11 General Measurement Tips

11.1 Field Measurement Tips

With the aim of obtaining correct field measurements some common sense rules have to be followed. A set of suggestions will be offered below with the intention of preventing some common mistakes. Even when some of the ideas herein presented are known, having them collected in an ordered form could help in preparing field works. These rules are divided according to different phases in the data acquisition process, such as deciding the use of an instrument, installing it in the field, assuring data quality, etc.

Instrument's users have to be familiar with the potentialities and limitations of their instrument before installing them in the field. For this reason, at the end of the chapter, a case study with instruments and sensors available in most laboratories is presented. It is intended to show why researchers should perform their own tests on instruments before using them.

11.1.1 Before Deciding the Use of an Instrument

Let us assume that a given instrument already exists at the laboratory, but the future users do not have any experience with it. In this case, it is convenient that users become familiar with the instrument's capabilities before deciding to use it in field work. With the purpose of getting acquainted with the instrument's performance some testing should be done. Perhaps, in these preliminary steps, users will discover that the instrument is not adequate for the work they have in mind.

In the process of recognizing the instrument's capabilities for the desired measuring task we find the following recommendations useful:

1. Read the **original** manual of the instrument.
2. Understand exactly the working principle of the instrument.
3. Know what the **assumptions** that underlie the measuring method are. All methods are based on some conditions that must be met for the data to be reliable. For example, in Section (6.2.3) it was assumed that buoys follow the sea surface water particle orbit, and in Section (5.4.6) that particles are moving at flow velocity.
4. Study how the instrument processes data internally before recording a final data output. For example, Radio Acoustic Sounding System (Section (8.7)) average samples in time and space, so their data are quite different from that acquired by radiosondes or traditional anemometers.
5. Carefully read the manufacturer's specifications to find the instrument's limitations.

6. Test the instrument to make sure that it is performing according to the specifications.
7. Mimic laboratory environmental conditions to those in which the instrument will be used. Tests should be performed under similar temporal and spatial scales and similar environmental conditions (temperature, humidity, electrical noise, etc.)
8. Process data recorded during these tests to be sure that their format is compatible with your software and data processor unit.

11.1.2 Simple Examples to Materialize Previous Ideas

In order to make it clear what we refer to in step 6, we present some simple examples with sensors that have been described in previous chapters.

In the case of non-contact level meters using acoustic transducers (Section (6.2.3)) or radio frequency antennas, a simple test is to place the equipment on the floor pointing toward the ceiling and let it run for as long a time interval as possible. The instrument should measure a constant value. Making changes in the instrument's level, for example by placing the sensor on a table, and then back on the floor, the instrument repeatability could be verified, and some information on time response obtained. It is useful to simultaneously measure air temperature and humidity to verify whether they could have some influence on level measurements.

Also, this kind of instrument could be suspended from the roof with a rope, pointing down and balanced as a pendulum. By measuring the length of the pendulum and its oscillation period with a watch, the real pendulum movement can be calculated and compared with the data as measured by the instrument. This test could give information about the dynamic response of the instrument.

These are examples with one kind of instrument, but each singular instrument requires its own test and readers should find the most adequate for their particular instruments.

11.1.3 Before Installing an Instruments in the Field

Initial functioning tests of the equipments at the factory (or after a repair) are usually short and they are not normally representative of field-use conditions. It therefore happens that a certain percentage of new or recently repaired instruments fail within a short time of use. This early failure behavior is known as "instrument infant mortality".

If the installation of the equipment is expensive, as happens with instruments placed on board oceanic buoys moored at hundreds of kilometers from the coast, it is necessary to exhaust all efforts to ensure that instruments will work for a long time.

For this to happen, it is advisable to follow a strategy of "use prior to installation" of equipment.

For new or recently repaired instruments, it is convenient to have them running for a while, under known and controlled conditions, prior to field installation. Whether a weak component or hidden construction defect exists, hopefully a failure would occur before site installation. Obviously, the operating conditions of the tests should be as similar as possible to those find in the field.

11.1.4 Suggested Steps for a Field Measuring Campaign

The steps we recommend in preparing instruments for the acquisition of field data are summarized in Table 11.1. Instruments' users sometimes skip some of these steps, whereas other steps are not viewed as part of the measuring process. However, all of them have some influence on the evaluation of the data quality, and users should find it convenient to meet them all.

One rule for increasing the chances of assuring reliable data is to calibrate the equipment before and after measuring campaigns.

Table 11.1: Steps for a field measuring campaign

Order	Step
1	Tests to verify proper operation of instrument.
2	Calibration
3	Transportation and installation
4	Measuring
5	Instrument recovery and back transportation
6	Re-calibration
7	Comparison of calibrations
8	Evaluation (to see if the instrument retains its ability to measure; repeat some of the tests made in step 1).

The first step mentioned in Table 11.1 has already been described in item 6 of Section (11.1) The next step is instrument calibration; it consists of comparing its measurements with others taken simultaneously by a standard instrument of better quality (Section (2.2.3)). The following stages are transportation and installation.

The transport and installation must be done carefully enough so that the instrument does not change its calibration. After the measuring step, it is necessary to recover the instrument and transport it with care, keeping the measuring capabilities unchanged. Once the instrument is back at the laboratory, it should be recalibrated and both pre and post calibrations compared. Finally, it is appropriate to make some measurements to verify that the equipment works as before the field campaign.

Whether there were any abnormal or unwanted actions, notes should be taken in a log book for each of the above steps. For example, any hit during transportation or during recovery, or any sign of vandalism observed should be reported. Also, it is important to record what happens during step 8, and also whether some events outside the measuring range of the instrument appear during the data processing. This information could help in validating field data.

