SAC/EPSA/AOSG/SR/06/2018

A Pilot Study of Upper Air Observation Campaign at Kavaratti for INSAT-3D/3DR Calibration and Validation, 5-12 Dec 2016

Aditya Chaudhary, K.N. Babu, Seemanth M. and P. K. Thapliyal
Space Applications Centre, ISRO
Ahmedabad 380015, India

February 2018

Document Control Sheet

1	Date	February 2018
2	Title	A Pilot Study of Upper Air Observation Campaign at Kavaratti for INSAT-3D/3DR Calibration and Validation, 5-12 Dec 2016
3	Version	1.0
4	Document No.	SAC/EPSA/AOSG/SR/06/2018
5	Type of Report	Scientific Note
6	No. of pages	21
7	Author(s)	Aditya Chaudhary, K.N. Babu, Seemanth M. and P. K. Thapliyal
8	Originating Unit	EPSA, SAC, Ahmedabad, India
9	Abstract	In order to validate the temperature and humidity profiles of INSAT 3D/3DR sounder, a validation campaign was planned and carried out at the calibration/validation site of ISRO located at Kavaratti, Lakshadweep during 5-12 December 2016. In this campaign, several Pisharorty-Sonde observations were made coinciding with the satellite observations at different time of the day to validate the temperature and humidity profiles. The present report presents the validation results using collocated observations taken during the campaign.
10	Classification	Not Restricted
11	Circulation	All concerned

Table of Contents

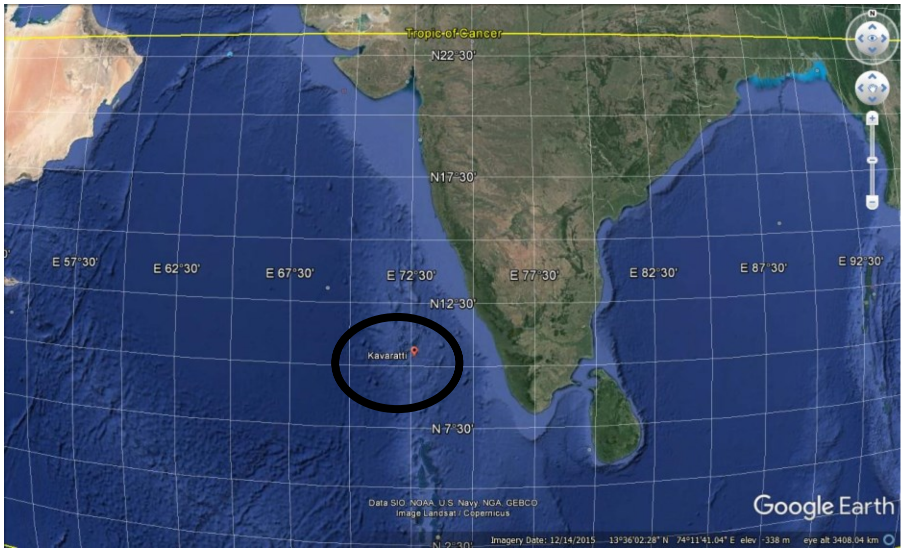
1. Introduction

The INSAT-3D and its repeat mission INSAT-3DR are the geostationary advanced meteorological satellites from ISRO to fulfill the demand of the meteorological data over Indian subcontinent as well as surrounding areas covering full-disc of Earth visible from the geostationary orbit. Both of these satellites have Sounder payloads that makes observation in 18 infrared channels (plus a visible channel for daytime cloud identification) and provide atmospheric temperature and humidity profiles at 40 fixed pressure levels. Proper validation of the satellite products is very important activity to remove the biases in the retrieval and improve the product quality. Validation at regular time interval is also important to monitor the product quality and make necessary corrections, if required. The India Meteorological Department (IMD) has several stations where radiosonde/GPS-sonde observations are made to measure atmospheric temperature and humidity profiles. However, these observations are mostly located over Indian landmass and operates at fixed time, 0 and 12 GMT, to provide global synoptic observations of upper atmosphere. Due to large variability in near surface temperature and humidity, these observations are not very ideal for calibration and validation exercises. Moreover, these observations may not coincide exactly with the satellite overpass and will not be able to provide a complete diurnal behavior. A dedicated ship-cruise is an alternative to provide such observations over uniform and less variable ocean areas, but they are very expensive. Such observations over a small island can serve as an ideal location as it can provide a uniform and less variable background for calibration and validation.

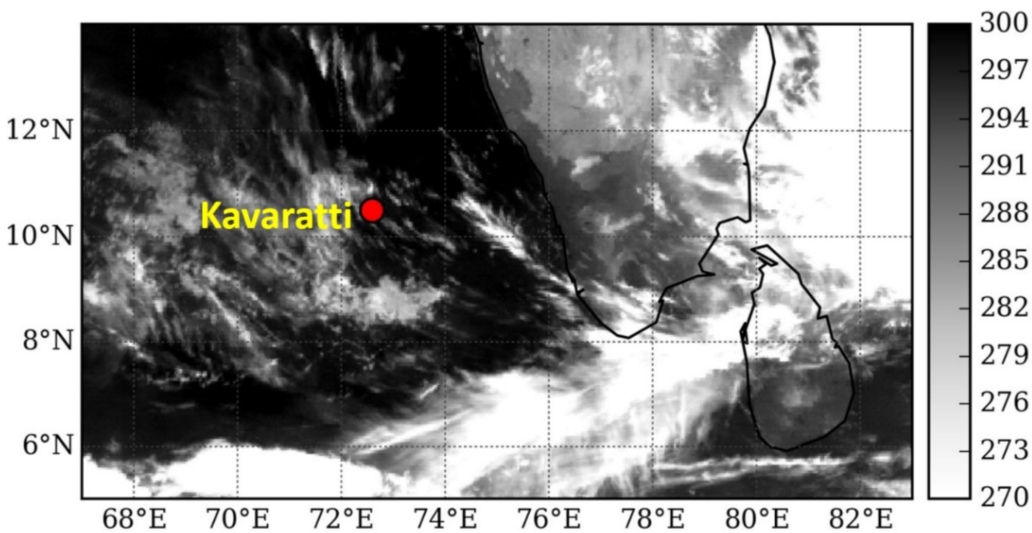
Therefore, in order to validate the temperature and humidity profiles, a validation campaign was planned and carried out at the calibration/validation site of ISRO located at Kavaratti, Lakshadweep during 5-12 December 2016. Location of Kavaratti is 72.64^{0}E, 10.57^{0}N as shown in Figure-1 (a) and (b). In this campaign, several Pisharorty-Sonde observations were made coinciding with the satellite observations at different time of the day to validate the temperature and humidity profiles. The present report presents the validation results using collocated observations taken during the campaign.

Kavaratti being on the tropical location is overcast most of the time. As infrared observations from Sounder are completely obscured by cloud, it can not provide information on temperature and humidity profiles in the atmospheric column in presence of the cloud. Therefore, we have carefully chosen the time of the radiosonde launches so that the sky is clear during satellite observation over Kavaratti. This was decided based on the VIS and TIR images from INSAT3D and INSAT 3DR Imagers around Kavaratti, as well as visual inspection of the sky immediately before the Pisharorty -sonde launch. Since INSAT-3D and INSAT-3DR operates in staggered mode at 15 minute interval, we have made tried to adjust the launch time such that collocation from both the satellites is available within the collocation criteria.

We have also tried to collocate operational international satellite mission that provide high quality hyperspectral sounding observations in order to use these Pisharorty-sonde measurements for inter-satellite calibration under GSICS and also for inter-satellite validatio of the atmospheric profiles. The Aqua-AIRS makes observations over Kavaratti around 01:30 noon/mid-night, whereas the Metop-IASI make observations at 09:30 morning/evening. Apart from this there is another reason for chosing a morning and noon ascent as this provides two contrasting profiles of temperature and humidity in the atmosphere. The Pisharorty-Sonde observations provide with the temperature and humidity profiles at very high vertical resolution, and that is an advantage to precisely collocate satellite derived profiles at any given pressure levels, especially at finer vertical levels of hyperspectral sounder.



