Towards a Combined Surface Temperature Dataset for the Arctic from the Along-Track Scanning Radiometers (ATSRs)

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Surface Temperature (ST) changes in the Polar Regions are predicted to be more rapid than either global averages or responses in lower latitudes. Observations increasingly confirm these findings, their urgency, and their significance in the Arctic. It is, therefore, particularly important to monitor Arctic climate change.

Satellites are particularly relevant to observations of Polar Regions as they are well-served by low-Earth orbiting satellites. Whilst clouds often cause problems for satellite observations of the surface, in situ observations are much sparser. The ATSRs are accurate infra-red satellite radiometers, designed explicitly for climate standard observations and particularly suited to surface temperature observations. ATSR radiance observations have been used to retrieve sea and land surface temperature for a series of three instruments over a period greater than twenty years. This series will be extended with the launch of SLSTR on Sentinel 3, which has the same key design features necessary for providing climate quality surface temperature datasets.

We have combined land, ocean and sea-ice surface temperature retrievals from ATSR-2 and AATSR to produce a new surface temperature dataset for the Arctic; the ATSR Arctic combined Surface Temperature (AAST) dataset. We aim to use the most accurate ATSR ST data. We define four main Arctic surface types: open-land, land-ice, open-ocean and sea-ice. Ice refers to both snow and ice surfaces. We use a masking algorithm (Figure 1) to determine the surface type, determine the ST retrieval algorithm, and detect cloud. The masking algorithm uses information from the ST products utilised for AAST, as well as auxiliary ice data from the Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA) and Northern Hemisphere Interactive Multisensor Snow and Ice Mapping System (IMS NH) daily snow maps, to determine surface temperature and detect cloud. Over land and ice the GlobTemperature 1 km L2 Land and Sea-ice ST (GT_ATS_2P) product is utilised while over open ocean the ATSR Reanalysis for Climate (ARC) 1 km L2P SST is employed (Ghent, 2012; Merchant et al, 2012).

