The Weather Research and Forecasting (WRF) Model

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Preamble

Weather Prediction an “Initial value problem“

- Hence, Earth Observing System (EOS) involving land based, remote & space based observations and rapid data transmission are back-bone of weather forecasting
- Well recognized and demonstrated that weather/climate prediction at all time scales (short, medium, extended, seasonal and climate) can be achieved only by numerical models
- NWP is the most appropriate approach for weather/climate prediction

Components of NWP

- **EOS to obtain initial state of the atmosphere**
- **Rapid collection/transmission of all forms of observations**
- **Data Processing and quality control**
- **Data assimilation**
- **Advanced NWP Modeling System**
- **Post processing and Derivation of products for different stake holders for various applications**
- **Efficient dissemination of forecast products**

Principal Technological Requirements

- Dense and High quality Observational platforms
- High speed Transmission
- High Performance Computational Resources
- Visualization of massive observations/Analysis/ forecast products
- Various methods of dissemination of forecast products
- Highly qualified skilled man power

Developments in NWP

- Present Observation System is Synoptic Scale

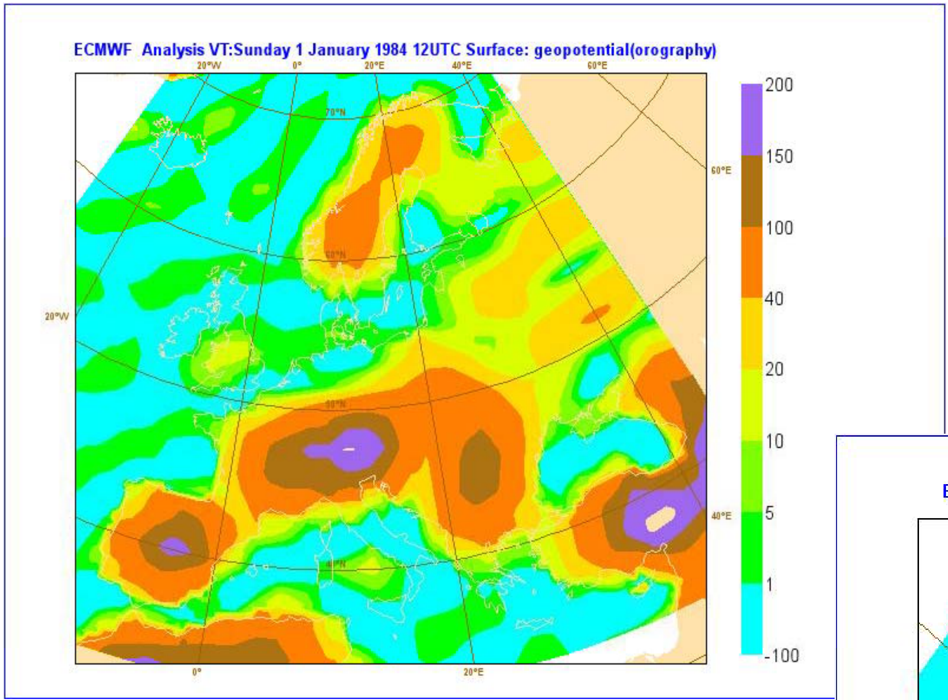
- Most of NWP models of 80-90's are of Synoptic scale models. Dynamics of atmosphere is given more importance and physical process are not properly resolved due to limitation of computer power

- Advancement in Satellite & Radar observation made it possible to get the mesoscale observations such as satellite winds, temperature and moisture profiles at highly spatial and temporal resolution.

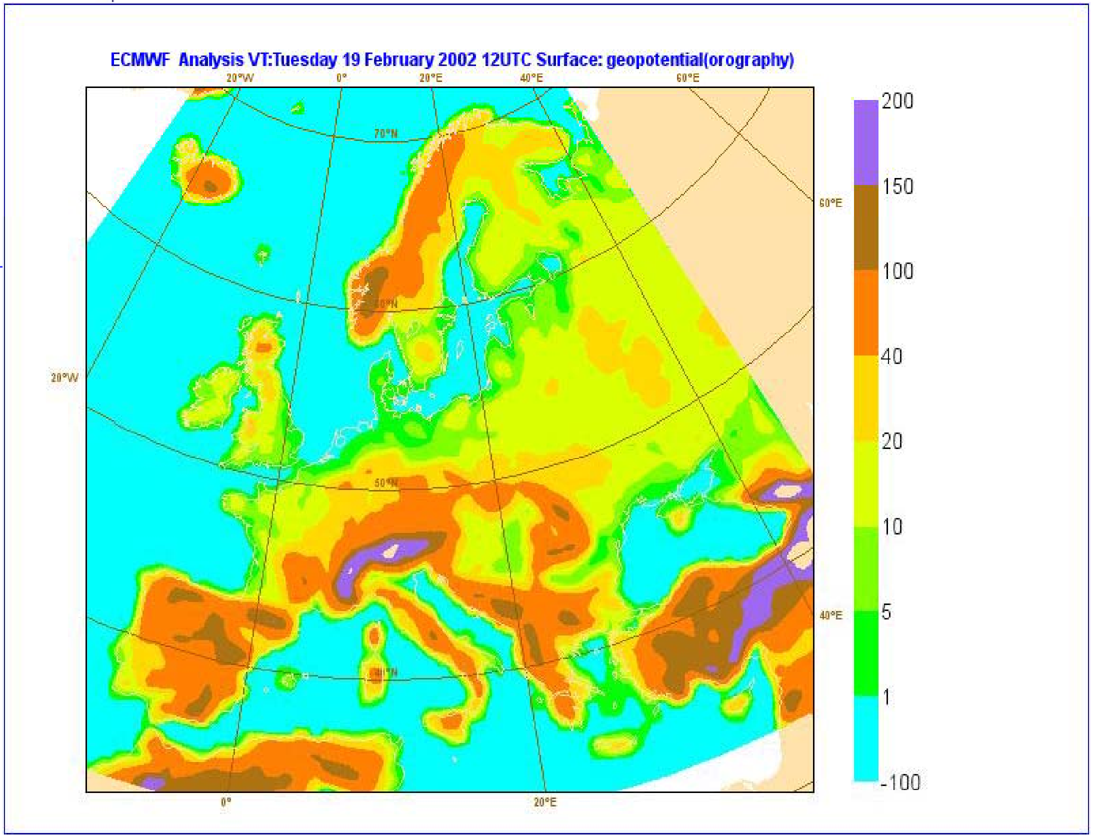
- Advancement in computer made it possible for mesoscale model forecast

- Public Demand for mesoscale forecast

Resolution changes



T63 –1985 (200 km)

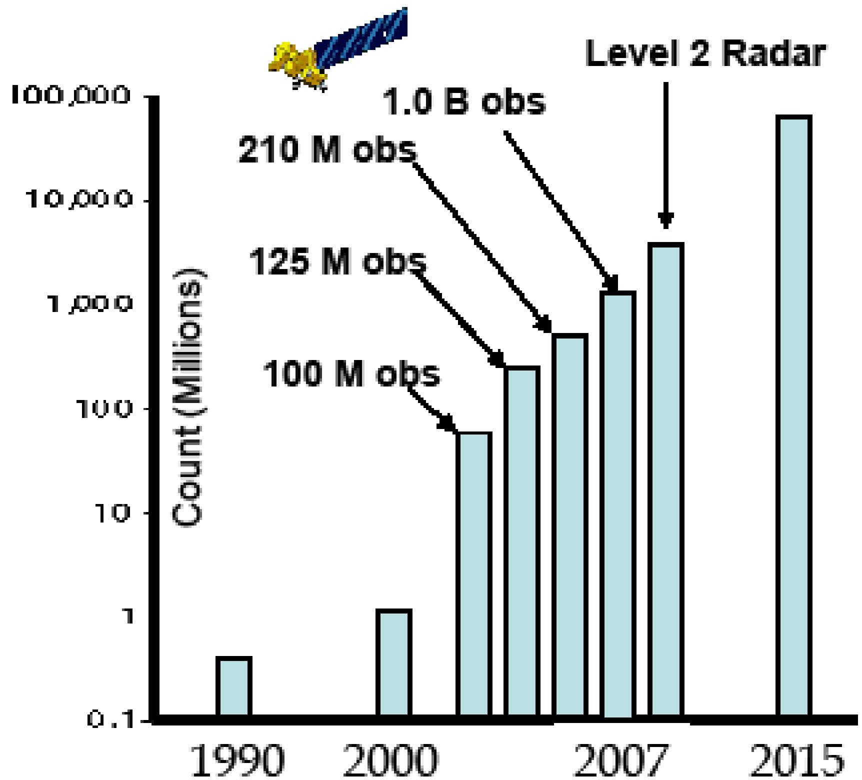


T511 – 2000 (40 km)

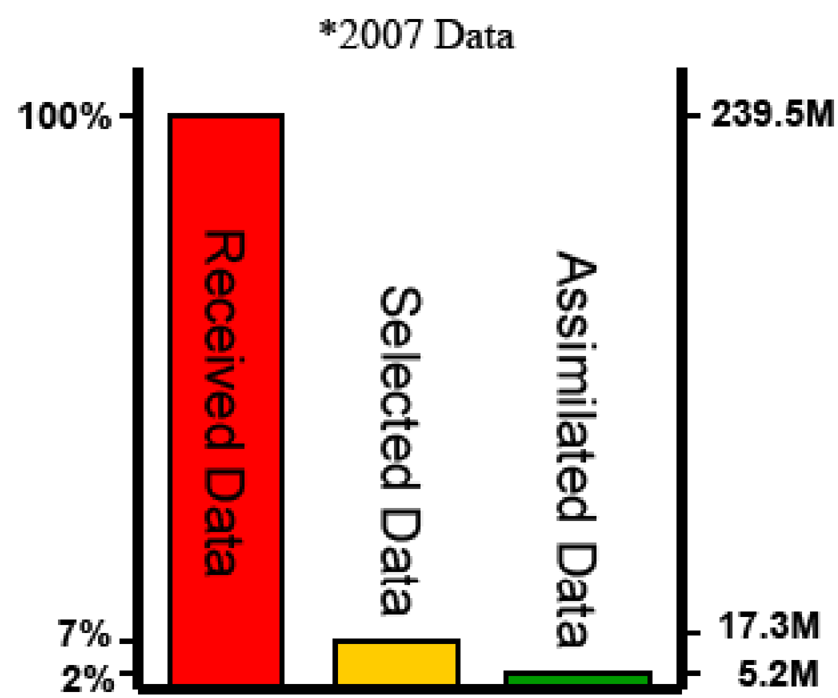
NASA-NOAA-DOD Joint Center for Satellite Data Assimilation (JCSDA)

Satellite Data Ingest

Daily Satellite & Radar Observation Count



Daily Percentage of Data Ingested into Models



Motivating Factors for the JCSDA

Five Order of Magnitude Increases in Satellite Data Over Fifteen Years (2000-2015)

Received = All observations received operationally from providers
Selected = Observations selected as suitable for use
Assimilated = Observations actually used by models

Present Operational NWP mesoscale models

NCEP, USA Global Model: T382/L64 (35 km) Eta 12 km/60 L, RUS 20 km/50 L (later WRF), NCAR – MM5 (later WRF)

ECMWF Global Model T-799/L60 (25 km)

EUROPE LIMITED AREA MODEL group

HIRLAM Denmark Hydrostatic 22 and 11 km grid > 40 levels

Non-hydrostatic 11 and 2.5 km grid > 50 levels

UKMO Unified model

Hydrostatic 12 km 38 levels

Non-hydrostatic 3km grid > 70 levels

COSMO of Germany,Greece, Italy and Switzerland.

Non-hydrostatic - 7 km grid 35 levels

Non-hydrostatic 1 km grid > 50 levels

ALADIN Meteo-France Austria, Belgium, Bulgaria, Croatia, Czech Republic, France, Hungary, Poland, Portugal, Romania, Slovakia and Slovenia.

Hydrostatic 9 km 31 levels ; Non-hydrostatic 2-3 km

Environment Canada - Non-Hydrostatic 10, 2 and 0.2 km grid 70 levels

What’s WRF ?

