National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

Instruments Used for Measurement of Sea Level (Tide Gauges)

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National Oceanography Centre, Liverpool

Sea Level Training Course, St Lucia, 17-21 October 2016

Sea Level Measurements

- Sea level is measured by a <u>tide gauge</u>
- Values of sea level (or sea surface height) are either spot-measurements at regular time intervals, or averages (called integrations) over certain short time intervals.
- For most tidal, storm surge or Mean Sea Level work, time intervals of 5, 6, or 15 minutes are adequate.
- For tsunami work, time intervals of a minute or less are usually needed.

Types of Gauge

- Tide poles (or tide staffs)
- Float tide gauges
- Acoustic gauges in tube (2 types)
- Pressure gauges (several types)
- Radar gauges (several types)
- Importance of calibration of radar gauges
- Other technologies of tide gauges
- GPS techniques (later lecture)

Float Gauge,
Antarctica

Radar Gauge,
Liverpool

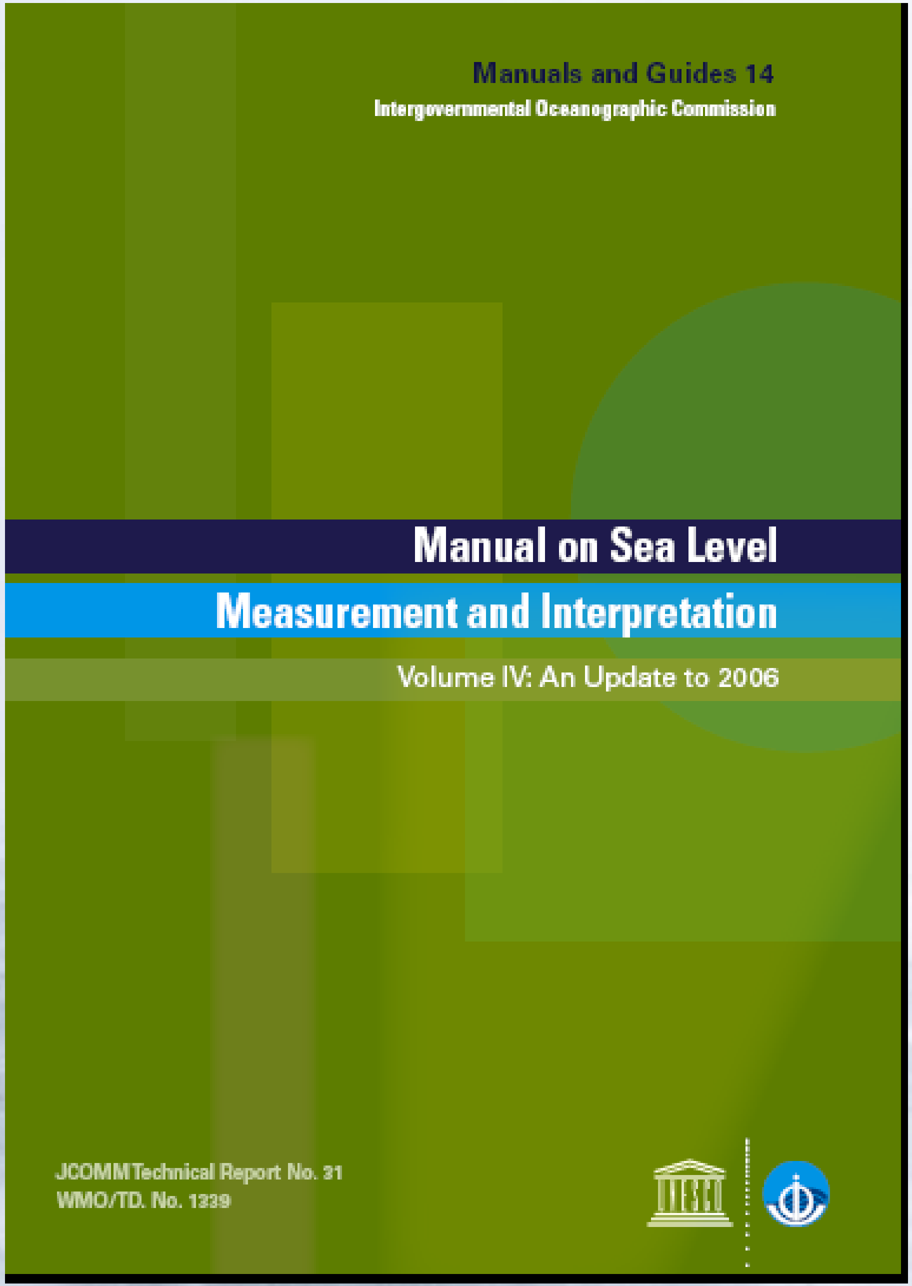
Float Gauge,
Venice

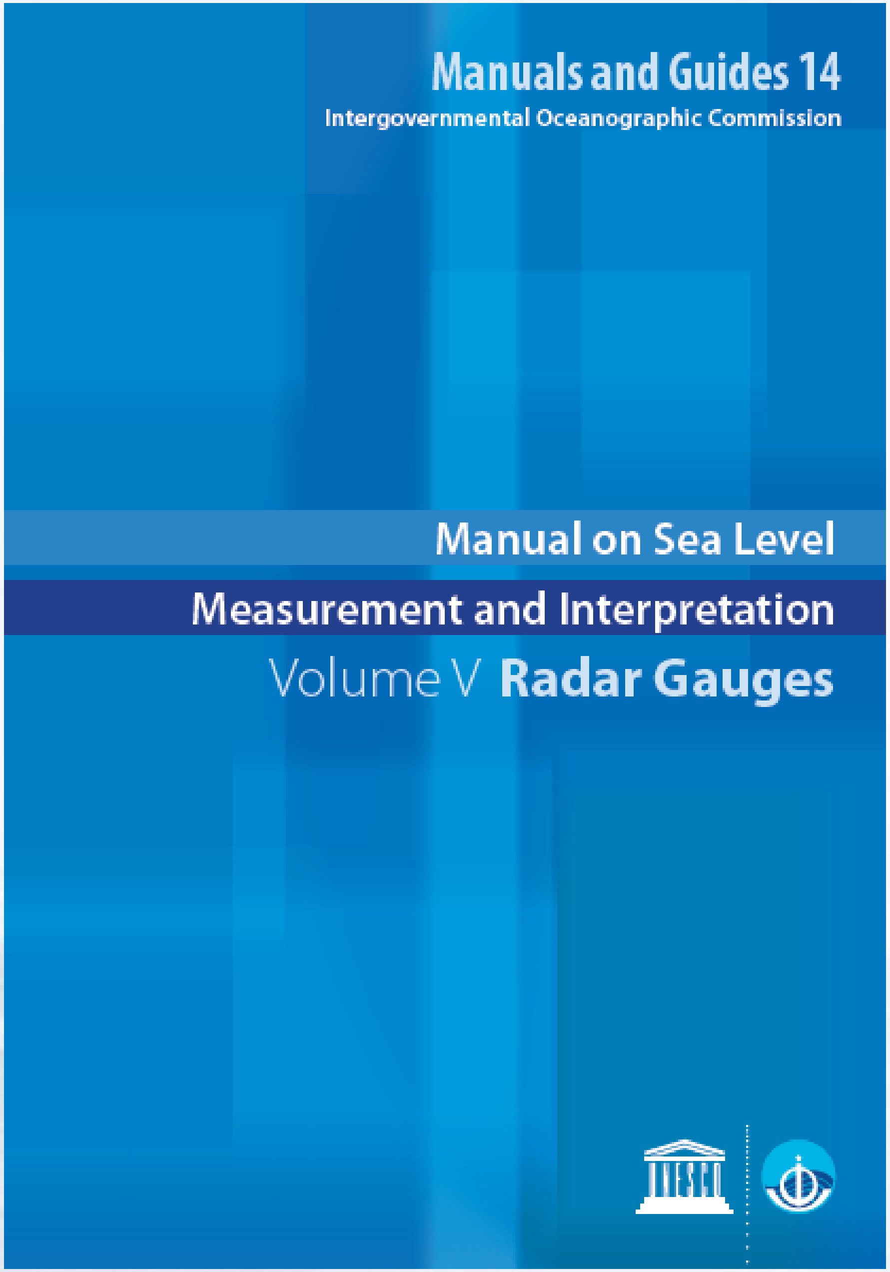
Acoustic Gauge,
Australia

General References

IOC Manuals I-V, especially Manuals IV and V

These can be downloaded from
http://www.psmsl.org/train_and_info/training/

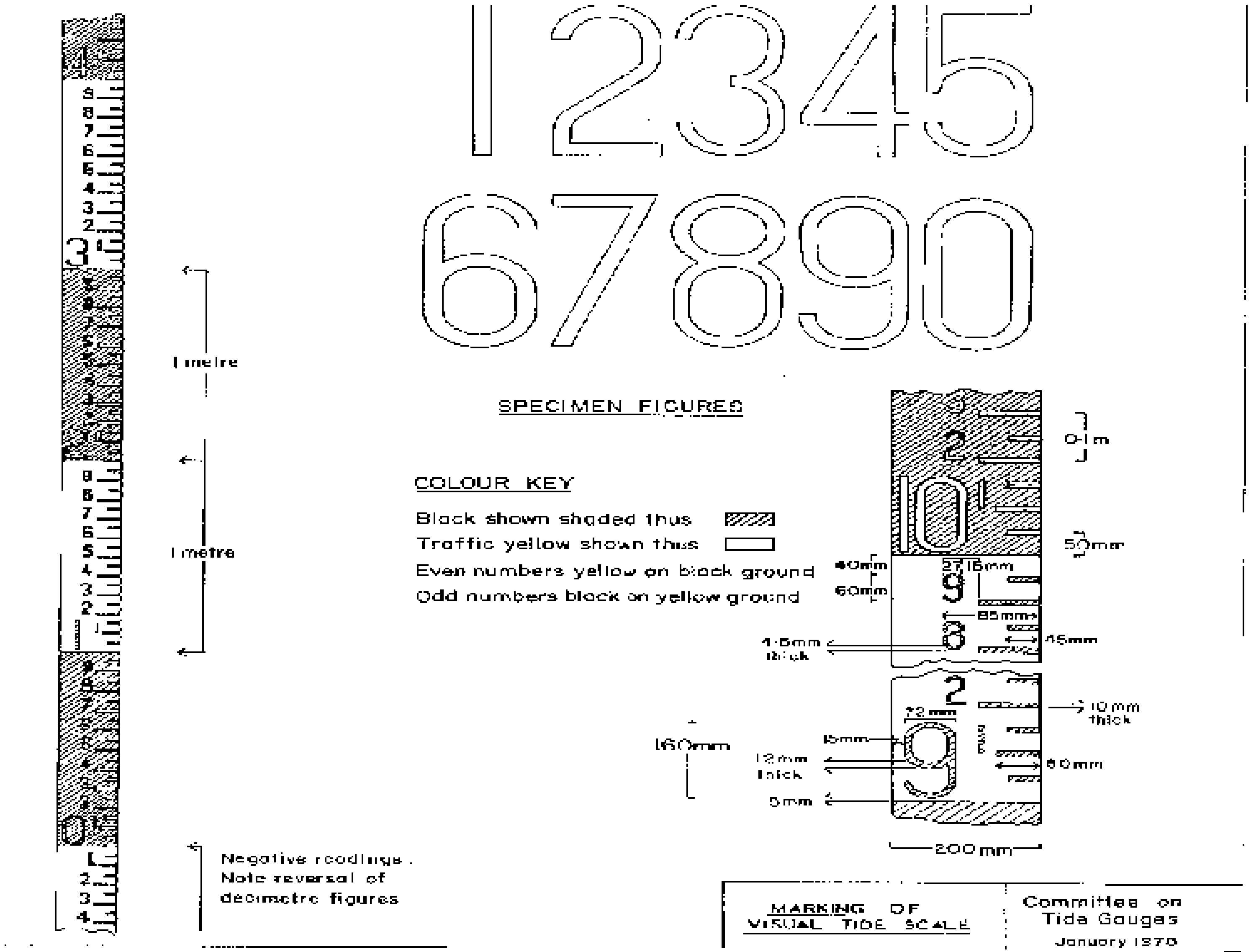

Manuals and Guides 14
Intergovernmental Oceanographic Commission
Manual on Sea Level
Measurement and Interpretation
Volume IV: An Update to 2006
JCOMM Technical Report No. 31
WMO/TD. No. 1339


Manuals and Guides 14
Intergovernmental Oceanographic Commission
Manual on Sea Level
Measurement and Interpretation
Volume V Radar Gauges

Three Things I Want to Stress

- Calibration of the measurements made by the tide gauge (especially radar and pressure gauges)
- Attention to the datum of the measurements with respect to a reference level on land
- Need to remember that good data will be used eventually for multiple purposes (e.g. real-time flood warning or long-term scientific studies), so we must provide the best data we can

Tide Pole (or Tide Staff) Gauges


12345
67890
SPECIMEN FIGURES
COLOUR KEY
Black shown shaded thus
Traffic yellow shown thus
Even numbers yellow on black ground
Odd numbers black on yellow ground
1 metre
1 metre
Negative readings.
Note reversal of
decimetre figures
0·1 m
50mm
40mm
60mm
27·15mm
85mm
45mm
4·5mm
thick
10mm
thick
12mm
15mm
160mm
12mm
thick
60mm
5mm
200mm
MARKING OF
VISUAL TIDE SCALE
Committee on
Tide Gauges
January 1970

A tide pole at a UK stilling well/float tide gauge station

Falkland Islands 2009

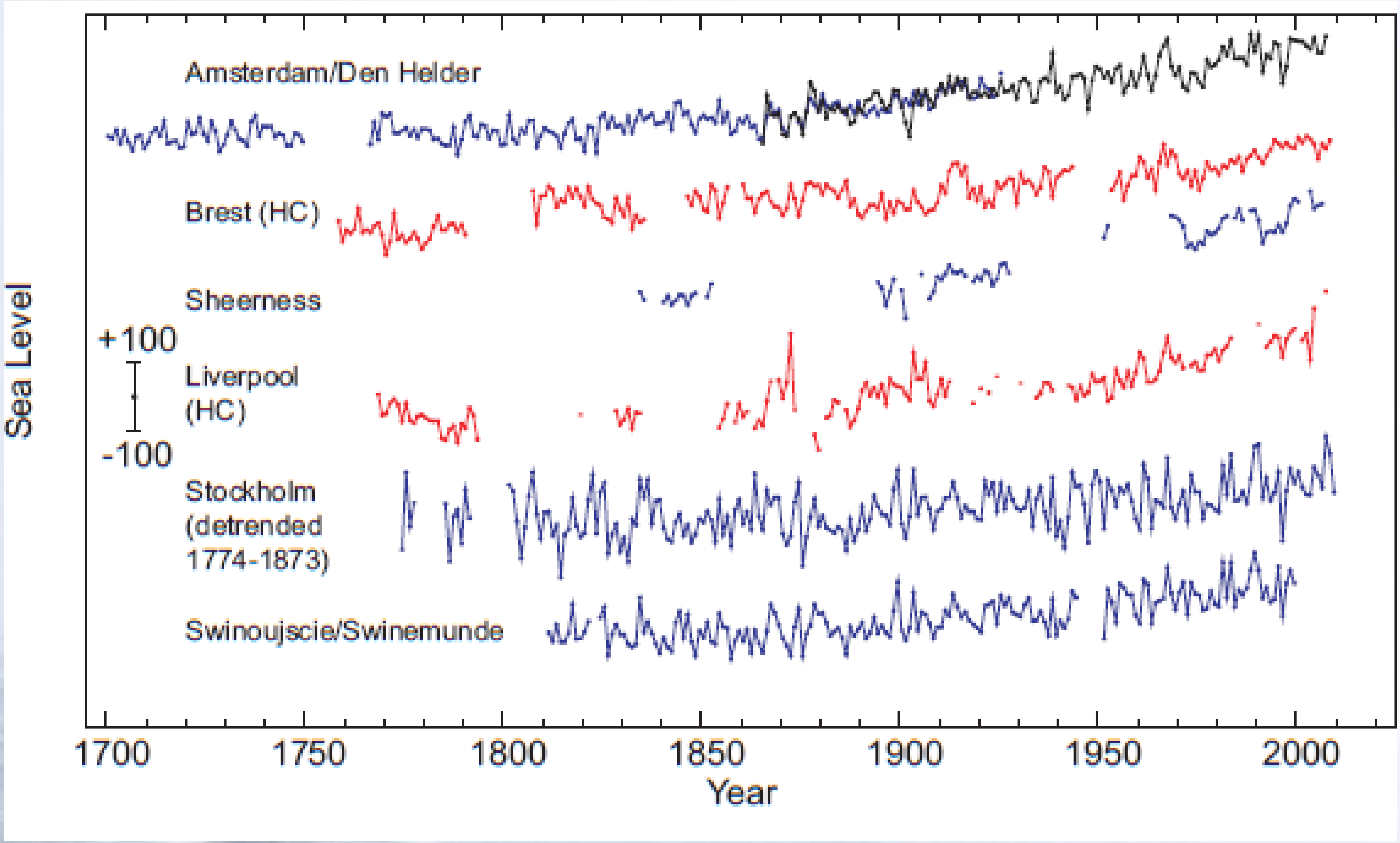

TIDAL DATUM
OLD DOCK SILL.
XXIV
XXIII
XXII
XXI
XX
XIX
XVIII

William Hutchinson measured heights and times of high water at Liverpool 1764-1793

1771

Figure A-1. The Stockholm sluice in the 1790s. The picture shows the part of the sluice where the sea level observations were made. (Coloured lithograph by F Verner 1824, based on a drawing from the 1790s by J P Cumelin.)

