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Ocean atmospheric coupled model to estimate energy and path of cyclone near the coast

RAMKRISHNA DATTA

Regional Meteorological Centre, Kolkata, India

e mail : ramkrishna_datta@rediffmail.com

सार – यह देखा गया है कि बंगाल की खाड़ी में अधिकांशतः चक्रवात, हरीकेन आदि जैसी वायुमंडलीय परिघटनाएँ अपनी गति के दाँई ओर बढ़ती हैं। एसी घटनाओं का अध्ययन करने के लिए हमने वायुमंडलीय गति युग्मित, महासागर की तरल गतिकीय पर विचार किया है। इस अध्ययन में हमने चक्रवातीय तंत्र के केन्द्र को लिया है जिसमें तरल गतिकीय स्रोत तथा थोडी सी दूरी पर तरल गतिकीय सिंक होता है। इस प्रकार बिम्ब तंत्र के तरल गतिकीय द्विक (डब्लेट) निर्मित होता है। तदुपरांत बिम्ब तरंग और उसके प्रतिबिम्ब तरंग के तरल गतिकीय द्विक (डब्लेट) पर ठोस दीवार (यहाँ पर समुंद्र का किनारा) के संबंध में विचार किया गया। इसमें बिम्ब तंत्र, प्रतिबिम्ब तंत्र और धारा गति से संबंधित मिश्रित बिम्ब के तरल गतिकीय समीकरण पर कार्य किया गया है। बिम्ब तंत्र, प्रतिबिम्ब द्विक (डब्लेट) तथा धारा गति के मिश्रित विभव पर इस शोध पत्र में विचार किया गया है। गति सदिश, फलस्वरूप दाब को तरल गति के बरनौली के समीकरण की सहायता से पुनः प्राप्त किया गया। तदुपरांत समुद्र के किनारे अर्थात् दीवार पर न्यूनतम/अधिकतम दाब की विश्लेषणात्मक गणना की गई। अतः यह देखा गया कि चक्रवात अथवा हरीकेन की मौजूदा पवन और ऊर्जा कुछ प्रचलित स्थितियों के आधार पर समुद्र तट की ओर अथवा उसकी गति के दाँई ओर जाती है।

ABSTRACT. It is seen that in the Bay of Bengal or in the Gulf, most of the time the atmospheric phenomena, like, cyclone, hurricane etc. move towards right to its motion. To study such occurrences; we have considered fluid dynamics of ocean coupled with atmospheric motion. In the present study we have considered the eye of the cyclonic system that consist of fluid dynamical source and fluid dynamical sink at a small distance apart, and thus, constitute the fluid dynamical doublet of the object system. Then the fluid dynamical doublet of the object system and its image system has been considered with respect to a firm wall (here the sea shore). The fluid dynamical equation of complex potential with respect to the object system, the image system and the stream velocity have been undertaken. The complex potential of the object doublet, image doublet and the stream velocity have been considered. The velocity vector, consequently the pressure has been retrieve with the help of Bernoulli's equation of fluid motion. Then the minimum /maximum pressure on the wall that is on the sea shore has been calculated analytically. Thus, it is found that on the basis of some prevailing conditions existing wind and energy the cyclone or hurricane move towards the sea coast or to the right of its motion.

Key words – Fluid dynamical source, Sink, Object doublet, Image doublet and Complex potential.

