SEA SURFACE TEMPERATURE RETRIEVAL FROM INSAT-3D : Initial Results

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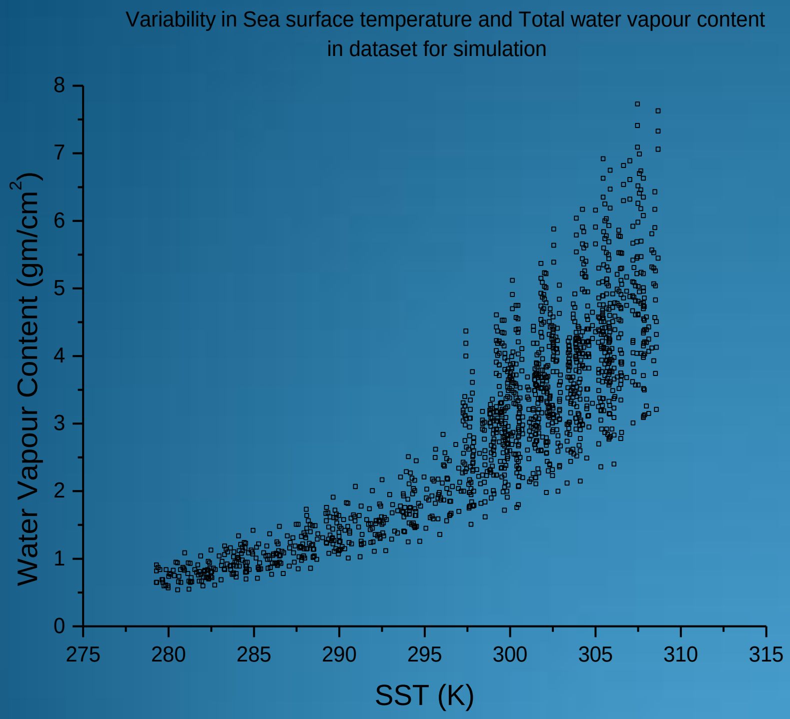
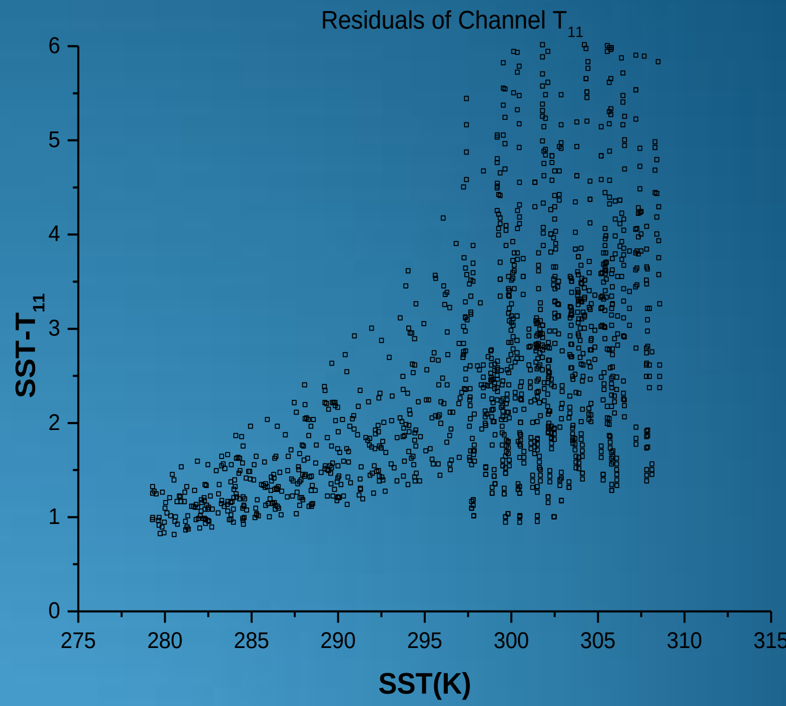
Importance for the country

- Impact of oceans in terms of national economy is enormous since India is having a long coastline with Arabian sea, Bay of Bengal and Indian Ocean surrounding it.
- Potential Fisheries Zone prediction, Ocean State Forecasting, Numerical Weather Prediction for Monsoon, Acoustic propagation and Climate change are the fields directly related to Sea Surface Temperature

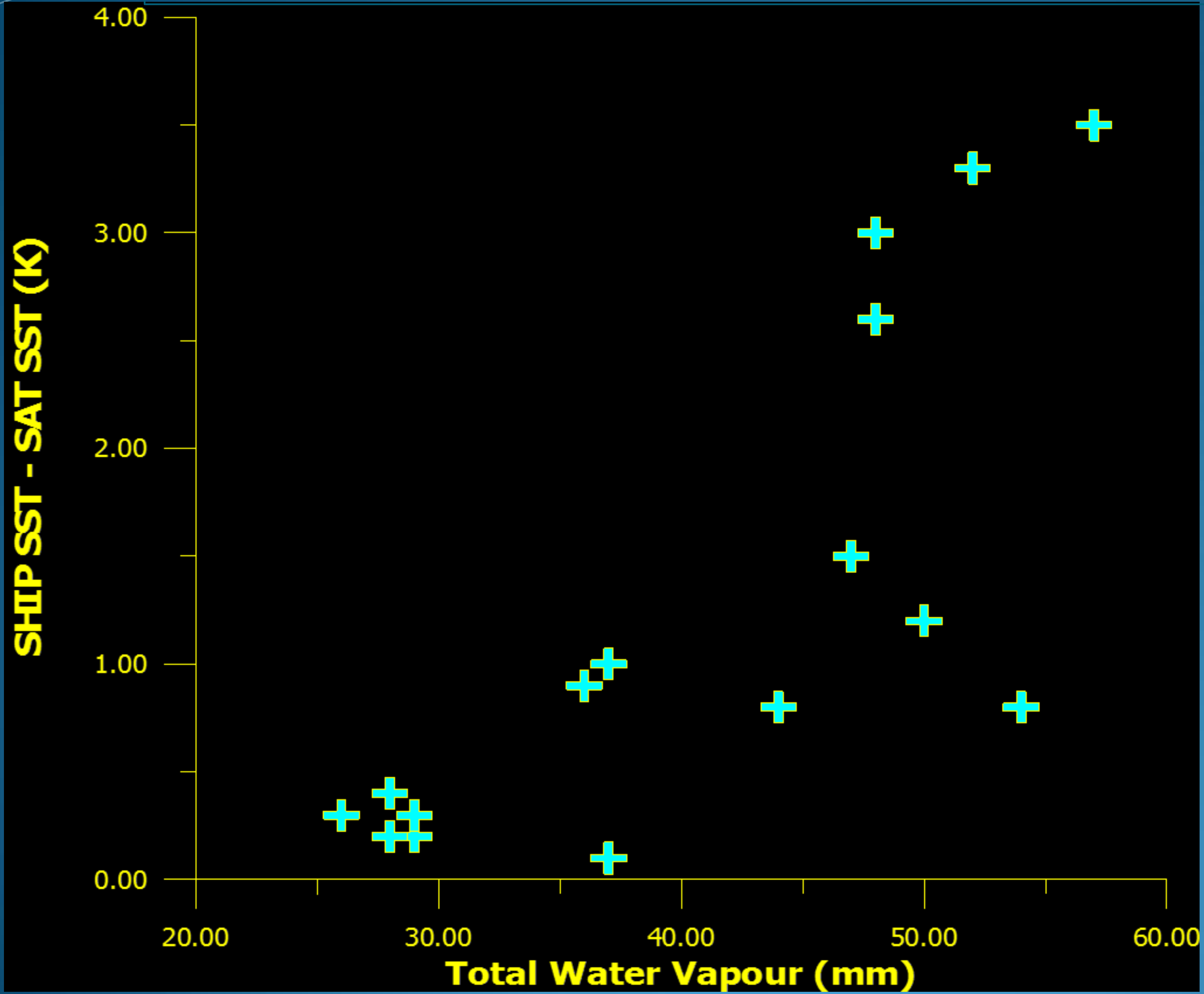
Peculiarity of Tropics





Higher moisture > 40 mm leads to non-unique SST solutions

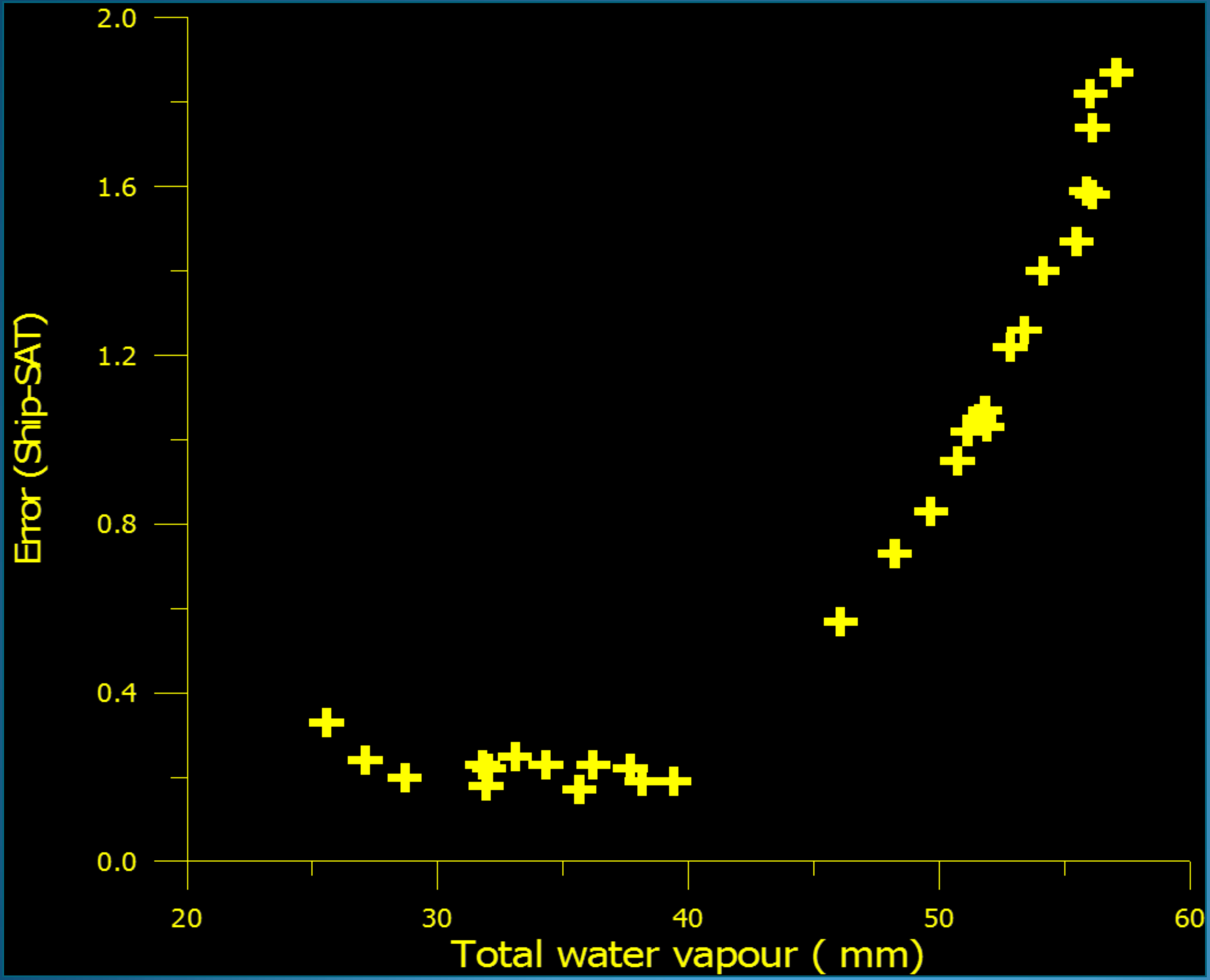
IMPACT OF WV ON SST RETRIEVAL FROM AVHRR



NOAA AVHRR

Global SST algorithm (MCSST) produces errors (1-3.5 K) in Indian regions when total water vapour content exceeds 45 mm.
(Mathur et al, 1991)

IMPACT OF WV ON SST RETRIEVAL FROM ATSR



ERS-1 ATSR

Global algorithm for ATSR Produces errors (1-2K) in Indian oceans under moist conditions.
(Mathur et al, IJRS, 2002, Gohil et al, IJRS, 1994)

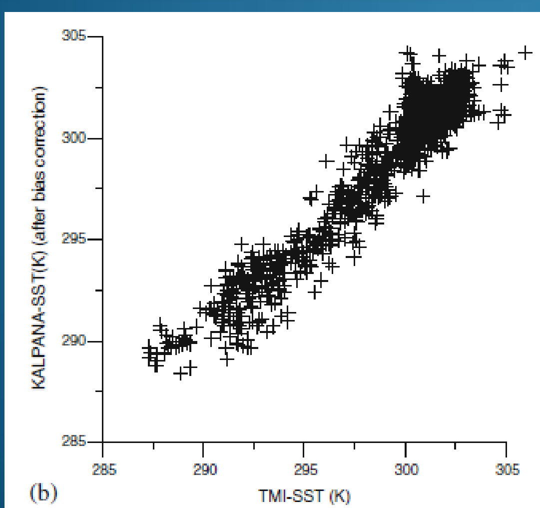
ISRO's initiative

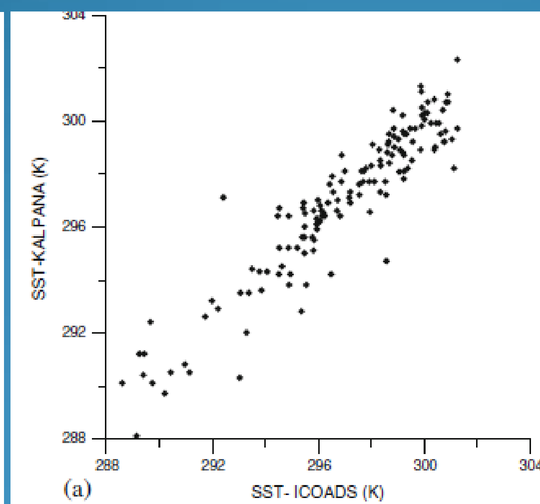
KALPANA (launched September 12, 2002, 74 deg East)
TIR(10.5-12.5 µm) – 8 km resolution
Every half an hourly SST available at MOSDAC/IMD

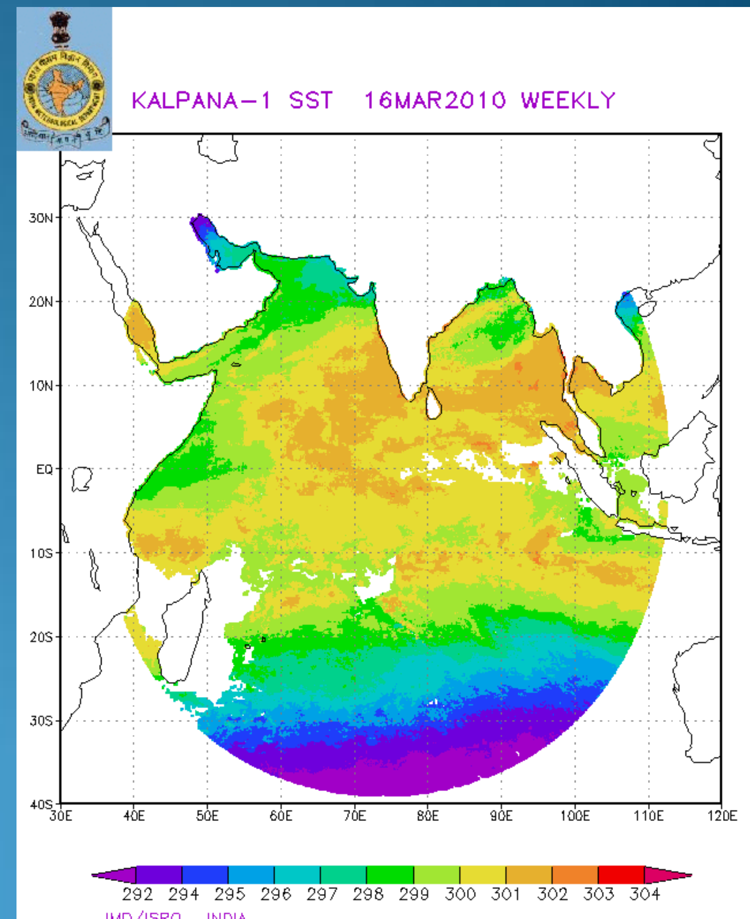
$$SST = A(\theta) + B(\theta)\ TB$$

$$SST' = A'(\theta) + B'(\theta)\ TB + C'(\theta)WV,$$

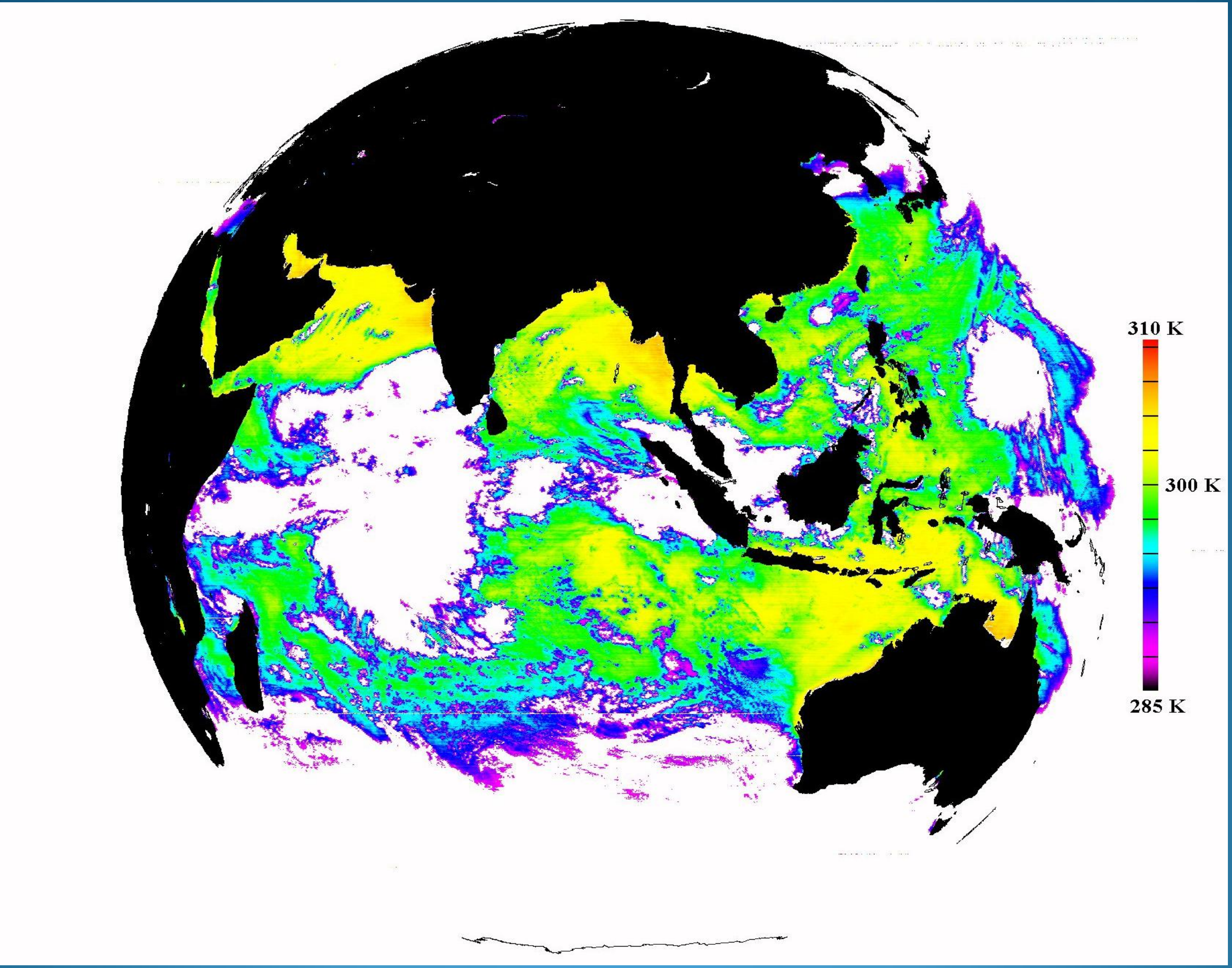
RMSE(SST) >2K
RMSE (SST')– 1.02 K with TMI/ICOADS







SST from single channel INSAT-3A
21 OCT 2004: 1130 IST



Launch-10 April 2003

OCEANSAT-1 /MSMR

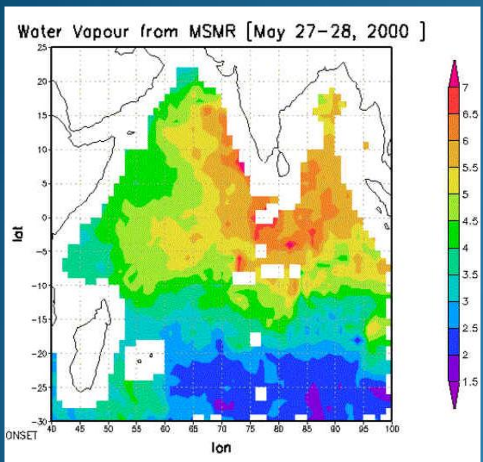
May 26, 1999 to October 2001

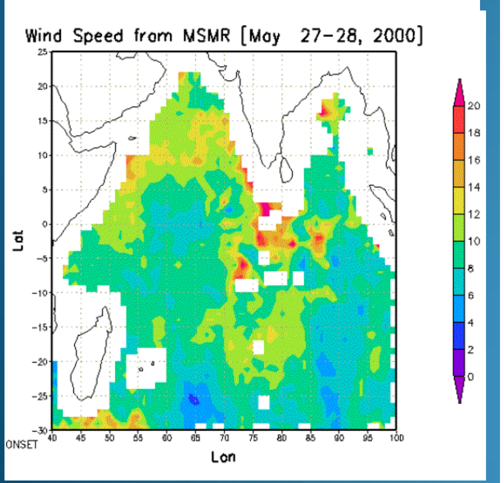
MSMR(multichannel scanning microwave radiometer) Freq (V & H) - 6.6, 10.6, 18, 21GHz

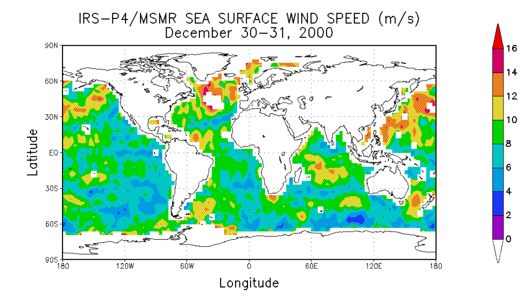
OCM bands 8 (402-885 nm) SST, TPW, WS and CLW (products)

