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A Technical Overview of the North Carolina ECONet

Sheila M. Saia^a, Sean P. Heuser^a, Myleigh D. Neill^a, William A. LaForce IV^a,
John A. McGuire^a, Kathie D. Dello^a

^a *State Climate Office of North Carolina, North Carolina State University, Raleigh, NC, USA*

Corresponding author: Sheila M. Saia, ssaia@ncsu.edu

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ABSTRACT

Regional weather networks—also referred to as mesonets—are imperative for filling in the spatial and temporal data gaps between nationally supported weather stations. The North Carolina Environment and Climate Observing Network (ECONet) fills this regional role; it is a mesoscale network of 44 (as of 2022) high-frequency, automated weather stations across North Carolina. This paper provides a technical overview of ECONet, including a description of the siting criteria, station maintenance procedures, data quality control procedures, and data availability. We also summarize unique aspects of ECONet data collection as well as innovative research and applications that rely on ECONet data. Each ECONet station consists of research-grade sensors measuring 15 environment and weather variables every minute. Measured variables include air temperature, precipitation, relative humidity, barometric pressure, wind speed, wind direction, total solar radiation, photosynthetically active radiation, soil temperature, soil moisture, leaf wetness index, and black globe temperature. All data undergo quality control procedures and are made freely available to the public via data portals hosted by the State Climate Office of North Carolina at North Carolina State University. ECONet data are used by many sectors including, but not limited to, emergency management, natural resources management, public health, agriculture, forestry, science education, outdoor recreation, and research. ECONet data and data-powered applications offer valuable insights to local, regional, and federal partners yet opportunities to expand ECONet research and applications remain.

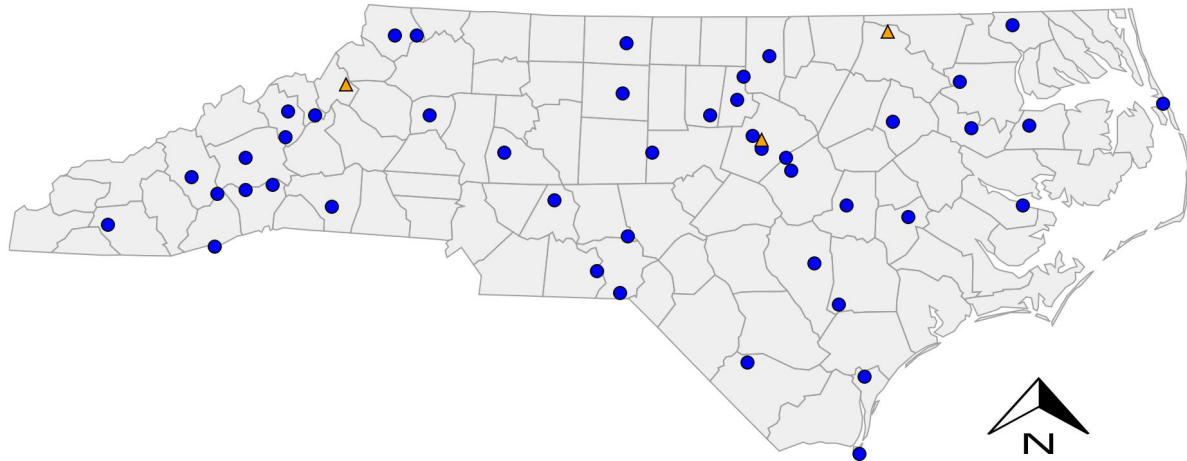
SIGNIFICANCE STATEMENT

We wrote this paper to explain the ongoing and emerging impacts of a state-wide weather station network called the North Carolina Environment and Climate Observing Network (ECONet). ECONet is made up of 44 (as of 2022) high-frequency, automated weather stations located across North Carolina. Each station collects 15 environment and weather variables every minute. ECONet data and data-powered applications offer valuable insights to local, regional, and federal partners. There are many opportunities to expand ECONet-based research and applications.

38 **1. Introduction and Historical Context**

39 The State Climate Office of North Carolina (SCO) at North Carolina State University
40 (NCSU) operates and maintains 44 (as of 2022) high frequency, automated weather and
41 environmental sensing stations across North Carolina (Fig. 1). Specifically, observations are
42 recorded at one minute intervals and sent to SCO computer servers every five minutes via
43 cellular communication where they are stored for downstream use. The mission of this mesonet,
44 called the North Carolina Environment and Climate Observing Network (ECONet), is to serve
45 the data, research, and application needs of North Carolinians for a wide range of sectors;
46 including but not limited to, agriculture, forestry, public health, emergency management, natural
47 resource management, outdoor recreation, science education, and research. Additionally, the
48 SCO works with regional partners to advise the maintenance of three (as of 2022) ECONet
49 Extended (ECOExt) stations (Fig. 1). These stations do not have all the sensors and equipment of
50 a standard ECONet station but complement ECONet. Most importantly, ECOExt stations
51 provide publicly accessible data to regional partners and North Carolina communities. The goal
52 of this technical overview is to provide researchers as well as other local, regional, and federal
53 partners a detailed description of ECONet, including: standard siting criteria and station layout,
54 station maintenance procedures, data quality control procedures, data availability, and a
55 discussion of existing and emerging ECONet data-driven applications. Furthermore, this work
56 summarizes unique aspects of data collection, processing, and applications that set ECONet apart
57 from other regional mesonets and also contributes to a growing number of publications
58 demonstrating the important impact of state-lead mesonets on weather and environmental
59 monitoring, research, and applications (Brock et al. 1995; McPherson et al. 2007; Brotzge et al.
60 2020; Patrignani et al. 2020).

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63 **Fig. 1.** Map of North Carolina Environment and Climate Observing Network (ECONet)
64 stations. Standard ECONet stations are shown as blue circles and non-standard ECONet
65 Extended (ECOExt) stations are shown as orange triangles.

66

67 The development of the ECONet spans three major periods: (1) an initial focus on
68 agricultural research and applications in the late 1970s to late 1990s, (2) a new chapter in
69 ECONet research and applications in the late 1990s to mid 2010s that included agriculture but
70 began to expand to other important sectors, and (3) the mid 2010s to present day period that
71 focuses on providing high-resolution, high quality, publicly accessible weather and
72 environmental data for a wide range of research, applications, and users. The first ECONet
73 station was established in 1978 at the Central Crops Research Station in Clayton, North Carolina.
74 This station along with 13 others established on state and university research farms from 1978-
75 1987 were supported by the North Carolina Department of Agriculture and Consumer Services
76 (NCDA&CS) and NCSU). In these early days, the network was known as the Agricultural
77 Network (AgNet) and its user base consisted mainly of scientists conducting basic and applied
78 agricultural research such as developing cucumber harvest date models (Perry and Wehner
79 1990). From 1991 to 1996, the NCSU Department of Horticultural Sciences managed and
80 maintained AgNet with support from the NCSU Department of Horticultural Sciences' North
81 Carolina Agricultural Weather Program and NCDA&CS.

82 In 1997, the supervision of AgNet was transferred to the SCO and the network mission grew
83 beyond its initial focus on agriculture. Specifically, the SCO collaborated with state and local
84 agencies between 1997 and 2000 to establish weather stations that were relevant to emergency
85 management and air quality management; these weather stations were designated as members of
86 the Emergency Management Network (EMNet) and Department of Air Quality Network
87 (DAQNet), respectively. By 2000, all 20 weather stations under the SCO's purview were
88 updated from 3 m tripods to 10 m towers to meet World Meteorological Organization standards
89 (WMO 2011). In 2001, the various distinct networks (i.e., AgNet, EMNet, DAQNet) were
90 merged into the modern-day ECONet. Throughout the 2000s and 2010s, the number of ECONet
91 stations increased steadily with several stations being established at K-12 grade schools and for
92 fire weather management applications.

93 By 2007, ECONet stations had a standard set of sensors (see Sections 2 and 3), relied on a
94 common data standard for data storage and reporting, and collected measurements at 1-min
95 intervals. In 2012, the SCO was awarded a National Mesonet Program contract to support
96 ECONet station maintenance and data delivery moving forward. To date, all ECONet data are
97 freely available to the public through the SCO Cardinal data portal
98 (<https://products.climate.ncsu.edu/cardinal/>) and CLimate Office Unified Data System
99 (CLOUDS) application programming interface (<https://api.climate.ncsu.edu/>). ECONet data are
100 also available to the National Weather Service (NWS) and other federal agencies through the
101 Meteorological Observational Database and Data Delivery System (MADIS;
102 <https://madis.noaa.gov/>) and on the Weather Information Management System (WIMS)
103 maintained by the National Wildfire Coordinating Group. While ECONet stations were
104 originally established for and supported by the agricultural sector, ECONet data currently
105 supports research and applications in a wide range of sectors across North Carolina from
106 agriculture, to weather forecasting, forestry and forest fire management, emergency
107 management, air quality, science education, public health, and much more.

