NEON ALGORITHM THEORETICAL BASIS DOCUMENT (ATBD): SUMMARY WEATHER STATISTICS

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Change Record

REVISION	DATE	ECO #	DESCRIPTION OF CHANGE
A	06/21/2018	ECO-05613	Initial release
B	04/20/2022	ECO-06809	• Updated Neon logo • Added NEON to document title

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LIST OF TABLES AND FIGURES

1 DESCRIPTION

Contained in this document are details concerning the generation of weather summary statistics, Level 4 (L4) Data Products (DPs). Weather summary statistics will be generated from Level 1 (L1) DPs at NEON core sites. The L1 data products used to generate weather summary statistics are:

1. 2D wind speed
2. Triple Aspirated Air Temperature
3. Barometric Pressure
4. Primary Precipitation
5. Shortwave Radiation
6. Relative Humidity

Data for these data products are continuously monitored at NEON core sites using methodologies outlined in AD[12] through AD[17].

The means, minima, maxima, variances, and standard errors of the mean will be reported for the finest temporal resolution (typically 1-minute) aggregated primary measurement for appropriate data products. For Primary Precipitation only total precipitation values will be reported.

For 2D Wind data products, summary statistics shall be reported for mean wind speed only.

1.1 Purpose

This document details the algorithms used for creating NEON Level 4 data products from Level 1 data. Information detailing measurement theories and implementations, appropriate theoretical backgrounds, data product provenances, quality assurance and control methods, approximations and/or assumptions made, and applicable uncertainty estimates can be found for specific data products in the references throughout.

1.2 Scope

The theoretical background and algorithmic processes used to derive Level 4 data from the six Level 1 data products are described in this document. This document does not provide computational implementation details, except for cases where these stem directly from algorithmic choices explained here.

2 RELATED DOCUMENTS, ACRONYMS AND VARIABLE NOMENCLATURE

2.1 Applicable Documents

AD[01]	NEON.DOC.000001	NEON OBSERVATORY DESIGN
AD[02]	NEON.DOC.002652	NEON Level 1, Level 2 and level 3 Data Products Catalog
AD[03]	NEON.DOC.000782	ATBD QA/QC Data Consistency
AD[04]	NEON.DOC.011081	ATBD QA/QC plausibility tests
AD[05]	NEON.DOC.000783	ATBD De-spiking and time series analyses
AD[06]	NEON.DOC.000746	Evaluating Uncertainty (CVAL)
AD[07]	NEON.DOC.000785	TIS Level 1 Data Products Uncertainty Budget Estimation Plan
AD[08]	NEON.DOC.001113	Quality Flags and Quality Metrics for TIS Data Products
AD[09]	NEON.DOC.000653	ATBD Barometric Pressure
AD[10]	NEON.DOC.000654	ATBD Triple Redundant Aspirated Air Temperature
AD[11]	NEON.DOC.000780	ATBD 2D Wind Speed and Direction
AD[12]	NEON.DOC.000809	ATBD Net Radiometer
AD[13]	NEON.DOC.000851	ATBD Humidity and Temperature Sensor
AD[14]	NEON.DOC.000898	ATBD Primary Precipitation (DFIR)

2.2 Reference Documents

RD[01]	NEON.DOC.000008	NEON Acronym List
RD[02]	NEON.DOC.000243	NEON Glossary of Terms
RD[03]	NEON.DOC.002651	NEON Data Product Numbering Convention

2.3 Acronyms

Acronym	Explanation
AIS	Aquatic Instrument System
ATBD	Algorithm Theoretical Basis Document
CVAL	NEON Calibration, Validation, and Audit Laboratory
DAS	Data Acquisition System
DP	Data Product
FDAS	Field Data Acquisition System
GRAPE	Grouped Remote Analog Peripheral Equipment
L0	Level 0
L1	Level 1
N/A	Not Applicable
NOAA	National Oceanic Atmospheric Administration
PRT	Platinum Resistance Thermometer
RTD	Resistance Temperature Detectors
SAAT	Single Aspirated Air Temperature
SAATS	Single Aspirated Air Temperature Sensor

2.4 Verb Convention

"Shall" is used whenever a specification expresses a provision that is binding. The verbs "should" and "may" express non-mandatory provisions. "Will" is used to express a declaration of purpose on the part of the design activity.

