Meeting report: Second Annual EarthTemp Network Meeting, 12 - 14 June 2013, Copenhagen

Surface Temperature in Data-Sparse and Extreme Regions:
Focus on High Latitude and High Altitude Domains

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Abstract

The EarthTemp Network was established in 2012 to accelerate progress in observing temperatures at the Earth surface and increase communication and international collaboration between groups working in different domains of surface temperature observation.

This report documents the Second Annual EarthTemp meeting, held at the Danish Meteorological Institute (DMI) in Copenhagen on 12-14 June 2013. The 2013 meeting focused on observing surface temperatures in data-sparse and extreme regions with an emphasis on monitoring surface temperature at high latitudes and at high altitudes, bringing together experts in both in situ and remote Earth observation. The scope of the meeting encompassed temperature observation over the broad range of surfaces present in these remote regions, aiming to build up communication, understanding and collaboration between the various fields of surface temperature observation.

This report reviews progress on activities supported by the EarthTemp Network in the year following the First Annual EarthTemp meeting in Edinburgh, UK, reports on the outcomes of the Second Annual EarthTemp meeting and outlines upcoming EarthTemp activities.

1. The EarthTemp Network

The EarthTemp Network aims to improve understanding of surface temperatures as an integrated subject area by facilitating knowledge exchange and collaboration between related fields of Earth observation relevant to temperatures near to the Earth's surface. The term surface temperature is commonly used in reference to a range of geophysical parameters including land surface skin temperatures, sea surface temperature, air temperatures and sea ice surface temperatures. A main objective of the EarthTemp Network is to identify gaps in our knowledge and develop action plans to improve our understanding of surface temperatures their observation. This includes temperatures measured in situ near to the Earth's surface and temperatures derived from radiometric measurements obtained using either in situ devices or remotely by satellite instruments.

The first EarthTemp Network meeting was held at the University of Edinburgh in June 2012. This meeting identified key scientific and societal needs for surface temperature understanding and information. These requirements are presented in the EarthTemp Community Paper[1] (Merchant et al. 2013) along with steps towards meeting the EarthTemp Networks's goals, grouped into 10 broad recommendations:

- Recommendation 1: develop more integrated, collaborative approaches to observing and understanding Earth's various surface temperatures
- Recommendation 2: build understanding of the relationships between different surface temperatures, where presently inadequate
- Recommendation 3: demonstrate novel underpinning applications of various surface temperature datasets in meteorology and climate
- Recommendation 4: make surface temperature datasets easier to obtain and exploit, for a wider constituency of users
- Recommendation 5: consistently provide realistic uncertainty information with surface temperature datasets
- Recommendation 6: undertake large-scale systematic intercomparisons of surface temperature data and their uncertainties
- Recommendation 7: communicate differences and complementarities of different types of surface temperature datasets in readily understood terms
- Recommendation 8: rescue, curate and make available valuable surface temperature data that are presently inaccessible
- Recommendation 9: maintain and/or develop observing systems for surface temperature data
- Recommendation 10: build capacities to accelerate progress in the accuracy and usability of surface temperature datasets

In all, 28 specific steps towards the above recommendations are described in detail in the EarthTemp Community Paper.

1.2 Progress in EarthTemp supported activities

The EarthTemp Network operates a visiting scientist scheme which exists to support visits and exchanges of scientists working on subjects related to observation of surface temperatures. Over the past year, two activities have been supported in this way:

- The EarthTemp Network SST-ICOADS exchange of visiting scientists was held at the National Oceanography Centre Southampton, UK and the UK Met Office over 4-10 April 2013. This meeting discussed advances in the analysis of SST and proposed new international collaborative arrangements to facilitate future developments of the International Comprehensive Ocean-Atmosphere Dataset (ICOADS). A summary of this meeting can be found on the EarthTemp website[2].

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[1] Merchant, C. J., et al. (2013). The surface temperatures of Earth: steps towards integrated understanding of doi:10.5194/gi-2-305-2013.

[2] http://www.earthtemp.net/visiting_scientists/reports/EarthTemp_VS_SST-ICOADS-2013.pdf

- The EarthTemp visiting scientist scheme supported work on the creation of the EarthTemp Arctic Matchup Database, the first database for land surface temperature/ice surface temperature matchups between satellite retrievals and in-situ measurements. This builds upon the matchup database developed at the University of Leicester under the ESA Project - Long Term Land Surface Temperature Validation (Ghent 2012[3]).

A dedicated EarthTemp session was held at the European Geosciences Union General Assembly 2013 entitled “Taking the temperature of the Earth: Temperature Variability and Change across all Domains of Earth's Surface” 9 April 2013, Vienna.

2. EarthTemp 2013

The first EarthTemp Network meeting focused on identifying gaps in our current understanding and barriers to progress toward an integrated understanding of surface temperatures resulting in the Community Paper recommendations. The second EarthTemp meeting focused on turning these recommendations into actions. The meeting featured a series of plenary discussions, breakout groups on specific subject areas and networking activities designed to encourage cross discipline discussion and future collaborative activities.

