Applying Wavelet and Fourier Transform Analysis to Large Geophysical Datasets

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Regularity in ecosystem factors

- The recurrence of periodic environmental states is important to many systems of study, and particularly to the life cycles of plants, animals and economies that depend on them.
- For example, the adequacy of ecosystem factors such as water supply are determined not only by the average amount of water available in a year, but also by its regularity.

Importance of regular ecosystem cycles

- Ecosystems in which drought risk is high and rains are likely to fail entirely during a given year are characterized both by low precipitation levels, and by extreme variability in precipitation.

Land cover change near Lake Chad.

Importance of regular ecosystem cycles

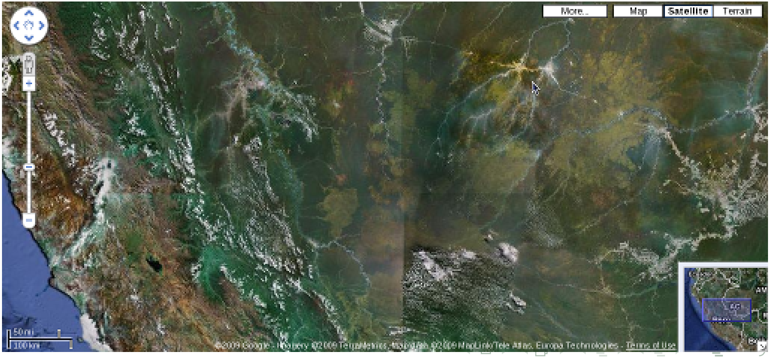
- Such unpredictability is of concern, especially since the analysis of global datasets has revealed that variability of rainfall and per capita income are strongly and negatively correlated.

Land cover change near Lake Chad.

Importance of regular ecosystem cycles

- Therefore there is interest in the development of automated routines for identifying changes in the regularity of seasonal, annual or interannual cycles that can aid in diagnosing model behavior and locate climate transitions.

Deforestation of the Amazon rainforest near Rio Branco.



Data mining challenges

1. Climate models generate data at rates that outpace our capacity to analyze the output. Useful methods for data reduction must be employed.
2. There are many climate models in use, which produce differing model results (*e.g.* CASA' and CN). Quantitative evaluation methods, such as those used by C-LAMP and C^4MIP could benefit by incorporating cyclicity analysis components.

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Fig. 1. Cyclic data.

The mean subtracted time series, $\{(t_i, x_i)\}_{i=1}^{200}$, of precipitation data for one Middle Eastern land cell.

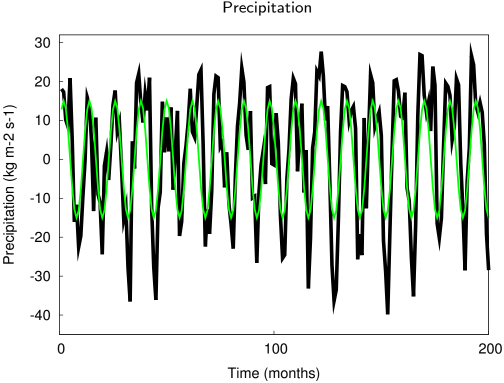


Fig. 2. Data reduction.

The discrete Fourier transform power spectrum (DFTPS) plot of that same time series in Fig. 1.

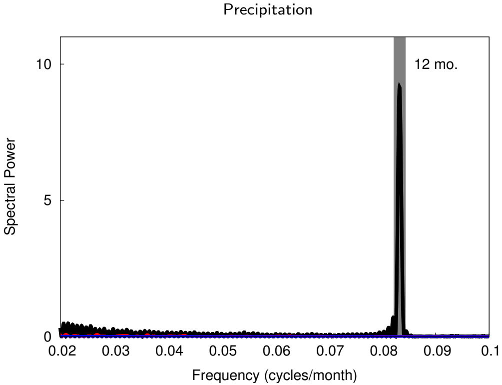


Fig. 3. Global ecoregion map.

