Confirmation of the Northern Delta Aquariids (NDA, IAU #26) and the Northern June Aquilids (NZC, IAU #164)

David Holman[1] *and Peter Jenniskens*[2]

This paper resolves confusion surrounding the Northern Delta Aquariids (NDA, IAU #26). Low-light level video observations with the Cameras for All-sky Meteor Surveillance project in California show distinct showers in the months of July and August. The July shower is identified as the Northern June Aquilids (NZC, IAU #164), while the August shower matches most closely prior data on the Northern Delta Aquariids. This paper validates the existence of both showers, which can now be moved to the list of established showers. The August Beta Piscids (BPI, #342) is not a separate stream, but identical to the Northern Delta Aquariids, and should be discarded from the IAU Working List. We detected the Northern June Aquilids beginning on June 14, through its peak on July 11, and to the shower's end on August 2. The meteors move in a short-period sun grazing comet orbit. Our mean orbital elements are: $q = 0.124 \pm 0.002$ AU, $1/a = 0.512 \pm 0.014$ AU^{-1}, $i = 37.63° \pm 0.35°$, $\omega = 324.90° \pm 0.27°$, and $\Omega = 107.93 \pm 0.91°$ (N = 131). This orbit is similar to that of sungrazer comet C/2009 U10.

1 Introduction

There is some confusion regarding the nature of the Northern Delta Aquariids (NDA, IAU #26). The shower was discovered by Wright et al., 1957, who photographed two meteors north of the ecliptic plane with orbital elements very similar to the Southern Delta Aquariids. Those meteors were photographed on August 18, 1952, and on August 5, 1953. They had low perihelion distances of 0.065 and 0.075, respectively, and inclinations of 23.8 and 16.9°.

The IAU Working List puts the peak of the Northern Delta Aquariids at solar longitude 123.4°, based on visual observations, when the radiant is said to be at R.A. = 344.7°, Decl. = +0.4°, v_g = 40.5 km/s. Jenniskens, 2006 provides orbital element data from eight sources that agree well and nearly all put the peak around solar longitude 140°, near the peak of the Perseids. These mean orbits have inclinations in the range 18.0° - 23.0°, slightly lower than those of the Southern Delta Aquariids (≈ 26°), while the longitude of perihelion is in the range = 104.9° - 112.2°. In comparison, the Southern Delta Aquariids have a longitude of perihelion = 97.3° - 101.8°, just slightly lower. This suggests that both showers could be part of the Machholz complex. When the nodal line rotates, the inclination and perihelion distance change a lot, but the longitude of perihelion stays much the same Jenniskens, 2006.

SonotaCo, 2009 put the activity period for the Northern Delta Aquariids from solar longitude 118.4° to 128.4° in late July, based on the SonotaCo video observations, and identified a separate shower active in August. The new shower was named the "August Beta Piscids", subsequently included in the IAU Working List as #342 (BPI), with a peak at solar longitude 140.0°, R.A. = 346.4°, Decl = +1.4°, v_g = 38.3 km/s, active from solar longitude 128.8° to 151.17°. This position, however, is the same as that of photographed Northern Delta Aquariids.

The Canadian Meteor Orbit Radar (CMOR) project (Brown et al., 2009, Brown et al., 2012) also put the peak of the Northern Delta Aquariids at the time of the Perseid maximum (solar longitude 139°). In addition, they detected a shower in June and July active from solar longitude 71° to 123° (a 53-day period), with a maximum at 101°. At maximum, the radiant was at R.A. = 310.4°, Decl. = -4.2°, moving at +0.845°/° (degrees of coordinate change per degree of solar longitude)in Right Ascension and +0.182°/° in Declination, with geocentric speed v_g = 37.5 km/s. This translates to orbital elements q = 0.116 AU, i = 39.5°, ω = 327.49°, and Ω = 101.0° (Π = 68.49°).

This June-July shower was already in the IAU Working list as the Northern June Aquilids (NZC). The shower was so named because Sekanina, 1976 detected it before in Harvard radar data in much of June, but CMOR extended the activity range much further into July.

Observations made during the months of June, July, and August of 2011 by the Cameras for All-sky Meteor Surveillance (CAMS) video system confirm the presence of two distinct showers in July and August. The radiants are well separated from those of the alpha Capricornids (CAP) and Southern delta Aquariids (SDA), but the nature of the two showers is very different. The July shower is that identified by CMOR as the Northern June Aquilids. That shower was also recognized from IMO single-station video observations (Molau, 2008) and identified in the latest SonotaCo video observations as an unnamed shower with provisional designation "sm_025".

