On the reaction of atmospheric characteristics in the Gulf of Mexico to the origin of hurricanes based on satellite microwave radiometric measurements

A G Grankov, A A Milshin, E P Novichikhin and N K Shelobanova
Fryazino Branch of the Kotel’nikov Institute of Radioengineering and Electronics
RAS, Vvedenskii Sq. 1, 141190 Fryazino Moscow Region, Russia
agrankov@inbox.ru

Abstract. Based on satellite microwave radiometric measurements, the spatial and temporal variability of the brightness temperature in the spectral band of the resonant radiation of atmospheric water vapor, as well as meteorological parameters in the Gulf of Mexico during the origin and development of the tropical hurricanes Humberto and Lorenzo in September-October 2007, were analyzed. The results of the analysis indicate that large areas of the Gulf of Mexico are involved in the formation of the brightness temperature response to the origin of hurricanes. The role of spatial dispersion of atmospheric moisture content over the Gulf of Mexico is evaluated as a quantitative indicator of the processes of origin and development of the hurricanes Humberto and Lorenzo.

1. Introduction
The development of technologies for the diagnostics of the characteristics of the atmosphere and ocean in the areas of activities of tropical hurricanes (TH) at different stages of their existence, via satellite radiophysical means, is an urgent task [1, 2]. One of the promising ways for its solution is the use of the intensity of natural microwave (MCW) radiation, characterized by the brightness temperature (BT) of the ocean-atmosphere system, measured from satellites in the vicinity of the 1.35 cm line (22.235 GHz) in the spectrum of resonance radiation of atmospheric water vapor. In this region of the MCW range, there is a close relationship between the BT and the total (integral) content of water vapor in the atmosphere, a characteristic that would be more accurate to call the total vapor content of the atmosphere but is more often called its moisture content. This characteristic is widely used in studies of the genesis and development of tropical hurricanes, as evidenced, for example, by [3, 4], where the relationship between the satellite MCW radiometric estimates of the total atmospheric moisture content and the tropical cyclogenesis in the world’s oceans has been studied, by [5, 6] where the role of tropospheric advective fluxes of latent heat concentrated in water vapor in the intensification of THs, and the possibility of estimating the rate of water vapor transport and localization of energy sources using MCW radiometric methods, is considered, and by [7] where the possibility of using the brightness temperature and atmospheric water vapor content as indicators of the dynamics of hurricanes at various stages of their development is demonstrated.

The aim of this work is to study the relationship between the processes of hurricane formation in the Gulf of Mexico and the spatial and temporal variability of the atmospheric moisture content over its water area. The idea of using the variability of the atmospheric moisture fields in the Gulf to localize the location and time of the origin of hurricanes, based on satellite measurements at a wavelength of
1.35 cm, using the apparatus of conjugate equations, is based on the assumption of the existence of such a relationship [8]. Here, water vapor is considered as a turbulent-diffusive admixture of the atmosphere, like the passive impurities (pollutants) are considered by [9, 10] as the admixtures in the waters of Sea of Azov when their localization with the MODIS satellite scanner.

The main focus is on hurricanes that originated in the Gulf of Mexico and did not come from the Caribbean Sea or the Atlantic Ocean, already in mature form. The Humberto and Lorenzo TH considered in the article are among the few tropical formations that originated in the waters of the Gulf of Mexico. For example, in the period May-October 2007, 14 tropical hurricanes and storms were observed in the Gulf, but 10 of them arose in the Atlantic Ocean or in the Caribbean Sea. Between 1995 and 2017, only 9 hurricanes originated in the Gulf, while the number of incoming ones that hit the coasts of the United States and Mexico during this period is estimated at several dozen.

The article presents the results of analysis of the characteristics of spatial and temporal variability of the BT in the resonant band of the atmospheric water vapor radiation, as well as the atmospheric moisture and cloud liquid water content during the origin and development of the tropical hurricanes Humberto and Lorenzo in September-October 2007 in the Gulf of Mexico. The significance of the spatial dispersion of the atmospheric moisture content over the area as a quantitative indicator of the processes of origin and development of these hurricanes is estimated.

