Validation of atmospheric circulation in CMIP5 GCMs over southern South America

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Why atmospheric circulation?
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Because circulation factors are among the most important factors of climate
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There is a relatively tight link between large-scale circulation and weather
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Because circulation factors are among the most important factors of climate

There is a relatively tight link between large-scale circulation and weather

Errors in model simulations of circulation lead to errors in temperature, precipitation, probability of extremes, etc.
How is atmospheric circulation analysed/compared?
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Due to the complexity of circulation patterns (fields), many approaches are possible.
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- Mean fields of circulation variables
- Cyclone tracks and intensity
- Jet stream position, strength and waviness
- Blocking
- Modes of atmospheric circulation
- Types of atmospheric circulation
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- Mean fields
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- Blocking
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- Types of atmospheric circulation
Circulation modes
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• Modes can be seen as main building blocks of atmospheric circulation
Circulation modes

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- Each circulation pattern can be approximated by a linear combination of a few modes
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Circulation modes
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Circulation modes

-0.49*

-0.48*

-0.03*
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Circulation modes

-0.49* + -0.05*
-0.48* + -0.3*
-0.03* + 0.65*
Validation of atmospheric circulation in CMIP5 GCMs over southern South America

Validation of circulation modes in CMIP5 GCMs
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Validation of circulation modes in CMIP5 GCMs

• In reality, we do not know the modes...
Validation of circulation modes in CMIP5 GCMs

• In reality, we do not know the modes...
• PCA is used to decompose time series of circulation patterns and identify leading modes
Validation of circulation modes in CMIP5 GCMs

• In reality, we do not know the modes...
• PCA is used to decompose time series of circulation patterns and identify leading modes

• Mean monthly 20-90S 500hPa GPH patterns for JJA 1961–2000 (120 patterns)
• Simulated by NCEP/NCAR reanalysis and 25 CMIP5 GCMs
• PCA of each dataset (separately) and compare the spatial structure of the modes among the datasets
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Validation of circulation modes in CMIP5 GCMs

NCEP/NCAR modes:

- mode 1: SAM
- mode 2: PSA1
- mode 3: PSA2
- ...

Expl. var: 18.3% 10.9% 8.4%
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Validation of circulation modes in CMIP5 GCMs

SAM simulated better than PSA modes, but not in all GCMs

Some modes do not occur in some GCMs

GCM ranking: later...
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1. SAM

<table>
<thead>
<tr>
<th></th>
<th>ERA-40</th>
<th>NCEP-1</th>
<th>JRA-55</th>
<th>ERA-20C</th>
<th>CERA-20C</th>
<th>20CRv2</th>
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</thead>
<tbody>
<tr>
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<td>21.3 %</td>
<td>18.3 %</td>
<td>22.0 %</td>
<td>21.4 %</td>
<td>24.8 %</td>
<td>22.1 %</td>
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<table>
<thead>
<tr>
<th>Pattern corr</th>
<th>ERA-40</th>
<th>NCEP-1</th>
<th>JRA-55</th>
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<th>20CRv2</th>
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<tbody>
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<td>0.98</td>
<td>0.99</td>
<td>0.95</td>
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<td>NCEP-1</td>
<td>X</td>
<td>0.97</td>
<td>0.93</td>
<td>0.90</td>
<td>0.91</td>
<td></td>
</tr>
<tr>
<td>JRA-55</td>
<td>X</td>
<td>0.97</td>
<td>0.95</td>
<td>0.96</td>
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<td></td>
</tr>
<tr>
<td>ERA-20C</td>
<td>X</td>
<td>0.98</td>
<td>0.95</td>
<td>0.96</td>
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<td></td>
</tr>
<tr>
<td>CERA-20C</td>
<td>X</td>
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<td>0.98</td>
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</tbody>
</table>
Circulation types

- Unlike modes (ingredients), circulation types show typical patterns (meals)
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- There are many methods („classifications of atmospheric circulation patterns“) to find types, both manual (synoptic catalogues) and automated (computer-assisted) and their various combinations
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• Every method has its strengths and limitations
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- Every method has its strengths and limitations.
- **Classification: two steps**
  1. Describing the spectrum of (daily) patterns by a few types.
  2. Classifying the patterns to these types.
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Circulation types

