Autonomous Drifting Ocean Station (ADOS)

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Low-cost drifter platforms can be used to gather an enhanced suite of data that is essential for integrating present and future satellite measurements of biological and physical processes with *in situ* observations. Working together, Clearwater Instrumentation, Inc. and Scripps Institution of Oceanography have successfully completed a program implementing a novel thermistor data-chain and a novel biological irradiance sensor system for Lagrangian drifters, which have been successfully used in WOCE in large numbers. These new sensors have been integrated with WOTAN, a digital, acoustic wind sensor already developed by SIO into an AUTONOMOUS DRIFTING OCEAN STATION (ADOS). ADOS facilitates simultaneous *in situ* observation of winds, surface layer thermal structure response to mixing, and productivity resulting from nutrient upwelling. ADOS features a thermistor string of SmartSensors that measures seawater temperature at 13 levels from the surface to 120 meters and pressure at four levels. SmartSensors are autonomous mini-instruments that communicate with the ADOS surface float by inductive signals sent through hydrographic cable. ADOS measures irradiance and ocean color at SeaWiFs frequencies. Three sets of SeaWiFs sensors are mounted on the surface sphere in closed housings which protect the sensors from bio-fouling until the caps are pushed off at pre-programmed intervals. ADOS implements WOTAN placing it on the thermistor string and by adapting the SmartSensor inductive modem to communicate between WOTAN and the surface sphere. An in-situ calibration and testing program and recovery of instruments at sea has been completed. ADOS were deployed off the California coast along with Minimet drifters from Scripps and followed in a research vessel outfitted with data telemetry and meteorological instrumentation. Results from this cruise verified sensor operation.

1 Introduction

We were confronted with the challenge of making concurrent measurements to enhance NASA observations of the physical forcing of biological response in the ocean surface layer. Our solution was to place a highly integrated sensor suite in a ruggedly constructed surface drifter to make an Autonomous Drifting Ocean Station - ADOS.

The Autonomous Drifting Ocean Station ADOS is an innovative drifter that represents a major step in the level of integration of sensors on a single instrument that will allow concurrent observation of ocean physical and biological processes. ADOS measures, surface wind velocity, ocean surface thermal structure, and ocean color. The data from these sensors will be used together with funded NASA scientific study to enhance observations of the physical forcing of biological response in the ocean surface layer. Besides integrating three sensor systems ADOS performs two of these measurements, ocean color and surface layer thermal structure with novel systems developed under this contract.

1.1 ADOS Ocean Color Sensors

ADOS' approach to ocean color measurement places SeaWiFs color sensors in housing with removable caps, which can be programmed to be pushed off at specific intervals allowing aged sensors to be compared with a fresh sensor. One of the ocean color sensors can be seen in Figure 1 that shows the ADOS surface sphere with all of the caps removed. Caps are removed with very high torque electric motors, which can break tough bio-fouling, if it should occur. A sensor in the mast at the top of the surface sphere measures incident solar radiation.

1.2 ADOS SmartSensor Thermistor String

ADOS' solution to measuring ocean surface layer thermal structure is achieved by placing self-contained electronic thermometers called SmartSensors on ordinary steel-core oceanographic wire. SmartSensors communicate with the ADOS surface float by inductive modem. SmartSensors are battery-powered thermistor sensor with miniature controllers to perform measurements and modem communications. Because SmartSensors are on hydrographic wire, the thermistor string is very rugged; it does not require multi-conductor cables with complicated, sensitive, waterproof breakouts for sensor power and communication.

1.3 WOTAN Wind Sensor

The ADOS thermistor string includes the WOTAN (Weather Observations through Ambient Noise) developed by the Scripps Institution of Oceanography. The SIO WOTAN measures wind speed by implementing digital signal processing of ocean sound. As the case is with SmartSensors, WOTAN is a stand-alone instrument with its own power supply; WOTAN data is transmitted using the inductive modem circuitry of the SmartSensor.

2 ADOS Instrumentation and Sampling

ADOS is a sophisticated oceanographic instrument employing the latest microprocessor technology to make measurements in the ocean surface layer and satellite telecommunications to return the data to the user.

The MasterModem located in the ADOS surface sphere manages sampling of WOTAN, PAR sensor, ocean color sensors, and SmartSensors. PAR and ocean color sensors are located on the surface sphere. WOTAN and SmartSensors are placed on hydrographic wire suspended below the surface float. Commands and data communication between the surface float the subsurface instrumentation are accomplished by inductive modem. All sensors report calibrated outputs except for WOTAN which must be post-converted to obtain wind speeds. Minimal conversion is required to convert Argos messages to engineering units.

Figure 1 ADOS surface sphere.

A PAR sensor is located in the black mast on top of the ADOS surface float (see Figure 1). Each ADOS sphere is fitted with three ocean color sensors in housing in the lower hemisphere. The housing are covered by caps, which are pushed off the first when ADOS is deployed, then at predetermined intervals. The housings protect the ocean color sensors from fouling until the caps are removed and the sensors exposed.

The SmartSensor thermistor string including the WOTAN case hangs below the ADOS surface float. Figure 2 shows the SmartSensor thermistor string, but not the WOTAN case with its acoustic transducer.

2.1 SmartSensor Temperature and Pressure Thermistor String

Twelve SmartSensors measure temperature with thermistors between 10 and 120 meters. The SmartSensor at 10 meters is located inside the WOTAN; it senses *in situ* conditions with a thermistor in a stainless steel probe. Sea surface temperature is measured with a sensor mounted on the surface float. Depth is measured at 20, 50 80 and 110 meters along the thermistor string with stainless steel absolute pressure transducers. SmartSensors are located Temperature is measured by digitizing the voltage across a thermistor in series with a precision resistor. The SmartSensor temperature measurement is the mean of four digitized voltage measurements made across the thermistor over approximately 200 ms.

SmartSensor pressure measurements are the mean of four 16-bit A/D measurements of the output voltage of the pressure transducers. Measured pressure is the ratio of the digitized measurement divided by the full-scale measurement times the full-scale pressure

Surface layer temperature is sampled once a minute. The MasterModem sends a command to the SmartSensors to take temperature and pressure measurements. These are returned to the MasterModem where the five most recent readings for each sensor are averaged then formatted for the Argos message. Thermistor response in the SmartSensor circuit has been characterized by a table of digitized values stored in the MasterModem for the voltage across the thermistor at temperatures between –5 to 44 degrees. MasterModem software determines the appropriate temperature by linear interpolation.