From 'The Changing Level of the Baltic Sea' (Ekman, 2009)

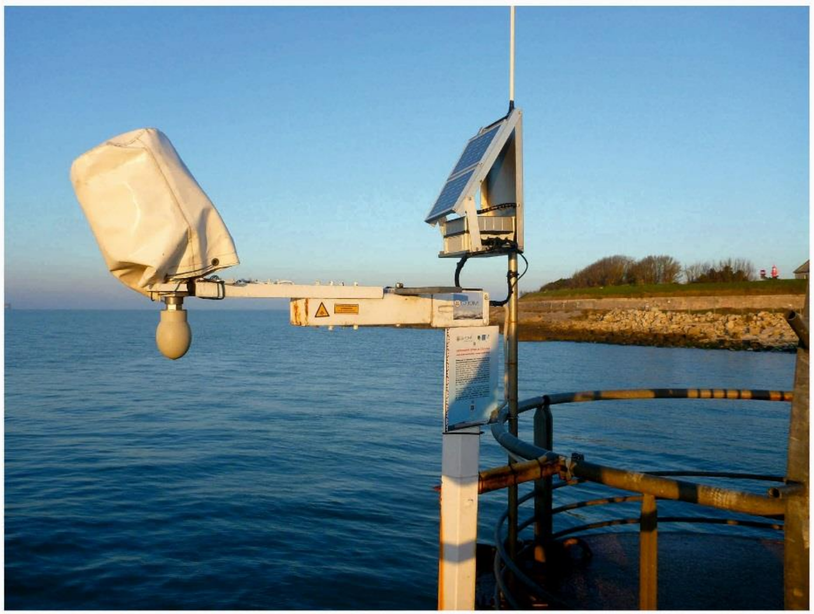


Long tide gauge records from northern Europe

Nileometers at Rawda Island, Cairo and Elephantine Island, Aswan

Tide pole gauges

- The simplest possible system, and lowest cost
- Very educational
- Important common sense ‘reality check’ alongside modern black box digital tide gauge systems
- Of course, tide poles have not for many years been a primary source of sea level data. However, it is always worth having a simple tide pole at every gauge site as a check.
- Although they are simple, there is a need for datum control, just as there is for more expensive and complicated gauges



Tide Pole alongside a Krohne Radar Gauge at Ile d’Aix, France

Float Gauges

Classical Float Gauge

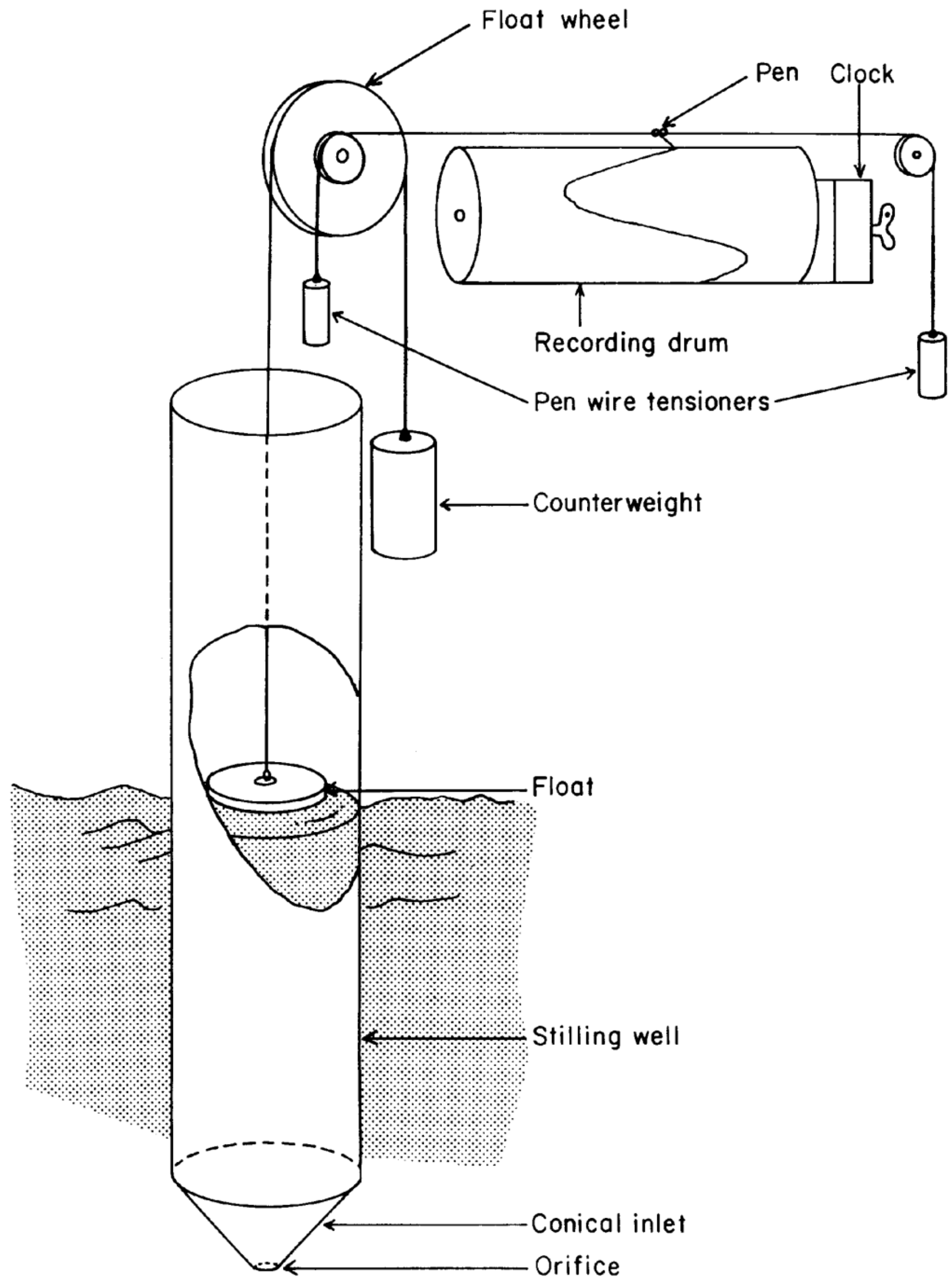
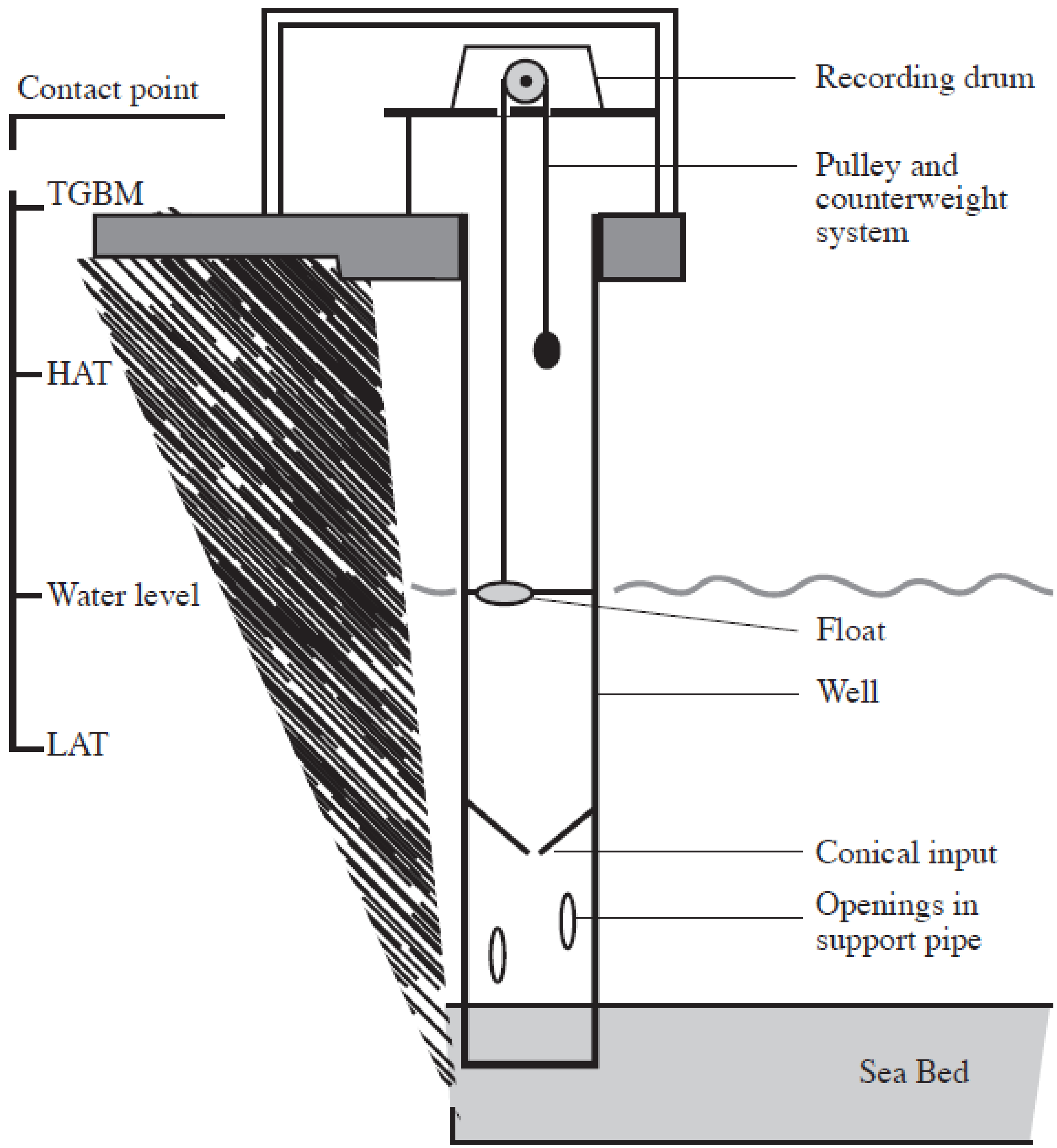


Figure 3.1

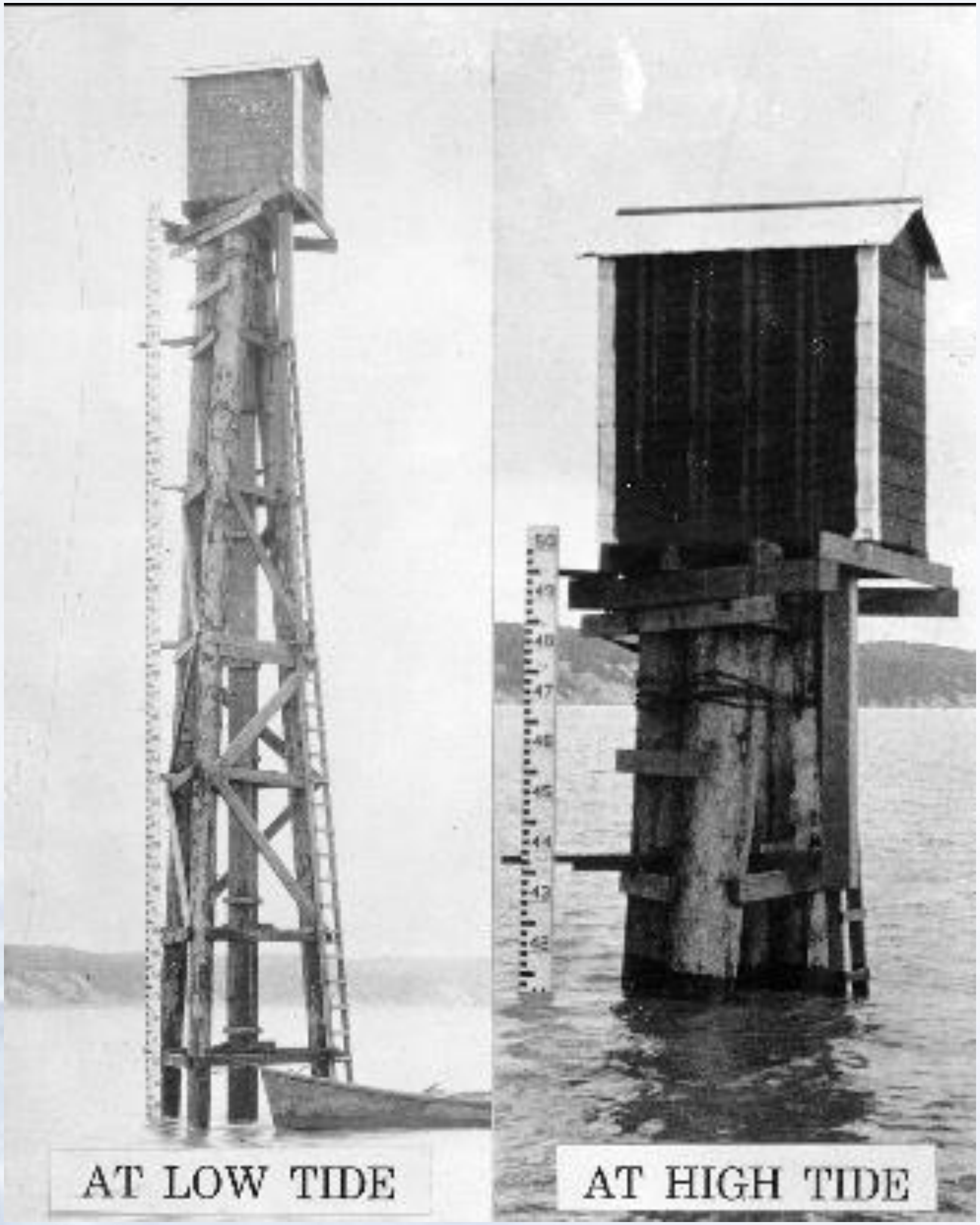

Contact point
TGBM
HAT
Water level
LAT
Recording drum
Pulley and counterweight system
Float
Well
Conical input
Openings in support pipe
Sea Bed

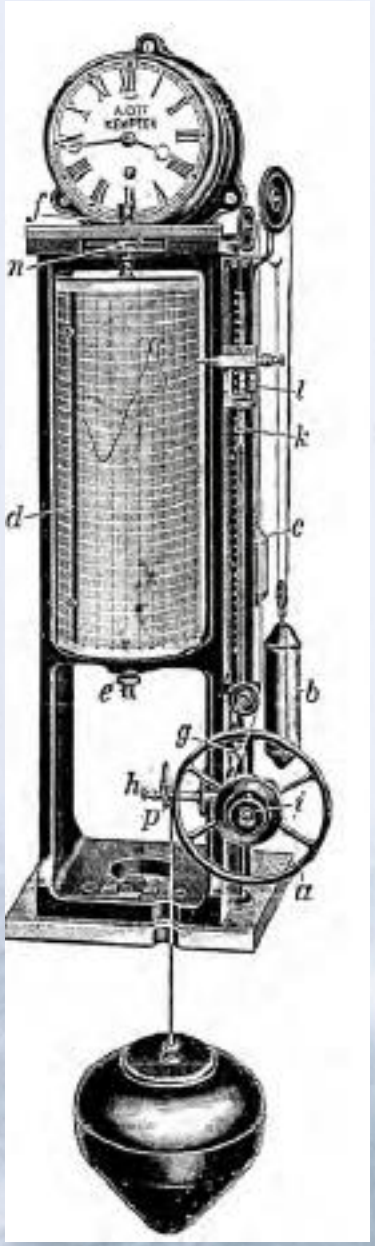
A simple dipper for testing for the level of water in a stilling well (or borehole).

When the tip of the probe hits the water it completes an electric circuit and a bell rings and light flashes.

