AN INSTRUMENTAL HISTORY OF THE SCRIPPS VISIBILITY LABORATORY

Kenneth J. Voss
University of Miami
Physics Department
Coral Gables, Fl. 33124

Roswell Austin
SDSU CHORS
6505 Alvarado Road, Ste 206
San Diego, CA 92120

The Visibility Laboratory (VisLab) at Scripps Institution of Oceanography was a center for the development of instruments in ocean (and atmospheric) optics in the United States and the world. Several of the data sets and papers still being used in current research are based on these instruments and many current instruments are direct descendents of these instruments and ideas. In this extended abstract we will give a brief overview of the laboratory history and then name some of the instruments that were developed at the VisLab.

OVERVIEW OF VISLAB HISTORY

The Visibility Laboratory, VisLab, was founded at MIT in 1939 by Dr. Seibert Quimby Duntley and MIT physics Chair Dr. Arthur Hardy. Initial laboratory funding came from the Works Progress Administration (WPA), and some of the earliest work dealt with problems of camouflage and misdirection in the event of an anticipated aerial bombardment of Boston. When World War II started, the National Defense Research Committee (NDRC) funded the laboratory and expended research into target location, visibility of submerged objects in the sea, the location of enemy submarines and recovery of downed pilots.

In 1948 an ad hoc working group of the National Research Council recommended that a group, headed by Dr. Duntley, be funded to investigate visibility issues in ocean water. This added to the ocean optics focus of the laboratory. With the increased emphasis on ocean optics problems and at the urging of the Navy the Visibility Laboratory moved to Scripps Institution of Oceanography (SIO) in 1952. It was located in temporary buildings at the Naval Electronics Laboratory on Point Loma, San Diego. The original statement of Work in the Navy contract was broad: essentially “Become a center of expertise in the solution of Visibility Problems”. At SIO the VisLab investigated many aspects of visibility, ocean optics and atmospheric optics. Since this is an Ocean Optics conference we will concentrate on the ocean optics aspects of the work.

As part of the NRC recommendations, a field station was founded on Diamond Island, Lake Winnipesaukee, New Hampshire. The NRC committee felt that many aspects of in-water visibility would be transferable from here to the ocean, and the measurement program would progress more quickly in a protected, friendlier environment. Much of the early Vislab research on visibility and the transmission of natural and artificial light was done during summers at the Diamond Island site.

The VisLab was totally supported by contracts and grants from the Navy, Air Force, and NASA throughout its history. The size of the VisLab varied through the years from 20-30 to over a hundred employees. The lab had machinists, designers, and engineers along with the scientists and several names associated with the VisLab stand out.

Dr. John Tyler came with Duntley from MIT and was a foremost experimentalist in the group. Many of the papers describing the early optical oceanographic instruments bear his name. The classic set of radiance distribution measurements from Lake Pend Oreille were taken with an early photometer under his guidance.

Dr Rudolph Preisendorfer was at the laboratory for many years developing ideas on hydrologic optics, atmospheric optics and radiative transfer. He brought many of these ideas together in his 6 volume treatise Hydrologic optics (based on many VisLab and SIO Reports).

Mr. Ted Petzold was a mechanical engineer who designed many of the underwater instruments (such as the VisLab Spectral Transmissometer, and General Angle Scatter Meter). The classic report on light scattering in ocean water by Petzold (1972) is still the experimental basis for many radiative transfer studies and models.

Dr. Raymond Smith started his ocean optics career at the VisLab working with John Tyler. While at the lab, Ray extended the work of Tyler in radiance distribution measurements and ocean color remote sensing. During his time at the VisLab, Ray invented the term "Bio-Optics", which is used everywhere today to describe the connection of ocean optics and biological oceanography.

One of the authors (Roswell Austin) was also a central figure in the development of many of the in-water ocean optics instruments including the transmissometer, a small angle forward scattering meter, ALSCAT, and many others. In addition, Ros was heavily involved with ocean color remote sensing during the CZCS era.

The above descriptions neglect mentioning the work done by the many other engineers (such as Gerry Edwards, and Richard Ensminger to name a couple) and technicians who played a role the development and fielding of these instruments.

INHERENT OPTICAL PROPERTIES

In describing the instrumentation it seems appropriate to split the instruments into categories based on Preisendorfers work. We will start with a summary of the instruments that measure the inherent optical properties: those that are independent of the radiance distribution in the water and are fundamental to radiative transfer.

Transmissometers

It is difficult to find a record of the first transmissometers designed and built at the Visibility Laboratory. The earlier designs found in the literature were collimated beam types such as the transmissometer used in the water clarity meter. (Austin, 1959). But there were many other similar transmissometers available at the time, an example is shown in Tyler et al.(1959).

