FY-3C VIRR Operational SST Product ---------Lesson learned

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Outline

1. **Introduction**
2. **Scheme of FY LEO IR SST**
3. **Summary and Future work**

Introduction

- FY-3 is the second generation of polar-orbiting meteorological satellite of China.
- The first batch FY-3 includes two testing satellites, FY-3A and FY-3B that were launched on 27 May 2008, and 5 November 2010, respectively.
- As the first operational polar-orbiting satellite of the second batch of FY-3, FY-3C was launched on 23 September 2013, and operated in a sun-synchronous morning orbit with a local equator-crossing time of 10 AM in descending node.
- VIRR (visible infrared radiometer) is a 10-channel radiometer for multi-purpose imagery with 1.1km resolution at nadir.
- VIRR has 3 infrared channels, CH3(3.55~3.93μm) CH4(10.3~11.3μm) and CH5(11.5~12.5μm), which can be used to estimate SST.

Scheme of FY LEO IR SST

- **Matchup**
  - Quality controlled in situ data from iQUAM was used.
- **Regression**
  - Outlier removal
  - Dual regression
  - Algorithm performance evaluate
- **Retrieval**
  - Quality control
- **Validation and Discussion**
  - Validate SST against in situ data
  - Compare SST against Global gridded L4 SST
  - There are some abnormal of FY3 SST, is algorithm stable?
  - Anomaly records

Matchup

- Quality controlled in situ data from iQUAM is used in FY-3C/VIRR SST matching up procedure.
- Matchup window: within 3km in space and 1hour in time
- 3×3 pixel box centered on the VIRR measurements with the “confident clear” and “probably clear” flag in Cloud Mask product are matching up.

The operational MDB(matchup database) is built with a 20 days delay to insure a good collection of the in situ data.

Regression

All the screening and outlier removal are handled in the regression code. Currently the following conditions are set:

- Matchup window: within 1.1km in space and 1hour in time
- Only high-accuracy drifter is used
- Regression is performed separately for daytime and nighttime based on the solar zenith angle (SZA<85^{o} daytime ; otherwise nighttime)

- Least-Square Regression is used for estimating the first-guess coefficients.
- Further outliers are removed using Median$\pm$2STD(STD: standard deviation).
- The final coefficients of dual regression are estimated.

SST Algorithms

day

night

MCSST(D/N): $T_s = a_0 + a_1 T_{11} + a_2 (T_{11} - T_{12}) + a_3 (T_{11} - T_{12})(\sec\theta - 1)$

QDSST(D/N): $T_s = a_0 + a_1 T_{11} + a_2 (T_{11} - T_{12}) + a_3 (T_{11} - T_{12})^2 + a_4 (\sec\theta - 1)$

NLSST(D/N): $T_s = a_0 + a_1 T_{11} + a_2 T_{FG} (T_{11} - T_{12}) + a_3 (T_{11} - T_{12})(\sec\theta - 1)$

TCSST(N): $T_s = a_0 + a_1 T_{11} + a_2 T_4 + a_3 T_{12} + a_4 (T_4 - T_{12})(\sec\theta - 1) + a_5 (\sec\theta - 1)$

DNSST(N): $T_s = a_0 + a_1 T_{11} + a_2 T_{FG} (T_4 - T_{11}) + a_3 (\sec\theta - 1)$

T_S: satellite-derived SST T_{FG}: first-guess SST θ: satellite zenith angle $a_0 \sim a_5$:coefficients

T_4, T_{11},T_{12}: brightness temperature in 3.7μm(CH3)、10.8μm(CH4)、12μm(CH5) bands

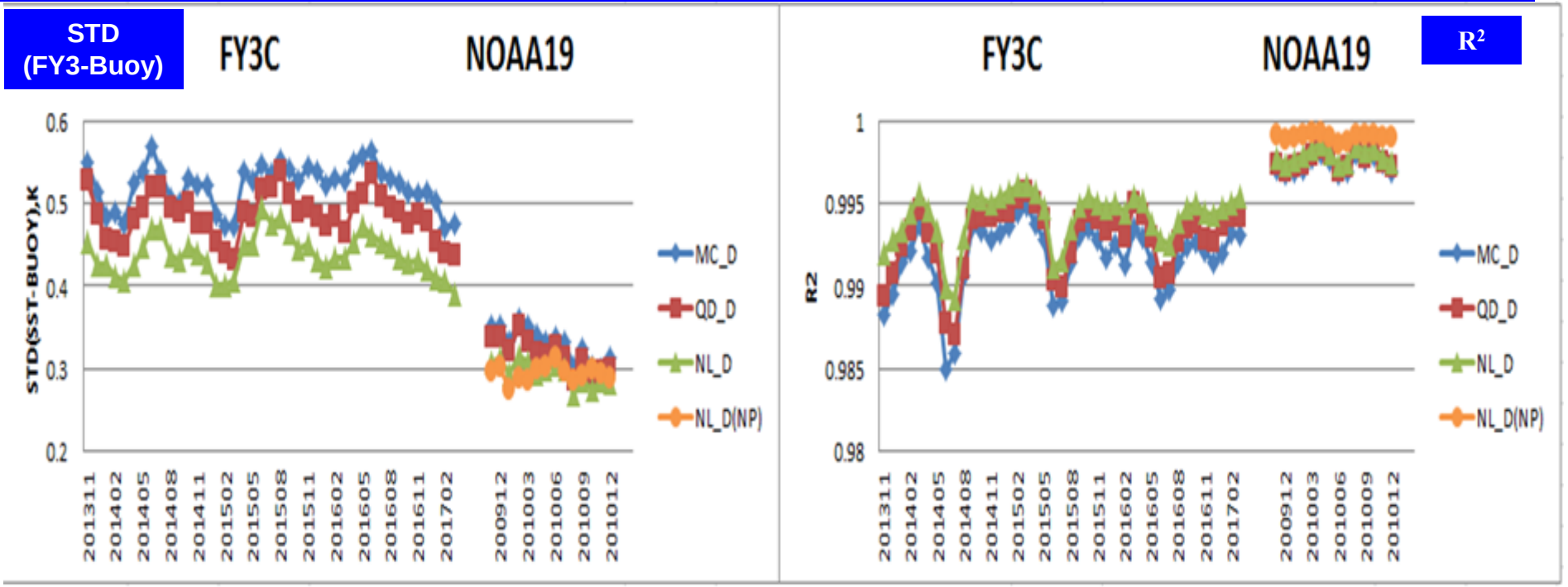
Table 1. List of acronyms of SST Algorithms used in comparison between sensors.

