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The Variations of Land Water Storage from 2003 to 2016 an Inversion of GRACE of Central African Republic

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Abstract: ***Accurate acquisition of land water reserve changes has important scientific significance and social and economic benefits for analyzing the spatial and temporal distribution characteristics of regional water reserve changes, understanding large and medium-scale hydrological processes, studying water resources changes and effective management, and predicting drought and flood disasters. Water is strange, is life. The objective of this study is to have the variation of water resulting from different seasons. In fact, given that we are using the map directly, we have realized that there are strip errors and noises which means that we cannot accurately determine the variation of water storage in different seasonal .For this reason, we use the Gaussian method to correct the errors and the noise to be able to analyze and compare with precision the focuses on the spatial filtering method, analyses and compares the filtering effects of different filtering methods, and chooses the Central African Republic as the experimental area to analyze the variation law of terrestrial water reserves in this area over the years, and to explore the origin of its generation also the method for improving the accuracy of estimation of terrestrial water reserves by combining GRACE data and GLDAS data to use GRACE'S land water reserve data and GLDAS model from 2003 to 2016 to simulate soil water content data, and to calculate the change of the variations water storage in this area.***

Keywords: ***GRACE; Land Water Storage; Filtering; Central African Republic***

1. Introduction

In recent years, with the remarkable change of global climate and the rapid growth of population, water resources, as a basic natural storage resource, occupy a strategic position in the economic field is also constantly rising globally. It not only affects and restricts the sustainable development of modern society, but also has become the primary issue of global resources and environment in the 21st century .With the high-intensity exploitation and utilization of water resources, the imbalance of water distribution in river basins is becoming more and more serious, which leads to a series of ecological environment problems, which lead to the decrease of biodiversity, the more serious problems of salinization, desertification and imbalance of water resources distribution, the more obvious fragility of ecological environment, and the more protruding contradiction between human and water. The imbalance of water and salt has become an important factor restricting the development of oasis. Arid and semi-arid areas occupy about 1/3 of the earth's surface. Shortage of water resources and imbalance of water and salt in river basins often lead to serious ecological problems. Water resources are one of the important factors affecting the development of region economy, and they also have a key significance in protecting the ecological environment.

Water is an indispensable resource for human survival and the main component of organisms. It is also a key factor affecting economic and social development. Accurate acquisition of land water reserve changes has important scientific significance and social and economic benefits for analyzing the spatial and temporal distribution characteristics of regional water reserve changes, understanding large and medium- scale hydrological processes, studying water resources changes and effective management, and predicting drought and flood disasters. The GRACE (Gravity Recovery and Climate Experiment) satellite launched in 2002 has made it possible to obtain time-varying gravity field information of medium and long spatial scales all-weather, high precision and high efficiency, and has provided people with a method to monitor the change of the earth's quality

2. Strip Errors

When we use the spherical harmonic coefficient of grace gravity field to retrieve water storage, the spherical harmonic coefficient provided by grace is not expanded to infinity, but is truncated by a certain order. Therefore, when we calculate the equivalent water height, there is inevitably a truncation error. Moreover, there are more physical information in the higher-order terms of spherical harmonic coefficient, but also more noise. As shown in Figure 1, the error distribution map provided by grace rl06 GSM data in October 2010 is given. It can be seen that the spherical harmonic coefficient error of grace gravity model increases rapidly with the increase of order, and the error in high-order terms is more obvious.

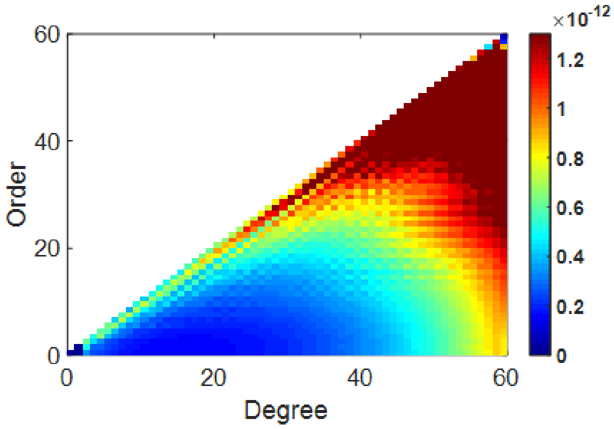

Figure 1: Error distribution in grace rl06 data products in October 2010

As shown in Fig. 2, the inversion result without preprocessing is shown. It can be seen that the image is full of stripe noise along the latitude direction, which is called stripe error. The existence of errors has covered up the real physical information, and it is difficult to extract effective information from it. Therefore, filter processing is introduced. If no filtering is carried out, a large number of stripes will appear in the spatial distribution map of global terrestrial water storage changes, and these stripes will conceal the real signal of water storage changes.The distribution of these stripes is north-south. If these stripes are not removed by certain methods, there will be great uncertainty and even opposite conclusions drawn by directly using the reversed information of land water storage change.