Keynote speakers presented overviews of the current state of the art in high latitude surface temperature observation.

- High-latitude surface temperature: synthesis of datasets and what they tell us - Kevin Wood (NOAA)
- Arctic land surface temperature: variability and change - Claude Duguay (University of Waterloo)
- Sea surface temperature changes in the Arctic - Pierre le Borgne (Météo-France/CMS, Lannion)
- Sea-ice surface temperature measurement: status and utility - Jacob Hoyer (Danish Meteorological Institute)

Each was followed by a panel discussion. Breakout groups were tasked with proposing actions towards the EarthTemp Community Paper recommendations; discussing techniques for matching measurements and retrievals across different platforms; discussing the measurement of high-latitude SST; and discussing measurement of satellite LST in high latitude and high altitude domains. Outcomes from these breakout sessions were collated and are presented in Section 3 and 4 of this meeting report. Attendees were also invited to present posters on relevant work in two poster sessions. Presented posters are available from the EarthTemp website[4].

[3] Ghent, D., 2012. LST Validation and Algorithm Verification Report, ESA Contract Number: 19054/05/NL/FF

[4] http://www.earthtemp.net/themes/2_data-sparse/participants.html

3. Surface Temperature Observation in the Arctic (and high altitude regions) – issues for individual domains

3.1 Overview of surface temperature observation in the Arctic

The keynote presentation **"**High-latitude surface temperature: synthesis of datasets and what they tell us**"** outlined how high latitude surface temperature observation has been achieved through an ever evolving, but always sparse, constellation of assets. This keynote presentation described the development of Arctic and Antarctic surface observations from early expedition records dating back to the early 19th century, through the establishment of the highly valuable circumpolar stations in the 1920s to the development of more modern observing systems including drifting stations, satellites and, most recently, research drones.

Historical features of Arctic surface temperatures were discussed, with an emphasis on uncertainty arising from both the sparsity of available observations and instability of the historical observing network. The importance of metadata describing observing practices and measurement equipment was emphasised and the role of supporting information from dynamical reanalyses and other corroborating data was discussed in relation to understanding events such as the Early Twentieth Century Warming (ETCW) pattern in the Arctic. The presentation outlined the importance of understanding both the distribution and quality of the data underlying any representation of regional temperatures, without which misleading results are guaranteed.

The keynote demonstrated the capabilities of the modern observing network in studying emerging features in the Arctic. A case study of the Mackenzie River plume was presented, utilising observations of satellite retrieved sea surface temperatures together with observations from wave gliders. Also discussed were the difficulties in putting emerging phenomena into their historical context in the absence of a stable and comprehensive historical observing network.

The keynote promoted the importance of data rescue efforts such as Old Weather[5] and efforts lead by the Atmospheric Circulation Reconstructions over the Earth[6] (ACRE) initiative, which are invaluable for digitising the data required to understand historical temperatures. Transcribed observations from these initiatives are currently being used in at least 4 reanalyses: 20CR V3[7], ERA-Clim (ECMWF), SODA (Texas A&M), HURDAT (NOAA). In addition to feeding into dynamical reanalyses, data rescue projects are feeding into the International Comprehensive

[5] http://www.oldweather.org/
[6] http://www.met-acre.org/
[7] Compo, G.P., J.S. Whitaker, P.D. Sardeshmukh, N. Matsui, R.J. Allan, X. Yin, B.E. Gleason, R.S. Vose, G. Rutledge, P. Bessemoulin, S. Brönnimann, M. Brunet, R.I. Crouthamel, A.N. Grant, P.Y. Groisman, P.D. Jones, M. Kruk, A.C. Kruger, G.J. Marshall, M. Maugeri, H.Y. Mok, Ø. Nordli, T.F. Ross, R.M. Trigo, X.L. Wang, S.D. Woodruff, and S.J. Worley, 2011: The Twentieth Century Reanalysis Project. Quarterly J. Roy. Meteorol. Soc., 137, 1-28. DOI: 10.1002/qj.776

Ocean Atmosphere Data Set[8] (ICOADS) and the International Surface Temperature Initiative (ISTI) databank[9].

3.2 Domain specific issues

This section draws together domain specific issues for observing Ice Surface Temperature (IST), Sea Surface Temperature (SST), Land Surface Temperature (LST) and Surface Air Temperatures (SAT) in the Arctic. For each of these domains, an overview of related keynotes, posters and domain specific discussions in breakout groups is given.

Ice Surface Temperature (IST)

The keynote presentation "Sea-ice surface temperature measurement: status and utility" began by quoting the results of a recent European Space Agency (ESA) Climate Change Initiative (CCI) sea ice data user survey that found users of sea ice data rank IST 4th out of 22 sea ice parameters in terms of importance. There are currently very few near real time in situ observations of IST in the Arctic. There is however a large range of satellite derived IST products available (Modis Aqua and Terra, AVHRR Polar Pathfinder dataset, Metop-A, ATSR, AMSR-E, VIIRS, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), IASI, Enhanced Thematic Mapper Plus (ETM+)).