108 **2. Network Spatial Configuration, Station Siting, and Station Layout**

109 *2.1. Network Spatial Configuration*

110 ECONet spatial configuration strategies have shifted over time as local, state, and federal
111 partners' needs and the mission of the network have changed. While non-uniform, the initial
112 distribution of ECONet stations emphasized agricultural centers of the state, which are mainly
113 located in central and the eastern North Carolina. As the SCO began to partner with a wider
114 range of sectors (e.g., air quality management, emergency management, K-12 schools), the
115 distribution of ECONet stations prioritized the needs of the partner as well as areas that lacked
116 established automated weather stations. Starting in the 2000s, the SCO set an internal standard
117 that required new station locations to be at least 20 km away for another nearby automated
118 weather station, where applicable (Fujita 1962). This initially prioritized ECONet to expand into
119 and represent heterogeneous land use areas of central and western North Carolina and balances
120 the representation of diverse land uses and data applications with station coverage across the
121 state. Currently, SCO uses geographic information systems to determine potential areas of
122 interest that are 20 km or more from a current automated weather station. These potential areas
123 are then ranked by distance and targeted as tentative areas for new ECONet stations. However,
124 ECONet staff (henceforth, we) determine the final location of these stations based on stakeholder
125 interest and engagement, funding availability, and whether there is a location that maximizes
126 standard siting criteria as discussed in Section 2.2.

127 *2.2. Station Siting Requirements*

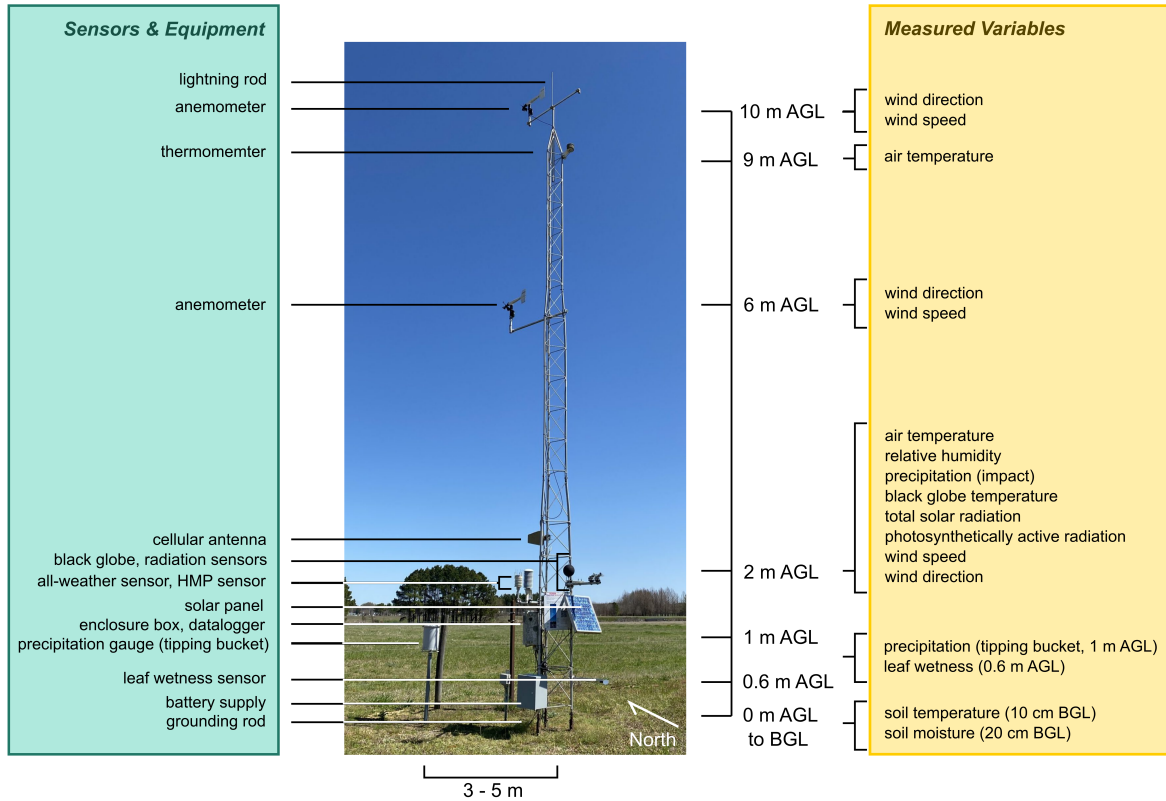
128 Upon selection of a general area for the placement of a new station, we follow World
129 Meteorological Organization (WMO 2011, 2018), United States Environmental Protection
130 Agency (USEPA 1987, 2000), American Association of State Climatologists (AASC; Bingham
131 et al. 1985), and American Society for Civil Engineers (ASCE, Ley 1993; Brown 1993)
132 guidelines combined with manufacture guidelines (e.g., Campbell Scientific 2022) as closely as
133 possible to ensure data accuracy and proper representation of the surrounding area (Section 2.4).
134 In the event that a proposed station location does not meet all WMO guidelines, we work directly
135 with station partner(s) to locate the most suitable location with the fewest limitations. There are
136 three key factors that we consider when determining the location for a new station. The first
137 factor is the distance from existing ECONet stations. To fill gaps in the network, new stations are
138 ideally placed 20 km or more away from existing stations. The second factor is distance from
139 obstructions (i.e., trees, buildings). Ideally, stations are located away from any obstructions at a

140 distance of 10 times the height of the obstruction (WMO 2011). The third factor is landscape
141 slope. Siting a station in an area with minimal slope ensures the station accurately represents the
142 surrounding area and can be more easily lowered into a horizontal position for maintenance.

143 *2.3. Station Layout*

144 The standard layout of an ECONet station is depicted in Fig. 2. Each ECONet station is
145 located on a plot of land roughly 10 m by 7 m following the WMO preferred guidelines (WMO
146 2011). Every station consists of a 10 m aluminum tower (9-30, Universal Towers) set in a 1.2 m
147 length by 1.2 m width by 1.2 m depth concrete base. In locations that experience high wind
148 gusts, the size and depth of the concrete base is larger and the tower is further stabilized by three
149 galvanized steel guy wires extending 6 m out from each of the three legs of the tower. Each
150 station also includes a 45.7 cm long by 40.6 cm wide by 22.9 cm deep weather-resistant,
151 fiberglass-reinforced, polyester enclosure box (ENC16/18, Campbell Scientific), which houses
152 the datalogger and other sensitive components. Additionally, each station includes a
153 communications antenna, a power supply (Section 3.1), and a suite of environmental sensors that
154 are both surrounding and attached to the tower.

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157 **Fig. 2.** Image displaying the standard layout of an ECONet station, including: sensors,
 158 equipment, and measured variables. The tower pictured is the Goldsboro, North Carolina
 159 (GOLD) ECONet station in March 2022.

160

161 The suite of environmental sensors located on the tower are as follows. We mount a leaf
 162 wetness sensor to one end of a 1 m long section of aluminum corner trim and attach it
 163 horizontally to the tower at a height of 0.6 m above ground level with the sensor facing due
 164 north. The 90° angle property of the aluminum corner trim boom facilitates the mounting of the
 165 leaf wetness sensor at a 45° angle. At a height of 2 m above ground level, we mount a variety of
 166 sensors on booms extending roughly 0.6 m from the tower. These include an all-weather sensor,
 167 an air temperature and relative humidity sensor housed in a radiation shield, and a pair of
 168 radiation sensors measuring solar radiation and photosynthetically active radiation. The all-
 169 weather sensor measures air temperature, relative humidity, precipitation (i.e., impact sensor),
 170 barometric pressure, wind speed and wind direction. Therefore, all ECONet stations have some

171 redundancy in temperature, precipitation, and relative humidity observations at 2 m above
172 ground level. We measure black globe temperature, which can be used to measure heat risk and
173 danger, at 2 m above ground level by mounting it on a 0.3 m boom that is perpendicular to one of
174 the 0.6 m booms. We position the black globe thermometer so it is not shadowed by or does not
175 cast a shadow on other sensors; shadows will interfere with measurements. We mount propeller-
176 based anemometers at the end of 0.9 m long booms to measure wind speed and direction at 6 m
177 and 10 m. In addition to measuring air temperature at 2 m above ground level, each ECONet
178 station has a radiation shield that we mount just off the tower at a height of 9 m. This radiation
179 shield houses a sensor to measure air temperature higher up in the tower profile. To limit damage
180 to the tower and the many sensitive components in the event of a lightning strike, a lightning rod
181 sits atop the tower connected to a grounding rod that we bury underground. See Section 3.3 for a
182 full description of sensors on the tower.

183 Surrounding the tower, we measure soil temperature and soil moisture below natural
184 vegetation at depths of 10 cm and 20 cm, respectively, and at a distance of 2 to 3 m away from
185 the tower with cables that are buried along a 10 cm deep trench. We place soil moisture and
186 temperature sensors near, but not directly under, the tipping bucket precipitation gauge to best
187 account for the response of these measurements to precipitation. We install the primary
188 precipitation measurement, an unheated tipping bucket rain gauge, at a distance of 3 to 5 m from
189 the tower at a height where the rim of the funnel orifice is 1 m above ground level. See Section
190 3.3 for a full description of sensors surrounding the tower.

191 **3. Sensors, Equipment, and Data**

192 The foundation of ECONet station data collection starts with each individual sensor
193 measuring a particular weather or environmental variable (e.g., wind speed, Fig. S1a). Once
194 these observations are collected by the sensor, these data are aggregated and saved on the tower
195 datalogger (Fig. S1b) before being transmitted offsite (Fig. S1c). Once transmitted offsite,
196 ECONet data are received and managed by SCO and NCSU Office of Information Technologies
197 staff via a combination of Windows and Linux computer servers (Fig. S1d), and ultimately,
198 made publicly available through several SCO data portals (Fig. S1e). In Sections 3.1 to 3.4, we
199 discuss key sensing and equipment components for standard ECONet stations, including: sensors

200 (Section 3.1), data acquisition, sampling, and power (Section 3.2), communications (Section
201 3.3), and data storage and sharing (Section 3.4).