3 DATA PRODUCT DESCRIPTION

3.1 Variables Reported

The weather summary statistics related L1 DPs provided by the algorithms documented in this ATBD are displayed in the accompanying file wss_datapub_NEONDOC004737.txt.

3.2 Input Dependencies

Table 1, 2, and 3 details the L1 DPs used to produce L4 Daily, Monthly, and Yearly Weather Summary Statistics DPs in this ATBD.

Table 1. List of L1 DPs that are transformed into L4 Daily weather summary statistics DPs in this ATBD.

Field Name	Temporal Resolution	Units	Data Product Number
windSpeedMean	2-Minute	$m\ s^{-1}$	NEON.DOM.SITE.DP1.00001.001.00340.000.VER.001
windSpeedMinimum	2-Minute	$m\ s^{-1}$	NEON.DOM.SITE.DP1.00001.001.00341.000.VER.001
windSpeedMaximum	2-Minute	$m\ s^{-1}$	NEON.DOM.SITE.DP1.00001.001.00342.000.VER.001
windSpeedVariance	2-Minute	$m^2\ s^{-2}$	NEON.DOM.SITE.DP1.00001.001.00343.000.VER.001
windSpeedNumPts	2-Minute	*NA*	NEON.DOM.SITE.DP1.00001.001.00344.000.VER.001
windSpeedFinalQF	2-Minute	*NA*	NEON.DOM.SITE.DP1.00001.001.00379.000.VER.001
tempTripleMean	1-Minute	°C	NEON.DOM.SITE.DP1.00003.001.00315.000.VER.001
tempTripleMinimum	1-Minute	°C	NEON.DOM.SITE.DP1.00003.001.00316.000.VER.001
tempTripleMaximum	1-Minute	°C	NEON.DOM.SITE.DP1.00003.001.00317.000.VER.001
tempTripleVariance	1-Minute	$°C^2$	NEON.DOM.SITE.DP1.00003.001.00318.000.VER.001
tempTripleNumPts	1-Minute	NA	NEON.DOM.SITE.DP1.00003.001.00319.000.VER.001
finalQF	1-Minute	NA	NEON.DOM.SITE.DP1.00003.001.00314.000.VER.001
staPresMean	1-Minute	kPa	NEON.DOM.SITE.DP1.00004.001.00451.000.VER.001
staPresMinimum	1-Minute	kPa	NEON.DOM.SITE.DP1.00004.001.00452.000.VER.001
staPresMaximum	1-Minute	kPa	NEON.DOM.SITE.DP1.00004.001.00453.000.VER.001
staPresVariance	1-Minute	kPa^2	NEON.DOM.SITE.DP1.00004.001.00454.000.VER.001
staPresNumPts	1-Minute	*NA*	NEON.DOM.SITE.DP1.00004.001.00455.000.VER.001
staPresFinalQF	1-Minute	*NA*	NEON.DOM.SITE.DP1.00004.001.00490.000.VER.001
corPres	1-Minute	kPa	NEON.DOM.SITE.DP1.00004.001.00491.000.VER.001
corPresFinalQF	1-Minute	*NA*	NEON.DOM.SITE.DP1.00004.001.00530.000.VER.001
priPrecipBulk	5-Minute	mm	NEON.DOM.SITE.DP1.00006.001.00248.HOR.VER.000
priPrecipFinalQF	5-Minute	*NA*	NEON.DOM.SITE.DP1.00006.001.02118.HOR.VER.000
shortRadMean	1-Minute	$W\ m^{-2}$	NEON.DOM.SITE.DP1.00022.001.00940.000.VER.001
shortRadMinimum	1-Minute	$W\ m^{-2}$	NEON.DOM.SITE.DP1.00022.001.00941.000.VER.001
shortRadMaximum	1-Minute	$W\ m^{-2}$	NEON.DOM.SITE.DP1.00022.001.00942.000.VER.001
shortRadVariance	1-Minute	$W^2\ m^{-4}$	NEON.DOM.SITE.DP1.00022.001.00942.000.VER.001
shortRadNumPts	1-Minute	*NA*	NEON.DOM.SITE.DP1.00022.001.00942.000.VER.001
finalQF	1-Minute	*NA*	NEON.DOM.SITE.DP1.00022.001.00314.000.VER.001
RHMean	1-Minute	%	NEON.DOM.SITE.DP1.00098.001.00653.000.VER.001
RHMinimum	1-Minute	%	NEON.DOM.SITE.DP1.00098.001.00654.000.VER.001