2. Response of BT in the Gulf of Mexico to the origin of the Humberto TH

Hurricane Humberto originated in September 2007 in the northwestern part of the Gulf of Mexico, and within a day reached the American coast near the state of Texas. This tropical formation, not characterized by high intensity (category 1 on the Saffir-Simpson scale), reached a record speed of its intensification from the stage of a tropical depression to the stage of a hurricane, for example, an increase in the driving wind speed from 25 to 80 nautical knots occurred within 19 hours (September 12-13). More detailed information about the synoptic history of the development of the Humberto TH is given in [11].

We analyzed the BT variability based on satellite MCW radiometric measurements in the Gulf of Mexico during the development of the Humberto TH in the areas where the buoy stations of the NOAA observation network are located (figure 1). Network stations located near the Gulf coastline are excluded from consideration in order to avoid distortions of the BT estimates caused by land falling into the field of view of the satellite radiometer antennae.

![Figure1. The scheme of location of buoy stations in the Gulf of Mexico. On the vertical axis – degrees of North latitude, on the horizontal axis – degrees of West longitude.](image)

The RSS (Remote Sensing Systems) archive of measurement data of the multichannel scanning MCW radiometer AMSR-E on the ascending and descending orbits of the EOS Aqua satellite (Advanced Microwave Scanning Radiometer) was used, presented as a grid of BT values for squares of 0.25 x 0.25° about the earth's surface, with a time resolution of 12 hours. The AMSR-E radiometer is a
scanning six-frequency system that measures the BT of the natural MCW radiation at an observation angle of $52^\circ$ at the horizontal and vertical polarizations in the 1400 km viewing band, and provides a global coverage of the Earth in three days, and incomplete coverage in a day [12]. The operating frequencies of the two radiometer channels, 23.8 GHz (1.26 cm) and 18.7 GHz (1.6 cm), correspond to the spectral band of the resonant radiation of atmospheric water vapor.

The RSS archive provides for the selection and rejection of data from individual measurements that were affected by the illumination of the Sun's radio emission, external radio interference, and heavy precipitation zones [13]. To eliminate omissions, we interpolated the data in such archive fragments.

Figure 2 shows the BT variations at a wavelength of 1.26 cm (23.8 GHz) at vertical polarization during the origin and development of the tropical formation Humberto for a number of buoy stations adjacent to the area of its origin at the stage of a tropical depression.

One can observe a cooperative effect in the BT response to the origin of the Humberto TH in areas of the Gulf of Mexico that are located at a considerable distance (up to 300–500 km) from the area of its origin. According to the analysis in these areas, a few days before the intensification of the tropical Humberto formation to the hurricane stage (September 13), there was a decrease in the value of $T_{b,1.26}$ by 15–20 K on the vertical polarization. Stronger BT variations at this wavelength (30–40 K) were observed in the horizontal polarization where the value of $T_{b,1.26}$ is sensitive not only to the moisture content of the atmosphere, but also to the wind speed in the near-surface layer of the atmosphere. The channel of the AMSR-E radiometer at a wavelength of 1.6 cm (18.7 GHz), which reacts to both of these atmospheric parameters, also gave a clear signal for the origin of the Humberto TH.

3. Response of the total atmospheric moisture content and near-surface wind speed to the origin of the TH Lorenzo

TH Lorenzo originated shortly after hurricane Humberto in the northwestern part of the Gulf of Mexico (20.5°N, 96.3°W), and its synoptic history is described in [14]. The increase in the near-surface wind speed from 25 to 80 nautical knots occurred here over 42 hours (September 25-27).

In certain areas of the Gulf of Mexico the variability of the daily values of the total atmospheric moisture content, $Q$, and the wind speed in its near-surface layer (0–10 m), $V$, were analyzed using the
NSIDC archive (National Snow & Ice Data Centre), presented on a 0.25 x 0.25° spatial grid with a time resolution of 24 hours, and based on the results of thematic processing of measurement data from the AMSR-E radiometer of the EOS Aqua satellite.

Figure 3 illustrates the variability of the daily values of the atmospheric water vapor content in the area of 19−25° N, 82−98° W, Gulf of Mexico, for a number of points in the vicinity of the origin of TH Lorenzo.

![Figure 3](image)

**Figure 3.** Variations of the atmospheric water vapor content in the area of the origin of TH Lorenzo in the period September 15 - October 5, 2007. A circle marks the area of origin of a tropical depression.

