FY-3C/VIRR SST Algorithm and Cal/Val Activities at NSMC/CMA

Sujuan Wang(wangxj@cma.gov.cn)
Xiaohu Zhang, Peng Cui, Peng Zhang,
Maonong Ran, Feng Lu, Weihe Wang

National Satellite Meteorological Center, CMA

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- SST algorithms
- The implement of FY-3C/VIRR SST
- The best algorithm to retrieve SST
- The validation of FY-3C/VIRR SST
- Summary and Future work

Introduction

- Fengyun-3 (FY-3) is the second generation of polar-orbiting meteorological satellite of China.
- The first series 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 series 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 10:00 AM in descending node.
- The visible infrared radiometer (VIRR) is a 10-channel radiometer for multi-purpose imagery with 1.1km resolution at nadir. The swath of the VIRR is 2800km.
- The 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.
- At present, the operational SST algorithm of FY-3 is MCSST.

SST Algorithms

day

MCSST(D/N)	$T_s = a_0 + a_1T_{11} + a_2(T_{11} - T_{12}) + a_3(T_{11} - T_{12})(\sec\theta - 1)$
QDSST(D/N)	$T_s = a_0 + a_1T_{11} + a_2(T_{11} - T_{12}) + a_3(T_{11} - T_{12})^2 + a_4(\sec\theta - 1)$
NLSST(D/N)	$T_s = a_0 + a_1T_{11} + a_2T_{FG}(T_{11} - T_{12}) + a_3(T_{11} - T_{12})(\sec\theta - 1)$
TCSST(N)	$T_s = a_0 + a_1T_{11} + a_2T_4 + a_3T_{12} + a_4(T_4 - T_{12})(\sec\theta - 1) + a_5(\sec\theta - 1)$
DNSST(N)	$T_s = a_0 + a_1T_{11} + a_2T_{FG}(T_4 - T_{11}) + a_3(\sec\theta - 1)$

T_S： satellite-derived SST
T_{FG}： first-guess SST
θ： satellite zenith angle
$a_0 \sim a_4$： coefficients
T_4， T_{11}， T_{12}： brightness temperature in 3.7μm(CH3)、10.8μm(CH4)、12μm(CH5) bands

The 3.7μm band is very transparent and is available for SST retrievals at night, while during daytime it is contaminated by solar reflectance.

SST Algorithms(cont.)

day

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

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).

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 implement of FY-3C/VIRR SST: Matchup

- Quality controlled in situ data from the iQUAM(in situ Quality monitor) is used in FY3C/VIRR SST matching up procedure.
- Matchup window: within 3km in space and 1hour in time between in situ SST measurements and FY-3C/VIRR measurements.
- 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.

The implement of FY-3C/VIRR SST: Regression

All the screening and outlier removal are handled in the regression code, depending on configurations in the control file. Currently the following conditions are set:

- Matchup maximum Distance: 1.1 km
- Matchup maximum Time difference: 60 minutes
- The high-accuracy drifters and tropical moorings are used
- Regression is performed separately for day and night based on the solar zenith angle (85^o)
  - After all the pre-screening and screening, Least-Square Regression is used for estimating the first-guess coefficient and SST residuals.
  - Further outliers are removed using Median±2STD(STD: standard deviation).
  - The final coefficients of dual regression are estimated.

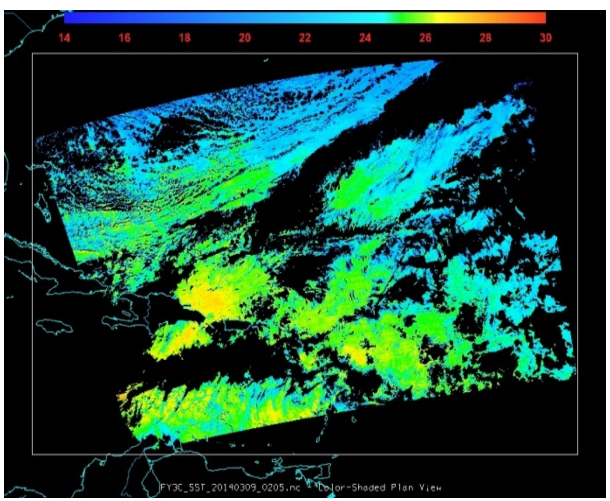
In order to perform the inter-comparison, all the 3 daytime equations and 5 nighttime equations are used to estimate the SST with the same FY-3C/VIRR MDB.

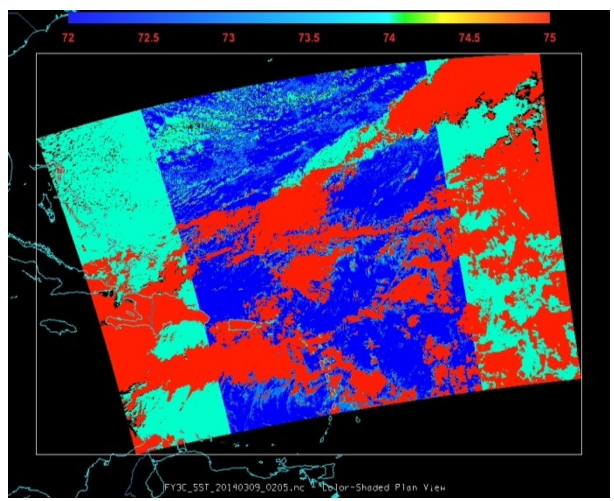
The implement of FY-3C/VIRR SST: Retrieval

