Forecasting annual maximum water level for Negro River at Manaus

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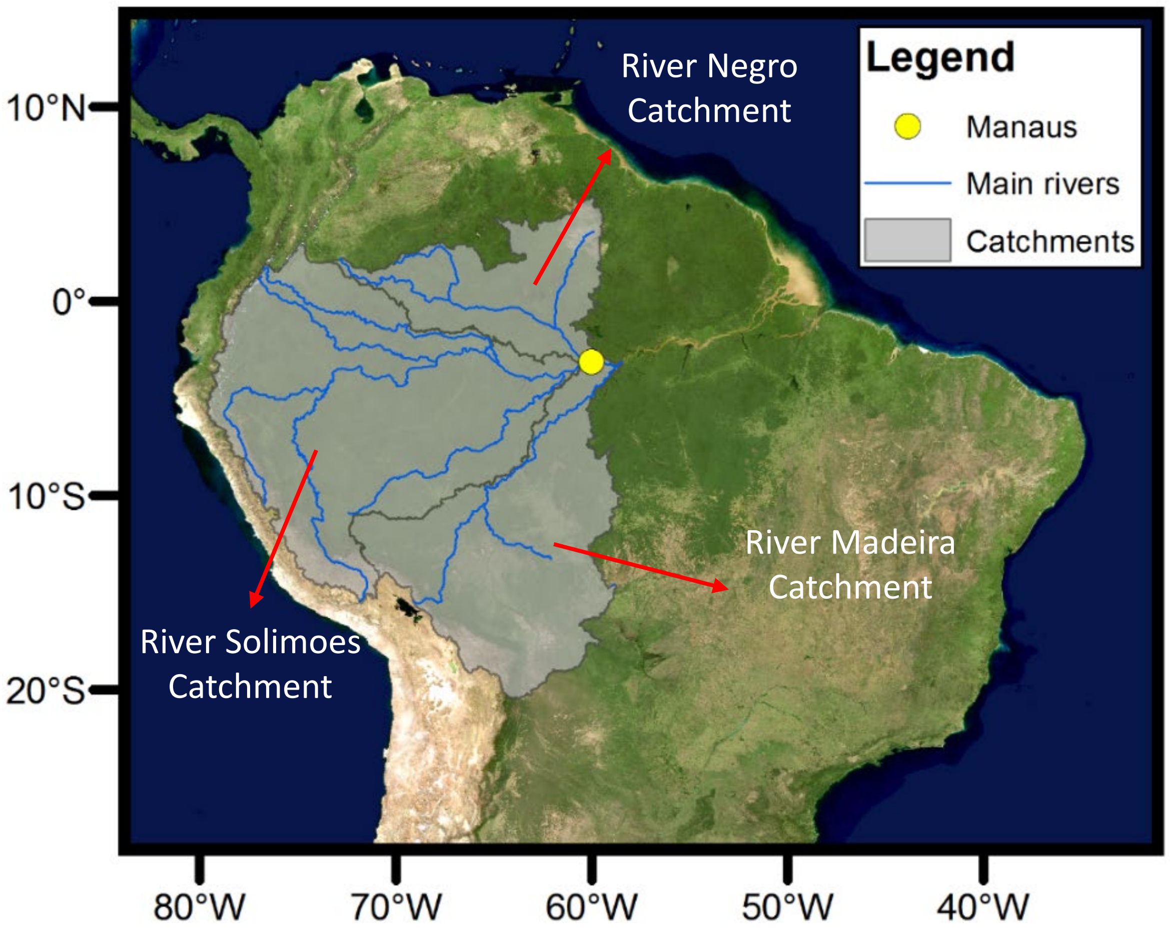
Predicting the Evolution of the Amazon Catchment to Forecast the Level Of Water (PEACFLOW)

O1 Determine the observed connection between **antecedent rainfall in the Amazon catchment** and **the annual maximum water level** in Manaus.

O2 **Determine the performance of seasonal forecast models**, for predicting rainfall in the Amazon catchment.

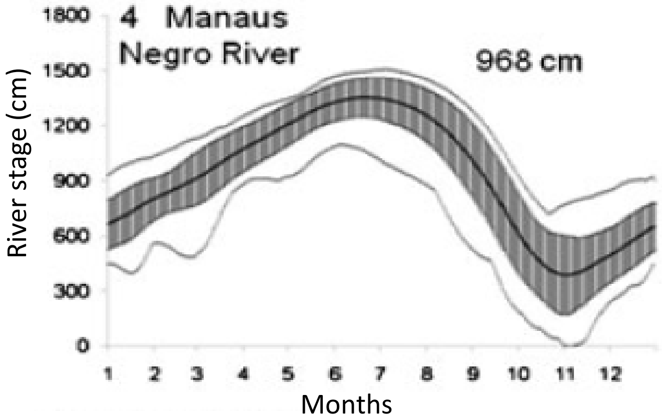
O3 **Develop a statistical model** that links antecedent rainfall in the Amazon catchment to the annual maximum water level in Manaus.

O4 **Validate the statistical model** against the existing *CPRM and INPA models* for the annual maximum water level at Manaus.