RHMaximum	1-Minute	%	NEON.DOM.SITE.DP1.00098.001.00655.000.VER.001
RHVariance	1-Minute	$\%^2$	NEON.DOM.SITE.DP1.00098.001.00656.000.VER.001
RHNumPts	1-Minute	*NA*	NEON.DOM.SITE.DP1.00098.001.00657.000.VER.001
RHFinalQF	1-Minute	*NA*	NEON.DOM.SITE.DP1.00098.001.00692.000.VER.001
dewTempMean	1-Minute	°C	NEON.DOM.SITE.DP1.00098.001.00733.000.VER.001
dewTempMinimum	1-Minute	°C	NEON.DOM.SITE.DP1.00098.001.00734.000.VER.001
dewTempMaximum	1-Minute	°C	NEON.DOM.SITE.DP1.00098.001.00735.000.VER.001
dewTempVariance	1-Minute	$°C^2$	NEON.DOM.SITE.DP1.00098.001.00736.000.VER.001
dewTempNumPts	1-Minute	*NA*	NEON.DOM.SITE.DP1.00098.001.00737.000.VER.001
dewTempFinalQF	1-Minute	*NA*	NEON.DOM.SITE.DP1.00098.001.00772.000.VER.001

Table 2. List of L4 Daily DPs that are transformed into Monthly L4 weather summary statistics DPs in this ATBD.

Field Name	Temporal Resolution	Units	Data Product Number
wssWindSpeedMean	1-Day	$m\ s^{-1}$	NEON.DOM.SITE.DP4.00001.001.04954.HOR.VER.01D
wssWindSpeedMinimum	1-Day	$m\ s^{-1}$	NEON.DOM.SITE.DP4.00001.001.04955.HOR.VER.01D
wssWindSpeedMaximum	1-Day	$m\ s^{-1}$	NEON.DOM.SITE.DP4.00001.001.04953.HOR.VER.01D
wssWindSpeedVariance	1-Day	$m^2\ s^{-2}$	NEON.DOM.SITE.DP4.00001.001.04957.HOR.VER.01D
wssWindSpeedStdErMean	1-Day	*NA*	NEON.DOM.SITE.DP4.00001.001.04956.HOR.VER.01D
wssWindSpeedNumPts	1-Day	*NA*	NEON.DOM.SITE.DP4.00001.001.05114.HOR.VER.01D
windSpeedQF	1-Day	*NA*	NEON.DOM.SITE.DP4.00001.001.04924.HOR.VER.01D
wssTempTripleMean	1-Day	°C	NEON.DOM.SITE.DP4.00001.001.04949.HOR.VER.01D
wssTempTripleMinimum	1-Day	°C	NEON.DOM.SITE.DP4.00001.001.04950.HOR.VER.01D
wssTempTripleMaximum	1-Day	°C	NEON.DOM.SITE.DP4.00001.001.04948.HOR.VER.01D
wssTempTripleVariance	1-Day	$°C^2$	NEON.DOM.SITE.DP4.00001.001.04952.HOR.VER.01D
wssTempTripleStdErMean	1-Day	NA	NEON.DOM.SITE.DP4.00001.001.04951.HOR.VER.01D
wssTempTripleNumPts	1-Day	NA	NEON.DOM.SITE.DP4.00001.001.05113.HOR.VER.01D
tempTripleQF	1-Day	NA	NEON.DOM.SITE.DP4.00001.001.04923.HOR.VER.01D
wssStaPresMean	1-Day	kPa	NEON.DOM.SITE.DP4.00001.001.04944.HOR.VER.01D
wssStaPresMinimum	1-Day	kPa	NEON.DOM.SITE.DP4.00001.001.04945.HOR.VER.01D
wssStaPresMaximum	1-Day	kPa	NEON.DOM.SITE.DP4.00001.001.04943.HOR.VER.01D
wssStaPresVariance	1-Day	kPa^2	NEON.DOM.SITE.DP4.00001.001.04947.HOR.VER.01D
wssStaPresStdErMean	1-Day	*NA*	NEON.DOM.SITE.DP4.00001.001.04946.HOR.VER.01D
wssStaPresNumPts	1-Day	*NA*	NEON.DOM.SITE.DP4.00001.001.05112.HOR.VER.01D
staPresQF	1-Day	*NA*	NEON.DOM.SITE.DP4.00001.001.04922.HOR.VER.01D
wssCorPres	1-Day	kPa	NEON.DOM.SITE.DP4.00001.001.04926.HOR.VER.01D
corPresQF	1-Day	*NA*	NEON.DOM.SITE.DP4.00001.001.04916.HOR.VER.01D
wssPrecipTotal	1-Day	mm	NEON.DOM.SITE.DP4.00001.001.04932.HOR.VER.01D
precipQF	1-Day	*NA*	NEON.DOM.SITE.DP4.00001.001.04918.HOR.VER.01D
wssShortRadMean	1-Day	$W\ m^{-2}$	NEON.DOM.SITE.DP4.00001.001.04939.HOR.VER.01D
wssShortRadMinimum	1-Day	$W\ m^{-2}$	NEON.DOM.SITE.DP4.00001.001.04940.HOR.VER.01D
wssShortRadMaximum	1-Day	$W\ m^{-2}$	NEON.DOM.SITE.DP4.00001.001.04938.HOR.VER.01D
wssShortRadVariance	1-Day	$W^2\ m^{-4}$	NEON.DOM.SITE.DP4.00001.001.04942.HOR.VER.01D
wssShortRadStdErMean	1-Day	*NA*	NEON.DOM.SITE.DP4.00001.001.04941.HOR.VER.01D

