SAFARI Surface Mooring
Level-3 and Level-4 Data Documentation

WHOI — Preliminary Data Review

October 26, 2026

1 Background

The SAFARI surface mooring product combines ASIMET meteorological and ocean measurements with Campbell CR6 logger streams and SBG motion/navigation measurements. Both the ASIMET and Campbell loggers have their own SBE37; logger-qualified names distinguish these instruments throughout. Active L2 and L3 are cropped to the ASIMET rain record, 21 November 2025 00:40 through 6 September 2026 01:00 UTC; uncropped sources are retained in the archive. L4 uses the anchor-over start and a current exclusive processing upper bound of 6 September 2026 02:50 UTC, although its available L3 data end earlier. This bound does not identify the recovery time. The confirmed recovery time will be documented from the recovery record.

2 Data Overview

Level 2 contains native-resolution observations. Level 3 combines the observations on a common 5-minute time axis with 83,237 bins, from 2025-11-21T00:40:00 to 2026-09-06T01:00:00 UTC (bin-start labels). Level 4 contains COARE 3.6 fluxes calculated from twenty-minute L3 inputs.

Table 1: SAFARI surface-moored buoy data products covered in this report.

Item	Detail
Platform	SAFARI surface mooring; ASIMET, Campbell CR6, SBG and auxiliary instruments
Active L2/L3 span	ASIMET rain coverage: 21 November 2025 00:40–6 September 2026 01:00 UTC
L2 streams	ASIMET logger, Campbell 1 Hz, and Campbell 10 Hz native observations
L3 product	Common-coordinate 5-minute averages; 83,237 bins
L4 product	20-minute COARE 3.6 fluxes (uop_coare) with current-relative wind over the current processing interval
Key L3 variables	Meteorology, radiation, corrected rain, surface temperature and salinity, Nortek current, and GPS/IMU navigation

3 Platforms and Instrumentation

3.1 Mooring Platform

The SAFARI platform is a surface mooring supported by an instrumented buoy. Its payload includes an ASIMET logger, a Campbell CR6 logger with 1 Hz and 10 Hz streams, SBG navigation/motion sensors, and auxiliary meteorological and ocean instruments.

3.2 Instrument Status

Figure 1 shows that most listed observations span nearly the full active L3 period. WXT rainfall is brief, PTB110 pressure begins later, and SBG heading is intermittent and ends before the other navigation records. The Gill sonic never returned usable data; IR20 measurements are marked all bad and retained for diagnostics only. The timeline shows finite observations, not instrument health.

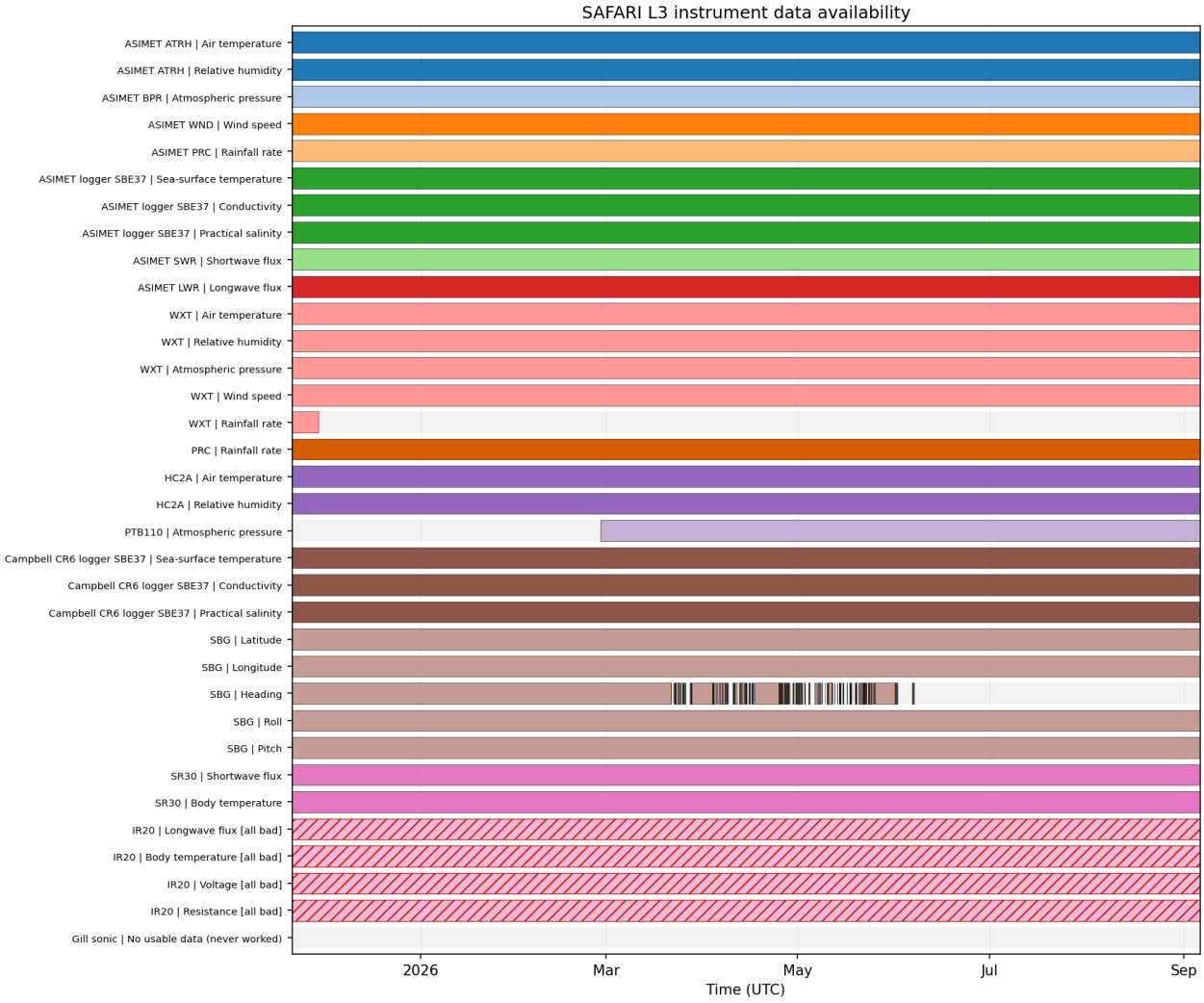


Figure 1: SAFARI instrument data status over the active L3 span. Colored segments indicate finite five-minute bins, not sensor health.

3.3 Motion and Reference Frames

The SBG position and motion variables are retained as supplied by the logger and averaged to five-minute L3 bins. No additional motion correction is applied. The ASIMET and WXT east/north wind components are plotted together in their shared platform-relative frame. The Nortek velocities are earth referenced and are not motion corrected.

3.4 Instrument Details and Logger Redundancy

The ASIMET and Campbell CR6 loggers each carry an SBE37; logger names distinguish their separate records. Table 2 lists each Level-2 instrument marker, its main measurement role, and nominal sampling rate and height where available. Some markers conflict with variable descriptions (PTB110 and ASIMET pressure, and WXT wind components), so sensor assignments follow the variable descriptions and models. Nortek pressure is omitted from L3 because it has no finite observations.

Table 2: Level-2 instruments, measurement roles, sampling rates, and heights.

Instrument / marker	Measurement role	Rate; height
`INST_SBG` / SBG	Position, navigation, platform motion and GPS status	1 and 10 Hz
`INST_SR30` / SR30	Downwelling shortwave; body temperature	1 Hz; 2.85 m
`INST_IR20` / IR20	Downwelling longwave; diagnostic signals (rejected)	1 Hz; 2.85 m
`INST_WXT` / WXT	Air temperature/RH, pressure, wind, precipitation, compass	1 Hz; 2.42 m
`INST_HC2A` / HC2A	Air temperature and relative humidity	1 Hz; 2.28 m
`INST_PTB` / PTB	Atmospheric pressure (PTB110)	1 Hz; 2.18 m
`INST_BMP390` / BMP390	Internal buoy-well pressure	1 Hz
`INST_SBE37` / SBE37	SST, conductivity; practical salinity derived	1 Hz; -1.45 m
`INST_PRC` / PRC	Precipitation level/counter (Campbell PRC)	1 Hz; 2.57 m
`INST_ATRH_ASIMET` / ATRH (ASIMET)	Air temperature and relative humidity	0.0167 Hz; 2.27 m
`INST_BPR_ASIMET` / BPR (ASIMET)	Atmospheric pressure	0.0167 Hz; 2.44 m
`INST_LWR_ASIMET` / LWR (ASIMET)	Downwelling longwave radiation	0.0167 Hz; 2.83 m
`INST_SWR_ASIMET` / SWR (ASIMET)	Downwelling shortwave radiation	0.0167 Hz; 2.84 m
`INST_PRC_ASIMET` / PRC (ASIMET)	Precipitation level/counter	0.0167 Hz; 2.59 m
`INST_WND_ASIMET` / WND (ASIMET)	Wind speed/direction and components; vane/compass	0.0167 Hz; 2.67 m
`INST_SST_ASIMET` / SST (ASIMET)	SST, conductivity and practical salinity	0.0167 Hz; -1.45 m
`INST_NORTEK` / NORTEK	Water velocity, temperature, attitude and instrument status	10 Hz bursts; 5-min L2

4 Level-3 Bulk Meteorological Data Processing

4.1 Inputs and Time Preparation

The archived source is `L2_SAFARI.nc`, with separate `time_ASIMET`, `time_1Hz`, and `time_10Hz` coordinates. `SAFARI_L3_5min.py` decodes source time units and assigns finite observations to left-closed, right-open UTC five-minute bins. The time label is the interval start. Unsorted timestamps are assigned by their decoded time; repeated timestamps remain separate contributing samples. Invalid timestamps do not contribute. Source streams are combined on the union time grid and entirely missing bins remain NaN.

4.2 Averaging and Missing Values

For each ordinary numeric variable, the mean is the sum of finite L2 observations divided by their count within a bin. Chunk-local sums and counts are combined before division; chunks are not averaged with equal weights. Compass headings, wind directions, vane angles, and courses use circular means, $\theta = \text{atan2}(\sum \sin\theta_i, \sum \cos\theta_i)$, reported on $[0, 360)$ degrees. Near-zero circular resultants are undefined and stored as NaN. Scalar and instrument metadata variables are copied. Suffix removal and collision handling are traceable through the variable-map CSV and each variable's source attributes.

L2 fill values are excluded and packed scale/offset values are decoded. The five-minute averaging itself applies no range masking, lidar-specific literal-value screening, despiking, interpolation, or reference-frame rotation. Three documented later steps modify or add L3 variables: the derived rain products, the paired-native and despiked salinities, and the merged Nortek record, each described below. Some signed wind variables have incorrect nonnegative valid limits in their metadata; applying these limits indiscriminately would remove negative components. Apart from these documented steps, the L3 data remain descriptive averages of L2, not a fully quality-controlled product. Finite values can still be faulty.

4.3 Surface Salinity Calculation and Despiking

The active L3 file `L3_SAFARI_5min.nc` carries the corrected rain products, paired-native salinity, corroborated salinity despiking, and the Nortek record (`src/SAFARI_L3_update.py`); the previous L3 is archived. For both ASIMET and Campbell SBE37 records, practical salinity is calculated from paired finite native conductivity and temperature samples using `GSW SP_from_C` at an assumed pressure of 0 dbar, then averaged into the existing five-minute bins. Conductivity is converted from S m^{-1} to mS cm^{-1} before calculation. This avoids artifacts caused by calculating salinity from separate conductivity and temperature means with unequal valid-sample support. Each salinity variable's `comment` documents the repair; unrelated L3 variables are unchanged.

Both salinity records are then despiked with cross-sensor corroboration. A point is flagged when it departs by more than 0.05 from a centered six-hour (73-bin) running median of its own record. A flagged point is kept when the other SBE37 record has a flagged departure of the same sign within one five-minute bin, because such events (for example, rain freshening) are seen by both sensors. Uncorroborated flags are set to missing and filled by linear interpolation in time when the resulting gap is at most 30 minutes; longer or mixed gaps remain missing. The undespiked values are kept as `salinity_*_raw` and each point is classified in `salinity_*_spike_flag` (0 good, 1 corroborated and kept, 2 removed and interpolated, 3 removed and not filled). Example events are shown in `img/L3/SSS_despike/SAFARI_SSS_despike_examples.png`. The Campbell CR6 SBE37 record contains flat (stuck) stretches, for example near the end of the record; it is not masked. ASIMET supplied SST and salinity throughout the saved L4 run; the Campbell record is retained for comparison and is not used in the L4 calculation. During those stretches ASIMET spikes cannot be corroborated and are interpolated.

