Examining Precipitation and Temperature Relationships at Global Scales

Timothy Donato[1], Paul Houser[1], and Ruixin Yang[1]

[1]George Mason University

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Abstract

Empirical Mode Decomposition (EMD) is used to examine the relationship between precipitation and surface temperature from six regions. Three regions are defined by physiography: world, ocean, and land. The other three regions are defined by averaged precipitation: dry, normal and wet. Monthly averaged daily precipitation rate from the Global Precipitation Climatology Project are compared with average monthly surface air temperature anomalies from the Goddard Institute for Space Studies using EMD. The EMD process produces component time series referred to as intrinsic mode functions (IMFs). Theses IMFs are ordered by frequency from high to low. Eight IMFs were produced for each the time series. The first three IMFs corresponded to seasonal, semi-annual and annual variations, respectively. IMF 4 to 6 corresponded to a biennial, pentennial and decadal climate signals, respectively. IMF 7 was related to the broad 20-30 year period, with the trend being revealed in IMF 8. The time series spanned the period from January 1980 to December 2015 at monthly intervals. Temperature and precipitation time series from six sampling regions were analyzed for evidence of correlation. Results from the analysis reveal the following: (1) The EMD process reveals both linear and non-linear trends. The trends are not entirely consistent between regions though they are highly correlated. (2) Apparent wave-to-wave interactions between high and low frequency components appear to be observed in the IMF 1 and 2. These distortions appear to correspond to the troughs and peaks in the decadal cycle captured in IMF 6 and may related to the solar cycle. (3) The correlation between precipitation and temperature increases with increasing IMF number.

Examining the Relationship Between Precipitation and Temperature Using Empirical Mode Decomposition

Timothy F. Donato, Paul Houser, and Ruixin Yang

Department of Geography and Geoinformation Science, George Mason University, Fairfax, VA

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Introduction

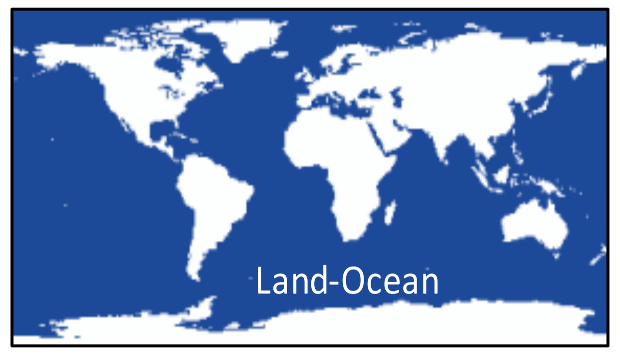
- The relationship between global monthly mean precipitation and global monthly mean surface temperature anomaly are examined using a data driven analysis method called Empirical Mode Decomposition (EMD).
- The goal is to determine if there is a relationship between precipitation and temperature in lower frequency bands that are not captured by traditional analysis.

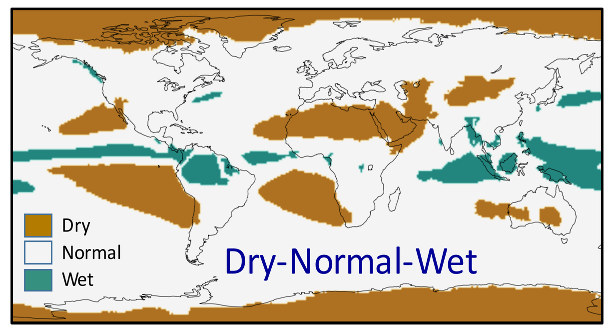
Material and Methods

DATA

- Analysis Period: 1980-2015
- Precipitation Data: Global Monthly Average Precipitation Data
  Global Precipitation Climatology Project (Adler et al. 2018)
- Global Monthly Average Surface Temperature NASA (GISTEMP)
  Hansen et al. (2010)

