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Peter Thorne, Kate M. Willett, Rob Allan, Stephan Bojinski ...+14 more authors

Institutions: North Carolina State University, Met Office, World Meteorological Organization, University of Alabama in Huntsville ...+8 more institutions

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GUIDING THE CREATION OF A COMPREHENSIVE SURFACE TEMPERATURE RESOURCE FOR TWENTY-FIRST-CENTURY CLIMATE SCIENCE

BY PETER W. THORNE, KATE M. WILLETT, ROB J. ALLAN, STEPHAN BOJINSKI, JOHN R. CHRISTY, NIGEL FOX, SIMON GILBERT, IAN JOLLIFFE, JOHN J. KENNEDY, ELIZABETH KENT, ALBERT KLEIN TANK, JAY LAWRIMORE, DAVID E. PARKER, NICK RAYNER, ADRIAN SIMMONS, LIANCHUN SONG, PETER A. STOTT, AND BLAIR TREWIN

THE BASIC SCIENCE CHALLENGE. Historically, temperature measurements were made by a variety of individuals and organizations to primarily serve weather-related needs where modest precision (a degree or two) was satisfactory to observe a passing cold front, day-to-night cooling, or winter-to-summer warming. However, one man's signal is another man's noise: noise arising from changing measurement errors, due to changes to instrumentation, siting, and observing practices, can be acceptable, or even desirable, if the changes result in more absolutely accurate or timely data for weather purposes. Such change has therefore been ubiquitous. This noise becomes problematic for characterizing climate change, however, where signals of tenths of a kelvin per decade are noteworthy. While great progress has been made in developing methods to identify and adjust for these complex, sometimes subtle, nonclimatic influences while retaining the true data characteristics, even greater attention to this is required. Add to the mix a substantially varying geographical coverage and density—and the fact that some areas of the globe have never been, and probably never will be, directly observed by in situ measurements—and the challenge becomes substantial. Hence, we need to fully quantify and understand the uncertainties.

CREATING SURFACE TEMPERATURE DATASETS TO MEET TWENTY-FIRST-CENTURY CHALLENGES

WHAT: An international group of climatologists, statisticians, metrologists (measurement scientists), software experts, and others met to plan the best way forward to create a comprehensive, traceable data bank of global surface temperature and to facilitate the creation of high-quality, robust data products to meet the needs of the twenty-first century

WHEN: 7–9 September 2010

WHERE: Exeter, United Kingdom

Importantly, we are not starting from scratch. While there is no unambiguous how-to guide for backing out these myriad influences, precluding a definitive solution, very substantial and valuable efforts do exist. This effort is focused on building on and augmenting these efforts and creating new products where necessary to better meet evolving demands.

CHANGING SOCIETAL DEMANDS OF THE DATA. In the late twentieth century, climate scientists were interested in quantifying how climate had changed at the largest spatial scales, and elucidating underlying causes. Several pioneering datasets of surface temperature and other variables were produced and analyzed, at very considerable effort, and on limited budgets. These datasets are largely fit for the purpose of identifying long-term changes over large scales, as evidenced, for instance, by extensive use in Intergovernmental Panel on Climate Change (IPCC) assessment reports. However, they do not meet all of the twenty-first-century requirements.

Observational datasets are now expected by society to provide robust, traceably documented information about our changing climate at much finer spatial and temporal scales than ever before. This observational evidence underpins all aspects of climate change science and emergent climate services. Better characterization of, for example, regional changes, changes in extremes, and the role of natural variability is needed. Products at finer time scales (daily or shorter) and greater spatial density than many existing global data products, including the commonly cited long-term Goddard Institute for Space Studies (GISS) surface temperature analysis (GISTEMP; http://data.giss.nasa.gov/gistemp/), National Oceanic and Atmospheric Administration (NOAA)–National Climatic Data Center (NCDC; see www.ncdc.noaa.gov/cmb-faq/anomalies.php) data, and Hadley Centre Climatic Research Unit temperature anomaly (HadCRUT; see www.cru.uea.ac.uk/cru/info/warming/) estimates, with well-understood uncertainties, are required. Monitoring in near-real time, drawing upon multiple methodologically independent products, would also help underpin robust advice and give historical perspective, as extreme events such as the summer 2010 Moscow heat wave unfold and phenomena such as ENSO develop.

