New Developments in Wavelet Modeling: Implications for International Finance

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https://github.com/kcraath/2018INFINITI_Workshop

Roadmap

1. Why Now and Why use Time-varying Techniques
2. Why Wavelets
3. How does this translate into Investment Horizons
4. Application Example: Water-Energy Nexus
5. R code Specifically used for this Example

Mission: Deliver complex information in an interpretable and reproducible manner
Vision: Encourage Action

Why Now and Why use time-varying Techniques

- **Rebirth** in using spectral analysis in finance and economics since advances in **non-stationary signal analysis.**

- Various economics and finance marketplaces, for example **commodity markets**, are **complex** with a wide variety of participants having **different objectives.**

- Resulting in **non-stationary time series** formed by combinations of different components operating at different frequencies.

- **Wavelets** are mathematical functions that detect common time-localized oscillations in non-stationary signals.

Motivation for using Wavelets

- **Fourier analysis** is used to identify links between periodicities of different time series, but the ability to identify **abrupt changes in the mean behavior** is difficult because the time information is sometimes not captured for non-stationary price series.

- In a paper by Dr. Andrew Lo called ***Spectral Portfolio Theory,*** he suggests that the **flexibility of the wavelets transform** could potentially be used to overcome various difficulties of the Fourier transform for spectral portfolio analysis.

- **Augment traditional portfolio management** tools by distinguishing across multiple investment horizons.

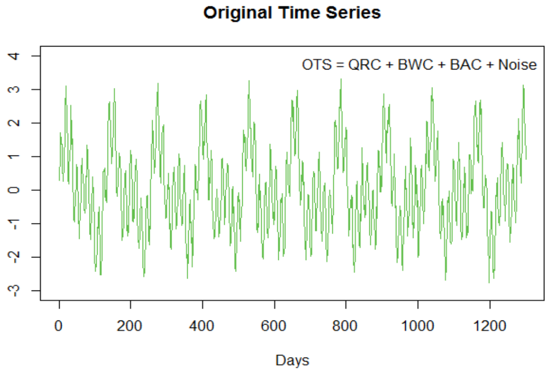
Investment Horizons

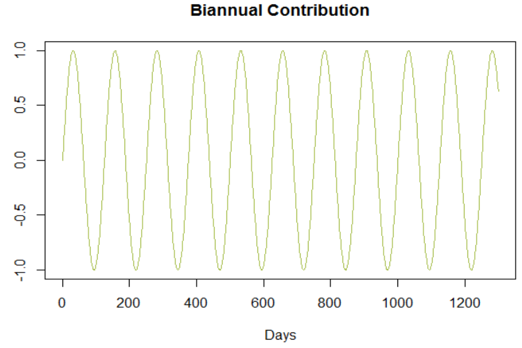
- Decision-making Horizons of Investors are **rarely the main focus of attention**

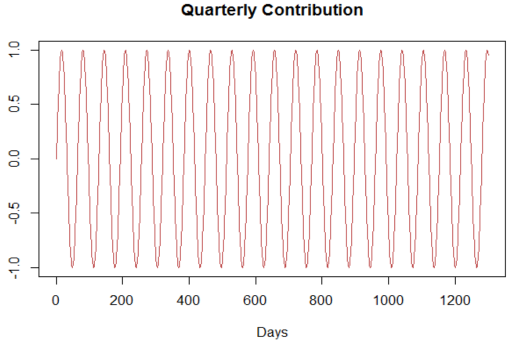
- By identifying the **particular frequencies** responsible for a given strategy's expected returns and volatility
  - **Additional dimension** for investor to manage risk/reward of portfolio can be applied to all aspects of portfolio theory since **most of the time-domain statistics have frequency domain counterparts**:
    - Linear factor models, performance and risk attribution, capital budgeting, risk management

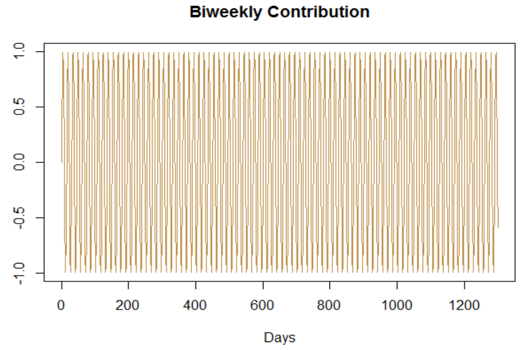
Visualization of the **structure** in multidimensional data illustrates the **value added** in applying **time-varying techniques** to quantify the relationships between non-stationary time series.

