**LTAR**

**Recommended Observations for the LTAR Met Site and Interim Procedures for Making These Observations Available to the National Ag. Library**

***(Penultimate Draft)***

*(Penultimate Draft – July 3, 2015)*

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1. **Introduction**

At the 2015 annual LTAR meeting in Beltsville, MD the Meteorological Breakout group (Attendees in Appendix A) convened with two major objectives.

1. Finalize the list of observations and recommended instruments required for the meteorological observatory at each LTAR site.
2. Initiate discussions and procedures to supply the National Agricultural Library with a subset of meteorological observations and a phenocam image on a regular basis this fiscal year.

Some initial discussion on the LTAR philosophy of measurement and monitoring was conducted concluding that the most expensive aspect of the LTAR program is and will be the scientists and support staff that will be developing and analyzing the data from the network.  It is important to avoid the false economy of attempting to save money in the initial stages of LTAR development by purchasing low-cost instrumentation.  Such instruments will likely have a shorter life span, produce data with greater on unknown precision and uncertainty, require more maintenance, repair and replacement, and ultimately make it more difficult to compare results across the network.  We are hoping that the LTAR network is to be in place for decades.  We need the instrumentation to be robust and reliable so that the data have a known and consistent accuracy and uncertainty, and can be compared across the network.  Developing the network reference meteorology sites using research-quality instruments that are at least certified as “Second-Class” (not as stable, or as expensive as bench-quality instruments, but with known precision and uncertainty) will be cost effective, reliable and robust enough to provide quality data for years to come.

**II. Meteorological Observatory Measurements**

Prior to the 2015 meeting most LTAR scientists considered that observations associated with the “Business as Usual” (BAU) portion of the common experiment would qualify as long-term observatory observations. However, during general discussion it was pointed out that BAU would very likely change with time as producers adapted to climate and markets. For long-term observatory meteorological observations it was decided that they would ideally be located in a place that is controlled by the LTAR sites that would be less subject to relocation and changing conditions. The observatory Met site is more about network inter comparability versus comparisons from BAU to IA sites. The meteorology observations were also confined to incoming drivers that are relatively uniform over larger areas and not site-specific measurements such as skin temperature and soil moisture among others except where an instrument is designed to take both incoming and surface measurement (i.e. radiometers). These as well as meteorology observations will be made as part of met-flux towers deployed at the BAU and Intensive Agricultural (IA) experimental sites.

Table 1 contains the core meteorological measurements. If your LTAR has an existing stable meteorology station making high-quality measurements for the variables listed in Table 1, these measurements may be used for the data stream to the National Ag. Library. If you are starting from scratch and/or buying new instruments there is a recommended set of instruments in an associated spreadsheet (File: LTAR-Met-July-2015.xlsx). This list was developed from the Smart Forest (SF) list and from ARS experts with updates for new instruments based on a thorough review by John Sadler. For the measurements outlined, as well as auxiliary equipment (mounting brackets, power sources, batteries, enclosures, etc.), there are often several options for manufacturers and suppliers for much of the equipment needed. It matters not which manufacturer and model are used so long as they are from a reputable company with documented calibrations and specifications. For most of these sensors, calibrations are tied to specific standards. Likewise, field and laboratory instrument re-calibrations (or calibration checks) must follow manufacturer recommendations. When Met instrumentation needs to be replaced for LTAR’s with existing Met instruments it is recommended that we move toward the common set of instruments listed in Table 1. If developing a new site World Meteorological Organization protocols are recommended for set-up, siting and installation (see www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html - part 1, chapter 1, Figure 1-1). In most cases manuals are available for each instrument that discuss accuracy, installation, maintenance, and calibration requirements.

Initial imaging equipment for the LTAR observatory met locations will consist of a phenocam (StarDot NetCam SC 5.0 IR[[1]](#footnote-1)). The National Phenocam Network has well developed instrumentation and installation protocols (<http://phenocam.sr.unh.edu/webcam/> - also see Appendix B for further background). The frequently asked section of this web site (<http://phenocam.sr.unh.edu/webcam/faq/>) contains valuable information including costs and vendor information for the ‘standard PhenoCam 5MP bundle’. This web site (<https://sites.google.com/site/phenocamdatalogger/fileexchange>) gives some critical information about how to handle Phenocam images with CSI loggers. It has a pdf of some blog dialog explaining things, and the CR1000 coding to get it done. The phenocams received by the Walnut Gulch LTAR came preloaded with settings that enable them to upload images directly to UNH’s FTP server.  Currently the Walnut Gulch LTAR site (USDA-ARS Tucson, AZ) has its web site is linked directly to the latest image on that server. They can either be pulled off that site or we could also program them to send them directly to another ftp site.

