ISSN 1068-3739, Russian Meteorology and Hydrology, 2023, Vol. 48, No. 8, pp. 666–671. Allerton Press, Inc., 2023.
Russian Text The Author(s), 2023, published in Meteorologiya i Gidrologiya, 2023, No. 7, pp. 35–42.

Connection of Cyclogenesis in the Gulf of Mexico to the Water Vapor Transport in the Tropical Atlantic According to Satellite Microwave Radiometers

A. G. Grankov[a]*, A. A. Mil'shin[a]†, E. P. Novichikhin[a]

[a]Kotel'nikov Institute of Radio Engineering and Electronics, Fryazino Branch, Russian Academy of Sciences, pl. Vvedenskogo 1, Fryazino, Moscow oblast, 141190 Russia

**e-mail: agrankov@inbox.ru*

Received June 14, 2022
Revised June 14, 2022
Accepted October 11, 2022

Abstract—The results of satellite monitoring of the transatlantic transport of water vapor in the atmosphere from the western coast of Africa to the Gulf of Mexico are presented. Using the data of the DMSP, EOS Aqua, GCOM-W1 satellite microwave radiometer measurements, the zones with high concentrations of water vapor in the air over the tropical Atlantic are identified, and the dynamics of their movement towards the Gulf of Mexico in the periods preceding the initiation of hurricanes Bret (1999), Lorenzo (2007), Katia (2017) in the gulf is analyzed. The connection of the atmospheric water vapor transport over the tropical Atlantic to the cyclogenesis in the Gulf of Mexico is discussed.

DOI: 10.3103/S1068373923080034

Keywords: Initiation of hurricanes, the Gulf of Mexico, water vapor transport over the Atlantic Ocean, satellite microwave radiometric measurements

INTRODUCTION

The development of technologies for diagnosing atmospheric and oceanic characteristics in the areas of tropical hurricane (TH) activity using spaceborne radiophysical observation instruments is a relevant problem [1, 4].

The paper deals with some issues of using satellite microwave radiometric methods for analyzing atmospheric humidity fields in the areas of tropical cyclogenesis. These methods have been widely used due to the network of satellite instruments providing high spatial coverage and temporal regularity of radio-thermal field observations in the ocean and atmosphere.

Basic attention is focused on local hurricanes initiated in the Gulf of Mexico but not coming here from the Caribbean Sea or the Atlantic Ocean in a mature form. The number of such hurricanes is small, for example, during 1995–2011, 15 hurricanes were generated in the gulf, while the number of hurricanes that reached the coast of the USA and Mexico over that period is several dozen.

Studying this category of hurricanes will provide better understanding of regional mechanisms of their initiation and progress in developing early detection technologies. For example, the consideration of some local tropical cyclones (Bret (1999), Humberto (2007), Lorenzo (2007), Katia (2017)) made it possible to discover that the group response of the field of total precipitable water (TPW) over the Gulf of Mexico has an effect on the generation and evolution of tropical hurricanes [2]. In particular, the common feature for these cyclones was revealed: an increasing spatial variability of TPW over the gulf for several days and its subsequent decrease before the final stage, namely, the hurricane emergence.

† Deceased.

The urgent problem of further research is the consideration of processes beyond the Gulf of Mexico that can predetermine the occurrence of local hurricanes 7–10 days before the beginning of their generation at the earliest stages (tropical depression, tropical storm). According to the National Hurricane Center (USA), one of such processes is tropical waves propagating through the Atlantic region from the western coast of Africa to the Gulf of Mexico, which transport air masses to the west by prevalent eastern winds along the tropics and subtropics near the equator. Tropical waves can lead to the initiation of hurricanes in the North Atlantic, the Caribbean Sea basin, and the Gulf of Mexico. In terms of the connection of cyclogenesis in the Gulf of Mexico to external conditions, it may be interesting to consider the Intertropical Convergence Zone, which is a strip along the equator between trade winds in the Northern and Southern hemispheres that coincides with the equatorial depression, which is a zone of low air pressure along the equator.

The paper analyzes a possibility of indication of these processes in the Atlantic region between the western coast of Africa and the Gulf of Mexico using the TPW fields retrieved from the data of microwave radiometers on board the DMSP, EOS Aqua, GCOM-W1 satellites and evaluates the relationship between the temporal dynamics of TPW and the processes of initiation and evolution of hurricanes Bret, Lorenzo, and Katia. The results of the thematic processing of satellite data from the RSS (Remote Sensing System), NSIDC (National Snow and Ice Data Center), and JAXA Data Providing Service datasets are used.