The figure shows a cooperative response of the atmospheric water vapor to the origin of TH Lorenzo at various points in the Gulf of Mexico, located at a distance of 300–500 km from the area of its origin. There is a noticeable decrease in $Q$ by 15–20 kg/m² in the areas adjacent to the point of origin of the hurricane for 5–7 days at the initial stage of the hurricane (tropical depression), and a strong increase by 20–25 kg/m² over the next 4–5 days with the intensification of the tropical formation of Lorenzo to the hurricane stage (September 28).

Figure 4 shows the results of the analysis of the variability of the daily values of wind speed in the near-surface layer of the atmosphere at various stages of the development of hurricane Lorenzo for a number of points in the area of 19–22° N, 95–98° W, the Gulf of Mexico, adjacent to the area of its origination.

In all the selected points of this area, the intensification of this tropical formation to the hurricane stage is accompanied by a sharp increase in the near-surface wind speed (from 2–3 to 10–15 m/s).

These examples indicate that the formation of the Humberto and Lorenzo THs is accompanied by a distinct reaction of the atmospheric moisture content, near-surface wind speed, and brightness temperature in the spectral band of the resonant radiation of atmospheric water vapor, not only in the areas of origin of these hurricanes, but also in the vast waters of the Gulf of Mexico adjacent to them.
Figure 4. Variations in the near-surface wind speed in the vicinity of the origin of TH Lorenzo in the period September 15 - October 5, 2007. A circle marks the area of origin of a tropical depression.

4. Group response of the atmospheric water vapor and cloud liquid water content to Humberto and Lorenzo THs

The coherency of the responses of the $\Delta T^{1.26}_{b}$ and $\Delta Q$ values to the origin of the Humberto and Lorenzo THs in various areas of the Gulf of Mexico, with their response in the centers of origin of these hurricanes, suggests that it is appropriate to study the group (formed by the entire Gulf area) response of these characteristics and their relationship to the histories and prehistories of the origin and development of these THs.

Using data from the NSIDC archive, statistical characteristics of the spatial variability of the atmospheric moisture content $Q$ and cloud liquid water content $W$ in the Gulf of Mexico region of $21.75^\circ$–$28^\circ$ N, $85.5^\circ$–$95.75^\circ$ W, were analyzed during the period September 1 - October 5, 2007, fully covering the synoptic stories of the Humberto and Lorenzo THs, as well as their backstories. For this area, which covers a significant part of the Gulf of Mexico, data arrays are formed in the shape of $42 \times 26$ matrices, the elements of which are the daily values of the $Q$ and $W$ parameters in spatial cells of $0.25 \times 0.25^\circ$.

The results of the analysis show a common feature for these tropical formations – the strengthening of the spatial dispersion of the atmospheric vapor over the Gulf of Mexico over several days, and further weakening before the final stage – the appearance of a hurricane (figure 5).

A similar result is also observed in the analysis of the group response to the origin of the Humberto and Lorenzo THs, in the spatial dispersion for the liquid water content of clouds in the Gulf of Mexico (figure 6).

At the same time, the time dynamics of the average values of the parameter $W$ has similar features to the dynamics of changes in the parameter $\sigma_w$ during the development of both hurricanes (figure 7).

It should be noted that the similarity of the responses of the parameters $\sigma_0$ and $\sigma_w$ to the activity of the Humberto and Lorenzo THs is not hindered by the difference in their synoptic histories. The reason for the formation of the first one was a local factor – the movement of the atmospheric trough from the southern coast of Florida to the northwestern part of the Gulf of Mexico (Blake 2007), and the origin of TH Lorenzo occurred due to the arrival of a tropical wave from the West coast of Africa in the Gulf of Mexico [14].
Figure 5. Standard deviations of the atmospheric water vapor content in the Gulf of Mexico during the origin and development of the Humberto (a) and Lorenzo (b) THs. Arrows mark the moments when the tropical formations transit to the hurricane stage.

Figure 6. Standard deviations of the total content of cloud liquid water from the average values in the Gulf of Mexico during the periods of origin and development of the Humberto (a) and Lorenzo (b) THs. Arrows mark the moments when the tropical formations transit to the hurricane stage.