Two Stilling Wells with Float Gauges at Holyhead, UK

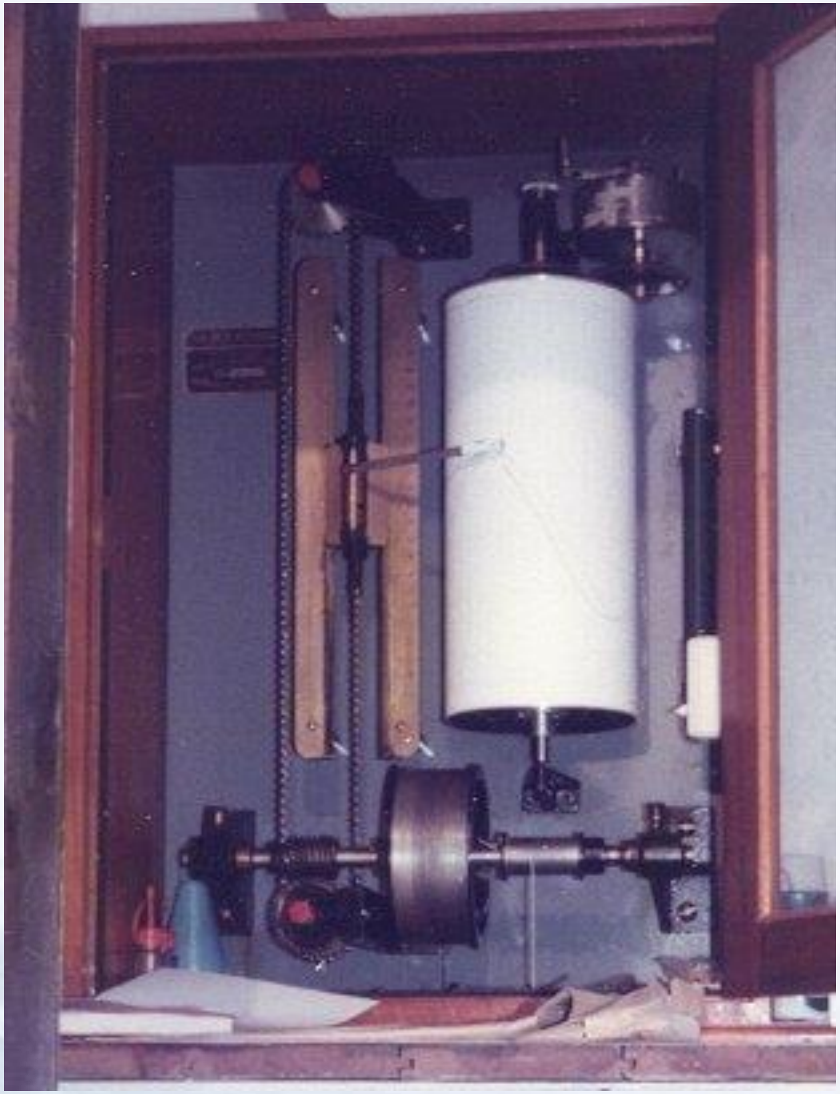
Classical stilling well float gauge from a station with large tidal range in the USA





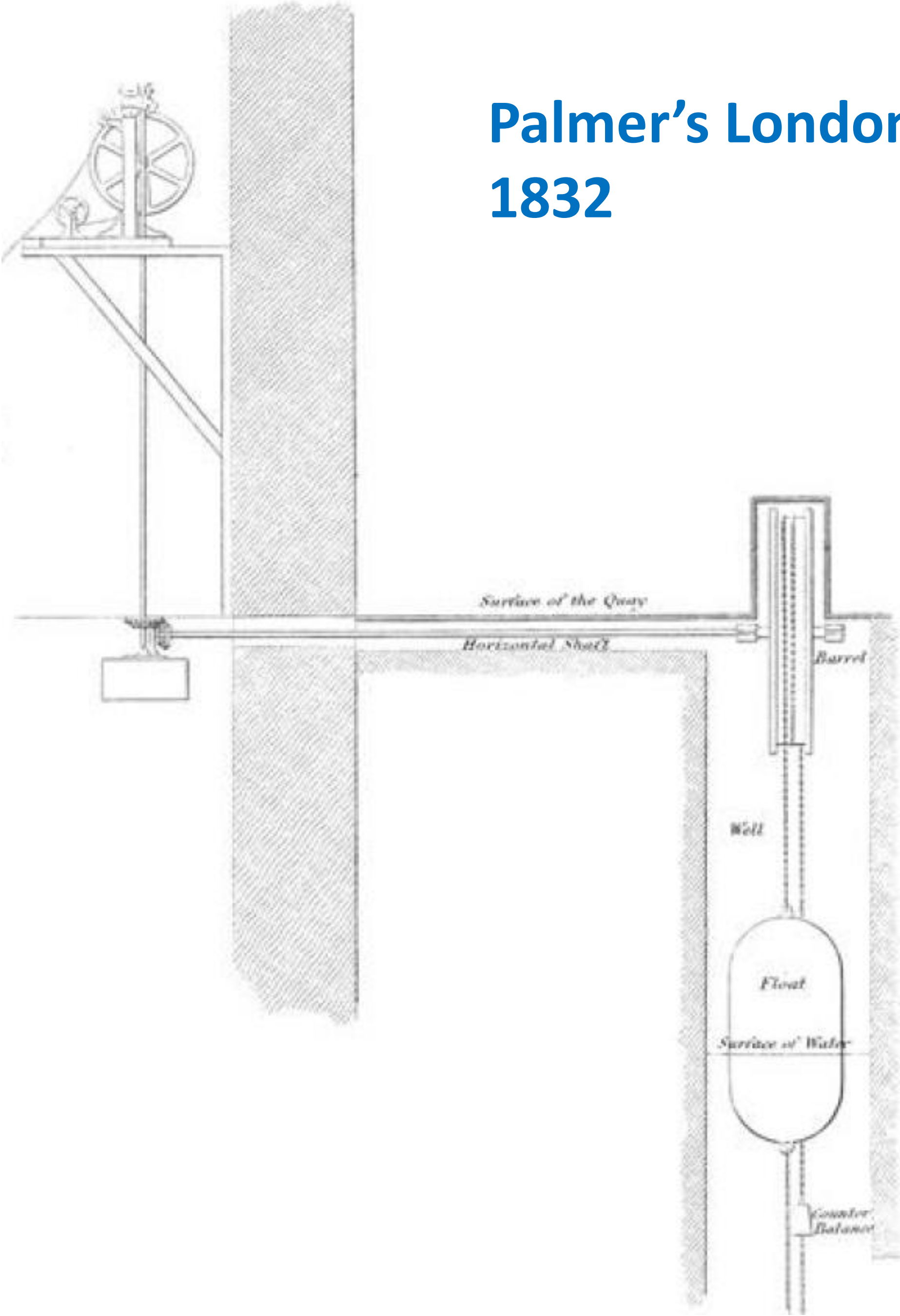
One of the first commercial float gauges by A. Ott (Kempten, Germany) 1885.

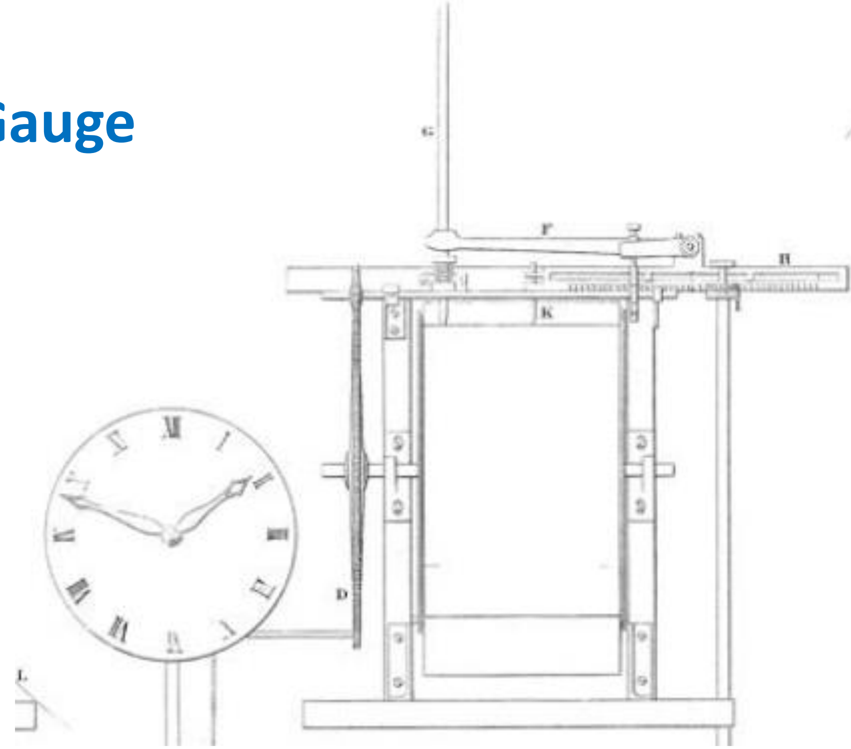
(Others at this time by Lord Kelvin etc.)

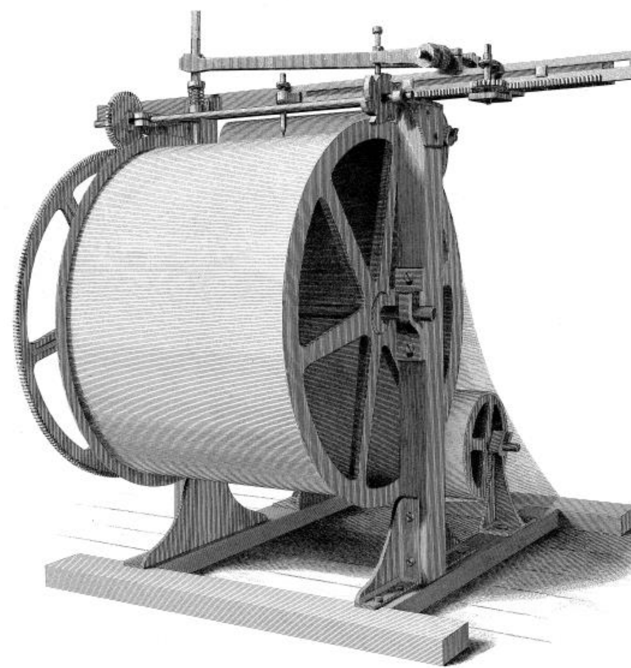


Lea chart recorder for a float gauge (photo taken in 1983)

Palmer’s London Gauge 1832







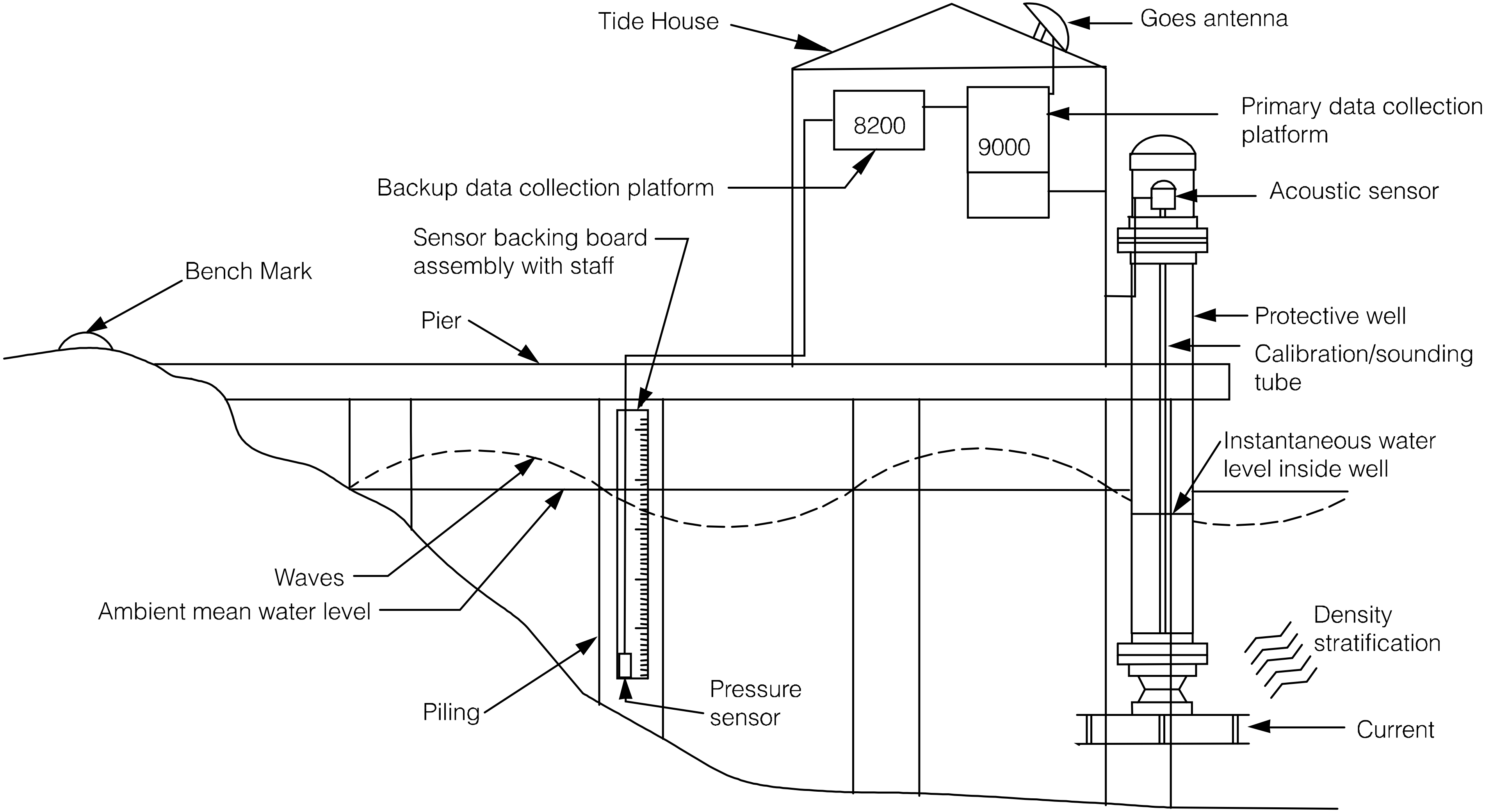
Importance of Float Gauges

- They still form a large part of the global network
- No need for paper charts now. They can be made digital with the use of shaft encoders
- Even if they are now being replaced with acoustic, pressure and radar systems, they were the source of most of the historical record

Acoustic Gauges

Acoustic gauges

- Acoustic systems in tube with Aquatrak transducer (NGWLMS or SEAFRAME) with various data loggers. They became something of a GLOSS standard in many areas
- Acoustic systems in open air or inside the stilling wells of float gauges. Cheap but several groups have not been successful in operating them to good standards

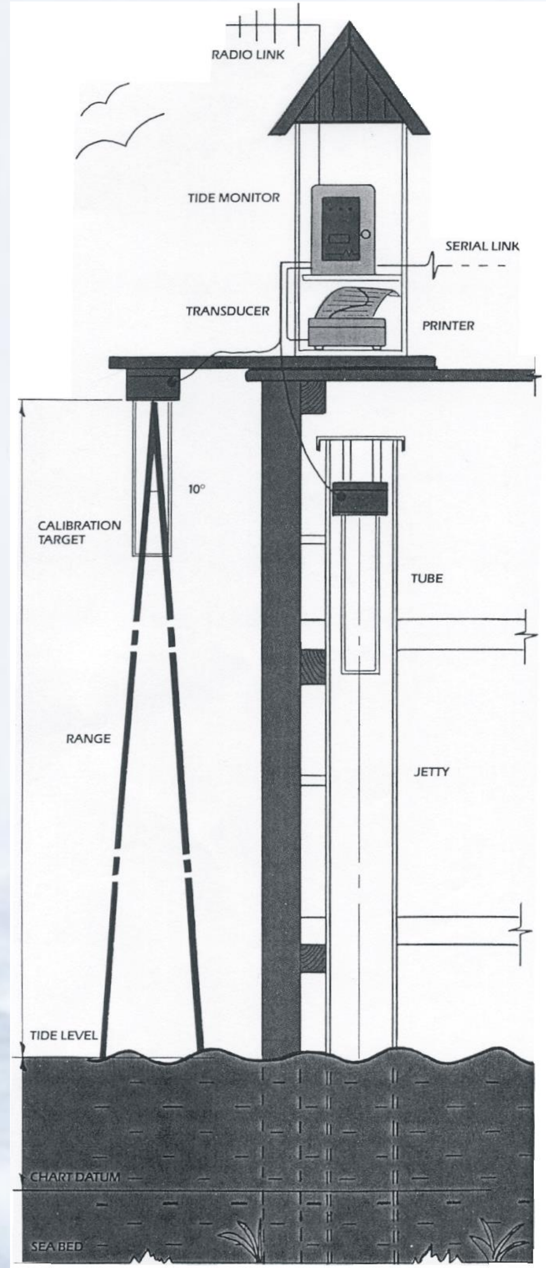


Schematic of the NGWLMS/SEAFRAME system

Acoustic SEAFRAME Gauge at Hillarys, West Australia

Acoustic tide monitor in a well or in open air – Spain and South Africa have used these not very successfully and have since replace them with radar gauges.

Similar systems are manufactured by other companies e.g. MORS



SRD TIDE MONITOR

The SRD Tide Monitor has been developed with the active assistance and advice from port authorities and survey companies to meet the requirements for a lightweight, robust, highly accurate and versatile system to replace the float, pressure and bubbler systems now in use. It has been extensively tested and copies of the test results are available from the company on request.

The system is quick and easy to install and no maintenance other than chart checking is required. The reference datum gives the unit excellent accuracy with no recalibration requirements. The telemetry output allows the chart to be printed any distance from the tide gauge using an SRD Tide Monitor Receiver, or for the connection of the tide monitor to a central Tide Data Control.

The use of low cost dot matrix printers with the self printing graph record removes the requirement for pre-printed charts and ensures accurate time and height records.

