Hybrid (empirical-dynamical) EUROBRISA forecasting system

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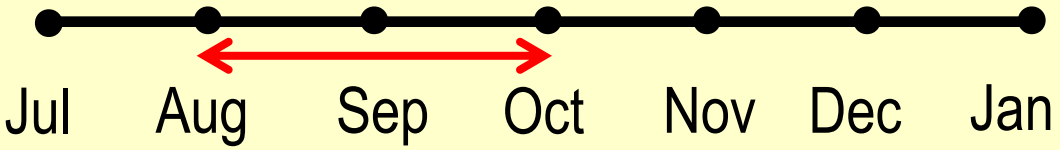
PLAN OF TALK

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

Introduction

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

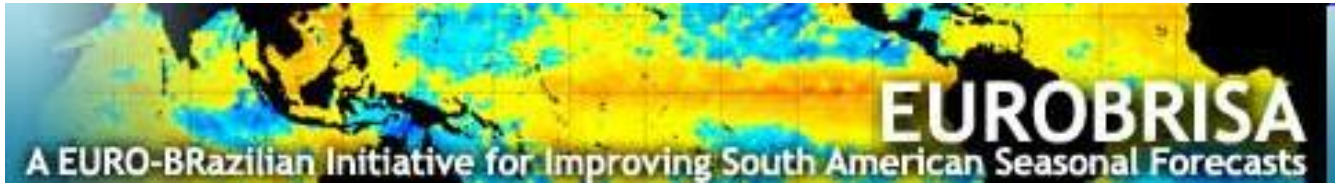
Comparing statistical and dynamical prediction systems:

	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)?

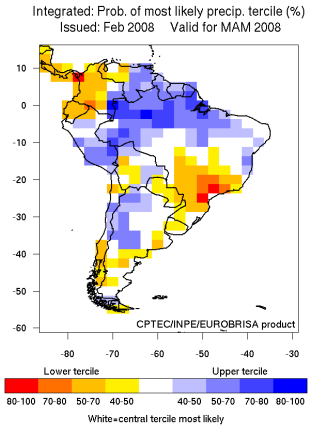
EUROBRISA Integrated (combined and calibrated) precipitation seasonal forecasting system for South America

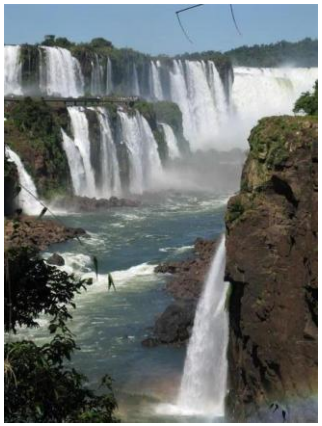
EUROBRISA aims

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

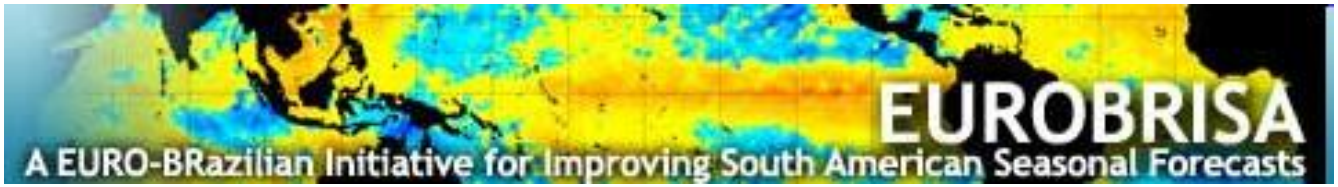
- Produce improved seasonal climate forecasts for South America using recent scientific advances in both coupled ocean-atmosphere modelling and statistical calibration and combination of multi-model ensemble forecasts;

- 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!

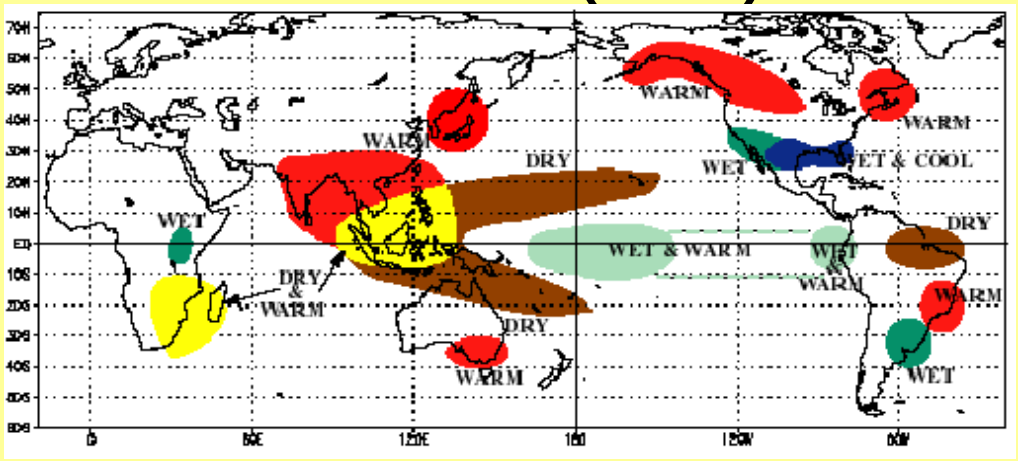


http://eurobrisa.cptec.inpe.br

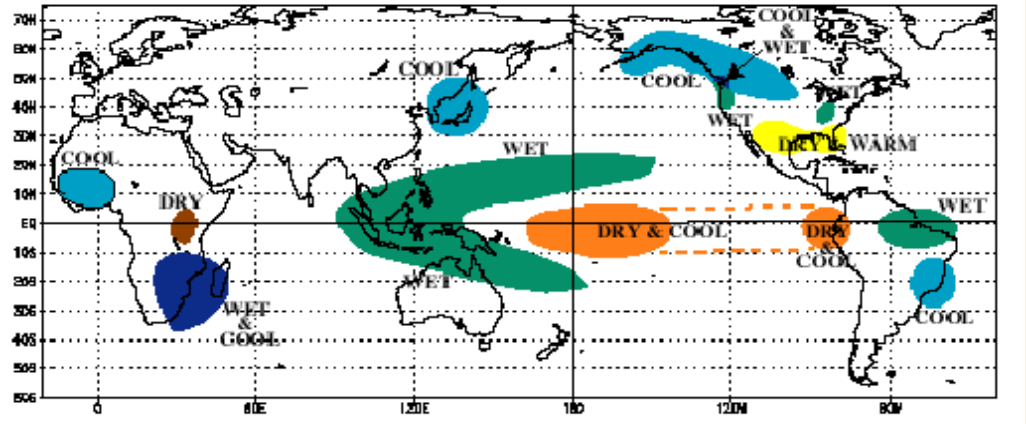
Why South America?

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

El Niño (DJF)

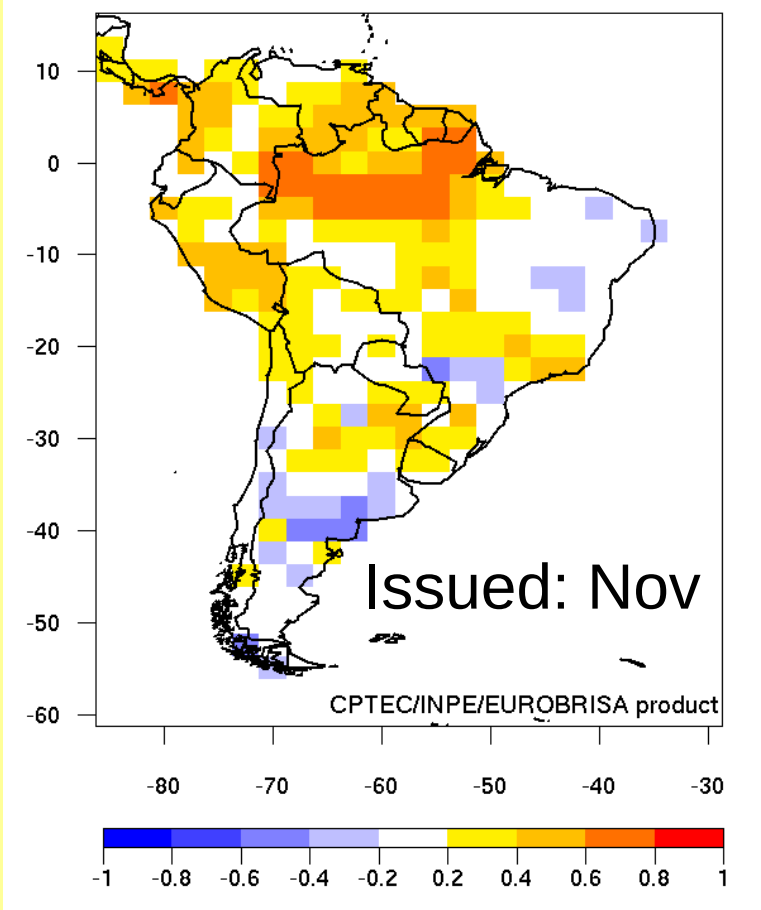


La Niña (DJF)



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

Correlation skill precipitation forecasts for DJF

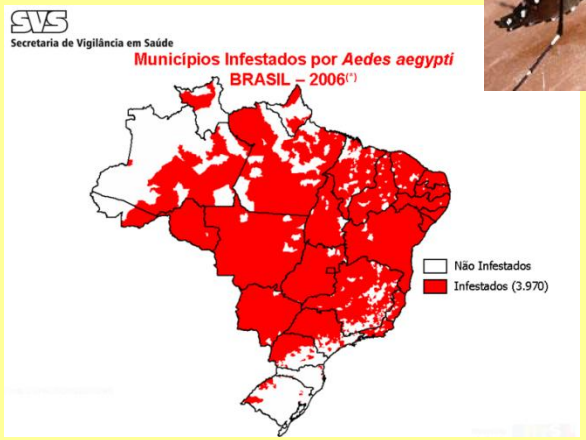


Pos. values: moderate-good skill

Application areas in need of seasonal forecasts

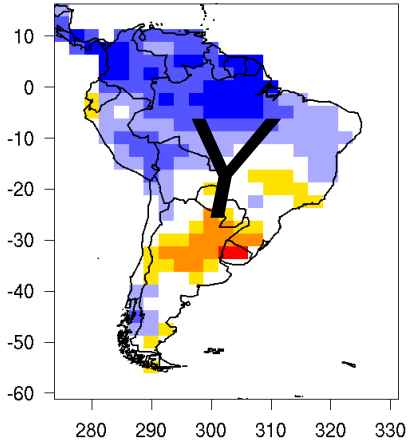
→ Electricity: Brazil, about 70% produced by hydropower stations

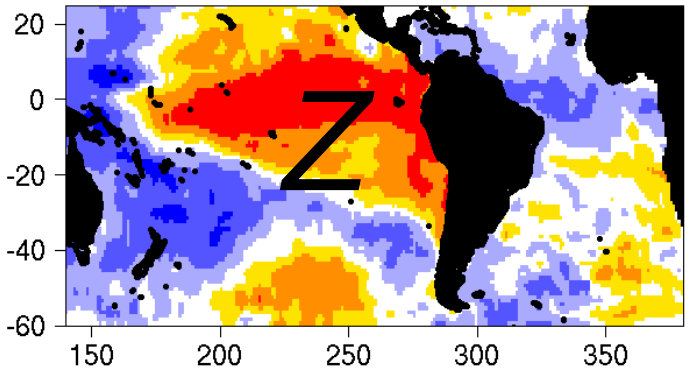
→ Agriculture (e.g. crop yield)



→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

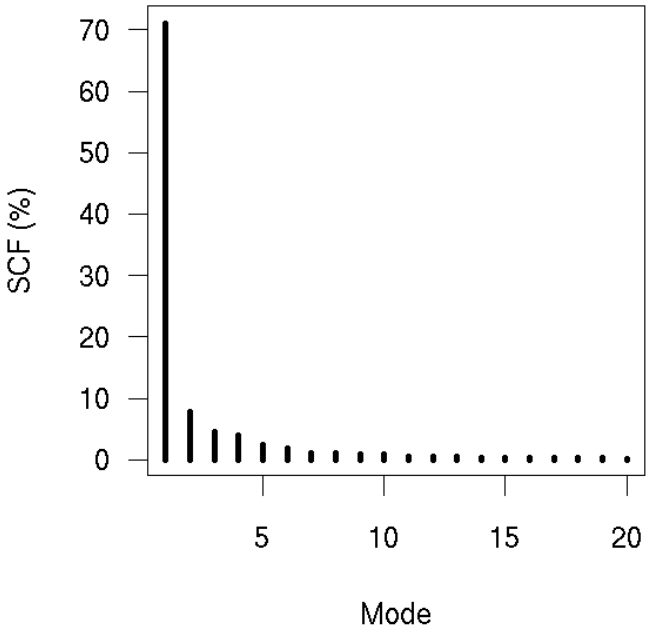
Z: October sea surface temp. (SST)

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

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

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

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**

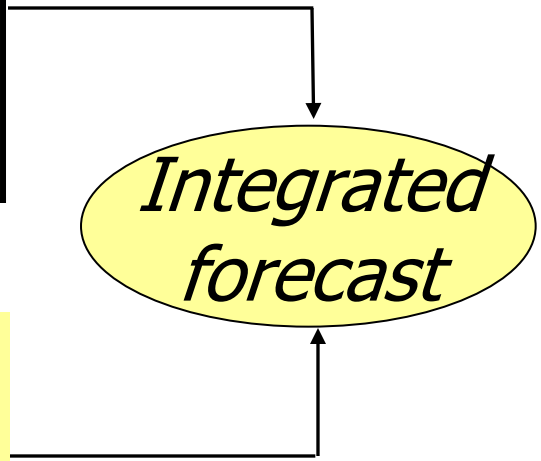
First version: EUROBRISA integrated forecasting system for South America

