CAPSTONE PROJECT

CYCLONE INTENSITY ESTIMATION

USING INSAT-3D IR

PROJECT OVERVIEW

The motivation behind this project stems from the need for more accurate and timely predictions of tropical cyclone intensity, which is crucial for saving lives and minimizing damage during these powerful storms. Traditional methods of estimating cyclone strength often struggle in the early stages of cyclone formation, mainly because they rely on pinpointing the cyclone's center — a task that's particularly challenging when the storm's structure is still forming.

To address this, we are leveraging computer vision (CV) and deep learning techniques. Our goal is to create a model that can analyze satellite images and estimate the cyclone's intensity without depending on the exact location of the cyclone's center. This approach allows for more accurate intensity predictions during the critical early stages of a cyclone's formation when traditional methods fall short.

PROBLEM STATEMENT

PROBLEM: THIS PROBLEM IS TAKEN FROM SMART INDIA HACKATHON 2022, UNDER DISASTER MANAGEMENT CATEGORY. (PS_NO - SS591)

8	Department of Space, Indian Space Research Organisation (ISRO).	Deep Learning based Cyclone Intensity estimation using INSAT-3D IR imagery	Software	SS591	66	Disaster Management

Estimating the intensity of tropical cyclones is challenging, especially during their early formation stages when the cyclone's center is difficult to pinpoint. Traditional methods rely on accurate center determination, which can be problematic in the initial stages of cyclone development. This can lead to delays and inaccuracies in intensity predictions, impacting early warning systems and preparedness.

RESEARCH PAPER ANALYSIS

PAPER	RELATED WORK
1 .A CNN-Based Hybrid Model for Tropical Cyclone Intensity Estimation in Meteorological Industry(2020)	• To improve the TCI Traditional methods could not helped. CNN has good results. In this paper proposed a hybrid CNN model(reg+classification techniques) for TCI accuracy enhancement. • This outperformed the existing models even with a single infrared band.
2 .Cyclone Intensity Estimation Leveraging Graph Convolution Recurrent Networks and INSAT 3D Imagery (2024)	• using GCRNs and INSAT 3D imagery, to enhance CI estimation by integrating spatial and temporal data. • The proposed solution utilizes advanced ML &DL techniques, including (CNNs),(RNNs),(GNNs),
3.A Lightweight Multitask Learning Model With Adaptive Loss Balance for Tropical Cyclone Intensity and Size Estimation	• Simultaneous estimation of intensity and size of TC with adaptive loss balancing. More accurate, reliable estimations of TCI and size compared to existing methods. • Multitask learning with adaptive loss balancing improved the intensity and size estimation of TC through DL methods.
4. A Multiscale and Multilayer Feature Extraction Network With Dual Attention for Tropical Cyclone Intensity Estimation	• TCIENet & TCICENet: These models use Convolution Block Attention Modules (CBAM) to enhance tropical cyclone classification and estimation, addressing data source limitations and model complexity. • The dual attention mechanisms improve feature extraction from satellite images, boosting overall estimation accuracy.

5 .A Novel Tensor Network for Tropical Cyclone Intensity Estimation	• ML approaches improve automation but suffer from issues with low-quality, distorted single-channel IR images and complex, task-dependent Tensor Network (TN) models. • novel TN model combining tensor analysis with CNNs, TC intensity estimation using high-quality FY-4 MSI data
6.A Semisupervised Deep Learning Framework For TCI	• CNN for feature extraction and iteratively refines predictions by selecting reliable labels from unlabeled data. • Dropout and stochastic gradient descent enhance accuracy, leveraging both labeled and unlabeled data for improved results.
7. Cyclone Intensity Estimation using Infrared Satellite Imagery	• Dvorak, Advanced Dvorak, and Deviation-Angle Variance focusing on enhancing prediction accuracy while addressing challenges such as data noise and operational latency.
8.Deepti: Deep-Learning-Based Tropical Cyclone Intensity Estimation System	• Automated Advanced Dvorak technique, which faces challenges with weaker storms. DVAT For SYMMETRY analysis. • Lastly, passive microwave imagery aids in cyclone structure analysis but suffers from limited observation frequency.
9.-Net: A Deep Learning Approach for Tropical Cyclone Intensity Prediction	• 2D-CNN and hybrid models show promise but require larger datasets for optimization. The proposed TCI-Net model aims to enhance prediction accuracy, utilizing the TCIR dataset from multiple channels.

KEY METHODOLOGIES

DVORAK TECHNIQUE:

- Dvorak Technique is a widely used manual method for estimating tropical cyclone intensity from satellite images.
- It involves analyzing cloud patterns, cloud top temperatures, and other satellite-derived features.
- The method categorizes cyclones based on patterns like the central dense overcast (CDO), eye feature, and banding features to assign a "T-number" which corresponds to wind speeds and intensity.

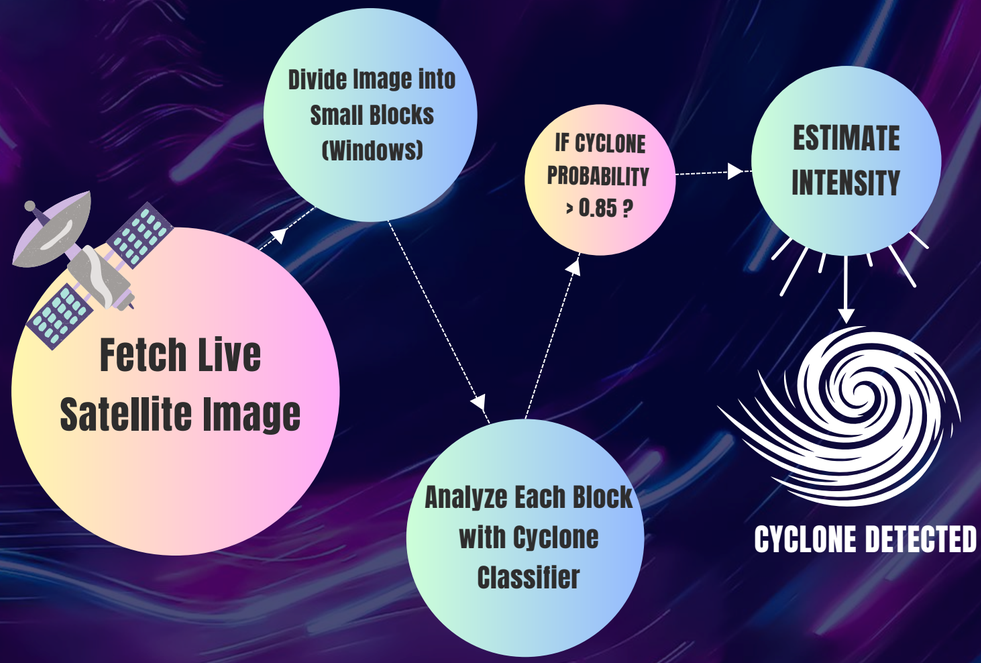
DEVIATED MEAN ANGLE TECHNIQUE (DMAT):

