Current Measurement Technology Development Progress in the '90s - A Review

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Abstract - **In the last six years, measurement of water current in the ocean has progressed from predominantly rotor and vane or propeller type instruments to acoustic Doppler type instruments. Long term measurements of the type of flow important to understanding the general circulation still use the older mechanical current meters but these are being equipped with modern data loggers. The ADCP, initially used as a profiler on ships, has developed a life as a moored instrument, protected in a cage from trawling for bottom mounted deployments. In addition, the acoustic Doppler and acoustic travel time techniques have spawned precise point measurements, useful for turbulence and dissipation measurements, wave and boundary layer measurements, and sediment transport studies. Radar backscatter at HF and VHF from surface waves have provided surface current maps. Broadband ADCPs provide finer resolution in space and velocity but require greater care in their use to avoid biases from fish among other things. Miniature current sensors are becoming available for inclusion in instrument suites. Vorticity and heat flux are possible in addition to vector flow for wave reduction when shear is wanted and mixing rates are to be estimated. Electromagnetic sensing is still useful but development has been slower. Laser Doppler velocimetry has also developed only slowly, principally being useful for dissipation studies. Current meter development is a vigorous field with the number of ADCPs on the market doubling every three years. Intercomparison between current meters is an essential task that is being steadily if slowly pursued. Use of current meters is increasing in coastal studies, environmental work, and in conjunction with other measurements but is still not ubiquitous, a situation that should be corrected. Thus there is still a challenge to those of us in the water flow measurement business to make current measurements easier, more accurate, and less expensive.**

I. Introduction

The Current Measurement Technology Committee of the IEEE Oceanic Engineering Society has held five conferences since 1978. The proceedings of these conferences serve as an accessible record of current meter development over the last two decades. They provide a biased picture and conclusions drawn from that picture must be tempered by an understanding of how contributions came to be included in the conference proceedings. Papers generally include reports of current meter use, current meter intercomparisons and validations, and current meter developments. The distribution has sometimes been weighted toward development, sometimes toward use. Development papers may lead in several years time to an instrument but they may not. Use papers may reflect present practice or may be an application of an older technology that is passing or has passed out of present practice. This review is intended to put the present into context by encapsulation of the past 20 years and especially the last six years. Proceedings of the Working Conferences on Current Measurement give the long view while proceedings of the Oceans conferences expand that view for the last six years.

II. History

The five proceedings of the CMTC conferences can be scanned for subject content and grouped by technology, by approach, and by stage of development. This can demonstrate trends in current measurement technology.

A. First Conference on Current Measurement - 1978

The first CMTC conference was held at the University of Delaware in Newark, DE January 11-13, 1978[1]. William Woodward and Christopher Mooers were the co-conveners. Actually, this conference was not strictly a CMTC conference since it predated the formation of CMTC and was sponsored by the Office of Ocean Engineering of NOAA and by the Sea Grant College Program of University of Delaware. However it addressed the technology of current measurement at the time and anticipated the technology of the future, some of which has come to pass, some is still to come, and some of which was preempted by unanticipated developments.

Near surface current measurements and the degradation of current measurements by surface mooring motion were themes of the conference. The need to obtain accurate measurements with vertical mooring motion and zero mean horizontal motion was stressed. Also, the need of the offshore community for current measurements was great. The use of current meter data was a major part of the conference (16 papers out of 25). Only three papers were on development of techniques although four discussed what should be measured. Four papers were intercomparisons between sensors or tests of instruments. Most of the instruments considered (19) were or were desired to be at the production stage and none were being retrofitted. Six papers considered instruments in the testing stage or they were about prototype instruments.

By far the dominant sensor mentioned was mechanical with 11 of the 21 references made or implied being to mechanical rotor/vane or propeller sensors. Lagrangian

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measurements were the next most often cited at four. Three electric field measuring or electromagnetic sensors and one each acoustic travel time and radar backscatter sensors were discussed. Notably absent was any reference to acoustic Doppler except in a wish list. LDV was also absent although there were such sensors in development at the time.

B. Second Conference on Current Measurement - 1982

The second CMTC conference was held at Hilton Head, SC January 19-21, 1982[2]. William Woodward was general chair and Maureen Dursi and William Woodward were editors of the proceedings.

Acoustic Doppler measurements and profiles were discussed in three papers, which was a recognition of a velocity measuring technique that had previously been used routinely only in ships logs. Mechanical sensors still were in the lead with nine references to rotor/vane or propeller sensors of a total of 31. Lagrangian drifters and electromagnetic sensors each had five. Acoustic travel time and radar backscatter or satellite radar altimetry tied acoustic Doppler at three references each. Laser Doppler velocimetry appeared for the first time. Several other, less recognized techniques were also mentioned.

