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NEON's Approach to Consistency in Measurement for 30 years

A31A-03: Assessing Atmospheric Instrumental Uncertainty and Measurement Consistency I

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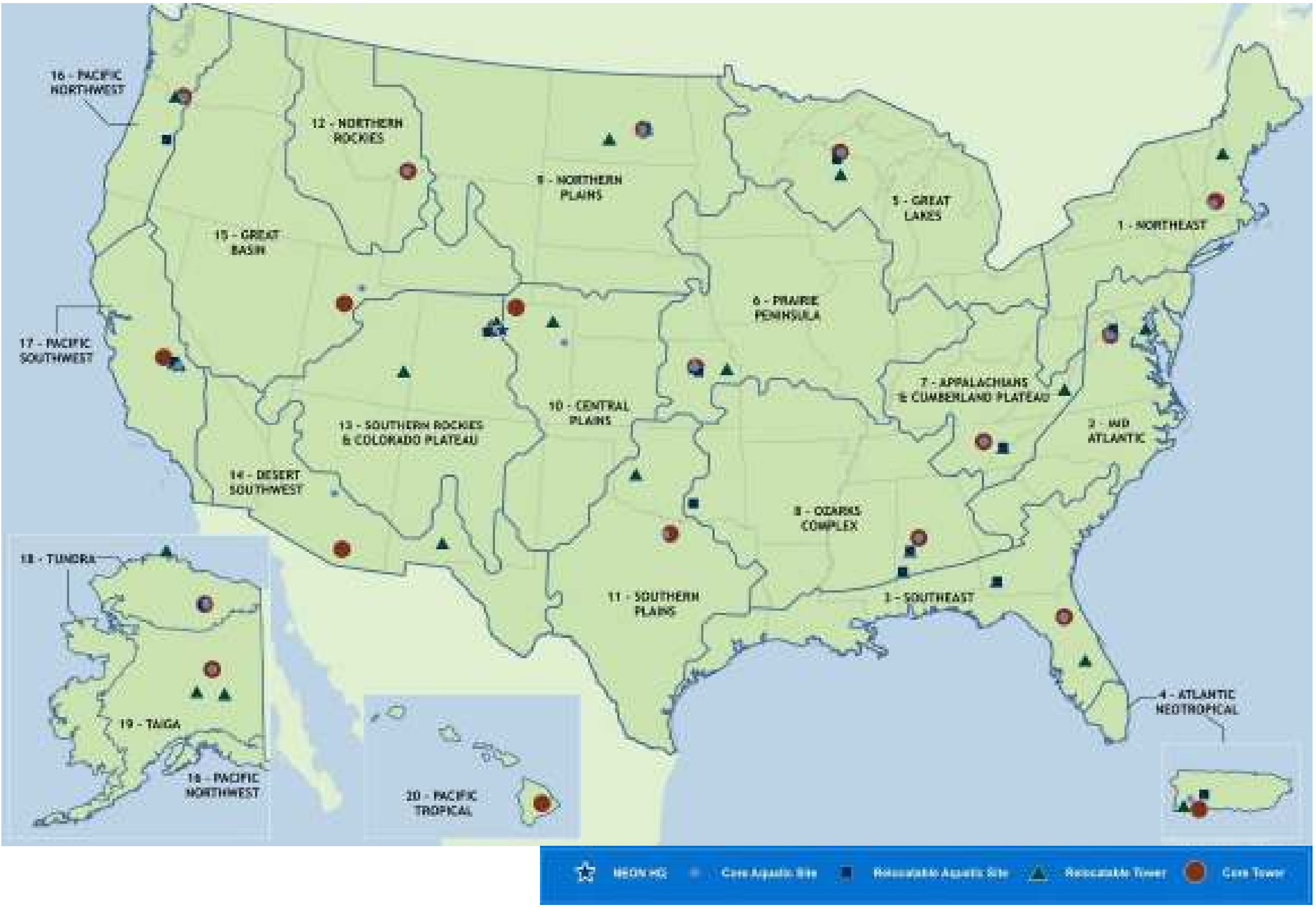
NEON Introduction

What is the National Ecological Observatory Network (NEON)?

The National Science Foundation’s NEON project is a continental-scale ecological observation facility operated by Battelle. NEON provides:

- Free and open data on the drivers of and responses to ecological change
- A standardized and reliable framework for research and experiments
- Data interoperability for integration with other national and international network science projects
- 30 years of operations = collect and provide data, educational resources and infrastructure to users.