Figure 2 SmartSensor thermistor string. WOTAN pressure case is not shown.

SmartSensors measure temperature with a thermistor mounted at the just inside the SmartSensor hull. This placement gives the SmartSensor an approximately 20-minute time constant which smoothes rapid temperature fluctuation. Figure 6.12 shows the approach of the 110 and 120-meter SmartSensors to *in situ* temperature. The figure also includes estimated data for the 120-meter sensor with the fitted time constant of 19 minutes.

2.2 Irradiance and Ocean Color

The ADOS surface sphere has a Satlantic ED-20 downwelling irradiance sensor and three Satlantic Lu-50 radiance sensors for measuring light and color at SeaWiFs bandwidths. Satlantic sensors meet specifications for SeaWiFs sensors on drifting buoys.

The ED-20 is mounted in the top of the mast on the ADOS surface sphere and points skyward. The ED-20 is a single channel sensor measuring incident radiation with a cosine response field of view for the spectral range 400 – 700 nm.

Each Lu-50 has three sensors; two of the Lu-50's have discrete sensors for 443, 490, and 555 nm; a third Lu-50 has sensors for 490, 670, and 683 nm. The Lu-50's have a 7-degree field of view and are mounted on the bottom of the sphere aiming 10 degrees from normal. The Lu-50's spectral bandwidth is 10 nm. The three LU-50's are contained in the housings on the bottom half of the surface sphere. Initially, caps cover all of the housing. The first cap is programmed to be removed within an hour after ADOS is started. Caps two and three are programmed to be removed 1 month and three months after the initiation of the ADOS mission.

Incident solar radiation and ocean color are sampled once per minute; the previous 32 samples are averaged every minute, then the mean and standard deviation are placed in the Argos message buffer.

2.3 WOTAN Wind Speed

ADOS measures wind speed by measuring the intensity of ocean noise from 0 to 20 kHz in six discrete frequency bands. A WOTAN unit made by Pacific Gyre, Inc. is installed in a pressure case and mounted on the thermistor string at 10 m. WOTAN digitally samples an acoustic transducer for 300 seconds to record ocean noise. The acoustic information is then processed on a DSP board to determine the acoustic power spectrum, certain components of which are proportional to wind speed. WOTAN communicates to the surface sphere through a SmartSensor inductive modem. WOTAN is queried at 20, 15, 10, and 5 minutes before the hour (arbitrary to starting of ADOS). The Argos message is revised on the hour.

2.4 Wind Direction

ADOS measures wind direction by sensing the heading of the ADOS surface float that is fitted with a vane that causes it to turn into the wind. A Precision Navigation electronic compass in the ADOS surface float senses its orientation relative to magnetic North. The compass is sampled 160 times at a rate of one a second. The headings are binned and the largest bin count is reported as the wind direction.

2.5 Location and Data Transmission

ADOS communicate its data to the user via the Argos satellite data telemetry system. Argos is a LEO system employing 2-3 satellites in orbits inclined 15 degrees from the pole. Argos platform transmitter terminals broadcast at 401.65 MHz. Argos satellite telemetry establishes a position derived from the Doppler shift of the received signal. Incident solar radiation and ocean color, surface layer temperature structure, and wind velocity data are each placed into a 256-bit message, or page, which is transmitted in turn. Argos message formats are described in Figures 6.32 and 6.33. One message is sent every 90 +/- 6 seconds. The block diagram for transmission is shown in Figure 6.3. The user probably can expect to receive daily from ADOS between 10 to 15 pages for each group of sensors.

3 Sea Trials

Scripps Institution of Oceanography and Clearwater Instrumentation, Inc. jointly conducted a cruise off the coast of Santa Barbara, California between 26 and 29 April 2000. Two complete ADOS were deployed along with two Minimets, SIO instruments fitted with barometers and WOTAN acoustic wind sensors. The cruise plan was to deploy the equipment and to heave to at least a mile from them to avoid contaminating the acoustic data obtained by the WOTAN, and to record data with an Argos uplink receiver. The RV McGaw would steam out to the Santa Barbara Channel in the early morning. When we could be reasonably assured of being able to retrieve the instruments in the evening, we would deploy one, or more instruments. At the end of the day we picked up the instruments to ensure that they did not become lost or too dispersed to permit intensive logging data. In addition to logging data on the Argos Uplink receiver, some data also were received by the Argos satellites.

It was noticed that ADOS rode roughly, bobbing considerably as the sea state increased. The motion was characterized by ADOS tipping in the direction of the vane as much as 45 degrees, and then snapping back to vertical. This motion, which had not been observed, previously has been attributed to an unbalanced distribution of mass in the surface sphere, specifically the batteries and wind vane, and reduced tension on the tether caused by supplying some additional buoyancy in the WOTAN pressure case. In future ADOS batteries must be positioned to offset the weight of the wind vane and the buoyancy of the WOTAN case will be reduced.

3.1 Study Area

All of the deployments of ADOS and Minimets were within a small area near 34.27 N and 119 85 W. Approximate locations of deployments and stations for 27 April are typical and are shown in Figure 3. Positions were determined by Service Argos from the equipment transmissions. Tracks leaving the mapped area indicate steaming two and from the deployment area.

Because of the rough conditions, one Minimet and one ADOS were deployed on 26 April, 2000, the first day of the cruise. The second day, conditions were less trying; two Minimets and two ADOS were deployed for the longest duration of the cruise. On the third day, conditions were deteriorating as the day progressed and although all four instruments were deployed, the deployment was shorter.

3.2 PAR and Ocean Color

Both ADOS were in the water and operating before local noon. They remained in the water until 5 pm local time. Data for 25681 and 25688 for 27 – 28 April 2000 are in Figures 4 and 5. The color of the ocean was observed to be primarily blue. Outliers at the beginning and ends of the charts represent intervals before ADOS were launched and after they were brought back on board the McGaw.