→Combined and calibrated coupled + empirical precip. forecasts

→Hybrid multi-model probabilistic system

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

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

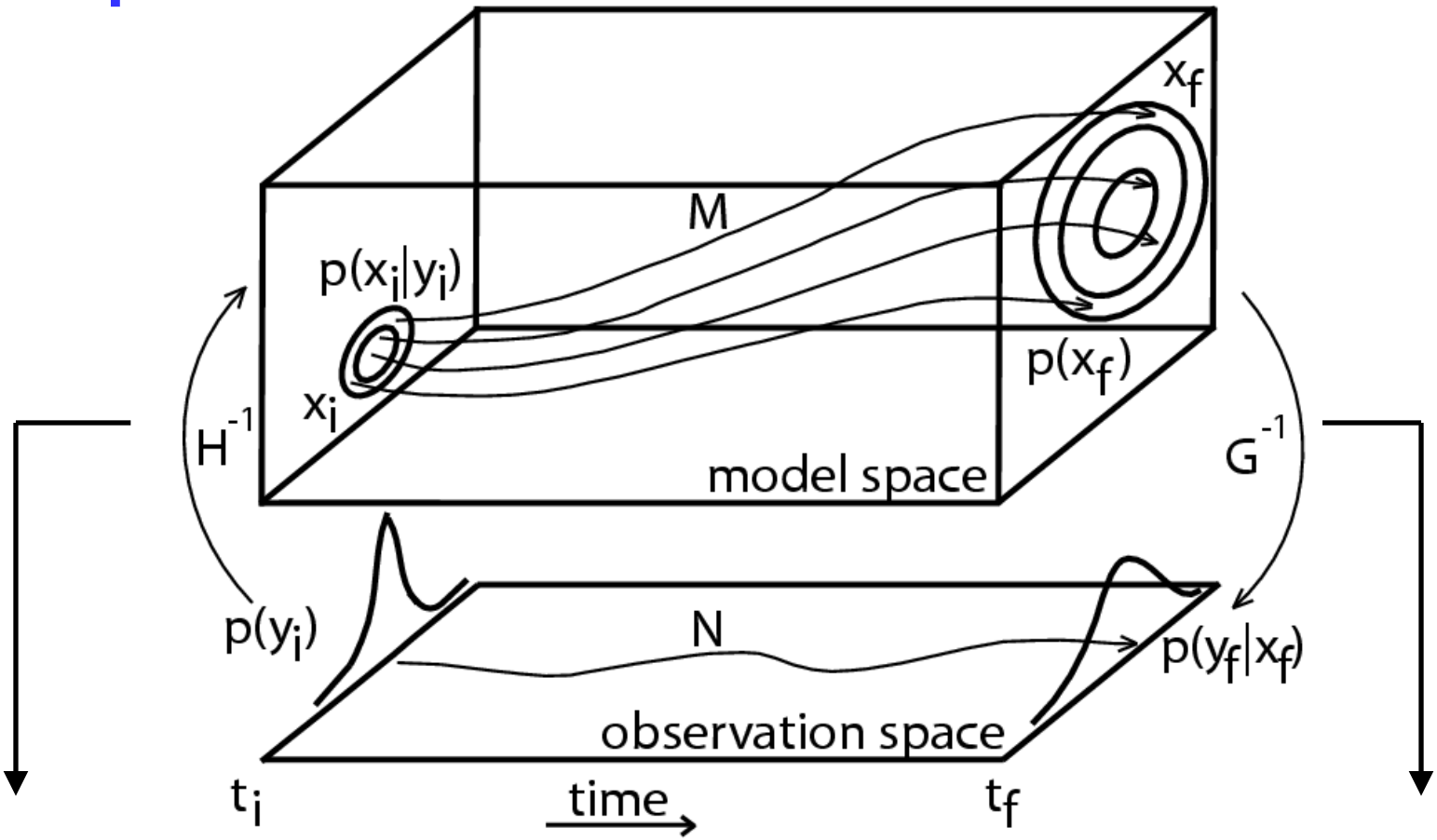


Produced with forecast assimilation
Stephenson et al (2005)
Tellus A . Vol. 57, 253-264

Hindcast period: 1987-2001

Implemented in Oct 2007

Conceptual framework



Data Assimilation

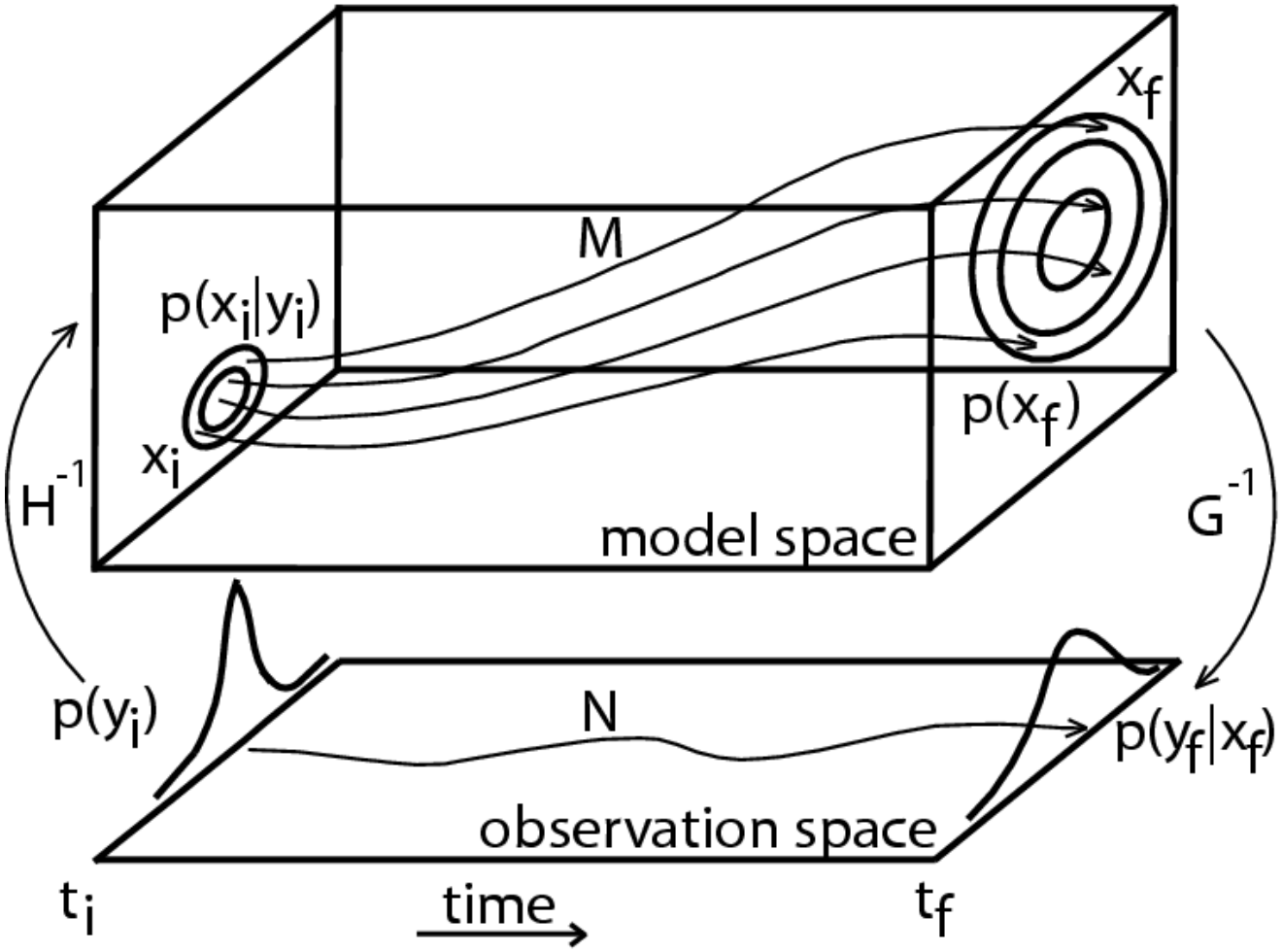
$$p(x_i \mid y_i) = \frac{p(y_i \mid x_i)p(x_i)}{p(y_i)}$$

"*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)

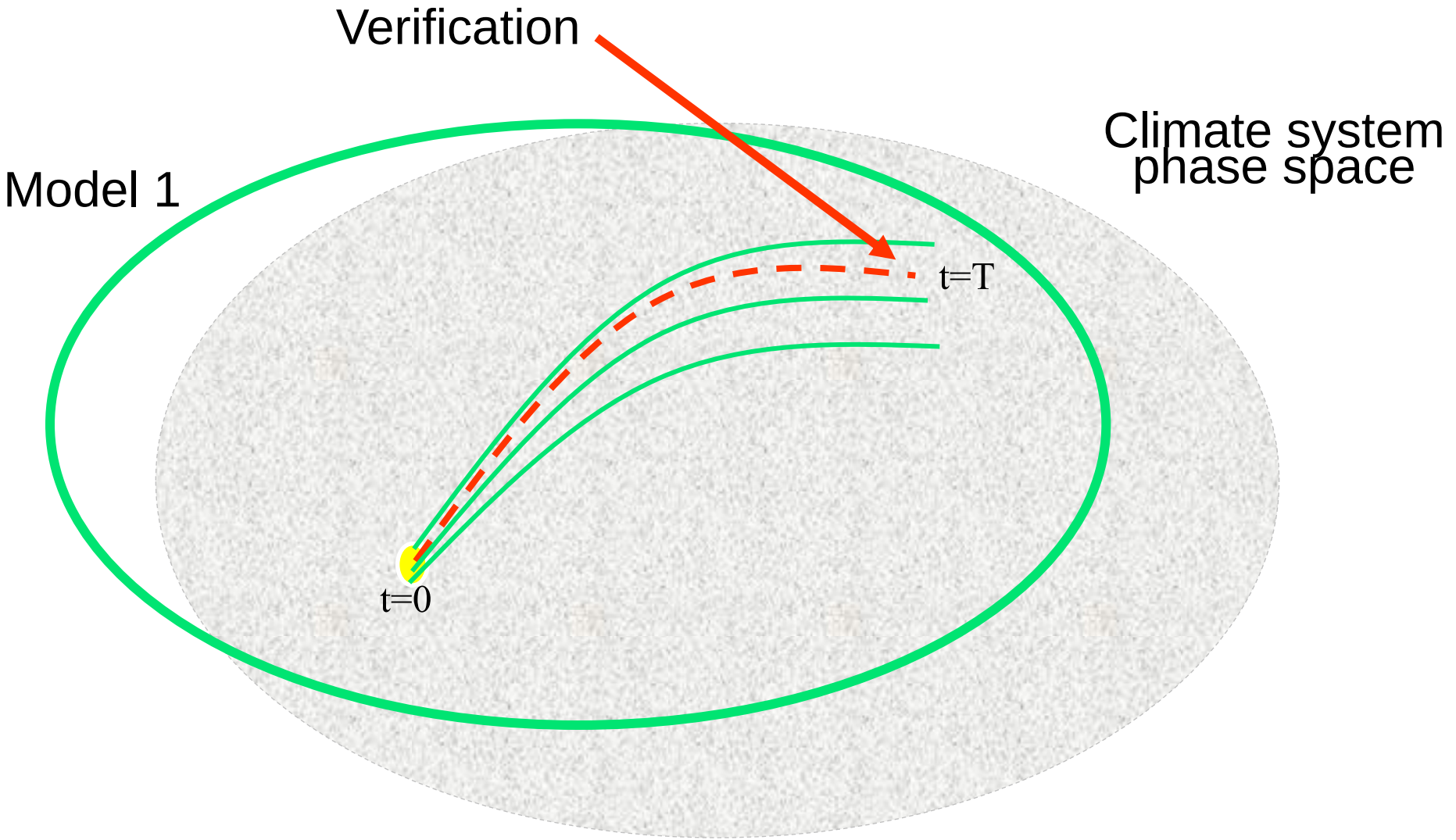
Motivation for use of multi-model ensemble



Sampling of two sources of uncertainties:

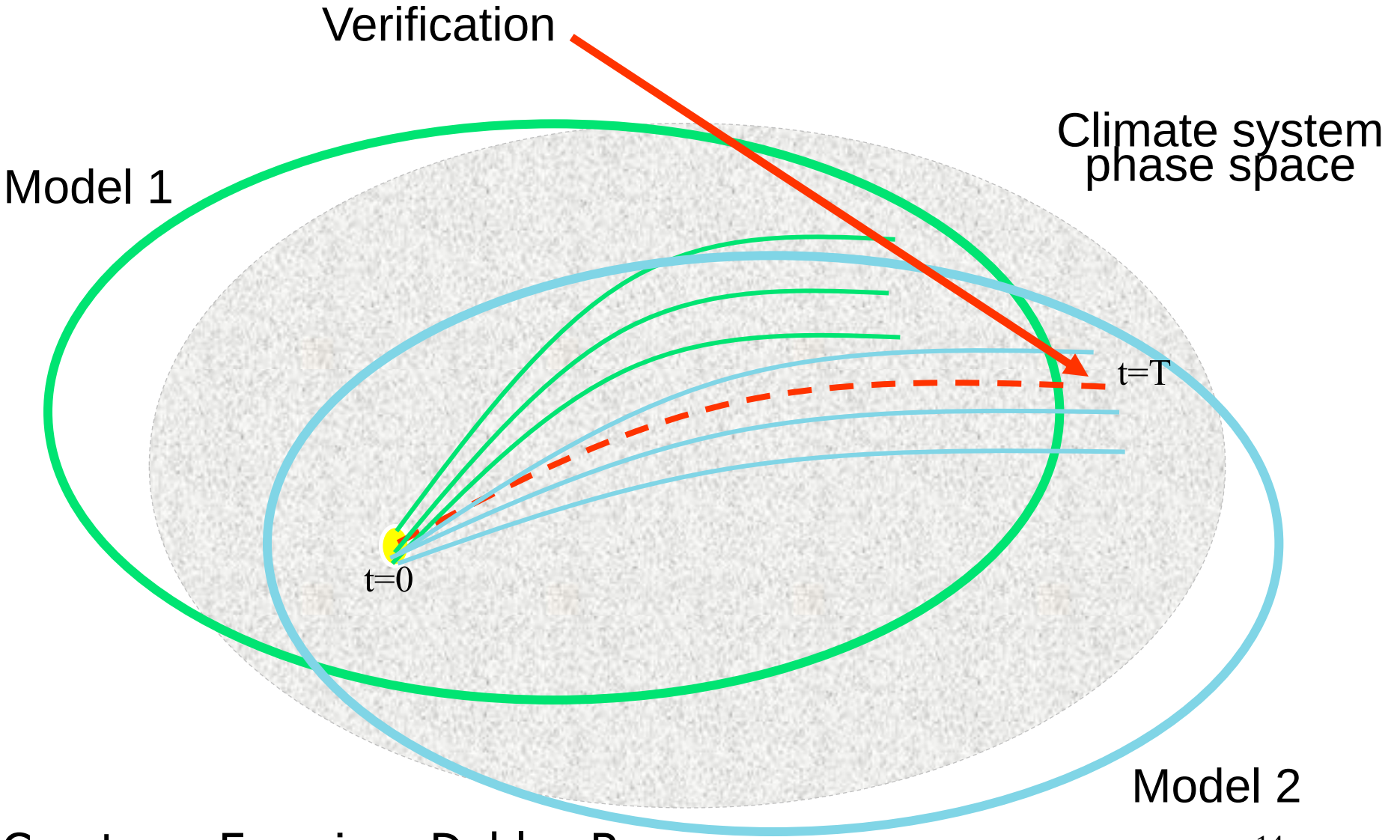
- initial conditions
- model formulation

Motivation for combination: Multi-model ensemble forecasts



Courtesy: Francisco Doblas-Reyes

Motivation for combination: Multi-model ensemble forecasts



Courtesy: Francisco Doblas-Reyes

Calibration and combination procedure: Forecast Assimilation

Stephenson *et al.* (2005)
Tellus, 57A, 253-264

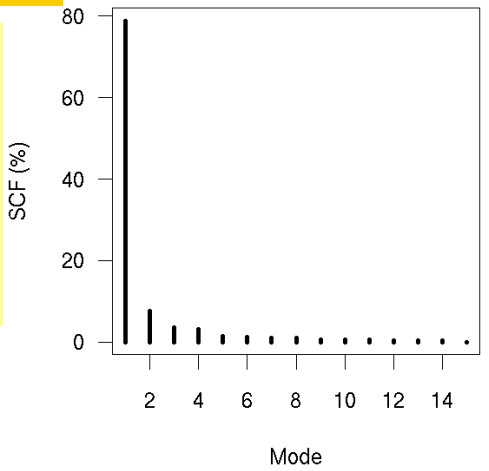
$$p(Y \mid X) = \frac{p(X \mid Y)\,p(Y)}{p(X)}$$

