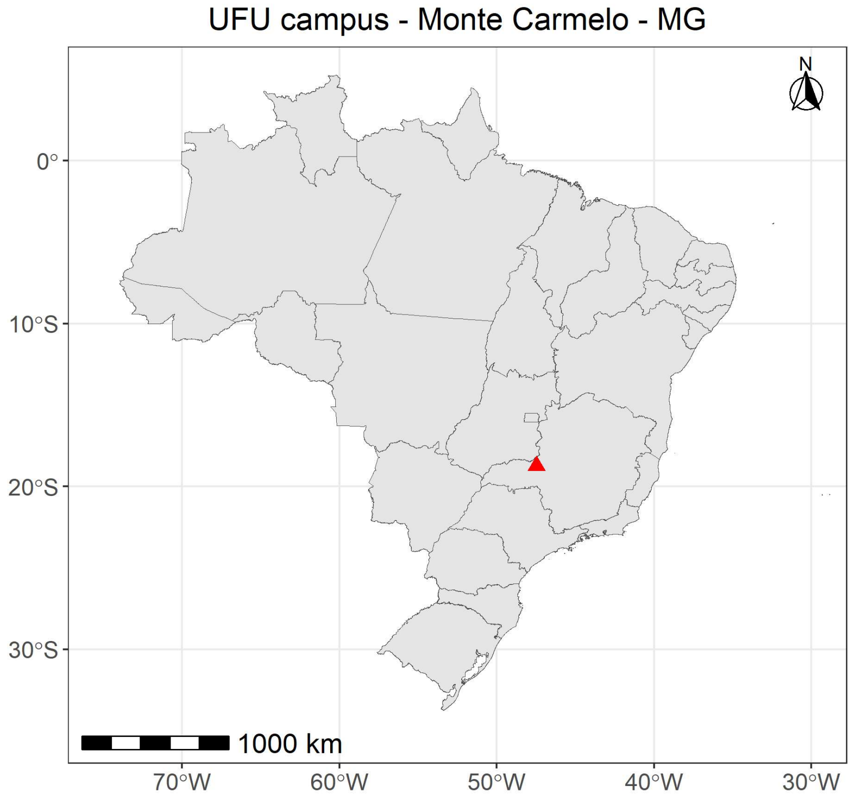
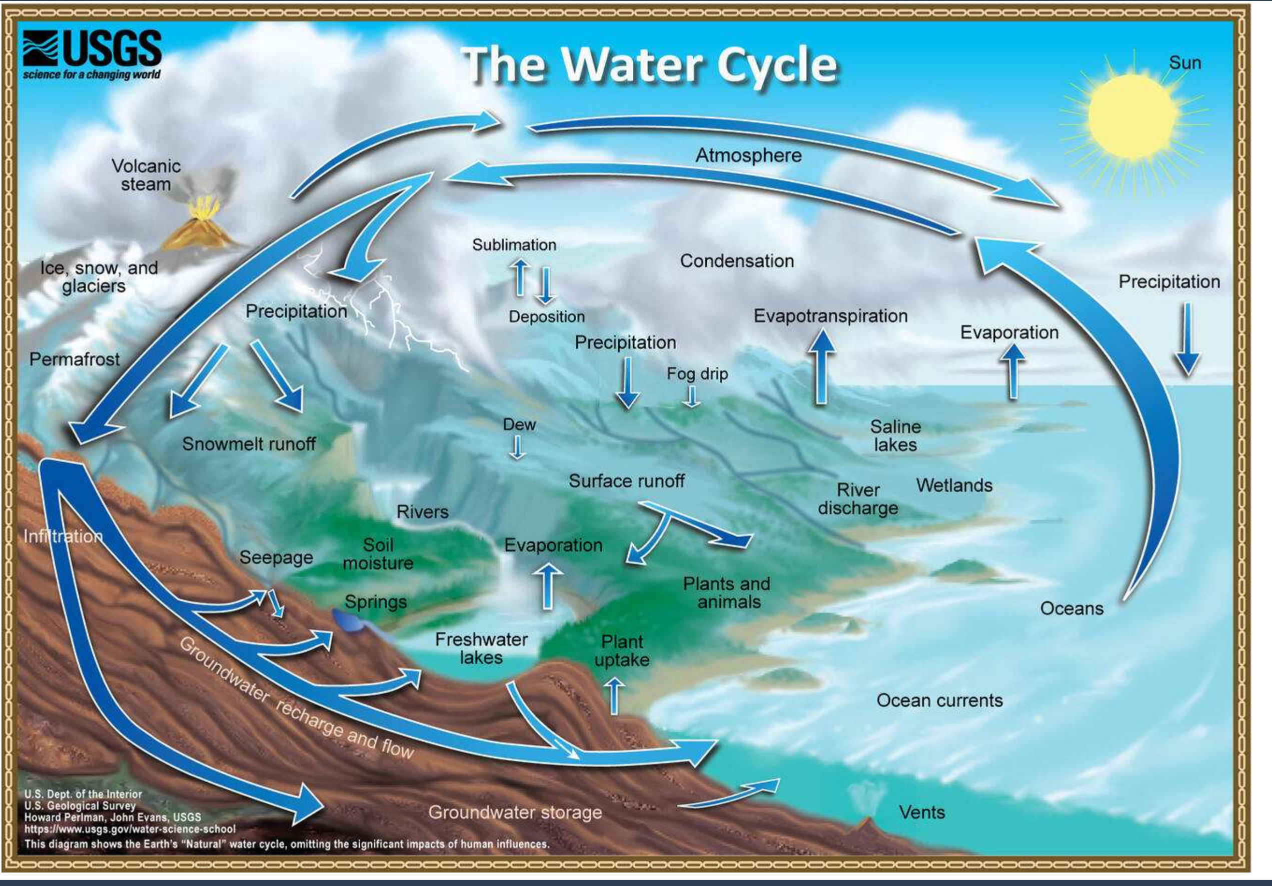
Long-Term Evaluation of Zenith Wet Delay Time Series and Its Relationship with Precipitation in the Brazilian Territory