202 *3.1. Sensors*

203 Each ECONet station has 12 categories of sensors (Table 1). Several of these categories use
204 multiple approaches to measure particular variables (e.g., tipping bucket versus impact sensor
205 precipitation observations) and are located at various elevations along the tower profile (Fig. 2).
206 As a result, there are a total of 18 uniquely measured variables per ECONet station and each
207 measured variable (Fig. S1a). We install and maintain all sensors according to manufacturer
208 sensor specifications (Table 1), this includes but is not limited to the measurement elevation,
209 installation preparations, and the sensor replacement frequency. For example, we replace soil
210 temperature sensors every two years according to the manufacturer recommendations (Table 1).
211 All measured variables undergo quality control checks, which we describe generally in Table 1
212 and in full detail in Section 5. As of 2022, ECONet is the only regional mesonet to be fully-
213 instrumented with black globe thermometers at 2 m. These data power an innovative current
214 conditions wet bulb globe temperature tool that visualizes hourly heat risk across the state
215 (Section 6.1.2).

216 **Table 1.** Summary of standard ECONet sensors, corresponding manufacturer information, quality control checks performed, and
 217 replacement and calibration frequency. See Section 5 for specific quality control (QC) checks performed for each sensor.
 218 Abbreviations: above ground level (AGL), below ground level (BGL), pressure, temperature and humidity (PTU), air temperature
 219 (Ta), relative humidity (RH), range check (R), buddy check (B), intersensor check (I), trend check (Z).

Measured Variable	Height	Sensor Manufacturer and Code	Sensor Range	Sensor Accuracy	QC Checks Performed	Manufacturer Reference	Replacement/Calibration Frequency
Air temperature	2 m, 9 m AGL	Vaisala WXT-536 at 2 m	-52 C to +60 C	± 0.3 C at +20 C	R, B, Z	Vaisala WXT, 2022	PTU module replaced every 2 years
		Vaisala HMP155 at 2 m	-80 C to +60 C	$\pm(0.226 - 0.0028 * Ta)$ C from -80 o to +20 C; $\pm(0.055 + 0.0057 * Ta)$ C from +20 to +60 C	R, B, Z	Vaisala HMP, 2021	Replaced with either a factory recalibrated or new sensor every 2 years
		Campbell Scientific (CS) 109 Temperature Probe at 9 m	-50 C to +70 C	± 0.1 C from 0 C to +70 C increasing to ± 0.5 C at -50 C	R, B, Z	Campbell Scientific 109, 2022	Replaced every 2 years
Barometric pressure	2 m AGL	Vaisala WXT-536	500-1100 hPa	± 0.5 hPa from 0 C to +30 C; ± 1 hPa from -52 C to +60 C	R, B, Z	Vaisala WXT, 2022	PTU module replaced every 2 years
Black globe temperature	2 m AGL	Campbell Scientific BlackGlobe-L	-5 C to +95 C	$< \pm 0.2$ C from 0 C to +70 C, and ± 0.3 at +95 C	R, Z	Campbell Scientific BG 2022	Replaced every 5 years
Leaf wetness index	0.6 m AGL	METER Group PHYTOS 31	250 -1,250 mV	+/- 10 mV	R	METER PHYTOS, 2022	Replaced every 2 years
Photosynthetically active radiation	2 m AGL	Apogee Instruments SQ-100X-SS	0-2500 $\mu\text{mol m}^{-2} \text{s}^{-1}$	$\pm 5\%$	R, I, Z	Apogee SQ, 2022	Replaced with either a factory recalibrated or new sensor every 2 years)

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Precipitation (tipping bucket, liquid)	1 m AGL	HyQuest Solutions TB3	0-700 mm h ⁻¹	±2% from 0-250 mm h ⁻¹ and ±3% from 250-500 mm h ⁻¹	R, I, Z	HyQuest TB3, 2022	Calibration checked once per year, Recalibrated as needed
Precipitation (impact, liquid)	2 m AGL	Vaisala WXT-536	0-200 mm h ⁻¹	±5% for daily accumulation (weather dependent)	R, I, Z	Vaisala WXT, 2022	Replace the whole unit as needed
Relative humidity	2 m AGL	Vaisala WXT-536	0-100%	±3% RH from 0 to 90% RH and ±5% from 90 to 100% RH	R, B, Z	Vaisala WXT, 2022	PTU module replaced every 2 years,
		Vaisala HMP155	0-100%	±(1.2 + 0.012 * reading)% RH from -40 C to -20 C; ±(1.0 + 0.008 * reading)% RH from -20 C to +40 C; ±(1.2 + 0.012 * reading)% RH from +40 C to +60 C	R, B, Z	Vaisala HMP, 2021	Replaced with either a factory recalibrated or new sensor every 2 years
Soil moisture	20 cm BGL	Delta-T ML3	0-1.0 m ³ m ⁻³	±0.01 m ³ m ⁻³ from 0 to 0.5 m ³ m ⁻³ range with soil specific calibration	R, B, Z	Delta-T ML3, 2022	Replaced every 5 years
Soil temperature	10 cm BGL	Campbell Scientific 109 Temperature Probe	-50 C to +70 C	±0.1 C from 0 C to +70 C and increasing to ±0.5 C at -50 C	R, B, Z	Campbell Scientific 109, 2022	Replaced every 2 years
Total solar radiation	2 m AGL	Apogee Instruments SP-510-SS	0 - 2000 Wm ⁻²	±5% for daily total irradiance	R, I, Z	Apogee SP, 2022	Replaced with either a factory recalibrated or new sensor every 2 years)
Wind direction	2 m, 6 m, 10 m AGL	R.M. Young 05103	0°-360°	±3°	R	R.M. Young 2022	Whole unit replaced every 10 years
Wind speed	2 m, 6 m, 10 m AGL	R.M. Young 05103	0-100 ms ⁻¹	±0.3 ms ⁻¹ or 1% of reading	R, B, I, Z	R.M. Young 2022	Propeller shaft bearings replaced every 2 years, Whole unit replaced every 10 years

221 3.2. *Data Acquisition, Sampling, and Power*

222 Each ECONet station is equipped with an electronic datalogger (Fig. S1b), typically a
223 Campbell Scientific CR1000, or in some rare cases, a Campbell Scientific CR1000X or CR3000.
224 The datalogger is placed within a weather resistant enclosure box and serves to collect and store
225 all observations from all sensors on an ECONet tower before these data are transmitted off-site
226 via various data communication methods (see Section 3.3). Observations are stored locally on
227 the datalogger as a data table within the device's dedicated random-access memory. In terms of
228 the frequency of recorded observations for a given sensor—often referred to as data sampling—we
229 set the datalogger to record wind speed, wind direction, and precipitation at 5-second intervals.
230 We average wind speed and wind direction over a 1-minute period. We record wind gusts as the
231 maximum 5-second wind speed value sampled over a 1-minute period and record precipitation as
232 the total sum of precipitation observed over a 1-minute period. We record all other measured
233 variables once per minute (i.e., instantaneously).

234 Of the 44 ECONet stations (as of 2022), 31 are powered via solar power, and the remaining
235 13 are powered via alternating current (AC) power. For solar powered stations, a 20 W solar
236 panel provides power to the datalogger and charges a 12 V deep cycle marine battery via a
237 charging regulator (CH150, Campbell Scientific). Overnight, the station runs off battery power
238 from the 12 V deep cycle marine battery. For AC powered stations, electricity is provided via an
239 underground power line running to a power box near the ECONet tower. The power box
240 typically contains a surge protector and an AC-DC converter. The electricity is then run via
241 another underground cable from the nearby power box to the charging regulator within the
242 station enclosure box attached to the tower. The charging regulator funnels electricity to the
243 datalogger and a 12 V 7 Ah backup battery, the latter of, which can power the station for a
244 limited amount of time in the event of an AC power outage.

245 3.3. *Communications*

246 ECONet stations communicate data back to the SCO every five minutes using various
247 communication methods (Fig. S1c). The most common method of data communication method
248 that we use is a cellular modem connection. As of 2022, 36 stations communicate via Sierra
249 Wireless RV50 cellular modems, and three stations communicate via Campbell Scientific

250 CELL210 cellular modems. Alternative methods of communication include RF Radio and IP
251 (two stations), WiFi (two stations), and landline telephone (one station). We rely on using these
252 alternative communication methods when the cellular communications signal is weak or the
253 alternative method is more economical than cellular communications.

254 *3.4. Data Storage and Sharing*

255 As described in Sections 3.2 and 3.3, all ECONet observations are stored locally as a data
256 table within the random-access memory of the datalogger until they can be transmitted back to
257 the SCO at five minutes intervals. Specifically, ECONet observations are initially stored in data
258 tables using Loggernet software (Campbell Scientific) installed on one of two Windows
259 machines (Fig. 3d). One of the Windows machines is a desktop computer located in the SCO,
260 which receives communications from landline-based ECONet stations. The other Windows
261 machine is a virtual machine hosted by the NCSU Office of Information Technologies, which
262 receives communications from the remaining ECONet stations. Once stored in Loggernet
263 software-formatted data tables using standard manufacturer methods (Campbell Scientific 2020),
264 we have a custom, timed shell script that moves ECONet data from Loggernet into a series of
265 SCO-managed, Linux-based databases every five minutes (Fig. S1d). The multiple database
266 structure minimizes data access latency issues and provides redundancy by backing up data. In
267 addition to custom, timed shell scripts that run every five minutes, we have a series of ECONet
268 data ingest scripts that are scheduled to run in the early morning each day for the purpose
269 completing automatic quality control checks of ECONet data (Section 5.1) and generating
270 summary quality control score emails (Section 5.2). See Section 5 for a full description of data
271 quality control processes.