Algorithm	Algorithm Description	Algorithm Flag	Day/Night Flag
MCSST	split-window MultiChannel SST	MC	D/N
QDSST	split-window QuaDratic term MCSST	QD	D/N
NLSST	split-window NonLinear SST	NL	D/N
TCSST	Triple-window MCSST	TC	N
DNSST	Dual-window NLSST	DN	N

The Algorithm Flag and Day/Night Flag are used to identify a SST algorithm (e.g. MC_D is used to identify the daytime MCSST).

Algorithm performance evaluated from MDB Daytime

Suffix with NP is the result from NESDIS/STAR



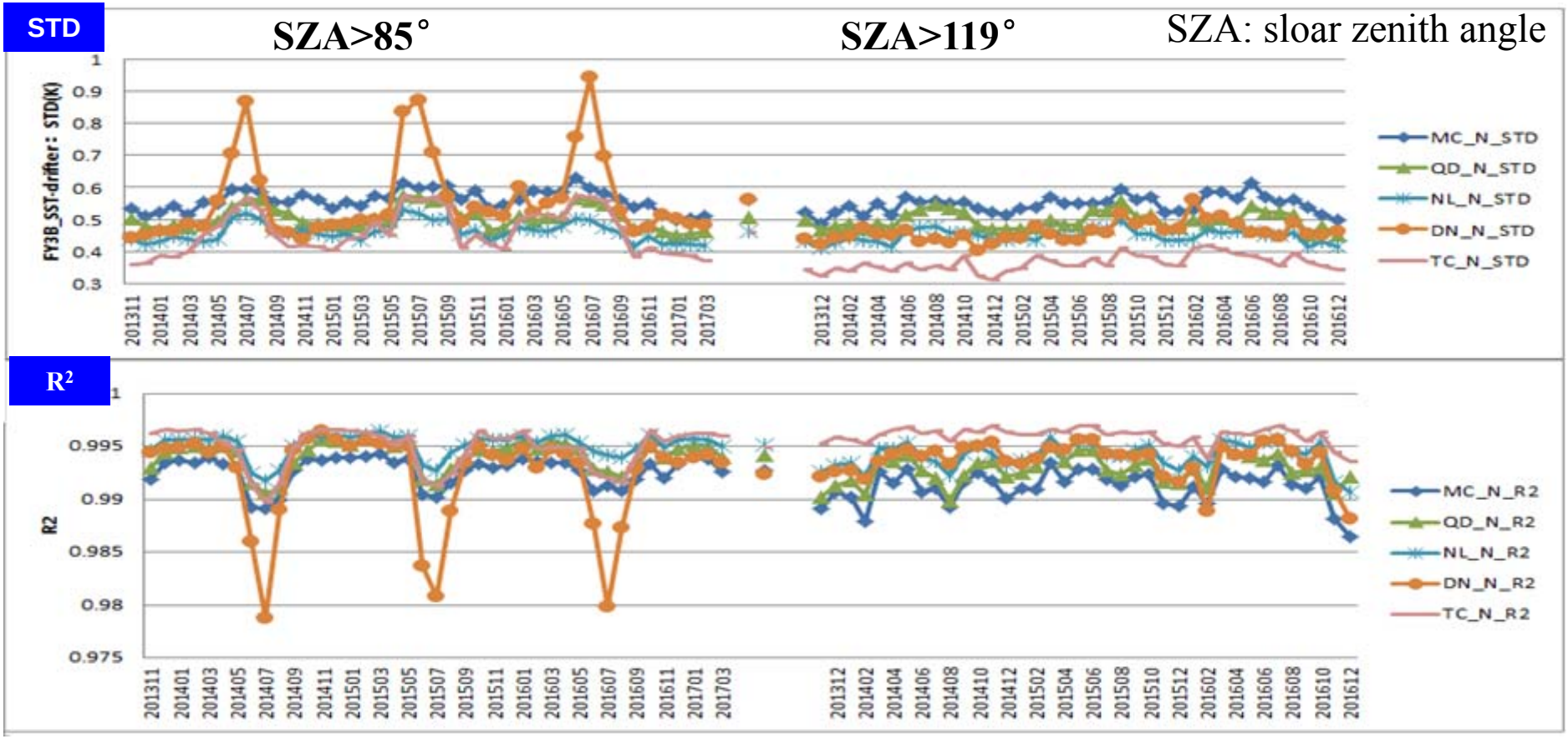
FY3C: November 2013 ~ March 2017

NOAA19: November 2009 ~ December 2010

For inter-sensor comparison, the same procedure are implemented to FY-3C and NOAA-19 MDB. Validation statistics are generated on monthly basis.