- DMAT is a more modern, automated technique that uses satellite data to estimate the cyclone's intensity.
- It calculates the deviation of cloud mass relative to the cyclone center using geostationary satellite imagery.
- This technique quantifies the angular deviation between the radial and tangential cloud structures to determine the intensity.

METHODOLOGY

OUR STUDY UTILIZES IR SATELLITE IMAGES FOR CYCLONE CLASSIFICATION, DETECTION, AND INTENSITY ESTIMATION. IMAGES ARE PREPROCESSED TO 64X64 GRAYSCALE AND SEGMENTED USING FELZENSZWALB'S ALGORITHM FOR FEATURE EXTRACTION, INCLUDING TEXTURE, SHAPE, AND INTENSITY METRICS. FOR DETECTION, LIVE SATELLITE IMAGES ARE DIVIDED INTO BLOCKS ANALYZED BY A CLASSIFIER, WITH INTENSITY THRESHOLDS IDENTIFYING CYCLONES. INTENSITY ESTIMATION EMPLOYS DEEP LEARNING MODELS SUCH AS DENSENET, XCEPTION, MOBILENETV3, RESNET, AND EFFICIENTNET. A FLASK WEB APP FACILITATES REAL-TIME IMAGE UPLOADS, SEGMENTATION, AND PREDICTIONS, ENABLING EFFICIENT CYCLONE ANALYSIS.

REALTIME CYCLONE DETECTION



CYCLONE CLASSIFICATION

DATASET:

- LABELED IMAGES (CYCLONE/NON-CYCLONE), RESIZED TO 64X64 PIXELS, CONVERTED TO GRAYSCALE.

FEATURE EXTRACTION:

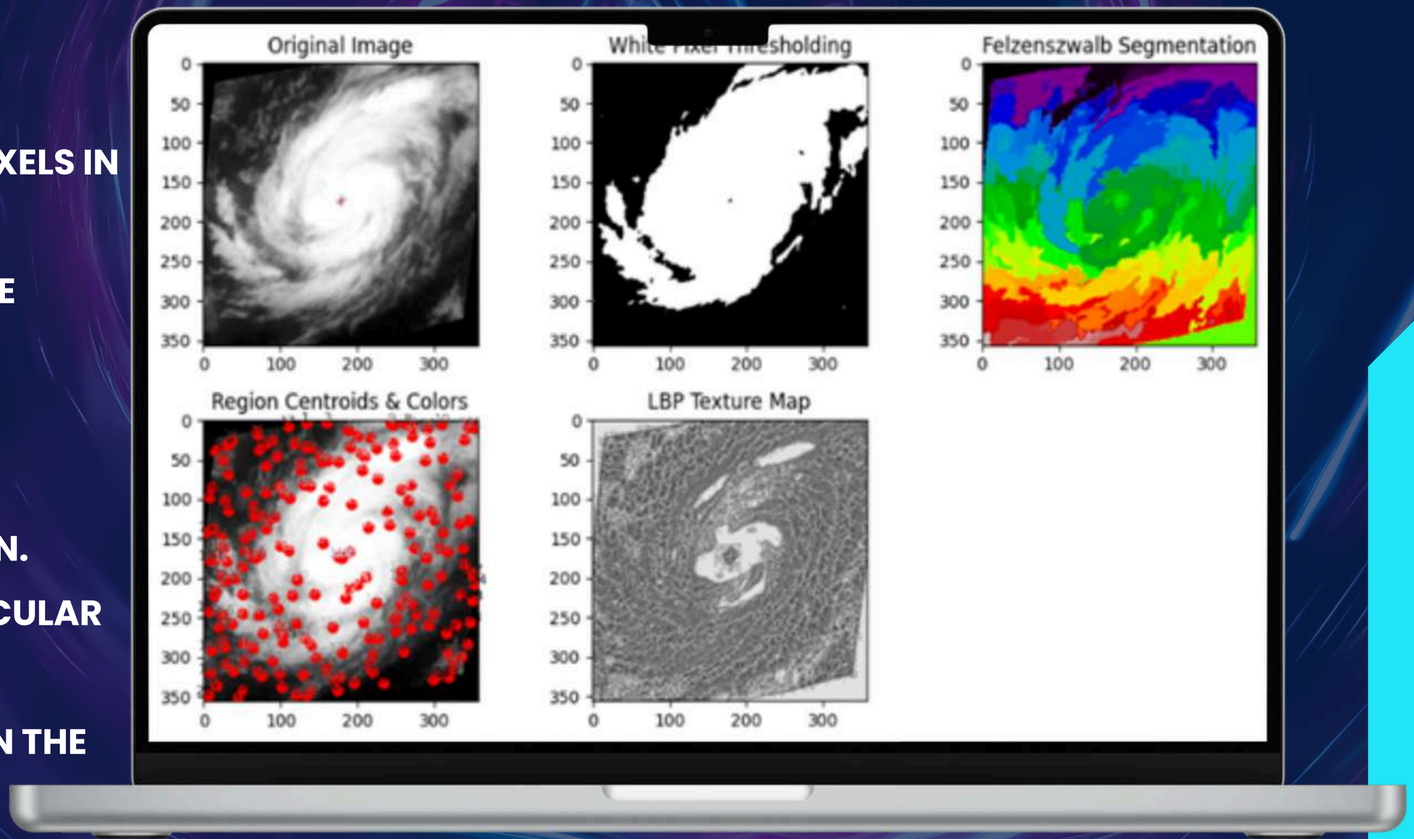
SEGMENTATION: FELZENSZWALB'S ALGORITHM.