(a)



(b)

Fig.1: (a) Location of the Kavaratti island on map and (b) INSAT-3DR IR TIR1 Image (21:45, 10Dec16)

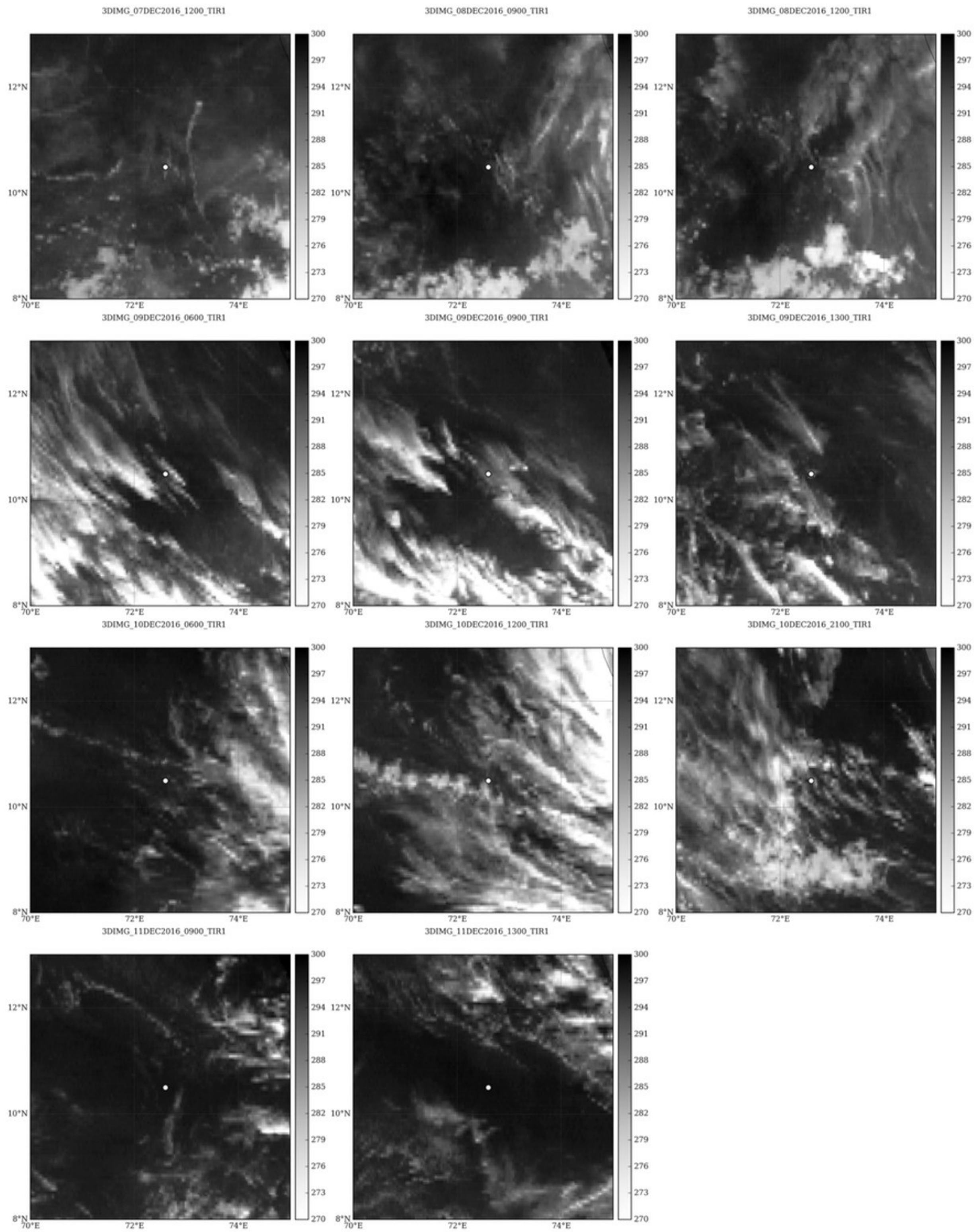


Fig.2(a): Cloud conditions over Kavaratti island (white dot in the middle) in INSAT-3D TIR1 images for various Pisharoty-sonde ascent

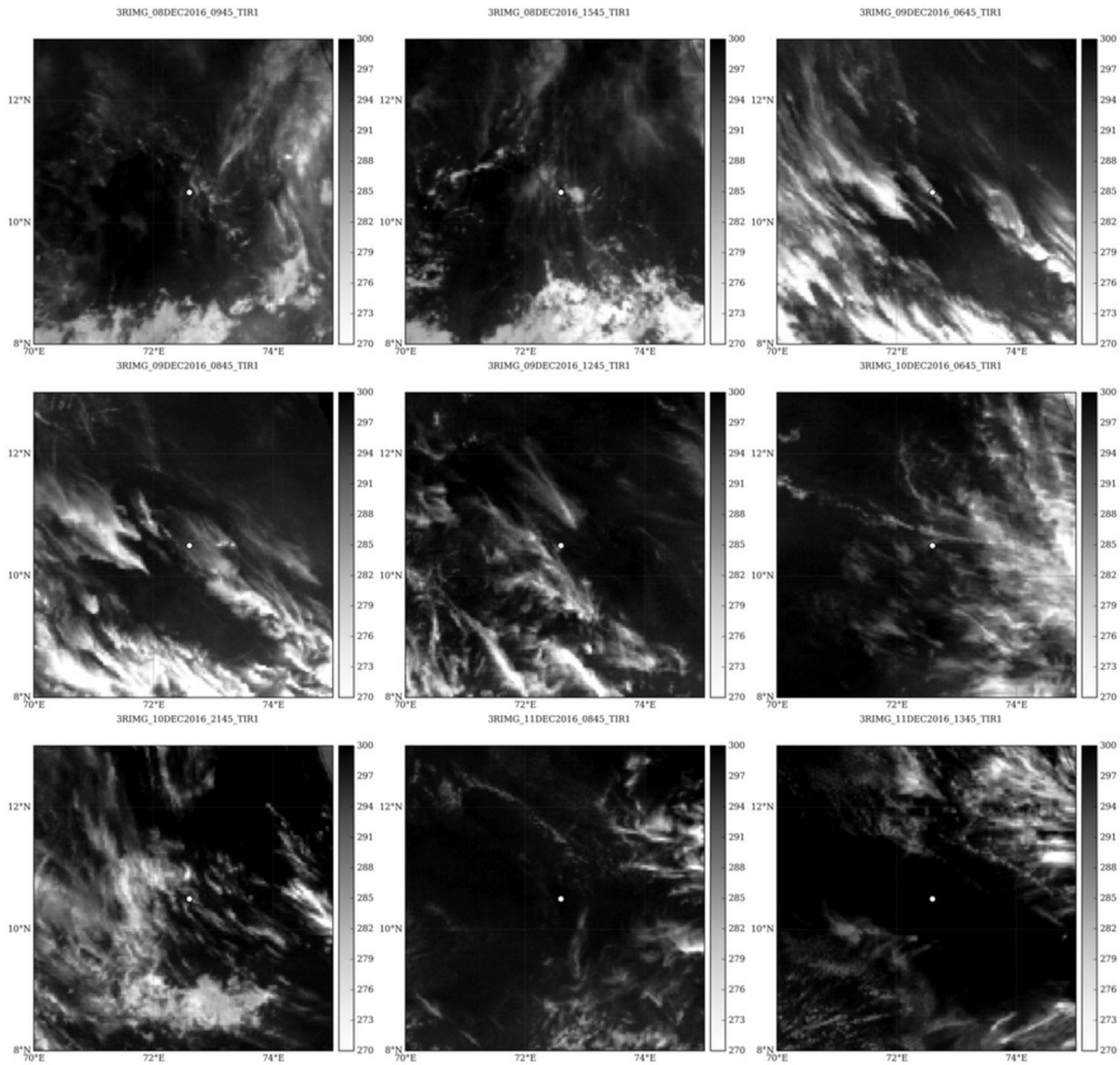


Fig.2(b): Cloud conditions over Kavaratti island (white dot in the middle) in INSAT-3DR TIR1 images for various Pisharoty-sonde ascent

Another aspect considered in the validation campaign was to make use of clear sky conditions. This is due to the fact that the infrared observations are obscured by the presence of clouds, therefore, presence of even a small piece of cloud in the field-of-view of the infrared sensor would contaminate the observation. This make the atmospheric profile measurement from an infrared sounder impossible or erroneous. We used INSAT-3D/3DR high resolution TIR1 and VIS imageries prior to the Pisharorty-sonde ascent to find out a probable clear sky time window. Again, prior to the balloon ascent a visual inspection is carried out for the clear sky conditions just above the Kavaratti island. If significant cloud presence exists immediately before the ascent, the planned ascent is postponed/cancelled. Fig.1(a) and Fig.2(b) shows the cloud conditions during the various ascents as observed from the INSAT-3D and 3DR Imager TIR1 channel.

2. Collocated dataset

All collocations of the INSAT-3D and INSAT-3DR were performed with 25 km collocation distance and 30 minutes' collocation time. We were able to get a total of 12 Pisharorty-Sonde profiles during this campaign matching these collocation criteria. For INSAT-3D there were 11 collocated profiles, whereas, a total of 9 collocated profiles obtained for the INSAT-3DR. List of these collocated profiles can is inferred from Table-1 (for INSAT-3D) and Table-2 (for INSAT-3DR). These profile numbers will be in the same sequence in all the following plots.

