Numerical analysis on mesoscale dynamics and mechanism of the extreme rainfall event (May 2016) over Sri Lanka

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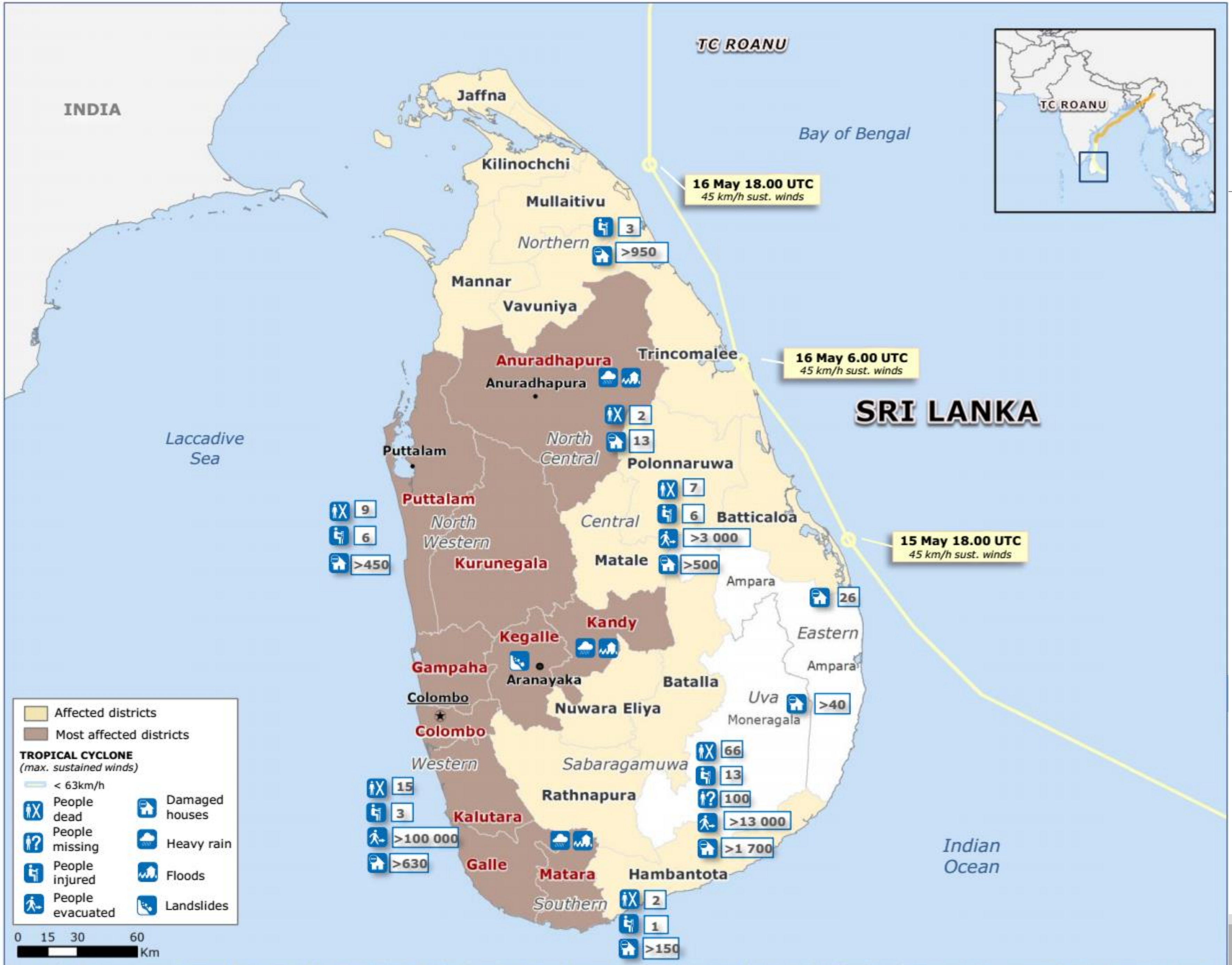
Observed development of the low pressure system / later tropical cyclone '*Roanu*' over the Bay of Bengal (14-22 May 2016)

Date	Synoptics
14th May 2016	Meteorology Department issued a severe weather advisory for twelve hours commencing 11:30 am (local). **Low pressure area** developed over southwest Bay of Bengal
15th May 2016	Nearly 100mm of rainfall was reported in many areas in western & southern Sri Lanka. Several parts of the capital Colombo were flooded
16th May 2016	The system paralleled the east coast of Sri Lanka & developed in to a **depression** (D) Water levels on the major rivers rising and the flooding
17th May 2016	By the morning the system is already passed Northern part of the island. Several landslides in central part of the country
18th May 2016	Intensified into a **deep depression** (DD) 0300 UTC Water levels on the *Kelani* River rose rapidly, Flooding continued
19th May 2016	Further drifted North & intensified into a **cyclonic storm** (CS) 0000 UTC
21th May 2016	Landfall into Bangladesh coast north of *Chittagong*, Bangladesh 1000 UTC Gradually weakened into a **DD** over *Mizoram* 1800 UTC
22th May 2016	Gradually weakened into a **D** near Myanmar and adjoining *Manipur* – 0000 UTC well marked low pressure area over Myanmar – 0300 UTC

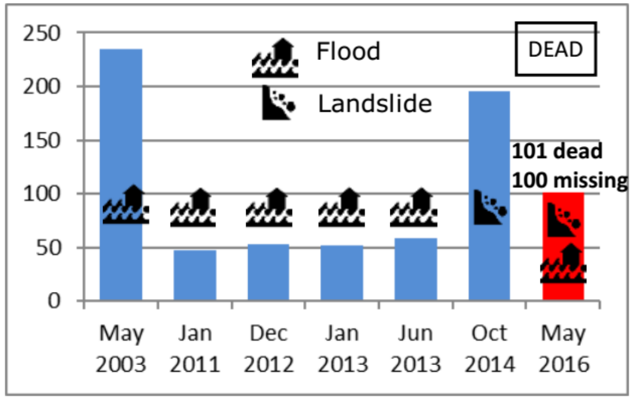
Source: India Meteorological Department, 2016

The flooding event

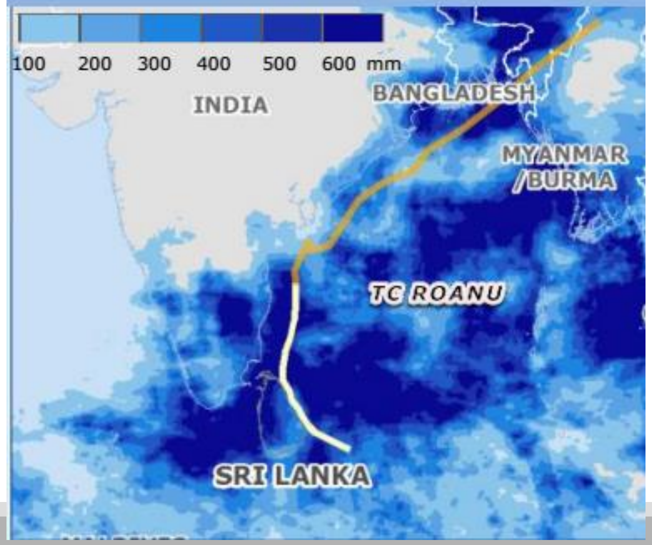
- A depression in the Bay of Bengal in the Indian Ocean to the South East of Sri Lanka caused heavy rainfall across Sri Lanka since 14 May 2016
- Causing wide spread heavy rains, flooding and land slide in as many as 22 districts,.
- **According to the Meteorology Department the last four days had seen one of the highest rainfalls in Sri Lanka**
- Total number of people affected 427,918, 101 deaths, 100 missing (landslide)
- Worst affected district - Colombo (Capital) – 185,835 affected
- Kelani Ganga is one of the main river basin in Sri Lanka which experienced **large scale flooding and sub sequent damage to property and livelihoods**.



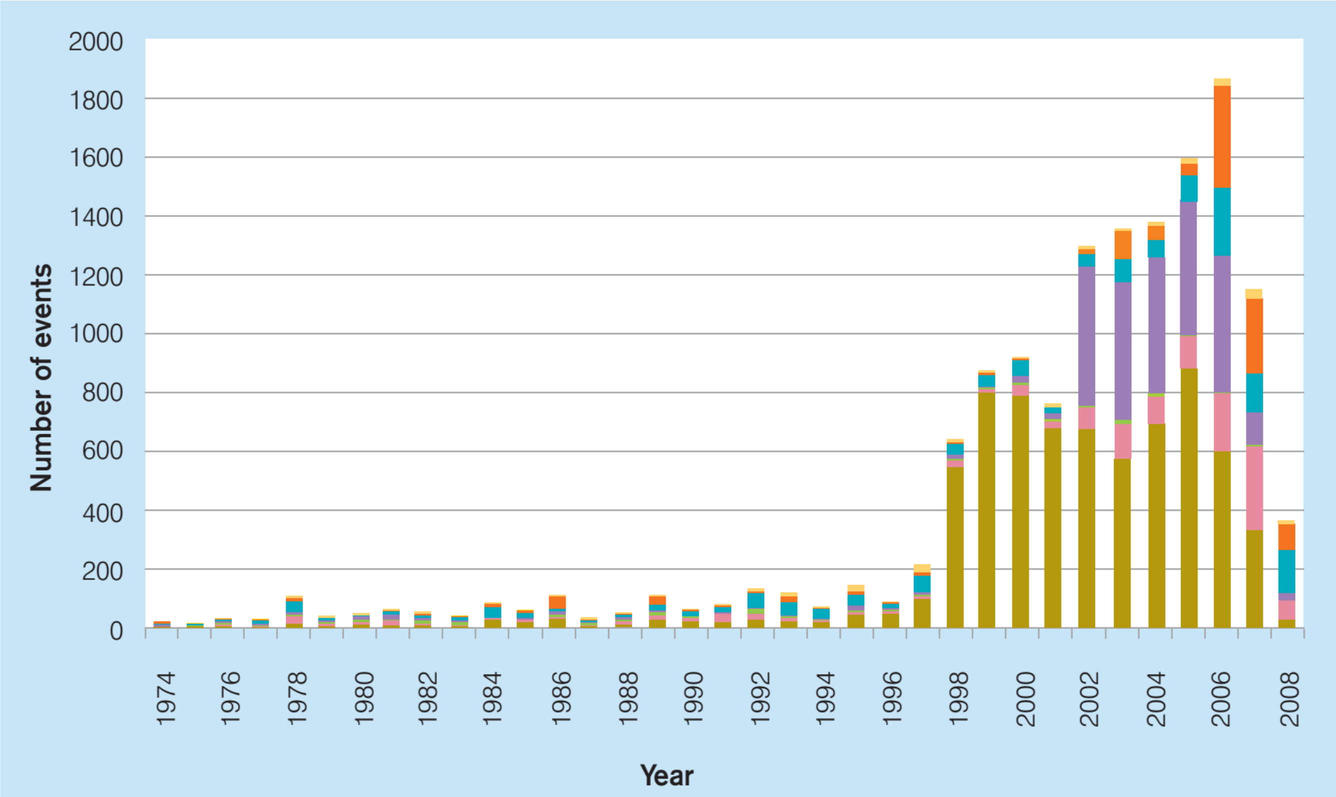
The Floods and Landslides included in the Top 10 Natural Disasters in Sri Lanka (CRED/EM-DAT) for the period 2000-2016 sorted by number of dead are shown below (current event is in RED):



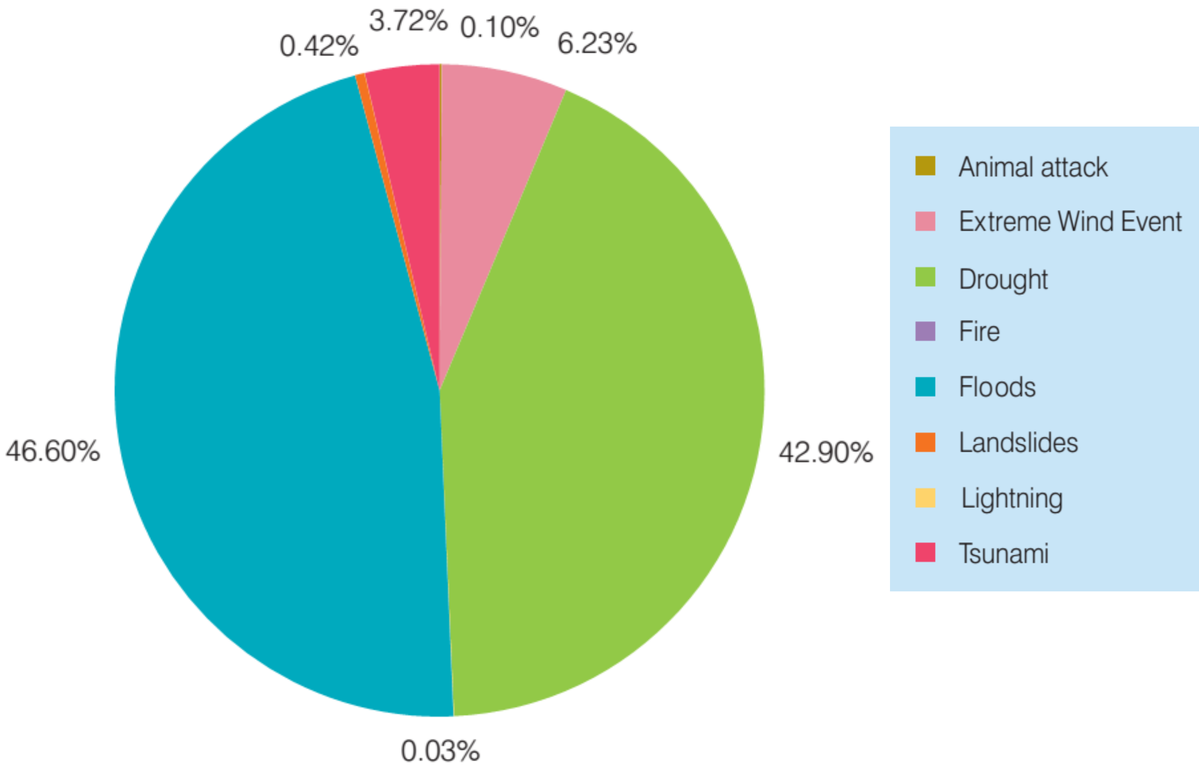
Precipitation accumulation over the last 14 days
(as of 24 May, NASA)



Natural Disaster profile of Sri Lanka



Disaster Event Trend : 1974 - 2008



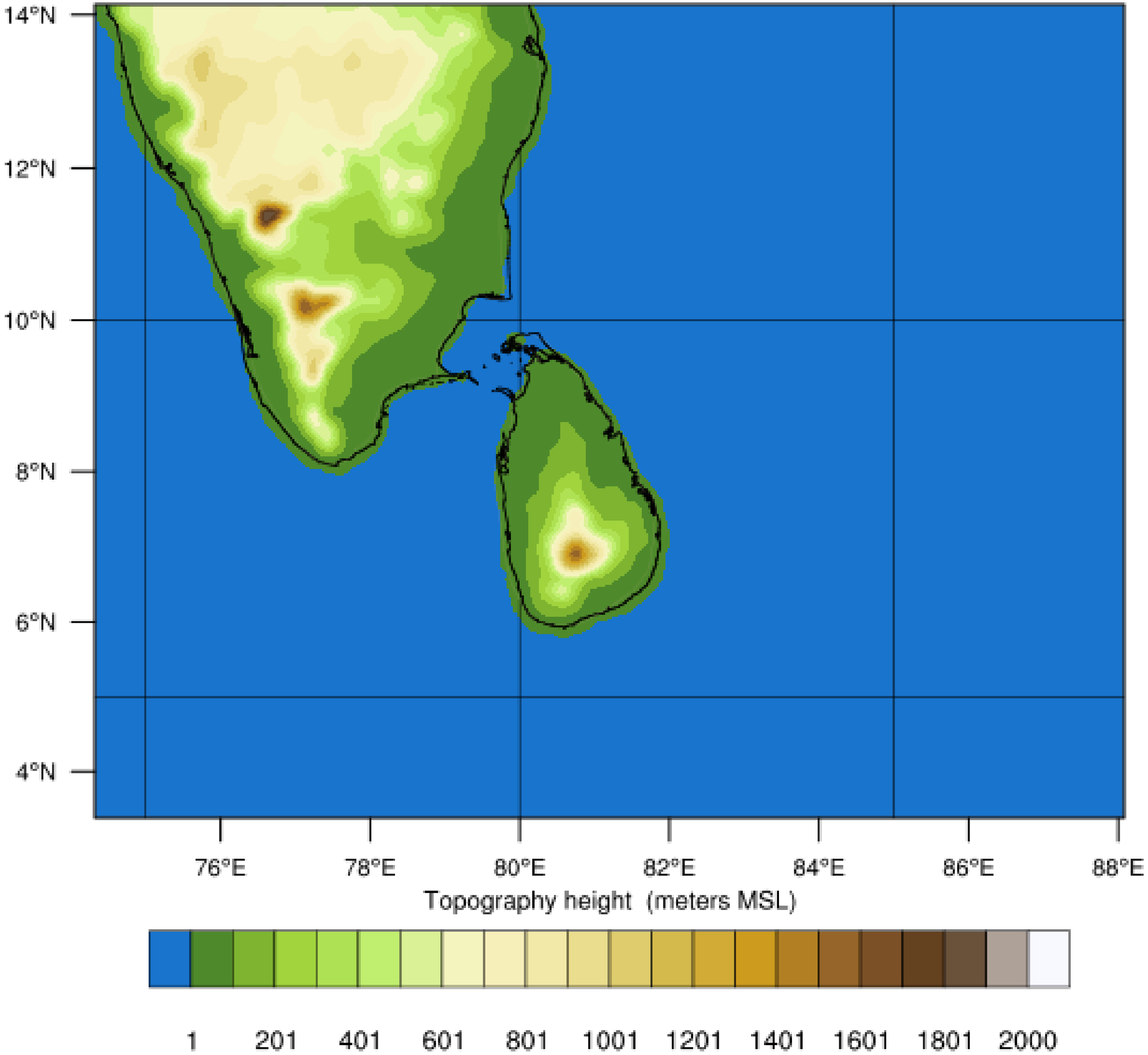
Profile of the people affected due to disasters : 1974 - 2008

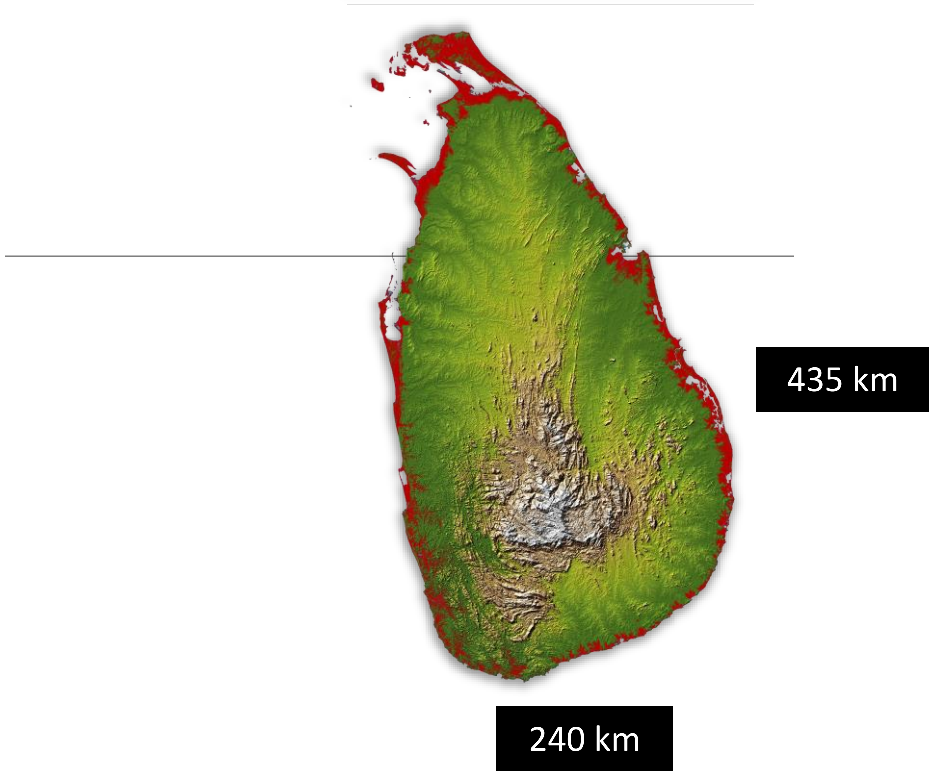
- Flood is a frequent disaster event and also the most affected disaster event in Sri Lanka

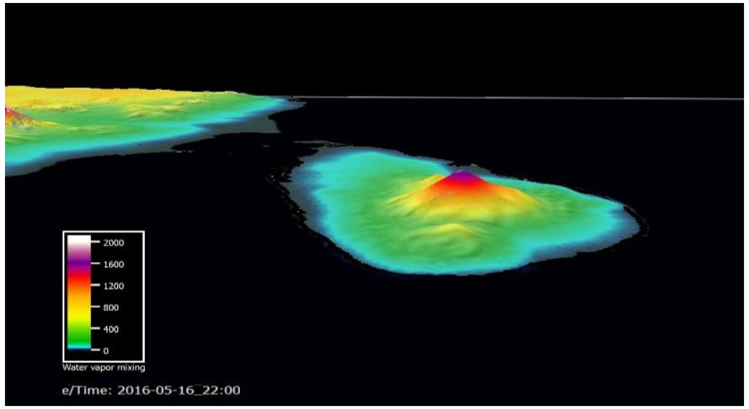
Source: DMC/www.desinventar.lk

Questions & Assumptions of the study

- What was the main cause for the heavy rainfall and flooding in western part of Sri Lanka?
  - Main cause for the heavy rainfall was the low pressure system.
- Why May 15 & 16 received the maximum rainfall over western part of Sri Lanka?
  - May 15 & 16 was the period low pressure system approaching and passing along Sri Lanka
- Why only western part of Sri Lanka received relatively maximum rainfall and why not the eastern part of Sri Lanka?
  - Location of the heavy rainfall was following the low pressure system
  - Westerlies and the low pressure system winds were interacting with mountain only over western part of Sri Lanka







Max actual = 2,524 m

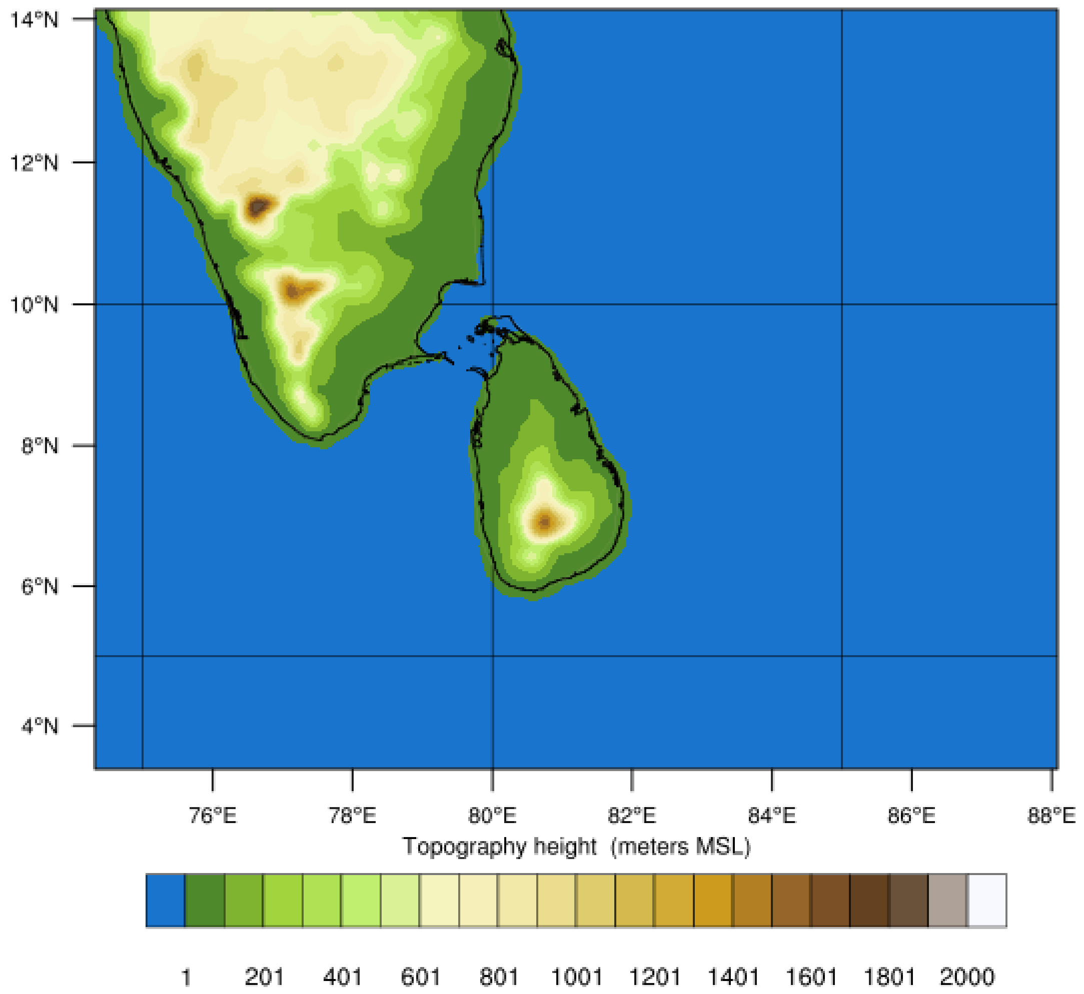
Max in the model results = 1,992m

Model deficit = 532m

WRF Model Configuration

- **Model:**
  Weather Research and Forecasting (WRF) Advanced Research (ARW) Version 3.6.1
- **Time period:**
  May 14th 0000 – 21st May 0000, 2016
- Initial and Boundary Conditions:
  NCEP (CFSv2) 6-hourly
- Re-initialize WRF every 6 hours

Domain 01



WRF Model parametrization & configuration

Horizontal Resolution	3 km (170 X 135 grids) / 9km
Time interval (Δt)	60 mins
Run time	4 days (96 hours)
Vertical Levels	38
Feedback	Off
Radiation	LW: RRTM; SW: Dudhia
Surface Layer	Revised MM5 Monin-Obukhov scheme
Land Surface Model	unified Noah land-surface model
Boundary Layer	YSU
Cumulus	Kain-Fritsch (new Eta) scheme
Microphysics	Lin et al. scheme
Nudging	Grid nudging, Initial conditions 6hrs
SSTs	SST update

Observational Data

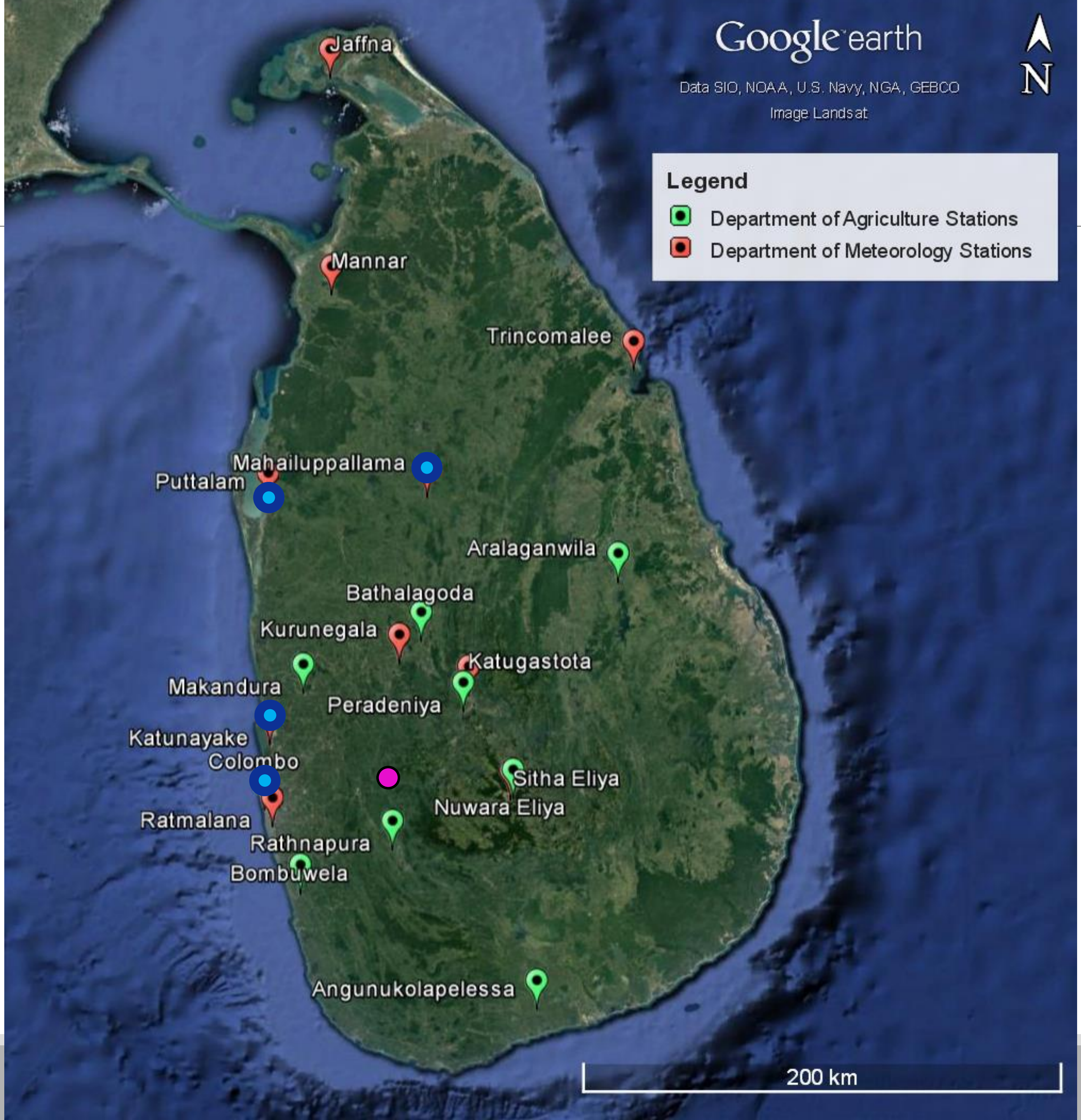
Satellite Data –

- Rainfall - NASA - GPM, (TRMM+Other)
- Cloud - Eurosat - Meteosat VISSR

Ground based Rainfall Data

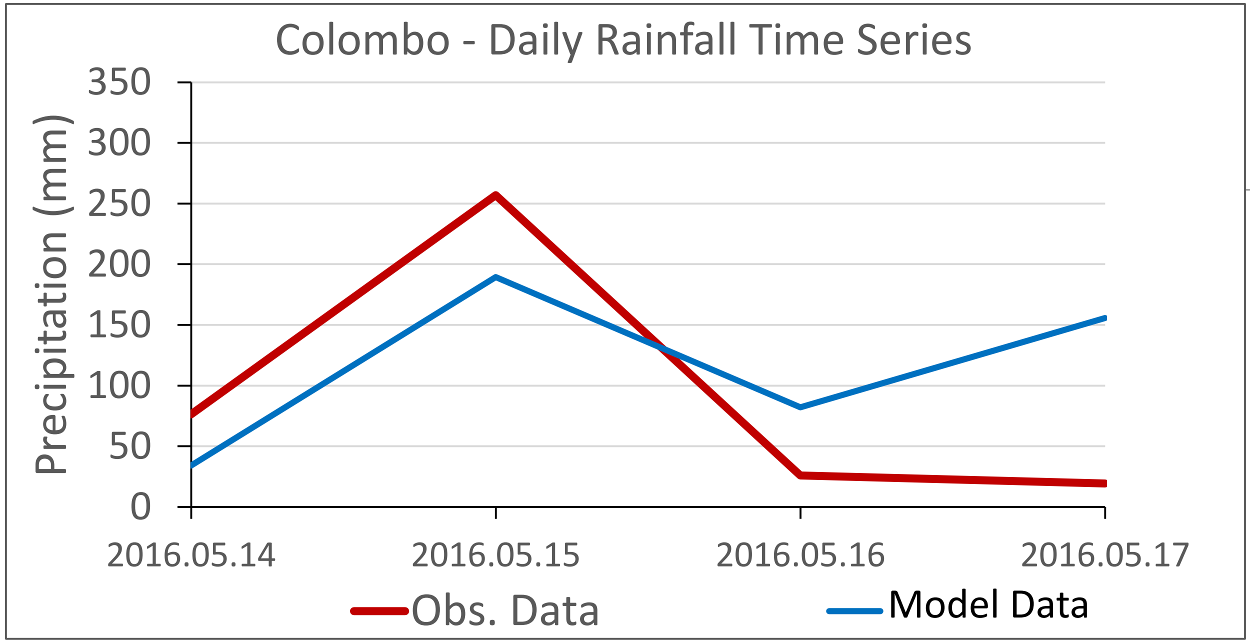
- Metrological Department of Sri Lanka
- Department of Agriculture, Sri Lanka

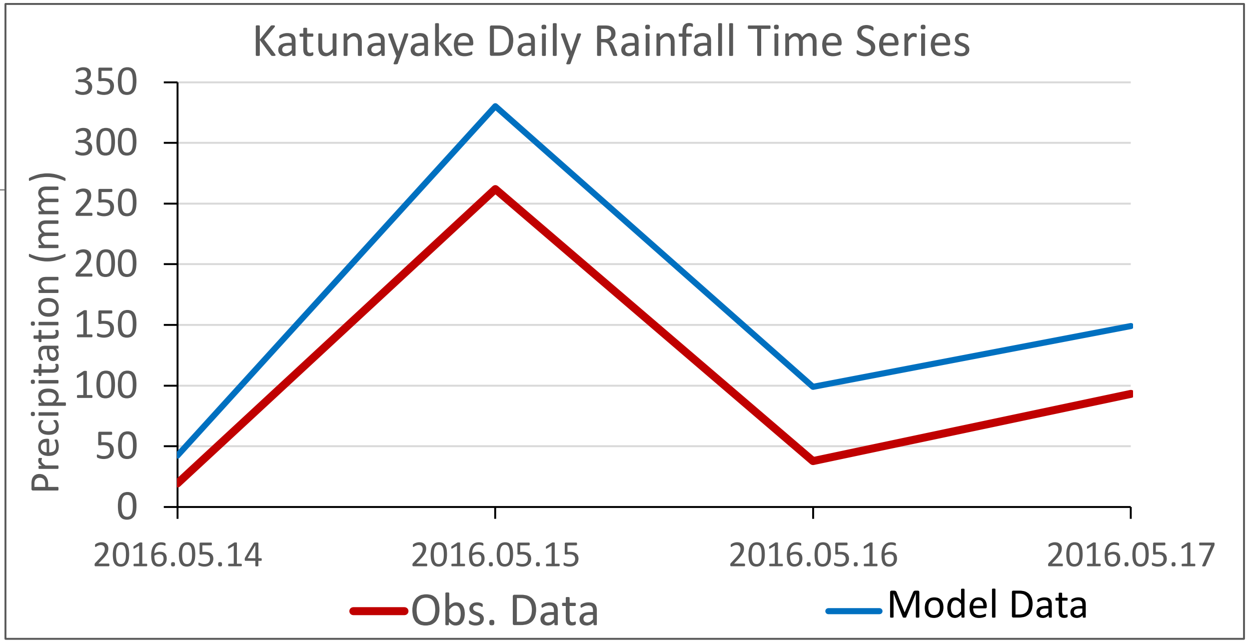
Stations with available Rainfall Data

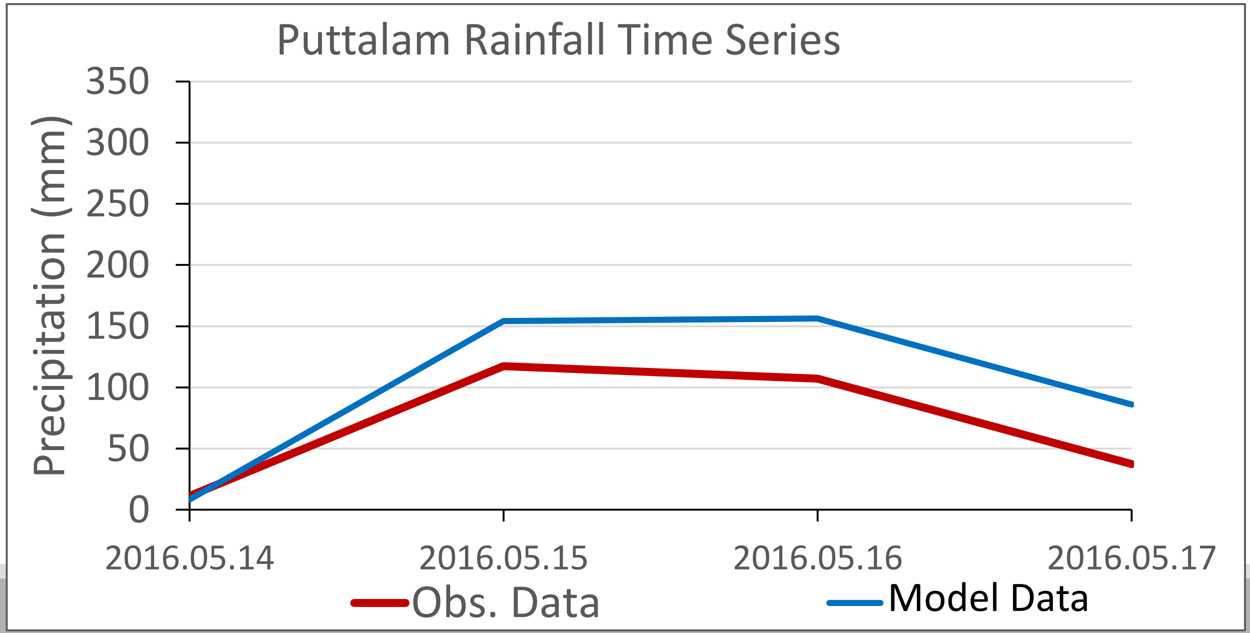


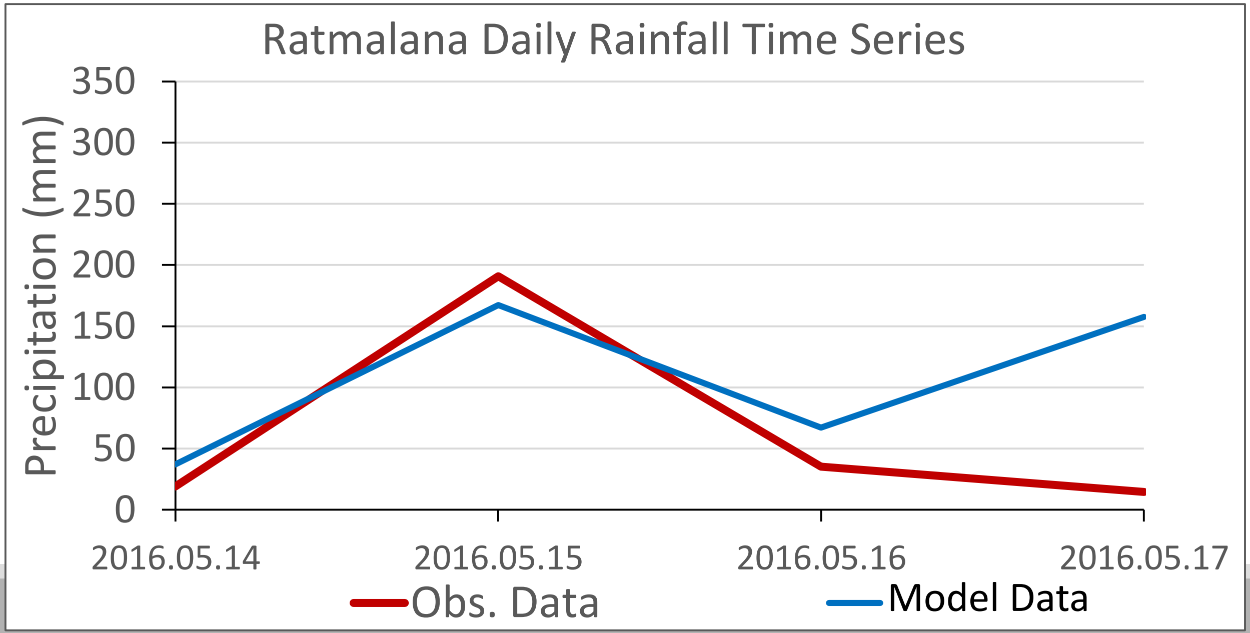
Weather stations with uninterrupted hourly data for 2016.05.14th 0900 – 17th 0900

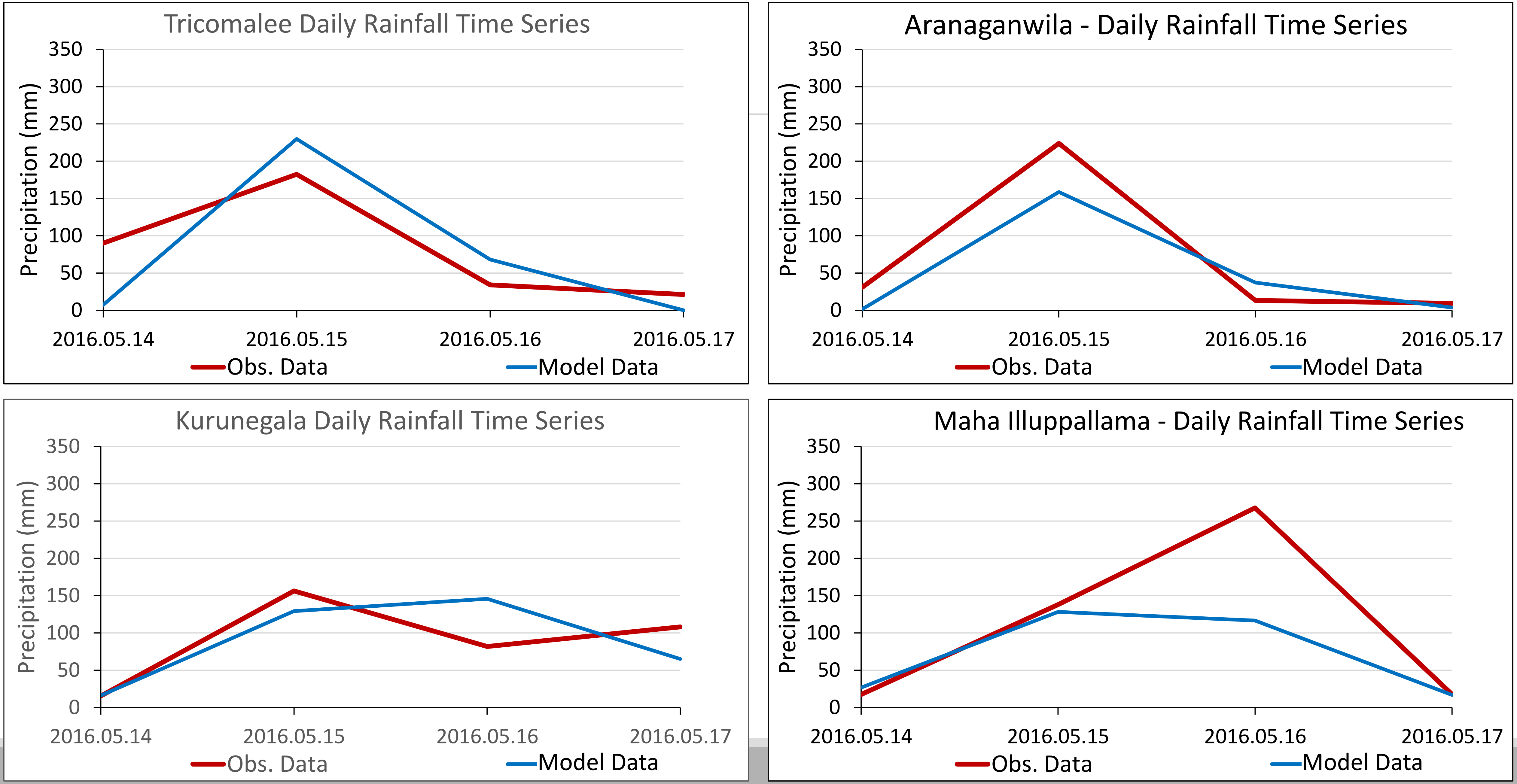
Highest rainfall was recorded on 2016.05.15 as 355.5 mm at *Deraniyagala* gauge station A Department of Irrigation Weather Station

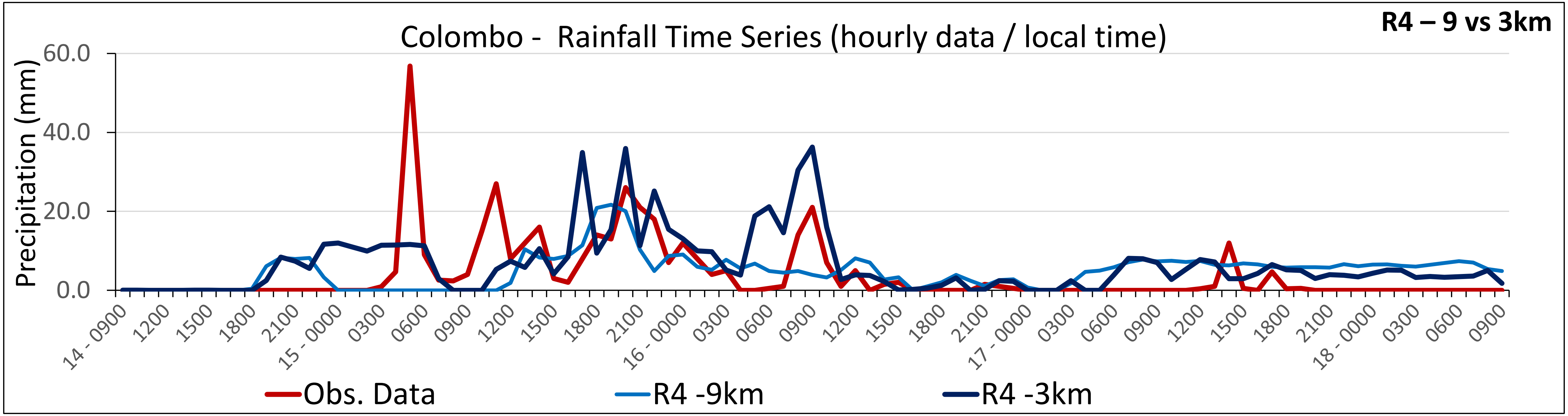

Colombo - Daily Rainfall Time Series
Precipitation (mm)
350
300
250
200
150
100
50
0
2016.05.14
2016.05.15
2016.05.16
2016.05.17
Obs. Data
Model Data


Katunayake Daily Rainfall Time Series
Precipitation (mm)
350
300
250
200
150
100
50
0
2016.05.14
2016.05.15
2016.05.16
2016.05.17
Obs. Data
Model Data

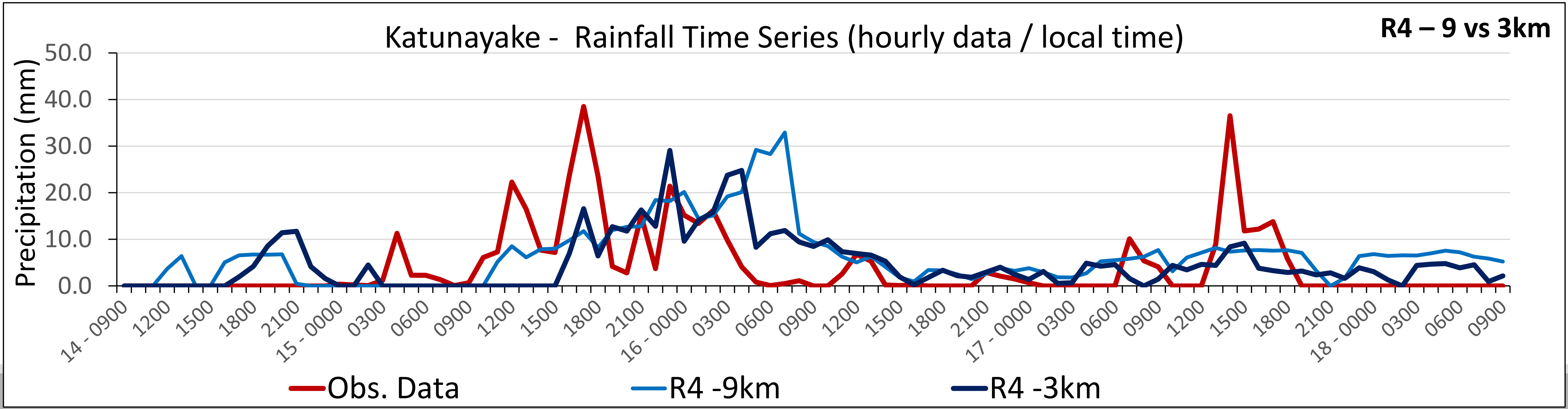

Puttalam Rainfall Time Series
Precipitation (mm)
350
300
250
200
150
100
50
0
2016.05.14
2016.05.15
2016.05.16
2016.05.17
Obs. Data
Model Data


Ratmalana Daily Rainfall Time Series
Precipitation (mm)
350
300
250
200
150
100
50
0
2016.05.14
2016.05.15
2016.05.16
2016.05.17
Obs. Data
Model Data

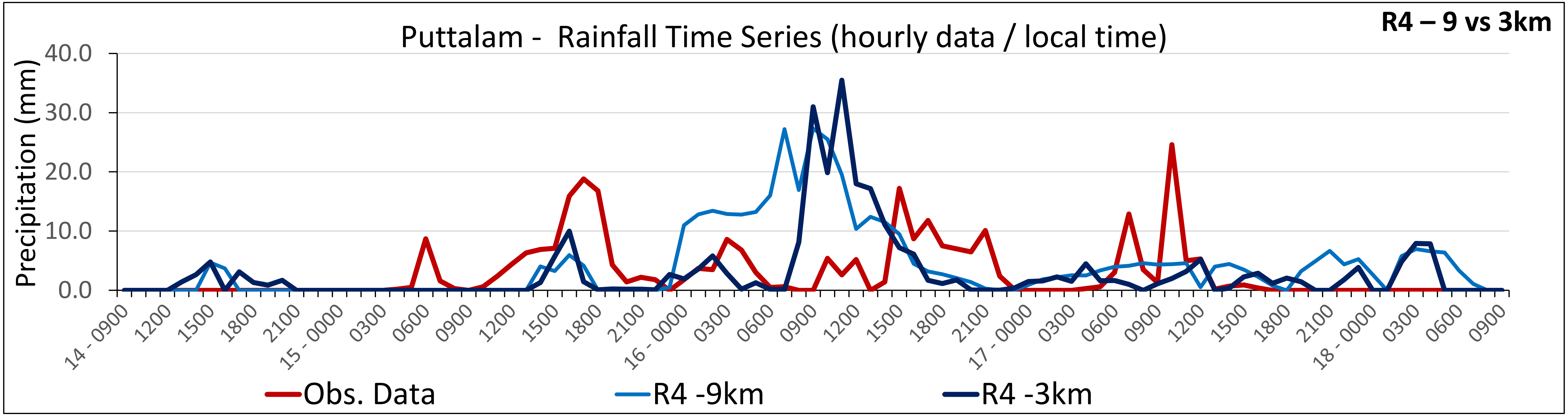

Tricomalee Daily Rainfall Time Series
Precipitation (mm)
350
300
250
200
150
100
50
0
2016.05.14
2016.05.15
2016.05.16
2016.05.17
Obs. Data
Model Data
Aranaganwila - Daily Rainfall Time Series
Precipitation (mm)
350
300
250
200
150
100
50
0
2016.05.14
2016.05.15
2016.05.16
2016.05.17
Obs. Data
Model Data
Kurunegala Daily Rainfall Time Series
Precipitation (mm)
350
300
250
200
150
100
50
0
2016.05.14
2016.05.15
2016.05.16
2016.05.17
Obs. Data
Model Data
Maha Illuppallama - Daily Rainfall Time Series
Precipitation (mm)
350
300
250
200
150
100
50
0
2016.05.14
2016.05.15
2016.05.16
2016.05.17
Obs. Data
Model Data