- METRICS:
  - WHITE PIXEL RATIO (INTENSITY ANALYSIS).
  - SHAPE FEATURES: MEAN COLOR, AREA, PERIMETER, CIRCULARITY.
  - TEXTURE: COLORFULNESS, LBP HISTOGRAMS.
  - SPATIAL: NORMALIZED CENTROIDS.
- MODEL TRAINING: COMBINED FEATURES INTO A VECTOR TO TRAIN A CLASSIFIER FORCYCLONE DETECTION.

CLASSIFICATION

Features Taken for the Decision Tree:

1. WHITE PIXEL RATIO – PROPORTION OF WHITE PIXELS IN THE IMAGE.
2. MEAN COLOR – AVERAGE COLOR VALUES OF THE REGION.
3. AREA – SIZE OF THE SEGMENTED REGION (PIXEL COUNT).
4. PERIMETER – BOUNDARY LENGTH OF THE REGION.
5. CIRCULARITY – MEASURE OF THE REGION'S CIRCULAR SHAPE.
6. COLORFULNESS – DIVERSITY OF COLORS WITHIN THE REGION.
7. LOCAL BINARY PATTERN (LBP) – TEXTURE ANALYSIS THROUGH PIXEL INTENSITY PATTERNS.



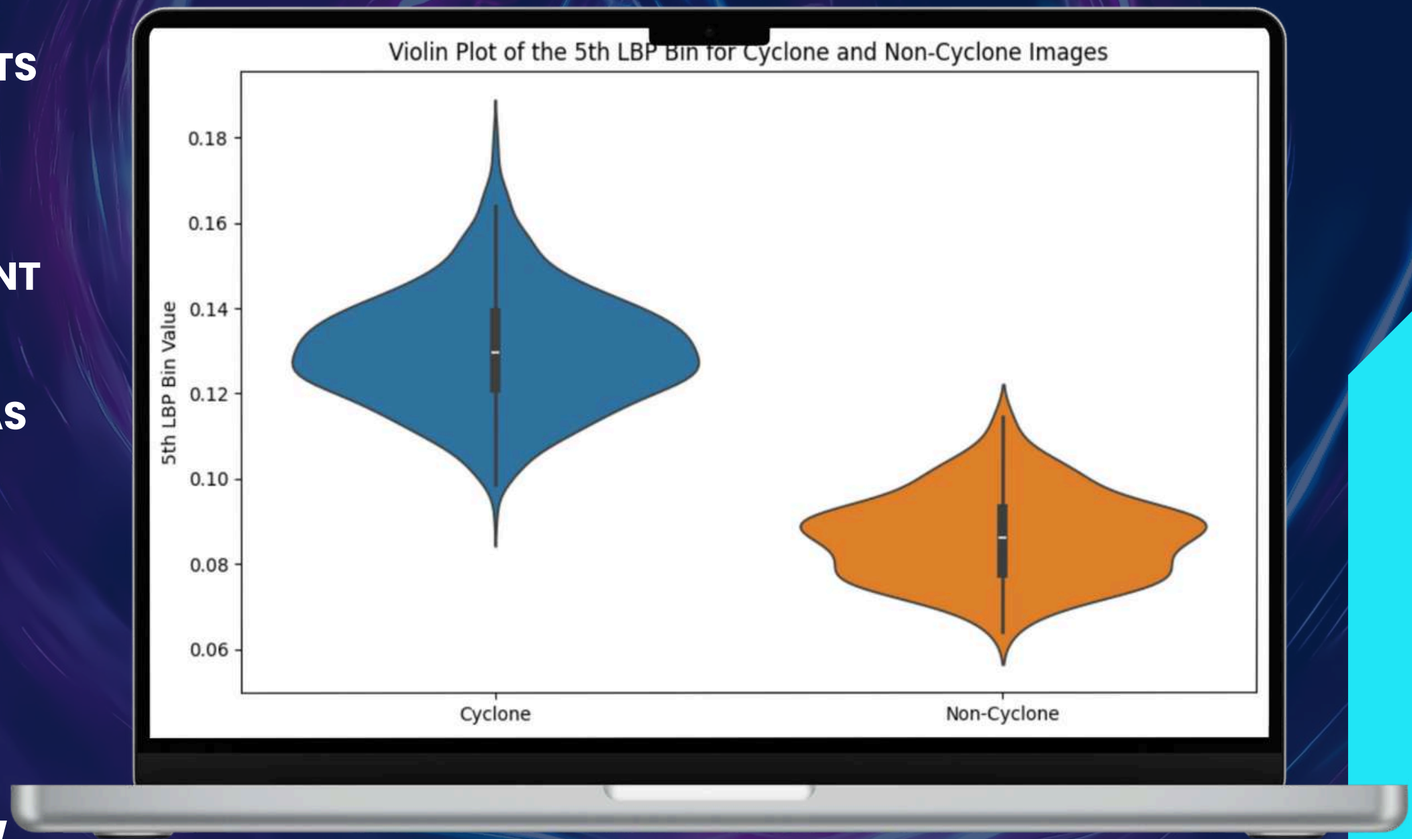
INTERMEDIATE STEPS

ACCURACY : 100%

CLASSIFICATION

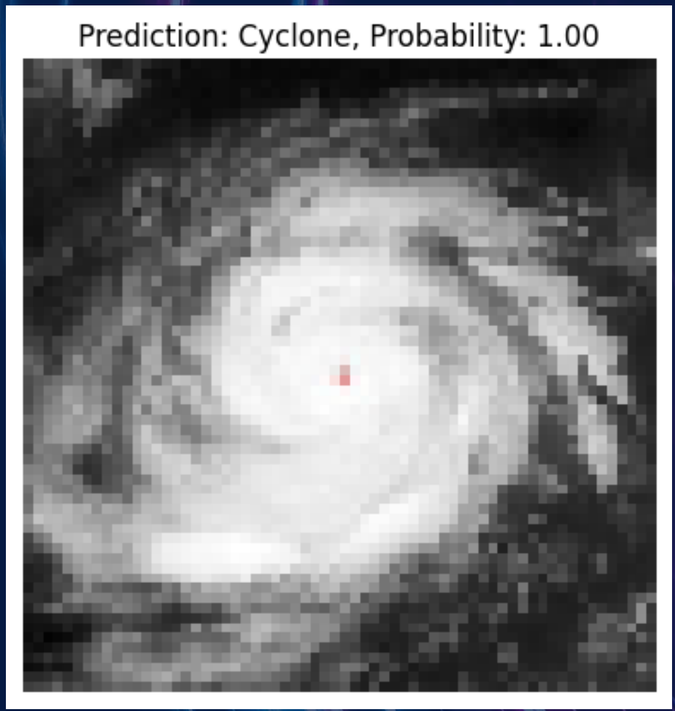
Main Features:

