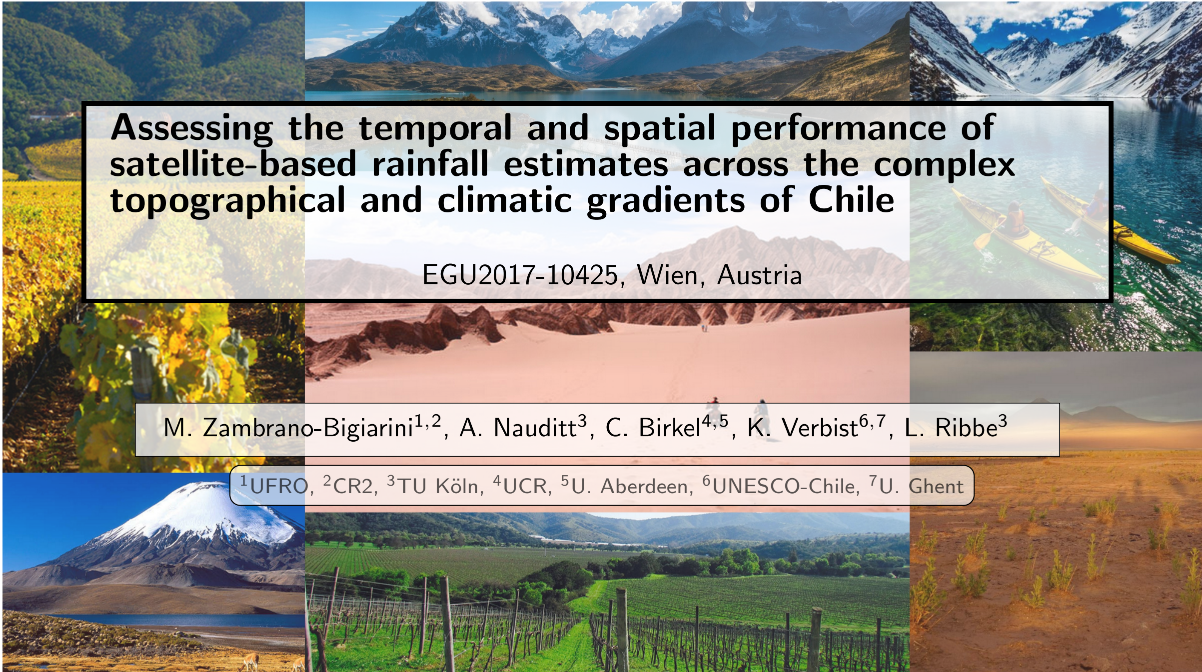


Assessing the temporal and spatial performance of satellite-based rainfall estimates across the complex topographical and climatic gradients of Chile

EGU2017-10425, Wien, Austria

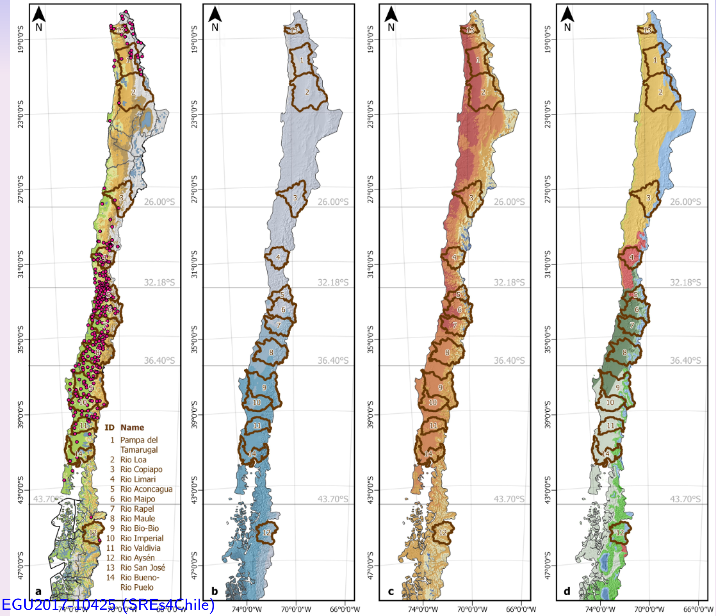
M. Zambrano-Bigiarini[1,2], A. Nauditt[3], C. Birkel[4,5], K. Verbist[6,7], L. Ribbe[3]

[1]UFRO, [2]CR2, [3]TU Köln, [4]UCR, [5]U. Aberdeen, [6]UNESCO-Chile, [7]U. Ghent

Motivation

- Chile has a **complex topography** with very **different climates**.
- Chile has **few** long-term and high-quality **meteorological data**.
- Since ∼ 2010 a **severe drought** is undergoing → we need to carry out reliable hydrological simulations in order to **support decision making**.
- There are several satellite-based rainfall estimates (SREs) available, but literature has reported **some issues** that need to be addressed before using them (e.g., biases, false detection).

