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Tropical Cyclone: Equilibrium Translation Model and Rapid Intensification during Landfall

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ABSTRACT. Summarizing the first decade of developing equilibrium translation model (ETM) the focus is made on the phenomenon of rapid intensification (RI) of tropical cyclone (TC) during landfall. Among 38 strong TCs fourth and fifth categories, hit land around the globe in 2004 - 2013, 16 strengthened during landfall causeing considerable portion of the total damage (e.g., TCs Charley 2004, Giri 2010, Vicente 2012 explosively intensified during landfall). Despite this, the weakening during landfall was predicted in all the cases, without exception, revealed thereby fundamental limitations of the conventional approaches to the analysis and modeling. Apparently here we face a fairly typical problem with the proper combination of numerical methods with adequate qualitative physical models complicated in this case due to the lack of analysis on the integral scale. ETM bridges this gap by linking TC development with conformity of dynamic and thermal fields in the system ocean-cyclone-atmosphere (SOCA) on integral scale, considering TC as self-organized open dissipative system internally targeted at intensification. This trend is gaining momentum on the transition of TC to the so-called equilibrium translation (ET), when the highest efficiency is reached in the transformation of the oceanic heat into cyclonic motion. The trend is reflected by dimensionless alignment number, incorporating integral thermal and dynamical parameters of the SOCA. Approaching the critical alignment number predicts TC intensification, including RI (alignment effect). As shown in the relevant analysis, if the monitoring of alignment number was conducted, predicting high probability RI of landfalling TC would be possible in almost all the real cases.
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Key words: *tropical cyclone, rapid intensification, landfall, equilibrium translation, alignment number*

Characteristic scales of tropical cyclone (TC) vary by nearly nine orders from the sprayed by wind water droplet to the outer diameter of tangent winds. Description of such an extremely complex multi-scale phenomenon requires consideration of a wide range of interrelated irreversible thermo-hydrodynamic processes taking place in the system ocean-cyclone-atmosphere (SOCA). That is why, during the last decades, numerical models became a major tool in the relevant studies, including important problem of forecasting TC track and intensity. Several generations of numerical models were developed and extensively involved in the forecasting procedures [1].

Currently, this "great numerical attack" comes with certain achievements, such as clear improvement in TC track forecasting, although progress in intensity forecasting is assessed as insufficient [1-4].

The situation is really critical with forecasting of intensification of landfalling TC, representing the most dangerous event in terms of impact on coastal areas. Permanent, without exception, misprediction of intensification landfalling TCs by regular forecast advisories, during 2004-2013, compels us to conclude that the approaches and theories backing the advanced numerical models identify this important real physical phenomenon as impossible in principle.

If the problem with predicting RI is discussed in the context of the prospects for progress in the future improvement of the resolution of the numerical models [1-4], the left outside discussion concrete problem of RI landfalling TCs fundamentally changes the entire context.

The matter is potentially fundamental incompatibility of the theoretical models with physical reality that can put on the agenda the problem of radical revision of the foundations of the existing approaches.

ETM [5-8] considers TC as self-organized dissipative system internally targeted at intensification. During equilibrium translation (ET), when the main driver of TC, the large-scale environmental wind, and the internal driving tendency of TC are found to be in agreement, this huge natural heat engine becomes the most effective in conversion of oceanic heat into cyclonic motion of atmosphere and intensifies rapidly (alignment effect).

Uncovered within ETM dimensionless alignment number, incorporating integral thermal and dynamical parameters of the SOCA, named in [9] as the Shekriladze number, acquires the role of the basic predictor of upcoming TC development, including probability of RI.

Below we summarize a decade of development of ETM, placing in the center of consideration the phenomenon of intensification landfalling TC.

Conceptual Basics of ETM

As already noted, ETM considers TC as self-organized system internally geared to intensification. The oceanic heat is seen as the only energy source. This assumption does not cover the range of low HHPs and small diameters of TC, when energy of air inflow becomes valuable. It is also assumed that TC translation always is influenced by certain internal driving force (IDF) directed toward increasing sea surface temperature (SST) and powered by asymmetry of the latter, at outer boundary. The IDF is linked to more intense upstream flow in front of the eye wall cloud with a minimum air pressure and less intense upstream flow with more air pressure in the eye wall back part. As the eye wall cloud is a dynamic core of the whole system, a pressure drop between its rear and front (ΔP_s) is seen as a basis for IDF.