Table-1: Collocated INSAT-3D files with Radiosonde

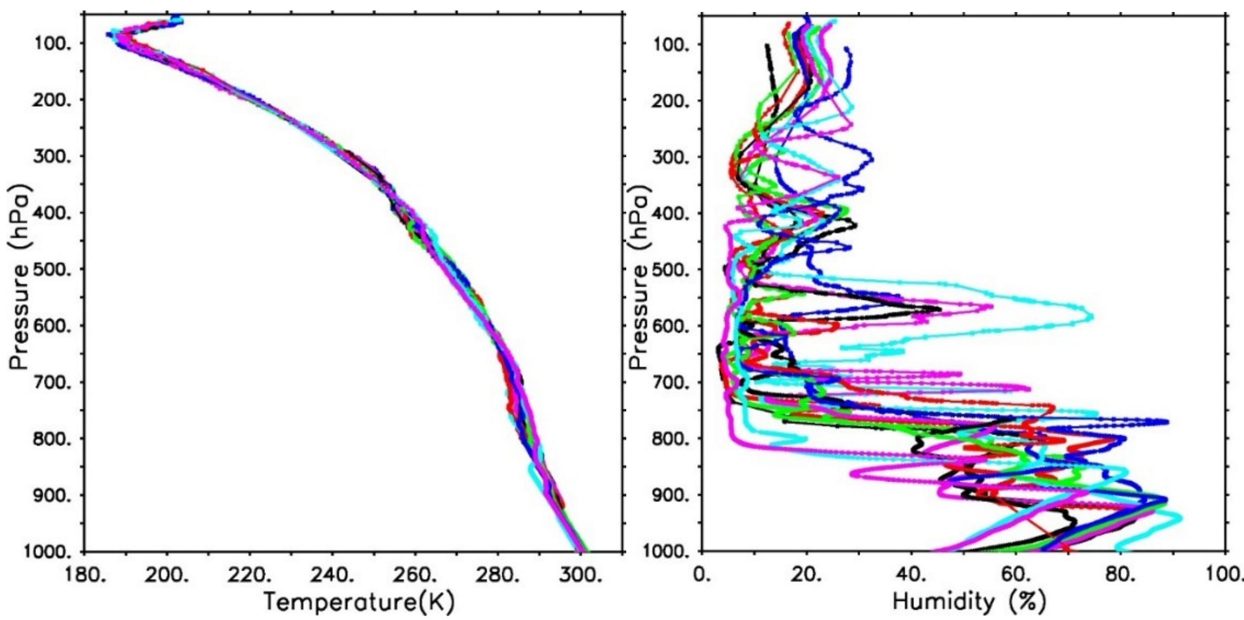
Profile number	INSAT-3D file	Radiosonde release time	INSAT-3D time	Time diff. (mins)
1	3DSND_07DEC2016_1200_L2B_SA1.h5	12:55:10	12:47:41	7
2	3DSND_08DEC2016_0900_L2B_SA1.h5	10:02:27	09:47:40	15
3	3DSND_08DEC2016_1200_L2B_SA1.h5	12:36:52	12:47:41	11
4	3DSND_09DEC2016_0600_L2B_SA1.h5	06:56:44	06:47:40	9
5	3DSND_09DEC2016_0900_L2B_SA1.h5	09:42:29	09:47:40	5
6	3DSND_09DEC2016_1300_L2B_SA1.h5	13:43:40	13:47:4	4
7	3DSND_10DEC2016_0600_L2B_SA1.h5	06:53:54	06:47:33	6
8	3DSND_10DEC2016_1200_L2B_SA1.h5	12:27:28	12:47:40	20
9	3DSND_10DEC2016_2100_L2B_SA1.h5	21:54:44	21:47:37	7
10	3DSND_11DEC2016_0900_L2B_SA1.h5	09:24:40	09:47:40	23
11	3DSND_11DEC2016_1300_L2B_SA1.h5	13:51:53	13:47:41	4

Table-2: Collocated INSAT-3DR files with Radiosonde

Profile number	INSAT-3DR file	Radiosonde release time	INSAT-3DR time	Time diff. (mins)
1	3RSND_08DEC2016_0930_L2B_SA1.h5	10:02:27	10:17:35	15
2	3RSND_08DEC2016_1530_L2B_SA1.h5	16:32:41	16:17:35	15
3	3RSND_09DEC2016_0630_L2B_SA1.h5	06:56:44	07:17:36	21
4	3RSND_09DEC2016_0830_L2B_SA1.h5	09:42:29	09:17:35	25
5	3RSND_09DEC2016_1230_L2B_SA1.h5	13:43:40	13:17:35	26
6	3RSND_10DEC2016_0630_L2B_SA1.h5	06:53:54	07:17:35	24
7	3RSND_10DEC2016_2130_L2B_SA1.h5	21:54:44	22:17:37	23
8	3RSND_11DEC2016_0830_L2B_SA1.h5	09:24:40	09:17:35	7
9	3RSND_11DEC2016_1330_L2B_SA1.h5	13:51:53	14:17:35	26

3. Analysis of Pisharorty -Sonde Profiles

The Figure-3 shows all the Pisharorty-sonde temperature and humidity profiles plotted together. This figure shows variability among different profiles. It may be noted that the variability in the temperature profiles is very small, which is typical of the maritime environment. However, there is large variability in the humidity profiles varying from different time of the day as well as on different days. This figure also shows that there is a need to make such observations over a longer duration of time, typically over a year to capture the larger variability in temperature as well as humidity profiles. The present pilot phase of the validation campaign provides a beginning of a detailed validation strategy for present as well as the future Indian satellites.



(a) (b)

Fig.3: Pisharorty-Sonde measured (a) temperature profiles, and (a) humidity Profiles

4. Validation Results

4.1. Individual Profiles

In this section, we have made comparison of individual temperature and humidity profiles measured from the Pisharoty-Sonde with that obtained from INSAT-3D and INSAT-3DR Sounder.

Figure-4(a) shows the INSAT-3D individual temperature profiles and Figure-4(b) shows the individual mixing ratio profiles from the matchup data. There is a good match in the temperature profiles, whereas, the humidity profiles show little over-estimation in the INSAT-3D Sounder retrieved humidity. The INSAT-3D Sounder does not show the fine-structure of the vertical humidity profiles, which is due to the fact that the INSAT-3D Sounder provides humidity profiles from 3 WV channels having broad weighting function, thereby, providing much smooth humidity profile in the vertical.

Figures-5(a-b) show the comparison of temperature and humidity profiles of INSAT-3DR, respectively, with that obtained from the Pisharoty-Sonde. It is clear that though the INSAT-3DR temperature profiles are closely matching with the Pisharoty-Sonde profiles, the humidity retrieved from INSAT-3DR are little more over-estimated as compared to that of INSAT-3D. This is due to the fact that the RT model dependent bias corrections are still required to be applied on the INSAT-3DR observations during retrieval processing. The validation exercise will be carried out again once the new version of data is ready and processed.