272 Once ingested into the Linux-database and quality controlled, ECONet data are freely
273 available to the public (Fig. 3e) via the SCO Cardinal data portal and Station Scout tool
274 (<https://products.climate.ncsu.edu/cardinal/>), CLimate Office Unified Data System (CLOUDS)
275 application program interface (API, <https://api.climate.ncsu.edu/>), and Station Scout allows users
276 to explore ECONet data availability as well as the availability of a number of other publicly
277 accessible weather station network data for North Carolina. Once a user has a handle on which
278 stations, measured variables, data frequency, and data duration that they would like to obtain,
279 they can create a free SCO data access account and use Cardinal to build and submit a data

280 request. For users who are more familiar with programmatically requesting data using a
281 computer programming language, they can create a free SCO data access account and use the
282 CLOUDS API to build and submit a data request. Notably, ECONet data are one of several local,
283 state, and national weather networks included in the SCO Cardinal data portal, Station Scout
284 tool, and CLOUDS API; therefore, users of these tools benefit from the aggregation of these
285 weather data. ECONet data are also available to the National Weather Service (NWS) and other
286 federal agencies through the Meteorological Observational Database and Data Delivery System
287 (MADIS; <https://madis.noaa.gov/>) and on the Weather Information Management System
288 (WIMS) maintained by the National Wildfire Coordinating Group.

289 **4. Station Maintenance**

290 We perform routine and emergency maintenance periodically throughout the calendar year to
291 ensure ECONet stations are functioning as expected. Routine maintenance occurs three times a
292 year while emergency maintenance is done all year round provided there is safe access to the
293 station of concern. Specifically, a number of ECONet stations are located along the southern
294 extent of the Appalachian Mountains; therefore, these high elevation stations are subject to heavy
295 ice and snowfall. Oftentimes during the winter months, roads are inaccessible or closed
296 completely making emergency maintenance difficult, if not impossible.

297 Routine maintenance takes places during three seasons: spring, summer and fall. Spring
298 maintenance runs are often the busiest and consist of either replacing or rotating in newly
299 calibrated leaf wetness sensors, radiation sensors, HMP-155 sensors which measure both
300 temperature and relative humidity, and the barometric pressure, temperature, and relative
301 humidity (PTU) modules in the Vaisala WXT-536. Summer maintenance runs consist of
302 calibrating the rain gauges using a field calibration device (FCD-314 or FCD-653, HyQuest
303 Solutions) and checking the integrity of or replacing the soil moisture and temperature sensors.
304 During fall maintenance runs, we lower towers into a horizontal position via a hinge mechanism
305 at the base. This allows us to access and replace propeller shaft bearings in the anemometers at 6
306 m and 10 m as well as the 9 m air temperature sensor.

307 Emergency maintenance consists of restoring a station to its fully-functioning state, or in rare
308 cases, restoring as much functionality as possible until a longer-term solution can be
309 implemented. Typical emergency maintenance station visits include replacing dead or failing

310 batteries, replacing damaged or malfunctioning sensors, and investigating power or
311 communication issues. While rarer, emergency maintenance may also involve repairing or
312 replacing equipment after it has been vandalized. To help save time and resources, we may
313 complete routine maintenance during an emergency maintenance visit when the timing coincides
314 closely with regularly scheduled maintenance.

315 Before heading out into the field for routine or emergency maintenance, we create an
316 itinerary outlining the tasks to be completed along with a generalized time schedule. We will
317 bring this itinerary along with the station notebook to each station visit. Every ECONet station
318 has a dedicated field notebook, which contains a detailed log of past visits and metadata along
319 with station-specific wiring diagrams and other relevant station notes and directions. Upon
320 arrival at a station, we perform a quick visual and audible inspection of the site, examining for
321 any signs of potential damage. During the inspection, audible clues give us insights into the
322 overall operations of the tower. For example, absence of a faint chirping noise, particularly from
323 the Vaisala WXT-536, indicates either a loss of power to the station or the sensor itself. Dull
324 grinding noises from above likely means the bearings in the anemometers need to be replaced.
325 After identifying any potential problems, we will fix any issues and make note of these repairs in
326 the station notebook. We then conduct routine or emergency maintenance according to SCO
327 standard operating procedures as well as checking and performing other maintenance tasks as
328 needed during each visit. These include: (1) clearing vegetation that is obstructing sensor
329 operation (i.e., weeding, mowing the grass), (2) wiping off equipment and sensors such as the
330 solar panel, black globe thermometer, and other sensors that have built up dust, grime, and
331 pollen, (3) removing pests including ant hills and wasps nests, and (4) removing any debris
332 clogging or inhibiting proper tipping bucket precipitation gauge operation.

333 Before leaving an ECONet station site, we will verify data quality and ensure data
334 communications are flowing uninterrupted back to the SCO computer servers. We will also take
335 metadata photos of the station surroundings in all eight cardinal and intercardinal directions as
336 well as a profile photo of the full station. Upon returning to the office, we upload these photos to
337 the ECONet website, which enables us to keep a visual, spatial and temporal record of station
338 surroundings.

339 **5. Data Quality Control**

340 ECONet observations are continuously monitored using automated (Section 5.1) and manual
341 (Section 5.2) quality control checks to ensure these publicly available data are high quality. All
342 observations from ECONet are stored in a database with an associated flag column that includes
343 the automated and manual quality control flags for a given observation. While we may append
344 additional labels to manual quality control flags denoting instances of erroneous data, we never
345 change ECONet observations. Therefore, users must take care to view and use the quality control
346 flags that are available along with ECONet observations obtained from the Cardinal and Scout
347 data portals and the CLOUDS API (Section 3.4). A custom, internal software interface (see
348 Section 5.2) helps SCO staff determine the quality of ECONet observations and assign manual
349 quality control flags, as needed.

350 *5.1. Automated Quality Control*

351 Raw (i.e., pre-quality controlled) ECONet observations are stored in a database every five
352 minutes (Section 3.4) and timed scripts run a series of four automated quality control checks run
353 every 30 minutes to ensure ECONet data is high quality. These four quality control checks
354 include: (1) range check, (2) buddy check, (3) intersensor check, and (4) trend check. We
355 describe each of these automated quality control checks in further detail below.

356 The first automated quality control check is a range check, which runs in two phases: static
357 and dynamic. Every ECONet observation undergoes the static phase range check and the purpose
358 of this check is to determine whether an observation value is within the physical bounds of the
359 sensor. For example, any temperature observation reported from the Vaisala WXT-536 that is
360 below $-52\text{ }^{\circ}\text{C}$ or above $60\text{ }^{\circ}\text{C}$ (Table 1) will automatically fail the static phase range check and
361 not undergo any additional quality control checks. Similar to air temperature values, relative
362 humidity values below 0% or above 100%, wind speed values greater than 100 ms^{-1} , negative
363 precipitation values, and negative radiation values will all fail the static phase range check and
364 not undergo any additional quality control processing. If observations pass the static phase range
365 check, then the dynamic phase range check. The purpose of the dynamic phase range check is to
366 determine whether observation values fall within the North Carolina climatological range for the
367 given time of year. Observation values that fall outside either the static or dynamic range checks
368 are given a quality control flag associated with the level of failure ranging from R0 (pass) to R4
369 (highest level of failure).

370 Following the range check, the second automated quality control check is the buddy check.
371 The purpose of the buddy check is to ensure spatial consistency between data points. Not all
372 measured variables are subjected to the buddy check; see Table 1 for a complete list of measured
373 variables that undergo a buddy check. First, an interpolated value is assigned to the observation
374 using inverse distance weighting of nearest neighbors. The number of stations is limited to either
375 15 stations or all stations within a 50 km radius, whichever is fewer. If the interpolated value and
376 observed value are within a margin of error, the observation value passes the buddy check. We
377 assign a quality control flag to an observation based on how close the observed value is to the
378 interpolated value. Buddy check quality control flags range from B0 (pass) to B5 (highest level
379 of failure).

380 The third automated quality control check is the intersensor check, which applies to
381 redundant measured variables (e.g., air temperature at 2 m above ground level is measured by
382 two different sensors at each ECONet site, see Table 1). The purpose of the intersensor check is
383 to ensure that the redundant sensor measurements are reporting similar values. Based on the
384 difference between the redundant sensors, we assign an observation value an intersensor flag,
385 which has three possible values: I0 (pass), I2 (suspect), or I4 (failure).

386 The fourth automated quality control check is the trend check. Not all measured variables are
387 subjected to a trend check; see Table 1 for a complete list of measured variables that undergo a
388 trend check. The purpose of the trend check is to look for short-term asymmetries (e.g., spikes)
389 in ECONet observations over time. The trend check compares values from the previous hour for
390 a given observation and determines whether the observation is expected given values from the
391 previous hour. The trend check also identifies data that remains constant, or flatlines, for a
392 prolonged period of time. Identifying flatlining observations is useful when, for example, the
393 anemometer propeller freezes over during winter storms. Another example of when it is
394 beneficial to identify flatlining observations is when soil moisture sensors approach either field
395 capacity or wilting point. Trend check flags include either Z0 (pass), Z2 (suspect), or Z4
396 (failure).

397 All automated check flags are combined into one flag serial code (e.g., R0B0I0Z0; Table S2)
398 and saved in a column of the database. We then use this combined flag serial code to calculate an
399 automated quality control score. The quality control score ranges from -1 (i.e., value not quality

400 controlled) to 3 (i.e., value fails quality control). A quality control score of 0 indicates the
401 observation passed all automated quality control checks. We received an email summary of all
402 quality control scores at the start of each day to inform manual quality control processes (Section
403 5.2, Fig. 3). For a list of all quality control score definitions and quality control flag
404 combinations, see Tables S1 and S2, respectively.