4.4 Nortek Current Record

The five-minute Nortek AquaDopp L2 record already lies on the L3 time grid and is merged without re-averaging. All merged variables carry the `Nortek_` prefix; battery voltage is not carried into L3. The east and north components reproduce the stored current speed and direction; no platform

motion correction is applied.

4.5 Rain rate calculation and QC

The ASIMET and PRC self-siphoning gauges measure collected water level, which rises during rainfall and may decrease through evaporation, spillage, or drainage. The WXT precipitation record is an accumulation counter; `rain_intensity` is a separate acoustic measurement from WXT. Although the source fields are named `rainfall_rate*`, they are treated as levels or counters. Negative derived rates reflect measurement noise or declining tube water levels, not negative precipitation.

Rain rate is derived using the following procedure. Small positive and negative fluctuations are retained to avoid the positive bias introduced by removing negative noise alone.

1. **Difference the measurements.** Compute adjacent differences on each native clock (one minute for ASIMET/WXT; one second for PRC), rejecting missing endpoints, invalid times, and cadence discontinuities. Assign differences by interval start and sum into one-minute increments with complete temporal support (Figure 2).

2. **Remove negative spikes and interpolate.** Independently for each instrument, mask one-minute increments satisfying $\Delta L_i < -1.5$ mm for all three rain gauges in a single screening pass. Increments at the threshold, smaller decreases, and all positive increments are retained. Linearly interpolate bounded flagged runs lasting at most 30 minutes. This cutoff applies to level or counter increments rather than the averaged rain rate. It preserves the inspected near-cancelling rebound pairs. Interpolation requires finite endpoints, with negative anchors within the screening threshold and positive anchors at or below 100 mm hr^{-1} . Data gaps and flagged runs with unsuitable endpoints remain missing (Figure 3).

3. **Re-integrate and calculate rate.** Cumulatively sum the corrected increments within each valid segment to obtain accumulation. Calculate rain rate from the summed corrected increments over a trailing ten-minute window, convert to mm per hour, and average complete estimates into five-minute bins. Missing increments invalidate overlapping rate windows; segment-relative accumulation restarts after unfilled gaps (Figure 4).

These signed estimates include the effects of evaporation and other water losses. Thresholds and interpolated rainfall during drainage require instrument review.

4.6 Grouped L3 Products

Report-selected five-minute values are plotted without decimation or additional QC. Missing values break lines. Rejected IR20 measurements are omitted from grouped plots and shown as rejected in the instrument-status timeline; their stored values and metadata are retained in L3. Variables marked all bad in metadata are labeled diagnostic only and must not be used as accepted measurements. Circular wrap crossings are broken for display only; the stored data and statistics are unchanged. ASIMET and WXT wind-component comparisons use their shared platform-relative frame; wind directions are shown as the direction the wind blows toward, clockwise from true north.

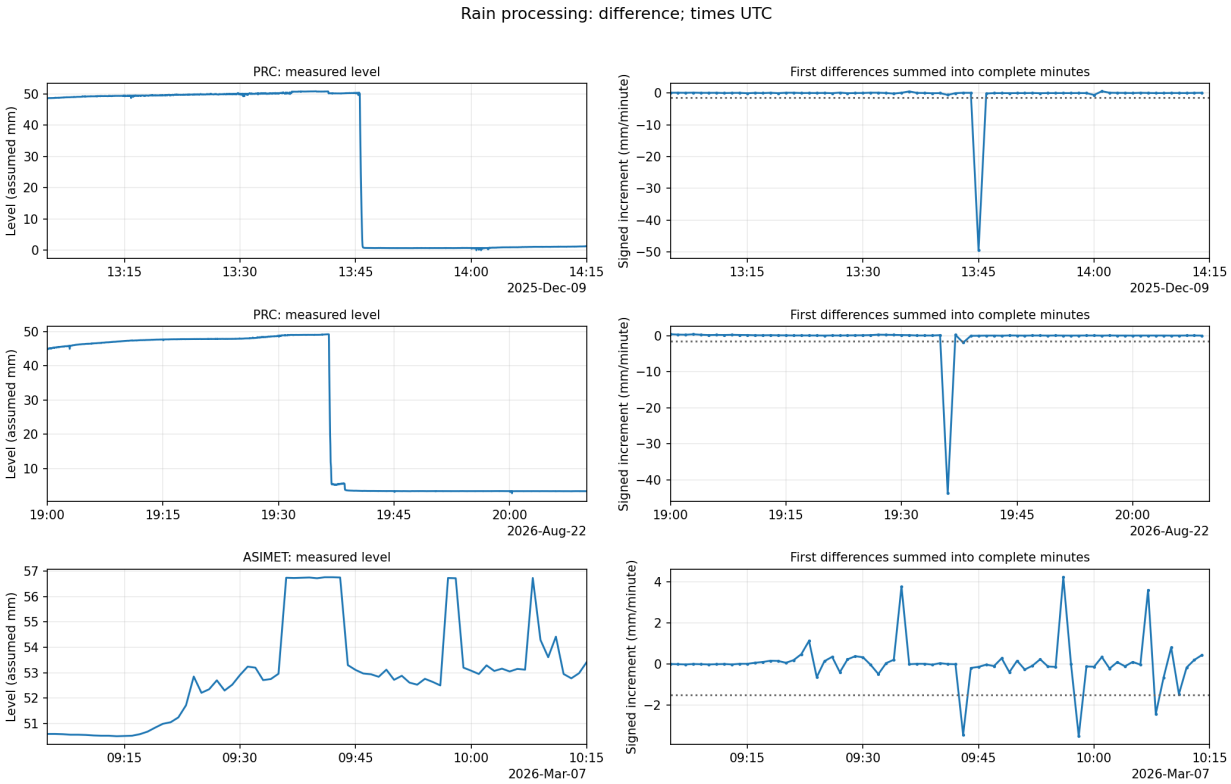


Figure 2: Step 1: measured levels (left) and signed first differences summed into complete minutes (right). Abrupt drainage and smaller fluctuations remain visible before filtering. Examples are PRC on 9 December and 22 August, and ASIMET on 7 March.

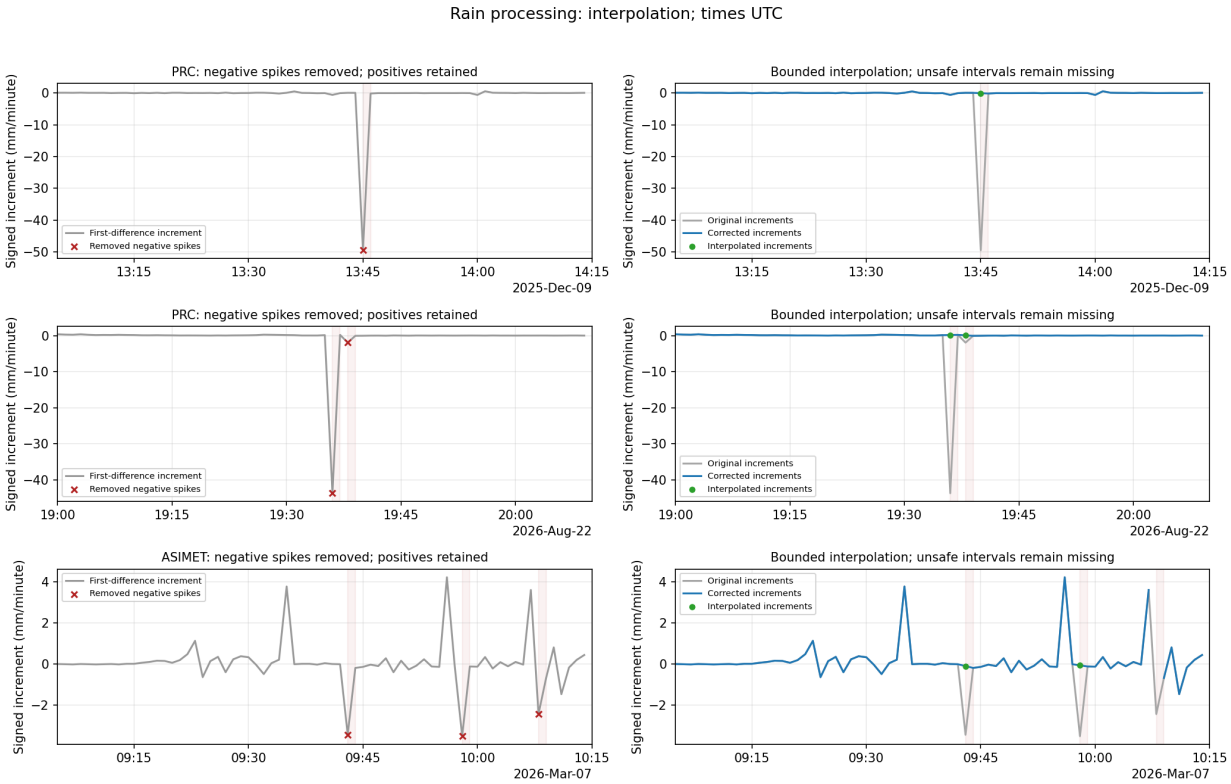


Figure 3: Step 2: red crosses mark one-minute increments below −1.5 mm for all instruments, including large drainage drops (left). Corrected increments and green interpolated points are shown on the right. Only large negative increments are removed. Positive increments and small signed fluctuations are preserved; shaded negative runs without acceptable interpolation anchors remain missing. The examples match Figure 2.

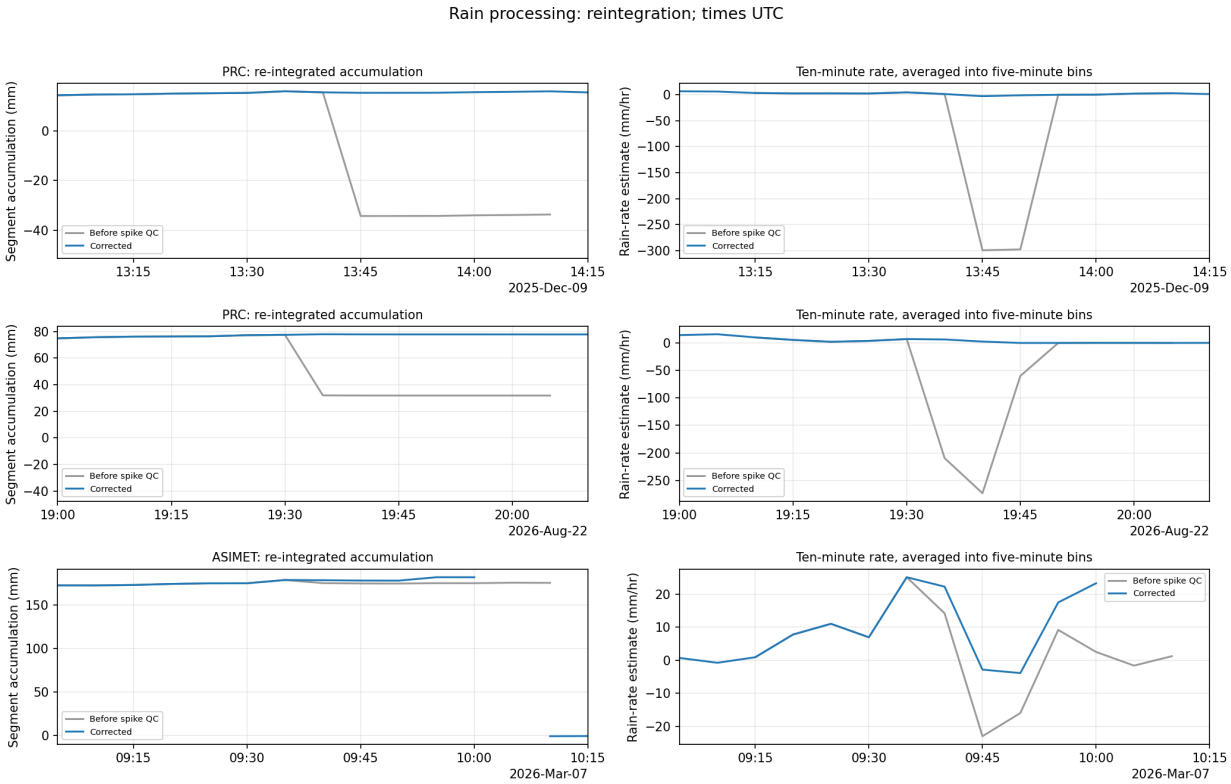


Figure 4: Step 3: accumulation (left) and rain rate (right) before and after independent negative-spike QC. Unfilled increment intervals break overlapping rate windows and restart segment-relative accumulation.