DYNAMICS OF TPW OVER THE ATLANTIC REGION DURING THE PERIOD PRECEDING THE INITIATION OF HURRICANE BRET

Hurricane Bret was originally formed as the tropical depression off the Yucatan Peninsula coast in the Gulf of Mexico on August 18, 1999 at 19.5 N, 94.4 W and gained full strength (wind speed ~230 km/hour) in the area of the gulf at 26.2 N, 96.1 W at noon on August 22 close to the southern coast of the USA (Texas) [7]. The period of its activity coincided with the time of operation of the DMSP F11 (December 1991–May 2000), F13 (May 1995–November 2009), and F14 (May 1997–August 2008) satellites.

Using the RSS data on TPW over the World Ocean based on the measurements of the SSM/I (Scanning Sensor Microwave Imager) radiometers on board the F11, F13, F14 satellites, the TPW variations were studied in the zone of 20 –30 N, 70 –30 W in the tropical Atlantic with a spatial resolution of 0.25 0.25 in the period preceding the initiation of Hurricane Bret in the Gulf of Mexico. The results are presented in Fig. 1 as the time sequence of satellite scans.

Figure 1 demonstrates the existence of the zone with high TPW (up to 50–60 kg/m^2) in the Atlantic region, which moves toward the Gulf of Mexico during the period corresponding to the time of the tropical wave propagation from the western coast of Africa to the gulf [7]. The evolution of this zone cannot be associated with other tropical formations that, according to the National Hurricane Center archives, were initiated approximately at the same time as Hurricane Bret but had completely different trajectories.

It should be noted that data on the spatiotemporal evolution of this zone could be more complete (up to six observations per day) if the results of satellite surveys were not limited by the blind zones (gaps), which were formed due to the diverging swaths of radiometers at the low (equatorial) latitudes. The detailed analysis of the revealed effect on the completeness of the spatial coverage and temporal regularity of atmospheric humidity fields has been performed in [3] by the example of the Gulf of Mexico.

DYNAMICS OF TPW OVER THE ATLANTIC REGION DURING THE PERIOD PRECEDING THE INITIATION OF HURRICANE LORENZO

Hurricane Lorenzo was generated from the tropical wave that passed through the western coast of Africa on September 11, 2007. It was initially formed as a tropical depression in the southwestern Gulf of Mexico on September 25, 2007 at 21.8° N, 94.8° W and reached the hurricane stage on September 28 at 20.5° N, 96.3° W [6]. An increase in wind speed from 45 to 130 km/hour occurred here during 42 hours (September 25–27, 2007).

Using the measurement data of the AMSR-E (Advanced Microwave Scanning Radiometer) on board of the EOS Aqua satellite (the NSIDC archive), the spatiotemporal variability was studied for the TPW field in the zone of 20°–30° N, 40°–70° W in the tropical Atlantic during the period preceding the initiation of Hurricane Lorenzo, as well as for the TPW field in the Gulf of Mexico in the zone of 20.75°–28° N, 85.5°–97.75° W in the same period.

Figure 2 presents the images of the processes, except for the areas of the Florida Peninsula, the Bahamas, and Cuba. This is caused by regular gaps in the NSIDC archive data on TPW, sea surface wind speed, and other meteorological parameters due to the impact of the following factors on the reliability of satellite

