A Numerical Weather Prediction-Based Infrastructure for Tropical Meteorology Research and Operations in Brunei

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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:

- TJ36.3 The DOTSTAR Observations in Improving Tropical Cyclones Forecast using Ensemble-based Data Assimilation

Conference on Transition of Research to Operations:

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

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:

- 1.2 On-going Utilization and Evaluation of a Coupled Weather and Outage Prediction Service for Electric Distribution Operations
- 10.1 Precision Wind Power Forecasting via Coupling of Turbulent-Scale Atmospheric Modeling with Machine Learning Methods
- 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

A Numerical Weather Prediction-Based Infrastructure for Tropical Meteorology Research and Operations in Brunei

- Motivation and background
- Approach
- Examples
- Project plans and status

Motivation and Background

- Improve understanding of weather- and climate-related issues in Brunei Darussalam
- Impact of weather-induced disasters
  – Coupled modelling with data sets from Brunei for flood forecasting
- Impact of climate change
  • Rainforest and local weather
- Precision agriculture
  • Crop modelling (soils, crop yields)
- Explore alternate energy resources
  – Solar and wind farms
- Build research capacity for both environmental and computational sciences at the Universiti Brunei Darussalam (UBD)

Geography of Brunei

- Location: northwestern Borneo
  (04º 53' N, 114º 56' E)
- Land Statistics
  - 161 km of coastline
  - 5770 sq km areal coverage (500 sq km is water)
- Four districts: Belait, Brunei-Muara, Temburong and Tutong
- About 400,000 people

- Most of Brunei is a fertile (80% forest), hilly lowland, with the exception of the mountainous areas in the east
- Numerous rivers drain the inland regions, including the Belait, Pandaruan and Tutong
- Coastal areas along the South China Sea are a wide swampy plain
- Complex terrain and rainforests throughout Borneo
- Consideration of the “Borneo Vortex”, which occurs during the northern hemisphere winter when cold fronts from Siberia blow across the South China Sea and interact with the Equatorial trough and is modulated by the Arctic Oscillation and the El-Niño-Southern Oscillation.

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 and Belait districts

The number of flood prone areas in Brunei could increase in the future due to heavy rainfall, rising sea levels, increasing urbanization

20 January 2009 Flash Flood in Brunei

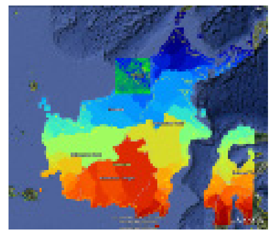
- Heavy rainfall for 4 to 5 hours with a record 145.8mm in 24 hours.
- Widespread disruption of electric distribution, transportation and communications systems

Approach

- Create a core NWP-based forecasting system focused on Brunei
  - 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 high resolution
  - Foundation for coupled business applications (analytics and visualization) with actual end users to address usability and effectiveness and for atmospheric and computational research
- 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

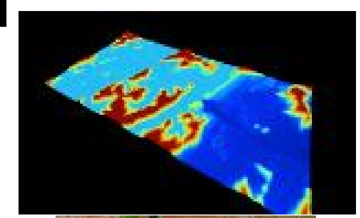
High-Resolution, National Scale, Multi-Purpose Models

Visualization
Mobile (small), large display



Renewable Energy Forecasting

Urban Flood Impact



Environmental Sensing: Data

High Resolution Weather Model (1.5km x 1.5km, 48 hour)

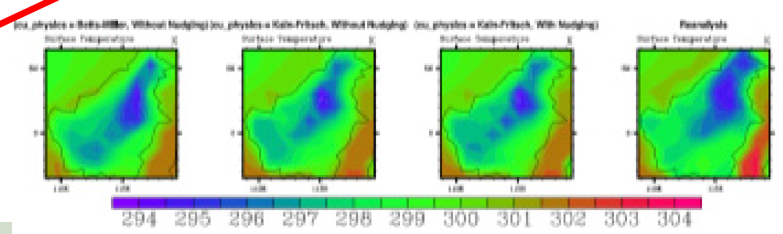
Hydrological Models

Crop Productivity

Forest Impact (fires, deforestation …)

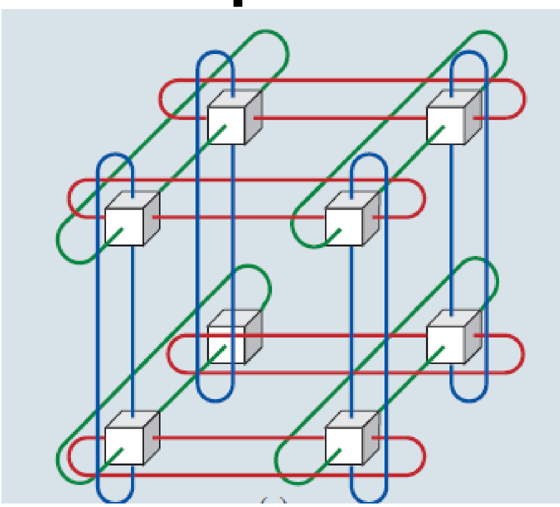
Regional Climate Model (10kmx10km, 6 months – 30 years)

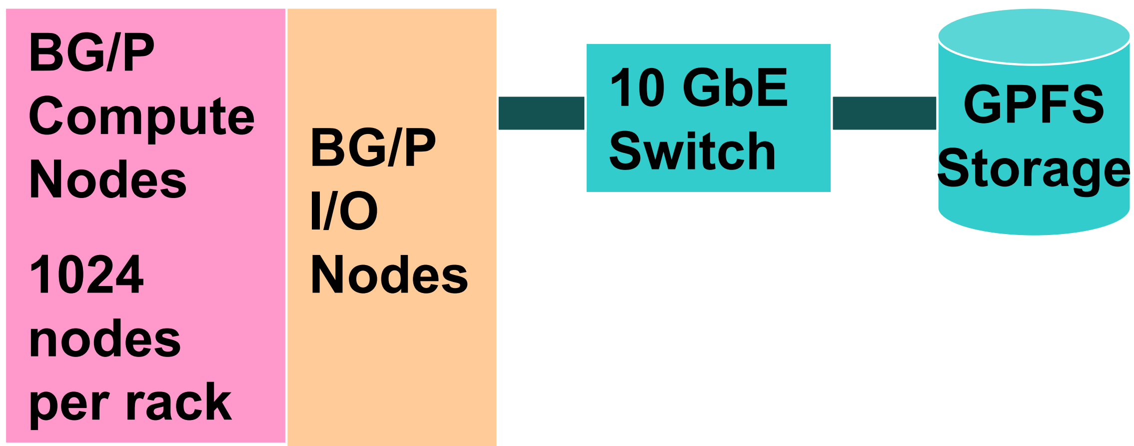
Long-term effects



Computing Platform for Brunei – IBM Blue Gene/P

- **Each rack of Blue Gene/P has 1024 compute nodes (13.9 TF peak)**
  - **Each compute node has four PowerPC 450 cores @ 0.85 GHz containing 2GB memory**
  - **Up to 16 I/O nodes for file I/O per rack**
- **Compute nodes connected through a 3d torus network for point-to-point messaging at 435 MB/s per link**