11.1.5 Assuring Data Quality

We will use the term “reliable data” for data that has a very high probability of being within the errors specified by the manufacturer, and the term “unreliable data” for data with high probability of being wrong.

When, after following all the steps of Table 11.1, it is found that both calibrations coincide (steps 2 and 7), and that in step 8 it is possible to repeat tests as in step 1, then the probability that the collected data is reliable is very high. Instead, in the event that in step 7 calibrations do not match within a certain range, it is not possible to assure the data quality because it is not usually possible to know when the calibration changed.

If the instrument’s transference change is small, some kind of estimate about how the calibration changed with time can be made. For example, changes could be attributed to a linear aging process. But this kind of estimate must be made very carefully while knowing very well the characteristics of the instrument being used. Sometimes, the log book could help to identify the causes of calibration mismatch; for example a hit during transport from field to laboratory. This, in turn, could help to determine to what extent data could be used or should be disregarded.

An undesirable situation that occurs with some frequency is that the instrument fails during the measurement campaign (step 4), and then the suggested strategy to ensure the quality of the data cannot be applied.

11.1.6 Some Kind of Failures Likely Found in Data Records

Sometimes, when analyzing the data acquired during field work we can find a point at which the data suffer an obvious alteration. This “abnormal behavior” could indicate that the instrument has probably stopped working properly and that the data are unreliable. Examples of failures are shown in Figure 11.1.

The first of the failure modes (a) shows that at a certain moment, the instrument continuously records a constant value. We will refer to the fail detection instant

(FDI) as the point in the time series at which the acquired information begins to be "suspicious". In (b), alternately nulls and out of scale values appear from FDI on. In (c) there is noise beginning at FDI. In (d) the instrument alternates periods where it seems to measure well with periods of apparent malfunctioning. In (e) the instrument shows a failure, but then it continues to measure apparently well.

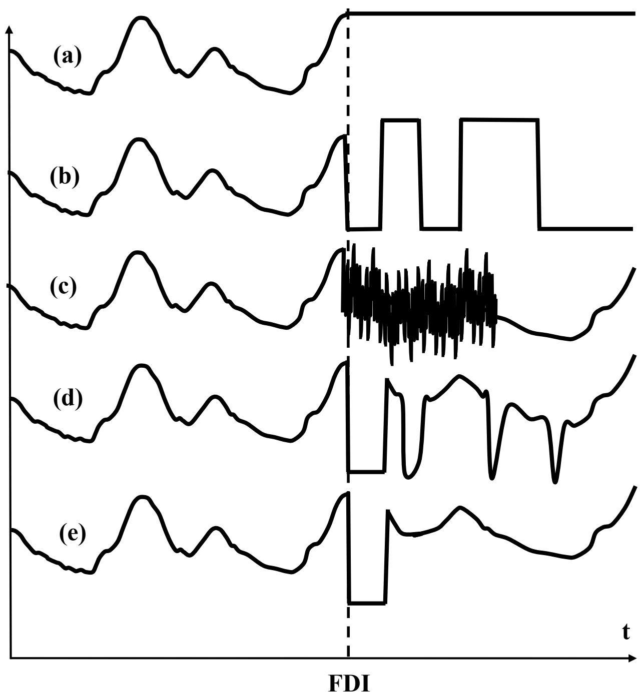

Fig. 11.1: Some failures beginning at FDI are observed in the data recorded: (a) the instrument begins to record a constant value; (b) data alternates between zero and out of scale; (c) noise appears preventing the signal from being rescued; (d) the instrument measures intermittently because of random failures; (e) there is a circumstantial cause producing a partial loss of data.

Following the FDI there could be periods with useful data, but doubts appear about their quality. Sometimes, it is possible to recover data from an instrument that has some of the faults shown in Figure 11.1. For this to be possible a good knowledge of the operating principle of the instrument is required, as well as having followed the steps suggested in Table 11.1. So to use those data it would be necessary to check whether the instrument has regained its ability to generate correct data after the FDI.

Items (a) and (b) in Figure 11.1 suggest that the instrument stopped working and it is not possible to rescue data beyond FDI. In cases (c), (d) and (e), on the other hand, there could be data with errors due to temporary interferences induced by sources external to the instrument. That is to say, the instrument can be measuring well, but temporarily suffering from data losses due to an external factor. For example, failures (c) and (d) could be due to external electromagnetic noise introduced into some stage of the instrument (usually in the sensor). In case (e), the behavior is similar to what happens when an instrument is circumstantially without power. It could be, for example, the case of a battery-powered instrument that is recharged from a solar panel. If solar radiation is not enough to recharge the battery, it may cause a loss of data, but after some time of sunshine, the battery recovers and the instrument continues to record data normally.

If for cases (c) and (e) the user could check that after field work (steps 7 and 8) the instrument works as before the campaign (step 1 and 2), some data after FDI could be rescued and used as reliable data. In case (d) it is a bit more difficult to distinguish reliable data from faults because noise has similar frequency components as the signal.

In the examples (a) and (b) we will assume that the instrument effectively ceased operation and therefore it is not possible to carry out the tests described in steps 7 and 8. In this case we should wonder whether data before FDI could be considered reliable. Researchers sometimes assume that all data collected up to FDI are correct. This is a somewhat risky position, since it is possible that measurement problems, which are displayed from FDI on, have begun much earlier, and what is observed beyond FDI is the end of a process of gradual deterioration of the instrument.

Obviously, in cases where instruments stop working during field work, there is no way to define what data is reliable, but a methodological analysis based on the knowledge of the instrument's working principle could help in defining the degree of reliability of the data. This is another reason why it is important to know how instruments work and the way in which they acquire and process the data.

11.1.7 How Instruments Pass from Correct Operation to Failure

It is important to know when the instrument stopped working properly. In Figure 11.1a and b, the data could be incorrect from some time before FDI. For example, an instrument with mechanical parts could be suffering from some wearing that ends in the failure that appears at FDI. The data collected may have begun to be wrong long before the failure becomes evident.