To meet the requirements of getting near real-time data to NAL the LTAR met station designated as your long-term observatory station (if you have more than one) must be equipped with radio or cell-based telemetry that will transmit data on at least an hourly basis. For the purposes of the FY15 pilot project if daily data are currently transmitted that will be acceptable. In addition, complete metadata will need to be developed for each LTAR met station. Metadata requirement must still be developed or adopted from an acceptable standard (see companion document entitled “LTAR Common Observatory Meteorology Data Concept of Operations” for more on metadata).

IIa. Replication of Observations and QA/QC

Replication of observations is important in order to fill data gaps when an instrument goes down. Minimizing loss of data is a function of both instrument redundancy and the ability to quickly detect and replace bad instruments. If your LTAR site does not have a current met station it is recommended that two of each instrument be purchased and co-located at the same site. If replicate instruments are deployed in this manner they must be calibrated and maintained in tandem. If you have two existing met stations that are reasonably close to together they can be used to cross-check one another and supply a degree of redundancy. To minimize data loss it is essential that the data be viewed (graphically is preferred) as well as system indicators such a battery voltages.

Network wide QA/QC procedures and software will be developed. USFS Smart Forest has a Matlab based program that they reviewed and is now used routinely for their locations. Dr. Lindsay Rustad, who leads the Smart Forest effort, noted that this program will routinely flag about 70% of problem data but still recommend a daily visual check of that data. Participants noted the expense of a Matlab at each location maybe prohibitive. Whether a central Matlab license at NAL would address this issue will be explored (see document entitled “LTAR Common Observatory Meteorology Data Concept of Operations” for more on QA/QC discussion).

Table 1. LTAR Observatory Meteorological Measurements (See File: LTAR-Met-July-2015.xlsx for recommended instruments to make these measurements)



**III. Transmission of a Subset of Met Observations and Phenocam Images to NAL**

The group then discussed what observations would be selected for the prototype effort to stream near real-time data to NAL for ingestion and display through a NAL – URL. At this time, for the demonstration, the observations for the variables can be instantaneous values or averages over a 15 min reporting interval. In the case of precipitation the quantity reported would be the accumulated precipitation over 15 minutes.

Table 2. Meteorological Measurements for Transmission to NAL

|  |  |
| --- | --- |
| **Meteorological Observatory Measurements** | **Phase\*** |
| Air temperature/ relative humidity | 1 |
| Wind speed and direction | 1 |
| Precipitation | 1 |
| Phenology camera | 1 |
| Barometric pressure | 2 |
| Short and long-wave radiation (incoming and reflected if combined in a single instrument) | 2 |
| Photosynthetically-active radiation (PAR) incoming | 2 |

\*Phase 1 common measurements are to be implemented by the end of FY15.

Since this is a demonstration effort and the funded network sites are required to have data from their sites retrieved by NAL for display we expect that the recommendations discussed below will evolve. In particular uniform guidelines for variable sampling, averaging, and reporting will need to be developed. Guidance is available from the Commission for Instruments and Methods of Observations (*CIMO*) “Guide To Meteorological Instruments And Methods Of Observation (WMO-No. 8)”. Appendix C provides some background from CIMO on sampling and reporting guidelines. Recommendations are also available from the NOAA National Climate and Data Center (NCDC) that differ somewhat from those of CIMO. These differences will be resolved and detailed recommendations will be developed by variable observed for which observed and computed quantities (averages, variance, max, min) will be stored and transmitted.

To meet the time constraint we recommend LTAR sites use existing met station observations wherever possible. Unless the local LTAR site has adequate time and resources we do not suggest reprogramming data loggers until final specifications are developed. Instead we envision that it will be most efficient to reformat existing met station data that the location is already receiving from the field and reformatting it into the data fields specified in the “LTAR Common Observatory Meteorology Data Concept of Operations” so it can be ingested by NAL. Dr. Jeff Campbell from NAL stated that he would rather pull the data from the locations from a secure ftp site and have it pushed to him.