Figure 7. Average values of the liquid water content in the clouds $W$ in the Gulf of Mexico during the origin and development of the Humberto (a) and Lorenzo (b) THs. Arrows mark the moments when the tropical formations transit to the hurricane stage.
5. Differentiation of the Gulf of Mexico regions by the water vapor fields evolutions in the period preceding the origin of the hurricanes

Visual characteristics of the response of the atmosphere in the Gulf of Mexico to the formation of hurricanes can be the time evolution of the fields of its total moisture content, cloud liquid water content, and the speed of the near-surface wind. As an example, figure 8 shows a series of images of the distribution of the water vapor in the Gulf during the time period preceding the origin of TH Lorenzo. This illustration gives a fairly complete picture of its evolution during this period, despite the fact that its fragments are constructed from measurements of the EOS Aqua satellite with a time resolution of 24 hours. For the fields of the cloud liquid water and near-surface wind speed, which are characterized by significant spatial and temporal variability in comparison with the fields of water vapor, this time resolution cannot be achieved.

Figure 8 clearly reflects the arrival of a warm tropical wave from the North-East direction to the area of origin of TH Lorenzo and the dynamics of its propagation, accompanied by an increase in the total moisture content of the atmosphere over the Gulf of Mexico during the period preceding the formation of the hurricane. There is also a sharp decrease in dispersion of the water vapor content in the period of September 23-25, before the birth of Lorenzo.

![Figure 8](image_url)

**Figure 8.** Evolution of the water vapor spatial distribution in the Gulf of Mexico during September 20 (a), 21 (b), 22 (c), 23 (d), 24 (e), and 25 (f).

The possibility of using daily reports to indicate the evolution of the atmospheric water vapor content in the form of horizontal sections of its spatial distribution in the Gulf of Mexico in the period preceding the origin of the Humberto TH, is also shown in figure 9. Here are the spatial variations of the $Q$ parameter on the 0.25 x 0.25° grid in the Northern part of the Bay (26−28° N, 85.5−95.75° W.) and the southern part (21.75−26° N, 85.5−95.75° W.) during the September 8-10 period preceding the occurrence of a tropical depression on September 13, which later transformed into hurricane Humberto. As can be seen in figure 9, this process is accompanied by a strong restructuring of the water vapor field exclusively in the Northern part of the Gulf of Mexico, bounded by the atmospheric cavity off the southern coast of Florida and the area of hurricane origin off the coast of Texas. Despite the low regularity of satellite measurements, the observation of this process for 3 days allows us to identify areas...
with a high dispersion of water vapor content and record their movements from the atmospheric trough to the area of origin of the Humberto TH.

**Figure 9.** Horizontal sections of the atmospheric water vapor content in the northern (A) and southern (B) parts of the Gulf of Mexico: (a), (d) – 08.09.2007; (b), (e) – 09.09.2007; (c), (f) – 10.09.2007.

6. Discussion of the results

The analysis of the relationship between the origin of hurricanes Humberto and Lorenzo in the Gulf of Mexico and the spatial and temporal variability of the MCW radiation and meteorological characteristics of the atmosphere over its water area, based on the measurement data of the AMSR-E radiometer of the EOS Aqua satellite, allows us to mark several results:

1. Strong BT variations (tens of Kelvins) are observed as measured by the 23.8 GHz (1.26 cm) and 18.7 GHz (1.6 cm) radiometer channels in the spectral band of the water vapor natural radiation, as well as satellite estimates of variations of the total vapor content at various stages of formation and development of the Humberto and Lorenzo tropical formations. Even a few days before their intensification to the stage of hurricanes, noticeable disturbances in the microwave radiation and meteorological characteristics of the atmosphere were recorded and which persisted even after they moved from the Gulf of Mexico to land. Subsequently, these characteristics returned to their previous (undisturbed) values.
2. The above-mentioned features of the evolution of MCW radiation and the meteorological characteristics of the atmosphere at different stages of the formation of hurricanes Humberto and Lorenzo were manifested not only in the areas of their origin, but also in areas of the Gulf of Mexico located at a considerable distance (up to 300–500 km) from them. This makes it possible, in particular, to talk about the possibility of a cooperative (group) effect for different parts of the Gulf in the formation of the response of the atmospheric moisture content and brightness temperature to the processes of the origin and development of hurricanes in the Gulf.

