



**Tropical Ecology, Assessment and Monitoring
(TEAM) Initiative**

Climate Monitoring Protocol

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Introduction

In the coming years, the effects of global climate change will continue to impact a wide range of ecosystems. Most researchers agree that anthropogenic CO₂ has already caused an increase in average global temperatures of .6° C. Indeed, the 90s were a particularly warm decade by historical standards, and this trend is expected to continue well into this century, even if immediate actions are taken to curtail CO₂ emissions. The subsequent effect on precipitation patterns could be profound. Some regions could be plagued by drought while others could see more severe flooding. Sea levels may also undergo a drastic change, altering marine, freshwater, and terrestrial interfaces (IPCC 2001). It should be noted, moreover, that anthropogenic CO₂ is not the only large-scale global climatic phenomenon. The eruption of Mount Pinatubo in 1991, for example, significantly affected the available diffuse radiation (Gu, Baldocchi et al. 2003), thus impacting the photosynthesis process in plants.

Yet much remains unknown about how climate change impacts the environment, especially tropical forests. Among the world's ecosystems, tropical montane forests are thought to be the most sensitive to climate change—they are extremely sensitive not only to changes in average temperatures but also to changes in the cloud base. As a result, climate change could have a substantial impact on the diversity and composition of tropical montane species (Pounds, Fogden et al. 1999). As for lowland tropical forests, the potential effects of climate change are unclear. Phillips *et al.* argue that lowland forests may function as carbon sinks, causing an accumulation of forest biomass as CO₂ levels increase (Phillips, Malhi et al. 1998). Others argue that increased temperatures may cause tropical forests to become CO₂ sources rather than sinks, thus further aggravating global climate change (Clark 2002).

The need for more climatic data from a wider range of sites is acute, especially in the tropics, where the harsh environmental effects on climatic monitoring equipment make it difficult to gather consistent data (Clark and Clark 1994; Root and Schneider 1995; IPCC 2001; Enquist 2002). Consistently gathered long-term climate data are necessary if future climatic phenomena and trends, as well as their impact on biodiversity, are to be identified and understood (WMO 1998). The protocol described below allows TEAM field stations to gather long-term climatic data that will lead to a greatly expanded knowledge of how climate change is impacting tropical biodiversity.

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Climate Variables in the Protocol: (WMO 1983)

1. Temperature
2. Relative Humidity
3. Photosynthetically Active Radiation (PAR)
4. Soil Moisture
5. Sunshine and Diffuse Radiation
6. Wind
7. Precipitation

Spatial Layout

This section specifies the proper location for climatic monitoring equipment at each field station.

Spatial layout of the main weather sensors

The main weather station should be placed in one of the following locations, listed in order of preference:

1. On an above-canopy tower. Place wind and sunshine sensors as high as possible. Other sensors should be placed just above the ground.
2. In a large forest clearing, where the view of the east-west horizon is least obstructed. Wind sensors should be raised as high as possible. Sunshine sensors should be raised but should also be accessible for regular cleaning.
3. If elevation change is more than 1000 m, then an additional weather station will be needed.

If the field station has a pre-existing weather station that is used for non-TEAM research, options might be explored for sharing the station with TEAM. In such instances, TEAM could upgrade the station and add sensors if necessary. TEAM data gathered using a shared weather station will be made available to any non-TEAM researchers using the station.

Spatial layout of weather sensors within the Integrated Monitoring Array (IMA)

Each 1-ha plot in the IMA should contain a small temperature sensor and a relative humidity sensor. These sensors measure the temperature and relative humidity of the forest understory. Understory data will be compared with data from the main weather station as a way of analyzing the microclimate within each 1-ha plot as well as the variation of microclimates throughout the IMAs.

Equipment List

The following equipment is recommended for use in gathering climatic data at TEAM field stations.