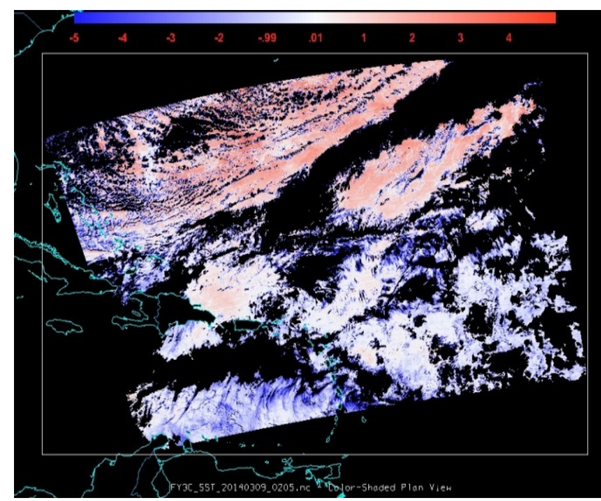
- **Retrieval**
  - **SST Quality control**
    - Uniformity test **(3*3 pixel box)**
      - ✓ MaxTB-MinTB <= 3K
      - ✓ |SST-TB11| <= 10K
    - Ref SST test **(sst.ltm.1981-2010.nc)**
      - ✓ |SST-RefSST|<=4K
  - **SST Quality Flag**

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)

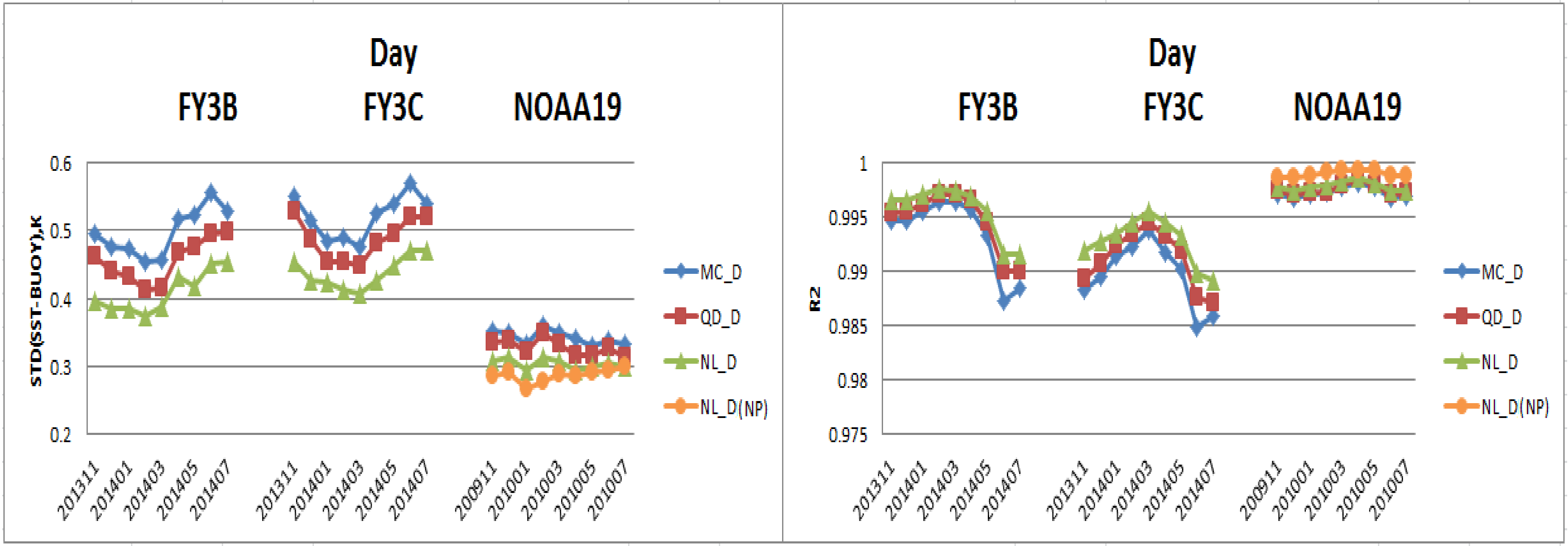






The best algorithm to retrieve the SST Daytime

Suffix with NP is the result from NESDIS/STAR



FY3B/C: November 2013 ~ July 2014

NOAA19: November 2009 ~ July 2010

For inter-sensor comparison, the same procedure are implemented to FY-3B/C and NOAA19 MDB. Validation statistics are generated on a monthly basis.

