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To the 75th anniversary of the discovery of African Easterly Waves

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1. Introduction

On the occasion of the 75th anniversary of the discovery of African Easterly Waves (AEWs) in 2011, this contribution is dedicated to the publications of the two German meteorologists Regula and Piersig that appeared in the year of 1936, as well as to other earlier work on this phenomenon. Regula (1936) and Piersig (1936) simultaneously published their research on surface pressure variations along the West African coast and cyclonic disturbances in the trade wind zone off the northwest African Coast, respectively. While Piersig's work has been translated into English and published in the Bulletin of the American Meteorological Society in 1944 (Piersig 1944), the work of Regula is less well-recognized in the Anglophone literature. Therefore, their findings are both discussed from the viewpoint of our present knowledge about AEWs. The presentation will also allude to other early work on AEWs by, for example, Hubert and Riehl, as well as to what extent this early work was recognized in the seminal papers on AEWs by Carlson (1969a,b), Burpee (1972; 1974); and Reed et al. (1977).

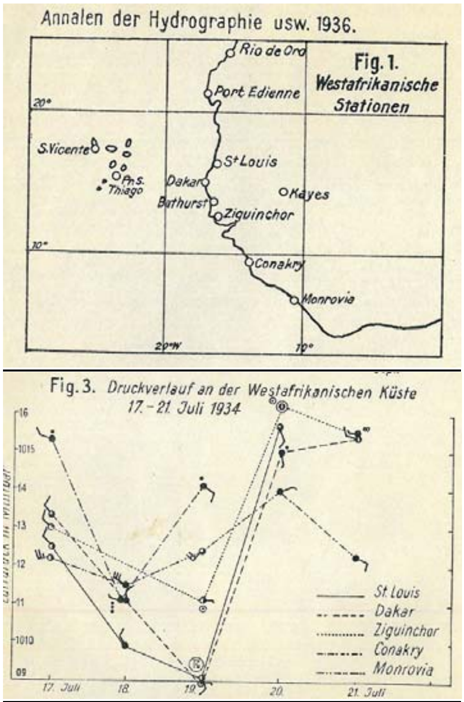

FIG. 1: (Top) Map of stations for which Regula (1936) investigated surface pressure variations in 1934. (Bottom) 24-hourly pressure variations from 00 UTC readings at West African coastal stations between Monrovia (6°N) and St. Louis (16°N) from 17 to 21 July 1934. Also shown are cloud, wind, and significant weather observations.

2. The work of the German meteorologists Regula and Piersig

Regula (1936) investigated surface pressure variations at costal stations in West Africa and the Cape Verde Islands in 1934. Pressure fluctuations in the tropics are usually of low amplitude. Due to problems with unknown altitudes of inland stations and with the accuracy of shipborne mercury barometer readings, Regula decided to use only reliable pressure data from selected costal stations shown in Fig 1 (top). In addition, Regula looked into weather reports from early seaplanes, catapulted into the air from German steam ships, as well as from zeppelins that flew at low levels off the West African Coast.

Regula described examples of station pressure oscillations with a periodicity of four days at coastal stations from Monrovia (6°N) northward to St. Louis (16°N). He noted that the amplitudes of these pressure variations increase from south to north and occur earlier at the southern stations. The example for the period 17-21 July 1934 shows that the pressure minimum at Monrovia (6°N) and Conakry (9°N) was observed 24-hours earlier than at Dakar and St. Louis. Moreover, the amplitude of the pressure variations was 2-3 hPa at the former stations while the pressure rose by 7 hPa at the latter after the pressure minimum on 00 UTC

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19 July 1934. This constitutes a remarkable tendency for tropical latitudes (Fig. 1). Note that 24-hour pressure oscillations had to be used to filter out the diurnal and semidiurnal pressure tides in the tropics.

From wind changes observed at a flight of the airship "Graf Zeppelin", Regula concluded that the four-day pressure variations, associated with a shift from onshore to offshore low-level winds, occur as far north as Rio d'Oro (now Ad Dhakla, 24°N). Thus, he stated that the for-day pressure oscillations occur over a latitudinal extent of 2000 km from Monrovia to Rio d'Oro. Regula also observed that squall lines ("termed tornadoes by him") preferably occurred during the period of rapid pressure increase (other examples, not shown here).

