Towards 2nd Reanalysis of NOAA AVHRR GAC Data (RAN2): Evaluation

Victor Pryamitsyn[1, 2], Alexander Ignatov[1], Boris Petrenko[1,2], Olafur Jonasson[1,2], Yury Kihai[1,2]

[1] NOAA STAR, [2] GST Inc.

Background

Data of NOAA-7, 9, 11, 12, and 14 AVHRR/2s and NOAA-15, 16, 17, 18, and 19 AVHRR/3s, suitable for SST retrievals from bands 3/3b, 4 and 5 (centered at 3.7, 10.8 and 12 µm) have been available since Sep 1981. This allows creation of long-term global SST records [1-7]. At NOAA, such activity is conducted under the AVHRR GAC Reanalysis (RAN) project. Earlier, the RAN1 dataset has covered a period from 2002-2015 [1]. The ongoing second phase of this project (RAN2) will cover the full period 1981-on. NOAA enterprise Advanced Clear-Sky Processor for Ocean (ACSPO) SST system is used in both RANs. As of May 2020, the initial "beta" version of the RAN2 dataset (RAN2 B01) has been produced by reprocessing AVHRR GAC data from NOAA-7, 9, 11, 12, 14, 15 and 16 for a period from Sep 1981 – Dec 2003.

Objectives

We compare performance of RAN2 B01 SST with two other available data sets for this period: the NOAA-NASA Pathfinder v5.3 (PF) [2-4] and ESA Climate Change Initiative v2.1 (CCI) [5-6]. All SST products are uniformly validated against drifters and tropical moorings from the NOAA *in situ* SST Quality Monitor (*i*Quam; [8]). Time series of monthly biases and standard deviations of retrieved SSTs minus *in situ* SSTs, and clear-sky ratio (CR; fraction of clear-sky ocean pixels to the total ice-free ocean) are monitored in another NOAA system, SST Quality Monitor (SQUAM; [9]).

Data

RAN2 beta 01 AVHRR SST dataset for 1981-2003 (This study and [7])

- ❑ AVHRR GAC SST RAN1 L2P/3U dataset was produced at NOAA STAR in 2015 (Ignatov et al., 2016). It covered 2002-2015
- ❑ RAN2 is currently under development. It will span 1 Sep 1981 – on from NOAA-07/09/11/12/14/15/16/17/18/19 GAC
- ❑ Initial RAN2b01 dataset was produced from NOAA-07/09/11/12/14/15/16 covering 1 Sep 1981 – 31 Dec 2003
- ❑ NOAA Advanced Clear Sky Processor for Ocean (ACSPO) is used, modified for the historical reprocessing of AVHRR GAC
- ❑ ACSPO retrievals are performed in the full AVHRR swath (View Zenith Angle, -68°<VZA<+68°)
- ❑ Bands Used for Retrievals:
  NOAA-07: 2 bands (10.8 and 12 µm) used during both day and night
  NOAA-09, -11, -12, -14, -15, -16: 3 bands (3.7, 10.8 and 12 µm) during night, and 2 bands (10.8 and 12 µm) during day
- ❑ Two SST products are produced by ACSPO and available to users in the L2P/3U product files:
  Global Regression (GR), aka "Sub-skin" SST: Sensitive to "skin" SST with mean sensitivities of ~0.98 for three-bands algorithm and ~0.94 for two-bands algorithm. Trained using global *i*Quam matchups and de-biased wrt "depth" SST
  Piecewise Regression (PWR), aka "Depth" SST: A better proxy of "depth" SST (trained using subsets of the same matchups)
- ❑ Variable SST coefficients are used for both, recalculated daily using sliding time windows:
  1±45 days for GR SST 1±180 days for PWR SST
- ❑ First guess SST is used in ACSPO for a) Cloud screening/Quality Control; and b) as the first guess in the NLSST equation
  CCI L4 for NOAA-07, -09, -11 (CCI v2.1 available from 1981-2018);
  CMC for NOAA-12, -14, -15, -16 (CMC is available from 09.1991-pr)
- ❑ For more details on the retrieval algorithms and produced dataset, see [7]
- ❑ This presentation evaluates L2P data with QL=5 (L3U data are also available)