- **For the three daytime SST algorithms, NL_D is the best algorithm.**
- **The accuracy of NOAA-19/AVHRR is better than FY-3C/VIRR.**

Algorithm performance evaluated from MDB Nighttime



- **Based on MDB analysis, when SZA>119° ,TC_N is the best. But when used in SST retrieval, the performance of TC_N is worse than MC_N.**

When sloar zenith angle(SZA) between 85° and 118° , the calibration of 3.7μm band is contaminated by solar reflectance. It can be seen from the left figure that the DN_N is more sensitive in summer. The correction has implemented since December 2016.

Retrieval

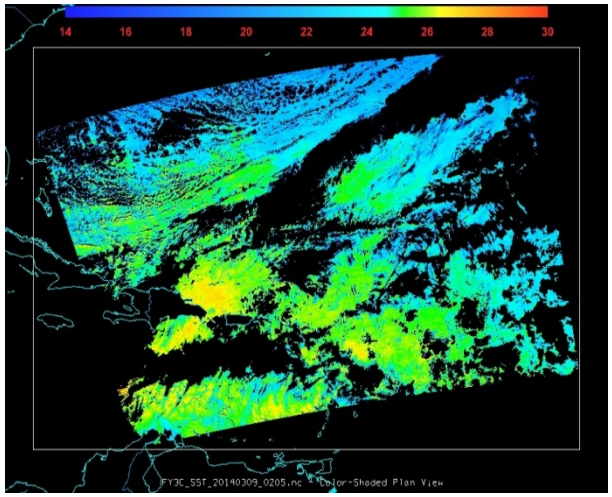
➢ Quality control

- **SST Quality control**
  - Uniformity test(3*3 pixel box)
  - Ref_SST test (sst.ltm.1981-2010.nc)
  - Zenith angle test
  - Glint test
- **SST Quality Flag is stored in a packed 8-bit WORD**

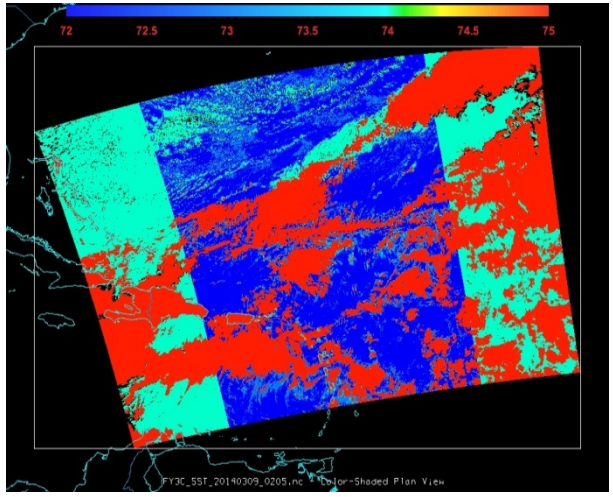
SST QC specification (packed 8-bit word)

Bit(s)	Description
1-2	SST QC: Optimal (0) : 00 Sub-Optimal (1) : 01 Poor (2) :10 Not processed (3) :11
3	No ice (0) Ice (1)
4	No-glint (0) Glint (1)
5	Ocean (0) Coast (1)
6	Night (0) Day (1)
7	External CM Used (0) External CM Not used(1)
8	Channel value Valid(0) Channel value Invalid(1)

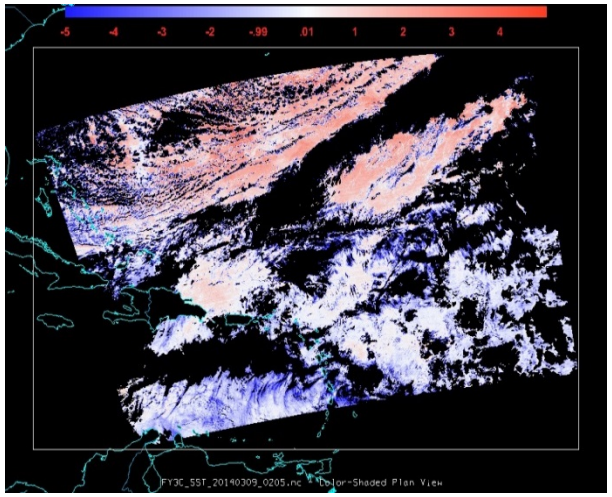
FY3C/VIRR 5-minute grannel (2014/3/9 02:05 UTC)



sea surface temperature



quality flag



deviation from reference SST

The validation of FY-3C/VIRR SST

➢ Validate SST against in situ data (matchup analyses)

- Coefficients are derived from October to December 2015 MDB.
- An independent MDB from November 2016 to January 2017 are used for validation.
- matchup window：within 1hour and 1.1km
- FY3C_SST-BuoySST(satellite SST minus buoy SST)

