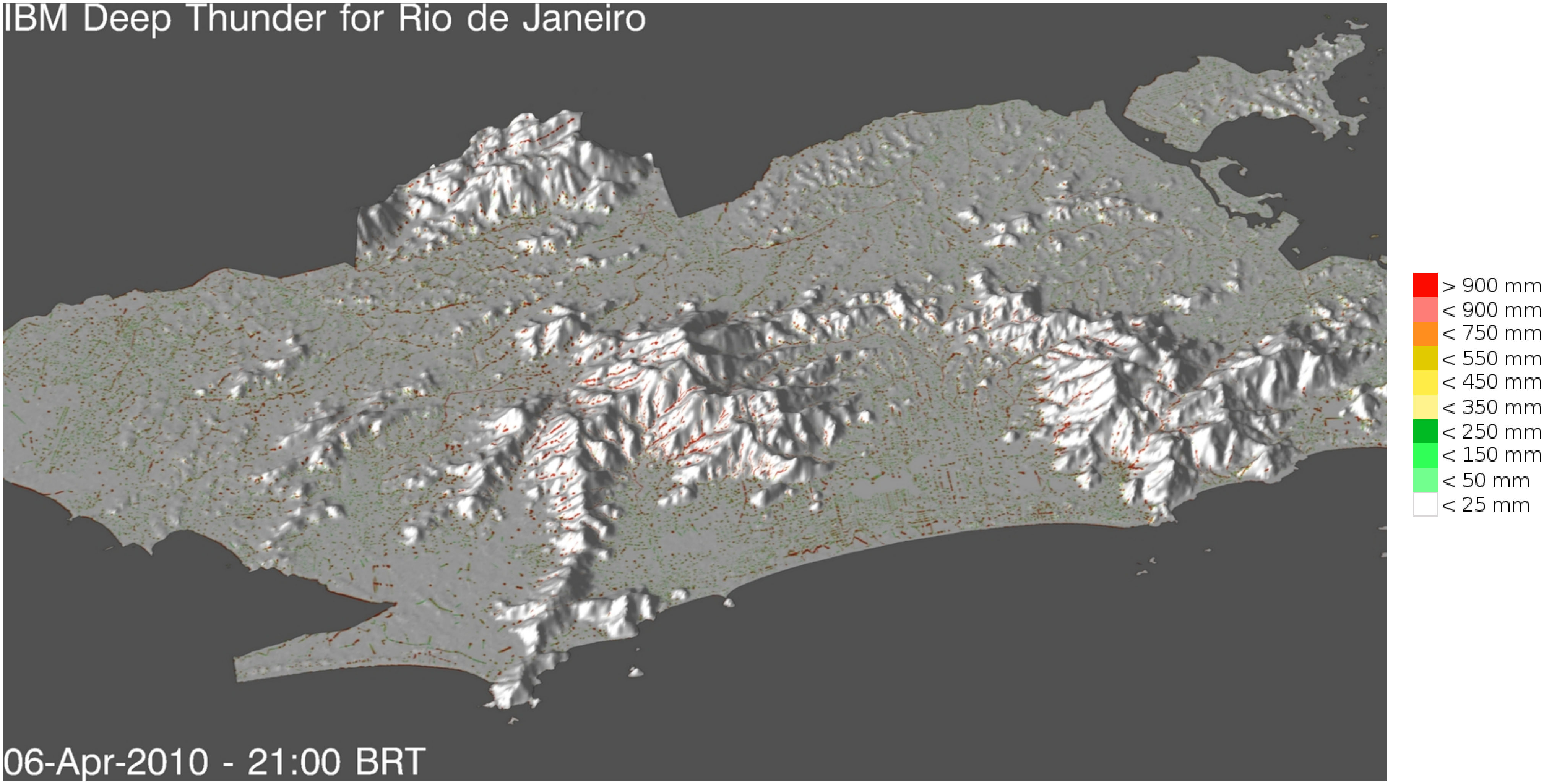


- **Given available data developed a simplified high-resolution analytical model for flood prediction**
  - Detailed (1km resolution) precipitation and runoff forecasts from Deep Thunder
  - 1m LiDAR Digital Terrain Models (DTMs)
  - GIS maps of soil type, land occupation, and city structure (streets, 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**

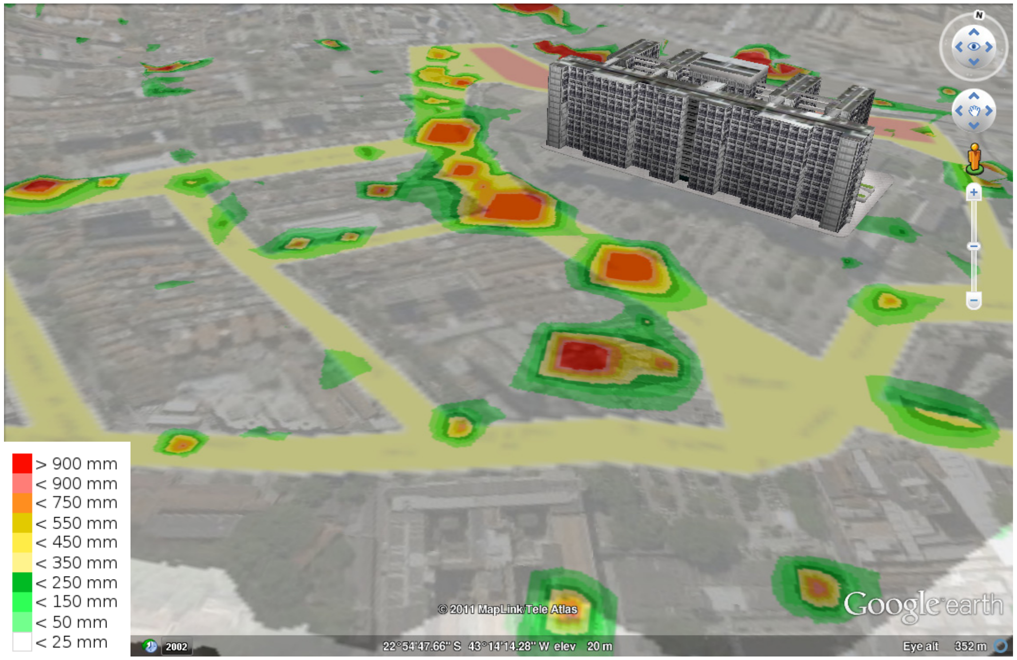


Flood Model Example – April 2010 Event Hindcast



- **Final frame of an animation that depicts hourly changes of the flooding through 48 hours**
- **The gravity-driven terrain channeling is shown**

April 2010 Event Hindcast: Mangue –Maracanã Area



- 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, migrate to newer version
  - Incorporate additional local data (in situ and remotely sensed) to improve surface representation
- **Enhance hydrological model and delivery**
  - Operational implementation of a more comprehensive hydrological model for flood and impact forecasting

