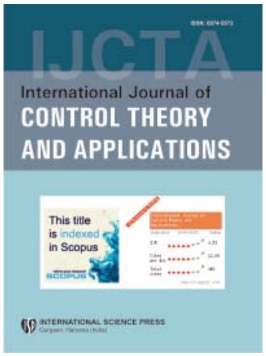

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Prediction and Tracking of Natural Disasters Through Real-time Detection of Tropical Depression

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Abstract: Natural Disasters are the major adverse effect resulting from the natural processes of earth. Weather forecasting based on various earth orbiting satellites and aircrafts reports are done now a days. It is not at all efficient for using these reports for disaster management since they are having delay in availability and processing. The most widely used weather forecasting method is satellite image processing. Now satellite sensors are used for getting more real-time weather data over a particular region. It is not at all reliable for using a single polar orbiting satellite for weather forecasting since it has limited spatial and temporal coverage. Earlier detection of cyclones and tracking such events in a continuous manner is limited due to the lack of temporal coverage. Usage of data from heterogeneous satellite sensors on multiple orbits are the only solution to avoid such problems. In this paper we are proposing an automated real-time tropical depression discovery and tracking method, thereby we can track the natural disasters such as cyclones, heavy rainfall, storm etc. Our proposed method deals with the challenges such as mining, data discovery and processing on high dimensional data. Some of the satellites may send data in a particular time interval which may be hours or days. In our proposed system we can use data streams from multiple satellite sensors. The four modules in our method deals with the processing of sensor resolution values to get exact values ,extraction of wind vectors and classification of this vectors and sharing the knowledge from the multiple satellite sensors.

Keyword: *Bit Processing; Hadoop; Satellite Sensor data; Cyclone; Heavy Rain, Storm; Detection; Tracking; SVM.*

1. INTRODUCTION

Earth's climate system is heavily dependent on tropical and extra tropical depression. Some of these depression may leads to heavy rain, storm and cyclone which may cause huge devastation. It also incurs fatality and affect people livelihood. The proposed method can identify a tropical depression in real-time. Warning can be given in maximum real time if we can analyse the satellite sensor data and identify the tropical depression earlier. Usually the upper air observations are concentrated on North American coasts. The (Tropical Prediction Centre) National Hurricane Centre uses conventional surface and upper-air observations and reconnaissance aircraft reports [1]. This paper consist of a method to provide global coverage in both developed and developing nations. Most common method used for analysing the weather is analysing the satellite images by a human expert. This method is time consuming and will take hours to detect the tropical depression on a particular region.

Detecting the storm, rainfall and cyclones etc. by finding out the tropical depression on a particular region is our goal. Conventional techniques do not provide global coverage and it is not possible to use the data from a single orbiting satellite to detect a tropical depression or tracking the effects of such sudden depression due its different spatial dimensions. Usage of data from heterogeneous satellite sensors on multiple orbits are the only solution to avoid such problems. The additional challenges such as resolving the resolution of the satellite sensor data, difference in spatial and temporal resolution of multiple satellite data.

Our proposed method can discover the tropical depression which cause heavy rainfall, storm and cyclone by using the heterogeneous satellite sensor data. Major challenges associated with processing the data are mining, data discovery from multiple satellite sensors and processing those data. Mainly wind vector data from QuikSCAT and Merged precipitation data from TRMM is used for analysing the tropical variations in our system. Other satellites which are orbiting in polar orbit can be used in our proposed system. There by we can improve the efficiency and helps to create error free warning on natural disasters. Scatterometer is used in QuikSCAT for the detection of wind speed and direction in a particular region. The four modules in our system are used to process these data. The sensor resolution data backscatter coefficients are processed using inverse/ambiguity resolving algorithm to get the required values. The wind speed and direction is extracted from this obtained value. In the third module the extracted features are send to a particular ensemble classifier. Finally the data from multiple satellites are incorporated to get better results.

2. RELATED WORK

Some of the solutions currently exists that uses multiple remote satellite sensor measurements to efficiently detect and track tropical depression are based on database data. Few studies are successful in using visible images for weather forecasting. The images from the satellites which are infrared are analysed by human expert. Tropical depression is the main reason for the circular motion of wind and there by formation of cyclones, this can be identified by Dvorak technique. This is mainly used to classify tropical depressions to identify the original cyclic motion. Various intensity, forecast and tracking models are computed based on a location where a cyclic motion of wind detected. All these models require a human expert to detect the abnormality in the data and to avoid false predictions. Our tropical depression forecasting system provides an error free efficient environment which leads to the detection of rainfall, storm, and cyclones.