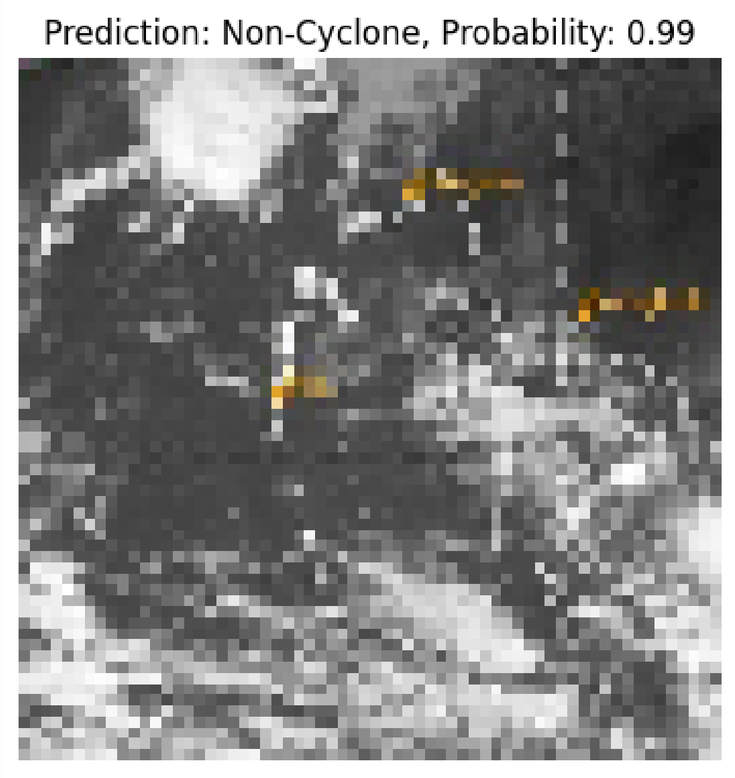
- THE DECISION TREE WAS SELECTED DUE TO ITS ABILITY TO AUTOMATICALLY IDENTIFY THE MOST IMPORTANT FEATURES WHILE EFFECTIVELY IGNORING WEAK OR IRRELEVANT ONES.
- AMONG THE FEATURES, THE LBP 5TH BIN WAS IDENTIFIED AS PARTICULARLY CRUCIAL FOR DISTINGUISHING BETWEEN CYCLONE AND NON-CYCLONE IMAGES.
- TO HIGHLIGHT THE SIGNIFICANCE OF THIS FEATURE, A VIOLIN PLOT WAS USED TO VISUALIZE ITS ROBUSTNESS, SHOWING HOW CONSISTENTLY IT SEPARATES THE TWO CLASSES.

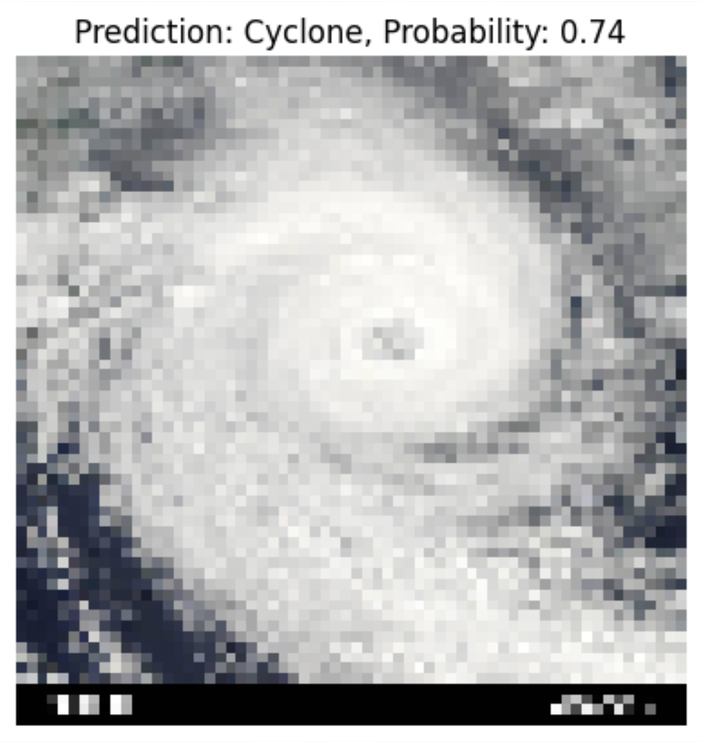


VIOLIN PLOT OF LBP(5TH BIN)

SAMPLE OUTPUTS(OF VALIDATION IMAGES):