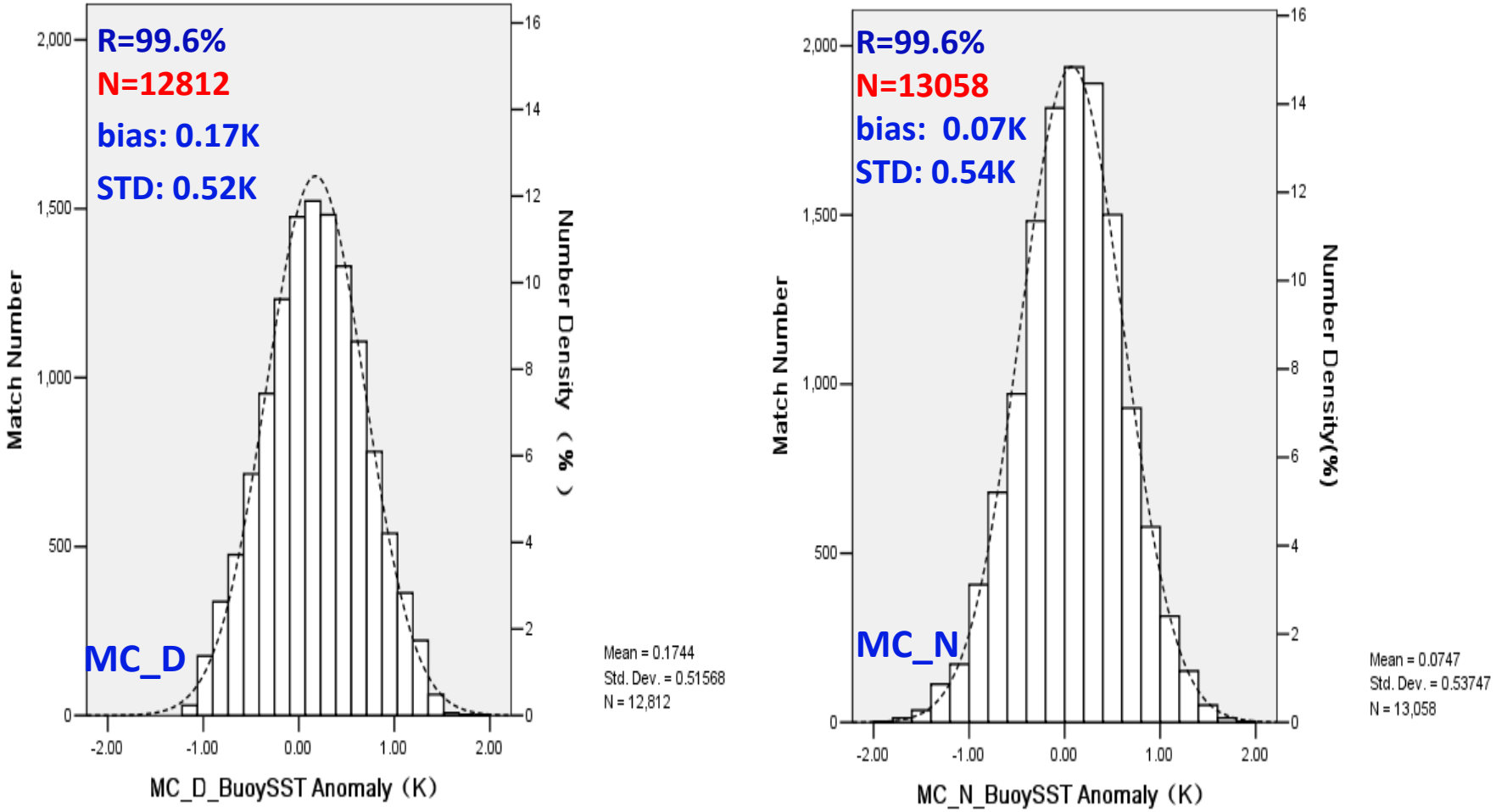
➢ Compare SST against Global gridded L4 SST : OISST

- matchup window ： within 1 Day and 1.1km
- OISST is bilinearly interpolated to sensor's pixels
- FY3C_SST-OISST
- Statistics are generated according to quality flag

Reynolds OI v2 daily 0.25° SST(hereafter OISST) was chosen as reference SST for FYSST anomaly analyses.

Validate FY-3C/VIRR SST against in situ data

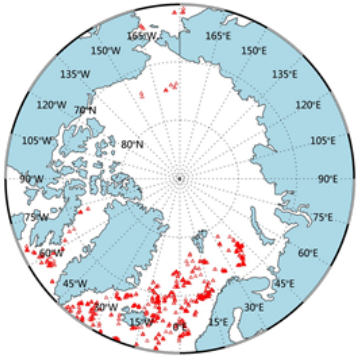
(matchup analyses 2016.11~2017.1)



The coefficients are derived from October to December 2015 MDB, an independent MDB from November 2016 to January 2017 was used to assess the FY-3C/VIRR SST accuracy.