Decision making in response to climate change and variability requires confidence in each climate product/service. This means giving careful attention to the more mundane but essential aspects, such as the use of metadata (data about the data), measurement uncertainty, provenance of data and data products, version control, and benchmarking (i.e., assessing against a reference) of methodological performance. Critically, we should also quantify and provide advice to users as to the suitability of the data for a given application; requirements could range from hourly observations at a single location to global mean changes on the time scale of centuries. Data applications will include optimal decision making (e.g., deriving building specifications, health capacity planning, land use management, flood defenses). Products will have distinct uncertainties whose nature—systematic or random—may have different influences. Hence, there can be no "one size fits all" solution and a renewed, vigorous effort at creating, comparing, and assessing multiple independently derived data products is needed from a truly comprehensive and publicly available data bank of the "raw" data.

THE MEETING. The Met Office, on behalf of the U.K. government, proposed such an effort to the fifteenth session of the World Meteorological Organization Commission for Climatology in Turkey in February 2010, recognizing the need for multiple international and interdisciplinary partners. Additional expert viewpoints to those of traditional climatologists are essential. It was unanimously endorsed. A meeting took place at the Met Office in September 2010 to investigate potential scope of this program. Participants included climatologists from every continent, metrologists (measurement scientists), statisticians with environmental and economic expertise, software engineers, and citizen scientists. Recognizing that the meeting could not possibly host all interested participants, the organizing committee led the production of white papers. These were available for public comment through a blog prior to the meeting. Comments were then fed into discussions.

AFFILIATIONS: Thorne—Cooperative Institute for Climate and Satellites, North Carolina State University, and NOAA/National Climatic Data Center, Asheville, North Carolina; Willett, Allan, Kennedy, Parker, Rayner, and Stott—Met Office Hadley Centre, Exeter, United Kingdom; Bojinski—Global Climate Observing System, World Meteorological Organization, Geneva, Switzerland; Christy—Earth System Science Center, University of Alabama in Huntsville, Huntsville, Alabama; Fox—National Physical Laboratory, Teddington, United Kingdom; Gilbert—Met Office, Exeter, United Kingdom; Jolliffe—University of Exeter, Exeter, United Kingdom; Kent—National Oceanography Centre, Southampton, Southampton, United Kingdom; Klein Tank—KNMI, De Bilt, Netherlands; Lawrimore—NOAA/National Climatic Data Center Asheville, North Carolina; Simmons—European Centre for Medium-Range Weather Forecasts, Reading, United Kingdom; Song—China Meteorological Administration, Beijing, China; Trewin—Bureau of Meteorology, Melbourne, Victoria, Australia
CORRESPONDING AUTHOR: Kate Willett, Met Office Hadley Centre, Fitzroy Road, Exeter EX1 3PB, United Kingdom.
E-mail: kate.willett@metoffice.gov.uk

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OPENNESS AND TRANSPARENCY. A key aspiration is openness and transparency. This means more than making data, code, products, and intermediate processing steps available. It also means doing the hard work to ascertain provenance (source, owner, physical location, etc.) and associated quality assurance of observations, and applying strict revision control and versioning. These aspects increase process overheads substantially but add significant value in terms of product robustness, quantifying uncertainties, and user confidence in products. Ultimately, full transparency at every step from raw data to final products enables many pairs of expert and nonexpert eyes to consider data and data products, and improves understanding.