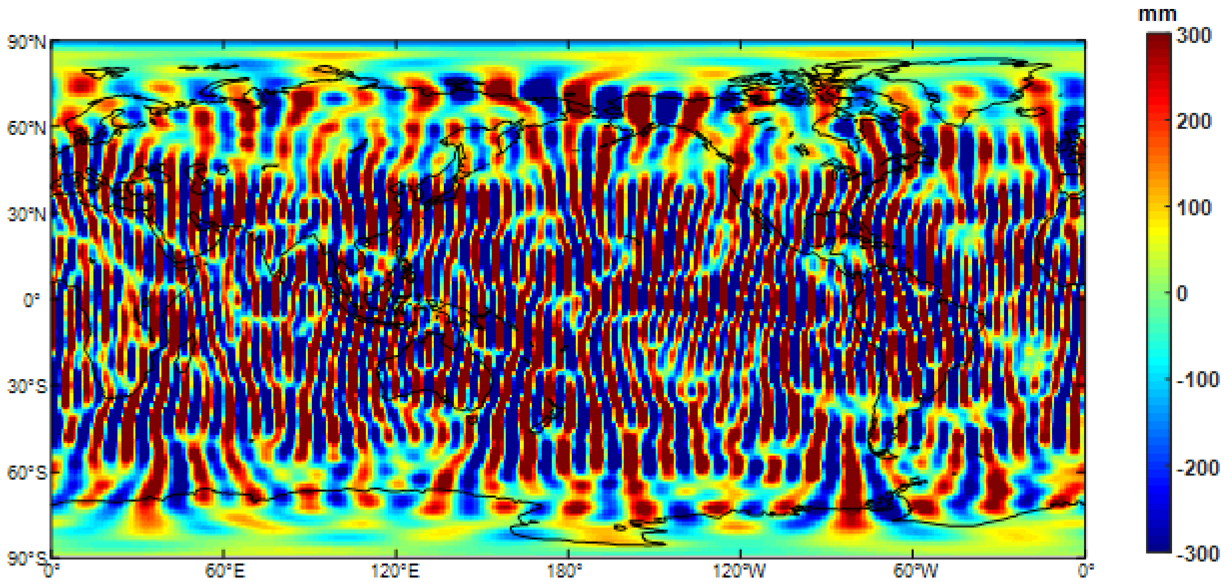

Figure 2: The inversion result without preprocessing

3. Gaussian filtering

There are many common filtering methods, such as Gaussian filtering, fan filtering, DDK filtering and so on. Gaussian filter is widely used because of its simple principle and convenient use. Gaussian filtering is an isotropic filtering method. In view of this error distribution law, the smoothing function $W(\theta,\lambda,\theta^{'},\lambda^{'})$ is used to deal with it.W($\varphi,\lambda,\varphi',\lambda'$) is only a function of the two-point $(\varphi,\lambda),(\varphi',\lambda')$ angular distance on the spherical surface. The relationship between the two is W($\varphi,\lambda,\varphi',\lambda'$)=W(γ), where $\cos\gamma=\cos\varphi\cos\varphi'+\sin\varphi\sin\varphi'\cos(\lambda-\lambda')$, available:

$$\Delta\sigma=\frac{a\rho_{ave}}{3}\sum_{n=0}^{\infty}\sum_{m=0}^{n}\frac{2n+1}{1+k_n}W_{nm}\overline{P}_{nm}(\sin\varphi)[\Delta\overline{C}_{nm}\cos(m\lambda)+\Delta\overline{S}_{nm}\sin(m\lambda)]$$

Where: $W_n=\int_0^{\pi}W(\varphi)\overline{P}_n(\cos\gamma)\sin\gamma d\gamma$ is the Gaussian filter weight coefficient only related to the order, $\overline{P}_n$ is the Legendre polynomial, $\overline{P}_n=\frac{P_{nm}=0}{\sqrt{2n+1}}$