Motivation

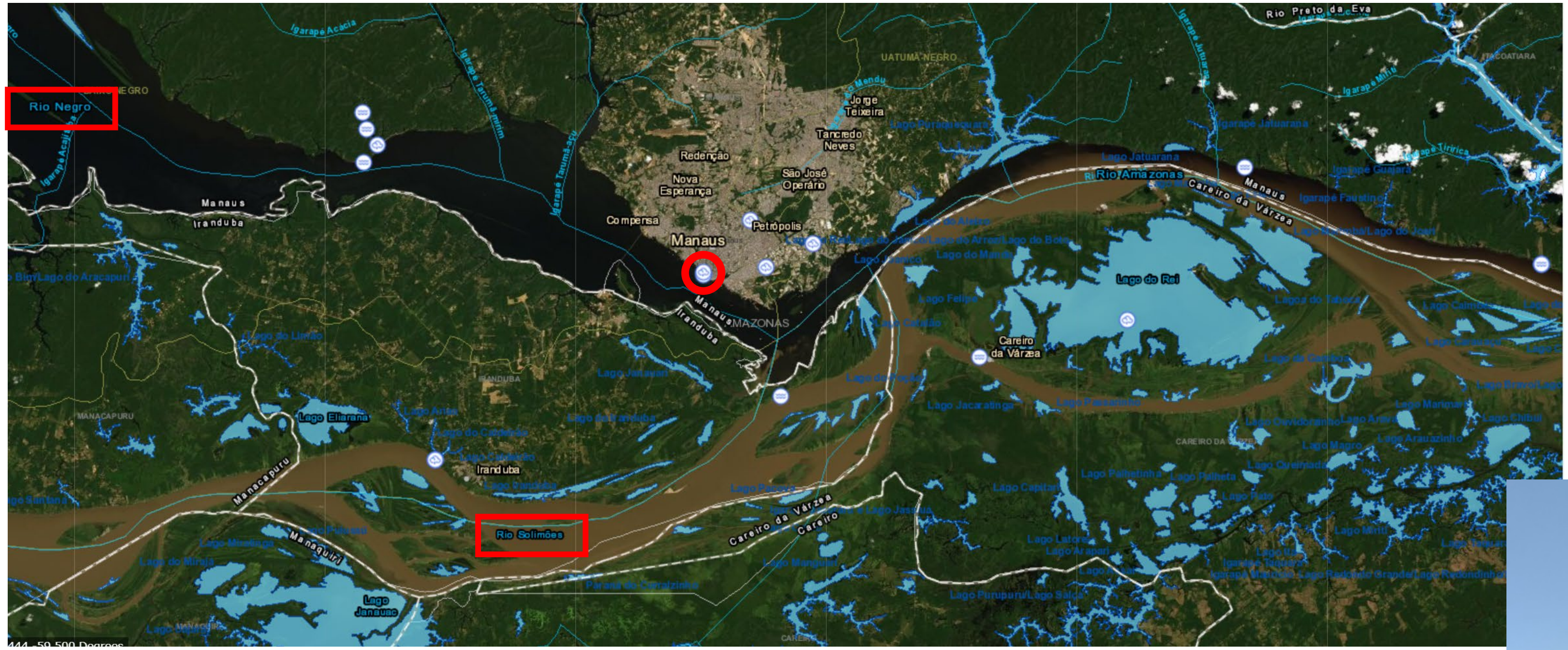
- Amazonian rivers present regular and **predictable hydrological cycles**
- High-water period followed by a low-water period during the annual cycle with **large inter-annual variability**
- **Recent floods**: 2009, 2012, 2013, 2014, 2015 and 2019
- Floods have affected hundreds of thousands of people living in the floodplains



Hydrograph for 1983 to 2005 (Junk et al. 2011)

Station	**Manaus**
River	Rio Negro
Location	3.14° S; 60.03°W
Data type	Daily river level
Data length	Sep-1902 – Present

Manaus and meeting of the rivers



- Meeting of **Rivers Negro and Solimoes** at Manaus
- Measurement station at Manaus, is for River Negro
- River levels influenced by **backwater effect**

Annual levels

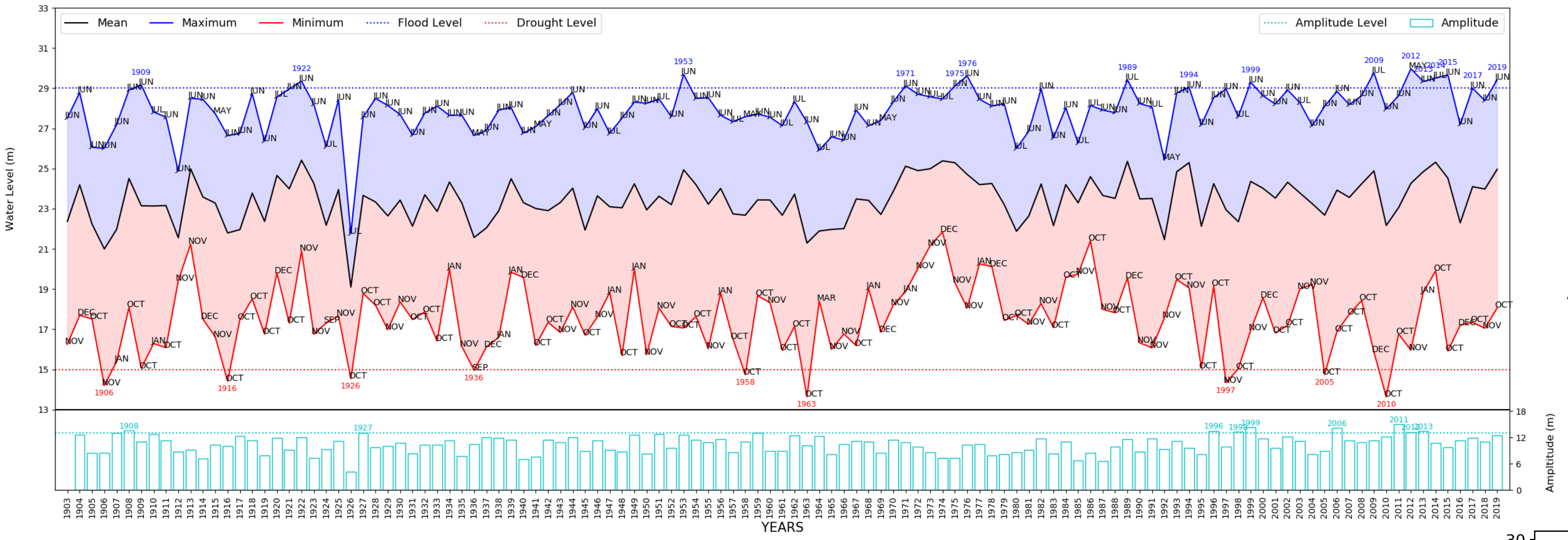
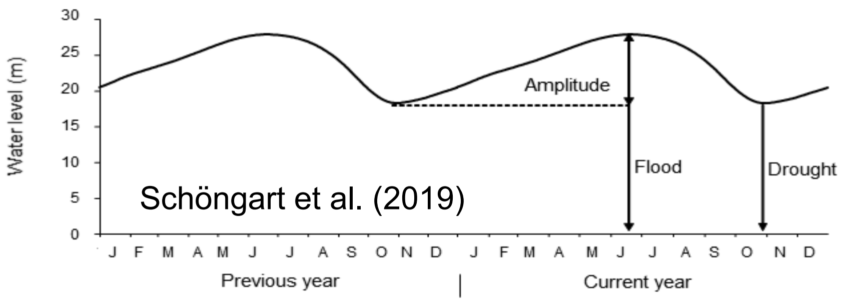
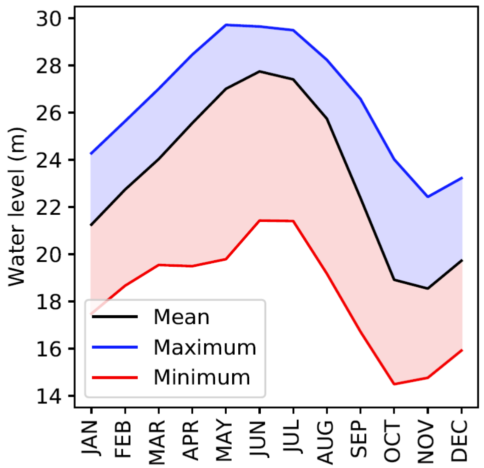


