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GENERAL INSTRUCTIONS FOR TERRESTRIAL-BASED IN-SITU INSTRUMENT AND ALGORITHM INTERCOMPARISONS FOR THE PURPOSE OF CLIMATE DATA CONTINUITY

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SUMMARY OF REVISIONS: This directive supersedes National Weather Service Instruction 10-2101, "*General Instructions for Terrestrial-Based In-Situ Instrument and Algorithm Intercomparisons for the Purpose of Climate Data Continuity*," dated October 5, 2005. This revision was made to reflect the NWS Headquarters reorganization effective on April 1, 2015.

_signed__________________________ 12/14/2017___
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Director
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General Instructions for Terrestrial-Based in-Situ Instrument and Algorithm Intercomparisons for the Purpose of Climate Data Continuity

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1 Introduction

Climate and climate change research and applications require historical observational data from sources well distributed over and well-sited within regions of interest. Climate data provides information about the atmospheric, ocean, and terrestrial environments that impacts almost all aspects of human endeavor. For example, these data have been used to determine where to build homes by calculating the return periods of large floods, whether the length of the frost-free growing season in a region is increasing or decreasing, and the potential variability in demand for heating fuels. However, for these and other long-term climate analyses to be accurate and comparable, particularly climate change analyses, where decade changes of as little as 0.1 degrees Celsius are significant for climate change assessment, the climate data used must be homogeneous. A homogeneous climate data set is defined as one where variations are caused only by variations in weather and climate and not by the biases introduced due to inconsistent observational periods, performance differences between sensors (instrument bias) and instrument platforms (bias introduced by geographical separation and surrounding landscape) used to collect a climate data set. As such, it is important that data be inter-comparable over the entire period of record.

Data continuity is defined as the compatibility of past, present, and future data such that the observational record is free of variations caused by instrument changes, sampling procedure changes, data processing changes, and physical location changes. Continuity is critical for constructing and using compatible data sets to accurately monitor and access climate variability and change, and to put current conditions into accurate historical perspective.

Unfortunately, many long-term climatological time series are affected by a number of non-climatic factors that make these data non-representative of the actual climate variation occurring over time. These factors include changes in: instruments, observing practices, station locations, transfer equations to convert engineering data to meteorological data, formulae used to calculate means, and non-representative or changing station environments. Some changes cause sharp discontinuities while other changes, particularly change in the environment around the station, can cause gradual biases in the data. Inhomogeneities can bias a time series and lead to misrepresentations and misinterpretations of the studied climate.

It is important to remove the inhomogeneities or at least document and account for the possible error they may cause. Intercomparisons, in the lab and under actual operational field configurations, conducted on the different manufacturer and sensor types (designs, models, and performance characteristics) are one means of accounting for instrument-induced differences. Documenting changes to sampling rates and recording methodologies provide additional information for accounting for human-induced biases. Therefore, this policy instruction is considered a generalized checklist of tasks to be performed and as guidance to develop sensor-specific (instrumentation bias) intercomparison plans, assuming that other siting characteristics are effectively unchanged.

2 Continuity of Climatological Data

As new instruments are introduced, studies to determine instrument transfer functions are required to account for differences between old and new sensors and gauges. Beyond specific instrument differences, comparisons under operational conditions (overlapping observations) are necessary to further account for changes in shelters and site locations. The purpose is to preserve the temporal continuity of station databases and make the changes as seamless as possible in terms of the official long-term historical climate record.

In cases of significant changes in sensor devices or station location, a sufficiently long period of overlap is needed (preferably five years) for surface-based observations with dual operation of old and new systems to enable comparisons and reliable transfer functions to be made for identification of data inhomogeneities, thus allowing calculation of reliable normals through the older station's period-of-record (POR). It is critical that the earlier station's full POR be captured in terms of the newer station's POR being fitted to it in a reliable and scientifically acceptable manner.