NEON's field sites and data products

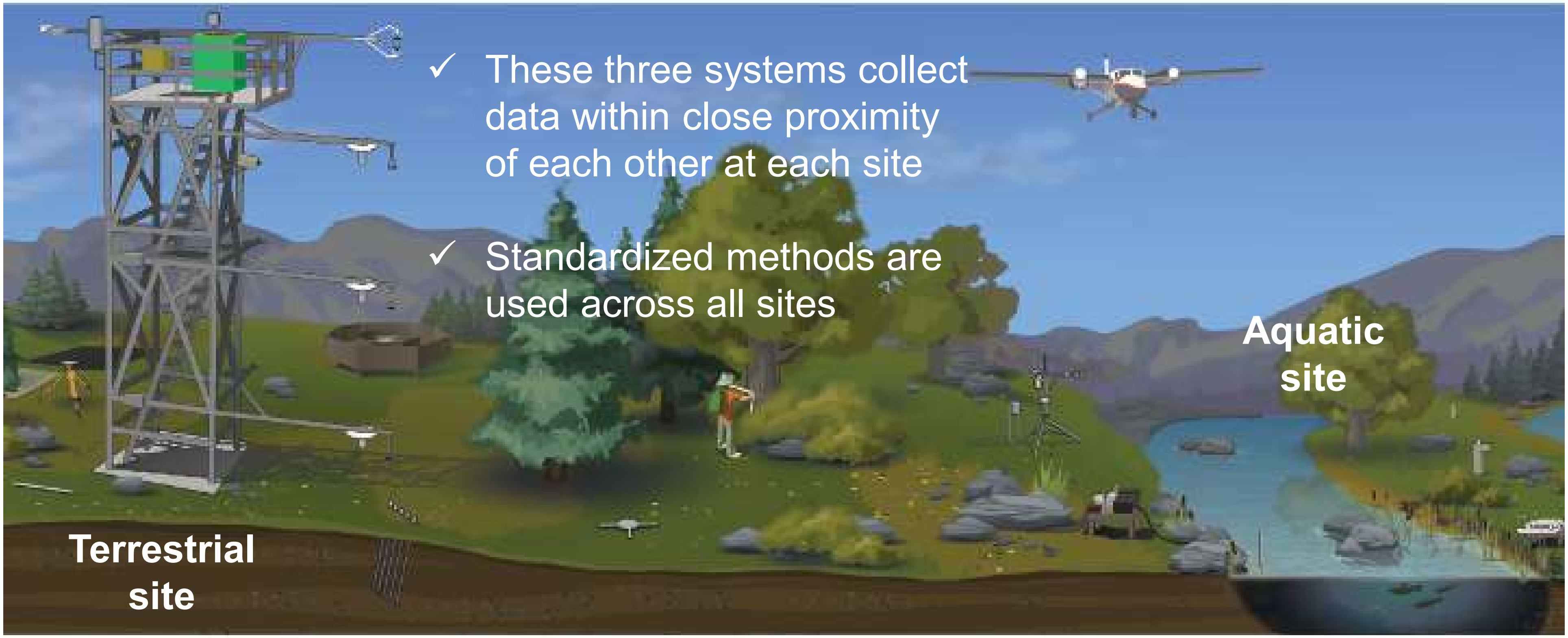


81
FIELD SITES

- 47 terrestrial
- 34 aquatic

Over
180
DATA PRODUCTS

NEON's data collection methods



Airborne remote sensing

Observational sampling

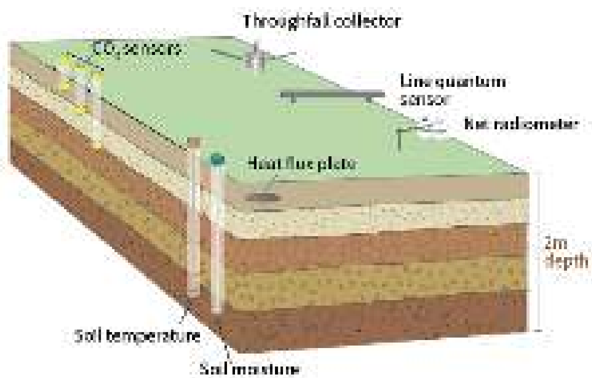
Automated instruments

Automated instruments

Ground, lakes and streams at aquatic sites providing water quality

Micrometeorology station at aquatic sites

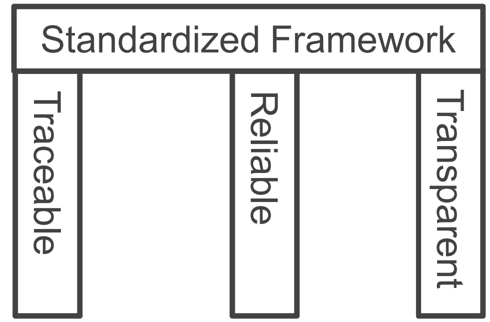
Flux tower at terrestrial sites



An array of soil plots near the flux tower at terrestrial sites collect soil health data