Fig: Annual mean, maximum, minimum depth and amplitude at Manaus.

Amplitude = Max(yr) – Min(yr-1)

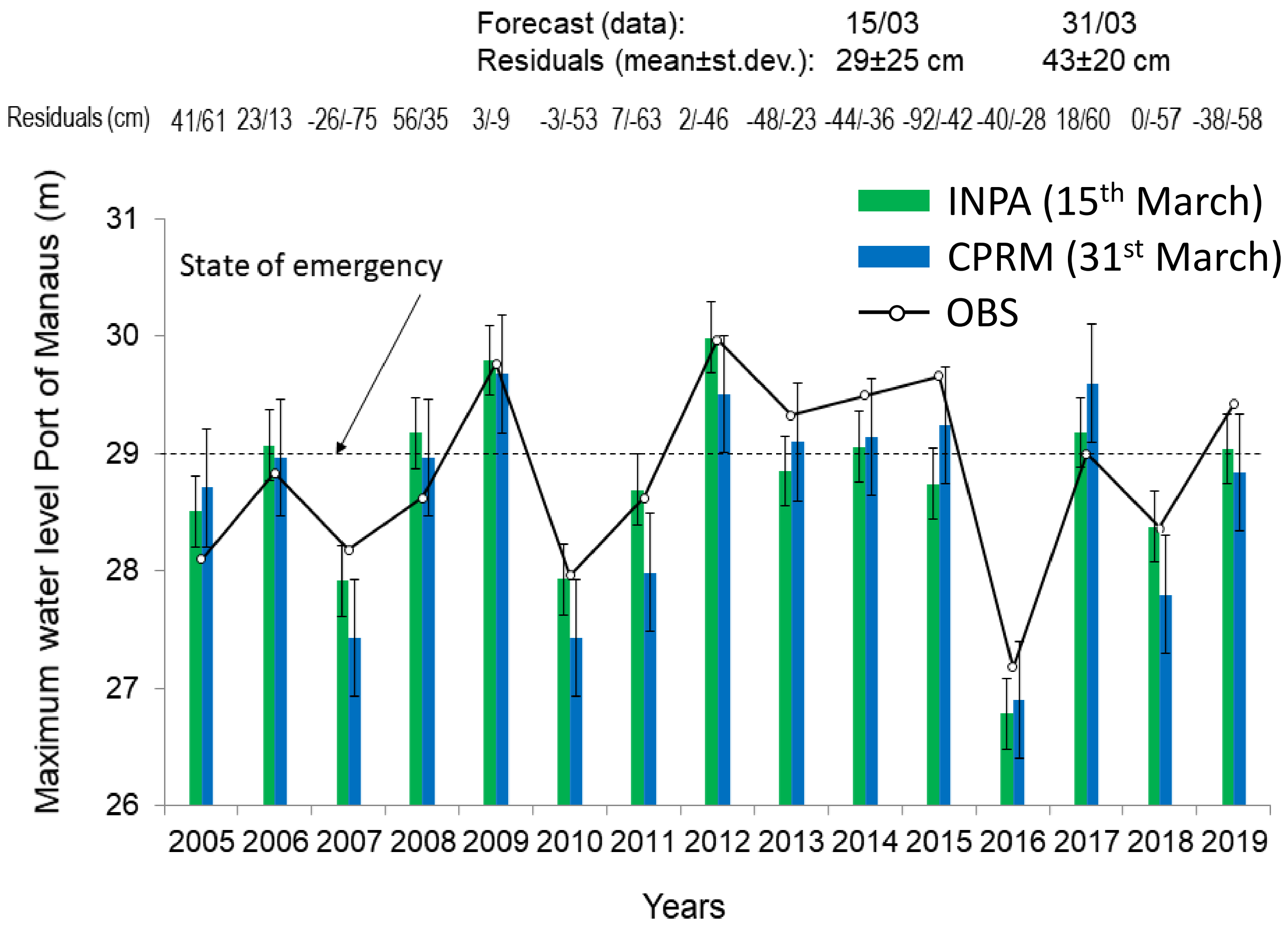
- Threshold for extremes:
  - Flooding: ≥29m
  - Drought: ≤ 15m
  - Amplitude: ≥13m





Existing Models

- Operational forecasts by the Brazilian Geological Survey (**CPRM**):
  - March: March water levels
  - April: April water levels
  - May: May water levels
- Improved forecasts by National Institute of Amazonian Research (**INPA**):
  - Schöngart & Junk (2007): Level_Feb, SOI_Feb
  - Schöngart & Junk (2020): Niño3.4_DJF, SOI_NDJ, PDO_Feb, Pmin, Level_7Mar

