Climate Variability and Change over South America (and other places)

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Outline

This presentation will describe research output from my time at IRI, where I am part of the Climate Program and, in particular, of the Near-Term Climate Change (NTCC) group.
Project:

1. Develop metrics and baselines for estimating the quality of decadal predictions

2. Determine the fidelity of the surface expression of oceanic decadal variability, and the associated climate teleconnections, in several state-of-the-art CGCMs
Develop metrics and baselines for estimating the quality of decadal predictions

Collaboration with US CLIVAR’s Decadal Predictability Working Group

A verification framework for interannual-to-decadal predictions experiments

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Received: 10 October 2011 / Accepted: 31 July 2012 © The Author(s) 2012. This article is published with open access at Springerlink.com

Abstract Decadal predictions have a high profile in the climate science community and beyond, yet very little is known about their skill. Nor is there any agreed protocol for estimating their skill. This paper proposes a sound and coordinated framework for verification of decadal hindcast experiments. The framework is illustrated for decadal hindcasts tailored to meet the requirements and specifications of CMIP5 (Coupled Model Intercomparison Project phase 5). The chosen metrics address key questions about the information content in initialized decadal hindcasts. These questions are: (1) Do the initial conditions in the hindcasts lead to more accurate predictions of the climate, compared to un-initialized climate change projections? and (2) Is the prediction model’s ensemble spread an appropriate representation of forecast uncertainty on average? The first question is addressed through deterministic metrics that compare the initialized and uninitialized hindcasts. The second question is addressed through a probabilistic
Develop metrics and baselines for estimating the quality of decadal predictions

My roles in the activity:

- to program, test and document a set of deterministic and probabilistic metrics to evaluate the skill of the CMIP5 decadal hindcasts
- to search for adequate scales for temporal and spatial averaging
- to develop a website to share the hindcasts evaluation and the Matlab code I developed

Prototype:
http://iri.columbia.edu/~gonzalez/DPWG/

Final Version:
http://clivar-dpwg.iri.columbia.edu/
Develop metrics and baselines for estimating the quality of decadal predictions

The deterministic verification metrics face **Question 1:**

*Do the initial conditions in the hindcasts lead to more accurate predictions of the climate?*

The probabilistic verification metrics face **Question 2:**

*Is the model's ensemble spread an appropriate representation of forecast uncertainty on average?*

And **Question 3:**

*In the case that the forecast ensemble does offer information on overall forecast uncertainty, Does the forecast-to-forecast variability of the ensemble spread carry meaningful information?*
Develop metrics and baselines for estimating the quality of decadal predictions

- **Initialized hindcasts**
  - every 5 years (standard CMIP5 output)

- **Uninitialized hindcasts or 'historical' runs**
  - every year

**Verification Metrics**

- **Deterministic**
  - Mean Squared Skill Score (MSSS) and components: Correlation & Conditional Bias

- **Probabilistic**
  - Continuous Rank Probability Skill Score (CRPSS)

**Spatial scales**
- grid scale
- spatially smooth

**Temporal scales:**
- Year 1, years 2-5, years 6-9, years 2-9
Develop metrics and baselines for estimating the quality of decadal predictions

Multi-model Ensemble Mean (12 models) – MSSS – years 2-5 – annual means

Temperature
MME temp MSSS: year 2-5 ann
Initialized - Uninitialized

Precipitation
MME prcp MSSS: year 2-5 ann
Initialized - Uninitialized
Develop metrics and baselines for estimating the quality of decadal predictions

Multi-model Ensemble Mean (12 models) – Correlation – years 2-5 – annual means

Temperature

Precipitation

Correlation: Initialized Hindcast

Correlation: Uninitialized Hindcast
Develop metrics and baselines for estimating the quality of decadal predictions

MME (12 models) – Conditional Bias – years 2-5 – Spatially smooth - annual means

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MME temp Conditional Bias: year 2-5 ann</td>
<td>MME prcp Conditional Bias: year 2-5 ann</td>
</tr>
<tr>
<td>[Initialized] - [Uninitialized]</td>
<td>[Initialized] - [Uninitialized]</td>
</tr>
</tbody>
</table>

**Temperature**

- Conditional Bias: Initialized Hindcast
- Conditional Bias: Uninitialized Hindcast

**Precipitation**

- Conditional Bias: Initialized Hindcast
- Conditional Bias: Uninitialized Hindcast
Develop metrics and baselines for estimating the quality of decadal predictions

