ATMOSPHERIC RIVERS DETECTION ALGORITHM

Introduction

- Atmospheric rivers are relatively long, narrow regions in the atmosphere – like rivers in the sky – that transport most of the water vapor outside of the tropics. While atmospheric rivers can vary greatly in size and strength, the average atmospheric river carries an amount of water vapor roughly equivalent to the average flow of water at the mouth of the Mississippi River. When the atmospheric rivers make landfall, they often release this water vapor in the form of rain or snow.

- The primary objective of our algorithm is to detect Atmospheric Rivers (ARs) and accurately determine their landfall times. This enables early identification of potential high-impact weather events, allowing for timely disaster preparedness and mitigation measures in vulnerable regions.

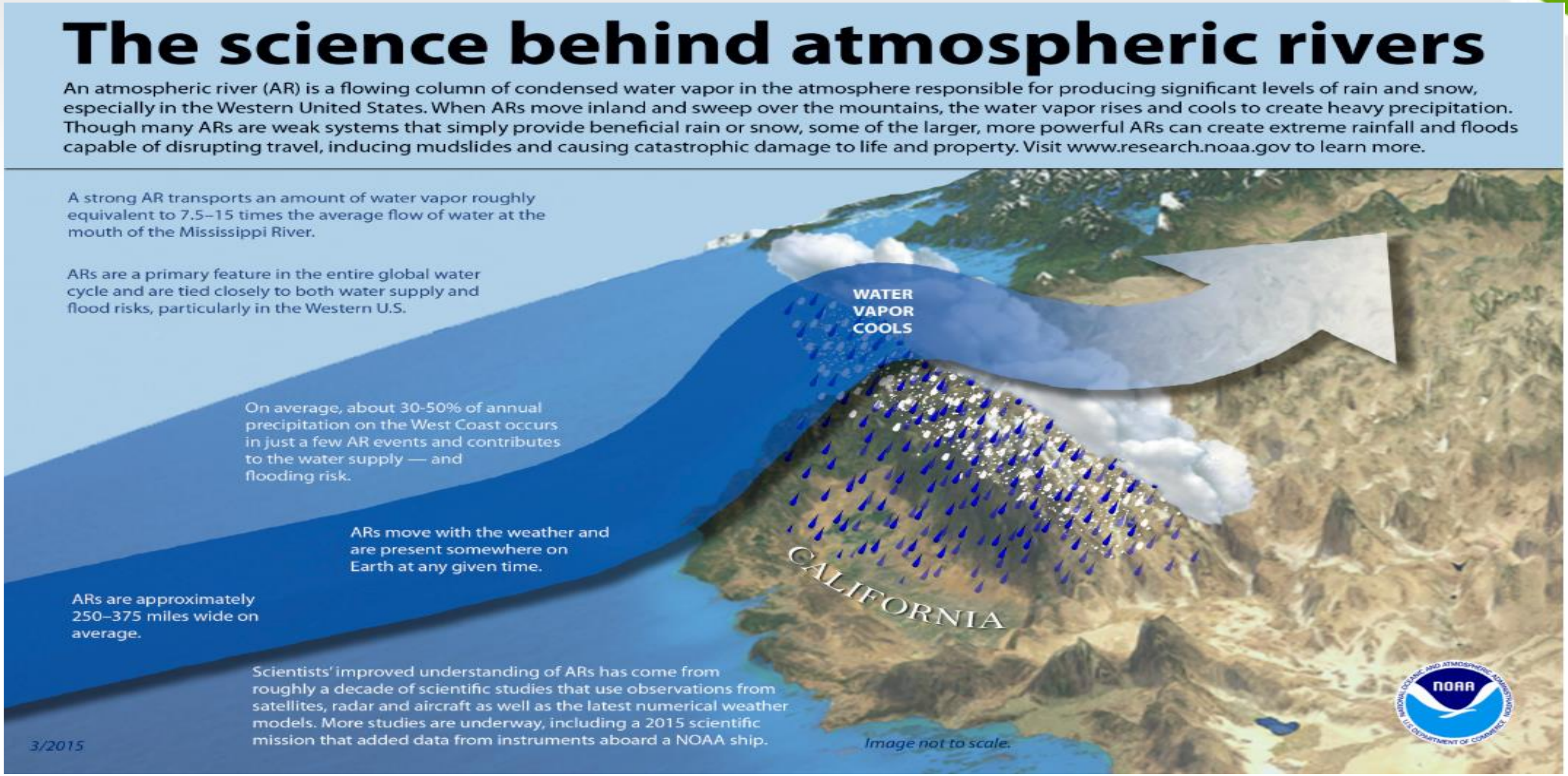


Figure 1 : Illustration explaining the science behind atmospheric rivers, highlighting their moisture transport mechanisms and impacts on the U.S. West Coast (Source: NOAA, 2015).

OBJECTIVE

1. **IVT Calculation:**

- Compute the Integrated Vapor Transport (IVT) values over the area of interest using reanalysis data.

2. **AR Object Identification:**

- Apply a set of detection criteria to the IVT field to identify potential Atmospheric River (AR) objects. These criteria typically include:
- Minimum length threshold
- Length-to-width ratio constraint
- Predominantly poleward IVT direction

3. **Object Segmentation and Boundary Detection:**

- Delineate the spatial boundaries of each identified AR object to isolate it from the surrounding atmosphere.

4. Axis Identification:

- Trace the central axis of each AR object, typically aligned along the highest IVT values within the object's boundary, representing the AR’s main transport corridor.

5. Cross-sectional IVT Calculation:

- For each AR object, draw lines perpendicular to its axis and compute the total IVT across these cross-sections. This helps in quantifying the intensity and structure of moisture transport.

6. Test the algorithm with different data available

DATA USED:

- ERA5 Reanalysis data (hourly data on pressure levels from 1940 to present) for IVT calculation

  Source: European Centre for Medium-Range Weather Forecasts (ECMWF) through the Copernicus Climate Data Store (CDS).

- ERA5 Reanalysis data(hourly data on single levels from 1940 to present) for IWV calculation

  Source: European Centre for Medium-Range Weather Forecasts (ECMWF) through the Copernicus Climate Data Store (CDS).

- INSAT 3D/3R satellite data

  Source: India Meteorological Department (IMD) and Indian Space Research Organisation (ISRO).

- AMSR satellite data

  Source: NASA’s Earthdata portal.

- GFS data (Forecast data)

  Source: National Centers for Environmental Prediction (NCEP), accessed via NOAA.

TOOLS USED:

Development Environment:

Spyder IDE: Used for writing, debugging, and executing Python scripts for AR detection and analysis.

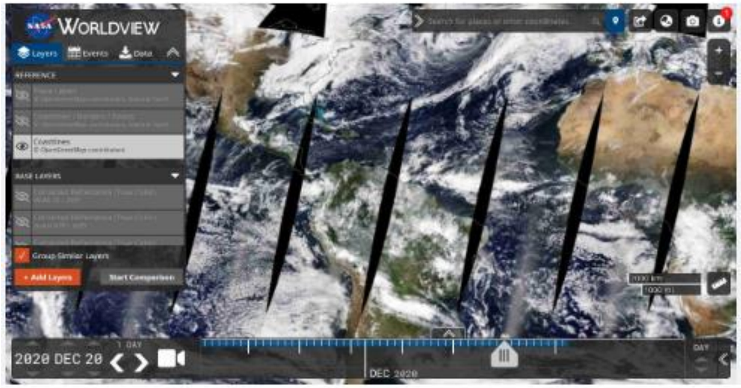
Data Sources:

ERA5 Reanalysis Data – Downloaded from the Copernicus Climate Data Store

INSAT-3D/3R Data – Accessed from the MOSDAC website

AMSR2 TPW Data – Sourced from the NASA Worldview.

GFS Forecast Data – Retrieved from the National Weather Service



Visualization Tools:

Panoply: Used to view and quickly inspect NetCDF and HDF5 datasets.

File Transfer:

FileZilla: Used for secure FTP-based data transfer between local systems and remote servers or repositories.

PYTHON LIBRARIES USED:

Numerical & Scientific Computing:

numpy – for array operations and numerical analysis

scipy – for image processing and object labeling (ndimage, label, sum, mean)

File Handling & Data Formats:

netCDF4 – to read and process NetCDF climate data

h5py – to read HDF5-formatted satellite data (e.g., AMSR2)

glob, os – for file and directory operations

Date & Time Handling:

datetime – for working with timestamps and dates

Geospatial Calculations:

geopy.distance – to compute distances on Earth for AR length/width

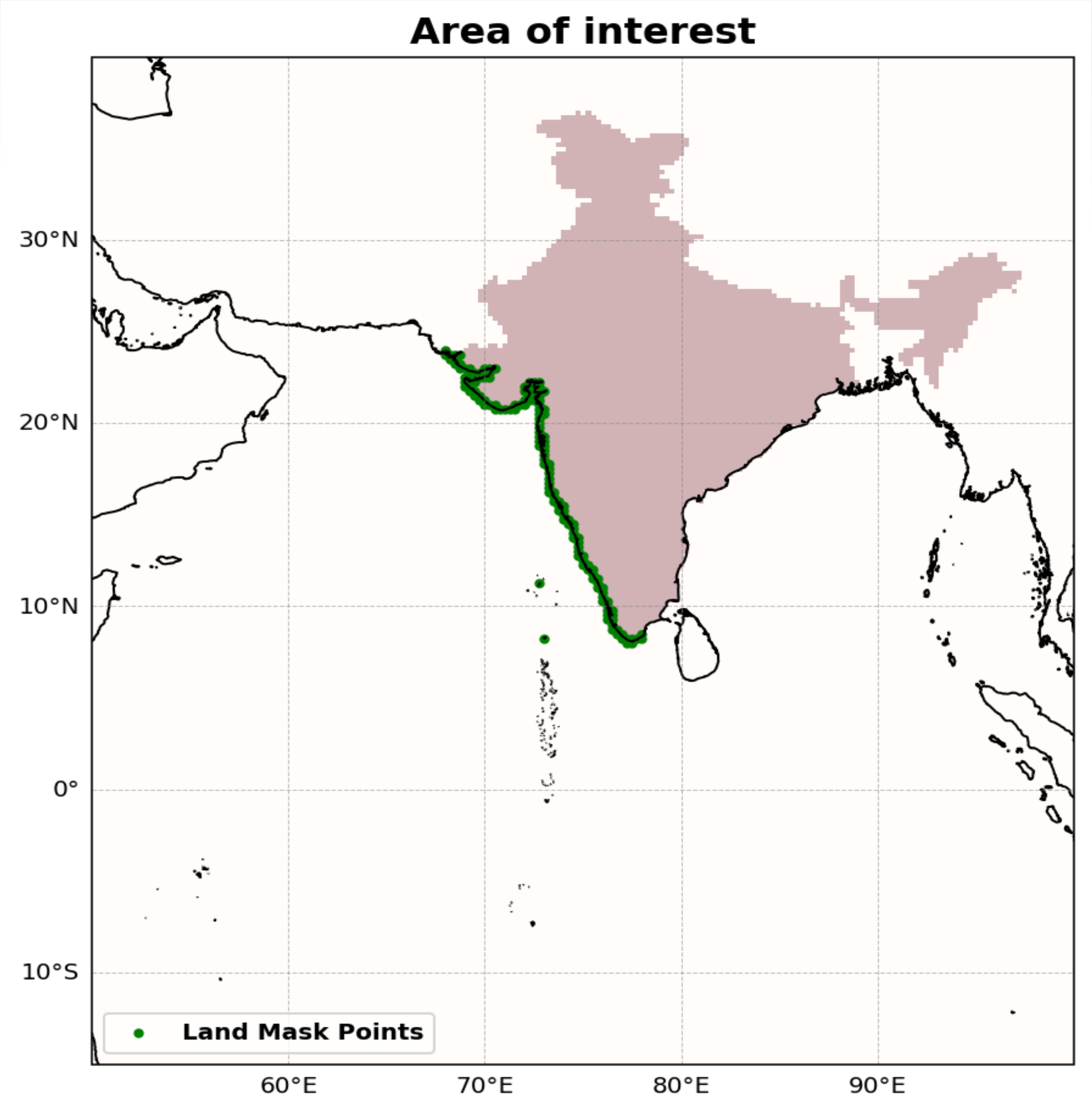
Plotting & Visualization:

matplotlib.pyplot – for plotting IVT, TPW, and AR axes

cartopy.crs, cartopy.mpl.ticker – for geospatial map projections and coordinate formatting

matplotlib.ticker – for axis formatting in plots

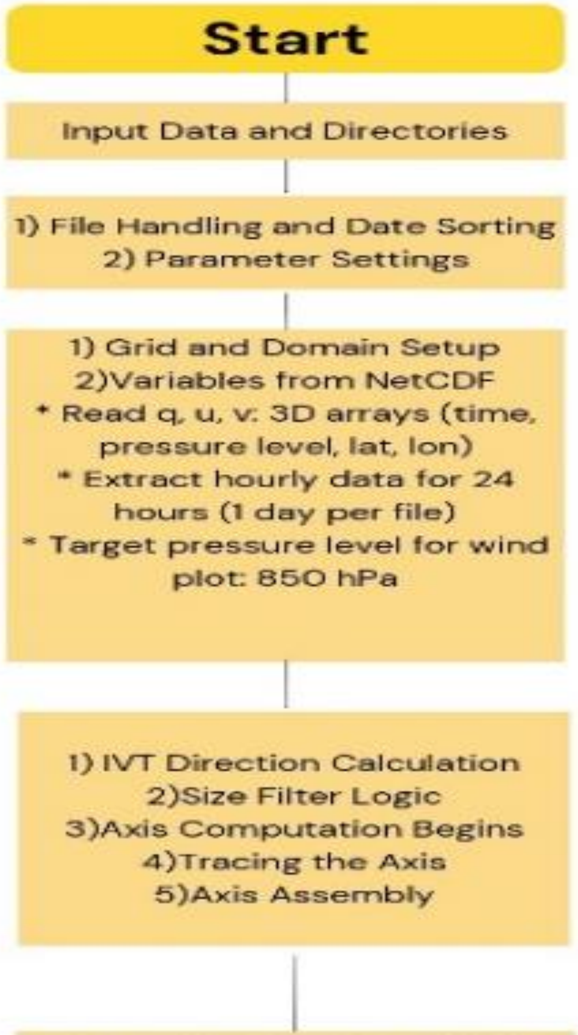
AREA OF INTEREST



North: 40 degrees
South: -15 degrees
West: 50 degrees
East:100 degrees

Fig2: The red-shaded region represents the area of interest used in the analysis, while the green dots represent coastal grid cells along the Indian landmass used for landfall detection logic

STEPS IN THE AR DETECTION ALGORITHM



1) Length Estimation of AR
2)Computing the surface area of the AR
3) Calculating the width of the AR

Checking the criteria for Atmospheric Rivers
1) Length>2000km
2) Length:Width ratio >2
3)Poleward IVT direction is > 50

1)Filtering and Initialization: Iterates over detected AR, skipping those that fail multiple filters
2) 850 hPa Wind Extraction and Plotting
3)IVT Visualization: Highlights the current AR , and plots the IVT field with the AR object boundary in green and its axis in yellow.

1)Total Integrated Vapour Transport (TIVT)
2)Annotation and Saving

Finish

FORMULAE USED

- 1)IVT Calculation:

$$\mathrm{IVT_x} = 1/g \int_{1}^{N} q_i \times u_i \times \Delta p_i \times 100$$

$$\mathrm{IVT_y} = 1/g \int_{1}^{N} q_i \times v_i \times \Delta p_i \times 100$$

$$\mathrm{IVT} = 1/g \sqrt{\left(\int_{1}^{N} q_i \times u_i \times \Delta p_i \times 100\right)^2 + \left(\int_{1}^{N} q_i \times v_i \times \Delta p_i \times 100\right)^2}$$

where:

$q_i = specific\ humidity\ at\ the\ i^{th}\ pressure\ layer$

$u_i = Zonal\ wind\ at\ the\ i^{th}\ pressure\ layer$

$v_i = Meridonial\ wind\ at\ the\ i^{th}\ pressure\ layer$

$\Delta p_i = Pressure\ difference\ at\ the\ i^{th} layer$

$g = 9.8\ m/s^2 : gravitational\ acceleration$

$N = Number\ of\ pressure\ layers$

2) IVT sums and means:

$$IVT_{sum} = sum(IVT)$$

$$IVTx_{sum} = sum(IVT_x)$$

$$IVTy_{sum} = sum(IVT_y)$$

The IVT values along the pressure dimension are summed up.
IVT sums are generated for each hour

3) IVT_Direction:

$$IVT\_dir = \{\tan^{-1}(Eastward\_IVT/Northward\_IVT) \times (180/\pi) + 180\}\,\%360$$

IVT_dir stores the direction(in degrees) from North (0^o)

Multiplying by $180/\pi$ gives the direction in degrees

%360 gives the remainder when divided with 360. This is essential to ensure that the direction does not go out of bounds [0-360]

4) IVT_Threshold:

Calculated based on the 85th percentile of IVT from the previous 1 day.