For permanent installations or where the line of sight of the transducer is likely to be interrupted, it is strongly recommended that the system operate down a plastic tube. The tubes can be supplied to suit the particular application. No additional maintenance is required for the tube, and no flow filter is required as with float systems. The transducer is mounted inside the tube forming a completely protected system.

Operation

The SRD Tide Monitor obtains the distance from the transducer to the sea surface by measuring the time elapsed between transmission and reception of an acoustic pulse. This time is converted to distance using a calibration velocity obtained from the fixed range target measurement. This distance is subtracted from the set datum to give the TIDE LEVEL which is then averaged over the selected period, displayed on the four digit display, printed on the graph and transmitted by whatever telemetry method is selected.

Installation

The fully waterproof transducer is installed at a convenient site, at a minimum height of 2M above the maximum tide height. The transducer has to be mounted within 2 degrees of horizontal to achieve optimum results. The view of the transducer should be unobstructed within a 10 degree conical angle to avoid interfering targets. The required datum, averaging interval, printing options, time and date are selected by a series of rotary switches.

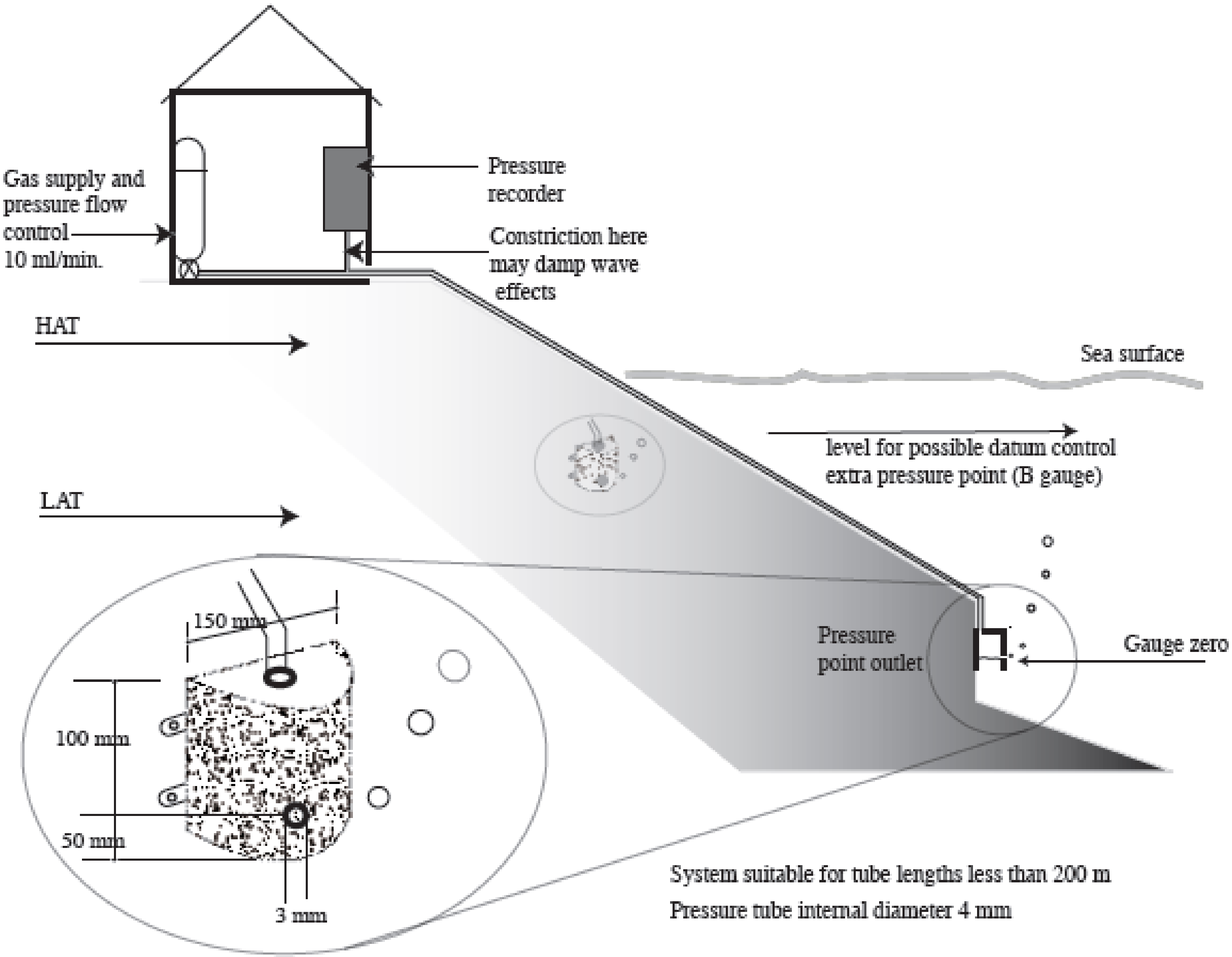
Reference Target

The speed of sound in air is significantly temperature dependent. A temperature sensor in the transducer can go some way to compensate for temperature variations, but the most effective compensation is to use a fixed range target to measure the actual speed of sound. The target provided is fixed 75cm from the transducer and will correct the distances measured to within 0.05%. The correct operation of the reference target compensation is indicated on the tide graph by a target at a fixed range of 1.0M. This information can also be transmitted.

Pressure Gauges

Pressure gauges

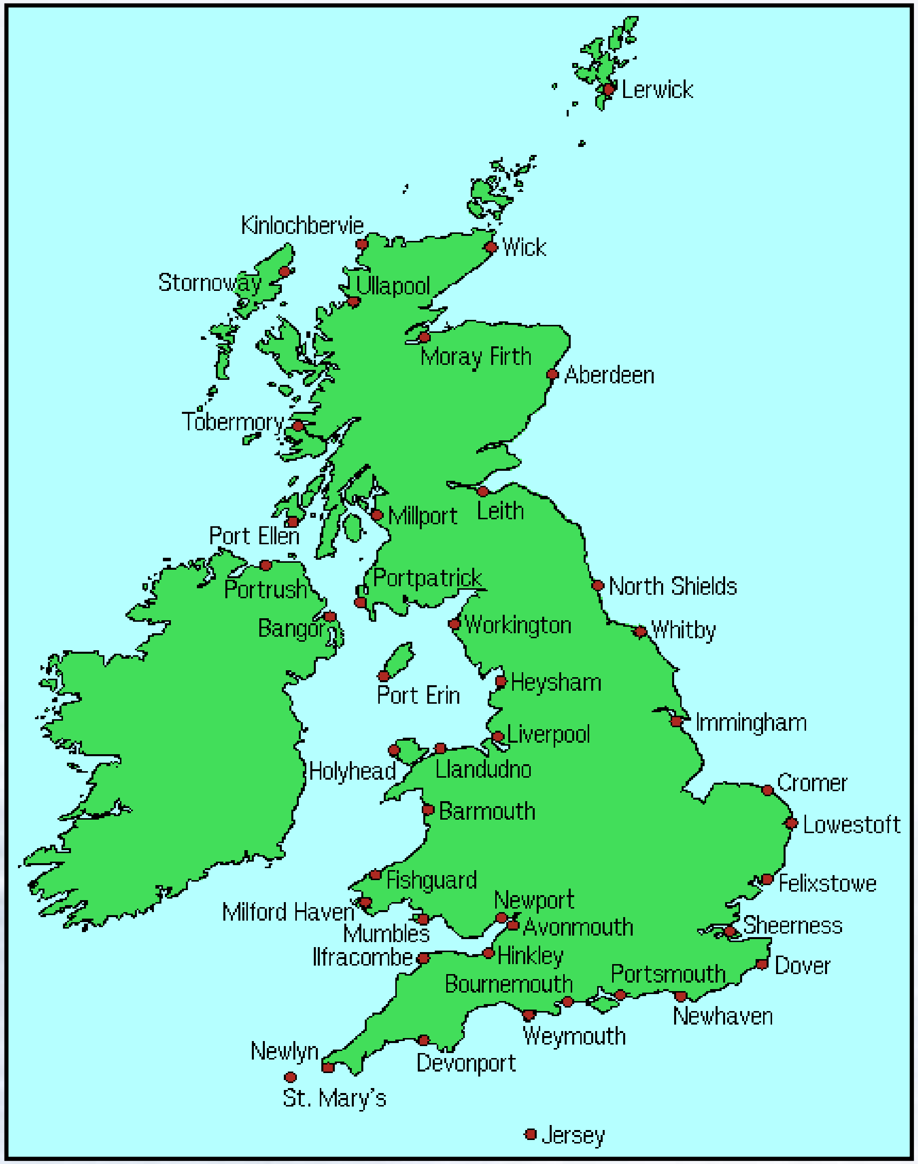
- Bubbler gauges
- Transducer in the sea gauges
- ‘B’ (or ‘triple’) pressure systems

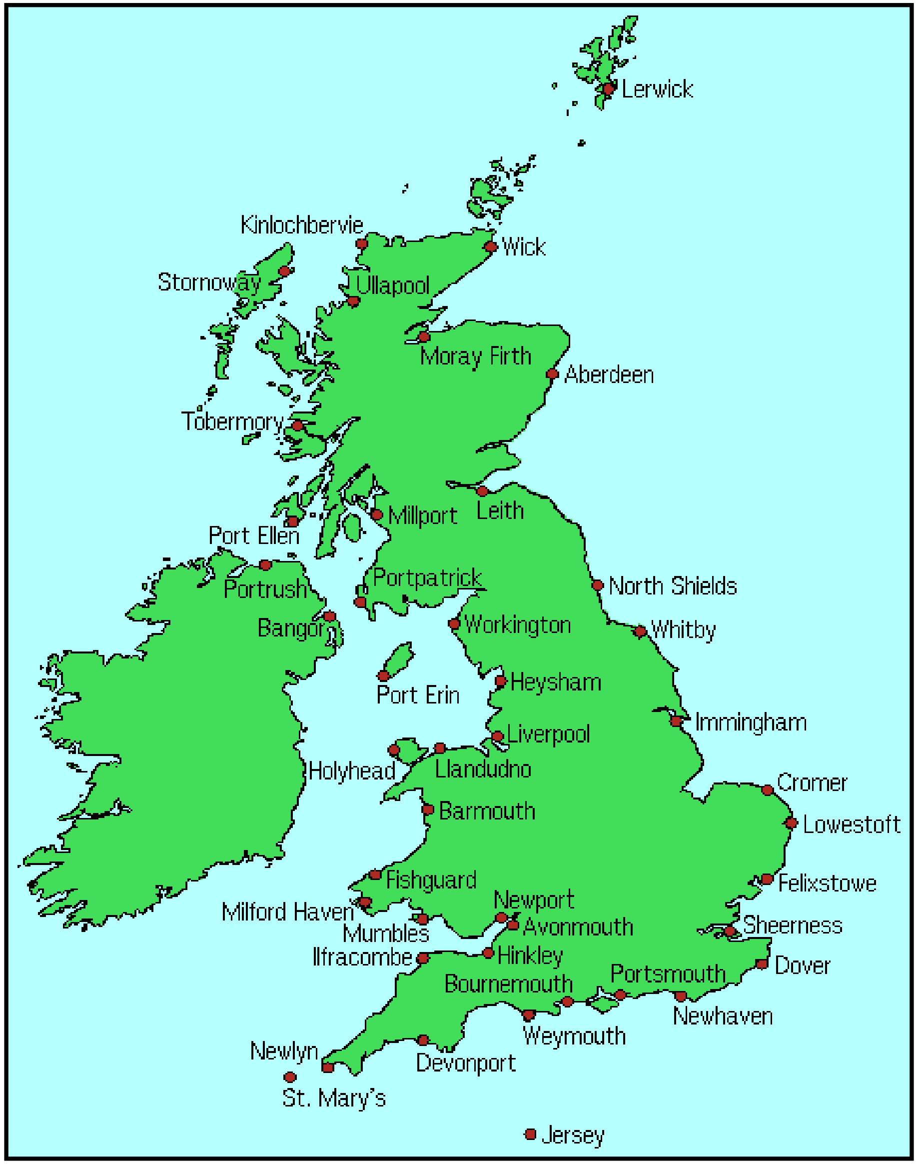


Schematic of a bubbler tide gauge

The UK National Tide Gauge Network

- 45 stations.
- Real-time data used for flood warning.
- Delayed-mode data quality controlled for scientific research.

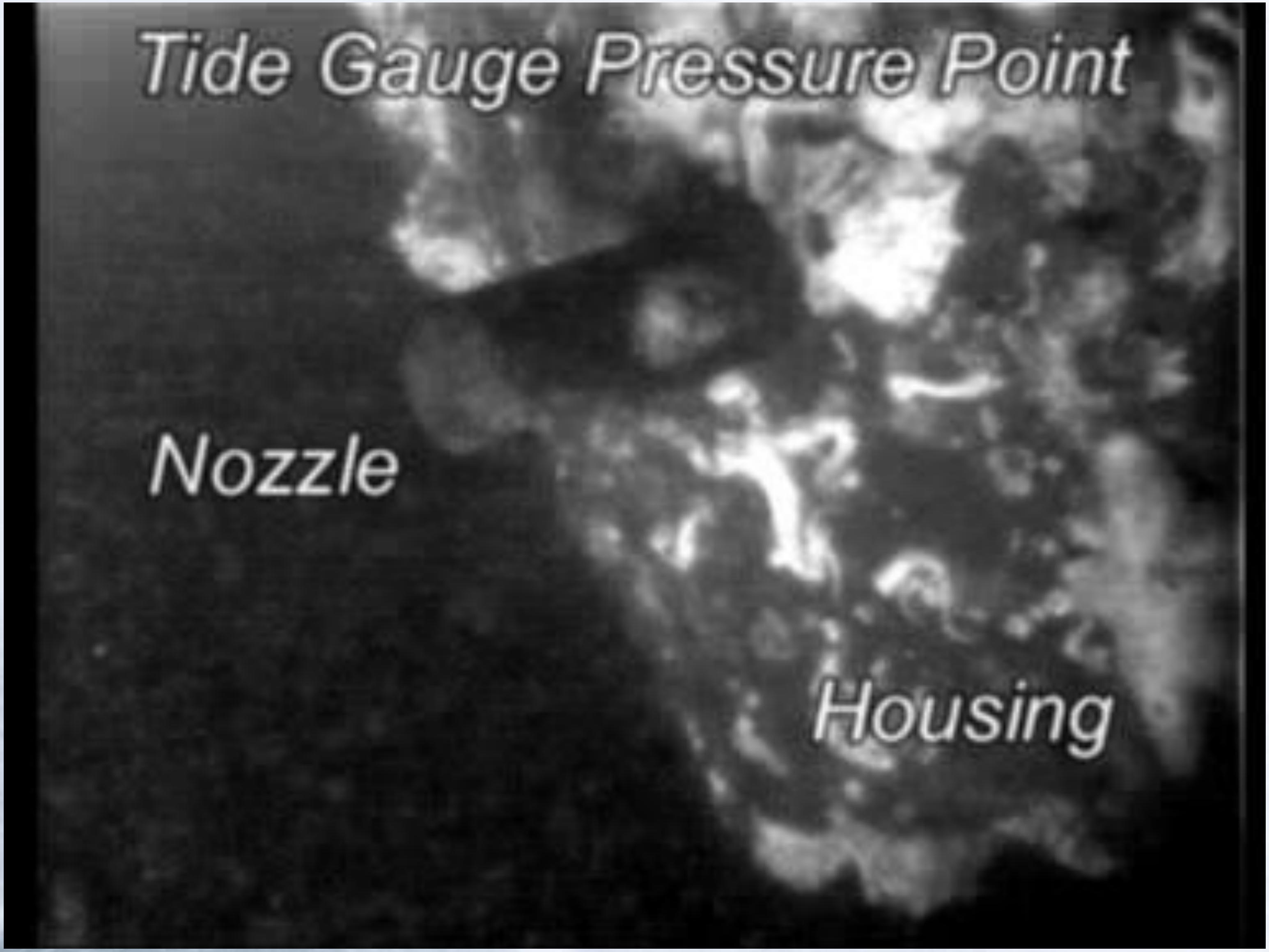


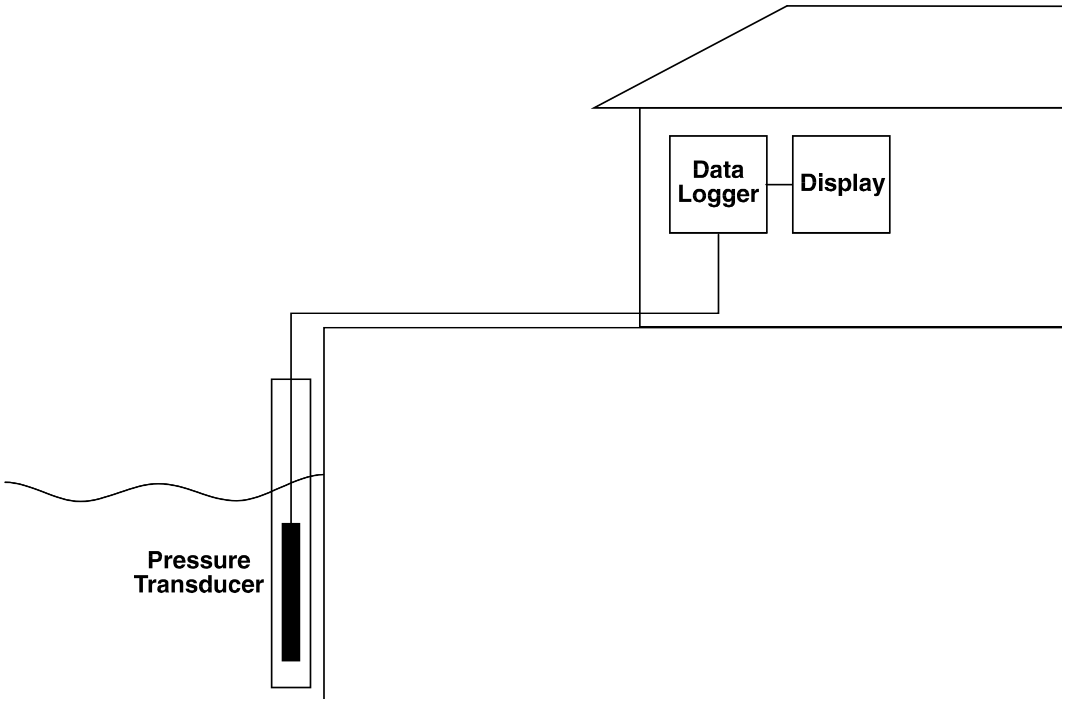


UK National Network

Newlyn

Float gauge 1915-1981 when replaced by Aanderaa presssure gauge then in September 1983 by an 'A Class' bubbler gauge.

