SST ALGORITHMS IN ACSPO REANALYSIS OF AVHRR GAC DATA FROM 2002-2013

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Objectives

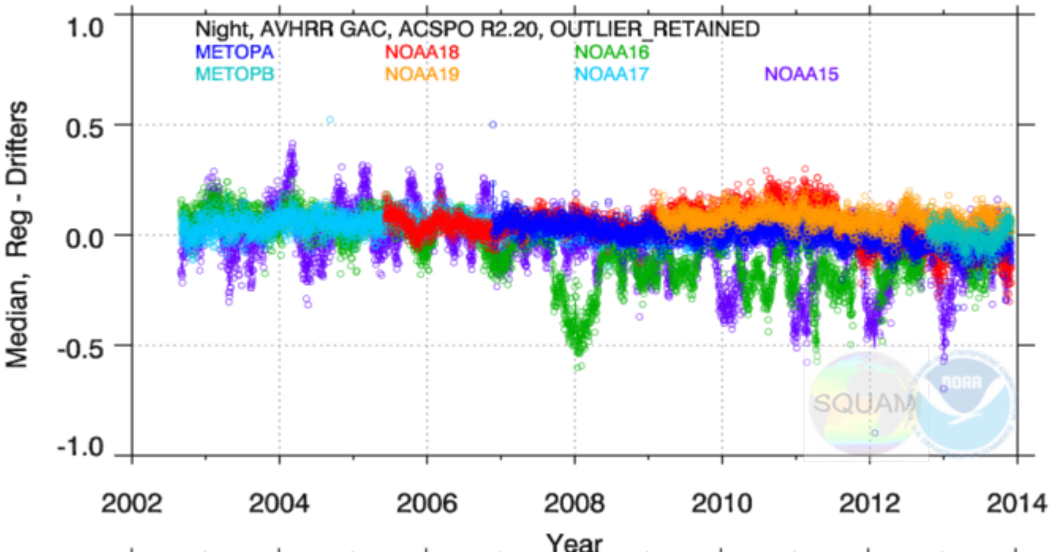
- Currently, multiyear 4 km AVHRR GAC data from NOAA-16, -17, -18, -19, MetOp-A and –B are being reprocessed at NESDIS, following a request from NOAA Coral Reef Watch program.
- The objective is to create consistent multiyear L2P SST data sets to meet as much as possible the following requirements:
  - ✓ Minimum regional SST biases
  - ✓ Close reproduction of SST variations
  - ✓ Temporal stability
  - ✓ Cross-platform consistency
- This presentation discusses the SST algorithms used in ACSPO-RAN

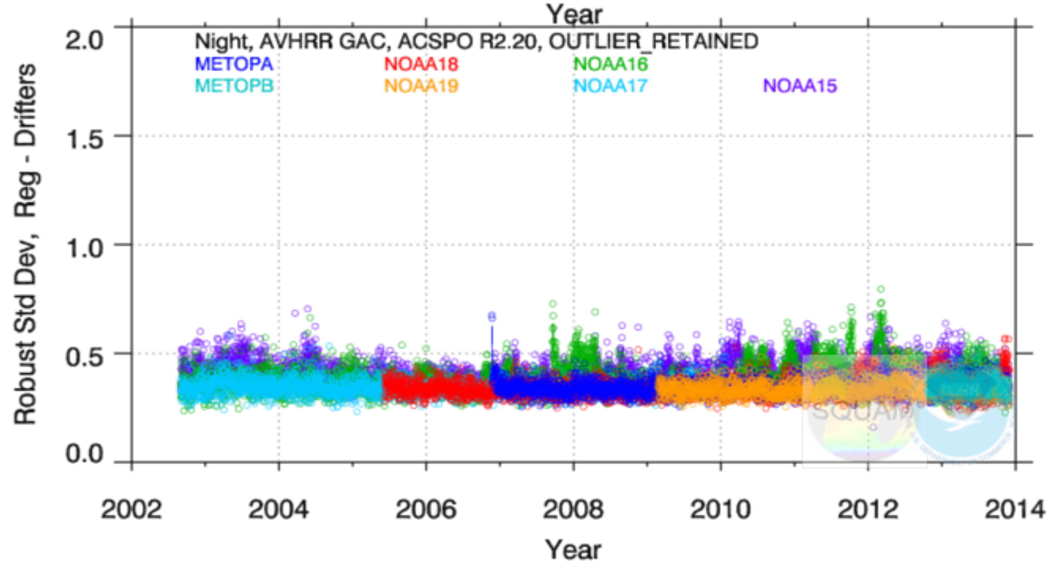
Stages of ACSPO-RAN

- **RAN1**:
  - AVHRR data from 2002-2013 reprocessed with ACSPO v. 2.20 (heritage regression SST algorithm + ACSPO Clear-Sky Mask)
  - Multiyear sets of matchups were created from clear-sky AVHRR BTs and QCed drifting/moored buoys' from iQuam; (www.star.nesdis.noaa.gov/sod/sst/iquam/)
  - The matchups were used to evaluate the SST algorithms.

- **RAN2**:
  - Selected SST algorithms implemented in ACSPO (v.2.31) RAN2
  - Separate L2P products generated with each algorithm
  - Results evaluated in MICROS (www.star.nesdis.noaa.gov/sod/sst/micros/) and SQUAM (www.star.nesdis.noaa.gov/sod/sst/squam/)
  - GHRSST CDAF methodology will be also explored

RAN1: Daily Nighttime Median and Robust SD for NOAA and MetOp AVHRRs (SQUAM)





- Daily statistics noisy (small match-up sample, geographic biases)
- Metop-A, -B, N-17, -18 are more stable, N-15, -16, -19 are less stable
- Instabilities in SST are strongly linked to calibration problems
- The work on recalibration of AVHRRs is underway
- Here, we will compare results for N-17, N-18 and MetOP-A only, because of better stability and longer time of operation

Explored SST algorithms

- **Regression**
  - ACSPO RAN1 (v2.20): heritage NOAA regressions are used
  - ACSPO v2.30 (NOAA operations) and 2.31 (RAN2): NOAA equations were replaced with OSI-SAF equations to minimize regional SST biases (*Petrenko et al., JGR, 2014*)

- **Incremental Regression**
  - Correlates deviations of SST from first guess with deviations of observed BT from simulations
  - Developed for GOES-R ABI *(Petrenko et al., RSE, 2011), r*eported at GHRSST-XII
  - Shown to perform at least comparably with other RTM-based algorithms *(Merchant et al., RSE, 2008, 2009; Le Borgne et al., RSE, 2011)*

OSI-SAF Regression Equations

Day:

$$T_S = a_0 + (a_1 + a_2 S_\vartheta) T_{11} + [a_3 + a_4 T_S^0 + a_5 S_\vartheta] (T_{11} - T_{12}) + a_6 S_\vartheta$$

Night:

$$T_S = b_0 + (b_1 + b_2 S_\vartheta) T_{3.7} + (b_3 + b_4 S_\vartheta) (T_{11} - T_{12}) + b_5 S_\vartheta$$

$T_{11}, T_{12}, T_{3.7}$ observed BTs

$S_\vartheta = 1/\cos(\vartheta)$ ϑ is satellite view zenith angle

T_S^0 first guess SST (in °C)

a’s and ***b***’s regression coefficients

- OSI-SAF equations explicitly include angular dependencies in all regression coefficients – beneficiary when working within a full swath

Incremental Regression Equations

- Day: $$T_S = T_S^0 + c_0 + c_1\Delta T_{11} + c_2(\Delta T_{11} - \Delta T_{12})T_S^0 + $$
$$+ c_3 S_\vartheta + c_4\vartheta + c_5 W + c_6 W^2 + c_7\varphi + c_8\varphi^2$$

- Night: $$T_S = T_S^0 + d_0 + d_1\,\Delta T_{3.7} + d_2\,\Delta T_{12} + $$
$$+ d_3 S_\vartheta + d_4\vartheta + d_5 W + d_6\varphi + d_7\varphi^2$$

ΔT_{11}, ΔT_{12}, $\Delta T_{3.7}$	BT increments (OBS – CRTM)
W	Total water vapor content in the atmosphere
φ	Latitude
c's and ***d***'s	"Least squares" regression coefficients

- The coefficients are derived from matchups of SST and BT increments
- The terms independent of ΔT are to correct for M-O biases
- Coefficients at ΔT are scaled to maintain sufficient sensitivity.

