Extreme Rainfall in Paraguay during the 2015-16 Austral Summer

Causes and S2S Predictive Skill

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September 9, 2017

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Setup

This is a case study presented to an audience with very diverse backgrounds.

- Please stop me if I use jargon you don't understand!
- My goal is that through this case study, you can learn something about:
    1. this particular event
    2. extreme river floods in general
    3. quantitative tools for dealing with uncertain climate forecasts

I'll be delighted to follow up more detailed questions – look for contact info on last slide!

NDJF 2015-16

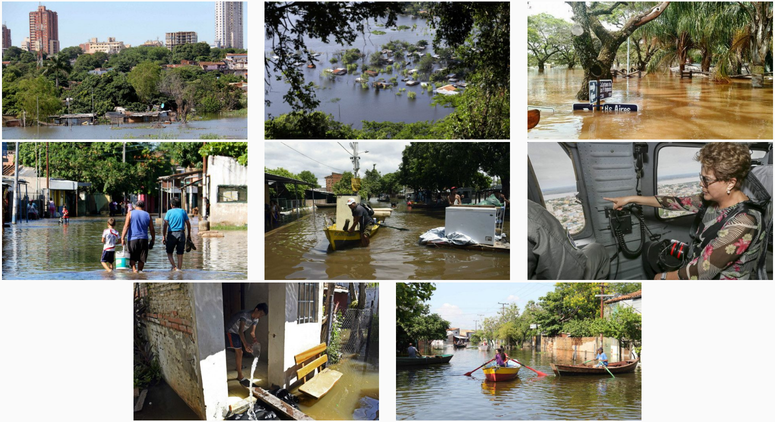


Figure 1: ≈ 170 000 displaced in Paraguay, also Uruguay, Argentina, Brasil [1]. Images: BBC & Affiliates

Study Area

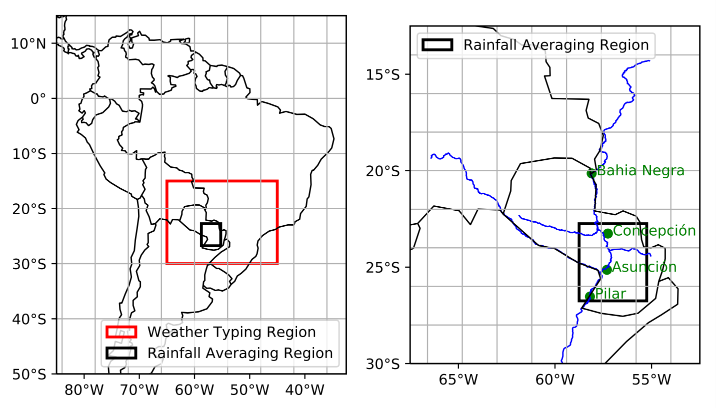


Figure 2: The study area. (L): all of South America. (R): The Paraguay River and its tributaries, from the Natural Earth database `www.naturalearthdata.com`

Streamflow

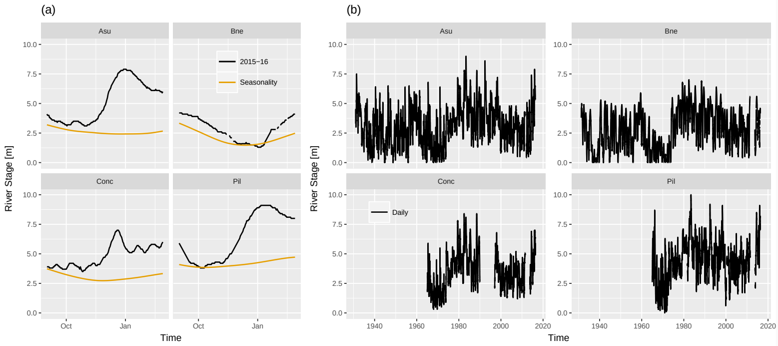


Figure 3: River stage (height; in m) for the Paraguay River at four gauges along the Paraguay River. (a) Seasonality (black) and time series of 2015-16 observations (orange) at each stream gauge. The seasonality was fit using local polynomial regression as implemented in the `locfit` package in the **R** statistical programming environment [4]. (b) Time series of daily stage measurements from 1929 to 2016.

