JOURNAL OF MECHANICS OF CONTINUA AND MATHEMATICAL SCIENCES
www.journalimcms.org

ISSN (Online) : 2454 -7190 Vol.-17, No.-2, February (2022) pp 41-51 ISSN (Print) 0973-8975

RSRW DATA, CSP AND CYCLONE TRACK PREDICTION

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https://doi.org/10.26782/jmcms.2022.02.00005

(Received: November 13, 2021; Accepted: January 22, 2022)

Abstract

Tropical cyclones are gradually becoming an increasing menace to the coastal human civilization throughout the World. This is due to their increased frequency and intensity of occurrence nowadays. With the global increase of sea surface temperature a marked increase in the percentage of their formation from depression happening especially in the tropical oceans of the World. The Coromandel Coast of India is not an exception to these. To mitigate their devastation effect on mankind we need to study the details of their dynamics governing equations and hence develop suitable solutions. In this paper the numerical value of a stability parameter, viz. CSP is determined employing the RSRW data of one tropical cyclone that has hit the Coromandel Coast of India in 2010. CSP is a dimensionless parameter that we obtained from the analytic solution of cyclone dynamics governing equations.

Keywords: CSP, Radial velocity, Cross-radial velocity, RSRW, Cyclone eye, Tropical cyclone.

I. Introduction

The word 'cyclone' in 'tropical cyclone' is described as a bulk scale atmospheric wind and pressure system signified by low pressure at its centre and followed by subsequent circular wind motion. The direction of the wind motion is counterclockwise in the northern hemisphere and clockwise in the southern hemisphere. The word 'tropical' in tropical cyclones relates to its development and genesis in tropical oceans. Tropical cyclones forms over tropical oceans of location between 5^0 and 22^0 latitude with warm sea waters of sea surface temperatures $(> 26.5^0\text{C})$, low vertical shear and sufficient thorough moisture instability. Tropical cyclones completely devastate the coastal communities of the world in terms of threatening millions of lives, causing damage to properties and infrastructure worth billions of dollars. Climate change which occurred globally specially in recent times has greatly changed the behaviour of devastations related to natural hazards (Köhle et al. 2016). Around 66 % of the world population lives within a few kilometres of the 1.16 million Km long extended global coastline. The lives and properties of such a huge population are greatly impacted by different natural phenomena such as waves, winds, tides, rainfall etc. which reaches extraordinary magnitudes during the occurrence of severe events like tropical cyclones and Tsunamis (Rezapour 2015). The necessary critical factors behind the formation of tropical cyclones (Ghosh and Chakravarty 2018) are as follows:-

i) The sea surface temperature should be $26.5°\text{C}$ (80^0 F) or warmer. This warm water depth must be at least 50 m from the ocean surface.

ii) Location of a pre-existing atmospheric perturbation and circulation near the surface of the warm water layer is favourable for the generation of a tropical cyclone.

iii) The decrease of atmospheric temperature concerning the geopotential must be strong enough to support the formation of deep convective clouds.

iv) A sufficient humid and moisture containing middle atmosphere (at a height of around 5000 m from the earth's surface) helps in the increase of potential energy of the tropical cyclone.

v) The cyclone genesis site location should be at least 500 Km (300 miles) away from the equator.

vi) Existence of a low vertical shear environment from the sea surface up to the extent of the boundary level of the troposphere for the easy transport of sea surface moisture is also necessary for the generation of tropical cyclones.

A power dissipation index that signifies the intensity of tropical cyclones was developed by Emanuel (2005). This index shows a marked increase in recent years. This index increases with the increase of global mean sea surface temperature. Again, due to global warming and global climate change, the sea surface temperature is increasing day by day and serving as an important factor behind tropical cyclone development. Goff et al. (2016) studied the terrestrial and marine deposits of the Cook Islands of Lake Tiriara to distinguish the deposit patterns from Tsunamis and cyclones that have struck that place in the recent past. In this way, we can distinguish their dynamics. In a similar fashion Nott (2003) studied the dynamical behaviour of prehistoric cyclones. A detailed functional comparison of Weather Research and Forecasting (WRF) and Coupled Ocean-Atmosphere Wave Sediment Transport (COWAST) models regarding cyclone forecasting analysis was done by Baisya et al. (2020). Speaking of cyclone forecasting climate models, the work of Tapiador (2008) regarding the identification of hurricanes under the low-resolution Global Climate