3.2.1 Solar Irradiance.

On April 26 ADOS 25688 was in the water for after local noon and irradiance decreases from 125 to less than 25 $\mu W/cm^2/nm/sr$. On April 27 both ADOS were in the water from one hour before local noon to three hours after. Both irradiance sensors peak out at approximately 150 25 $\mu W/cm^2/nm/sr$. On April 28 ADOS 25681 went in the water shortly after sunrise and was removed shortly before local noon; 25688 was launched about three hours after 25681 and came out after a little more than one hour. Agreement between the irradiance sensors is reasonable.

3.2.2 670 and 683 nm (Red).

These bands in red have the lowest values. Values for 670 consistently are lower than those for 683. On April 26 both bands are at their highest, 0.16 to 0.20 $\mu W/cm^2/nm$ respectively, and their difference is greatest, approximately .04$\mu W/cm^2/nm$. On April 27 during the middle hours of the day, both bands hover around 0.1 $\mu W/cm^2/nm$. On April 28 both bands have approximately the same values and are slightly lower than the previous day, although the time was earlier in the morning and the irradiance was not as strong.

3.2.3 555 nm (Yellow).

This band has the highest values reported for the sensors. All 555 sensors compare well between ADOS and on each ADOS where there are two sensors on different LU-50's. The maximum values at midday are .65 $\mu W/cm^2/nm$.

3.2.4 490 nm (Blue).

490 nm cells are in each of the Satlantic LU-50's, so there are three on each ADOS. Blue light levels are run 10% lower than yellow (555 nm). On April 26, the two operational sensors did not track as well as on subsequent days. Maximum values in this band are about 0.55 $\mu W/cm^2/nm$.

3.2.5 443 nm (Indigo).

443 values generally run about 50% of 555 nm values. These bands which are present in two of the LU-50's, did tracked reasonably well. Maximum values attained 0.4 $\mu W/cm^2/nm$.

3.3 Surface Layer Temperature Structure.

Surface layer temperature structure is measured at the sea surface (SST) with a thermistor probe, at 10 meters with a SmartSensor probe mounted on the WOTAN pressure case; and at 11 depths below WOTAN by SmartSensors fitted with imbedded thermistor sensors.

3.3.1 SmartSensor Temperature Response.

While the SST probe has a fast response, the SmartSensor thermistor has a slower response since it is imbedded in the potting material near the outer wall of the SmartSensor. Figure 6 shows the response of SmartSensors at 110 and 120 meters where the temperature structure was stable for the length of the deployments. SmartSensor temperature response was modeled with exponential decay and a response factor of 19 minutes provided the best fit. Fitted data for 120 meters is shown in Figure 6.12. SmartSensors could be fitted with thermistors in probes to increase their response time.

3.3.2 XBT

Two XBT cast were made on April 26 and one cast on April 27. Results of XBT casts are reported in the Figures for surface layer temperature structure.

3.3.3 Temperature Profiles for April 26, 2000.

Figure 7 shows the temperature structure for April 26 for selected times at approximately half hour intervals. XBT's were taken earlier that the profiles reported in the Figure; earlier were available but the SmartSensors had not yet stabilized. The SmartSensor temperatures closest to the time of the XBT's agree well, particularly below 30 meters. SmartSensors failed at 70, 90, 100, 120 meters. These SmartSensors were of an early design that had not been pressure tested and had a design flaw in sealing the pressure sensor fitting. Later models have been tested and have an improved seal which is believed to eliminate the flaw..

3.3.4 Temperature Profiles for April 27, 2000.

Figure 8 shows a much longer record extending for over five hours for 25681. At the surface, the temperature advances from 14.5 C to almost 17 C at 2100 UT. The SST is a probe with faster response than the SmartSensors; even so, there is similar motion at 20 and 30 meters. Notice the stability of the temperature at 120 meters; it varies only a few hundredths of a degree over the time of the observations. The agreement between the XBT and SmartSensors is very good; this is well illustrated by the fit at the greater depths where there is less variability.

3.4 Wind April 27, 2000

ADOS have two acoustic transducers on them. They were deployed along with Minimet drifters built by SIO. ADOS and Minimet use the same systems for measuring acoustic winds speeds. Both also have an electronic compass in the surface float for measuring wind direction by sensing the heading of the surface float. All directions are magnetic; corrected directions have had measured compass error removed.

3.4.1 Winds April 28, 2000.

Minimets and ADOS reported winds from just after 1400 UT until 2000. During this time the wind turned from northwest to west by southwest (Figure 9). All wind heading are within reasonable agreement.

Acoustic power results are presented for Minimet 15941 and ADOS 25681-0, 25681-1, and 25688-1 in Figures 10 and 11. Results for the dual sensors on ADOS 25681 give reasonable agreement.

4 Conclusions and Future Work

ADOS development can be considered complete now that fully functional systems have been deployed and operated for a limited period of time. Correctable problems were found with SmartSensors and the ADOS surface sphere. A leak was found in some of the early SmartSensors that were not pressure tested. Later SmartSensors have been pressure tested and fitted with seals to correct the problem. The ADOS surface float needed better mass distribution of batteries and less buoyancy in the subsurface WOTAN housing. These changes have been made.

4.1 ADOS April 2001 Deployment.

What remains to be done is to deploy ADOS to obtain sufficient data to assess long-term viability and to inform sampling procedures, especially for removal of ocean color sensor housing. Deployments in 2001 will be made after incorporating any necessary changes in measurement techniques and sampling strategies.

5 Acknowledgements

We are pleased to acknowledge the generous support of NASA through SBIR Contract NAS5-98056 and purchase orders from the Scripps Institute of Oceanography.