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

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

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

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



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

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

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

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

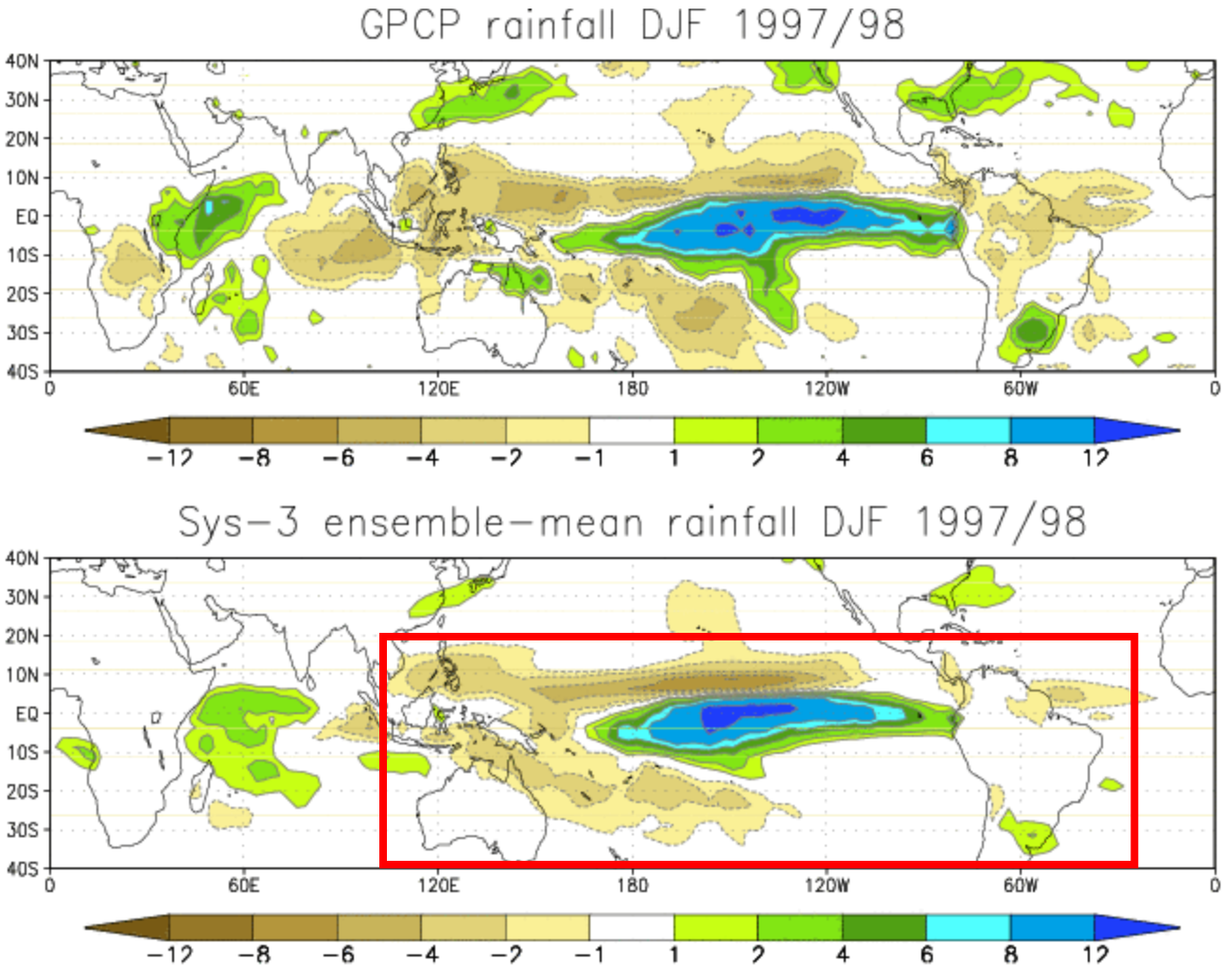
Posterior: $Y \mid X \sim N(Y_a, D)$

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

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

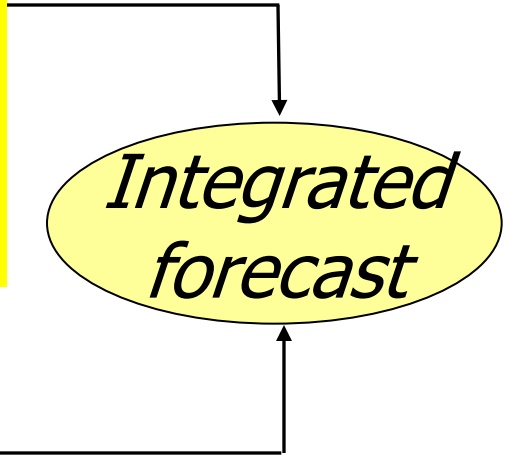
Source: Franco Molteni (ECMWF)

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 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

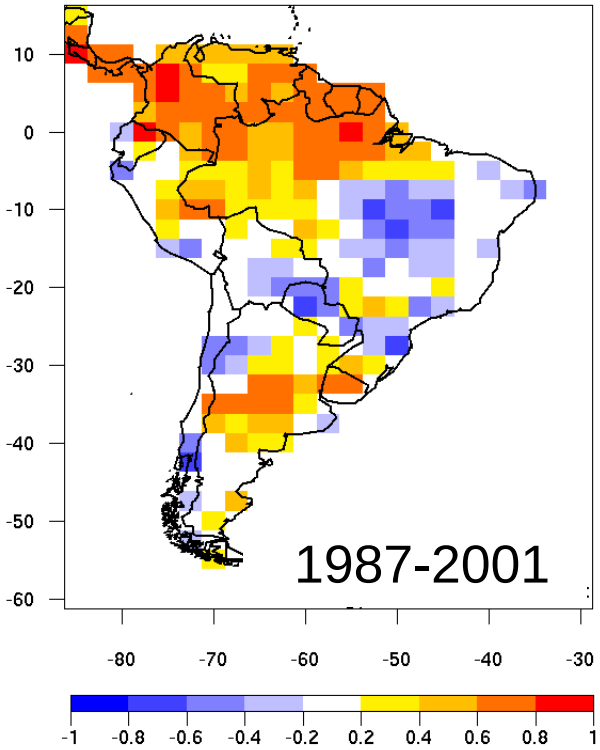
Produced with forecast assimilation
Stephenson et al (2005) Tellus A . Vol. 57, 253-264

Hindcast period: 1981-2005

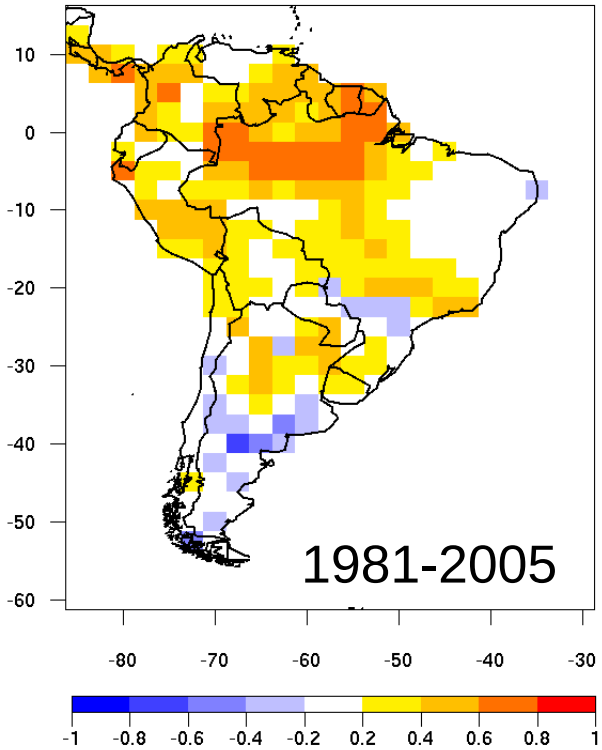
Implemented in Mar 2012

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)

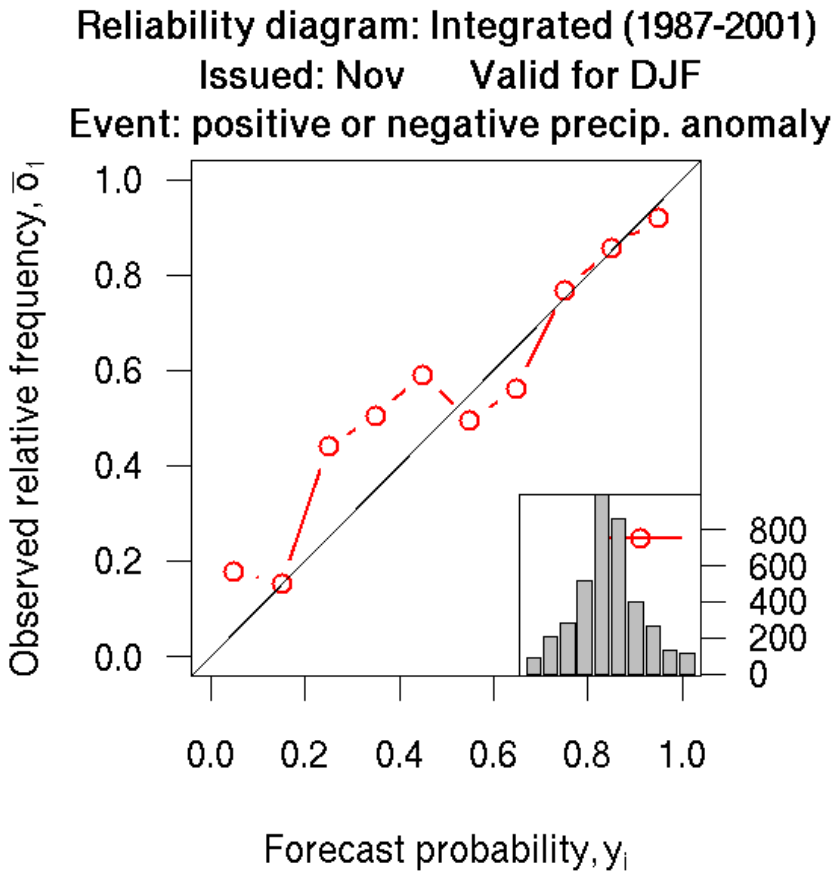


South America + Pacific domain:
ECMWF, UKMO, MF, CPTEC
and empirical (diff. hind. periods)

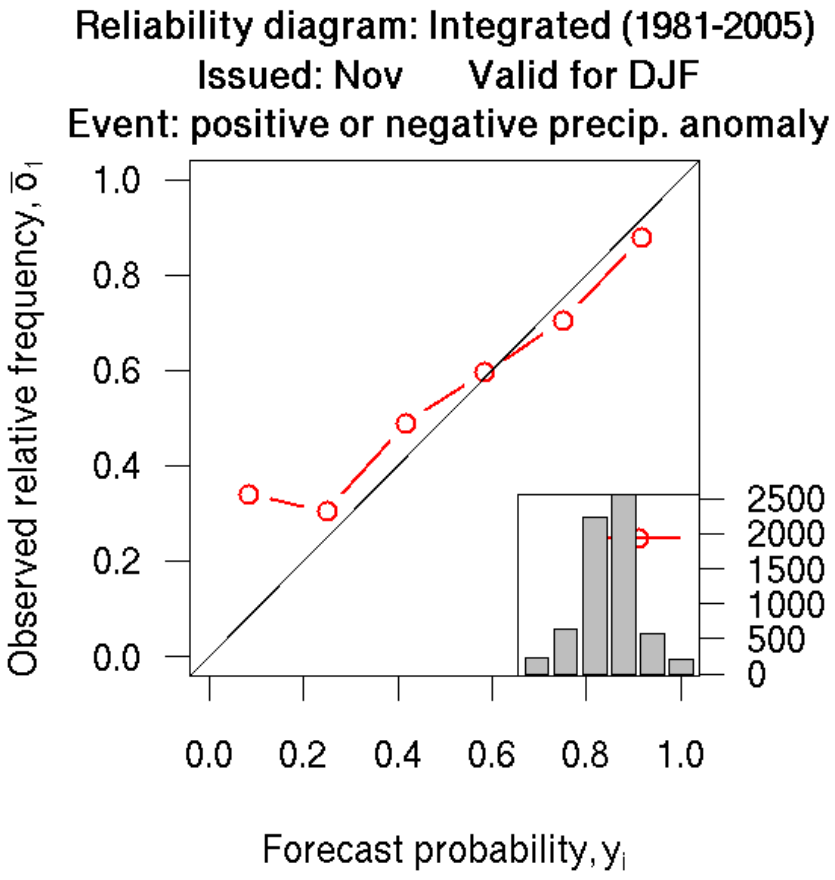
Issued: Nov
Valid: DJF

→ 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)