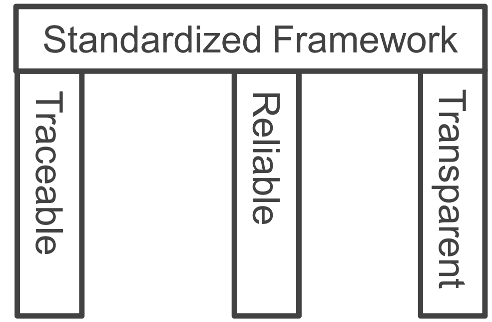
Consistency in Measurement

Standardized Framework

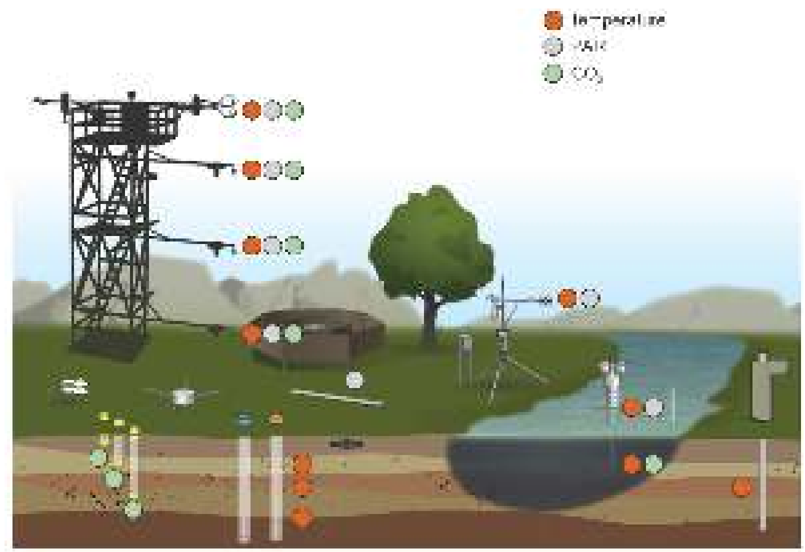


- Traceability
  - Measurement Traceability to National and International Standards
    - **In-house Metrology Lab for Annual Calibrations and Validations of Instruments**
  - Following protocols and standards set forth by other observatories and governing bodies (USCRN, WMO, ISO, NIST, WRC, etc.)
    - Inform requirements
    - Calibration methods
    - Field collection methods
    - Uncertainty Analysis

Standardized Framework



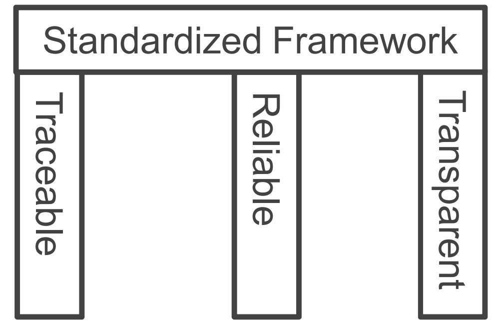
- Transparency
  - Algorithm Theoretical Basis Documents (ATBDs)
    - Theory of measurement
    - Theory of algorithms
      - converting from raw data to calibrated data
    - QA/QC
    - Temporal averaging (Level 1 data products)
      - One- and thirty-minute averages
    - Uncertainty estimates
      - Measurement uncertainty published with data products



  - Versioning/Revisioning System
    - System or algorithm changes substantially, product REV field will increment with overlap for at least 1 year

$$T_i = \sum_{k=1}^{4} D_k \left(R_{t_i}/R_0 - 1\right)^k$$

Standardized Framework

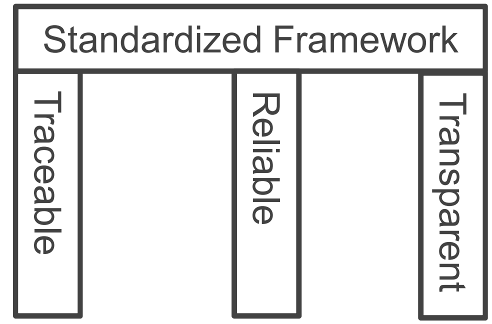


- Reliability
  - Commissioning: Data products tested and verified.
  - Network of field scientists to address on-site sensor maintenance and problem identification.
  - Automated and Manual QA/QC of data products
    - Automated flagging of data defined in ATBDs.
      - Uncertainty informs thresholds for some of the QA/QC tests to make confident inferences between signal and noise.
      - Comparisons of measurements to nearby measurement levels and/or at sites nearby (spatially) NEON sites (used in post-processing but may be used for automated flagging in future).
    - Automated State-of-Health System: Near real-time monitoring of all IS-related data streams throughout the Observatory, ensuring that problems can be identified and remedied in an efficient manner

      Using Automated Data Quality Monitoring to Improve Sensor Maintenance at a Continental-Scale Observatory