From the data of GRACE RL05 which has been published, the highest degree is 60. The data is not infinite, but truncated to 60th degree. This result will inevitably produce truncation error and eliminate high-order ball harmonics. The influence of coefficient error on the calculation of areal density requires the introduction of a smoothing factor Wn to weaken the effects of truncation error and high-order error. Gaussian filtering is based on the principle of using the Gaussian filter coefficient proposed by Jekeli. It is related to the degree of the spherical harmonic coefficient, and has nothing to do with order. The Jekdi Gaussian filter coefficients are as follows:

$$W(\varphi,\lambda,\varphi',\lambda')=W(\gamma)=\frac{b}{2\pi}\frac{\exp(-b(1-\cos\gamma))}{1-\exp(-2b)}$$

Among them, $b=\frac{\ln 2}{1-\cos(r/a)}$, a is the radius of the Earth's equator, r is the spherical distance between two points when $\gamma=0$, the smoothing kernel function value is reduced to $\frac{1}{2}$ which is the filtering radius. At the same time, Gaussian filter weight coefficients of different degrees can be recursively solved by the following three formulas:

$$W_0=1$$

$$W_1=\frac{1+e^{-2b}}{1-e^{-2b}}-\frac{1}{b}$$

$$W_n=-\frac{2n-1}{b}W_{n-1}+W_{n-2}$$

According to the above formula, the Gaussian smoothing operator of each order can be recursively derived. Chambers found that the algorithm has uncertainty when the spherical harmonic order is higher than 50 in 2006, and proposed an improved smoothing function

$$W_l=\exp\left[-\frac{(lr/a)^2}{4\ln 2}\right] \quad (3.9)$$

Figure 3 shows the weight coefficients of the two Gaussian smoothing methods under the filtering radius of 300km, 500km and 800km respectively. It can be seen from the figure that under the same filtering radius, the weight factors of each order calculated by Chambers' improved Gaussian smoothing function are larger than those calculated by jekeli Gaussian smoothing function, so the improved Gaussian smoothing function can retain more physical information and play a good role in denoising. At the same time, it can be seen that with the increasing of the filter radius, the corresponding weight factor convergence is faster and faster, and the effect of eliminating high-order term error is getting better and better.

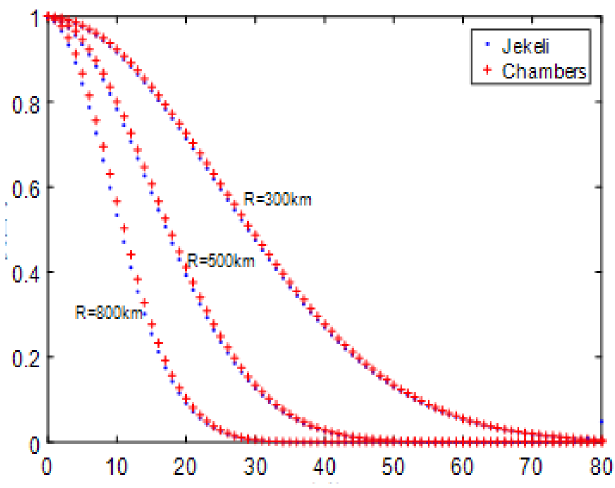

Fig. 3 the weight factors of jekeli and chambers Gaussian method under different filtering radius

Although the larger the filter radius, the better the denoising effect is, it is not that the larger the filter radius is, the better the denoising effect is. When the filter radius is large, the physical information will be eliminated when the high-order term error is removed, so the selection of filter radius is very important. The following figure shows the results of water reserve changes in October 2010 retrieved by grace under different filtering radii. It can be seen that without Gaussian filtering, the image is full of noise, which has covered up the real physical information, and it is difficult to extract effective information from it; when the filtering radius is 300km for smoothing processing, it can be seen that the filtering effect is obvious, compared with the results without filtering processing, a lot of noise has been eliminated, and the physical information in high latitude area is clear It can be seen that, however, there are still north-south strip errors in low latitude areas; when the filtering radius is 500 km for smoothing processing, it can be seen that most of the noise has been eliminated, and the global water reserve change signal can be clearly seen; when the filtering radius is 800 km, the error processing is the best compared with the above three maps, but the effective physical information is also eliminated The amplitude of signal change is greatly reduced, and the time-varying information is not obvious. Therefore, the selection of filtering radius is related to the effect of high-order error processing and the display of physical information. The optimal smoothing radius can be selected by calculating the signal-to-noise ratio before and after filtering.