6 Figures and Tables

Figure 3. Argos Positions 27 April 2000
Universal Time

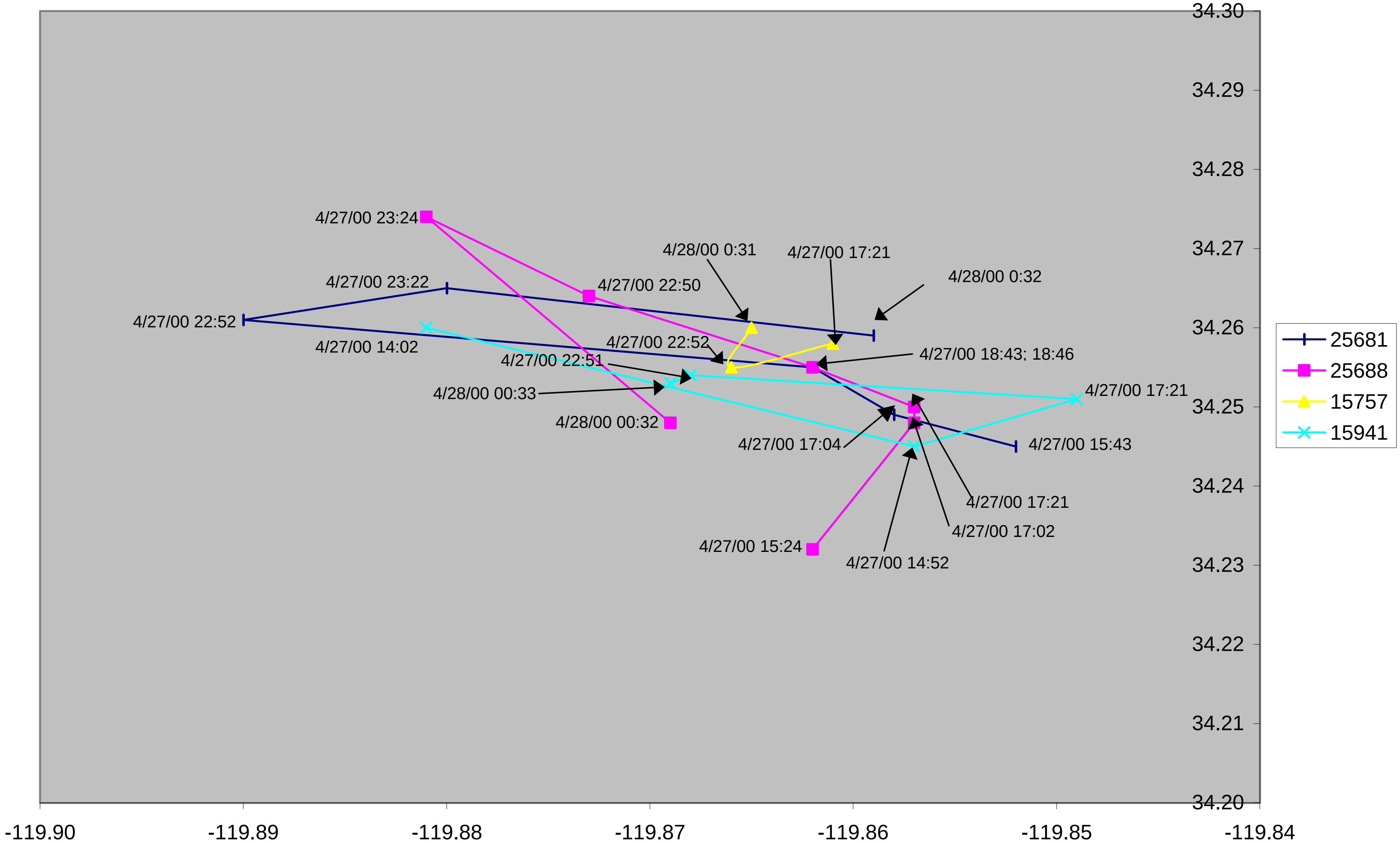


Figure 4. 27 - 28 April 2000