- **Weather Research and Forecasting (WRF) model is a next-generation mesoscale forecast model and assimilation system designed to place new and existing US research and operational models under a commen software architecture.**
- **In, WRF it is possible to mix and match the dynamic cores and physics packages of different models to optimize performance since each model has strengths and weaknesses in different areas. This feature is particularly advantageous for inter model comparison and sensitivity studies.**
- WRF is being developed in collaborations with universities and other government agencies in the USA (*NCAR, NCEP, FSL, AFWA, and OU)*

MM5 Version 3.7 released in December 2004

Version 3.7.2 released in May 2005 with modification of 3.7

With WRF development MM5 development has been ended and the model is considered frozen

The WRF model is designed to be a flexible, state-of-the-art, portable code that is efficient in a massively parallel computing environment. Present version 2.1.2 released in January 2006.

A modular single-source code is maintained that can be configured for both r esearch and operations.

It offers numerous physics options, thus tapping into the experience of the broad modeling community.

It is suitable for use in a broad spectrum of applications across scales ranging from meters to thousands of kilometers such as downscaling climate simulation, driving air quality models, atmosphere-ocean coupling, and idealized simulations (e.g boundary-layer eddies, convection, baroclinic waves).

There are different versions of WRF

- ARW (Advanced Research WRF), NCAR, USA
- WRF NMM (Nonhydrostatic Mesoscale Model), NCEP, USA
- **WRF Non-hydrostatic Meso-Scale Model (WRF-NMM) is a sub-set of ARW. Dynamical core developed by NOAA/NCEP/EMC). It i ncludes: initialization (WRF-NMM SI) and post-processing c omponents**
- **Physics and software framework are shared with WRF-ARW**
- Hurricane WRF, NCEP/NOAA, USA – Air-Sea coupling, Movable 1-2 way nesting facilities expected to be made operational by the end of 2007 to replace the present operational hurricane model – GFDL at NCEP model.

- **This study aims in evaluating the ability of WRF model to predict Heavy Rainfall events.**
- **Case-I: Based on Initial Conditions of 02 September 2009 and 01 November 2009.**
- **Case-II: Impact of Resolution (20, 9 and 3 kms).**

WRF Model

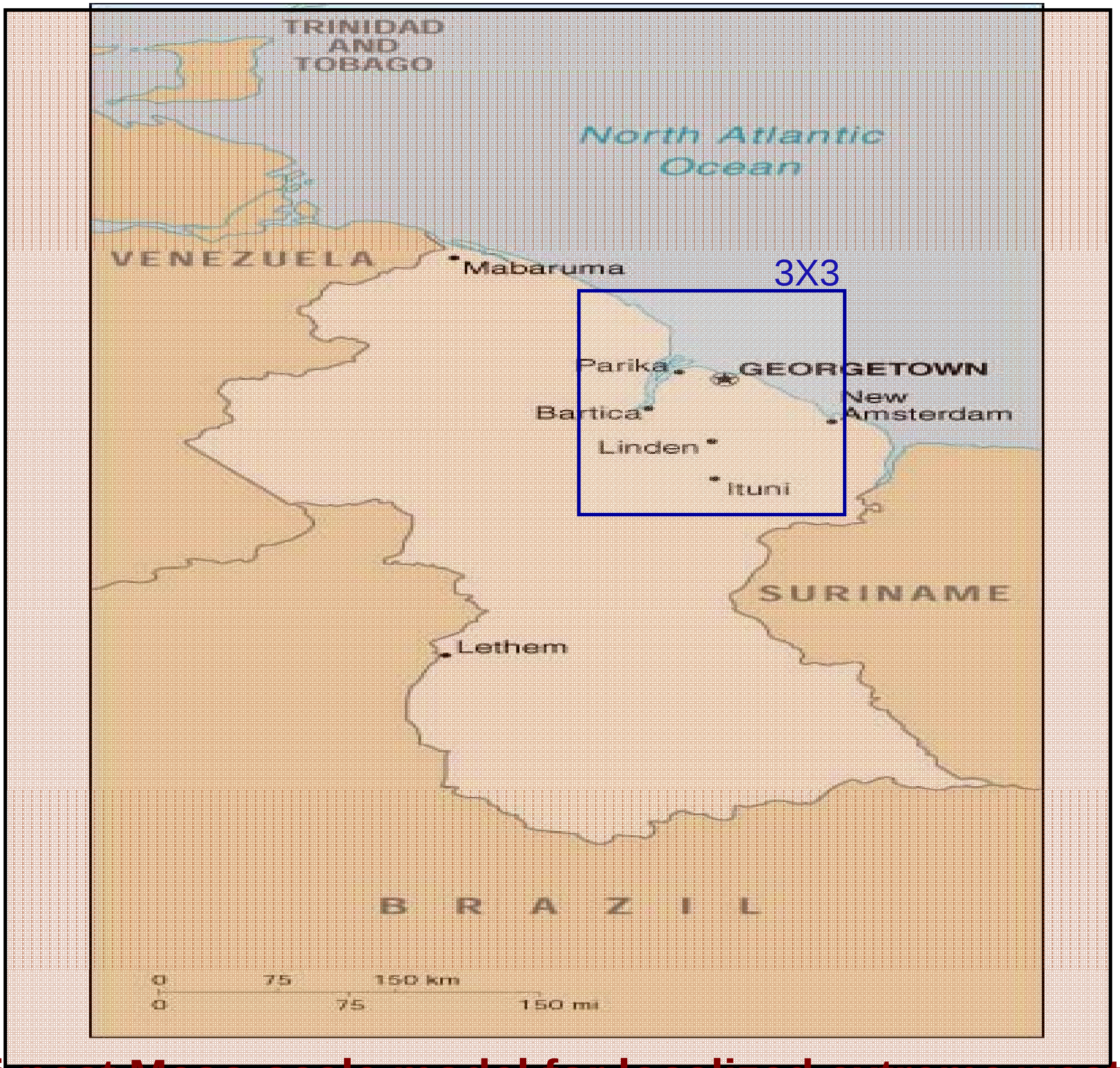
- Dynamics:Non-hydrostatic Version (2.2)
- Dynamical core: ARW (Advanced research WRF)
- Single domain
- Horizontal Resolution: **20, 9 & 3 km**
- Vertical Resolution: 28 **Sigma levels**
- Domain: **-5S^0-15^{0}N; 66^{0}W-48^{0}W**
- Time step: 100 sec
- Map projection: Mercator
- Horizontal Grid system: Arakawa- C grid
- Time Integration scheme: Third order Runge-Kutta scheme
- Real-data using Standard Initialization (SI) conversion from Grib files
- Spatial differencing scheme: 2nd to 6th order schemes
- 6 hourly boundary conditions
- **Forecast run up to 72 hours (3 days)**
- **PHYSICS**
- **Microphysics (WSM 3 simple ice scheme)**
- **Cumulus parameterization (Kain-Fritsch scheme)**

Input data types

- **NCEP Global Analyses/Forecast (GFS) at 1^{0}x1^0 lat./long. resolution in GRIB format**
- Terrestrial data
  - 30 sec (and 10 minute) topography data
  - 30 sec land use (data from USGS Version 2.0)
  - 30 sec soil type (data from 30 sec STATSGO (US) and 5 min UN/FAO (global)) (two layers)
  - 10 min 12 monthly vegetation fraction data
  - 1 degree deep soil temperature data

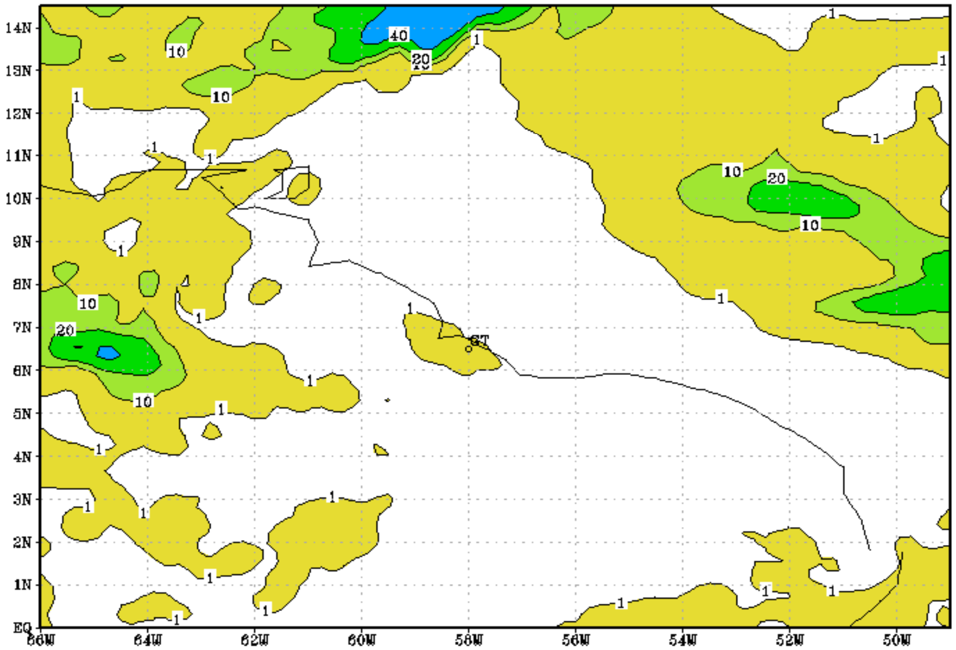
Post Processing: A simple conversion program to convert NetCDF data to GrADS

9X9



Multi-nest Meso-scale model for localized extreme weather prediction

WRF(20 KM) GUYANA RAINFALL(mm) FORECAST (24 hr)
based on 00 UTC 02-09-2009 valid for 00 UTC of 03-09-2009



WRF(09 km) GUYANA RAINFALL(mm) FORECAST (24 hr)
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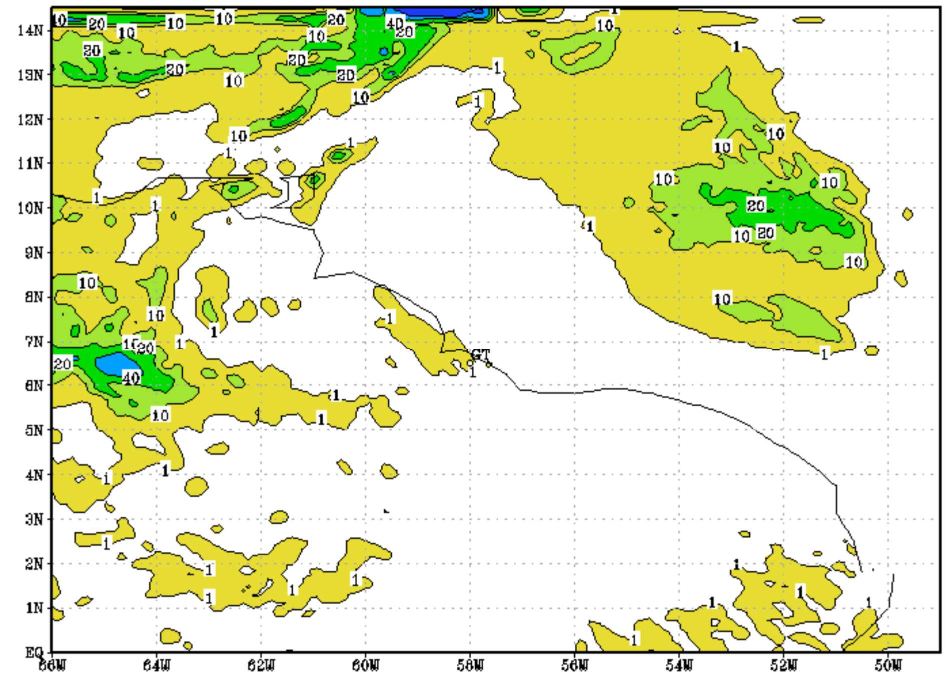
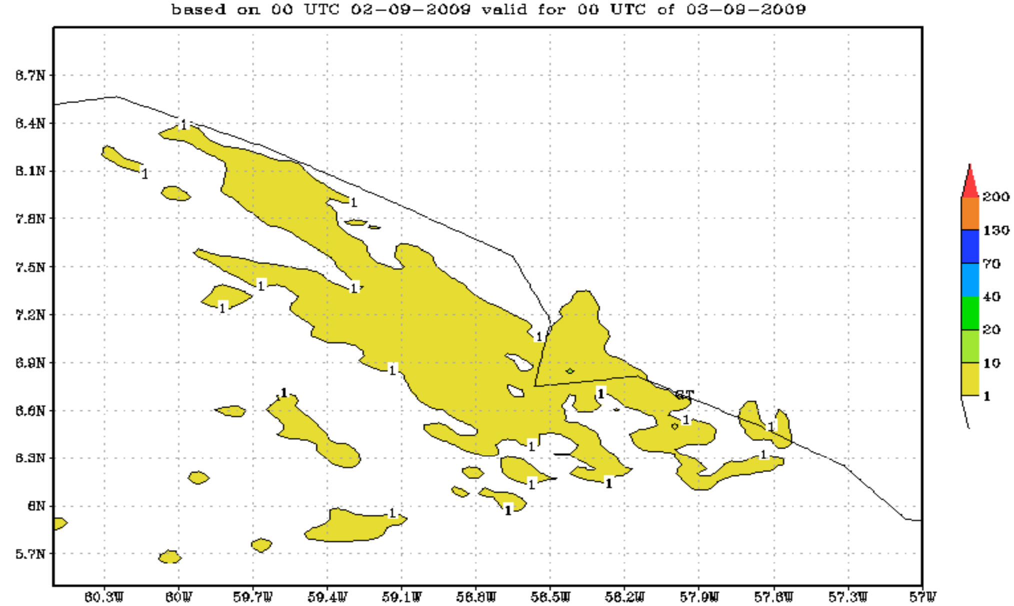