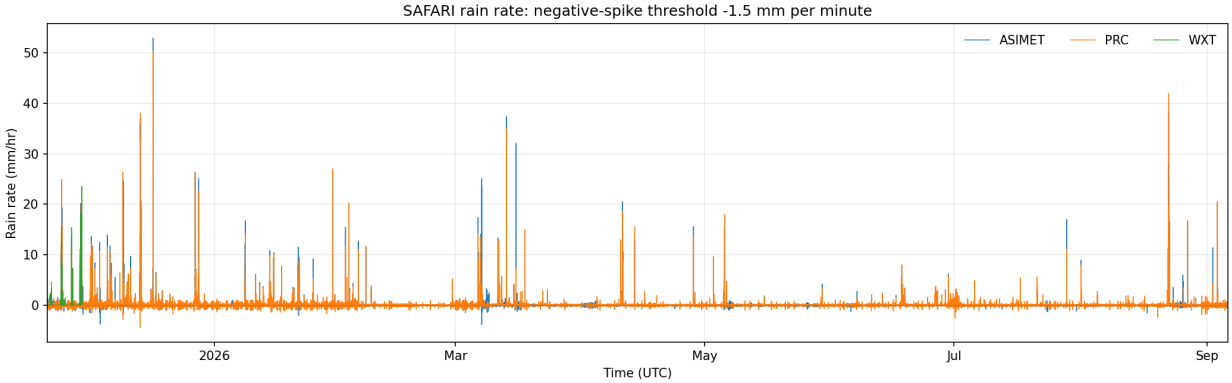


Figure 5: Final ASIMET, PRC, and WXT rain-rate estimates following the single-pass −1.5 mm negative-spike screening and bounded interpolation. Active L2/L3 are cropped to ASIMET rain coverage; uncropped files preserve the additional PRC-only leading and trailing observations in the archive. Ten-minute estimates are averaged into five-minute bins. Retained water-level declines can produce negative rates; gaps indicate incomplete valid support.

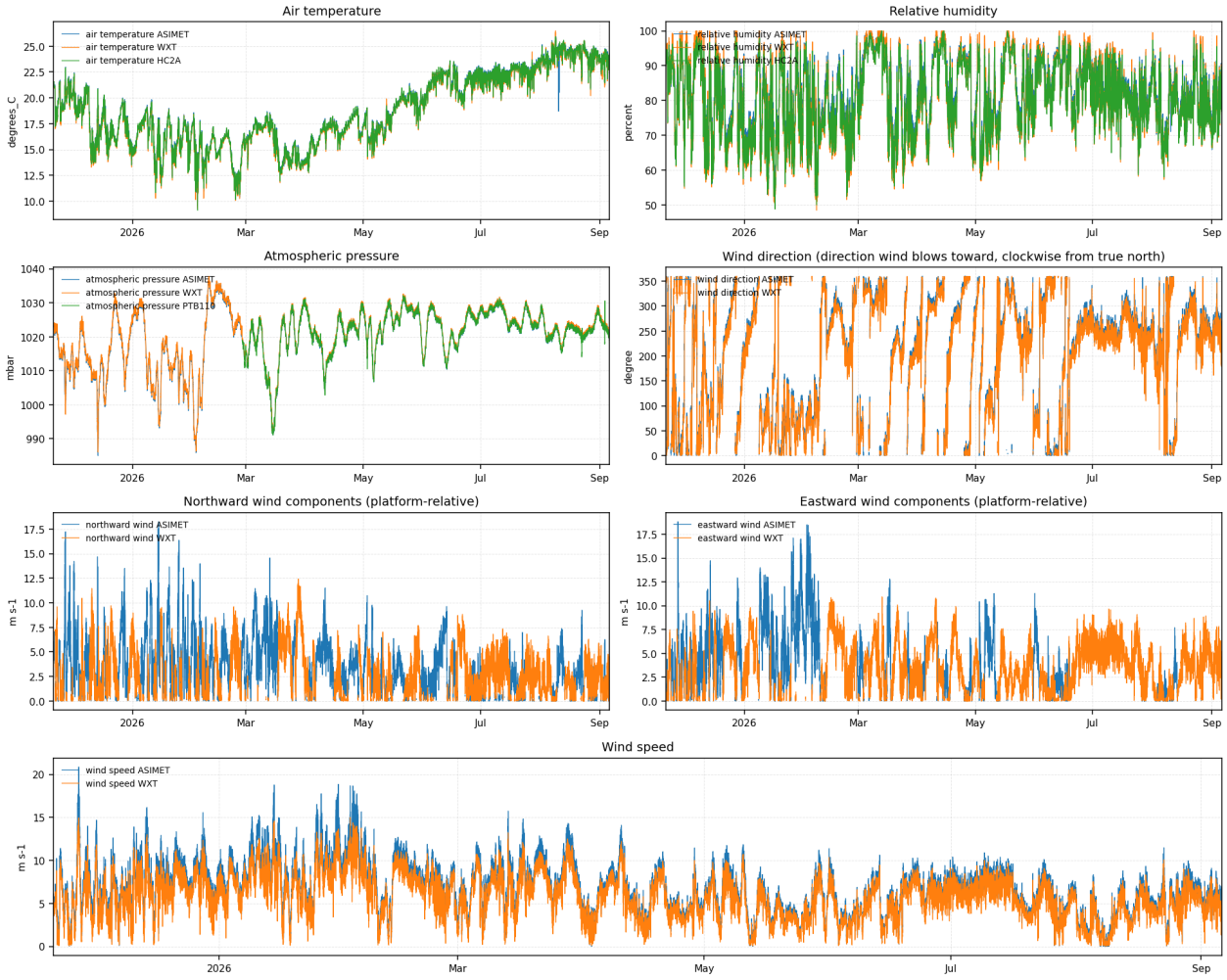


Figure 6: Five-minute SAFARI observations: Air temperature; Relative humidity; Atmospheric pressure; Wind direction (direction wind blows toward, clockwise from true north); Northward wind components (platform-relative); Eastward wind components (platform-relative); Wind speed. Sensor labels identify the instrument or logger. Wind directions indicate where the wind blows toward; component plots retain the supplied reference frames.

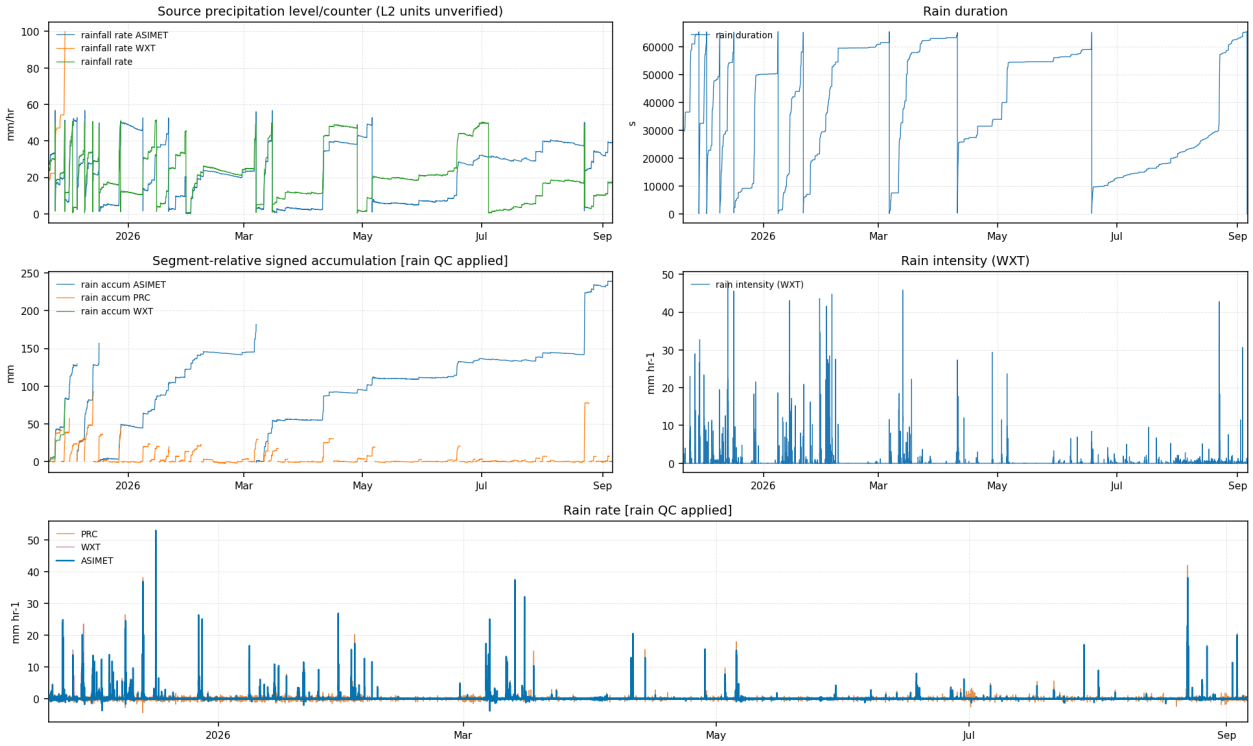


Figure 7: Five-minute SAFARI observations: Source precipitation level/counter (L2 units unverified); Rain duration; Segment-relative signed accumulation; Rain intensity (WXT); Rain rate. Rain rates use corrected native increments, a ten-minute rate window, and five-minute averaging. Increments below -1.5 mm are masked; bounded flagged runs up to 30 minutes are interpolated. Small negative changes are retained.

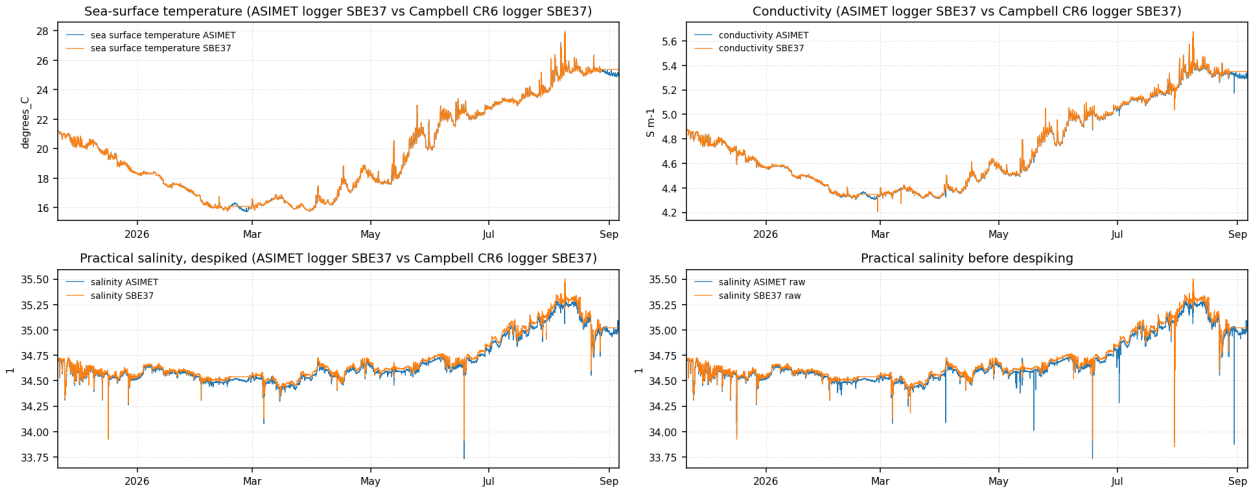


Figure 8: Five-minute SAFARI observations: Sea-surface temperature (ASIMET logger SBE37 vs Campbell CR6 logger SBE37); Conductivity (ASIMET logger SBE37 vs Campbell CR6 logger SBE37); Practical salinity, despiked (ASIMET logger SBE37 vs Campbell CR6 logger SBE37); Practical salinity before despiking. ASIMET and Campbell CR6 logger SBE37 records are shown separately. Salinity is recalculated from paired native conductivity and temperature; the despiked records retain corroborated events and interpolate isolated uncorroborated spikes over gaps up to 30 minutes.