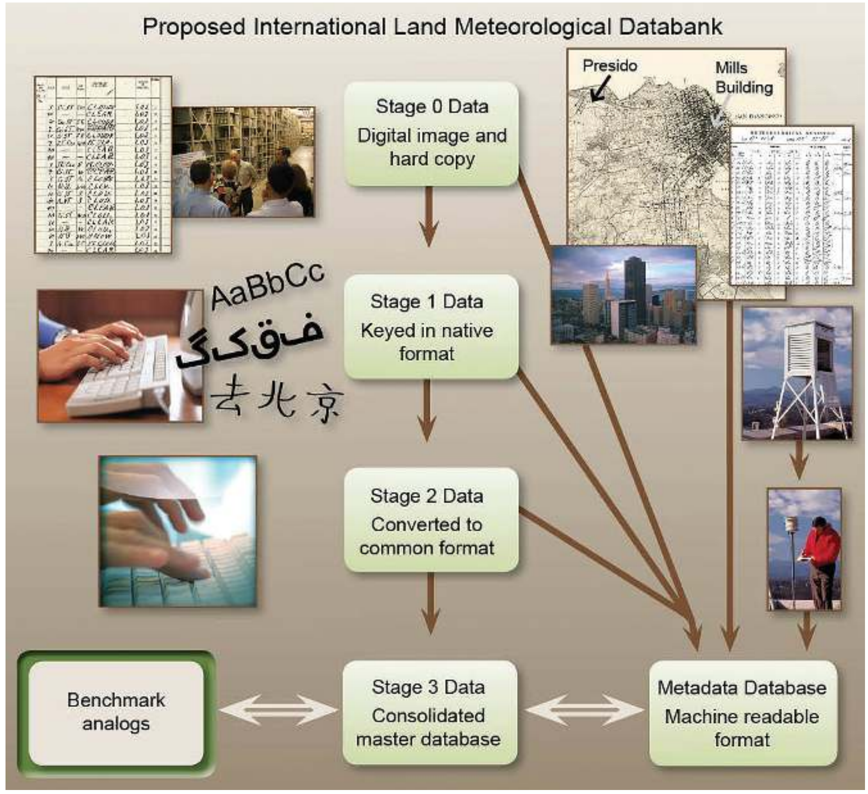
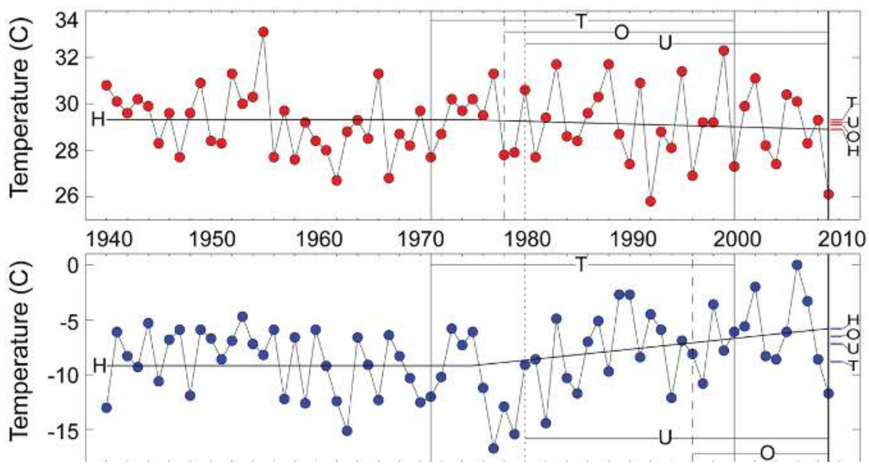


FIG. 1. Conceptual diagram of the envisaged comprehensive data bank structure and its relation to the benchmark analogs described later. (Image courtesy of NCDC graphics team.)

However, exceptions will always exist and data policy is complex. Existing datasets that have limited traceability and/or accessibility are still very valuable. For example, climate index datasets, such as the Hadley Centre global climate extremes indices (HadEX) dataset, provide information covering large data gaps that would remain void for many years if open source data were an absolute requirement. Similarly, dynamical reanalyses are highly complex, assimilating far more than surface data, often with proprietary code. They will undoubtedly constitute a key future product but cannot, almost by definition, have absolute transparency. Hence, although having full openness and transparency is the ultimate goal and primary principle, there will always remain a role for approaches that exploit data that, at present, would otherwise be unavailable or that cannot be made fully traceable for practical or legal reasons.