As shown through qualitative considerations [5-8], within accepted assumptions, TC not only tries to shift toward increasing SST, but it also tends to establish certain equilibrium between translation speed and integral heat influx (i.e., with IDF). We call this target mode "equilibrium translation" (ET). ET leads to the specific relationship between ET and HHP. Ceteris paribus there should be strong enough direct relationship between HHP and ΔP_s: strengthening of ascending flow with increasing HHP cannot but lead to an increase in ΔP_s. Corresponding increase in IDF necessarily shifts ET to lower translation speeds, other things being equal. Thereby, ET is slower at high HHPs and more rapid at low HHPs. The inverse dependence allows us to characterize ET by roughly constant so-called heat involvement factor equal to the share of initial HHP removed by TC through passage of the given area.

Further we are optimistic to assume that just the transition to ET and its maintenance is the basic condition for maximum intensification of TC, realizing that only adequate description of the field data can confirm the validity of the assumption. ETM results in dimensionless alignment number (An), incorporating integral thermal and dynamical parameters of the SOCA [5-8]. Its critical value (An_{cr}) is defined as precondition for ET and alignment effect [5-8]:

$$An_{cr} = \frac{Q \cdot \delta S_c}{A \cdot q} = Const\,, \qquad (1)$$

where A is an area covered by TC; Q is HHP before entering TC, averaged inside A; q is integral heat flux (sensitive and latent) averaged inside A; S_c is increment of sea surface cooled by TC (cooled surface remaining behind TC during unit time).

Unfortunately, the analysis of broad field data on TCs within the framework of the basic equation (1) is still unfulfilled. There exist two obstacles: the first is absence, in open access, of needed data on all the parameters are specified in (1), except Q. The second is thorough lack of the interest to ETM among researchers potentially having such data.

At the same time, fortunately, it turned possible to introduce equivalent to (1) approximate value of An_{cr}, recorded using the parameters specified in the regular forecast advisories and HHP maps. In this way, the condition (1) is rewritten as follows [5-8]:

$$An_{cr} = \frac{Q \cdot U_{bb}}{R_{ef} \cdot q} = Const \qquad (2)$$

Where all the parameters are determined for an area inside or at tangent wind 34 knots (e.g., minimum tangent wind speed specified in forecast advisories); U_{bb} is translational speed of TC back boundary center; W_{34} is TC transverse size; $R_{ef} = \frac{2A_{34}}{\pi W_{34}}$.

Equation (2) is supplemented by the empirical formula designed for average integral heat flux from sea surface to TC, specifically during ET [7-8]:

$$q = \left[400\left(R_1^2 - R_2^2\right) + 600\left(R_2^2 - R_3^2\right) + 1,200\left(U_{\max}/130\right)R_3^2\right]R_1^{-2} \ \mathrm{W{\times}m^{-2}}, \qquad (4)$$

where R_1, R_2 and R_3 are average outer radii of the first, second and third zones, to be determined according the procedure [8]; U_{max} is maximum tangent wind speed in knots; 130 is maximum tangent wind speed in reference TC Opal (1995) in knots.

Equation (4) proceeds from leveling of the role of HHP by above negative feedback between TC translation and HHP and links heat flux to only tangential wind field. At the same time, accepted approach neglects the role of possible changes in inflowing air humidity, practically assuming that this parameter will always be equal to that which was in the reference case of TC Opal. Related potential consequences are discussed below.

The complete procedure of calculating of An using the data specified in forecast advisories is presented in [8]. There also is presented methodological rationale for the use of two alternative versions of the calculation, for assessing the accuracy of determination. Based on the analysis of the field data on the most powerful TCs observed in 2004-2010 the following approximate assessment of critical alignment number is made [7]:

$$An_{cr} = 35 \pm 20\%, \qquad (5)$$

The procedures, methodology and results [8] are used below in the analysis of the field data on landfalling TCs.

Finally, as above rationale of ETM loses grounds without accurate fitting of TC in steering wind, we must return to dominant role of the latter.

The achievement of dynamical conformity is quite complex process. Even location of warmer waters ahead of TC at all is not a guarantee of directing IDF along TC translation: due to the spiral flow inside TC, the warmest air masses can reach any side of eye wall cloud, resulting in different directions of IDF. It seems that just various mutual directions of steering wind and IDF can lead to observed specific trajectories of TCs, such as a zigzag, turns up to 180° and so on although such reasoning requires detailed study.

Here we assume that TC self-organization includes aiming the spiral flow at delivering most heated airflow to the front of eye wall cloud. Ideally, this could be the airflow exactly by one turn of the helix from the front of TC to the front of the eye wall cloud, while this or equivalent modes cannot be treated as regularly achievable.

At the same time, quite extensive field data confirm the link of the "fitting" to intensification in the both northwestern Pacific and north Atlantic [10-11], where "very intense TCs could only develop under a narrow range of translational speeds between 3 and 8 m×s^{-1}", that is, in the speed range of the trade winds.