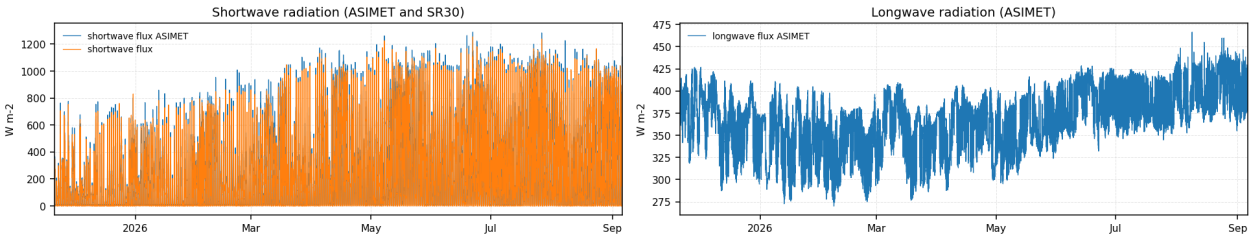


Figure 9: Five-minute SAFARI observations: Shortwave radiation (ASIMET and SR30); Longwave radiation (ASIMET). Shortwave radiation from ASIMET and SR30 is compared in one panel; ASIMET is the selected L4 input. Longwave radiation is shown from ASIMET only. Rejected IR20 measurements are not plotted.

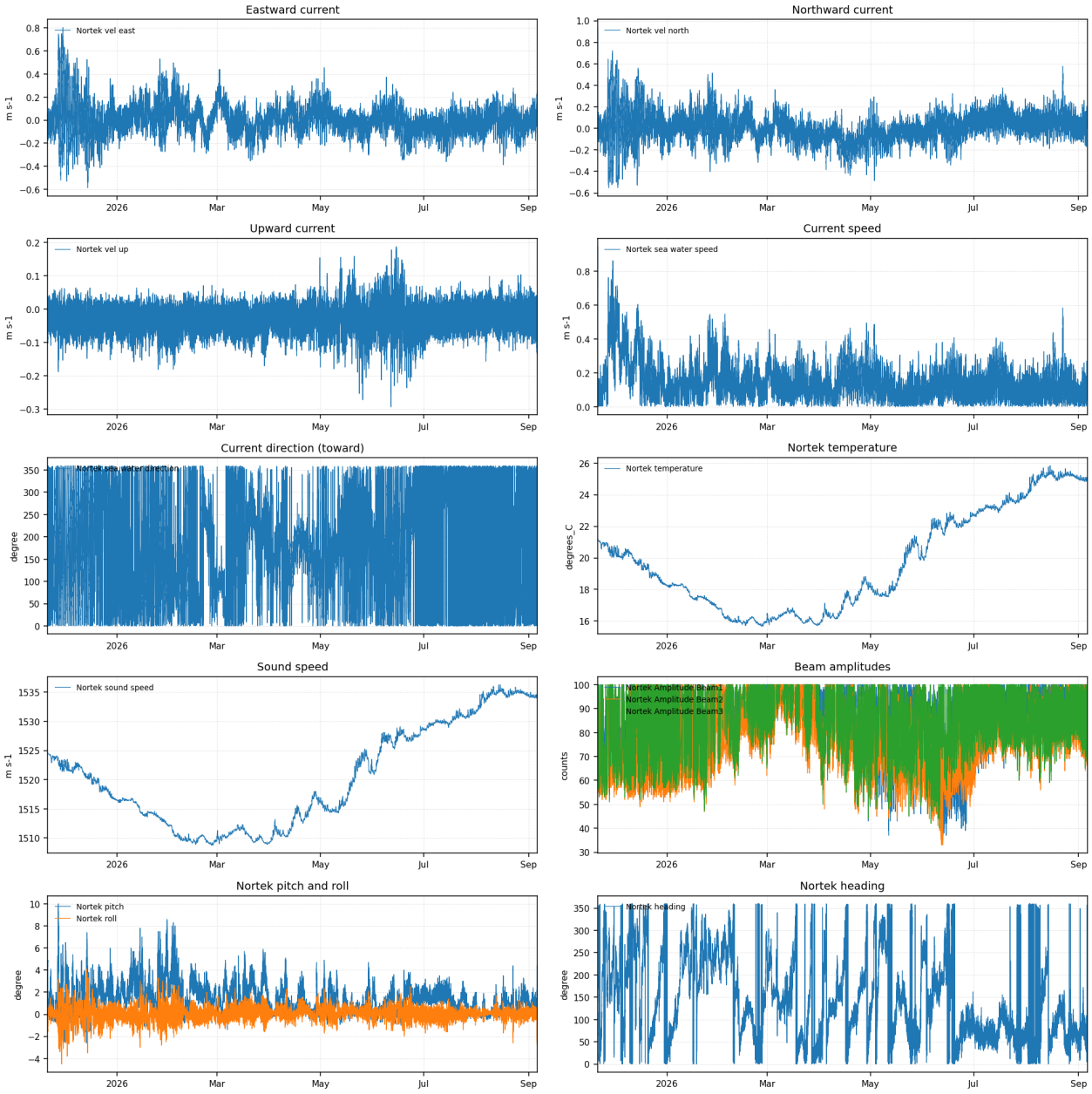


Figure 10: Five-minute SAFARI observations: Eastward current; Northward current; Upward current; Current speed; Current direction (toward); Nortek temperature; Sound speed; Beam amplitudes; Nortek pitch and roll; Nortek heading. Nortek five-minute records are retained without re-averaging or platform motion correction. Current direction is measured toward, clockwise from north.

5 Level-4 Data Processing

5.1 Processing Provenance

The SAFARI L4 beta product uses uop_coare (COARE 3.6, version 1.3.1) to calculate bulk air–sea fluxes from twenty-minute means of the five-minute L3 observations. Processing source: d43c0a5a8252 (`github.com/jtomfarrar/SAFARI_buoy_processing`).

5.2 Input Selection and Processing

L4 uses one configured source per input role: ASIMET supplies wind speed and direction, pressure, radiation, processed rain rate, SST, and practical salinity; HC2A supplies air temperature and relative humidity; SBG supplies position; and Nortek supplies current. WXT, SR30, and the Campbell CR6 logger SBE37 are retained for sensor comparison and are not substituted into L4. The five-minute comparison of available sensors is shown in Figure 11; the selected, averaged inputs passed toward COARE are shown in Figure 12. Nortek eastward and northward currents are smoothed with a centered one-hour running mean of twelve five-minute records, then averaged to twenty minutes. The measured wind is converted to a vector and the current is subtracted inside uop_coare. ASIMET wind direction is stored as wind-to; adding 180 degrees converts it to the meteorological wind-from convention expected by COARE. Magnetic correction was already applied at a lower processing level; no additional magnetic correction is applied here.

Scalar inputs. Instrument heights are read from the INST_* metadata of the selected source variables; reference heights are 10 m for wind and 2 m for temperature and humidity. Wave phase speed and significant wave height are unspecified.

Table 3: Scalar inputs to COARE 3.6. Instrument heights are read from the selected sensor metadata.

Setting	Value	Units
zi	600.0	m
zrf_u	10.0	m
zrf_t	2.0	m
zrf_q	2.0	m
coolskin	True	–
albedo	Payne1972	–
wind_direction	wind_direction_ASIMET (to; +180 deg passed to COARE)	–
zu	wind_speed_ASIMET: 2.67	m
zt	air_temperature_HC2A: 2.28	m
zq	relative_humidity_HC2A: 2.28	m

Input screening and flux policies.

1. Remove nonfinite fill values, reject variables marked all bad, and apply variable-specific ranges; missing or rejected inputs remain missing.

2. Form twenty-minute means only when all 4 constituent five-minute inputs are accepted for that variable; wind direction uses a circular mean. Incomplete boundary bins are excluded.

3. Require zero Nortek error codes and complete twelve-sample current-smoothing windows. Intervals without valid currents remain missing; there is no wind-only calculation or L4 gap filling.

4. Average signed ASIMET rainfall before imposing the COARE nonnegative policy. Means between -0.5 and 0 mm hr^{-1} are assigned zero; means below -0.5 or above 100 mm hr^{-1} are rejected. The signed mean and policy flag are retained.

5. Run COARE only where every required input is finite.

Albedo processing. The selected shortwave albedo method is Payne1972. The COARE implementation follows Payne (1972) using a lookup table indexed by solar altitude and atmospheric shortwave transmission, estimated as measured downwelling shortwave divided by clear-sky solar irradiance at the surface; transmission is capped at 2 for the lookup. The resulting ocean albedo varies with solar altitude and atmospheric conditions, and is generally lower at high solar altitude near local noon than at low sun angles. Solar geometry is calculated from time and position. Net solar radiation is downwelling shortwave multiplied by one minus albedo. The albedo is saved in the L4 product and is set to zero when the sun is below the horizon (Payne, 1972). COARE also offers a constant albedo of 0.055; this product does not use that option.



Figure 11: Available sensor candidates within the deployment crop, including corrected rain-rate series, corroborated-despiked salinity, ASIMET/WXT wind direction and the five-minute Nortek current. ASIMET rain, SST, and salinity are the configured L4 inputs; PRC/WXT rain are comparison series. The Campbell CR6 SBE37 is a comparison sensor and is not an L4 input. ASIMET and Campbell each have their own SBE37, identified by logger name.

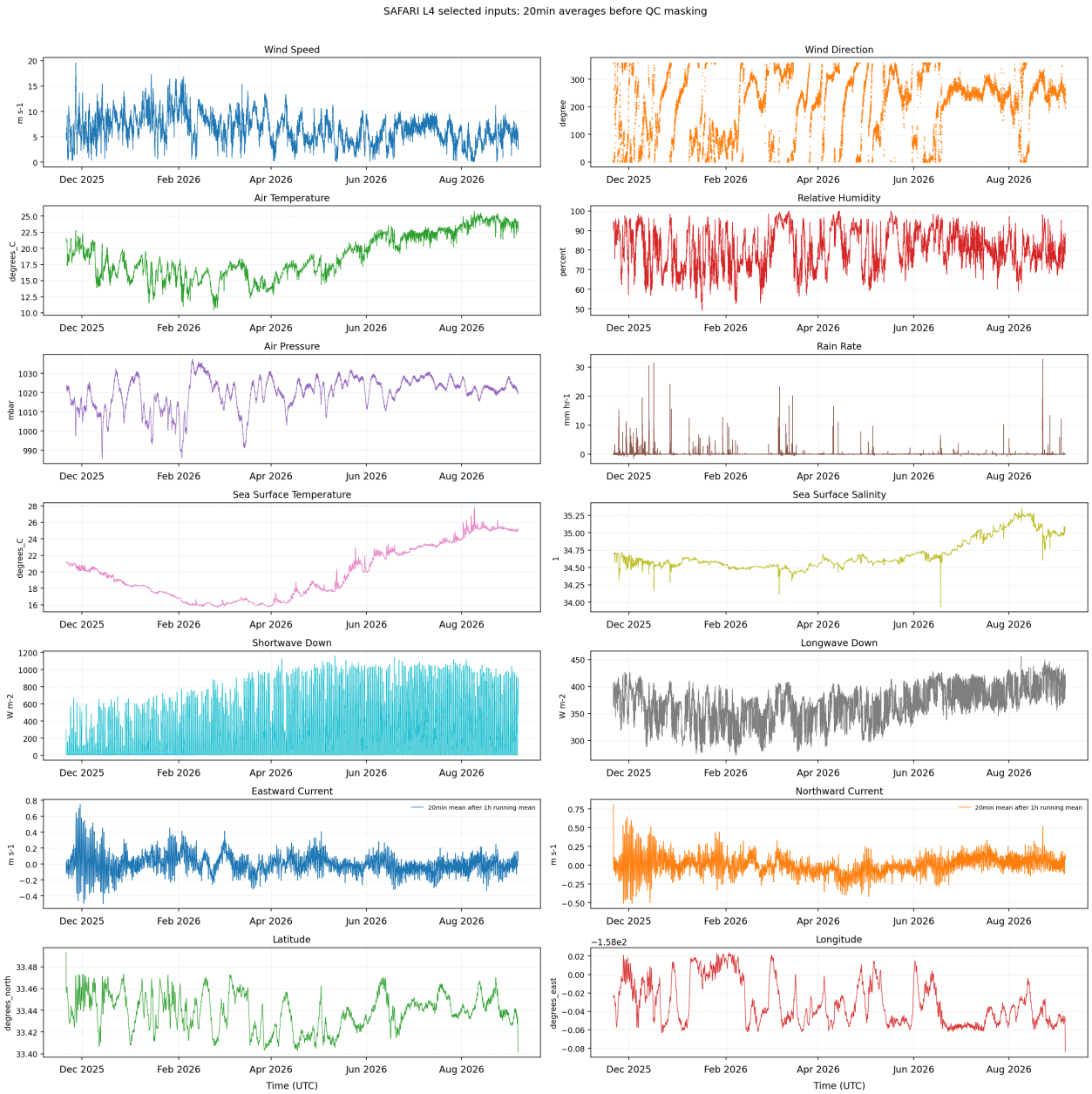


Figure 12: Selected L4 inputs: 20-minute averages of the five-minute L3 observations, before L4 screening. Unlike the preceding five-minute candidate comparison, this figure shows the selected, averaged inputs used by the L4 calculation. Rain rates retain signed values before the nonnegative COARE input policy; the eastward and northward Nortek currents show only the 20-minute means after 1-hour running averaging, as supplied to COARE.

