# Radiative Transfer Model based Bias Correction in INSAT-3D/3DR Thermal Observations to Improve Sea Surface Temperature Retrieval

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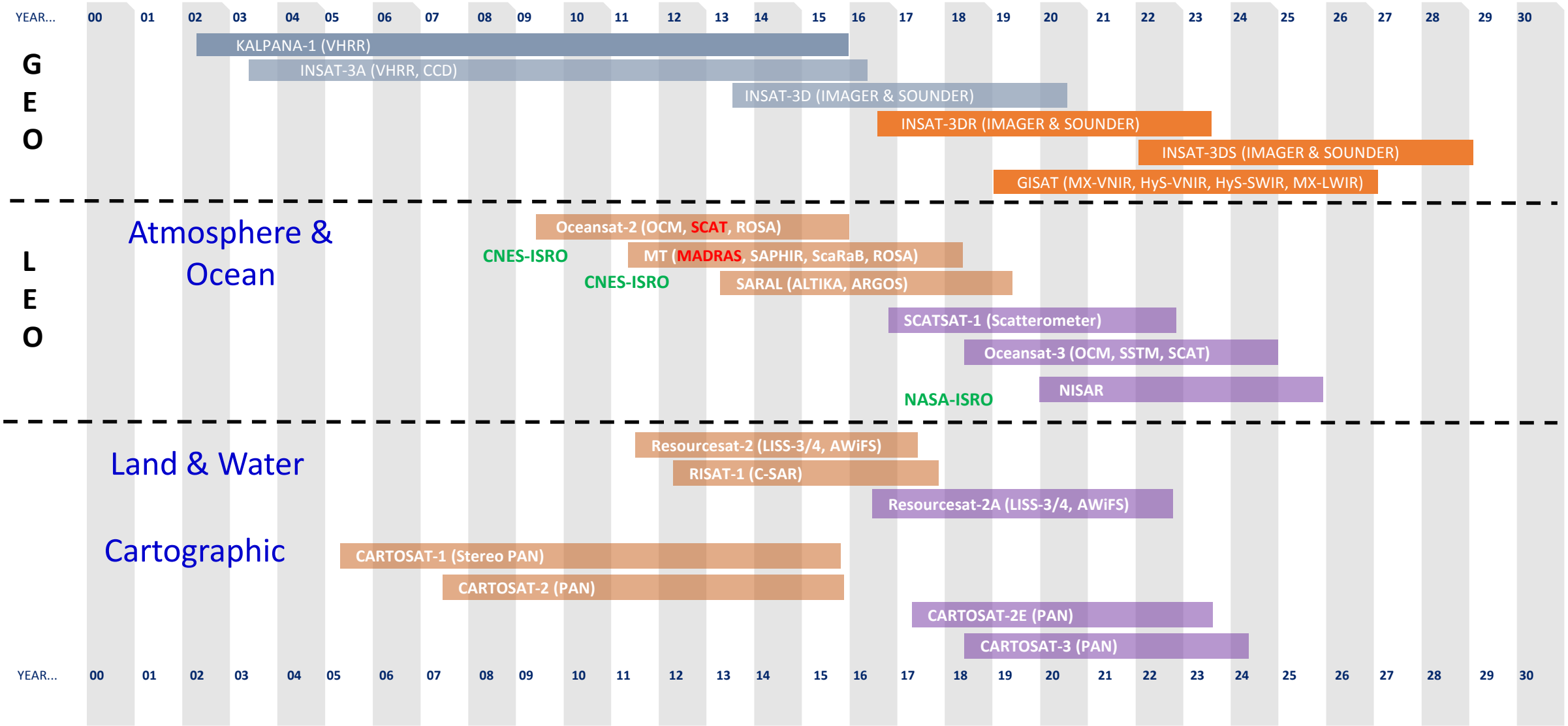
# ISRO Current satellites for Earth Observations



# INSAT-3D/3DR/3DS Sounder

## Launch

3D: 26-Jul-2013, 82E
3DR: 08-Sep-2016, 74E

## Sounder Products

- Vertical Profiles of:
  - Temperature
  - Humidity
- Surface Skin Temperature
- Total Column Integrated Ozone

## Derived Products

* Geopotential height
* Layer and total precipitable water
* Lifted index
* Dry microburst index
* Maximum vertical theta-e differential
* Wind index

| Detector | Ch. No. | $\lambda_c$ (μm) | $\nu_c$ ($cm^{-1}$) | NEΔT @300K | Principal absorbing gas | Purpose |
|---|---|---|---|---|---|---|
| LWIR | 1 | **14.67** | 682 | 0.17 | $CO_2$ | Stratosphere temperature |
| | 2 | **14.32** | 699 | 0.16 | $CO_2$ | Tropopause temperature |
| | 3 | **14.04** | 712 | 0.15 | $CO_2$ | Upper-level temperature |
| | 4 | **13.64** | 733 | 0.12 | $CO_2$ | Mid-level temperature |
| | 5 | **13.32** | 751 | 0.12 | $CO_2$ | Low-level temperature |
| | 6 | **12.62** | 793 | 0.07 | water vapor | Total precipitable water |
| | 7 | **11.99** | 834 | 0.05 | water vapor | Surface temp., moisture |
| MWIR | 8 | **11.04** | 906 | 0.05 | window | Surface temperature |
| | 9 | **9.72** | 1029 | 0.10 | ozone | Total ozone |
| | 10 | **7.44** | 1344 | 0.05 | water vapor | Low-level moisture |
| | 11 | **7.03** | 1422 | 0.05 | water vapor | Mid-level moisture |
| | 12 | **6.53** | 1531 | 0.10 | water vapor | Upper-level moisture |
| SWIR | 13 | **4.58** | 2184 | 0.05 | $N_2O$ | Low-level temperature |
| | 14 | **4.53** | 2209 | 0.05 | $N_2O$ | Mid-level temperature |
| | 15 | **4.46** | 2241 | 0.05 | $CO_2$ | Upper-level temperature |
| | 16 | **4.13** | 2420 | 0.05 | $CO_2$ | Boundary-level temp. |
| | 17 | **3.98** | 2510 | 0.05 | window | Surface temperature |
| | 18 | **3.76** | 2658 | 0.05 | window | Surface temp., moisture |
| Visible | 19 | 0.695 | 14367 | - | visible | Cloud |