In searching which are useful data in records from instruments that failed during field work, the way instruments usually fail must be analyzed. There are some instruments that pass from a correct operating condition to a fault condition abruptly (Fig. 11.2a). Others (Fig. 11.2b) alternate periods with correct and incorrect data until they fail completely and others pass gradually from correct operation to malfunctioning (Fig. 11.2c).

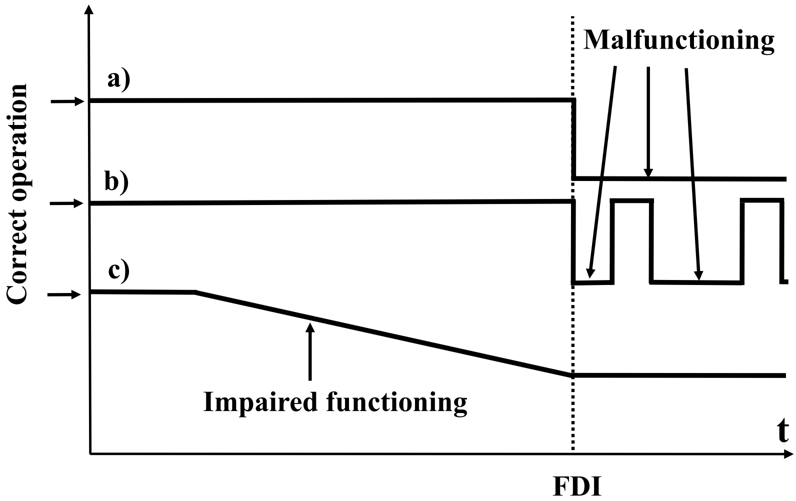

Fig. 11.2: Different ways in which instruments pass from correct operating condition to fault condition. The top horizontal line on the left indicates proper operating condition, and the low line on the right indicates fault condition. (a) The instrument passes abruptly from one condition to the other at FDI. (b) Some failure begins at FDI but the instrument alternates correct operation and fault condition. (c) The data quality suffers from a gradual deterioration until the instrument stops working at FDI.

Unfortunately, the same instrument can have different ways for passing from the correct operating condition to the condition of malfunctioning. But sometimes, instruments have a typical way of changing from one mode to the other, and this characteristic could be useful to decide which data can be taken as correct. Therefore, to decide which data could be valid in cases where the instrument stopped working during the field data collection, it should be checked whether the manufacturer describes some typical form of instrument failure. This feature could be found in the manuals, usually under titles such as analyzing data or system troubleshooting.

Just to illustrate the above ideas, we could say that an inductive conductivity meter (Section (4.10.2)) is more likely to change from a correct working condition to a fault condition as shown in Figure 11.2a and b, while one using electrodes in contact with the fluid (Section (4.10.1)) might behave as in Figure 11.2c. This could happen because the fluid influence on the inductive sensor is low, whereas in the conductivity cell, the electrodes can suffer from gradual changes in their physical or electrical characteristics due to the liquid, beginning with an impaired functioning and ending in a failure.

Even in a correct working condition some instruments can produce data that must be discarded (Fig. 11.3). This can happen with instruments whose measuring capability depends on some conditions of the medium where they are working, as in the case of remote measurement techniques (Sections (8.4) and (8.5)) or in the case of ADCP and ADV (Sections (5.4.4) and (5.4.6)). This kind of instrument performs a statistical analysis of the signal and determines the signal / noise ratio (SNR), which defines the quality of the data being recorded. When the SNR is below a certain value, the manufacturer recommends considering the data as unreliable. Therefore, users should disregard these data, resulting in time series records having periods with useless information.

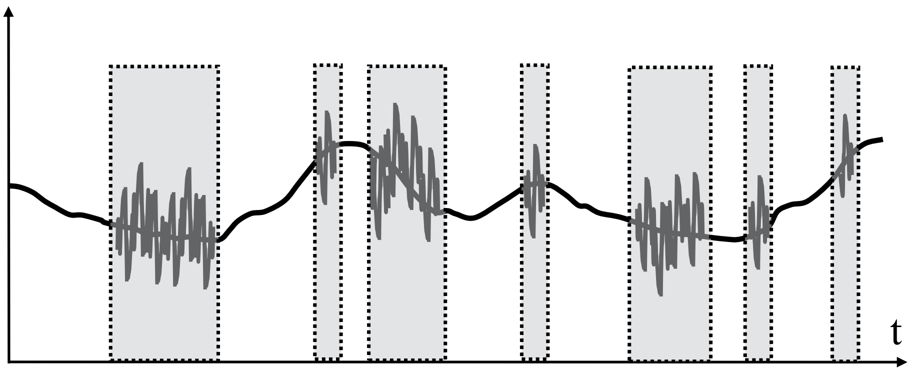

Fig. 11.3: Record of an instrument in a correct working condition that produces a time series with areas in which the signal to noise ratio is very low. In those sections, indicated by a gray rectangle, it is not possible to recover the signal and these pieces of the record must be removed.

11.1.8 Some Ideas for Collecting Continuous Data Series

There are studies in which events to be recorded have very low recurrence. In this case, in order to acquire the data of interest for the study, which could last a few minutes, it is necessary to measure continuously for a long time (could be several years). Measuring a tsunami or an extraordinary rainfall are two simple examples. In these cases where data time series has to be continuously recorded and instruments should not fail it is necessary to know the working life of the instrument producing correct data. Instrument replacement must be done before the possibility of a failure.