Recommended equipment for the main weather station: (courtesy of Yadvinder Malhi)

Hardware and Power

1. Campbell Scientific CR23X Datalogger
2. Campbell Scientific 23XB-1 Logger Base Mount
3. Campbell Scientific ENC 16/18 Enclosure
4. Campbell Scientific 03C Sensor Fitting/Testing
5. Campbell Scientific SM4M Memory Module
6. Campbell Scientific 04C Peripheral Fit/Test
7. Campbell Scientific SC532 Interface
8. Campbell Scientific BP24E-LA Power Supply Unit
9. Campbell Scientific SOP10/X Solar Panel

Sensors and associated equipment

10. Campbell Scientific HMP45C Temperature/Relative Humidity Sensor
11. Campbell Scientific URS1 Radiation Shield
12. Campbell Scientific 009019-003 Mounting Arm
13. Campbell Scientific LI 190SB Quantum Sensor
14. Campbell Scientific SKE211 Levelling Arm
15. Campbell Scientific 05103 Wind Monitor
16. Campbell Scientific 017E Mounting Arm
17. Campbell Scientific CS616 Water Content Reflectometer Sensor
18. Campbell Scientific 107 Temperature Probe (5 mtr)
19. Campbell Scientific TB4-L Rain Gage

20. Campbell Scientific RGB1 Levelling Plate
21. Delta-T Instruments BF-3 Sunshine and diffuse radiation sensor
22. Delta-T Instruments 1m cross-arm
23. Delta-T Instruments 10 m cable

Recommendations for weather equipment within the IMA:

1. HOBO H8 Pro RH/Temperature Logger (1 per 1 ha plot)
2. HOBO Shuttle data transporter
3. BoxCar Pro Starter Software
4. Batteries
5. HOBO Shuttle interface cable
6. Rain shield
7. Post on which to attach sensor

Method

The weather station sensors should be configured to collect samples at 1-second frequencies and then calculate an average for each 30-minute period of sampling. To ensure the quality of the data, it should be downloaded from the data logger every 2–4 weeks.

Field Data Forms

No field data forms are used for gathering climate data. Instead, the data are automatically downloaded from the data logger to a laptop computer.

Data Entry

Data will be downloaded from the data logger and then uploaded to the TEAM database. No manual data entry will be required.

Data Checking

Data will be regularly reviewed to ensure that the sensors and data loggers are functioning properly.

Data Analysis

Analyze data for daily, monthly and yearly climatic trends in temperature, relative humidity, wind speed, PAR, soil moisture, sunshine and diffuse radiation, and precipitation.

Literature Cited

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- Root, T. L. and S. H. Schneider (1995). "Ecology and Climate: Research Strategies and Implications." *Science* **269**.
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Recommended Reading

See Literature Cited.

Glossary

IMA (Integrated Monitoring Array): The 1 km by 1 km square that is the basis for all of TEAM's Standardized Biodiversity Monitoring Protocols. Each IMA is divided into 100 1-ha squares (100 m²), marked with PVC pipe and coordinates.

1 ha plot: A 100 m by 100 m (or 1 hectare) plot. Within each 1-ha plot, all trees are measured annually if their diameter at breast height (dbh) is 10 cm or greater.

Climate Protocol Data Collection Event: This consists of all of the data downloaded from the weather station's datalogger during the monthly data download. If a satellite link is available, then the data collection event will be whenever the data is uploaded to the database.

Appendix 1: Equipment Suppliers

Main weather station equipment:

(Recommendations courtesy of Yadvinder Malhi)

1. Campbell Scientific CR23X Datalogger
2. Campbell Scientific 23XB-1 Logger Base Mount
3. Campbell Scientific ENC 16/18 Enclosure
4. Campbell Scientific 03C Sensor Fitting/Testing
5. Campbell Scientific SM4M Memory Module
6. Campbell Scientific 04C Peripheral Fit/Test
7. Campbell Scientific SC532 Interface
8. Campbell Scientific HMP45C Temperature/Relative Humidity Sensor
9. Campbell Scientific URS1 Radiation Shield
10. Campbell Scientific 009019-003 Mounting Arm
11. Campbell Scientific LI 190SB Quantum Sensor
12. Campbell Scientific SKE211 Levelling Arm
13. Campbell Scientific 05103 Wind Monitor
14. Campbell Scientific 017E Mounting Arm
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17. Campbell Scientific TB4-L Rain Gage
18. Campbell Scientific RGB1 Levelling Plate
19. Campbell Scientific BP24E-LA Power Supply Unit
20. Campbell Scientific SOP10/X Solar Panel
21. Delta-T Instruments BF-3 Sunshine and diffuse radiation sensor
22. Delta-T Instruments 1m cross-arm
23. Delta-T Instruments 10 m cable

