Hybrid (empirical-dynamical) EUROBRISA forecasting system

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PLAN OF TALK
1. Introduction: seasonal precipitation prediction practice in South America
2. EUROBRISA forecasting system and its evolution
3. System performance since 2007
4. Contribution to seasonal forecasting practice in S. America
5. Summary

MedCOF Training Workshop on Verification of Operational Seasonal Forecasts in the Mediterranean region
Rome, Italy, 15-18 November 2016
Seasonal prediction: Expected (mean) climate conditions for next 3-6 months

South American seasonal precipitation predictions have been produced since around the mid-nineties using both empirical (statistical) models and physically based dynamical models.

Empirical (statistical): based on past (historical) observations for the predictand (e.g. precipitation over South America) and for relevant predictors (e.g. SST)

Dynamical: based on prognostic physical equations

• 2-tier systems (first predict SST, next climate variables)
• 1-tier systems (predict ocean and atmos. together)

Both empir. and dyn. predic. are expressed probabilistically
## Comparing statistical and dynamical prediction systems:

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Entirely based on real-world past climate observations</td>
<td>• Depends on quality and length of past climate observations</td>
</tr>
<tr>
<td>• Simple to build: many climate relationships are quasi-linear, quasi-Gaussian</td>
<td>• Does not fully account for changes in climate or new climate conditions</td>
</tr>
<tr>
<td>• Cheap (fast) to run</td>
<td>• Physical laws must be abbreviated or statistically estimated, leading to errors and biases</td>
</tr>
<tr>
<td>• Uses well established laws of physics</td>
<td>• Expensive to run (require powerful computers)</td>
</tr>
<tr>
<td>• Can potentially reproduce climate conditions never previously observed</td>
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</table>
Seasonal forecast availability

- Empirical/statistical models
- Dynamical atmospheric models
- Dynamical coupled (ocean-atmosphere) models

EUROBRISA conception

Why not combine all available state-of-the-art forecast information from both sources (empirical and dynamical)?

EUROBRISA Integrated (combined and calibrated) precipitation seasonal forecasting system for South America

http://eurobrisa.cptec.inpe.br
EUROBRISA aims

• Strengthen collaboration and promote exchange of expertise and information between European and South American climate scientists;

• Produce improved seasonal climate forecasts for South America using recent scientific advances in both coupled ocean-atmosphere modelling and statistical calibration and combination of multi-model ensemble forecasts;

• Develop forecast products for non-profitable governmental use in South America (e.g. reservoir management, hydropower production, agriculture and health).

A GREAT OPPORTUNITY TO DO SOMETHING REALLY USEFUL!

http://eurobrisa.cptec.inpe.br
Why South America?
**EUROBRISA key Idea:** To improve seasonal forecasts in S. America, a region where there is seasonal forecast skill and useful value.

El Niño (DJF)

La Niña (DJF)

Source: Climate Prediction Center (http://www.cpc.ncep.noaa.gov)

Correlation skill precipitation forecasts for DJF

Pos. values: moderate-good skill

Issued: Nov
Application areas in need of seasonal forecasts

→ Electricity: Brazil, about 70% produced by hydropower stations

→ Agriculture (e.g. crop yield)

→ Health (e.g. dengue)
The Empirical model

\[ Y|Z \sim N(M(Z - Z_o), T) \]

**Y**: DJF precipitation

**Z**: October sea surface temp. (SST)

\[ M = S_{YZ}S_{ZZ}^{-1} \]

\[ M Z_o = \bar{Y} - \bar{ZM} \]

\[ T = S_{YY} - S_{YZ}S_{ZZ}^{-1}S_{YZ}^T \]

*Model uses first three leading Maximum Covariance Analysis (MCA) modes of the matrix \( Y^T Z \).*

Data sources:

- SST: Reynolds OI v2
  Reynolds et al. (2002)

- Precipitation: GPCP v2
  Adler et al. (2003)

Coelho et al. (2006)

*J. Climate, 19, 3704-3721*
First version: EUROBRISA integrated forecasting system for South America

- Combined and calibrated coupled + empirical precip. forecasts
- Hybrid multi-model probabilistic system

<table>
<thead>
<tr>
<th>Coupled model</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECMWF System 3</td>
<td>International</td>
</tr>
<tr>
<td>UKMO (GloSea 3)</td>
<td>U.K.</td>
</tr>
</tbody>
</table>

Empirical model
Predictors: Atlantic and Pacific SST
Predictand: Precipitation
Coelho et al. (2006) J. Climate, 19, 3704-3721

Hindcast period: 1987-2001
Implemented in Oct 2007

Produced with forecast assimilation
Conceptual framework

Data Assimilation

\[ p(x_i | y_i) = \frac{p(y_i | x_i)p(x_i)}{p(y_i)} \]

"Forecast Assimilation"

\[ p(y_f | x_f) = \frac{p(x_f | y_f)p(y_f)}{p(x_f)} \]

Stephenson et al. (2005)
Motivation for use of multi-model ensemble

Sampling of two sources of uncertainties:
- initial conditions
- model formulation
Motivation for combination: Multi-model ensemble forecasts