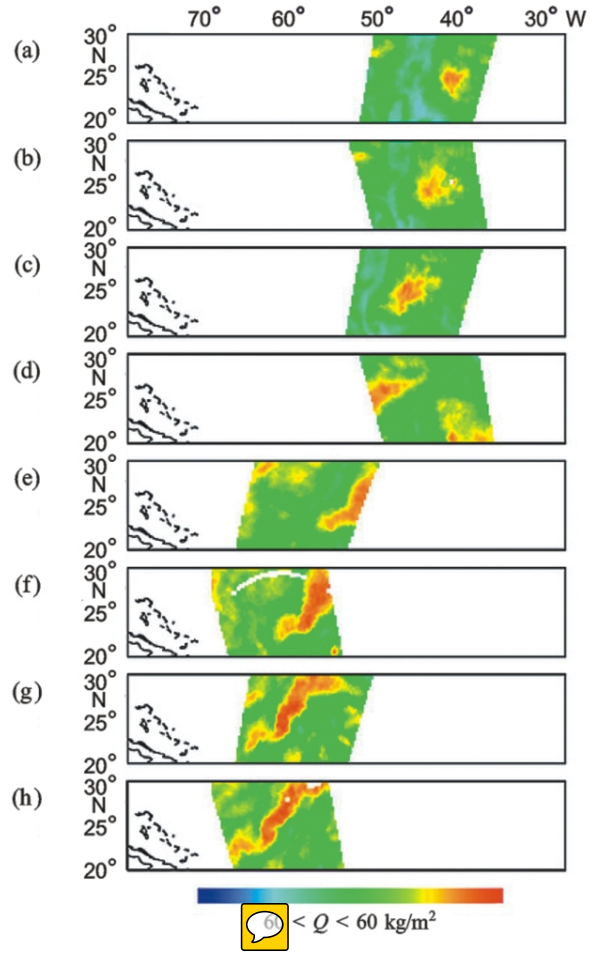

Fig. 1. The evolution of the field of total precipitable water in the distinguished Atlantic region in the period of August 13–16, 1999 according to the SSM/I radiometers on board of the F11, F13, F14 satellites at ascending (A) and descending (D) orbits: (a) August 13, F14, D; (b) August 13, F11, A; (c) August 14, F13, D; (d) August 14, F13, A; (e) August 15, F14, D; (f) August 15, F11, A; (g) August 16, F14, D; (h) August 16, F13, A.

microwave measurements and results of their interpretation: proximity to the land; heavy precipitation; solar radio waves; telecommunication and industrial radio interference.

Figure 2 indicates the presence of an extensive zone with high TPW moving toward the Gulf of Mexico in the Atlantic zone of 20°–30° N during the period of September 21–27 preceding the generation of Hurricane Lorenzo and simultaneously the TPW growth in the southwestern part of the gulf, which is the zone of the hurricane initiation, in that period.

According to the National Hurricane Center data, the evolution of this zone in the Atlantic region cannot be associated with the processes of generation of other tropical formations at that time (Hurricane Karen on September 25–29, tropical storms Jerry on September 23–24 and Melissa on September 28–30), since they were generated approximately at the same time as Lorenzo but had another nature and trajectories.

DYNAMICS OF TPW OVER THE ATLANTIC REGION DURING THE PERIOD PRECEDING THE INITIATION OF HURRICANE KATIA

Hurricane Katia was initiated as a tropical depression at noon on September 5, 2017 in the southwestern part of the Bay of Campeche [5], reached the stage of a tropical storm on September 6, and was transformed into hurricane that moved to the Mexican coast at a speed of 170 km/hour.

Using the data of group measurements of the SSMIS (Special Sensor Microwave Imager Sounder) radiometer on the board of the DMSP F17 satellite (the RSS archive) and the AMSR2 (Advanced Microwave Scanning Radiometer) on the board of the GCOM-W2 satellite (the JAXA Data Providing Service archive),