Data Sources

- Reanalysis data: NCEP-NCAR I [3]
- Rainfall: CPC Unified [9]
- Streamflow: Paraguay Navy
- Sub-seasonal forecasts: ECMWF [8]

Observed Anomalies

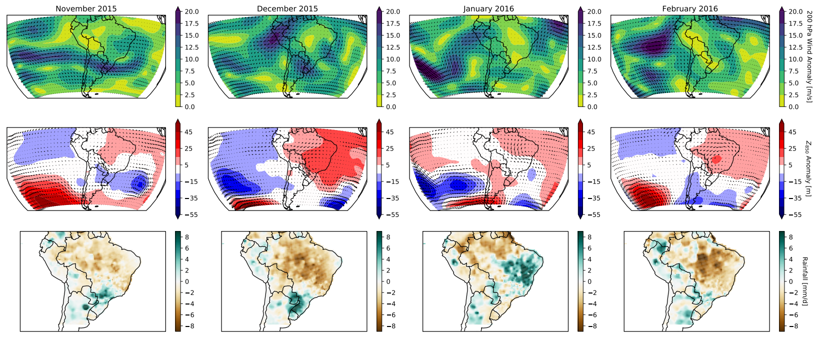


Figure 4: Monthly circulation anomalies during NDJF 2015-16. Top: 200 hPa wind (m/s) anomaly. Middle: 850 hPa GPH (m) and wind (m/s) anomaly. Bottom: rainfall anomalies in $\mathrm{mm\,d^{-1}}$. For reference: $8\,\mathrm{mm\,d^{-1}} \times 30\,\mathrm{d} \approx 9.4\,\mathrm{in}$.

Weather Typing

Clustering daily weather patterns sacrifices inter-cluster variation *but* allows examination of sequences. See Muñoz et al. [7] for discussion. Basic procedure:

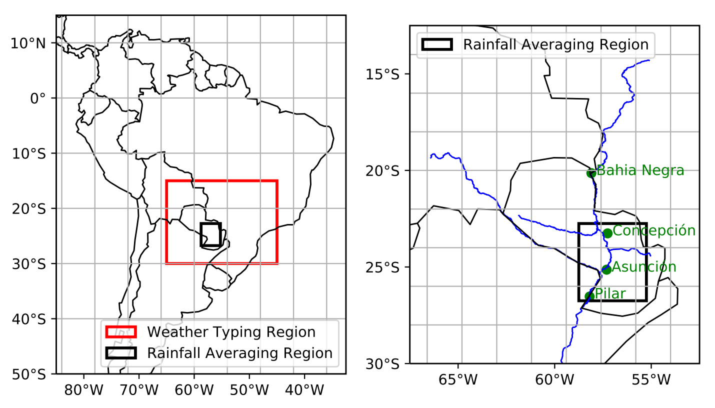
Dimension Reduction Project Z_{850} (over red box) onto leading principal components

Cluster Cluster using k-means with random starting points; repeat many times.

Optimize For each set of clusters, compute classifiability index [6]; basically a stability criterion. Select best assignment.

Assign Assign each day of record to a weather type.

Study Area Again



Weather Types

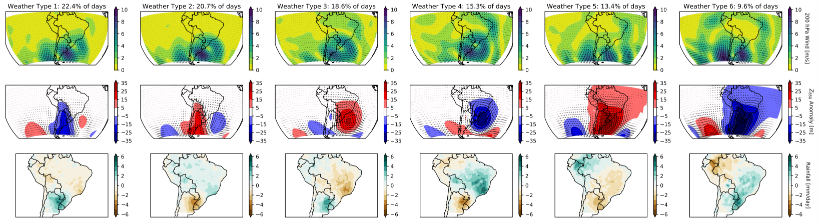


Figure 5: Circulation anomalies associated with each weather type. Top: 200 hPa wind (m/s) anomaly. Middle: 850 hPa GPH (m) and wind (m/s) anomaly. Bottom: rainfall anomalies in mm d^{-1}.

