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Results of some investigations by A. Colding on the storm surge in the Baltic Sea from November 12 to 14, 1872 and on the relationships of the winds to the currents and water levels

Translated from German by Ingrid Bork

Former Federal Maritime and Hydrographic Agency, BSH

Summary

Regarding the cause of the extraordinary high water levels in the Baltic Sea during the storm on November 13, 1872, there are mainly two conceptions. While Baensch (1875) founded the idea of an already overfilled western Baltic met by the storm, Colding (1881) postulated the high water levels as purely wind induced. Because of the still ongoing debate of this issue a translation of an excerpt of Colding's work is given.

Keywords

Baltic Sea, storm surge, 1872 Baltic Sea flood

Zusammenfassung

Zur Ursache der außergewöhnlich hohen Wasserstände in der Ostsee während des Sturms am 13. November 1872 gibt es hauptsächlich zwei Vorstellungen. Während Baensch (1875) die Idee begründete, dass der Sturm auf eine bereits überfüllte westliche Ostsee traf, postulierte Colding (1881) die hohen Wasserstände als rein windbedingt. Wegen der noch heute andauernden Debatte zu diesem Thema wird die Übersetzung eines Auszugs von Coldings Originalarbeit gegeben.

Schlagwörter

Ostsee, Sturmhochwasser, Hochwasserkatastrophe 1872

1 Preface

„Ergebnisse einiger Untersuchungen von A. Colding über die Sturmfluth vom 12. bis 14. November 1872 in der Ostsee und über die Beziehungen der Winde zu den Strömungen und Wasserständen." is an anonymous German summary which appeared in „Annalen der Hydrographie und Maritimen Meteorologie" (10, 1–5, 1882). The original work "Nogle Undersøgelser over Stormen over Nord- og Mellem Europa af 12te–14de November 1872 og over den derved fremkaldte Vandflod i Østersøen. Avec un résumé en Français." was published in Copenhagen in 1881 and is readily available in academic libraries.

While the work of Baensch (1875), presented in its English translation in this issue of "Die Küste", is valued today primarily for its collection of reliable, official data in "digital" form, Codling's paper derives its importance from the physical theories presented therein. Colding laid special emphasis on the experimental confirmation of his physical theories. Therefore, he used all available data on the storm surge of 1872, especially those collected by Baensch, to modify his ideas on sea level response to wind, which Colding had developed in the context of an engineering project. Based on his analyses of air pressure and the derived wind fields, he was able to make an important contribution to the still lasting controversy about the cause of the extreme water levels during the storm surge of 1872.

Ludvig August Colding (1815–1888) was a Danish physicist and engineer.

After an apprenticeship as a carpenter, he enrolled at the Polytechnic Institute in Copenhagen and graduated in mechanics in 1841.

He worked as a teacher before being appointed inspector of roads and bridges in Copenhagen in 1845. Codling's importance and influence grew until he was appointed state engineer for Copenhagen in 1857. He oversaw a vast range of public housing, transport, lighting and sanitation projects and gained a high reputation throughout Denmark and internationally. He retired from professional engineering in 1886.

Besides these projects Colding found time for private scientific work in fluid mechanics, hydrology, oceanography and meteorology as well as electromagnetism and thermodynamics. He was largely responsible for founding the Danish Meteorological Institute in 1872.

In his first scientific paper in 1839 he summarised work on compression and friction of various materials. He is better known as a pioneer of the mechanical theory of heat. In particular, he postulated the law of conservation of energy independent of Joule. His contribution was initially little appreciated, although in 1843 he published his theses in the Notices of the Danish Academy of Sciences.

From 1856 he was a member of the Royal Danish Academy of Sciences and from 1875 also a member of the Royal Swedish Academy of Sciences. In 1871 he became a full professor and Honorary Doctor of the University of Edinburgh, the contemporary centre for natural sciences.

2 Results of some investigations by A. Colding on the storm surge in the Baltic Sea from November 12 to14, 1872 and on the relationships of the winds to the currents and water levels[1].

The Danish engineer Prof. Dr. A. Colding is one of the co-founder of the mechanical theory of heat and the author of several papers promoting the theory of the flow of water and air in the writings of the "Royal Danish Academy of Sciences at Copenhagen", 1870–1876[2]. In the paper cited in note 1, he discussed in detail the results of his own earlier investigations (1858) on the relations of the winds to the current and water level conditions at Copenhagen. In the same direction, he also discussed in detail the numerous reports that he had received about the great storm surge of November 12 to 14, 1872.