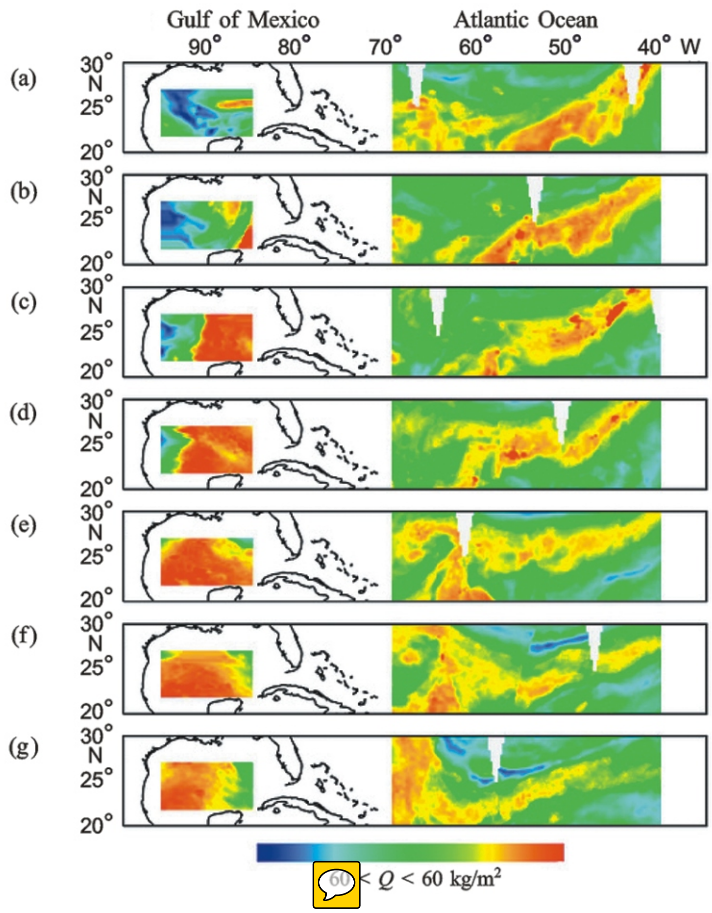

Fig. 2. The evolution of the field of total precipitable water in the Gulf of Mexico during the approach of the high TPW zone in the Atlantic region in the period preceding the initiation of Hurricane Lorenzo: (a) September 21; (b) September 22; (c) September 23; (d) September 24; (e) September 25; (f) September 26; (g) September 27, 2007 (according to the AMSR-E/EOS Aqua measurements). The spatial resolution of the images is 0.25 0.25 , and the white areas are the AMSR-E blind zones.

the spatiotemporal variability of TPW and sea surface wind speed in the tropical Atlantic (15°–35° N, 20°–70° W) in the period preceding the generation of Hurricane Katia was studied.

A zone was detected in the Atlantic Intertropical Convergence Zone (Fig. 3) that was characterized by high TPW (50–60 kg/m^2) and storm values of sea surface wind speed (>25 m/s) and moved from the western coast of Africa to the Gulf of Mexico during the period of August 29–September 4 preceding the formation of Hurricane Katia. The trajectory of movement of this zone is similar to the one of the topical wave, which according to [5] was a reason for the initiation of Hurricane Katia.

However, the movement of this zone toward the Gulf of Mexico is delayed by several days as compared to the propagation of the tropical wave (judging by the time of its passage over the area of the Windward Islands in the Caribbean Sea, south of the Florida Peninsula) and may evidently be considered only as a secondary (derivative) factor associated with the initiation of Hurricane Katia.

CONCLUSIONS

The presented results demonstrate that the effect of the microwave radiometer scan line divergence on board of polar orbiting satellites at the low (equatorial) latitudes has an essential impact on the quality of the simulation of atmospheric humidity fields that play a significant role in the cyclogenesis in the Gulf of Mexico. This effect leads to gaps (blind spots) in the images of atmospheric water vapor fields in the area of the propagation of tropical waves initiating hurricanes in the gulf from the western coast of Africa to the Gulf of Mexico.