A SINGLE GLOBAL DATA BANK. Global data access needs significant improvement. There is still no single recognized data repository for land meteorological data, which exists for ocean data (World Ocean Database), weather balloons (Integrated Global Radiosonde Archive), and surface ocean measurements [International Comprehensive Ocean–Atmosphere Data Set (ICOADS)]. Our primary objective is therefore a universal data bank of land meteorological observations (ultimately including variables other than temperature, such as humidity, rainfall, and wind speed), developed in close coordination with existing repositories. There are several "stages" to such a data bank: starting with raw observations in written form (hard copy) or voltage/digital count for electronic data, and progressing to a unified data bank holding in a consistent format (Fig. 1). This can require reconciling multiple sources with records from the same location. We aim to include as many stages as possible for all data, ideally with a documented and traceable quality indicator [see the Quality Assurance Framework for Earth Observation (QA4EO) documentation online at www.qa4eo.org] and known provenance, from the individual observation to monthly summaries. This is a substantial challenge, even for holdings that are already available in a common digital data format (a number of which were proposed). Early release of those holdings is necessary to allow scientific analysis, even if full provenance information is not attained.



	January Temperature (°C)			July Temperature		
Normals Method	Mean	Maximum	Minimum	Mean	Maximum	Minimum
1971-2000*	-4.7	-0.7	-8.8	24.2	29.3	19.1
1980-2009	-3.5	0	-7.2	24.3	29.2	19.4
OCN	-3	0.2	-6.5	24.2	29.1	19.3
Hinge Fit	-2.5	0.8	-5.8	24.2	28.9	19.6
Probability of longer than period freeze free days	0.1	0.3	0.5	0.7	0.9	
Consecutive Days	214	198	187	175	159	
	Jan	Feb	March	April	May	Jun
Growing degree days	0	0	5	27	138	336
Heating degree days	1288	1017	805	462	203	28
Cooling degree days	0	0	0	4	82	199
Mean number of days below freezing	16.3	10.9	3.4	0.1	0	0
Mean number of nights below freezing	28.1	23	18.5	5.5	0.4	0
Mean number of days exceeding 32°C	0	0	0	0.1	1.3	4.6
Monthly maximum extreme	19.4	23.8	30	33.3	38.9	41.7
Monthly minimum extreme	-31.7	-28.9	-21.7	-12.2	-2.2	1.7

Fig. 2. Example of a subset of the type of output that could be returned if a station daily resolution time series were to be provided. Data are from Chicago Midway airport in Illinois. Top graphic shows monthly-mean Jul maximum (red) and Jan minimum (blue) temperatures and four potential ways to calculate their normals (see further reading for details), also given in the table below. Also shown is the probability of frost/freeze-free length in any given year, which could be useful for agricultural planning. The bottom of the table includes a suite of indicators that could be useful for agriculture (growing degree days, records, frost occurrence), energy planning (heating and cooling degree days indicating when domestic heating/air conditioning would be required), health planning (records, frost exceedances), and a myriad of other users. The table includes only a subset of the parameters and does not consider the additional output available for precipitation and other meteorological elements. Note that this analysis is on the raw data, so no uncertainty estimates are possible. In the future, analysis of the data products with additional uncertainty estimates could follow. (Data courtesy of Anthony Arguez NCDC; graphics preparation by NCDC graphics team.)

Many of these existing records do not, for various reasons, have an unbroken chain back to the hard copy source.

Beyond existing open source data, two distinct data groups are of great value. The first consists of data in digital form that are not currently freely available. Many national meteorological/hydrometeorological services require a return on investment. So, they sell their data commercially and are reluctant to lose this income stream. In other cases, data are perceived to hold substantial geopolitical value. Clearly, no one-size-fits-all approach will work—it is necessary to ascertain the issues preventing free data access on a case-by-case basis and then seek to persuade rights holders of the value of open exchange. In part, this might be achieved through provision of value-added products, such as station summaries that encapsulate other characteristics (Fig. 2) in addition to climate normals (30-yr means characterizing the average climate of a station). Making these calculations consistently across different networks adds substantial value.

The second group comprises data existing only in hard copy or as a digital image but in principle otherwise freely available. The NOAA foreign data library alone stores over more than 50 million imaged station observations and NOAA's National Climatic Data Center has more than 2000 boxes of uncataloged data. Scientific data programs, such as Atmospheric Circulation Reconstructions over Earth (ACRE; www.met-acre.org), Data Rescue (DARE; www.wmo.int/pages/prog/wcp/wcdmp/dare/index_en.html), and Mediterranean Climate Data Rescue (MEDARE; www.omm.urv.cat/MEDARE/index-medare-initiative.

html#atitol), have identified large holdings, as has World Data Centre B [Russian Research Institute of Hydrometeorological Information (RIHMI)]. It is likely that other large holdings of records exist elsewhere. The challenge is to identify, rescue, and convert these data into a common digital format. Doing this professionally is expensive. Following the meeting, optical character recognition (OCR) suitability and crowdsourcing (utilizing citizen scientist volunteers) of both OCR quality checking and digitization of data not suitable for OCR are being investigated. Old data sources are being lost; our call to preserve and digitize data is urgent.