25681 PAR and Ocean Color

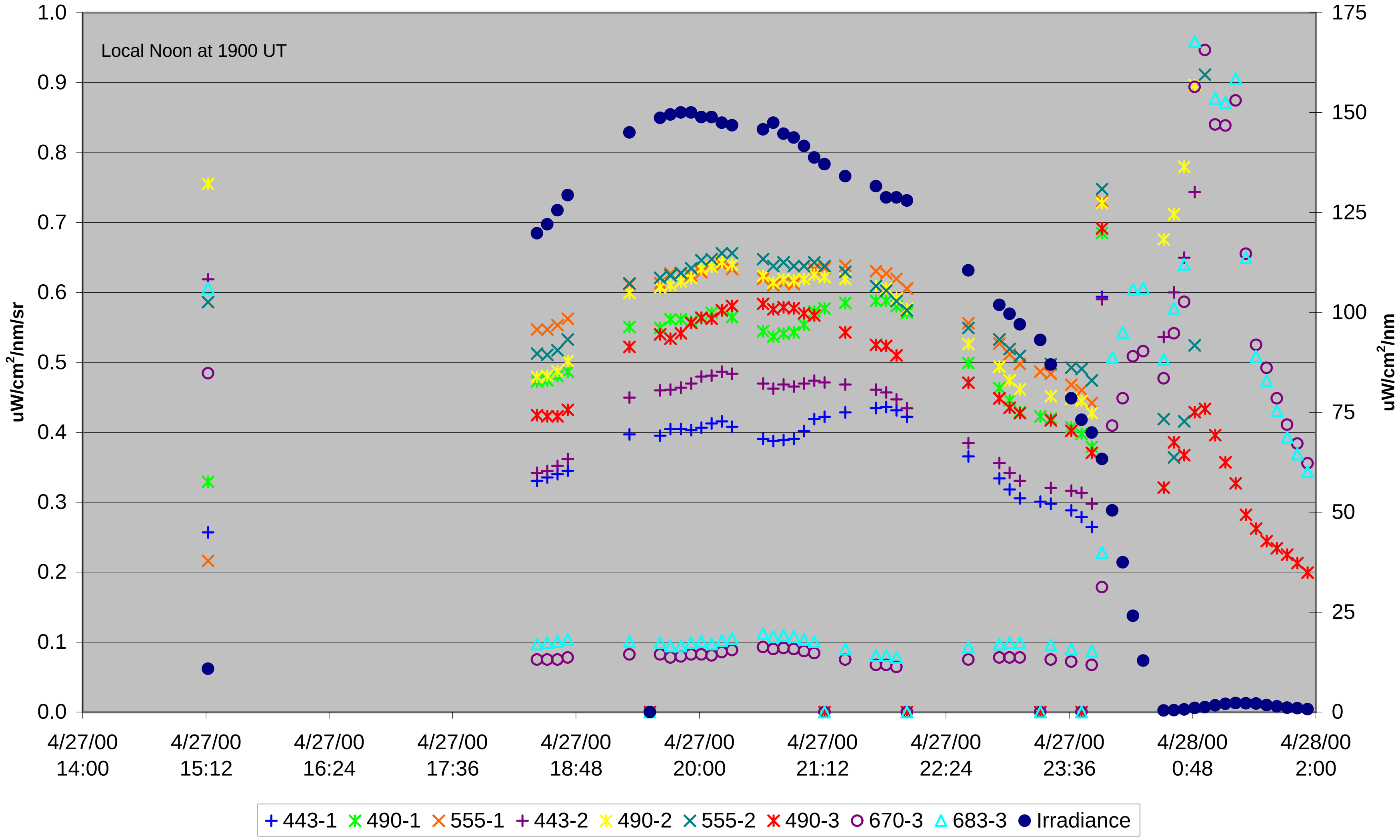


Figure 5. 27 - 28 April 2000
25688 PAR and Ocean Color