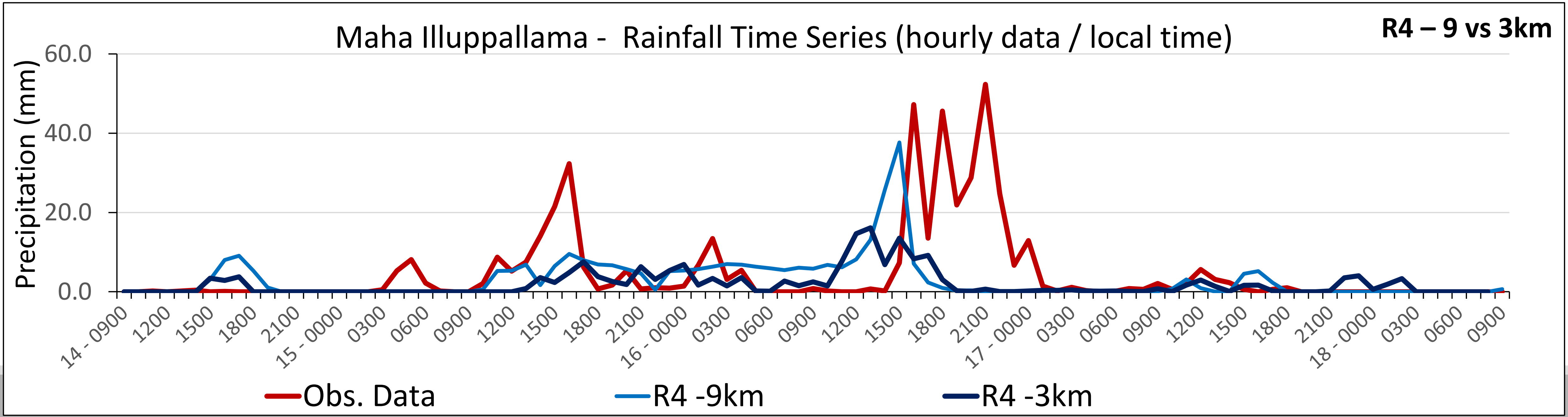
R4 – 9 vs 3km
Colombo - Rainfall Time Series (hourly data / local time)
Precipitation (mm)
60.0
40.0
20.0
0.0
14 - 0900
1200
1500
1800
2100
15 - 0000
0300
0600
0900
1200
1500
1800
2100
16 - 0000
0300
0600
0900
1200
1500
1800
2100
17 - 0000
0300
0600
0900
1200
1500
1800
2100
18 - 0000
0300
0600
0900
Obs. Data
R4 -9km
R4 -3km



R4 – 9 vs 3km
Katunayake - Rainfall Time Series (hourly data / local time)
Precipitation (mm)
50.0
40.0
30.0
20.0
10.0
0.0
14 - 0900
1200
1500
1800
2100
15 - 0000
0300
0600
0900
1200
1500
1800
2100
16 - 0000
0300
0600
0900
1200
1500
1800
2100
17 - 0000
0300
0600
0900
1200
1500
1800
2100
18 - 0000
0300
0600
0900
Obs. Data
R4 -9km
R4 -3km



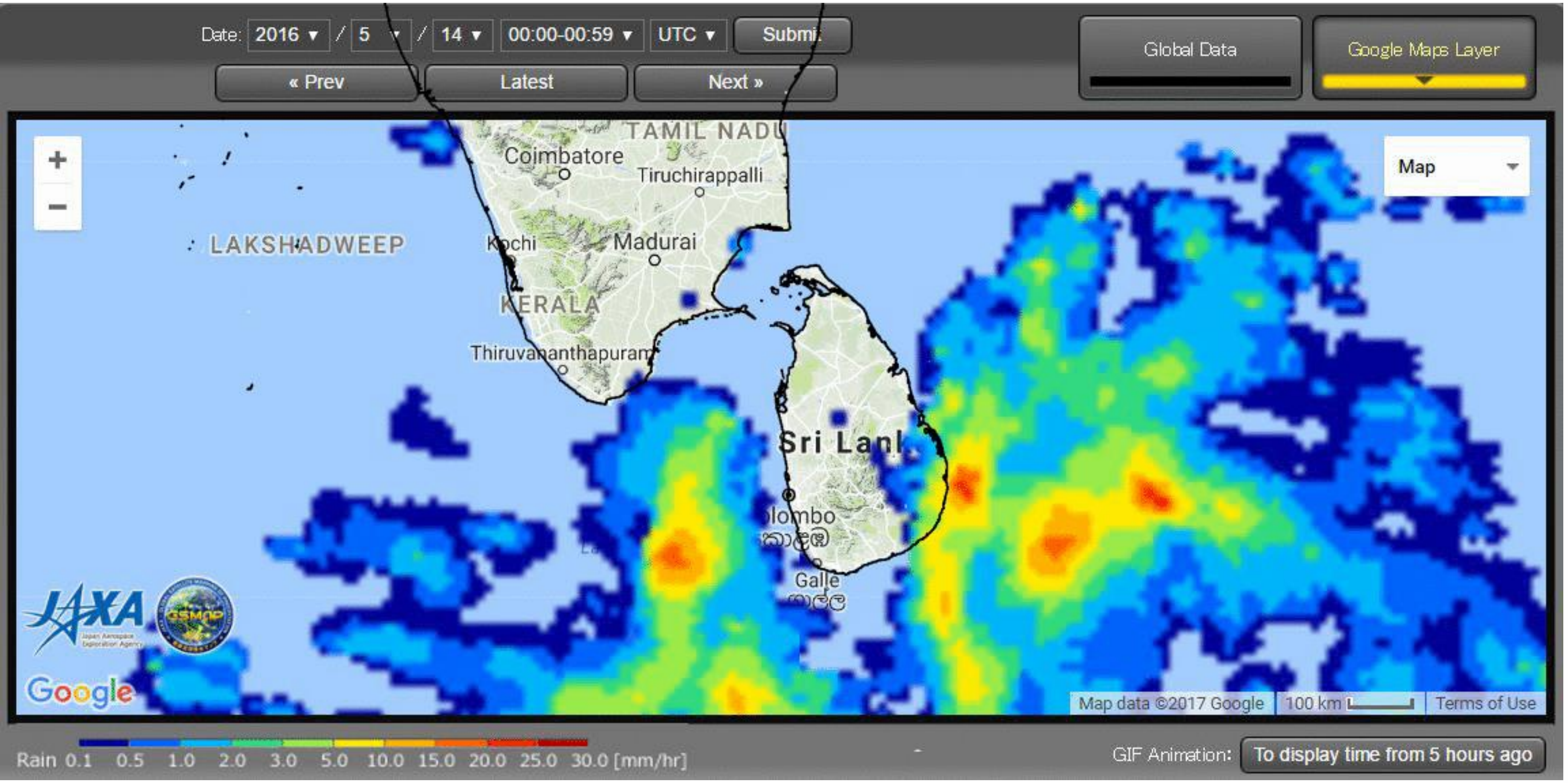
R4 – 9 vs 3km
Puttalam - Rainfall Time Series (hourly data / local time)
Precipitation (mm)
40.0
30.0
20.0
10.0
0.0
14 - 0900
1200
1500
1800
2100
15 - 0000
0300
0600
0900
1200
1500
1800
2100
16 - 0000
0300
0600
0900
1200
1500
1800
2100
17 - 0000
0300
0600
0900
1200
1500
1800
2100
18 - 0000
0300
0600
0900
Obs. Data
R4 -9km
R4 -3km



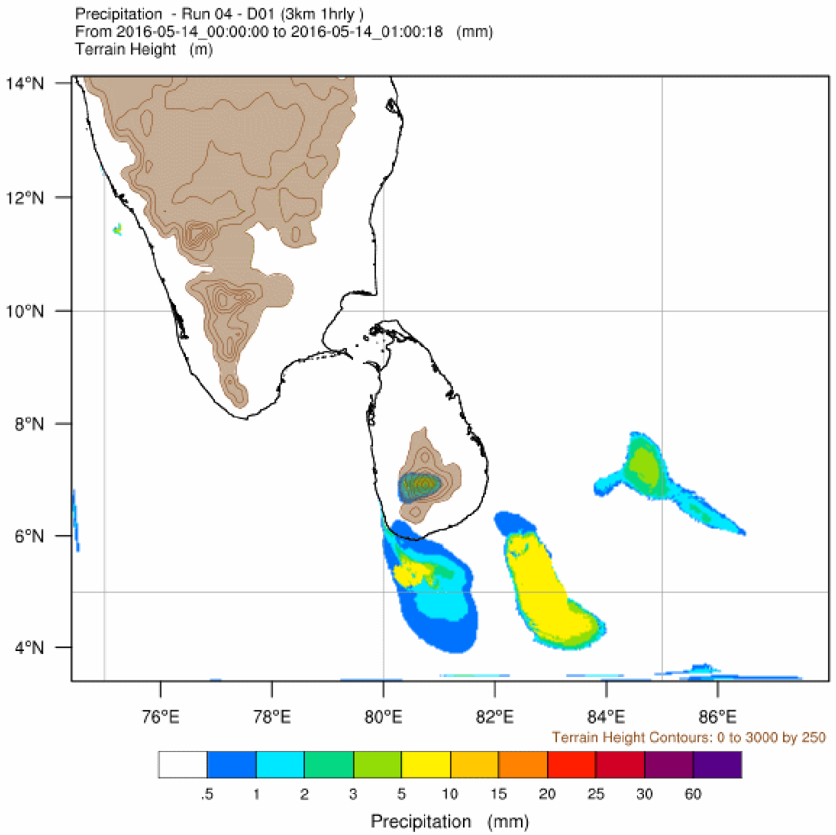
R4 – 9 vs 3km
Maha Illuppallama - Rainfall Time Series (hourly data / local time)
Precipitation (mm)
60.0
40.0
20.0
0.0
14 - 0900
1200
1500
1800
2100
15 - 0000
0300
0600
0900
1200
1500
1800
2100
16 - 0000
0300
0600
0900
1200
1500
1800
2100
17 - 0000
0300
0600
0900
1200
1500
1800
2100
18 - 0000
0300
0600
0900
Obs. Data
R4 -9km
R4 -3km

Rainfall comparison –
Satellite data Vs Model results

Rainfall - Satellite Observation Vs Model simulation



Global Rainfall Map in Near-Real-Time (GSMaP_NRT) by JAXA Global Rainfall Watch'

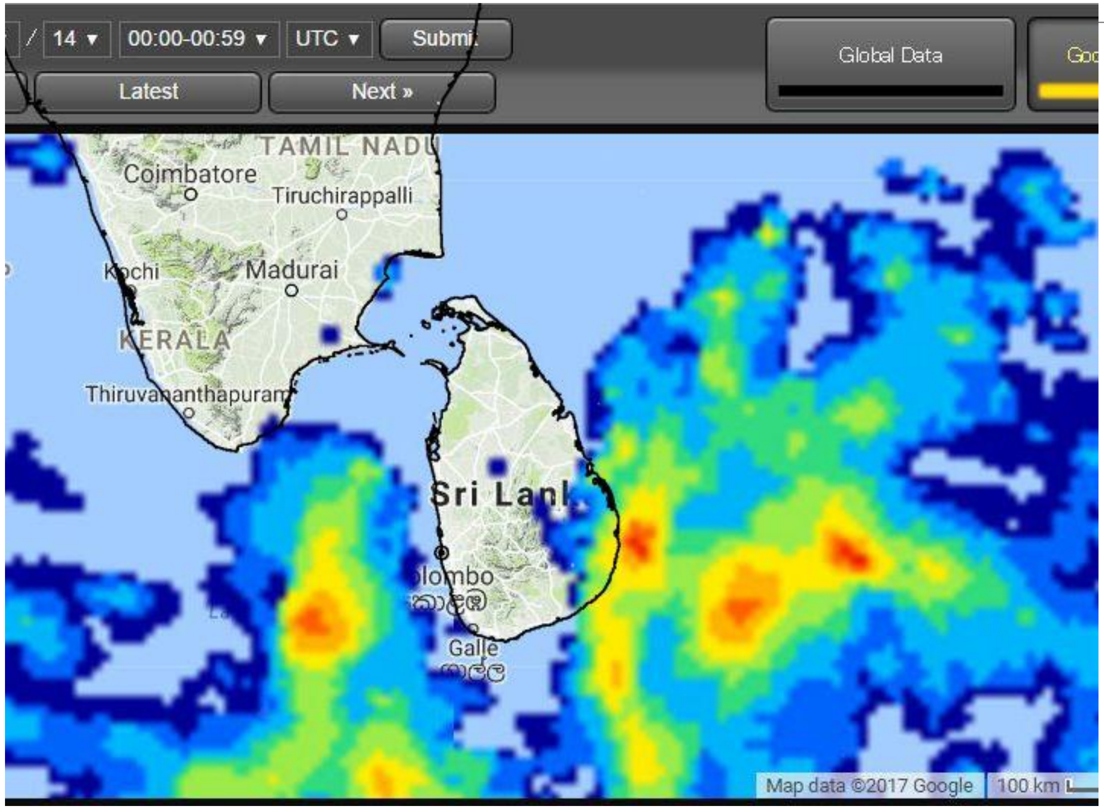


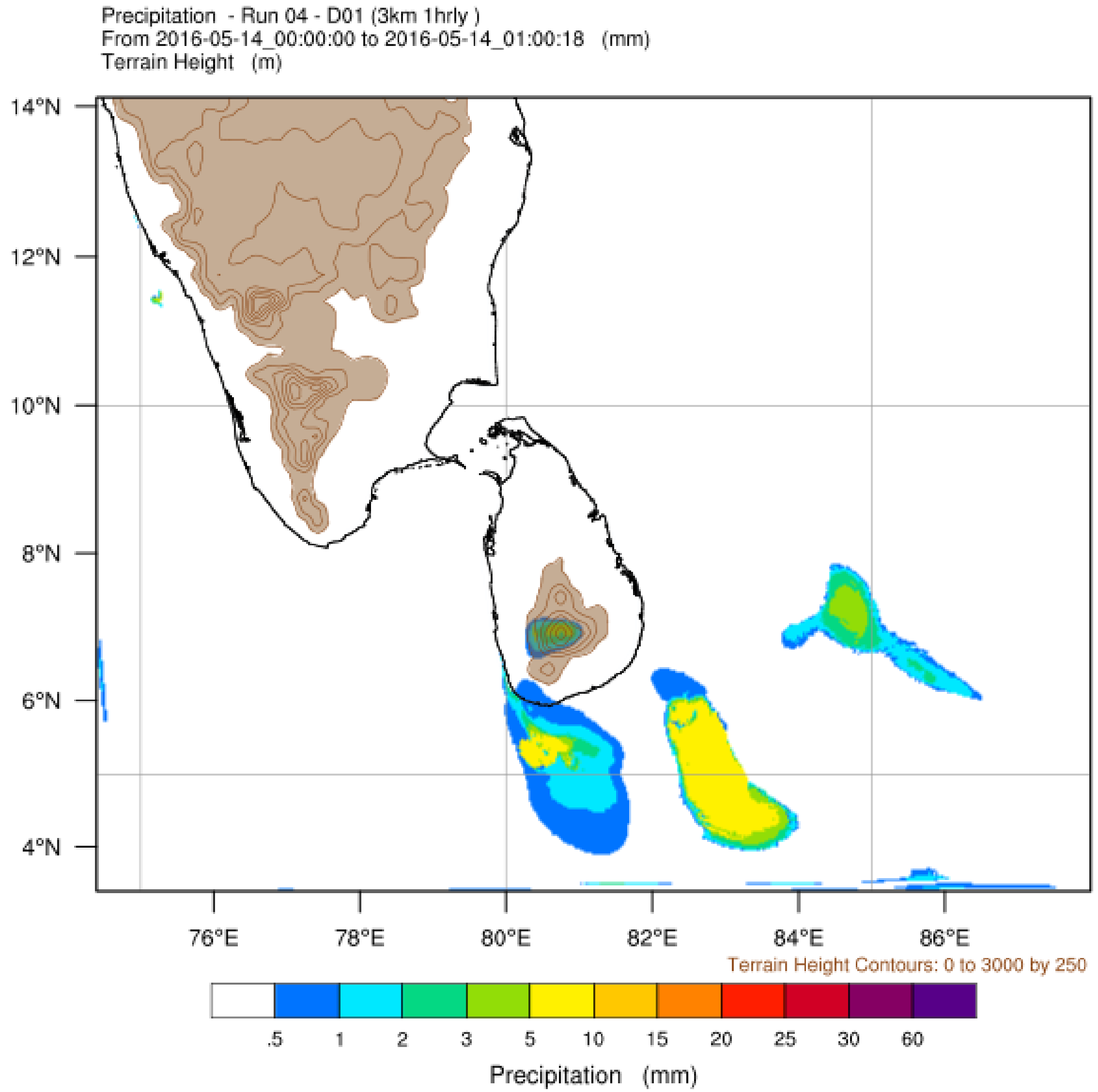
Rainfall from - WRF Results

Global Precipitation Measurement (GPM) mission (GPM-GSMaP Ver.6) algorithm

[A Combine product of MW-IR algorithm using GPM-Core GMI, TRMM TMI, GCOM-W1 AMSR2, DMSP series SSMIS, NOAA series AMSU, MetOp series AMSU, and Geostationary IR]

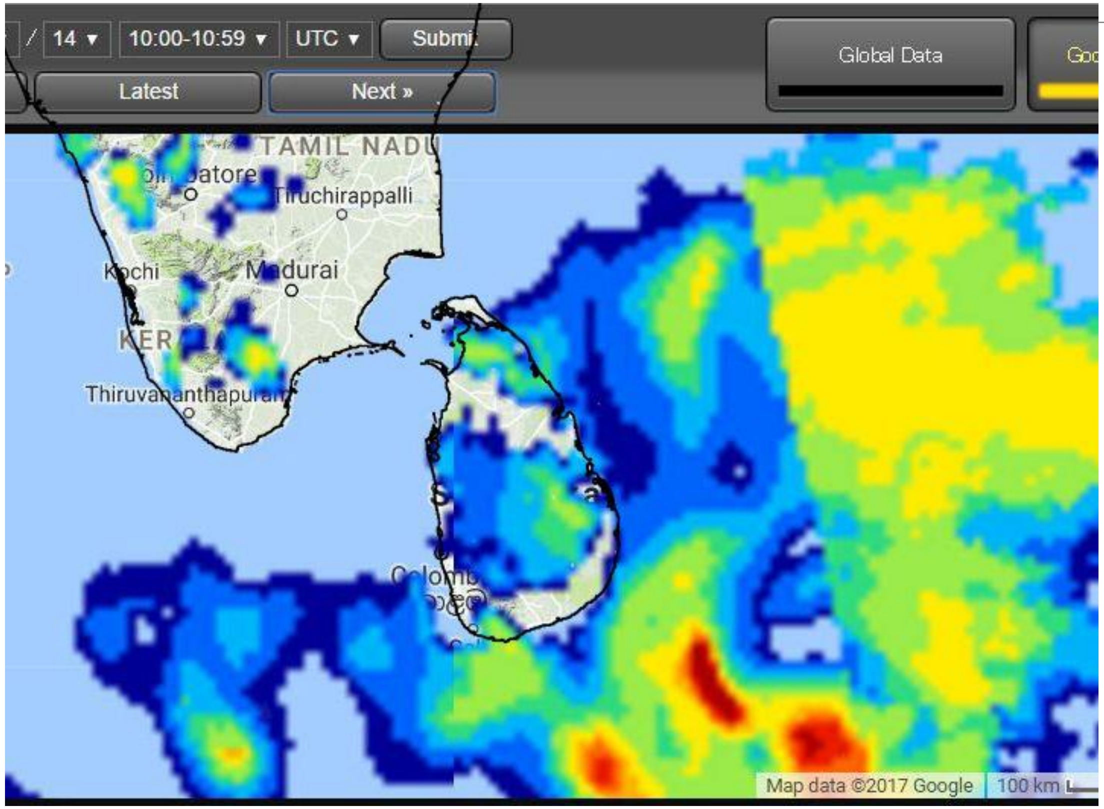
Rainfall - Satellite Observation Vs Model simulation

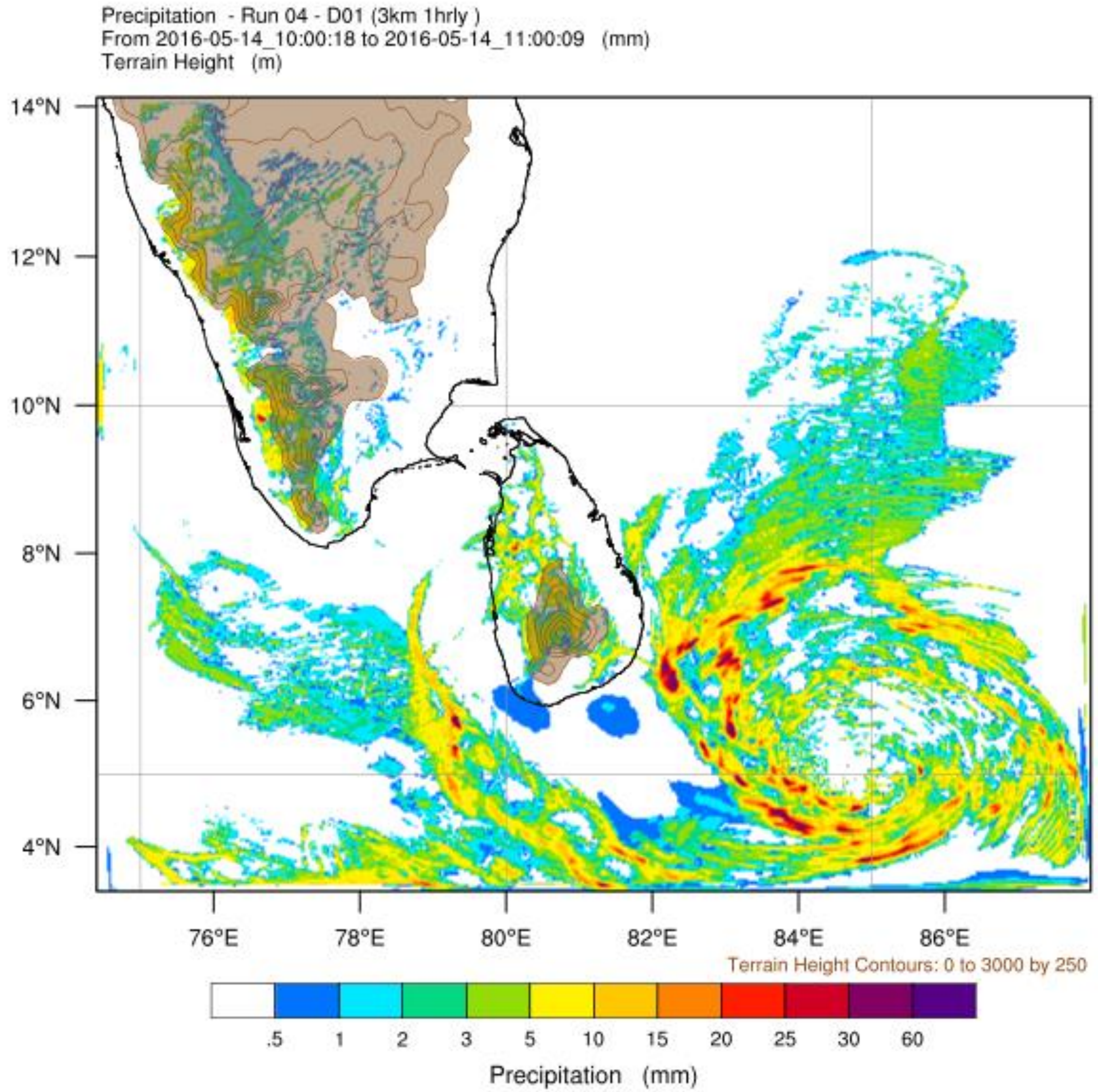




2016.05.14 : 0100

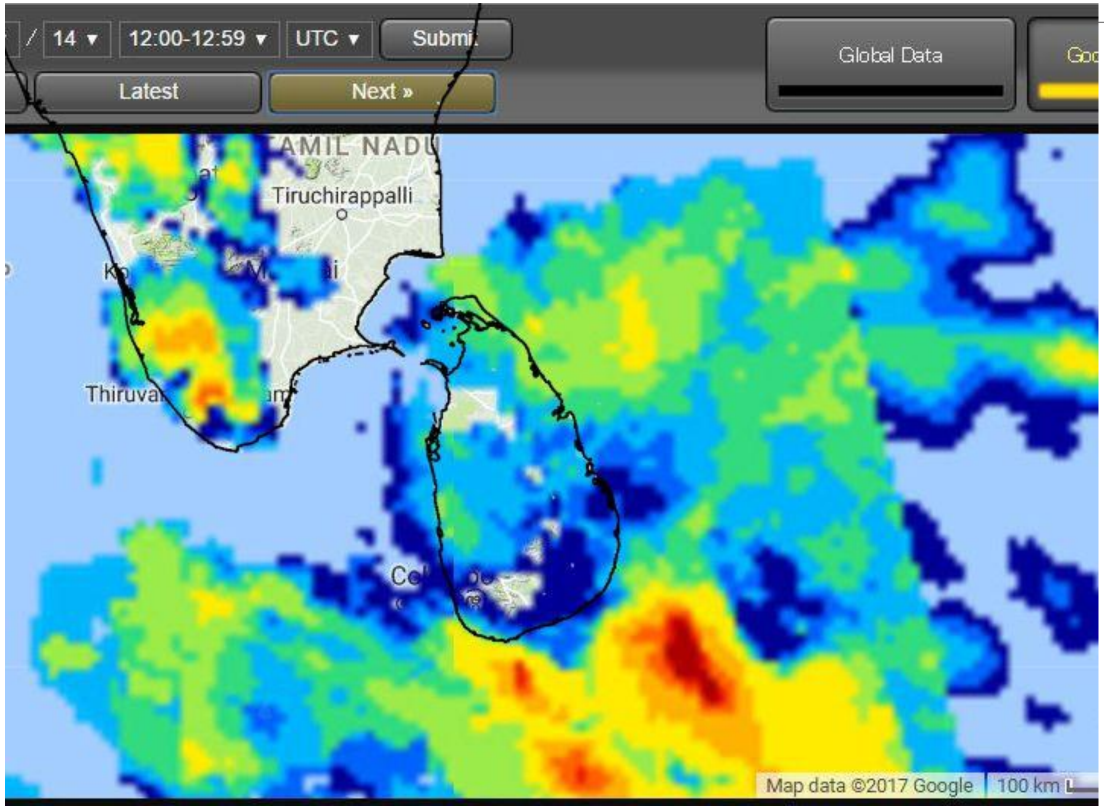
Rainfall - Satellite Observation Vs Model simulation

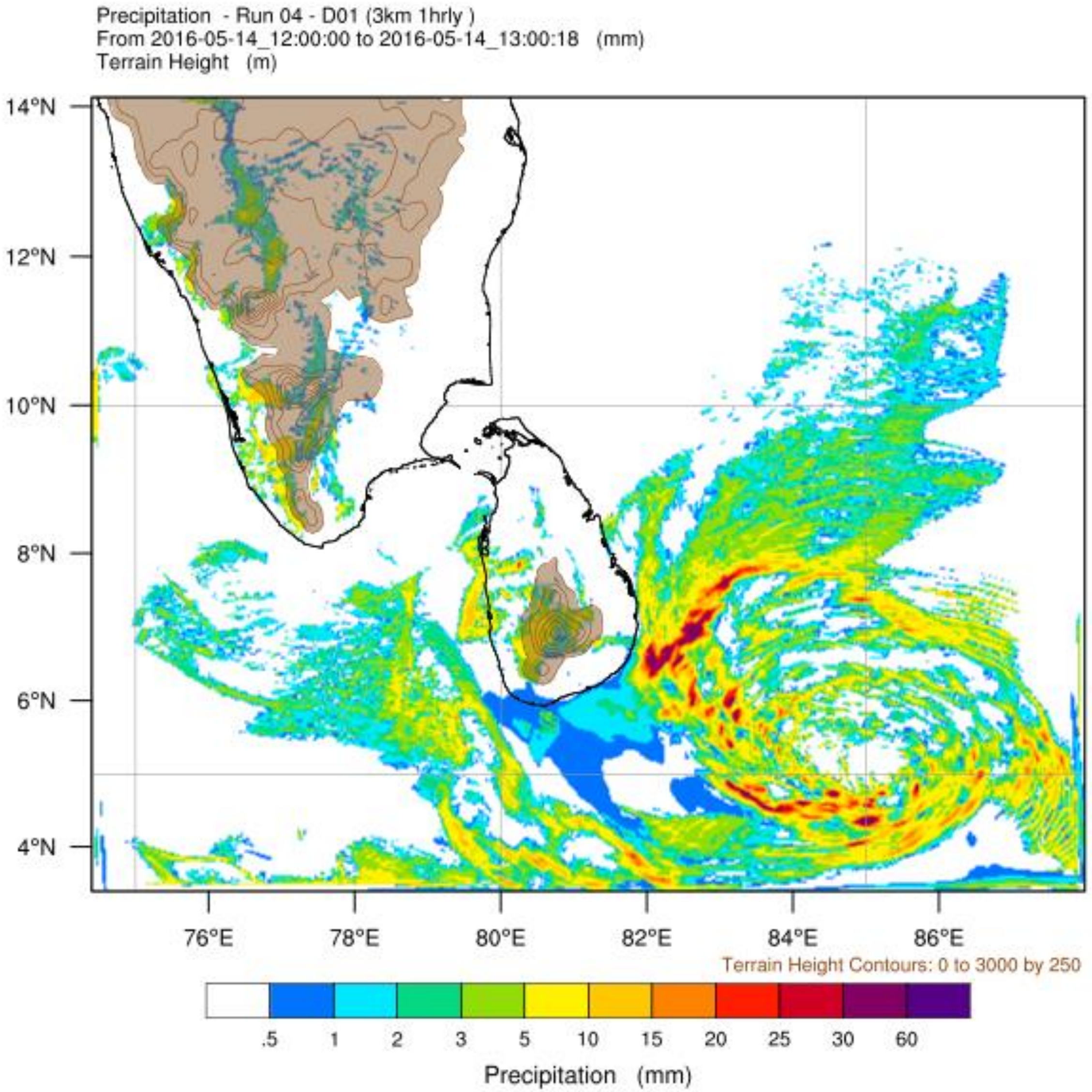




2016.05.14 : 1100

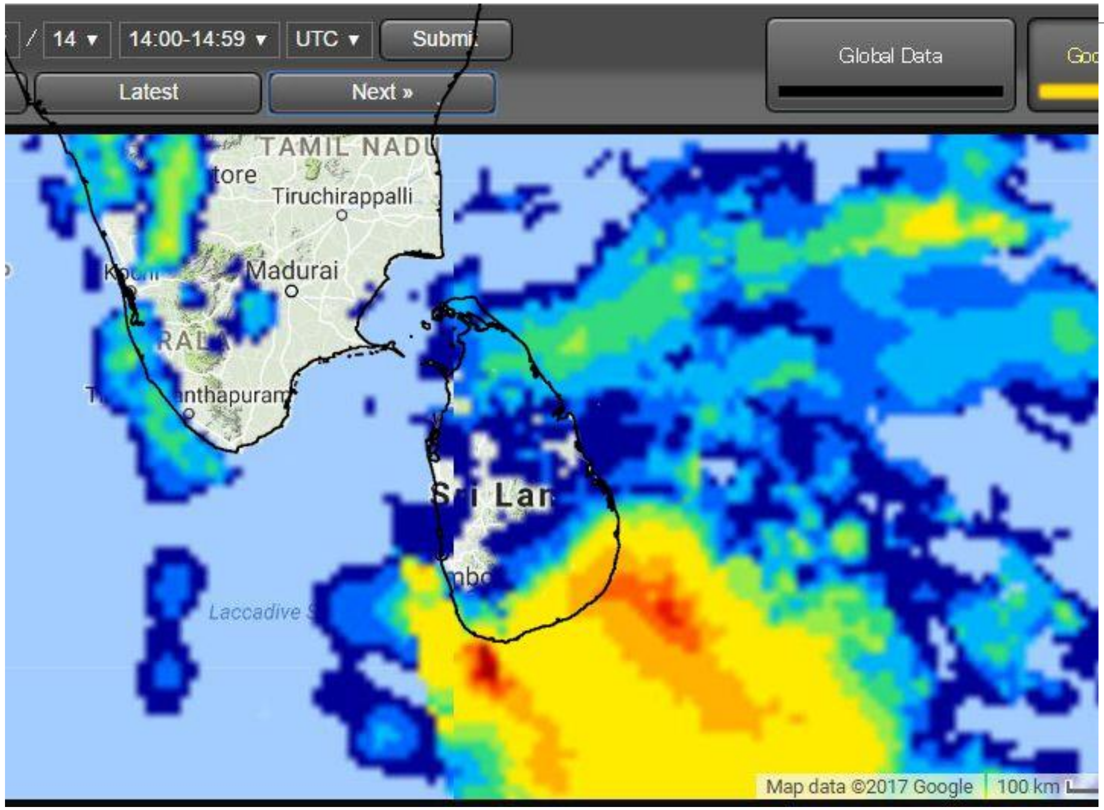
Rainfall - Satellite Observation Vs Model simulation

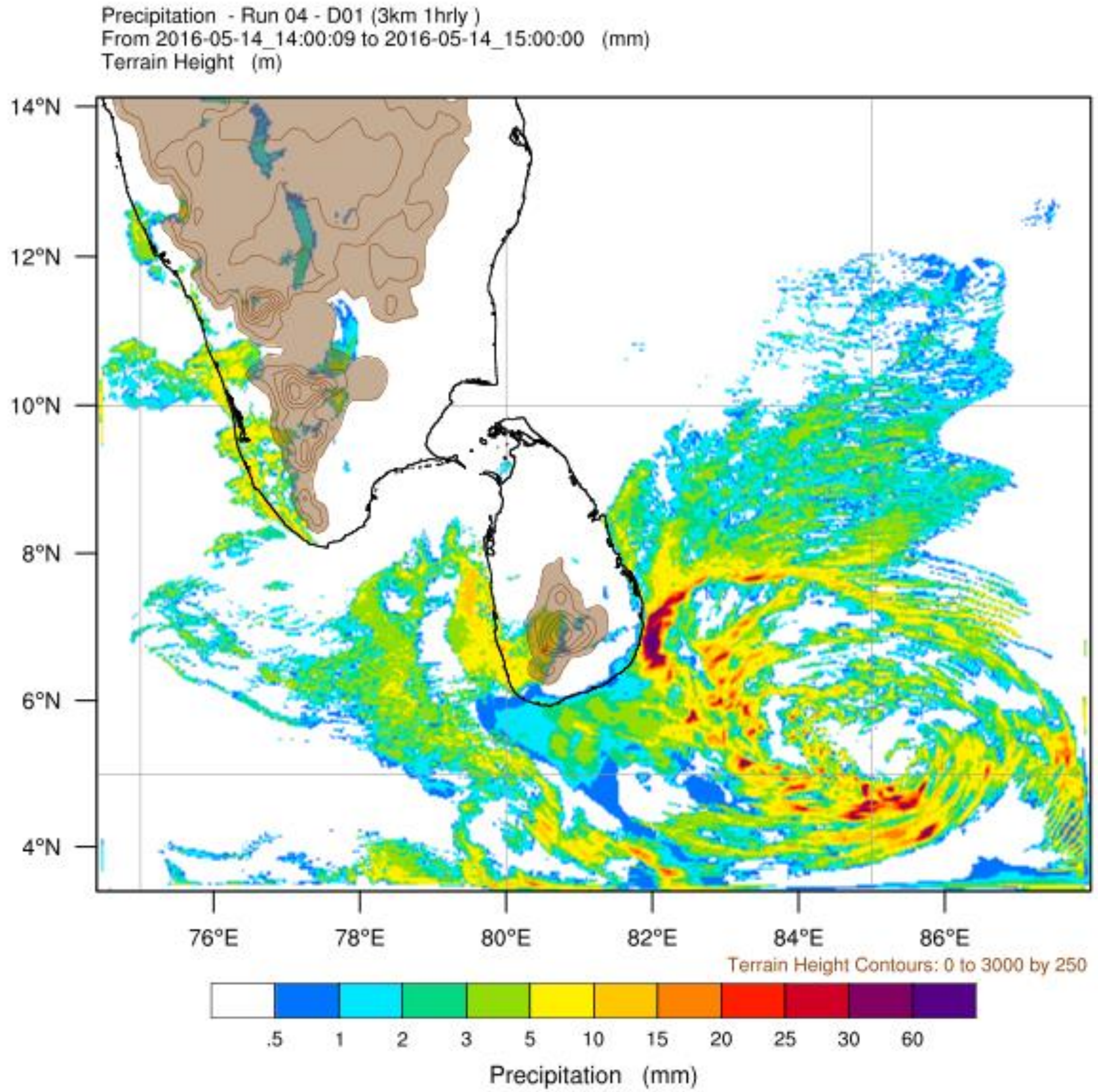




2016.05.14 : 1300

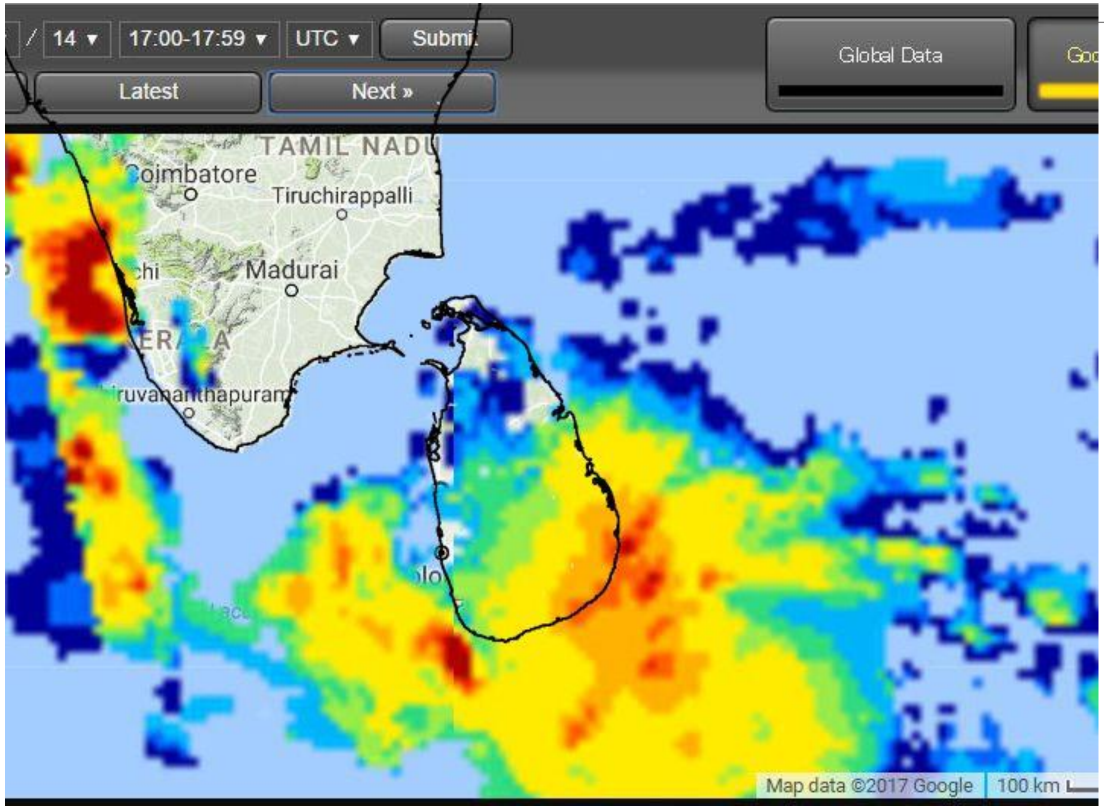
Rainfall - Satellite Observation Vs Model simulation

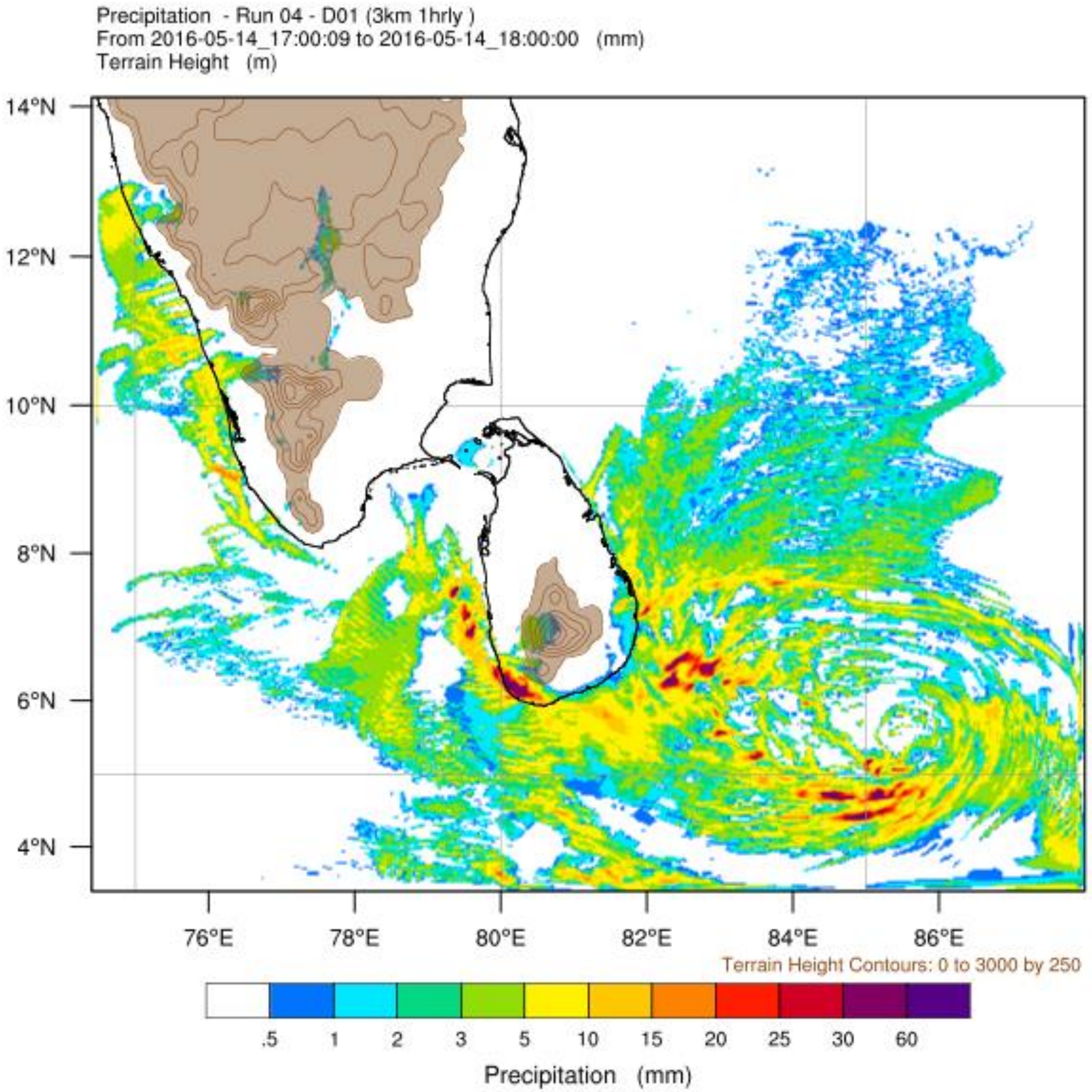




2016.05.14 : 1500

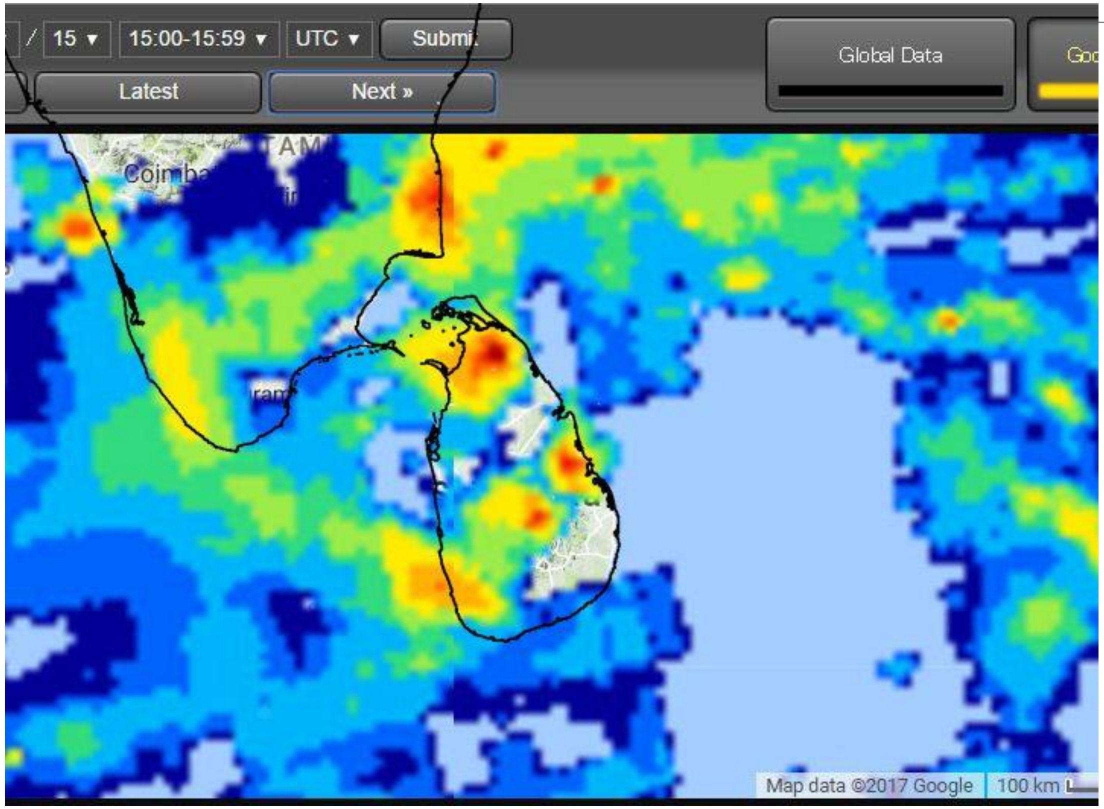
Rainfall - Satellite Observation Vs Model simulation

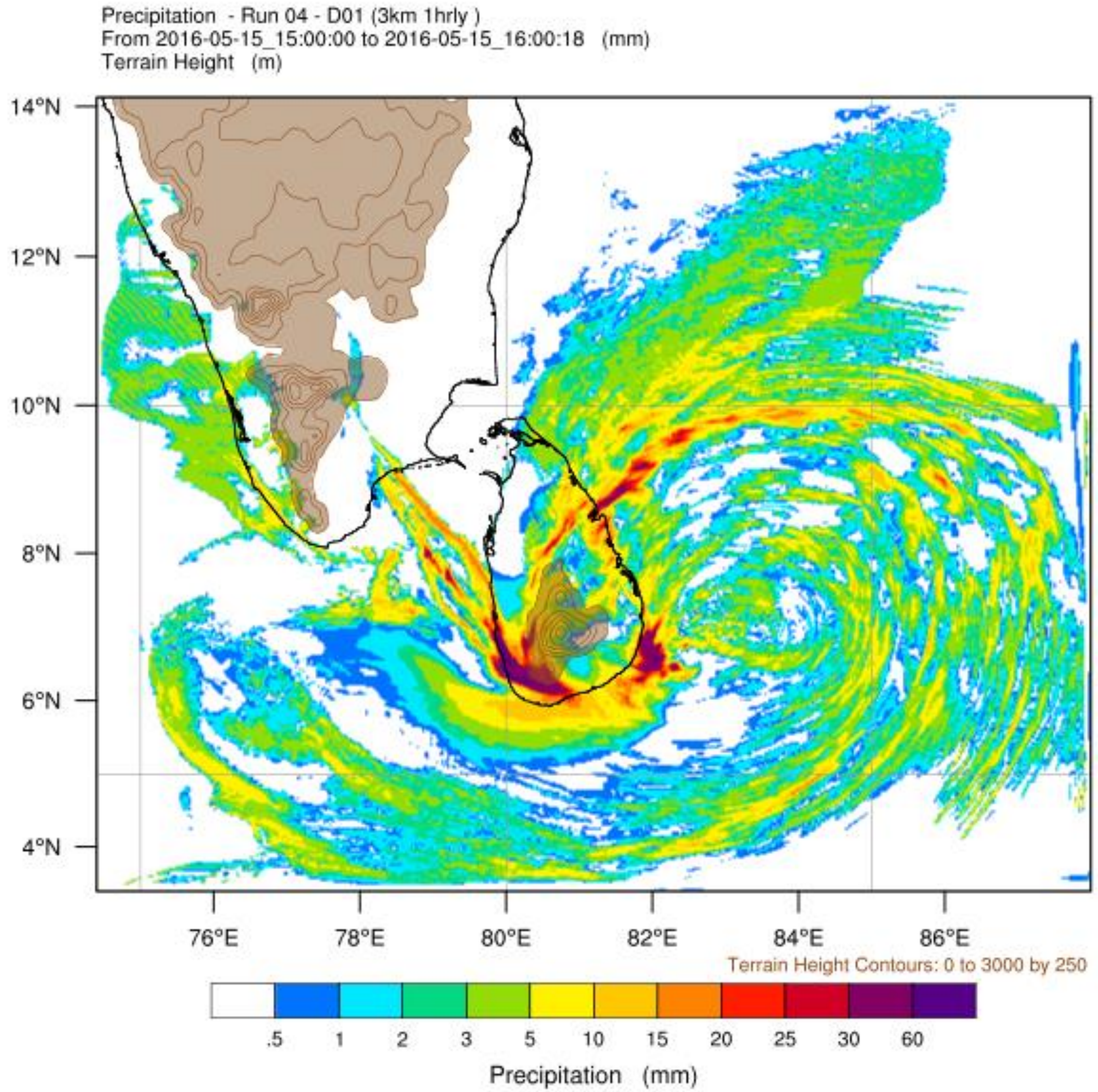




2016.05.14 : 1800

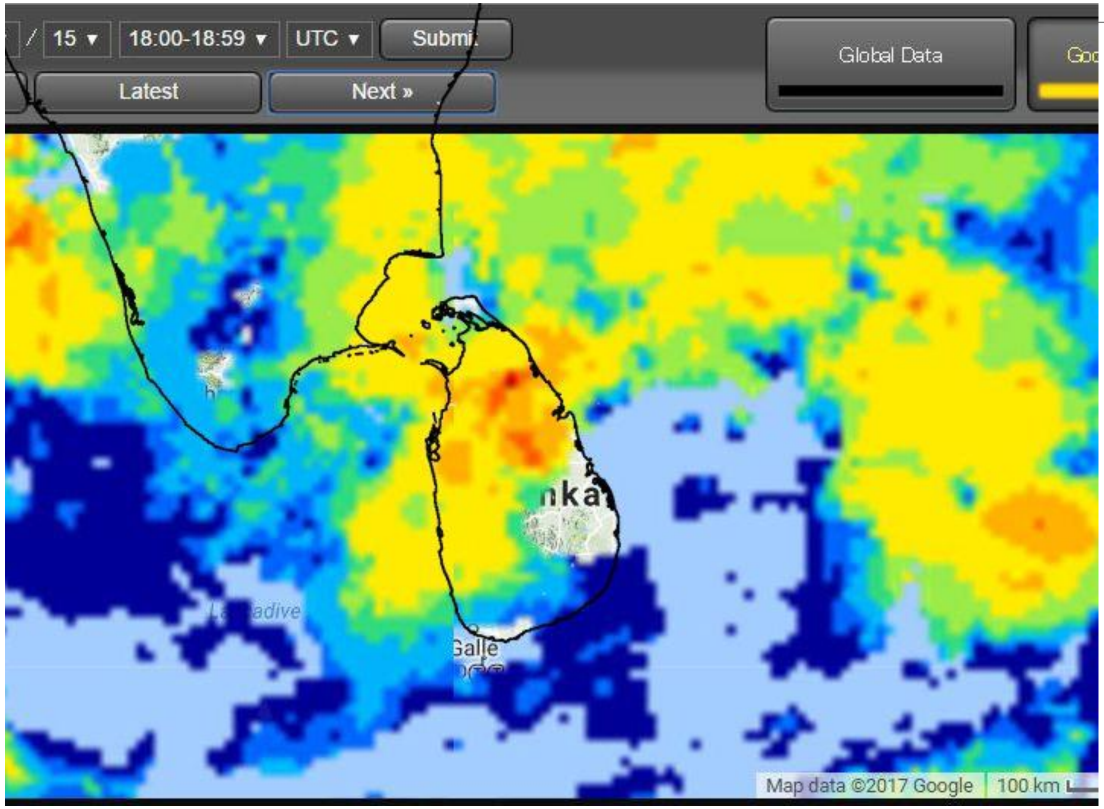
Rainfall - Satellite Observation Vs Model simulation