Weather equipment within the IMA:

1. HOBO H8 Pro RH/Temperature Logger (1 per 1 ha plot)
2. HOBO Shuttle data transporter
3. BoxCar Pro Starter Software
4. Batteries
5. HOBO Shuttle interface cable
6. Rain Shield
7. Post on which to attach sensor

Weather station company Web sites:

1. Campbell Scientific: www.campbellsci.com/index.html
2. Delta-T Instruments: www.delta-t.co.uk
3. Forestry Suppliers (for the HOBO equipment): www.forestry-suppliers.com

Appendix 2: Instructions for Weather Station Sensor Recalibration and Maintenance

Recalibration instructions

Campbell Scientific HMP45C Temperature/Relative Humidity Sensor

Campbell Scientific recommends that this sensor be returned to the company annually for recalibration. Before returning the sensor, contact the company to obtain a Returned Material Authorization (RMA) Number. Visit the company's Web site (www.campbellsci.com) to locate the nearest Campbell Scientific representative.

Campbell Scientific LI 190SB Quantum Sensor

Consult the product manual for instructions (available online, see Appendix 3).

Campbell Scientific CS616 Water Content Reflectometer Sensor

Consult the product manual for instructions (available online, see Appendix 3).

Campbell Scientific 107 Temperature Probe

According to Campbell Scientific, for most uses it is "unnecessary to recalibrate the 107 to eliminate the temperature offset," but, if necessary, it can be done. Consult the product manual for instructions (available online, see Appendix 3).

Campbell Scientific TB4-L Rain Gage

The Rain Gage's calibration should be checked annually, using the following procedure (taken from the product manual, available online—see Appendix 3):

1. Remove the housing assembly from the base by removing the three screws and lifting upward on the housing.
2. Check the bubble level to verify the rain gage is level.
3. Pour water through the inner funnel to wet the two bucket surfaces. Using a graduated cylinder, slowly pour 314 cc (19.16 in³) of water, over a 15 minute period, into the collection funnel. This volume of water is equal to .39 inches of rainfall (10mm).

4. After the water has passed through the rain gage, the tipping bucket should have tipped 39 times.
5. If the rain gage fails to record the correct number of tips, return the unit to Campbell Scientific for recalibration.

If the Rain Gage needs to be returned for recalibration, contact Campbell Scientific for a Returned Material Authorization (RMA) Number before sending the Rain Gage in. Visit the company's Web site (www.campbellsci.com) to locate the nearest Campbell Scientific representative.

Delta-T Instruments BF-3 Sunshine and diffuse radiation sensor

The BF-3 needs to be recalibrated every two years. This can be done either by sending the sensor back to Delta-T or by following the instructions in the technical manual (<http://www.deltat.co.uk/downloads/Manuals/BF3%20Technical%20manual.pdf>). The sensor should only be recalibrated by someone who has experience with recalibrating similar sensors and has all the necessary equipment.

Maintenance Instructions

(See Appendix 3 for more information on maintenance)

General maintenance of weather station

Every 2-4 weeks, the weather station should be maintained, which should include cleaning the light sensors and solar panels (beeswax and dust are the usual problems). Cables on the ground should be encased in tough hosepipe to prevent damage from rodents. Every 2 months the entire station should receive a thorough check (e.g., check for beeswax accumulation on moving parts).

Campbell Scientific HMP45C Temperature/Relative Humidity Sensor

Campbell Scientific recommends that the radiation shield be cleaned of debris every month. The black screen at the end of the sensor should also be checked for debris.

Campbell Scientific 05103 Wind Monitor

Campbell Scientific recommends checking the anemometer bearings once every two years.

