OCEANS AND ATMOSPHERE
www.csiro.au

Southern Ocean Time Series (SOTS) Quality Assessment and Control Report Temperature Records

Version 2.0

2006-2020

Peter Jansen, Elizabeth Shadwick, Thomas W. Trull
April 2021

Citation

Jansen P, Shadwick EH and Trull TW (2021). Southern Ocean Time Series (SOTS) Quality Assessment and Control Report Temperature Records Version 2.0. CSIRO, Australia. DOI: 10.26198/gfgr-fq47 (https://doi.org/10.26198/gfgr-fq47)

Copyright

Important disclaimer

Contents

Figures

Tables

Acknowledgments

SOTS is supported by the NCRIS IMOS program, CSIRO Oceans and Atmosphere, Bureau of Meteorology, Antarctic Climate and Ecosystems CRC, Australian Marine National Facility, Australian Antarctic Program Partnership, and Australian Antarctic Division. Data was sourced from Australia's Integrated Marine Observing System (IMOS) – IMOS is enabled by the National Collaborative Research Infrastructure Strategy (NCRIS). It is operated by a consortium of institutions as an unincorporated joint venture, with the University of Tasmania as Lead Agent.

Executive summary

The Southern Ocean Time Series (SOTS) Observatory located near 141°E and 47°S provides high temporal resolution observations in Subantarctic waters. It is focused on the Subantarctic Zone because waters formed at the surface in this region by deep wintertime convection slide under warmer subtropical and tropical waters, carrying CO_2 and heat into the deep ocean, where it is out of contact with the atmosphere. This process also supplies oxygen for deep ocean ecosystems, and exports nutrients that fuel ~70% of global ocean primary production. Local biological production also impacts carbon cycling and the SOTS moorings measure several variables important to these processes.

This report describes the quality control (QC) procedures applied to temperature data collected from the SOTS moorings between 2006 and 2019. These measurements quantify heat and fresh water transfers, help to distinguish Eulerian from Lagrangian influences on seasonal records, and contribute to understanding controls on surface mixed layer depth (and thus light availability to primary production). The quality-controlled datasets are publicly available via the Australian Ocean Data Network (AODN) Portal. This report should be consulted when using the data.

The QC procedures apply automated tests following QARTOD recommendations for in-situ temperature and salinity data quality control (Bushnell and Worthington, 2020), with the test parameters tailored to reflect regional oceanography. QARTOD is an initiative of the US Integrated Ocean Observing System for Quality Assurance of Real Time Oceanographic Data: https://ioos.noaa.gov/project/qartod/. The procedures detailed in this document yield QC flags for each observation, as well as uncertainty estimates for the overall results. They also now provide some temperature adjustments, but do not produce a gridded data set (that task will be addressed in a subsequent report).

Document Versions

Version 1.0 of this report provided QC flags, but without production of adjusted or gridded data.

Version 2.0 (this report) now also provides adjusted temperatures.

The adjustment process is described in an expanded section 6.5. The adjusted values overwrite the previous temperature values, with their QC flags changed from '3 probably bad but potentially adjustable' to '2 probably good'. The adjustments are indicated in the attributes of the netCDF data file, and the filename follows the IMOS FV01 nomenclature to indicated that values have been adjusted. The raw temperature data remain available in the FV00 file.

1 Introduction

The Southern Ocean Time Series (SOTS) Observatory provides high temporal resolution observations in Subantarctic waters. Observations are broad and include measurements of physical, chemical and biogeochemical parameters from multiple deep-water moorings in the Subantarctic Zone southwest of Tasmania (Figure 1). The emphasis is on seasonal and inter-annual variations of lower atmosphere and upper ocean properties and their influence on exchange with the deep ocean. The continuous time-series information allows the study of ocean physics and chemistry, climate change, carbon cycling and biogeochemical controls on marine productivity. These moorings provide cost-effective observations and overcome the infrequent availability of ships in the region. The Southern Ocean Time Series is an Australian contribution to the international OceanSITES global network of time series observatories (www.OceanSITES.org) and is one of the few comprehensive Southern Ocean sites globally. More information on the SOTS Sub-Facility is available on-line at http://www.imos.org.au/.

The Southern Ocean (south of 30°S) is responsible for ~40% of the total global ocean uptake of human-induced CO_2 emissions, and 75% of the additional heat that these emissions have trapped on Earth. The Southern Ocean Time Series site is focused on the Subantarctic Zone because waters formed at the surface in this region, the Subantarctic mode and Antarctic Intermediate waters, slide under warmer subtropical and tropical waters and carry this CO_2 and heat into the deep ocean, out of contact with the atmosphere. This process also supplies oxygen for deep ocean ecosystems, and exports nutrients that fuel ~70% of global ocean primary production. The Subantarctic Zone and these processes are expected to change with global warming but the potential impacts of these changes are not yet known.

The Southern Ocean Time Series site southwest of Tasmania is comprised of a number of elements including a deep ocean sediment trap mooring (SAZ), a surface biogeochemistry mooring (Pulse) and an air-sea flux mooring (SOFS). Located in the Subantarctic Zone near 141°E, 47°S, the site is particularly vulnerable to the extreme weather events that typify the area including very large waves, strong currents and severe storms, presenting significant technical and engineering challenges.

The SOTS site (red star in Figure 1) is located in a low current region, north of the Subantarctic Front (SAF) that marks the northern edge of the Antarctic Circumpolar Current. It is located in deep waters (>4500m) west of the Tasman Rise (the shallow region south of Tasmania; with waters less than 2000m deep, shown in blue). The SOTS site exhibits oceanographic properties representative of the Australian sector of the Subantarctic Zone (from ~90 to 145 °E; Trull et al., 2001). Waters flowing southward in the East Australian Current reach this region by transiting through channels in the Tasman Rise (Herraiz-Borreguero et al., 2011).

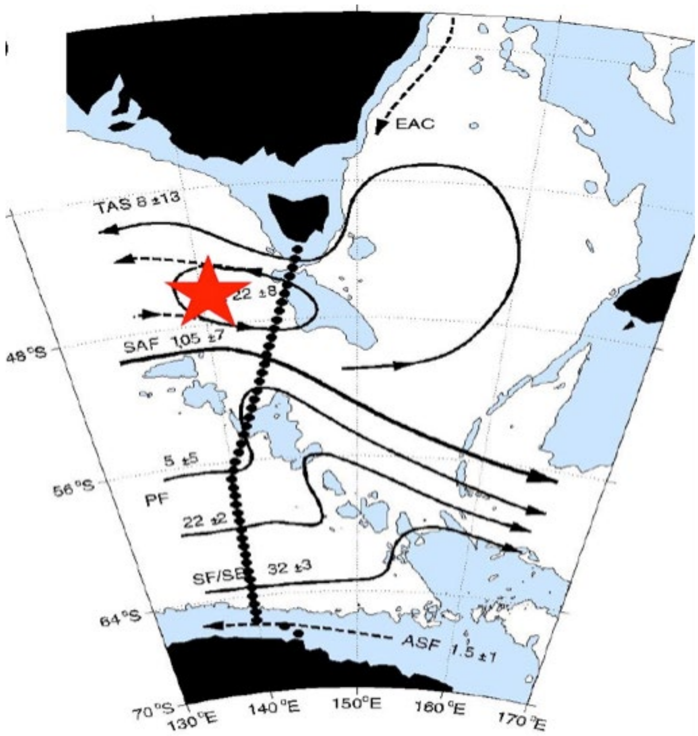


Figure 1. Location of the SOTS observatory.
EAC – East Australia Current, TAS – Tasman Sea Leakage, SAF-Subantarctic Front, PF-Polar Front, SF/SB – Slope Front/Southern Boundary, ASF, Antarctic Shelf Flow. Adapted from Herraiz-Borreguero et al., 2011

2 Moorings Description

The Southern Ocean Time Series moorings are the Pulse biogeochemistry mooring, the Subantarctic Zone (SAZ) sediment trap mooring, and the Southern Ocean Flux Station (SOFS).

The Pulse biogeochemistry mooring is used to measure upper ocean carbon cycle and phytoplankton productivity processes. Measured parameters include temperature, salinity, dissolved oxygen, total dissolved gases, nitrate, chlorophyll fluorescence and optical particulate backscatter. This mooring also collects water samples for measurements of dissolved carbon and nutrients, and phytoplankton microscopic identification.

The SAZ sediment trap mooring collects sinking particles to quantify carbon fluxes, and provides current meter measurements and a deep ocean CTD to measure heat contents below the depth of Argo profiling float measurements.

The SOFS meteorological tower mooring has dual sets of incoming solar radiometers, temperature and humidity sensors, precipitation gauges and sonic anemometers, and a pCO_2 sensor provided by NOAA. Surface photosynthetically active radiation (PAR) is also measured to help assess light available for phytoplankton production.

All three moorings are anchored to the ocean floor ~4.5 kilometres below the surface. The SOFS and Pulse moorings are s-tether designs that are longer than this, and correspondingly their surface floats move in large 'watch circles'. In contrast, the SAZ mooring is a stiff subsurface mooring with all components more than 700m below the surface. The moorings record hourly sensor observations until they are swapped with a duplicate mooring the following year.

In the 2016-17 year, the SOFS and Pulse capabilities were combined into a single prototype mooring known as FluxPulse-1. After this initial trial, the combined mooring nomenclature continued using the SOFS prefix.

Surface data collected from Pulse and SOFS are relayed back by satellite. The sub-surface data are stored and downloaded when the moorings are retrieved (approximately a year later). All data are available via the Australian Ocean Data Network (AODN) Portal.

3 Summary of Instruments

A total of ten different instrument types for measuring ocean temperature were deployed at SOTS between 2006 and 2019. These instruments were deployed on the three different mooring designs, at varying depths ranging from the surface to close to the bottom. The specific depths and mounting depths of the sensors for each mooring are provided in the SOTS Annual Sensor Reports. In general, the sensors were deployed as follows:

1. On the Pulse and SOFS moorings, as sets of individually logged instruments spaced from the surface to about 400m depth to determine mixed layer depth.
2. On the SAZ moorings, in association with its sediment traps at ~1000, 2000, and 3800m depth, and an additional near bottom instrument deployed as a contribution to the OceanSITES and Deep Ocean Observing System (DOOS) "Deep Heat Challenge".
3. In two main functional categories:
   i. thermistors alone
   ii. thermistors paired with any or all of the following: pressure sensors, conductivity cells to determine salinity, dissolved oxygen sensors.

Data logging was in all cases internal to the instruments, and in general was only recovered when the moorings were recovered (with the exception of surface water data telemetered from the SOFS moorings).

Figure 2 shows the times of the mooring deployments. Table 1 lists all the temperature sensors.

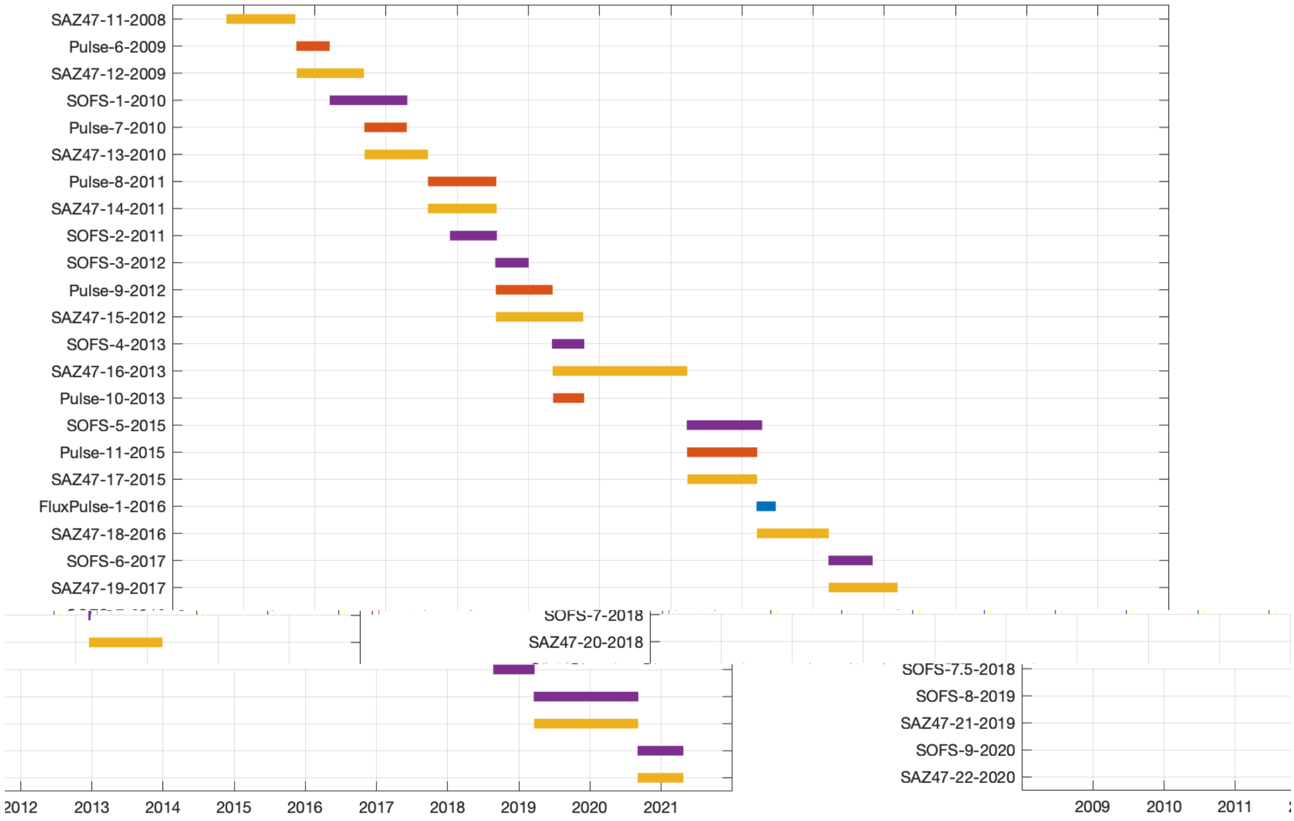


Figure 2 SOTS mooring deployments covered in this report (SAZ in yellow, Pulse in Orange, and SOFS in purple).

Table 1. SOTS Temperature Sensors 2006-2020

Deployment	Depth (m)	Instrument
SAZ45-11-2008	1000	RBR: TDR-2050: 14785
SAZ45-11-2008	2850	RBR: DR1050P: 13294
Pulse-6-2009	37.5	Sea-Bird Electronics: SBE16plusV2: 6331
Pulse-6-2009	45	Vemco: Minilog-Classic: 6098
Pulse-6-2009	50	Vemco: Minilog-Classic: 4823
Pulse-6-2009	55	Vemco: Minilog-Classic: 4824
Pulse-6-2009	60	Vemco: Minilog-Classic: 6100
Pulse-6-2009	65	Vemco: Minilog-Classic: 4825
Pulse-6-2009	70	Vemco: Minilog-Classic: 4826
Pulse-6-2009	75	Vemco: Minilog-Classic: 4827
Pulse-6-2009	85	Vemco: Minilog-Classic: 4828
Pulse-6-2009	100	Sea-Bird Electronics: SBE37SM: 6962
Pulse-6-2009	120	Vemco: Minilog-Classic: 4829
Pulse-6-2009	140	Vemco: Minilog-Classic: 4830
Pulse-6-2009	160	Vemco: Minilog-Classic: 6101
Pulse-6-2009	630	RBR: TDR-2050: 14788
SAZ47-12-2009	1000	RBR: TDR-2050: 14785
SAZ47-12-2009	3800	RBR: DR1050P: 13294
SOFS-1-2010	0.66	Sea-Bird Electronics: SBE37SM: 7409
SOFS-1-2010	1.2	Sea-Bird Electronics: SBE37SM: 1840
SOFS-1-2010	10	Vemco: Minilog-Classic: 6097
SOFS-1-2010	20	Vemco: Minilog-Classic: 4831
SOFS-1-2010	29	Vemco: Minilog-Classic: 4832
SOFS-1-2010	40	Vemco: Minilog-Classic: 4833
SOFS-1-2010	50	Vemco: Minilog-Classic: 4834
SOFS-1-2010	55	Vemco: Minilog-Classic: 4835
SOFS-1-2010	60	Vemco: Minilog-Classic: 4836
SOFS-1-2010	65	Vemco: Minilog-Classic: 4837
SOFS-1-2010	70	Vemco: Minilog-Classic: 4838
SOFS-1-2010	75	Vemco: Minilog-Classic: 6099
SOFS-1-2010	85	Vemco: Minilog-Classic: 4839
SOFS-1-2010	100	Sea-Bird Electronics: SBE37SM: 2971
SOFS-1-2010	110	Vemco: Minilog-Classic: 4840
SOFS-1-2010	120	Vemco: Minilog-Classic: 4841
SOFS-1-2010	140	Vemco: Minilog-Classic: 4842
SOFS-1-2010	160	Vemco: Minilog-Classic: 4843
Pulse-7-2010	31.1	Sea-Bird Electronics: SBE16plusV2: 6331
Pulse-7-2010	45	Vemco: Minilog-Classic: 6098
Pulse-7-2010	50	Vemco: Minilog-Classic: 4823
Pulse-7-2010	55	Vemco: Minilog-Classic: 4824
Pulse-7-2010	60	Vemco: Minilog-Classic: 6100
Pulse-7-2010	65	Vemco: Minilog-Classic: 4825
Pulse-7-2010	70	Vemco: Minilog-Classic: 4826
Pulse-7-2010	75	Vemco: Minilog-Classic: 4827
Pulse-7-2010	85	Vemco: Minilog-Classic: 4828
Pulse-7-2010	100	Sea-Bird Electronics: SBE37SM: 6962
Pulse-7-2010	120	Vemco: Minilog-Classic: 4829

Deployment	Depth (m)	Instrument
Pulse-7-2010	140	Vemco: Minilog-Classic: 4830
Pulse-7-2010	160	Vemco: Minilog-Classic: 6101
Pulse-7-2010	475	RBR: TDR-2050: 14788
Pulse-7-2010	630	RBR: TDR-2050: 14789
SAZ47-13-2010	1000	RBR: TDR-2050: 14785
SAZ47-13-2010	3900	RBR: DR1050P: 13294
Pulse-8-2011	34	Sea-Bird Electronics: SBE16plusV2: 6330
Pulse-8-2011	45	Vemco: Minilog-Classic: 6098
Pulse-8-2011	50	Vemco: Minilog-Classic: 4823
Pulse-8-2011	55	Vemco: Minilog-Classic: 4824
Pulse-8-2011	60	Vemco: Minilog-Classic: 6100
Pulse-8-2011	65	Vemco: Minilog-Classic: 4825
Pulse-8-2011	70	Vemco: Minilog-Classic: 4826
Pulse-8-2011	75	Vemco: Minilog-Classic: 4827
Pulse-8-2011	85	Vemco: Minilog-Classic: 4828
Pulse-8-2011	105	Sea-Bird Electronics: SBE37SM: 6962
Pulse-8-2011	120	Vemco: Minilog-Classic: 4829
Pulse-8-2011	140	Vemco: Minilog-Classic: 4830
Pulse-8-2011	160	Vemco: Minilog-Classic: 6101
Pulse-8-2011	475	RBR: TDR-2050: 14788
Pulse-8-2011	630	RBR: TDR-2050: 14789
SAZ47-14-2011	3900	RBR: TDR-2050: 16370
SAZ47-14-2011	4400	Sea-Bird Electronics: SBE37SM: 1778
SOFS-2-2011	-2.83	Sea-Bird Electronics: SBE39: 5269
SOFS-2-2011	1.5	Sea-Bird Electronics: SBE37SM: 1840
SOFS-2-2011	1.5	Sea-Bird Electronics: SBE37SM: 7409
SOFS-2-2011	10	Vemco: Minilog-Classic: 6097
SOFS-2-2011	20	Vemco: Minilog-Classic: 4831
SOFS-2-2011	29	Vemco: Minilog-Classic: 4832
SOFS-2-2011	40	Vemco: Minilog-Classic: 4833
SOFS-2-2011	50	Vemco: Minilog-Classic: 4834
SOFS-2-2011	55	Vemco: Minilog-Classic: 4835
SOFS-2-2011	60	Vemco: Minilog-Classic: 4836
SOFS-2-2011	65	Vemco: Minilog-Classic: 4837
SOFS-2-2011	70	Vemco: Minilog-Classic: 4838
SOFS-2-2011	75	Vemco: Minilog-Classic: 6099
SOFS-2-2011	85	Vemco: Minilog-Classic: 4839
SOFS-2-2011	100	Sea-Bird Electronics: SBE37SM: 2971
SOFS-2-2011	110	Vemco: Minilog-Classic: 4840
SOFS-2-2011	120	Vemco: Minilog-Classic: 4841
SOFS-2-2011	140	Vemco: Minilog-Classic: 4842
SOFS-2-2011	160	Vemco: Minilog-Classic: 4843
Pulse-9-2012	38.5	Sea-Bird Electronics: SBE16plusV2: 6331
Pulse-9-2012	45	Vemco: Minilog-II-T: 353253
Pulse-9-2012	50	Vemco: Minilog-II-T: 353254
Pulse-9-2012	55	Vemco: Minilog-II-T: 353255
Pulse-9-2012	60	RBR: DR-1050: 14521
Pulse-9-2012	60	Vemco: Minilog-II-T: 353256
Pulse-9-2012	65	Vemco: Minilog-II-T: 353257

Deployment	Depth (m)	Instrument
Pulse-9-2012	70	Vemco: Minilog-II-T: 353258
Pulse-9-2012	75	Vemco: Minilog-II-T: 353259
Pulse-9-2012	85	Vemco: Minilog-II-T: 353260
Pulse-9-2012	100	Sea-Bird Electronics: SBE37SMP-ODO: 9515
Pulse-9-2012	120	Vemco: Minilog-II-T: 353261
Pulse-9-2012	140	Vemco: Minilog-II-T: 353262
Pulse-9-2012	160	RBR: DR-1050: 14522
Pulse-9-2012	160	Vemco: Minilog-II-T: 353263
Pulse-9-2012	475	RBR: TDR-2050: 14786
Pulse-9-2012	630	RBR: TDR-2050: 14787
SAZ47-15-2012	3900	RBR: TDR-2050: 16371
SAZ47-15-2012	4422	Sea-Bird Electronics: SBE37SM: 8597
SOFS-3-2012	-2.8	Sea-Bird Electronics: SBE39: 5282
SOFS-3-2012	1	Sea-Bird Electronics: SBE37SM: 8764
SOFS-3-2012	1	Sea-Bird Electronics: SBE37SM: 8765
SOFS-3-2012	10	Vemco: Minilog-II-T: 353264
SOFS-3-2012	20	Vemco: Minilog-II-T: 353265
SOFS-3-2012	29	Vemco: Minilog-II-T: 353266
SOFS-3-2012	30	Sea-Bird Electronics: SBE37SMP-ODO: 9513
SOFS-3-2012	40	Vemco: Minilog-II-T: 353267
SOFS-3-2012	55	Vemco: Minilog-II-T: 353268
SOFS-3-2012	60	Vemco: Minilog-II-T: 353269
SOFS-3-2012	65	Vemco: Minilog-II-T: 353270
SOFS-3-2012	70	Vemco: Minilog-II-T: 353271
SOFS-3-2012	75	Vemco: Minilog-II-T: 353272
SOFS-3-2012	85	Vemco: Minilog-II-T: 353273
SOFS-3-2012	100	Sea-Bird Electronics: SBE37SMP-ODO: 9514
SOFS-3-2012	100	Vemco: Minilog-II-T: 353275
SOFS-3-2012	110	Vemco: Minilog-II-T: 353276
SOFS-3-2012	120	Vemco: Minilog-II-T: 353277
SOFS-3-2012	140	Vemco: Minilog-II-T: 353290
SOFS-3-2012	160	Vemco: Minilog-II-T: 353291
SOFS-3-2012	200	RBR: DR-1050: 14520
SOFS-3-2012	200	Vemco: Minilog-II-T: 353292
SOFS-3-2012	240	Vemco: Minilog-II-T: 353293
SOFS-3-2012	280	Vemco: Minilog-II-T: 353294
SOFS-3-2012	320	Vemco: Minilog-II-T: 353295
SOFS-3-2012	360	Vemco: Minilog-II-T: 353296
SOFS-3-2012	400	Vemco: Minilog-II-T: 353297
SOFS-3-2012	440	Vemco: Minilog-II-T: 353298
SOFS-3-2012	480	Vemco: Minilog-II-T: 353299
SOFS-3-2012	501	Sea-Bird Electronics: SBE37SMP: 9185
SOFS-4-2013	-1.8	Sea-Bird Electronics: SBE39: 5269
SOFS-4-2013	1.01	Sea-Bird Electronics: SBE37SM: 7408
SOFS-4-2013	1.01	Sea-Bird Electronics: SBE37SM: 7409
SOFS-4-2013	10	Vemco: Minilog-II-T: 353264
SOFS-4-2013	20	Vemco: Minilog-II-T: 353265
SOFS-4-2013	29	Vemco: Minilog-II-T: 353266
SOFS-4-2013	40	Vemco: Minilog-II-T: 353267

Deployment	Depth (m)	Instrument
SOFS-4-2013	55	Vemco: Minilog-II-T: 353268
SOFS-4-2013	60	Vemco: Minilog-II-T: 353269
SOFS-4-2013	65	Vemco: Minilog-II-T: 353270
SOFS-4-2013	70	Vemco: Minilog-II-T: 353271
SOFS-4-2013	75	Vemco: Minilog-II-T: 353272
SOFS-4-2013	85	Vemco: Minilog-II-T: 353273
SOFS-4-2013	100	Sea-Bird Electronics: SBE37SM: 8985
SOFS-4-2013	110	Vemco: Minilog-II-T: 353276
SOFS-4-2013	120	Vemco: Minilog-II-T: 353277
SOFS-4-2013	140	Vemco: Minilog-II-T: 353290
SOFS-4-2013	160	Vemco: Minilog-II-T: 353291
SOFS-4-2013	200	Vemco: Minilog-II-T: 353292
SOFS-4-2013	240	Vemco: Minilog-II-T: 353293
SOFS-4-2013	280	Vemco: Minilog-II-T: 353294
SOFS-4-2013	320	Vemco: Minilog-II-T: 353295
SOFS-4-2013	360	Vemco: Minilog-II-T: 353296
SOFS-4-2013	400	Vemco: Minilog-II-T: 353297
SOFS-4-2013	440	Vemco: Minilog-II-T: 353298
SOFS-4-2013	480	Vemco: Minilog-II-T: 353299
SOFS-4-2013	500	Sea-Bird Electronics: SBE37SMP: 9185
SAZ47-16-2013	3800	RBR: TDR-2050: 16370
SAZ47-16-2013	4300	Sea-Bird Electronics: SBE37SM: 1778
Pulse-10-2013	28	Sea-Bird Electronics: SBE16plusV2: 6330
Pulse-10-2013	45	RBR: DR-1050: 14520
Pulse-10-2013	45	Vemco: Minilog-II-T: 354194
Pulse-10-2013	50	Vemco: Minilog-II-T: 354195
Pulse-10-2013	55	Vemco: Minilog-II-T: 354196
Pulse-10-2013	60	Vemco: Minilog-II-T: 354197
Pulse-10-2013	65	Vemco: Minilog-II-T: 354198
Pulse-10-2013	70	Vemco: Minilog-II-T: 354199
Pulse-10-2013	75	Vemco: Minilog-II-T: 354200
Pulse-10-2013	85	Vemco: Minilog-II-T: 354201
Pulse-10-2013	100	Sea-Bird Electronics: SBE37SMP-ODO: 9538
Pulse-10-2013	120	Vemco: Minilog-II-T: 354202
Pulse-10-2013	140	Vemco: Minilog-II-T: 354203
Pulse-10-2013	160	Vemco: Minilog-II-T: 354204
Pulse-10-2013	200	Sea-Bird Electronics: SBE37SMP-ODO: 9513
Pulse-10-2013	200	Vemco: Minilog-II-T: 354205
Pulse-10-2013	240	Vemco: Minilog-II-T: 354206
Pulse-10-2013	280	Vemco: Minilog-II-T: 354207
Pulse-10-2013	320	Vemco: Minilog-II-T: 354208
Pulse-10-2013	360	Vemco: Minilog-II-T: 354209
Pulse-10-2013	400	Vemco: Minilog-II-T: 354210
Pulse-10-2013	440	Vemco: Minilog-II-T: 354211
Pulse-10-2013	475	RBR: TDR-2050: 14788
Pulse-10-2013	480	Vemco: Minilog-II-T: 354212
Pulse-10-2013	650	RBR: TDR-2050: 14789
Pulse-11-2015	28	Sea-Bird Electronics: SBE16plusV2: 6330
Pulse-11-2015	45	RBR: DR-1050: 14520

Deployment	Depth (m)	Instrument
Pulse-11-2015	45	Vemco: Minilog-II-T: 354194
Pulse-11-2015	50	Sea-Bird Electronics: SBE37SMP-ODO: 9538
Pulse-11-2015	50	Vemco: Minilog-II-T: 354195
Pulse-11-2015	55	Vemco: Minilog-II-T: 354196
Pulse-11-2015	60	Vemco: Minilog-II-T: 354197
Pulse-11-2015	65	Vemco: Minilog-II-T: 354198
Pulse-11-2015	70	Vemco: Minilog-II-T: 354199
Pulse-11-2015	75	Vemco: Minilog-II-T: 354200
Pulse-11-2015	85	Vemco: Minilog-II-T: 354201
Pulse-11-2015	100	Sea-Bird Electronics: SBE37SMP-ODO: 9513
Pulse-11-2015	120	Vemco: Minilog-II-T: 354202
Pulse-11-2015	140	Vemco: Minilog-II-T: 354203
Pulse-11-2015	150	Sea-Bird Electronics: SBE37SMP-ODO: 9514
Pulse-11-2015	160	Vemco: Minilog-II-T: 354204
Pulse-11-2015	200	Vemco: Minilog-II-T: 354205
Pulse-11-2015	240	Vemco: Minilog-II-T: 354206
Pulse-11-2015	280	Vemco: Minilog-II-T: 354207
Pulse-11-2015	320	Vemco: Minilog-II-T: 354208
Pulse-11-2015	360	Vemco: Minilog-II-T: 354209
Pulse-11-2015	400	Vemco: Minilog-II-T: 354210
Pulse-11-2015	440	Vemco: Minilog-II-T: 354211
Pulse-11-2015	475	RBR: TDR-2050: 14788
Pulse-11-2015	480	Vemco: Minilog-II-T: 354212
Pulse-11-2015	650	RBR: TDR-2050: 14789
SAZ47-17-2015	3800	RBR: TDR-2050: 16371
SAZ47-17-2015	4250	Sea-Bird Electronics: SBE37SM: 8985
SOFS-5-2015	-1.8	Sea-Bird Electronics: SBE39: 5282
SOFS-5-2015	1.01	Sea-Bird Electronics: SBE37SM: 7409
SOFS-5-2015	1.1	Sea-Bird Electronics: SBE37SM: 7408
SOFS-5-2015	10	Vemco: Minilog-II-T: 353264
SOFS-5-2015	20	Vemco: Minilog-II-T: 353265
SOFS-5-2015	29	Vemco: Minilog-II-T: 353260
SOFS-5-2015	30	Sea-Bird Electronics: SBE37SM: 6962
SOFS-5-2015	40	Vemco: Minilog-II-T: 353267
SOFS-5-2015	55	Vemco: Minilog-II-T: 353268
SOFS-5-2015	60	Vemco: Minilog-II-T: 353269
SOFS-5-2015	65	Vemco: Minilog-II-T: 353270
SOFS-5-2015	70	Vemco: Minilog-II-T: 353271
SOFS-5-2015	75	Vemco: Minilog-II-T: 353272
SOFS-5-2015	85	Vemco: Minilog-II-T: 353273
SOFS-5-2015	100	Sea-Bird Electronics: SBE37SM: 4908
SOFS-5-2015	110	Vemco: Minilog-II-T: 353276
SOFS-5-2015	120	Vemco: Minilog-II-T: 353277
SOFS-5-2015	140	Vemco: Minilog-II-T: 353290
SOFS-5-2015	160	Vemco: Minilog-II-T: 353291
SOFS-5-2015	200	Vemco: Minilog-II-T: 353292
SOFS-5-2015	240	Vemco: Minilog-II-T: 353293
SOFS-5-2015	280	Vemco: Minilog-II-T: 353294
SOFS-5-2015	320	Vemco: Minilog-II-T: 353295

Deployment	Depth (m)	Instrument
SOFS-5-2015	360	Vemco: Minilog-II-T: 353296
SOFS-5-2015	400	Vemco: Minilog-II-T: 353297
SOFS-5-2015	440	Vemco: Minilog-II-T: 353298
SOFS-5-2015	480	Vemco: Minilog-II-T: 353299
SOFS-5-2015	500	Sea-Bird Electronics: SBE37SM: 4909
FluxPulse-1-2016	-2	Sea-Bird Electronics: SBE39: 5269
FluxPulse-1-2016	1.01	Sea-Bird Electronics: SBE37SM: 10136
FluxPulse-1-2016	1.01	Sea-Bird Electronics: SBE37SM: 8764
FluxPulse-1-2016	10	Vemco: Minilog-II-T: 353253
FluxPulse-1-2016	20	Vemco: Minilog-II-T: 353254
FluxPulse-1-2016	30	Sea-Bird Electronics: SBE16plusV2: 6331
FluxPulse-1-2016	40	Vemco: Minilog-II-T: 353255
FluxPulse-1-2016	45	Vemco: Minilog-II-T: 353256
FluxPulse-1-2016	50	Vemco: Minilog-II-T: 353257
FluxPulse-1-2016	55	Vemco: Minilog-II-T: 353258
FluxPulse-1-2016	60	Vemco: Minilog-II-T: 353259
FluxPulse-1-2016	70	Vemco: Minilog-II-T: 353261
FluxPulse-1-2016	75	Sea-Bird Electronics: SBE37SMP-ODO: 9880
FluxPulse-1-2016	80	Vemco: Minilog-II-T: 353263
FluxPulse-1-2016	100	Vemco: Minilog-II-T: 354213
FluxPulse-1-2016	110	Vemco: Minilog-II-T: 354214
FluxPulse-1-2016	125	Sea-Bird Electronics: SBE37SMP-ODO: 9515
FluxPulse-1-2016	140	Vemco: Minilog-II-T: 354215
FluxPulse-1-2016	160	Vemco: Minilog-II-T: 354216
FluxPulse-1-2016	180	Vemco: Minilog-II-T: 354217
FluxPulse-1-2016	200	Sea-Bird Electronics: SBE37SMP-ODO: 9881
FluxPulse-1-2016	240	Vemco: Minilog-II-T: 354218
FluxPulse-1-2016	280	Vemco: Minilog-II-T: 354219
FluxPulse-1-2016	320	Vemco: Minilog-II-T: 354220
FluxPulse-1-2016	360	Vemco: Minilog-II-T: 354221
FluxPulse-1-2016	400	Vemco: Minilog-II-T: 354222
FluxPulse-1-2016	440	Vemco: Minilog-II-T: 354223
FluxPulse-1-2016	480	Vemco: Minilog-II-T: 354224
FluxPulse-1-2016	500	Sea-Bird Electronics: SBE37SMP-ODO: 14024
SAZ47-18-2016	3800	RBR: TDR-2050: 16370
SAZ47-18-2016	4500	Sea-Bird Electronics: SBE37SM: 8597
SAZ47-19-2017	1000	Sea-Bird Electronics: SBE37SMP: 7901
SAZ47-19-2017	2000	Sea-Bird Electronics: SBE37SMP: 7896
SAZ47-19-2017	3800	RBR: TDR-2050: 16371
SAZ47-19-2017	4500	Sea-Bird Electronics: SBE37SM: 2971
SOFS-6-2017	-2	Sea-Bird Electronics: SBE39: 5269
SOFS-6-2017	1	Sea-Bird Electronics: SBE37SM: 10136
SOFS-6-2017	1	Sea-Bird Electronics: SBE37SM: 8764
SOFS-6-2017	11	Vemco: Minilog-II-T: 354194
SOFS-6-2017	20	Vemco: Minilog-II-T: 354195
SOFS-6-2017	29	Vemco: Minilog-II-T: 354196
SOFS-6-2017	30	Sea-Bird Electronics: SBE37SMP-ODO: 9538
SOFS-6-2017	40	Vemco: Minilog-II-T: 354197
SOFS-6-2017	45	Vemco: Minilog-II-T: 354198

Deployment	Depth (m)	Instrument
SOFS-6-2017	50	Vemco: Minilog-II-T: 354199
SOFS-6-2017	55	Vemco: Minilog-II-T: 354200
SOFS-6-2017	60	Vemco: Minilog-II-T: 354201
SOFS-6-2017	70	Vemco: Minilog-II-T: 354202
SOFS-6-2017	75	Star Oddi: Starmon mini: T-4777
SOFS-6-2017	80	Vemco: Minilog-II-T: 354203
SOFS-6-2017	100	Vemco: Minilog-II-T: 354204
SOFS-6-2017	110	Vemco: Minilog-II-T: 354205
SOFS-6-2017	125	Sea-Bird Electronics: SBE37SMP-ODO: 9513
SOFS-6-2017	140	Vemco: Minilog-II-T: 354206
SOFS-6-2017	160	Vemco: Minilog-II-T: 354207
SOFS-6-2017	180	Vemco: Minilog-II-T: 354208
SOFS-6-2017	200	Sea-Bird Electronics: SBE37SMP-ODO: 9514
SOFS-6-2017	240	Vemco: Minilog-II-T: 354209
SOFS-6-2017	280	Vemco: Minilog-II-T: 354210
SOFS-6-2017	320	Vemco: Minilog-II-T: 354211
SOFS-6-2017	360	Vemco: Minilog-II-T: 354212
SOFS-6-2017	400	Vemco: Minilog-II-T: 353297
SOFS-6-2017	440	Vemco: Minilog-II-T: 353298
SOFS-6-2017	480	Vemco: Minilog-II-T: 353299
SOFS-6-2017	500	Sea-Bird Electronics: SBE37SMP-ODO: 14700
SOFS-7-2018	-2	Sea-Bird Electronics: SBE37SM: 3141
SOFS-7-2018	-2	Sea-Bird Electronics: SBE39: 5282
SOFS-7-2018	1	Sea-Bird Electronics: SBE37SM: 7408
SOFS-7-2018	1	Sea-Bird Electronics: SBE37SM: 7409
SOFS-7-2018	11	Star Oddi: Starmon mini: T-4035
SOFS-7-2018	20	Star Oddi: Starmon mini: T-4039
SOFS-7-2018	30	Sea-Bird Electronics: SBE37SMP-ODO: 15969
SOFS-7-2018	40	Star Oddi: Starmon mini: T-4047
SOFS-7-2018	45	Star Oddi: Starmon mini: T-4048
SOFS-7-2018	50	Star Oddi: Starmon mini: T-4049
SOFS-7-2018	55	Star Oddi: Starmon mini: T-4050
SOFS-7-2018	60	Star Oddi: Starmon mini: T-4051
SOFS-7-2018	70	Star Oddi: Starmon mini: T-4052
SOFS-7-2018	75	Star Oddi: Starmon mini: T-4053
SOFS-7-2018	80	Star Oddi: Starmon mini: T-4058
SOFS-7-2018	100	Star Oddi: Starmon mini: T-4060
SOFS-7-2018	110	Star Oddi: Starmon mini: T-4061
SOFS-7-2018	125	Sea-Bird Electronics: SBE37SMP-ODO: 15970
SOFS-7-2018	140	Star Oddi: Starmon mini: T-4062
SOFS-7-2018	160	Star Oddi: Starmon mini: T-4063
SOFS-7-2018	180	Star Oddi: Starmon mini: T-4066
SOFS-7-2018	200	Sea-Bird Electronics: SBE37SMP-ODO: 15971
SOFS-7-2018	240	Star Oddi: Starmon mini: T-4068
SOFS-7-2018	280	Star Oddi: Starmon mini: T-4069
SOFS-7-2018	320	Star Oddi: Starmon mini: T-4070
SOFS-7-2018	360	Star Oddi: Starmon mini: T-4071
SOFS-7-2018	400	Star Oddi: Starmon mini: T-4077
SOFS-7-2018	440	Star Oddi: Starmon mini: T-4778