# INSAT-3D/3DR/3DS Imager

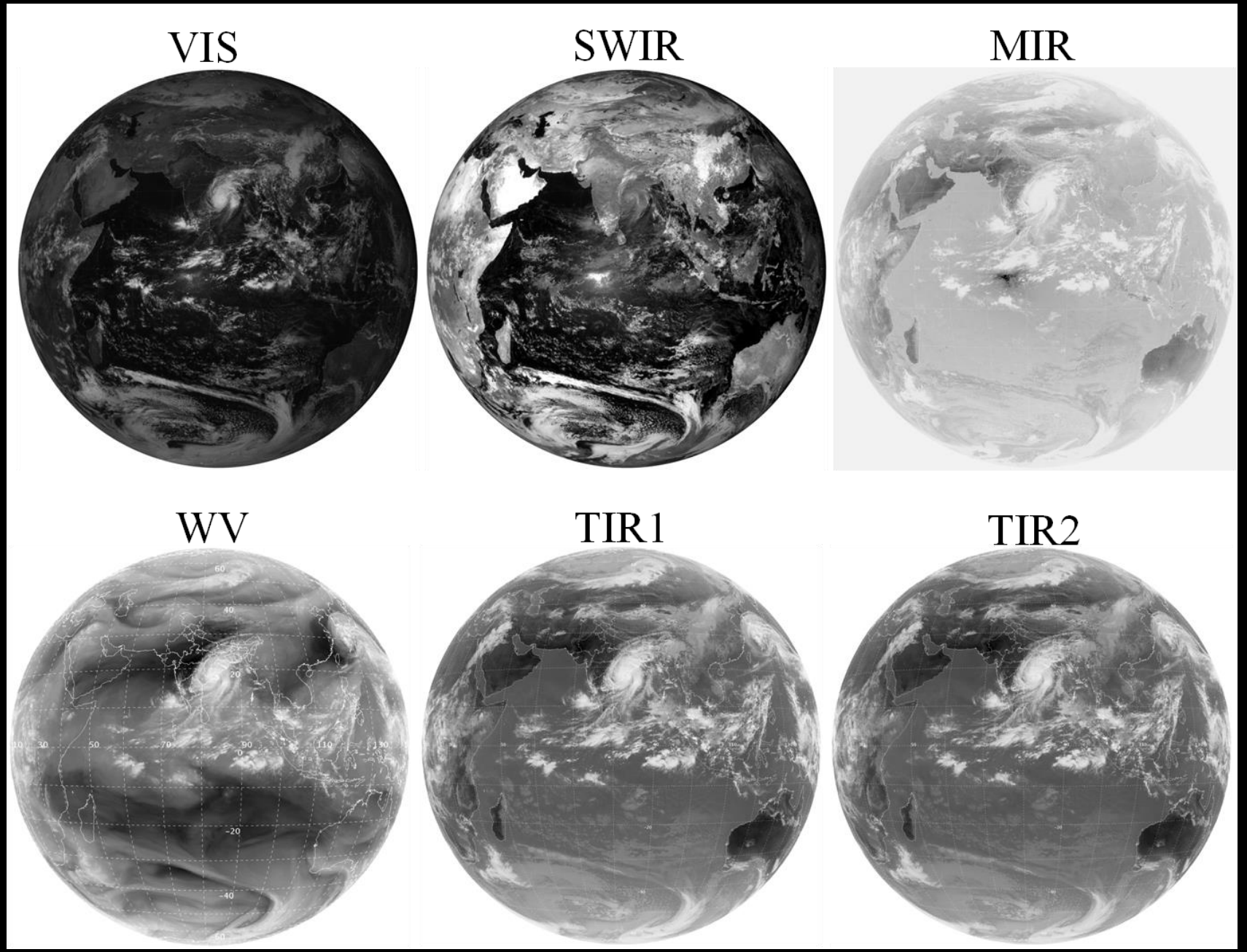
## Channels

| Channel | Wavelength (μm) | Resolution (Km) |
|---|---|---|
| 1 | 0.55-0.75 | 1 |
| 2 | 1.55-1.70 | 1 |
| 3 | 3.8-4.0 | 4 |
| 4 | 6.5-7.1 | 8 |
| 5 | 10.2-11.3 | 4 |
| 6 | 11.5-12.5 | 4 |

## Products

- Atmospheric Motion Vector (AMV)
  - Cloud Motion Vector (CMV)
  - Water Vapor Winds (WVW)
- Outgoing Longwave Radiation (OLR)
- Upper Tropospheric Humidity (UTH)
- Rainfall (QPE) – GPI, IMSRA
  – Hydro-Estimator (H-E)
- Sea Surface Temperature (SST)
- Cloud Mask
- Fog
- Snow Cover
- Aerosol
- Fire
- Smoke

# INSAT-3D Imager



# FUTURE INDIAN GEO SATELLITES: (GISAT)

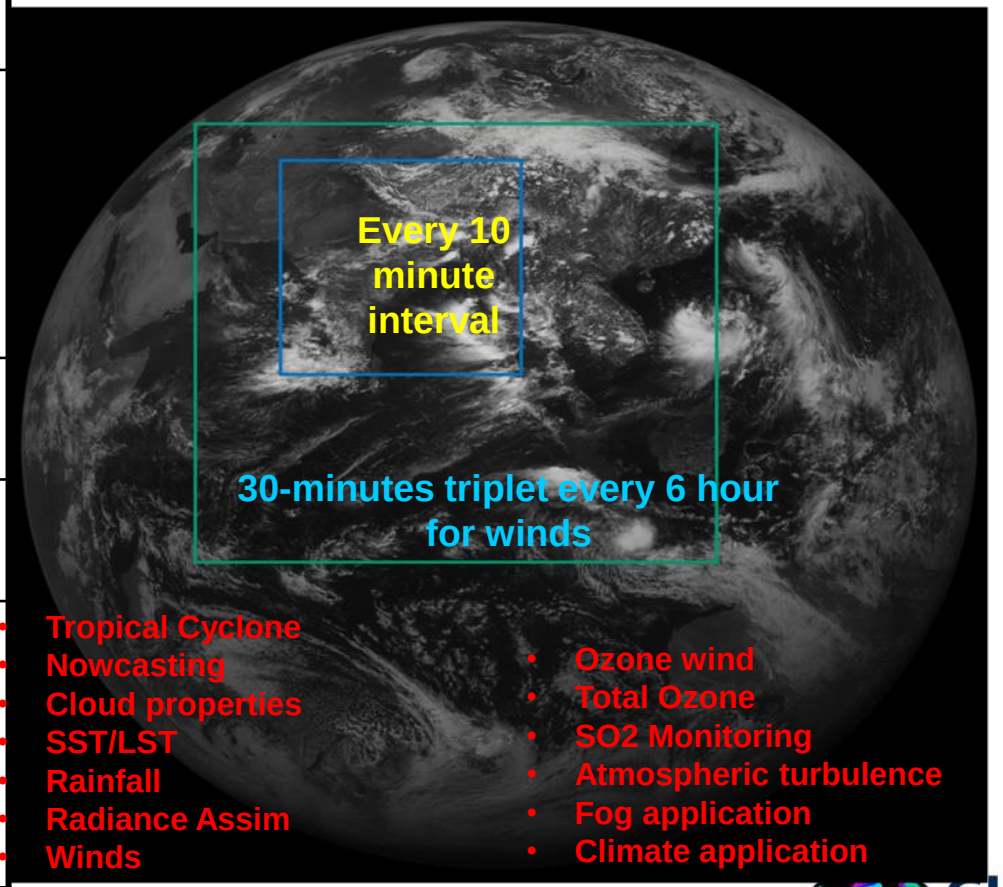
## Launch Schedule: 2019, Geostationary orbit, 83E

MX-VNIR: Multispectral - Visible Near Infrared, HySI-VNIR: Hyperspectral Imager - Visible Near Infrared, HySI-SWIR: Hyperspectral Imager - Short Wave Infrared, MX-LWIR: Multispectral - Long Wave Infrared.

| Band | Ch | SNR/ NEdT | IFOV (m) | Range (μm) | Channels (μm) |
|---|---|---|---|---|---|
| MX-VNIR | 4 | > 200 | 50 | 0.45 - 0.875 | B1: 0.45-0.52<br>B2: 0.52-0.59<br>B3: 0.62-0.68<br>B4: 0.77-0.86<br>B5N: 0.71-0.74<br>B6N: 0.845-0.875 |
| HyS-VNIR | 60 | > 400 | 500 | 0.375 - 1.0 | $\Delta\lambda$ < 10 nm |
| HyS-SWIR | 150 | > 400 | 500 | 0.9 - 2.5 | $\Delta\lambda$ < 10 nm |
| MX-LWIR | 6 | NEdT < 0.15K | 1500 | 7.0 – 13.5 | CH1: 7.1-7.6<br>CH2: 8.3-8.7<br>CH3: 9.4-9.8<br>CH4: 10.3-11.3<br>CH5:11.5-12.5<br>CH6: 13.0-13.5 |

## GISAT Scan scenario

Scan area for two scan scenario (5° & 10 °)



# INSAT-3D Operational SST Algorithm

- Based on simulated dataset (MODTRAN RT Model).
- Basic Data set: Thermodynamic Initial Guess Retrieval (TIGR)
- INSAT-3D Spectral Response Functions and NE∆T.
- Coefficients generation for seven satellite zenith angles (0, 24, 36, 42, 48, 54, 60 deg)
- **Day-time Equation:**

$$SST = A_0 + A_1 * T_{11} + A_2 * (T_{11} - T_{12}) + A_3 * (T_{11} - T_{12})^2$$

- **Night-time:**

$$SST = B_0 + B_1 * T_{3.9} + B_2 * (T_{11} - T_{12}) + B_3 * (T_{11} - T_{12})^2$$

where, '*A*' and '*B*' are the regression coefficients. $T_{11}$, $T_{12}$ and $T_{3.9}$ are the brightness temperatures of TIR-1, TIR-2 and MIR channels, respectively.

# New Algorithm

- Based on simulated dataset (PFAAST RT Model), ECMWF diverse training dataset
- SST Equation:

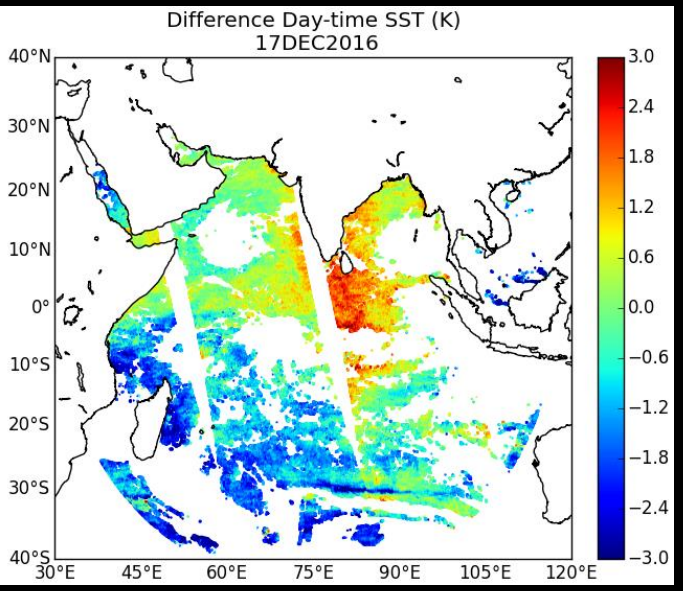
$$SST = A_0 + A_1 * T_{11} + A_2 * (T_{11} - T_{12}) + A_3 * (T_{11} - T_{12})^2 + A_4 * (T_{11} - T_{12}) * [\sec(\theta) - 1]$$

- Cloud detection algorithm to identify clear pixels (using VIS, MIR, TIR1, TIR2)
- Averaging brightness temperature of clear pixels in the neighboring 3 x 3 pixels to reduce the noise
- Computation of SST using modified retrieval algorithm.
- Quality control of the derived SST:
  - Only those retrievals are retained that satisfy the following condition:

$$(SST_{clim} - 3\ \sigma) <= SST <= (SST_{clim} + 3\ \sigma)$$

where, σ is the standard deviation of the daily climatological SST and $SST_{clim}$ is the climatological value of daily SST.