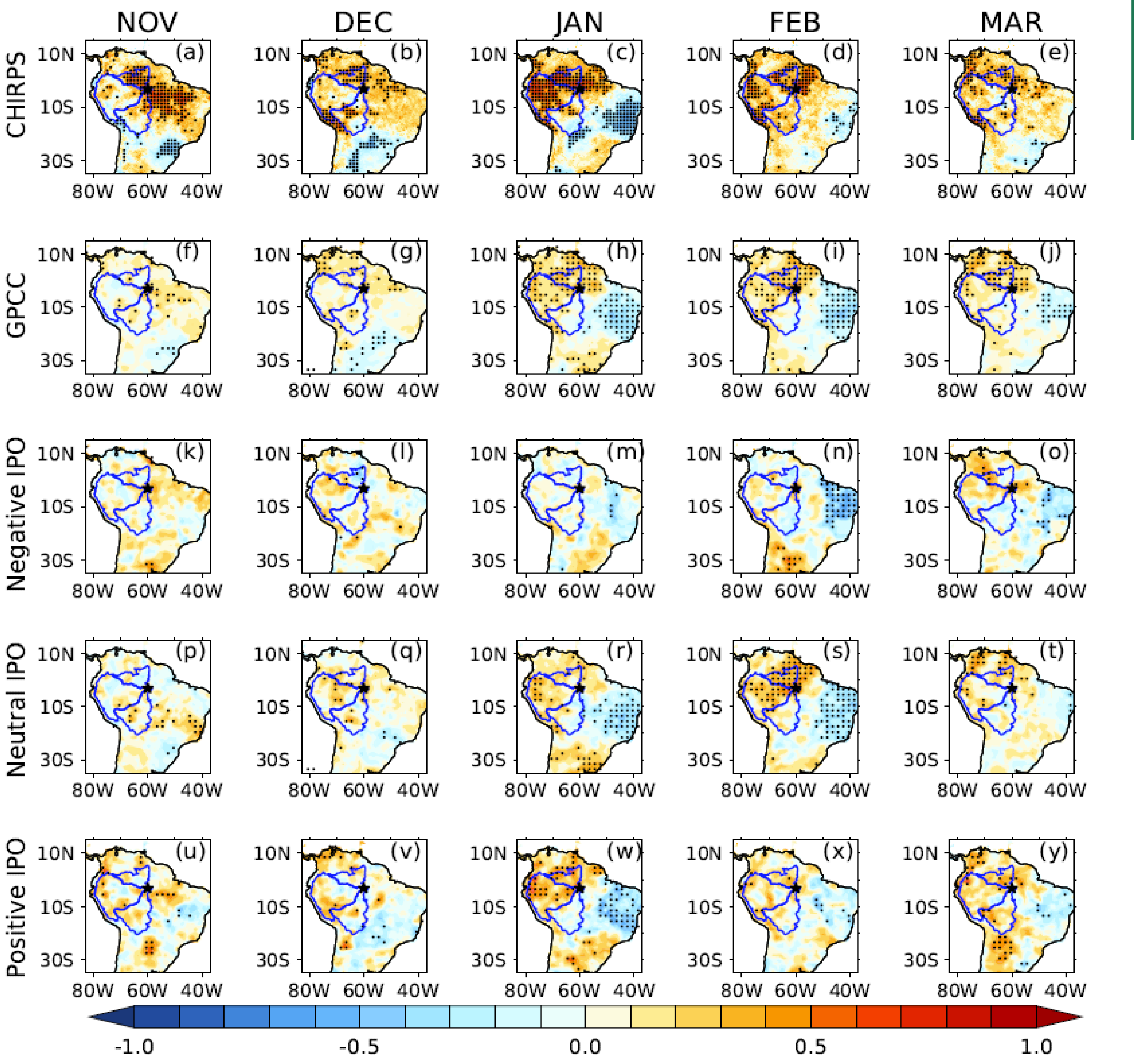


Comparison of the forecast of annual maximum water levels for the period 2005-2019 between models (Schöngart & Junk 2020)