Deployment	Depth (m)	Instrument
SOFS-7-2018	480	Sea-Bird Electronics: SBE37SMP-ODO: 15972
SAZ47-20-2018	1000	Sea-Bird Electronics: SBE37SM: 1777
SAZ47-20-2018	2000	Sea-Bird Electronics: SBE37SM: 3124
SAZ47-20-2018	3800	RBR: TDR-2050: 16370
SAZ47-20-2018	4500	Sea-Bird Electronics: SBE37SM: 2955
SOFS-7.5-2018	-2	Sea-Bird Electronics: SBE39: 5282
SOFS-7.5-2018	-1	Sea-Bird Electronics: SBE37SM: 3141
SOFS-7.5-2018	1	Sea-Bird Electronics: SBE37SM: 7408
SOFS-7.5-2018	1	Sea-Bird Electronics: SBE37SM: 7409
SOFS-7.5-2018	11	Star Oddi: Starmon mini: T-4035
SOFS-7.5-2018	20	Star Oddi: Starmon mini: T-4039
SOFS-7.5-2018	30	Sea-Bird Electronics: SBE37SMP-ODO: 15969
SOFS-7.5-2018	40	Star Oddi: Starmon mini: T-4047
SOFS-7.5-2018	45	Star Oddi: Starmon mini: T-4048
SOFS-7.5-2018	50	Star Oddi: Starmon mini: T-4049
SOFS-7.5-2018	55	Star Oddi: Starmon mini: T-4050
SOFS-7.5-2018	60	Star Oddi: Starmon mini: T-4051
SOFS-7.5-2018	70	Star Oddi: Starmon mini: T-4052
SOFS-7.5-2018	75	Star Oddi: Starmon mini: T-4053
SOFS-7.5-2018	80	Star Oddi: Starmon mini: T-4058
SOFS-7.5-2018	100	Star Oddi: Starmon mini: T-4060
SOFS-7.5-2018	110	Star Oddi: Starmon mini: T-4061
SOFS-7.5-2018	125	Sea-Bird Electronics: SBE37SMP-ODO: 15970
SOFS-7.5-2018	140	Star Oddi: Starmon mini: T-4062
SOFS-7.5-2018	160	Star Oddi: Starmon mini: T-4063
SOFS-7.5-2018	180	Star Oddi: Starmon mini: T-4066
SOFS-7.5-2018	200	Sea-Bird Electronics: SBE37SMP-ODO: 15971
SOFS-7.5-2018	240	Star Oddi: Starmon mini: T-4068
SOFS-7.5-2018	280	Star Oddi: Starmon mini: T-4069
SOFS-7.5-2018	320	Star Oddi: Starmon mini: T-4070
SOFS-7.5-2018	360	Star Oddi: Starmon mini: T-4071
SOFS-7.5-2018	400	Star Oddi: Starmon mini: T-4077
SOFS-7.5-2018	440	Star Oddi: Starmon mini: T-4778
SOFS-7.5-2018	480	Sea-Bird Electronics: SBE37SMP-ODO: 15972
SOFS-7.5-2018	4550	Sea-Bird Electronics: SBE39: 6273
SOFS-8-2019	-2	Sea-Bird Electronics: SBE39: 5269
SOFS-8-2019	1	Sea-Bird Electronics: SBE37SM: 15728
SOFS-8-2019	1	Sea-Bird Electronics: SBE37SM: 1840
SOFS-8-2019	11	Star Oddi: Starmon mini: T-5298
SOFS-8-2019	20	Star Oddi: Starmon mini: T-5299
SOFS-8-2019	30	Sea-Bird Electronics: SBE37SMP-ODO: 20126
SOFS-8-2019	40	Star Oddi: Starmon mini: T-5300
SOFS-8-2019	45	Star Oddi: Starmon mini: T-5301
SOFS-8-2019	50	Star Oddi: Starmon mini: T-5303
SOFS-8-2019	55	Star Oddi: Starmon mini: T-5304
SOFS-8-2019	60	Star Oddi: Starmon mini: T-5305
SOFS-8-2019	65	Star Oddi: Starmon mini: T-5306
SOFS-8-2019	70	Star Oddi: Starmon mini: T-5307
SOFS-8-2019	75	Star Oddi: Starmon mini: T-5308

Deployment	Depth (m)	Instrument
SOFS-8-2019	85	Star Oddi: Starmon mini: T-5309
SOFS-8-2019	100	Star Oddi: Starmon mini: T-5310
SOFS-8-2019	110	Star Oddi: Starmon mini: T-5311
SOFS-8-2019	125	Sea-Bird Electronics: SBE37SMP-ODO: 9513
SOFS-8-2019	140	Star Oddi: Starmon mini: T-5312
SOFS-8-2019	160	Star Oddi: Starmon mini: T-5313
SOFS-8-2019	180	Star Oddi: Starmon mini: T-5315
SOFS-8-2019	200	Sea-Bird Electronics: SBE37SMP-ODO: 9514
SOFS-8-2019	240	Star Oddi: Starmon mini: T-5316
SOFS-8-2019	280	Star Oddi: Starmon mini: T-5319
SOFS-8-2019	320	Star Oddi: Starmon mini: T-5320
SOFS-8-2019	360	Star Oddi: Starmon mini: T-5322
SOFS-8-2019	400	Star Oddi: Starmon mini: T-5324
SOFS-8-2019	440	Star Oddi: Starmon mini: T-5325
SOFS-8-2019	480	Star Oddi: Starmon mini: T-5327
SOFS-8-2019	510	Sea-Bird Electronics: SBE37SMP-ODO: 20127
SOFS-8-2019	4550	Sea-Bird Electronics: SBE39plus: 39p-8690
SAZ47-21-2019	1000	Sea-Bird Electronics: SBE37SM: 4906
SAZ47-21-2019	2000	Sea-Bird Electronics: SBE37SM: 4907
SAZ47-21-2019	3800	RBR: TDR-2050: 16371
SAZ47-21-2019	4500	Sea-Bird Electronics: SBE37SM: 8985
SOFS-9-2020	1	SBE37SM-RS485:03707408
SOFS-9-2020	1	SBE37SM-RS485:03707409
SOFS-9-2020	11	Starmon mini:4035
SOFS-9-2020	20	Starmon mini:4039
SOFS-9-2020	30	SeaFETv1:1001
SOFS-9-2020	40	Starmon mini:4047
SOFS-9-2020	45	Starmon mini:4048
SOFS-9-2020	50	Starmon mini:4049
SOFS-9-2020	55	Starmon mini:4050
SOFS-9-2020	60	Starmon mini:4051
SOFS-9-2020	65	Starmon mini:4042
SOFS-9-2020	70	Starmon mini:4052
SOFS-9-2020	75	Starmon mini:4053
SOFS-9-2020	85	Starmon mini:4058
SOFS-9-2020	100	Starmon mini:4060
SOFS-9-2020	110	Starmon mini:4061
SOFS-9-2020	125	SBE37SMP-ODO-RS232:03715970
SOFS-9-2020	140	Starmon mini:4062
SOFS-9-2020	160	Starmon mini:4063
SOFS-9-2020	180	Starmon mini:4066
SOFS-9-2020	200	SBE37SMP-ODO-RS232:03714700
SOFS-9-2020	240	Starmon mini:4068
SOFS-9-2020	280	Starmon mini:4069
SOFS-9-2020	300	SBE37SMP-ODO-RS232:03715971
SOFS-9-2020	320	Starmon mini:4070
SOFS-9-2020	360	Starmon mini:4071
SOFS-9-2020	400	Starmon mini:4077
SOFS-9-2020	440	Starmon mini:4778

Deployment	Depth (m)	Instrument
SOFS-9-2020	480	Starmon mini:4995
SOFS-9-2020	510	SBE37SMP-ODO-RS232:03715972
SAZ47-22-2020	2000	SBE37-SM:3124
SAZ47-22-2020	4500	SBE37-SM:2955

*Depth is nominal, as estimated from mooring designs and anchor positions. Pressure records provide the best estimates of actual depths. See Annual Sensor Reports for details and data files for pressure time series.

4 Summary of Instrument Handling and Data Processing

Pre-deployment preparation

Instruments were prepared following manufacturer recommendations, including drying of pressure cases, greasing of seals, and insertion of new batteries. Instrument clocks were set to UTC via on-line synchronization. Instruments were mounted and measurement frequencies were scheduled as described for each instrument in the SOTS Annual Sensor reports. In general, mounting was via clamping to the mooring wires for thermistors and within instrument cages for CTDs, with the instruments downward-facing. Measurement frequency was at least hourly and as frequent as every 1 minute for some sensors.

In some cases, batches of the instruments were operated either in a common water bath or on the CTD-Rosette at sea prior to deployment to provide an inter-comparison of their outputs. These data did not reveal any sensors with major failures, or any offsets between sensors beyond those identified from observations in the ocean (see below). For these reasons and because these data were only available from a few deployments, they not used to make any data adjustments. The approach remains useful for quality assurance and may become useful for quality control if it becomes possible to carry out on a more systematic basis.

Post-deployment evaluations

After recovery, the instruments were connected to a UTC time-synchronized computer and any clock drift was noted. These were generally very small (order a few minutes per annum) and no clock corrections were made.

Instrument Calibrations

Pre- and post-deployment calibrations were carried out either by the manufacturer or the CSIRO Hydrochemistry Facility. Comparison of the results from pre- and post-calibration suggest that there are small differences, of order 0.02 C, but not in a systematic direction. Because the applicability of the post-deployment calibrations to the deployment period is inherently uncertain, all results presented here are based on the pre-deployment calibrations. Differences between calibrations are simply noted and contribute to the overall uncertainty assessment of the temperature records.

Common time scale product

In this report, sensor data is examined at its full temporal resolution, which varied from every minute to every two hours. No interpolation to a common grid is provided. This effort will be pursued during the future production of a gridded multi-variable product.

5 QC Specifics

Our overall Quality Control philosophy is to remove no data, only to indicate probable data quality for each observation using a system of QC flags, as shown in Table 2. Flags 1 to 4 are standard in the US IOOS, QARTOD, and Argo programs (citations below). Flag 5 is added here to indicate data collected before or after mooring deployment, which has not been evaluated further. This data can be useful for testing sensor responses (for example sensors on deck before deployment can be compared to ship air temperature sensors).

Table 2. Flags used in temperature quality control

FLAG	DESCRIPTION
Pass, Good data = 1	Data have passed the highest level of quality control
Probably good = 2	Data were unable to be evaluated by at least one test, but were not flagged as suspect or fail by any other tests
Suspect or of high interest = 3	Data have failed one or more tests indicating suspicious values, however it is possible that sensor failure has not occurred
Fail = 4	Data have failed one or more tests indicating instrument or mooring failure
Sensor active but not deployed = 6	Data obtained when the sensor was out of water, or not at the assigned depth.

As the starting point for delayed mode quality control (DMQC) we adopted the hierarchy of tests, listed in Table 3, as recommended by the Integrated Ocean Observing System (IOOS) for Quality Assurance of Real-Time Oceanographic Data (QARTOD; https://ioos.noaa.gov/project/QARTOD), using Version 2.1 of the Manual for Real-Time Quality Control of In-situ Temperature and Salinity Data.

Each test was applied to all data points, including those that had been flagged as fail (flag=4) or suspect (flag=3) in previous tests. At the end of the sequence of tests, the highest flag produced by any test was assigned to each data point. In addition, if more than 0.1% of the data was flagged 4, then all other data points were assigned flag 3, to indicate that the sensor experienced abnormally high frequency of problems and thus should be considered carefully before use.

In this version 2.0 (and subsequent) reports, flag 3 temperatures which have been adjusted based on sensor offsets (see section 6.5 below) are now assigned flag 2.

Table 3. QC tests recommended by QARTOD

TEST GROUP	TEST NO.	TEST NAME	CONDUCTED
Group 1 *Required*	1	Timing/Gap Test	Yes
	2	Syntax Test	Yes
	3	Location Test	Yes
	4	Gross Range Test	Yes
	5	Climatology Test	Yes
Group 2 *Strongly Recommended*	6	Spike Test	Yes
	7	Rate of Change Test	Yes
	8	Flat Line Test	No
Group 3 *Suggested*	9	Multivariate Test	No
	10	Attenuated Signal Test	Yes
	11	Neighbour Test	Via visualization
	12	TS Curve/Space Test	No
	13	Density Inversion Test	No

5.1 Applied tests

Visualizaation of the temperature records and the flagging results made it clear that some tests functioned better than others, and many tests required compromises. Defining thresholds for flagging the data represents an compromise between too many false positives (i.e. data is accepted, even though it is bad) versus too many false negatives (i.e. data is rejected, even though it is good). This optimal compromise depends on the use of the data. If quantifying the annual thermal cycle is the target, then flagging occasional short-lived high temperature periods in surface temperatures (which might be either instrumental spikes or rare warming events) as bad eliminates noise in the seasonal cycle, and represents little loss of fidelity. However, if identification of very shallow stratification events that could influence ocean productivity is the target, it is better not to exclude these results.

Ideally, the sensor records would unambiguously separate rare but real events from episodic sensor faults, but this can be very hard to assess, especially if there is only one sensor in the region of interest and if the full nature of the oceanic variability in the region is not yet known. The second of these problems is particularly problematic in the Southern Ocean at very shallow depths, because rough conditions generally mean that CTD casts sample the top 5m of the sea poorly if at all, and the large footprints of satellite sea surface temperature measurements mean that spatially restricted high intensity events would not be visible.

Visualisation is an essential tool to define the nature of sensor noise and thus the selection of appropriate thresholds for the tests. Several typical failure modes (Figure 3) were observed:

- temperatures records that episodically exceeded 'reasonable' values.
- noisy temperature records, often with the noise increasing over time.
- temperature records with 'biased noise', e.g. more spikes towards higher temperatures than spikes toward lower temperatures.

These failure modes informed the selection of thresholds for the QARTOD tests to flag 'bad' (flag 4) and 'suspect' (flag 3) data, as detailed for each test below. Figure 3 also illustrates how successive tests (gross range, climatology, spike, and rate of change) tighten the bounds of quality control and identify more and more bad data, but also that the boundary between bad data and good data becomes very hard to discern, with this most clearly revealed by comparison to the neighbouring sensor at 80m which did not exhibit these noise features. A closer look at these temperature sensors records (Figure 4) shows that small 'spikes' occur in the compromised temperature record (at 75m depth, shown in blue) with similar amplitude and duration to real oceanic variability (as represented by the 80m depth sensor, shown in yellow). Thus, complete separation of spikes from variability is very difficult, and compromise is required. The spike threshold as shown in Figure 4 avoids removing data that may be good, but correspondingly, and because the noise is biased towards high temperatures, even a smoothed record (shown in red) can yield systematic, though small, over-estimation of the temperature. This is one reason why we added the additional flagging criteria that when more than 0.1% of a record is flagged as 4, then the entire series is assigned a flag of 3, to notify users that the data merits careful evaluation relative to purpose before use. With these perspectives in mind, we next detail our implementation of the QARTOD tests in the sequence they are applied.

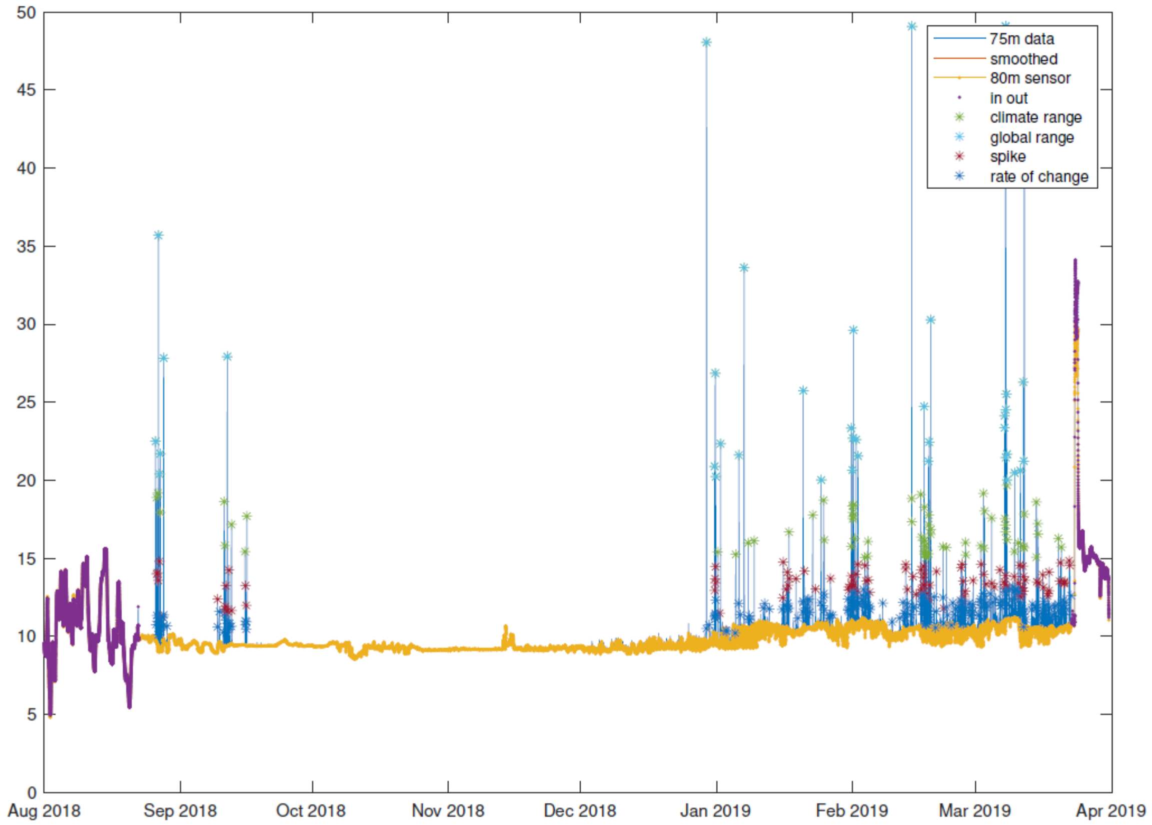


Figure 3 SOFS_7.5_mooring 75m Starmon-Mini temperature record reveals 3 problems : inappropriately high temperatures, increase in "noise" over time, and "biased noise".

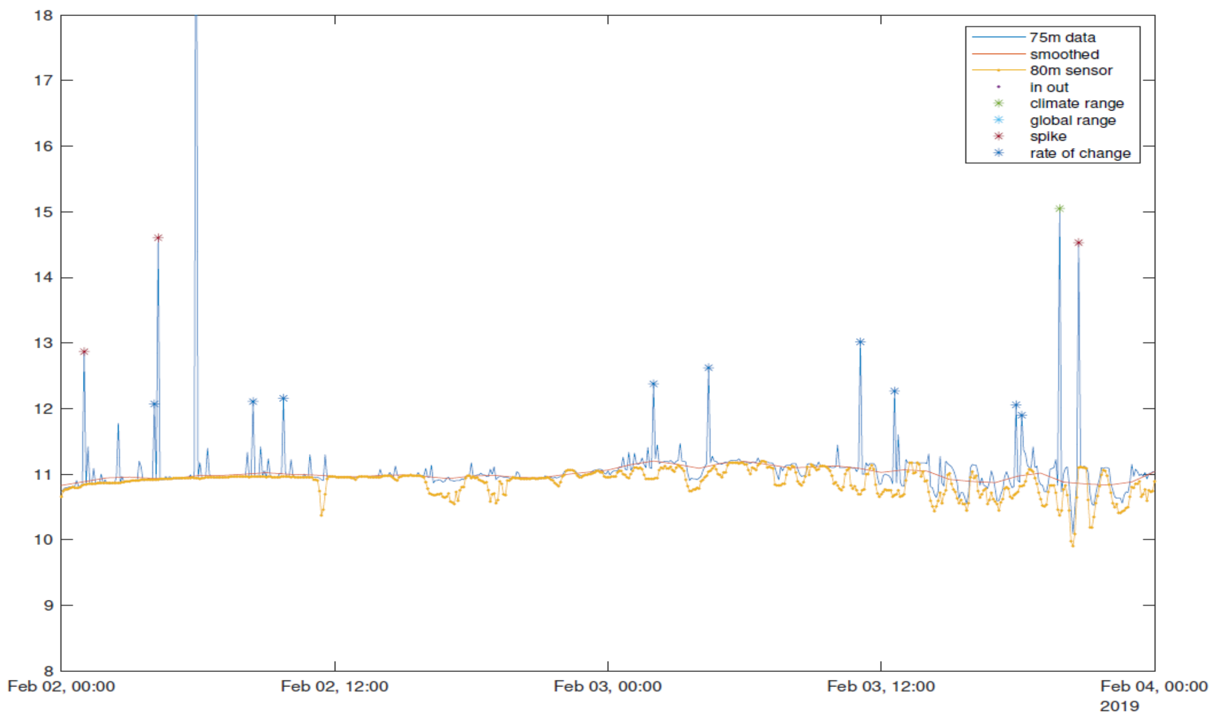


Figure 4 Close-up of the SOFS_7.5_mooring 75m Star-Oddi Starmon-Mini temperature record.

Test 1) Timing/Gap Test (Required)

Check for arrival of data.		
Test determines that the most recent data point has been measured and received within the expected time window (TIM_INC) and has the correct time stamp (TIM_STMP). **Note:** For those systems that do not update at regular intervals, a large value for TIM_STMP can be assigned. The gap check is not a solution for all timing errors. Data could be measured or received earlier than expected. This test does not address all clock drift/jump issues.		
Flags	**Condition**	**Codable Instructions**
Fail=4	Data have not arrived as expected.	If NOW – TIM_STMP > TIM_INC, flag = 4
Suspect=3	N/A	N/A
Pass=1	Applies for test pass condition.	N/A
Test Exception: None.		
Test specifications to be established locally by the operator. **Example:** TIM_INC = 1 hour		

Implementation for SOTS delayed mode QC was as follows:

This test is designed for real time data, and its application to delayed mode is very limited.

For SOTS instruments we retain all time-stamped data, and do not do any flagging or filling if a time point is missing. In other words, we accept missing intervals and expect the user to recognize that the time series may not be evenly spaced. Thus, calculations should always estimate the time interval when integrating values across adjacent data points, e.g. when calculating heat content changes.

For time stamps which are missing values of one or more variables (T, S, etc.), these are set to NaNs when the data is parsed from the instrument transmissions. These values are then flagged by Test 4) Gross Range Test (below).

Test 2) Syntax Test (Required)

Check to ensure that the message is structured properly		
Received data message (full message) contains the proper structure without any indicators of flawed transmission such as parity errors. Possible tests are: a) the expected number of characters (NCHAR) for fixed length messages equals the number of characters received (REC_CHAR), or b) passes a standard parity bit check, cyclic redundancy check (CRC), etc. Many such syntax tests exist, and the operator should select the best criteria for one or more syntax tests. Capabilities for dealing with flawed messages vary among operators; some may have the ability to parse messages to extract data within the flawed message sentence before the flaw. A syntax check is performed only at the message level and not within the message content. In cases where a data record requires multiple messages, this check can be performed at the message level but is not used to check message content.		
Flags	**Condition**	**Codable Instructions**
Fail=4	Data sentence cannot be parsed to provide a valid observation.	If REC_CHAR ≠ NCHAR, flag = 4
Suspect =3	N/A	N/A
Pass=1	Expected data sentence received; absence of parity errors.	
Test Exception: None.		
Test specifications to be established locally by the operator. **Example:** NCHAR = 128		

This test is designed for real time data, and its application to delayed mode is very limited.

If the message cannot be parsed, then the record will show a missing time stamp. No flagging is done.

Test 3) Location Test (Required)

Check for reasonable geographic location.		
Test checks that the reported present physical location (latitude/longitude) is within operator-determined limits. The location test(s) can vary from a simple impossible location to a more complex check for displacement (DISP) exceeding a distance limit (RANGEMAX) based upon a previous location and platform speed. Operators may also check for erroneous locations based upon other criteria, such as reported positions over land, as appropriate.		
Flags	**Condition**	**Codable Instructions**
Fail=4	Impossible location.	|LAT | > 90 or |LONG | > 180
Suspect=3	Unlikely platform displacement.	DISP > RANGEMAX
Pass=1	Applies for test pass condition.	N/A
Test Exception: Test does not apply to fixed deployments when no location is transmitted.		
Test specifications to be established locally by the operator.		
Example: Displacement DISP calculated between sequential position reports, RANGEMAX = 20 km		

Implementation for SOTS delayed mode QC was as follows:
The locations of the sensors were designated as being the locations of the mooring anchor positions (as estimated from the anchor drop position and/or acoustic triangulation - details are in the SOTS Annual Overview Reports). This location information is provided as a single pair of latitude and longitude values in the NetCDF files.

In addition, for the SOFS and Pulse surface floats, which collect and transmit GPS positions, this information is provided as time series of latitudes and longitudes, with flagging of:
Flag 4, QARTOD conventions for impossible latitudes and longitudes
Flag 3, latitude outside 30-60°); longitude outside 130-150 °E.
Note that this wide range does NOT flag data outside the mooring 'watch circles', that has at times been collected after surface portions of the moorings have broken free and drifted. Note also that the locations of the annual re-deployments of the SOTS moorings have typically varied by ~10 miles, and at times by as much as 60 miles.
Users who wish to limit data to within a watch circle, to some other restricted area, or to examine variations with location should use these time series of latitudes and longitudes, rather than the nominal positions provided by the anchor locations.

We also extended this test to include flagging the pressure records of the sensors (as an indication of their depth location). This allows us to flag data collected before and after the mooring has reached its resting place on the sea floor. This data can be useful for testing changes in calibrations, examining pressure effects on sensors, etc. After visualizing the mooring pressure records, we set a single pair of date/time stamps for the beginning and end of the moored period for all sensors on each mooring, and all data before and after these times is assigned Flag 5 to indicate that it was not collected as part of the 'moored observations' period (An example of these temporal bounds is shown by the purple coloured sections of the 75m temperature record in Figure 3). Note that the pressures of individual sensors may still vary in this period, and this should be assessed using those records (just as the locations may vary and must be assessed using the latitude and longitude variables as described above).

Test 4) Gross Range Test (Required)

Data point exceeds sensor or operator-selected min/max. Applies to T, SP, C and P.		
All sensors have a limited output range, and this can form the most rudimentary gross range check. No values less than a minimum value or greater than the maximum value the sensor can output (T_SENSOR_MIN, T_SENSOR_MAX) are acceptable. Additionally, the operator can select a smaller span (T_USER_MIN, T_USER_MAX) based upon local knowledge or a desire to draw attention to extreme values. **NOTE:** Operators may choose to flag as suspect values that exceed the calibration span but not the hardware limits (e.g., a value that sensor is not capable of producing or negative conductivity).		
Flags	**Condition**	**Codable Instructions**
Fail=4	Reported value is outside of sensor span.	If T_n < T_SENSOR_MIN, or T_n > T_SENSOR_MAX, flag = 4
Suspect=3	Reported value is outside of operator-selected span.	If T_n < T_USER_MIN, or T_n > T_USER_MAX, flag = 3
Pass=1	Applies for test pass condition.	
Test Exception: None.		
Test specifications to be established locally by the operator. **Examples:** The following global range min/max are applied on some climate and forecast standard-names in the IMOS toolbox: depth: -5/12,000 m sea_water_pressure: -5/12,000 decibars (dbar) sea_water_pressure_due_to_sea_water: -15/12,000 dbar sea_water_salinity: 2/41 sea_water_temperature: -2.5/40 °C		

Flag 4: Value outside of two ranges depending on sensor locations:

1. in air sensors: T_Sensor_Min = -20 T_Sensor Max = +50
2. in water sensors: T_Sensor_Min = -2 T_Sensor Max = +30

Flag 3: no thresholds or flags assigned

Test 5) Climatology Test (Required)

Test that data point falls within seasonal expectations. Applies to T and SP.		
This test is a variation on the gross range check, where the thresholds T_Season_MAX and T_Season_MIN are adjusted monthly, seasonally, or at some other operator-selected time period (TIM_TST). Expertise of the operator is required to determine reasonable seasonal averages. Longer time series permit more refined identification of appropriate thresholds. The ranges should also vary with water depth, if the measurements are taken at sites that cover significant vertical extent and if climatological ranges are meaningfully different at different depths (e.g., narrower ranges at greater depth).		
Flags	**Condition**	**Codable Instructions**
Fail=4	Because of the dynamic nature of T and S in some locations, no fail flag is identified for this test.	N/A
Suspect=3	Reported value is outside of operator-identified climatology window.	If T_n < T_Season_MIN or T_n > T_Season_MAX, flag = 3
Pass=1	Applies for test pass condition.	N/A
Test Exception: None.		
Test specifications to be established locally by operator: A seasonal matrix of T_{max} and T_{min} values at all TIM_TST intervals. **Examples:** T_SPRING_MIN = 12 °C, T_SPRING_MAX = 18.0 °C		

Flag 4, none assigned

Flag 3, assigned as follows, based on CTD casts near SOTS (show below at Figure 13), all mooring observations, and review of the World Ocean Atlas set depth-dependent thresholds were set as follows, in °C:

Depth (dbar)	T_Season_Min	T_Season_Max
In air	-10	30
0- 10	6	20
10-600	5	16
600-1500	2	12
>1500	0.8	5

Because mean seasonal temperature changes are small at SOTS (~3°C) and similar to short term changes driven by passage of water parcels or local vertical mixing, these thresholds were held constant throughout the year. These bounds are shown in Figure 5 relative to the maxima and minima observed in all the moored sensor records as well as CTD casts at the SOTS site.

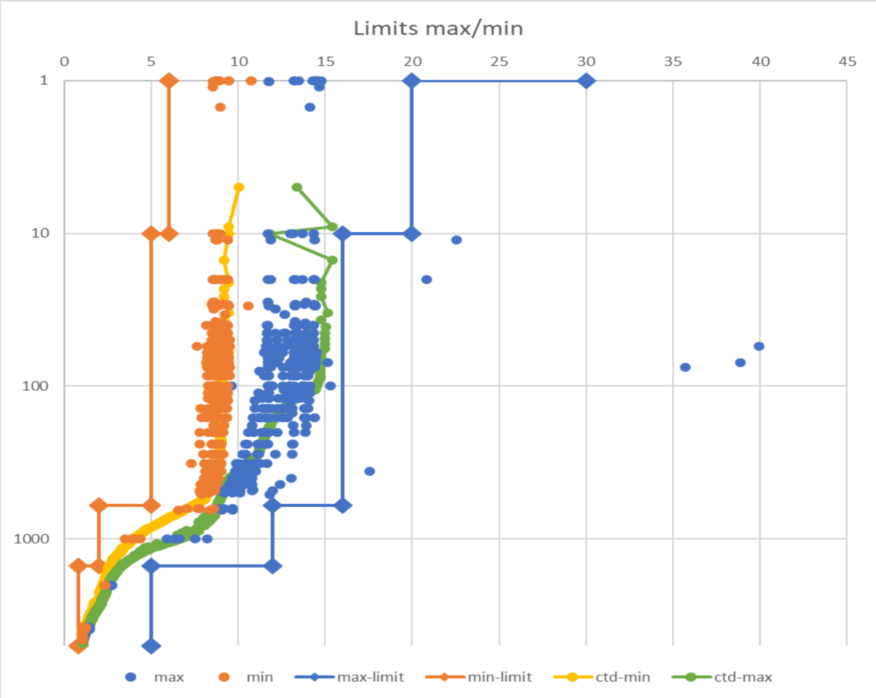


Figure 5 Climatology Test 5 bounds relative to moored and CTD temperature records

Test 6) Spike Test (Strongly Recommended)

Data point *n*-1 exceeds a selected threshold relative to adjacent data points. Applies to T, SP, C, and P.		
This check is for single value spikes, specifically the value at point *n*-1. Spikes consisting of more than one data point are difficult to capture, but their onset may be flagged by the rate of change test. The spike test consists of two operator-selected thresholds, THRSHLD_LOW and THRSHLD_HIGH. Adjacent data points (n_{-2} and n_0) are averaged to form a spike reference (SPK_REF). The absolute value of the spike is tested to capture positive and negative spikes. Large spikes are easier to identify as outliers and flag as failures. Smaller spikes may be real and are only flagged suspect. The thresholds may be fixed values or dynamically established (for example, a multiple of the standard deviation over an operator-selected period).		
Flags	**Condition**	**Codable Instructions**
Fail=4	High spike threshold exceeded.	If $\lvert T_{n-1} - SPK\_REF \rvert >$ THRSHLD_HIGH, flag = 4
Suspect=3	Low spike threshold exceeded.	If $\lvert T_{n-1} - SPK\_REF \rvert >$ THRSHLD_LOW and $\lvert T_{n-1} - SPK\_REF \rvert \leq$ THRSHLD_HIGH, flag = 3
Pass=1	Applies for test pass condition.	N/A
Test Exception: None.		
Test specifications to be established locally by the operator. **Examples:** THRSHLD_LOW = 3 °C, THRSHLD_HIGH = 8 °C		

Oceanographic temperature variability tends to decrease with depth, and thus as for Test 5, we implemented depth dependent thresholds to assign Flag 4 (and did not assign Flag 3):

Depth (dbar)	**Spike threshold °C**
In air	5
0- 10	2
10-600	2
600-1500	2
>1500	0.1

Comparison of these thresholds to observed spikes is provided in Figure 6.

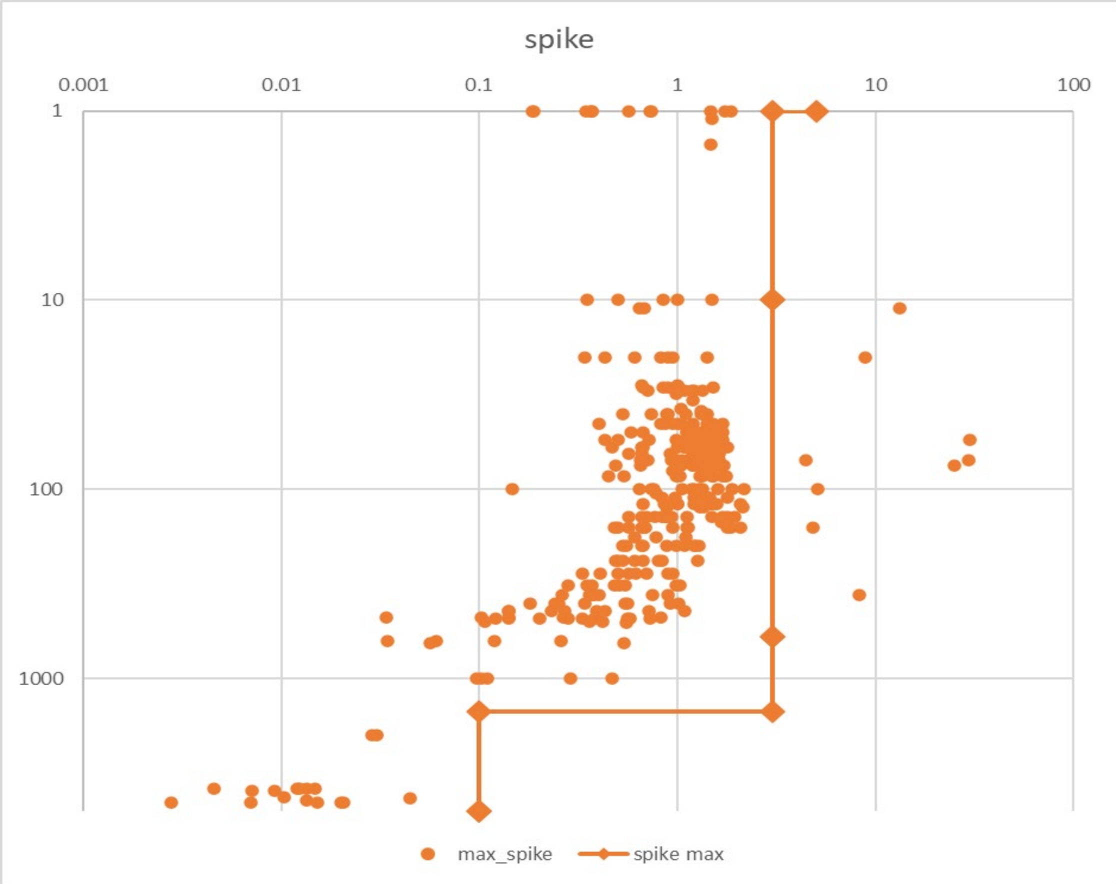


Figure 6 Depth varying spike thresholds compared to maximum spikes from all sensors.

Test 7) Rate of Change Test (Strongly Recommended)

<table>
<tr><td colspan="3">Excessive rise/fall test. Applies to T, SP, C, and P.</td></tr>
<tr><td colspan="3">This test inspects the time series for a time rate of change that exceeds a threshold value identified by the operator. T, SP, C, P values can change substantially over short periods in some locations, hindering the value of this test. A balance must be found between a threshold set too low, which triggers too many false alarms, and one set too high, making the test ineffective. Determining the excessive rate of change is left to the local operator.
The following shows two different examples of ways to select the thresholds provided by QARTOD VI participants. Implementation of this test can be challenging. Upon failure, it is unknown which of the points is bad. Further, upon failing a data point, it remains to be determined how the next iteration can be handled.
Example 1
The rate of change between temperature T_{n-1} and T_n must be less than three standard deviations (3*SD). The SD of the T time series is computed over the previous 25-hour period (operator-selected value) to accommodate cyclical diurnal and tidal fluctuations. Both the number of SDs (N_DEV) and the period over which the SDs (TIM_DEV) are calculated and determined by the local operator.
Example 2
The rate of change between temperature T_{n-1} and T_n must be less than 2 °C +2SD.
$|T_{n-1} - T_{n-2}| + |T_{n-1} - T_n| <= 2*N\_DEV*SD$ (example provided by EuroGOOS).</td></tr>
<tr><th>Flags</th><th>Condition</th><th>Codable Instructions</th></tr>
<tr><td>Fail=4</td><td>No fail flag is identified for this test.</td><td>N/A</td></tr>
<tr><td>Suspect=3</td><td>The rate of change exceeds the selected threshold.</td><td>If $|T_n - T_{n-1}|$>N_DEV*SD, flag = 3</td></tr>
<tr><td>Pass=1</td><td>Applies for test pass condition.</td><td>N/A</td></tr>
<tr><td colspan="3">Test Exception: None.</td></tr>
<tr><td colspan="3">Test specifications to be established locally by operator.
Example: N_DEV = 3, TIM_DEV = 25</td></tr>
</table>

Implementation for SOTS delayed mode QC was as follows:

We discuss the implementation of this test in some detail, for several reasons, including that:

i. the QARTOD test description has some internal inconsistencies

ii. choosing thresholds for this test requires careful comparison of sampling frequency to oceanographic event frequencies and durations

iii. the Australian IMOS Toolbox offers alternate algorithms which we examined but chose not to use

i. QARTOD Inconsistencies

We note that the text and formula for Example 2 from the QARTOD manual are not in accord. The text suggests that the rate of change must be less than the sum of a constant threshold of 2°C plus 2 times the standard deviation over the previous TIM_DEV period, but the formula compares the average rate of change over the past 2 intervals (n vs n_{-1} and n_{-1} vs n_{-2}) with the N standard deviations SD, without any constant threshold. The formula as written also fails to include consideration of the sampling interval. An appropriate formula for a variable V including a constant threshold rate, V_t, with augmentation when the signal is noisy (as represented by N_DEV times the standard deviation SD calculated over the past time period TIM_DEV) would read:

Flag 3 if $[|V_n - V_{n-1}|] / [t_n - t_n - 1] > V_t + N\_DEV*SD$

Note that this formulation means that R_t should be selected as the threshold change in the rate of change variable V_t over the time period TIM_DEV, and that TIM_DEV should be selected to cover a reasonable number of prior observations so that its SD is well behaved. This formulation would avoid excessive flagging of records with low variability, by setting a minimum rate of change V_t.

ii. Examples of observed rates of change at SOTS and their influence on threshold choices

An example T time series illustrates the challenges of determining whether data should be flagged as bad or suspect based on rate of change. For the SOFS surface float, SBE37 unpumped CTDs sampling at high temporal frequency occasionally exhibit rapid temperature changes, e.g. the warming in the second week of December as shown in Figure 7. Expanding the scale shows that this warming had complex structure and multi-day duration, as shown in Figure 8. The sampling frequency was sufficient that this data is not flagged as suspect by the spike test (see bottom panel of Figure 7), yet has very high rates of change (reaching 100°C $hour^{-1}$, second panel from bottom of Figure 7). This high rate of change suggests the possibility of sensor problems, but comparison to a duplicate sensor at the same location reveals an identical record (Figure 8) and thus that this high rate of change is actually oceanographic – presumably because a filament of warmer water with very sharp spatial boundaries passed the mooring in a matter of minutes. This illustrates the great value of Neighbour tests as discussed further below. [As an aside, we also note that Figure 7 shows that salinity excursions to fresh values are more frequent than rapid warming events. In work to be reported in a forthcoming salinity QC report, we show that these arise in part from the temporal mismatch of conductivity cell and thermistor readings as density-compensated filaments pass the mooring, much as they arise in CTD records when CT sensors transit sharply defined vertical gradients.]