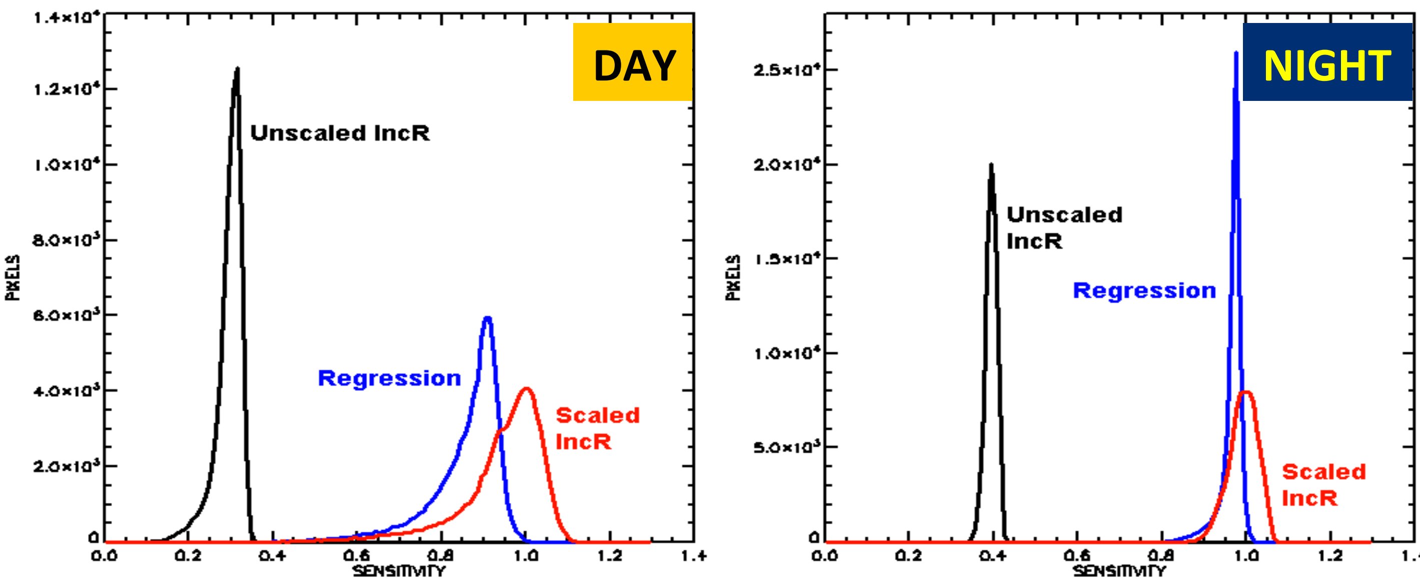
Scaling Incremental Regression Coefficients

Sensitivity μ of IncR SST to true SST is:

Day: $\mu=\alpha[c_1 D_{11} + c_2(D_{11} - D_{12})T_S^0]$,

Night: $\mu=\alpha[d_1 D_{3.7} + d_2 D_{12}]$

$D_{3.7}$, D_{11}, D_{12} are derivatives of BT wrt SST (from CRTM)



- The histograms of μ are shown for 2005 NOAA-17 matchups
- The sensitivity of unscaled IncR is unacceptably low
- Scaling brings the mean IncR sensitivity closer to 1 (on average, higher than for regression)

The effect of bias correction on IncR coefficients

(1) Daytime IncR, without bias correction:

$$T_S = T_S^0 + c_0 + c_1\Delta T_{11} + c_2(\Delta T_{11} - \Delta T_{12})T_S^0$$

(2) Daytime IncR, with bias correction:

$$T_S = T_S^0 + c_0 + c_1\Delta T_{11} + c_2(\Delta T_{11} - \Delta T_{12})T_S^0 + c_3 S_{\vartheta} + c_4 \vartheta + c_5 W + c_6 W^2 + c_7 \varphi + c_8 \varphi^2$$

Coefficient	(1)	(2)	(1) - (2), %
c_1	0.97426	.97046	-0.39%
c_2	.11718	.11794	-0.64%

- S_{ϑ}, ϑ, W and φ are statistically independent from $T_s^{in\ situ} - T_S^0$
- The use of BC terms insignificantly changes coefficients at BT increments

The effect of bias correction on Regression coefficients

(1) Regular regression equation:

$$T_S = a_0 + (a_1 + a_2 S_\vartheta) T_{11} + [a_3 + a_4 T_S^0 + a_5 S_\vartheta] (T_{11} - T_{12}) + a_6 S_\vartheta$$

(2) Same, with bias correction:

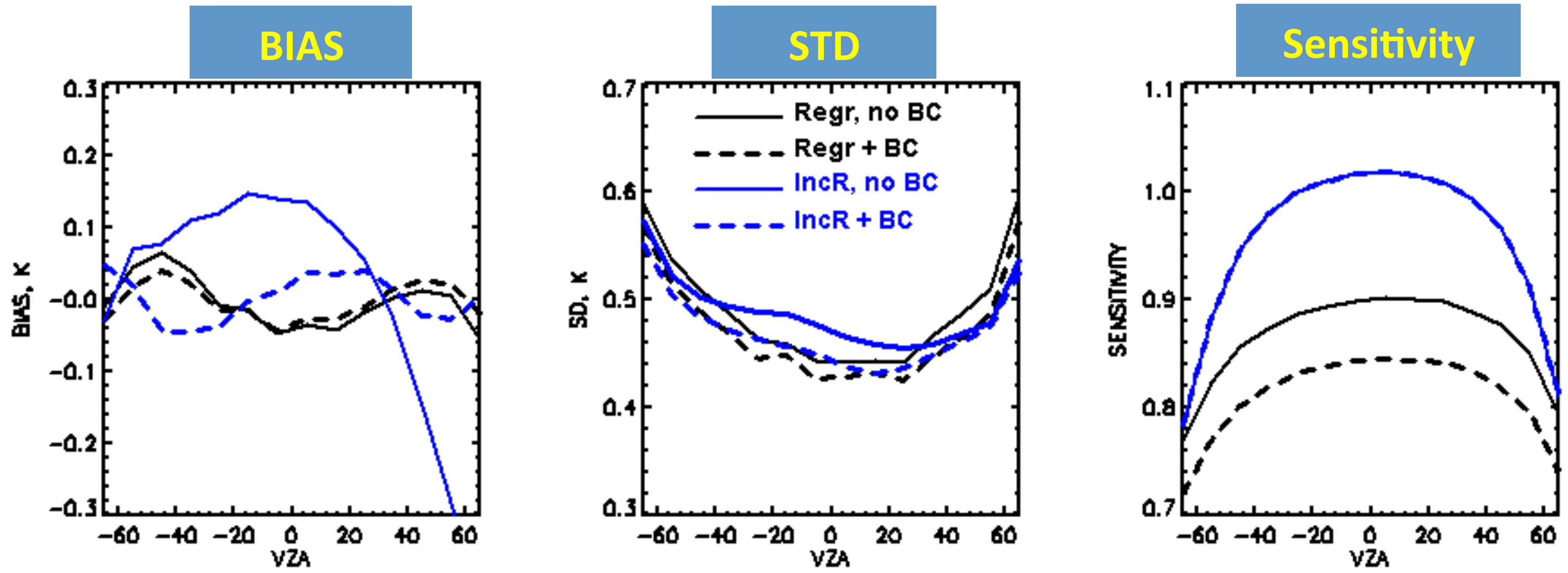
$$T_S = a_0 + (a_1 + a_2 S_\vartheta) T_{11} + [a_3 + a_4 T_S^0 + a_5 S_\vartheta] (T_{11} - T_{12}) +$$

$$+ a_6 S_\vartheta + a_4 \vartheta + a_5 W + a_6 W^2 + a_7 \varphi + a_8 \varphi^2$$

Coefficient	(1)	(2)	(1) - (2), %
a_1	9.4618e-01	9.0154e-01	-4.7%
a_2	1.4057e-02	1.2866e-02	-8.5%
a_3	1.6072e-01	1.3747e-01	-14.4%
a_4	7.6304e-02	6.8404e-02	-10.4%
a_5	5.7218e-01	5.6049e-01	-2.0%

- Due to correlation between $T_s^{in\ situ}$, W and φ, changes in regression coefficients are much greater than in IncR coefficients

The effect of bias correction on daytime statistics of SST as functions of VZA

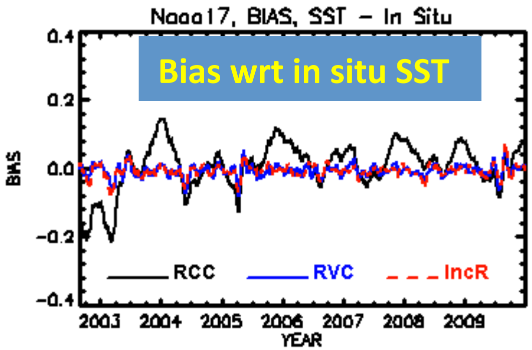


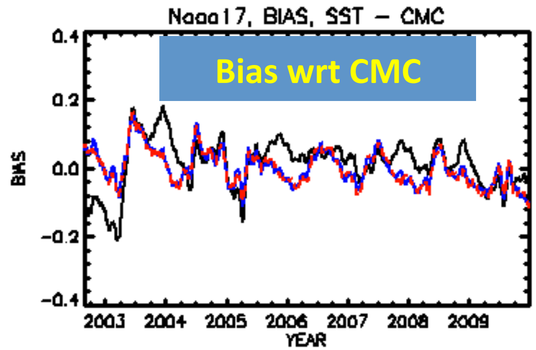
- Statistics are shown for 2005 NOAA-17 matchups
- Bias correction slightly improves Regression bias and SD, but significantly reduces sensitivity
- IncR without bias correction produces very large biases
- IncR with bias correction minimizes SST biases and SDs, but does not change sensitivity