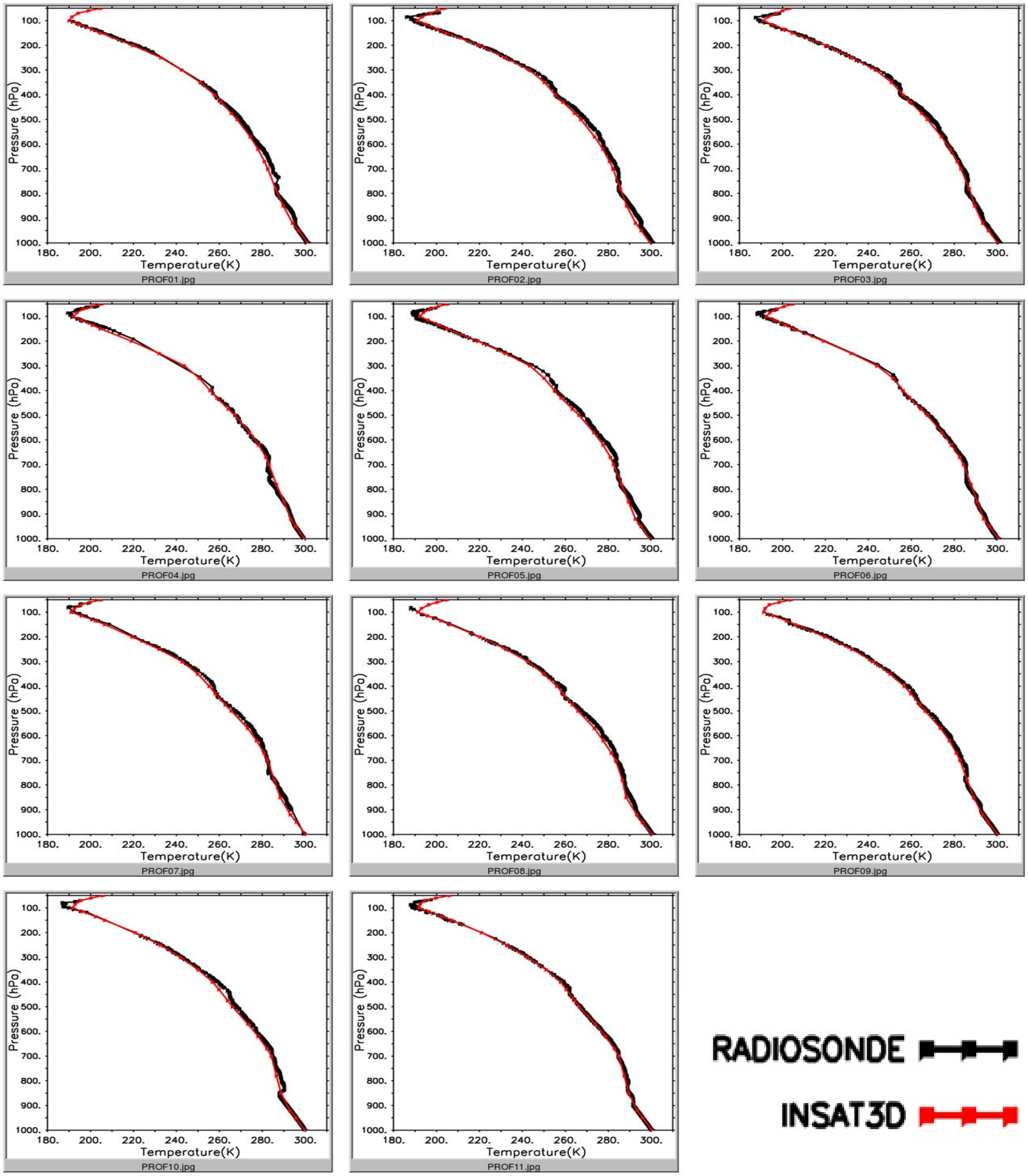


Fig.4(a): INSAT -3D Temperature Profiles collocated with Radiosonde at Kavaratti

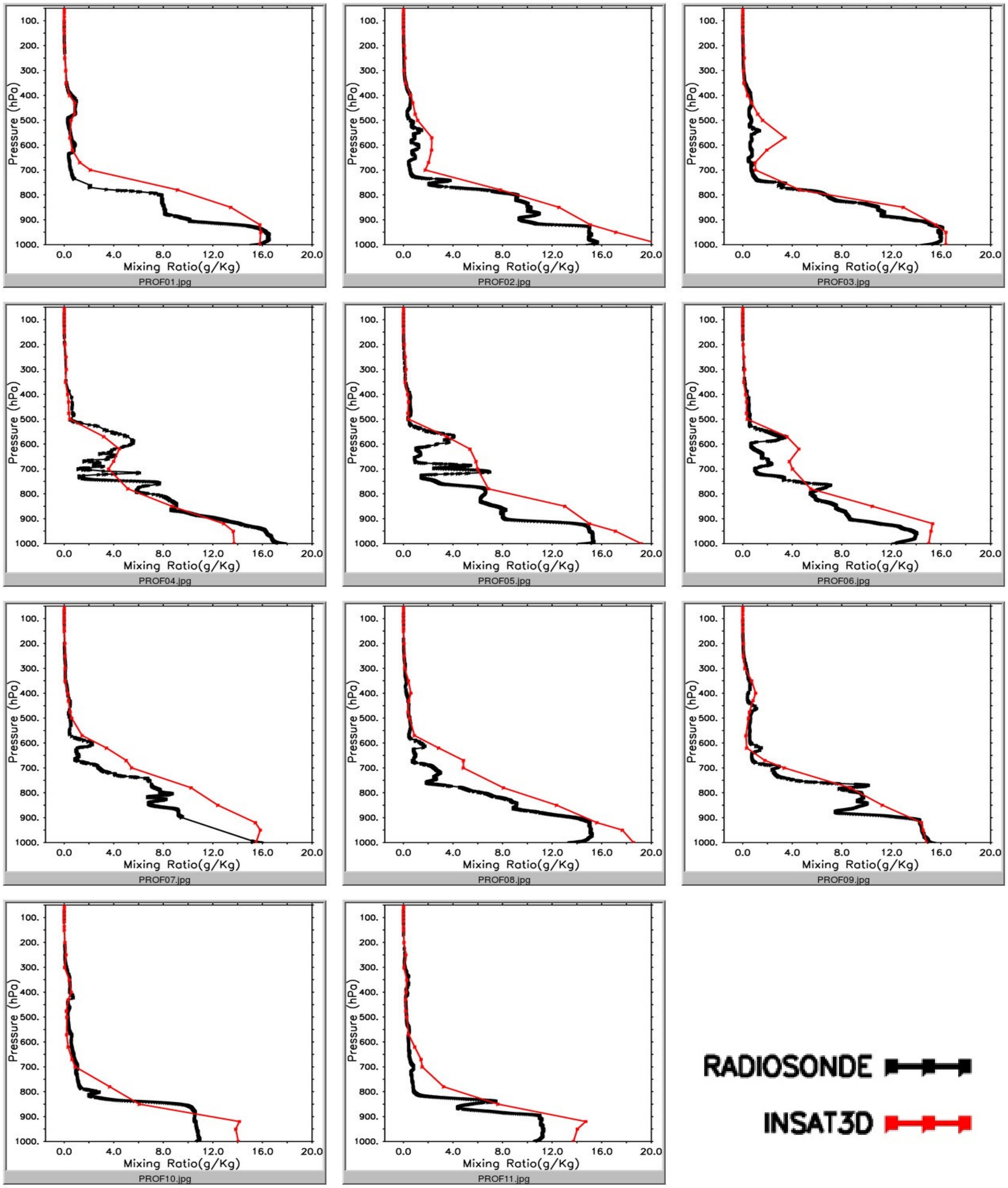


Fig.4(b): INSAT -3D Mixing Ratio Profiles collocated with Radiosonde at Kavaratti.

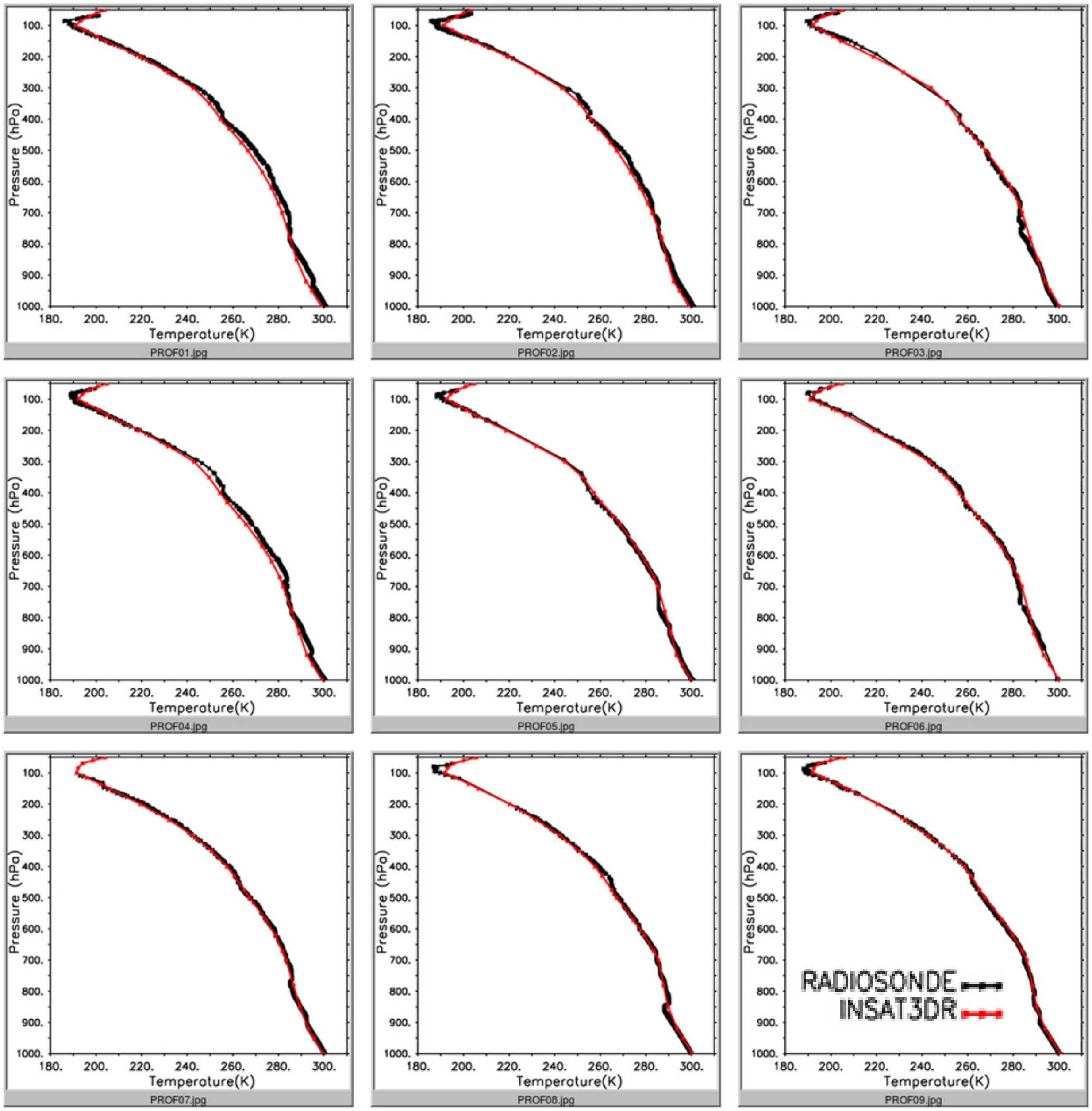


Fig.5(a): INSAT -3DR Temperature Profiles collocated with Radiosonde at Kavaratti.