Which SRE(s) should we use in Chile?



ID	Name
1	Pampa del Tamarugal
2	Rio Loa
3	Rio Copiapo
4	Rio Limari
5	Rio Aconcagua
6	Rio Maipo
7	Rio Rapel
8	Rio Maule
9	Rio Bio-Bio
10	Rio Imperial
11	Rio Valdivia
12	Rio Aysén
13	Rio San José
14	Rio Bueno-Rio Puelo

Legend

a

● Weather Station

▭ Pilot region

☐ River basin (>10.000 km²)

Altitude

- >3000 - 5876 m
- >2000 - 3000 m
- >1000 - 2000 m
- >500 - 1000 m
- 0 - 500 m
- Glaciated area
- Water body

b

Mean annual precipitation (1950-2000)

- >300 mm
- >200 - 300 mm
- >100 - 200 mm
- >50 - 100 mm
- <=50 mm
- no rain

0 250 500 km

1:15,000,000

c

Mean annual temperature (1950-2000)

- >15 °C
- >10 - 15 °C
- >5 - 10 °C
- >0 - 5 °C
- <=0 °C

d

Climate Zones

- 🟥 Bsk: Cold and arid steppe
- 🟧 BSn: Semi-arid with abundant clouds
- 🟨 BWhn: Hot desert with abundant clouds
- 🟧 Bwk: Cold Arid desert
- 🟨 BWn: Mild desert with abundant clouds
- 🟩 Cfb: Temperate, warm summer, without dry season
- 🟩 Cfc: Temperate, cold summer, without dry season
- 🟩 Csb: Temperate with hot and dry summer
- 🟩 Csc: Cold Temperate with winter rainfall
- 🟦 EF: Polar frost
- 🟦 ET: Polar/ tundra

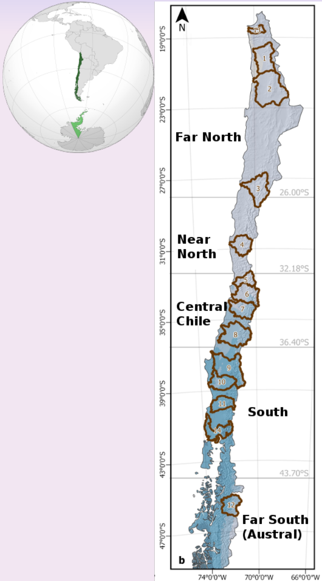
Study area

Selected macroclimatic zones (adapted from DGA (2016)):

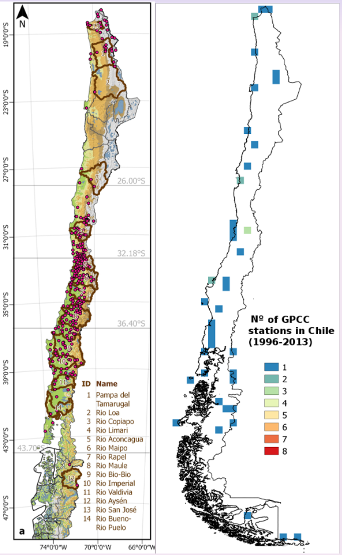
- Far North : 17.50 - 26.00°S
- Near North : 26.00 - 32.18°S
- Central Chile : 32.18 - 36.40°S
- South : 36.40 - 43.70°S
- Austral / Far South: 43.70 - 56.00°S

Major precipitation controlling factors:

- **Interdecadal** variability linked to the **PDO** (Mantua et al., 1997).
- **Interannual** variability affected by **ENSO** (Garreaud and Battisti, 1999).
- Most of the time it is of **frontal origin**.
- It tends to **increase with latitude and altitude** (Quintana and Aceituno, 2006).



Rain gauges



Raw dataset:

- 781 stations analysed, from Chilean datasets (CR2/DGA-DMC).
- Available time period: Jan/1940 - Dec/2015.