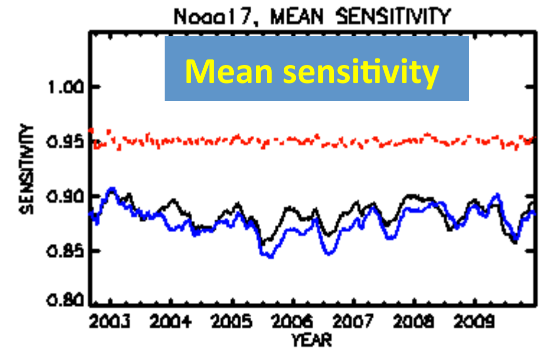
Using variable coefficients

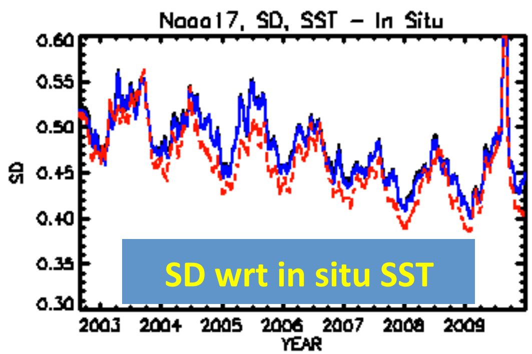
- In the NOAA operations, regression coefficients are calculated once and used for a long period of time; global biases may vary due to calibration trends in AVHRR BTs and changes in seasonal pattern of SST domain
- In the reprocessing, regression and IncR coefficients recalculated on a daily basis using matchups within 3 months running window (current day ±45 days).
- Here, we compare three SST algorithms:
  - Conventional regression with constant coefficients (**RCC)** - benchmark
  - Regression with variable coefficients (**RVC**) – improvement over the RCC
  - Incremental regression with variable coefficients (**IncR**) – improvement over the RVC

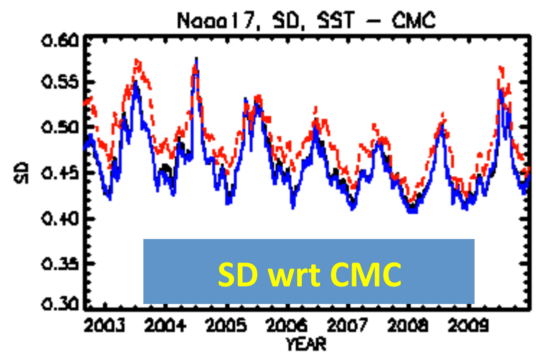
NOAA-17 (DAY): Time series of global monthly bias, SD and mean sensitivity