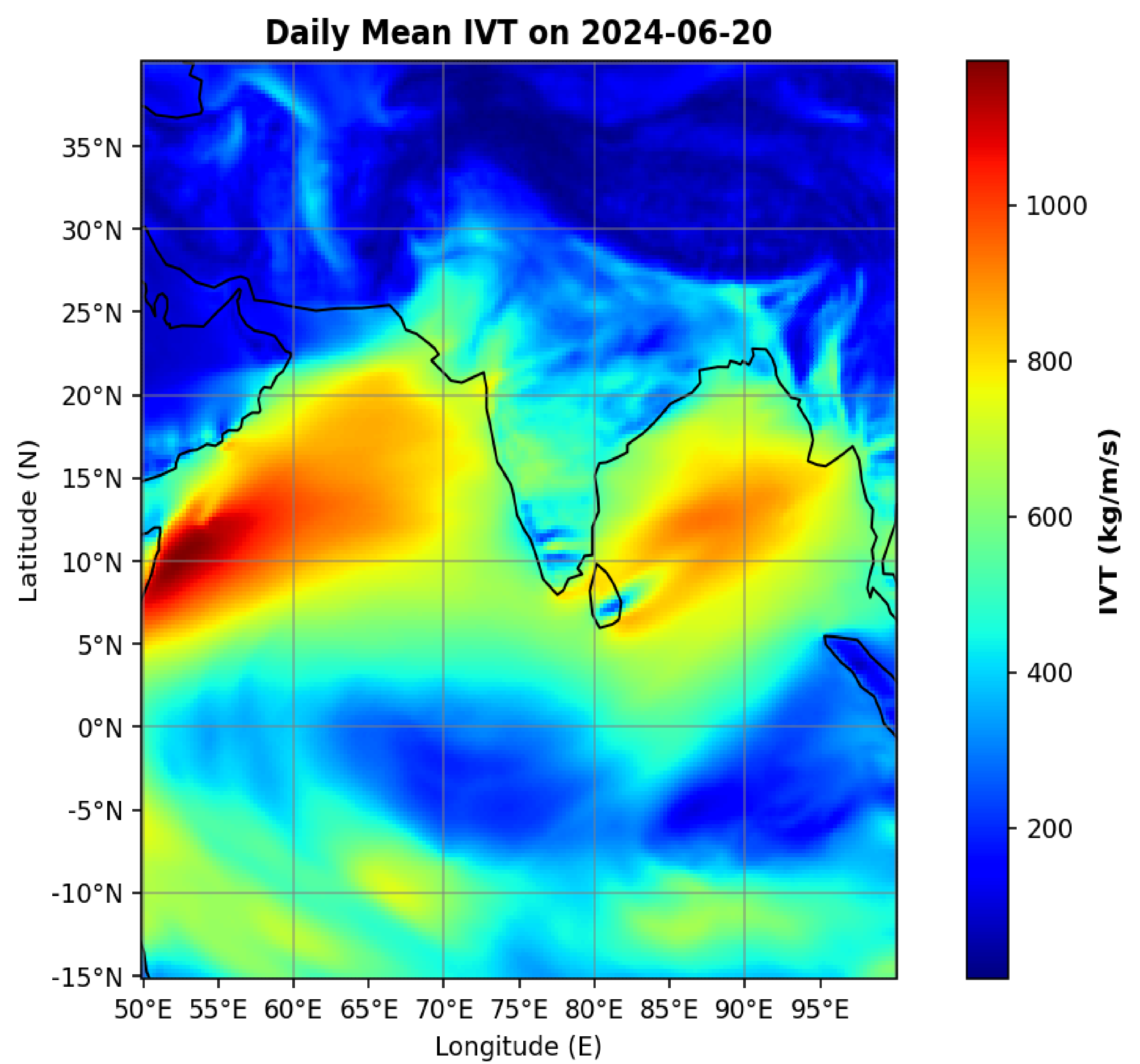
$$IVT_{min} = 150\ kg.m^{-1}.s^{-1}$$

$IVT_{threshold}$ is calculated as the

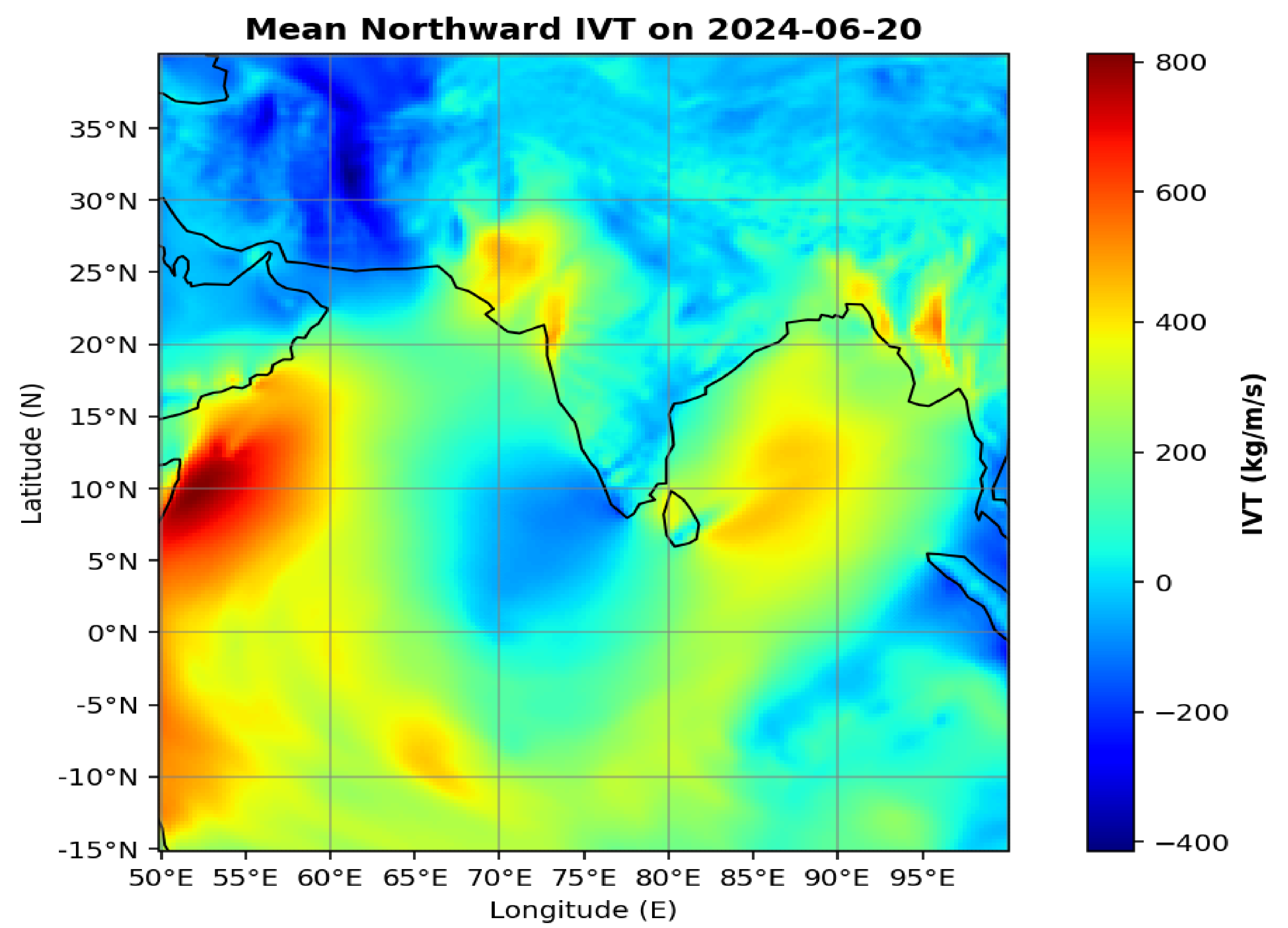
$$maximum\ between\ IVT_{min}\ and\ IVT_{85th\ percentile}$$

Sequential flow of the algorithm: 20 June 2024

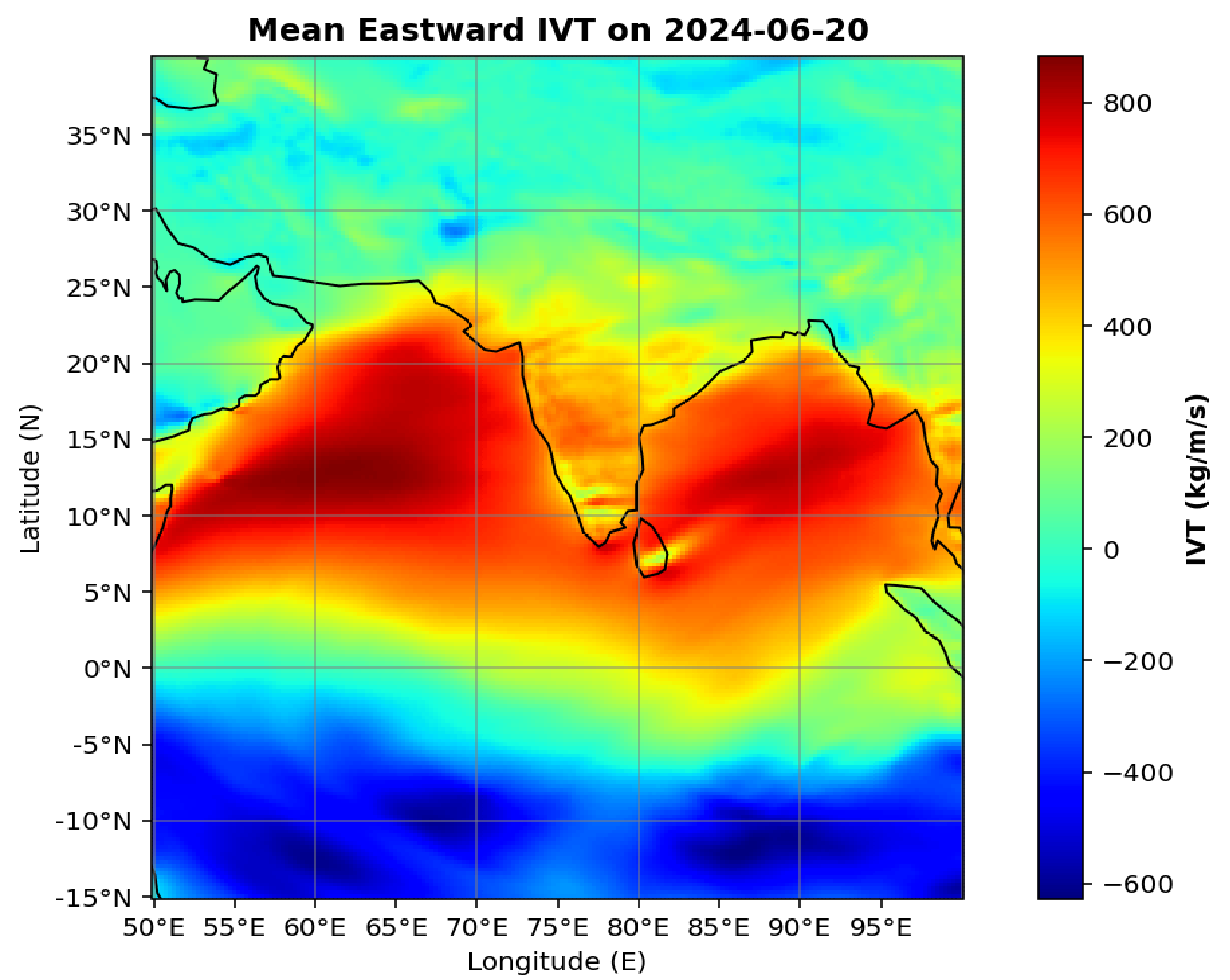
1) IVT:



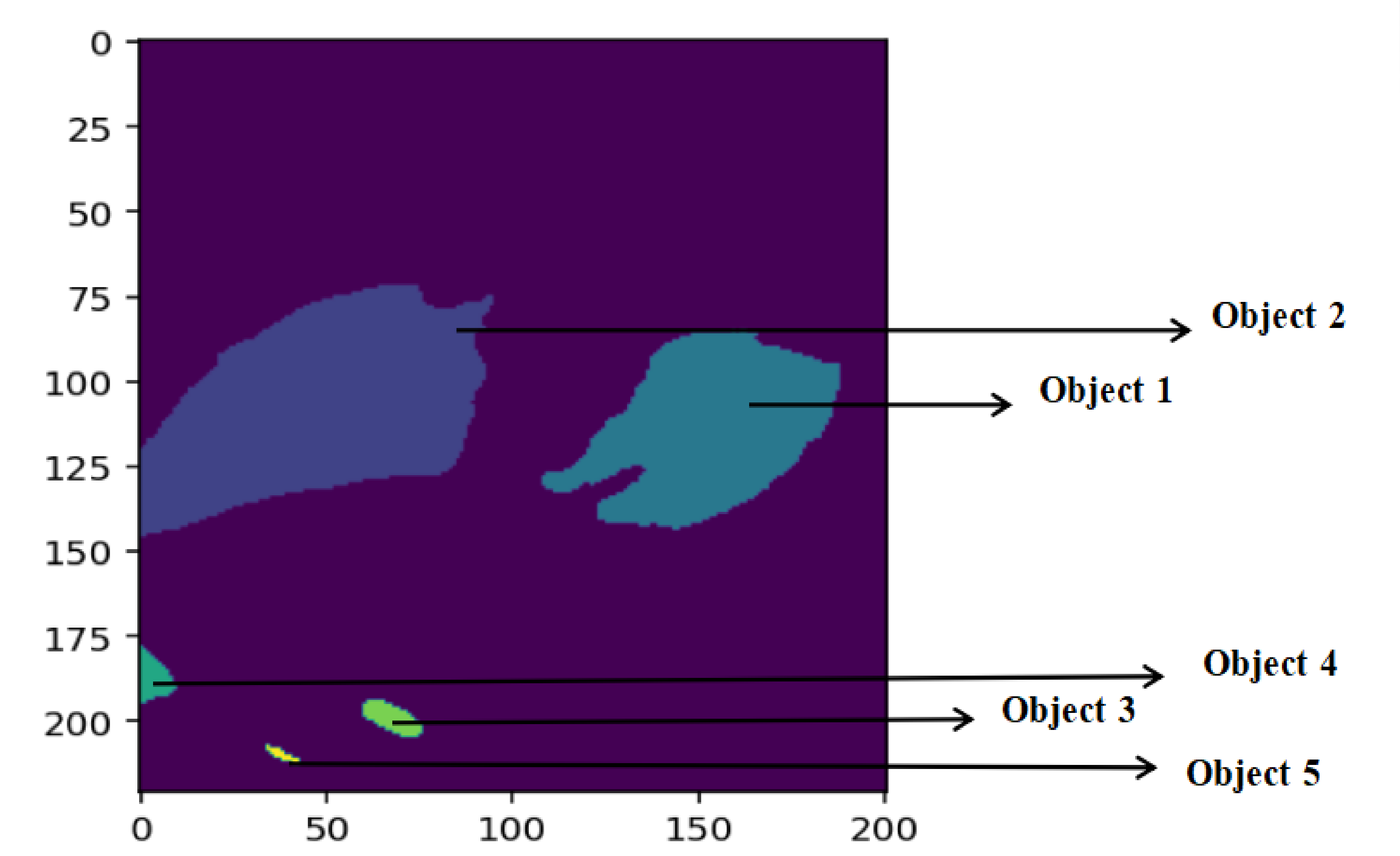
- Northward IVT:



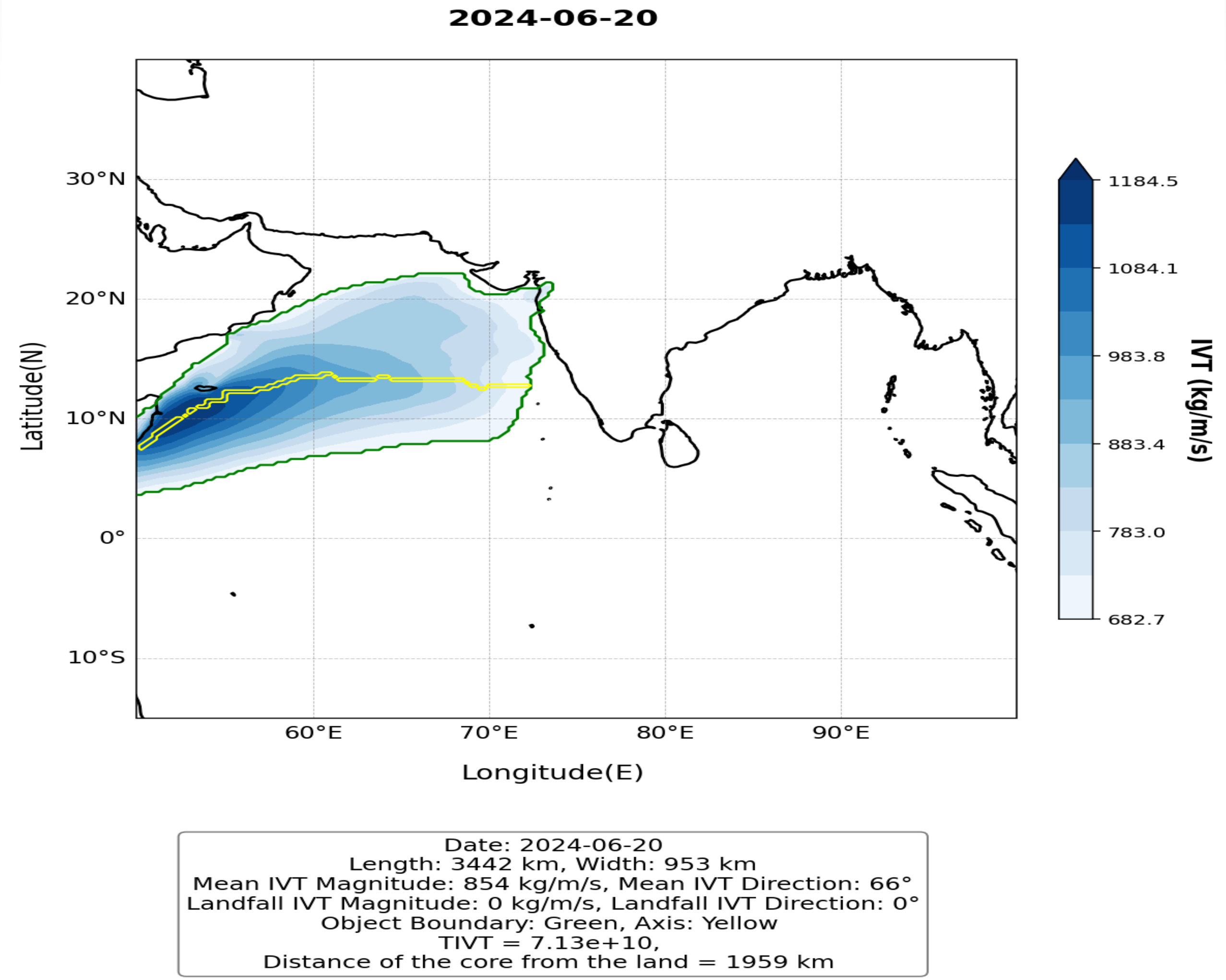
- Eastward IVT:



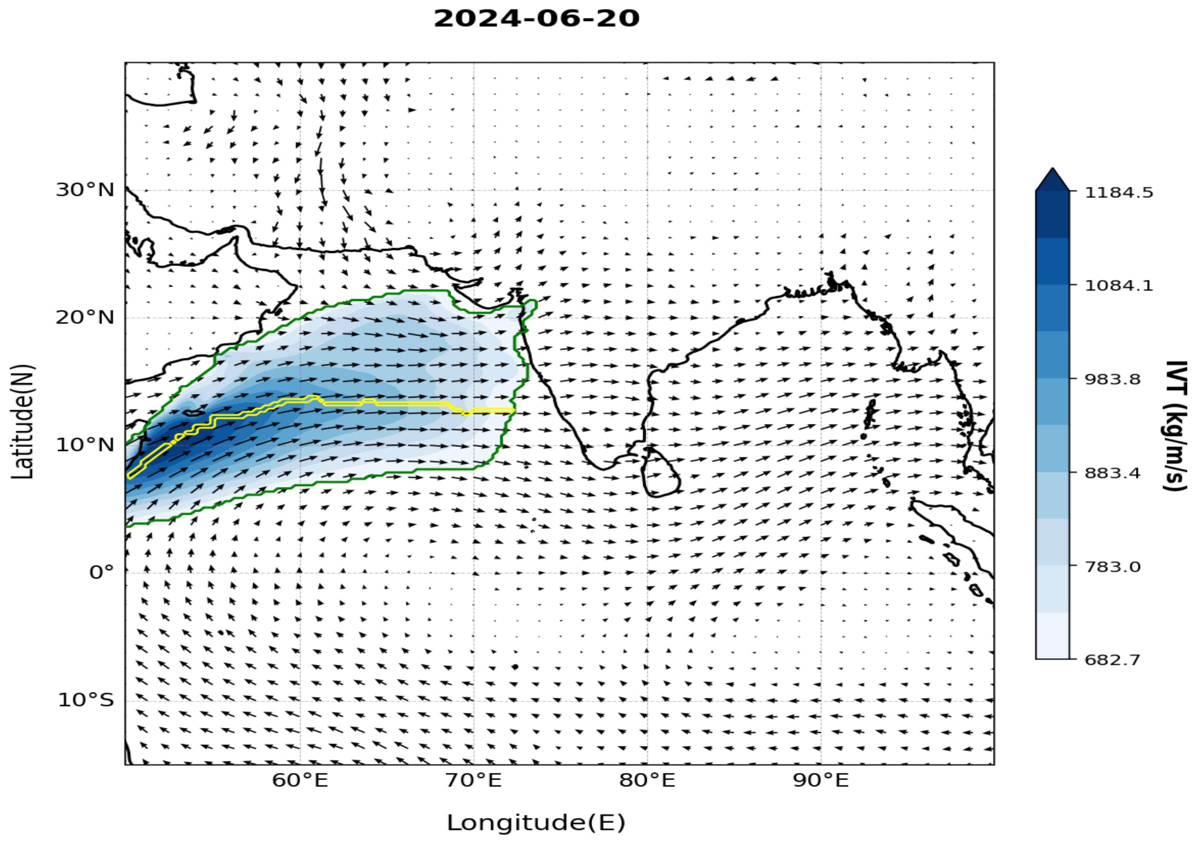
2) Labelled mask:



3) AR Snapshot:

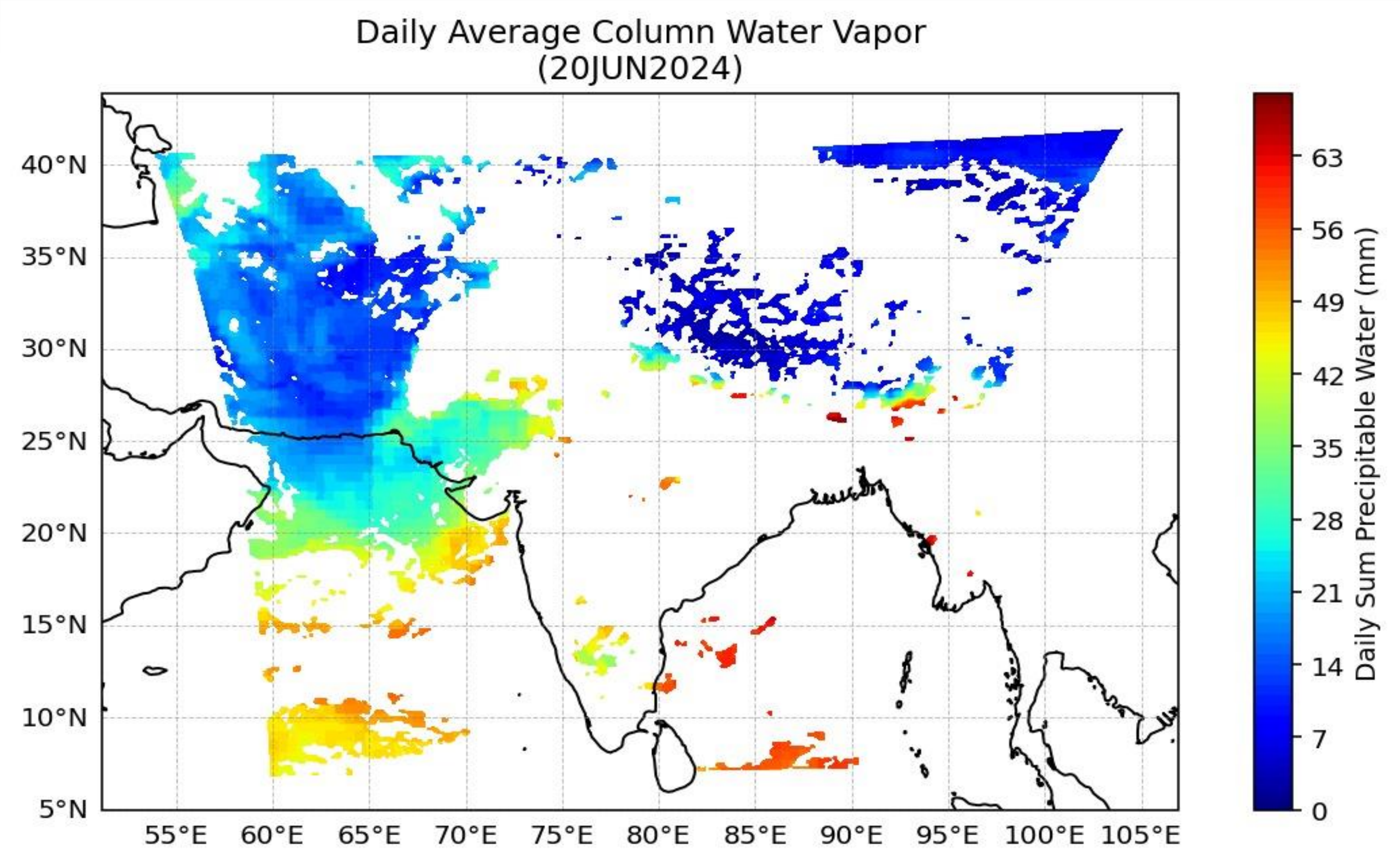


4) Quiver plot:

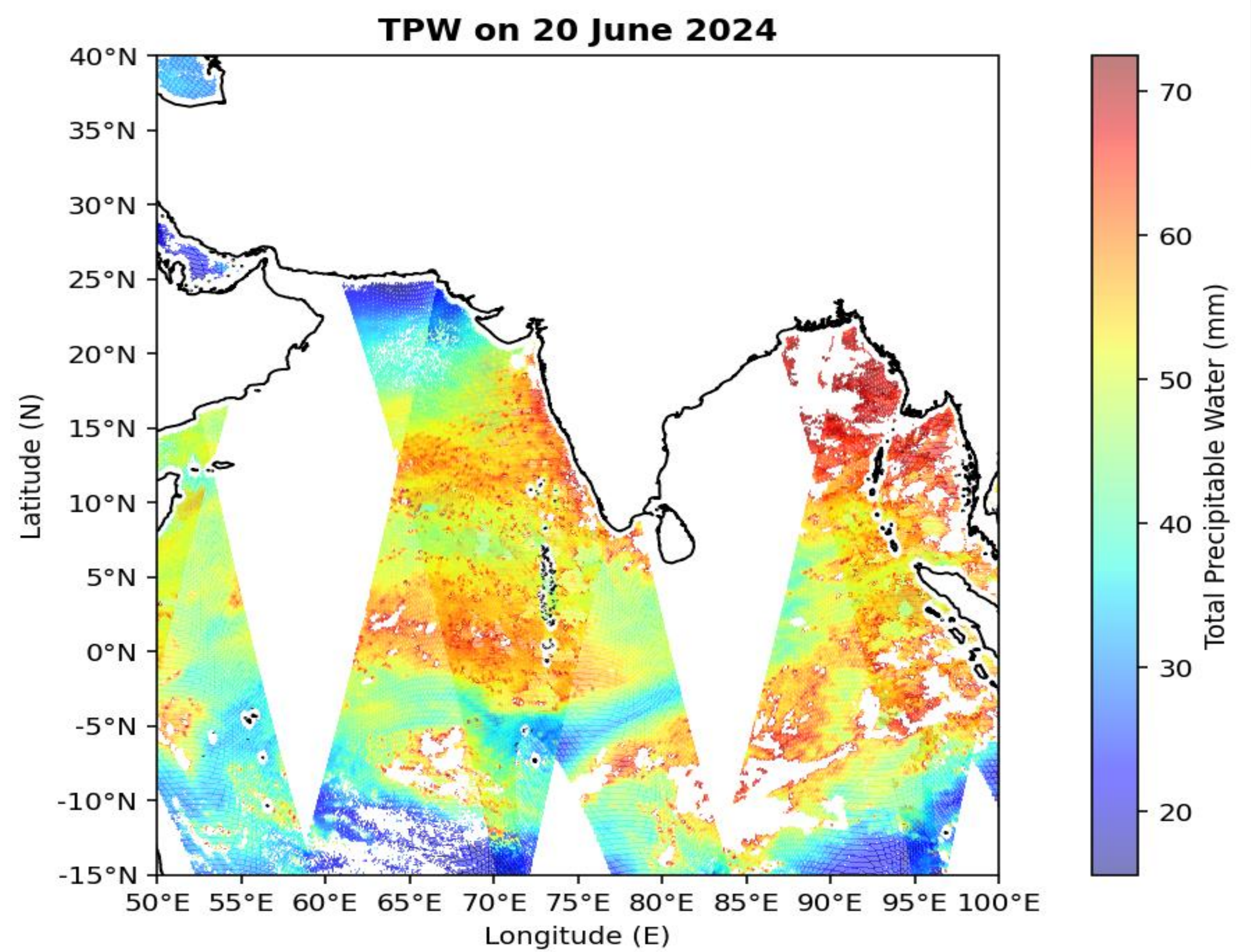


Date: 2024-06-20
Length: 3442 km, Width: 953 km
Mean IVT Magnitude: 854 kg/m/s, Mean IVT Direction: 66°
Landfall IVT Magnitude: 0 kg/m/s, Landfall IVT Direction: 0°
Object Boundary: Green, Axis: Yellow
TIVT = 7.13e+10,
Distance of the core from the land = 1959 km

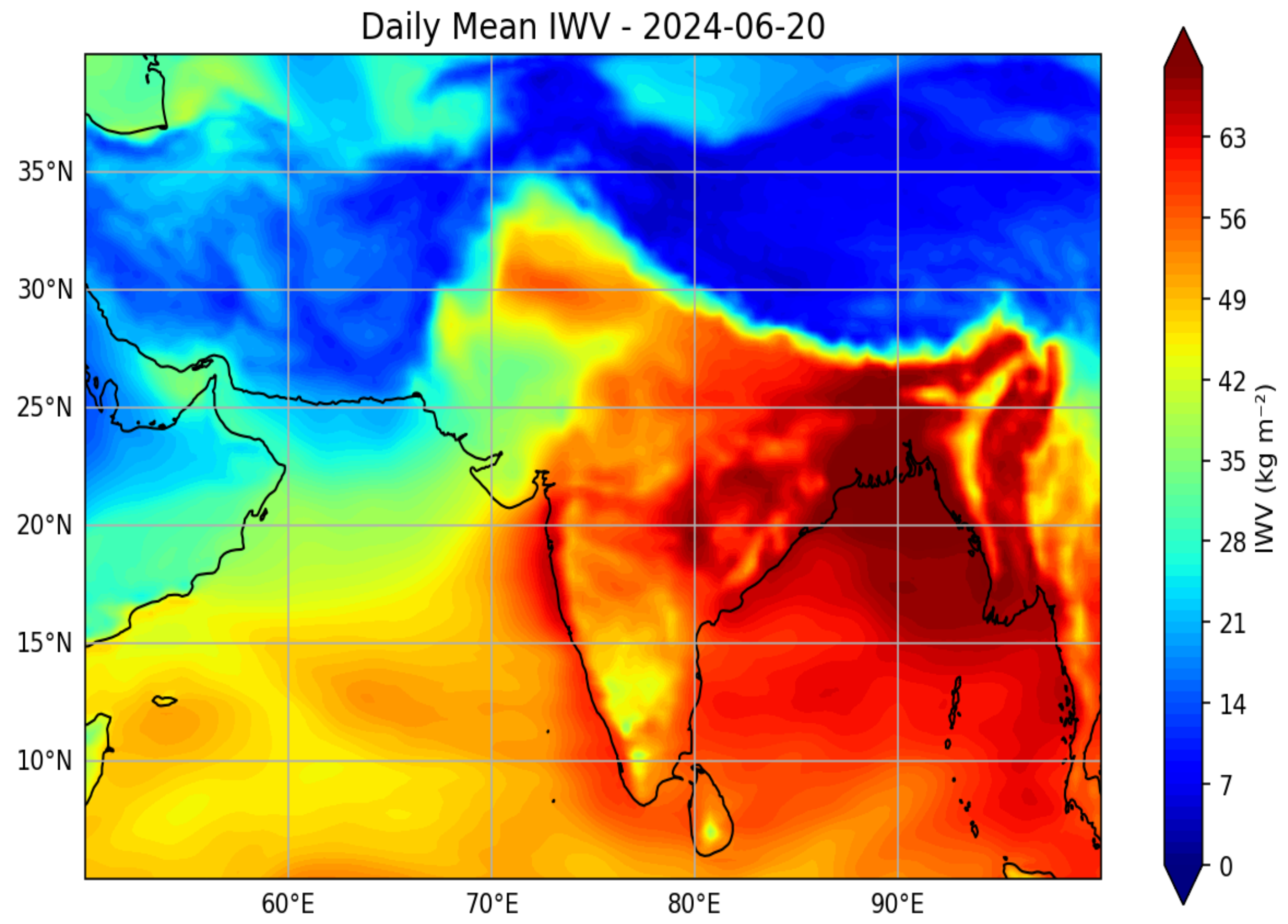
5) INSAT 3R Observation:

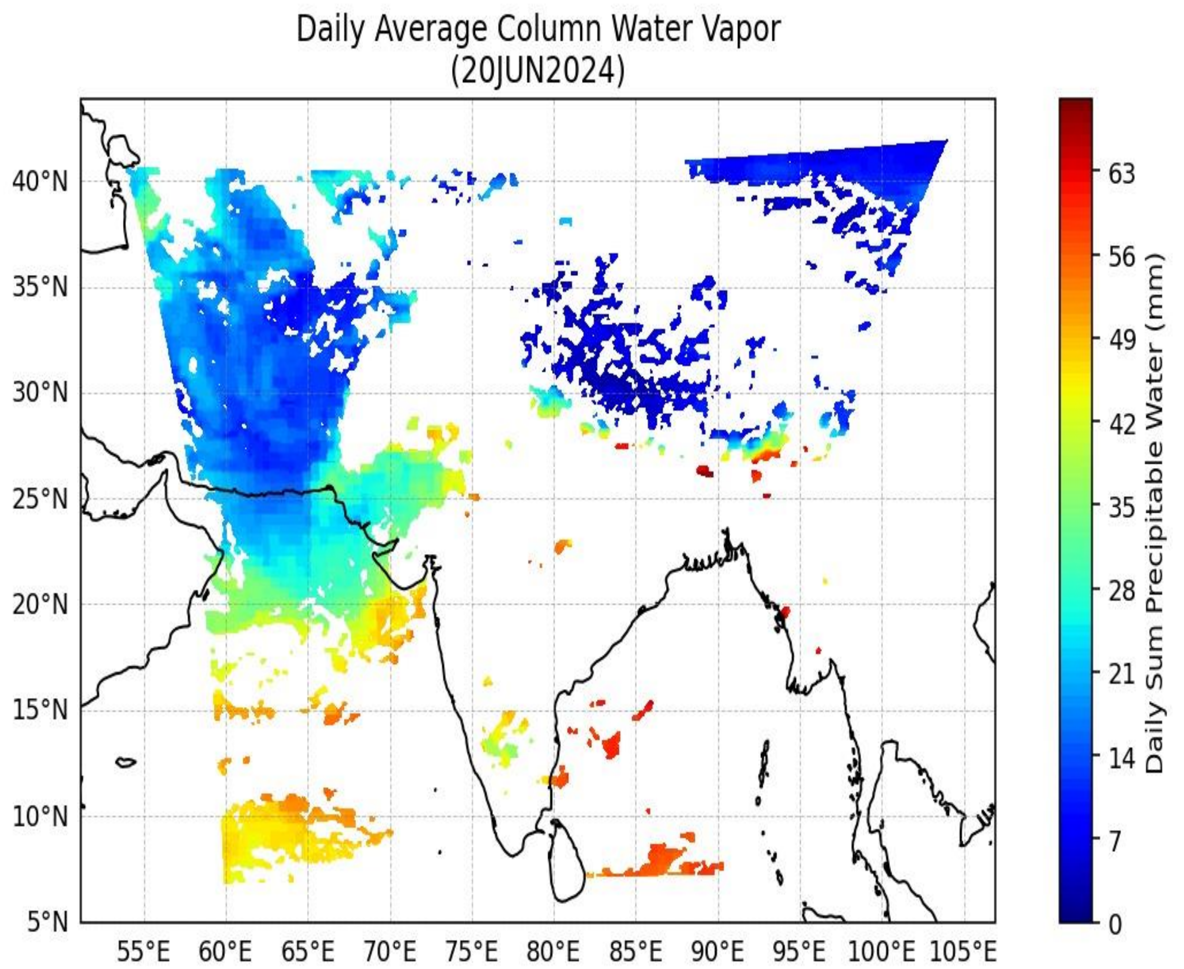


6) AMSR Satellite:



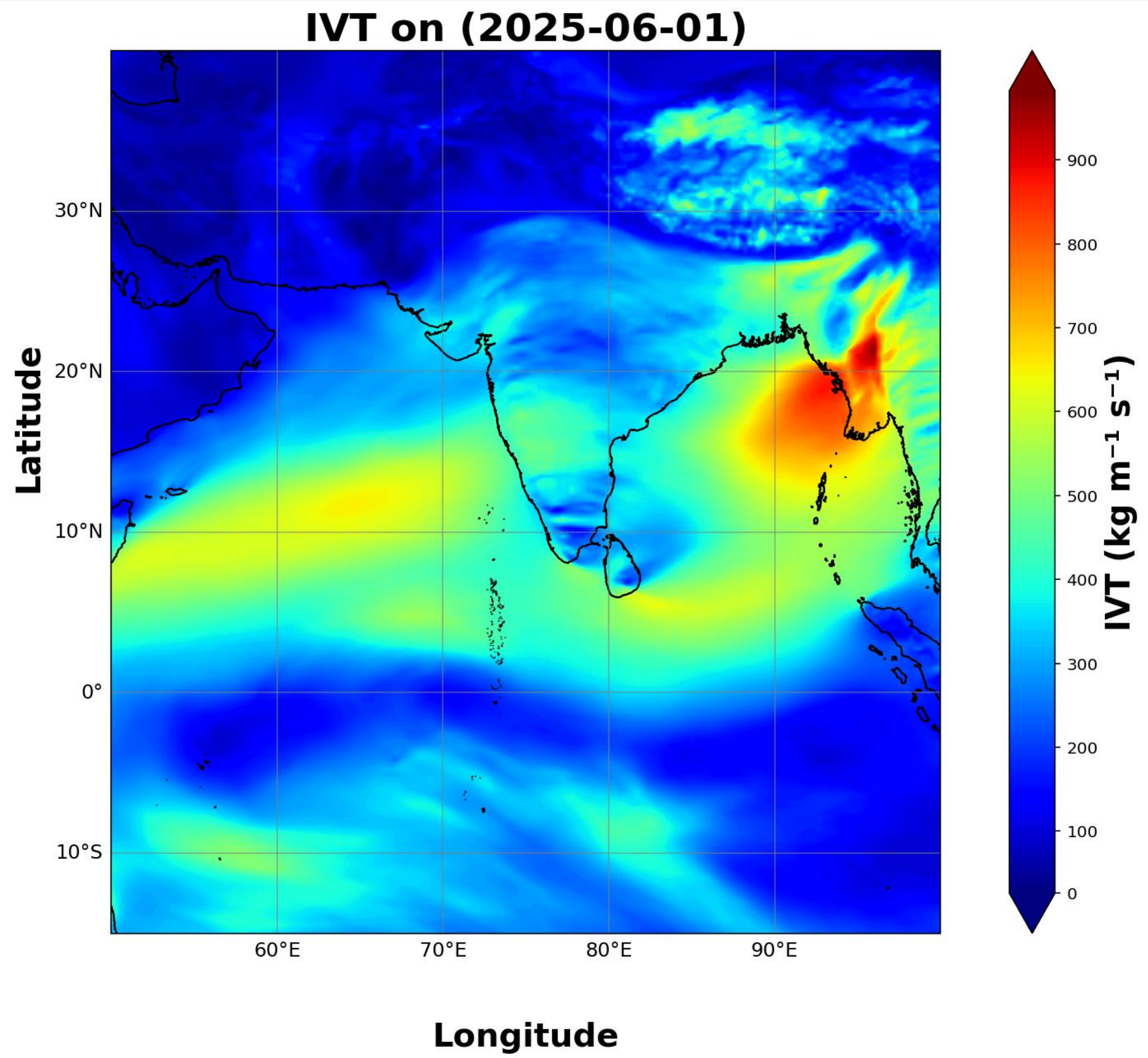
COMPARISON PLOTS

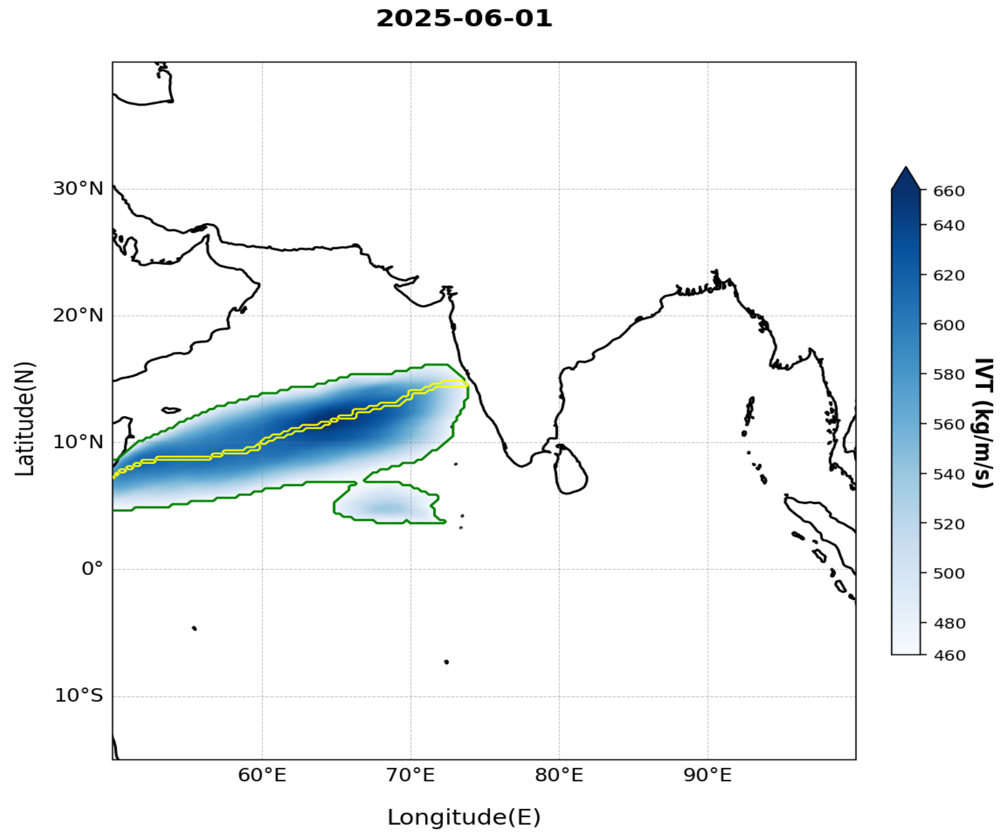


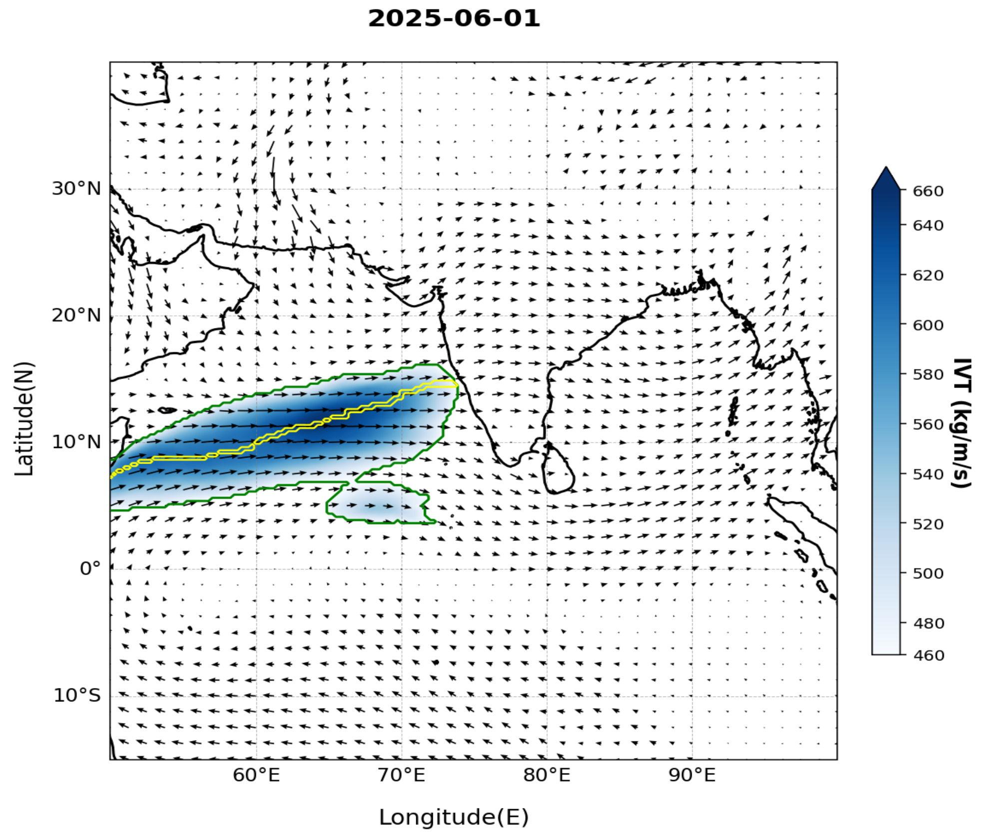


AR Detection
Forecast Results for the entire week(2025/06/01 to 2025/06/11)

1st June 2025



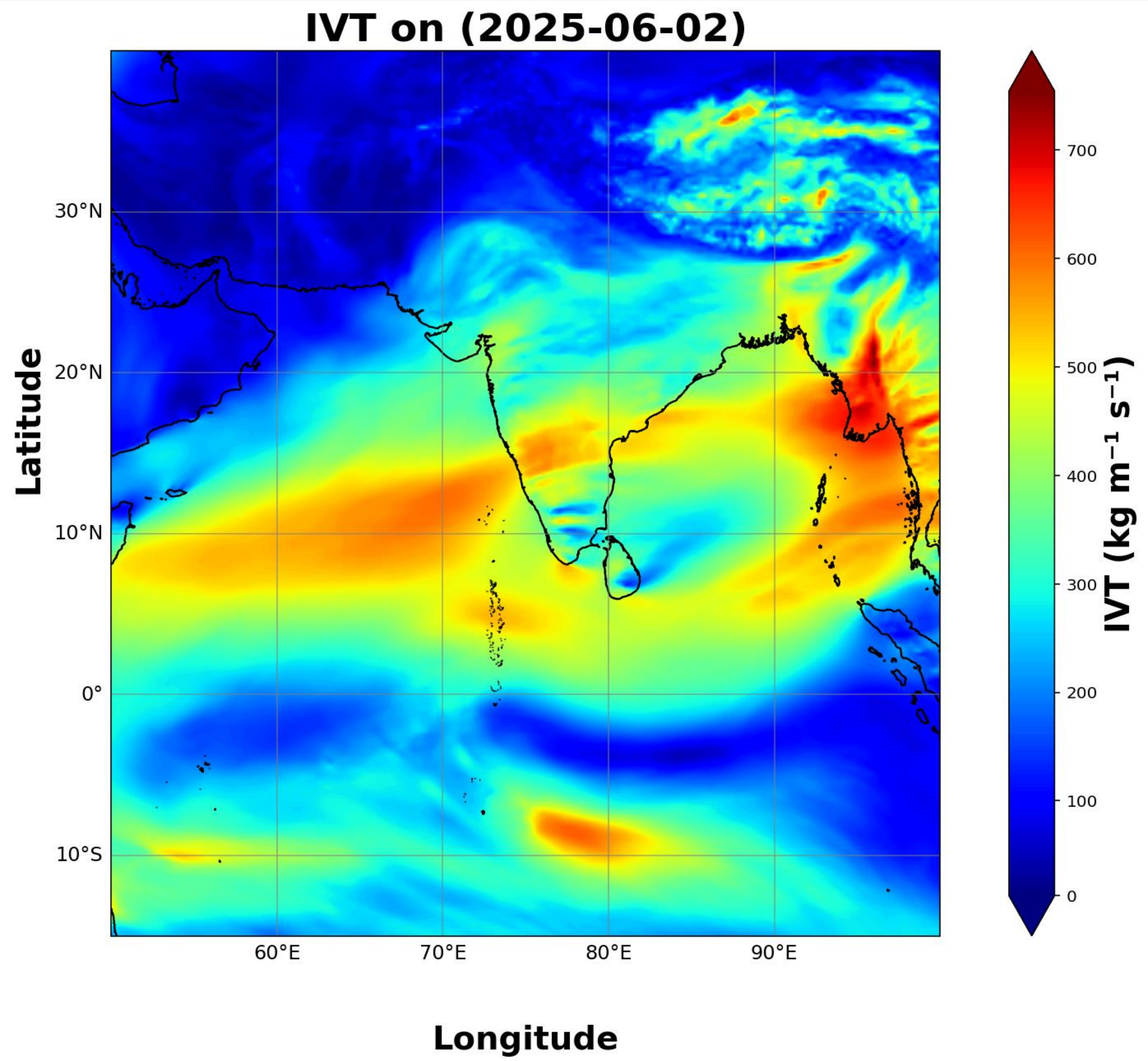


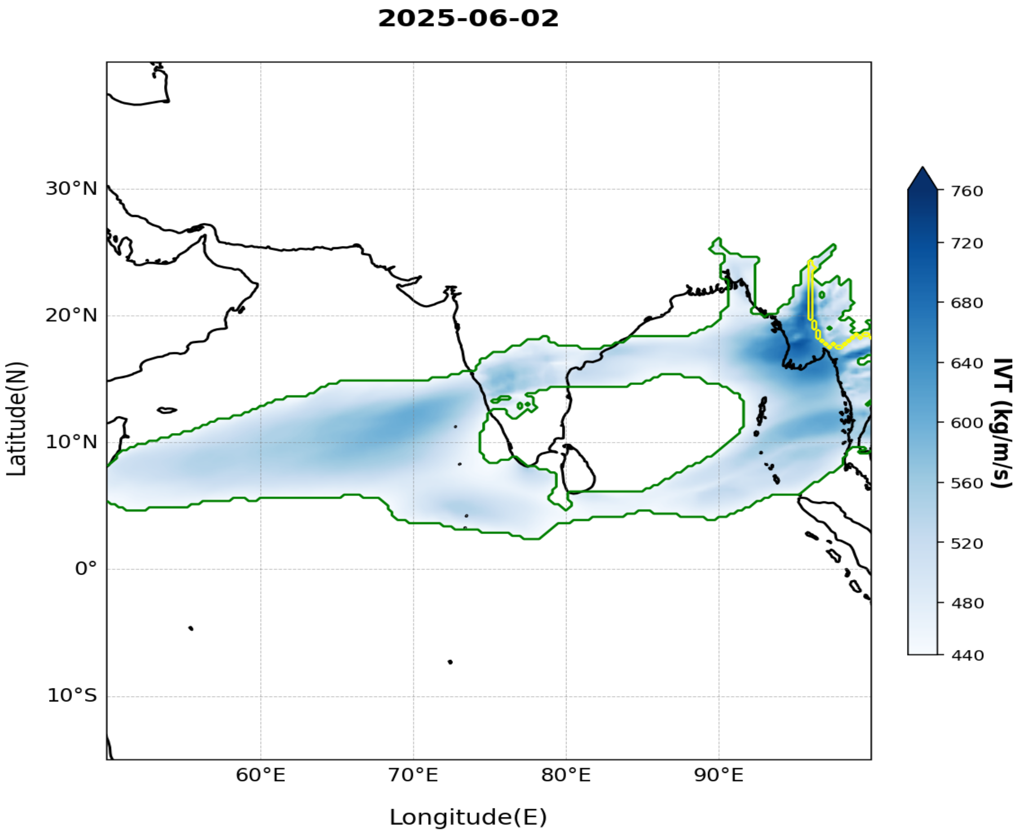


Date: 2025-06-01
Length: 2488 km, Width: 893 km
Mean IVT Magnitude: 553 kg/m/s, Mean IVT Direction: 79°
Core value of the AR:654 kg/m/s
Object Boundary: Green, Axis: Yellow
TIVT = 4.75e+10 kg/m/s,
Distance of the core from the land = 896 km

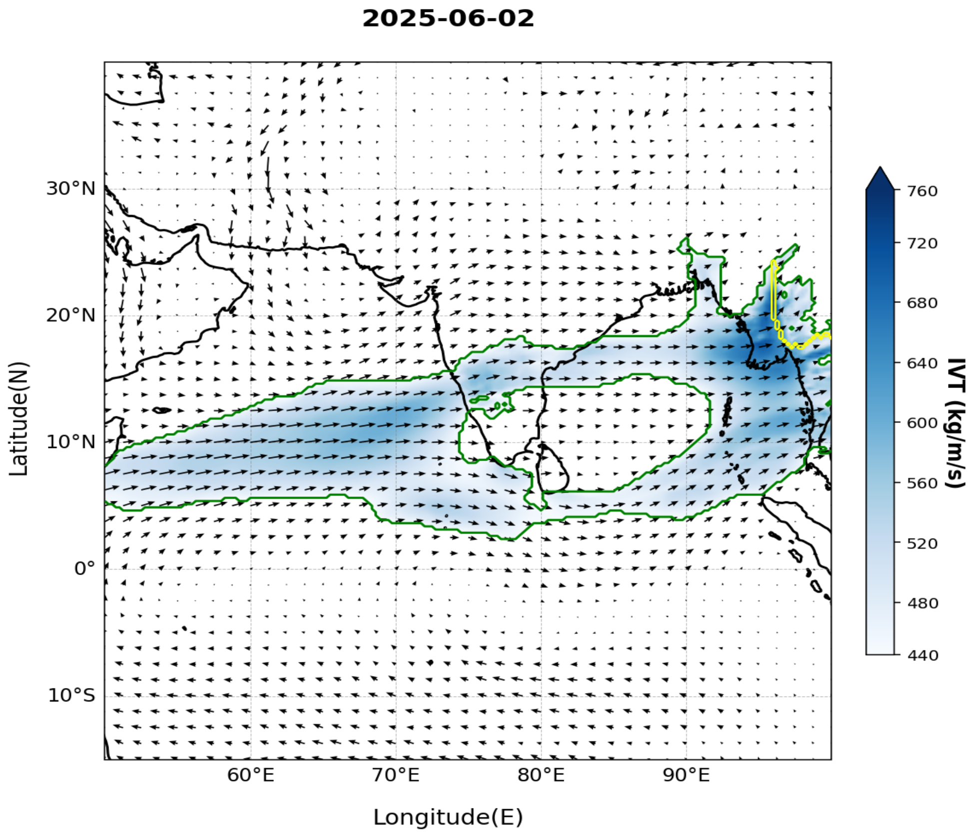
Date: 2025-06-01
Length: 2488 km, Width: 893 km
Mean IVT Magnitude: 553 kg/m/s, Mean IVT Direction: 79°
Core value of the AR:654 kg/m/s
Object Boundary: Green, Axis: Yellow
TIVT = 4.75e+10 kg/m/s,
Distance of the core from the land = 896 km