2 CAMS: Cameras for All-sky Meteor Surveillance

CAMS is a three-station 60-camera meteor surveillance system using Watec Wat902 H2 cameras equipped with 12-mm focal length lenses. During the summer of 2011 the CAMS network stations were located at Fremont

[1]SETI Institute, 189 N. Bernardo Ave., Suite 100, Mountain View, CA 94043, USA
Email: daveh@lmi.net
[2]SETI Institute, 189 N. Bernardo Ave., Suite 100, Mountain View, CA 94043, USA
Email: petrus.m.jenniskens@nasa.gov

Peak Observatory, at Lick Observatory, and at a low altitude site near Lodi, California. The CAMS video system has been described in detail in previous works (Jenniskens et al., 2011), and more information about the CAMS network can be found on the project web-site at: `http://cams.seti.org`.

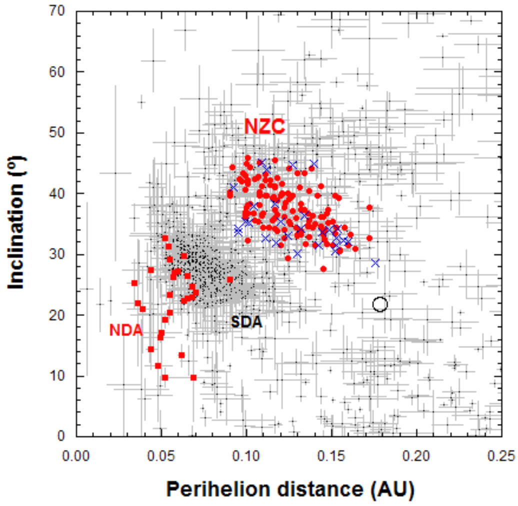

Figure 1 – NZC (•) and NDA (squares) orbital elements relative to other meteors in the period June 14 to August 2, 2011. The crosses without error bars are SonotaCo sm_025 orbits from 2007 to 2009. The open circle are orbital elements from radar observations by Nilsson, 1964.

3 Confirmation of the Northern June Aquilids

We first noticed this shower on orbital element plots of our July 2011 observations (Figure 1). The meteors are well separated from the Southern and Northern Delta Aquariids by having a higher perihelion distance and higher inclination. They were initially mistaken for the Northern Delta Aquariids, but daily plots of the radiant position show clearly a shower in late July and early August with a radiant consistent to the Northern Delta Aquariids, and a separate shower that is active during most of July. Figure 2 shows the radiant position of this July shower during the period June 14 to August 2.

The extended period of activity and the daily radiant drift causes the radiants to spread out as they do in Figure 2. At all times, however, the shower is well separated from the alpha Capricornids (CAP). It is recognized as a compact cluster of radiants from 88° solar longitude to 130°.

4 D-Criterion Testing

To determine shower association with the Northern June Aquilids using dissimilar D-criteria methods D (Southworth & Hawkins, 1963) and D_D (Drummond, 1981), we define an appropriate cut-off level, Dc, using the definition from Lindblad, 1971:

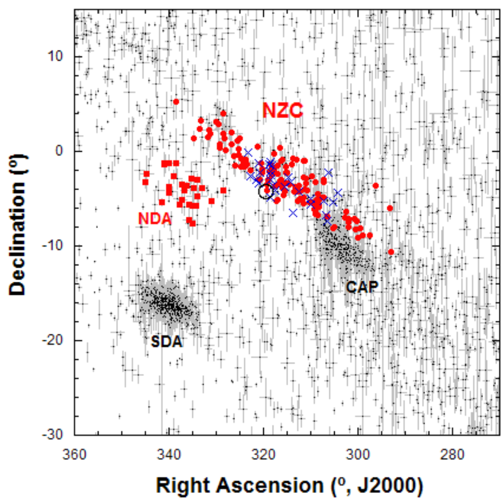

Figure 2 – As Fig. 1: NZC (•) and NDA (squares) radiant positions relative to other meteors in the period June 14 to August 2, 2011. The crosses without error bars are SonotaCo sm_025 orbits from 2007 to 2009.