# Bias correction in observations with respect to RT simulations




SST(INSAT-3D) – SST(MODIS)

**For INSAT-3D:**

$$BT_{corr}(TIR-1) = BT_{obs}(TIR-1) - (-0.0011 * \theta^2 + 0.013 * \theta + 0.93)$$

$$BT_{corr}(TIR-2) = BT_{obs}(TIR-2) - (-0.00089 * \theta^2 + 0.0092 * \theta + 0.39)$$

$$BT_{corr}(MIR) = BT_{obs}(MIR) - (-0.00041 * \theta^2 - 0.024 * \theta + 2.4)$$

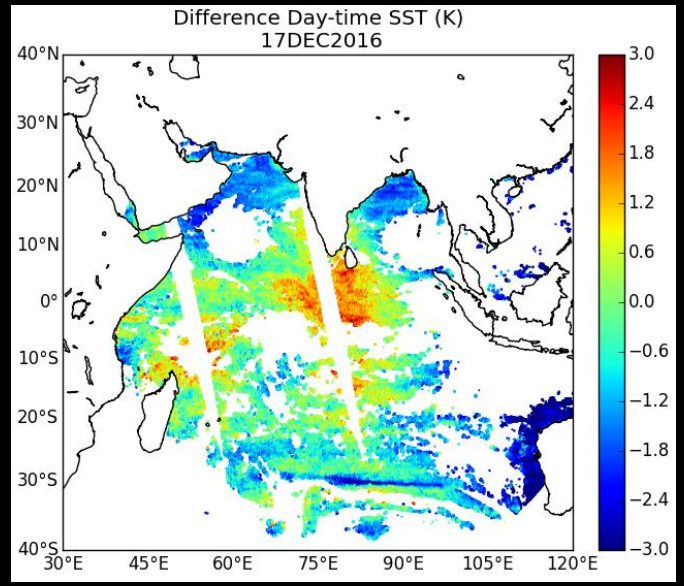
**For INSAT-3DR:**

$$BT_{corr}(TIR-1) = BT_{obs}(TIR-1) - (-0.00063 * \theta^2 - 0.024 * \theta + 1.6)$$

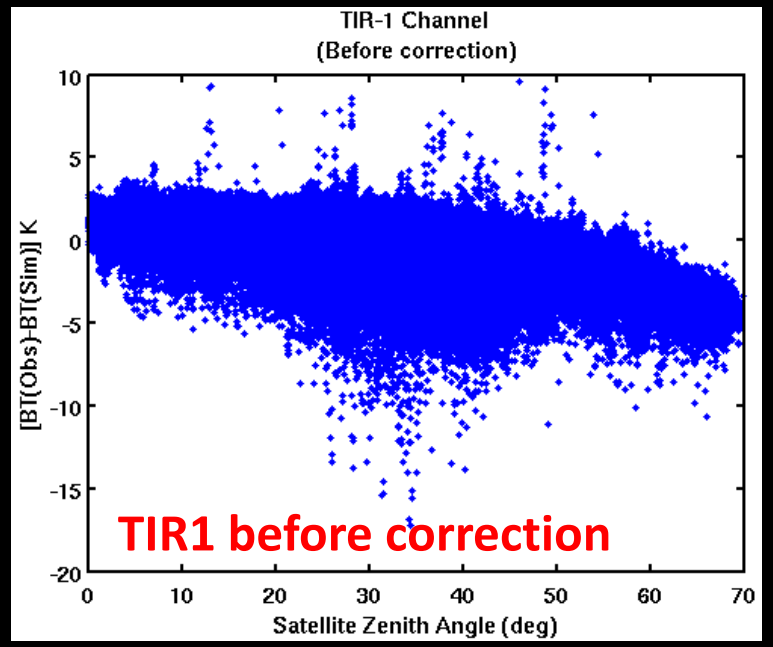
$$BT_{corr}(TIR-2) = BT_{obs}(TIR-2) - (-0.00055 * \theta^2 - 0.029 * \theta + 1.2)$$

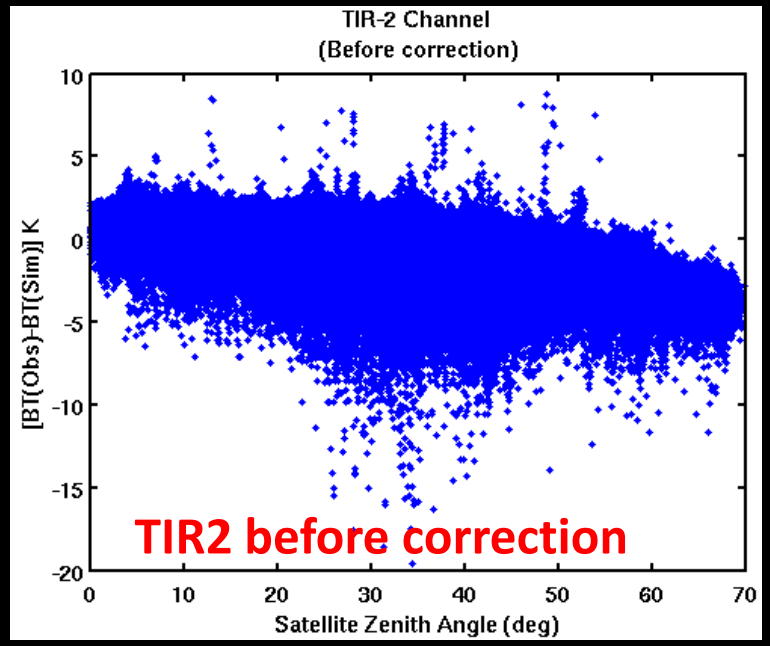
$$BT_{corr}(MIR) = BT_{obs}(MIR) - (-0.00036 * \theta^2 - 0.0083 * \theta + 2.5)$$

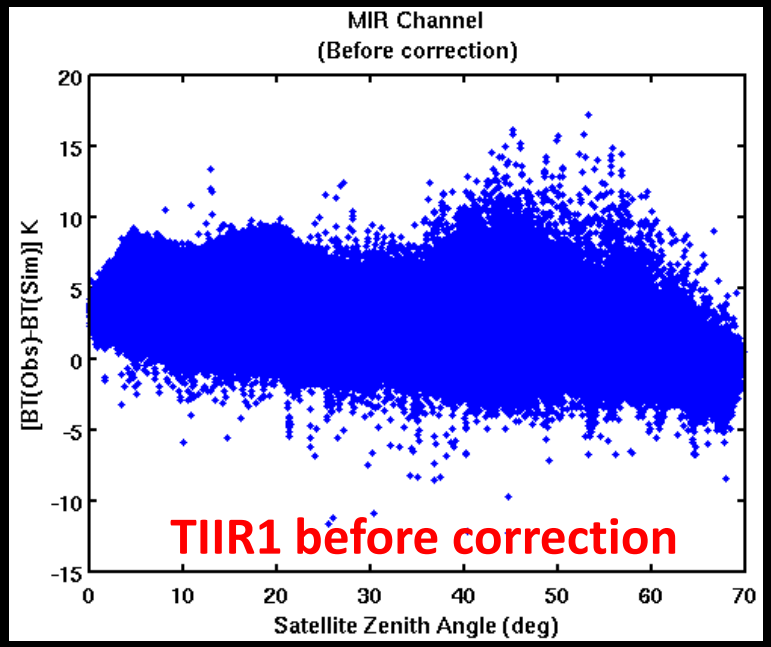
SST(INSAT-3DR) – SST(MODIS)