Backup

Slides

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

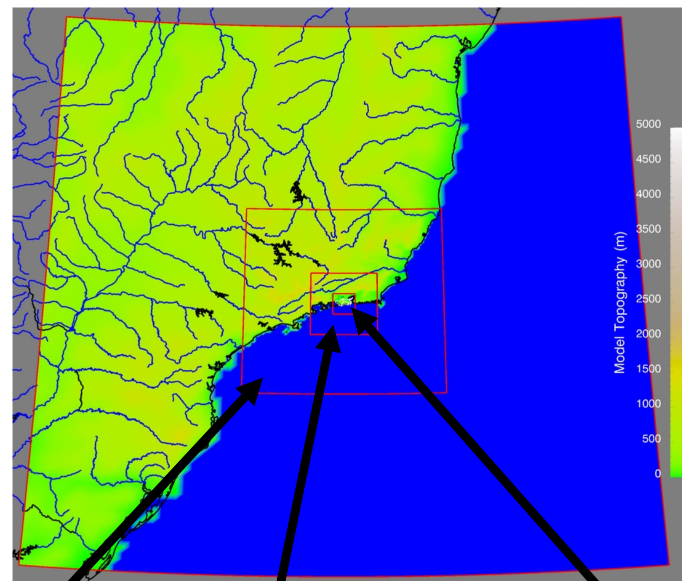
Observations

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)

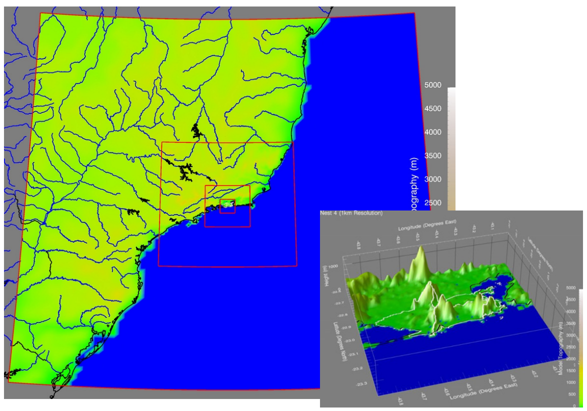
Rio Águas

(Water Levels, Lakes, Hydrographic Basins, Ocean)

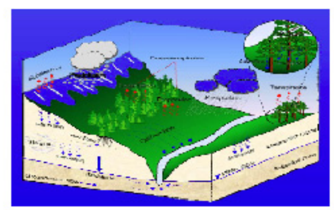
IPP

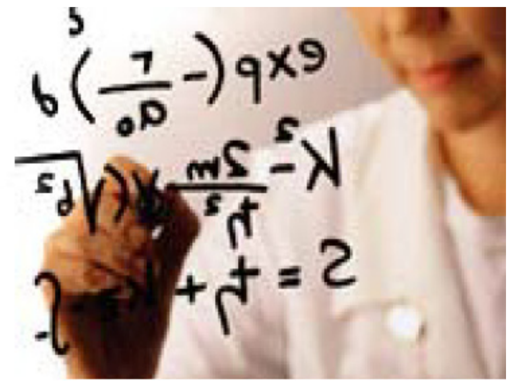
Instituto Pereira Passos

(Geography, cartography, topography, vegetation, urban occupancy and soil usage)