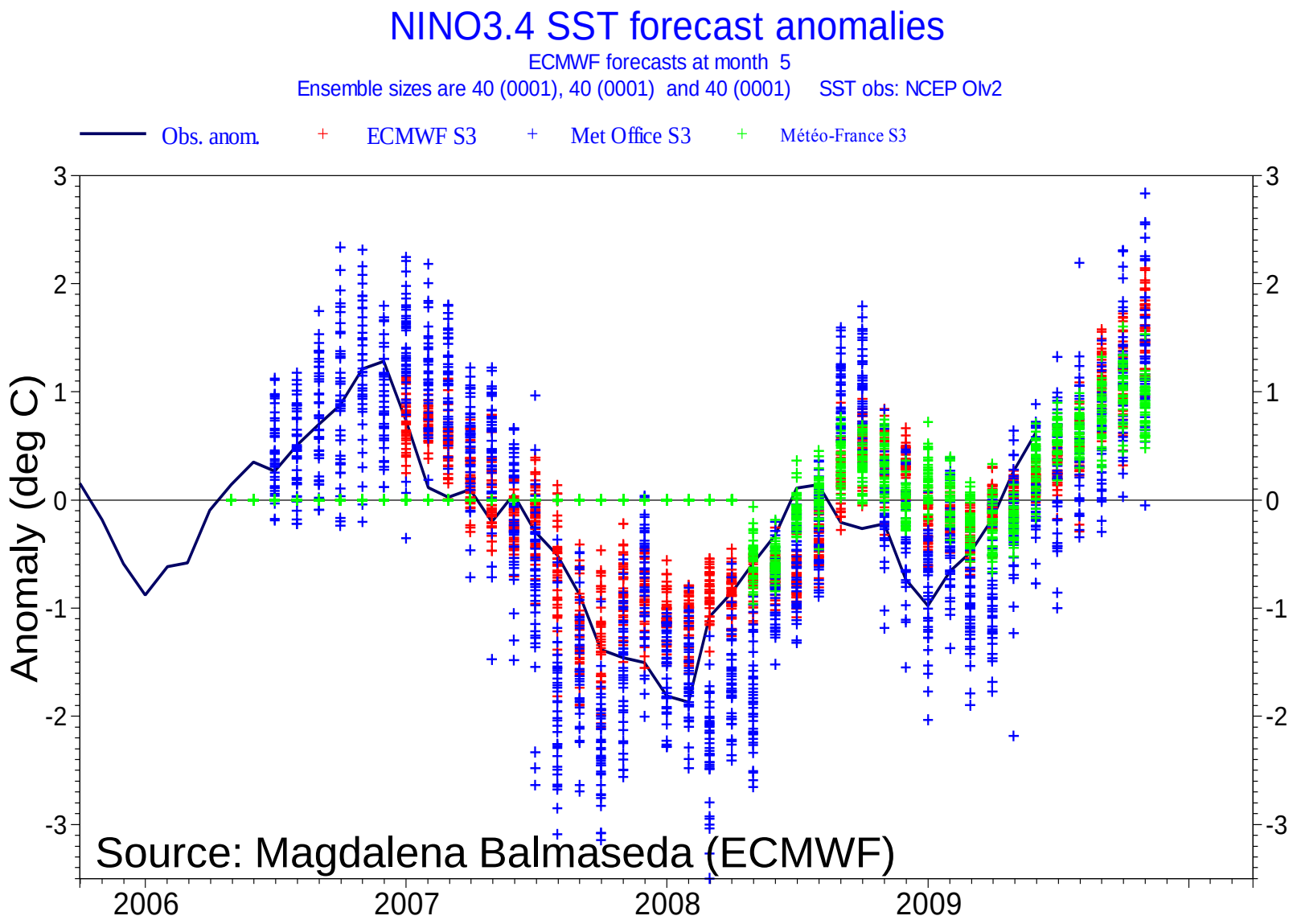


South America + Pacific domain:
ECMWF, UKMO, MF, CPTEC
and empirical (diff. hind. periods)

→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

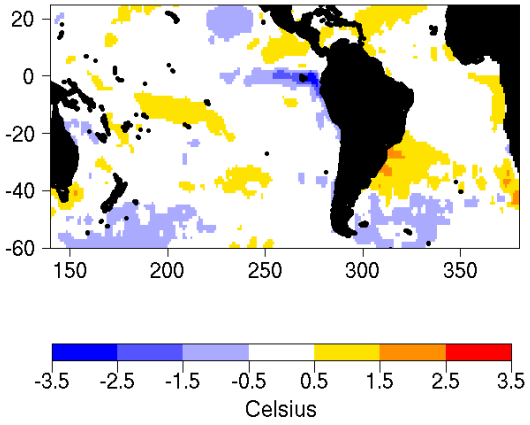


The EUROSIP multimodel captured well the onset, amplitude and long duration of La Nina conditions

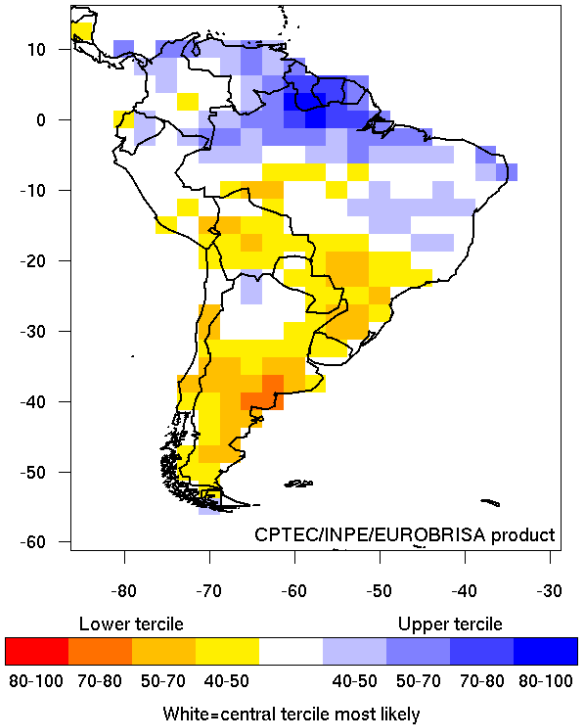
EUROBRISA integrated forecast for JJA 2007

Issued: May 2007

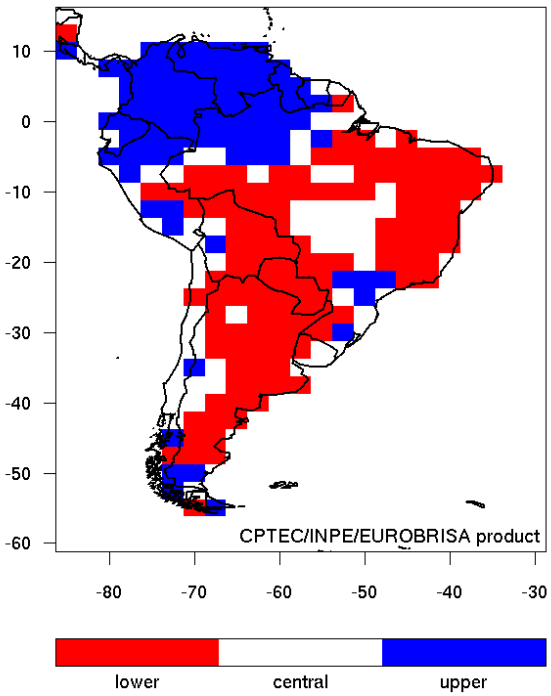
Obs. SST anomaly Apr 2007



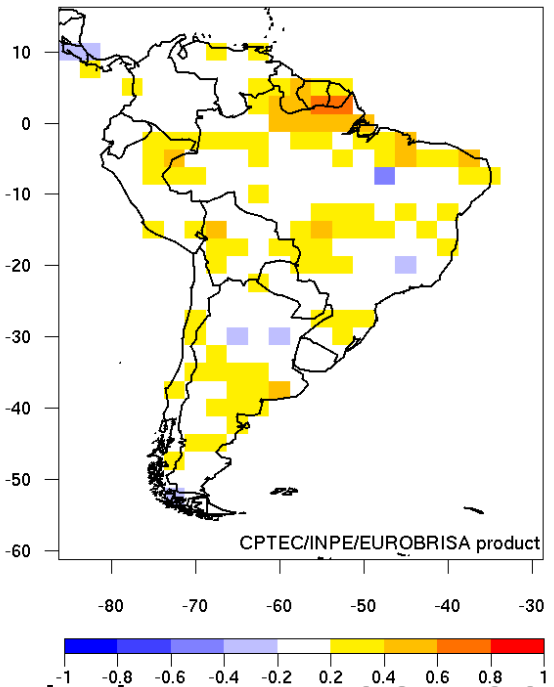
Prob. of most likely precip. tercile (%)



Observed precip. tercile



Gerrity score (tercile categories)

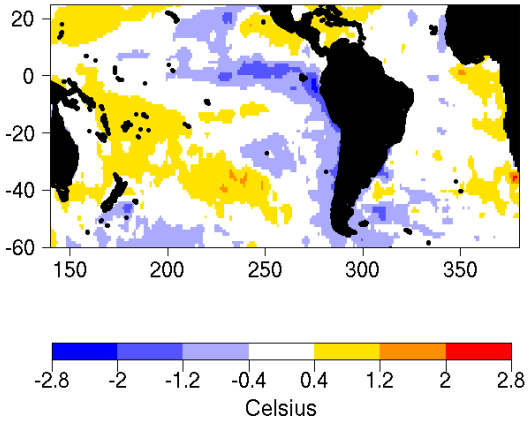


Hindcasts: 1981-2005

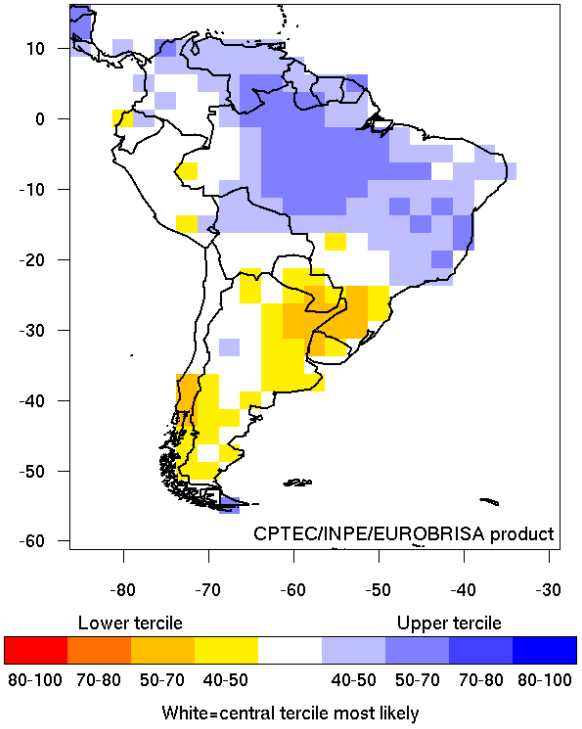
EUROBRISA integrated forecast for SON 2007

Issued: Aug 2007

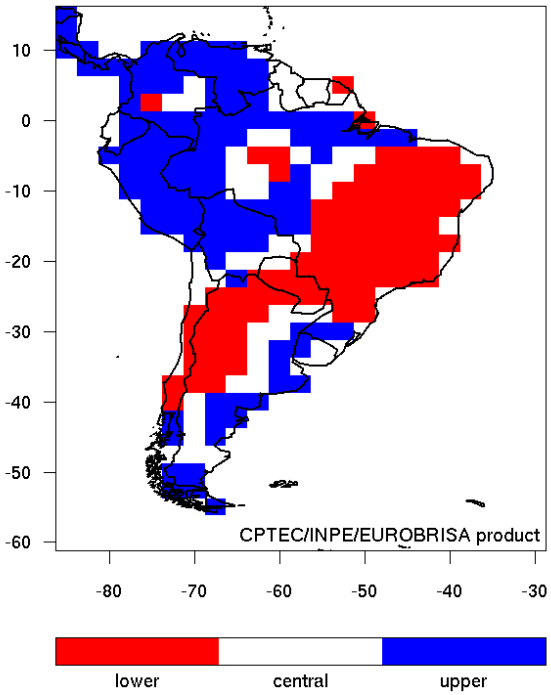
Obs. SST anomaly Jul 2007



Prob. of most likely precip. tercile (%)



Observed precip. tercile



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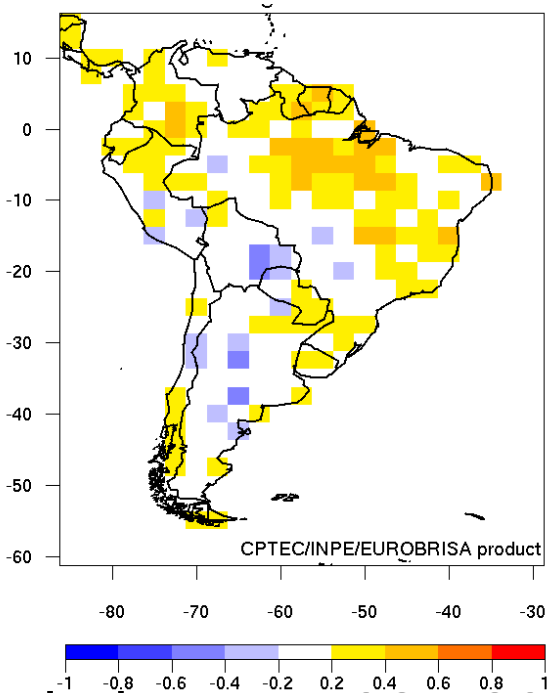
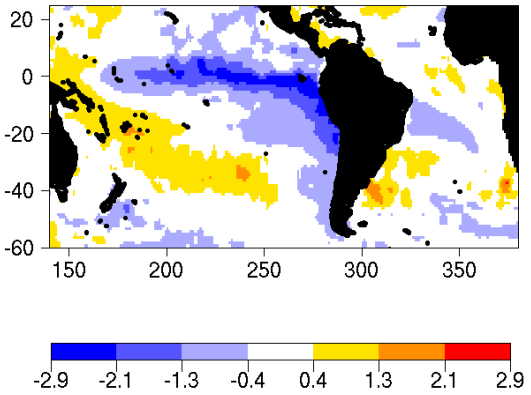


Hindcasts: 1981-2005

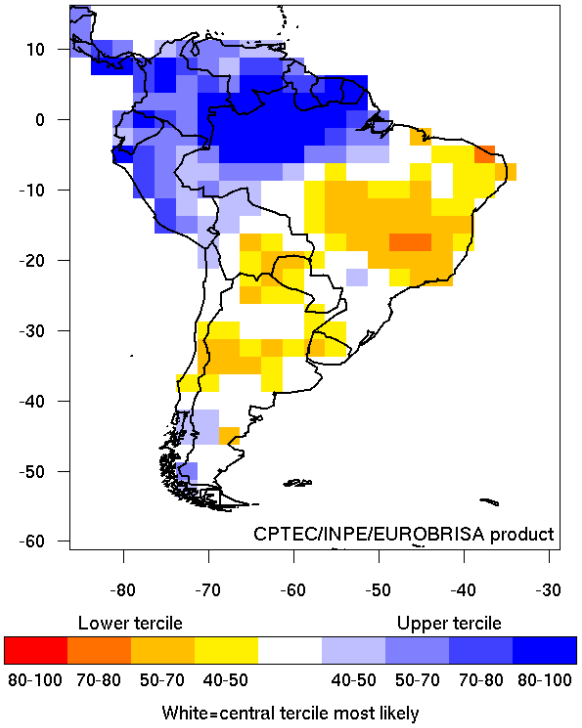
EUROBRISA integrated forecast for DJF 2007/2008

Issued: Nov 2007

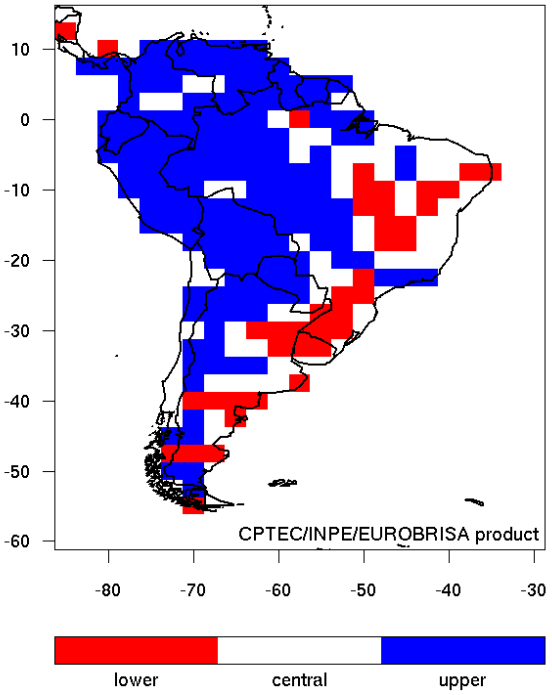
Obs. SST anomaly Oct 2007



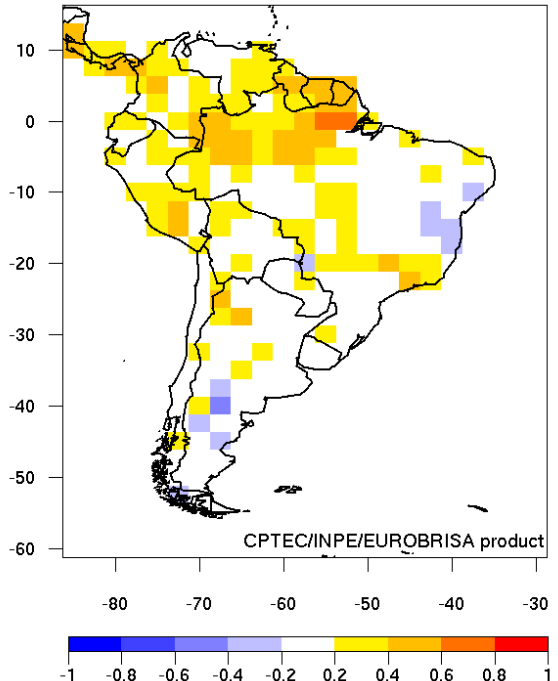
Prob. of most likely precip. tercile (%)