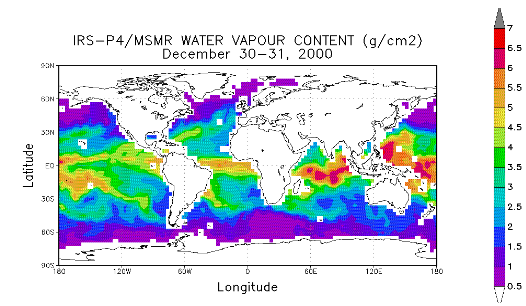
Monsoon onset

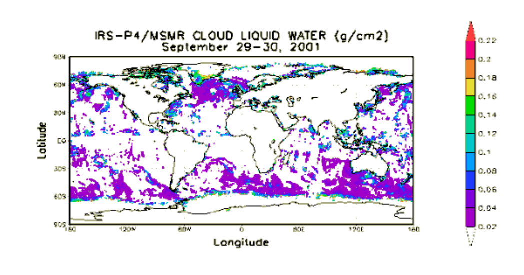
SST RMSD ~1.2K

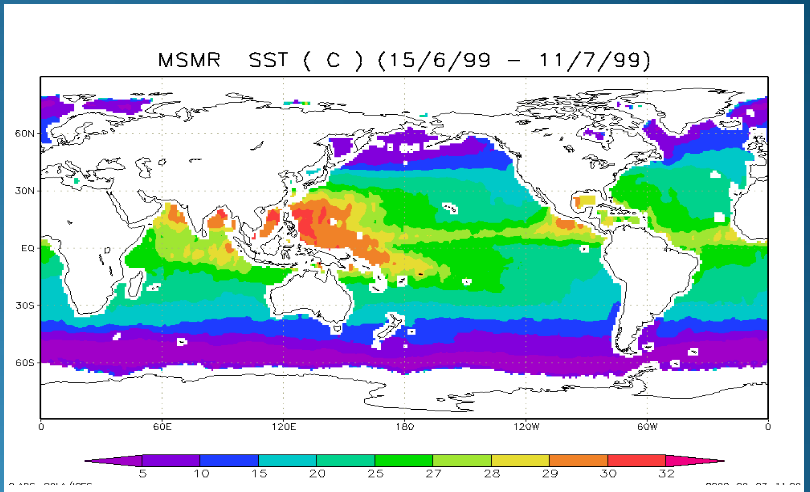


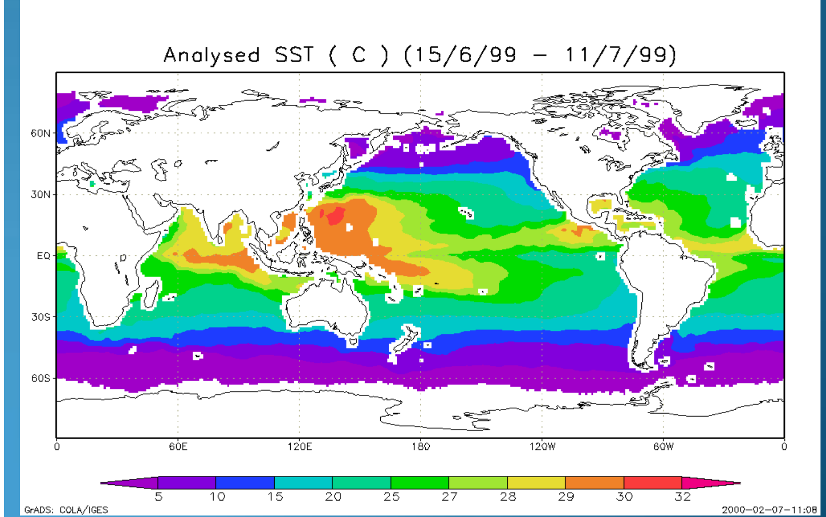




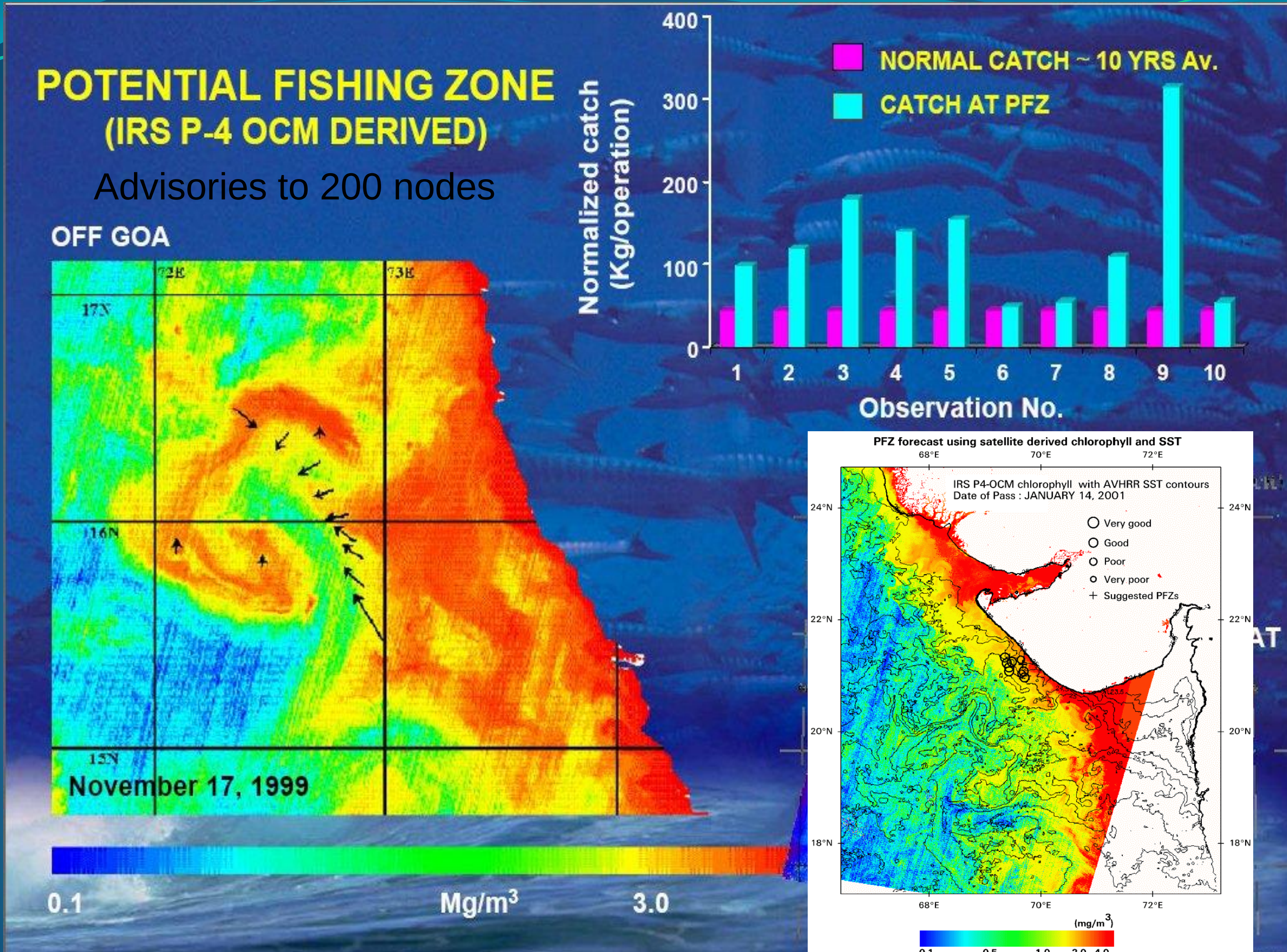






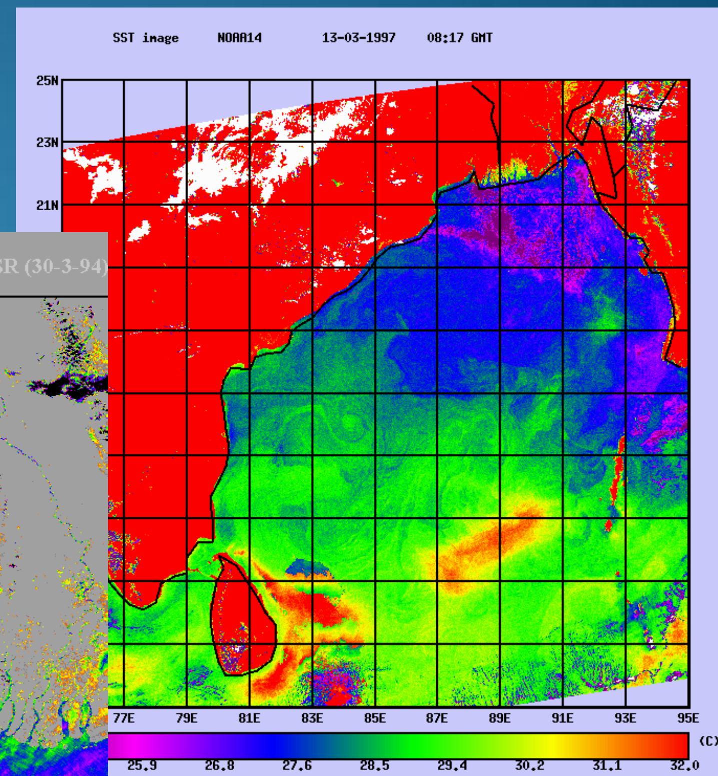


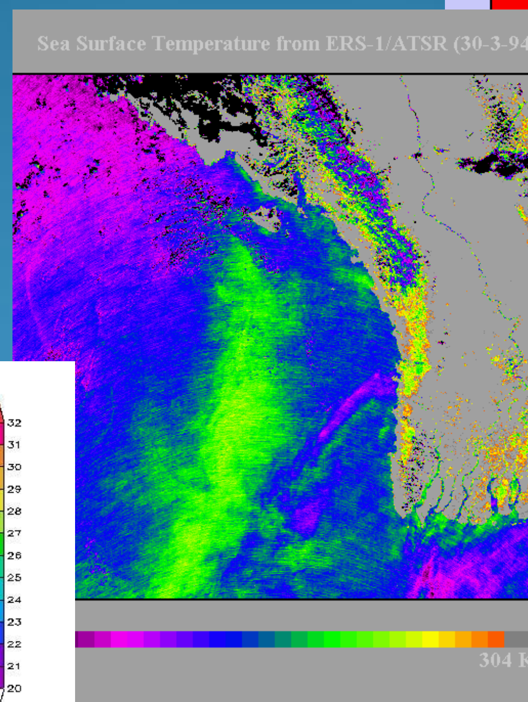
OCEANSAT-1/OCM Applications

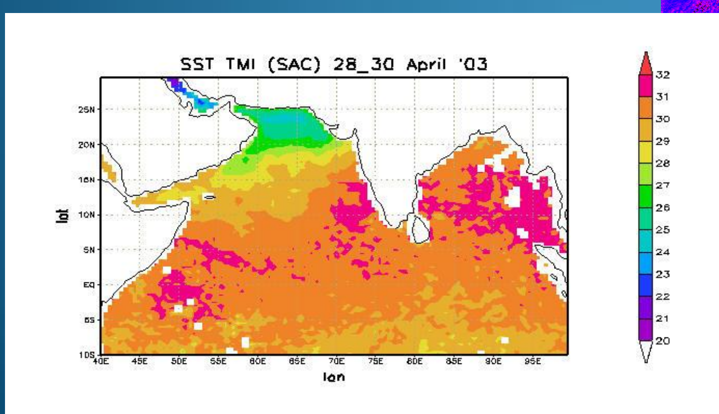


Experience with other satellites

- NOAA-AVHRR-HIRS
- ERS-1/ATSR (AO)
- TRMM/TMI
- TERRA/AQUA-MODIS

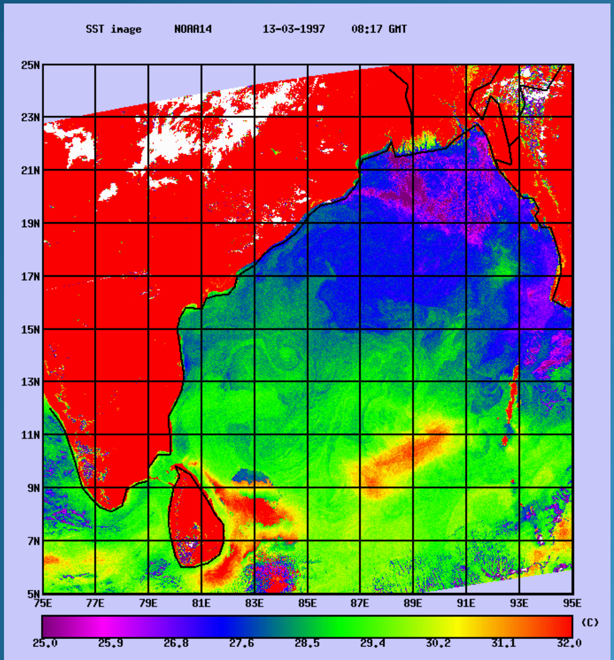






Indian Competence

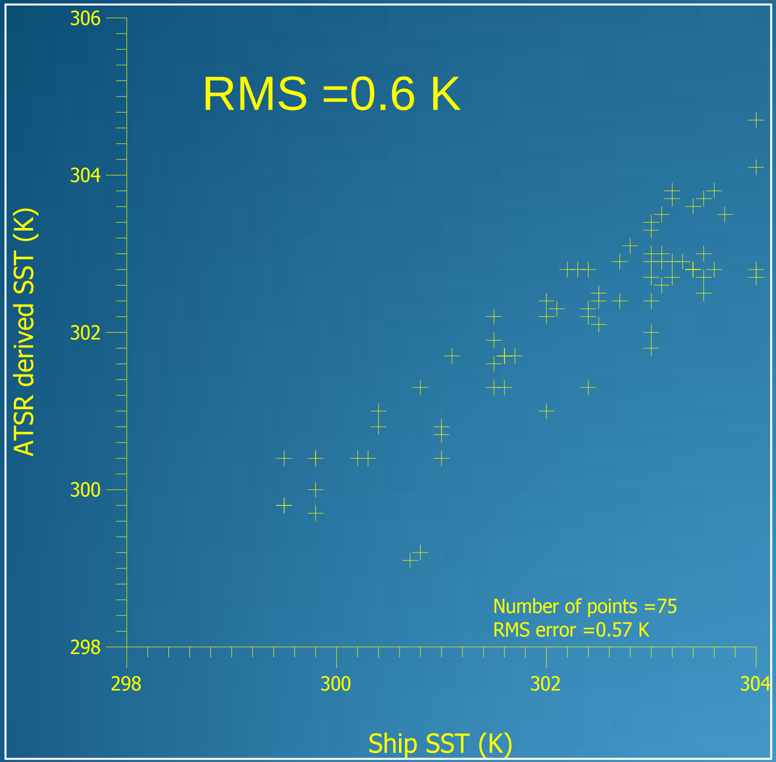
Improved SST derived from NOAA/AVHRR and its validation

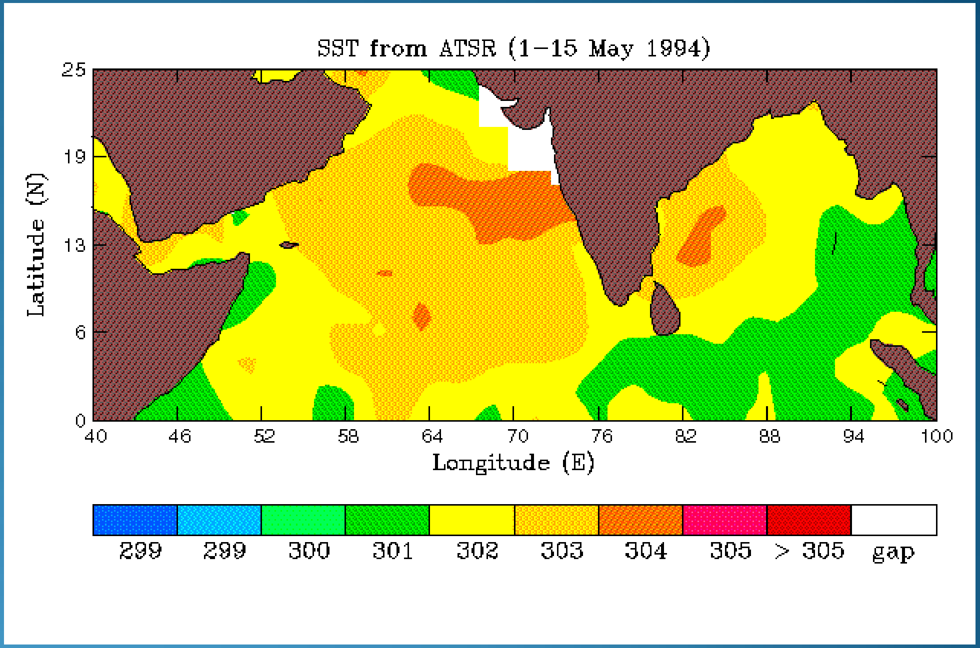


Difference(Sat-ship)	No. of Pts
0 – 0.5 K	23
0.6 – 1.0 K	24
1.1 – 1.5 K	1
1.6 – 2.0 K	8.

RMS ~0.6K

Validation of SST derived from ERS/ATSR

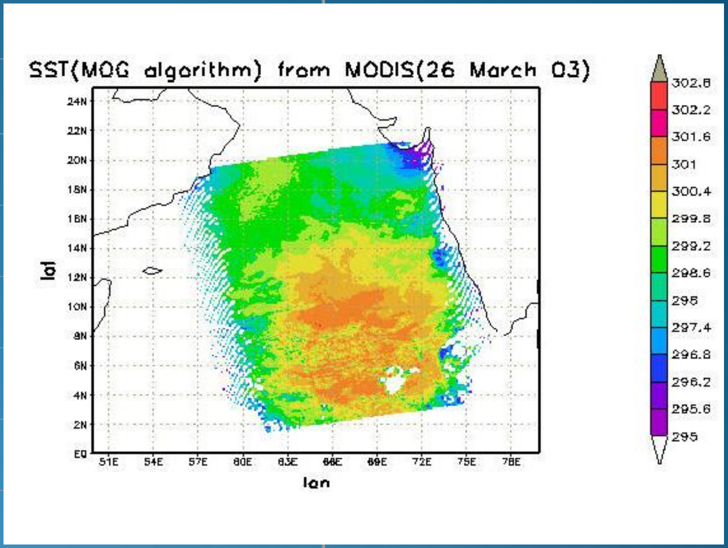




TERRA-AQUA/MODIS

Statistics of the comparisons between pyrometer skin temperature(PSST) and SST derived from MODIS far ($MSST_{nf}$ and $MSST_{df}$) and mid ($MSST_{m}$) infrared channels

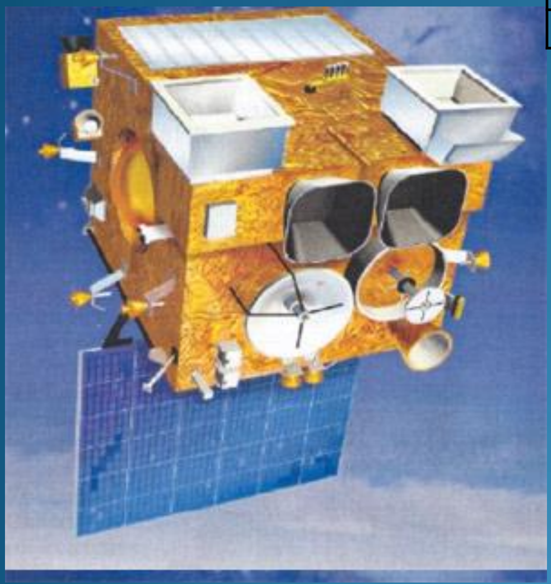
Daytime		
	$PSST\text{-}MSST_{df}$	
RMS Deviation (K)	0.79	
Bias(K)	0.44	
RMS after bias (K)	0.65	
Correlation	0.80	
Number of obs	32	
Nighttime		
	$PSST\text{-}MSST_{nf}$	$PSST\text{-}MSST_{m}$
RMS Deviation (K)	0.58	0.63
Bias(K)	0.05	-0.26
RMS after bias (K)	0.57	0.57
Correlation	0.67	0.69
Number of observations	24	29



INSAT-3D

IMAGER

Channel no.	Spectrum (µm)	IGFOV (µrad)	Ground Resolution (Km)	S/N or NEDT (K)	Scene condition
1	0.52 – 0.72	28	1	150:1	100% albedo
2	1.55 – 1.70	28	1		
3	3.80 – 4.00	112	4	0.27K	300K
4	6.50 – 7.00	224	8	0.18K	230K
5	10.3 – 11.2	112	4	0.10K	300K
6	11.5 – 12.5	112	4	0.25K	300K

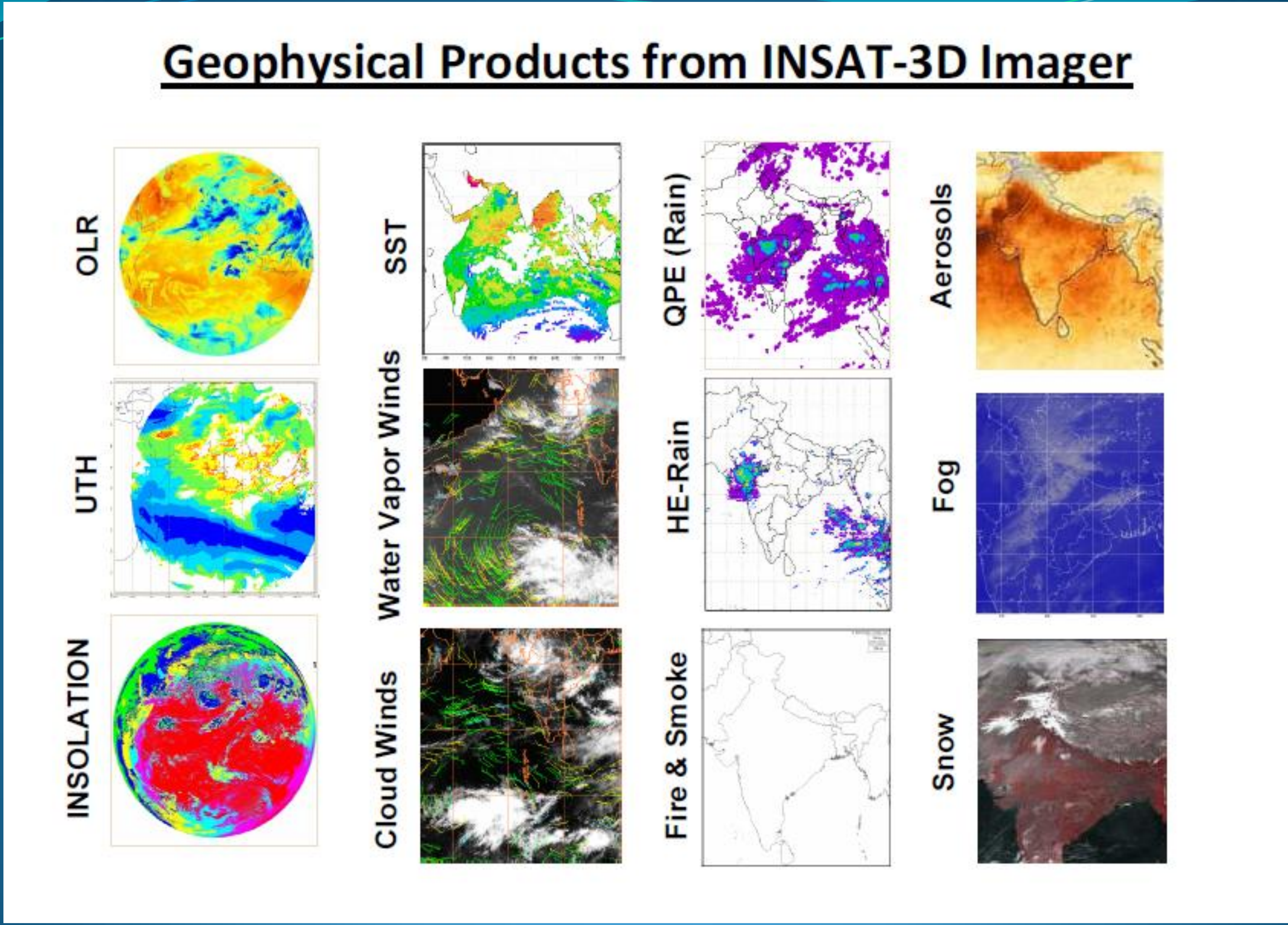


Launch- 26 July 2013

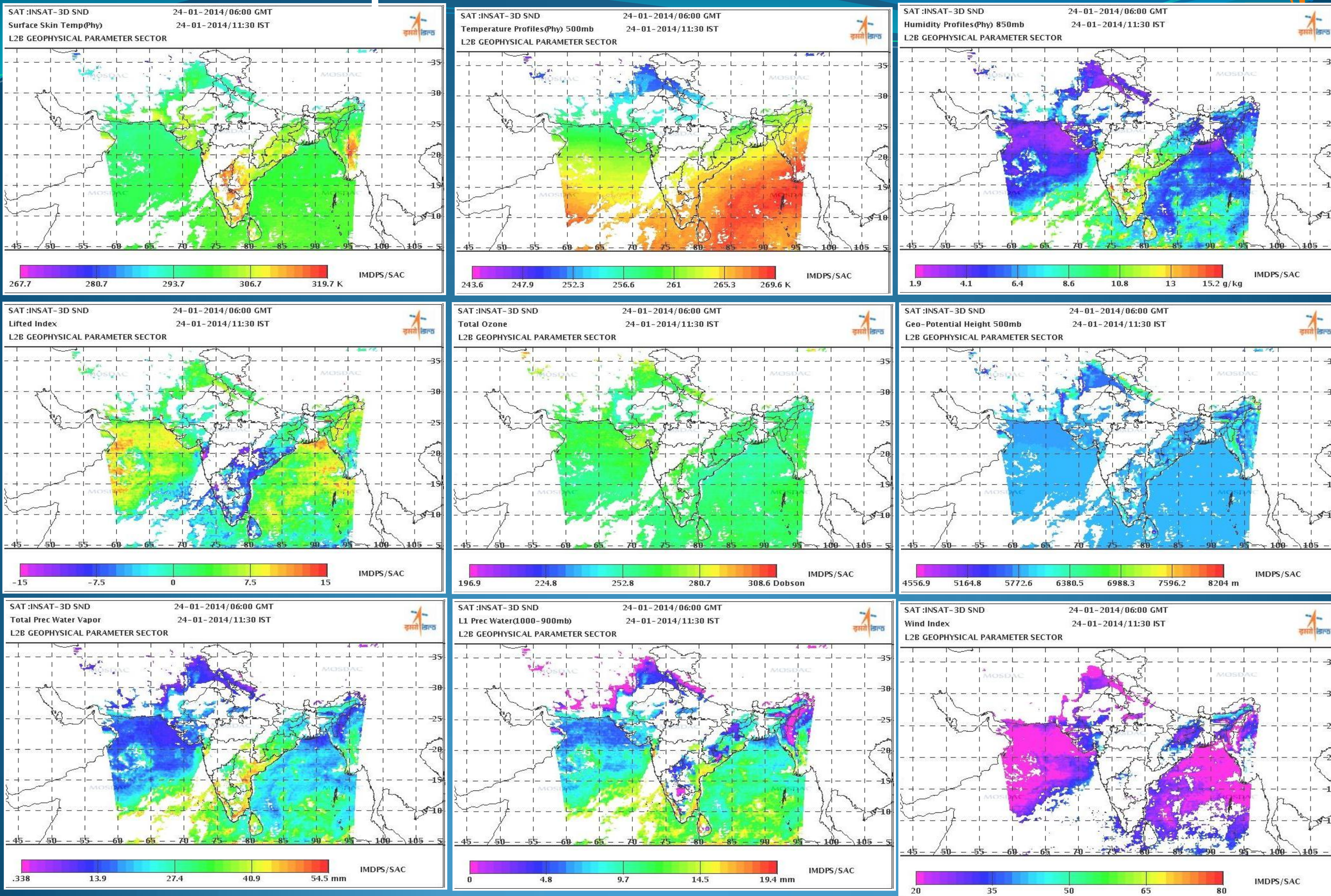
SOUNDER

Channel No.	Centre Wavelength µm (cm-1)	Bandwidth µm (cm-1)	NEDT AT 300K (typical) K
1	14.71 (680)	0.281 (13)	1.5
2	14.37 (696)	0.268 (13)	1
3	14.06 (711)	0.256 (13)	0.5
4	13.69 (730)	0.298 (16)	0.5
5	13.37 (749)	0.286 (16)	0.5
6	12.66 (790)	0.481 (30)	0.3
7	12.02 (832)	0.723 (50)	0.15
8	11.03 (907)	0.608 (50)	0.15
9	09.71 (1030)	0.235 (25)	0.2
10	07.43 (1345)	0.304 (55)	0.2
11	07.02 (1425)	0.394 (80)	0.2
12	6.51 (1535)	0.255 (60)	0.2
13	4.57 (2188)	0.048 (23)	0.15
14	4.52 (2210)	0.047 (23)	0.15
15	4.45 (2245)	0.0456 (23)	0.15
16	4.13 (2420)	0.0683 (40)	0.15
17	3.98 (2513)	0.0663 (40)	0.15
18	3.74 (2671)	0.140 (100)	0.15
19	0.695 (14367)		0.1% albedo