The larger the filtering radius is, the smaller the coefficient corresponding to the higher-order term will be, that is, the error of the higher-order term will be reduced by weighting. In order to more intuitively compare the effects of Gaussian filtering and sector filtering corresponding to different radii, we respectively selected different filtering radii to invert the equivalent water thickness of global land water storage changes in a certain month. The results are shown in Figure 4 below. As can be seen from the figure, the larger the filtering radius is, the better the smoothing effect is, but at the same time, the more serious the loss of the effective signal of the change of land water storage is. If smoothing is not carried out, as shown in Fig. (a), the signal of changes in land water storage is covered by a large number of stripes, and correct and effective information cannot be extracted. As shown in Fig. (b), after filtering at 300km, the fringe was significantly reduced. With the increasing of the filtering radius, the fringes become less and less. When the filtering radius reaches 800km, the fringes basically cannot be seen, but at this time, part of the useful information about the change of land water storage is also weakened. How to choose an appropriate filtering radius is also one of the hot topics of GRACE related application research.The right radius should be so that the effective signal is retained while smoothing out most of the north-south fringe error.

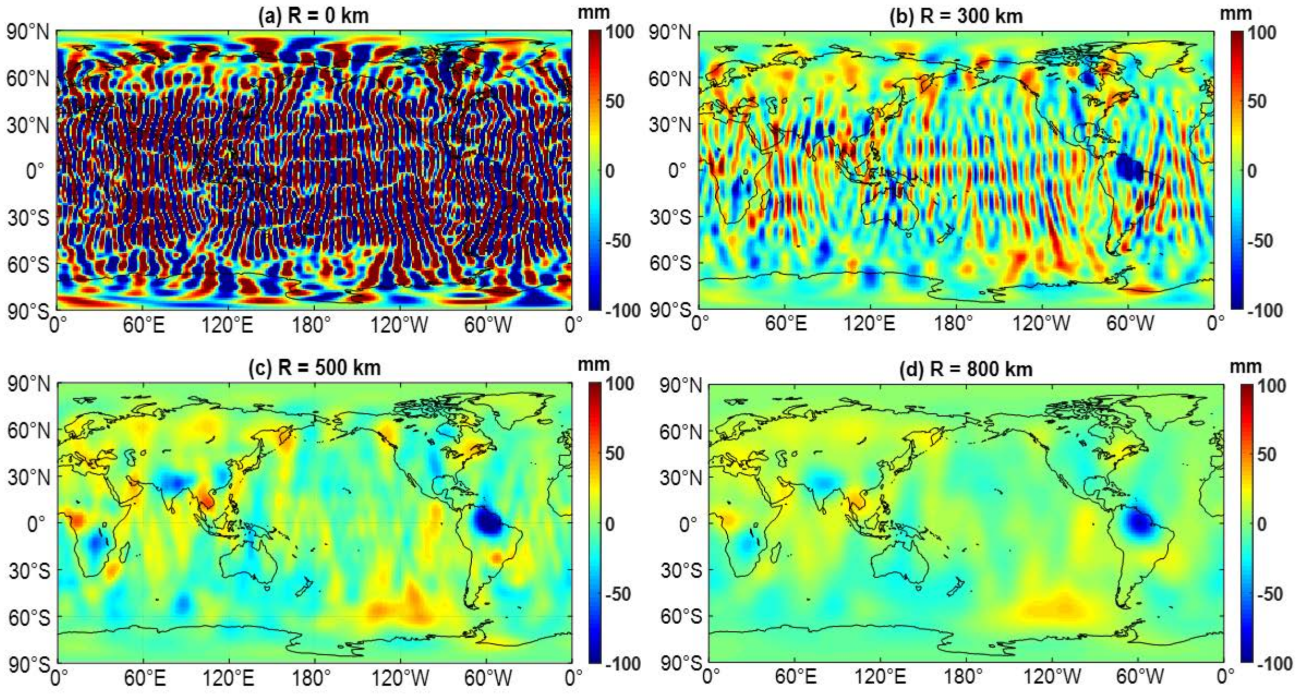

Figure 4: Change of global water reserves in October 2010 by grace inversion under different filter radius
(a) No filtering is carried out; (b) filtering radius r = 300km;
(c) filtering radius r = 500km; (d) filtering radius r = 800km

