GOES-R AWG SST Team: Sea Surface Temperature Algorithm

GOES-R AWG Annual Meeeting , June 7 - 11 2010

Presented by: Boris Petrenko

The AWG SST Team and Collaborators

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  - » Land – Wei Guo, Felix Kogan, Peter Romanov, Bob Yu, Dan Tarpley
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  - » Proxy – Fuzhong Weng, Min-Jeong Kim, Tong Zhu

Outline

- Executive Summary
- Requirements Specification Evolution
- ADEB and IV&V Response Summary
- Algorithm Description
- Validation Strategy and Results
- Summary

Executive Summary

- This ABI SST Algorithm generates the Option 1 product of Sea Surface Temperature
- Version 4 of SST code was delivered in May 2010. ATBD (100%) is on track for a July 2010 delivery
- A unique Hybrid SST algorithm has been developed to combine the advantages of previously known Regression and Radiative Transfer Model (RTM) Inversion algorithms.
- A Quality Control for SST (SST QC) was developed for thorough selection of pixels, usable for SST, and cross-tested with the ABI Cloud Mask
- Extensive validation of SST products was performed with MSG2 SEVIRI and AVHRR data. Analyses suggest that GOES-R ABI SST will meet the recently adopted stricter spec.

Requirements and Specifications Evolution

Name	User & Priority	Geographic Coverage (G, H, C, M)	Vertical Res.	Horiz. Res.	Mapping Accuracy	Measurement Range	Measurement Accuracy	Refresh Rate / Coverage Time Option (Mode 3)	Refresh Rate	Data Latency	Product Measurement Precision
Sea Surface Temperature (Skin)	GOES-R	CONUS, Full Disk, Mesoscale	N / A	2km	1 km	270 to 313 K	2.1 K with known emissivity, atmospheric correction, and 80% channel correlation; 3.1 K otherwise 0.4 K	60 min	5 min	806 sec	1.0 K 0.8 K

- The initial requirements of 2.1 K accuracy and 1 K precision were too liberal.
- Request to change the requirements to 0.4 K accuracy, 0.8 K precision has been recently granted by GPO

ADEB and IV&V Response Summary

- All ATBD comments have been addressed:
  - The spec is too weak
  - Clean up the writings
  - More explicit specification of retrieval uncertainties
  - Further validation with AVHRR

- No feedback required modifications to the approach

Runoff / Selection Environment: Candidate Algorithm Selection

- **Previously used SST Algorithms:**
  - » Regression
    - McClain et al., *JGR*, 1985;
    - Walton et al., *JGR*, 1998.
  - » RTM Inversion
    - Merchant et al., *RSE*, 2008, 2009.

- **Strategy:**
  - » Implement Regression and Inversion SST algorithms with GOES-R proxies
  - » Optimize, cross-evaluate
  - » Merge into a more efficient Hybrid algorithm

- **Available GOES-R ABI proxies:**
  - AVHRR
  - MSG SEVIRI

Regression Algorithm

NLSST (Day): $T_S = a_o + a_1 T_{11} + a_2 T_{FG} (T_{11} - T_{12}) + a_3 (T_{11} - T_{12})(\sec\theta - 1)$

MCSST (Night): $T_S = a_o + a_1 T_4 + a_2 T_{11} + a_3 T_{12} + a_4 (T_4 - T_{12})(\sec\theta - 1) + a_5 (\sec\theta - 1)$,

T_S	retrieved SST
T_{FG}	first guess SST from the analysis field
T_{11}, T_{12}, T_4	brightness temperatures in channels 11, 12 and 3.9 μm
θ	view zenith angle
a's	regression coefficients

- **Advantages:** Simple, computationally efficient, has extensive heritage (AVHRR, MODIS, VIIRS)
- **Disadvantages:** Non-uniform accuracy due to angular and regional biases

- NLSST and MCSST are used with AVHRR (MODIS, VIIRS)
- Only NLSST is used with SEVIRI, due to suboptimal radiometric performance of Ch 3.9 μm

RTM Inversion Algorithm

Optimal Estimation: $\boldsymbol{X}=\boldsymbol{X}_{FG} + (K^T\Delta^{-1}K+S^{-1})^{-1}K^T\Delta^{-1}[\boldsymbol{T}_B - \boldsymbol{T}_{BFG}]$,

$\boldsymbol{X}$	vector of unknown variables (SST and the atmospheric transmission parameter)
$\boldsymbol{X}_{FG}$	first guess of $\boldsymbol{X}$
$\boldsymbol{T}_{BFG}$	first guess of $\boldsymbol{T}_B$
K	Jacobian of the RTM function *at* $\boldsymbol{X}=\boldsymbol{X}_{FG}$
Δ	covariance matrix of measurement errors (weighs observations in the solution)
S	covariance matrix of *a priori* errors (weighs *a priori* information in the solution)

- **Advantage:** More uniform accuracy and precision than with Regression Algorithm
- **Disadvantages:**
  - » Requires accurate RTM Jacobian
  - » Involves optimization problems:
    - Low-dimensional parameterization of RTM
    - Optimal weighting observations and *a priori* information in the solution
  - » OE recommendations on weighting of observations and *a priori* information result in suppression of space/time SST variations.