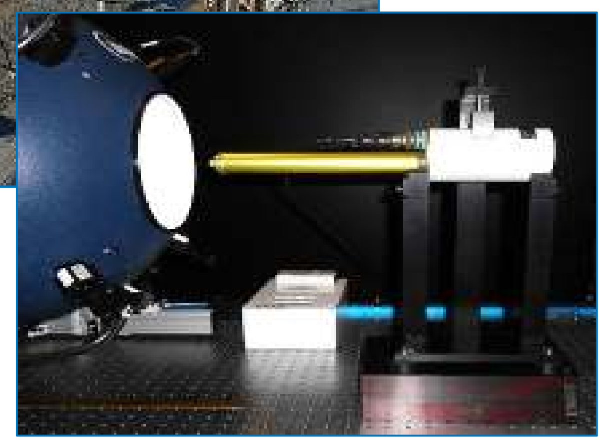
      Thursday 8:00 am – 12:20 pm Moscone South Poster Hall
    - Field audits to ensure spatial/temporal consistency in maintenance and operational procedures

Standardized Framework



****NEON's In-house Metrology Lab:**
Calibration, Validation and Audit Lab (CVAL)**

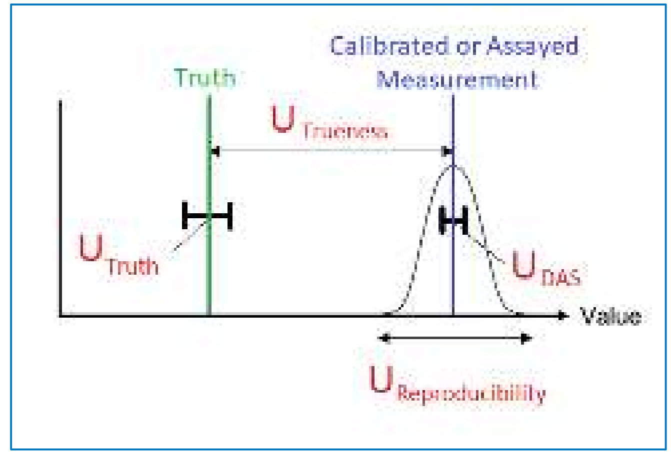
- Ensure consistency in measurement throughout the network:
  - Annual calibration of sensors and data acquisition systems (DAS's)
    - Calibrations provide traceability to national/international standards
    - Calibrations to the same standards and methods
    - **Internal assessment of measurement uncertainty and drift**
    - Control over quality by ensuring performance of sensors and DAS's meeting project requirements
  - Provide standards used in the field for in-situ calibrations and validations
- Ensure consistency in measurement to other labs: Comparison of measurements to other national labs in round robins (NOAA, NREL, etc)
- Ensure consistency over 30 years of operation: Comparison of new versions or different sensors for the same measurand with the same standards to understand technology changes



Calibration Uncertainty

Uncertainty: informing the quality of measurement

- **Assessment Standard:** *JCGM, 2008, Evaluation of measurement data – Guide to the expression of uncertainty in measurement (GUM), JCGM 100:2008.*
- **NEON Uncertainty Methods Publication:** *Csavina, J., J. A. Roberti, J. R. Taylor, and H. W. Loescher. 2017. Traceable measurements and calibration: a primer on uncertainty analysis. Ecosphere, 8(2):e01683.*



Calibration with uncertainties
DAQ: Data Acquisition System

- **Type A:** evaluated by statistical methods. Experimental variance of independent observations which differ in value because of random variations.

- **Type B:** evaluated by other means. Estimates obtained using available published knowledge such as manufacturer's specs, calibration certificates, reference data from handbooks, etc.

Specifications	
Spectral range (50 % points)	(400 to 700) ± 4 nm
Sensitivity	4 to 10 µV/µmol/m²s
Response time (95%)	< 1 µs
Non-linearity (0 to 10,000 µmol/m²s)	< 1%
Temperature dependence	< -0.1 %/°C
Sensitivity change per year	< 2%
Directional error (up to 80° zenith angle)	< 3%
Impedance	240 Ω
Field of view	180 °
Operating temperature	-50 °C to +70 °C
Relative humidity	0 - 100 % RH
Ingress protection	IP67

Calibration Uncertainty

- **Truth:** Uncertainty of the reference or "truth"
  - Typically a value obtained by Type B analysis