INSAT-3D


Geophysical Products from INSAT-3D Imager
OLR
SST
QPE (Rain)
Aerosols
UTH
Water Vapor Winds
HE-Rain
Fog
INSOLATION
Cloud Winds
Fire & Smoke
Snow

Sample INSAT-3D Sounder L2 Products



Sea Surface Temperature retrieval from INSAT-3D

Pre-launch forward modelling and algorithm testing

Details of the BT Simulations based on Radiative Transfer Model

- Moderate resolution radiance and Transmittance Code (MODTRAN)

  Band resolution (~ 2 cm-1)

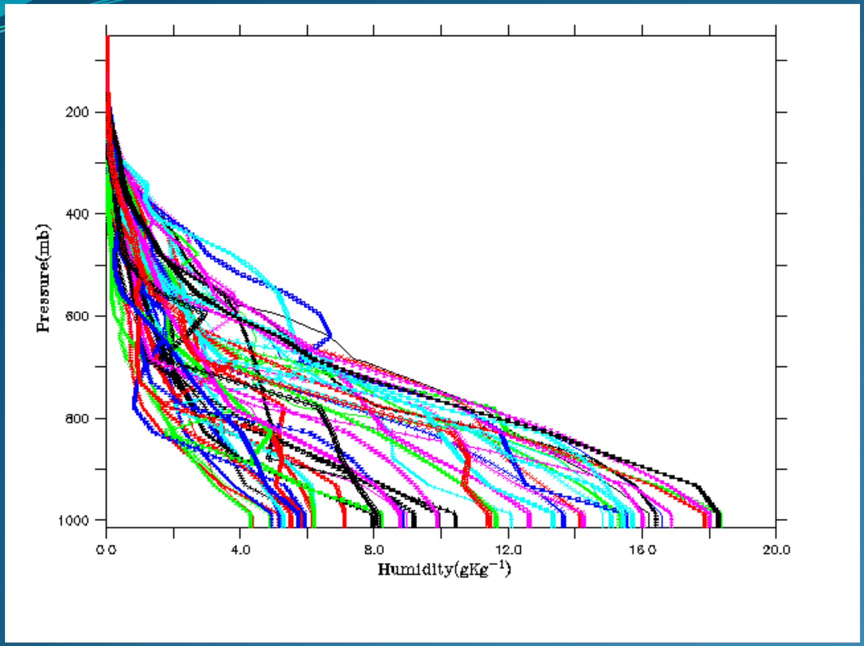
- Basic Data set: Thermodynamic Initial Guess Retrieval (TIGRE) (extracted for Indian region domain)

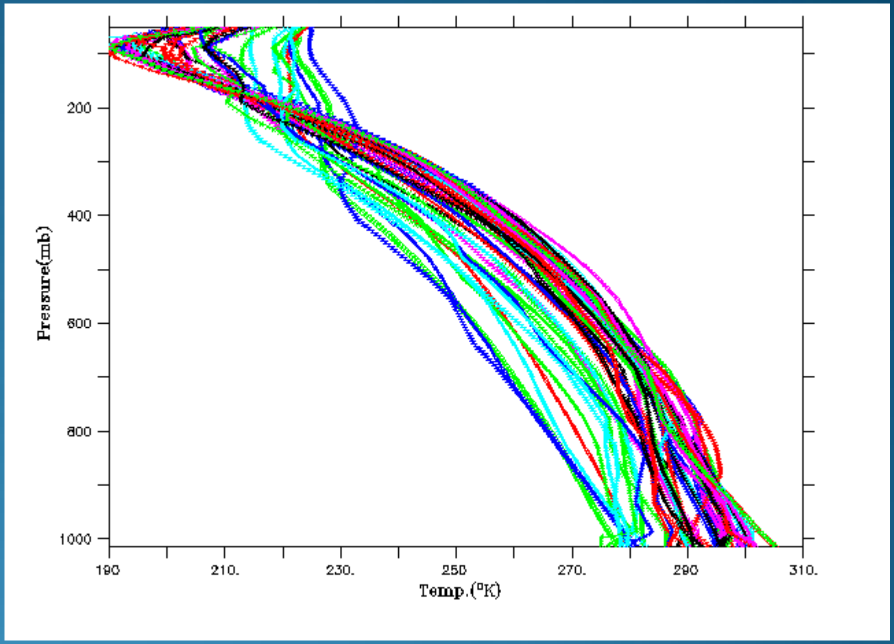
- INSAT-3D Spectral Response Functions and NEdT (0.12 and multiples of)

- Emissivity corrections due to satellite zenith angle

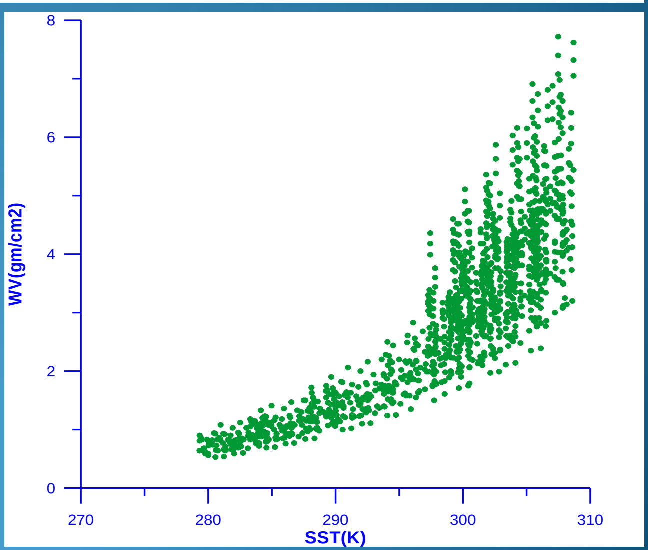
- Coefficients generation for seven satellite zenith angles (0,24,36,42,48,54,60 deg)

Pre-launch Forward modelling





TIR-1, TIR-2, MIR channels (GOES, FY-2D/E, INSAT-3D) simulated radiances using MODTRAN and TIGRE (tropical profiles) for different zenith angles



Methodology: Atmospheric Correction

The regression equation to correct for atmospheric absorption and emission has the form

$$SST = A_0 + A_1 T_{11} + A_2 dT + A_3 dT^2$$

where A_0, A_1, A_2, A_3 are coefficients determined by regression and are satellite zenith angle dependent ,

$$dT = T_{11} - T_{12}$$

where T_{11} and T_{12} are brightness temperatures for the split-window channels.

To determine the regression coefficients in the above equation, buoy reports collocated with simulated INSAT-3D imager radiance measurements are used. The important step in regression is to ensure that the sample dataset is fully and solely representative of the population for which the SST is to be derived.

Cloud Checks : INSAT-3D

1. Visible/IR Threshold technique
2. Spatial Coherence
3. Cloud flag from Cloud Mask Routine
4. Split channel difference

SST Computation: INSAT-3D

Day time

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

In case of failure of any one (split)channel:

$SST = a_0 + a_1 T_{11} + dt$; $dt = w_1 + w_2(TWV)$

$SST = b_0 + b_1 T_{12} + dt'$; $dt' = w_3 + w_4(TWV)$

Nighttime

$SST = c_0 + c_1 T_{3.9} + c_2 (T_{11} - T_{12}) + c_3(T_{11} - T_{12})^2$

In case of failure of any one/two channels

1	→	2,3	1,2	→	3+TWV
2	→	1,3	1,3	→	2+TWV
3	→	1,2	2,3	→	1+TWV

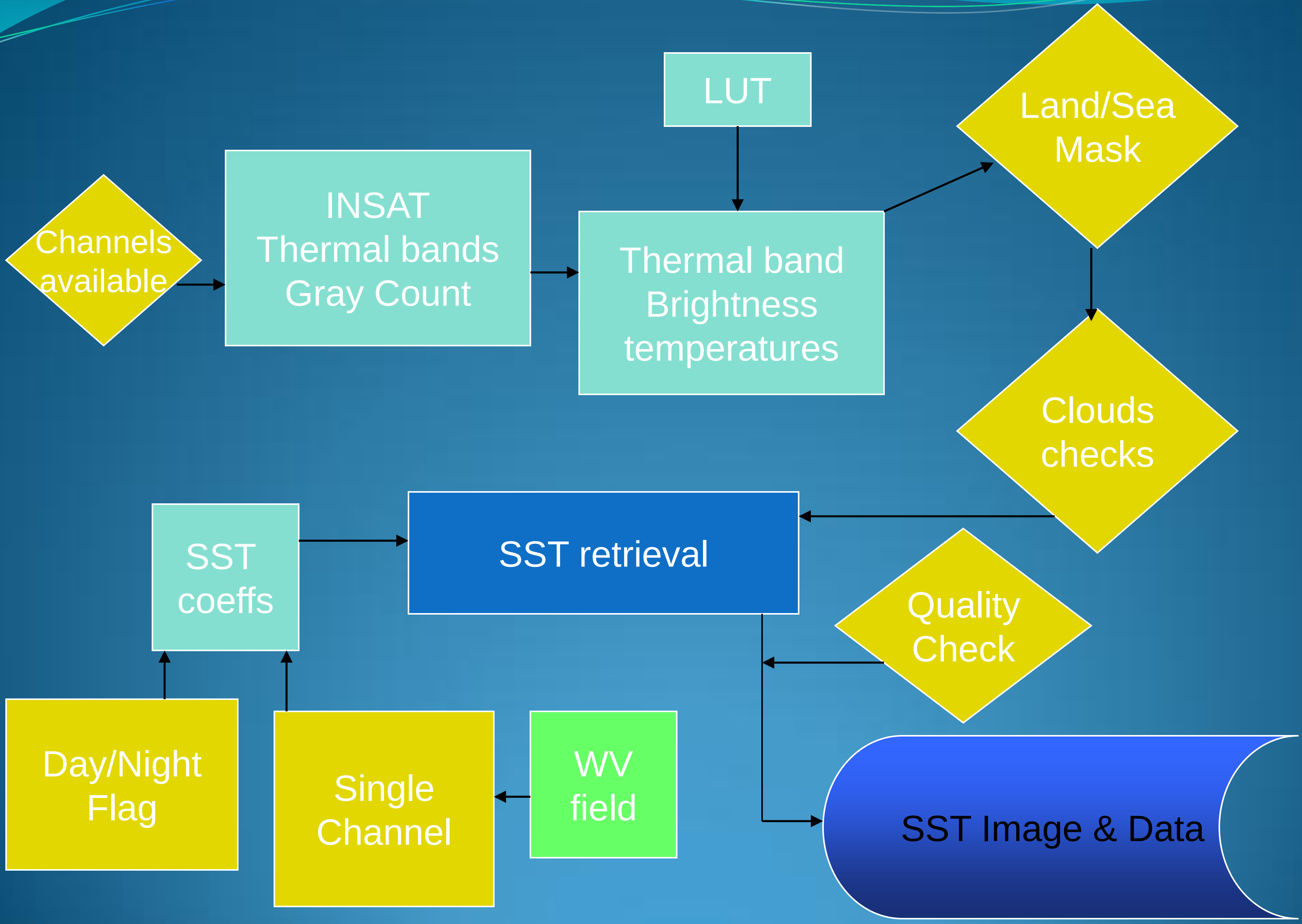
Quality Control

1. Deviation from previous cycle SST
2. Deviation from weekly climatological SST (Reynolds 1^0 X 1^0)

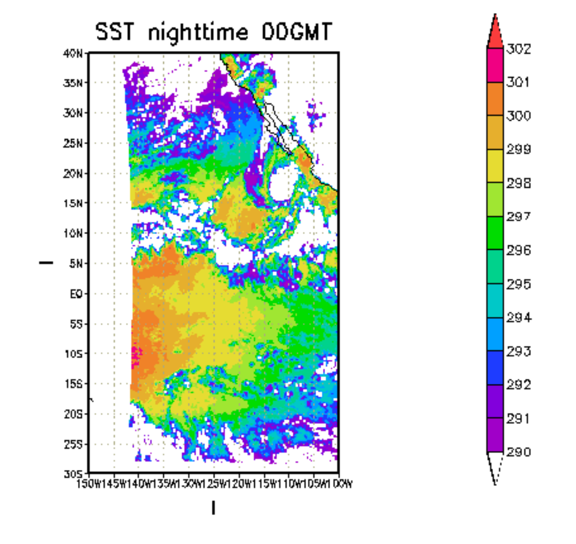
Validation

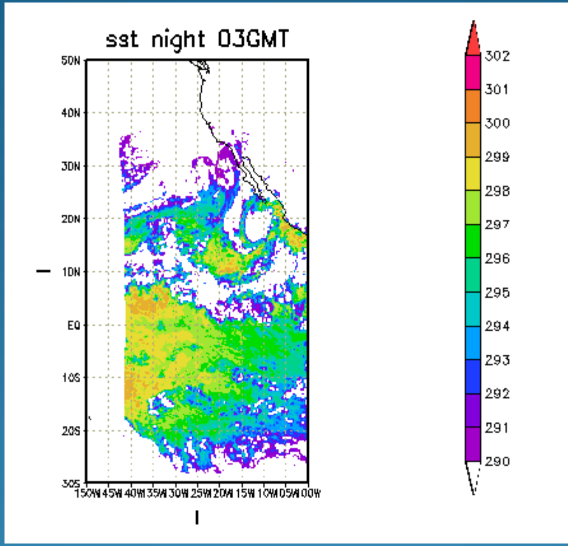
- Buoys (ARGO, NIOT, TRITON)
- Data collected onboard research vessels
- Other contemporary satellite SST fields e.g. MODIS, GHRSST

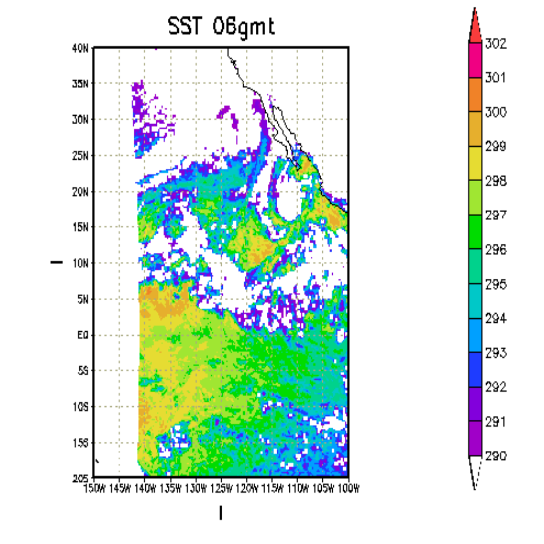
FLOW CHART OF SST RETRIEVAL

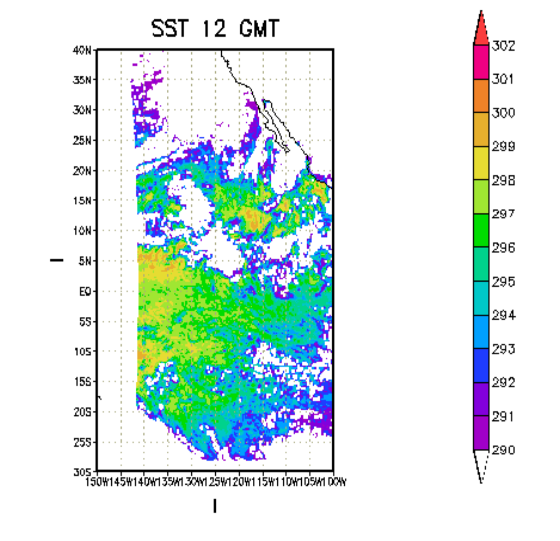


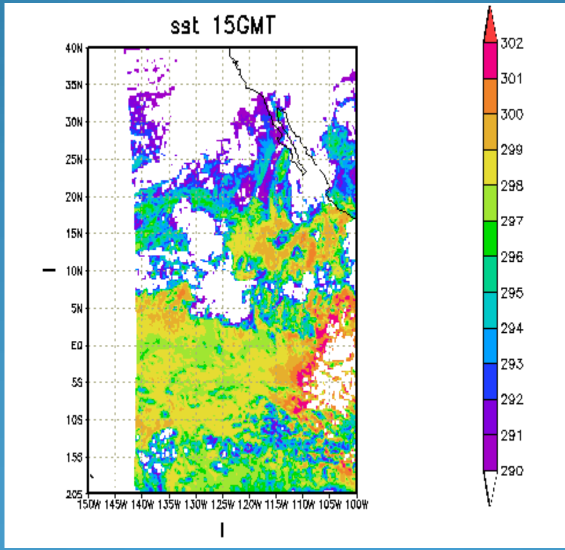
Day and Night time algorithms for SST- GOES-11 Data

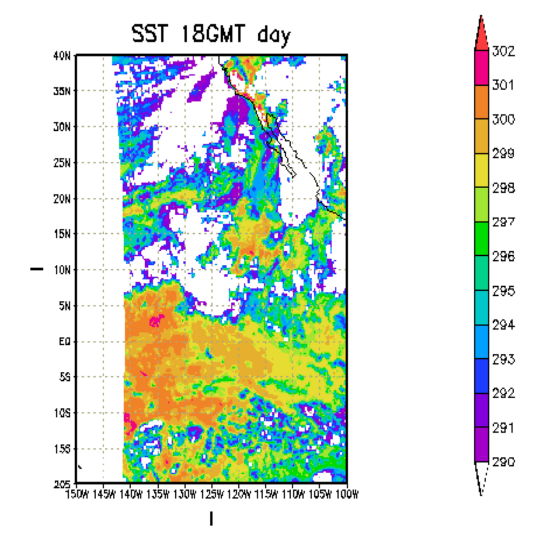












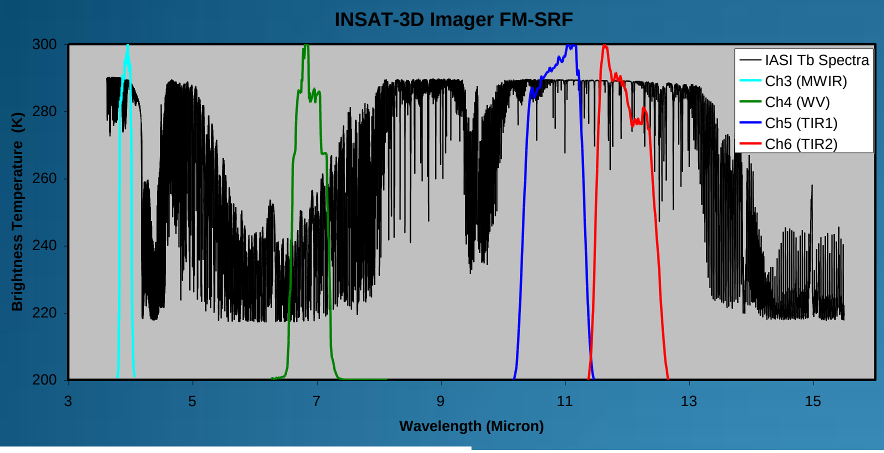
RMSD (with ship)~0.6K

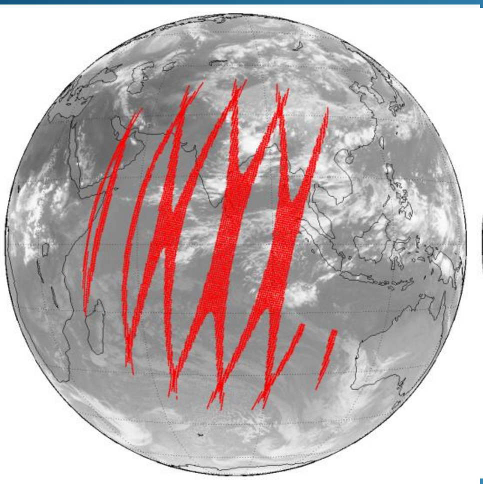
Post- Launch

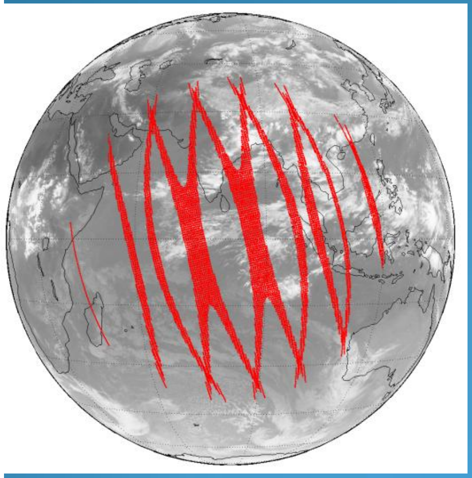
1. Bias Correction GSICS
2. Validation with buoy, satellite SST

Global Space-based Inter-Calibration System (GSICS)

Monitored instrument: INSAT-3D Imager / Reference instrument: IASI







Data Source: IASI L1C (Eumetcast)

Temporal Collocation: < 5 Minutes

Spatial Collocation: within IASI pixel (12 km)

Zenith angle collocation: $\left|\frac{\cos(geo\_zen)}{\cos(leo\_zen)} - 1\right| < \max\_zen$

maxzen = 0.1-0.4 depending upon the absorption

Spatial homogeneity test:

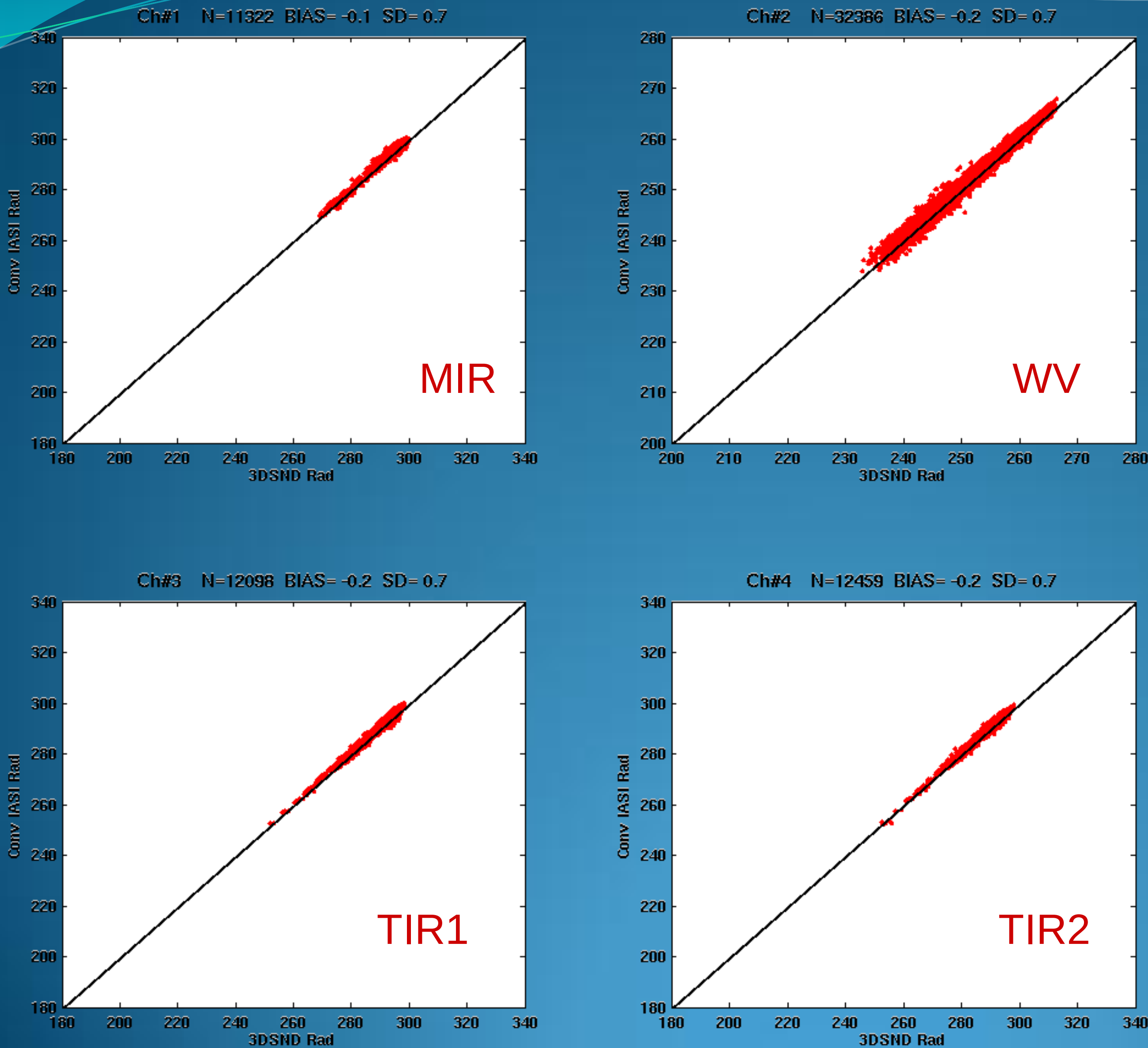
Std. Dev. of INSAT-3D (7x7 pixel) and IASI (5x5) radiances within environment surrounding the target pixel

- Convolved radiance of broadband sensor using 'n' number of hyperspectral sounders channels may be computed using:

$$R_{conv} = [\sum_{i=1}^{n} R_{IASI}^{i} S_{INSAT}^{i} \Delta v] / [\sum_{i=1}^{n} S_{INSAT}^{i} \Delta v]$$

- R_{conv} is convolved broadband radiance, R_{IASI} is radiance of hyper-spectral sounder, superscript 'i' is hyper-spectral channel index, S_{INSAT} is the sensor response function of INSAT-3D channels at the central wavenumber of hyper-spectral channel 'i', and 'n' is the total number of hyper-spectral channels in broadband sensor's SRF range.

INSAT-3D Imager intercalibration with IASI

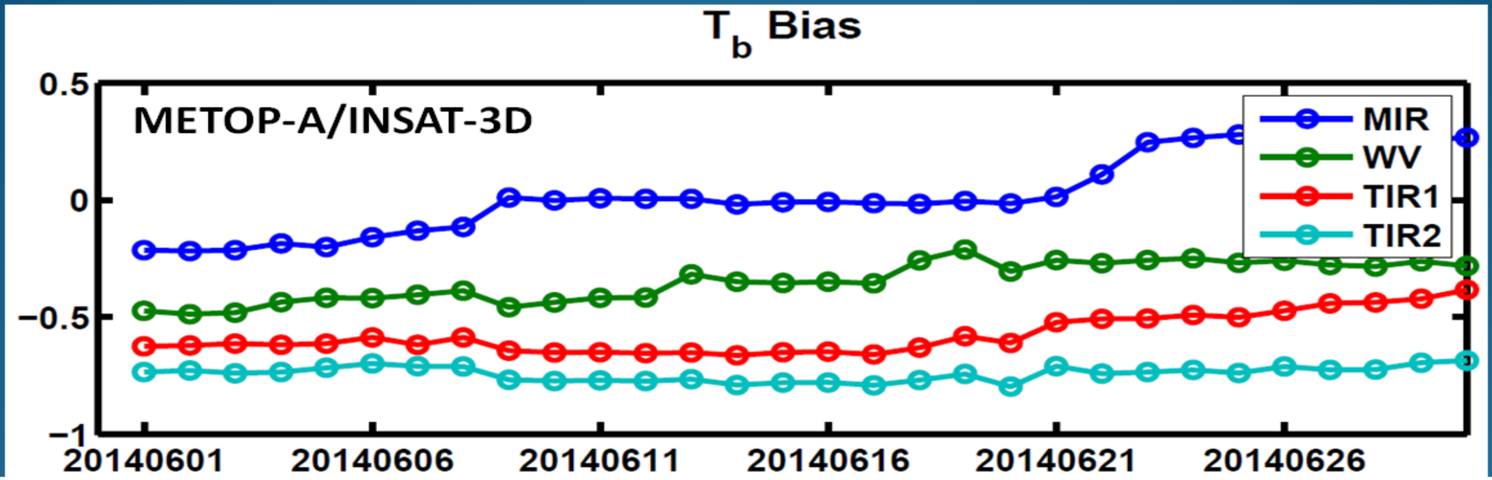


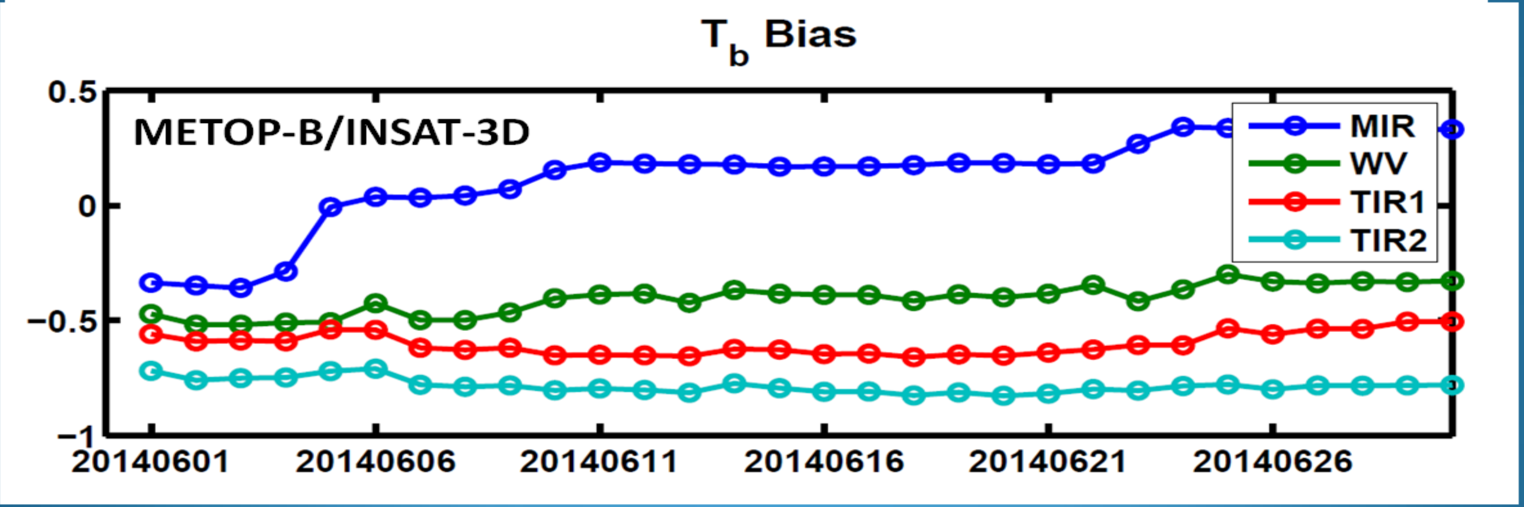
Night (13-15Z), Temporal Collocation : 5 Min, Spatial homogeneity: ENV_TB_SD = 1K

Oct-Nov 2013

Ch#	BIAS (K)	SD (K)
MIR	-0.1	0.7
WV	-0.2	0.7
TIR1	-0.2	0.7
TIR2	-0.2	0.7

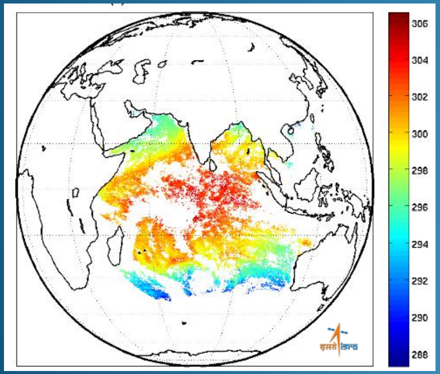
INSAT-3D Imager inter-calibration with IASI (Metop-A/B)



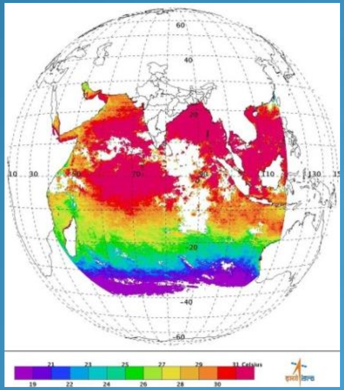


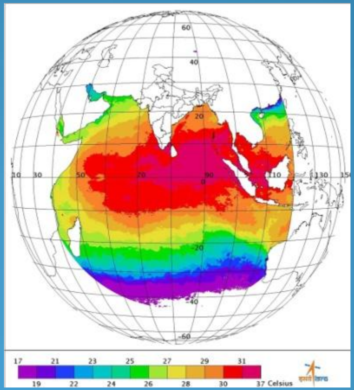
Sea Surface Temperature from INSAT-3D

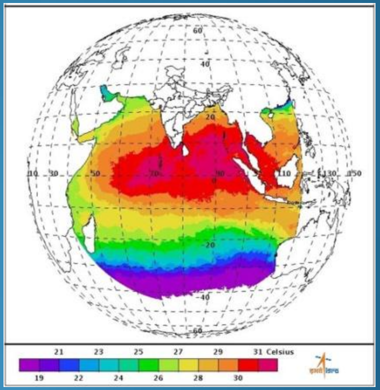
- SST has been operationally derived using INSAT-3D thermal split window channels i.e. TIR-1(11 µm) and TIR-2(12 µm) for every half an hourly acquisition since 1st Oct 2013 on pixel resolution i.e. 4 kms
- Half hourly, daily, weekly and monthly SST products are available to PIs from IMD and MOSDAC



Half hourly

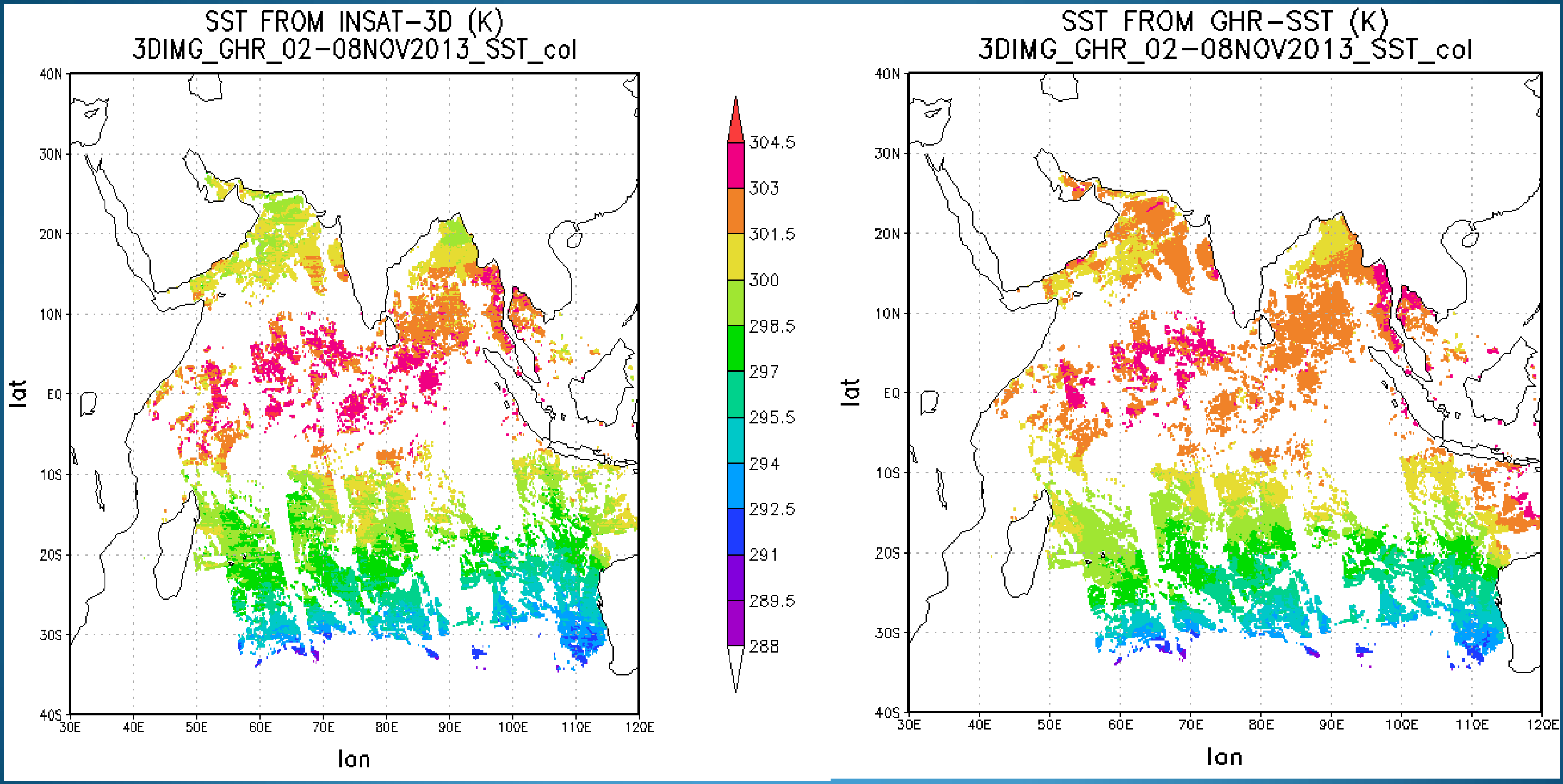

Daily

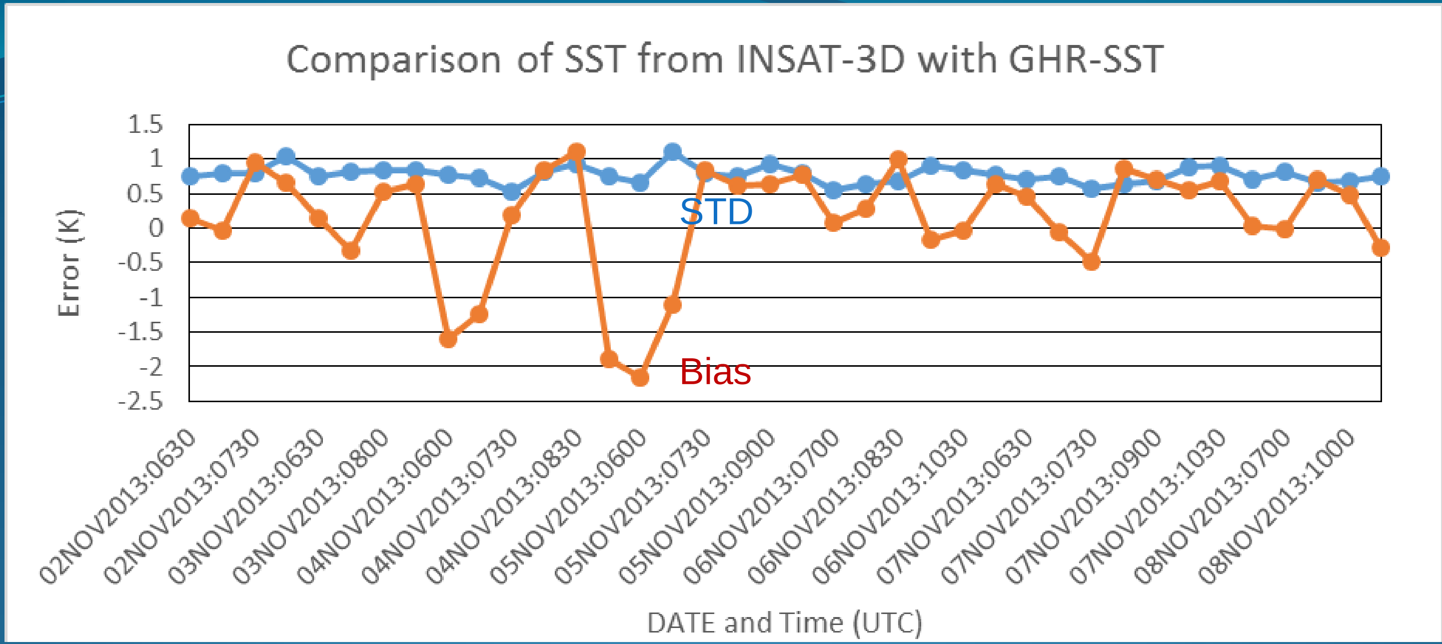

Weekly


Monthly

SST Validation

With NPP-GHRSST





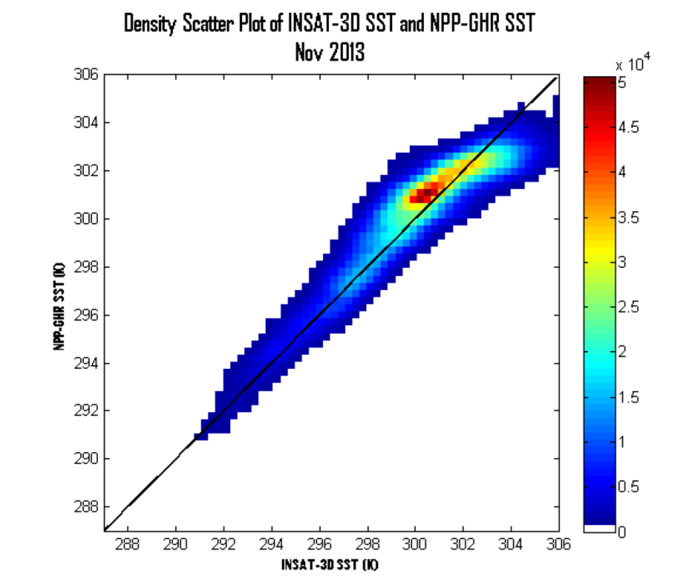
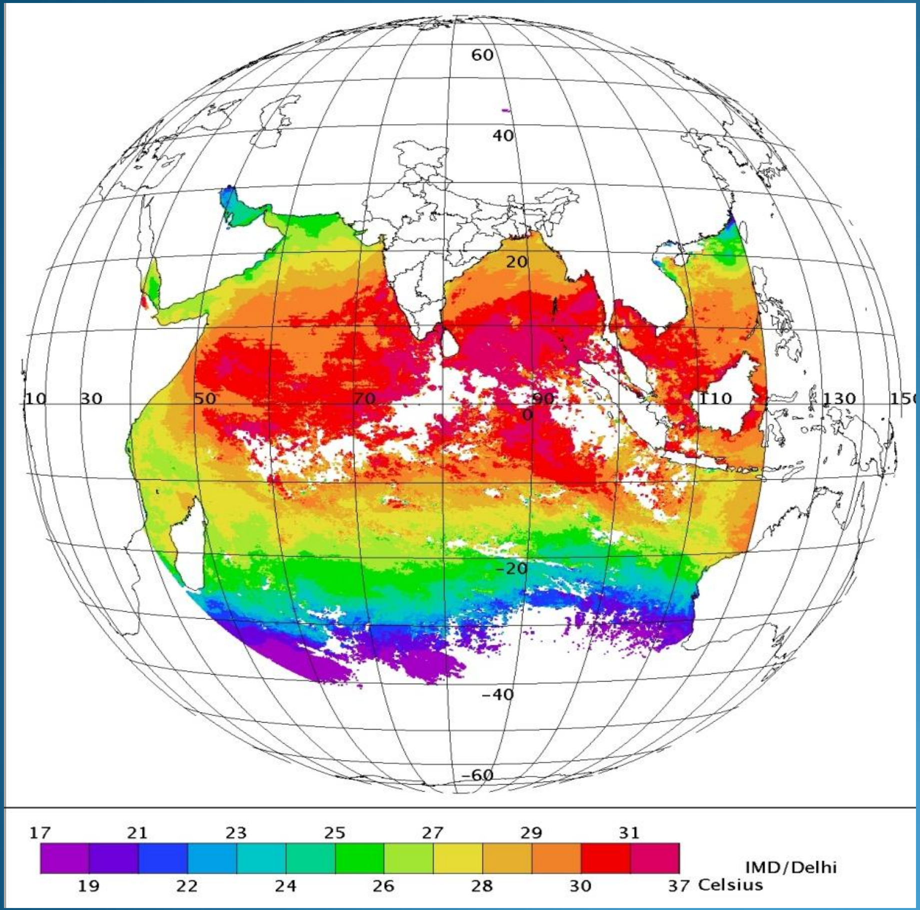


