RAPID INTENSIFICATION OF HURRICANE IAN DURING LANDFALL IN SOUTHWEST FLORIDA (2022)

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Abstract. *Rapid intensification (RI) of tropical hurricane (TH) Ian during landfall is examined within the framework of equilibrium translation model (ETM). The development of RI in the rarest conditions of constant TH sizes and translation speed, as well as the availability of relatively accurate hurricane heat potential (HHP) maps, significantly increases the accuracy of the determination of the alignment number (An). The results strengthen the conclusion previously made about ETM and An as the model and similarity number basically characterizing TH development.*

Key words: *Tropical hurricane, rapid intensification, equilibrium translation, alignment number.*

Introduction. During its life cycle, TH Ian (September 23 – 30, 2022) made successive landfalls in Cuba, southwest Florida, and South Carolina [1]. It became one of the costliest hurricanes in the history of observations with the lion's share of damage in Florida. Like its famous predecessor TH Charley (2004) [2] Jan's landfall in roughly the same area of Florida was also accompanied by RI, highlighting the still unresolved problem with predicting the parameters of such development.

Below Ian's RI during landfall is considered within the framework of ETM. The work succeeded in increasing the accuracy of ***An*** determination, which was facilitated by very specific conditions of RI occurrence and the availability of relatively accurate HHP maps.

Methods. The long-term inability to correctly predict RIs, reflecting the need to overcome the lack of understanding of the thermohydrodynamics of decisive interactions in the sea-hurricane-atmosphere system (SHAS), has attracted the author's attention since the 2000s [3-4].

At the first stage of a purely qualitative analysis, the conclusion was made that, in TH, an internal thermal drive arises in the direction of the sea surface temperature (SST) gradient (Fig. 1). Next, the presence of a negative feedback between the internal thermal drive and TH translation speed was established, which made it possible to introduce the concept of TH equilibrium translation.

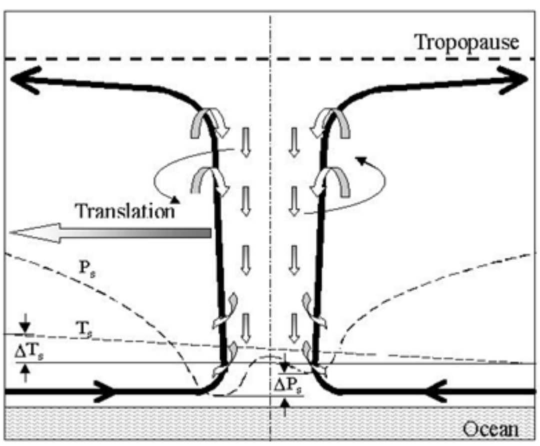

Fig. 1. Scheme of internal thermal drive.

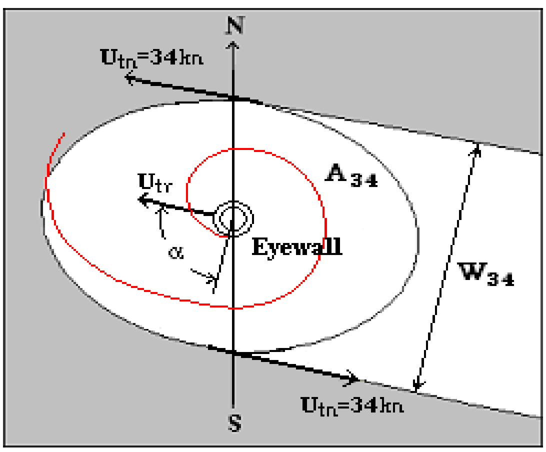

Fig. 2. The occurrence of TH lateral movement.

Next, the key assumption was made that equilibrium translation mode is the basis of RI phenomenon. In other words, it was assumed that when the main TH drive, large-scale environmental wind and internal TH thermal drive are in a certain conformity, this huge natural heat engine becomes most efficient in converting sea water heat into wind energy, resulting in RI.

The validity of the corresponding model (ETM) can be assessed by the adequacy of its final product - the dimensionless similarity number, named by the author Alignment number – ***An*** (Dr. Gvelesiani suggested calling this parameter the Shekriladz*e* number [5]).

However, such an assessment is still hampered by the total disregard of ETM. Even the obvious interpretation of the mysterious so-called "unusual tracks" of TH by the above two, external and internal drives still has not been noticed (the problem of unusual tracks is the second, after RI, among the main unresolved problems of tropical cyclogenesis).

Considering the direction of internal thermal drive along the underlying large-scale SST gradient (Fig. 1), ETM assumes that the warmest seawater crossing the TH leading boundary further spirals within the TH to the same leading edge of the eye wall cloud, resulting in coincidence directions for both drives (the internal thermal drive is formed on the eye wall cloud and the equality $\alpha = 0$ (Fig. 2) is one of the preconditions for the equilibrium translation).