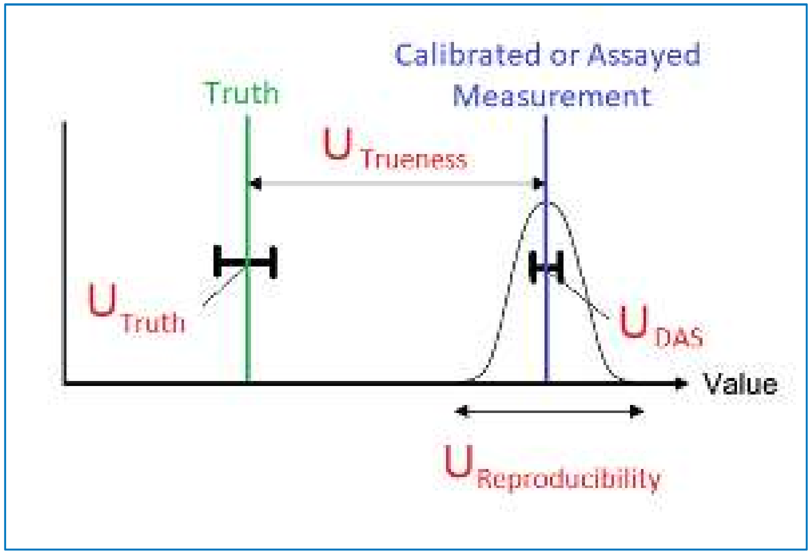
    u_{truth} = standard's calibration sheet

- **Trueness:** Difference between the truth and measurement

$$u_{trueness} = s(q) = \left[\frac{1}{n}\sum_{j=1}^{n}(q_j - truth_j)^2\right]^{\frac{1}{2}}$$

- **DAS:** Uncertainty of data acquisition system

$$u_{DAS} = \left(\frac{\partial q}{\partial x_{DAS}}\right) \cdot u(x_{DAS})$$



- **Reproducibility:** Measurements taken under varied conditions

$$u_{reproducibility} = s(q) = \left[\frac{1}{(n-1)}\sum_{j=1}^{n}(q_j - \bar{q})^2\right]^{\frac{1}{2}}$$

- **Repeatability:** Measurements taken under the same conditions

$$u_{repeatability} = s(\bar{q}) = \left[\frac{1}{(n-1)}\sum_{j=1}^{n}(q_j - \bar{q})^2\right]^{\frac{1}{2}}$$

Traceable Calibrations to Measurement Uncertainty

- Calibration Combined Uncertainty

$$u_{c,calibration} = \sqrt{{u_{truth}}^2 + {u_{trueness}}^2 + {u_{reproducibility}}^2 + {u_{DAQ}}^2}$$

- Measurement Combined Uncertainty
  - Option 1 – Analytical ground up method:

$$u_{c,measurement} = \sqrt{{u_{c,calibration}}^2 + {u_{repeatability}}^2 + {u_{other}}^2}$$

    - Note: $u_{repeatability}$ may be based on calibration estimate or if measurement involves temporal averaging, then standard deviation of the mean is used here
    - u_{other} would be defined in the ATBDs
    - Generally used for Level 1 data products (raw data to calibrated data)
  - Option 2 – Modeling Bayesian – Monte Carlo
    - $u_{calibration}$ is fed into this modeling of uncertainty as a component.
    - Used for higher level data products
- Expanded uncertainty (95% CL) provided as output with data products.

$$u_{95\%} = k_p * u_c$$

Annual Drift – *in development*

- These estimates will quantify the degradation of the sensor/change in calibration over the year.
  - Drift due to sensor fouling, etc. will not be encompassed in this estimate.
- Calibration Drift Calculation

$$D_i = \left(M_{as\ found\ j(i)} - Truth_{j(i)}\right) - \left(M_{as\ left\ k(i)} - Truth_{k(i)}\right)$$

- Average Annual Drift: D_{annual} intended to be provided with data

$$D_{annual} = \left[\frac{1}{(n)} \sum_{i=1}^{n} (D_i)\right] \frac{365.25}{days\ since}$$

- Drift Correction – a, b,c, and days since to be provided with data, uncertainty associated with correction, and potential code package to correct measurement for drift.

$$M_{corrected} = M_{field} - \left[a\left(M_{field}\right)^2 + b\left(M_{field}\right) + c * M_{field}\right] * days\ since$$