wssShortRadNumPts	1-Day	*NA*	NEON.DOM.SITE.DP4.00001.001.05111.HOR.VER.01D
shortRadQF	1-Day	*NA*	NEON.DOM.SITE.DP4.00001.001.04921.HOR.VER.01D
wssRHMean	1-Day	%	NEON.DOM.SITE.DP4.00001.001.04934.HOR.VER.01D
wssRHMinimum	1-Day	%	NEON.DOM.SITE.DP4.00001.001.04935.HOR.VER.01D
wssRHMaximum	1-Day	%	NEON.DOM.SITE.DP4.00001.001.04933.HOR.VER.01D
wssRHVariance	1-Day	$\%^2$	NEON.DOM.SITE.DP4.00001.001.04937.HOR.VER.01D
wssRHStdErMean	1-Day	*NA*	NEON.DOM.SITE.DP4.00001.001.04936.HOR.VER.01D
wssRHNumPts	1-Day	*NA*	NEON.DOM.SITE.DP4.00001.001.05110.HOR.VER.01D
RHQF	1-Day	*NA*	NEON.DOM.SITE.DP4.00001.001.04920.HOR.VER.01D
wssDewTempMean	1-Day	°C	NEON.DOM.SITE.DP4.00001.001.04928.HOR.VER.01D
wssDewTempMinimum	1-Day	°C	NEON.DOM.SITE.DP4.00001.001.04929.HOR.VER.01D
wssDewTempMaximum	1-Day	°C	NEON.DOM.SITE.DP4.00001.001.04927.HOR.VER.01D
wssDewTempVariance	1-Day	$°C^2$	NEON.DOM.SITE.DP4.00001.001.04931.HOR.VER.01D
wssDewTempStdErMean	1-Day	*NA*	NEON.DOM.SITE.DP4.00001.001.04930.HOR.VER.01D
wssDewTempNumPts	1-Day	*NA*	NEON.DOM.SITE.DP4.00001.001.05109.HOR.VER.01D
dewTempQF	1-Day	*NA*	NEON.DOM.SITE.DP4.00001.001.04917.HOR.VER.01D

Table 3. List of L4 Monthly DPs that are transformed into L4 Yearly weather summary statistics DPs in this ATBD.

