

Evaluation of low-cost, tree-mounted temperature loggers for validation of satellite-based flood mapping on the Amazon floodplain

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Abstract. The spatial extent, duration, and depth of inundation are key factors in the functioning of floodplain ecosystems. Satellite-based methods have been developed for mapping flooding extent and water surface height across large floodplain reaches, but on the Amazon floodplain, ground measurements for rigorous validation of these products currently exist for only a few instrumented sites. Here we report results of a field test of networks of ThermoChron iButtons® – low-cost temperature logging devices – for documenting dates of the onset and recession of floodwaters during the 2008-2009 flood cycle at two sites on the Amazon floodplain. Of 237 iButtons deployed on tree trunk gauges at the Mamirauá and Piagaçu Sustainable Development Reserves on the Amazon floodplain during the period 26 November to 11 December 2008, 193 iButtons were retrieved in October-November 2009 and 81 (42%) of those were readable. Flooded and non-flooded phases were clearly identifiable for each iButton by the reduced amplitude of the daily temperature wave when flooded. Based on 6 calibration iButtons attached to staff gauges in Mamirauá Lake, the date of flooding could be estimated within ± 3 days. We conclude that ThermoChron iButtons provide a relatively low-cost means of acquiring information on inundation period, which can be used for validating satellite-based mapping or hydrologic models. However, because of the harsh conditions occurring on deeply inundated floodplains, improved waterproofing containers are necessary to ensure iButton performance. Further calibration experiments are recommended in order to refine metrics for estimating the flooding date with greater precision.

Palavras-chave: ThermoChron iButton, tropical floodplains, inundation mapping, flood detection, diurnal temperature wave

1. Introduction

The spatial extent, duration, and depth of inundation are key factors in the functioning of floodplain ecosystems, affecting primary productivity, nutrient cycling, trace gas emissions, distributions of plant and animal communities, and livelihoods of floodplain residents. Direct measurements of water levels on floodplains of large rivers such as the Amazon are almost entirely limited to a sparse network of gauges located on major river channels. Satellite-based methods have been developed for mapping flooding extent (Hess et al. 2003) and water surface height (Calmant et al. 2008), but on the Amazon floodplain, ground measurements for rigorous validation of these products currently exist for only a few instrumented sites. Standard methods of measuring water levels in the field are impractical as a basis for validation datasets for extensive areas because of inability to record readings year-round (e.g., using staff gauges) or high cost per sampling point (e.g., level loggers). Here we report results of a field test of networks of Thermochron iButtons® – low-cost temperature logging devices – for documenting dates of the onset and recession of floodwaters during the 2008-2009 flood cycle at two sites on the Amazon floodplain.

Consisting of a computer chip enclosed in a 16 mm thick stainless steel can, the iButton is a low-cost (approximately US\$15) data logger, readable by direct contact using a probe and PC. Although certified by the manufacturer as water-resistant rather than waterproof, iButtons have been used successfully for water temperature measurement in previous studies (Dale & Miller 2007, Johnson et al. 2005) at depths of up to 5 m. The Amazon floodplain, however, presents harsh conditions for both the device and the mounting system, including submersion in several meters of water with high sediment and organic debris content and rapid current during the flood phase, and intense solar radiation during the dry phase. A field campaign was therefore designed in order to 1) determine whether iButtons would function throughout a flood season on the Amazon floodplain; 2) design a cheap, effective mounting system with minimum environmental impact; and 3) test the hypothesis that the flooded/non-flooded transition should be detectable in the iButton record owing to dampening of the diurnal temperature wave.

2. Methods

iButtons (model DS1921H, manufactured by Maxim Integrated Products) were deployed at the Mamirauá and Piagaçu Sustainable Development Reserves during the period 26 November to 11 December 2008. The two sites (Fig. 1) contain typical várzea habitats, and both are located at confluences of major tributaries (Japurá and Purus rivers), with resulting complex timing of flood waves. After being programmed to record temperature at 6-hour intervals, iButtons were sealed in pint-sized zip-style plastic bags, enclosed within quart-sized bags, and mounted on trees at 50 cm intervals, starting at 20 to 50 cm above ground, using plastic cable ties (Fig. 2). These iButton "station" locations were targeted for maximum along-reach and across-reach coverage.

A Trimble Pro XRS GPS unit enabled with reception capability for Omnistar satellite-corrected positions was used to obtain vertical and horizontal measurements of the iButton positions. Base heights of the tree gauges ranged from 27 to 37 m elevation above sea level at Mamirauá and 16 to 27 m at Piagaçu. Estimated horizontal location precision was less than 1.0 meter for 31 of the 36 gauges; estimated vertical location precision was less than 1.5 m for 27 of the 36 gauges. Maximum estimated errors were 1.5 m (horizontal) and 2.4 m (vertical). A total of 237 iButtons were deployed: 136 were installed at 23 stations at Mamirauá and 101 at 15 stations at Piagaçu. iButtons were retrieved in October and November 2009, and temperature records downloaded using the DS9490R USB probe and OneWireViewer

software. As reported by Santana et al. (2010), calibration testing of a sample of 20 iButtons was conducted at the Meteorological Instrumentation Laboratory (LIM) of INPE/CPTEC in March-April 2009, verifying that the tested units were operating within manufacturer's specifications in terms of precision of temperature readings.