Fig 13: Density scatter plot of INSAT-3D SST and GHRSST

With ARGO-Drifter Buoys



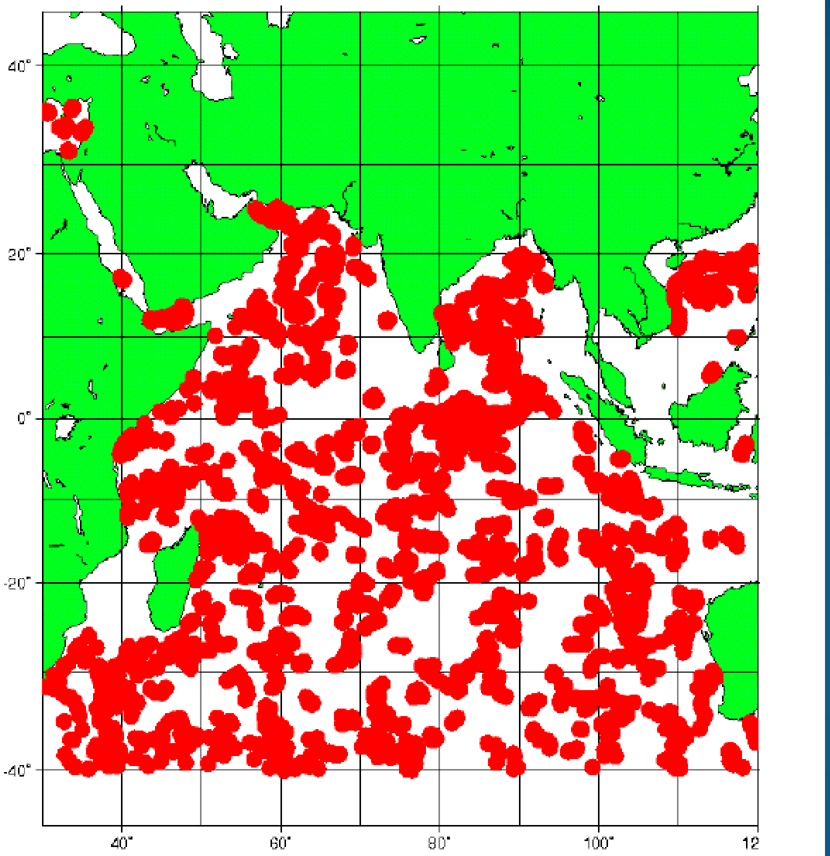
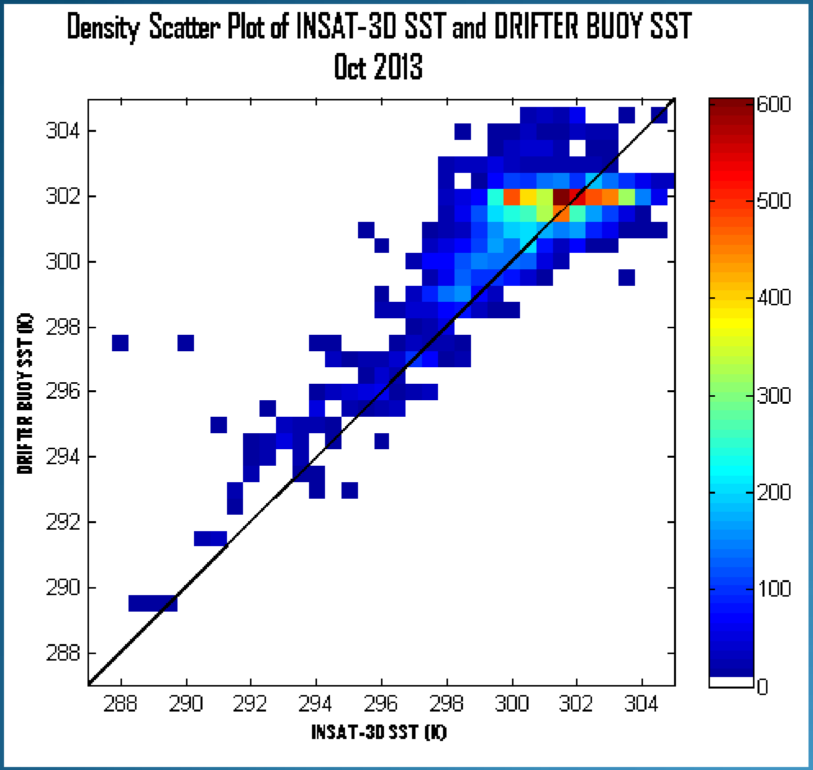
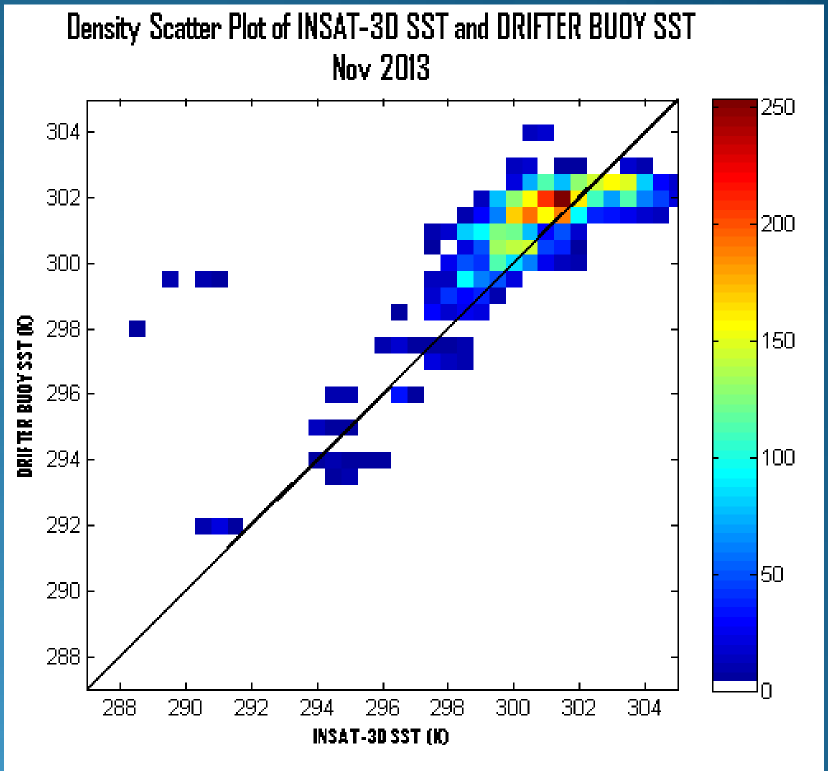


Fig 2: Coverage of ARGO drifter buoys for Oct-Nov 2013

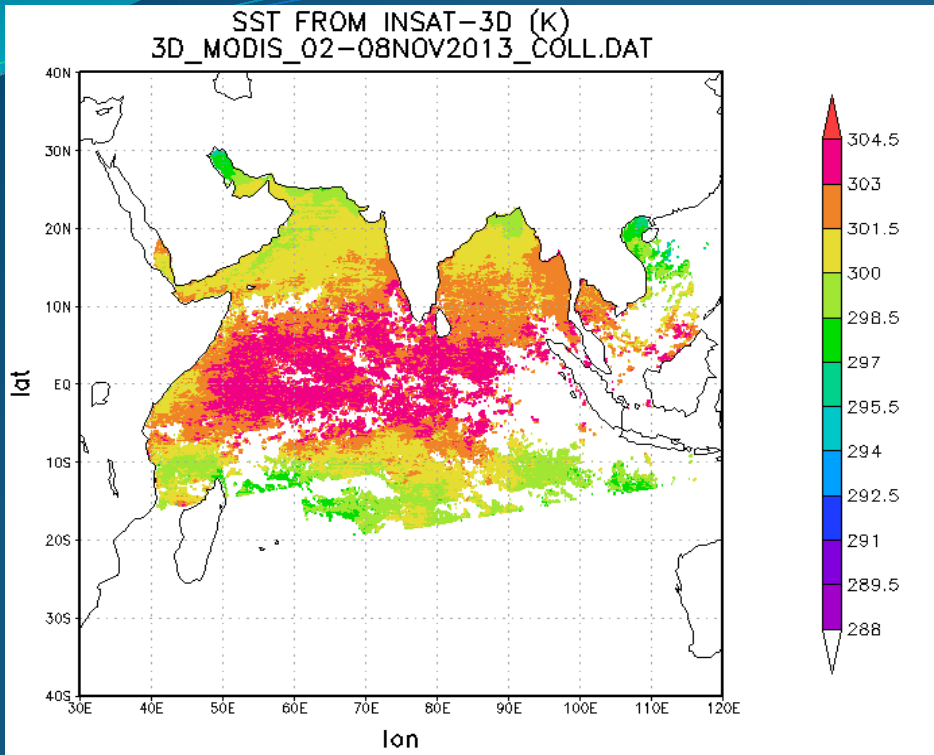
Comparison of INSAT-3D SST with Drifter Buoy SST for Oct-Nov 2013
Δt=30 min and Δx=0.1 deg

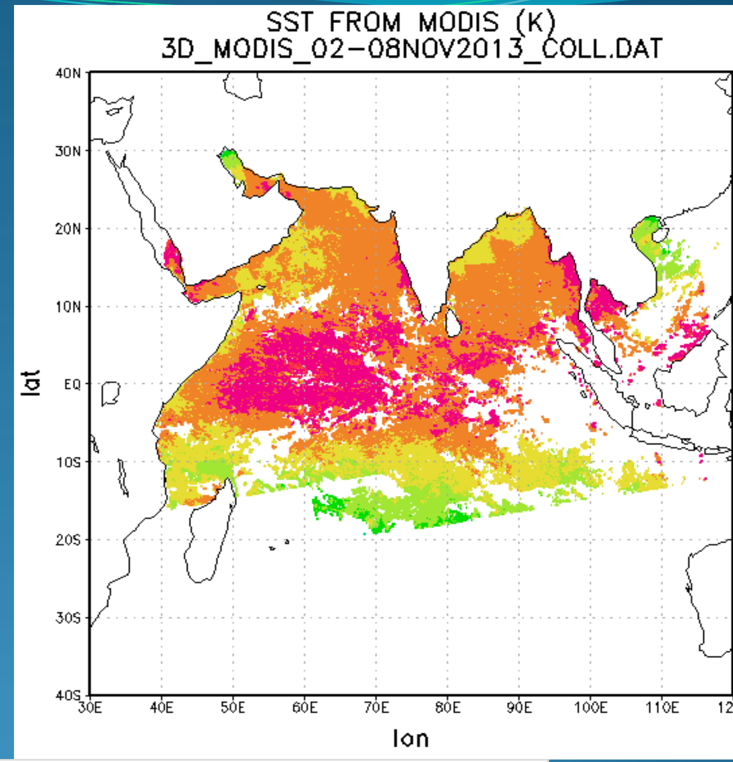


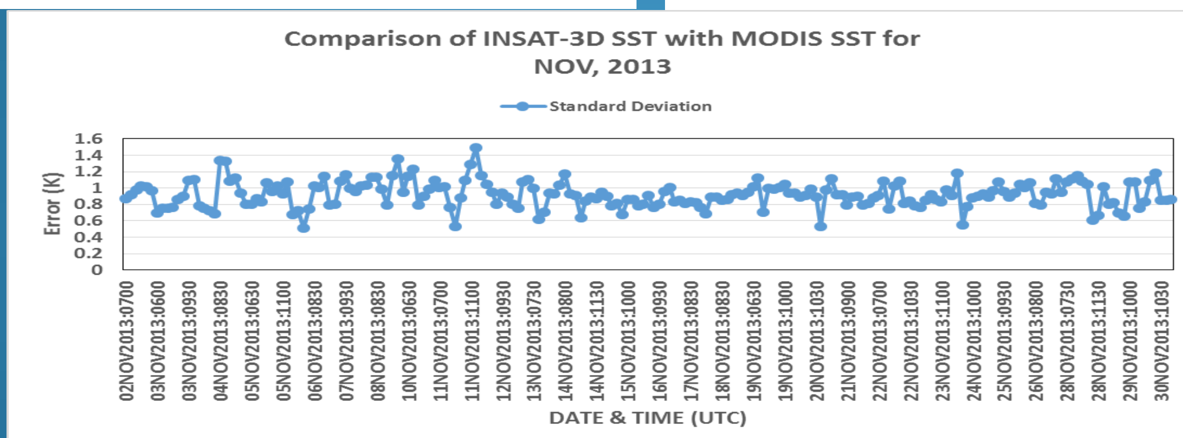


Data used	BIAS (K)	Std (K)	Number of collocated points
Oct 2013	-0.68	1.57	15463
Nov 2013	-0.47	1.33	5970

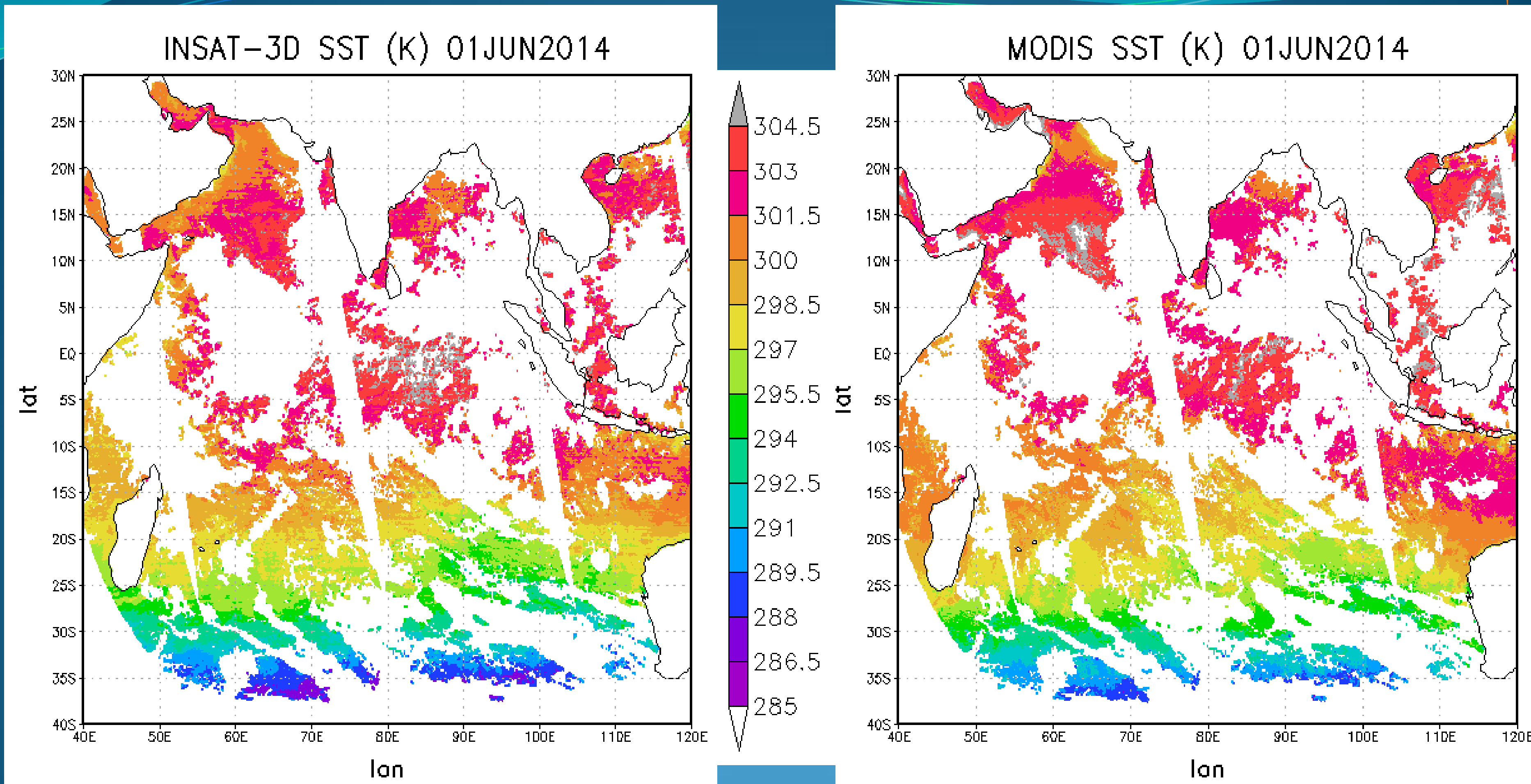
With MODIS SWATH data (November 2013)





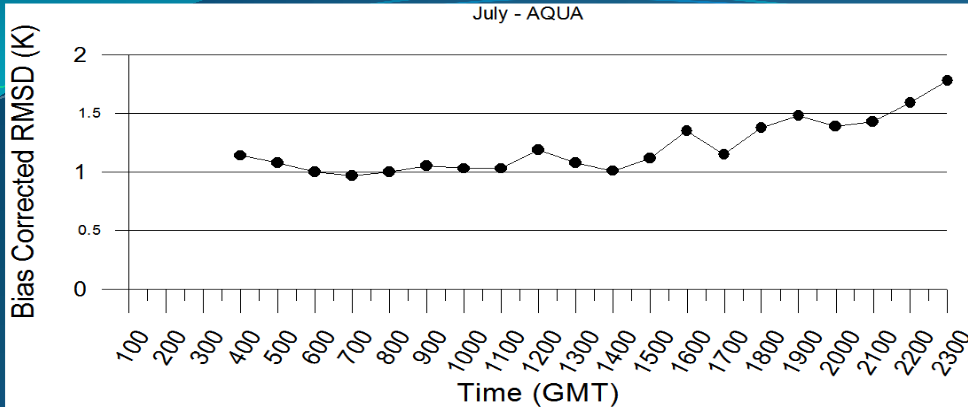


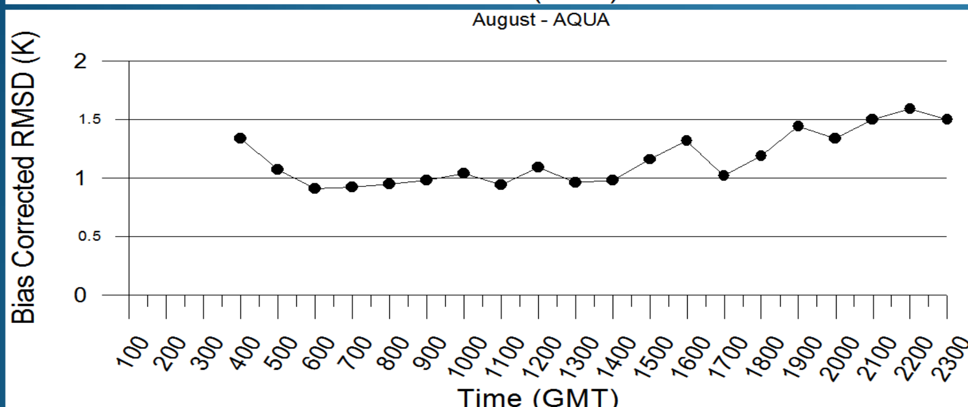
Validation of INSAT-3D SST with MODIS SST (June –Dec 2014)

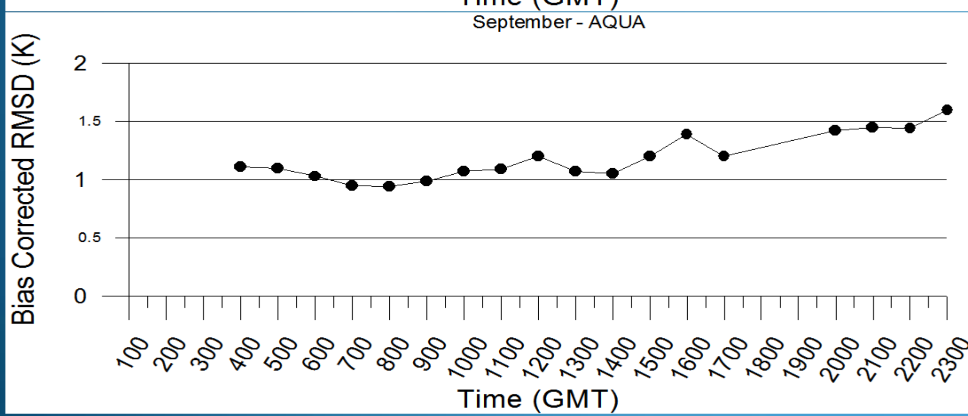


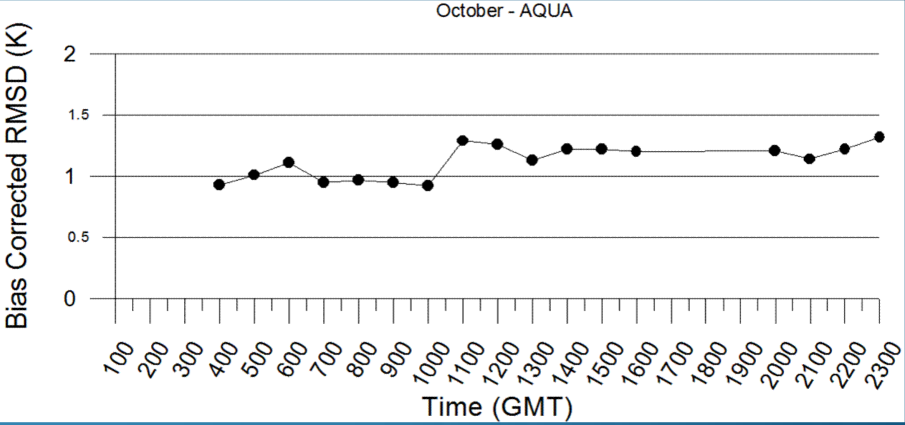
June, 2014	Number of points	BIAS (K)	STD (K)
± 30 minutes, 4 km	19272399	-0.57	0.87

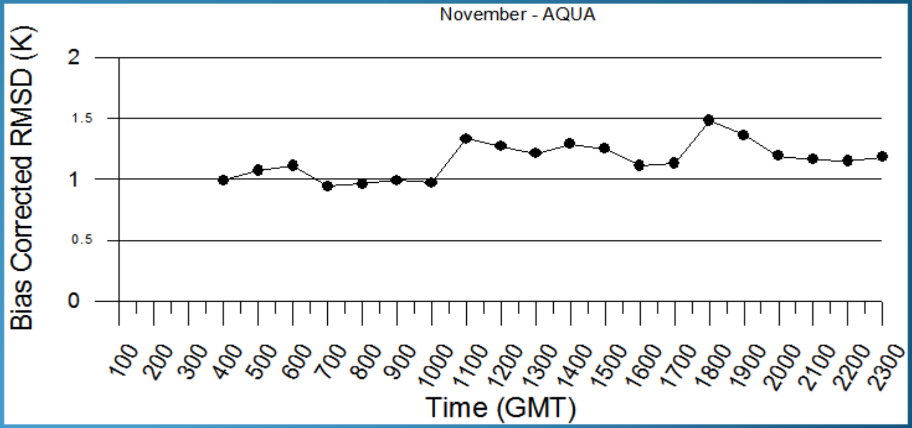
Standard Deviation (STD) (INSAT-MODIS) SST