Definition: in 7 reanalyses
Daily SLP data
JJA 1961–2000

<table>
<thead>
<tr>
<th>Name</th>
<th>Institute</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERA-40</td>
<td>European Centre for Medium-Range Weather Forecasts</td>
</tr>
<tr>
<td>NCEP/NCAR</td>
<td>National Centers for Environmental Prediction, National Center for Atmospheric Research</td>
</tr>
<tr>
<td>JRA-55</td>
<td>Japan Meteorological Agency</td>
</tr>
<tr>
<td>ERA-20C</td>
<td>European Centre for Medium-Range Weather Forecasts</td>
</tr>
<tr>
<td>CERA-20C</td>
<td>European Centre for Medium-Range Weather Forecasts</td>
</tr>
<tr>
<td>20CRv2</td>
<td>NOAA Earth System Research Laboratory, University of Colorado CIRES Climate Diagnostics Center</td>
</tr>
<tr>
<td>20CRv2c</td>
<td></td>
</tr>
</tbody>
</table>

7 reanalyses are used to create a robust reference dataset and to find out whether the choice of reference reanalysis has an impact on model validation (rank)
Circulation types

To eliminate artifacts of methods, eight classifications are used in parallel (75 types in total)

<table>
<thead>
<tr>
<th>Method acronym</th>
<th>Method name</th>
<th>Number of CTs</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>GWT</td>
<td>Grosswettertypes</td>
<td>10</td>
<td>Hybrid (Threshold-based)</td>
</tr>
<tr>
<td>JCT1</td>
<td>Jenkinson–Collison</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>JCT2</td>
<td></td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>LND</td>
<td>Lund</td>
<td>9</td>
<td>Leader algorithm</td>
</tr>
<tr>
<td>PCT</td>
<td>T-mode PCA obliquely rotated</td>
<td>9</td>
<td>PCA</td>
</tr>
<tr>
<td>CKM</td>
<td>k-means by dissimilar seeds</td>
<td>9</td>
<td>Cluster analysis (Optimization methods)</td>
</tr>
<tr>
<td>SAN</td>
<td>simulated annealing (SANDRA)</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>KMD</td>
<td>k-medoids</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

example: PCT (Southern domain)
Circulation types

- GCM data – each simulated daily pattern is classified with the most similar type (8-times, once for each classification)

- Frequency + persistence (of each type in each dataset)

- We compare
  - each model vs each reanalysis
  - the GCM-ensemble median vs the reanalysis-ensemble
**GCM errors in frequency**

Length of bars:
Median percentage absolute error

50% means that half of the 75 types have frequency of either 50% or 150% of the reanalysis frequency (e.g. 5 or 15 days per season instead of 10)

Circulation is simulated considerably better over the southern tip of SA.
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GCM errors in frequency

Ranking –
GCM errors in frequency

Ranking –

- Domain-dependant
GCM errors in frequency

Ranking –

- Domain-dependent
- Reference-dependent (shifts of up to 15 positions)
GCM errors in frequency

Ranking –

• **Domain-dependent**

• **Reference-dependent**
  (shifts of up to 15 positions)

• **Approach-dependent**
  (modes vs types)
GCM errors in frequency

Ranking –

- Domain-dependent
- Reference-dependent (shifts of up to 15 positions)
- Approach-dependent (modes vs types)
- Classification-dependent (not shown)
Do errors depend on flow indices?
(such as direction, strength and vorticity of flow)
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Northern region: GCM-ensemble errors in circulation type...

...frequency

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**Validation of atmospheric circulation in CMIP5 GCMs over southern South America**

**Northern region:** GCM-ensemble errors in circulation type...

- **Frequency**
- **Persistence**

### Diagram Details

#### Flow Strength (hPa/10^9) vs. Flow Direction

- **CT rel. frequency (%)**
  - GCM median: 5, 10, 20, 25
  - Vorticity: C, AC
  - Error of CT rel. frequency (% of reanalysis median): 40.74

#### Flow Strength (hPa/10^9) vs. Flow Direction

- **CT persistence (days)**
  - GCM median: 1, 1.5, 2, 2.5
  - Vorticity: C, AC
  - Error of CT persistence (% of reanalysis median): 8

### Notes

- 40.74 = median absolute error (% points)
- 8 = median absolute error (% points)
**Northern region:** GCM-ensemble errors in circulation type...