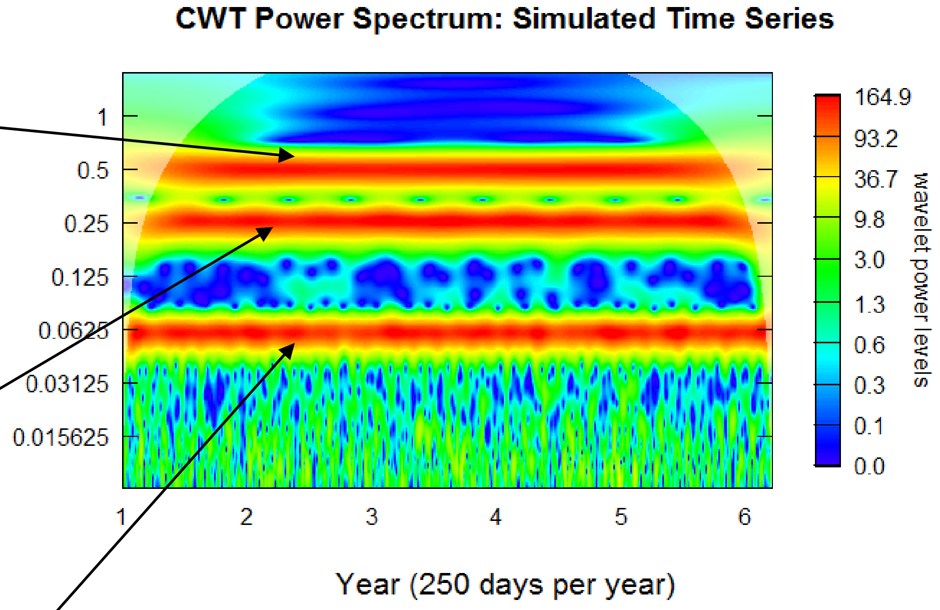
Simulated Example







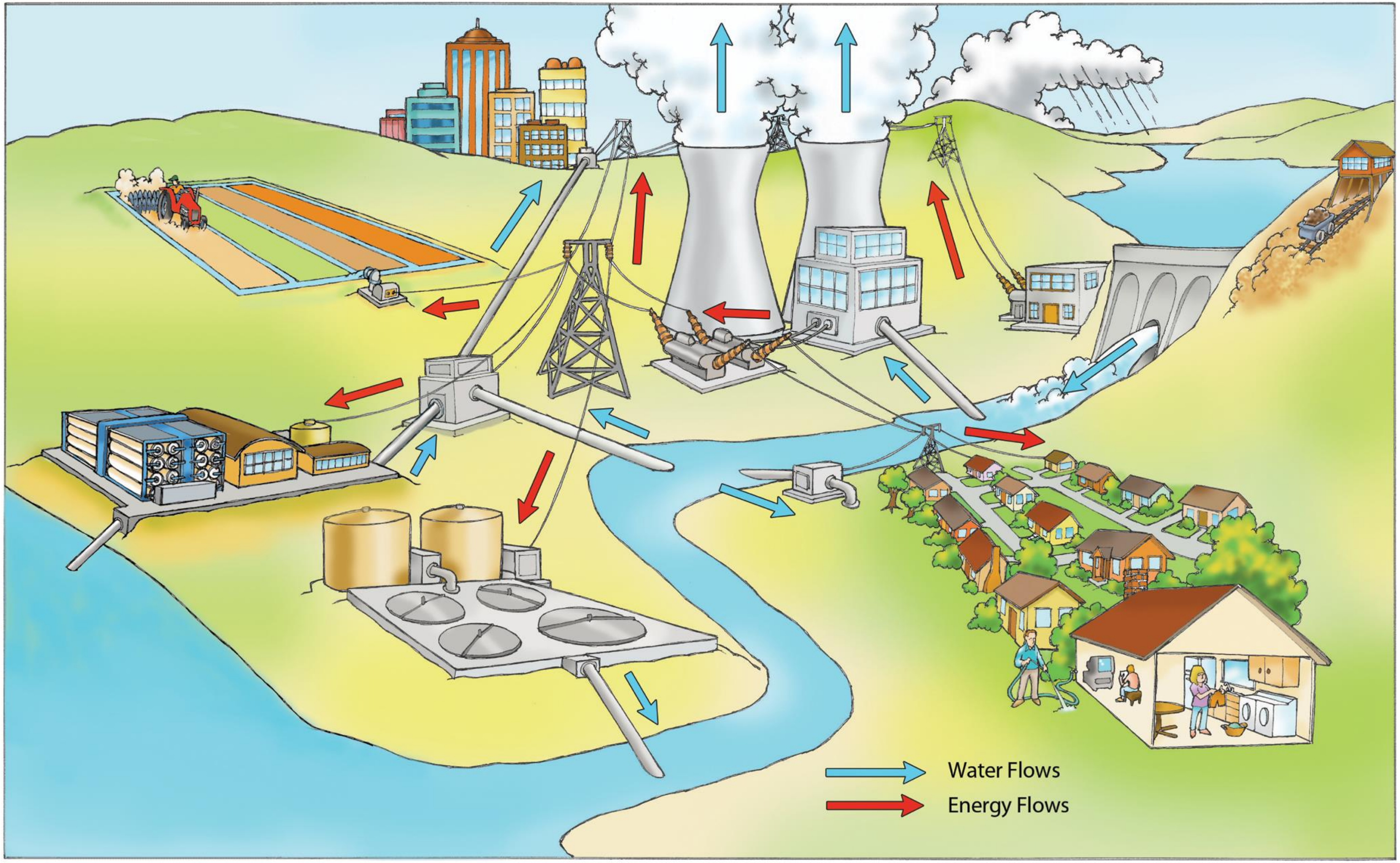




	1	…	1300
0.50	39.8	…	74.0
0.25	34.1	…	45.1
…	…	…	…
0.064	40.0	…	40.6

Application Example: Water-Energy Nexus

What is the Water-Energy Nexus?



Adapted from Energy, Department U. S.. Energy Demands on Water Resources In Report to Congress on the Interdependency of Energy and Water. Albuquerque, NM: Sandia National Laboratories, 2006.

Why do I care?

