**Detecting ENSO events using GRACE satellites in South America**

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1. **Introduction**

The unique Gravity Recovery and Climate Experiment (GRACE) and its successor Gravity Recovery and Climate Experiment-Follow-On (GRACE-FO) have been orbiting the earth since 2002 and uses gravity to map water masses and their changes. Its variable Total Water Storage (TWS) change is defined as changes in water stored on the surface (e.g., lakes and reservoirs, rivers, and snow water equivalent), over the entire soil profile, and in groundwater (Long et al., 2015). TWS changes reflect the balance or imbalance of water fluxes (precipitation, evapotranspiration, and runoff) into and out of a region and are strongly affected by regional climate conditions, such as droughts, floods, and extended periods of high temperature (Shengnan, et al., 2018).

The El Nino-Southern Oscillation (ENSO) is the dominant interannual variability of Earth’s climate system and plays a central role in global climate prediction. Outlooks of ENSO and its impacts often follow a two-tier approach: predicting ENSO sea surface temperature anomaly in tropical Pacific and then predicting its global impacts (Lin & Qian, 2019). El Niño and La Niña events denote sea-surface temperature (SST) conditions in the tropical Pacific that are, respectively, warmer and colder than average (McPhaden et al., 2006), as seen in Figure 1 by Chiodi & Harrison, 2015.

Diagram

Description automatically generated

In the Southern Hemisphere there is a visible change in precipitation patterns due to ENSO (Phillips et al.,2012, Alexander et al.,2002), and Muñoz et al., 2016, describes the effects of this system in Figure 2. As a starting point to understand the variability in South America this internship focus on the two major river basins: Amazon and La Plata. For the desired study area the expected pattern during El Niño the Amazon (La Plata) basin is dry (wet) from June (September) to march (January). The pattern during La Niña for the Amazon (La Plata) basin is wet (dry) from June (August) to march (December).

Diagram

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Since ENSO affects the rainfall, which is the primary contributor to TWS, it is expected to be able to predict ENSO’s events by decomposing GRACE’s TWS.

The main questions are:

a) Can GRACE TWS be fit into a sine model?

b) Can GRACE TWS detect ENSO’s events?

1. **Methods**

**2.1** WMO Basins

The study area comprehends the 2 biggest major river basins from South America, Amazon and Rio de La Plata, shown in Figure 3. The geometry was extracted from the WMO Basins 3rd, revised and extended edition 2020, available at <https://www.bafg.de/GRDC/EN/02_srvcs/22_gslrs/223_WMO/wmo_regions_node.html#doc2763412bodyText7>.

The major basins were calculated by dissolving the ‘WMOBB\_BASI’ attribute and summoning the ‘Shape\_Area’.

South America has 43 major basins. The two biggest ones are Amazon with approximately 4.9 M km2, followed by Rio de La Plata with 3.0 M km2.

Map

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2.2 ONI

The Oceanic Niño Index (ONI) is NOAA's primary indicator for monitoring El Niño and La Niña, which are opposite phases of the climate pattern called the El Niño-Southern Oscillation, or “ENSO” for short. NOAA considers El Niño conditions to be present when the Oceanic Niño Index is +0.5 or higher, indicating the east-central tropical Pacific is significantly warmer than usual. La Niña conditions exist when the Oceanic Niño Index is -0.5 or lower, indicating the region is cooler than usual. The dataset is available at <https://www.cpc.ncep.noaa.gov/data/indices/oni.ascii.txt>

The ONI tracks the running 3-month average sea surface temperatures in the east-central tropical Pacific between 120°-170°W. This area is called the Niño 3.4 region, and its shown in Figure 4.

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Find ENSO events

2.3 GRACE

The Gravity Recovery and Climate Experiment (GRACE) and the Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) missions are a partnership between NASA and the German Research Centre for Geosciences (GFZ). GRACE-FO, 2018- onwards, is a successor to the original GRACE mission that orbited the earth from 2002-2017. These satellites map the gravity field, and since the surface changes at a very slow rate in comparison with water, these monthly changes are mostly attributed to water moving over and below the surface and on the oceans. Data was acquired from the PO.DAAC Drive (https://podaac-tools.jpl.nasa.gov/drive/files/allData/grace/L3/land\_mass/RL06/v03/ and https://podaac-tools.jpl.nasa.gov/drive/files/allData/gracefo/L3/land\_mass/RL06/v03/) for all the different centres' solutions processing: Center for Space Research (CSR), the Jet Propulsion Laboratory (JPL) and GFZ. The monthly data has a spatial resolution of 1° latitude x 1°longitude for all the landmasses. The variable total water storage anomalies (TWS) represents the anomalies of the sums the total of the water mass contained in different hydrological reservoirs, including surface, soil moisture, groundwater, and snowpack component (Hasan et al., 2019). A spatial sum for the area inside of the shapefile (and individual geometries) was performed, resulting in a time series of 163 months for GRACE, starting from April 2002 to June 2017; and for GRACE-FO a time series of 31 months, starting from June 2018 to February 2021.

