# VARIATIONS IN SEA LEVEL AT MONACO. NOTE ON COMPUTATION OF RATIO FACTOR

by J. ROUCH

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Under the direction of R. CHAUVET, a civil engineer of the French public highway administration (*Ponts et Chaussées*), tidal observations were carried out at Monaco during a continuous 20-year period, from 1902 to 1921. The general results of these observations were published in *Bulletin de l'Institut Océanographique* No. 481 dated 3 July 1926.

The range of the tide proper is 17 centimetres. But random variations in level due to the effect of wind and barometric pressure are far greater than the oscillation due to the astronomical tide.

The mean monthly level in relation to the general mean level (MML); the mean monthly range, i.e. the mean of the differences in level each month (MMR); the absolute range, i.e. the difference between the highest and lowest level each month over a 20-year period (MAR), are given in millimetres in the following table :

| | Jan. | Feb. | Mar. | Apr. | May | Jun. |
|---|---|---|---|---|---|---|
| M. M. L. ..... | — 4 | + 13 | + 1 | — 6 | — 33 | — 37 |
| M. M. R. ..... | 397 | 402 | 440 | 372 | 366 | 347 |
| M. A. R. ..... | 730 | 720 | 970 | 560 | 580 | 660 |

| | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|
| M. M. L. ..... | — 37 | — 30 | — 10 | + 29 | + 55 | + 55 |
| M. M. R. ..... | 316 | 323 | 390 | 408 | 416 | 438 |
| M. A. R. ..... | 660 | 560 | 680 | 780 | 690 | 750 |

The sea level at Monaco shows a mean annual oscillation of about 9 centimetres. The November-December maximum has been observed at numerous Mediterranean ports.

During the cold October-March season, the monthly and absolute ranges are higher than during the warm April-September season.

During the 20-year period, the mean annual level varied by 24 millimetres. The mean variation each year was 60.7 centimetres, and the total variation in 20 years was 97 centimetres. It is likely that over a longer period of observation the absolute variation in sea level would exceed 1 metre.

According to CHAUVET, the heavier tides correspond to winds from the NE-SE sector, towards which the entrance to the bay of Monaco is oriented; the smaller tides correspond to the NW-SW winds, and are frequently delayed 24 to 48 hours.

On the basis of available observations, we have attempted to show the variation in sea level due to the variation in barometric pressure.

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From 1911 to 1921, the mean monthly levels of the sea at Monaco and the mean monthly barometric pressure were determined, making a total of 132 observations, listed in an appendix to this paper.

Treated by the least-squares method, these observations give the following results.

The correlation factor between variations in barometric pressure and sea level variations has the rather low value of 0.31. With such a low correlation factor, computation of the ratio (or regression) factor no longer has significance. This factor is found to have the value of — 6.8, which means that for a variation of 1 millimetre in atmospheric pressure, we get a sea level variation in the opposite direction amounting to 6.8 millimetres, whereas it is generally assumed that this sea level variation is about 13 millimetres.

These disappointing results are due to the small variations in monthly barometric pressure. Out of 132 observations, 48 show a difference with respect to the mean less than or equal to 1 millimetre, and 82 a difference less than or equal to 2 millimetres. If we take the highest and lowest levels observed at the same time as the barometric pressure (these 17 observations are tabulated in the appendix), the correlation factor is 0.87 and the ratio factor — 33.2. With regard to such exceptional tides, which show differences of at least 30 centimetres in relation to mean level, the effect of barometric pressure is hence very marked. This may moreover be a general law : the ratio factor between sea level variations and barometric pressure variations is not constant : its value is greater than 13 for large variations in barometric pressure, and smaller than 13 for small pressure variations.

These large pressure variations result in a much more extensive marine disturbance around the place of observation, such that the variation in sea level as dependent on the variation in barometric pressure can no longer be considered as a static variation.