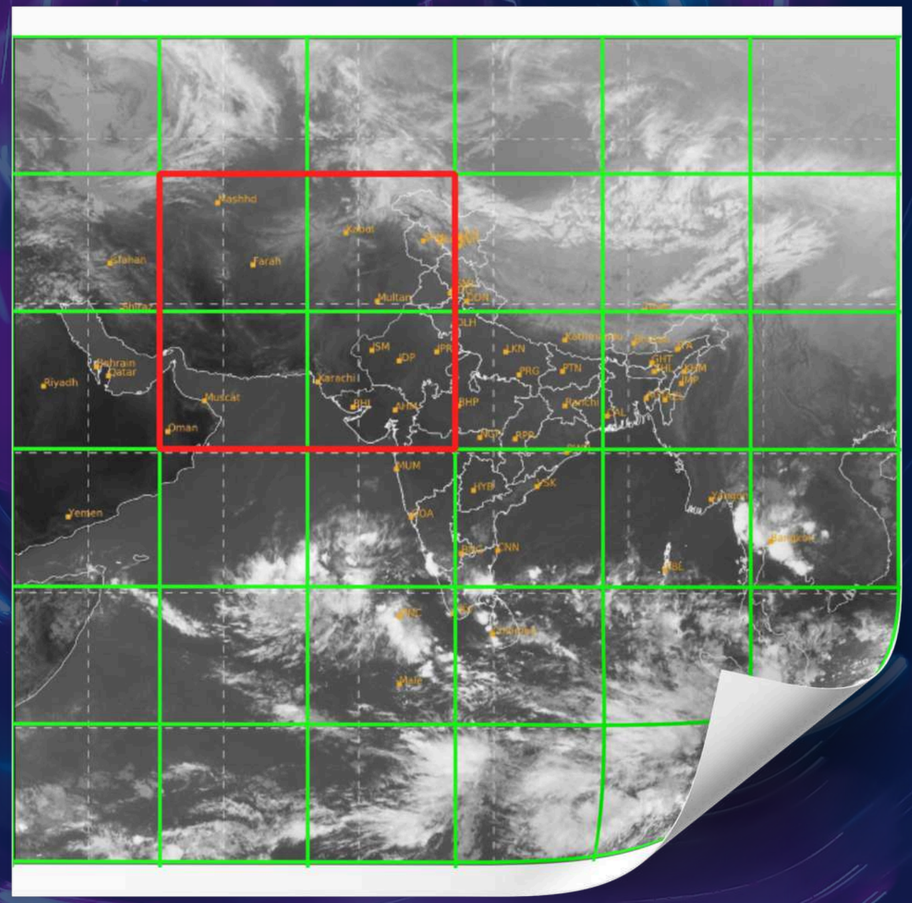






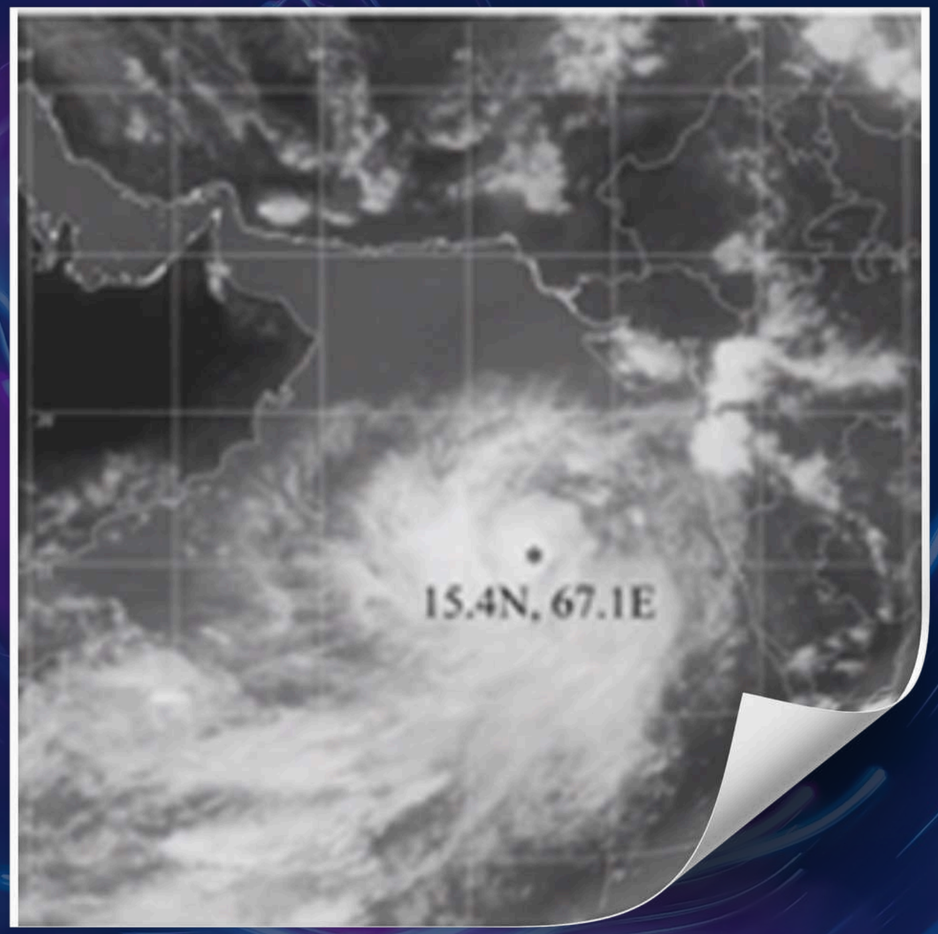
DETECTION

- A SLIDING WINDOW TECHNIQUE WAS USED TO DIVIDE SATELLITE IMAGES INTO SMALLER OVERLAPPING BLOCKS FOR DETAILED ANALYSIS.
- EACH BLOCK WAS ANALYZED BY A CYCLONE CLASSIFIER TO IDENTIFY POTENTIAL CYCLONE FEATURES.
- IF THE CYCLONE PROBABILITY WAS GREATER THAN 85%, THE BLOCK WAS CLASSIFIED AS A CYCLONE.
- THIS APPROACH ENSURES PRECISE LOCALIZATION, ACCURATE DETECTION OF CYCLONES, AND REDUCES COMPUTATIONAL COSTS.



ESTIMATION

- INTENSITY ESTIMATION INVOLVES ANALYZING DETECTED CYCLONE REGIONS TO PREDICT THEIR STRENGTH.
- DENSENET WAS USED AS THE PRIMARY MODEL FOR ITS ABILITY TO CAPTURE FINE DETAILS AND ACHIEVE HIGH ACCURACY.
- FEATURES LIKE TEXTURE, SHAPE, AND INTENSITY VARIATIONS WERE EXTRACTED FOR PRECISE PREDICTIONS.
- THIS METHOD HELPS IN PROVIDING EARLY WARNINGS AND SUPPORTING DISASTER MANAGEMENT EFFORTS.