Pathfinder (PF) v.5.3 *(Kilpatrick, Podesta and Evans, JGR, 2001)*:

- ❑ Available from 1 Sep 1981 – 31 Dec 2019 (periodically updated). Only QL=4&5 are used in this analysis as recommended.
- ❑ "Skin" L3C SST (0.17 K was subtracted from satellite SST trained against *in situ* SST; in this ppt, +0.17K was added back)
- ❑ Produced by Global Regression using only two LWIR bands 10.8 and 12 µm (3.7 µm band not used)
- ❑ Regression coefficients are calculated on a monthly basis and stratified in terms of BT11-BT12
- ❑ Limited swath: -55°<VZA<+55°; No "depth" SST available and no sensitivity estimates are provided
- ❑ All data are aggregated in 0.04° (~4km) L3C (various overpasses collated, into 2 files/day – Day and Night)

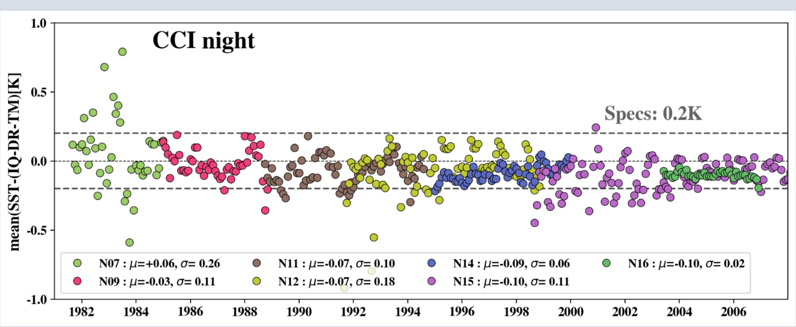
Climate Change Initiative (CCI) L2P v.2.1 *(CCI - Merchant et al., 2014, 2019)*:

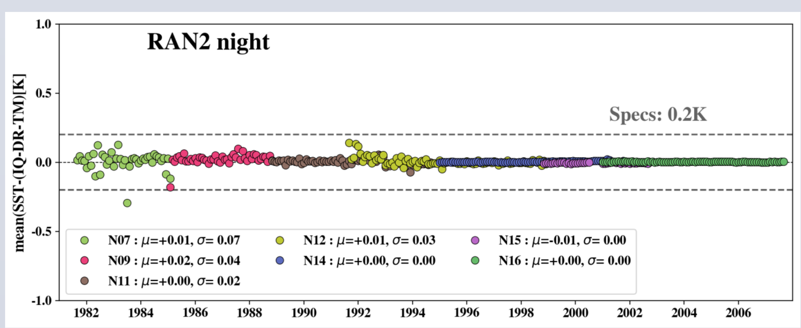
- ❑ Available from 1 Sep 1981 – 31 Dec 2016. L2P and 0.05° L3U/C data are available. Only L2P data are analyzed here.
- ❑ "Skin" SST derived by Optimal Estimation (in this ppt, +0.17 K was added back, to facilitate comparisons with RAN)
- ❑ Estimated sensitivity of "Skin" SST is close to 1
- ❑ "Depth" SST derived from "Skin" SST using model of near-surface SST stratification
- ❑ Independent from *in situ* SST as much as possible (mainly since 1995). Instead, tuned to ATSR where available/possible
- ❑ Used bands: Daytime, SZA <92.5°: 2 bands 10.8 and 12 µm; Nighttime, SZA >=92.5°: 3 bands 3.7, 10.8 and 12 µm
- ❑ Quality levels: QL≤2 for VZA > 60°; QL≤3 for twilight zone (60° < VZA < 92.5°). QL=4&5 recommended & used in this ppt