Samantha N. S. Martins Almeida – Master Degree Candidate
Dr. Marcelo Tomio Matsuoka
Dr. Vinicius Francisco Rofatto

Universidade Federal de Uberlândia – Monte Carmelo-MG Brasil



Source: The author, based on data from IBGE (2020) /Comunica-UFU

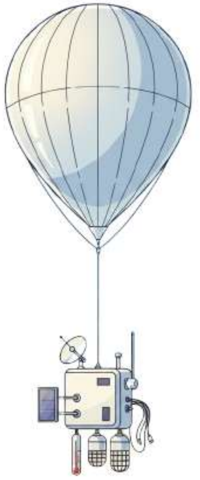

USGS
science for a changing world
The Water Cycle
Sun
Atmosphere
Volcanic steam
Ice, snow, and glaciers
Precipitation
Permafrost
Sublimation
Deposition
Condensation
Evapotranspiration
Evaporation
Precipitation
Fog drip
Precipitation
Dew
Snowmelt runoff
Saline lakes
Surface runoff
River discharge
Wetlands
Rivers
Infiltration
Seepage
Soil moisture
Evaporation
Springs
Plants and animals
Oceans
Freshwater lakes
Plant uptake
Groundwater recharge and flow
Ocean currents
Groundwater storage
Vents
U.S. Dept. of the Interior
U.S. Geological Survey
Howard Perlman, John Evans, USGS
https://www.usgs.gov/water-science-school
This diagram shows the Earth's "Natural" water cycle, omitting the significant impacts of human influences.

Source: USGS

- Highly variable water vapor → can trigger rapid weather changes;
- Water vapor amplifies climate change through feedback processes. (IPCC, 1990)
- Water vapor stores latent heat that fuels storms.
- IWV ↑ ≈ 1% per decade (Allan et al., 2022).

- **How to measure the amount of water vapor (IWV)?**

  - Radiometers
  - Very Long Base Interferometry (VLBI)
  - Radiossondes (Ning, 2012; Sapucci, 2001)
  - GNSS Meteorology (Gouveia et al., 2020)



$$L=\int_S n\,ds$$

$$\Delta L(\varepsilon,\Phi)=\underbrace{\boxed{\int_S (n-1)\,ds}}_{(1)}+\underbrace{\boxed{S-S_g}}_{(2)}$$

(1) Path delay due refraction
(2) Geometrical delay

Elgered (1993), Ning (2012)

Considering (1) :

$$N=10^6(n-1)$$

$$N=\underbrace{\boxed{k_1 R_d \rho}}_{(a)}+\underbrace{\boxed{k'_1 \frac{p_w}{T} Z_w^{-1}+k_3 \frac{p_w}{T^2} Z_w^{-1}}}_{(b)}$$

(a) hydrostatic
(b) non-hydrostatic

Thayer (1974), Rofatto (2014), Owens (1967), Davis et al (1985), Sapucci, 2001.