Model (GCM) deserves a special mention in this regard. Perfect track and intensity prediction of tropical cyclones is indeed a challenging task for atmospheric researchers nowadays. In this paper, a humble attempt has been made towards such an important matter by analysing the RSRW (Radio Sonde Radio Wind) data for one tropical cyclone that has hit the Coromandel Coast of India in 2010. A detailed idea regarding RSRW data interpretation can be obtained from the work of Posada et al. (2012). Alongside cyclone track prediction the intensity prediction of formed depressions tending to develop as a tropical cyclone is also a challenging task nowadays for meteorologists all over the world. Lala et al. (2014) gave an explanation of the reasoning behind the lower frequency of occurrence of cyclones in undulating landforms rather than plain landforms.

II. Anatomy of a tropical cyclone

By extensive literature survey, a basic outline of the internal structure of a tropical cyclone can be obtained. Ritchi and Vigh (2010) did important work regarding the inner core dynamics of tropical cyclones. The relationship between tropical cyclone structure and its consequent thunderstorm activity has been derived by Shevtsov et al. (2015). The work on intensification and contraction of cyclone eyewall and their mutual relationship was studied by Stern et al. (2015).

In general tropical cyclones are analogically comparable to a rotating, hollow, compact and circular cylinder materialistic in the form of a storm and in general around 318 Km (200 miles) in diameter consisting of a wind swirl in the form of a gigantic fluid parcel around a core region of low atmospheric pressure. The inner core low pressure of a tropical cyclone structure and earth's rotation jointly generates a strong Coriolis force that draws the wind inwards towards the core (anticlockwise or cyclonic in the northern hemisphere) and outwards away from the core (clockwise or anticyclonic in the southern hemisphere). The total wind field consisting of wind flux (Ghosh and Chakravarty 2018) may be divided into four regions: -

II. i. The eye

Considering the rotating dynamical analogue as the basic cyclone structure, the most innermost core portion is the cyclone eye. The cyclone eye has a comparatively calm and humid atmosphere in comparison to the other parts of a cyclone. The total radial extent of the eye roughly varies from 30- 65 Km from the cyclone axis. Due to the calm atmosphere of cyclone eye low vertical shear environment prevails there. Consequently, warm ocean moisture gets raised to great heights from the ocean surface without much disturbance, in the eye region of the cyclone. In high altitudes during condensation, these moistures release latent heat and this acts as a fuelling factor behind the generation of potential energy responsible for causing the violent destruction.

II. ii. The eyewall

The most violent and destructive portion of the cyclone is cyclone eyewall. The wind speed is maximum in the eyewall and it reaches around a maximum of 225 Km/h for super cyclonic storm. Heavy rainfall associating with strong winds makes cyclone eyewall the most lethal portion of the storm.

II. iii. The wall cloud region

The region of tropical cyclone that comes after cyclone eyewall is the wall cloud region and it extends upto the spiral rain bands. This region is also characterised by strong winds associated with heavy rainfall. The radial extent of the wall cloud region is around 8 Km.

II. iv. Rain bands

The outermost portion of the cyclone eye is characterised by strong rainfall but comparatively calm wind, is the rain bands.

A detailed anatomical picture of a tropical cyclone is given by Zhender (2019).

III. Cyclone Stability Parameter (CSP)

In our previous work, we have shown CSP $= \frac{V}{U}$ is a crucial parameter for determining the stability of a cyclone (Ghosh and Chakravarty 2018).Where V and U are respectively the cross-radial and radial velocity of a concerned fluid parcel within the cyclonic system at a certain instant of time. In this work, the RSRW data of one tropical cyclone that has hit the Coromandel Coast of India on 2010 is analysed and the respective CSP has been calculated starting from the day of genesis to the day of termination of the cyclone (as per availability of data). In this analysis, we choose two RSRW coastal stations in such a way that the lines joining from the respective stations to the eye of the cyclone are nearly orthogonal to each other. The CSP has been calculated at different geopotential heights for the respective RSRW coastal stations.

