The use of seasonal climate predictions in South America

Caio A. S. Coelho
Centro de Previsão de Tempo e Estudos Climáticos (CPTEC)
Instituto Nacional de Pesquisas Espaciais (INPE)
caio.coelho@cptec.inpe.br

PLAN OF TALK

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

ECMWF Seminar on Seasonal prediction: science and applications
Reading, 3-7 September 2012

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)

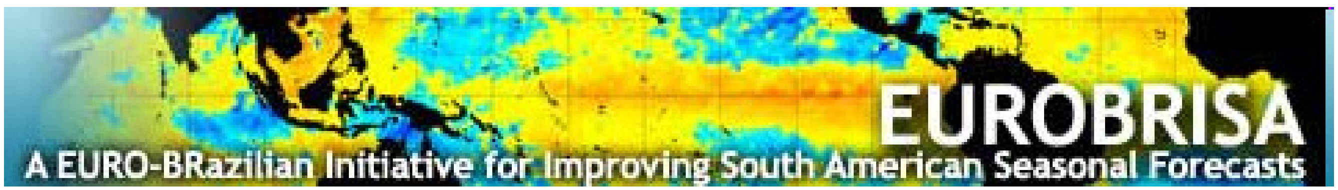
Comparing statistical and dynamical prediction systems:

	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

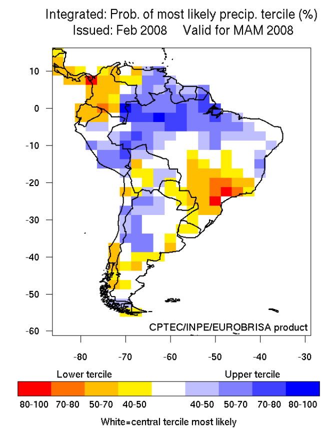
Why not combine all available state-of-the-art forecast information from both sources (empirical and dynamical)?

↓

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

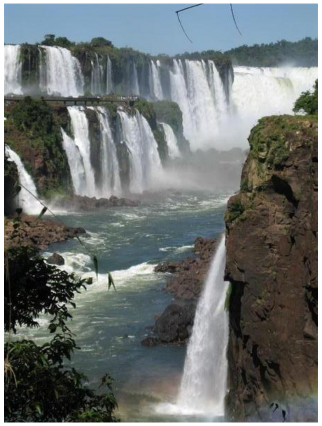
EUROBRISA aims

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

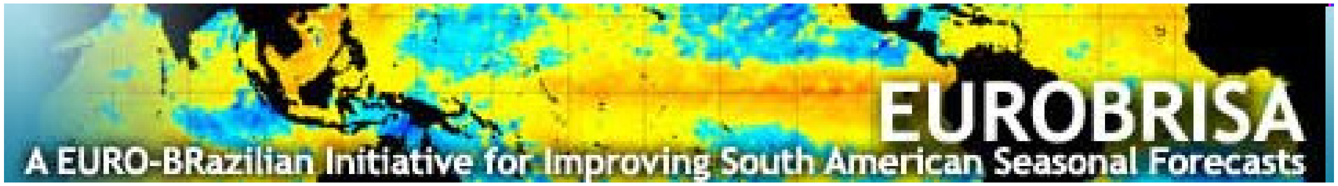


- Produce improved seasonal climate forecasts for South America using recent scientific advances in both coupled ocean-atmosphere modelling and statistical calibration and combination of multi-model ensemble forecasts;

- 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!

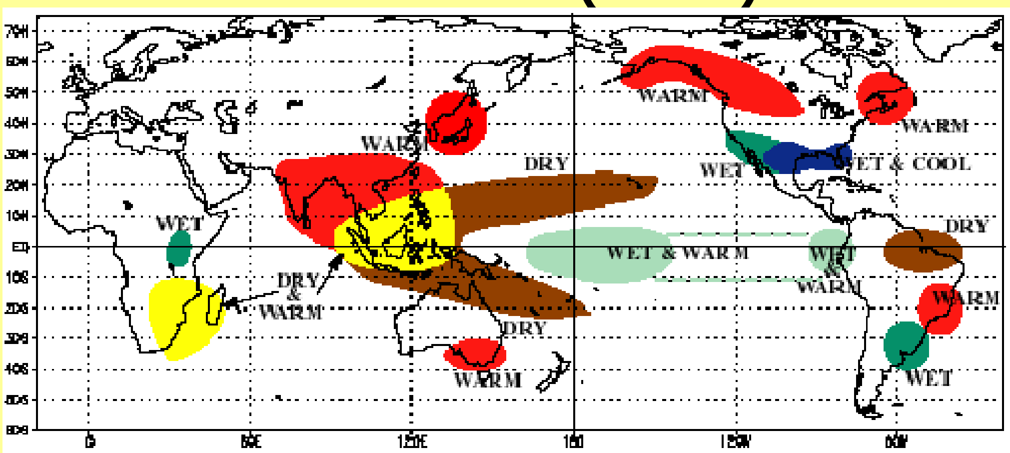


http://eurobrisa.cptec.inpe.br

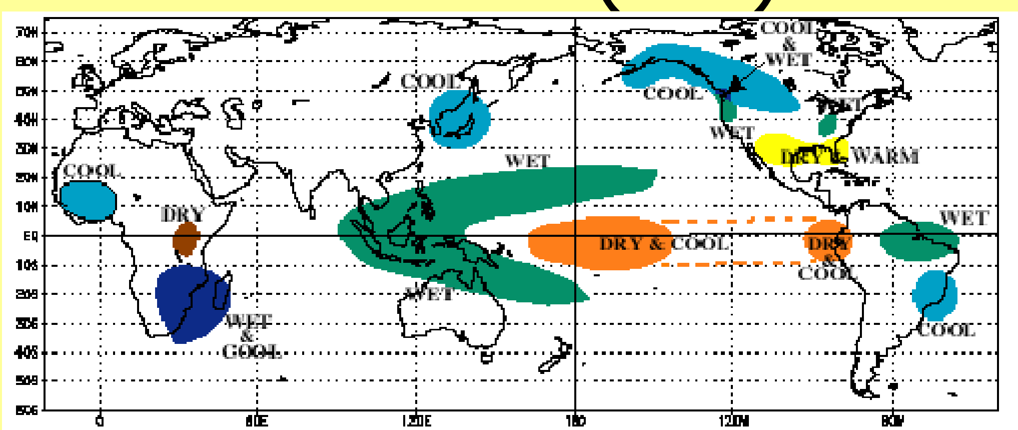
Why South America?

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

El Niño (DJF)

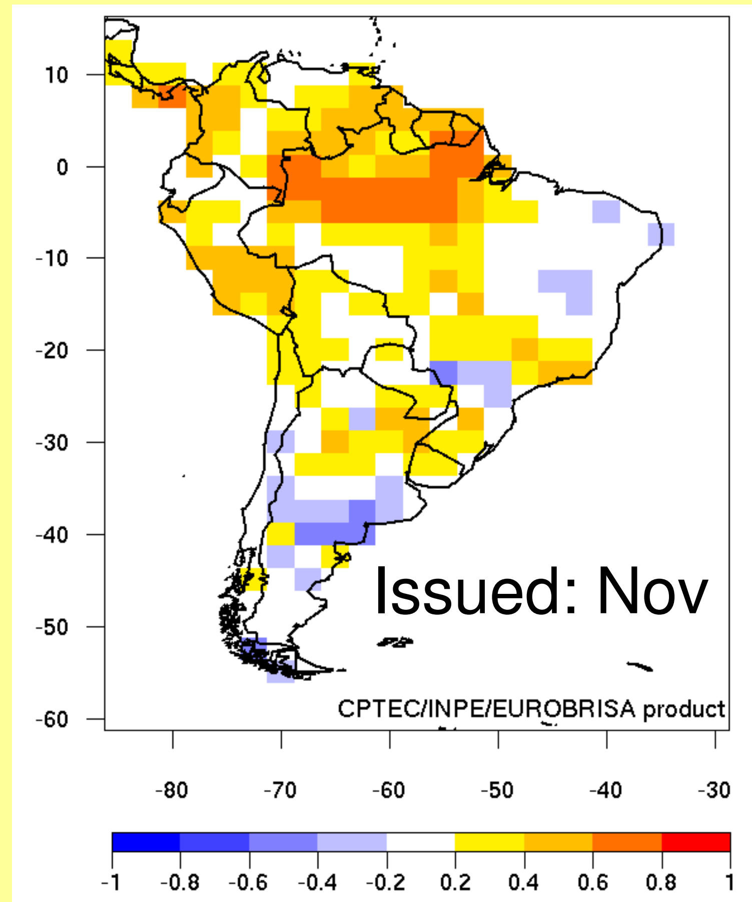


La Niña (DJF)



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

Correlation skill precipitation forecasts for DJF



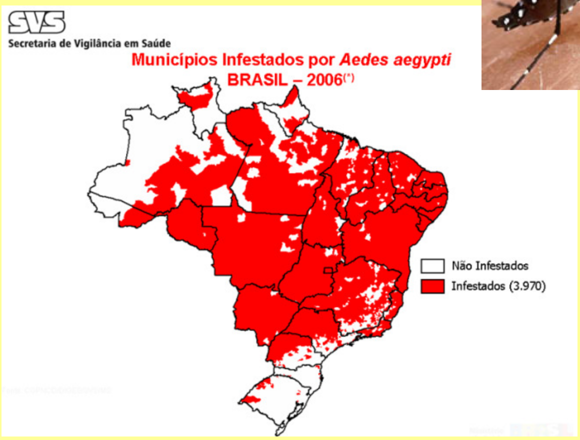
Pos. values: moderate-good skill

Application areas in need of seasonal forecasts

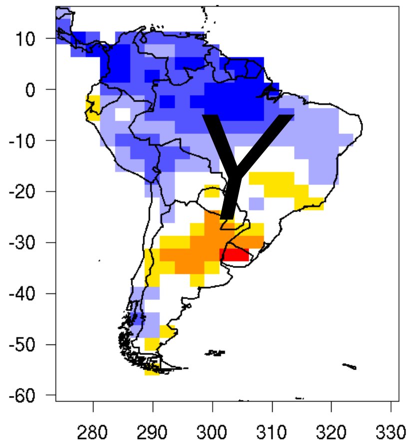
→ Electricity: Brazil, about 70% produced by hydropower stations

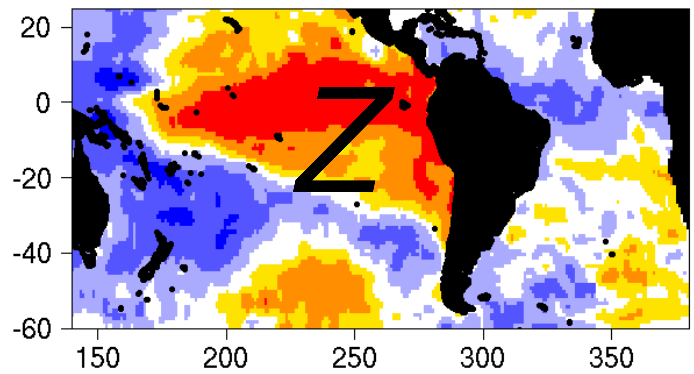
→ Agriculture (e.g. crop yield)

→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

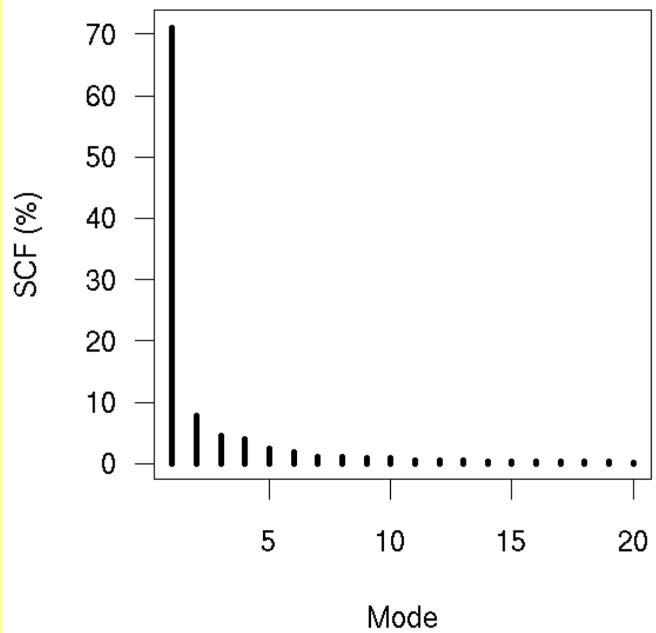
Z: October sea surface temp. (SST)

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

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

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

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.

Integrated forecast

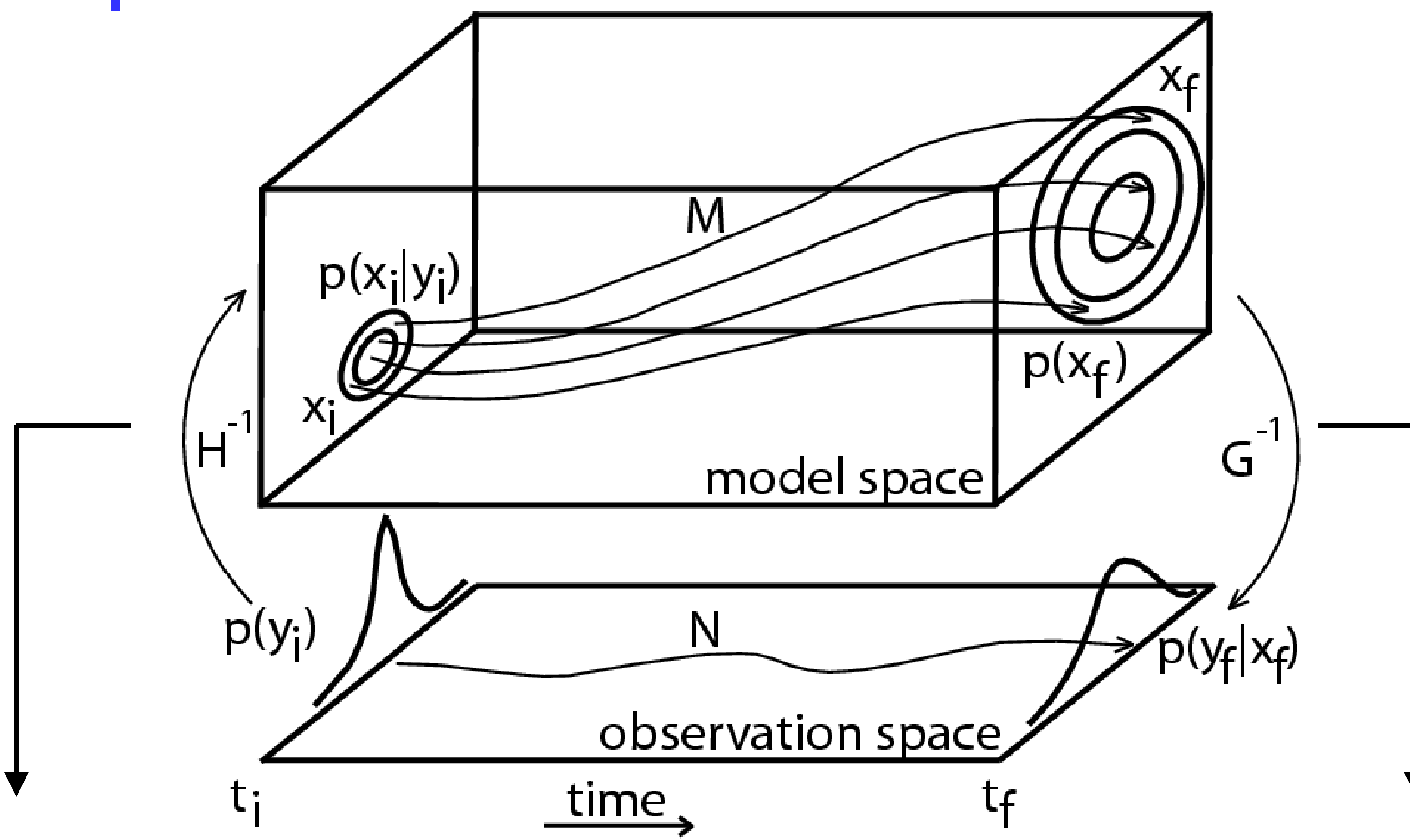
Empirical model
Predictors: Atlantic and Pacific SST
Predictand: Precipitation
Coelho *et al.* (2006) *J. Climate, 19*, 3704-3721