Spatial Distribution

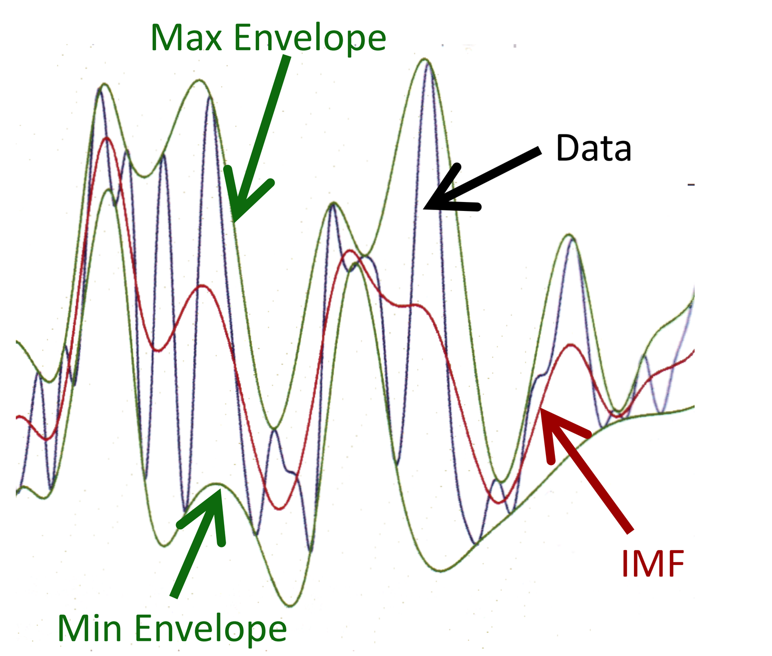




- Six Regions include:
  - World (64800 samples),
  - Ocean (43492 samples),
  - Land (21308 samples,
- Precipitation Regimes
  - Wet regions (3425 samples)
    > 5 mm/day
  - Normal regions (43487 samples)
    1-5 mm/day
  - Dry (17376 samples)
    < 1 mm/day.

Methodology

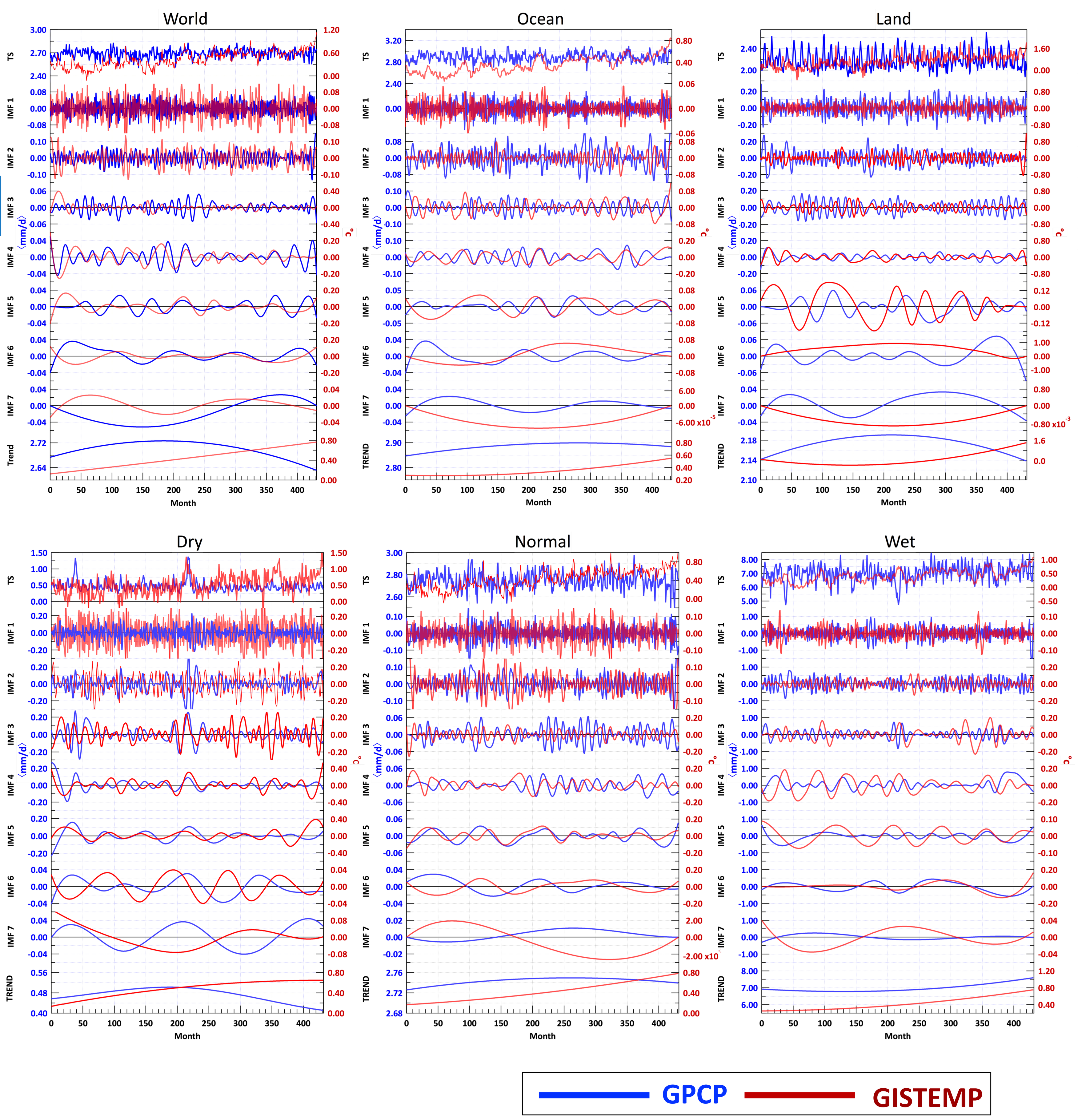
- GISTEMP and GPCP time series were deconstructed using an extended version of EMD known as Ensemble Empirical Mode Decomposition (EEMD)
- EEMD reduces a nonstationary, nonlinear time series into a set of derived oscillating time series (*Intrinsic Mode Functions-IMF*) of decreasing frequency until a non-oscillating trend is reached. This achieved by taking the mean of the extrema envelope of the initial data and subtracting it from the original time series then repeated until no additional extreme envelopes and only a final trend remains.