Testing and intercomparisons were discussed almost as often as use and applications. Development was considered half as often as testing and intercomparisons. Most of the sensors were prototypes or developments in the testing phase (13 out of 26 references). Only 10 papers were concerned with production instruments (38% vs 66% in 1978). I believe this period to be the start of a surge in current meter development.

C. Third Conference on Current Measurement - 1986

The third CMTC conference was held in Airlie, VA January 22-24, 1986[3]. Gerald Appell and William Woodward were editors of the proceedings. This is the conference in which acoustic Doppler made a major appearance. 13 references to acoustic Doppler techniques surpassed 12 references to mechanical techniques to measure current. Acoustic travel time was the third most often mentioned technique, followed by electromagnetic sensors. Radar backscatter and Lagrangian drifters were each mentioned twice. No LDV reference appeared.

Intercomparisons were the subject of more than three times as many papers as either use and application papers or instrument development papers. Development was up compared to use.

Most of the instruments considered were production instruments, reflecting the increased number of commercial current meters that were available. The first mention was made of an instrument no longer in production but still used.

D. Fourth Conference on Current Measurement - 1990

The fourth CMTC conference was held at Colony South Hotel in Clinton MD April 3-5, 1990[4]. Gerald Appell and Thomas Curtin were editors of the proceedings. At the time of this conference, Gerald Appell had replaced William Woodward as general chairman of CMTC.

Development had become fashionable again in 1990 with 17 of 31 submissions that I could classify falling into that approach. Use and intercomparison or testing were matched at seven each. Acoustic Doppler techniques were the most often reported with 14 out of 37. Mechanical sensors were next but the VACM had to be considered a retrofit instrument since it was no longer in production and the VMCM was shortly to follow. Then came electromagnetic followed by acoustic travel time and that followed by radar backscatter. Drifters came last. Again, there was no reference to an LDV measurement. The availability of production instruments permitted most of the sensors tested or used to be commercially available although three had gone out of production.

E. Fifth Conference on Current Measurement - 1995

The fifth CMTC conference was held in St. Petersburg, FL February 7-9, 1995[5]. Steven Anderson, Gerald Appell, and Albert Williams were editors and Gerald Appell was general chair of CMTC. At this conference, the ADCP nearly eclipsed the other sensors. The largest number of papers (16) focused on acoustic Doppler techniques with radar backscatter (7), acoustic travel time (6), and drifters or Lagrangian techniques (5) trailing. Mechanical sensors were considered in two papers and electromagnetic sensors in one. The LDV was not included.

The preponderance of ADCP papers reflected the availability of several commercial acoustic Doppler sensors at that time. They had begun to replace other sensors in studies of boundary layers and estuarine flow. Most of the papers (20) referred to production instruments although a substantial number (17) referred to prototype instruments or developments in the testing phase. Development was stressed more than use in 1995 (20 papers on development of techniques vs 16 papers on use or applications). There had been a maturing of certain aspects of the current measuring field. The technology had advanced to support environmental studies in shallow water, to provide telemetry systems for real time data return, and to increase coverage vertically with profilers and horizontally with radar backscatter sensors. There was a new class of problems that had become more visible in 1990 and more so in the 1995 conference: turbulence and boundary layer flow measurements. Where the ability to make quality measurements in the surface layer was a theme in 1978, the ability to resolve turbulence in a boundary layer was addressed by a number of authors in 1995.

F. Trends

Possibly only the most obvious trends can be derived from papers in conferences. Development papers about mechanical sensors in each conference were all concerned with

retrofits for improved response or more modern logging systems. Recent papers on use of current meters or applications of current measurements cite acoustic Doppler sensors where they cited measurements from mechanical sensors twenty years before. Acoustic Doppler sensors are evolving. ADCPs are available in more frequencies, more sizes, from more manufacturers, and filling specialized niches. The price is even dropping, the sign of a maturing technology. Acoustic travel time current sensors are also evolving but at a slower rate. There is a roll-over in manufacturers with about as many dropping out as starting up. This is not yet a mature technology. Radar backscatter use is increasing and there are several different systems in the marketplace at a range of frequencies. These have extended uses. For example, depth can be measured in addition to surface current but there is still some validation and testing to do to fully qualify these new uses.

Table I. summarizes the five CMTC conference proceedings in three sections: by type of current sensor, by the approach of the author, and by the stage of development of the instrument. For example, in 1978, more than half of the instruments considered in the papers were mechanical sensors (Mech.). Acoustic Doppler (AD), which were absent in 1978, became 43% of the instruments considered in 1995. Electromagnetic current sensors (EM) declined modestly while acoustic travel time (AT) rose from 5% to about 15%. Radar backscatter (RB) sensors increased substantially in 1995 to 19%. Lagrangian drifters (L/D) have been between 5% and 20% for the total period and will probably remain a small but important part of the current monitoring picture. Laser Doppler velocimetry (LDV) was only represented once, in 1982. Used extensively in the lab, it hasn't been presented at CMTC conferences.