So, we have:

$$N=N\,hidrostatic+N\,non\,hidrostatic$$

$$\Delta L(\varepsilon,\Phi)=D_{trop}$$

$$D_{trop}=\boxed{D_{ZH}+D_{ZW}}$$ (Sapucci, 2001)

- Saastamoinen (1973)
- Hopfield (Seeber, 1993)

$$ZTD=ZHD+ZWD$$ (Ning, 2012)

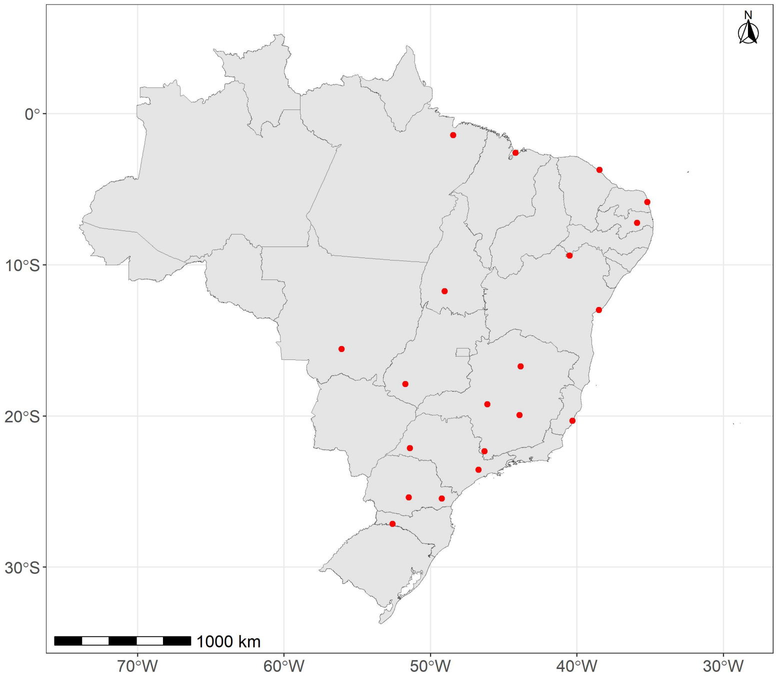
ZWD → $IWV=Q.ZWD$ (Bevis et al 1994)

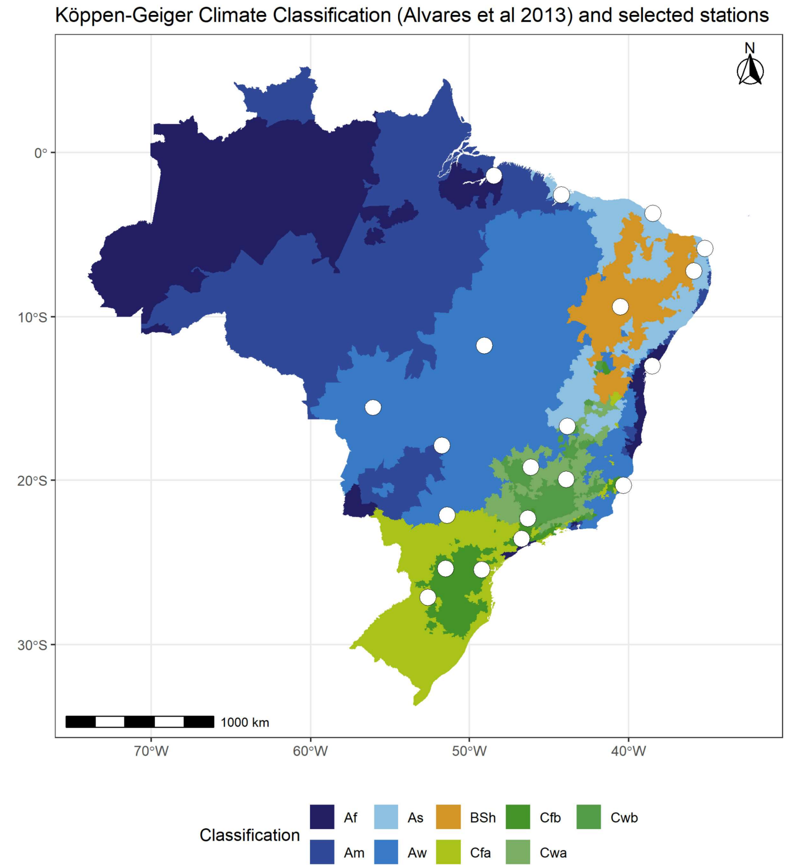
- ZWD is the variable analyzed in this work.
- Analyze Zenith Wet Delay (ZWD) data from 20 GNSS stations distributed across Brazil.
- Compare ZWD time series with precipitation records from nearby meteorological stations.
- Assess how the relationship between ZWD and precipitation varies under different climatic conditions across the Brazilian territory (Köppen-Geiger Classification).