Government gives green light for shale gas fracking in Karoo

2017-03-30 16:09

Jenna Etheridge, News24

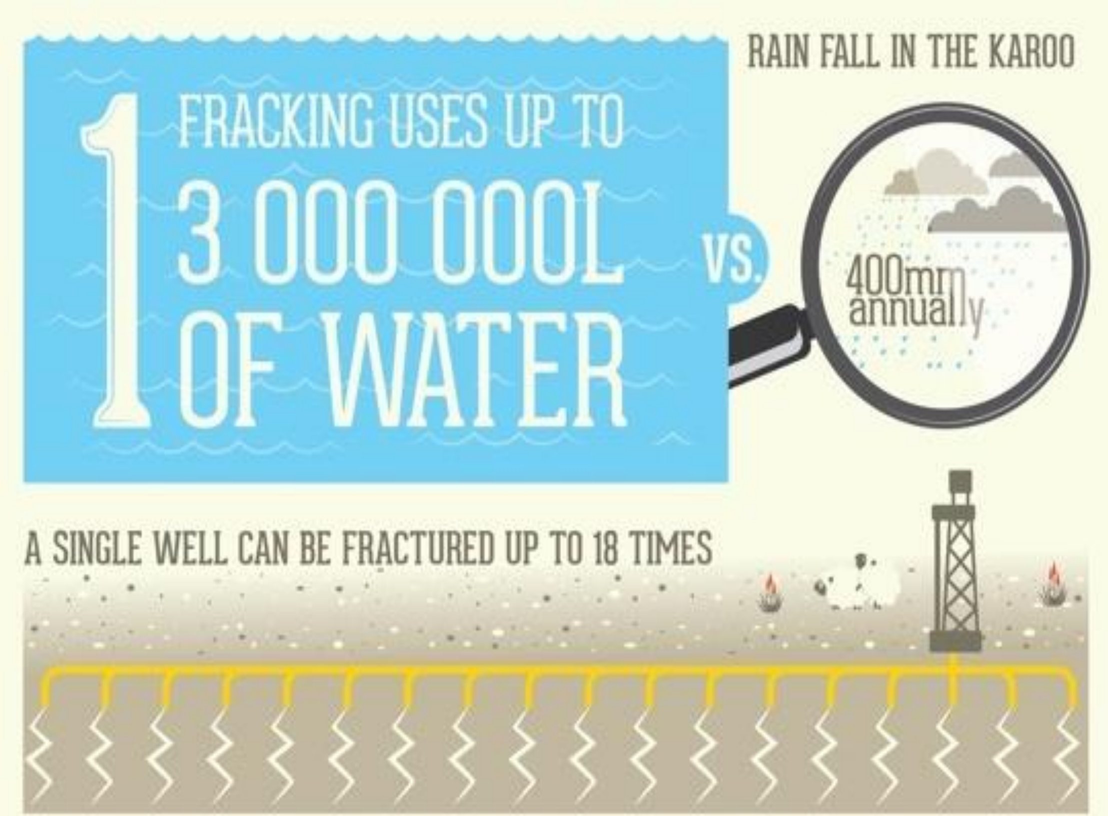
news24

March 30, 2018

Cape Town Water Crisis: A terrifying global trend

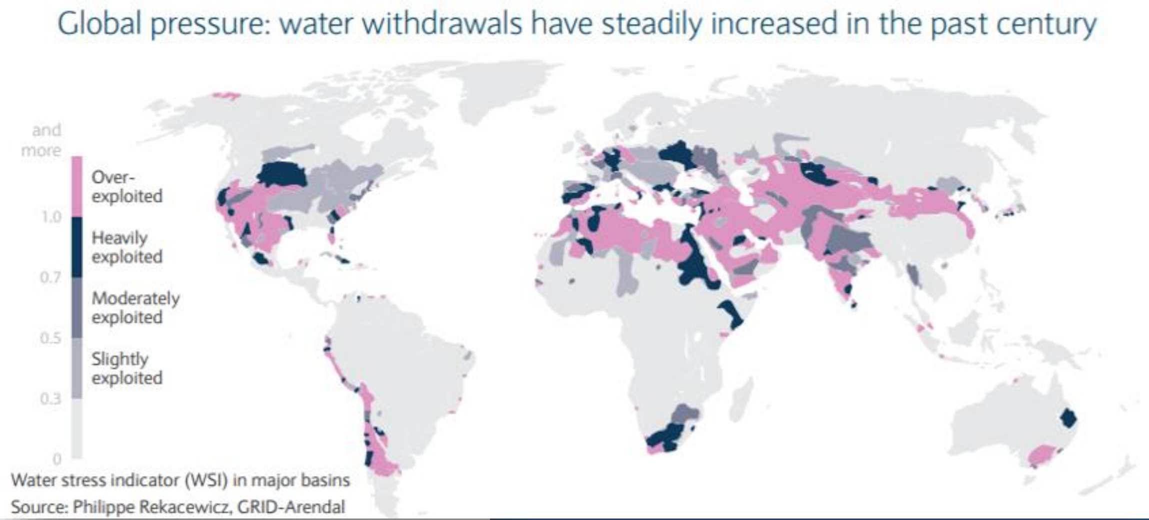
Amar Batra · Opinion [Cape Town Water Crisis]