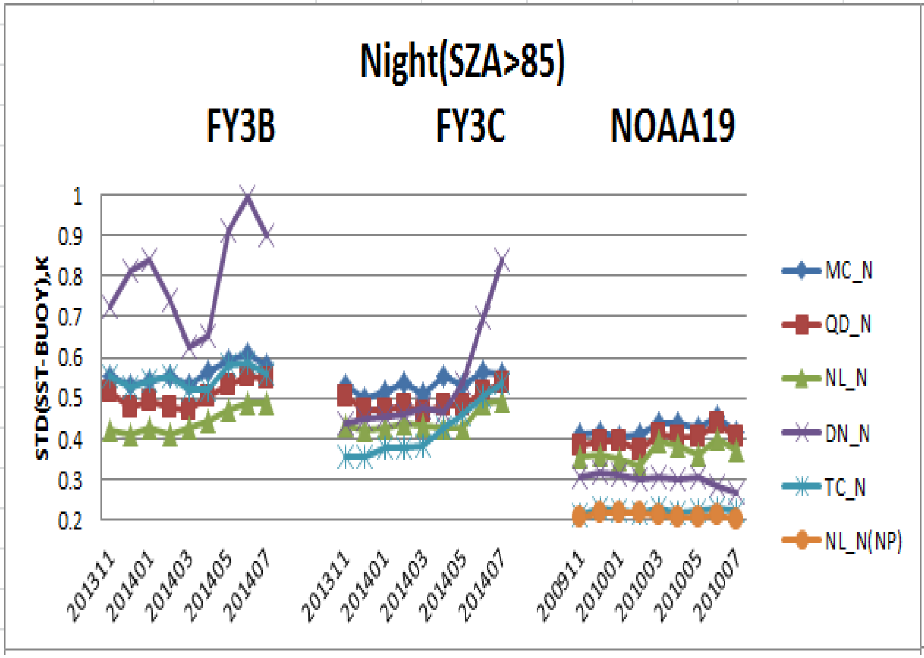
- **For the three daytime SST algorithms, NL_D is the best algorithm, QD_D is better than MC_D.**
- **FY-3B's best algorithm NL_D is better than FY-3C's NL_D.**
- **The precision of NOAA-19/AVHRR is better than FY-3B/VIRR and FY-3C/VIRR .**
- **For NOAA-19/AVHRR, STAR/NESDIS's best daytime SST algorithm NL_D(NP) is better than NSMC/CMA'S NL_D.**

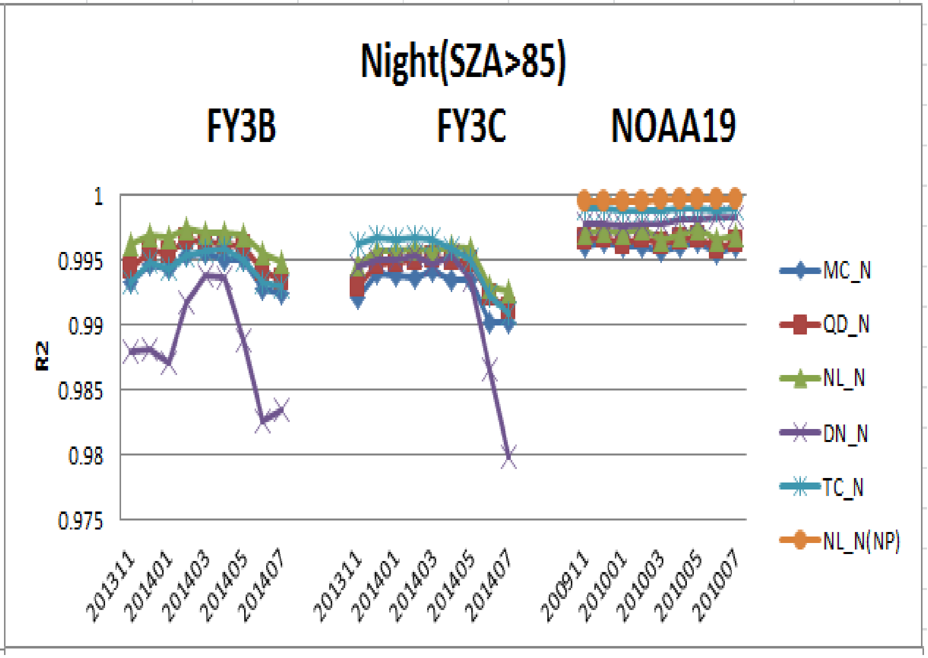
The best algorithm to retrieve the SST Nighttime

- When solar zenith angle(SZA) between 85º and 118º the calibration of 3.7μm band is contaminated by solar reflectance (the improvement is underway).
- So the nighttime MDB is created twice, one for SZA>85º (namely MDB_V1), another for SZA>119 º (namely MDB_V2).

The best algorithm to retrieve the SST Nighttime (MDB_V1)