405 *5.2. Manual Quality Control*

406 We do manual quality control each morning to first verify when one or more automated
407 quality control routines failed the day before and then append manual quality control labels to
408 automatic quality control flags. Specifically, we receive an email that details the quality control
409 score percentages for each ECONet station (Fig. 3). This allows us to quickly pinpoint ECONet
410 stations that have a potential sensor malfunction. Each station ID in the email is a URL
411 hyperlink. When we click on this URL hyperlink, we are directed to an internal quality control
412 software program called the ECONet Quality Control Data Viewer (QCDV; Fig. 4). The daily
413 email alert and corresponding QCDV were custom developed and implemented in PHP and
414 Javascript code by a member of our team (John McGuire) to: (1) simplify manual quality control
415 processes, (2) visualize temporal and spatial patterns in automated quality control checks, and (3)
416 minimize human-induced quality control errors. Within the QCDV, we can select an ECONet
417 station, measured variable, and time frame. Most importantly, we can visualize and append a
418 manual flag to the automatic quality control flags. QCDV will append a U0 (passed by human
419 check) or a U4 (failed by human check) to the front of all human-updated versions of the
420 automated quality control flags. Manual quality control is important to override automated
421 quality control checks for correct observations occurring during extreme weather conditions or
422 denoting incorrect observations made during routine maintenance (e.g., cleaning or calibration of
423 the rain gauge).

424

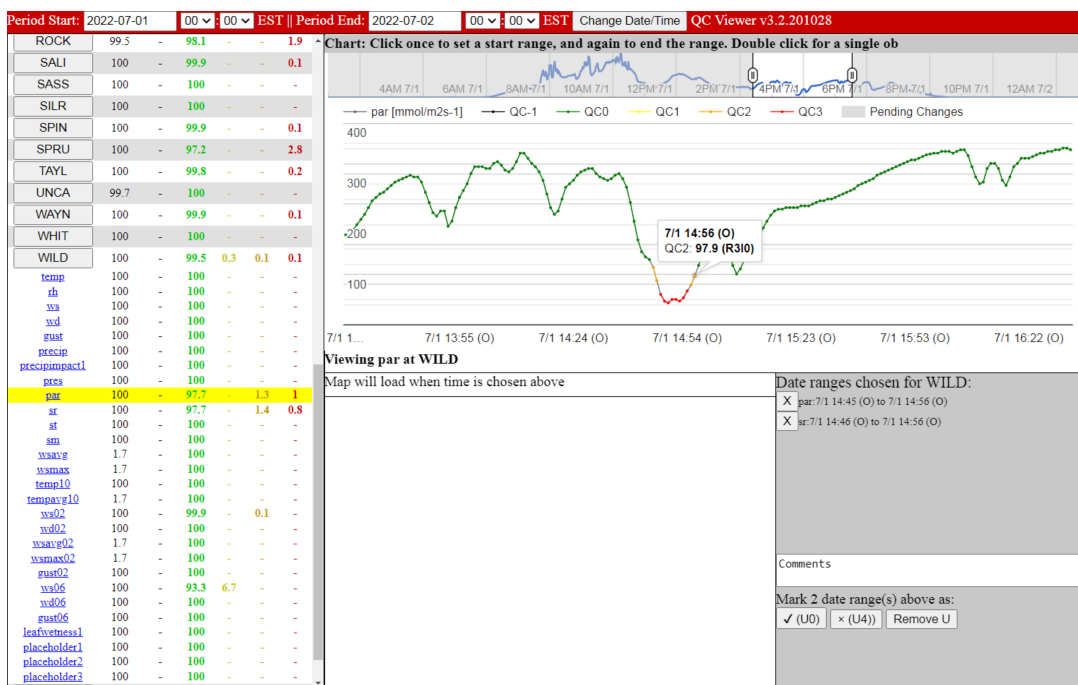
QC Status of all ECONet Stations:
From 2022-06-30 05:05:00 EST To 2022-07-01 05:05:00 EST

Station	Var	Count	QC-1	QC0	QC1	QC2	QC3	Last Ob
		%	?	✓	✓?	x?	x	
ROCK	ob	97	1.4%	96.2%	9#	92#	2.1%	2022-07-01 05:24:00
SPRU	ob	97	1.4%	97%	30#	62#	1.3%	2022-07-01 05:24:00
REID	ob	97	1.4%	97.8%	27#	106#	135#	2022-07-01 05:24:00
MITC	ob	96.7	1.4%	95.7%	2%	220#	92#	2022-07-01 05:20:00
NCAT	ob	97	1.4%	97.9%	10#	120#	89#	2022-07-01 05:24:00
BUCK	ob	97	1.4%	98%	59#	69#	80#	2022-07-01 05:24:00
SALI	ob	97	1.4%	98.2%	3#	62#	75#	2022-07-01 05:24:00
LILE	ob	97	1.4%	98.2%	8#	52#	61#	2022-07-01 05:24:00
OXFO	ob	97.1	1.5%	98.1%	7#	89#	60#	2022-07-01 05:25:00
DURH	ob	97	1.3%	98.1%	19#	86#	60#	2022-07-01 05:24:00
JEFF	ob	97	1.4%	97.2%	26#	1.2%	59#	2022-07-01 05:24:00
WAYN	ob	97	1.4%	96.6%	1.6%	63#	59#	2022-07-01 05:24:00
AURO	ob	97	1.4%	98.3%	2#	48#	54#	2022-07-01 05:24:00
BALD	ob	97	1.4%	98.1%	15#	67#	54#	2022-07-01 05:24:00
CLAY	ob	97	1.4%	98.1%	10#	101#	50#	2022-07-01 05:24:00

425

426 **Fig. 3.** Example of a daily quality control score table email from June 30, 2022 at 5:05 am
 427 EST. The table shows the automated quality control scores by station to guide subsequent
 428 manual quality control and potential station maintenance. Stations are ordered by their unique
 429 four-digit identifier in descending order based on the percentage of all sensor observations (ob)
 430 receiving a quality control score of three (QC3), which indicates a poor quality control score. A
 431 number followed by a “#” symbol indicates the number of total observations, when less than 1%
 432 of all observations failed automated quality control checks (Section 5.1).

433



434
 435 **Fig. 4.** ECONet Quality Control Data Viewer (QCDV) graphical user interface window
 436 showing photosynthetic active radiation (PAR) observations at the Williamsdale Field Lab
 437 ECONet station (WILD) in Wallace, North Carolina on July 1, 2022. Left panel shows results for
 438 all stations and each individual sensor and the right top panel shows the time series plot for the
 439 selected sensor measurement variable (e.g., PAR) with observations colored by quality control
 440 score. Right bottom panel shows a map, any manual quality control notes, and user flag indicator
 441 selection. User notes and user flags provide more context in manual quality control processing
 442 (Section 5.2). Orange or red points in the time series indicate observations that have a quality
 443 control (QC) score of two or three, respectively, and need further investigation.

444 6. Applications, Outreach, & Research

445 6.1. Applications

446 In addition to the extensive monitoring of real-time data, the SCO and its collaborators create
 447 applications that use ECONet data to help local, state, and federal partners make quick and data-
 448 driven decisions. Many of these applications are typically in a map, graph, or tabular form and
 449 are presented as a web page or web application. A list of popular applications that use ECONet
 450 data can be found in Table 2 and three specific applications are highlighted below in Sections
 451 6.1.1 and 6.1.2. In Section 6.1.3, we discuss the unique benefits of ECONet data for two North

452 Carolina agencies (i.e., North Carolina Department of Air Quality and North Carolina
453 Emergency Management).

454

455 **Table 2.** Description of applications using ECONet data (as of 2022). All ECONet measured variable elevations are given in
 456 above ground level units.

Number	Application Name	Description	ECONet Measured Variables	Application URL
1	Peanut Disease Monitoring & Alerts	Daily alert during growing season to alert growers whether spraying is needed due to the number of hours of high relative humidity values.	2 m air temperature, 2 m relative humidity, 2 m leaf wetness	http://ncsupeanut.blogspot.com/
2	Inversion Monitoring	Map displaying the current conditions rating for herbicide spraying.	2 m and 9 m air temperature, 6 m wind speed	https://econet.climate.ncsu.edu/inversion
3	Wet Bulb Globe Temperature	Map displaying current and recent conditions of wet bulb globe temperature	2 m air temperature, 2 m relative humidity, 2 m wind speed, 2 m black globe temperature	https://econet.climate.ncsu.edu/wbgt
4	Growing Degree Days	Time series displaying the cumulative number of growing degree days over the course of a year	2 m air temperature	https://products.climate.ncsu.edu/cardinal/scout
5	Wind Rose	Rose chart showing the frequency of winds from different directions, at different speeds, over a period of time	10 m wind speed and wind direction	https://airquality.climate.ncsu.edu/wind/
6	Ambient Information Reporter	Map displaying current weather and air quality conditions	2 m air temperature, 2 m wind speed, 2 m wind direction, 2 m relative humidity, 2 m black globe temperature, 2 m total solar radiation, 1 m precipitation	https://airquality.climate.ncsu.edu/air/
7	Fire Weather Intelligence Portal	Map displaying past, current, and future fire risk conditions.	2 m air temperature, 6 m wind speed, 6 m wind direction, 1 m precipitation, 2 m relative humidity, 2 m solar radiation, soil moisture, soil temperature	https://products.climate.ncsu.edu/fwip/

457

458 6.1.1. CROP MONITORING TOOLS

459 Crop disease monitoring represents an original and ongoing use case of ECONet data. In
 460 2005, SCO researchers collaborated with researchers in the NCSU Department of Crop and
 461 Soil Sciences to develop a peanut disease monitoring and alert tool to alert users when
 462 current weather conditions favor peanut plan fungal disease outbreaks (Table 2). Early leaf
 463 spot and late leaf spot fungal disease outbreaks are favorable in peanut crops when air
 464 temperatures are between 16 and 20 °C with high (> 93%) relative humidity (Shew et al.
 465 1988). This application relies on air temperature, relative humidity, and leaf wetness
 466 observations at ECONet stations located in areas of high peanut production. Users located
 467 within a warning region receive a daily alert email explaining the potential for early leaf spot
 468 and late leaf spot disease outbreak as the number of favorable hours for disease formation
 469 (“favorable hours” in Fig. 5). The peanut disease monitoring and alert tool notifies peanut
 470 producers of potential fungal outbreaks in real-time and can reduce the number of fungicide
 471 North Carolina peanut producers apply during the growing season.