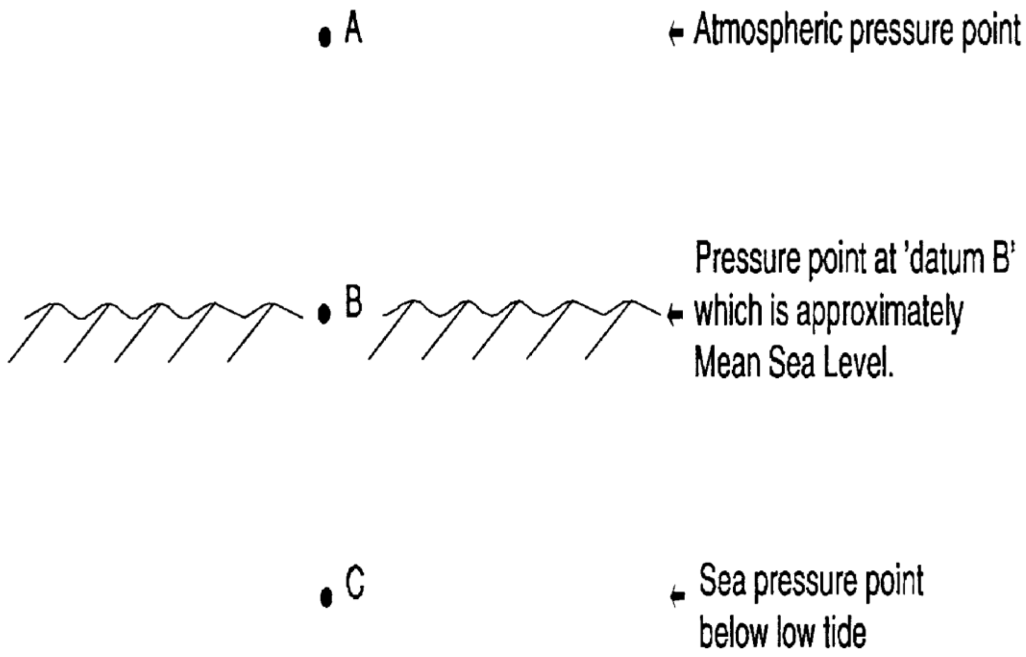

Tide Gauge Pressure Point
Nozzle
Housing

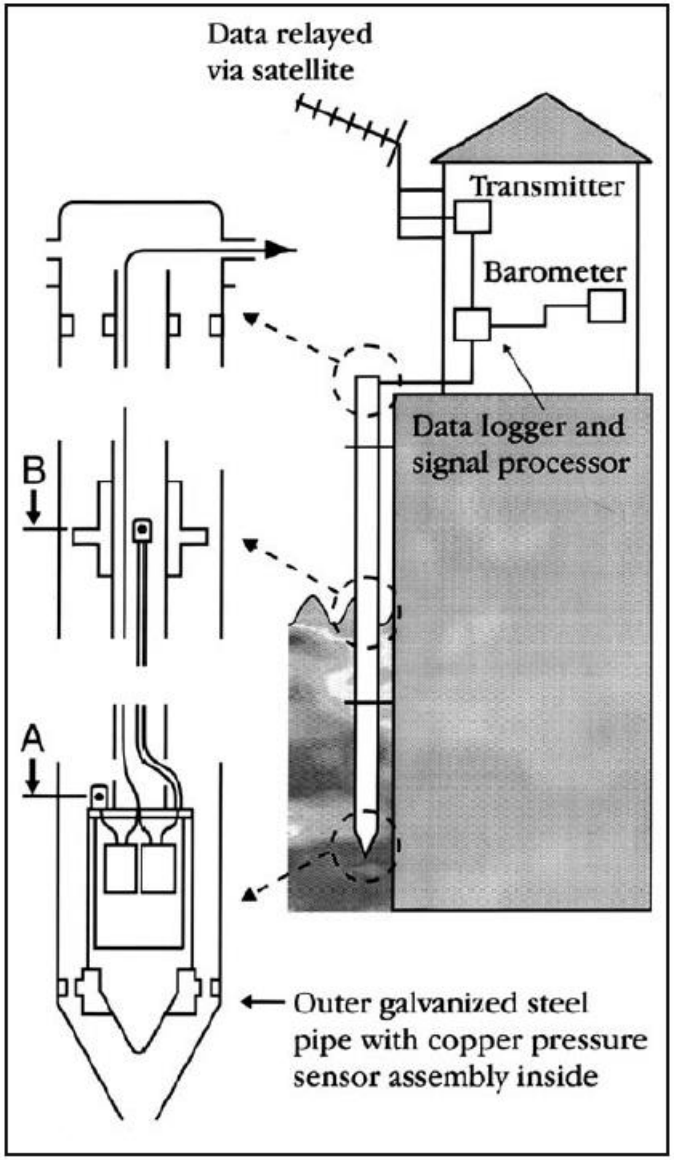


Port Stanley, Falkland Is.

Transducer in the sea pressure system

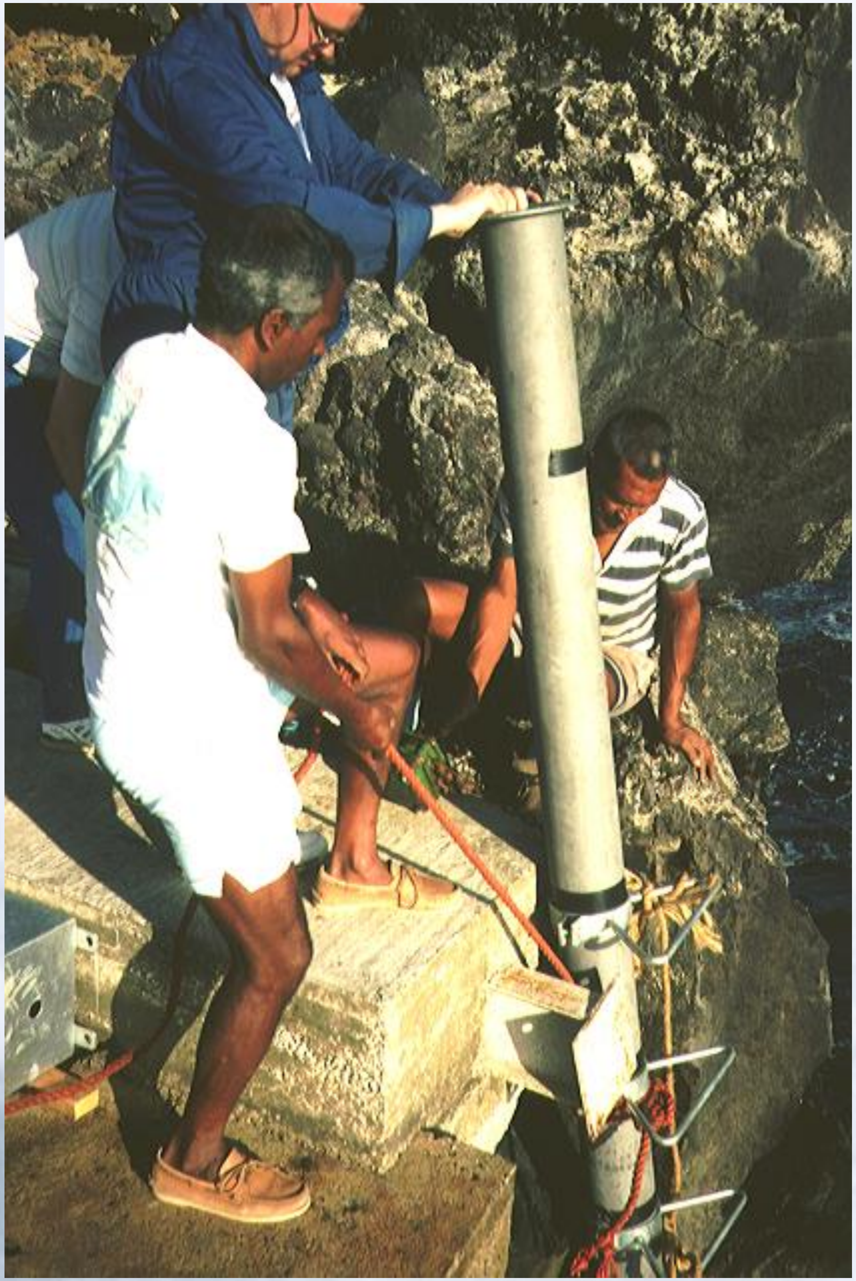
Appropriate also for tsunami monitoring





A Triple (or ‘B’) pressure gauge setup with 3 pressure transducers, can provide ongoing datum control to the ‘C’ data

Installation of a ‘B gauge’ at Ascension Island, central Atlantic



Radar Gauges

Radar Gauges – Different Types

- Open-air pulsed radars – measures the time of flight of many radar pulses
- Open-air FMCW (frequency modulated continuous wave)– uses continuous frequency and measures the phase shift between the transmitted and received waves
- Radar in a sounding tube
- Guided Wave Radar (down a wire)

Merits of Radar Gauges

- Relatively cheap
- Easily installed (no need for divers or stilling wells etc.)
- Digital so can be ‘real time’
- New technology, but experience so far generally favourable
- Several manufacturers
- But that means not all can be rigorously tested

Open Air Pulsed or FMCW Radar Gauges

- Relatively cheap and easy to install (*)
- Used by many groups around the world
- Preferences between Pulse and FMCW?
- Some examples below

(*) There are some gauges (e.g. MIROS) that are very expensive but can also measure waves reliably.


measured value
0.511
-
+
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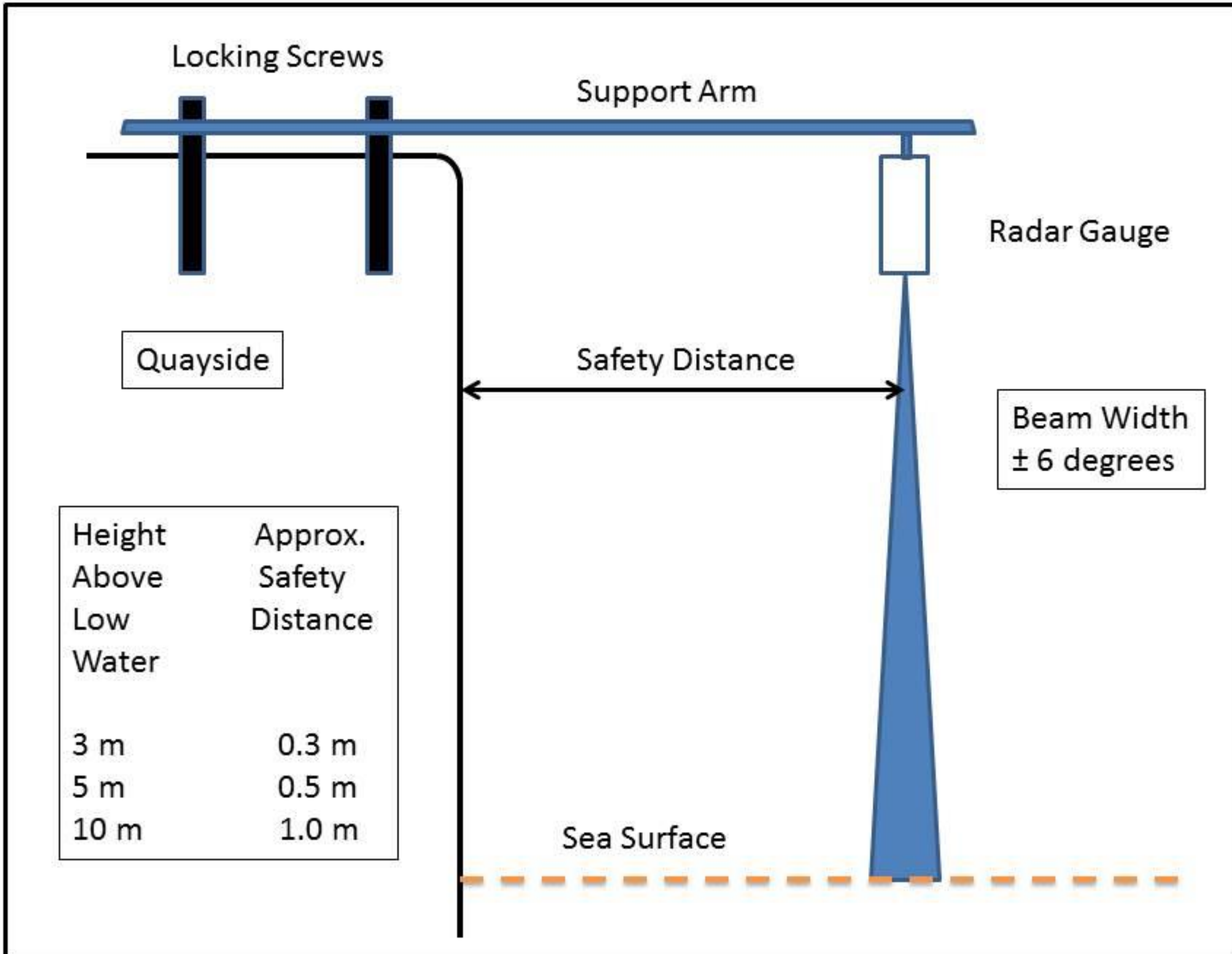
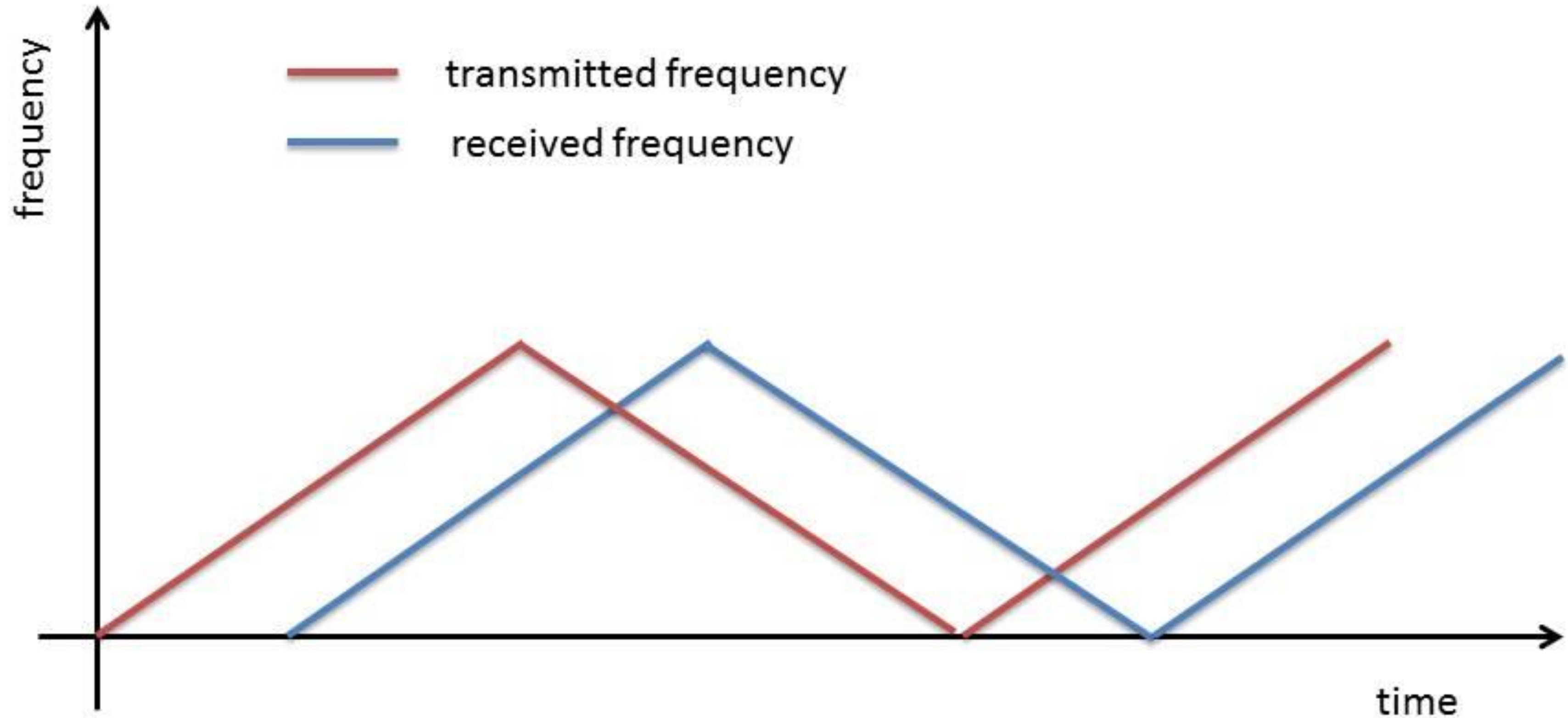

Locking Screws
Support Arm
Radar Gauge
Quayside
Safety Distance
Beam Width
± 6 degrees
Height Above Low Water
Approx. Safety Distance
3 m 0.3 m
5 m 0.5 m
10 m 1.0 m
Sea Surface



Principle of FMCW Radar

Table 2.1

Pros and Cons of Pulse and FMCW Systems

Pulse Systems

Pros

- Pulse systems are a proven technology with long history.
- Long range measurements are possible with high power devices.
- They can be set up to deal with unwanted nearby reflectors easily.
- They have high power requirements during the pulse itself but, due to transmissions occurring over a small percentage of the time, they have lower overall power requirements than FMCW devices.