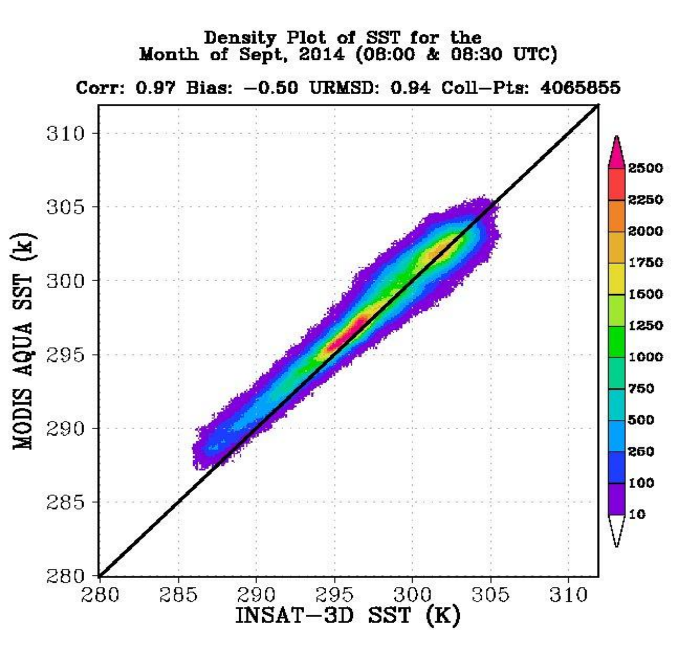


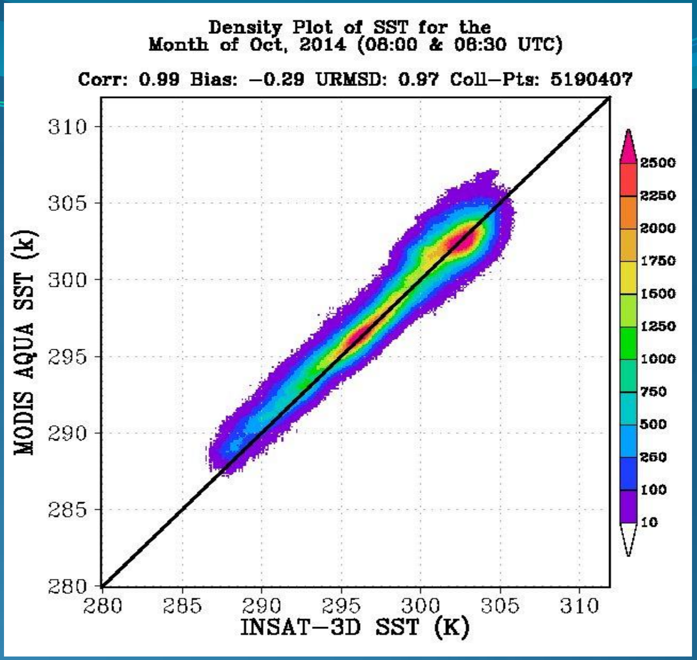


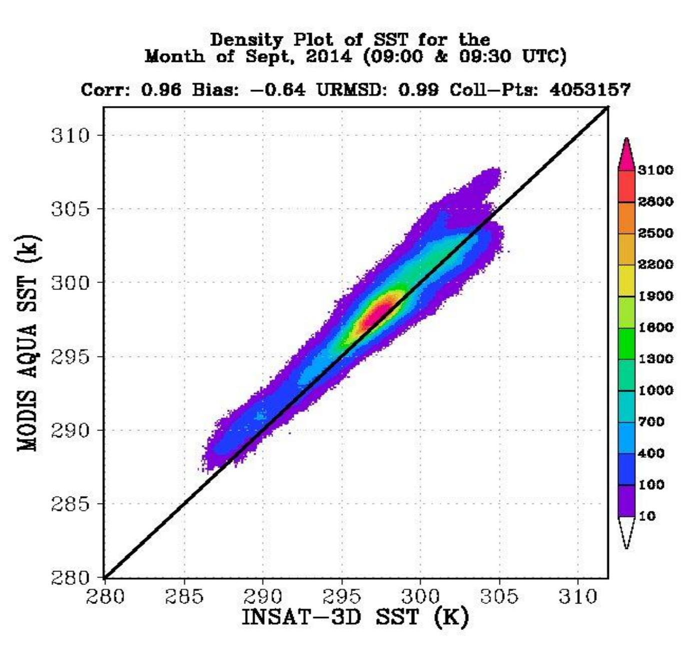


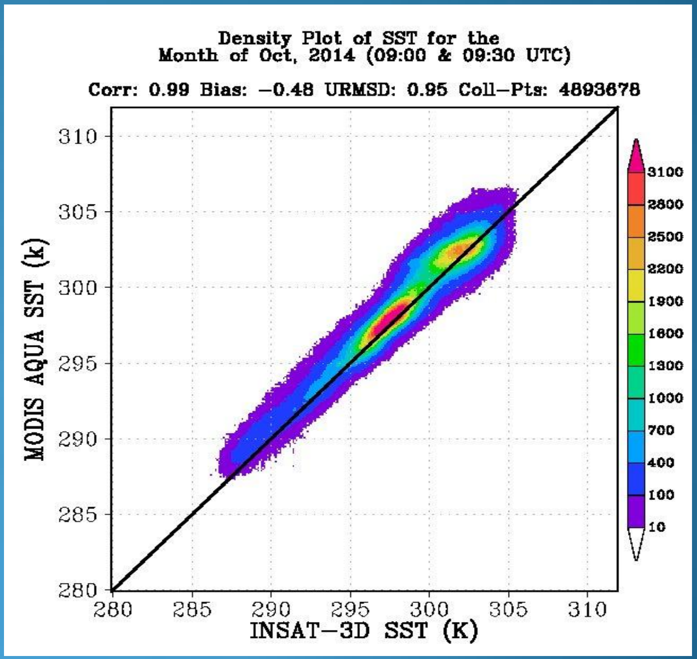


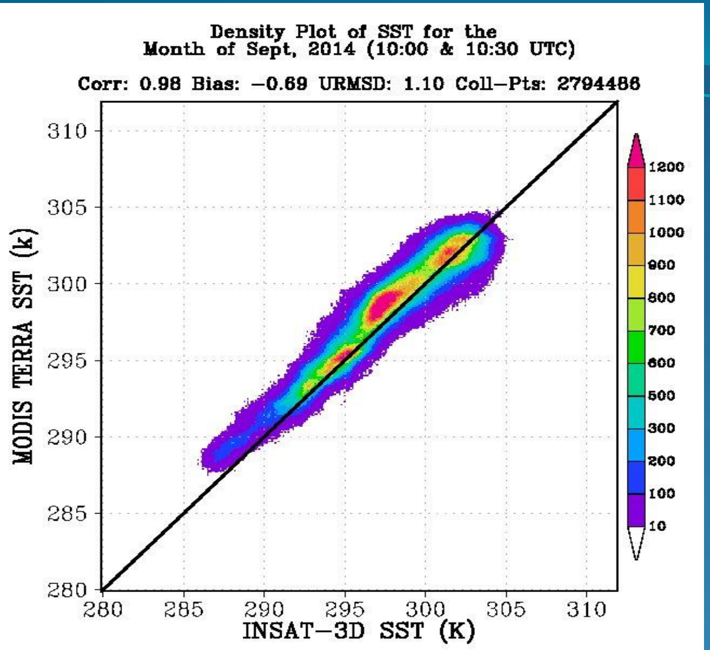
Similar trends in STD were observed with TERRA also

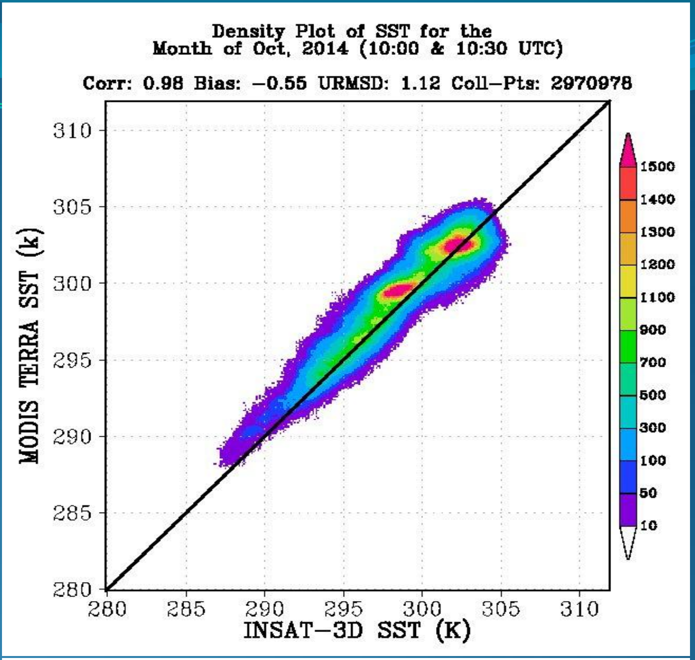

Density Plot of SST for the
Month of Sept, 2014 (08:00 & 08:30 UTC)
Corr: 0.97 Bias: −0.50 URMSD: 0.94 Coll−Pts: 4065855
MODIS AQUA SST (k)
INSAT−3D SST (K)
280 285 290 295 300 305 310
2500 2250 2000 1750 1500 1250 1000 750 500 250 100 10

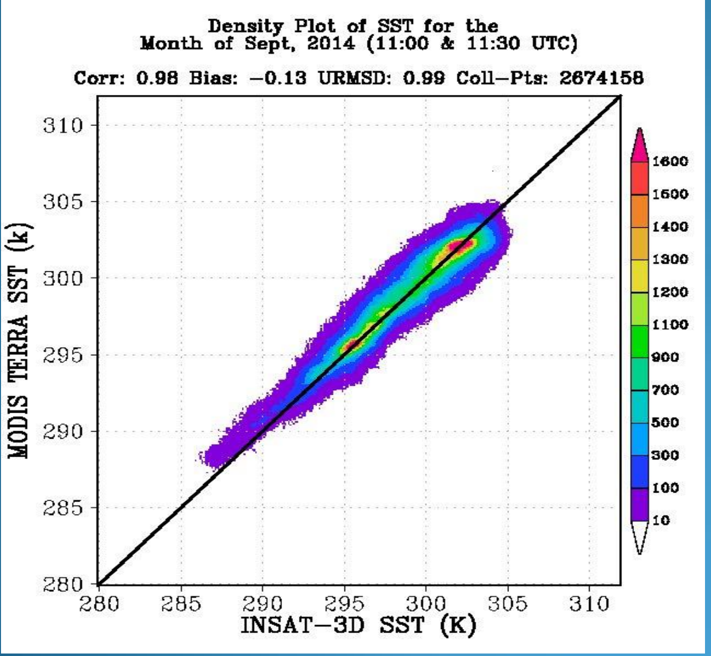

Density Plot of SST for the
Month of Oct, 2014 (08:00 & 08:30 UTC)
Corr: 0.99 Bias: −0.29 URMSD: 0.97 Coll−Pts: 5190407
MODIS AQUA SST (k)
INSAT−3D SST (K)
280 285 290 295 300 305 310
2500 2250 2000 1750 1500 1250 1000 750 500 250 100 10

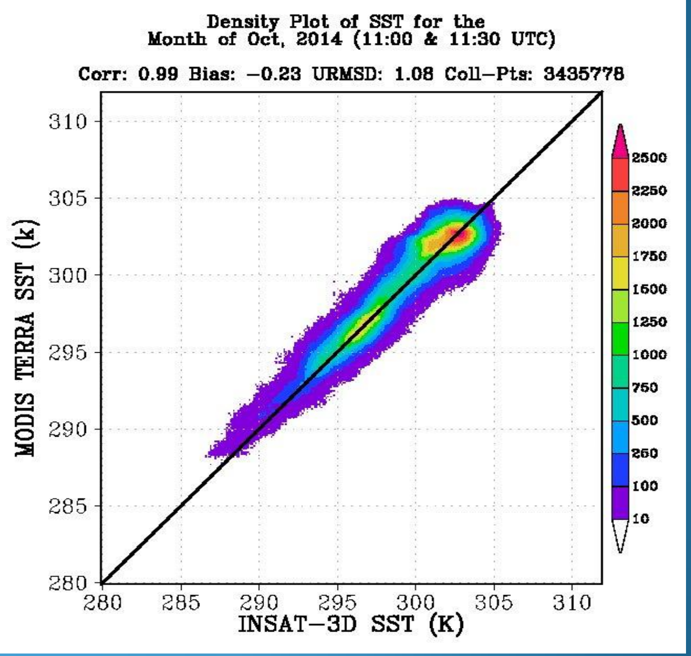

Density Plot of SST for the
Month of Sept, 2014 (09:00 & 09:30 UTC)
Corr: 0.96 Bias: −0.64 URMSD: 0.99 Coll−Pts: 4053157
MODIS AQUA SST (k)
INSAT−3D SST (K)
280 285 290 295 300 305 310
3100 2800 2500 2200 1900 1600 1300 1000 700 400 100 10

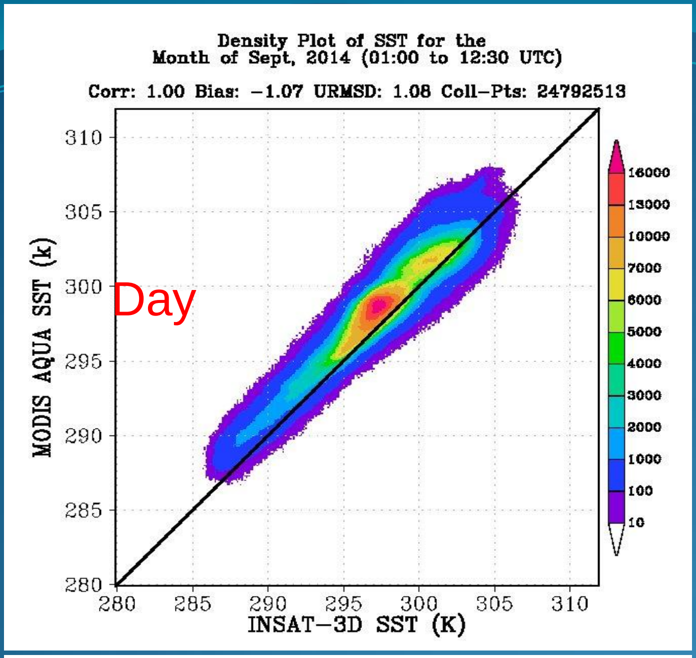

Density Plot of SST for the
Month of Oct, 2014 (09:00 & 09:30 UTC)
Corr: 0.99 Bias: −0.48 URMSD: 0.95 Coll−Pts: 4893678
MODIS AQUA SST (k)
INSAT−3D SST (K)
280 285 290 295 300 305 310
3100 2800 2500 2200 1900 1600 1300 1000 700 400 100 10

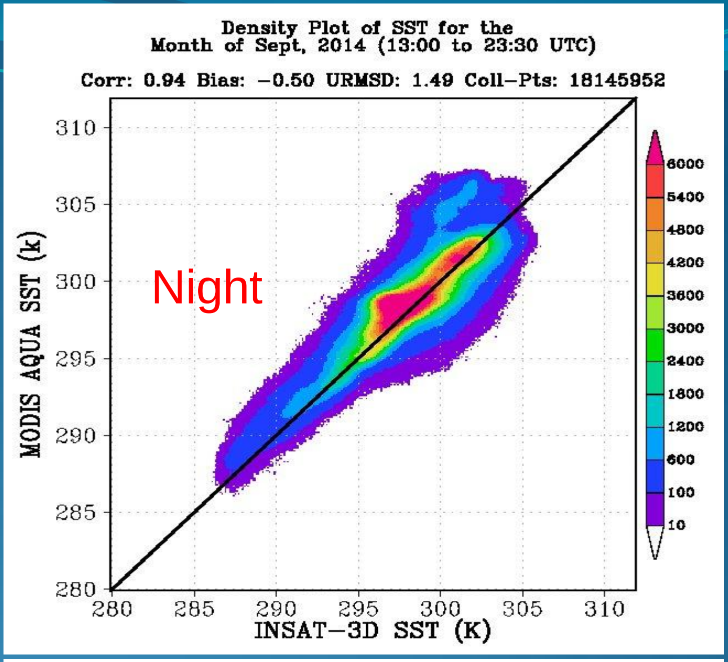

Density Plot of SST for the
Month of Sept, 2014 (10:00 & 10:30 UTC)
Corr: 0.98 Bias: −0.69 URMSD: 1.10 Coll−Pts: 2794486
MODIS TERRA SST (k)
INSAT−3D SST (K)
280 285 290 295 300 305 310
1200 1100 1000 900 800 700 600 500 300 200 100 10

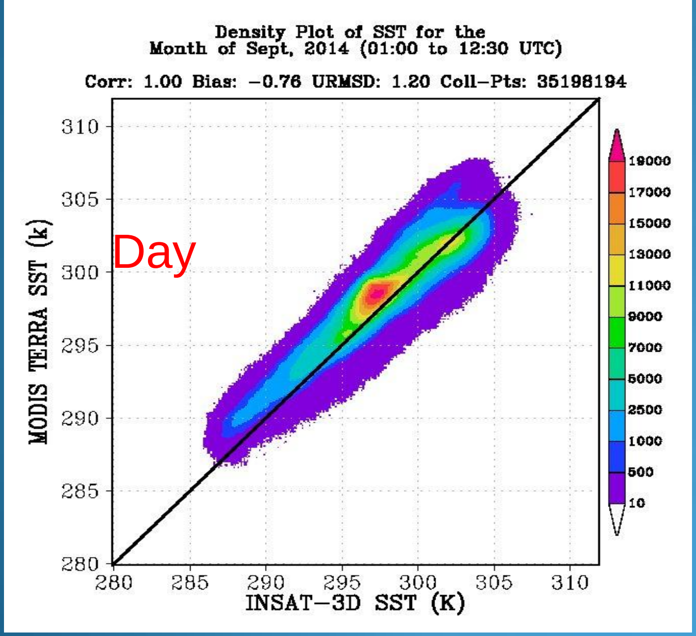

Density Plot of SST for the
Month of Oct, 2014 (10:00 & 10:30 UTC)
Corr: 0.98 Bias: −0.55 URMSD: 1.12 Coll−Pts: 2970978
MODIS TERRA SST (k)
INSAT−3D SST (K)
280 285 290 295 300 305 310
1500 1400 1300 1200 1100 900 700 500 300 100 50 10

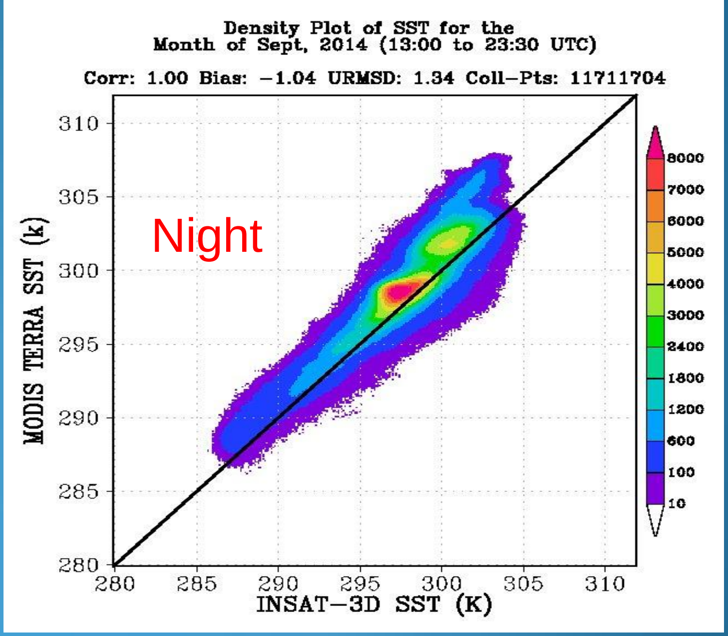

Density Plot of SST for the
Month of Sept, 2014 (11:00 & 11:30 UTC)
Corr: 0.98 Bias: −0.13 URMSD: 0.99 Coll−Pts: 2674158
MODIS TERRA SST (k)
INSAT−3D SST (K)
280 285 290 295 300 305 310
1600 1500 1400 1300 1200 1100 900 700 500 300 100 10


Density Plot of SST for the
Month of Oct, 2014 (11:00 & 11:30 UTC)
Corr: 0.99 Bias: −0.23 URMSD: 1.08 Coll−Pts: 3435778
MODIS TERRA SST (k)
INSAT−3D SST (K)
280 285 290 295 300 305 310
2500 2250 2000 1750 1500 1250 1000 750 500 250 100 10

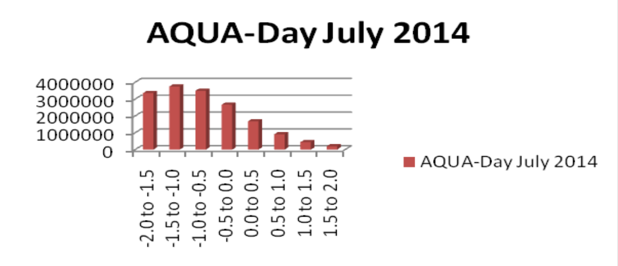

Density Plot of SST for the
Month of Sept, 2014 (01:00 to 12:30 UTC)
Corr: 1.00 Bias: −1.07 URMSD: 1.08 Coll−Pts: 24792513
Day
MODIS AQUA SST (k)
INSAT−3D SST (K)
310
305
300
295
290
285
280
16000
13000
10000
7000
6000
5000
4000
3000
2000
1000
100
10

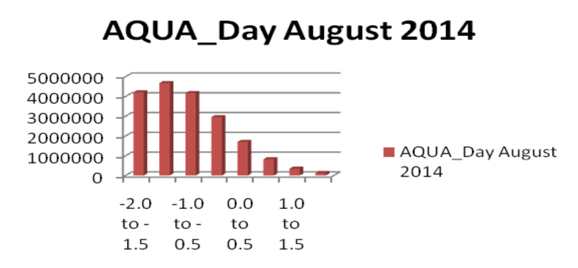

Density Plot of SST for the
Month of Sept, 2014 (13:00 to 23:30 UTC)
Corr: 0.94 Bias: −0.50 URMSD: 1.49 Coll−Pts: 18145952
Night
MODIS AQUA SST (k)
INSAT−3D SST (K)
310
305
300
295
290
285
280
6000
5400
4800
4200
3600
3000
2400
1800
1200
600
100
10

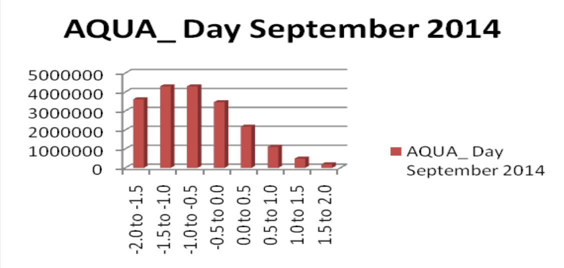

Density Plot of SST for the
Month of Sept, 2014 (01:00 to 12:30 UTC)
Corr: 1.00 Bias: −0.76 URMSD: 1.20 Coll−Pts: 35198194
Day
MODIS TERRA SST (k)
INSAT−3D SST (K)
310
305
300
295
290
285
280
19000
17000
15000
13000
11000
9000
7000
5000
2500
1000
500
10

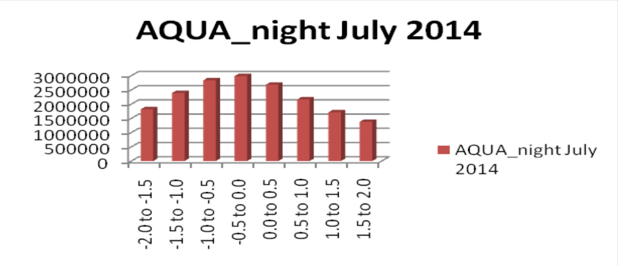

Density Plot of SST for the
Month of Sept, 2014 (13:00 to 23:30 UTC)
Corr: 1.00 Bias: −1.04 URMSD: 1.34 Coll−Pts: 11711704
Night
MODIS TERRA SST (k)
INSAT−3D SST (K)
310
305
300
295
290
285
280
8000
7000
6000
5000
4000
3000
2400
1800
1200
600
100
10