472

```

-----
July 3, 2019 PEANUT LEAF SPOT ADVISORY FOR WHIT
Border Belt Tobacco Res Stn (Whiteville, NC)
setDate = 2019-06-24 07:00:00
lethal conditions = false
favorable hours = 38
LESD = 2019-06-13
WHIT Advisory: do not spray today
Growing degree days (base 56) since LESD = 483.7
Growing degree days (base 56) since May 1 = 1322.7
Records count: 216 out of 217
Most recent db ob to 8am EDT: 2019-07-03 08:00:00
-----

```

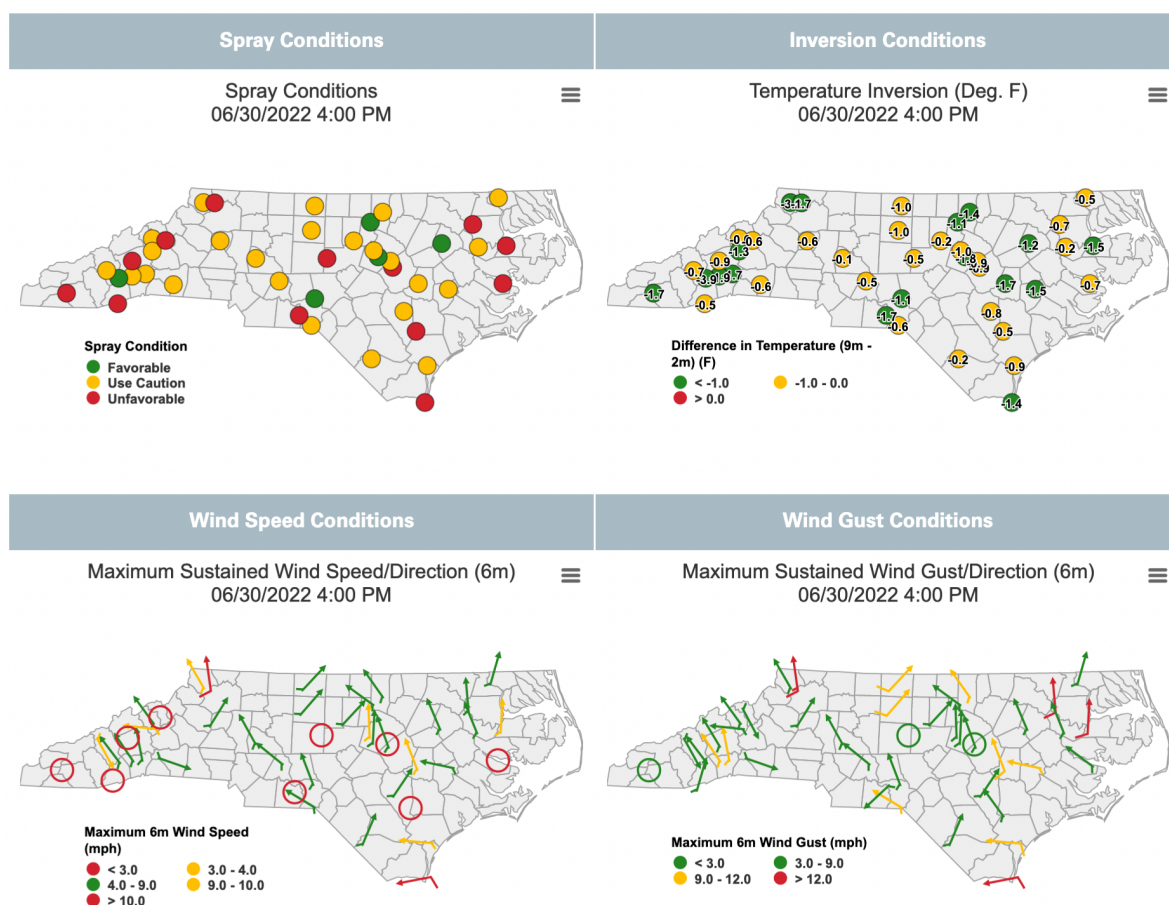
473

474 **Fig. 5.** Portion of a daily email alert sent to peanut disease advisory tool users that proves
 475 recommended spraying practices based on past weather conditions based on the Whiteville,
 476 North Carolina ECONet station (WHIT).

477

478 With the addition of 9 m air temperature sensors in 2019, SCO staff collaborated with
 479 researchers in the NCSU Department of Crop and Soil Sciences to develop the inversion
 480 monitoring tool (Table 2). This application detects temperature inversions—when 9 m air
 481 temperatures are higher than 2 m air temperatures—and determines the current viability of
 482 spraying herbicide. Herbicides, such as dicamba, are volatile and more likely to drift off-site
 483 during temperature inversions (Bish and Bradley 2017; Egan and Mortensen 2012). By using
 484 2 m and 9 m air temperature data and 6 m wind speed data from ECONet stations, this tool
 485 summarizes inversion conditions for the local area around the station and visualizes the
 486 favorability of current weather conditions so growers can optimize herbicide application (Fig.
 487 6).

488



489

490 **Fig. 6.** ECONet Inversion Monitoring tool screenshot from June 30, 2022 at 4pm EST
 491 showing current favorability classifications for pesticide spray conditions (top left), current
 492 temperature inversion conditions (top right), current maximum sustained wind speed (bottom
 493 left), and current maximum wind gust (bottom right).

494

495 6.1.2 WET BULB GLOBE TEMPERATURE TOOL

496 Human and animal heat health is a prevalent topic in North Carolina due to the humid
 497 temperate climate of the region. First used to combat heat stress illnesses within the United
 498 States military, wet bulb globe temperature (WBGT) values are used to determine the
 499 potential impact of heat stress on the human body (Budd 2008). The United States
 500 Occupational Health and Safety Administration (OSHA), the American Center of
 501 Governmental Industrial Hygienists (ACGIH), and the NWS offer categorical guidelines
 502 based on WBGT values (OSHA 2017; ACGIH 2017; NWS 2022; Dimiceli et al. 2011).
 503 These guidelines explain how long a person needs to rest out of direct sunlight to avoid heat
 504 stress. For example, under WBGT “elevated” conditions OSHA recommends that people take
 505 a 15 minute break out of direct sunlight for every hour they are working or exercising in
 506 direct sunlight. WBGT is a function of air temperature, relative humidity, wind speed, and
 507 total solar radiation. Under a solar load (i.e., daylight hours), we calculate WBGT as follows
 508 (Hunter and Minyard 1999):