Any of the near real-time data from LTAR sites displayed via the NAL URL will clearly be labeled as provisional. Post QA/QC’ed data will be submitted to NAL at a later time with a latency TBD.

IIIa. Data Formats for Both Overall LTAR Data Transmission and for the Limited Set of Demonstration Variables Listed Above

For the demonstration it is anticipated a simple .cvs format will be used for the small subset of variables listed above. A suggested format will be developed at forwarded with the next version of this document. Given the complexity and size of the full set of LTAR data types that will eventually come on-line it is likely that a more robust data format will be required in the future. See the companion document entitled “LTAR Common Observatory Meteorology Data Concept of Operations” for more specific guidance on data formats.

IIIa. LTAR Points of Contact for Data Reformatting and Transmission

A point of contact for each LTAR location was identified at the end of the meeting to work on data reformatting and posting with NAL. Those contacts are listed in Table 3.

Table 3. LTAR Location Data Contacts

|  |  |  |
| --- | --- | --- |
| Name | Email | LTAR Site |
| Kye Ewing | [kewing@archbold-station.org](mailto:kewing@archbold-station.org) | ABS |
| Betsey Boughton | [eboughton@archbold-station.org](mailto:eboughton@archbold-station.org) | ABS |
| David Huggins | [dhuggins@wsu.edu](mailto:dhuggins@wsu.edu) | CAF |
| John Sadler | [John.sadler@ars.usda.gov](mailto:John.sadler@ars.usda.gov) | CMRB |
| David Smith | [David.smith@ars.usda.gov](mailto:David.smith@ars.usda.gov) | CPER |
| Kevin King | [Kevin.king@ars.usda.gov](mailto:Kevin.king@ars.usda.gov) | ECB |
| David Bosch | [David.bosch@ars.usda.gov](mailto:David.bosch@ars.usda.gov) | GACP |
| Mark Seyfried | [mark.seyfried@ars.usda.gov](mailto:mark.seyfried@ars.usda.gov) | GB |
| Kris Havstad | [khavstad@nmsu.edu](mailto:khavstad@nmsu.edu) | JER |
| Sven Bohm | [bohms@msu.edu](mailto:bohms@msu.edu) | KBS |
| Jude Maul | [Jude.maul@ars.usda.gov](mailto:Jude.maul@ars.usda.gov) | LCB |
| Michel Cavigelli | [Michel.cavigelli@ars.usda.gov](mailto:Michel.cavigelli@ars.usda.gov) | LCB |
| JR Rigby | [Jr.rigby@ars.usda.gov](mailto:Jr.rigby@ars.usda.gov) | LMRB |
| Mark Liebig | [Mark.liebig@ars.usda.gov](mailto:Mark.liebig@ars.usda.gov) | NP |
| Andy Suyker | [asuyker@unl.edu](mailto:asuyker@unl.edu) | PRHPA |
| Dennis Wallin | [Dennis.wallin@ars.usda.gov](mailto:Dennis.wallin@ars.usda.gov) | SP |
| Daren Harmel | [Daren.harmel@ars.usda.gov](mailto:Daren.harmel@ars.usda.gov) | TG |
| Jeff Gonet | Jeffery.Gonet@ars.usda.gov | UCB |
| Tom Moorman | [Tom.moorman@ars.usda.gov](mailto:Tom.moorman@ars.usda.gov) | UMRB |
| Abdullah Jaradat | [Abdullah.jaradat@ars.usda.gov](mailto:Abdullah.jaradat@ars.usda.gov) | UMRB |
| Jason Wong | [Jason.wong@ars.usda.gov](mailto:Jason.wong@ars.usda.gov) | WGEW |

**Appendix A. Attendees of Meteorological Observations Breakout Group**

NOTE: This list is incomplete as roll call was not taken. Please notify David Goodrich if you would like your name to be added to the list.

Breakout Leads

* + - * + John Baker
        + David Goodrich

Attendees

* + - * + Daniel Moriasi
        + Claire Baffaut
        + Kevin King
        + JR Rigby
        + Jeff Campbell
        + Lindsey Rustad

Others on the Met e-mail list

- David Smith

**Appendix B. Phenocam Sensors for LTAR Tower Instrumentation**

Developed by: Dawn Browning (USDA-ARS, Las Cruces, NM), and Guillermo Ponce (USDA-ARS, Tucson, AZ)

The cost per unit which includes the five Megapixel color-infrared camera, 6.2mm lens, and outdoor exclosure is $950.00 (quote from 6/18/2014 copied below). One camera for each treatment (aspirational, “business as usual” agriculture) is recommended. For the near term one of the cameras should be placed at the LTAR Met station if the Flex towers are not yet operational. This is based on the assumption that there would be a flux tower in each treatment area. Telemetry or cell connectivity via the flux tower and costs associated with data transmission are not included in the $950.00/camera quote).