Table 1. Strong TCs hit land around the globe over 2004-2013

No	TC name, year, maximum intensity during landfall (in knots)	Weak. or str. during landfall	Note	No	TC name, year, maximum intensity during landfall (in knots)	Weak. or str. during landfall	Note
1.	Gafilo, 2004, 140	Weak.	LD	20.	Felix, 2007, 140	Str.	
2.	Fay, 2004, 115	Str.	LD	21.	Wipha, 2007, 120	Weak.	
3.	Charley, 2004, 125	Str.		22.	Krosa, 2007, 125	Weak.	
4.	Nanmadol, 2004, 130	Weak.	LD	23.	Sidr, 2007, 135	Weak.	
5.	Ingrid, 2005, 130	Str.	LD	24.	Ivan, 2008, 115	Weak.	
6.	Dennis, 2005, 120	Weak.		25.	Nargis, 2008, 115	Str.	
7.	Haitang, 2005, 120	Weak.		26.	Gustav, 2008, 120	Weak.	
8.	Emily, 2005, 115	Weak.		27.	Jangmi, 2008, 135	Weak.	
9.	Katrina, 2005, 140	Weak.		28.	Haguput, 2008, 120	Weak.	
10.	Khanun, 2005, 115	Weak.		29.	Giri, 2010, 135	Str.	
11.	Longwang, 2005, 115	Weak.		30.	Megi, 2010, 145	Weak.	
12.	Wilma, 2005, 120	Weak.		31.	Yasi, 2011, 135	Str.	
13.	Mala, 2006, 115	Weak.		32.	Naglae, 2011, 130	Str.	
14.	Saomai, 2006, 130	Weak.		33.	Giovanna, 2012, 125	Weak.	
15.	Xangsane, 2006, 125	Str.		34.	Vicente, 2012, 115	Str.	
16,	Cimaron, 2006, 140	Str.		35.	Bopha, 2012, 140	Weak.	
17.	Chebi, 2006, 115	Str.		36.	Utor, 2013, 130	Str.	
18.	Durian, 2006, 135	Str.		37.	Phailin, 2013, 140	Weak.	
19.	Dean, 2007, 145	Str.		38.	Hayan, 2013, 170	Str.	

LD – lack of the data required for analysis within ETM.

Forecasting Intensity of Landfalling TC

According to UNISYS weather[12], 38 strong TCs, with the fourth or fifth intensity categories during landfall, crashed into the shore around the world during 2004-2013 (here landfall is counted from the first contact of the frontal gale force winds to the shore).

Among these TCs almost half (16 TCs or 42%) strengthened during landfall and caused considerable portion of the total damage. There were different degrees of intensification of landfalling TCs, including rapid and even explosive intensification (e.g., TCs Charley (2004), Giri (2010), Vicente (2012)). These 38 TCs are listed in Table 1.

Proper short-term forecasting of TC behavior closer to the shore is one of the most important tasks in terms of mitigating the damage caused by tropical storm. Presented in Table 1 balance "weakening – strengthening" only emphasizes this priority.

Against this background, unfortunately, the actual forecasting tradition simply looking through this difficult dilemma: in all 38 cases, without exception, forecast advisories predicted TC weakening during landfall [12]. Besides, the situation is complicated by the fact that this acute problem not only is left out of the scientific discussion, but even still has not been identified as such.

Over the years, a reaction to the "unexpectedly" strengthening landfalling TCs gradually becomes weaker. For instance, if misprediction of the explosive intensification of Charley during landfall in 2004 provoked wide public resonance, the same with Vicente in 2012 was not discussed at all.

Lack of discussion of this important issue hampers thorough conclusions with regard to what we confine ourselves to considerations of presumptive character.

In general, landfalling always leads to gradual

Table 2. TCs 5th category in offshore zone or intensified up to 4th or 5th category during landfall

No	TC name, year, maximum intensity (knots)	Offshore or landfall	An_c	An_b	More/Less	An_m	Note
1.	Charley, 2004, 125	Landfall	34.5	34.6	1.003	34.6	
2.	Katrina, 2005, 150	Offshore	25.1	22.8	1.1	25.1	
3.	Wilma, 2005, 150	Offshore	38.1	24.0	1.59	31.1	LE
4.	Saomai, 2006, 140	Offshore	37.4	37.1	1.008	37.2	
5.	Xangsane, 2006, 125	Landfall	27.6	27.2	1.015	27.4	
6.	Cimaron, 2006, 140	Landfall	28.0	13.1	2.14	20.6	LE
7.	Chebi, 2006, 115	Landfall	45.7	63.9	1.4	54.8	LE
8.	Durian, 2006, 135	Landfall	37.2	32.8	1.13	35.0	
9.	Dean, 2007, 145	Landfall	55.3	58.3	1.05	56.8	
10.	Felix, 2007, 140	Landfall	28.8	27.9	1.03	28.4	
11.	Felix, 2007, 145	Offshore	120	123	1.02	121	SR
12.	Nargis, 2008, 115	Landfall	30.7	24.6	1.25	27.7	
13.	Giri, 2010, 135	Landfall	27.9	27.3	1.03	27.6	
14.	Megi, 2010, 155	Offshore	35.5	30.5	1.16	33.0	
15.	Yasi, 2011, 135	Landfall	21.0	24.3	1.15	22.7	
16.	Naglae, 2011, 130	Landfall	44.2	32.2	1.37	38.2	LE
17.	Vicente, 2012, 115	Landfall	26.3	33.2	1.26	28.8	
18.	Bopha, 2012, 140	Offshore	59.0	52.8	1.12	55.9	
19.	Utor, 2013, 130	Landfall	38.6	31.4	1.23	35	
20.	Phailin, 2013, 140	Offshore	27.0	27.9	1.0	27.5	
21.	Hayan, 2013, 170	Landfall	64.0	57.0	1.12(1.82)	60.5	