The new instrument should record simultaneously with the old one during a certain period in order to ensure that both instruments measure in a similar manner. This procedure would allow numerical adjustments on data collected by the new instrument to coincide with the instrument that is being replaced (Section (7.2.4.1)). Sometimes, this is a quite difficult task because the new instrument may be of a different technology (different operating principle) than the instrument already installed. If it is possible to adjust both instruments to give similar measurements, long continuous data series can be achieved.

Sometimes, the life of the instrument under the conditions in which it will be used is unknown even by the manufacturer, so it cannot be estimated when to perform the replacement of the instrument in use by a new instrument. In this case, the method known as “canary test” can be employed to detect when the time of possible failure is approaching.

The method consists in using an additional measuring instrument made purposely weaker than those used for the real desired continuous measurements. This weaker instrument is called “canary instrument”. It is expected that the canary instrument will fail before the instruments performing the continuous measurements. Thus, when the canary fails, the instruments whose series should not be interrupted must be replaced preventively.

11.1.9 Before Buying an Instrument

Some suggestions to be considered before buying an instrument are listed below.

1. Select the instrument according to the problem being solved at the present time. Avoid buying any instrument thinking about potential measurement problems that may (or may not) occur in the future.

A common mistake is trying to buy measuring instruments thinking about problems that do not exist at the time of purchase, or about applications with little chance of occurrence. Typically, the greater the measuring flexibility offered by instruments, the higher the prices. Therefore, overrating measuring requirements may not be the most appropriate solution for the actual study for which the equipment is needed.

For example, if it is required to measure pressures up to 0.1 kgr/cm^2 with an error of 0.001 kgr/cm^2, it is desirable to avoid the frequent temptation to buy a sensor that can measure in a range of 1 kgr/cm^2 for potential future work. For the same quality of instrument (similar price range), the instrument of higher range will measure with greater error (probably around 0.01 kgr/cm^2), thus it would be no longer useful for the initial application.

Instead, if it is decided to buy a sensor for the range of 1 kgr/cm^2 having errors less than 0.001 kgr/cm^2, it must be an instrument of higher quality, so you would have to pay a higher price. Therefore, unless it is certain that the instrument will be used in other work, and that it is therefore convenient to make a major investment to cover all future measurement requirements, you should focus on the characteristics of the instrument required to solve the present case.

1. Clearly define the temporal and spatial characteristics of the phenomenon to be measured. This information is essential to select the right instrument.
2. Clearly specify the environment in which the instrument will be measuring (range of temperature, pressure, humidity, environmental aggressiveness, noise presence, energy availability, probability of vandalism, media to transmit data, etc.). It is essential to verify that the instrument can measure within the expected error in the specified environment.
3. Define the maximum unattended period required, as this will determine the memory needed to store the data and the kind of electrical source required. It should be considered whether instruments can be powered with batteries or if they require power sources such as solar panels or wind generators.
4. If there is any doubt on the specifications provided by the manufacturer, it is highly advisable to contact the manufacturer directly and ask specifically if the instrument is able to measure what the researcher wants.

11.2 Case Study (I): Static Pressure Sensor Test

11.2.1 Introduction

As standard practice, before using under field conditions any instrument that has not been in use for a time, it is convenient to make some measurements of well-known quantities in a controlled environment to verify the correct functioning of the instrument. As an example, a real case will be presented in which some tests were performed on water level data loggers with pressure sensors.

It was desired to perform research work where it was very important to measure the difference in an aquifer level between several boreholes. The instruments at hand had been purchased five years before, but they had been scarcely used.

To verify the quality of the data that could be obtained with these level loggers, some simple tests were performed. Some conclusions regarding the results that could be expected from these instruments in future field work will be presented.

There were five water level data loggers of the same model with the following manufacturer's specifications:

Range: 9 m
Resolution: 0.2 cm
Accuracy: 0.1 % of full scale
Accuracy of the internal clock: ± 1 minute per year
Working temperature range: -20 to 80 °C
We called these five sensors L1, L2, L3, L4 and L5.

11.2.2 Test Description and Preliminary Results

The data loggers were made ready and installed in a swimming pool where it was possible to change the depth of the instruments in known steps. At the beginning the data loggers were placed at a depth of 0.93 m for a week, then they were put at a depth of 0.72 m for a day, and finally at 0.48 m for another day. Figure 11.4 shows the data recorded for the last four days approximately. The changes in depth can be seen at about 8,500 and 10,000 minutes.

Even though the sensors were placed at a constant depth, the records show a wave-like pattern due to changes in the atmospheric pressure. It can be seen that most of the records follow those changes in a similar way. The difference between the maximum and minimum of the undulations during the nine-day test was 0.2 m. This indicates that if the aquifer's level in a well is to be measured, it is **necessary** to subtract the atmospheric pressure because it introduces changes that could be easily confused with real water level changes.

In the research in which the five data loggers are intended to be used, all of them will be placed at short distances from each other, so that the atmospheric pressure they will bear will be the same. Besides, the only variable of interest in this investigation is the difference in water level. *Therefore, if all the sensors would have the same response to the atmospheric pressure, it would be enough to measure the pressure difference between the instruments because the contribution of the atmospheric pressure to the hydrostatic pressure would be the same for all the sensors*.

It can be seen from Figure 11.4 that the atmospheric pressure variations are similar for the five tested sensors. However, sensor L4 behaves rather differently from the rest. Not only does it measure smaller values than the other four, it also exhibits rapid oscillations with amplitudes up to 0.08 m. Sensor L4 must hence be rejected for the field work planned because its oscillations could mask the phenomenon to be measured.