Potential Predictors

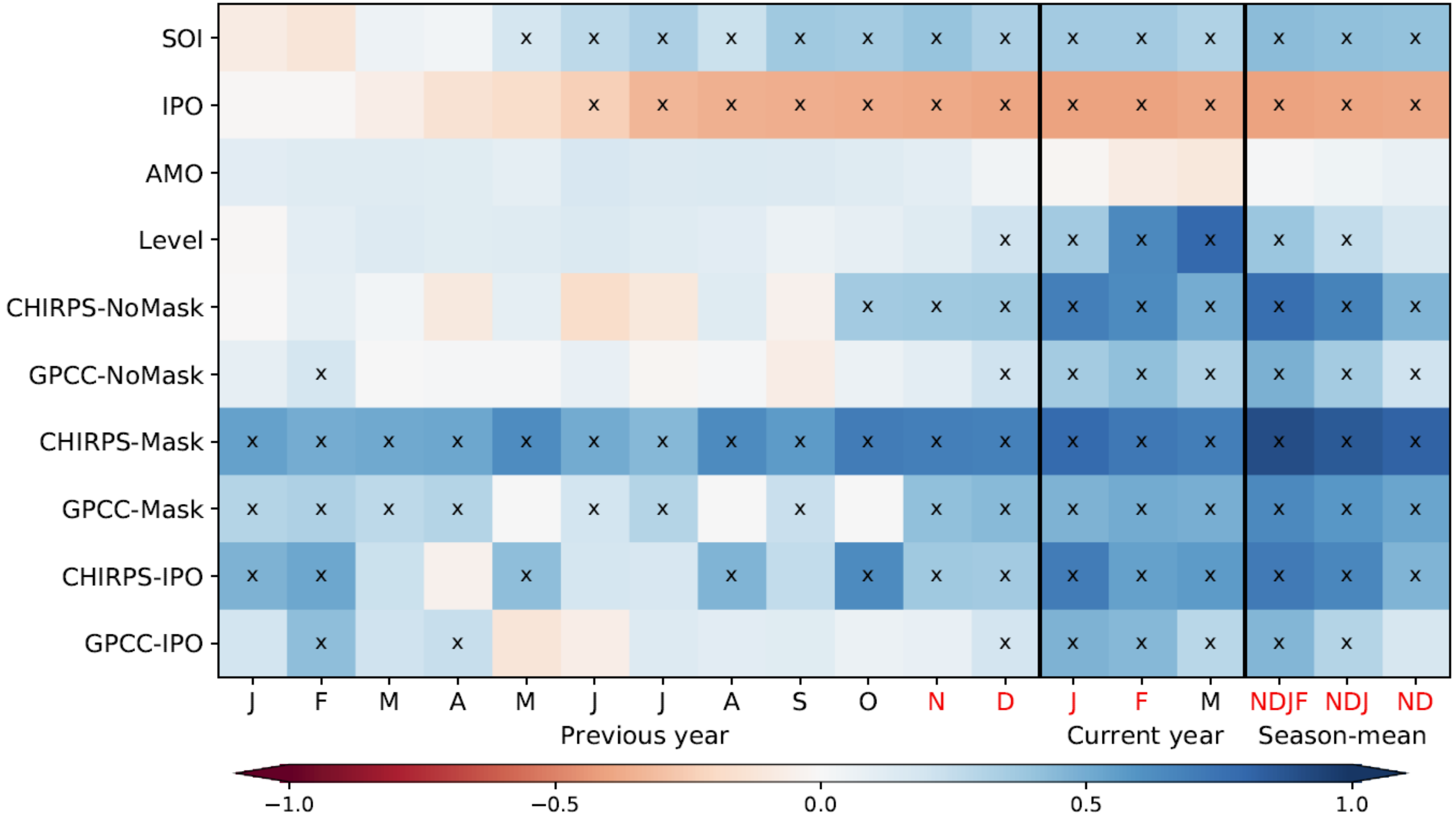
Rainfall data

Data	CHIRPS	GPCC
Version	2.0	2018
Spatial Resolution	0.05°	1.0°
Temporal Extent	1981 – Present	1891 – Present
Reference	Funk et al. (2015)	Schneider et al. (2013)



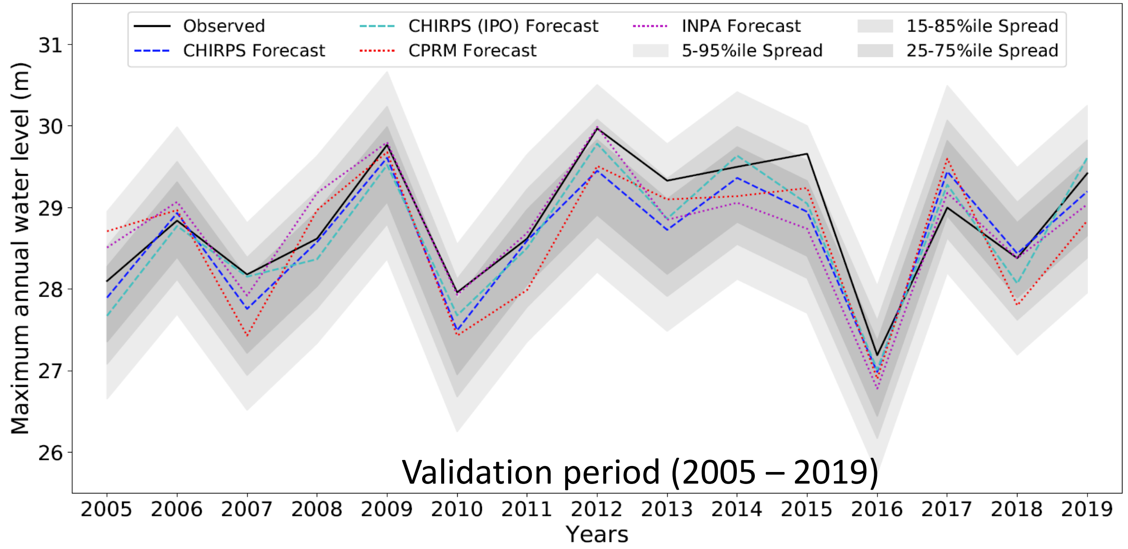
Potential Predictors

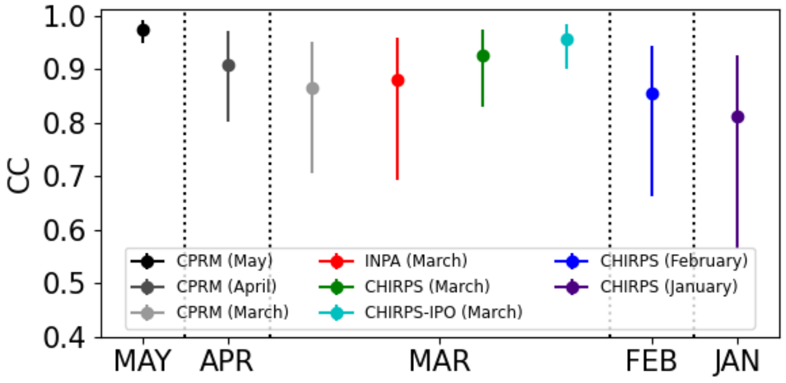
- Antecedent **masked rainfall**
- Preceding **water levels**
- Large-scale modes of **climate variabilities**:
  - Atlantic SSTs
  - Pacific SSTs
- **Previous minimum** (r = 0.13)
- **Linear trend** (Time; r = 0.33*)

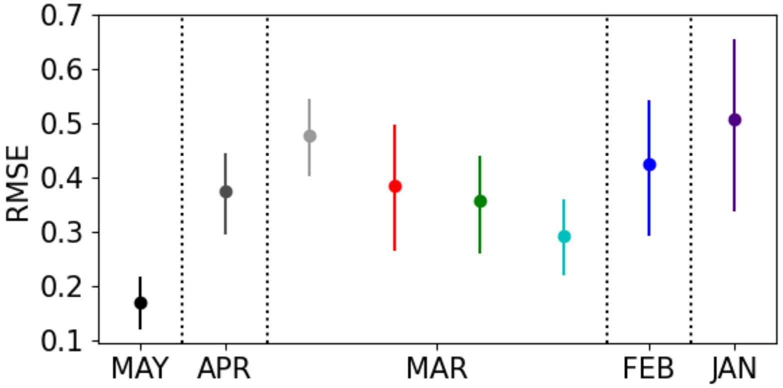


Forecast Models and Validation

- **Multiple linear regression** used to find the best fit during the **training period (1904—2004)**
- **Screening regression approaches**:
  - Forward selection
  - Backward elimination
- Forecast uncertainty is based on the **empirical distribution of residuals** in the training period
- **Operational forecast date**:
  - CHIRPS models: 15th March
  - INPA: 15th March
  - CPRM: 31st March