Weather Types: NDJF 2015-16

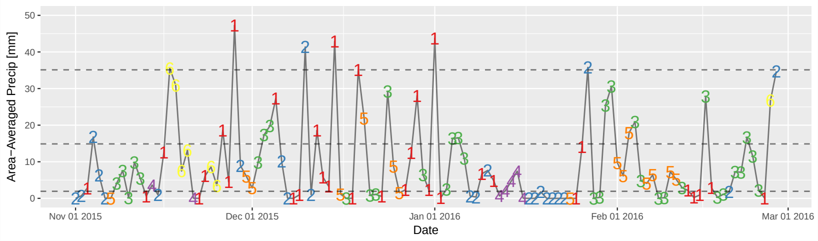
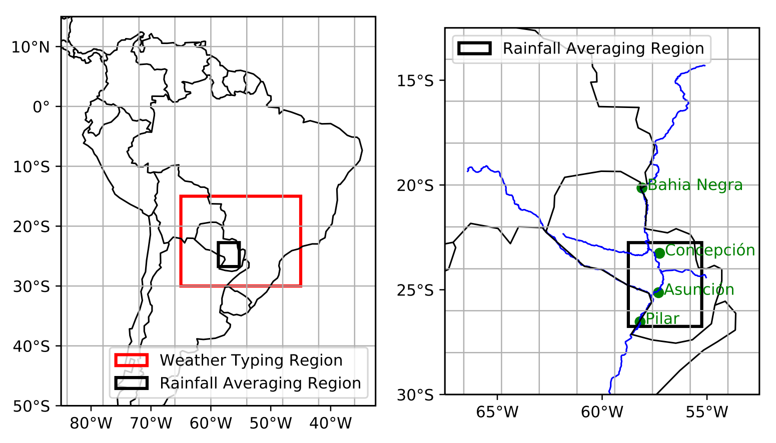


Figure 6: Time series of area-averaged rainfall and weather type for each day of NDJF 2015-16. Dashed lines indicate the climatological 50th, 90th, and 99th percentiles of NDJF area-averaged rain.

Study Area Again

We're going to be concerned with daily rainfall averaged over black box:



What did the S2S Model Forecast?

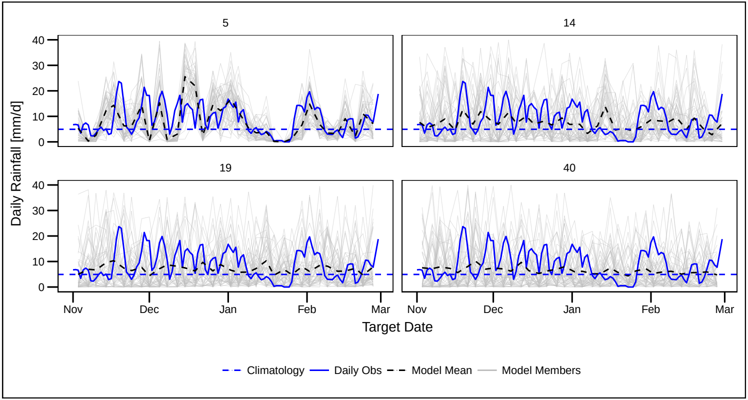


Figure 7: Forecast time series from the ECMWF S2S model are shown for several lead times of each individual ensemble member (gray), the ensemble mean (black, dashed), and smoothed observed (blue) rainfall.

Can We Improve? MOS or Statistical-Dynamical Modeling

Idea: models capture large-scale circulation patterns better than local/regional rainfall [i.e. 2].

Model	(Y0,Y1,X0,X1)	Final predictor(s) selected
Raw	(-39,-17,-66,-49)	Ensemble mean, computed using members from the two initializations. No correction performed.
XLR	(-39-17,-66,-49)	Ensemble mean, computed using members from the two initializations
PCR	(-60,0,-80,-30)	Linear combination of model's EOFs, computed using both initializations as independent predictors (10 EOFs).
CCA	(-60,0,-80,-30)	Canonical modes computed using both initializations as independent predictors. (10 predictor EOFs, 4 predictand EOFs, 4 canonical modes)

Preliminary Model Results

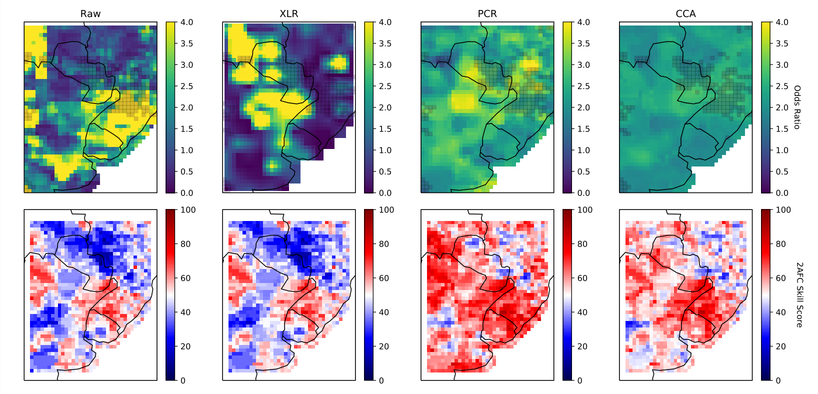


Figure 8: Preliminary results computed using IRI CPT [5]. Each column is a different model. Top: probability of 90th percentile exceedance, divided by climatology (10%). Observed 90th percentile exceedances are shaded. Bottom: 2AFC skill score.

