J3.19 Seasonal Characteristics of the Gulf of Mexico-Caribbean Basin Water Budget during One Semiannual Cycle as Retrieved from Satellite

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1. Introduction

This study describes a satellite-based retrieval algorithm designed to obtain the atmospheric water budget over the open ocean. The algorithm requires optical visible and infrared measurements from a geosynchronous imager and passive microwave measurements from a polar orbiting satellite. To test the methodology, a combination of data sets derived from the GOES-8 5-channel Imager and the DMSP passive microwave instrument suite (SSM/I) have been acquired for the Gulf of Mexico-Caribbean Sea basin. Whereas the methodology was applied over this basin, the algorithm is designed for portability to any open-ocean region.

The algorithm design takes advantage of the high temporal resolution of the GOES-8 measurements as well as the physical relationship between the SSM measurements and water vapor, cloud liquid water, and rainfall. Used together, these measurements can be used to retrieve the geophysical parameters in the water budget equation.

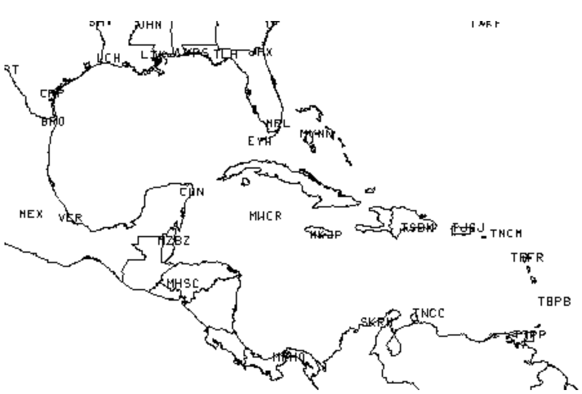


Figure 1. Region of study and station upper air network.

The region of study (Fig. 1) consists of the Gulf of Mexico and Caribbean Sea Basin. This region is surrounded by a network of upper air stations (shown in Fig. 1) providing an independent estimate of the water vapor transport into the region. The study extended beyond an annual cycle, consisting of six months:

October-97, January-98, April-98, July-98, October-98, and January-99. A main goal of the study was to document the daily and monthly properties, including seasonal variability, of all the terms in the atmospheric water budget equation over a complete annual cycle. The results presented in this paper are a small subset from a paper currently in preparation for publication.

2. Scientific Objectives

Past research on the atmospheric water budget has concentrated its efforts in studying the seasonal and annual properties of the water budget on both regional as well as global scales. In doing so, a simplified form of the water budget equation that consists of a balance between evaporation minus precipitation (E - P) and the divergence of water vapor transport ($\nabla \bullet Q$) has been used (Benton and Estoque, 1954; Starr et al., 1958; Hastenrath, 1966; Rasmusson, 1967, 1971; Starr and Peixoto 1971; Peixoto and Oort, 1983; Chen and Pfaendtner, 1993). In this study, such a balance was not assumed. Instead, the scientific objectives of this research were focused on testing the following hypothesis: local changes of storage of precipitable water and condensates within convectively active regions are significant and should be considered in space-time restricted water budget calculations. Thus, the conventional time-averaged form of the water budget equation used in previous studies, consisting of the balance mentioned above, does not generally retain its validity when the budget calculations are made at monthly (or at smaller times scales) or regionally, particularly over convectively active regimes.

With this in mind, the scientific objectives of this research were two fold: (1) to develop a purely satellite-based retrieval methodology, using multi-spectral measurements from GOES-8 and SSM/I, to calculate the atmospheric water budget over the Gulf of Mexico-Caribbean Sea Basin; (2) to quantify the uncertainty in a convectively active tropical-subtropical region stemming from the assumption that the local rate of change of precipitable water and cloud liquid water are negligible in the context of the regional-monthly-seasonal atmospheric water balance.