This global map of 2,796 PCM land surface cells taken from Hoffman and others (2005) illustrates a central problem. For example one one-hundred-year run of a monthly T42 model can generate: $2,796 \times 12 \times 100 = 3,355,200$ values $\times$ the number of geophysical parameters.

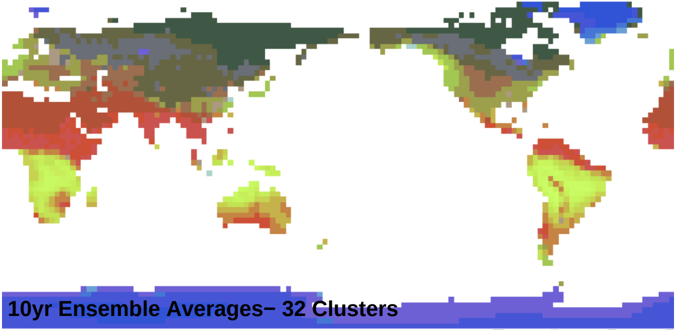


Fig. 4. Basic procedure

The general procedure for determining the intensities and periods of signals that occur within windows of a time series. **nw** is the number of windows within the time series, and **ne** is the number of elements, in this case months (**x**), within each window.

procedure pcm_locate
input: time series, $\{(t_i, x_i)\}_{i=1}^{nterms}$
output: a_k (amplitude), and tau_k

```
for k = 1,nw do
   w = x[i:i+ne]
   w_n = w/std_dev(w)
   w_ft = fft(w_n)
   w_sp = w_ft * conj(w_ft)
   a_k = real(w_sp)
   tau_k = imaginary(w_sp)
end do
```

Fig. 4. Basic procedure

For each parameter the grid cell variance, standard deviation, and endpoint difference between first and last decades are accumulated.

procedure pcm_locate (cont.)

```
! accumulate all peak
! amplitudes and their periods.
gpa[h,i:i+nw] = pa[i:i+nw]

! accumulate differences in
! amplitude (first - last).
gda[h,i:i+nw] = pa[1] - pa[9]

! accumulate variance in amp.
gva[h,i:i+nw] = var(pa)
```

Output analysis

- The `pcm_locate` routine locates the period and intensity of cycles.
- Output of variance, standard deviation, difference between endpoints, etc. can be ranked in order to identify grid cells that show unusual changes in period or intensity or to contextually compare cells.

DFTPS Peak Amplitude

Grid Cell	% Difference (first-last dec.)	Variance
1	-12.18351	0.00120
2	-13.90443	0.00305
3	-11.03531	0.00154
4	-8.27324	0.00066
5	-12.29046	0.00458
6	16.73336	3.14184
7	-10.40686	0.00559
8	7.05960	0.00500
9	0.13787	0.00413
10	-1.94514	0.00913

Answerable Questions

1. Which land cells are at risk for climate transition?

Land cover change near Lake Chad.

Fig. 5. Intensity difference of temperature cycle.

Histogram representing the distribution of 2,796 grid cells according to the difference in DFTPS temperature intensity between first and last decades. Negative percentage changes indicate net decreases in the strength of the temperature cycle between model year 2001 and 2099.

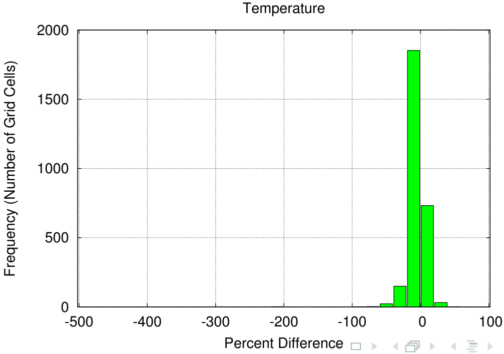


Fig. 6. Intensity difference of precipitation cycle.