$$D_c = 0.80N^{-0.25} \qquad (1)$$

With N = 350, we get $D_c = 0.185$, and so use values of $D \leq 0.18$ as evidence of association within our sample area. The mean orbit against which all other orbits were tested was determined by taking the mean of the 11 orbits in our preliminary data set that occurred on the peak night of July 11. These orbits were compared to their own mean, and two of those orbits were eliminated as outliers. The resulting mean of the remaining 9 orbits was used to test the association of all other NZC candidates. D-criterion tests were performed on all orbits occurring during the NZC activity period in our sample area. The resulting set of verified NZC orbits (N = 131) are those shown by "•" symbols in Figures 1 and 2. The number of detected shower members as a function of solar longitude is shown in the histogram of Figure 3. We observed the peak to occur on July 11 ($\lambda_\odot = 108°$) in 2011. The activity profile is broad and symmetric.

This extends the range of activity further into July and early August compared to the CMOR activity period of 71° to 123°, with a peak at 101°o solar longitude. There is a hint in the radiant plot of Fig. 2 that activity might extend to even later times. The activity profile is symmetrical in time (57.6% appearing before the maximum). Days with no activity occurred on clear nights, but reflect the low-number statistics of detected rates.

We also tested the SonotaCo "sm_025" data (N = 38) using the same mean orbit and D_c, and as a result removed 10 orbits from that data set. The reduced set is shown in Figures 1 and 2 with crosses, and listed in Table 1. All orbits in the vicinity of the NDA radiant (N = 57) were similarly D tested using $D_c = 0.29$ from equation (1), and the mean radar orbit of Kashcheyev & Lebedinets, 1963. The resulting set of verified NDA

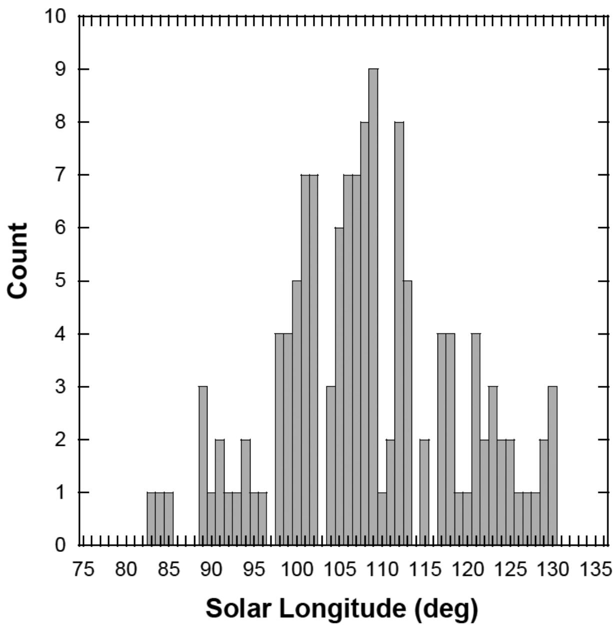

Figure 3 – The number of detected NZC shower members from CAMS data for each solar longitude in 2011.

orbits (N = 12) are those shown by "black square" symbols in Figures 1 and 2.

table 1 here

5 Orbital Elements and Drift Rates

In Table 1 we compare the various observations of this shower. CAMS data is shown for both the peak night and the entire activity period, and the SonotaCo data is shown after our D-criterion testing. The SonotaCo data agree well with our data in all respects. This is also shown in Figures 1 and 2, where NZC candidate orbits are plotted with SonotaCo orbits in RA vs. DEC and perihelion distance vs. inclination. The IMO Video Meteor Network (VMN) detected this shower's radiant using single-station observations made from July 1993 to July 2008, and an automated radiant detection process. In the first analysis of the VMN data by Molau, 2006, the NZC shower was split into three parts with a total of ca. 350 orbits that were designated as showers 16, 19, and 24. Shower 24 was thought to be the descending branch of shower 19 in the 2006 analysis. A second improved analysis made in 2008 combined the three previous showers into one, with ca. 900 orbits, designated as shower 25 (Molau, 2008). The radiant is a good match, but their v_g is somewhat higher than in our data.