11.2.3 Subtracting Atmospheric Pressure

The mean value of the measured atmospheric pressure (**map**) for each sample was calculated from the data recorded by the four instruments that present reliable pressure variations. This mean value was then subtracted from each measurement of the four sensors. The result is illustrated in Figure 11.5. It can be seen that the variations in the atmospheric pressure no longer appear when the mean value is subtracted. This indicates that all the sensors can measure the atmospheric pressure variations in a fairly similar way. *Therefore, they are able to carry out differential measurements with negligible influence of the atmospheric pressure.*

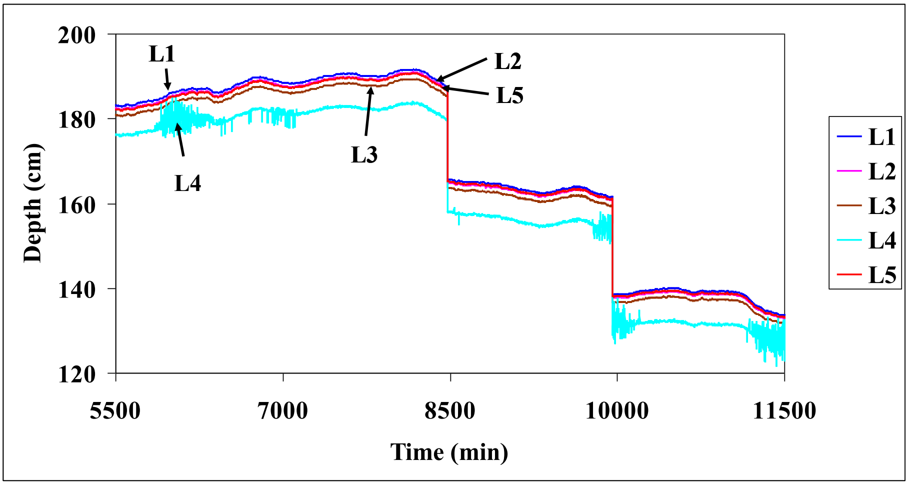

Fig. 11.4: Level outputs as recorded by the five data loggers with pressure sensors (Data courtesy of Leandro Rodrigues Capitulo and Eduardo E. Kruse, Faculty of Natural Sciences, National University of La Plata).

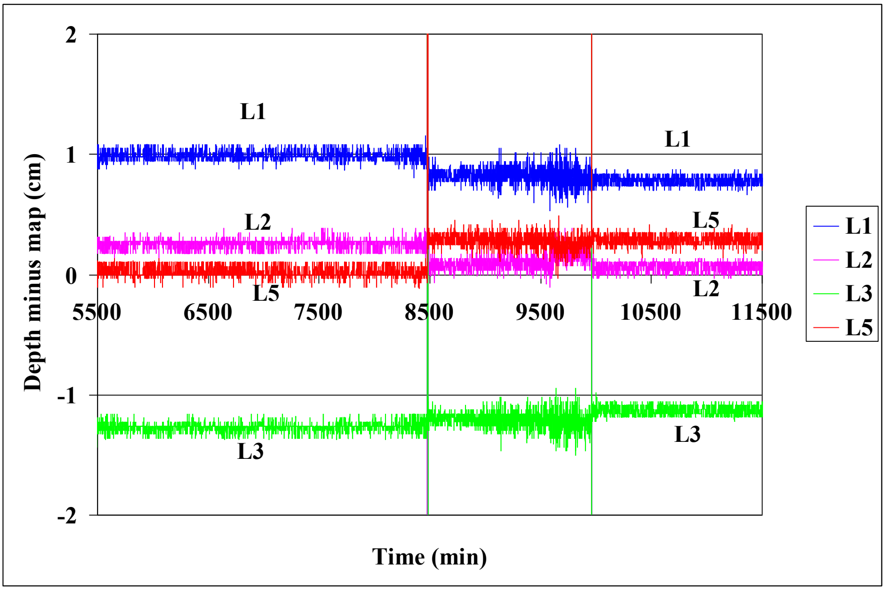

Fig. 11.5: Outputs of the four data loggers selected for field work when the measured average level is subtracted. All instruments have quite stable outputs. Manufacturer calibration was used. L2 and L5 measured closer to the average than the others.

11.2.4 Evaluating Potential Errors for the Particular Field Work

All the sensors have some background noise of about 0.002 m, which corresponds to the resolution specified by the manufacturer. In some cases the background noise reaches 0.004 m. Sensors L2 and L5 exhibit (at different times) a difference of about 0.004 m with respect to the mean value, represented by the horizontal line corresponding to the zero of ordinates. Sensors L1 and L3 show differences up to +0.010 and -0.012 m, respectively. It can thus be concluded that interchanging any one of these sensors, differential measurements could be made with a maximum expected error of 0.022 m (0.010 + 0.012) m. These comparisons were done using the calibration provided by the manufacturer. By calibrating the four data logger simultaneously at the users' laboratory, and calculating a new transference for each one, all of them (L1, L2, L3 and L5) could probably work within differences under 0.004 m.

It must be emphasized that in this example the maximum depth at which the sensors were tested was 0.93 m; therefore the abovementioned maximum expected error of 0.022 m **is valid only for this range**. It must be a standard practice to test the functioning of instruments over the whole range of the variable they are intended to be used. It is not possible to extrapolate this result to other ranges.

If these instruments are used to measure in the full range, the calibration error could produce a measurement error greater than the expected maximum of 0.022 m. For example, if it were considered that the differences found are attributable to different gains (slope of each of the transferences), and the instruments were used to measure a 9 m water column (about ten times greater than the tested depth), errors would probably increase proportionally (0.022×10) and would reach a value of about 0.2 m.

11.2.5 Evaluating the Gain of Each Instrument

It can also be noted in Figure 11.5 that the pressure differences change with respect to the average pressure at 8,500 and 10,000 minutes, just when the sensors were moved to different depths. This indicates that each sensor responds in a different way to a same change in depth, a typical behavior of instruments having differences in their calibration. If the instruments are supposed to have linear transferences (Section (2.2)) they would have offsets or slopes, or both, slightly different.