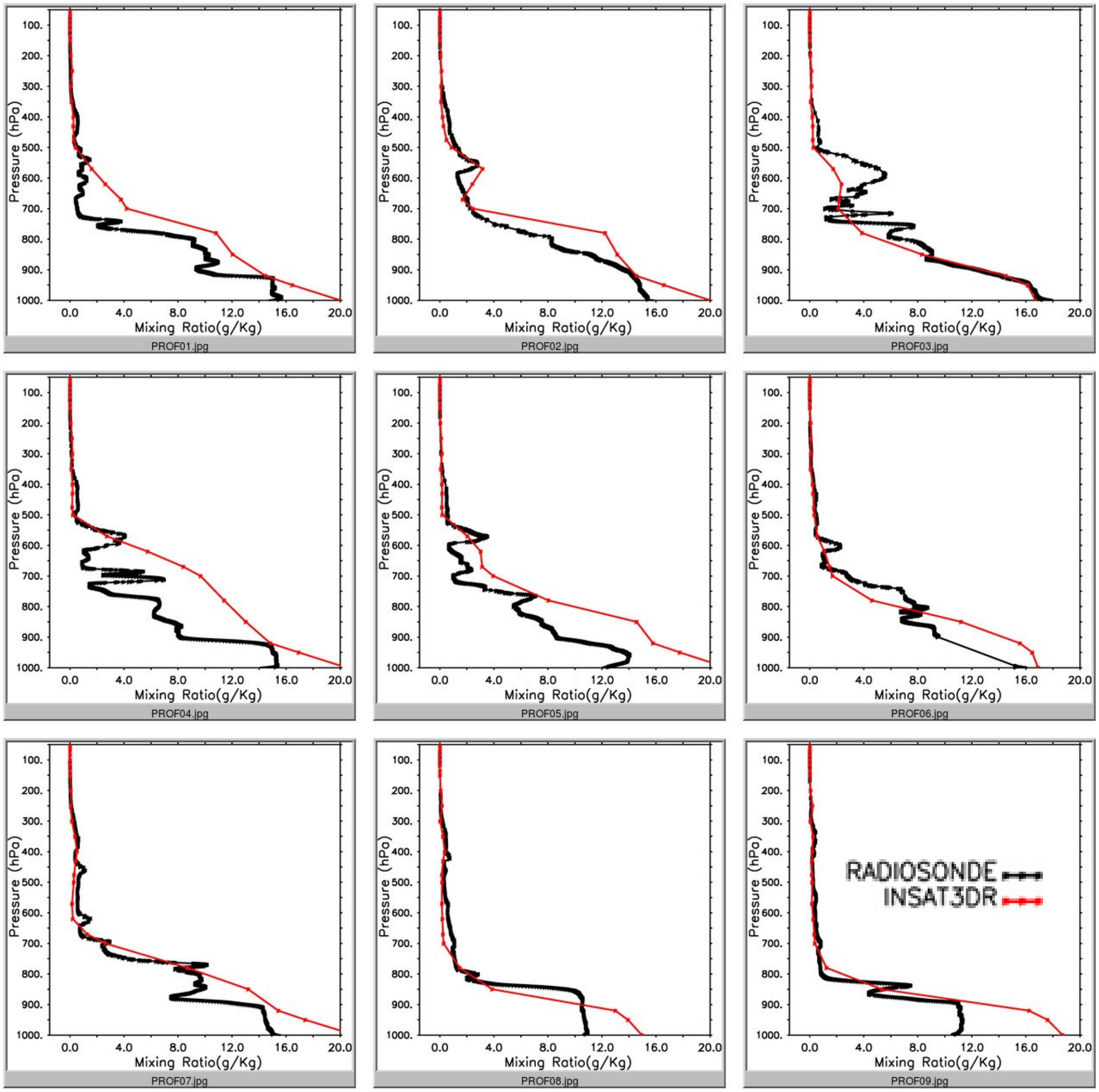


Fig.5(b): INSAT -3D Mixing Ratio Profiles collocated with Radiosonde at Kavaratti.

4.2 Overall Statistics:

The validation statistics has been generated for atmospheric temperature and humidity profiles retrieved from INSAT-3D and INSAT-3DR using available collocated points from the matchup data. Figure-6(a) shows various statistical parameters for the INSAT-3D temperature profile and Figure-6(b) shows similar statistics for mixing ratio/humidity profiles. Figure-6(a) shows that the RMSE (top left panel) of temperature profile is close to 1K for all the vertical pressure levels, but the physical retrieval (Phy) shows higher values ~1.5K in the mid-troposphere (300-700 hPa) as compared to the forecast first guess (FG). This is primarily due to the higher biases in the physical retrieval (as seen in the top-right panel) at these atmospheric layers, 1-1.5K, as compared to the bias of 0.5-1.0K in the first guess. The median absolute deviation (bottom-left panel) and the standard deviation of the differences (bottom-right panel) in the INSAT-3D temperature profile (Phy) and FG w.r.t. the Pisharoty-sonde profiles show that there is very small difference. This bias in the INSAT-3D sounder derived profiles may be due to the biases in the radiances that need to be corrected before they are subjected to the physical retrieval. From Fig.6(b) it is evident that the INSAT-3D derived water vapor mixing ratio profile (humidity profile) has large errors of 2-3 g/kg, as compared to 1-2 g/kg in the forecast first guess. This is again due to the fact that the biases in the INSAT-3D retrieved water vapor is quite large (2-3 g/kg) as compared to the first guess. The standard deviation of error is around 2-2.5 g/kg at near surface levels and 1 g/kg around mid-troposphere. This concludes that there is a need of bias correction in the INSAT-3D Sounder radiance observation and the same need to be applied at a regular interval in the physical retrieval algorithm for sounder.

From Figure.7(a) it may be noted that the INSAT-3DR Sounder derived temperature profile is very close to the first guess, although it has shown a small deterioration that is possible due to the noise in the Sounder radiance observations. The bias in temperature profile is very close to the first guess but the standard deviation is little large as compared to the first guess, that indicate the presence of larger uncertainties in the sounder radiances. This may also be due to the partial cloudiness that might go unnoticed on various occasions. The Fig.7(b) indicates that there are large biases in the sounder derived water vapor mixing ratio profiles and that needs to addressed through suitable bias correction procedure. These biases in the INSAT-3DR derived products are higher than that of INSAT-3D. It may be noted that in the INSAT-3DR algorithms the RT model dependent bias correction procedure is yet to be implemented as requires at least 6 months of high quality collocated radiosonde data and Sounder radiances that are consistent without calibration uncertainties over this period of time. These products will be evaluated again, once the INSAT-3DR products with bias correction procedure are available.

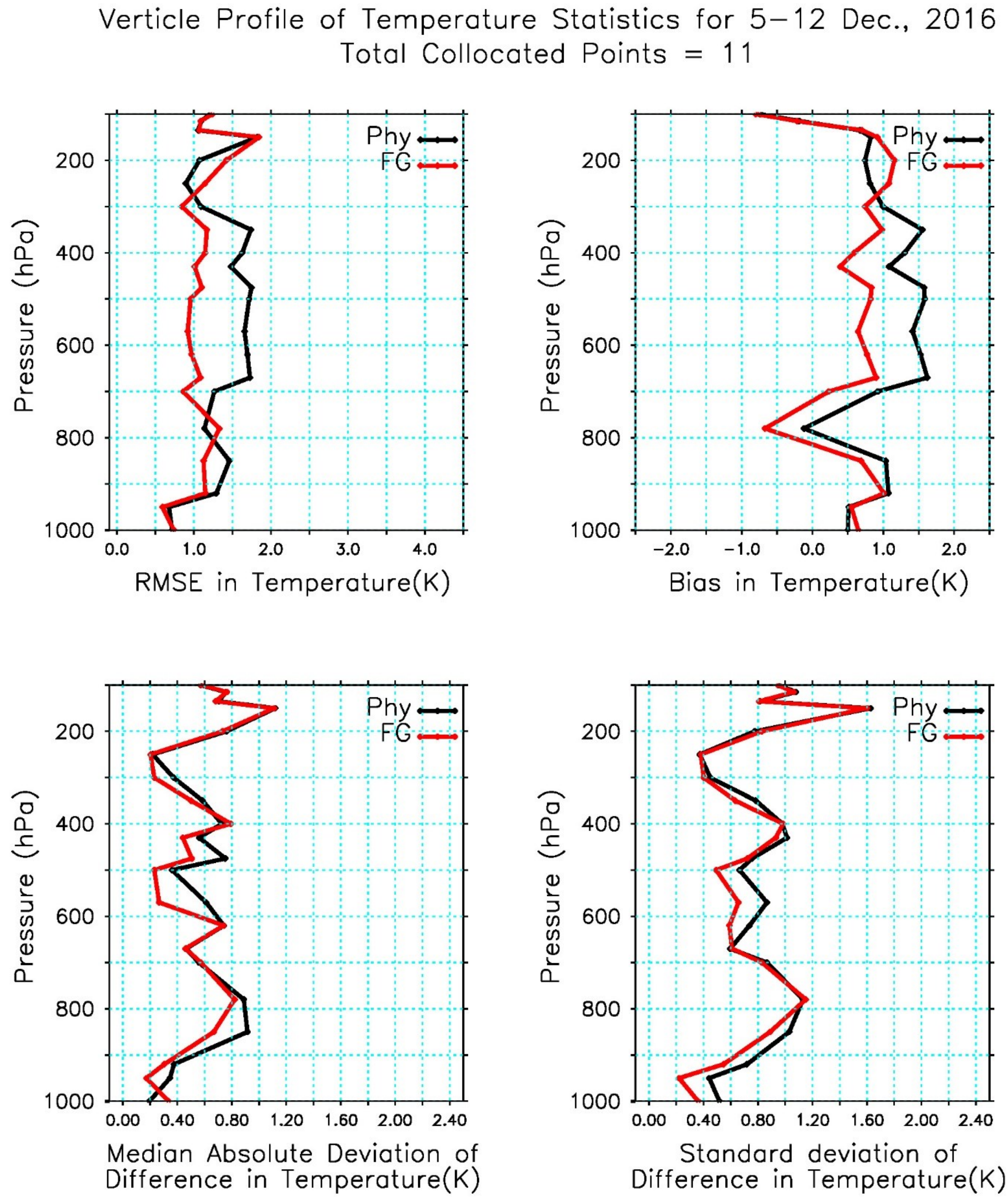


Fig.6(a): INSAT-3D validation statistics for INSAT-3D Temperature Profiles over Kavaratti.