3. Methodology

The regionally averaged atmospheric water balance equation is given by:

$$\left[\frac{\partial(PW+LWP)}{\partial t}\right]+[\nabla \bullet Q]=[E-P] \qquad (1)$$

where the brackets represent a regional average, PW is the vertically integrated water vapor or precipitable water, LWP is the vertically integrated liquid water or liquid water path, Q is the vertically integrated water vapor transport $q\vec{V}$, $\nabla \bullet Q$ is the divergence of Q, E is the surface evaporation, and P is precipitation. The first two terms in the left hand side of equation 1 are the local rate of change of PW + LWP also referred to as the vapor-cloud water storage terms.

The methodology consisted of retrieving the precipitation, surface evaporation, and vapor-cloud water storage terms from a combination of satellite techniques using high frequency GOES-8 measurements and SSM/I microwave measurements. The water vapor advection term is then obtained as a residual from the balance equation. This leads to a purely satellite-based method for deriving the full set of terms required for the atmospheric water budget equation without requiring information on the wind velocity profile.

To validate the algorithm, the divergence of the water vapor transport term derived from it was compared to two independent estimates. The first independent estimate was obtained from a network of land-based upper air stations that uniformly surround the basin (Fig. 1), and 2) the second estimate was obtained from initial analysis fields obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) global spectral model.

Hourly composites for each month for each of the terms in the balance equation were analyzed throughout the period of the study. The analysis concentrated on documenting the daily and monthly/seasonal characteristics of the budget over one annual cycle. The results were used to emphasize the changing relationship of E-P, as well as the varying roles of storage and advection in balancing E-P on daily and monthly time scales and on localized and basin space scales. As part of developing the retrieval algorithm, different algorithms from the scientific literature were tested and inter-compared in the context of sensitivity testing to help understand the intrinsic uncertainties in the water budget terms.

4. Validations

Figure 2 shows a comparison between the time series of the divergence term in equation 1 obtained from satellite and the estimates of the same parameter from the ECMWF initial analysis fields. The time series are from days 6 to 25 for the 12Z cycle in July 1998.

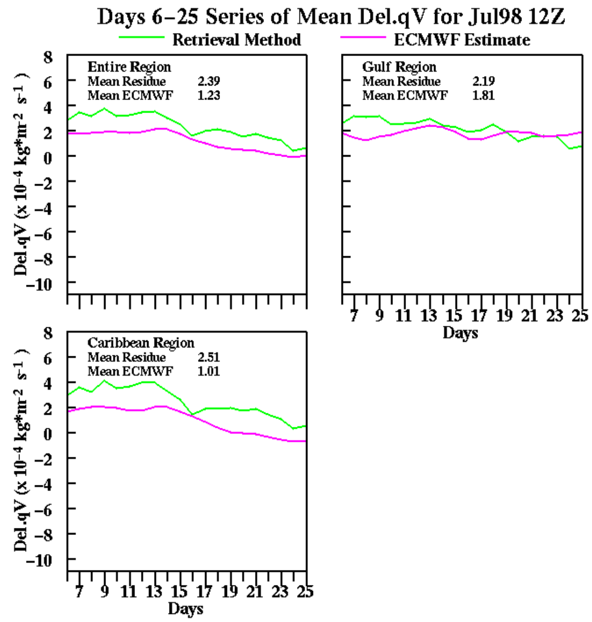


Figure 2. Days 6 to 25 time series of the 12Z mean divergence of the vertically integrated water vapor transport obtained from satellite (green line) and ECMWF initial analysis (purple line) for July 1998. Each day represents a 12Z 11 days running average used to mitigate cloud contamination associated with instantaneous retrievals.

This figure highlights the ability of the satellite retrieval to capture the water vapor divergence term along with its daily variability. A more complete set of validation results are currently in preparation for publication. They include both comparisons to ECMWF estimates as well as sounding estimates along with a discussion on the impact of the limited sounding coverage around the study basin on the validation results.