2020	CPRM (MAY)	CPRM (APR)	CPRM (MAR)	INPA (MAR)	CHIRPS (MAR)	CHIRPS (IPO)	CHIRPS (FEB)	CHIRPS (JAN)
Forecast	28.60	28.25	28.30	28.48	28.44	28.52	28.84	29.37
Bias	+0.08	-0.27	-0.22	-0.04	-0.08	0.00	+0.32	+0.85

Sensitivity tests

Model based on unconditional masks

Spatial extent: Different basins | Box region

Masks: No mask | CHIRPS | GPCC

Predictors: Monthly | Seasonal

Model based on conditional masks

Indices: SOI | AMO | IPO

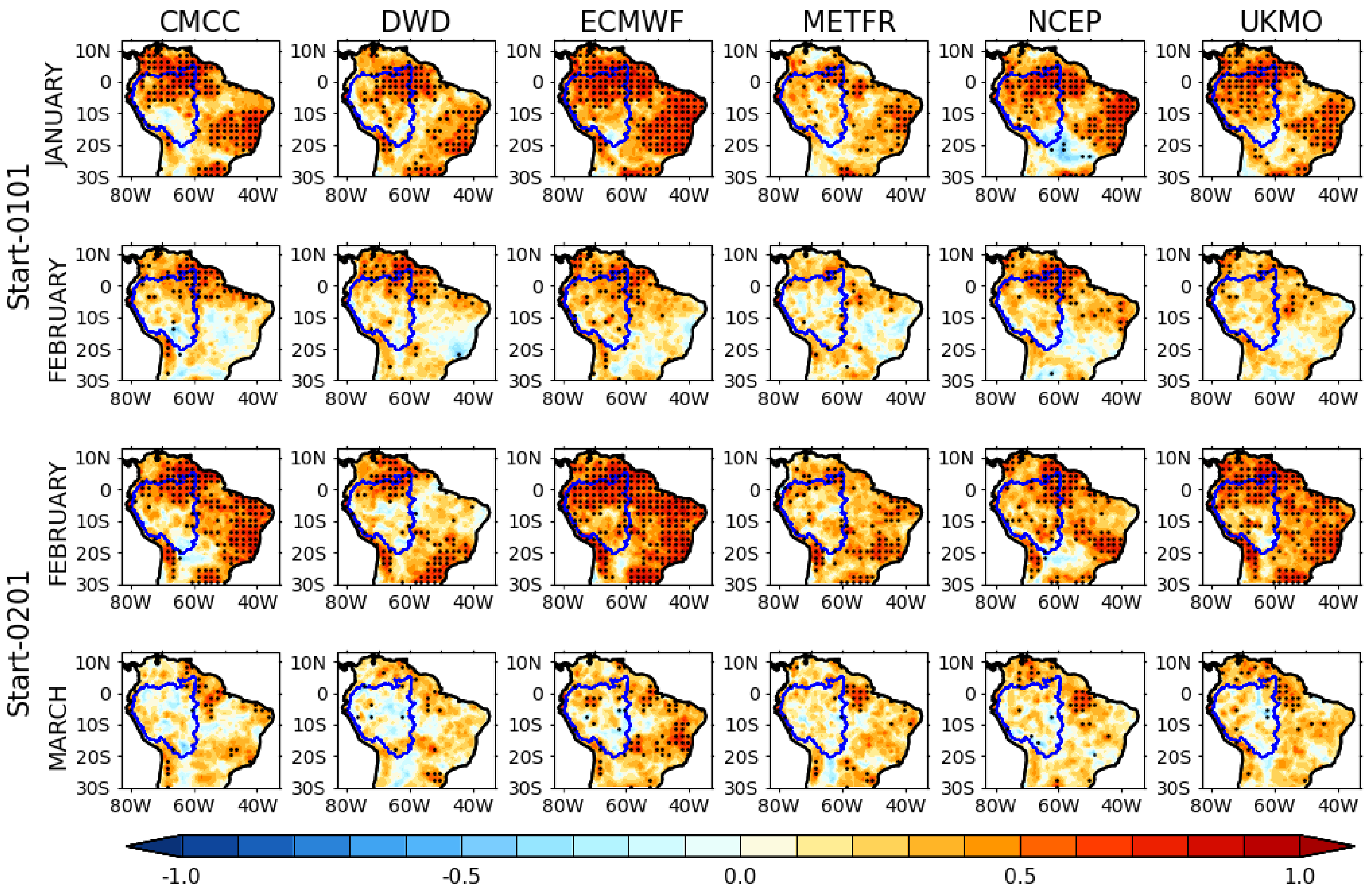
Significance level: 0.1 | 0.05

Categories of phases: Tercile | Quartiles

Masks: Monthly | Seasonal masks

Seasonal Hindcasts

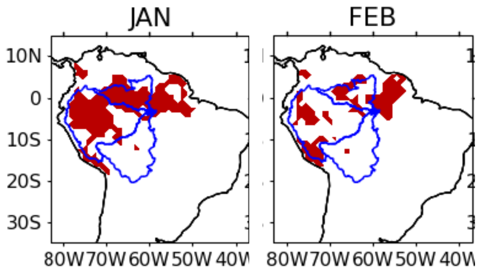
System	Model	Ensemble	Time Extent
CMCC	SPSv3	40	1993-2016
DWD	GCFS2.0	30	1993-2016
ECMWF	SEAS5	25	1981-2016
METFR	Météo-France System 7	25	1993-2016
NCEP	CFSv2	28 (Jan); 24 (Feb)	1993-2016
UKMO	GloSea5	28	1994-2016