Observed precip. tercile



Gerrity score (tercile categories)

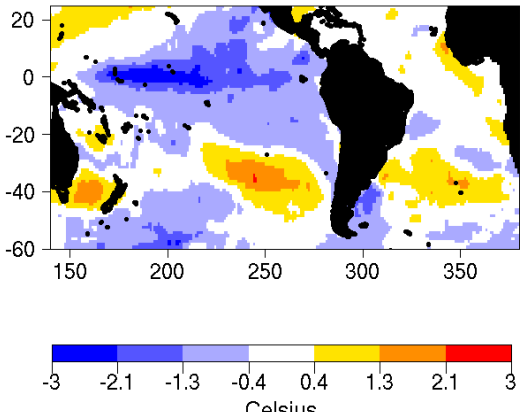


Hindcasts: 1981-2005

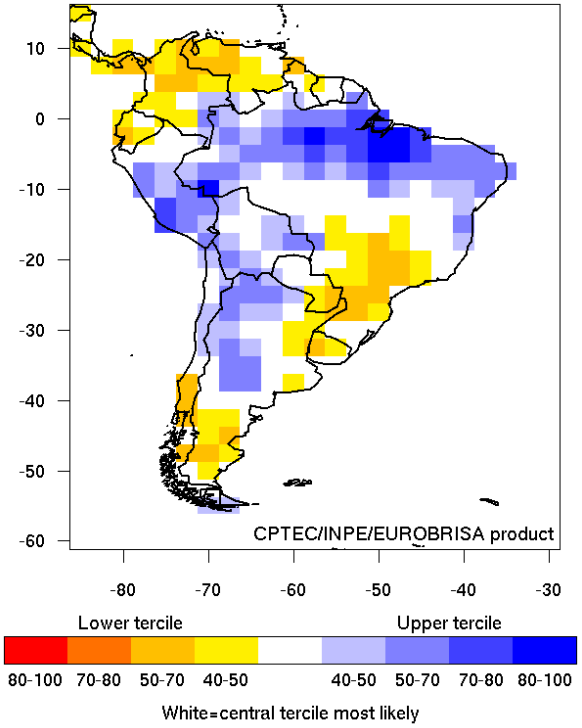
EUROBRISA integrated forecast for MAM 2008

Issued: Feb 2008

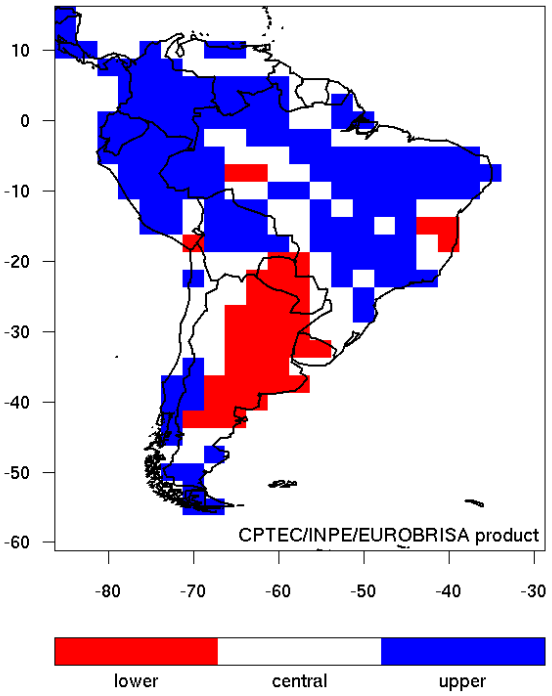
Obs. SST anomaly Jan 2008



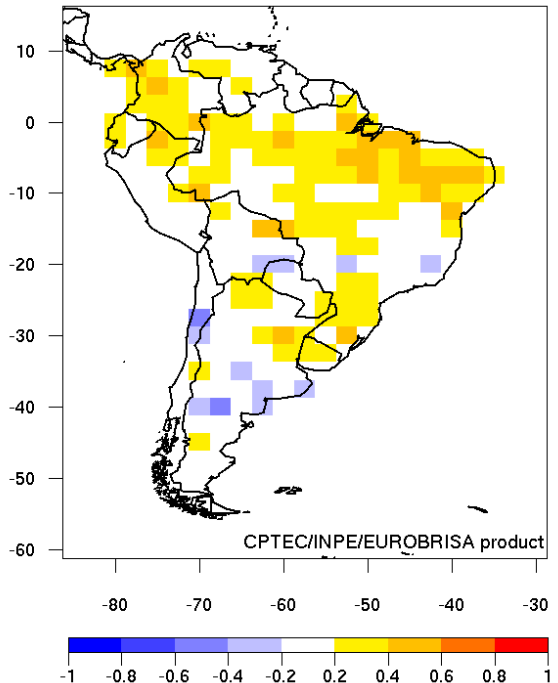
Prob. of most likely precip. tercile (%)



Observed precip. tercile



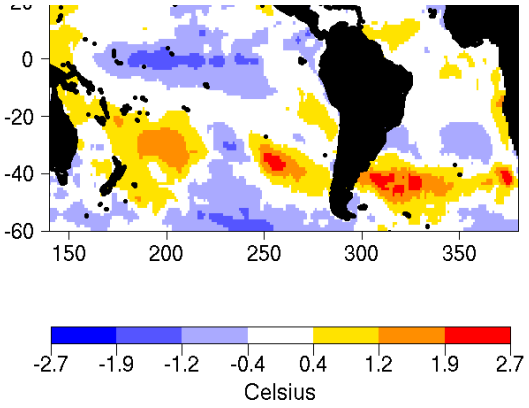
Gerrity score (tercile categories)



Hindcasts: 1981-2005

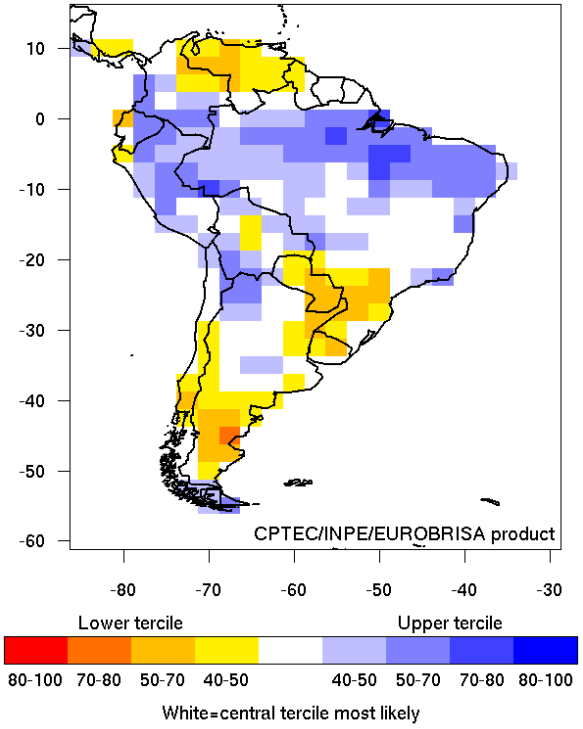
EUROBRISA integrated forecast for MAM 2009

Obs. SST anomaly Jan 2009

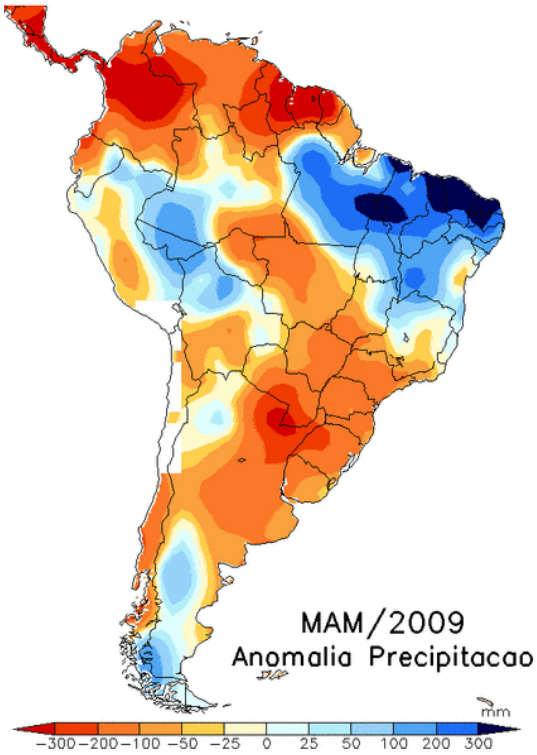


Issued: Feb 2009

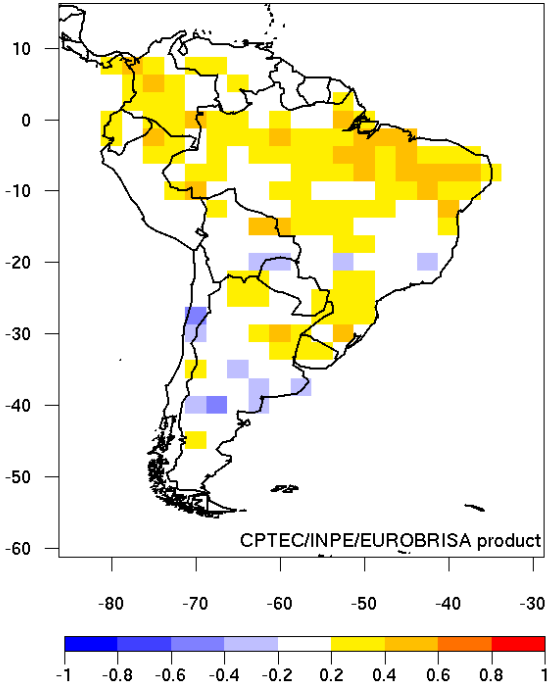
Prob. of most likely precip. tercile (%)



Observed precip.



Gerrity score (tercile categories)

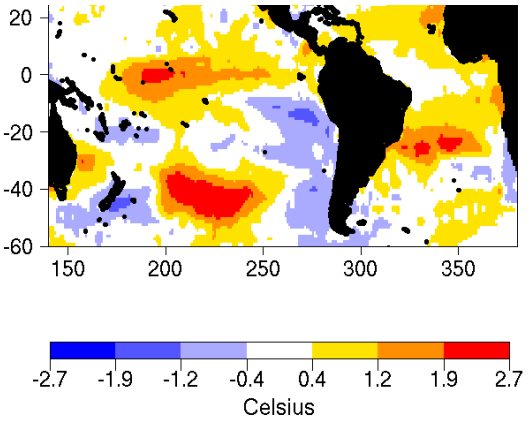


Hindcasts: 1981-2005

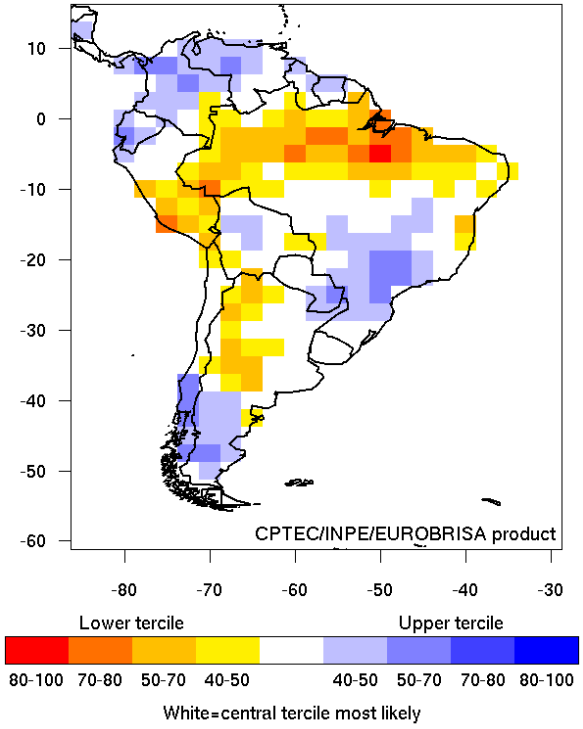
EUROBRISA integrated forecast for MAM 2010

Issued: Feb 2010

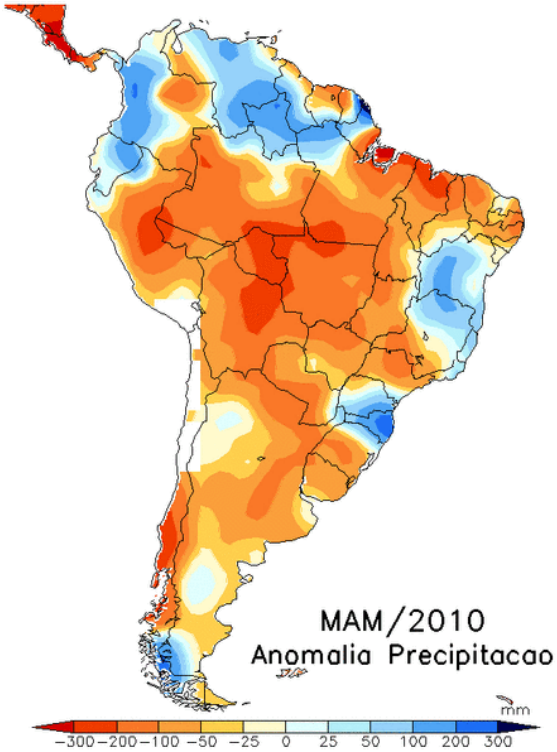
Obs. SST anomaly Jan 2010



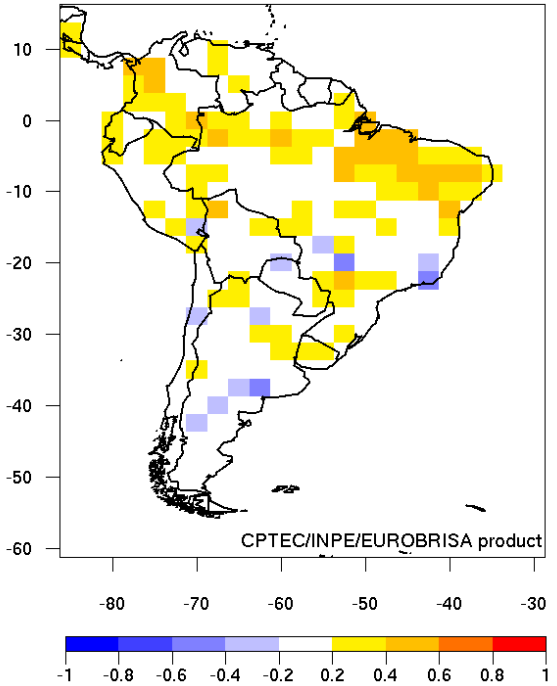
Prob. of most likely precip. tercile (%)



Observed precip.