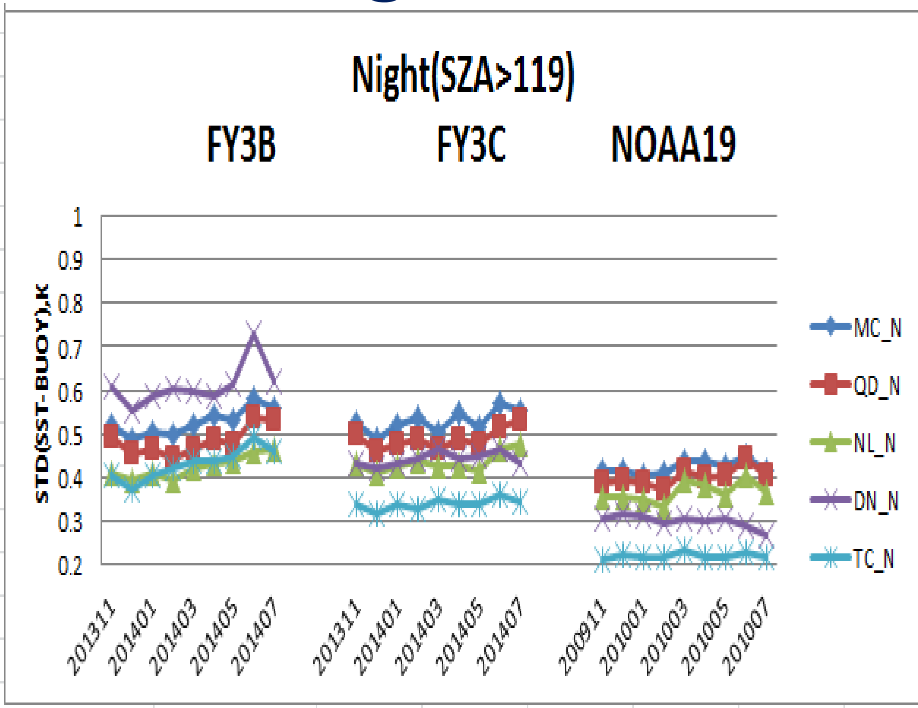
Suffix with NP is the result from NESDIS/STAR

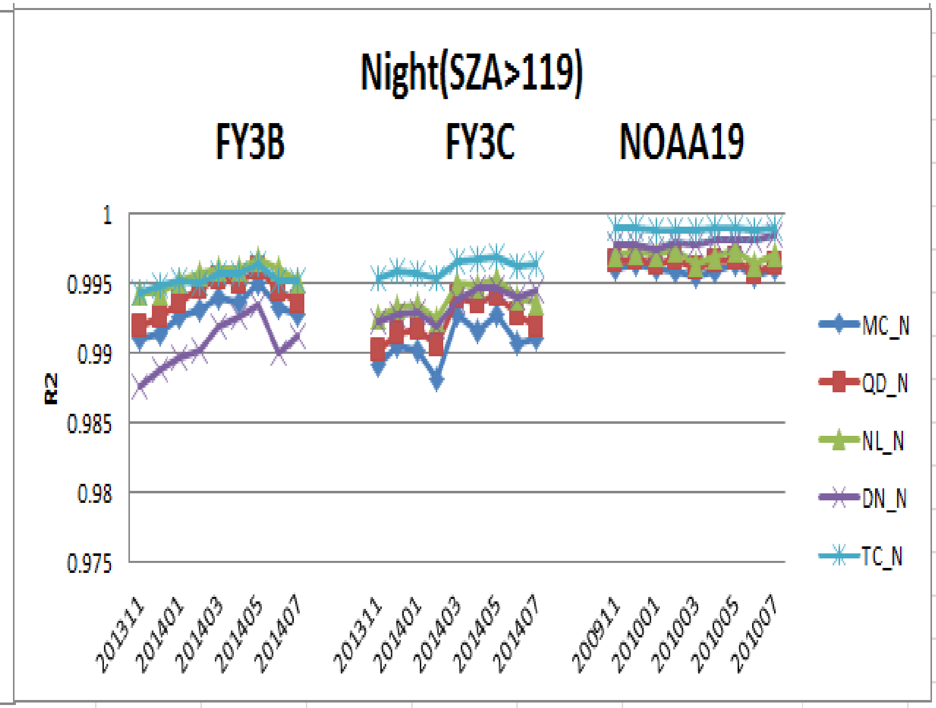




- **For FY3C, TC_N is the best before March 2014, after that it is worse than NL_N.**
- **For FY3B, NL_N is the best, QD_N is better than other three nighttime SST algorithms. TC_N is similar to MC_N, DN_N is the worst and is very unstable.**
- **For NOAA19, TC_N is the best, DN_N is better than other three algorithms, QD_N is similar to MC_N.**
- **Based on NOAA-19/AVHRR MDB_V1, NSMC/CMA'S best nighttime SST algorithm TC_N is similar to STAR/NESDIS's TC N(NP).**

The best algorithm to retrieve the SST Nighttime (MDB_V2)