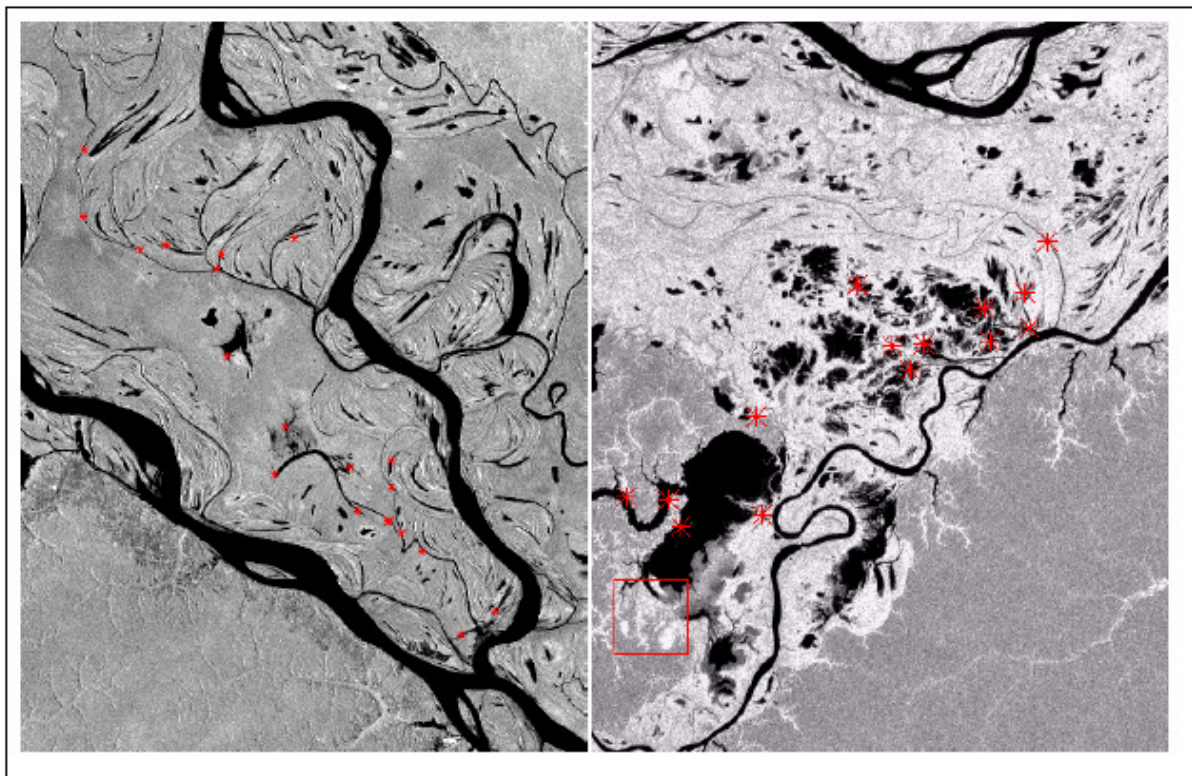


Figure 1: Locations of iButton stations at Mamirauá (left) and Piagaçu (right).



Figure 2: Upper: Thermochron iButton; iButton mount at installation; iButton mount at retrieval. Lower: Examples of iButton stations

3. Results and discussion

3.1 iButton performance

During field visits in October-November 2009 to retrieve the iButtons, all stations at Piagaçu were visited, but four Mamirauá stations were not accessible by boat because of low water levels, and were too distant for retrieval on foot. Further attempts at retrieval were successful only for one of those stations. Of the total 237 iButtons deployed, 193 were retrieved, 24 were missing, and 20 could not be accessed for retrieval (Table 1). In the case of missing iButtons, in most instances the bags and cable ties still remained attached to the tree, but the outer bags were torn, with iButtons missing. At two of the stations, the cable ties appeared to have been deliberately cut, and the bags with iButtons had been removed. Water, sediment, and organic debris was found in both the inner and outer bags for all the iButtons. Of the iButtons that were retrieved, temperature logs were readable for 38% (73 of 193; Table 2). Eight of the retrieved iButtons were functioning normally but did not provide temperature profiles because the data logging mission had not been activated. It was ascertained that some of the iButtons had not been initialized at the factory, resulting in the mission activation errors.