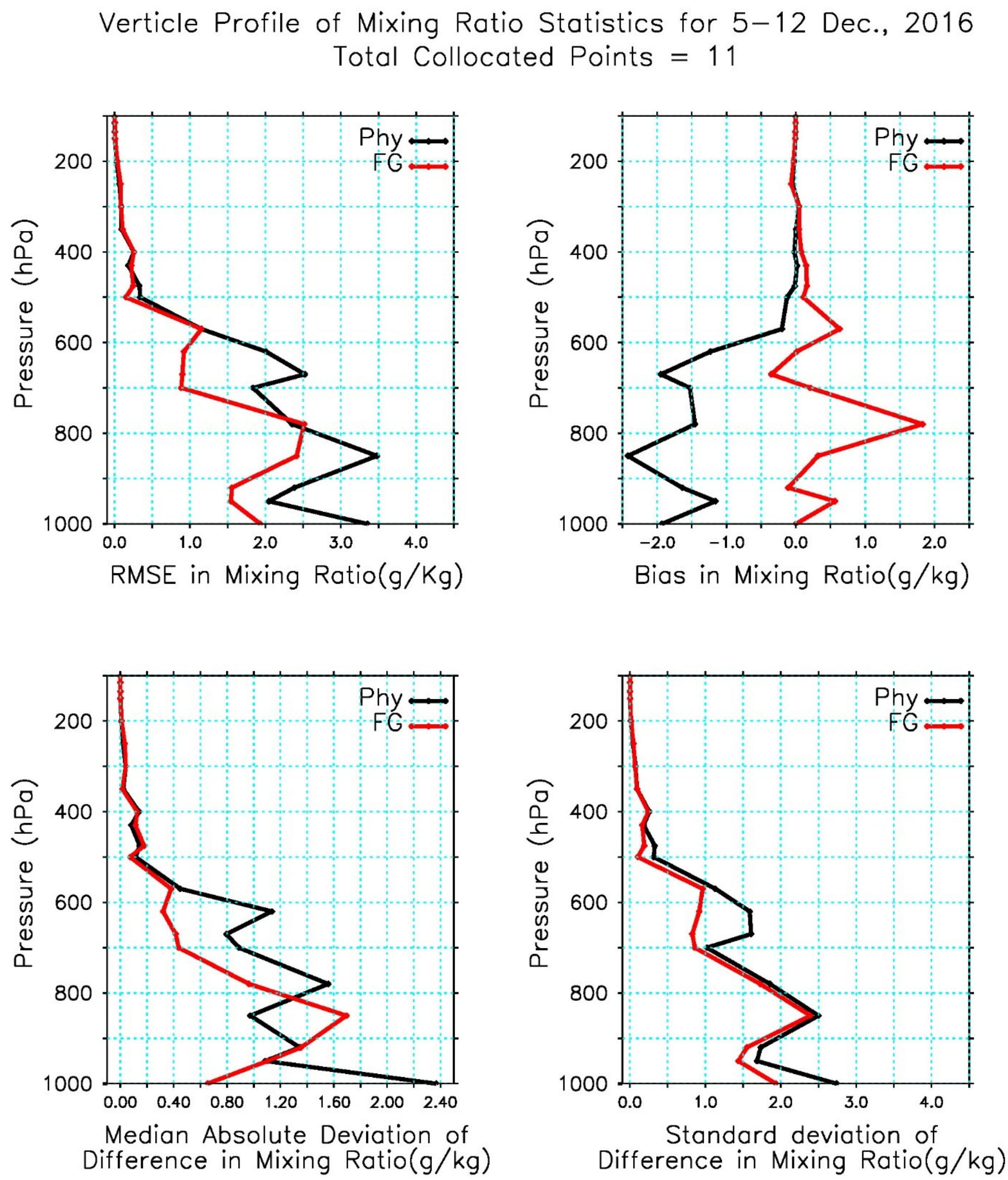


Fig.6(b): INSAT-3D Validation statistics for INSAT-3D Humidity Profiles over Kavaratti

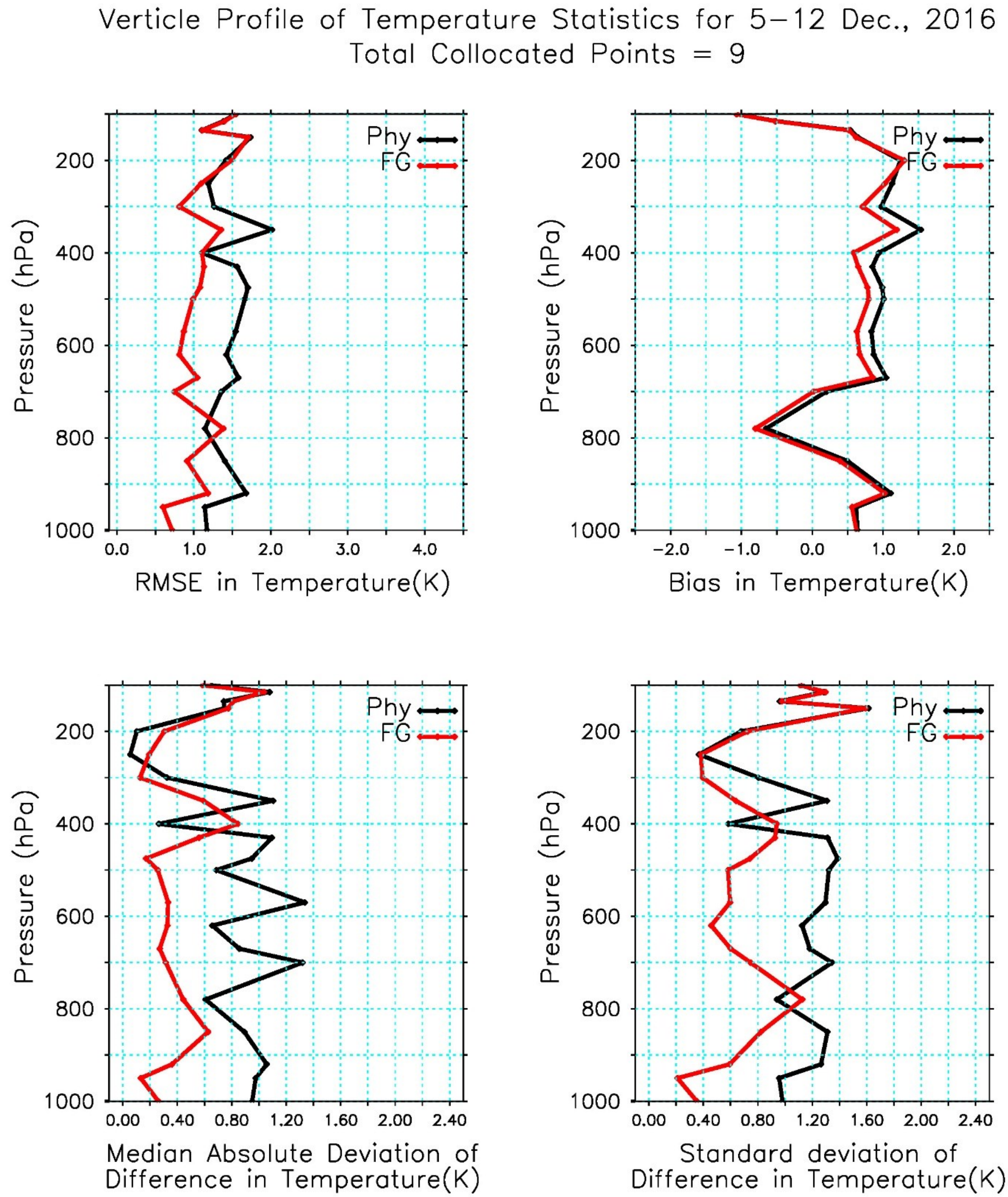


Fig.7(a): INSAT-3D validation statistics for INSAT-3DR Temperature Profiles over Kavaratti

