Advances in South America seasonal precipitation predictions

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

VAMOS Modeling Workshop, Petrópolis, Brazil, 4-6 Jun 2012
Assessing Progress and Defining the Future Directions
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)
Comparing statistical and dynamical prediction systems:

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Statistical</strong></td>
<td><strong>Dynamical</strong></td>
</tr>
<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>• Uses well established laws of physics</td>
</tr>
<tr>
<td></td>
<td>• Can potentially reproduce climate conditions never previously observed</td>
</tr>
<tr>
<td></td>
<td>• Physical laws must be abbreviated or statistically estimated, leading to errors and biases</td>
</tr>
<tr>
<td></td>
<td>• Expensive to run (require powerful computers)</td>
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</tbody>
</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
Why South America?
EUROBRISA key Idea: To improve seasonal forecasts in S. America, a region where there is seasonal forecast skill and useful value.
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

Data sources:
- SST: Reynolds OI v2 Reynolds et al. (2002)
- Precipitation: GPCP v2 Adler et al. (2003)

\[ Y \mid Z \sim N \left( M (Z - Z_o), T \right) \]

Y: DJF precipitation
Z: October sea surface temp. (SST)

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

\[
M = S_{YZ} S_{ZZ}^{-1} \\
- M Z_o = \bar{Y} - \bar{Z} M \\
T = S_{YY} - S_{YZ} S_{ZZ}^{-1} S_{YZ}^T
\]

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
Integrated forecast
Produced with forecast assimilation

Implemented in Oct 2007
Conceptual framework

Data Assimilation
\[ p(x_i \mid y_i) = \frac{p(y_i \mid x_i)p(x_i)}{p(y_i)} \]

“Forecast Assimilation”
\[ p(y_f \mid x_f) = \frac{p(x_f \mid y_f)p(y_f)}{p(x_f)} \]

Stephenson et al. (2005)
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:

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

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

\[ p(Y \mid X) = \frac{p(X \mid Y) p(Y)}{p(X)} \]

\( X: \text{precip. fcsts (coupled + empir.)} \)

\( Y: \text{DJF precipitation} \)

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)
Current EUROBRISA integrated forecasting system for South America

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

### Couple model

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<th>Model</th>
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<tr>
<td>ECMWF Sys 4 (New!)</td>
<td>International</td>
</tr>
<tr>
<td>UKMO GloSea 4</td>
<td>U.K.</td>
</tr>
<tr>
<td>Meteo-France Sys 3</td>
<td>France</td>
</tr>
<tr>
<td>CPTEC</td>
<td>Brazil</td>
</tr>
</tbody>
</table>

### Empirical model

Predictors: Atlantic and Pacific SST
Predictand: Precipitation

Coelho et al. (2006) *J. Climate, 19*, 3704-3721

Hindcast period: 1981-2005

Produced with forecast assimilation
Stephenson et al (2005)
Tellus A. Vol.  57, 253-264

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)

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)

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

Issued: Nov  Valid for DJF
Event: positive or negative precip. anomaly

Issued: Nov  Valid for DJF
Event: positive or negative precip. anomaly

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?
La Niña 2007/2008/2009

NINO3.4 SST forecast anomalies

ECMWF forecasts at month 5
Ensemble sizes are 40 (0001), 40 (0001) and 40 (0001)  SST obs: NCEP OIv2

The EUROSIP multimodel captured well the onset, amplitude and long duration of La Nina conditions

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

Issued: May 2007

Prob. of most likely precip. tercile (%)  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
EUROBRISA integrated forecast for DJF 2007/2008

Issued: Nov 2007

Obs. SST anomaly Oct 2007

Prob. of most likely precip. tercile (%)

Observed precip. tercile

Gerrity score (tercile categories)

Hindcasts: 1981-2005
EUROBRISA integrated forecast for MAM 2008

Issued: Feb 2008

Obs. SST anomaly Jan 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

Obs. SST anomaly Jan 2009

Prob. of most likely precip. tercile (%)

Observed precip.

Gerrity score (tercile categories)

Hindcasts: 1981-2005
EUROBRISASA integrated forecast for MAM 2011

Issued: Feb 2011

Observed precip.

Prob. of most likely precip. tercile (%)

Gerrity score (tercile categories)

Obs. SST anomaly Jan 2011

Hindcasts: 1981-2005
New version of EUROBRISA system updated in March 2012
http://eurobrisa.cptec.inpe.br

Hybrid (empirical-dynamical) multi-model ensemble system for South America
New version of EUROBRISA system updated in March 2012
http://eurobrisa.cptec.inpe.br

Real-time forecast and verification products

Hybrid (empirical-dynamical) multi-model ensemble system for South America
New version of EUROBRISA system updated in March 2012

EUROSIP: ECMWF (System 4) (NEW)
UKMO (GloSea 4)
Meteo-France (System 3)
CPTEC Empirical (SST based)
Integrated (Combination of 5 models above)

Real-time forecast and verification products

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

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

SST
Most recent EUROBRISIA integrated fcst for JJA 2012

Empirical

ECMWF

UKMO

CPTEC

Meteo-France

Integrated

Obs. SST anomaly Apr 2012

Prob. of most likely precipitation tercile (%) 

Issued: May 2012
Summary: EUROBRISA

- 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
- Neutral ENSO phase: EUROBRISA forecast for JJA 2012 is for below normal precipitation in northern South America and above normal precipitation in central and south South America
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
EUROBRISA articles: impact studies


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