The earliest detection we found are 3 orbits identified by Nilsson, 1964 using short baseline forward-scatter radar observations made during 1961 from Adelaide, Australia, which he designated as Group 61.7.9. The forward-scatter radar observations match our radiant very well (open circles in Figures 1 and 2), but some orbital elements differ significantly. The values given for mean $\lambda_\odot$ and Ω are dependent on his observation periods, which all occurred after the peak of activity we observed, so they cannot be compared here to the other observed values of $\lambda_\odot$ and Ω. Of interest is that in addition to the observations made on July 22-29 and August 1-3, during which his 3 orbits were recorded, the radar was also operating from July 11-15 but detected no NZC meteors during that interval. Nilsson does not specify the date and time of appearance of his 3 orbits. Nilsson's radiant, v_g, and eccentricity are all good matches to our data, but q and a are both somewhat larger. The values for q and a shown in Table 1 are both calculated from Nilsson's given values of e and $1/a$. Most troublesome is Nilsson's calculated mean inclination of 21.8°, which is much lower than the mean value found in our data, and also far lower than the lowest inclination orbit found in our data (30°). The detected inclination drift in our data is not enough to reduce the mean inclination to Nilsson's value, even including his large error tolerances.

The NZC meteors intercept the Earth's orbit at the streams descending node. The stream then continues on past the sun to its perihelion point. After perihelion the stream quickly ascends at about a third of the mean distance of Mercury's orbit from the sun, after which the meteoroids move out towards Jupiter. The mean aphelion point is 4.11 AU from the sun, just inside of Jupiter's orbit, and 1.71 AU above the ecliptic plane, at some distance from Jupiter.

table 2 here

Table 2 shows the measured drift rates for our NZC data compared to those reported by SonotaCo, CMOR, and VMN. Nilsson was not able to detect reliable drift rates from only three orbits. The radiant drift rates we measure have very good regression coefficients, and generally agree with SonotaCo and CMOR. These drift rates confirm a normal radiant drift. The radiant drift rates from VMN are in rough agreement.

Our data shows the most statistically significant orbital element drift rates are in q, i, ω, Π, and the heliocentric distance to the ascending node, $r+$, but do not always agree well with SonotaCo's drift rates, which may be due to the lower numbers of NZC meteors recorded by SonotaCo. All other orbital element drift rates measured by CAMS have low regression coefficients combined with low drift rates, so we assume those elements to be constant during the activity period. The regression coefficients for each orbital element from both CAMS and SonotaCo are similar, even when the element values disagree. SonotaCo data show possibly significant drifts in magnitude and geocentric velocity that CAMS does not.

6 Physical Properties and Zenith Hourly Rate

The magnitude range of all detected NZC meteors is −1.0 to +4.2, with a mean absolute magnitude (at 100 km distance) of M_v = +2.21 (N=131), mostly determined by the detection efficiency of the camera system. The magnitude distribution index averages to $\chi = 4.1$ for interval -1 to +2 magnitude, or $\chi = 4.7$ for -1 to +1. We adopt $\chi = 4.4$, making this shower rich in faint meteors. Above +2, the count is incomplete, detecting approximately fractions of P(m) = 0.96 for +2, P(m)

= 0.13 for +3 and P(m) = 0.02 for +4.

The light curves are fairly symmetric, suggesting relatively frail meteoroids. The F-skew mean is a relatively low 0.53, typical for symmetric light curves that peak slightly after the middle of their trajectory, but with a range from F = 0.13 to 0.94. Seventy-six NZC meteors, or 58% of the sample, have F-values of 0.50 or greater.

The beginning and end heights of the NZC fall in the same height range of other meteors of similar velocity. The beginning heights range from 91.3 to 103.6 km with a mean of 96.8 km. The end heights range from 82.1 to 93.9 km with a mean of 86.9 km. For both beginning and ending heights, the lower height range is the same for NZC meteors and all other meteors, but the higher height range of NZC meteors is about 3 - 4 km less than that for all other meteors.

From the magnitude distribution index, the peak Zenithal Hourly Rate (ZHR) for the NZC can be calculated. The ZHR is calculated using the formula given by Jenniskens, 1994:

$$ZHR = \frac{N}{t_{eff}} \chi^{6.5-L_m} C_p \sin(h_r)^{-\gamma} F \qquad (2)$$

where N is the number of meteors counted during t_{eff}, the effective time interval in hours. h_r is the radiant height at the middle of the t_{eff} period, $\gamma = 1 + 1.08\log(\chi) = 1.69$, and C_p is the observers perception coefficient ($C_p = 1.0$). The extra factor "F" accounts for the relative efficiency for detecting meteors above 32° by a visual observer compared to that by CAMS.