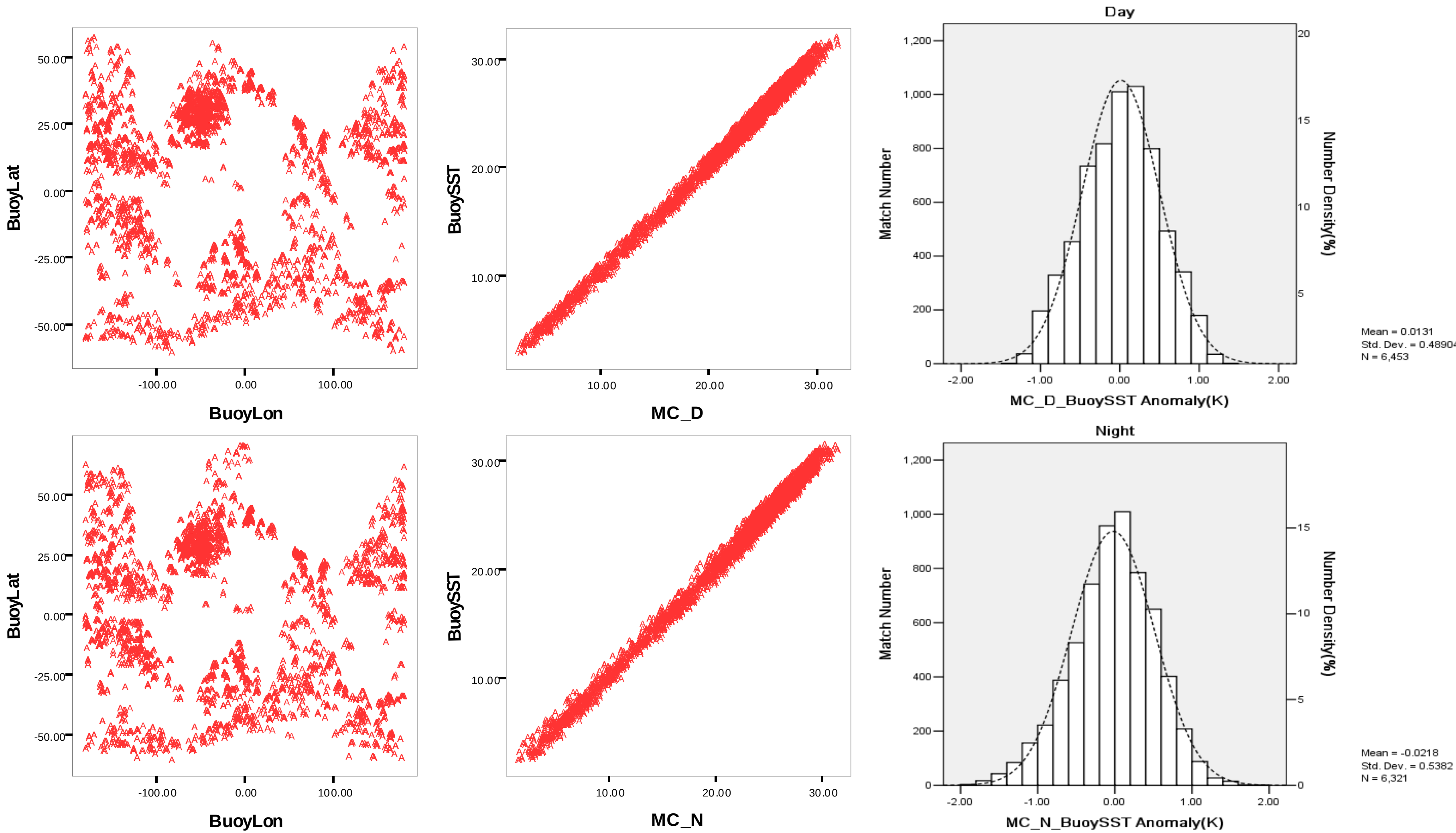
- **For FY3C, TC_N is the best algorithm, DN_N is similar to NL_N.**
- **For FY3B, NL_N is similar to TC_N. But, DN_N (also used 3.7) is still the worst one.**
- **For NOAA19, TC_N is the best, DN_N is better than other three algorithms.**
- **Based on MDB_V2,the overall performance of FY3B/C VIRR SST algorithms are better than MDB_V1.**

The validation of FY-3C/VIRR SST

- **Validate SST against in situ data (matchup analyses)**
  - **Coefficients are derived from MDB since November to December 2014 .**
  - **An independent MDB of January 2015 are used for validation.**
  - **match window：within 60 minutes and 1.1km**
  - **FY3C_SST-BuoySST(satellite SST minus buoy SST)**

- **Compare SST against Global gridded L4 SST : OISST**
  - **match window ： within 1 Day and 1.1km**
  - **OISST is bilinear interpolated to sensor’s pixels**
    - **daily 0.25º × 0.25º (lat/lon grid)**
  - **FY3C_SST-OISST**
  - **Statistics are generated according to quality flag**

Validate FY-3C/VIRR SST against in situ data (matchup analyses 2015.1)



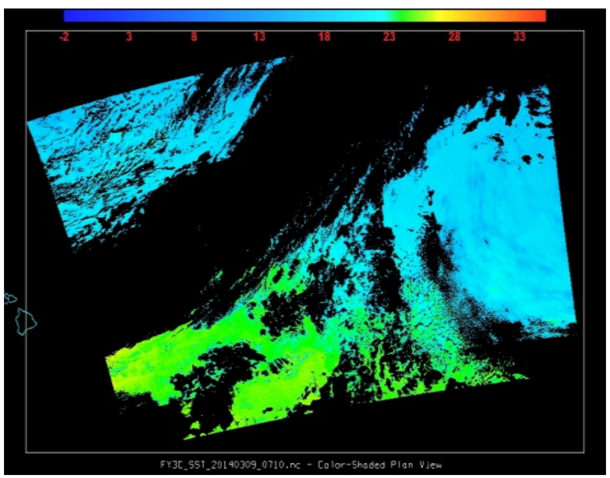
The coefficients are derived from November to December 2014 MDB, an independent MDB of January 2015 was used to assess the FY-3C/VIRR SST accuracy.