Passive microwave IST observations were discussed as a potential approach to overcoming the cloud screening problems in infrared (IR). Merging passive microwave observations with IR is problematic however because of difference in resolution and the depth into which microwave observations observe. The keynote however presented some recent work (Tonboe et al., 2011[10]) showing good agreement between snow ice interface temperatures and 6 GHz brightness temperatures when modelling relationships between the two observation types using combined thermodynamic and MW emission models.

Validation of IST retrievals is challenging because of poor coverage of accurate validation data. The data currently available for validation are drawn from a wide range of observing platforms including infrared radiometers, drifting buoys, thermocrons, temperature-depth profiles from ice mass balance buoys, and air temperature and radiometers observations from Automatic Weather Stations (AWS).

The IST keynote outlined comparisons between satellite IST and in-situ observations undertaken in a number of studies:

- Validation of MODIS retrieved IST (Hall et al., 2004, 2012, Scambos et al., 2006)

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[8] Woodruff, S.D., S.J. Worley, S.J. Lubker, Z. Ji, J.E. Freeman, D.I. Berry, P. Brohan, E.C. Kent, R.W. Reynolds, S.R. Smith, and C. Wilkinson, 2011: ICOADS Release 2.5: Extensions and enhancements to the surface marine meteorological archive. *Int. J. Climatol.* (CLIMAR-III Special Issue), **31**, 951-967 (doi:10.1002/joc.2103).

[9] http://www.surfacetemperatures.org/

[10] Tonboe, R.T., Dybkjær, G., and Høyer, J.L. Simulations of the snow covered sea ice surface and microwave effective temperature. TELLUS, 63A, 1028-1037, 2011

- Validation of AVHRR retrieved IST (Key and Haefliger, 1992, Key et al., 1997, Scambos et al., 2006)
- Validation of Metop_A retrieved IST (Dybkjær et al., 2012)[11]

Compared to AWS and drifting ice buoys, satellite retrieved IST products typically showed cold biases of 1-3°C and standard deviations of matchups of 1-3°C. Validation results for satellite retrieved IST products were improved when validated using infrared radiometer observations (Scambos et al, 2006, Dybkjær et al., 2012)[9], multi-satellite intercomparisons (Hall et al., 2008)[9] and when using additional cloud masking (Dybkjær et al., 2012).

The keynote highlighted a number of challenges for users of ice surface temperature data. Results showed representivity problems relating to large diurnal variation and clear sky biases in temperature retrievals. Vertical temperature variability and large temperature gradients in snow and ice were also identified. Promising results were shown for modelling relationships between surface air temperatures and snow surface temperatures (Tonboe et al., 2011)[8].

Land Surface Temperature (LST)

The Keynote presentation "Arctic land surface variability (and change)" outlined the current state of Arctic LST monitoring, intercomparison of Arctic LST products and validation of satellite retrievals of Arctic LST against in situ observations. The presentation gave examples of the use of satellite LST in Arctic monitoring activities.

Validation results were shown comparing satellite retrieved LST with in situ radiometers and near-surface air temperatures measurements. Comparison of MODIS L2 LST with Thermal camera information (Lena River Delta, Samoylov Island, Langer et al., 2010[12]; Brøgger Peninsula, Svalbard, Westermann et al., 2011[13]) found agreement in temperatures typically to less than 2 K

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[11] Dybkjær, G., Tonboe, R., and Høyer, J. L.: Arctic surface temperatures from Metop AVHRR compared to in situ ocean and land data, Ocean Sci., 8, 959-970, doi:10.5194/os-8-959-2012, 2012.
Hall, DK, Key, JR, Casey, KA, Riggs, GA, Cavalieri, DJ (2004). Sea ice surface temperature product from MODIS. *IEEE Transactions on geoscience and remote sensing*, 42(5), 1076-1087.
Hall, DK; Comiso, JC; DiGirolamo, NE; Shuman, CA; Key, JR; Koenig, LS (2012). A Satellite-Derived Climate-Quality Data Record of the Clear-Sky Surface Temperature of the Greenland Ice Sheet. *Journal of Climate*, 25(14), 4785-4798.
Key, J.R., J.B. Collins, C. Fowler, R.S. Stone, High-latitude surface temperature estimates from thermal satellite data, Remote Sensing of Environment, Volume 61, Issue 2, August 1997, Pages 302-309, ISSN 0034-4257, http://dx.doi.org/10.1016/S0034-4257(97)89497-7.
Scambos, T. A., Haran, T. M., Fahnestock, M. A., Painter, T. H., & Bohlander, J. (2007). MODIS-based Mosaic of Antarctica (MOA) data sets: Continent-wide surface morphology and snow grain size. *Remote Sensing of Environment*, *111*(2), 242-2
Key, J., *and* M. Haefliger *(*1992*)*, Arctic ice surface temperature retrieval from AVHRR thermal channels, J. Geophys. Res., 97*(*D5*)*, 5885–5893, *doi:*10.1029/92JD00348.