Comparisons of VIRR and MODIS SST with in situ data

P13GHRSST2016LGuan of 17th GHRSST



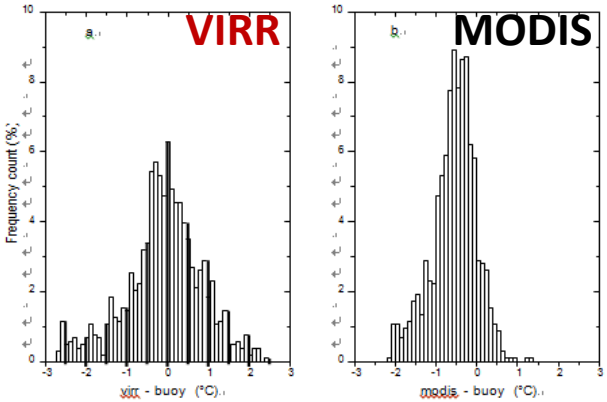


Fig.1 Matchup Locations Fig. 2 Histograms of SST difference

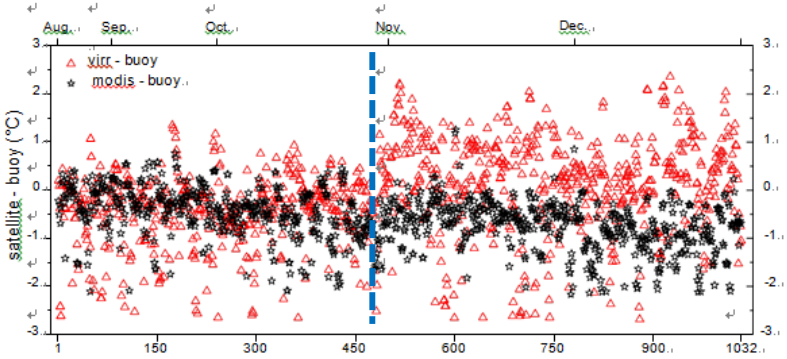


Fig. 3 Time series of SST difference between satellite and buoy data

Sensor	STD (°C)
VIRR	0.91
Buoy	0.20
MODIS	0.51

Table 1 Derived standard deviations for different observations

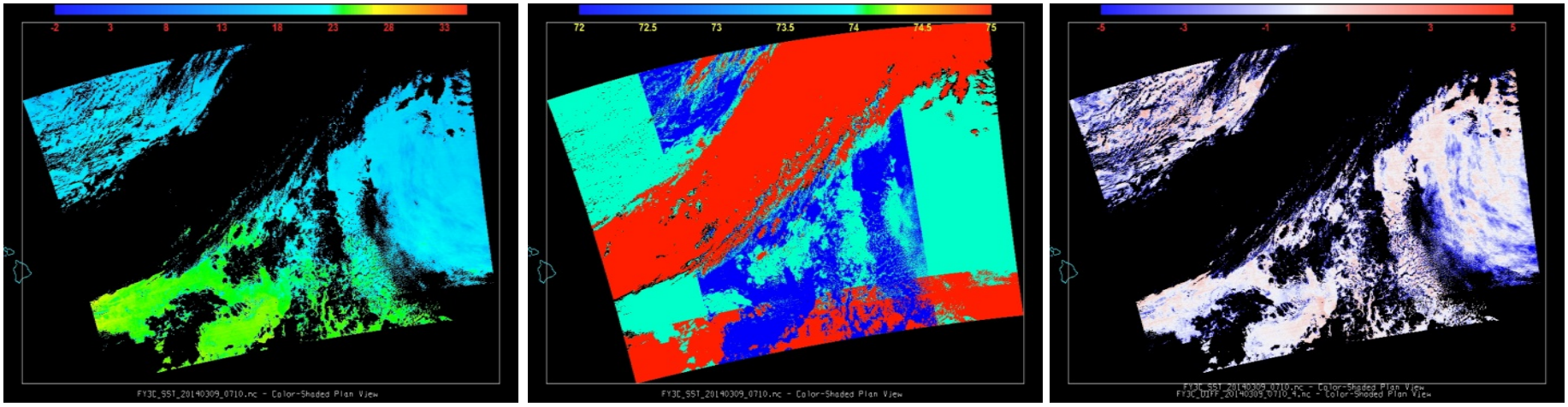
- **The SST difference between VIRR and buoy SST encompasses a warm bias after October(Lei Guan).**
- **On 30 Oct. 2014 the Cal_Coefs were updated, the SST_Coefs were updated two months later.**
- **During 31 Oct. 2014 and Jan. 2015 the bias of SST is increased.**

Courtesy of Prof. Lei Guan

The validation of FY-3C/VIRR SST(cont.)

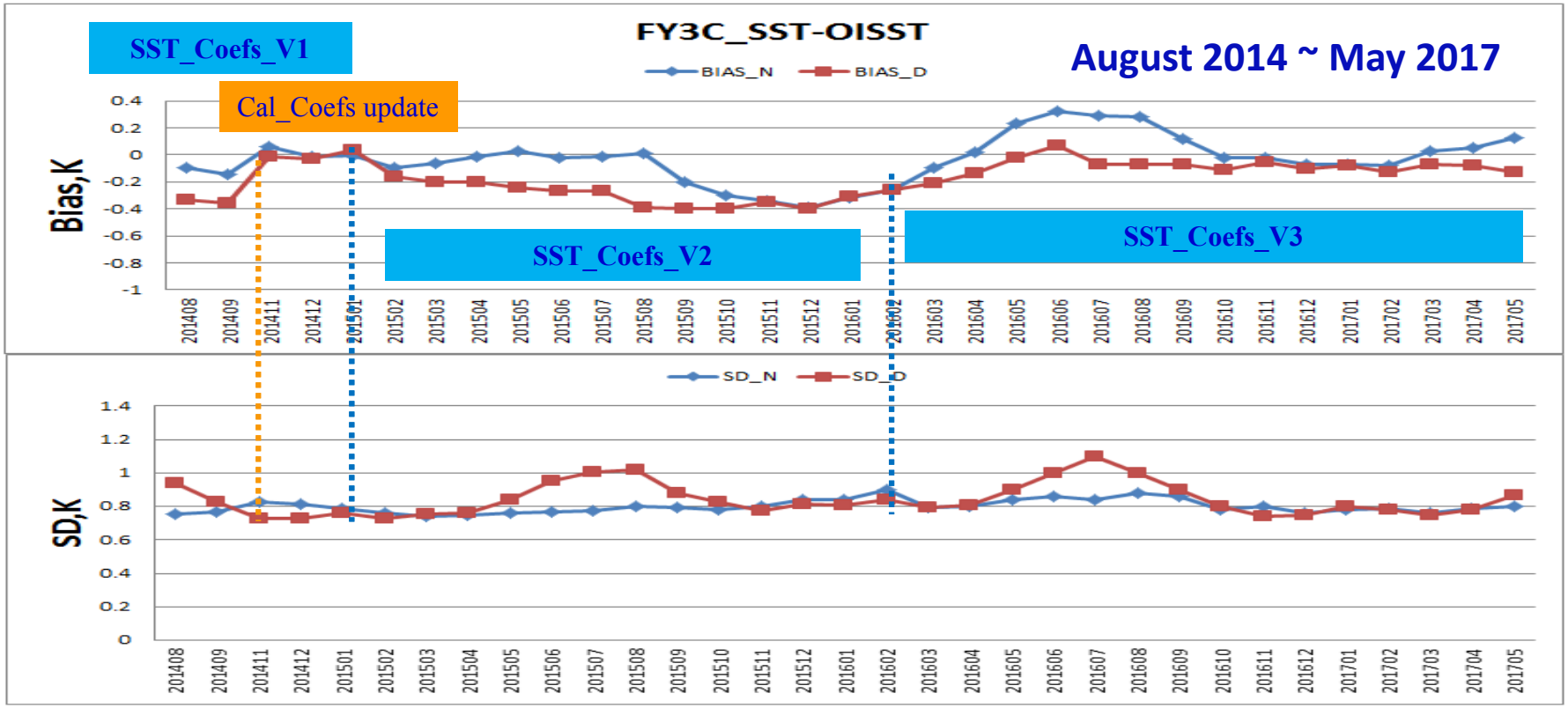
- **Validate SST against in situ data (matchup analyses)**
  - **matchup window：within 1hour Min and 1.1km**
  - **FY3C_SST-BuoySST**
- **Compare SST against Global gridded L4 SST : OISST**
  - matchup window： within 1 Day and 1.1 km
  - OISST is bilinearly interpolated to sensor's pixels
    - **daily 0.25° × 0.25° (lat/lon grid)**
  - Statistics are based on FY3C_SST-OISST according to quality flag