5.3 Overview of Main Level-4 Variables

Stored flux sign conventions follow the L4 metadata: sensible, latent, and net radiative heat fluxes are positive when heating the ocean; COARE rain heat flux is positive when cooling the ocean. Figures show stored twenty-minute values without additional smoothing.

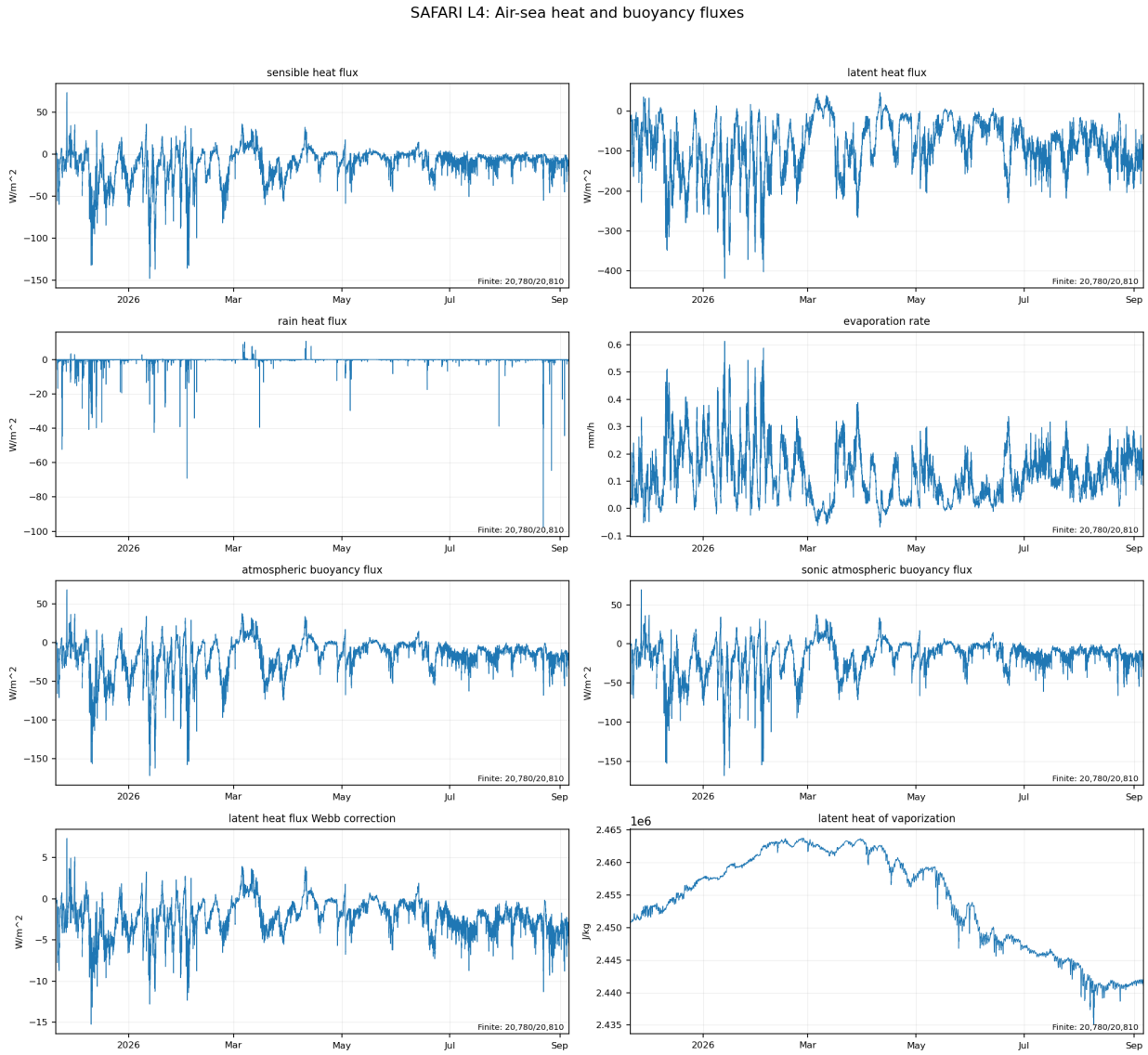


Figure 13: Air-sea heat and buoyancy fluxes. All stored twenty-minute values are shown; missing values break the curves.

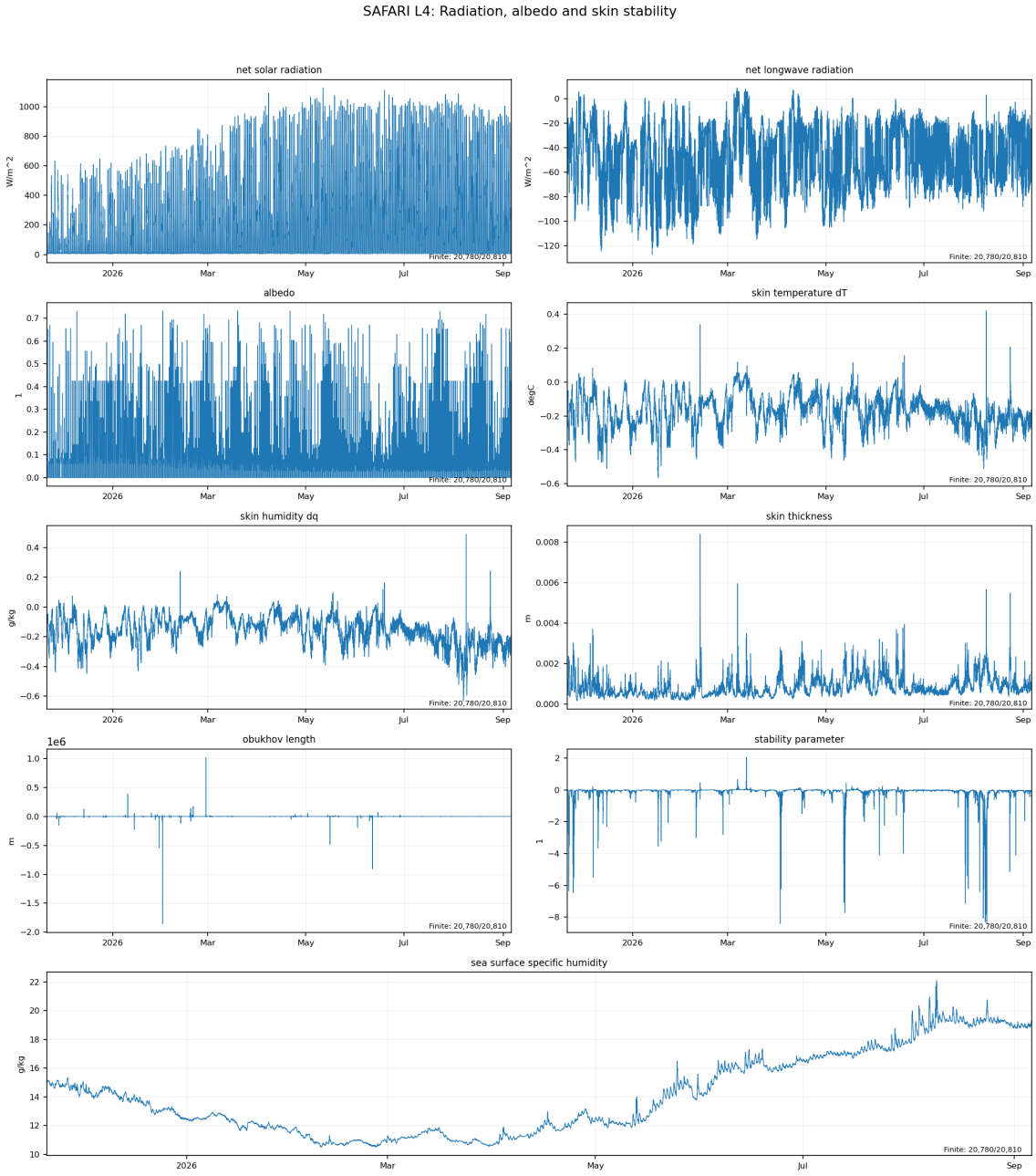


Figure 14: Radiation, albedo and skin stability. All stored twenty-minute values are shown; missing values break the curves.

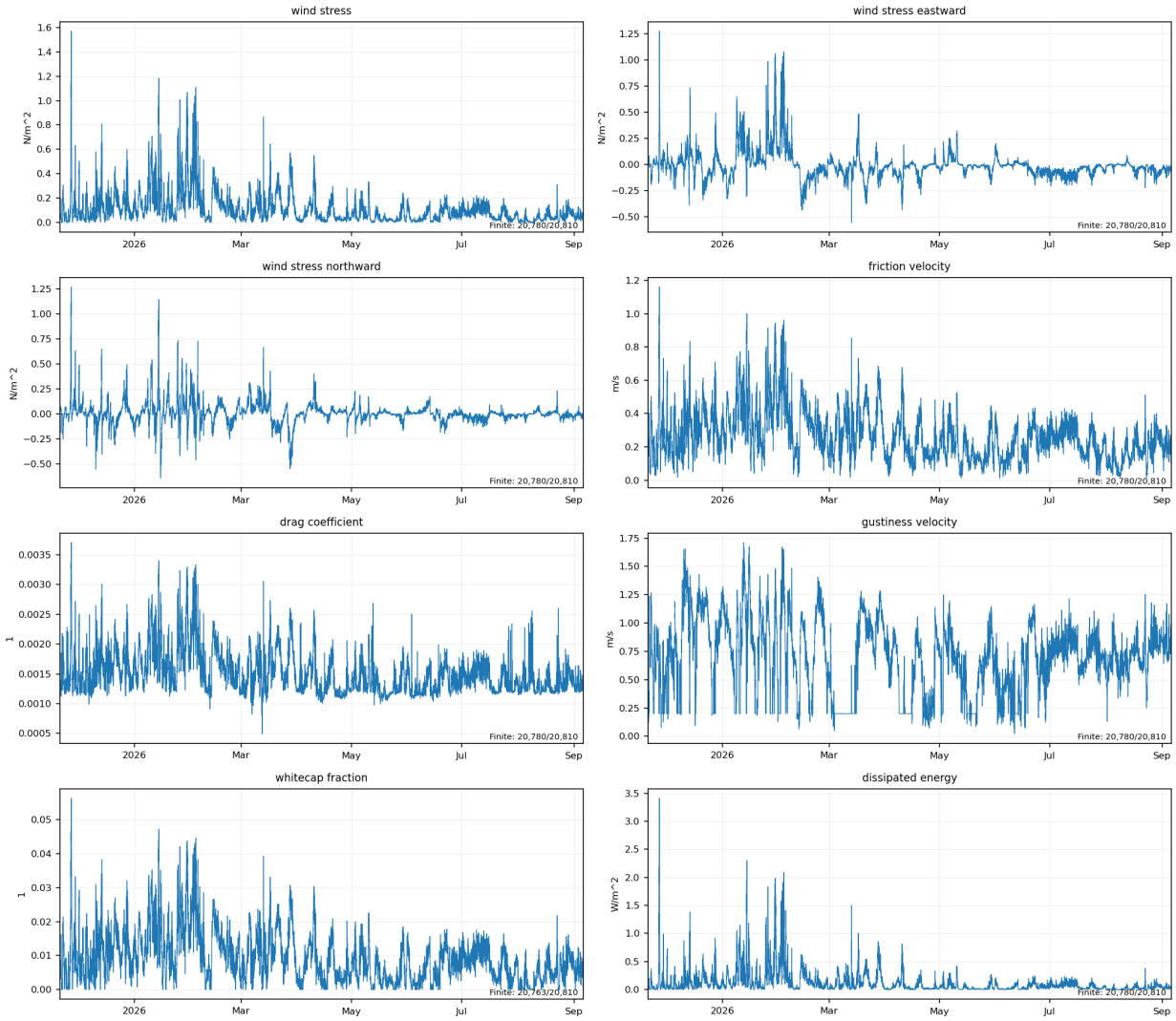


Figure 15: Momentum and surface exchange. All stored twenty-minute values are shown; missing values break the curves.