4. Applications

4.1 Description of Study Area

4.1.1 Topographic

The Central African Republic (CAR) is a country in central Africa. The Central African Republic is bounded by Sudan in the east, the Democratic Republic of Congo (DRC) in the south, the Republic of Congo (RC) in the south-west, Cameroon in the west and Chad in the north. The total area of the country is 623,000 sq km. In the Central African Republic, as in all equatorial countries, there is a tropical climate. Unlike in Europe or the USA, there is almost no difference between the seasons. The daylight hours vary little, and the temperature differences between summer and winter are also lesser. Depending on the season, the average daytime temperatures range between 30 and 36 degrees. In some parts of the country the temperature raises up to 40 °C. In the colder months and depending in the region, the temperature lowers down to 17°C in a month's average.

Relief. The country is an undulated plateau 600 to 900 m high, which separates the basins of the Congo River and Lake Chad. The greater part of the CAR is occupied by the Azande Uplands (600-900 m high). It is divided into the eastern and the western part. The eastern part has an overall southward inclination towards the Mbomu (Bomu) and Ubangi Rivers. In the north extends the Firth Range, which consists of groups of isolated mountains and ridges (over 900 m in height), such as Aburaseyn, Dar-Shalla and Mongo (over 1,370 m). In the south, there are residual rocks. In the west of the plateau lies the Yade Range, which runs well into the territory of Cameroon.

National Parks and Reserves. The CAR's national parks which include Saint Floris, Bamingi-Bangoran in the north-east, Andre-Felix, Dzanga-Ndoki and Dzanga-Sanguie are undoubtedly a decoration of the country. These are true islands of virgin tropical rain forests, which used to occupy the entire region, with all the diversity of unique flora and fauna typical of these unique natural environments. Access to such national parks as Dzanga and Ndoki is limited for tourists and they are open as purely scientific and environmental centers that have global significance. Angling in the Ubangi and the Sangha Rivers is simply fascinating.

Sightseeing. Bangui is the capital of the Central African Republic. This is an incredibly picturesque city, which resembles a huge park. Major places for night recreation are concentrated in the Kay-Chink district, 5 km from the center of the city. Here there are a large number of bars, discos, night clubs as well as the largest market in the country. The Boganda National Museum displays excellent examples of African art as well as a unique collection of folk musical instruments and the most complete exposition in this area, describing Pygmy life and culture. 99 km north-west of the capital lie the picturesque Buali waterfalls, which are particularly affluent during the rainy period.

Climate. The climate of the Central African Republic is hot subequatorial, with average temperatures ranging from+21°C in January to +31°C in July. Precipitation (1,000-1,200 mm in the north and the south 1,500-1,600) falls mainly in summer due to the invasion of wet monsoons. The best time for visiting the country is from November to April.

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Figure 5: Central African map of Köppen climate classification.