- **Operational forecasting and research/development (weather, coupled weather-flood, weather-wind models, etc.)**

Simplified *Deep Thunder* Processing Data Flow for Brunei

NOAA (NCEP)

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

Observations

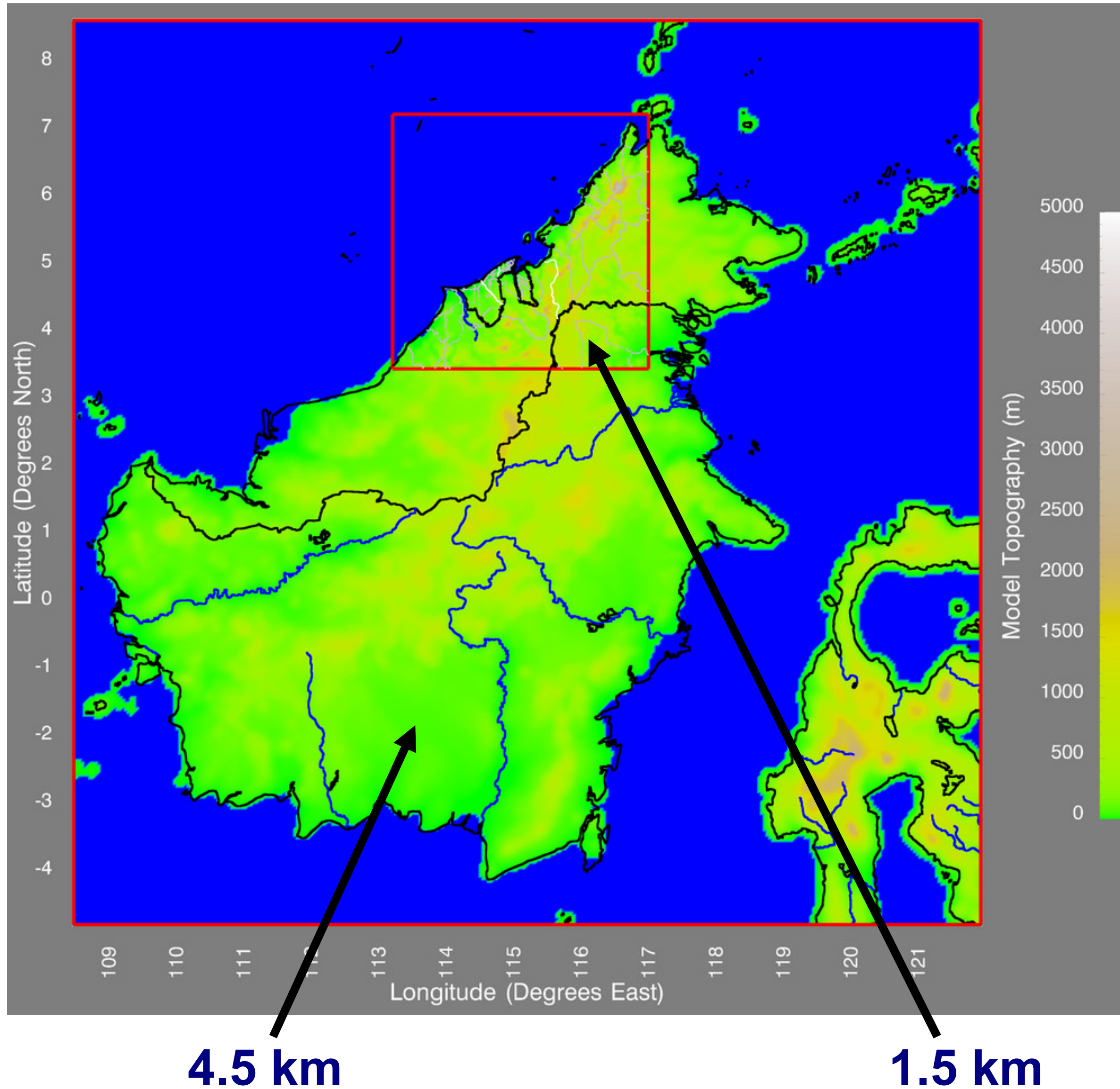
Surface Observations and Local Radar

Data Used to Generate

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

Initial Weather Model Configuration

- **WRF-ARW (v3.2.1)**
  - Three 2-way nests at 13.5, 4.5 and 1.5 km horizontal resolution focused on Brunei
  - 45 vertical levels with ~10 in the planetary boundary layer to ensure capturing of orographic effects
  - 48 hour runs once daily (initialized at 0 UTC), produced operationally since October 2011
  - 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