We study the following cyclone,

III. i. Cyclone Laila analysis

Cyclone Laila was the first cyclonic storm to affect South-East India since the 1990 Andhra Pradesh super cyclone. On 18thMay 2010 its first birth took place in the form of depression over the Bay of Bengal Ocean bed. Liala got intensified further as it moved north-westward and developed as a severe cyclonic storm on the following day. On 20th May 2010, Laila made landfall over Andhra Pradesh and weakened on the very next day as simple rainfall causing depression. Taking the RSRW data of Chennai and Bhubaneswar for the boundary layer we calculated CSP for Laila from 18th to 21st May 2010 respectively (Tables 1 to 4 which are self-explanatory). We also plot the $U - V$ graph with CSP (Figs. 1 to 4). We observe from the tables and graphs that the cyclonic system tends to drift towards Chennai as the CSP value is greater than unity.

IV. Result and Discussions

In this study, we have used the velocity data which were obtained from RSRW observations of 2 different India Meteorological Department (IMD) observatories (viz. Chennai and Bhubaneswar). For the study, we have chosen cyclone Laila. As we do not have any data within a cyclonic system, to validate our previous analytic work (Ghosh and Chakravarty 2018) we calculate CSP values of cyclone Laila at different geopotential heights, which have been shown in tables 1 to

4. Also, the graphs are drawn in figs. 1 to 4. If we critically study the tables and graphs of Laila, we observe that in most of the cases CSP values are greater than unity, which resembles the result (Ghosh and Chakravarty 2018).

V. Conclusions

This paper validates the analytical work of CSP analysis (Ghosh and Chakravarty 2018). The CSP value obtained is greater than unity signifying cyclone Laila to be a stable circulation.CSP value greater than unity also implies cross-radial velocity i.e. *V* is greater than radial velocity i.e. *U* and subsequently the cyclonic system will be drifted towards the station for which we consider the cross-radial velocity i.e. *V* and in reality, that has happened.

VI. Acknowledgments

The author I.G. is highly grateful to the Director (Prof. Dr. (Col) Probhas Bose) of the College of Engineering and Management, Kolaghat for providing the necessary opportunity to continue this research and make it a success. The author N.C. is highly grateful to the Director-General, India Meteorological Department (Dr. Mrutyunjay Mohapatra) for his continuous support and encouragement to do this work. The author N.C. is highly obliged and thankful to National Data Canter (IMD Pune) for providing necessary RSRW data for this research work.