The cameras are web-enabled, providing remote access to visualize the greenness patterns in real time as well as to transmit images to an FTP server at the University of New Hampshire as part of the National Phenocam Network (http://phenocam.sr.unh.edu/webcam/). The data are archived there and available for download. The frequently asked questions (FAQ) page of the National Phenocam Network (<http://phenocam.sr.unh.edu/webcam/faq/>) provides a wealth of additional information for installation and operation of phenocams. Installation instructions are contained in the file: Phenocam\_Install\_Instructions.pdf.

Once the cameras are installed, data maintenance needs for the phenocam images are minimal. They are archived as part of the Phenocam Network; both raw images and greenness values are available for download. Based on experience at the Jornada Experimental Range, it has been one of the easiest data streams to use and manage. We have occasionally received notices from someone at the Phenocam Network that no images had been received for a few days; each time, a Biological Science Technician solved the problem with our solar panel array.

1) Level of expertise required (e.g. Tech., support scientist, post-doc, scientist) to operate, maintain, collect data, QC data, and analyze the data to useful products. A t*echnician can trouble-shoot occasional problems with power or camera configuration.*

2) Estimate of the amount of time (person-years) of persons with the appropriate expertise to operate, maintain, collect data, QC data, document the data, and archive the data (assume that some database structure and data entry procedures will be developed).

*This time is minimal because of support provided by the National Phenocam Network. I would estimate 1.5 days every two months (9 days/year = 0.04 person/year).*

3) What auxiliary equipment (not-field deployed) is required to provide high-quality data products (e.g. calibration equipment, a gas chromato-graph to analyze non-automated chamber based measurements, etc.).

*Not applicable. There is no good calibration protocol for the phenocams. Even if one were to mount a white panel in the field of view, there are no established protocols for adjusting the digital numbers in the image. The primary data product from the phenocam images are estimates of greenness that are processed (using tools provided by the National Phenocam Network) robustly to characterize patterns of primary productivity.*

4) An estimate of the maintenance and calibration frequency.

*Not applicable. See above.*

5) An estimate of the useful life of the instruments – replacement schedule. A reasonable estimate of the number of spare instruments that should be purchased and available to minimize gaps in observation continuity.

*We have had our cameras up for two years and others as part of the National Phenocam Network have been operational since 4/4/2008. A reasonable and conservative expectation is that the cameras would operate for at least six years.*



**Appendix C. Sampling and Reporting Guidelines**

Source: Commission for Instruments and Methods of Observations (*CIMO*) “Guide To Meteorological Instruments And Methods Of Observation (WMO-No. 8)” <https://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html> (See Chapter 1 - Measurements At Automatic Weather Stations: Pages II.1 – 11 to II.1 – 12; Also see Part III – Chapter 2 – Sampling Meteorological Variables)

**1.3.2.2 Sampling and filtering**

Sampling can be defined as the process of obtaining a well‑spaced sequence of measurements of a variable. To digitally process meteorological sensor signals, the question arises of how often the sensor outputs should be sampled. It is important to ensure that the sequence of samples adequately represents significant changes in the atmospheric variable being measured. A generally accepted rule of thumb is to sample at least once during the time-constant of the sensor. However, as some meteorological variables have high frequency components, proper filtering or smoothing should be accomplished first by selecting sensors with a suitable time-constant or by filtering and smoothing techniques in the signal-conditioning modules (see Part III, Chapter 2).

Considering the need for the interchangeability of sensors and homogeneity of observed data, it is recommended:

(a) That samples taken to compute averages should be obtained at equally spaced time intervals which:

(i) Do not exceed the time-constant of the sensor; or

(ii) Do not exceed the time-constant of an analogue low-pass filter following the linearized output of a fast response sensor; or

(iii) Are sufficient in number to ensure that the uncertainty of the average of the samples is reduced to an acceptable level, for example, smaller than the required accuracy of the average;

(b) That samples to be used in estimating extremes of fluctuations should be taken at least four times as often as specified in (i) or (ii) above.