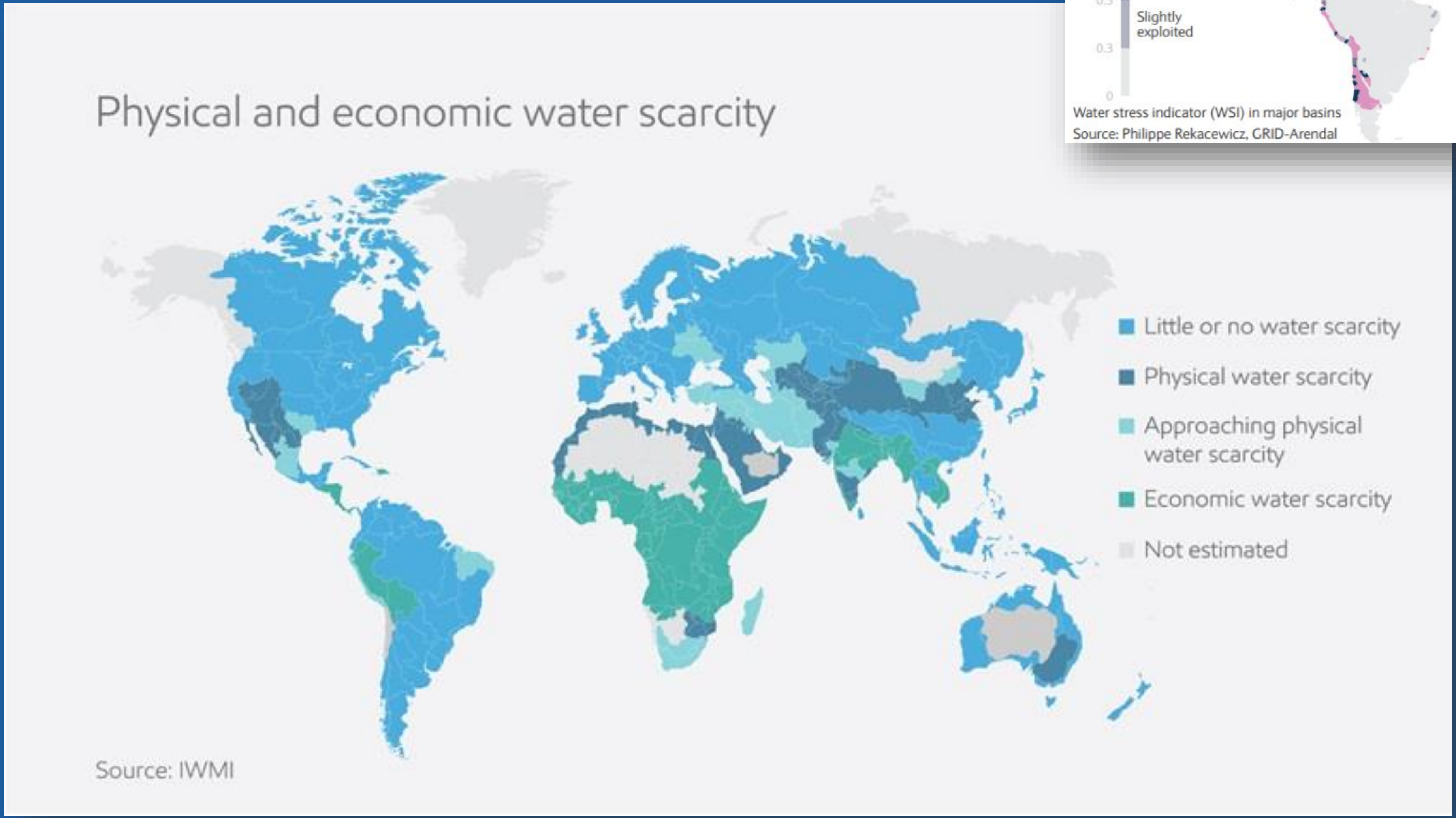
[Map South Africa, Karoo Nick Roux 2006]