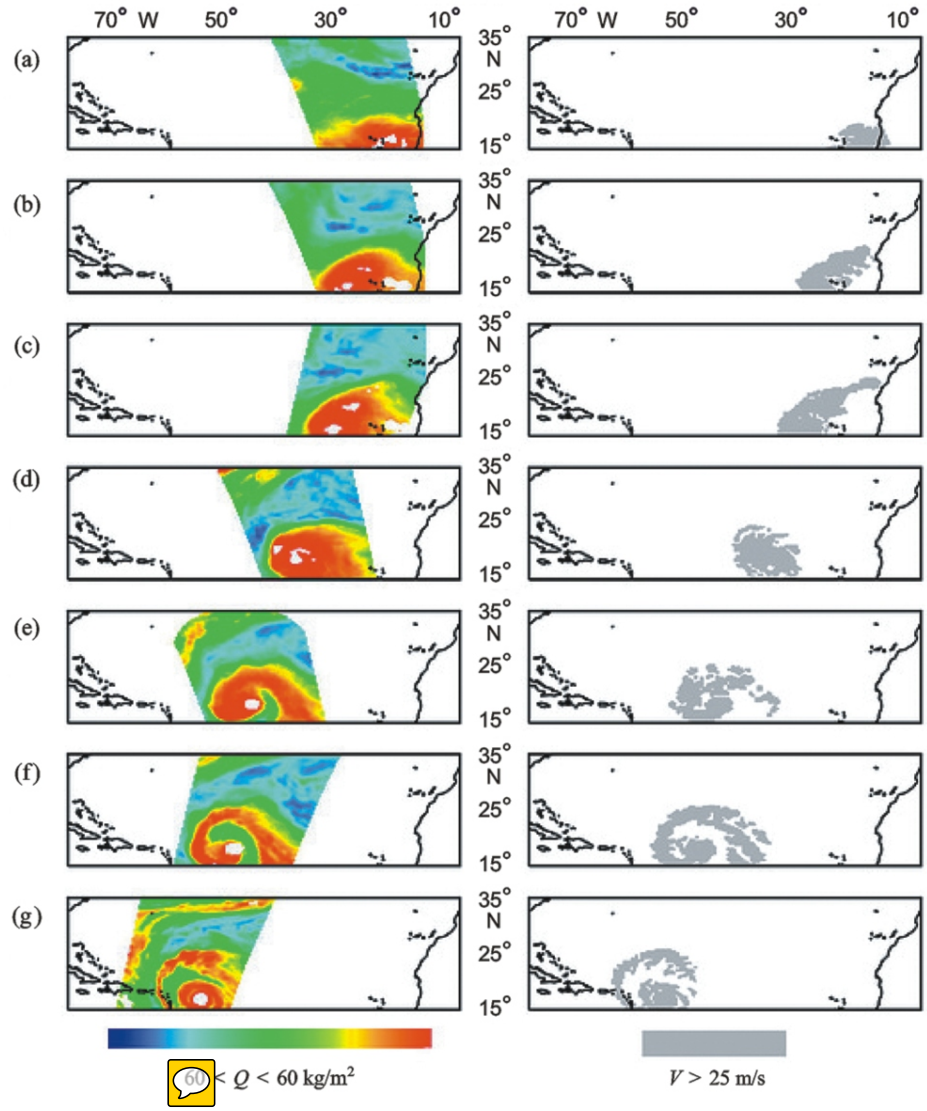

Fig. **3.** The spatiotemporal variability of TPW (left column) and sea surface wind speed (right column) in the tropical Atlantic during the period preceding the initiation of Hurricane Katia according to theSSMIS/DMSP F17 and AMSR2/GCOM W1 radiometers at ascending (A) and descending (D) orbits: (a) August 29, F17, A; (b) August 30, F17, A; (c) August 31, F17, D; (d) September 1, GCOM, A; (e) September 2, F17, A; (f) September 3, F17, D; (g) September 4, 2017, GCOM, D.

The efficiency of combining measurement data simultaneously from several satellites is demonstrated by several examples. Such a method provides useful excess, when some results of measurements are duplicated and other ones fill gaps in blind zones. In addition, is possible to confidently distinguish areas characterized by high TPW values (50–60 kg/m^2) that precede the initiation of hurricanes in the gulf, to monitor the pace of their approach to the Gulf of Mexico, and to evaluate the connection of their evolution to the cyclogenesis.

Further efforts may be aimed at studying the connection of the spatiotemporal variability of atmospheric humidity in the area between the western African coast and the Gulf of Mexico not only with the hurricanes initiating in the gulf but also with tropical storms and depressions to get a more complete pattern of cyclogenesis in this region.

ACNOWLEDGMENTS

The authors thank N.K. Shelobanova for the processing of the DMSP SSM/I и SSMIS radiometer measurement data.

FUNDING

The research was performed in the framework of the Governmental Assignment of Kotel'nikov Institute of Radio Engineering and Electronics of Russian Academy of Sciences.

REFERENCES

1. V. G. Bondur and V. F. Krapivin, *Space Monitoring of Tropical Cyclones* (Nauchnyi Mir, Moscow, 2014) [in Russian].
2. A. G. Grankov, "Relationship between the Atmosphere Humidity Fields in the Gulf of Mexico and the Processes of Hurricane Origin and Development," Izv. Akad. Nauk, Fiz. Atmos. Okeana, No. 4, **57** (2011) [Izv., Atmos. Oceanic Phys., No. 4, 57 (2011)].
3. A. G. Grankov and A. A. Milshin, "On the Efficiency of the Integration of Satellite Microwave Radiometric Means for Monitoring Atmospheric Humidity Fields in the Zones of Hurricane Origin," Radiotekhnika i Elektronika, No. 7, **67** (2022) [J. Commun. Technol. Electron., No. 7, **67** (2022)].
4. E. A. Sharkov, "Remote Studies of Atmospheric Disasters," Issledovanie Zemli iz Kosmosa, No. 1 (2010) [in Russian].
5. L. A. Avila, *Tropical Cyclone Report: Hurricane Katia, 5–9 September 2017* (National Hurricane Center, Miami, 2019).
6. J. L. Franklin, *Tropical Cyclone Report: Hurricane Lorenzo, 22–28 September 2007* (National Hurricane Center, Miami, 2007).
7. M. B. Lawrence and T. B. Kimberlain, *Tropical Cyclone Report: Hurricane Bret, 18–25 August 1999* (National Hurricane Center, Miami, 2001).
8. F. J. Wentz, K. A. Hilburn, and D. K. Smith, R*emote Sensing Systems DMSP SSM/I Daily Environmental Suite on 0.25 deg Grid, Version 7* (Remote Sensing Systems, Santa Rosa, CA, 2012), www.remss.com/missions/ssmi.