

Advances in South America seasonal precipitation predictions

Caio A. S. Coelho

Centro de Previsão de Tempo e Estudos Climáticos (CPTEC)

Instituto Nacional de Pesquisas Espaciais (INPE)

caio.coelho@cptec.inpe.br



The Leverhulme Trust

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

Introduction

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:

Advantages

Disadvantages

**Stati-
stical**

- Entirely based on real-world past climate observations
- Simple to build: many climate relationships are quasi-linear, quasi-Gaussian
- Cheap (fast) to run

- Depends on quality and length of past climate observations
- Does not fully account for changes in climate or new climate conditions

**Dyna-
mical**

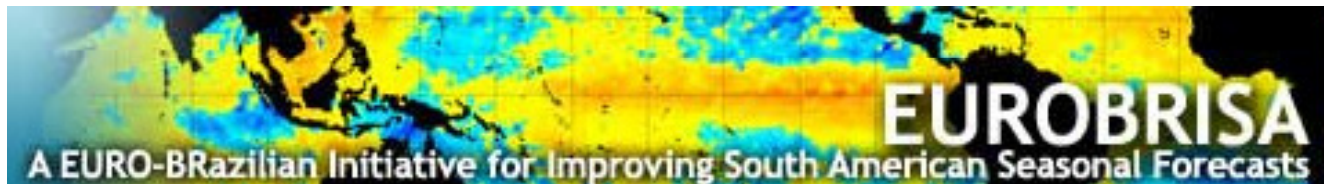
- Uses well established laws of physics
- Can potentially reproduce climate conditions never previously observed

- Physical laws must be abbreviated or statistically estimated, leading to errors and biases
- Expensive to run (require powerful computers)

Seasonal forecast availability

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

EUROBRISA conception



<http://eurobrisa.cptec.inpe.br>

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

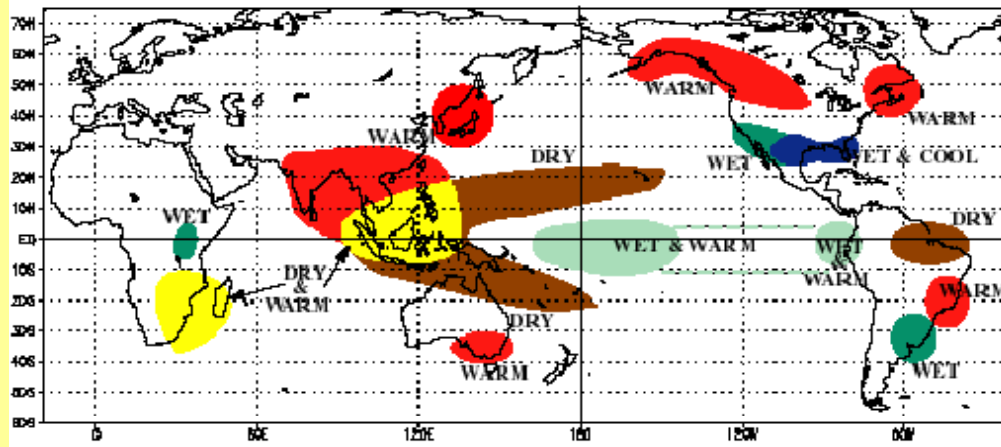


EUROBRISA Integrated (combined and calibrated) precipitation seasonal forecasting system for South America

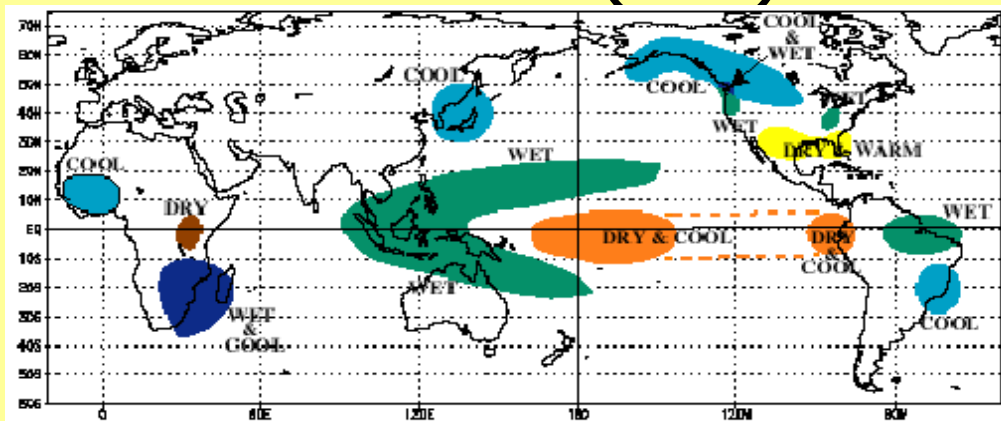
Why South America?

EUROBRISA key Idea: To improve seasonal forecasts in S. America a region where there is seasonal forecast skill and useful value

El Niño (DJF)

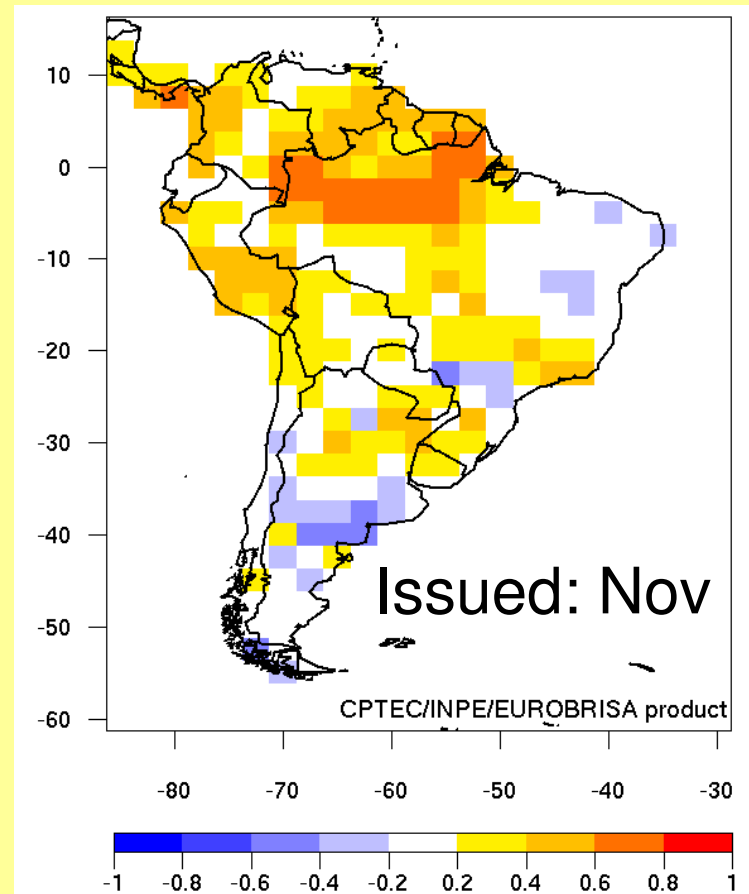


La Niña (DJF)



Fonte: Climate Prediction Center
(<http://www.cpc.ncep.noaa.gov>)

Correlation skill precipitation forecasts for DJF



Pos. values: moderate-good skill

Application areas in need of seasonal forecasts

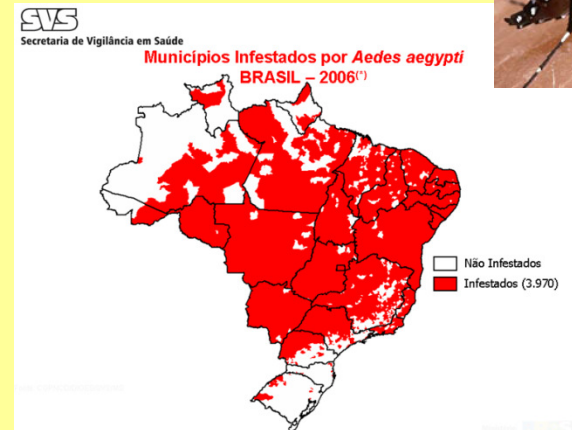
→ Electricity: Brazil, about 70% produced by hydropower stations



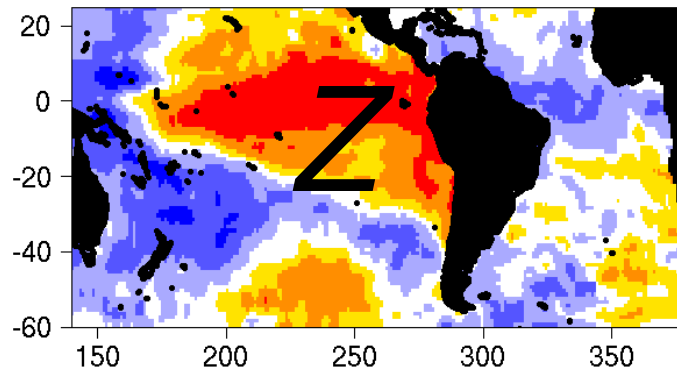
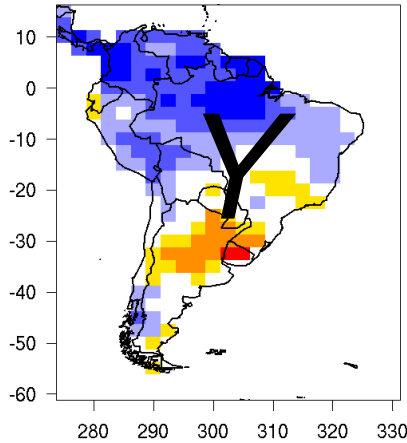
→ Agriculture (e.g. crop yield)



→ Health (e.g. dengue)



The Empirical model



Data sources:

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

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

Y: DJF precipitation

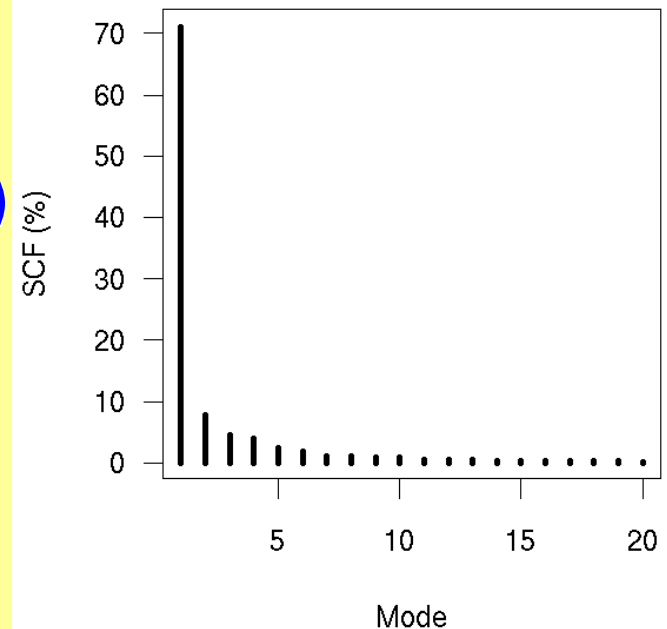
Z: October sea surface temp. (SST)

$$M = S_{YZ} S_{ZZ}^{-1} \quad Y : n \times q$$

$$-M Z_o = \bar{Y} - \bar{Z} M \quad Z : n \times v$$

$$T = S_{YY} - S_{YZ} S_{ZZ}^{-1} S_{YZ}^T \quad T : q \times q$$

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



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

Coupled model	Country
ECMWF System 3	International
UKMO (GloSea 3)	U.K.