[12] Langer M., W. Moritz; S. Westermann, J. Boike (2010): Spatial and temporal variations of summer surface temperatures of wet polygonal tundra in Siberia - implications for MODIS LST based permafrost monitoring. *Remote Sensing of Environment*, 114(9), 2059-2069, doi:10.1016/j.rse.2010.04.012

[13] Sebastian Westermann, Moritz Langer, Julia Boike, Spatial and temporal variations of summer surface temperatures of high-arctic tundra on Svalbard — Implications for MODIS LST based permafrost monitoring, Remote Sensing of Environment, Volume 115, Issue 3, 15 March 2011, Pages 908-922, ISSN 0034-4257, http://dx.doi.org/10.1016/j.rse.2010.11.018.

but revealed erroneous temperature retrievals (5-15 K cooler that thermal camera temperatures) in the presence of undetected clouds.

An example of the use of a dedicated validation site was given with recent validation results for satellite-in situ matchups at the Barrow ARM site[14] revealing cool mean biases of the order of 1-2 K in LST retrievals for AATSR, MODIS and AVHRR retrievals in comparison to in situ radiometric measurements. Larger cool biases were found in comparison to 2 m air temperature measurements at the site.

Examples were shown of the use of Aqua and Terra LST-day and LST-night acquisitions to compute daily averages and comparison of these with in situ air temperature measurements. Similar comparisons of LST to ground temperatures measured 3-5 cm below the surface show much less agreement than comparisons with air temperatures, with greatly reduced diurnal variability in ground temperatures (Hachem et al., 2012[15]).

Examples were shown of the use of MODIS LST anomalies for Arctic monitoring including monitoring of glaciated regions in the Arctic (Wolken et al., 2013)[16] and monitoring of average Greenland Ice sheet temperatures (Tedesco et al 2013)[17].

The breakout group “Satellite LST in high latitude and high altitude domains” identified the following areas in which present understanding was considered to be limited:

- Relationships between LST and air temperatures are currently not well understood. Relating LST and air temperature in mountainous areas is a challenge due to topography (shadowing/solar radiation/wind).

- Transition seasons are a major issue for Arctic LST monitoring. The related effects on surface properties are a major challenge, for example change from snow to bare soil/tundra. Similarly, decoupling of high and low altitude glaciers is an issue. For satellite retrievals, sub-pixel scale variability remains a challenge and questions remain on how retrievals for mixed pixels (for example containing land, lakes, snow, ice) can be validated. Diurnal effects can also be problematic as acquisition times differ from satellite to satellite.

- Short satellite data record lengths are a problem for studying changes because of questions about stability over required time scales (~30 years).

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[14] Darren Ghent, Stephan Matthiesen, Jacob Høyer, Gorm Dybkjær, Karen Veal, Christopher Whyte, and John Remedios: An EarthTemp Matchup Database for the Arctic Region

[15] Hachem, S., Duguay, C. R., and Allard, M.: Comparison of MODIS-derived land surface temperatures with near-surface soil and air temperature measurements in continuous permafrost terrain, The Cryosphere Discuss., 5, 1583-1625, doi:10.5194/tcd-5-1583-2011, 2011.

[16] Wolken. G., M. Sharp, M.-L. Geai, D. Burgess, A. Arendt, and B. Wouters, 2013: [Arctic]. Glaciers and ice caps (outside Greenland). [in "State of the Climate in 2012"]. Bull. Amer. Met. Soc. 94, S119-S121.

[17] Tedesco, M., J.E. Box, J. Cappelen, X. Fettweis, T. Jensen, T. Mote, A.K. Rennermalm, L.C. Smith, R.S.W. van de Wal, and J. Wahr, 2013: [Arctic] Greenland ice sheet [in "State of the Climate in 2012"]. *Bull. Amer. Meteor. Soc.*, **94** (8), S121-S123.

- Differences in cloud masking for different products are problematic, with cloud masked better for some sensors than others. Snow detection and density estimation is also an issue that is closely related to cloud detection and emissivity issues.

- Use of passive microwave sensors is complicated by questions on the depth into the snow pack being observed and relationships between temperatures at the observed depth and skin temperatures.

For merging of different types of LSTs questions were raised over whether intercomparisons should compare satellite LST retrievals or compare radiances using a consistent retrieval algorithm. Validation of microwave, infra-red and model based LST was identified as a requirement for combining different datasets, for example to fill in cloud related gaps in IR products using microwave observations. Questions were also raised on whether the use of different wavebands by different sensors can introduce a difference in retrieved LST. Thermodynamic models were proposed as a method to combine observations from different sensors.

The breakout group highlighted the need for more and better validation of satellite retrievals. At present very few validation sites are available in high latitude and high altitude regions and validation site measurement methods and protocols are not standardised. The establishment of radiometer measurements at existing stations was proposed to increase the number of sites available for validation. Sites in both homogeneous and heterogeneous regions were requested, with as stable surface properties as possible. Sites were requested at locations representative of a wide range of surfaces, including semi-arid areas, surfaces of different emissivities, croplands, trees, lakes, hummocks, permafrost patterned ground and mountainous regions.