Piersig (1936) analyzed the so-called Hoffmeyer maps between 1881 and 1911, as well as surface station and ship weather reports. The Hoffmeyer maps are daily mean-sea level pressure charts compiled by the Danish Meteorological Institute and the "Deutsche Seewarte" for the North Atlantic Ocean and adjacent continents. Piersig tried to extract typical tracks of cyclonic disturbances in the trade wind regime off the northwest coast of Africa from the Hoffmeyer maps.

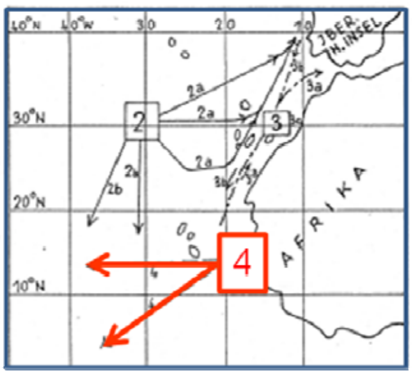

FIG. 2: Typical cyclonic disturbances in the trade wind zone of the coast of West Africa (Piersig 1936). "Type 4 Cyclonic Disturbances" are reminiscent of AEW tracks.

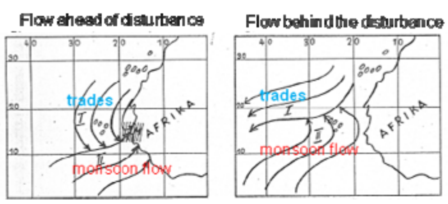

FIG. 3: Characteristic surges of the monsoon and trade wind flows during the passage of the "Type 4 Cyclonic Disturbances". The shaded area in the left panel indicates a region with parallel flow of the two air masses (Piersig 1936).

Piersig' "Type 4 Cyclonic Disturbances" most likely represent AEW cases (Fig. 2). They occurred between late May (earliest occurrence) and early November (latest occurrence) and peaked in August/September. They were associated with characteristic surges of the low-level southwesterly monsoon and northeasterly trade wind flows (Fig. 3). Piersig considered the "Type 4 Cyclonic Disturbances" as transient detachments from the West African heat low. Note that Piersig had no weather observations over continental Africa available.

Piersig discussed a case at the end of August 1909. He described the passage of the system over the West African Coast near Dakar on 30 August 1909 and its propagation towards the Cape Verde Islands. At these islands, two weather stations were reporting as were ships along the route from and to South America that crossed the Cape Verde Islands region. From this and other cases, Piersig concluded that rainfall occurs usually ahead of the surface low in the Cape Verde Island region. He also speculated on a link between "Type 4 Cyclonic Disturbances" and Atlantic tropical cyclones.

3. The work of the French meteorologist Hubert

After the publications of Regula and Piersig in 1936, the origin and tracks of AEWs over the African continent were still unknown and the link between AEW-like disturbances and Atlantic tropical cyclones remained largely speculative. This knowledge gap was mostly filled by the French meteorologist Henry Hubert in 1939.

Hubert compiled Hovmoeller maps of 24-hour pressure tendencies from station observations over West Africa in 1938 and drew isallobars (i.e. lines of constant pressure increase or decrease). This technique not only filters out the (semi-)diurnal pressure tides, but also circumvents the problem of the reduction of station pressure to mean-sea level in case of inaccurately known altitudes or inaccurate instrument calibrations.