For in-situ sites, the first year of dual station operations captures seasonal differences at a low confidence level of 81-86 percent for precipitation and temperature while a second year serves to increase the seasonal normals to the slightly better, but still low level at the 84-89 percent confidence level. The third through the fifth years are necessary to bring the confidence level of the full POR of the legacy station to a statistical level considered most appropriate. The confidence levels at the five-year overlap period in dual station operations rise to 91-92.5 percent for temperature and precipitation. This is a sufficiently high level (>90 percent) as to provide fairly seamless, reliable, and justifiable POR fitting of two stations.

Ten years of dual station operation provide the most optimum data confidence level (93-95 percent) for climate normals estimation and POR fitting. Ten years of dual operation is not economically feasible, and thus a five-year overlap in operations is advised as sufficiently defensible for the climate science community. Moderate-length overlap periods of 4-5 years provide an acceptable level of dual station operations. Studies have shown the 90 percent confidence interval is achieved during the third year for temperature, and late in the fourth year (about 4.7-4.8 years) for precipitation.

For upper air sites, biases caused by changes in instrumentation should be evaluated by conducting a sufficient overlapping period (as much as a year) or by making use of the results of instrument intercomparisons made at designated field sites.

The observing system manager initiating the sensor and/or site change(s) is responsible for ensuring a data continuity plan is written and executed, conducting the comparison, recording the data, and providing the results of the comparison evaluation. The cost of the comparison study must be part of the observing system funding profile.

3 Objectives of Intercomparisons

The initiator of the observing system change will form an Organizing Committee (OC) (see paragraph 4.1 below). The OC will develop an intercomparison plan that states the objectives, timelines, and achievements to be expected from the intercomparison. The intercomparison plan will describe the procedures, participant responsibilities, and deliverables of the intercomparison. The plan should also identify any particular problems that may be expected.
The plan will also document the criteria to be used in the evaluation of results. The OC should make use of any previous intercomparisons, if applicable, to ensure success. Errors and associated correction factors determined by the intercomparisons should be given the widest possible distribution including, but not limited to inclusion in the Sensor Intercomparison Report (see Section 8); posting on appropriate NOAA web pages; addition to the platform's metadata (station history) that is delivered to the National Centers for Environmental Information (NCEI), the National archive facility; and publication in peer-reviewed journal articles.

4 Participation and Responsibilities

In general, the NWS is responsible for budgeting for resources needed to conduct intercomparisons in the program planning process, conducting the intercomparisons, and transferring the data to the NCEI. As the national archive facility and by virtue of its mission, NCEI evaluates the data, publishes results, and applies adjustments to the climate record to maximize data continuity. Detailed guidance is listed below.

4.1 Organizing Committee (OC)

The office responsible for initiating a change to equipment, sampling and recording algorithm, or physical station relocation will provide the chairperson for the OC and be responsible for creating the membership of the OC. Also see paragraph 3. above: Objectives of Intercomparisons. The membership of the OC, at a minimum, should consist of a representative from the Office of Observations (OBS), the Analyze, Forecast, and Support Office (AFS), the (NCEI), Regional Headquarters (the focal point for the specific observing program), and members of the academic and research community with relevant expertise.

4.2 Project Leader (PL)

The OC has the discretion to designate a PL from its membership, hire a contractor to serve as a PL, and form integrated work teams to accomplish the intercomparison or perform the work itself. The PL should possess an in-depth knowledge of the observing programs and instrumentation, possess a fundamental knowledge of data management requirements in support of climate data needs, and have good organizational skills. The PL should oversee the development of draft plans or statements of work (if a contractor is used), and interim and final reports for the intercomparison. These draft documents will be reviewed and finalized by the OC. The PL will coordinate with National Weather Service Headquarters (NWSH) (AFS Climate Services Branch (AFS23) and the Surface & Upper Air Division (OBS3) and Regional Headquarters to ensure effective communication with offices participating in the intercomparison. The PL may also serve as the Contracting Officer Technical Representative (COTR) if a contractor is hired to plan and oversee the intercomparison. Additional responsibilities are also mentioned in the following paragraphs within this instruction.