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

$$p(x_i \mid y_i) = \frac{p(y_i \mid x_i)\,p(x_i)}{p(y_i)}$$

"*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

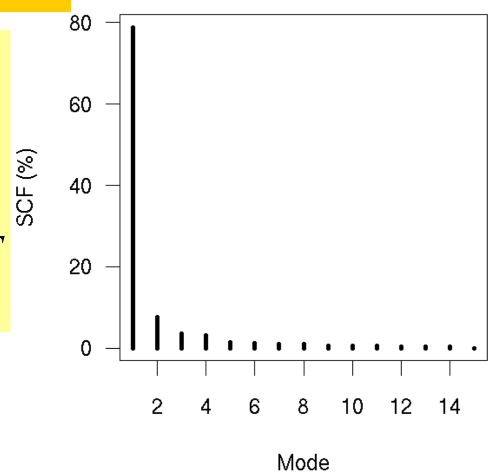
$$p(Y|X) = \frac{p(X|Y)\,p(Y)}{p(X)}$$

X: precip. fcsts (coupled + empir.)
Y: DJF precipitation

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

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

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



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

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

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.: $Y_b = \overline{Y} \qquad C = S_{YY}$

FA becomes: $Y \mid X \sim N(L(X - X_o), D)$

$$L = S_{YX} S_{XX}^{-1}$$
$$-LX_o = \overline{Y} - \overline{X}L$$
$$D = S_{YY} - S_{YX} S_{XX}^{-1} S_{YX}^{T}$$

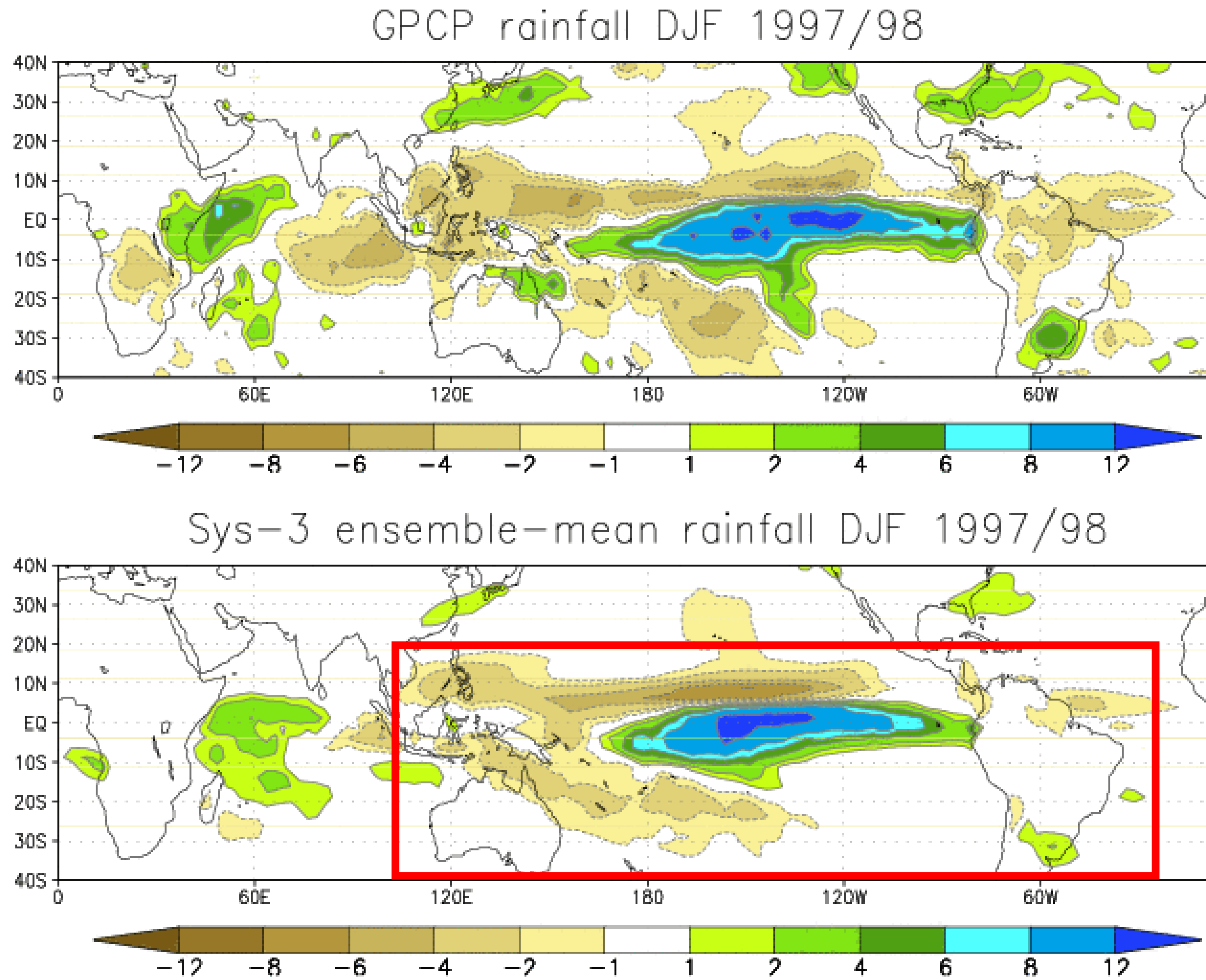
Posterior: $Y \mid X \sim N(Y_a, D)$

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

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?



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

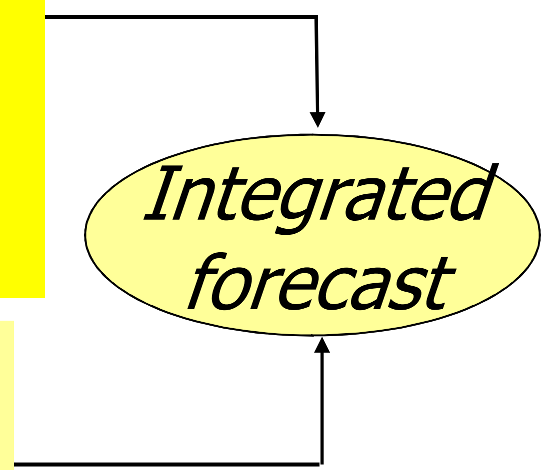
Source: Franco Molteni (ECMWF)

Current EUROBRISA integrated forecasting system for South America

→Combined and calibrated coupled + empirical precip. forecasts

→Hybrid multi-model probabilistic system

Couple model	*Country*
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

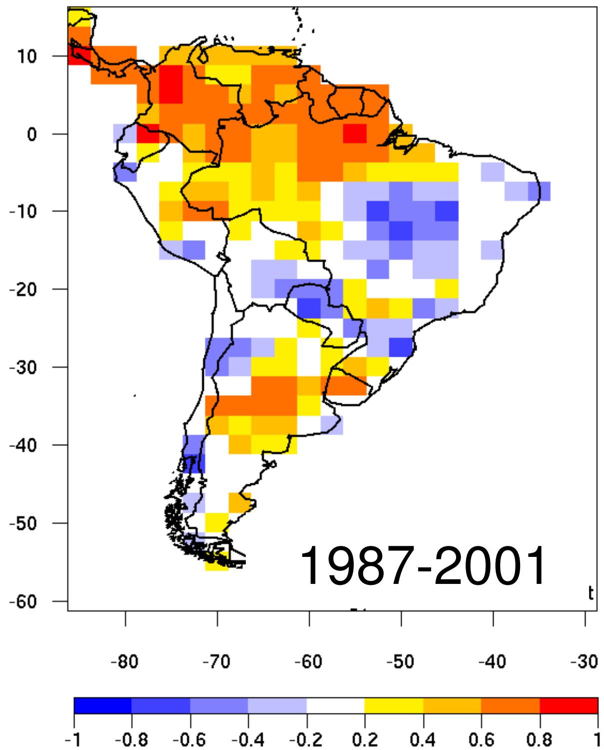
Produced with forecast assimilation
Stephenson et al (2005) Tellus A . Vol. 57, 253-264

Hindcast period: 1981-2005

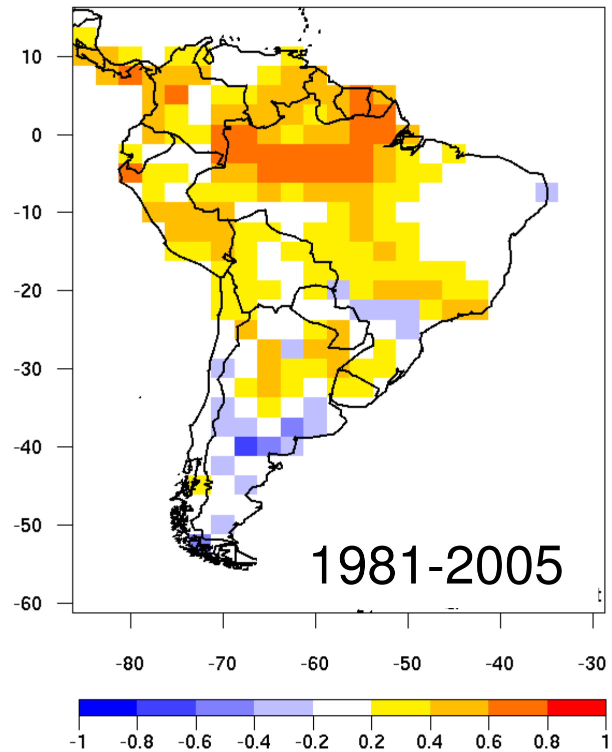
Implemented in Mar 2012

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)

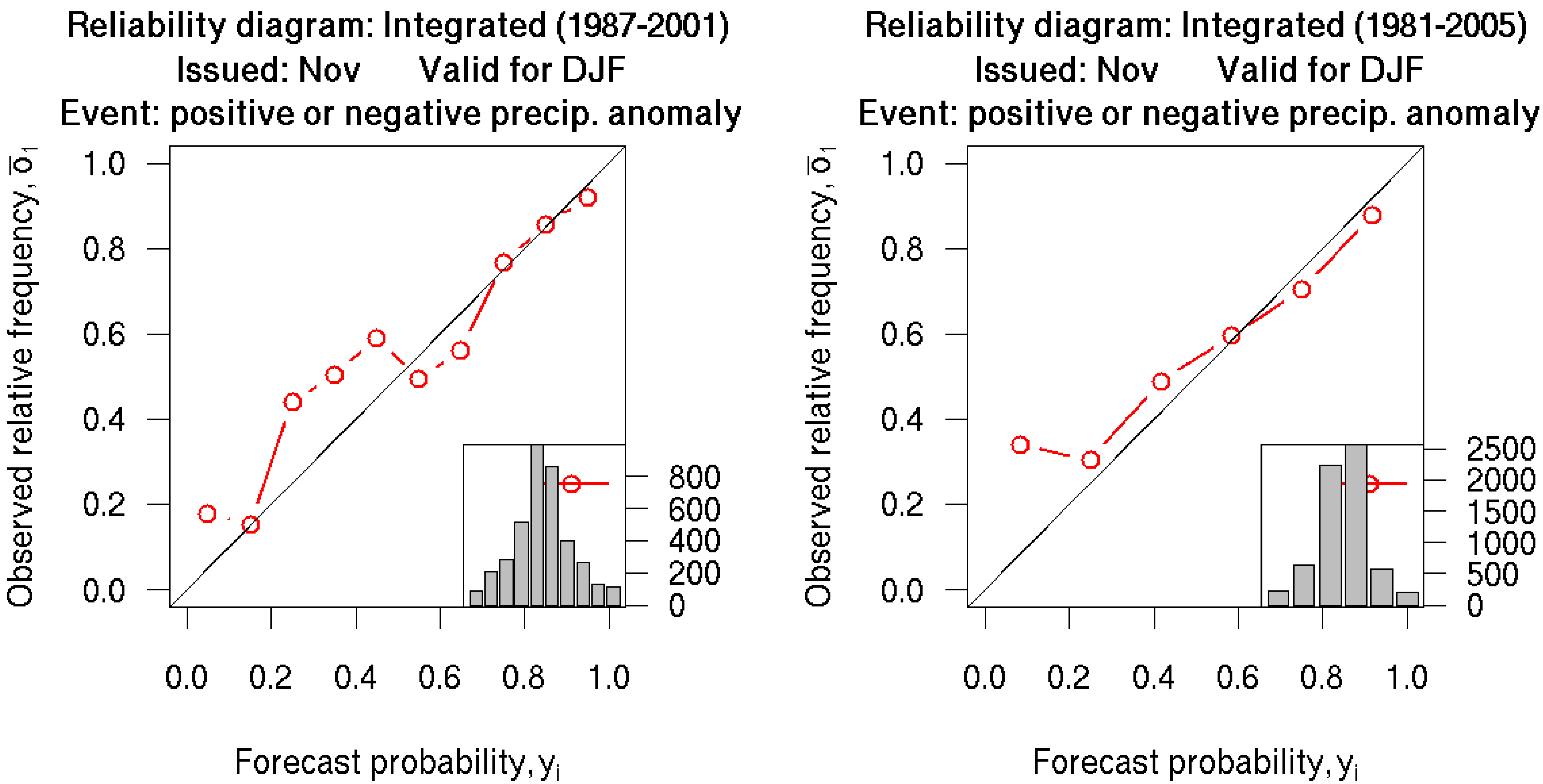


South America + Pacific domain:
ECMWF, UKMO, MF, CPTEC
and empirical (diff. hind. periods)

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?



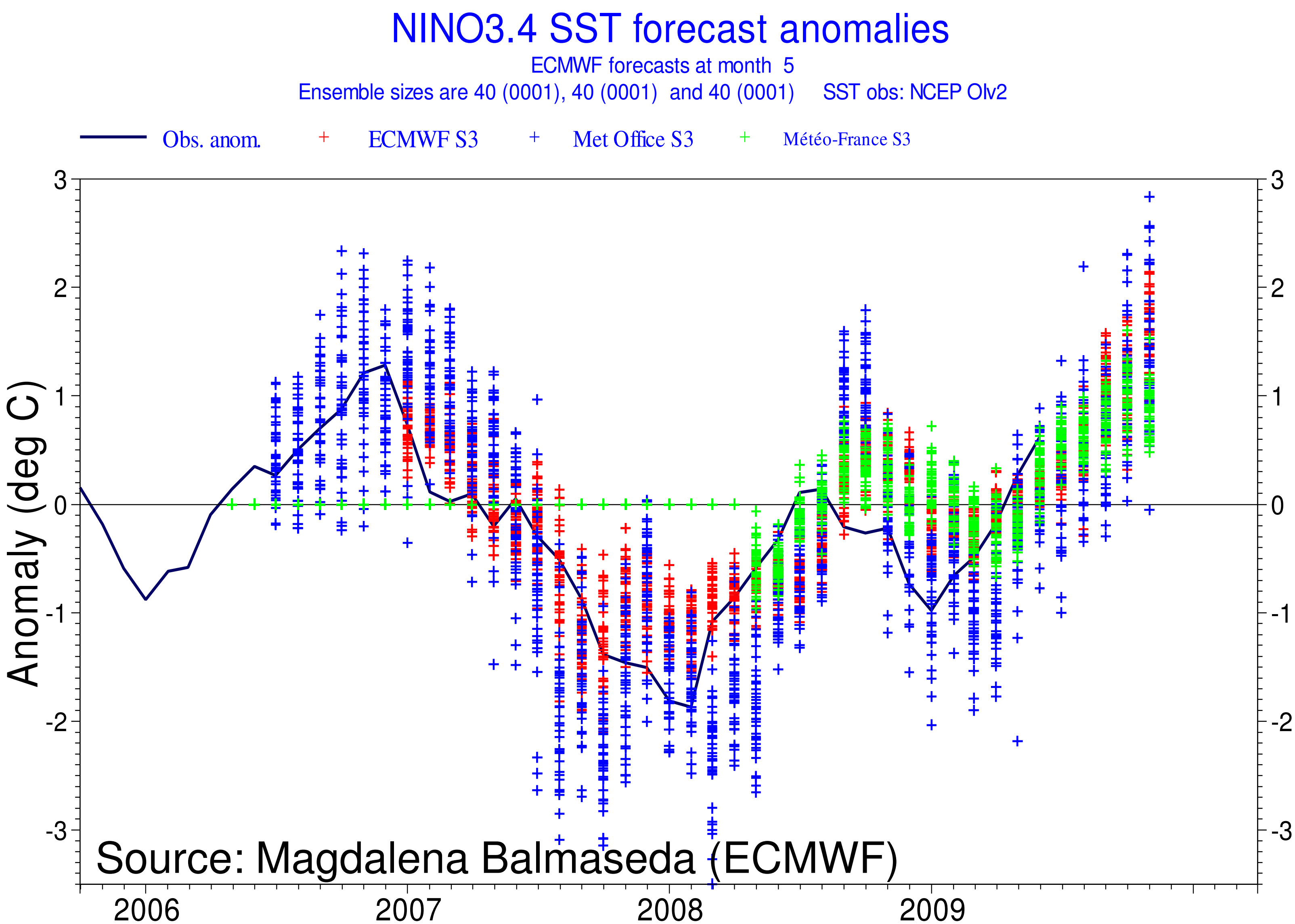
South America domain:
ECMWF, UKMO and empirical
(limited to common hindcast period)