Another existing system is the tropical cyclone forecasting system which is a framework for the forecaster to analyse the information such as circular motion of wind and associated tropical depression. Finally a Numerical weather prediction model data has been developed. Own conclusions are created based on the information available from the data model. All these works are focussing on detecting the tropical depression and tracking the circular wind motion. The advantage of all these models are only for the North American regions and human experts are required for intermediary actions.

The another method which are used for region wise weather forecasting is done by using aerial reconnaissance aircraft data and local area radar data. The main disadvantage of these system is that it is providing only a less coverage and lack of global coverage. The most advanced algorithm for the weather forecasting radar [5] Doppler has been developed for heavy wind detection and tracking. The importance of detecting the tropical depression and analysing the weather data is kept under study and proposed a variant of the vorticity feature by Sinclair. An automated[3][4] approach for the Dvorak technique is developed by Lee and Liu using an elastic graph dynamic link model based on elastic contour matching. All the approaches are mainly concerned with the heavy wind and cyclone detection which require a human expert in order to identify the location. The data retrieval process on these system is a tedious process also. Some of the already existing and developing information systems which can be accessed via web and stores satellite measurements of wind vectors or tropical depression can be used for scientific purposes. These web based information systems are working based on track information from National Hurricane Centre. Two products of JAXA (Japan Aerospace Exploration Agency) related to our research are the “AMSR-E Typhoon Real-Time Monitoring” for the Western Pacific region and a global real-time monitor using the TRMM satellite. Again, these products involve human detection and tracking. One interesting development in event monitoring is the Autonomous Science-craft Experiment (ASE) which automatically prioritizes and schedules observations on regions of interest. Currently, this technology is used for monitoring of events such as volcano activities and floods. The data stored in a database can be processed by hierarchical K-means clustering method to identify storms and their motions at different scales.

The accuracy of the tropical depression detection on a particular region can be improved by manual retrieval of the satellite images which are captured by infrared cameras. Such methods are comparatively slow and time consuming. Detection and tracking of the natural disasters such as cyclones need earlier and maximum real time detection of the tropical and extra tropical depression which is the major component in earth climate system. It exhibit variability at different temporal and spatial scales. A human expert is analysing all these factors in this models. The time consuming process of analysing this data is losing so much time which has to be used for taking disaster management steps. The cyclone landfall affects people property and life. To identify and track the variation in tropical weather system upper air observations are commonly used.

Our proposed method can analyse the real time stream of data from the satellite and can give error free alarm warning by processing these data and there by analysing the tropical weather system in an automated method. It provides a global coverage and there by the benefits of the work is given to all other nations such as Africa and Asian countries etc. The conventional time consuming process can be replaced by this work. Human expert can be avoided since the processing of data and locating the cyclone is done by the system. More accurate decision making on natural disaster warning is also a major concern in this proposed work.

3. PROPOSED WORK

The real time data streams from the multiple satellites orbiting on multiple orbits are processed together to identify the tropical and extra tropical depression and variations. Our proposed system is mainly focusing on developing an automated tropical and extra tropical depression detection and tracking. The data from the QuikSCAT scatterometer which is having sensor resolution has been identified and processed. There are mainly two types of satellite sensor measurements the merged precipitation data and wind data. The merged precipitation data is obtained from the TRMM satellite and the Wind data is obtained from the QuikSCAT satellite. The major challenge to be addressed is the problem with mining the heterogeneous data from multiple orbiting satellites with different temporal and spatial resolutions as in figure 1.Some of the polar orbiting satellite sensors may miss the events in atmosphere due to lack of resolution or difference on orbit. So it is impossible to detect a tropical depression by data from a single satellite sensor. In our proposed method we are using knowledge sharing method to share the data from multiple sensors by resolving its spatial and temporal resolution. The wind data from the scatterometer is used to identify the location of a tropical depression and the data from the TRMM detector sensor is used to focus on a local region so that it can provide error free warning of natural disaster in near real-time during the event.