1. Introduction

The atmospheric phenomena, like cyclone, tropical revolving storm (TRS) typhoon or hurricane etc. cause a violent massive disturbance on the surface of ocean. Chenthalu *et al.,* (2002) have described such phenomena in the Bay of Bengal. Here, we have studied those phenomena using fluid dynamics (Acheson, 1990). The 'EYE' region of such phenomena can be regarded, on the basis of abstract idea of fluid dynamics as the combination of fluid dynamical source and fluid dynamical sink [(Faber (1995); Patterson (1983)] at a small distance apart. This system of source and sink are also being considered as of equal and opposite in magnitude. So the said EYE could be assumed to constitute a fluid dynamical two dimensional doublet (Holt & Winston, 1985) of finite strength (Homsy, 2008). This is here the object doublet. Now the seashore can be regarded as the real line x in the two dimensional complex plane where as y is the imaginary axis. It is assumed that there are no flows of fluid across the real line (wall). Then the said object doublet can be placed at a perpendicular distance a from the real line x in the complex plain. It is also assumed that the axis of the object doublet makes an angle 180 degree with the real axis x. Therefore, the image doublet will be at just opposite side of the object doublet. Here the fluid can be regarded as non viscous, incompressible fluid and it is moving with a certain velocity U at infinity in the direction of x axis. The motion of the fluid is wholly two dimensional in the x-y plane. On the consideration of fluid dynamical complex potential, here the whole system consists of object doublet, image doublet and the stream velocity U parallel to x axis. Then, the fluid dynamical equation of the complex potential w can be obtained with the parameters of the strengths of doublets and stream velocity with respect to complex coordinate z (= $x + iy$). The velocity vector q is determined from the differentiation of w with respect to z. Then to determine pressure at any point x on the line (wall), Bernoulli's equation for steady motion has been applied. Such system, coupled with zonal stream moves towards right in the Bay of Bengal and gulf of Mexico. Eventually this can be used to explain analytically that the cyclones of the Bay of Bengal are stronger than that of at Atlantic ocean. The same observation had been written by Sir John Eliot, the first Director General of Observatory of India Meteorological Department in 1889 (Eliot 1944).

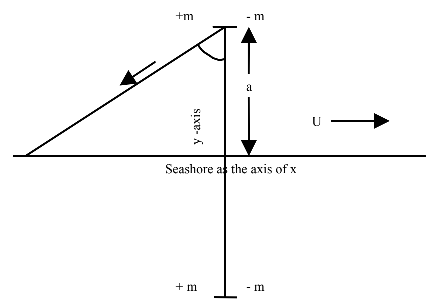

Fig. 1

2. Data and methodology

In Fig. 1 the seashore has been considered as the rigid boundary line (wall) of the ocean and taken as the real x axis of the complex coordinate system. The perpendicular direction has been considered as the imaginary y axis of the said coordinate system. The EYE of the atmospheric phenomena (here cyclone, hurricane etc. in the northern hemisphere) has been positioned at a distance a from the boundary wall on the positive direction of y axis. Here it is the fluid dynamical system, imagined on the basis of abstract idea of fluid dynamical source and sink which constitute the doublet. The source and sink are of magnitude + m and – m respectively. The strength of the object doublet is μ (finite) which is equal to the product of m and the distance between the source and the sink. The points of source and sink in the doublet are taken in the negative direction of x axis. Hence the axis of the doublet makes an angle π with the axis of x axis. The image of the said doublet is an equal doublet symmetrically oriented at z = - ia, obviously on the opposite side of the axis of y. We consider the stream velocity of the ocean be U in the positive direction of x axis. The motion of the fluid is two dimensional in the complex plain. From the Milne-Thomson circle theorem which provides the complex potential due to a doublet of certain strength at a certain distance and making a certain angle with the real axis. Here the present system consists of object doublet, image doublet and the stream velocity U. Therefore using the said Milne-Thomson's theorem, the complex potential w of these total system can be is given by

$$w = \frac{\mu e^{i\pi}}{z - ia} + \frac{\mu e^{i\pi}}{z + ia} - Uz \qquad (1)$$

$$w = -\frac{\mu}{z - ia} + \frac{\mu}{z + ia} - Uz$$

$$= -\frac{2\mu z}{a^2 + z^2} - Uz \qquad (2)$$

We know from Lagrange's stream function ψ (x, y) and velocity potential ϕ (x, y) the complex potential is $w = \phi + i\,\psi$ and $z = x + iy$. Here, the symbols have their usual meaning. Therefore, w is analytic function of z and differentiating w with respect to z, we get,

$$\frac{dw}{dz} = -u + iv$$

Therefore,

$$\left| -\frac{dw}{dz} \right| = \sqrt{\left(u^2 + v^2\right)} = q = \left| U + \frac{2\mu\left(a^2 - z^2\right)}{\left(a^2 + z^2\right)^2} \right| \qquad (3)$$

With the help of equation (2), where q is the magnitude of velocity.