ACTUAL: 49

PREDICTED: 45.85

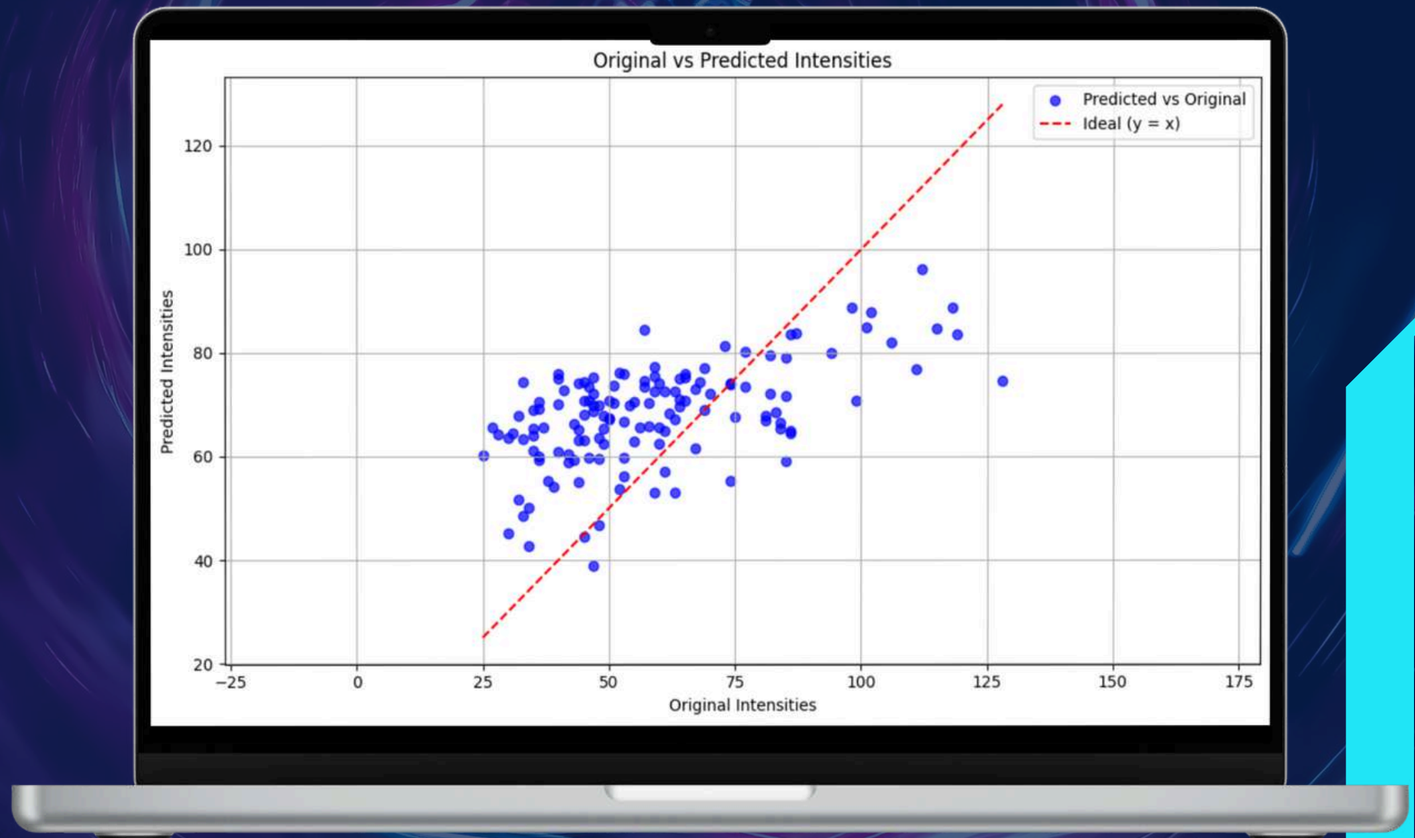
OUTCOMES OF THE MODELS

RESNET

Residual Network, can be employed in the estimation of cyclone intensity by utilizing its architecture to learn and **analyze complex patterns in data, such as satellite imagery or meteorological variables**. By facilitating deeper networks without performance degradation, ResNet models are advantageous in improving prediction accuracy for cyclone intensity.