Hydrological Model





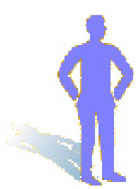
Center of Operations

CET-RIO

Mayor's Office

Rio Águas

Alerta Rio

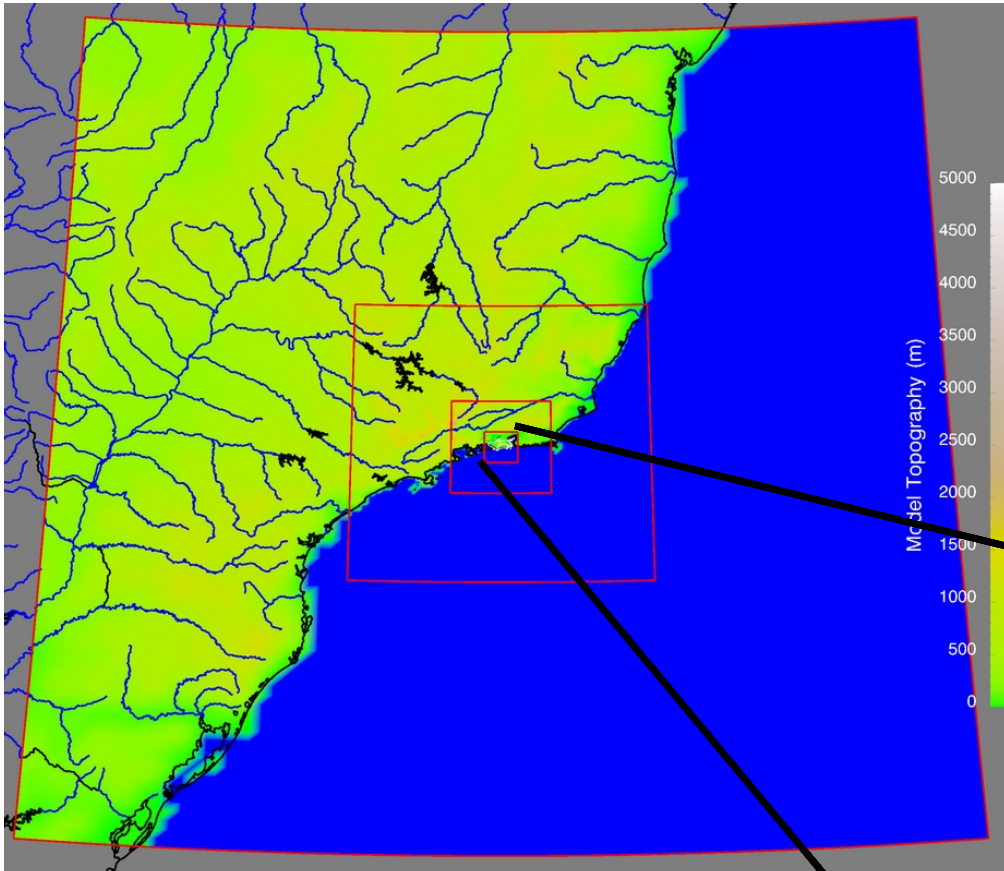


User

Command Center for Rio de Janeiro

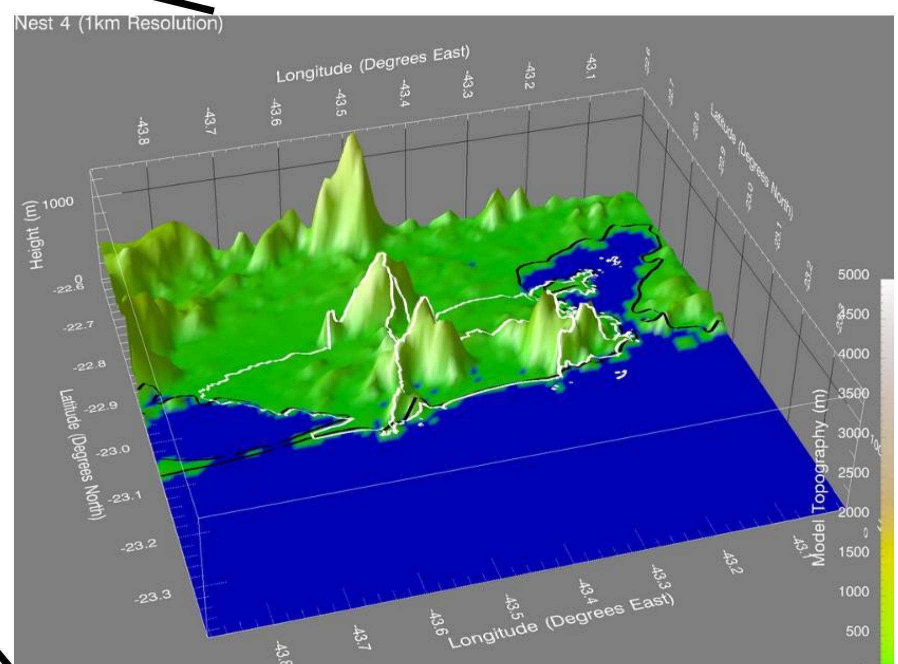
IBM