We are communicating the following excerpts from the resume attached by Prof. Colding to his paper as an appendix.

In 1858 Prof. Colding, in his capacity as City Engineer of *Copenhagen*, had been commissioned to examine the project of the extension of the harbour of *Copenhagen*[3] southwards by means of a shipping canal to be built along the quays, through the *Kallebo-Strand*[4] and to

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open out in the deeper parts of the *Kjöge* Bay[5], preferably with regard to the resulting changes in the masses of pure water flowing into the harbour from *Kjöge* Bay from south to north on the one hand and from the Sound from north to south on the other. For this purpose, Prof. Colding carried out a series of observations on the movements of the water in the harbour of *Copenhagen* and its surroundings at different wind directions from October 18 to November 1, 1858 three times a day, 7 am·, noon and 5 pm, which revealed a decisive influence of the wind on the direction of the current. The wind conditions at that time were very favourable for the above mentioned purpose, as the wind direction as well as the strength were very different and caused characteristic currents and water levels on the coasts concerned.

The places of observation were as follows: In the *Sound* and along the east coast of *Amager* at Fort *Treskroner* and at *Dragör*; on the west coast from *Amager* to *Kongelund*; along the coast of *Zealand*: Customs House at *Copenhagen*, *Gammelholm*, *Langebro*, *Gasanstalt*, *Strandegaard* and *Hudinge-Strand*.

A discussion of these observations, which are originally set out in a table, shows that the easterly winds accumulate the water in *Kjöge* Bay in such a way that the level of the water rises with the direction of the wind from the east coast of *Amager* towards the coast of *Zealand*, and that these winds produce a northward setting current[6] both in the *Sound* and in the harbour of *Copenhagen*. If the wind now turns from east to north, the speed of the current will decrease, while in *Kjöge* Bay the water level follows the turn of the wind and sinks the more the more northerly the wind gets. The westerly winds, on the other hand, drive the water out of *Kjöge* Bay eastwards towards the Swedish coast, so that there is a lower water level on the Zeeland coast and a high water level on the east coast of *Amager;* at the same time these winds cause a southward setting current in the *Sound* and in the harbour of *Copenhagen*.

On the basis of these observations, Prof. Colding sets up the following two sentences for the relationships between the winds, the currents and the water level in the Baltic Sea (see loc. cit. page. 295; Résumé page. 53):

1. "The west winds drive the water of the Baltic Sea towards the coasts of Russia and raise the water level there, while it is lower on the Swedish coasts, south of them, and on the southern coasts of the Baltic Sea and along the Danish islands. This low water level south of Falsterbo in turn causes a current to flow from the Sound to the Baltic Sea. These same westerly winds also drive the water of the North Sea into the Kattegat, at the same time as the water of the Kattegat is forced from the Jutland coast to the Swedish coasts, so that there is a high water level at Elsinore. Taken together, these various effects of the westerly winds provide the conditions for a strong southward current through the Sound."
2. "The east winds exert an opposite effect; they drive the waters of the Kattegat into the North Sea and far away from the Swedish coast; this produces a low water level at Elsinore, and satisfies the condition for a current from south to north through the Sound. On the other hand, the easterly wind accumulates the water of the Baltic Sea on the Danish coasts south of Sweden, and this high water level south of Falsterbo, combined with the low one at Elsinore, consequently produces a comparatively strong north-setting current in the Sound."

The great storm surge of November 13, 1872 gave Prof. Colding reason to check his above-mentioned observations and opinions about the effects of the wind on the currents and the water level with regard to their correctness also for other places on the coasts of the *Baltic Sea*. The terrible and immensely fast propagating inundations on the Danish and German coasts were out of all proportion to the strength of the storm, which was no greater than on other occasions, and this led Prof. Colding to the opinion that the storm surge of November, 1872 was an effect – albeit much greater and far more widespread – of the same cause which he had proved in the vicinity of *Copenhagen* in October 1858.