Selection of stations:

- Time period : Jan/2003 - Dec/2010 (due to SREs)
- Criterion : < 2% of missing values
- Stations selected: 366

Selected satellite-based rainfall estimates (SREs)

SRE	Full name (with hyperlink)	Latitudinal Coverage	Spatial Resol.	Temporal Coverage	Temporal Resol.	References
CMORPH	NOAA **C**limate Prediction Center (CPC) **MORPH**ing technique	60°N-60°S	0.07°, 0.25°	Dec-2002 - present	half-hourly, 3-hourly, daily	Joyce et al. 2004; CPC-NCEP-NWS-NOAA-USDC 2011
PERSIANN-CDR	PERSIANN **C**limate **D**ata **R**ecord, Version 1 Revision 1	60°N-60°S	0.25°	Jan-1983 - present	daily	Sorooshian et al. 2014; Ashouri et al. 2015
3B42v7	**T**RMM **M**ulti-satellite **P**recipitation **A**nalysis research product 3B42 Version 7	50°N-50°S	0.25°	Jan-1998 - present	3-hourly, daily	Huffman et al. 2007, 2010
CHIRPSv2	**C**limate **H**azards group **I**nf**r**ared **P**recipitation with **S**tations Version 2.0	50°N-50°S	0.05°	Jan-1981 - present	daily, pentadal, monthly	Funk et al. 2015
MSWEPv1.1	**M**ulti-**S**ource **W**eighted-**E**nsemble **P**recipitation Version 1.1	90°N-90°S	0.25°	Jan-1979 Dec-2014	3-hourly, daily	Beck et al. 2017
PERSIANN-CCS-adj	**P**recipitation **E**stimation from **R**emotely **S**ensed **I**nformation using **A**rtificial **N**eural **N**etworks	16°S-57°S	0.04°	Jan-2003 - present	daily	Yang et al. 2016; Hong et al. 2004
PGFv3	**P**rinceton University **G**lobal Meteorological **F**orcing Version 3	17°S-57°S	0.25°	Jan-1979 Dec-2010	daily	Peng et al. 2016; Sheffield et al. 2006

Comparison SREs vs rain gauges (Zambrano-Bigiarini et al., 2017)

Point-to-pixel procedure (Thiemig et al., 2012):

1. **Identify** the SRE **grid cell** that corresponds to each rain gauge.
2. **Aggregate** SRE files and rain gauge data into 7 different temporal scales (daily → monthly → 4 seasons → annual).
3. **Classify** each daily value of precipitation (SREs and raigauges) into 5 different classes.
4. **Continuous** and **categorical** performance indices were used to compare SREs vs rain gauges.

All the previous steps were carried out using the **raster** (Hijmans, 2016), **hydroTSM** (Zambrano-Bigiarini, 2016b), and **hydroGOF** (Zambrano-Bigiarini, 2016a) **R** packages (R Core Team, 2016)

Continuous performance indices (`hydroGOF`)

Modified Kling-Gupta efficiency (KGE', Kling et al. 2012)

It was used along with its three individual components (r, β, γ) to identify possible sources of **systematic errors** in each SRE.

1. $KGE' = 1 - \sqrt{(r-1)^2 + (\beta-1)^2 + (\gamma-1)^2}$: **pseudo multi-objective** index
2. $r = \frac{Cov(S,O)}{\sigma_S \cdot \sigma_O}$: **linear correlation**
3. $\beta = \frac{\mu_s}{\mu_o}$: **bias**
4. $\gamma = \frac{CV_s}{CV_o} = \frac{\sigma_s/\mu_s}{\sigma_o/\mu_o}$: **variability**

where:

- S: Satellite-based precipitation values, [mm].
- O: Precipitation values observed at the rain gauge, [mm].