To determine the pressure at any point on the wall we use the Bernoulli's equation

$$\frac{p}{\rho} + \frac{1}{2} q^2 = C \qquad (4)$$

(Symbols have their usual meaning)

From the equation (4) we get using the following boundary conditions

$p = \pi$, $q = U$ when $z = \infty$

$$\frac{\pi - p}{\rho} = \frac{1}{2}\left(q^2 - U^2\right)$$

$$= \frac{2\mu^2\left(a^2 - z^2\right)^2}{\left(z^2 + a^2\right)^4} + \frac{2\mu\, U\left(a^2 - z^2\right)}{\left(z^2 + a^2\right)^2} \qquad (5)$$

Applying equation (3),

Clearly for any point on the sea shore $z = x$

Therefore differentiating equation (5) with respect to x we get,

$$\frac{1}{\rho}\frac{\mathrm{d}p}{\mathrm{d}x} = \frac{4\mu x\left(3a^2 - x^2\right)}{\left(a^2 + x^2\right)^5}\left[2\mu\left(a^2 - x^2\right) + U\left(a^2 + x^2\right)^2\right] \quad (6)$$

To find extreme values of p, we make,

$\frac{\mathrm{d}p}{\mathrm{d}x} = 0$ which gives $x = 0, \pm a\sqrt{3}$

We see, that when $x = \pm a\sqrt{3}$

$$\frac{\mathrm{d}^2 p}{\mathrm{d}x^2} > 0 \text{ if } \mu > 4a^2 U \quad (7)$$

So, p the pressure is minimum at $x = \pm a\sqrt{3}$

We also see that, when $x = \pm a\sqrt{3}$

$$\frac{\mathrm{d}^2 p}{\mathrm{d}x^2} < 0 \text{ and if } \mu < 4a^2 U \quad (8)$$

So, p the pressure is maximum at $x = \pm a\sqrt{3}$

3. Conclusions

The cyclones which generated or passes through deep sea, generally posses a tremendous amount of energy. From equation (7) and its consequences, we see that when the turbulence (here the object doublet at $y = a$) is super cyclonic in nature that is $\mu > 4a^2 U$. We get minimum pressure at $x = \pm a\sqrt{3}$ on the sea shore. Such cyclones, from its very beginning, possess a tremendous amount of energy. The general circulation of the stream near the sea could impact little on its motion. Such system coupled with minima at shore moves towards the normal to sea coast and strike the shore vigorously. And in general, they never move parallel to the coast. Figs. 2(a-d) describes such systems.

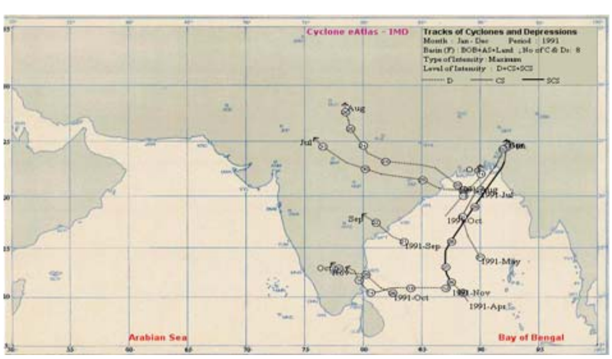

Fig. 2(a). Bangladesh Cyclone (1991, *Courtesy* : Cyclone eAtlas-IMD, www.imd.gov.in)

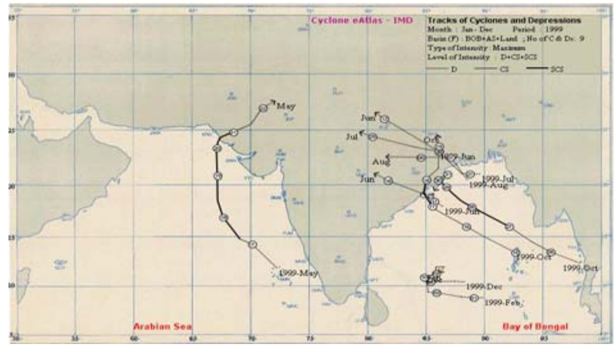

Fig. 2(b). Super cyclone of Orissa (1999, *Courtesy* : Cyclone eAtlas - IMD , www.imd.gov.in)

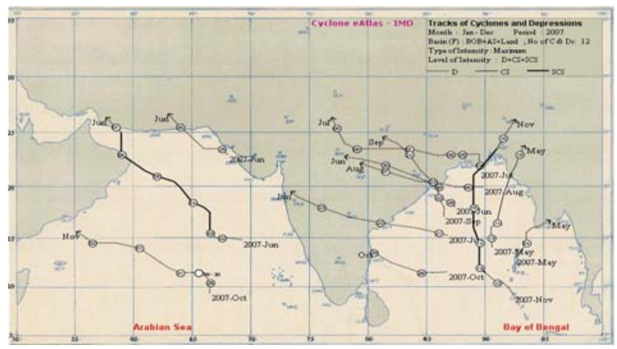

Fig. 2(c). Bangladesh cyclone SIDR (2007, *Courtesy* : Cyclone eAtlas - IMD, www.imd.gov.in)

Fig. 2 (d). Cyclone THANE (2011, *Courtesy* : Cyclone eAtlas – IMD, www.imd.gov.in).