Table 1: Summary of iButtons deployed and retrieved.

| | Mamirauá | Piagaçu | Total |
|------------------------------|----------|---------|-------|
| Retrieved – iButton present | 106 | 87 | 193 |
| Retrieved – iButton absent | 10 | 14 | 24 |
| Not accessible for retrieval | 20 | 0 | 20 |
| Total deployed | 136 | 101 | 237 |

Table 2: Data quality for retrieved iButtons.

| | Mamirauá | Piagaçu | Total |
|-------------------------------|----------|---------|-------|
| Readable – data downloaded | 47 | 26 | 73 |
| Readable – mission not active | 0 | 8 | 8 |
| Damaged – unreadable | 59 | 53 | 112 |
| Total retrieved | 106 | 87 | 193 |

These results are similar to those of Wolaver & Sharp, Jr. (2007), who noted a failure rate of nearly 40% for a small sample of iButtons installed at water depths of 2 to 6 m, and in contrast to those of Johnson et al. (2005), who reported a failure rate of only 8% for 500 loggers submerged up to 5 m below the water table and operating up to 12 months. Johnson et al. noted four principal advantages of iButtons over commonly used wired and other stand-alone logging devices: 1) the wireless instruments do not require installation of a control-recording system; 2) the small size allows easy installation in a variety of situations; 3) multiple loggers are easily suspended in a monitoring well, allowing collection of high-resolution temperature profile data; and 4) the low cost allows deployment of the loggers in large numbers. In order to realize these advantages, improved waterproofing methods should be used to ensure a low failure rate for work on tropical floodplains. Possible improvements include 1) enclosure in waterproof iButton Capsules (model DS9107) which, however, triples the cost for each iButton to about \$45; 2) sealing with silicone; 3) sturdier plastic bags with stronger seals.

3.2 Temperature records

Examples of daily temperature range plots for four iButton stations are shown in Figure 3. Daily temperature range during the non-flooded period varied depending on iButton position above ground, aspect, and amount of canopy shading, with minimal daily ranges as low as 3 degrees and maximum ranges greater than 25 degrees. During the flooded period, the daily temperature was greatly reduced, ranging from 0 to 0.25 degrees. For iButtons 11-02 and 13-01 in Figure 3, two flooding periods can be seen: the main flood, and preceding it the "repiquete", when river stage falls slightly before rising again.

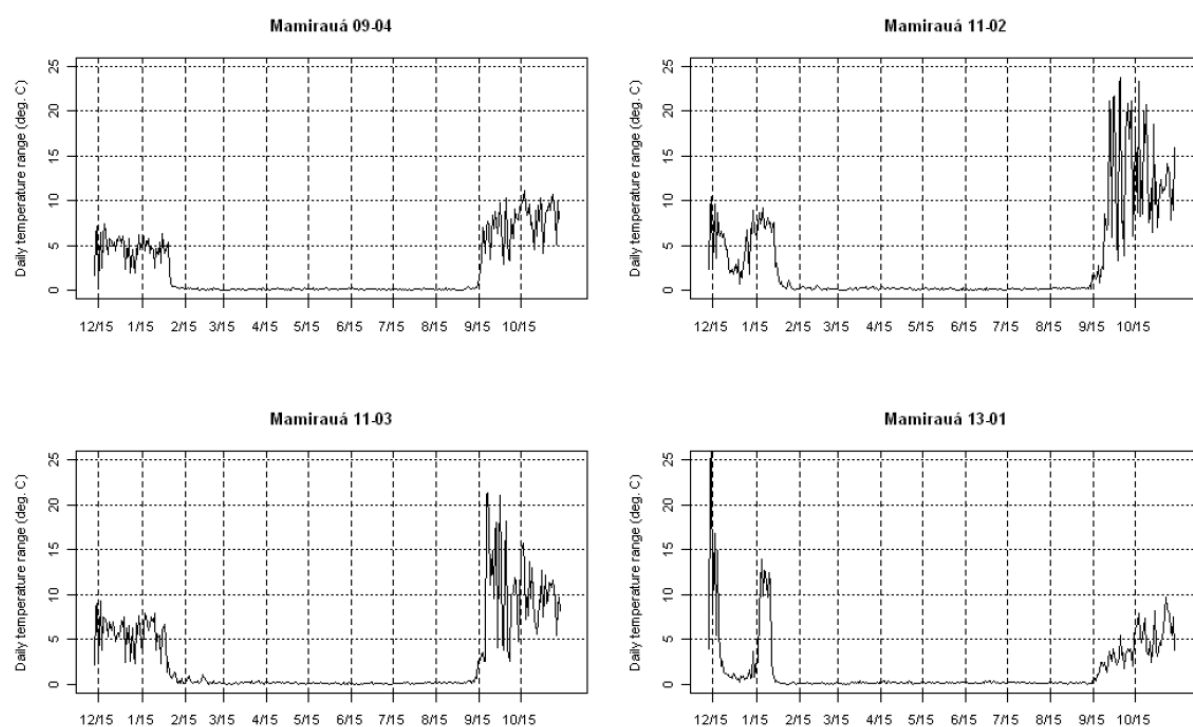


Figure 3: Daily temperature range plots for four iButton stations in Mamirauá. X axis is the date (month/day) and Y axis is temperature ($^{\circ}\text{C}$).

Based on 6 calibration iButtons attached to staff gauges in Mamirauá Lake, the date of flooding could be estimated within ± 3 days. Several metrics including daily minimum temperature, daily temperature range, and rate of change of daily minimum temperature or temperature range, have been evaluated. It is recommended that further gauge-based comparisons be conducted before definitive conclusions can be made regarding the optimum metric for identifying dates of flooding and emergence.

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