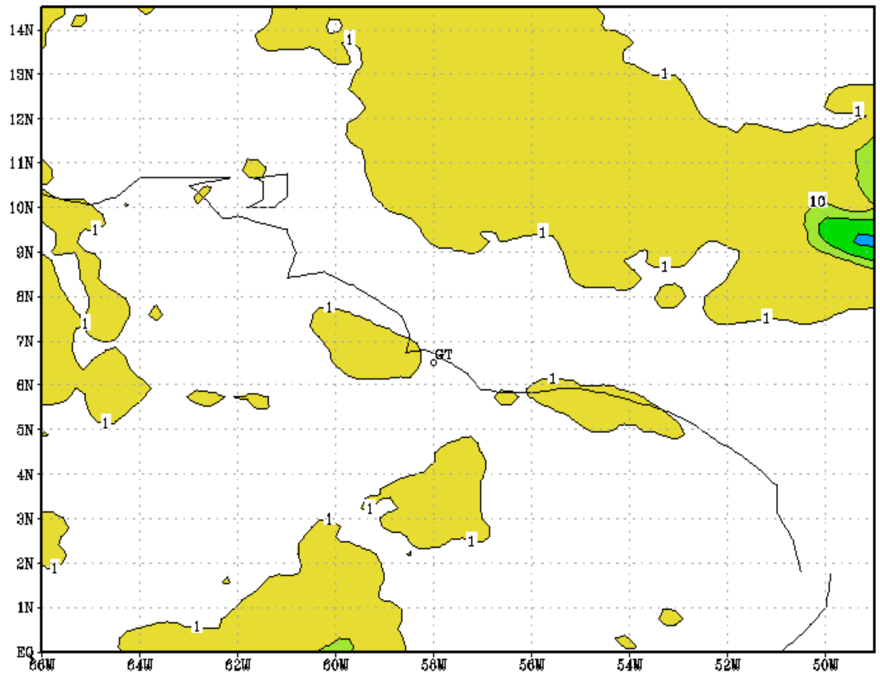
WRF(03 km) GUYANA RAINFALL(mm) FORECAST (24 hr)
based on 00 UTC 02-09-2009 valid for 00 UTC of 03-09-2009



Based on Initial Conditions of 02 September 2009.

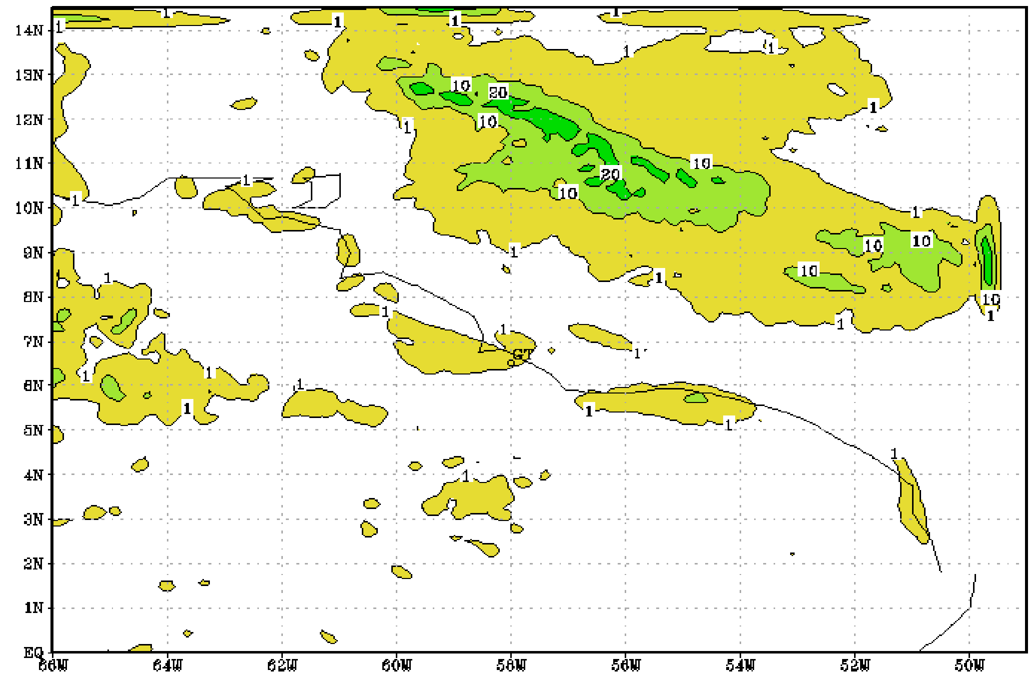
WRF(20 KM) GUYANA RAINFALL(mm) FORECAST (48 hr)

based on 00 UTC 02-09-2009 valid for 00 UTC of 04-09-2009



WRF(09 km) GUYANA RAINFALL(mm) FORECAST (48 hr)

based on 00 UTC 02-09-2009 valid for 00 UTC of 04-09-2009



WRF(03 km) GUYANA RAINFALL(mm) FORECAST (48 hr)

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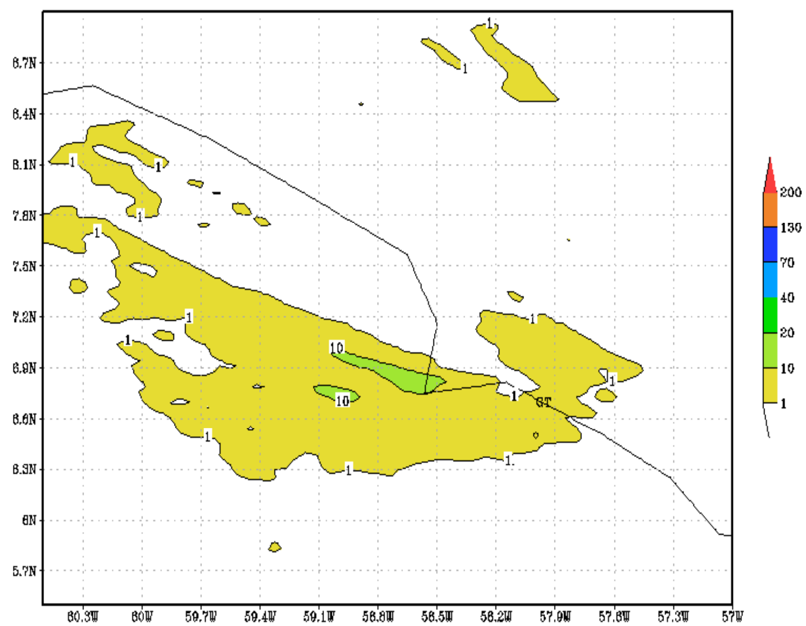
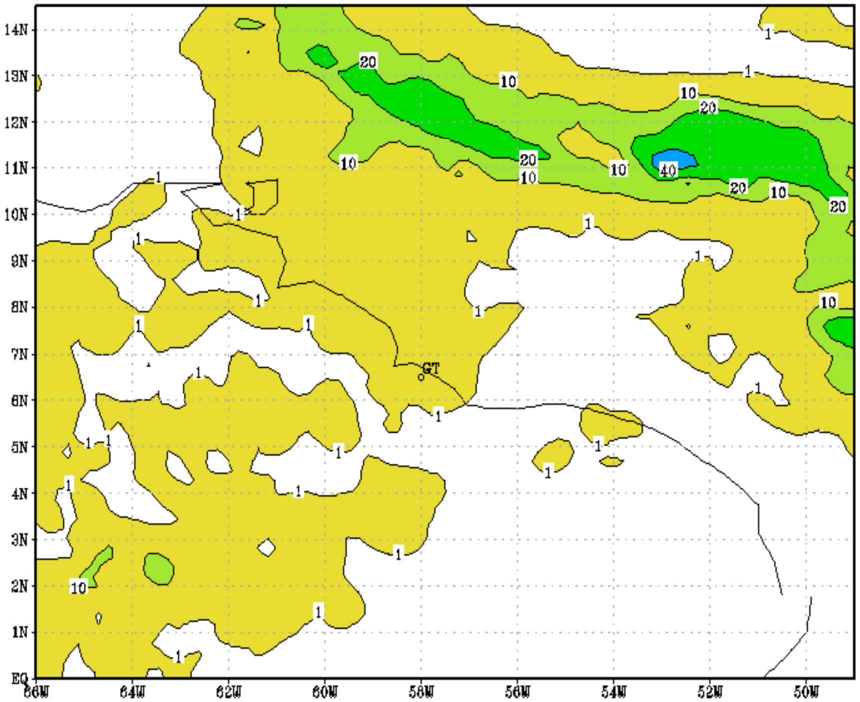


WRF(20 KM) GUYANA RAINFALL(mm) FORECAST (72 hr)
based on 00 UTC 02-09-2009 valid for 00 UTC of 05-09-2009



WRF(09 km) GUYANA RAINFALL(mm) FORECAST (72 hr)
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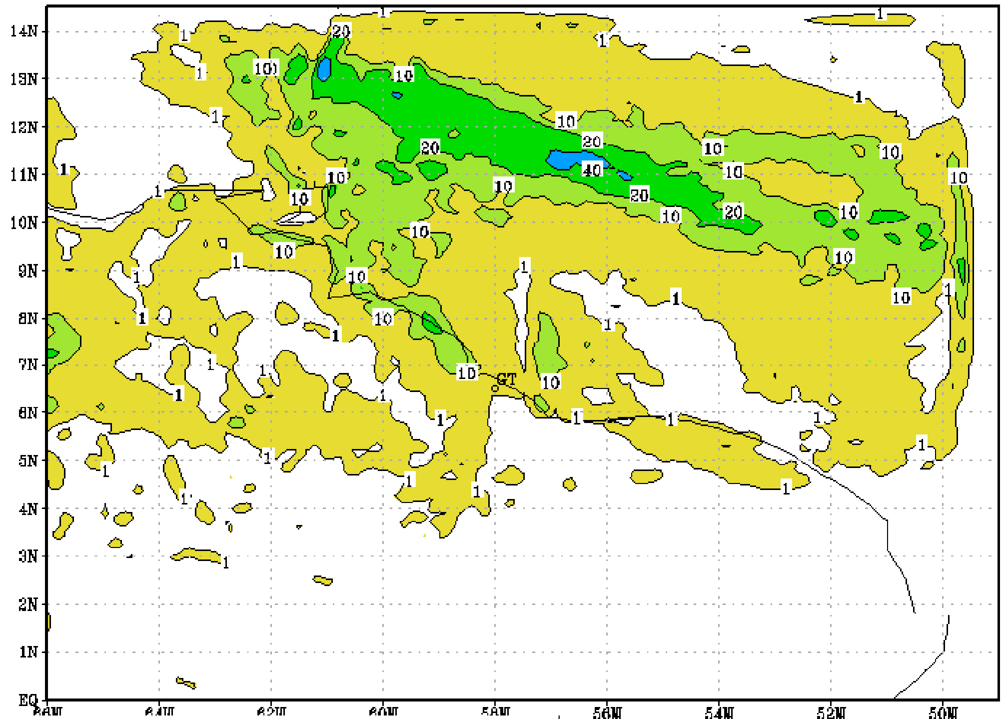