2014/3/9 07:10 UTC



FY3C_SST **FY3C-QC** **FY3CSST-OISST**

There are some abnormal of FY3 SST, is algorithm stable?

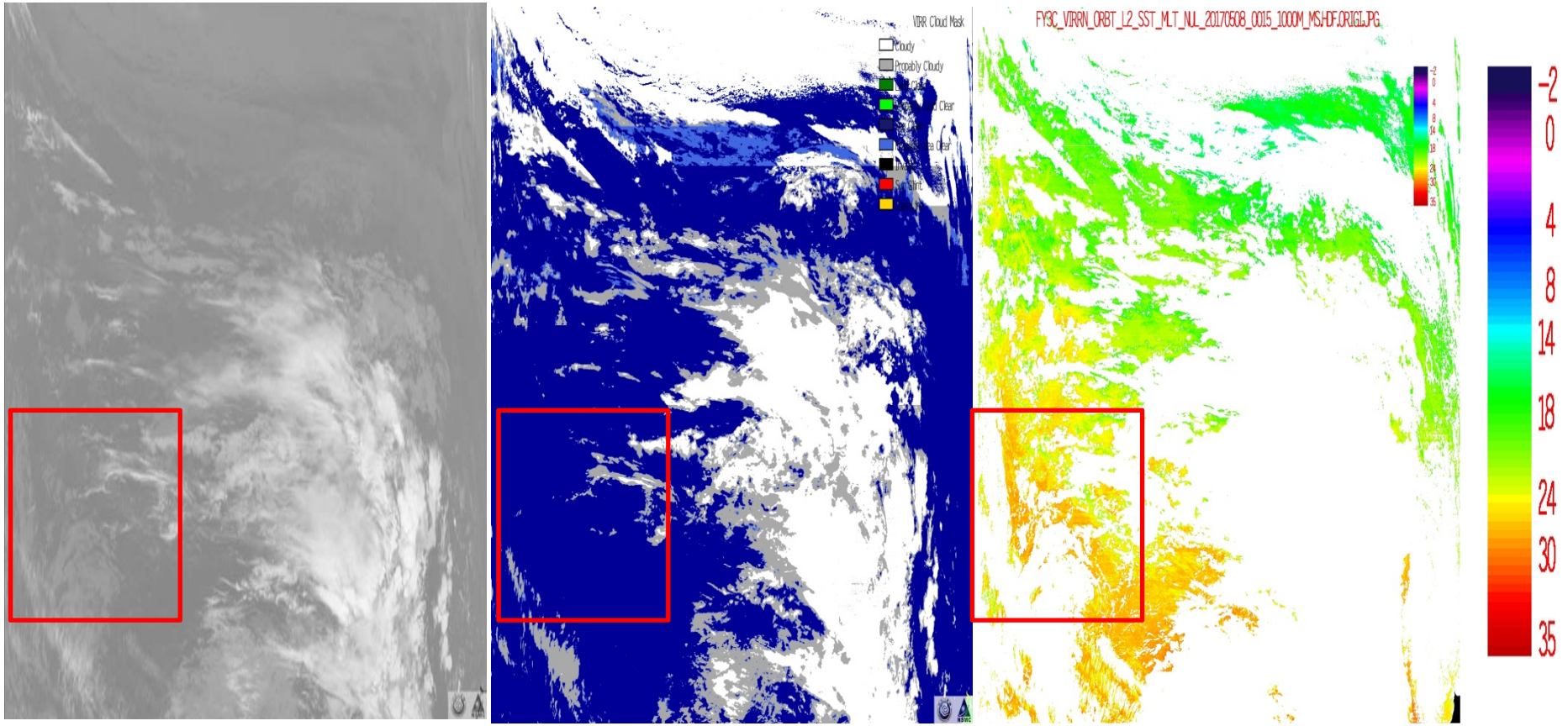


The monthly time series of anomaly statistics of FY-3C/VIRR operational SST from August 2014 to May 2017 for the quality flag with optimal(0)。