Work is already underway to create an initial data bank version. When a stable version exists, it will be advertised. New versions will then be issued as the data bank holdings increase and provenance issues are better ascertained, but we strongly encourage its usage as soon as possible—user feedback is essential to progress. The data are not the end of the story, though; metadata are equally important and valuable, and data without metadata are generally ambiguous. Metadata are crucial to confirming and attributing nonclimatic influences. They must be considered as one entity.

CREATING MULTIPLE DATA PRODUCTS. Many national-, regional-, and global-scale products already exist. However, quality assurance information is sparse, documentation quality is mixed, and different source data choices and methods can make meaningful intercomparison hard. Climate has no respect for national and regional boundaries, so an individual event that impacts many countries requires a coherent context—not a patchwork quilt approach. Multiple independently produced data products, with consistently defined and described quality metrics from the data bank, are necessary to remedy many of these issues and meet the different user needs. Global, regional, and local products will be required at hourly, daily, and monthly time scales.

Multiple products are the only conceivable way to get even a simple estimate of the structural (methodological choices) uncertainty; we need to attack the problem from many different a priori assumptions to create an ensemble of estimates. Measurement uncertainty is larger at finer scales of space and time where residual systematic and random errors are least likely to cancel out. A single estimate of the truth is inadequate no matter how meticulous the research group responsible. Although unable to eradicate uncertainty, multiproduct approaches can elucidate it. For data products covering large regions or long periods, automation is vital for data product creation. This yields substantial challenges but also benefits in terms of being able to create plausible ensembles and fully replicable products.

The data product creation step is a broad scientific challenge and therefore will not be actively managed. However, in line with current Global Climate Observing System (GCOS) guidelines (available online at www.wmo.int/pages/prog/gcos/Publications/gcos-143.pdf), data product developers will be requested to accurately cite the data bank version used and clearly document process steps, methodological choices, and associated uncertainties with strong preference given to complete openness, including code provision. Where this is not practical or possible for legal, intellectual property, or proprietary reasons, exceptions will need to be documented. What precisely, if anything, would constitute minimum acceptance criteria for a data product to be considered an output of this effort was left open; opinions were broad with disagreement on the balance between desirable clarity and discouraging overregulation. Contributions from nontraditional participants will be particularly welcome in yielding useful insights from people attacking the problem by thinking "outside the box."

SPATIAL INTERPOLATION. Many end users require spatially complete fields. However, even in the most densely observed regions, it is rare to have <10 km separation between sites. Station separations of several hundred kilometers (or more) in some developing countries, and in sparsely populated areas such as the polar regions, are common. There is therefore a need to create estimates where no measurements were made. Creation of spatially complete fields is not a certain, unambiguous science. There will need to be several independent algorithms developed that users can apply. These algorithms need to be assessed in a rigorous manner, akin to the need for a consistent data product benchmark test (see next section). The meeting initiated undertaking of such an analysis, working with existing efforts.

CONSISTENT BENCHMARKING AND ASSESSMENT. If, as hoped, multiple groups create data products for a given region and period, it will be necessary to objectively compare products to aid users. Creation of a consistent set of synthetic test cases with which to assess software and methods is required. These analog datasets would have the same spatiotemporal sampling and similar climatology, variability, and interstation statistics as the consolidated master database (stage 3 data; Fig. 1). To these would be added a range of "non-climatic influences" to mimic white noise random sampling errors and systematic abrupt and gradual red noise errors analogous to a station move, instrument change, or urban encroachment. Data product creators would be given these "analog" datasets and would be required to apply their methodology, returning a best guess as to what the original data were and their associated uncertainty. Unlike in the real world, in these analog cases, the "answer" is known and so strengths and weaknesses of each data product methodology can be ascertained.