Hybrid SST Algorithm

RTM Inversion

- Adopts first guess SST T_{SFG} from analysis and first guess BT T_{BFG} from simulations
- Retrieves T_S-T_{SFG} from T_B-T_{BFG} using OE

Regression

- Retrieves T_S from T_B using regression

Hybrid

- Adopts first guesses for BT and SST
- Retrieves T_S- T_{SFG} from T_B-T_{BFG} using regression

Advantages:

» Compared to Regression:
- More uniform accuracy and precision across all observational conditions

» Compared to RTM Inversion:
- Less ambiguous
- Does not depend on Jacobian accuracy

Planned SST Algorithm Usage

- Hybrid algorithm is the baseline SST algorithm (needs Reynolds SST, GFS atmospheric fields, CRTM)
- Regression is a back-up algorithm (in case GFS data is not available)
- RTM inversion algorithm is currently used as a part of SST QC

Validation Proxies for ABI

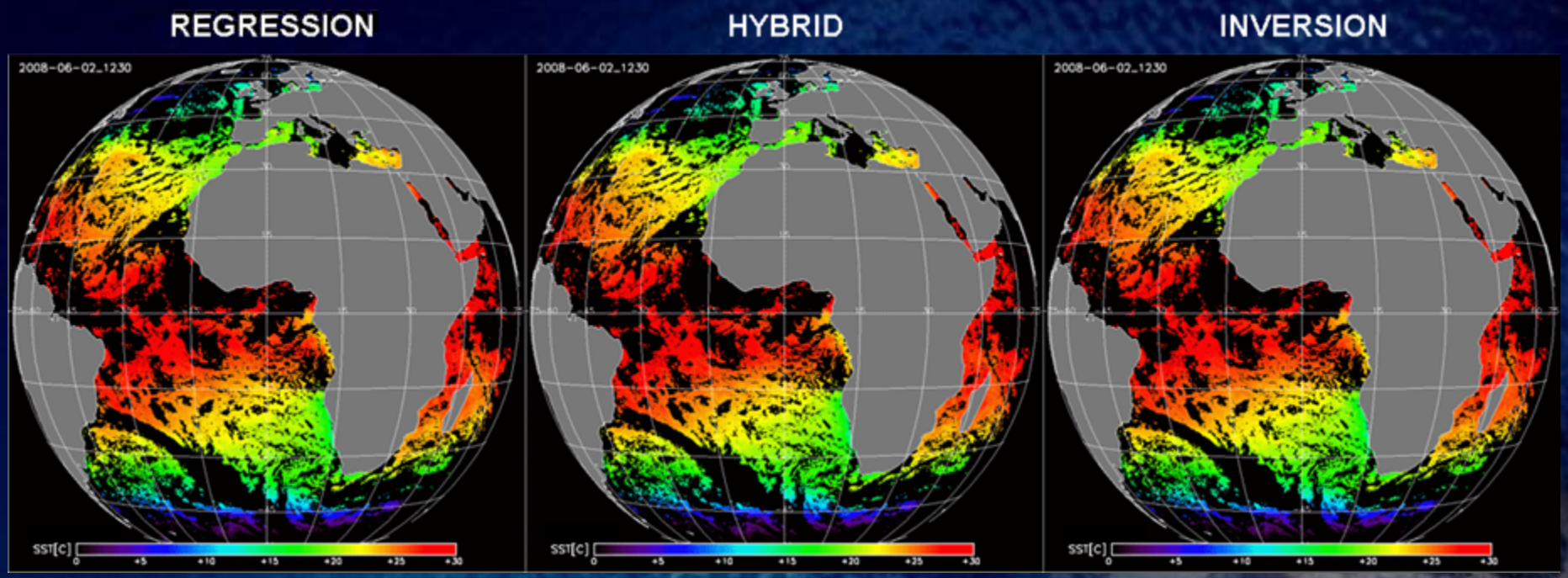
- Geostationary SEVIRI (MSG1, MSG2) is the primary proxy for ABI
- Polar-orbiting AVHRR (NOAA-16, 17, 18, 19, and MetOp-A) is also used as proxy
- MODIS can be used as proxy beyond 100% ATBD

