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ATMOSPHERIC AND HYDROSPHERIC PHYSICS

Dynamics of Surface Heat Fluxes in the Tropical Zone of the Atlantic during Periods of Origination of Hurricanes

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Abstract—The results of an analysis of the images of surface heat fluxes obtained from satellite microwave and infrared radiometric measurements in the areas of the origination of hurricanes in the Gulf of Mexico and tropical Atlantic are presented. It is stated that the intensity of the latent and sensible heat fluxes over 4–5 days preceding the origination of hurricanes increases and the fluxes are localized in certain areas—hurricane centers. The maximum values of the heat fluxes are reached simultaneously with the transition of tropical formations from the stage of a tropical storm to the stage of a tropical hurricane.

Keywords: origination of hurricanes, tropical Atlantic, surface heat fluxes, gradients of fluxes, satellite images, archive of HOAPS

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INTRODUCTION

The development of technologies for diagnostics of the origination of tropical hurricanes (THs) with the use of satellite-based radiophysical methods is an urgent task. The results obtained recently [1–3] evidence that one of the promising ways for solution of this task is monitoring the total moisture content of the atmosphere (TMC). A close connection between the origination of THs in the Gulf of Mexico and the spatial and temporal variability of the TMC field over the water area has been established on the basis of satellite-based microwave radiometric measurements in different years. It was revealed that there is the effect of decreasing spatial dispersion (smoothing) of the water vapor field of the atmosphere in the gulf a few days before the transition of tropical formations from the stage of a tropical storm to the stage of tropical hurricane.

This work considers an approach to the processes of cyclogenesis on the basis of origination of tropical hurricanes resulting from termination of the conditions under which the stationary mode in the heat exchange between the ocean and the atmosphere exists. It is similar to N.N. Semyonov's theory of combustion and explosion, when the appearance of the nonstationary mode—thermal explosion—is formulated as the condition for the disappearance of the stationary mode (exothermic reaction with heat release under the conditions of heat removal), at which the processes of the heat release are not balanced by the processes of heat removal [5]. It should be expected that, in our case, at the moment of origination of the TH, the maximum heat flux at the ocean–atmosphere interface will be observed, which is a clear indicator of changes in the heat balance between the ocean and the atmosphere.

Several examples demonstrate the specific features of the formation of the fields with vertical turbulent fluxes of sensible and latent heat on the surface of the ocean in the areas of origination of the TH. They can be used not only to define the time of origination of the hurricane, but also to determine the location of hurricane centers. The values of surface fluxes of the latent and sensible heat in the World Ocean with 6-hour temporal resolution on a $0.5° \times 0.5°$ grid from the global archive HOAPS (The Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite) are used as the initial data [6]. The archive is based on long-term microwave radiometric measurements from the DMSP (Defense Meteorological Satellite Program) satellites and infrared radiometric measurements from NOAA (National Oceanic and Atmospheric Administration) satellites. The former are used to determine the temperature, air humidity, and wind speed in the near-surface layer of the atmosphere, and the latter

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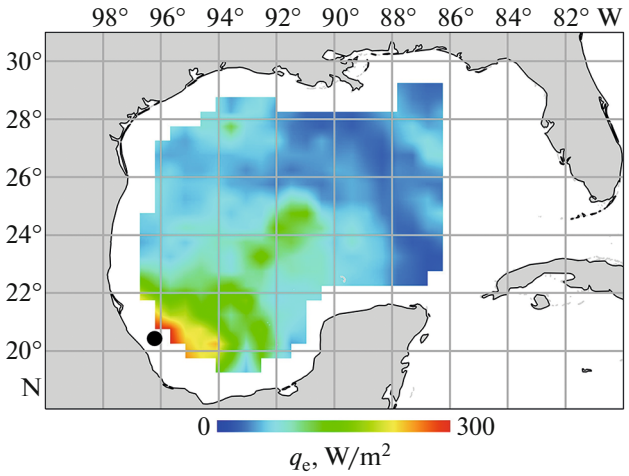

Fig. 1. The spatial distribution of the latent heat fluxes in the Gulf of Mexico, September 27, 2007, 6 am. The point is the area of origination of TH Lorenzo.