**1.3.2.3 Raw-data conversion**

The conversion of raw sensor data consists of the transformation of the electrical output values of sensors or signal-conditioning modules into meteorological units. The process involves the application of conversion algorithms making use of constants and relations obtained during calibration procedures. An important consideration is that some sensors are inherently non-linear, namely their outputs are not directly proportional to the measured atmospheric variables (for example, a resistance thermometer), that some measurements are influenced by external variables in a non-linear relation (for example, some pressure and humidity sensors are influenced by the temperature) and that, although the sensor itself may be linear or incorporate linearization circuits, the variables measured are not linearly related to the atmospheric variable of interest (for example, the output of a rotating beam ceilometer with photo detector and shaft-angle encoder providing backscattered light intensity as a function of angle is nonlinear in cloud height). As a consequence, it is necessary to include corrections for non-linearity in the conversion algorithms as far as this is not already done by signal-conditioning modules. Linearization is of particular importance when mean values must be calculated over a certain time. Indeed, when the sensor signal is not constant throughout the averaging period, the “average then linearize” sequence of operations can produce different results from the “linearize then average” sequence. The correct procedure is to only average linear variables.

* + - 1. **Instantaneous meteorological values**

The natural small‑scale variability of the atmosphere, the introduction of noise into the measurement process by electronic devices and, in particular, the use of sensors with short time constants make averaging a most desirable process for reducing the uncertainty of reported data. In order to standardize averaging algorithms it is

recommended:

(a) That atmospheric pressure, air temperature, air humidity, sea-surface temperature, visibility, among others, be reported as 1 to 10 min averages, which are obtained after linearization of the sensor output;

(b) That wind, except wind gusts, be reported as 2 or 10 min averages, which are obtained after linearization of the sensor output.

These averaged values are to be considered as the “instantaneous” values of meteorological variables for use in most operational applications and should not be confused with the raw instantaneous sensor samples or the mean values over longer periods of time required from some applications. One‑minute averages, as far as applicable, are suggested for most variables as suitable instantaneous values. Exceptions are wind (see (b) above) and wave measurements (10 or 20 min averages). Considering the discrepancy of observations between the peak gust data obtained from wind measuring systems with different time responses, it is recommended that the filtering characteristics of a wind measuring chain should be such that the reported peak gust should represent a 3 s average. The highest 3 s average should be reported. In practice, this entails sampling the sensor output and calculating the 3 s running mean at least one to four times a second. Some specific quantities for which data conversion is necessary and averaging is required before conversion are given in Part III, Chapter 2 (<https://www.wmo.int/pages/prog/www/IMOP/publications/CIMO-Guide/Ed2008Up2010/Part-III/WMO8_Ed2008_PartIII_Ch2_Up2010_en.pdf>).

From Part III, Chapter 2: (pages III-2.1 -

**2.1.1 Definitions**

For the purposes of this chapter the following definitions are used:

*Sampling* is the process of obtaining a discrete sequence of measurements of a quantity.

A *sample* is a single measurement, typically one of a series of spot readings of a sensor system. Note that this differs from the usual meaning in statistics of a set of numbers or measurements which is part of a population.

An *observation* is the result of the sampling process, being the quantity reported or recorded (often also called a measurement). In the context of time‑series analysis, an observation is derived from a number of samples.

The ISO definition of a *measurement* is a “set of operations having the object of determining the value of a quantity”. In common usage, the term may be used to mean the value of either a sample or an observation.

The *sampling time* or *observation period* is the length of the time over which one observation is made, during which a number of individual samples are taken. The *sampling interval* is the time between successive observations.

The *sampling function* or *weighting function* is, in its simplest definition, an algorithm for averaging or filtering the individual samples.

The *sampling frequency* is the frequency at which samples are taken. The *sample spacing* is the time between samples.

*Smoothing* is the process of attenuating the high frequency components of the spectrum without significantly affecting the lower frequencies. This is usually done to remove noise (random errors and fluctuations not relevant for the application).

A *filter* is a device for attenuating or selecting any chosen frequencies. Smoothing is performed by a *low-pass* filter, and the terms *smoothing* and *filtering* are often used interchangeably in this sense. However, there are also *high-pass* and *band-pass* filters. Filtering may be a property of the instrument, such as inertia, or it may be performed

electronically or numerically.

1. Including product names is for information only and does not constitute an endorsement. [↑](#footnote-ref-1)