4.3 Weather Forecast Office (WFO) Staff

Responsible WFO participants for intercomparisons include, but are not limited to, the Meteorologist-in-Charge, Observation Program Leader (or Data Acquisition Program Manager), Electronics Systems Analyst, and electronics staff. The operation and maintenance of both legacy and new systems, including electronics installation, calibration, and certification, is crucial to the success of an intercomparison. The history of all changes or modifications to sensors involved in an intercomparison must be documented in the station metadata file and available for evaluation by the OC and others as needed.

4.4 Other Intercomparison Participants

Collaborators in the intercomparison process should include, but are not limited to:

- NOAA/NCEI
- NOAA/NWS Headquarters
- NOAA/NWS Climate Prediction Center (CPC)
- Academic and research communities
- NOAA/Air Resources Laboratory (ARL)
- NOAA/Earth System Research Laboratory (ESRL)
- NOAA Climate Program Office (CPO)
- National Aeronautics and Space Administration (NASA)
- National Center for Atmospheric Research (NCAR)/University Corporation for Atmospheric Research (UCAR)
- NOAA/NWS/OBS3/Sterling Field Support Center (SFSC)
- Regional Climate Centers (RCC)
- State Climatologists (SC)

5 Location, Data Acquisition, and Duration

Intercomparison plans will address the following considerations.

5.1 Determine intercomparison location based on the type of sensor and climate region

5.1.1 Document the various climate regimes used for the intercomparison.

5.1.2 Selected locations should represent the widest range of conditions that would be expected during normal operations. Environmental conditions should be represented that are thought to exacerbate the differences between these sensors. There are multiple factors that cause large differences (e.g., temperature measurement with snow pack, solar albedo, low wind speeds, and high solar radiation).

5.1.3 Sensor operating principles can help guide where to do comparisons. For example, temperature measurements are impacted by solar albedo and wind. Thus, the range of conditions would include high solar areas and low solar areas.

5.1.4 Careful selection of locations can minimize the number of comparison sites that will be needed.

5.1.5 Understanding the physics impacting the sensor observations is aided by auxiliary measurements such as solar, wind, dew point, cloud cover, etc. Where possible, perform the intercomparisons where additional information is also being gathered. Consider taking these additional observations during the overlap period.

5.2 Determine Intercomparison Data Acquisition Procedures

5.2.1 The OC should agree on appropriate data acquisition procedures, such as frequency of measurement, data sampling, averaging, data reduction, data formats, real-time quality control, etc. When data reports have to be made by participants during the time of the intercomparison or when data are available as chart records or visual observations, the OC should agree on the responsibility for checking these data, on the period within which the data should be submitted to the PL, and on the formats and media that would allow permanent storage of these data in the database of the host. When possible, direct comparisons should be made with the reference instrument (WMO 8, ANNEX 5.B, 8.5.5). ASTM D4430 provides guidance on the number of observations needed.

5.2.2 The sampling frequency is relevant. Samples are taken in pairs, but the time interval between pairs of samples should be no less than four times the response time of the sensor system. The time between paired samples or measurements must be as small as possible, but not exceed one tenth the response time.

5.2.3 The exposure or siting is also relevant. The best approach is to have the instruments as close as possible without creating interference between the two. Sensors involved in the intercomparison should not shade each other, nor should they interfere with the flow of wind over one another. Thus, the direction of predominant wind may be relevant to the intercomparison.

5.3 Determine Duration of Intercomparison

5.3.1 The OC should examine the suitability of the proposed site and facilities, propose any necessary changes, and agree on the site and facilities to be used. A full site and environmental description should then be prepared by the PL. The OC, in consultation with the PL, should decide on the date for the start and the duration of the intercomparison (WMO 8, ANNEX 5.B, 3.2).