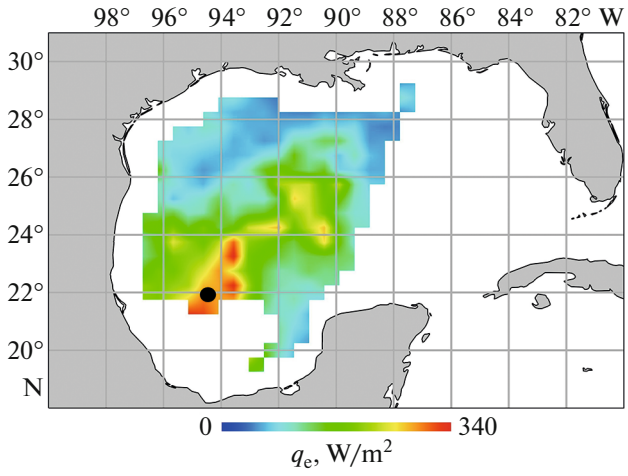

Fig. 2. The spatial distribution of the latent heat fluxes in the Gulf of Mexico, August 20, 1999, 12 noon. The point is the area of origination of TH Bret.

determine the surface temperature of the ocean. These and other parameters together allow us to calculate the surface sensible and latent heat fluxes using the formulas of the heat and moisture exchange between the ocean and the atmosphere—Bulk formulas.

Areas of interest include waters of the tropical Atlantic, characterized by high cyclonic activity due to the regular influence of tropical waves propagating from the west coast of Africa to the Caribbean Sea and the Gulf of Mexico, and the Gulf of Mexico, for which we intend to understand better the regional mechanisms of the origin of local hurricanes.

RESULTS

Preliminary analysis of the HOAPS archive data shows that some time-sampled satellite images of the fields of surface heat fluxes in the Gulf of Mexico are incompletely (fragmentarily) represented in the archive, which can be explained by the presence of blind spots formed as a result of the divergence of scanning bands of microwave radiometers of the DMSP satellites at lower (tropical) latitudes, which are the area of interest in our study. This feature is taken into consideration when analyzing the spatial and temporal variability of heat fluxes in the regions of origination of the Lorenzo, Bret, and Ivan tropical hurricanes considered below. The necessary quality of the quantitative description of the heat flux fields is achieved by selecting images with the minimal influence of blind spots in the studied water areas.

Spatial Dynamics of Heat Fluxes in the Regions of Origination of the Tropical Hurricanes Lorenzo and Bret

According to the history of development [7], Hurricane Lorenzo was formed initially as a tropical depression in the southwestern part of the Gulf of Mexico on September 25, 2007, at 21.8° N, 94.8° W, reaching the stage of a hurricane on September 28 at 20.5° N, 96.3° W.

Using the HOAPS archive, we analyzed the spatial variability of the fields of sensible and latent heat fluxes in the water area of the Gulf of Mexico, adjacent to the area of origination of the TH Lorenzo at different stages of its development.

It was established that, in the time period preceding origination of the hurricane, there is a significant gradient of the latent heat flux in the direction to the area of origination of the hurricane, where the maximum values of heat fluxes are localized.

Figure 1 illustrates this conclusion on the example of one of the 6-h time- sampled satellite images of the field of latent heat fluxes 18 h before origination of the hurricane.

Hurricane Bret was formed initially as a tropical depression off the coast of the Yucatan Peninsula in the Gulf of Mexico on August 18, 1999, at 19.5° N, 94.4° W [8]. TH Bret is noteworthy for having been the most powerful hurricane among the hurricanes that originated in the Gulf of Mexico in the entire history of observations.

Figure 2 shows an example of the spatial distribution of the latent heat fluxes in the Gulf of Mexico at 12 p.m. on August 20, 1999, that is, 12 h before the origin of TH Bret. Here, as in the case of TH Lorenzo, a significant gradient of the latent heat flux is observed in the direction toward the site of origination of the hurricane, where the maximum values of heat fluxes are located.

According to the HOAPS archive data, the intensity of the sensible heat fluxes in the area where the THs Lorenzo and Bret originated was an order of mag-

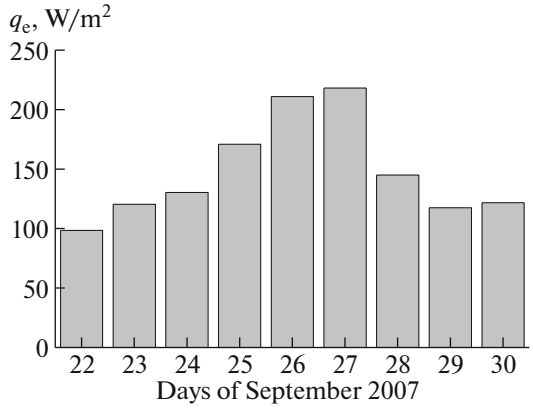

Fig. 3. Dynamics of the increase in daily fluxes of the latent heat in the area of origination of TH Lorenzo origin—1° × 1° square with the coordinates of the center 20.5° N, 96.3° W. The beginning of the tropical storm stage on September 27.