$$509 \quad WBGT = 0.7T_w + 0.2T_g + 0.1T_a$$

510 Without a solar load (i.e., nighttime hours), we calculate WBGT as:

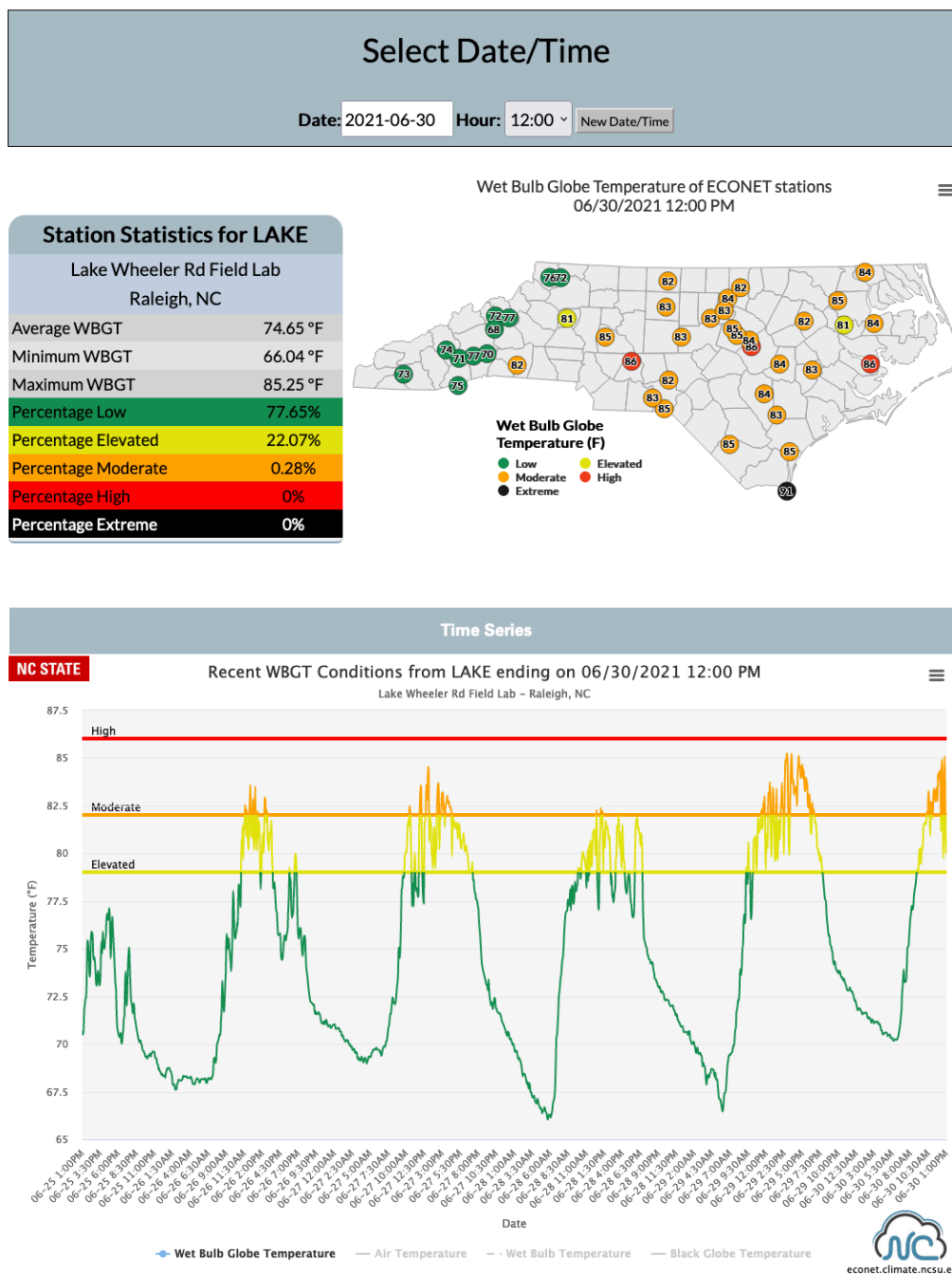
$$511 \quad WBGT = 0.7T_w + 0.3T_g$$

512 where T_w represents natural wet bulb temperature in degrees Celsius, T_g represents globe
 513 temperature in degrees Celsius, and T_a represents air temperature in degrees Celsius. We
 514 convert the final WBGT value to degrees Fahrenheit for easy interpretation by United States
 515 stakeholders, including but not limited to military personnel, agricultural workers, athletic
 516 associations, and local weather forecast staff, who regularly work outdoors during hot, humid
 517 summers in North Carolina.

518 As of 2022, ECONet is the only regional mesonet to directly measure air temperature and
 519 black globe temperature at all sites. Therefore, we only need to estimate natural wet bulb
 520 temperature to determine WBGT. We estimate T_w using methods from Bernard and
 521 Pourmoghani (1999), Stull (2011), Dimiceli et al. (2011), and a revised Dimiceli et al. (2011)
 522 method implemented by the NWS for the National Digital Forecast Database (Boyer 2022).
 523 The Bernard and Pourmoghani (1999) method estimates T_w as a function of air temperature,
 524 relative humidity, wind speed, and black globe temperature while the Stull (2011) and
 525 Dimiceli et al. (2011) methods are a function of air temperature and relative humidity. The
 526 Boyer (2022) method is a function of air temperature, relative humidity, wet bulb depression,

527 wind speed, and solar radiation. We combine estimates for T_w with air temperature and black
528 globe temperature observations from each ECONet station to determine WBGT (Table 2).
529 We then show these ECONet WBGT values on a map that we color-code (Fig. 7) according
530 to NWS WBGT heat stress categories (NWS 2022). WBGT tool users can select a date, time,
531 and ECONet station location of interest to view associated WBGT data over time. We
532 provide this interactive WBGT tool to stakeholders so they can make informed decisions
533 about outdoor activity. At this time (as of 2022), WBGT calculations on our website use the
534 Boyer (2022) method to estimate natural wet bulb temperature and we are collaborating with
535 our local NWS weather forecast office to standardize our visualizations with methods used by
536 other regional and national NWS offices.

537



538

539 **Fig. 7.** Wet bulb globe temperature (WBGT) tool screenshot with a map of ECONet
 540 WBGT values from June 30, 2022 at 12pm EST (top) and time series of WBGT for the Lake
 541 Wheeler ECONet station (LAKE) in Raleigh, North Carolina (bottom). ECONet station
 542 locations are color-coded according to National Weather Service WBGT heat stress
 543 categories. Results presented here use the Boyer (2022) method to estimate natural wet bulb
 544 temperature. This tool is available online at <https://econet.climate.ncsu.edu/wbgt/>.

545

546 6.1.3 STATE AGENCY APPLICATIONS

547 Many individuals and organizations in North Carolina leverage ECONet data in novel
548 ways to make important decisions over the period of hours to years and across the various
549 state ecological regions (i.e., the Mountains, Piedmont, and Coastal Plain). Here, we highlight
550 the benefits of ECONet data to three state agencies: North Carolina Department of Air
551 Quality, North Carolina Emergency Management, and North Carolina Forest Service. North
552 Carolina Department of Air Quality forecasters benefit from high-elevation ECONet sites
553 because these stations, in tandem with their own monitors, can provide an indication of large-
554 scale westerly wind patterns that may spread pollution or create poor air quality across North
555 Carolina (see the Wind Rose and Ambient Information Reporter tools in Table 2). North
556 Carolina Department of Air Quality forecasters also use ECONet air temperature and wind
557 speed data during heat events to track potential ozone formation, which is most likely to
558 occur during hot temperatures and stagnant winds.

559 North Carolina Emergency Management staff use ECONet data for (1) state-wide impact
560 summaries for hurricane maximum wind gusts and total rain and snow accumulations, (2)
561 location-specific meteorological data summaries after natural disasters, and (3)
562 communications relevant to winter weather outlooks and weather extremes. For example,
563 during Hurricane Florence in September 2018, North Carolina Emergency Management staff
564 included total rainfall and maximum wind gust maps, which included ECONet data, in
565 weather announcements to senior agency leadership and to communications that reached
566 hundreds of organizations across the state working to support individuals and communities
567 impacted by the event.

568 North Carolina Forest Service supported the addition of 6 m wind speed and wind
569 direction sensors to all ECONet towers in 2011 and since then shares ECONet data with the
570 Weather Information Management System (WIMS) maintained by the National Wildfire
571 Coordinating Group. Data submitted to WIMS are used to calculate National Fire Danger
572 Rating System parameters, which can be visualize in the Fire Weather Intelligence Portal
573 (Table 2). More specifically, this application leverages ECONet data and several other
574 weather station networks to provide a high density of weather information and fire risk
575 estimates across North Carolina and 12 other states. Lastly, North Carolina Forest Service
576 staff use data from some ECONet stations to set district-level readiness plans (e.g.,
577 https://www.ncforestsERVICE.gov/fire_control/fc_rpmmap.asp) based on their calculated fire
578 danger.

579 *6.2 Outreach*

580 ECONet data and stations provide many opportunities for the SCO to engage with the
581 public; especially in areas where weather data is difficult to access. As part of their standard
582 school curriculum, K-12 grade students often meet with us at a local ECONet station to learn
583 more about the role of weather stations, how each sensor measures a particular atmospheric
584 and environmental variable. K-12 school students and teachers can access ECONet data on
585 SCO data portals (Section 3.4) and use ECONet data for science experiments and science and
586 mathematics lessons. K-12 educators can also access pre-developed lesson plans such as the
587 “Measuring Weather and Climate” lessons that use ECONet data
588 (<https://climate.ncsu.edu/learn/how-do-we-measure-the-weather-and-climate/>). These lessons
589 are available on the SCO education website ([https://climate.ncsu.edu/learn/about-our-](https://climate.ncsu.edu/learn/about-our-climate/)
590 [climate/](https://climate.ncsu.edu/learn/about-our-climate/)). For larger public events, we set up a small-scale ECONet station, record real-time
591 conditions on site, and share ECONet tools and visualizations to discuss ECONet stations and
592 the mission of the SCO. These outreach events provide an opportunity to directly interact
593 with North Carolina communities and data users. Additionally, these interactions can often
594 catalyze discussions regarding the installation of new ECONet stations and ECONet data
595 applications.

596 *6.3 Research*

597 ECONet data are used in a wide range of research conducted in the fields of agricultural
598 sciences, atmospheric sciences, environmental sciences, health sciences, and more. For
599 example, ECONet data have been used to explore the mechanisms behind regional weather
600 patterns (e.g., Sims and Raman 2016), the application of ECONet data to pressing weather
601 and climate issues (e.g., Rennie et al. 2021), the development of crop models (e.g., Perry and
602 Wehner 1990), among others. A summary of peer-reviewed studies using ECONet data (as of
603 2022) are shown in Table 3.
604

605 **Table 3.** Description of peer-reviewed studies using ECONet data (as of 2022).