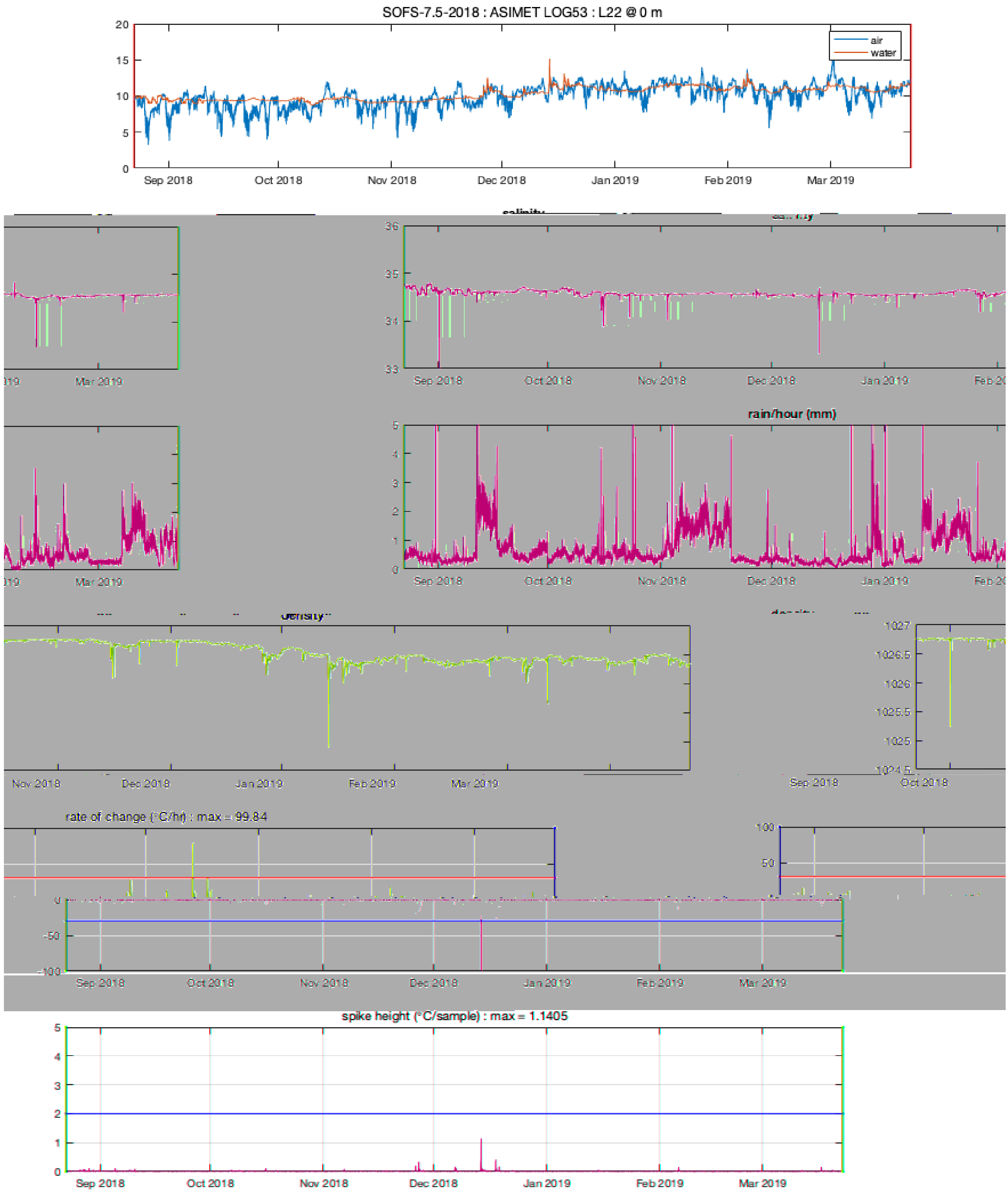


Figure 7 Temperatures and salinities measured at ~1 m depth on SOFS-7.5 float (and other properties).

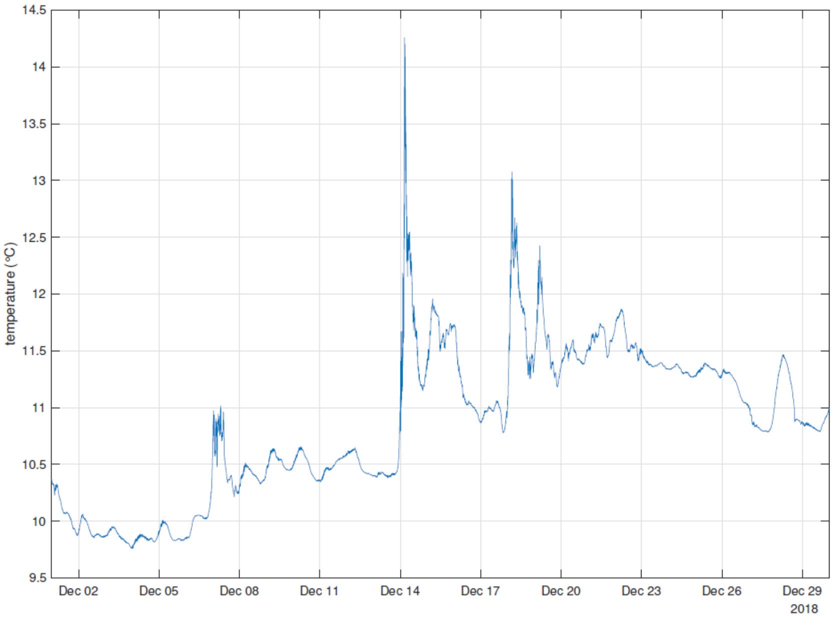


Figure 8 Close-up of warming events in December 2018, for same sensor as in Figure 6.

The observable rate-of-change clearly depends on the sampling frequency, and most sensors at SOTS sample more slowly. Thus, a single rate-of-change threshold for all sensors can be difficult to define. For simplicity, and to avoid flagging good data as bad, we have chosen a high rate of change threshold for all sensors. This approach could inappropriately miss flagging rapid changes in lower frequency records, but in practice we found that those problems are often detected by the Test 6 spike algorithm. As with Tests 5 and 6, we implemented depth dependent thresholds (assigning only Flag 3):

Depth (dbar)	Rate of Change Threshold °C $hour^{-1}$
In air	100
0- 10	80
10-600	80
600-1500	20
>1500	3

This depth dependence scales the thresholds to the observed variability, an aspect which the use of the measurement standard deviation was intended to do in the QARTOD formulation (with or without the addition of a minimum threshold V_t), but importantly without the problem that the standard deviation increases as the proportion of bad data increases. In other words, boot-strapping thresholds from standard deviations can only be successful when the variability is actually oceanographic and data is both infrequent and intermittent, and thus it is better to choose thresholds from the best performing sensors and apply them across all sensors, rather than setting thresholds from individual records. Figure 9 compares the rate of change thresholds and moored observations.

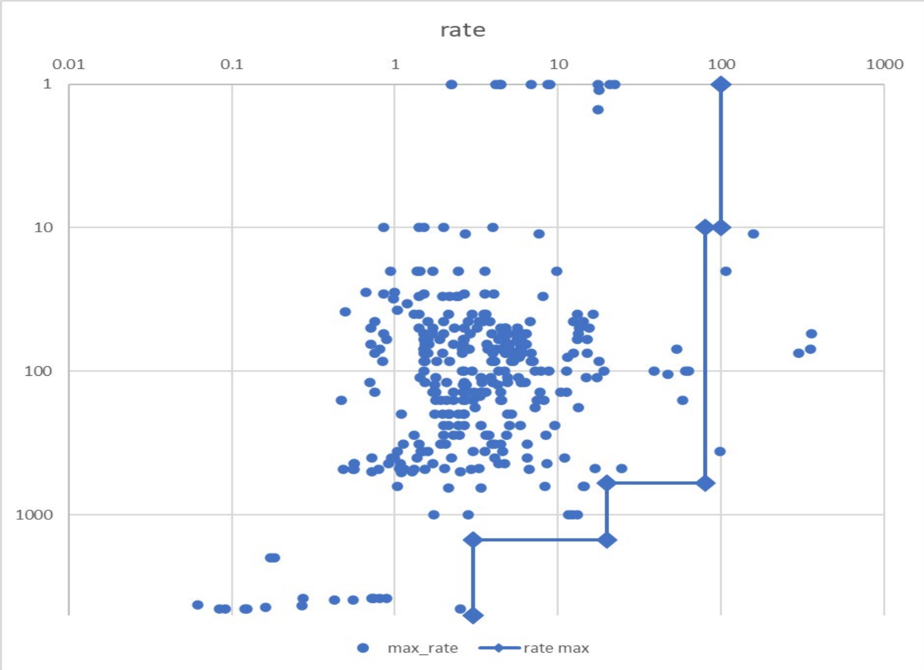


Figure 9 Comparison of Test 7 rate of change thresholds and observed rate of change maxima.

iii. consideration of IMOS Toolbox Spike / Rate of Change tests

The IMOS Toolbox offers two interesting algorithms, known as Hampel and Otsu in reference to the early works that introduced the concepts (Hampel, 1974; Otsu, 1979).

The Hampel algorithm is very similar to the QARTOD rate of change test – in that it uses a window (e.g. 25 hours) over which variability is determined to derive a threshold that is then used to throw out spikes. It differs from the QARTOD rate of change only in that the variability measure is linear (rather than squared, i.e. standard deviation). Because the window can be much wider than the measurement interval (up to the whole record length), it effectively separates the spikes from the unaffected data based on whether short-duration amplitudes are larger than long duration average variability amplitudes. Thus, it suffers from the same general problem as discussed above for the QARTOD algorithm – it drives thresholds from compromised data, and specifically if high rates of change from sensor errors are frequent, they determine the variability and thus cannot be distinguished from good data.

The Otsu algorithm, as developed for image recognition, is more interesting. It makes a histogram of the rate of change amplitudes between adjacent points (so it is sort of an estimate of the probability distribution of all the variability), and then divides this into two classes – acceptable variability and unacceptable variability - in a way that maximizes the difference between the two classes. This works as long as the spikes are steeper than the data. In its simplest form it uses the full record to define the histogram, but of course that can be chopped into bits. Again, it can only work when some of the record is good, so that there is a portion that defines the acceptable variability. In practice, this same goal was achieved by our setting of thresholds via visualisation of the SOTS records, including comparison of Neighbour records. Future work to pursue quantitative examination of the variability probability distribution functions of good records may well prove useful, but was beyond the scope of this report.

Test 8) Flat Line Test (Strongly Recommended)

Invariant value. Applies to T, SP, C, and P.		
When some sensors and/or data collection platforms fail, the result can be a continuously repeated observation of the same value. This test compares the present observation *n* to a number (REP_CNT_FAIL or REP_CNT_SUSPECT) of previous observations. Observation *n* is flagged if it has the same value as previous observations within a tolerance value, EPS, to allow for numerical round-off error. Note that historical flags are not changed.		
Flags	**Condition**	**Codable Instructions**
Fail=4	When the five most recent observations are equal, T_n is flagged fail.	CNT = 0 For *I* = 1,REP_CNT_FAIL If $\lvert T_n - T_{n-i} \rvert$<EPS, CNT = CNT+1 If CNT = REP_CNT_FAIL, flag = 4
Suspect=3	It is possible but unlikely that the present observation and the two previous observations would be equal. When the three most recent observations are equal, T_n is flagged suspect.	CNT = 0 For *I* = 1,REP_CNT_SUSPECT If $\lvert T_n - T_{n-i} \rvert$<EPS, CNT = CNT+1 If CNT = REP_CNT_SUSPECT, flag = 3
Pass=1	Applies for test pass condition.	N/A
Test Exception: None.		
Test specifications to be established locally by the operator. **Examples:** REP_CNT_FAIL = 5, REP_CNT_SUSPECT= 3, EPS = 0.05°		

NOT Implemented for SOTS delayed mode QC of temperature

The choice of tolerance value for this test is very important, and testing with SOTS data found there were two situations: i) for sensors with high digital-analog resolution (SBE37, SBE16, etc.) five repeated values were not observed and ii) for sensors with low digital-analog sensitivity (VEMCO) repeated values were common when temperature changes were small but inside the DAC resolution. Thus, in neither case did the test yield value. Therefore, the test was not implemented.

Test 9) Multi-Variate Test (Suggested)

Comparison to other variables. Applies to T, SP, and P.		
This is an advanced family of tests, starting with the simpler test described here and anticipating growth towards full co-variance testing in the future. It is doubtful that anyone is conducting tests such as these in real time. As these tests are developed and implemented, they should be documented and standardized in later versions of this manual. This example pairs rate of change tests as described in test 7. The T (or SP or P) rate of change test is conducted with a more restrictive threshold (N_T_DEV). If this test fails, a second rate of change test operating on a second variable (salinity or conductivity would be the most probable) is conducted. The absolute value rate of change should be tested, since the relationship between T and variable two is indeterminate. If the rate of change test on the second variable fails to exceed a threshold (e.g., an anomalous step is found in T and is lacking in salinity), then the T_n value is flagged. Note that Test 12, TS Curve/Space Test is a well-known example of the multi-variate test.		
Flags	**Condition**	**Codable Instructions**
Fail=4	No fail flag is identified for this test.	N/A
Suspect=3	T_n fails the rate of change and the second variable does not exceed the rate of change.	If $\|T_n - T_{n-1}\|$>N_T_DEV*SD_T AND $\|SP_n - SP_{n-1}\|$<N_SP_DEV*SD_SP, flag = 3
Pass=1	N/A	N/A
Test Exception: None.		
Test specifications to be established locally by the operator. **Examples:** N_T_DEV = 2, N_TEMP_DEV = 2, TIM_DEV = 25 hours		

NOT Implemented for SOTS delayed mode QC of temperature

We did not find use of pressure (P) or salinity (S) data useful for QC of SOTS T data and did not implement this test. We suspect that this is commonly the case, for the following reasons:

i. Because mooring dynamics allow P to vary and its record is provided, comparison of T to P reveals these dynamics rather than identifying bad data. Understanding the dynamics is of course important, and if a T time series at fixed P is desired, T data should be filtered using this P variable.

ii. Because salinity errors are more common since the conductivity cell is more readily compromised than the thermistor probe, and salinity is derived from conductivity and temperature and thus is not independent of T.

In contrast, we note that this approach is very useful for salinity QC (and will be applied in the forthcoming report on salinity QC).

Test 10) Attenuated Signal Test (Suggested)

A test for inadequate variation of the time series. Applies to T, SP, C, and P.		
A common sensor failure mode can provide a data series that is nearly but not exactly a flat line (e.g., if the sensor head were to become wrapped in debris). This test inspects for an SD value or a range variation (MAX-MIN) value that fails to exceed threshold values (MIN_VAR_WARN, MIN_VAR_FAIL) over a selected time period (TST_TIM).		
Flags	**Condition**	**Codable Instructions**
Fail=4	Variation fails to meet the minimum threshold MIN_VAR_FAIL.	If During TST_TIM, SD <MIN_VAR_FAIL, or During TST_TIM, MAX-MIN <MIN_VAR_FAIL, flag = 4
Suspect=3	Variation fails to meet the minimum threshold MIN_VAR_WARN.	If During TST_TIM, SD <MIN_VAR_WARN, or During TST_TIM, MAX-MIN <MIN_VAR_WARN, flag = 3
Pass=1	Applies for test pass condition.	N/A
Test Exception: None.		
Test specifications to be established locally by the operator. **Examples:** TST_TIM = 12 hours MIN_VAR_WARN = 0.5 °C, MIN_VAR_FAIL = 0.1 °C		

Implementation for SOTS delayed mode QC was as follows:

The definition of the minimum variability thresholds (MIN_VAR_FAIL/WARN) requires precise understanding of the oceanographic expectation, and will vary strongly with depth. In this sense it has overlaps with Tests 6 and 7 for spikes and rates of change. Also, as noted in the introduction, such expectations of minimum variability are still under development for the Southern Ocean owing to the sparse history of temporally resolved observations. In practice, the best estimate of the expectation comes from sensors at SOTS that are considered to have functioned without attenuation, and thus are equivalent to an aspect of Neighbour tests. For this reason, we did not perform Test 10 separately; rather its information was captured by our implementation of Test 11. In future, as knowledge of minimum variability is obtained, separate implementation of Test 10 may become useful.

Test 11) Neighbor Test (Suggested)

Comparison to nearby sensors. Applies to T, SP, C, and P.		
This test is potentially the most useful when a nearby sensor has a similar response. Ideally, redundant sensors using different technology would be co-located and alternately serviced at different intervals. This close neighbor would provide the ultimate QC check, but cost often prohibits such a deployment However, there are few instances where a second sensor is sufficiently proximate to provide a useful QC check. Just a few hundred meters in the horizontal and less than 10 m vertical separation can often yield greatly different results. Nevertheless, the test should not be overlooked where it may have application. This test is the same as Test 9), *Multi-variate Check – comparison to other variables* where the second variable is the second sensor. The selected thresholds depend entirely upon the relationship between the two sensors as determined by the local knowledge of the operator. In the instructions and examples below, data from one site (T1) are compared to a second site (T2). The standard deviation for each site (SD1, SD2) is calculated over the period (TIM_DEV) and multiplied as appropriate (N_T1_DEV for site T1) to calculate the rate of change threshold. Note that an operator could also choose to use the same threshold for each site, since they are presumed to be similar.		
Flags	**Condition**	**Codable Instructions**
Fail=4	No fail flag is identified for this test.	N/A
Suspect=3	$T1_n$ fails the rate of change and the second sensor $T2_n$ does not exceed the rate of change.	If $T1_n - T1_{n-1}$|>N_T1_DEV*SD1 AND |$T2_n - T2_{n-1}$|<N_T2_DEV*SD2, flag = 3
Pass=1	N/A	N/A
Test Exception: There is no adequate neighbor.		
Test specifications to be established locally by the operator. **Examples:** N_T1_DEV = 2, N_T2_DEV=2, TIM_DEV = 25 hours		

Implementation for SOTS delayed mode QC was as follows:

In principle, this is a powerful test, particularly when sensors are mounted in pairs and thus either they reinforce the fidelity of the data when they are indistinguishable or emphasize that at least one of the sensors has failed when they differ. Obviously, examination of all neighbouring sensors provides the most powerful approach. Moreover, other aspects than the standard deviation need examination– for example two sensors may have the same standard deviation but may drift relative to each other. For these reasons, we did not codify paired tests, but instead used parallel visualization of all temperature sensors on each mooring to search for problems. That effort is detailed in the next section, after implementation of the remaining QARTOD tests is described.

Test 12) TS Curve/Space Test (Suggested)

Comparison to expected TS relationship. Applies to T, SP.		
The TS curve is a classic tool used to evaluate observations, especially in the open ocean below the thermocline. Site-specific TS curve characteristics are used to identify outliers. The curve could be either a fitted equation or numerical table. For a given T_n, SP_n is expected to be within SPfit $\pm$ SP_fit_warn or SP_fit_fail, operator-provided values. The value SPfit is obtained from the equation or table.		
Flags	**Condition**	**Codable Instructions**
Fail=4	For a given temperature, the observed salinity falls outside the TS curve failure threshold.	If $\lvert SP_n\text{-SPfit}\rvert >$ SP_fit_fail, flag = 4
Suspect=3	For a given temperature, the observed salinity falls outside the TS curve warning threshold.	If $\lvert SP_n\text{-SPfit}\rvert \leq$ SP_fit_fail and $\lvert SP_n\text{-SPfit}\rvert >$ SP_fit warn, flag = 3
Pass=1	N/A	N/A
Test Exception: The test will probably not be useful in estuaries or ocean surface waters.		
Test specifications to be established locally by the operator. **Examples:** At the Bermuda Atlantic Time Series site, for a temperature of 18 °C, SPfit = 36.5 SP_fit_fail = 0.05, SP_fit_warn = 0.02		

NOT Implemented for SOTS delayed mode QC of temperature, for the reasons given at Test 9.

Test 13) Density Inversion Test (Suggested)

Checks that density increases with pressure (depth).		
With few exceptions, potential water density σ_θ will increase with increasing pressure. When vertical profile data are obtained, this test is used to flag as failed T, C, and SP observations, which yield densities that do not sufficiently increase with pressure. A small, operator-selected density threshold (DT) allows for micro-turbulent exceptions. Here, $\sigma_{\theta n}$ is defined as one sample increment deeper than $\sigma_{\theta n\text{-}1}$. With proper consideration, the test can be run on downcasts, upcasts, or down/up cast results produced in real-time. From a computational point of view, this test is similar to the rate of change test (test 7), except that the time axis is replaced by depth. The same code can be used for both, using different variables and thresholds. As with the rate of change test, it is not known which side of the step is good versus bad. An example of the software to compute sigma-theta is available at http://www.teos-10.org/software.htm.		
Flags	**Condition**	**Codable Instructions**
Fail=4	Potential density does not sufficiently increase with increasing depth.	If $\sigma_{\theta n\text{-}1}$ +DT > $\sigma_{\theta n}$, flag = 4
Suspect=3	No suspect flag is identified for this test.	N/A
Pass=1	Potential density sufficiently increases with increasing depth.	If $\sigma_{\theta n\text{-}1}$ +DT ≤ $\sigma_{\theta n}$, flag = 1
Test Exception: None.		
Test specifications to be established locally by the operator. **Examples:** DT = 0.03 kg/m^3		

NOT Implemented for SOTS delayed mode QC of temperature, for the reasons given at Test 9.

The results of the automated QARTOD tests yielded the following flags:

Deployment	Instrument	serial_#	depth	flag 1	flag 2	flag 3	flag 4	flag 6	% flag 3 or 4
SAZ47-11-2008	TDR-2050	14785	1000	1019399	0	0	0	7026	0.00
Pulse-6-2009	SBE16plusV2	1606331	37.5	4059	0	0	0	169	0.00
	Minilog-T	6098	45	7799	0	0	0	265	0.00
	Minilog-T	4823	50	15727	0	0	0	529	0.00
	Minilog-T	4824	55	15727	0	0	0	529	0.00
	Minilog-TD	6100	60	24636	0	0	0	1215	0.00
	Minilog-T	4825	65	15727	0	0	0	529	0.00
	Minilog-T	4826	70	15727	0	0	0	529	0.00
	Minilog-T	4827	75	15727	0	0	0	529	0.00
	Minilog-T	4828	85	15727	0	0	0	529	0.00
	SBE37SM-RS232	6962	100	246364	0	0	0	15733	0.00
	Minilog-T	4829	120	15727	0	0	0	529	0.00
	Minilog-T	4830	140	15726	0	1	0	529	0.01
	Minilog-TD	6101	160	24636	0	0	0	1226	0.00
	TDR-2050	14788	630	985459	0	0	0	53602	0.00
SAZ47-12-2009	TDR-2050	14785	1000	994047	0	0	0	15080	0.00
SOFS-1-2010	ASIMET LOG53	L22	0	573359	0	0	0	77585	0.00
	ASIMET LOG53	L23	0	573359	0	0	0	42897	0.00
	SBE37SM-RS485	3707409	0.66	114662	0	0	0	16092	0.00
	Minilog-T	6097	10	8003	0	0	0	61	0.00
	Minilog-T	4831	20	9554	0	1	0	946	0.01
	Minilog-T	4832	29	9555	0	0	0	946	0.00
	Minilog-T	4833	40	9555	0	0	0	946	0.00
	Minilog-T	4834	50	9555	0	0	0	946	0.00
	Minilog-T	4835	55	9555	0	0	0	946	0.00
	Minilog-T	4836	60	9554	0	1	0	947	0.01
	Minilog-T	4837	65	9555	0	0	0	946	0.00
	Minilog-T	4838	70	9555	0	0	0	958	0.00
	Minilog-TD	6099	75	9555	0	0	0	947	0.00
	Minilog-T	4839	85	9555	0	0	0	947	0.00
	SBE37-SM	2971	100	57336	0	0	0	4674	0.00
	Minilog-T	4840	110	9555	0	0	0	959	0.00
	Minilog-T	4841	120	9555	0	0	0	958	0.00
	Minilog-T	4842	140	9555	0	0	0	947	0.00
	Minilog-TD	4843	160	9554	0	1	0	948	0.01
Pulse-7-2010	SBE16plus	1606331	31.1	5228	0	0	0	690	0.00
	Minilog-T	6098	45	7871	0	0	0	193	0.00
	Minilog-T	4823	50	15871	0	0	0	385	0.00
	Minilog-T	4824	55	15871	0	0	0	385	0.00
	Minilog-TD	6100	60	20911	0	0	0	1559	0.00
	Minilog-T	4825	65	15871	0	0	0	385	0.00
	Minilog-T	4826	70	15871	0	0	0	385	0.00
	Minilog-T	4827	75	15871	0	0	0	385	0.00
	Minilog-T	4828	85	15871	0	0	0	385	0.00
	SBE37SM-RS232	3706962	100	19694	0	1	0	6971	0.01

Deployment	Instrument	serial_#	depth	flag 1	flag 2	flag 3	flag 4	flag 6	% flag 3 or 4
	Minilog-T	4829	120	15871	0	0	0	385	0.00
	Minilog-T	4830	140	15871	0	0	0	385	0.00
	Minilog-TD	6101	160	20911	0	0	0	1556	0.00
	TDR-2050	14788	475	1254719	0	0	0	71063	0.00
	TDR-2050	14789	630	1254719	0	0	0	93066	0.00
SAZ47-13-2010	TDR-2050	14785	1000	936815	0	0	0	13700	0.00
Pulse-8-2011	SBE16plus	1606330	34	5296	0	0	0	139	0.00
	Minilog-T	6098	45	4210	0	0	0	235	0.00
	SBE56	5600531	45	33683	0	0	0	1987	0.00
	Minilog-T	4823	50	3933	0	0	0	212	0.00
	Minilog-T	4824	55	3933	0	0	0	212	0.00
	Minilog-TD	6100	60	2965	0	0	0	23	0.00
	Minilog-T	4825	65	4210	0	0	0	235	0.00
	Minilog-T	4826	70	4210	0	0	0	235	0.00
	Minilog-T	4827	75	4210	0	0	0	235	0.00
	Minilog-T	4828	85	4210	0	0	0	235	0.00
	SBE37SM-RS232	6962	105	505246	0	0	0	9011	0.00
	Minilog-T	4829	120	4210	0	0	0	235	0.00
	Minilog-T	4830	140	4210	0	0	0	235	0.00
	Minilog-TD	6101	160	2076	0	1	0	23	0.05
	TDR-2050	14788	475	1010491	0	0	0	55502	0.00
	TDR-2050	14789	630	1010491	0	0	0	55527	0.00
SAZ47-14-2011	TDR-2050	16370	3900	507599	0	0	0	4139	0.00
SOFS-2-2011	ASIMET LOG53	L22	0	346979	0	0	0	51518	0.00
	SBE37SM-RS485	3707409	1.5	69396	0	0	0	10358	0.00
	Minilog-T	6097	10	5782	0	0	0	460	0.00
	Minilog-T	4831	20	5782	0	0	0	460	0.00
	Minilog-T	4832	29	5782	0	0	0	460	0.00
	Minilog-T	4833	40	5782	0	0	0	460	0.00
	Minilog-T	4834	50	5782	0	0	0	460	0.00
	Minilog-T	4835	55	5782	0	0	0	460	0.00
	Minilog-T	4836	60	5782	0	0	0	461	0.00
	Minilog-T	4837	65	5782	0	0	0	460	0.00
	Minilog-T	4838	70	5782	0	0	0	461	0.00
	Minilog-TD	6099	75	5447	0	0	0	121	0.00
	Minilog-T	4839	85	5782	0	0	0	461	0.00
	SBE37-SM	2971	100	34698	0	0	0	2302	0.00
	Minilog-T	4840	110	5781	0	1	0	461	0.02
	Minilog-T	4841	120	5782	0	0	0	657	0.00
	Minilog-T	4842	140	5782	0	0	0	461	0.00
	Minilog-TD	4843	160	5782	0	0	0	461	0.00
SOFS-3-2012	ASIMET LOG53	L25	0	247199	0	0	0	64690	0.00
	SBE37SM-RS485	3708764	1	49440	0	0	0	11854	0.00
	SBE37SM-RS485	3708765	1	49421	0	0	0	11637	0.00
	Minilog-II-T	353264	10	16479	0	0	0	917	0.00
	Minilog-II-T	353265	20	16479	0	0	0	917	0.00

Deployment	Instrument	serial_#	depth	flag 1	flag 2	flag 3	flag 4	flag 6	% flag 3 or 4
	Minilog-II-T	353266	29	16479	0	0	0	917	0.00
	SBE37SMP-ODO-RS232	9513	30	8240	0	0	0	1154	0.00
	Minilog-II-T	353267	40	16479	0	0	0	917	0.00
	Minilog-II-T	353268	55	16479	0	0	0	918	0.00
	Minilog-II-T	353269	60	16479	0	0	0	918	0.00
	Minilog-II-T	353270	65	16479	0	0	0	918	0.00
	Minilog-II-T	353271	70	16479	0	0	0	918	0.00
	Minilog-II-T	353272	75	16479	0	0	0	918	0.00
	Minilog-II-T	353273	85	16479	0	0	0	929	0.00
	SBE37SMP-ODO-RS232	9514	100	8240	0	0	0	1157	0.00
	Minilog-II-T	353275	100	16479	0	0	0	919	0.00
	Minilog-II-T	353276	110	16479	0	0	0	919	0.00
	Minilog-II-T	353277	120	16479	0	0	0	919	0.00
	Minilog-II-T	353290	140	16479	0	0	0	919	0.00
	Minilog-II-T	353291	160	16479	0	0	0	919	0.00
	Minilog-II-T	353292	200	16479	0	0	0	919	0.00
	Minilog-II-T	353293	240	16479	0	0	0	919	0.00
	Minilog-II-T	353294	280	16479	0	0	0	919	0.00
	Minilog-II-T	353295	320	16479	0	0	0	919	0.00
	Minilog-II-T	353296	360	16479	0	0	0	919	0.00
	Minilog-II-T	353297	400	16478	0	1	0	919	0.01
	Minilog-II-T	353298	440	16479	0	0	0	1203	0.00
	Minilog-II-T	353299	480	16479	0	0	0	919	0.00
Pulse-9-2012	SBE16plusV2	1606331	38.5	4653	0	0	0	776	0.00
	Minilog-II-T	353253	45	28008	0	0	0	1002	0.00
	Minilog-II-T	353254	50	28008	0	0	0	1002	0.00
	Minilog-II-T	353255	55	28008	0	0	0	1002	0.00
	Minilog-II-T	353256	60	28008	0	0	0	1002	0.00
	Minilog-II-T	353257	65	28008	0	0	0	1002	0.00
	Minilog-II-T	353258	70	28008	0	0	0	1002	0.00
	Minilog-II-T	353259	75	28008	0	0	0	1002	0.00
	Minilog-II-T	353260	85	28008	0	0	0	1002	0.00
	SBE37SMP-ODO-RS232	3709515	100	14003	0	2	0	999	0.01
	Minilog-II-T	353261	120	28008	0	0	0	1002	0.00
	Minilog-II-T	353262	140	28008	0	0	0	1003	0.00
	TDR-2050	14786	475	28008	0	0	0	817	0.00
	TDR-2050	14787	630	28008	0	0	0	816	0.00
SAZ47-15-2012	TDR-2050	16371	3900	644579	0	0	0	3647	0.00
	SBE37SM-RS232	3708597	4422	128916	0	0	0	3308	0.00
SOFS-4-2013	ASIMET LOG53	L23	0	239694	0	0	0	75862	0.00
	SBE37SM-RS485	3707409	1.01	47939	0	0	0	13705	0.00
	SBE37SM-RS485	3707408	1.01	47939	0	0	0	11983	0.00
	Minilog-II-T	353264	10	15979	0	0	0	1589	0.00
	Minilog-II-T	353265	20	15979	0	0	0	1589	0.00
	Minilog-II-T	353267	40	15978	0	1	0	1589	0.01
	Minilog-II-T	353268	55	15979	0	0	0	1590	0.00

Deployment	Instrument	serial_#	depth	flag 1	flag 2	flag 3	flag 4	flag 6	% flag 3 or 4
	Minilog-II-T	353269	60	15979	0	0	0	1591	0.00
	Minilog-II-T	353270	65	15979	0	0	0	1591	0.00
	Minilog-II-T	353271	70	15979	0	0	0	1591	0.00
	Minilog-II-T	353272	75	15978	0	1	0	1591	0.01
	Minilog-II-T	353273	85	15979	0	0	0	1602	0.00
	SBE37SM-RS232	3708985	100	239695	0	0	0	9353	0.00
	Minilog-II-T	353276	110	15979	0	0	0	1591	0.00
	Minilog-II-T	353277	120	15979	0	0	0	1591	0.00
	Minilog-II-T	353290	140	15979	0	0	0	1591	0.00
	Minilog-II-T	353291	160	15979	0	0	0	1591	0.00
	Minilog-II-T	353292	200	15978	0	1	0	1591	0.01
	Minilog-II-T	353293	240	15979	0	0	0	1591	0.00
	Minilog-II-T	353294	280	15979	0	0	0	1591	0.00
	Minilog-II-T	353295	320	15978	0	1	0	1592	0.01
	Minilog-II-T	353296	360	15978	0	1	0	1592	0.01
	Minilog-II-T	353297	400	15979	0	0	0	1592	0.00
	Minilog-II-T	353298	440	15979	0	0	0	1587	0.00
	Minilog-II-T	353299	480	15979	0	0	0	1592	0.00
	SBE37SM-RS232	3709185	500	47939	0	0	0	1654	0.00
SAZ47-16-2013	TDR-2050	16370	3800	994919	0	0	0	16192	0.00
	SBE37	1778	4300	99318	0	0	0	3466	0.00
Pulse-10-2013	SBE16plus	1606330	28	3828	0	0	0	28	0.00
	Minilog-II-T	354194	45	15310	0	0	0	2261	0.00
	Minilog-II-T	354195	50	15310	0	0	0	2261	0.00
	Minilog-II-T	354196	55	15310	0	0	0	2261	0.00
	Minilog-II-T	354197	60	15310	0	0	0	2261	0.00
	Minilog-II-T	354198	65	15310	0	0	0	2262	0.00
	Minilog-II-T	354199	70	15310	0	0	0	2261	0.00
	Minilog-II-T	354200	75	15310	0	0	0	2262	0.00
	Minilog-II-T	354201	85	15310	0	0	0	2261	0.00
	SBE37SMP-ODO-RS232	3709538	100	7655	0	0	0	516	0.00
	Minilog-II-T	354202	120	15309	0	1	0	2262	0.01
	Minilog-II-T	354203	140	15310	0	0	0	2262	0.00
	Minilog-II-T	354204	160	15310	0	0	0	2262	0.00
	SBE37SMP-ODO-RS232	3709513	200	7655	0	0	0	518	0.00
	Minilog-II-T	354205	200	15310	0	0	0	2261	0.00
	Minilog-II-T	354206	240	15310	0	0	0	2262	0.00
	Minilog-II-T	354207	280	15310	0	0	0	2262	0.00
	Minilog-II-T	354208	320	15310	0	0	0	2262	0.00
	Minilog-II-T	354209	360	15310	0	0	0	2262	0.00
	Minilog-II-T	354210	400	15310	0	0	0	2262	0.00
	Minilog-II-T	354211	440	15310	0	0	0	2262	0.00
	TDR-2050	14788	475	214880	0	0	0	12760	0.00
	Minilog-II-T	354212	480	15310	0	0	0	2262	0.00
	TDR-2050	14789	650	229646	0	0	0	24787	0.00
SOFS-5-2015	ASIMET LOG53	L23	0	556903	0	0	0	44721	0.00

Deployment	Instrument	serial_#	depth	flag 1	flag 2	flag 3	flag 4	flag 6	% flag 3 or 4
	ASIMET LOG53	L26	0	556903	0	0	0	56817	0.00
	SBE37SM-RS485	3707409	1.01	111381	0	0	0	5266	0.00
	SBE37SM-RS485	3707408	1.1	111381	0	0	0	5247	0.00
	Minilog-II-T	353264	10	37127	0	0	0	1572	0.00
	Minilog-II-T	353265	20	37127	0	0	0	1573	0.00
	Minilog-II-T	353260	29	37127	0	0	0	1572	0.00
	SBE37SM-RS232	3706962	30	55690	0	0	0	1356	0.00
	Minilog-II-T	353267	40	37127	0	0	0	1571	0.00
	Minilog-II-T	353268	55	37127	0	0	0	1573	0.00
	Minilog-II-T	353269	60	37127	0	0	0	1573	0.00
	Minilog-II-T	353270	65	37127	0	0	0	1572	0.00
	Minilog-II-T	353271	70	37127	0	0	0	1572	0.00
	Minilog-II-T	353272	75	37127	0	0	0	1574	0.00
	Minilog-II-T	353273	85	37127	0	0	0	1596	0.00
	SBE37-SM	4908	100	55690	0	0	0	1196	0.00
	Minilog-II-T	353276	110	37127	0	0	0	1573	0.00
	Minilog-II-T	353277	120	37127	0	0	0	1573	0.00
	Minilog-II-T	353290	140	37127	0	0	0	1573	0.00
	Minilog-II-T	353291	160	37127	0	0	0	1573	0.00
	Minilog-II-T	353292	200	37127	0	0	0	1573	0.00
	Minilog-II-T	353293	240	37127	0	0	0	1573	0.00
	Minilog-II-T	353294	280	37127	0	0	0	1573	0.00
	Minilog-II-T	353295	320	37127	0	0	0	1655	0.00
	Minilog-II-T	353296	360	37127	0	0	0	1573	0.00
	Minilog-II-T	353297	400	37127	0	0	0	1574	0.00
	Minilog-II-T	353298	440	37127	0	0	0	1573	0.00
	Minilog-II-T	353299	480	37127	0	0	0	1574	0.00
	SBE37-SM	4909	500	55690	0	0	0	2076	0.00
Pulse-11-2015	SBE16plus	1606330	28	8614	0	0	0	242	0.00
	Minilog-II-T	354194	45	34601	0	0	0	1501	0.00
	SBE37SMP-ODO-RS232	3709538	50	17301	0	0	0	900	0.00
	Minilog-II-T	354195	50	34601	0	0	0	1501	0.00
	Minilog-II-T	354196	55	34601	0	0	0	1502	0.00
	Minilog-II-T	354197	60	34601	0	0	0	1502	0.00
	Minilog-II-T	354198	65	34601	0	0	0	1500	0.00
	Minilog-II-T	354199	70	34601	0	0	0	1501	0.00
	Minilog-II-T	354200	75	34601	0	0	0	1502	0.00
	Minilog-II-T	354201	85	34601	0	0	0	1501	0.00
	SBE37SMP-ODO-RS232	3709513	100	17301	0	0	0	903	0.00
	Minilog-II-T	354202	120	34601	0	0	0	1501	0.00
	Minilog-II-T	354203	140	34601	0	0	0	1500	0.00
	SBE37SMP-ODO-RS232	3709514	150	17301	0	0	0	904	0.00
	Minilog-II-T	354204	160	34601	0	0	0	1500	0.00
	Minilog-II-T	354205	200	34601	0	0	0	1495	0.00
	Minilog-II-T	354206	240	34601	0	0	0	1496	0.00
	Minilog-II-T	354207	280	34601	0	0	0	1501	0.00

Deployment	Instrument	serial_#	depth	flag 1	flag 2	flag 3	flag 4	flag 6	% flag 3 or 4
	Minilog-II-T	354208	320	34601	0	0	0	1501	0.00
	Minilog-II-T	354209	360	34601	0	0	0	1501	0.00
	Minilog-II-T	354210	400	34601	0	0	0	1501	0.00
	Minilog-II-T	354211	440	34601	0	0	0	1500	0.00
	TDR-2050	14788	475	34601	0	0	0	1809	0.00
	Minilog-II-T	354212	480	34601	0	0	0	1501	0.00
	TDR-2050	14789	650	34601	0	0	0	1809	0.00
SAZ47-17-2015	TDR-2050	16371	3800	514730	0	0	0	34186	0.00
	SBE37SM-RS232	3708985	4250	51473	0	0	0	1394	0.00
FluxPulse-1-2016	ASIMET LOG53	L22	0	141836	0	0	0	33764	0.00
SAZ47-18-2016	TDR-2050	16370	3800	530708	0	0	0	22440	0.00
	SBE37SM-RS232	3708597	4500	53071	0	0	0	784	0.00
SOFS-6-2017	ASIMET LOG53	L22	0	326879	0	0	0	180418	0.00
	SBE37SM-RS485	3708764	1	65376	0	0	0	29640	0.00
	SBE37SM-RS485	3710136	1	65355	0	0	0	29618	0.00
	Minilog-II-T	354194	11	21791	0	0	0	3450	0.00
	Minilog-II-T	354195	20	21791	0	0	0	3450	0.00
	Minilog-II-T	354196	29	21791	0	0	0	3451	0.00
	SBE37SMP-ODO-RS232	3709538	30	10896	0	0	0	823	0.00
	Minilog-II-T	354197	40	21791	0	0	0	3450	0.00
	Minilog-II-T	354198	45	21791	0	0	0	3451	0.00
	Minilog-II-T	354199	50	21791	0	0	0	3451	0.00
	Minilog-II-T	354200	55	21791	0	0	0	3451	0.00
	Minilog-II-T	354201	60	21791	0	0	0	3451	0.00
	Minilog-II-T	354202	70	21791	0	0	0	3451	0.00
	Starmon mini	4777	75	65375	0	0	0	32254	0.00
	Minilog-II-T	354203	80	21791	0	0	0	3451	0.00
	Minilog-II-T	354204	100	21791	0	0	0	3451	0.00
	Minilog-II-T	354205	110	21791	0	0	0	3451	0.00
	SBE37SMP-ODO-RS232	3709513	125	10895	0	1	0	823	0.01
	Minilog-II-T	354206	140	21791	0	0	0	3451	0.00
	Minilog-II-T	354207	160	21791	0	0	0	3451	0.00
	Minilog-II-T	354208	180	21791	0	0	0	3452	0.00
	SBE37SMP-ODO-RS232	3709514	200	10896	0	0	0	823	0.00
	Minilog-II-T	354209	240	21791	0	0	0	3452	0.00
	Minilog-II-T	354210	280	21791	0	0	0	3451	0.00
	Minilog-II-T	354211	320	21790	0	1	0	3451	0.00
	Minilog-II-T	354212	360	21791	0	0	0	3451	0.00
	Minilog-II-T	353297	400	21791	0	0	0	3450	0.00
	Minilog-II-T	353298	440	21791	0	0	0	3450	0.00
	Minilog-II-T	353299	480	21791	0	0	0	3450	0.00
	SBE37SMP-ODO-RS232	3714700	500	10896	0	0	0	824	0.00
SAZ47-19-2017	SBE37SM-RS232	3707901	1000	50915	0	0	0	807	0.00
	SBE37SM-RS232	3707896	2000	50915	0	0	0	809	0.00
	TDR-2050	16371	3800	509142	0	0	0	8112	0.00
	SBE37-SM	2971	4500	50915	0	0	0	803	0.00