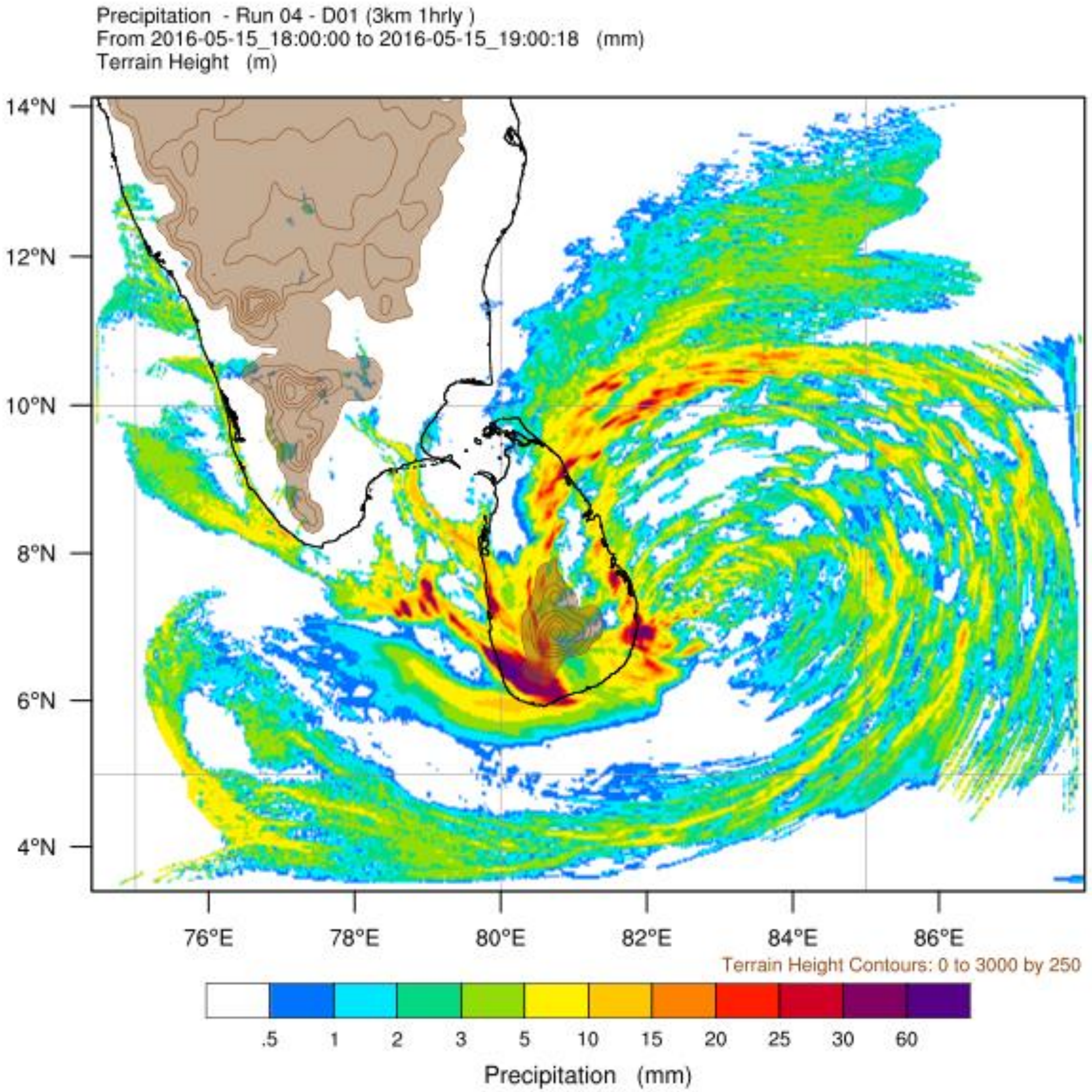




2016.05.15 : 1600

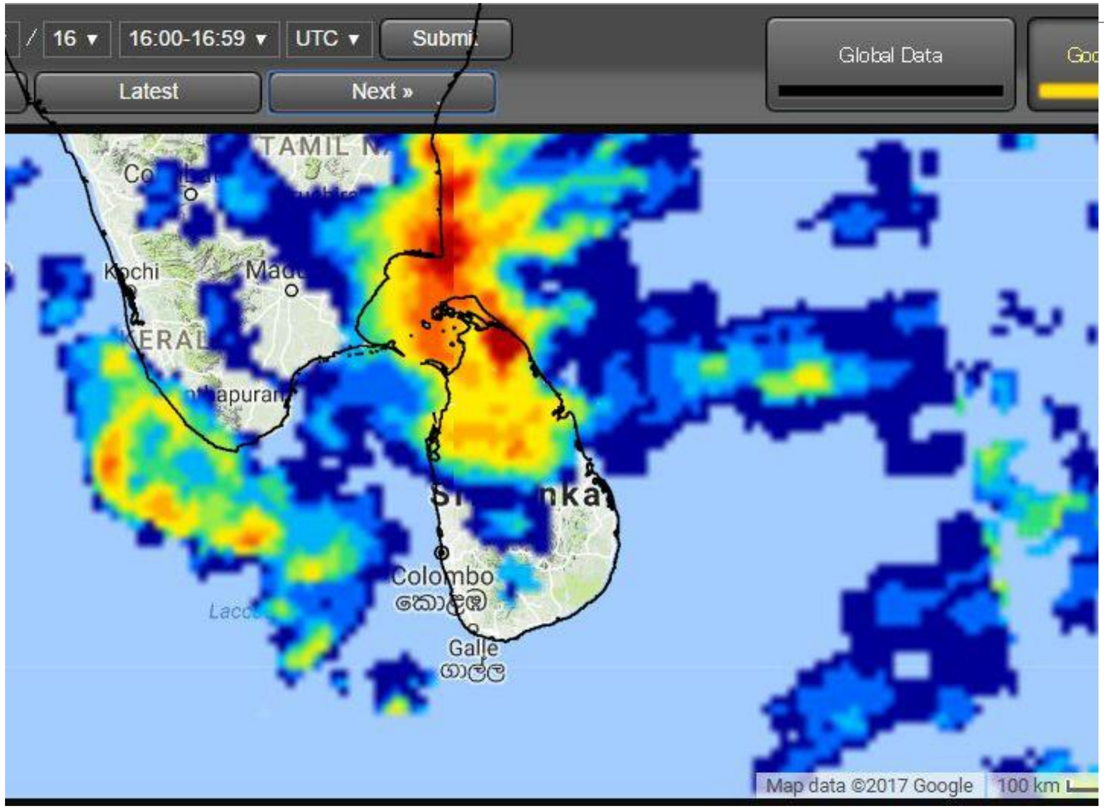
Rainfall - Satellite Observation Vs Model simulation

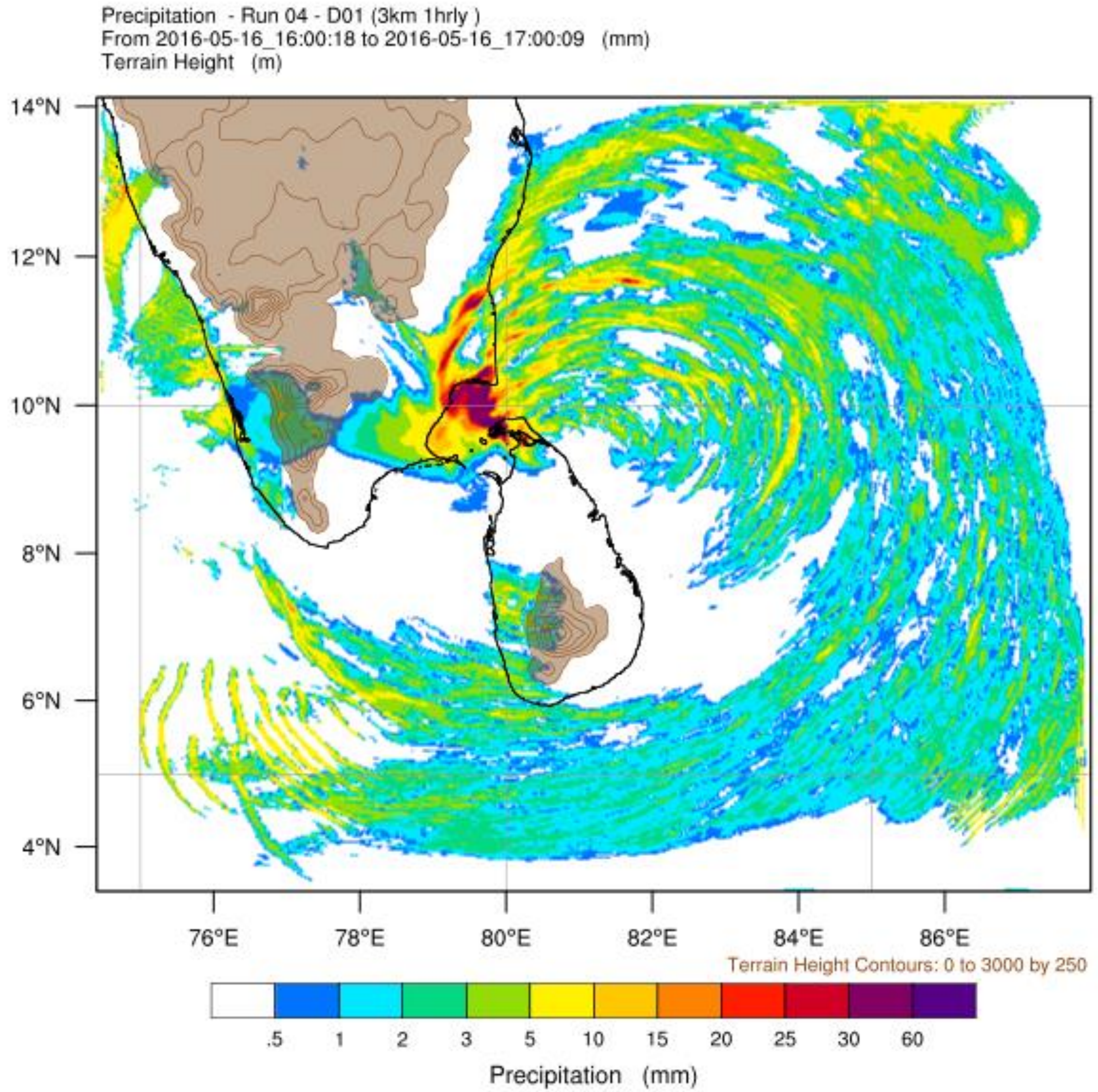




2016.05.15 : 1900

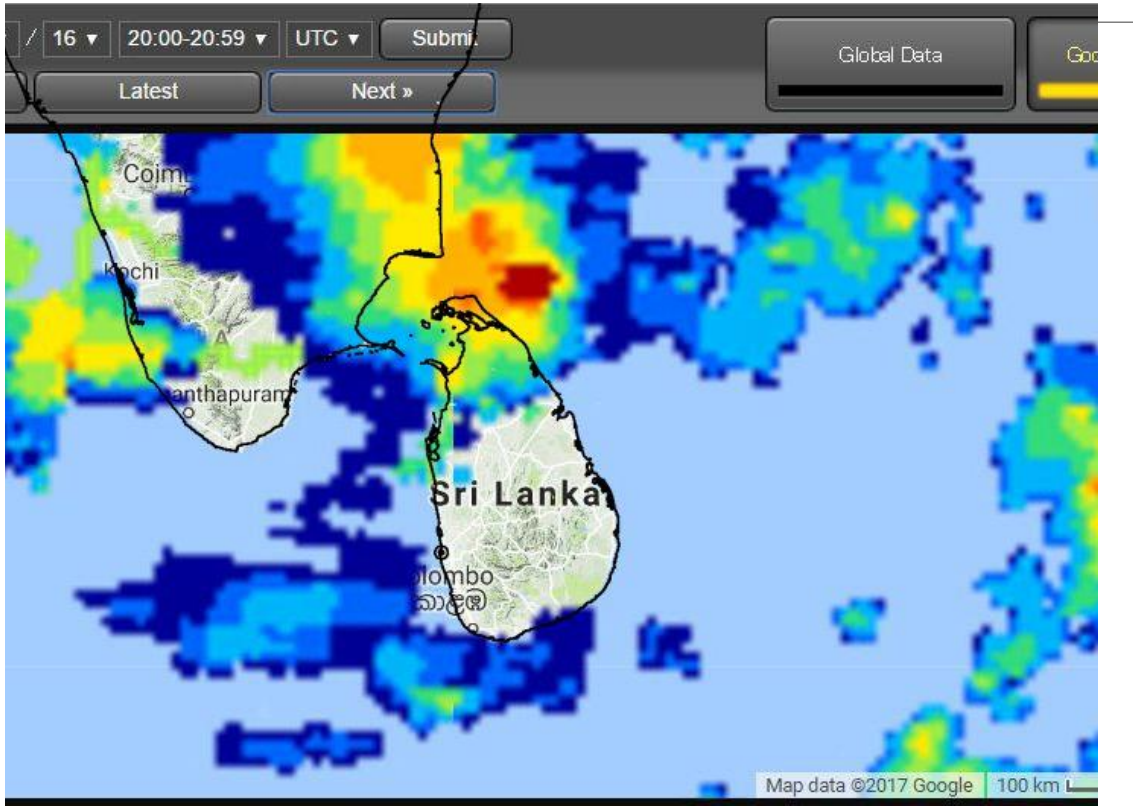
Rainfall - Satellite Observation Vs Model simulation

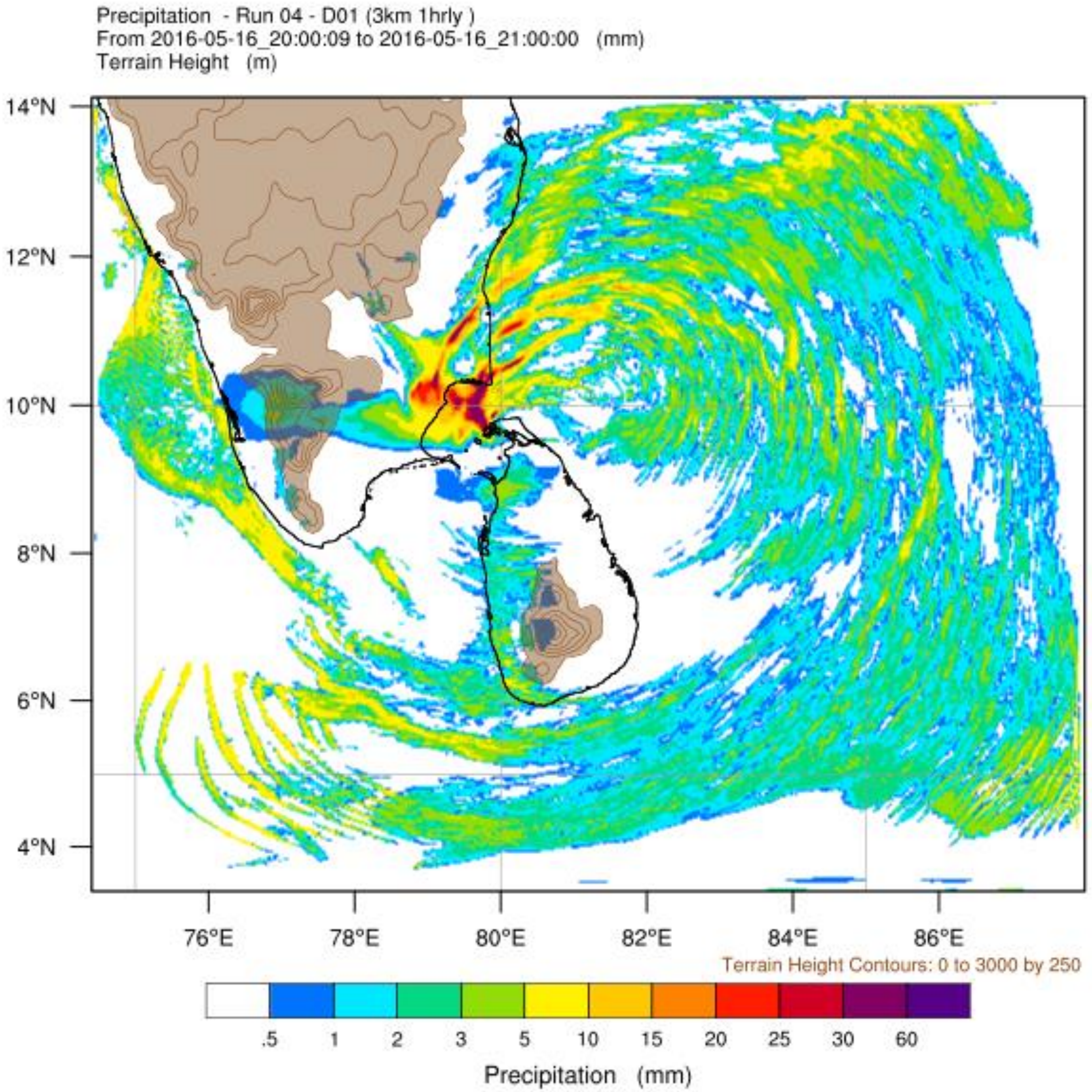




2016.05.16 : 1700

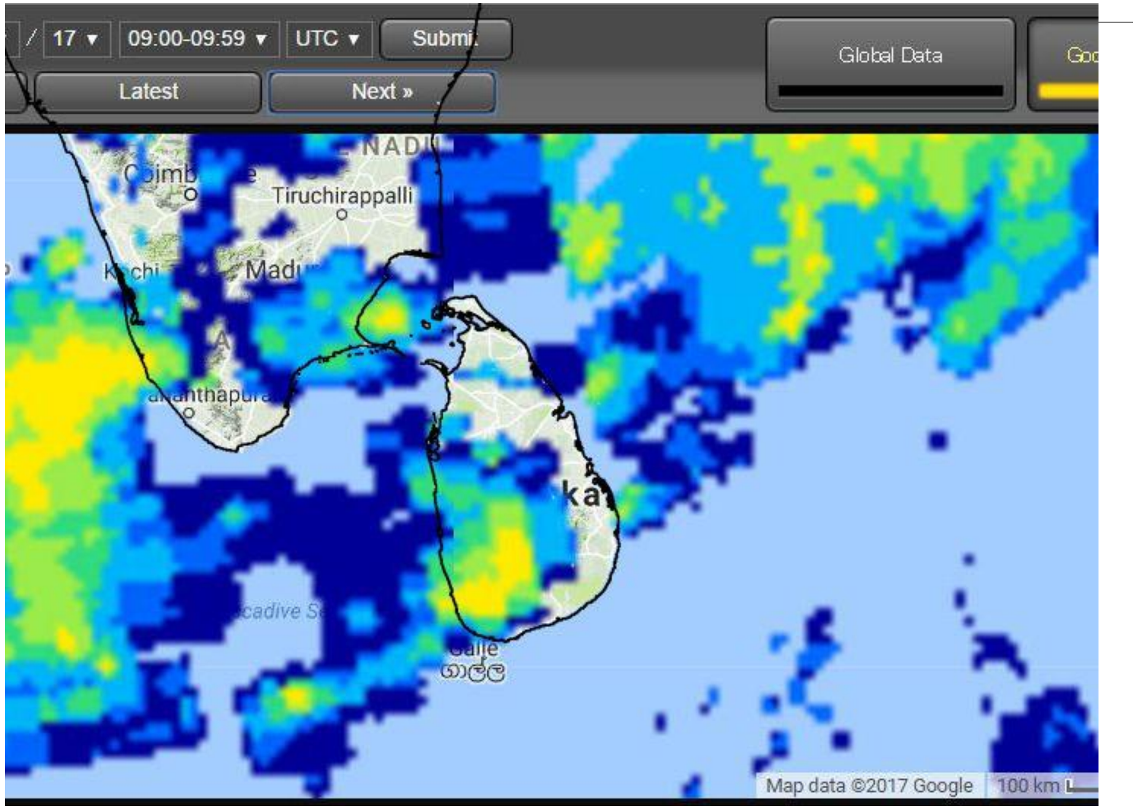
Rainfall - Satellite Observation Vs Model simulation

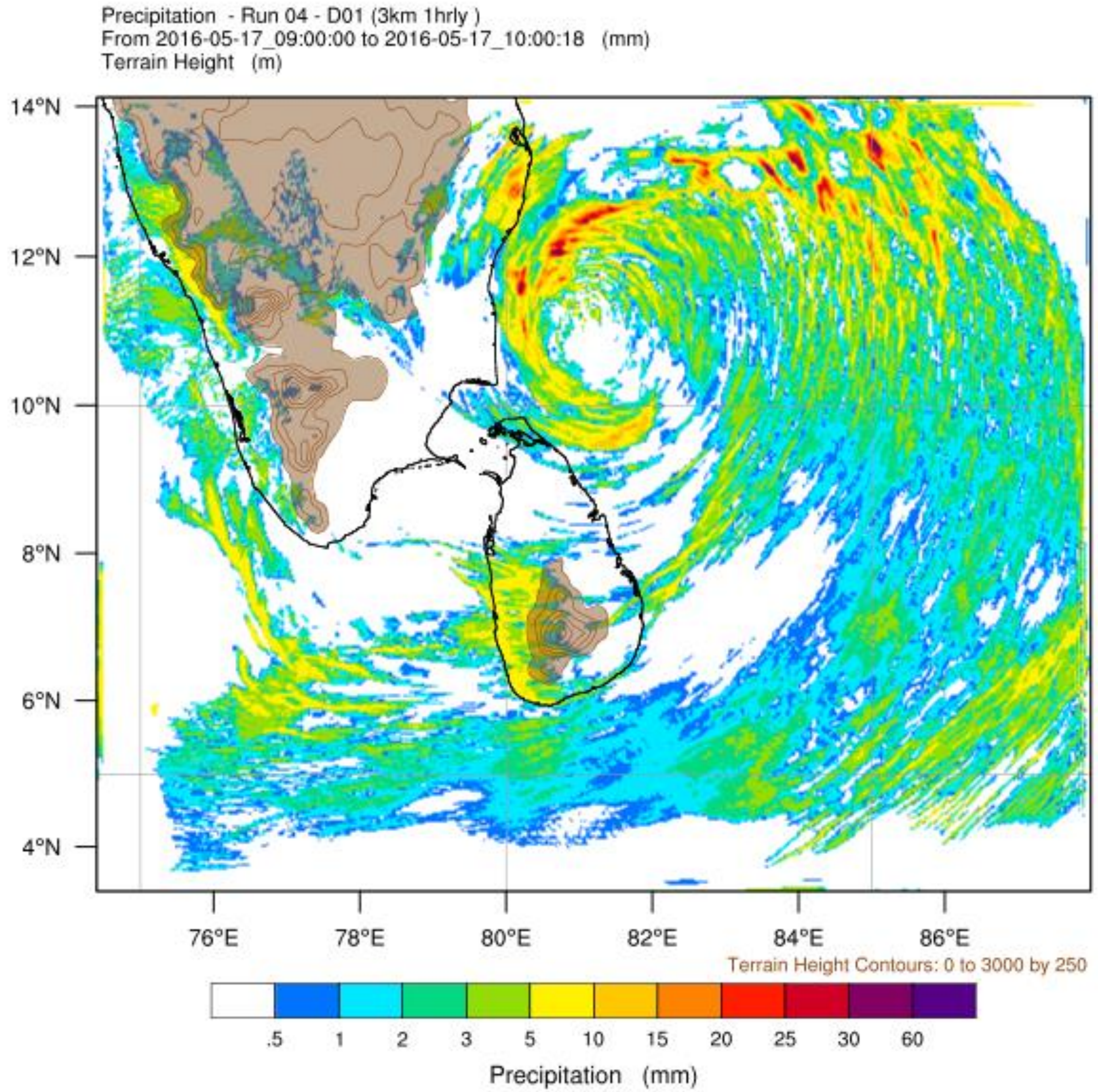




2016.05.16 : 2100

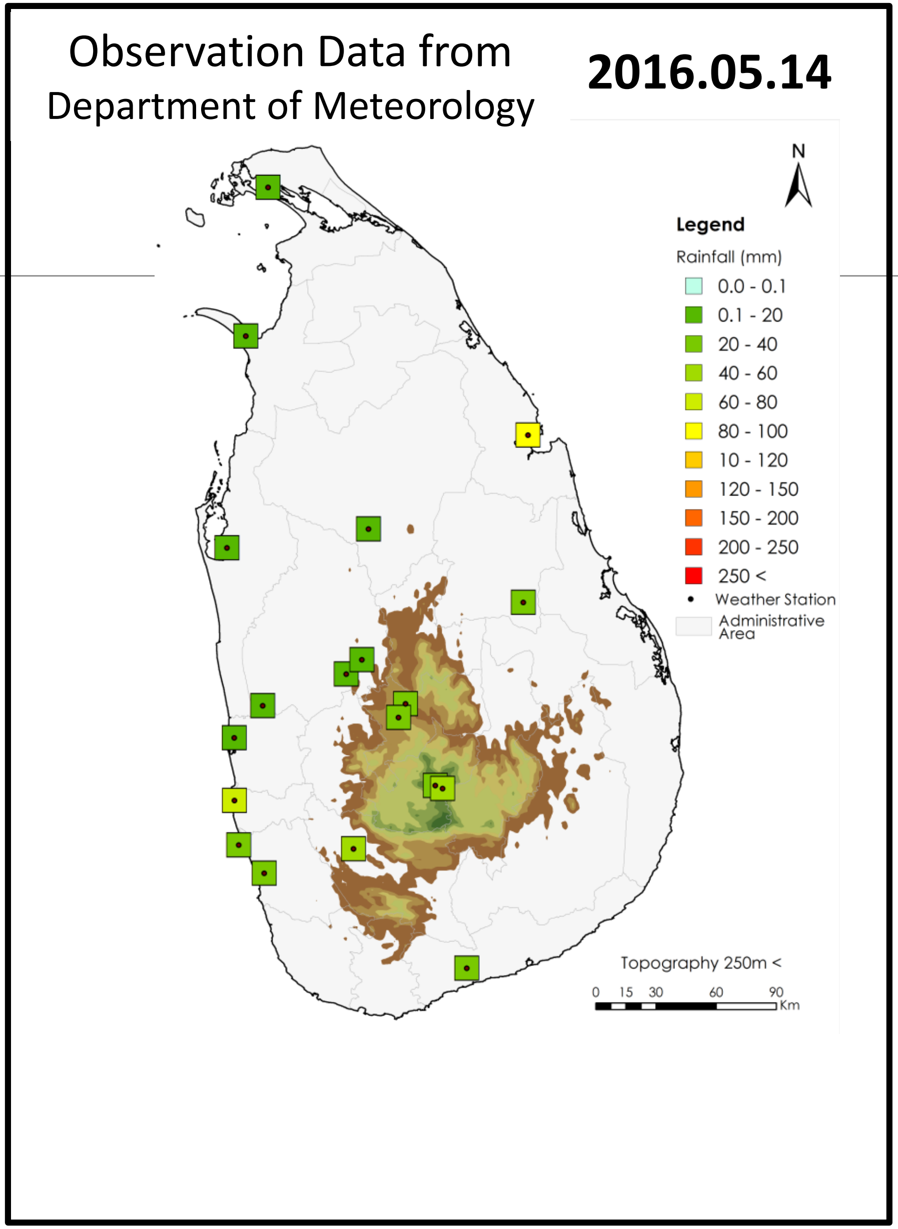
Rainfall - Satellite Observation Vs Model simulation

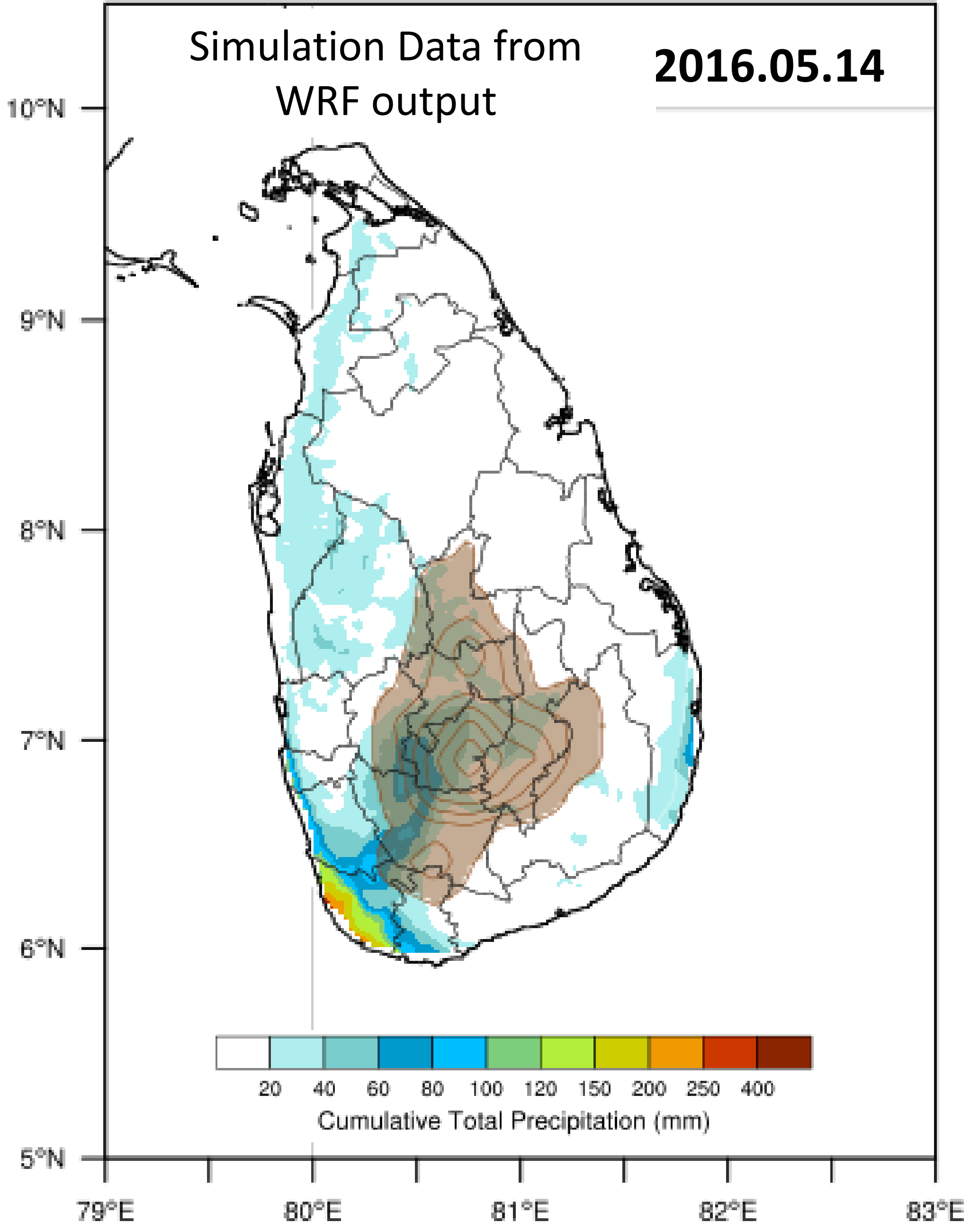




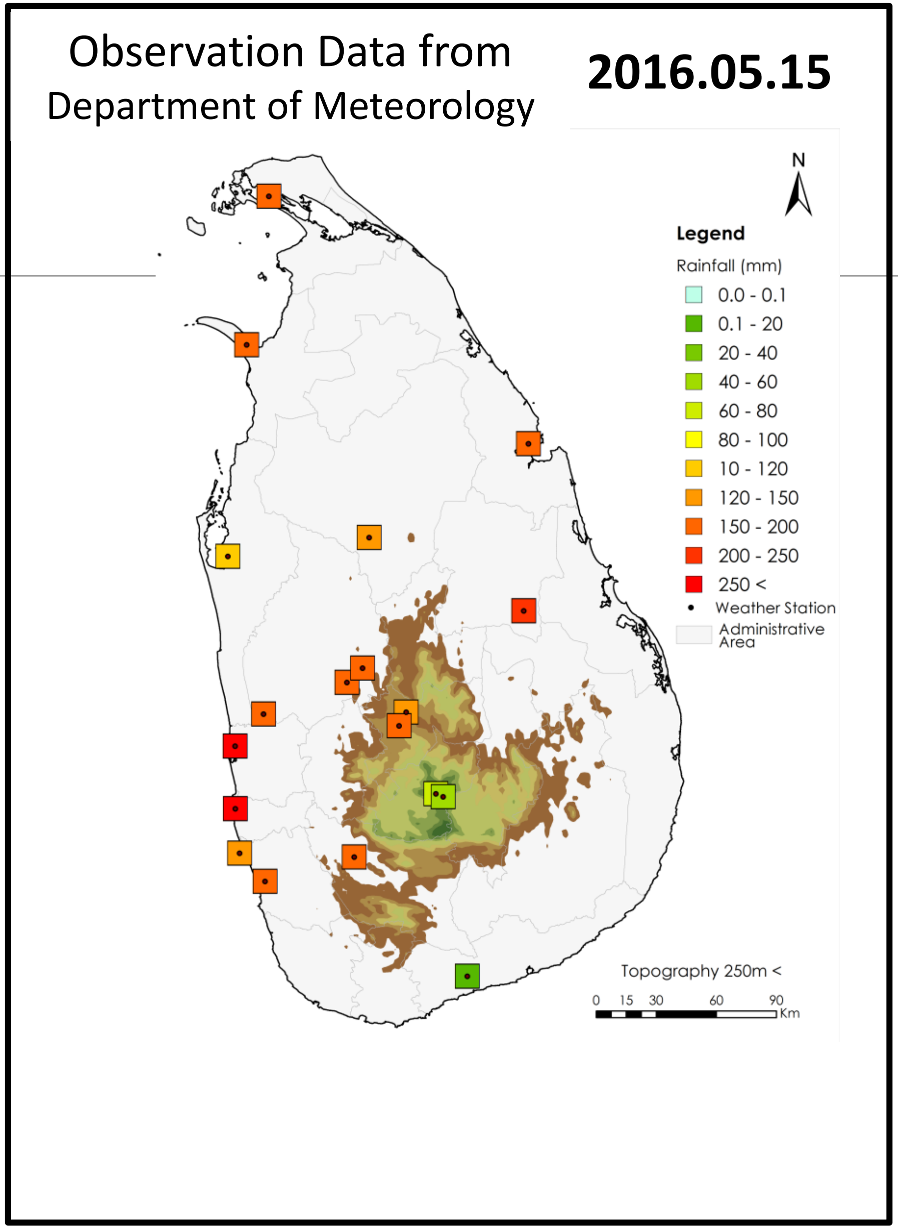
2016.05.17 : 1000

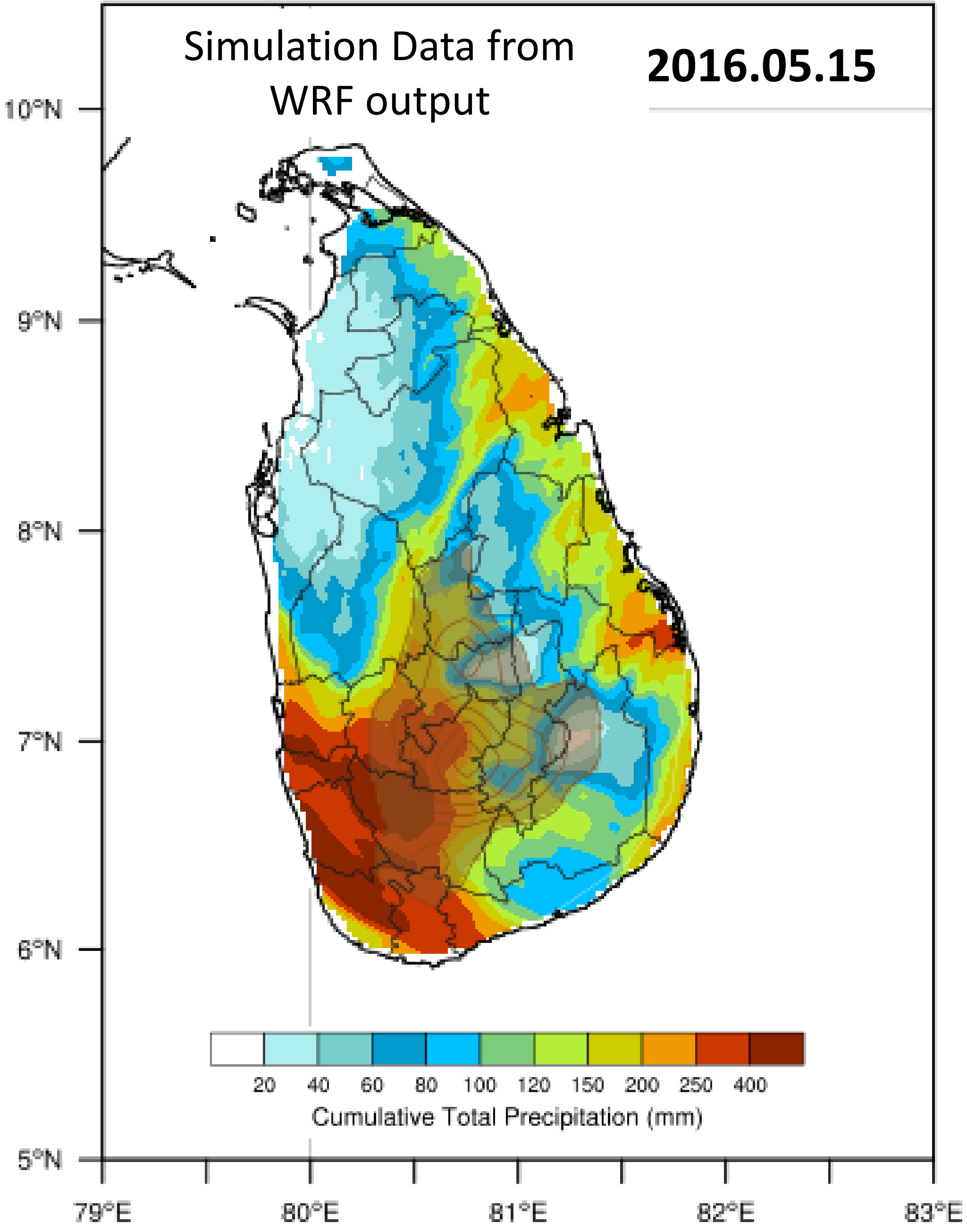
Rainfall comparison –
Ground Observational data Vs Model results



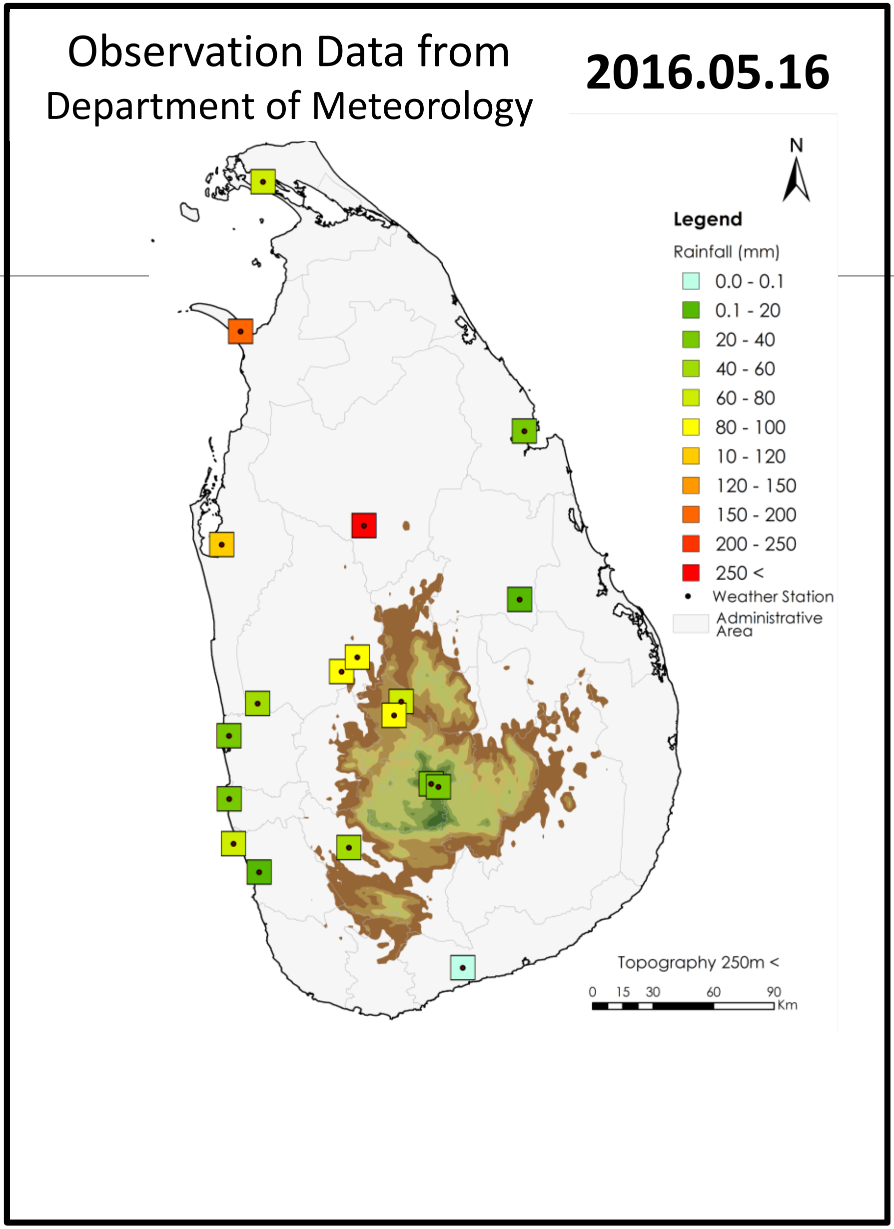


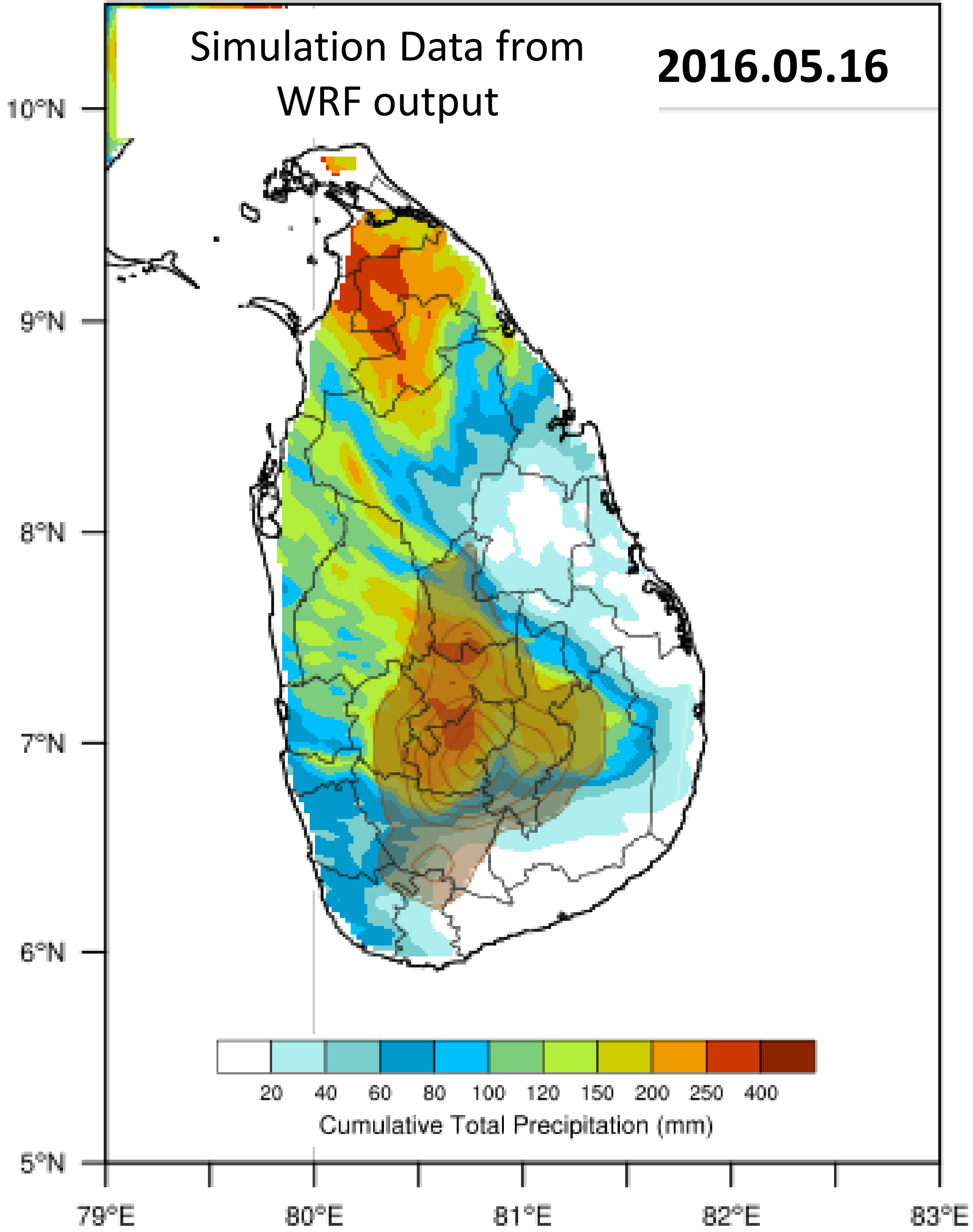
Daily Cumulative Rainfall – Observation Vs Model Results



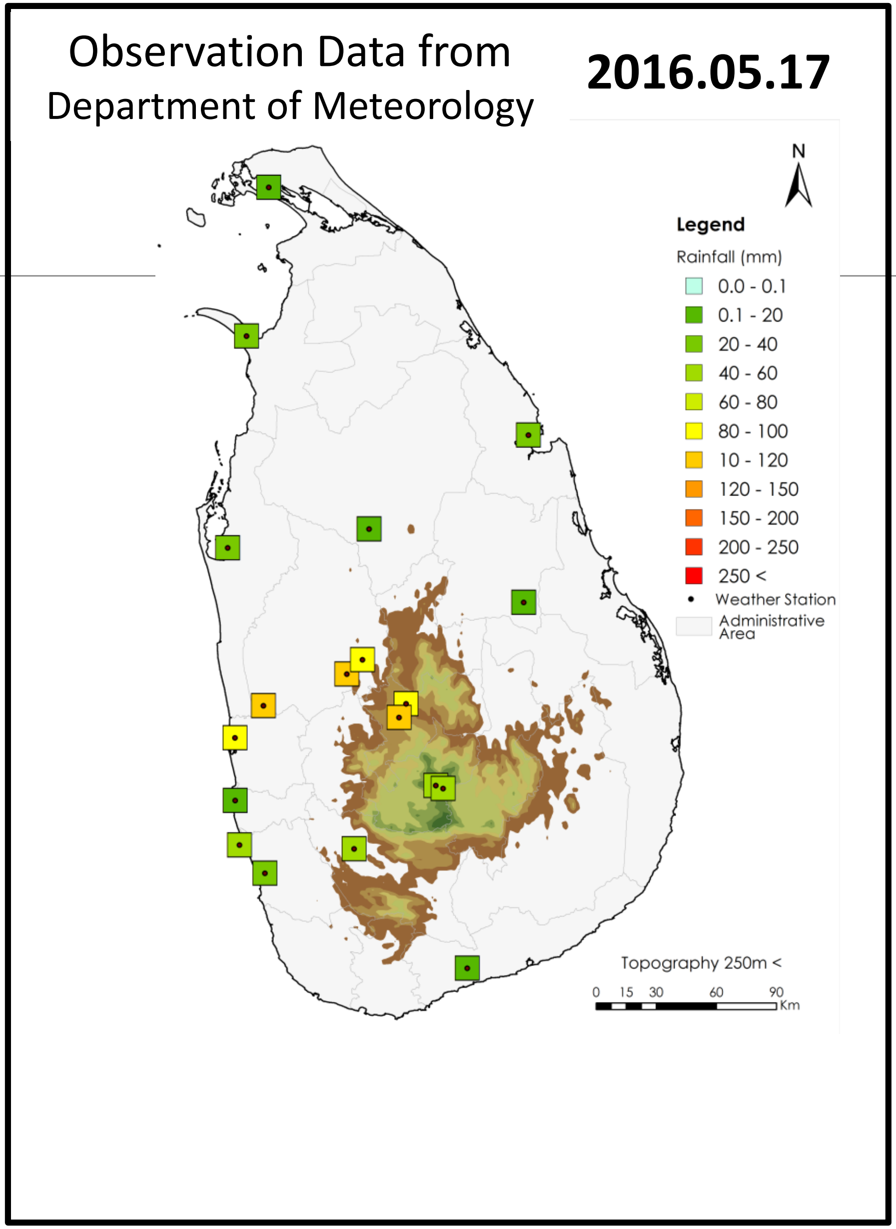


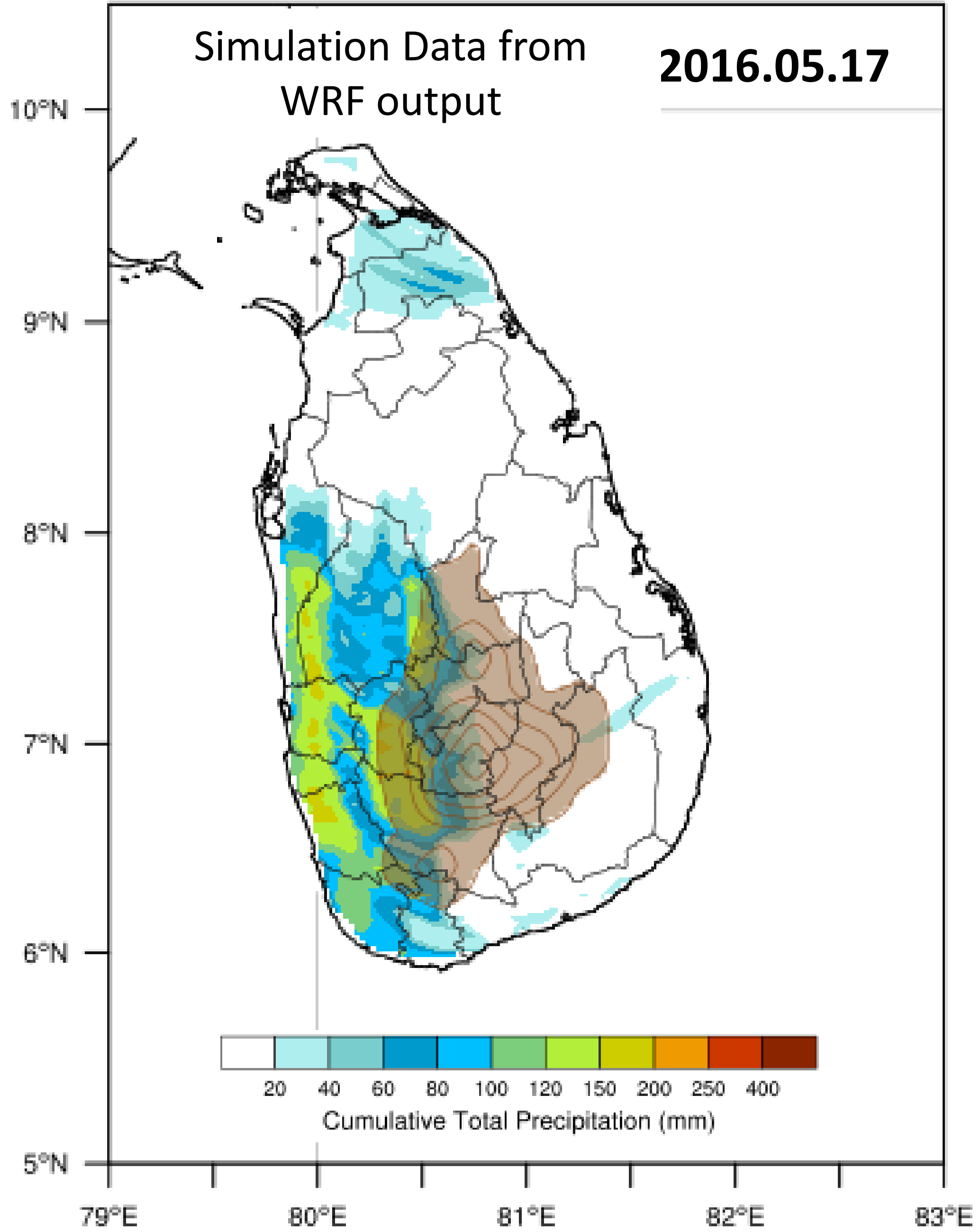
Daily Cumulative Rainfall – Observation Vs Model Results