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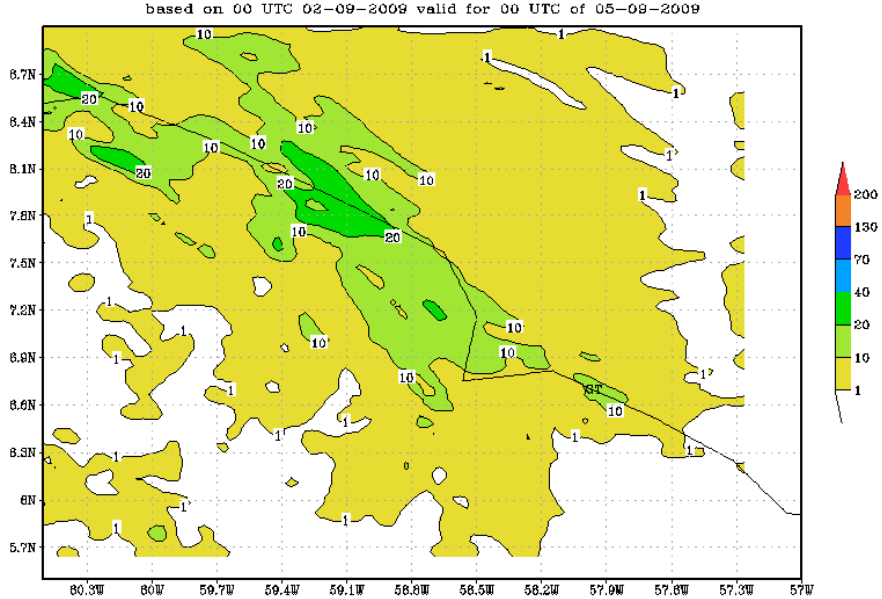
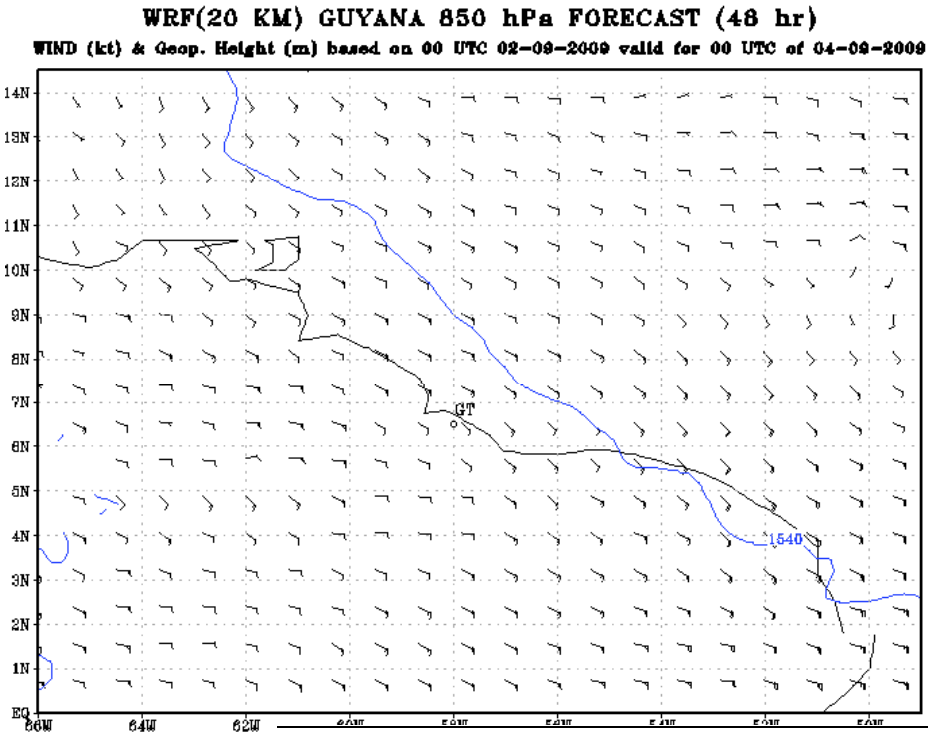
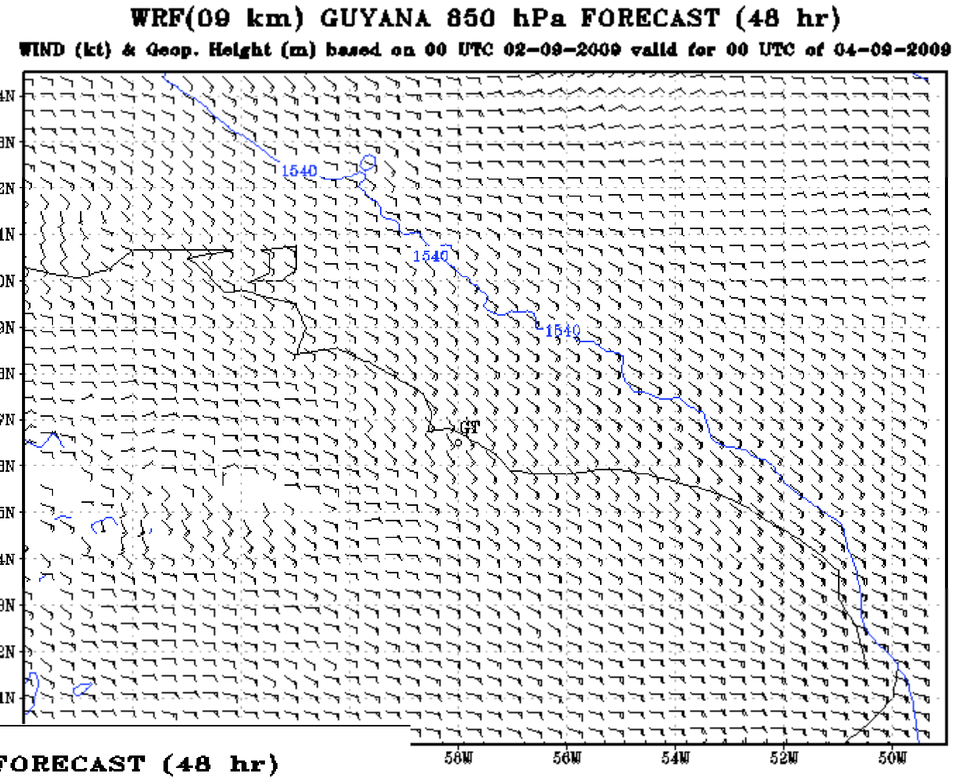



WRF(20 KM) GUYANA 850 hPa FORECAST (48 hr)
WIND (kt) & Geop. Height (m) based on 00 UTC 02-09-2009 valid for 00 UTC of 04-09-2009
14N
13N
12N
11N
10N
9N
8N
7N
6N
5N
4N
3N
2N
1N
EQ
66W
64W
62W
GT
1540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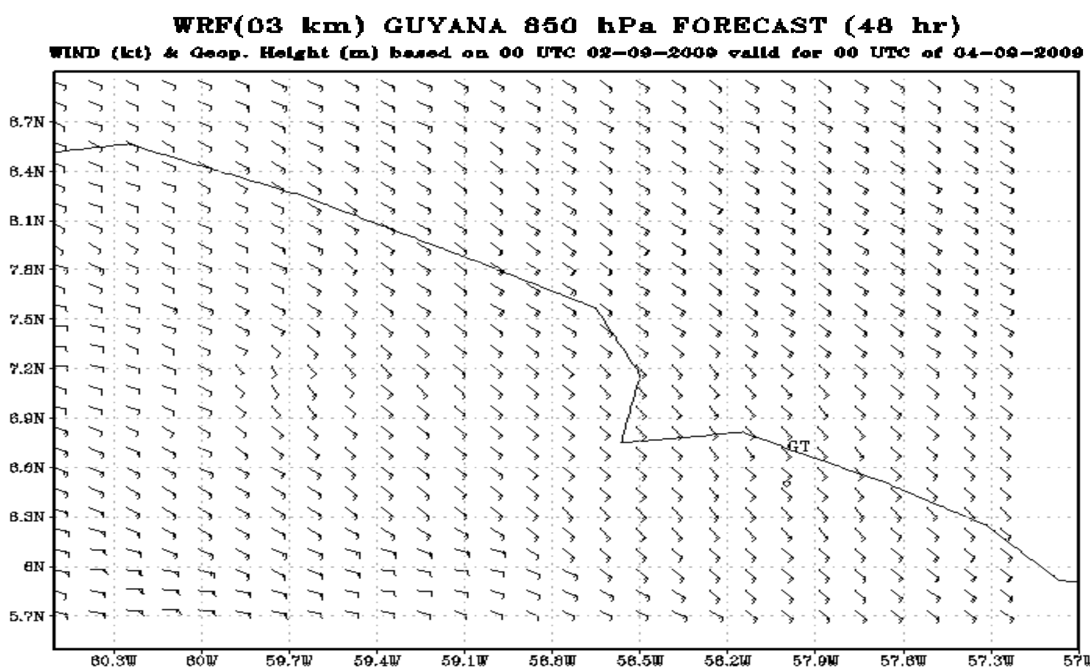
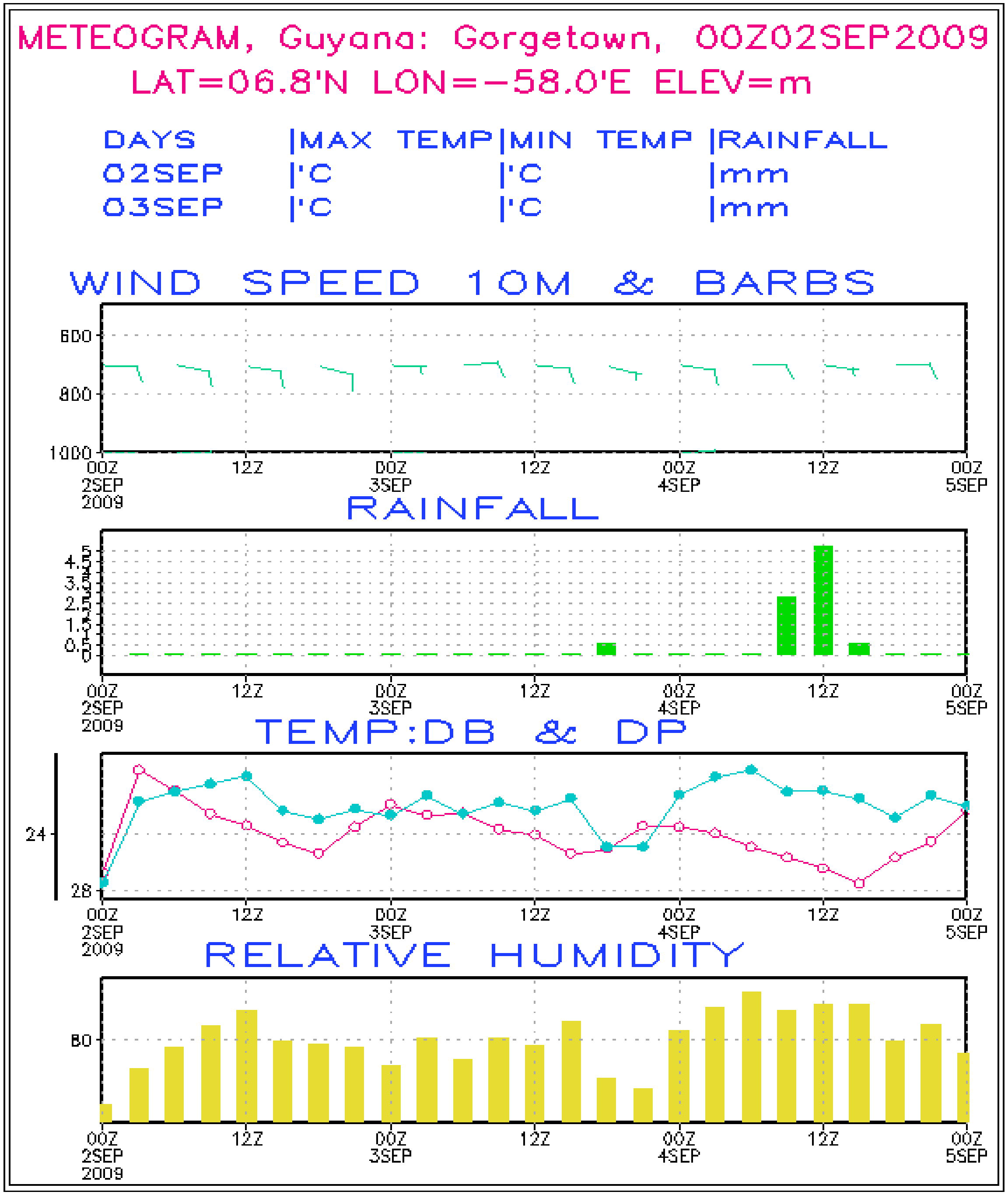
WIND (kt) & Geop. Height (m) based on 00 UTC 02-09-2009 valid for 00 UTC of 04-09-2009
14N
13N
12N
11N
10N
9N
8N
7N
6N
5N
4N
3N
2N
1N
58W
56W
54W
52W
50W
GT
1540