The balance between intercomparison and testing papers (Comp.), use and applications (Use), and development papers (Devel.) has shifted over the years. Intercomparison and testing of current sensors peaked at 62% in 1986. Development has increased at the last two conferences to about 50%. One could imagine a sequence of development followed by testing which in turn was followed by use. This would be true for each sensor coming into use. Table I does not show that clearly except that intercomparisons and testing in 1986 preceded increased use in 1995. If this were true, the boom in development papers in 1990 and 1995 should lead to more intercomparisons in 1999 and these in turn to more papers on use in 2004.

There is a clearer picture in the sequence from idea papers (Idea) in which a new concept is presented but not yet reduced fully to practice and prototype testing and use papers (Test) in which they are used but not yet in production. The peak of idea papers in 1978 could be coupled to the peak in testing in 1982. This could then be related to the peak in papers referring to production instruments (Prod.) in 1986. The tail end, in which an instrument has gone out of production but is still being used and requires retrofitting (Retro.) peaks in 1990. The last conclusion, that in four or five years after papers report

TABLE I

SENSOR TYPES, AUTHOR APPROACHES, AND STAGE OF DEVELOPMENT

YEAR	1978	1982	1986	1990	1995
Type of Current Sensor in Papers by Percent					
Mech.	52	29	32	16	5
EM	14	16	8	14	3
AT	5	10	14	11	16
AD	-	10	35	35	43
RB	5	10	5	8	19
LDV	-	3	-	-	-
L/D	19	16	5	5	14
Other	5	6	-	8	-
Approach Taken by Authors in Papers by Percent					
Comp.	21	37	62	23	12
Use	67	44	19	23	39
Devel.	13	19	19	55	21
Stage of Current Sensors in Papers by Percent					
Idea	17	12	9	9	5
Test	25	50	30	37	40
Prod.	58	38	57	46	48
Retro.	-	-	4	9	7

much use from a production instrument, that instrument will be out of production, is certainly not true. But it is true that such work horses as the VACM and the VMCM (Vector Averaging Current Meter and Vector Measuring Current Meter) were producing a lot of data in 1978, were still producing data in 1995, but went out of production, replaced by newer current meters less costly to build and maintain.

III. RECENT HISTORY

A tabulation of the papers from Oceans conferences of 1990 through 1995 is shown in Table II in the same format as the papers from the CMTC conferences[6,7,8,9,10,11]. Although there are fewer papers in each year at Oceans then each conference of CMTC, the trend can still be seen towards acoustic Doppler and radar backscatter and away from mechanical current sensors with acoustic travel time,

TABLE II
SENSOR TYPES, AUTHOR APPROACHES, AND STAGE OF DEVELOPMENT

YEAR	1990	1991	1992	1993	1994	1995
TYPE OF CURRENT SENSOR IN PAPERS BY PERCENT						
Mech.	-	12	7	-	13	-
EM	-	-	-	5	-	10
AT	25	6	13	24	13	10
AD	25	47	60	48	19	70
RB	-	-	-	14	19	10
LDV	-	-	-	5	-	-
L/D	-	18	13	5	38	-
Other	50	18	7	-	-	-
APPROACH TAKEN BY AUTHORS IN PAPERS BY PERCENT						
Comp.	-	25	31	19	13	10
Use	25	19	-	33	20	50
Devel.	75	56	69	48	67	40
STAGE OF CURRENT SENSORS IN PAPERS BY PERCENT						
Idea	-	12	36	5	-	10
Test	75	47	14	33	60	-
Prod.	25	41	50	62	33	90
Retro.	-	-	-	-	7	-

Lagrangian drifters, and electromagnetic measurements about steady. More commercial instruments are available. Some testing and intercalibration is done but most of the papers are about development of techniques and applications of the techniques.

A. Acoustic Doppler Sensors

Acoustic Doppler current profilers, acoustic Doppler single point current meters, and correlation sonars have come of age. They have dominated every Oceans conference in the last six years but one. With their digital signal processors, high performance acoustic transducers and amplifiers, and large data rates, they are truly beneficiaries of advances in high tech fields such as digital speech processing and laptop computers, but they also have pushed certain technologies themselves. Broadband techniques have broken the sample frequency-speed resolution-range product limit of the earlier incoherent ADCPs and permitted their application in some configurations to turbulence measurements which require rapid sampling and high resolution of speed to resolve turbulent spectra. The penalty of sophisticated processing is the danger of tracking something other than the water velocity be it surface reflections, fish, or some combination of mooring motion and side lobes. This problem with false tracking has been addressed in papers at several Oceans conferences in recent years.