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

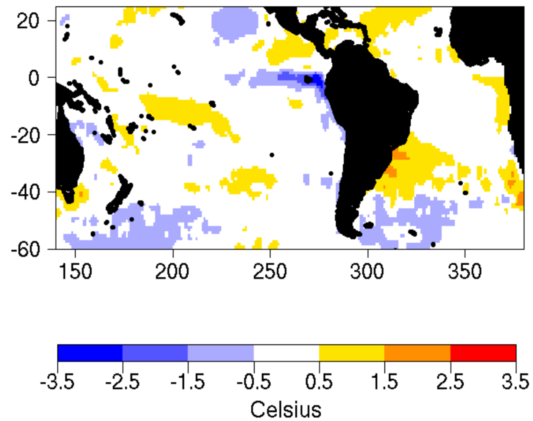


The EUROSIP multimodel captured well the onset, amplitude and long duration of La Nina conditions

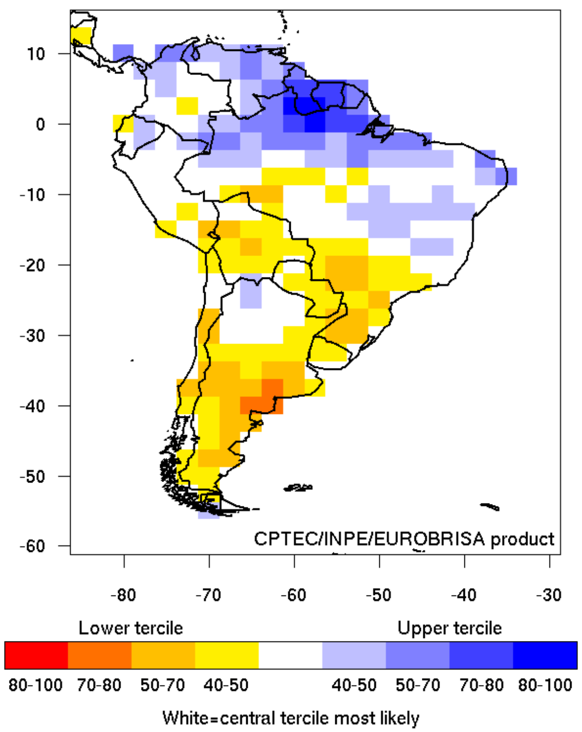
EUROBRISA integrated forecast for JJA 2007

Issued: May 2007

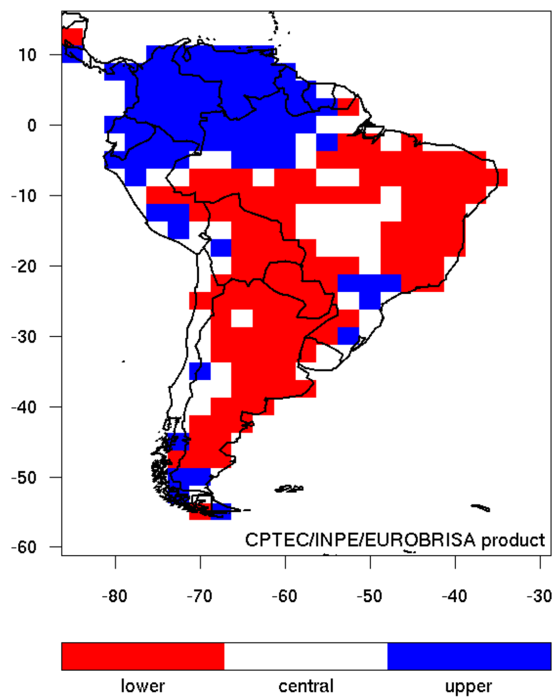
Obs. SST anomaly Apr 2007



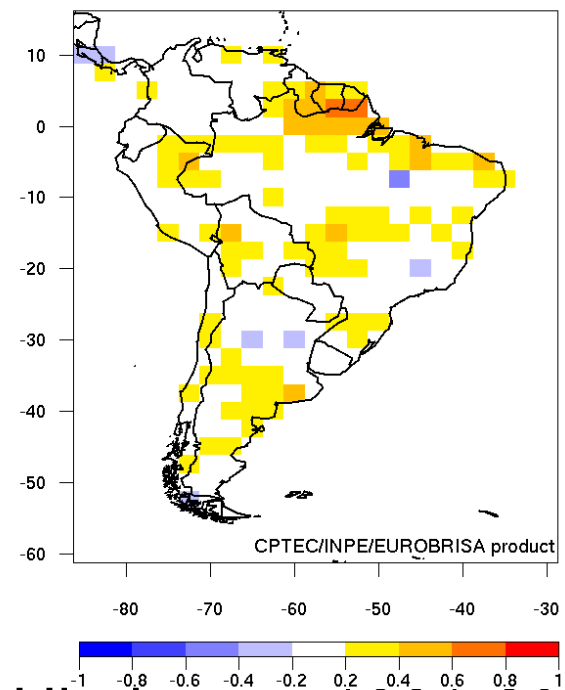
Prob. of most likely precip. tercile (%)



Observed precip. tercile



Gerrity score (tercile categories)

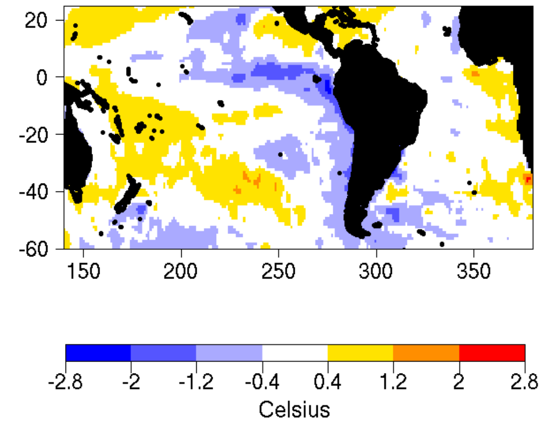


Hindcasts: 1981-2005

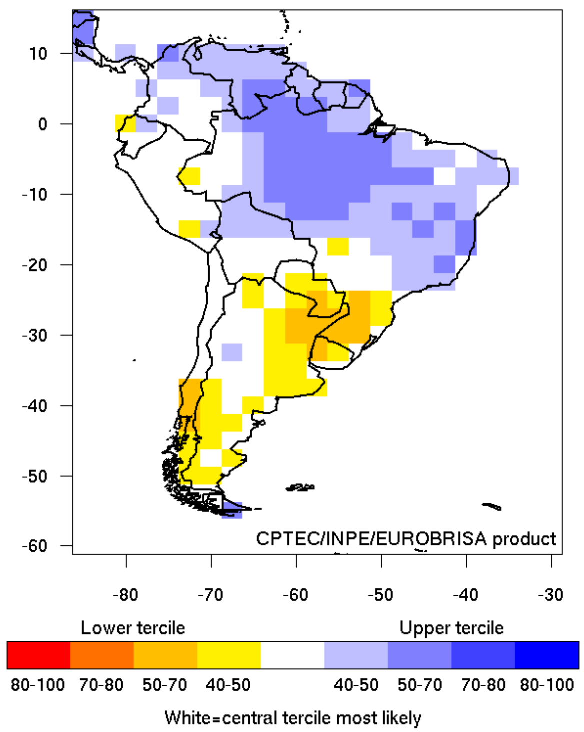
EUROBRISA integrated forecast for SON 2007

Issued: Aug 2007

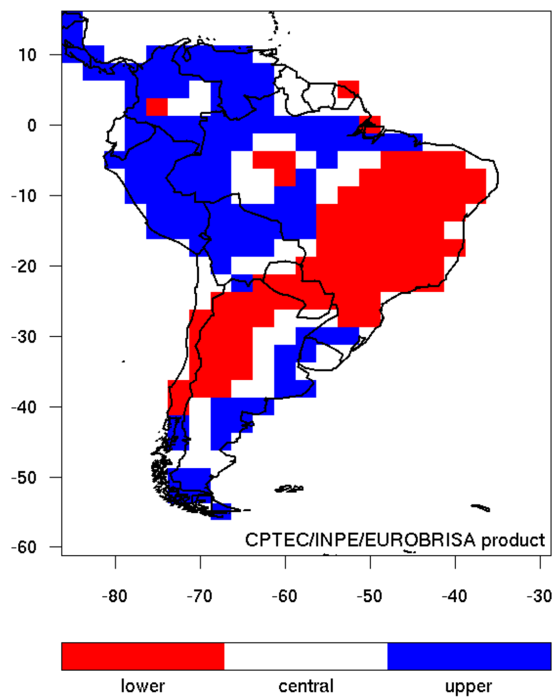
Obs. SST anomaly Jul 2007



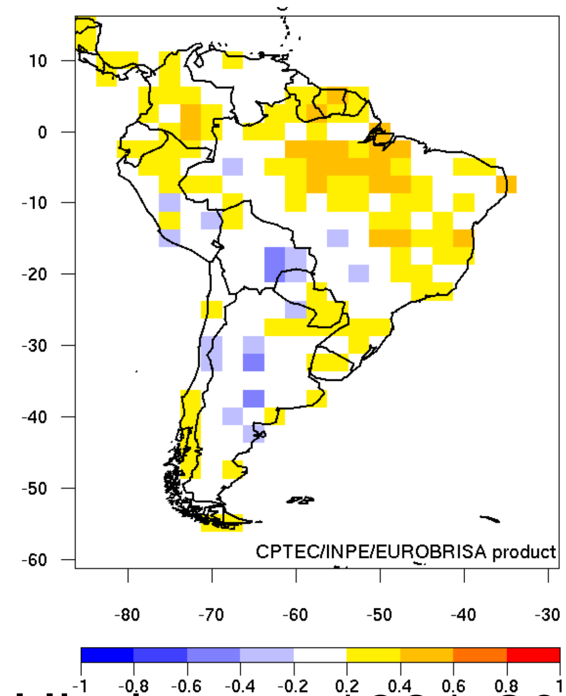
Prob. of most likely precip. tercile (%)



Observed precip. tercile



Gerrity score (tercile categories)

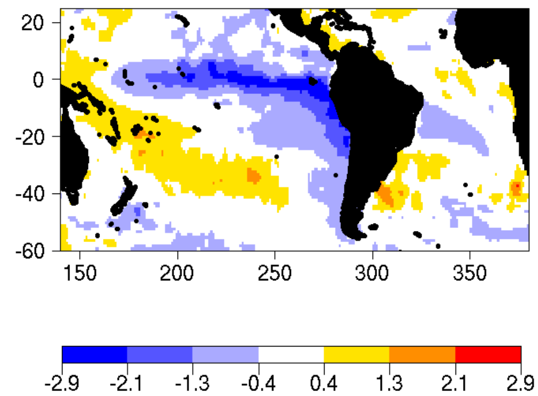


Hindcasts: 1981-2005

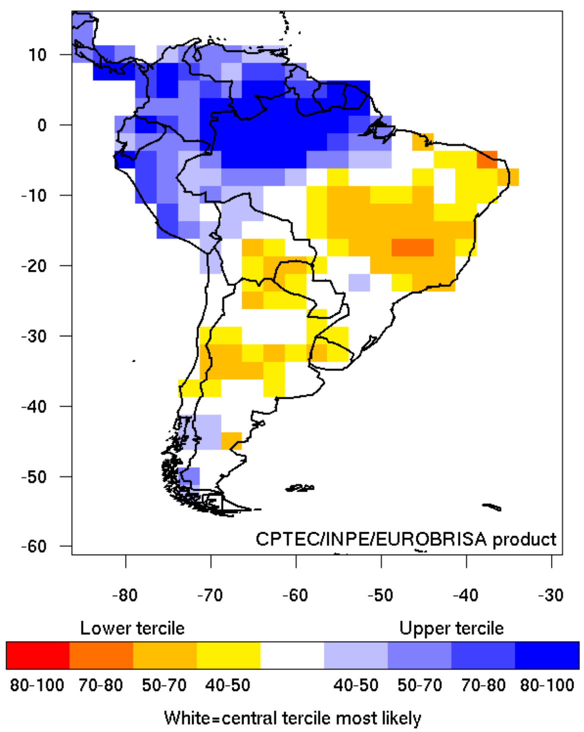
EUROBRISA integrated forecast for DJF 2007/2008

Issued: Nov 2007

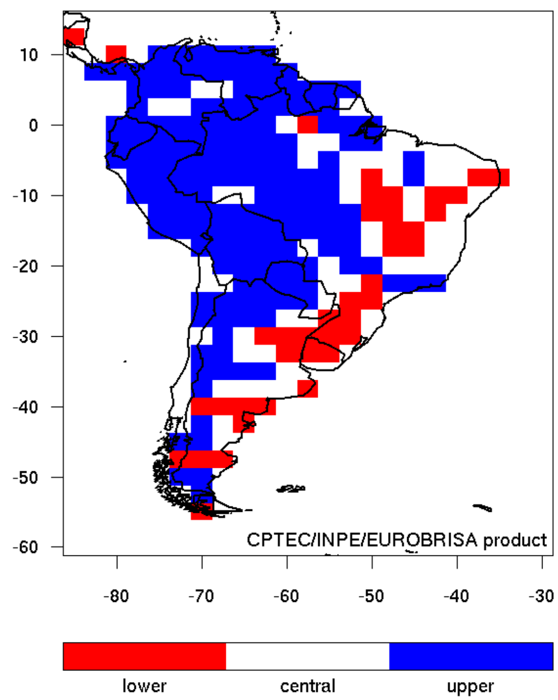
Obs. SST anomaly Oct 2007



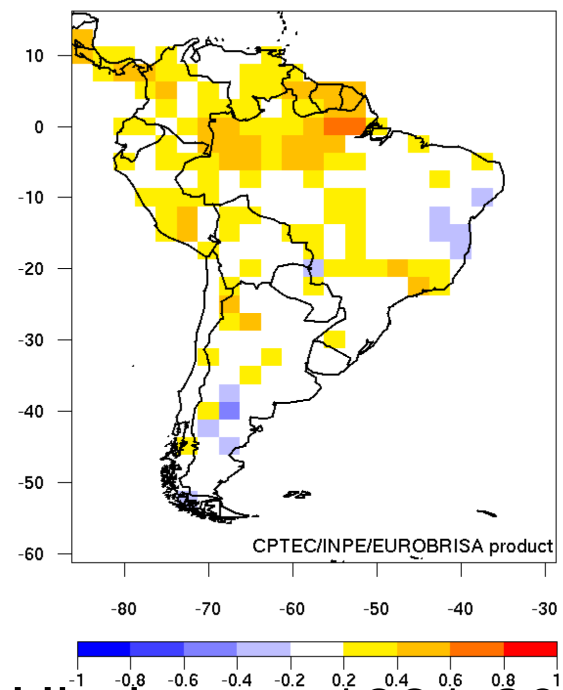
Prob. of most likely precip. tercile (%)



Observed precip. tercile



Gerrity score (tercile categories)

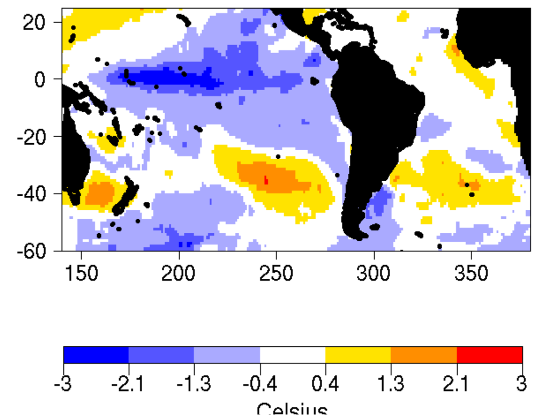


Hindcasts: 1981-2005

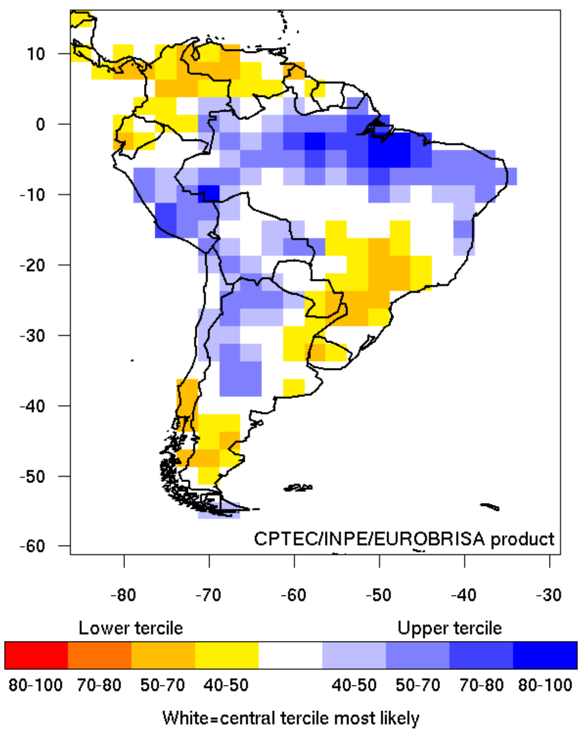
EUROBRISA integrated forecast for MAM 2008