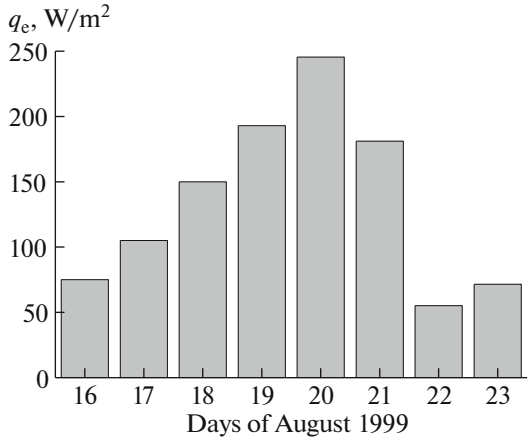

Fig. 4. Dynamics of the increase in daily fluxes of the latent heat in the area of origination of TH Bret—1° × 1° square with the coordinates of the center 21.9° N, 94.5° W. Beginning of the tropical storm stage on August 20.

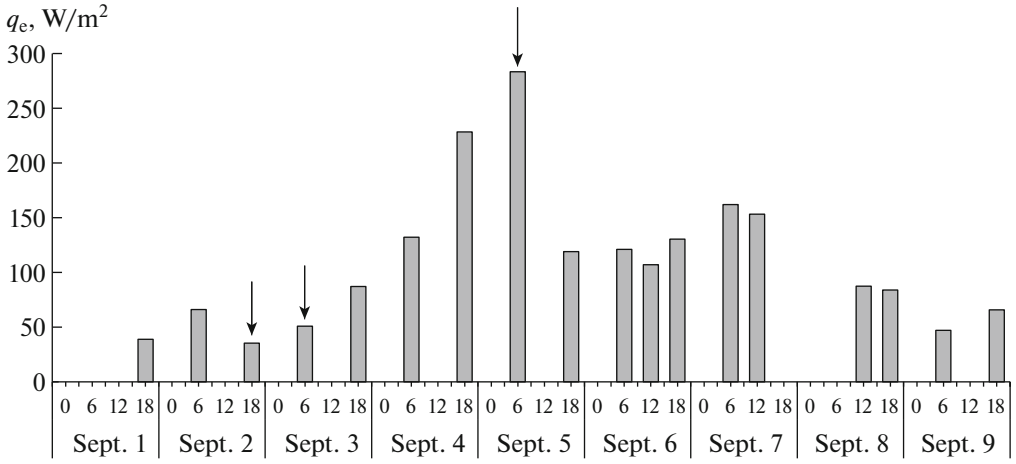

Fig. 5. Variations of the surface fluxes of latent heat q_e in the region of the origin of TH Ivan during the period September 1–9, 2004. The arrows indicate the dates and times of the beginning of the tropical depression (September 2), tropical storm (September 3), and tropical hurricane (September 5) stages. The omission of individual 6-h samples is due to the lack of relevant data in the HOAPS archive.

nitude lower than the intensity of the latent heat fluxes. This result is consistent with the known data showing that, in tropical latitudes, the processes of moisture exchange between the ocean surface and the atmosphere predominates over the processes of heat exchange.

The spatial distribution of the sensible heat fluxes has the same basic features as the distribution of the latent heat fluxes. For example, the field of sensible heat fluxes also shows a significant gradient toward the areas of hurricane origination, and areas the hurricane origination themselves are clearly distinguished.

The result obtained, which demonstrates the distinct spatial localization of the fields of surface fluxes of sensible and latent heat in the areas of origination of tropical hurricanes, should be emphasized, because it allows us to answer an important question positively: can this characteristic be used to determine the location of hurricane centers?

Temporal Dynamics of Heat Fluxes in the Areas of Origination of Hurricanes Lorenzo and Bret

The temporal variability of the sensible and latent heat fluxes at different stages of the development of the tropical formations Lorenzo and Bret in the areas of their origination was analyzed using HOAPS archive data; Figs. 3 and 4 show the results for the temporal dynamics of the latent heat fluxes.