When Prof. Colding asked various newspapers and authorities in *Denmark* and *Germany* to send him observations and investigations concerning this storm surge, he received 400 communications, the most important of which was the treatise by Mr. Geh. Baurath Baensch: „Die Sturmfluth an den Ostseeküsten des Preußischen Staates vom 12/13. November 1872. 33 pp. folio with 10 copperplates, on behalf of the Ministry of Trade, Commerce and Public Work, Berlin 1875."[7]

From the information obtained from this and from synoptic maps made available to him by the Danish Meteorological Institute in *Copenhagen* on the distribution of air pressure, the direction and strength of the wind in the area from *southern Europe* to *Spitsbergen* and from *America* to the interior of *Russia* in the days from November 12 to 14, 1872, Prof. Colding graphically depicted the water levels, air pressure, wind speed and direction for 274 locations within the above-mentioned areas on 6 plates for the days from November 12 to 14, 1872. Prof. Colding also constructed synoptic charts for *Northern* and *Central Europe* on 8 plates for these three days from 6 to 6 hours, and a chart for November 13, 2 pm., at which time the floods on the Danish coasts reached their maximum.

Prof. Colding summarizes the conclusions drawn from these maps as follows (see ibid, pp. 298–304 resp. 56–62):

"When examining the isobars drawn on these maps, it will be seen from their position that during the storm there was an extraordinary disturbance of equilibrium throughout the atmosphere, which had as a necessary consequence an corresponding tendency of the air masses, to restore the same through large, long-lasting atmospheric currents according to the location of the isobars."

"The motion of these air currents follows, of course, the general laws for currents of fluid bodies, according to which 1) the trajectories of motion are determined by the magnitude and direction of the driving forces; 2) the currents are the more powerful, the greater these forces and the air masses in a state of motion are; 3) the resistance experienced by the movements of these currents close to the surface increases with the unevenness of the latter. This resistance is therefore larger on the continents and islands than on the seas; the atmospheric currents therefore tend to travel preferentially over the seas, where this resistance is a minimum[8]. But even here there is a noticeable friction between the water of the sea and the mass of air sweeping over it; owing to the active force thereby produced, the latter lags behind the water on the surface of the sea, and thereby the surface water is urged forward in the direction of the wind. By the friction of the water molecules against each other, this surface movement of the sea gradually spreads to the lower layers, and if the wind blows steadily from the same direction, the movement of the water particles caused by it will be propagated from the surface to the entire depth of the sea, with a maximum at the surface and a minimum at the bottom[9]. Furthermore, because the surface on which the wind exerts its action is either horizontal or inclined, and because in calm weather the water is thereafter either at rest or in motion in the direction of the slope, a large number of special currents arise in the seas due to the action of the wind on the surface, as I have proved in “Vidensk. Selbskabs Skrift”, 5^{e} series, Vol. 11, No. III, 1876.[10]

“If namely, the wind blows over an immovable sea, which is so limited that the current produced by the wind is hindered in its movement or finds no outlet on the coasts, the force of the wind will damming up the water against the obstacles of its movement in such a way that the surface of the sea then forms an inclined surface, the slope of which is directed opposite to the direction of the wind. Owing to this inclination of the surface, the water is affected in its movement not only by the force of the wind which urges it forward, but also by the gravity which tends to draw it backward; the simultaneous effect of these two forces is expressed in a double current, namely, an upper one in the direction of the prevailing wind, and a lower one in the opposite direction at the bottom of the sea. This latter current, however, is of very low strength. But if the wind persists for a long time, the level rises to a certain height, which for the place in question depends only on the strength of the wind; once that height is reached, the lower stream carries with it at every instant a quantity of water equal to that carried by the upper stream.”

“When examining the distribution of air pressure over the whole large area hit by the storm in the period from November 12 to 14, it turns out that at midnight on November 12 the air pressure rose to 780 mm in northern *Sweden* and *Norway*, while in the southern part of the *Baltic Sea* it remained at the mean level of 760 mm, and was below the mean throughout *Central Europe*, with a minimum of 745 mm in the vicinity of *Vienna*. If one connects the centre of the highest with that of the lowest pressure by a straight line, one finds that at this time (midnight of November 12 to 13) this line is directed almost exactly from north to south. In the following 12 hours, up to noon on November 13, the air pressure in northern *Sweden* and in *Norway* was still increasing, and the air masses were moved more and more to the SE; in the southern part of the *Baltic Sea* the air pressure remained approximately at the same mean level of 760 mm, while the minimum of the same propagated without great change in the barometer reading from *Vienna* to the Bohemian border near *Eger* and the line connecting the centres of high and low air pressure was directed from NNE to SSW. Still 12 hours later, at midnight of November 13 to14, the air pressure in northern *Sweden* and in *Norway* was still 780 mm, but the air masses had been pushed even more to the SE; the centre of the lowest pressure had moved from *Eger* to *Amsterdam*, with the air pressure increasing to 750 mm. The line connecting the centres of the highest and lowest air pressure had taken on the direction NE – SW.”