...frequency & persistence for E to SW flow (~ 60° – 220°)

GCMs underestimate frequency & persistence for E to SW flow (~ 60° – 220°)
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Northern region: GCM-ensemble tabule errors in circulation type...

...frequency

GCMs overestimate frequency & persistence for SW to NE flow (≈ 230° – 50°)

...persistence

<table>
<thead>
<tr>
<th>CT rel. frequency (%) (GCM median)</th>
<th>vorticity</th>
<th>Error of CT rel. frequency (% of reanalysis median)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 10 20 25</td>
<td>C AC</td>
<td>-100 0 100</td>
</tr>
</tbody>
</table>

40.74 = median absolute error (% points)

<table>
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<th>CT persistence (days) (GCM median)</th>
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</thead>
<tbody>
<tr>
<td>1 1.5 2 2.5</td>
<td>C AC</td>
<td>-30 0 30</td>
</tr>
</tbody>
</table>

8 = median absolute error (% points)
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**Southern region**: GCM-ensemble errors in circulation type

**Frequency**

- CT rel. frequency (%)
- Vorticity
- Error of CT rel. frequency (% of reanalysis median)

**Persistence**

- CT persistence (days)
- Vorticity
- Error of CT persistence (% of reanalysis median)

15.24 = median absolute error (% points)

3.24 = median absolute error (% points)
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**Southern region:** GCM-ensemble errors in circulation type frequency and persistence

The prevailing westerly types with strong flow are somewhat less frequent and biased toward cyclonic vorticity.
Conclusions

• Validation of GCMs (good understanding of model biases) – important part for projecting climate

• Marked errors in synoptic-scale GCM circulation over northern SSA

• Raking of GCMs is extremely sensitive to various criteria such as the choice of spatial domain, methods of analysis of circulation, and reference dataset

• The usefulness of reanalysis outputs for the pre-satellite era is very questionable over SSA
Thank you for your attention!

ACKNOWLEDGEMENTS

We acknowledge the following organizations for providing their reanalysis datasets: NOAA/OAR/ESRL PSD, Boulder, Colorado, USA for NCEP/NCAR, and 20th Century Reanalysis V2 and V2c, ECMWF for ERA-40, ERA-20C, and CERA-20C, and JMA for JRA-55. All climate modelling groups are greatly appreciated for providing their model outputs.

Thanks are also due to all developers of the COST733 software, which was used to compute all circulation classifications.
### RESULTS: Modes

#### 2. PSA1

<table>
<thead>
<tr>
<th>Pattern corr</th>
<th>ERA-40</th>
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<tbody>
<tr>
<td>ERA-40</td>
<td>X</td>
<td>0.79</td>
<td>0.70</td>
<td>0.81</td>
<td>0.67</td>
<td>0.64</td>
<td>0.90</td>
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<td>NCEP-1</td>
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**Explained var**

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<td></td>
<td>10.5 %</td>
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<td>7.7 %</td>
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<td>7.8 %</td>
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### RESULTS: MODES

#### 3. PSA2

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<tr>
<td>20CRv2c</td>
<td>X</td>
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</tbody>
</table>
Comparison of calendars

RESULTS: TYPES

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Differences in frequency of occurrence

RESULTS: TYPES

---

**ERA-40 type frequency (%)**

- 5
- 15
- 25
- 35

**Vorticity**

- C
- AC

**Deviation of type frequency (%) of reference**

-100 0 100

---

**Flow direction**

- Central SA
- Southern SA
- 20CRv2c dev from ERA-40

---

**Flow strength**

- 0° 90° 180° 270° 360°
- 0 3 6 9 12 15 18 21 24 27 30 33 36 39 42

---

**Map of South America**

- Central South America
- Southern South America
- 20CRv2c dev from ERA-40

---

**Graphs**

- Scatter plot showing flow direction and strength with different markers for ERA-40 and 20CRv2c dev from ERA-40.