Cons

- There can be difficulties at short ranges due to short signal travel time.

FMCW Systems

Pros

- Because FMCW devices transmit continuously (typically in practice approximately 50% of the time compared to 1% for pulse systems), there is little delay in updating measurements.
- Their greater bandwidth makes them potentially more accurate than pulse radars and more suitable as wave recorders (although there is no reason in principle why pulse radars should not also be able to sample fast enough for waves)
- Peak emitted radiation is lower than for pulse systems (with safety implications).
- Lower peak power requirements also imply lower peak power consumption in the supporting electronics.

Cons

- On the other hand, FMCW systems need high-quality FFT processing to achieve high accuracy, which implies more complex hardware and software and higher overall power requirements.
- The higher overall power requirements for FMCW devices than pulse systems means that they may be less suitable for operations at remote sites.
- Due to their generally lower peak power output, they can have reduced range compared to pulse systems (although this is not likely to be a major factor for radar tide gauges).
- Because they transmit continuously across a frequency band, FMCW systems are more susceptible to interference (e.g. in busy harbours).
- They have approximately 30% more components than pulse systems, and economies of manufacturing scale are not as large for FMCW as for pulse systems, so they tend to be more expensive.

Many examples of open-air pulse and FMCW radars

Liverpool - UK

Radar gauge at Alexandria, Egypt installed with assistance from NOC, UK and IOC

South Africa – installation of an OTT Kalesto radar gauge

OTT Kalesto at Kirinda – Sri Lanka

St. Helena – OTT RLS (replacement for Kalesto)

Radar Gauges in the Caribbean

Christa G. von Hillebrandt-Andrade[1], Rolf Vieten[2], Carolina Hincapié-Cárdenas[1] and Sebastien Deroussi[3]

[1] NOAA, National Weather Service Caribbean Tsunami Warning Program, Mayagüez, Puerto Rico, christa.vonh@noaa.gov

[2] Marine Science Department, University of Puerto Rico at Mayagüez, Puerto Rico, rolf-martin.vieten@upr.edu

[3] Institut de Physique du Globe de Paris Volcanological and Seismological Observatories of Guadeloupe, deroussi@ipgp.fr

To be published in the Supplement to IOC Manual-5.

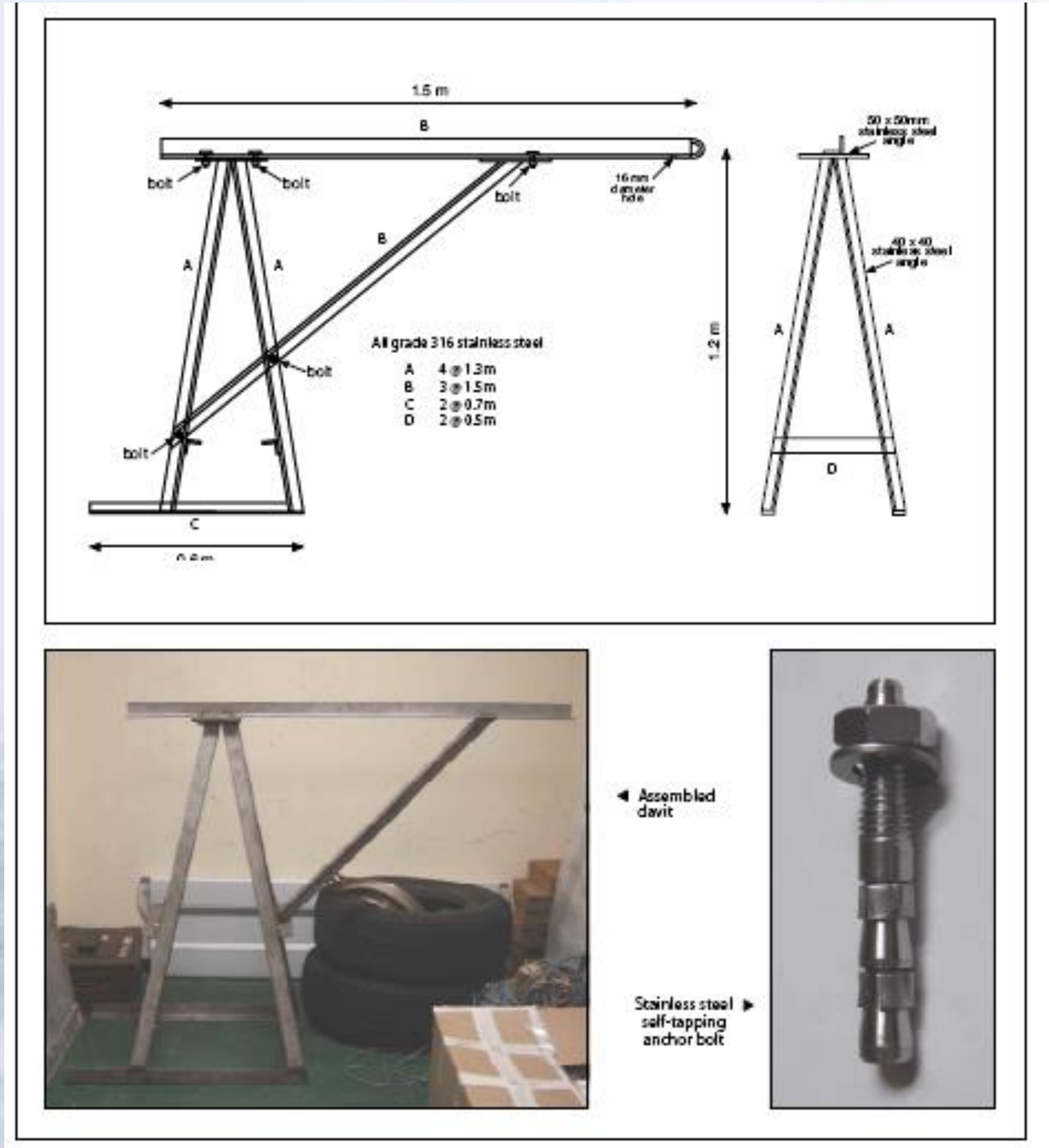
Yellow star = radar tide gauge contributing to CARIBE EWS

Single radar setup (Sutron radar?) at Punta Cana, one of 10 in the region installed in collaboration with UHSLC.

Two horn radar gauges (Waterlog H-3611) at Mayaguez, PR

Infrastructure needed for Open Air Radar

- An arm for the radar gauge
- Or a mounting collar arrangement (see examples in Manual 5)
- Also general factors as for all gauges (power, security etc.)



As used at Pemba

Radar Gauges – Different Types

- Open-air pulsed radars – measures the time of flight of many radar pulses
- Open-air FMCW (frequency modulated continuous wave)– uses continuous frequency and measures the phase shift between the transmitted and received waves
- Radar in a sounding tube (in this case the tube acts as a waveguide)
- Guided Wave Radar


YUASA
YUASA

Radar Gauges – Different Types

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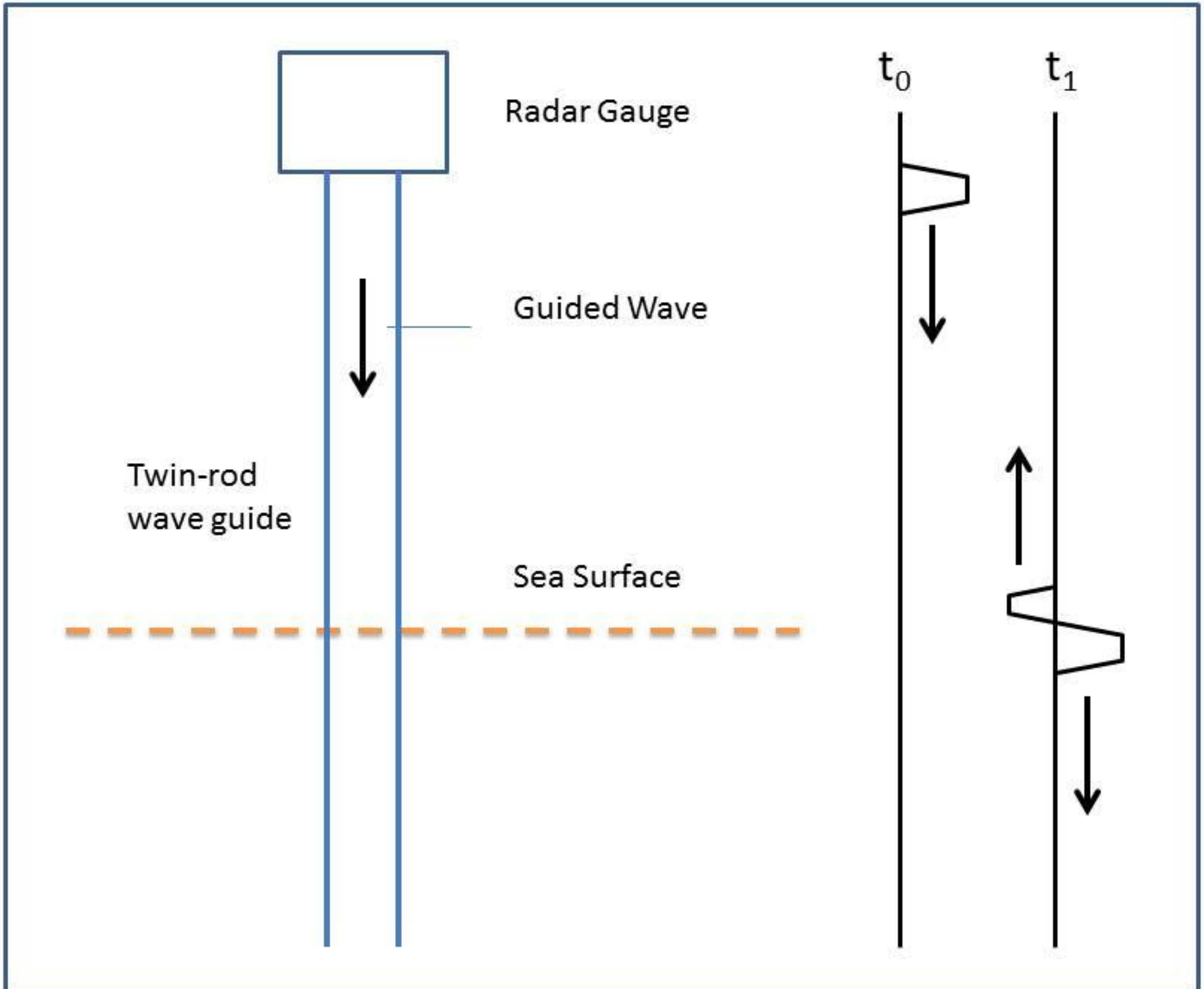
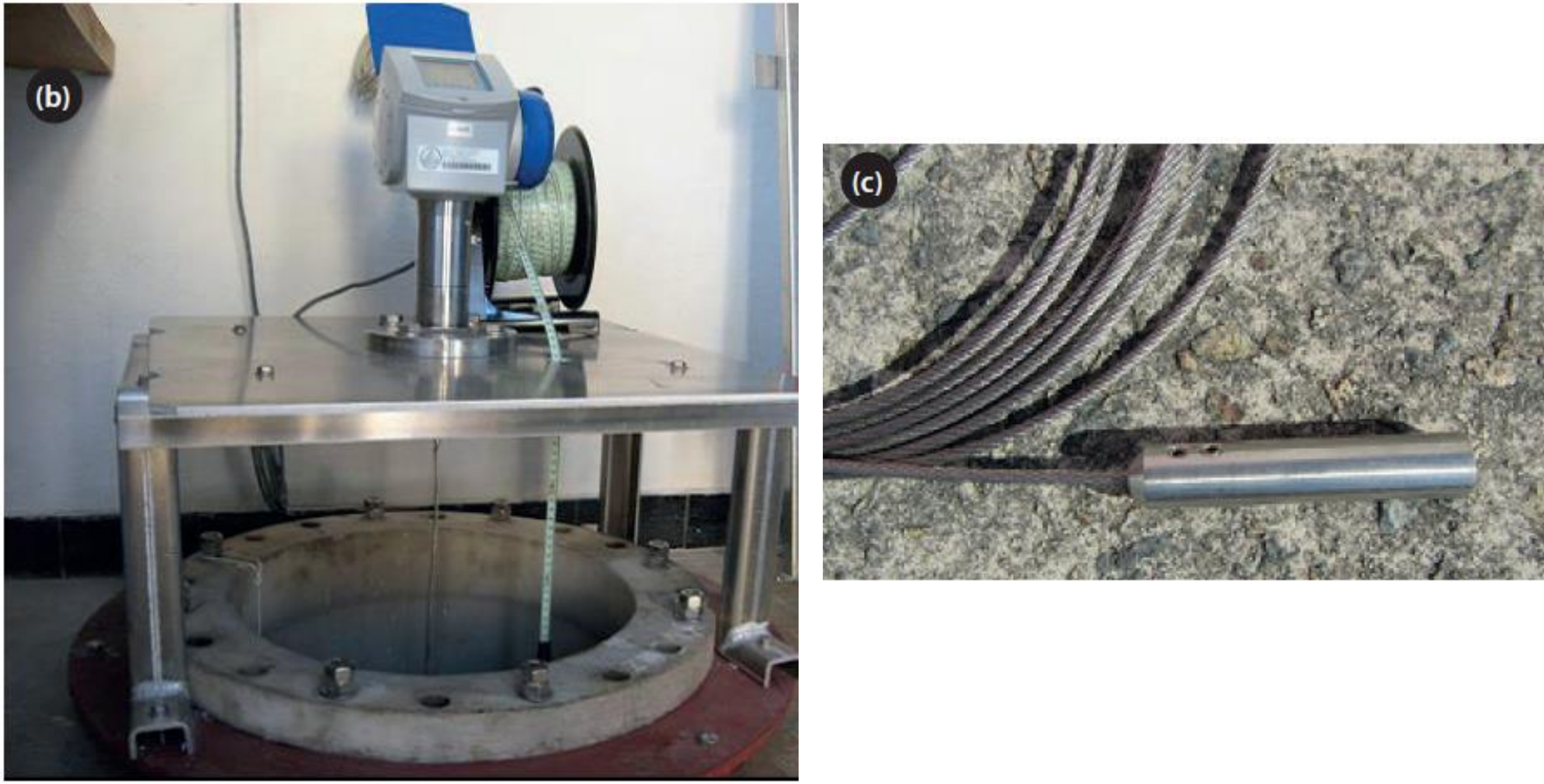

Radar Gauge
Guided Wave
Twin-rod
wave guide
Sea Surface
t0
t1

VEGAflex

Heated 'stilling well' tube


VEGA



Khrone Optiflex

Time domain reflectometry radar gauge at Deshaies, Guadaloupe
(stainless steel cable in a stilling well)

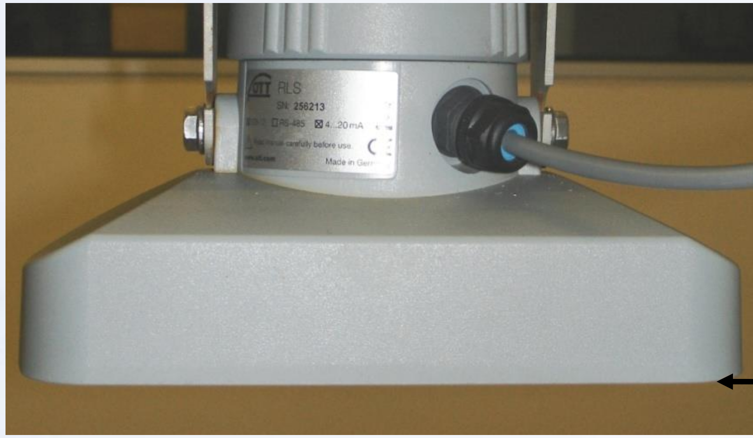
Calibration Needed for All Radar Gauges (and for all gauges in general)

- Calibration of the range measurement by the gauge
- You CANNOT trust that a sensor measures the recorded range from an assumed contact point
- You must find any offset
- (And in principle the offset could be wave dependent, for example, but let’s leave that aside for now)

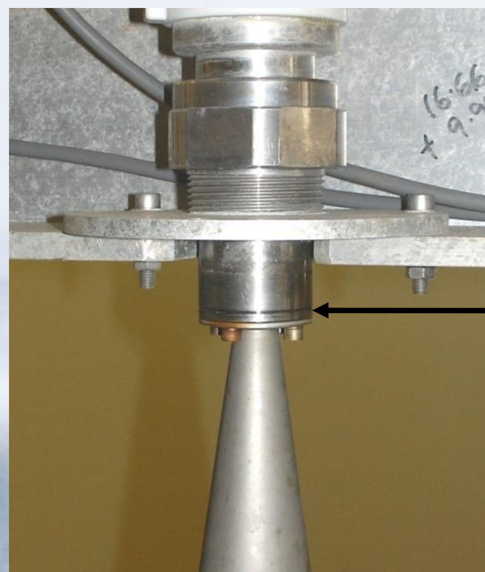
Contact Points and Range Calibration

- A first step is to find if the sensor has a stated reference level – if there isn’t one then make one!
- This reference level we call the Contact Point
- Second make some radar range measurements to a surface which is a known distance from the Contact Point.
- Some examples follow.