Poster sessions exhibited recent work on comparisons between satellite retrieved LST and in situ observations, including descriptions of validation methods and existing validation sites[18], comparison of satellite retrieved LST and LSAT observations at high altitudes[19], and study of LST and LSAT on the ice cap of King George Island, Western Antarctica[20].

Difficulties in identification of cloud over ice/snow covered issues were discussed particularly relating to the challenge of using thermal channels to detect clouds during time of polar darkness. A closer look at cloud screening in ice/snow covered surfaces from the different satellite sensors is required.

Towards the above aims, the following actions were proposed by breakout groups:

Recommendation: Investigation of cloud screening over ice/snow covered surface from different satellite sensors including the use of thermal channels to detect clouds during polar darkness.

Recommendation: Development of a consistent retrieval and cloud detection algorithm across platforms, recognizing different channels.

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[18] Folke Olesen, Frank Göttsche: Land Surface Temperature: Comparison methods and regional validation initiative
[19] Elena Istomina, O. V. Vasilenko:
Interrelation Between In-situ Measured LST and LAT and Landsat Thermal data in the Tunkinskaya Valley

[20] Ulrike Falk, Hernán Sala, Damián López, Claudio Matko, Matthias Braun, Gunter Menz
Land surface temperature and land surface air temperature measurements on the ice cap of King George Island, West Antarctica

Recommendation: Use of thermal and passive microwave synergy accounting for satellite footprint scaling of around 1km to 25km.

Recommendation: Investigation of relationships between different ways of measuring temperature (LSTs, air temperatures) and field studies and modelling to look at the relationship between LST and air temperatures.

Recommendation: Encourage funding and deployment of radiometers on current weather stations.

High Latitude Sea Surface Temperature (SST)

The keynote presentation entitled “Sea surface temperature changes in the Arctic” described the current state of the art in the challenging field of SST observation at high latitudes.

The keynote highlighted diurnal features of high latitude SST. Diurnal warming was observed at high latitudes in both in situ drifting buoy observations and METOP/AVHRR SST retrievals. Results were shown for matchups with in-situ observations from buoys, although the number of available matchups were few, save for the European Arctic region. More numerous buoy measurements were requested, particular surrounding North America and Siberia. It was suggested that frequent polar orbiter overpasses could be used to resolve diurnal variability in the Arctic and that diurnal variability models could also be used, noting that a precedent exists for merging LST with models to resolve diurnal variability.

Atmospheric profile corrections for high latitude regions were also discussed in the keynote presentation. The utility of NWP based brightness temperature simulations as an alternative to in situ matchups was demonstrated, revealing that errors in high latitude SST retrievals appear to be related to the shape of atmospheric profiles. Summer temperature inversions were found to lead to large positive errors that were found to be well modelled by NWP-based brightness temperature simulations. Cloud contamination was found to introduce negative errors whereas ice related errors were not evident.

Several methods were proposed to account for atmospheric absorption, including multisensory bias corrections (Hoyer et al, 2013, RSE, in press), regional algorithms (Hoyer 2012) and NWP derived correction methods. NWP based correction methods were discussed in detail, including optimal estimation (Merchant et al 2008, 2009, 2013) and bias correction methods (LeBorgne et al, 2011, Petrenko et al, 2011)

The breakout group discussing measurement of high latitude SST identified the following problems:

- Limited in-situ data in high latitude regions – high risk areas for in situ observations
- Unable to define climatological SSTs in new ice-free areas where SST is undefined during the climatological base period.

For study of SST in marginal ice zones there is a need for observations located as close to the ice edge as possible. Available measurements within the marginal ice zone are sparse. Sources of additional observations were discussed in breakout groups. Ships of opportunity such as merchant vessels were proposed as one possible source for additional observations in this region. Ice buoys were also suggested as a potential source of data in this region if they can be adapted to float following ice melt. Other suggested options included the development of low cost radiation buoys, ideally expendable and deployable from the air in areas deemed to be high-risk areas for other forms of in situ observation. A further recommendation was also suggested for satellite SST to be made available as close as possible to ice edges to allow study of this region.

Recommendation: satellite SST to be made available as close as possible to ice edges.

Relating to the discussion in the keynote on observing SST in high latitude regions, diurnal surface layer heating in the Arctic was discussed along with issues relating to surface stratification associated with river outflow plumes. Questions were raised about whether effects similar to those relating to the Mackenzie River plume can be found around Siberian river outflows and of the effects of such a plume relating to atmospheric forcing, winds, radiative fluxes and salinity. It was suggested that a meeting be organised to discuss what is currently known and unknown about SST in the Arctic, potentially leading to a review paper.

Recommendation: project comparing the situation in different river plumes using a combination of satellite and in situ observations.

Recommendation: meeting on Arctic SST leading to a review paper.

The existence of a number of different data repositories was highlighted as an issue for accessing a wide range of data. The existence of data that are not readily available in existing data repositories was also identified as a problem for the study of SSTs in the sparsely observed high latitude regions.

Recommendation: use the EarthTemp website to link to existing repositories of SST information

Recommendation: Encourage archiving of field campaign data in commonly used data repositories and the use of data journals to publish this data.