Gerrity score (tercile categories)

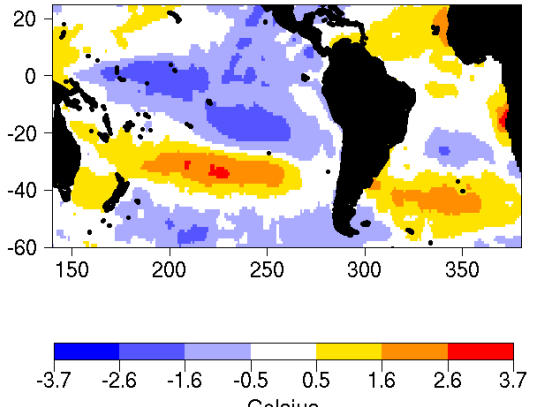


Hindcasts: 1981-2005

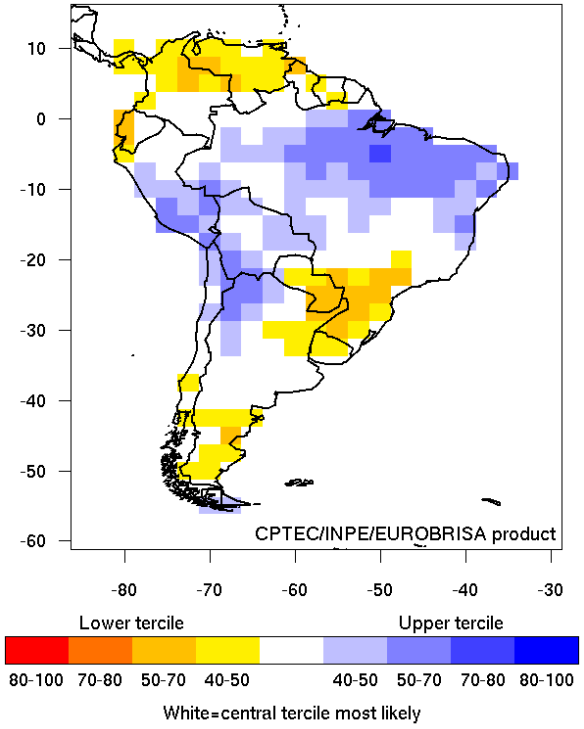
EUROBRISA integrated forecast for MAM 2011

Issued: Feb 2011

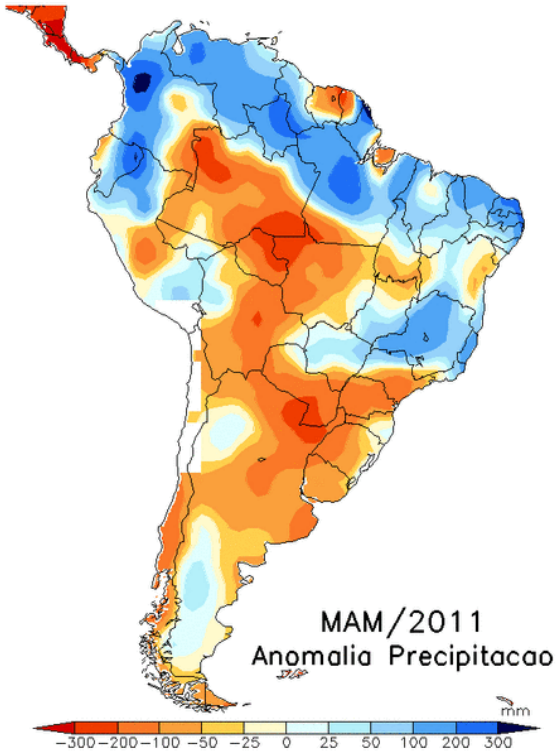
Obs. SST anomaly Jan 2011



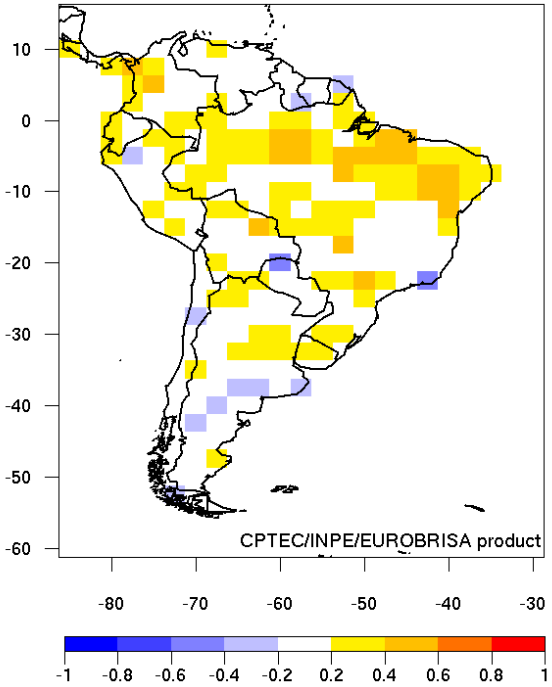
Prob. of most likely precip. tercile (%)



Observed precip.



Gerrity score (tercile categories)

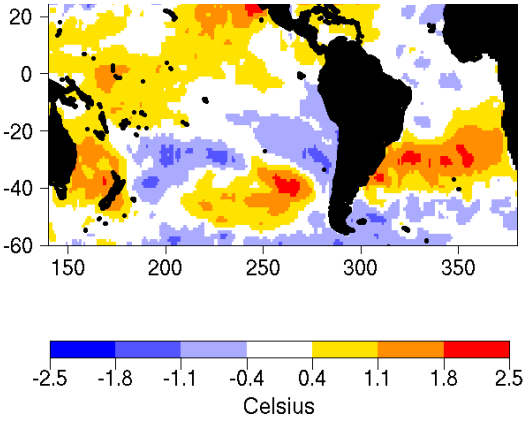


Hindcasts: 1981-2005

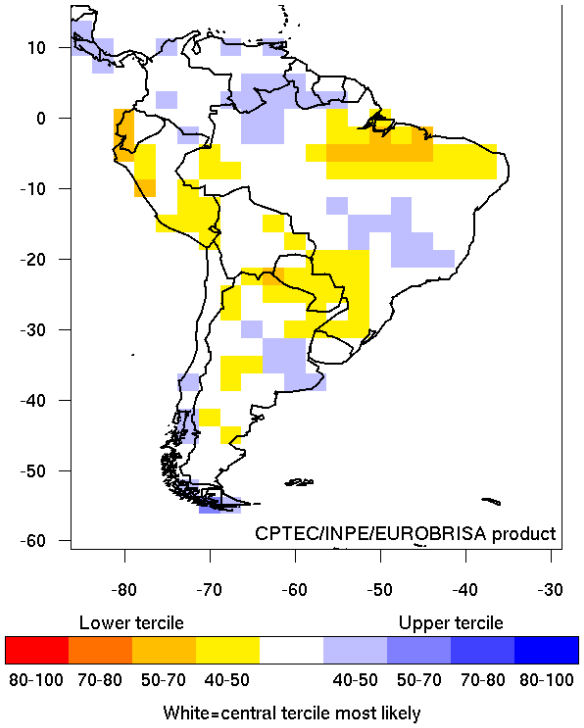
EUROBRISA integrated forecast for MAM 2015

Issued: Feb 2015

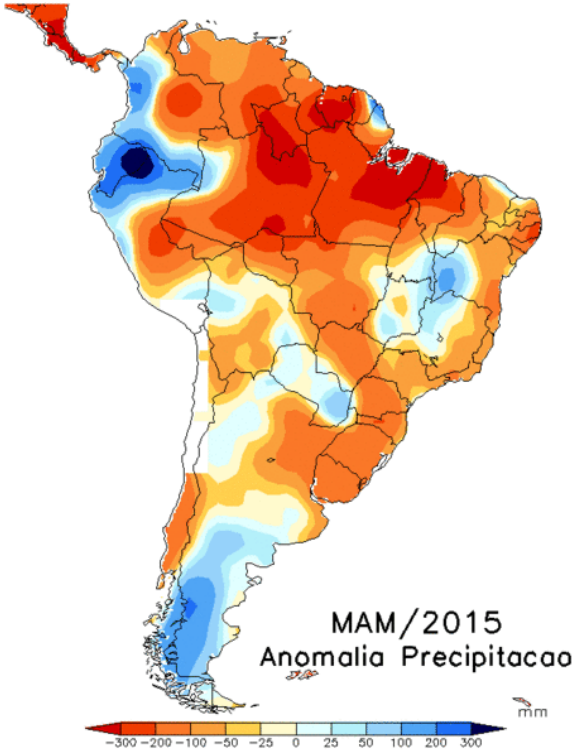
Obs. SST anomaly Jan 2015



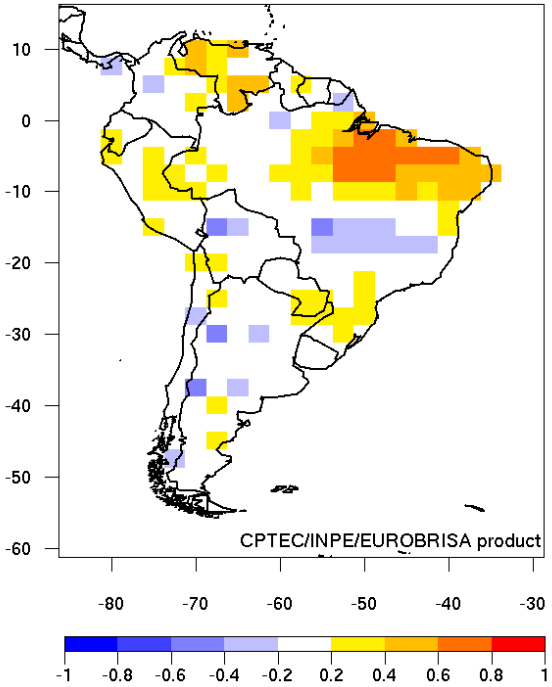
Prob. of most likely precip. tercile (%)



Observed precip.



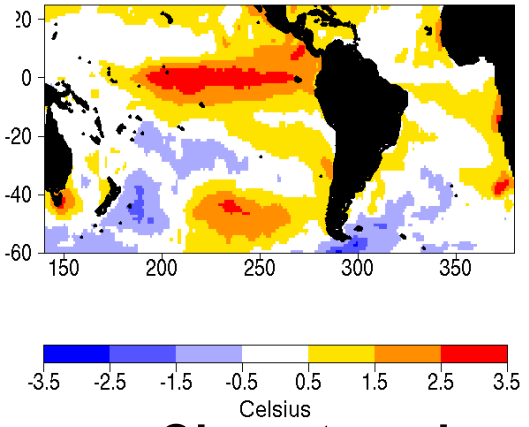
Gerrity score (tercile categories)



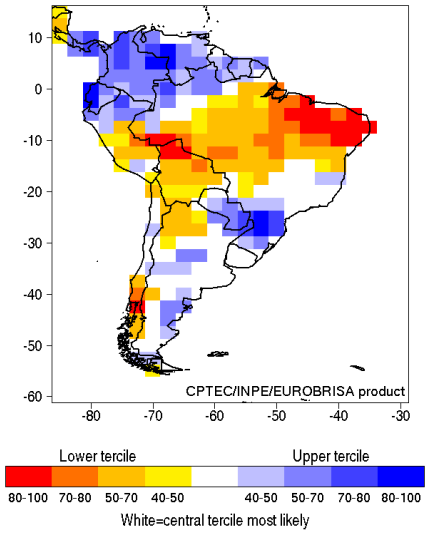
Hindcasts: 1981-2010

EUROBRISA integrated fcst for MAM 2016
Issued in Feb 2016

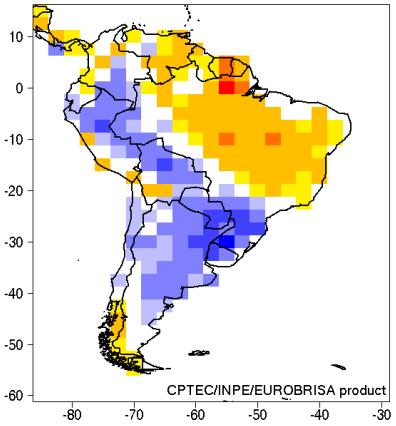
Obs. SST anomaly Jan 2016



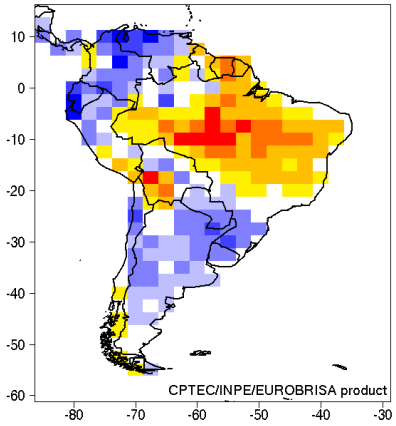
Empirical



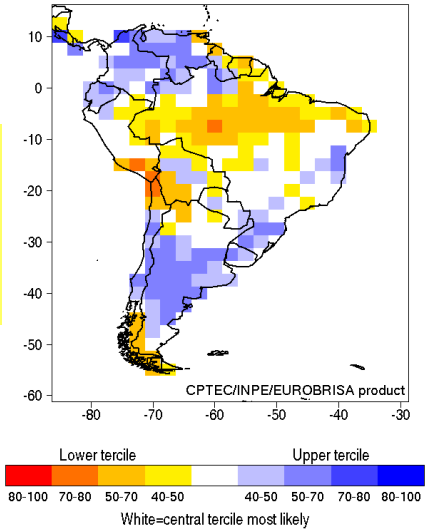
ECMWF



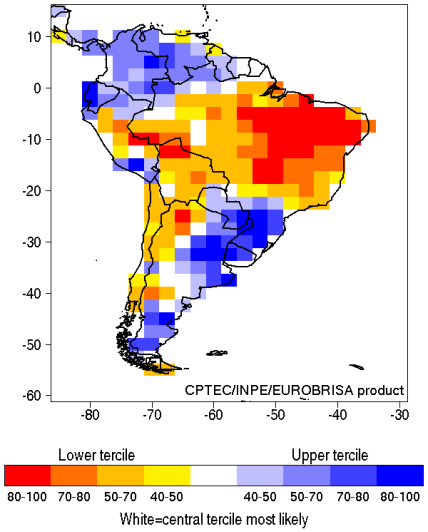
UKMO



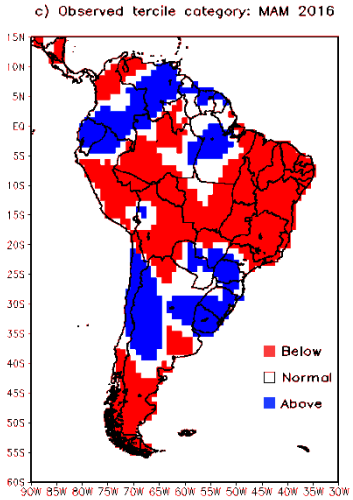
Meteo-France



Integrated



Obs categories: MAM 2016



Empirical (based on Jan 2016 SST) and integrated forecasts indicated pronounced deficit over NE Brazil