A group was established at the meeting to lead this benchmarking. Crucially, creation of analog datasets, including specific error models and assessment of the data product creators' best guesses, are to be carried out by a third party, ensuring a double-blind assessment. These analogs will systematically explore likely real-world data issues ranging from overly optimistic to overly pessimistic in their assumptions. Benchmarks will have a limited 3-yr lifecycle with a workshop at the end attended by all parties (Fig. 3). In other fields, such as software engineering, such a program has led to significant methodological advancement.

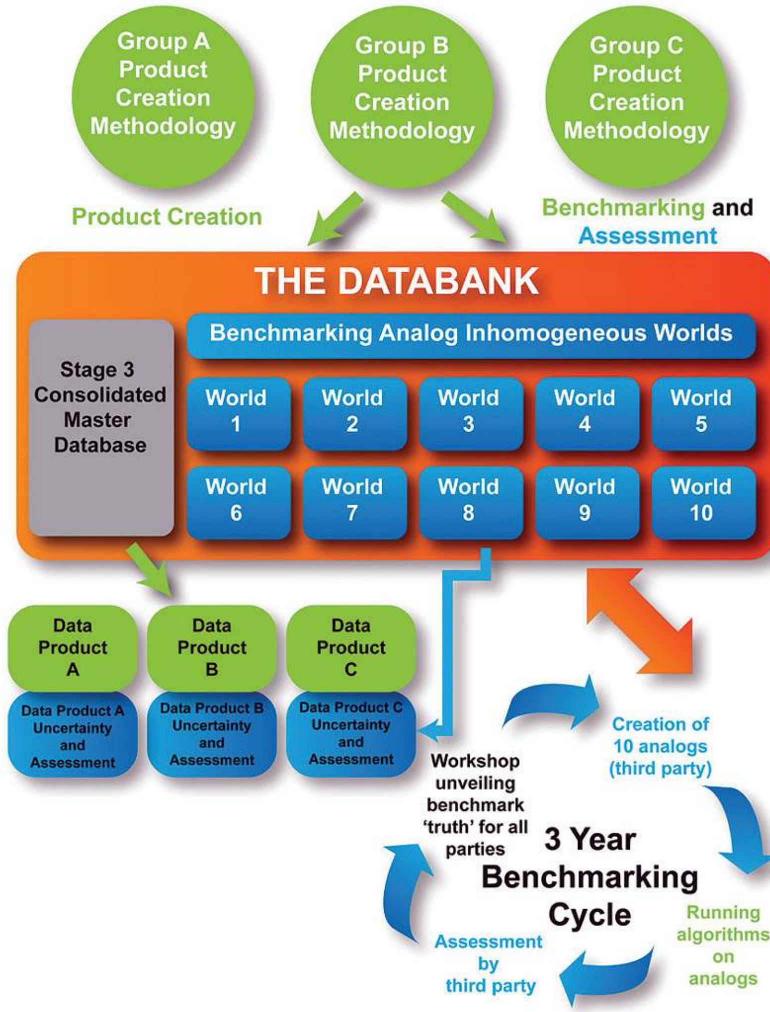


Fig. 3. Conceptual flow diagram of scientific outputs from the data bank, starting with methodologies used to create data products (e.g., homogenization algorithms to produce daily mean time series for a region) through the data bank to the end products, and the benchmarking and assessment cycle. (Image courtesy of NCDC graphics team.)

In addition, an overall assessment of each product is needed in terms of fitness for its intended purpose. Issues of ease of use, reproducibility and traceability, provision of uncertainty estimates (very highly desirable), and other aspects are important to users.

HOSTING OF DATA PRODUCTS AND GENERATING TOOLS AND VISUALIZATIONS FOR END USERS. It is envisaged that all temperature data products created from the data bank will be hosted in an unrestricted data product portal, with aids for users to access and compare data products. The first requirement is to employ the results of the benchmarking and assessment to guide users in their choice of products for their particular problem through a decision tree. Then a suite of tools is required to visualize, tabulate, and manipulate that data product to suit their needs (Fig. 4). A key challenge will be communicating the uncertainty to all users in a succinct and useful manner. Such requirements have implications for how the data products are managed, formatted, and stored, necessitating a group to manage this process. This group has not yet been established.