Weather Model Configuration

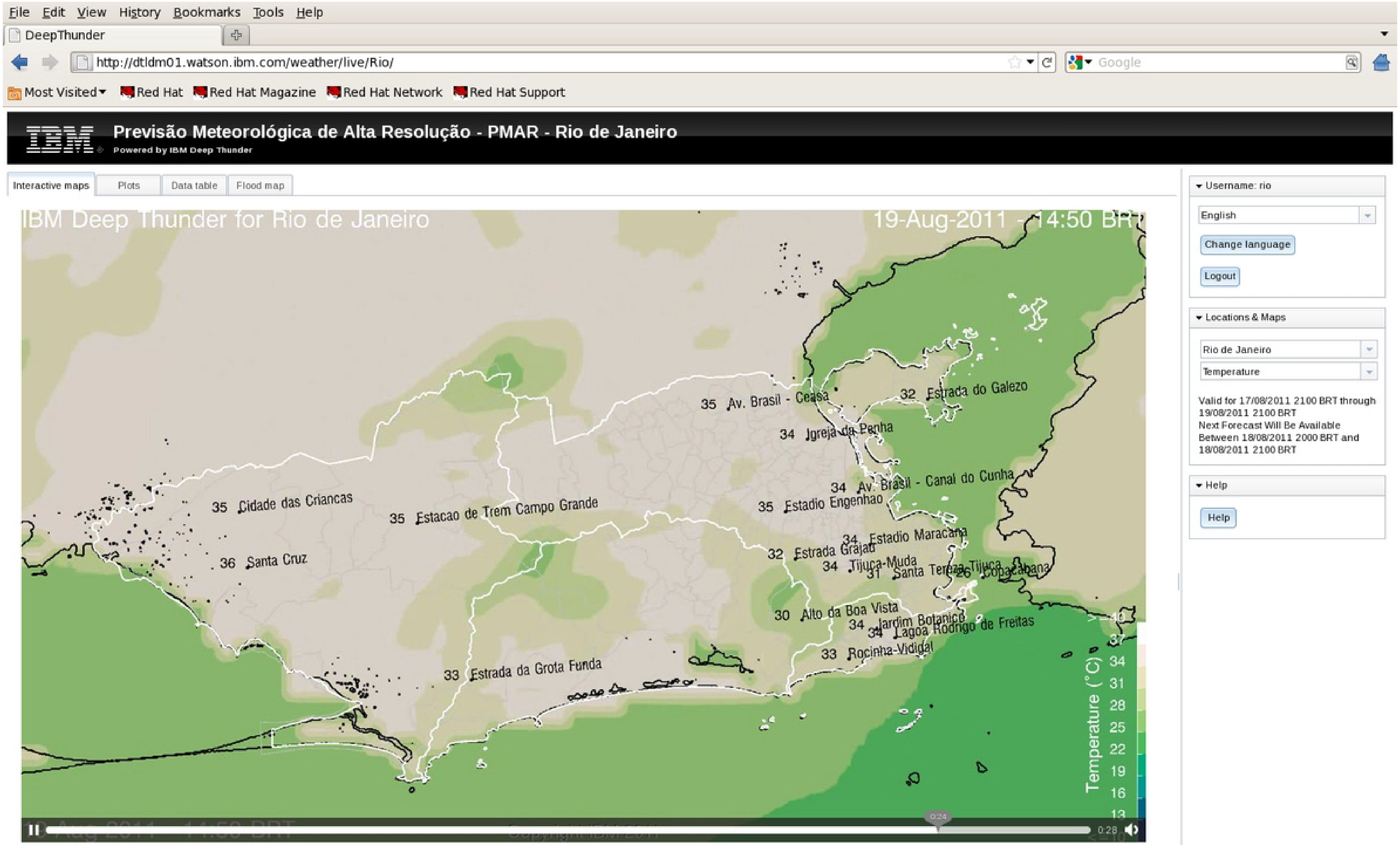


Four 2-way telescoping nests at 27, 9, 3 and 1 km horizontal resolution focused on Rio de Janeiro

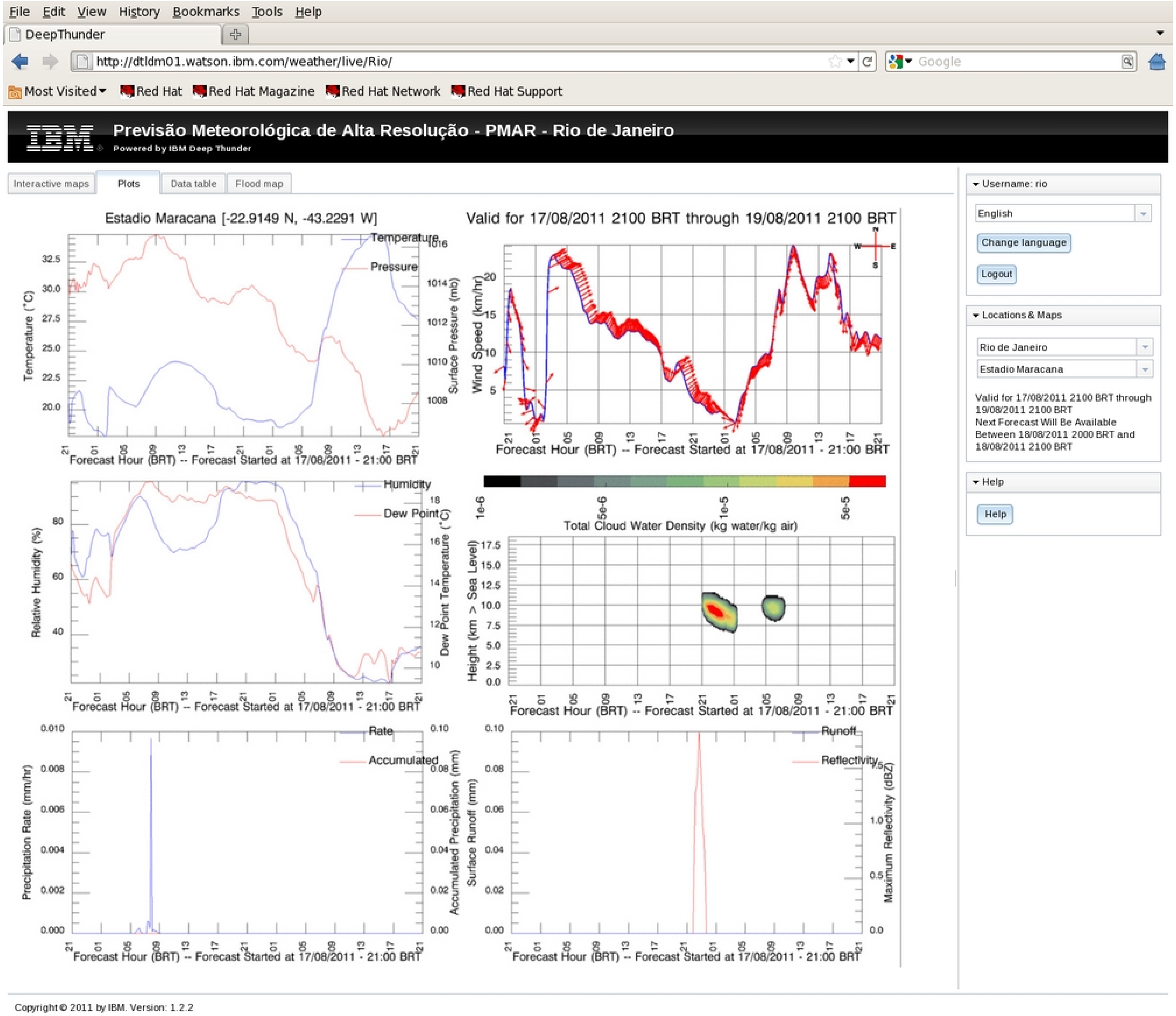
65 vertical levels with 10 to 20 in the planetary boundary layer