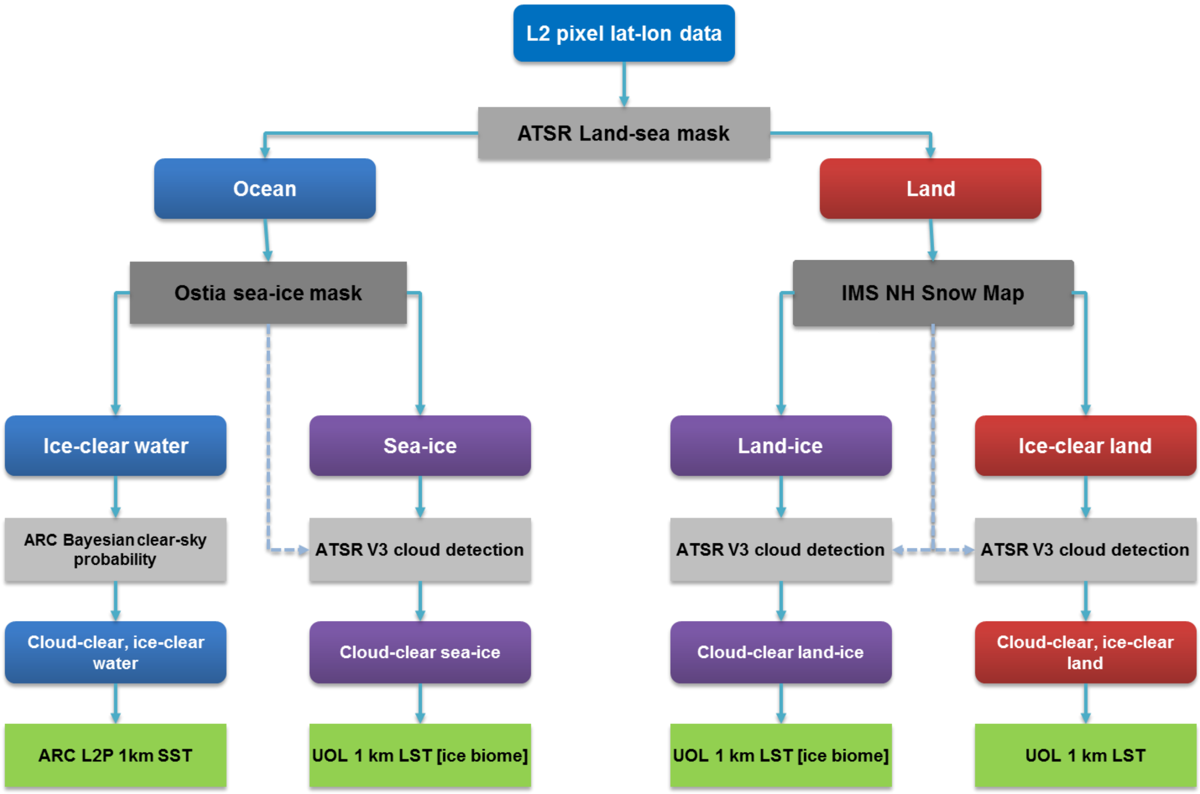

Figure 1: AAST Masking Algorithm

Ice Surface Temperatures (ISTs) were validated against in situ ISTs from land and sea ice stations, and against Surface Air Temperatures from Greenland Ice Sheet Stations (Figure 2). ATSR ISTs derived using the several different IST retrieval algorithms (Table 1) generally showed good agreement with the in situ validation data in the Arctic (Figure 3). Those derived using the ESA DUE GlobTemperature ATSR LST L2 algorithm (used for the GT_ATS_2P product) showed the best agreement with in situ data. The ISTs agree with a median difference of -0.58K, -2.03K, -2.90K over land, ice sheet and sea ice respectively (Figure 4). Uncertainty calculation and propagation has been implemented and will be included in the new version of AAST. The uncertainties were calculated and propagated following the methods employed by initiatives such as the GlobTemperature project (http://www.globtemperature.info/) and SST CCI (http://www.esa-sst-cci.org/).

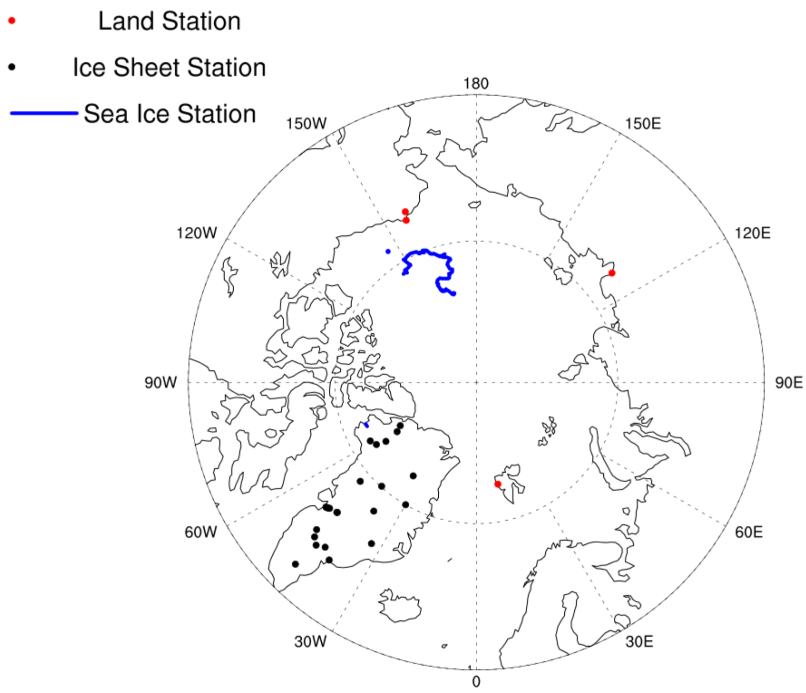

Figure 2: The location of in situ validation stations located on land, the Greenland ice sheet and sea ice.