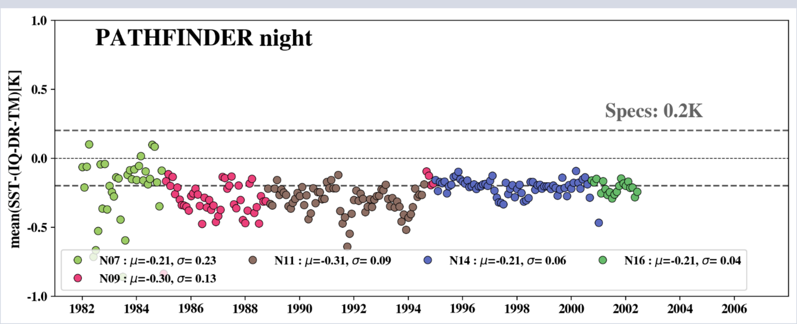
Global Monthly Mean Biases

"(Sub)-skin" SST vs. *i*Quam *in situ* SSTs: Monthly Bias:

✓ 0.17 K was added to PF and CCI skin SST to facilitate comparisons with RAN "Sub-Skin" SST



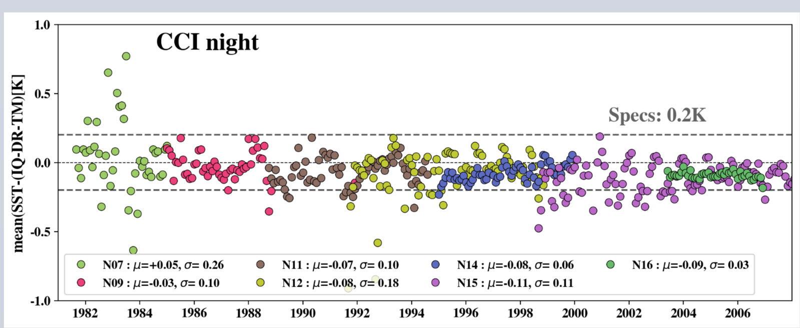


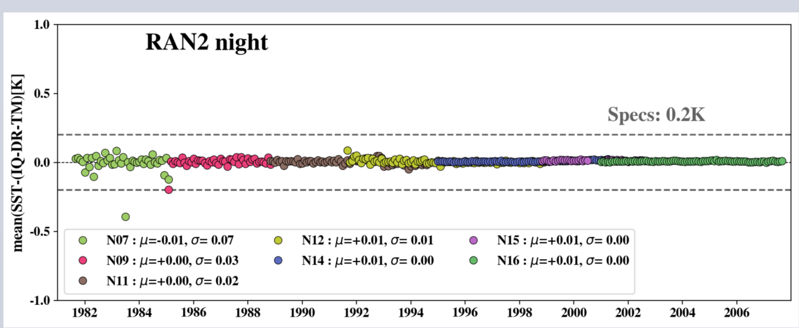


- CCI "Sub-Skin" SST is ~centered at *in situ* data and less stable than in RAN. Biased a little cold, more so for N11/12/14/15/16. More scatter for N07 is likely due to suboptimal sensor/*in situ* data in the early 1980s.
- Mean biases for RAN2 "Sub-Skin" SST are close to zero, due to retraining the regression coefficients within a 3-month sliding window. Deviations occur for sensor with short-term instabilities (N07/12)
- PF "Sub-Skin" SST is less stable than in RAN. For N07/09/11, stability is comparable to CCI & improves for N14/16. All time series appear to be biased cold relative to *in situ* data, by ~0.2-0.4K.

"Depth" SST vs. *i*Quam *in situ* SSTs: Monthly Bias:

✓ "Depth" SST is only reported in CCI and RAN and not available in PF

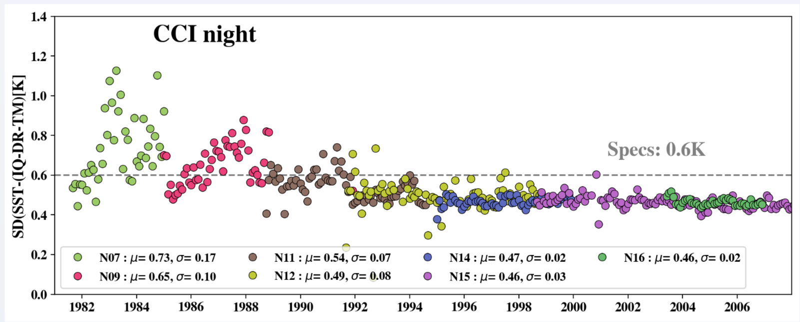


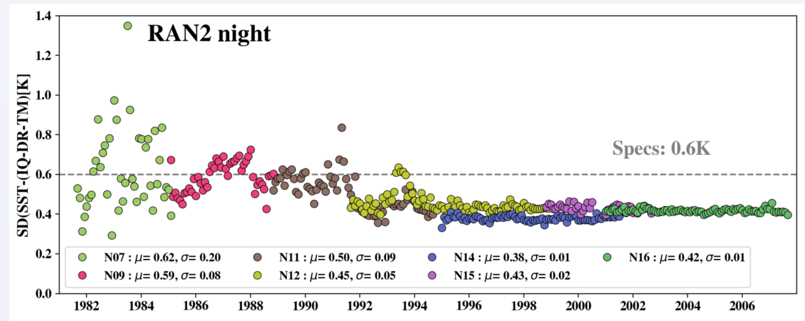


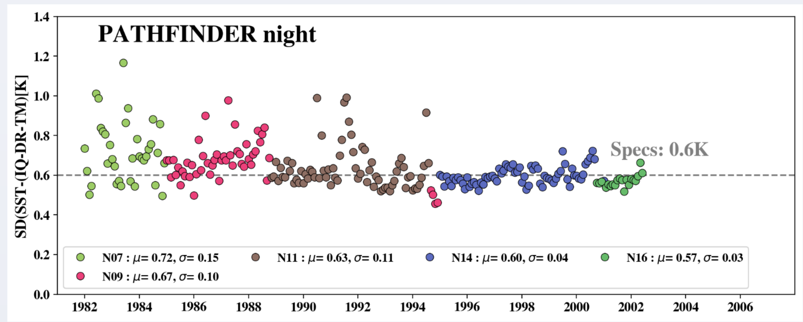
- CCI "Depth" SST remains (approximately) centered at *in situ* data (although biased cold, more so for N11/12/14/16). Less stable than RAN (which was anchored to *in situ* data). More scatter for N07 is due to suboptimal AVHRR & *in situ* data in the earlier 1980s.
- Mean biases for RAN2 "Depth" SST are closer to zero than for "Sub-Skin" SST, due to using the piece-wise regression (PWR), with regression coefficients retrained within a 12-month sliding window. Some short-term sensor instabilities are mitigated (N12).

Global Monthly Standard Deviations (SD)