LE – large error; SR – small radius of TC.

reduction in active sea surface under TC with decrease of integral heat flow removed by it. In the hypothetical case when the oceanic heat is the only source of energy and TC intensity is uniquely determined by it, landfalling will always be accompanied by weakening of TC.

Apparently, just similar conception underlies approaches and theories backing advanced numerical models, used, for its part, in forecasting procedures.

If we consider TC as a giant natural heat engine, its intensity is determined not only by absorbable heat flow, but also by efficiency of heat conversion into mechanical energy. In this context, the above conception is equivalent to acceptance of constancy of TC efficiency before and during landfall.

If the temperature difference between the bottom and top of TC can be equated to 50 °C , the maximum theoretically attainable ideal Carnot cycle efficiency would be about 15%. The real TC efficiency, of course, always is considerably lower. According to ETM it may vary within wide range reaching pronounced maximum during ET (at critical alignment number).

In this regard, it is hypothetically possible transition of TC to ET during landfall with dramatic increase the efficiency (e.g.., from 1.0% to 5%), which may even lead to explosive intensification, despite the reduction of heat inflow.

We shall attempt below to show the thoroughness of this conclusion and its value in terms of correct prediction of behavior landfalling TC.

Maximum Intensity and Critical Alignment Number

The field data on 20 TCs [12-13], selected from the above 38, were analyzed in order to verify ETM. The results are presented in Table 2.

When selecting it is assumed that extraordinary TC, intensifying to 4th or 5th category during landfall (during reduction of heat inflow) can only run at critical alignment number. 14 such TCs from total 16 were selected, except Fay (2004) and Ingrid (2005) not provided with the necessary field data.

Reaching by TC of 5th category in the offshore zone is also seen as evidence of its running at An_{cr}. 7 such TCs are selected from total 8, except Gafilo (2004) (the same lack of the field data), besides Felix (2007) fell into both categories of selection.

The remaining 15 TC cannot be linked to ET as they not only weakened during landfall, but never reached the fifth category in the offshore zone.

According to [8], taking in account restricted accuracy of determination An using forecast advisories, ratio of the two values of An, calculated through translation speeds of TC center (An_c) and TC back boundary center (An_b), was used as an indicator of the accuracy of determining alignment number. In particular, 4 TCs with the ratio 1.37 and more were excluded from consideration as those potentially containing unacceptably large error. Due to aforementioned restricted validity of ETM at small TC radii, the data on maximum intensity of TC Felix in offshore zone were also excluded due to its small size at corresponding stage of life cycle.

Next, using arithmetic mean (An_m) of An_c and An_b, we define the arithmetic mean of An_{cr} of all selected 16 TCs that turns equal to 35.2 (with mean deviation 26%).

Thus, the regularity (5) is reaffirmed once again, at rather broad field data. At the same time, the deviation of 3 TCs (Dean, Bopha and Hayan) from the An_{cr} makes up (50-70)%, significantly exceeding our estimate of the error in determining An_{cr} (±30%).

According to Table 2, in these cases, similar to Felix, all observed values are considerably higher of the above mean value. If in the case of Felix, this is due to underestimation energy inflow by equation (4) at small radii, in the cases Dean, Bopha and Hayan the same may be due to exclusively high humidity of air inflow. We shall return later to this matter.

As for RI during landfall, the major subject of our interest, among the 11 TCs adopted when determining the mean critical alignment number, only the two - Dean and Hayan fall significantly out of general regularity that is not so bad.

Intensification and weakening during Landfall and Alignment Effect

Next let us trace the life cycles of TCs strengthening or weakening during landfall in the framework of ETM, showing graphically change of HHP, TC intensity and alignment number in time (along TC track).

At each calculation An_{cr}, the two forecast advisories were used, first related to the given point, second, the position prior to given point, plus HHP map for the previous day. This ensured the use of the parameters already available before release of the advisory related to the given point. So, the calculations could be used in forecasting.