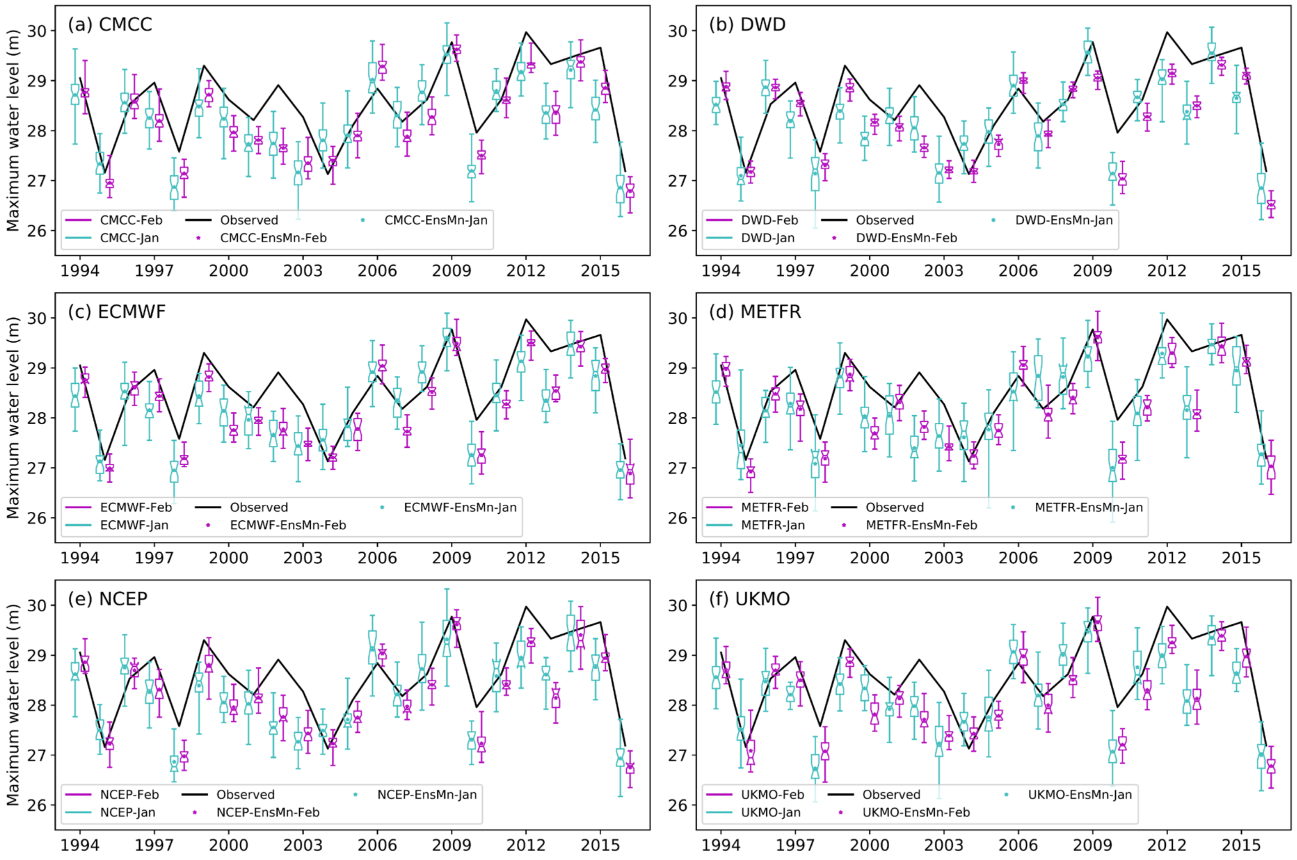


Forecast Models

- Rainfall masks for the seasonal hindcasts are **adapted from the original CHIRPS rainfall masks**
- Forecasts using hindcast with **lead time** of:
  - February = observed NDJ + F seasonal hindcast
  - January = observed ND + JF seasonal hindcast
- **Compared against**:
  - Original rainfall models
  - Forecasts using climatology
  - Forecasts using persistence