Table 1: IST algorithms selected for validation.

Algorithm Name	Short Name	Satellite Instrument	Algorithm	References
ESA DUE GlobTemperature ATSR LST L2 Algorithm	GlobT L2	ATSR	$a + b(T_{11} - T_{12})^n + (b + c)T_{12} + \Delta LST$	Ghent et al, 2014; Prata, 2002
Key et al Polar IST Algorithms	Key AVHRR	AVHRR, MODIS	$a + bT_{11} + c(T_{11}-T_{12}) + d(T_{11}-T_{12})(\sec\theta - 1)$	Key et al, 1997
	Key ATSR	ATSR	$a + bT_{11,\,nadir} + cT_{11,\,forward} + dT_{12,\,nadir} + eT_{12,forward}$	Stroeve et al, 1995; Key et al, 1997
	Key VIIRS	VIIRS	$a + bT_{11} + c(T_{11}-T_{12}) + d(\sec\theta - 1)$	Yu et al, 1995; Key et al, 2013

T_{11} is the brightness temperature of the 11 µm channel; T_{12} is the brightness temperature of the 12 µm channel; *a, b, c, d, e* are coefficients; θ is the sensor scan angle; *nadir* and *forward* refer to the two viewing angles of ATSR (nadir and 55° forward along track); ΔIST is the uncertainty in the model fitting; *n* is a non-linearity term (dependent on satellite view angle).

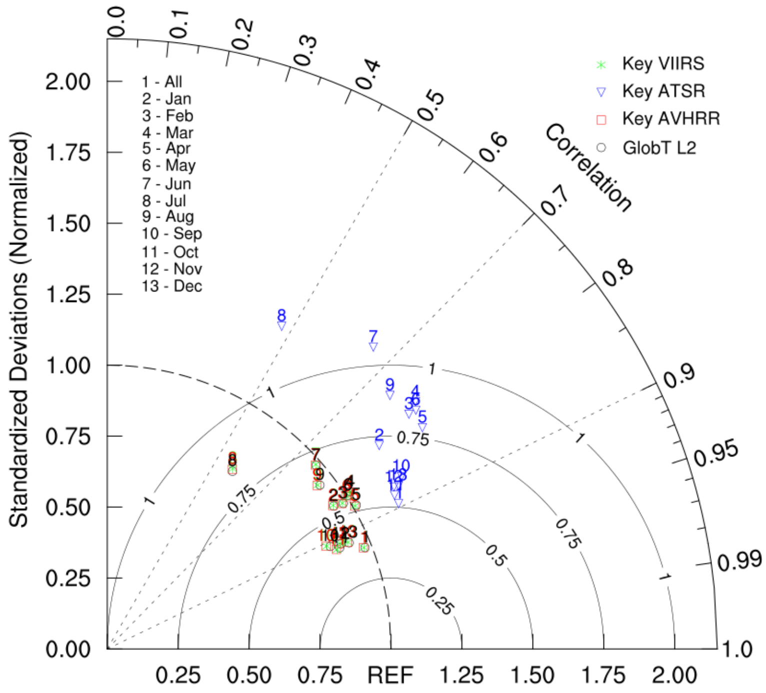

Figure 3: Taylor Diagram comparing ISTs derived by each satellite algorithm to the *in situ* ISTs. Each symbol plotted represents a month of the year or the annual value, across all *in situ* stations, for a particular algorithm. Correlation of satellite IST with *in situ* IST is shown by the angle with respect to the x-axis. The standard deviations, normalised with respect to the reference (*in situ*) standard deviation, can be read from the y-axis. The root mean square difference between satellite and in situ ISTs is proportional to the distance to the point on the x-axis identified as REF (shown by the concentric circles marked 0.25 to 1).