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

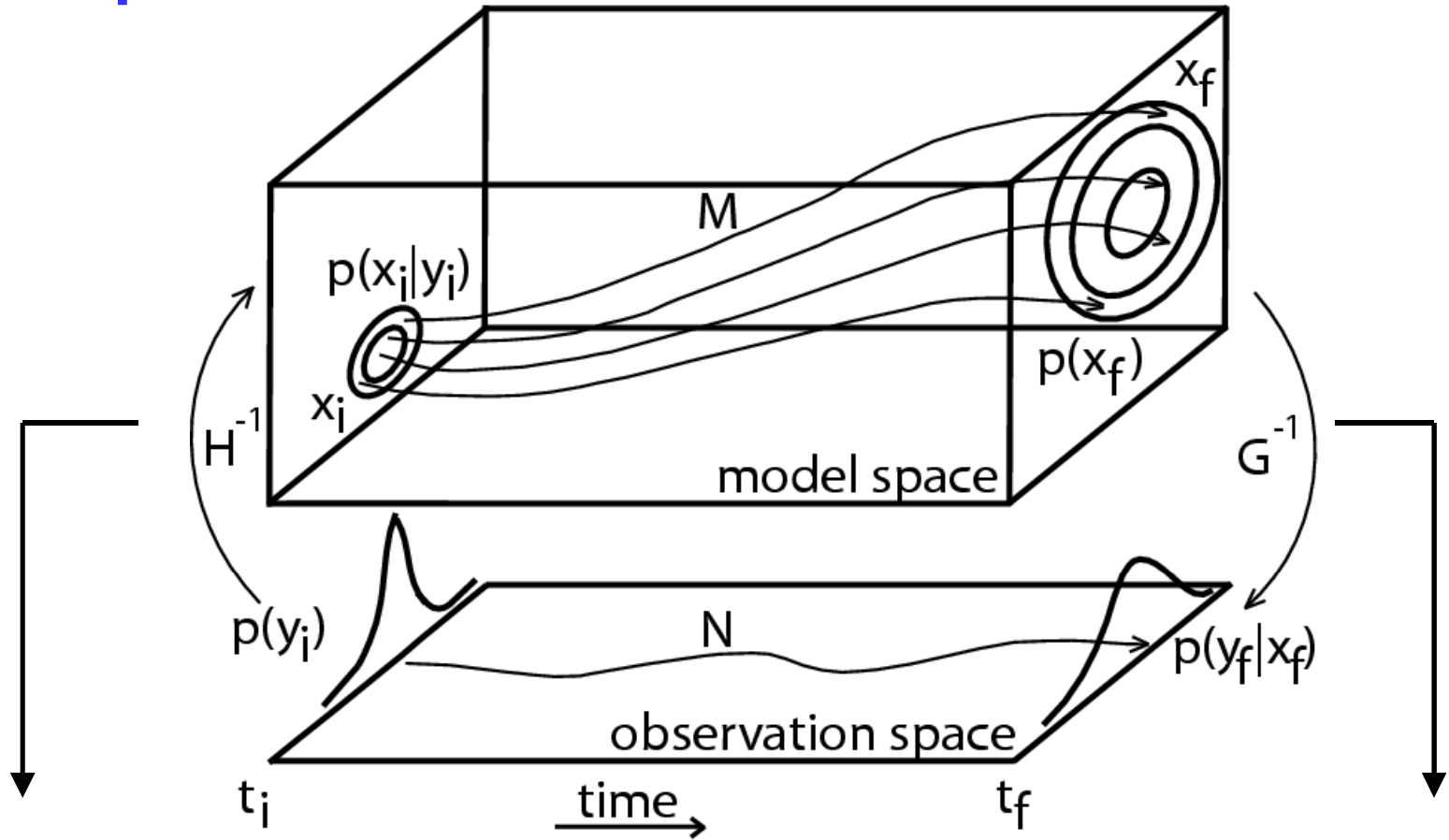
*Integrated
forecast*

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

Hindcast period: 1987-2001

Implemented in Oct 2007

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)

Calibration and combination procedure:

Forecast Assimilation

Stephenson *et al.* (2005)

Tellus, 57A, 253-264

$$p(Y | X) = \frac{p(X | Y)p(Y)}{p(X)}$$

X : precip. fcsts (coupled + empir.)

Y : DJF precipitation

Prior:

$$Y \sim N(Y_b, C)$$

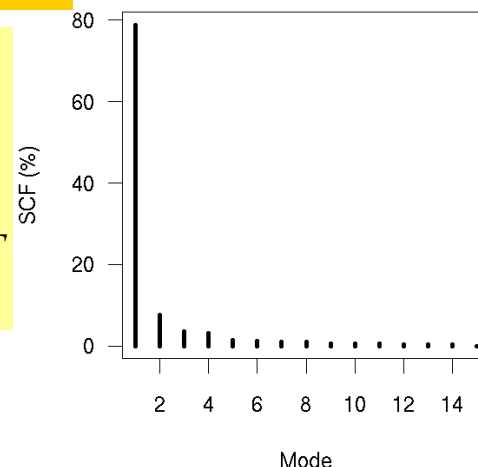
Likelihood:

$$X | Y \sim N(G(Y - Y_o), S)$$

$$G = S_{XY} S_{YY}^{-1}$$

$$-GY_o = \bar{X} - \bar{Y}G$$

$$S = S_{XX} - GS_{YY}G^T$$



Matrices

$$X : n \times p$$

$$Y : n \times q$$

$$Y_b : 1 \times q$$

$$C : q \times q$$

$$S : p \times p$$

$$Y_a : n \times q$$

$$D : q \times q$$

Posterior:

$$Y | X \sim N(Y_a, D)$$

$$Y_a = Y_b + L(X - G(Y_b - Y_o))$$

$$D = (G^T S^{-1} G + C^{-1})^{-1} = (I - LG)C$$

$$L = CG^T (GCG^T + S)^{-1}$$

11

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

X : precip. fcsts (coupled + empir.)

Y : DJF precipitation

If prior param.:

$$Y_b = \bar{Y} \quad C = S_{YY}$$

FA becomes:

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

$$L = S_{YX} S_{XX}^{-1}$$

$$-LX_o = \bar{Y} - \bar{X}L$$

$$D = S_{YY} - S_{YX} S_{XX}^{-1} S_{YX}^T$$

Posterior:

$$Y | X \sim N(Y_a, D)$$

$$Y_a = Y_b + L(X - \bar{X})$$

Matrices

$X : n \times p$

$Y : n \times q$

$Y_b : 1 \times q$

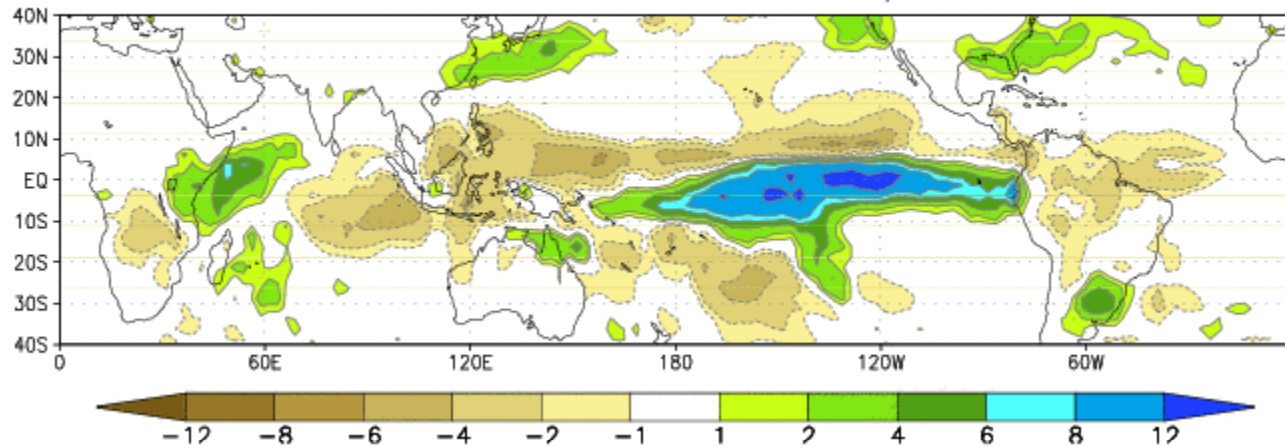
$C : q \times q$

$Y_a : n \times q$

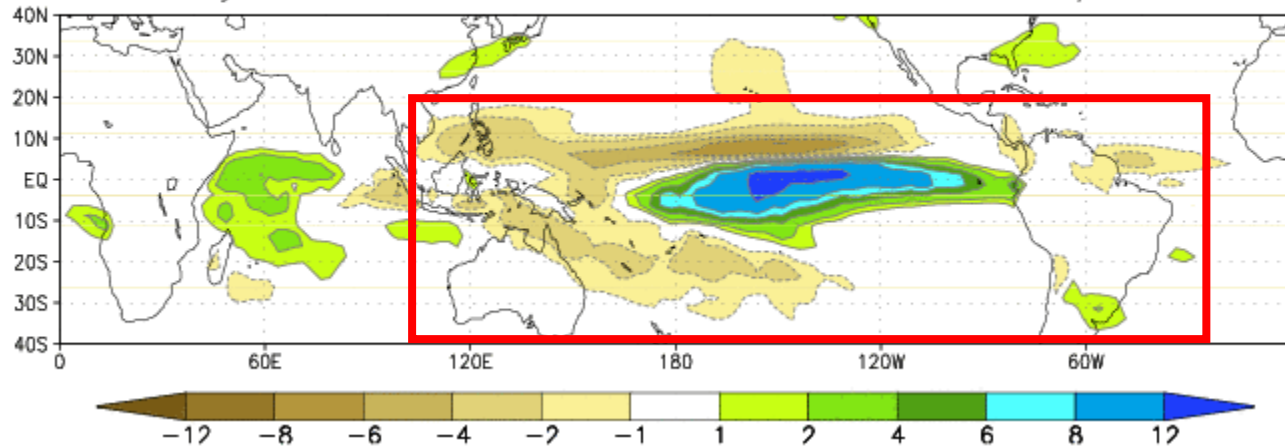
$D : q \times q$

Can precipitation forecasts over the Pacific help improve forecasts over land?

GPCP rainfall DJF 1997/98



Sys-3 ensemble-mean rainfall DJF 1997/98



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

<i>Couple model</i>	<i>Country</i>
ECMWF Sys 4 (New!)	International
UKMO GloSea 4	U.K.
Meteo-France Sys 3	France
CPTEC	Brazil

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

The diagram illustrates the integration process. On the left, a yellow box lists various coupled models and their countries. Below it, another yellow box describes an empirical model using SST as predictors and precipitation as the predictand. Arrows from both boxes point to a central yellow oval labeled 'Integrated forecast'. A separate arrow points from the empirical model box to a text block at the bottom right.