Rainfall Masks

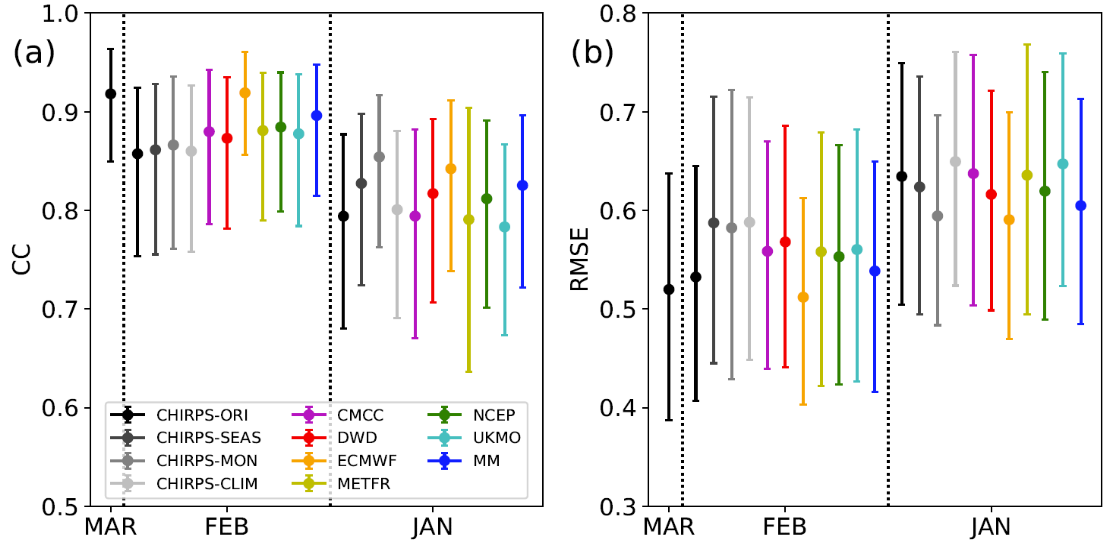




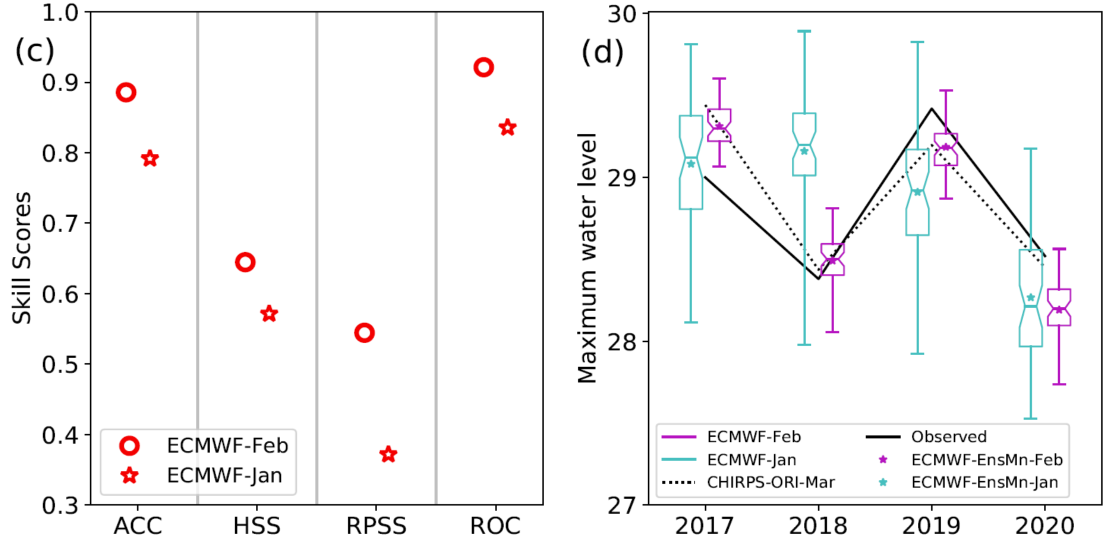
Model Validation

- **ECMWF (February lead time) forecasts outperform** all the other models as well as forecasts with climatology and persistence
- **ECMWF (Feb) forecasts** for February have **same skill as original March forecasts** using observed data
- ECMWF (Jan) forecasts are n**ot significantly better than the observed monthly persistence** (Jan) forecasts
- **Lower and upper terciles show higher skill** than the middle tercile category
- ECMWF seasonal forecast can be used for **real-time operational forecasting** and has been tested for the hindcast years 2017—2020

Validation Period (1994—2016)



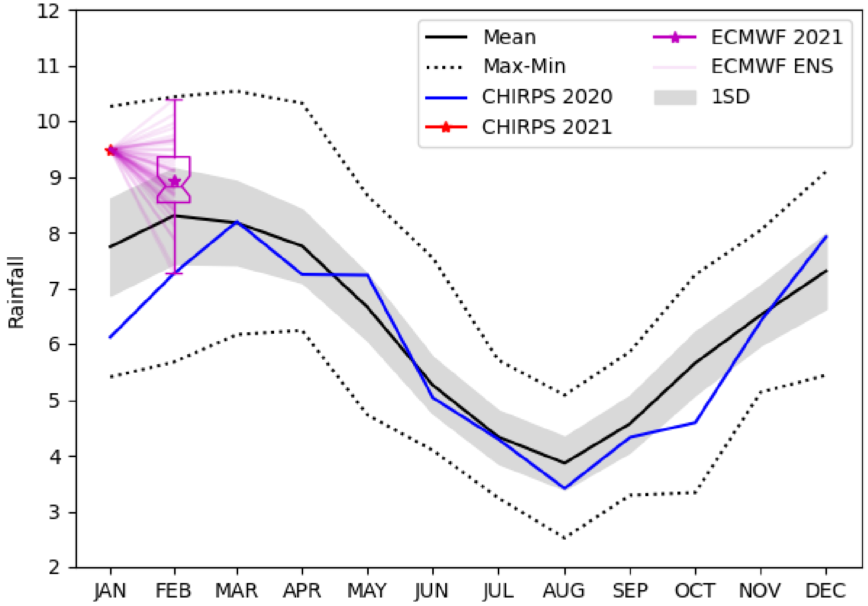
Validation Period (1981—2020)

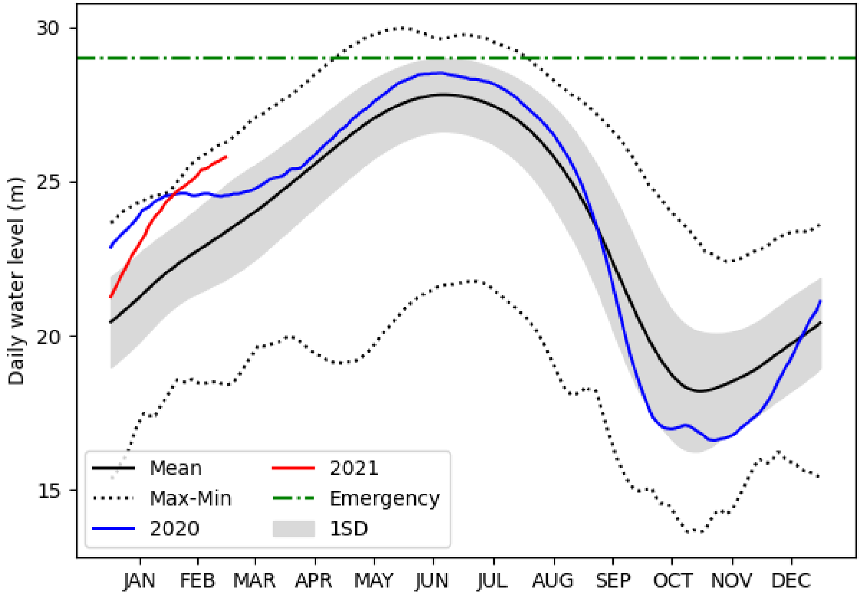


Operational Forecasting

- These statistical models **can be implemented for operational forecasting** for Manaus and have been **tested for 2020 hindcast and 2021 forecast**
- Forecasts for **2021 >29m**, with all models, forecasting an **extreme flood event in Manaus**
- GitHub **open-source models** https://github.com/achevuturi/PEACFLOW_Manaus-flood-forecasting

Model		2020 Forecast (Bias)	2021 Forecast
Input	Lead-time		
Observations	March	28.44 (-0.08)	29.38
	February	28.84 (+0.32)	29.45
	January	29.37 (+0.85)	29.06
Observations + ECMWF Forecasts	February	28.19 (-0.33)	29.20
	January	28.27 (-0.27)	29.26
Observed annual maximum water level at Manaus for 2020 was 28.52m			





Conclusions and future work

- Rainfall-based models provide an **additional one-month lead time** compared to existing models
- Using ECMWF seasonal reforecasts **increases lead-time by another one month**
- Models implemented for operational use and forecast an extreme flood for 2021
- GitHub **open-source models** https://github.com/achevuturi/PEACFLOW_Manaus-flood-forecasting
- Same method can be used to develop models for:
  - **minimum water level**
  - **other regions of Amazon**