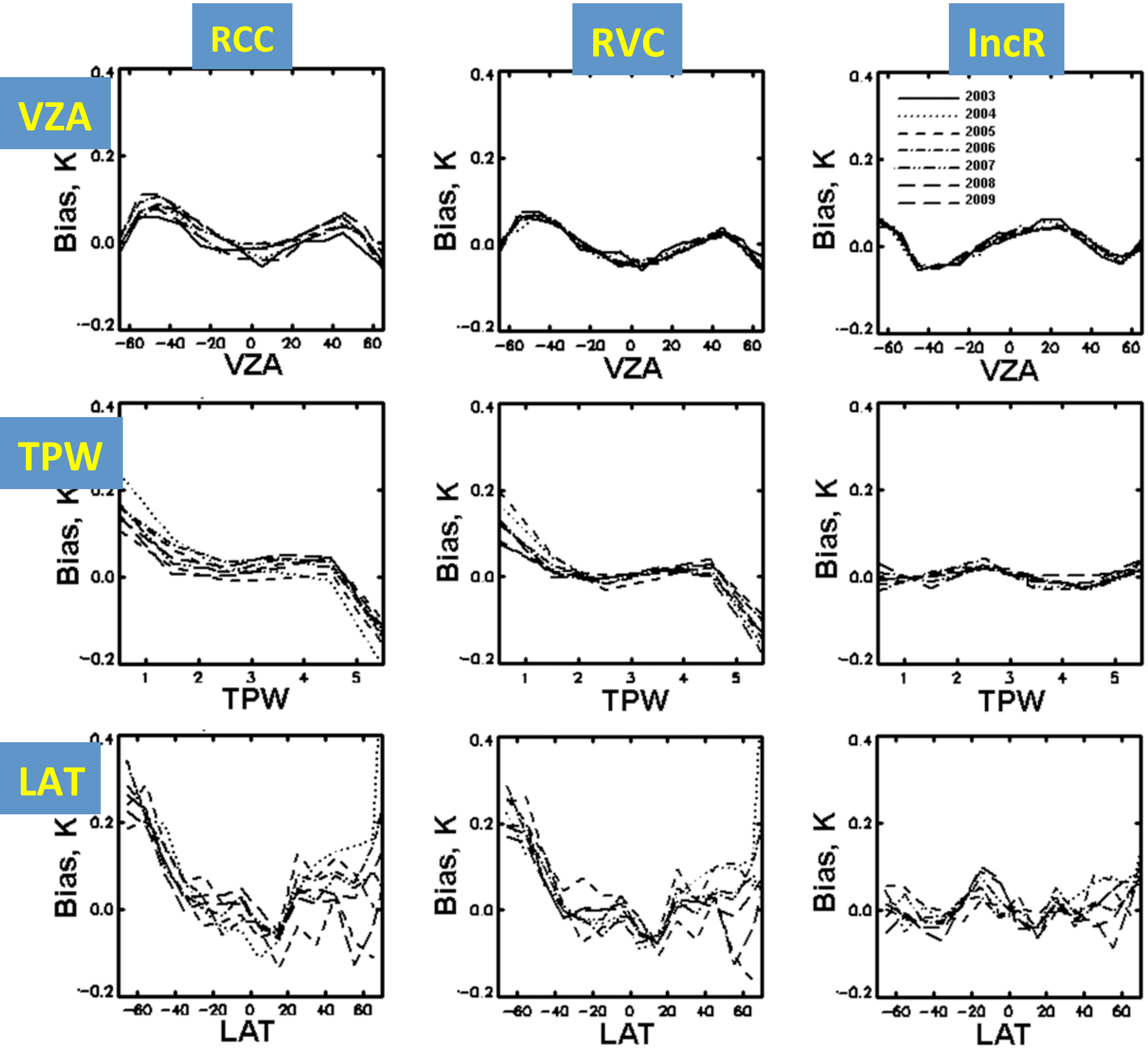




CMC is L4 SST produced by the Canadian Met Centre

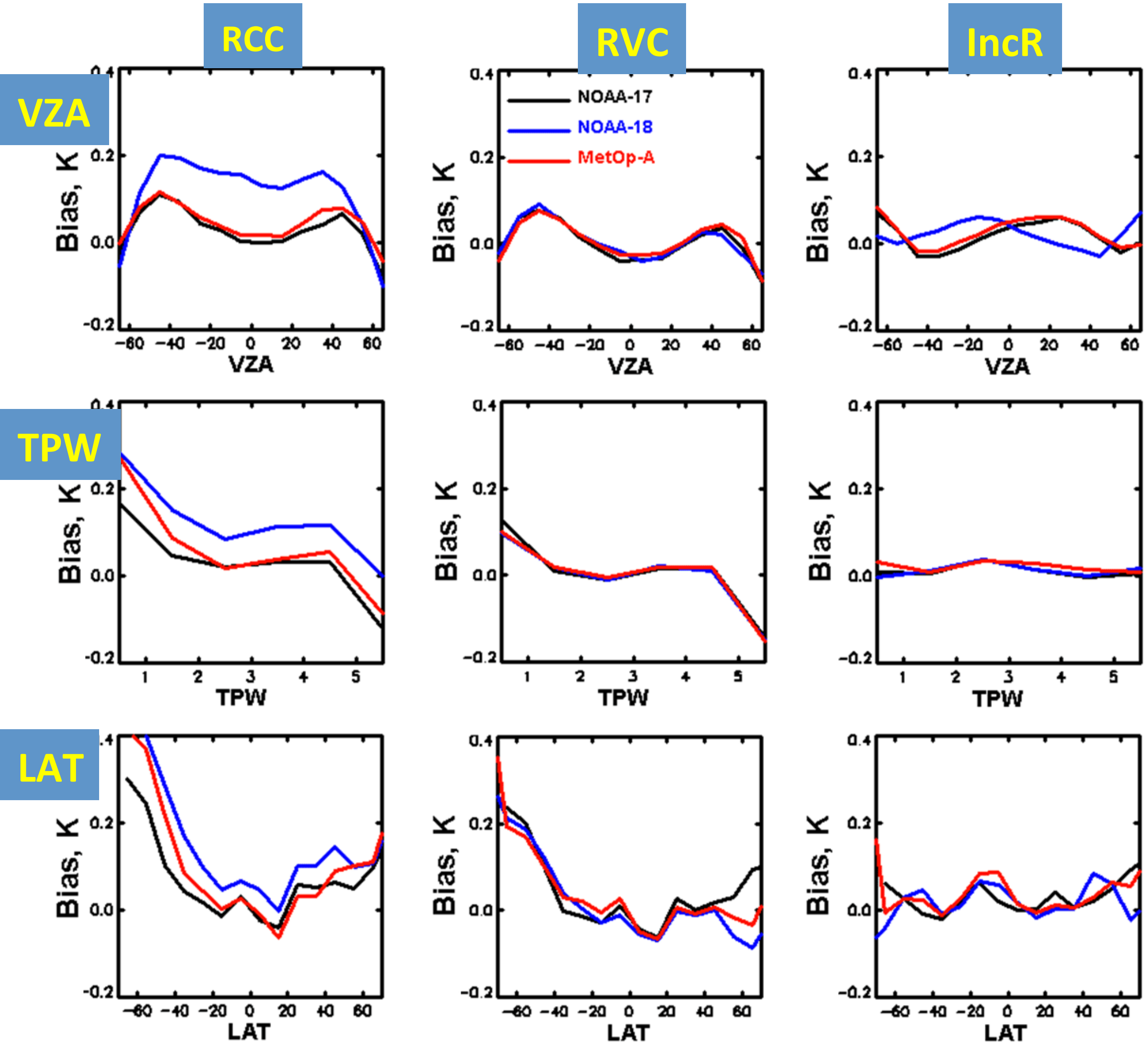
- RVC and IncR biases wrt *in situ* SST reduced from ~0.2 K to < 0.05 K
- SD wrt *in situ* SST is smaller for IncR SST than for RCC and RVC
- SD wrt CMC is greater for IncR than for both regression algorithms
- Mean sensitivity for IncR is ~.95, and <0.9 for regression algorithms

NOAA-17 (DAY): Annual Mean SST Biases as Functions of VZA, TPW and LAT



- Dependencies are shown for 7 full years of NOAA-17 operation
- **RCC** biases are most variable and non-uniform
- **RVC** biases are less variable than **RCC** biases
- **IncR** biases are more uniform than **RCC** biases

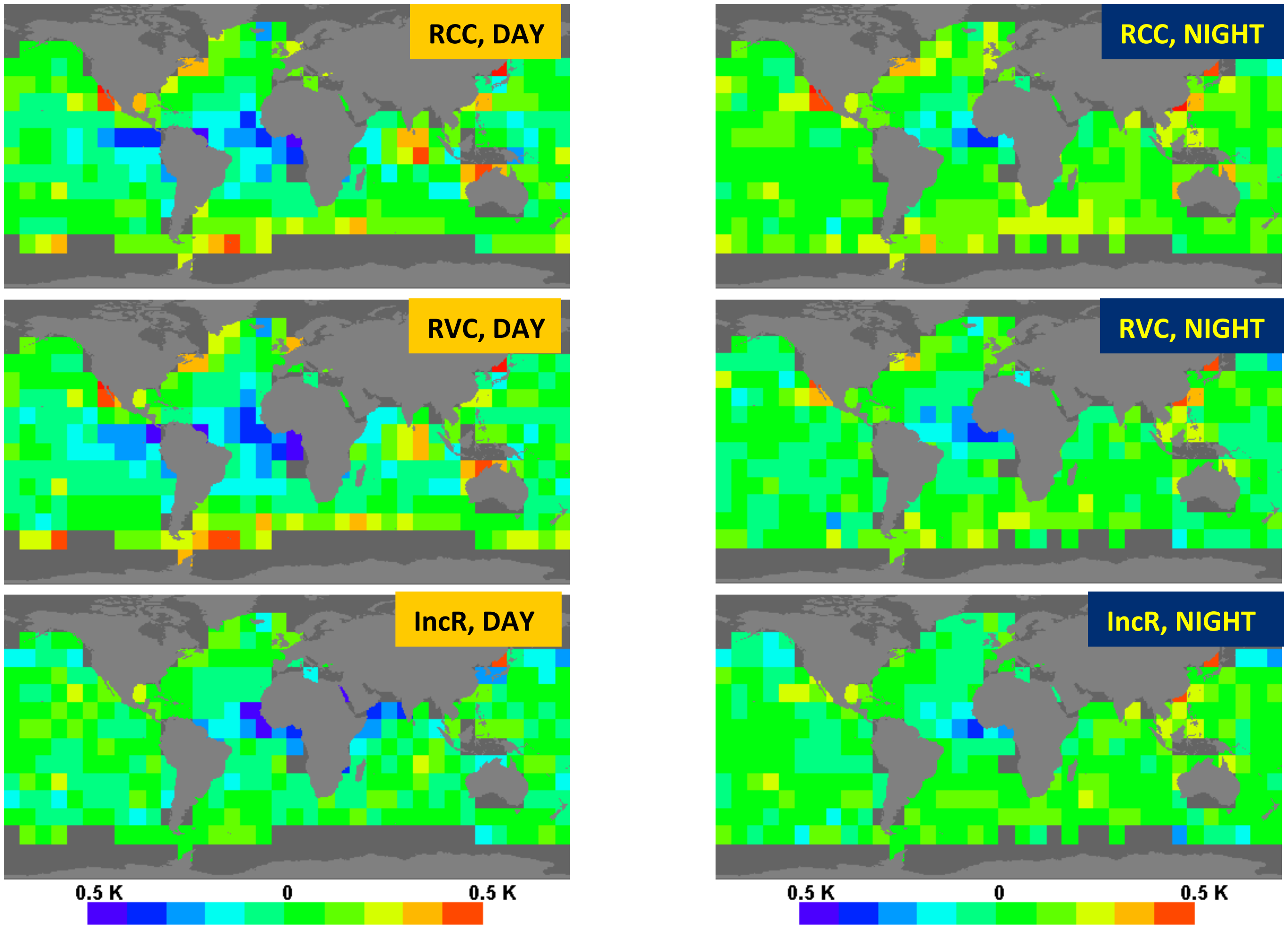
NOAA-17, -18 and MetOp-A: Multiyear Mean Biases as Functions of *VZA*, TPW and LAT



- The biases are averaged over the following years: 2003-2009 for NOAA-17 2006-2013 for NOAA-18 2007-2013 for MetOp-A
- **RCC** biases are most variable between the satellites
- **RVC** biases are less variable between the satellites but relatively non-uniform
- **IncR** biases are most uniform, for all three satellites