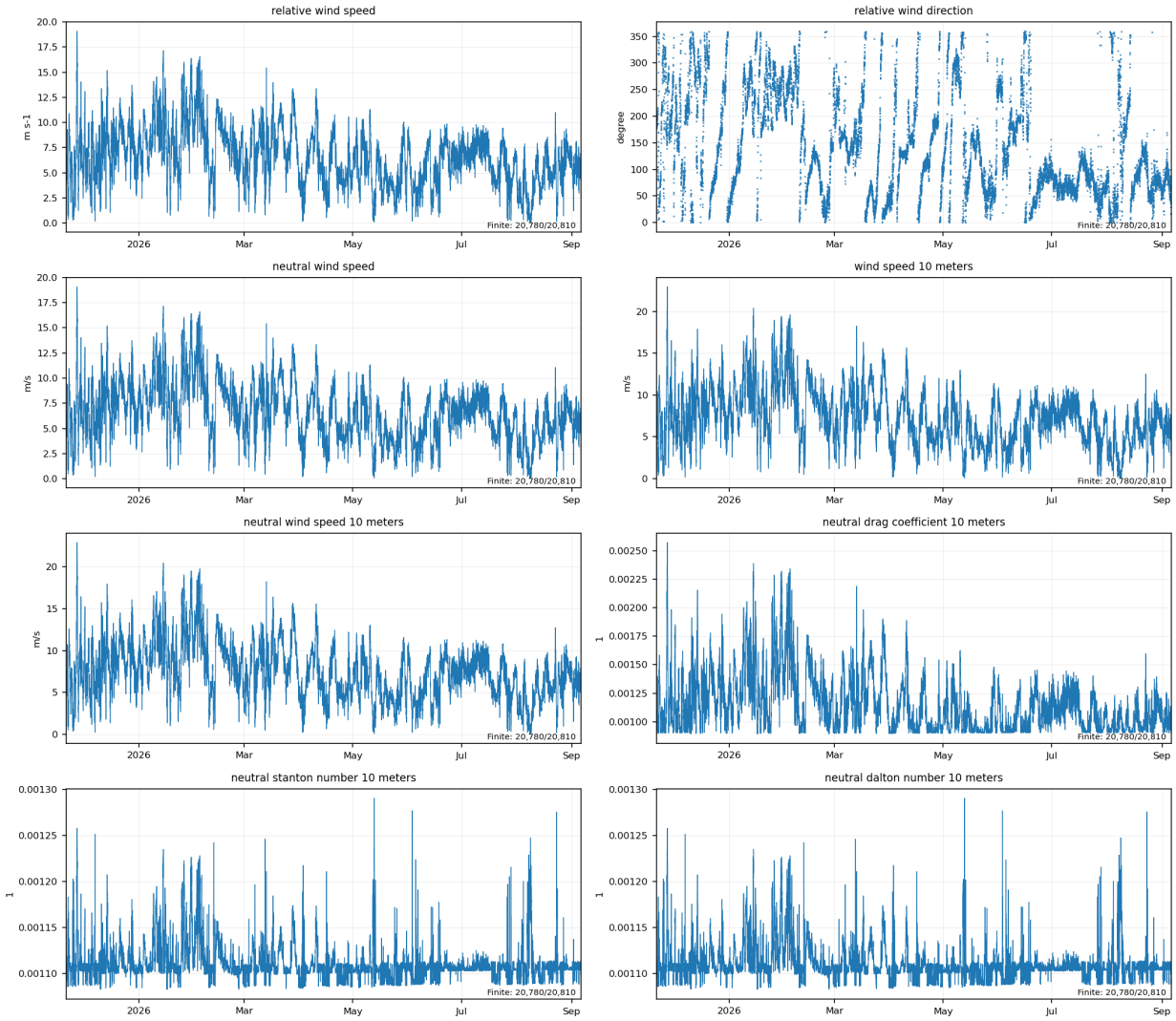


Figure 16: Current-relative wind and neutral exchange coefficients. All stored twenty-minute values are shown; missing values break the curves.

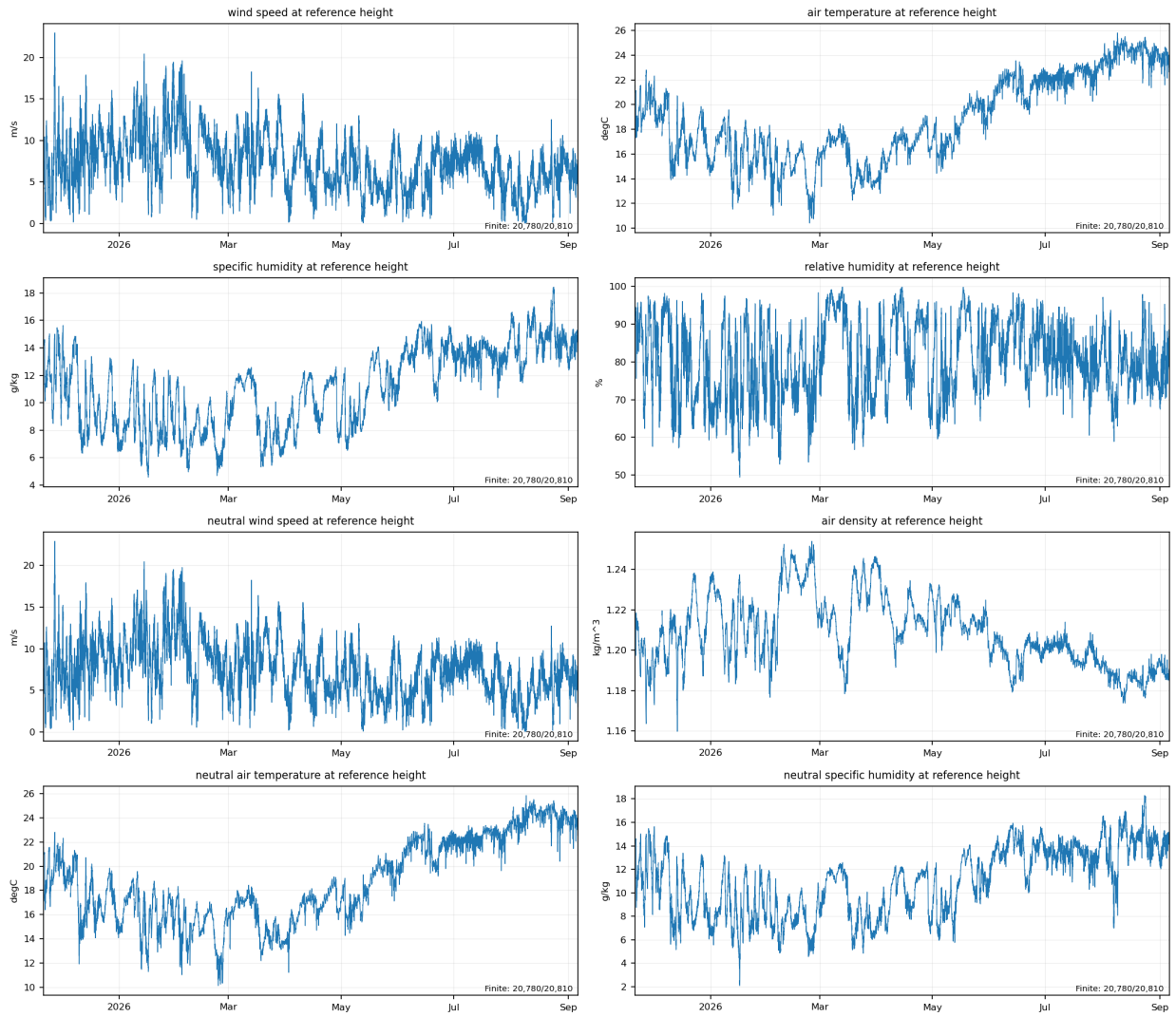


Figure 17: Reference-height atmospheric variables. All stored twenty-minute values are shown; missing values break the curves.

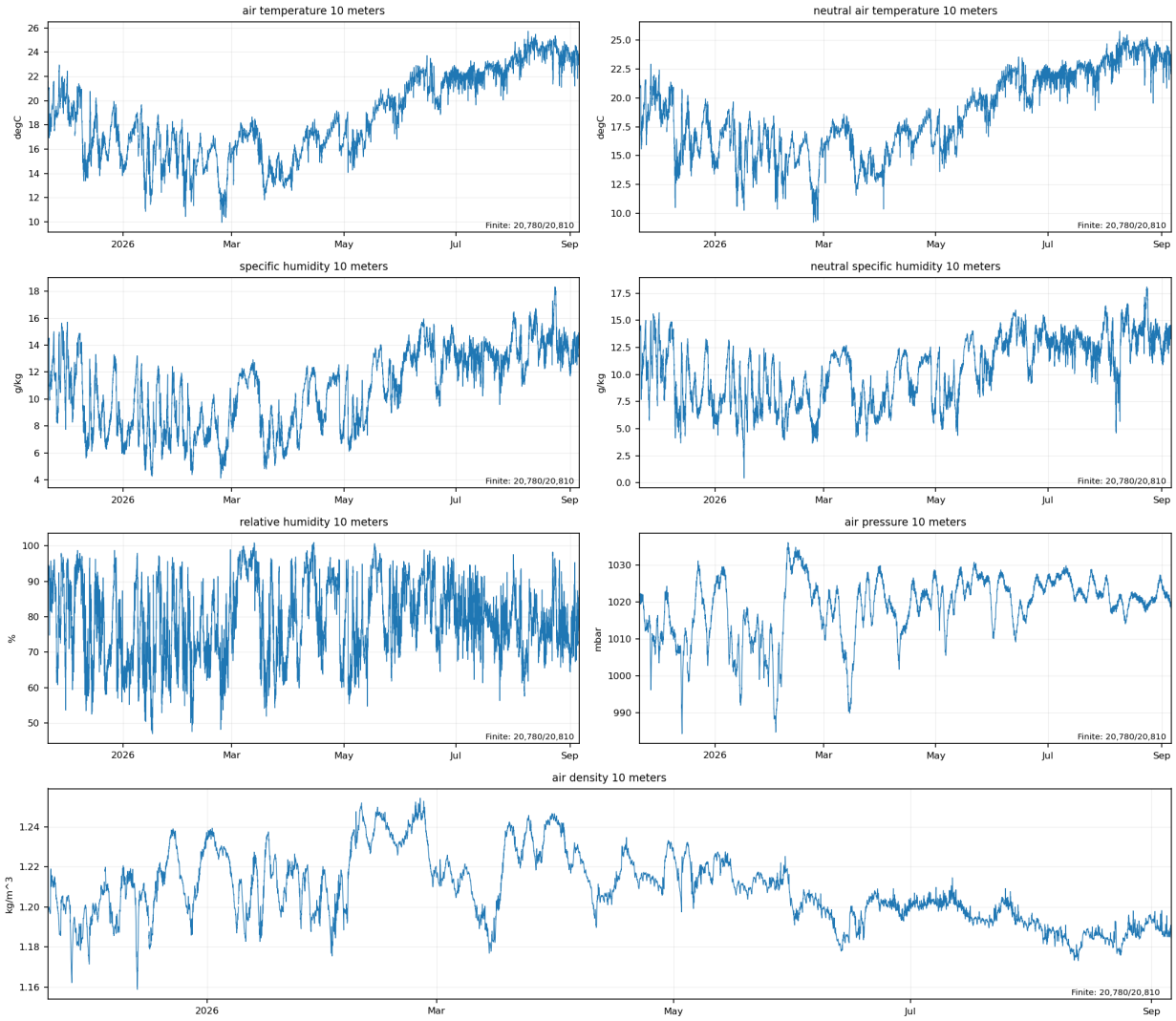


Figure 18: Ten-meter atmospheric variables. All stored twenty-minute values are shown; missing values break the curves.