Issued: Feb 2008

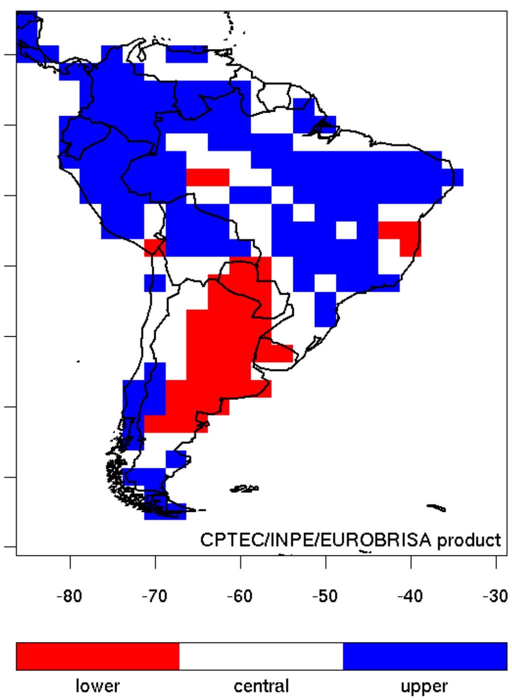
Obs. SST anomaly Jan 2008



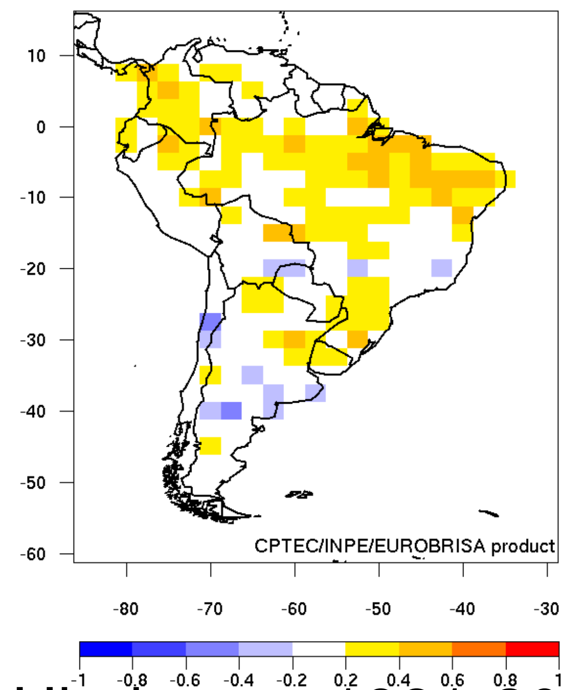
Prob. of most likely precip. tercile (%)



Observed precip. tercile



Gerrity score (tercile categories)

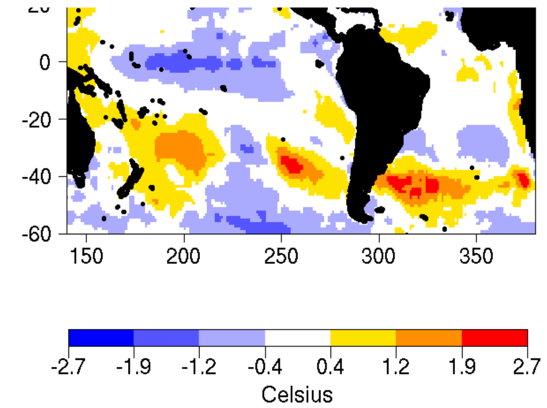


Hindcasts: 1981-2005

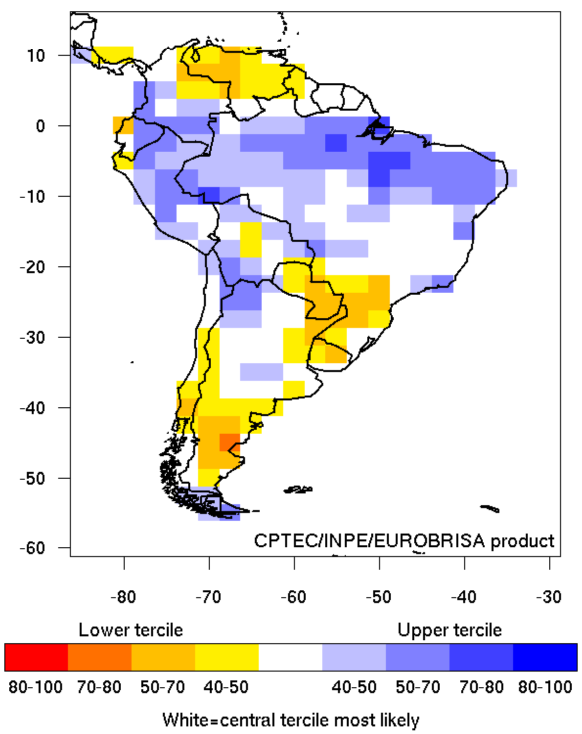
EUROBRISA integrated forecast for MAM 2009

Issued: Feb 2009

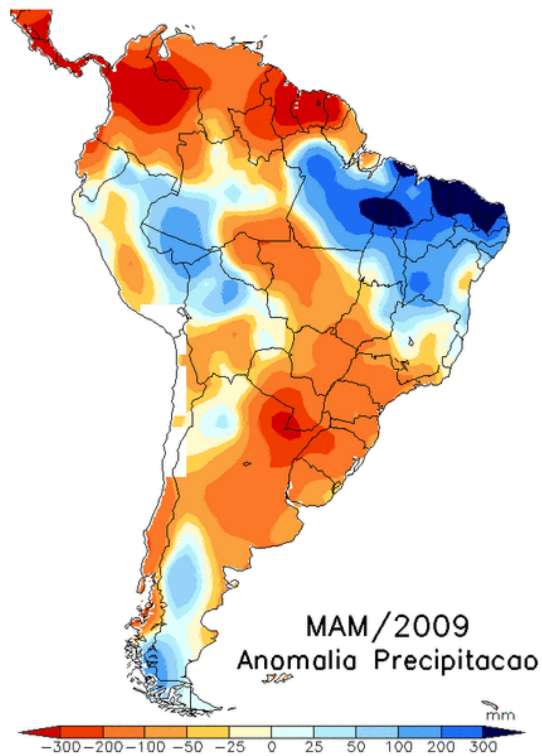
Obs. SST anomaly Jan 2009



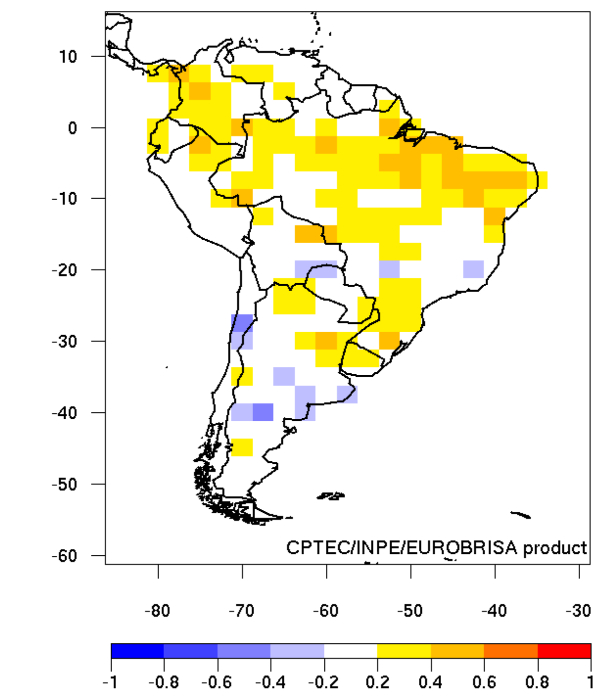
Prob. of most likely precip. tercile (%)



Observed precip.



Gerrity score (tercile categories)

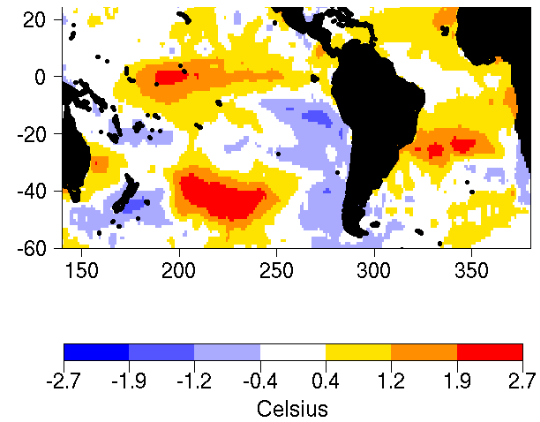


Hindcasts: 1981-2005

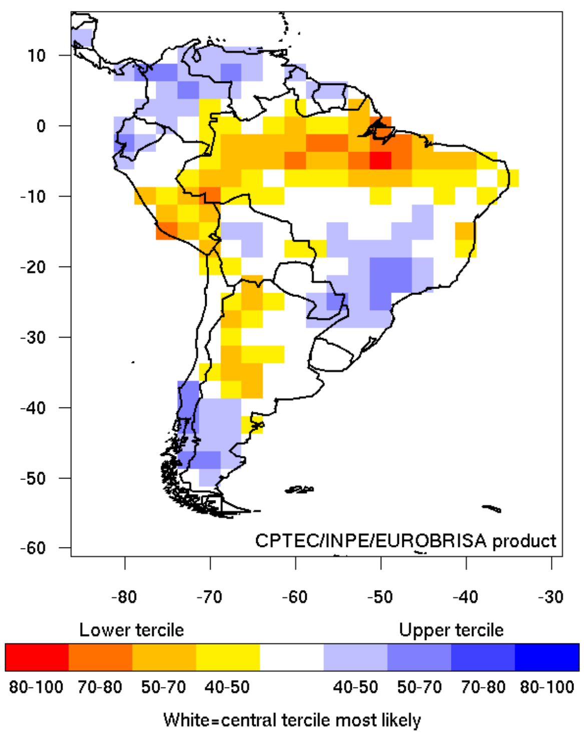
EUROBRISA integrated forecast for MAM 2010

Issued: Feb 2010

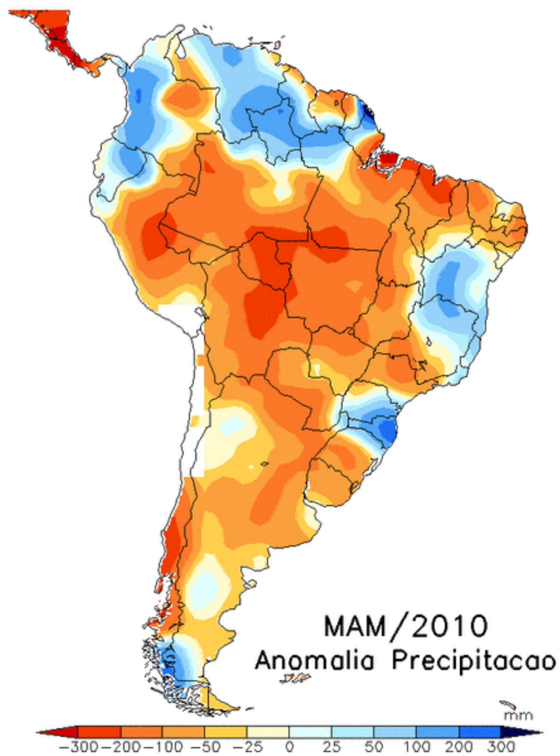
Obs. SST anomaly Jan 2010



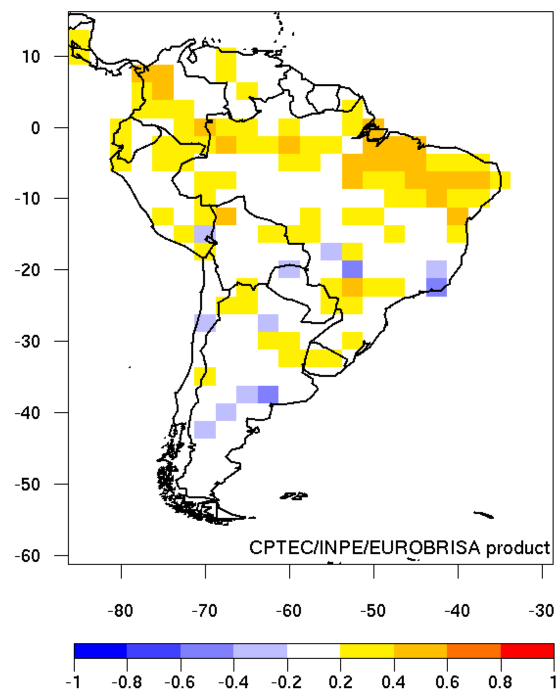
Prob. of most likely precip. tercile (%)



Observed precip.



Gerrity score (tercile categories)

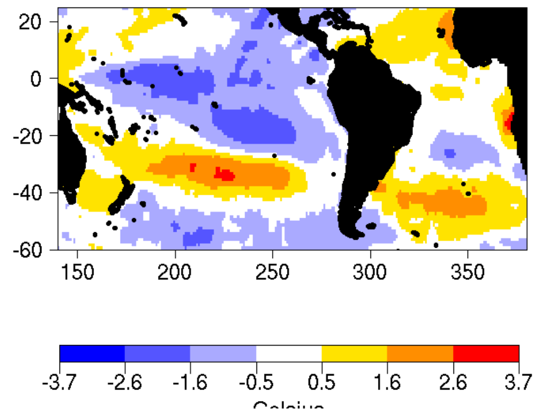


Hindcasts: 1981-2005

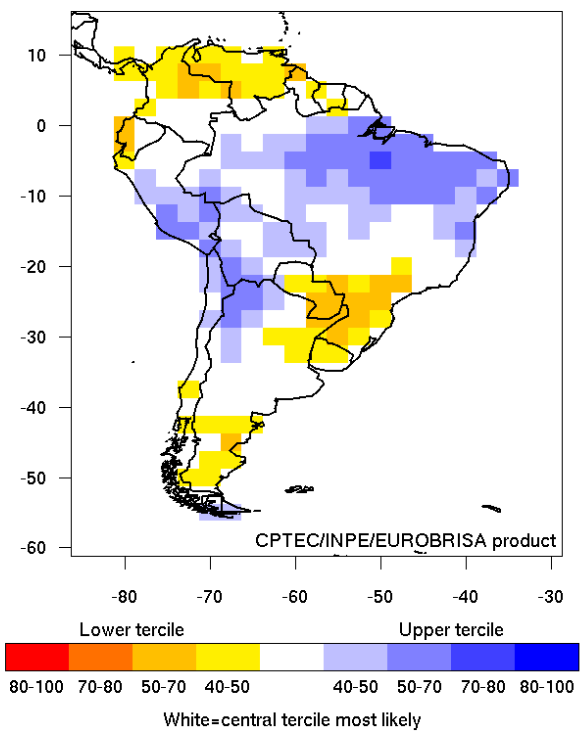
EUROBRISA integrated forecast for MAM 2011

Issued: Feb 2011

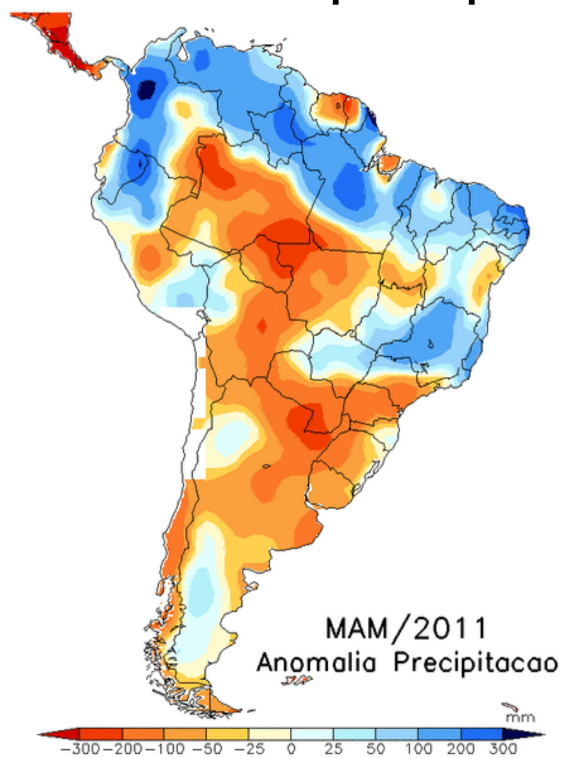
Obs. SST anomaly Jan 2011



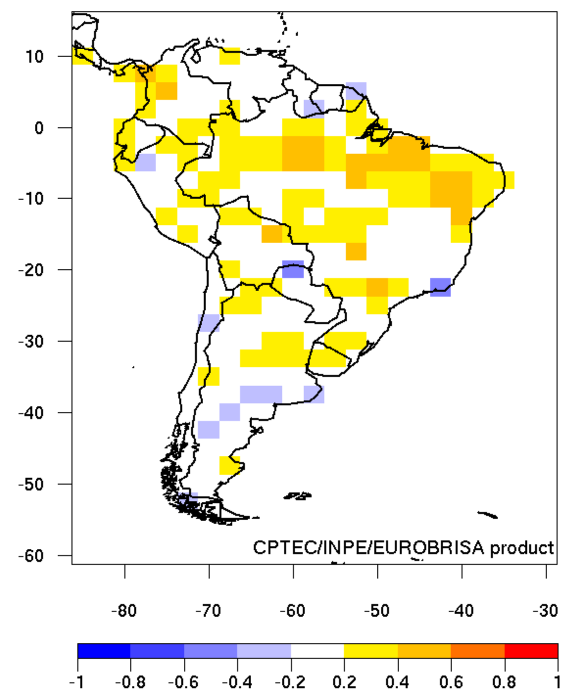
Prob. of most likely precip. tercile (%)



Observed precip.