* 1. Analysis
     1. ENSOs most intense events
     2. A comparison between the centers’ solution

Summoning all TWS in the basin for each month

A simple comparison

* + 1. Modelling the seasonal signal using Non-Linear Least-Squares Minimization and Curve-Fitting (LMFIT), Seasonal Decomposition (SD), and Seasonal-Trend decomposition using LOESS (STD)

Model using LMFIT using the sine equation \*\*\*

Decompose the signal using scipy Sd and STD

compare the amplitude, frequency and correlation

* + 1. Detecting ENSO events using interannual variability from the available models

Extract the interannual variability signal (trend)

Calculate the slope of the curve

Estimate the threshold for ENSO events

1. **Results and Discussion**
   1. Comparing the centers’s solution

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Chart

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* 1. GRACE’s Seasonal Models

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* 1. Detecting ENSO events using interannual variability

Chart, line chart

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Chart, line chart

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Chart, histogram

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1. **Conclusions**

GRACE TWS solution from the 3 different centres' was very similar, they all show the existence of a wet and dry season, one cycle takes approximately 12 months to complete.

For the Amazon basin, the dry (wet) season is during the austral summer (winter). La Plata has an inverse relation, exhibiting wet (dry) summer (winter).

Since GRACE has a cyclic pattern on its signal it was possible to fit into a sine function using several approaches, such as Non-Linear Least-Squares Minimization and Curve-Fitting, Seasonal decomposition using moving averages, and Seasonal-Trend decomposition using LOESS. They all yield similar results in the seasonal signal analysis. Although there are some notable differences, LMFIT and SD provide a solution with a fixed amplitude, while STL can adjust its amplitude according to the input data.

Amazon has a clear seasonality on its signal, this resulted in a correlation between 86% and 88%, La Plata signal is very noisy, hence the lower correlation between 55% and 59%. In both cases, STL had the highest correlation.

A simple comparison between the computed trend and ONI was not precise in pointing the relationship between them. An untrained eye might think about a phase shift but a closer inspection of the curve pattern indicates that the slope has a closer relationship with ONI and can be used to detect ENSO events.

The Amazon basin was able to detect 75% of all ENSO events, but the duration was not matched, it tends to underestimate the length of long La Nina and overestimate the short ones.

La Plata detected 87.5% of El Ninos but only 50% of La Nina, and again the duration was not matched, there was a tendency in overestimating El Nino and underestimating La Nina.

All models are capable of representing GRACE's TWS signal, and the slope of the trend is useful in identifying ENSO episodes, albeit it should be used carefully and more refinement in the method is needed

**References**

Abelen, Sarah, Florian Seitz, Rodrigo Abarca-del-Rio, and Andreas Güntner. "Droughts and floods in the La Plata basin in soil moisture data and GRACE." Remote Sensing 7, no. 6 (2015): 7324-7349.

Cao, Yueqian, Wu Zhang, and Wenjing Wang. "Evaluation of TRMM 3B43 data over the Yangtze River Delta of China." Scientific reports 8, no. 1 (2018): 1-12.

Chambers, Don P. "Evaluation of new GRACE time‐variable gravity data over the ocean." Geophysical Research Letters 33, no. 17 (2006).

Chen, J. L., C. R. Wilson, B. D. Tapley, Z. L. Yang, and Guo-Yue Niu. "2005 drought event in the Amazon River basin as measured by GRACE and estimated by climate models." Journal of Geophysical Research: Solid Earth 114, no. B5 (2009).

Erfanian, Amir, Guiling Wang, and Lori Fomenko. "Unprecedented drought over tropical South America in 2016: significantly under-predicted by tropical SST." Scientific reports 7, no. 1 (2017): 1-11.

GRDC (2020): WMO Basins and Sub-Basins / Global Runoff Data Centre, GRDC. 3rd, rev. ext. ed. Koblenz, Germany: Federal Institute of Hydrology (BfG).

Hasan, Emad, Aondover Tarhule, Yang Hong, and Berrien Moore. "Assessment of physical water scarcity in Africa using GRACE and TRMM satellite data." Remote Sensing 11, no. 8 (2019): 904.

Kummerow, Christian, J. Simpson, O. Thiele, W. Barnes, A. T. C. Chang, E. Stocker, R. F. Adler et al. "The status of the Tropical Rainfall Measuring Mission (TRMM) after two years in orbit." Journal of applied meteorology 39, no. 12 (2000): 1965-1982.

Landerer, Felix W., and S. C. Swenson. "Accuracy of scaled GRACE terrestrial water storage estimates." Water resources research 48, no. 4 (2012).

Long, Di, Laurent Longuevergne, and Bridget R. Scanlon. "Global analysis of approaches for deriving total water storage changes from GRACE satellites." Water Resources Research 51, no. 4 (2015): 2574-2594.

MacRitchie, K., G. Huffman, and D. Bolvin. "README Document for the Tropical Rainfall Measurement Mission (TRMM)." NASA GES DISC (2015).

Swenson, S. C. "GRACE monthly land water mass grids NETCDF RELEASE 5.0." CA, USA (2012).