2nd June 2025



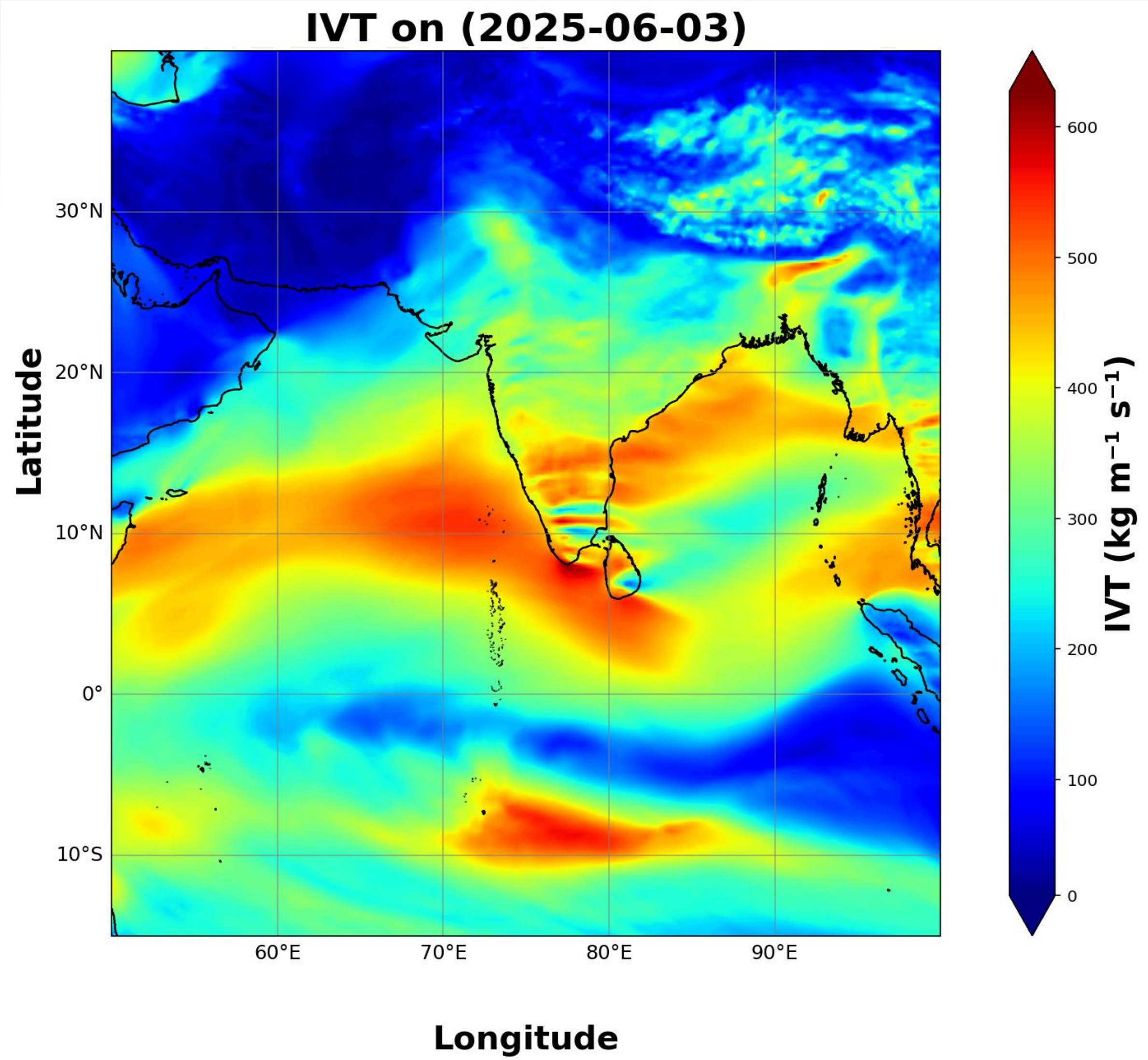


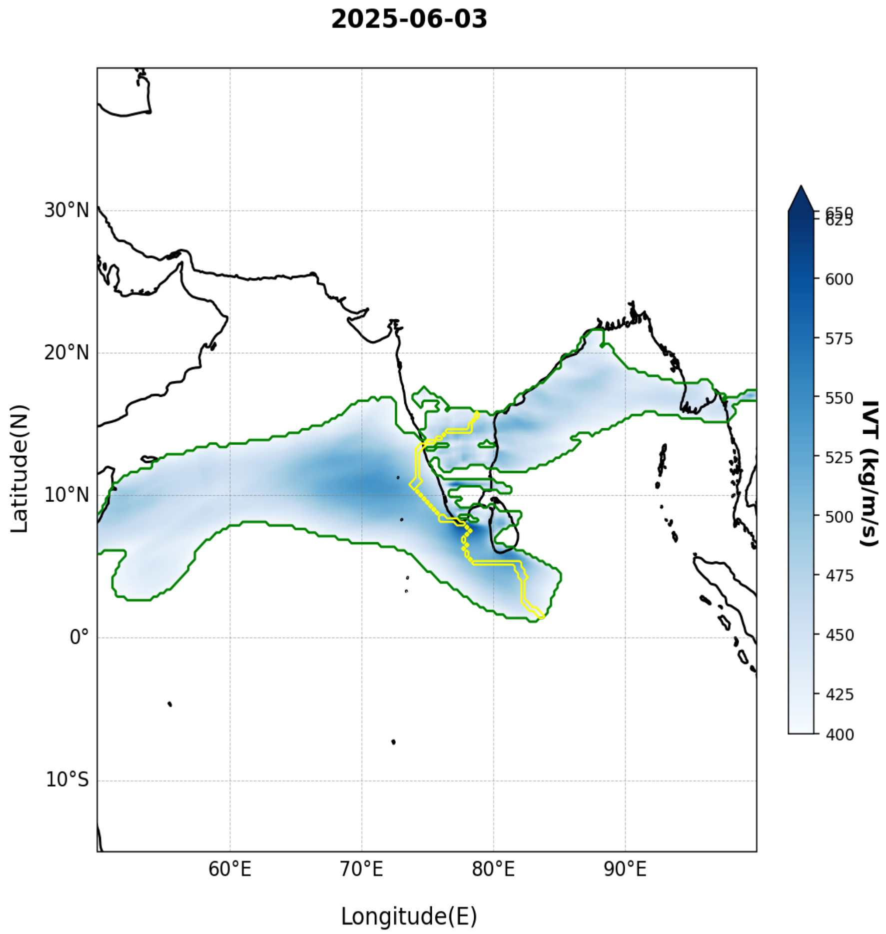
Date: 2025-06-02
Length: 5394 km, Width: 1041 km
Mean IVT Magnitude: 518 kg/m/s, Mean IVT Direction: 74°
Core value of the AR:755 kg/m/s
Object Boundary: Green, Axis: Yellow
TIVT = 1.72e+10 kg/m/s,



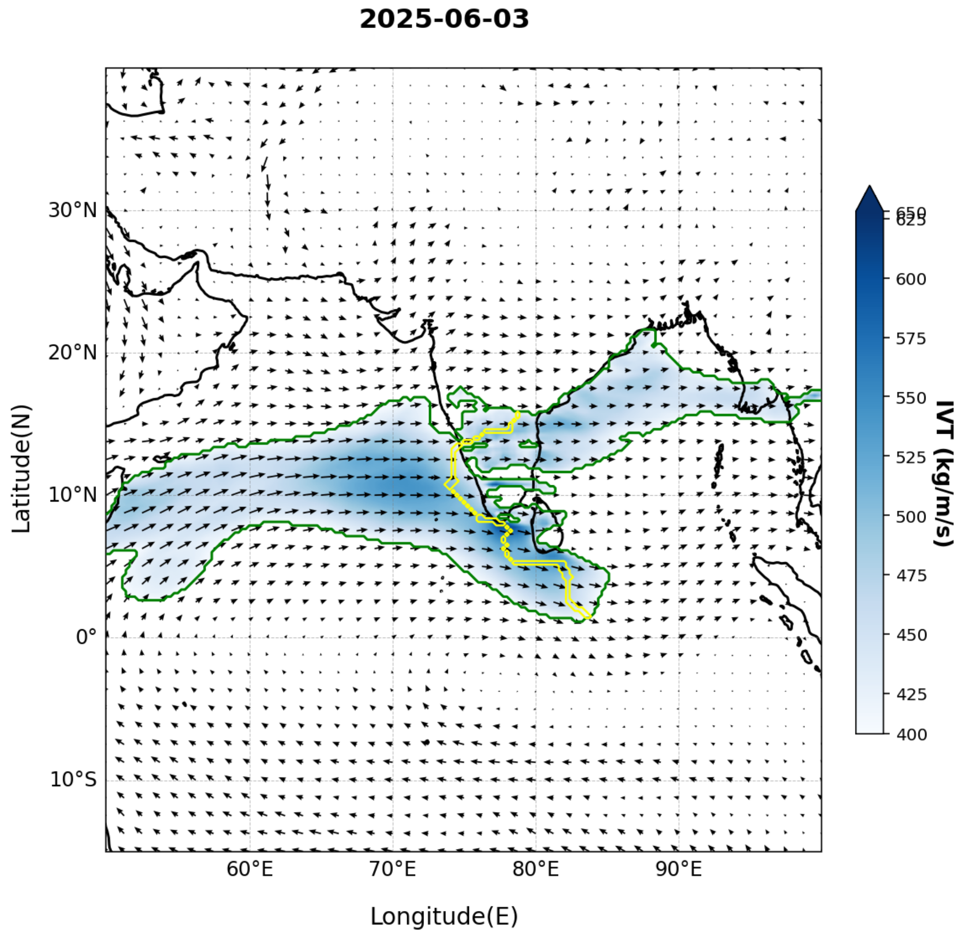
Date: 2025-06-02
Length: 5394 km, Width: 1041 km
Mean IVT Magnitude: 518 kg/m/s, Mean IVT Direction: 74°
Core value of the AR:755 kg/m/s
Object Boundary: Green, Axis: Yellow
TIVT = 1.72e+10 kg/m/s,

3rd June 2025



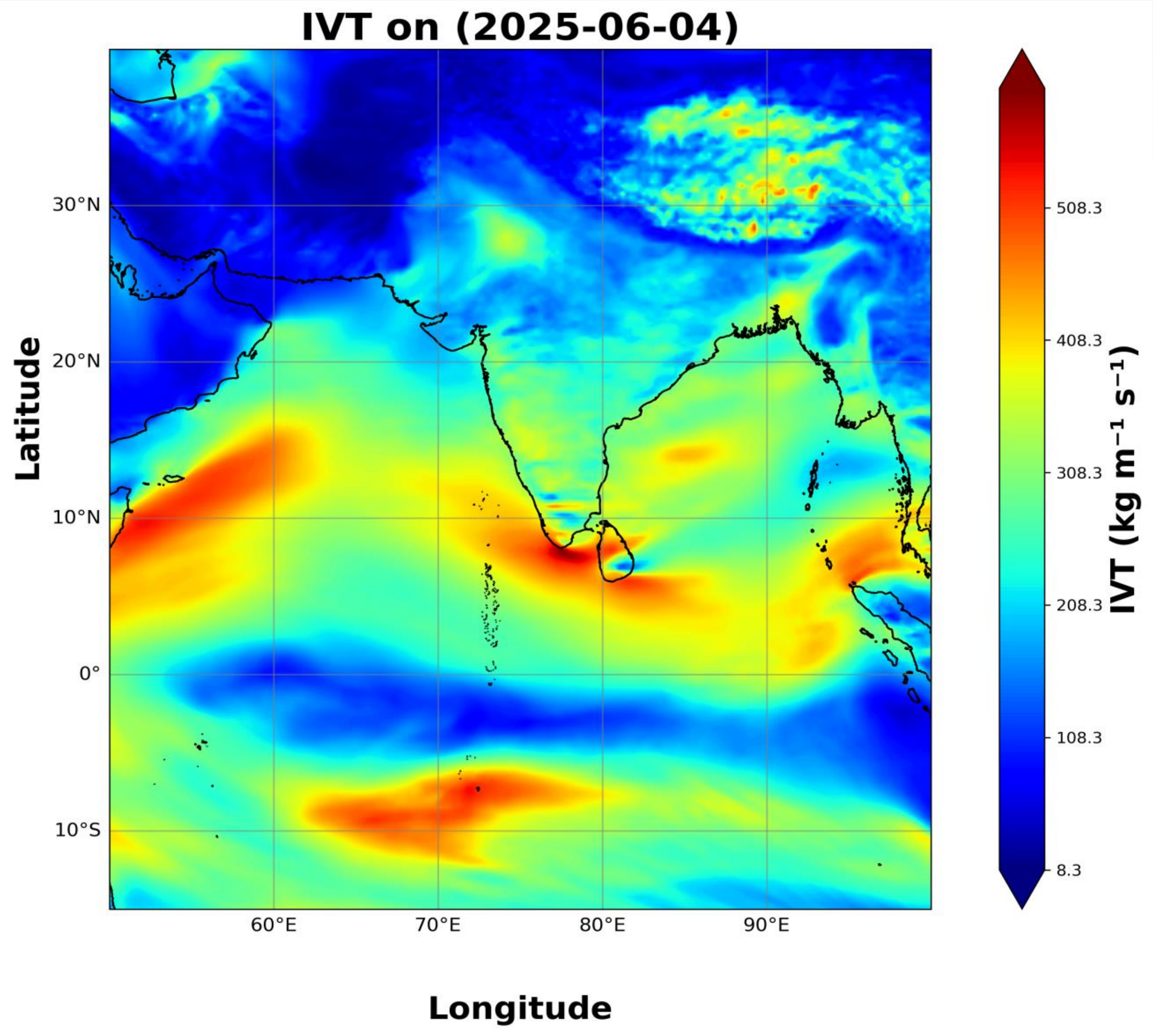


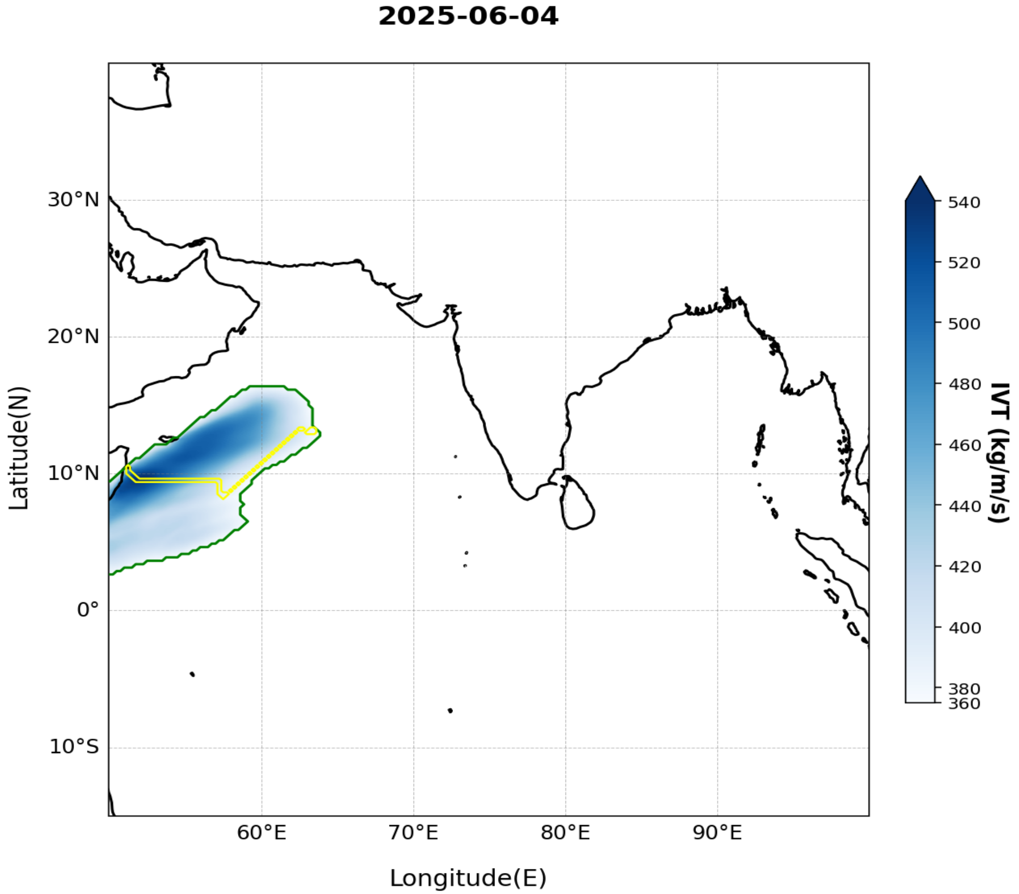
Date: 2025-06-03
Length: 5543 km, Width: 778 km
Mean IVT Magnitude: 461 kg/m/s, Mean IVT Direction: 79°
Core value of the AR:627 kg/m/s
Object Boundary: Green, Axis: Yellow
TIVT = 1.88e+10 kg/m/s,
Distance of the core from the land = 419 km



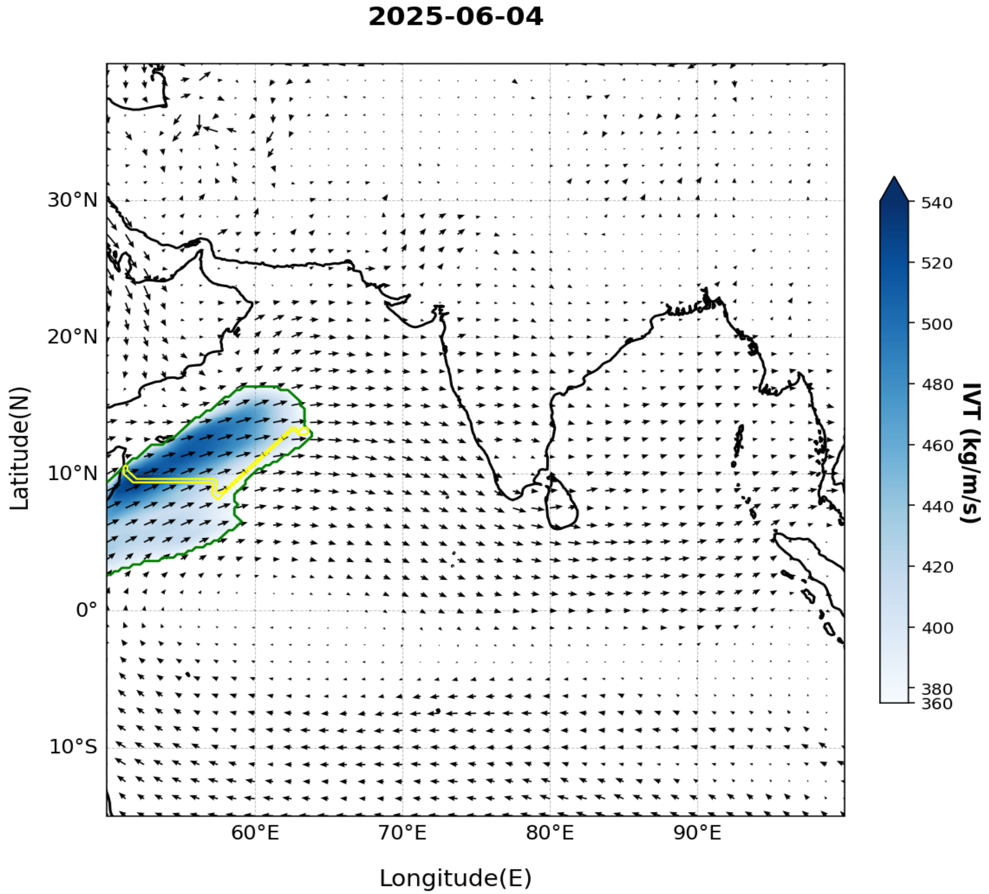
Date: 2025-06-03
Length: 5543 km, Width: 778 km
Mean IVT Magnitude: 461 kg/m/s, Mean IVT Direction: 79°
Core value of the AR:627 kg/m/s
Object Boundary: Green, Axis: Yellow
TIVT = 1.88e+10 kg/m/s,
Distance of the core from the land = 419 km