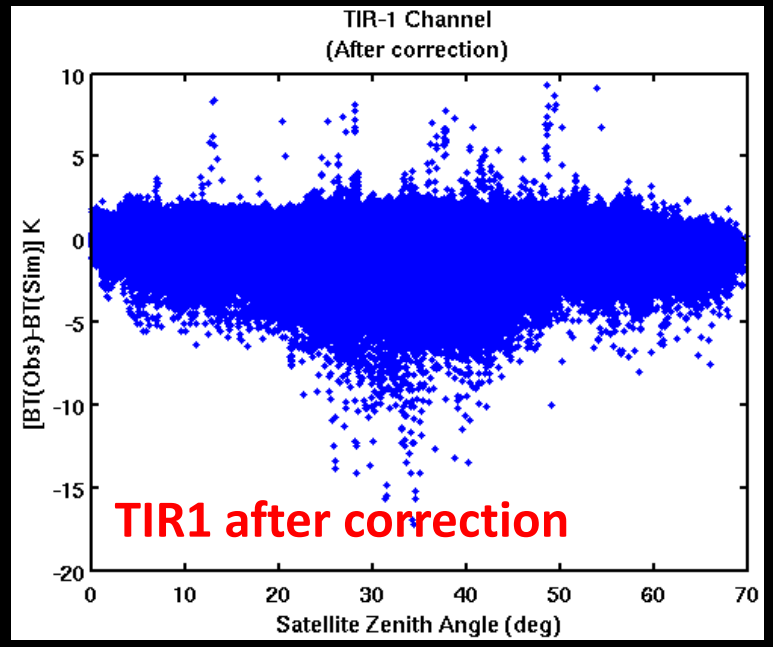


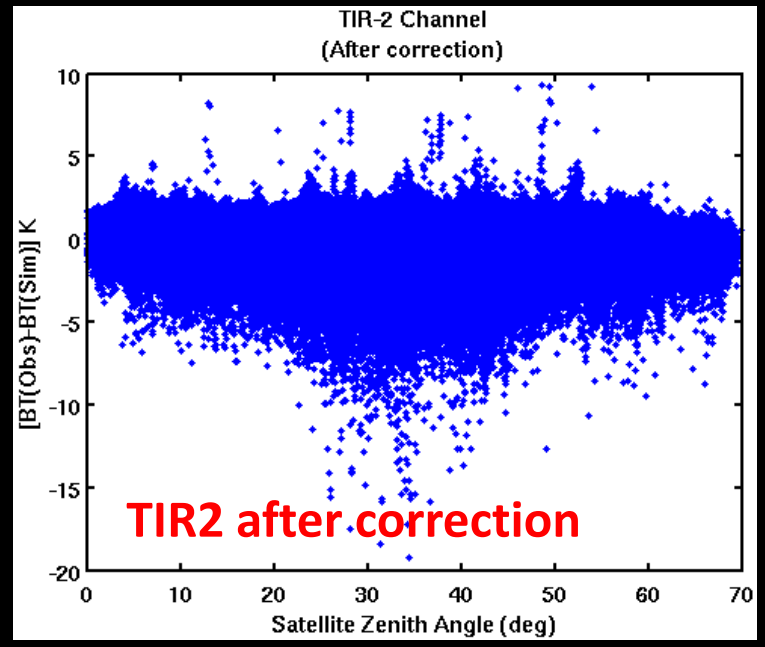

| Channel | | Bias (K) | RMSD (K) | STD (K) |
|---|---|---|---|---|
| TIR-1 | Before | -0.15 | 1.26 | 1.25 |
| | After | -0.13 | 0.88 | 0.87 |
| TIR-2 | Before | -0.52 | 1.30 | 1.19 |
| | After | -0.09 | 0.96 | 0.96 |
| MIR | Before | 1.46 | 2.30 | 1.76 |
| | After | 0.36 | 1.61 | 1.57 |

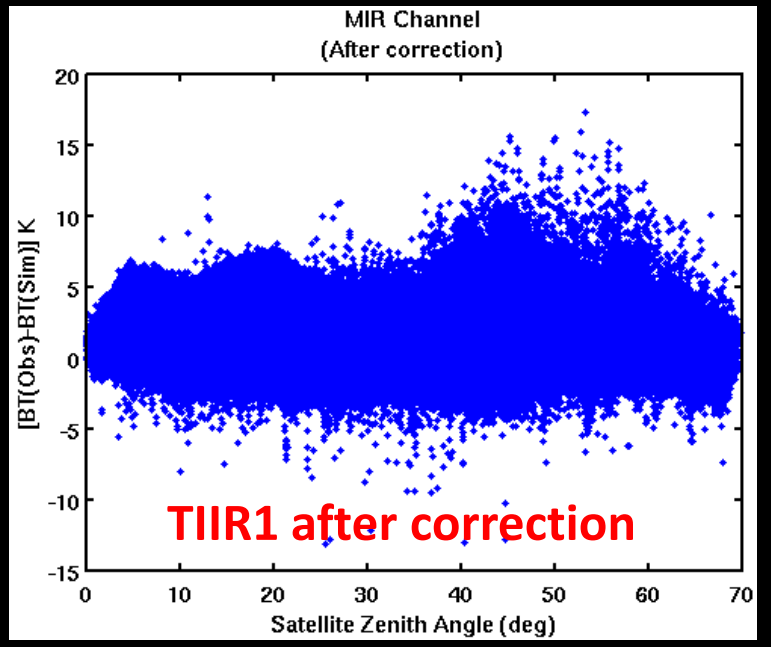

TIR-1 Channel
(Before correction)
[BT(Obs)-BT(Sim)] K
Satellite Zenith Angle (deg)
TIR1 before correction


TIR-2 Channel
(Before correction)
[BT(Obs)-BT(Sim)] K
Satellite Zenith Angle (deg)
TIR2 before correction


MIR Channel
(Before correction)
[BT(Obs)-BT(Sim)] K
Satellite Zenith Angle (deg)
TIIR1 before correction

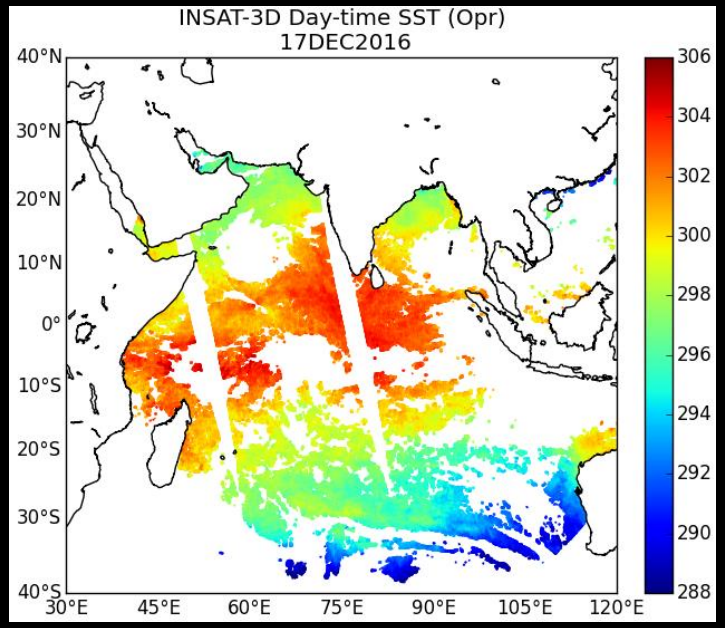

TIR-1 Channel
(After correction)
[BT(Obs)-BT(Sim)] K
Satellite Zenith Angle (deg)
TIR1 after correction

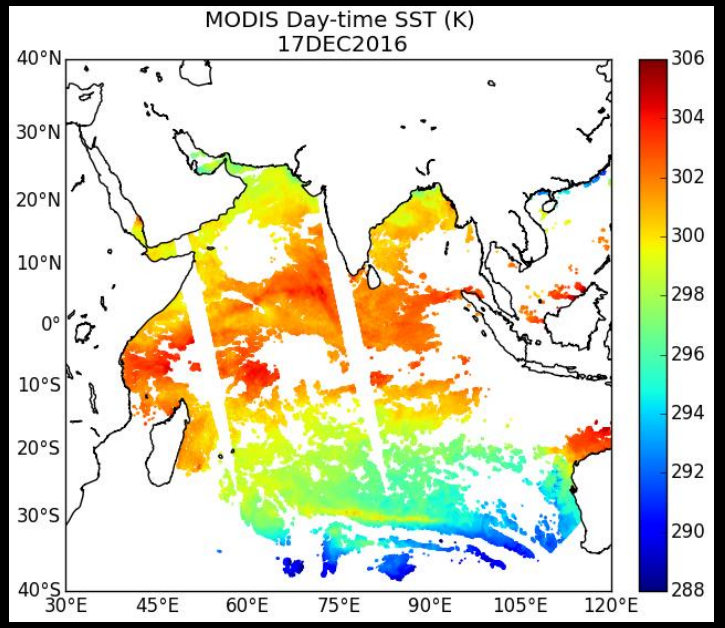

TIR-2 Channel
(After correction)
[BT(Obs)-BT(Sim)] K
Satellite Zenith Angle (deg)
TIR2 after correction