CCSM4 – MSSS – years 2-5 – annual means

Temperature
CCSM4 temp MSSS: year 2-5 ann
Initialized - Uninitialized

Precipitation
CCSM4 prcp MSSS: year 2-5 ann
Initialized - Uninitialized
Determine the fidelity of the surface expression of oceanic decadal variability, and the associated climate teleconnections

2 Main presentations

WCRP Open Science Conference (2011)

“Assessment of changes in regional precipitation and temperature regimes associated with decadal variability and the ability of climate models to reproduce them”

37th NOAA Climate Diagnostics and Predictability Workshop (2012)

“Diagnosing decadal-scale climate variability in current generation coupled models”
Observations (1961-2006)

SAHEL

TEMPERATURE

PRECIPITATION

Seasonality

Time scales decomposition

AMV influence
SAHEL

Seasonality

Time scales decomposition

AMV influence

Hadley Centre – DePreSys

TEMPERATURE

PRECIPITATION

SAHEL
Determine the fidelity of the surface expression of oceanic decadal variability, and the associated climate teleconnections.
Relationship between AMV and regional climate anomalies in CMIP5

TEMPERATURE

PRECIPITATION
Relationship between AMV and regional climate anomalies in CMIP5

Example: Observations - precipitation – Sahel vs SW US

**SAHEL**

- Sah Histograms: CRU TS3.1 std det 9yr-smoooth prcp - JJA
  - 57.4%
  - 42.6%

- Positive events - ERSST 9yr AMVI
  - 42.9%
  - 57.1%

- Negative events - ERSST 9yr AMVI
  - 85.2%
  - 14.8%

**SW US**

- SWUS Histograms: CRU TS3.1 std det 9yr-smoooth prcp - JJA
  - 51.5%
  - 48.5%

- Positive events - ERSST 9yr AMVI
  - 85.7%
  - 14.3%

- Negative events - ERSST 9yr AMVI
  - 25.9%
  - 74.1%
Relationship between AMV and regional climate anomalies in CMIP5

Example: historical/piControl - precipitation – Sahel vs SW US

- The influence in the precipitation anomalies in some regions like Sahel seems more robust that in some others like SW USA.
- The discrimination is generally weaker in the piControl experiments.
- We are exploring whether the multi-decadal variability in the Tropical Atlantic Ocean has more robust teleconnections with some of these regions.
Exploring seasonal-to-decadal predictability and teleconnections in CMIP5 decadal hindcasts

AGU Fall Meeting (2011)

“Seasonal-to-interannual variability of precipitation over Southeastern South America en CMIP5 decadal hindcasts”

CFSv2 Evaluation Workshop (2012)

“Seasonal-to-interannual variability of precipitation over Southeastern South America en CMIP5 decadal hindcasts”

★ including 12 hindcasts

Updates of this work will be presented at:
- International Workshop on seasonal to decadal prediction
- DACA-13, Interannual to decadal climate variability and change
Seasonal cycle

GPCCv4 DJF Precipitation Mean Field

Standard Deviation of Mean Seasonal Cycle

Mean Seasonal Cycle
1961-2010

RMSE of Mean Seasonal Cycle Across Months
1961-2010
The warm ENSO events of 1982/83 and 1997/98 are represented as both lead 7 and lead 2 in the decadal hindcasts ensemble.
Exploring seasonal-to-decadal predictability and teleconnections in CMIP5 decadal hindcasts

El Nino 97/98 as 7-year lead
Exploring seasonal-to-decadal predictability and teleconnections in CMIP5 decadal hindcasts

El Nino 97/98 as 2-year lead
SST Anomalies

Obs: 97/98
Regressions SESA precipitation vs SSTA

Files:
- Fcst: 7-Year Lead
- Fcst: 2-Year Lead
- Obs
- CFSv2
- HadCM3_i3
- CCSM4
Exploring seasonal-to-decadal predictability and teleconnections in CMIP5 decadal hindcasts

**SESA precipitation - Interannual-to-decadal skill (RMSE)**

- CNRM_CM5
- IPSL_CM5A_LR
- MIROC5
- MIROC4h
- MPI_ESM_LR
- MRI_CGCM3
- HadCM3_i2
- HadCM3_i3
- DePreSys
- CanCM4
- CFSv2
- CCSM4

3-month lead seasonal forecast - ECHAM4.5 (24-member ensemble)
Development of multi-scale regional climate information

Projects:


Integration of Decadal Climate Predictions, Ecological Models and Human Decision-making Models to Support Climate-resilient Agriculture in the Argentine Pampas. NSF EaSM. Lead PI: Guillermo Podesta (Univ. of Miami).
A Framework for the Development of Multi-scale Regional Climate Information

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The International Research Institute for Climate and Society, The Earth Institute at Columbia University, Palisades, NY, United States.