Field Name	Temporal Resolution	Units	Data Product Number
wssWindSpeedMean	1-Month	$m\ s^{-1}$	NEON.DOM.SITE.DP4.00001.001.04954.HOR.VER.01M
wssWindSpeedMinimum	1-Month	$m\ s^{-1}$	NEON.DOM.SITE.DP4.00001.001.04955.HOR.VER.01M
wssWindSpeedMaximum	1-Month	$m\ s^{-1}$	NEON.DOM.SITE.DP4.00001.001.04953.HOR.VER.01M
wssWindSpeedVariance	1-Month	$m^2\ s^{-2}$	NEON.DOM.SITE.DP4.00001.001.04957.HOR.VER.01M
wssWindSpeedStdErMean	1-Month	*NA*	NEON.DOM.SITE.DP4.00001.001.04956.HOR.VER.01M
wssWindSpeedNumPts	1-Month	*NA*	NEON.DOM.SITE.DP4.00001.001.05114.HOR.VER.01M
windSpeedQF	1-Month	*NA*	NEON.DOM.SITE.DP4.00001.001.04924.HOR.VER.01M
wssTempTripleMean	1-Month	°C	NEON.DOM.SITE.DP4.00001.001.04949.HOR.VER.01M
wssTempTripleMinimum	1-Month	°C	NEON.DOM.SITE.DP4.00001.001.04950.HOR.VER.01M
wssTempTripleMaximum	1-Month	°C	NEON.DOM.SITE.DP4.00001.001.04948.HOR.VER.01M
wssTempTripleVariance	1-Month	$°C^2$	NEON.DOM.SITE.DP4.00001.001.04952.HOR.VER.01M
wssTempTripleStdErMean	1-Month	NA	NEON.DOM.SITE.DP4.00001.001.04951.HOR.VER.01M
wssTempTripleNumPts	1-Month	NA	NEON.DOM.SITE.DP4.00001.001.05113.HOR.VER.01M
tempTripleQF	1-Month	NA	NEON.DOM.SITE.DP4.00001.001.04923.HOR.VER.01M
wssStaPresMean	1-Month	kPa	NEON.DOM.SITE.DP4.00001.001.04944.HOR.VER.01M
wssStaPresMinimum	1-Month	kPa	NEON.DOM.SITE.DP4.00001.001.04945.HOR.VER.01M
wssStaPresMaximum	1-Month	kPa	NEON.DOM.SITE.DP4.00001.001.04943.HOR.VER.01M
wssStaPresVariance	1-Month	kPa^2	NEON.DOM.SITE.DP4.00001.001.04947.HOR.VER.01M
wssStaPresStdErMean	1-Month	*NA*	NEON.DOM.SITE.DP4.00001.001.04946.HOR.VER.01M
wssStaPresNumPts	1-Month	*NA*	NEON.DOM.SITE.DP4.00001.001.05112.HOR.VER.01M
staPresQF	1-Month	*NA*	NEON.DOM.SITE.DP4.00001.001.04922.HOR.VER.01M
wssCorPres	1-Month	kPa	NEON.DOM.SITE.DP4.00001.001.04926.HOR.VER.01M
corPresQF	1-Month	*NA*	NEON.DOM.SITE.DP4.00001.001.04916.HOR.VER.01M
wssPrecipTotal	1-Month	mm	NEON.DOM.SITE.DP4.00001.001.04932.HOR.VER.01M

precipQF	1-Month	*NA*	NEON.DOM.SITE.DP4.00001.001.04918.HOR.VER.01M
wssShortRadMean	1-Month	$W\ m^{-2}$	NEON.DOM.SITE.DP4.00001.001.04939.HOR.VER.01M
wssShortRadMinimum	1-Month	$W\ m^{-2}$	NEON.DOM.SITE.DP4.00001.001.04940.HOR.VER.01M
wssShortRadMaximum	1-Month	$W\ m^{-2}$	NEON.DOM.SITE.DP4.00001.001.04938.HOR.VER.01M
wssShortRadVariance	1-Month	$W^2\ m^{-4}$	NEON.DOM.SITE.DP4.00001.001.04942.HOR.VER.01M
wssShortRadStdErMean	1-Month	*NA*	NEON.DOM.SITE.DP4.00001.001.04941.HOR.VER.01M
wssShortRadNumPts	1-Month	*NA*	NEON.DOM.SITE.DP4.00001.001.05111.HOR.VER.01M
shortRadQF	1-Month	*NA*	NEON.DOM.SITE.DP4.00001.001.04921.HOR.VER.01M
wssRHMean	1-Month	%	NEON.DOM.SITE.DP4.00001.001.04934.HOR.VER.01M
wssRHMinimum	1-Month	%	NEON.DOM.SITE.DP4.00001.001.04935.HOR.VER.01M
wssRHMaximum	1-Month	%	NEON.DOM.SITE.DP4.00001.001.04933.HOR.VER.01M
wssRHVariance	1-Month	$\%^2$	NEON.DOM.SITE.DP4.00001.001.04937.HOR.VER.01M
wssRHStdErMean	1-Month	*NA*	NEON.DOM.SITE.DP4.00001.001.04936.HOR.VER.01M
wssRHNumPts	1-Month	*NA*	NEON.DOM.SITE.DP4.00001.001.05110.HOR.VER.01M
RHQF	1-Month	*NA*	NEON.DOM.SITE.DP4.00001.001.04920.HOR.VER.01M
wssDewTempMean	1-Month	°C	NEON.DOM.SITE.DP4.00001.001.04928.HOR.VER.01M
wssDewTempMinimum	1-Month	°C	NEON.DOM.SITE.DP4.00001.001.04929.HOR.VER.01M
wssDewTempMaximum	1-Month	°C	NEON.DOM.SITE.DP4.00001.001.04927.HOR.VER.01M
wssDewTempVariance	1-Month	$°C^2$	NEON.DOM.SITE.DP4.00001.001.04931.HOR.VER.01M
wssDewTempStdErMean	1-Month	*NA*	NEON.DOM.SITE.DP4.00001.001.04930.HOR.VER.01M
wssDewTempNumPts	1-Month	*NA*	NEON.DOM.SITE.DP4.00001.001.05109.HOR.VER.01M

