Heavy Rainfall Prediction Using Satellite Observations

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Some of Our Activities at ISRO

• Sensor Definition for meteorological, oceanographic observations

• Impact assessment of new sensors

• Development of assimilation methods and techniques for new satellite sensors.

• Observation system simulation studies for decision on new satellite sensors

• Improved weather prediction to support ISRO’s launch program
Constellation of Meteorological Satellites
Indian Geostationary Satellites for Weather Applications

- INSAT-1D VHRR 1990
- INSAT-2A/2B VHRR 1992/93
- INSAT-2E VHRR, CCD 1999
- KALPANA-1 VHRR 2002
- INSAT-3A VHRR, CCD 2003
- INSAT-3D Imager/ Sounder 2013
- INSAT-3DR Imager/ Sounder 2016
- GISAT MX-LWIR/MX-VNIR/ Hys-VNIR/Hys-SWIR 2020
INSAT-3D Radiance: 0030 UTC, 18th August 2013

WV Channel

FY2D Observed Radiance

INSAT-3D Observed Radiance

INSAT-3D Simulated Radiance
Sample of cyclone centric satellite products during landfall of TC VARDAH by Insat3D imager

These products are very useful for cyclone structural analysis and predictions.
Geophysical Products from INSAT-3D Imager

- OLR
- UTH
- INSOLATION
- Cloud Winds
- Water Vapor Winds
- SST
- QPE (Rain)
- Aerosols
- Fire & Smoke
- Fog
- Snow
Winds derived from GEO satellites are highly useful for prediction of cloud systems and cyclones. Data from GEO-Sounders is useful for prediction of thunderstorms.
Assimilation of radiances from INSAT-3D
WV-Channel from Imager Sounder Radiances
Indian LEO-Satellites for Weather Applications

**OCEANSAT–1 (1999)**
- MSMR, OCM
- SST, Sea Surface Wind Speed, TPW, Rain, Aerosol

**OCEANSAT–2 (2009)**
- OSCAT, OCM, ROSA
- Sea Surface Wind Vector, Aerosol, T/Q Profile

**SARAL (2011)**
- Altimeter
- SSH, Waves, Winds

**Megha-Tropiques**
- MADRAS, SAPHIR, ScaRaB, ROSA
- TWV, Rainfall, T/Q Profile, Radiation Budget

**OCEANSAT–3 (2020)**
- OSCAT, OCM, ROSA
- Sea Surface Wind Vector, Aerosol, T/Q Profile

**GCOM-W2 (2017)**
- Scatterometer, AMSR-2
- Sea surface wind vector, SST, TPW, CLW, Rain

MOSDAC Site
These Satellite Data’s are available in MOSDAC site
www.mosdac.gov.in
How Satellites see a cloud in different channels

3-Dimensional Clouds seen by Microwave Radar
Megha Tropiques

For studying water cycle and energy exchanges in the tropical belt

Low inclination (20º) for frequent simultaneous observations of tropics
- Water vapour
- Clouds
- Cloud condensed water
- Precipitation
- Sea surface wind speed
- Water vapour Profile
- Temperature Profile

SAPHIR
- Water vapour profile
- Six atmospheric layers upto 12 km height
- 10 km Horizontal Resolution

SCARAB
- Outgoing fluxes at TOA
- 40 km Horizontal Resolution

MADRAS
- Precipitation and cloud properties
- 89 & 157 GHz: ice particles in cloud tops
- 18 & 37 GHz: cloud liquid water, precipitation and ssw speed
- 23 GHz: Integrated water vapour
- Temperature and Humidity Profile

ROSA
- Temperature and Humidity Profile

Contributing to Global Precipitation Mission (GPM)
Inter-Satellite Comparison (2nd Approach)

SAPHIR vs. MHS on NOAA-18/19 and MetOp

**SAPHIR Channels**
- $S_1$ 183.31 ± 0.2 GHz
- $S_2$ 183.31 ± 1.1 GHz
- $S_3$ 183.31 ± 2.8 GHz
- $S_4$ 183.31 ± 4.2 GHz
- $S_5$ 183.31 ± 6.8 GHz
- $S_6$ 183.31 ± 11 GHz