“From this it follows in evidence that during the storm the whole atmosphere moved ‘with the sun’, whereby the high pressure air masses steadily advanced to the SE, while those of low pressure continued to the NW. This rotational movement of the air still continued on November 14 and 15. With this rotation of the air masses of the entire atmosphere during the duration of the storm, the isobars and the wind directions at the same time performed this same rotating movement ‘with the sun’.

“Because as a result of this movement the wind direction during the storm turned from NE through east to SE, the wind gradually pushed the water from the *Gulf of Finland* and from the northern parts of the *Baltic Sea* southwards and later more and more towards the German and Danish coasts, where it rose to the extraordinary height just before the wind had turned sufficiently to the SE to give the water a free outlet through the *Sound*, the *Great* and the *Little Belt* and thereby to bring about an end to the flooding.”

In order to be able to compare closely the observed actual changes in the water level with those which the storm itself might have produced, Prof. Colding drew on eight larger-scale maps (larger in scale than the eight maps for *Northern and Central Europe* mentioned above) those countries and their coasts, from which he had records of changes in the height of the water level, i.e. along the coasts of the *Baltic Sea* and *Denmark*, and in different colours, the isobars (black), the wind paths (red) with indication of the direction of the moving air masses by arrows with the wind and strength by numbers, finally the heights of the water level (above mean) observed at the respective time in Danish feet at the places indicated by these numbers (blue). From these latter data he further deduced the heights of the water levels for a large number of intermediate points and, by connecting these with the locations of the water levels actually observed on the surface of the seas, he drew the lines of equal water level (blue).

From these three systems of curves Prof. Colding (loc. cit. pp. 301–304 and Résumé. pp. 59–62) derives the following conclusions.

"While the direction of the wind at all places is related to the lines of equal pressure in such a way that the wind paths intersect all isobars at an angle of about 30°, the curves of the water level clearly show a tendency to intersect the wind direction at right angles wherever local conditions permit the sea to be raised by the force of the wind without causing a pressure capable of producing a lateral pressure. But if the local conditions are not such as to force the wind-induced rise of the sea to follow the direction of the wind, while the sea level forms an inclined plane and the water has a lateral outflow, the horizontal curves of the level can no longer intersect the wind direction at right angles because this deviates from the direction in which the ocean current is moving."

"But since, during the storm of November 13, 1872, the horizontal level curves on the surface of the sea tended to perpendicularly intersect the wind direction, where the original, driving forces which had disturbed the balance of the sea water were the only dominant ones, as follows from the eight maps drawn, it turns out at every point of the sea that the resultant of the effective forces which caused the inundation of November 13 had exactly the same direction as the wind. Thereafter, there can be no doubt that the effect of the storm on the surface of the sea a l o n e caused the inundation. But this conclusion can only be regarded as correct if it can be proved that the force which produced the whole series of raises of the sea not only had the same direction as the wind, but also had the same strength.

In the above (note 2c) mentioned treatise "On the effect of the wind on ocean currents" Prof. Colding gave formulae which can also be applied to those currents that are not only caused by gravity, but by gravity in connection with the wind.

If one now with the help of these formulae, which are valid for all points of the coast under consideration, where the level curves of the sea are perpendicular to the direction of the wind, and where, consequently, the water cannot flow off sideways, calculates the height to which the wind, according to its strength and the depth of the water, can raise the surface of the sea, it is found that everywhere this height coincides so closely with that actually observed, that the difference is certainly only due to errors of observation. This remarkable agreement between the elevation of the sea, calculated from the strength of the wind, and that observed during the storm of November 13, 1872, is clear proof that the storm and the path it took must be regarded as the s o l e cause of the flood of November 13.[11]"

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Finally, Prof. Colding, using the formulae developed in the above-mentioned treatise, drew up a series of profiles of the water levels from one coast to the other, showing the rise and fall of the water which took place during the storm in the time between one observation and the other.

"By means of these formulae one can on the one hand calculate the amount of water which, at a given point in time, flows into the *Kattegat* through the *Sound*, the *Great* and the *Little Belt*, and on the other hand, by determining at the same time how much the sea level rises from one moment in time to the next over an area of known size, one can derive that amount of water that accumulates from second to second below the rising level in the *Sound* and the *Belts* during the period considered."