Histogram representing the distribution of 2,796 grid cells according to the difference in DFTPS precipitation intensity between first and last decades. Negative percentage changes indicate net reductions in the strength of the precipitation cycle between model year 2001 and 2099. Note left skewed tail.

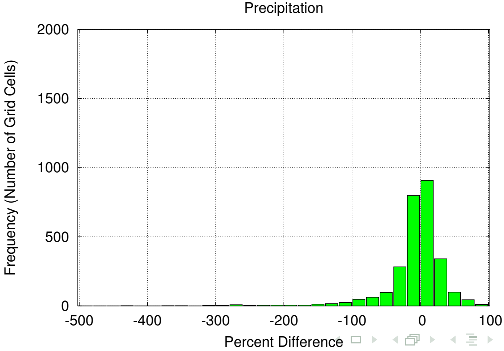
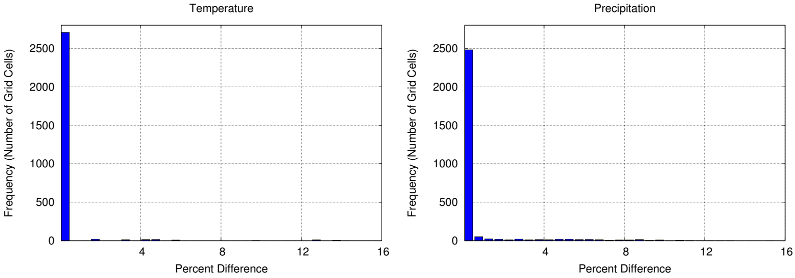


Fig. 7. Variance in period across decades.

Comparison of decadal variance in the frequency of the peak temperature cycle (left) and precipitation cycle (right).



Answerable Questions

2. What kind of climate transition might a particular cell undergo?

Deforestation of the Amazon rainforest near Rio Branco.

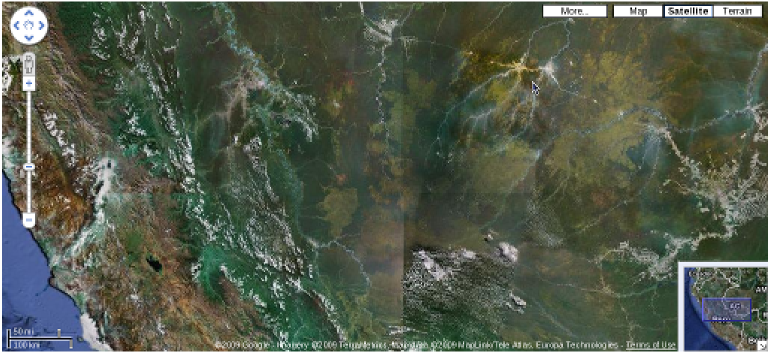


Fig. 8. Soil moisture wavelet spectrogram.

The paul wavelet spectrogram illustrates the irregularity of the annual soil moisture cycle for one Mid East land cell. Hot colors (red) indicate high spectral power (a strong cycle), whereas blue indicates little spectral intensity (a weak cycle).

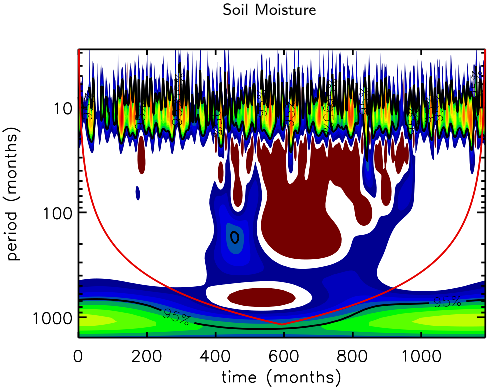
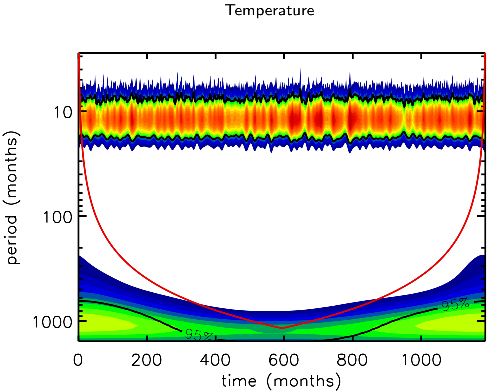