**MHS Channels**
- M1 89.0 GHz
- M2 157 GHz
- M3 183.3 ± 1.0 GHz
- M4 183.3 ± 3.0 GHz
- M5 183.3 ± 7.0 GHz
SAPHIR Radiances: Quality & Assimilation

- Inter-Satellite Comparison
  - Triple-Collocation
    - Space
    - Time
    - Geometry

Instruments similar to SAPHIR
- AMSU-B (NOAA series of Satellites)
- MHS (NOAA-18/19, Metop)
- MWHS (FY-3A)
Monitoring the Quality of SAPHIR Radiances using RTM and NCEP Analysis (1\textsuperscript{st} Approach)

Radiative Transfer Model: RTTOV v10

Collocated (space & time) atmospheric profiles (NCEP Analysis)

SAPHIR
- Geometry
- SRF

NCEP Analysis (00, 06, 12, 18 Z)
Resolution
$0.5\degree \times 0.5\degree$
Time Window
$\pm 90$ Minutes

Non Precipitating Regions
SAPHIR – RTM Computed Radiances (using NCEP Analyzed Profiles)
SAPHIR Vs. RTM Computed Radiances (using Radiosonde and AIRS Profiles)

- **Radiosonde AIRS**

- **AIRS -> Clear-Sky**
Comparison Between MHS and SAPHIR Radiances

(a) \( S_2;M_3 \)

Bias = 1.3 K
Rmsd = 1.5 K
Corr = 0.99

(b) \( S_3;M_4 \)

Bias = -0.8 K
Rmsd = 0.9 K
Corr = 0.99

(c) \( S_5;M_5 \)

Bias = 0.3 K
Rmsd = 0.5 K
Corr = 0.98

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Simulated

(a) \( S_2;M_3 \)

Bias = 1.0 K
Rmsd = 2.5 K
Corr = 0.96

(b) \( S_3;M_4 \)

Bias = -0.9 K
Rmsd = 1.7 K
Corr = 0.98

(c) \( S_5;M_5 \)

Bias = -0.1 K
Rmsd = 1.3 K
Corr = 0.98

Observed
Assimilation Experiments: Entire May 2012

Assimilated Observations

Control run: Conventional, Meteosat AMVs, SSM/I, AMSU-A and HIRS Radiances

Experimental run: Control run + SAPHIR Radiances

Quality Control

a. Channel Selection (Channel 6 is assimilated only over ocean)
b. Precipitation Detection (S2 - S5 > -8 K; Funatsu et al (2007))
c. Observation – Background Check
d. Orography
Three channels vs. six channels, July 2012

![Graph showing the comparison between three and six channels in terms of improvement and pressure.](image)

- **Y-axis:** Pressure (hPa)
- **X-axis:** Improvement (%)

![Graph showing the equitable threat score for CNT and EXP in terms of rainfall threshold.](image)

- **Y-axis:** Equitable Threat Score (ETS)
- **X-axis:** Rainfall Threshold (cm/day)
# ISRO’s Future TSU/HSU Mission: Sensor Specifications