Radar Gauge Contact Points



Radar Contact Points



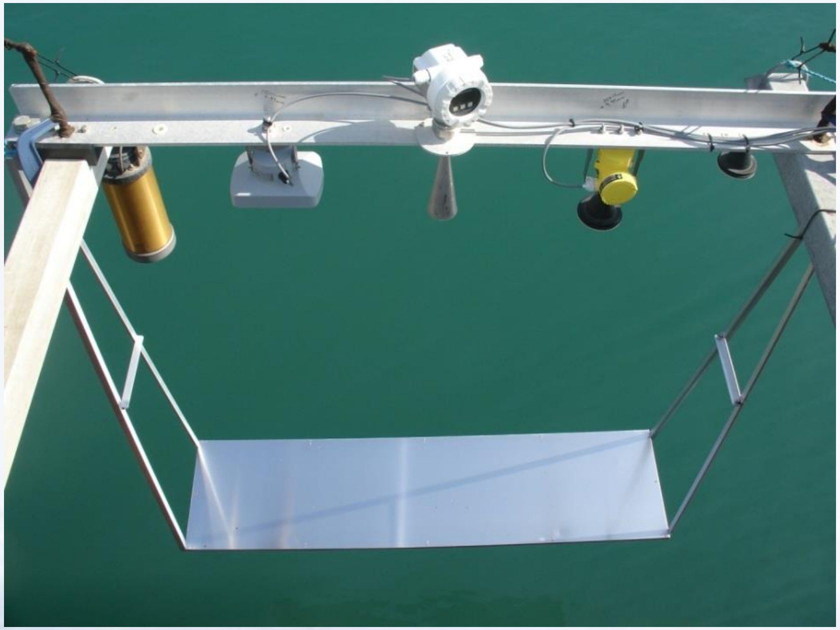
If there is no obvious contact point on the radar gauge – make one!

Laboratory Targets

Both the Water and Metal Plate Targets

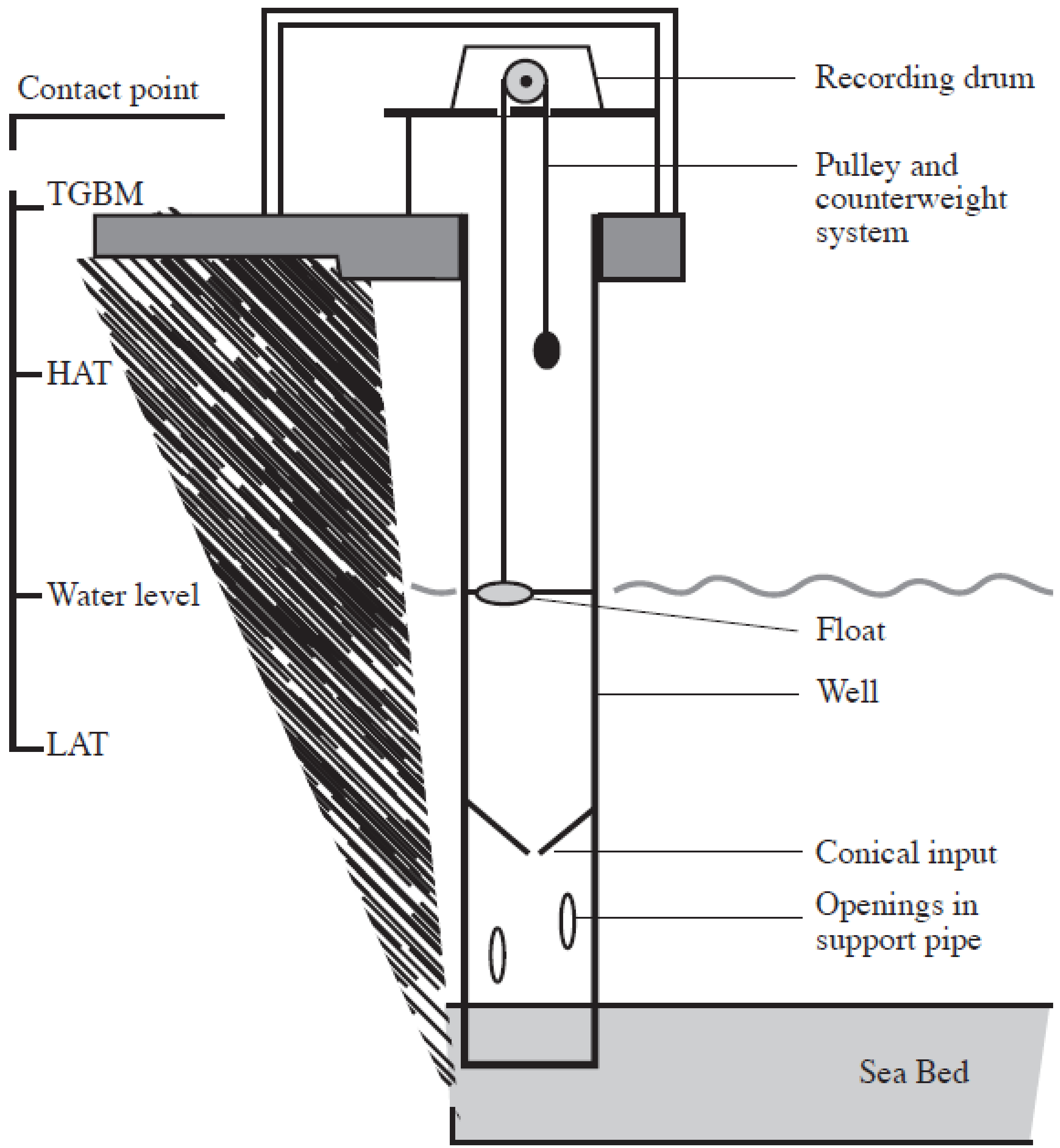
Holyhead Target Tests

Radar Target



Target in Situ

Figure 4.9 An example of a laboratory target used to determine a Sensor Offset (SO) using a range measurement of approximately one metre. The circular flange of the sensor is set flush against the outside surface of the mount, and the distance to the inside surface at the other end of the mount is measured accurately by tape. The distance recorded by the radar is then compared to the tape-measured value giving SO = Tape Range – Radar Range. (Photograph R. Heisenrether, NOAA).


Contact point
TGBM
HAT
Water level
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Recording drum
Pulley and counterweight system
Float
Well
Conical input
Openings in support pipe
Sea Bed

A simple dipper for testing for the level of water in a stilling well (or borehole).

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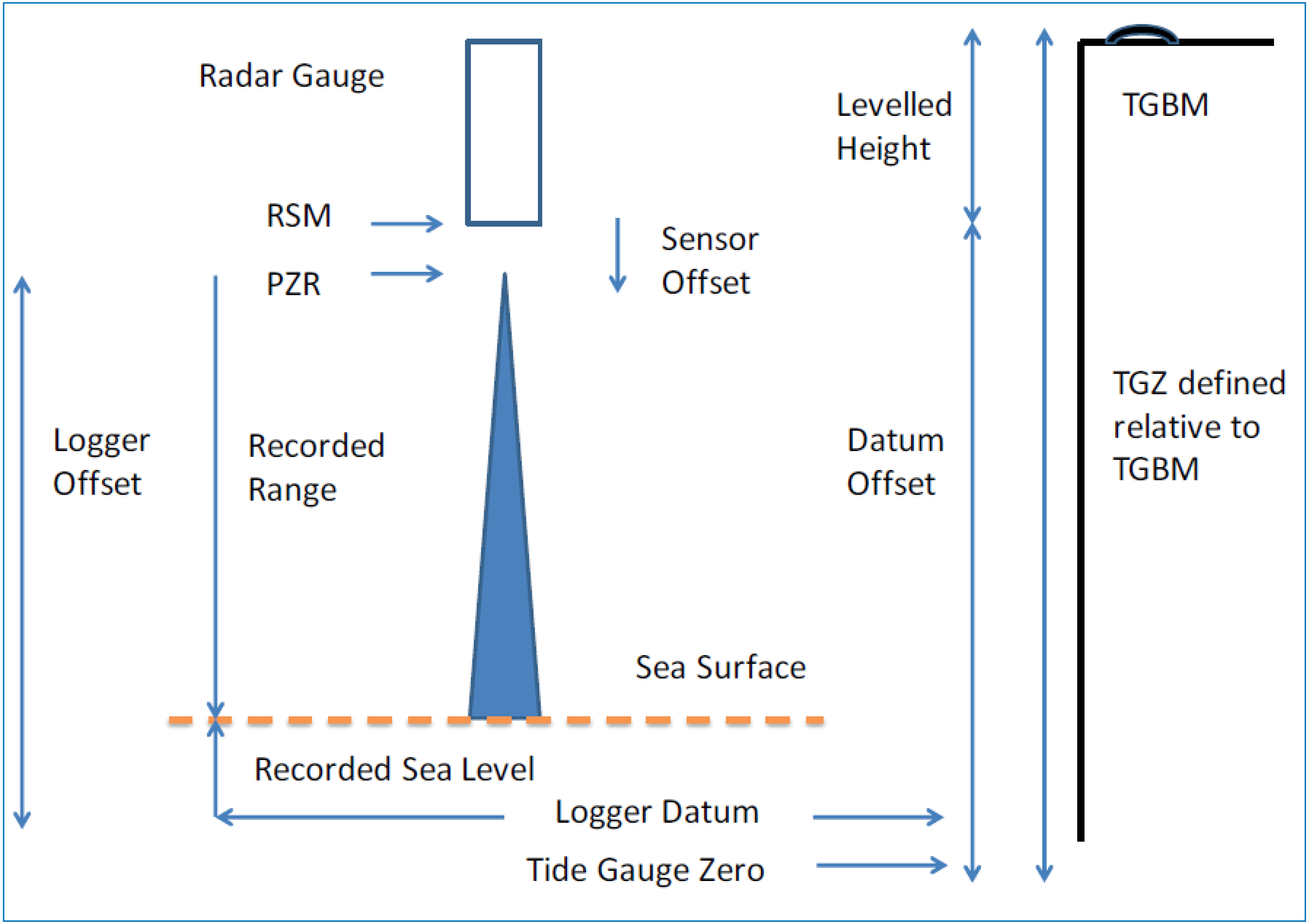


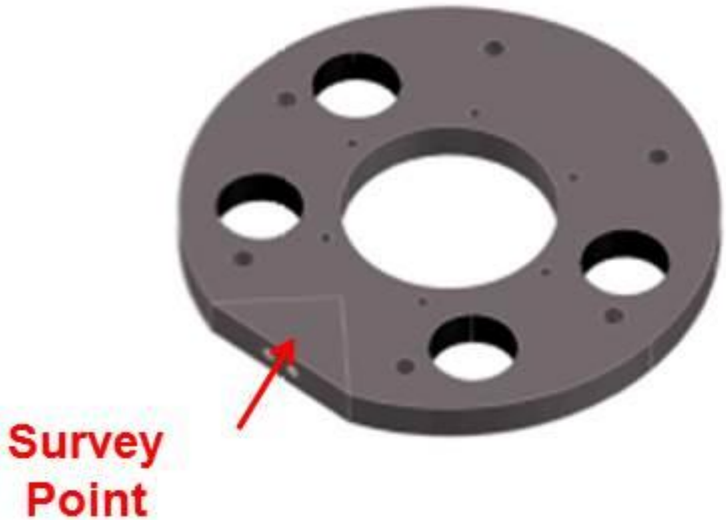
Figure 4.8 Schematic of a radar gauge, the Reference Survey Mark (RSM) on its casing, its Point of Zero Range (PZR), Logger Datum, Tide Gauge Zero (TGZ), and the Tide Gauge Benchmark (TGBM). All of these levels must be known relative to each other.

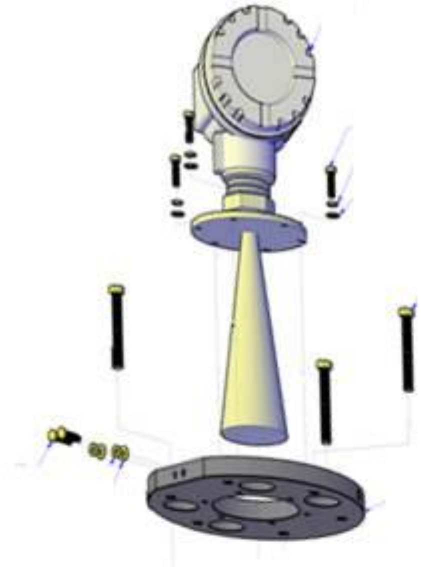
Benchmark

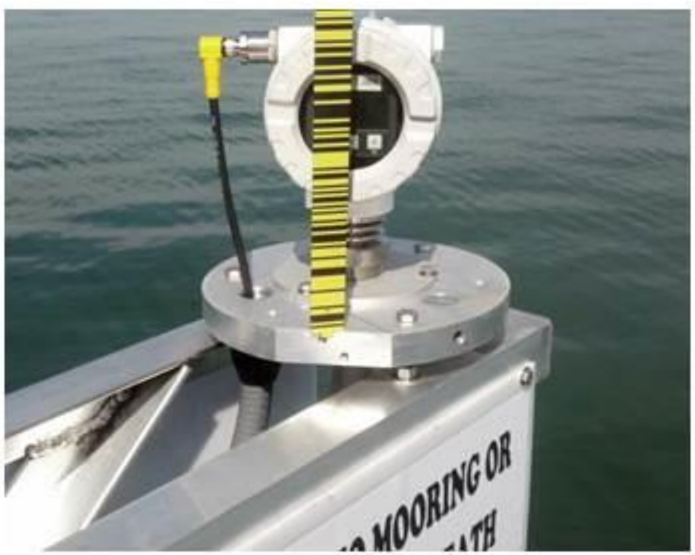
A benchmark (BM) is a fixed point of reference for the height of the tide gauge Contact Point.

Offset between CP and the TGBM

- After you have calibrated the sensor then you know any offset between the CP (or Reference Survey Mark) and the real zero range point of the sensor (Point of Zero Range)
- If the RSM and PZR turn out to be the same, then great! But that would be surprising.
- So you can take all your data, apply an offset and your data is then expressed as sea level with respect to the CP.
- Next step is to know the actual height difference between the CP and TGBM which is done by levelling.


Survey
Point




MOORING OR

Tide Pole and/or Dipping Measurements

- As a check that your calibrated system is measuring the sea level you think it is, also make some visual measurements using a tide pole, with the zero of the pole at a known distance below the TGBM.
- Or, if you have some kind of stilling well nearby, make dipping measurements (with the zero of the tape at a know distance below the TGBM).
- These two ways were how we calibrated a dozen radar gauges for the ODINAFRICA project.

- Document each step of your work: the range calibration, the levelling between CP and TGBM, and any tide pole or dipping measurements.
- This sort of information should be part of the metadata of the tide gauge data set that you will provide to data centres.

Tsunami Stations?

- We reject the idea that a tide gauge should function as only a ‘tsunami station’, given the expense that goes into its installation.
- There should be only ‘sea level stations’ that are capable of providing data for many areas of science (storm surges, long-term mean sea level change) and for that you need good calibration and datum control of CP to TGBM.
- Even if tsunamis are your main concern, there will always be interest in relating the height of the observed waves to heights of run-up on land so datum control is also important for “tsunami stations”.