*Integrated
forecast*

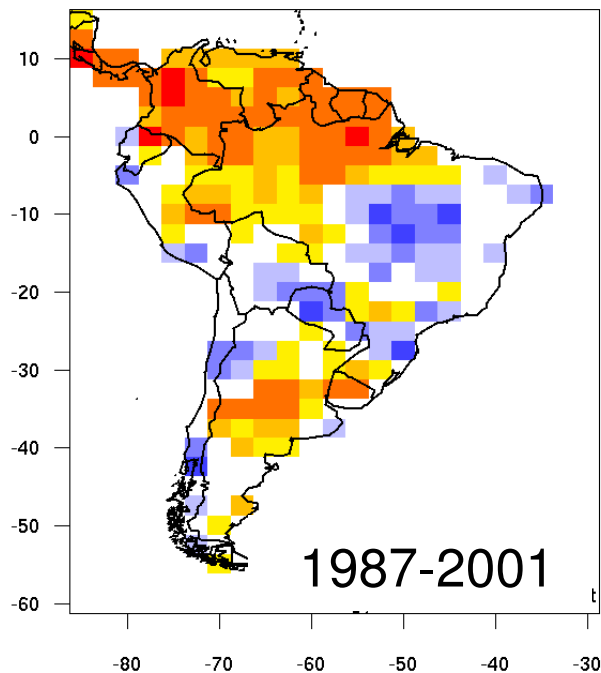
Produced with
forecast assimilation
Stephenson *et al* (2005)
Tellus A . Vol. 57, 253-264

Hindcast period: 1981-2005

Implemented in Mar 2012

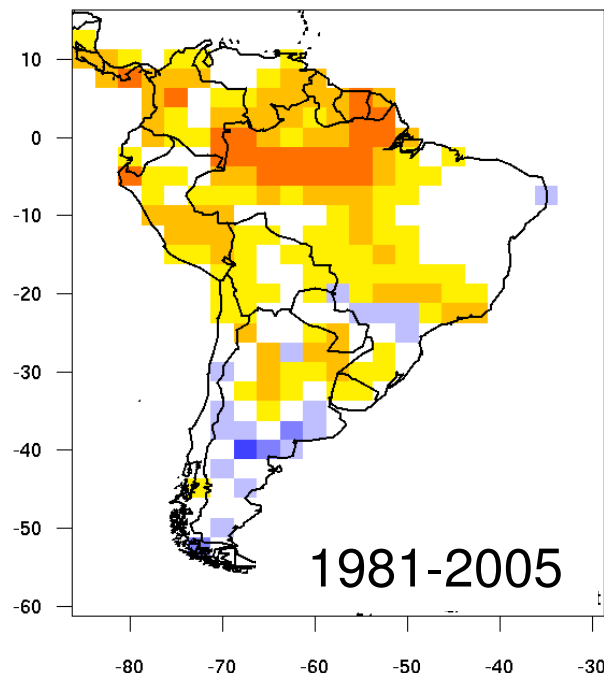
Can skill be improved by adding more models to the system and using forecasts over the Pacific?

Correlation skill: Integrated forecast (precipitation)



South America domain:

ECMWF, UKMO and empirical
(limited to common hindcast period)



South America + Pacific domain:

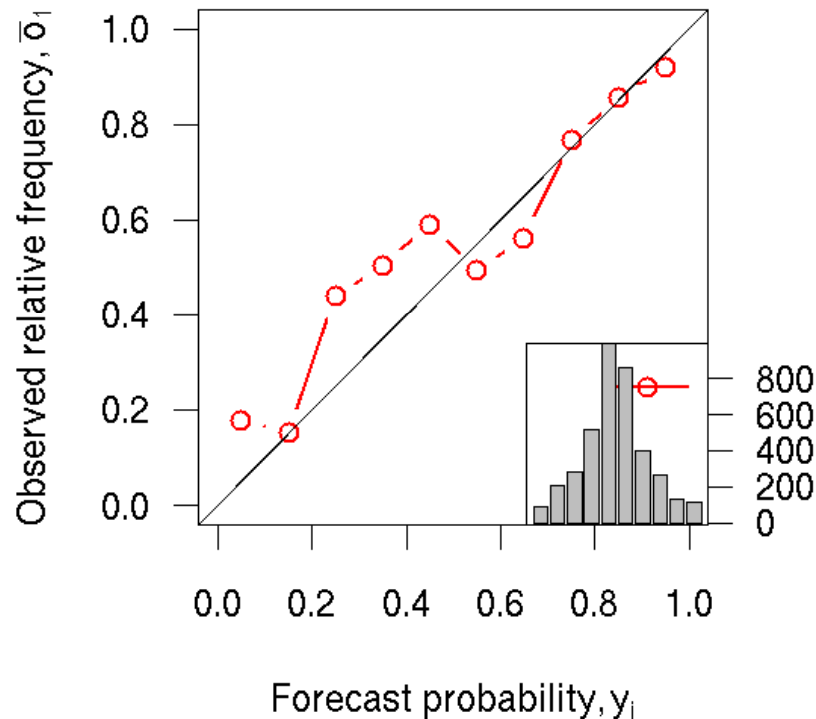
ECMWF, UKMO, MF, CPTC
and empirical (diff. hind. periods)

Issued: Nov
Valid: DJF

→ Adding more models and using precip. fcsts over Pac. does help improve fcst. skill in S. America

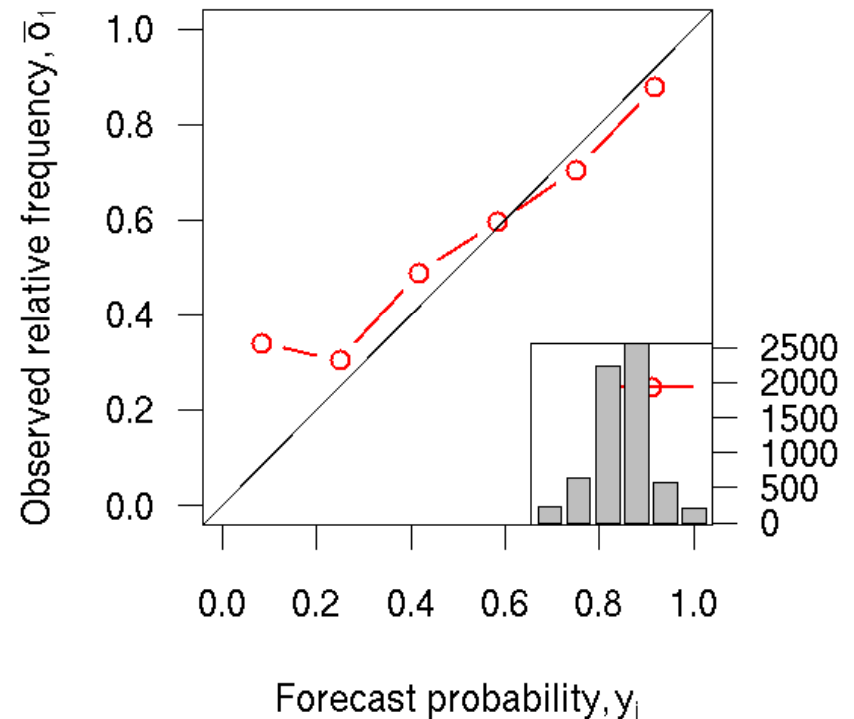
How reliable are EUROBRISA integrated precipitation forecasts?

Reliability diagram: Integrated (1987-2001)
Issued: Nov Valid for DJF
Event: positive or negative precip. anomaly



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

Reliability diagram: Integrated (1981-2005)
Issued: Nov Valid for DJF
Event: positive or negative precip. anomaly



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

→ Current system (right) has improved reliability comp. to previous (left)

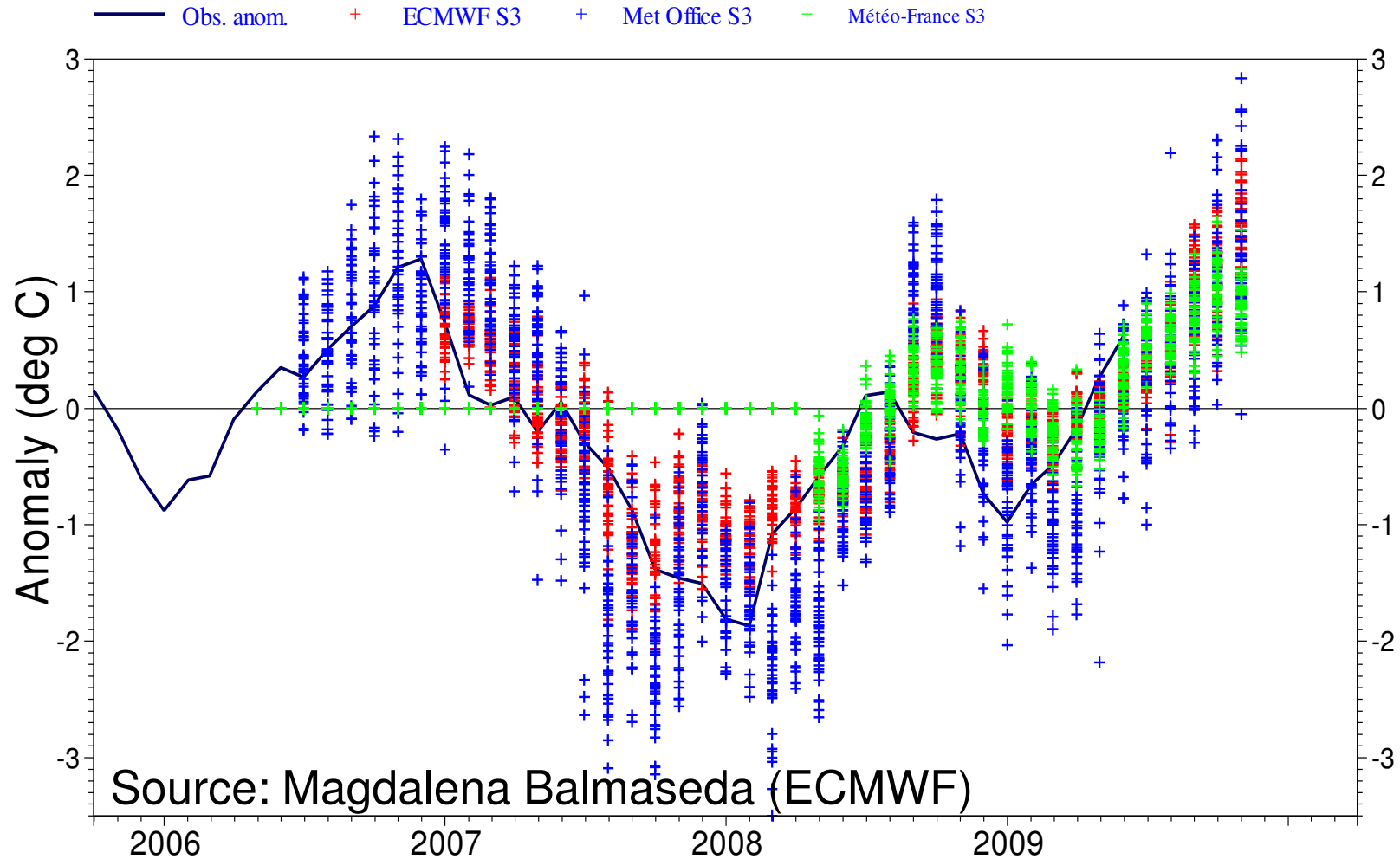
**How did the EUROBRISA
integrated forecasting system perform
since 2007?**

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 Olv2

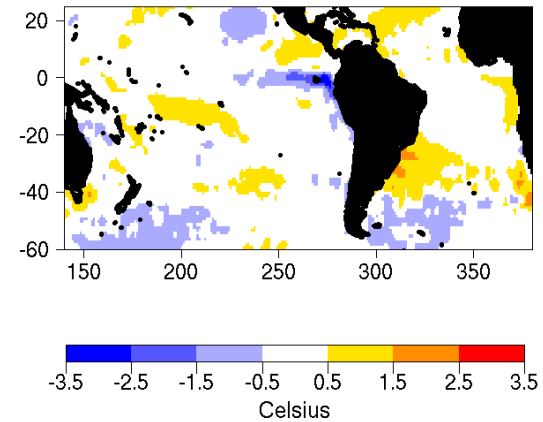


The EUROSIP multimodel captured well the onset, amplitude and long duration of La Niña conditions

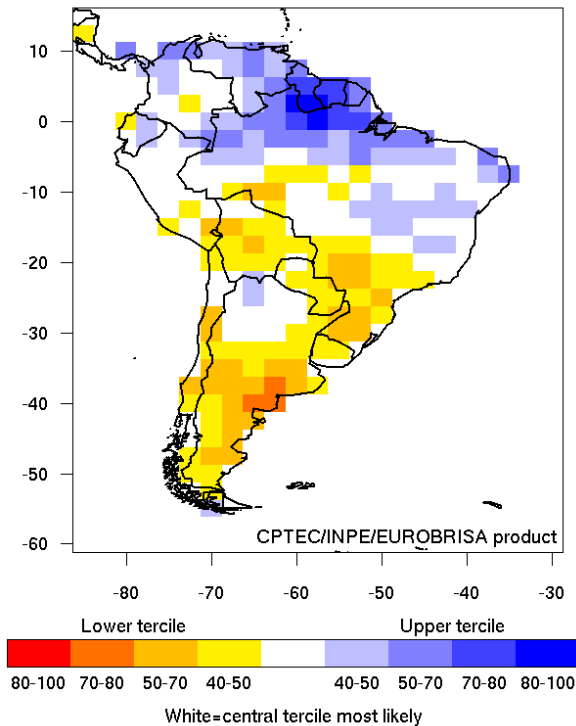
EUROBRISA integrated forecast for JJA 2007