Sensor	Band ##	FOV (km)	Band Center (μm)	Bandwidth (μm)	NEdT @300K
ABI	7	2	3.9	0.2	0.10
	13	2	10.4	0.5	0.10
	14	2	11.2	0.8	0.10
	15	2	12.3	1.0	0.10
SEVIRI	4	5	3.9	0.9	0.35(0.17)
	10	5	10.8	2.0	0.25(0.11)
	11	5	12.0	2.0	0.37(0.15)
AVHRR	3B	4 (1)	3.75	0.4	<0.12
	4	4 (1)	10.8	1.0	<0.12
	5	4 (1)	12.0	1.0	<0.12
MODIS	20	1	3.75	0.18	0.05
	22	1	3.96	0.06	0.07
	31	1	11.0	0.50	0.05
	32	1	12.0	0.50	0.05

Validation Progress

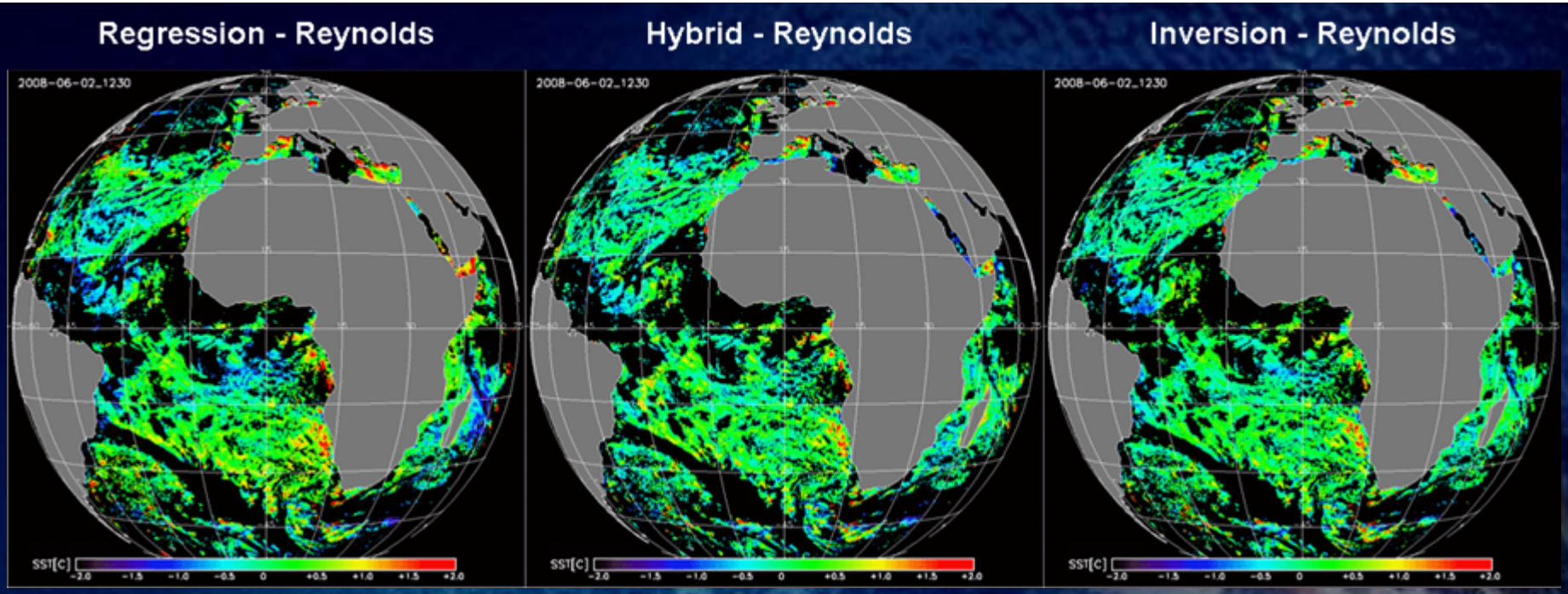
Instrument	80% ATBD	100% ATBD
SEVIRI	•Regression, Inversion, and Hybrid algorithms implemented and tested •Only 2 channel algorithm formulations were used (CRTM in 3.9 μm band shows anomalies; work underway to resolve) •SST QC implemented	•Regression and Hybrid coefficients recalculated; •Inversion algorithm adjusted to mitigate suppression of SST variations •SST QC and ABI Cloud Mask cross-evaluated
AVHRR	•Regression algorithm (2 channel NLSST and 3 channel MCSST) implemented and extensively tested in operational environment •SST QC implemented	•Hybrid algorithm implemented, extensively tested and inter-compared with Regression