- GipsyX/RTGx: processed data was downloaded for Brazilian stations (Nevada Geodetic Lab, University of Nevada, Reno)
- GipsyX estimates Zenith Total Delay (ZTD) from GNSS signals using Precise Point Positioning (PPP).
- The hydrostatic part (ZHD) is modeled from surface pressure.
- The remaining part, after subtracting ZHD, is the Zenith Wet Delay (ZWD) — directly linked to atmospheric water vapor.

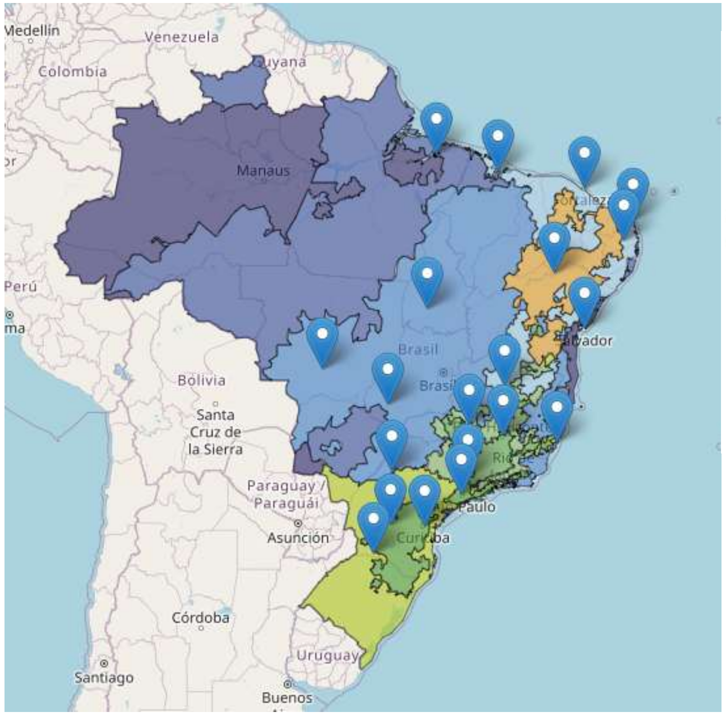
$$ZTD = ZHD + ZWD$$

- 20 stations with ZWD data were choosen in the period of 2011-2023;
- These stations were paired with meteorological stations from INMET (precipitation data);
- For each station, the climate classification (Köppen-Geiger) was obtained (Alvares, 2013);
- Correlation was calculated (ZWD - Precipitation)