Deployment	Instrument	serial_#	depth	flag 1	flag 2	flag 3	flag 4	flag 6	% flag 3 or 4
SOFS-7-2018	SBE37SM-RS485	3707408	1	3025	0	0	0	5907	0.00
	SBE37SM-RS485	3707409	1	3025	0	0	0	5902	0.00
	SBE37SMP-ODO-RS232	3715969	30	504	0	0	0	2340	0.00
	SBE37SMP-ODO-RS232	3715970	125	504	0	0	0	981	0.00
	SBE37SMP-ODO-RS232	3715971	200	504	0	0	0	983	0.00
	SBE37SMP-ODO-RS232	3715972	480	504	0	0	0	983	0.00
SAZ47-20-2018	SBE37-SM	1777	1000	54404	0	0	0	1322	0.00
	SBE37-SM	3124	2000	54404	0	0	0	1313	0.00
	TDR-2050	16370	3800	544035	0	0	0	13210	0.00
	SBE37-SM	2955	4500	54403	0	0	0	929	0.00
SOFS-7.5-2018	ASIMET LOG53	L22	0	305781	0	2	0	92027	0.00
	SBE37SM-RS485	3707408	1	61122	0	0	0	8224	0.00
	SBE37SM-RS485	3707409	1	61157	0	0	0	8227	0.00
	Starmon mini	4035	11	61157	0	0	0	8645	0.00
	Starmon mini	4039	20	61157	0	0	0	8645	0.00
	SBE37SMP-ODO-RS232	3715969	30	10193	0	0	0	1266	0.00
	Starmon mini	4047	40	61157	0	0	0	8645	0.00
	Starmon mini	4048	45	61157	0	0	0	8644	0.00
	Starmon mini	4049	50	61157	0	0	0	8644	0.00
	Starmon mini	4050	55	61157	0	0	0	8643	0.00
	Starmon mini	4051	60	61157	0	0	0	8642	0.00
	Starmon mini	4052	70	59846	0	1293	18	8642	2.19
	Starmon mini	4053	75	60846	0	302	9	8642	0.51
	Starmon mini	4058	80	61157	0	0	0	8640	0.00
	Starmon mini	4060	100	61145	0	12	0	8647	0.02
	Starmon mini	4061	110	61157	0	0	0	8638	0.00
	SBE37SMP-ODO-RS232	3715970	125	10193	0	0	0	1131	0.00
	Starmon mini	4062	140	61157	0	0	0	8637	0.00
	Starmon mini	4063	160	61157	0	0	0	8636	0.00
	Starmon mini	4066	180	61157	0	0	0	8635	0.00
	SBE37SMP-ODO-RS232	3715971	200	10193	0	0	0	1131	0.00
	Starmon mini	4068	240	61157	0	0	0	8634	0.00
	Starmon mini	4069	280	61157	0	0	0	8634	0.00
	Starmon mini	4070	320	61157	0	0	0	8631	0.00
	Starmon mini	4071	360	61157	0	0	0	288207	0.00
	Starmon mini	4077	400	61157	0	0	0	8627	0.00
	Starmon mini	4778	440	61157	0	0	0	8053	0.00
	SBE37SMP-ODO-RS232	3715972	480	10193	0	0	0	1131	0.00
	SBE 39	6273	4550	61157	0	0	0	5476	0.00
SOFS-8-2019	ASIMET LOG53	L25	0	746959	0	0	0	49849	0.00
	ASIMET LOG53	L26	0	772577	0	1	0	102127	0.00
	SBE37SM-RS485	3715728	1	154436	0	0	0	10552	0.00
	Starmon mini	5298	11	66365	0	37	0	13081	0.06
	Starmon mini	5299	20	154510	0	5	0	14813	0.00
	SBE37SMP-ODO-RS232	3720126	30	25753	0	0	0	1984	0.00
	Starmon mini	5300	40	154515	0	0	0	14816	0.00

Deployment	Instrument	serial_#	depth	flag 1	flag 2	flag 3	flag 4	flag 6	% flag 3 or 4
	Starmon mini	5301	45	154515	0	0	0	14816	0.00
	Starmon mini	5303	50	154515	0	0	0	14816	0.00
	Starmon mini	5304	55	154455	0	52	8	14819	0.04
	Starmon mini	5305	60	154515	0	0	0	14817	0.00
	Starmon mini	5307	70	154511	0	4	0	14820	0.00
	Starmon mini	5308	75	154515	0	0	0	14820	0.00
	Starmon mini	5309	85	154515	0	0	0	14825	0.00
	Starmon mini	5310	100	154515	0	0	0	14816	0.00
	Starmon mini	5311	110	154515	0	0	0	14820	0.00
	SBE37SMP-ODO-RS232	3709513	125	25751	0	2	0	1986	0.01
	Starmon mini	5312	140	154515	0	0	0	14821	0.00
	Starmon mini	5313	160	154496	0	19	0	14822	0.01
	Starmon mini	5315	180	154515	0	0	0	14822	0.00
	SBE37SMP-ODO-RS232	3709514	200	25753	0	0	0	1997	0.00
	Starmon mini	5316	240	154515	0	0	0	14814	0.00
	Starmon mini	5319	280	154515	0	0	0	14824	0.00
	Starmon mini	5320	320	154515	0	0	0	14812	0.00
	Starmon mini	5322	360	44093	0	37	0	13081	0.08
	Starmon mini	5324	400	154515	0	0	0	14825	0.00
	Starmon mini	5325	440	44130	0	0	0	13081	0.00
	Starmon mini	5327	480	154515	0	0	0	14812	0.00
	SBE37SMP-ODO-RS232	3720127	510	22970	0	0	0	1991	0.00
	SBE39plus	3908690	4550	5453805	0	0	0	138600	0.00
SAZ47-21-2019	SBE37	4906	1000	76830	0	0	0	1423	0.00
	SBE37	4907	2000	76829	0	1	0	1413	0.00
	TDR-2050	16371	3800	632400	0	0	0	12001	0.00
SOFS-9-2020	SBE37SM-RS485	3707408	1	67605	0	0	0	50764	0.00
	SBE37SM-RS485	3707409	1	67636	0	0	0	47860	0.00
	Starmon mini	4035	11	67636	0	0	0	59117	0.00
	Starmon mini	4039	20	67636	0	0	0	59120	0.00
	SeaFETv1	1001	30	90788	0	728	0	820	0.80
	Starmon mini	4047	40	67636	0	0	0	59122	0.00
	Starmon mini	4048	45	67636	0	0	0	59117	0.00
	Starmon mini	4049	50	67636	0	0	0	59382	0.00
	Starmon mini	4050	55	67636	0	0	0	59125	0.00
	Starmon mini	4051	60	67636	0	0	0	59379	0.00
	Starmon mini	4042	65	67636	0	0	0	59380	0.00
	Starmon mini	4052	70	0	0	0	67636	59114	100.00
	Starmon mini	4053	75	67636	0	0	0	59373	0.00
	Starmon mini	4058	85	67636	0	0	0	59112	0.00
	Starmon mini	4060	100	67636	0	0	0	59383	0.00
	Starmon mini	4061	110	67635	0	1	0	59373	0.00
	SBE37SMP-ODO-RS232	3715970	125	11271	0	1	0	1596	0.01
	Starmon mini	4062	140	67636	0	0	0	59121	0.00
	Starmon mini	4063	160	67636	0	0	0	59110	0.00
	Starmon mini	4066	180	67636	0	0	0	59112	0.00

Deployment	Instrument	serial_#	depth	flag 1	flag 2	flag 3	flag 4	flag 6	% flag 3 or 4
	SBE37SMP-ODO-RS232	3714700	200	11272	0	0	0	5167	0.00
	Starmon mini	4068	240	67636	0	0	0	59124	0.00
	Starmon mini	4069	280	67636	0	0	0	59115	0.00
	SBE37SMP-ODO-RS232	3715971	300	11272	0	0	0	4178	0.00
	Starmon mini	4070	320	67636	0	0	0	59120	0.00
	Starmon mini	4071	360	67636	0	0	0	59121	0.00
	Starmon mini	4077	400	67636	0	0	0	59379	0.00
	Starmon mini	4778	440	67636	0	0	0	59371	0.00
	Starmon mini	4995	480	67636	0	0	0	59385	0.00
	SBE37SMP-ODO-RS232	3715972	510	11272	0	0	0	5023	0.00
SAZ47-22-2020	SBE37-SM	3124	2000	33770	0	0	0	1566	0.00
	SBE37-SM	2955	4500	33770	0	0	0	942	0.00

5.2 Manual Flagging via Neighbouring sensor visualizations

After extensive exploration, we settled on 3 plot types to visualize possible sensor problems (and provide these for all deployments below, with annotation of sensor errors that they revealed):

1. Time series of each temperature record over the whole deployment, shown together on a single plot, with the shallowest record shown at its measured temperature and each sensor below it shown sequentially offset 1°C. These lines are close together (vertically separated by 1°C) when the water column is well mixed and all temperatures are the same. Thermally stable gradients (i.e. monotonic downward temperature decreases) separate the traces further, and periods where the traces converge closer than 1°C indicate warm waters underlying cooler waters which must be stabilized by opposing salinity gradients. This plot type is illustrated in Figure 10.
2. Time series of all pressure sensor records to provide ready reference to mooring motions, because, when thermal gradients are present, these can cause aliasing of mooring dynamics into the temperature records, which if un-recognized could be confounded with temperature sensor noise. Applying these insights requires some knowledge of the mooring structures and dynamics, especially for the two deepest sensors on the Pulse mooring, owing to them i. being placed above and below the shallow s-tether and ii. the mooring landing at different depths on the bottom as a result of very hilly topography and difficult sea conditions during deployments. This is shown in Figure 11 which reveals the variations in the location of these sensors relative to each other. The S-tether design also means that as the stiff lower section and its temperature sensor is subducted by strong current events, the surface-suspended upper section and its sensor is elevated. This leads to opposing temperature variations when temperature gradients are present.
3. Vertical profiles of temperatures every 15 days. These can reveal persistent offsets or drifts of individual sensors relative to their neighbouring sensors above and below, as illustrated in Figure 12.

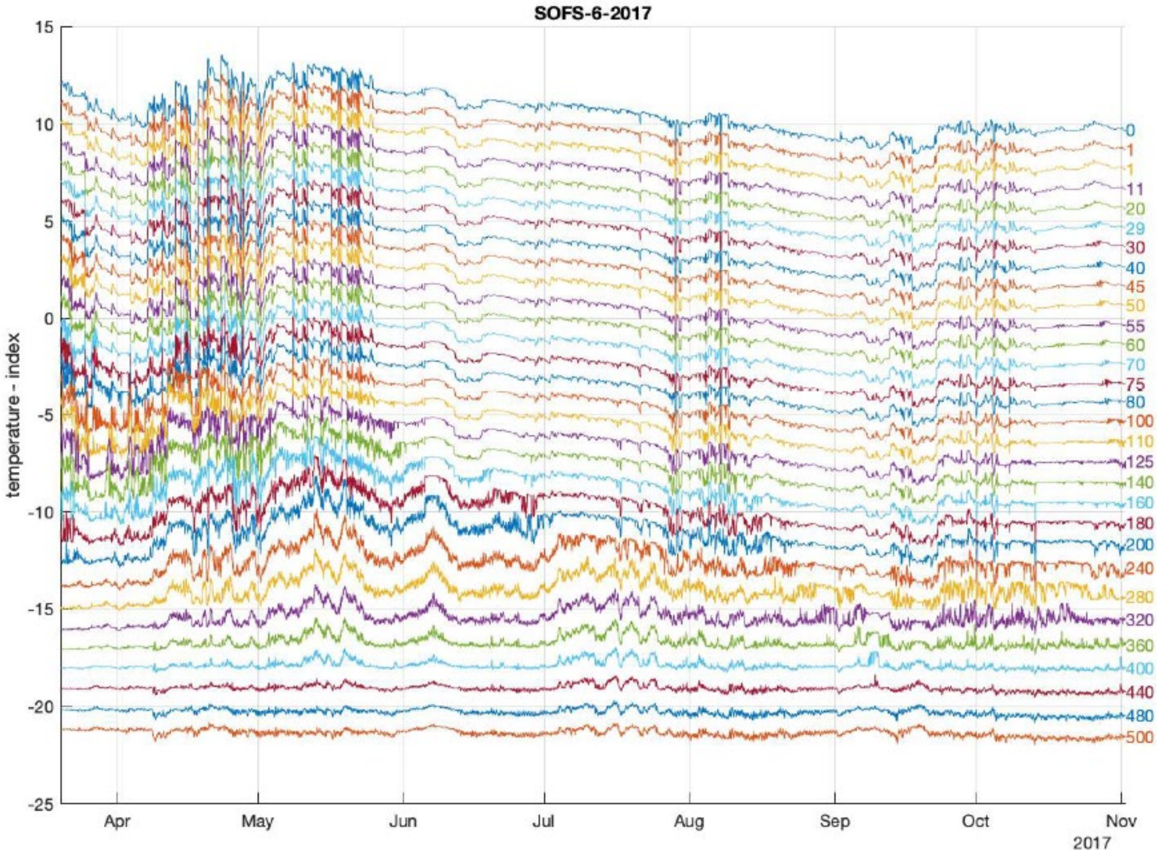


Figure 10 Illustration of stacked time series of all temperature sensors.
The top trace is plotted at the measured temperature. Each subsequent sensor is plotted 1 °C further below its measured temperature. Sensor depths are indicated in the same colour on the right.

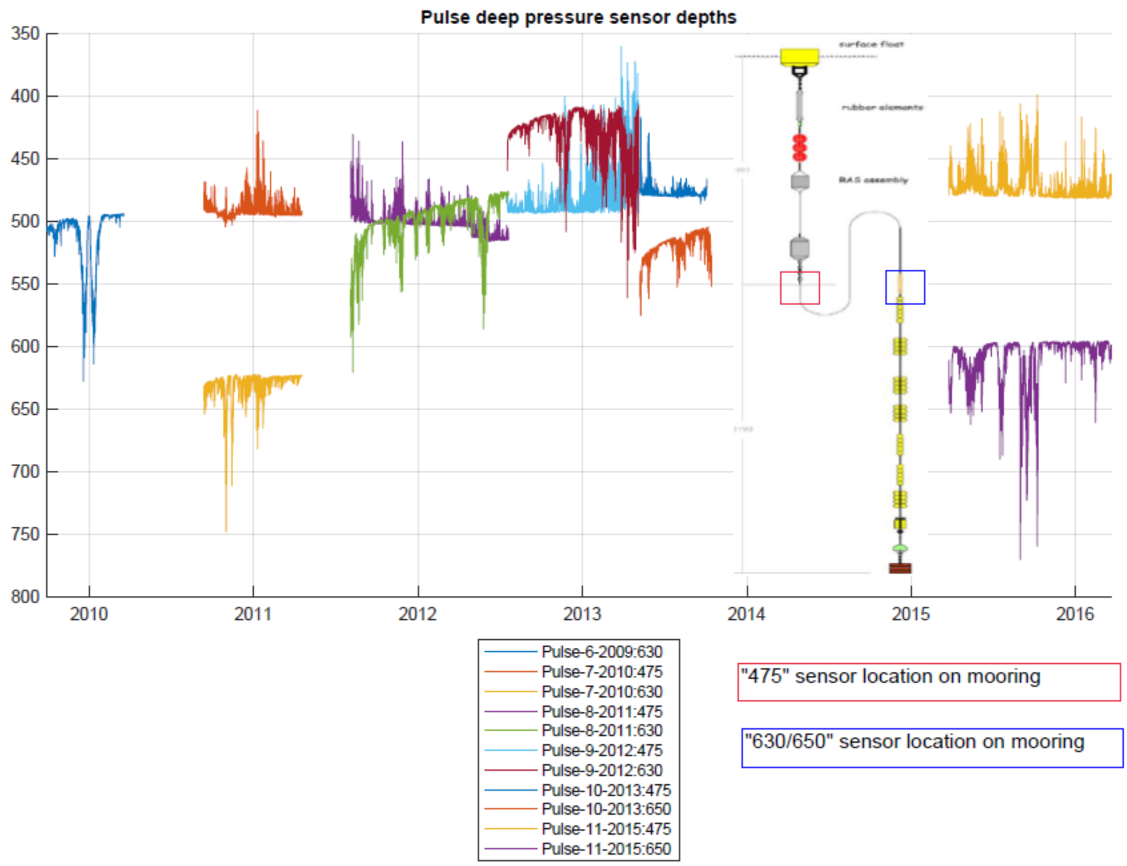


Figure 11 Pulse mooring design impact on locations of sensors above and below the s-tether.

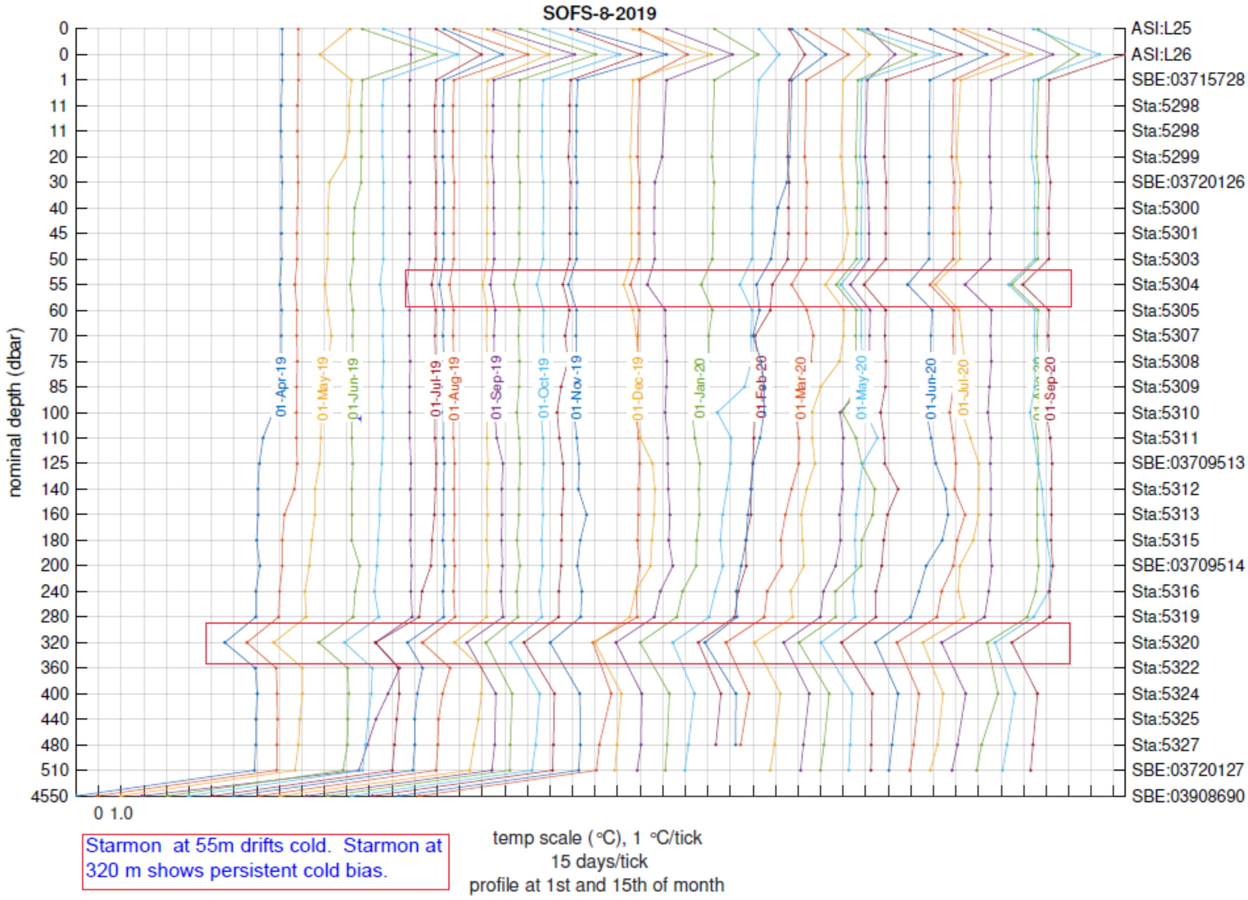


Figure 12 Example of waterfall plot of temperature profiles every fortnight
Dates are shown on each profile. The right-hand y-axis identifies each sensor model and serial number. Two sensors clearly show aberrant behaviour as described in the boxed legend.

Identification of more subtle sensor problems using these plots requires understanding of typical water column temperature profiles as revealed by CTD casts (as shown in Figure 13), to separate temperature offsets among neighbouring sensors from water column temperature variations. When the water column is well-mixed these observations can also provide a path to correcting temperature offsets between sensors, as discussed below.

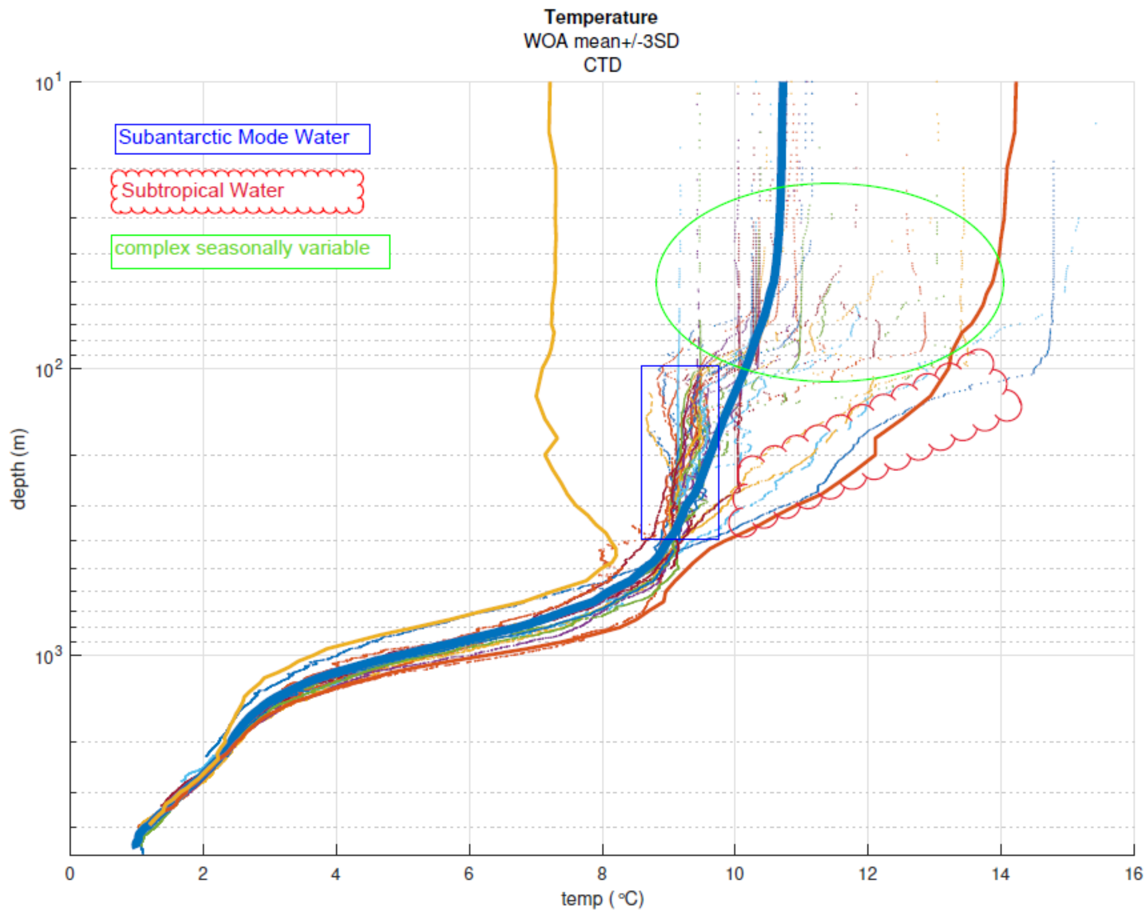


Figure 13 Common vertical temperature variations revealed by SOTS Ship-CTD profiles. The profiles range from Subantarctic (with constant temperature mode waters between 100 and 400 or more meters deep) to Subtropical (with strong gradients in this depth range).

Expanded views of each type of plot is also useful to further evaluate sensor problems, for example Figure 14 shows that possible temperature variations with depth that were revealed in a waterfall plot were not the result of clock offsets and were persistent and constant. This constancy suggests calibration errors and offers a pathway to data adjustment by removing these offsets, as discussed below.

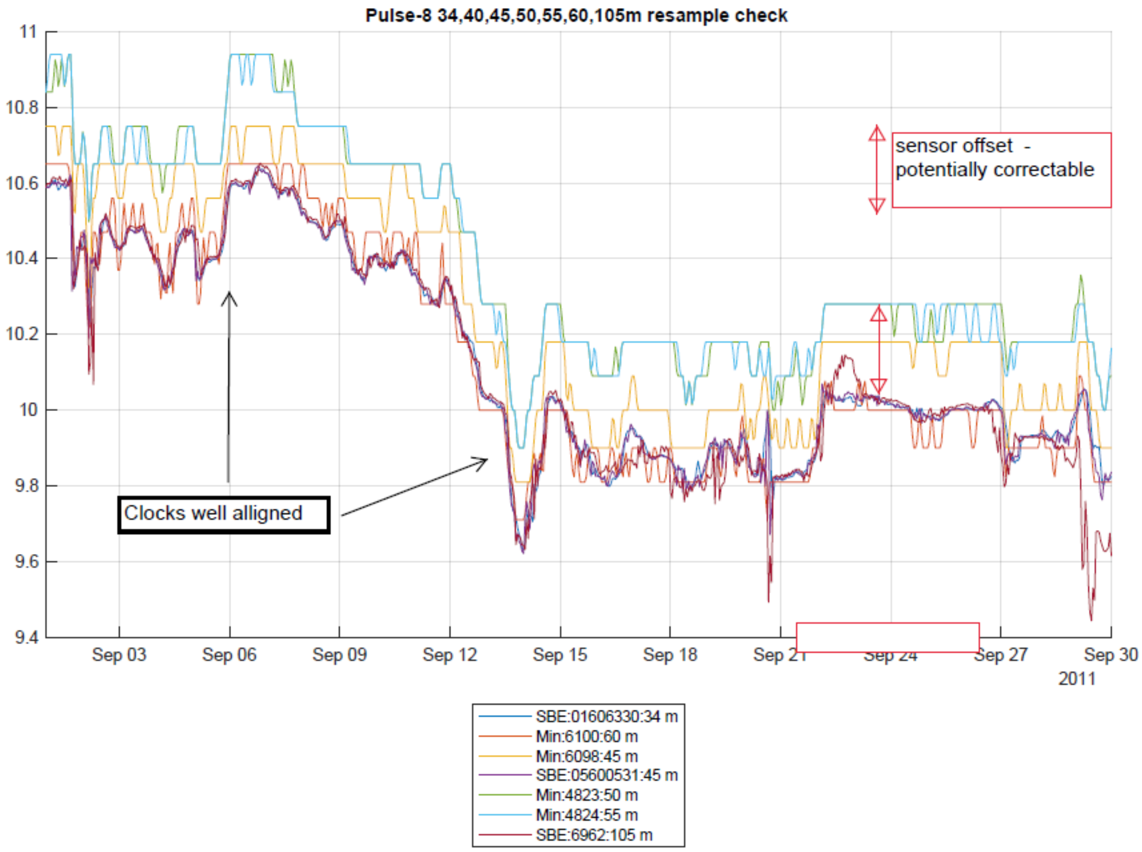


Figure 14 Expanded portion of temperature time series revealing no problem with clock offsets. Thus the temperature variations with depth revealed in waterfall profile plots derive from sensor calibration offsets, opening a pathway to sensor adjustments.

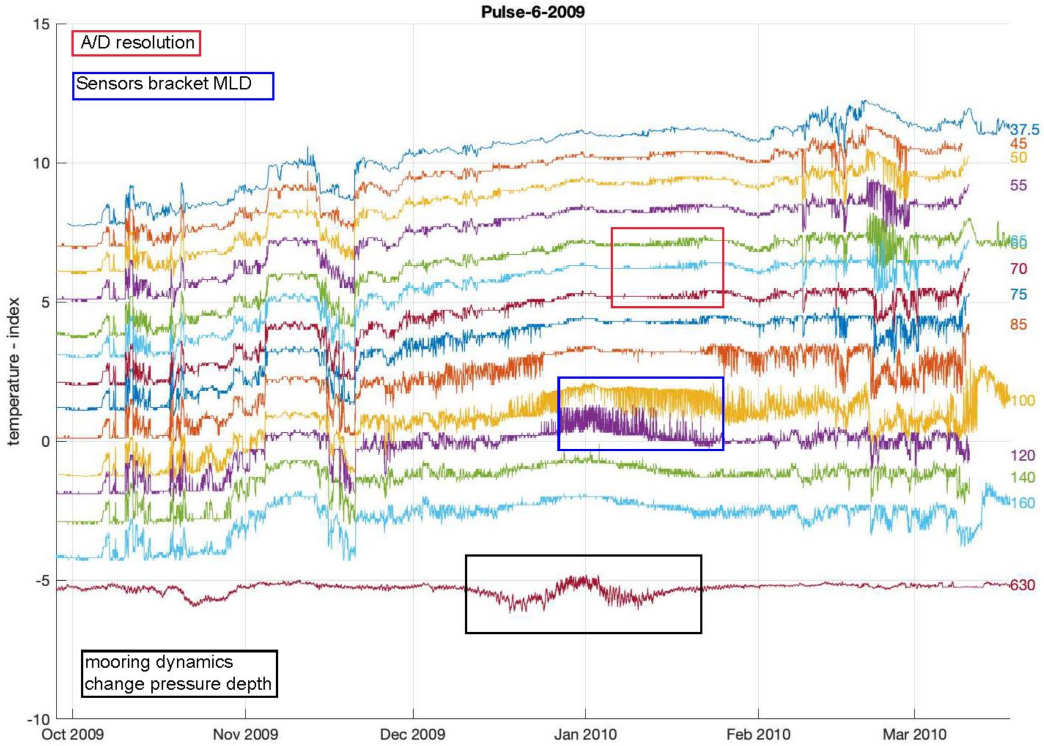
Using these plots and associated expanded investigations, several problematic sensor records were identified and flagged, as listed in Table 4. In this new version 2.0 report, these offsets are corrected to yield adjusted temperatures (see section 6.5).

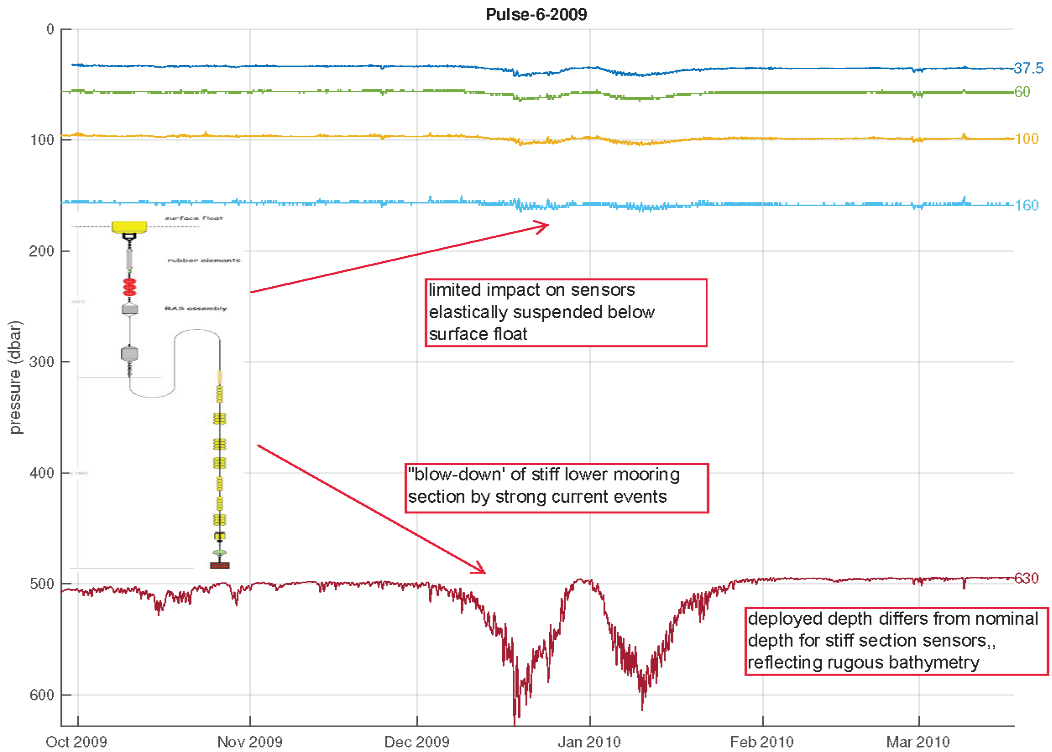
Table 4. Manual flag assignments from Neighbour test visualizations

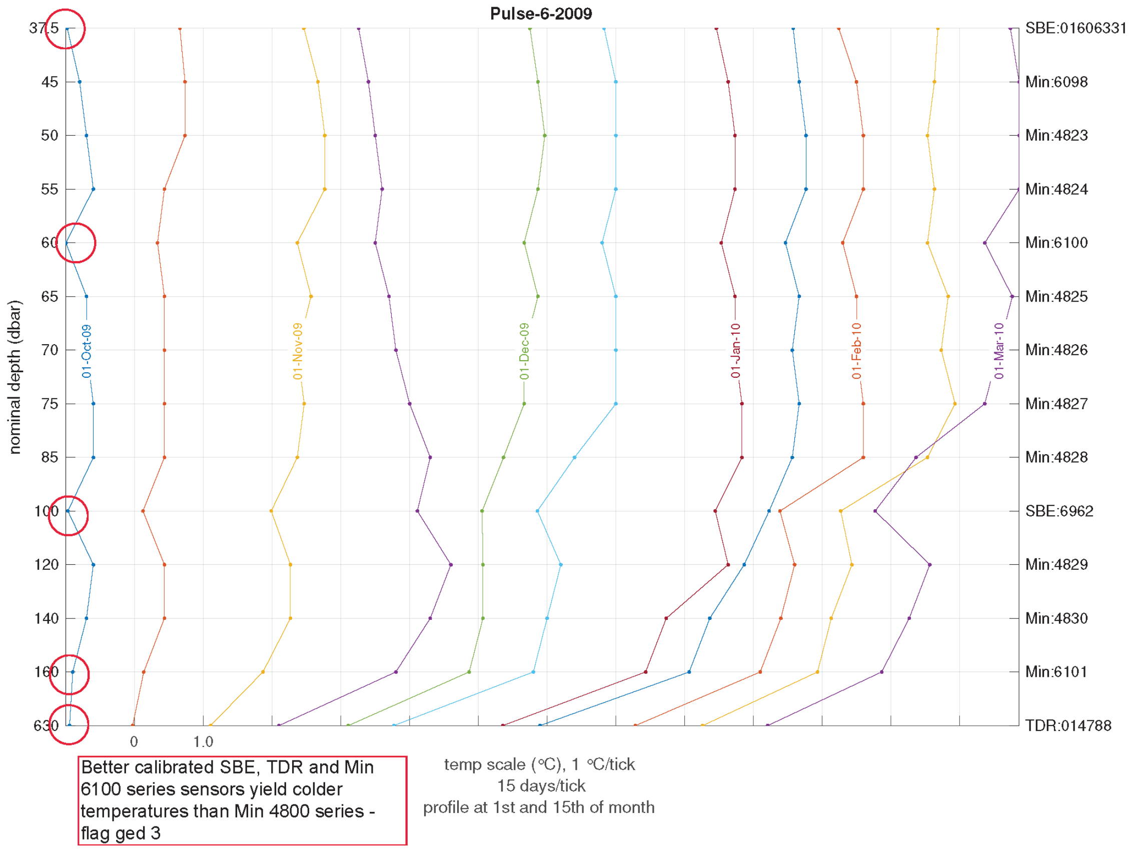
Mooring	Feature identified	Flag assignment
Pulse-6 (and others)	Sensor A/D resolution pixilation	no flagging
Pulse-6,7,8 **SOFS 1,2**	Vemco Min sensors with SN < 10000 show warm offsets relative to better calibrated SBE and TDR sensors	Initially assigned flag 3, with subsequent temperature adjustments (see section 6.5) and reassignment to flag 2 in those cases where offsets were steady and well defined
Pulse-8	decreasing battery power causes loss of P records and raises doubt about T values prior to their later loss	flag 3 for T as soon as P records fail
Pulse-9	P failures and mooring dynamics	flag 3 for T as soon as P records fail
SOFS-7.5	Starmons exhibit positive bias noise at 70 and 75m suggesting failure possibly related to sealant	flag 4
SOFS-8	Starmons at 55 and 320m show bias and drift	flag 4

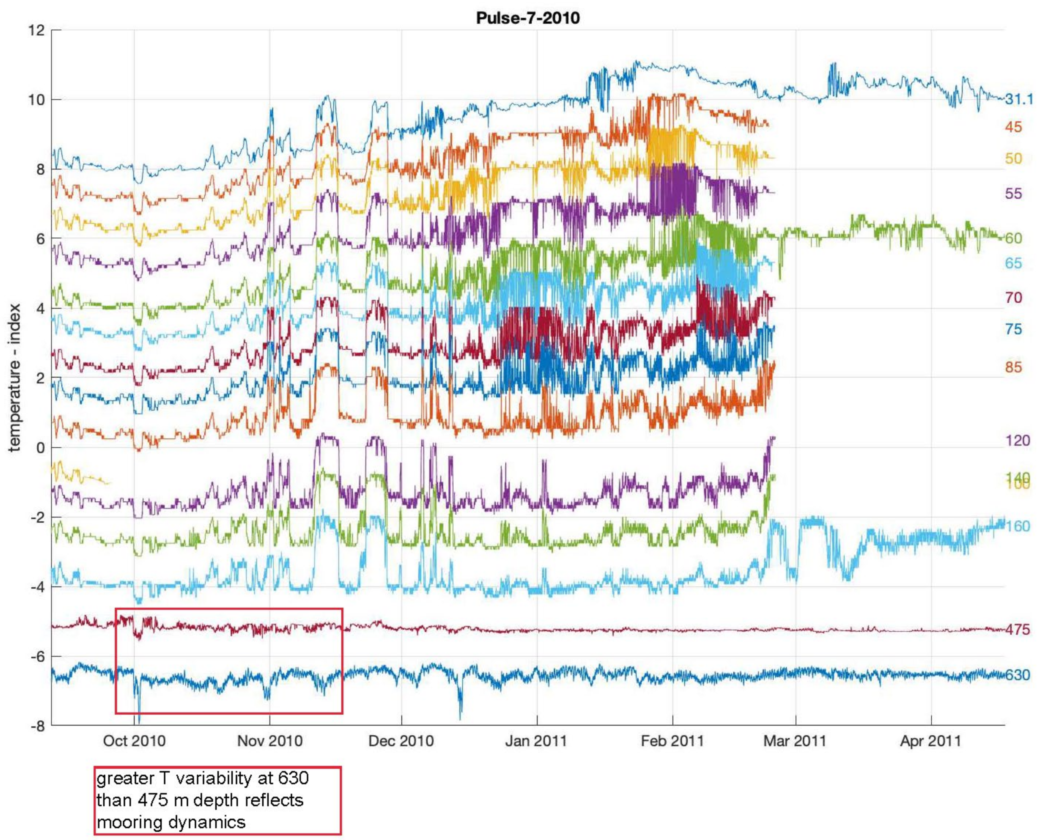
For completeness and to further illustrate how to apply this visualization approach, the full set of plots for all deployments follows, many with annotations to explain the methods by which possible sensor problems, as suspected from highly varying temperatures, were either confirmed or identified as actual oceanographic variability. To avoid excessive repetition, repeated faults are generally indicated at ony their first, or first few, occurrences.