Similarities in ice and cloud tops, strong temperature gradients in ice/water and twilight conditions are a challenge for cloud masking in marginal ice zones. There is a need for continued research and development, both in more sophisticated image/data processing and considering whether additional channels of observation can assist future missions with these challenges.

Arctic Surface Air Temperature

Validation of ice surface and land surface temperatures against in situ air temperature observation was a common theme in keynote talks and posters presented at the meeting. Arctic monitoring using interpolated air temperature and combined air temperature and sea-surface temperature products featured heavily in the keynote presentations referring to the 2012 Arctic Report Card update. Two posters focused on the use of interpolation techniques, one investigating the use of interpolation techniques for monitoring global average temperatures using a combination of in situ and satellite observations[21] and one investigating the suitability of interpolation techniques for estimating surface air temperature change in the Arctic[22].

[21] Kevin Cowtan: Coverage bias in the HadCRUT4 temperature series and its impact on recent temperature trends

[22] Emma May Ann Dodd, Chris Merchant, Simon Tett, Nick Rayner (under review): Interpolating and Extrapolating Temperature Anomalies Across the Arctic: An Investigation using ERA-Interim and Meteorological Station Coverage between 1850 and 2011

4. Gaps/synthesis – focus on merging/comparison across fields

4.1 Matching across platforms

High latitude and high altitude regions contain a diverse range of surface types and consequently there are a diverse range of observational methods used to observe these regions. In these regions matching observations between different observing platforms is required for validation of retrievals against in-situ observations, intercomparisons of retrievals from different platforms and synergy of observation into combined data products. Group discussion at the meeting identified a number of barriers to integration of measurements from different platforms relating to differences in quantities being observed and to the presentation of observations in available data sets.

Observations from different platforms may be of different geophysical parameters, such as LST and air temperature, introducing uncertainty in comparisons between platform types arising from uncertainty in the relationships between parameters. Measurement may also be representative of different length scales at the surface, for example for in situ point observations and areal information from satellite observations. Heterogeneity of observed surfaces and changes in surface properties are problematic as this introduces uncertainty in the properties of surface being observed.

Limited data record lengths were identified as being problematic for the combination of data products with differing climatology periods. For satellite data, problems relating to differences in observing angles and emissivity anisotropy were identified as barriers to integration of data products. Absolute calibration of datasets was also raised as an issue for merging. Differences in satellite overpass times and differences in standard observing times in different countries are also a problem.

A number of issues relating to the provision of observational data were identified as potential barriers to integrating measurements. Uncertainty information is required for combined use of observations from differing platforms but uncertainty information is often not available and uncertainty budgets may be inconsistent between data products. Metadata required for merging observations from different datasets is often unavailable. Differences in data and metadata formats are also a potential barrier to combined use of data products. Issues relating to communication of what datasets are available and near real-time availability of data were also raised.

The breakout group tasked with discussing the topic of matching measurements and retrievals across platforms recognised that merged SST products produced under the Group for High Resolution SST (GHRSST) as most probably the most mature merged products currently available. Although there has been much work in validation of satellite retrievals in domains other than SST, there are few examples of merged surface temperature data products in other domains or cross domain merging.

Towards the creation of merged products, the breakout identified the following gaps in present knowledge and areas for further research:

- Although different instruments observe temperatures of different surfaces, these temperatures are physically related. An improved understanding of relationships between different measurands is required to facilitate merging of surface temperature information from different platforms.

- An improved understanding of relationships between temperature observations at different scales is needed for merging of IR and MW satellite products and for validation of satellite retrievals against in situ observations.
- Improved understanding on the effect of varying topography is needed.
- An improved understanding of diurnal effects and temperature depth profiles is needed.

Differences between sensors can be bridged using in-situ radiometers that provide an absolute reference that products can be compared against. One such site is the Lake Tahoe SST/LST site. It was strongly recommended that existing LST radiometer sites and ship deployed SST observing radiometers continue to be maintained. A further requirement was identified for radiometer sites to be situated on both glacial ice and sea ice.

Recommendation: Data providers should provide regional error characterisation as part of their products to facilitate merging.

Recommendation: Maintain LST radiometer sites and ship deployed radiometers for measuring SST.

Recommendation: Validation sites are needed on sea ice.

4.2 Measurement Matchup Databases

Breakout groups identified a need for agreement on validation standards, instrumentation and measurement practices. Such standards are now established for SST but protocols for LST validation sites are currently embryonic. Breakout groups proposed that recommendations could be made for validation standards and recommended that users' requirements should be taken into consideration in the construction of validation standards.

Uncertainty information for multisensory matchups was highlighted as a requirement for matchup databases, including descriptions of how uncertainties interrelate over space and time. Available radiometer deployment in polar regions is a limiting factor in validation of polar observations. Deployment of more radiometers in polar regions was requested. A review of other required/desirable elements for inclusion in matchup databases was suggested such as observations of non-temperature parameters required for retrieval algorithms and data from dynamical reanalyses.

Recommendation: support the installation of radiometers at existing Arctic stations.