Verification

Model 1

Climate system phase space

t=0

t=T

Courtesy: Francisco Doblas-Reyes
Motivation for combination: Multi-model ensemble forecasts

Model 1

Model 2

Climate system phase space

Verification

Courtesy: Francisco Doblas-Reyes
**Calibration and combination procedure:**

**Forecast Assimilation**

Stephenson *et al.* (2005)

*Tellus, 57A, 253-264*

**Prior:**

\[ Y \sim N(Y_b, C) \]

**Likelihood:**

\[ X \mid Y \sim N(G(Y - Y_o), S) \]

\[
G = S_{XY}S_{YY}^{-1} - GY_o = \bar{X} - \bar{Y}G \\
S = S_{XX} - GS_{YY}G^T
\]

**Posterior:**

\[ Y \mid X \sim N(Y_a, D) \]

\[
Y_a = Y_b + L(X - G(Y_b - Y_o)) \\
D = (G^T S^{-1} G + C^{-1})^{-1} = (I - LG)C \\
L = CG^T (GCG^T + S)^{-1}
\]

**Matrices**

\[
X : n \times p \\
Y : n \times q \\
Y_b : 1 \times q \\
C : q \times q \\
S : p \times p \\
Y_a : n \times q \\
D : q \times q
\]

Forecast assimilation uses the first three MCA modes of the matrix \( Y^T X \).
Calibration and combination procedure:

Forecast Assimilation

*Stephenson et al. (2005)*

Tellus, 57A, 253-264

*If prior param.*:

\[ Y_b = \overline{Y} \quad C = S_{YY} \]

**FA becomes:**

\[ Y | X \sim N(L(X - X_o), D) \]

\[ L = S_{YX} S_{XX}^{-1} \]

\[ -LX_o = \overline{Y} - \overline{X}L \]

\[ D = S_{YY} - S_{YX} S_{XX}^{-1} S_{YX}^T \]

**Posterior:**

\[ Y | X \sim N(Y_a, D) \]

\[ Y_a = Y_b + L(X - \overline{X}) \]

*X: precip. fcsts (coupled + empir.)*

*Y: DJF precipitation*

**Matrices**

\[ X : n \times p \]

\[ Y : n \times q \]

\[ Y_b : 1 \times q \]

\[ C : q \times q \]

\[ Y_a : n \times q \]

\[ D : q \times q \]
Can precipitation forecasts over the Pacific help improve forecasts over land?

Taking advantage of forecast skill over the Pacific to improve forecasts over land

Source: Franco Molteni (ECMWF)
EUROBRISA integrated forecasting system for South America

→ Combined and calibrated coupled + empirical precip. forecasts
→ Hybrid multi-model probabilistic system

**Empirical model**
Predictors: Atlantic and Pacific SST
Predictand: Precipitation

**Hindcast period:** 1981-2005

Produced with forecast assimilation

**Implemented in Mar 2012**
Can skill be improved by adding more models to the system and using forecasts over the Pacific?

Correlation skill: Integrated forecast (precipitation)

1987-2001

South America domain:
ECMWF, UKMO and empirical (limited to common hindcast period)

1981-2005

South America + Pacific domain:
ECMWF, UKMO, MF, CPTEC and empirical (diff. hind. periods)

→ Adding more models and using precip. fcsts over Pac. does help improve fcst. skill in S. America
How reliable are EUROBRISA integrated precipitation forecasts?

South America domain: ECMWF, UKMO and empirical (limited to common hindcast period)

South America + Pacific domain: ECMWF, UKMO, MF, CPTEC and empirical (diff. hind. periods)

→ Current system (right) has improved reliability comp. to previous (left)
How did the EUROBRISA integrated forecasting system perform since 2007?
The EUROSIP multimodel captured well the onset, amplitude and long duration of La Niña conditions.

Source: Magdalena Balmaseda (ECMWF)
EUROBRISA integrated forecast for JJA 2007

Issued: May 2007

Prob. of most likely precip. tercile (%)

Obs. SST anomaly Apr 2007

Observed precip. tercile

Gerrity score (tercile categories)

Hindcasts: 1981-2005
EUROBRISIA integrated forecast for SON 2007

Issued: Aug 2007

Prob. of most likely precip. tercile (%)

Observed precip. tercile

Gerrity score (tercile categories)

Obs. SST anomaly Jul 2007

Hindcasts: 1981-2005

CPTEC/INPE/EUROBRISIA product
EUROBRISMA integrated forecast for DJF 2007/2008

Issued: Nov 2007

Prob. of most likely precip. tercile (%)

Observed precip. tercile

Gerrity score (tercile categories)

Hindcasts: 1981-2005
EUROBRISASA integrated forecast for MAM 2008

Issued: Feb 2008

Prob. of most likely precip. tercile (%)

Observed precip. tercile

Gerrity score (tercile categories)

Hindcasts: 1981-2005
EUROBRISA integrated forecast for MAM 2009

Issued: Feb 2009

Observed precip.

Prob. of most likely precip. tercile (%)

Obs. SST anomaly Jan 2009

Gerrity score (tercile categories)

Hindcasts: 1981-2005
EUROBRISIA integrated forecast for MAM 2010

Issued: Feb 2010

Prob. of most likely precip. tercile (%)

Observed precip.