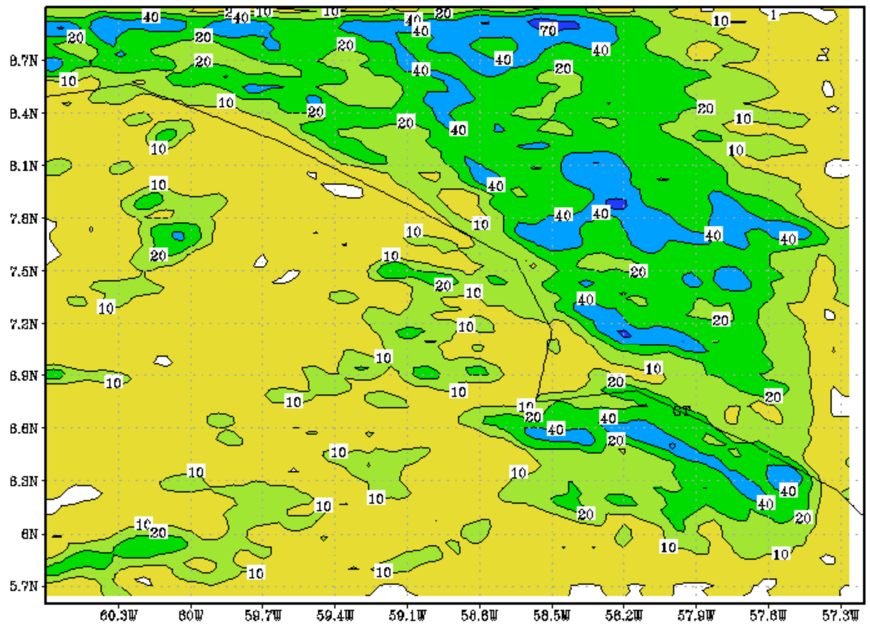

WRF(03 km) GUYANA 850 hPa FORECAST (48 hr)
WIND (kt) & Geop. Height (m) based on 00 UTC 02-09-2009 valid for 00 UTC of 04-09-2009
6.7N
6.4N
8.1N
7.8N
7.5N
7.2N
6.9N
6.6N
6.3N
6N
5.7N
60.3W
60W
59.7W
59.4W
59.1W
58.8W
58.5W
58.2W
57.9W
57.6W
57.3W
57W
GT


METEOGRAM, Guyana: Gorgetown, 00Z02SEP2009
LAT=06.8'N LON=-58.0'E ELEV=m
DAYS |MAX TEMP|MIN TEMP |RAINFALL
02SEP |'C |'C |mm
03SEP |'C |'C |mm
WIND SPEED 10M & BARBS
600
800
1000
00Z 2SEP 2009
12Z
00Z 3SEP
12Z
00Z 4SEP
12Z
00Z 5SEP
RAINFALL
0
0.5
1.5
2.5
3.5
4.5
5
TEMP:DB & DP
24
28
RELATIVE HUMIDITY
80

Based on Initial Conditions of 01 November 2009.

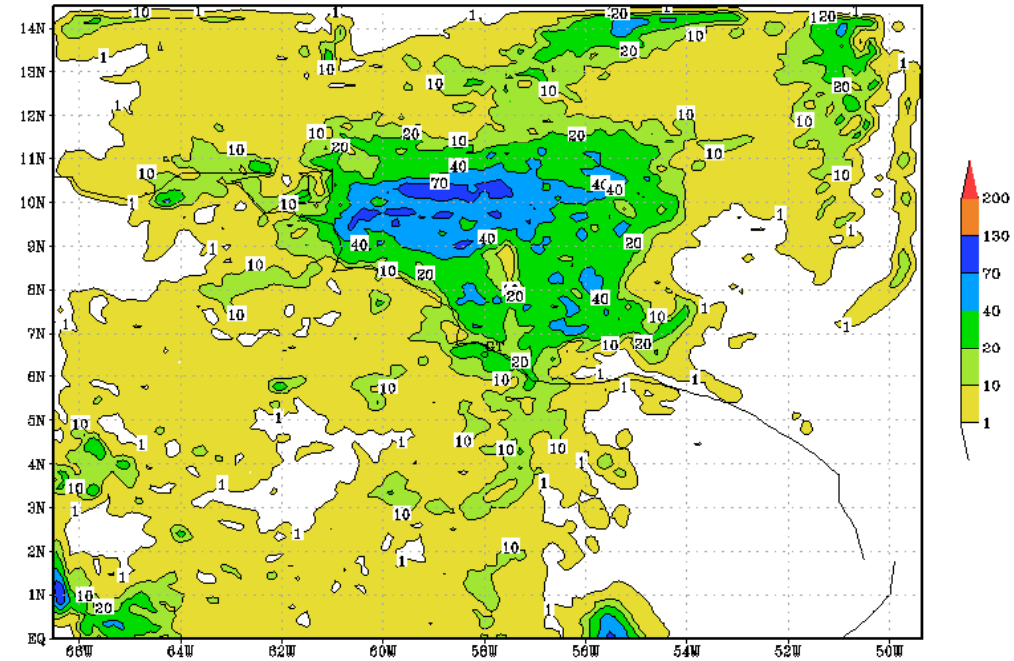
WRF(03 km) GUYANA RAINFALL(mm) FORECAST (24 hr)

based on 00 UTC 01-11-2009 valid for 00 UTC of 02-11-2009



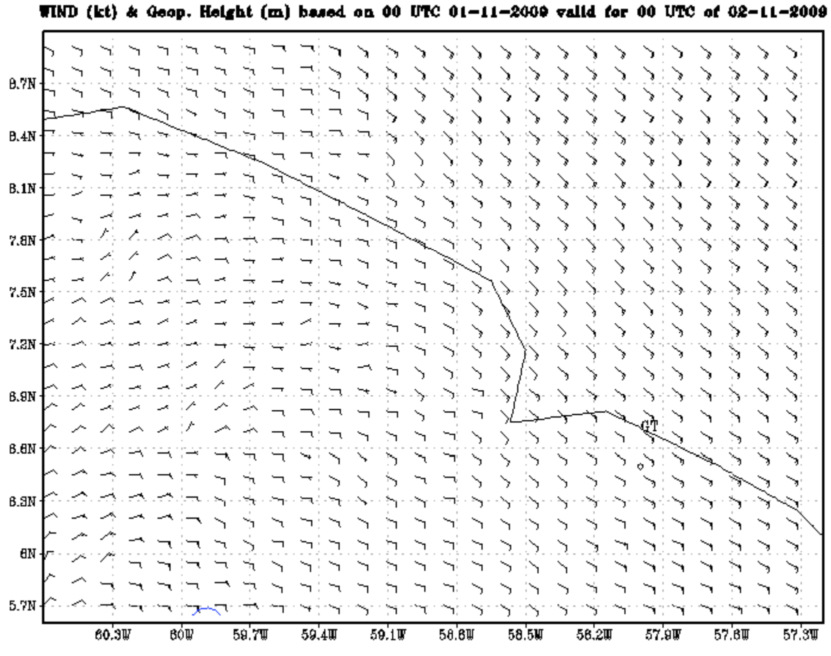
WRF(09 km) GUYANA RAINFALL(mm) FORECAST (24 hr)

based on 00 UTC 01-11-2009 valid for 00 UTC of 02-11-2009



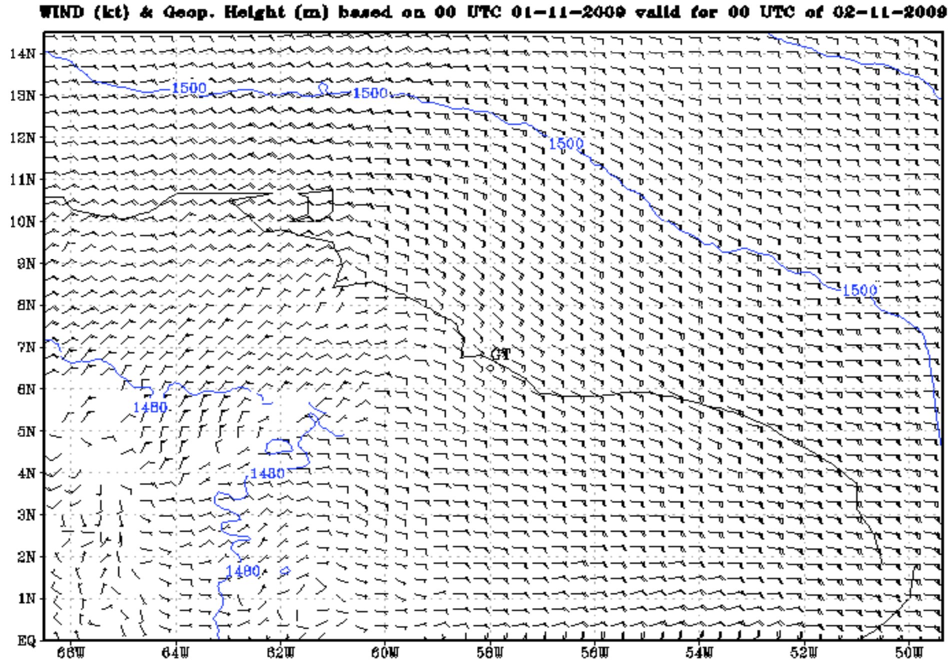
WRF(03 km) GUYANA 925 hPa FORECAST (24 hr)

WIND (kt) & Geop. Height (m) based on 00 UTC 01-11-2009 valid for 00 UTC of 02-11-2009



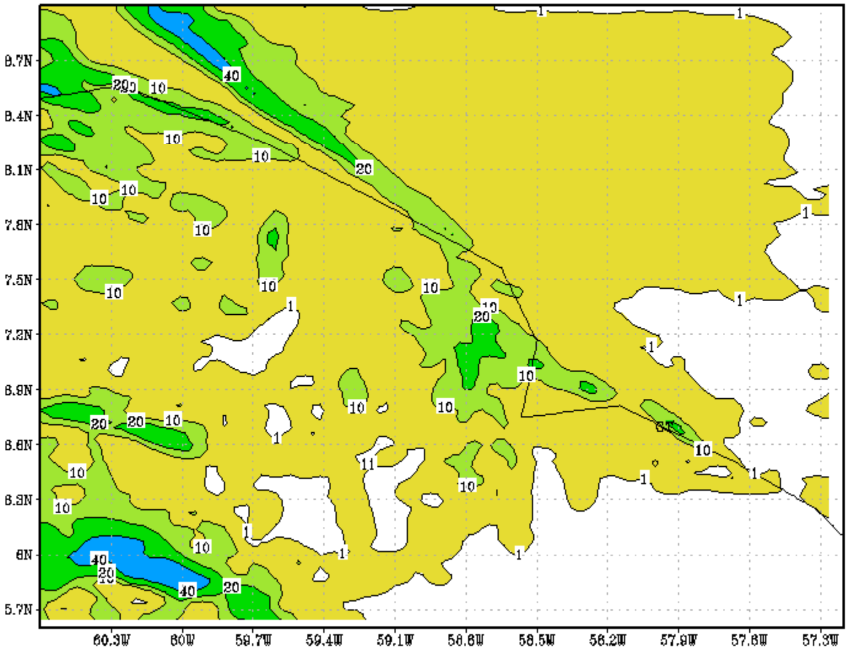
WRF(09 km) GUYANA 925 hPa FORECAST (24 hr)