In later years the transmissometer optical design shifted from collimated to a cylindrically limited design. In this type of transmissometer , rather than focusing the projector at infinity, the projector field stop is focused at the receiver entrance aperture (in air). The receiver then is set to focus the projector aperture onto the receiver field stop when the instrument is in the water. In this way, in both air and water, all of the light from the projector that is not scattered or absorbed is collected by the receiver. The advantage of this system is that it is more efficient at using an extended source, such as a lamp, then a collimated system. While the small angle acceptance is easily defined for a collimated system, this error term is more difficult to define in a cylindrically limited system. Basically any light that once scattered still appears to be coming from the projector aperture is accepted. Thus the scattering angular range that is accepted depends on the individual light rays initial path. In any case, the scattering correction can be calculated, and is similar to that of a collimated system with a 1 degree acceptance angle. (Voss and Austin, 1993).

This optical design was the basis for many different transmissometers for which the electronics or spectral range varied. Examples were a null-balance transmissometer (Petzold and Austin, 1968) and the Vislab Spectral Transmissometer, VLST (Shannon, 1974). There were many other variations of this instrument, built in combination with other sensors, such as a microprocessor controlled transmissometer (Austin and Ensminger, 1978) that had both a transmissometer and up/downwelling irradiance. This was also the instrument design that was used commercially in the Martek Transmissometers.

Light Scattering

The volume scattering function is a fundamental parameter needed to describe the transmission of light in the ocean. The VisLab had an extensive history of making instruments to measure this parameter both in-situ and in the laboratory, beginning with the work of Tyler. The first description of a VisLab design for a submersible scattering instrument was by Tyler and Richardson (1958). This instrument used a collimated illumination beam, similar receiving optics, and a Waldram stop (Waldram, 1945, Middleton, 1952). The Waldram stop maintains a constant scattering volume over the angular range of the instrument. Measurements performed with this instrument were detailed in a later paper (Tyler, 1961).

In 1964 a scattering meter is described which has features used in the later instruments (Tyler and Austin, 1964). This instrument was designed to be mounted on the USN deep submersible TRIESTE, thus operate at 1430 atm. This instrument had collimated optics for both source and collector, however the electronic circuit on the receiver was a version of a Sweet circuit (Sweet, 1946, 1950). This circuit handles the large dynamic range experienced in an oceanic volume scattering function by varying the gain of the receiver circuit. Effectively the receiver photomultiplier tube voltage is varied to maintain a constant photo-current, and the voltage used to obtain this photo-current is inversely related to the light flux on the photomultiplier tube. Since the gain of the photomultiplier is logarithmically related to the applied voltage, this circuit can work over a very large dynamic range. Calibration consists of relating the variation of this applied voltage with incident flux (effectively a linearity calibration).

Probably the most famous scattering instrument built at the VisLab was the General Angle Scattering Meter, GASM. This instrument was the basis for the large angle measurements reported in Petzold's famous scattering paper, “Volume Scattering Functions For Selected Ocean Waters” (1972). This instrument has cylindrically limited optics for both the projector and aperture, and a Sweet circuit controlling the receiver.

Since the Petzold (1972) reference this instrument was fitted with a spectral filter wheel allowing 6 separate spectral bands to be measured. This instrument is still working and being used (Voss and Phinney, 2002).

Along with the above instruments for measurement of large angle scattering (>10 degrees), several small angle scattering instruments were developed. One early instrument, is described in Petzold (1972). This instrument allowed measurement of 3 small scattering angles (nominally 1.5, 3, and 6 milliradians) and beam transmission at a single wavelength. The instrument had a collimated projector and a collimated receiver, and different annular stops were placed over the receiver to determine the scattering angle collected. It had a fixed 0.5 m scattering path.

A follow-on instrument also measured the attenuation coefficient and small angle volume scattering function (ALSCAT), but did so at several different wavelengths (Austin and Petzold, 1975). This instrument had several features that improved on the earlier instrument including 10 separate spectral filters and the ability to vary the pathlength from 0.5 m to 2.0 m.

MEASUREMENT OF THE LIGHT FIELD

The VisLab had several instruments that were important in understanding the in-water light field and the structure of this light field. We will just mention the two most important areas.

Irradiance

The most important instrument, for the literature was the Scripps Spectroradiometer (Tyler and Smith, 1966). The optical design of this instrument was based on a double Ebert monochromator. Over time the collection optics of the instrument were improved (Smith, 1969), and measurements using this instrument in many varied environments are detailed in Tyler and Smith, 1970. The irradiance collector design was used in many commercial instruments, such as those by Biospherical Instruments.

There were many other instrumental designs devised at the Visibility lab, measuring irradiance and radiance, with monochromators and filters. Another example in the literature was the design of a scalar irradiance meter that used fisheye optics (Smith and Wilson, 1972).

Radiance distribution

Another area where older results from the VisLab are still being referenced is in the measurement of the in-water radiance distribution. The earliest instrument built at the VisLab to measure this parameter was the Scripps radiance photometer (Duntley, 1955). It was this instrument that was used to produce the often cited Lake Pend Oreille data set in 1957 (Tyler, 1958). The next advance in radiance distribution measurements was the development of the photographic fisheye camera system (Smith, Austin, and Tyler, 1970). This instrument allowed a very rapid measurement of the entire radiance distribution by using two fisheye cameras, one looking up and one looking down, to capture the entire radiance distribution in the two images. However data analysis with this system involved densitometry of the photographic film and was difficult. The next advance in the measurement of the radiance distribution was the electronic radiance distribution camera system (Voss, 1989). In this system an electronic CID camera and a remotely controllable filter wheel replaced the photographic camera to allow measurement of the spectral radiance distribution, without the problem of film densitometry. The development of this system has continued into the present.