## Table-1: Temperature Sounding Unit (TSU) specifications

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Frequency (MHz)</th>
<th>Polarization</th>
<th>Bandwidth (MHz)</th>
<th>NEDT (K) Specs</th>
<th>NEDT (K) Desirable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23.8</td>
<td>V</td>
<td>300</td>
<td>0.6</td>
<td>0.3</td>
</tr>
<tr>
<td>2</td>
<td>31.5</td>
<td>V</td>
<td>300</td>
<td>0.6</td>
<td>0.3</td>
</tr>
<tr>
<td>3</td>
<td>50.3</td>
<td>V</td>
<td>300</td>
<td>0.6</td>
<td>0.3</td>
</tr>
<tr>
<td>4</td>
<td>52.9</td>
<td>H</td>
<td>300</td>
<td>0.6</td>
<td>0.3</td>
</tr>
<tr>
<td>5</td>
<td>53.4</td>
<td>H</td>
<td>300</td>
<td>0.6</td>
<td>0.3</td>
</tr>
<tr>
<td>6</td>
<td>54.4</td>
<td>H</td>
<td>300</td>
<td>0.6</td>
<td>0.3</td>
</tr>
<tr>
<td>7</td>
<td>54.95</td>
<td>H</td>
<td>300</td>
<td>0.6</td>
<td>0.3</td>
</tr>
<tr>
<td>8</td>
<td>55.5</td>
<td>H</td>
<td>300</td>
<td>0.6</td>
<td>0.3</td>
</tr>
<tr>
<td>9</td>
<td>56.65</td>
<td>H</td>
<td>300</td>
<td>0.7</td>
<td>0.3</td>
</tr>
<tr>
<td>10</td>
<td>57.55</td>
<td>H</td>
<td>100</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>11</td>
<td>58.8</td>
<td>H</td>
<td>300</td>
<td>1.0</td>
<td>0.6</td>
</tr>
<tr>
<td>12</td>
<td>59.38</td>
<td>H</td>
<td>240</td>
<td>1.0</td>
<td>0.6</td>
</tr>
<tr>
<td>13</td>
<td>58.39</td>
<td>H</td>
<td>60</td>
<td>1.5</td>
<td>0.9</td>
</tr>
<tr>
<td>14</td>
<td>56.99</td>
<td>H</td>
<td>20</td>
<td>2.0</td>
<td>1.2</td>
</tr>
<tr>
<td>15</td>
<td>56.95</td>
<td>H</td>
<td>20</td>
<td>2.2</td>
<td>1.3</td>
</tr>
<tr>
<td>16</td>
<td>59.6</td>
<td>H</td>
<td>10</td>
<td>3.5</td>
<td>2.5</td>
</tr>
<tr>
<td>17</td>
<td>59.57</td>
<td>H</td>
<td>20</td>
<td>3.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>

## Table-2: Humidity Sounding Unit (HSU) specifications

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Frequency (MHz)</th>
<th>Pol.</th>
<th>BW (MHz)</th>
<th>NEDT (K) Specs</th>
<th>NEDT (K) Desirable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>89</td>
<td>V</td>
<td>3000</td>
<td>0.6</td>
<td>0.3</td>
</tr>
<tr>
<td>2</td>
<td>183.31 ± 0.96</td>
<td>H</td>
<td>400-500</td>
<td>1.5</td>
<td>0.9</td>
</tr>
<tr>
<td>3</td>
<td>183.31 ± 2.8</td>
<td>H</td>
<td>600-1000</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>4</td>
<td>183.31 ± 4.5</td>
<td>H</td>
<td>1000-2000</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>5</td>
<td>183.31 ± 7</td>
<td>H</td>
<td>1000-2000</td>
<td>1.0</td>
<td>0.4</td>
</tr>
<tr>
<td>6</td>
<td>183.31 ± 11.56</td>
<td>H</td>
<td>1000-2000</td>
<td>1.0</td>
<td>0.3</td>
</tr>
<tr>
<td>7</td>
<td>183.31 ± 15</td>
<td>H</td>
<td>1000-2000</td>
<td>1.0</td>
<td>0.3</td>
</tr>
</tbody>
</table>

*** Bandwidth of channels#2-7 may be increased suitably (upto 500 MHz for Ch#2, 1000 MHz for Ch#3, and 2000 for Ch#4-7) in order to reduce the NEDT, if needed.
OSE Assimilation System
Configuration

Entire July 2012

Model: WRF V3.4
Horizontal Resolution: 25 km
Cumulus Scheme: Kain Fritsch
Moisture Scheme: WSM 6 Class
LW Radiation Scheme: RRTM
SW Radiation Scheme: Dudhia
PBL Scheme: YSU
DA Method: 3D-Var
Assimilation Cycle: 6 hour

\[ J = \frac{1}{2} (x - x_b)^T B^{-1} (x - x_b) + \frac{1}{2} (y - H(x))^T R^{-1} (y - H(x)) \]
Experiment Format