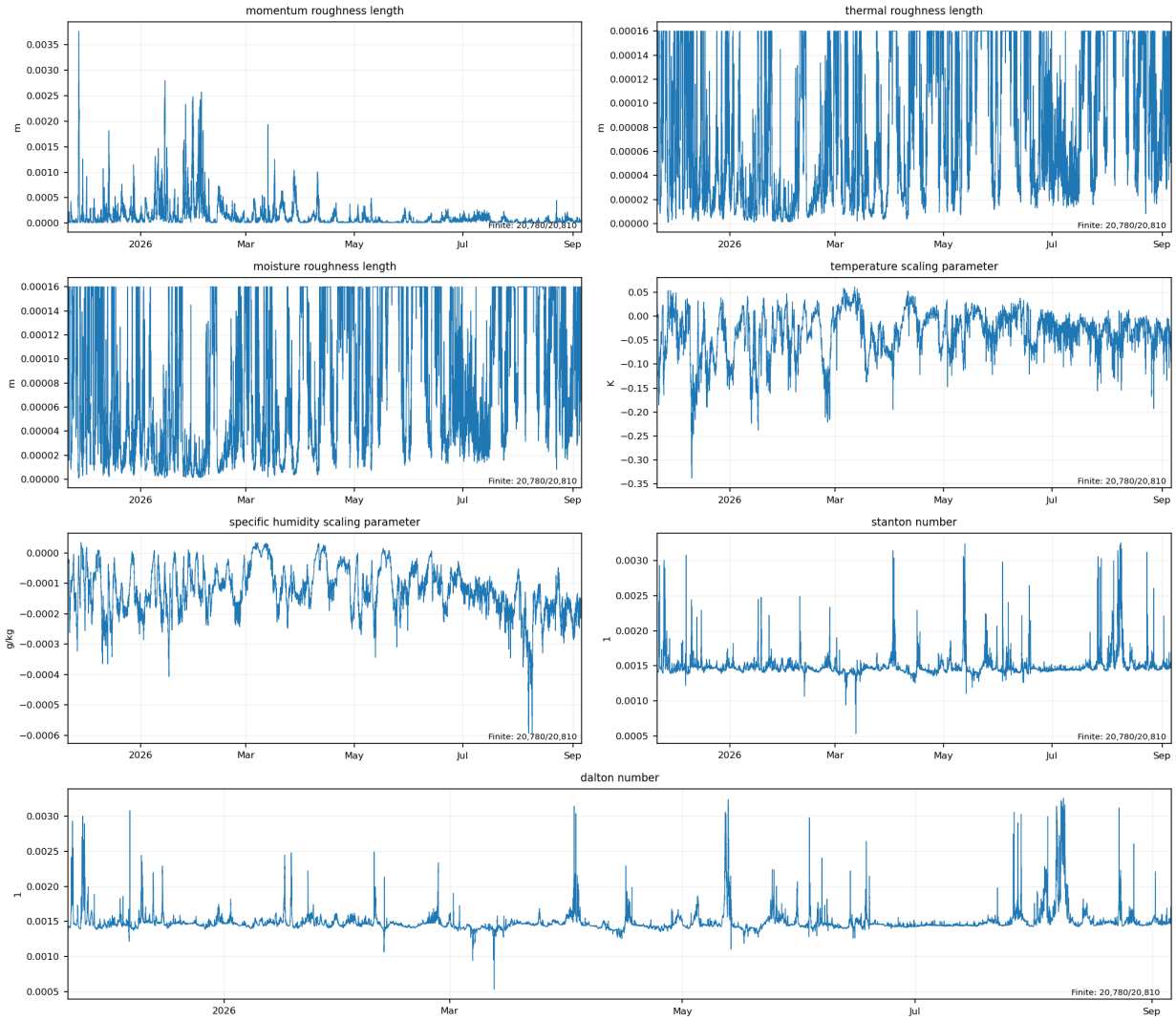


Figure 19: Roughness and scaling parameters. All stored twenty-minute values are shown; missing values break the curves.

6 References

Fairall, C. W., E. F. Bradley, J. E. Hare, A. A. Grachev, and J. B. Edson (2003). Bulk Parameterization of Air–Sea Fluxes: Updates and Verification for the COARE Algorithm. *Journal of Climate*, 16(4), 571–591.

IOC, SCOR, and IAPSO (2010). *The International Thermodynamic Equation of Seawater – 2010: Calculation and Use of Thermodynamic Properties*. Intergovernmental Oceanographic Commission, Manuals and Guides No. 56.

Payne, R. E. (1972). Albedo of the Sea Surface. *Journal of the Atmospheric Sciences*, 29(5), 959–970.

A Navigation and Platform Diagnostics

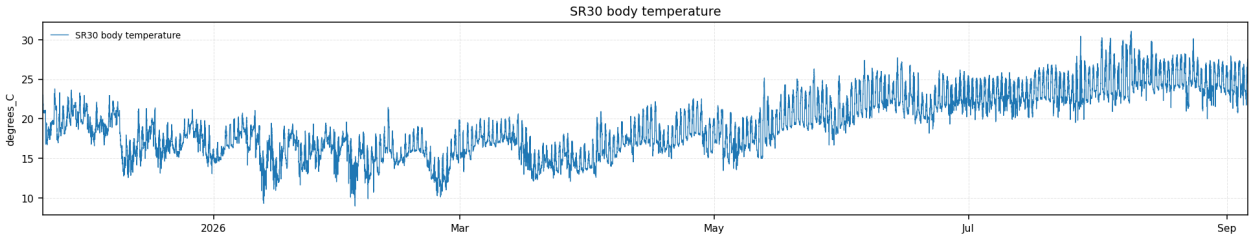


Figure 20: Five-minute SAFARI observations: SR30 body temperature. SR30 body temperature is retained as an instrument diagnostic and is not a COARE input.

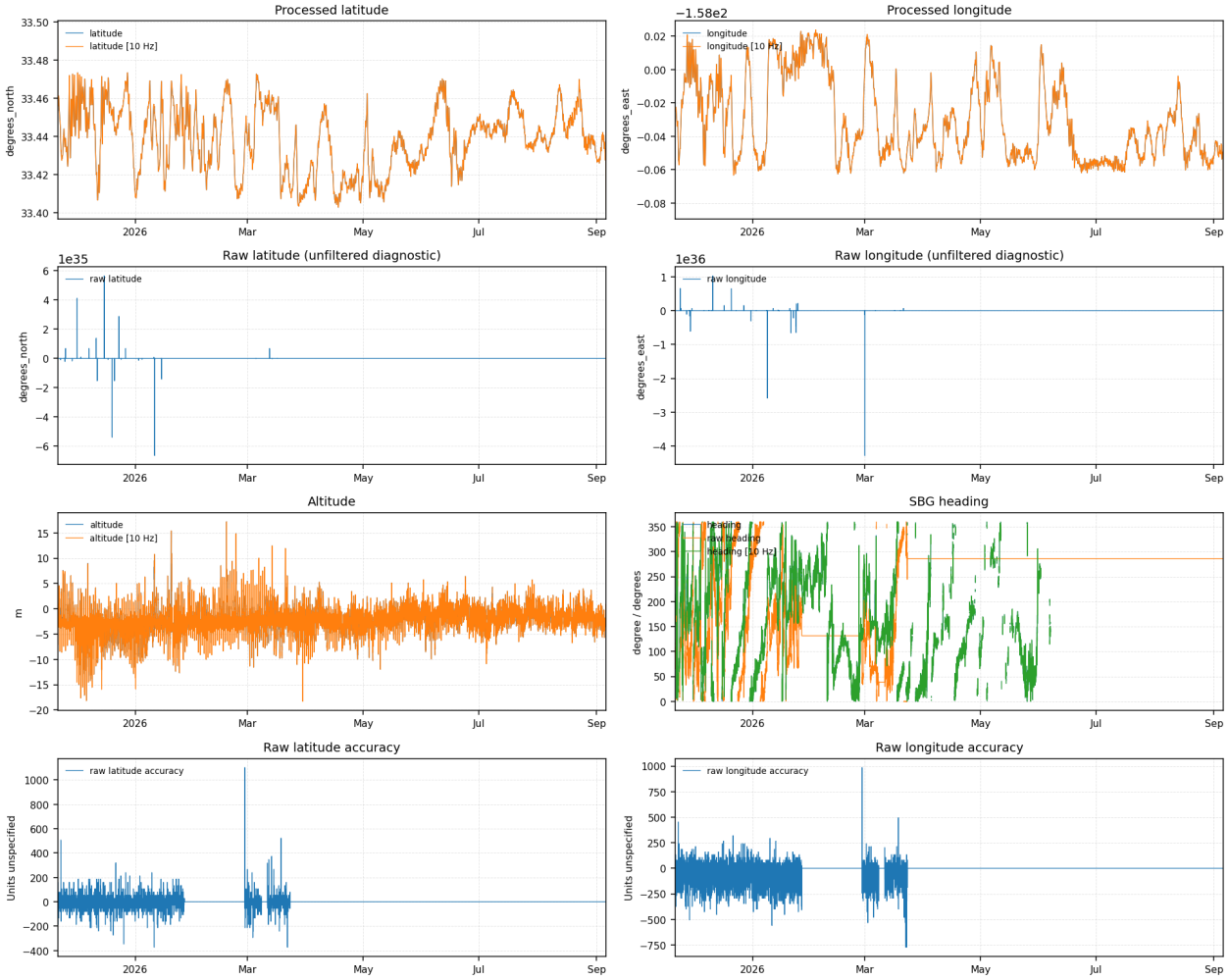


Figure 21: Five-minute SAFARI observations: Processed latitude; Processed longitude; Raw latitude (unfiltered diagnostic); Raw longitude (unfiltered diagnostic); Altitude; SBG heading; Raw latitude accuracy; Raw longitude accuracy. Processed and raw GPS position and orientation measurements are distinguished by their labels. Circular wrap crossings are broken for display only.