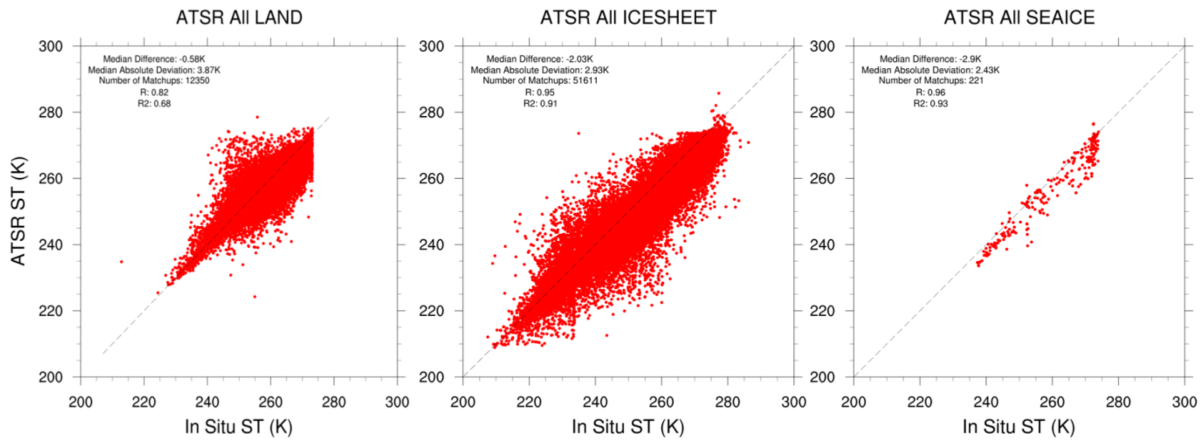

Figure 4: Scatter plot of validation results over Arctic land, ice sheet and sea ice across all ATSR instruments and years.

Early results show mean Arctic STs increased from 1997 to 2012 (Figure 5). The time series for open ocean in the Arctic Polar Region shows a significant warming trend during the AATSR mission. Time series for land, land-ice and sea-ice show high variability as expected but also interesting patterns.