4th June 2025



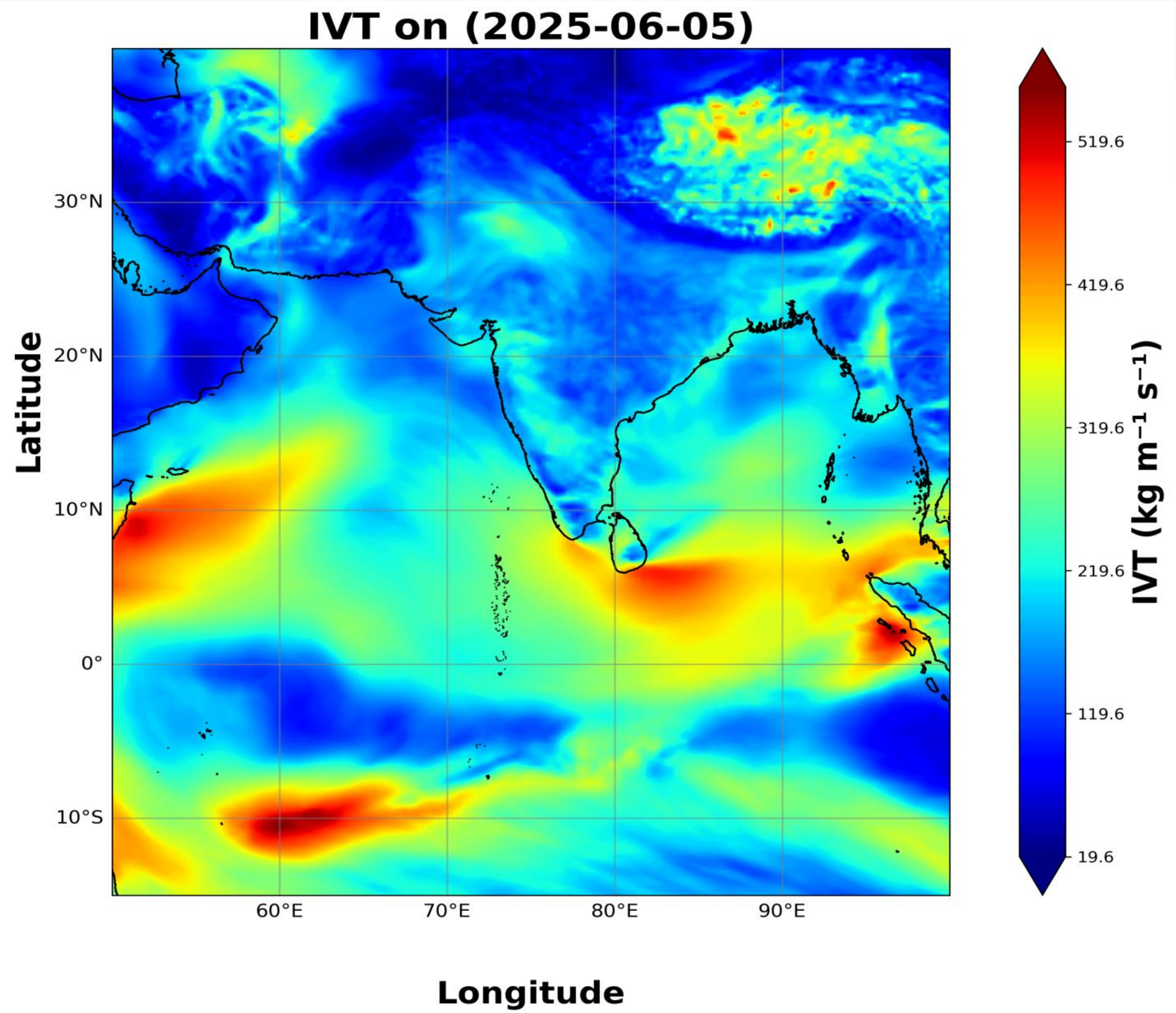


Date: 2025-06-04
Length: 1716 km, Width: 728 km
Mean IVT Magnitude: 435 kg/m/s, Mean IVT Direction: 58°
Core value of the AR:539 kg/m/s
Object Boundary: Green, Axis: Yellow
TIVT = 1.84e+10 kg/m/s,
Distance of the core from the land = 1993 km

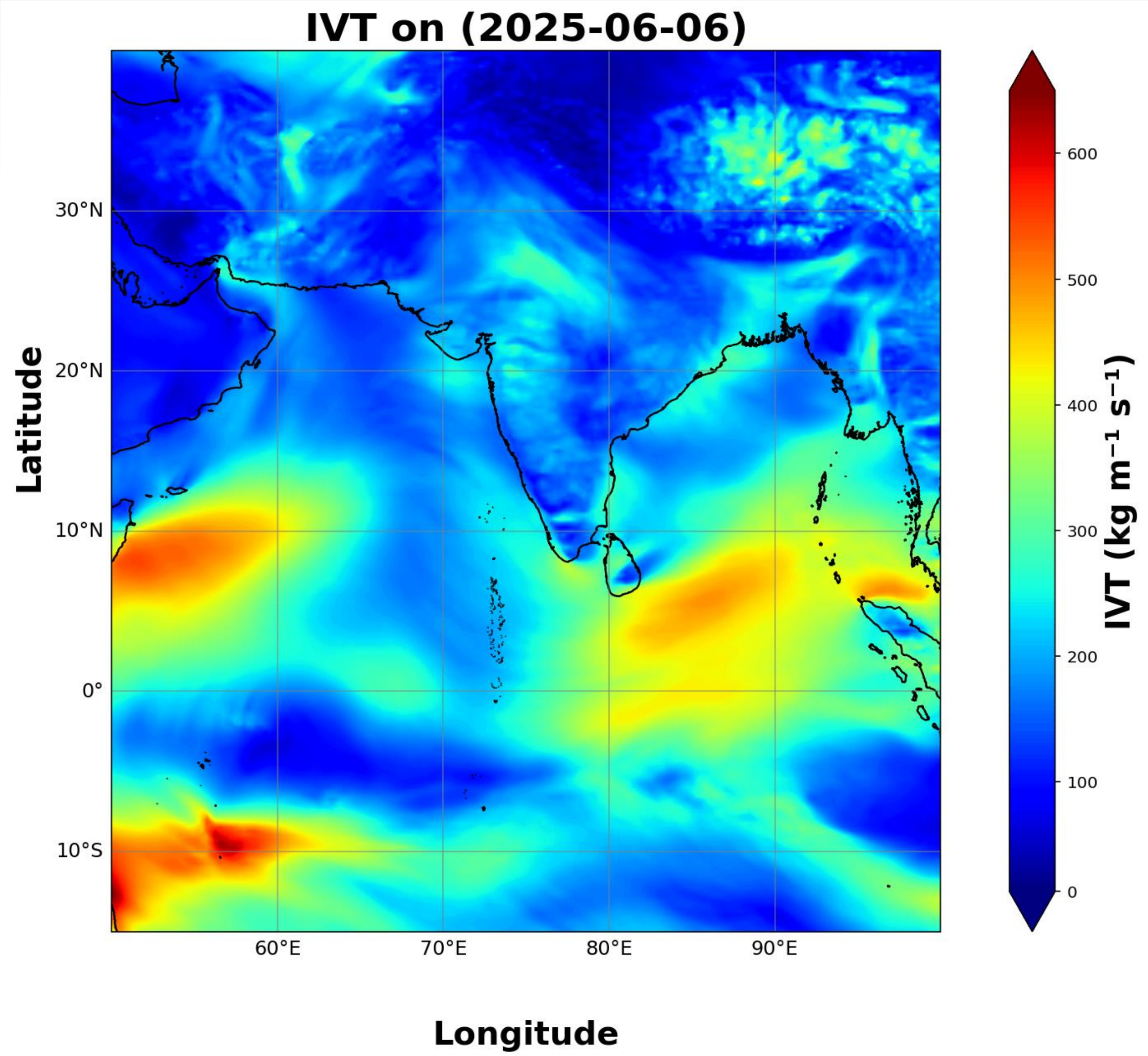


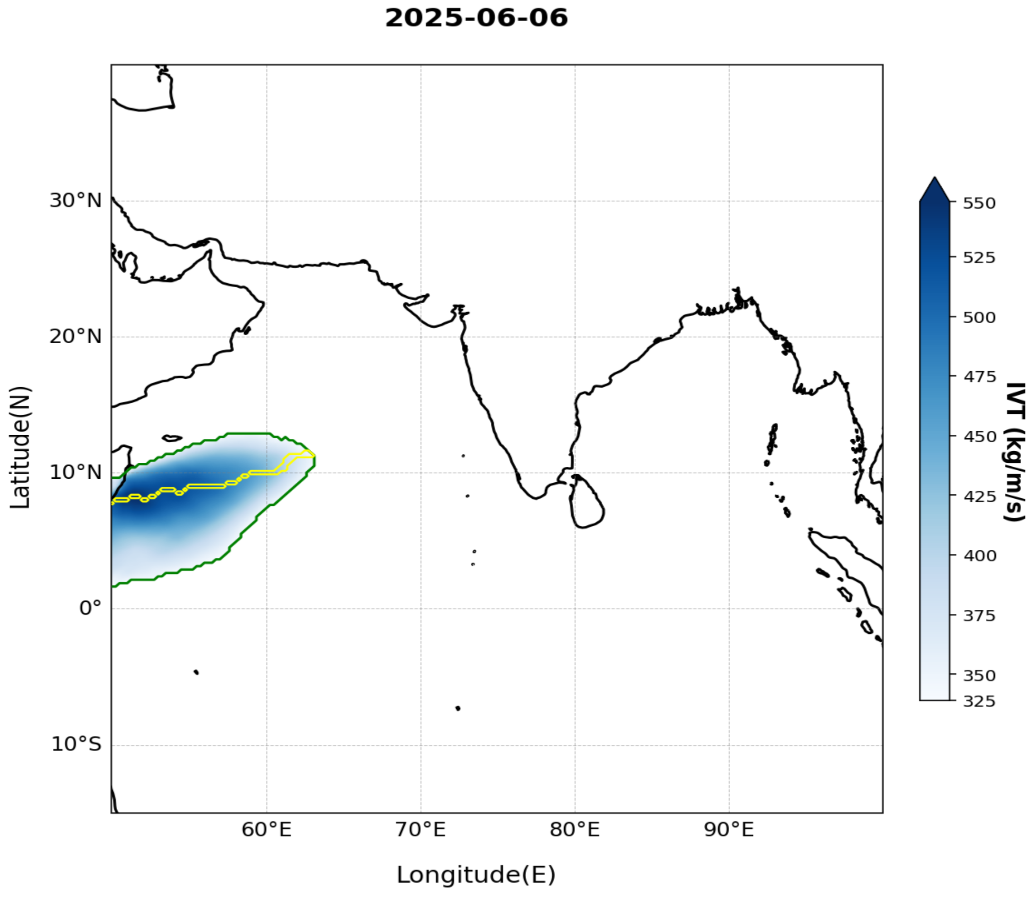
Date: 2025-06-04
Length: 1716 km, Width: 728 km
Mean IVT Magnitude: 435 kg/m/s, Mean IVT Direction: 58°
Core value of the AR:539 kg/m/s
Object Boundary: Green, Axis: Yellow
TIVT = 1.84e+10 kg/m/s,
Distance of the core from the land = 1993 km

5th June 2025

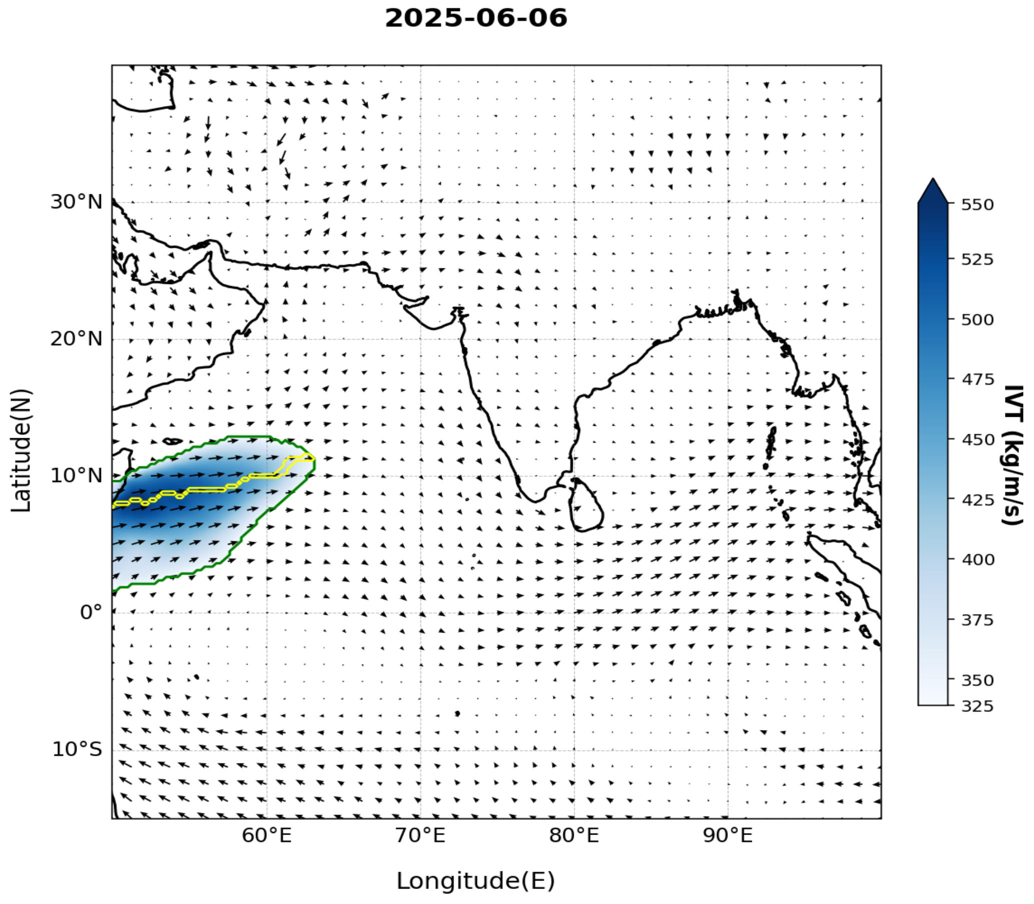


6th June 2025



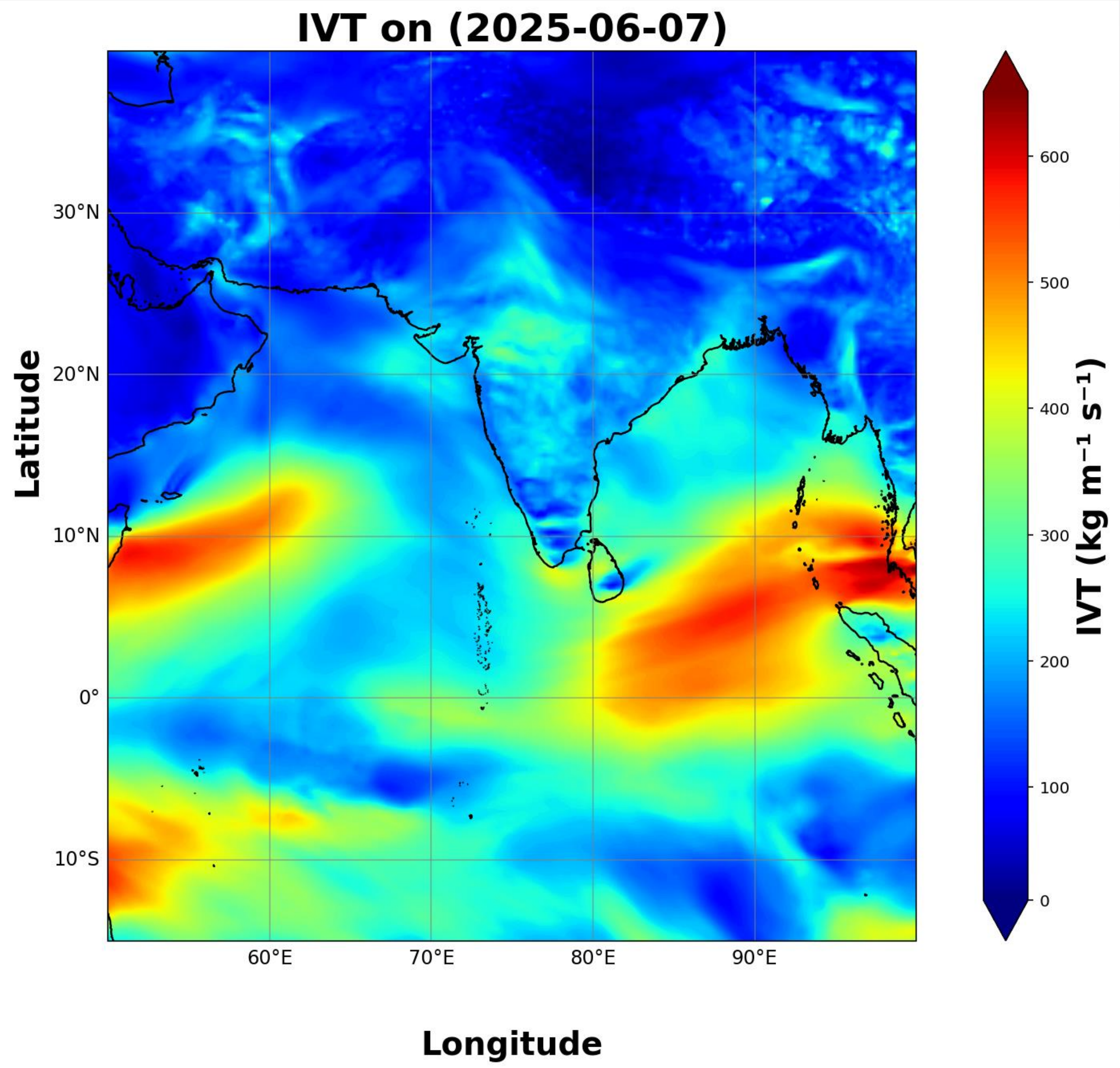


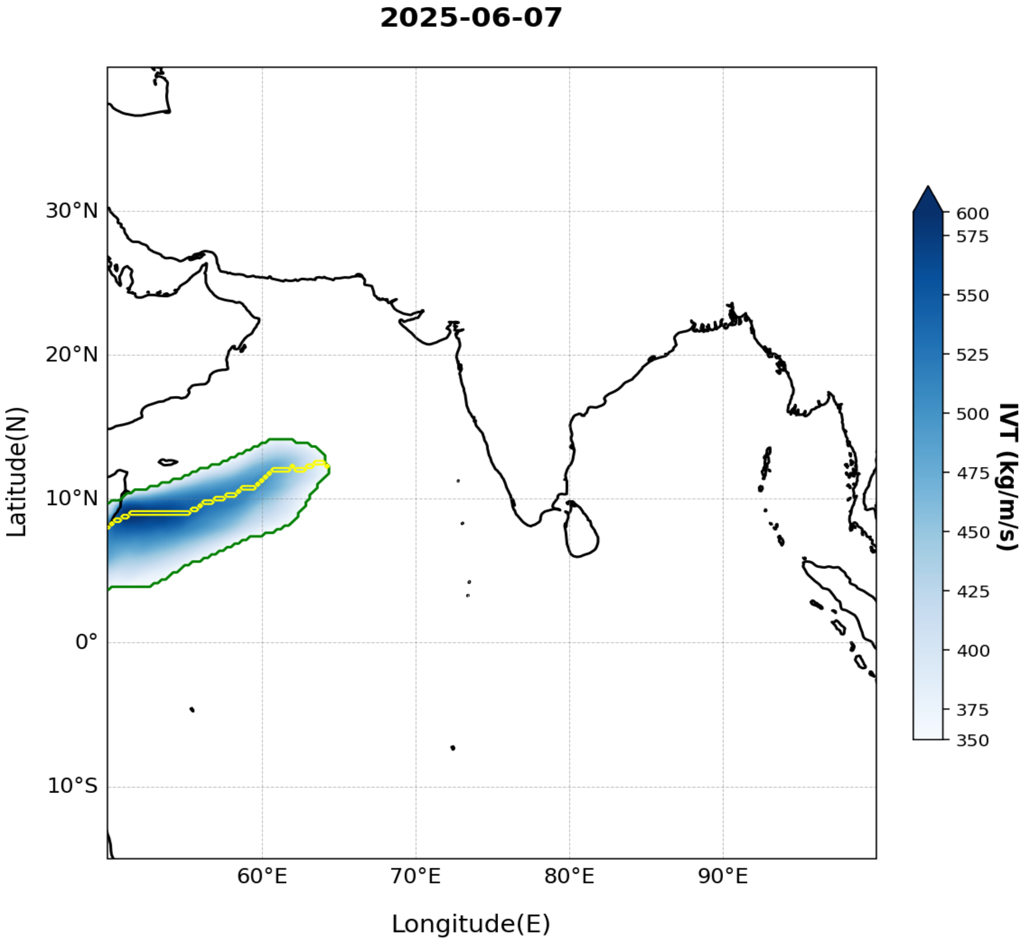
Date: 2025-06-06
Length: 1593 km, Width: 727 km
Mean IVT Magnitude: 429 kg/m/s, Mean IVT Direction: 68°
Core value of the AR:548 kg/m/s
Object Boundary: Green, Axis: Yellow
TIVT = 2.71e+10 kg/m/s,
Distance of the core from the land = 1986 km