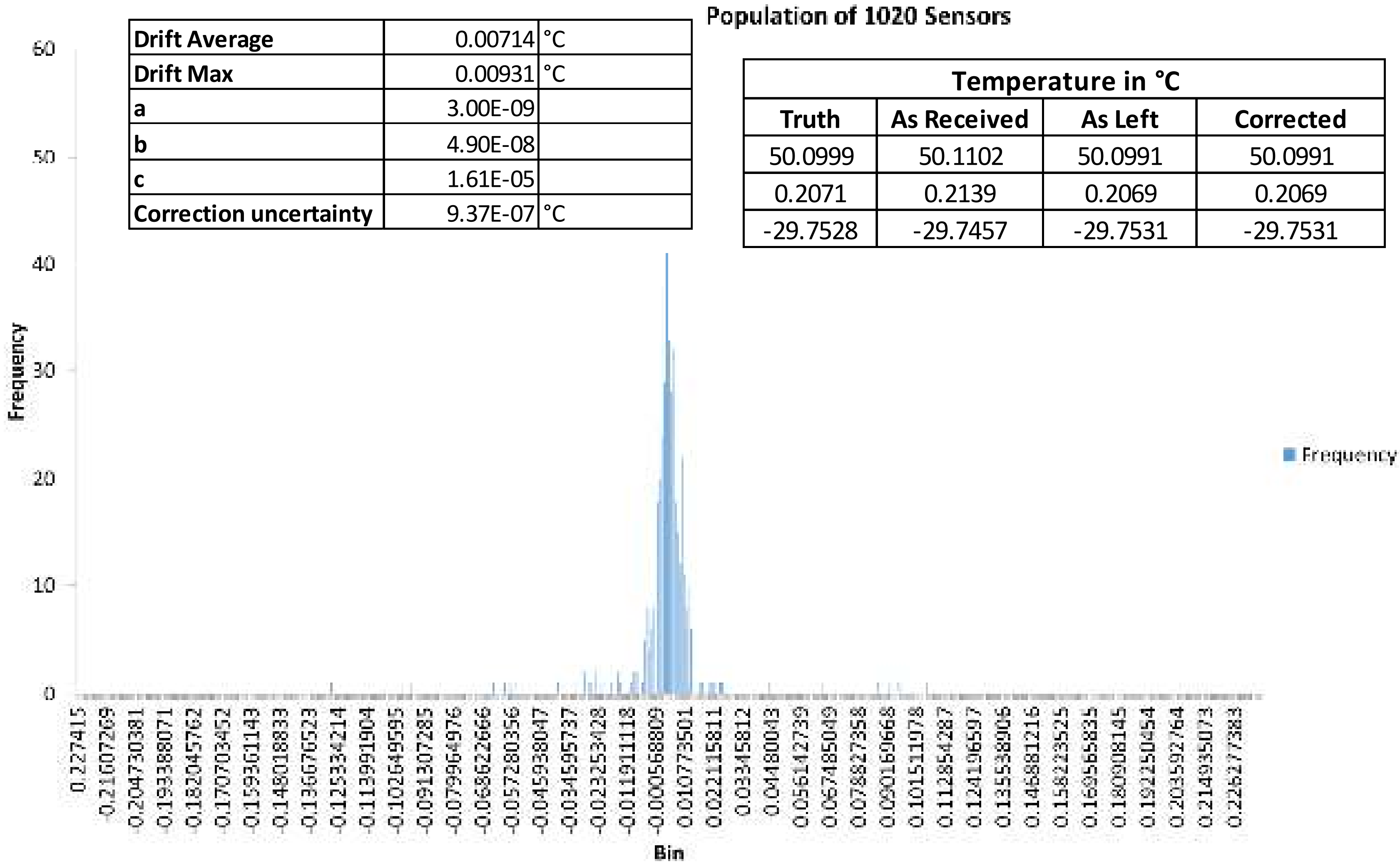
Temperature Measurement
Example Uncertainty Estimates

All Uncertainties given in °C		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	SPRT Calibration	A	29	3.1E-04
Drift	SPRT Drift	B	100	9.8E-04
Trueness	Calibration Trueness	A	60	1.1E-03
DAS	(2x) CVAL NI DMM ED4305 PXI-4071	B	100	1.4E-05
Mux Box	(2x) Testing with 115 ohm resistor	A	32	9.1E-05
Reproducibilty	Calibration Roproducibility	A	11	3.4E-03
Combined Calibration	Calibration Combined Uncertainty	eff	14	0.0037
Repeatability	30 minute Standard Error	A	1800	5.8E-03
Field DAS	Field DAS Uncertainty	A	139	6.1E-02
Combined Measurement	30-min Averaged Combined Uncertainty	eff	141	0.062
Expanded Measurement	30-min Averaged Expanded Uncertainty	k	1.98	0.12

Temperature Measurement
Example Drift Estimates

Drift Average	0.00714	°C
Drift Max	0.00931	°C
a	3.00E-09	
b	4.90E-08	
c	1.61E-05	
Correction uncertainty	9.37E-07	°C