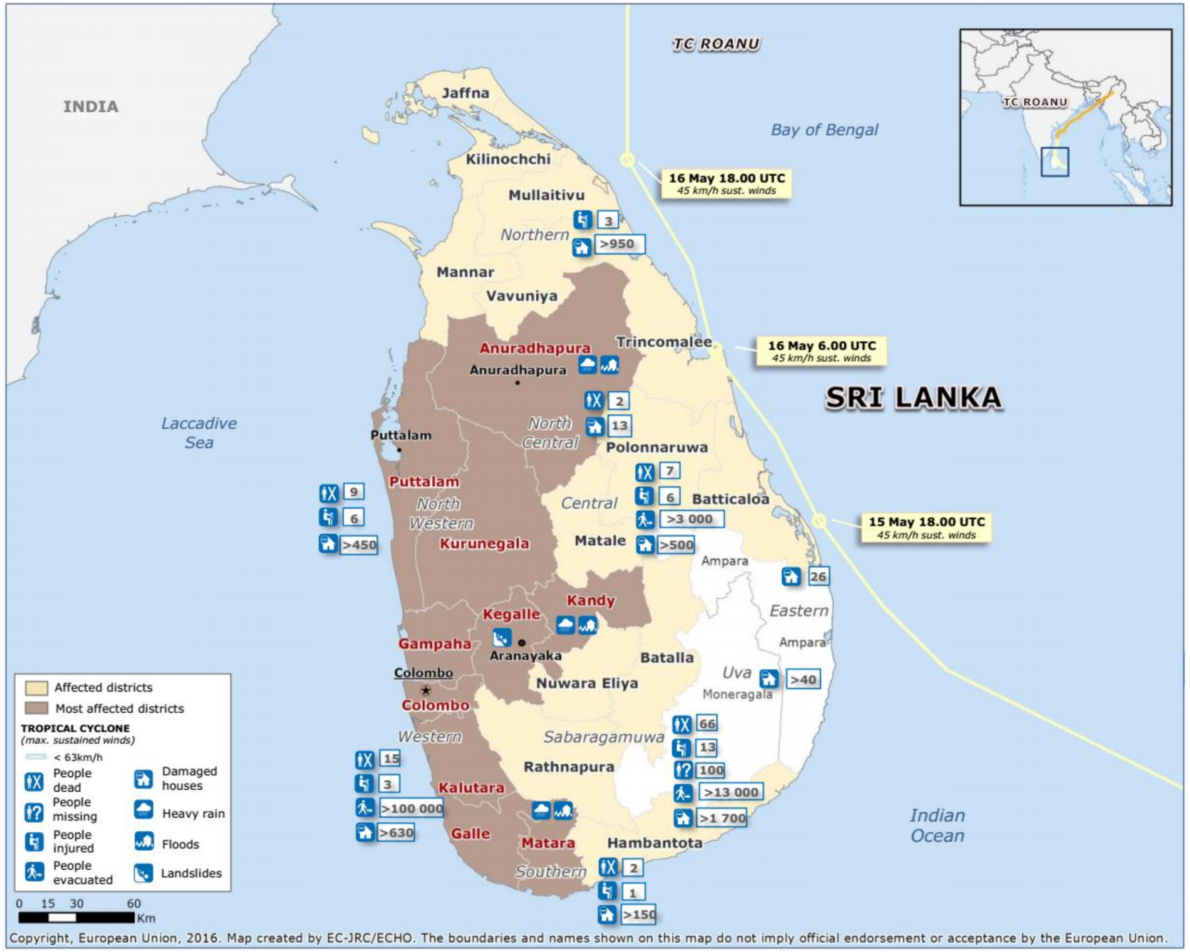
Daily Cumulative Rainfall – Observation Vs Model Results

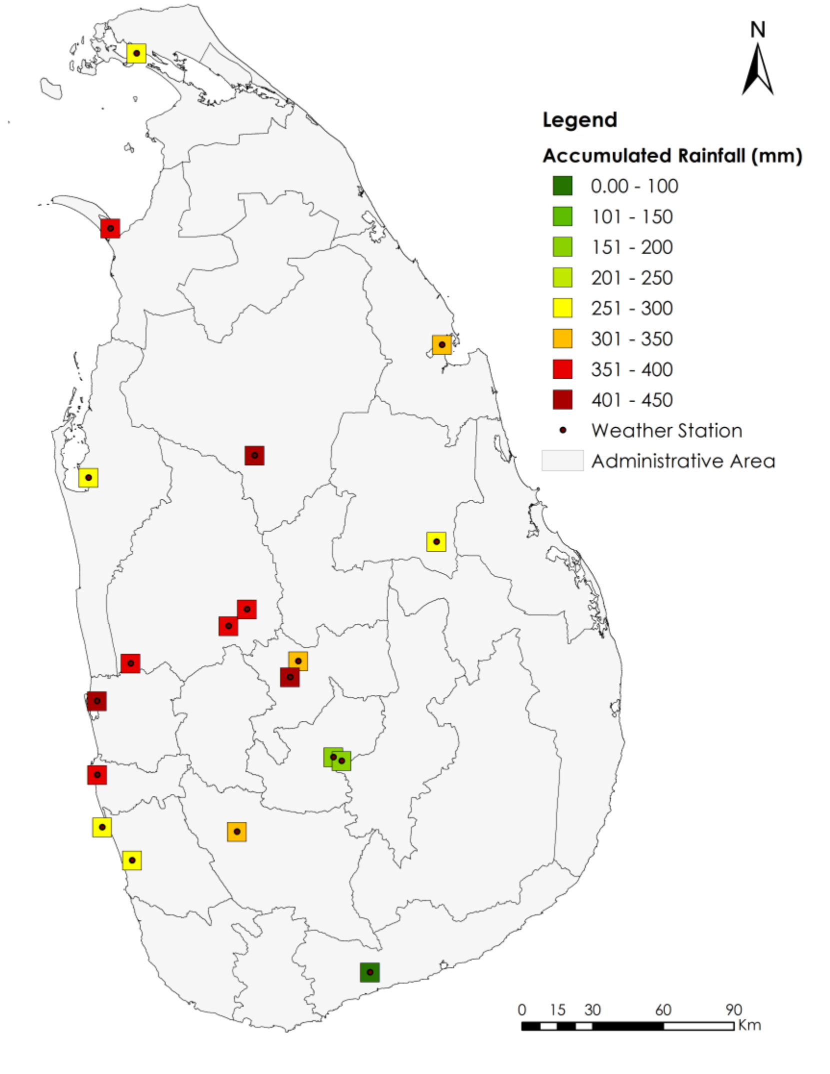




Daily Cumulative Rainfall – Observation Vs Model Results

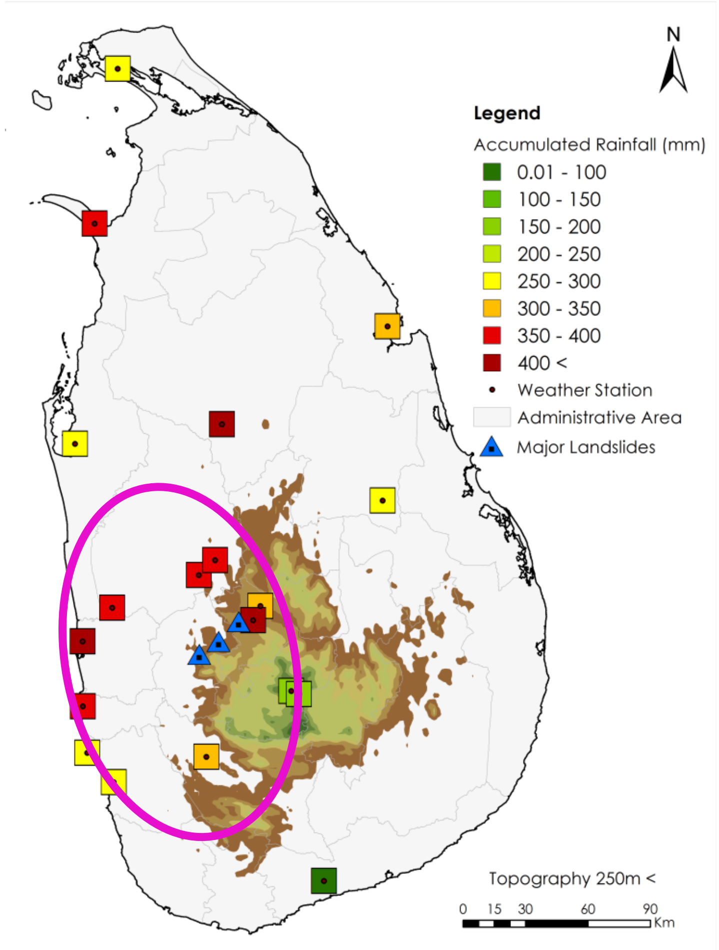
Why the heavy rainfall and flooding in western part of Sri Lanka?



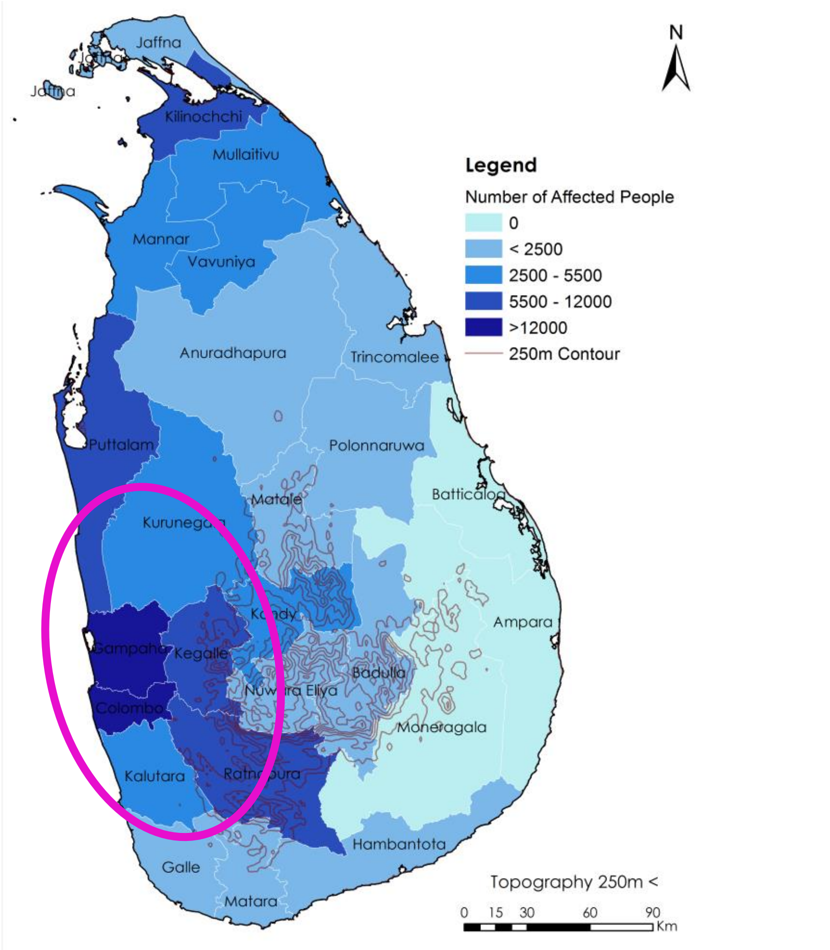


Observation (Weather Station Data) **2016.05.14 -17**

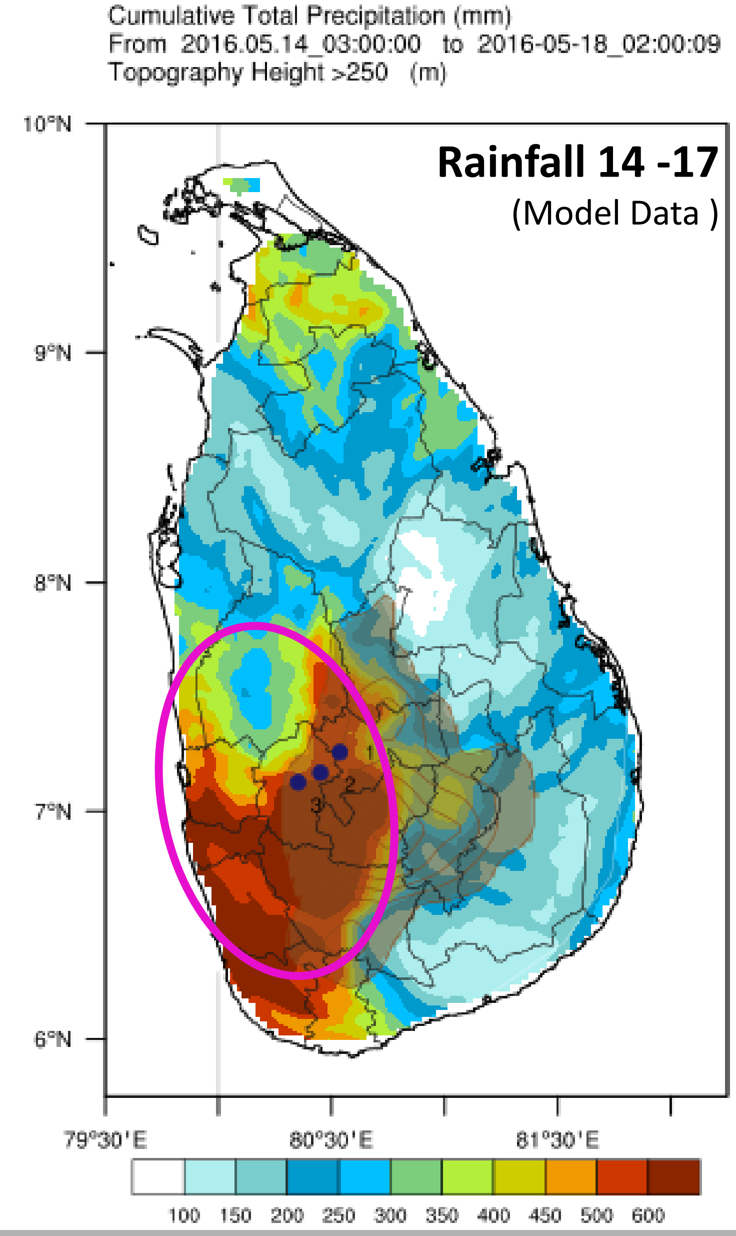
Why the heavy rainfall and flooding in western part of Sri Lanka?



Source: Department of Meteorology

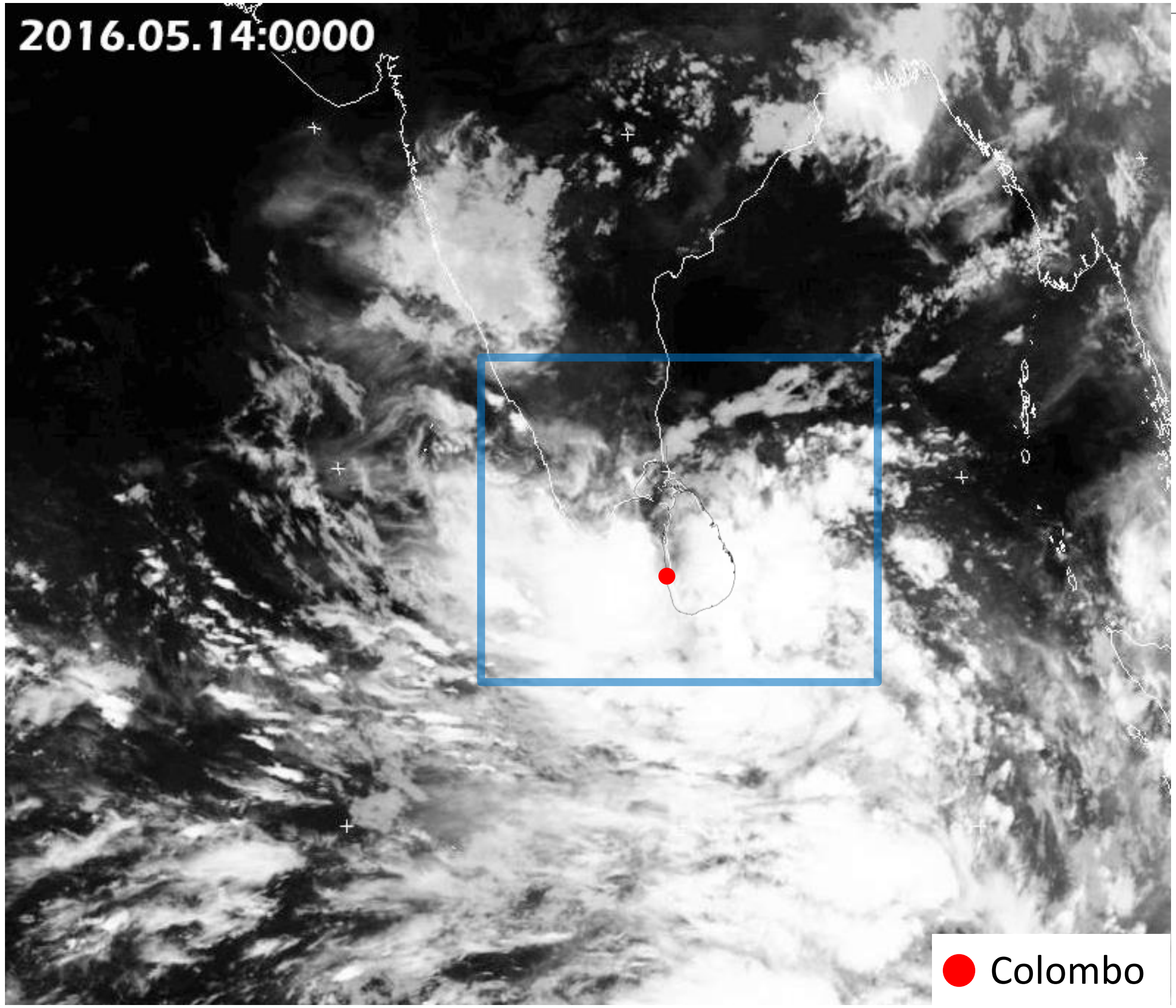


Source: Disaster Management Center (DMC)

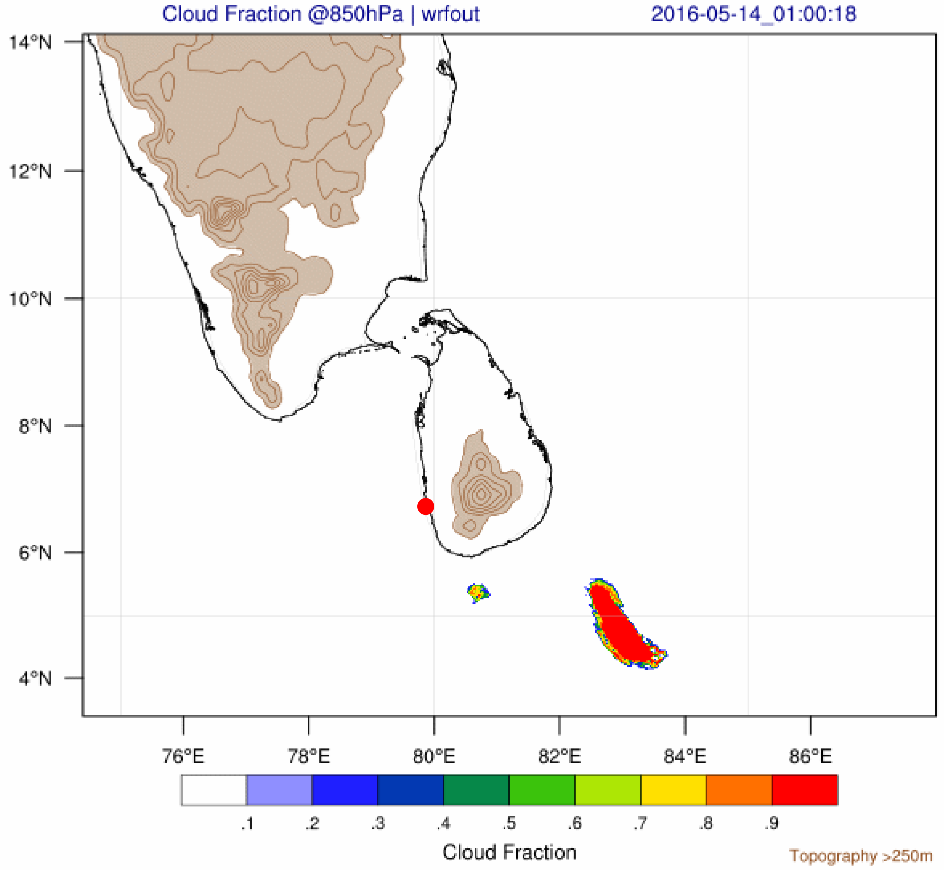


Rainfall 14 -17 (Weather Station Data) **No of Affected People as of 2016.05.22**

Low Pressure System Development

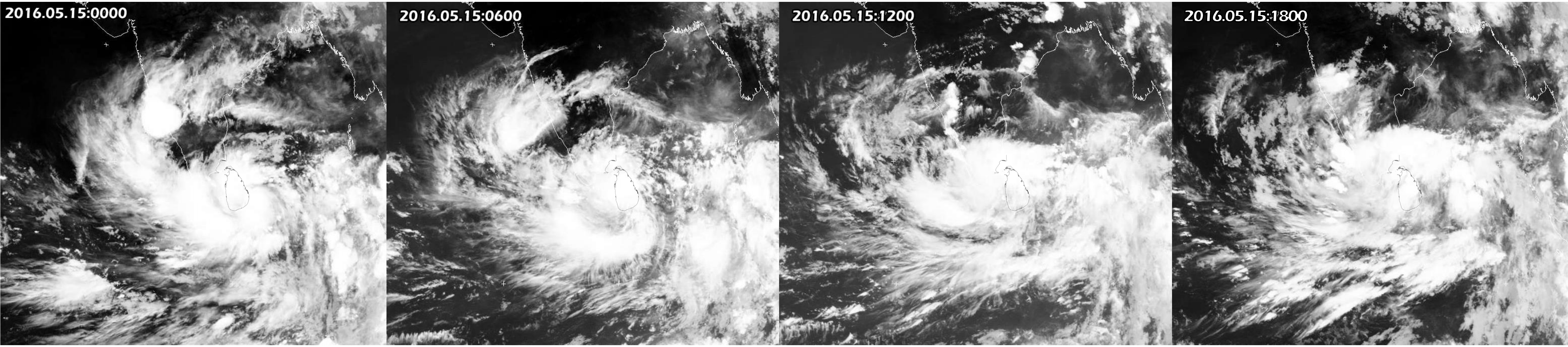


Thermal Infrared Satellite Images
Meteosat VISSR Indian Ocean Data Coverage (IODC)
Dundee Satellite Receiving Station, UK

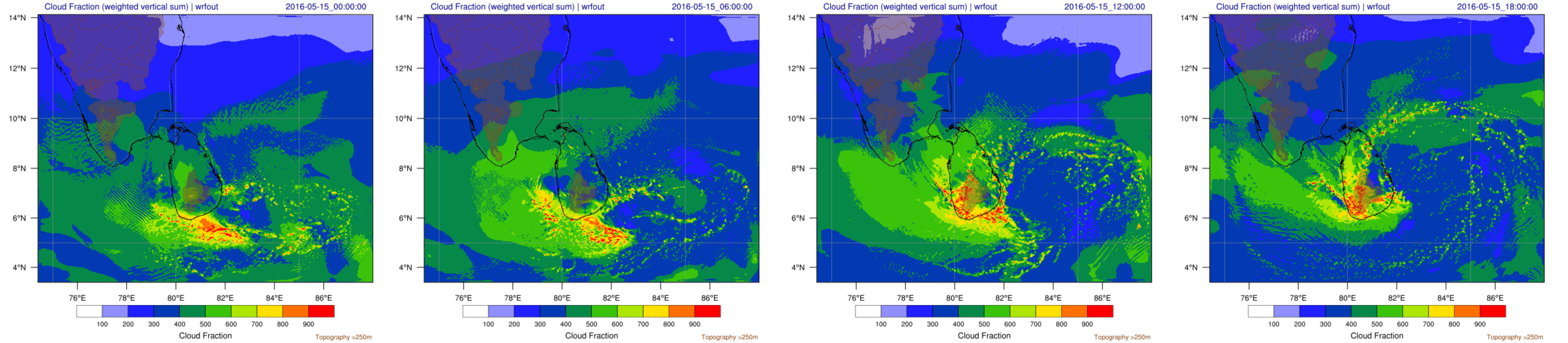


WRF Results
Precipitation and 10m wind vectors

Cloud Image – TIR Satellite Images

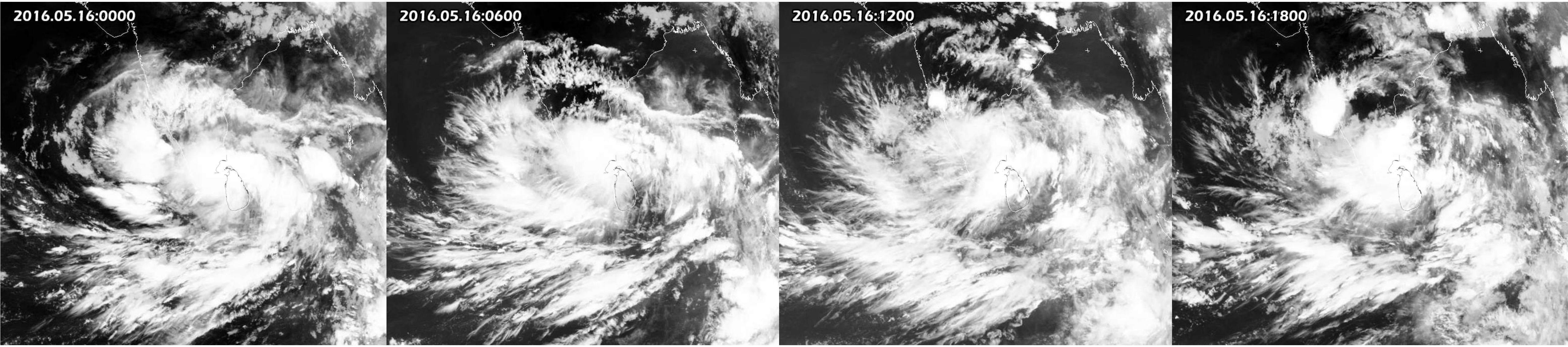


Model Results / wrfout

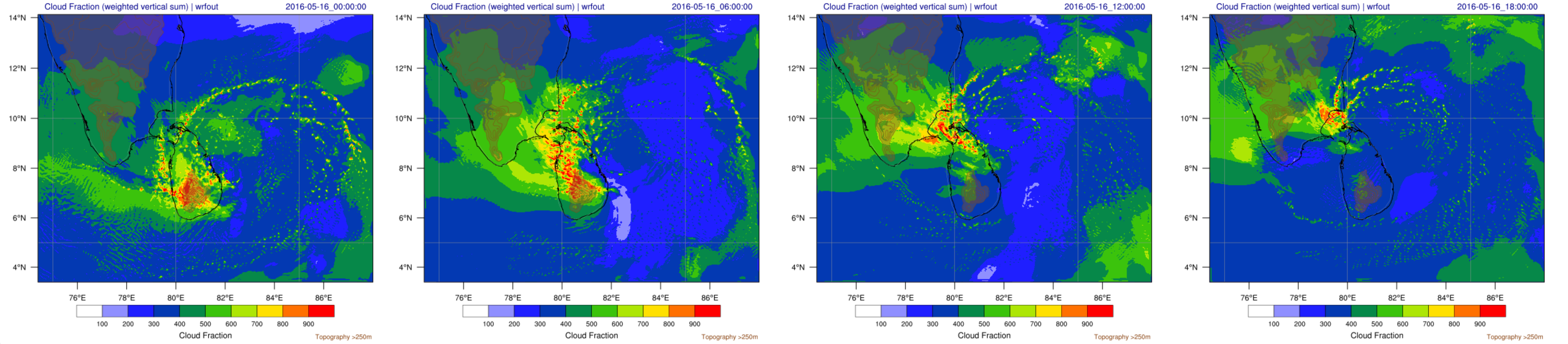


Cloud Image (Satellite) and Cloud Fractions (weighted vertical column sum) (WRF)– 1hourly

Met_em Data / NCEP_CFSv2

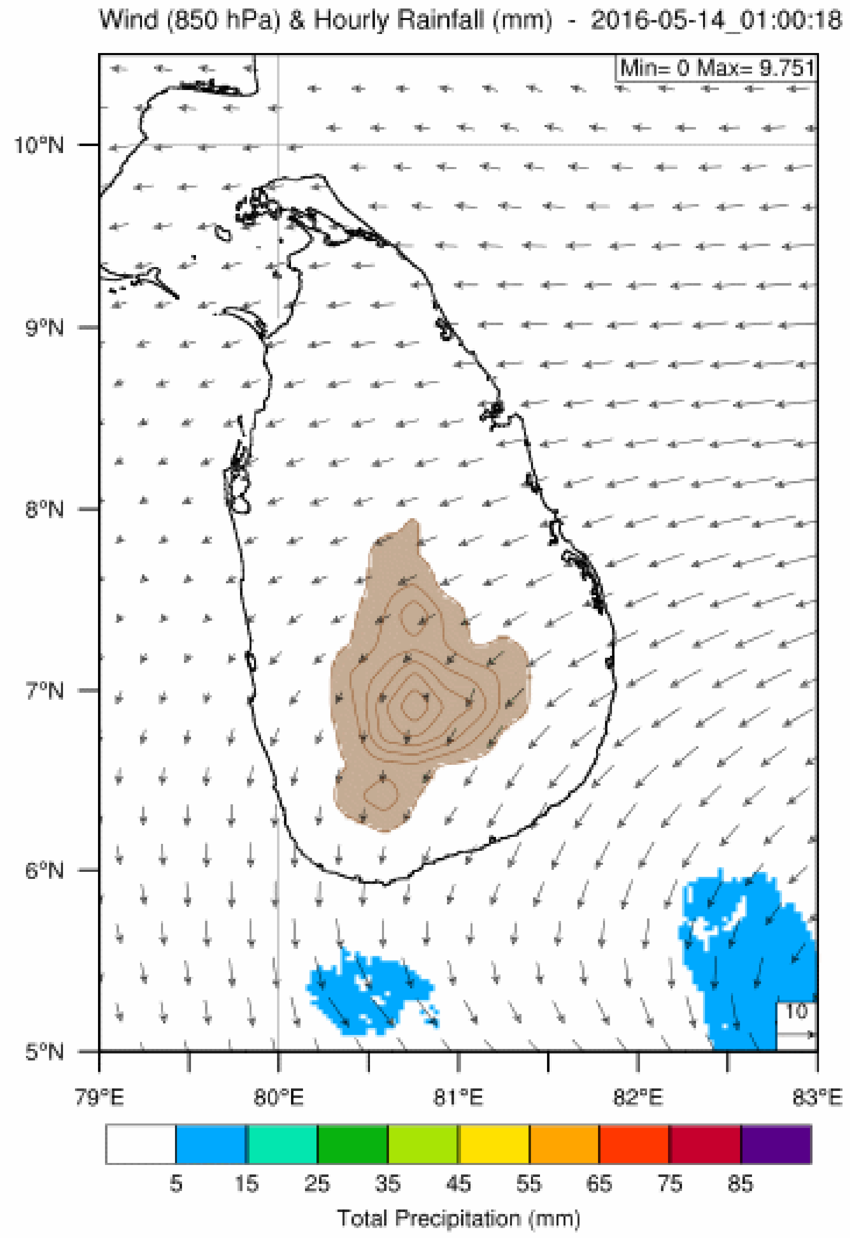


Model Results / wrfout

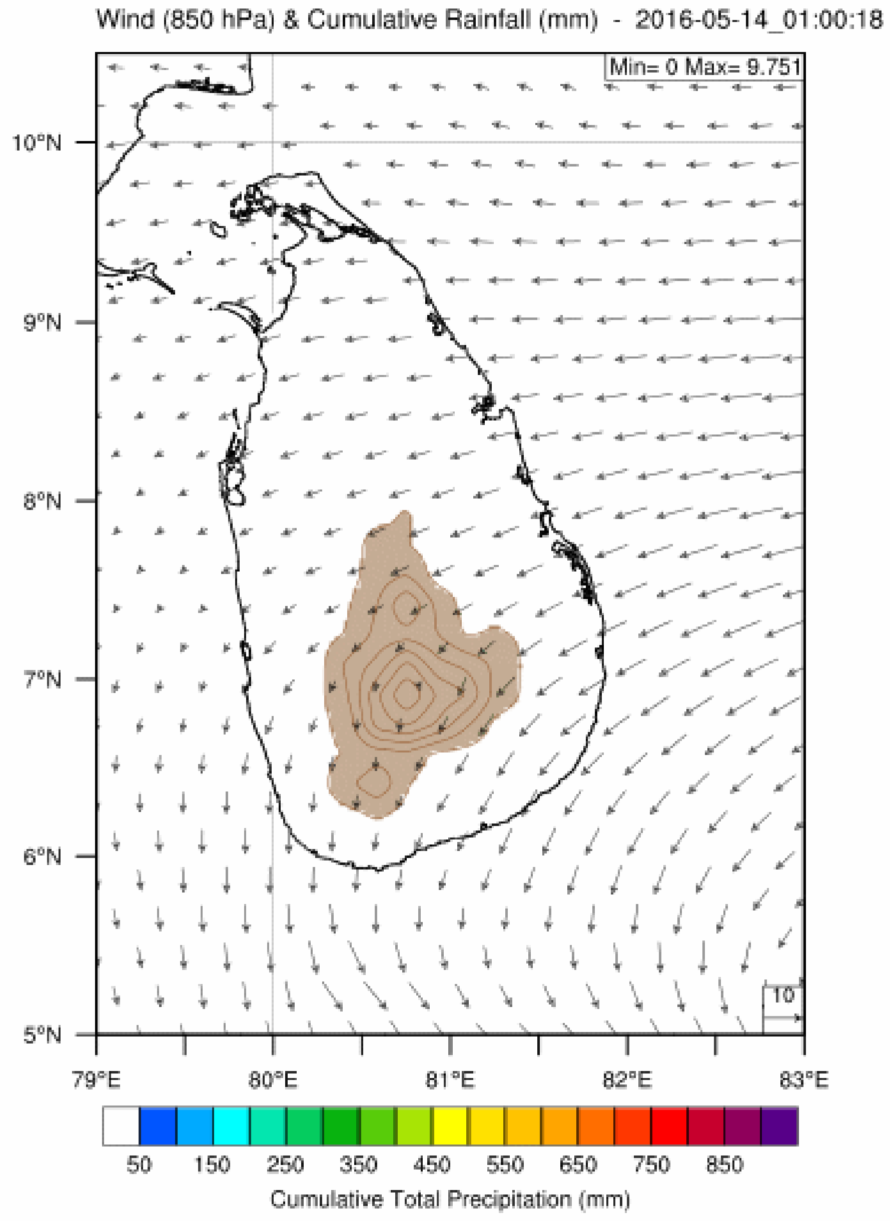


Cloud Image (Satellite) and Cloud Fractions (weighted vertical column sum) (WRF)– 1hourly

Hourly Rainfall (mm)

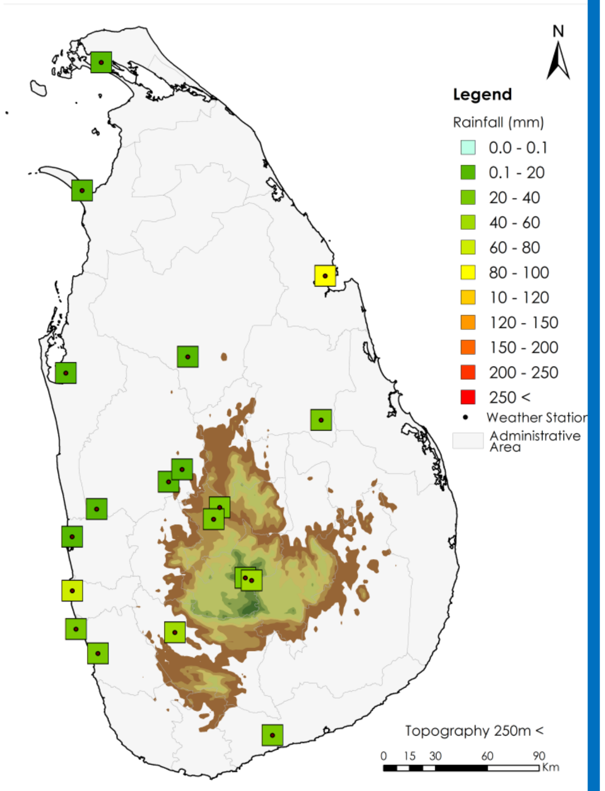


Cumulative Rainfall (mm)

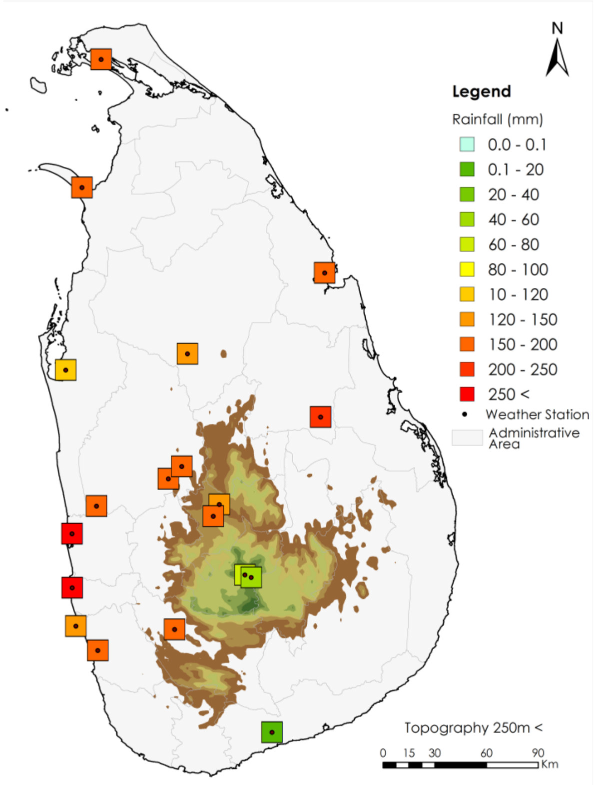


from 2016.05.14:0000 to 2016.05.16:2300

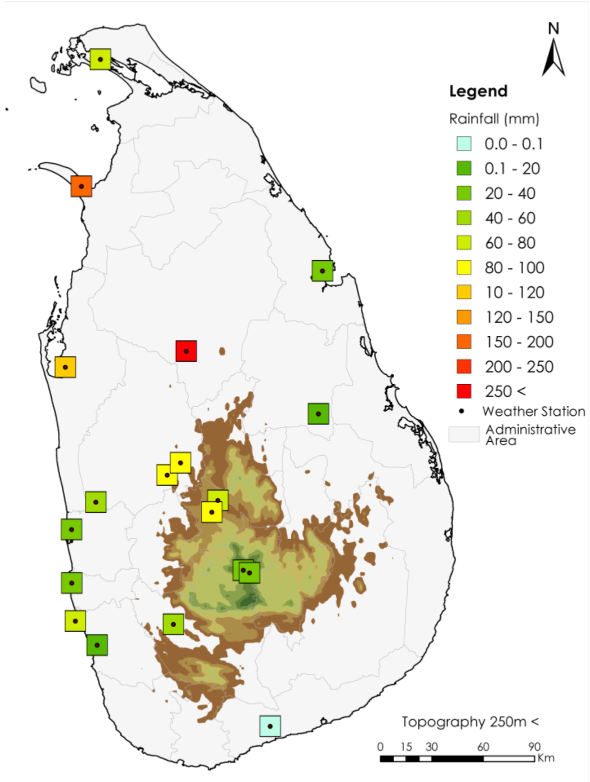
Why May 15th & 16th received the maximum rainfall over western part of Sri Lanka?



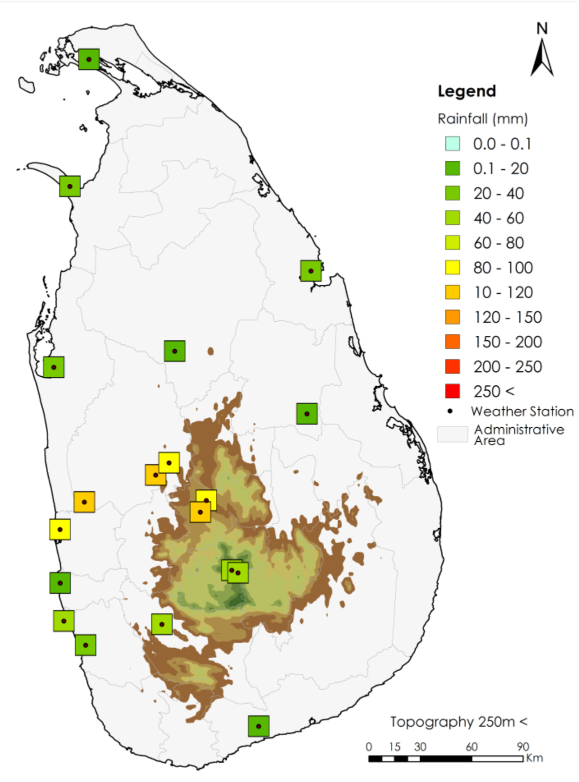
2016.05.14



2016.05.15

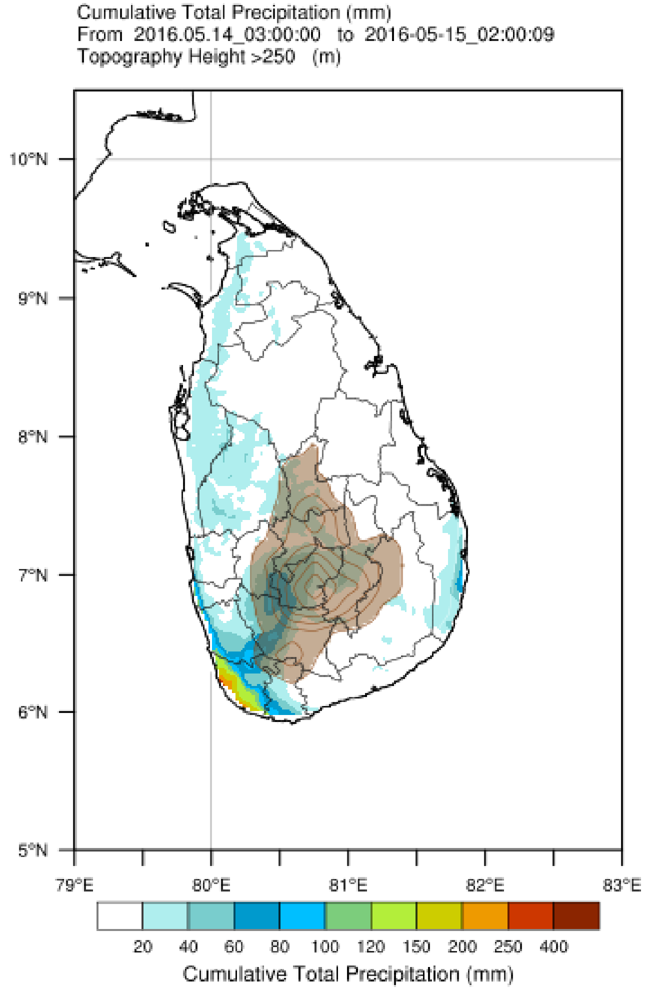


2016.05.16

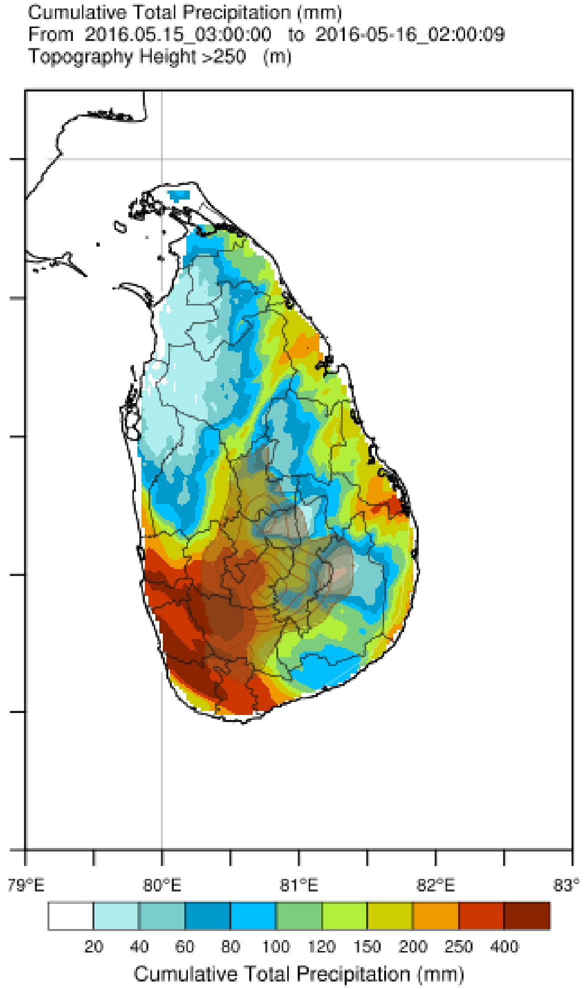


2016.05.17

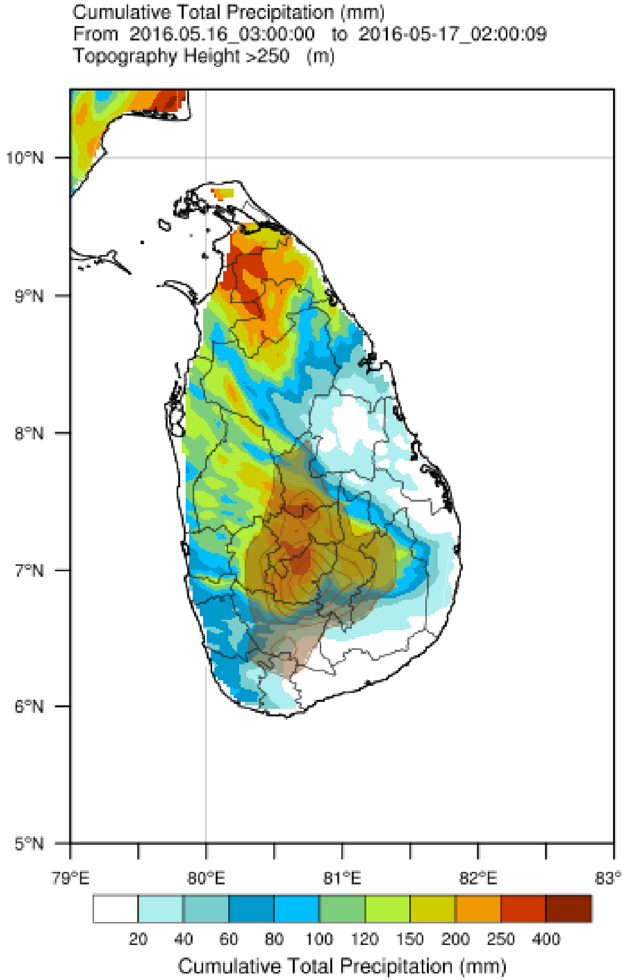
Why May 15th & 16th received the maximum rainfall over western part of Sri Lanka?