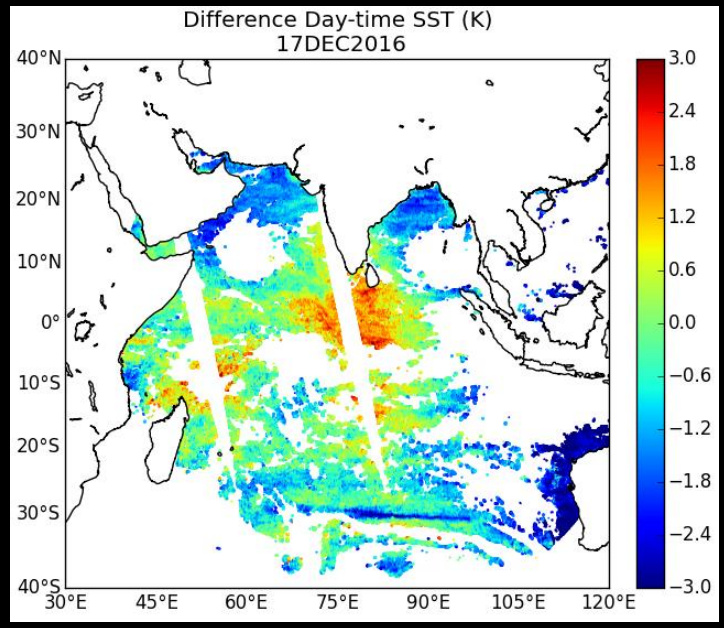

MIR Channel
(After correction)
[BT(Obs)-BT(Sim)] K
Satellite Zenith Angle (deg)
TIIR1 after correction