Accordingly, if similar conformity of the dynamic and thermal fields is not satisfied and the same water crosses the boundary of the eye wall cloud with a non-zero value of angle α, the internal thermal drive can be directed with virtually any deviation from the main drive generated by the large-scale environmental wind, causing “unusual” movements of TH.

It is easy to see that any “unusual track” can be explained in ETM framework by the time-varying values of the angle α and the ratio of the two drives.

At the same time, the author’s main goal from the very beginning was to demonstrate the effectiveness of ETM in studying RI as the most important among unsolved problems, in order to gain the interest of tropical cyclogenesis researchers in further wide development of the model.

The basic equation for ***An*** can be written as follows [3-4]:

$$An = \frac{Q \cdot \delta S_{sc}}{A_{34} \cdot q} \quad (1)$$

where A_{34} is an area inside tangent wind velocity 34 knots (corresponding to the TH outer boundary, as assumed in regular forecast advisories) (m^2); q is integral heat flux (sensitive and latent) from the sea surface to the TH averaged inside A_{34} (w / m^2); Q is hurricane heat potential (*HHP*) averaged inside A_{34} (J / m^2); δS_c is increment of the cooled sea surface (cooled surface remaining behind TH during unit time) (m^2 / s).

Here, the role of the tangential wind speed field is reflected by the parameter q, determined by a special empirical equation based on accounting this field [6]. The role of the combined effect of the environmental wind and internal driving force is reflected by the parameter δS_c.

Finally, TH equilibrium translation accompanied by RI corresponds to a critical value $An_{cr} = const$.

Accurate and reliable establishment of such a correspondence is only possible by the relevant leading research and monitoring centers that are able to determine with high accuracy the values of all parameters of Eq. (1), including the most difficult to determine δS_c, which, unfortunately, still is not done. The same centers can continuously monitor the value of An.

At the same time, in order to at least approximately verify ETM (according to the above main goal), another equation was introduced [3-4], only roughly equivalent to (1), but definable solely on the basis of publicly available information, such as regular forecast advisories and daily updated HHP maps:

$$An = \frac{Q \cdot U_{bb}}{R_{ef} \cdot q} \quad (2)$$

where U_{bb} is TH back boundary center translation speed; $R_{ef} = 2A_{34} / \pi W_{34}$ is effective radius of TH (in the case of circular TH it is equal to the radius), W_{34} is the transverse size of A_{34}.

In Eq. (2) the role of the $\delta S_c / A_{34}$ ratio is reflected by the ratio U_{max} / R_{ef} roughly proportional to it, while A_{34}, W_{34} and R_{ef} are determined by the data from the relevant forecast advisories [7] using the methods [6].

Based on Eq. (2), a number of studies [2-4,6,8-9] were conducted analyzing the life cycles of numerous real THs by constructing curves of the correlation of the maximum tangential wind speed (U_{max}) and An over time. The high repeatability of the correlation between $Umax$ and An_{cr} over a sufficiently large number of THs allowed us to conclude that ETM has fundamental potential in terms of understanding and describing TH development. However, these results still could not shake the wall of total disregard.

The present study is still based on Eq. (2)

Results and discussion. The correlation between U_{max} and An during Ian's landfall can be traced by Fig. 3. The data covers a segment of Ian's life cycle from the northern coast of Cuba to Southwest Florida. The main interest, of course, is the landfall stage, which began around the 60th hour (here we assume that landfall begins with the transition to land of 10 ÷ 15% of the A_{34} area.). Time 0 in Fig. 3 corresponds to 21:00 UTC 09/25/2022.

The curves are constructed based on discrete points, each of which corresponds to a specific forecast advisory issued at a given point in time [7].

The Q parameter is determined from the hurricane heat potential (HHP) map for the previous day [10]. The standard time step for issuing the advisory is 6 hours, however, during the landfall they were issued more often, which is accordingly reflected in Fig. 3.

Ultimately, any An value corresponds to a specific advisory, and all parameters used are among the parameters available at that time to the compilers of the corresponding advisory.

An important parametric feature of Ian from the point of view of the accuracy of our analysis is the constancy of its sizes and translation speed of its center upon landfall (three filled points on each curve). Such a rare coincidence with the landfall stage allowed us to equate in Eq. (2) U_{bb} to the TH center's translation speed, reflected in the advisory itself.

As a result, we got rid of the need for an approximate determination of U_{bb} using the method [6], which tangibly improved the accuracy of determining An.

The accuracy of determining An has also been improved thanks to the availability of new, more accurate HHP maps [10] (with a richer range of colors).

Ultimately, according to our rough estimate, the accuracy of An_{cr} determination was close to ± 25%.