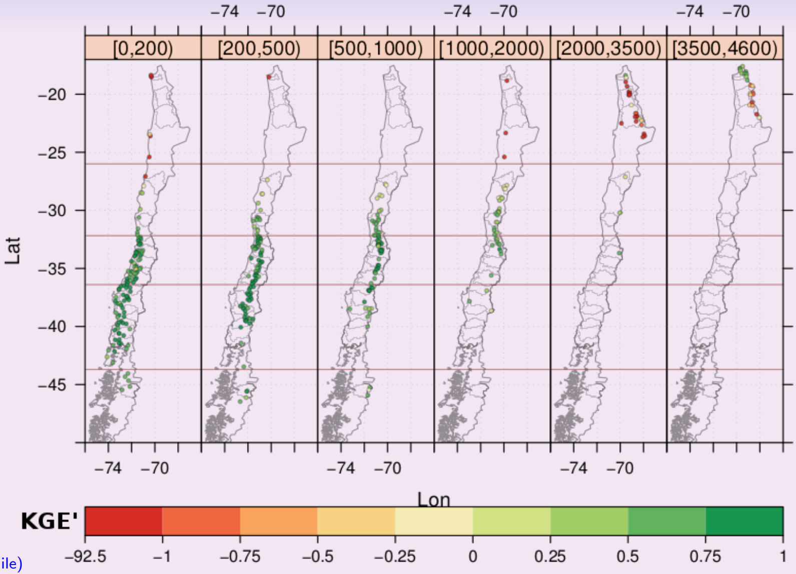
Categorical performance indices (`hydroGOF`)

Rainfall event	**Intensity (i), [mm d^{-1}]**
No rain	[0 , 1)
Light rain	[1 , 5)
Moderate rain	[5 , 20)
Heavy rain	[20 , 40)
Violent rain	≥ 40

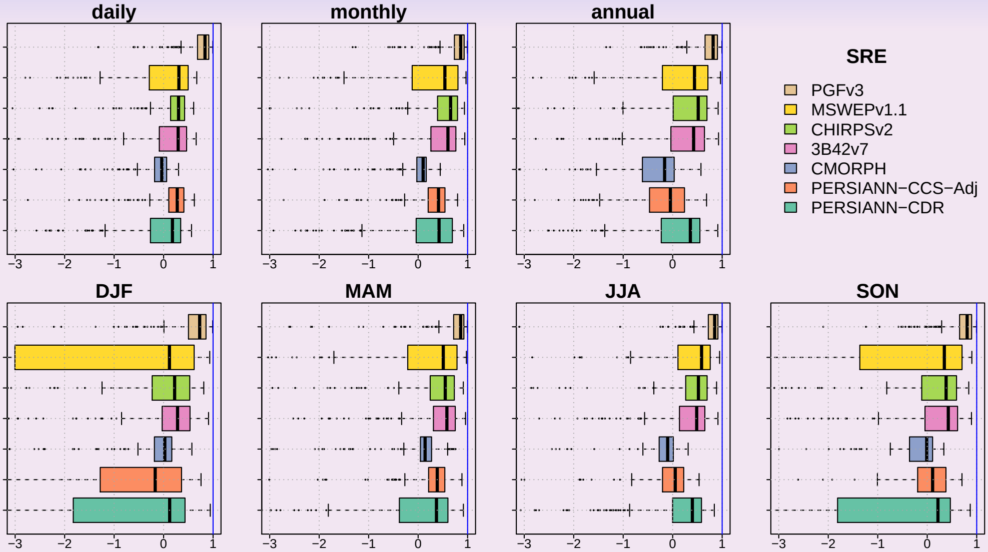
Satellite-product	**Observed rainfall**		
	Yes	No	**Total**
Yes	Hit (H)	False Alarm (FA)	$H + FA$
No	Miss(M)	Correct Negative (CN)	$M + CN$
Total	$H + M$	$FA + CN$	Ne

1. **Percent correct**: $PC = \frac{H+CN}{Ne}$ $(0 \leqslant PC \leqslant 1)$
2. **Probability of detection**: $POD = \frac{H}{H+M}$ $(0 \leqslant POD \leqslant 1)$
3. **False alarm ratio**: $FAR = \frac{FA}{H+FA}$ $(0 \leqslant FAR \leqslant 1)$
4. **Equitable threat score**: $ETS = \frac{H-H_e}{(H+F+M)-H_e}$ $(-1/3 \leqslant ETS \leqslant 1)$
5. **Frequency bias**: $fBias = \frac{H+F}{H+M}$ $(-\infty \leqslant fBias \leqslant \infty)$