# Comparison of INSAT-3D Day-time SST with MODIS for 17 December, 2016

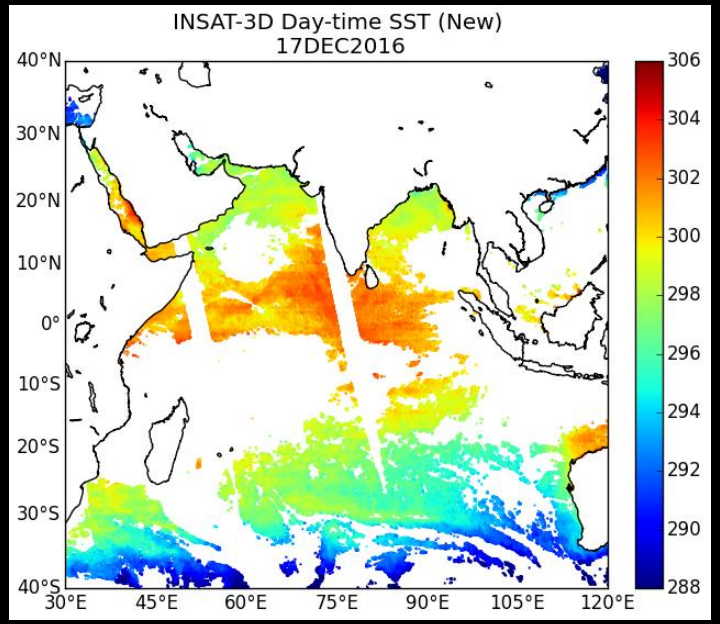
Operational

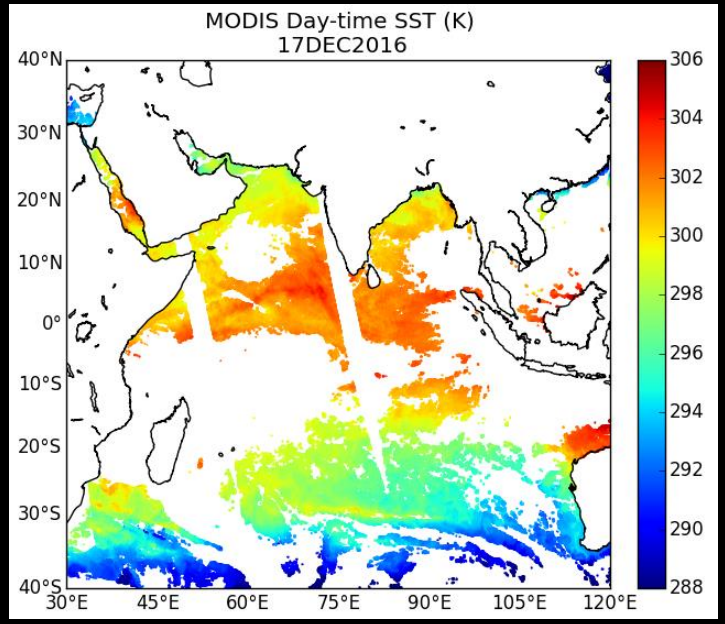


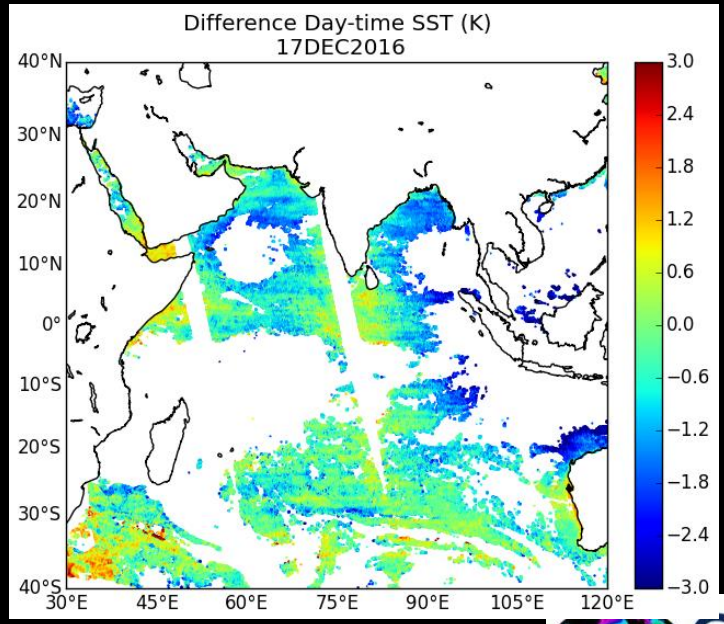




Modified

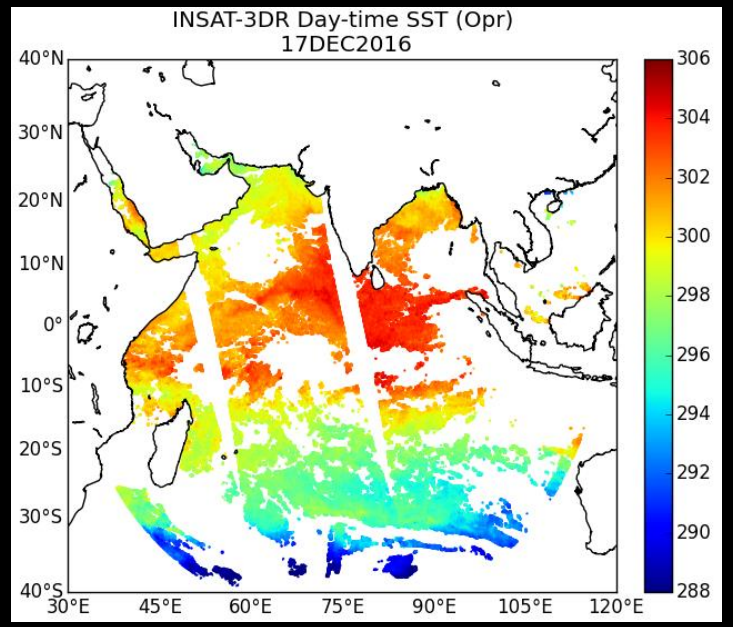


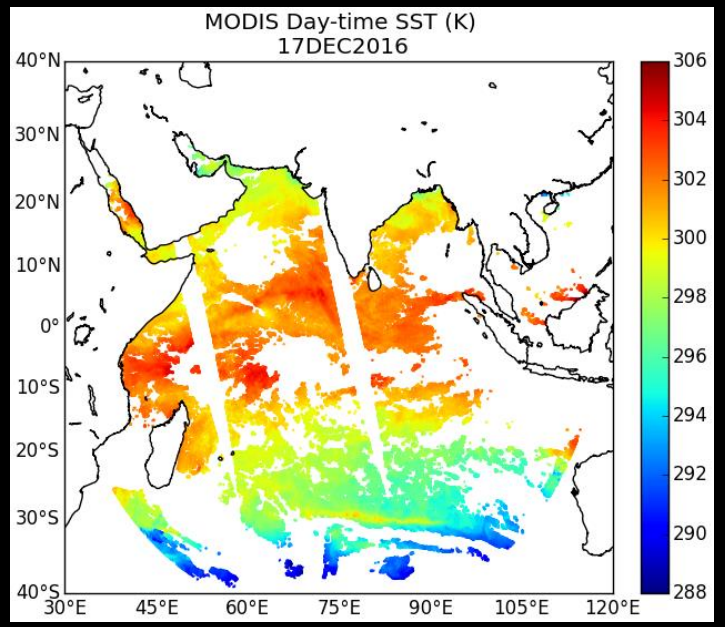



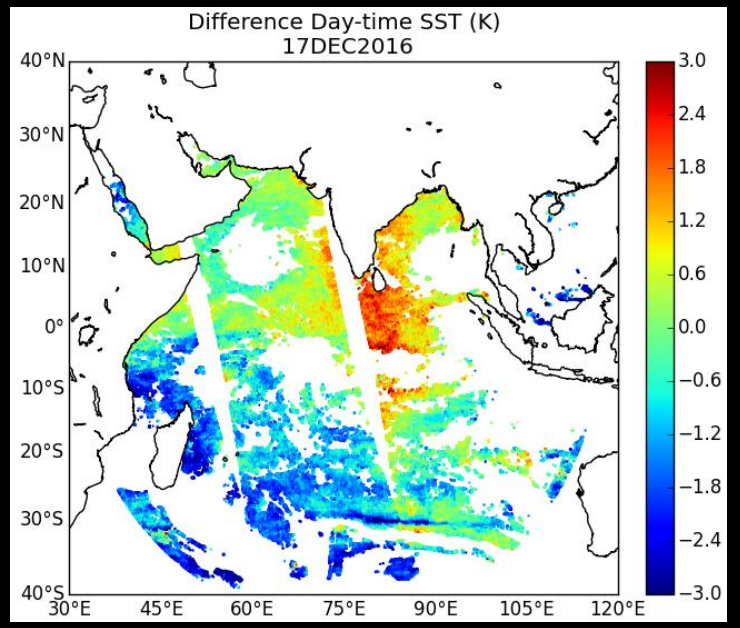



# Comparison of INSAT-3DR Day-time SST with MODIS for 17 December, 2016

Operational

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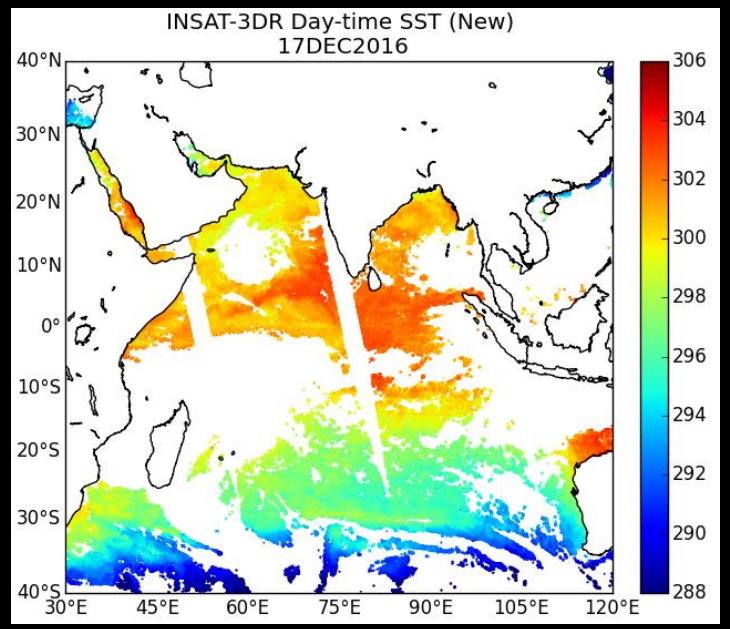
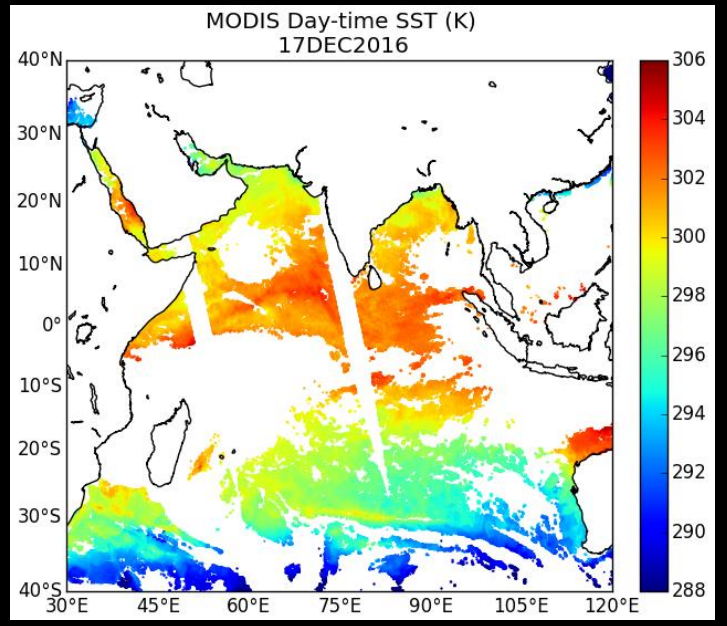
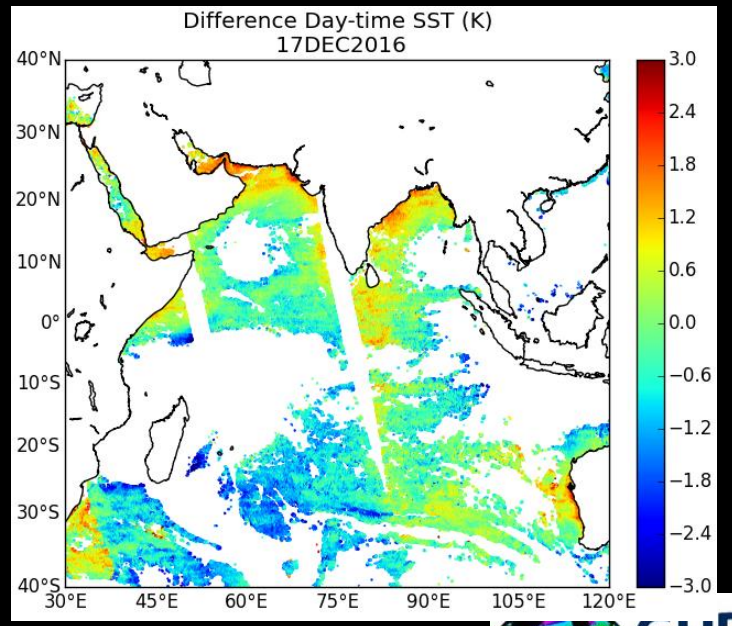
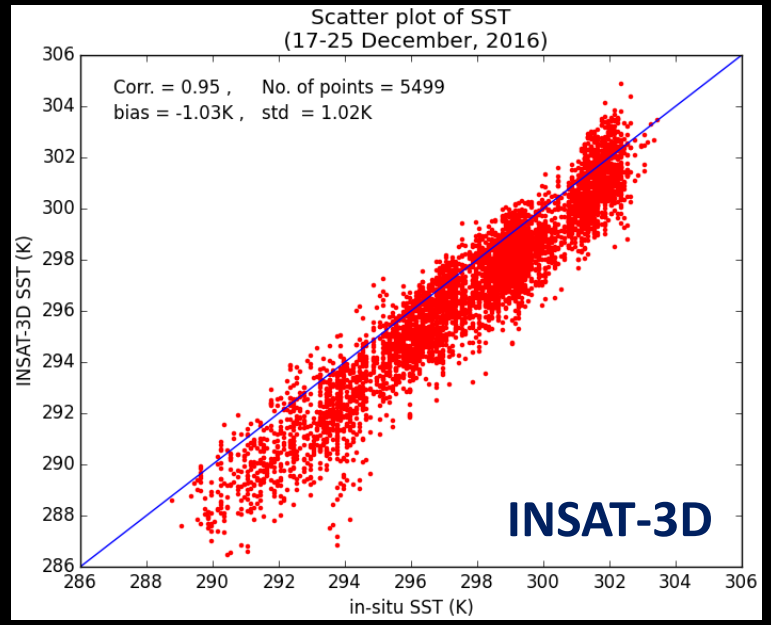