5. Preliminary Results

Figure 3 shows the time series of the monthly mean water budget processes for the entire region, Gulf of Mexico, and Caribbean regions, respectively. This figure highlights one key finding: that in the monthly/seasonal scales, the water budget is indeed a balance between the divergence term and E-P. Given the small seasonal variability in the surface evaporation, the divergence term plays a crucial role pumping moisture in/out of the region in order to maintain the regional water balance. For the Gulf region, a peak in surface rainfall is noted on January 1998. For the Caribbean region, the peak in surface rainfall is noted on October 1998. Both months were characterized by extreme events with January 1998 being an El Niño winter accompanied by above normal storminess across the Gulf of Mexico while October 1998 was the month that hurricane Mitch moved across the Western Caribbean for a period of 10 days. The regional impact of Hurricane Mitch is noted in the time series for the entire region that shows the peak in rainfall during that month.

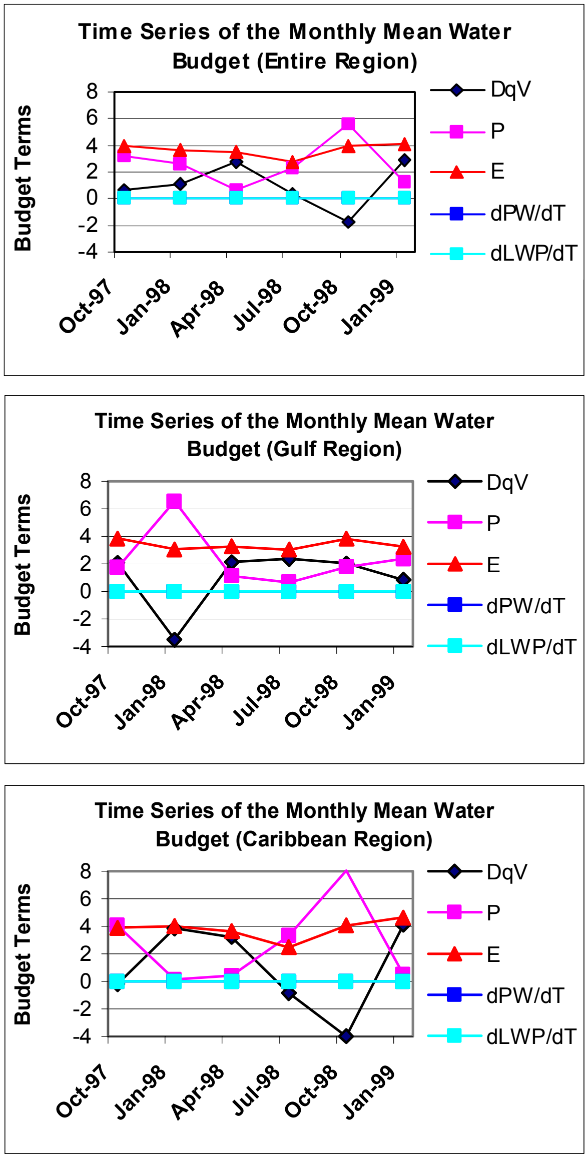


Figure 3. Time series of the monthly mean water budget processes. Units are $x10^{-5} kg \cdot m^{-2} \cdot s^{-1}$. Legend is as follows: **DqV** is the $\nabla \bullet Q$ term, **P** is surface evaporation, **E** is surface evaporation, and **d(PW+LWP)/dt** the vapor-cloud water storage terms.

Further insight into the role that the water budget processes play in the regional water balance is obtained from analyzing their contribution to the total water budget balance. This is highlighted in Figure 4.

Considering the entire region first, the contribution of evaporation to the total water budget exceeds that of rainfall for all but one month, i.e., October 1998. This means that with the exception of October 1998, the entire region served as a moisture source to surrounding regions. However in October 1998 the region was mostly a moisture sink, highlighting the significant impact Hurricane Mitch had on the regional water balance for the monthly period.