CONCLUSION

This is just a short example of some of the instruments that were developed at the laboratory. As could be guessed from the title, the VisLab was also deeply involved with aspects of visibility and made many more instruments that measured quantities central to these studies. These instruments included beam and point spread function systems, long pathlength transmissometers, and water clarity meters. Extensive studies of visibility and diver visibility were performed, and the theory of contrast transmittance was developed. Other work was performed on imaging devices, such as the TVI system (Duntley et al., 1974). This system used a laser scanning system and remote receiver to image in-water objects.

As stated earlier, this abstract focuses on the ocean optics aspects of the VisLab, there was just a research program just as extensive on atmospheric optics and visibility problems, including work in the early manned space missions. Overall the VisLab was a very dynamic and important organization in the field of environmental optics.

REFERENCES

Austin, R. W., 1959, SIO. Ref. 59-9.

Austin, R. W. and R. L. Ensminger, 1978, “A microprocessor controlled instrument for measuring the transmittance and reflectance of ocean waters”, SIO Ref. 78-23.

Austin, R. W., and T. J. Petzold, 1975, “An instrument for the measurement of spectral attenuation coefficient and narrow angle volume scattering function of ocean waters”, SIO Ref. 75-25 (1975).

Duntley, S. Q., R. J. Uhl, R. W. Austin, A. R. Boileau, and J. E. Tyler,1955, “An underwater photometer”, J. Optical Soc. Of Am., **45**, 904.

Duntley, S.Q., R. W. Austin, R. L. Ensminger, T. J. Petzold, and R. C. Smith, 1974, “Experimental TVI System Report”, Visibility Laboratory Technical Report 74-1.

Petzold, T. J., 1972, “Volume Scattering Functions for Selected Ocean Waters”, SIO Ref 72-78.

Smith, R. C., 1969, “An underwater spectral irradiance collector”, J. Marine Research, **27**, 341-351.

Smith R. C., and W. J. Wilson, 1972, “Photon Scalar Irradiance”, Applied Optics, **11**, 934 – 938.

Smith, R. C., R. W. Austin and J. E. Tyler,1970, “An oceanographic Radiance Distribution Camera System”, Applied Optics, **9**, 2015 – 2022.

Sweet, M. H.,1946, Electronics, **19**, 105.

Sweet, M. H., 1950, J. Soc. Motion Picture Television Engrs., **54**, 35.

Tyler, J. E., W. H. Richardson, and R. W. Holmes,1959, “Method for obtaining optical properties of large bodies of water”, J. Geophys. Res. **34**, 667 – 673.

Tyler, J. E. and W. H. Richardson, 1958, “Nephelometer for the Measurement of Volume scattering function in-situ”, JOSA **48**, 354-357.

Tyler, J. E.,1961, “Measurement of the Scattering Properties of Hydrosols”, J. Optical Soc. Of Am., **51**, 1289-1293.

Tyler, J. E., 1964, “A scattering meter for Deep water”, Applied Optics, **3**, 613- 620.

Tyler, J. E., and R. C. Smith, “Submersible Spectroradiometer”, 1966, J. Optical Soc. Am., **56**, 1390-1396.

Tyler J. E., and R. C. Smith, 1970, Measurements of Spectral Irradiance Underwater, Gordon and Breach, New York, pp. 103.

Tyler, J. E.,1958, “Radiance Distribution as a function of depth in the Submarine Environment”, SIO Ref 58-25.

Voss, K. J., 1989, "Electro-optic camera system for measurement of the underwater radiance distribution", Optical Engineering, **28**: 241-247.

Voss, K. J. and R. W. Austin, 1993, "Beam Attenuation Measurement Error Due to Small -Angle Scattering Acceptance", J. Atmosph. and Ocean. Techn., **10**: 113-121.

K. J. Voss and D. Phinney, 2002, “Light scattering measurements in the coastal zone, Gulf of Mexico”, 2002 AGU Ocean Sciences Meeting,, Honolulu, Hi., February.

Petzold, T. J. and R. W. Austin, 1968, SPIE Underwater Photo-optical instrument application proceedings, 133-137.

Shannon, J. G., 1974, . “Light Attenuation Measurements with a Unique Transmissometer System,” Proc. Ocean-74, IEEE International Conference on Engineering in the Ocean Environment, Vol **2**. Halifax, N.S..

Waldram, J. M. 1945, Trans Illum Eng. Soc **10**, 147 – 188.

Middleton, W. E. K., 1952,Vision through the Atmosphere, University of Toronto Press, Toronto, 1952.