- ✓ **Before Jan 2015, the SST_Coefs_V1 was used by retrieval**
- ✓ **On 30 Oct. 2014, the Cal_Coefs was updated.**
- ✓ **On 19 Jan.2015, the SST_Coefs_V2 was available.**
- ✓ **Since Sep.2015, the cold bias was increased.**
- ✓ **On 19 Jan.2016,the SST_Coefs_V3 was used ever since then.**

- May 2014–Jan. 2015, Coefs_V1
- Feb. 2015–Jan. 2016, Coefs_V2
- Jan. 2016– today, Coefs_V3

Anomaly records: Cloud Contamination

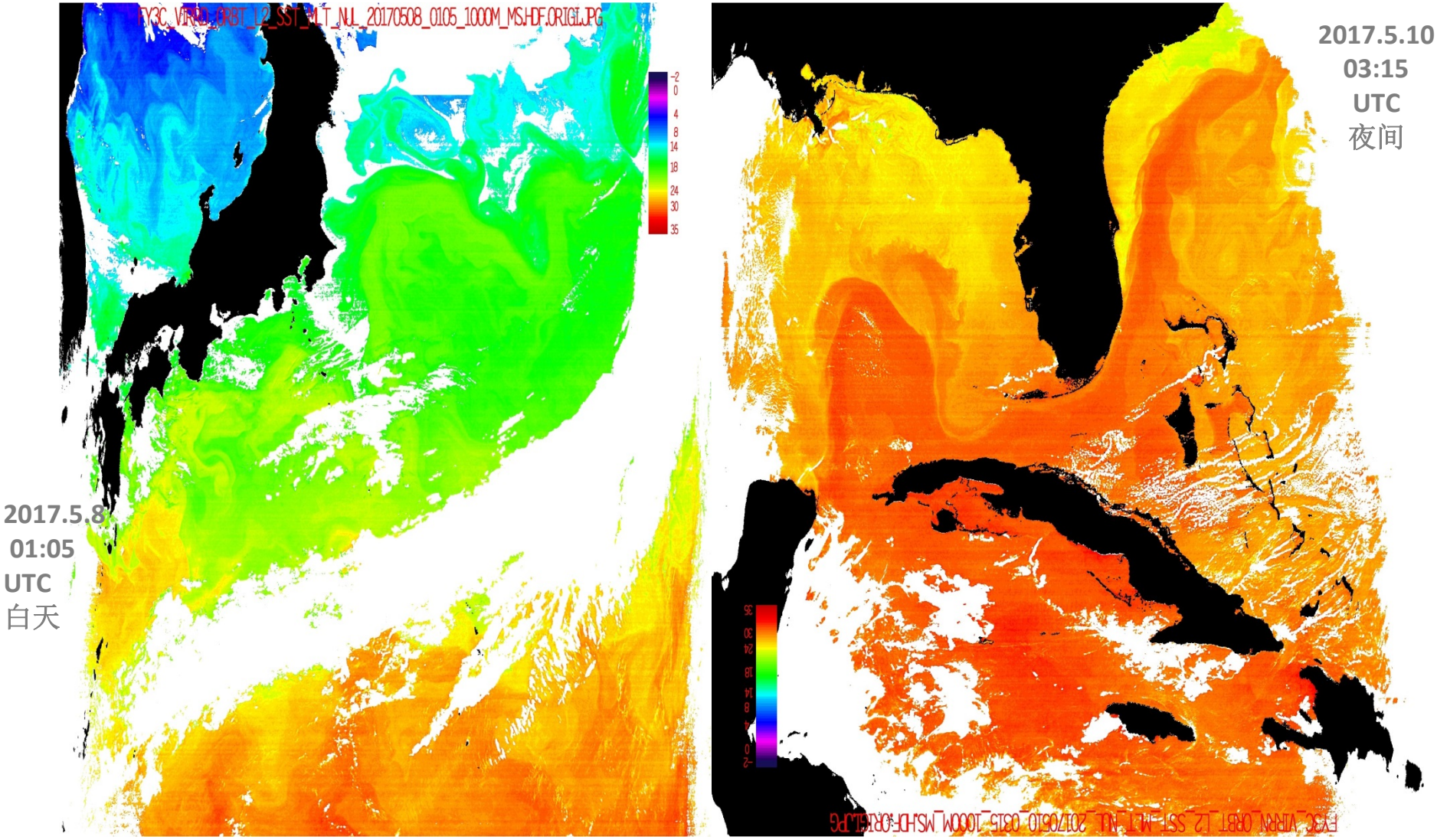


IR **Cloud Mask** **SST**

FY-3C VIRR 2017/5/8 00:15 UTC

After spacial uniformity test and reference SST test of FY-3C/VIRR SST retrieval, the undetected cloud is reduced. But the cloud contamination still exist.

Anomaly records: :Stripe



Stripe is clearly visible in VIRR level 2 SST images. This can cause SST anomaly.