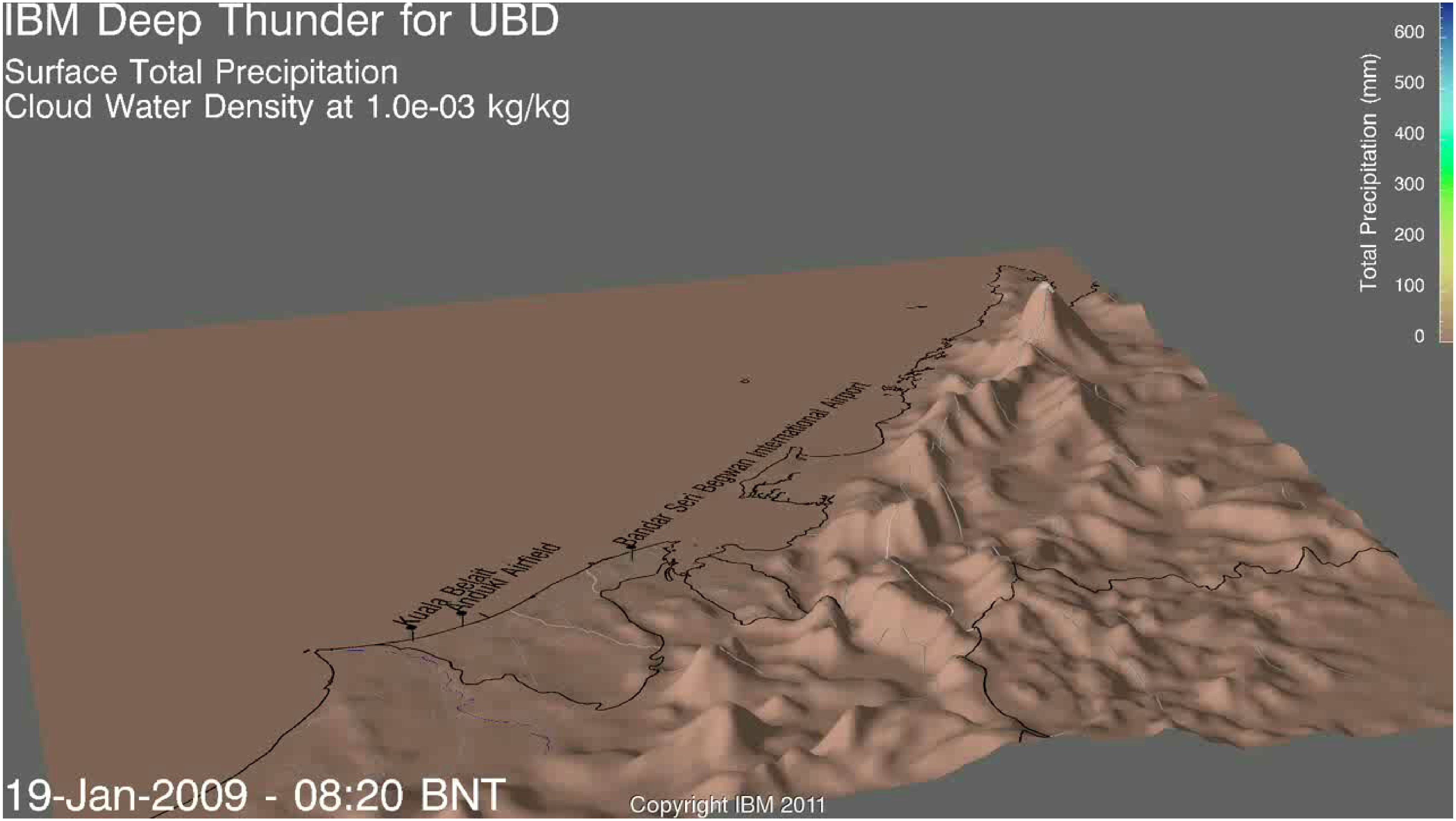


Innermost Two Nests with Model Orography

20 January 2009 Flash Flood in Brunei

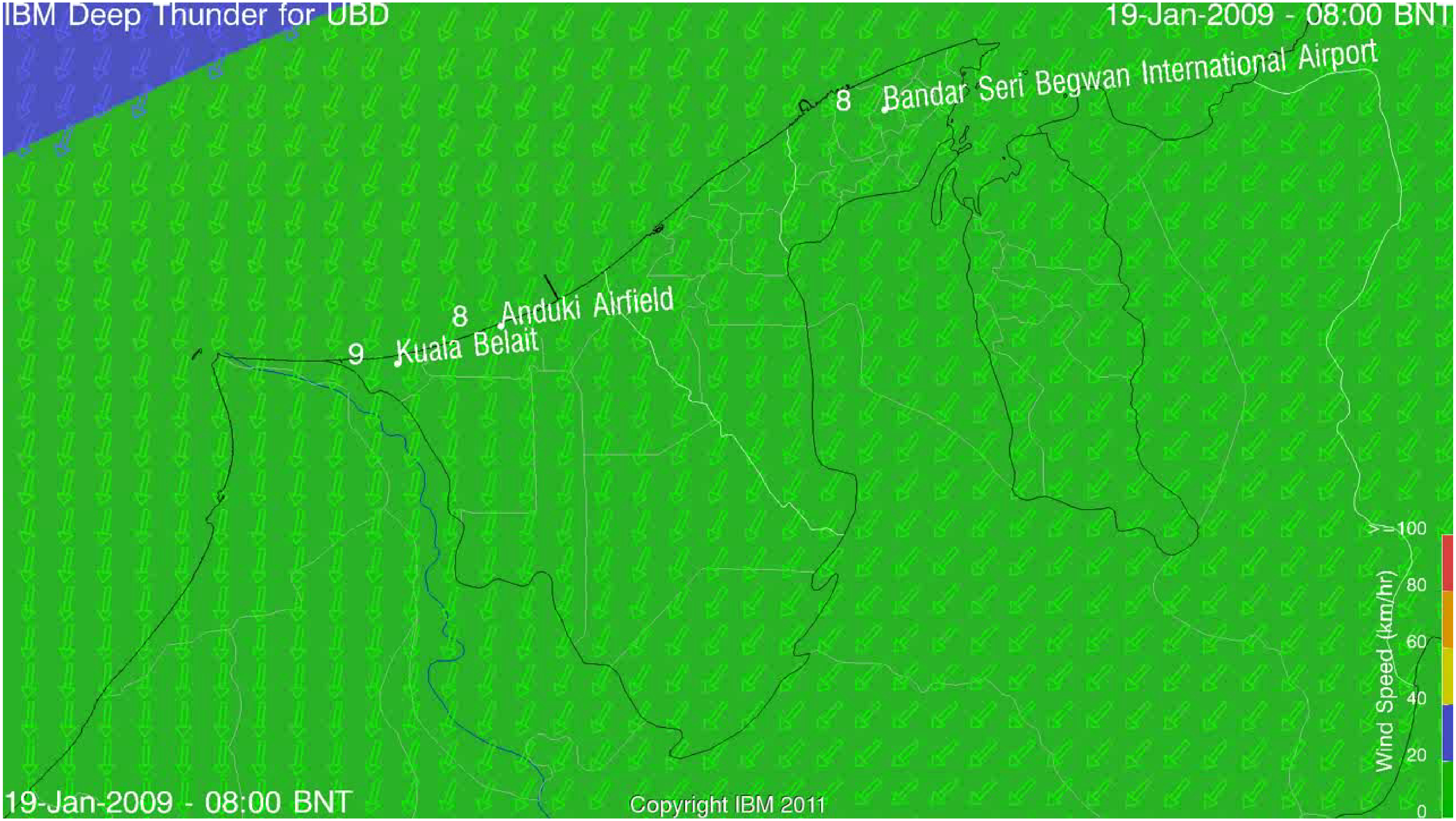
- **Heavy rainfall for 4 to 5 hours with a record 145.8mm in 24 hours.**
- **Widespread disruption of electric distribution, transportation and communications systems**