Observations of mean monthly levels and of mean monthly barometric pressure at Venice have been published by G. MAGRINI. 11 years of observations (1917-1927) have been processed in the same way as the Monaco observations. The correlation factor between barometric pressure variations and sea level variations is 0.19 for the observations as a whole;

the regression factor is 6.2. If among the Venice observations we take only those (16 in number) in which the differences of barometric pressure relative to the mean have an absolute value above 4 millimetres, the correlation factor is 0.85, and the regression factor — 20. The Venice and Monaco observations, treated similarly, give comparable results.

In a discussion on tides observed in the Antarctic on the *Pourquoi-Pas ?* (*Bulletin de l'Institut Océanographique,* No. 870), we showed that the influence of barometric pressure on sea level could clearly be brought out if instead of considering differences referred to mean sea level and mean barometric pressure, we examined differences in relation to preceding values. Miss Eugénie LISITZIN drew upon this method in studying the tides at Monaco : when the differences from one month to the next in sea level and barometric pressure for the period 1911-1921 are determined, the regression factor is then in the neighbourhood of 13 (*Bulletin de l'Institut Océanographique,* No. 1040, 20 March 1954).

## NOTE ON COMPUTATION OF RATIO FACTOR

If deviations from the observational mean are designated as $x$ and $y$, then the ratio (or regression) factor is equal to $\frac{\text{sum } (x\,y)}{\text{sum } y^2}$, according to the method of least squares.

Use of this method of computation supplied a factor of 6.8 for the Monaco observations.

Various authorities prefer to compute the ratio factor as follows : the observations are divided into two groups, one corresponding to barometric pressures above the mean, and the other to pressures below. Then the means of the corresponding levels are taken. The ratio of differences in the two groups supplies the ratio factor.

This method supplies a factor of 5.5 for the Monaco observations.

Another method occasionally used consists in averaging all the $x$'s and all the $y$'s, regardless of sign; the ratio factor is then equivalent to the ratio of the two means. The value then obtained for the Monaco observations is 2.5, which diverges considerably from those obtained by the other methods.

Such discrepancies between the three computation methods manifestly result from the small number of observations analysed in the present instance. They do show, however, that in order to compare ratio factor values obtained by different authorities, it may be well to ascertain the similarity of computation methods.