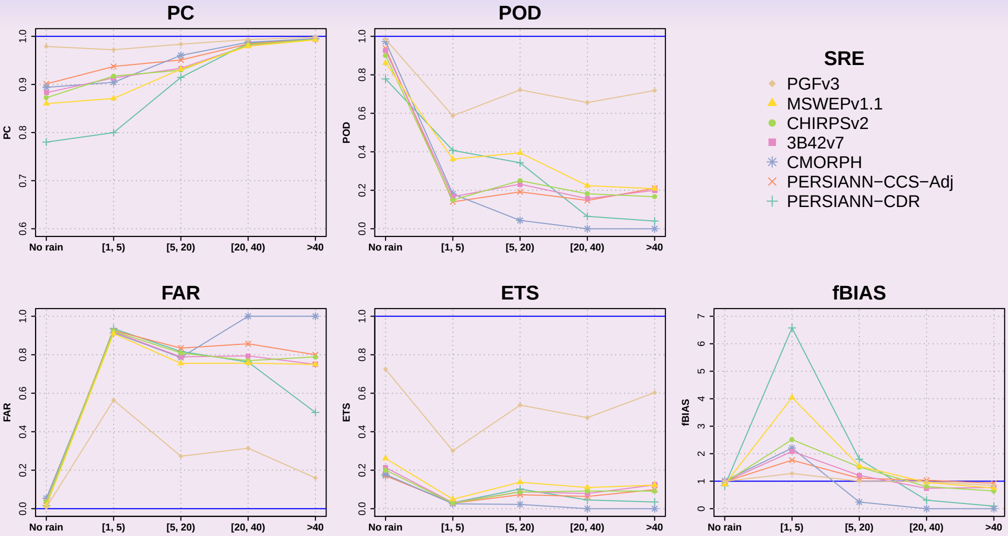
E.g. performance of CHIRPSv2 (KGE', monthly)



KGE' for different temporal scales



SRE performance for different precipitation intensities



Conclusions

1. Lack of rain gauges at **high-elevation zones** (over 2000 m a.s.l., south of 26.0°S), **prevented** an exhaustive assessment of SREs in such areas.
2. Most SREs **performed best** in the humid South (36.4-43.7°) and the Mediterranean Central Chile (32.2-36.4°S).
3. Most SREs **performed worst** in the high-elevation areas ($\geqslant$ 2000 m asl) of the hyper-arid Far North (17.5-26.0°S).
4. All SREs **performed best** (KGE') during the **wet seasons** (autumn and winter, MAM-JJA) compared to summer (DJF) and autumn (SON).
5. Overall, the best SRE product was **PGFv3** followed by **CHIRPSv2**, **3B42v7** and **MSWEPv1.1**.
6. We **recommend** the use of KGE' (r, β, γ) to understand whether possible mismatches are due to errors in representing the **shape**, **magnitude** and/or the **variability** of observed P.
7. We **recommend** the use of *POD* and *fBias* to assess the ability of SREs to capture different **rainfall intensities**.

`< mauricio.zambrano @ ufrontera.cl >`

References I

Ashouri, H., Hsu, K.L., Sorooshian, S., Braithwaite, D.K., Knapp, K.R., Cecil, L.D., Nelson, B.R., Prat, O.P., 2015. PERSIANN-CDR: Daily precipitation climate data record from multisatellite observations for hydrological and climate studies. Bulletin of the American Meteorological Society 96, 69–83. doi:10.1175/BAMS-D-13-00068.1.

Beck, H.E., van Dijk, A.I.J.M., Levizzani, V., Schellekens, J., Miralles, D.G., Martens, B., de Roo, A., 2017. MSWEP: 3-hourly 0.25° global gridded precipitation (1979-2015) by merging gauge, satellite, and reanalysis data. Hydrology and Earth System Sciences 21, 589. doi:10.5194/hess-21-589-2017.

Carrasco, J., 2006. Precipitation events in central chile and its relation with the MJO, in: Proc. Eighth Int. Conf. on Southern Hemisphere Meteorology and Oceanography, pp. 1719–1722.

CPC-NCEP-NWS-NOAA-USDC, 2011. NOAA CPC Morphing Technique (CMORPH) Global Precipitation Analyses. Technical Report. Boulder CO. doi:10.5065/D6CZ356W. [Last Accessed: 25.Jan.2016].

DGA, 2016. Atlas del Agua 2016. Santiago, Chile. Available on line at http://www.dga.cl/atlasdelagua/. [Accessed on 29-Aug-2016].

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A., Michaelsen, J., 2015. The climate hazards infrared precipitation with stations-a new environmental record for monitoring extremes. Sci Data 2, 150066. doi:10.1038/sdata.2015.66.

References II

Garreaud, R., Battisti, D.S., 1999. Interannual (enso) and interdecadal (enso-like) variability in the southern hemisphere tropospheric circulation. Journal of Climate 12, 2113–2123.

Hijmans, R.J., 2016. raster: Geographic Data Analysis and Modeling. URL: `https://CRAN.R-project.org/package=raster`. r package version 2.5-8.