NOAA-17: Annual Regional Biases for 2005

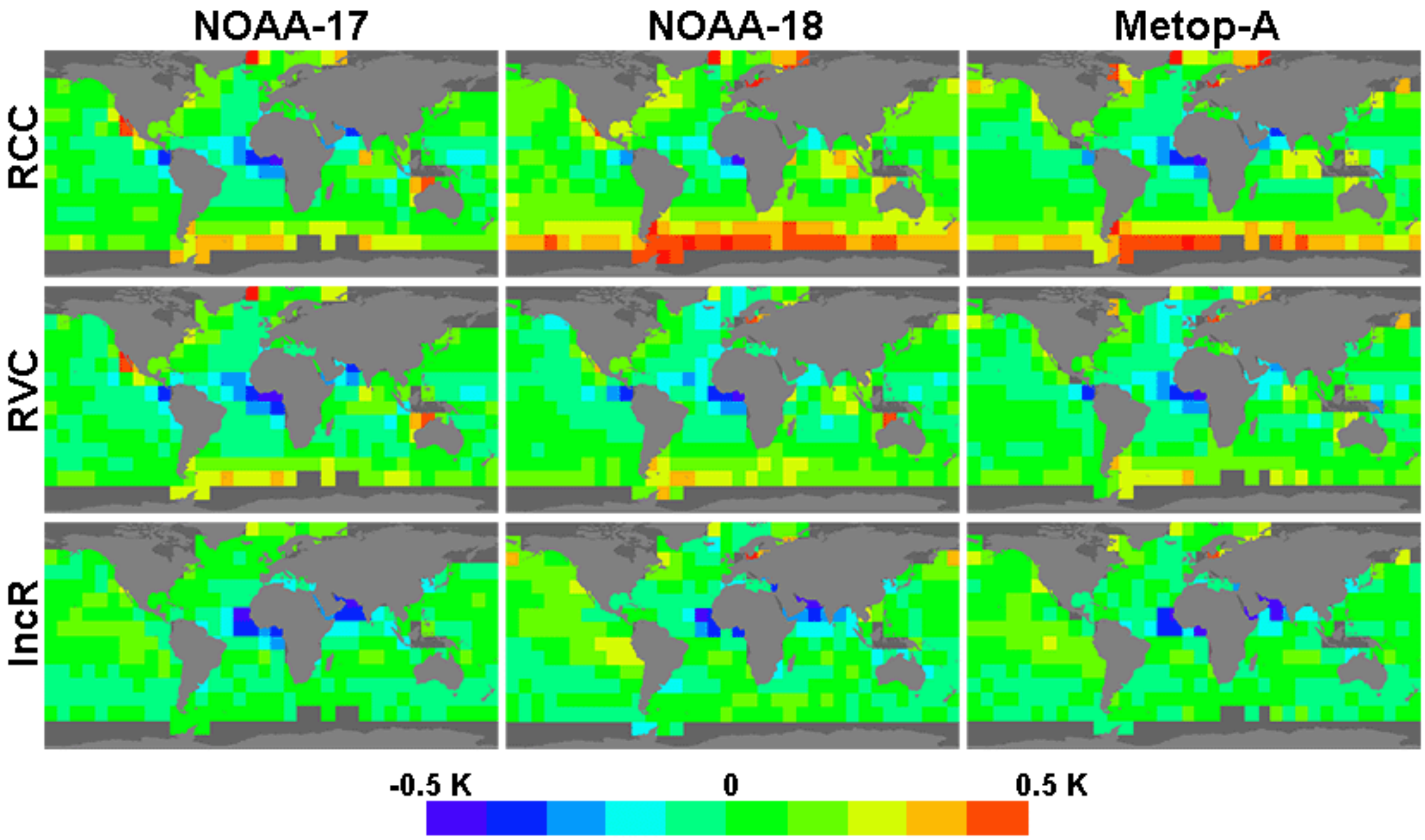
B_A=median(| T_S - T_s^{insitu} |), within $10^o \times 10^o$ lat/lon box



- The IncR biases appear to be most uniform, both for day and night
- Saharan dust is the problem for all algorithms

NOAA-17, NOAA-18, MetOp-A: Multiyear median regional biases (Day)

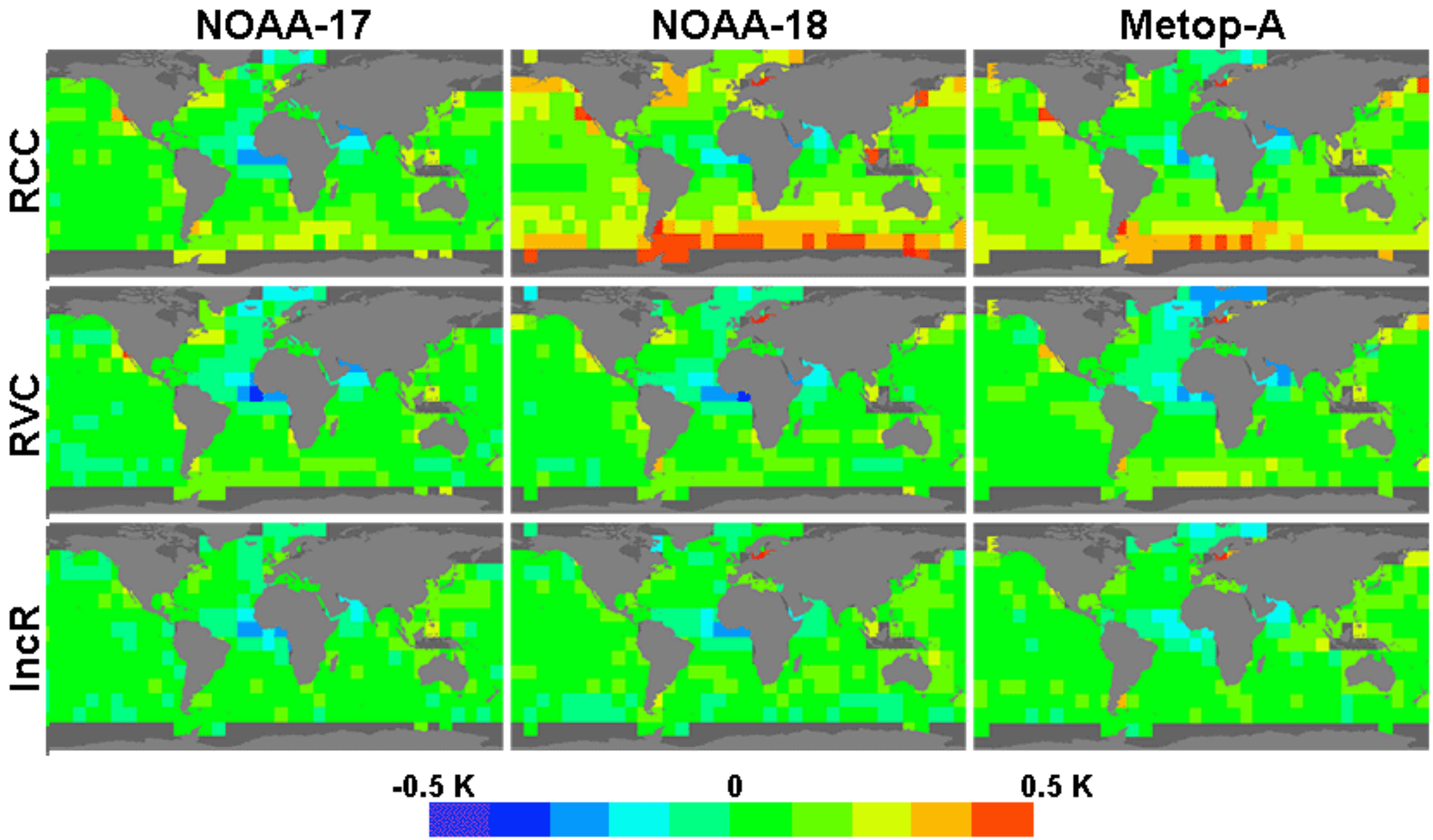
B_M=median(B_A), within each $10^o \times 10^o$ lat/lon box



- The maps show medians of annual biases over all full years of operation of a given satellite
- Regional biases are least uniform for RCC and most uniform for IncR

NOAA-17, NOAA-18, MetOp-A: Multiyear median regional biases (Night)

B_{IA}=**median(B_{IA})**, within each $10^o \times 10^o$ lat/lon box



- Regional biases are least uniform for RCC and most uniform for IncR
- The difference between RVC and IncR biases is smaller than for day

Spatial variability of multiyear biases

V_1=median(|B_{IA}-median(B_{IA})|),
B_{IA} is a set of annual biases within all $10^o \times 10^o$ lat/lon boxes

Algorithm	NOAA-17	NOAA-18	MetOp-A
		Day	
RCC	0.070 K	0.096 K	0.084 K
RVC	0.061 K	0.075 K	0.056 K
IncR	0.047 K	0.057 K	0.047 K
		Night	
RCC	0.040 K	0.063 K	0.051 K
RVC	0.038 K	0.038 K	0.035 K
IncR	0.034 K	0.040 K	0.033 K

