Taking Rain Gauges to Sea

Global Climate Monitoring Gets New Tool: Rain-Induced Optical Scintillation for Measuring Precipitation at Sea

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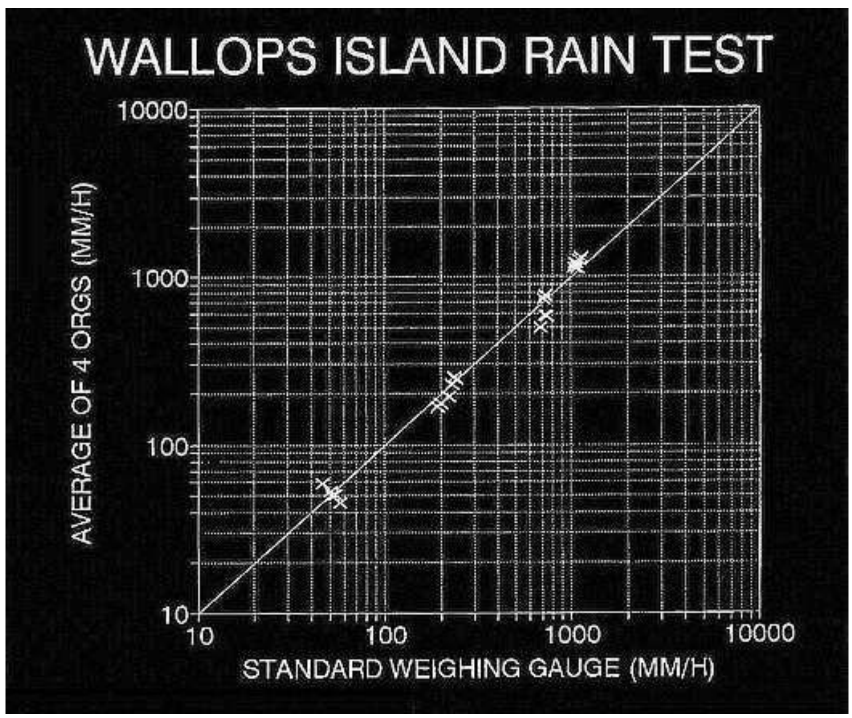
Ocean instrumentation and measurement systems for precipitation parameters are critically needed to satisfy global-scale climate monitoring requirements. The major source of data will be estimates of rainfall amount derived from threshold infrared (IR) histograms of geostationary satellite observations. Since these are space-based indirect measurements, it will be necessary to assess the validity of these estimates through some means using ground based measurements over land and ocean test sites where rainfall parameters are recorded.

At the present time, one of the major problems of the global precipitation monitoring system is the lack of ocean-based precipitation data. Reliable precipitation measurements at sea have been almost impossible until the recent development of non-contacting, electro-optical techniques.

Traditionally, rain measurements are made by some form of collecting device. The mechanism by which the rain amount was gauged varied from simple straight-walled containers with a measuring stock to more complicated devices that weigh the amount of rain in a bucket.



Above graph shows excellent correlation between four optical rain gauges and the standard weighing gauge during the artificial rain test program at Wallops Island.

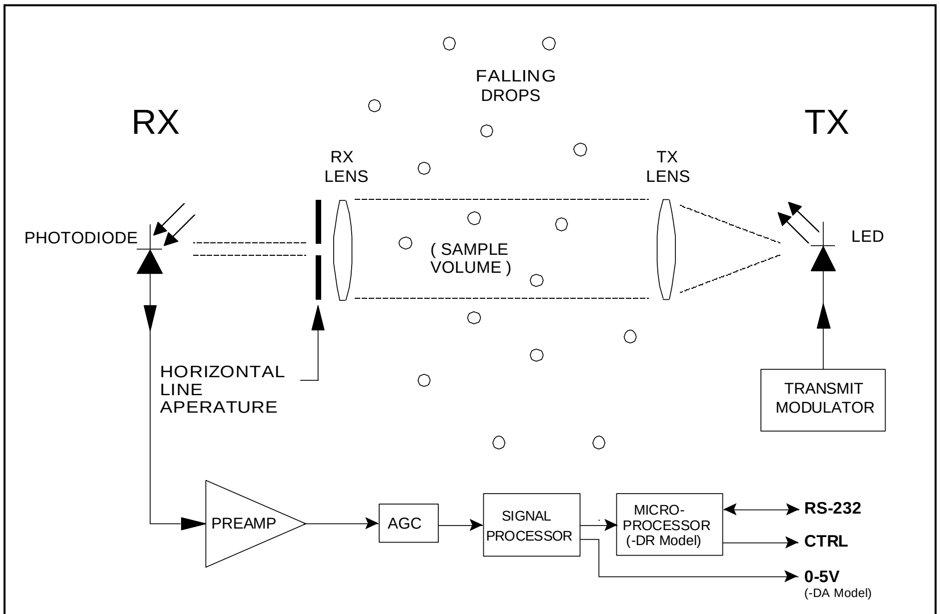
Like any sensor, each of these collecting-type of rain gauges has advantages and disadvantages. Traditional gauges that collect precipitation suffer from systematic and random errors related to wind field deformations, surface wetting, evaporation, splash-in/ splash-out, orifice clogging due to insects, bird nesting and droppings, wind-blown debris, and limited dynamic range. The biggest disadvantage however is their inability to operate on a moving ship or buoy. Quite simply, they don’t work on a platform subject to sea-induced vibration, pitch, and roll.