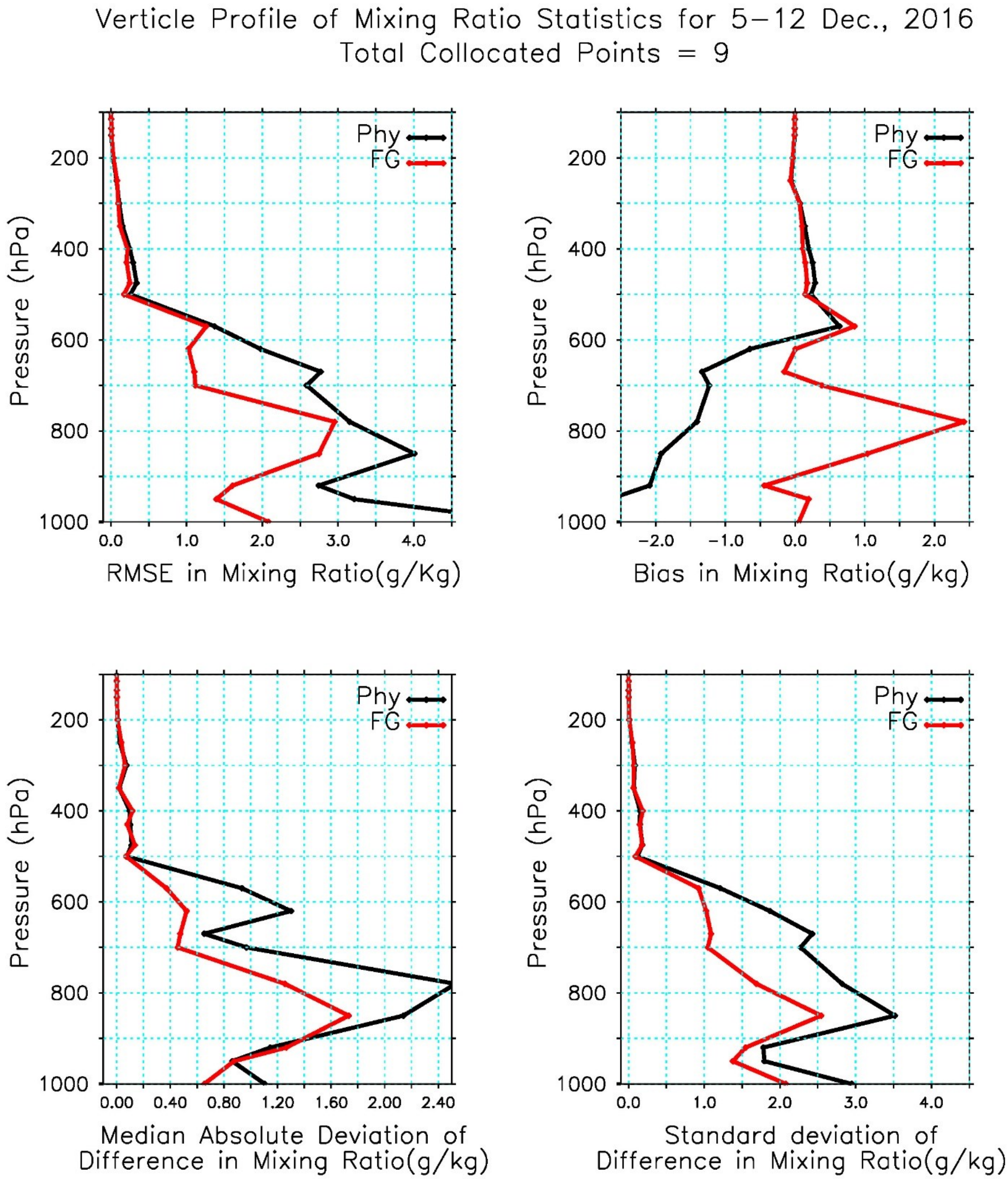


Fig.7(b): Validation statistics for INSAT-3DR Humidity Profiles over Kavaratti

4.3 Comparison with the NWP Model

In order to assess/cross-check the quality of the Pisharoty-sonde profiles, an exercise was carried out to compare the INSAT-3D/3DR and Pisharoty-sonde profiles with the ECMWF analysis. Since ECMWF analysis is available only at 0, 6, 12, 18 GMT, only 3 collocation pairs were obtained within a window of 2 hours in time and 25 km in space. These profiles are plotted in the Fig.8 for INSAT-3D and Fig.9 for INSAT-3DR. These profiles are labelled as follows:

- Profile#1: 08-12-2016 16:32, ECMWF: 18:00, INSAT-3D: 17:47:42, INSAT-3DR: 18:17:35
- Profile#2: 09-12-2016 06:56, ECMWF: 06:00, INSAT-3D: 05:47:40, INSAT-3DR: 06:17:38
- Profile#3: 10-12-2016 06:53, ECMWF: 06:00, INSAT-3D: 05:47:40, INSAT-3DR: 06:17:37

Comparison with the ECMWF analysis brings out the fact that mere 3 profiles are not sufficient to reach any conclusion about their relative superiority.

INSAT-3D: Figure-8 for profile#1 and profile#3 shows that the temperature profiles of ECMWF analysis and Pisharoty-sonde match well, whereas the INSAT-3D shows a small discrepancy at many levels below 300 hPa. For the profile#2 & 3 all the INSAT-3D, ECMWF and Pisharoty-sonde temperature profile are very close. However, the comparisons for mixing ratio profiles are different for all three profiles. At a few levels the INSAT-3D mixing ratio matches with the Pisharoty-sonde, at the same time it has a better match with ECMWF at other levels. There are many levels where ECMWF and Pisharoty-sonde match well but the INSAT-3D profile differs from both of these. This makes it clear that for any conclusive comparison a large number of collocated observations are needed. This will require a dedicated campaign of larger time-duration for the study.

INSAT-3DR: Figure-9 shows similar comparison for the three collocated profiles for INSAT-3DR. These profiles display similar behavior for temperature as seen in INSAT-3D. However, for mixing ratio profiles the INSAT-3DR profiles are much closer to the Pisharoty-sonde than that of ECMWF.

Overall, INSAT-3D and 3DR mixing ratio profiles have a satisfactory match with both ECMWF and Pisharoty-sonde, except for a few levels where bias correction may be required to achieve accurate humidity sounding.

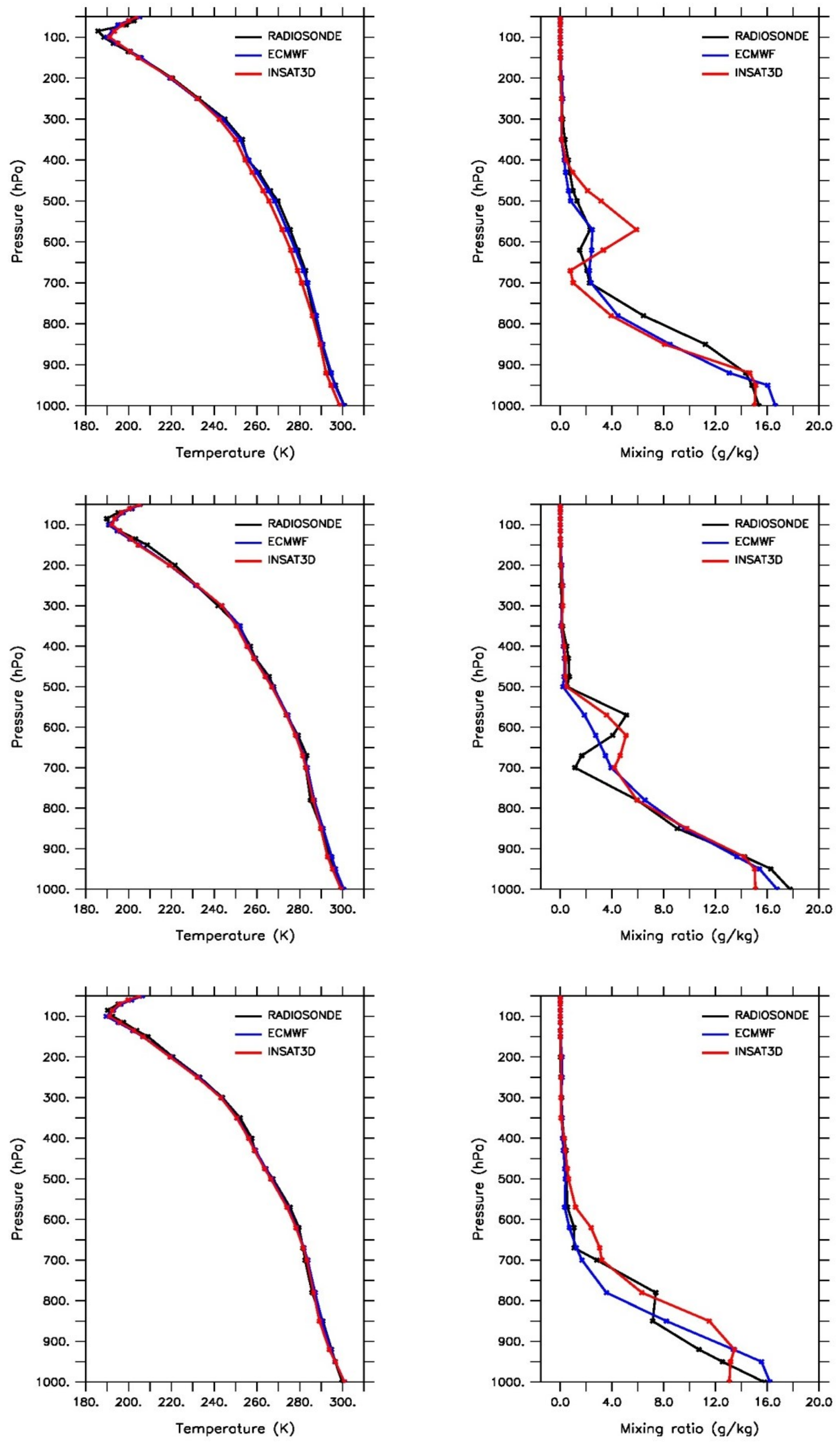


Fig.8: Plots of temperature and humidity profiles over 3 collocated pairs for INSAT-3D