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/

Google

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
18/08/2011	01:10	BRT	17.4	81.2	0	0	1015.1	2.7	50.4	14.1
18/08/2011	01:20	BRT	17.4	80.4	0	0	1014.9	2.3	58.6	13.9
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
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18/08/2011	02:50	BRT	21.4	77	0	0	1014.4	27.2	259	17.1
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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

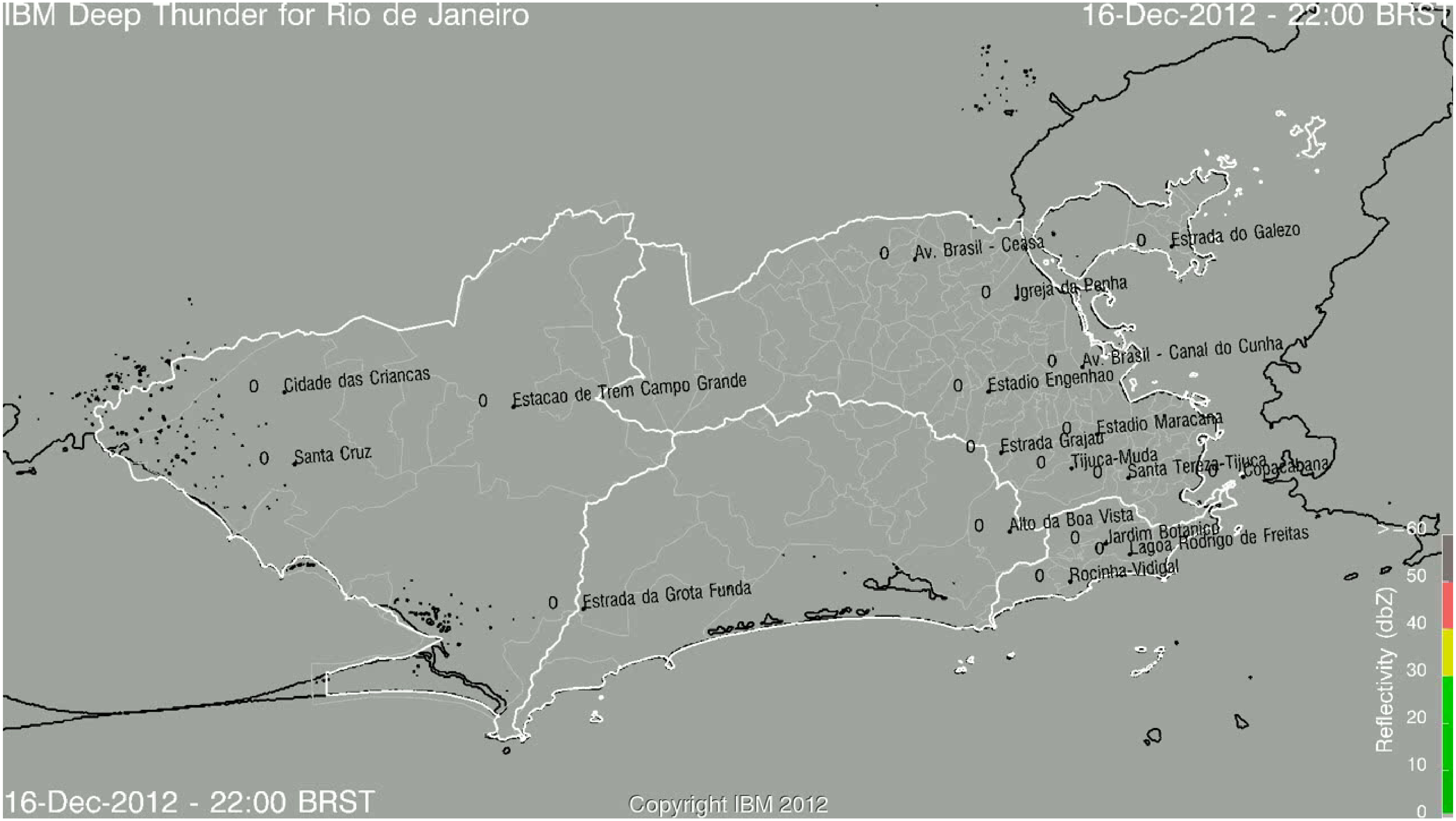
Alto da Boa Vista

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

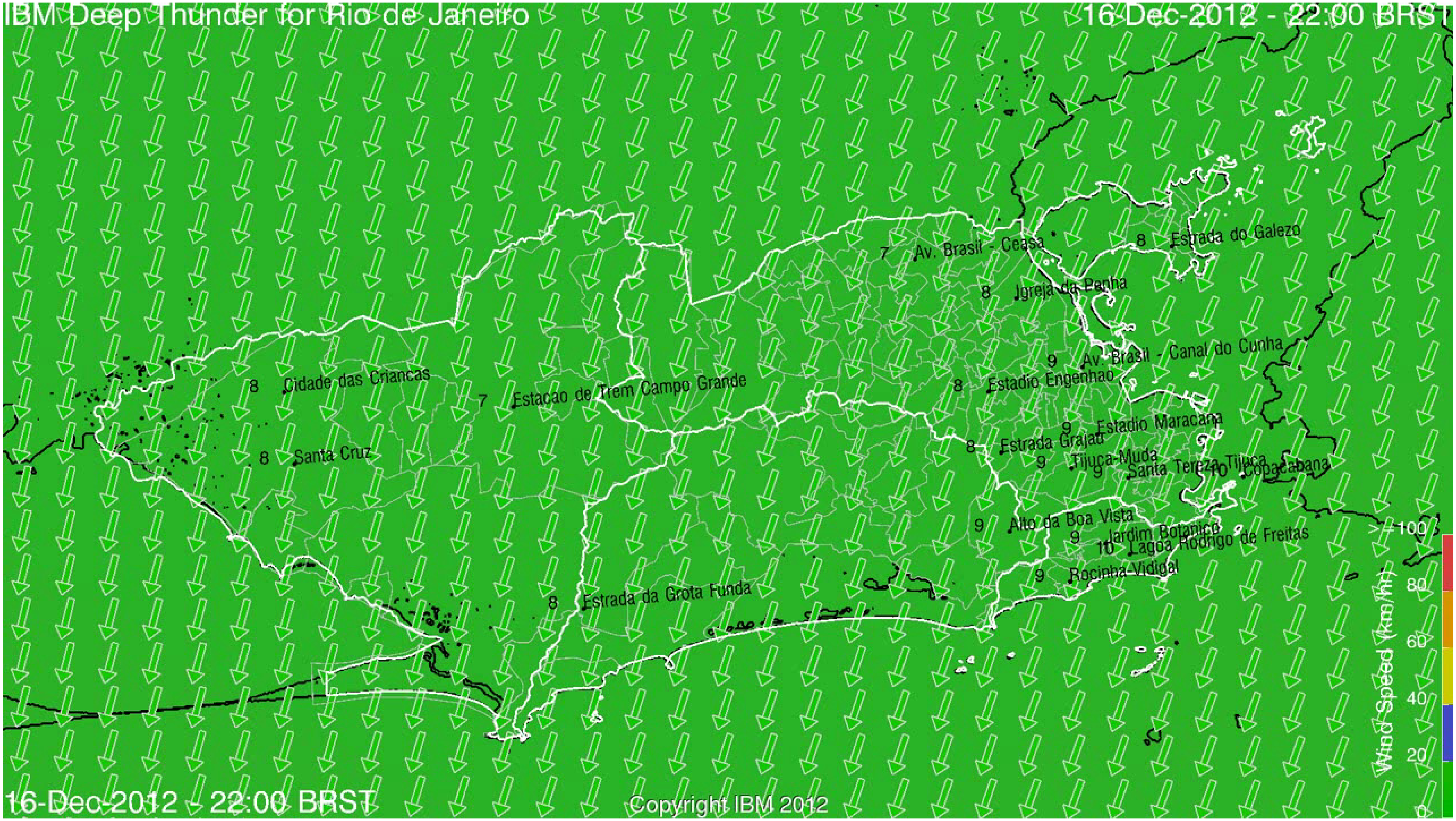
Help

Operational Forecast of 17 December 2012 Rainfall Event



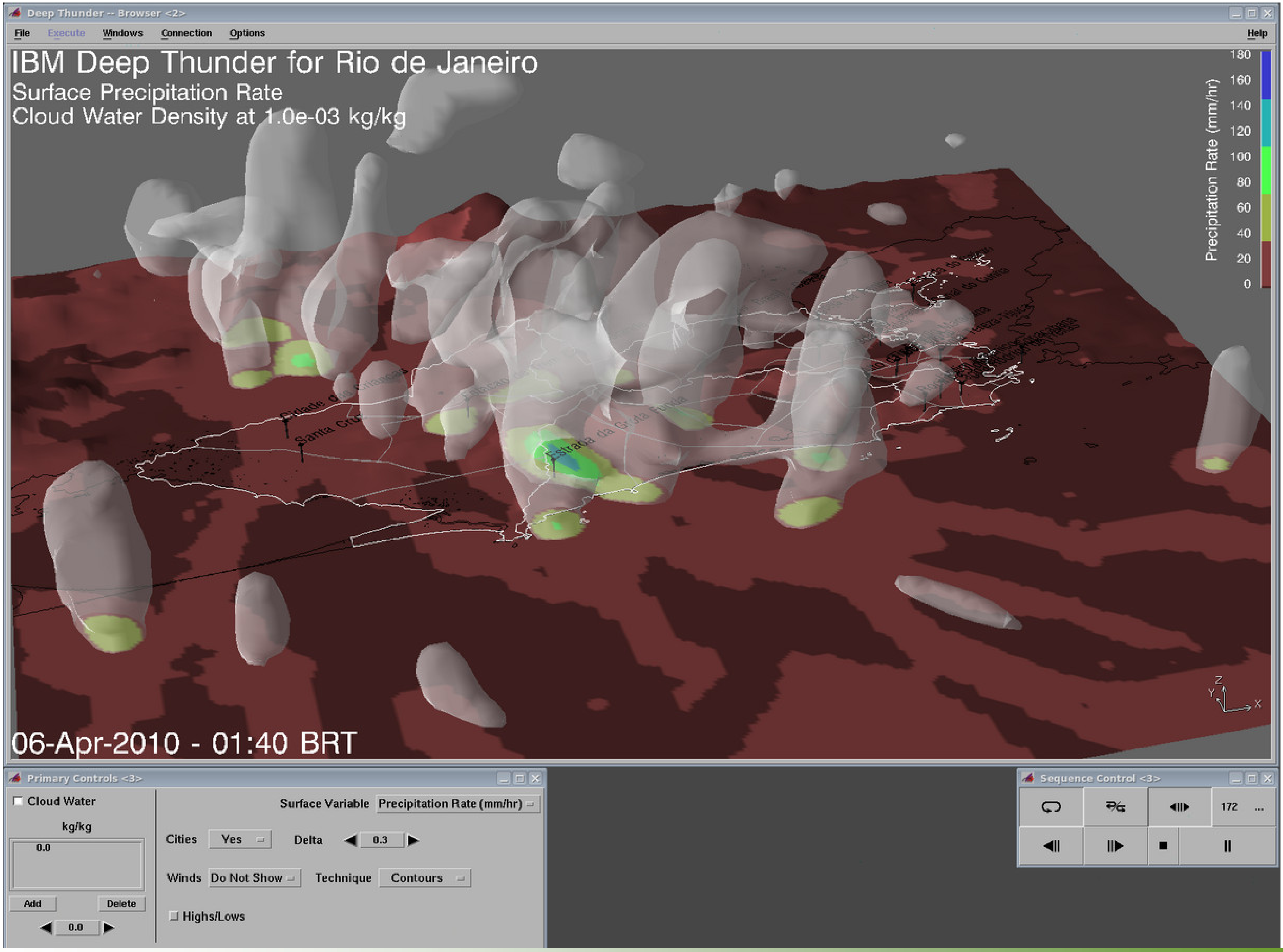
Animation of forecasted reflectivity

Operational Forecast of 17 December 2012 Rainfall Event

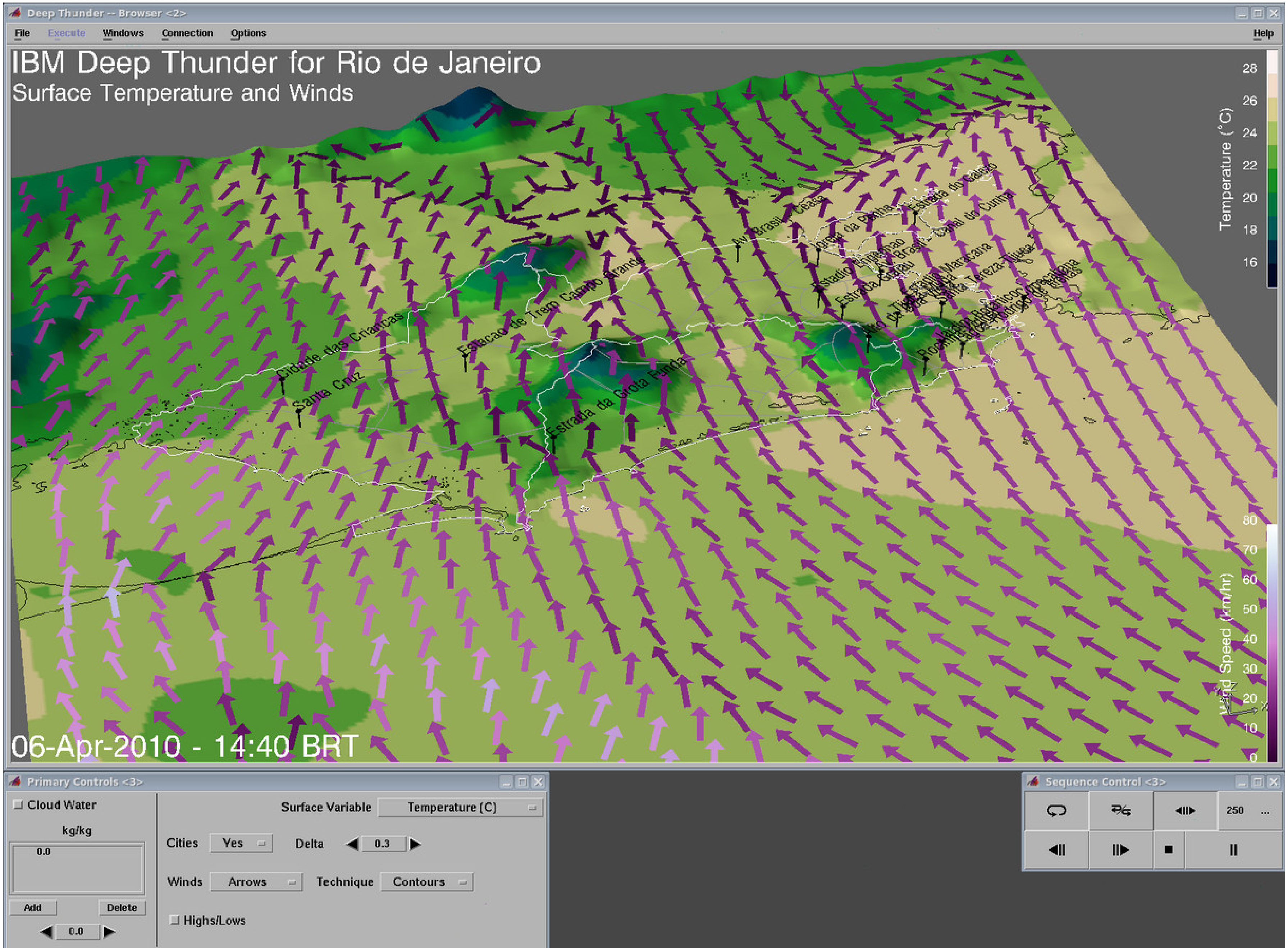


Animation of forecasted wind

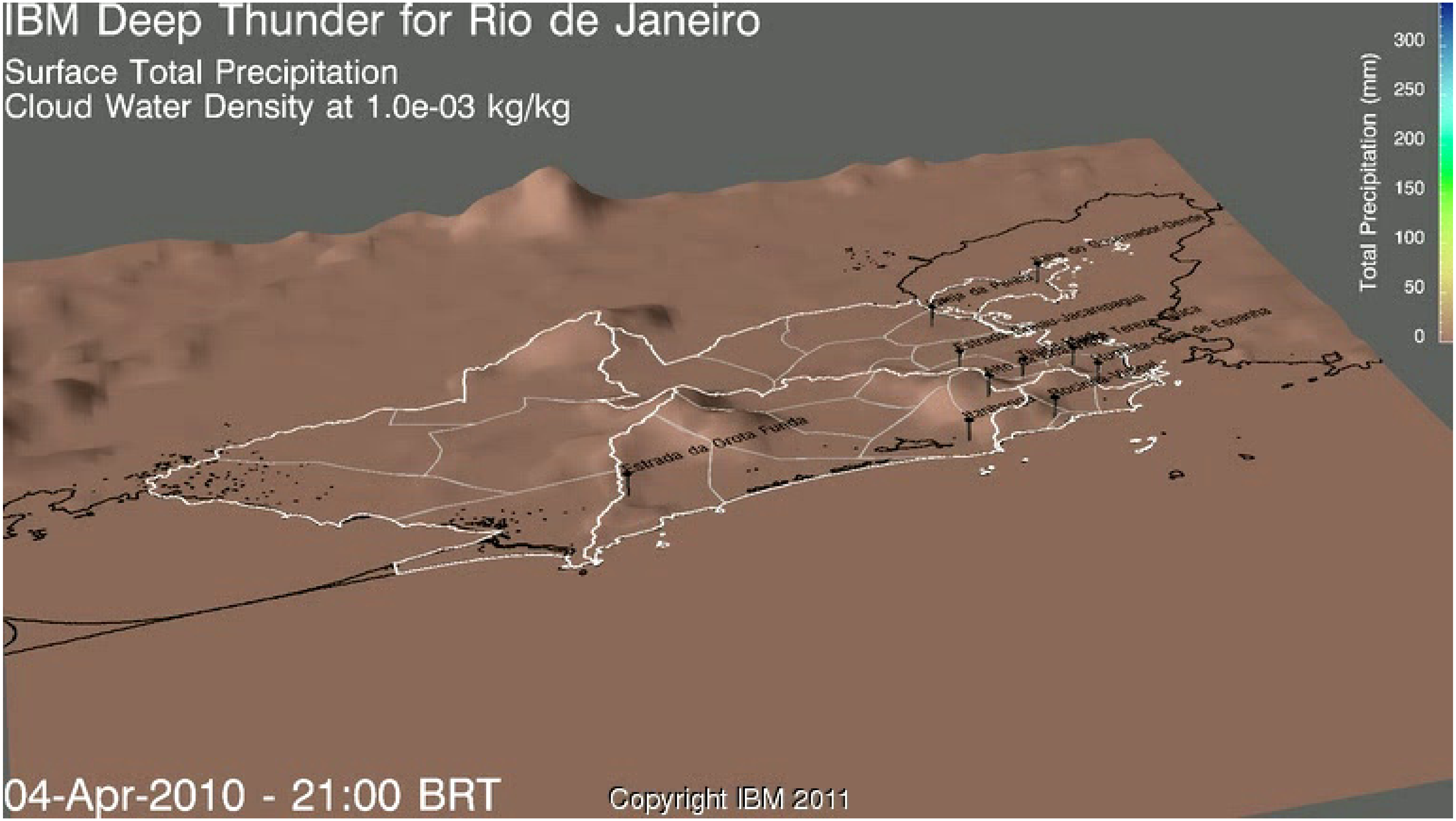
Interactive 3d Visualization Application