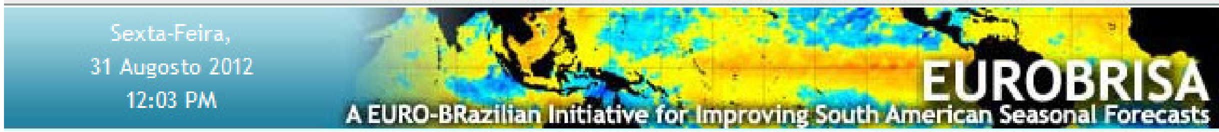
Gerrity score (tercile categories)



Hindcasts: 1981-2005

New version of EUROBRISA system updated in March 2012

http://eurobrisa.cptec.inpe.br



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

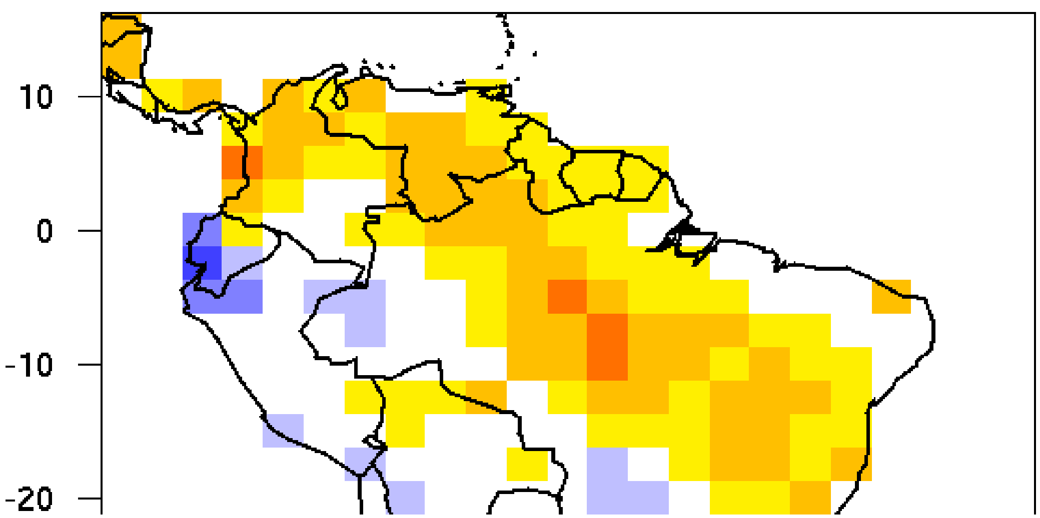
PRODUCTS

Product: Forecast Variable: precip. Model: Integrated Date Issued: Aug 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: Aug 2012 Valid for SON 2012



HOME

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

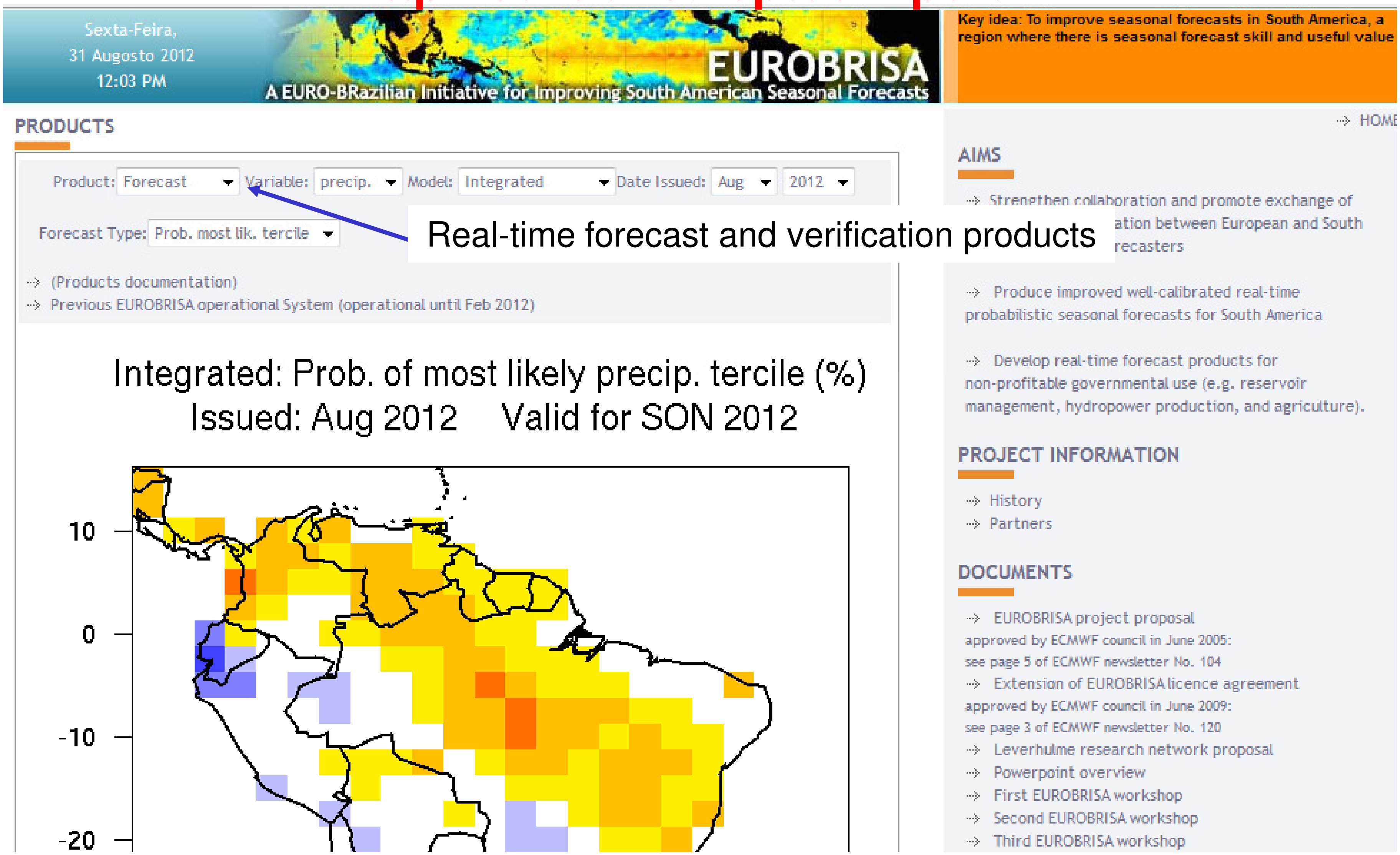
DOCUMENTS

- 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

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

New version of EUROBRISA system updated in March 2012

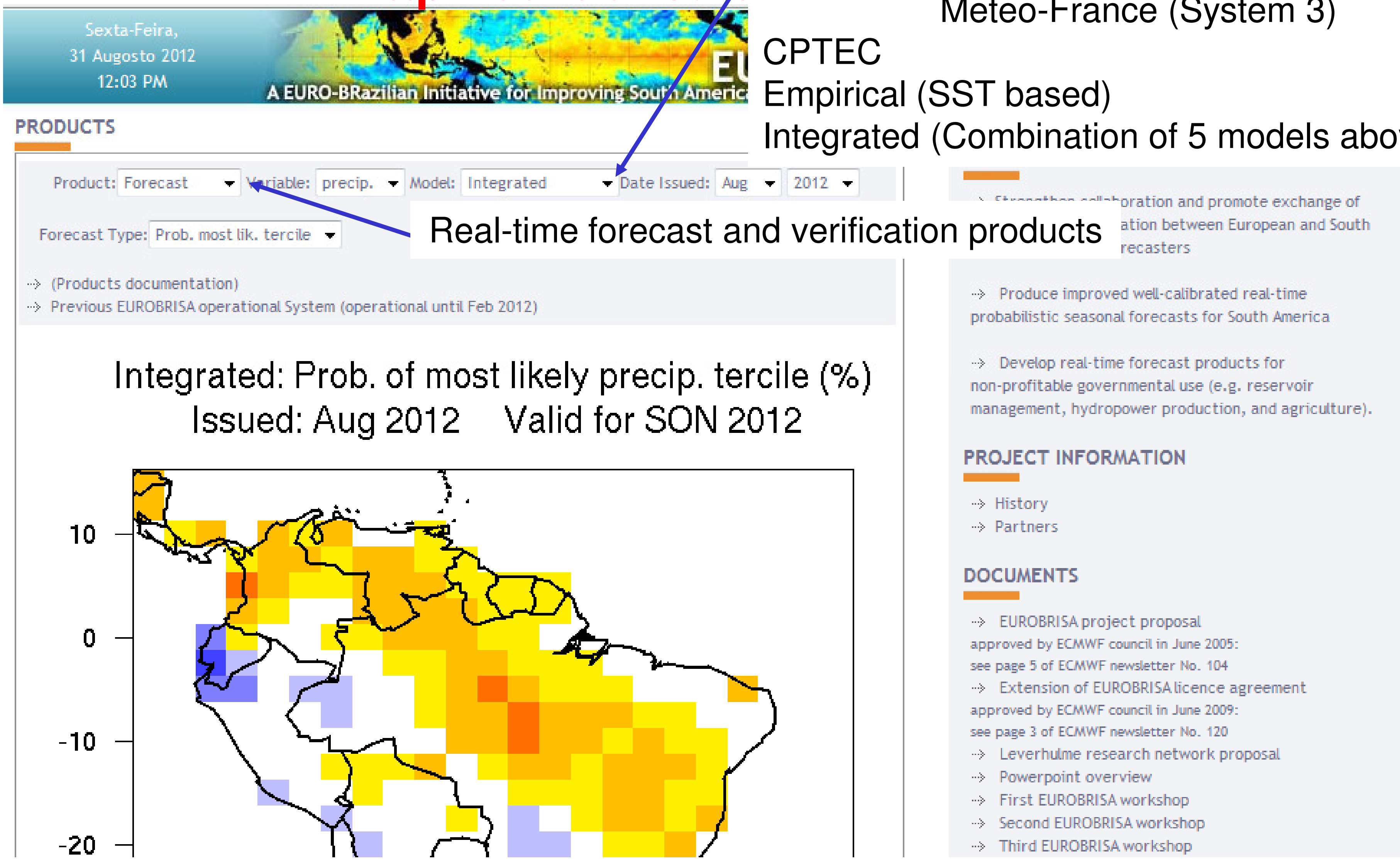
http://eurobrisa.cptec.inpe.br



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

New version of EU
updated in
http://eurobrisa.c

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)