## APPENDIX I

| Year | J. | F. | M. | A. | M. | J. | J. | A. | S. | O. | N. | D. | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | MEAN LEVELS AT PORT OF MONACO (in millimetres) | | | | | | | | |
| 1911 ..... | 445 | 506 | 495 | 461 | 464 | 360 | 418 | 426 | 460 | 507 | 536 | 623 | 475 |
| 1912 ..... | 535 | 514 | 477 | 513 | 486 | 469 | 426 | 505 | 542 | 489 | 513 | 466 | 495 |
| 1913 ..... | 502 | 571 | 425 | 496 | 425 | 418 | 448 | 440 | 507 | 594 | 512 | 500 | 487 |
| 1914 ..... | 537 | 466 | 495 | 446 | 464 | 504 | 534 | 477 | 507 | 513 | 600 | 559 | 508 |
| 1915 ..... | 560 | 556 | 527 | 479 | 455 | 498 | 494 | 493 | 445 | 436 | 495 | 458 | 487 |
| 1916 ..... | 335 | 479 | 643 | 431 | 450 | 421 | 421 | 455 | 464 | 503 | 582 | 603 | 482 |
| 1917 ..... | 594 | 519 | 445 | 461 | 432 | 365 | 427 | 457 | 411 | 529 | 394 | 508 | 462 |
| 1918 ..... | 491 | 337 | 443 | 534 | 460 | 428 | 436 | 470 | 450 | 416 | 437 | 619 | 460 |
| 1919 ..... | 634 | 656 | 601 | 590 | 526 | 489 | 542 | 565 | 587 | 601 | 672 | 550 | 484 |
| 1920 ..... | 523 | 465 | 513 | 544 | 449 | 473 | 509 | 436 | 529 | 572 | 609 | 552 | 515 |
| 1921 ..... | 486 | 503 | 491 | 519 | 461 | 466 | 499 | 444 | 493 | 541 | 614 | 572 | 508 |
| | | | | | MEAN BAROMETRIC PRESSURE (700 mm +) | | | | | | | | |
| 1911 ..... | 60,4 | 61,5 | 53,9 | 55,0 | 54,1 | 58,0 | 59,0 | 56,5 | 57,2 | 57,3 | 55,6 | 57,9 | 57,2 |
| 1912 ..... | 57,1 | 55,2 | 56,5 | 55,5 | 57,1 | 55,6 | 55,5 | 55,2 | 57,2 | 57,4 | 56,1 | 62,1 | 56,7 |
| 1913 ..... | 58,0 | 60,3 | 60,4 | 53,1 | 54,9 | 57,1 | 54,0 | 55,7 | 56,2 | 58,7 | 59,1 | 57,5 | 57,1 |
| 1914 ..... | 56,9 | 58,4 | 53,3 | 58,8 | 56,3 | 55,4 | 54,6 | 57,1 | 57,7 | 55,8 | 54,2 | 56,6 | 56,3 |
| 1915 ..... | 48,0 | 53,6 | 53,4 | 55,1 | 55,6 | 55,5 | 55,8 | 55,8 | 56,5 | 54,9 | 55,2 | 55,8 | 54,8 |
| 1916 ..... | 63,4 | 54,7 | 49,0 | 52,9 | 55,6 | 54,5 | 55,8 | 55,1 | 54,9 | 58,7 | 54,0 | 51,1 | 55,0 |
| 1917 ..... | 49,8 | 56,2 | 51,2 | 53,7 | 56,6 | 58,9 | 57,1 | 50,4 | 59,6 | 54,2 | 58,3 | 56,7 | 55,2 |
| 1918 ..... | 61,7 | 63,2 | 57,0 | 53,0 | 56,6 | 56,7 | 56,6 | 57,5 | 56,4 | 55,5 | 57,9 | 58,2 | 57,5 |
| 1919 ..... | 53,6 | 52,6 | 53,4 | 52,9 | 57,6 | 61,4 | 56,0 | 57,7 | 57,9 | 56,2 | 52,4 | 56,3 | 55,7 |
| 1920 ..... | 58,2 | 63,9 | 56,8 | 54,3 | 58,4 | 55,3 | 56,9 | 56,0 | 57,9 | 55,9 | 59,9 | 56,3 | 57,5 |
| 1921 ..... | 60,4 | 59,7 | 60,3 | 53,9 | 55,3 | 54,2 | 57,6 | 55,0 | 59,4 | 60,3 | 56,2 | 57,3 | 57,5 |

*Note.* — In the following tables read the commas between figures as decimal points.

## APPENDIX II

## EXTREMES IN SEA LEVEL VARIATION AT MONACO

| DATE | LEVEL FIGURE in mm | PRESSURE in mm |
|---|---|---|
| | HIGHEST LEVELS | |
| 4 March 1916 | 980 | 741,3 |
| 8 March 1917 | 1000 | 743,0 |
| 9 March 1917 | 1000 | 754,1 |
| | LOWEST LEVELS | |
| 7 June 1913 | 150 | 762,0 |
| 2 February 1914 | 140 | 773,3 |
| 3 February 1914 | 140 | 771,5 |
| 14 March 1914 | 30 | 765,7 |
| 8 September 1915 | 170 | 766,7 |
| 16 January 1916 | 180 | 768,0 |
| 12 April 1919 | 200 | 767,0 |
| 23 May 1919 | 180 | 765,5 |
| 19 June 1919 | 100 | 764,3 |
| 18 July 1919 | 100 | 761,1 |
| 12 September 1919 | 110 | 766,2 |
| 22 October 1919 | 100 | 766,0 |
| 20 December 1919 | 190 | 763,8 |
| 13 March 1920 | 200 | 758,0 |

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