Anomaly records : Sensor Performance degrade

TCSST(N) $$T_s = a_0 + a_1 T_{11} + a_2 T_4 + a_3 T_{12} + a_4 (T_4 - T_{12})(\sec\theta - 1) + a_5 (\sec\theta - 1)$$

T_4， T_{11}， T_{12}：brightness temperature in 3.7μm(CH3)、10.8μm(CH4)、12μm(CH5) bands

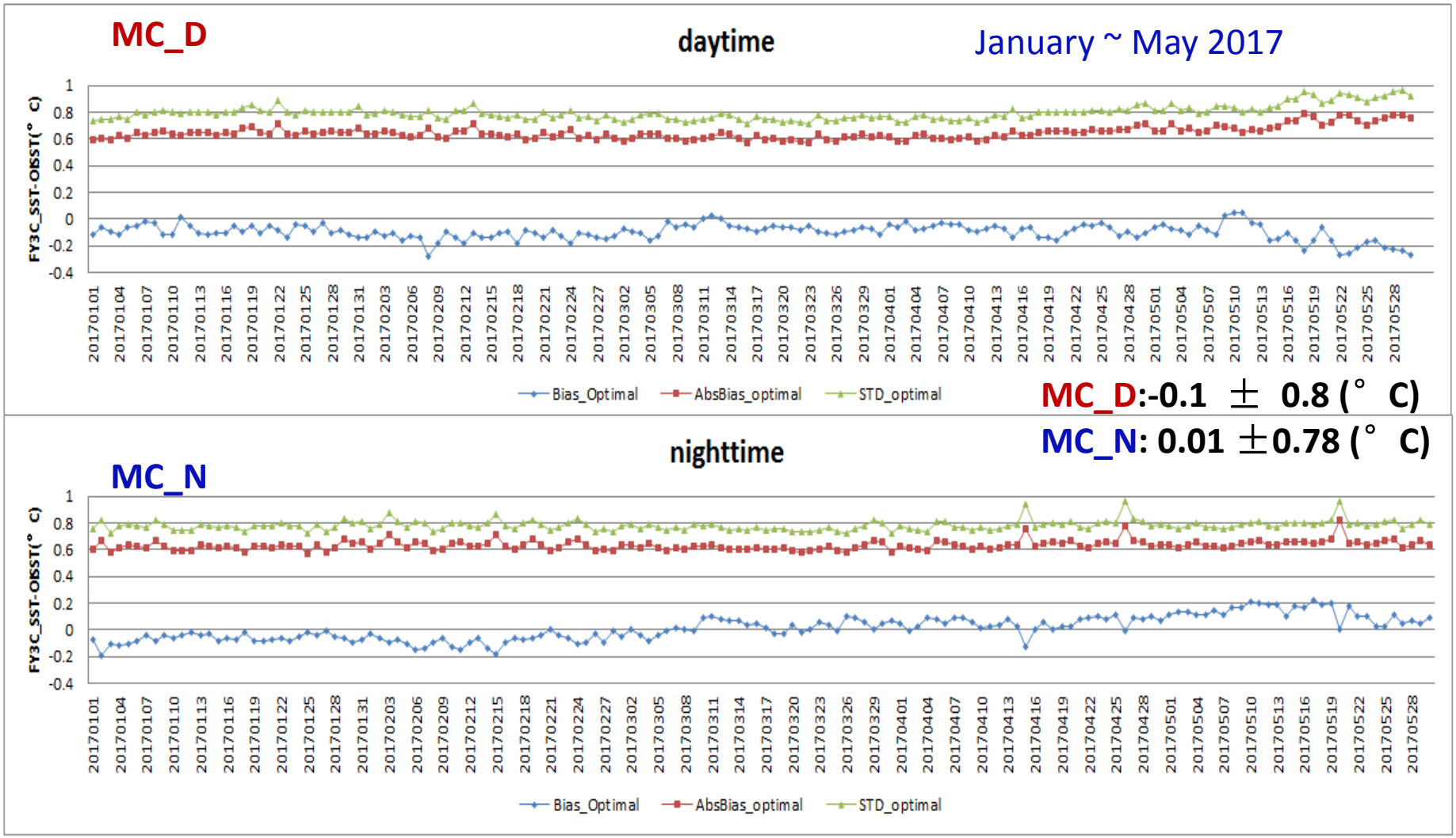
Sat/Sensor	a0	a1	a2	a3	a4	a5	RMS (K)	R^2	NOBS	Month
NOAA-19/ AVHRR(NP)	-275.815	0.5623	1.0432	-0.5922	0.2018	1.1280	0.2421	0.999	**8462**	201012
FY-3B/VIRR	-284.223	2.1226	0.6939	-3.0863	0.0922	1.5118	0.5763	0.993	**4813**	201612
FY-3C/VIRR	-284.450	1.9625	0.7764	-1.6893	0.1282	1.5697	0.3729	0.996	**5118**	201612

Comparison of nighttime TCSST Algorithm between FY3B /C and NOAA19

- **NOAA19:** $|a_2|$ is **bigger** than $|a_1|$ and $|a_3|$
- **FY3B:** $|a_2|$ is **smaller** than $|a_1|$ and $|a_3|$
- **FY3C:** $|a_2|$ is **smaller** than $|a_1|$ and $|a_3|$

The performance of 3.7μm band of FY3B/C VIRR is worse than NOAA19/AVHRR.

Compare FY-3C/VIRR operational SST against Daily OISST



The daily time series of anomaly statistics of FY-3C/VIRR operational SST from January to May 2017 for the quality flag with optimal(0)。

Summary and Future work

❑ Summary

FY-3C minus in situ (Time period: Nov. 2016 ~ Jan. 2017)

- the daytime bias is 0.17K with a standard deviation of 0.52K,
- the nighttime bias is 0.07K with standard deviation of 0.54K.

FY-3C minus OISST (Time period: Jan.~May 2017)

- the bias of daytime is -0.1K with a standard deviation of 0.8K,
- the nighttime bias is 0.01K with standard deviation of 0.78K.

❑ Future work

1. **Populate MDB and do Validation**
2. **Developing quality index**
3. **Discussion with Calibration Team to improve input sensor data quality**

Acknowledgements

Thanks to NOAA/NESDIS/STAR for iQUAM in situ SST and Cal/Val data.

Thanks to NOAA/NCDC for Reynolds OI v2. daily SST.

Thanks to NOAA/OAR/ESRL for the long term monthly means OISST.

Thank you!