Hindcast of the Severe Rainfall Event of 20 Jan 2009 at 1.5 km Resolution



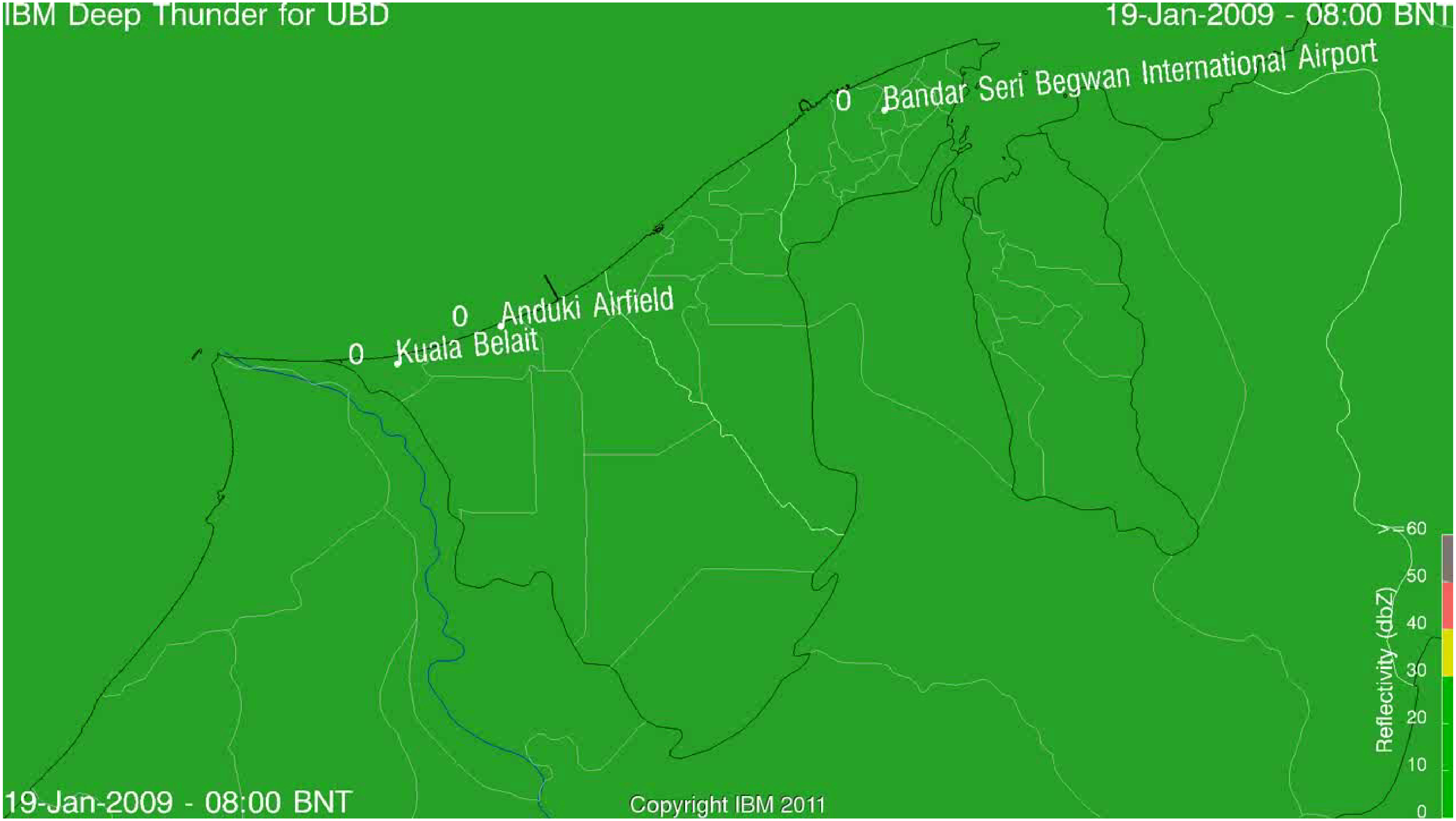
Animation of three-dimensional forecasted clouds with terrain surface and precipitation