ABSTRACT

Climate information for the next few decades is required for both risk management and planning purposes. On this time horizon natural and anthropogenic factors can be equally important. We introduce here a strategy for the layering of information on different timescales - anthropogenically forced climate change, natural low-frequency fluctuations and year-to-year variability - each with its associated uncertainty range. The approach involves the combination of dynamical and statistical projections, with specific methodologies being regionally tailored.

The example of South Eastern South America will be presented. Here, such information can play a crucial role in the development of land-use and water management policies. Approaches of varying complexity are considered in order to take advantage of observations, IPCC climate change projections and initialized decadal predictions, and to address the uncertainties in these sources of information.

EXAMPLE: OND precipitation in South Eastern South America (SESA)

- OND was chosen for its strong coherent variability and trend, and for the importance of rainfall in that period to regional agriculture.
- The dataset chose was WMO's GPCC and one of the results might change slightly with different datasets.

1) Understanding the past: 20th Century Variability And Change:

2) Looking towards the future

TREND

- The CMIP 3 coupled models used in the IPCC/AR4 highly underestimate the observed increase in SESA precipitation.
- To forecast short periods in the future, linear trend extrapolation may be a better estimate of the increase.
- If the time horizon is longer (i.e., 50 years), the regression with the ensemble mean global temperature may be a better choice since it includes information from emission scenarios.

VARIABILITY

- "Decadal climatology" - characterization of variability that represents likely magnitude and persistence of anomalies, by generating numerous synthetic realizations based on historical observations.

i) Dynamical predictions: seasonal to interannual forecasts have skill during ENSO extremes, but not for decadal timescales in this model.
ii) Statistical predictions: seasonal to interannual forecasts have skill during ENSO extremes, but not for decadal timescales in this model.

iii) Statistical predictions: an alternative to dynamical predictions, possibly merged with dynamical forecasts if predictors can be represented by the models.
- Observational predictors with large (decadal) lags are particularly useful.
- Example: Multiple linear regression model built with 1.3 EN 3.4 index (OND: y > 0); Brazil current SSTA index (BC) [SON (1-10 yrs)]: before and after the NE Tropical Atlantic SSTA index (NETA) [SON (1-22 yrs)]. The model was trained using a moving 30-year window within 1901-2000.

3) Putting it together

Combining: dynamical predictions (One year lead EN3.4) + statistical simulations + trend estimations

Conclusions

This framework (work in progress) needs information on all timescales, which is not always available from a single tool (i.e.: a dynamical model).
- Observed trends are not correctly represented in dynamical models.
- Statistical models can complement information from dynamical models.
- "Decadal climatology" based on past observations is needed when there is no signal or skill in deterministic prediction tools.
Multi-scale Climate Information for Agricultural Planning in Southeastern South America for Coming Decades


Motivation
The agricultural frontier of SE South America has expanded over the past several decades due to large increases in regional precipitation. Are these increases likely to persist in the future, or are they part of decadal variability, or both?

Objective
To better understand the causes of climate variability and change in the region, and with that information, develop actionable climate information that can support agriculture planning for future decades.

Attribution: Decadal Variability versus Anthropogenic Change

Observations: Time Scale Decomposition

- Trends in precipitation are a significant indicator of climate change in the south west of Brazil in the 1980s and 1990s. It is not clear what other factors contributed to or dynamics explained.
- The observed trend for the region is not explained by a simple monsoonal pattern. It could be due to changes in the atmosphere-ocean interaction in the 1990s.

Models: O$_3$ versus GHG

- The observed trend for the region is not due to a simple monsoonal pattern. It could be due to changes in the atmosphere-ocean interaction in the 1990s.
- The observed trend for the region is not due to a simple monsoonal pattern. It could be due to changes in the atmosphere-ocean interaction in the 1990s.

Future Climate Information

CMIP5 Models

- Employed models are able to capture the magnitude of the observed 30-year trend, though they fail to capture the longer term warming trend.
- The precipitation trend for this region is due to a change in atmospheric circulation.

Layering Trend + Natural Variability

- A properly distributed observation record a decomposed into trend, seasonal, and interannual components.
- Precipitation trends, if any, are not significant.
- An extreme regional change in precipitation by event, sector, and sector-averaged (given the high variability of average seasonal precipitation in this region).

Stochastic Simulations

- Stochastic simulations suggest the contribution from warming to increased precipitation in this region is between 50% and 60% of total change.