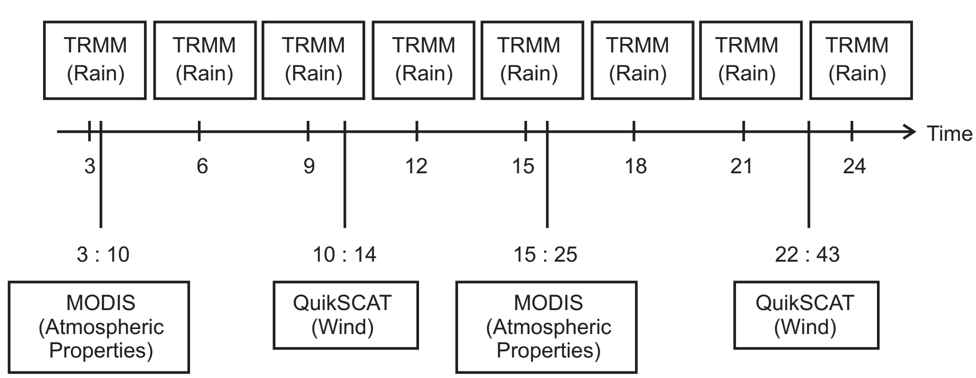

Figure 1: Data availability timeline

In our proposed method we are developing a simulator based on the specification of the temporal resolution of a particular satellites. The data from the NASA satellite is taken from the archived database and the simulator works on this database so that it can read and transmit the data as in the normal temporal conditions. The polar orbiting satellites typically cannot monitor a particular region continuously since it is revolving around the planet at a particular angle. The figure 1 consist of data from MODIS, QuikSCAT and TRMM Satellite. The difference in temporal resolution is evident from the timeline. These challenges can be reduced by sharing the knowledge from multiple satellite sensors.

3.1. QuikSCAT Data Processing

The data obtained from the QuikSCAT consist of wind vectors such as wind speed and wind direction. The data which is the backscatter coefficient has to be processed by some simple semi-empirical models and the result is used by the inverse or ambiguity resolving algorithm to get the accurate wind vector.

3.2. QuikSCAT Data Processing

Table 1
Features Extracted

Field	*Unit*	*Minimum*	*Maximum*
WVC latitude	Deg E	–90.00	90.00
WVC longitude	Deg E	0.00	359.99
Selected speed	m/s	0.00	50.00
Selected direction	Deg from North	0.00	359.99

In our proposed method of tropical depression detection and tracking, the required features which is going to make a significant change in the climate has to be selected and extracted from the QuikSCAT satellite data. The simulator which sends data in our system is using the Level 2B data of the QuikSCAT satellite from the NASA database. This data consists of ocean wind Vector information in sensor resolution organised in full orbital revolution of the satellite. A single polar orbital revolution takes about 100 minutes. The data are grouped by rows of wind vector cells. The data can be available in 25km spatial resolution and 12.5 km spatial resolution. The 25km resolution data consist of earth circumference which is completely covered by 1624 Wind vector cell rows. The 12.5km resolution data consist of earth circumference which is completely covered by 3248 Wind vector cell rows. There for the Level 2B data contains 76 wind vector cells at 25km spatial resolution data and 152 wind vector cells at 12.5km spatial resolution data. The features which are required for the processing of the data are the latitude, longitude, wind speed and the corresponding direction of the wind. The table1 consist of the features required for the data processing. The Level2B data is to be distributed over a uniformly gridded surface. Thus we can reduce the non-uniformity in the measurements taken by the QuikSCAT satellite sensors. Histograms are created based on the wind speed and wind direction to calculate the underlying probability density.

Direction to speed ratio can be calculated as

$$\mathrm{DSR}\,(i, j) \;=\; \mathrm{D}(i, j)/\mathrm{WS}(i, j)$$

Consider a strong wind with wind circulation, the Direction to speed ratio at a wind vector cell will be small. A histogram constructed to estimate the underlying probability density of Direction to speed ratio in a region will have a skewed distribution towards the smaller value. Consider a weak (or no) wind with no circulation, Direction to speed ratio histogram does not have the skewed characteristics. Our proposed method use a bin size of 4, 30, and 5 for Wind speed, Wind direction, and Direction to speed ratio, respectively. There is a marked difference between a cyclone event that is the formation of tropical depression and a none cyclone event that is a depression which is not enough to develop a cyclone in their wind speed, wind direction and direction to speed ratio estimated probability density using histogram. These histogram features are helpful in discriminating between the two events. When a region contains a depression, the wind speed histogram shows a density estimate that skewed towards the larger values. Furthermore, wind direction histogram shows a "near uniform" distribution.