3.3 Product Instances

Weather summary statistics are generated for each Core terrestrial site in all 20 of NEON's domains.

3.4 Temporal Resolution and Extent

Daily, monthly, and yearly minima, maxima, means, variances, and standard errors of the underlying L1 DPs will be calculated to form the L4 DPs. One-minute data products of air temperature, barometric pressure, relative humidity, and radiation will be used for L4 data product generation. Five-minute and two-minute data products for precipitation and wind speed, respectively, will be used for L4 data product generation.

3.5 Spatial Resolution and Extent

Weather summary statistics will be generated using L1 DPs generated from sensors located at core NEON terrestrial sites. Specifically, level 1 data products of shortwave radiation, air temperature and relative humidity taken at the tower-top measurement level, 2D Wind Speed and Direction L1 data products from measurement level 1 to the measurement level below tower-top (n-1), and barometric pressure L1 data products from between measurement level 1 and 2 or 2 and 3 (depending on the site) will be used in the development of L4 DPs. Primary precipitation is measured using a Double Fence Intercomparison Reference (DFIR) weighing rain gauge located near the base of the tower.

4 SCIENTIFIC CONTEXT

The data products used for computing summary weather statistics represent fundamental meteorological parameters and are commonly monitored by many meteorological networks (e.g., USCRN, SCAN, etc.).

Wind plays an important role in atmospheric and environmental sciences. A function of differential heating of Earth's surface and subsequent pressure gradients, horizontal and vertical winds are responsible for advection of atmospheric pollutants, moisture, heat and momentum (Stull 1988).

Temperature is one of the most fundamental physical measurements. It is a primary driving factor for countless physical, chemical, and biological processes.

Precipitation records are fundamental to an array of ecological studies. As such, precipitation data is often used as ancillary data for more detailed investigations. Furthermore, precipitation records help inform storm surge statistics and abate social, economic, and environmental losses from floods.

The sun's energy is emitted to the earth mainly in the form of incoming short wave (SW) radiation, with a small portion it falling LW radiation wavelengths. Pyranometers serve to quantify SW radiation and in turn provide a foundation for investigations of the Earth's climate. Incoming SW radiation, which is composed primarily of ultraviolet, visible, and a portion of infra-red wavelengths, is the primary driver for the Earth's climate. As such, the observations of incoming shortwave radiation are of great interest to the scientific and broader community in assessing the Earth's energy budget.

Barometric pressure, or static atmospheric pressure, is a vital measurement for NEON. Barometric pressure is significant in influencing weather conditions as well as aqueous chemistry (e.g. the amount of gas that can dissolve in solution). Recording static atmospheric pressure will allow atmospheric gas mixing ratios to be converted into mass quantities.

Relative humidity and dew point temperature are both important indicators of the amount of water vapor present in the atmosphere. As such, measurements of both relative humidity and dew point temperature are crucial to understanding both meteorological and ecologic conditions.

4.1 Theory of Measurement

Measurement theories for each sensor-type are provided in AD[09] through AD[14].