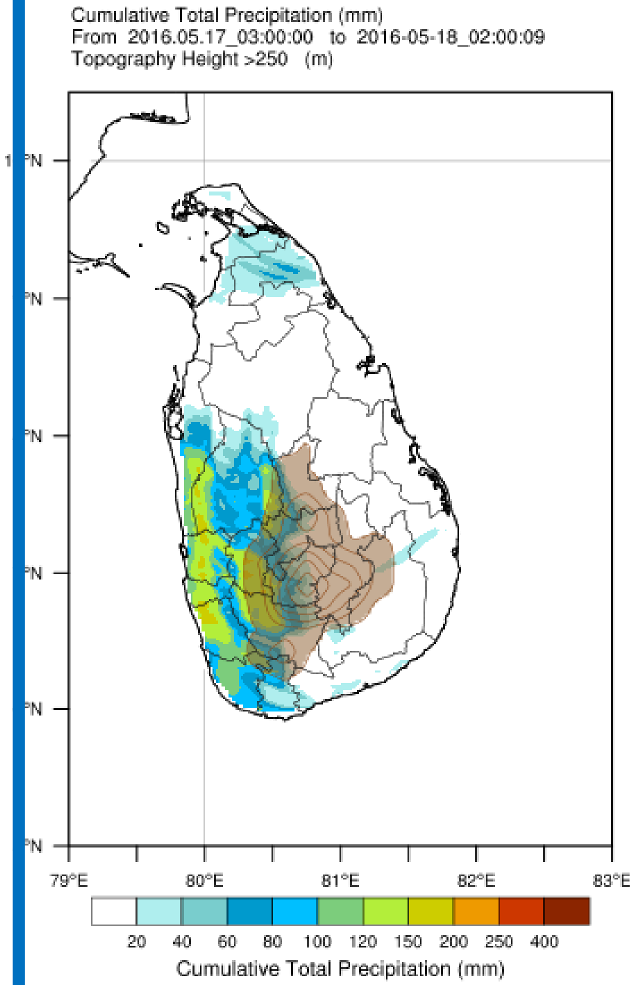
2016.05.14



2016.05.15

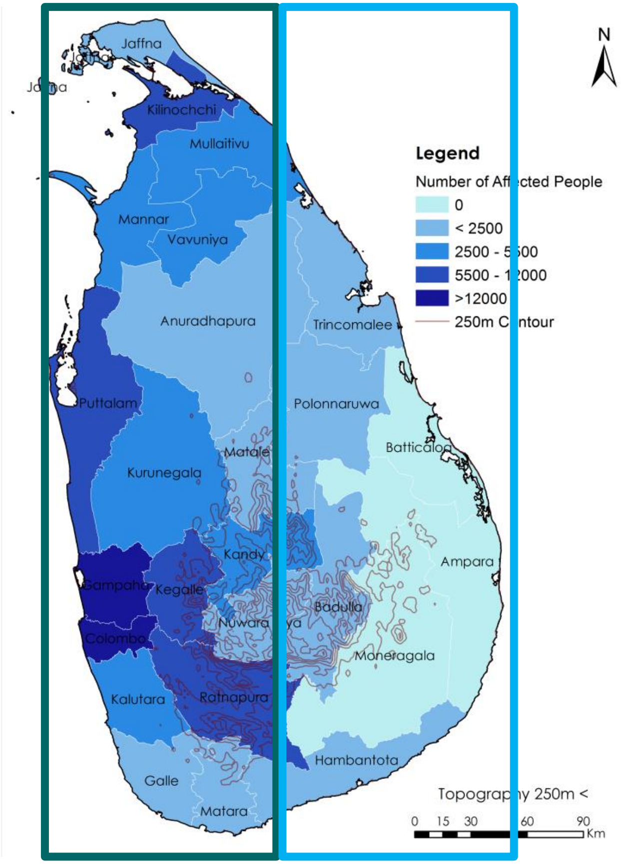


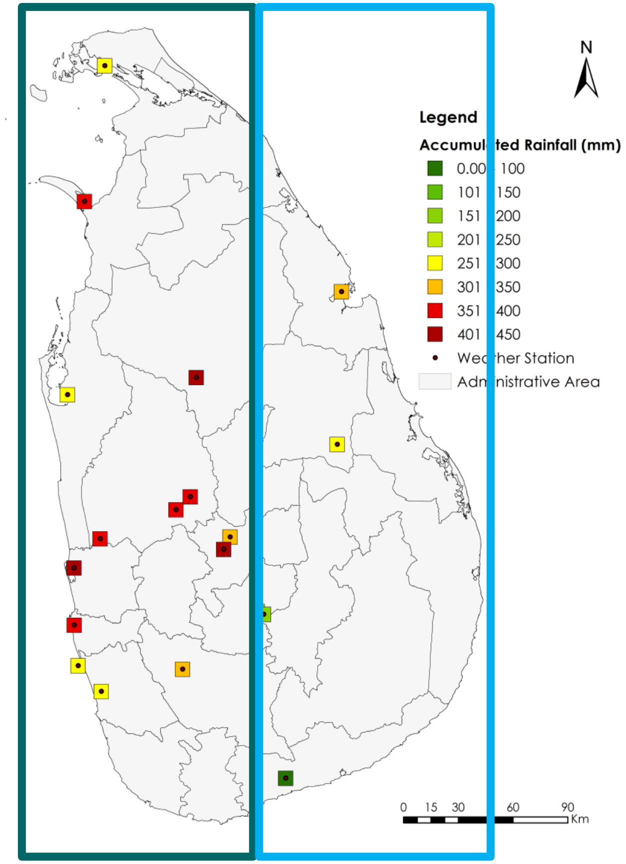
2016.05.16



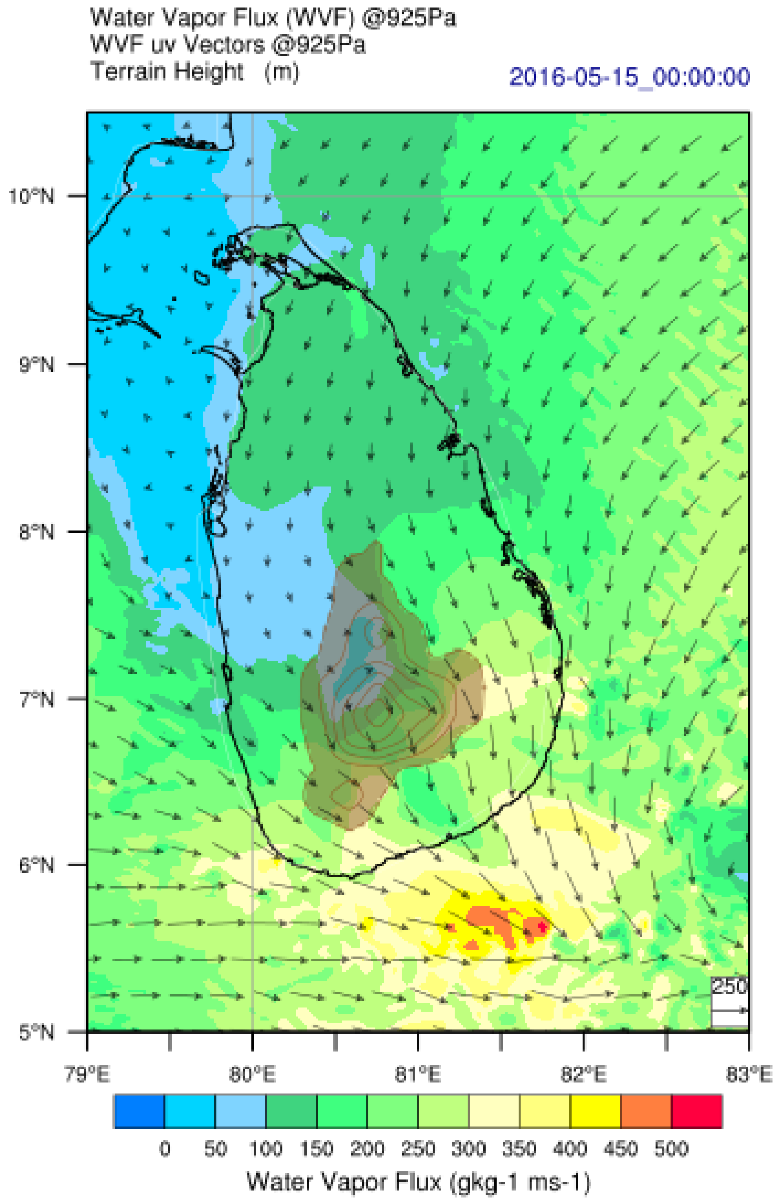
2016.05.17

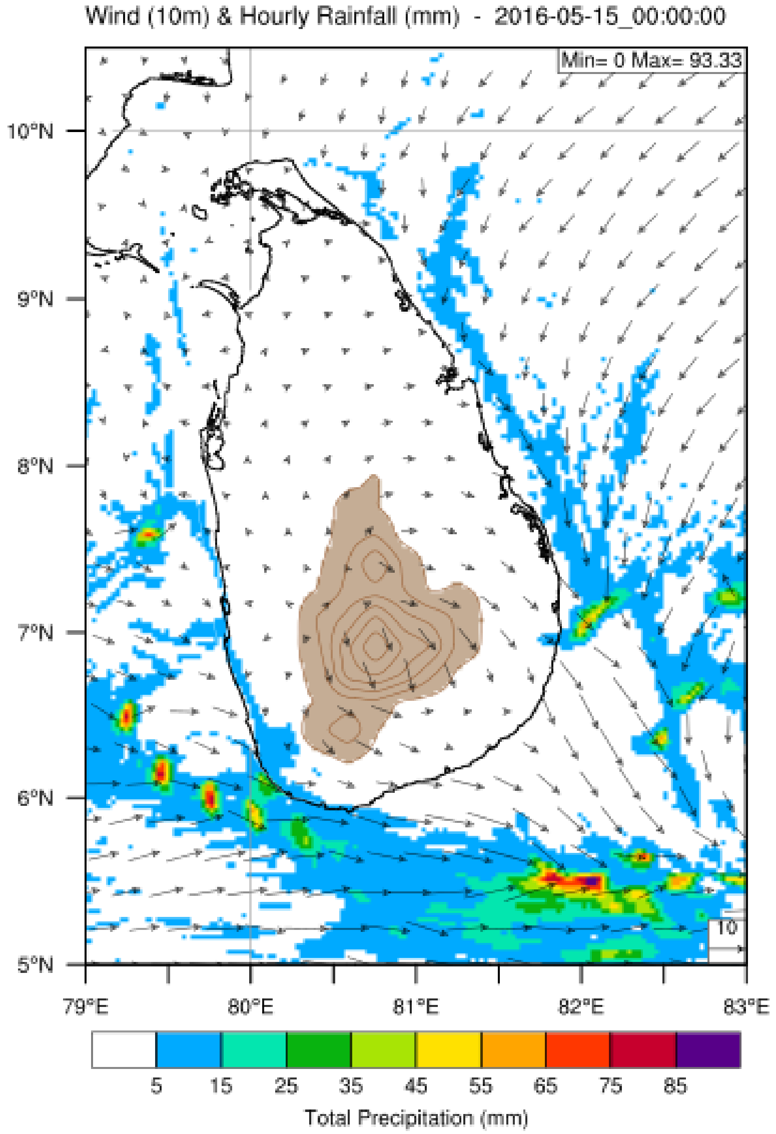
Why only western part of Sri Lanka received relatively maximum rainfall and why not the eastern part of Sri Lanka?