5.3.2 In cases of significant[1] changes in sensor devices or station location, a sufficiently long period of overlap is needed (optimally five years) for surface-based observations with dual operation of old and new systems to enable comparisons and reliable transfer functions to be made for identification of inhomogeneities and other measurement characteristics. The first year captures seasonal differences while the second year serves to validate the findings. The first year of dual station operations captures seasonal differences at a low confidence level of 81-86 percent for precipitation and temperature, while a second year serves to increase the seasonal normals to the slightly better, but still low at the 84-89 percent confidence level. The third through the fifth years are necessary to bring the confidence level of the full POR of the legacy station to a statistical level considered most appropriate. The confidence levels at the five-year overlap period in dual station operations rise to 91-92.5 percent for temperature and precipitation. This is sufficiently high (>90 percent) as to provide relatively seamless, reliable, and justifiable POR fitting of the two stations.

Ten years of dual station operation provides the most optimum data confidence level (93-95 percent) for climate normals estimation and POR fitting. Ten years of dual operation is most likely not economically feasible, so a five-year overlap in operations is advised as sufficiently defensible for the climate science community. Moderate length overlap periods of four to five years provide an acceptable level of dual station operations. Studies have shown the 90 percent confidence interval is achieved during the third year for temperature, and late in the fourth year (4.7-4.8 years) for precipitation.

For upper air sites, biases caused by changes in instrumentation should be evaluated by a sufficient overlapping period (as much as a year) or by making use of the results of instrument intercomparisons made at designated field sites.

Archiving and Access. All essential data and metadata, including related meteorological and environmental data, must be submitted to NCEI for archive. The data submitted should be the highest possible temporal resolution or lowest incremental measurement. The OC coordinates with NCEI to ensure all pertinent data and metadata from the old sensor (instrument) and new sensor (instrument) are retained for the intercomparison study. All essential data, including all overlapping observations by both instruments, is submitted in a common-format database for further analysis. The OC will coordinate with NCEI to agree on a common format for the data. Participants must provide near-real-time monitoring, timely and complete metadata updates, and quality control checks to ensure valid data is collected. During the period of intercomparison, NCEI, will be provided the format of the new data and data stream and the associated metadata information.

6 Analysis

NCEI is responsible for data analysis. The analysis of the intercomparison data is necessary to develop the appropriate conclusions including consistent (systematic) differences between the new and legacy sensors and the resultant correction factors. It is important that the analysis be independent, i.e., removed from any influence by the program office responsible for the

[1] In this context, “significant” refers to anything that could potentially change the sensor output to include but not limited to preprocessing and post processing of the data.

sensor/platform upgrade. This document cannot fully guide the details of every assessment, and the OC should ensure the independence of the data acquisition, analyses, and reporting. The analysis should include assessments of changes in means and extremes in the data. These changes may result from seasonal or regional variations. The statistical distributions of the differences may or may not be consistent. Specifically, measurement differences may change with the magnitude of the measurement. To test data for such dependence, the range of measurements will be divided into no less than three class intervals and each class will have a sufficient number of samples to represent the class. The following subparagraphs (a-e) were taken from WMO Handbook No. 8, ANNEX 5.B and may be used as a guide in the analysis.

6.1 The OC, utilizing the expertise of the NCEI and academic and research members should propose a framework for data analysis and processing and for the presentation of results. It will address data conversion; calibration and adjustment algorithms that can be applied to make the historical data consistent with the new data; and prepare a list of terms, definitions, abbreviations, and relationships (where these differ on commonly accepted and documented practice). Calibration and general maintenance of both the new and legacy sensors during the term of intercomparison data acquisition should be closely coordinated with the local, regional, and national offices with maintenance responsibility. The framework should elaborate and prepare a comprehensive description of statistical methods to be used that correspond with the intercomparison objectives (WMO 8, ANNEX 5.B, 6.2).

6.2 Whenever a direct, time-synchronized, one-on-one comparison would be inappropriate (e.g., in the case of spatial separation of the instruments under test), other methods of analysis based on statistical distributions should be considered. Where no reference instrument exists, instruments should be compared against a relative reference selected from the instruments under test, based on median or modal values, care being taken to exclude unrepresentative values from the selected subset of data (WMO 8, ANNEX 5.B, 6.2.2).