Interactive 3d Visualization Application

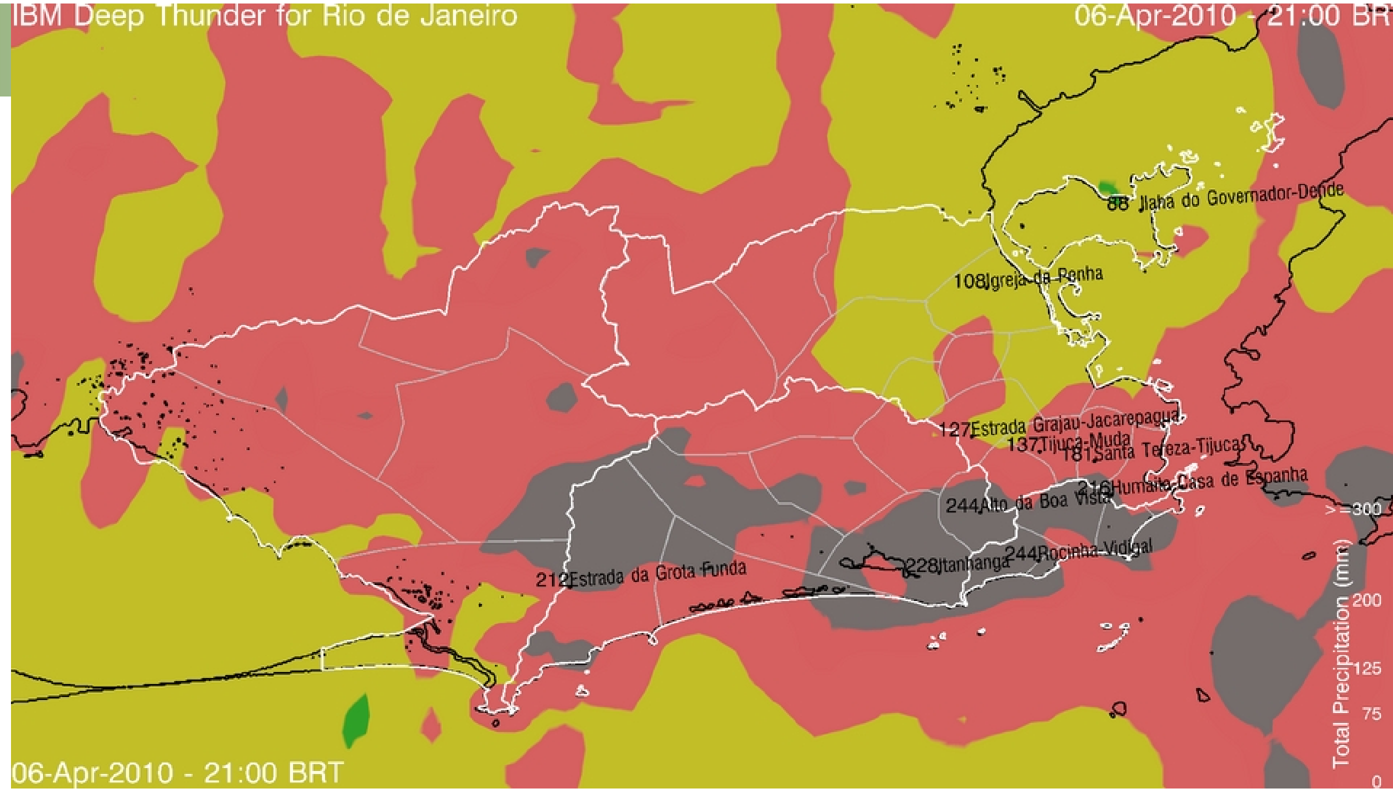


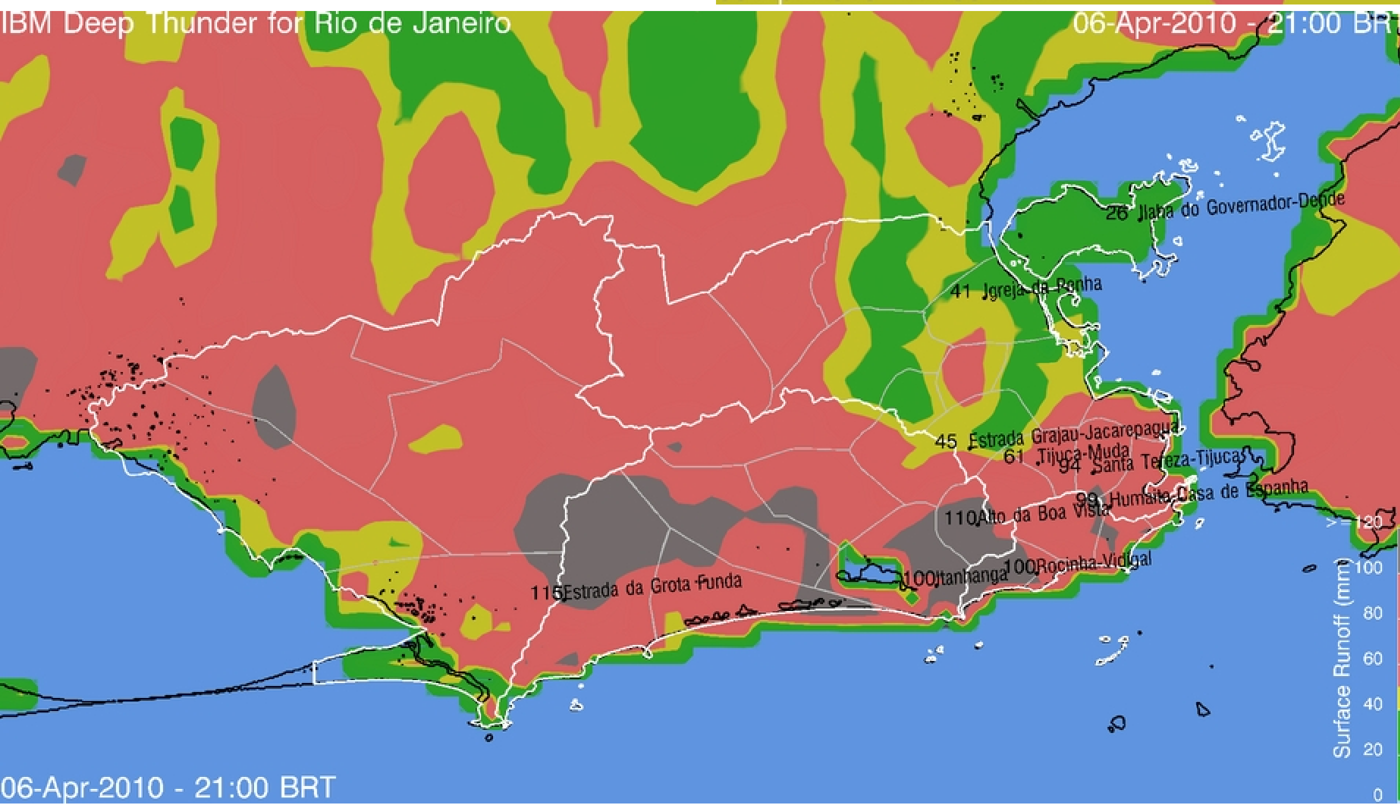
Hindcast of the Severe Rainfall Event of 5-6 April 2010 at 1 km Resolution