SEVIRI SST Images with Three Algorithms



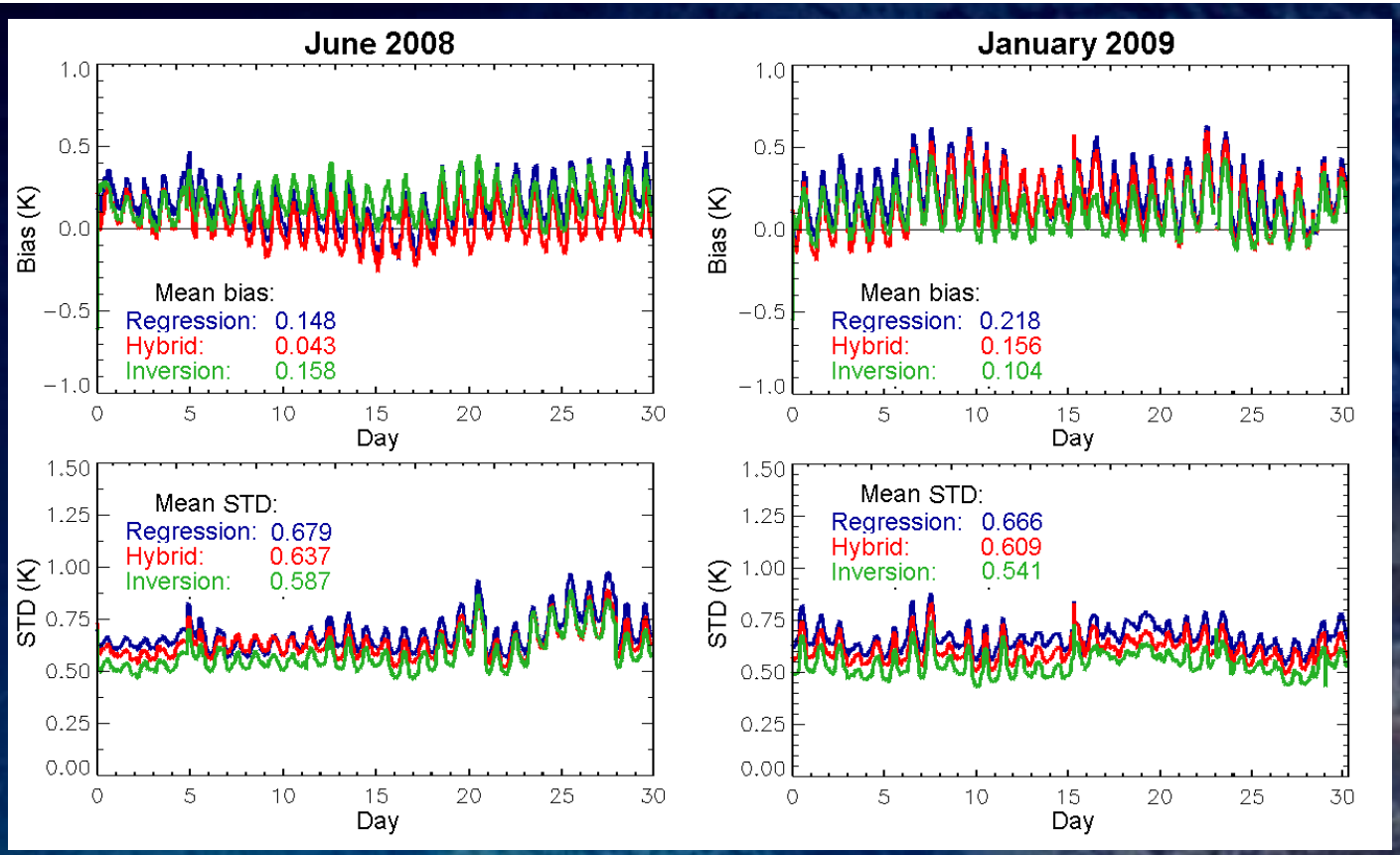
Due to large range of SST variability of ~30K, the difference between the three SST products is not easily discernible