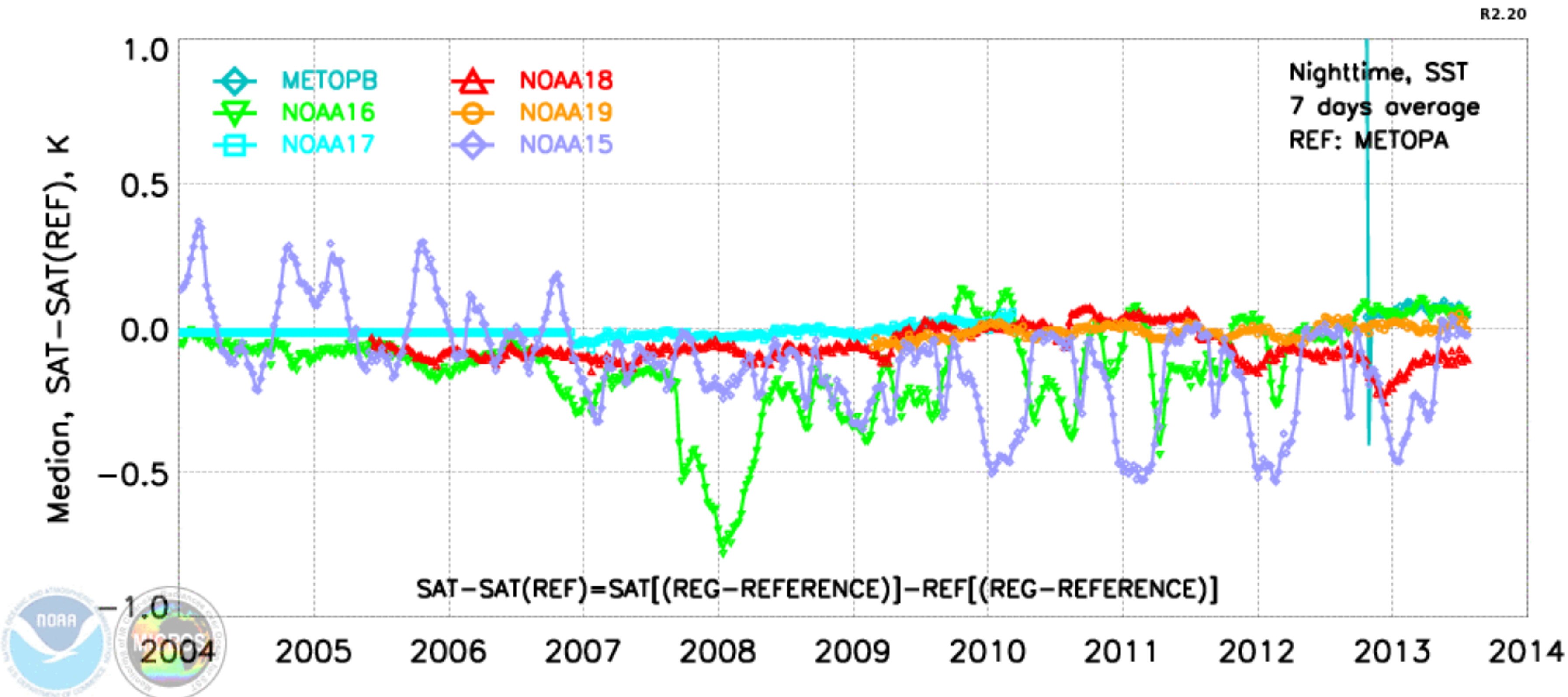
- For day, variability of regional biases is highest for RCC and the lowest for IncR
- For night, variability of regional biases for RVC and IncR is close.

Summary and Future Work

- The Regression and Incremental Regression SST algorithms were explored using NOAA-17, -18 and MetOp-A matchups collected during ACSPO-RAN1, for 2002-2013
- Recalculation of coefficients on a daily basis reduces variations in global and regional SST biases for both types of algorithms
- The IncR further flattens out SST biases as functions of VZA, TPW and LAT and reduces regional SST biases
- At the second stage of reprocessing (RAN2), the multiyear L2P datasets will be produced with RCC, RC and IncR and evaluated in SQUAM and MICROS
- The assessment methodology proposed in GHRSST Climate Data Assessment Framework *(Merchant et al., 2013)* will be also explored
- Possible improvements in the AVHRR calibration algorithms will be also explored. This is expected to further improve temporal and regional stability of SST biases, especially, for the less stable AVHRR sensors onboard NOAA-15, -16 (since mid-2004) and NOAA-18 (since mid-2011).

THANK YOU

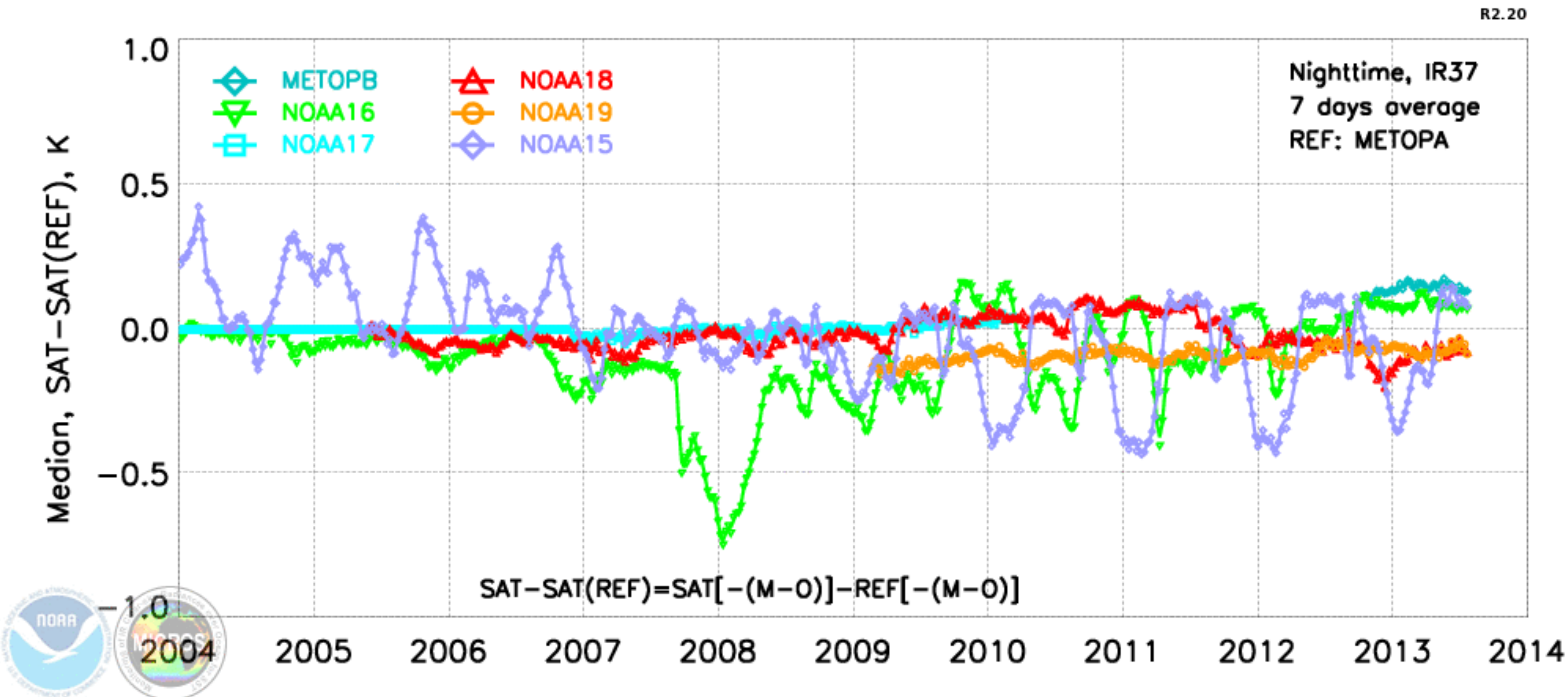
NIGHT Double Differences SST (Ref = N-17/Metop-A)



- ***Shape of DDs similar to VAL vs. In situ***
- ***Most stable N-17 and Metop-A were used as references; N-19 relatively stable***
- ***Least stable are N-15, -16 (after mid-2006), -18 (especially after mid-2011)***

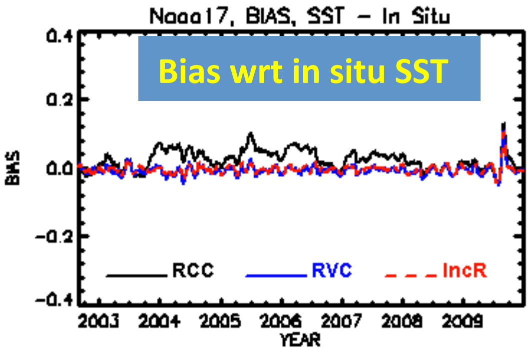
5/6/2014 Reprocessing AVHRR GAC 22

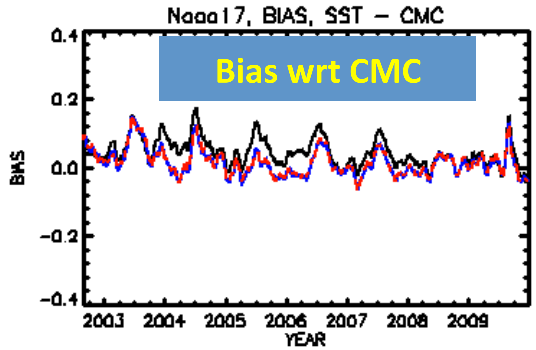
NIGHT Double Differences Brightness Temp @3.7µm