In carrying out these investigations for the time of the storm and floods of November 12 to 14, 1872, Colding finally found that for all places from which he had received records of the water level, the calculation of the water movement was in complete agreement with the observation.

3 Acknowledgement

The translation was made, taking into account suggestions from translators Google and DeepL. Colding's CV is based on information given by the Dänish and English Wikipedia.

I especially thank Jürgen Jensen and Gudrun Rosenhagen for their support and for checking the translation.

4 Notes

1 Report and excerpt from the treatise by Prof. Dr. A. Colding, City Engineer in Copenhagen: "*Nogle Undersögelser over Stormen over Nord- og Mellem-Europa af 12 te –14de November 1872 og over derved fremkaldte Vanflod i Östersöen. Med 23 Planen and Kort. (Avec un résumé en français). Kjöbenhav.1881. Copy from "Vidensk. Selsk. SKr. 6. R., naturvidensk, og mathem.. Afd* .", Vol. I, 4, pp. 247–304.

2 These treatises are:
   a. Strömungsforholdene i almindelige Ledninger og i Havet, med 3 Tavler (1870);
   b. Lovene for Vandet's Bevägelse i Jorden, med 2 Tavler (1872);
   c. Fremstilling af Resultarterne af nogle Undersöglerser over de ved Vindenskraft fremkaldte Ströminger i Havet (1876).

3 See „Segelhandb. f. d. Ostsee", I, pp. 211–215.

4 Ibid. page 227.

5 Ibid. page 228.

6 About the currents in the Baltic Sea see „Segelhandb. f. d. Ostsee", part I, chap. II, pp. 50–61.

7 This treatise, based on a wealth of official material, gives a very detailed presentation (in text, tables and plates) of the overall course of this phenomenon and its consequences for the beach districts of the German coast of the Baltic Sea and the buildings located within them.

8 Cf. on this the remarkable treatise by S. M. Guldberg and H. Mohn in Christiania: „Ueber die gleichförmige Bewegung der horizontalen Luftströme" in the Austrian journal f. Meteor., 1877, pp. 49–60. Note of referee.

9 Cf. the essays by Prof. K. Zöppritz: „Zur Theorie der Meeresströmungen" in these Annals, 1878, pp. 239–243 and 1879, pp. 155–159. Note of referee.

10 See note 2 – sub c.

11 The abnormal height of the storm surge may also have been caused by the inflow of water from the *North Sea* through the *Sound* etc. into the *Baltic Sea* under strong SW storms (from November 1 to 9) shortly before it, which dammed up the water in the latter towards the east and raised its level. The return current generated by the east storm thus had to bring back all the more powerful water masses to the southern and western coasts of the *Baltic Sea* and produce higher water levels on these.
Geh. Baurath Baensch divides in the above mentioned treatise (page 21) the development of the enormous swell of water on the west side of the Baltic Sea basin into three periods: 1) from October 31 to November 9, 1872: Filling of the Baltic Sea with North Sea water and closure of the "Vorfluth"; 2) from November 9 to 12 in the evening: swinging out of the Baltic Sea water to the west with the basin overfilled; 3) on November 13: impact of the northeast hurricane-force wind on the western part of the Baltic Sea, the level of which had already reached a significant height due to the earlier supply of North Sea water. Note of referee.

5 References

Anonymous: Ergebnisse einiger Untersuchungen von A. Colding über die Sturmfluth vom 12. bis 14. November 1872 in der Ostsee und über die Beziehungen der Winde zu den Strömungen und Wasserständen. Annalen der Hydrographie und Maritimen Meteorologie. 10. Jahrgang, 1–5, 1882.

Baensch, O. F. B.: Die Sturmfluth an den Ostsee-Küsten des Preußischen Staates vom 12./13. November 1872. Separat-Abdruck aus der Zeitschrift für Bauwesen, 25. Jahrgang. Berlin, 1875.

Colding, A.: Nogle Undersøgelser over Stormen over Nord- og Mellem Europa af 12te-14de November 1872 og over den derved fremkaldte Vandflod i Østersøen. Avec un résumé en français. Videnshkabernes Seldkabs Skrifter, 6. Raekke, naturwiderskabelig og mathematisk Afdeling 1, 4, Kopenhagen, 1881.

https://da.wikipedia.org/wiki/L.A._Colding

https://en.wikipedia.org/wiki/Ludwig_A._Colding