Since the calculations attract a number of parameters from the forecast advisories [12], the best track data are not used that can result in only a slight distortion.

The calculations produce discrete values presented in the figures below by points. As for the smoothed curves, they are of purely conventional character. In order to make easier the playback the graphs by other researchers An is accepted equal to An_c.

Application of equation (2) is allowed only before crossing the coast by TC center. Gradual decrease in sea surface covered by landfalling TC not taken into account, as Q and q are invariant to such a change and, in addition, R_{ef} above sea surface be-

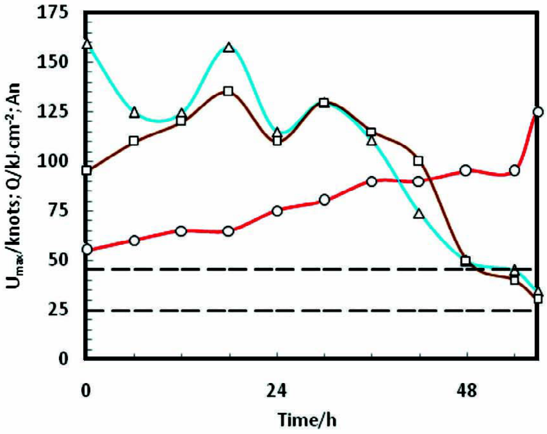

Fig. 1. Correlation of the field data on TC Charley: ○ – maximum tangent wind; □ – HHP; △ – *An*; horizontal dotted lines An_{cr}=35±30%; the position 0 - 9:00 hour (UT), 11 AUG 2004.

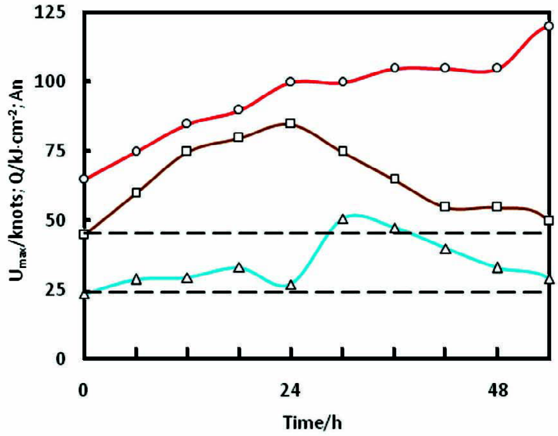

Fig. 2. Correlation of the field data on TC Hagupit: ○ – maximum tangent wind; □ – HHP; △ – *An*; horizontal dotted lines An_{cr}=35±30%; the position 0 - 12:00 hour (UT), 21 SEP 2008.

gins changing due to the reduction of the covered sea surface only after the crossing.

Let us look at the first TC Charley (Fig. 1).

After crossing Cuba, at 56th hour, regular forecast advisory predicted the practical constancy of Charley's intensity over the next 9 hours with significant decrease to 60 knots over the next 12 hours. In fact, against the prediction, the special forecast advisory had to fix explosive intensification of Charley to 125 knots during the past three hours. Besides, it took place with TC transition to significantly cooler waters (*Q* reduced from 1.1 GJ/m^2 to 0.3 GJ/m^2 nearing Florida peninsula). Seemingly, just this fact has predetermined the prediction of Charley's weakening.

In reality, Charley's RI is directly linked to the transition to An_{cr}, despite the dramatic reduction of HHP. By the way, the paper [4] has already been published at that time and, in principle, strengthening of Charley was predictable.

Very similar correlations between the intensity and An_{cr} can be traced also when analyzing the life cycles of TCs Hagupit (2008) (Fig. 2) and Iasi (2011) (Fig. 3).

Behavior of TCs weakened during landfall is no less interesting. TC Saomai seems especially remarkable, in terms of demonstration the role of *An* (Fig. 4). Here you should pay attention to three stages: first – a pause of TC intensification after the 12th hour, in the wake the transition to the higher HHPs, to say, warmer waters (in reality, due to leaving by *An* the critical zone), the second - a renewal of TC intensification after the 24th hour in the wake the transition to less HHPs, to say, cooler waters (because of the return *An* in the critical zone), and the third - TC weakening during landfall due to another leaving by *An* the critical zone. By the way, in contrast to the first and second stages, at the third stage *An* has "authorized" HHP field to appear as a controller of TC intensity during landfall.

It appears TC Saomai has a chance to become something like teaching tool of ETM. Unlike to Saomai, in the case of Katrina (Fig. 5), *An* has "authorized" HHP field to appear as a controller of TC intensity during the entire life cycle.