Hindcast of the Severe Rainfall Event of 20 Jan 2009 at 1.5 km Resolution



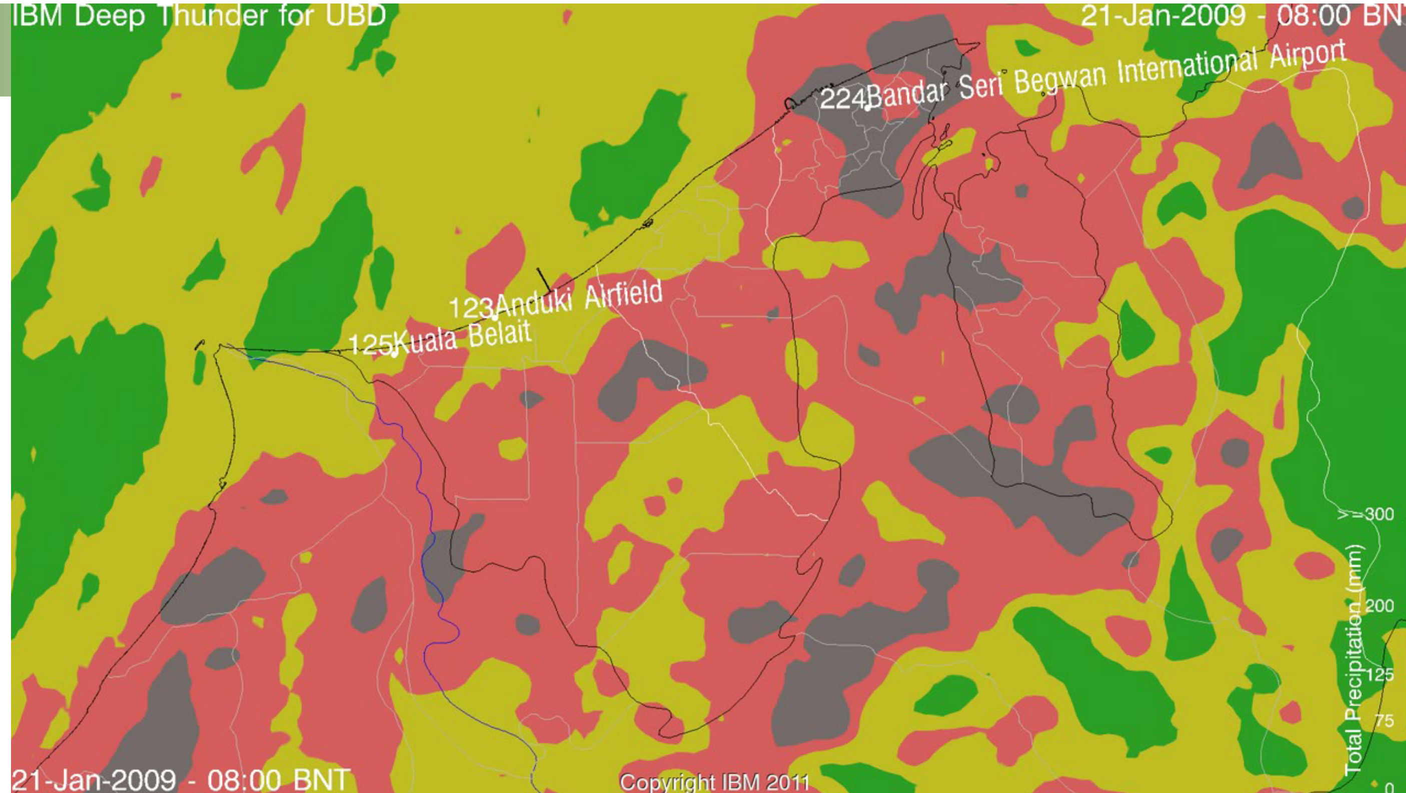
Animation of forecasted winds

Hindcast of the Severe Rainfall Event of 20 Jan 2009 at 1.5 km Resolution

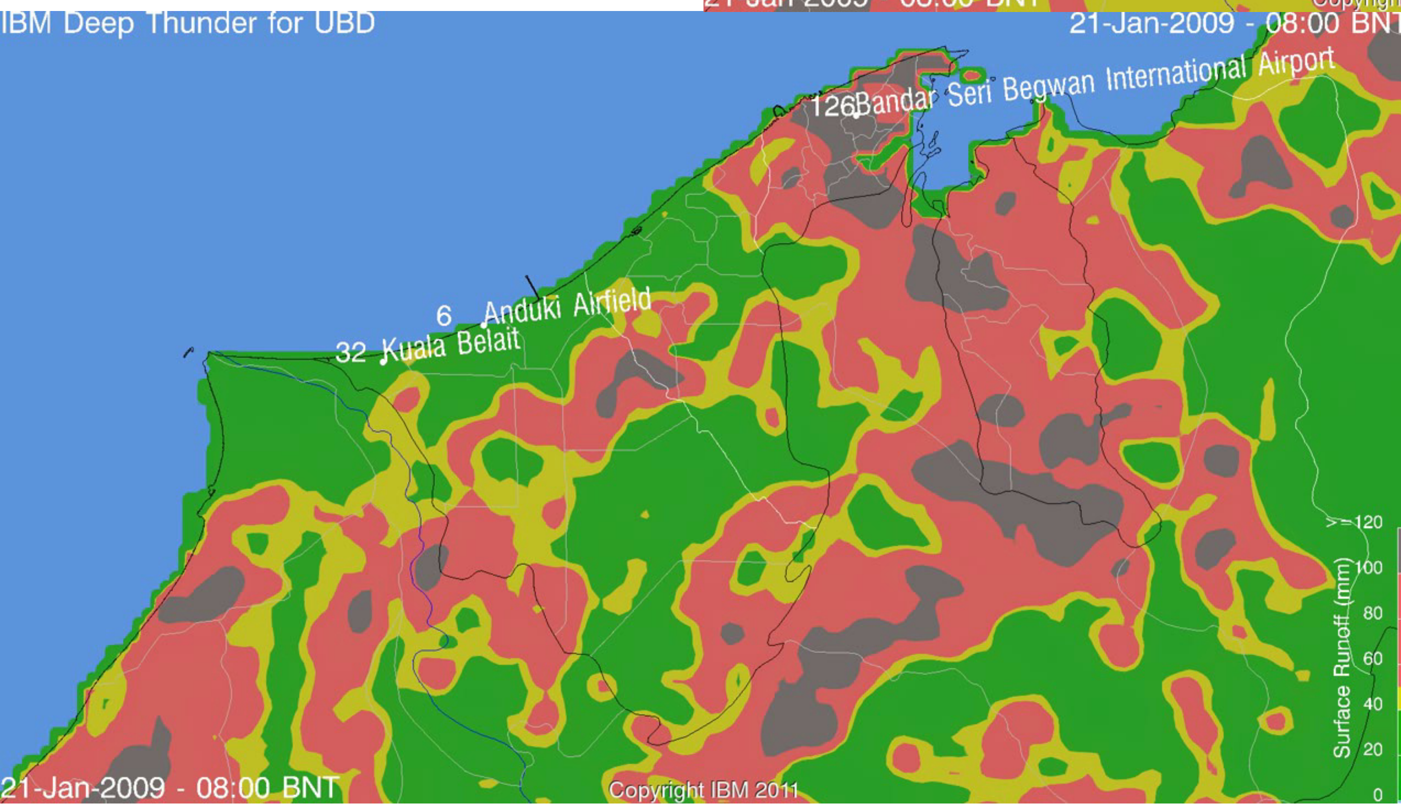


Animation of storm intensity

Hindcast of the Severe Rainfall Event of 20 Jan 2009 at 1.5 km Resolution

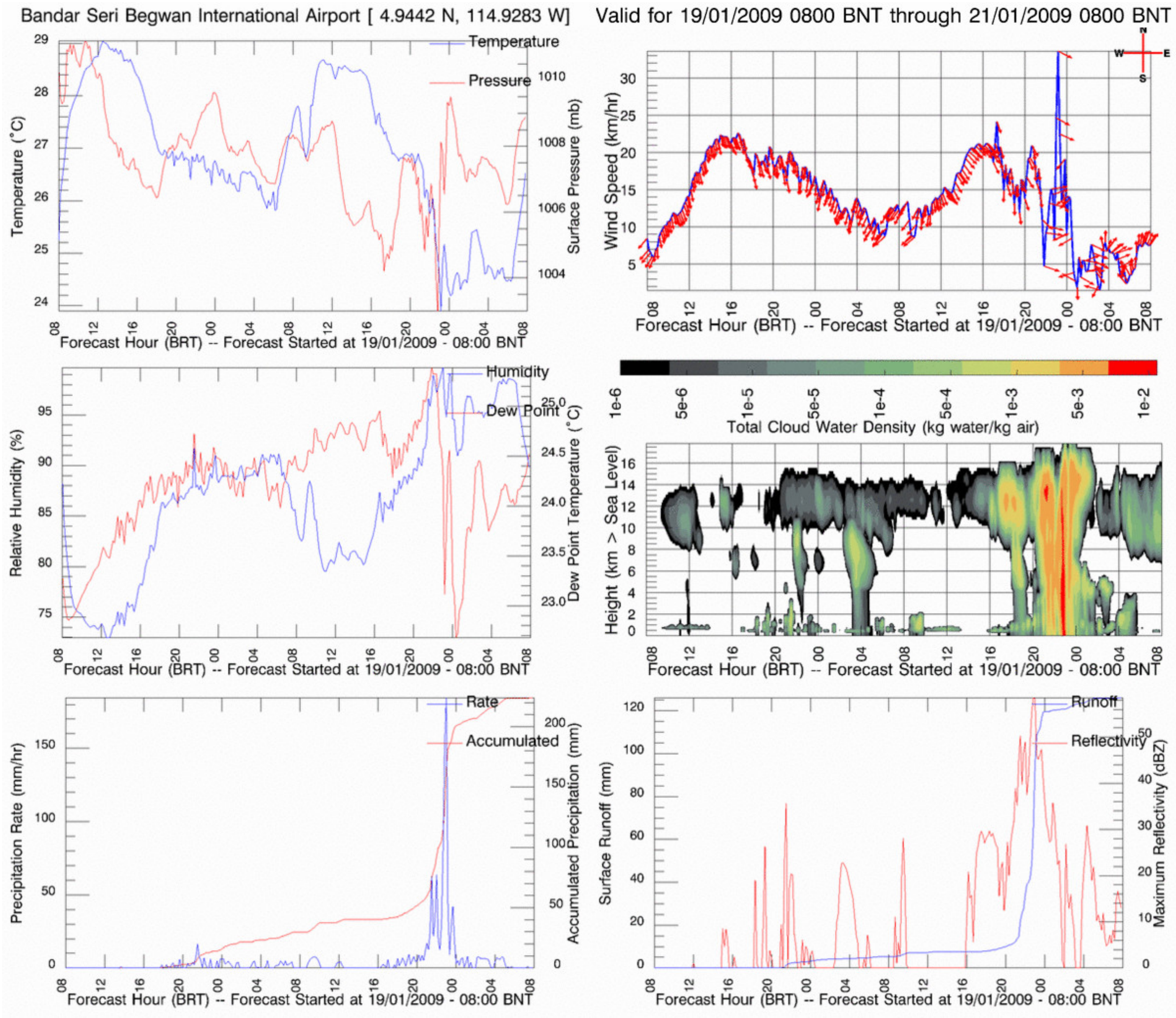


Rainfall Totals



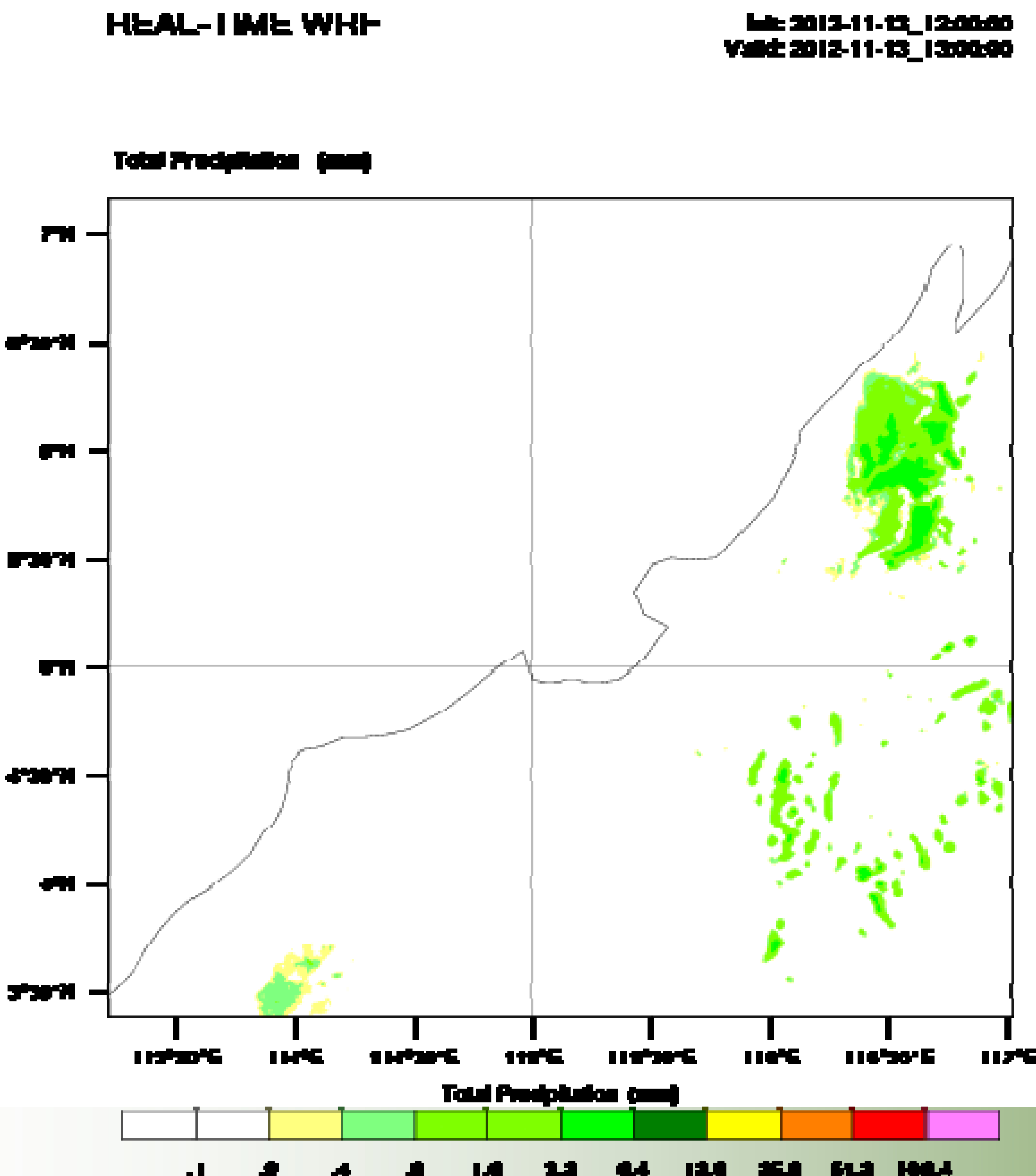
Runoff Totals

Hindcast of the Severe Rainfall Event of 20 Jan 2009 at 1.5 km Resolution



Site-specific forecast at the location of a weather station

Heavy Rainfall Event:
Forecast valid from Nov 13 8pm – Nov 15, 8pm Brunei Time



Belait Met Station

- Forecast shows about 100mm of rain to be received from Nov 15, 0000 to 0400
- Awaiting actual weather station data for verification

Mobile Platform Access to Deep Thunder

- Receive a detailed forecast for a specific address or location in the Brunei or your current position
- Temperature, wind speed or rain can be shown (48 hours every 10 minutes)

- Supported on iOS (iPhone, iPad) and Android (3+ phones and tablets) and web browsers

Enable Direct Flood Prediction Driven by the Meteorology

- **Leveraging work done in Rio de Janeiro and New York City, and high-resolution surface data from the Brunei government**
  - Using surface runoff from WRF LSM (NOAH) as input
  - Overland flood model using publicly available 90m NASA SRTM for gravity-driven flow assuming zero infiltration and no drainage network (diffusion model approximation for the Shallow Water equations)
  - Water height provides a rough estimate of flood prone regions
  - Web-based dissemination of flood forecasts using GoogleEarth under development
- **Scalability studies of the current overland flow model to identify potential bottlenecks**
- **Developed an OpenMP-based intra-watershed-based parallel version to reduce the load imbalance**

Efforts to Improve Flood Model

- **Incorporate local land use, drainage and soil data**
- **Beginning to work with local LiDAR terrain data**
  - LiDAR data pre-processing (such as filling gaps, geo-coding, etc.) to create a single DEM at higher resolution
  - Automatic extraction of river characteristics such as cross-section width from LiDAR data
  - Received a few cross-section data values for the Tutong River
  - These data will be used for verification and fine-tuning of code to automatically extract data from LiDAR tiles
- **Couple with our SPRINT river flow model (see Hydrology poster 533 on Wednesday)**
- **Validate the model(s) using ground truth**

Direct Flood Model Output

Accumulated Water (m)