WIND (kt) & Geop. Height (m) based on 00 UTC 01-11-2009 valid for 00 UTC of 02-11-2009



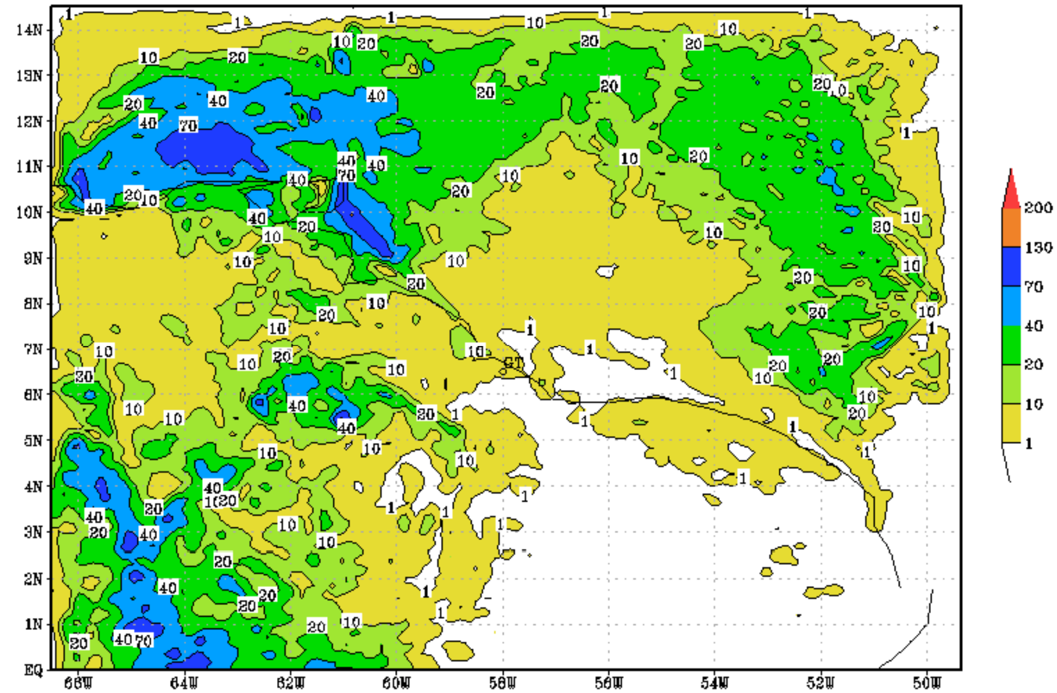
WRF(03 km) GUYANA RAINFALL(mm) FORECAST (48 hr)

based on 00 UTC 01-11-2009 valid for 00 UTC of 03-11-2009



WRF(09 km) GUYANA RAINFALL(mm) FORECAST (48 hr)

based on 00 UTC 01-11-2009 valid for 00 UTC of 03-11-2009



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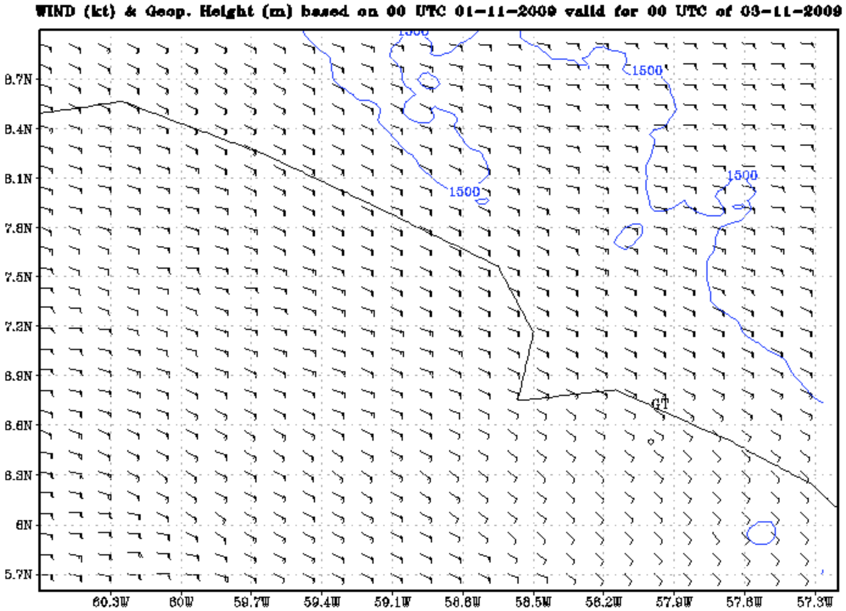

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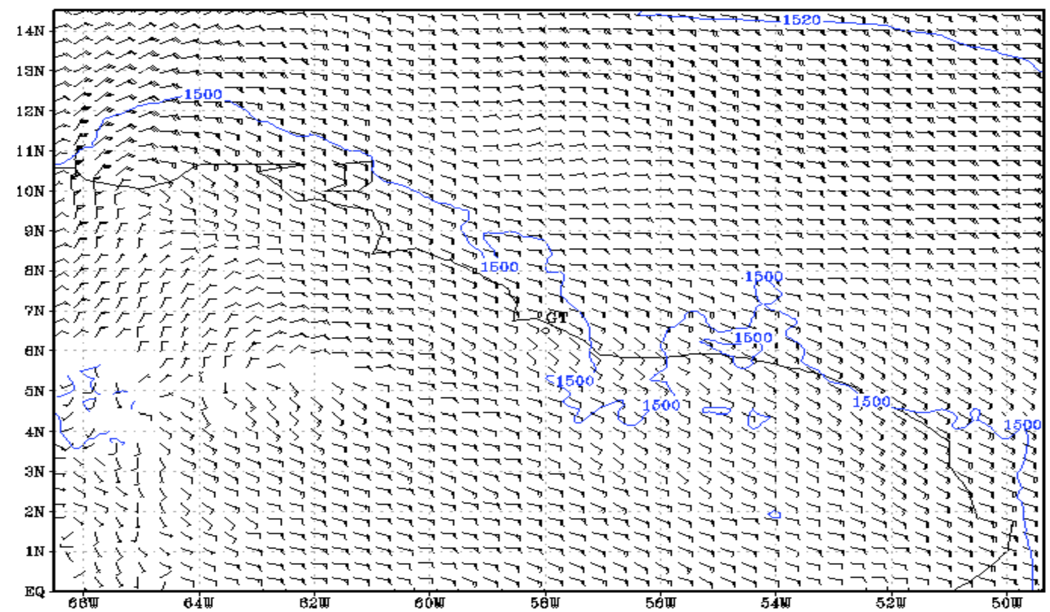
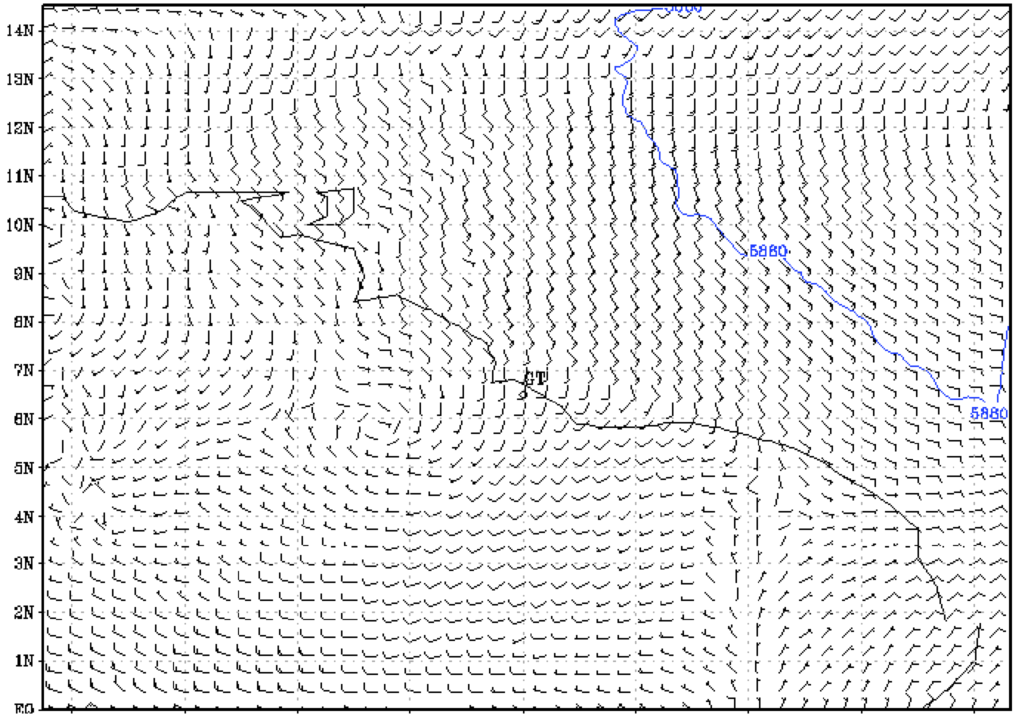
WIND (kt) & Geop. Height (m) based on 00 UTC 01-11-2009 valid for 00 UTC of 03-11-2009



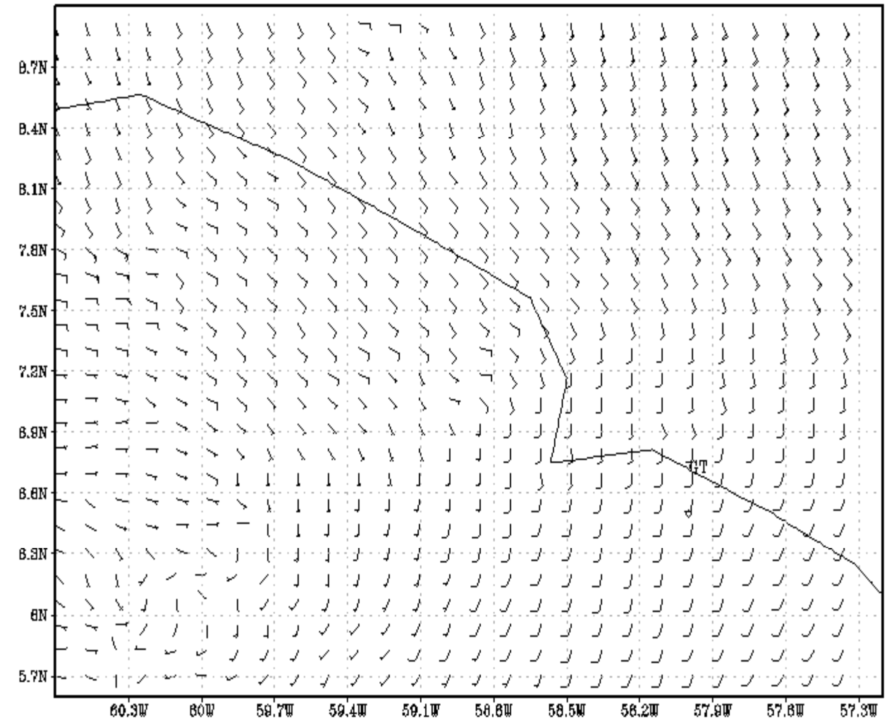
WRF(09 km) GUYANA 500 hPa FORECAST (24 hr)

WIND (kt) & Geop. Height (m) based on 00 UTC 01-11-2009 valid for 00 UTC of 02-11-2009



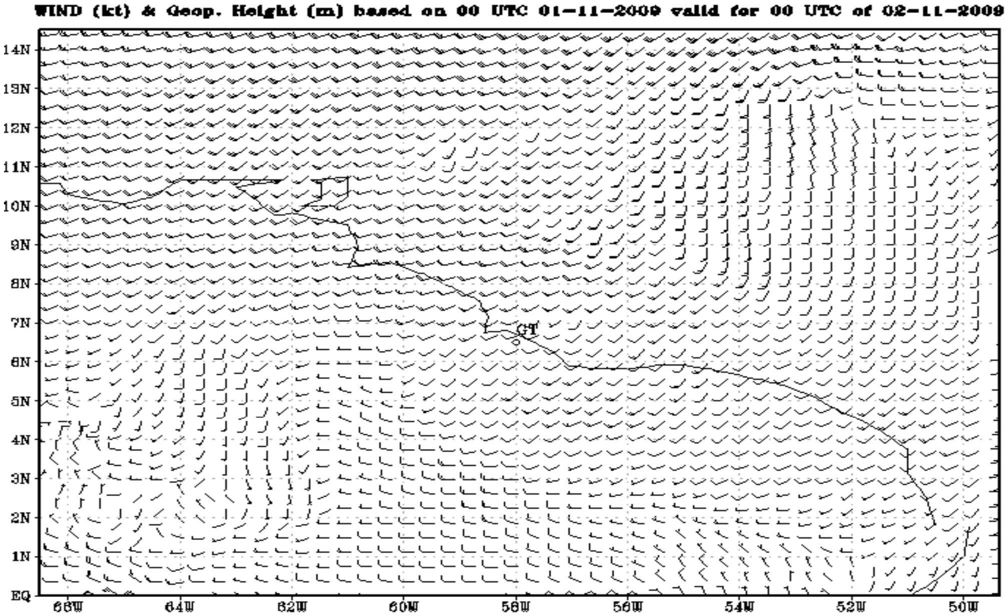
WRF(03 km) GUYANA 500 hPa FORECAST (24 hr)