There also are TCs among those weakened during landfall, noticeably deviating from the above regularity, although total number of such TCs, including Dean, Bopha and Hayan, make 20% of the examined. As shown below, examining the influence of the humidity of the inflowing air represents a serious potential to further improvement of description of the field data and, most importantly, still the full potential of the base equation (1) have not been used.

Finally we can conclude that the considerable majority of landfalling TCs really demonstrate the dependence of efficiency of oceanic heat conversion into cyclonic motion on ET with pronounced

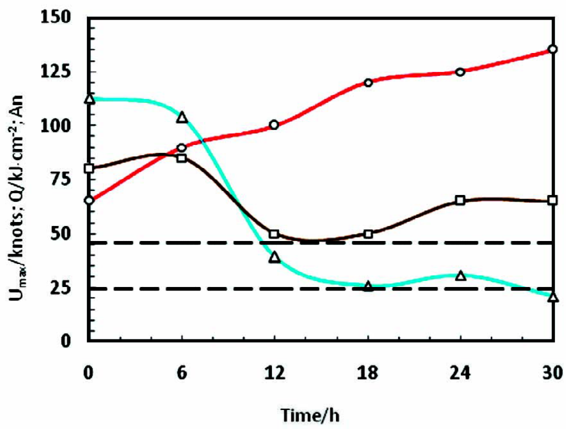

Fig. 3. Correlation of the field data on TC Yasi: ○ – maximum tangent wind; □ – HHP; △ – *An*; horizontal dotted lines An_{cr}=35±30%; the position 0 - 0:00 hour (UT), 31 JAN 2011.

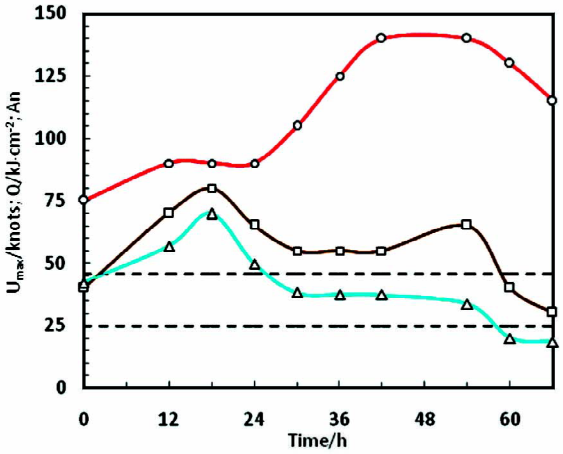

Fig. 4. Correlation of the field data on TC Saomai: ○ – maximum tangent wind; □ – HHP; △ – *An*; horizontal dotted lines An_{cr}=35±30%; the position 0 - 18:00 hour (UT), 7 AUG 2006.

maximum at critical alignment number. Besides, as a rule, the strengthening influence of alignment effect in times exceeds the weakening effect of significant reduction in the sea surface covered by TC and even substantial reduction HHP. Thus, we overcome the theoretical veto on physically observable phenomenon.

Unfortunately, equilibrium translation model and alignment number still remain outside the attention of researchers, despite the fairly wide publication since 2004, including the open access materials of the 27th (2006), 28th (2008) and 29th (2010) Conferences on Hurricanes and Tropical Meteorology [14-16]: no analysis, no assessment, no criticism, no support, no use and development.

What is particularly surprising, it is disregard of the criterion comprehended nature of TC development for the first time in the history of tropical cyclone theory.

TC Intensity and Inflowing Air Humidity

The adoption of the sea water as the sole source of heat is practically equivalent to the assumption by equation (4) of the inflowing air humidity always equaled to that in the reference TC Opal (1995). In fact this parameter may vary within certain limits affecting the integral energy basis of the updraft.

According to [17], the average monthly relative humidity of ambient air varies within 70-85% over the tropical ocean during the hurricane season. In particular cases, of course, these limits are wider and presumably could reach 65-90%. At the same time, According to the field data [18], the share of latent heat is decisive in integral heat flow. Therefore, relating to the possible limiting values heat flows can tangibly deviate from equation (4).

Since we do not possess similar data for particular TC, below, on the basis of certain assumptions, we try to give a rough preliminary assessment of the possible impact of the inflowing air humidity.

The multiannual average relative air humidity in the Gulf of Mexico at the junction September-October may be taken as 78%, which we provisionally assign to TS Opal (1995) [17].