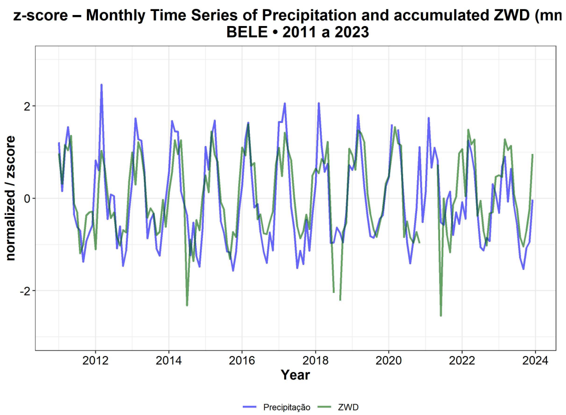


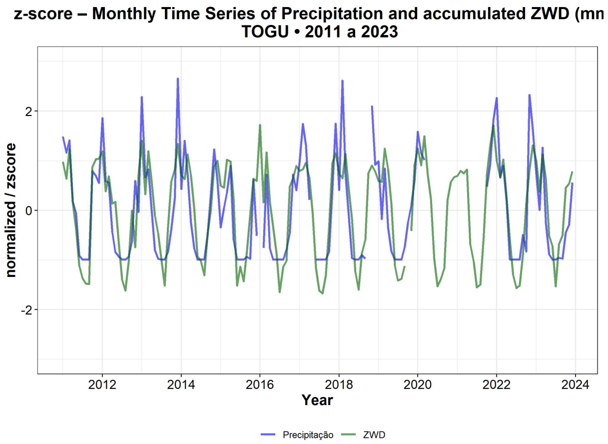

Köppen-Geiger Climate Classification (Alvares et al 2013) and selected stations
N
0°
10°S
20°S
30°S
1000 km
70°W
60°W
50°W
40°W
Classification
Af
Am
As
Aw
BSh
Cfa
Cfb
Cwa
Cwb

- Time-series – 20 stations

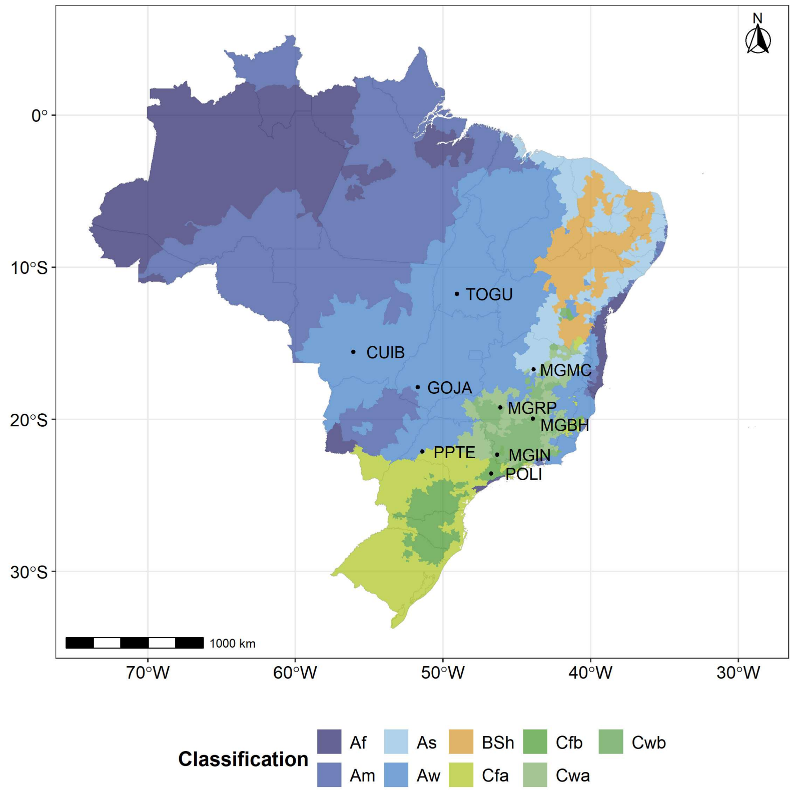


Examples:

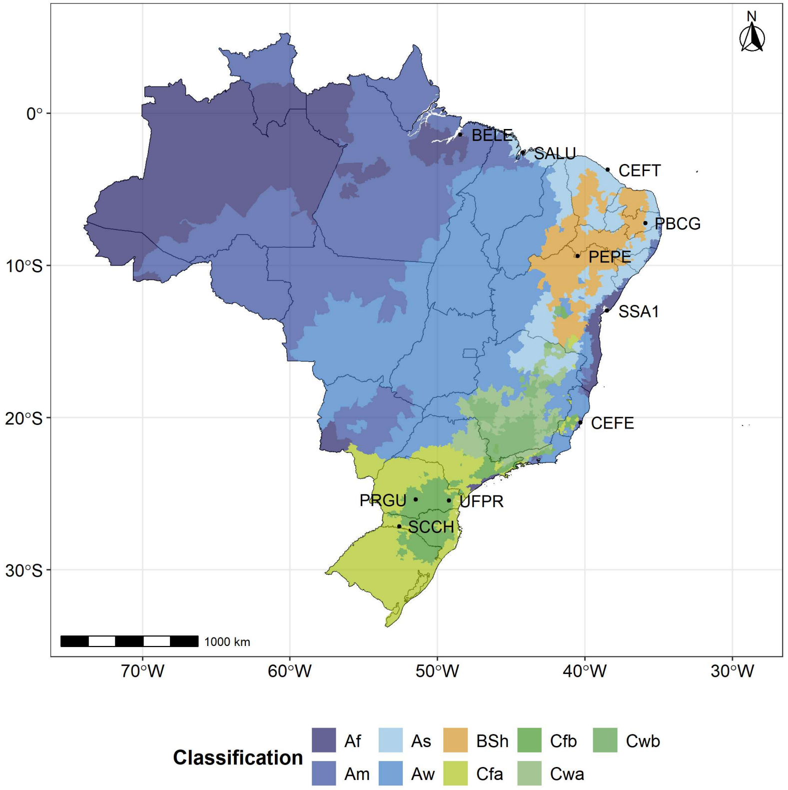




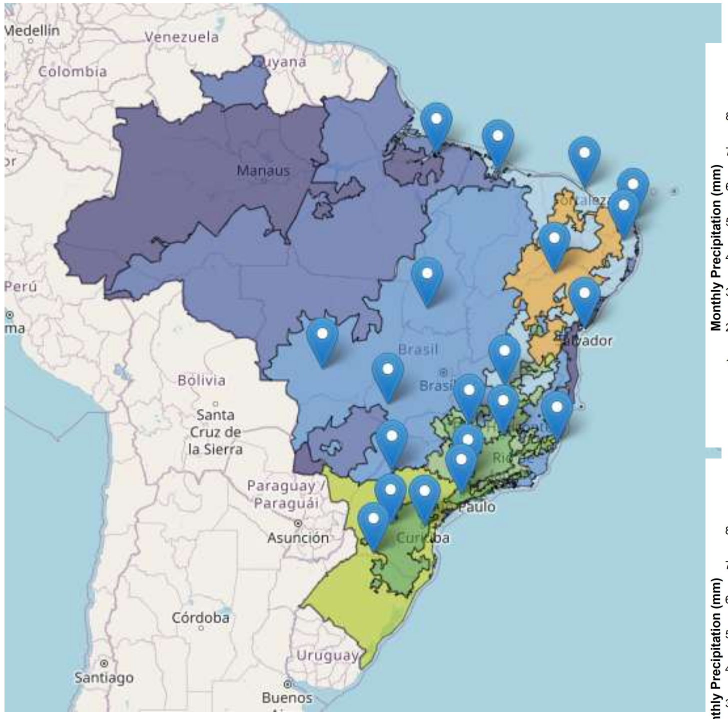
GROUP 1							
Station	**corr**	**t_value**	**df**	**p_value**	**CI_lower**	**CI_upper**	**CCK**
PPTE	0,72	12,62	144	4,55E-25	0,64	0,79	Aw
MGBH	0,74	13,60	154	3,48E-28	0,66	0,80	Cwb
MGRP	0,74	12,73	133	8,79E-25	0,65	0,81	Cwb
POLI	0,75	13,28	136	2,46E-26	0,67	0,82	Cfb
MGMC	0,76	14,24	151	1,06E-29	0,68	0,82	Aw
CUIB	0,76	14,54	153	1,24E-30	0,69	0,82	Aw
TOGU	0,78	14,50	133	3,65E-29	0,71	0,84	Aw
MGIN	0,80	15,74	143	5,21E-33	0,73	0,85	Cwb
GOJA	0,83	18,11	153	6,83E-40	0,77	0,87	Aw



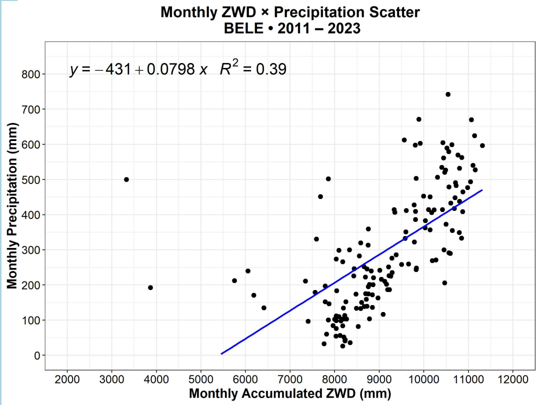
GROUP 2							
Station	**corr**	**t_value**	**df**	**p_value**	**CI_lower**	**CI_upper**	**CCK**
SCCH	0,27	2,38	71	1,99E-02	0,04	0,47	Cfa
CEFE	0,49	6,32	127	4,00E-09	0,35	0,61	Am
SSA1	0,54	7,62	142	3,37E-12	0,41	0,65	Af
PEPE	0,58	8,77	151	3,50E-15	0,47	0,68	BSh
UFPR	0,59	8,27	130	1,37E-13	0,46	0,69	Cfb
PBCG	0,61	9,01	138	1,48E-15	0,49	0,70	As
PRGU	0,62	8,53	117	6,08E-14	0,49	0,72	Cfb
CEFT	0,63	8,80	120	1,19E-14	0,50	0,72	As
BELE	0,63	9,89	150	4,45E-18	0,52	0,72	Af
RNNA	0,64	9,67	134	4,19E-17	0,53	0,73	As
SALU	0,66	10,92	153	6,89E-21	0,56	0,74	As