4.3 Surface Temperatures in Marginal Zones

Study of surface temperatures in marginal zones such as the Marginal Ice Zone (MIZ) is challenging because of uncertainties in what surface or combination of surfaces is being observed. There are a few examples of merged products encompassing the marginal ice zone. The OSI-SAF Metop-A IST product is a merged product in which SST and IST observations are merged over the MIZ for retrievals from a single instrument. This product integrates high latitutde SST, IST and Marginal Ice Zone Temperature temperatures, based on Metop AVHRR. Surface type flagging, such the provision of snow flags provided by ATSR, is desirable for the development of merged products in marginal regions and is preferable to data masking.

4.4 Cross Domain Issues/Commonality

Cloud contamination was identified as an issue in all domain specific keynote presentations and was frequently referred to as an issue in breakout groups. This was highlighted as a particular issue in high latitude and high altitude domains owing to similarity between surface skin temperatures and cloud top temperatures. Cloud clearing is also problematic during permanent night time conditions during winter at high latitudes.

Recommendation: Cross domain collaboration on development and validation of cloud clearing algorithms in high latitude regions.

Physical modelling may allow observations from different platforms to be merged. An example of the use of modelling for this purpose was given in the invited IST talk in which thermodynamic and mirowave emission modelling was used to relate microwave measurements to snow-ice interface temperatures.

Blending of observations with diurnal variability models has been studied at lower latitude for SST but has not been applied at high latitudes to resolve diurnal effects. It was reported that the GlobTemperature project intends to investigate merging of LST from geostationary and polar LST products and is investigating diurnal variability modelling for LST.

4.5 Use of Reanalysis Data

The keynote presentation "High-latitude surface temperature: synthesis of datasets and what they tell us" demonstrated the use of sparse input reanalyses to coroborate historical temperature reconstructions. The breakout group discussing merging of observations across platforms identified uses of dynamical reanalyses both for validation purposes and to provide information on parameters required by temperature retrieval algorithms. Data assimilation residuals from dynamical reanalyses were also considered to be a valuable source of information for the study of observational errors. There was however some discussion of uncertainties in simulated surface temperatures from reanalyses in regions where they may be weakly constrained by observations.

Recommendation: Include reanalysis data required by retrieval algorithms and for validation in matchup databases.

4.6 Turning the Community Paper Recommendations into Actions

A breakout group was tasked to propose actions to address each recommended step towards an integrated understanding of surface temperatures documented in the EarthTemp Community Paper (ETCP). The proposed actions are outlined below.

ETCP Recommendation 1: Develop more integrated, collaborative approaches to observing and understanding Earth's various surface temperatures

Towards the first community recommendation "develop more integrated, collaborative approaches to observing and understanding Earth's various surface temperatures" the Copenhagen meeting proposed that the EarthTemp Community Paper should be circulated to international bodies, including:

- GCOS Secretariat, WMO commissions (CCl, CBS, CIMO)
- CEOS, CGMS
- WCRP WGNE/WGCM Climate Model Metrics Panel and WCRP Data Advisory Council (WDAC)
- National space agencies (EUMETSAT, ESA)

Contact CEOS land product validation and GCOS adequacy assessment process to promote the acceptance of LSAT, LSWT, LST, SST and IST as part of the same surface temperature ECV and as a means to improve the LSAT ECV (e.g. for use in Climate Services)

ETCP Recommendation 2: Build understanding of the relationships of different surface temperatures, where presently inadequate

There has been some progress in building understanding of the relationships of different surface temperatures through creation of the EarthTemp Arctic Matchup Database in the EarthTemp Arctic case study. Breakout groups at the Copenhagen meeting proposed the following actions:

- LST algorithms should be extended into coastal zones towards development of a universal surface temperature algorithm.

- A task team should be formed to identify the best few extra permanent sites to measure multiple types of surface temperature in-situ for comparison with satellite retrievals, with a view to recommending these to appropriate bodies to fund them.

- There is a need for more engagement with teams working in Numerical Weather Prediction (NWP). The creation of a discussion forum on the reanalyses.org website should be organised as a means to engage in dialogue with the reanalysis community.

- Discuss within the EarthTemp Network and beyond the reservation of reference data for different purposes (e.g. ECV CDR evaluation).

- Setup a Greenland EarthTemp Case Study.

ETCP Recommendation 3: demonstrate novel underpinning applications of various surface temperature datasets in meteorology and climate

Towards this recommendation the following actions were suggested:

- A task team should be formed to identify priority cases for the further demonstration of combined surface temperatures, (e.g. example in coastal zones, marginal ice zones and urban fringes; emerging industrial activity in polar regions etc; explore examples in FuegoSAT synthesis study report).

- Sites with reasonable control and statistics for LSAT/LST intercomparison should be identified (3.4, 3.5 (leading towards 9.3&9.4))

It was also noted that there is currently effort to promote new demonstration cases under the GlobTemperature and ESA CCI projects towards the goals of this recommendation.

ETCP Recommendation 4: Make surface temperature datasets easier to obtain and exploit, for a wide constituency of users

- Make surface temperature datasets easier to obtain and exploit, for a wide constituency of users; form a working group to build on GHRSST and Obs4MIPS standard formats and work with these groups to extend them. Form a working group to agree standards.