Further, we can assume that the final relative humidity of the air before updraft is higher, the higher the humidity of the inflowing air, although the dependence should be weaker than linear. In such a case, sought influence of inflowing air humidity can be counted by the empirical correction factor C_h to equation (4):

$$q_h = qC_h = q\left(\frac{100 - H_{ref}}{100 - H_{in}}\right)^n, \qquad (6)$$

where H_{ref} is reference value of the average relative humidity of inflowing air in percent (75%); H_{in} is av-

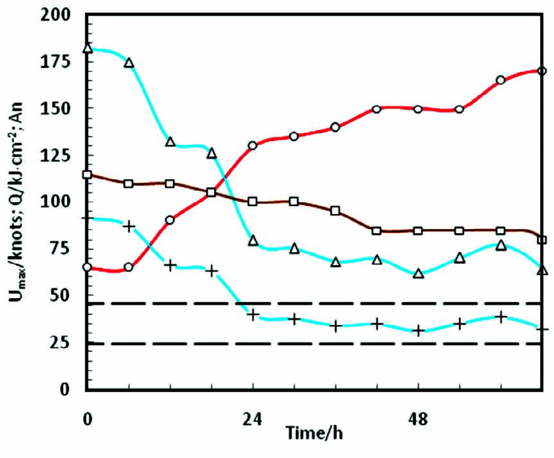

Fig. 5. Correlation of the field data on TC Katrina: ○ – maximum tangent wind; □ – HHP; △ – An_0; + – An_{0h}; horizontal dotted lines An_{cr}=35±30%; the position 0 - 0:00 hour (UT), 5 NOV 2013.

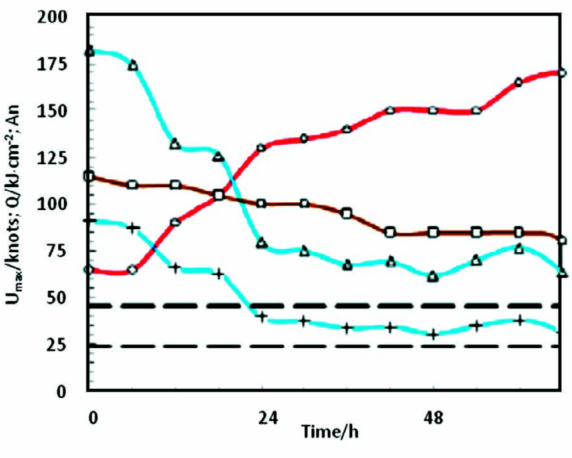

Fig. 6. Correlation of the field data on TC Haiyan: ○ – maximum tangent wind; □ – HHP; △ – An_0; + – An_{0h}; horizontal dotted lines An_{cr}=35±30%; the position 0 - 0:00 hour (UT), 5 NOV 2013.

erage relative humidity of inflowing air in the given case in percent; n is an exponent to fit the factor to field data.

In accordance with (6), taking into account the actual relative humidity of the inflowing air, the average integral heat flow defined by (4) will be more or less, if the actual humidity is higher or lower than 78% referenced. Refined using q_h alignment numbers will also differ from those listed in the Table 2.

Next let us consider correlation of the field data on TC Haiyan reached the highest intensity (170 knots) during landfall to Philippines in November 2013 (Fig. 6).

Since TC Haiyan established an absolute record of intensity for the period of modern methods of measurement, it just was the first candidate to run at the critical alignment number. In this connection we accept that large deviation of An calculated according to (4) from An_{cr} is caused by high relative humidity of inflowing air.

There is another indirect evidence of this, large diameter of TC Haiyan at the highest intensity, up to 500 km on the tangent wind 17.5 m/s, which corresponds to 700-1000 km for the "standard" boundary set on tangent wind 12 m/s (as known [19], high humidity contributes to the large diameter).

Accepting H_{in}=90% and fitting the exponent to the field data at the value n = 0.75, we shift the curve of Hayan's alignment number from the previous triangles (according (4)) to the crosses (according to (6)) (Fig. 6).

Next, legitimizing the exponent set for Haiyan (n = 0.75), we find out that average relative humidity had to be 85-87% to bring An of TCs Dean (2007) and Bopha (2012) in critical zone. There are also some TCs that are candidates to be "improved" in the same way, this time, by assigning lower values of the inflowing air humidity (65-70%).

As for the bulk of examined hurricanes, apparently, humidity of inflowing air was not so much deviated from the reference value, which is reflected in their satisfactory according to equation (5) without correction on inflowing air humidity.

In the context considered, comparison of TCs Dean and Felix, passed the same path in the Caribbean with an interval of two weeks in August and September 2007 is of special interest. According to estimates by the equation (6), significant difference in alignment numbers during landfall when calculated based on equation (4) can be attributed to higher relative humidity (~ 85%) during the passage of Dean and relatively low residual humidity (~ 75%) during the subsequent passage of Felix. By the way, Dean almost twice surpassed Felix in TC diameter at the landfall. Now let us return to the highest intensity of TC Haiyan directly associated with the problem of the maximum potential intensity (MPI).

The conclusion on the independence MPI on HHP in a fairly wide range of variation of the latter was made in [8] based on revealed within ETM negative feedback between TC translation and HHP during ET (just postulated in [8] rough constancy of average SST under acting TC during ET has allowed us to operate by relative humidity, without involving absolute humidity).