Special aspects of tsunami gauges

- Manuals 4 and 5 call for a new tide gauge site to have a primary sensor (e.g. radar) providing 3 minute averages or shorter, plus a tsunami sensor (i.e. pressure gauge) with 1 minute values
- Near-real time duplicate data telemetry
- Duplicate power
- Site selection and security

Many Other Types of Tide Gauge

- There are many possible technologies that can be used as tide gauges (e.g. Step gauges in the Netherlands).
- However, we do not have much experience with them and they are not necessarily advised for a national network or an international network such as GLOSS.

Merits of each technology of gauge (see Manuals 4 and 5)

- Practicalities given the local environment e.g. float gauges less useful in ice areas
- Multiple users
- Whether ‘off the shelf’ or not
- Whether local engineering needed
- Calibration required
- Sampling frequency vs. main applications
- Accuracy (GLOSS requies < 1 cm in all conditions)
- Proven technology history
- Cost of the basic equipment

- See Table 3.1 of the Manual 4

Choice of tide gauge site (Manuals 4 and 5)

- Environmentally safe area (e.g. no ice)
- Stable ground
- Not in river estuary or near outfalls or passing shipping
- Water depth
- Local benchmark network
- Mains power
- Access and security
- And several other factors

Datum Control of the Tide Gauge

- I have mentioned the need to know the height-difference between the Contact Point and the TGBM.
- But there is more to datum control than that, involving monitoring the stability of the TGBM, see a further lecture.

Telemetry

- Telemetry – all data has to be transmitted to a centre as fast as possible for two main reasons:

(1) 'Real-time' data can be used for flood warning or other operational purposes. A different community to 'science'. More users tends to mean funding and permanency.

(2) Faults can be identified and fixed fast, leading to better science data sets in the long term.

Table 7.1

Satellite data transmission systems mentioned in Section 7.3.1. For information on systems used for other marine data (e.g. Inmarsat C and D+, Globalstar etc.) see Meldrum (2013). Systems are listed in approximate order of increasing bandwidth. Latency means the likely delay in data reaching a data centre. 1-Way indicates that data flows from the tide gauge to the data centre only, with no possibility of interaction with the tide gauge by the user. 2-Way indicates that a user can also communicate with the tide gauge data logger. Costs are given as an approximate guide only and are shown in US dollars. Endpoint indicates the mechanism by which the data are made available to the user. GPRS is listed at the end of the table for comparison to the satellite systems.

System	Basic application	Orbit type	Bandwidth	Latency	1 or 2-Way	Equipment Costs	Recurrent Data Costs	Endpoint
ARGOS	Messaging	LEO	< 5 kbyte/day	Several hours	1	1500 for beacon	200 per year subscription + 1000 per year transmission cost	ARGOS server accessed by the user.
GOES, METEOSAT, MTSAT	Messaging	GEO	< 5 kbyte/day	Several minutes	1	3700 for DCP, antenna, mountings etc.	Free for WMO programmes	GTS
ORBCOMM	Messaging	LEO	< 50 kbyte/day	Several hours	2	200-300 for modem terminals	60 per month	Email server
IRIDIUM	Voice, but data modems only are adequate to access sea level data	Big LEO[13]	1 Mbyte/hr	Near Zero	2	2000 for modem and antenna	22 per month + 1.2 per minute for data only mode	User modem
INMARSAT BGAN	Broadband	GEO	492 kbits/s	Near Zero	2	1000 for antenna	Depends on contract.	Internet
VSAT	Broadband	GEO	4 kbits/s to 16 Mbits/s	Near Zero	2	3000 for router, antenna and cables	Variable rates depending on data volumes.	Internet
INMARSAT Global Xpress	Broadband	GEO	50 Mbits/s download and 5 Mbits/s upload	Near Zero	2	To be announced	To be announced	Internet
GPRS	Messaging	-	56-114 kbits/s	Seconds	2	350 for handset and modem	Comparable to mobile rates in each country	Internet

13 LEO systems can be divided into Little and Big LEO. Little LEO systems make use of small satellites providing mobile data and messaging services. They are used for data gathering, electronic facsimile, two-way paging and electronic mail. Big LEO systems make use of larger satellites which provide some or all of these services in addition to real-time voice.

Telemetry

- Telemetry – later lectures this week

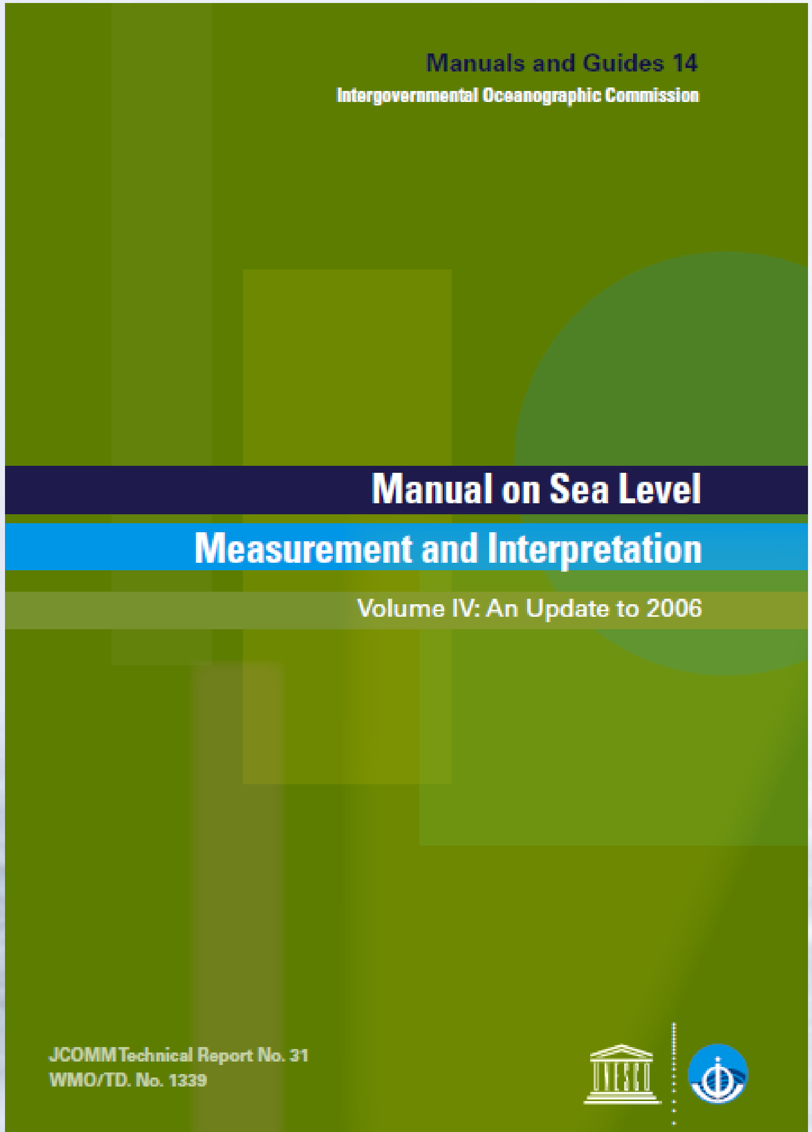
We have shown: There are many ways to measure sea level, none are perfect, and all require care in installation and maintenance and continuous inspection of the data.

With a good installation data are useful for:

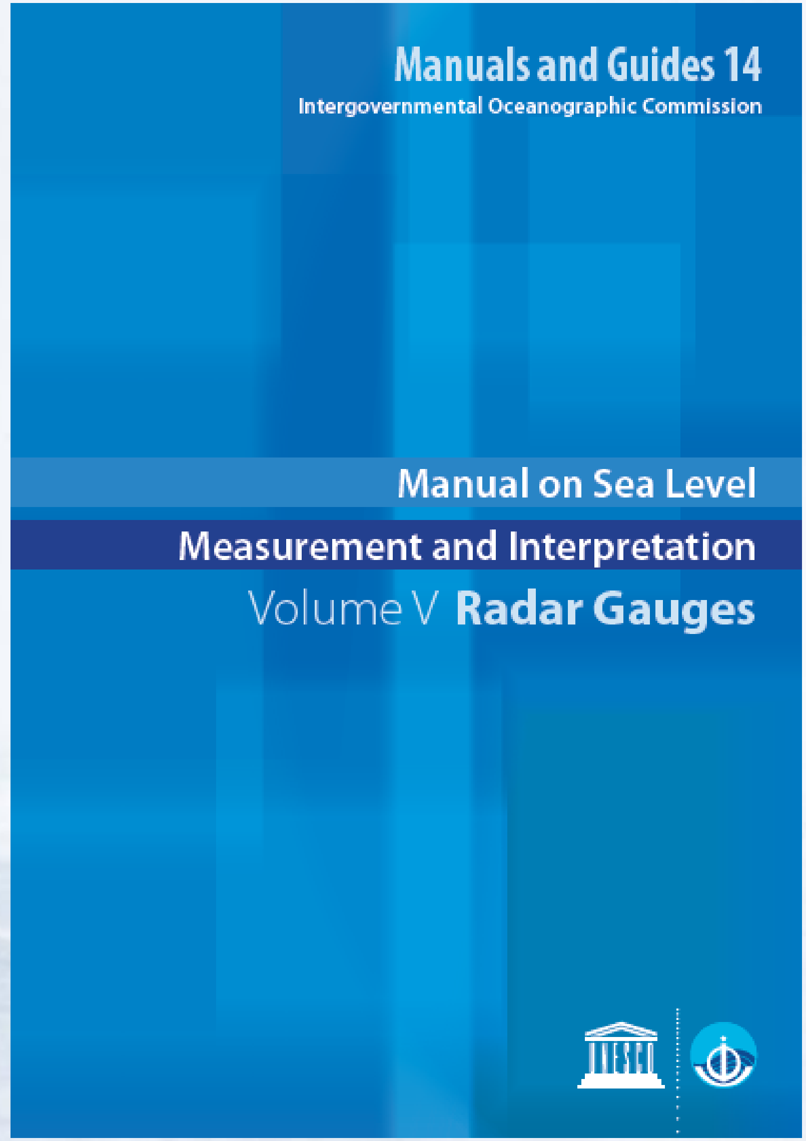
- Real time applications (tsunamis, storm surge flood warning, harbour navigation, hydrographic surveying)
- Delayed mode applications (wide range of science including ‘sea level rise’)
- Coastal engineering and geodetic applications (e.g. definition of land datums)
- Calibration of satellite altimeter data
- Even social and historical studies
- And many others …

The point is that good data can be used for many applications, so we should aim to produce the best data we can.

Please read

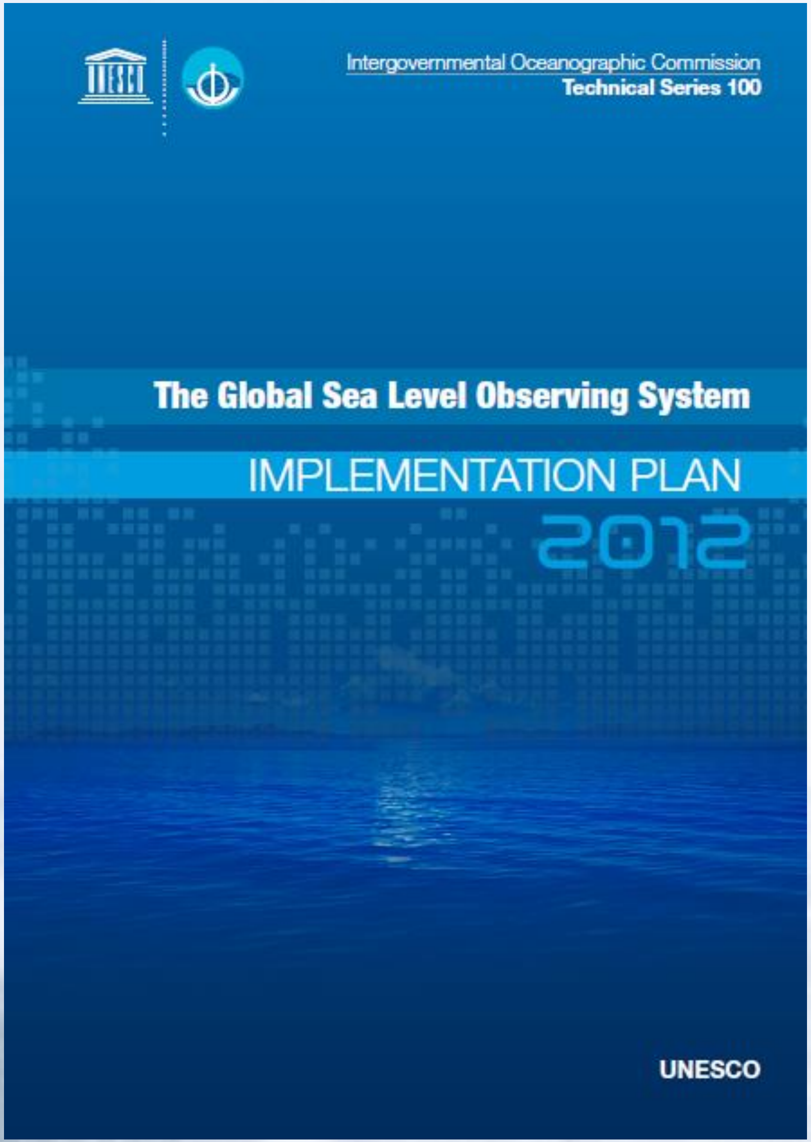


IOC Manual 4

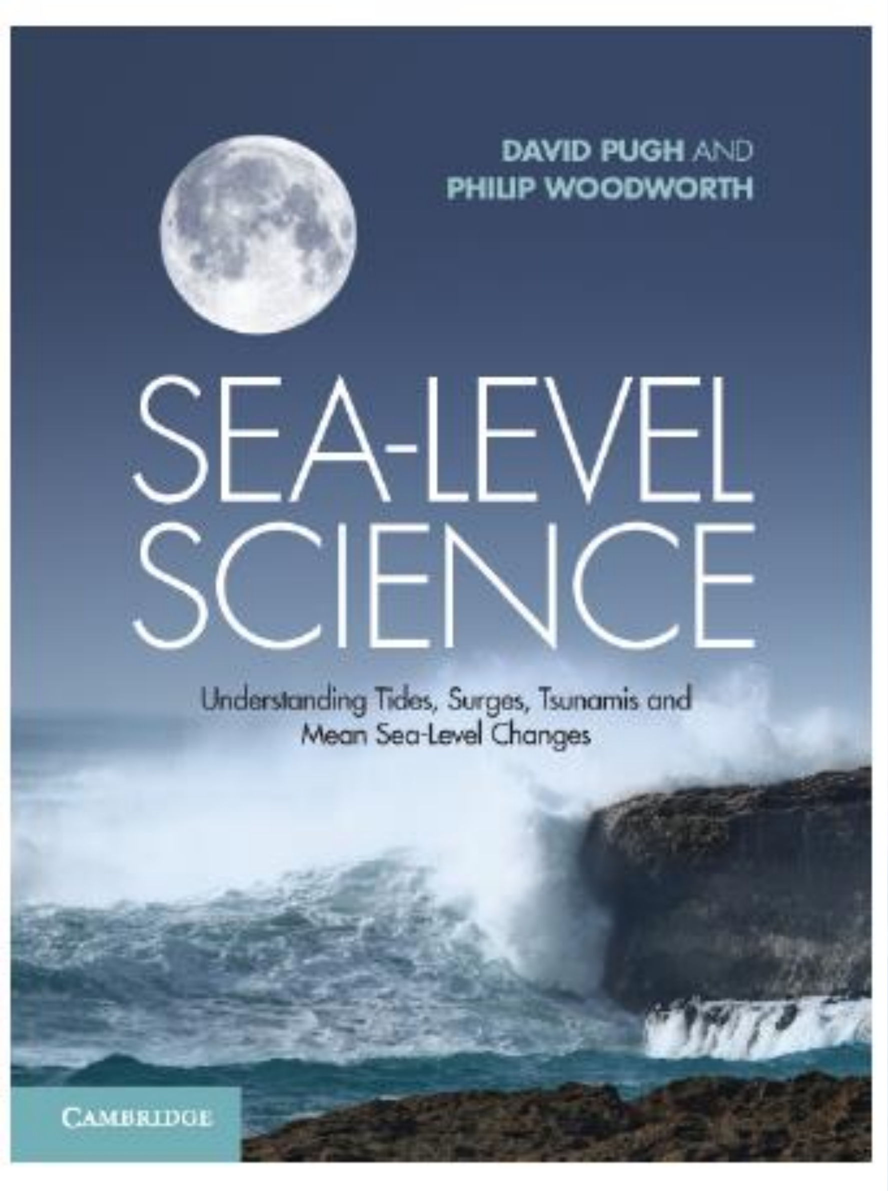


Manual 5

Please read



GLOSS Implementation Plan



More Reading:

See various chapters in

Sea-Level Science

By David Pugh and Philip Woodworth