One of the greatest impacts of ADCPs has been the reduction in mooring costs for bottom mounted instruments. Particularly in shallow water, a profile of the entire water column is possible, except for a 15% ambiguous region at the top where side lobe reflection from the surface interferes. But fishing activities put these bottom mounted instruments at risk and this danger inspired a cottage industry of trawler proof ADCP mounts. Designed to direct trawl nets over the top yet be recoverable on acoustic command, at least three designs have been developed and several presented at Oceans conferences.

B. Lagrangian Drifters

Surface drifters play a continuing role in ocean research. Tracked by Argos or relaying GPS positions by Cellular phone, drifters benefit from high tech systems already in place. Subsurface drifters have remained important components of circulation studies, also using satellite fixing and data communication.

Lagrangian floats play an important role in mixing studies as well and several investigators are vigorously developing novel floats to study deep convection, internal wave shear, and boundary layer deepening. A steady flow of papers at Oceans conferences tracks these efforts.

C. Radar Backscatter

Commercial VHF and HF radar backscatter systems and experimental systems using military radars have shown the benefits of long range horizontal coverage that are possible. The technology has matured with a variety of systems available. Interpretation is not as simple and intercomparisons between radar and drifter measurements are important. Clearly the radar systems yield excellent information often.

Satellite observations of ocean currents and wind have long been sought. The leap from laboratory developments of radar backscatter models to satellite measurements needs more observations at the intermediate scale where the commercial radar backscatter systems are providing data. I expect to see papers comparing these observations in the future.

D. Acoustic Travel Time

A personal favorite of mine is the direct measurement of velocity in a small, defined volume with acoustic travel time velocity measurements. Papers on such systems have continued at a steady rate at about the 15% level. As this field has matured, variations in geometry, frequency, and platform have allowed acoustic travel time measurements to invade both top and bottom boundary layers, wave boundary layers, and internal shear layers.

The acoustic current meter has made major inroads on the mechanical current meter for moorings, at least in the marketplace. In the current meter shops across America, there are still large inventories of well running rotor/vane and propeller current meters. Testing, calibration, and general acceptance of the acoustic current meter still lags the older mechanical technology, but this will pass as new papers suggest.

E. EM, LDV, and Other

The electromagnetic current meter in both commercial and experimental style is filling an important niche. EM current meters, used routinely in many studies, are frequently the standard against which other technologies, ADCP for example, are compared. In other configurations, electric field or magnetic field sensors are an important geophysical sensor and inadvertently a current sensor of vorticity sensor as well. Geomagnetic electro-kinetographs are alive as well.

LDV remains a small but important tool in turbulence studies, both as a small scale probe of turbulence and dissipation and to calibrate and intercompare with other sensors in flow near a boundary.

Correlation sonars, ship track discrepancies between GPS and dead reckoning, and wave gauge type measurements are grouped in Other in Table II. There are still more ways to measure current than those listed.

F. Approaches by Authors of Papers

In the last six years, most of the papers presented at Oceans in the current measurement area are development papers, either of a new instrument or of a technique of using the instrument. Fortunately, there have been a steady stream of comparisons between instruments or instrument test papers but it is at the 10% to 30% level. We need to know how well our measurement techniques work and calibration and intercomparison is one approach to this.

Use and interpretation of measurements by current sensors is ultimately the test of a new technology. Fortunately, papers on applications and use are present at the 20% to 50% level.

G. Stage of Development

A healthy mix of stages of development is represented by our papers over the last six years. Only in 1995 did I estimate dominance of reports of use and technique developments from instruments in production. Generally, half the instruments discussed have been commercial, the rest prototypes, special instruments, research tools, or ideas not yet reduced to practice.

An important part of our oceanographic business is keeping the stock of older, no longer supported current meters working. Upgrading loggers, adding sensors, and using rotor/vane and propeller current meters on new platforms, what I have classified as retrofitting, is effective and praiseworthy. A trickle of papers describing such endeavors is evident.

IV. Conclusion

Current measurement is a first order task in ocean process research, environmental monitoring, climate studies, ship traffic control, and offshore work. Vector measurements are always harder than scalar measurements, both to make and to interpret. Fortunately, we are working hard to provide these measurements and interpretations. The progression from idea, to prototype, to commercial product is evident in papers about current measurement over the last two decades. At least half a dozen techniques are developing in parallel, and each offers special advantages in certain tasks.

Some technologies, specifically acoustic Doppler and radar backscatter, have expanded rapidly. We still need testing, intercomparison, and most significantly interpreted data sets from measurements made with these techniques to gain an understanding of where they can be trusted and where not.

There is no saturation of the current measurement field. Although there is maturing in specific technologies, new technologies or re-inventions of older technologies spawn new cycles of development. This picture is invariant over the two decades reviewed.

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