4.1.2 Dry and Rainy Seasons: Central Africa Republic

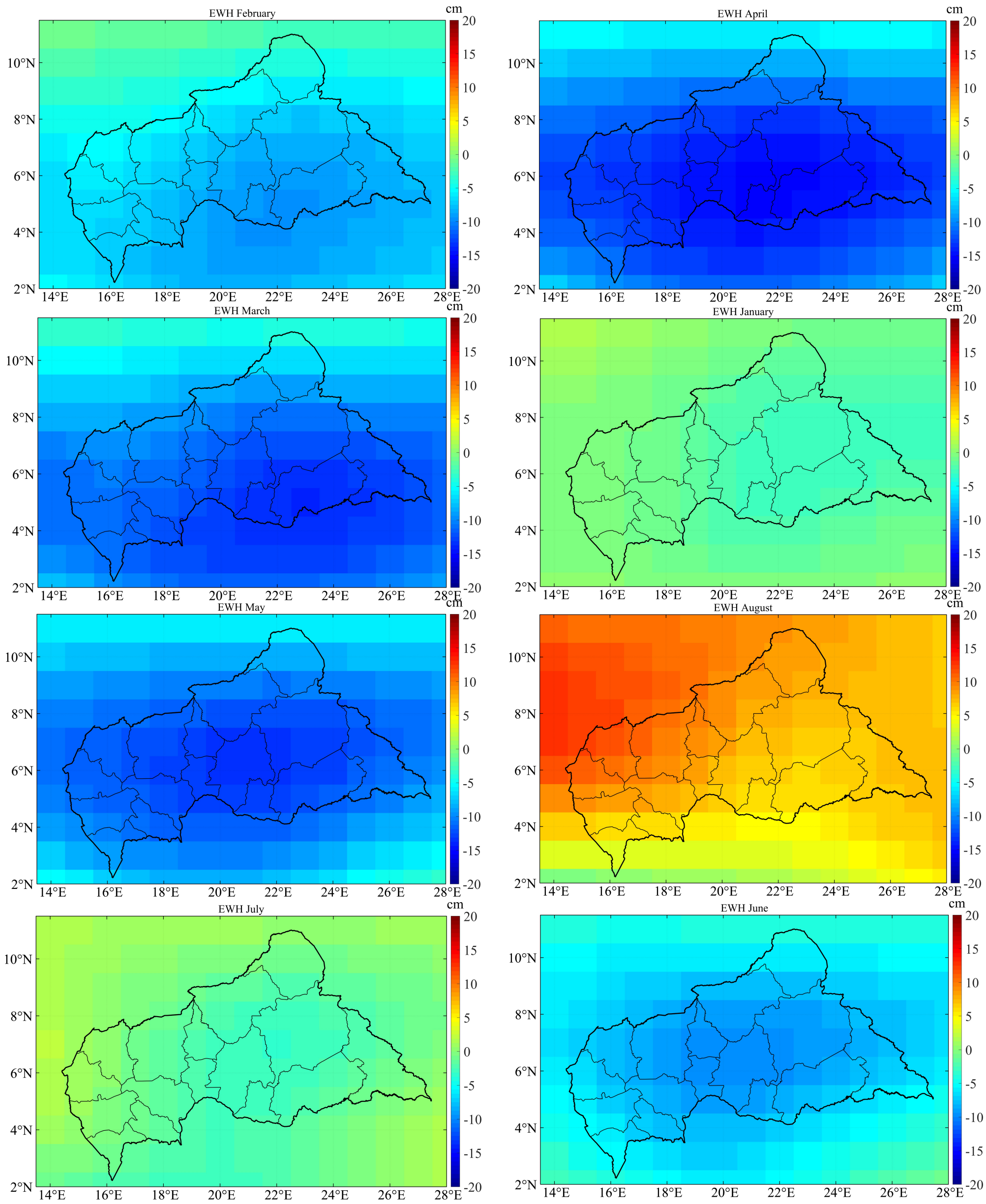
The climate in Central Africa is variable, areas on or near the equator are hot and humid all year round, with plenty of rainfall and no distinct dry season. Further away from the equator, the weather is still hot all year round but a short dry season offers some respite from the rain. It occurs from December to February north of the equator, and from June to September south of the equator. During the long rainy season, rain comes in heavy but short afternoon down.

4.1.3 Central African Republic rainy season

The Weather and Climate in Central African Republic. The Central African Republic has two climatic seasons: The rainy season from May to October, and the dry season from December to April. The wettest months begin in July up to September, with August as the rainiest month at an average of 225 mm (8.9 in.) of rainfall across 17 days.

4.1.4 Rainfall

To show variation within the months and not just the monthly totals, we show the rainfall accumulated over a sliding 31-day period centered around each day of the year. CAR experiences extreme seasonal variation in monthly rainfall.The rainy period of the year lasts for 11 months, from January 13 to December 26, with a sliding 31-day rainfall of at least 0.5 inches. The most rain falls during the 31 days centered around August 17, with an average total accumulation of 7.0 inches