4.2 Theory of Algorithm

Weather summary statistics are intended to provide the minimums, maximums, means, totals (precipitation only), variances and standard errors of the mean of weather-related data products from NEON's core terrestrial sites. Only Primary Precipitation and Air Pressure Corrected to Sea Level do not have a calculated variance, minima, maxima, or standard error. Only Primary Precipitation does not have a calculated mean (totals and a quality flag are reported).

To minimize the computation time required in calculating the reported statistics, values will be generated in a 'cascading' fashion:

1. Daily values will be calculated from 1-minute aggregated data (or in the case of 2D Wind Speed, 2-minute aggregated data, and in the case of Primary Precipitation 5-minute aggregated data), falling between 00:00:00 and 23:59:59 hours on a given day
2. Daily values generated in step 1 will be used to produce monthly values. Monthly summary statistics should only be generated once daily summary statistics have been processed for every day in the given month.
3. Yearly summary statistics should be generated from monthly values, once all monthly summary statistics values are available in a given year.

For all data products except for Primary Precipitation (DP1.00006.001) the daily, monthly, and yearly mean of a given value shall be calculated according to equation 1:

$$\overline{M_1} = \frac{1}{N}\sum_{i=1}^{g} M_i n_i \tag{1}$$

where, M_i represents the individual L1 DP of a given measurement type, n_i represents the number of data points in a group, and g is the total number of groups. N is the total number of data points in all groups of data, calculated as shown in equation 2.

$$N = \sum_{i=1}^{g} n_i \tag{2}$$

For example, in a hypothetical 1-minute aggregated data set there may be 60 individual measurements (measurements taken at 1 Hz) that are aggregated to a 1 minute data product. Over the course of a day, there are 1440 1-minute reported values (g=1440), each comprising 60 measurements (n_i=60). Thus, N would be 86400, representing the total number of 1 Hz measurements made during our 1 day period.

For all data products except Primary Precipitation (DP1.00006.001) and Air Pressure Corrected to Sea Level (DP1.00004.001), variances shall be calculated. To calculate variances for each temporal aggregation period of a data product the variances of the underlying data, number of data points represented in the underlying data, and the mean as calculated in equation 1 must be used. Equation 3 shows the method for calculating daily, monthly, and yearly variances (V) (Burton, 2016):

$$V = \frac{\sum_{i=1}^{g} V_i(n_i - 1) + \sum_{i=1}^{g} n_i(M_i - \overline{M_1})^2}{N - 1} \tag{3}$$

Where n_i is the number of data points used to produce the reported value, V_i is the variance of the population of data points, M_i is the mean value for the population of data points. M_1 and N are calculated as shown in equations 1 and 2, respectively.

The finest resolution raw data are always used for values n_i and N, and is typically 1-second for most data products. M_i and V_i are the means and variances of the next smallest temporal aggregation period relative to the one being calculated. For example, if M_i and V_i are the 1-minute means and variances (from L1 data) when calculating the daily variance then n_i represents the number of L0 data points used in calculating the 1-minute data; N would then be the total number of L0 points in a day.

When generating monthly means and variances, the total number of L0 data points are still considered, but rather than using 1-minute M_i and V_i values, daily values are instead used. For a 30-day month, there will be 30 M_i and V_i values used ($g = 30$), with N equaling the total number of L0 points in the month of interest, and n_i equaling the total number of L0 data points in a given day. The same concept is true for yearly data products.

Once variances have been calculated, the standard error of the mean (SE_1) can be generated for each timescale using equation 4:

$$SE_1 = \sqrt{\frac{V_1}{N}} \tag{4}$$

Where N and V_1 are defined in equations 2 and 3, respectively.

For Primary Precipitation, the minimum, maximum, mean and associated variances and standard error of the mean should *not* be calculated. Only the daily total should be calculated, by simple summing of the 5-minute aggregated precipitation values, P_i, as shown in equation 5.

$$\overline{P_1} = \sum_{i=1}^{n} P_i \tag{5}$$

Monthly summary statistics shall be generated from the daily statistics using the same procedure as outlined above, as will yearly statistics from monthly Statistics.