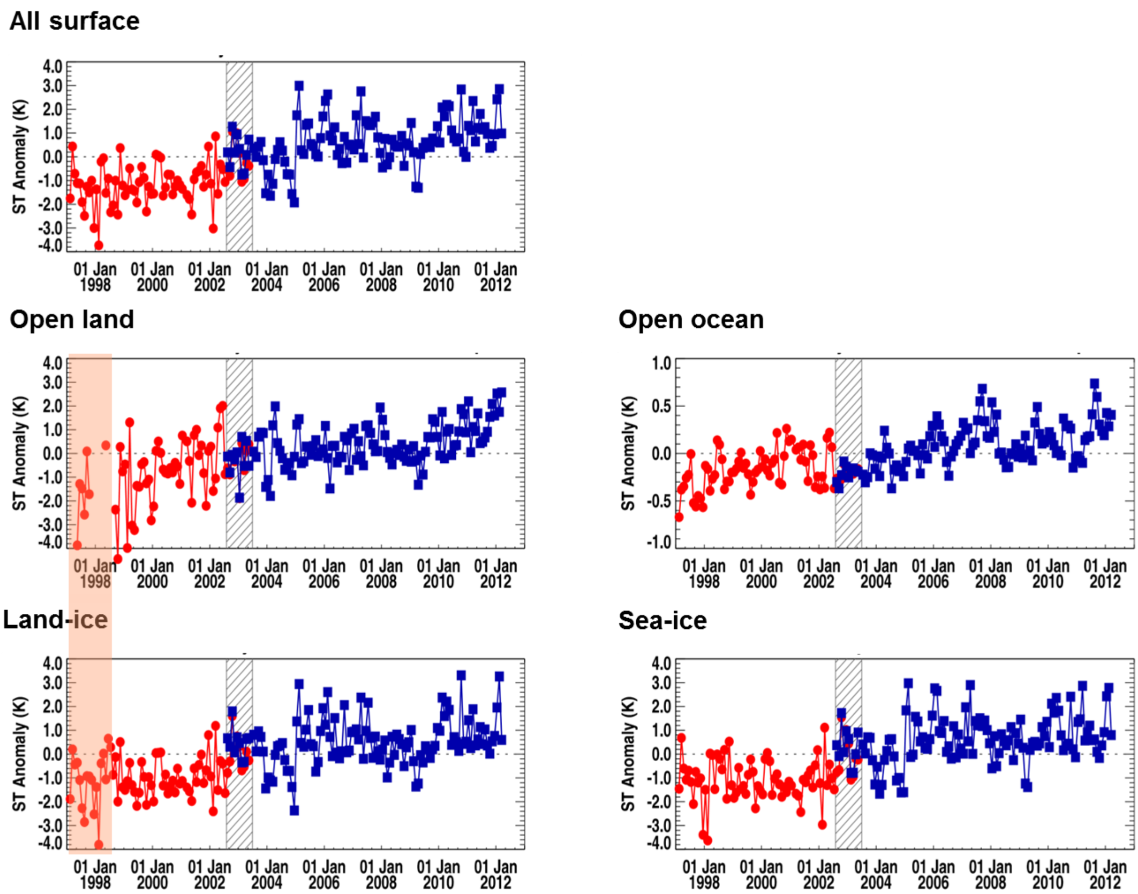

Figure 5: Time series of the monthly mean ST anomaly above 65 °N. ATSR-2 in red, AATSR in blue, orange areas indicate uncertainty in land-snow masking

Overall, our purpose is to present the state-of-the-art for ATSR observations of surface temperature change in the Arctic and hence indicate the confidence we can have in temperature change across all three domains, and in combination. Currently there is no plan to provide sea-ice ST as a core product from Sentinel 3. However, Arctic ST products derived from climate quality satellite data over all surfaces is of great importance for monitoring future changes in the Arctic. We make the case for a near real time Arctic ST product from SLSTR which would include surface temperatures for all three domains: land, sea *and* sea-ice.

References

Ghent, D., et al. (2014), Advancing the AATSR land surface temperature retrieval with higher resolution auxiliary datasets: Part A – product specification, *in preparation*

Ghent D., (2012), Land Surface Temperature Validation and Algorithm Verification *Report to European Space Agency UL-NILU-ESA-LST-VAV*

Key, J. R., J. B. Collins, C. Fowler, and R. S. Stone (1997), High-latitude surface temperature estimates from thermal satellite data, *Remote Sensing of Environment*, *61*(2), 302-309

Key, J. R., R. Mahoney, Y. Liu, P. Romanov, M. Tschudi, I. Appel, J. Maslanik, D. Baldwin, X. Wang, and P. Meade (2013), Snow and ice products from Suomi NPP VIIRS, *Journal of Geophysical Research: Atmospheres*, *118*(23), 12,816-812,830, doi: 10.1002/2013JD020459.

Merchant, C. J., et al. (2012), A 20 year independent record of sea surface temperature for climate from Along-Track Scanning Radiometers. *Journal of Geophysical Research: Oceans (1978–2012)* 117.C12

Prata, F. (2002), Land Surface Temperature Measurement from Space: AATSR Algorithm Theoretical Basis Document, *Tech. Rep.*, CSIRO Atmospheric Research, CSIRO Atmospheric Research, Aspendale, Australia.

Stroeve, J., M. Haefliger, and K. Steffen (1996), Surface Temperature from ERS-1 ATSR Infrared Thermal Satellite Data in Polar Regions, *Journal of Applied Meteorology*, *35*(8), 1231-1239, doi: 10.1175/1520-0450(1996)035<1231:STFAIT>2.0.CO;2.

Yu, Y., D. A. Rothrock, and R. W. Lindsay (1995), Accuracy of sea ice temperature derived from the Advanced Very High Resolution Radiometer, *Journal of Geophysical Research-Oceans*, *100*(C3), 4525-4532