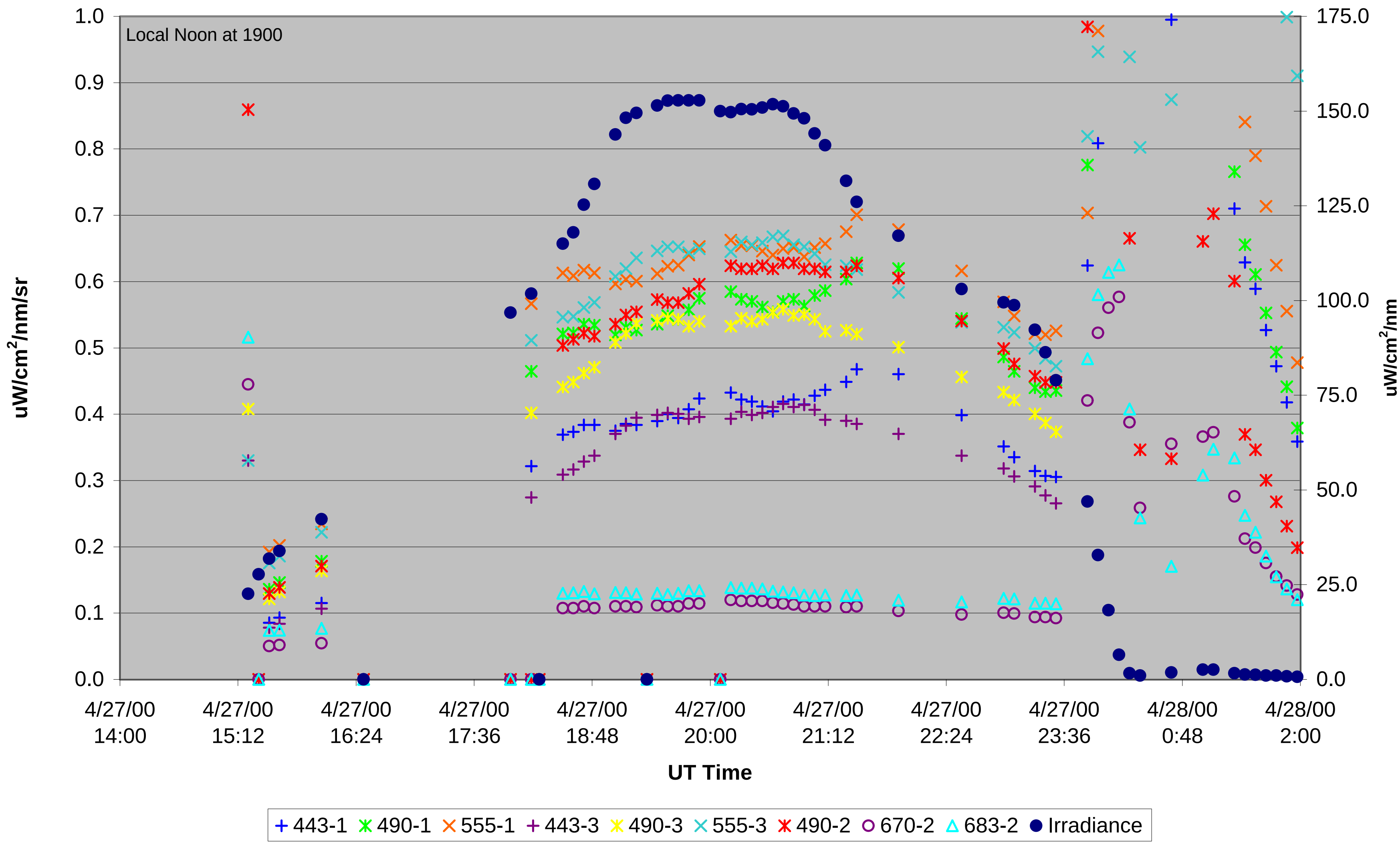


Figure 6. Temperature Response 25681
28 April 2000

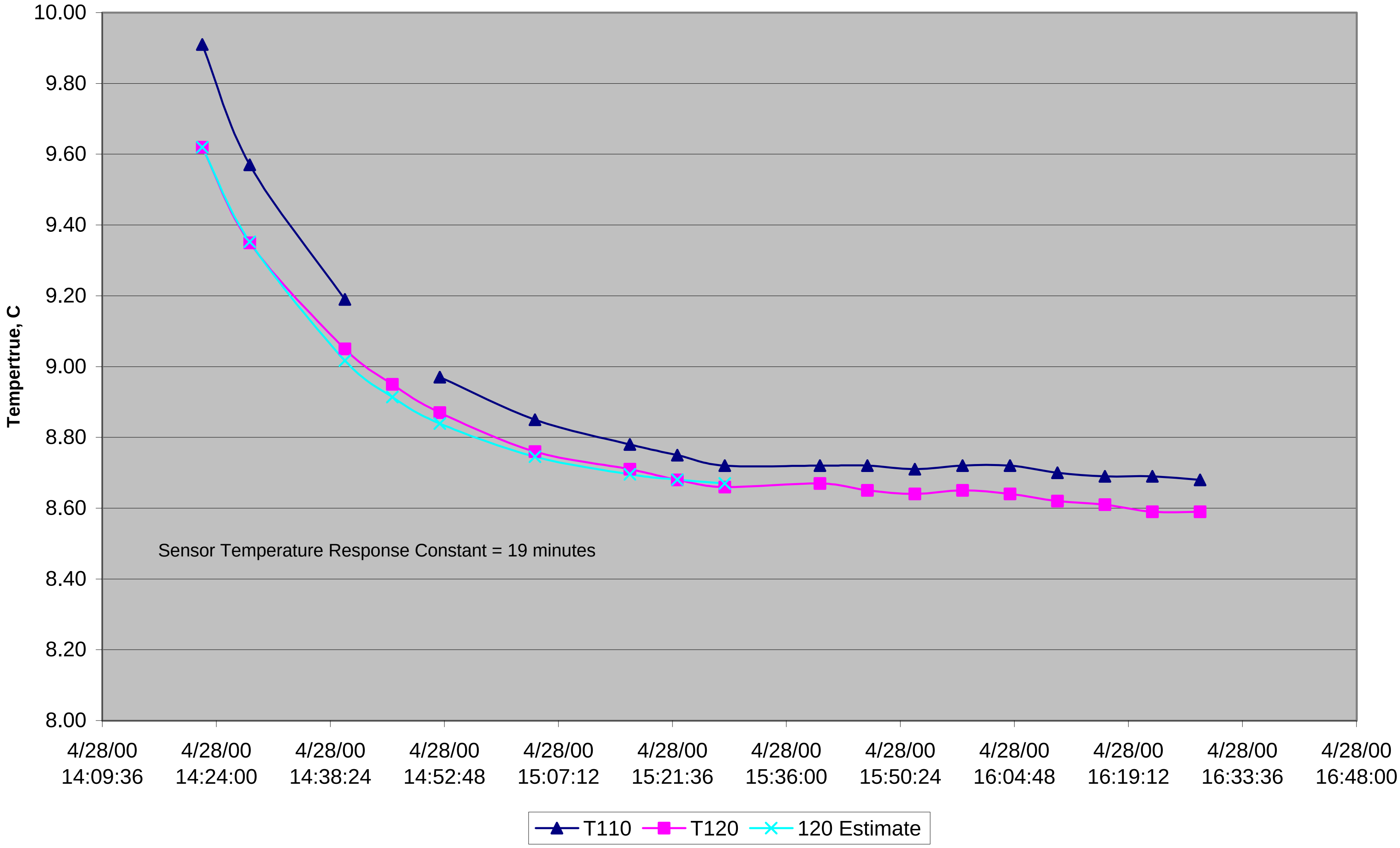