Weather Characteristics and Agriculture

Crop Yields depend on Weather Characteristics

- Temperature will explain variations in agricultural productivity.
- Precipitation and temperature interactions are important for understanding agricultural productivity.
- Yield responses to temperature and precipitation are important for understanding agricultural productivity.

References

MOTIVATIONS

SESA has experienced a strong wetting trend over the complete 20th Century.

Over the last decades, the wetting has been followed by the expansion of the agricultural frontiers.
Figure 3.13. **Trend of annual land precipitation amounts for 1901 to 2005 (top, % per century) and 1979 to 2005 (bottom, % per decade), using the GHCN precipitation data set from NCDC.** The percentage is based on the means for the 1961 to 1990 period. Areas in grey have insufficient data to produce reliable trends. The minimum number of years required to calculate a trend value is 66 for 1901 to 2005 and 18 for 1979 to 2005. An annual value is complete for a given year if all 12 monthly percentage anomaly values are present. Note the different colour bars and units in each plot. **Trends significant at the 5% level are indicated by black + marks.**
The trend explains in average 20% of the summer precipitation variance.
MOTIVATIONS: CMIP3/CMIP5 – 20th Century

CMIP3 and CMIP5 models fail to reproduce the 20th Century wetting.
MOTIVATIONS: annual means – 20th Century

GPCC annual mean precipitation linear trend magnitude - 1901-2000

CMIP5 historical ensemble mean annual precipitation trend magnitude - 1901-2000

OBS

MME CMIP5
CMIP5 historical – annual mean precipitation – 20th Century

Comparing the magnitudes of the trend

CMIP5 historical ensemble

fractional difference

magnitude of the trend

OBS

Comparing the % of variance explained by the trend
Can we trust century-long gridded datasets over SESA?
MOTIVATIONS: why ozone?

Ozone depletion has been shown to be one of the main drivers of climate change in the Southern Hemisphere (e.g. Polvani et al. 2011).

In particular, it has been linked to the observed wetting of the SH subtropics (Kang et al 2011).

The fact that the trend in SESA strengthens around 1960 and that this is only seen during summer could be evidences of the influence of ozone depletion.

* Some CMIP5 models do better (e.g. GFDL CM3) but the spread is still very large.

* These ensembles provide inconsistent evidences of the influence of ozone depletion.
### Impact of the 20th Century stratospheric ozone depletion on increasing precipitation in South Eastern South America

**DESCRIPTION OF THE ENSEMBLE**

<table>
<thead>
<tr>
<th>type</th>
<th>model</th>
<th>resolution</th>
<th>reference paper</th>
<th># integration name</th>
<th>brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>time-slice</td>
<td>CAM3</td>
<td>T42 L26 (low top)</td>
<td>Polvani et al. (2011a)</td>
<td>1 reference, 1 all-forcings, 1 GHG-only, 1 ozone-only</td>
<td>50 years, steady forcings @ 1960 levels, SSTs from obs as reference, but all forcings at @ 2000 levels as reference, but GHGs &amp; SSTs @ 2000 levels as reference, but ( O_3 ) @ 2000 levels</td>
</tr>
<tr>
<td></td>
<td>CMAM</td>
<td>T63 L71 (high top)</td>
<td>Sigmoid et al. (2010)</td>
<td>1 reference (CGCM), 3 ozone-only (CGCM), 1 reference (AGCM), 1 ozone-only (AGCM)</td>
<td>80 years, steady forcings @1979 levels, coupled model as CGCM reference, but ( O_3 ) @ 2005 levels as CGCM reference, atmosphere only (SSTs from reference) as AGCM reference, but ( O_3 ) @ 2005 levels</td>
</tr>
<tr>
<td>CAM3 transient</td>
<td>CAM3</td>
<td>T42 L26 (low top)</td>
<td>unpublished, but similar to Polvani et al. (2011a)</td>
<td>40 all-forcings, 40 GHG-only, 40 ozone-only</td>
<td>1950-2009, all forcings transient, SST from obs 1950-2009, only ( O_3 ) transient 1950-2009, only GHGs and SSTs transient</td>
</tr>
<tr>
<td>CCSM4/CMIP5 transient</td>
<td>CCSM4</td>
<td>(~1^\circ) L26 (low top)</td>
<td>Gent et al. (2011)</td>
<td>5 all-forcings, 3 GHG-only, 3 ozone-only</td>
<td>1850-2005, all forcings transient fixed 1850 forcings, but transient GHGs 1850-2005 fixed 1850 forcings, but transient ( O_3 ) 1850-2005</td>
</tr>
<tr>
<td>CCMVal-2 transient</td>
<td>WACCQ</td>
<td>(~2^\circ) L66 (high top)</td>
<td>Garcia et al. (2007)</td>
<td>3 all-forcings, 1 GHG-only, 1 ozone-only</td>
<td>1960-2100, all forcings transient, modeled SSTs (REF-B2) as REF-B2, but halogens @ 1960 levels (SCN-B2b) as REF-B2, but GHGs and SSTs @ 1960 levels (SCN-B2b)</td>
</tr>
<tr>
<td></td>
<td>CMAM</td>
<td>T31 L71 (high top)</td>
<td>McLandress et al. (2010)</td>
<td>3 all-forcings, 3 GHG-only, 3 ozone-only</td>
<td>1960-2100, all forcings transient, coupled GCM (REF-B2) as REF-B2, but halogens @ 1960 levels (SCN-B2b) as REF-B2, but GHGs and SSTs @ 1960 levels (SCN-B2c)</td>
</tr>
</tbody>
</table>