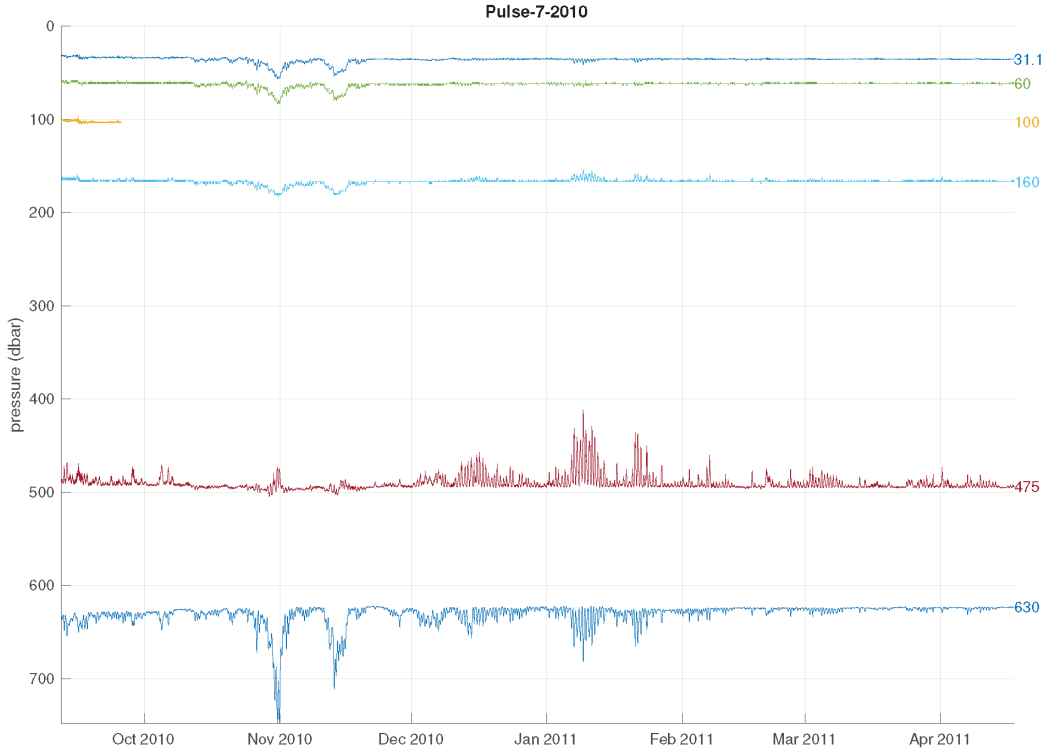
The temperature variations are fascinating in their diversity, rapidity, and origins. In particular: i. very rapid temporal variations in temperature occurred synchronously at all depths indicating very sharp and vertical boundaries between water parcels ii. vertical movements of isothermal surfaces can cause mirror imaging of rapid temperature fluctuations for sensors above and below thermal boundaries, and iii. thermal inversions below the wind-mixed surface layer were common (these were in general density-compensated by salinity increases, as will be illustrated in a forthcoming report on SOTS salinity variations).

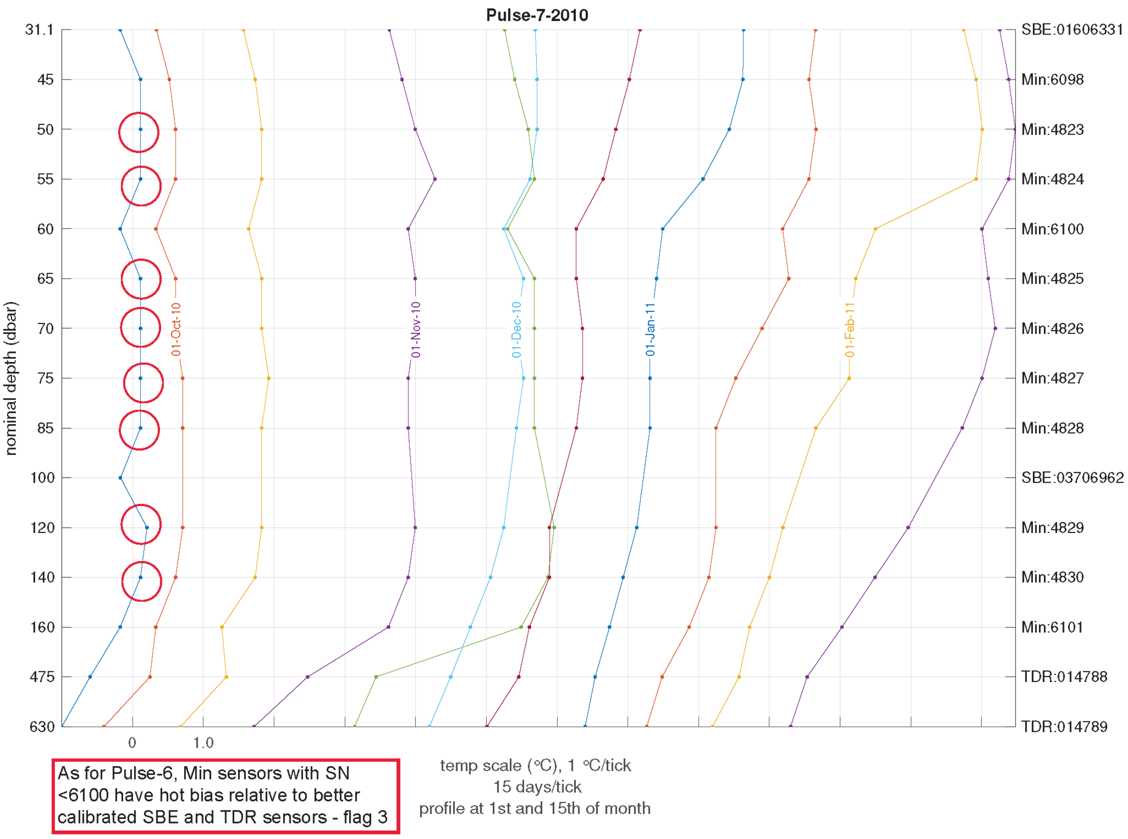

Pulse-6-2009
A/D resolution
Sensors bracket MLD
mooring dynamics
change pressure depth
temperature - index
37.5
45
50
55
60
65
70
75
85
100
120
140
160
630
Oct 2009
Nov 2009
Dec 2009
Jan 2010
Feb 2010
Mar 2010

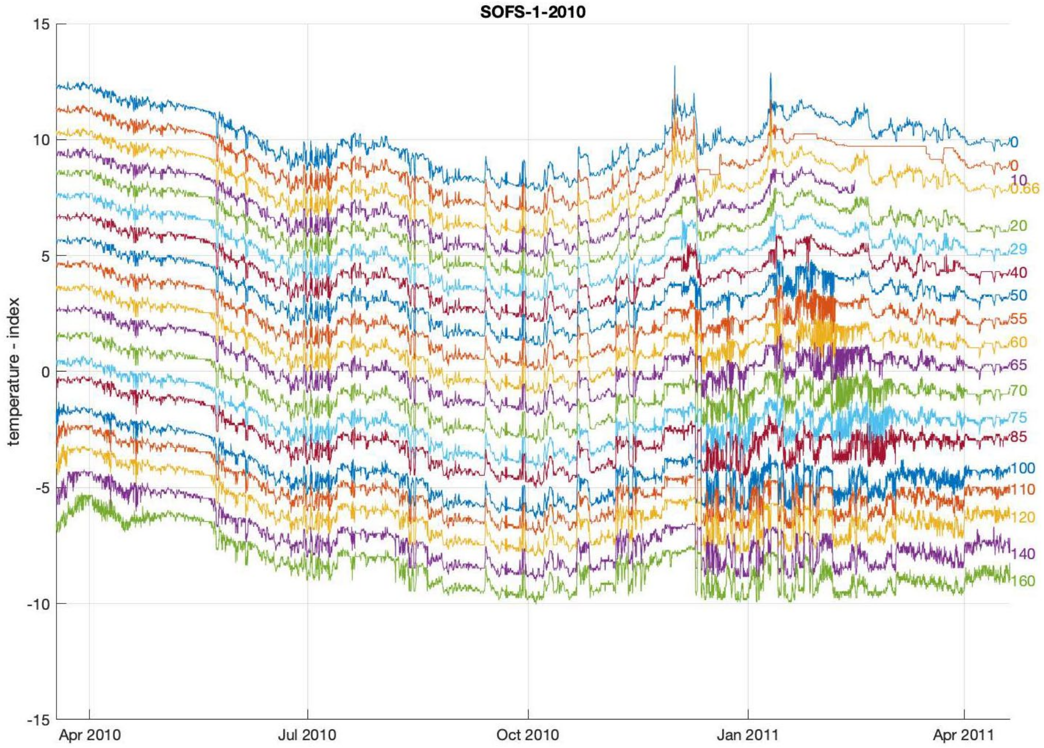

Pulse-6-2009
pressure (dbar)
limited impact on sensors
elastically suspended below
surface float
"blow-down' of stiff lower mooring
section by strong current events
deployed depth differs from nominal
depth for stiff section sensors,,
reflecting rugous bathymetry
37.5
60
100
160
630
Oct 2009
Nov 2009
Dec 2009
Jan 2010
Feb 2010
Mar 2010

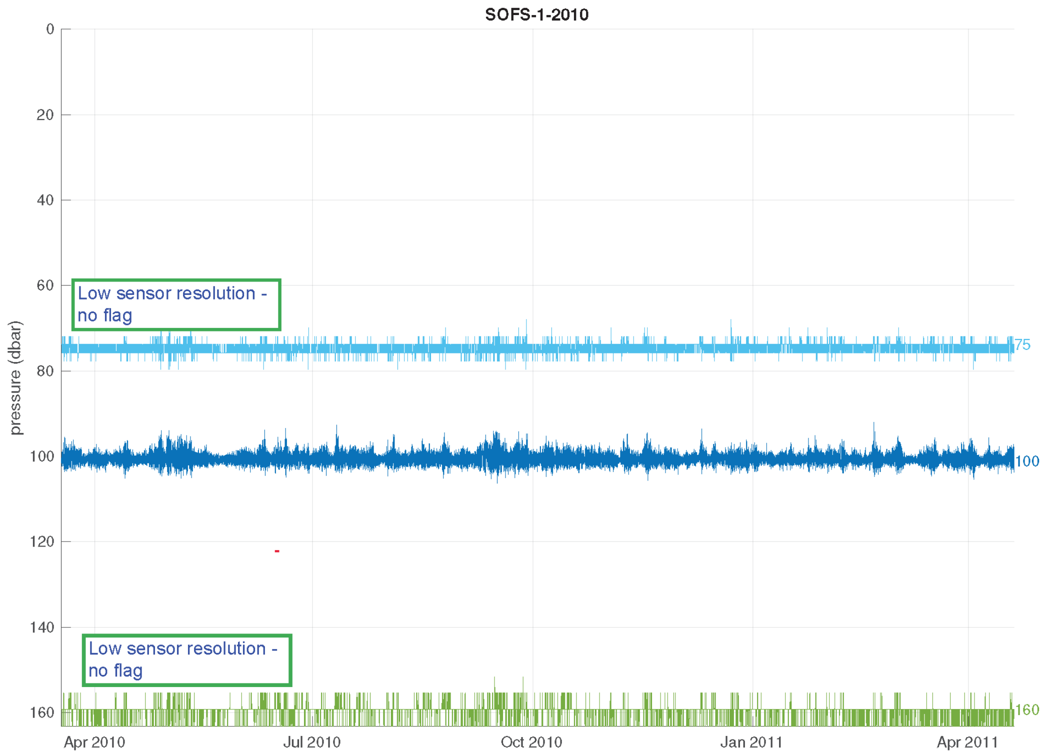

Pulse-6-2009
nominal depth (dbar)
37.5
45
50
55
60
65
70
75
85
100
120
140
160
630
SBE:01606331
Min:6098
Min:4823
Min:4824
Min:6100
Min:4825
Min:4826
Min:4827
Min:4828
SBE:6962
Min:4829
Min:4830
Min:6101
TDR:014788
01-Oct-09
01-Nov-09
01-Dec-09
01-Jan-10
01-Feb-10
01-Mar-10
0
1.0
Better calibrated SBE, TDR and Min 6100 series sensors yield colder temperatures than Min 4800 series - flag ged 3
temp scale (°C), 1 °C/tick
15 days/tick
profile at 1st and 15th of month

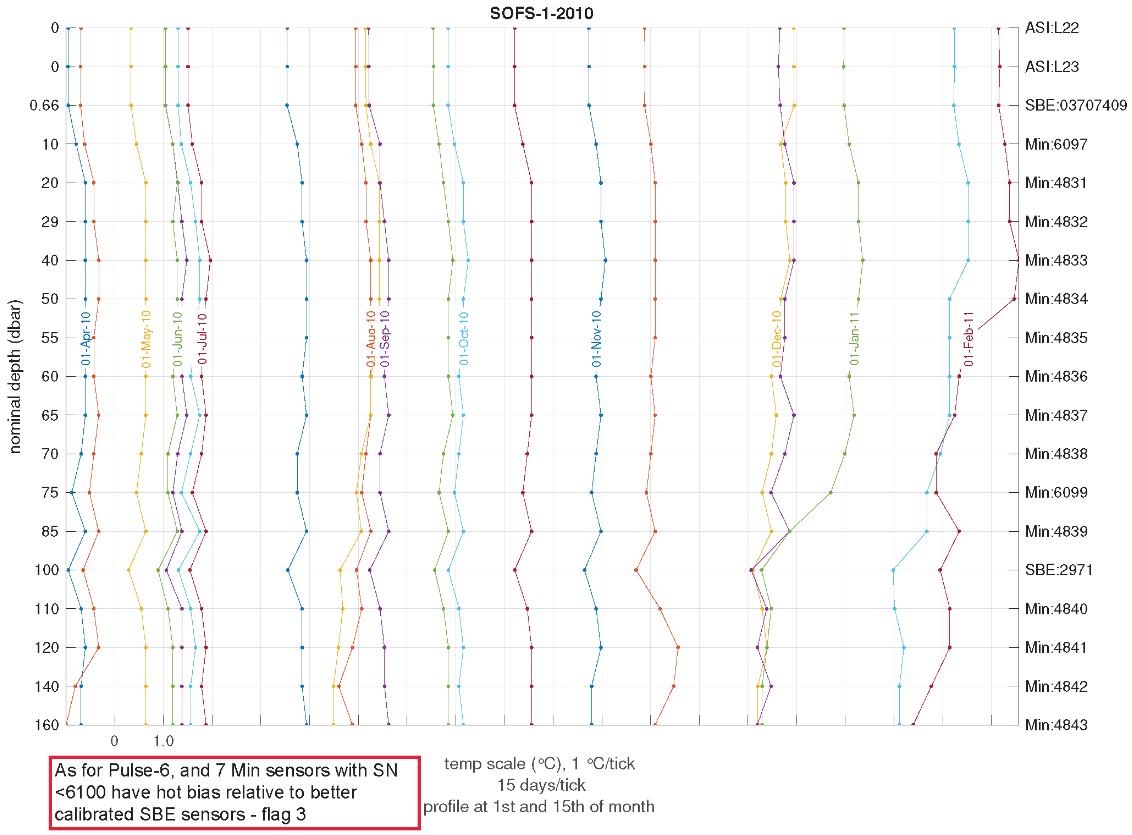

Pulse-7-2010
temperature - index
12
10
8
6
4
2
0
-2
-4
-6
-8
Oct 2010
Nov 2010
Dec 2010
Jan 2011
Feb 2011
Mar 2011
Apr 2011
31.1
45
50
55
60
65
70
75
85
120
140
100
160
475
630
greater T variability at 630 than 475 m depth reflects mooring dynamics

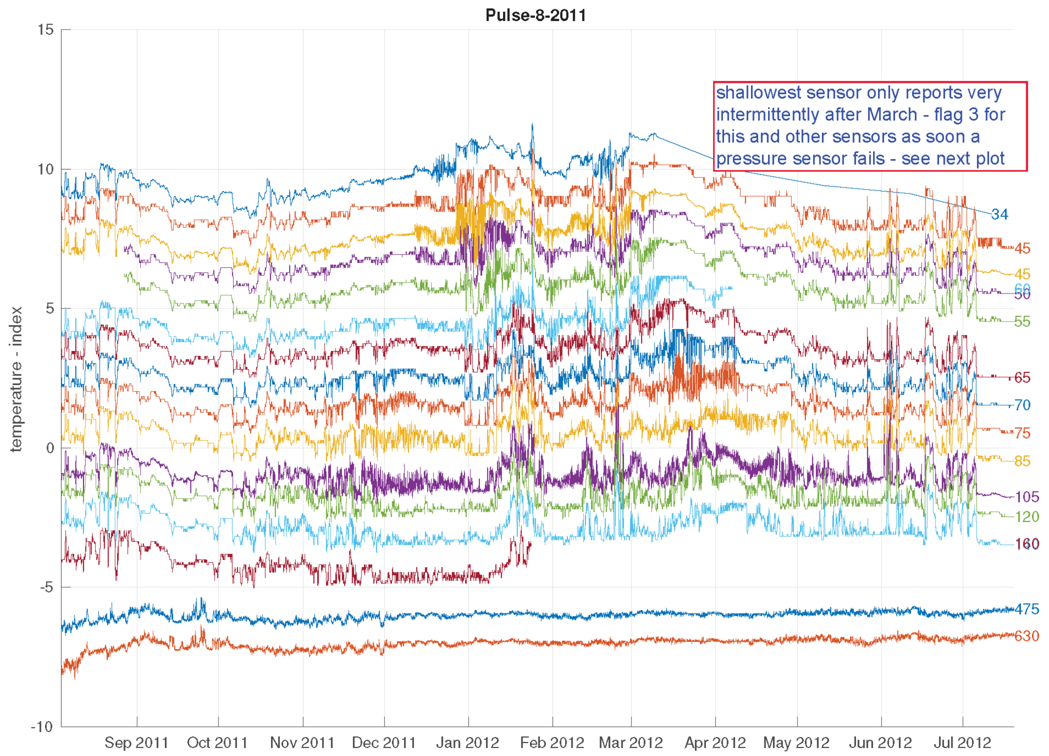

Pulse-7-2010
pressure (dbar)
0
100
200
300
400
500
600
700
31.1
60
100
160
475
630
Oct 2010
Nov 2010
Dec 2010
Jan 2011
Feb 2011
Mar 2011
Apr 2011


Pulse-7-2010
nominal depth (dbar)
31.1
45
50
55
60
65
70
75
85
100
120
140
160
475
630
0
1.0
01-Oct-10
01-Nov-10
01-Dec-10
01-Jan-11
01-Feb-11
SBE:01606331
Min:6098
Min:4823
Min:4824
Min:6100
Min:4825
Min:4826
Min:4827
Min:4828
SBE:03706962
Min:4829
Min:4830
Min:6101
TDR:014788
TDR:014789
As for Pulse-6, Min sensors with SN <6100 have hot bias relative to better calibrated SBE and TDR sensors - flag 3
temp scale (°C), 1 °C/tick
15 days/tick
profile at 1st and 15th of month

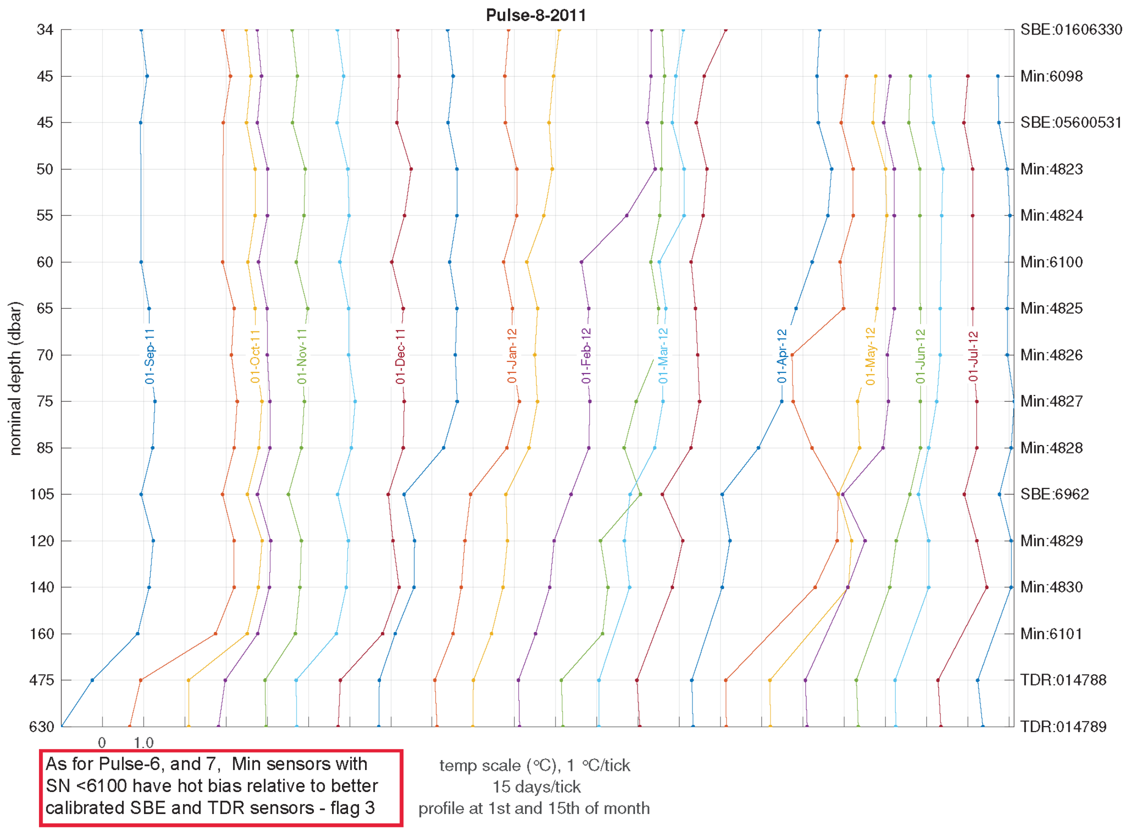

SOFS-1-2010
temperature - index
Apr 2010
Jul 2010
Oct 2010
Jan 2011
Apr 2011
0
0
10
0.66
20
29
40
50
55
60
65
70
75
85
100
110
120
140
160


SOFS-1-2010
pressure (dbar)
Low sensor resolution - no flag
75
100
Low sensor resolution - no flag
160
Apr 2010
Jul 2010
Oct 2010
Jan 2011
Apr 2011

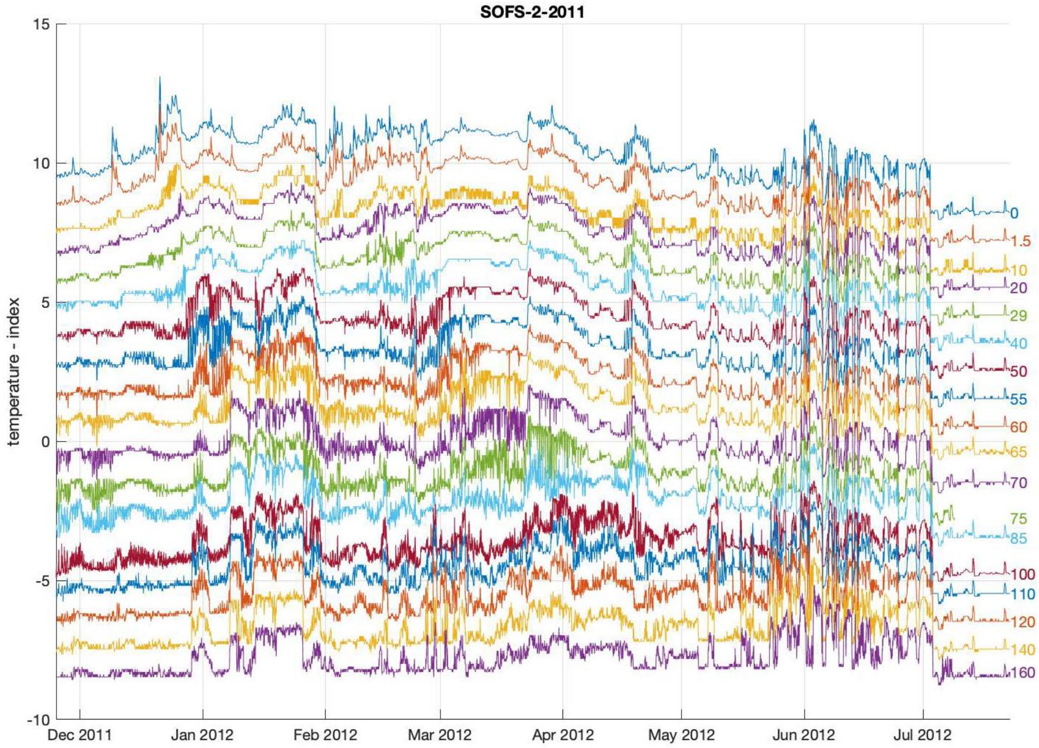

SOFS-1-2010
nominal depth (dbar)
temp scale (°C), 1 °C/tick
15 days/tick
profile at 1st and 15th of month
As for Pulse-6, and 7 Min sensors with SN <6100 have hot bias relative to better calibrated SBE sensors - flag 3
ASI:L22
ASI:L23
SBE:03707409
Min:6097
Min:4831
Min:4832
Min:4833
Min:4834
Min:4835
Min:4836
Min:4837
Min:4838
Min:6099
Min:4839
SBE:2971
Min:4840
Min:4841
Min:4842
Min:4843


Pulse-8-2011
temperature - index
shallowest sensor only reports very intermittently after March - flag 3 for this and other sensors as soon a pressure sensor fails - see next plot
Sep 2011
Oct 2011
Nov 2011
Dec 2011
Jan 2012
Feb 2012
Mar 2012
Apr 2012
May 2012
Jun 2012
Jul 2012

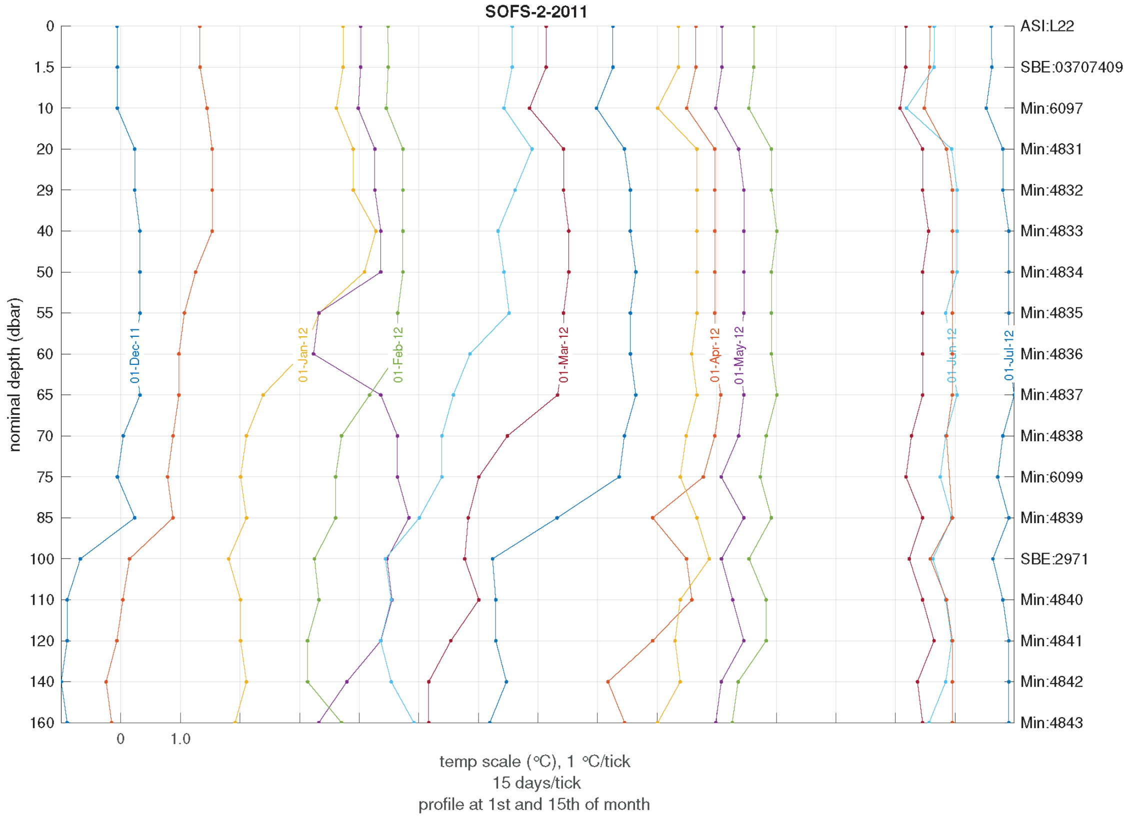
Pulse-8-2011
pressure (dbar)
0
100
200
300
400
500
600
34
60
105
160
630
475
Sep 2011
Oct 2011
Nov 2011
Dec 2011
Jan 2012
Feb 2012
Mar 2012
Apr 2012
May 2012
Jun 2012
Jul 2012
1 of 3 elastic tethers breaks, and suspended section lengthens, moving all sensors to lower depths by this offset. Battery failures on other pressure sensors mean that temperature records are uncertain - flag 3
stiff section with "630m "sensor and suspended section with "475m" sensor land at similar depths
strong current events subduct "630m "sensor but elevate "475m" sensor, producing mirrored records

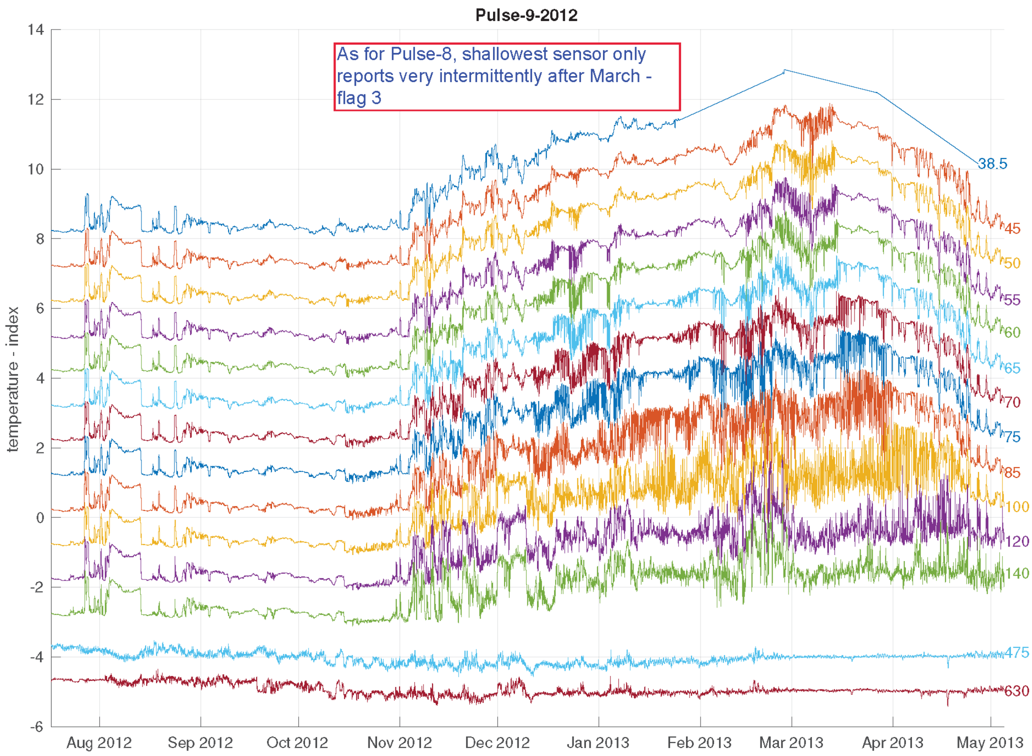


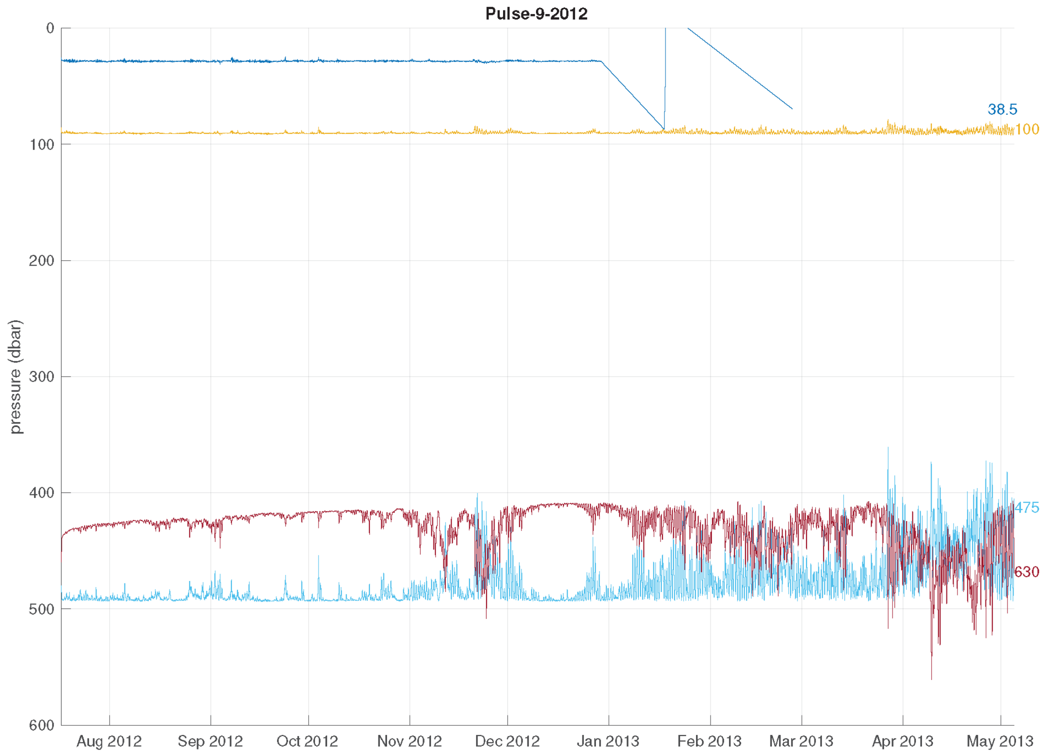
Pulse-8-2011
nominal depth (dbar)
34
45
45
50
55
60
65
70
75
85
105
120
140
160
475
630
SBE:01606330
Min:6098
SBE:05600531
Min:4823
Min:4824
Min:6100
Min:4825
Min:4826
Min:4827
Min:4828
SBE:6962
Min:4829
Min:4830
Min:6101
TDR:014788
TDR:014789
01-Sep-11
01-Oct-11
01-Nov-11
01-Dec-11
01-Jan-12
01-Feb-12
01-Mar-12
01-Apr-12
01-May-12
01-Jun-12
01-Jul-12
0
1.0
As for Pulse-6, and 7, Min sensors with SN <6100 have hot bias relative to better calibrated SBE and TDR sensors - flag 3
temp scale (°C), 1 °C/tick
15 days/tick
profile at 1st and 15th of month

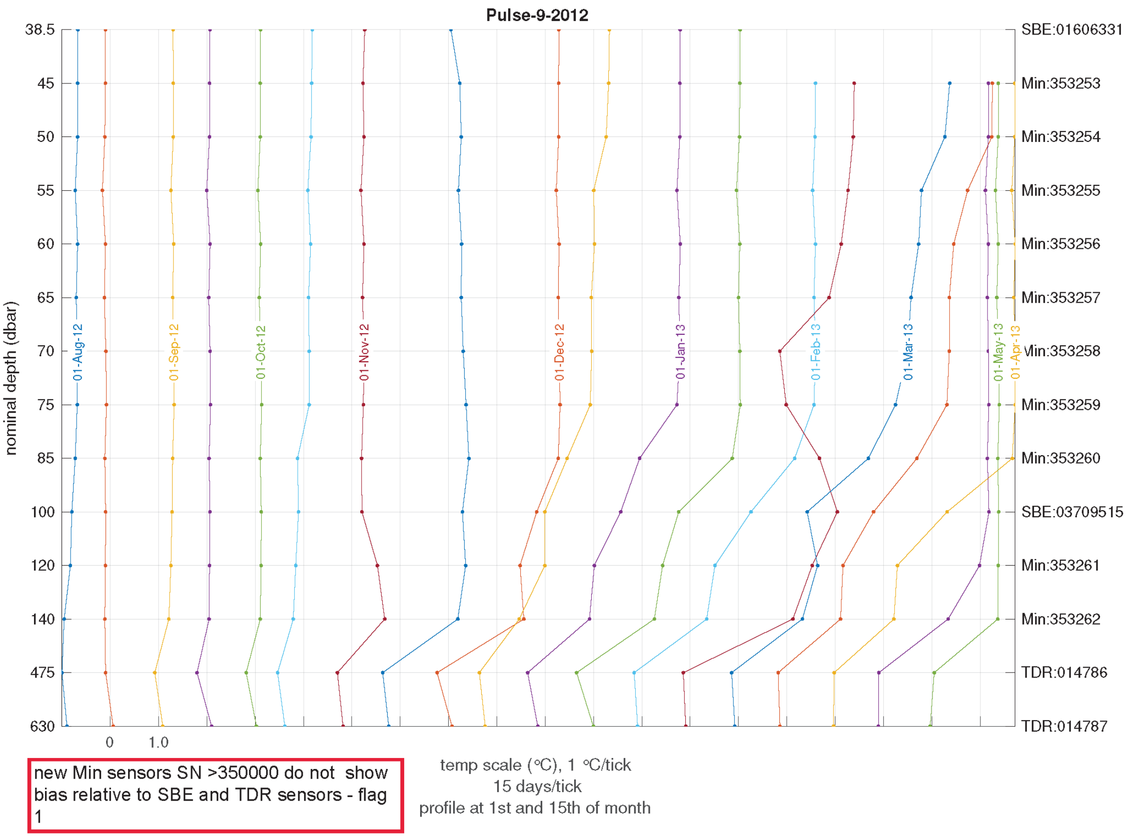

SOFS-2-2011
temperature - index
15
10
5
0
-5
-10
Dec 2011
Jan 2012
Feb 2012
Mar 2012
Apr 2012
May 2012
Jun 2012
Jul 2012
0
1.5
10
20
29
40
50
55
60
65
70
75
85
100
110
120
140
160

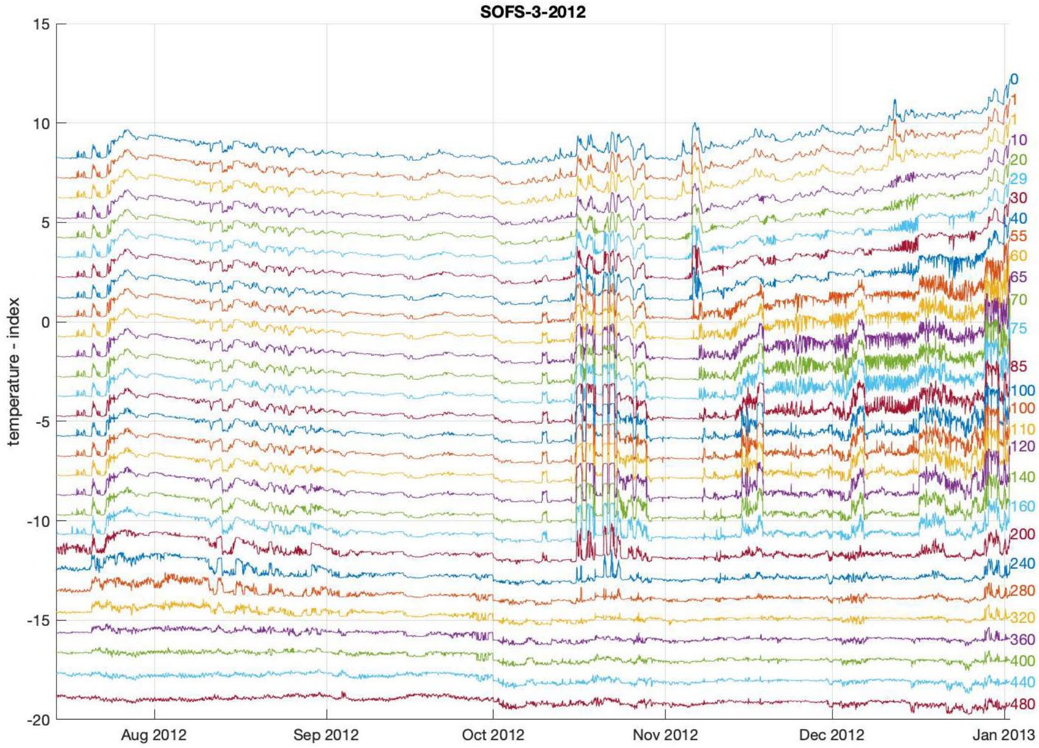

SOFS-2-2011
pressure (dbar)
0
20
40
60
80
100
120
140
160
Dec 2011
Jan 2012
Feb 2012
Mar 2012
Apr 2012
May 2012
Jun 2012
Jul 2012
75
100
160