WIND (kt) & Geop. Height (m) based on 00 UTC 01-11-2009 valid for 00 UTC of 02-11-2009



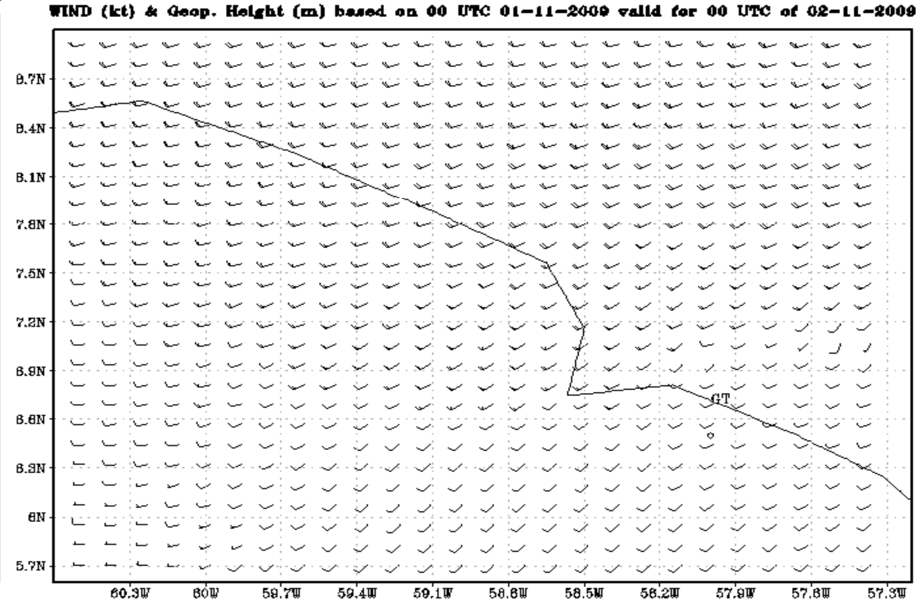
WRF(09 km) GUYANA 300 hPa FORECAST (24 hr)

WIND (kt) & Geop. Height (m) based on 00 UTC 01-11-2009 valid for 00 UTC of 02-11-2009



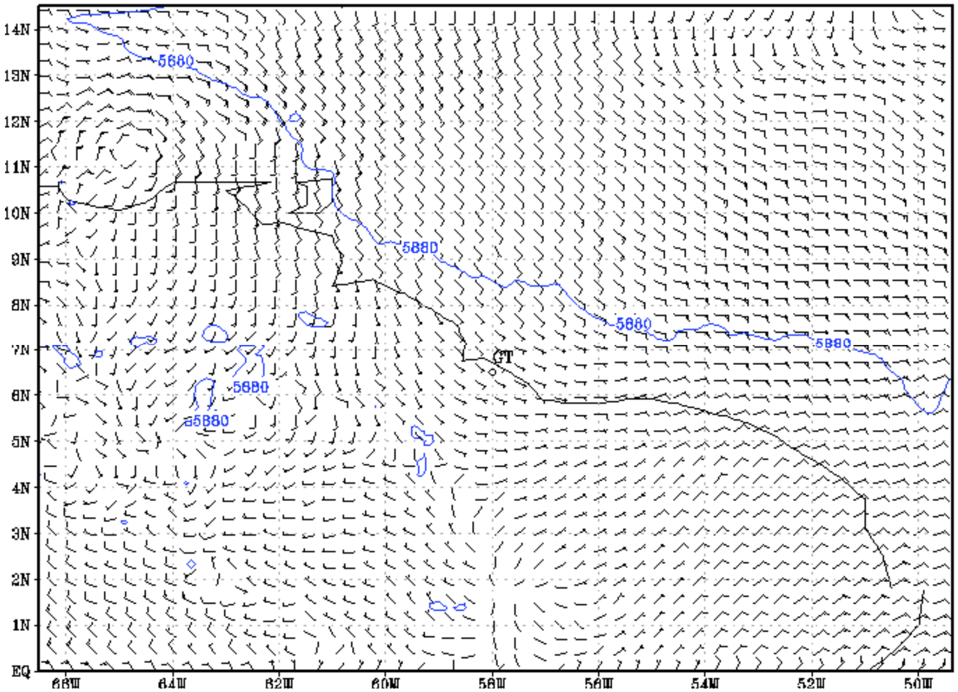
WRF(03 km) GUYANA 300 hPa FORECAST (24 hr)

WIND (kt) & Geop. Height (m) based on 00 UTC 01-11-2009 valid for 00 UTC of 02-11-2009



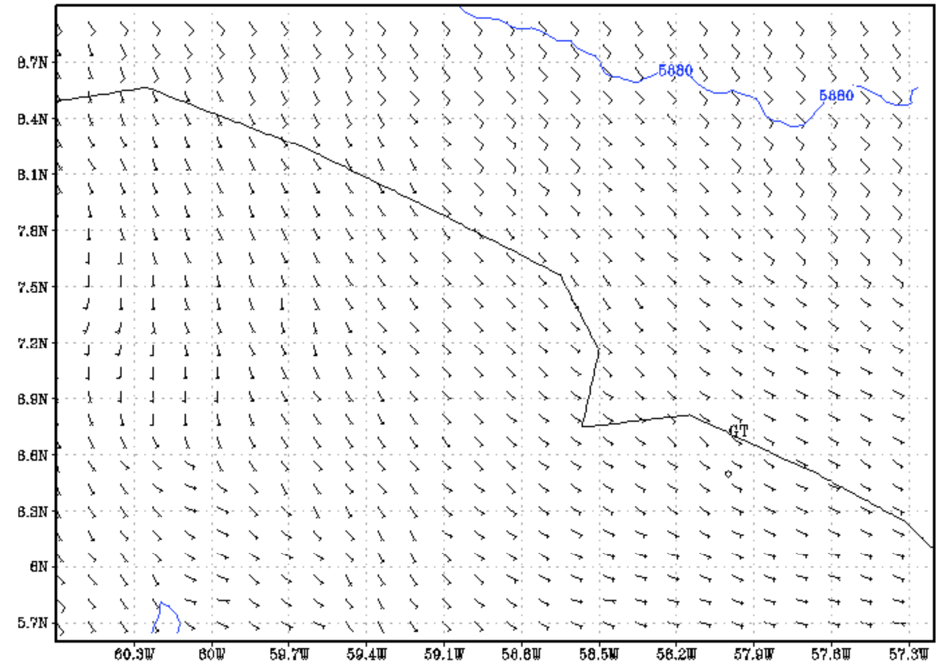
WRF(09 km) GUYANA 500 hPa FORECAST (48 hr)

WIND (kt) & Geop. Height (m) based on 00 UTC 01-11-2009 valid for 00 UTC of 03-11-2009



WRF(03 km) GUYANA 500 hPa FORECAST (48 hr)

WIND (kt) & Geop. Height (m) based on 00 UTC 01-11-2009 valid for 00 UTC of 03-11-2009



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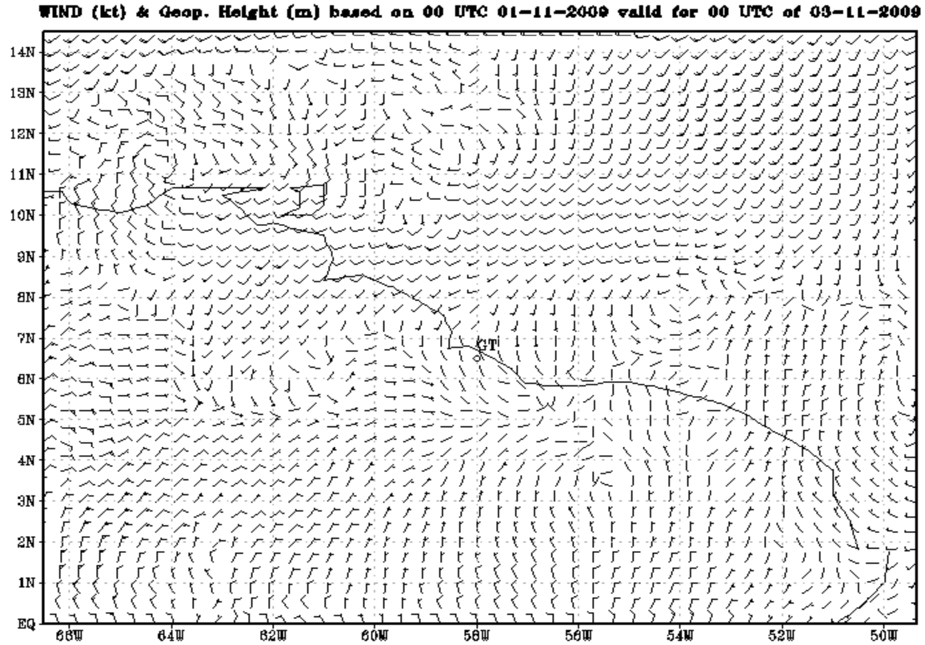
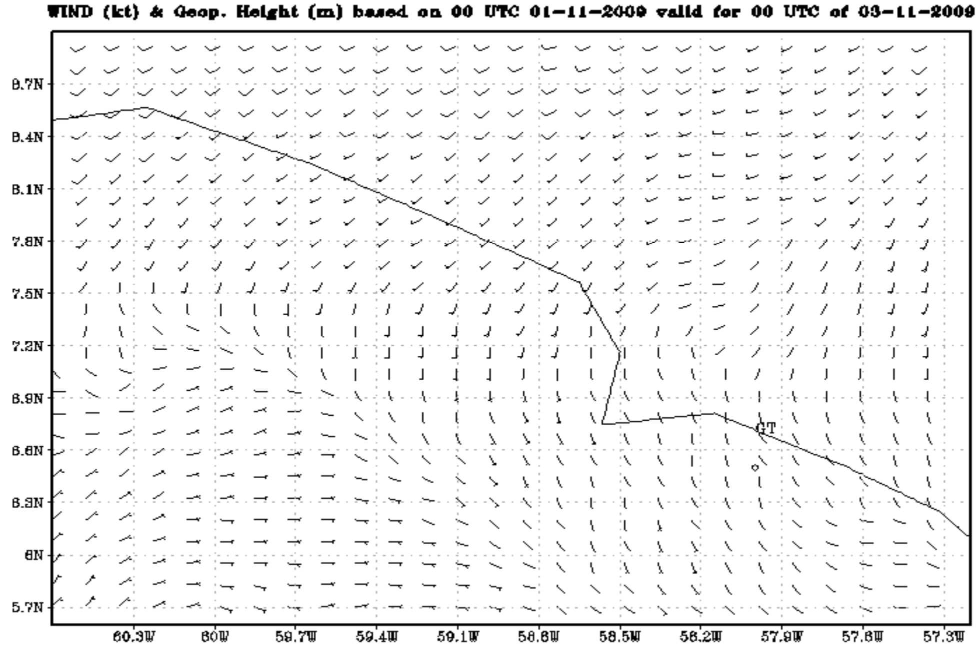
WIND (kt) & Geop. Height (m) based on 00 UTC 01-11-2009 valid for 00 UTC of 03-11-2009