ENGAGING PARTICIPATION BY PROGRAMS, COUNTRIES, SCIENTISTS, AND CITIZENS WORLDWIDE. Given that this work has the attention of multiple international agencies, this is the most opportune time for the community to take such analyses forward in an international

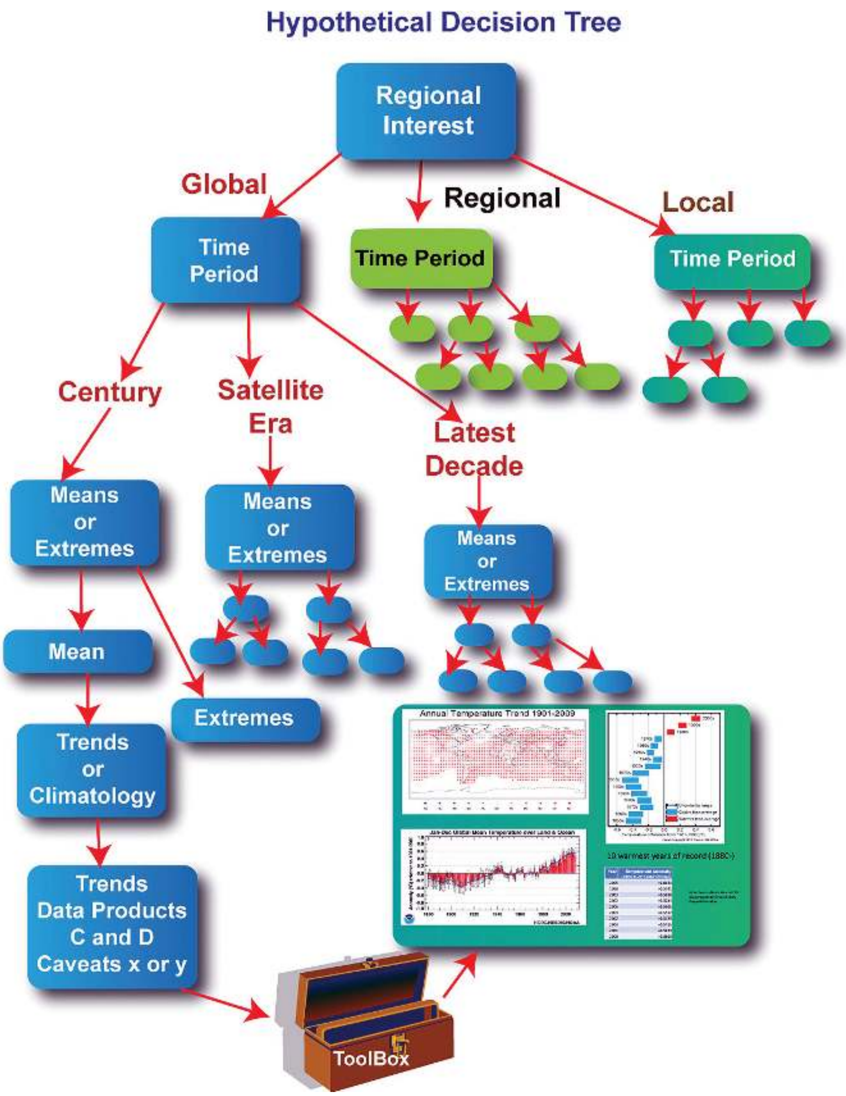


FIG. 4. Example of a type of decision tree that could help end users and some of the user tools that may be available to them. The decision tree may start by asking the user the geographical region of interest to narrow the candidate data products down, then ask about the period of interest, whether the mean, variability, trend, seasonality, etc., is wanted, and so on. Once user requirements are ascertained, an optimal set of products and easy to understand guidance and caveats along with visualization and tabulation tools would be made available. (Image courtesy of NCDC graphics team.)

and coordinated manner. This will happen only with broad "buy-in," participation, commitment, and input. Critically, this effort needs to partner strongly with existing programs, many of whom were represented. This includes overarching programs such as the World Meteorological Organization (WMO) Commission for Climatology (see www.wmo.int/pages/prog/wcp/ccl/index_en.html), the World Climate Research Programme, and the Global Climate Observing System. Perhaps more importantly, it needs to work with and learn from those activities already engaged in similar projects at the working level such as ICOADS, ACRE, EURO4M (European Reanalysis and Observations for Monitoring; www.euro4m.eu), COST HOME (homogenization project; www.homogenisation.org), crowd sourcing website projects such as www.oldweather.org and www.data-rescue-at-home.org, and the dynamical reanalyses in addition to existing data-product teams who have a wealth of experience to offer.