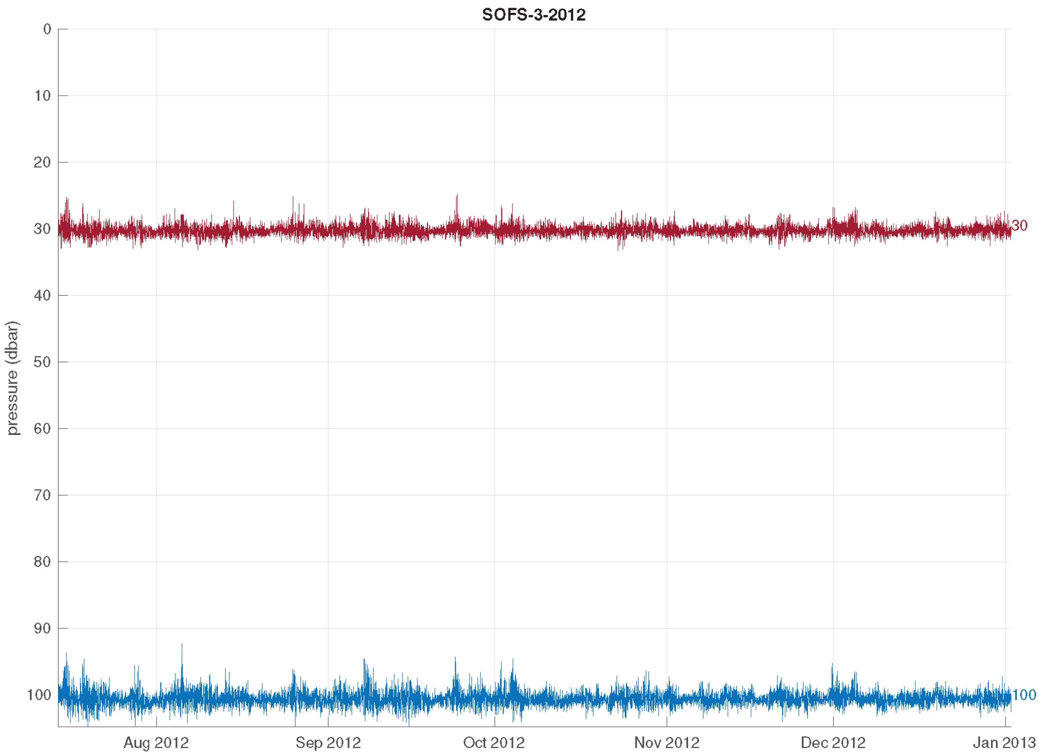

SOFS-2-2011
nominal depth (dbar)
0
1.5
10
20
29
40
50
55
60
65
70
75
85
100
110
120
140
160
ASI:L22
SBE:03707409
Min:6097
Min:4831
Min:4832
Min:4833
Min:4834
Min:4835
Min:4836
Min:4837
Min:4838
Min:6099
Min:4839
SBE:2971
Min:4840
Min:4841
Min:4842
Min:4843
01-Dec-11
01-Jan-12
01-Feb-12
01-Mar-12
01-Apr-12
01-May-12
01-Jun-12
01-Jul-12
0
1.0
temp scale (°C), 1 °C/tick
15 days/tick
profile at 1st and 15th of month

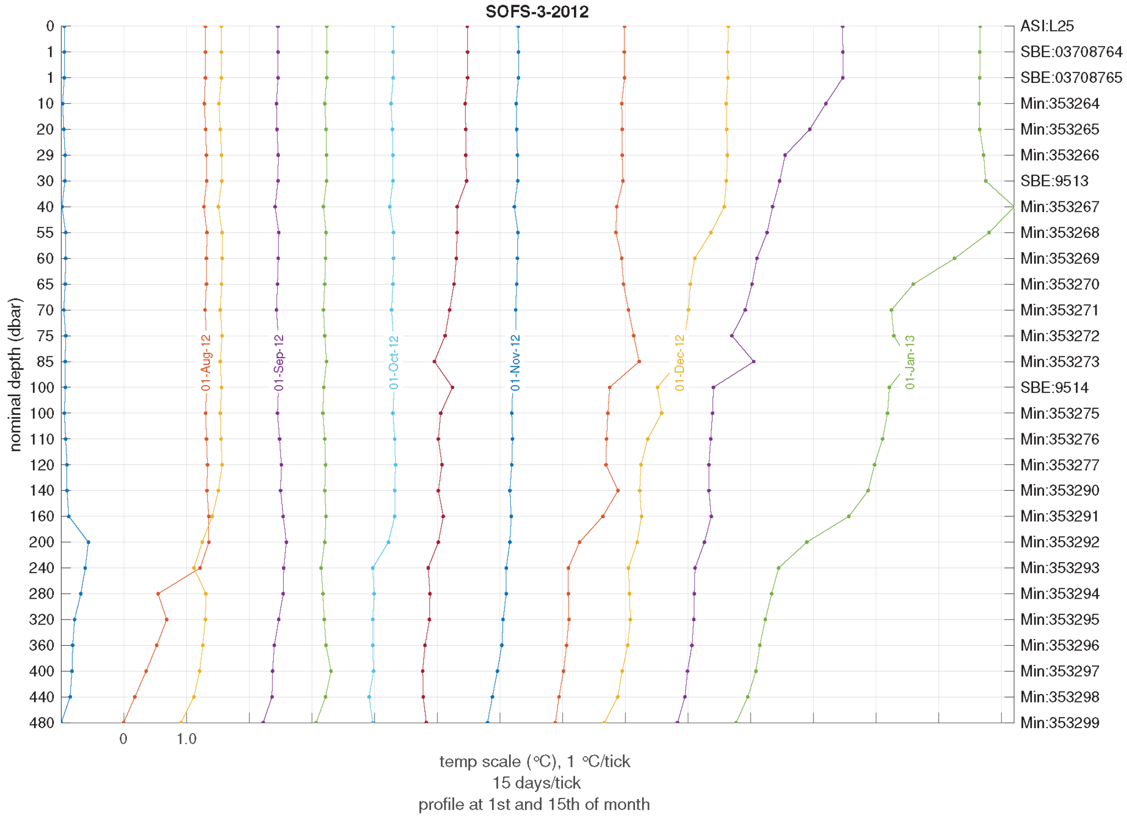

Pulse-9-2012
As for Pulse-8, shallowest sensor only reports very intermittently after March - flag 3
temperature - index
14
12
10
8
6
4
2
0
-2
-4
-6
38.5
45
50
55
60
65
70
75
85
100
120
140
475
630
Aug 2012
Sep 2012
Oct 2012
Nov 2012
Dec 2012
Jan 2013
Feb 2013
Mar 2013
Apr 2013
May 2013


Pulse-9-2012
pressure (dbar)
0
100
200
300
400
500
600
38.5
100
475
630
Aug 2012
Sep 2012
Oct 2012
Nov 2012
Dec 2012
Jan 2013
Feb 2013
Mar 2013
Apr 2013
May 2013

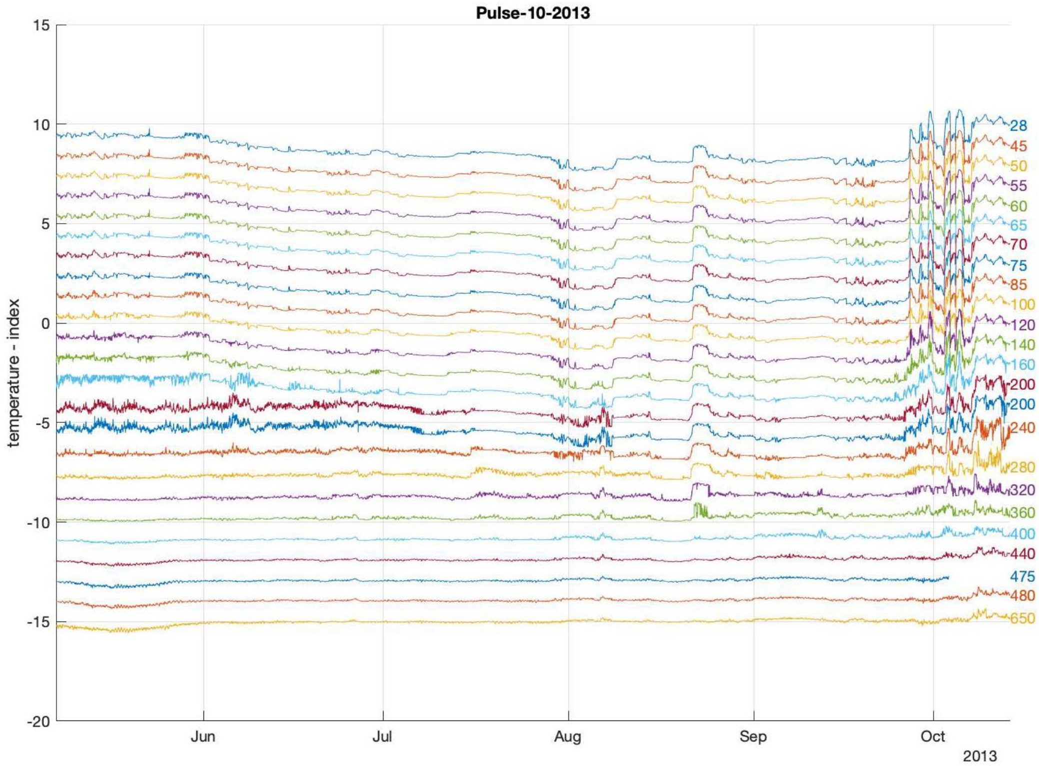

Pulse-9-2012
nominal depth (dbar)
38.5
45
50
55
60
65
70
75
85
100
120
140
475
630
SBE:01606331
Min:353253
Min:353254
Min:353255
Min:353256
Min:353257
Min:353258
Min:353259
Min:353260
SBE:03709515
Min:353261
Min:353262
TDR:014786
TDR:014787
01-Aug-12
01-Sep-12
01-Oct-12
01-Nov-12
01-Dec-12
01-Jan-13
01-Feb-13
01-Mar-13
01-May-13
01-Apr-13
0
1.0
new Min sensors SN >350000 do not show bias relative to SBE and TDR sensors - flag 1
temp scale (°C), 1 °C/tick
15 days/tick
profile at 1st and 15th of month


SOFS-3-2012
temperature - index
15
10
5
0
-5
-10
-15
-20
Aug 2012
Sep 2012
Oct 2012
Nov 2012
Dec 2012
Jan 2013
0
1
1
10
20
29
30
40
55
60
65
70
75
85
100
100
110
120
140
160
200
240
280
320
360
400
440
480

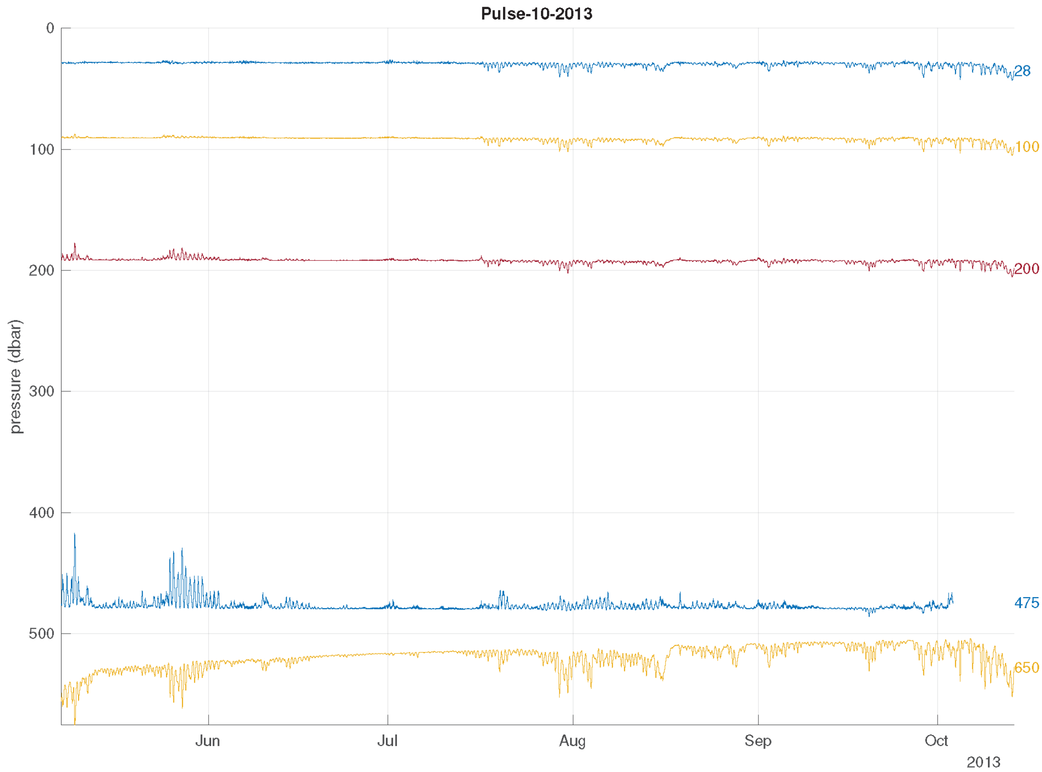

SOFS-3-2012
pressure (dbar)
0
10
20
30
40
50
60
70
80
90
100
Aug 2012
Sep 2012
Oct 2012
Nov 2012
Dec 2012
Jan 2013
30
100

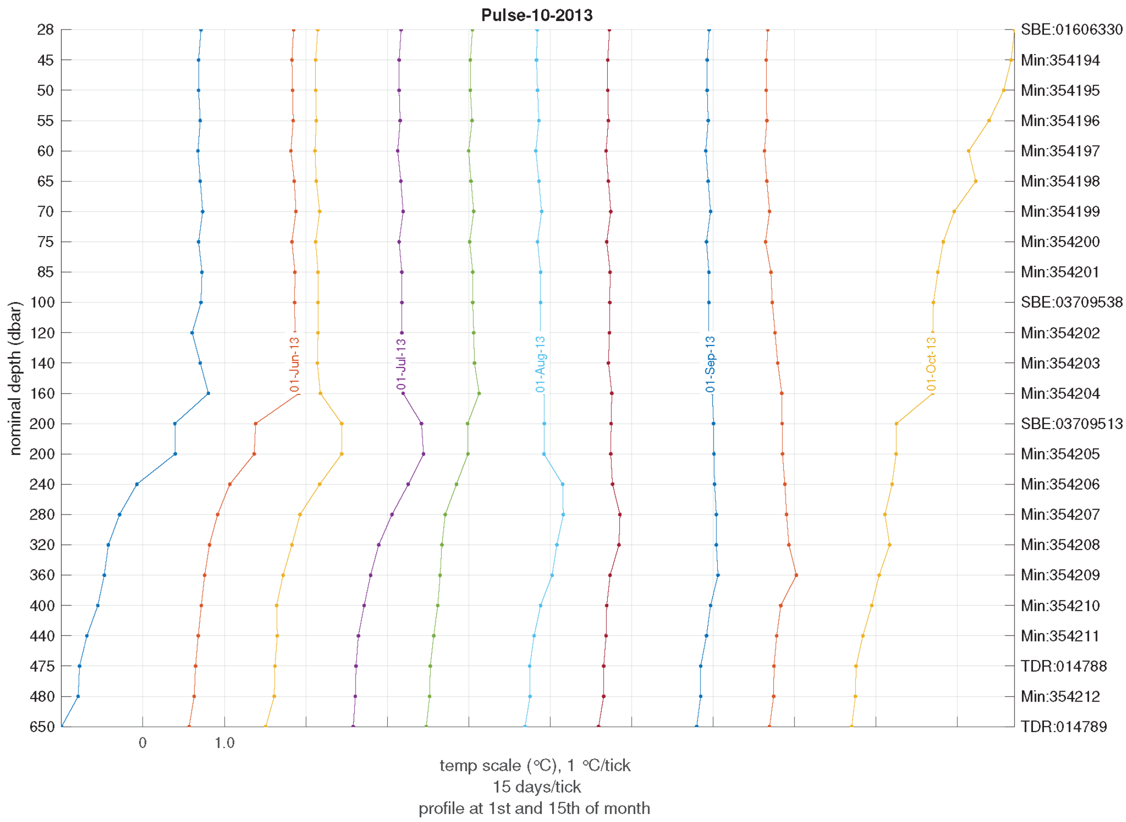


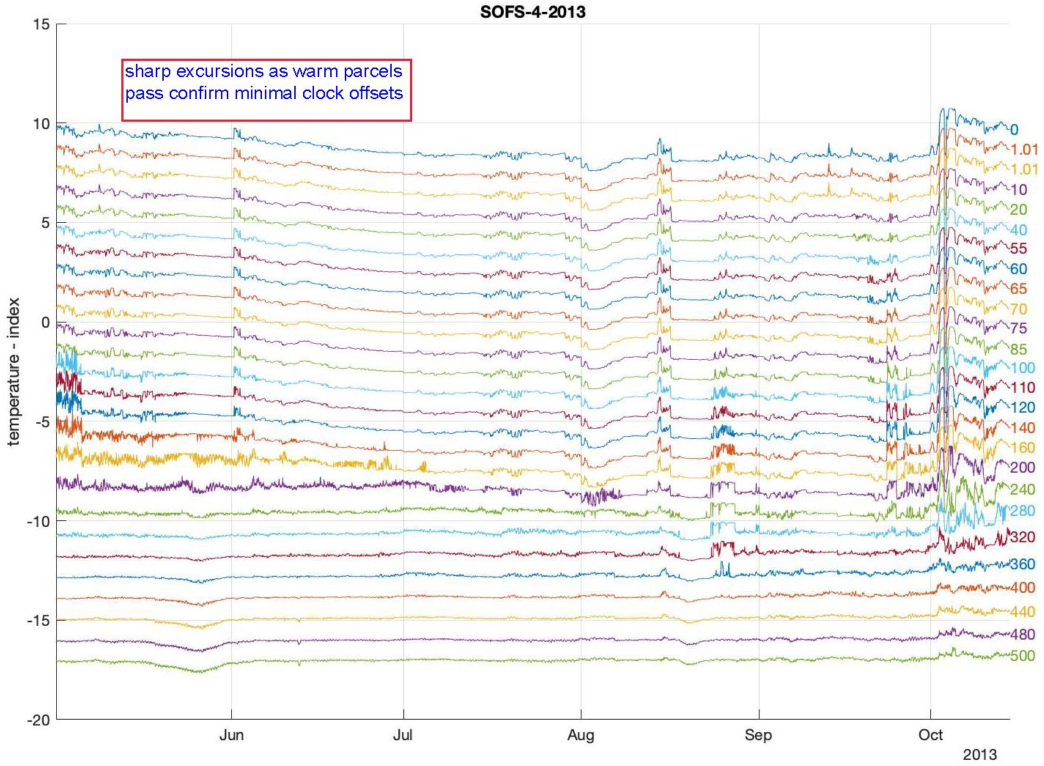
SOFS-3-2012
nominal depth (dbar)
0
1
1
10
20
29
30
40
55
60
65
70
75
85
100
100
110
120
140
160
200
240
280
320
360
400
440
480
ASI:L25
SBE:03708764
SBE:03708765
Min:353264
Min:353265
Min:353266
SBE:9513
Min:353267
Min:353268
Min:353269
Min:353270
Min:353271
Min:353272
Min:353273
SBE:9514
Min:353275
Min:353276
Min:353277
Min:353290
Min:353291
Min:353292
Min:353293
Min:353294
Min:353295
Min:353296
Min:353297
Min:353298
Min:353299
01-Aug-12
01-Sep-12
01-Oct-12
01-Nov-12
01-Dec-12
01-Jan-13
0
1.0
temp scale (°C), 1 °C/tick
15 days/tick
profile at 1st and 15th of month

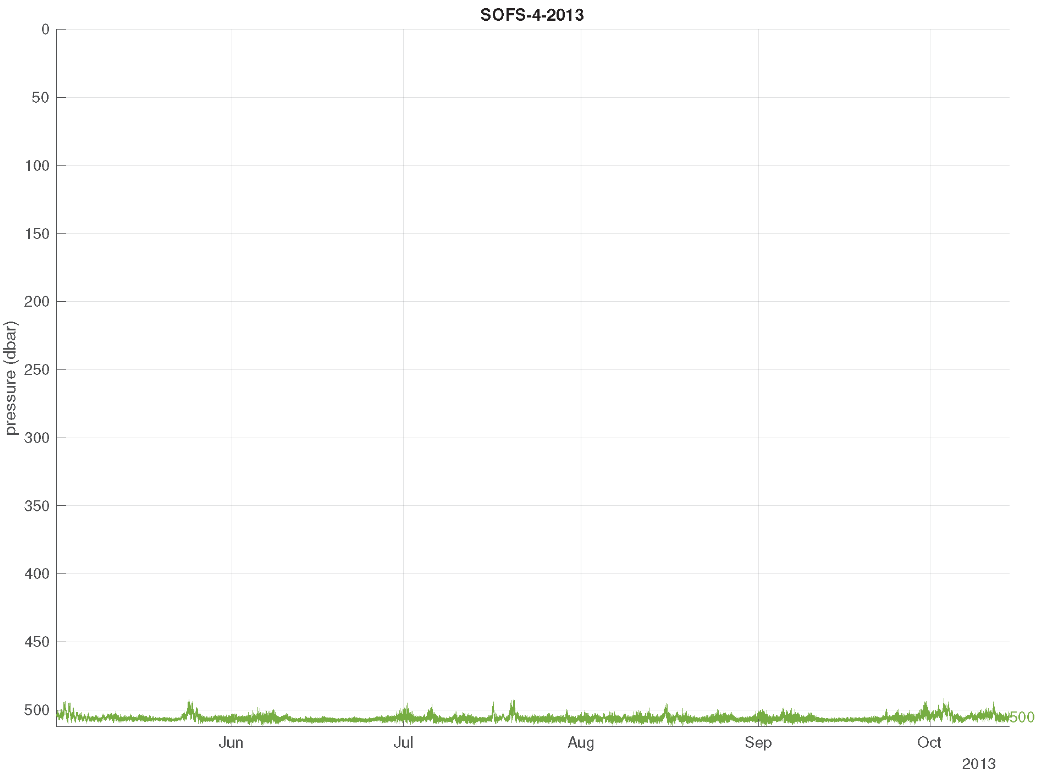


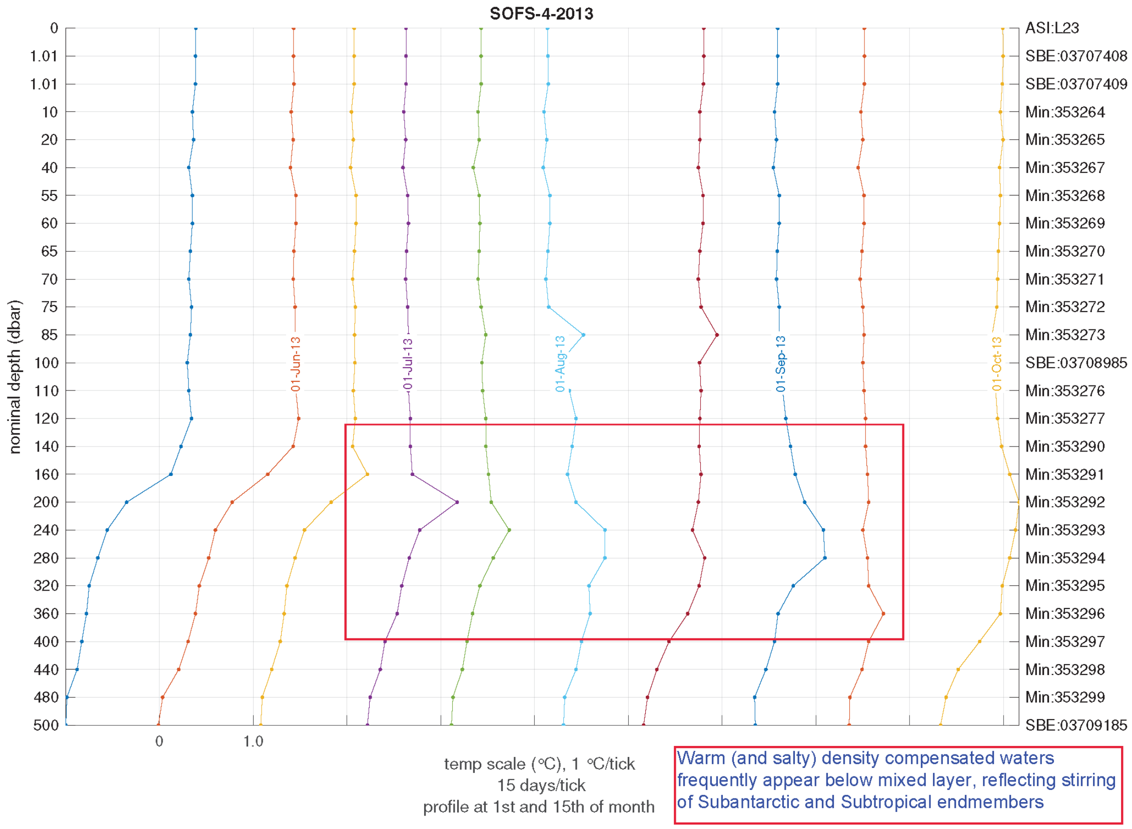
Pulse-10-2013
temperature - index
15
10
5
0
-5
-10
-15
-20
Jun
Jul
Aug
Sep
Oct
2013
28
45
50
55
60
65
70
75
85
100
120
140
160
200
200
240
280
320
360
400
440
475
480
650


Pulse-10-2013
pressure (dbar)
0
100
200
300
400
500
Jun
Jul
Aug
Sep
Oct
2013
28
100
200
475
650

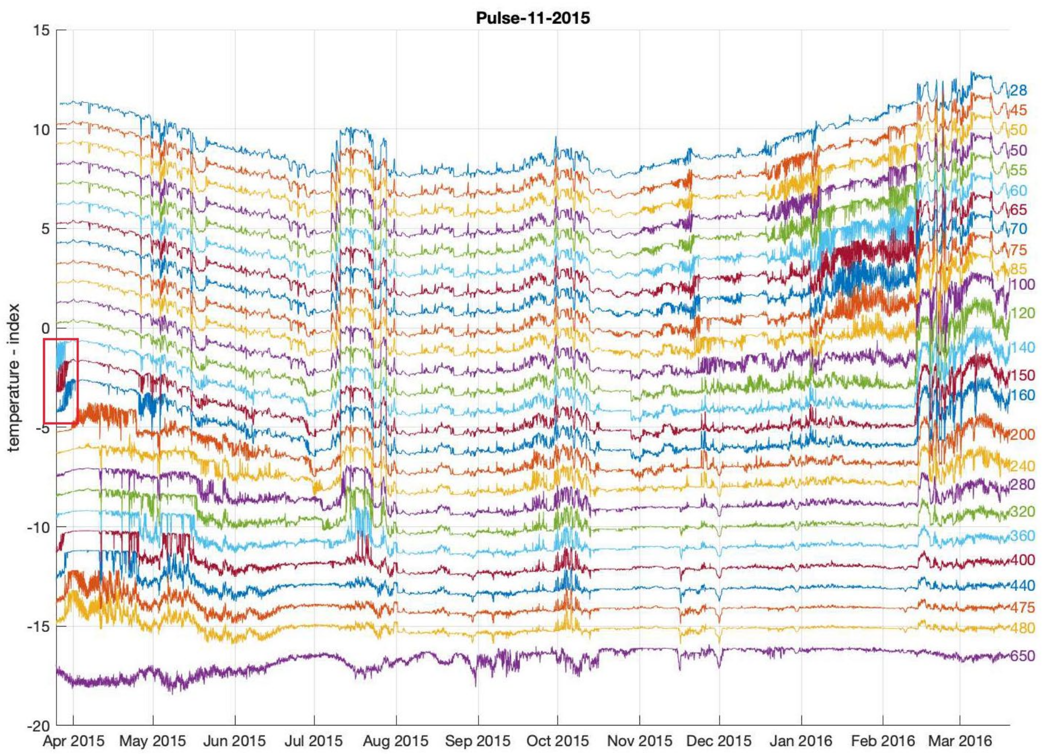

Pulse-10-2013
nominal depth (dbar)
28
45
50
55
60
65
70
75
85
100
120
140
160
200
200
240
280
320
360
400
440
475
480
650
SBE:01606330
Min:354194
Min:354195
Min:354196
Min:354197
Min:354198
Min:354199
Min:354200
Min:354201
SBE:03709538
Min:354202
Min:354203
Min:354204
SBE:03709513
Min:354205
Min:354206
Min:354207
Min:354208
Min:354209
Min:354210
Min:354211
TDR:014788
Min:354212
TDR:014789
01-Jun-13
01-Jul-13
01-Aug-13
01-Sep-13
01-Oct-13
0
1.0
temp scale (°C), 1 °C/tick
15 days/tick
profile at 1st and 15th of month


SOFS-4-2013
sharp excursions as warm parcels
pass confirm minimal clock offsets
temperature - index
15
10
5
0
-5
-10
-15
-20
Jun
Jul
Aug
Sep
Oct
2013
0
1.01
1.01
10
20
40
55
60
65
70
75
85
100
110
120
140
160
200
240
280
320
360
400
440
480
500

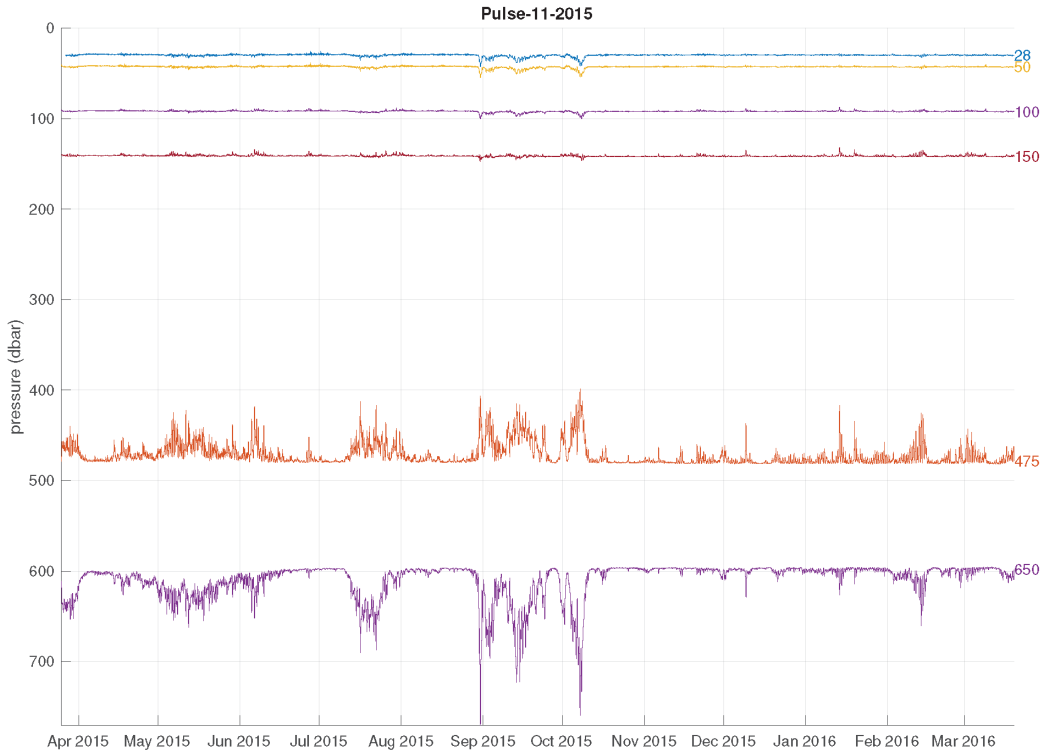

SOFS-4-2013
pressure (dbar)
0
50
100
150
200
250
300
350
400
450
500
Jun
Jul
Aug
Sep
Oct
2013
500

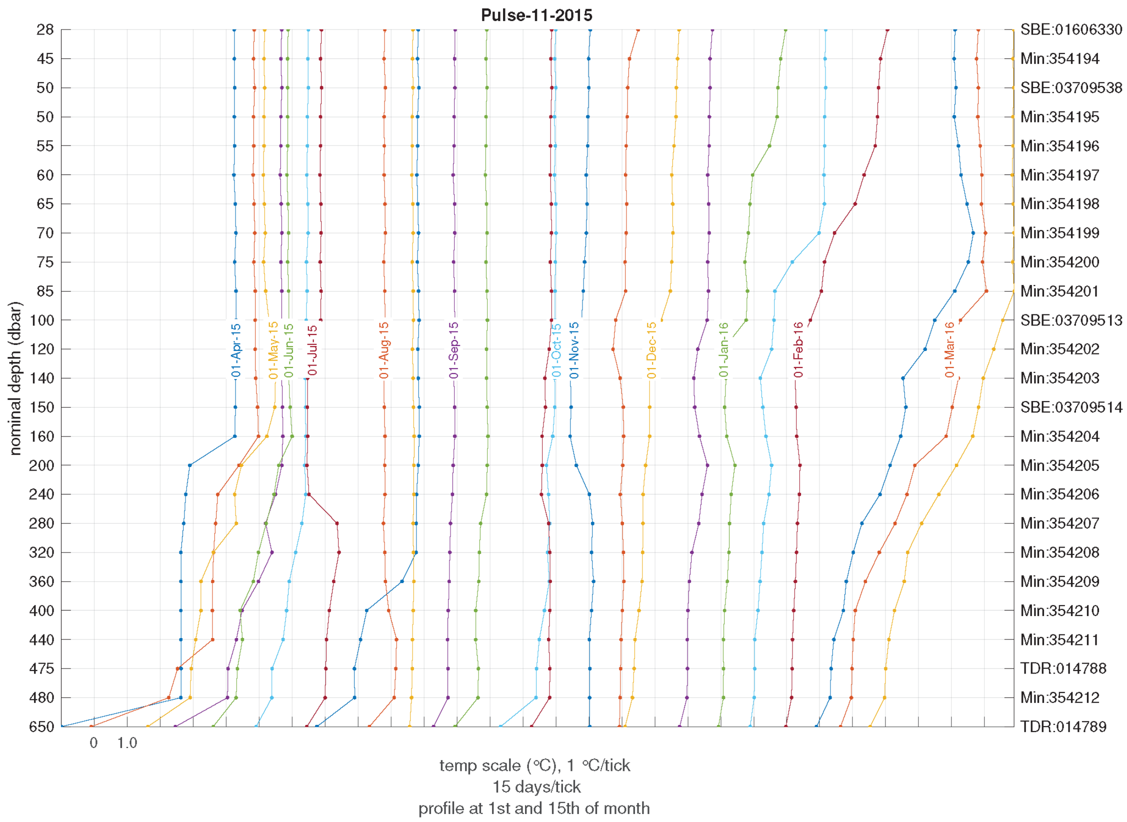


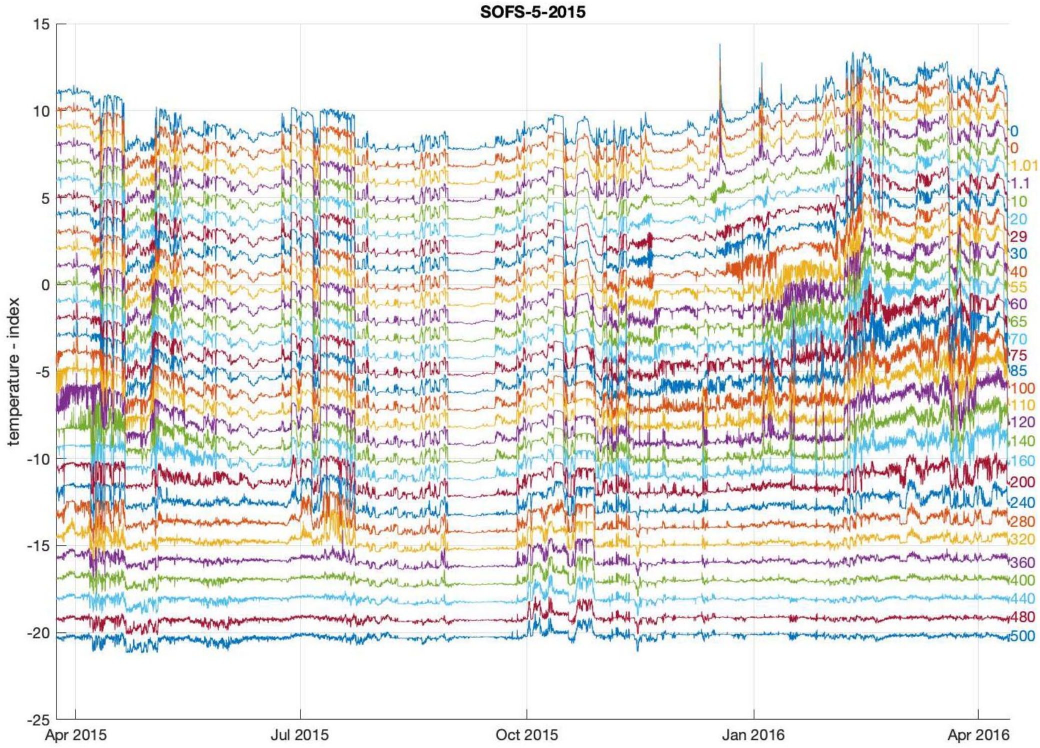
Warm (and salty) density compensated waters frequently appear below mixed layer, reflecting stirring of Subantarctic and Subtropical endmembers

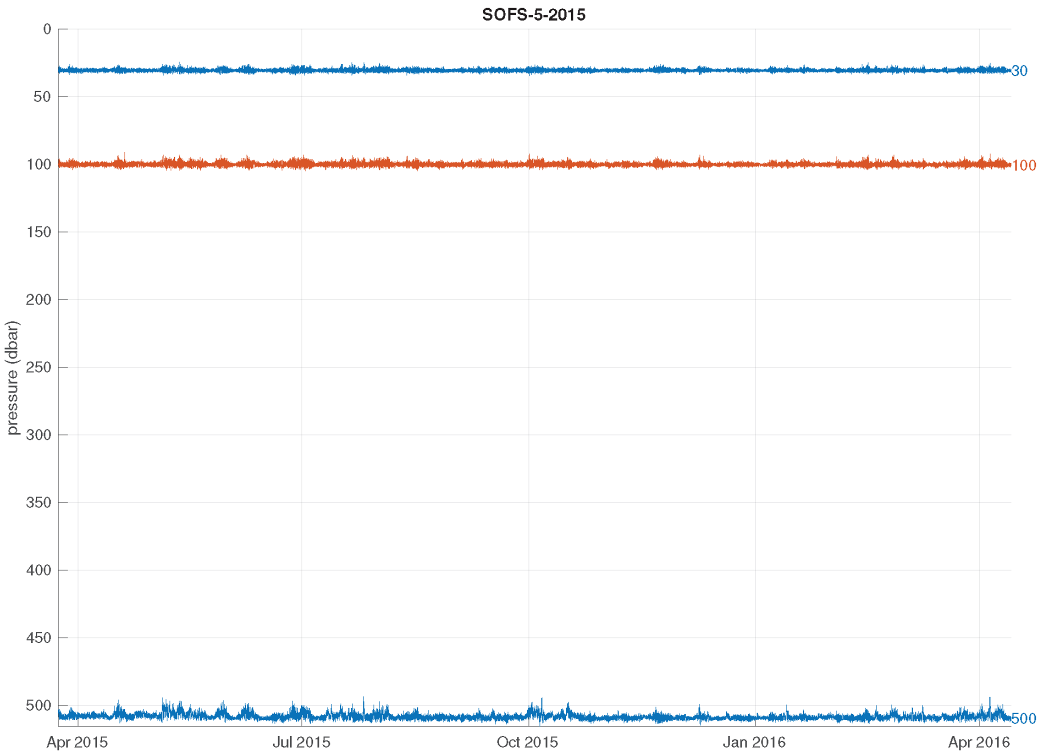


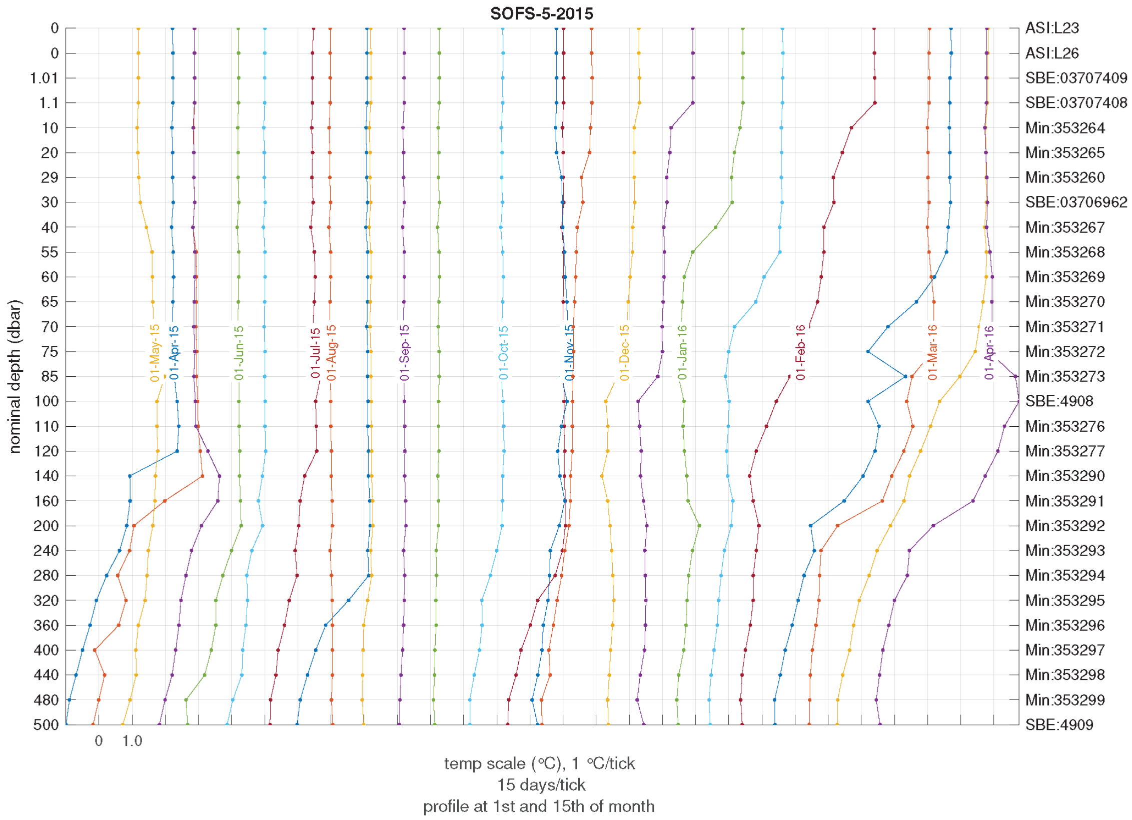
reflects passage of waters with deeper mixed layer, and is not sensor noise or mooring dynamics