EUROBRISA

A EURO-BRazilian Initiative for Improving South American Seasonal Forecasts

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:

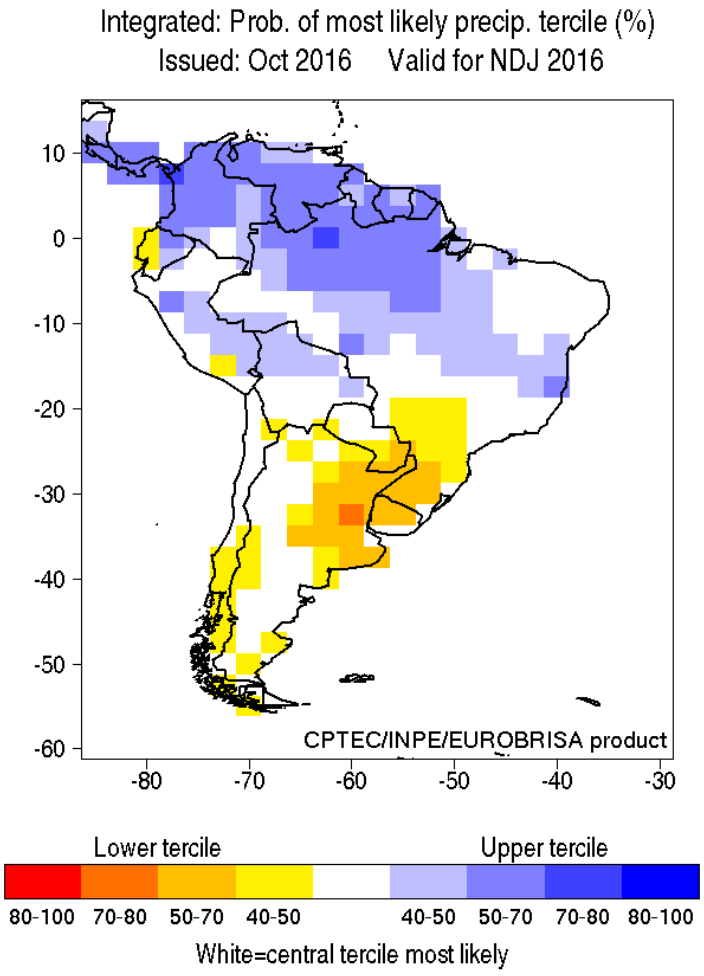
FAPESP

The Leverhulme Trust

Currently supported by:

SPECS
Seasonal-to-decadal climate Prediction for the improvement of European Climate Services

http://eurobrisa.cptec.inpe.br

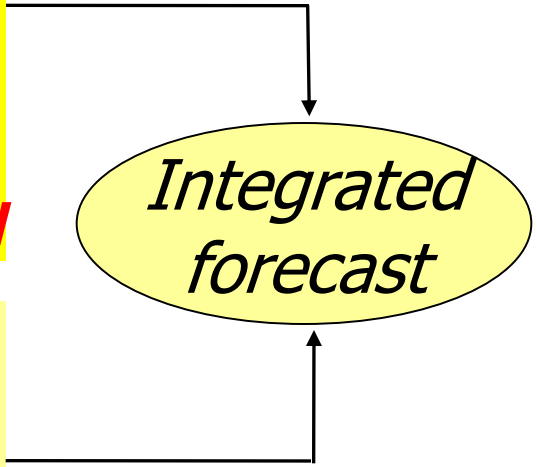


Current EUROBRISA integrated forecasting system for South America

→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

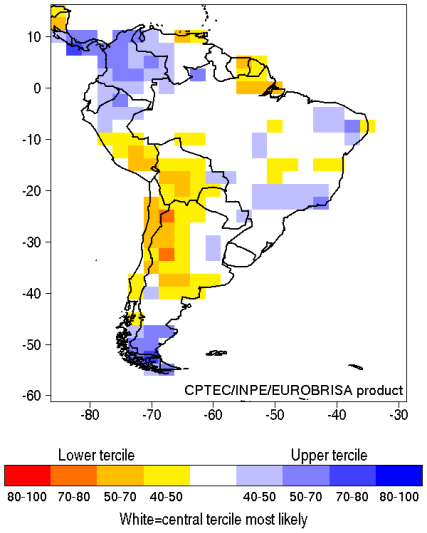
Produced with forecast assimilation
Stephenson et al (2005)
Tellus A . Vol. 57, 253-264

Hindcast period: 1981-2010

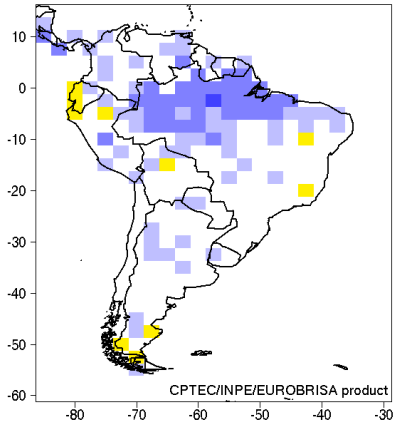
Updated in July 2016

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

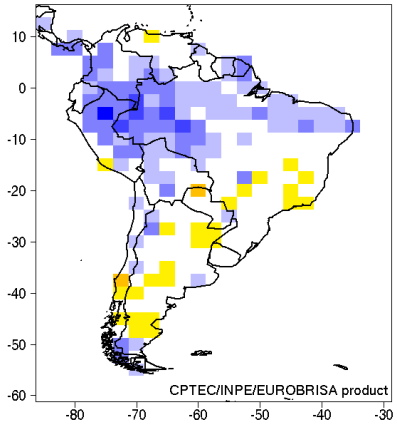
Empirical



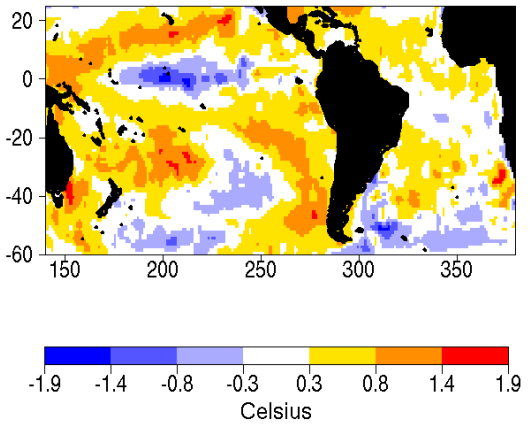
ECMWF



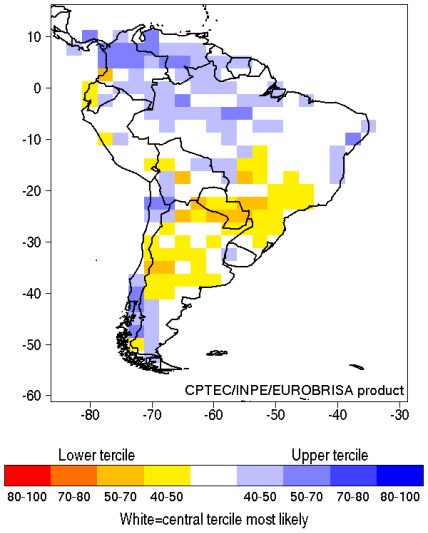
UKMO



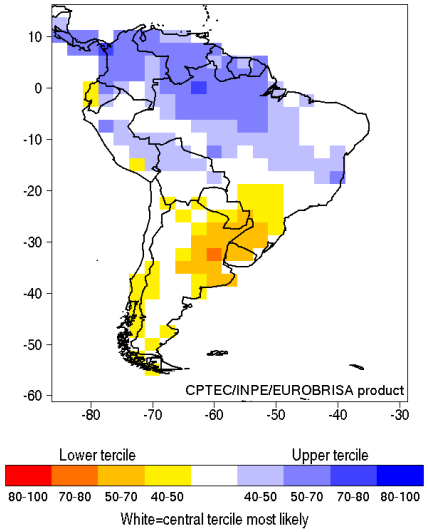
Obs. SST anomaly Sep 2016



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

EUROBRISA: A EURO-BRazilian Initiative for improving South American seasonal forecast

Home | Weather | Climate | Numerical Forecasts | Energy | Satellites | Waves | Observational Data | Met. Instrumentation | Air Quality

http://eurobrisa.cptec.inpe.br

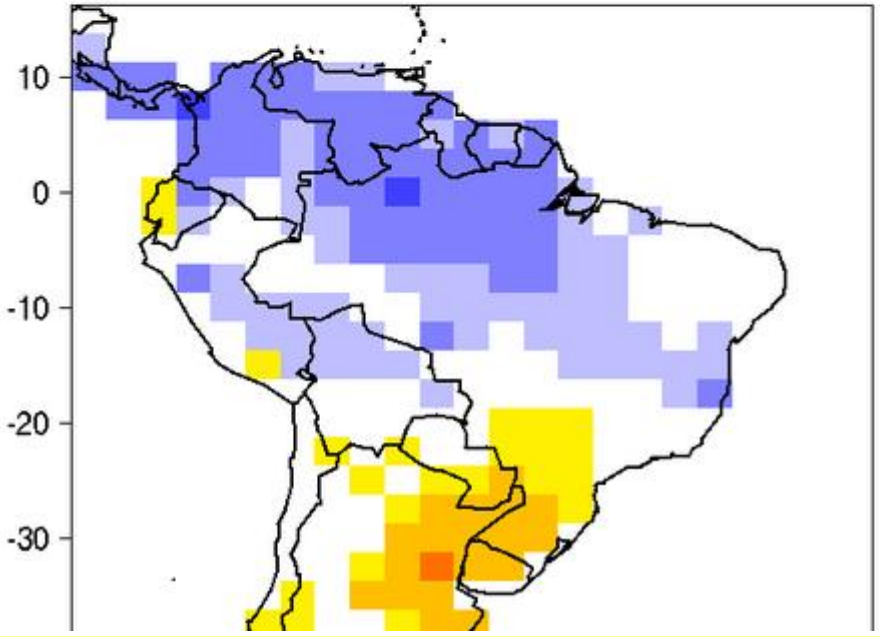
PRODUCTS.

Product: Forecast | Variable: precip. | Model: Integrated | Date Issued: Jul | 2016

Forecast Type: Prob. most lik. tercile

(Products documentation)
Previous EUROBRISA operational System (operational until Jun 2016)

Integrated: Prob. of most likely precip. tercile (%)
Issued: Oct 2016 Valid for NDJ 2016



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

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
Leverhulme research network proposal
Powerpoint overview

PRESENTATIONS

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

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PRODUCTS.

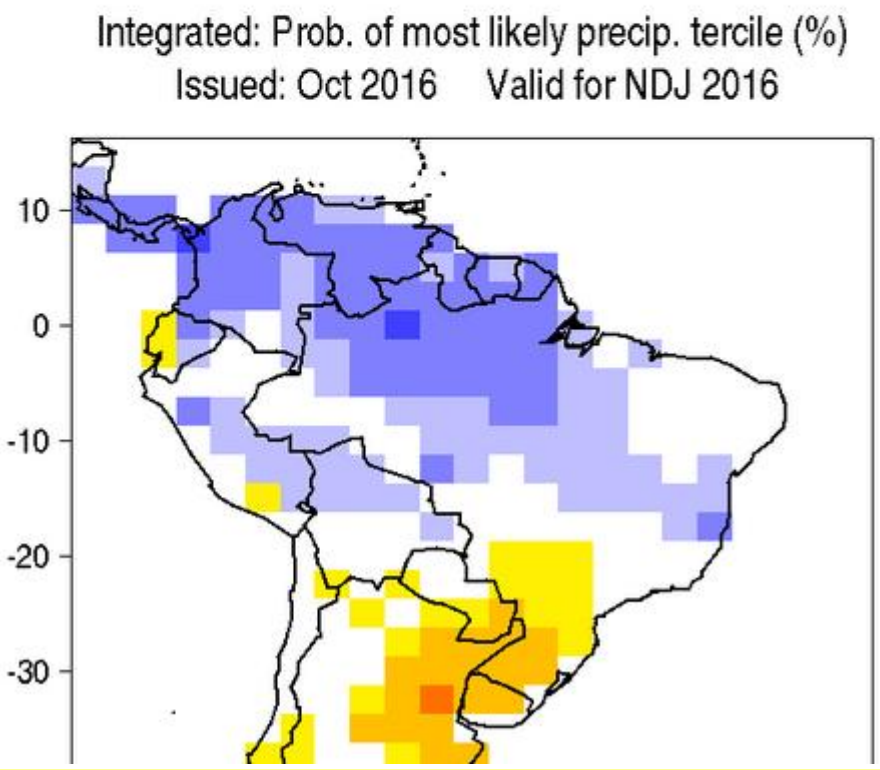
Product: Forecast | Variable: precip. | Model: Integrated | Date Issued: Jul | 2016

Forecast Type: Prob. most lik. tercile

Real-time forecast and verification products

→ (Products documentation)
→ Previous EUROBRISA operational System (operational until Jun 2016)

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



AIMS

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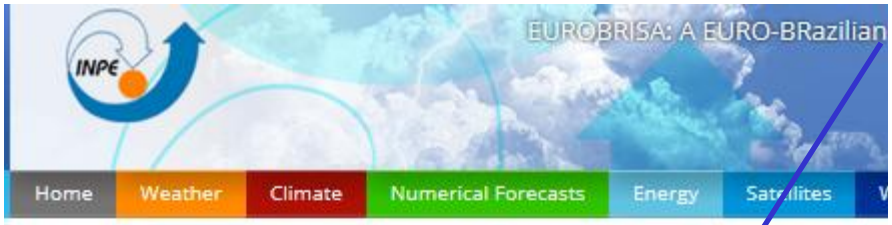
Hybrid (empirical-dynamical) multi-model ensemble system for South America