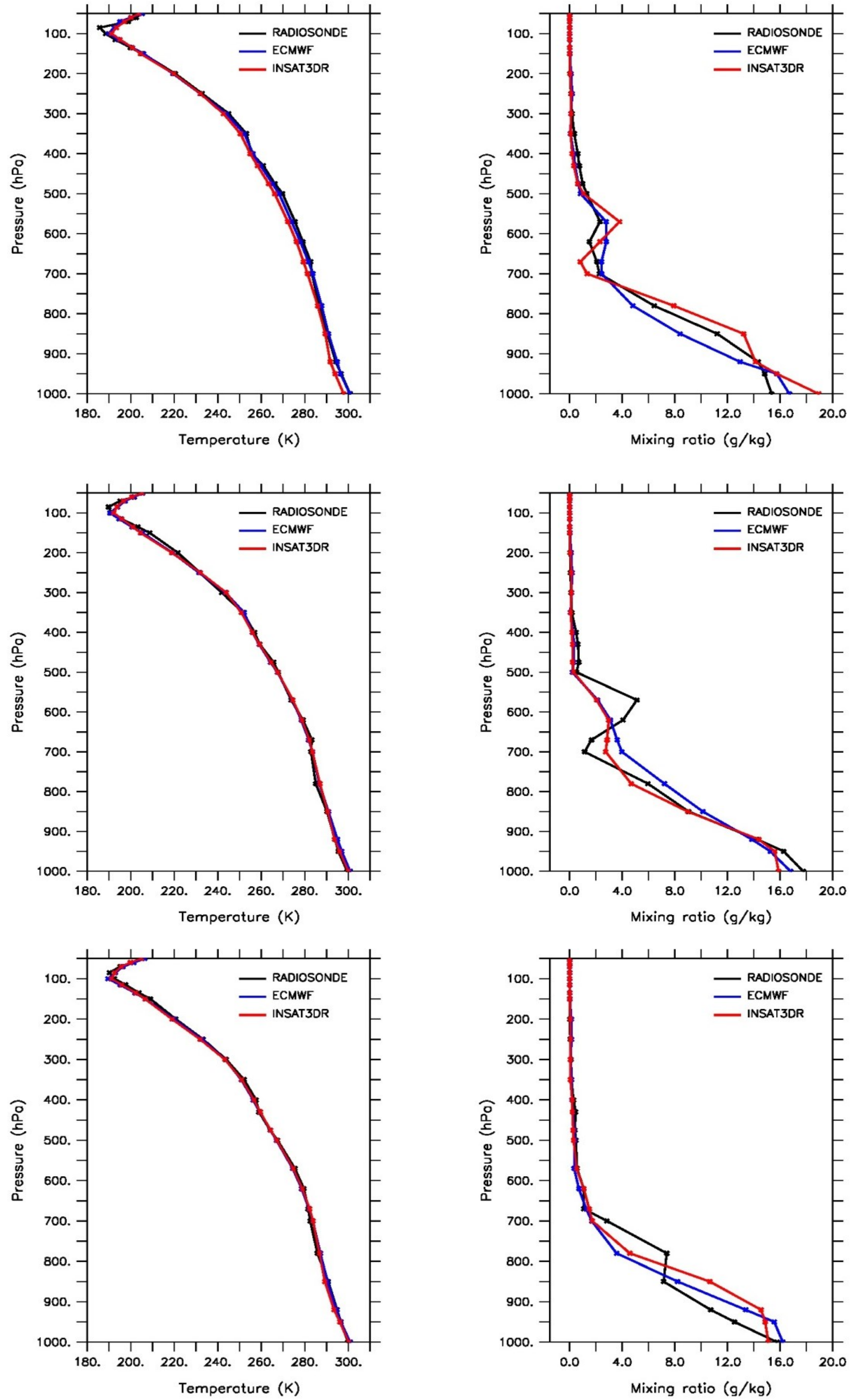


Fig.9: Plots of temperature and humidity profiles over 3 collocated-pairs for INSAT-3DR

5. Inference and conclusions

The present pilot study was carried out to explore a long term possibility of monitoring the product quality from INSAT-3D series of satellites over a small island station, where spatial and temporal variability is not very large that could otherwise lead to the errors in the validation statistics due to sampling differences in space and time. The observations from small island station also help in monitoring the biases in the radiances using observed temperature and humidity profiles in an accurate radiative transfer model. The CALVAL site of ISRO was selected for this pilot phase as it suites all the requirements being small in size and providing all the measurements needed for validation and radiance bias correction. The validation campaign was carried out for the duration 5-12 Dec 2016, where Pisharoty-sonde ascents were planned to match with INSAT-3D/3DR, Aqua-AIRS, Metop-IASI and ECMWF analysis. Apart from spatial/temporal collocation criteria it was also restricted to the clear sky conditions only. This was achieved by the high resolution INSAT-3D/3DR imageries as well as the visual inspection just prior to the ascent. Collocation criteria was chosen as 25 km in space and 30 minutes in time. Finally, a total of 12 Pisharoty-sonde were launched during this campaign matching these collocation criteria. These profiles provided small variability in the temperature profiles, but sufficiently large variability in the humidity profiles. This report deals with the validation aspect of the campaign and compares the temperature and humidity profiles from these different sources.

Results show that the INSAT-3D individual temperature profiles have a good match with the Pisharoty-sonde, however, the humidity profiles show little over-estimation in the INSAT-3D Sounder retrieved humidity. In case of INSAT-3DR also the temperature profiles are closely matching with the Pisharoty-sonde profiles, but the humidity retrieved from INSAT-3DR are little more over-estimated as compared to that of INSAT-3D. This may be due to the fact that the RT model dependent bias corrections are required to be applied on the INSAT-3DR observations during retrieval processing. The validation exercise needs to be carried out again after the new version of data is ready and processed.

The validation statistics generated for atmospheric temperature and humidity profiles retrieved from INSAT-3D and 3DR using available collocated points from the matchup data shows that the RMSE of temperature profile is close to 1K for all the vertical pressure levels, but the physical retrieval shows higher values ~1.5K in the mid-troposphere as compared to the forecast first guess, primarily due to the higher biases at these atmospheric layers. The INSAT-3D derived water vapor profile has large errors of 2-3 g/kg, as compared to 1-2 g/kg in the forecast first guess, again due to the large bias as compared to the first guess. This concludes that there is a need for the bias correction in the INSAT-3D Sounder radiance observation and the same need to be applied at a regular interval in the physical retrieval algorithm for sounder.

For INSAT-3DR Sounder the temperature profile is very close to the first guess. The bias in temperature profile is very close to the first guess but the standard deviation is little large as compared to the first guess indicating large uncertainties in the sounder radiances. This may also be due to the partial cloudiness that might go unnoticed on various occasions. There are large biases in the INSAT-3DR Sounder derived water vapor profiles that needs to addressed through suitable bias correction procedure. These biases in the INSAT-3DR derived products are higher than that of the INSAT-3D. It may be noted that in the INSAT-3DR algorithms the RT model dependent bias correction procedure is yet to be implemented as requires at least 6 months of high quality collocated radiosonde data and Sounder radiances that are consistent without calibration uncertainties over this period of time.

We have also carried out an exercise to compare the INSAT-3D/3DR and Pisharoty-sonde profiles with the ECMWF analysis. For ECMWF analysis only 3 collocation pairs were obtained within a window of 2 hours in time and 25 km in space. The temperature profiles from ECMWF analysis, Pisharoty-sonde and both INSAT-3D & 3DR match well for all 3 profiles, except for one profile where the INSAT-3D & 3DR show a small discrepancy at many levels. However, the comparisons for mixing ratio profiles are different for all three profiles. At different heights different pairs of profiles matches with each other. This makes it clear that for any conclusive comparison a large number of collocated observations are needed over a longer time-duration. Interestingly, the mixing ratio profiles from INSAT-3DR are much closer to the Pisharoty-sonde than that of ECMWF. Overall, INSAT-3D and 3DR mixing ratio profiles have a satisfactory match with both ECMWF and Pisharoty-sonde, except for a few levels where bias correction may be required to achieve accurate humidity sounding.

These INSAT-3D and 3DR sounder products will be evaluated again, once these products are available with bias correction procedure in the retrieval algorithm.

Acknowledgements

Authors are grateful to Director, Space Applications Centre (SAC), Deputy Director EPSA and Group Director, AOSG, and Heads CVD, OSD(E), and GRD for their kind motivation and support in carrying out this campaign. Authors would also like to thank Sri. R P Prajapati, Scientist CVD/EPSA and Mr. K. K. Idress Babu, Mr. Moosakunhi, Z. M and Mr. Mohammed Ziyad from CALVAL site at Kavaratti for their tireless efforts in supporting this campaign.