SEVIRI SST Anomaly Images with Three Algorithms



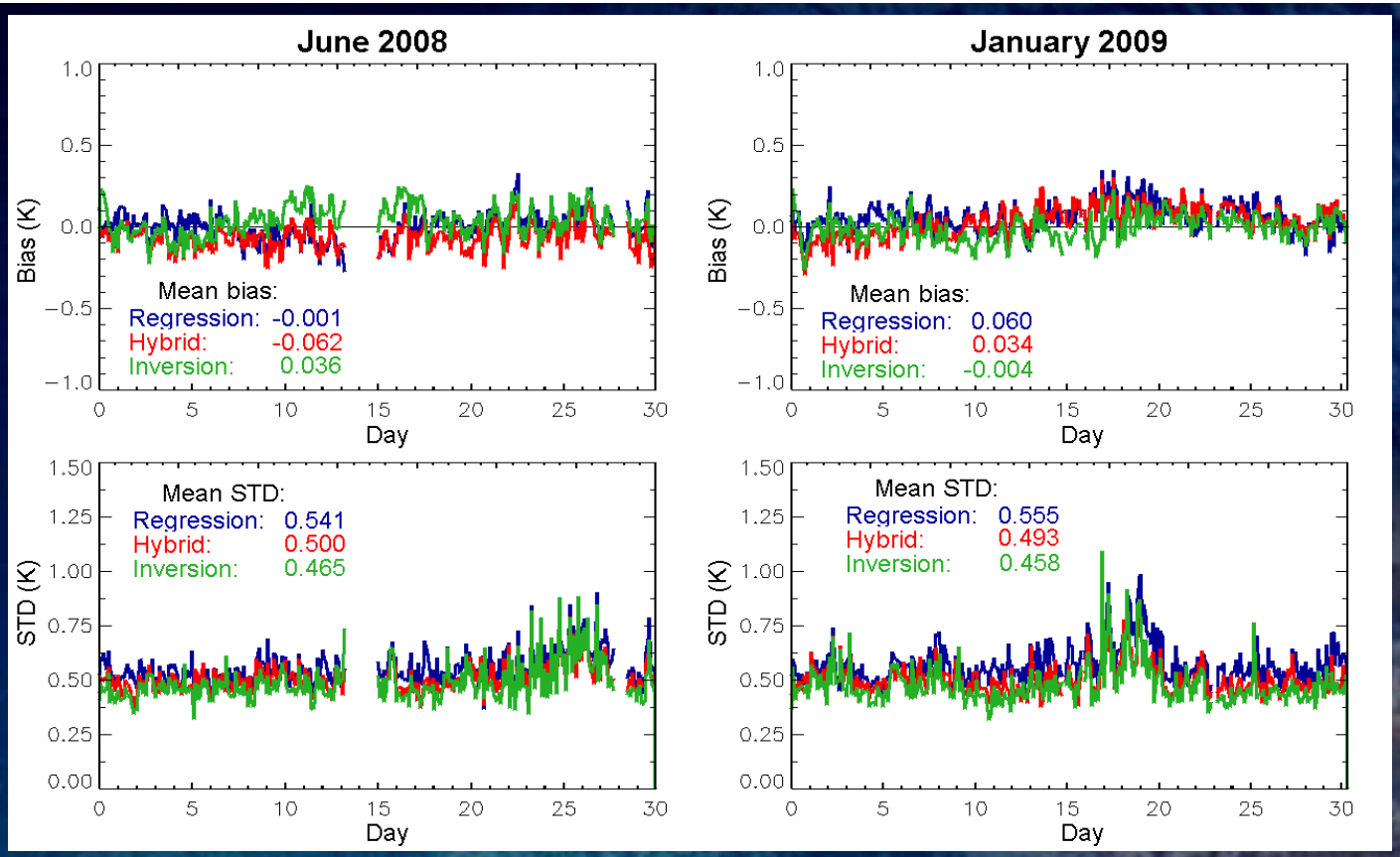
- *Regression algorithm:* Regional biases still exist.
- *Inversion algorithm:* suppression of SST variations mitigated. More optimization required.
- *Hybrid algorithm* is most reliable.

Time Series of Global Bias and STD of SEVIRI SST Anomalies



- All three algorithms show the diurnal cycle in global SST of ~ 0.3 K (peak-to-peak)
- Global STD for Regression SST is greater than for Hybrid SST

Time Series of Global Bias and STD of SEVIRI SST minus *in situ* SST



- All three algorithms show the diurnal cycle in global SST of ~ 0.2 K (peak-to-peak)
- Global STD for Regression SST is greater than for Hybrid SST

AVHRR

Global Statistics of AVHRR SST minus *in situ* SST with Regression and Hybrid Algorithms