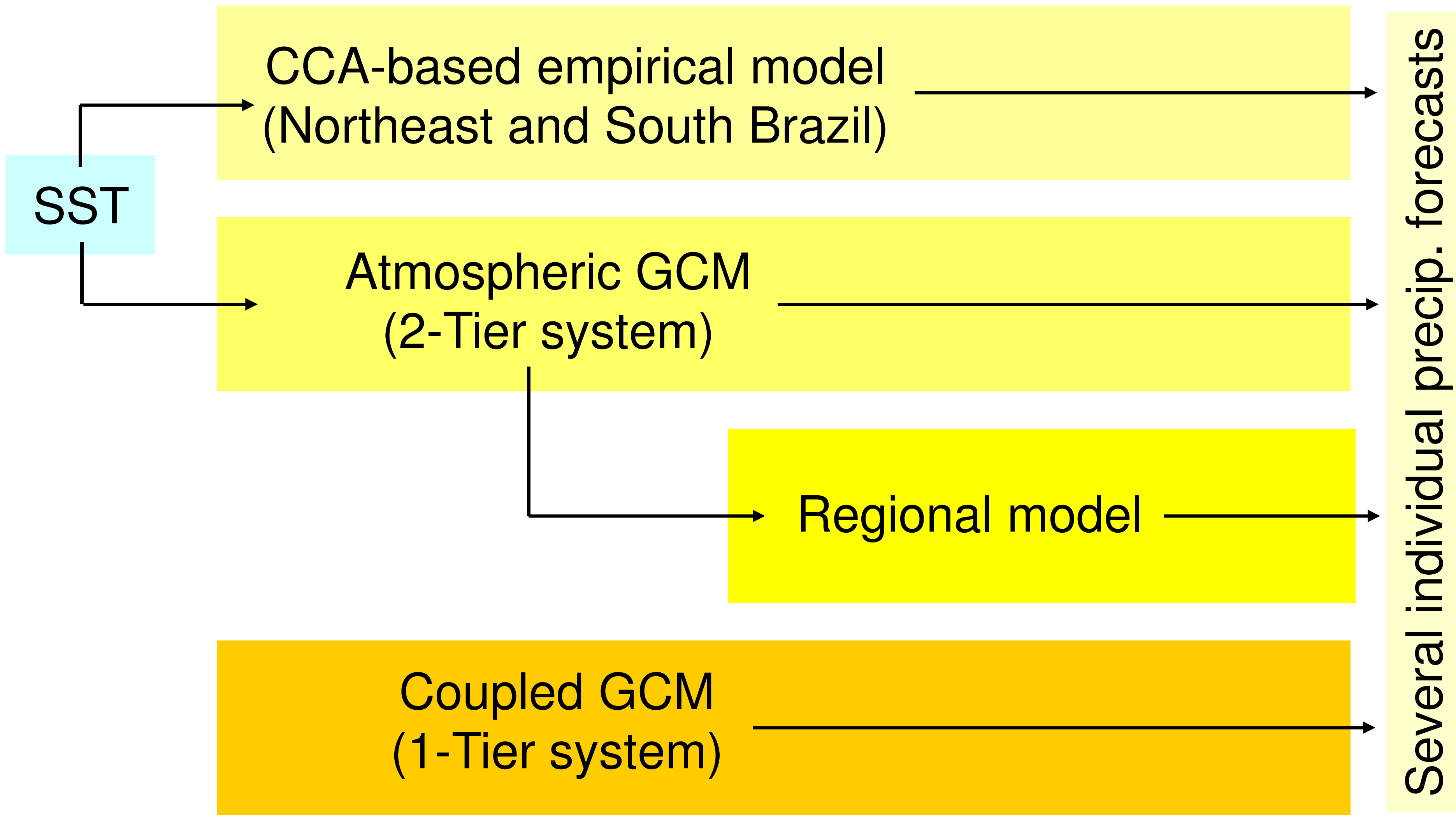


Real-time forecast and verification products

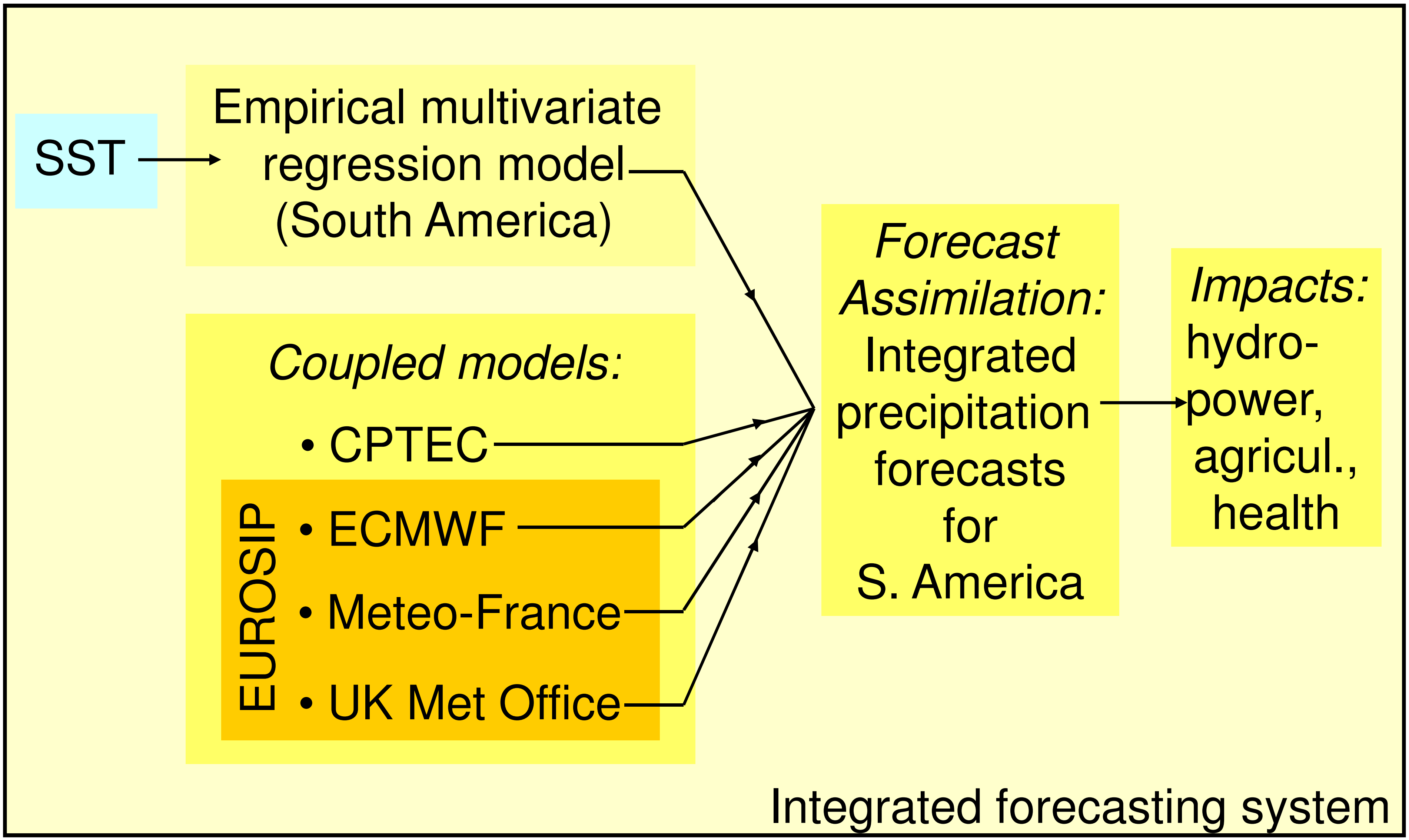
Hybrid (empirical-dynamical) multi-model ensemble system for South America

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

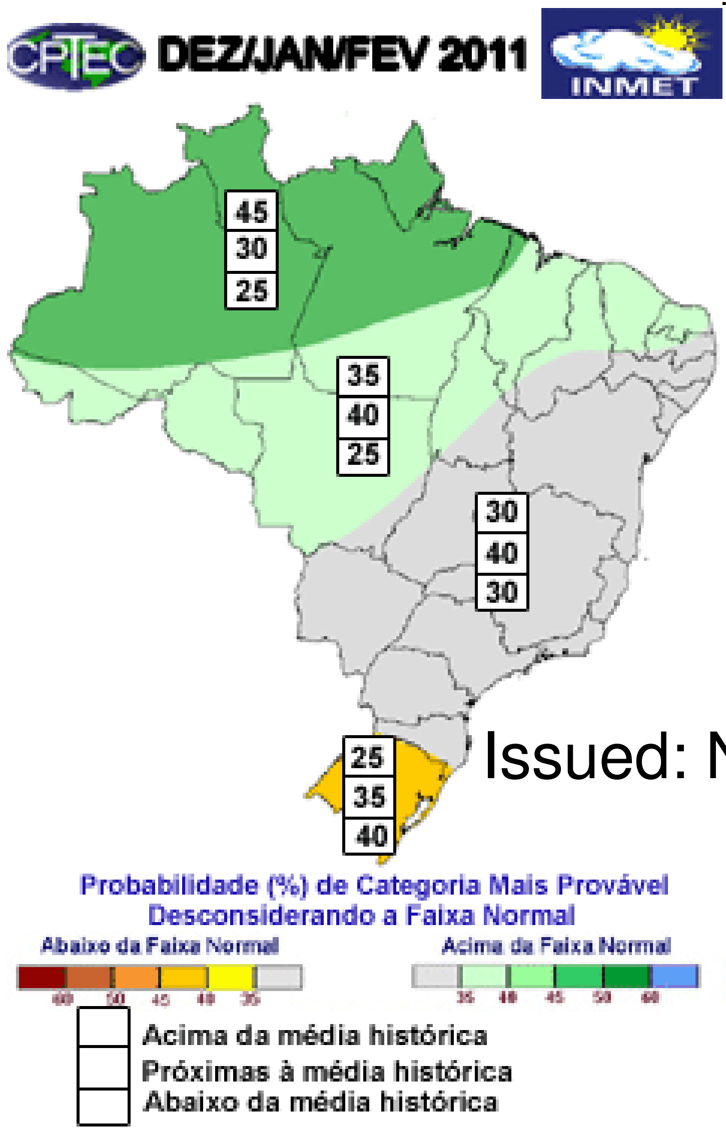
Seasonal forecasting system before EUROBRISA



After EUROBRISA

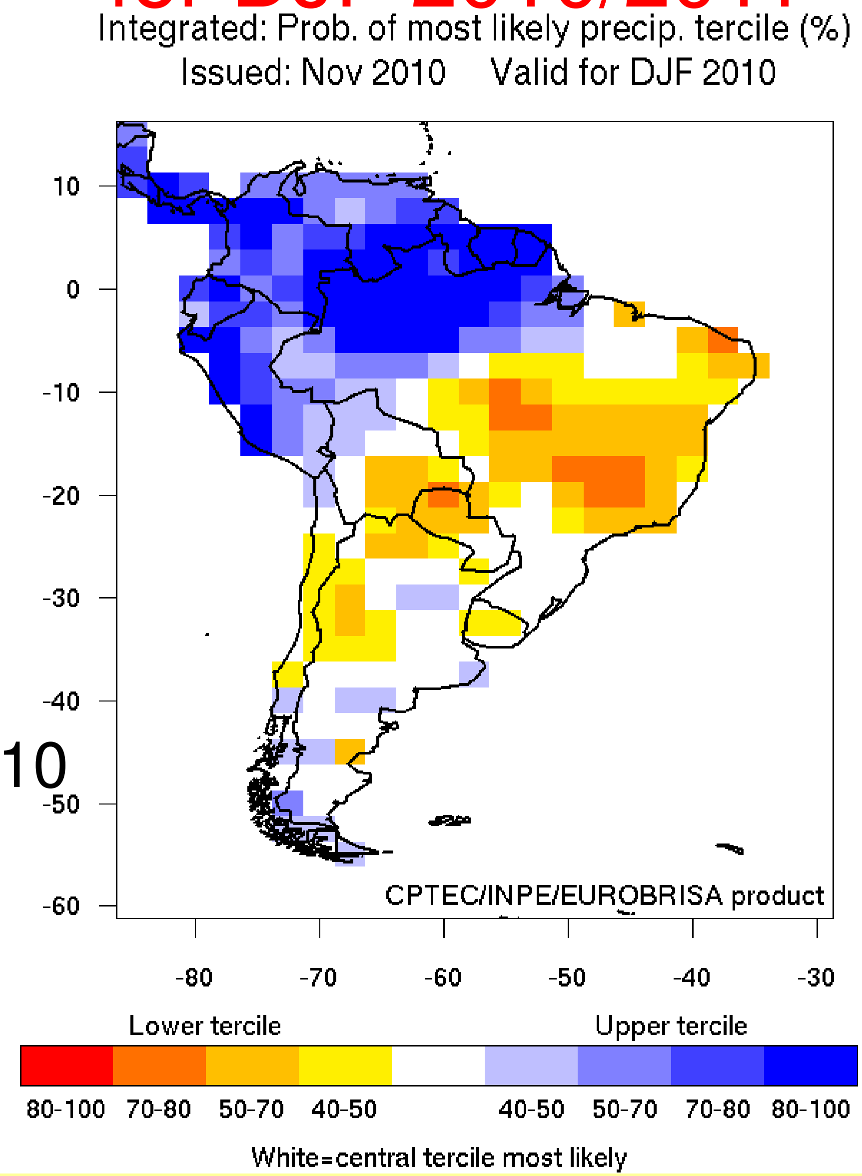


Official forecast for Brazil for DJF 2010/2011



Issued: Nov 2010

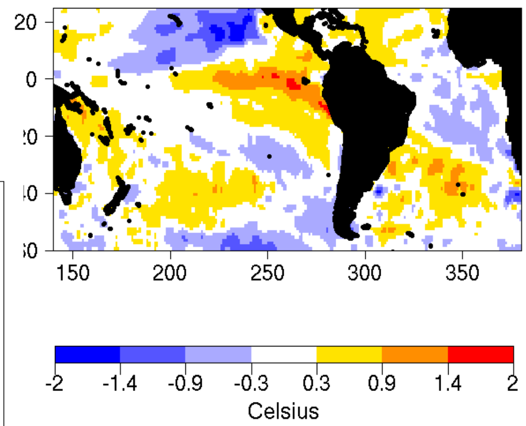
EUROBRISA forecast for DJF 2010/2011



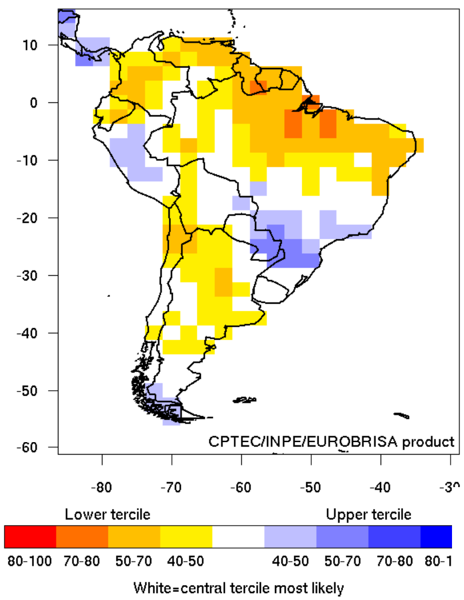
→EUROBRISA forecast helps define official seasonal forecast in Brazil

Most recent EUROBRISA integrated fcst for SON 2012

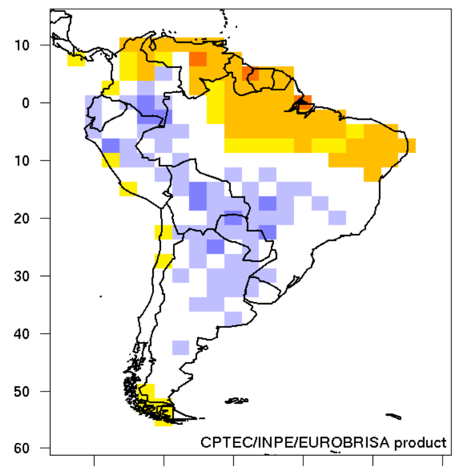
Obs. SST anomaly Jul 2012



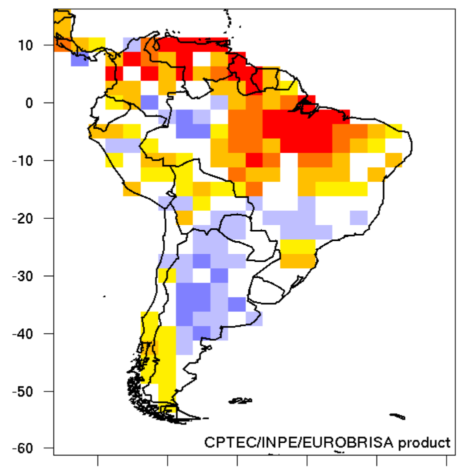
Empirical



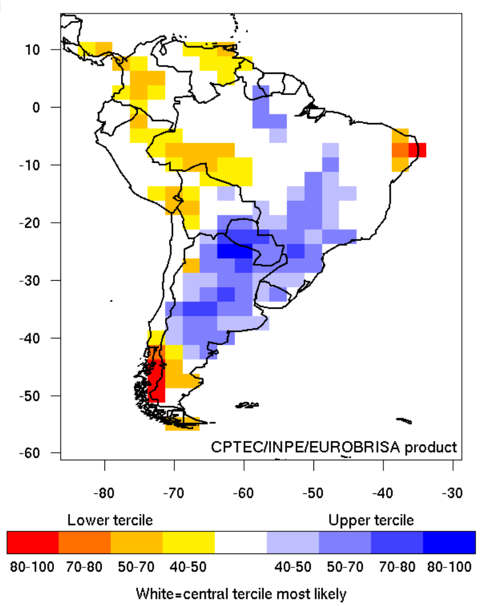
ECMWF



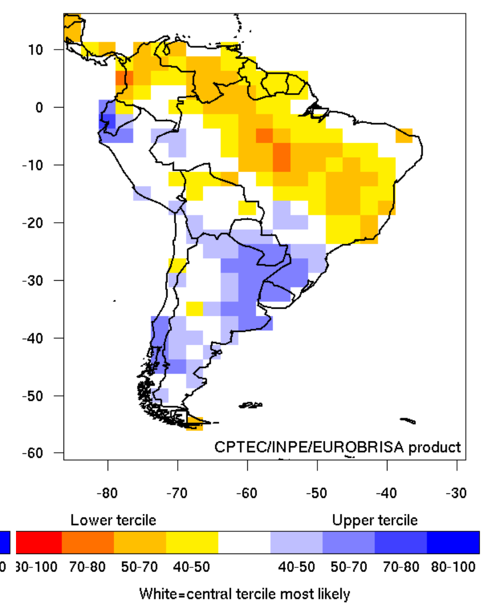
UKMO



Meteo-France



Integrated



Prob. of most likely precipitation tercile (%)

Issued: Aug 2012

Seasonal forecast applications:

Dengue risk transmission index predictions

Work by:
Caio Coelho
Rachel Lowe
Nicolas Degallier

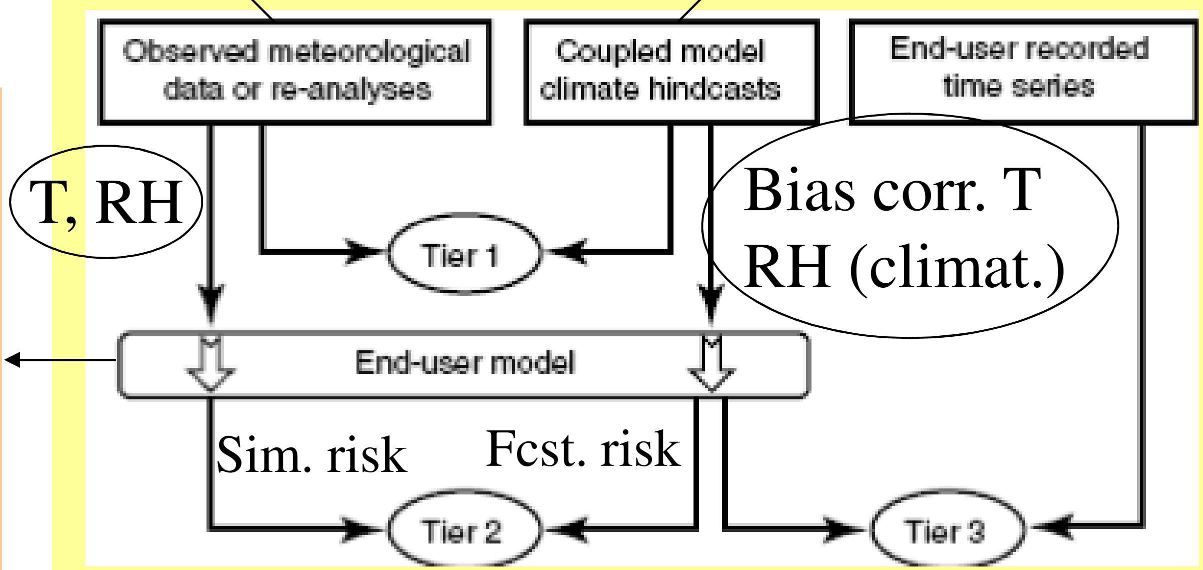
NCEP/NCAR Reanalysis:
Kalnay et al. (1996)
BAMS, 77(3), 437-471