Hong, Y., Hsu, K.L., Sorooshian, S., Gao, X., 2004. Precipitation estimation from remotely sensed imagery using an artificial neural network cloud classification system. Journal of Applied Meteorology 43, 1834–1853.

Huffman, G.J., Adler, R.F., Bolvin, D.T., Gu, G., Nelkin, E.J., Bowman, K.P., Hong, Y., Stocker, E.F., Wolff, D.B., 2007. The TRMM multisatellite precipitation analysis (TMPA): Quasi-global, multiyear, combined-sensor precipitation estimates at fine scales. Journal of Hydrometeorology 8, 38. doi:`10.1175/JHM560.1`.

Huffman, G.J., Adler, R.F., Bolvin, D.T., Nelkin, E.J., 2010. The TRMM multi-satellite precipitation analysis (TMPA), in: Gebremichael, M., Hossain, F. (Eds.), Satellite Rainfall Applications for Surface Hydrology. Springer Dordrecht Heidelberg, London New York, pp. 3–22. doi:`10.1007/978-90-481-2915-7_1`.

Joyce, R.J., Janowiak, J.E., Arkin, P.A., Xie, P., 2004. CMORPH: A method that produces global precipitation estimates from passive microwave and infrared data at high spatial and temporal resolution. Journal of Hydrometeorology 5, 487–503. doi:`10.1175/1525-7541(2004)005<0487:CAMTPG>2.0.CO;2`.

Kling, H., Fuchs, M., Paulin, M., 2012. Runoff conditions in the upper Danube basin under an ensemble of climate change scenarios. Journal of Hydrology 424-425, 264–277. doi:`10.1016/j.jhydrol.2012.01.011`.

References III

Mantua, N.J., Hare, S.R., Zhang, Y., Wallace, J.M., Francis, R.C., 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the american Meteorological Society 78, 1069–1079.

Peng, L., Sheffield, J., Verbist, K.M.J., 2016. Merging station observations with large-scale gridded data to improve hydrological predictions over Chile, in: 2016 AGU Fall Meeting Abstract, 12-16 December 2016, San Francisco, CA, USA.

Quintana, J., Aceituno, P., 2006. Trends and interdecadal variability of rainfall in Chile, in: Proceedings of, pp. 24–28.

R Core Team, 2016. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Vienna, Austria. URL: `https://www.R-project.org/`.

Sheffield, J., Goteti, G., Wood, E.F., 2006. Development of a 50-year high-resolution global dataset of meteorological forcings for land surface modeling. Journal of Climate 19, 3088. doi:`10.1175/JCLI3790.1`.

Sorooshian, S., Hsu, K., Braithwaite, D., Ashouri, H., NOAA CDR Program , 2014. NOAA Climate Data Record (CDR) of Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN-CDR), Version 1 Revision 1. [2003-2014]. Technical Report. NOAA National Centers for Environmental Information. doi:`10.7289/V51V5BWQ`. [access date: 30-Jan-2016].

References IV

Thiemig, V., Rojas, R., Zambrano-Bigiarini, M., Levizzani, V., De Roo, A., 2012. Validation of satellite-based precipitation products over sparsely gauged African river basins. Journal of Hydrometeorology 13, 1760–1783. doi:10.1175/JHM-D-12-032.1.

Yang, Z., Hsu, K., Sorooshian, S., Xu, X., Braithwaite, D., Verbist, K.M.J., 2016. Bias adjustment of satellite-based precipitation estimation using gauge observations-a case study in Chile. Journal of Geophysical Research: Atmospheres doi:10.1002/2015JD024540.

Zambrano-Bigiarini, M., 2016a. hydroGOF: Goodness-of-fit functions for comparison of simulated and observed hydrological time series. URL: http://CRAN.R-project.org/package=hydroGOF. R package version 0.4-0 [under-development].

Zambrano-Bigiarini, M., 2016b. hydroTSM: Time Series Management, Analysis and Interpolation for Hydrological Modelling. URL: http://CRAN.R-project.org/package=hydroTSM. r package version 0.5-0 [under-development].

Zambrano-Bigiarini, M., Nauditt, A., Birkel, C., Verbist, K., Ribbe, L., 2017. Temporal and spatial evaluation of satellite-based rainfall estimates across the complex topographical and climatic gradients of chile. Hydrology and Earth System Sciences Discussions , 1295–1320doi:10.5194/hess-21-1295-2017.