In [8], based on the field data available at the time, MPI was equated to about 160 knots at HHP more than $50 \times \mathrm{kJcm}^{-2}$. Thereby, the question arises: "What does the fact of reaching the intensity 170 knots, by Haiyan mean in this context?"

The answer to this question is clear: the set of parameters realized during unprecedented intensification of Haiyan became important confirmation of ETM and the conclusions [8]. Reaching the highest intensity at very moderate HHP (60-70 $\mathrm{kJ} \times \mathrm{cm}^{-2}$), closely nearing the above lower limit, and, already at the beginning of contact the frontal winds with the land, just emphasizes the independence of MPI on HHP, in certain, quite wide range of variation of the latter.

As for the adopted in [8] value of MPI, it was established on the basis of the available field data, without any other justification, and now should be replaced at 170 knots, without any ideological losses in terms of ETM or alignment effect.

Then the question remains how immutable is the last record itself?

It seems that possible answer is just related to the role of the humidity of inflowing air. If further comprehensive studies of Haiyan will show that the highest intensity was reached at sufficiently long-term development at critical alignment number in extremely humid environment and the latter has tangibly contributed to the highest intensity, the value 170 knots has a serious chance to become almost a physical constant in tropical meteorology.

Concluding Remarks

Among 38 strong TCs hit land around the globe in 2004 - 2013, 16 (42%) strengthened during landfall caused considerable portion of the total damage. Nevertheless, existing forecasting practice simply looks through the difficult dilemma of strengthening or weakening? In all the 38 cases, without exception, forecast advisories predicted TC weakening during landfall, revealing principal restrictions of the theories and advanced numerical models backing the forecasting system.

The matter is a potentially fundamental incompatibility of the theoretical models with physical reality that can put on the agenda the problem of radical revision of the foundations of the existing approaches.

The situation is complicated not only by leaving this vital issue outside the scientific discussion, but even with prolonged delay in identifying the problem itself. Simultaneously, over the years, a reaction to the "unexpectedly" strengthening landfalling TCs gradually become weaker. If misprediction of the explosive intensification of Charley in 2004 provoked wide public resonance, the same with Vicente in 2012 was not discussed at all.

During the same period, it remained outside the field of interests of researchers and forecasters criterion (alignment number), which allowed with high degree of probability to give the correct answer to this dilemma, serving as predictor of future short-term developments.

Alignment number represents the main outcome of the equilibrium translation model (ETM) considering TC as a self-organized dissipative system internally targeted at maximum intensification. ETM relates TC development to conformity of the thermal and dynamical fields in the SOCA. When the internal trend is in the harmony with the large-scale environmental wind, TC establishes the so-called equilibrium translation, leading to rapid intensification, even when the influx of energy in TC is to reduce, when moving to cooler waters or land.

The model is supported by extensive field data, it creates a new basis for overcoming the impasse in development of theory and numerical models.

გეოფიზიკა

ტროპიკული ციკლონი: წონასწორული ტრანსლიაციის მოდელი და ტროპიკული ციკლონის სწრაფი ინტენსიფიკაცია ხმელეთზე გადასვლისას

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წონასწორული ტრანსლიაციის მოდელის დამუშავების პირველი ათწლეულის შეჯამებისას აქცენტი გაკეთებულია ხმელეთზე გადასვლისას ტროპიკული ციკლონის სწრაფი ინტენსიფიკაციის მოვლენაზე. ბოლო ათწლეულში ხმელეთთან შეჯახებულ 38 მძლავრ ციკლონიდან ხმელეთზე გადასვლისას 16 გაძლიერდა, რამაც მნიშვნელოვნად აამაღლა გლობალურად მიყენებული საერთო ზიანი. პროგნოზირების არსებულმა სისტემამ ვერცერთი გაძლიერება ვერ იწინასწარმეტყველა, რითაც მკაფიოდ გამოვლინდა სერთოდ მიღებული მიდგომების, თეორიებისა და რიცხვითი მოდელების ფუნდამენტური შეზღუდვები. ნაჩვენებია, რომ წონასწორული ტრანსლიაციის მოდელი და, კერძოდ, ამ მოდელიდან გამომდინარე კრიტერიუმი, უგანზომილებო ე.წ. თანადობის რიცხვი, სწორად ასახავს ტროპიკული ციკლონის განვითარების თავისებურებებს. როგორც ანალიზმა აჩვენა, სწრაფი ინტენსიფიკაციის მაღალი ალბათობის პროგნოზირება პრაქტიკულად ყველა რეალურ შემთხვევაში იყო შესაძლებელი თანადობის რიცხვის მონიტორინგის გზით.

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