Matrix M

$$\begin{pmatrix} U(1,1) & V(1,1) \\ U(1,n) & V(1,n) \\ U(2,1) & V(2,n) \\ U(m\text{-}1,n) & U(m\text{-}1,n) \\ U(m,1) & B(m,1) \\ . & \\ - & \\ U(m,n) & V(m,n) \end{pmatrix}$$

According to the National Oceanic and Atmospheric Administration (NOAA), a cyclone is defined to be a "warm-core non-frontal synoptic-scale" system, with "organized deep convection and a closed surface wind circulation about a well-defined centre". To discriminate between cyclone and non-cyclone events based on this circulation property, we use two additional features: (*i*) a measure of relative strength of the dominant wind direction (DOWD), and (*ii*) the relative wind vorticity (RWV). $u(i, j)$ and $v(i, j)$ be the UV components of the wind direction WD(i, j) at location (i, j) constructs a ($m \times n$)-by-2 matrices M.

$\lambda 1$ and $\lambda 2$ be the eigenvalues of matrix M such that $\lambda 1 < \lambda 2$ The eigenvalue ratio of a bounding box B of dimension m by n is

$$ERb = \lambda 2 / \lambda 1$$

3.3. Ensemble classifier for cyclone detection

Ensemble classifier is making predictions based on new observations and majority vote from set of classifiers. Generally ensemble methods are algorithms that make predictions on new observations based on a majority vote from a set of classifiers or predictors. Our proposed method build an ensemble classifier to identify cyclones in QuikSCAT sensor data by accurate detection of tropical depression. The regions which are more prone to the occurrence of cyclones are localized based on wind speed as the first step. The result is then classified based on a threshold. The regions with area threshold below are removed. There are mainly five classifiers based on the features extracted from the QuikSCAT data which are constructed to identify the tropical depression. Two classifiers are thresholding classifiers based on dominant wind direction and relative wind vorticity. The rest of the three classifiers are support vector machine (SVM) which are using histogram features for wind speed and wind direction. The classification decision is based on a majority vote among the five classifiers. Figure 2 shows the ensemble classifier design on.

3.4. Knowledge sharing

The Proposed multi-sensor knowledge-sharing solution leverages the strength of each remote sensor type. QuikSCAT has excellent information for accurate cyclone detection but lacks sufficient temporal resolution (each pass-through is repeated every 12 hours). TRMM on the other hand has excellent temporal resolution of 3 hours, but lacks good discriminative ability for accurate cyclone detection. Therefore, we employ QuikSCAT for cyclone detection (every 12 hours), and TRMM data for tracking (every 3 hours) based on knowledge passed through by the cyclone detector classifier from QuikSCAT. This solution therefore ensures a high detection rate for cyclones while maintaining a fine temporal resolution during cyclone tracking. Our automated cyclone tracking using knowledge sharing is shown in Figure 2. Initially, QuikSCAT data is retrieved from the database or from real-time streaming information, and is input into the cyclone discovery module (Figure 3) to locate/identify possible cyclones.