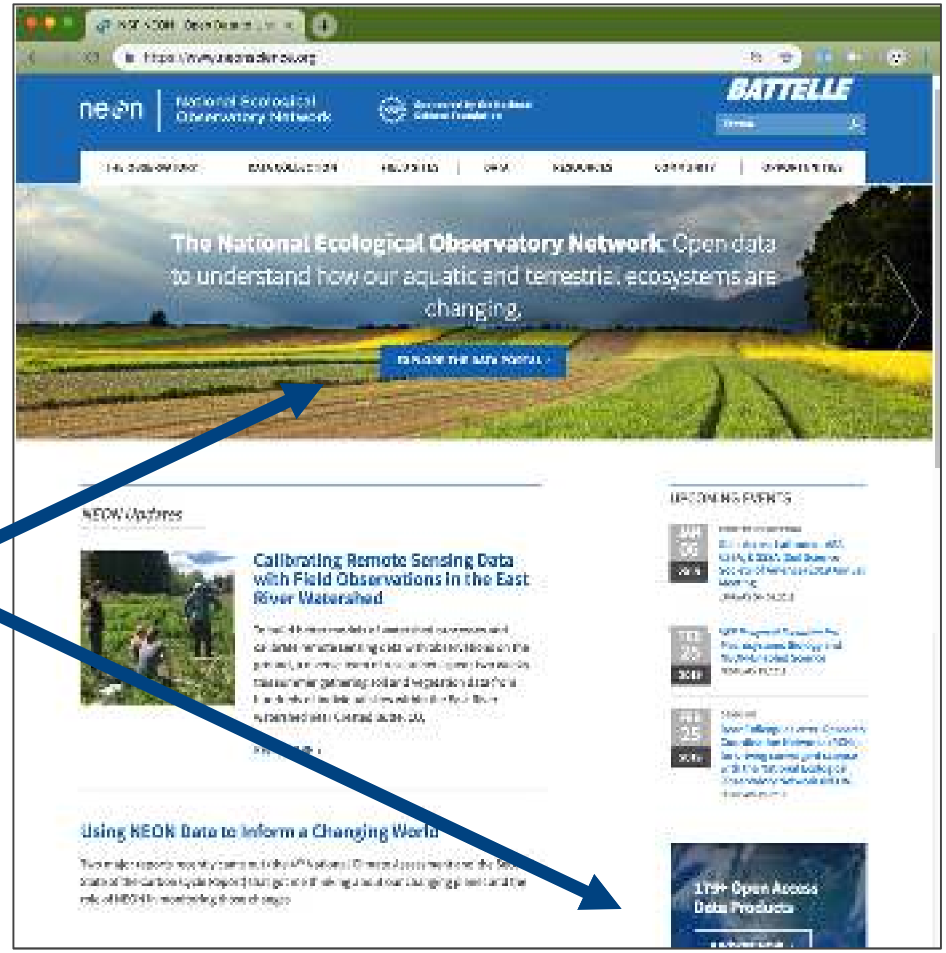
Temperature in °C			
Truth	**As Received**	**As Left**	**Corrected**
50.0999	50.1102	50.0991	50.0991
0.2071	0.2139	0.2069	0.2069
-29.7528	-29.7457	-29.7531	-29.7531



Using NEON

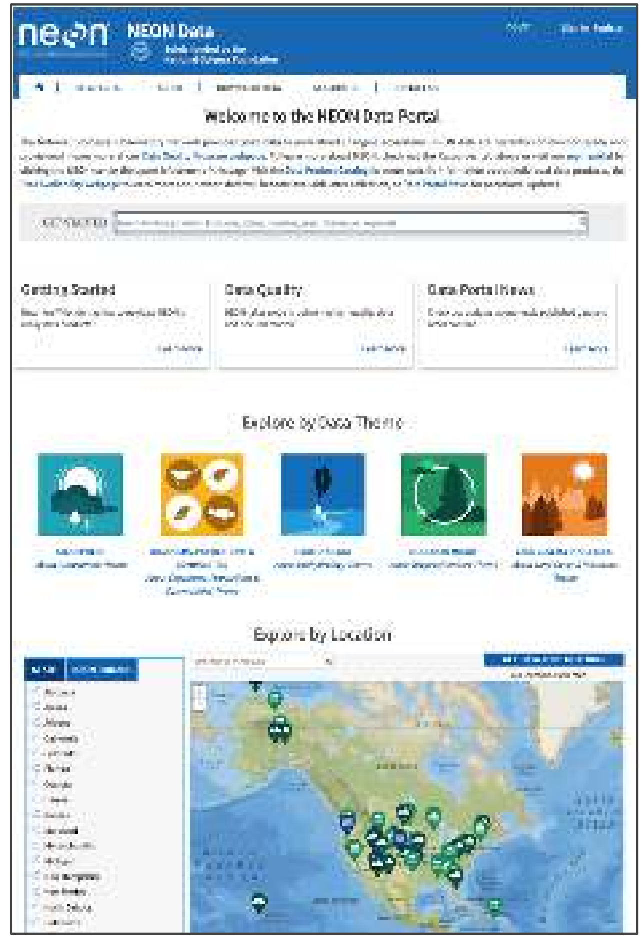
NEONScience.org

- Overview of data collection
- Field site maps
- Information for researchers
- Using NEON Infrastructure
- Access to the NEON Data Portal



Data.neonscience.org

- Explore and download data
- Information on programmatic access to NEON data
  - API
  - Code packages
- Access data product user guides, detailed protocols, and other important documents
- News on product updates and versions