However, the net also needs to be cast wider. It is envisaged that the oversight, once formally constituted, will include relevant metrological and statistical bodies, in addition to meteorological entities, and will have truly international representation. Governance needs to be light but effective—ensuring progress, inclusivity, and flexibility, but ultimately guaranteeing usability.

Finally, success or failure will not depend upon the governance structure or the number of associated acronyms but on the degree of meaningful engagement with scientists and citizen scientists. So, please consider how you and your colleagues can contribute as this initiative moves forwards (contact general.enquiries@surfacetemperatures.org) and keep an eye on the progress (at www.surfacetemperatures.org and http://surfacetemperatures.blogspot.com/).

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FOR FURTHER READING

Alexander, L. V., and Coauthors, 2006: Global observed changes in daily climate extremes of temperature and precipitation. *J. Geophys. Res.,* **111,** D05109, doi:10.1029/2005JD006290.

Allan, R. J., P. Brohan, G. P. Compo, R. Stone, J. Luterbacher, and S. Brönnimann, 2011: The International Atmospheric Circulation Reconstructions over Earth (ACRE) initiative. *Bull. Amer. Meteor. Soc.,* **92,** 1421–1425.

Arguez, A., and R. S. Vose, 2009: On improving NOAA's climate normals: An introduction to "optimal normal" of temperature. *Extended Abstracts, 21st Conf. on Climate Variability and Change,* Phoenix, AZ, Amer. Meteor. Soc., 9B.3. [Available online at http://ams.confex.com/ams/89annual/techprogram/paper_146498.htm.]

Brohan, P., J. J. Kennedy, I. Harris, S. F. B. Tett, and P. D. Jones, 2006: Uncertainty estimates in regional and global observed temperature changes: A new dataset from 1850. *J. Geophys. Res.,* **111,** D12106, doi:10.1029/2005JD006548.

COST, cited 2010: ACTION COST-ES0601: Advances in homogenization methods of climate series: An integrated approach. [Available online at www.homogenisation.org.]

Durre, I., R. S. Vose, and D. B. Wuertz, 2006: Overview of the Integrated Global Radiosonde Archive. *J. Climate,* **19,** 53–68

Hansen, J., R. Ruedy, M. Sato, and K. Lo, 2010: Global surface temperature change. *Rev. Geophys.,* **48,** RG4004, doi:10.1029/2010RG000345.

Sim, S. E., S. Easterbrook, and R. C. Holt, 2003. Using benchmarking to advance research: A challenge to software engineering. *Proc. 25th Int. Conf. on Software Engineering,* Portland, OR, ICSE, 74–83. [Available online at www.ics.uci.edu/~ses/papers/icse03-challenge.pdf.]

Smith, T. M., R. W. Reynolds, T. C. Peterson, and J. Lawrimore, 2008: Improvements to NOAA's historical merged land–ocean surface temperature analysis (1880–2006). *J. Climate,* **21,** 2283–2293.

Stott, P. A., and Thorne, P. W., 2010: How best to log local temperatures? *Nature,* **465,** 158–159

Thorne, P. W., D. E. Parker, J. R. Christy, and C. A. Mears, 2005: Uncertainties in climate trends: Lessons from upper-air temperature records. *Bull. Amer. Meteor. Soc.,* **86,** 1437–1442

WMO, cited 2011: World Climate Conference 3 declaration on climate services. [Available online at www.wmo.int/wcc3/declaration_en.php.]

WMO CCI, 2010: Fifteenth session of the WMO Commission for Climatology (www.wmo.int/pages/prog/wcp/ccl/index_en.html) WMO Rep. 1054, 80 pp. [Available online at www.wmo.int/pages/governance/tc/tc_reports_en.html.]

Woodruff, S. D., and Coauthors, 2010: ICOADS release 2.5: Extensions and enhancements to the surface marine meteorological archive. *Int. J. Climatol.,* **31,** 951–967, doi:10.1002/joc.2103.