Flood Drivers

- Repeated sequences of intense rainfall over relatively flat region
- Low-frequency variability?
- Low-level (850 hPa) injection of moisture and energy precede intense rainfall (Weather Type 1)
- Related to ENSO and MJO (not shown but I can!)
- Jet (850 hPa wind) exit region aligns with rainfall anomaly
- Remaining question: why didn't the jet penetrate further South (as typical for El Niño conditions)?

Statistical-Dynamical Models

- Goal: maximizing signal from numerical models for decision-making
- Raw model excels at weather timescales; skill decreases with lead time
- Models with *spatial* component promising but application is nontrivial
- Novel: using model rainfall (not GPH or wind) is a promising predictor
- Work presented is ongoing!

References

[1] G R Brakenridge. *Global Active Archive of Large Flood Events*. Tech. rep. 2016.

[2] Harry R Glahn et al. "The Use of Model Output Statistics (MOS) in Objective Weather Forecasting". *Journal of Applied Meteorology* 11.8 (1972).

[3] Eugenia Kalnay et al. "The NCEP/NCAR 40-Year Reanalysis Project". *Bulletin of the American Meteorological Society* 77.3 (1996).

[4] Clive Loader. *Local Regression and Likelihood /*. New York : Springer, 1999.

[5] Simon J Mason and Michael K Tippett. "Climate Predictability Tool version 15.5.10". (2017).

[6] Paul-Antoine Michelangeli et al. "Weather Regimes: Recurrence and Quasi Stationarity". *Journal of the Atmospheric Sciences* 52.8 (1995).

[7] Ángel G Muñoz et al. "CrossTime Scale Interactions and Rainfall Extreme Events in Southeastern South America for the Austral Summer. Part I: Potential Predictors". *Journal of Climate* 28.19 (2015).

[8] F Vitart et al. "The Sub-Seasonal to Seasonal Prediction (S2S) Project Database". *Bulletin of the American Meteorological Society* 98.1 (2016).

[9] Pingping Xie et al. "CPC Unified Gauge-Based Analysis of Global Daily Precipitation". *Preprints, 24th Conf. on Hydrology, Atlanta, GA, Amer. Meteor. Soc.* 2010.

Thanks!