We use the permanently installed Fremont Peak Observatory (FPO) station as our standard observer. For the peak night of July 11, 9 meteors were detected during the $t_{eff} = 5.53$ hours when the sun was more than 18° below the horizon and the camera $L_m = 5.4$ at FPO. CAMS is capable of accurately recording orbits during twilight periods when the sun is only about 9° below the horizon. However, on the peak night no NZC meteors occurred during twilight. The radiant altitude at the middle of this time interval is hr = 45.8°. To estimate the relative area covered by the cameras to that covered by a visual observer, we first multiply the video rate to that which would have been detected for a visual limiting magnitude of +6.5 above 30° elevation (limit of CAMS system), by multiplying with $\sum_m P(m)\chi_m$ (factor 44), then divide by that which a visual observer sees over the same region (strictly above 32° elevation): factor 96, hence F = 0.46. This results in a peak ZHR = 1.3 ± 0.4 /hr.

7 Parent Body

The short perihelion distance suggests looking for potential parent bodies among the anomalous sun-grazing comets found among the many SOHO and STEREO comet discoveries. We searched for a prograde moving comet with $q \leq 0.2$ AU and ≈ 73°. The large spread in node suggests that there was time for the parent to evolve at a different rate than the meteoroids by rotating the nodal line, or by changing the perihelion distance from perturbations by Jupiter at aphelion.

One object, C/2009 U10, is a promising candidate. Its parabolic orbit has Π = 64°, a little lower than expected, but the node is still close to that of the observed meteoroids (Table 1). If we assume that the perihelion distance was adjusted to the observed value, and the semi-major axis of the comet is that of the present meteoroids (a = 2.10 AU), then the theoretical radiant given in Table 1 follows from method "Q" of Neslusan et al., 1998. The predicted radiant is at slightly lower declination than observed, but that may merely reflect uncertainty in the comet orbit.

Another comet, C/1997 H2, as a better agreement in longitude of perihelion, but would need to be much more evolved along the nutation cycle if responsible for this stream. This makes the predicted radiant position (using method "H" of Neslusan et al., 1998) more uncertain.

8 Conclusions

We have solved confusion regarding the identity of the Northern Delta Aquariids, which can now be moved to the list of established showers, and confirm the existence of the Northern June Aquilids (NZC, IAU #164). We have shown that this stream is distinct from the Southern and Northern Delta Aquariids, and Alpha Capricornids. The low rates produced by this stream make it hard to detect the shower by visual methods, but require video or radar observations to provide statistically viable data. The orbital data, beginning and ending heights, and F-skew values of the NZC meteors indicate a cometary origin from a short-period sungrazer. Two such comets, C/2009 U10 and C/1997 H2, are presented as possible parent bodies, C/2009 U10 being the most similar in orbit to the meteoroids observed at Earth.

9 Acknowledgements

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References

Brown P., Weryk R. J., Wong D. K., and Jones J. (2012). "Cmor meteoroid stream survey v2.0". *NASA Planetary Data System*, pages EAR–A–I0688–5CMORMETEORB–V2.0.

Brown P., Wong D. K., Weryk R. J., and Weigert P. (2009). "A meteoroid steam survey using the canadian meteor orbit radar. ii: Identification of minor showers using a 3d wavelet transform". *Icarus*, **207**, 66–81.

Drummond J. D. (1981). "A test of comet and meteor shower associations". *Icarus*, **45**, 545–553.

Jenniskens P. (1994). "Meteor stream activity: I. the annual streams". *Astronomy and Astrophysics*, **287**, 990–1013.

Jenniskens P. (2006). *Meteor Showers and their Parent Comets*. Cambridge University Press.

Jenniskens P., Gural P. S., Dynneson L., Grigsby B., Newman K. E., Bordon M., Koop M., and Holman D. (2011). "Cams: Cameras for allsky meteor surveillance to validate minor meteor showers". *Icarus*, **216**, 40–61.

Kashcheyev B. L. and Lebedinets V. N. (1963). "Radar studies of meteors". *Smithsonian Contributions to Astrophysics*, **7**, 183–199.

Lindblad B. A. (1971). "A computerized stream search among 2401 photographic meteor orbits". *Smithsonian Contributions to Astrophysics*, **12**, 15–24.

Molau S. (2006). "How good is the imo working list of meteor showers? a complete analysis of the imo video meteor database". In Bettonvil F. and Kac J., editors, *Proc. IMC: Roden, The Netherlands xx*, pages 15–24.