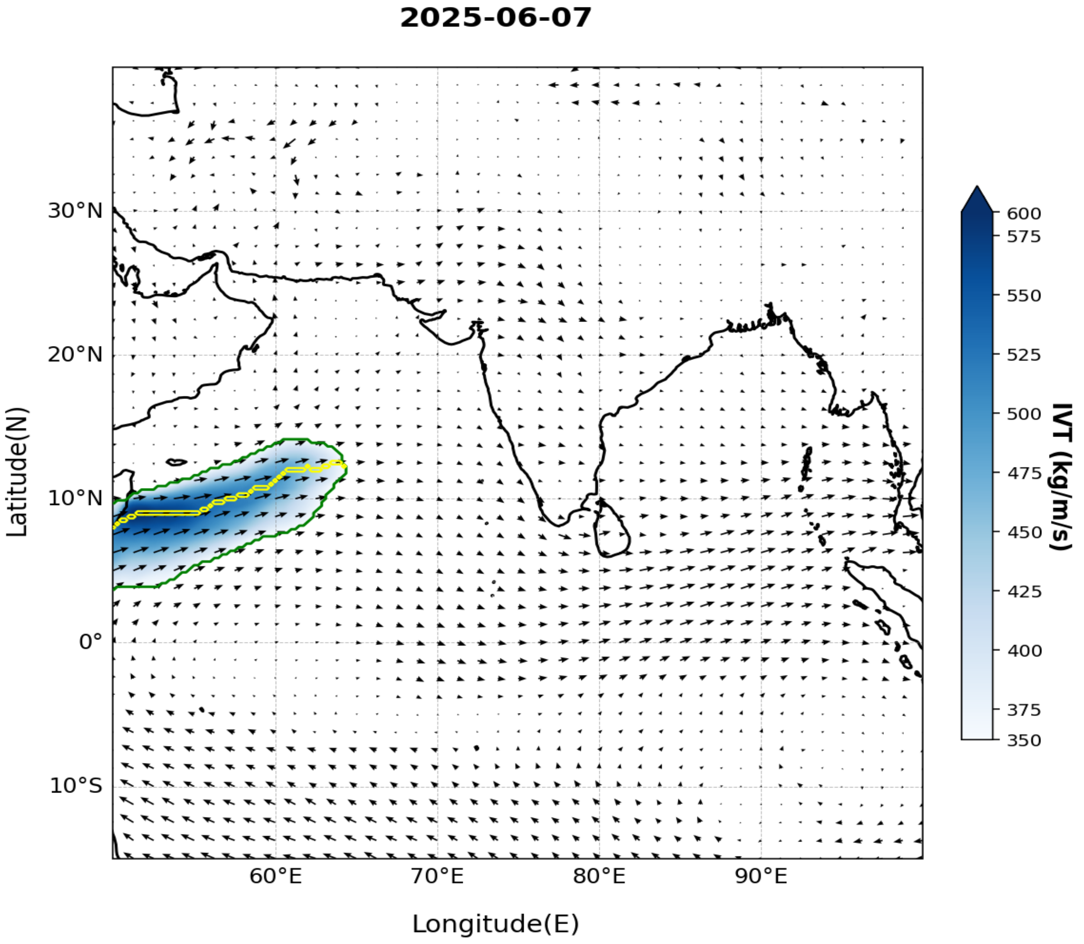
Date: 2025-06-06
Length: 1593 km, Width: 727 km
Mean IVT Magnitude: 429 kg/m/s, Mean IVT Direction: 68°
Core value of the AR:548 kg/m/s
Object Boundary: Green, Axis: Yellow
TIVT = 2.71e+10 kg/m/s,
Distance of the core from the land = 1986 km

7th June 2025



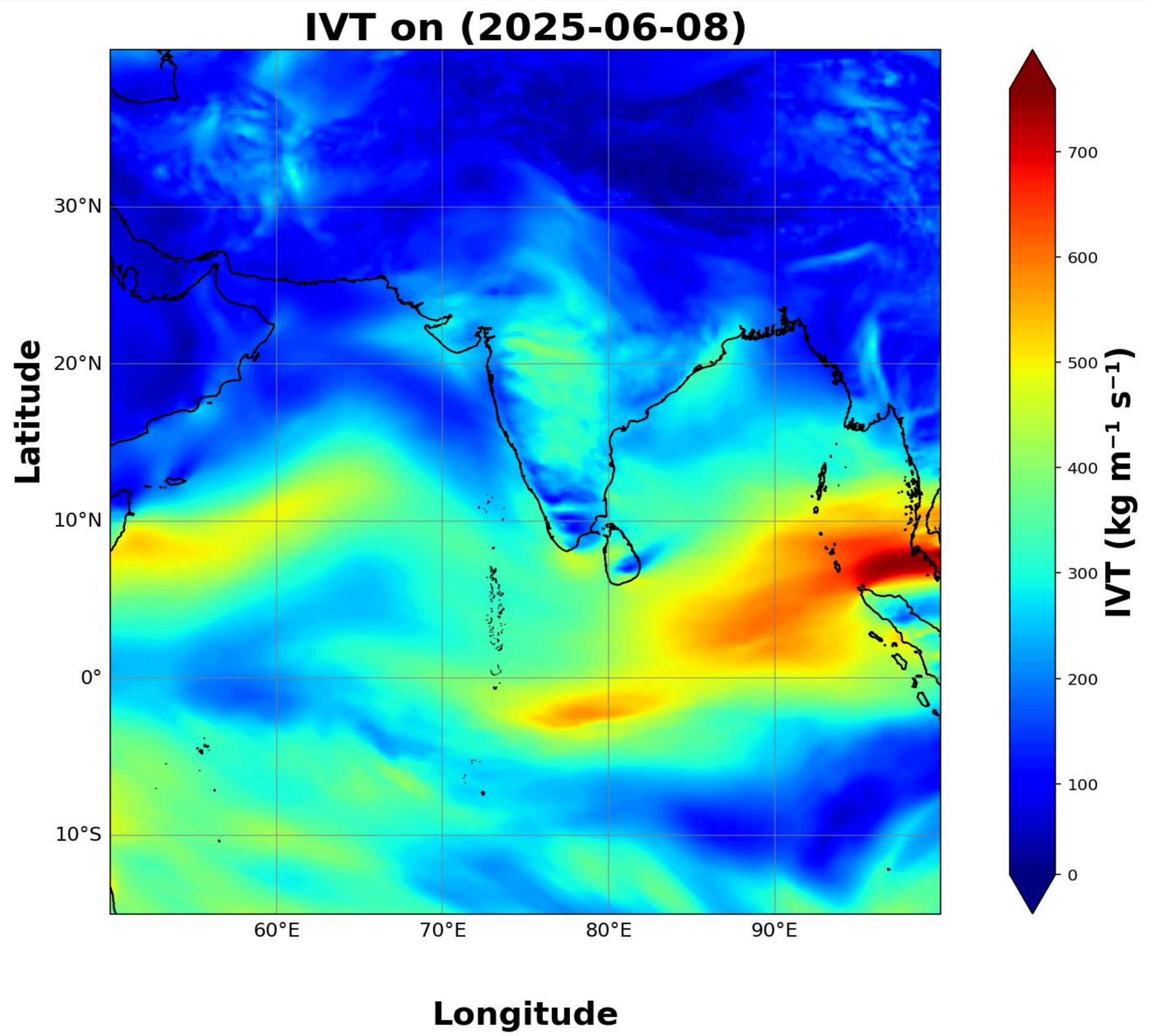


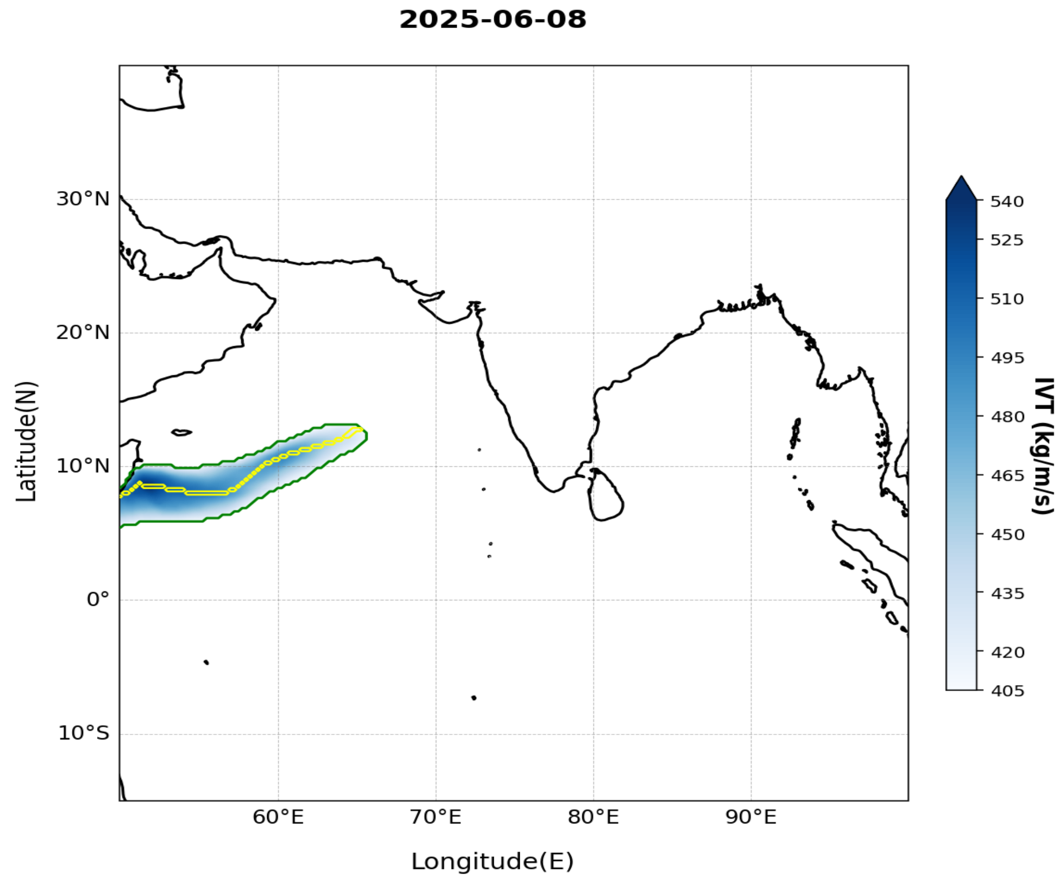
Date: 2025-06-07
Length: 1667 km, Width: 621 km
Mean IVT Magnitude: 455 kg/m/s, Mean IVT Direction: 65°
Core value of the AR:585 kg/m/s
Object Boundary: Green, Axis: Yellow
TIVT = 2.10e+10 kg/m/s,
Distance of the core from the land = 2019 km



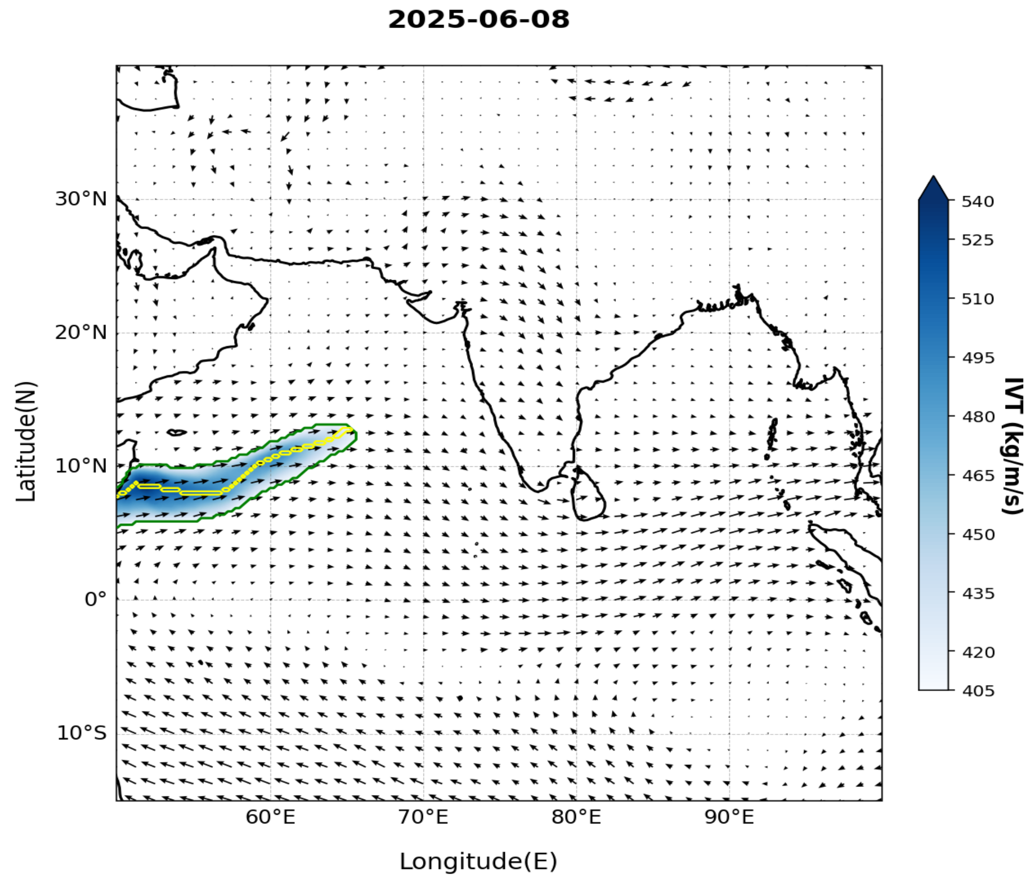
Date: 2025-06-07
Length: 1667 km, Width: 621 km
Mean IVT Magnitude: 455 kg/m/s, Mean IVT Direction: 65°
Core value of the AR:585 kg/m/s
Object Boundary: Green, Axis: Yellow
TIVT = 2.10e+10 kg/m/s,
Distance of the core from the land = 2019 km

8th June 2025



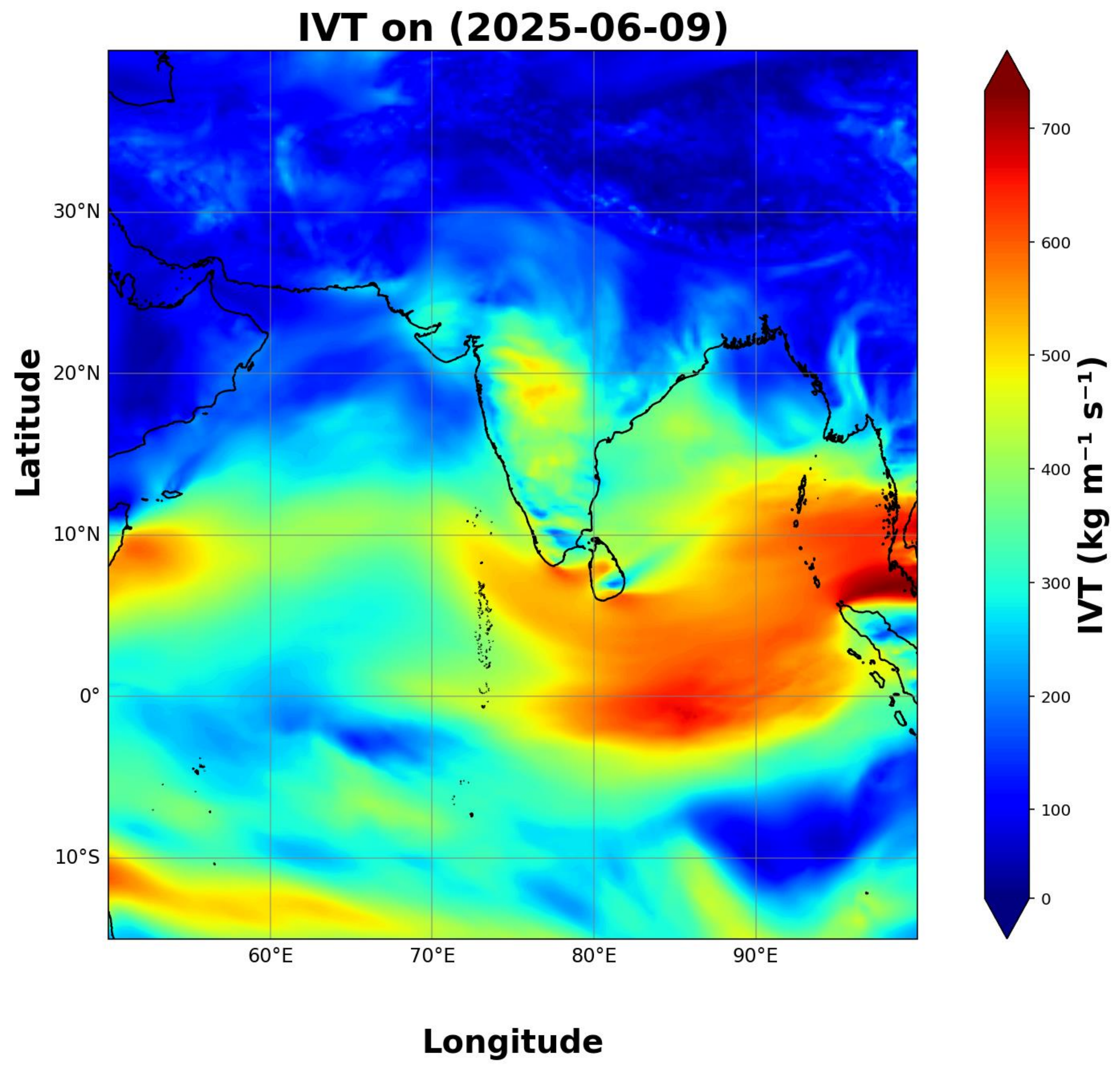


Date: 2025-06-08
Length: 1760 km, Width: 380 km
Mean IVT Magnitude: 462 kg/m/s, Mean IVT Direction: 68°
Core value of the AR:535 kg/m/s
Object Boundary: Green, Axis: Yellow
TIVT = 1.23e+10 kg/m/s,
Distance of the core from the land = 1972 km