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Climatology

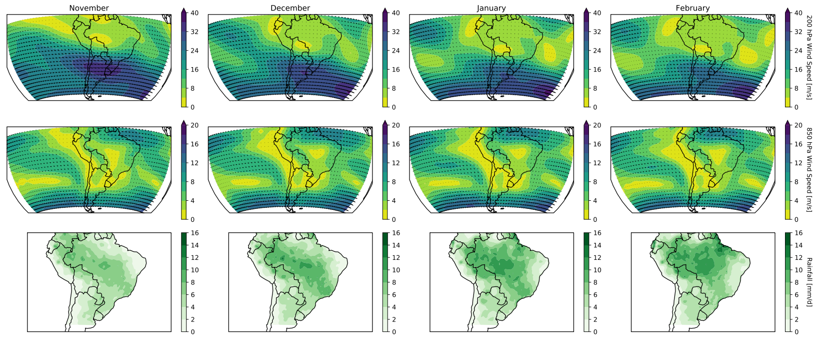

Figure 9: Climatology

Lagged Rainfall Plot

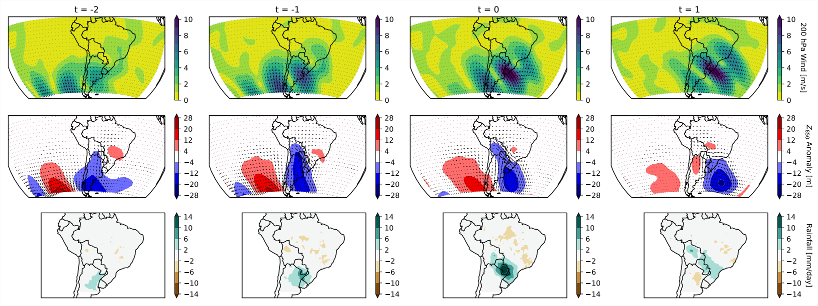

Figure 10: Lagged composite for 99th percentile exceedances of rainfall

ENSO

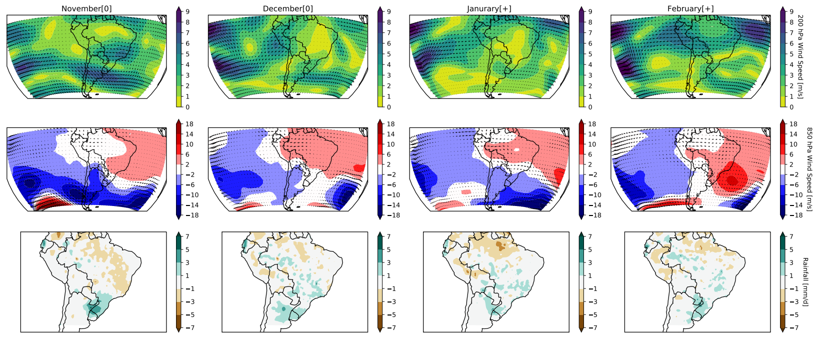

Figure 11: Mean anomalies during strong El Niño years.

MJO

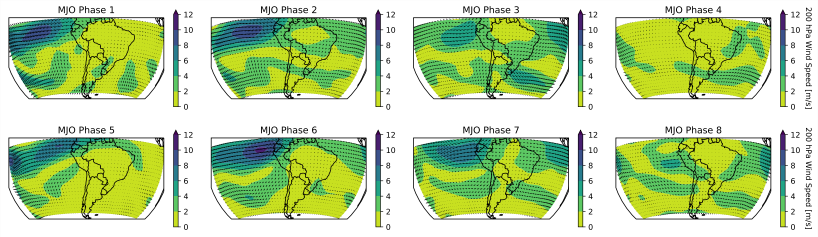

Figure 12: Mean anomalies during strong (amplitude > 1) MJO events

MJO NDJF 2015-16

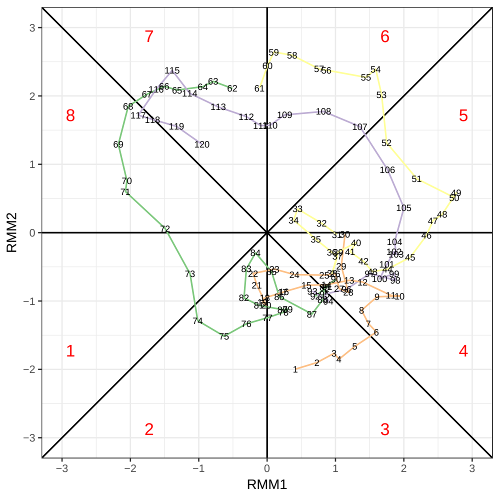

Figure 13: Time series of MJO during NDJF 2015-16. Numbers indicate days beginning on 01 November 2015.

Full Fields NDJF 2015-16

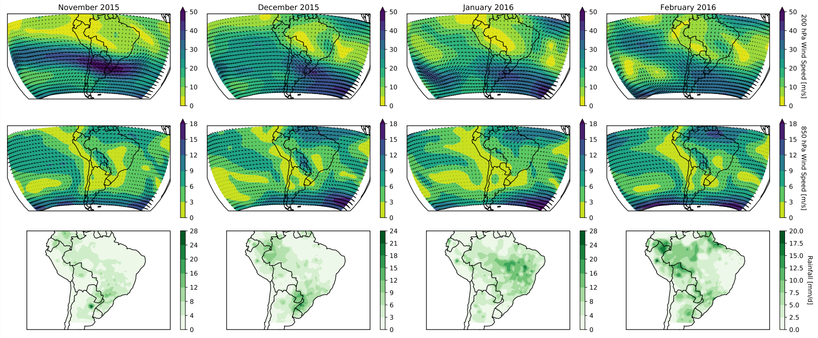

Figure 14: Full (not anomaly) fields observed during NDJF 2015-16.