Figure 7. 25688 Temperature Profile
26 - 27 April 2000 UT

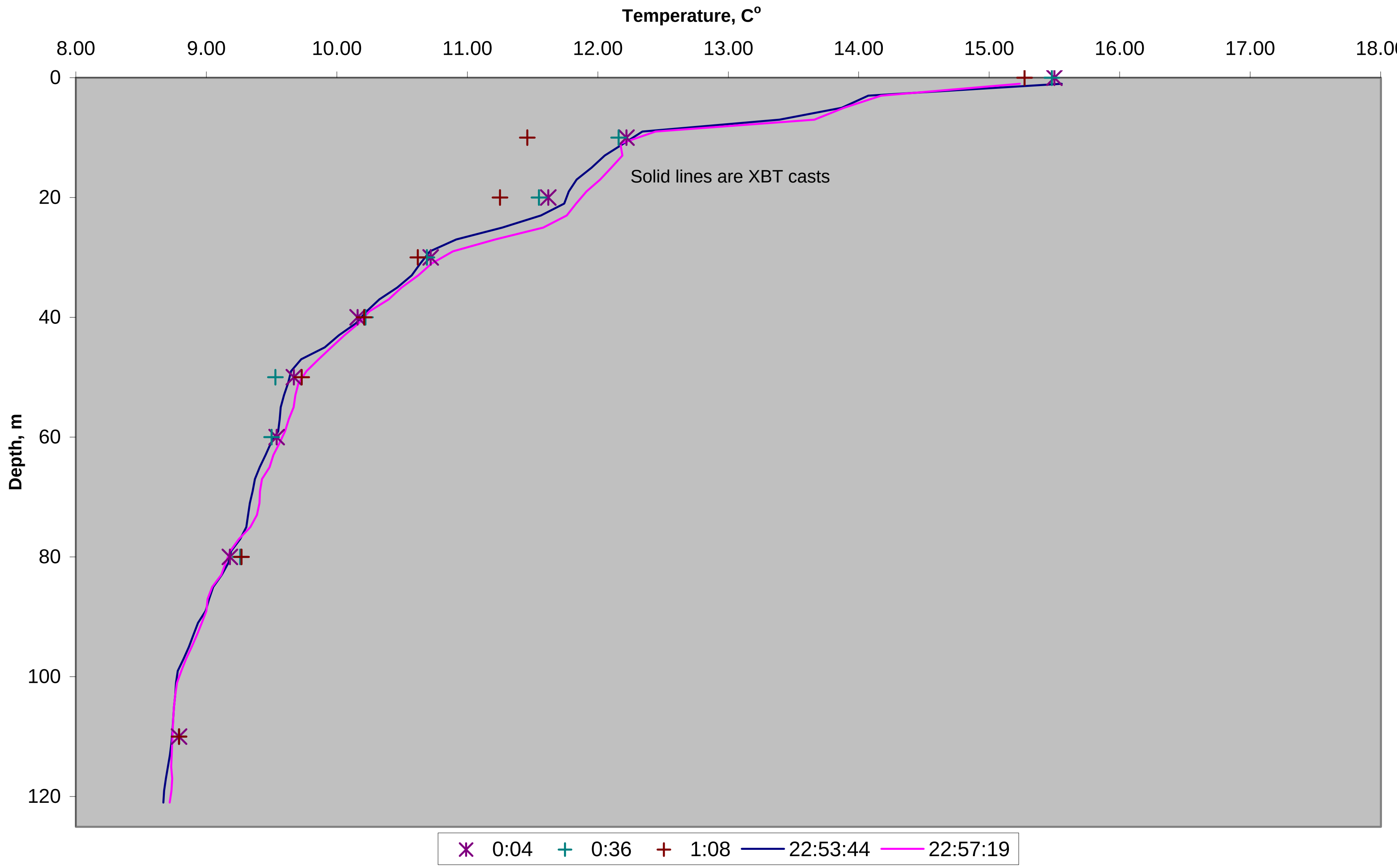
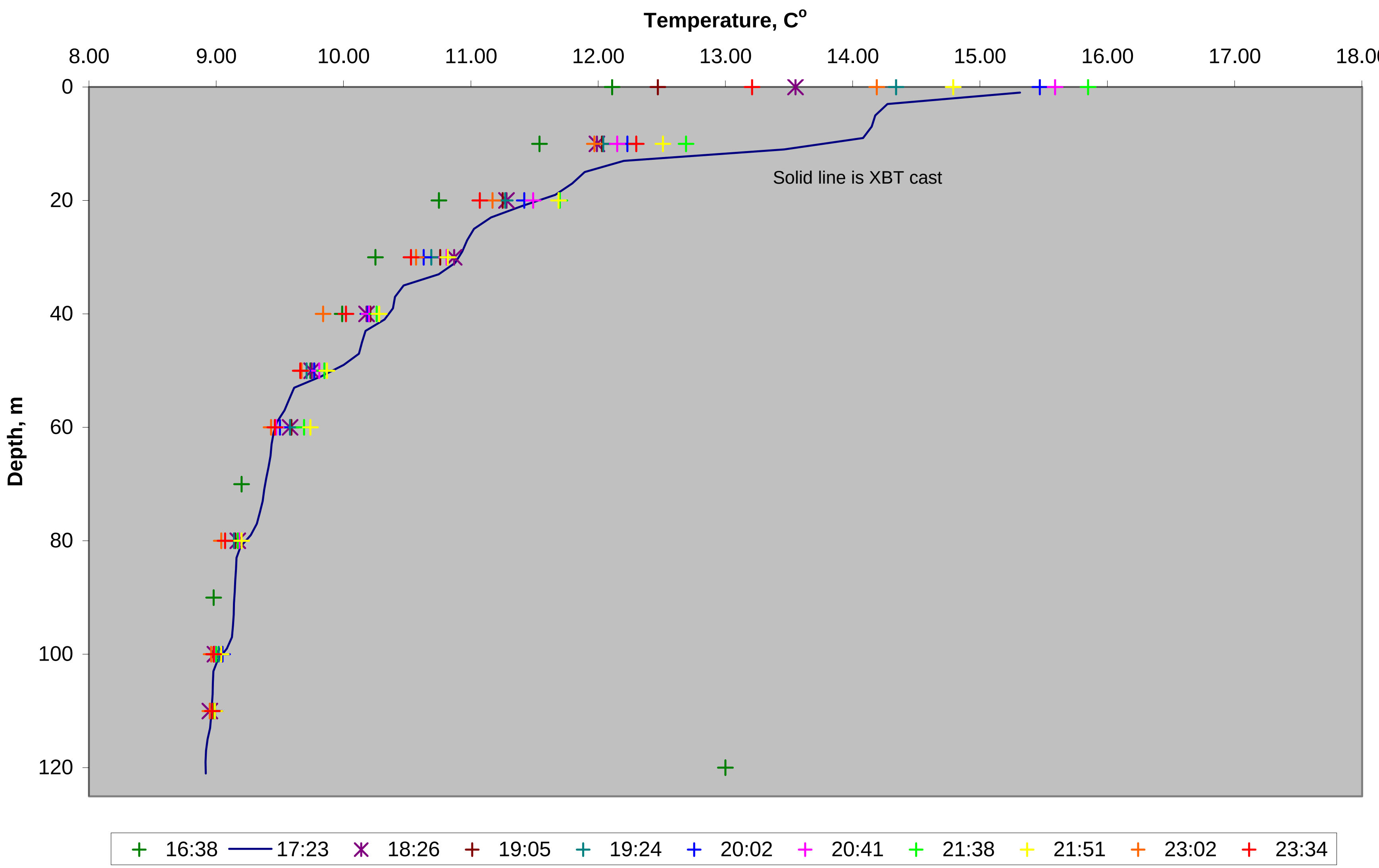