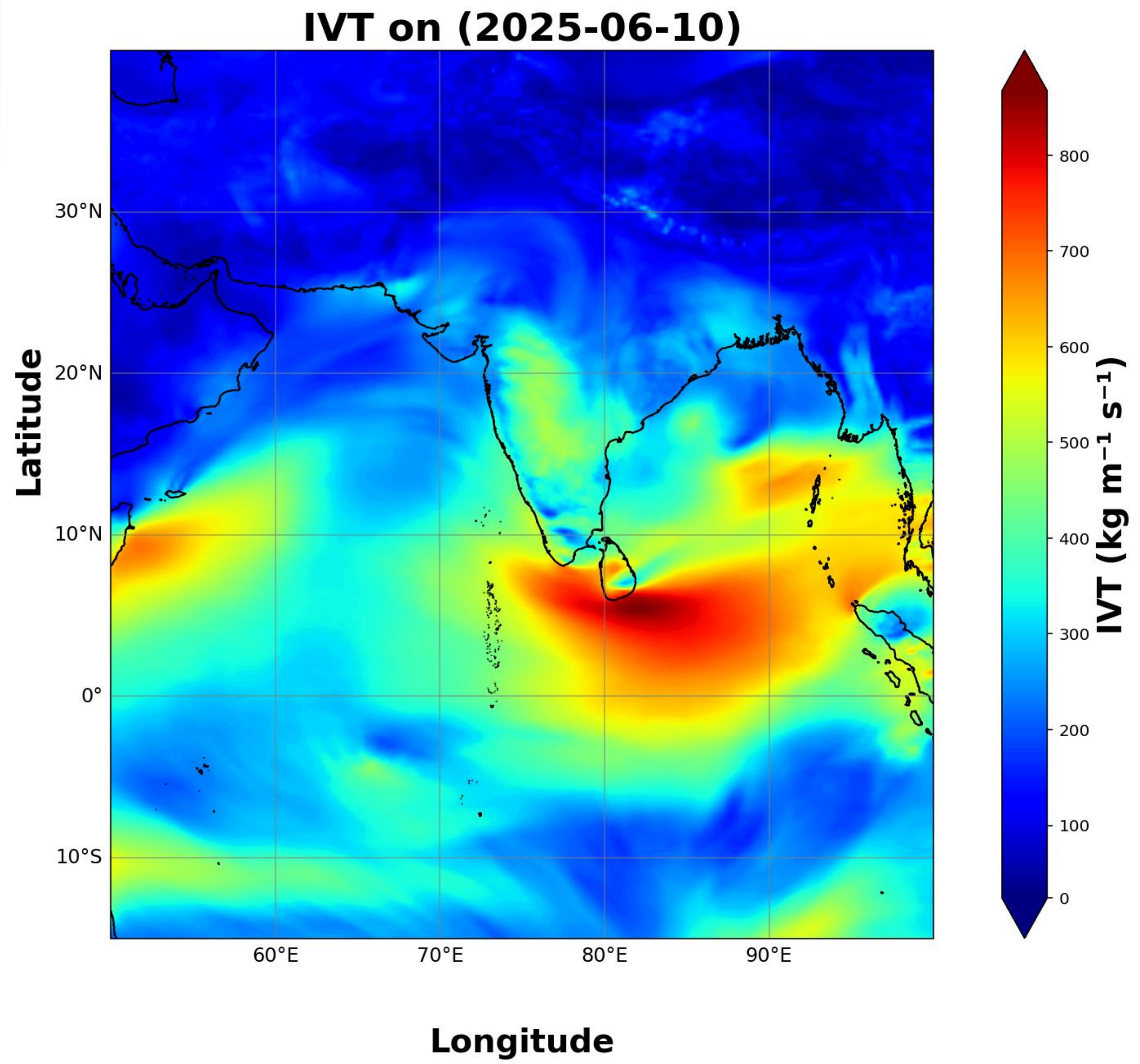


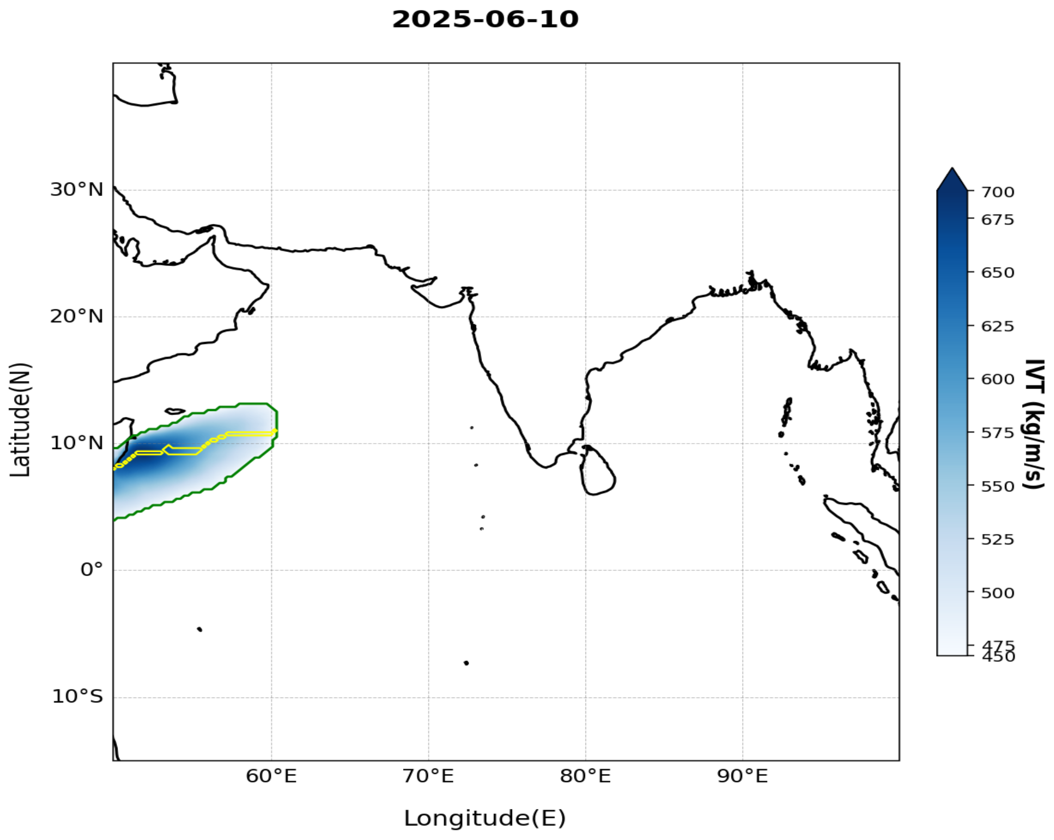
Date: 2025-06-08
Length: 1760 km, Width: 380 km
Mean IVT Magnitude: 462 kg/m/s, Mean IVT Direction: 68°
Core value of the AR:535 kg/m/s
Object Boundary: Green, Axis: Yellow
TIVT = 1.23e+10 kg/m/s,
Distance of the core from the land = 1972 km

9th June 2025

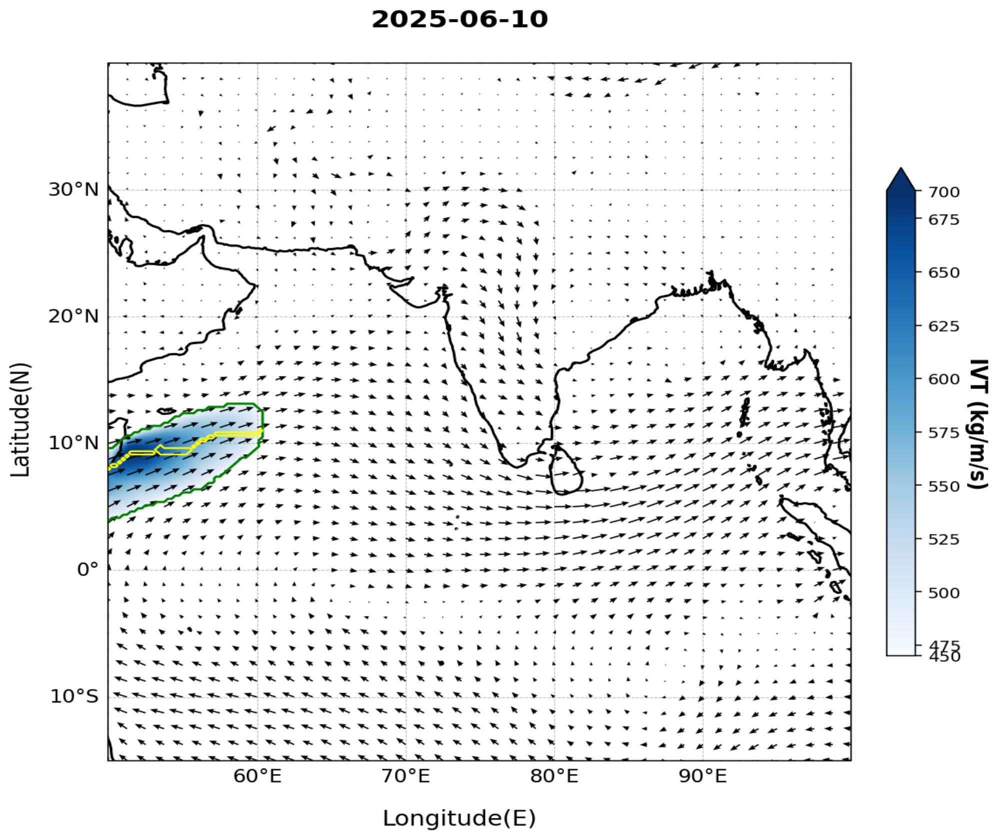


10th June 2025



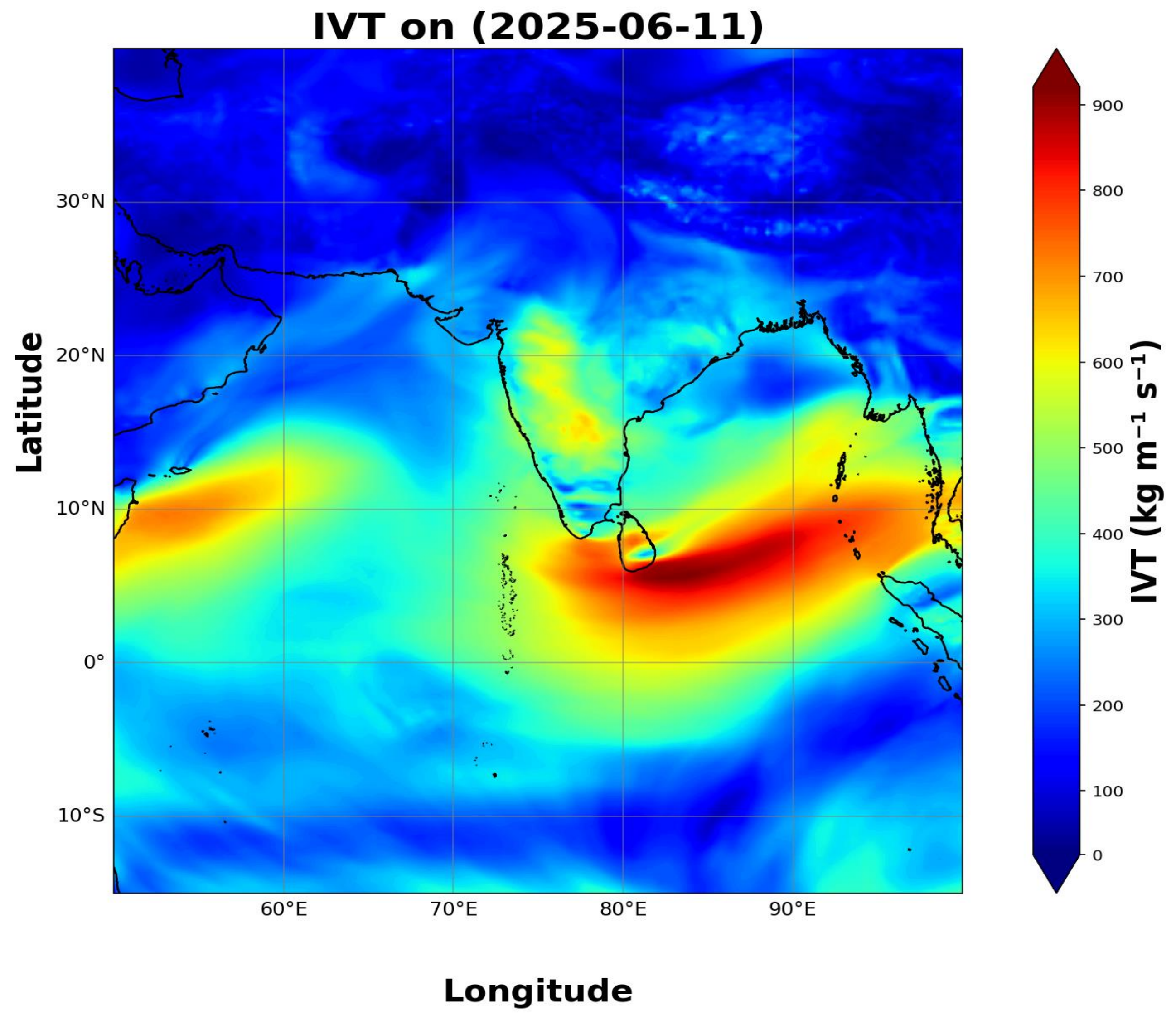


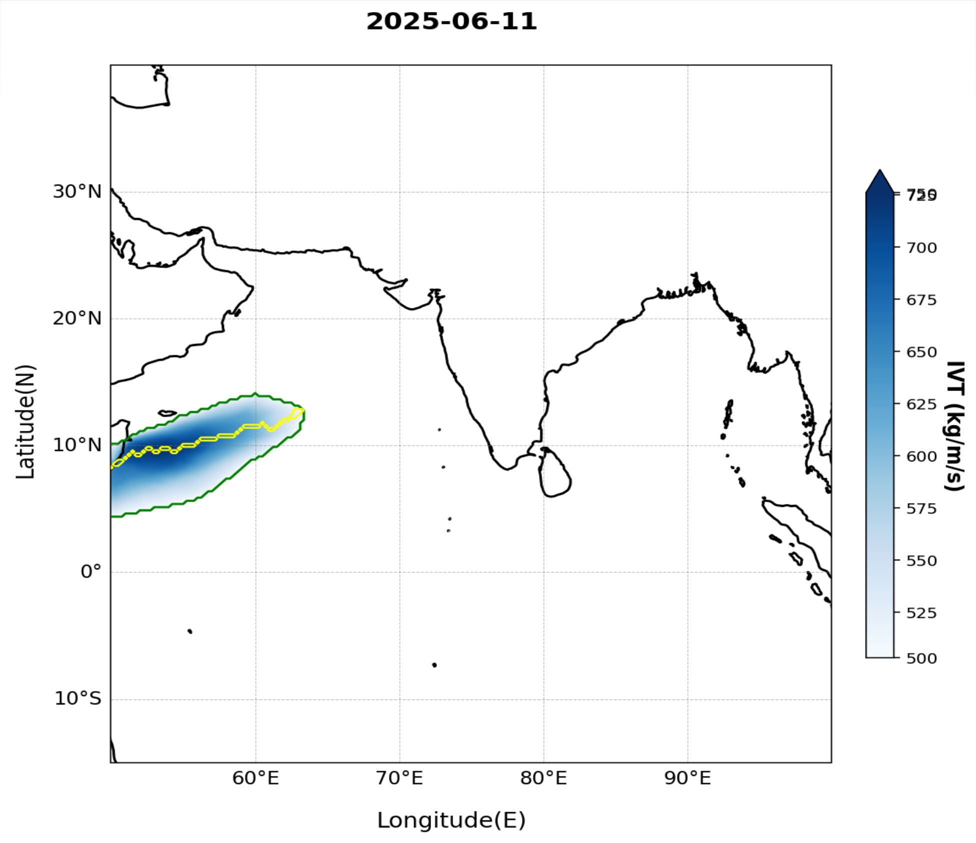
Date: 2025-06-10
Length: 1293 km, Width: 552 km
Mean IVT Magnitude: 552 kg/m/s, Mean IVT Direction: 62°
Core value of the AR:688 kg/m/s
Object Boundary: Green, Axis: Yellow
TIVT = 7.54e+08 kg/m/s,
Distance of the core from the land = 2006 km



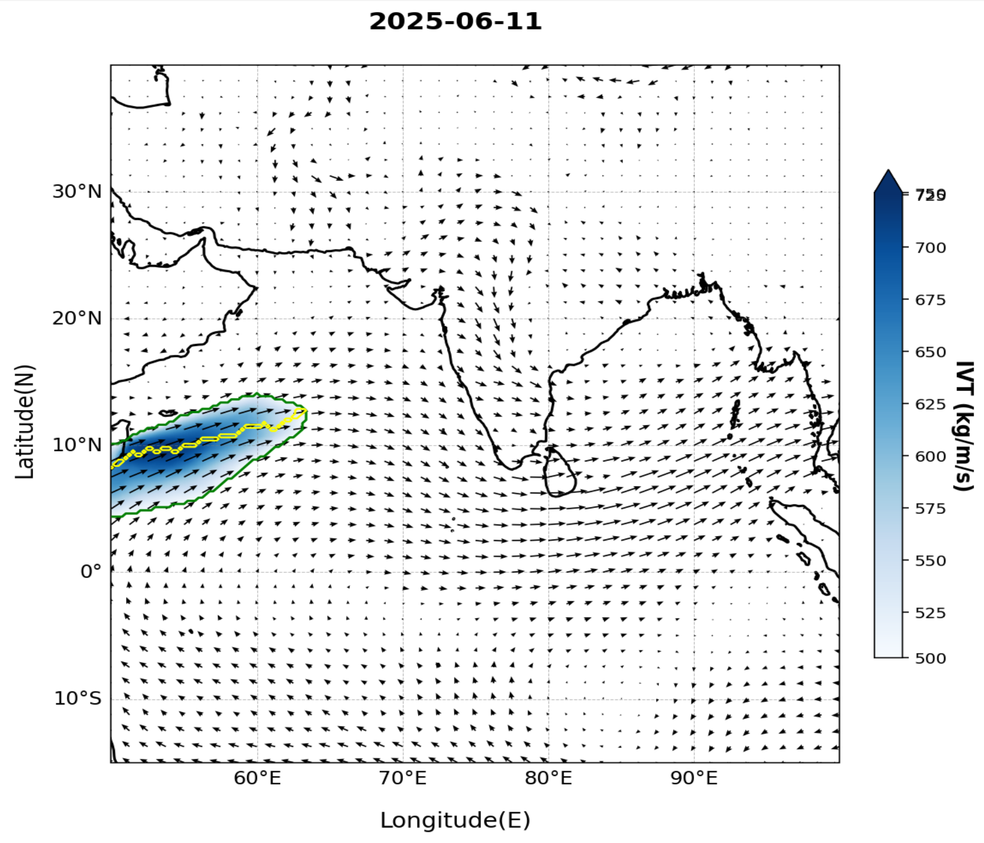
Date: 2025-06-10
Length: 1293 km, Width: 552 km
Mean IVT Magnitude: 552 kg/m/s, Mean IVT Direction: 62°
Core value of the AR:688 kg/m/s
Object Boundary: Green, Axis: Yellow
TIVT = 7.54e+08 kg/m/s,
Distance of the core from the land = 2006 km

11 June 2025


IVT on (2025-06-11)
Latitude
30°N
20°N
10°N
0°
10°S
60°E
70°E
80°E
90°E
Longitude
900
800
700
600
500
400
300
200
100
0
IVT (kg m⁻¹ s⁻¹)



Date: 2025-06-11
Length: 1620 km, Width: 565 km
Mean IVT Magnitude: 603 kg/m/s, Mean IVT Direction: 62°
Core value of the AR:726 kg/m/s
Object Boundary: Green, Axis: Yellow
TIVT = 2.90e+10 kg/m/s,
Distance of the core from the land = 1932 km



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