6.3 Whenever a second intercomparison is established sometime after the first, or in a subsequent phase of an ongoing intercomparison, the methods of analysis and the presentation should include those used in the original study. This should not preclude the addition of new methods (WMO 8, ANNEX 5.B, 6.2.3).

6.4 Normally the PL will be responsible for the data processing and analysis. The PL should, as early as possible, verify the appropriateness of the selected analysis procedures and, as necessary, prepare interim reports for comment by the members of the OC. Changes should be considered, as necessary, on the basis of these reviews (WMO 8, ANNEX 5.B, 6.2.4).

6.5 After completion of the intercomparison, the OC should review the results and analysis prepared by the PL, paying special attention to recommendations for the utilization of the results of the intercomparison and to the contents of the final report (WMO 8, ANNEX 5.B, 6.2.5).

7 Rules Governing Intercomparison.

7.1 The PL will exercise general control of the intercomparison on behalf of the OC. If a PL is not used, this responsibility will rest with the OC Chairperson.

7.2 The PL/OC, in coordination with national (e.g., Office of Observations), regional (e.g., Systems Operations Division) and local (e.g., WFO electronics staff) offices responsible for the system's operations and maintenance will ensure that the new and legacy sensors (hardware and software) are calibrated and are maintained in prescribed operational working order during the term of the intercomparison. Such changes will be included in permanent station and network metadata files.

7.3 No functional changes or modifications to the intercomparison equipment hardware or software will be permitted without the notification and concurrence of the PL/OC. Such changes will be documented according to NOAA Configuration Management guidelines and distributed to parties of interest. Such changes will be included in permanent station and network metadata files.

7.4 Routine, preventative, or corrective operational maintenance must be performed on intercomparison equipment. Minor repairs, such as the replacement of fuses, will be allowed with the concurrence of the PL/OC. Such routine checks and changes will be included in permanent station and network metadata files.

7.5 Calibration checks and equipment servicing by the participating WFO, which require specialist knowledge or specific equipment, will be permitted according to predefined procedures. Such routine checks and changes will be included in permanent station and network metadata files.

7.6 Any noted maintenance problems involving the intercomparison sensors or supporting systems will be documented and reported to the PL/OC within two working days. Such routine checks and changes will be included in permanent station and network metadata files.

7.7 The PL/OC may select a period during the intercomparison in which equipment will be operated with extended intervals between normal routine maintenance in order to assess its susceptibility to environmental conditions. The same extended intervals will be applied to all equipment (a-f: WMO 8, ANNEX 5.B, 9.). Such routine checks and changes will be included in permanent station and network metadata files. Such routine checks and changes will be included in permanent station and network metadata files.

7.8 Specific operating and maintenance instructions for both legacy and new sensors will be provided to the local office responsible for operations maintenance by the national and/or regional office responsible for managing system maintenance. All routine and out-of-cycle checks and changes will be included in permanent station and network metadata files.

8 Reporting Requirements

8.1 A final report will be sent to the Project Leader (PL) and then sent to the OC (or sent directly to the OC if a PL was not designated for the intercomparison).

8.2 The PL (or OC) will provide intercomparison data (including metadata) to the appropriate representative at NCEI. This report will be permanently archived at NCEI.

8.3 The report will detail background, methodology, and objectives. The final report of the intercomparison will contain, for each instrument sensor, a summary of key performance characteristics and operational factors. Results of statistical analysis should be presented in tables and graphs, as appropriate. Time-series plots should be considered for selected periods containing events of particular significance (WMO 8, ANNEX 5.B, 7.2).

8.4 All reports will get the widest possible distribution to the participants and broader user community (see Sections 3 and 4).

8.5 Final reports will include specific details of how the intercomparison data were obtained, including the duration of the data collection period (see Section 5.3.)

8.6 The PL (or OC) will request that the results of the analysis are reported by objectives and include determined and replicable correction factors or transfer equations for the new sensor, and where possible, the transfer function associated with geographical changes.