Issued: May 2007

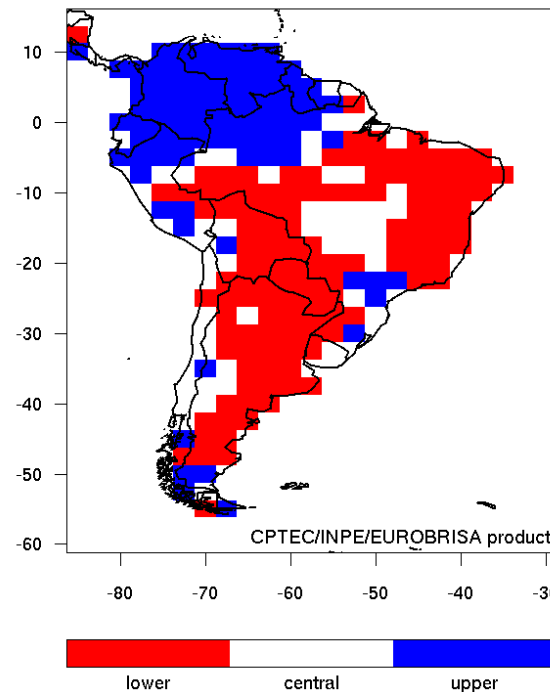
Obs. SST anomaly Apr 2007



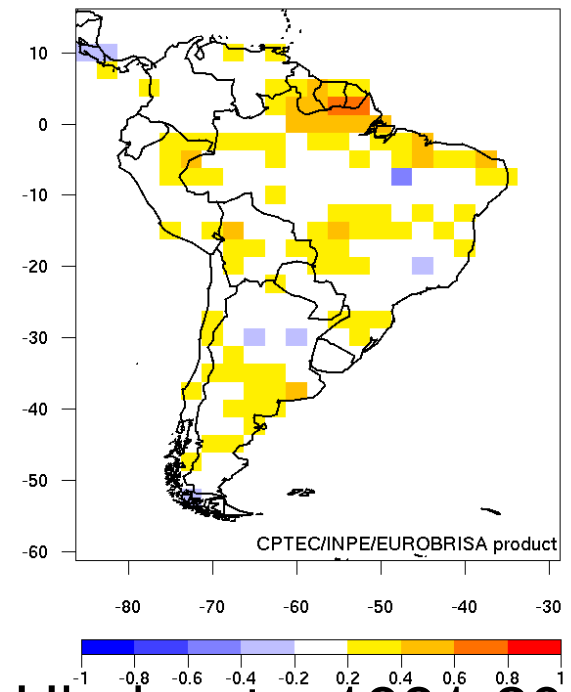
Prob. of most likely precip. tercile (%)



Observed precip. tercile



Gerrity score (tercile categories)

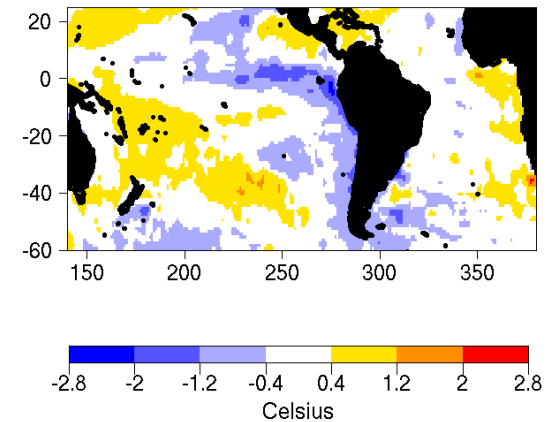


Hindcasts: 1981-2005

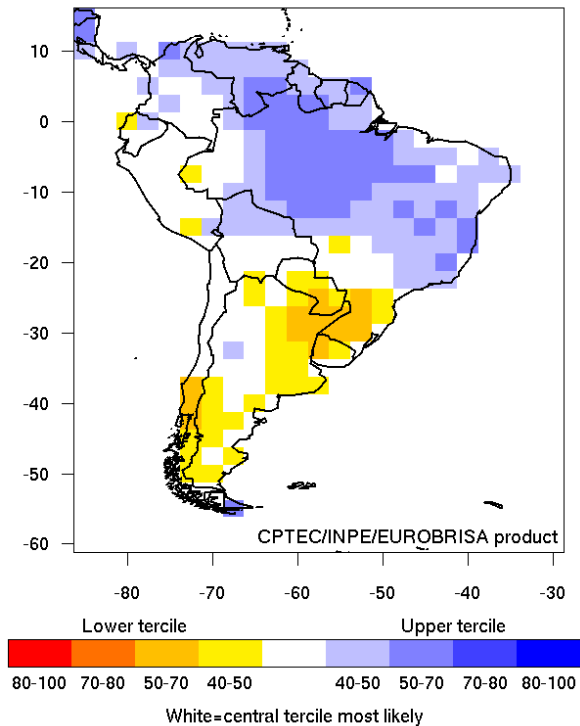
EUROBRISA integrated forecast for SON 2007

Issued: Aug 2007

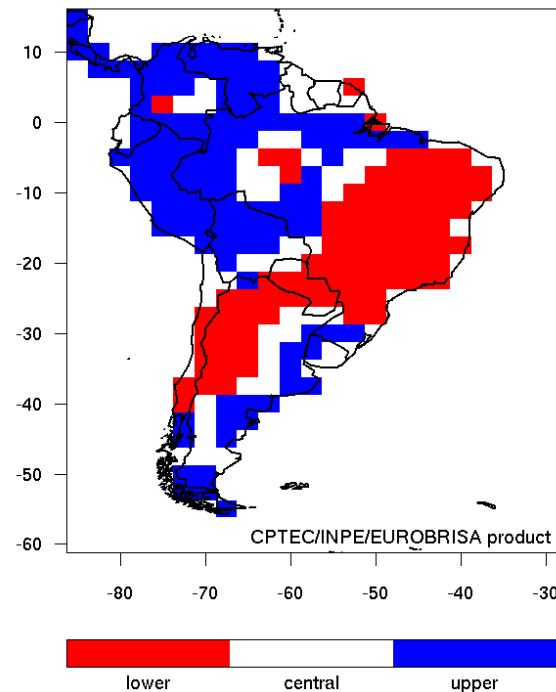
Obs. SST anomaly Jul 2007



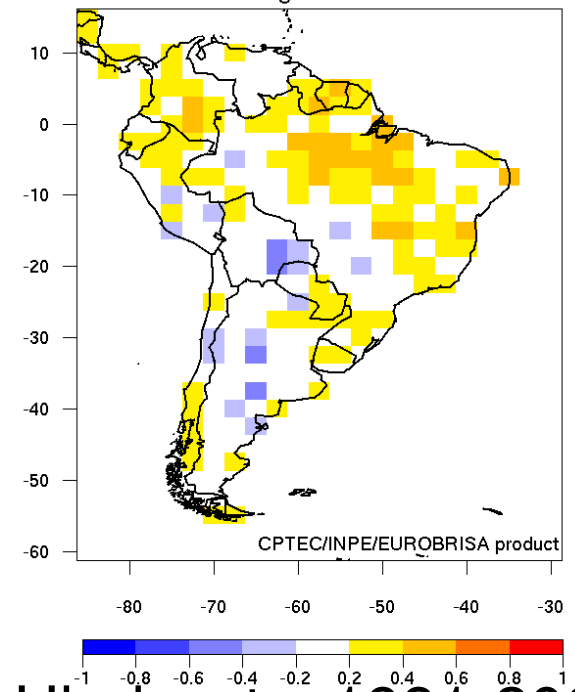
Prob. of most likely precip. tercile (%)



Observed precip. tercile



Gerrity score (tercile categories)

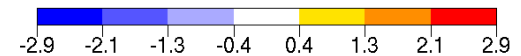
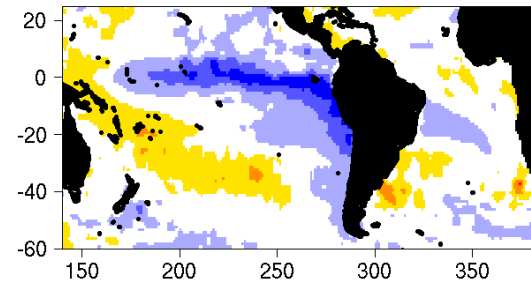


Hindcasts: 1981-2005

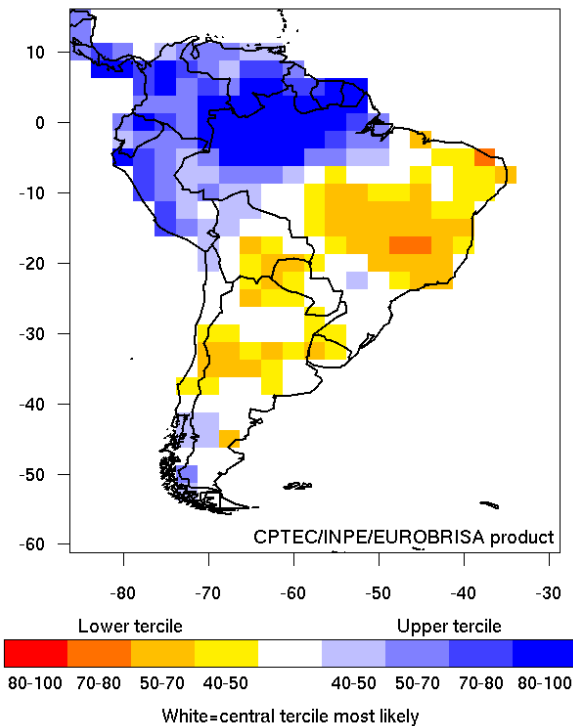
EUROBRISA integrated forecast for DJF 2007/2008

Issued: Nov 2007

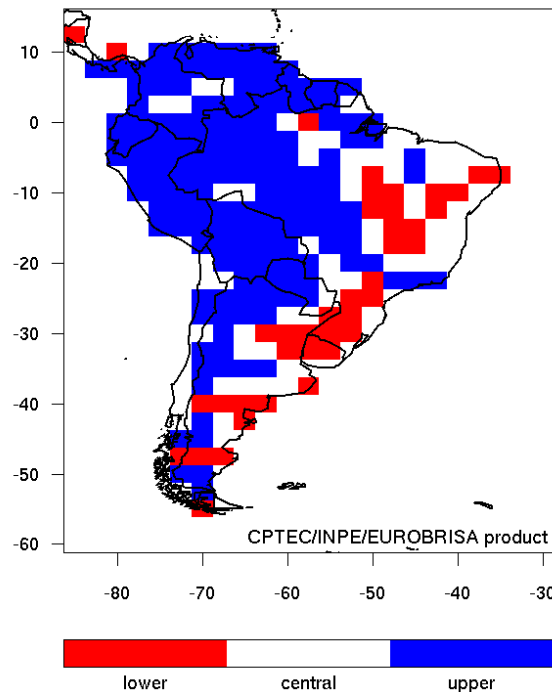
Obs. SST anomaly Oct 2007



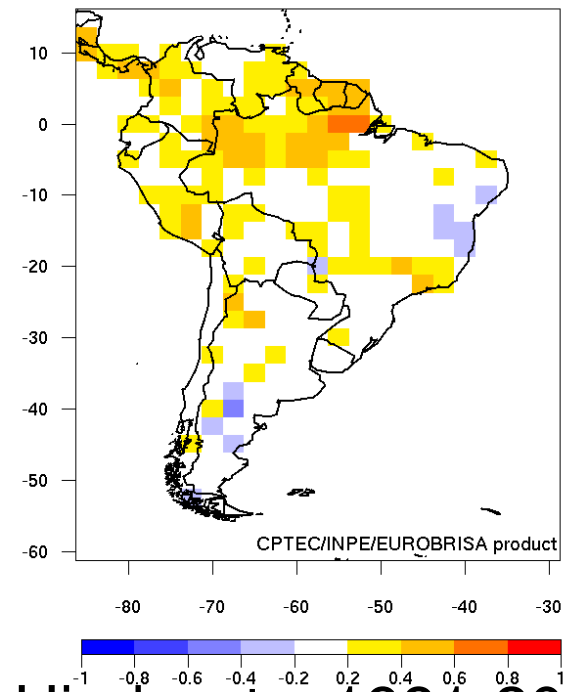
Prob. of most likely precip. tercile (%)