Regression coefficients were calculated from 18 August – 17 September 2010 data

Statistics were estimated for 1 – 7 January 2010

Hybrid SST better fits *in situ* SST in terms of global STD and correlation

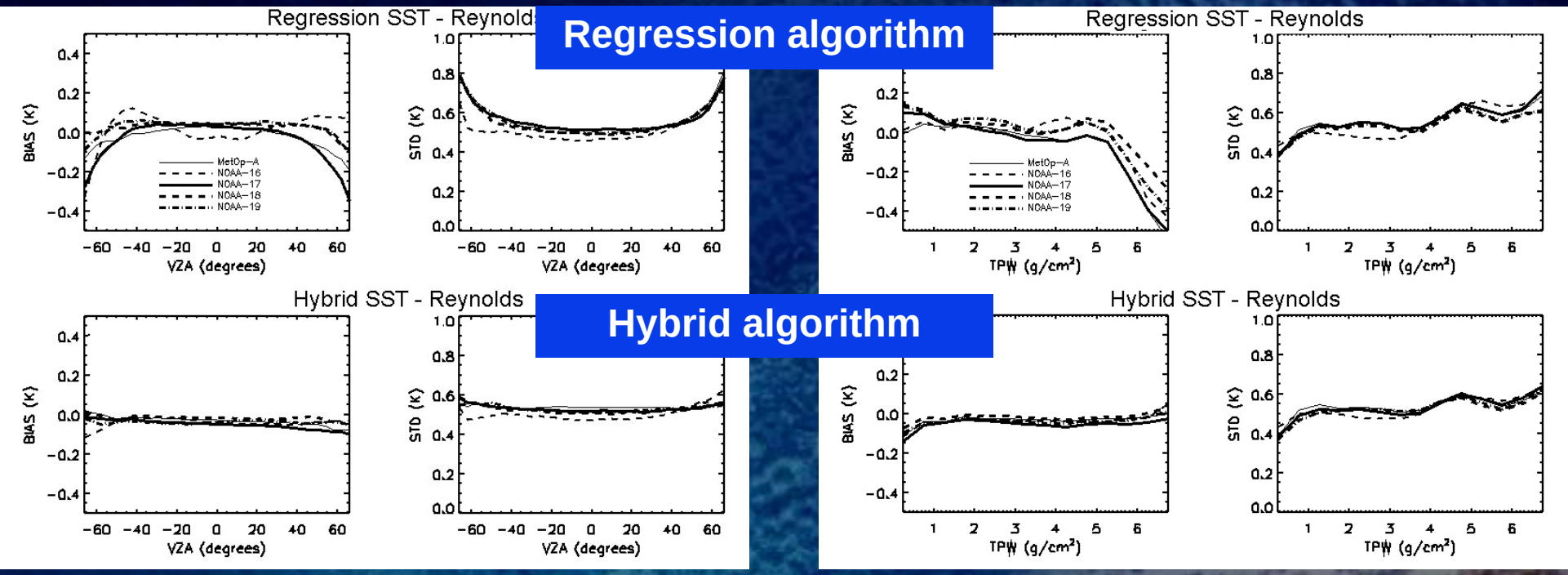
Statistics	Metop-A	NOAA-16	NOAA - 17	NOAA - 18	NOAA-19
Regression SST vs. *in situ SST*					
Bias (K)	-0.051	0.065	-0.103	0.049	0.095
STD (K)	0.565	0.528	0.515	0.536	0.540
Correlation	0.994	0.996	0.995	0.995	0.999
Hybrid SST vs. *in situ SST*					
Bias (K)	0.035	-0.018	-0.022	0.095	0.104
STD (K)	0.465	0.449	0.418	0.414	0.404
Correlation	0.997	0.998	0.996	0.998	1.000

AVHRR

Bias and STD of AVHRR SST minus Reynolds SST as Functions of Observational Conditions

Dependencies on view zenith angle

Dependencies on total precipitable water vapor content in atmosphere



Hybrid algorithm provides more uniform bias and STD across the whole range of observational conditions