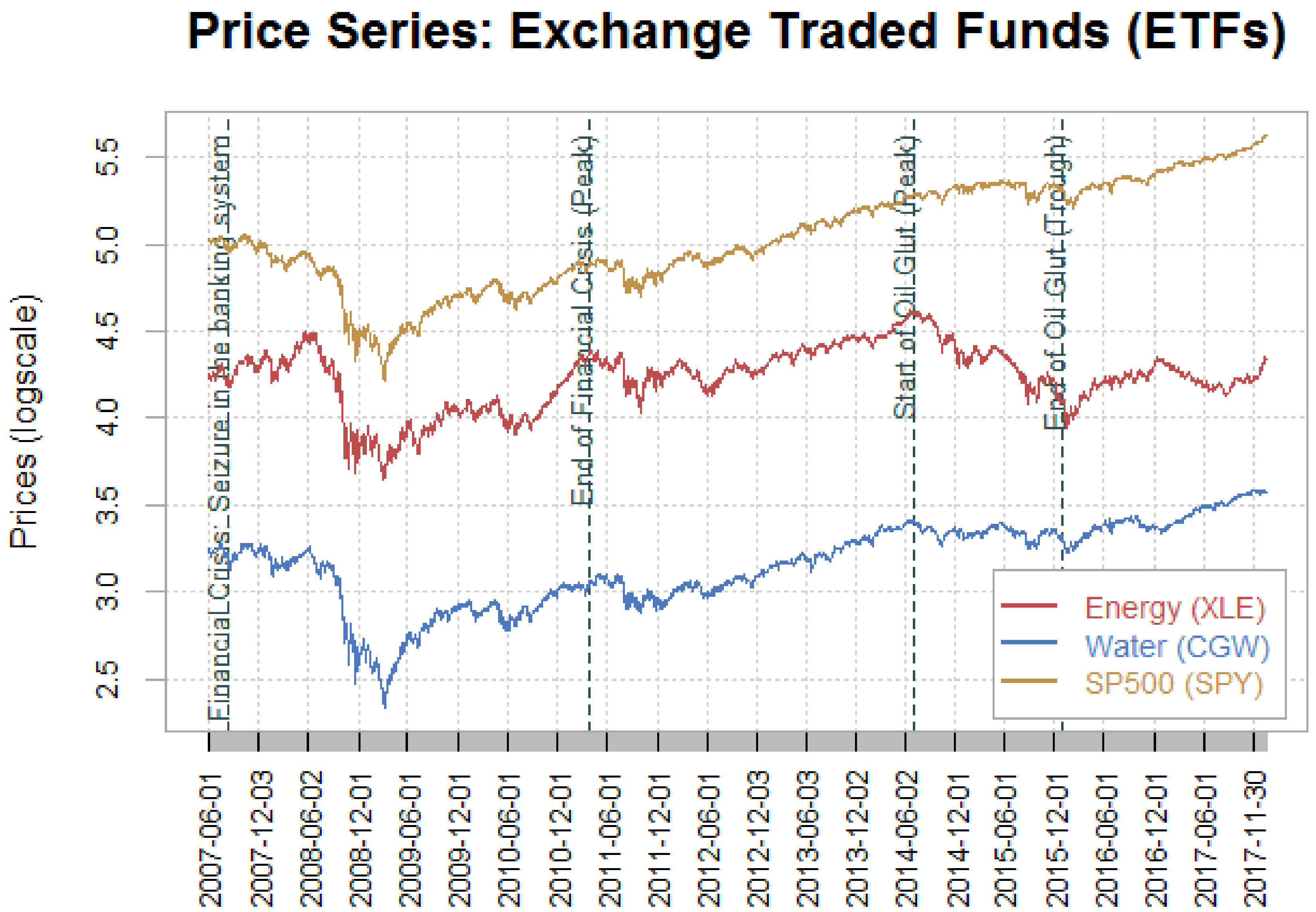
[Info Maverick]

Why should you care?





"Maybe you could consider this as a note from your future what is happening in Cape Town now might soon happen to all of us in relationship to water, energy, and air. We need to start solving these problems. We need to manage our resources more rationally and collectively because otherwise it would be day zero for all these central resources."
National Geographic