A tipping bucket rain gauge that is tilted as little as 3° off axis can experience an individual tip error as large as 16 percent due to the unbalance of the bucket. Accurate measurements with a traditional type of rain gauge require a firm, level, mounting surface.

Instantaneous Rainfall Parameters

To provide an *in-situ* precipitation sensor for unattended ocean observation sites, Scientific Technology Inc. (ScTI) (OSi) engineers developed a technology to measure surface instantaneous rainfall parameters using rain-induced optical scintillations. The technology is practical for unattended automated weather observations over platforms such as ships and data buoys to provide critical ground truth to satisfy global-scale climate monitoring requirements.

The electro-optical sensor measures precipitation rate based on the principle of rain-droplet-induced optical scintillation. Now in full production, the ScTI (OSi) ORG™ and Mini-ORG™ sensors overcome the limitations of traditional electromechanical gauges. Both sensors are used on ships and buoys in both research ground-truth networks as well as operational mesoscale networks. The ScTI (OSi) optical rain gauge uses a short separation between the source and receiver (less than 1/2 meter) enabling the entire instrument to be mounted on a single pedestal. This ensures ease of handling and eliminates the need for field alignment of the optics. The compactness and high mobility of the system is ideal for ocean platform deployment.



Optical Rain Gauge Block Diagram

Rain rates can be obtained by observing the occurrence of scintillations induced by falling raindrops randomly located along an optical path. When an optical wave front meets an object in the sample volume, a shadow will be cast on the receiving plane. The movement of the shadow will cause the fluctuation of the receiving light intensity (optical scintillation).

By analyzing the rain-droplet-induced optical scintillation, rain parameters can he obtained. A near-infrared source is used to obtain the signature of the raindrop-induced scintillation. From that, optimum parameters can he obtained to quantitatively measure rain parameters. It was demonstrated that a horizontally oriented line-detector is best suited for precipitation detection because it is sensitive to the vertical motion in which the precipitation falls but not to horizontal motion.

Artificial Rain Testing

Four ScTI (OSi) optical rain gauges were tested at the National Aeronautics & Space Administration test site at Wallops Island, Maryland from May 24 to May 28, 1989. Among these, ORG 1, ORG 2 and ORG 3 are identical units except the time constant of ORG 1 was modified to 3 seconds. ORG 2 and ORG 3 remain the typical 10-second time constant. ORG 4 is a Mini-ORG with a 15-second time constant.

The ORGs were set in the middle of the artificial shower range surrounded by tipping bucket rain gauges and one weighing rain gauge. Nominal rain rates of the artificial nozzles were set to 50 millimeters/hour, 200 mm/hr, 700 mm/hr, and more than 1,000 mm/hr. The averaged rain rates of all four ORGs versus the weighing gauge measurements were plotted. Each point indicates the average rain rate of each completed test run at one of the above rain rates. The general agreement is quite good though with some minor scatter of the data points. We believe that the scatter of the data is mainly caused by spatial variation of the test field. With this we can conclude that the calibrations of the ORGs are consistent and maintained as stated in the specification.

A comparison of all the rain rates measured by the standard weighing gauge (SID), optical rain gauges, and tipping bucket rain gauges (TB) are shown in the accompanying table. For rain rates up to 60 millimeters hour, the performance of both ORGs and TBs are reasonably close with an average of 7 percent difference for ORGs and 9 percent for TBs compared to weighing gauges. The measurement variations are likely caused by the non-uniformity of the artificial rain field. For rain rates heavier than 200 millimeters hour, the ORGs maintain excellent accuracy up to the limit of the rain rate test of 1,300 millimeters hour. However, the TBs' performance is definitely not acceptable even for rain rates in the 200- to 300-milhinieter hour range. For even heavier rain rates, the TBs completely failed.