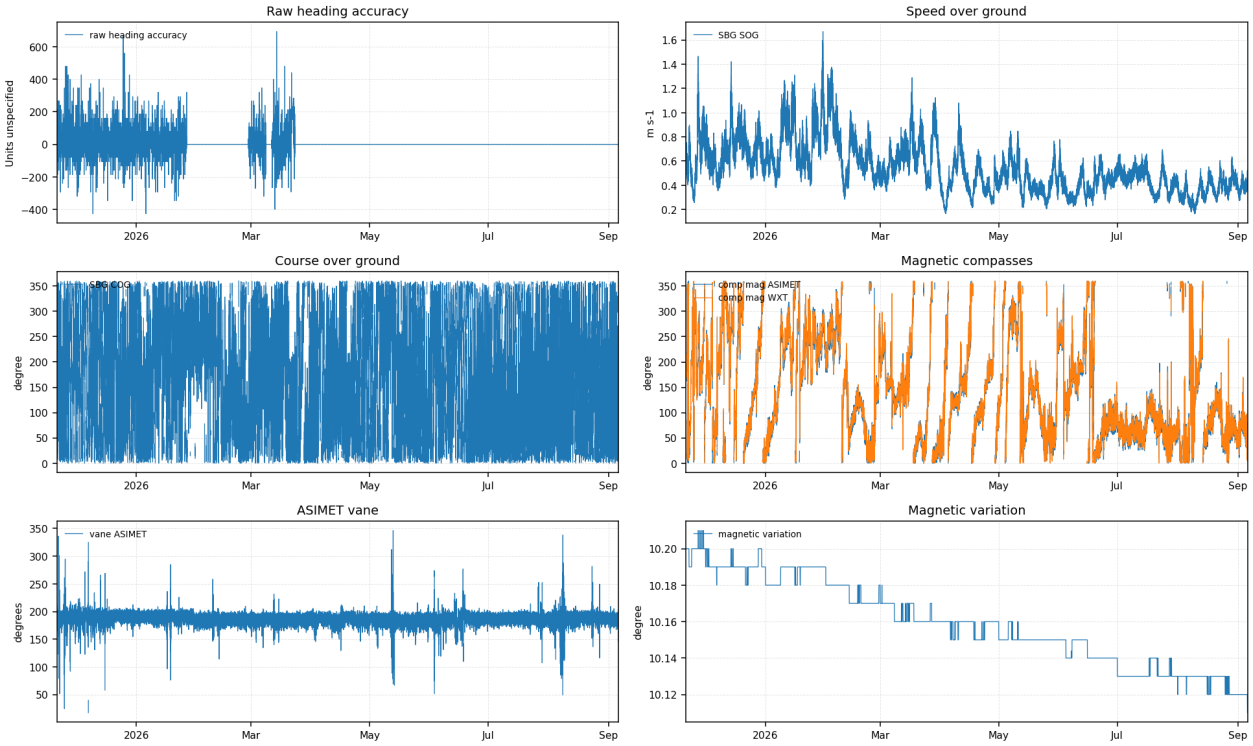


Figure 22: Five-minute SAFARI observations: Raw heading accuracy; Speed over ground; Course over ground; Magnetic compasses; ASIMET vane; Magnetic variation. Processed and raw GPS position and orientation measurements are distinguished by their labels. Circular wrap crossings are broken for display only.

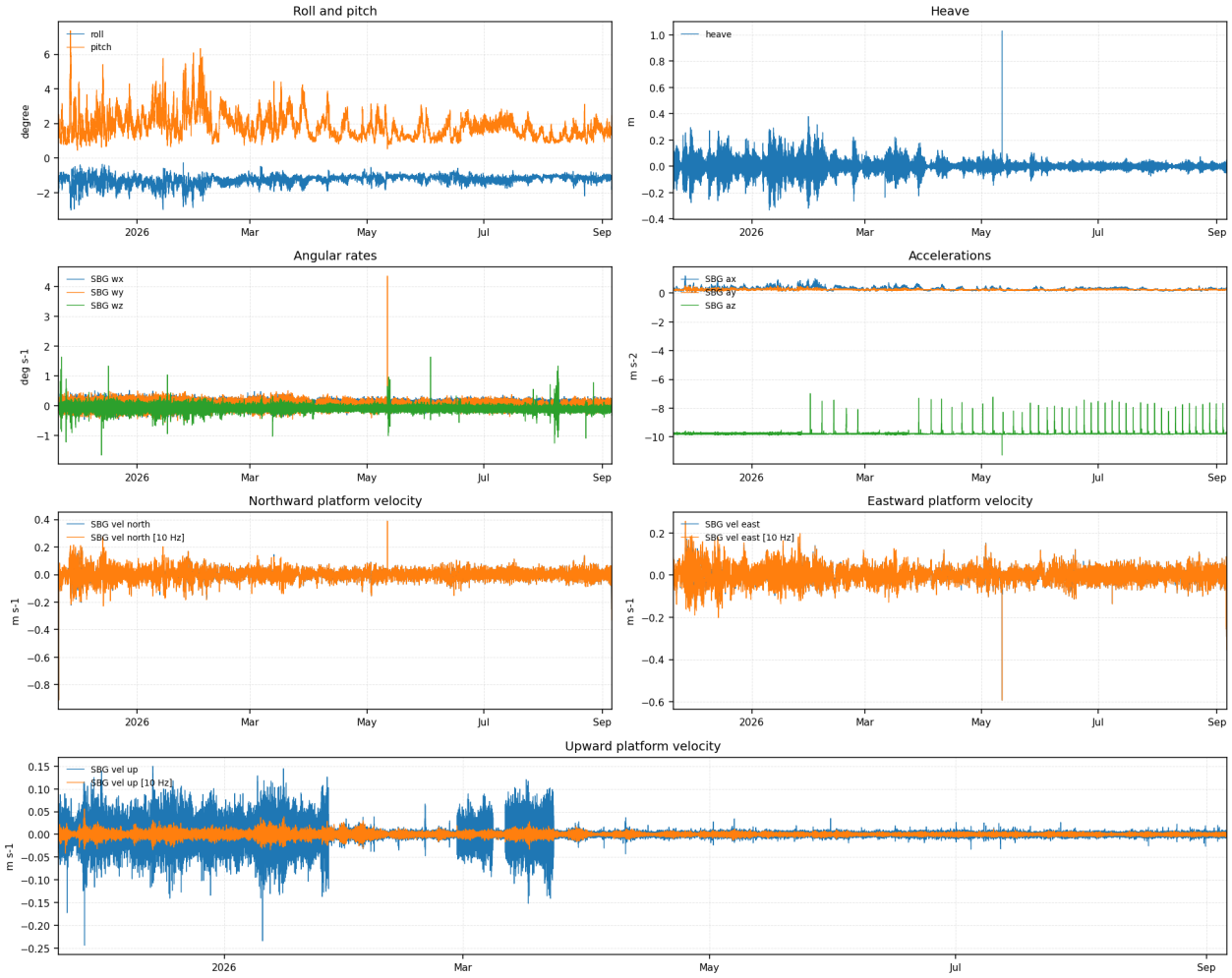


Figure 23: Five-minute SAFARI observations: Roll and pitch; Heave; Angular rates; Accelerations; Northward platform velocity; Eastward platform velocity; Upward platform velocity. Five-minute SBG platform-motion measurements; these averages do not resolve the native wave spectrum.

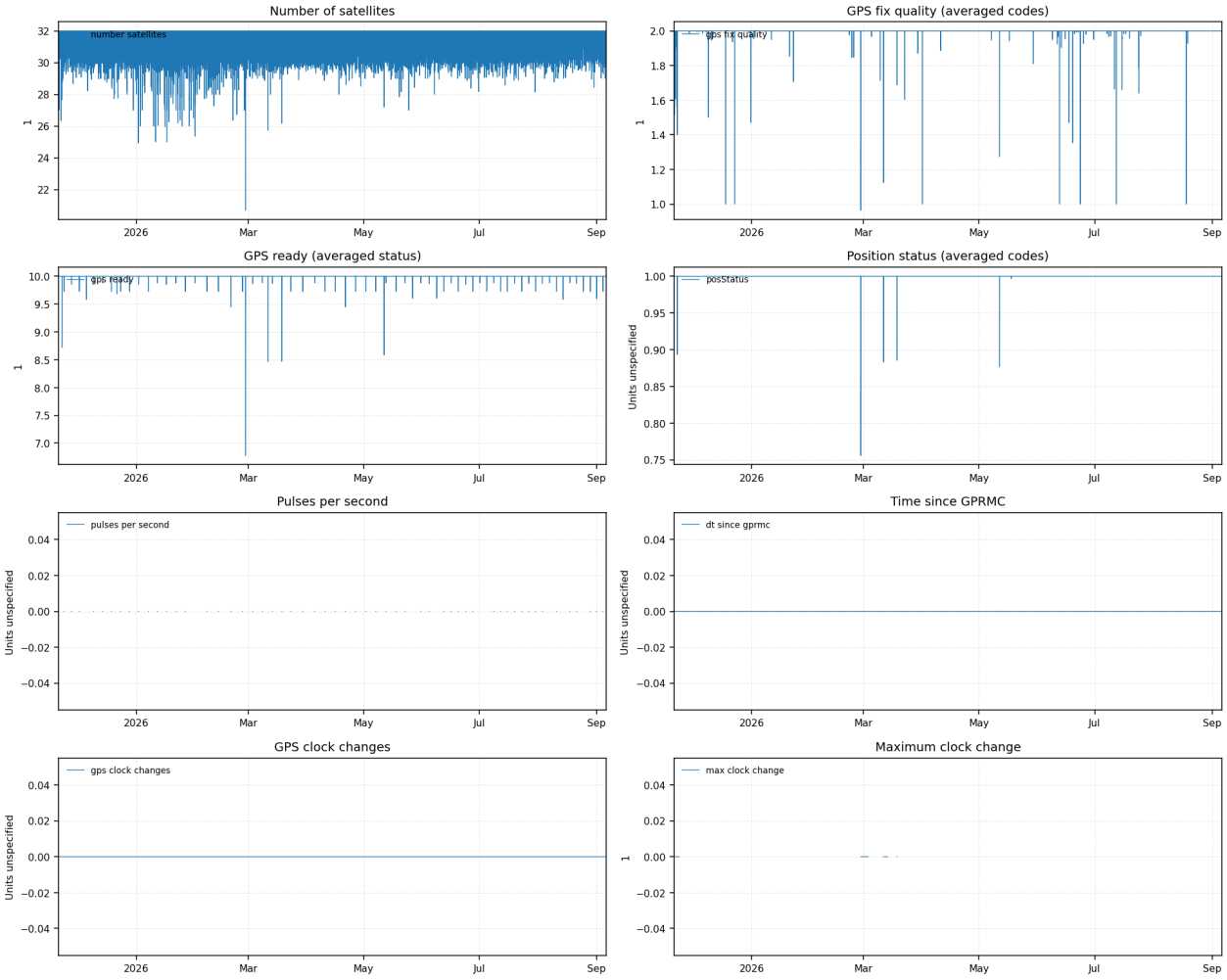


Figure 24: Five-minute SAFARI observations: Number of satellites; GPS fix quality (averaged codes); GPS ready (averaged status); Position status (averaged codes); Pulses per second; Time since GPRMC; GPS clock changes; Maximum clock change. GPS reception, clock, and status diagnostics averaged onto the five-minute time axis. Averaged codes are not categorical quality flags.

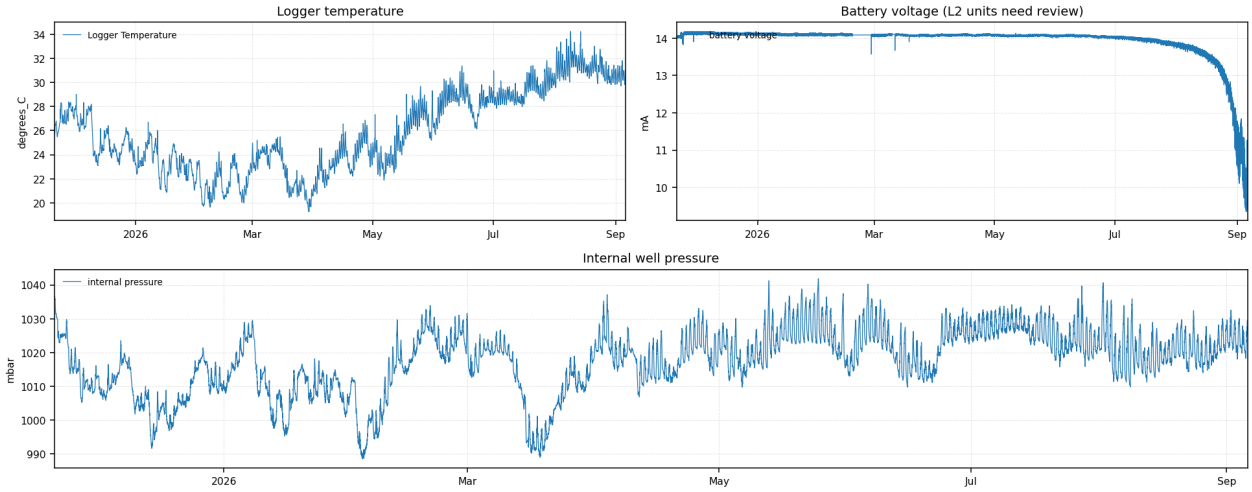


Figure 25: Five-minute SAFARI observations: Logger temperature; Battery voltage (L2 units need review); Internal well pressure. Buoy engineering measurements on the five-minute time axis; source units are retained.