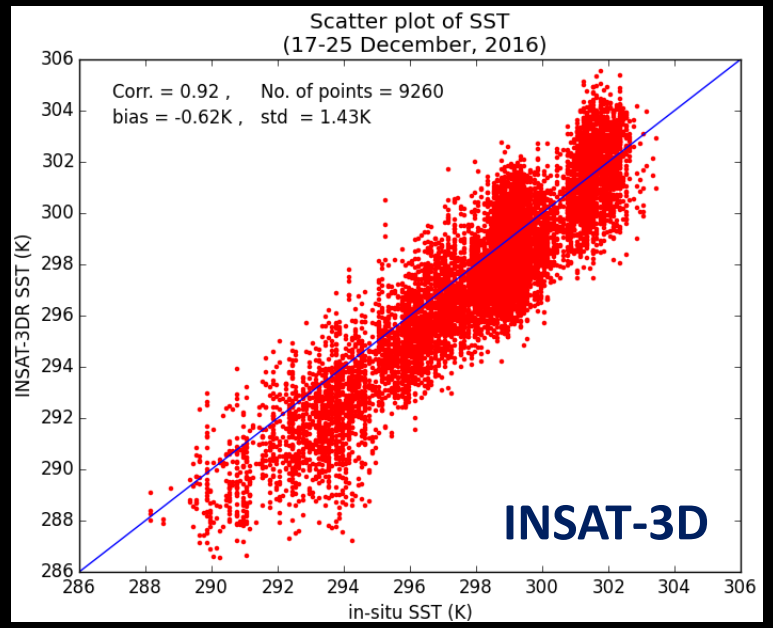



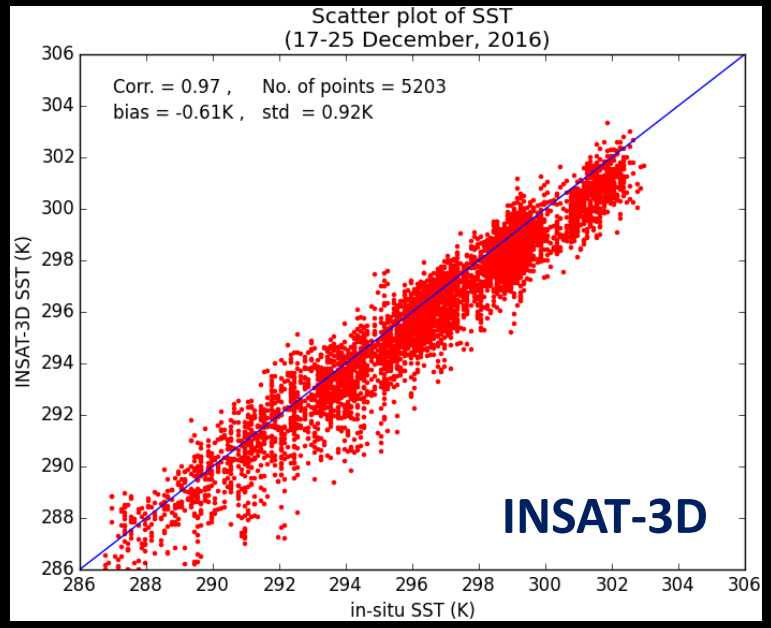
# Validation with in-situ SST measurements

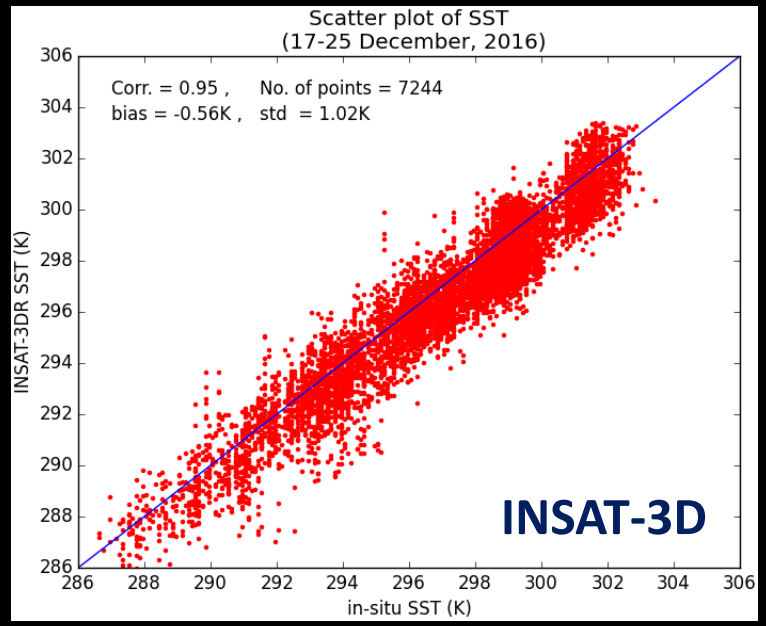
Operational



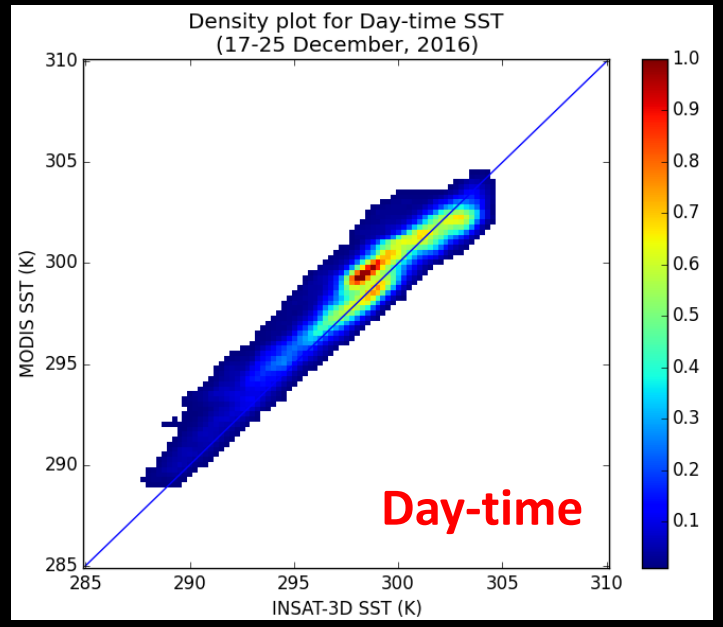

Modified

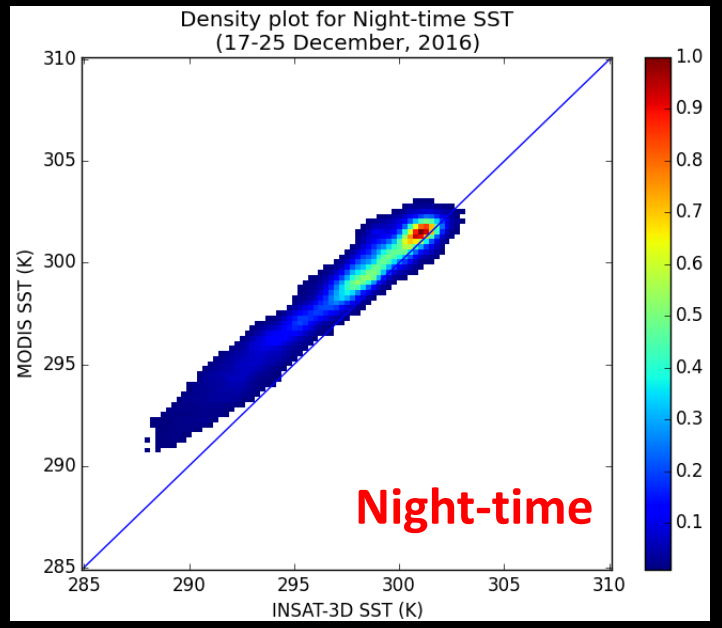


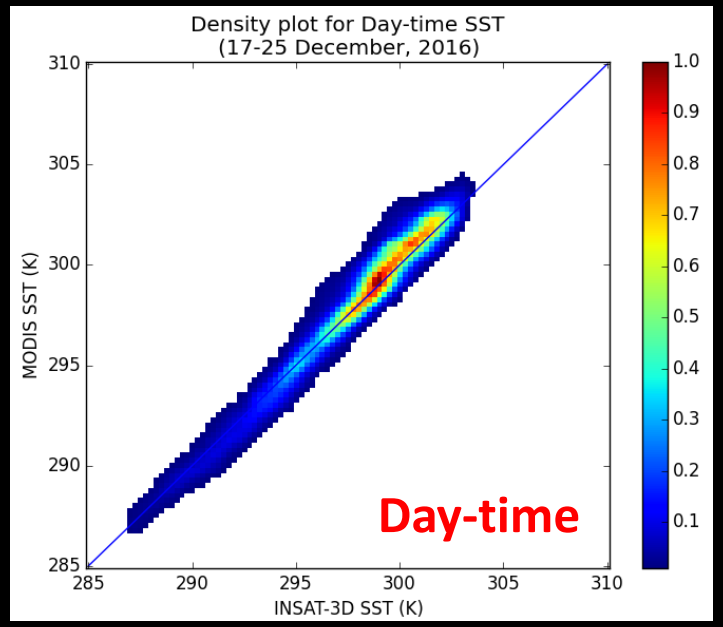
# Comparison of INSAT-3D SST with MODIS for 17-25 December, 2016