2016.05.15 : 0000

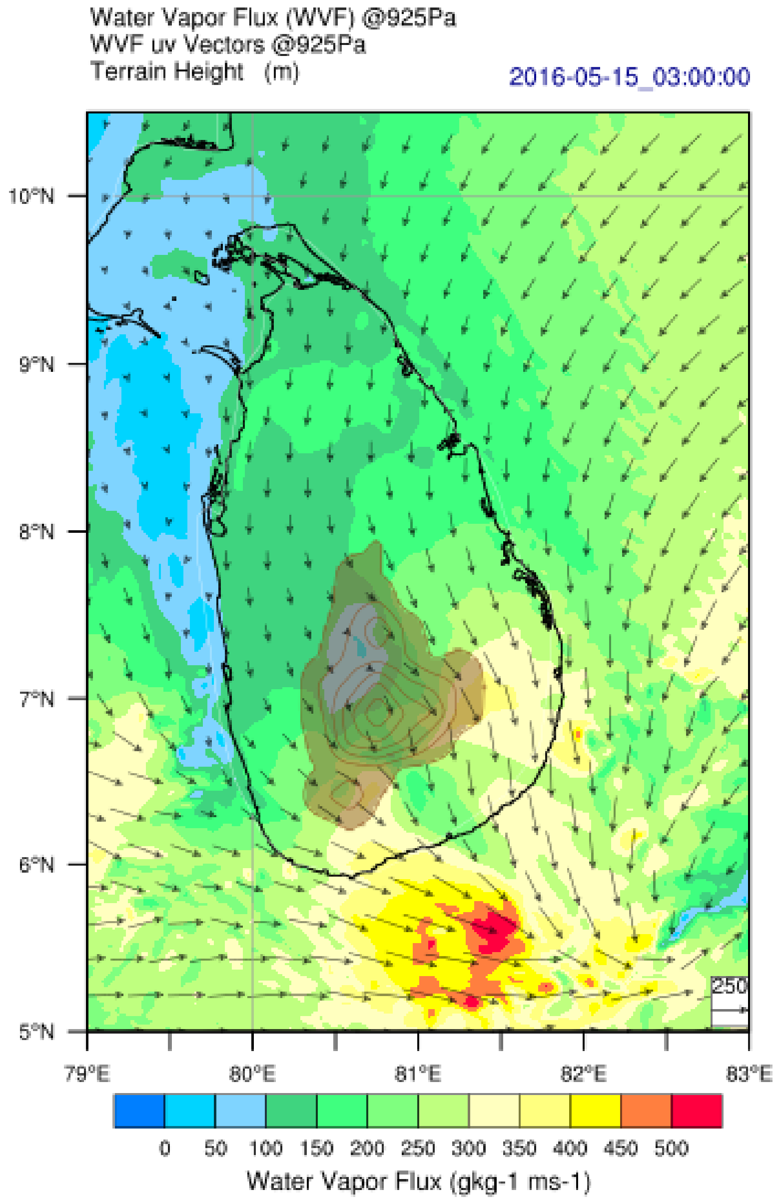


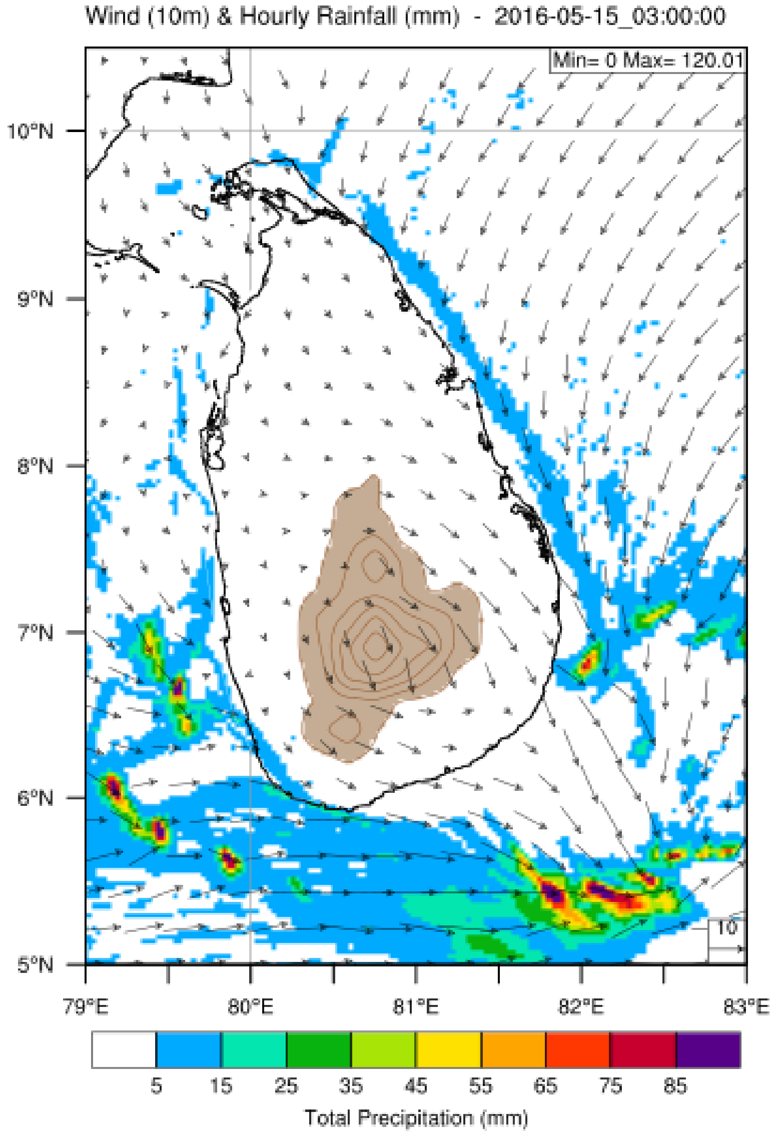


Water Vapor Flux

Total Rainfall

2016.05.15 : 0300

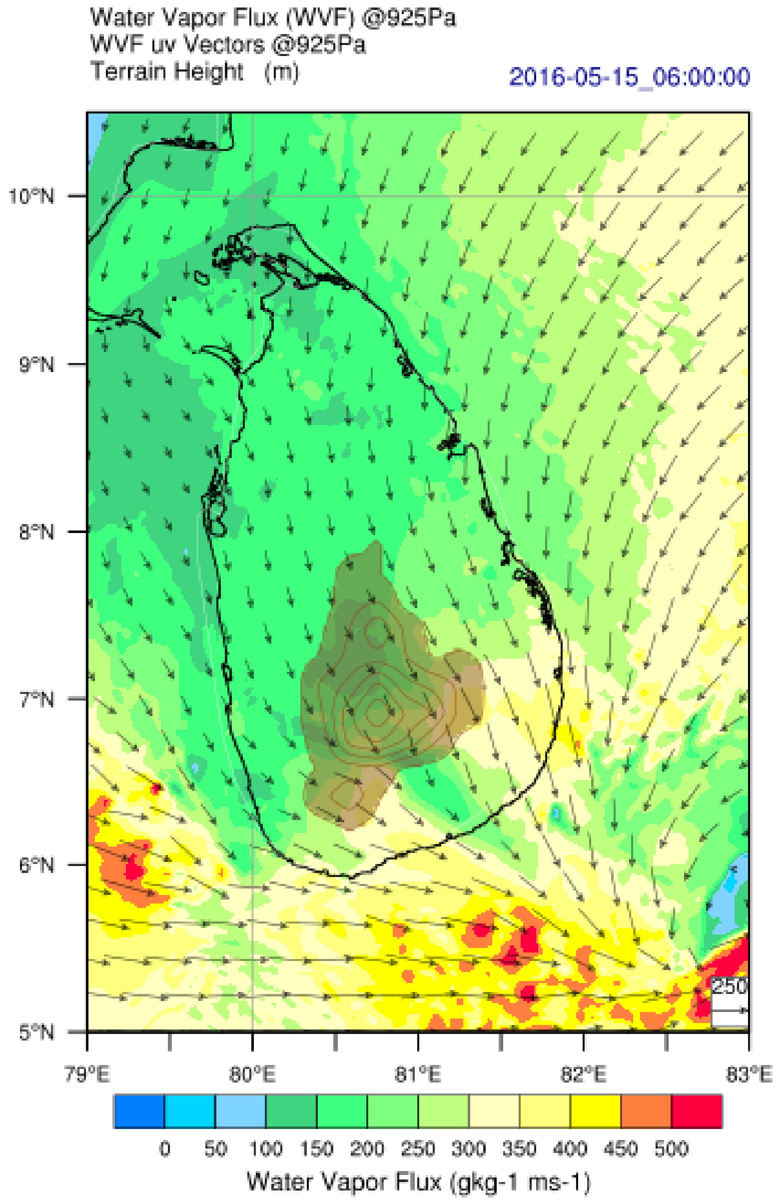




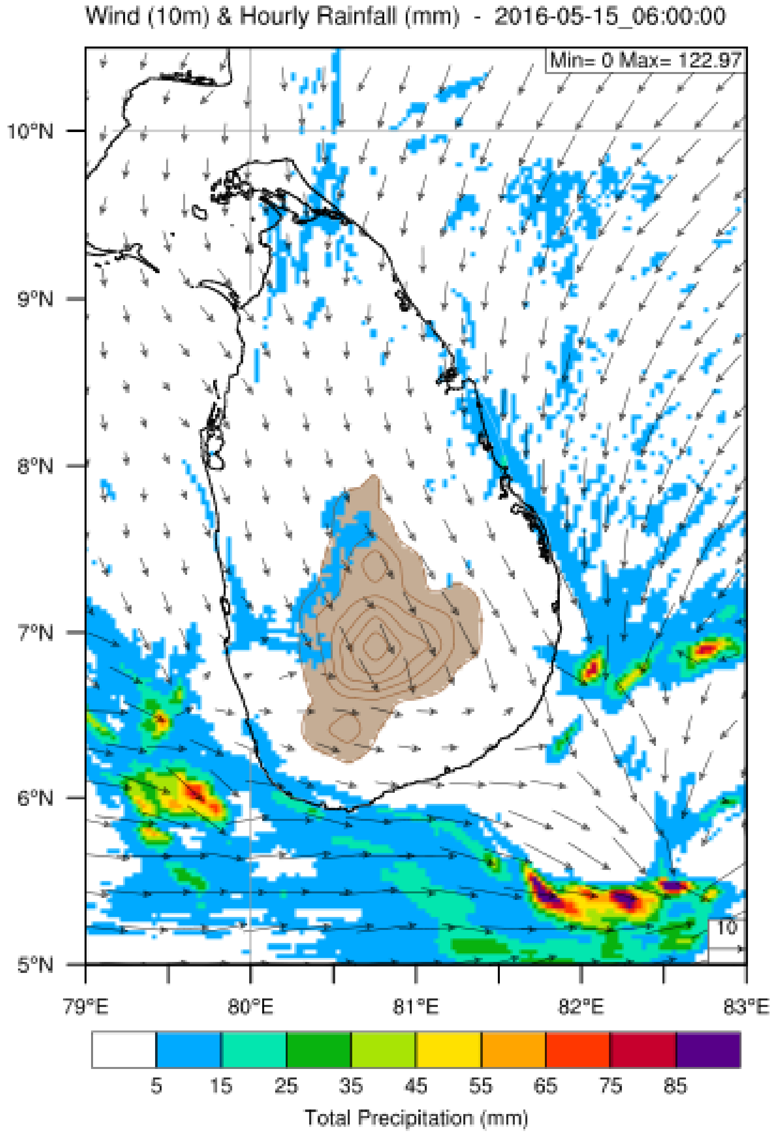
Water Vapor Flux

Total Rainfall

2016.05.15 : 0600

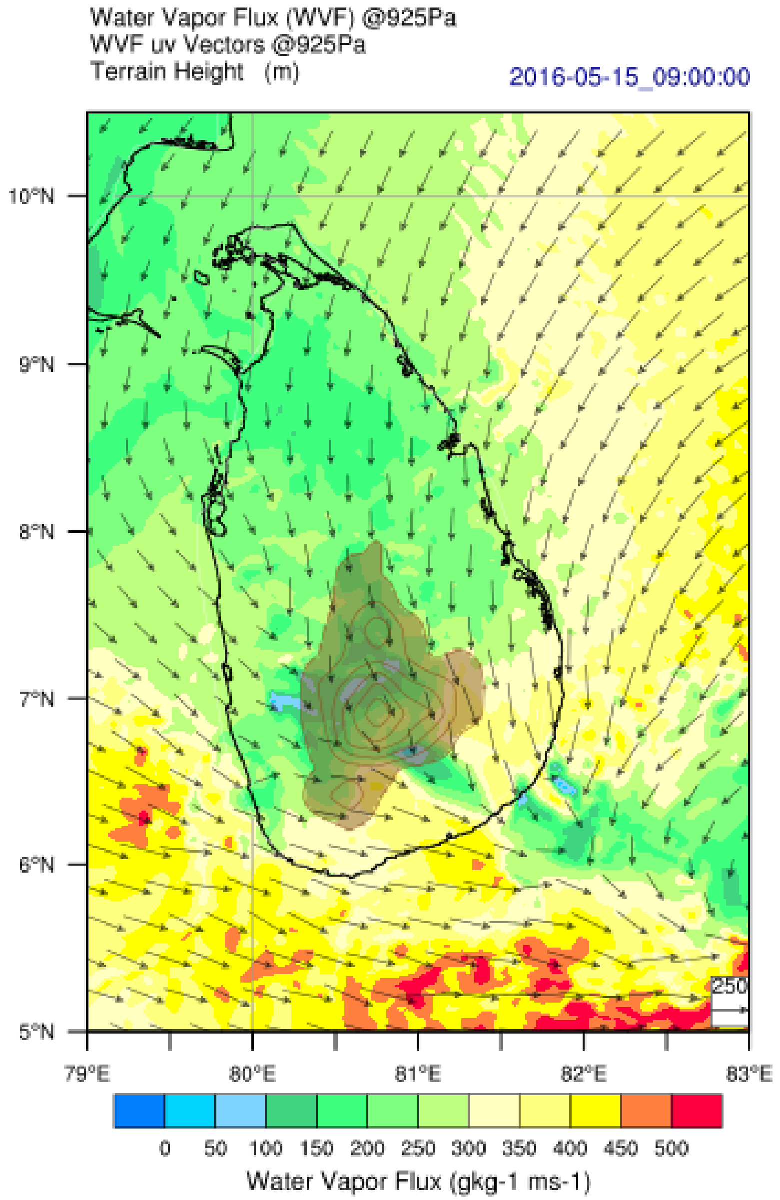


Water Vapor Flux

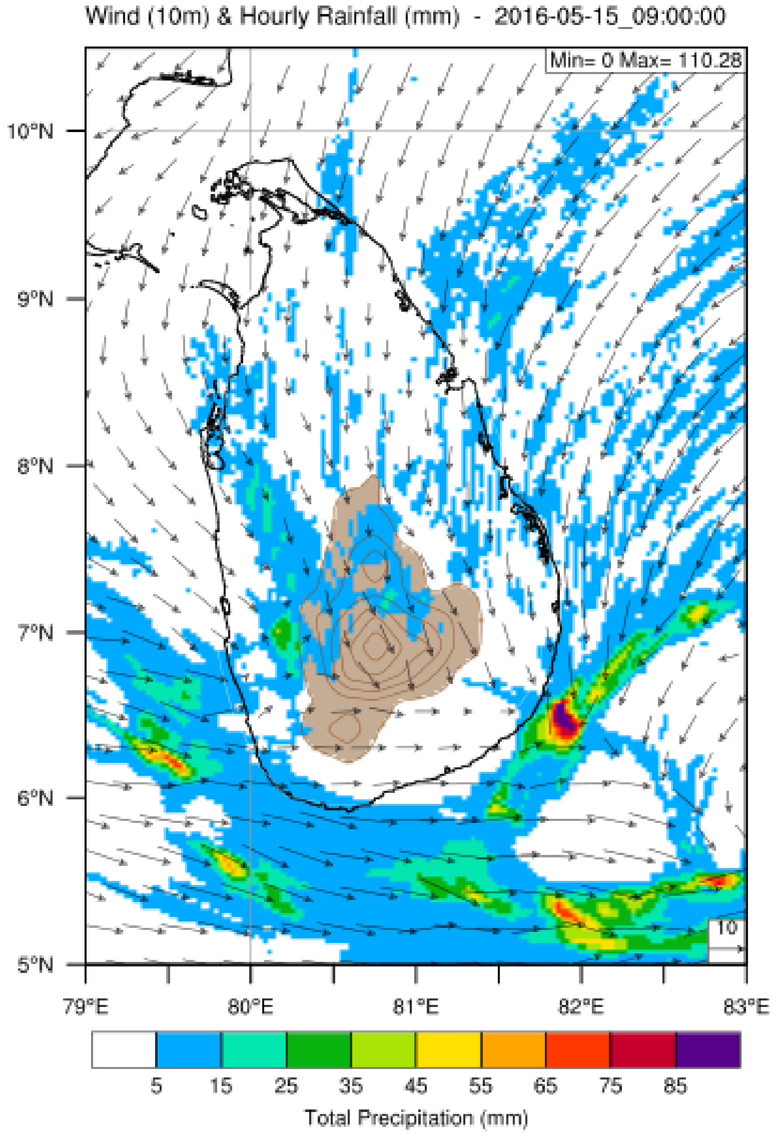


Total Rainfall

2016.05.15 : 0900

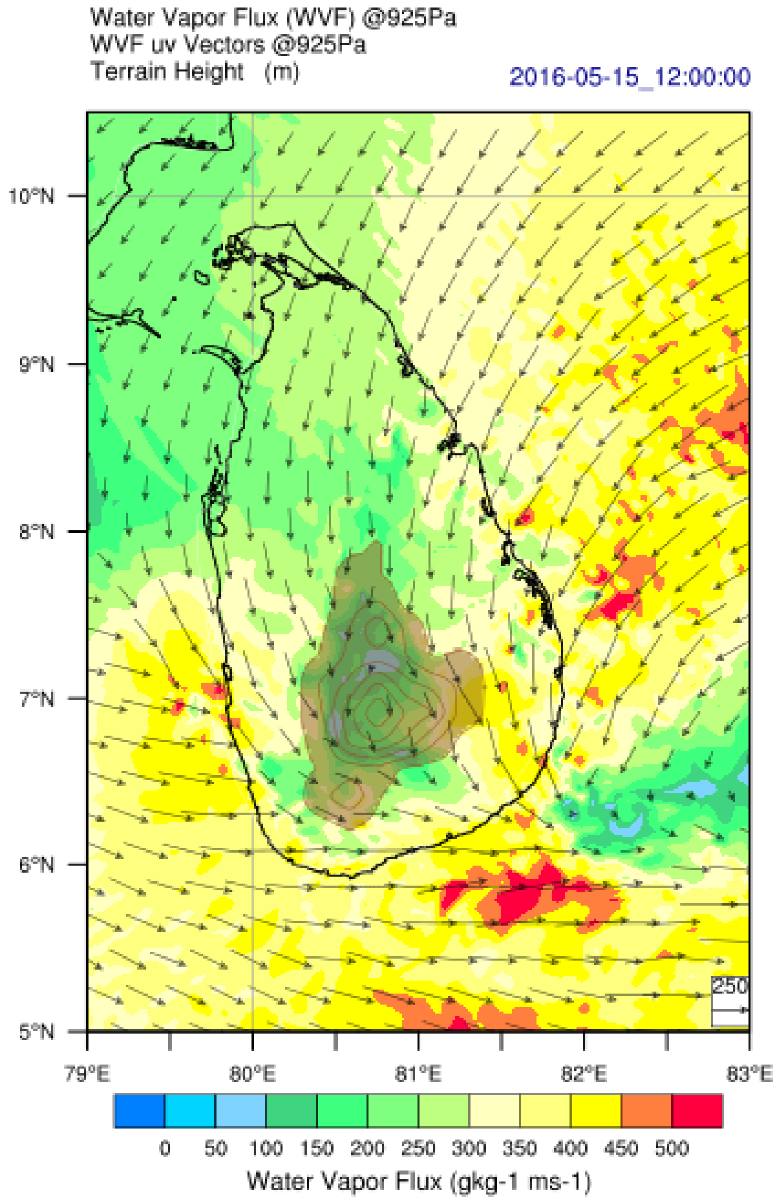


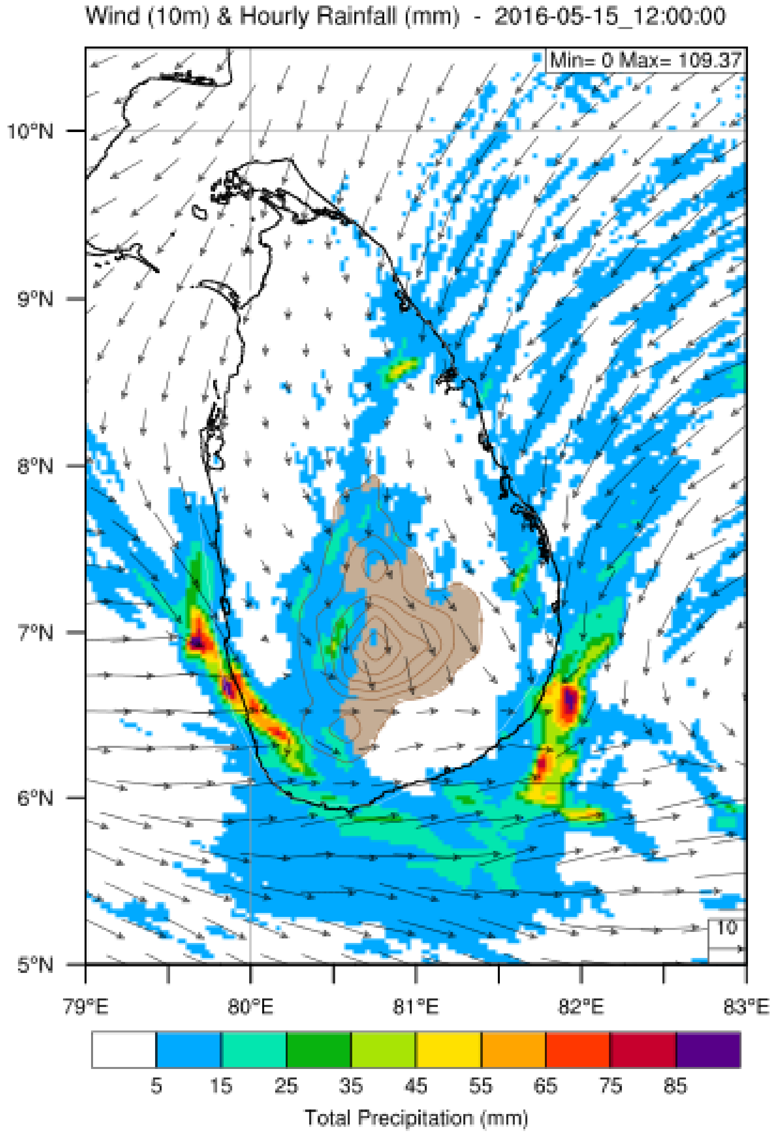
Water Vapor Flux



Total Rainfall

2016.05.15 : 1200

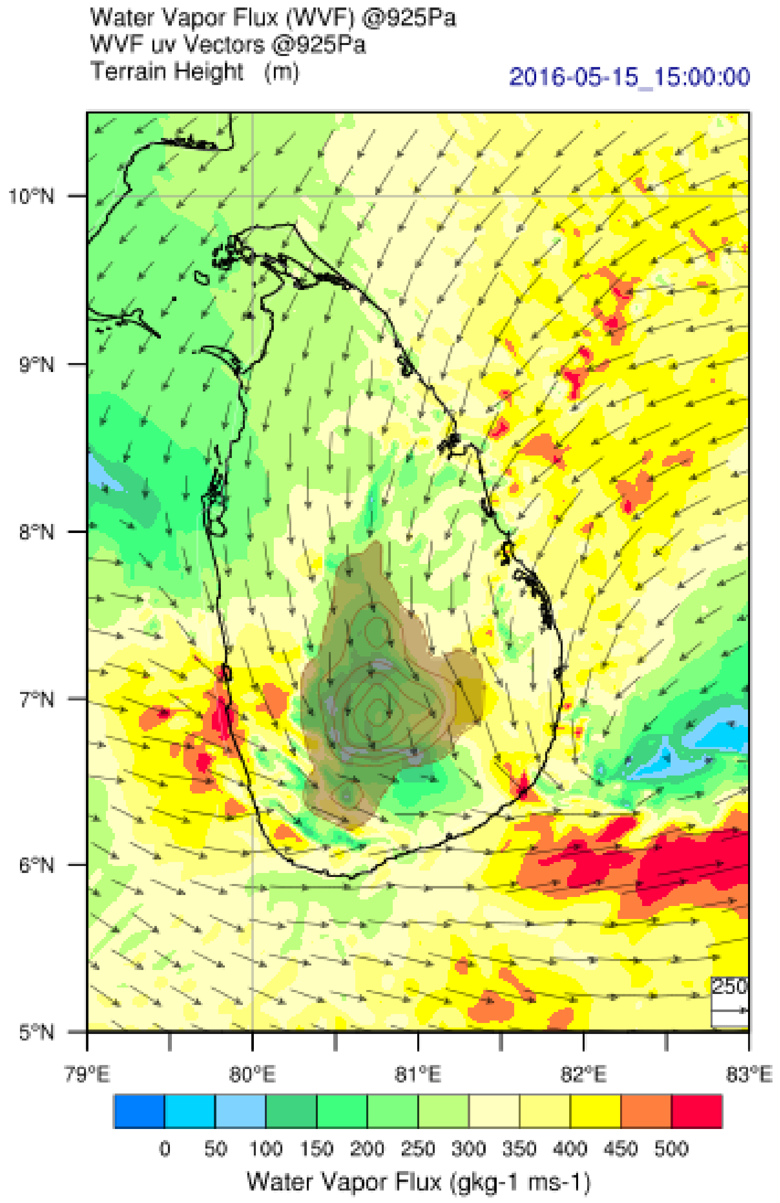


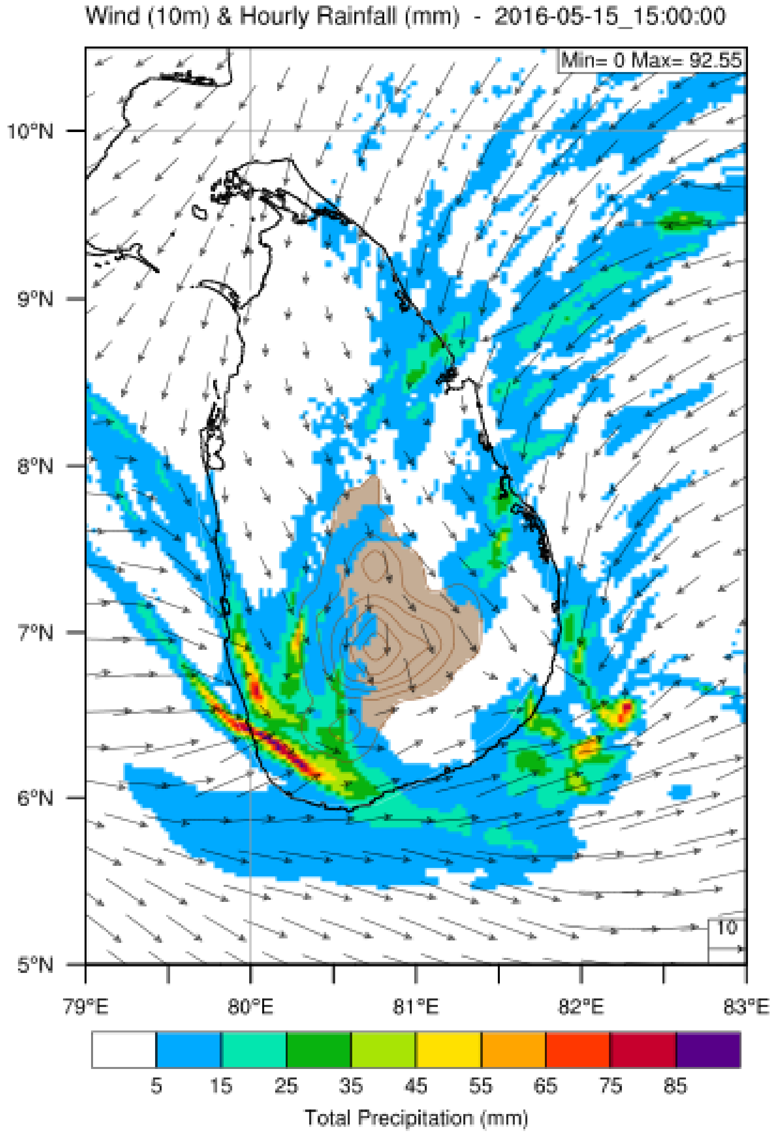


Water Vapor Flux

Total Rainfall

2016.05.15 : 1500

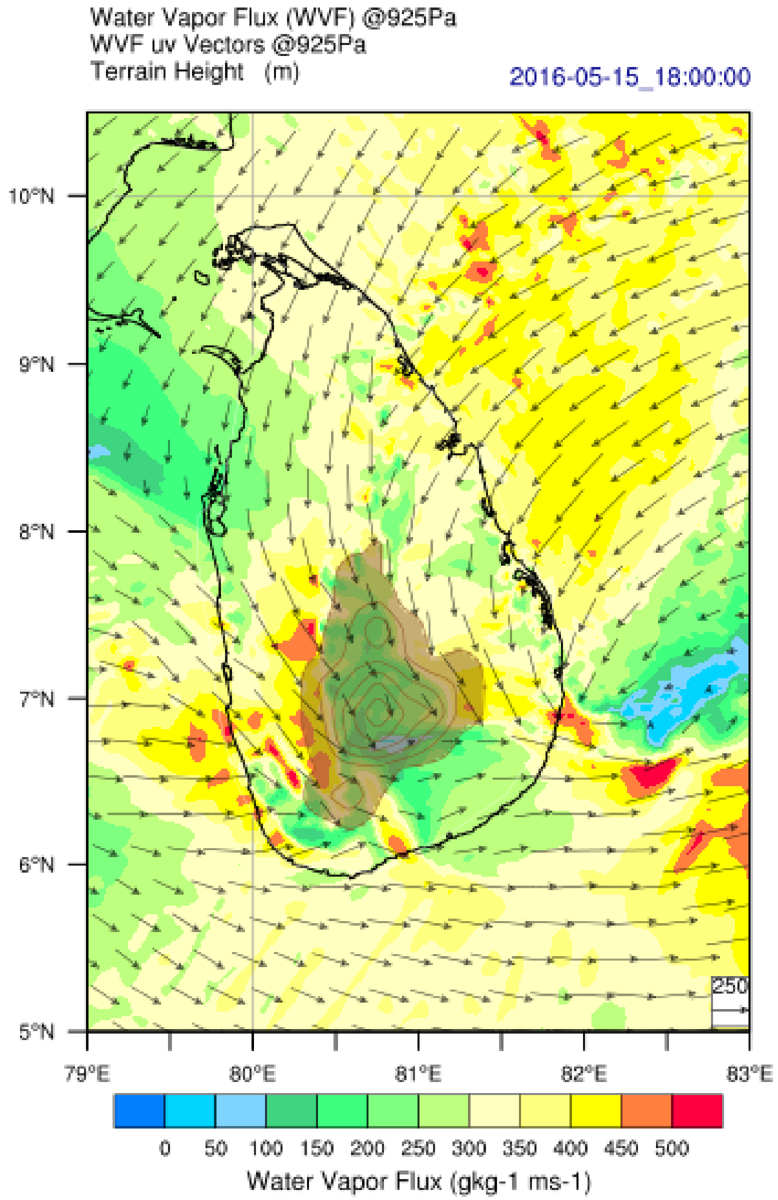


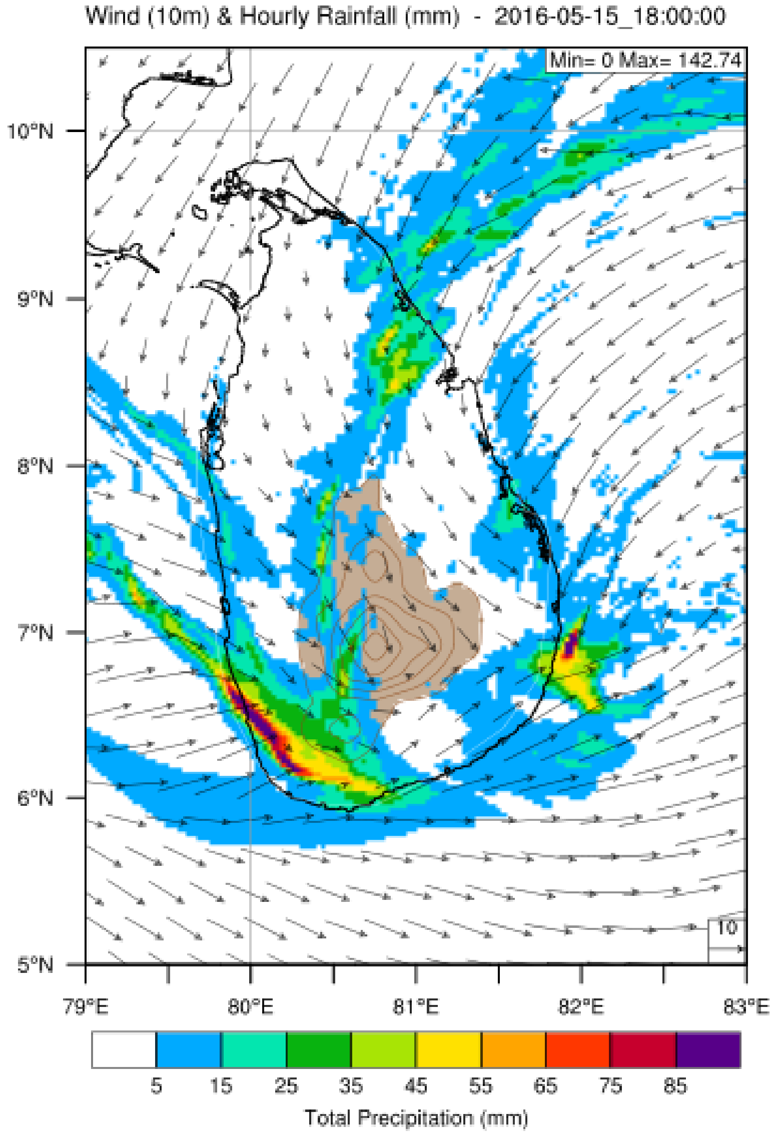


Water Vapor Flux

Total Rainfall

2016.05.15 : 1800

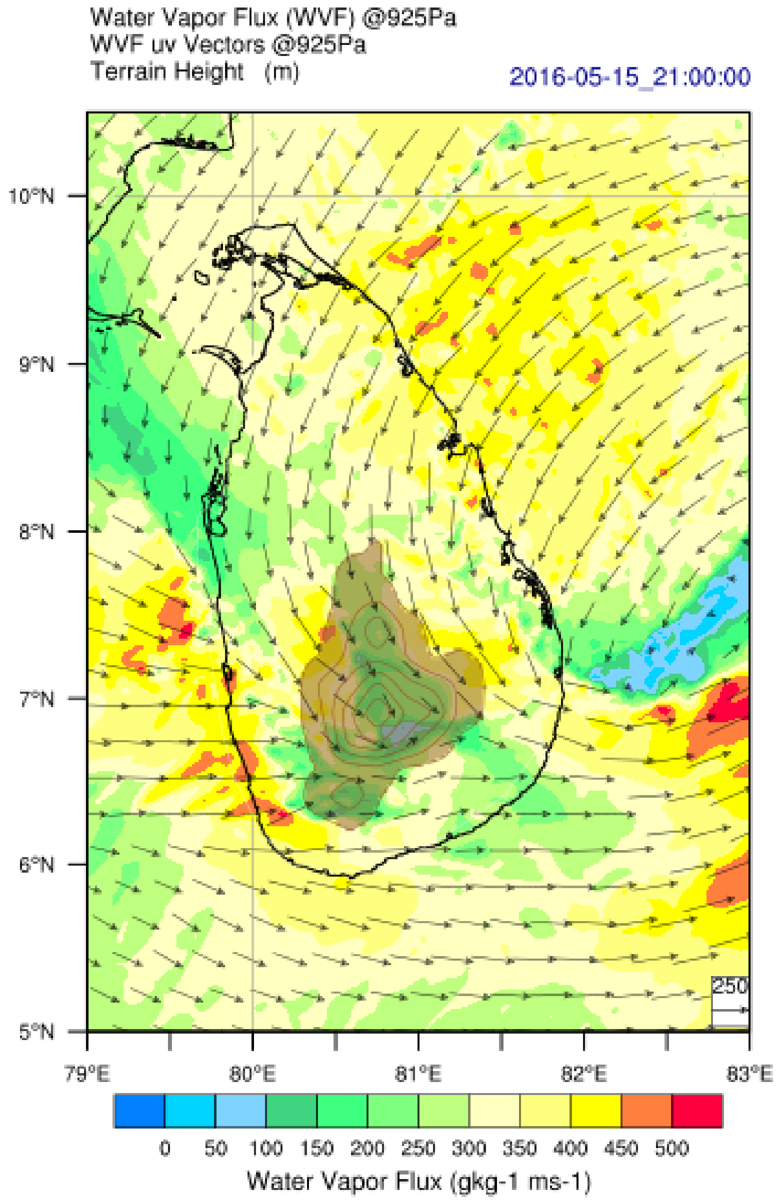




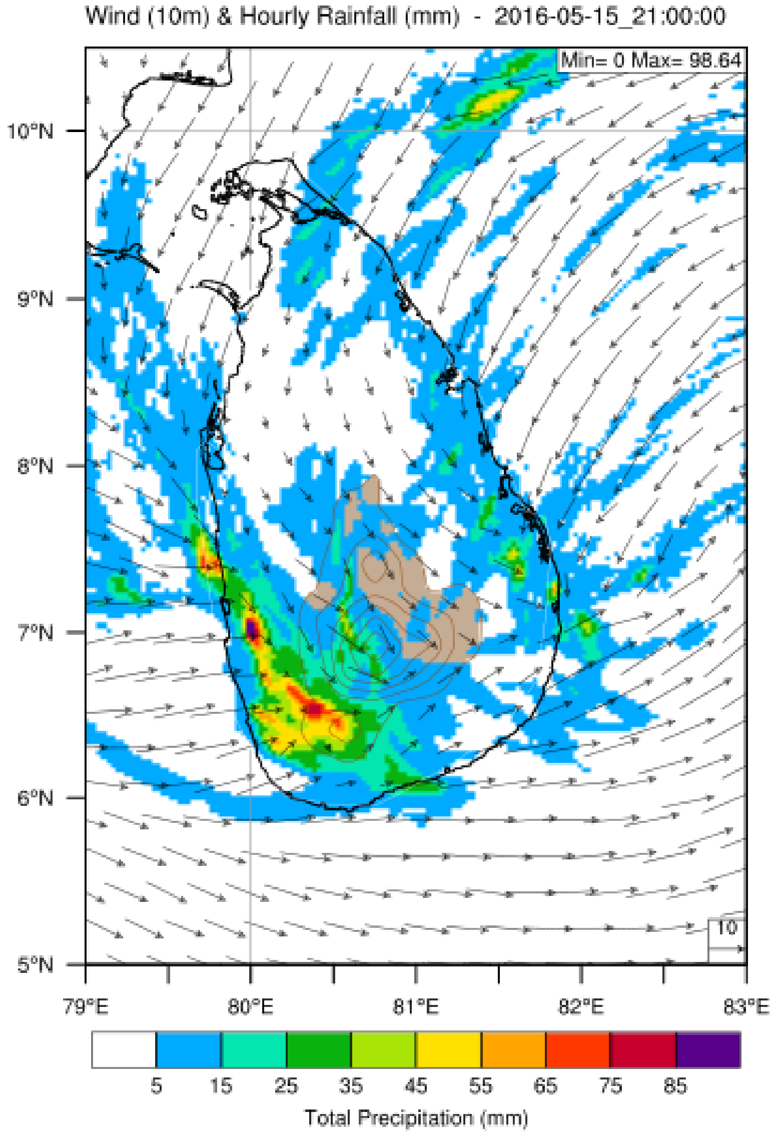
Water Vapor Flux

Total Rainfall

2016.05.15 : 2100

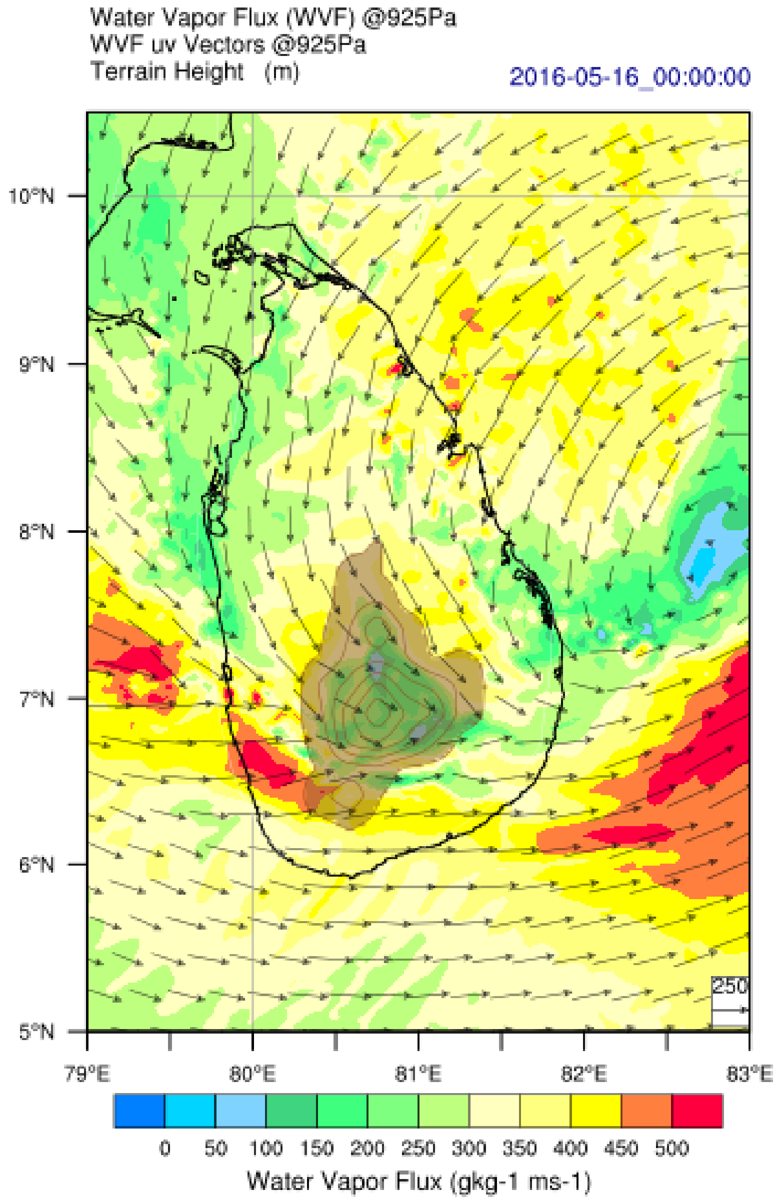


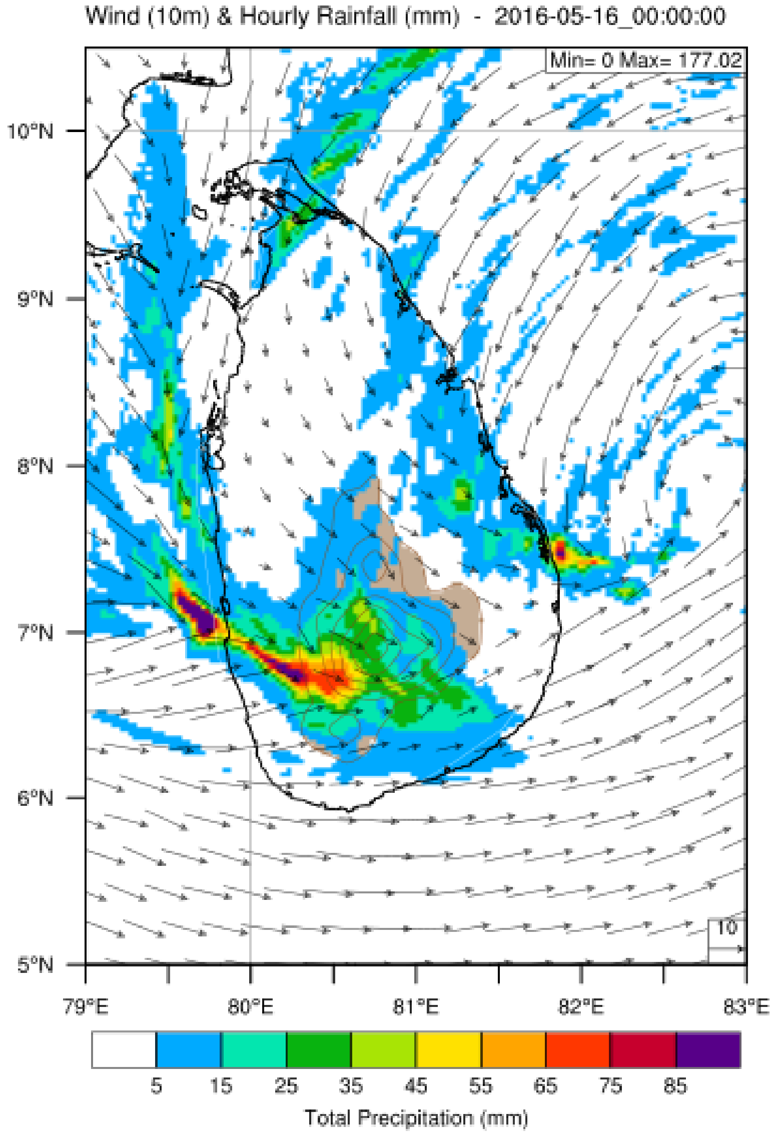
Water Vapor Flux



Total Rainfall

2016.05.16 : 0000

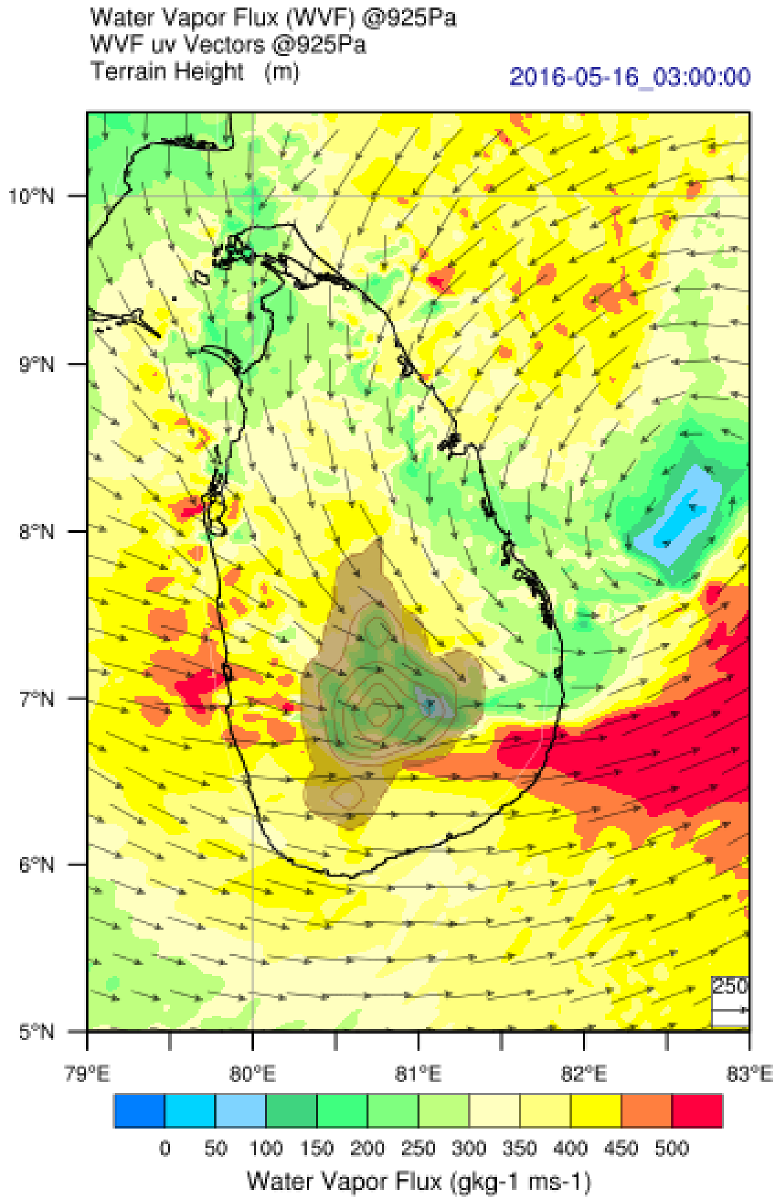


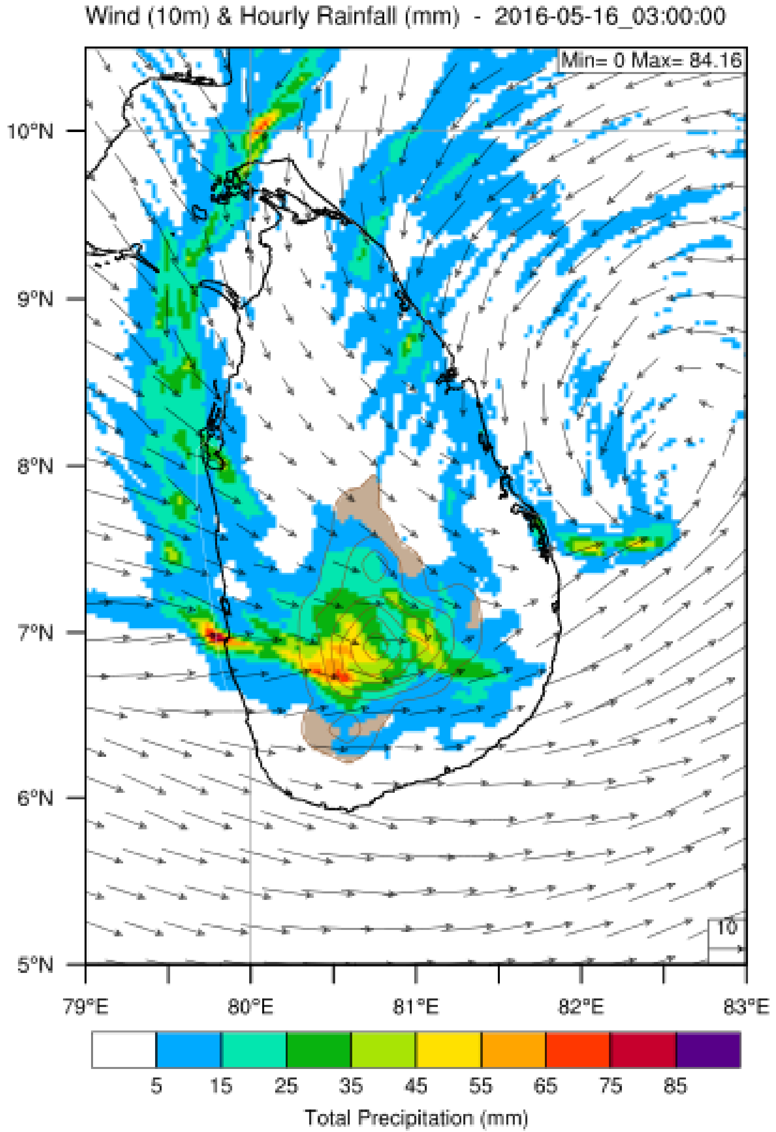


Water Vapor Flux

Total Rainfall

2016.05.16 : 0300

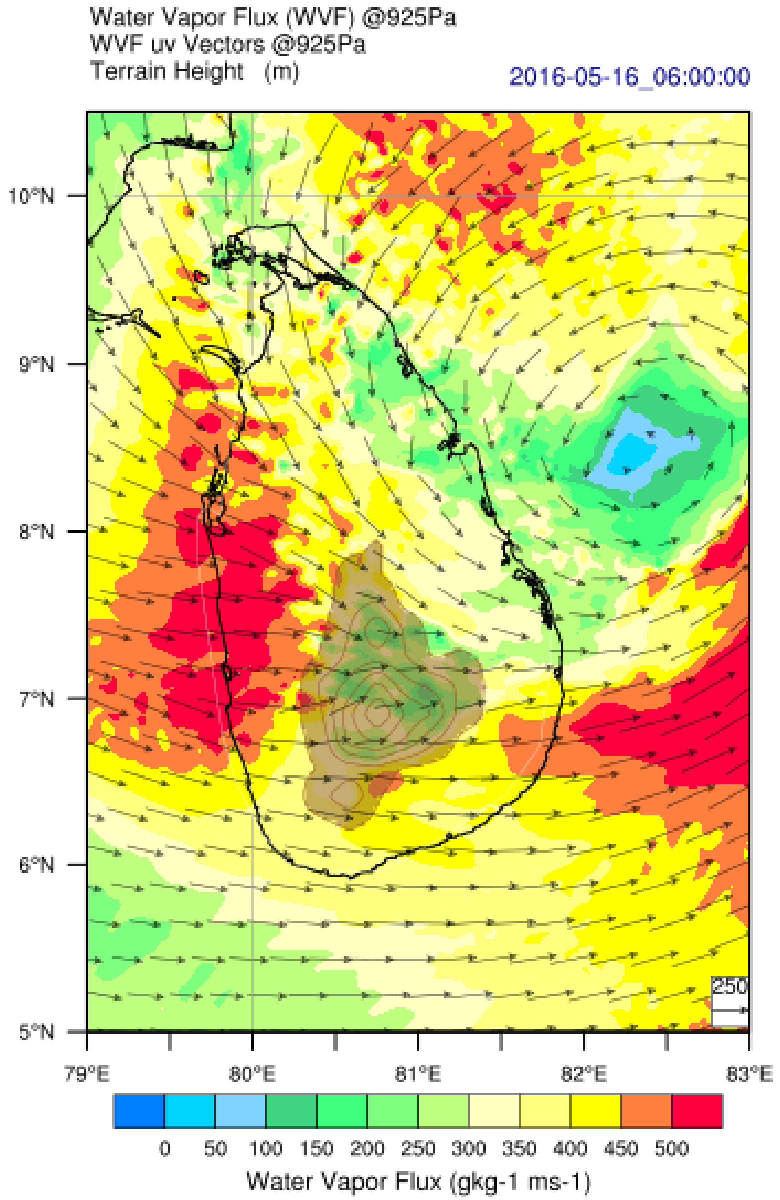


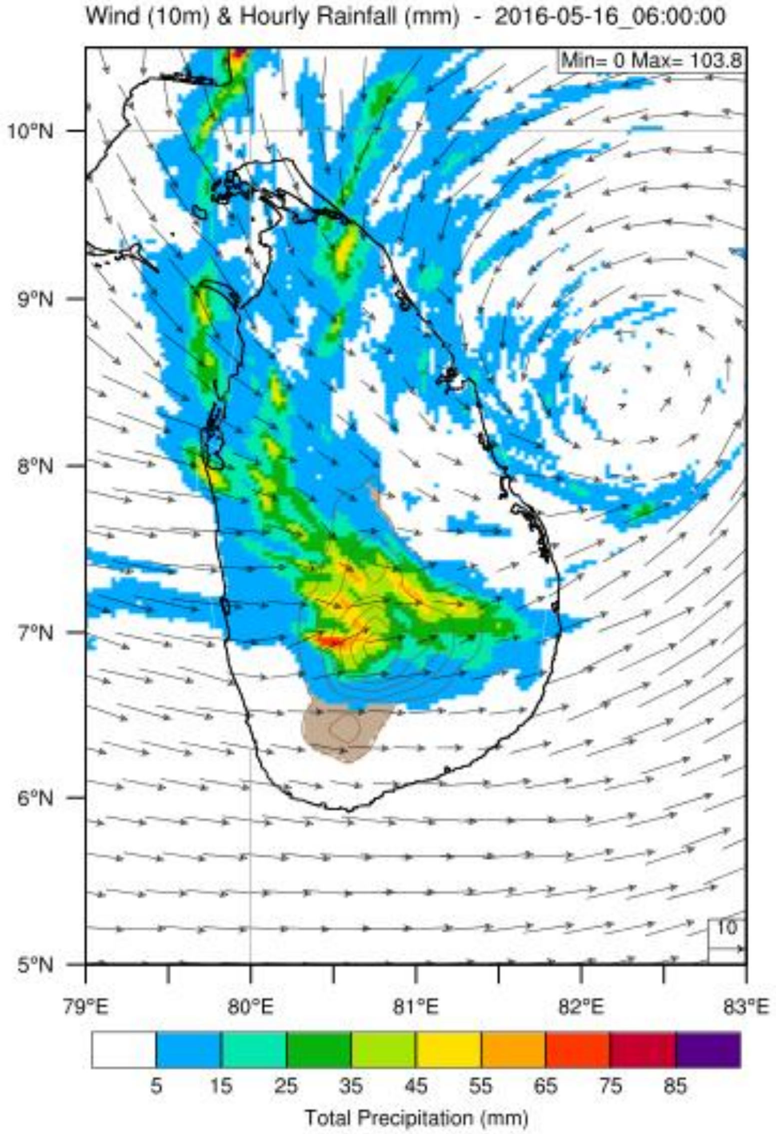


Water Vapor Flux

Total Rainfall

2016.05.16 : 0600





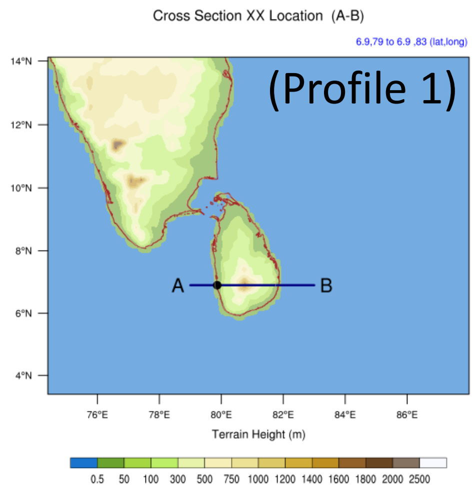
Water Vapor Flux

Total Rainfall

Horizontal & Vertical development

Horizontal

- **Precipitation + 10m wind**
- **Water vapor flux + WVF vectors@925hP**
- **Divergent Wind & Vertical wind velocity (w) @ 850 hPa**
- **Wind, Surface Temperature & Pressure**

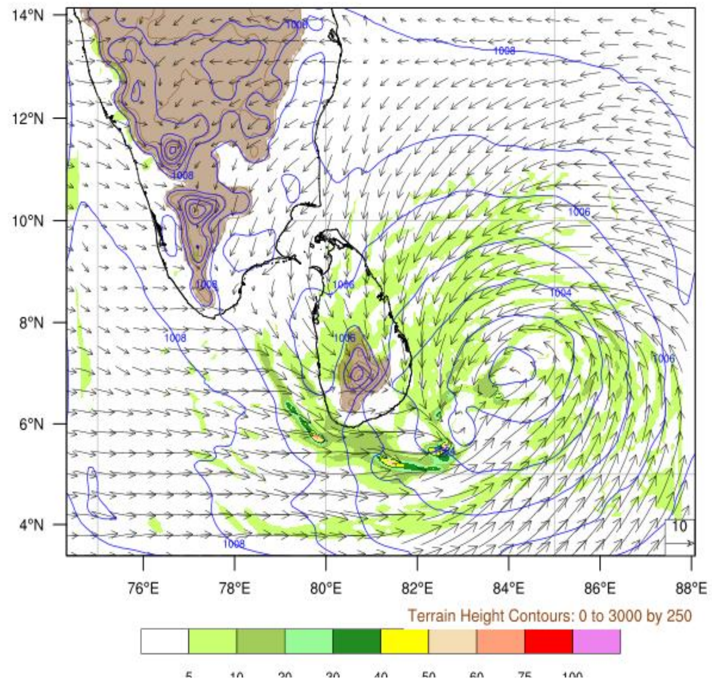


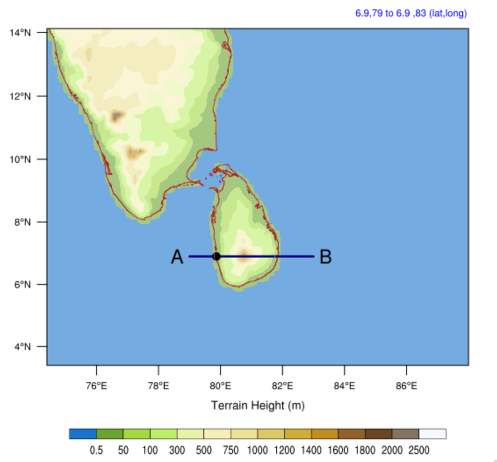
(Profile 2)

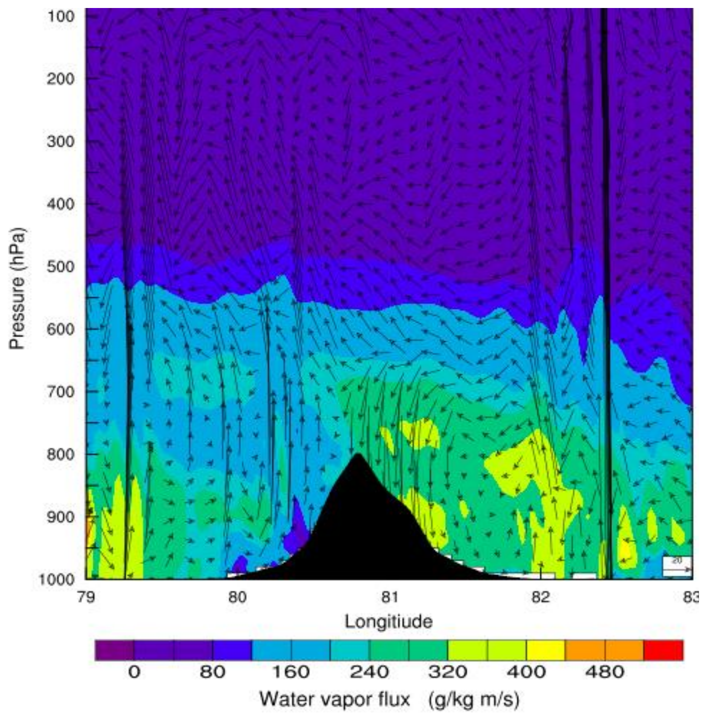
Horizontal & Vertical development

2016.05.15 : 0800

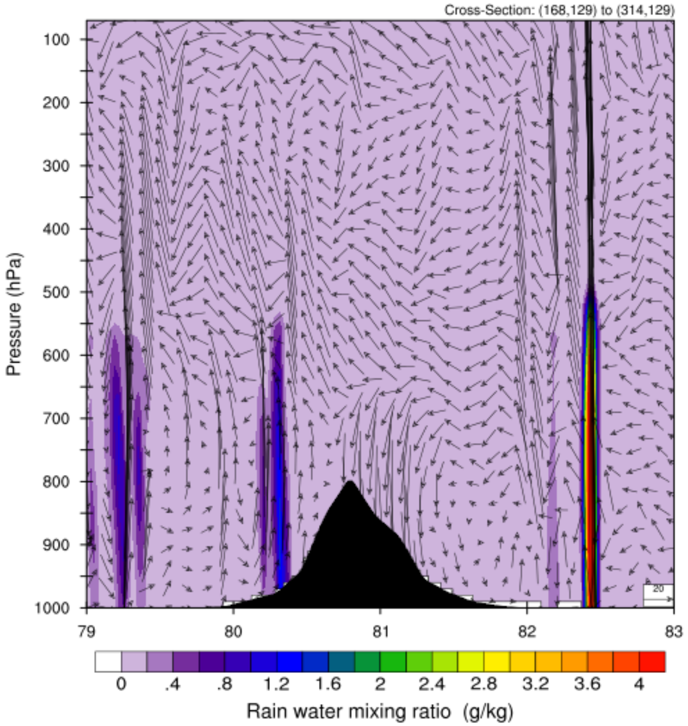
Precipitation + 10m wind





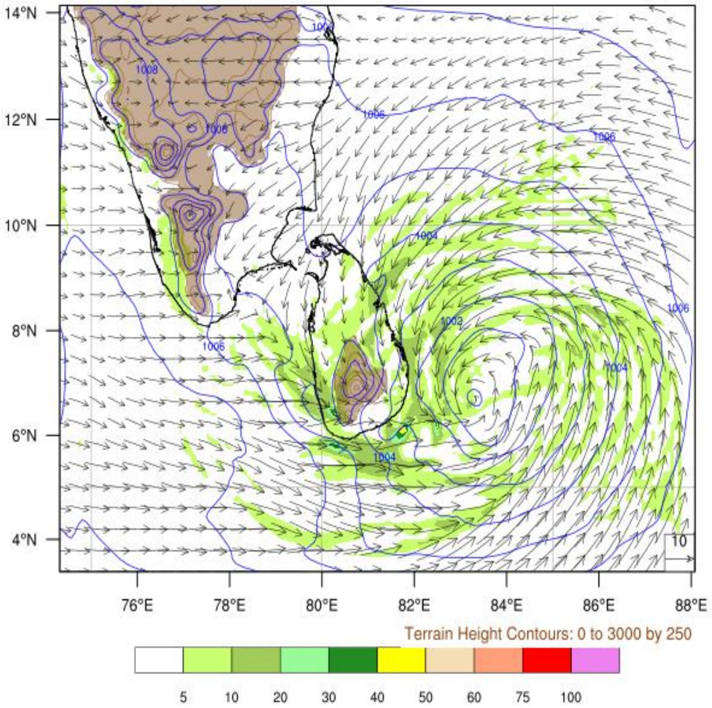


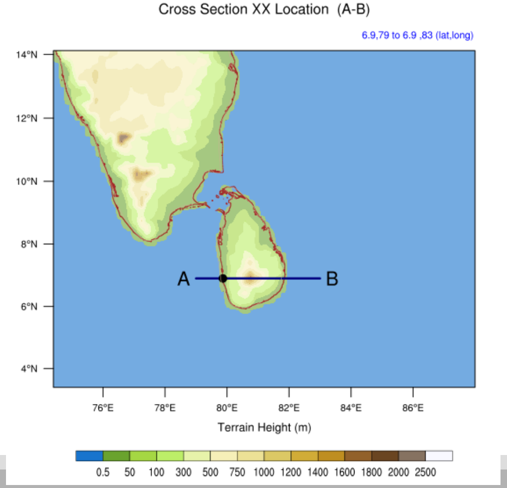
Water vapor flux + Vertical wind (uw)

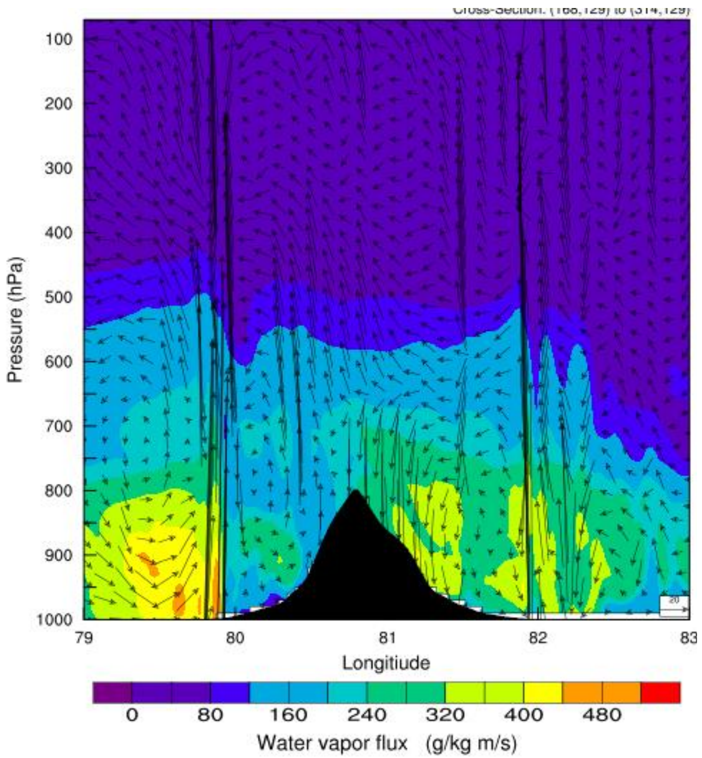


Rainwater mixing ratio

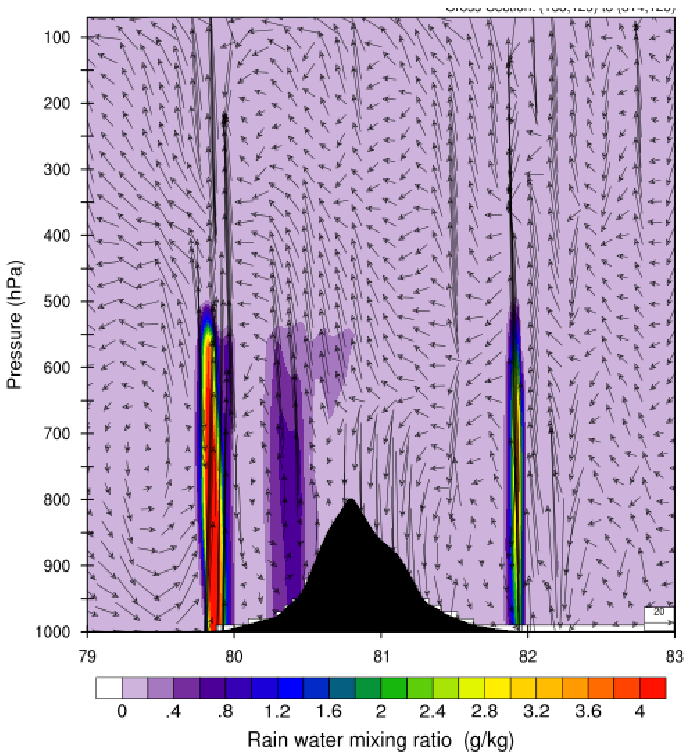
2016.05.15 : 1100





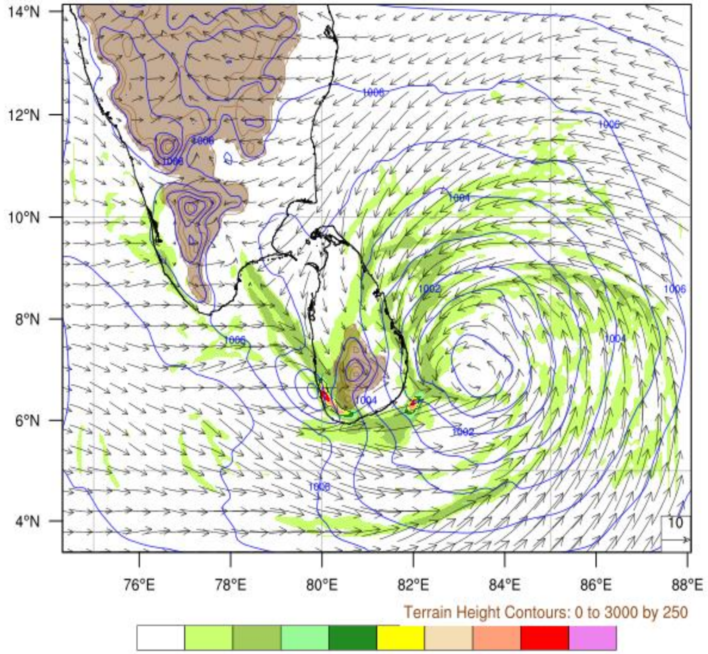


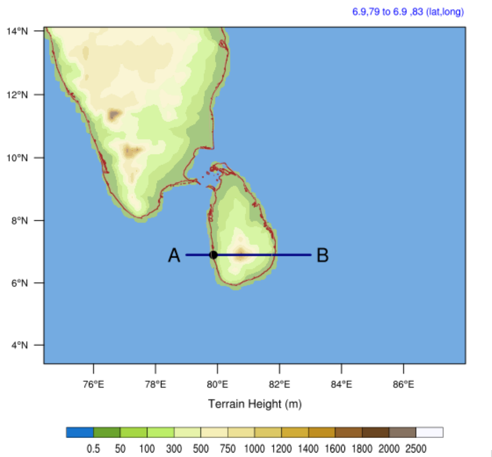
Water vapor flux + Vertical wind (uw)



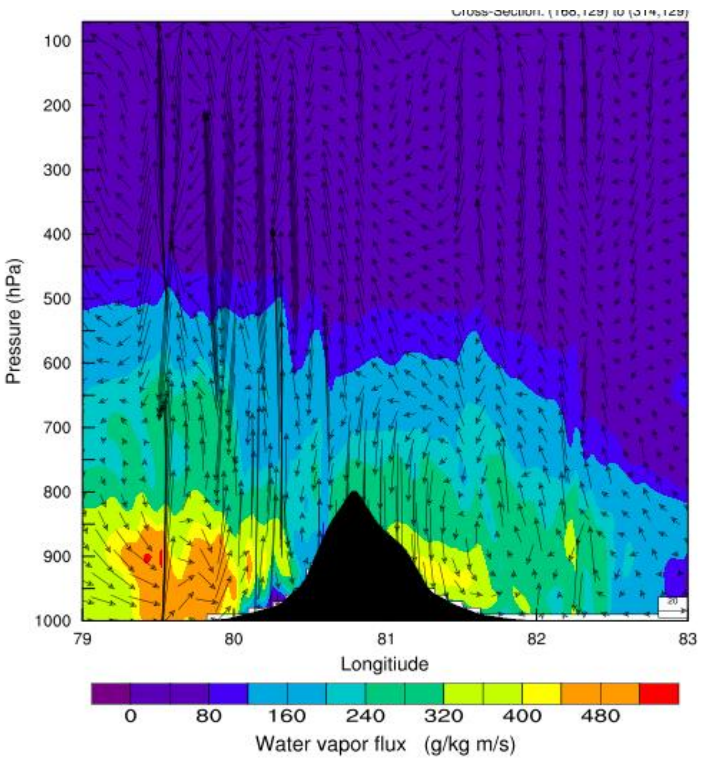
Rainwater mixing ratio

Precipitation + 10m wind

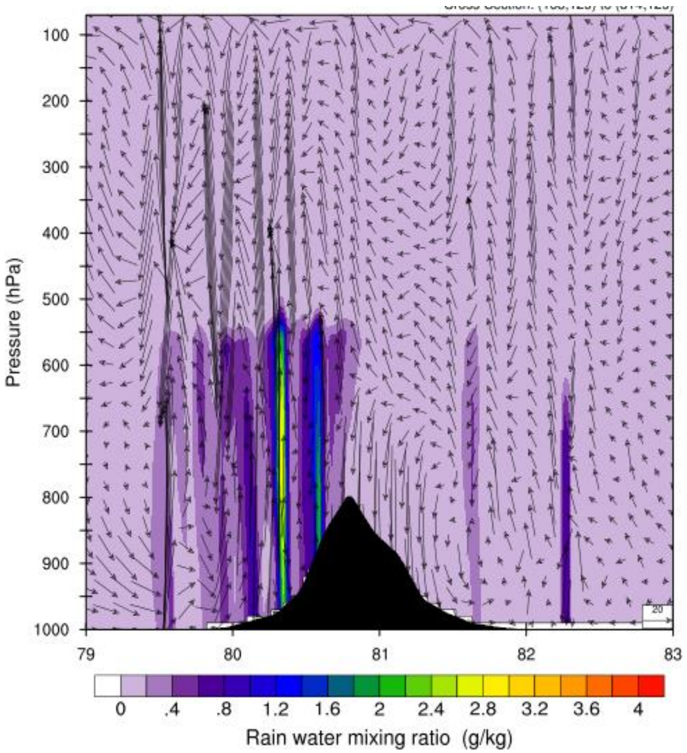




2016.05.15 : 1400

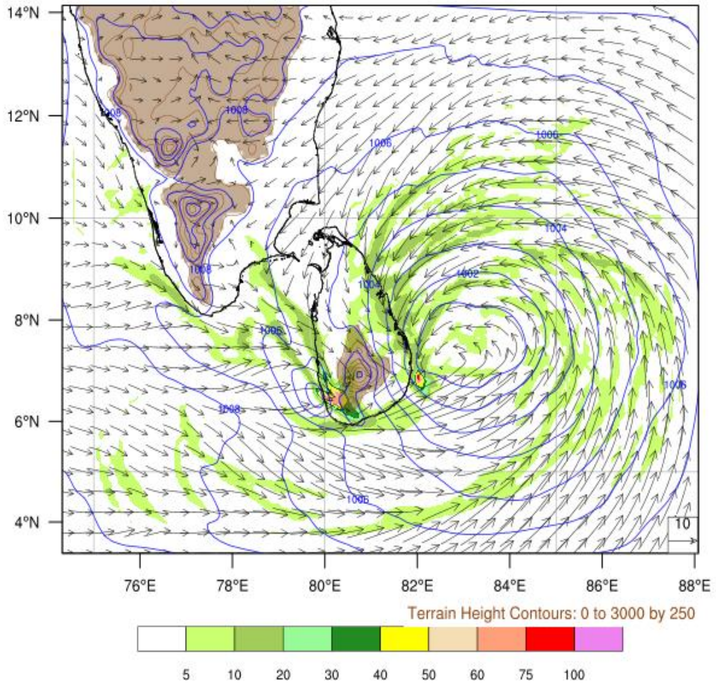


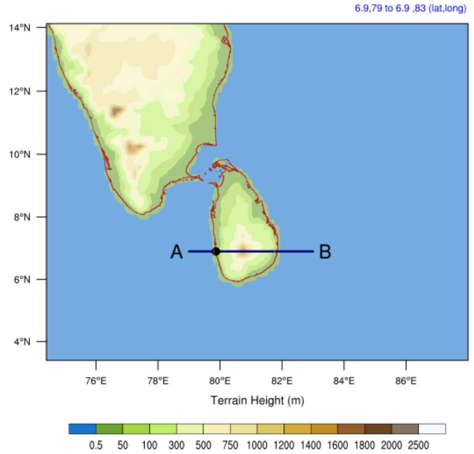
Water vapor flux + Vertical wind (uw)



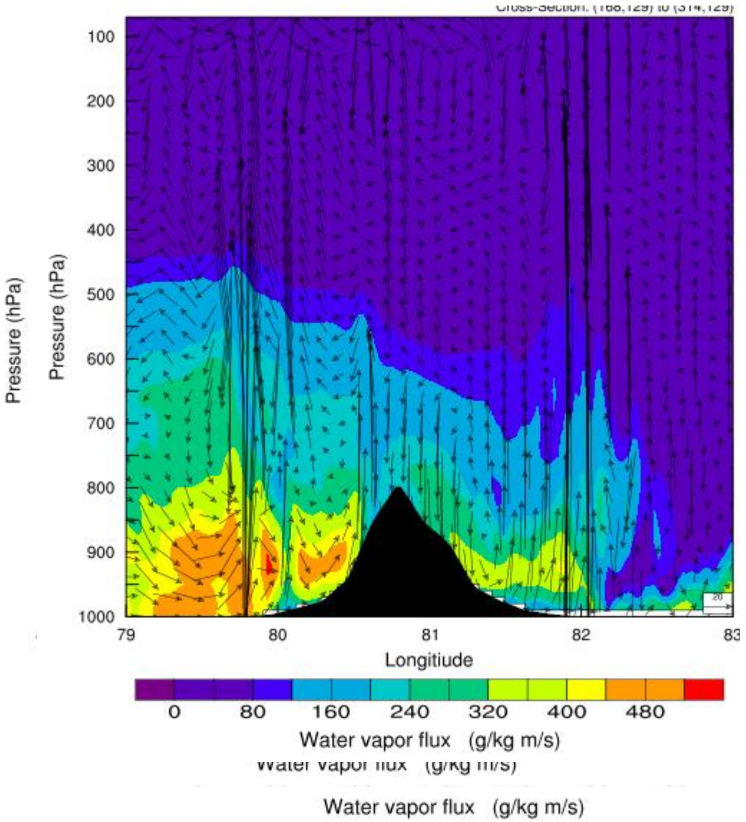
Rainwater mixing ratio

Precipitation + 10m wind

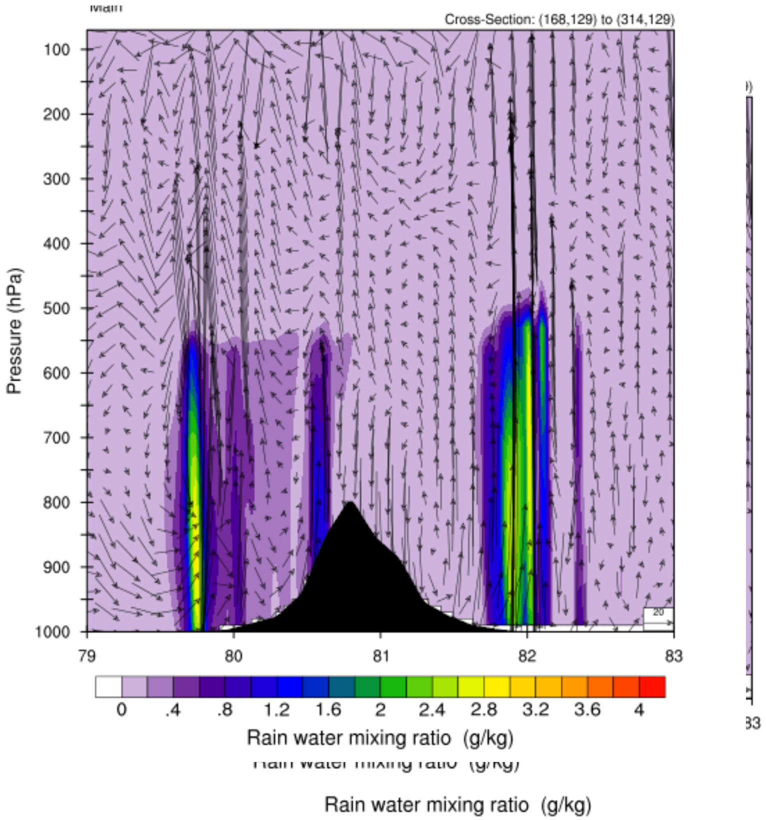




2016.05.15 : 1700

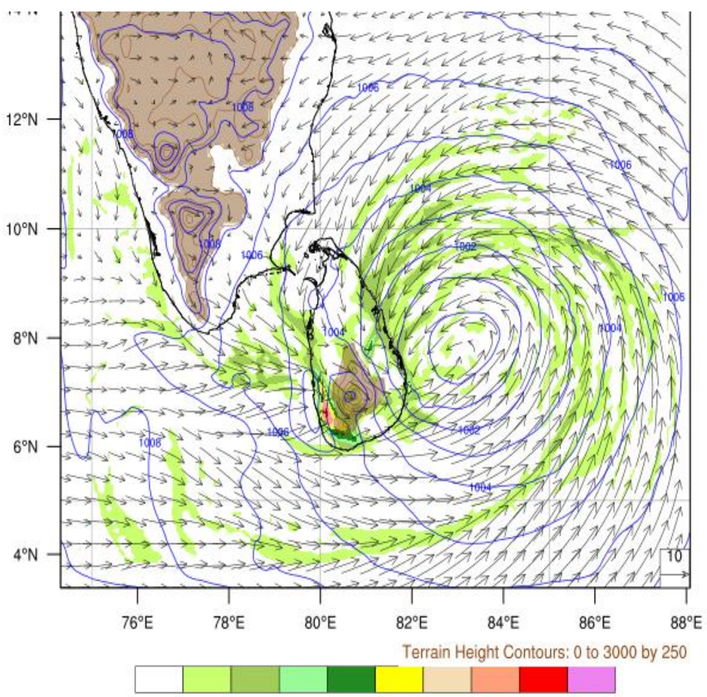


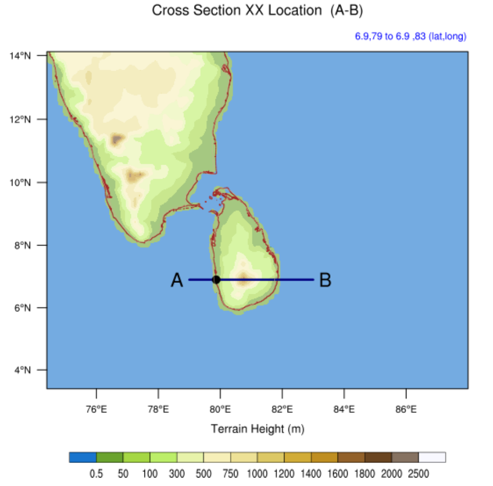
Water vapor flux + Vertical wind (uw)



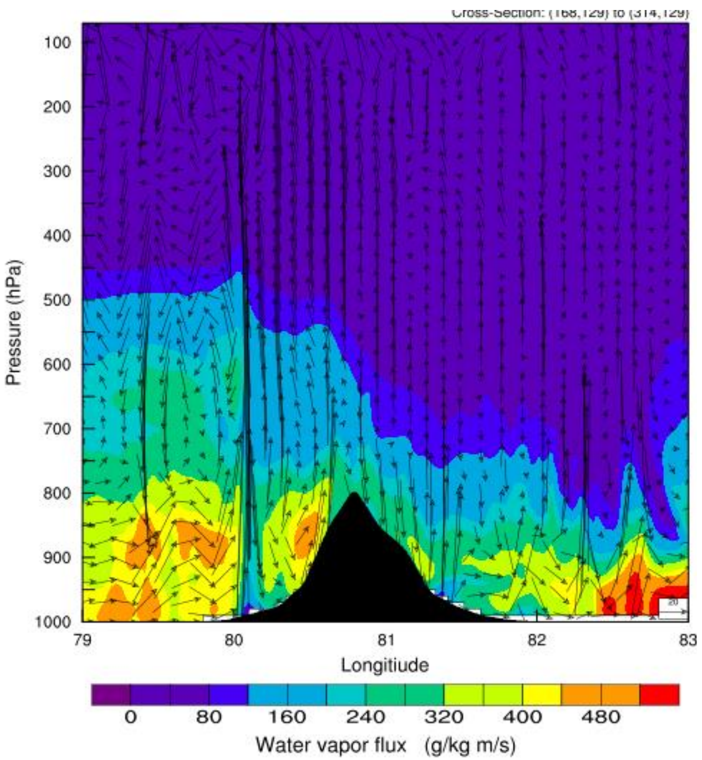
Rainwater mixing ratio

Precipitation + 10m wind

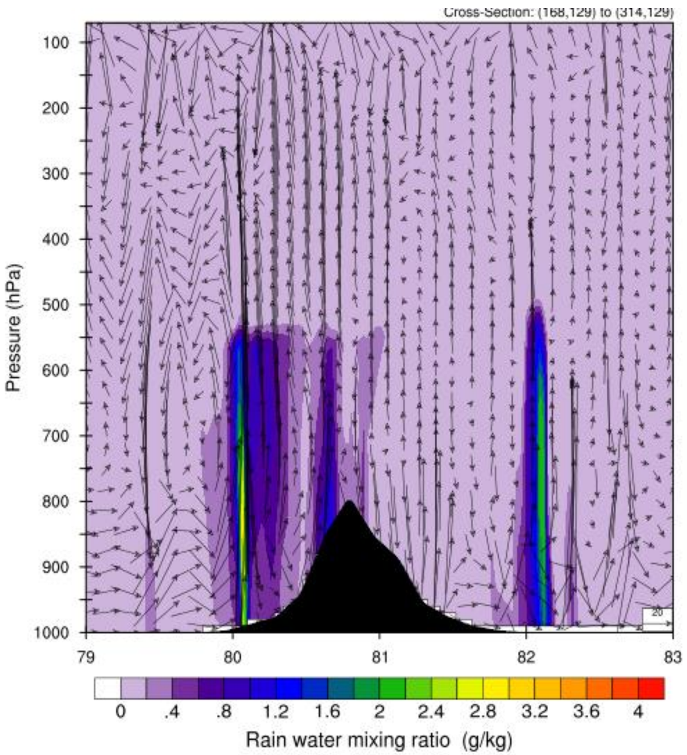




2016.05.15 : 2000

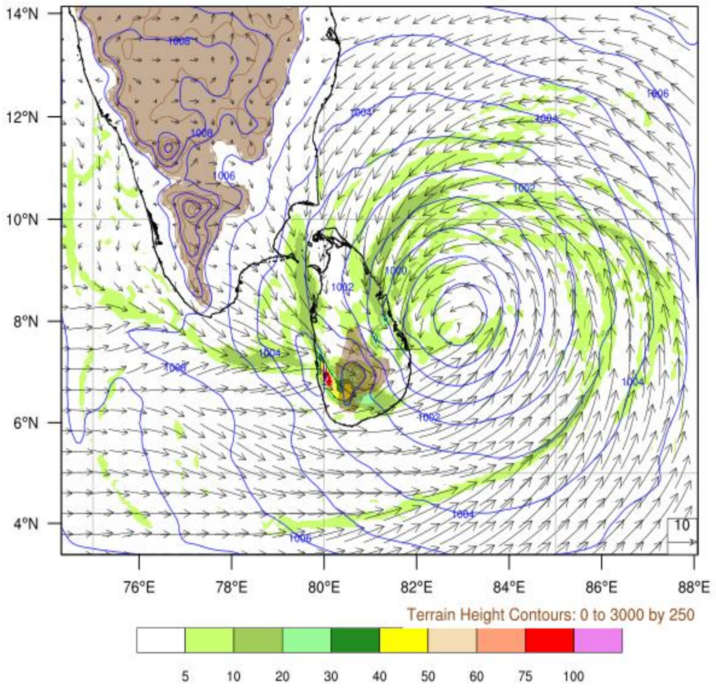


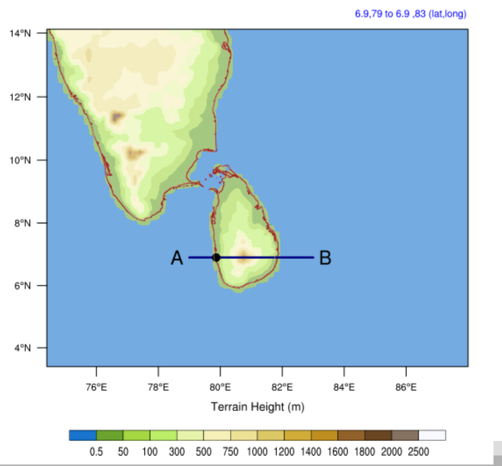
Water vapor flux + Vertical wind (uw)



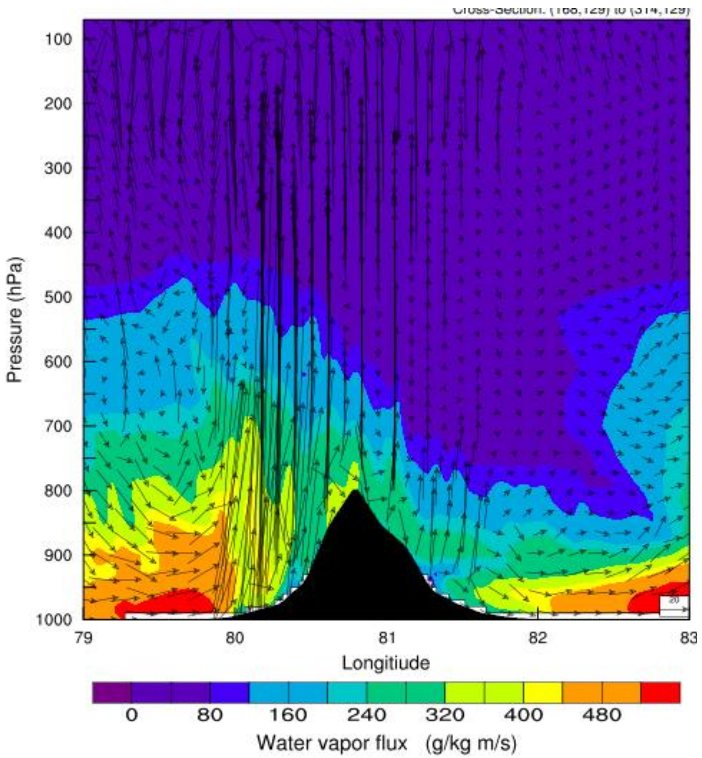
Rainwater mixing ratio

Precipitation + 10m wind

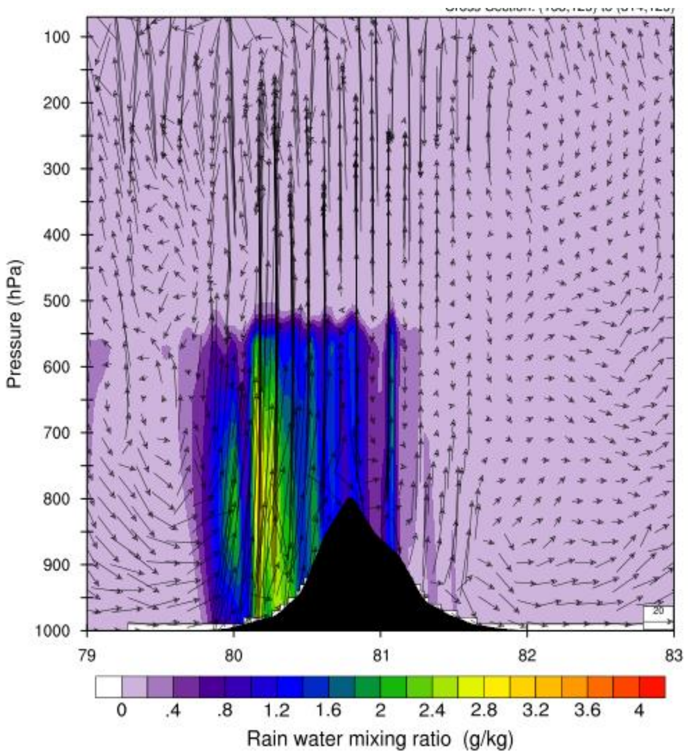




2016.05.15 : 2300

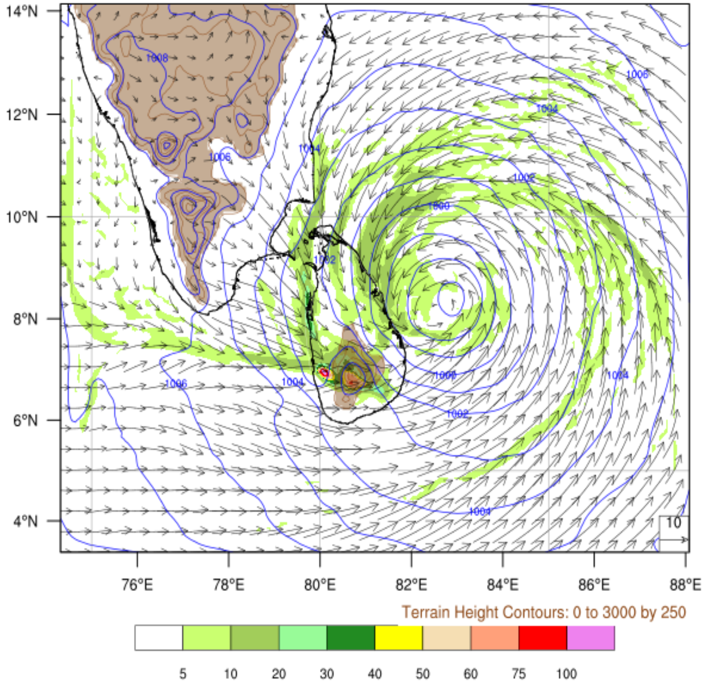


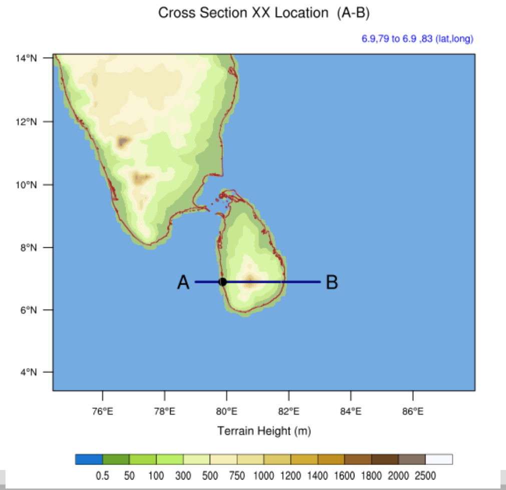
Water vapor flux + Vertical wind (uw)



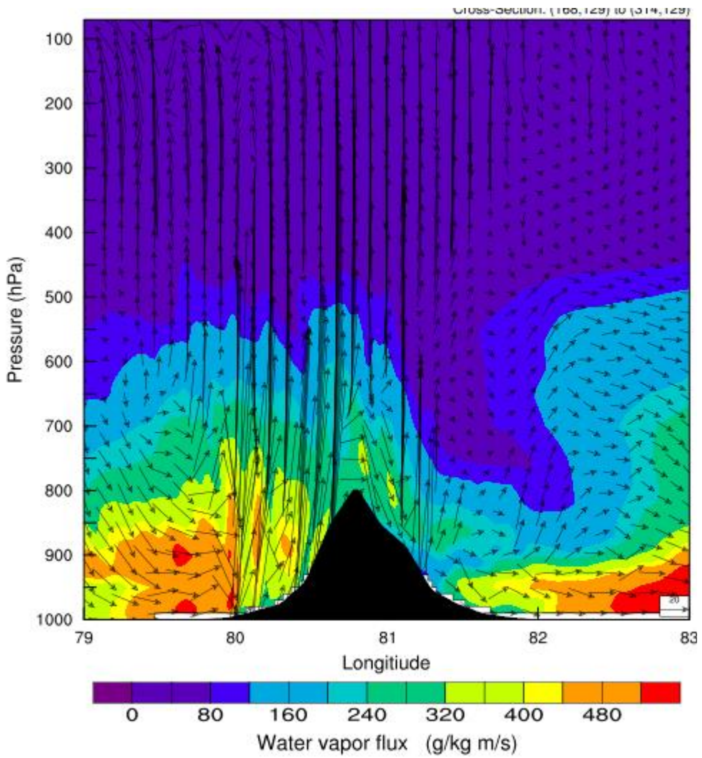
Rainwater mixing ratio

Precipitation + 10m wind

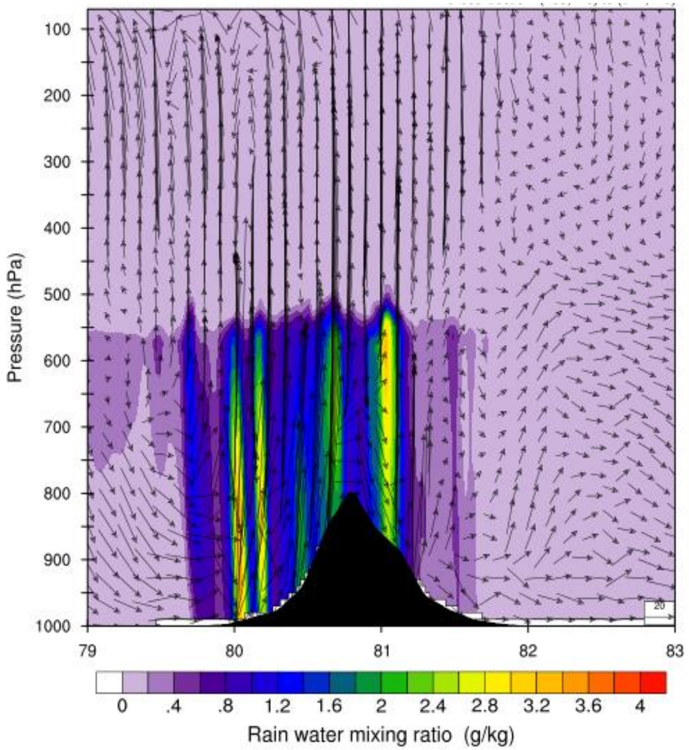




2016.05.16 : 0200

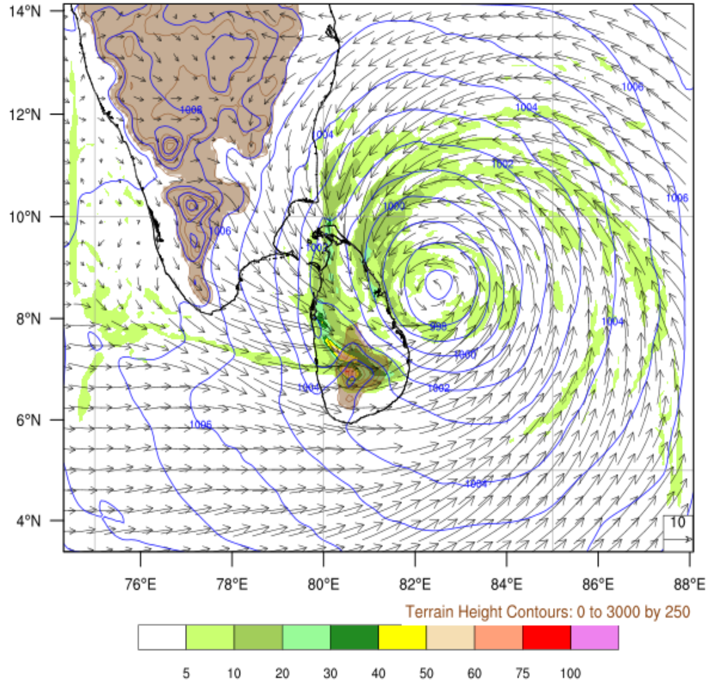


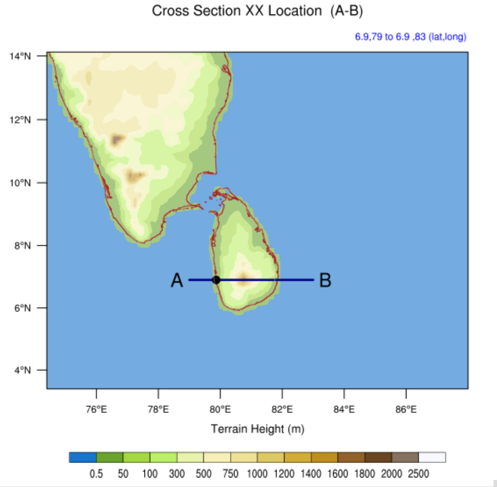
Water vapor flux + Vertical wind (uw)