1 **CONTROL**: Radiosonde, SYNOP, METAR, SHIP, BUOY, PILOT, SSM/I, OSCAT, AMVs, GPSREF, AMSU-A, HIRS, SAPHIR, MHS
2 **No_sonde**: CONTROL- Radiosonde
3 **No_surface**: CONTROL- Surface
4 **No_pilot**: CONTROL- PILOT
5 **No_gpsref**: CONTROL- GPSREF
6 **No_amv**: CONTROL- AMVs
7 **No_oscat**: CONTROL- OSCAT
8 **No_ssmi**: CONTROL- SSM/I
9 **No_saphir**: CONTROL- SAPHIR
10 **No_mhs**: CONTROL- MHS
11 **No_amsua**: CONTROL- AMSUA
12 **No_hirs**: CONTROL- HIRS
13 **No_sat**: CONTROL- all satellite observations
14 **No_mass**: CONTROL – all T, q, prs
15 **No_wind**: CONTROL – all wind observations

Impact is evaluated using moist total energy norm

\[
TE = \frac{1}{2D} \int_D \int_0^1 \left( u'^2 + v'^2 + \frac{c_p}{T_r} T'^2 + RT_r \left( \frac{p'}{p_r} \right)^2 + \frac{L^2}{c_p T_r} q'^2 \right) d\sigma dD
\]
Impact (α) =

\[ 100 \times \frac{\frac{1}{n} \sum_n (O - f^{exp})^2 - \frac{1}{n} \sum_n (O - f^{cnt})^2}{\sqrt{\frac{1}{n} \sum_n (O - f^{cnt})^2}} \]
Impact Parameter (α)

Rainfall Prediction Skill

Impact (%)

> 1 mm/day

> 15 mm/day
Satellite Observations of Precipitation: Rain-No-Rain Assimilation
Impact of TRMM rain/No-Rain assimilation on 48-H forecast of 2-m air temperature

Figure 3. Spatial distribution of percentage improvement parameter (Equation 2, in %) for (a) NRAS, (b) RAS, (c) AASK, and (d) AASG forecasts compared with the CNT experiments for low-level (850 hPa) 48 h temperature forecasts.
Impact of TRMM rain/No-Rain assimilation on 48-H forecast of rainfall

Figure 7. Spatial distribution of improvement parameter (Equation 1, in mm) for (a) NRAS, (b) RAS, (c) AASK, and (d) AASG forecasts as compared to the CNT experiments for 48 h rainfall forecasts when compared with the TRMM 3B42 rainfall.
Hydro-Estimator Rainfall from INSAT-3D

HE: 13AUG-19AUG 2018
Winds derived from GEO satellites are highly useful for prediction of cloud systems and cyclones. Data from GEO-Sounders is useful for prediction of thunderstorms.
Evaluation and Modification of GSMaP rainfall product with high density gauge observations over Karnataka, India

Spatial distribution of KSNDMC rain gauges network over Karnataka, India. Rain gauges stations over COASTAL (650), MALNAD (901), NIK (2737) and SIK (2214) regions are shown in green, red, blue and pink circles. Total number of stations are 6502 over Karnataka, India.

(a) RMSD and (b) BIAS statistics of GSMaP_Gauge and GSMaP_MVK product for different IMD rainfall classifications.

(a) Impact parameter and (b) absolute BIAS statistics for new (from SAC) and operational product of GSMaP_Gauge and GSMaP_MVK for different IMD rainfall classifications.
Probability density function (pdf) of daily rainfall during (a) JJAS 2016, (b) JJAS 2017, and (c) JJAS 2018.

Probability density function (pdf) of rainfall deviation (defined as GSMaP minus KSNDMC observation) during (a) JJAS 2016, (b) JJAS 2017, and (c) JJAS 2018.
Spatial distribution of improvement parameter (\(IP\)) for GSMaP_G (a,b,c) and GSMaP_MVK (d,e,f) product during JJAS2016, JJAS2017, and JJAS2018, respectively.

Improvement parameter is defined as
\[
IP = \frac{1}{N}\sum_{i=1}^{N}(GSMaP_{G or MVK} - KSNDCM) - \frac{1}{N}\sum_{i=1}^{N}(GSMaP_{G NEW or MVK NEW} - KSNDCM)
\]
Fig. 1 Process in taking effect for cloud lifetime
High Resolution Rapid Refresh (HRRR) Data Assimilation of DWR observations

- NCEP GFS 0.25 KM Resolution
- NCEP PREPBUFER
- SAPHIR onboard MT
- DWR Radial Velocity data
  - Frequency: 10 Min
  - Resolution: 0.25 Km
  - Height: 20 Km

27 Sep 18 : 72.4 MM
High Resolution Rapid Refresh (HRRR) Data Assimilation of DWR observations

Target: Dynamical Nowcasting, Use of Frequent and Dense observations, Model spin up.