ECMWF System 3:
Anderson et al. (2007)
ECMWF Tech. Memo,
503, pp 56

Dengue risk trans. model:

• Degalier et al. (2005)
Environ, Risques & Santé
4 (2), 1-5

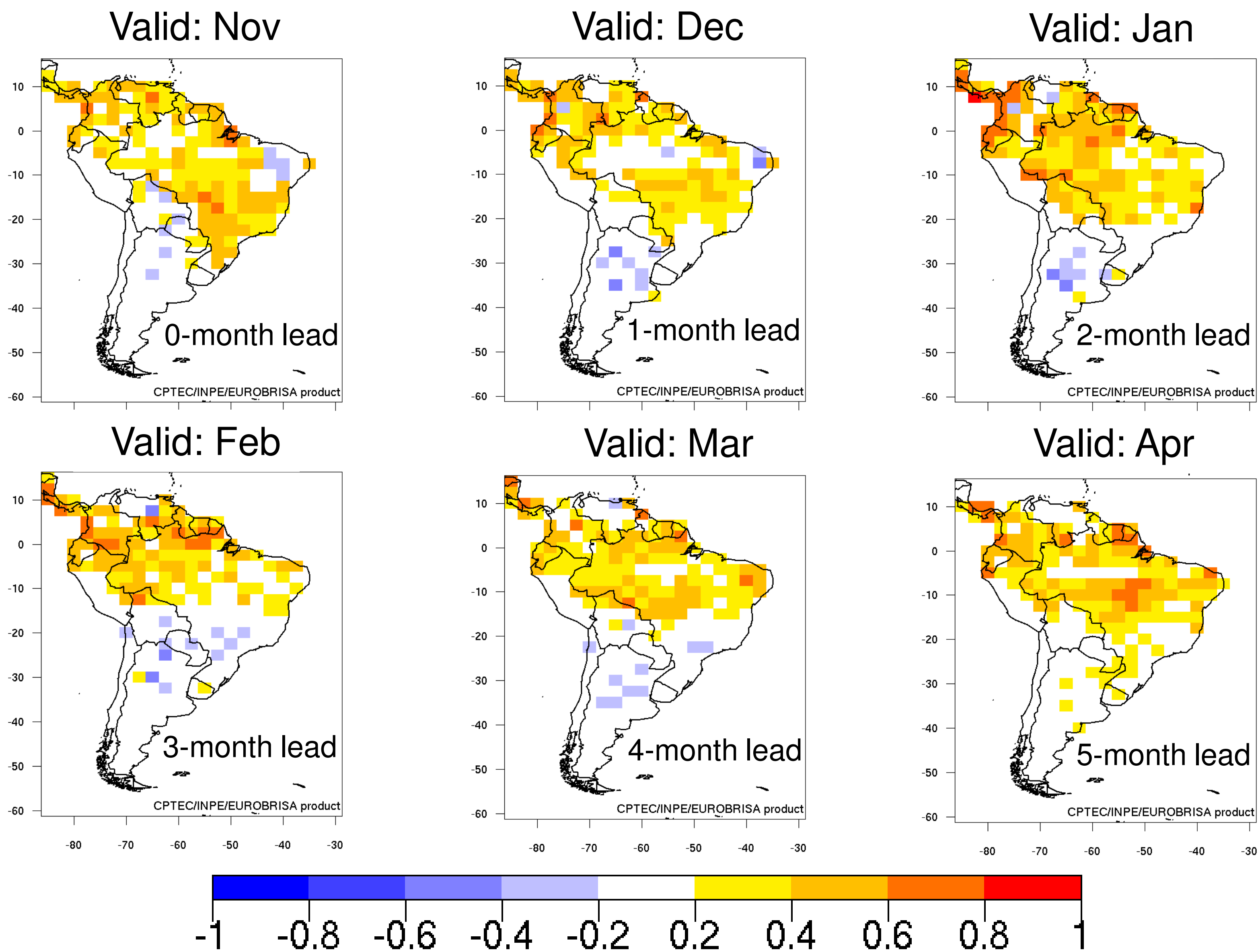
• Favier et al. (2006)
Trop. Med. and Int. Health
11 (3), 332–340



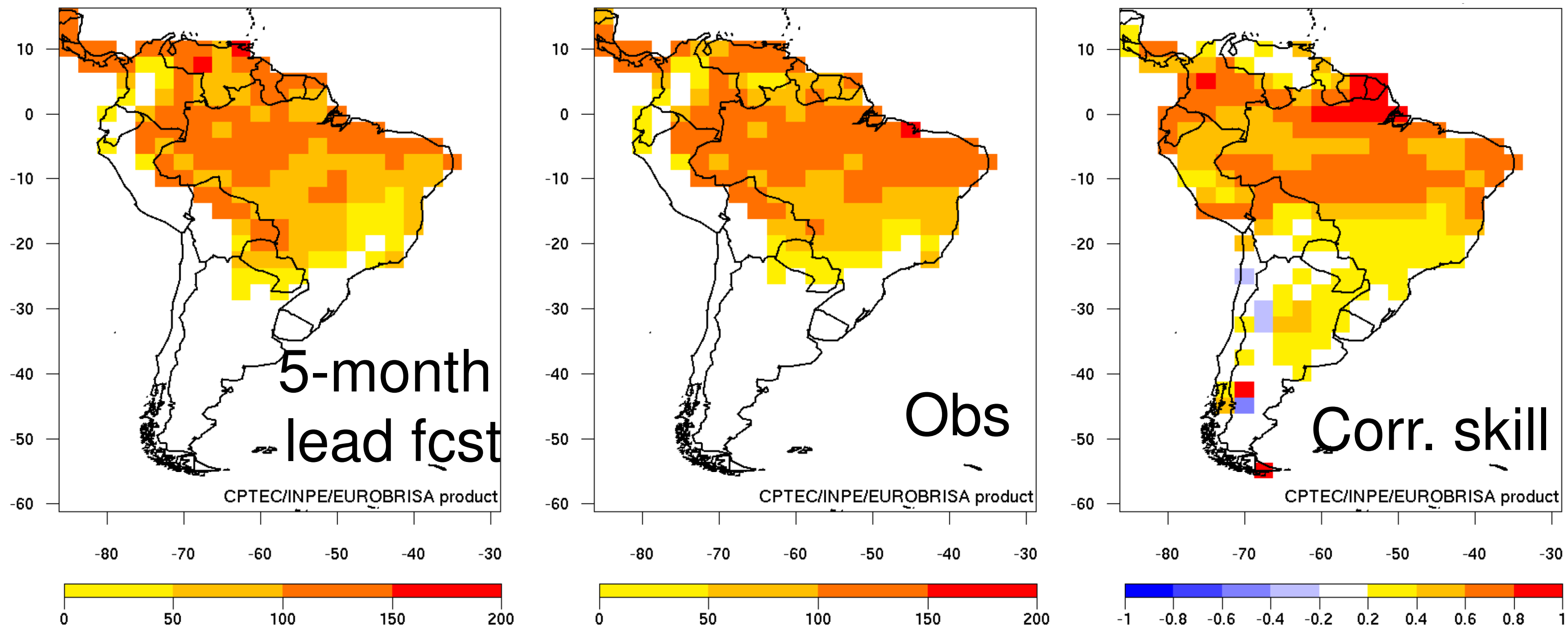
Morse et al. (2005)
Tellus, 57A(3), 464-475

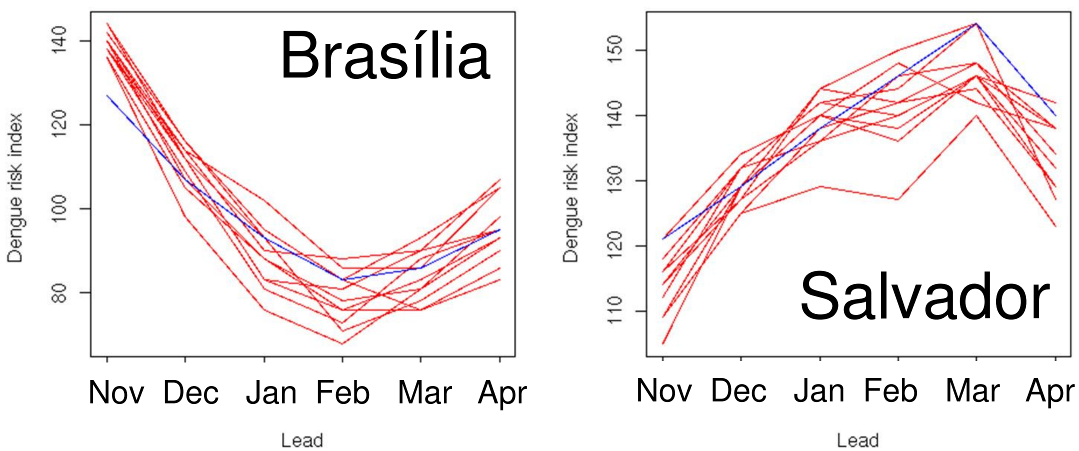
Hindcast period: 1981-2005
0 to 5 month lead predictions; 11 ensemble members

Skill assessment: Dengue risk transmission index prediction issued in Nov. (Gerrity score: terc. cat.)



Example: Dengue risk transmission index prediction issued in Nov 1997, valid for Apr 1998





Challenges for integrating seasonal climate forecasts in user applications: An illustration for crop yield predictions in Brazil

Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Environmental Sustainability

Challenges for integrating seasonal climate forecasts in user applications

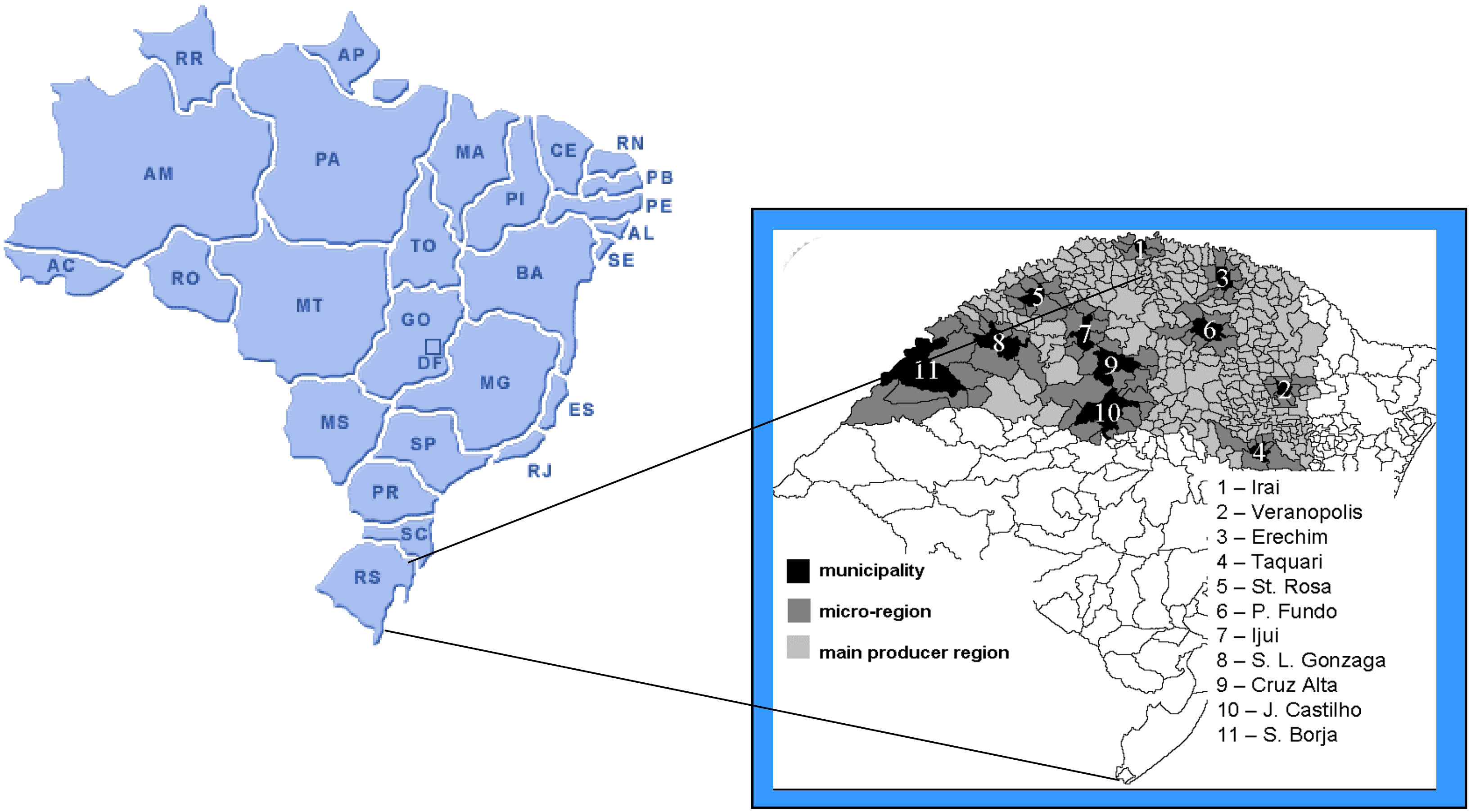
Caio AS Coelho and Simone MS Costa

This review discusses the challenges for integrating seasonal climate forecast information in user applications within the design of a simplified end-to-end forecasting system framework. Seasonal climate forecasts are operationally produced at various climate prediction centers around the world. However, these forecasts are rarely objectively integrated in application models to help the end user decision-making process, in spite of recent advances demonstrated through pilot projects in health, agricultural and water resources applications. An example of crop yield forecast produced as part of the EUROBRISA multi-institutional initiative is presented for illustrating some of the challenges. The challenges for moving toward a more objective use of seasonal climate forecasts to help support decision making involve more efficient interaction among climate scientists, system scientists and decision makers, with the end user

uncertainties in the forecasting process. For example, for addressing forecast uncertainty due to the lack of precise information about the initial state of atmospheric conditions when starting the forecast model, physically based dynamical seasonal forecasts are produced using slightly different initial conditions, generating an ensemble (i.e. a group) of forecasts [22]. For addressing uncertainties in model formulation the multi-model ensemble approach is used [14••,23••]. Empirical forecasts are based on statistical models built using past observations. For example, one can build a simple statistical model that relates past equatorial Pacific sea surface temperature observations and past rainfall observations over South America. Given a new observation of Pacific and Atlantic sea surface temperature one can use the derived statistical relationship to produce rainfall forecasts for South