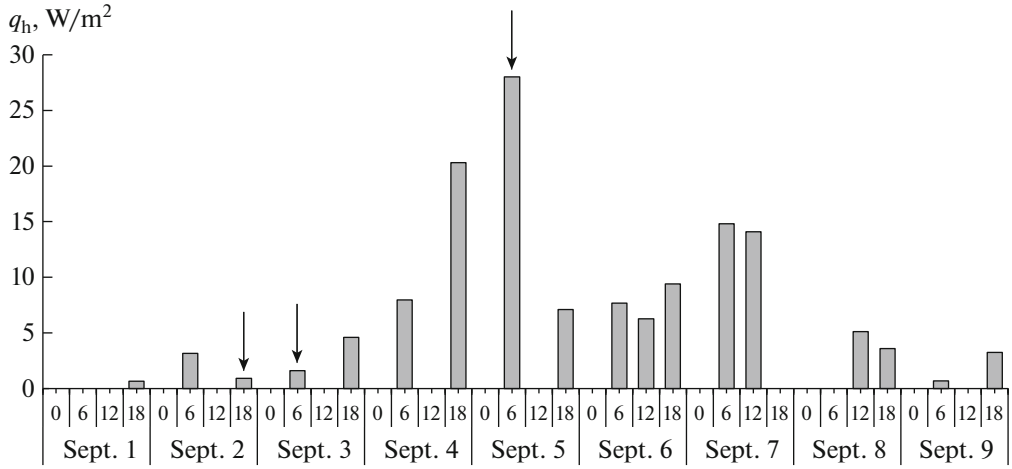

Fig. 6. Variations of the surface fluxes of sensible heat q_h in the region of origination of TH Ivan, September 1–9, 2004. The arrows indicate the dates and times of the beginning of the tropical depression (September 2), tropical storm (September 3), and tropical hurricane (September 5) stages. The omission of individual 6-hour samples is due to the absence of relevant data in the HOAPS archive.

The illustrations demonstrate that the origin of THs Lorenzo and Bret is preceded by a 5- to 6-day increase in latent heat fluxes, the maximum values of which indicate the beginning of the tropical hurricane stage. After the hurricanes leave the regions of their origin, the q_e value begins to decrease, returning to its initial values observed before the beginning of the cyclogenesis.

Similar features are observed in the temporal dynamics of the sensible heat fluxes in the areas of the origin of THs Lorenzo and Bret, which can be explained by the high correlation in tropical latitudes of the synoptic fields of air temperature and humidity in the near-surface (10-m) layer, which is key for the formation of turbulent fluxes of heat and moisture.

Temporal Dynamics of Heat Fluxes in the Area of Origination of Atlantic Hurricane Ivan

According to optical and infrared images obtained from the GOES-12 and MODIS geostationary satellites, TH Ivan was formed in the tropical Atlantic on September 5, 2004, at 9.5° N, 43.4° W [8]. The hurricane corresponds to the 5th category of intensity on the Saffir–Simpson Hurricane Scale with a maximum wind speed of 270 km/h.

On the basis of the HOAPS archive data, we analyzed the temporal variability of the sensible and latent heat fluxes at different stages of the development of TH Ivan. Figures 5 and 6 illustrate the results in the form of 6-h samples of the q_h and q_e values.

It follows from the illustrations that the origination of TH Ivan was preceded by an increase in the fluxes of sensible and latent heat for five days. The fluxes q_h and q_e reach their maximum values at the moment of the beginning of the tropical hurricane stage. After the hurricane leaves the area of its origin, the q_h and q_e values begin to decrease, returning to their initial values observed before the development of the hurricane.

CONCLUSIONS

(1) The results of the analysis of the spatial distributions of the heat fluxes in the areas of hurricane formation in the Gulf of Mexico were obtained on the basis of satellite-based measurements. These results indicate the possibility of determining the location of origination of hurricanes. From the examples of the formation of THs Lorenzo and Bret in the Gulf of Mexico, it was established that, in the process of their origin, there is a significant gradient of sensible and latent heat fluxes in the direction to the areas of origination of hurricanes, where they reach their maximum values.

(2) As the most significant result, it should be noted that for THs Lorenzo, Bret, and Ivan, the fluxes of sensible and latent heat reach the maximum values simultaneously with the beginning of the tropical hurricane stage. This result is obtained on the basis of data from the analysis of satellite observations, without having to interpret physically the nonstationary processes of heat and moisture exchange between the ocean and the atmosphere during the formation of hurricanes and without resort to analysis of the conditions of their occurrence, which is the task of additional research.

(3) The origin of THs Lorenzo, Bret, and Ivan is preceded by the increase in the sensible and latent heat fluxes for 5–6 days; this feature of their temporal dynamics can be used for diagnostics of the beginning of development of tropical hurricanes.

(4) The presence of blind spots, formed as a result of divergence of scanning bands of microwave radiometers of the DMSP satellites in the tropical latitudes of the ocean, leads to a decrease in the integrity of satellite images of the surface heat flux fields in the HOAPS archive and to a decrease in their temporal regularity. In particular, as is shown in the example of TH Ivan, the actual (taking into consideration the omissions in the archive) regularity of data on the fluxes of sensible and latent heat in the area of its origin is 12 h.

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CONFLICT OF INTEREST

The author of this work declares that he has no conflicts of interest.

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