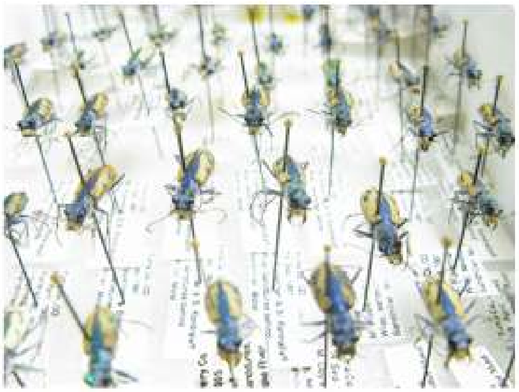


Using NEON infrastructure for research

The Assignable Assets Program: A formal request process to:

1) Request an airborne remote sensing survey
2) use a Mobile Deployment Platform (MDP)
3) add instruments to towers and other site infrastructure
4) access field sites for observational sampling purposes

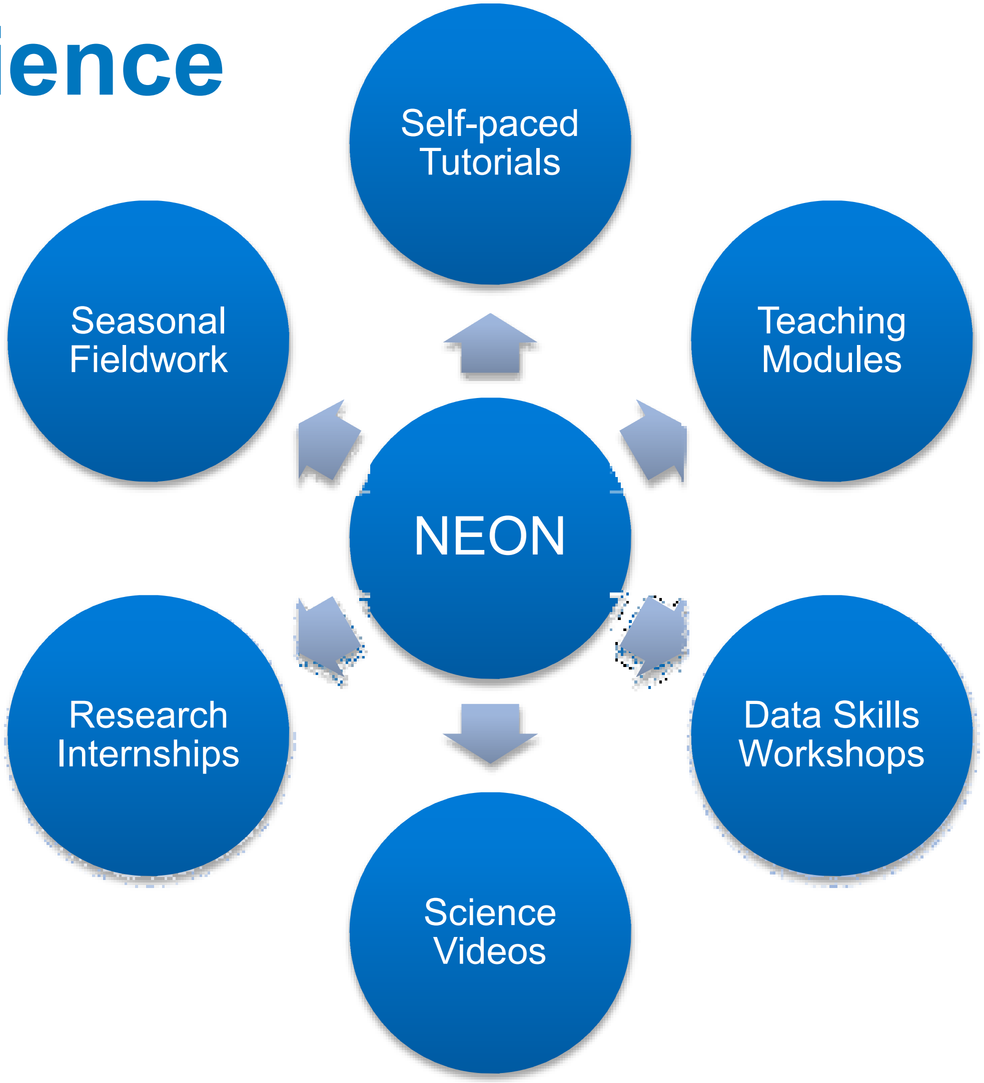
NEON Biorepository



- Small mammals*
- Fish*
- Ground beetles* & bycatch
- Mosquitos*
- Ticks*
- Zooplankton
- Benthic macroinvertebrates*
- Vascular plants, algae, bryophytes and lichens
- Soil microbes*
- Soil
- Dust
- Wet deposition

*including genomic extracts

Learn & Experience



Operated by Battelle

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