- **MC_D bias: 0.01K STD:0.49K**
- **MC_N bias: -0.02K STD:0.54K**

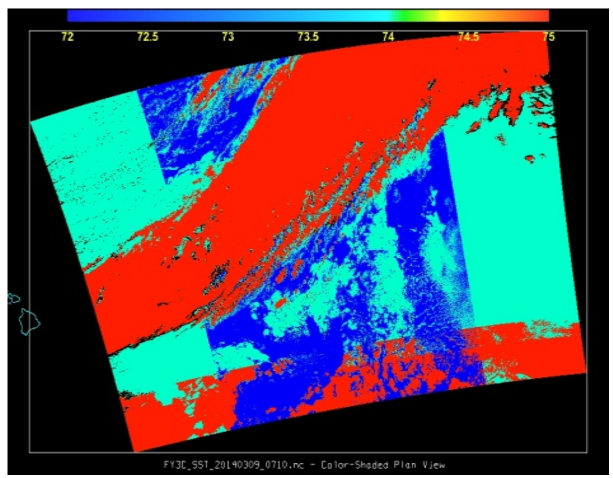
The validation of FY-3C/VIRR SST(cont.)

- Validate SST against in situ data (matchup analyses)
  - match window：within 60 Min and 1.1km
  - FY3C_SST-BuoySST
- **Compare SST against Global gridded L4 SST : OISST**
  - match window： within 1 Day and 1 IR pixel
  - OISST is bilinear interpolated to sensor’s pixels
    - daily 0.25º × 0.25º (lat/lon grid)
  - Statistics are based on FY3C_SST-OISST according to quality flag