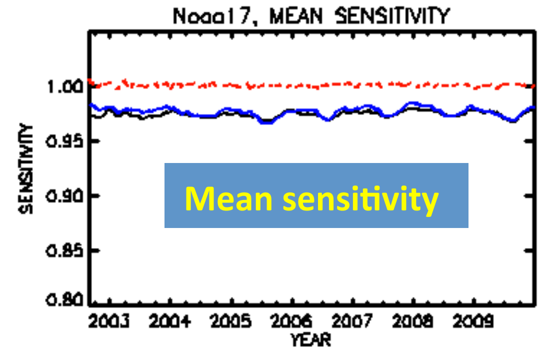


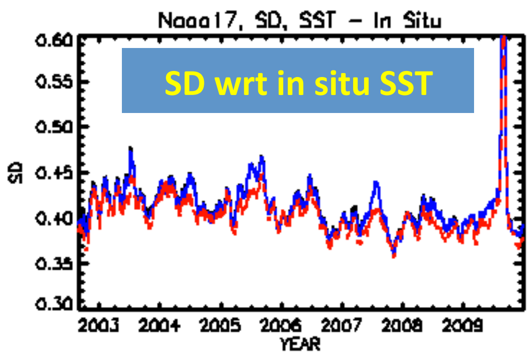
- *General shape of biases vs. Reynolds similar to vs. In situ*
- *Most stable Metop-A and -B, and N-17 and -19*
- *Least stable are N-15, -16 after 2006), -18 (after 2011)*

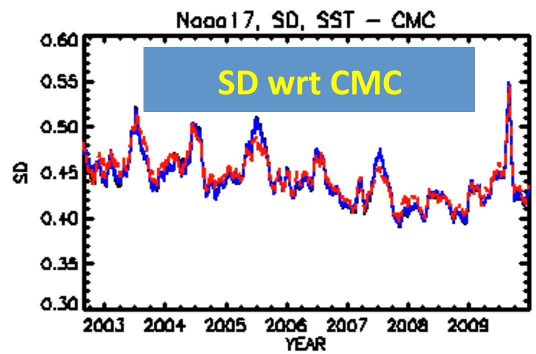
NOAA-17 (NIGHT): Time series of global mean bias, SD and mean sensitivity





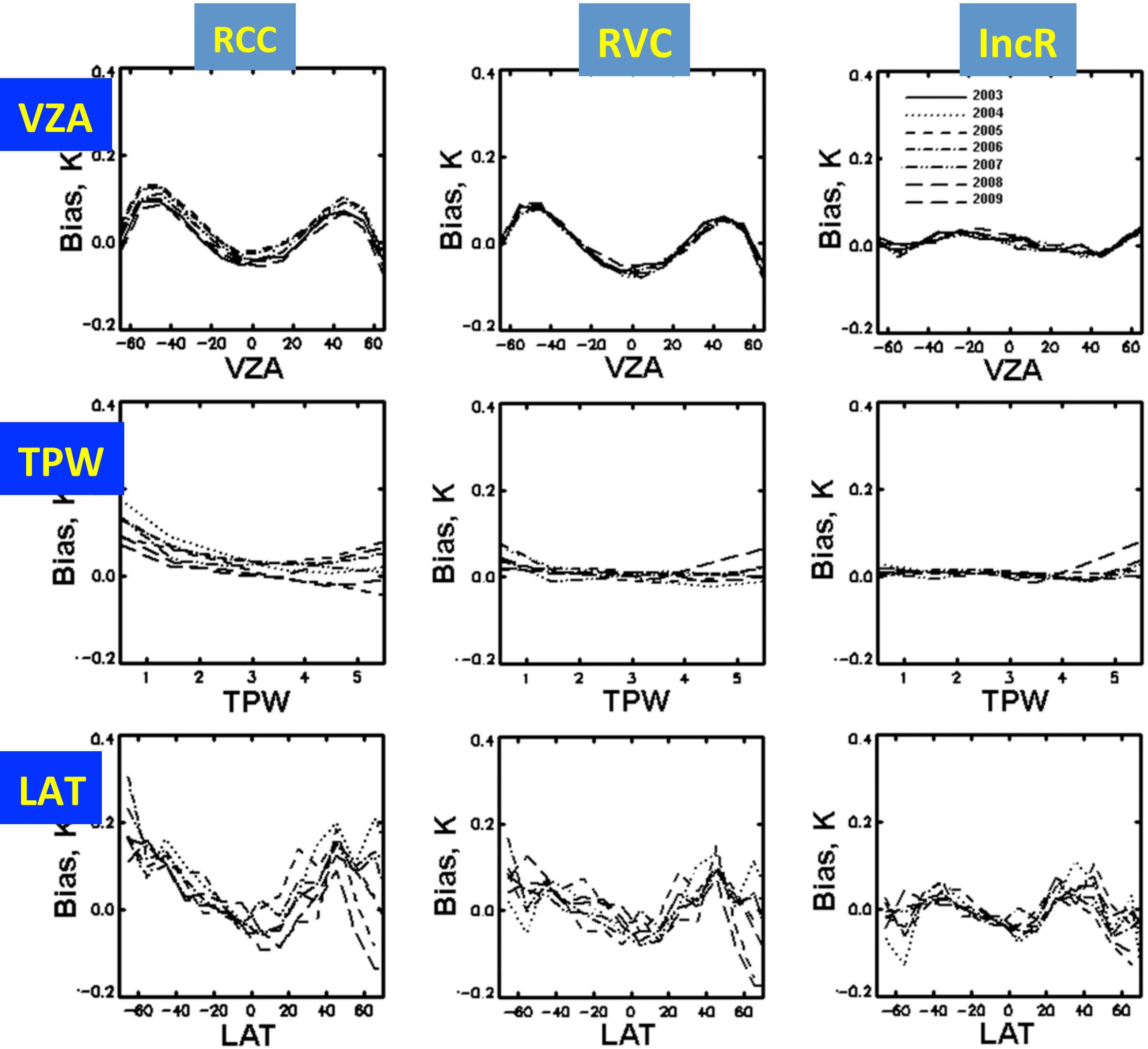






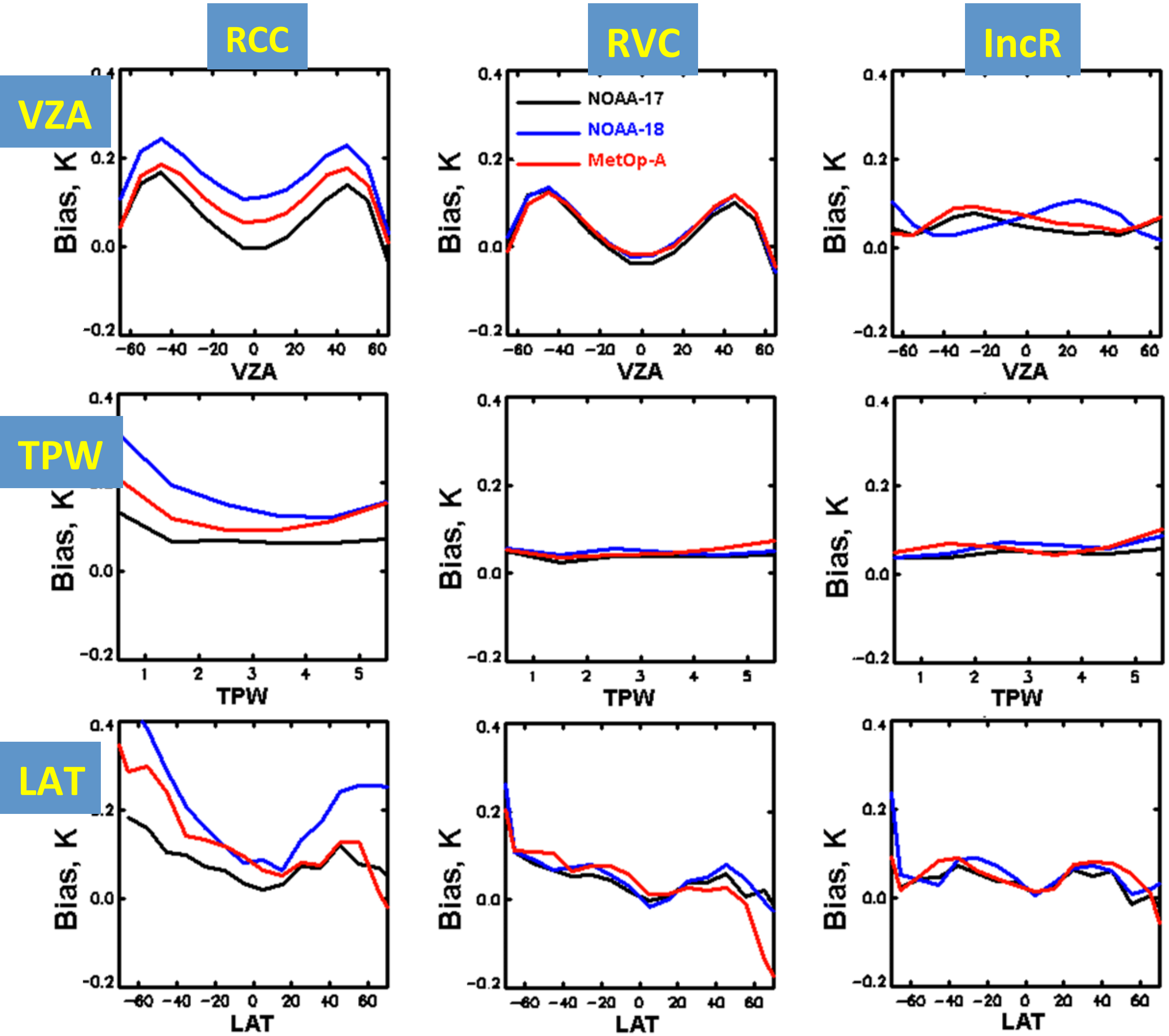
- Same features as for day, but with lesser difference between RVC and IncR
- For night, RVC and IncR statistics are very close
- Mean sensitivity is ~ 1 for IncR and ~0.98 for RCC and RVC