Figure 8. 25688 Temperature Profile
27 - 28 April 2000 UT



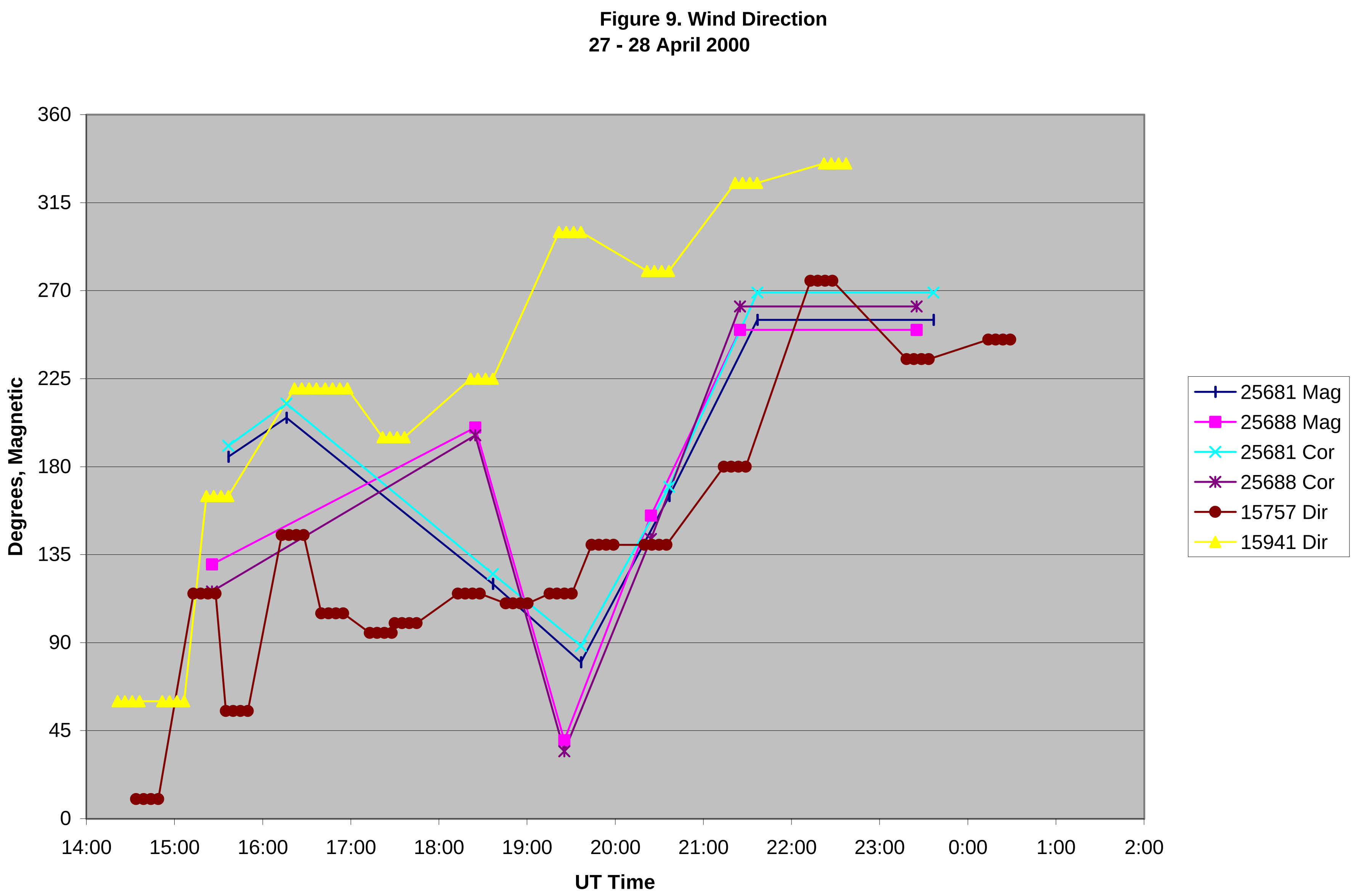


Figure 9. Wind Direction
27 - 28 April 2000
Degrees, Magnetic
0
45
90
135
180
225
270
315
360
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00
1:00
2:00
UT Time
25681 Mag
25688 Mag
25681 Cor
25688 Cor
15757 Dir
15941 Dir

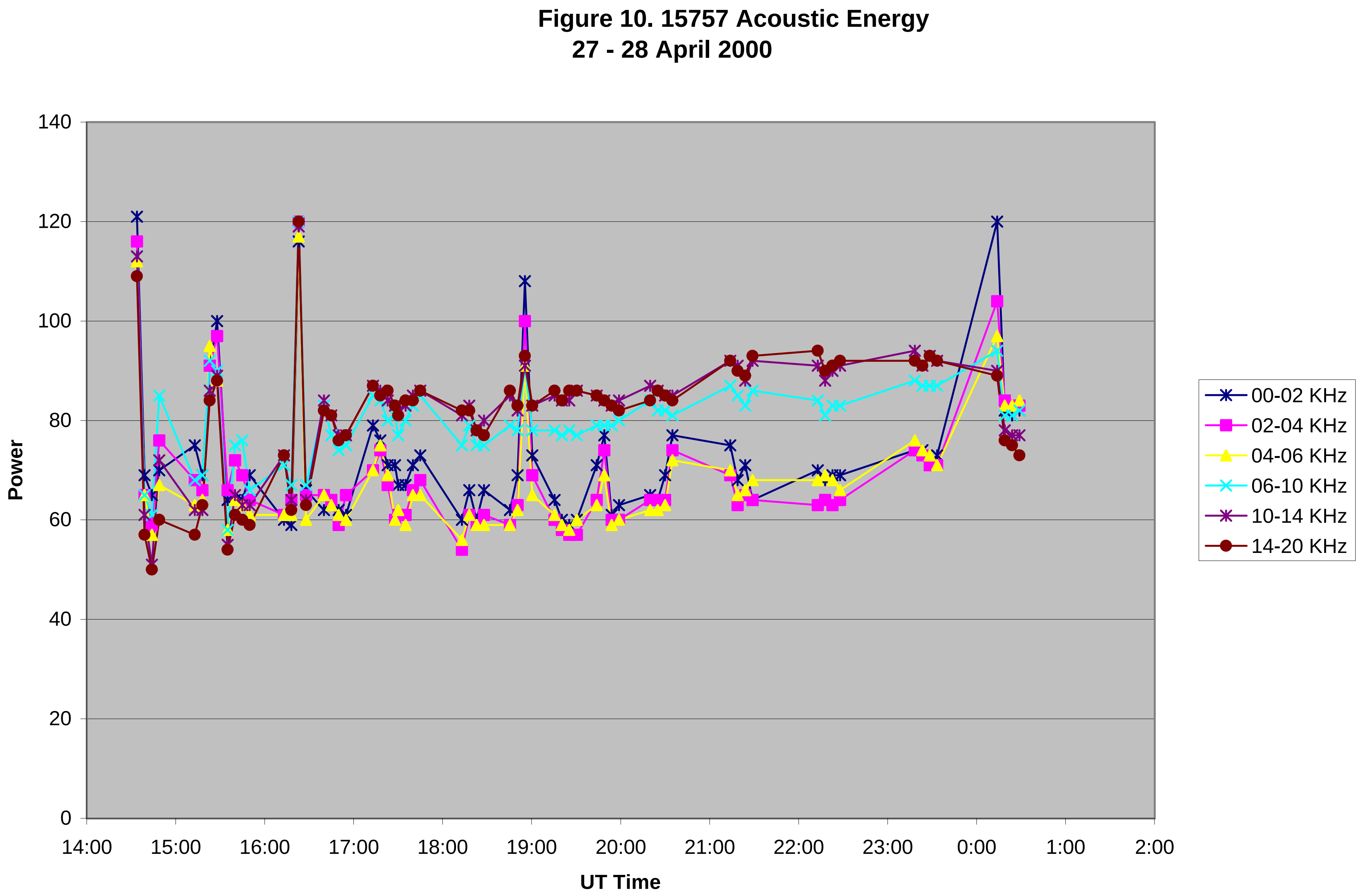


Figure 10. 15757 Acoustic Energy
27 - 28 April 2000
Power
UT Time
0
20
40
60
80
100
120
140
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00
1:00
2:00
00-02 KHz
02-04 KHz
04-06 KHz
06-10 KHz
10-14 KHz
14-20 KHz

Figure 11. 25681 - 0 Acoustic Power
27 - 28 April 2000