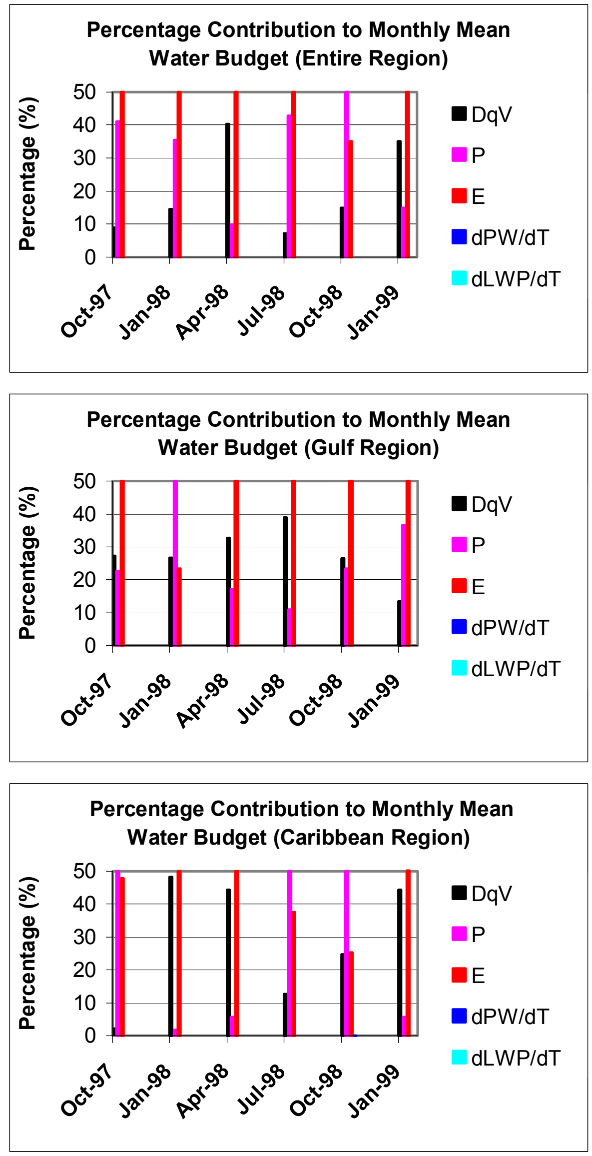


Figure 4. Percentage Contribution by each water budget term to the monthly mean mater budget for the Entire, Gulf, and Caribbean regions, respectively. Legend is as in Figure 3

For the Gulf of Mexico, surface evaporation accounts for most of the water budget despite its weak seasonal variability, with the noticeable outlier being El Niño month of January 1998 when rainfall was the dominant process. This means that the Gulf region served as a moisture source 5 out of the 6 months in the study period with the exception of January 1998 when the region was mostly a moisture sink, mostly in association with El Niño activity.

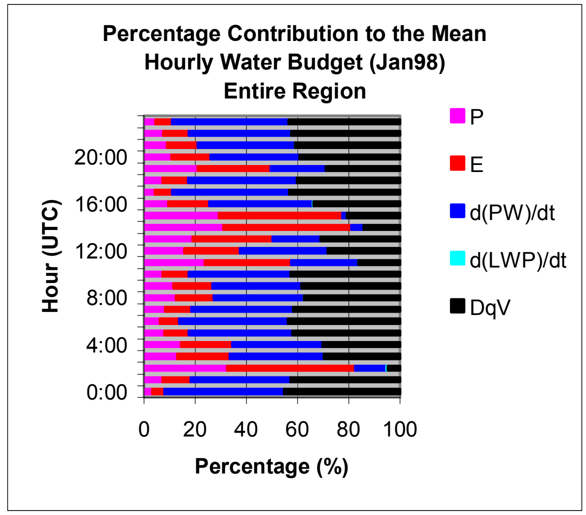
In contrast, in the Caribbean region surface evaporation was the dominant term during the winter and spring months with rainfall being the dominant process during the summer and fall seasons. This means that during the winter and spring seasons of the study period, the Caribbean served as a moisture source while in the summer and fall seasons it served as a moisture sink in association to tropical activity.