WALLOPS ISLAND RAIN TEST

	0-60 mm/hr	200-300 mm/hr	600-800 mm/hr	1000-1300 mm/hr
STD	53	236	721	1072
ORG 1	43	222	771	1221
ORG2	48	244	691	1266
ORG3	54	240	710	*995*
ORG4	*53*	*254*	856	1091
ORG AVG	50	240	757	1143
ORG AVG ER	*7%*	2%	5%	79/
TBI	48	115	596	TB
TB2	*52*	206	691	no
TB 3	49	125	32	longer
TB4	*44*	193	522	working!
TB AVG	48	160	441	N/A
TB AVG ER	9%	329/	399/	

In order to validate the artificial rain test results, a series of tests were conducted with natural rain. Reliable calibrations were obtained at both the Wallops Island facility and at the equatorial test sites where extremely heavy rain rates can he expected. The graph shows a comparison of an optical rain gauge with a high precision weighing gauge as the standard. The confidence gained in the optical rain gauge as a result of the artificial and natural rain tests has allowed full-scale deployment of gauges. For the first time, open ocean surface rainfall measurements have been made far removed from land influences and without the problems associated with shipboard measurements.

Real World Applications

NASA engineers are conducting several precipitation research experiments worldwide. In these programs, ScTI (OSi) optical rain gauges are being used to provide the ground-truth validation of the remote sensing techniques being developed by NASA. Reasons for the interest in worldwide precipitation are many. Beyond the desire to improve our understanding of the ocean-atmosphere interface, there are very practical applications that affect everyday lives. For example, extremely heavy rain as found in the tropics can cause a reduction in maximum lift coefficient of at least 10 to 20 percent of an aircraft. Tests have shown that the transition from dry wing to wet wing occurs in seconds. This short transition period leads to the need for measurement of rain intensity at high resolution on the order of several seconds. The optical rain gauge is the only instrument capable of providing the reliable, high resolution rain rate measurements on board ships and buoys to provide the validation of radar Z-R relationship and threshold IR histograms of geostationary satellite observations.

The Tropical Ocean Global Atmosphere / Coupled Ocean-Atmosphere Response Experiment (TOGA-COARE) is an international program designed to provide a comprehensive set of meteorological and oceanographic data from the western Pacific warm pool. This pool of warm water, extending from 10°N to 10°S latitude and 140° to 180°E longitude, is critical to the development of the climate of the entire Pacific basin and beyond. The COARE experiment focused on three components—the atmosphere, the ocean, and the interface between the two.

A four-month intensive observing period (IOP) was conducted from November 1992 to February 1993 by scientists from IS nations. The IOP used the full spectrum of observing techniques to determine how moisture, momentum, and heat move between the ocean and atmosphere. Instrumentation consisted of island-based surface measurements including radar, atmospheric profilers, sounders, disdrometers, and ScTI (OSi) optical rain gauges, as well as other synoptic measurements; ocean-based measurements from ships and buoys including radar. ScTI (OSi) optical rain gauges and other synoptic measurements: and aircraft—based measurements including radar and particle measurement probes.

Measuring Rain from Space

Another major program - the Tropical Rainfall Measuring Mission (TRMM) - is a joint U.S.-Japan space project. In 1997, the TRMM satellite will be launched into a low inclination orbit, using a suite of sensors including precipitation radar, microwave radiometer, infra red scanner, lightning sensor, and radiant energy sensor. The TRMM data will allow an enhanced assessment of global circulation, hydrological cycles, and climate models.

To prepare for this mission, the TRMM office has established a validation program at sites around the world. The range of activities in the validation program is broad. The ultimate goal is to calibrate the space borne precipitation radar. The ScTI (OSi) optical rain gauges are being used at the land and ocean sites to provide the instantaneous rain rate to validate the radar reflectivity - rainfall (Z-R) relationship. As with the TOGA-COARE program, the optical rain gauges are installed on islands, ships, and buoys. The direct measurements obtained from these ground truth ScTI (OSi) optical rain gauges are expected to greatly increase the confidence in large area estimates of rainfall derived from the TRMM spacecraft when it is launched.

These ocean-based programs have been in warm climates. The ScTI (OSi) gauges used were models designed for measuring liquid precipitation only. To make measurements below 0°C so the measurement of snow is also possible. Scientific Technology (Optical Scientific) has introduced a new version of the ORG. *[The new model ORG-815 sensor has enhanced sensitivity, the ability to more accurately report liquid water equivalent for snow, and options for analog or digital (RS-232) data output. In addition, OSi provides more advanced sensors that can identify precipitation type, detect hail and ice pellets and even measure visibility, all in one instrument.]* To assure compatibility with ocean platform power systems, the new sensors also operates with 12 VDC power.

Accurate ocean-based precipitation measurements have become a reality with the development of the ScTI (OSi) optical rain gauge family. The scientific community now has a proven tool to assist it in its understanding of the complexities of the ocean/atmosphere interface. Ocean-based deployment of the optical rain gauge will contribute to better understanding of a wide range of issues, from short-range synoptic weather forecasts to long-term climate change mechanisms. /st/