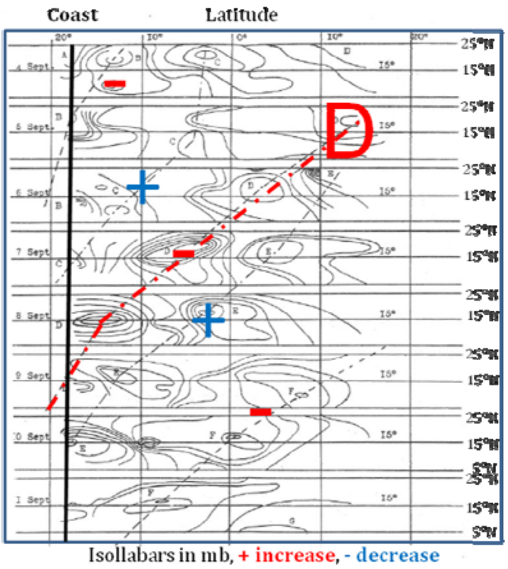

FIG. 4: Hovmoeller (longitudes stretched by a factor of three) diagram of 24-hour pressure changes over West Africa between 04 and 11 September 1938 (Hubert 1939). Positive and negative isallobars are both contoured with solid lines (contour interval 1 mb) and tracks of positive and negative anomalies are indicated by dashed lines and are alphabetically numbered. Positive (negative) isallobaric disturbances are highlighted by a blue (red) plus (minus) sign. The track of the "negative" disturbance "D" is also highlighted for reasons given in the text.

Hubert also noted a 3.5-4 day periodicity and desribed that squall lines occur in the second part of the low and less frequently in the first part of the high – very much confirming the results of Regula (1936). However, he was likely the first author who tracked AEW-like disturbances over West Africa. Thereby, he was able to assess (a) their longitudinal speed in the 15-20°N latitude belt, (b) their direction of propagation, (c) their longitudinal width, and (d) their geographic origin. Hubert stated a westward propagation speed of 500-1200 km/day or 6-14 m/s, a preferred west-southwestward direction of propagation, a longitudinal separation of the „0" isallobar of 1000-4000 km and an origin in the vicinity of the Hoggar Mountains, i. e. in the Tamanrasset-Bilma region.

Carlson (1969a) and Reed et al. (1977) assessed the AEW propagation speed to be 6.5-11 m/s and about 8 m/s, respectively. Thus the value given by Hubert is within the range of the latter findings from the satellite era. Furthermore, a general west-southwestward track of the northerly AEW vortex is clearly evident during the Global Atmospheric Research Program (GARP) Atlantic Tropical Experiment (GATE) in 1974 (Fink et al. 2004). Their Fig. 1 confirms the potential origin of northern AEW vortices in the Tamansrasset-Bilma region. Regarding the AEW wavelength, values range from 2500 km (Reed et al. 1977) to 4000 km (Burpee 1972), though the latter author states that the longer wave length are due to a statistical determination of this AEW property.

Another seminal finding of the work of Hubert is that he provided convincing clues that his African disturbance "D" in Fig. 4 later developed into the devastating New England Hurricane that hit Long Island on 21 September 1938. The track suggested by Hubert is shown in pink in Fig. 5. By interpolation between the tracks determined by the Weather Service of the French West Africa and the U.S. Weather bureau (the latter was corrected equatorward between 13 and 18 September 1938, cf. Fig. 5), he furnished reasonable arguments that the New England Hurricane developed from the AEW-like disturbances "D". If true, the origin of this hurricane can be traced back to the Tamanrasset-Bilma area on 04 September 1938 and the disturbance left the West African continent near Dakar on 09 September 1938. Hubert cautiously noted that the squall line system observed during the passage of the disturbance in the Cape Verde area was not the source of the hurricane, but the surface pressure disturbance.

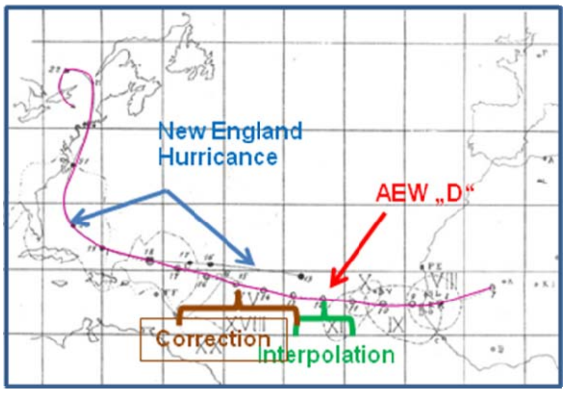

FIG. 5: The origin of the "New England Hurricane" of 1938. Suggested track of AEW-like disturbance "D" that, according to Hubert (1939), underwent tropical cyclogenesis over the Atlantic Ocean and made landfall in Long Island on 21 September 1938. The track is indicated in pink. Over West Africa and the Cape Verde area, disturbance "D" was tracked by sea-level pressure analyses of the meteorological service of French West Africa. The track starting in the central Atlantic Ocean was determined by the US Weather Bureau. Hubert (1939) interpolated and corrected the track of the U.S. Weather Bureau over the central Atlantic Ocean.