Study Number	Reference	Description
1	Perry and Wehner, 1990	Development and evaluation of a cucumber harvest date model
2	Perry et al., 1993	Development and evaluation of a pepper harvest date model
3	Perry, 1994	Discussion of current and future agricultural weather observation needs for cooperative extension services
4	Perry, 1998	Discussion of weather monitoring needs for frost and freeze protection of horticultural crops
5	Sims, 2001	Validation of a numerical mesoscale precipitation model for North Carolina
6	Boyles, 2006	Analysis of radar-based, mesoscale precipitation processes in North Carolina and South Carolina
7	Holder et al., 2006	Comparison of automated ECONet data and manual National Weather Service's Cooperative Observer Program data (COOP)
8	Pan et al., 2012	Classification of ECONet station soil types
9	Xia et al., 2015	Evaluation of automated quality control procedures for North American Soil Moisture Database (NASMD) products
10	Coopersmith et al., 2016	Validation of machine learning model-derived near surface soil moisture estimates
11	Doran and Golden, 2016	Analysis of temporal trends in urban heat islands for Raleigh-Durham, North Carolina
12	Quiring et al., 2016	Development and applications of the North American Soil Moisture Database (NASMD)
13	Sims and Raman, 2016	Analysis of summer mesoscale circulation patterns along the East Coast of the United State
14	Rennie et al., 2021	Validation of heat stress indices for the United States Climate Reference Network (USCRN)
15	Ahn et al., 2022	Validation of experimental wet bulb globe temperature hindcast across the United States
16	Shea et al., 2022	Evaluation of random forest models for liquid manure application identification in eastern North Carolina satellite images

606

607 **7. Future of the North Carolina ECONet**

608 Overall, the mission of the North Carolina ECONet is to serve the data, research, and
609 application needs of North Carolinians for a wide range of sectors; including but not limited
610 to, agriculture, forestry, public health, emergency management, natural resources

611 management, and outdoor recreation. Despite the numerous ECONet-driven tools, outreach,
612 and research outlined here, many opportunities remain to apply ECONet data to a wide range
613 of cutting-edge research questions and applications. In the short-term, ECONet will continue
614 to provide high frequency, quality-controlled data for various research projects and
615 applications pertinent to North Carolina stakeholders. In the long-term, we will establish
616 collaborations, conduct high quality research, and build out new value-added applications,
617 including web tools and data visualizations geared towards summarizing and improving the
618 accessibility of ECONet data for practical use cases. Given the regional focus and placement
619 of ECONet stations, we recognize there are opportunities to support and enable cutting-edge
620 research that would have otherwise been difficult due to limited data availability on private
621 lands (e.g., Shea et al., 2022). Additionally, several stations have over 30 years of data on
622 record; therefore, there are research opportunities for long-term trend analyses. We will work
623 to build new partnerships and establish ECONet and ECOExt stations that fill in data
624 coverage gaps while providing publicly available data access to North Carolina communities.
625 When combined, these short- and long-term goals mark a new phase of the ECONet—one
626 that focuses on leveraging past, present, and future ECONet data to support user-driven
627 weather and climate research and applications.

628 *Acknowledgments.*

629 We would like to acknowledge the United States National Oceanic and Atmospheric
630 Administration/National Weather Service National Mesonet Program, the North Carolina
631 State University College of Sciences, and the North Carolina State University College of
632 Agriculture and Life Sciences for supporting the North Carolina ECONet. Special thanks to
633 Josh Ledford for input on Section 5 and Corey Davis on Section 6. This manuscript is also
634 available as a preprint on the EarthArXiv (<https://eartharxiv.org/repository/view/3472/>). We
635 have no conflicts of interest to declare.

636 CRedIT Statement (<https://casrai.org/credit/>): SMS, SPH, MDN, WL, and JAM
637 formulated the manuscript concept, wrote the original draft, and reviewed revised versions.
638 KDD reviewed revised versions. SMS and SPH prepared the visualizations. SMS
639 administered the project and supervised work on the manuscript. KDD supervised work on
640 the manuscript.

641 *Data Availability Statement*

642 There is no code or data associated with this paper. Additional tables and figures are
643 included in the separate supplemental information document.

644

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806 Supplemental Material for

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808 **A Technical Overview of the North Carolina ECONet**

809

810 Sheila M. Saia^a, Sean P. Heuser^a, Myleigh D. Neill^a, William A. LaForce IV^a,
811 John A. McGuire^a, Kathie D. Dello^a

812 ^a *State Climate Office of North Carolina, North Carolina State University, Raleigh, NC, USA*

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815 **File Continents:**

816 This file contains Table S1, Table S2, and Figure S1 as referenced in the main text of the
817 article.

818

819 Number of Pages: 3

820

821 **Contents Metadata:**

822 This document includes the supporting tables for this study as referred to in the main text
823 of the article. The associated manuscript is also available as a preprint on the EarthArXiv
824 (<https://eartharxiv.org/repository/view/3472/>).

825 **Table S1.** Quality control (QC) scores and their associated descriptions.

QC Score	Description
QC -1	Data has not been quality controlled.
QC 0	Data has passed all QC tests.
QC 1	Data has failed 1 QC test, but is more likely good than not.
QC 2	Data has failed more than 1 QC test and is more likely bad than not.
QC 3	Data has failed all QC tests or has been determined erroneous by human QC.

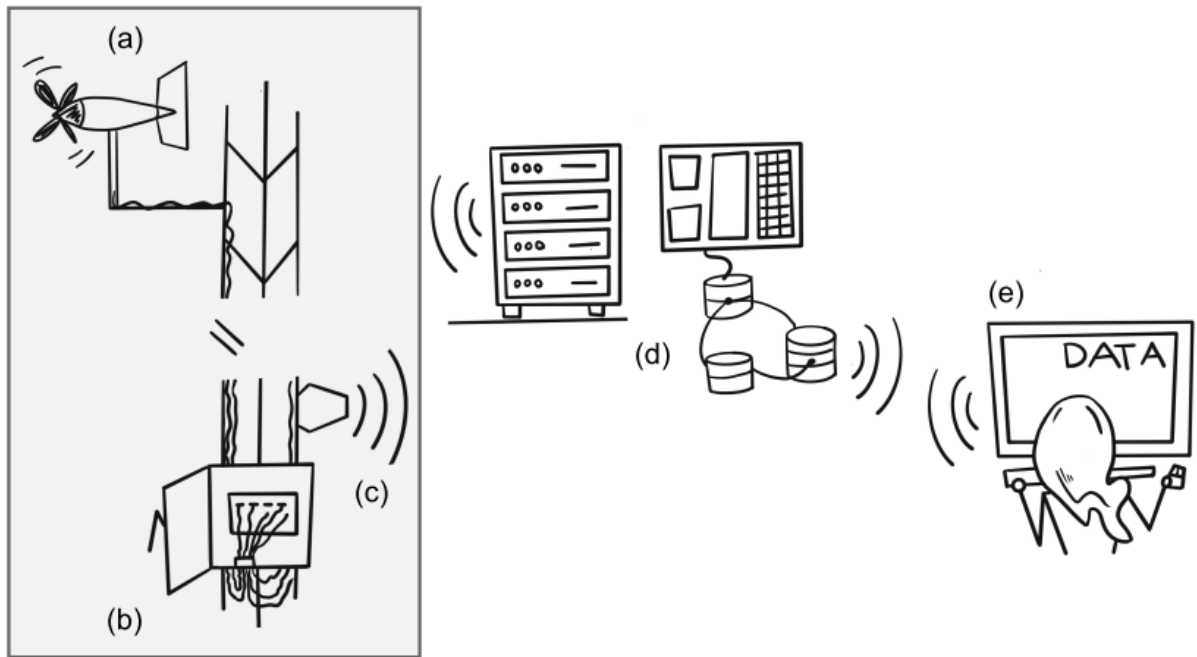
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827 **Table S2.** Quality control (QC) scores arranged according to QC flag combinations.

828 Abbreviations: manual State Climate Office of North Carolina staff/user check (U), range
 829 check (R), buddy check (B), intersensor check (I), trend check (Z). Numeric values following
 830 each letter (e.g., 0 in U0) in the QC flag indicate a range of QC outcomes from pass (0) to fail
 831 (4). See Section 5.1 of the main text for a detailed description of these numeric flag values.

QC 0		QC 1		QC 2		QC 3	
U0	R0Z0	R0Z2	R0I0Z2	R0Z4	R0I2	U4	R0I2Z4
R0	R0I0Z0	R0I0Z4	R0B2Z0	R0I2Z0	R0I4	R0I0Z4	R0B1Z4
R0I0	R0I1Z0	R0B3Z0	R1	R0I4Z0	R0B0Z4	R0I4Z4	R0B4Z0
R0I1	R0B0I0Z0	R1B0Z4	R1B1	R0B2	R0B2Z4	R0B3Z4	R0B5Z0
R0B0	R1Z0	R1B2Z0	R2Z0	R0B3	R1Z4	R0B4Z4	R4
R0B1Z0	R1B0Z0	R2B0	R2B2Z0	R1B1Z4	R1B2	R0B5Z4	R1B3Z4
R1B0	R2B0Z0	R3B0Z0	R3B1Z0	R1B2Z4	R1B3Z0	R1B3	R1B4Z4
R1B1Z0	I0	I1	B0Z4	R2	R2Z4	R1B4Z0	R1B5Z4
Z0	B0Z0	B1	B2Z0	R2B0Z4	R2B2	R1B5Z0	R2B3Z4
B0	B1Z0			R2B3Z0	R3	R2B2Z4	R2B4Z4

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834 **Fig. S1.** Diagram showing the flow of ECONet data from the (a) individual sensor, (b) to
 835 the station datalogger, and then (c) transmitting the data off-site using various communication
 836 methods, (d) to being stored on databases at computer servers located at the State Climate
 837 Office of North Carolina and North Carolina State University and (e) shared on public data
 838 portals. The grey shaded box around (a), (b), and (c) indicates processes taking place on-site
 839 (i.e., at the ECONet station location). This is separate from off-site processes like those in (d)
 840 and (e), which happen away from the ECONet station location.