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

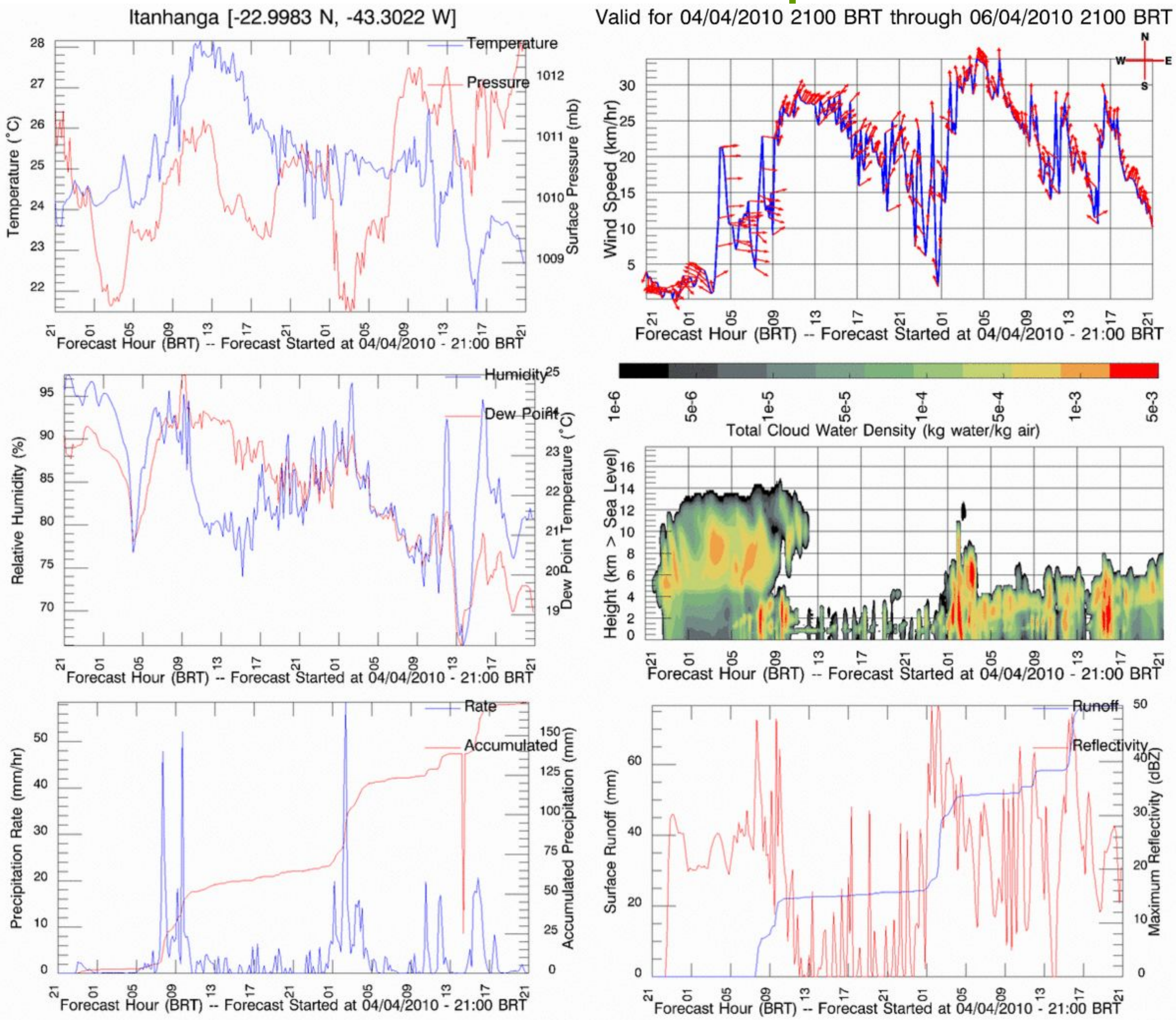




Rainfall Totals

Runoff Totals

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**

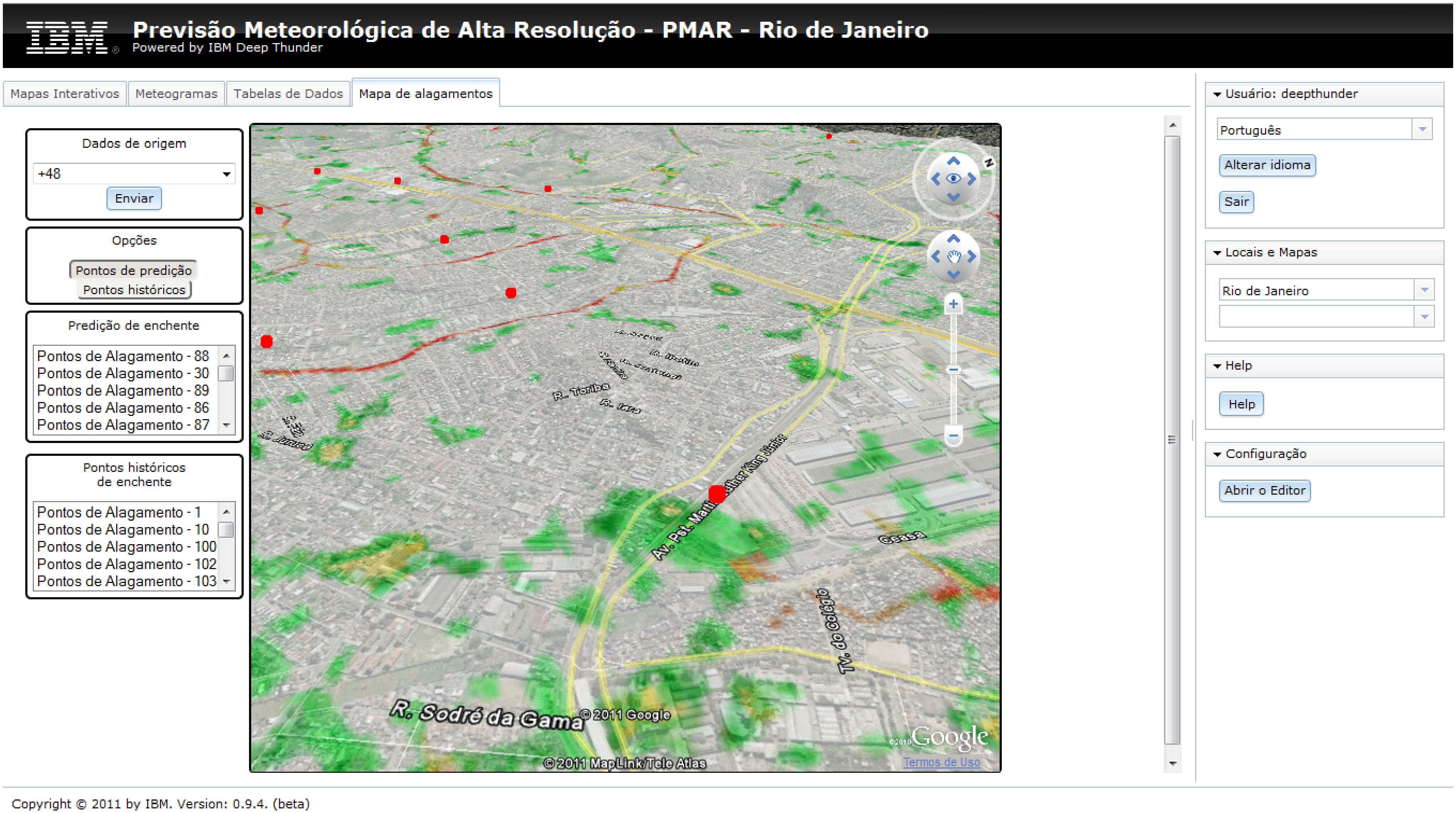
Measurement Category

Forecast Category

<u>Category</u>	**Weak**	**Moderate**	**Strong**	**Very Strong**
Weak	**x**			
Moderate		**x**		
Strong			**x**	
Very Strong				**x**

  - **Forecast <u>accuracy</u> 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



Traffic Simulation Using Flood Hindcast for April 5, 2010

Traffic Simulation Using Flood Hindcast for April 5, 2010