Gerrity score (tercile categories)

Hindcasts: 1981-2005
EUROBRISA integrated forecast for MAM 2011

Observed precip.

Prob. of most likely precip. tercile (%)

Issued: Feb 2011

Obs. SST anomaly Jan 2011

EUROBRISA integrated forecast for MAM 2011

Prob. of most likely precip. tercile (%)

Issued: Feb 2011

Obs. SST anomaly Jan 2011

EUROBRISA integrated forecast for MAM 2011

Prob. of most likely precip. tercile (%)

Issued: Feb 2011

Obs. SST anomaly Jan 2011

EUROBRISA integrated forecast for MAM 2011

Prob. of most likely precip. tercile (%)

Issued: Feb 2011

Obs. SST anomaly Jan 2011

EUROBRISA integrated forecast for MAM 2011

Prob. of most likely precip. tercile (%)

Issued: Feb 2011

Obs. SST anomaly Jan 2011
EUROBRISA integrated forecast for MAM 2015

Observed precip. and hindcasts: 1981-2010

Prob. of most likely precip. tercile (%)

Issued: Feb 2015

Obs. SST anomaly Jan 2015

Gerrity score (tercile categories)
Empirical (based on Jan 2016 SST) and integrated forecasts indicated pronounced deficit over NE Brazil.
EUROBRISA Integrated (empirical-dynamical combined and calibrated) precipitation seasonal forecasting system for South America

Collaborative effort:
INPE/CPTEC, Univ. Exeter, ECMWF, UK Met Office, Météo-France, UFPR, USP and INMET

Previously supported by:
The Leverhulme Trust

Currently supported by:
http://eurobrisa.cptec.inpe.br
Current EUROBRISA integrated forecasting system for South America

→ Combined and calibrated coupled + empirical precip. forecasts
→ Hybrid multi-model probabilistic system

**Couple model**   **Country**
ECMWF Sys 4           International
UKMO GloSea5 GC2       U.K.
Meteo-France Sys 5     France "NEW"

Updated empirical model
Predictors: Atlantic and Pacific SST
Predictand: Precipitation
Coelho et al. (2006) J. Climate, 19, 3704-3721

Hindcast period: 1981-2010


Updated in July 2016
EUROBRISA integrated fcst for NDJ 2016/17
Issued in Oct 2016: Most recent forecast

Obs. SST anomaly Sep 2016

Empirical
ECMWF
UKMO
Meteo-France
Integrated

Prob. of most likely precipitation tercile (%)

EUROBRISA fcsts disseminated in NCOFs/RCOFs in South America
New version of EUROBRISA system updated Jul 2016

Hybrid (empirical-dynamical) multi-model ensemble system for South America

http://eurobrisa.cptec.inpe.br
New version of EUROBRISA system updated Jul 2016

Hybrid (empirical-dynamical) multi-model ensemble system for South America

Real-time forecast and verification products

http://eurobrisa.cptec.inpe.br
New version of EUROBRISA

Hybrid (empirical-dynamical) multi-model ensemble system for South America

1-month lead forecasts
EUROSIP: ECMWF (System 4)
UKMO (GloSea 5 GC2)
Meteo-France (System 5) (NEW)

Empirical (SST based)
Integrated (Combination of 4 models above)

Real-time forecast and verification products

http://eurobrisa.cptec.inpe.br
How has EUROBRISA contributed for improving seasonal forecasting practice in S. America?
Seasonal forecasting system before EUROBRISA

- SST
  - CCA-based empirical model (Northeast and South Brazil)
- Atmospheric GCM (2-Tier system)
- Regional model
- Coupled GCM (1-Tier system)

Several individual precip. forecasts
Empirical multivariate regression model (South America)

**Coupled models:**
- CPTEC
- ECMWF
- Meteo-France
- UK Met Office

**Forecast Assimilation:** Integrated precipitation forecasts for S. America

**Impacts:** hydro-power, agricul., health

Integrated forecasting system
Official forecast for Brazil for DJF 2010/2011

EUROBRISA forecast helps define official seasonal forecast in Brazil

Issued: Nov 2010
Summary: EUROBRISA forecast system

- Successful initiative bringing together expertise on coupled ocean-atmosphere seasonal forecasting and statistical calibration and combination of multi-model ensemble forecasts
- Developed novel integrated precipitation seasonal forecasting system for South America
- Helped improve and advance seasonal forecasting practice in South America by objectively combining empirical and dynamical model seasonal forecasts
- Integrated forecasting system has shown reasonable performance since its implementation in 2007
- Use of precip. forecasts over Pacific improves robustness of predictors and forecast skill over South America
Acknowledgements

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• FAPESP foundation for research funding
• EU for funding the SPECS project that supported the maintenance of EUROBRISA

THANK YOU FOR YOUR ATTENTION!

Coelho C.A.S., 2009: Hybrid precipitation seasonal forecasts for South America. 9th International Conference on Southern Hemisphere Meteorology and Oceanography.


Available at http://eurobrisa.cptec.inpe.br/publications.shtml