- **4D-Var Assimilation**
  - 0600 UTC 01DEC17: TL Model
  - 0700 UTC 01DEC17: AD Model
  - DWR + Nowcast

- **Forecast Skill**
  - Numerical Models
  - Extrapolation
  - Blending

- **Rainfall (mm)**
  - AWS
  - CNT
  - ENS2DF S1
  - ENS2DF S3

- **Latitude (Degree)**
  - IMD
  - CWRF
  - DWRF

Large positive impact can be seen in DWRF run

HRRR data assimilation method has the best skill for future dynamical nowcasting
A high resolution simulation of catastrophic rainfall over Uttarakhand, India

Elevation map of the state of Uttarakhand (meters)

Orographic precipitation rate (mm/hr) as simulated by VDEL model
Spatial distribution of mean sea level pressure (shaded; hPa) and low-level (850 hPa) winds (vector; m/s) from ECMWF analysis at 0000 UTC of (a) 13 June, (b) 14 June, (c) 15 June and (d) 16 June 2013.
Wind profiles for three locations A (28.0 N, 76.0 E), B (30.5 N, 79.1 E) and C (28.0 N, 82.0 E). Location B showed the Kedarnath region.
Spatial distribution of accumulated merged-rainfall (mm) product from (a) CMORPH, (b) JAXA GsMap, and (c) TRMM 3B42 product during 0000 UTC 16 June 2013 to 0000 UTC 17 June 2013. (d) Spatial distribution of 24-h rainfall forecast (mm) from WRF model.
Satellite Based Nowcasting of Heavy Rainfall

![Graph showing forecast skill vs. forecast lead time with lines for Theory, Nowcasts, and Models.](image)
Colour coded (cloud types) nowcast images which predict dissipation of high cloud system during MT launch time (12Oct2011).

Last acquired image used for prediction
Tracking and Nowcasting of mesoscale Systems
Active contour Models

• The intensity distribution of cloud mass is modelled as an active flexible membrane

• The cloud mass is tracked in the consecutive images.

• Based on the tracking, future cloud mass is extrapolated by regression
Tracking and Nowcasting of Mesoscale Convective Systems (MCS)

Location of MCS on 13 August 2008 at 1030 GMT using Kalpana TIR BT image

Tracking of (a) Minimum Temperature (b) ratio (%) of deep convective area to the total area of MCS

Nowcasting of MCS using size parameters
Nowcasting of heavy rainfall events
Repetition of occurrence of ERE at the same place

A green marker implies that in this period there has been 1 ERE in in location, while red implies there were 3 instances of ERE
Nowcasting of ExTreme orographic RAin events (NETRA):

- Spatio-temporal analysis of Extreme rainfall events over Indian region
- Development of model
  - Relationship between cloud top cooling rate and heavy rainfall
  - Estimation of spatially varying thresholds
- Validation
- Real-time implementation and dissemination through MOSDAC

12/5/2019
Evolution of system NETRA for Catastrophic rain event at Uttarakhand 2013

Number of extreme rain events during 2001-2012 overlaid on terrain map (Mts)

Shukla et al., 2017, Satellite based nowcasting of extreme rainfall events over Western Himalayan region, IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING, Volume: 10 Issue: 5
Visualization of Climatology

- **Land Climatology**
  - Global 30-Year Mean Monthly Climatology 1961-1990 (New et al.)
    - Wet Day Frequency
    - Mean Temperature
    - Vapour Pressure
    - Wind
    - Maximum Temperature
    - Minimum Temperature
    - Radiation
    - Precipitation
    - Ground-frost Frequency
    - Diurnal Temperature Range
    - Cloud Cover

- **Ocean Climatology**
  - 30-Year Mean Monthly Climatology 1987-2016
    - Upwelling Index

[https://mosdac.gov.in/live](https://mosdac.gov.in/live)
THANKS