Future Work

- Refining weather model including migration to WRF 3.3.1 and 3.4.1, and incorporate NASA MODIS land use and JPL 1km SSTs
- Exploring availability of data for model input and verification
- Using operational NWP to enable a 500m LES nest for wind power forecasting
- Medium-range seasonal forecasting for Brunei, including the Borneo rainforest
- Sensitivity studies on the various configurations of a climate model
- Coupling of river and overland flow models
- Incorporating more accurate soil models
- Evaluate publicly available coarse data on soil type, land use, etc.
- Modelling at farm level to plan for irrigation of crops
- Validation of flood model using sensor data, crowd sourcing strategies and past historical data

Backup

Slides

Climatological Characteristics of Brunei

- **RAINFALL: High with average 2800mm observed (range: 2300 – 4000 mm)**
  - Higher rainfall in the interior region due to geographic effect (higher altitude)
  - Two well-known monsoons in the southeast Asia: Northeast (Dec-Mar,rainfall peaks in January, heavy intense rain events), Southwest (June-Oct, relatively less intense, continuous rainy season)
  - Rains are mostly in the form of thunderstorms with high intensity and localized distribution along the ITCZ (Inter Tropical Convective Zone) originating from localized small scale convection cells
- **AIR TEMPERATURE: Mostly uniform with very little seasonal variation (mean 27.5 C) while increased cloudiness in Dec-Jan results in slight decrease in temperature whereas the peaks are found in so called dry months (Mar-Apr) and elevated interior is cooler**
- **RELATIVE HUMIDITY and EVAPORATION: Very high humidity throughout the year with average of 92.6 % (Range: 89%-95%) and evaporation depending on wind, air temperature and relative humidity (maximum in dry months Mar-Apr)**
- **WINDS : Usually low winds with exception of squalls during the thunderstorm. Most common is 4-8 m/s. Wind direction is north to northeasterly during Nov-Mar and south to southwesterly during Apr–Oct**
- **FLOODING: There are three main classifications**
  - River Flood plain : Flood flows exceeds capacity of the river channels.
  - Tidal flooding : Occurs during Nov-Jan during extreme / high tides with the worst combination when high tides coincide with surges due to storm and wind conditions
  - Local floods are as a result of obstruction to channel

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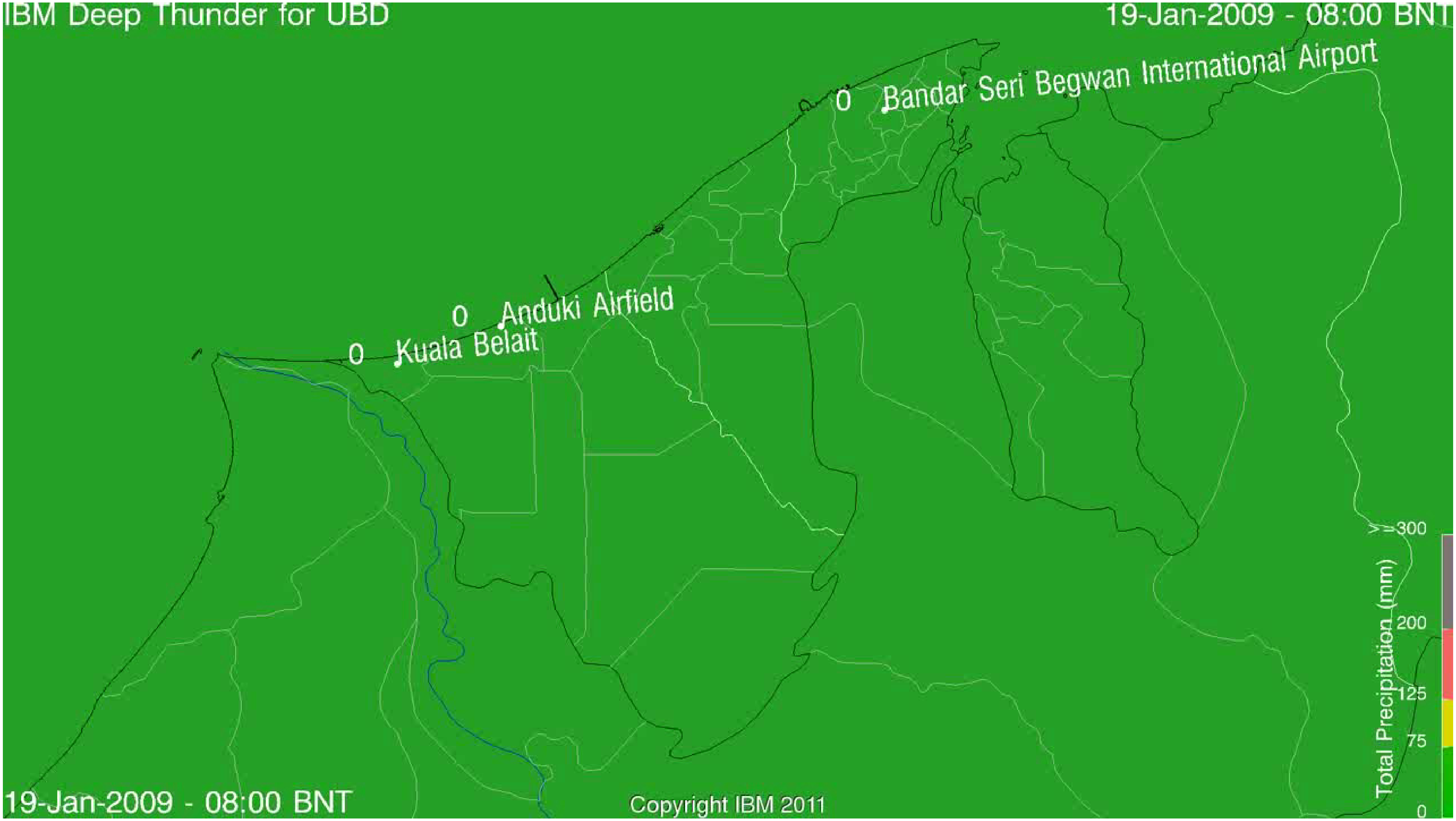
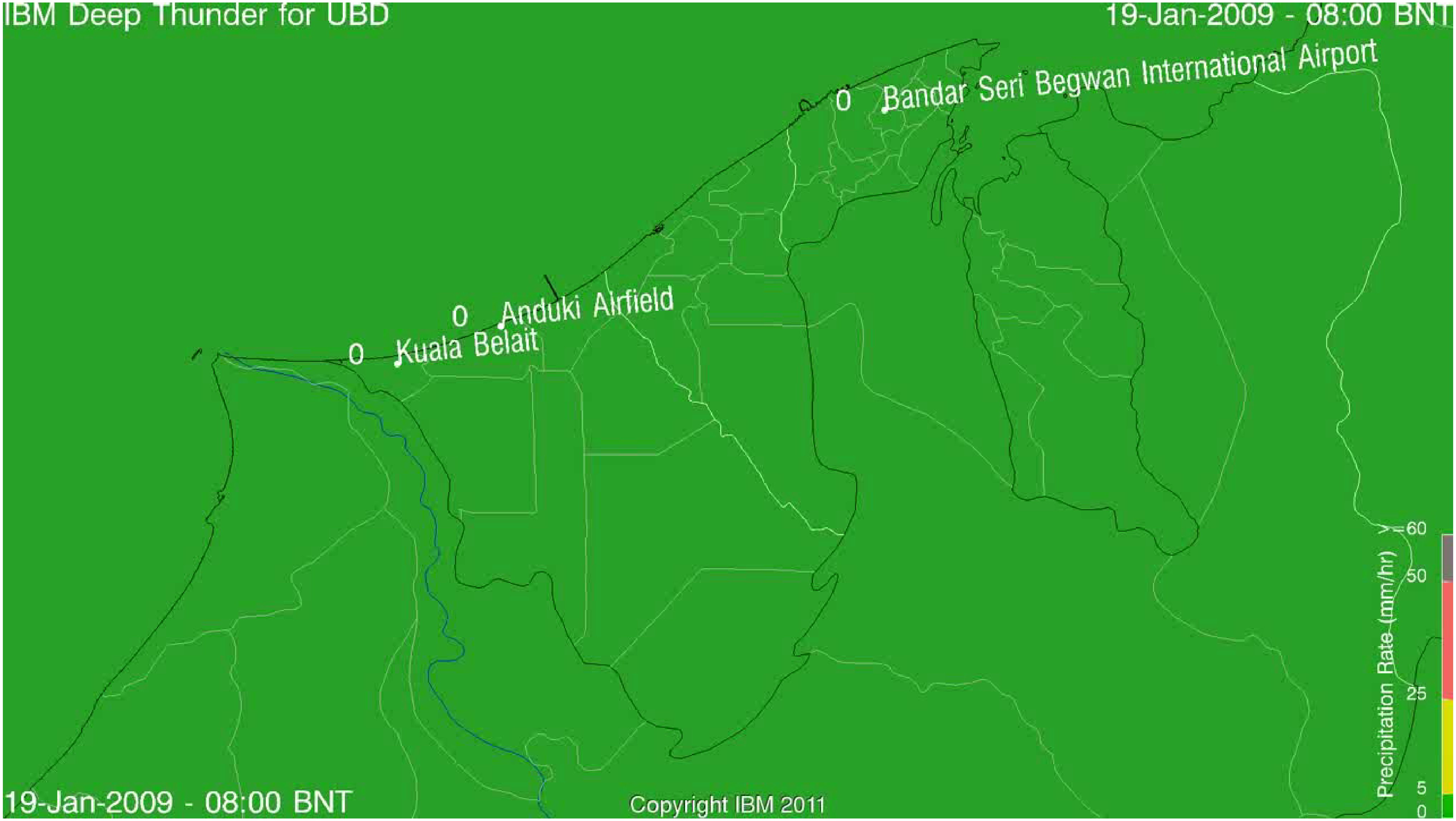