Rainwater mixing ratio

Precipitation + 10m wind





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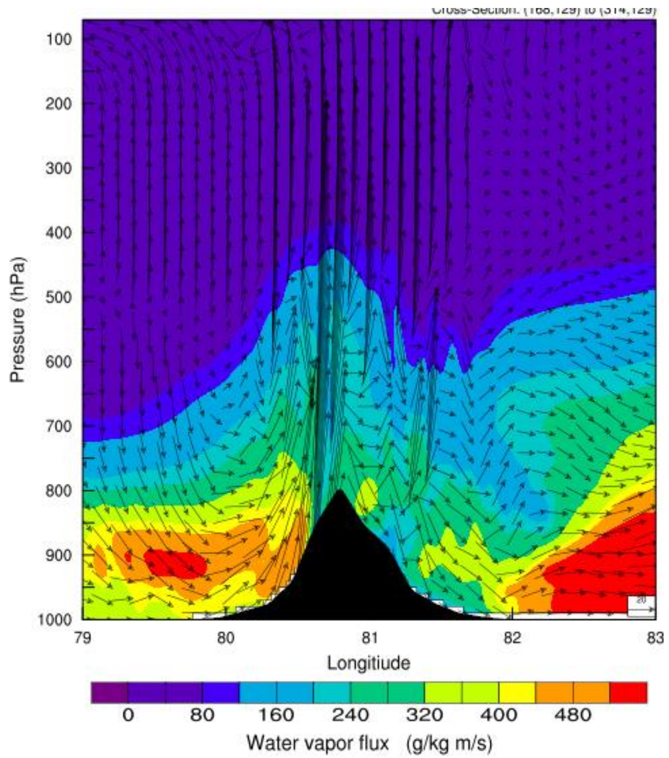
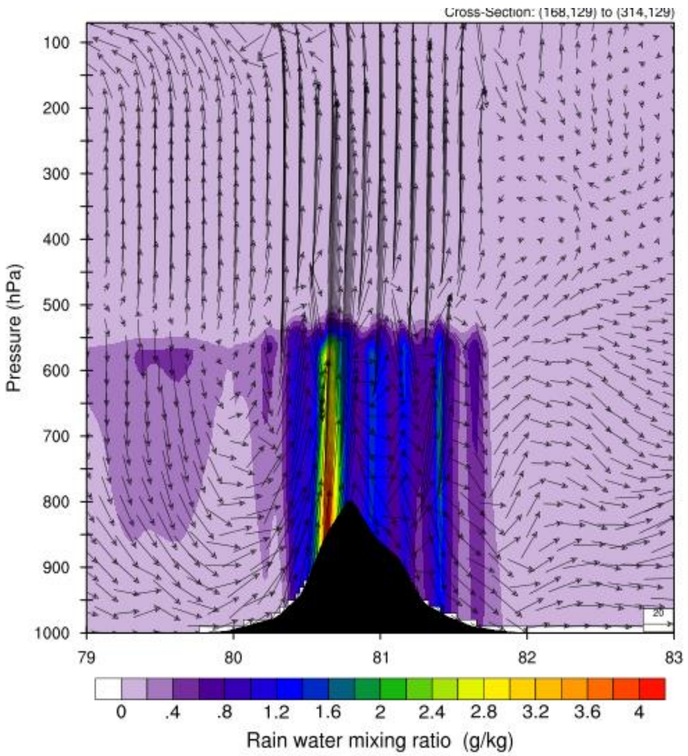
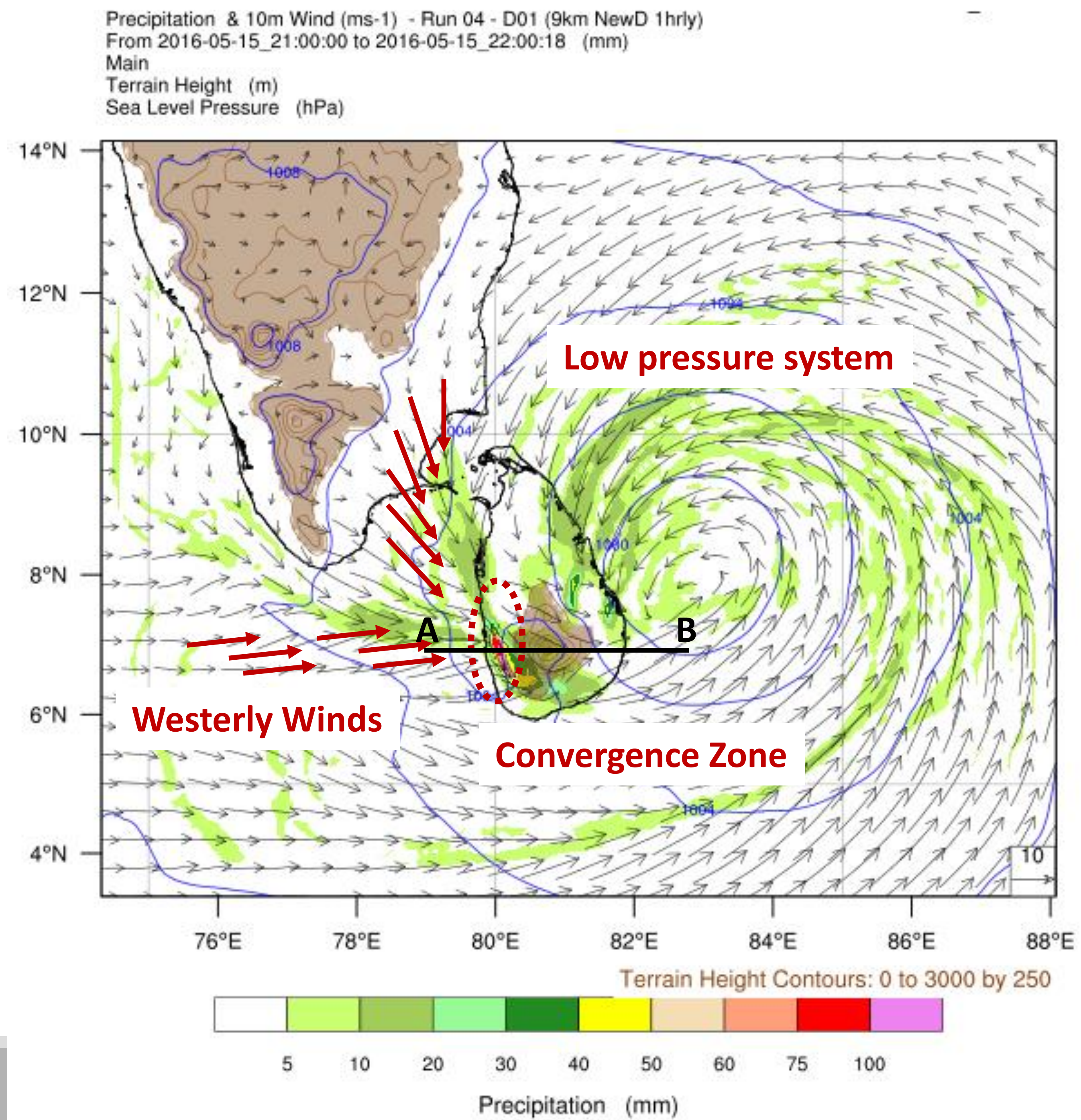
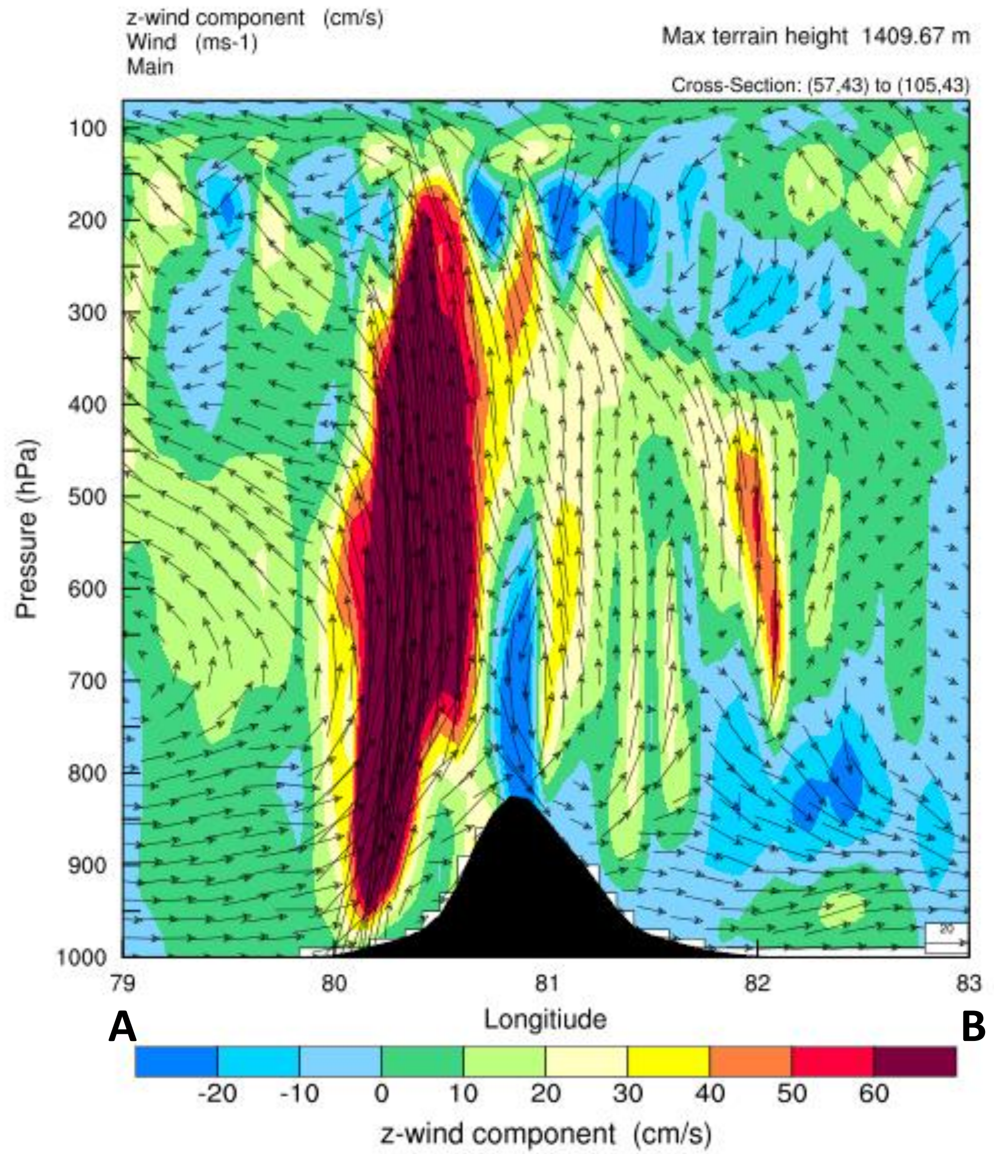


Water vapor flux + Vertical wind (uw)



Rainwater mixing ratio


Precipitation & 10m Wind (ms-1) - Run 04 - D01 (9km NewD 1hrly)
From 2016-05-15_21:00:00 to 2016-05-15_22:00:18 (mm)
Main
Terrain Height (m)
Sea Level Pressure (hPa)
14°N
12°N
10°N
8°N
6°N
4°N
76°E
78°E
80°E
82°E
84°E
86°E
88°E
Low pressure system
Westerly Winds
Convergence Zone
A
B
10
Terrain Height Contours: 0 to 3000 by 250
5
10
20
30
40
50
60
75
100
Precipitation (mm)


z-wind component (cm/s)
Wind (ms-1)
Main
Max terrain height 1409.67 m
Cross-Section: (57,43) to (105,43)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
1000
79
80
81
82
83
Longitiude
A
B
-20
-10
0
10
20
30
40
50
60
z-wind component (cm/s)

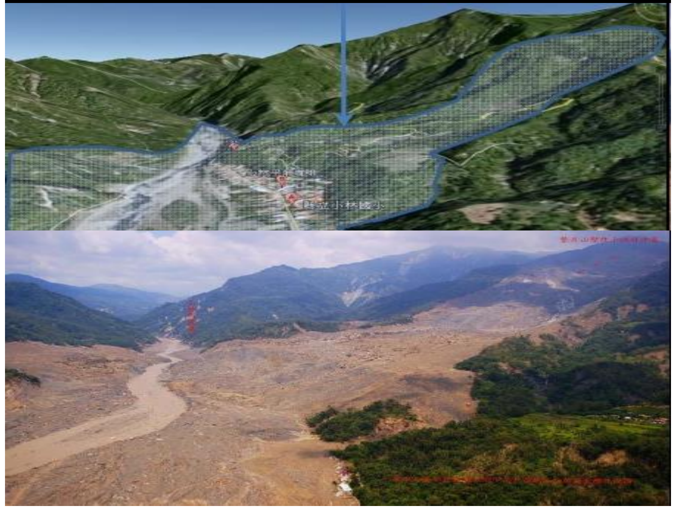
The possible mechanism of the weather system

- The low pressure system was moving along the east coast.
- While the observed rainfall was highest particularly in the western part of the country.
- Westerlies influenced by the south west monsoon converged with the winds of the low pressure system over the western part of Sri Lanka.
- This convergence zone sustain over western part of Sri Lanka the for relatively longer period with respect to the low pressure system movement.
- High vertical motion can enhance the convective activity and also bring more moisture.

Taiwan's case : Typhoon Morakot (2009)

■ Massive deep landsliding Caused by Morakot

***More than 400 killed** at this area*



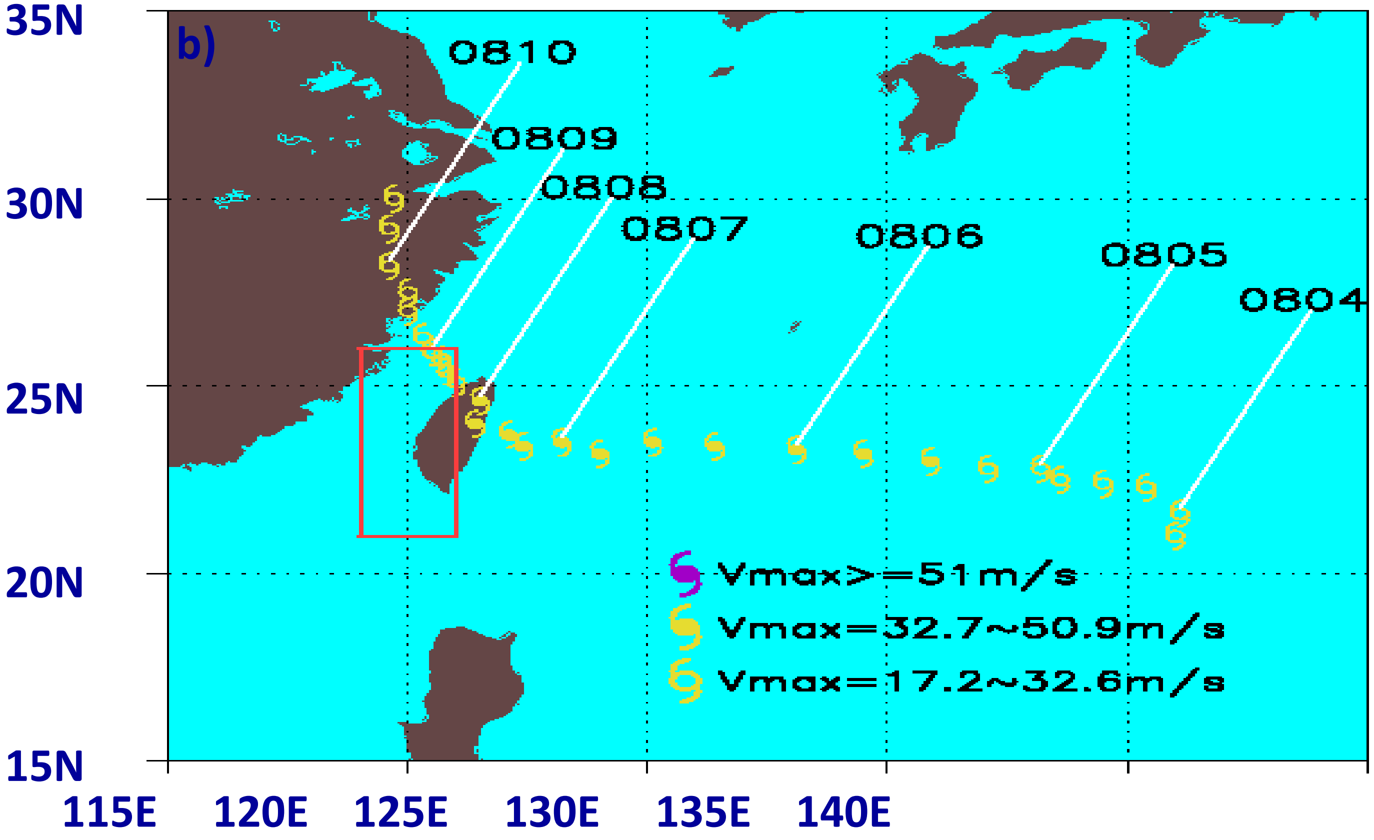
***32 killed** at this area*

Table 1. Record of the 10 highest typhoon rainfall accumulations during the last 50 years. Stations' elevation for A-Li station, An Pu and Chu Tze Hu are 2413 m, 826 m and 607 m, respectively (TC: Tropical Cyclone, NE: Northeasterly, SW: southwesterly).

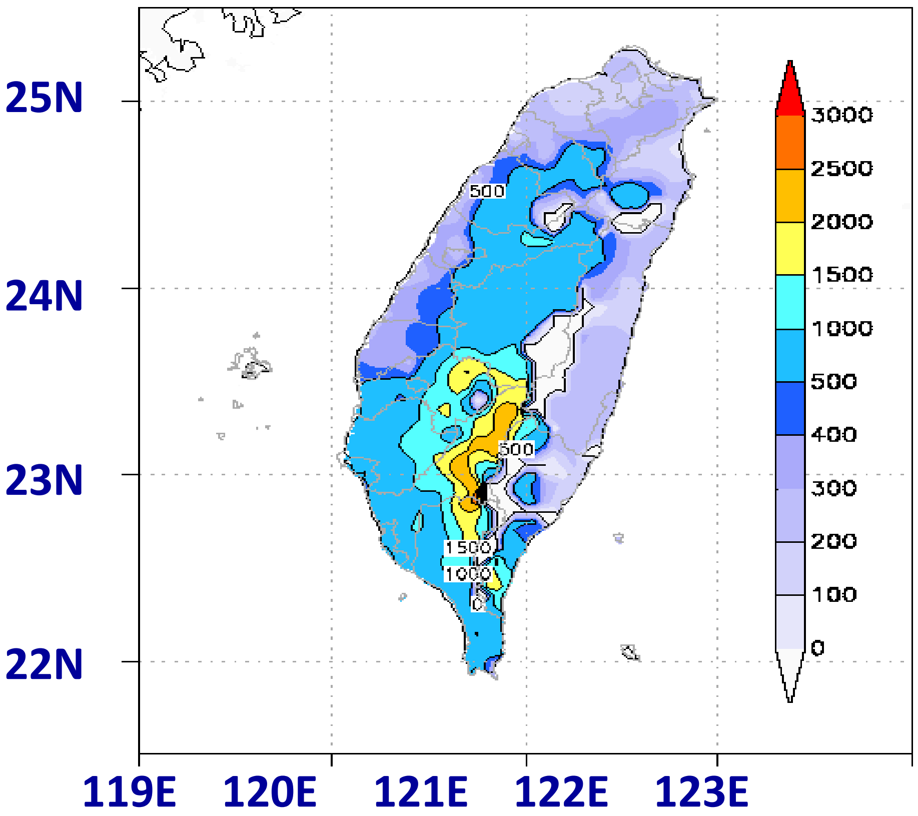
Typhoon name (CWB warning period)	Intensity classification* Characteristics	Accumulation rainfall in mm (duration) station	Casualties including Death and missing
MORAKOT 5–10 August 2009	Intermediate TC Traversing CMR+ SW monsoon	2855 mm (100 h) A-Li Shan	695
FLOSSIE 1–7 October 1969	Intermediate TC nearby + NE monsoon	2162 mm (120 h) An Pu	105
HERB 29 July–1 August 1996	Strong TC Traversing CMR	1987 mm (48 h) A-Li Shan	73
LYNN 23–27 October 1987	Strong TC nearby + NE monsoon	1497 mm (96 h) Chu Tze Hu	63
SINLAKU 9–17 September 2008	Strong TC Traversing CMR	1458 mm (96 h) A-Li Shan	21
ORA 11–14 October 1978	Intermediate TC nearby + NE monsoon	1434 mm (96 h) Chu Tze Hu	7
GLORIA 8–13 September 1963	Strong TC nearby + NE monsoon	1433 mm (96 h) A-Li Shan	363
NARI 6–20 September 2001	Intermediate TC Traversing CMR	1304 mm (72 h) Chu Tze Hu	104
HAITANG 16–20 July 2005	Strong TC Traversing CMR	1216 mm (72 h) A-Li Shan	15
MINDULLE 28 June–2 July 2004	Intermediate TC Traversing CMR	1182 mm (72 h) A-Li Shan	45

* The CWB's classification of typhoons is based on the maximum wind speed: the light typhoon: 17.2~32.6 m/s; the intermediate typhoon: 32.7~50.9 m/s; the severe typhoon: ≧51 m/s

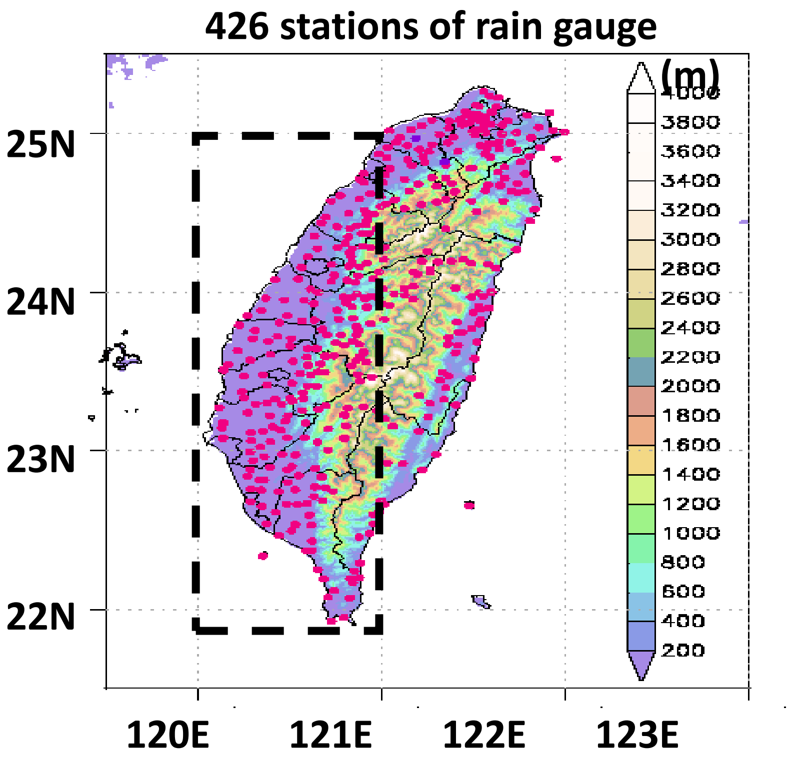
Track of Typhoon Morakot

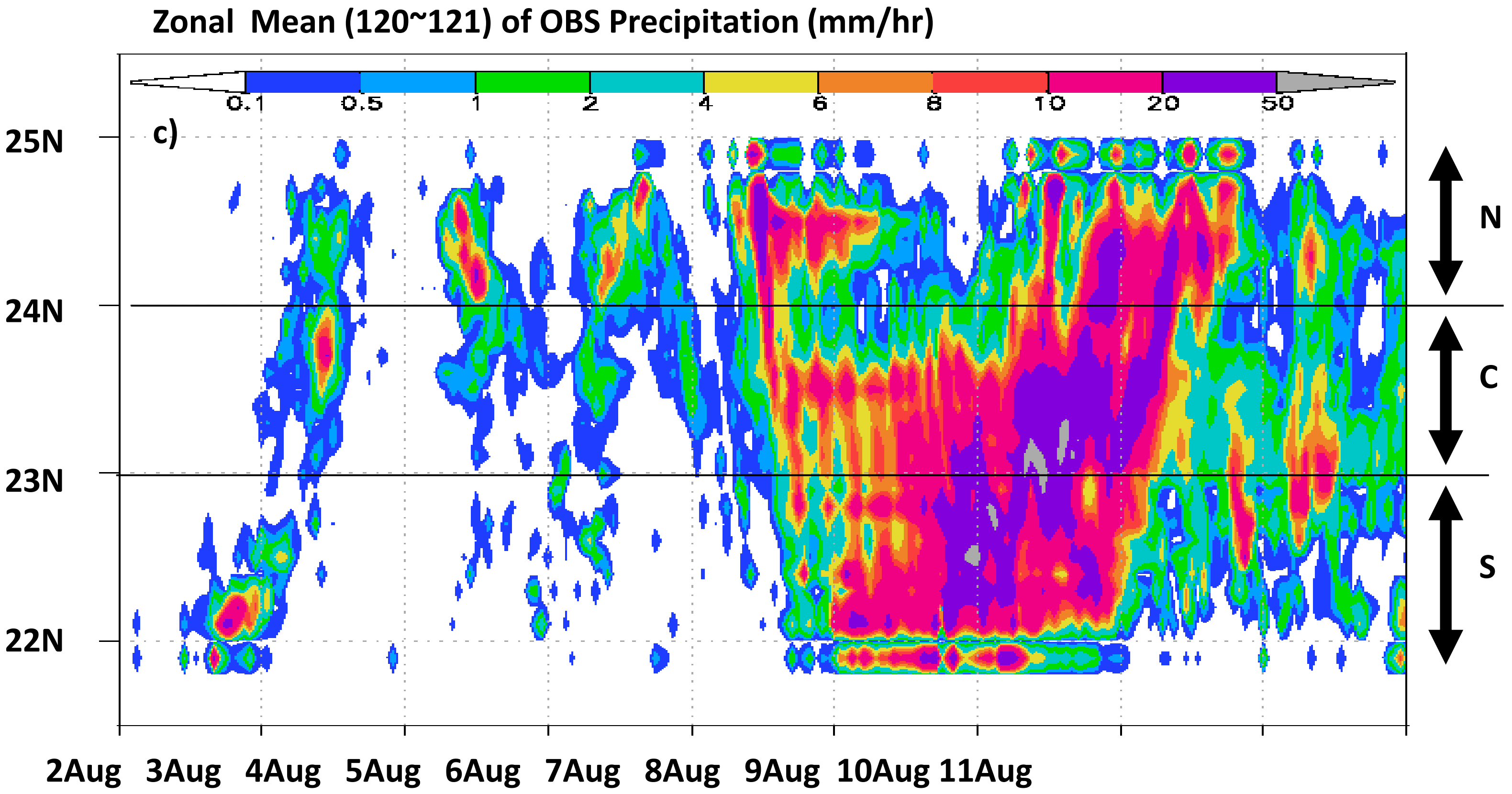


96 hrs observation rainfall (mm)



(Lin et al. 2011, ACP)





Spatial and temporal variations of the average rainfall in 0.1 deg latitude increments between 120 and 121 E over western Taiwan .

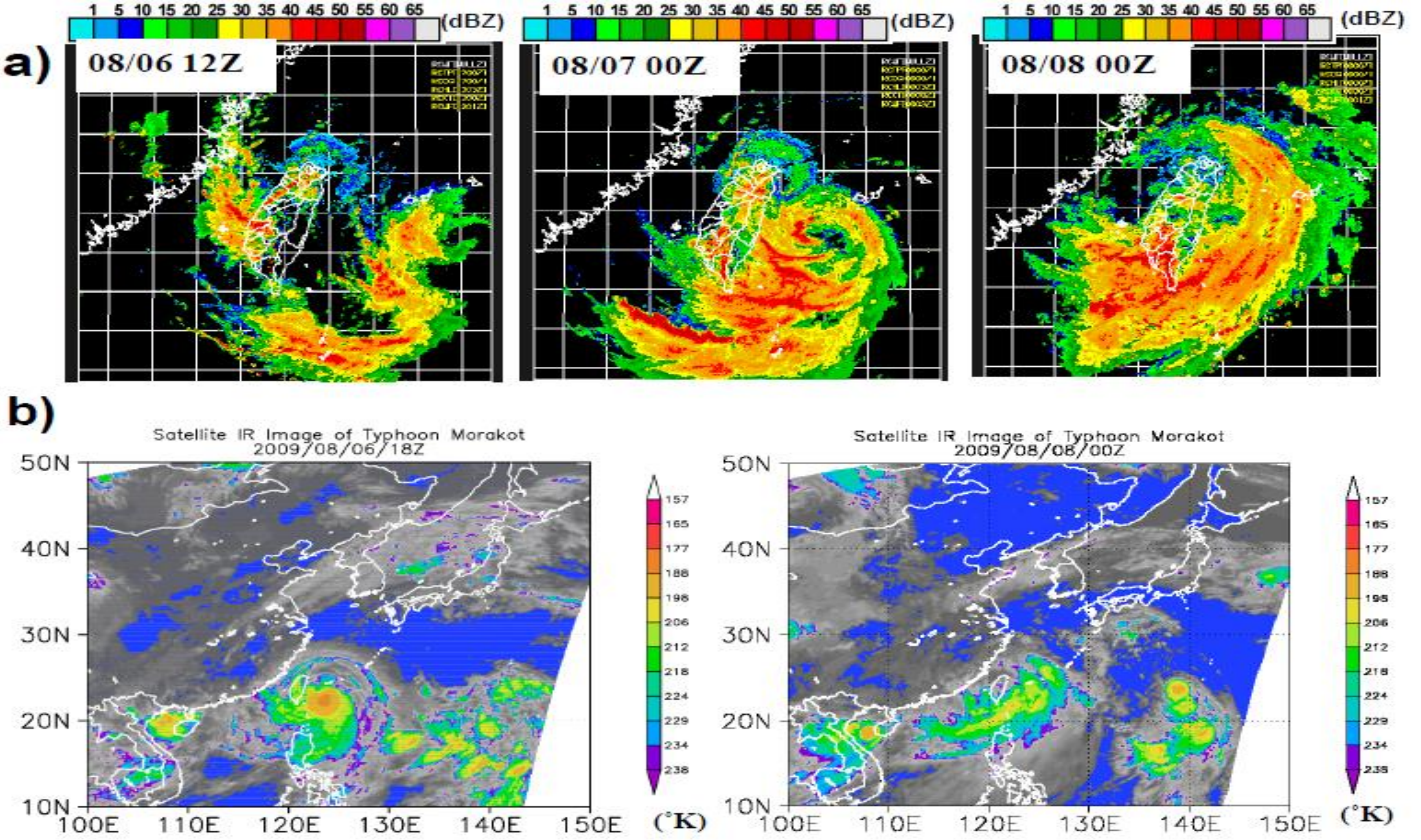


Fig. 2. (a) Composite of the maximum radar reflectivity in a volume (colored) at 12:00 UTC 6, 00:00 UTC 7 and 00:00 UTC 8 August, 2009. (b) Infrared Satellite image from Japan MTSAT satellite at 18:00 UTC 06 and 00:00 UTC 8 August 2009. The colored areas represent cold brightness temperatures (°K).

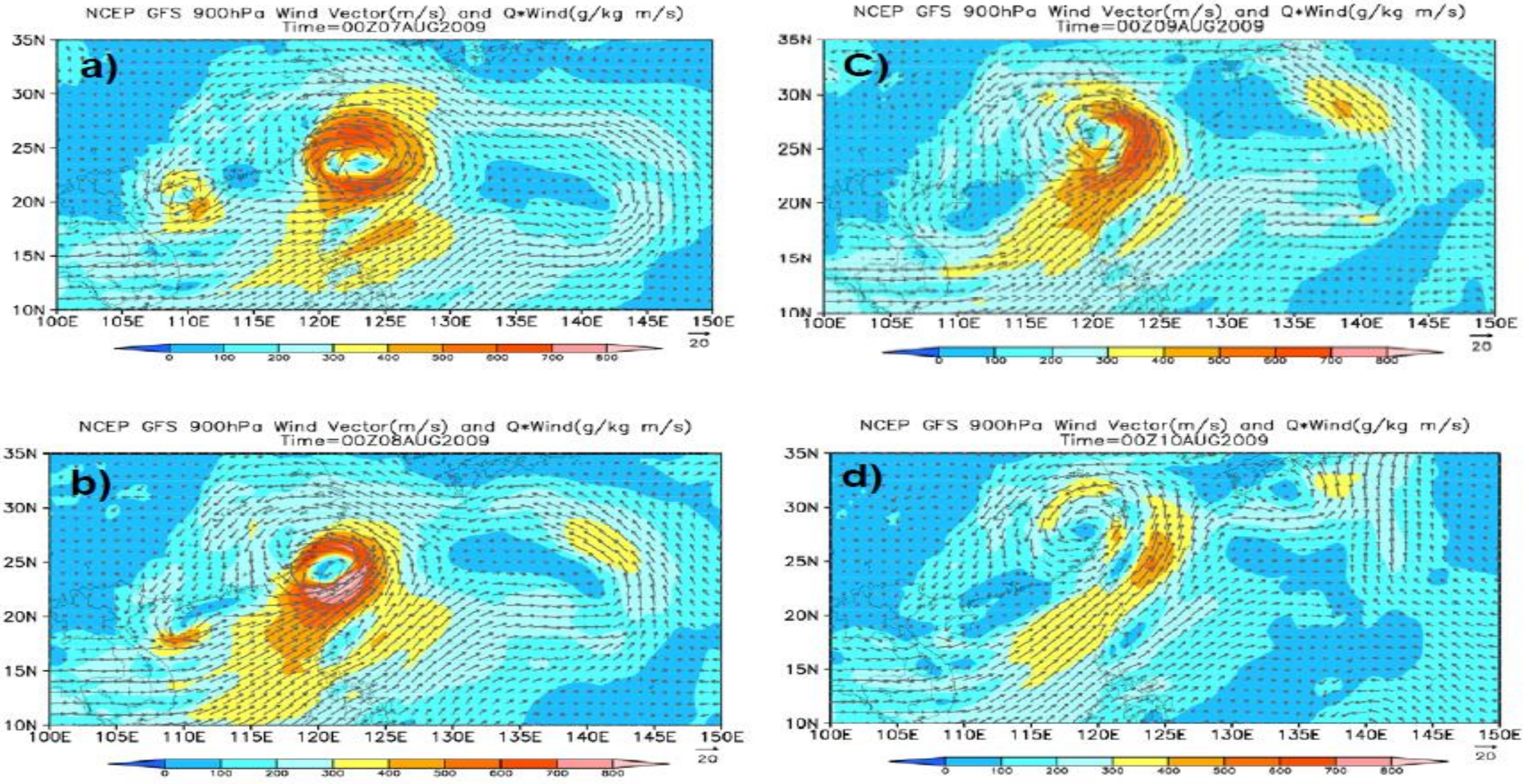
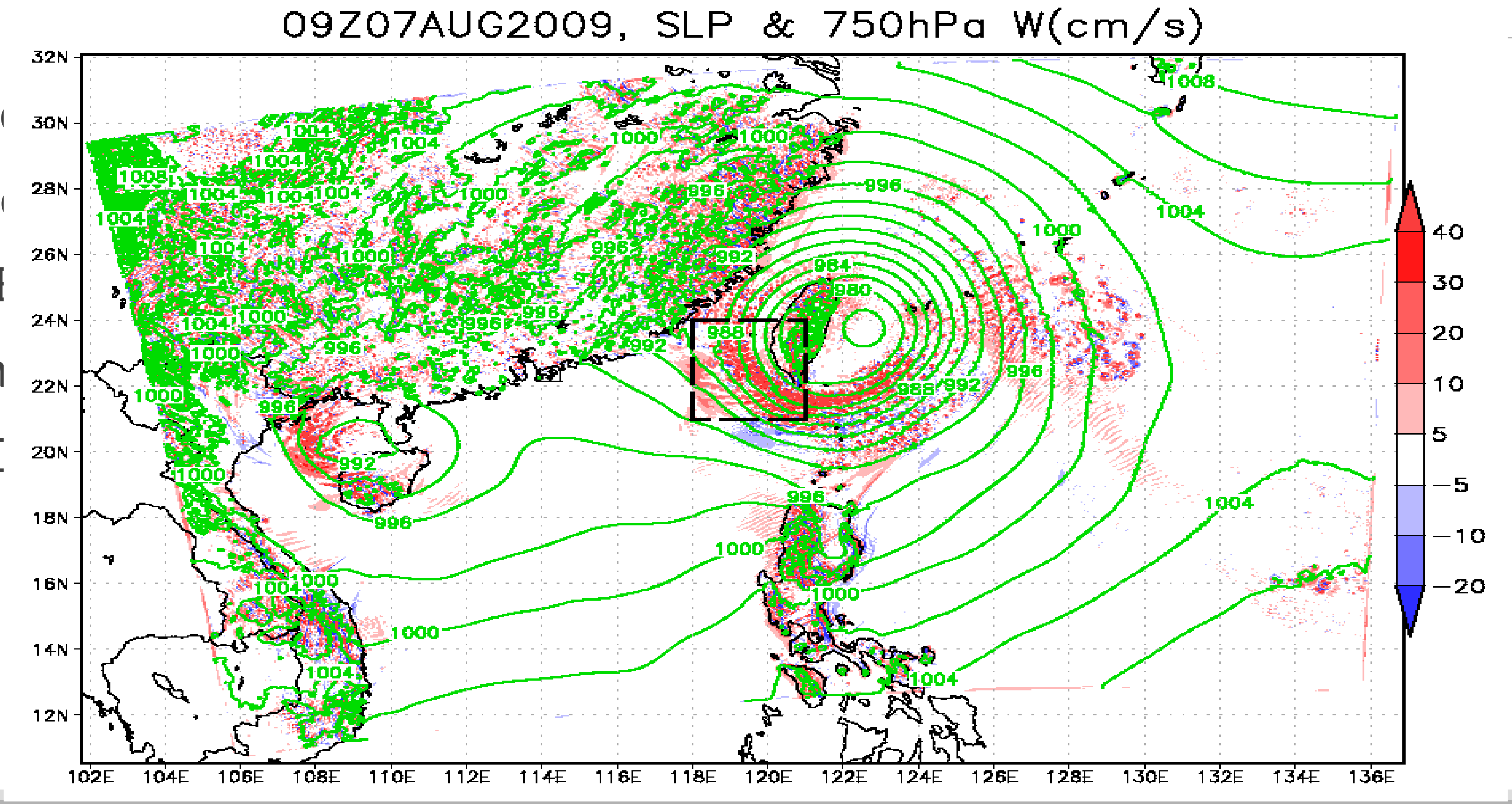
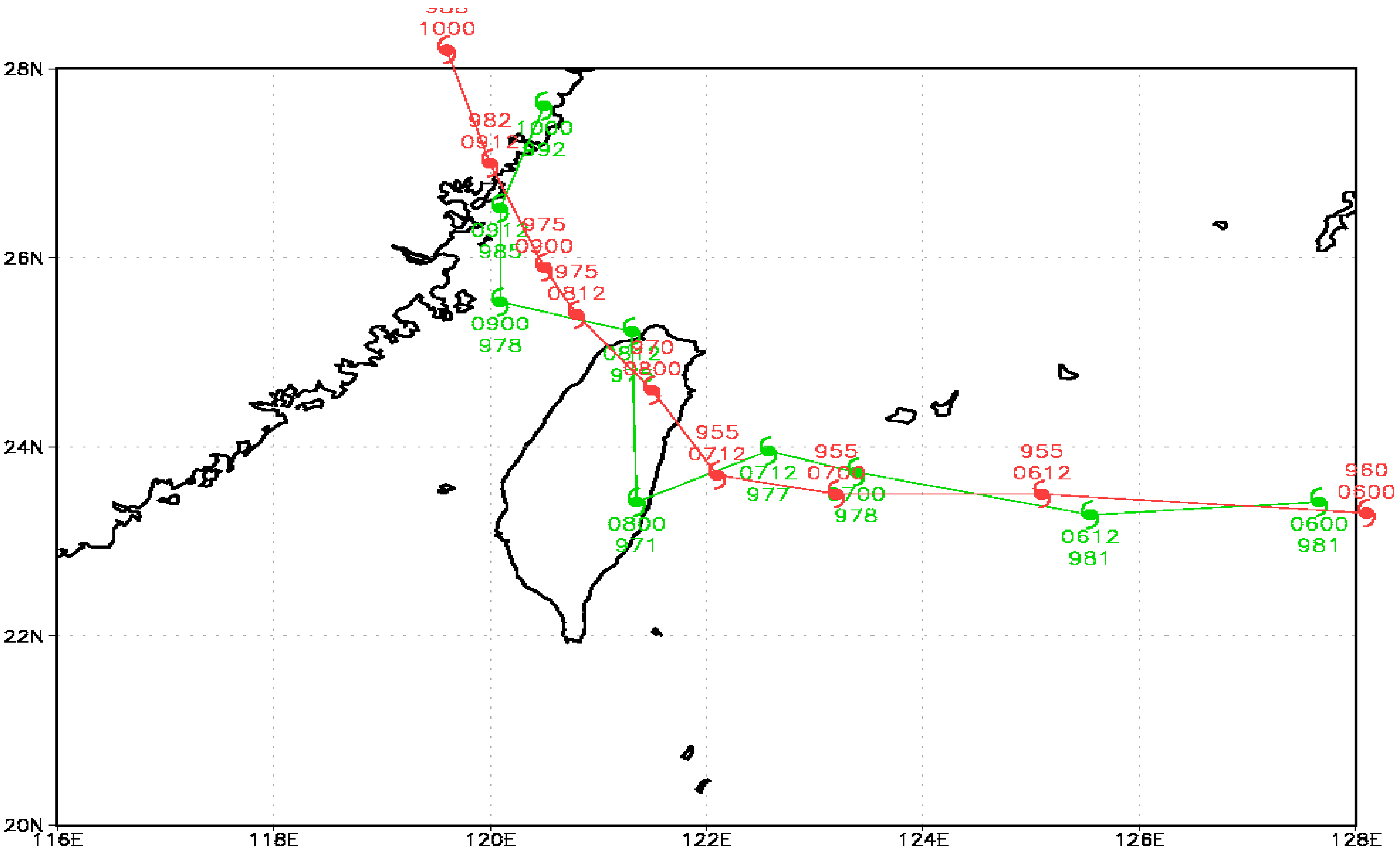


Fig. 3. **(a)**Moisture flux (colored) and wind field (arrow) deduced from NCEP GFS data at 900 hPa level at 00:00 UTC 7 August 2009. T colored scales represent the magnitude of moisture flux. The lower right corner of arrow denotes the scale of wind speed. **(b)** Same as but for 00:00 UTC 8 August 2009. **(c)** Same as **(a)** but for 00:00 UTC 9 August 2009. **(d)** Same as **(a)** but for 00:00 UTC 10 August, 200

WRF-ARW model

- D
- H
- P
- m
- F





1000
982
0912
975
0900
975
0812
970
0800
955
0712
955
0700
955
0612
960
0600
1000
992
0912
985
0900
978
0800
971
0712
977
0700
978
0612
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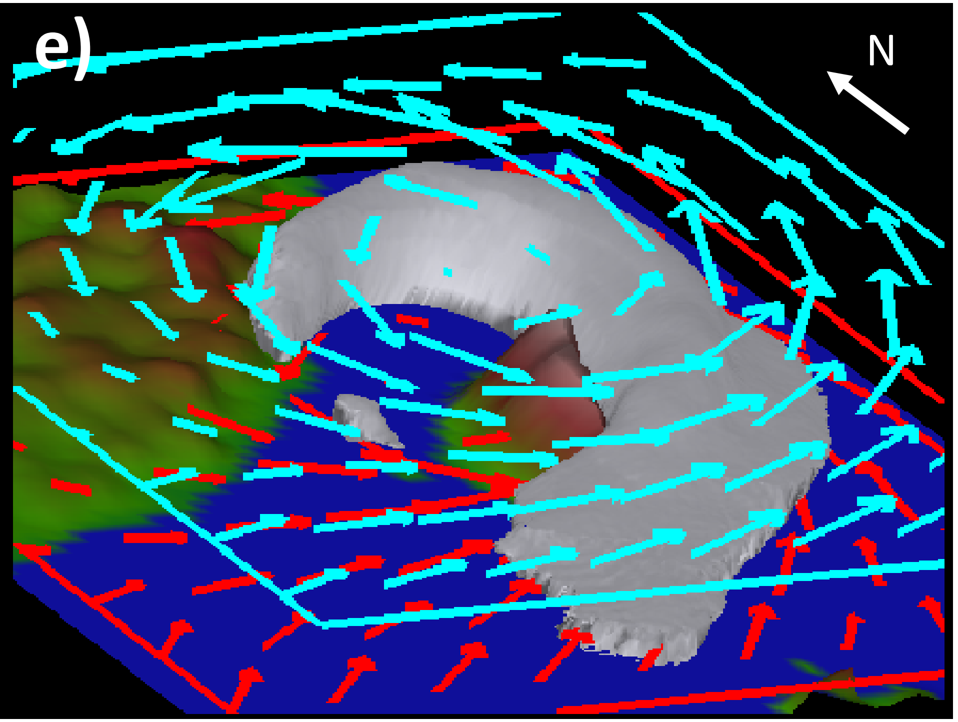
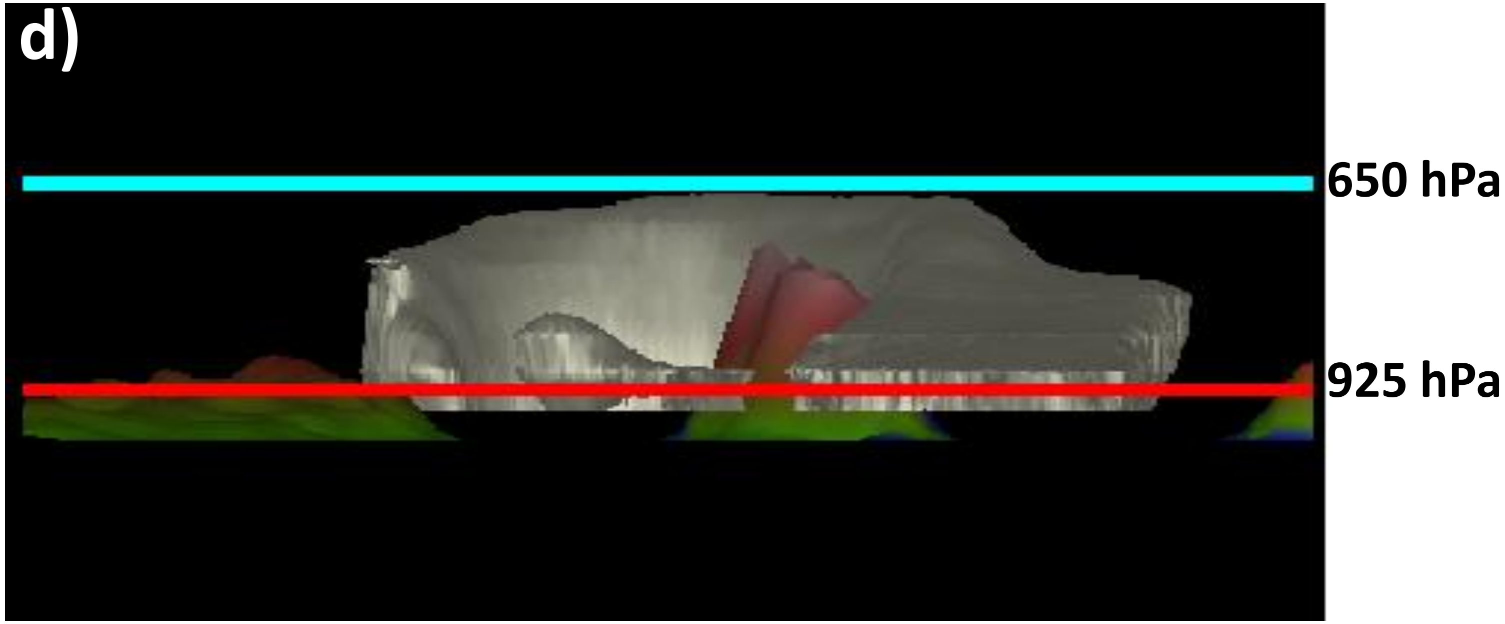
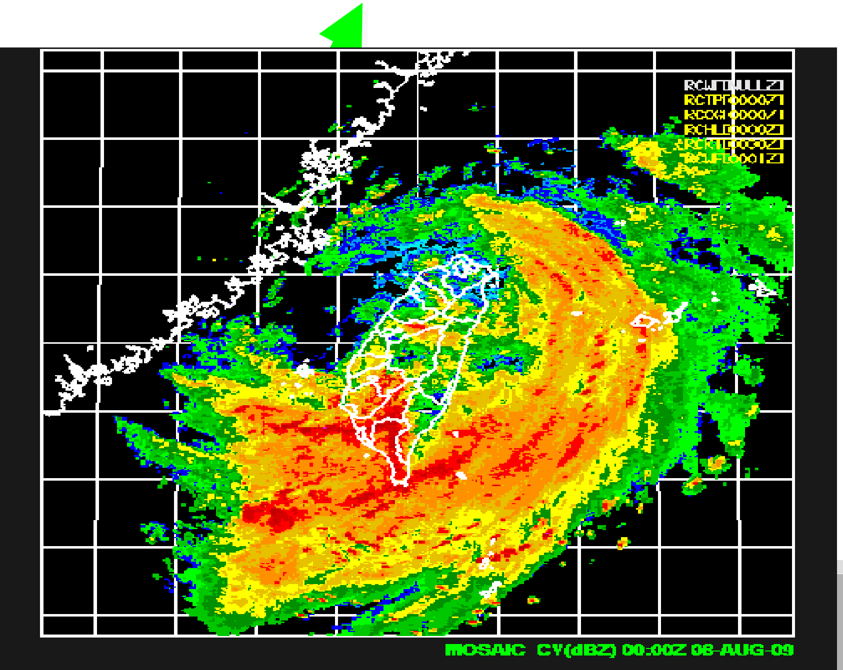
122E
124E
126E
128E







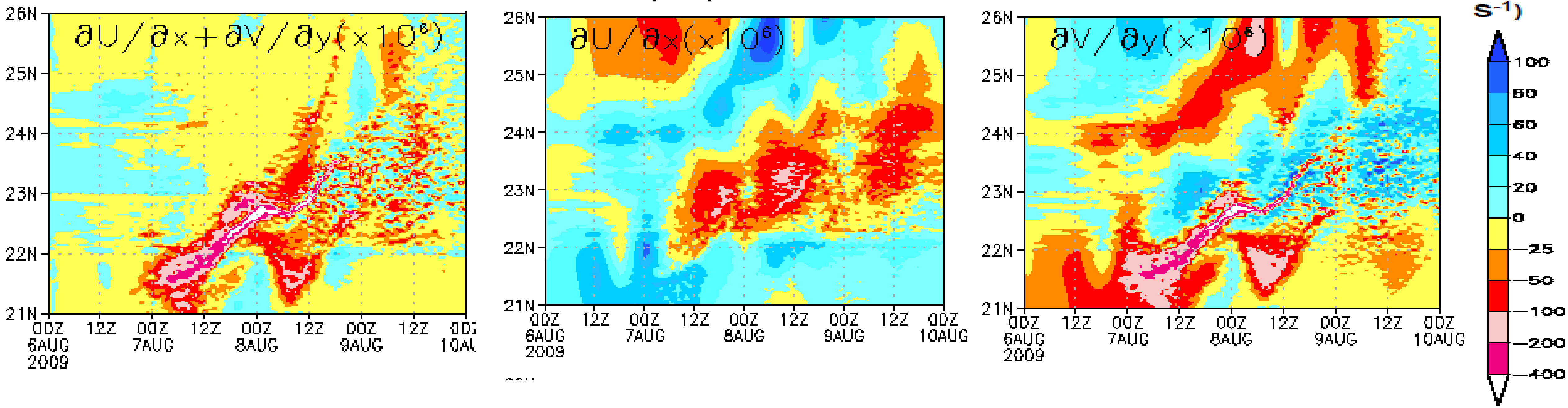
(d) A northwest-southeast vertical perspective views for depth by VIS5D for the moisture flux at 00:00 UTC 8 August taken from the direction of the arrow in (e) The grey shading is the moisture flux surface of 550 g/kg m/s.