Observed precip. tercile



Gerrity score (tercile categories)

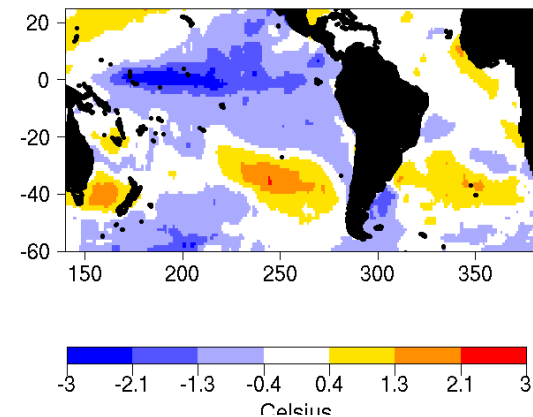


Hindcasts: 1981-2005

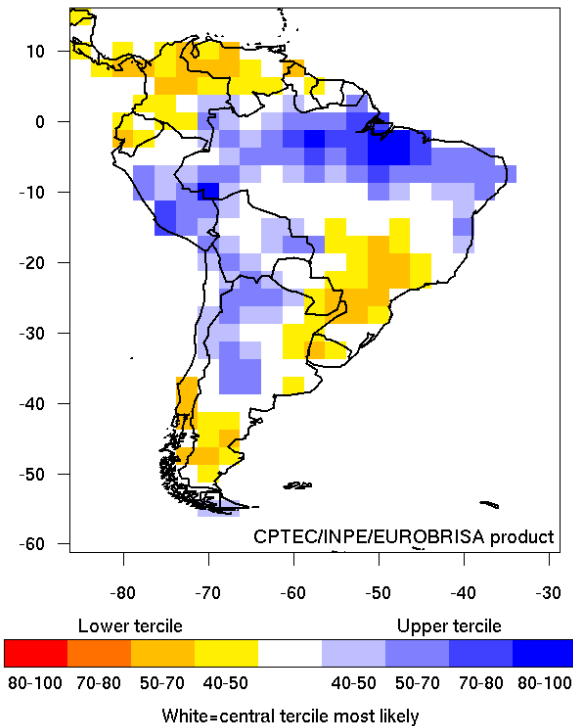
EUROBRISA integrated forecast for MAM 2008

Issued: Feb 2008

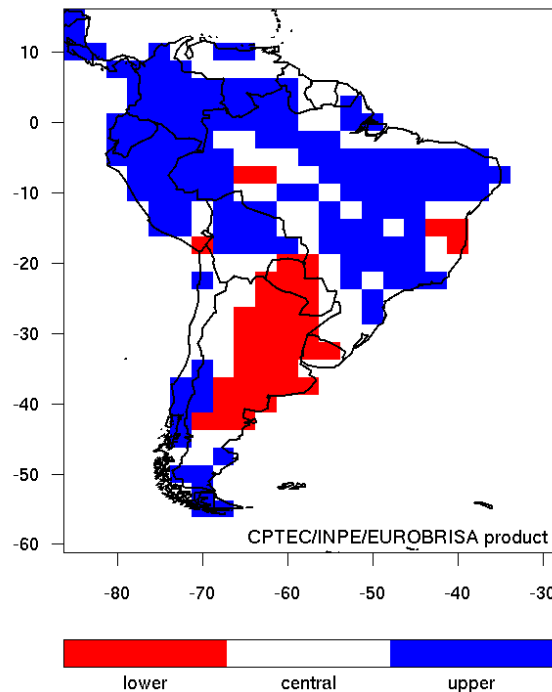
Obs. SST anomaly Jan 2008



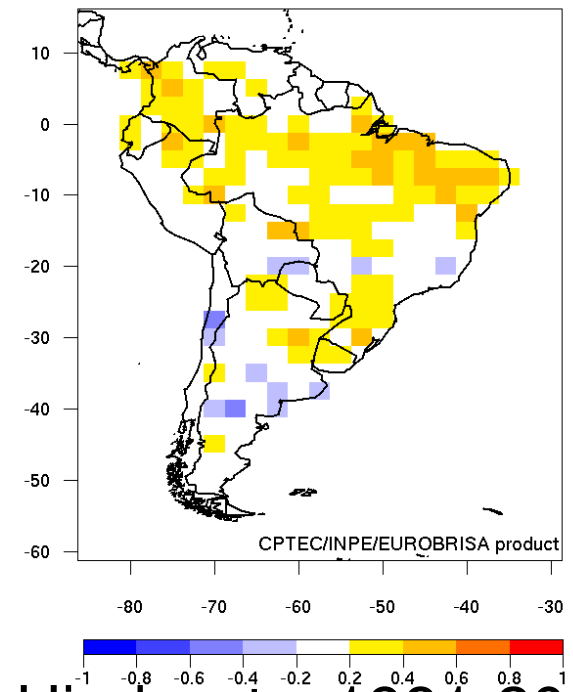
Prob. of most likely precip. tercile (%)



Observed precip. tercile



Gerrity score (tercile categories)

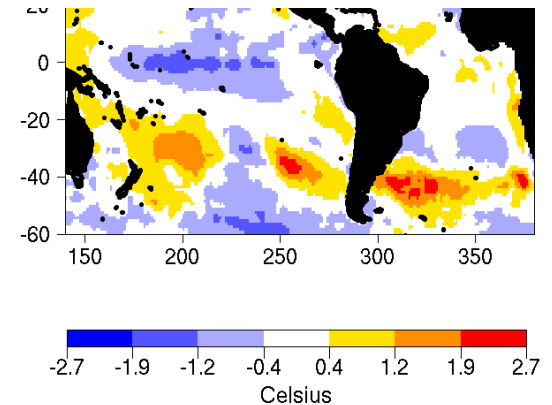


Hindcasts: 1981-2005

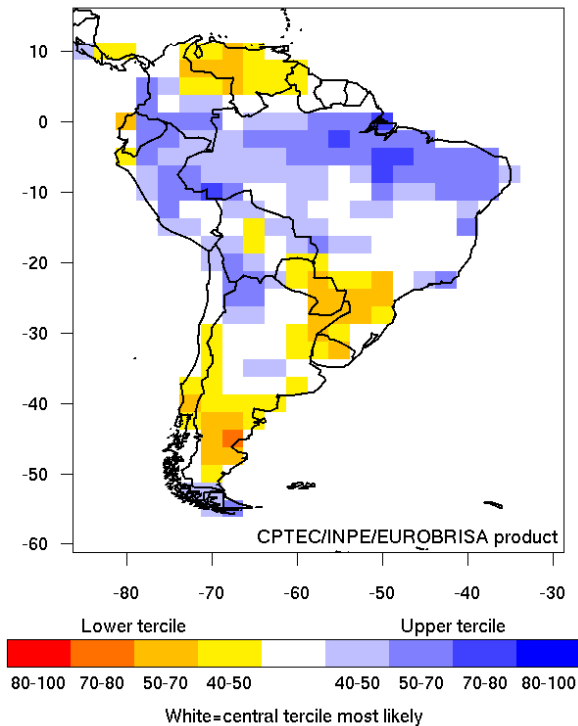
EUROBRISA integrated forecast for MAM 2009

Issued: Feb 2009

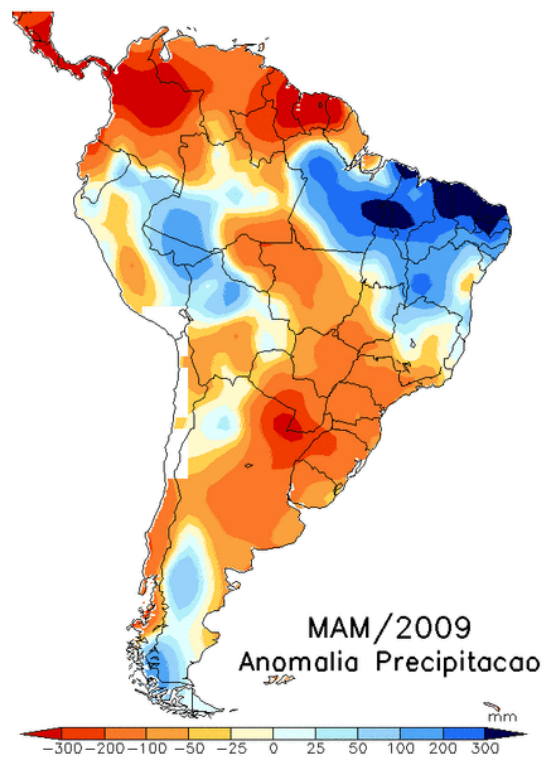
Obs. SST anomaly Jan 2009



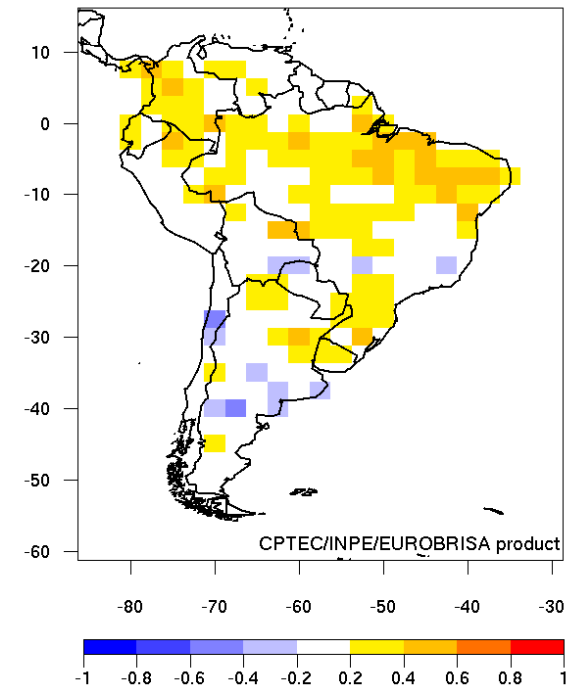
Prob. of most likely precip. tercile (%)



Observed precip.