4. Follow up work

Herbert Riehl (e.g. 1954) was first in explaining the dynamics of Easterly Waves (EW), as he observed them in the Caribbean, by using the theorem of conservation of potential vorticity and considering (a) curvature vorticity; (b) then vertical shear; and finally (c) curvature and shear vorticity. Fig. 9.3 and 9.5 in Riehl (1954) show the Riehl model of an archetypical EW in the Caribbean. Riehl was aware of the work of Piersig and Regula, but did not cite Hubert in his 1954 text book.

It must be noted, however, that EWs in the Carribean have a notably different structure and dynamics when compared to those over Africa. Only after the advent of satellite observations, the structure and dynamics of AEWs over West Africa and the adjacent East Atlantic Ocean were further investigated in a series of case and statistical studies. Carlson (1969a; b) was among the first who conducted extensive case studies using satellite information. He looked into the structure and properties of AEWs and linked them with tropical cyclones over the Atlantic Ocean. Carlson (1969b), for example, investigated 10000 ft (~700 hPa) maps, inferred a AEW wavelength of about 2400 km, and showed an archetypical AEW with northern and southern vortices. Carlson (1969a; b) did, however, not cite Piersig, Regula, and Hubert.

Burpee's seminal paper in 1972 yielded deep insight into AEW characteristics, origin, and dynamics: he inferred a periodicity of 3.1-5.7 days and a wavelength of up to 4000 km; he mentioned baroclinic (barotropic) vertical (horizontal) tilt; he referred to Charney-Stern criterion for barotropic instability; and he suggested an AEW origin between Ndjamena (15°E) and Khartoum (32°E). Burpee did cite Piersig and Regula. However, Burpee (1974), at least in the author's opinion, misinterpreted the 2000 km north-south extent of station pressure disturbances between Monrovia and Rio d'Oro, described by Regula (1936), as the AEW wavelength.

One of the outstanding and often cited GATE contributions is Reed et al.'s seminal paper in 1977: they inferred an AEW periodicity of 3.5 days, an AEW wavelength between 2200 and 2700 km, and a westward speed of 6-7°long. d^{-1} (~$8ms^{-1}$). They split AEWs into eight phases and presented composite of kinematic fields and associated weather, land-ocean differences, and wave energetics. Reed et al. (1997) did cite Regula, Piersig, and Hubert.

5. Conclusions

From the survey of literature, it appears that about 75 years ago, the German meteorologists Regula and Piersig first described of what is now known as African Easterly waves. Regula (1936) correctly noted the 4-day periodicity in station pressure at West African coastal stations. His observations of earlier pressure minima and weaker amplitudes at more equatorward stations is consistent with a southwest-northeast barotropic horizontal tilt of AEW troughs and stronger warm advection of hot Saharan air masses ahead of the trough in the north (cf. Carlson 1969b and Burpee 1972).

Piersig tracked AEW-type disturbances between the West African coast and the Cape Verde Islands and noted their seasonal cycle. Piersig's contribution to the AEW detection may be considered somewhat less important when compared to Regula's findings. Notwithstanding, his work was better perceived in the Anglophone literature likely due the fact that it was published in English in the Bulletin of the American Meteorological Society in 1944 (Piersig 1944).

The French meteorologist Hubert (1939) was likely the first who tracked AEWs over the West African continent, provided an estimate of the horizontal propagation speed and the AEW wavelength, and gave strong evidence of a physical link between AEWs and tropical cyclogenesis.

From looking into follow-up work of U.S. scientists, it seems that the work of the two German meteorologists was more considered when compared to the work of the French meteorologist Hubert (1939). It is interesting to note that the phase relation between AEWs and squall lines was likely not fully explored until the work of Payne and McGarry in 1977. Regula (1939) and Hubert (1939) note that squall lines occurred at pressure rise and in the second part of the surface low, respectively. This is in line with Payne and McGarry (1977), and much later, Fink and Reiner (2003) that squall lines tend to form ahead of the 700 hPa AEW trough.

Finally, it must be stressed that descriptions of AEWs may be present in unread or inaccessible French or British colonial literature. Therefore, the author would be happy to receive information regarding a potential earlier detection of AEWs.

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