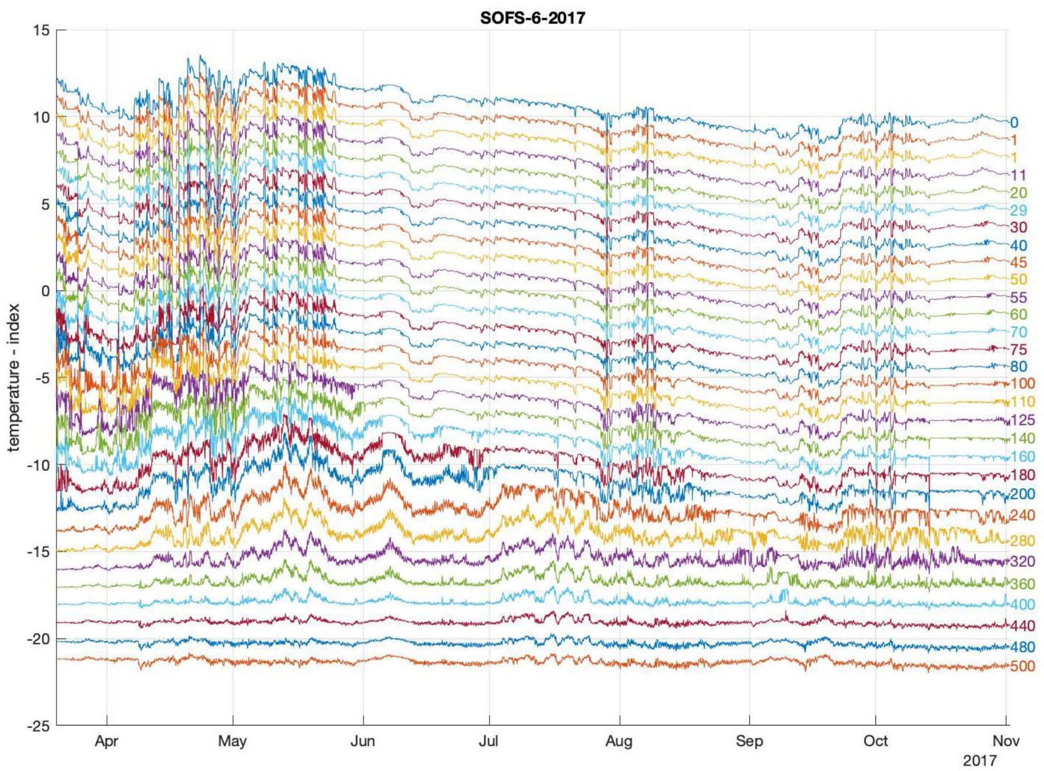

Pulse-11-2015
pressure (dbar)
0
100
200
300
400
500
600
700
28
50
100
150
475
650
Apr 2015
May 2015
Jun 2015
Jul 2015
Aug 2015
Sep 2015
Oct 2015
Nov 2015
Dec 2015
Jan 2016
Feb 2016
Mar 2016

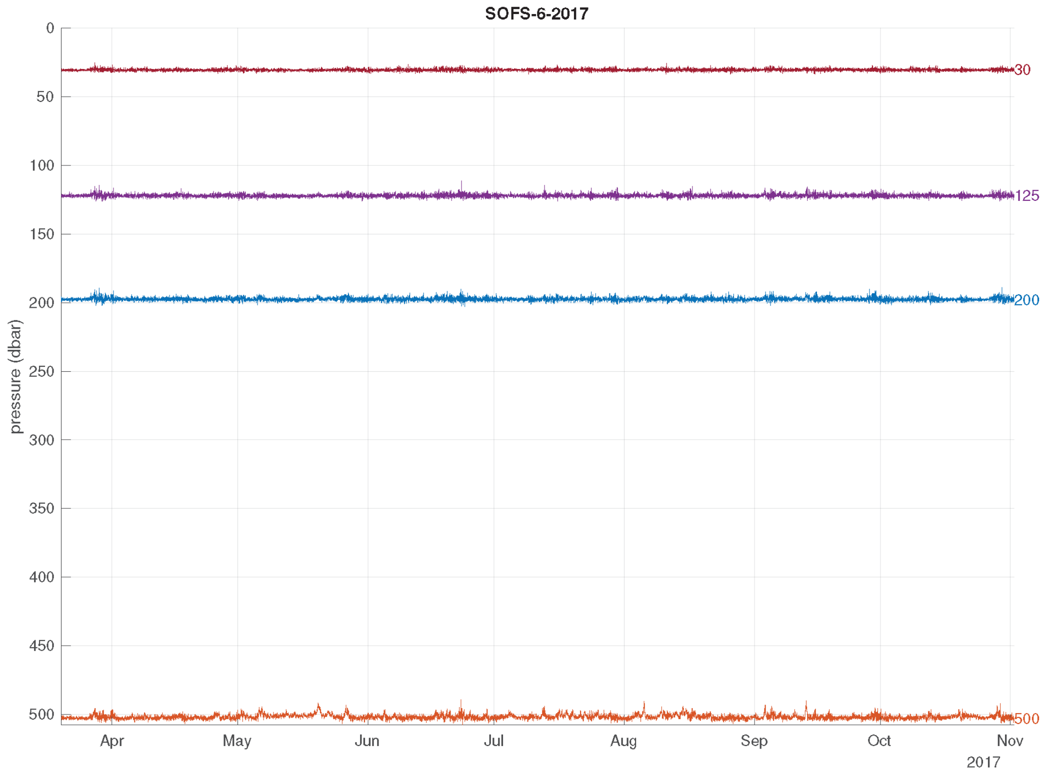

Pulse-11-2015
nominal depth (dbar)
28
45
50
50
55
60
65
70
75
85
100
120
140
150
160
200
240
280
320
360
400
440
475
480
650
SBE:01606330
Min:354194
SBE:03709538
Min:354195
Min:354196
Min:354197
Min:354198
Min:354199
Min:354200
Min:354201
SBE:03709513
Min:354202
Min:354203
SBE:03709514
Min:354204
Min:354205
Min:354206
Min:354207
Min:354208
Min:354209
Min:354210
Min:354211
TDR:014788
Min:354212
TDR:014789
01-Apr-15
01-May-15
01-Jun-15
01-Jul-15
01-Aug-15
01-Sep-15
01-Oct-15
01-Nov-15
01-Dec-15
01-Jan-16
01-Feb-16
01-Mar-16
0
1.0
temp scale (°C), 1 °C/tick
15 days/tick
profile at 1st and 15th of month

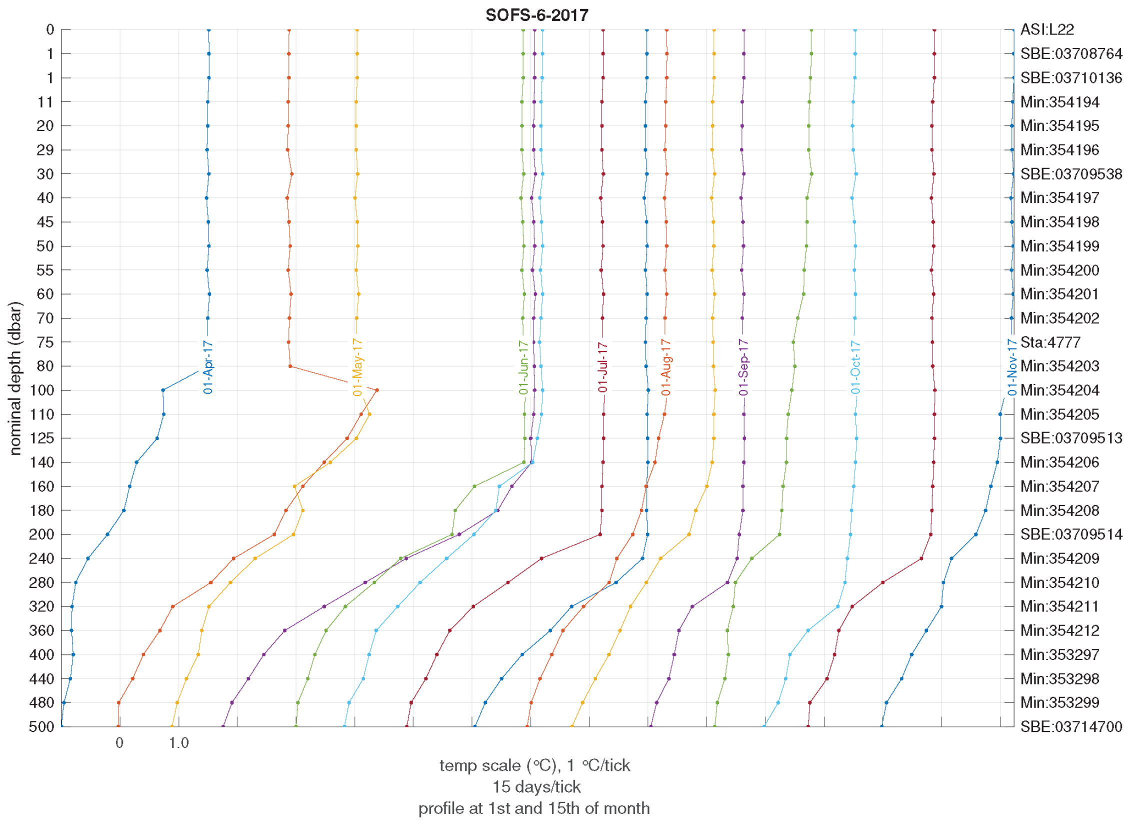

SOFS-5-2015
temperature - index
15
10
5
0
-5
-10
-15
-20
-25
Apr 2015
Jul 2015
Oct 2015
Jan 2016
Apr 2016
0
0
1.01
1.1
10
20
29
30
40
55
60
65
70
75
85
100
110
120
140
160
200
240
280
320
360
400
440
480
500

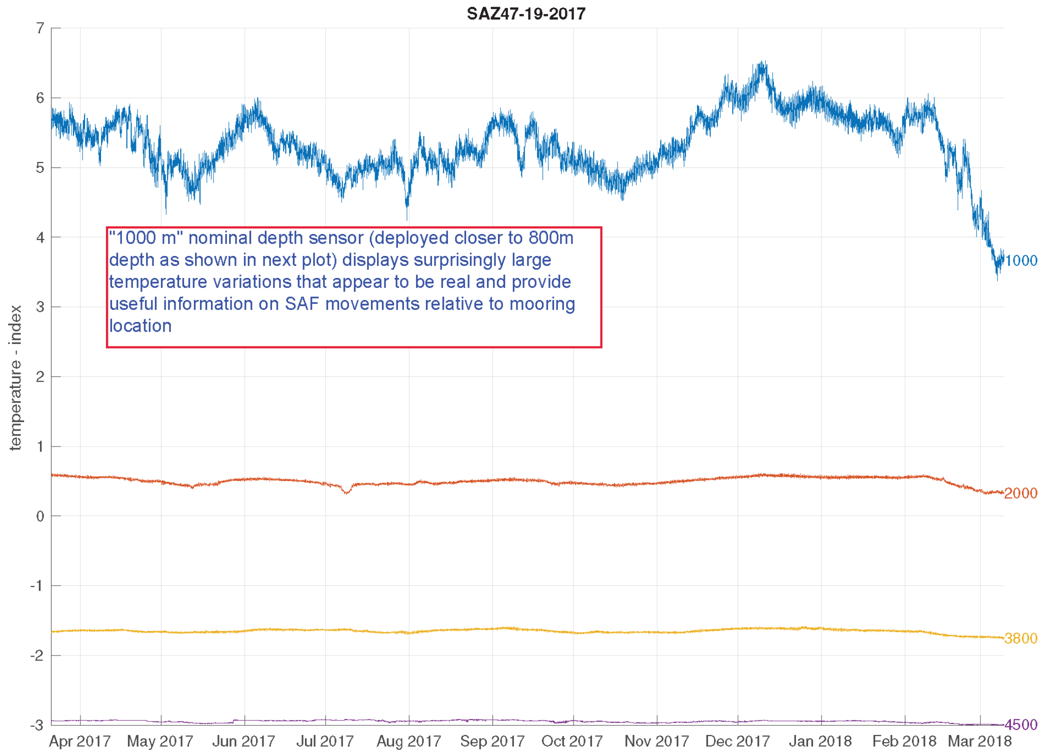

SOFS-5-2015
pressure (dbar)
0
50
100
150
200
250
300
350
400
450
500
Apr 2015
Jul 2015
Oct 2015
Jan 2016
Apr 2016
30
100
500

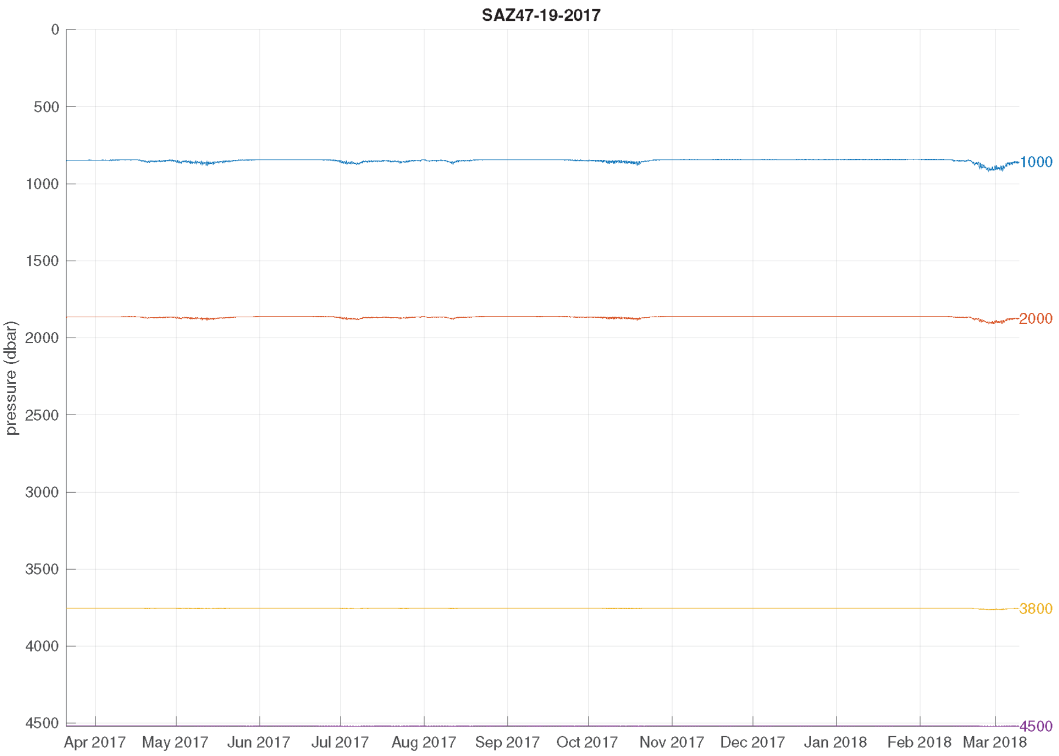

SOFS-5-2015
nominal depth (dbar)
temp scale (°C), 1 °C/tick
15 days/tick
profile at 1st and 15th of month

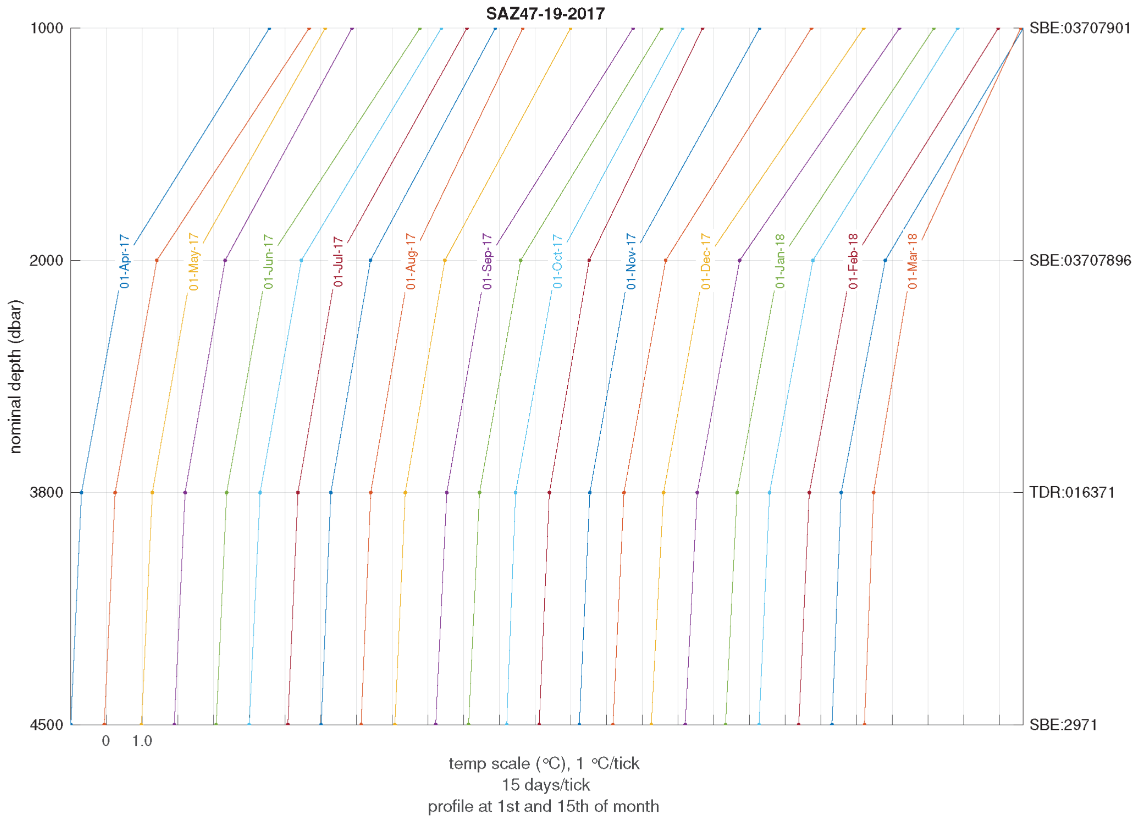

SOFS-6-2017
temperature - index
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
2017

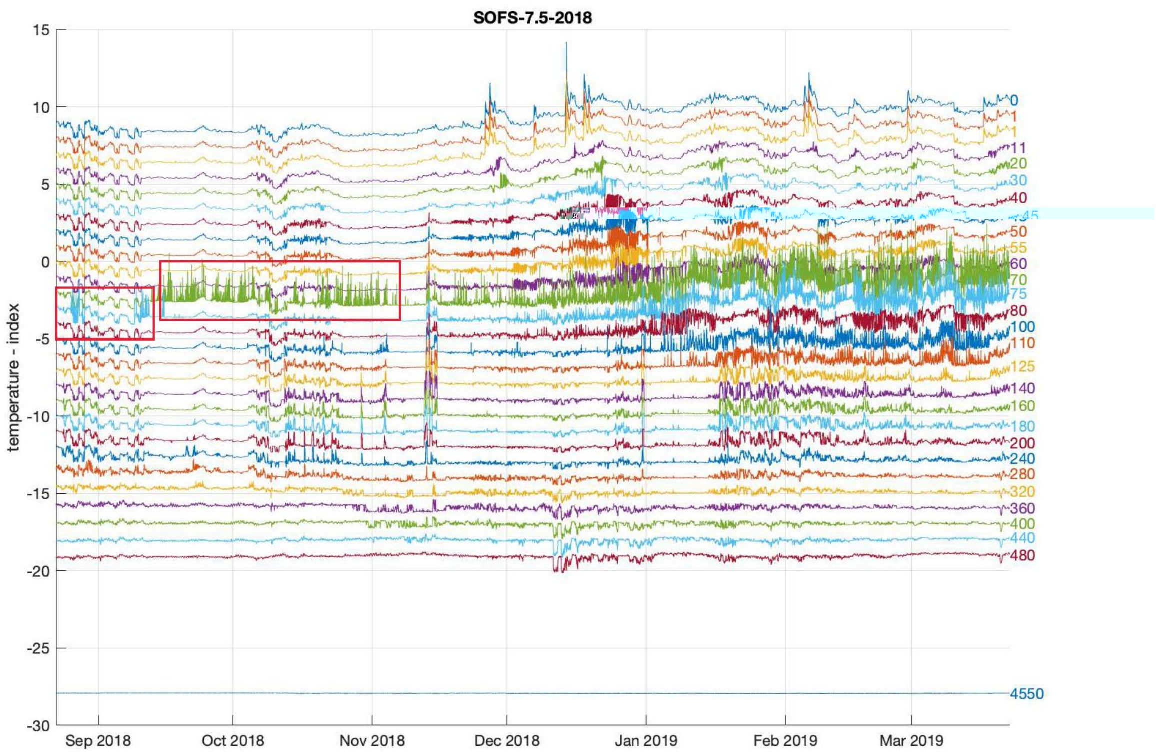

SOFS-6-2017
pressure (dbar)
0
50
100
150
200
250
300
350
400
450
500
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
2017
30
125
200
500


SOFS-6-2017
nominal depth (dbar)
0
1
1
11
20
29
30
40
45
50
55
60
70
75
80
100
110
125
140
160
180
200
240
280
320
360
400
440
480
500
ASI:L22
SBE:03708764
SBE:03710136
Min:354194
Min:354195
Min:354196
SBE:03709538
Min:354197
Min:354198
Min:354199
Min:354200
Min:354201
Min:354202
Sta:4777
Min:354203
Min:354204
Min:354205
SBE:03709513
Min:354206
Min:354207
Min:354208
SBE:03709514
Min:354209
Min:354210
Min:354211
Min:354212
Min:353297
Min:353298
Min:353299
SBE:03714700
01-Apr-17
01-May-17
01-Jun-17
01-Jul-17
01-Aug-17
01-Sep-17
01-Oct-17
01-Nov-17
0
1.0
temp scale (°C), 1 °C/tick
15 days/tick
profile at 1st and 15th of month

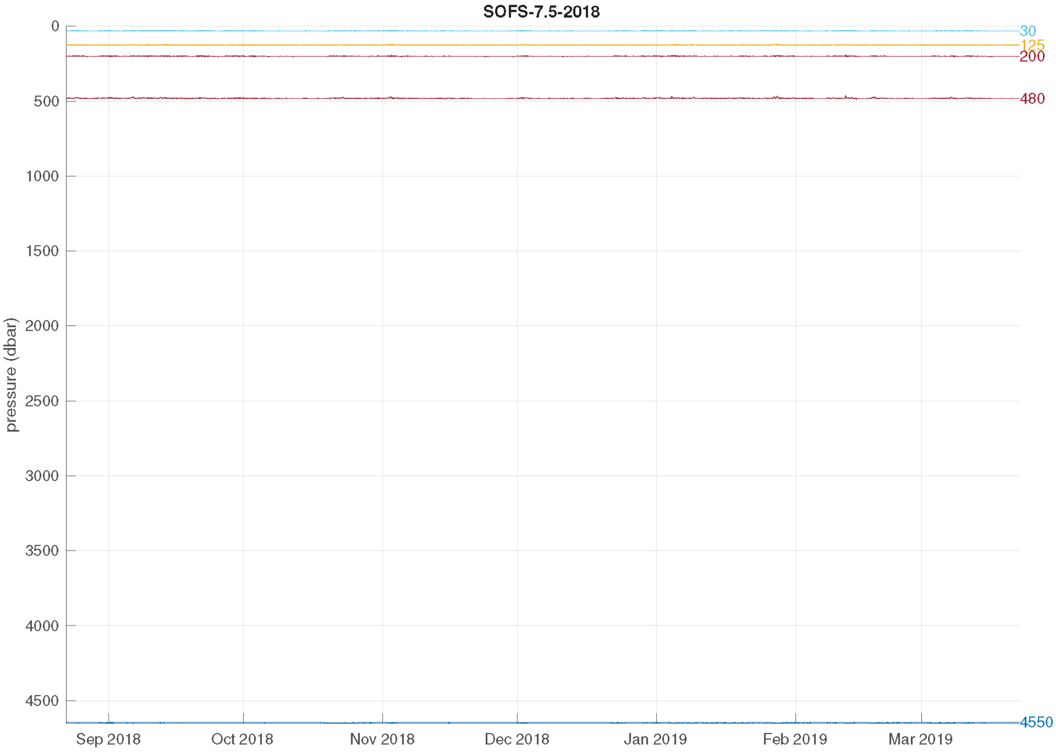

SAZ47-19-2017
temperature - index
"1000 m" nominal depth sensor (deployed closer to 800m depth as shown in next plot) displays surprisingly large temperature variations that appear to be real and provide useful information on SAF movements relative to mooring location
1000
2000
3800
4500
7
6
5
4
3
2
1
0
-1
-2
-3
Apr 2017 May 2017 Jun 2017 Jul 2017 Aug 2017 Sep 2017 Oct 2017 Nov 2017 Dec 2017 Jan 2018 Feb 2018 Mar 2018

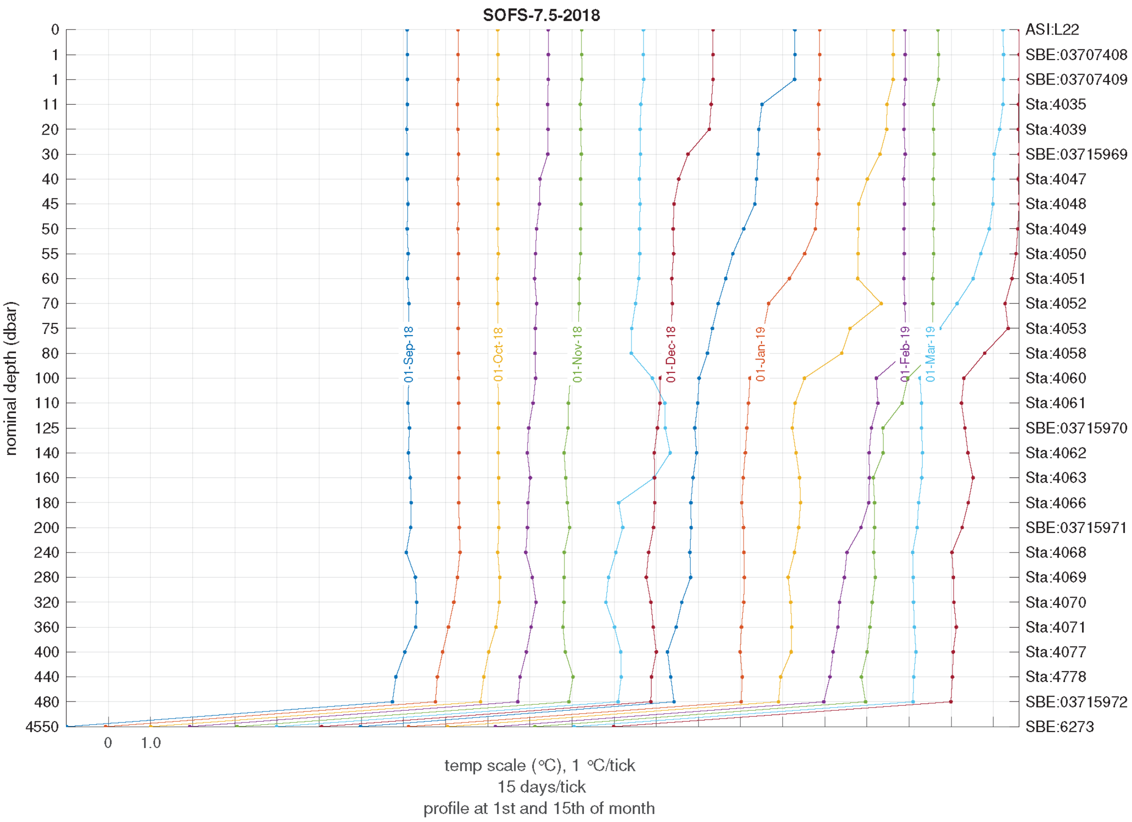

SAZ47-19-2017
pressure (dbar)
1000
2000
3800
4500
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Apr 2017 May 2017 Jun 2017 Jul 2017 Aug 2017 Sep 2017 Oct 2017 Nov 2017 Dec 2017 Jan 2018 Feb 2018 Mar 2018

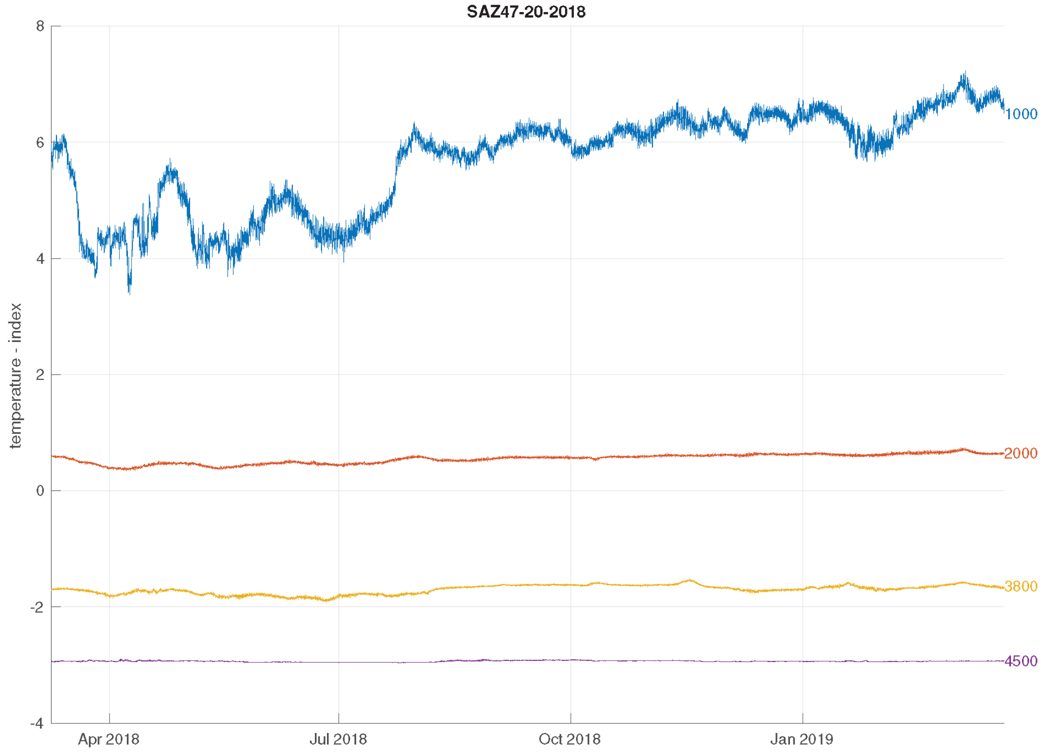


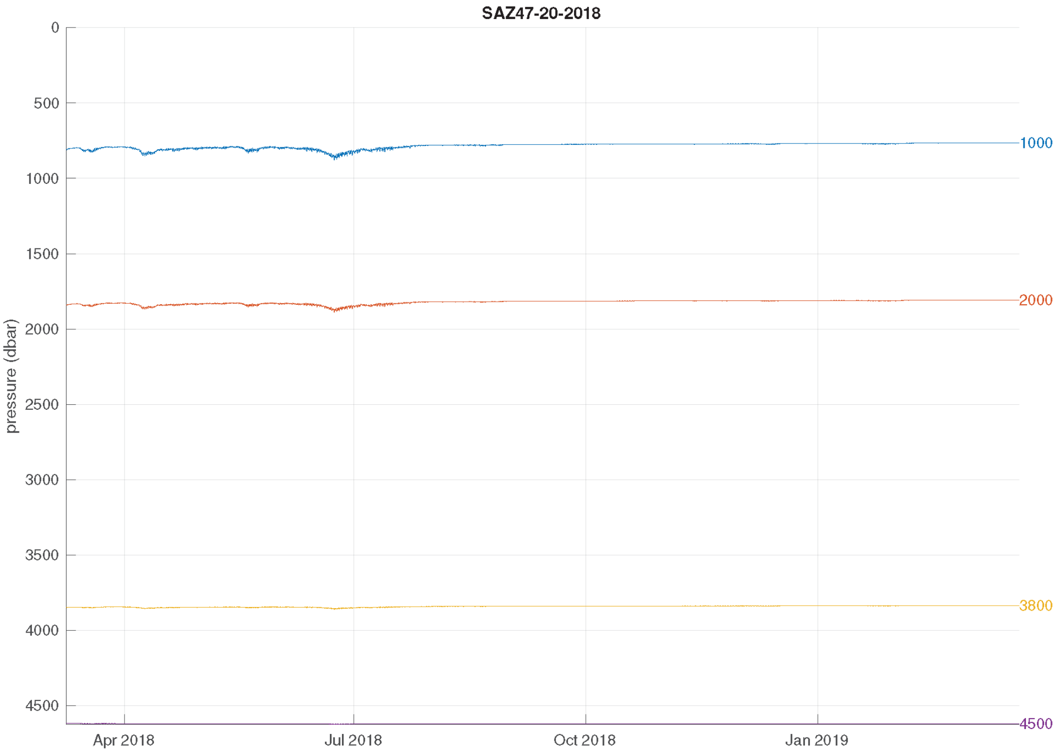


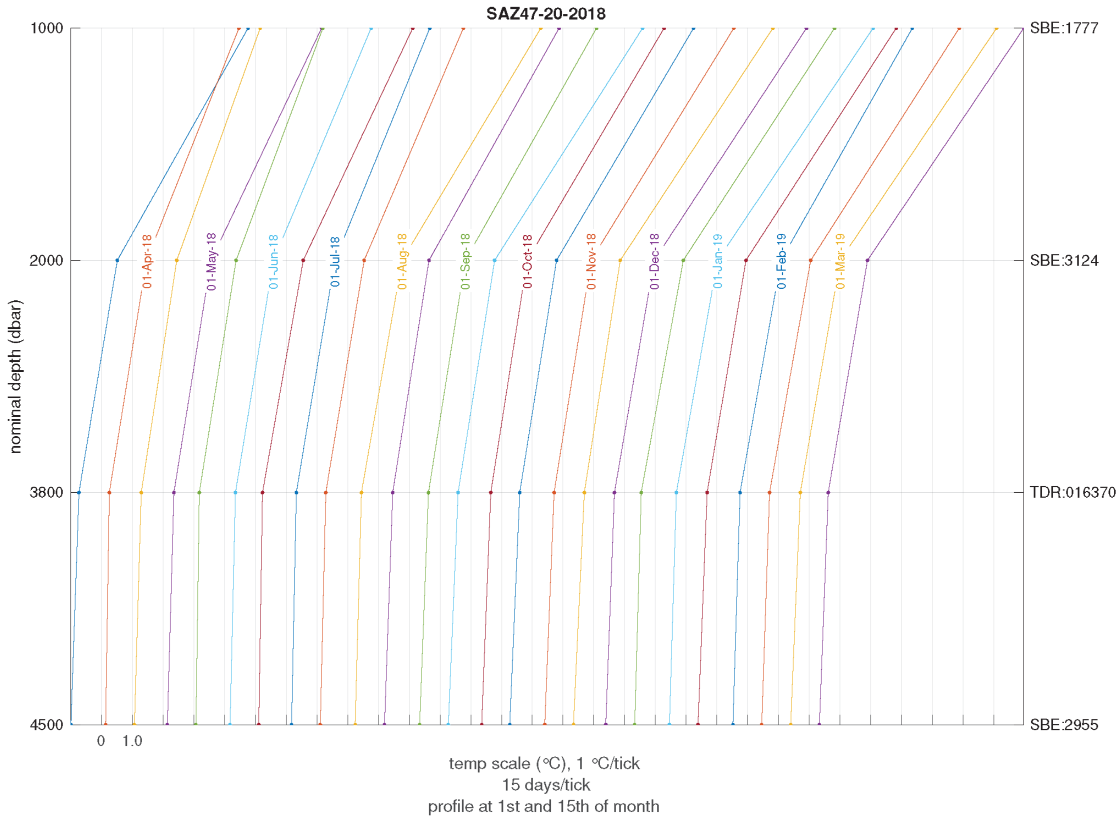
70 and 75 m sensors exhibit noise soon after deployment that worsens over time, its 'positive bias' aspect is common for failing Starmon Mini sensors - flag 4

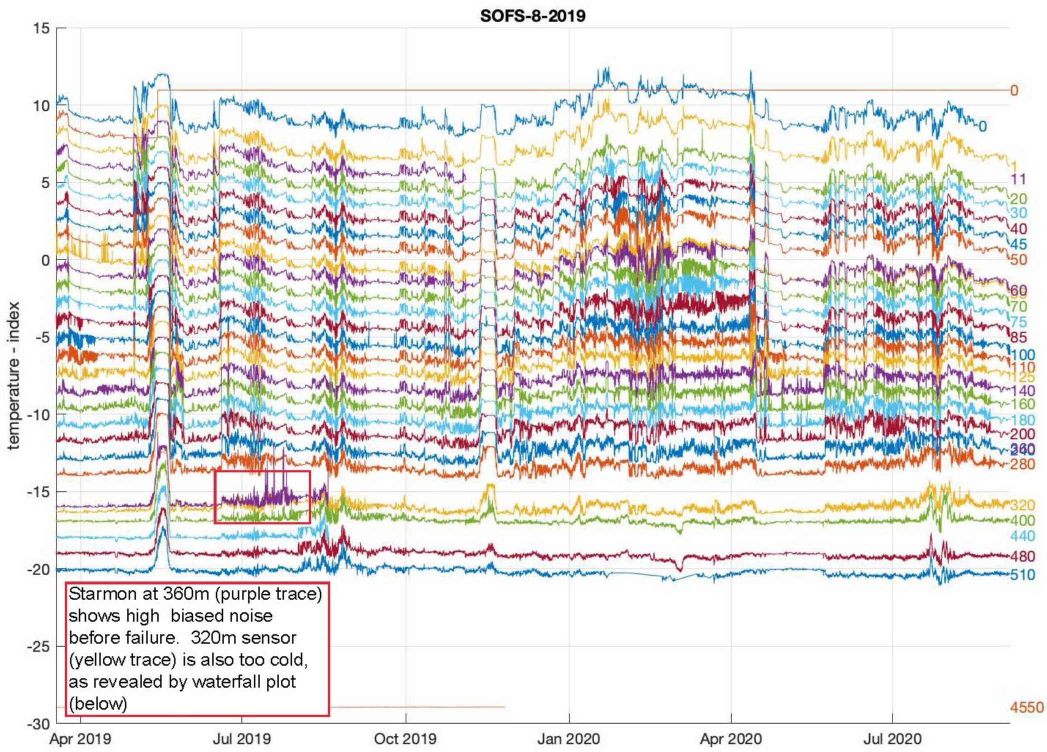

SOFS-7.5-2018
pressure (dbar)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
30
125
200
480
4550
Sep 2018
Oct 2018
Nov 2018
Dec 2018
Jan 2019
Feb 2019
Mar 2019

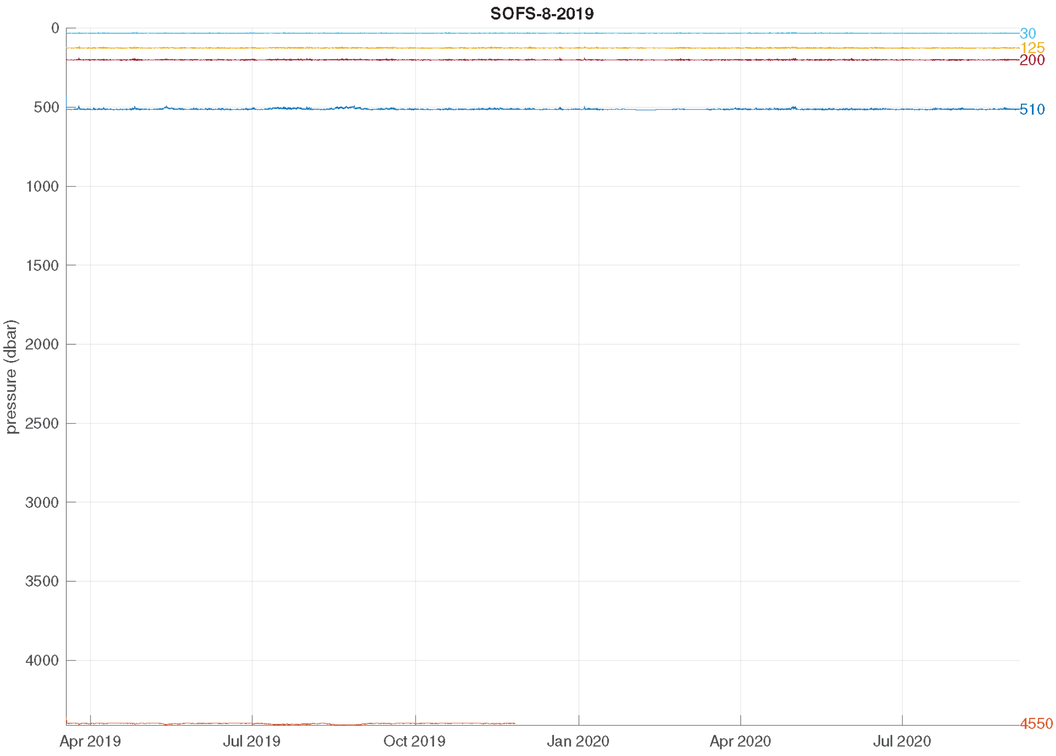

SOFS-7.5-2018
nominal depth (dbar)
0
1
1
11
20
30
40
45
50
55
60
70
75
80
100
110
125
140
160
180
200
240
280
320
360
400
440
480
4550
ASI:L22
SBE:03707408
SBE:03707409
Sta:4035
Sta:4039
SBE:03715969
Sta:4047
Sta:4048
Sta:4049
Sta:4050
Sta:4051
Sta:4052
Sta:4053
Sta:4058
Sta:4060
Sta:4061
SBE:03715970
Sta:4062
Sta:4063
Sta:4066
SBE:03715971
Sta:4068
Sta:4069
Sta:4070
Sta:4071
Sta:4077
Sta:4778
SBE:03715972
SBE:6273
01-Sep-18
01-Oct-18
01-Nov-18
01-Dec-18
01-Jan-19
01-Feb-19
01-Mar-19
0
1.0
temp scale (°C), 1 °C/tick
15 days/tick
profile at 1st and 15th of month