Sub-Skin SST vs. *i*Quam *in situ* SSTs: Monthly Standard Deviations



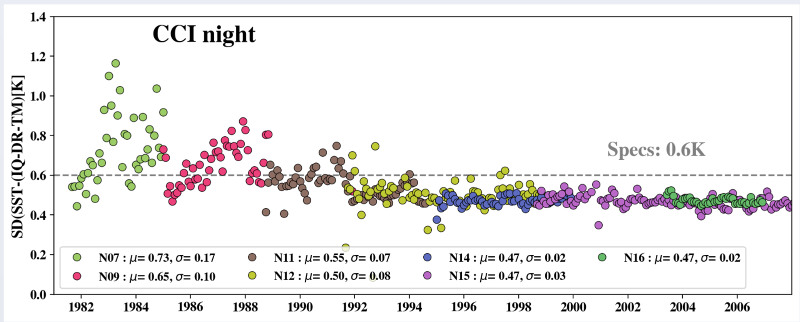


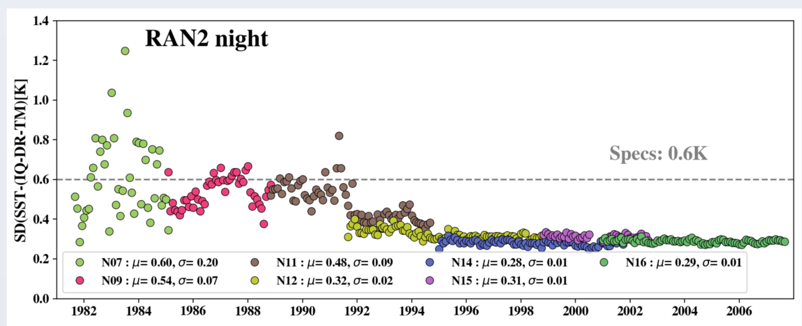


- SDs for RAN2 Sub-Skin SST are ~0.4K for most N12/14/15/16 data. Spike in 1991 is due to volcanic eruptions (Mt. Pinatubo, Mt. Hudson). We are looking at various options to mitigate the effect of volcanic eruptions.
- Increased SDs in 1980s are due to reduced quality satellite & *in situ* data.
- CCI Std. Dev's are generally larger than in RAN2, except in 1991 following the volcanic eruptions.
- PF Std. Dev's are larger than in both RAN2 and CCI 2.10.
- Effects of degraded satellite and in situ data in the 1980s, and volcanic eruptions in 1991, are also present.

Depth SST vs. *i*Quam *in situ* SSTs: Monthly Standard Deviations

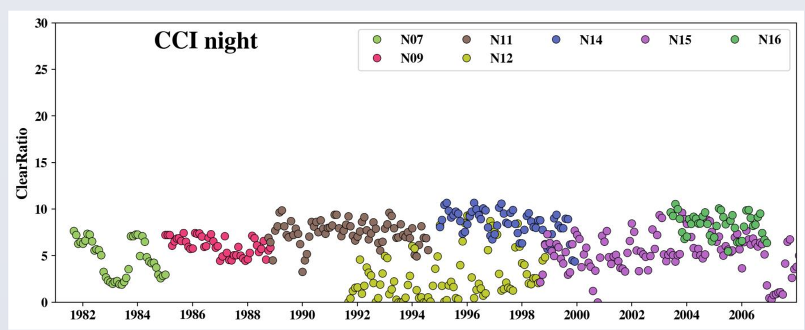
✓ "Depth" SST is only reported in CCI and RAN and not available in PF

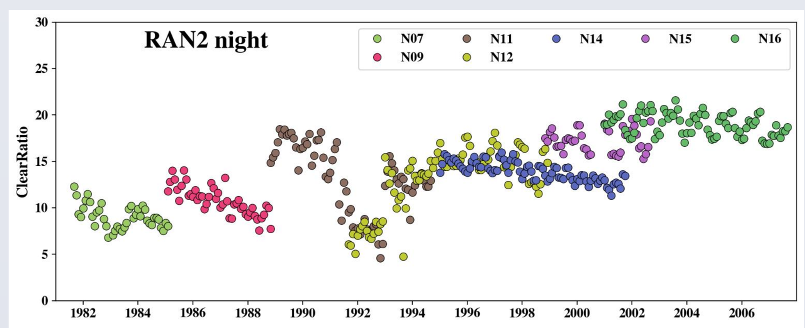


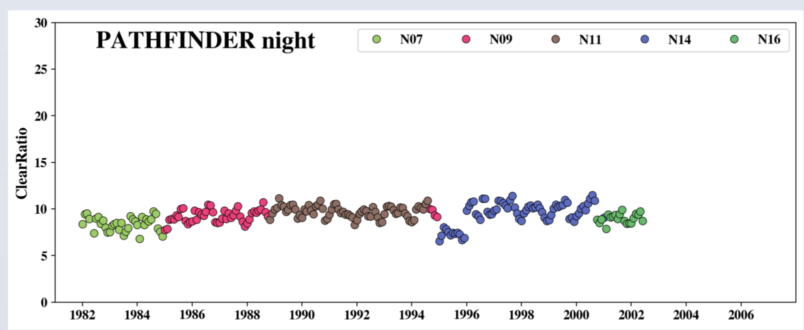


- Std. Dev's of RAN2 "Depth" SSTs are reduced, compared to the corresponding "Sub-Skin" statistics. Statistics remain degraded in the 1980s and following Mt. Pinatubo / Mt. Hudson eruptions.
- CCI "Depth" Std. Dev's are larger than in RAN2, and comparable to those of CCI "Skin" SST. Typical increases in the 1980s and ~1991, due to degraded AVHRR sensors, in situ data, and volcanoes.