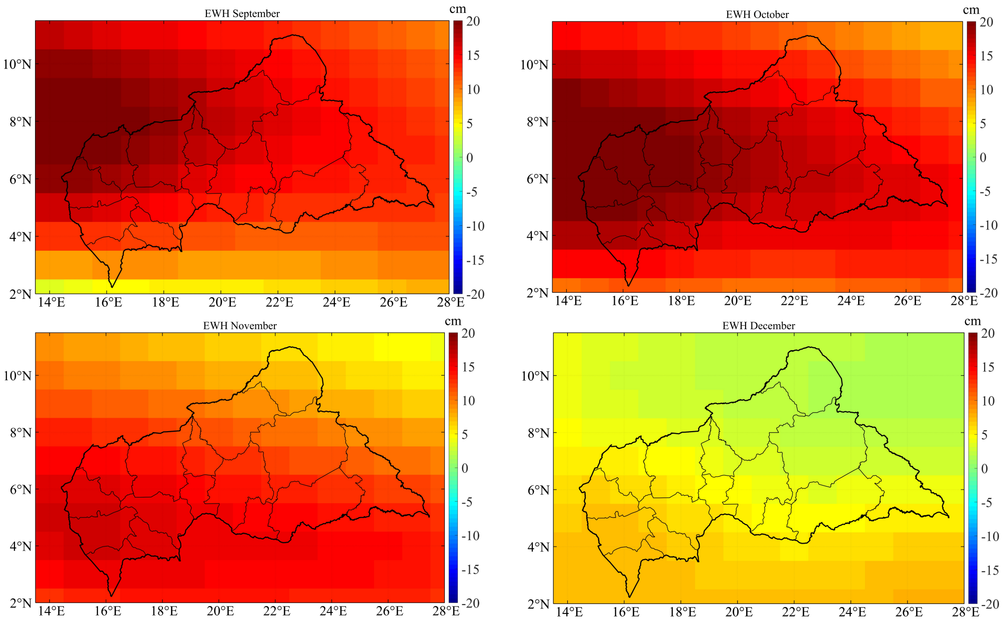


Figure 6: Dry and Rainy Seasons of CAR river basin over the year (Figures pages).

5. Conclusion

To encompass the future on the studies related to other space-borne geodetic sensors, as well as, the hydro-geodetic approaches for measuring components of the water cycle more studies like those presented here may help a broad range of scientists to better understand the Earth System。By reason of data availability issues, no in-situ dataset were used in this thesis. Thus, VWS estimates obtained could not be validated by any ground observation. More so, closing the Central African Republic water budget could have been an interesting addition to this work. However, since adequate dicharge data was not available, this could not be pursued, while soil moisture and water level datasts could have been used to aid the seperation of VWS into its constituents to provide a more comprehensive overview available water resource over the region.

Additionally, anthropogenic influence on VWS was not significantly accounted for in this thesis, which could be subject of future works. Furthermore, the Central African Republic climate has been showed to be linked more sea surface temperatures modes in the Atlantic, pacific and Indian Oceans. In this study, only four major ocean-atmosphere couplings in the Atlantic and Pacific were considered. Further work, with spatial comparisons with these modes, stand to produce more insights to water storage variations over the region. Although ANN has been proved to adequately predict hydrological variables, consideration of the other complimentary algorthms suchas, wavelets and fuzzy logic can enhance accuracies of the predictions. Additionally, deep-learning neural networks could be used to improve estimates. Consequently, future works could consider different algorithms for the improvement of obtainable accuracies.

List of Acronyms

AEM Atlantic Equatorial Mode
AMM Atlantic Meridional Mode
AMMA African Monsoon Multidisciplinary Analysis
AMO Atlantic Multi-decadal Oscillation
ANN Aritificial Neural Networks
ARCv2 African RainfallClimatology Version2
BEST Bivariate ENSO Time Series
CI Conditioon Index
CMI Crop Moisture Index
CMORPH Climate Prediction Centrer Morphing Technique
CNES Centre National d'Etudes Spatiales
CPCA Complex Principal Component Analysis
DEOS Delft institute of Earth Observation, Space Systems
DLR Deutsche Forschungsanstalt fur Luft Und Raumfahrt
ENSO Southern Oscillation
EOF Empirical Orthogonal Functions
ERA-Interim European Centre for Medium-Range Weather Forecasts Re-analyses data
ESA European Space Agency
EUMESAT European Organization for the Exploitation of Metorological Satellites
GFZ GeoForschungsZentrum
GGOS Global Geodetic Observing System
GIMMS Global Inventory Monitoring And Modeling System
GLDAS Global Land Data Assimilation Model
GNSS Global Navigation Satellite System
GPCC Global Precipitation Climatology centre
GPM Global Precipitation Mapper
GPS Global Positioning System
GRACE Gravity Recovery and Climate Experiment
GRACE-FO Grace Follow-On
ICESat Ice, Cloud, and Land Elevation
IGCP International Geo-science Programme
CAR Central African Republic

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Author Statement

Josette-Gila ABA-BIKOUMOSSALI-MBESSO: Conceptualization, Methodology, Software, Writing-Original Draft, Visualization, Resources.

YueDongjie: Supervision, Writing- Reviewing and Editing,.

Data availability

All data included in this study are available upon reasonable request from the corresponding author.

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