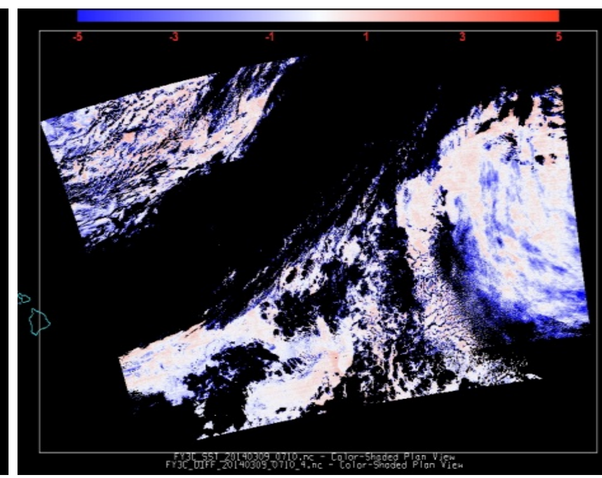
2014/3/9 07:10 UTC



FY3C_SST



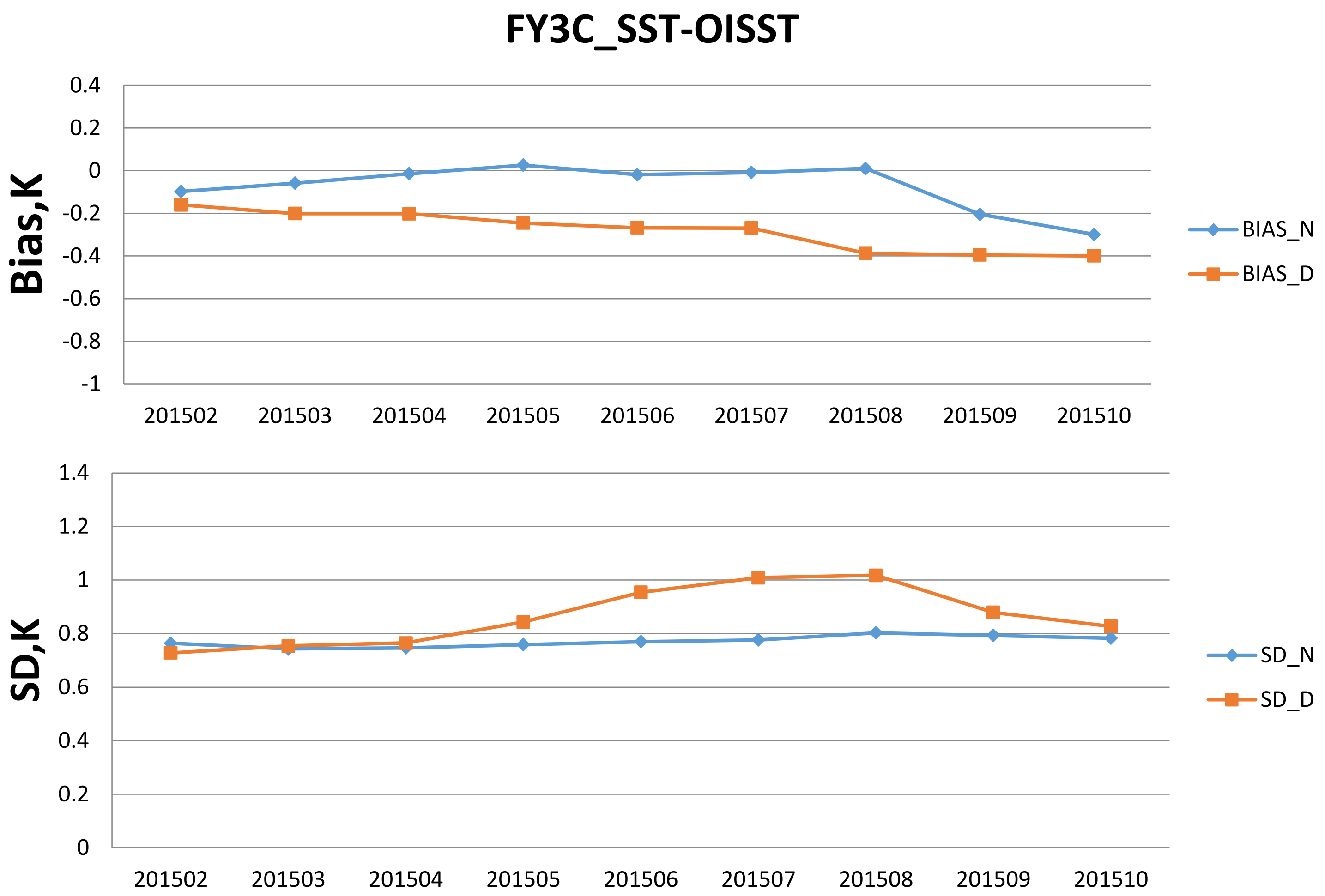
FY3C-QC



FY3CSST-OISST

L2 SST Analysis is based on the 5-minute granule of FY3CSST-OISST

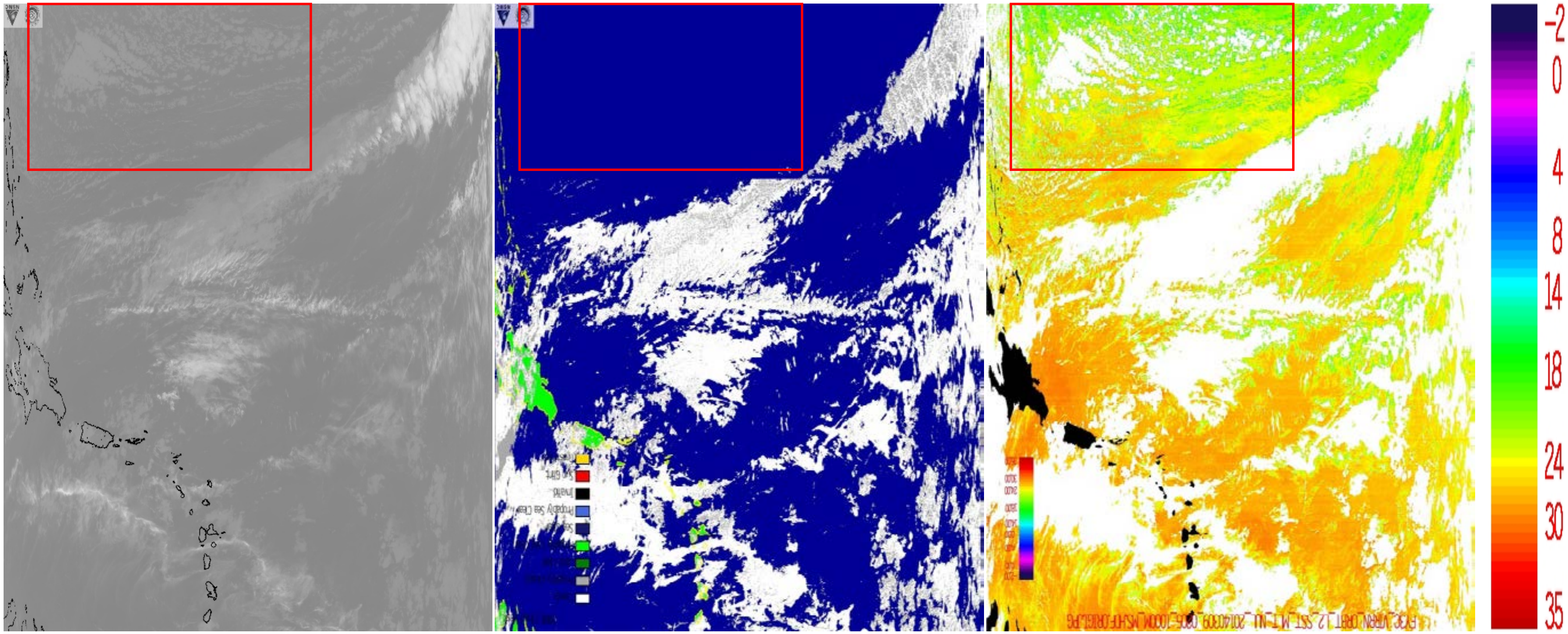
Compare FY-3C/VIRR operational SST against Daily OISST



the time series of anomaly statistics of FY-3C/VIRR operational SST of February to October 2015 for the quality flag with optimal(0).