Coelho & Costa, 2010

The Study Area for Maize yield

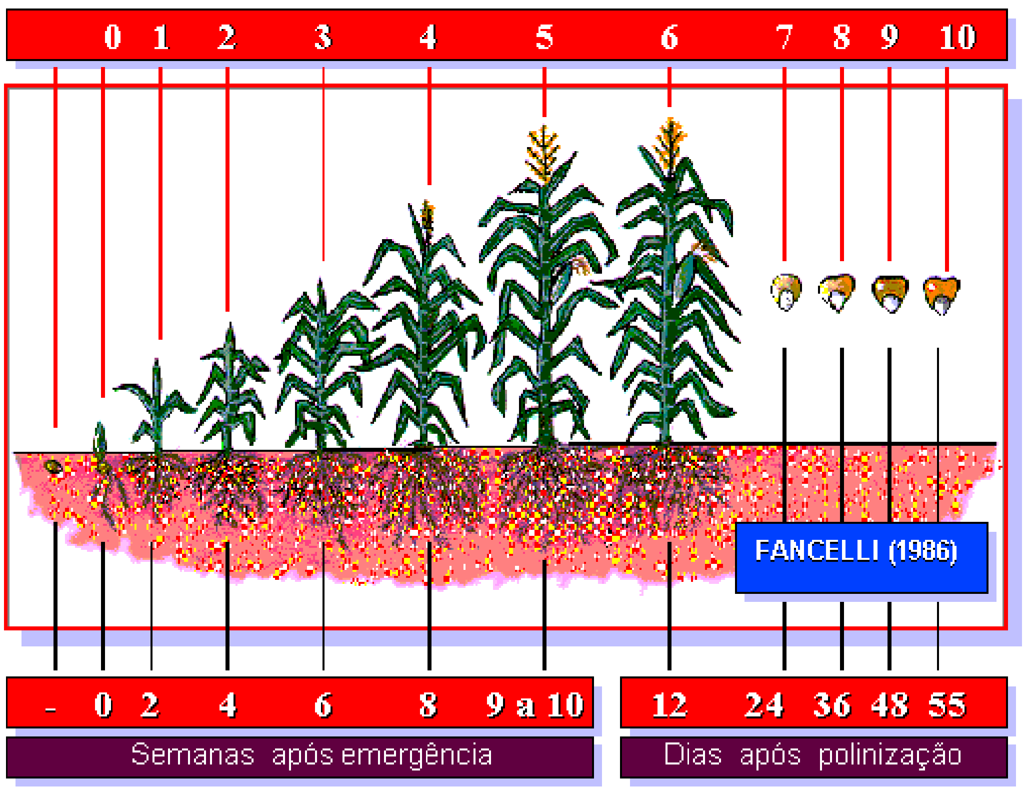


27.2°- 29.8°S/51.2°- 56.0°W

Rio Grande Do Sul State (RS)

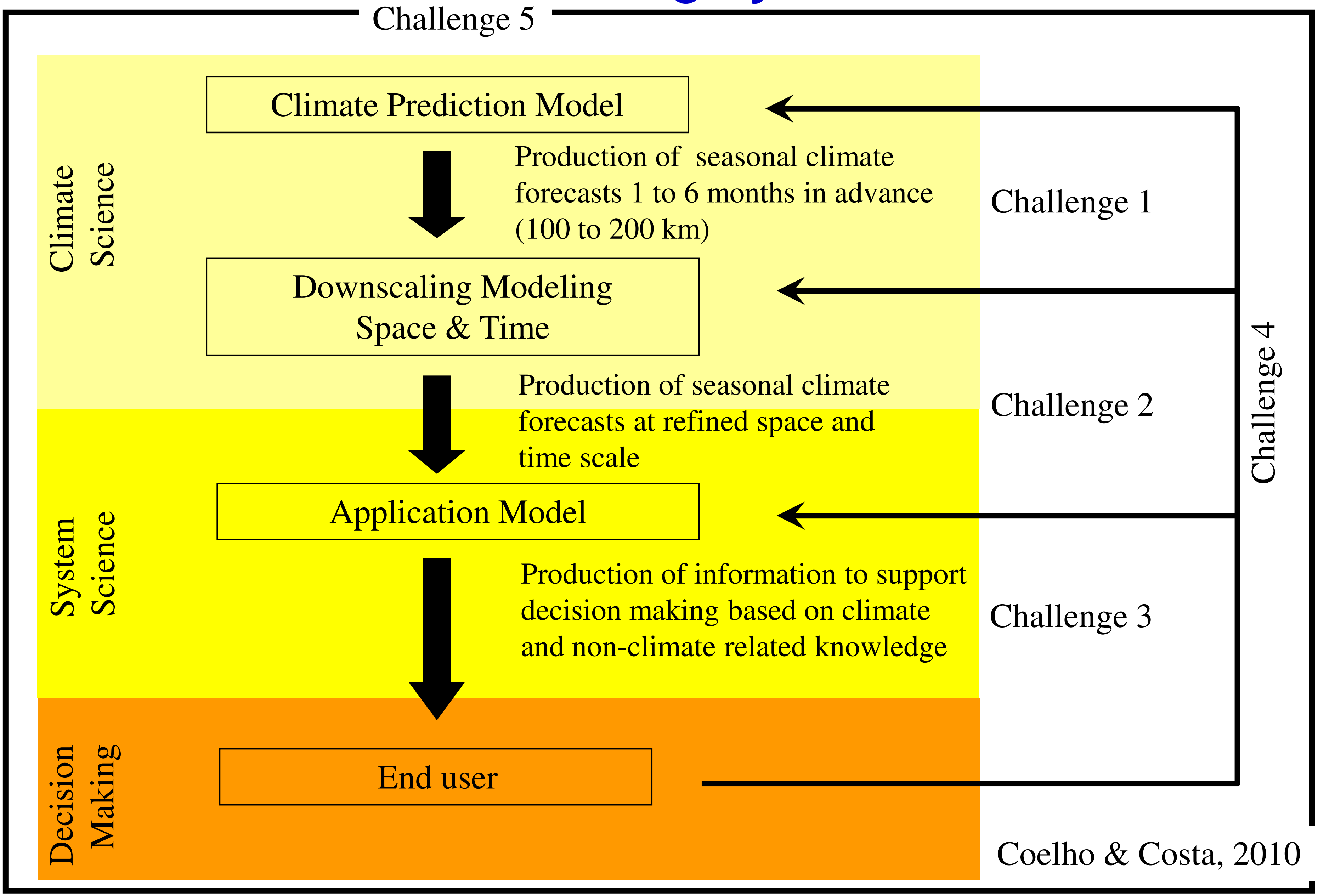
Maize in Rio Grande do Sul (RS)

After USA and China, Brazil is the third largest maize producer, and RS is the second greatest producer in Brazil (IBGE, 2006).



Sowing Date: Sep/Oct
Harvest: Feb/March

A simplified framework for an end-to-end forecasting system



Verification procedure

Meteorological stations:
Daily data

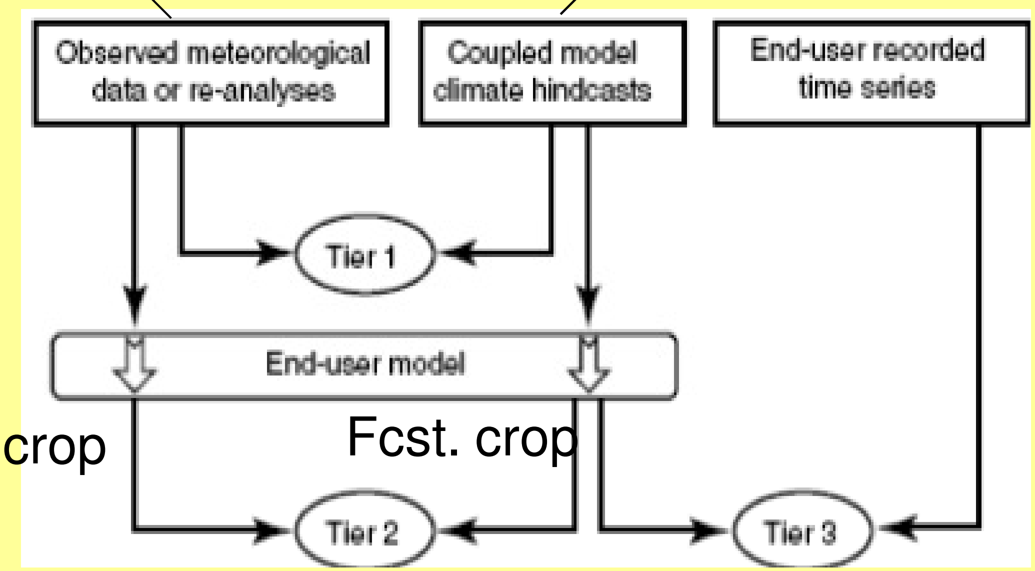
ECMWF monthly mean* and
EUROBRISA integrated
seasonal forecast

Rain,
T, S (climat)

GLAM model

- Challinor et al. 2003

Sim. crop



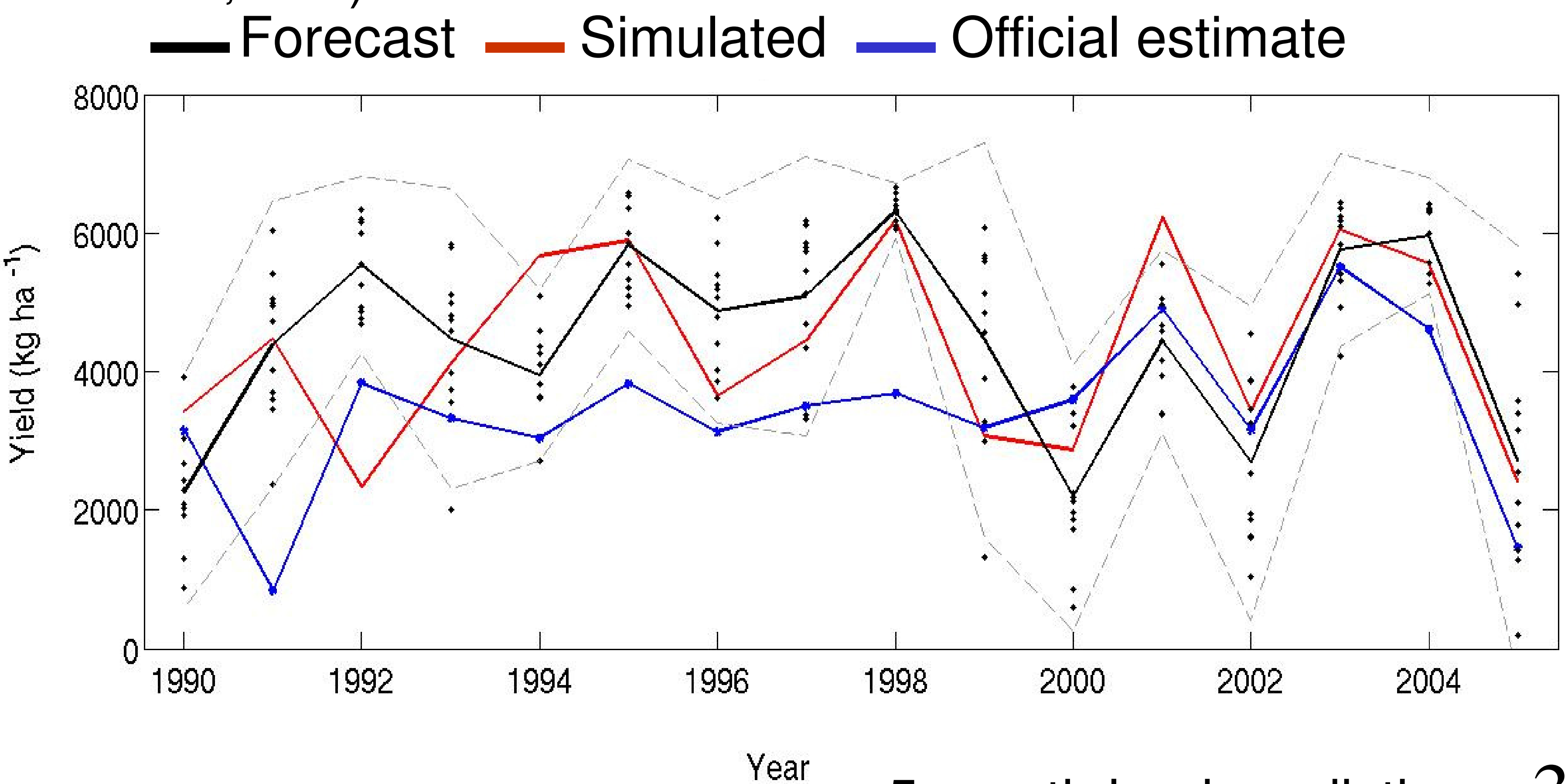
Fcst. crop

Morse et al. (2005)
Tellus, 57A(3), 464-475

* System 3: Anderson et al. (2007) ECMWF Tech. Memo, 503, pp 56

Grain yield prediction

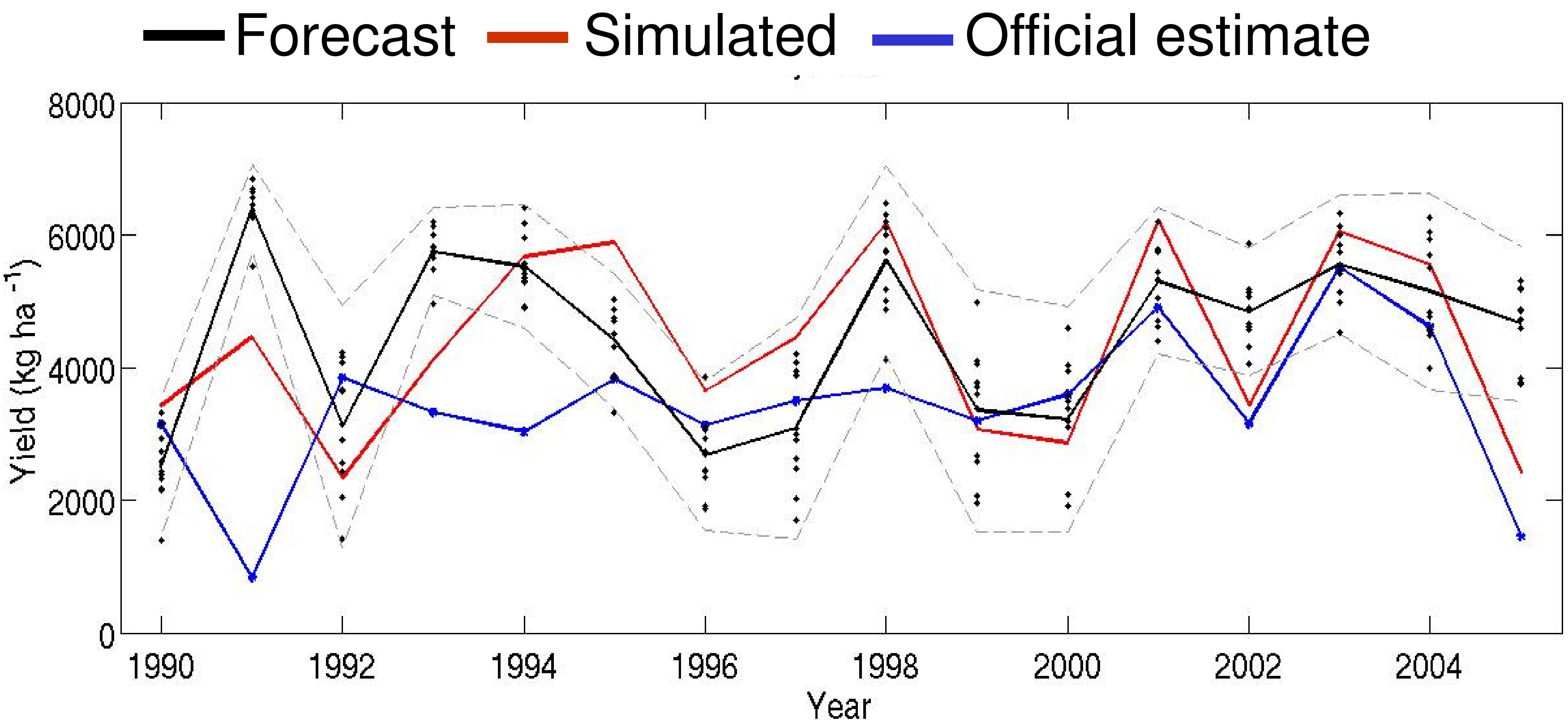
ECMWF (bias corrected) forecasts, 11 ensemble members issued in Sep (valid for Sep, Oct, Nov, Dec, Jan, Feb)



5-month lead predictions

Grain yield prediction

EUROBRISA Integrated forecasts, 11 sampled members
Issued: November, valid for Dec, Jan, Feb



3-month lead predictions

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

Summary: Forecast applications

- The success of integrating seasonal climate forecasts in user applications can only be achieved if the entire chain of challenges is thoroughly resolved
- Two examples of crop yield forecast produced as part of the EUROBRISA multi-institutional initiative were presented for illustrating some of the challenges
- Results demonstrate potential for use of rainfall forecasts produced by EUROBRISA integrated forecast and ECMWF coupled model for producing maize yield predictions for Rio Grande do Sul
- Results on health application (dengue) are encouraging for further developing research and use of seasonal forecasts in this area
- Web link **http://eurobrisa.cptec.inpe.br**

Acknowledgements

- Simone Costa (CPTEC- Brazil), Homero Bergamaschi (UFRGS, Brazil), Andrew Challinor (The University of Leeds-UK) , Vincent Moron (CEREGE, France), Rachel Lowe (IC3), Nicolas Degallier (IRD), + all EUROBRISA partners

- ECMWF, Météo France and UK Met Office for providing the seasonal forecast data for EUROBRISA

- Leverhulme Trust for funding the EUROBRISA network project (F/00144/AT)

- FAPESP foundation for research funding

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