Since a change in depth produces a level difference with respect to the previous value, it allows the gain of each instrument to be assessed independently of the zero or offset error. Table 11.2 shows the real change in depth of the instruments, the measurements made by each one of them, and the gains (G_1 and G_2) understood as the ratio between the change measured by the instrument and the real change.

If the calibration of the instruments were stable, the gain for each instrument, calculated with both depth changes should be the same ($G_1 = G_2$); both right columns should be equal, which is not the case. This could indicate that there are some changes in the calibration with time or that the "real changes in water depth" were measured with some error. Because students without experience collected the data of our example during a practical work, probably the second is true. This assumption is supported by results shown in Table 11.3, where the real changes in depth were modified to 0.218 and 0.231 m, resulting values of G_1 and G_2 much closer to 1 in both columns.

Table 11.2: Real change in depth versus measured change

Time (min)	8,500	10,000	G_1	G_2
Real change in depth (m)	0.210	0.240		
Instrument L1 (m)	0.220	0.231	1.047	0.963
Instrument L2 (m)	0.220	0.232	1.047	0.967
Instrument L3 (m)	0.217	0.230	1.033	0.958
Instrument L5 (m)	0.215	0.231	1.024	0.960

Table 11.3: Real change in depth versus measured change

Time (min)	8,500	10,000	G_1	G_2
Real change in depth (m)	0.218	0.231		
Instrument L1 (m)	0.220	0.231	1.009	1
Instrument L2 (m)	0.220	0.232	1.009	1.004
Instrument L3 (m)	0.217	0.230	0.995	0.995
Instrument L5 (m)	0.215	0.231	0.986	1

Since the method used to verify the functioning of the sensors is very basic, it is not possible to quantify accurately which is the zero error and which is the slope error for each sensor. In order to better quantify these errors it is necessary to carry out another type of test, as it will be described below.

11.2.6 Full Range Calibration

To find a new water level sensor transference (i.e. to get a new input/output curve (Section (2.2)) that allows level measurement errors to be reduced), each instrument should be calibrated by applying known pressures and recording the values measured by each one of them.

An efficient and precise way of detecting differences between the transferences is to calibrate all the instruments simultaneously. For this purpose the pressure inputs of all the sensors should be connected in parallel to a common pressure input, and then put at the same level (e.g. over a smooth horizontal floor). Then the common pressure input should be connected to a water-filled hose to apply different pressures to the instruments by changing the water level inside the hose in steps. Special care should be taken to avoid air bubbles in the water, so it recommended using a transparent hose.

The real value of the water level in the hose and the value measured by the sensors must be written down at each step of the calibration process. A table will result with a series of points within the operating range of the sensors (a reasonable number for a quasi linear sensor is between 5 and 10 points). Finally, correction coefficients can be calculated from the values of the table so that all the sensors have a similar transference.

It must be taken into account that the test for determining the transference of the sensors must be performed in a time interval short enough so that the variations of the atmospheric pressure and temperature are negligible.

If the measurements must be very accurate it is advisable that the calibrations be made a few days before the field work, because they could vary with time. If it is desired a greater certainty about the quality of the recorded data, the calibrations should be repeated after the field tests have been carried out.

11.2.7 Temperature Influence

Figure 11.6 shows water levels as recorded by the instruments at the moment they were submerged; it appears as a step with an initial peak and an exponential decay. It can be seen that it is required about ten minutes for the instruments to stabilize their outputs at the new values.

The time required for outputs to become constant is the same time needed by the data logger to change from air temperature (25 °C) to the water temperature (11 °C); this was found through the temperature records given by the same instruments.

It is seen that for a change of level of about 1 m, the additional increase in the mean level registered during the first ten minutes is of the order of 0.05 m, i.e., 5 %. This transient in depth records is not due to a change in depth, but to the change in temperature. In other words, the instruments were affected by a change in temperature that modified the transferences. It is most likely that the thermal shock has modified the behavior of the electronic circuits. It can then be concluded that in order to obtain reliable measurements, the temperature of the sensors should remain as constant as possible. Also, the first minutes of any records should be discarded when the initial instrument temperature is different from water temperature. Furthermore, to reduce errors, it is convenient to calibrate the instrument at a temperature similar to that of the aquifer.

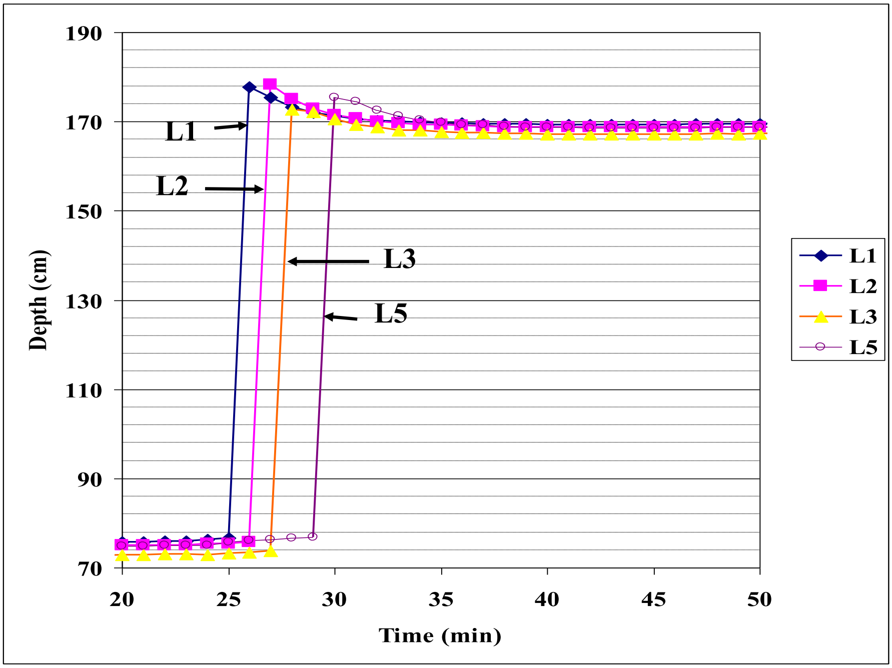

Fig. 11.6: Water level recorded by the sensors at the moment they were submerged in water.