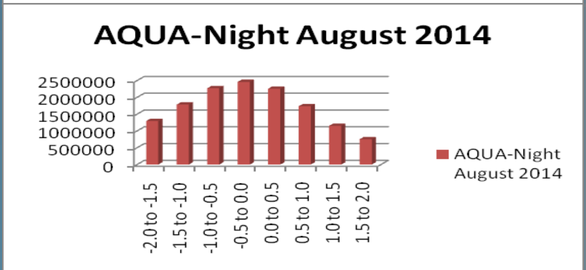
Histogram of mean difference

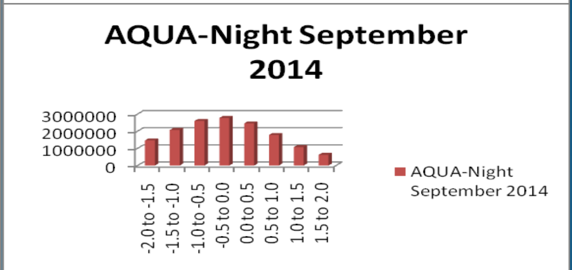


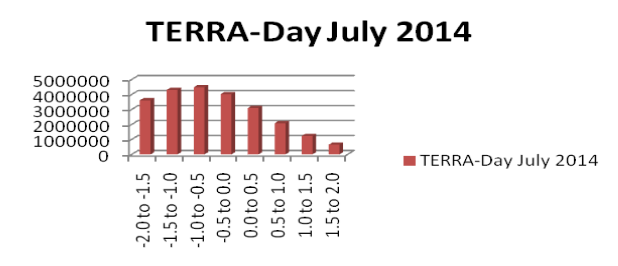


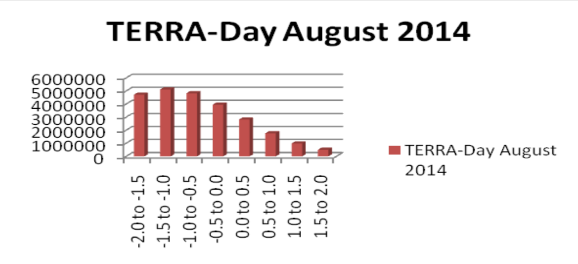


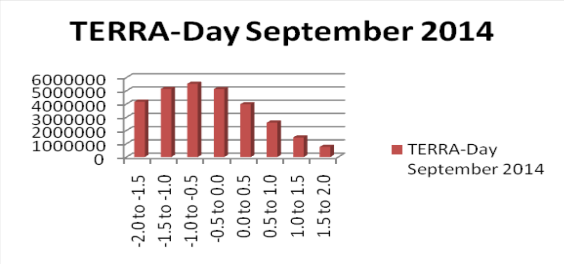


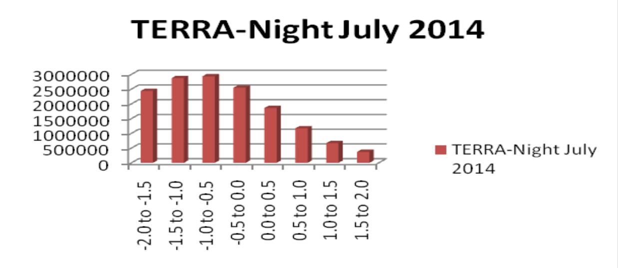


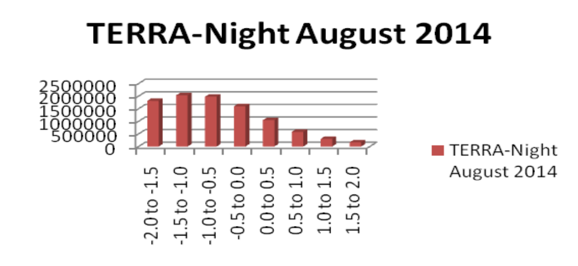


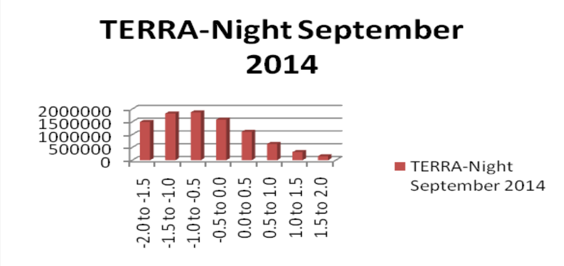






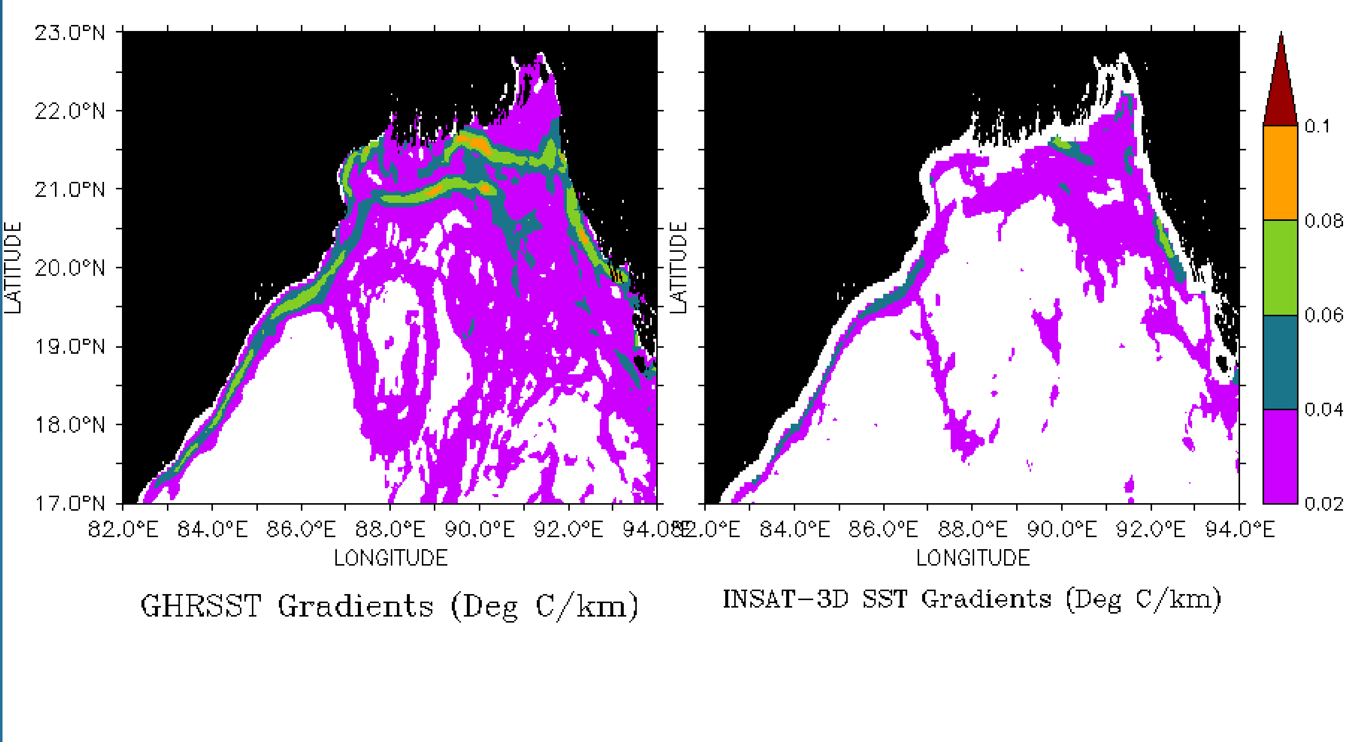




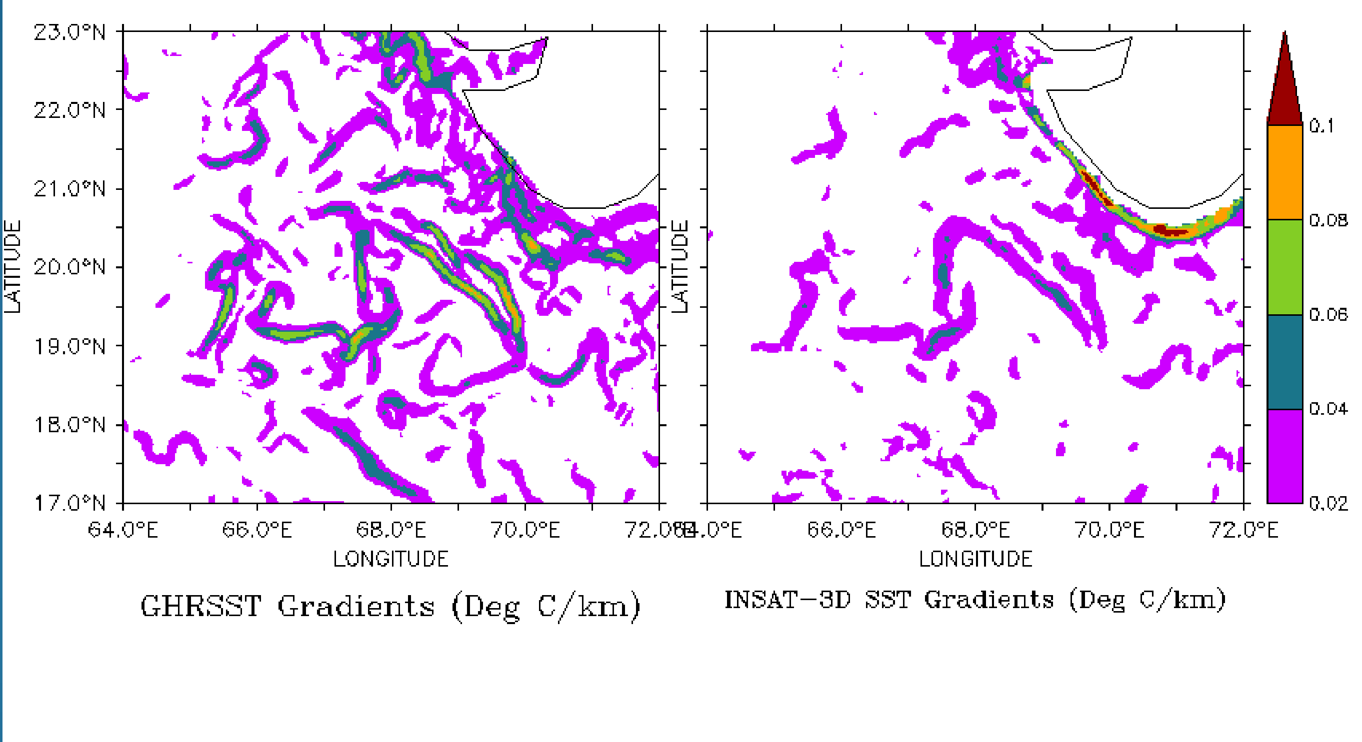


INSAT-3D SST Application

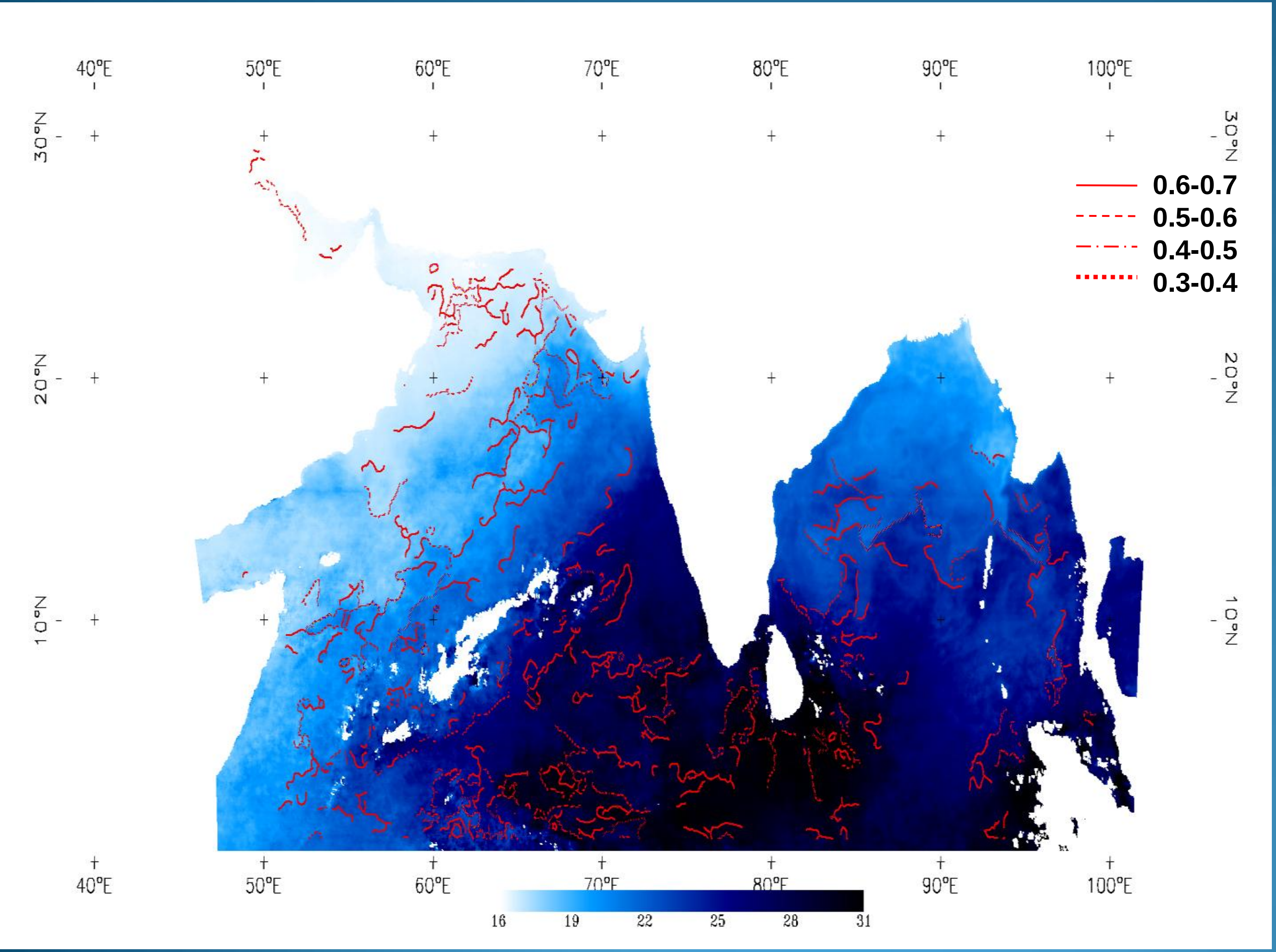
Thermal Gradients : INSAT-3D Vs GHRSST (North Bay of Bengal): 31 Dec, 2013



Thermal Gradients : INSAT-3D Vs GHRSST (Near Gujarat Region): 26 Feb, 2014



Potential Fishing Zone (PFZ) Advisories-INSAT 3D SST



- Evolution, magnitude and persistence of SST fronts qualifies as good zones for fishing for longer duration

- Monitoring the Shift in frontal locations possible from geostationary platform

Conclusions

- Initial validation of INSAT-3D SST with corresponding MODIS skin SST shows that the accuracy of INSAT-3D SST is ~1K during daytime i.e. between ~0100 and 1100 hrs GMT
- Able to capture SST gradients to find the PFZ with the help of chlorophyll content.

Degradation in accuracy(~1.5K) in nighttime can be partially attributed to

- sun intrusion impact on onboard blackbodies and payload
- lack of suitable GSICS calibration for conversion of radiance

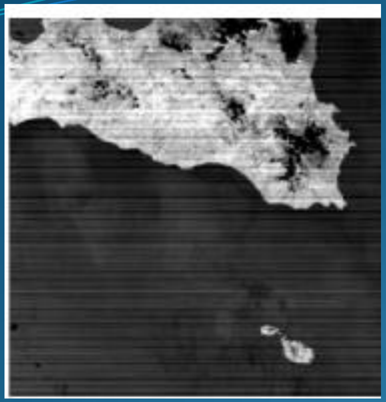
Issues (being resolved)

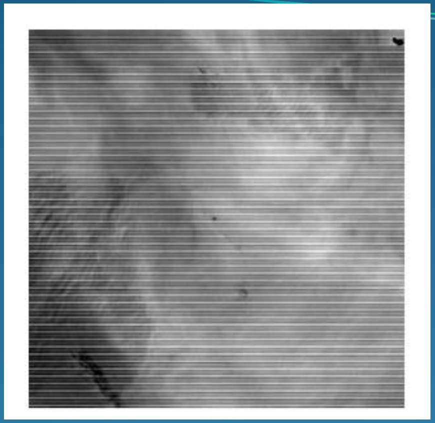
- problem of filtering out the low clouds
- performance of SST retrieval algorithm at the edges of the swath
- Geo location errors in TIR-1 and TIR-2 channels leading to errors in collocation
- difference in respective pixel resolutions of the thermal channels in MODIS and INSAT-3D
- satellite scan angle dependent collocation
- SST product in 10 Km resolution for better cloud filtering
- De-striping

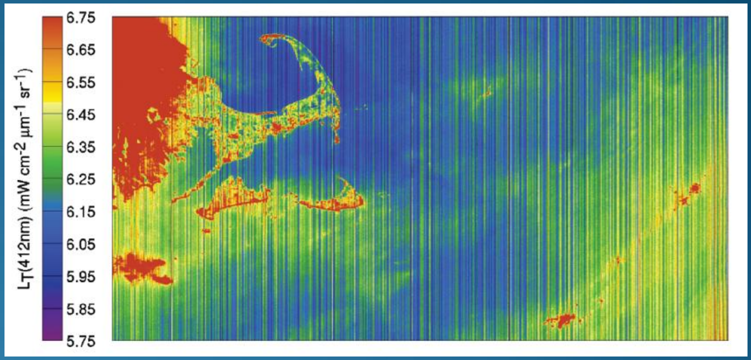
Destriping algorithm (oceans)

- Vertical/horizontal striping in satellite images occurs due to variable relative response of detectors across/along the satellite track
- Developed on relative gain correction along satellite track
- Works well over homogeneous (cloud-free)oceanic regions in small chunks(250 X 250)
- Algorithm is to be applied on each scene, so independent of detector response from one scene to other (e.g. day and night)
- Successfully applied on TIR-1/2 gray counts

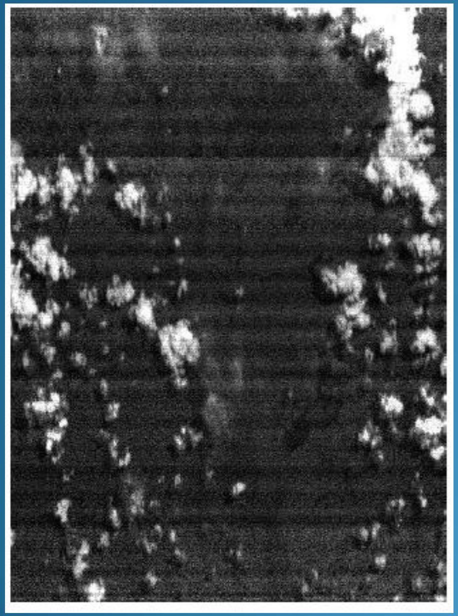
Common satellite imaging problem


MODIS TERRA Band 30

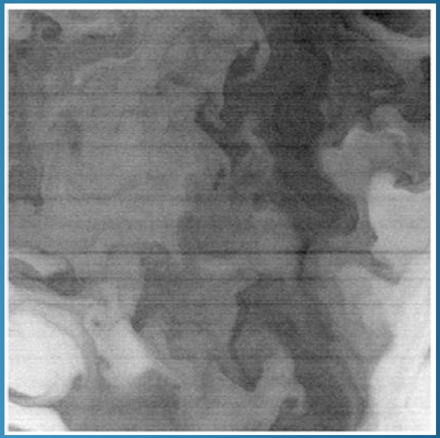

MODIS TERRA Band 27



OCM (412 nm)

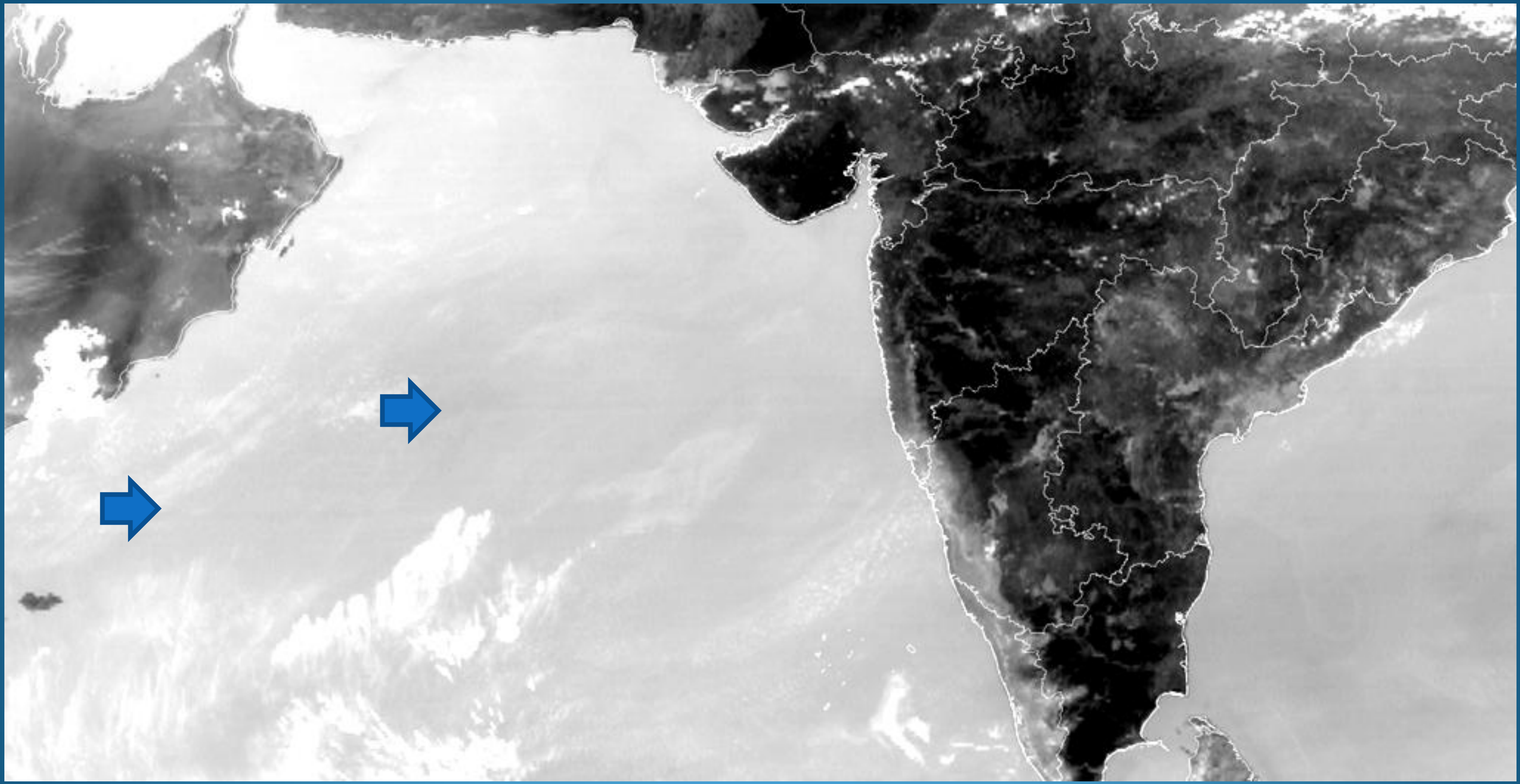

HJ-1 HSI


SPOT3

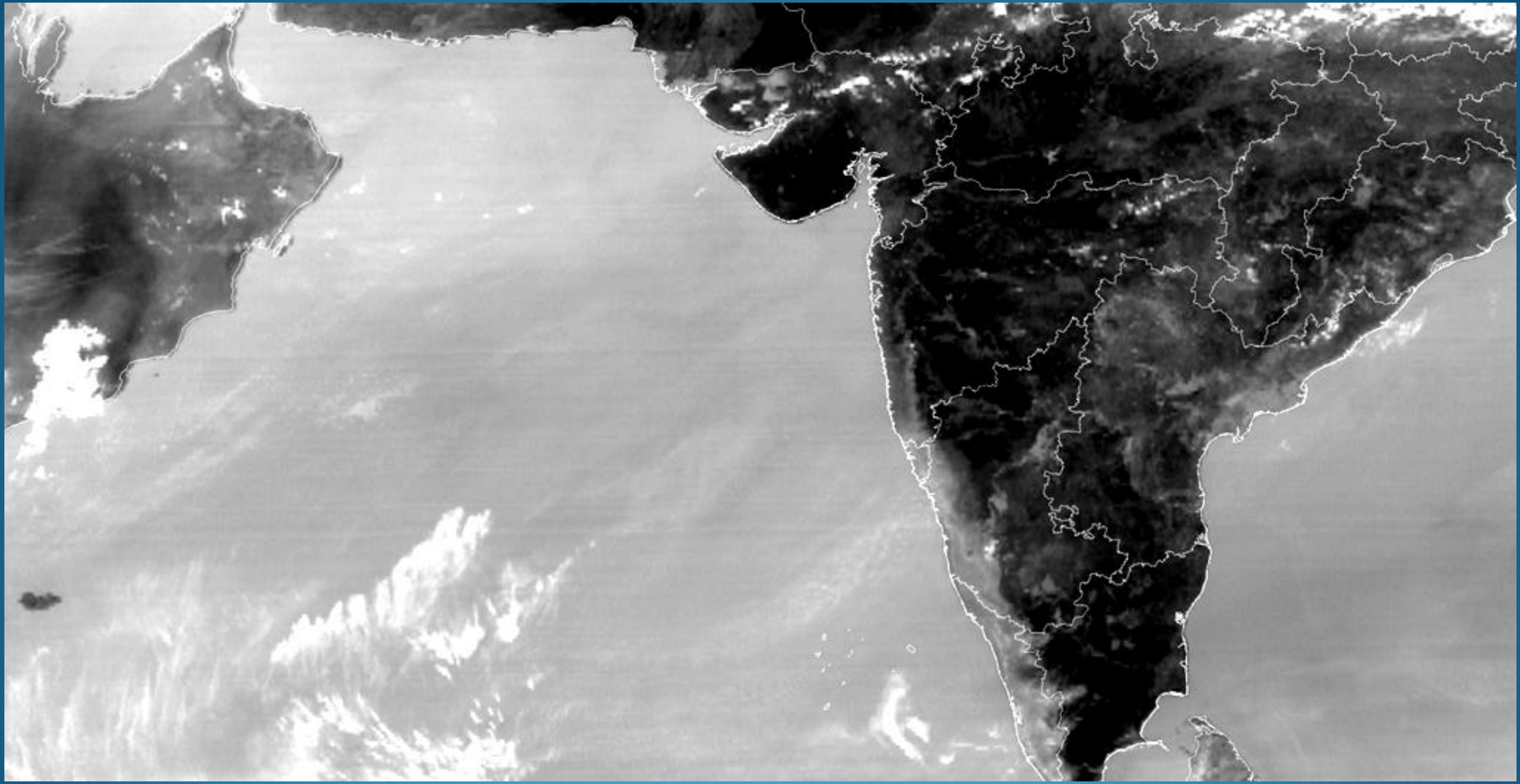

VIIRS/NPP SST image

- INSAT-3D also has similar horizontal striping in its TIR-1 and TIR-2 images.
- OCM-1 and OCM-2 have similar vertical striping issues specially for Band 1-4.