3. The existence of the cooperative effect makes it easier to track the evolution of atmospheric water vapor fields in the Gulf at various stages of the formation of hurricanes Humberto and Lorenzo, which may seem problematic due to the low regularity of the satellite measurements. It is possible to observe a distinct reaction of the atmospheric humidity characteristics over the Gulf of Mexico to the formation of hurricanes Humberto and Lorenzo with a common feature – an increase in the spatial dispersion of the total water vapor content in the atmosphere for several days and its further weakening (calm) before the final stage – the appearance of a hurricane.

7. Conclusion
The stated observations can serve as important prerequisites for developing methods for the early diagnostics of the onset of hurricanes in the Gulf of Mexico based on monitoring the spatial and temporal variability of the total moisture content of the atmosphere using satellite microwave radiometric methods.

The existence and recurrence of the cooperative response of the field of the total moisture content of the atmosphere in the Gulf of Mexico to the processes of the origin and development of local hurricanes indicates the possibility of formulating such a problem. It is likely that in the future it will be necessary to answer the following questions: (1) is the information on the evolution of the water vapor fields in the Gulf of Mexico sufficient to determine the time and location of origin of tropical hurricanes? (2) is it necessary to know about the spatial and temporal variability of wind speed and other parameters of the surface layer of the atmosphere?

We can state that the modern arsenal of foreign and Russian satellite microwave radiometric tools with a spatial resolution of 20–30 km and a survey regularity of 12–24 h would provide a solution to these problems.

References
[1] Sharkov E A 2000 Global tropical cyclogenesis. Berlin: Springer/Praxis p 361.
[2] Bondur V G, Krapivin V F 2014 Space monitoring of tropical cyclones. Moscow: Scientific World p 506.
[3] Pokrovskaya I V, Sharkov E A 1996 Remote studies of spatial fields of moisture content in the tropical atmosphere during cyclogenesis Issled. Zemli iz Kosmosa no 6 pp 18–27.
[4] Sharkov E A, Shramkov Ya N, Pokrovskaya I V 2012 Increased water vapour content in the atmosphere of tropical latitudes as a necessary condition for the genesis of tropical cyclones, Issled. Zemli iz Kosmosa no 2 pp 73–82.
[5] Ermakov D M, Sharkov E A, Chernushich A P 2014 The role of tropospheric advective flows of latent heat in the intensification of tropical cyclones Issled. Zemli iz Kosmosa no 4 pp 3–15.
[6] Ermakov D M 2017 Investigation of the features of long-term global atmospheric circulation via satellite radiothermvision, Progress in Electromagnetics Research Symposium – Spring (PIERS) pp 413–418.
[7] Grankov A G, Milshin A A, Novichikhin E P Shelobanova N K 2020 Use of satellite radiometric microwave measurements for analysis of the atmospheric moisture content in the development of tropical hurricanes Journal of Communications Technology and Electronics vol 10 no 10 pp 1122–1128.
[8] Grankov A G 2017 Tropical hurricanes: Perspective approaches for studying their beginning from satellites, In: Proc. Int. Symp. “Engineering Ecology”, Moscow 5–7 December 2017 Iss. IX pp
47–50.

[9] Kochergin V S, Kochergin S V, Stanichnii S V 2017 Identification of pollution sources in the Sea of Azov using the adjoint equation method Current Problems in Remote Sensing of the Earth from Space vol 14 no 1 pp 50–57.

[10] Kochergin V S, Kochergin S V 2015 Identification of a pollution source power in the Kazantip bay applying the variation algorithm // Physical Oceanography no 2 pp 69–76.

[11] Blake E S Tropical Cyclone Report: Hurricane Humberto, 12-14 September 2007 National Hurricane Centre, 28 November 2007.

[12] Kawanishi T, Sezai T, Y Ito et al 2003 The advanced microwave scanning radiometer for the Earth Observing System (AMSR-E), NASA’s contribution to the EOS for global energy and water cycle studies, IEEE Trans. Geosci. Remote Sens no 48 pp 173–183.

[13] RSS Technical Document 07032014SSMI: RSS SSM/I Version-7 Brightness Temperature Data Set netCDF File Format Specification. Version-7, Release 0, July 3, 2014.

[14] Franklin J L 2007 Tropical Cyclone Report: Hurricane Lorenzo, 22-28 September 2007 National Hurricane Centre.