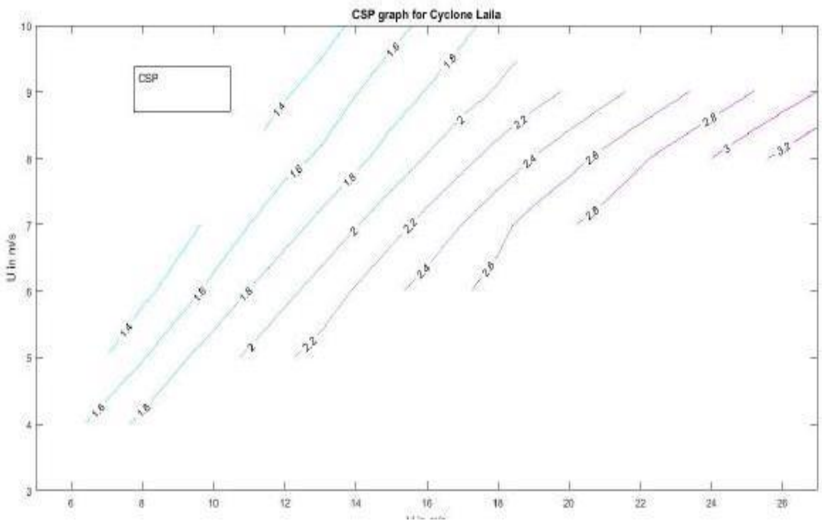

Fig. 1. CSP graph for cyclone Laila on 18^{th} May, 2010

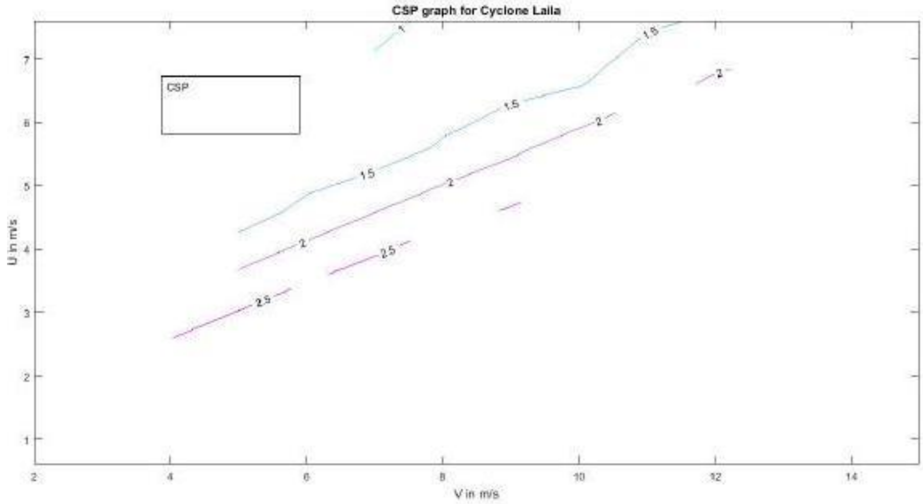

Fig. 2. CSP graph for cyclone Laila on 19th May, 2010

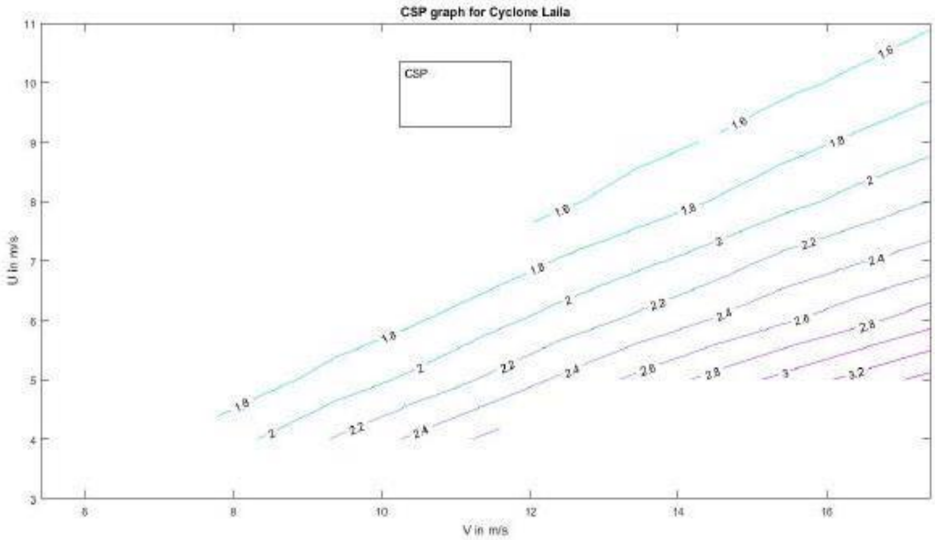

Fig. 3. CSP graph for cyclone Laila on 20th May, 2010

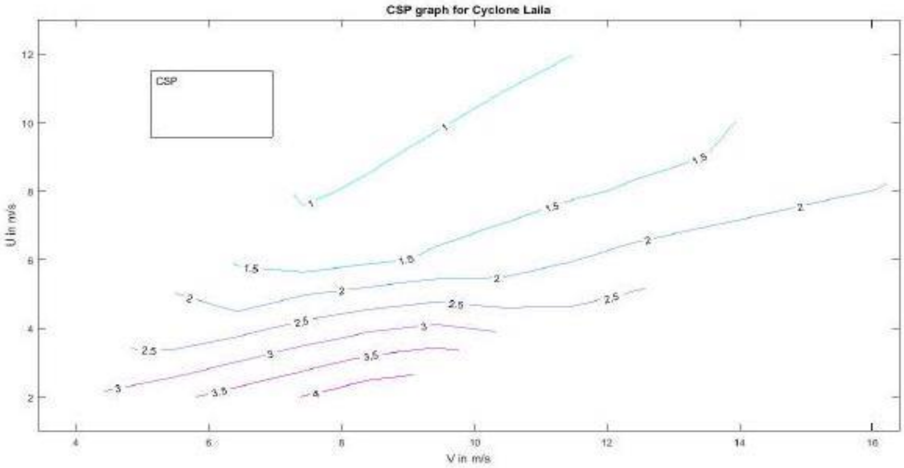

Fig. 4. CSP graph for cyclone Laila on 21st May, 2010

Table 1 : CSP analysis for cyclone Laila on 18th May, 2010

Altitude (m)	Bhubaneswar wind velocity (U) in m/s	Chennai wind velocity (V) in m/s	CSP=V/U
70	3.000000000	5	1.666666667
150	3.883002207	6	1.545196134
300	5.207505519	7	1.344213650
448	6.514348786	11	1.688580142
600	8.000000000	13	1.625000000
681	8.000000000	14	1.750000000
920	8.652694610	18	2.080276817
1015	9.000000000	20	2.222222222
1416	8.537190083	26	3.045498548
1500	8.000000000	27	3.375000000
1932	9.000000000	27	3.000000000
2477	7.775747508	23	2.957914976
3100	7.255319148	20	2.756598241
4500	10.65067651	13	1.220579743

Table 2: CSP analysis for cyclone Laila on 19th May 2010

Altitude (m)	Chennai wind velocity (V) in m/s	Bhubaneswar wind velocity (U) in m/s	CSP = V/U
45	2	0.600000000	3.333333
495	5	4.764705882	1.049383
552	6	5.266094420	1.139364
728	8	6.776824034	1.180494
943	10	8.000000000	1.250000
967	10	8.000000000	1.250000
1086	11	8.000000000	1.375000
1317	11	8.000000000	1.375000
1464	10	8.000000000	1.250000
1987	10	8.000000000	1.250000
2274	11	8.000000000	1.375000
2542	12	8.000000000	1.500000
2782	14	8.000000000	1.750000
3127	15	8.000000000	1.875000
3746	12	8.000000000	1.500000
4403	11	8.000000000	1.375000
5106	7	8.000000000	0.875000
5979	8	8.000000000	1.000000