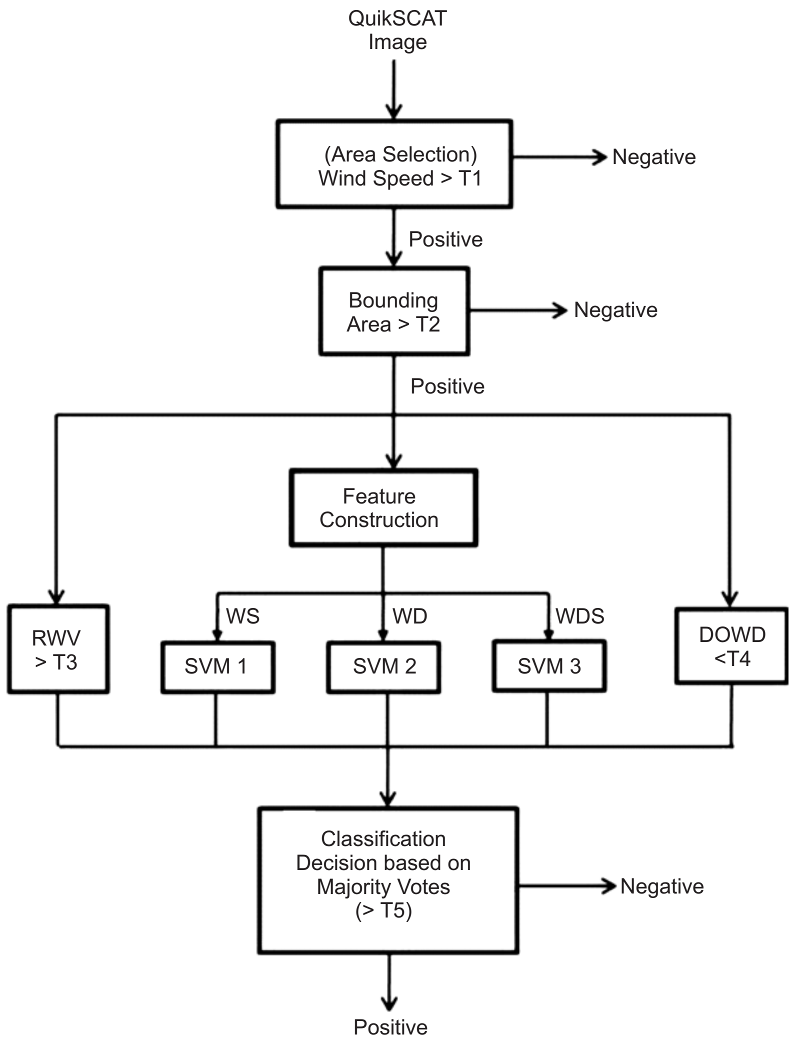

Figure 2: Ensemble Classifier (Cyclone Discovery Module)

Our proposed method identifies the location of the tropical depression and is used to predict the regions that are likely to contain circular motion of wind. This location is then used to predict all the areas which are more prone to natural disasters. Since we are using heterogeneous satellite sensor data the data streams may be different for different data resolutions. As per our proposed system 3B42 TRMM data is used for a constrained search. The algorithm which is used to make more precise values for missing values during processing and capability to predict is used for further processing which is the Kalman filter predictor. Thus by using this algorithm we can reduce the false alarms in case of any tropical depression which is not affecting the wind formation. The average search regions localizes a particular region that is where the tropical depression causes circular wind formation. Our proposed method can localize a cyclone event by applying a threshold to the TRMM precipitation rate. The correction factor can be applied to obtain the estimate of a new vector which is defining new state. The predicted location of the tropical depression may be there in the next observation.

$$X_{k+1} = A_{k+1}X_k + W_k$$
$$Z_k = H_kX_k + V_k$$

Where X_{k+1} is the vector which is used to define the state of a particular vector at a particular instance of time $k + 1$, The state vector thus obtained is used in this processing step in order to get the next iteration and get the next data level. Z_k which is an observation vector at time instance k and, A_{k+1} is the state transition matrix, H_k is the observation matrix, W_k and V_k are the parameters for Gaussian noise at a particular time instance k. An important novel contribution of our solution for knowledge sharing via prediction is the modeling of the tropical depression predictor and tracker that takes into account the widely varying spatial characteristics of cyclones. Natural disasters are dynamic events and their size evolves rapidly over time. Typical tracking and prediction techniques use the center of an object as the single point to track and predict over time.

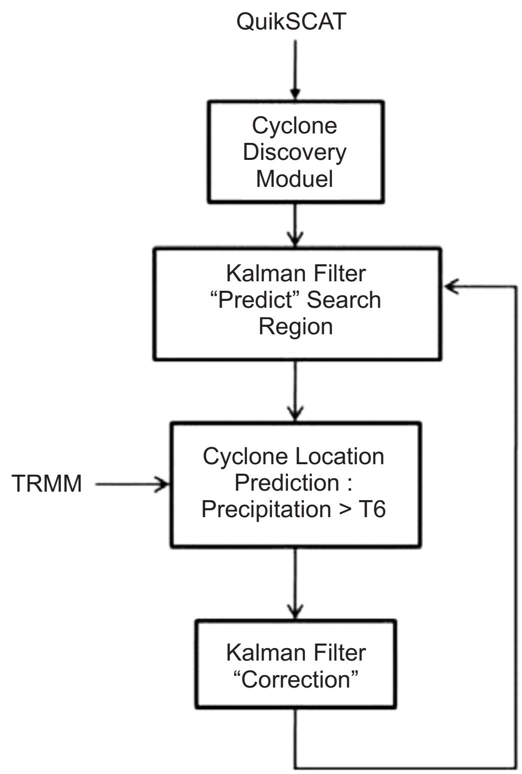

Figure 3: Knowledge sharing for Cyclone Tracking

The matrix form of the above system equations are as follows.