Gerrity score (tercile categories)

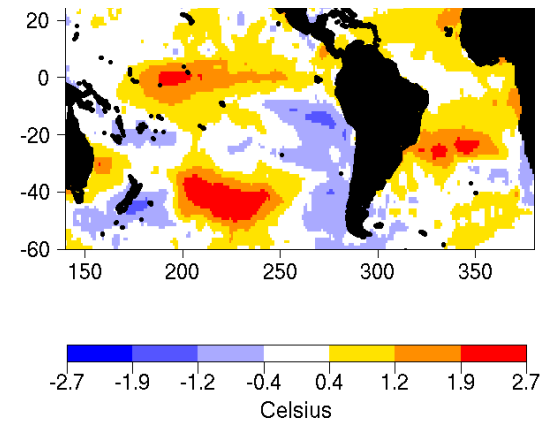


Hindcasts: 1981-2005

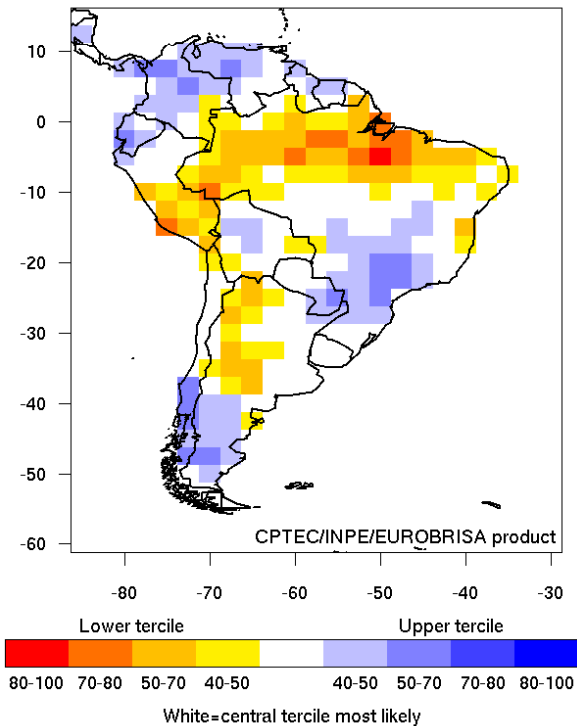
EUROBRISA integrated forecast for MAM 2010

Issued: Feb 2010

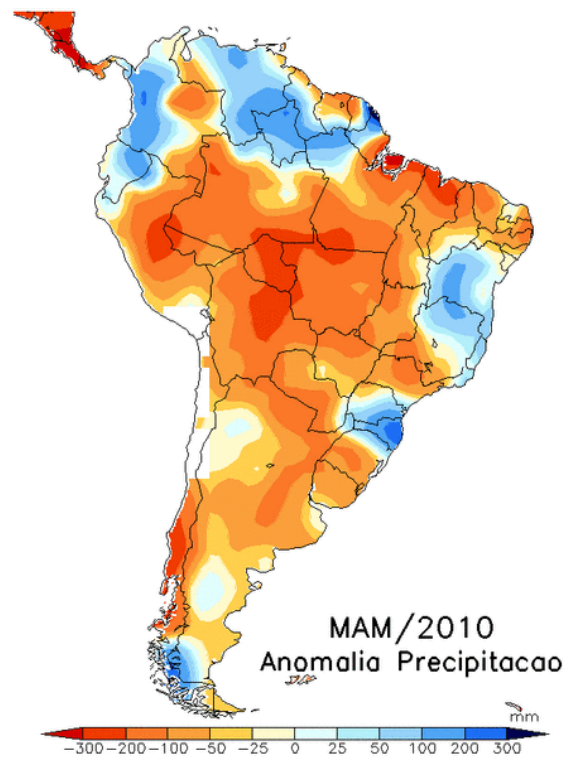
Obs. SST anomaly Jan 2010



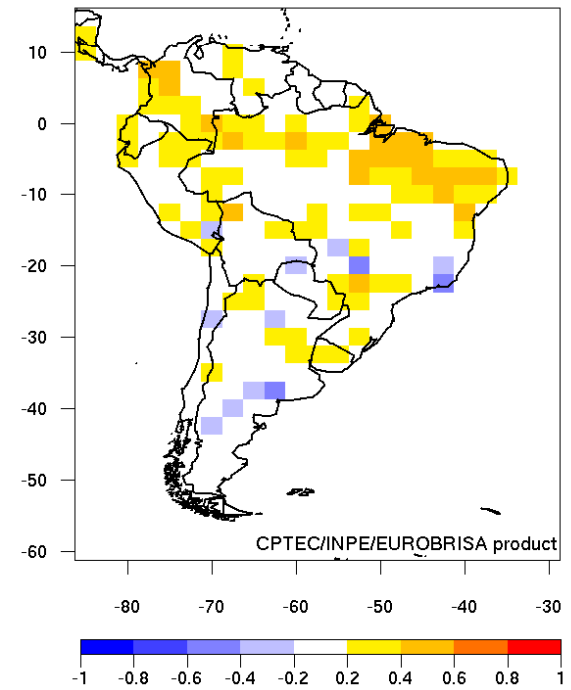
Prob. of most likely precip. tercile (%)



Observed precip.



Gerrity score (tercile categories)

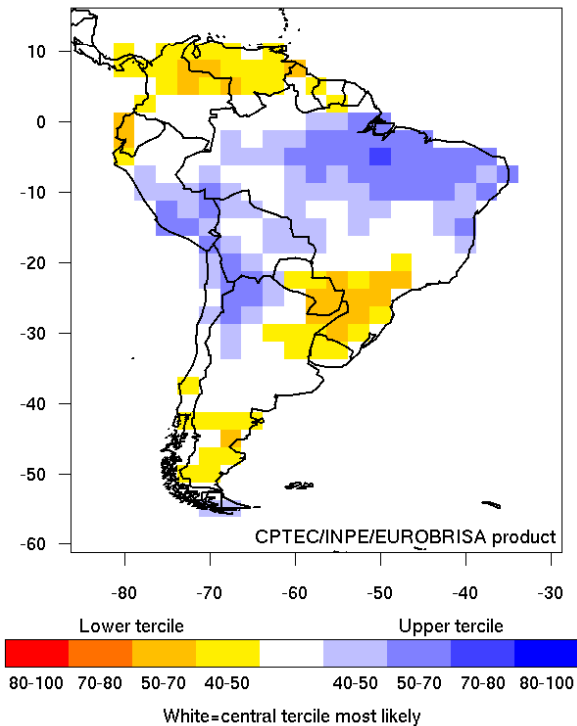


Hindcasts: 1981-2005

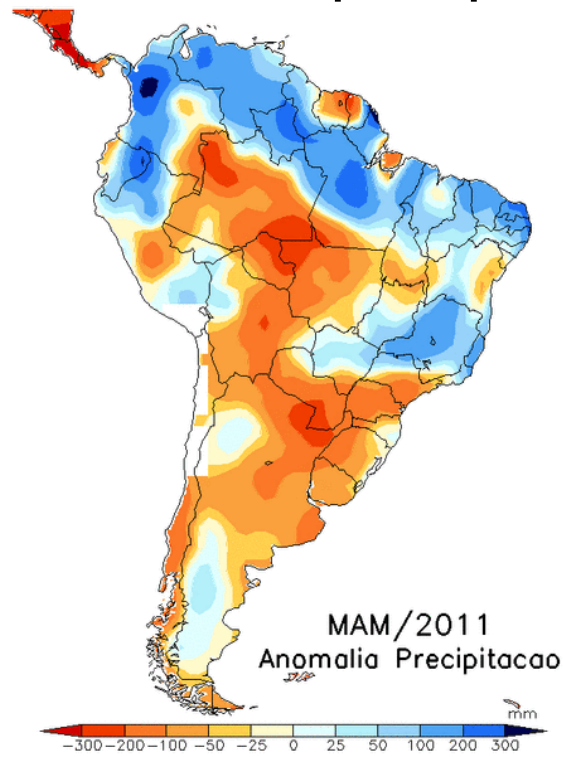
EUROBRISA integrated forecast for MAM 2011

Issued: Feb 2011

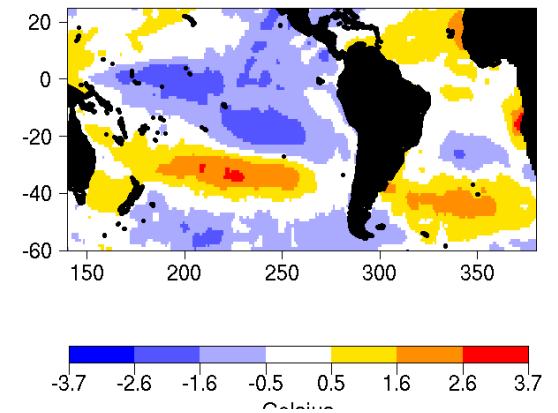
Prob. of most likely precip. tercile (%)



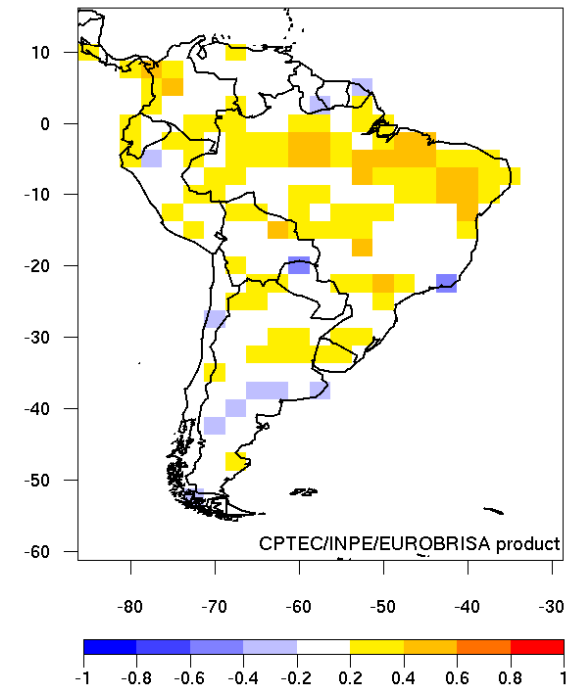
Observed precip.



Obs. SST anomaly Jan 2011



Gerrity score (tercile categories)

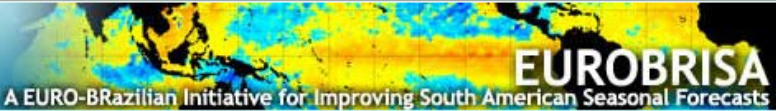


Hindcasts: 1981-2005

New version of EUROBRISA system updated in March 2012

<http://eurobrisa.cptec.inpe.br>

Domingo,
27 Maio 2012
1:19 PM



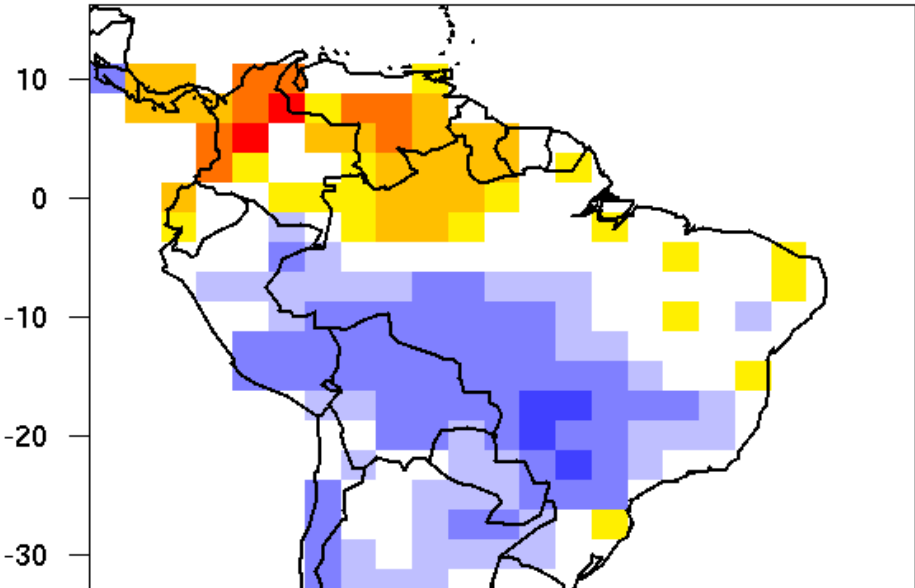
Key idea: To improve seasonal forecasts in South America, a region where there is seasonal forecast skill and useful value

PRODUCTS [→ HOME](#)

Product: Forecast Variable: precip. Model: Integrated Date Issued: May 2012
Forecast Type: Prob. most lik. tercile

[→ \(Products documentation\)](#)
[→ Previous EUROBRISA operational System \(operational until Feb 2012\)](#)

Integrated: Prob. of most likely precip. tercile (%)
Issued: May 2012 Valid for JJA 2012



AIMS

- Strengthen collaboration and promote exchange of expertise and information between European and South American seasonal forecasters
- Produce improved well-calibrated real-time probabilistic seasonal forecasts for South America
- Develop real-time forecast products for non-profitable governmental use (e.g. reservoir management, hydropower production, and agriculture).