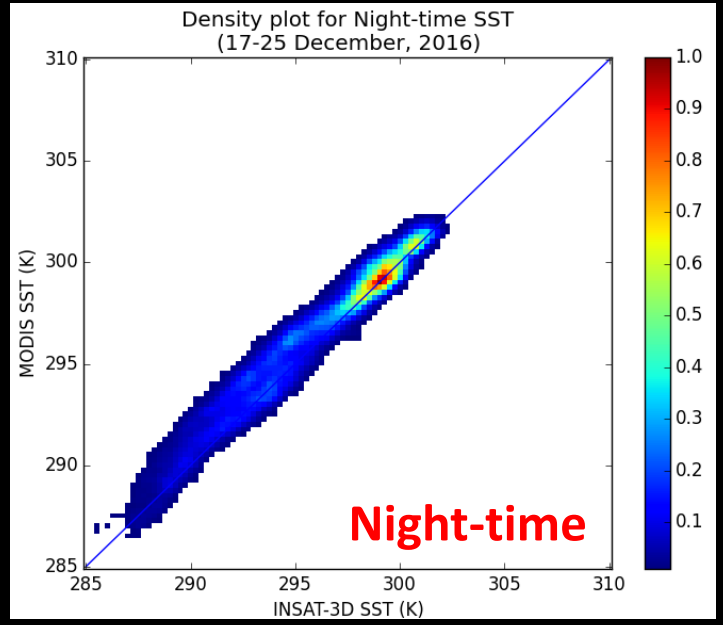
Operational




Modified

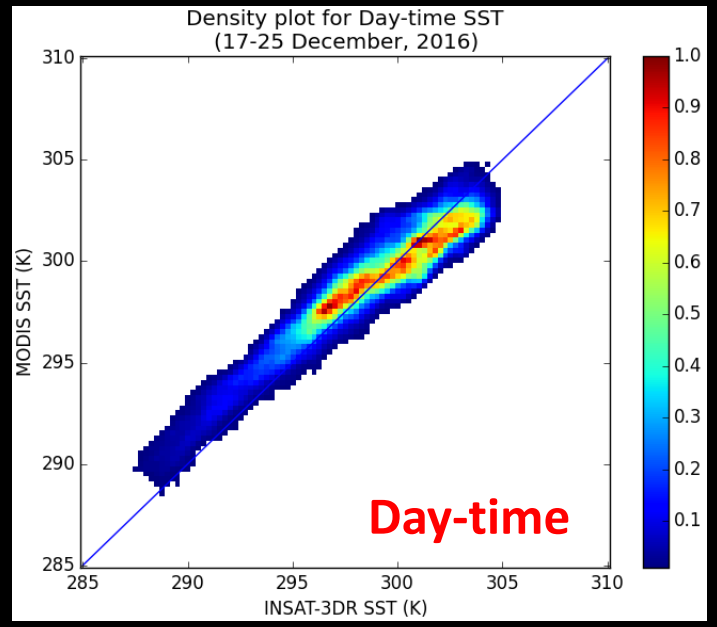


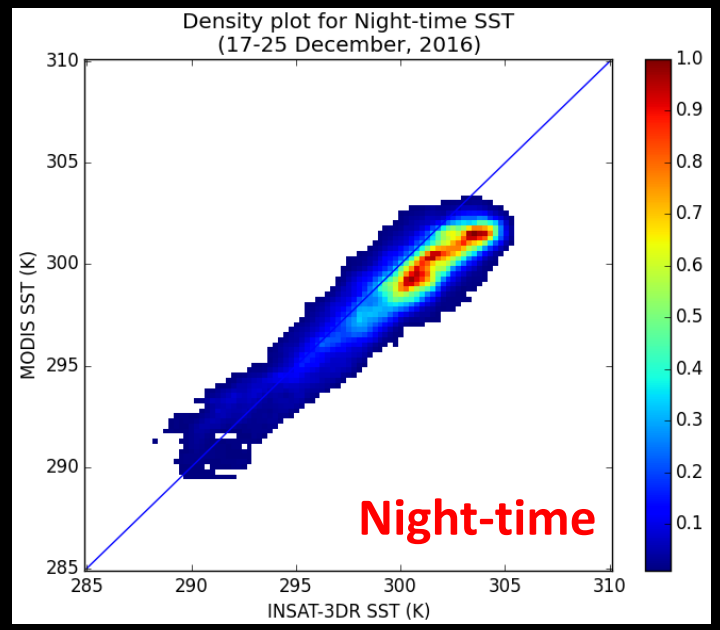




| Algorithm | Statistics | Day-time | Night-time |
|---|---|---|---|
| Operational | Bias (K) | -0.40 | -1.11 |
| | RMSD (K) | 1.10 | 1.47 |
| | STD (K) | 1.02 | 0.97 |
| Modified | Bias (K) | -0.23 | -0.50 |
| | RMSD (K) | 0.81 | 0.96 |
| | STD (K) | 0.78 | 0.82 |

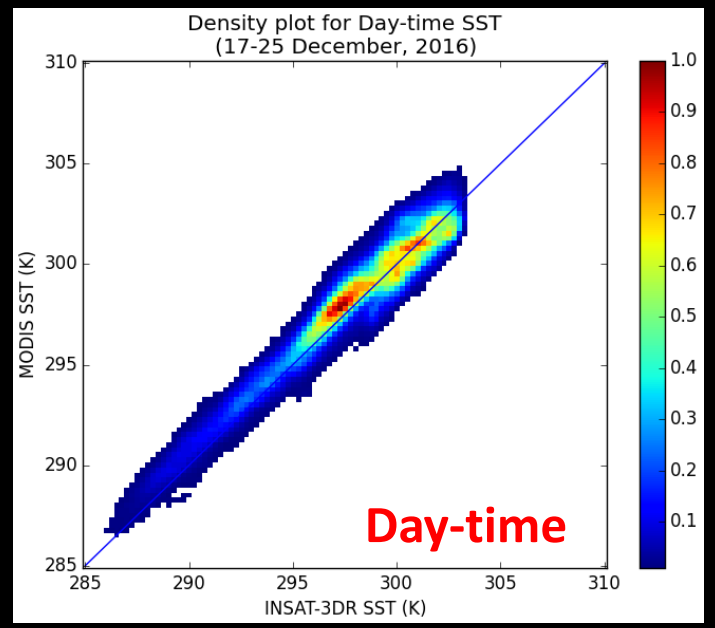
# Comparison of INSAT-3DR SST with MODIS for 17-25 December, 2016

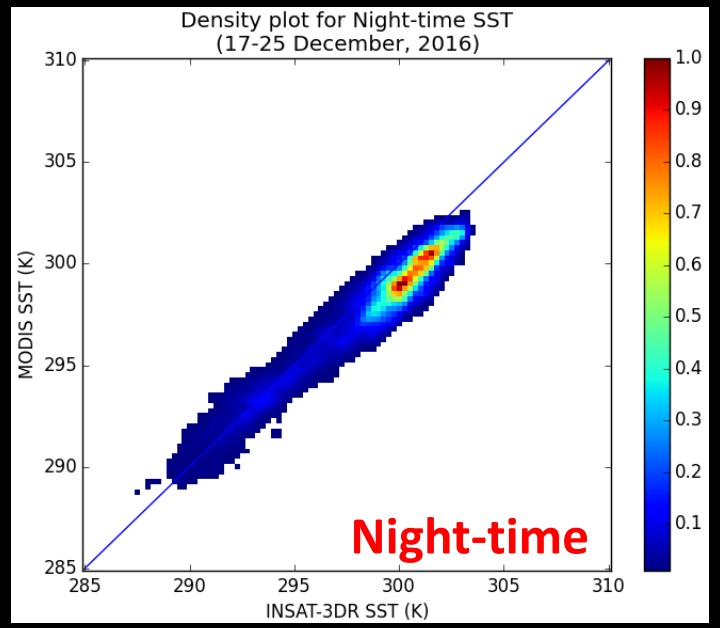
Operational




Modified




| Algorithm | Statistics | Day-time | Night-time |
|---|---|---|---|
| Operational | Bias (K) | -0.20 | 1.17 |
| | RMSD (K) | 1.20 | 1.72 |
| | STD (K) | 1.19 | 1.25 |
| Modified | Bias (K) | -0.31 | 0.89 |
| | RMSD (K) | 0.97 | 1.29 |
| | STD (K) | 0.92 | 0.92 |

# Conclusions

- SST products from INSAT-3D/3DR evaluated w.r.t. MODIS-SST shows that there are zenith angle dependent biases.
- Zenith angle dependent RT model bias correction procedure developed using ECMWF analysis and INSAT-3D/3DR matchup data.
- The modified algorithm shows an improvement over the operational algorithm for INSAT-3D/3DR observations.
- The zenith angle dependency in observed TIR-1/2 brightness temperatures need to be studied further.
- Further improvements will be attempted using LBL-RT model and improved cloud detection algorithm

# THANKS