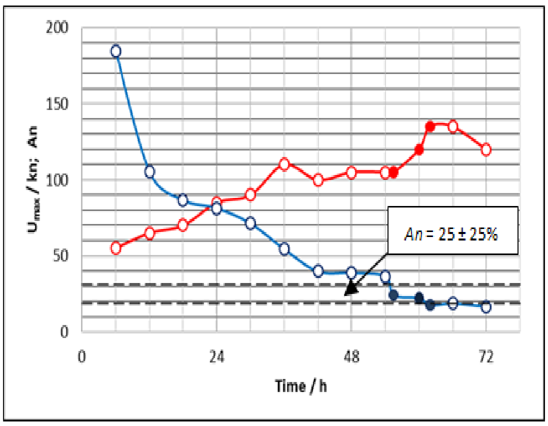

Fig. 3. Time course of U_{max} (red curve) and An (blue curve) of TH Ian before and during landfall in southwest Florida.

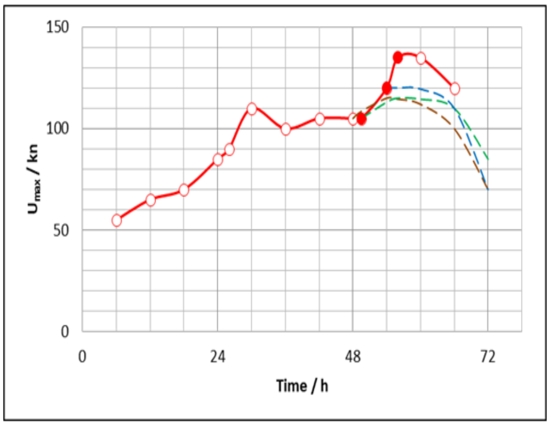

Fig. 4. forecasts of U_{max} of TH Ian according to forecast advisories № 22 (orange curve), № 23 (green curve) and № 24 (blue curve).

As follows from Fig. 3, in this case the correlation between ***Umax*** and An_{cr} during Ian's landfall in southwest Florida once again confirms the fundamental importance of ETM and its main outcome - ***An***, critical value of which corresponds to RI.

The value of Ancr identified here is consistent within the previously established range of 25 - 35 [2-4,6,8-9], although it is more accurate. At the same time, it does not make much sense to refine the An_{cr} value determined from Eq. (2), which is itself an approximation.

Ultimately, the sought critical value must be identified by the relevant research centers which can do this using the basic Eq. (1) with much greater accuracy (by the way, in this case another absolute value of An_{cr} will be identified, without changing anything in principle, remaining the same for different THs).

Forecasts of changes in U_{max} in time published in the relevant advisories are presented in Fig. 4.

These forecasts avoided the negative publicity of the forecasts made in 2004 for the TH Charley's landfall because they correctly predicted the TH intensification before the Ian's landfall. As for the TH Ian's landfall stage itself, they again erroneously maintained the iron tradition of not predicting intensification at this stage.

Here we are faced with the most pressing problem of predicting the intensity of TH precisely in the situation when its incorrectness becomes most critical for society.

For example [8], among 38 major THs hit land in total around the globe in 2004 - 2013, 16 (42%) strengthened during landfall. In all the 38 cases, without any exception, forecast advisories predicted TH weakening, revealing principal restrictions of the theories and numerical models backing the forecasting system. Apparently, numerical models do not take into account the fundamental fact that the power output of TH, as a giant natural heat engine, depends not only on the supplied sea water heat flow, but also on the efficiency of its conversion to wind energy, capable of varying widely regardless of changes in the heat inflow.

Conclusion. The results of the work this time more accurately confirmed the previous conclusion about the fundamental potential of equilibrium translation model (ETM) in terms of predicting TH development. In addition, identifying the ability of ETM to serve for the analysis of the second most important unresolved problem, TH unusual tracks highlights the model's potential breakthrough role in the comprehensive study of tropical cyclogenesis, in general.

Normally, a breakthrough potential, even if made by a lone outsider, is verified, picked up and developed by the relevant scientific community and ultimately becomes the property of the entire society.

In contrast, ETM from the very beginning became the object of total disregard. In other words, it was buried in the so-called corporate grave (CG), depriving its author even a vital opportunity to obtain independent public confirmation or refutation of his results.

Although similar course of events is not the rarest exception in modern science, this particular case still carries a fundamental novelty when the type of scientific product buried in the CG gives the situation a completely new coloring.

As far as I know, in this case, the first time in the history of science, the object of total disregard became the similarity number of a physical phenomenon, the only one of its kind, identified over a century of wide research into this phenomenon.

By the way, in fact, it was also possible to obtain the Alignment number without developing a specific physical model, using a well-known method of theoretical physics - dimensional analysis of the physical phenomenon. It remains a mystery why such a strategic challenge was not met much earlier, which would have greatly accelerated the study of the problem.

We are faced with the situation that has greatly slowed down the study of tropical cyclogenesis.

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