5 ALGORITHM IMPLEMENTATION

Processing L4 data will occur as 7 separate transitions for each of the data product groups being summarized. Before transitions are run, an Input Data Checker will look for data availability. If data for one output aren't available then the transition will not be run, but other transitions will be run. For example, if data underlying the summary statistic calculations for wind speed are missing then the transition will not run for wind speed, but other statistics such as shortwave radiation will still be transitioned. The output checker shall operate as follows:

1) L4 daily WSS transition will bail out if any of the 7 transitions' "finalQF" is empty for any of the six four-hour time windows of a given day. The time window for each of L0 to L1 transitions is usually four hours. If a finalQF is available in all six four-hour time windows of a given day, it means the required L0 to L1 transitions have been run. L4 daily WSS transitions should be run for to produce daily statistics.
2) L4 monthly transitions will bail out if any of the 7 transitions' L4 daily "finalQFs" are missing for any day of a given month. If L4 daily final QFs are in place, transitions for L4 monthly summary statistics should run.
3) L4 yearly transitions will bail out if any of the 7 transitions' L4 monthly "finalQFs" are missing for any month of a given year. If L4 monthly final QFs are in place for all 12 months, transitions for L4 yearly summary statistics should run.

Processing of L4 data will occur in the following order for each L1 data product used:

1. L1 data products shall be calculated from only one sensor at a site. Measurements from the tower top sensors shall be used to generate summary statistics for relative humidity, shortwave radiation, pressure, and triple aspirated air temperature. 2D wind measurements from the first level below the tower top shall be used to generate wind speed summary statistics, and only primary precipitation measurements from the DFIR shall be used for precipitation summary statistics. No measurements from the soil plots shall be used.
2. Daily minima, means, maxima, variances, and standard errors shall be calculated from 1 minute aggregated data for all L1 data products used, except for Primary Precipitation and Pressure Corrected to Sea Level. For Primary Precipitation, daily total data shall be calculated. For Pressure Corrected to Sea Level only the daily means shall be calculated.
3. Monthly minima, means, maxima, variances and standard errors shall be calculated from daily averaged data, except for Primary Precipitation and Pressure Corrected to Sea Level. For Primary Precipitation, monthly total data shall be calculated using daily totals. For Pressure Corrected to Sea Level only the monthly means shall be calculated.
4. Yearly minima, means, maxima, variances, and standard errors shall be calculated from monthly averaged data, except for Primary Precipitation and Pressure Corrected to Sea Level. For Primary Precipitation, yearly total data shall be calculated using monthly totals. For Pressure Corrected to Sea Level only the yearly means shall be calculated.

5. Quality flags will be produced for daily, monthly, and yearly calculated data based on the quantity of final quality flags present in the underlying (higher temporal resolution) data. A quality flag will be generated for each set of weather summary statistics if more than 20% of the underlying records have their final quality flag raised (QF_{final}=1).

QA/QC Procedure:

Level 4 data products rely on the QA/QC procedures of the underlying L1 data products to report data quality.

Quality Flags – A final quality flag shall be generated for each group of data products reported, based on the percent of the underlying data with a final quality flag raised. For example, a record of L4 daily barometric pressure statistics will contain a single final quality flag reported alongside the minimum, mean, maximum, variances, and standard errors values.

The 'cascading scheme' will be used to generate quality flags for each statistic group. The percentage of final quality flags raised (i.e., equal to 1) in L1 DPs will inform the quality flag state of the L4 daily DP, while the percentage of records with a raised quality flag in the L4 Daily DPs will inform the L4 Monthly DP quality flags (Smith 2014). The percentage of records with a raised quality flag in the L4 Monthly DPs will inform the L4 Yearly DP quality flags.

Raising a quality flag at a given temporal level shall require 20% or more data the underlying temporal level be missing or have a quality flag or final quality flag of 1.

6 UNCERTAINTY

Weather Summary Statistic data products are considered engineering grade data (RD[03]). As such, no uncertainty estimates will be provided. Uncertainty estimates of the L1 data products used to generate the weather summary statistics are provided in the respective download files.

7 FUTURE PLANS AND MODIFICATIONS

Future versions of this data product may incorporate summary statistics of additional L1 DPs, including wind direction summary statistics and soil temperature.

Statistics are currently reported in files by sensor location. In the future, output may be condensed into one file. Additionally, summaries for 2D wind data are currently reported for all measurement levels. In future versions, only the measurement level below the tower top may be reported.

8 BIBLIOGRAPHY

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