New version of EUROBRISA

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)



http://eurobrisa.cptec.inpe.br

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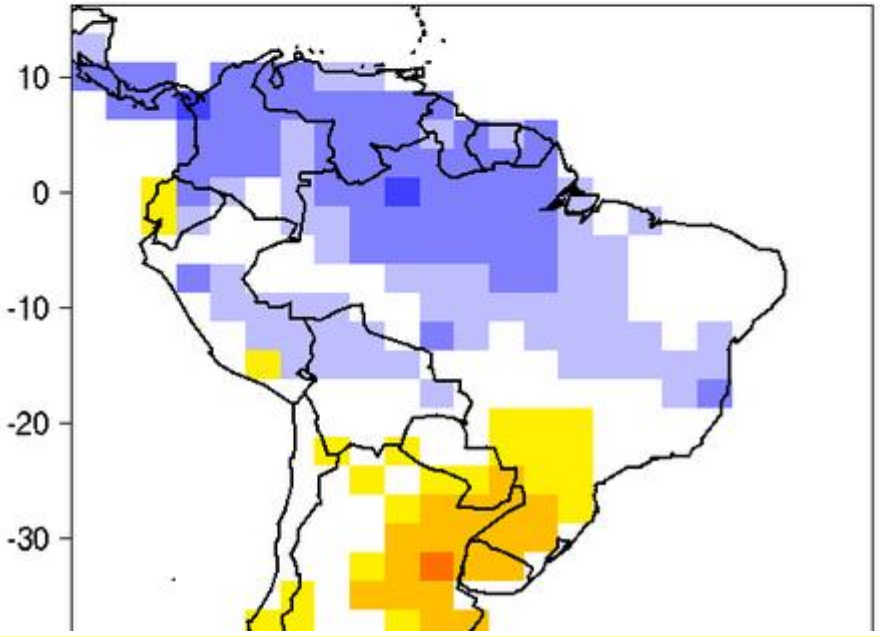
Real-time forecast and verification products

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

Integrated: Prob. of most likely precip. tercile (%)
Issued: Oct 2016 Valid for NDJ 2016



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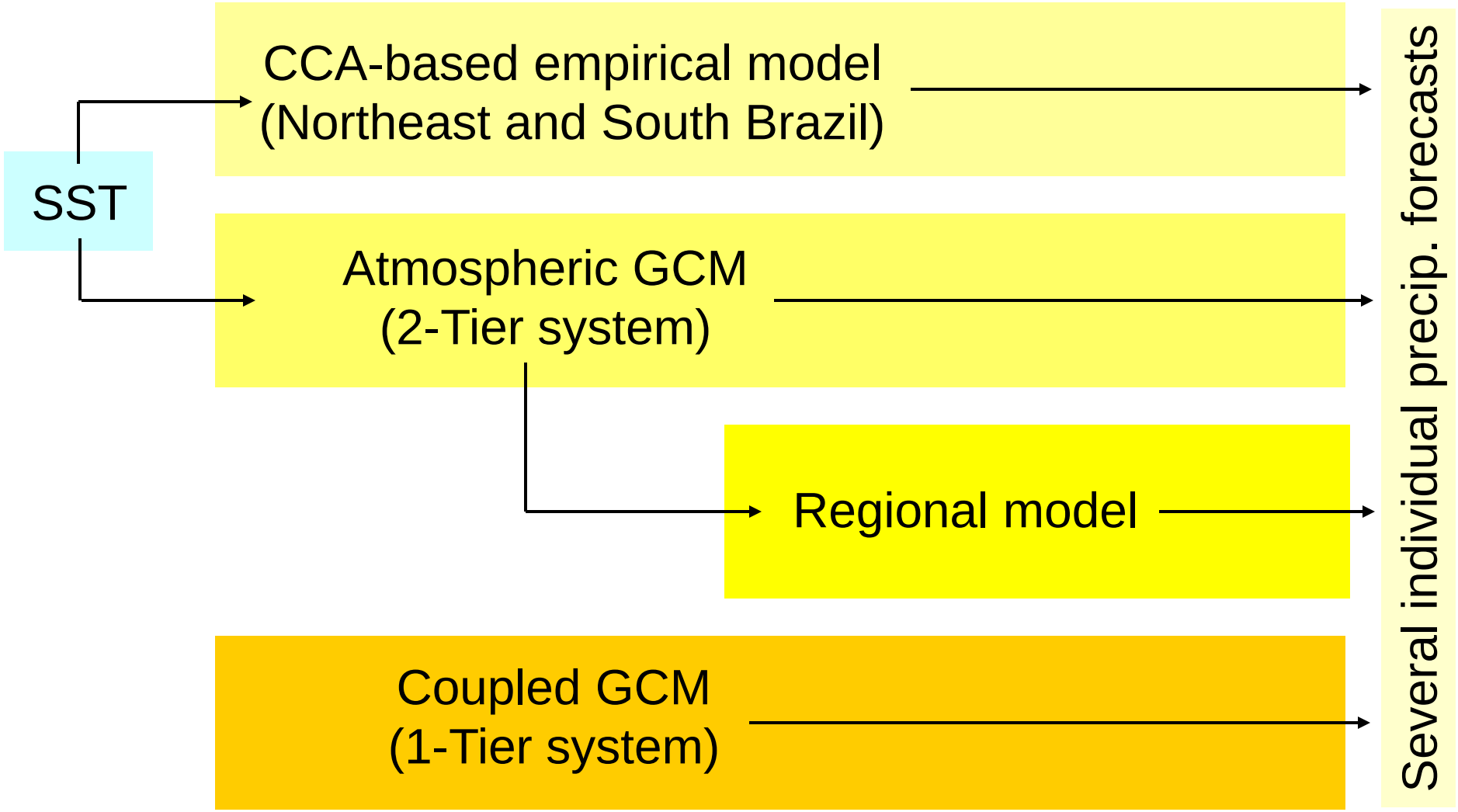
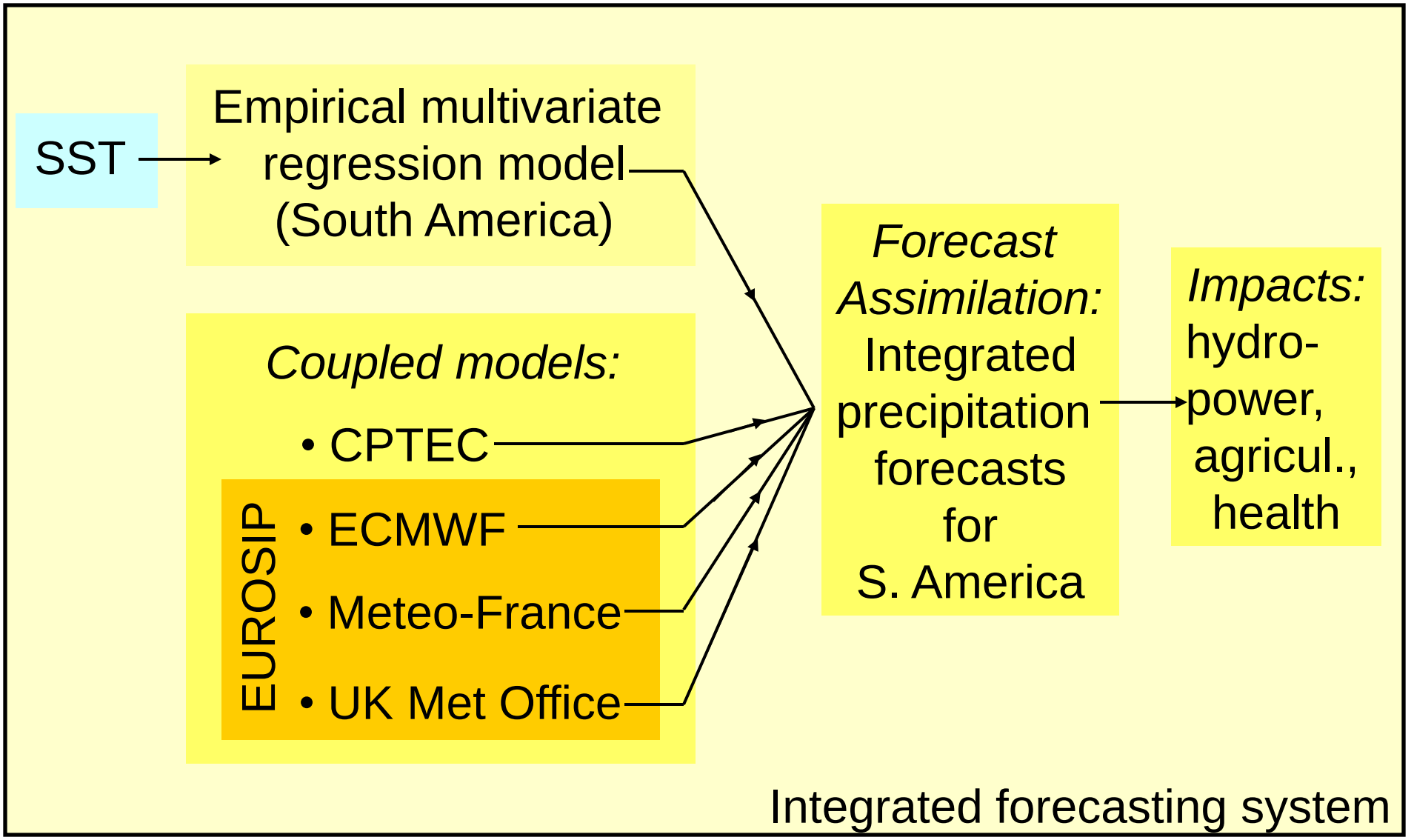
Hybrid (empirical-dynamical) multi-model ensemble system for South America

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

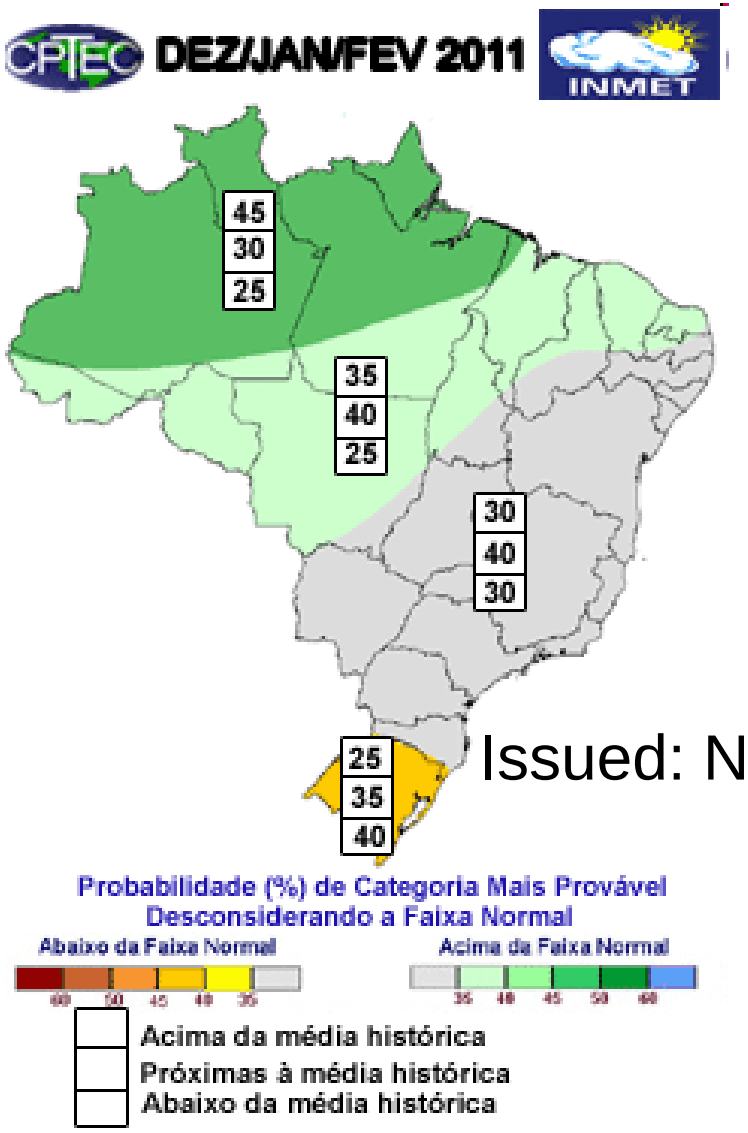
Seasonal forecasting system before EUROBRISA



After EUROBRISA

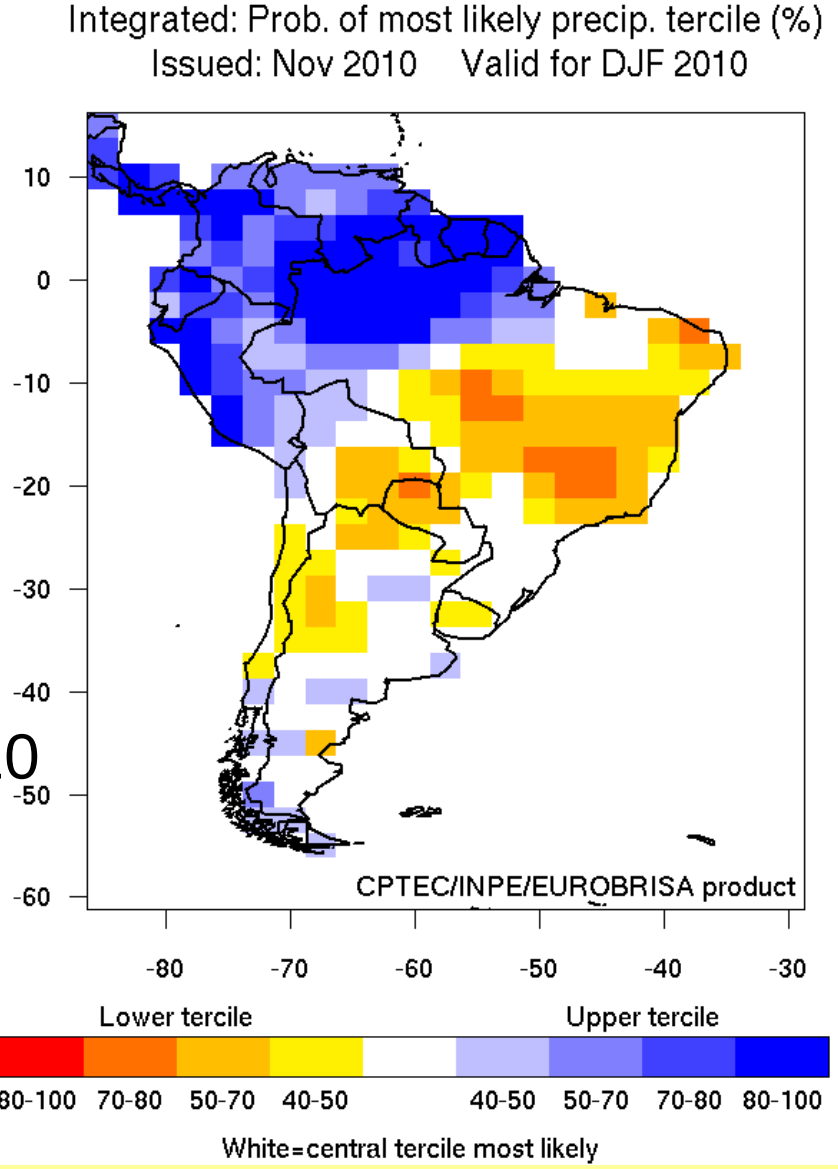


Official forecast for Brazil for DJF 2010/2011



Issued: Nov 2010

EUROBRISA forecast for DJF 2010/2011



→EUROBRISA forecast helps define official seasonal forecast in Brazil

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

- 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
- EU for funding the SPECS project that supported the maintenance of EUROBRISA

THANK YOU FOR YOUR ATTENTION!

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