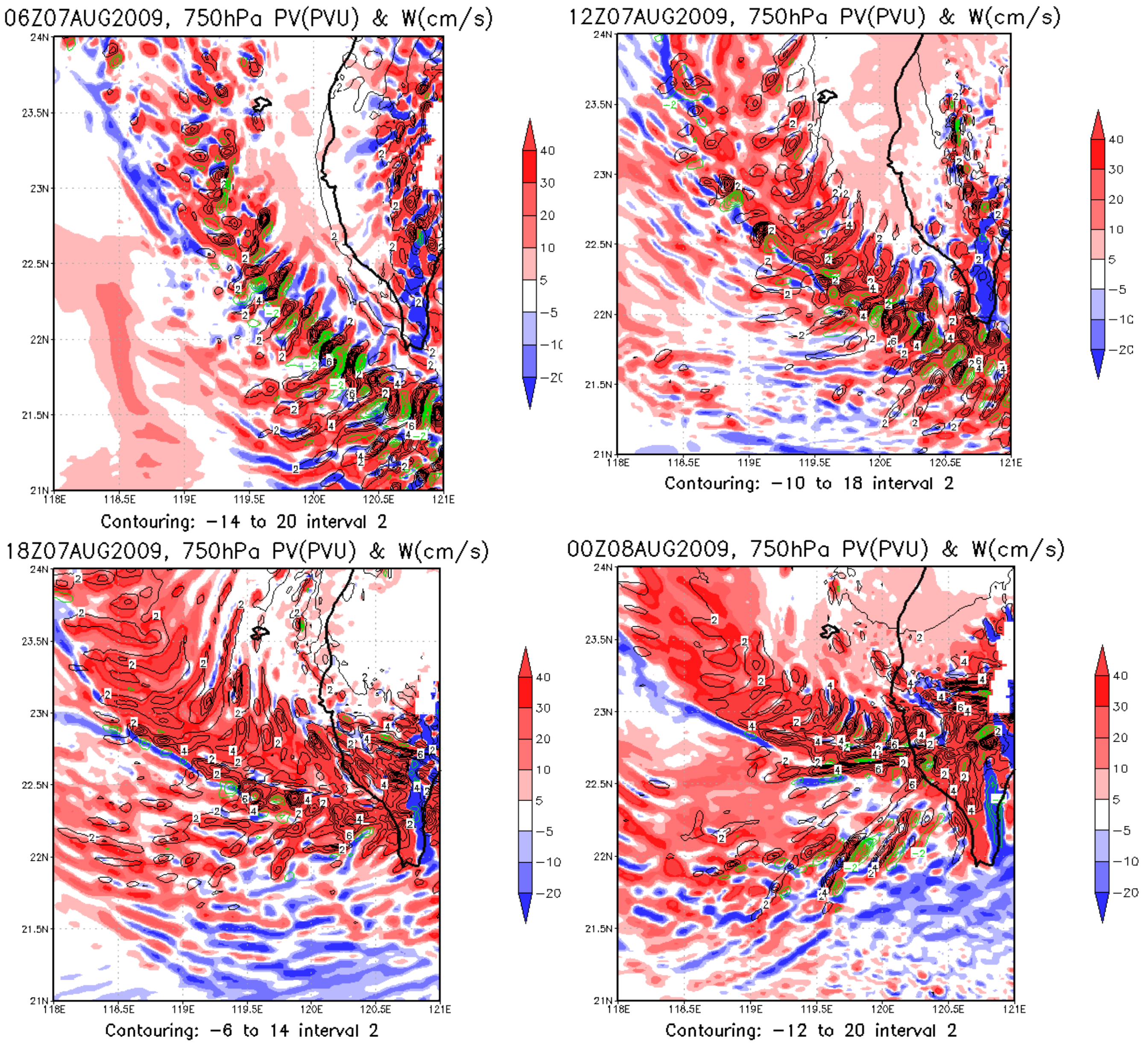
(e) Three-dimensional perspective views by VIS5D for the moisture flux at 00:00 UTC 8 August. The blue (red) arrow represents the wind field at 650 hPa (925 hPa). The grey shading is the moisture flux surface of 550 g/kg m/s.

(Lin et al. 2011, ACP)

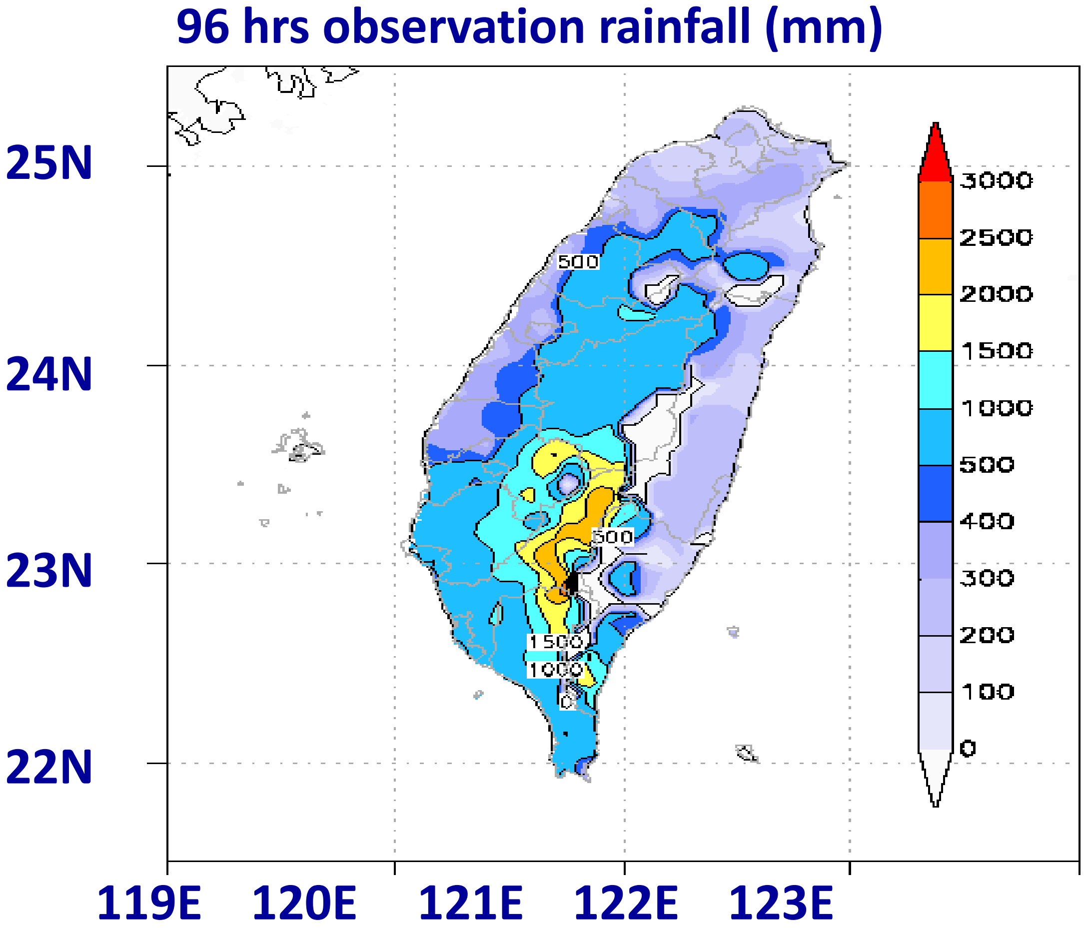
WRF 950~700 hPa Zonal Mean (120~121)
con.&div. (x10^6) contributed from E-W

Con.&div. (x10^6) contributed from NS

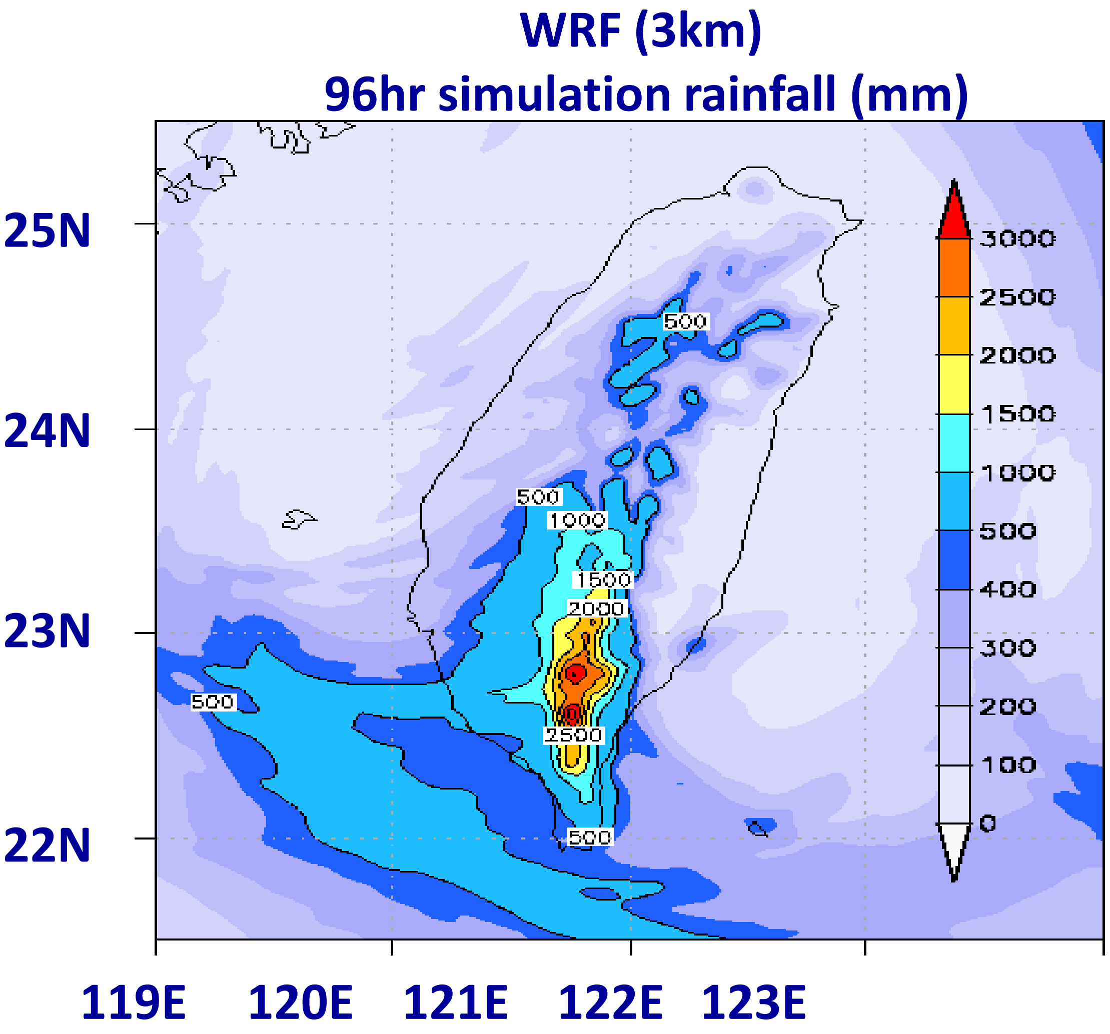




Simulation of vertical velocity fields (colored shades: positive in red and negative in blue) and potential vorticity (contours: positive in black and negative in green, interval:2 PVU) at 750 hPa for (a) 06Z 07 August (b), 12Z 07 August (c) 18Z 07 August and (d) 00Z 08 August.



96 hrs observation rainfall (mm)
25N
24N
23N
22N
119E
120E
121E
122E
123E
3000
2500
2000
1500
1000
500
400
300
200
100
0



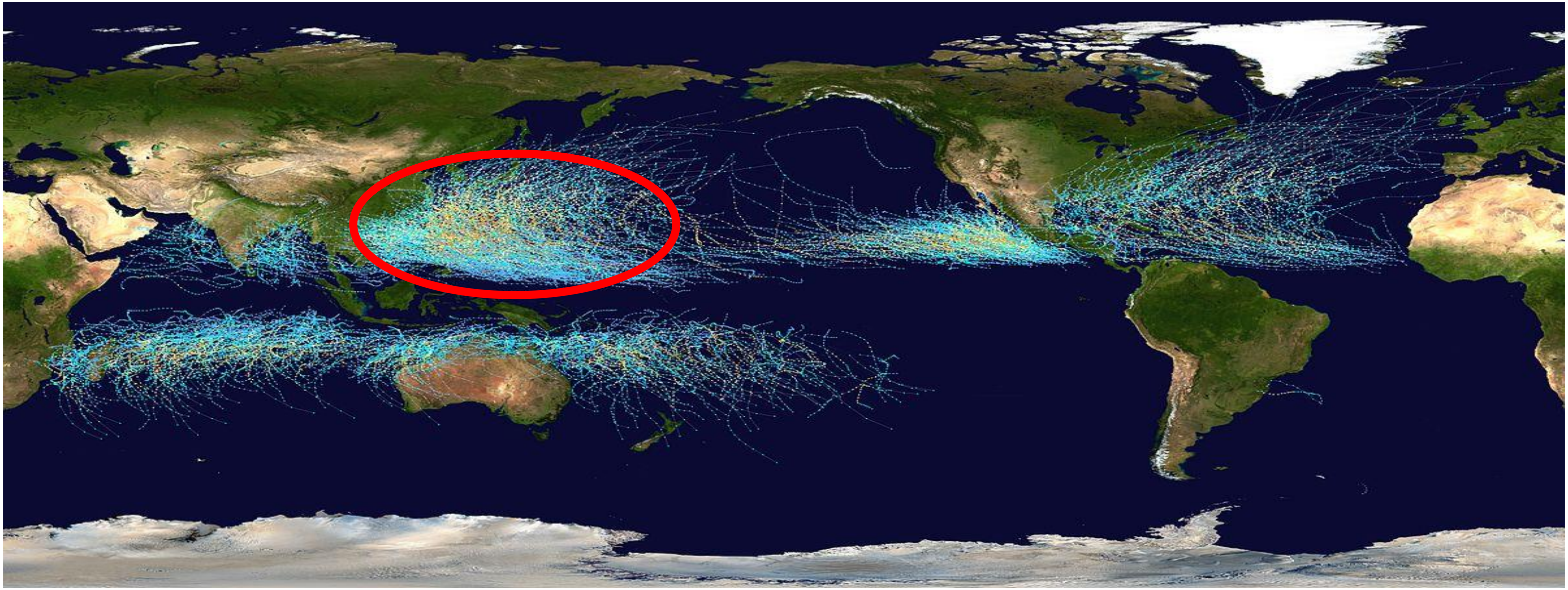
WRF (3km)
96hr simulation rainfall (mm)
25N
24N
23N
22N
119E
120E
121E
122E
123E
3000
2500
2000
1500
1000
500
400
300
200
100
0

Summary Morakot Typhoon study

- Based on our data analyses, the first stage of the heavy rainfall during 7 and early 8 August was dominated by the N-S convergence south of 23°N in the low troposphere, and the second stage during the rest of 8 August was controlled by the E-W convergence and mountain blocking between 22.5 and 24°N.

- From the fine-scale numerical simulation it seems that the heavy rainfall was caused not only by the convergence itself when it interacted with the topography, but also by the wave-train convective cells within the typhoon's main rainband.

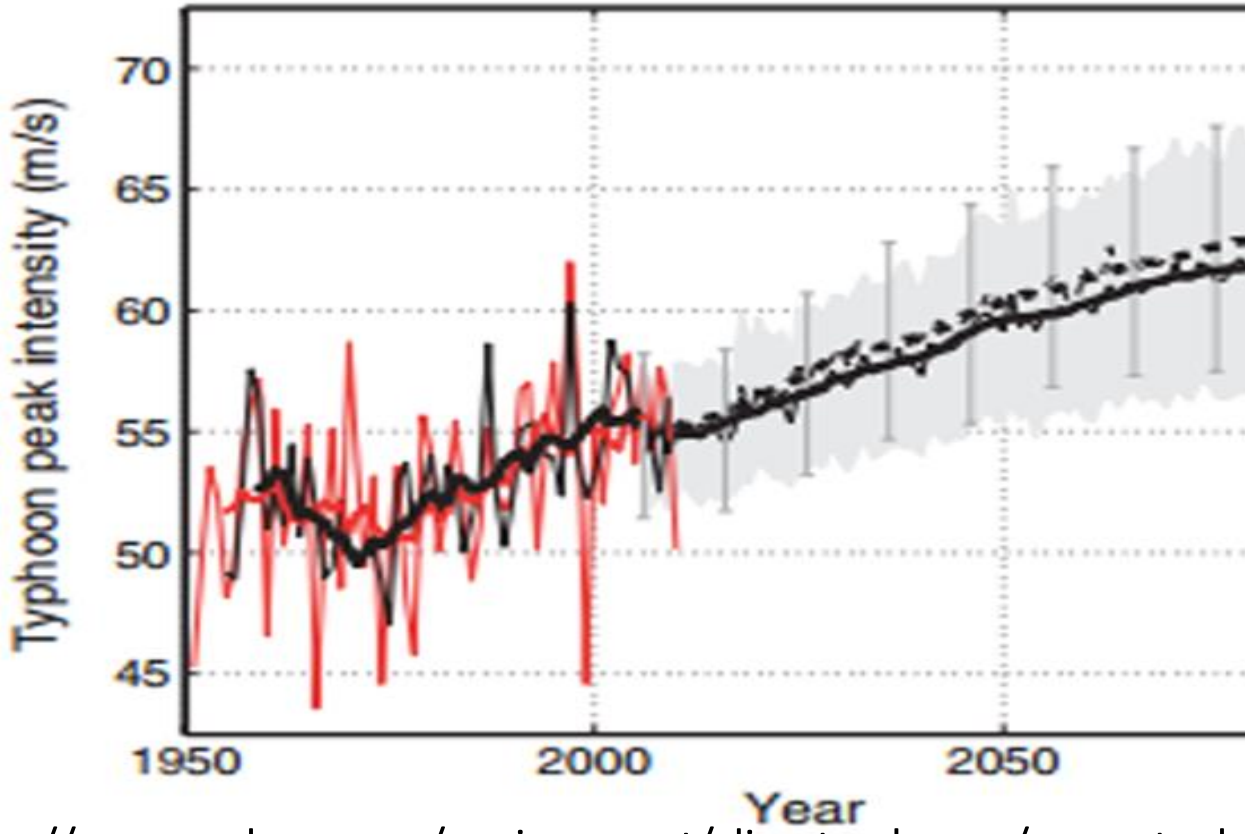
Thank you…



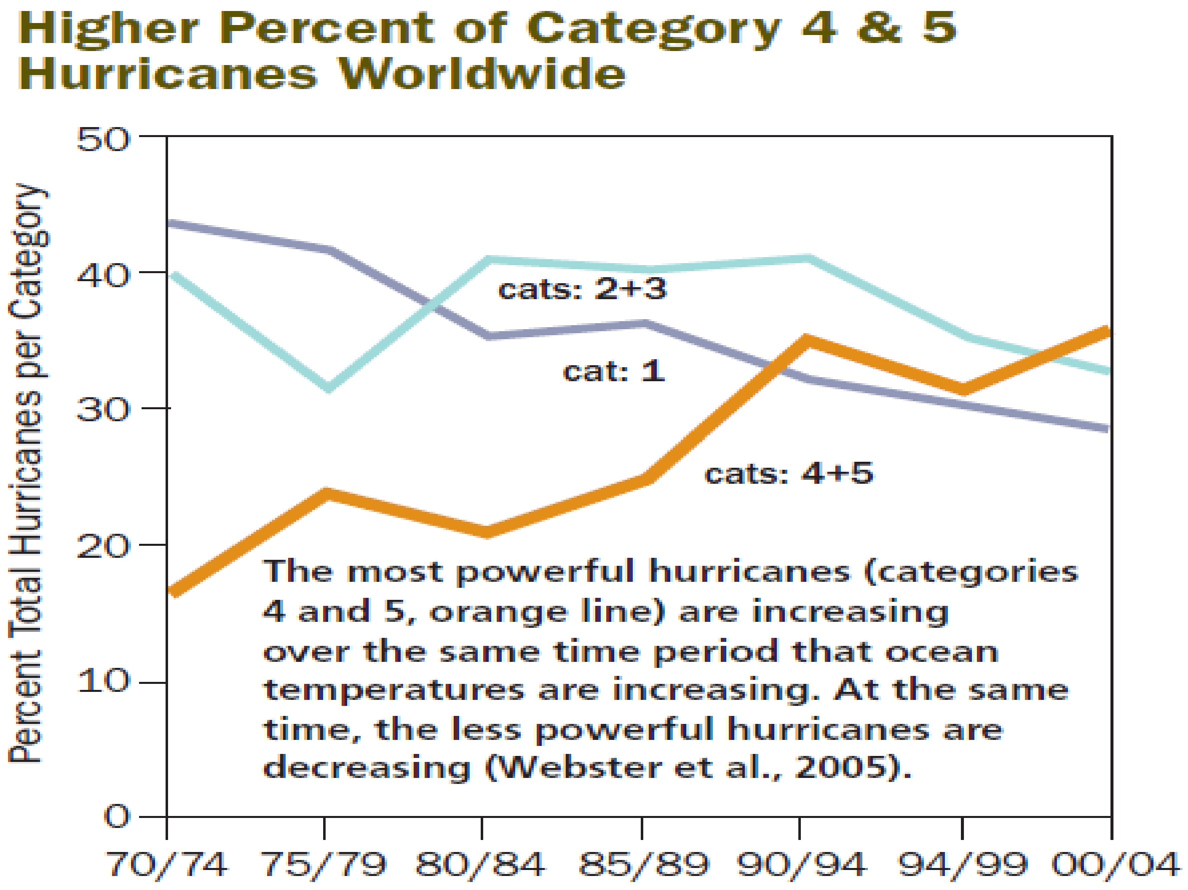
Tracks of all tropical cyclones which formed worldwide between 1985 and 2005.

(from Joint Typhoon Warning Center)

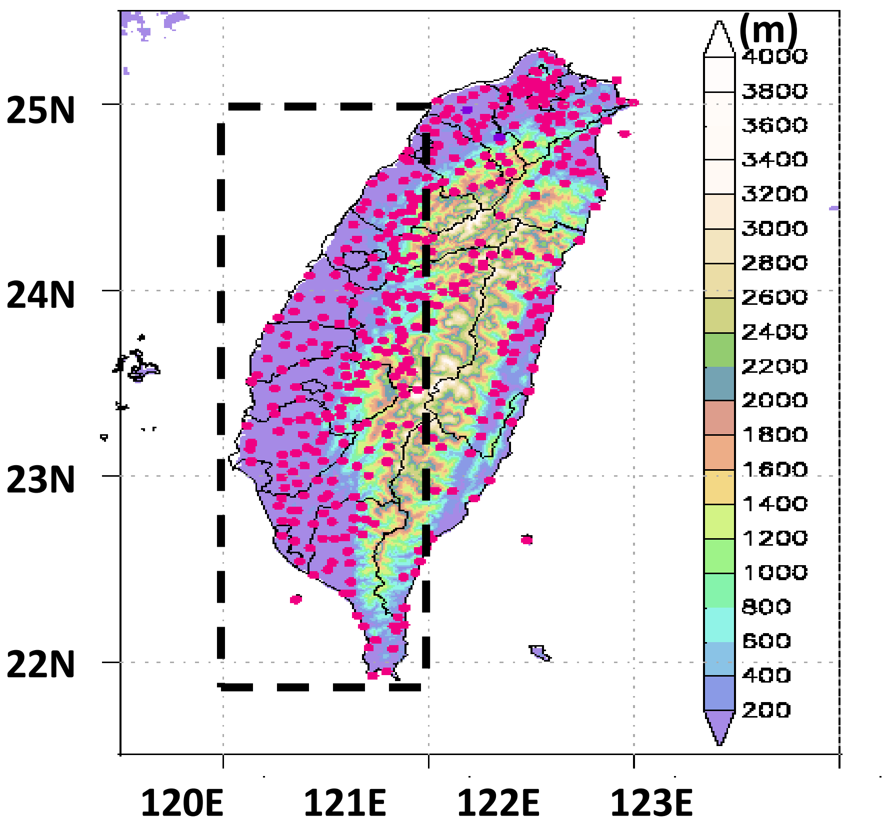
Future Warming and Typhoon

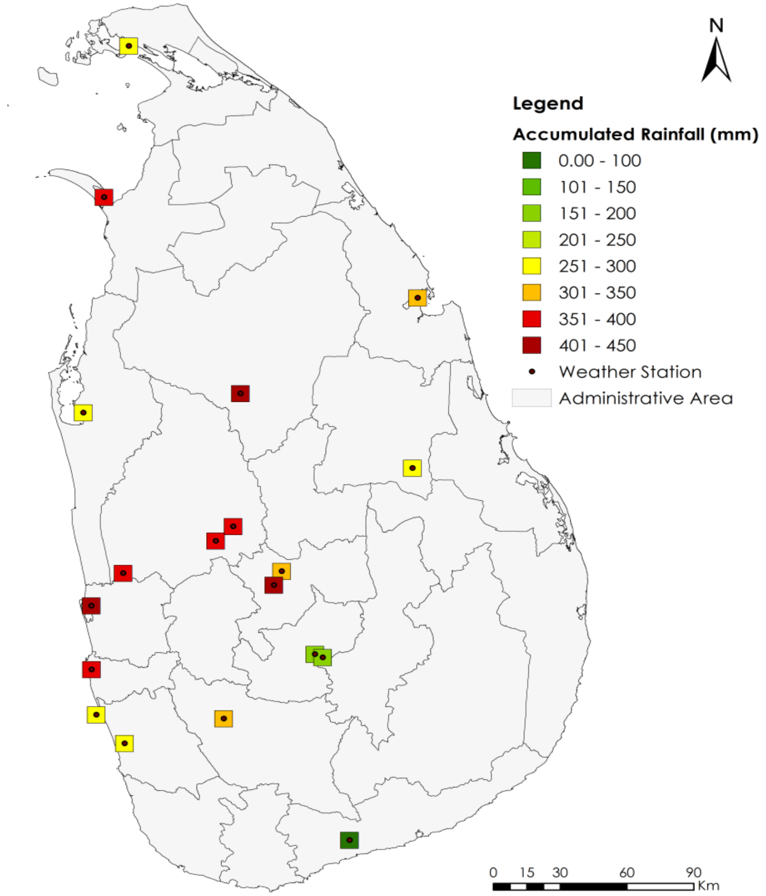


http://www.smh.com.au/environment/climate-change/super-typh
to-increase-in-strength-with-climate-change-researchers-find-2015υ5ʒ9-
ghcbfs.html



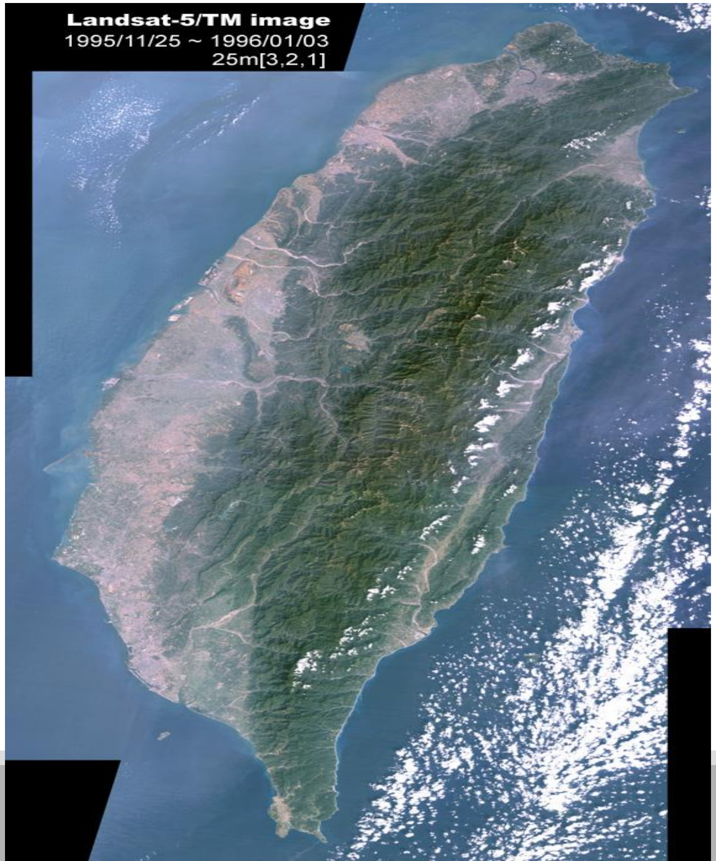
426 stations of rain gauge

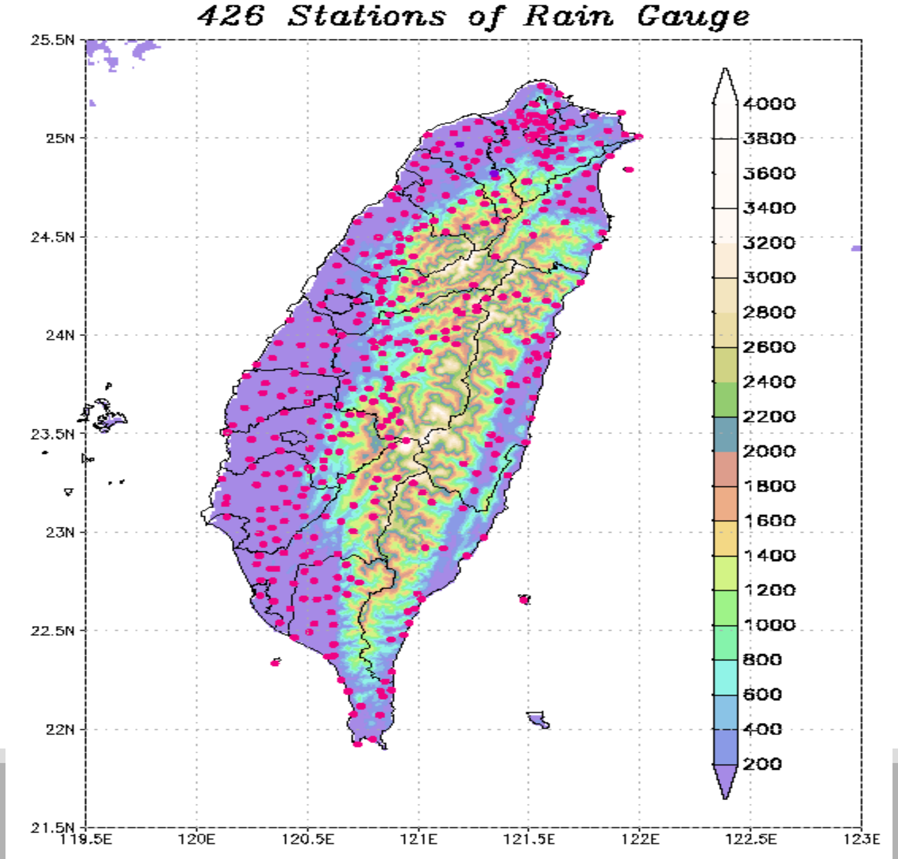




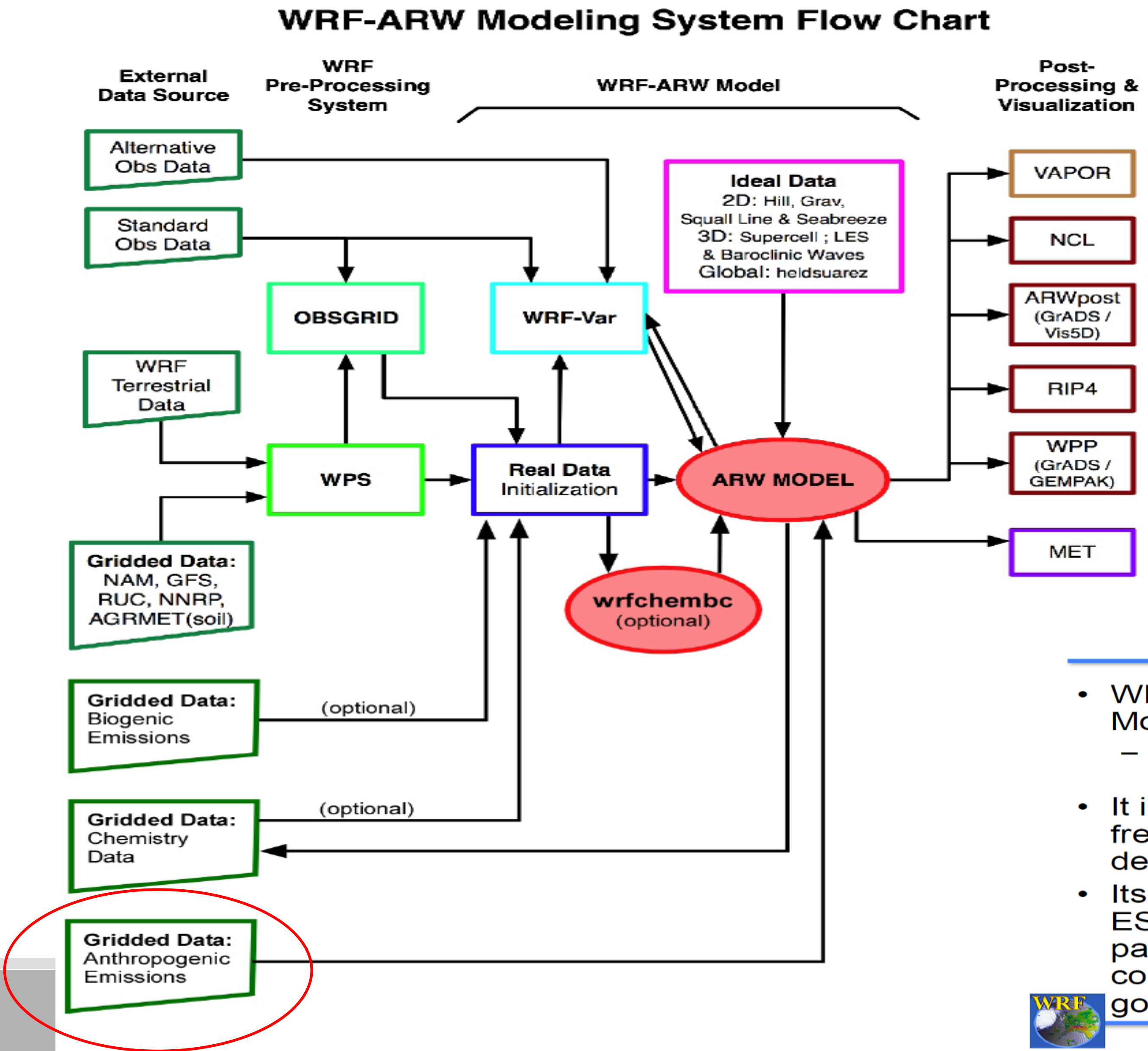
How good can we simulate (predict) typhoon ?

- I.C., B.C. and resolution :the forecasting of track, intensity
- dynamic of Typhoon circulation and their interaction with the Taiwan terrain
- mesoscale wind and precipitation distribution





Model:WRF/WRF-Chem

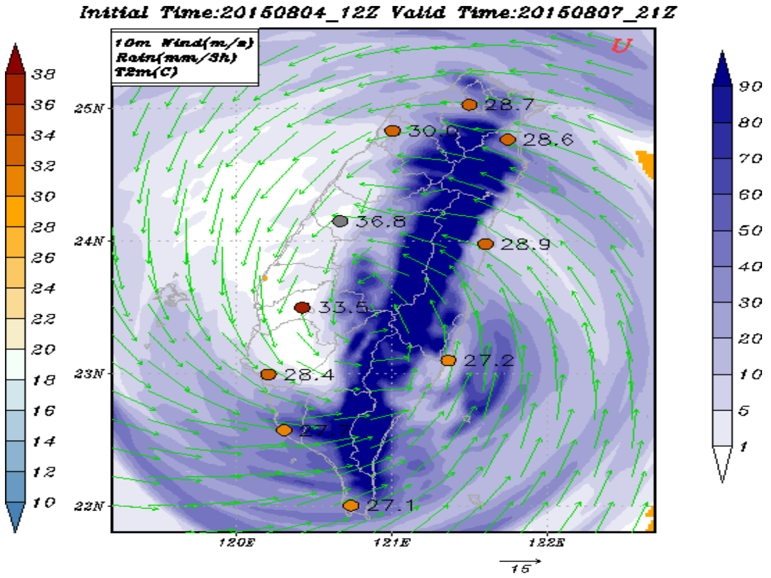


What is WRF?

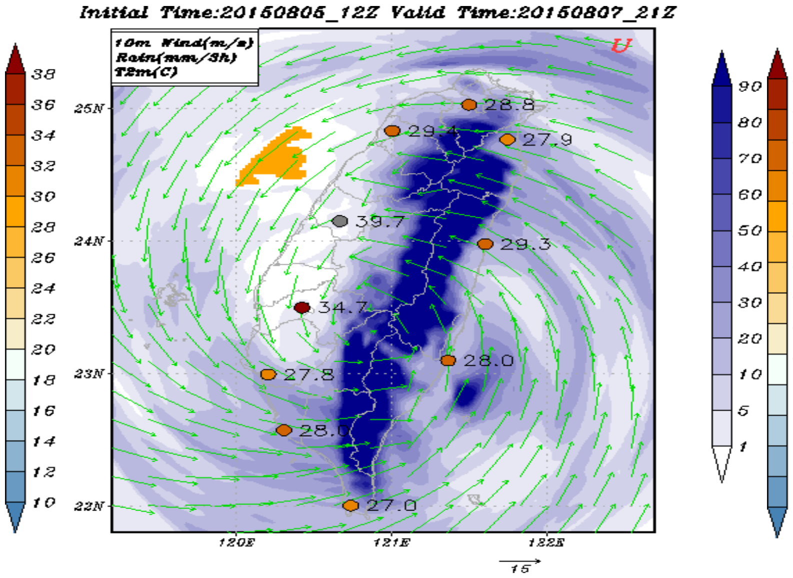
- WRF: Weather Research and Forecasting Model
  - Used for both research and operational forecasting
- It is a supported "community model", i.e. a free and shared resource with distributed development and centralized support
- Its development is led by NCAR, NOAA/ESRL and NOAA/NCEP/EMC with partnerships at AFWA, FAA, DOE/PNNL and collaborations with universities and other government agencies in the US and overseas

Initial condition impacts on landfall simulation

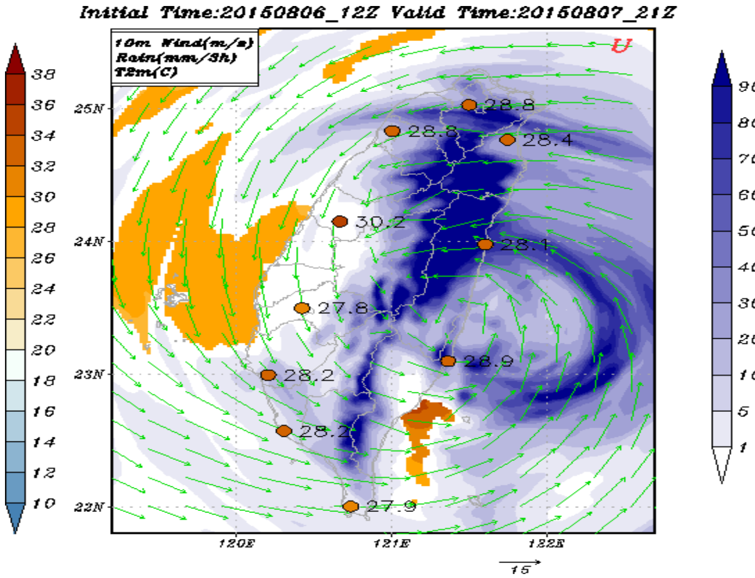
08/04-12Z



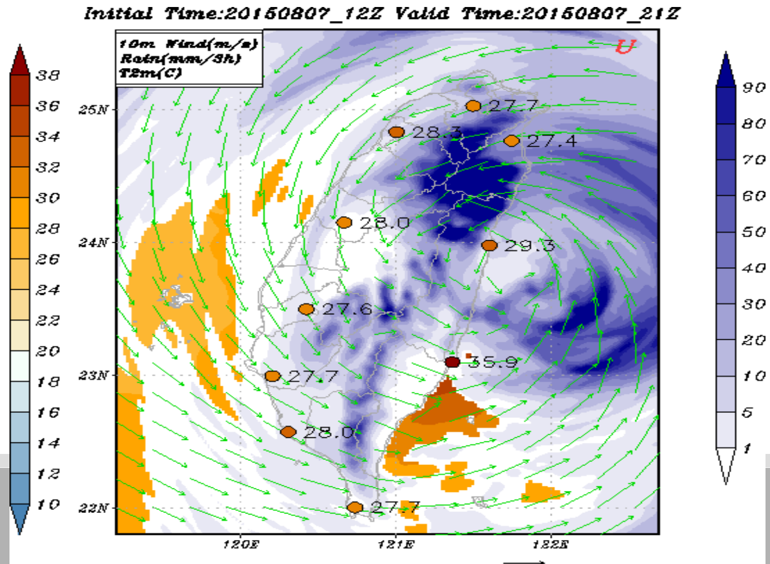
08/05-12Z

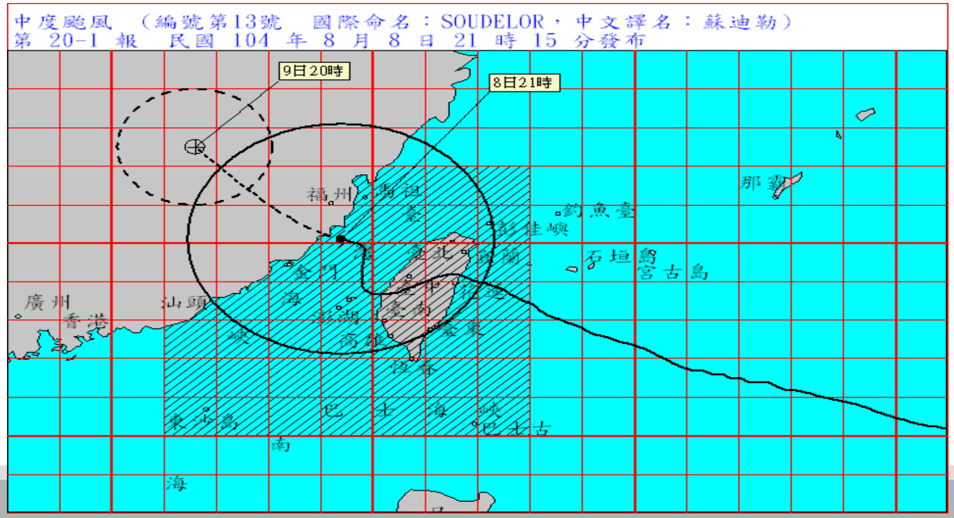


08/06-12Z

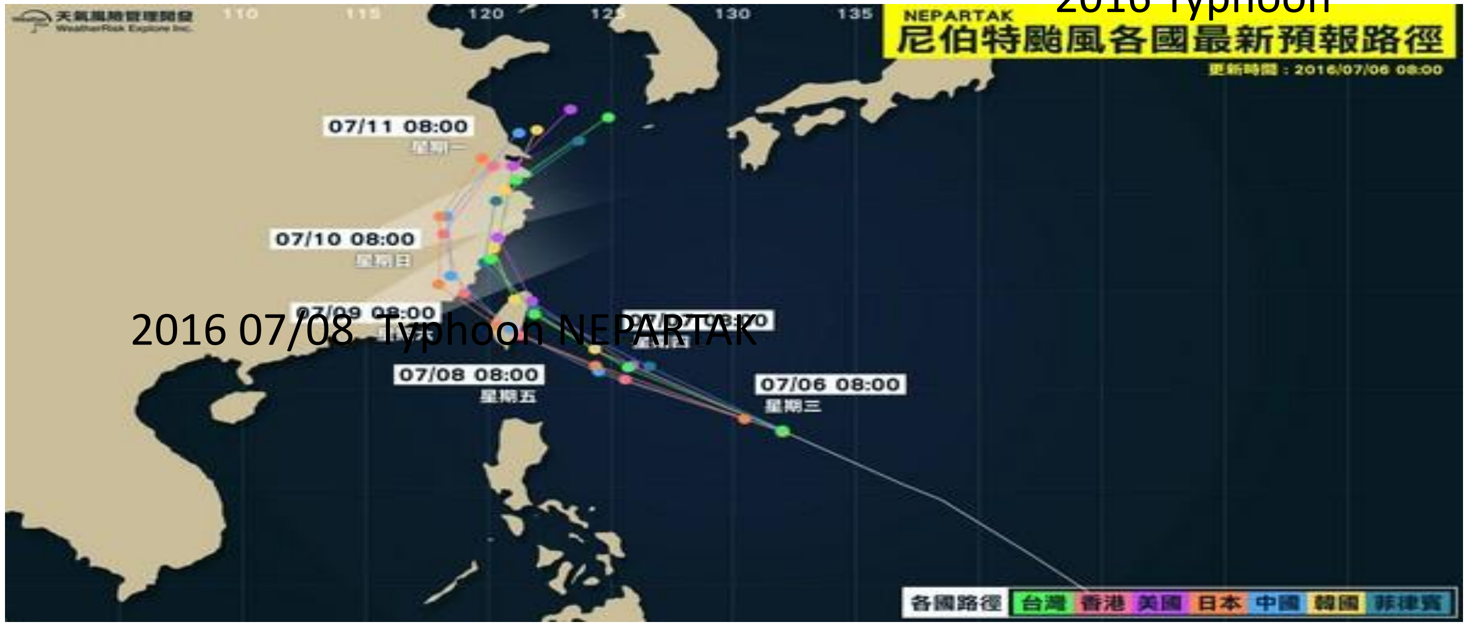


08/07-12Z

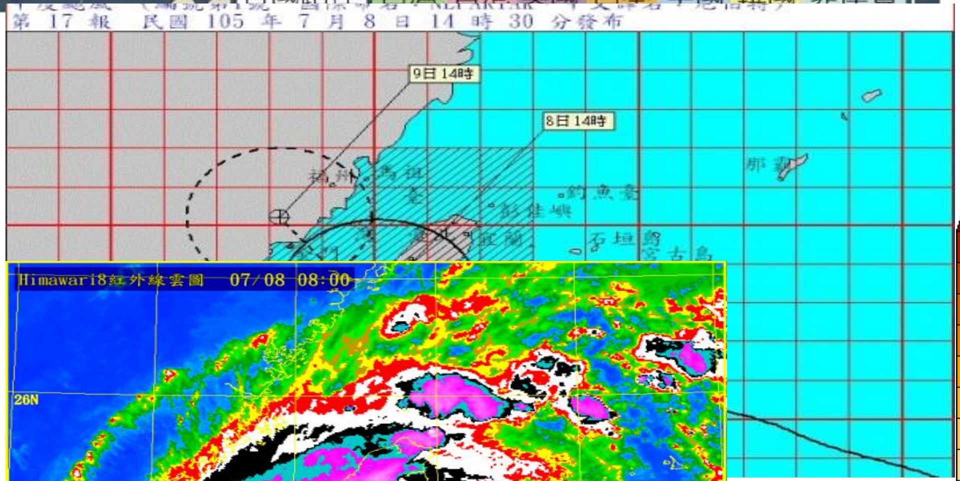


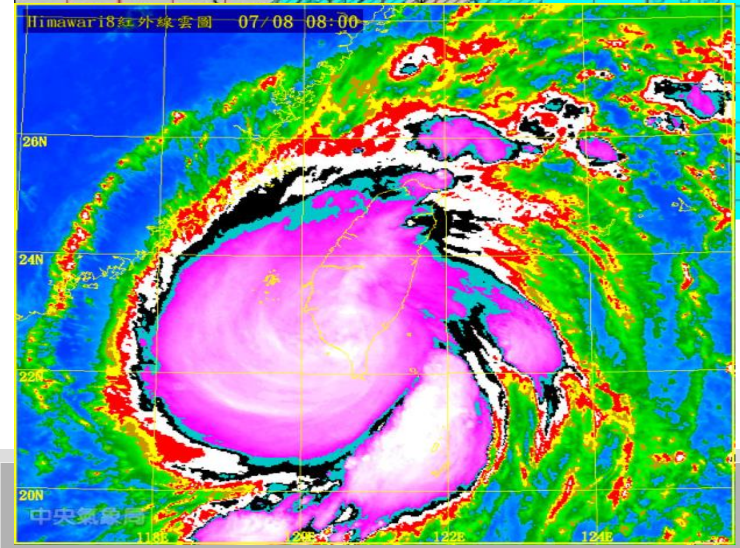


2016 Typhoon

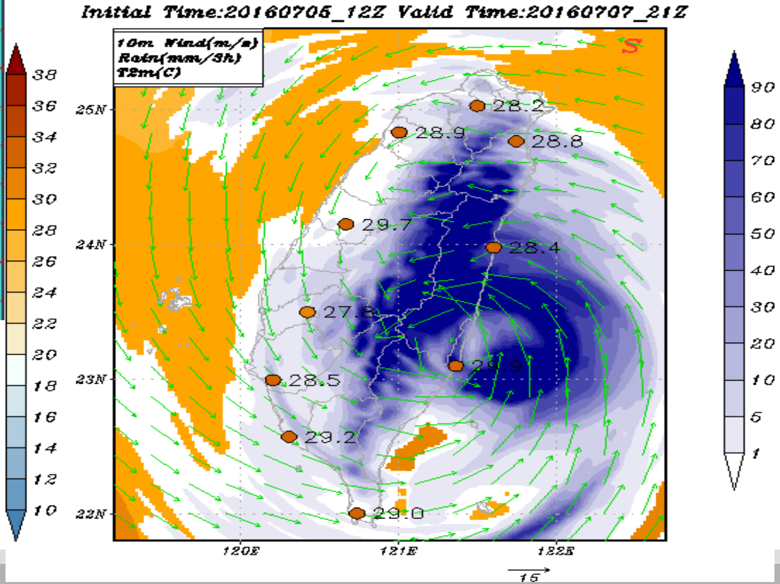


2016 07/08 Typhoon NEPARTAK





07/05 20LST → 07/08 05LST



07/06 20LST → 07/08 05LST