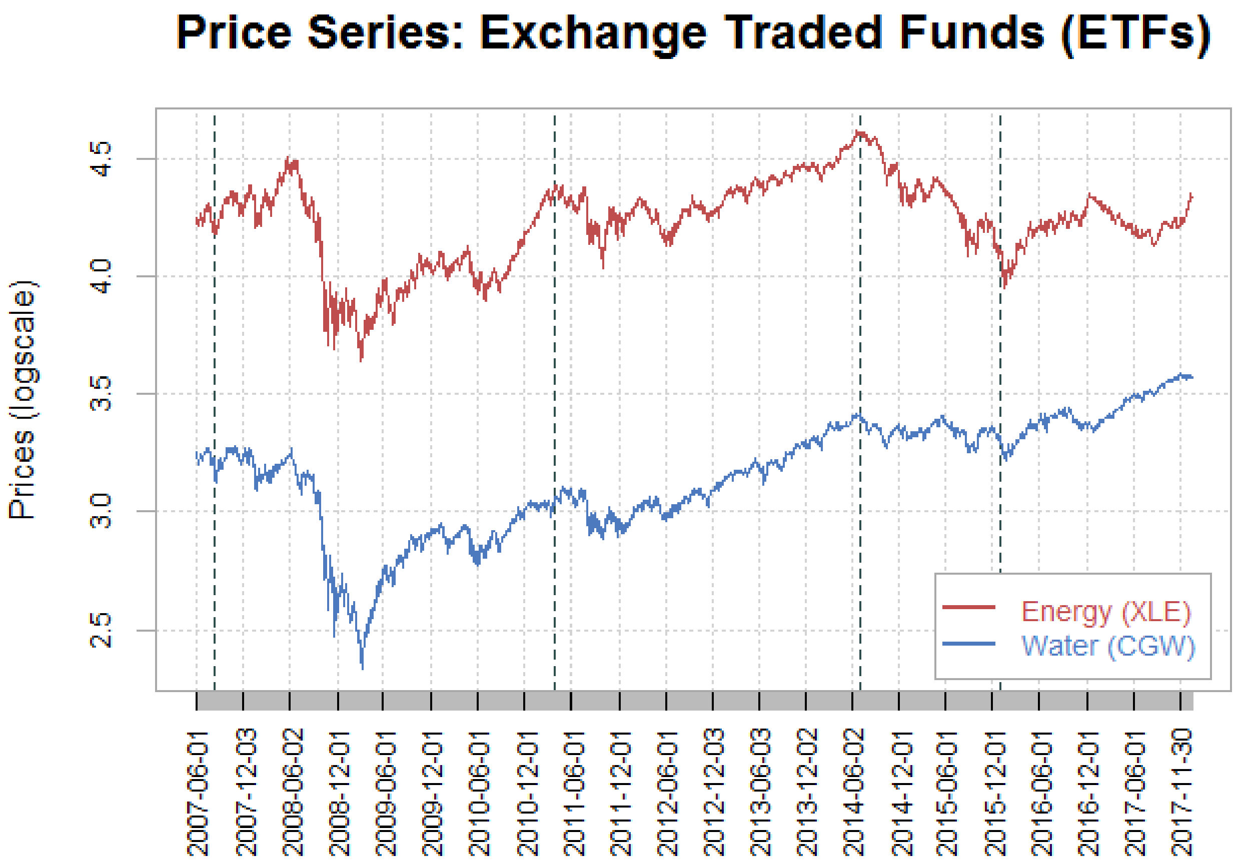
Financial Instruments:

- Indices are traditionally used to describe the **underlying behavior** of a commodity.
- ETFs **capitalize** on these behaviors by tracking commodity indices.