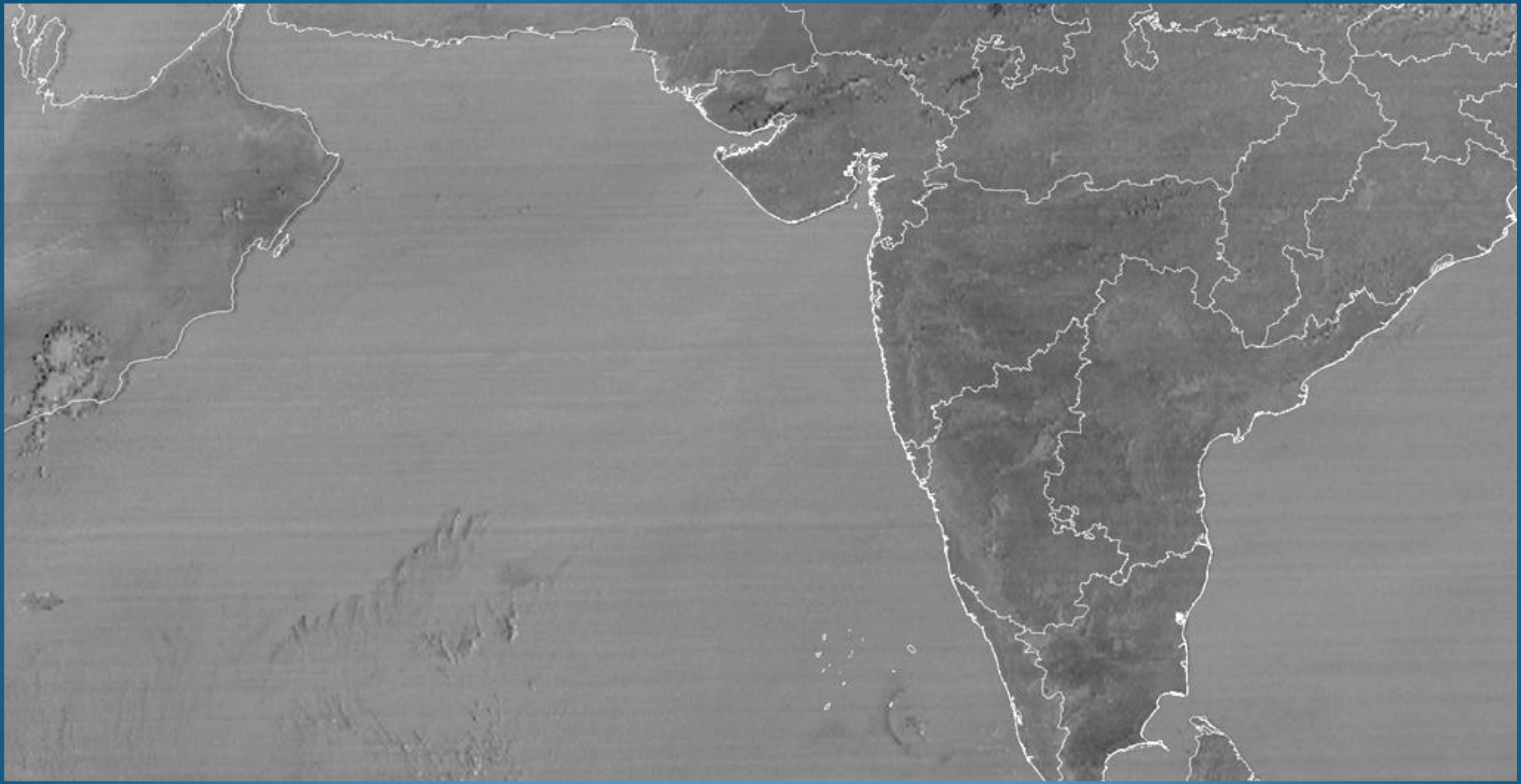
TIR-1 (10.8 um) Count



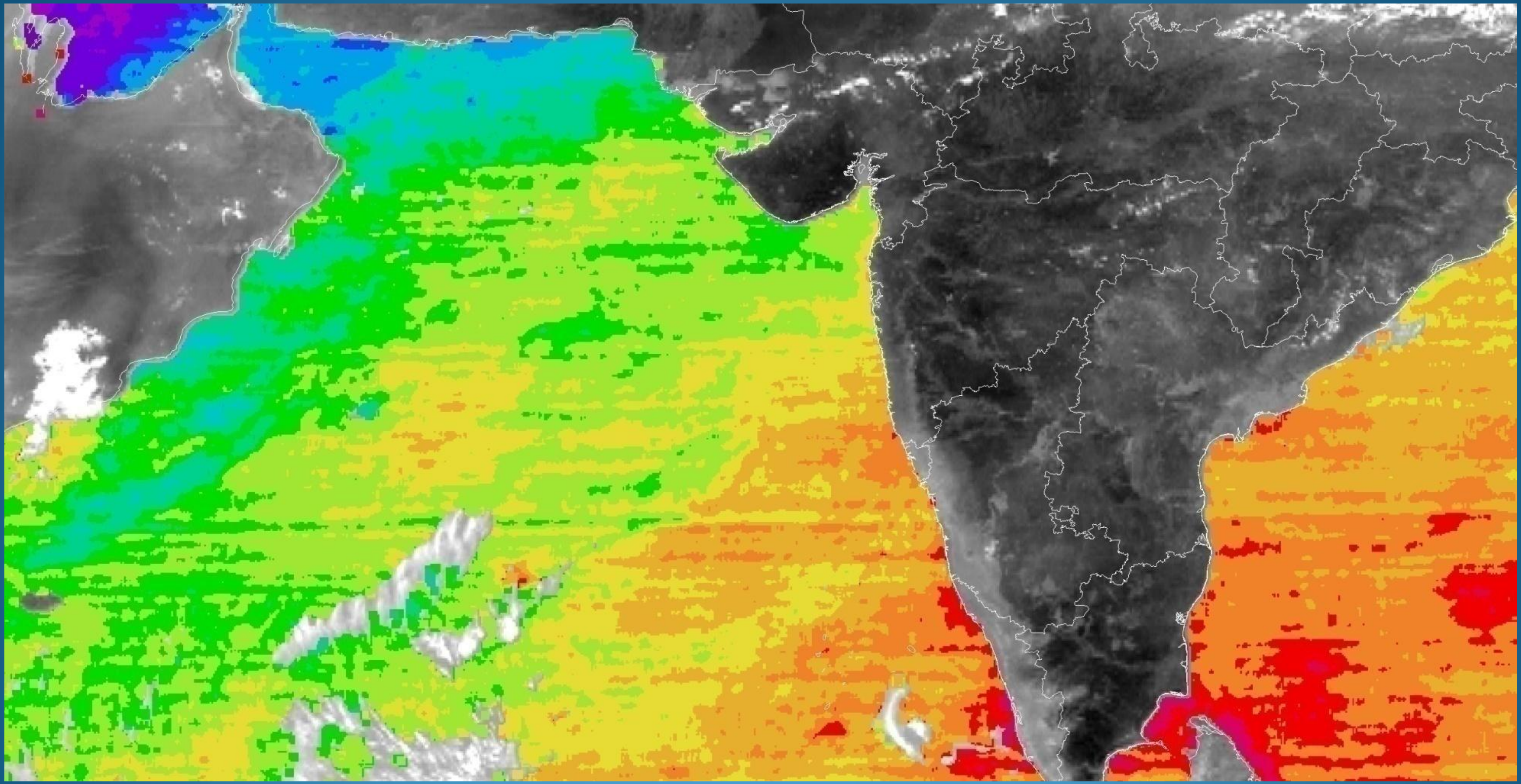
TIR-2 (12 um) Count



TIR1 Count-TIR2 Count (Difference Image)



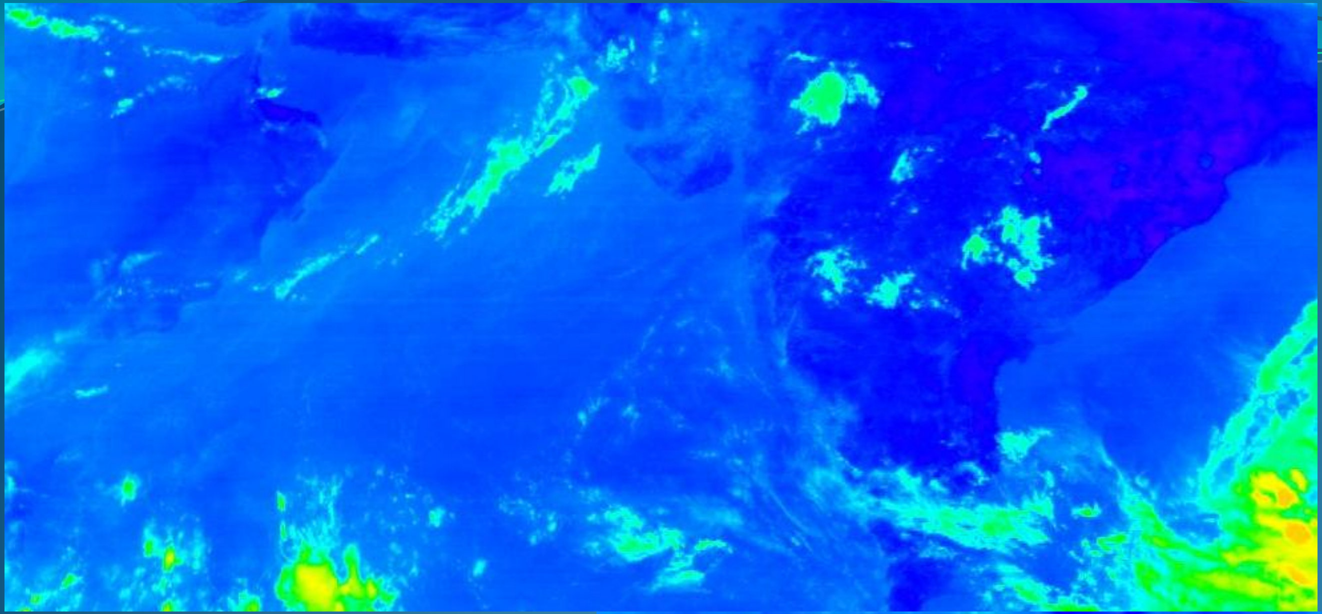
SST (Sea Surface Temperature)



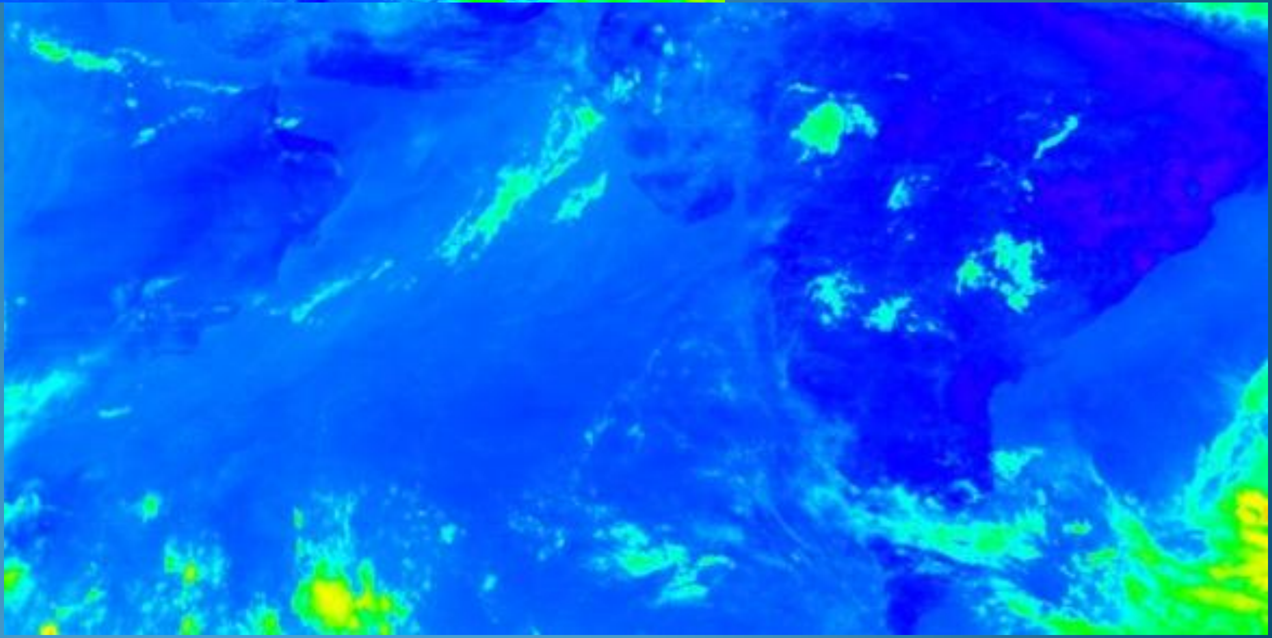
De-striping method for INSAT-3D /OCM

In the filtering method proposed, the smoothening of the data is achieved through a polynomial function which acts as a spatial frequency threshold to distinguish low frequency structure from high frequency structure and stripes through relative gain characterisation.

TIR-2 Gray count image (16 May2014-0330 GMT)

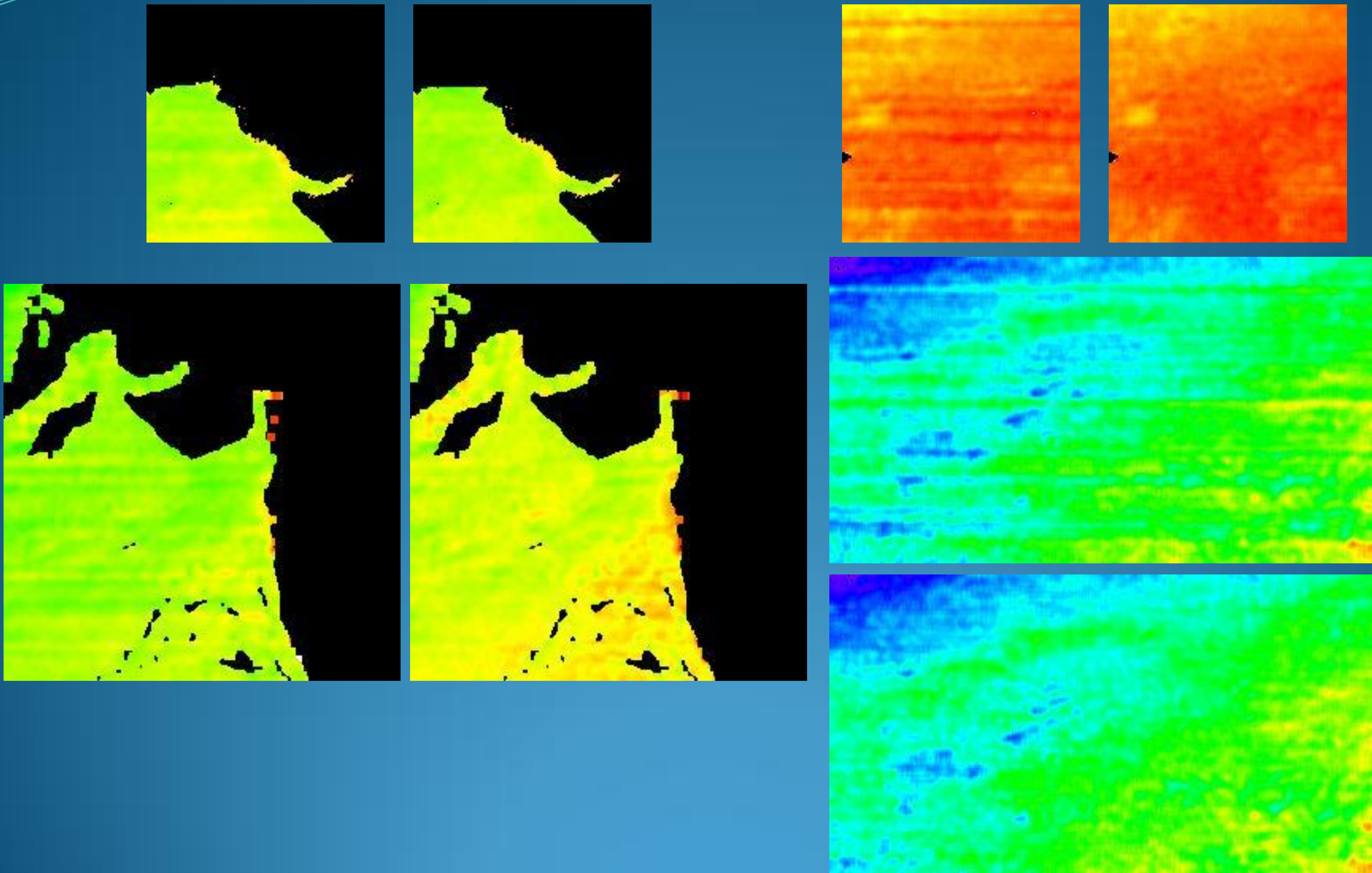


Before

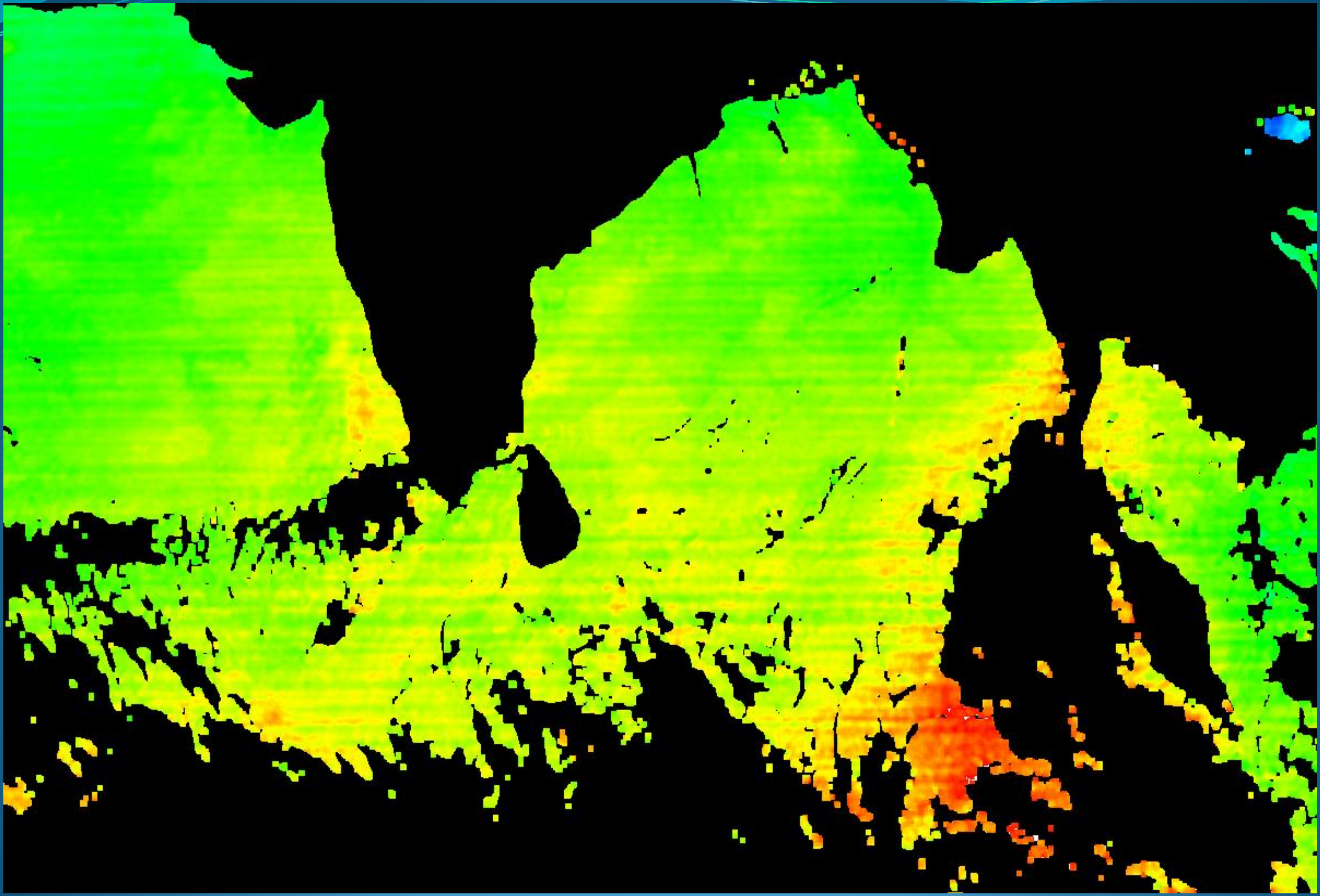


After

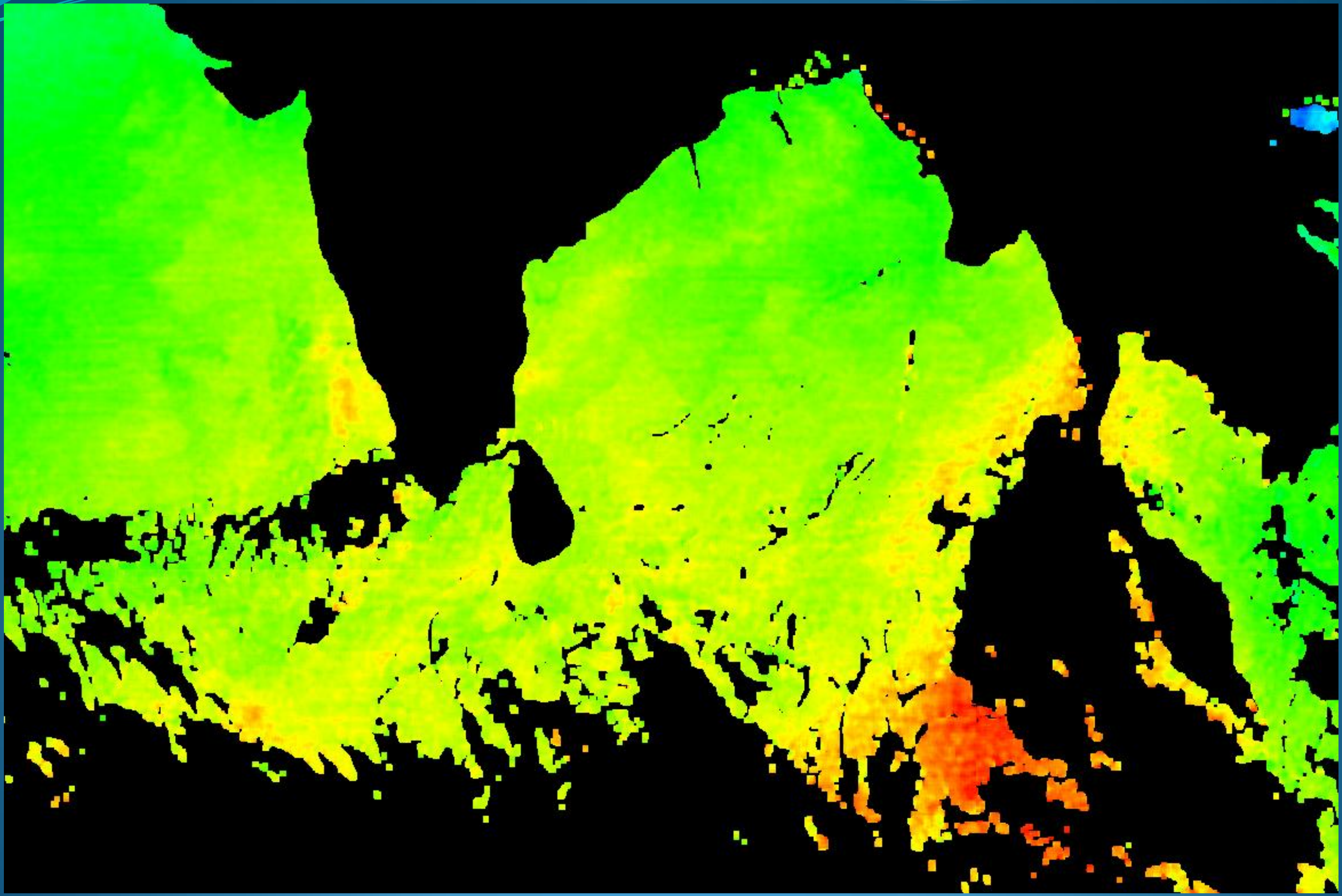
De-striping over SST image



Before de-striping



After de-striping



Future ISRO satellite missions for SST

INSAT-3D R (2016)
INSAT-3S (2017)
OCEANSAT-3 Series (SST-M) (tentatively 2017, 2019, 2020)

Issues related to GHRSST

1. INSAT-3D SST is skin SST
2. Conversion of skin SST into 1 meter depth requires skin to Bulk modelling (how other satellites operators doing it?, not much open literature available, we tried following some published papers, but not much successful. Empirical relationship with ARGO drifter buoy?)
3. Latency of GHRSST?
4. In view of Sun intrusion issues after 1100 hrs GMT, can INSAT-3D attempt for foundation SST (early morning hours SST)?

THANKS