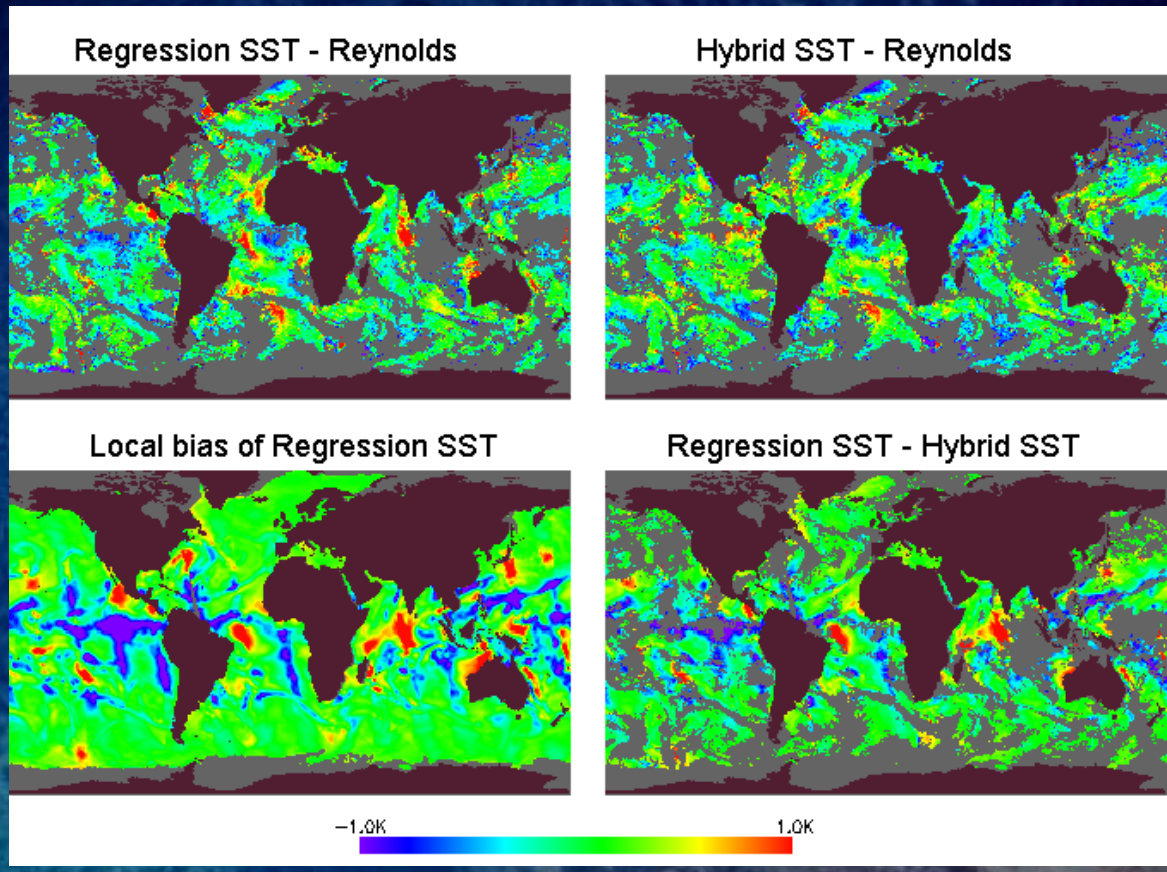
AVHRR

Regression and Hybrid SST Anomalies from Nighttime Metop-A Observations

- Local biases in Regression SST were estimated by substitution of simulated BTs into regression NLSST equation

- The difference between Regression and Hybrid SST is mainly due to local biases in Regression SST

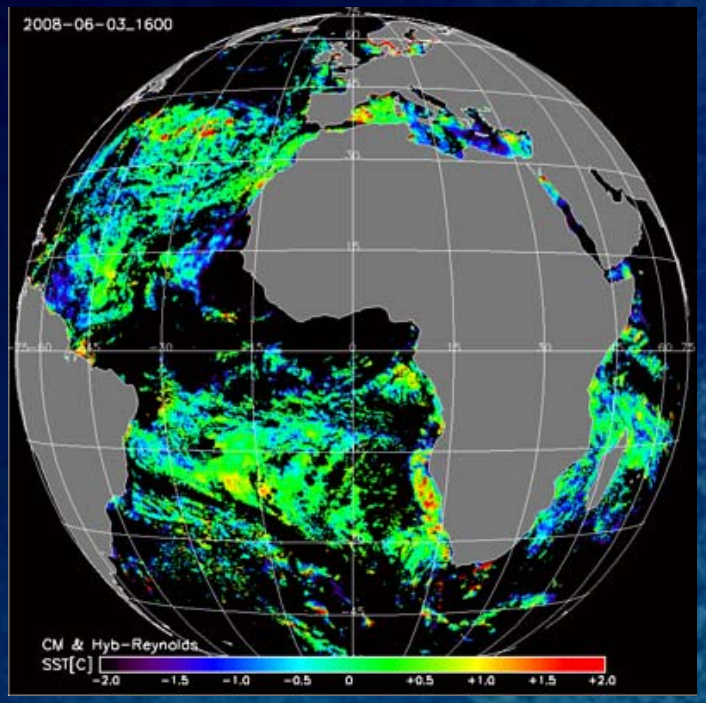
2 January 2010



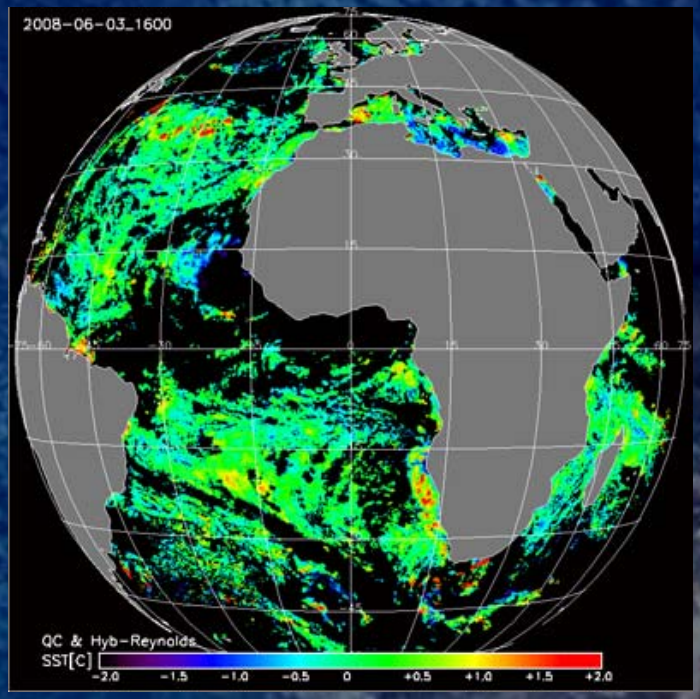
Cross-Testing of ABI Cloud Mask and SST Quality Control

Composite maps of Hybrid SST minus Reynolds SST with:

ABI Cloud Mask



SST Quality Control

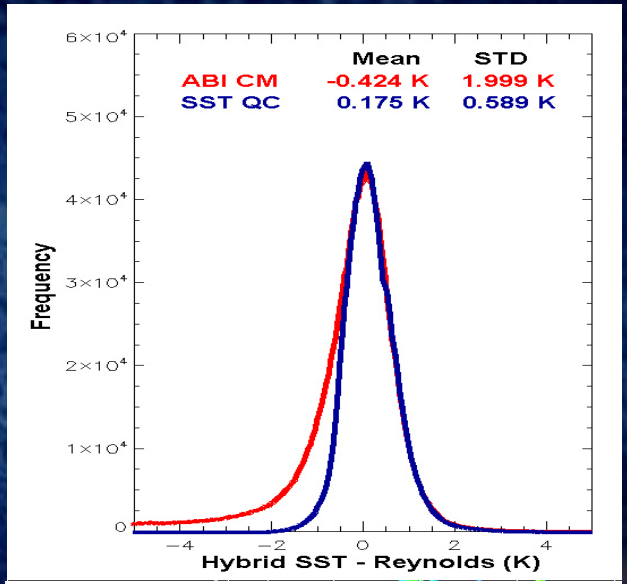


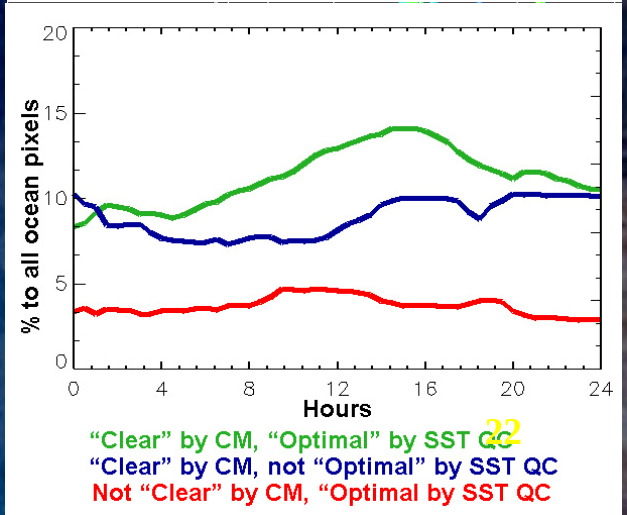
- **ABI CM is designed liberal to preserve pixels potentially usable for all applications**
- **SST QC more accurately selects the pixels usable specifically for SST**

SEVIRI

Cross-Testing of ABI Cloud Mask and SST Quality Control

- The histogram of SST anomalies is wider with ABI CM than with SST QC
- 10 – 12% of ocean pixels are classified "clear" by both ABI CM and SST QC
- 8 – 10% of ocean pixels are "clear" by ABI CM but not "clear" by SST QC – not a problem for SST
- 3 – 5% of ocean pixels (i.e. 20 to 30% of "clear" pixels) are "clear" by SST QC but not "clear" by ABI CM – further adjustment of ABI CM and SST QC is needed





Validation Summary

Requirements to SST target accuracy (0.4K) and precision (0.8K) are met both for AVHRR & SEVIRI.

AVHRR	Time Interval	Global Bias (K)	Global STD (K)	Diurnal Range (K)
BT, Ch3B (3.7 μm) / Day	Jan 2001 - Present	CRTM inaccurate during daytime		
BT, Ch3B (3.7 μm) / Night		+0.3	<0.5	N/A
BT, Ch4 (11 μm)		+0.5	0.55	N/A
BT, Ch5 (12 μm)		+0.5	0.65	N/A
SST (Regression)		±0.1	0.55	~0.3±0.1
SST (Hybrid)		±0.1	0.45	~0.3±0.1
SEVIRI	**Time Interval**	**Global Bias (K)**	**Global STD (K)**	**Global Diurnal Range (K)**
BT, Ch04 (3.9 μm) / Day	Jun 2008 & Jan 2009	CRTM is inaccurate during daytime		
BT, Ch04 (3.9 μm) / Night		-1.0	N/A	N/A
BT, Ch09 (10.8 μm)		+0.5	0.55	N/A
BT, Ch10 (12.0 μm)		+0.4	0.65	N/A
SST (Regression)		±0.2	0.55	0.3
SST (Inversion)		±0.2	0.46	0.23
SST (Hybrid)		±0.2	0.50	0.25

Summary

- SST target accuracy (0.4 K) and precision (0.8K) are met both for AVHRR & SEVIRI.
- The Hybrid SST algorithm will be used as a baseline ABI SST algorithm
- The Regression SST algorithm will be used as a back-up algorithm
- ABI Cloud Mask and SST Quality Control are 70-80% consistent. Some adjustment is still needed to resolve residual discrepancy.
- Version 4 SST code is delivered.
- Delivery of 100% ATBD is underway.