Global Monthly Clear-Sky Ratios (CR)







- CCI and PF CR is up to 12%, and RAN2 CR up to 20%
- RAN2 CR is reduced and non-uniform for earlier satellites N07/09/11/12 and following the volcanic eruptions in 1991. It increases & stabilizes after ~1993.
- CCI Clear-Sky Ratio is generally lower than in RAN2 and also unstable.
- PF CR is more uniform than in RAN2 and CCI, possibly due to the L3C collation, which is supposed to increase the coverage. On average, PF CR is lower than in RAN2.

CONCLUSION

1. As a first step towards full AVHRR GAC SST reanalysis-2 (RAN2), Beta 01 for 1981 – 2003 has been created from N07, 09, 11, 12, 14, 15 and 16 with the ACSPO system. RAN2 B01 focuses on satellites & periods not covered by RAN1, undertaken in 2015 and covering period 2002-2015.
2. Comparison of RAN2 B01 with the PF v5.3 and CCI v2.1 SSTs:
   - + RAN2 typically provides more clear-sky observations (larger clear-sky fraction)
   - + Accuracy/Precision of Sub-Skin SST w.r.t. *in situ* SST in RAN2 outperforms PF, and often CCI
   - + Temporal stability of RAN2 SST biases and SDs wrt *in situ* SSTs is typically better than in PF & CCI
   - + RAN2 depth SST validates against *in situ* SST better than the Sub-Skin SST. In CCI, performance margin between the skin and depth is narrower, and sometimes even reversed. PF data set does not report depth SST.
   - + The sensitivity of the CCI SST is closer to the optimum of 1 & less variable than in RAN2 B01 SST. PF does not report sensitivity.
   - ➢ The future improvements in RAN2 B01 will be aimed at more efficient mitigation of regional biases in retrieved SST (including those caused by volcanic eruptions), accounting for sensor information from AVHRR L1B data, and completing and archival of the full RAN2.

References

[1] Ignatov, A., et al, AVHRR GAC SST Reanalysis Version 1 (RAN1), *Remote Sens*., **8**, 315 (2016).
[2] Kilpatrick, et al, Overview of the NOAA/NASA AVHRR Pathfinder algorithm for SST and associated matchup database, *JGR*, **106**, 9179-9199 (2001).
[3] Climate Algorithm Theoretical Basis Document (C-ATBD), SST – Pathfinder (2016), www1.ncdc.noaa.gov/pub/data/sds/cdr/CDRs/Sea_Surface_Temperature_Pathfinder/AlgorithmDescription.pdf
[4] Saha, K., et al. AVHRR Pathfinder version 5.3 level 3 collated (L3C) global 4km SST from 1981-Present. NOAA NCEI (2018). https://doi.org/10.7289/v52j68xx. Accessed 02 May 2020.
[5] Merchant, C., et al, SST datasets for climate applications from Phase 1 of the European Space Agency Climate Change Initiative (SST CCI), *Geoscience Data Journal*, **1**, 179-1991 (2014).
[6] Merchant, C., et al., Satellite-based time-series of SST since 1981 for climate applications, *Scientific Data*, **6**, 223 (2019).
[7] Petrenko, et al, Towards 2nd Reanalysis of NOAA AVHRR GAC Data (RAN2): Methodology. GHRSST-XXI.
[8] Xu, F., Ignatov, A., *In situ* SST Quality Monitor (*i*Quam), *JTECH*, **31**, 164-180.
[9] Dash, P., et al, The SST Quality Monitor (SQUAM), *JTECH*, **27**, 1899-1917.

Acknowledgement

The project is aimed at creating long-term SST record consistent with JPSS SST. The views, opinions, and findings in this report are those of the authors and should not be construed as an official NOAA or U.S. government position or policy.

victor.pryamitsyn@noaa.gov