Campbell Scientific 107 Temperature Probe

Campbell Scientific recommends cleaning the radiation shield of debris every month.

Campbell Scientific TB4-L Rain Gage

The product manual recommends the following maintenance procedure: "during every site visit, remove any debris, insects, sediment, etc., from the collection funnel, debris screen, siphoning mechanism, or tipping bucket assembly. Verify the tipping bucket assembly moves freely, and that the datalogger records .01 inches for each bucket tip."

Delta-T Instruments BF-3 Sunshine and Diffuse Radiation Sensor

The batteries need to be replaced annually for the BF-3 Sensor. The dessicant in the dome of the BF-3 needs to be checked routinely; when the dessicant is pink in color, it will need to be replaced (See the User Manual for instructions on how to regenerate the dessicant. The dome will need to be cleaned regularly with isopropyl alcohol to remove any residue that might build up.

Appendix 3: Online Resources

Product literature, specifications, and manuals are available online for much of the equipment recommended in Appendix 1. URLs are listed below.

Campbell Scientific CR23X Datalogger

Product literature: <ftp://ftp.campbellsci.com/pub/outgoing/lit/cr23x.pdf>

Specifications: <ftp://ftp.campbellsci.com/pub/outgoing/lit/cr23xsp.pdf>

Campbell Scientific ENC 16/18 Enclosure

Product literature: <ftp://ftp.campbellsci.com/pub/outgoing/lit/encosur.pdf>

Campbell Scientific SM4M Memory Module

Product literature: ftp://ftp.campbellsci.com/pub/outgoing/lit/sm4m_16m.pdf

Manual: <ftp://ftp.campbellsci.com/pub/outgoing/manuals/sm4m-16m.pdf>

Campbell Scientific HMP45C Temperature/Relative Humidity Sensor

Product literature: <ftp://ftp.campbellsci.com/pub/outgoing/lit/hmp45c.pdf>

Manual: <ftp://ftp.campbellsci.com/pub/outgoing/manuals/hmp45c.pdf>

Campbell Scientific LI 190SBQuantum Sensor

Product literature: <ftp://ftp.campbellsci.com/pub/outgoing/lit/licor.pdf>

Manual: <ftp://ftp.campbellsci.com/pub/outgoing/manuals/li190sb.pdf>

Campbell Scientific Water Content Reflectometer

Product literature: <ftp://ftp.campbellsci.com/pub/outgoing/lit/cs616.pdf>

Manual: <ftp://ftp.campbellsci.com/pub/outgoing/manuals/cs616.pdf>

Campbell Scientific 05103 Wind Monitor

Product literature: <ftp://ftp.campbellsci.com/pub/outgoing/lit/windmon.pdf>

Manual: <ftp://ftp.campbellsci.com/pub/outgoing/manuals/05103.pdf>

Campbell Scientific 107 Temperature Probe

Product literature: ftp://ftp.campbellsci.com/pub/outgoing/lit/107_108.pdf

Manual: <ftp://ftp.campbellsci.com/pub/outgoing/manuals/107.pdf>

Campbell Scientific TB4-L Rain Gage

Product literature: <ftp://ftp.campbellsci.com/pub/outgoing/lit/tb4cs700.pdf>

Manual: <ftp://ftp.campbellsci.com/pub/outgoing/manuals/tb4-l.pdf>

Delta-T Instruments BF-3 Sunshine and diffuse radiation sensor

User Manual: <http://www.delta-t.co.uk/downloads/Manuals/BF3%20User%20manualW.pdf>

Technical Manual: <http://www.delta-t.co.uk/downloads/Manuals/BF3%20Technical%20manual.pdf>

Appendix 4: Climate Protocol Personnel Requirements

One or two students or technicians are needed to download the data from the main weather station every two to four weeks. Once a month, the data should be downloaded from the Temperature/Relative Humidity sensors in each of the 1-ha plots. Preliminary analysis and management of the weather data should then be carried out by the students or technicians. At the time the data are downloaded, sensors should also be maintained and calibrated, following the schedules described in Appendix 2.