PROJECT INFORMATION

- History
- Partners

DOCUMENTS

- EUROBRISA project proposal approved by ECMWF council in June 2005: see page 5 of ECMWF newsletter No. 104
- Extension of EUROBRISA licence agreement approved by ECMWF council in June 2009: see page 3 of ECMWF newsletter No. 120
- Leverhulme research network proposal
- Powerpoint overview
- First EUROBRISA workshop
- Second EUROBRISA workshop
- Third EUROBRISA workshop

PRESENTATIONS

- EUROBRISA Integrated System Talk in Portuguese - given at CPTec and INMET, May 2005

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

New version of EUROBRISA system updated in March 2012

<http://eurobrisa.cptec.inpe.br>

Domingo,
27 Maio 2012
1:19 PM

EUROBRISA
A EURO-Brazilian Initiative for Improving South American Seasonal Forecasts

Key idea: To improve seasonal forecasts in South America, a region where there is seasonal forecast skill and useful value

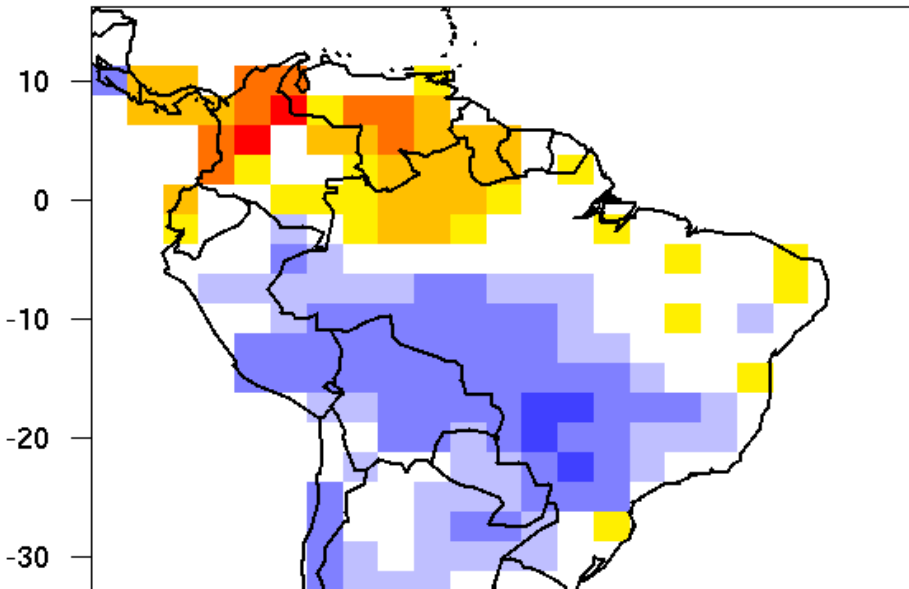
PRODUCTS → HOME

Product: Forecast Variable: precip. Model: Integrated Date Issued: May 2012
Forecast Type: Prob. most lik. tercile

→ (Products documentation)
→ Previous EUROBRISA operational System (operational until Feb 2012)

Real-time forecast and verification products

Integrated: Prob. of most likely precip. tercile (%)
Issued: May 2012 Valid for JJA 2012



AIMS

- Strengthen collaboration and promote exchange of information between European and South American meteorological services
- Produce improved well-calibrated real-time probabilistic seasonal forecasts for South America
- Develop real-time forecast products for non-profitable governmental use (e.g. reservoir management, hydropower production, and agriculture).

PROJECT INFORMATION

- History
- Partners

DOCUMENTS

- EUROBRISA project proposal approved by ECMWF council in June 2005: see page 5 of ECMWF newsletter No. 104
- Extension of EUROBRISA licence agreement approved by ECMWF council in June 2009: see page 3 of ECMWF newsletter No. 120
- Leverhulme research network proposal
- Powerpoint overview
- First EUROBRISA workshop
- Second EUROBRISA workshop
- Third EUROBRISA workshop

PRESENTATIONS

- EUROBRISA Integrated System Talk in Portuguese - given at CPTec and INMET, May 2005

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

New version of EUROBRISA updated in <http://eurobrisa.org>

1-month lead forecasts
EUROSIP: ECMWF (System 4) (NEW)
UKMO (GloSea 4)
Meteo-France (System 3)

CPTEC
Empirical (SST based)
Integrated (Combination of 5 models above)

Domingo, 27 Maio 2012 1:19 PM

A EURO-Brazilian Initiative for Improving South America

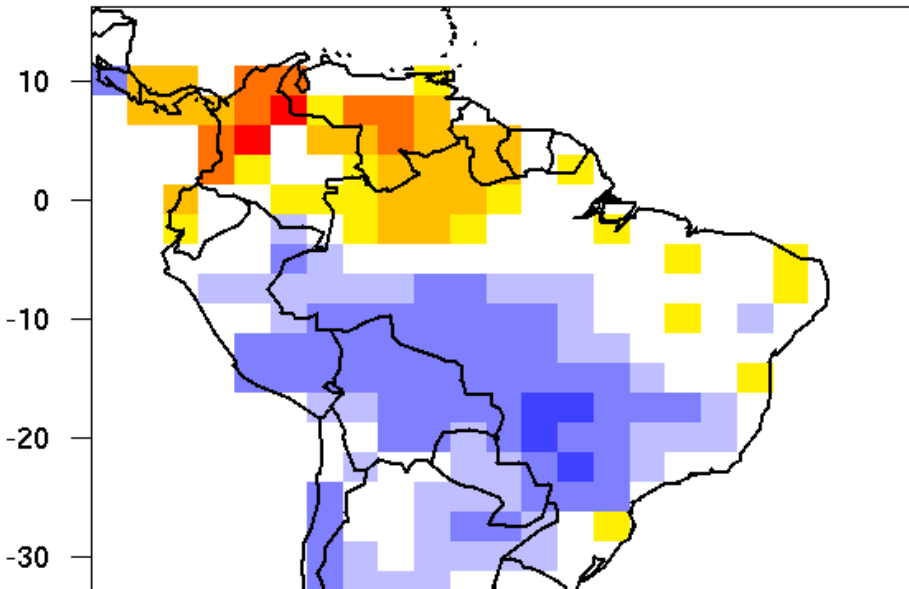
PRODUCTS

Product: Forecast Variable: precip. Model: Integrated Date Issued: May 2012

Forecast Type: Prob. most lik. tercile

Real-time forecast and verification products

Integrated: Prob. of most likely precip. tercile (%)
Issued: May 2012 Valid for JJA 2012



Strengthen collaboration and promote exchange of European and South

Produce improved well-calibrated real-time probabilistic seasonal forecasts for South America

Develop real-time forecast products for non-profitable governmental use (e.g. reservoir management, hydropower production, and agriculture).

PROJECT INFORMATION

- History
- Partners

DOCUMENTS

- EUROBRISA project proposal approved by ECMWF council in June 2005: see page 5 of ECMWF newsletter No. 104
- Extension of EUROBRISA licence agreement approved by ECMWF council in June 2009: see page 3 of ECMWF newsletter No. 120
- Leverhulme research network proposal
- Powerpoint overview
- First EUROBRISA workshop
- Second EUROBRISA workshop
- Third EUROBRISA workshop

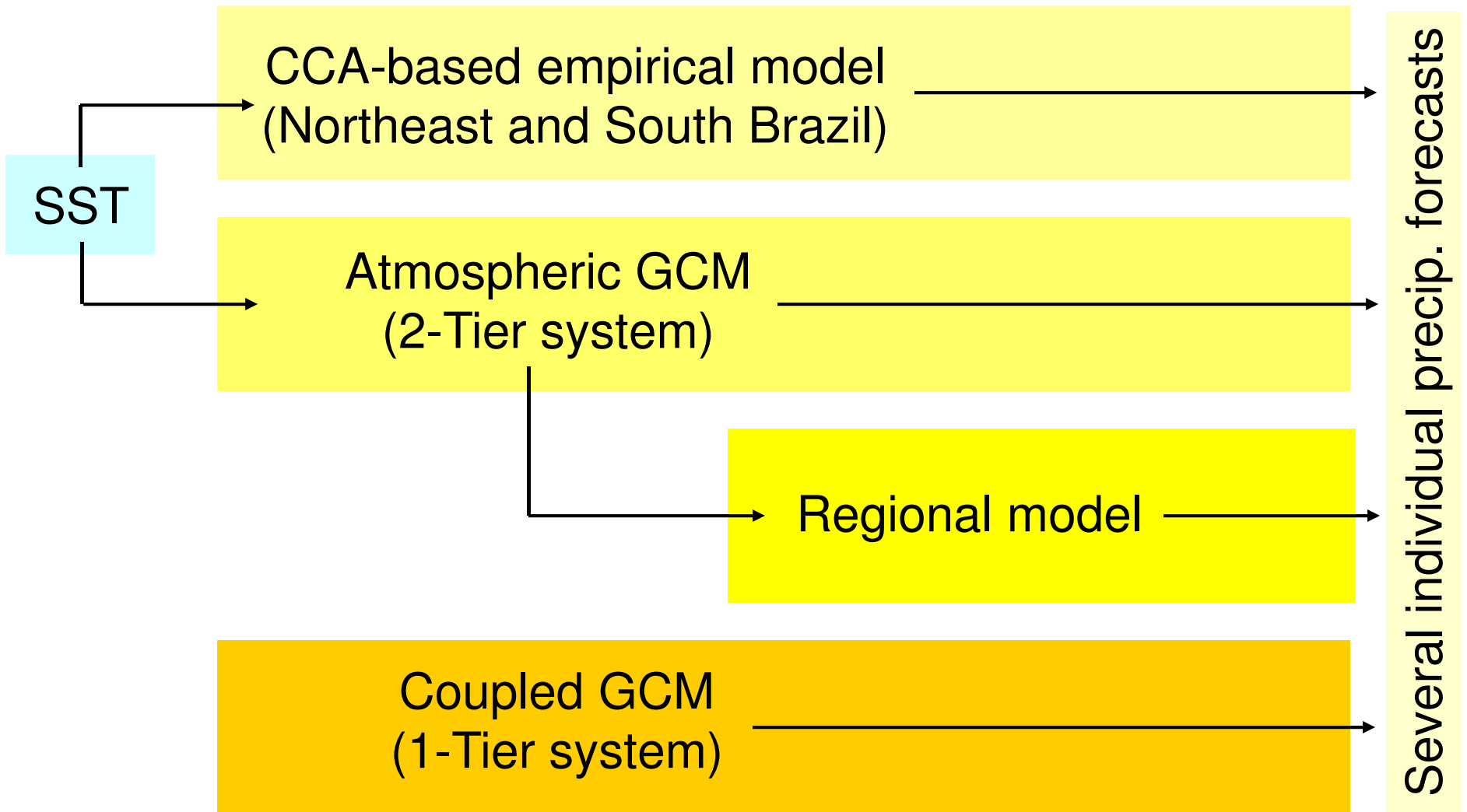
PRESENTATIONS

- EUROBRISA Integrated System Talk in Portuguese - given at CPTEC and INMET, May 2005