MSE 1028.2786

RMSE: 32.0668

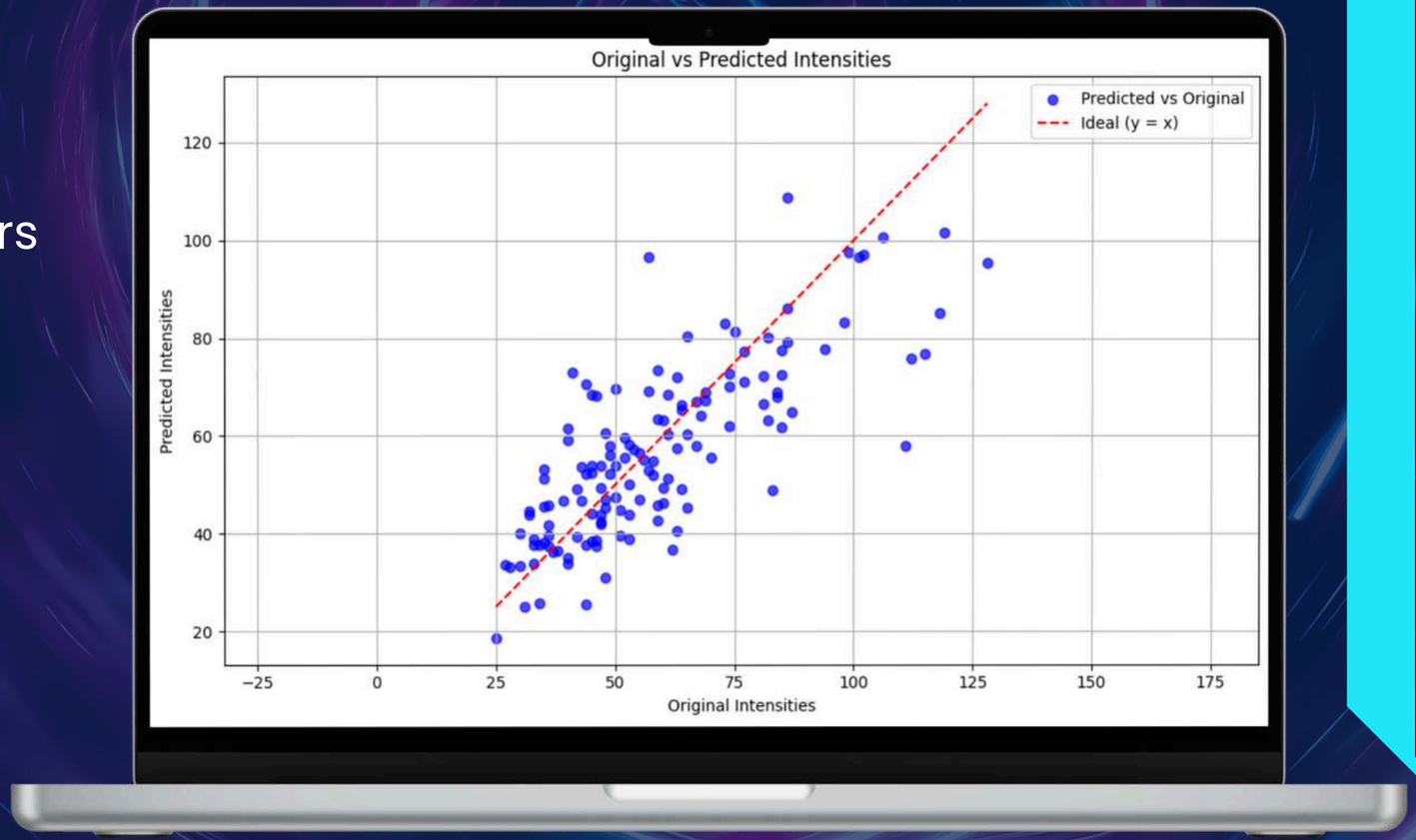


SCATTER PLOT ANALYSIS

OUTCOMES OF THE MODELS

USING EXCEPTION

A novel convolutional neural network (CNN) designed to estimate cyclone intensity, particularly measuring parameters like surface **wind speed and pressure.** This advanced model utilizes deep learning techniques to improve the accuracy of predictions based on image data from satellites and other sources.