Notice then that for the Caribbean region rainfall was the dominant process in the total water budget half the time while in the Gulf it was the dominant process only one month in the study period under abnormal circumstances, meaning El Niño. This is due to the fact that rainfall across the Caribbean, particularly during the summer and fall is tropical in nature and therefore has higher precipitation efficiency. This allows for convective systems across that region to turn more of its precipitable water into rain water compared to the Gulf systems. The result is rainfall having a more dominant role in the regional water budget across the Caribbean versus the Gulf of Mexico.

While the results shown above deny the hypothesis stated in section 2 on monthly scales, Figure 5 sustains it in the daily scale. Figure 5 shows the water budget hourly distribution across the entire region for the months of January and October 1998. No longer the water balance is between the divergence and E - P budgets. This figure clearly shows that in the daily scale, the storage terms, and particularly the vertically integrated water vapor storage term, play a crucial role in the regional water balance with their contribution sometimes exceeding 40% of the total water budget. In fact, more detailed calculations, not shown in this paper, indicate that in the daily time scale, the largest two terms are the divergence and water vapor storage terms. These two terms also show a stronger diurnal cycle than E and P. Therefore, on the daily scale, the storage terms play a crucial role and neglecting then can lead to substantial errors in determining the role played by different water budget processes in the regional water balance.

6. Summary

The development of a portable, purely satellite based algorithm for the retrieval of the atmospheric water budget over the Gulf of Mexico/Caribbean Sea basin is presented. The water budget calculations were made using a combination of multispectral measurements derived from the GOES-8 and SSM/I instruments. The results of the research tested whether ignoring the water vapor and cloud liquid water terms in the water balance equation is a valid assumption in estimating water budget processes at regional-daily-monthly-seasonal space-time scales, particularly for convectively active environments. It also tested if retrieving the water budget purely from satellite observations, without requiring a wind velocity profile, is a suitable approach by comparing the residue transport term obtained from the retrieval algorithm to conventional calculations obtained from upper air soundings surrounding the Gulf-Caribbean basin and independent estimates from the ECMWF global spectral model initial analysis fields.



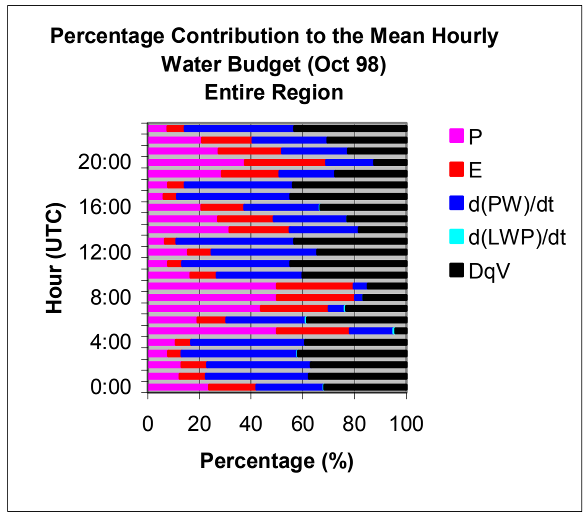


Figure 5. Percentage Contribution by each water budget term to the Hourly Mean Water Budget for the Entire region for the month of October 1998.

Preliminary results show that on monthly/seasonal time scales the regional water budget is a balance between the divergence term and the E – P budget. On the daily scale, results show that the balance is between the water vapor storage term, the divergence term, and the E – P budgets. Overall validation results indicate that the satellite technique is a suitable approach to study the regional water budget.

Results presented in this paper are preliminary. They are a small subset of a paper currently in preparation for publication. A final version along with complete results and discussions will be posted in the following websites by January 2003:

http://gandalf.met.fsu.edu/~psantos/research/bgt/
http://www.srh.noaa.gov/mia/newpage/research/bgt/

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