8.7 The report will include conclusions and recommendations.

8.8 Preparing a peer reviewed journal article is highly recommended.

8.9 All primary and secondary reports will submitted to NCEI for permanent archiving.

APPENDIX A - Considerations Prior to Conducting an Intercomparison

1 Site of Comparison. A sufficient number of sites should be evaluated to ensure robust results. The site(s) should be selected based on the range of conditions over which the intercomparison is desired. Sites should be avoided that might produce heterogeneity of microclimate factors within the area where sensors will be installed. The microclimate of the site should be considered with respect to surrounding trees and vegetation, buildings, bodies of water, large expanses of asphalt, or other features that would negatively impact the homogeneity of the environmental parameter being measured.

2 Time of Comparison. The amount of data needed to draw conclusions based on significant statistical findings related to the comparison of data from various sensors must be estimated. The start and stop time of the study should also take into account the astronomical seasons necessary to produce the range of conditions desired.

3 Methods. Methods to be used in the comparison of sensors must be explicitly defined. In the simplest case, comparisons can be made between the data from two sensors. Further, both sensors can be compared to a site reference sensor. Comparison of the mean differences and the standard deviation of differences is suggested. Differences between the sensors or between the sensor and a reference sensor should be arrayed against auxiliary measurements to determine how differences might change with environmental conditions.

4 Consideration of the Sensor's Characteristics.

4.1 Identify the sensor's spatial resolution, or field-of-view or sensor's footprint as it exists when installed in comparison (what the sensors are sampling).

4.2 Identify the sensor's temporal resolution, or response time constant which is related to the determination of sampling rate associated with the characteristics in field observations (how the sensors are sampling).

4.3 The sensing element in the sensor usually cannot be used for measurement. Only by applying a NIST-calibrated reference excitation (current or voltage) or reference resistors to the sensor system could the sensor be used for measurements. Therefore, the signal conditioning components and their routine re-certifications for accuracy are critical for quality measurement and certification.

4.4 Fitness of the sensor system and data acquisition system.

5 Standard Practices. The American Society for Testing and Materials (ASTM) (http://www.astm.org) produced a standard practice titled, "Standard Practice for Determining the Operational Comparability of Meteorological Measurements." The ASTM designation of the document is "D 4430" and is available for sale from ASTM. The standard is copyrighted by ASTM International and reprints may be obtained by contacting ASTM. It is highly recommended the OC and PL obtains reprints from ASTM for use in any intercomparison.

6 Checklist Prior to Conducting an Intercomparison.

- [ ] Develop a list of all sensors and systems to be intercompared, i.e., locations and associated field offices that have maintenance responsibility for the sensors. Include sensors that serve as a site reference and sensors that serve as a temporal bridge from the historical perspective.

- [ ] Collect technical documentation for each sensor. This should include a description of the sensor, the underlying principles related to the design and operation of the sensor, electronic schematics, specification data sheets, etc.

- [ ] Identify auxiliary sensors that will be needed to document the environment in which the sensors are tested, and which can be used to specify how sensor comparison varies with the magnitude of the auxiliary measurement, or which otherwise serves to sub-group the data to gain physical insight.

- [ ] Calibrate all sensors. The calibration must be accomplished in accordance with agency procedures. The calibration will be conducted prior to, during the time of actual measurement, and immediately after the completion of data collection for the intercomparison.

- [ ] Remove uncorrected measurement bias. To correctly express the uncertainty, both indoor (lab) test/calibration and outdoor intercomparisons should be conducted. Evaluate the measurement uncertainty by either statistical analysis of series of observations (termed Type A evaluation) or non-statistical analysis (termed Type B evaluation).

- [ ] A suitable technical design for the sensors used for the intercomparison should be developed. The design should include a schematic of the layout of the sensor placement. Digital photographs of the sensor layout are highly recommended. All components necessary for the collection and management of data should be included in the design statement. Sampling/averaging strategy, sensor interfaces, and communications should be explicitly specified. Particular attention should be paid to the need for signal conditioning and matching of electronic components. This design will be part of the intercomparison report, and will become a part of the metadata in the NCEI permanent archive.

APPENDIX B - References

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