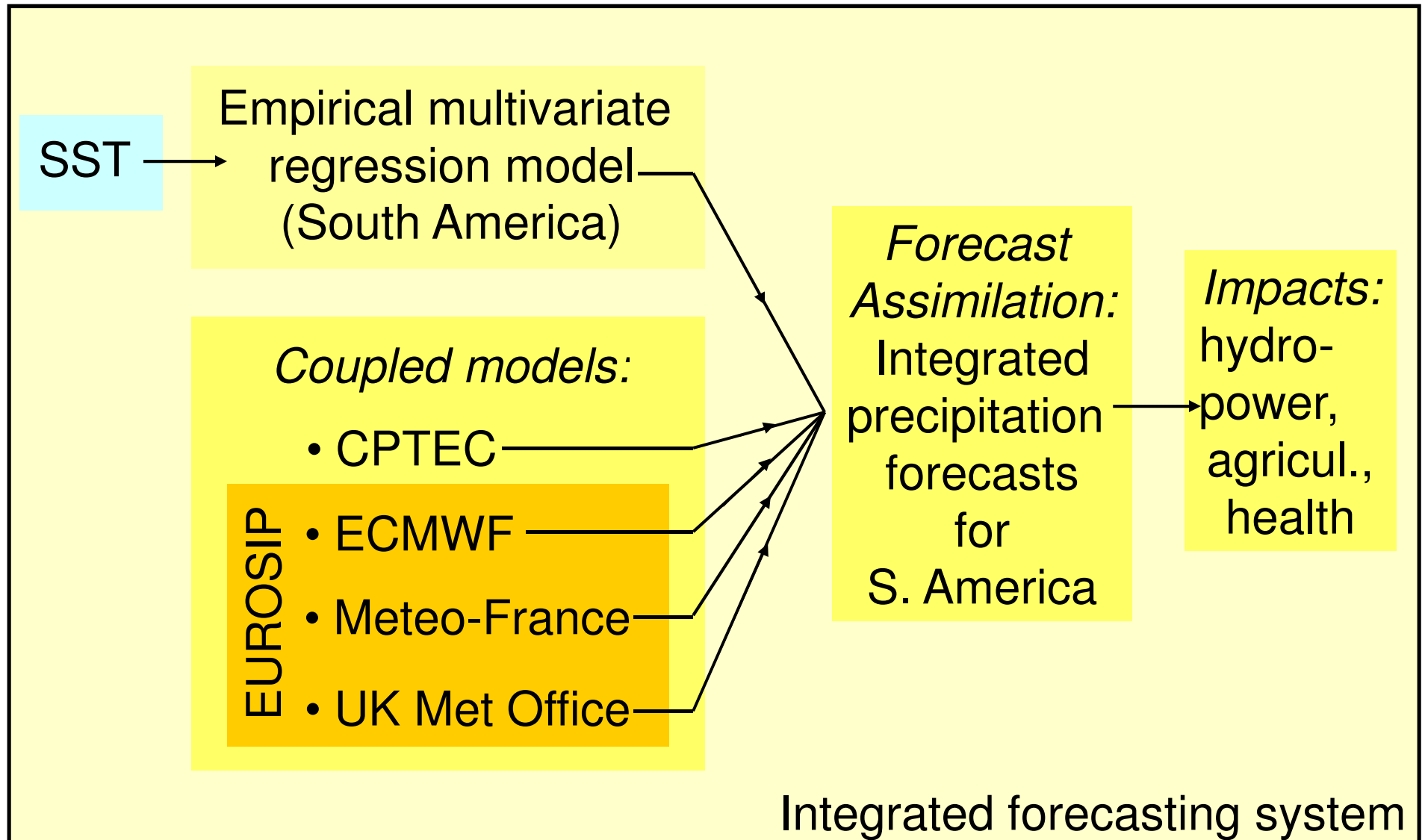
Hybrid (empirical-dynamical) multi-model ensemble system for South America

**How has EUROBRISA contributed for
improving seasonal forecasting practice
in S. America?**

Seasonal forecasting system before EUROBRISA

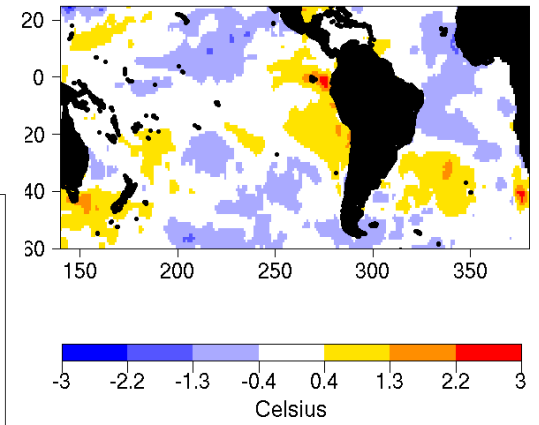


After EUROBRISA

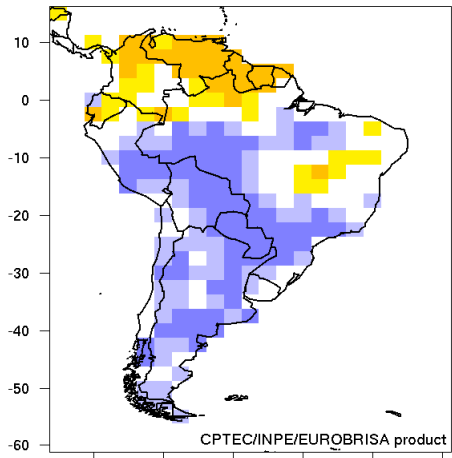


Most recent EUROBRISA integrated fcst for JJA 2012

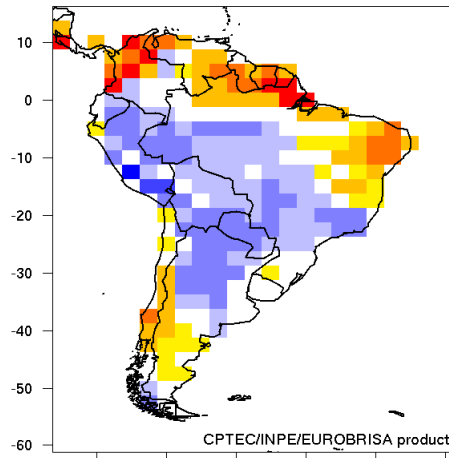
Obs. SST anomaly Apr 2012



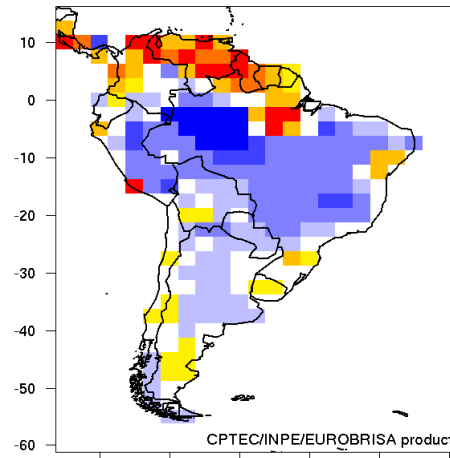
Empirical



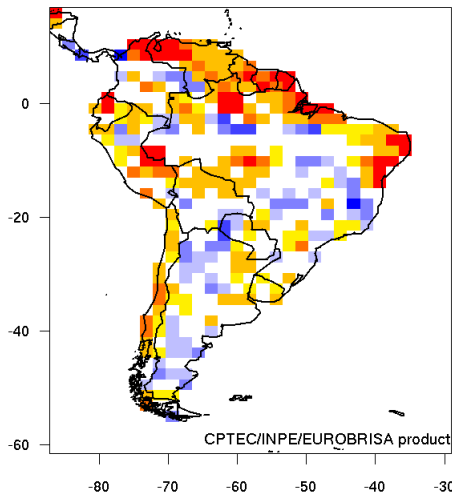
ECMWF



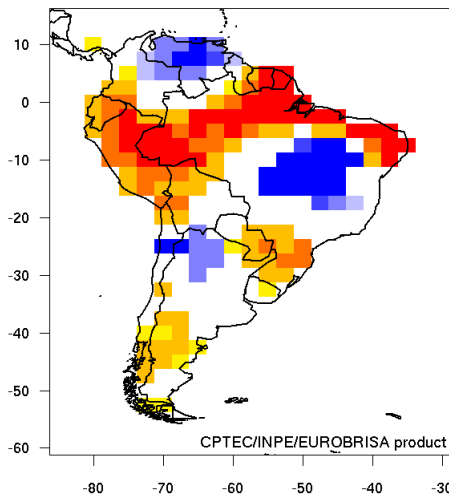
UKMO



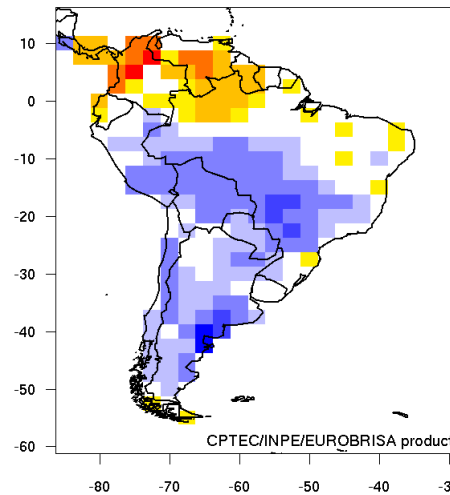
CPTEC



Meteo-France

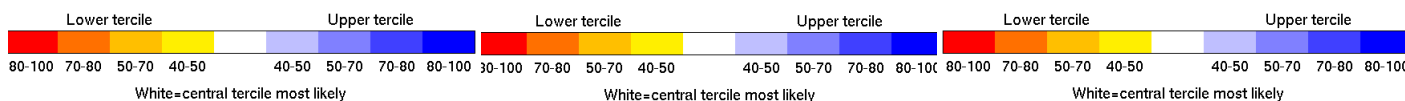


Integrated



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

EUROBRISA articles: forecasting system

- Coelho C.A.S., 2010: A new hybrid precipitation seasonal forecasting system for South America. XVI Brazilian congress of meteorology.
- Coelho C.A.S., 2009: Hybrid precipitation seasonal forecasts for South America. 9th International Conference on Southern Hemisphere Meteorology and Oceanography.
- Coelho C.A.S., 2008: EUROBRISA: A EURO-BRazilian Initiative for improving South American seasonal forecasts. XV Brazilian congress of meteorology.
- Coelho C.A.S., D.B. Stephenson, F.J. Doblas-Reyes, M. Balmaseda and R. Graham, 2007: Integrated seasonal climate forecasts for South America. CLIVAR Exchanges. No.43. Vol. 12, No. 4, 13-19.
- Tim E. Jupp, T. E., R. Lowe, C.A.S. Coelho and D. B. Stephenson, 2012: On the visualization, verification and recalibration of ternary probabilistic forecasts. *Phil. Trans. R. Soc. A*, 370, 1100–1120

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

EUROBRISA articles: impact studies

Coelho C.A.S. and S.M.S. Costa, 2010: Challenges for integrating seasonal climate forecasts in user applications. *Current Opinions in Environmental Sustainability*. Vol 2, Issues 5-6, December 2010, Pages 317-325. doi:10.1016/j.cosust.2010.09.002

Lowe R., T.C. Bailey, D.B. Stephenson, R.J. Graham, C.A.S Coelho, M. Sa Carvalho and C. Barcellos, 2010: Spatio-temporal modelling of climate-sensitive disease risk: Towards an early warning system for dengue in Brazil. *Computers & Geosciences*.
<http://dx.doi.org/10.1016/j.cageo.2010.01.008>

Balmaseda M.A., Y. Fujii, O. Alves, T. Lee, M. Rienecker, T. Rosati, D. Stammer, Y. Xue, H. Freeland, M. J. McPhaden, L. Goddard and C.A.S. Coelho, 2009: "Role of the ocean observing system in an end-to-end seasonal forecasting system." *OceanObs'09 Conference*.

Costa S.M.S. and C.A.S. Coelho, 2009: "Crop yield predictions using seasonal climate forecasts." Poster. Third international symposium of climatology.

Balbino H.T., L.T.G. Fortes, E.G.P. Parente, 2009: "Avaliacao do uso do modelo climatico global do Centro Europeu para antecipar a estimativa do risco associado a epidemias da ferrugem Asiatica da soja." Third international symposium of climatology.

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