- Price series are specifically used to capture the **changing mean behavior** in addition to other **investment horizons**.

Economic Behavior:

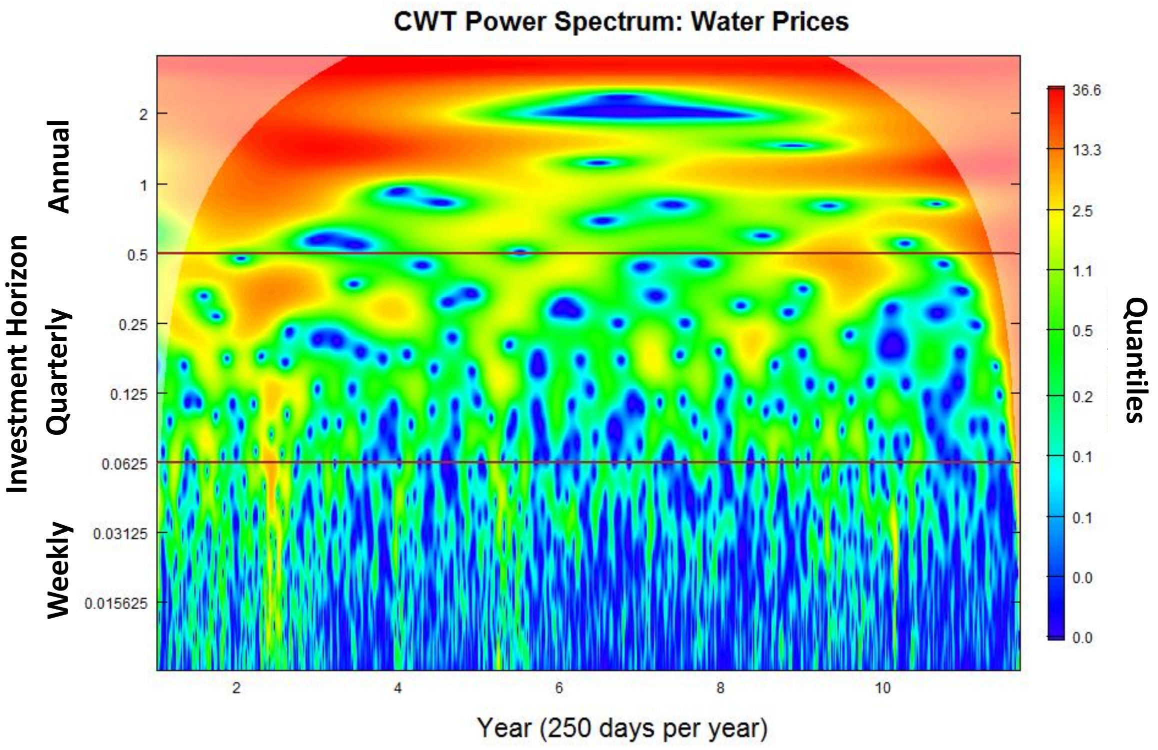
- 2008 Financial Crisis
- 2014/2015 Global Oil Glut