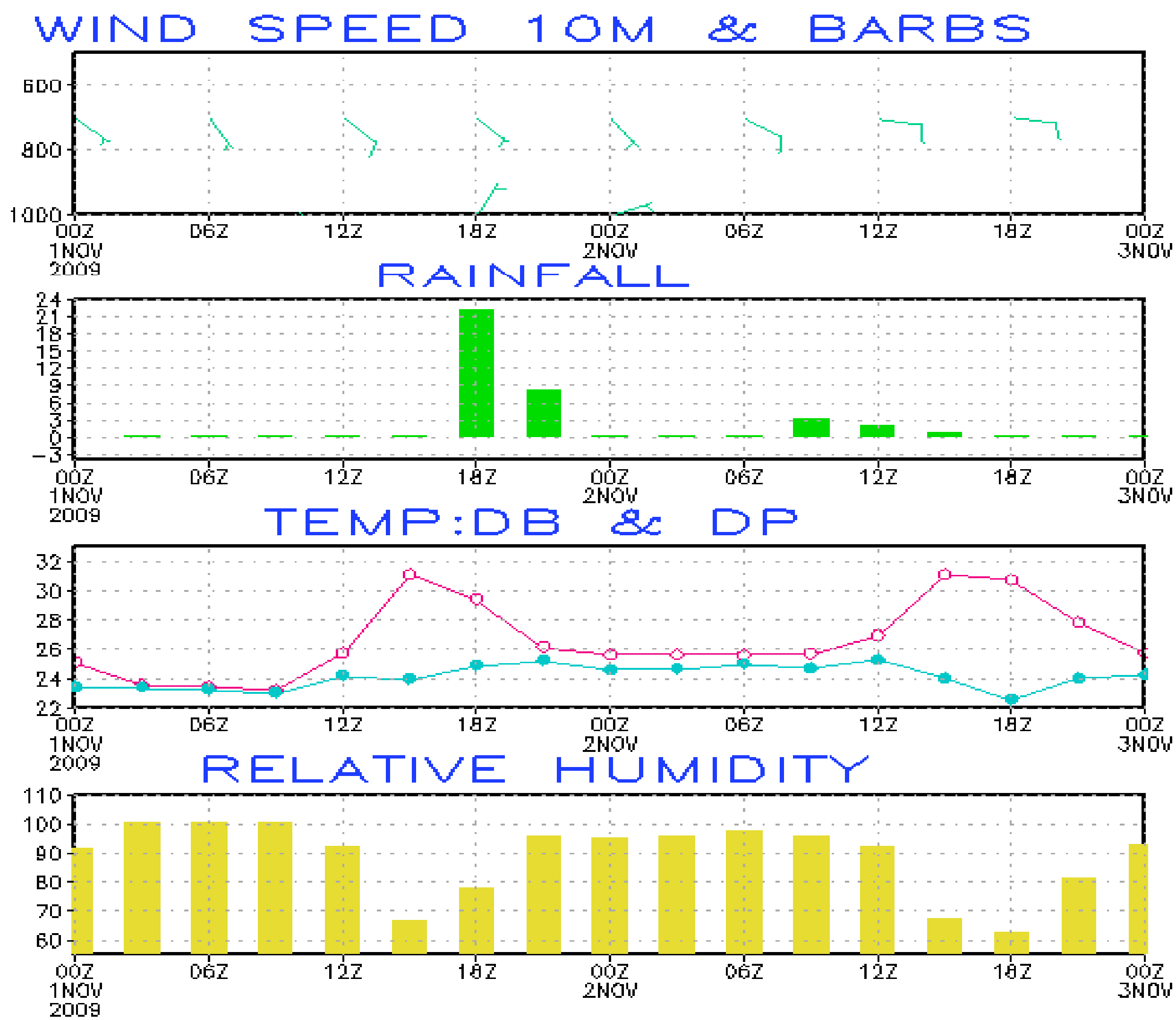
WRF(03 km) GUYANA 300 hPa FORECAST (48 hr)

WIND (kt) & Geop. Height (m) based on 00 UTC 01-11-2009 valid for 00 UTC of 03-11-2009



METEOGRAM, Guyana: Gorgetown, 00Z01NOV2009
LAT=06.80'N LON=-58.16'E ELEV=01m

DAYS	MAX TEMP	MIN TEMP	RAINFALL
01NOV	'C	'C	mm
02NOV	'C	'C	mm



Future Demands on Weather and Climate Prediction

- Develop, test and validate high resolution meso scale models (up to 0.3 km horizontal, >200 vertical levels) to predict high impact weather events.
- Advanced Mesoscale Data assimilation systems (3Dvar, 4Dvar and En-KF).
- Coupled Ocean Atmosphere meso scale models to predict genesis, movement, intensification and landfall of the tropical cyclones and associated storm surges.
- Incorporation of aerosol and atmospheric chemistry in high resolution meso-scale model to predict city air quality and mega-city out-door activities.
- Coupled global model with T-750 (27 km horizontal resolution) for seamless deterministic forecast of short, medium, extedended and seasonal scales.

Requirements

Observation:

- Enhancement of Surface and upper air observations over land and ocean
- Enhance remote sensing observation systems-DWRs, advanced satellites, GPS, Boundary Layer radar, wind profilers, Doppler Lidar, radiometer etc for more frequent and extensive probe of atmosphere
- Special observation systems like air craft with dropsonde and airborne DWR systems and UAV system for observations in and around core and environment of tropical cyclones
- Special field experiments on LSP, PBL, Cloud-aerosol-radiation, cloud micro physics, air sea interaction processes etc.

Communication, Dissemination and computational Resources:

- **Substantial enhancement of rapid communication system to collect/transmit vast observational data**
- **Technology for fast data processing and comprehensive quality control of different data sets**
- **Enhancement of computing platforms (several peta flops speed)**
- **Efficient communication systems such as dedicated weather TV channel**

Modeling and Man power :

- State of-the-art four dimensional data assimilation system for incorporation/utilization of all available data from different observational platforms
- State of-the-art coupled high resolution meso scale and global modeling systems
- Visualization and location specific representation through GIS platform
- Qualified manpower for NWP

Special requirements for Tropical Cyclones

- ❖ **Develop coupled mesoscale-atmosphere-ocean and wave model with moving nest capability for better simulation and prediction of TC.**
- ❖ **The future scope for the prediction of tropical cyclone's track and intensity through insertion of special observations like air craft with dropsonde, satellite radiance and airborne DWR systems and UAV system in and around core and environment of tropical cyclones.**
- ❖ **GPS refractivity assimilation for ground based stations and GPS occultation for satellite (e.g. CHAMP and COSMIC)**
- ❖ **Multi model ensemble and probabilistic forecast**
- ❖ **Special field experiments to study**
  - ✓ **TC formation/structure change**
  - ✓ **Mesoscale versus environment contribution to formation**
  - ✓ **Boundary layer impact on air-sea fluxes**
  - ✓ **Ocean variability impact on intensity and track**

Special requirements for Thunderstorms

- Establishment of dense meso network of observations.
- Probing of thunderstorm using multi-observational platforms such as satellites, aircrafts, mobile doppler weather radars, radiosondes, dropsondes, wind profilers and AWS.
- Comprehensive mesoscale data assimilation utilizing conventional and non-conventional observations from multi-observation platforms.
- Prediction of life cycle of thunderstorm along with associated hazards using very high resolution (1-0.3 km) state-of-the-art mesoscale models.
- Role of physical processes in particular deep convection, cloud microphysics, planetary boundary layer, land surface processes with high resolution meso-scale model and special field experiment datasets.
- Observation and understanding of cloud microphysics, aerosol concentration and atmospheric electricity in association with severe thunderstorms.

Special requirements for Heavy rainfall events

- Rainfall observation network is to be made dense and rainfall data to be made available in near real-time for operational purposes

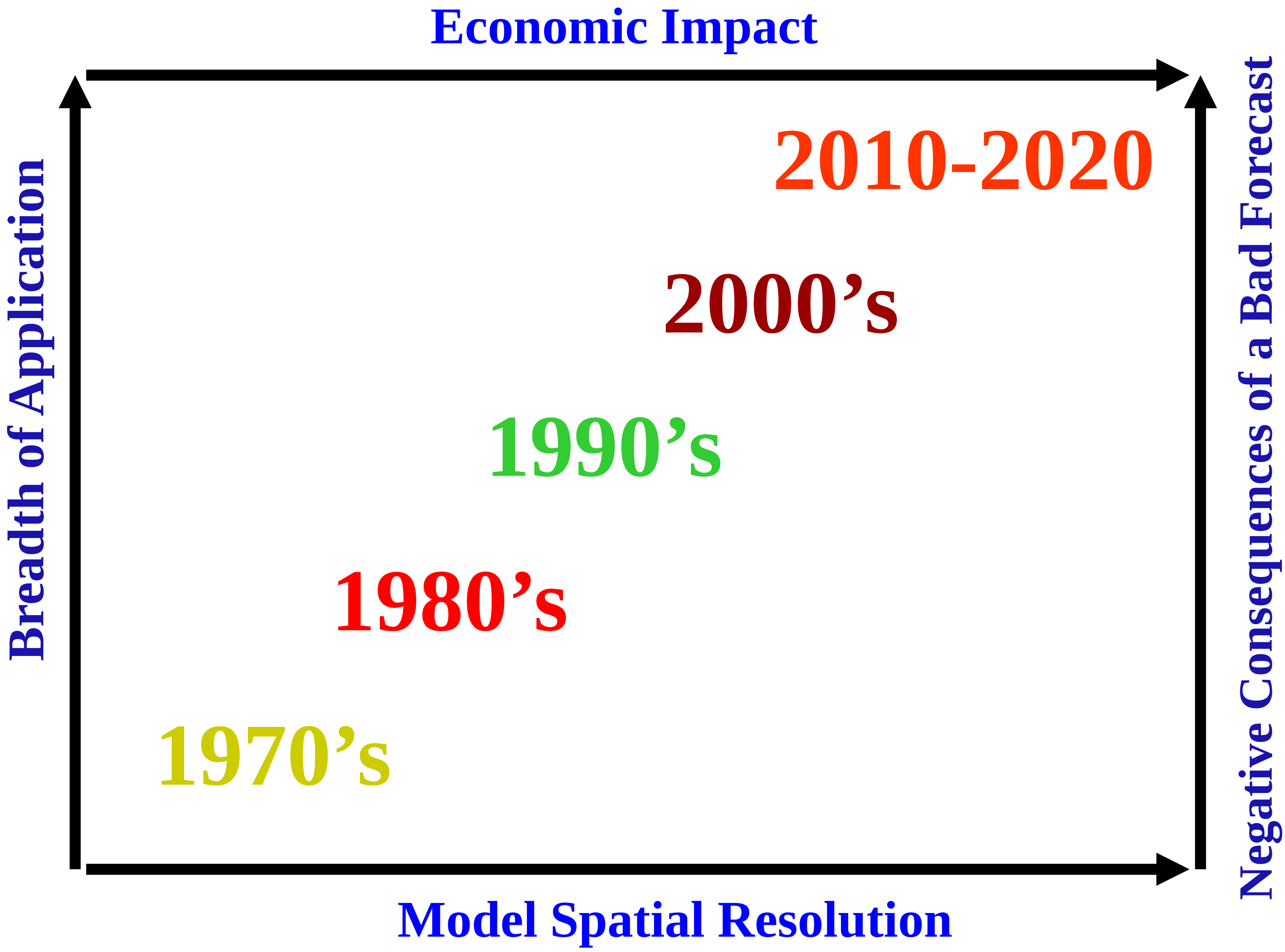
- Assimilation and ensemble techniques to be used of for better initial conditions in NWP models.

- To develop probability of precipitation type equations to forecast different categories of rainfall

- Inclusion of satellite derived precipitation estimates into the data assimilation system produces a substantial positive impact on short range rainfall forecasts. Mesoscale models at higher resolution could bring out the heavy rainfall event in hindcast mode.

NWP Vision

- Broader focus on application and impacts modelling
- Probabilistic forecasting generating a range of possible solutions to allow risk management
- High resolution modelling of the atmosphere for detail
- Fuller integration between atmospheric and dependent models (eg: oceanographic)
- Principal observed input from satellite-based instrumentation
- Flexible (on demand) ground based observations to meet NWP needs
- NWP output that is of sufficient detail, accuracy and reliability as not to require routine forecaster modification.


Economic Impact
Breadth of Application
Negative Consequences of a Bad Forecast
2010-2020
2000's
1990's
1980's
1970's
Model Spatial Resolution

Thanks