Molau S. (2008). "A new analysis of the imo video meteor database". In xxx, editor, *Proc. IMC: Sachticka, Slovakia xx*, pages 15–24.

Neslusan L., Svoren J., and Porubcan V. (1998). "A computer program for calculation of a theoretical meteor-stream radiants". *Astronomy and Astrophysics*, **331**, 411–413.

Nilsson C. S. (1964). "A southern hemisphere radio survey of meteor streams". *Australian Journal of Physics*, **17**, 205–256.

Sekanina Z. (1976). "Statistical model of meteor streams. iv. a study of radio streams from the synoptic year". *Icarus*, **27**, 265–321.

SonotaCo (2009). "A meteor shower catalog based on video observations in 2007-200". *WGN*, **37**, 55–62.

Southworth R. B. and Hawkins G. S. (1963). "Statistics of meteor streams". *Smithsonian Contributions to Astrophysics*, **7**, 261–285.

Wright F., Jacchia L. G., and Whipple F. L. (1957). "Photographic i-aquarid meteors and evidence for the northern delta aquarids". *Astrophysical Journal*, **62**, 225–233.

Table 1 – The mean orbital elements for NZC from various observers are listed. Error tolerances are given in standard error. Two possible parent comet orbits are also shown.

Observer	Obs. Type	Shower	$\lambda_\odot$	RA.	Dec.	v_g	q	a	i	ω	Π	Year
CAMS	MS video	NZC (All)	108.09	315.35	-3.07	38.33	0.124	2.11	37.60	324.94	73.03	2011
			±0.91	±0.81	±0.27	±0.19	±0.002	±0.06	±0.34	±0.27	±0.27	
CAMS	MS video	NZC (Peak)	108.55	315.49	-3.58	38.20	0.125	2.06	36.01	324.59	73.14	2011
			±0.02	±0.59	±0.39	±0.72	±0.007	±0.16	±1.39	±1.11	±1.11	
SonotaCo	MS video	sm_025	108.08	315.10	-3.56	37.68	0.129	2.00	35.34	324.52	72.60	2007-9
			±1.37	±1.11	±0.35	±0.36	±0.004	±0.14	±0.88	±0.80	±0.80	
CMOR	BSc radar	NZC	101	310.4	-4.2	37.5	0.1160	1.55	39.5	327.49	68.49	2002-6
Harvard	BSc radar	"June	85.8	297.1	-7.1	36.3	0.114	1.348	39.3	329.5	55.3	1968-9
		Aquilids"	±0.7	±0.6	±0.5	-.-	±0.004	-.-	±0.6	±0.6	±0.7	
Nilsson	FSc radar	61.7.9	121.4	319.6	-4.2	36.9	0.179	3.57	21.8	311.2	72.60	1961
			-.-	±1.9	±1.5	±1.4	-.-	-.-	±3.0	±4.0	±4.0	
IMO VMN	SS video	Shower 25	102.5	312.2	-5.0	43	-.-	-.-	-.-	-.-	-.-	1993-08
	2009 U10		100.32	306.6	-7.1	38.2	0.0544	inf.	32.24	323.46	63.78	
	1997 H2		103.44	310.6	-22.3	36.1	0.1361	inf.	18.32	201.47	67.29	

Table 2 – Drift rates for the NZC orbital elements and correlation coefficient (R).

	ΔRA	ΔDecl.	Δv_g	Δv_h	Δq	$\Delta 1/a$	Δi	$\Delta\omega$	$\Delta\Pi$	Δr^+	ΔM_v	ΔF_{max}
CAMS	+0.866	+0.253	-0.032	+0.020	+0.00067	-0.0015	-0.172	-0.123	+0.877	+0.00083	+0.0040	+0.0020
R	0.98	0.87	0.15	0.10	0.37	0.10	0.45	0.41	0.96	0.38	0.04	0.12
SonotaCo	+0.766	+0.183	-0.085	+0.038	+0.0016	-0.0030	-0.484	-0.267	-0.733	-.-	+0.0289	-.-
R	0.95	0.72	0.33	0.15	0.49	0.15	0.76	0.46	0.81	-.-	0.23	-.-
CMOR	0.845	0.182	-.-	-.-	-.-	-.-	-.-	-.-	-.-	-.-	-.-	-.-
	±0.01	±0.01										
IMO VMN	+0.7	+0.1	-.-	-.-	-.-	-.-	-.-	-.-	-.-	-.-	-.-	-.-