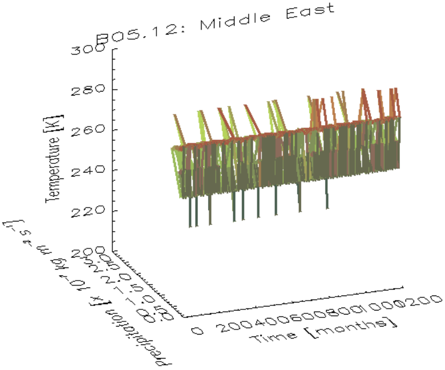
Fig. 9. Temperature wavelet spectrogram.

The regularity illustrated by the temperature spectrogram for the same Mid East land cell strongly contrasts from the soil moisture spectrogram. Changes to the periodicity of temperature are not useful indicators of climate transition.



Multivariate analysis

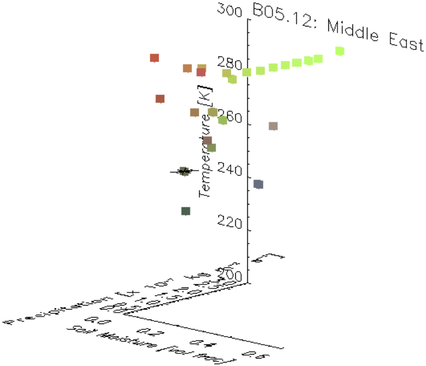
In multivariate analysis a land cell will occupy a single point in phase space as it traces out a climate trajectory (*i.e.* a manifold). Multivariate clustering techniques that illustrate climate trajectories could integrate periodicity axes.



Taken from Hoffman et al. (2005).

Multivariate analysis

When considering axes describing the total amount but also the regularity of various geophysical parameters grid cells that escape or transition out of their former manifold could be identified as climate change cells.



Taken from Hoffman et al. (2005).

Model Application

It is important that climate models accurately capture cyclicity when describing annual and interannual events such as monsoons.

- Projects such as C-LAMP already provide a basis for comparing climate models.
- The parameters of model intercomparisons could be extended to include cyclicity analysis products such as those presented here.
- When comparing multiple model runs each with different initial conditions, a basic routine such as `pcm_locate` could rapidly identify differences in ecosystem cyclicities.

Final Thoughts

- The automated routine described here is a flexible and fast implementation that will aid in identifying such grid cells.
- This routine could be useful to model intercomparison projects that have a need to rate similar models in terms of their ability to capture well known periodicities such as annual monsoons, and interannual El Niño events.
- Spectral analysis for areas such as the African Sahel, or the Tropical wet and dry climate of India, is particularly useful for identifying changes to the regularity of seasonal cycles.

Thank You. Questions?

Selected References

- This talk and its scripts and plots can be obtained from the following repository: www.climatemodeling.org/pcm/cyclicity/routines/.

- Randerson, J. T., Hoffman, F. M., Thornton, P. E. and 10 others. Systematic assessment of terrestrial biogeochemistry in coupled climate-carbon models. *Global Change Biology*. 10.1111/j.1365-2486.2009.01912.x.
- Hoffman, F. M., Hargrove, W. W. and Erickson, D. J. 2005. Using Clustered Climate Regimes to Analyze and Compare Predictions from Fully Coupled General Circulation Models. *Earth Interactions*. **9**(10): 1-27. doi: 10.1175/EI110.1

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