NOAA-17 (NIGHT): Annual mean SST biases as functions of VZA, TPW and LAT



- **RCC** biases are non-uniform and most variable
- **RVC** biases are less variable but still non-uniform
- **IncR** biases are most uniform and least variable
- The nighttime difference between RVC and IncR is smaller than for day

NOAA-17, -18 and MetOp-A: Multiyear mean biases as functions of VZA, TPW and LAT (Night)



- The biases are averaged over the following years: 2003-2009 for NOAA-17 2006-2013 for NOAA-18 2007-2013 for MetOp-A
- **RCC** biases are most variable between the satellites
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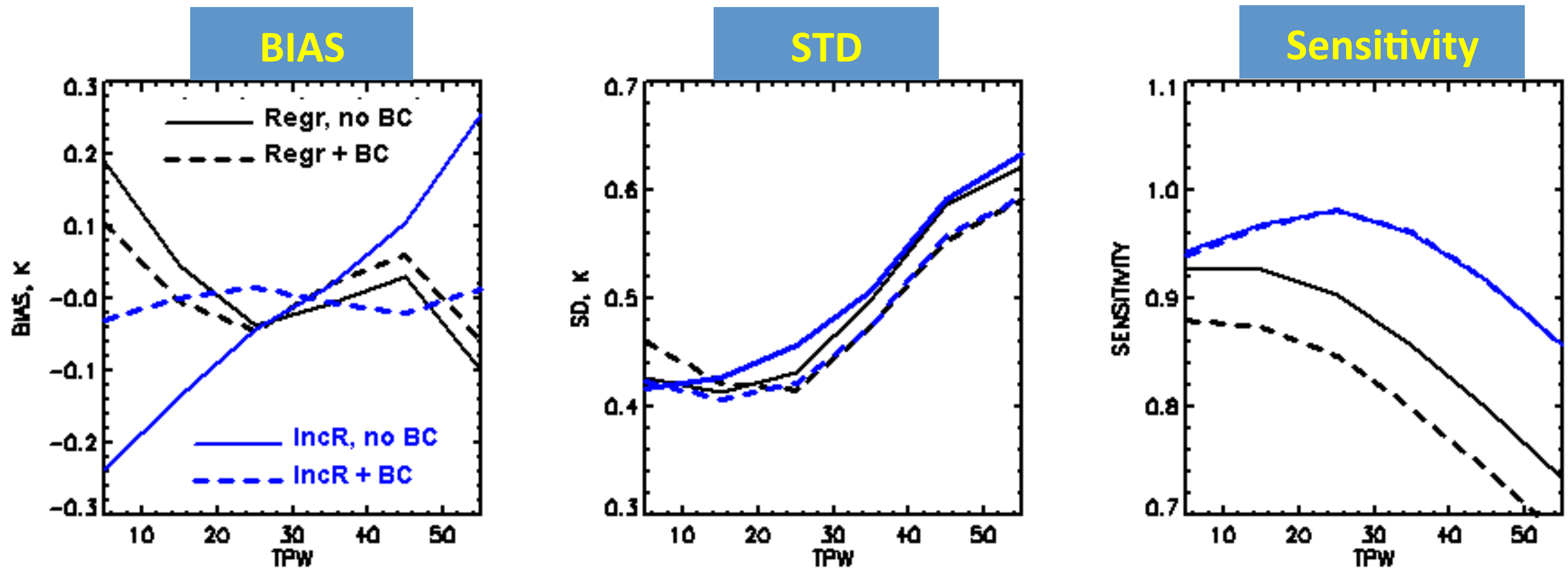
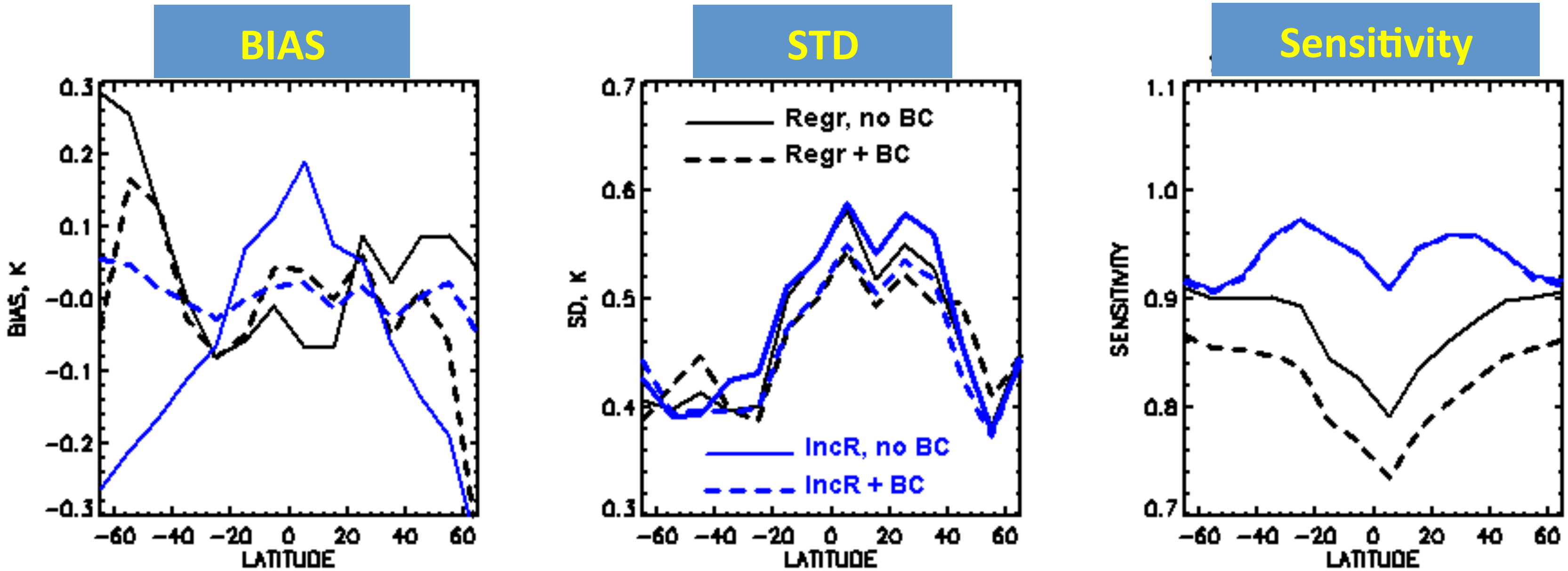
The effect of bias correction on daytime statistics of SST as functions of TPW



- Statistics are shown for 2005 NOAA-17 matchups
- Bias correction slightly improves Regression bias and SD, significantly reduces sensitivity
- IncR without bias correction produces unacceptably large biases
- IncR with bias correction minimizes SST biases and SDs, but does not change sensitivity

The effect of bias correction on daytime statistics of SST as functions of Latitude



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Multiyear median variability of annual biases

V_2=median(V_{IA}), V_{IA}=median($|B_A-B_{IA}|$)

V_{IA} is multiyear variability of annual biases in each $10^o \times 10^o$ lat/lon box

Algorithm	NOAA-17	NOAA-18	MetOp-A
Day			
RCC	0.044 K	0.049 K	0.042 K
RVC	0.045 K	0.046 K	0.038 K
IncR	0.041 K	0.040 K	0.036 K
Night			
RCC	0.040 K	0.052 K	0.036 K
RVC	0.035 K	0.039 K	0.031 K
IncR	0.032 K	0.035 K	0.029 K

•Regional biases are most variable for RCC and least variable for IncR, both for day and night