- Correlation analysis was performed on the decomposed GISTEMP and GPCP time series segments.

Results

Intrinsic Mode Functions



Correlation Analysis

GCPC vs GISTEMP

	TS	*IMF 1*	*IMF 2*	*IMF 3*	*IMF 4*	*IMF 5*	*IMF 6*	*IMF 7*	*Trend*
World	**0.118**	-0.002	**0.097**	**-0.118**	**0.324**	**0.150**	**-0.312**	**0.250**	**-5.090**
Ocean	**0.155**	**-0.113**	-0.043	**-0.015**	**0.267**	**0.108**	0.022	**0.183**	**0.500**
Land	**-0.112**	-0.048	-0.049	**-0.286**	**0.358**	-0.053	**-0.383**	**-0.155**	**-0.668**
Dry	**0.079**	-0.840	0.026	0.088	**-0.011**	**0.302**	**0.652**	**-0.963**	**0.940**
Wet	**0.181**	-0.013	0.029	-0.071	0.045	**-0.585**	**-0.508**	**-0.877**	**0.524**
Normal	**0.052**	0.058	0.012	**0.244**	**0.339**	**0.232**	**-0.289**	**-0.134**	**-0.353**

N=432 Significant Values at the 5% level are indicated in bold

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Interpretation

- The EMD Process generated eight Intrinsic Mode Functions.
- Each mode represents a unique frequency band with increasing mode number representing lower frequency components of the original signal.
- Results reveal the following:
- The EMD process reveals both linear and non-linear trends.
- Correlations within regions increase with IMF mode number,
- Each IMF mode corresponds to a unique frequency band
  - Mode 1 captures the monthly to seasonal variability.
  - Mode 2 captures the semi-annual variability
  - Mode 3 captures the annual variability.
  - Mode 4 Biennial variability
  - Mode 5 Pentadal variability
  - Mode 6 Decadal variability
  - Mode 7 20-30 year climate cycle
  - Mode 8 Trend

Conclusion

- All components show a strong correlation.
  - World, Land and Dry regions show negative relationships COD values ranging from 10 to 40%.
  - Positive correlations are exhibited by the Ocean, Wet and Normal regions with the wet region showing the strongest correlations (r = 0.94).
- Apparent wave-wave interactions between high and low frequency components appear to be observed in the IMF 1 and 2.
  - The low frequency component in these modes appears as distorted amplitude-frequency modulations that emerge in about a 10-year cycle.
  - Distortions appear to correspond to the troughs and peaks in the decadal cycle captured in IMF 6.
- EMD appears to by a uniquely valuable analysis tool for deconstructing signals from climate time series and comparing responses.
- EMD appears to capture relationships with physical meaning that are not captured by other analysis methods such as Empirical Orthogonal Functions and Fourier analysis

References

Hansen, J., R. Ruedy, M. Sato, and K. Lo, 2010: Global surface temperature change, Rev. Geophys., 48, RG4004, doi:10.1029/2010RG000345

Adler, R. F., M. Sapiano, G. J. Huffman, J.-J. Wang, G. Gu, D. Bolvin, L. Chiu, U. Schneider, A. Becker, E. Nelkin, P. Xie, R. Ferraro, and D.-B. Shin. 2018. The Global Precipitation Climatology Project (GPCP) Monthly Analysis (New Version 2.3) and a Review of 2017 Global Precipitation. Atmosphere, 9(4), 138, doi:10.3390/atmos9040138.

Data Sources

GPCP Dataset accessed 2018-02-01 http://eagle1.umd.edu/GPCP_ICDR/GPCP_Monthly.html

GISTEMP Team, 2018: GISS Surface Temperature Analysis (GISTEMP). NASA Goddard Institute for Space Studies. Dataset accessed 2018-02-01 at https://data.giss.nasa.gov/gistemp/.