- Create a list of available types of surface temperature and where to find them to be published on the EarthTemp website.

ETCP Recommendation 5: Consistently provide realistic uncertainty information with surface temperature datasets:

- Propose the Uncertainty Characterisation developed under the SST CCI to other domains within EarthTemp as a start to developing a common approach and vocabulary. Identify a case study from a different domain to try it out (VS opportunity).

- Trial interaction with users in the context of SST CCI User meetings. Attend GlobTemp User Consultation meetings.

- Propose the uncertainty characterisation developed under SST CCI to other domains within EarthTemp as a start to developing a common approach and vocabulary.

- Produce a review paper defining common vocabulary based on metrology. Establish whether a standardization organisation or influential group is required to set standards.

ETCP Recommendation 6: Undertake large-scale systematic intercomparisons of surface temperature data and their uncertainties

Large-scale systematic intercomparisons are a big task without standardisation across data sets. Standardisation is recommended and is a large task, requiring some degree of community consensus and engagement, and not always highly prioritised.

ETCP Recommendation 7: Communicate differences and complementarities of different types of surface temperature datasets in readily understood terms

- A Visiting Scientist programme funded workshop could be organised to discuss the effects of different LSAT observing practices.

- A Visiting Scientist programme workshop should be funded to start the proposed review paper on differences and complementarities of different types of surface temperature datasets. This review paper should explain to general scientific users the range of surface temperature measurands, their physical significance, their inter-relationships and the status of their corresponding measurements.

- The EarthTemp Network website should be updated to become a resource for users to find more information about surface temperature products, link to data repositories and provide guidance to data users.

- Either a single review paper on surface temperatures in edgelands should be produced or otherwise individual papers on individual domain interfaces such as surface temperature in the marginal ice zone or in coastal regions.

ETCP Recommendation 8: Rescue, curate and make available valuable surface temperature data that are presently inaccessible

- Publicise and link to existing citizen science activities through the EarthTemp website.

- There are several initiatives rescuing meteorological data, but not much focus on research campaign data. Extend list of surface temperature products on website to point to Research Campaign data (8.3). Identify field campaigns in areas of interest and get their data.

- Add the CEOS land product validation list to the EarthTemp webpage.

- Setup a wiki spaces page to allow data owners to upload their own information with periodic reminders for data owners to update this.

ETCP Recommendation 9: Maintain and/or develop observing systems for surface temperature data

- Observing systems for surface temperature data should continue to be maintained and developed. Efforts should be made to promote the instalment of radiometers at existing Arctic observing stations.

- There is a need to review experiences with existing sites and to identify suggestions/improvements. This should be achieved through organisation of a meeting and a review paper. Also, see actions under Recommendation 1.

ETCP 10 Recommendation 10: Build capacities to accelerate progress in the accuracy and usability of surface temperature datasets

No detailed actions were proposed towards the goals of this recommendation.

5. Forward looking

5.1 EarthTemp 2014-15

Surface temperature in key under-observed land regions is the principal scientific topic of the EarthTemp Network during its third year and will be the focus of the third annual meeting of the EarthTemp Network. As such, one focus region is Africa, which is particularly sparsely observed in available digital in-situ archives. In addition to exploring how to improve the data coverage in such areas there will be discussion on how to most appropriately analyse and use data from such regions given the sparsity of data. This will include synergies with satellite based measurement techniques. Land surface temperature (LST) (from satellite) has greater uncertainty, mainly because of emissivity variations with wavelength, view angle and surface changes in vegetation or snow cover, and it varies relatively rapidly compared to Sea Surface Temperature (SST) or Surface Air Temperature (SAT), making it harder to use for many applications. However, it is substantively more complete in its coverage over the recent decades.

The 3rd annual workshop will take place in Karlsruhe on 23-25 June 2014 and will feature substantial dialogue and networking activities as well as invited overview presentations, panel discussions and the opportunity to present participants' work in poster sessions. The EarthTemp workshop will be followed by a separate ESA GlobTemperature user consultation meeting which may also be interesting to EarthTemp participants, held in the same venue (25-26 June 2014).

The EarthTemp Network aims to bring researchers together towards progress in understanding surface temperatures over land in areas that are data sparse in in-situ measurements. The Earthtemp Network however remains inclusive and open to surface temperature researchers of all backgrounds who are interested in sharing knowledge and making connections across sub-discipline boundaries. Interested researchers are invited to contact the EarthTemp Network and to sign up for EarthTemp newsletters through the EarthTemp website[23]. The EarthTemp Network Visiting Scientist scheme exists to support visits and exchanges of scientist working on subjects related to observation of surface temperatures. Researchers are invited to submit proposals to the EarthTemp Visiting Scientist Scheme to support work leading to new research results related to surface temperature. Details on the application procedure can be found on the EarthTemp Network website.

Following granting of an unfunded extension to the EarthTemp project, there will be a 4th annual workshop focussed on urban temperature, in Reading, UK, in 2015.

[23] http://www.earthtemp.net