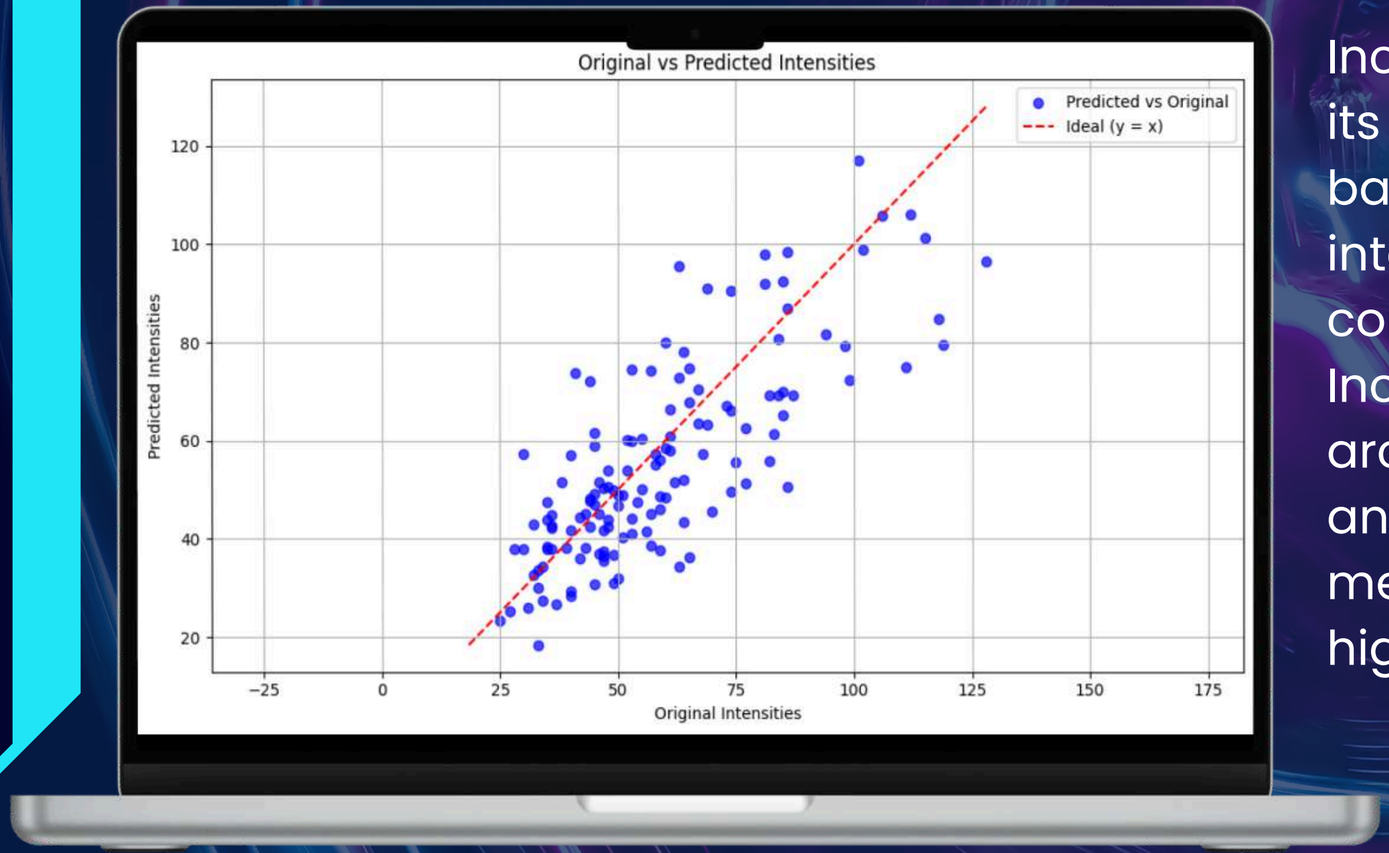
SCATTER PLOT ANALYSIS

MSE: 4.1763

RMSE: 2.0436

OUTCOMES OF THE MODELS

INCEPTION RESNET



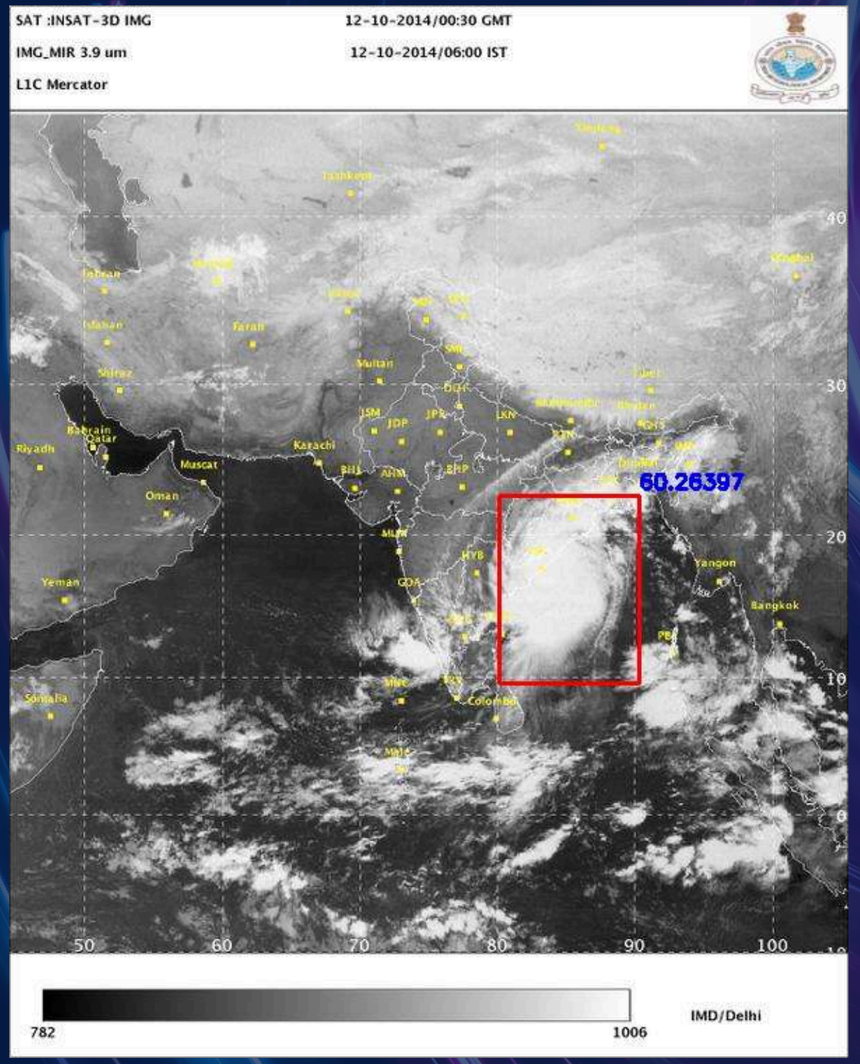
SCATTER PLOT ANALYSIS

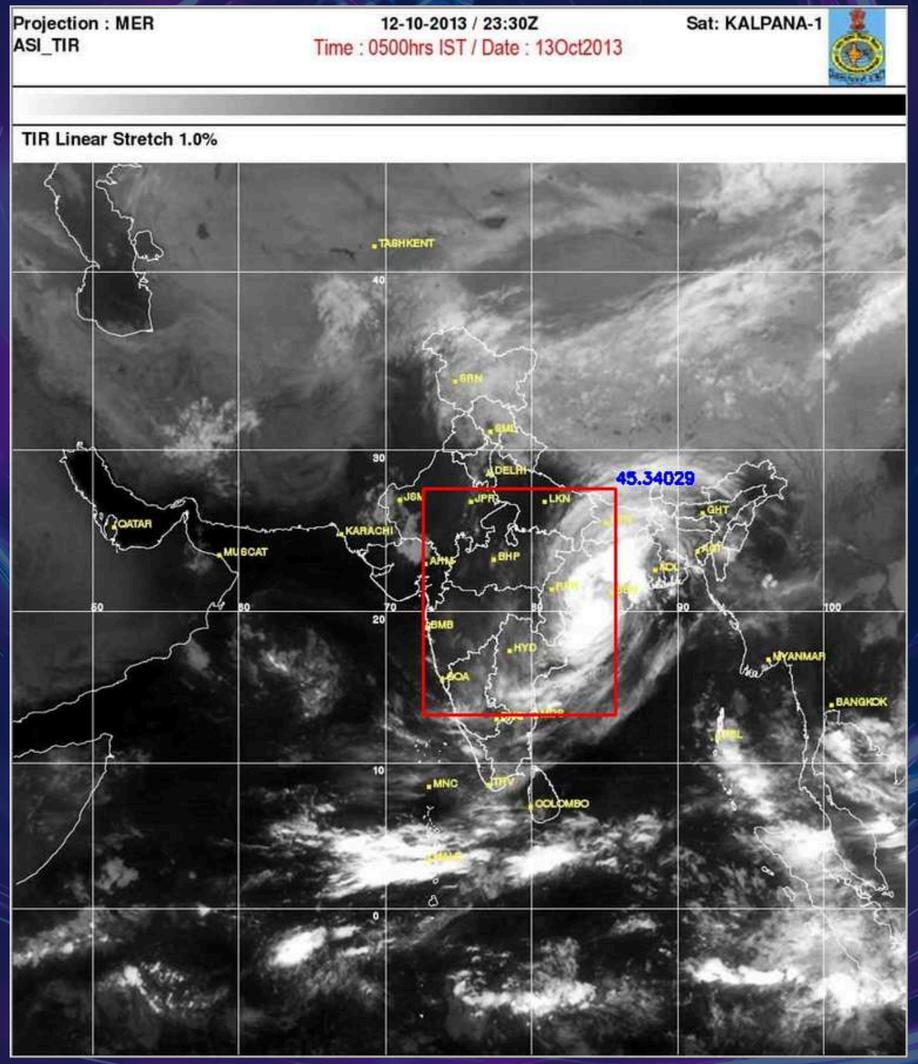
Inception-ResNet, renowned for its superior performance, is the backbone of our cyclone intensity estimation model. By combining the strengths of Inception modules and ResNet architecture, it efficiently analyzes complex meteorological data, providing highly accurate forecasts.

MSE: 3.1946

RMSE: 1.7873

FINAL RESULTS





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