$$\begin{pmatrix} X_{k+1} \\ Y_{k+1} \\ \Delta X_{k+1} \\ \Delta Y_{k+1} \end{pmatrix} = \begin{pmatrix} 1 & 0 & t_{k+1} & 0 \\ 0 & 1 & 0 & t_{k+1} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} X_k \\ Y_k \\ \Delta X_k \\ \Delta Y_k \end{pmatrix} + W_k$$

$$\begin{pmatrix} X\wedge_k \\ Y\wedge_k \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix} \begin{pmatrix} X_k \\ Y_k \\ \Delta X_k \\ \Delta Y_k \end{pmatrix} + V_k$$

Where ΔX_{k+1} is the time difference between the next satellite image and the current satellite image. This is a known parameter between two consecutive TRMM satellite images (3 hours), and between a current QuikSCAT image and the next TRMM satellite image. As mentioned earlier, since the spatial resolution varies for different satellite data, we use the longitude and latitude coordinates as the fixed *x-y* reference frame for the tracking computation. Our proposed model works well for rigid objects that do not change shape with time. However, modeling and predicting the evolution of a cyclone in space over time using only the cyclone center will be grossly inadequate since cyclones often increase in size as they evolve from a depression to a storm to a hurricane, and then decrease rapidly in size after hitting landfall. We therefore model the cyclone as a four dimensional state vector that is described by the maximum and minimum latitude/longitude of the bounding box spanned by the cyclone. Our hypothesis is that the bounding box that is described by the (x, y) spatial span of the cyclone evolves linearly in space over time. We expand (or contract) the estimated bounding box based on the estimated Kalman error covariance to define a search region for the cyclone in the TRMM image. This modeling approach significantly improves the quality of knowledge sharing between heterogeneous satellites as compared to using a predictor/tracker using only the center coordinates of the cyclone.

3.5. Satellite sensor data

In this project, we are mainly using two different satellites and sensor data. Both satellites and sensors are having different resolution. In order to locate a particular location which is having tropical depression we are using QuikSCAT Satellite sensor data for processing. For tracking the movement of the wind vectors and there by the tracking the cyclones we have to use TRMM Satellite precipitation data of rainfall. We can use all the geostationary and orbiting satellites data in our system.

1. **QuikSCAT wind data:** The QuikSCAT satellite consist of scatterometer sensor which track the wind vectors so that the wind speed and direction is tracked from at most 10 metre height. It provides high quality ocean wind data. It is a polar orbiting satellite with a wide range of measurement. It can reach a range of about 1800 km wide on earth surface. It has a coverage of two times a day and sends data in every 12 hours. The specialised microwave radar which is the scatterometer is used measure wind vectors. The main advantage is it is more efficient on almost all atmospheric conditions. Near real-time wind data is available at some extend. The spatial resolution of the sensor is 25km and some have 12 km. The ocean wind vector is used by the system for global weather forecasting and its modelling. This is very help full in identifying the tropical depressions which are causing the formation of the cyclones. The data from the QuikSCAT is used for the three dimensional variational data assimilation technique. By using this technique the depression rate can be analysed with higher intensity.

2. **Precipitation data from TRMM satellite:** TRMM is the satellite of a joint mission between NASA and the Japan Aerospace Exploration Agency (JAXA) designed to monitor and study tropical rainfall. It consist of a precipitation radar which is used to analyse the rain fall details over a particular region.

4. CONCLUSION

Conventional methods cannot handle massive unlabelled high-dimensional heterogeneous data in real time. These data remain largely unexplored and under-utilized due to the lack of human resources to manually analyse [2] such data using science experts, inadequate data mining techniques to process these data. Our solution provides a novel, first-of-a-kind solution to heterogeneous satellite data mining and knowledge sharing for event detection and tracking from real-time data streams and from massive historical science data sets. Autonomous knowledge discovery from massive heterogeneous satellite data is extremely desirable for advance scientific understanding of the global climate, environmental science, space science, and Earth science. Proposed software solution can process the real-time data streams and detect as well as predict the cyclones and other atmospheric depression and also track the movement of the cyclone in real time.

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