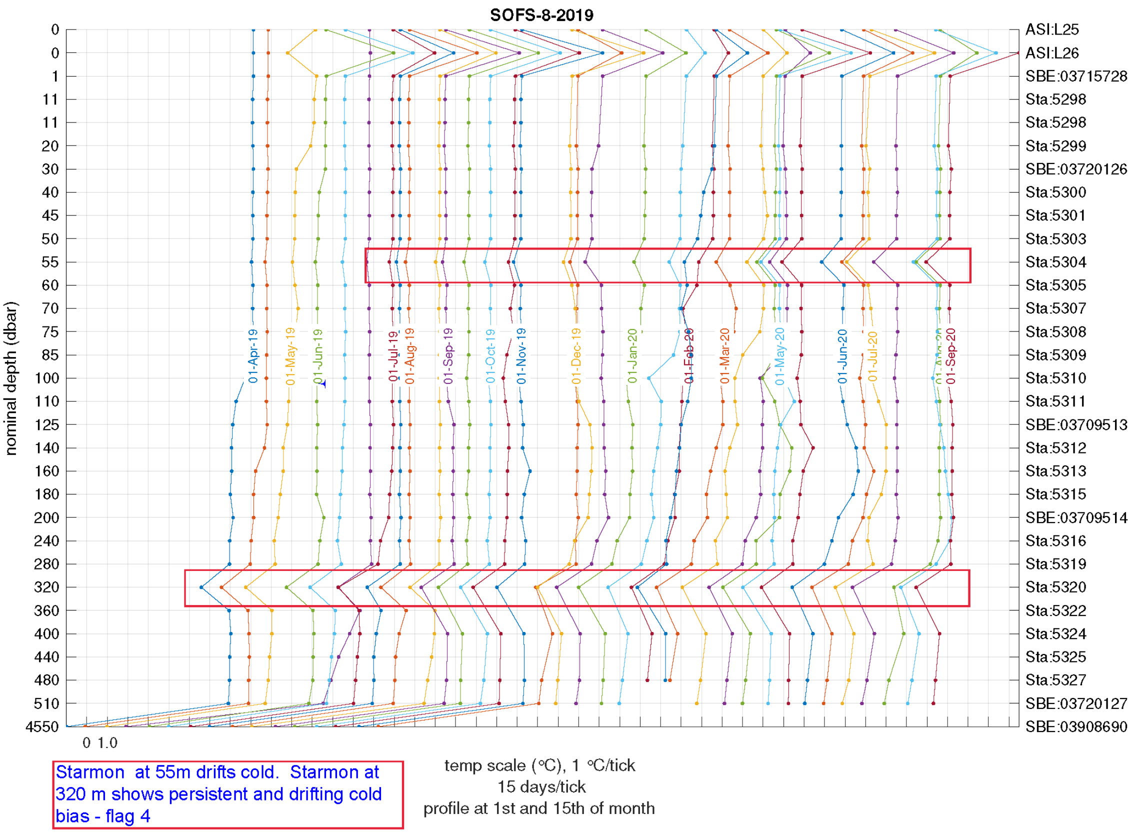

SAZ47-20-2018
temperature - index
8
6
4
2
0
-2
-4
Apr 2018
Jul 2018
Oct 2018
Jan 2019
1000
2000
3800
4500

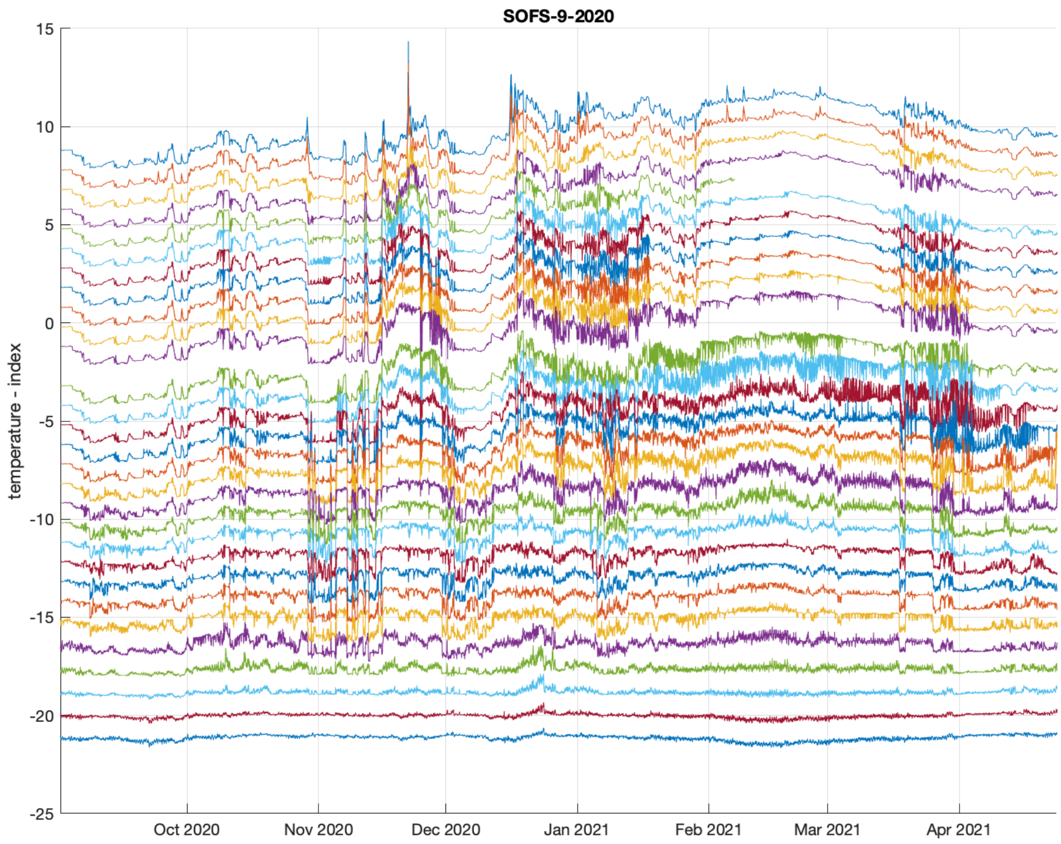

SAZ47-20-2018
pressure (dbar)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Apr 2018
Jul 2018
Oct 2018
Jan 2019
1000
2000
3800
4500

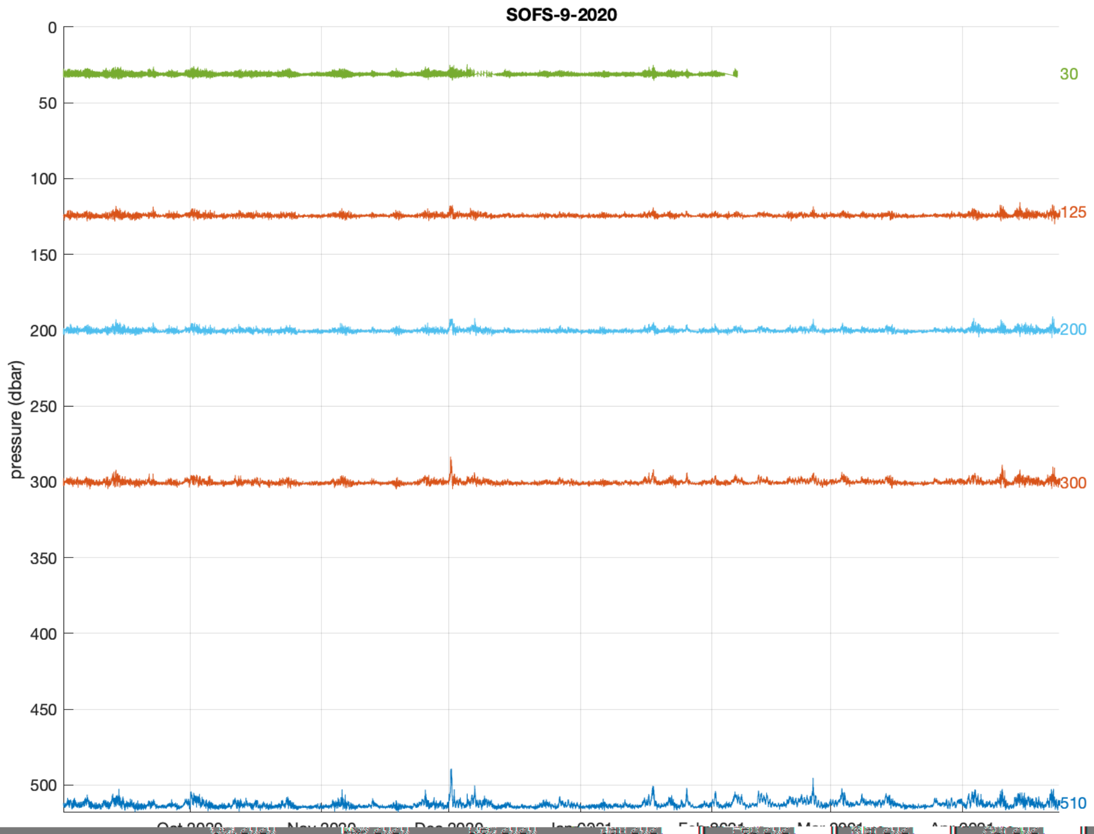

SAZ47-20-2018
1000
2000
3800
4500
nominal depth (dbar)
SBE:1777
SBE:3124
TDR:016370
SBE:2955
01-Apr-18
01-May-18
01-Jun-18
01-Jul-18
01-Aug-18
01-Sep-18
01-Oct-18
01-Nov-18
01-Dec-18
01-Jan-19
01-Feb-19
01-Mar-19
0 1.0
temp scale (°C), 1 °C/tick
15 days/tick
profile at 1st and 15th of month

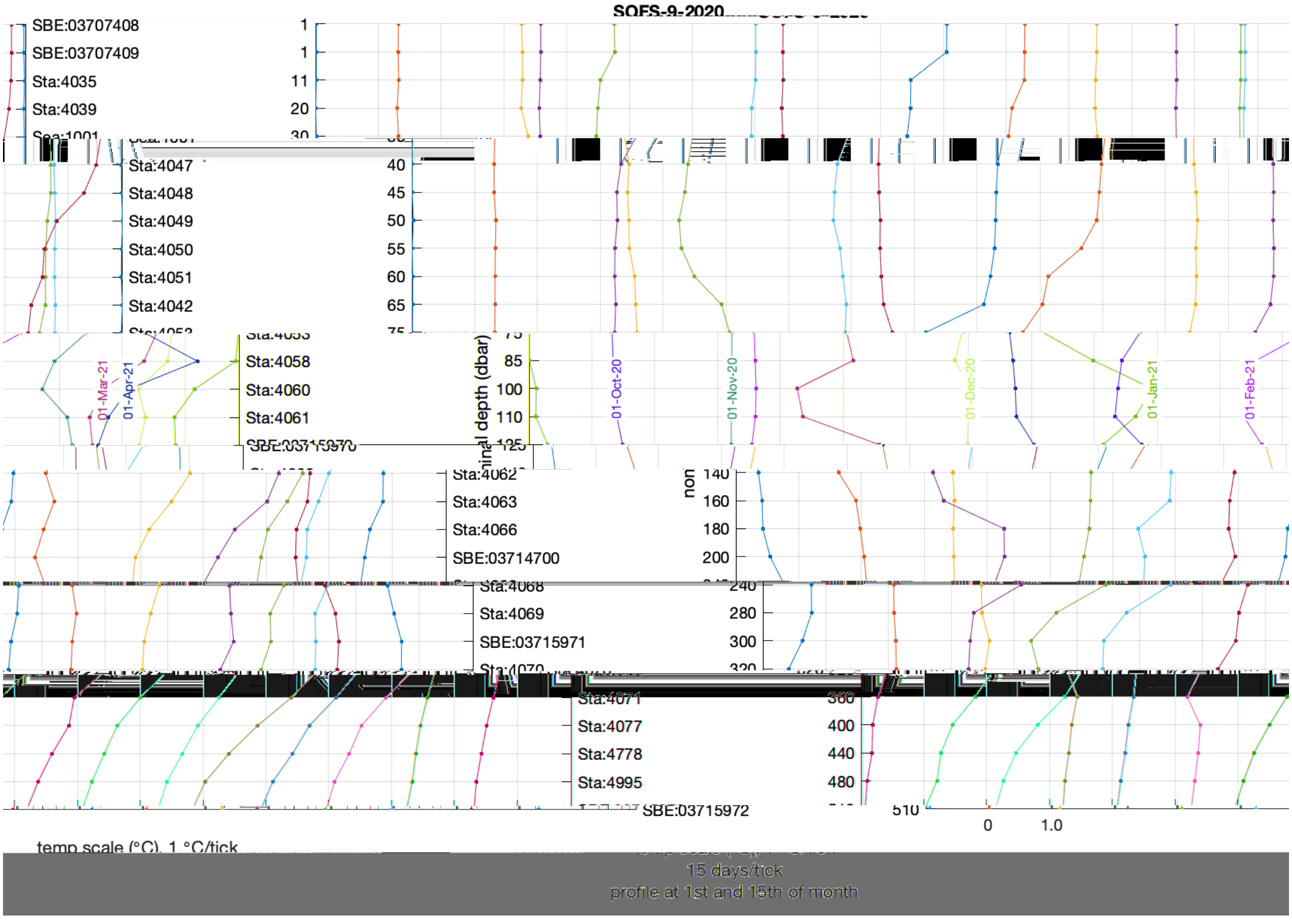

SOFS-8-2019
temperature - index
15
10
5
0
-5
-10
-15
-20
-25
-30
Apr 2019
Jul 2019
Oct 2019
Jan 2020
Apr 2020
Jul 2020
0
11
20
30
40
45
50
60
70
75
85
100
110
125
140
160
180
200
280
320
400
440
480
510
4550
Starmon at 360m (purple trace) shows high biased noise before failure. 320m sensor (yellow trace) is also too cold, as revealed by waterfall plot (below)

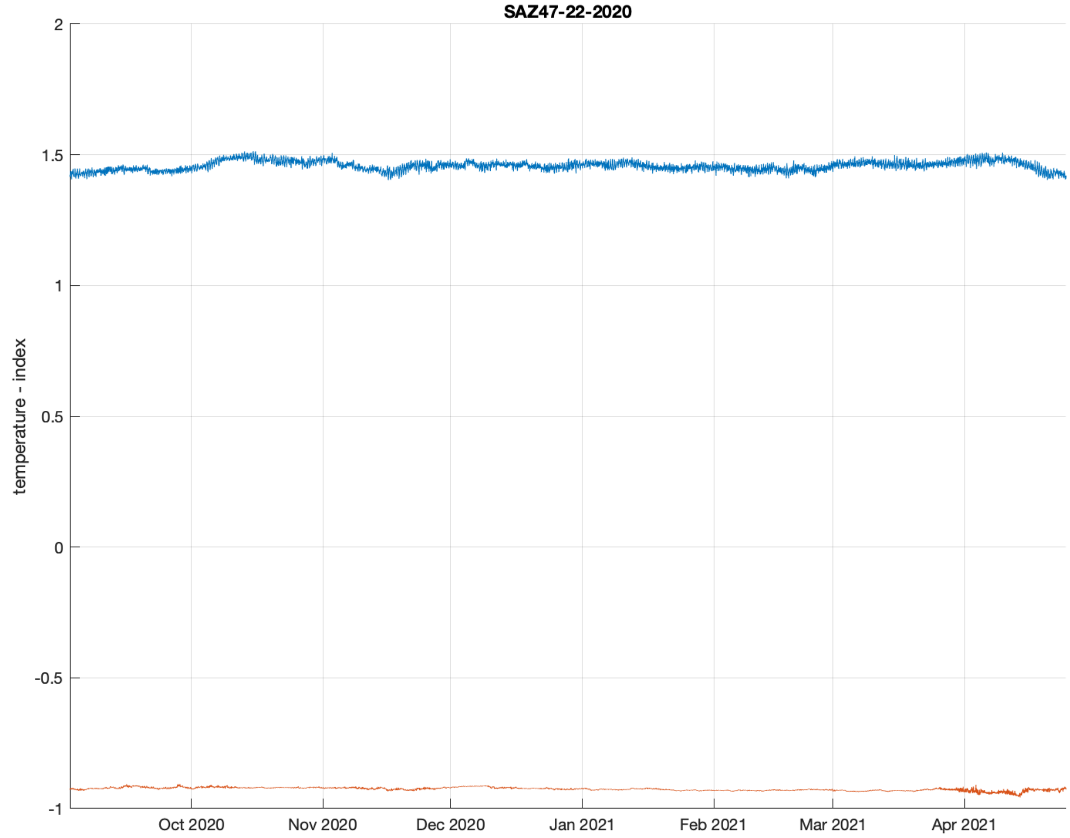

SOFS-8-2019
pressure (dbar)
30
125
200
510
4550
Apr 2019
Jul 2019
Oct 2019
Jan 2020
Apr 2020
Jul 2020

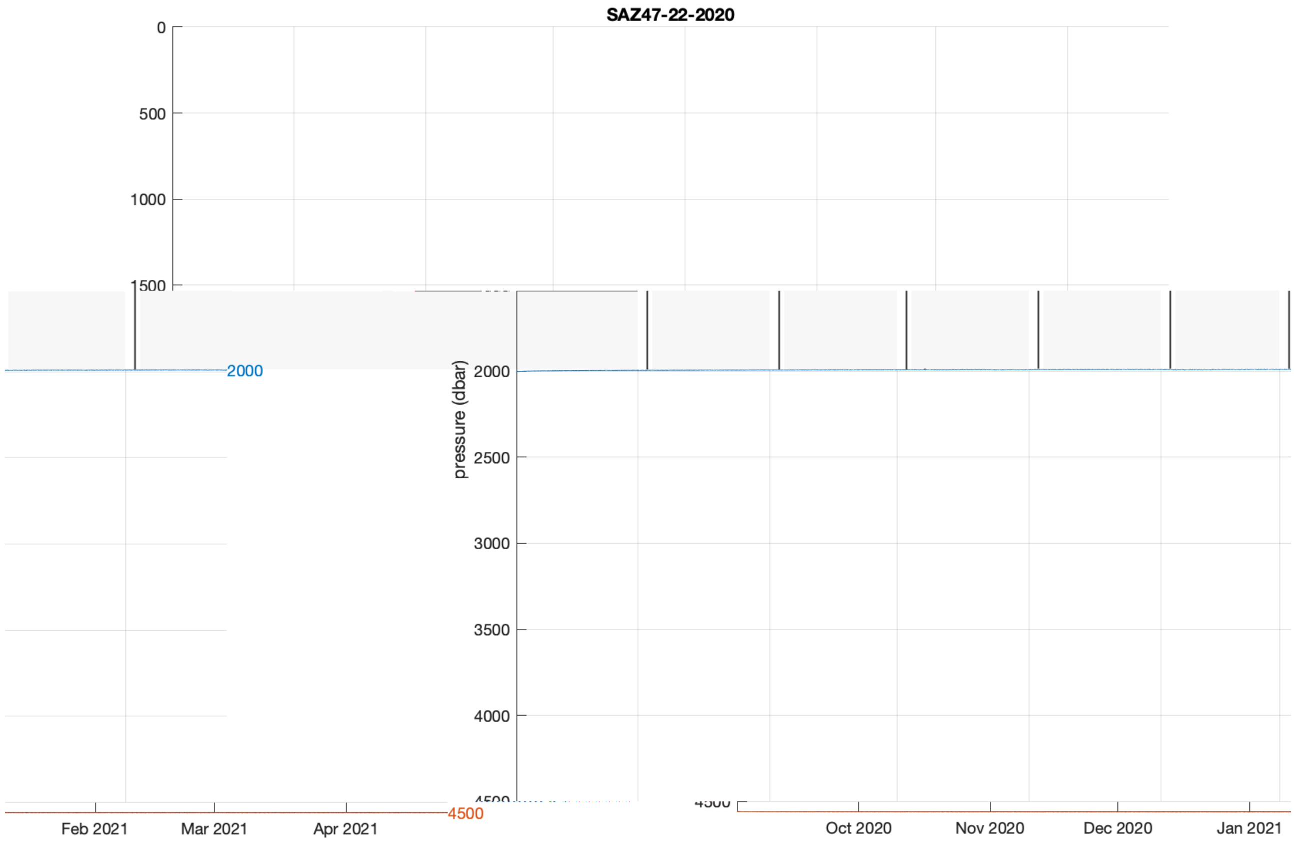

SOFS-8-2019
nominal depth (dbar)
ASI:L25
ASI:L26
SBE:03715728
Sta:5298
Sta:5299
SBE:03720126
Sta:5300
Sta:5301
Sta:5303
Sta:5304
Sta:5305
Sta:5307
Sta:5308
Sta:5309
Sta:5310
Sta:5311
SBE:03709513
Sta:5312
Sta:5313
Sta:5315
SBE:03709514
Sta:5316
Sta:5319
Sta:5320
Sta:5322
Sta:5324
Sta:5325
Sta:5327
SBE:03720127
SBE:03908690
0 1.0
Starmon at 55m drifts cold. Starmon at 320 m shows persistent and drifting cold bias - flag 4
temp scale (°C), 1 °C/tick
15 days/tick
profile at 1st and 15th of month


SOFS-9-2020
temperature - index
15
10
5
0
-5
-10
-15
-20
-25
Oct 2020
Nov 2020
Dec 2020
Jan 2021
Feb 2021
Mar 2021
Apr 2021


SOFS-9-2020
pressure (dbar)
0
50
100
150
200
250
300
350
400
450
500
30
125
200
300
510


SOFS-9-2020
SBE:03707408
SBE:03707409
Sta:4035
Sta:4039
Sta:4047
Sta:4048
Sta:4049
Sta:4050
Sta:4051
Sta:4042
Sta:4058
Sta:4060
Sta:4061
Sta:4063
Sta:4066
SBE:03714700
Sta:4069
SBE:03715971
Sta:4077
Sta:4778
Sta:4995
SBE:03715972
nominal depth (dbar)
01-Mar-21
01-Apr-21
01-Oct-20
01-Nov-20
01-Dec-20
01-Jan-21
01-Feb-21
temp scale (°C), 1 °C/tick
15 days/tick
profile at 1st and 15th of month


SAZ47-22-2020
temperature - index
2
1.5
1
0.5
0
-0.5
-1
Oct 2020
Nov 2020
Dec 2020
Jan 2021
Feb 2021
Mar 2021
Apr 2021


SAZ47-22-2020
pressure (dbar)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Oct 2020
Nov 2020
Dec 2020
Jan 2021
Feb 2021
Mar 2021
Apr 2021

6 Discussion and recommendations

6.1 QARTOD tests that were not performed:

Some of the recommended QARTOD tests were deemed not applicable, specifically Tests 1, 2, 8, 9, 10, 12, and 13. However, their intent, especially for Tests 1,2, and 8 was captured by other approaches. See Section 5.1 for full details.

6.2 Main causes for data flagging

As detailed in section 5.3 the most common reasons for data concern identified by the QARTOD automated procedures were from the spikes and rate of change tests, yet this affected only at most a few % of any record. Because those tests had relatively relaxed thresholds, the overall largest number of flags assigned by the automated procedure came from setting flags for entire records to 3 whenever sensors exhibited more than 0.1% of data identified as either bad (flag 4) or suspect (flag 3).

The Neighbour sensor visualizations identified two additional error modes that dominated the flagging – offsets from other sensors (especially for low serial number Vemco sensors used in the early years of deployments) and noise that increased over time (especially for Starmon sensors).

6.3 Did the QC tests work and how good are the data?

Evaluating the success of the tests requires determining whether they correctly identified and flagged only and all *truly* bad data (flag 4) and possibly bad data (flag 3) and retained only and all *truly* good (flag 1) and *probably* good (flag 2) data. This requires some independent understanding of which data is good. We examined this briefly in two ways:

6.3.1 Comparison to ship CTD temperature profiles

This showed that almost all data that fell outside the bounds of CTD temperature profiles was flagged as bad (Flag 4) or requiring caution (Flag 3), while also revealing that oceanographic variability as observed by the moored sensors exceeds that captured by the sparse CTD sampling (see Figure 13).

6.3.2 Comparison of pre- and post-deployment sensor calibrations

Changes in calibrations were generally very small and did not identify problems beyond those visible from the in ocean records, as addressed in section 6.5 below. For this reason, and because pre- and post-calibrations were not systematically available, no corrections for calibration changes were made (see also section 4 above).

6.4 Could the QC tests be improved? What are the implications for QA?

In future years, it may be possible for an improved climatology based in part on the SOTS observations to improve the QARTOD test thresholds, and/or to implement more sophisticated filters (e.g. using probability density functions as discussed at Test 7).

A few overall recommendations for Quality Assurance have emerged from the QC:

1. Check all sensor calibrations against the growing record of calibrations to verify that none are unusual and thus potentially suspect.
2. Favour pumped sensors over unpumped sensors (especially for salinity because of associated thermal mass and lag problems – see discussion at Test 9)
3. Pair sensors whenever possible, and favour deploying pairs of sensors at a few depths over single sensors at more depths.
4. Compare all sensors against each other before and after deployment, either in the laboratory or via a common deployment on the CTD or both.

6.5 Did the QC procedures identify opportunities to improve the data?

Yes, persistent temperature offsets between Vemco sensors deployed in the early years (Serial numbers <10000) and co-deployed SBE sensors were identified (as annotated in their time-series and water column profile plots above). This identification was possible during periods when the upper ocean was well mixed so that the SBE sensors all yielded indistinguishable values, as did the Vemco sensors (but offset from the SBE sensors). The identification and calculation of these offsets was automated based on periods when the sum of the absolute differences between the individual SBE sensors and their mean was <0.08 °C. This identifies their presence within a well-mixed layer (with higher confidence than the temperature offset of 0.3 °C used to define mixed layer depth at SOTS). This approach was sufficient for deployments with a SBE sensor at the deepest temperature sensor depth, but for deployments with Vemco sensors below the deepest SBE sensor, we also visually selected periods when the water column was well mixed (based on all the sensors, allowing for minor offsets between different sensor types), and used only those periods to define the offsets. During testing of these procedures, we also applied them to records with no visual indication of sensor offset problems and verified that only small differences within the uncertainties of the SBE sensors were identified, for which no corrections were applied.

The offsets and their uncertainties are provided Table 5. The offset corrections were applied to the full temporal records. The data from these sensors with offsets were initially flagged 3 in Version 1.0 of this report. In this new version 2.0, after correction (subtraction) of these offsets, we assigned flag 2 to the corrected values.

Table 5. Offsets used for temperature adjustments

DEPLOYMENT	SENSOR	DEPTH	SENSOR_OFFSET	SENSOR_STD
PULSE-6-2009	Minilog-T ; 6098	45	0.235	0.037
PULSE-6-2009	Minilog-T ; 4823	50	0.333	0.039
PULSE-6-2009	Minilog-T ; 4824	55	0.339	0.035
PULSE-6-2009	Minilog-TD ; 6100	60	0.028	0.048
PULSE-6-2009	Minilog-T ; 4825	65	0.281	0.040
PULSE-6-2009	Minilog-T ; 4826	70	0.283	0.042
PULSE-6-2009	Minilog-T ; 4827	75	0.376	0.039
PULSE-6-2009	Minilog-T ; 4828	85	0.352	0.021
PULSE-6-2009	Minilog-T ; 4829	120	0.356	0.026
PULSE-6-2009	Minilog-T ; 4830	140	0.338	0.040
PULSE-6-2009	Minilog-TD ; 6101	160	0.047	0.042
PULSE-7-2010	Minilog-T ; 6098	45	0.170	0.037
PULSE-7-2010	Minilog-T ; 4823	50	0.287	0.033
PULSE-7-2010	Minilog-T ; 4824	55	0.279	0.026
PULSE-7-2010	Minilog-TD ; 6100	60	0.043	0.043
PULSE-7-2010	Minilog-T ; 4825	65	0.239	0.041
PULSE-7-2010	Minilog-T ; 4826	70	0.225	0.041
PULSE-7-2010	Minilog-T ; 4827	75	0.366	0.030
PULSE-7-2010	Minilog-T ; 4828	85	0.324	0.049
PULSE-7-2010	Minilog-T ; 4829	120	0.330	0.054
PULSE-7-2010	Minilog-T ; 4830	140	0.286	0.023
PULSE-7-2010	Minilog-TD ; 6101	160	0.037	0.040
PULSE-8-2011	Minilog-T ; 6098	45	0.119	0.047
PULSE-8-2011	SBE56 ; 05600531	45	-0.001	0.008
PULSE-8-2011	Minilog-T ; 4823	50	0.260	0.035
PULSE-8-2011	Minilog-T ; 4824	55	0.262	0.039
PULSE-8-2011	Minilog-TD ; 6100	60	-0.018	0.040
PULSE-8-2011	Minilog-T ; 4825	65	0.223	0.043
PULSE-8-2011	Minilog-T ; 4826	70	0.216	0.044
PULSE-8-2011	Minilog-T ; 4827	75	0.326	0.040
PULSE-8-2011	Minilog-T ; 4828	85	0.294	0.040
PULSE-8-2011	Minilog-T ; 4829	120	0.300	0.040
PULSE-8-2011	Minilog-T ; 4830	140	0.266	0.056
PULSE-8-2011	Minilog-TD ; 6101	160	-0.040	0.058
PULSE-8-2011	TDR-2050 ; 014788	475	-0.992	0.171
PULSE-8-2011	TDR-2050 ; 014789	630	-0.996	0.165
SOFS-1-2010	Minilog-T ; 6097	10	0.117	0.046
SOFS-1-2010	Minilog-T ; 4831	20	0.271	0.047
SOFS-1-2010	Minilog-T ; 4832	29	0.278	0.047
SOFS-1-2010	Minilog-T ; 4833	40	0.389	0.045
SOFS-1-2010	Minilog-T ; 4834	50	0.364	0.043

SOFS-1-2010	Minilog-T ; 4835	55	0.326	0.042
SOFS-1-2010	Minilog-T ; 4836	60	0.294	0.045
SOFS-1-2010	Minilog-T ; 4837	65	0.383	0.040
SOFS-1-2010	Minilog-T ; 4838	70	0.235	0.044
SOFS-1-2010	Minilog-TD ; 6099	75	0.121	0.047
SOFS-1-2010	Minilog-T ; 4839	85	0.355	0.041
SOFS-1-2010	Minilog-T ; 4840	110	0.260	0.045
SOFS-1-2010	Minilog-T ; 4841	120	0.328	0.046
SOFS-1-2010	Minilog-T ; 4842	140	0.290	0.048
SOFS-1-2010	Minilog-TD ; 4843	160	0.315	0.060
SOFS-2-2011	Minilog-T ; 6097	10	-0.073	0.076
SOFS-2-2011	Minilog-T ; 4831	20	0.272	0.041
SOFS-2-2011	Minilog-T ; 4832	29	0.282	0.039
SOFS-2-2011	Minilog-T ; 4833	40	0.368	0.053
SOFS-2-2011	Minilog-T ; 4834	50	0.353	0.039
SOFS-2-2011	Minilog-T ; 4835	55	0.313	0.041
SOFS-2-2011	Minilog-T ; 4836	60	0.300	0.040
SOFS-2-2011	Minilog-T ; 4837	65	0.378	0.039
SOFS-2-2011	Minilog-T ; 4838	70	0.253	0.044
SOFS-2-2011	Minilog-TD ; 6099	75	0.088	0.053
SOFS-2-2011	Minilog-T ; 4839	85	0.343	0.041
SOFS-2-2011	Minilog-T ; 4840	110	0.275	0.044
SOFS-2-2011	Minilog-T ; 4841	120	0.320	0.046
SOFS-2-2011	Minilog-T ; 4842	140	0.290	0.076
SOFS-2-2011	Minilog-TD ; 4843	160	0.355	0.135

6.6 Which data should you use, and what are the associated uncertainties?

We recommend that you use all data with flag values of 2 or less. Users interested in rapid surface warming events should also consider use of Flag 3 data.

Our comparisons to CTD data and calibrations provide some insights into possible temperature errors that may remain after data flagging, and thus the overall uncertainty of the temperature records. Our selection of thresholds optimizes retention of data unless it can clearly be flagged as bad (Flag 4) or suspect (Flag 3), and thus the thresholds will allow some bad data to pass these filters (as discussed in the Introduction). Therefore, after flagging an individual unflagged datum could still be in error by as much as any of the thresholds used for the climatology, spike, and rate of change tests, which are quite large in surface waters (see the specific Tests for these values). Indeed, these bounds generally greatly exceed the standard deviation of any particular temperature time series, because while large temperature variations may occur in the ocean they happen rarely. Thus, the standard deviation of a record also provides an estimate of the uncertainty in the quality-controlled data, especially when taken over short sub-sets of the data that avoid the predominantly seasonal changes. Using running median filter to emphasize the typical rather than rare behaviour is thus also a useful approach to obtain a low uncertainty time series, but as described in the Introduction, the oceanographic feature(s) of interest must determine the appropriate smoothing and this is thus left to data users to select to fit their purposes.

7 Accessing the Data

Data are provided on-line from the Australian Ocean Data Network in CF compliant netcdf format files, with one file per deployment. We recommend using all data with flags of 1 or 2.

The URL for data access is: https://portal.aodn.org.au/

Data file structure

```
dimensions:
        TIME = 169340 ;
variables:
        double TIME(TIME) ;
                TIME:long_name = "time" ;
                TIME:units = "days since 1950-01-01 00:00:00 UTC" ;
                TIME:calendar = "gregorian" ;
                TIME:axis = "T" ;
                TIME:standard_name = "time" ;
                TIME:valid_max = 90000. ;
                TIME:valid_min = 0. ;
        float TEMP(TIME) ;
                TEMP:_FillValue = NaNf ;
                TEMP:units = "degrees_Celsius" ;
                TEMP:coordinates = "TIME LATITUDE LONGITUDE NOMINAL_DEPTH" ;
                TEMP:long_name = "sea_water_temperature" ;
                TEMP:standard_name = "sea_water_temperature" ;
                TEMP:valid_max = 40.f ;
                TEMP:valid_min = -2.5f ;
                TEMP:ancillary_variables = "TEMP_quality_control TEMP_quality_control_loc
TEMP_quality_control_gr TEMP_quality_control_spk TEMP_quality_control_roc" ;
        double LATITUDE ;
                LATITUDE:axis = "Y" ;
                LATITUDE:long_name = "latitude" ;
                LATITUDE:reference_datum = "WGS84 geographic coordinate system" ;
                LATITUDE:standard_name = "latitude" ;
                LATITUDE:units = "degrees_north" ;
                LATITUDE:valid_max = 90. ;
                LATITUDE:valid_min = -90. ;
        double LONGITUDE ;
                LONGITUDE:axis = "X" ;
                LONGITUDE:long_name = "longitude" ;
                LONGITUDE:reference_datum = "WGS84 geographic coordinate system" ;
                LONGITUDE:standard_name = "longitude" ;
                LONGITUDE:units = "degrees_east" ;
                LONGITUDE:valid_max = 180. ;
                LONGITUDE:valid_min = -180. ;
        double NOMINAL_DEPTH ;
                NOMINAL_DEPTH:axis = "Z" ;
                NOMINAL_DEPTH:long_name = "nominal depth" ;
                NOMINAL_DEPTH:positive = "down" ;
                NOMINAL_DEPTH:reference_datum = "sea surface" ;
```

```
            NOMINAL_DEPTH:standard_name = "depth" ;
            NOMINAL_DEPTH:units = "m" ;
            NOMINAL_DEPTH:valid_max = 12000. ;
            NOMINAL_DEPTH:valid_min = -5. ;
        byte TEMP_quality_control(TIME) ;
            TEMP_quality_control:_FillValue = 99b ;
            TEMP_quality_control:long_name = "quality flag for sea_water_temperature" ;
            TEMP_quality_control:standard_name = "sea_water_temperature status_flag" ;
            TEMP_quality_control:quality_control_conventions = "IMOS standard flags" ;
            TEMP_quality_control:flag_values = 0b, 1b, 2b, 3b, 4b, 6b, 7b, 9b ;
            TEMP_quality_control:flag_meanings = "unknown good_data probably_good_data
probably_bad_data bad_data not_deployed interpolated missing_value" ;
            TEMP_quality_control:comment = "maximum of all flags" ;
        byte TEMP_quality_control_loc(TIME) ;
            TEMP_quality_control_loc:_FillValue = 99b ;
            TEMP_quality_control_loc:long_name = "in/out of water flag for
sea_water_temperature" ;
            TEMP_quality_control_loc:units = "1" ;
            TEMP_quality_control_loc:comment = "data flagged not deployed (6) when out of
water" ;
        byte TEMP_quality_control_gr(TIME) ;
            TEMP_quality_control_gr:_FillValue = 99b ;
            TEMP_quality_control_gr:long_name = "global_range flag for sea_water_temperature"
;
            TEMP_quality_control_gr:units = "1" ;
            TEMP_quality_control_gr:comment = "Test 4. gross range test" ;
        byte TEMP_quality_control_spk(TIME) ;
            TEMP_quality_control_spk:_FillValue = 99b ;
            TEMP_quality_control_spk:long_name = "spike flag for sea_water_temperature" ;
            TEMP_quality_control_spk:units = "1" ;
            TEMP_quality_control_spk:comment = "Test 6. spike test" ;
        byte TEMP_quality_control_roc(TIME) ;
            TEMP_quality_control_roc:_FillValue = 99b ;
            TEMP_quality_control_roc:long_name = "rate_of_change flag for
sea_water_temperature" ;
            TEMP_quality_control_roc:units = "1" ;
            TEMP_quality_control_roc:comment = "Test 7. rate of change test" ;
```

8 References

Bushnell, M., and H. Worthington (2020), Manual for real-time quality control of in-situ temperature and salinity data : a guide to quality control and quality assurance for in-situ temperature and salinity observations, doi:https://doi.org/10.25923/x02m-m555.

Eriksen, R., T. W. Trull, D. Davies, P. Jansen, A. T. Davidson, K. Westwood, and R. van den Enden (2018), Seasonal succession of phytoplankton community structure from autonomous sampling at the Australian Southern Ocean Time Series (SOTS) observatory, Marine Ecology Progress Series, 589, 13-31, doi:10.3354/meps12420.

Hampel, F. R. (1974) The influence curve and its role in robust estimation, Journal of the American Statistical Association, 69, 382–393.

Herraiz-Borreguero, L., Rintoul, S.R. (2011), Regional circulation and its impact on upper ocean variability south of Tasmania (Australia). Deep-Sea Research II 58: 2071-2081.

Otsu, N. (1979), A threshold selection method from gray-level histograms, *IEEE transactions on systems, man, and cybernetics*, *9*(1), 62-66.

Rintoul, S. R., and T. W. Trull (2001), Seasonal evolution of the mixed layer in the Subantarctic Zone south of Australia, *Journal of Geophysical Research-Oceans*, *106*(C12), 31447-31462, doi:10.1029/2000jc000329.

Trull, T.W., Bray, S.G., Manganini, S.J., Honjo, S., François, R. (2001), Moored sediment trap measurements of carbon export in the Subantarctic and Polar Frontal Zones of the Southern Ocean, south of Australia. Journal of Geophysical Research 106: 31489-31510.

U.S. Integrated Ocean Observing System, 2020. Manual for Real-Time Quality Control of In-situ Temperature and Salinity Data Version 2.1: A Guide to Quality Control and Quality Assurance of In-situ Temperature and Salinity Observations. 50 pp. https://doi.org/10.25923/x02m-m555

Appendix A Python files used for processing

Please refer to the following link for access to the Python files involved in performing the QC tests described in this report:

https://github.com/petejan/imos-tools

Appendix B Sensor Calibration Sheets

Calibration sheets for all Temperature and Salinity sensors deployed at the SOTS site are available on the SOTS homepage, https://imos.org.au/facilities/deepwatermoorings/sots, under "Important Documents".

CONTACT US

t 1300 363 400
+61 3 9545 2176
e csiroenquiries@csiro.au
w www.csiro.au

FOR FURTHER INFORMATION

Oceans and Atmosphere
Peter Jansen
t +61 3 6232 5094
e Peter.Jansen@csiro.au

Oceans and Atmosphere
Thomas Trull
t +61 3 6232 5069
e Tom.Trull@csiro.au

Version	Date	Change Description	Revision Author
1.0	1 Apr 2021	Original version	Jansen et al.
2.0	1 Nov 2021	Implementation of temperature adjustments, update through 2020	Jansen, Shadwick, Trull

Bushnell, M.and Worthington, H. (2020). Manual for real-time quality control of in-situ temperature and salinity data : a guide to quality control and quality assurance for in-situ temperature and salinity observations. doi:https://doi.org/10.25923/x02m-m555