Table 3: CSP analysis for cyclone Laila on 20th May, 2010 (date of landfall)

Altitude (m)	Chennai wind velocity (V) in m/s	Bhubaneswar wind velocity (U) in m/s	CSP=V/U
45	5.404255319	3	1.801418440
321	17.12068966	6	2.853448276
478	18.00000000	7	2.571428571
712	18.00000000	9	2.000000000
860	18.00000000	10	1.800000000
951	18.00000000	10	1.800000000
994	18.00000000	11	1.636363636
1447	17.10927835	10	1.710927835
1969	15.93571429	11	1.448701299
2254	15.91785714	10	1.591785714
2523	15.04116638	8	1.880145798
2560	15.16809605	8	1.896012007
2813	16.03602058	6	2.672670097
3438	18.35968379	5	3.671936759
3726	17.90243902	7	2.557491289
4029	16.05487805	6	2.675813008
4385	13.57462687	6	2.262437812
4932	12.50522648	8	1.563153310
5261	13.27952167	8	1.659940209
5652	13.86397608	7	1.980568012
5841	14.01851852	6	2.336419753

Table 4 CSP analysis for cyclone Laila on 21st May, 2010

Altitude (m)	Bhubaneswar wind velocity (U) in m/s	Chennai wind velocity (V) in m/s	CSP=V/U
45	1	3.418604651	3.41860465
493	2	9.115702479	4.55785124
726	4	11.05434783	2.76358696
809	4	11.50543478	2.87635870
965	5	12.00000000	2.40000000
1143	5	11.42212190	2.28442438
1396	6	10.27990971	1.71331829
1459	6	10.00000000	1.66666667
1978	6	7.043298969	1.17388316
2234	8	7.853503184	0.98168790
2378	8	9.301075269	1.16263441
2527	8	10.90322581	1.36290323
2689	8	11.78730703	1.47341338
2824	9	13.96397942	1.55155327
3107	8	16.87650086	2.10956261
3504	8	14.59875260	1.82484408
3724	13	13.08823529	1.45424837
4380	9	7.145454545	0.79393939
5081	10	7.936666667	0.79366667
5839	13	11.00000000	0.84615385

Compliance with ethical standards: The authors declare no conflict of interest.

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