**Table 1** Descriptions of the model output analyzed in this paper and the experimental design. In the fifth column, the name of each ensemble is preceded by the number of integrations with identical forcings (i.e. the ensemble size).
EXPERIMENTS: CCSM4/CMIP5 transient runs

**CCSM4** (UCAR) coupled (CAM4/POP2) "1" - L26 all-forcings (5m) GHG-only (3m) ozone-only (3m) Gent et al. 2011
Impact of the 20th Century stratospheric ozone depletion on increasing precipitation in South Eastern South America

![Graph showing SESA DJF precipitation changes for 1960–1999]
EXPERIMENTS: Dynamics of the simulated change

- Poleward shift of extratropical jet
- Upper level eddy momentum flux divergence (Eq flank)
- Divergence balanced by southward upper tropospheric flow forcing upward motion
- Increase in PW and precipitation
CONCLUDING REMARKS

• Throughout the analyzed experiments stratospheric ozone depletion caused a precipitation increase in SESA

• In addition, the increase in GHGs cause smaller increases in precipitation or even a slight drying over SESA

• All the models considered underestimate the precipitation trend over SESA, but so do the CMIP3 and CMIP5 ensembles ...

• In the ozone-only experiment using CAM3 (40 members), as shown by Kang et al. (2011), the radiative-driven changes in the stratosphere force the extratropical jet to shift poleward. The associated changes in the eddy momentum fluxes in the vicinity of South America generate an upper level mass divergence that is compensated with upward motion and moisture convergence, forcing increased precipitation in SESA.
NEXT STEPS

• Through the associated changes in cloudiness, this mechanism might also be important to explain changes in local temperature, especially DJF Tmin (not a lot of available model output ...)

• Explore projections for future SESA change in “single-forcing” experiments
Other research for the SESA region

MOTIVATIONS

Tropical Oceanic Causes of Interannual to Multidecadal Precipitation Variability in Southeast South America over the Past Century

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Clim Dyn
DOI 10.1007/s00382-011-1141-y

Summer precipitation variability over Southeastern South America in a global warming scenario

C. Junquas · C. Vera · L. Li · H. Le Treut
Rotated EOF DJF precipitation anomalies

REOF 1

REOF 2

REOF 3

REOF 4
Temporal properties of PCs

PC1

\[ \text{trend}=0.033 \text{ mm/month} \]

PC2

\[ \text{trend}=0.142 \text{ mm/month} \]

PC3

\[ \text{trend}=-0.006 \text{ mm/month} \]

PC4

\[ \text{trend}=0.059 \text{ mm/month} \]

Welch Power Spectral Density Estimate – RPCs GPCC precip. REOF analysis

Temporal properties of SESA reconstructed precipitation
Correlation fields: PCs and SST anomalies
Correlation fields: PCs and SST anomalies
Seem more stable then EOFs for shorter period
1957-2006
Correlations between GPCC SESA DJF noEN34 precipitation and Kaplan SST anomalies

- SESA Precipitation after ENSO removal

- SESA Detrended Precipitation after ENSO removal
Correlations with BC Kaplan sstA
GPCC precipitation anomalies & Kaplan sst anomalies

Correlations with Correlations with BC Kaplan detrended sstA
GPCC precipitation anomalies & Kaplan sst anomalies
DJF PRECIPITATION LINEAR TREND

ENSO DISCRIMINATION?

COLD/WARM ENSO years show twice the trend than NEUTRAL years
Thanks!
¡Muchas Gracias!

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