Let us consider the Bangladesh super cyclone of 1991 [Fig 2(a)]. The Bangladesh super cyclone is represented by the above track (during 24th April 1991 to 30th April 1991). Obviously normal (approximately) to its coast of landfall.

The Orissa super cyclone 1999 represented by the track [Fig. 2(b)] (26th to 30th) is also normal to the coast of landfall.

The another track of Bangladesh cyclone of 2007 Fig. 2(c) (nearly a super cyclone) named SIDR

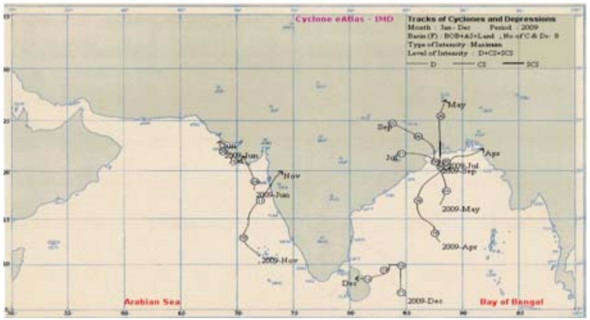

Fig.3 (a). Cyclone Aila. (2009, *Courtesy* : Cyclone eAtlas - IMD, www.imd.gov.in).

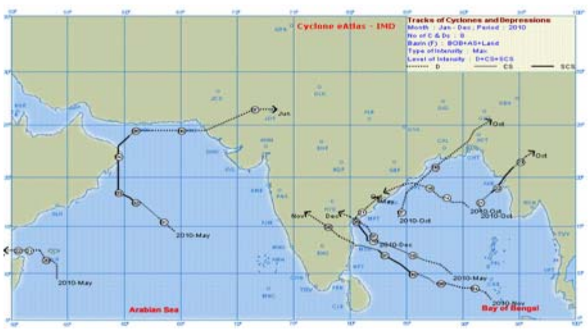

Fig.3(b). Laila (2010, *Courtesy* : Cyclone eAtlas- IMD, www.imd.gov.in)

(represented by 12th to 16th) moved almost along the normal to the coast.

The path of cyclone THANE of India [Fig. 2(d)] was also a vigorous one and its track was also towards the normal to the coast of landfall.

While from equation (8) and its consequences we see that when the turbulence (here the object doublet at $y = a$) is sub cyclonic in nature that is $\mu < 4a^2U$. We get maximum pressure at $x = \pm a\sqrt{3}$ on the **s**ea shore. Initially such system does not possess too much energy. They generated near the coast. Hence, the system tries to repel from the seashore high pressure zone. The general circulation of the stream near the sea coast now comes into play and acts in the negative direction of *x* axis. Thus, the general circulations of the stream push the system towards the right of its motion (along the coast). As such system gets energized gradually while moving and struck coast when the said conditions are achieved. It is to be mentioned here that the general circulation of the stream near the sea coast of Bay of Bengal is along the negative direction of *x* axis. The track of cyclones in the Bay of Bengal describes such motions [Figs. 3 (a&b)].

The track of cyclone 2009 AILA Fig. 3(a), (represented by 24th to 26th) was generated near the coast (not in the deep sea) so it was the case of ($\mu < 4a^2 U$). According to the track, although it was behaving the motion towards the normal to the land fall ($\mu > 4a^2 U$) but actually the cyclone AILA was not a severe one.

The track of cyclone 2010 Laila Fig. 3(b), (represented by 18th to 20th) was initially following the path of normal to the coast that is ($\mu > 4a^2 U$), but there after from 19th, it moves towards its right of the motion, thus case became of along the coast ($\mu < 4a^2 U$) after reducing energy. Here are many tracks of cyclones which were following the path along the coast and they were weaker in strength (that is $\mu < 4a^2 U$).

In addition, the analysis also depicts the cause of the movements of the most BOB cyclones having $\mu < 4a^2 U$ towards Bangladesh.

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