Fortunately, the temperature of an aquifer remains fairly constant and does not change significantly during short periods, so for the application at hand, there would be no need to take into account the gain changes due to temperature variations. But if it were desired to measure water levels in a medium with significant temperature variations, it would be necessary to add the errors due to temperature changes.

It was noted that during the 9 days in which the test was carried out the sensors measured pressure differences fairly constant (Fig. 11.5). This shows that their calibration remained stable with time.

11.2.8 Some Conclusions

A summary of the information obtained from this simple test is given below.

1. It was determined that one of the instruments was not suitable for field measurements.
2. It was verified that if the water level variations to be measured were less than 1 m, the maximum error in level difference with two sensors chosen at random would reach about 0.02 m. If instead, the sensors L2 and L5 were chosen, the error would be less than 0.005 m
3. It is not possible to measure water level variations less than 0.004 m because of the background noise.
4. In order to measure absolute aquifer levels it is necessary to subtract the atmospheric pressure variations. During the 9 days period of the tests the variations in the recorded level data due to atmospheric pressure variations were 0.2 m.
5. Four instruments out of the five tested measure the atmospheric pressure variation in a similar way. Hence it is possible to take differential measurements if the sensors are separated by a distance such that they are subjected to the same atmospheric pressure.
6. The calibration of each of the four sensors chosen is slightly different, and if it were desired to reduce the measurement errors, the transferences of the instruments would have to be found.
7. The calibration of the instruments remained stable during the entire testing period (9 days).
8. A change in temperature of 14 °C in the instrument produced a transient change of approximately 5 cm variation in level. It corresponds to a drift due to temperature (Section (2.2.6)) of 3.6 mm/°C.

11.3 Case Study (II): Dynamic Pressure Sensor Test

In some applications it is important to know the high frequency response of the sensor, but sometimes the manufacturer specifications of the time response are not easy to understand. That was the case of a commercial pressure sensor that triggers our curiosity. The sensor has a range from 0 to 10 m of water column (0 to 1 kgr/cm^2) and the manufacturer specifies the response time in this way: **Passive output ≤ 1 ms; Amplified devices ≤ 10 ms**. These specifications on their own are not clear, even for an experienced engineer.

The test described in Section (2.4.11 – P3) was conducted to learn more about the dynamic response of the sensor. The test consisted in applying a step of pressure to the sensor and measuring its output. The sensor was connected to one of the ends of an elastic cylinder (deflated balloon - orange in the internet version of the book)

(Fig. 11.7). The other end of the cylinder was connected to a manual pump, and the cylinder pressurized to about 0.5 kgr/cm^2 (Fig. 11.7 (bottom)). Figure 11.7 (top) shows details of the valve to inflate the balloon (left) and the sensor plugged to the balloon (right), both fastened with rubber bands.

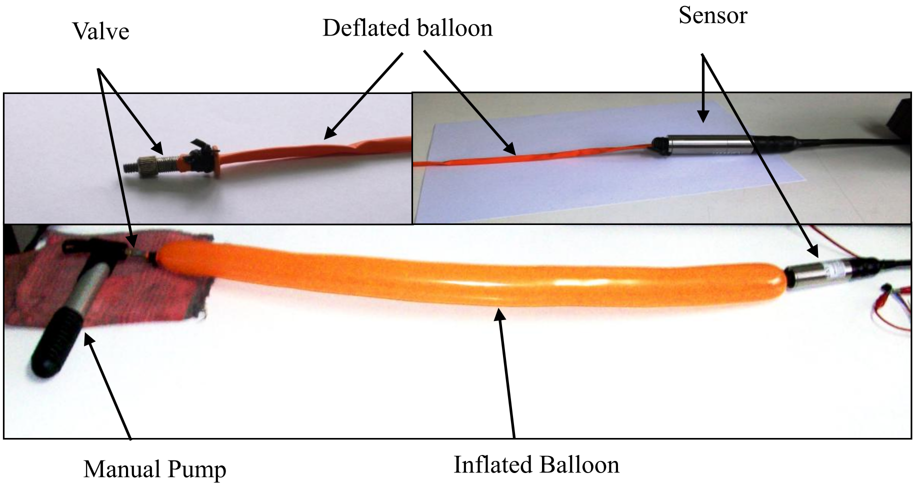

Fig. 11.7: Setup for testing a pressure sensor dynamically. An elastic cylinder (orange balloon) was connected to the sensor (top right) and to a valve (top left). The balloon is inflated through the valve by means of a manual pump.

The pressure sensor electrical output was connected to a digital oscilloscope with internal memory that works as a data logger. The balloon was inflated up to the point when it blows up; the oscilloscope pre-trigger function was used to record data during 12 ms before and after the balloon is blown up. The sudden change in pressure represented a negative pressure step input to the sensor. This step allows us to study the sensor response time.

The oscilloscope record of the sensor response is shown in Figure 11.8. The sensor's output samples before the balloon explosion have almost constant amplitudes of about 3 V. It is estimated that explosion occurred at 2.9 ms where amplitudes begin to fall up to 3.2 ms, reaching a minimum of about 0.5 V, where an attenuated oscillation of about 2 kHz begins. This oscillation is almost completely attenuated 7 ms after the explosion (not shown). This oscillation may be of mechanical or electrical origin. In the first case, it could be related to the resonance of the sensing membrane (Section (4.8.1)); in the second it could be due to the electronic circuit.