- **MC_D bias: -0.27K STD:0.87K**
- **MC_N bias: -0.05K STD:0.77K**

Error Analysis: Cloud Contamination



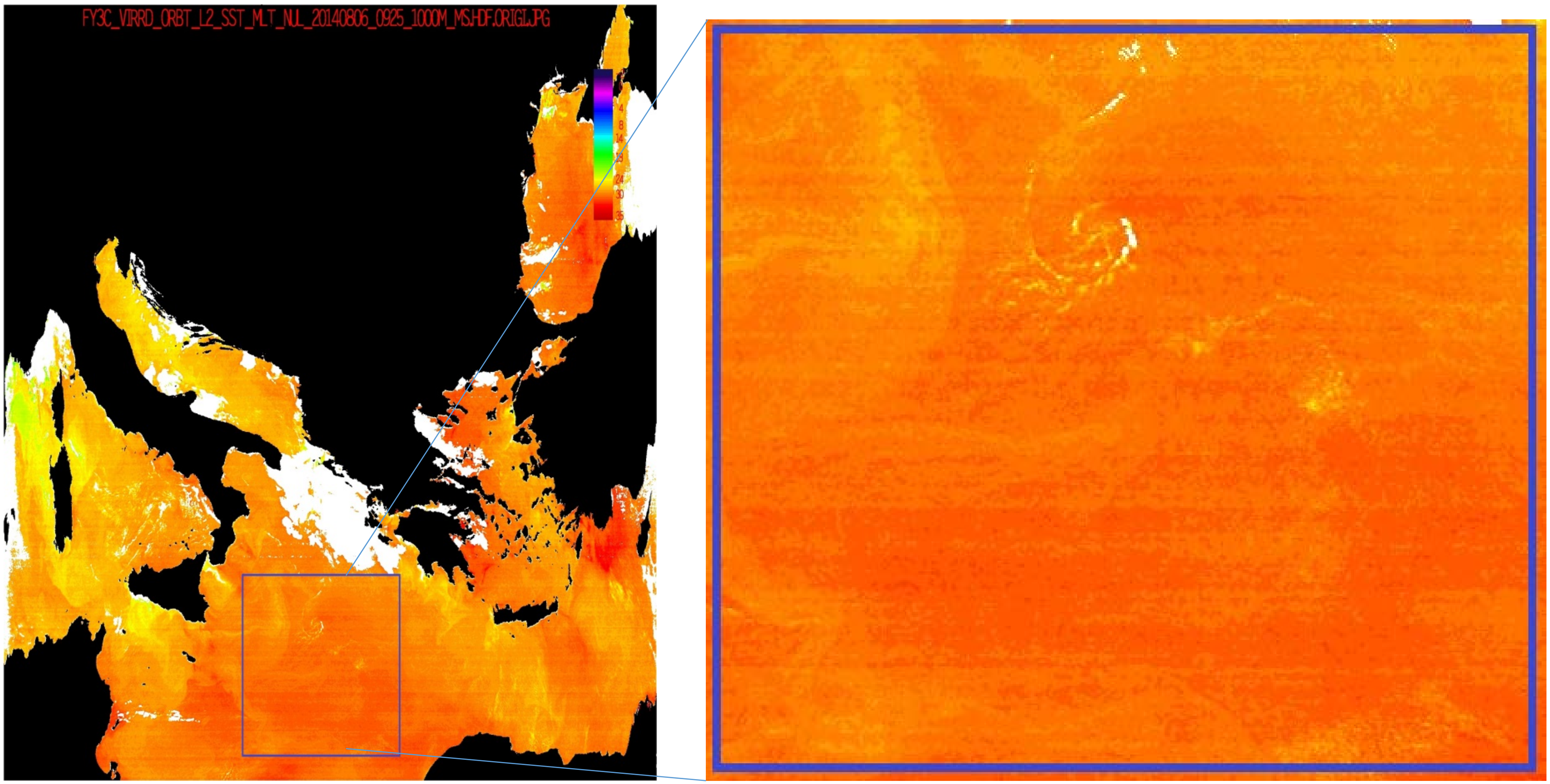
IR | Cloud Mask | SST

FY-3C VIRR 2014/3/9 02:05 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.

Error Analysis: Stripe

2014/8/6 09:25 UTC



Stripe is clearly visible in VIRR level 2 SST images. It is caused by the calibration coefficients of split-window bands don't match. This can introduce SST error.

Error Analysis: Sensor Performance

Comparison of nighttime TCSST Algorithm between FY3B /C and NOAA19

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)	−276. 60658	0. 32666	1. 146	−0. 45606	0. 1306	1. 3478	0. 2101 4	0. 9995	7046	201007
FY-3B/VIRR(MDB_V2)	−284. 22294	2. 12257	0. 69388	−1. 77498	0. 2324	1. 6420	0. 4583 3	0. 9951	5939	201407
FY-3C/VIRR(MDB_V2)	−285. 34442	1. 15173	1. 01402	−1. 11001	0. 1241	1. 7967	0. 3434 1	0. 9964	7424	201407

Based on MDB of July， the best nighttime SST algorithm of FY3C/VIRR and NOAA19/AVHRR is TC_N.

- **NOAA19:** $|a_2|$ is **bigger** than $|a_1|$ and $|a_3|$
- **FY3B:** $|a_2|$ is **smaller** than $|a_1|$ and $|a_3|$
- **FY3C:** **The performance of 3.7μm band of FY3C/VIRR is better than FY3B/VIRR, but worse than NOAA19/AVHRR.**

Summary and Future work

❑Summary

- The performance of 3.7μm band of FY-3C/VIRR is better than FY-3B/VIRR, but worse than NOAA-19/AVHRR.
- The best algorithm to retrieve FY-3C/VIRR SST for daytime is NL_D and for nighttime is TC_N.
- Based on the independent MDB from November to December 2014, the global accuracy of FY-3C/VIRR SST is

  0.01K±0.49K(MC_D), -0.02K±0.54K (MC_N).
- Comparison with FY-3C/VIRR operational SST and daily OISST, the global accuracy of FY-3C/VIRR operational SST is

  -0.27K±0.87K(MC_D), -0.05K±0.77K (MC_N).

❑Future work

- Continue to populate MDB and do Calibration/Validation based on MDB
- Continue refinement of atmospheric correction for SST algorithm
- Work with Sensor Calibration Team to improve SST

Thank you for your attention!