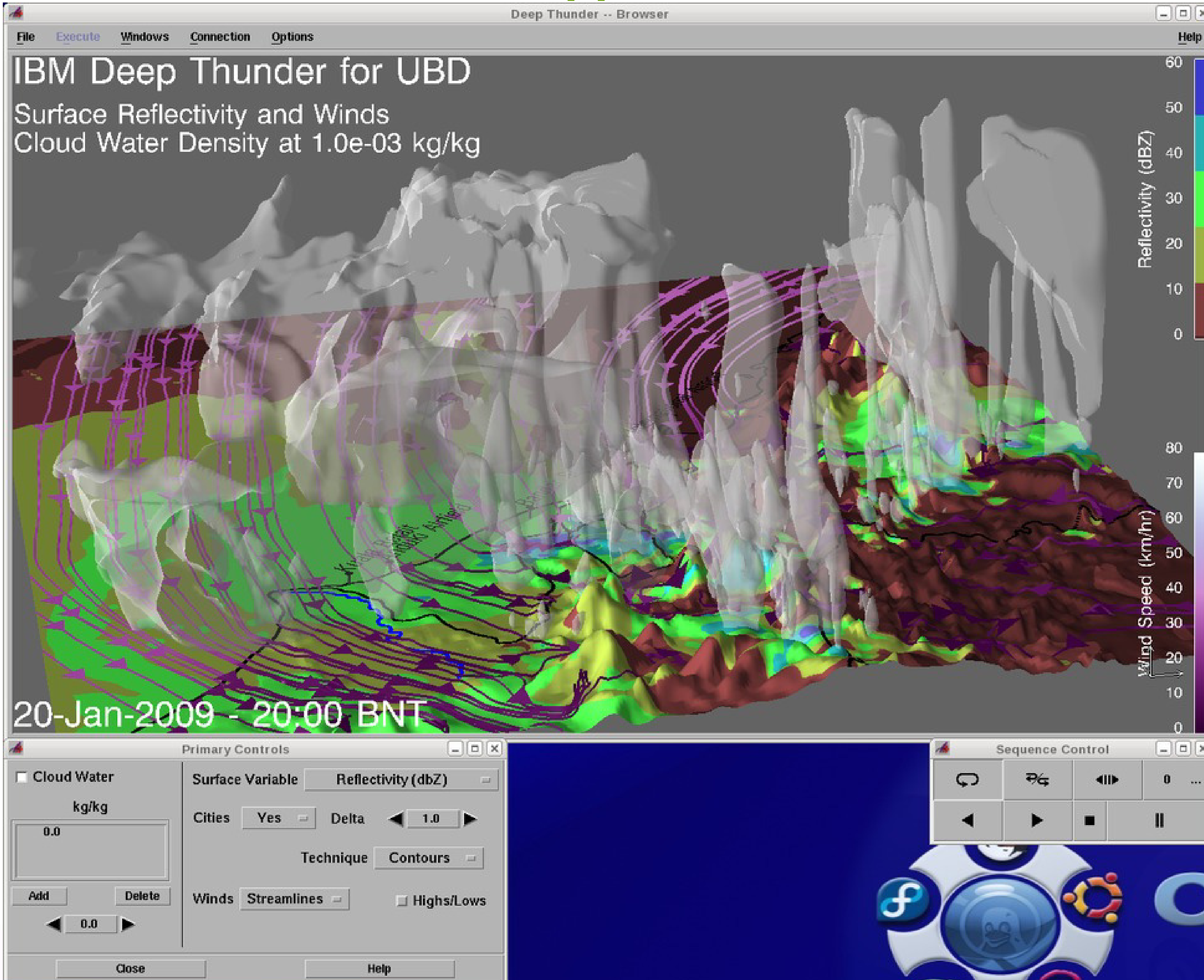
Animation of forecasted precipitation

Hindcast of the Severe Rainfall Event of 20 Jan 2009 at 1.5 km Resolution



Animation of forecasted precipitation rate

Interactive 3d Visualization Application



Interactive 3d Visualization Application