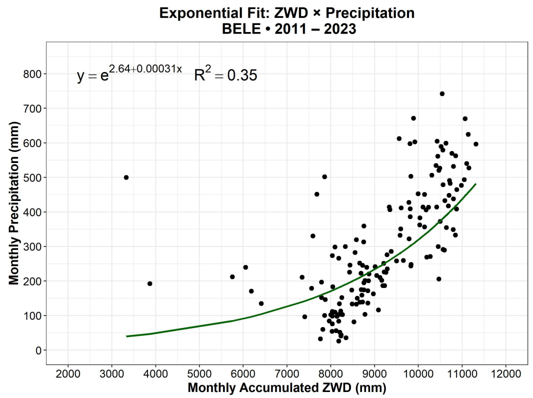


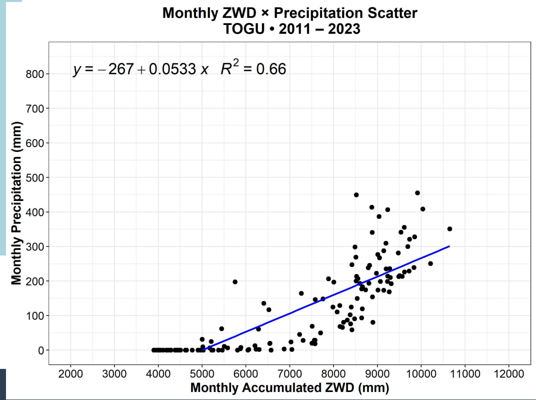
- Fit: linear x exponential

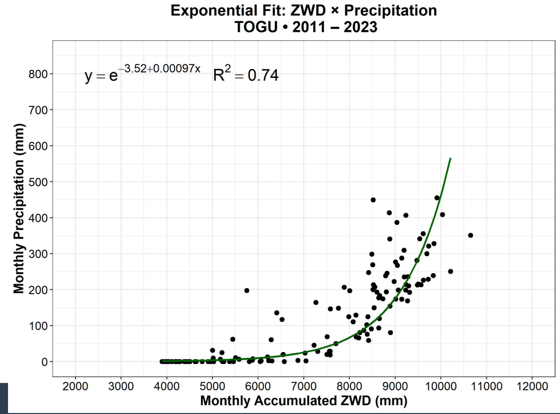


Examples:

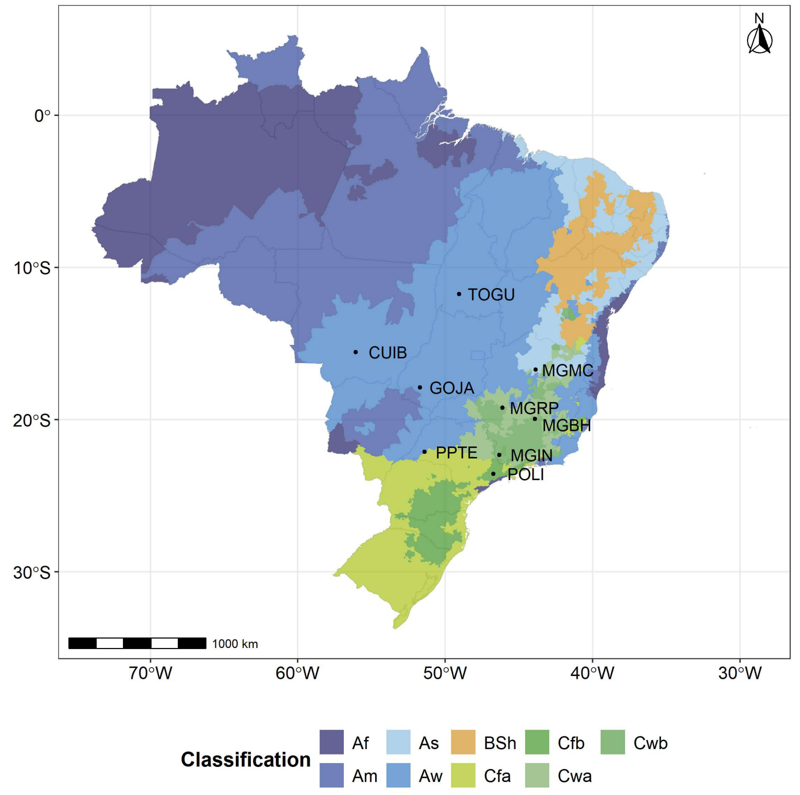




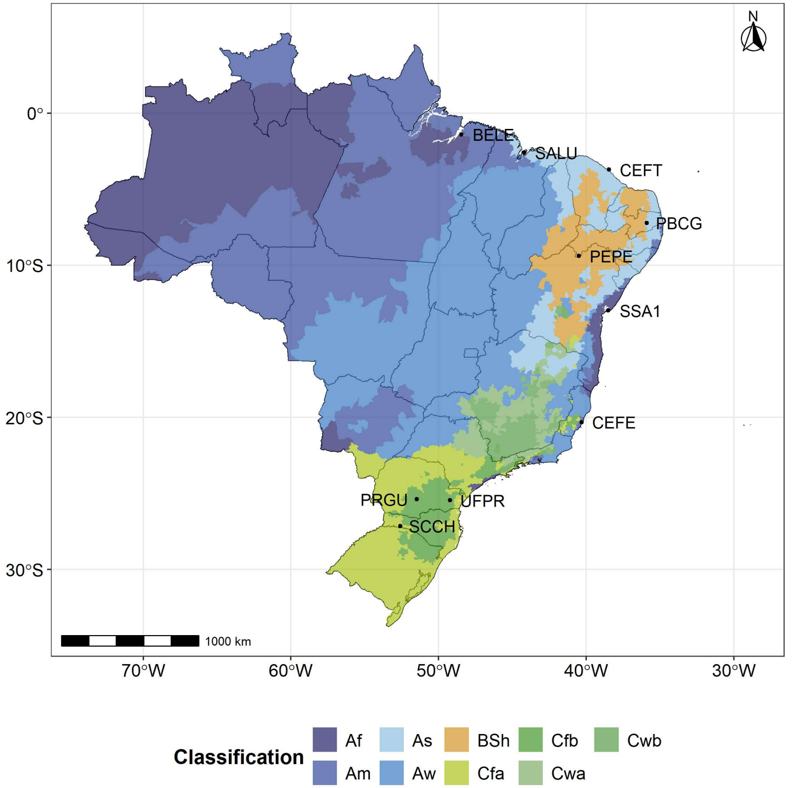




GROUP 1				
Station	CCK	df	R^2 Lin	R^2 Exp
PPTE	Aw	144	0,53	0,47
MGBH	Cwb	154	0,55	0,71
MGRP	Cwb	133	0,55	0,7
POLI	Cwb	136	0,56	0,5
MGMC	Aw	151	0,63	0,64
CUIB	Aw	153	0,58	0,76
TOGU	Aw	133	0,61	0,74
MGIN	Cwb	143	0,57	0,73
GOJA	Aw	153	0,68	0,75



GROUP 2				
Station	**CCK**	**df**	**R² Lin**	**R² Exp**
SCCH	Cfa	71	0,07	0,12
CEFE	Am	127	0,24	0,23
SSA1	Af	142	0,29	0,19
PEPE	BSh	151	0,34	0,44
UFPR	Cfb	130	0,34	0,34
PBCG	As	138	0,37	0,4
PRGU	Cfb	117	0,38	0,31
CEFT	As	120	0,39	0,45
BELE	Af	150	0,39	0,35
RNNA	As	134	0,41	0,41
SALU	As	153	0,44	0,4



- ZWD and precipitation show similar annual cycles, following local wet–dry seasonality.
- The ZWD–precipitation relationship is positive and significant across most stations.
- Exponential fits performed better in seasonal climates (Aw, Cwa, Cwb).
- Some stations have less precipitation data, which should be interpreted with caution.
- GNSS-derived ZWD is a valuable proxy for atmospheric moisture monitoring and climate studies.

Thank you!