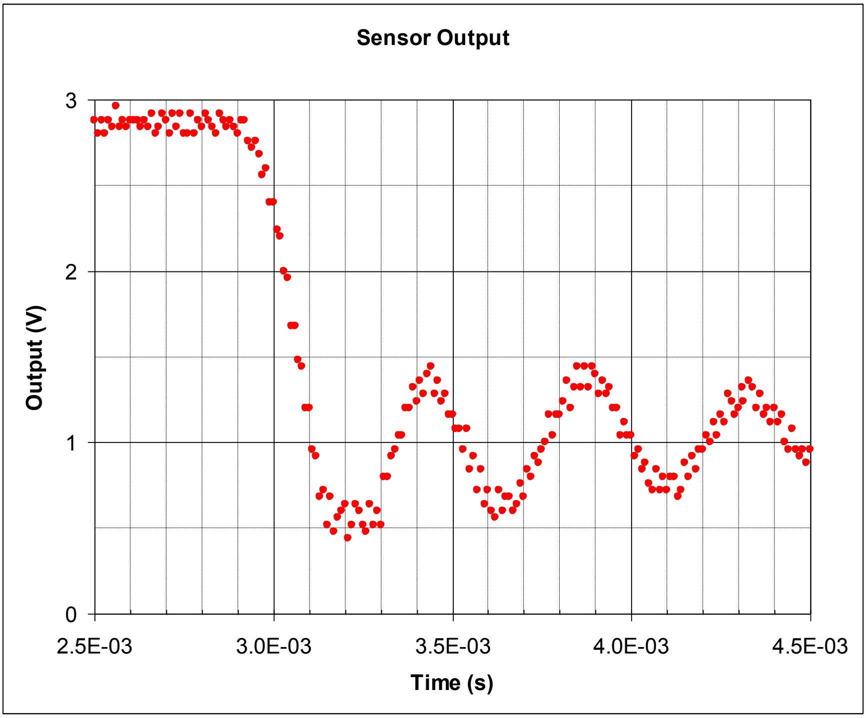

Fig. 11.8: Oscilloscope record of the sensor output when the balloon blows up.

The lesson learned from this test, which is not possible to figure out from the limited manufacturer's specification, is that the sensor has a preferential gain for a certain frequency about 2 kHz. Therefore, if dynamic air pressures should be measure with this sensor, the manufacturer's specifications do not help. The sensor will magnify signals present in the phenomenon with a frequency close to 2 kHz. In order that all frequencies have the same gain, pressure input signals should be limited to frequencies significantly below the oscillation frequency. A possible solution is to place a filter at about one decade below the oscillation (200 Hz) to prevent amplitude distortion due to sensor resonance. It should be noted that the test was carried out using air as the environment in which the sensor membrane is immersed, and this result should be considered valid only for a sensor working in air.

If the sensor will be working in water, the same test should be repeated using water to inflate the balloon and the balloon should also be immersed in water, so that the membrane will be in contact with water after the balloon blows up. If the oscillation were of mechanical origin, we estimate that being in water the oscillation would be more rapidly attenuated than in air because of a faster dissipation of the mechanical energy accumulated in the elastic membrane deformation.

11.4 Final Words

Almost all instrument manufacturers are serious, honest and publish reliable technical information about their products. But sometimes, in their eagerness to promote the benefit of their instruments when compared with those of the competition, manufacturers' brochures tend to confuse customers.

Frequently, customers do not know which characteristics of instruments are important for the desired measurements, how specifications have to be understood and what are the operating principles of instruments. Therefore, the unfamiliarity of customers with instruments contributes to the misinterpretation of manufacturers' brochures.

For example, some manufacturers specify the precision of their instruments, but say nothing about their accuracy, and then some customers think that they can measure with accuracy similar to the specified precision. As is made clear in this book there is a considerable difference between these concepts (Section (1.4)); the instrument can be very precise, but can be measuring with great errors.

Also, when manufacturers specify the accuracy, sometimes they do not make clear under what conditions it has been evaluated. Thus when users measure under other conditions or under variable conditions errors become unacceptable. Manufactures cannot be blamed for this omission because when the specifications are not clear, users should ask for details.

A common mistake of instruments users is to ignore the spatial and temporal characteristics of the instrument being used. In Table 6.1, the volume sampled by the different instruments presented varies 10^{13} times. Then the spatial resolutions of these methods are very different and it is the responsibility of the researcher to select which one is the most adequate scale for the problem being studied. The same happens with the time scale, as seen in the previous example in Section (11.3). The manufacturer specifies the time response in a way difficult to understand, and says nothing about oscillation. Perhaps the manufacturer has never tested the sensor in air, because most customers use the sensor in a medium other than air. Therefore, users should make clear to the manufacturers the specific conditions in which they will use the product to be acquired, asking for instruments performances in that particular condition.

Remote sensing instruments deserve a special consideration. They depend on the conditions of the media where a wave propagates (i.e. atmospheric conditions for wind radars and RASS (Sections (8.6) and (8.7)). Therefore, data is not always accessible. Also, individual measurements suffer a complex data processing and results are highly influenced by the algorithms utilized. Users should know how instruments calculate the final result. For example, if data are passed through a process of consensus averaging it could be of interest to know what the rules are for this averaging because the temporal scale could depend on it.

A good practice for instruments users is to consult manufactures about the specific needs they have before buying a new instrument. Instead, if the instrument has already been acquired an excellent attitude is to test it in known and controlled conditions before using it.

Understanding how a given instrument works and how the parameter recorded by the instrument is related to the measurand we want is essential in understanding the phenomenon we want to research.