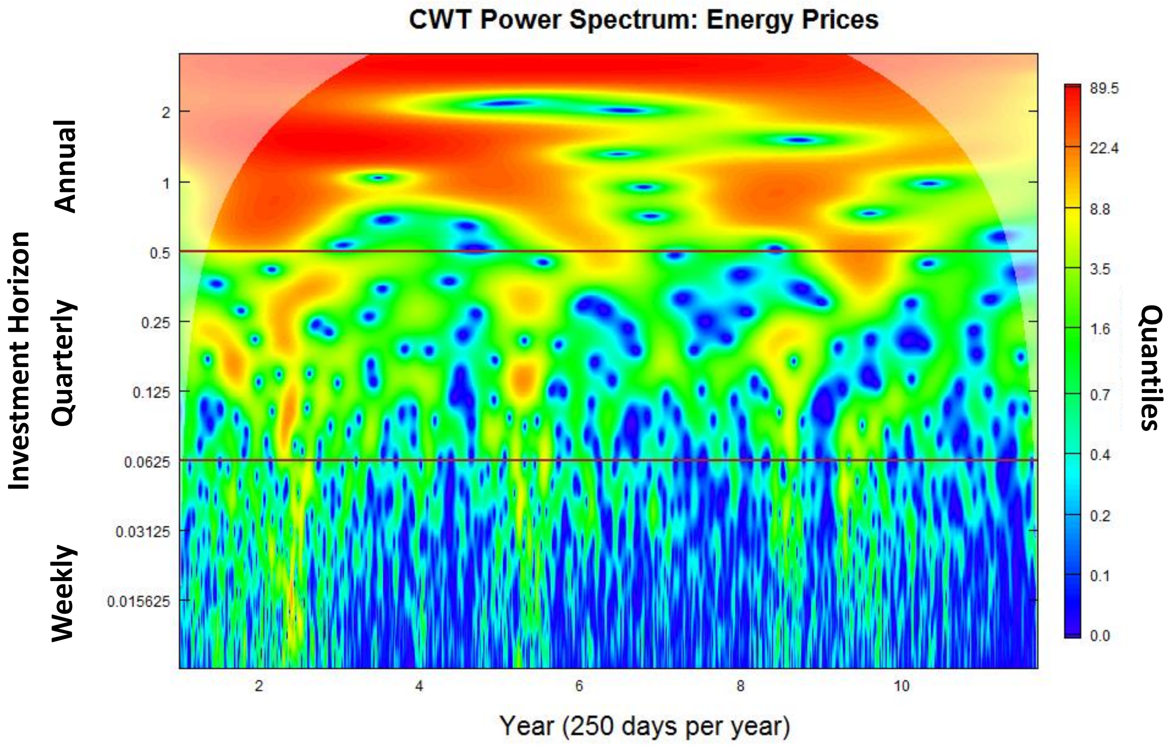
Applied to Water and Energy Commodities



Using daily water and energy commodity ETF price data from 2007 to 2017 we **deconstruct** each of the time series into different **investment horizons** and **evaluate their respective wavelet transforms**.

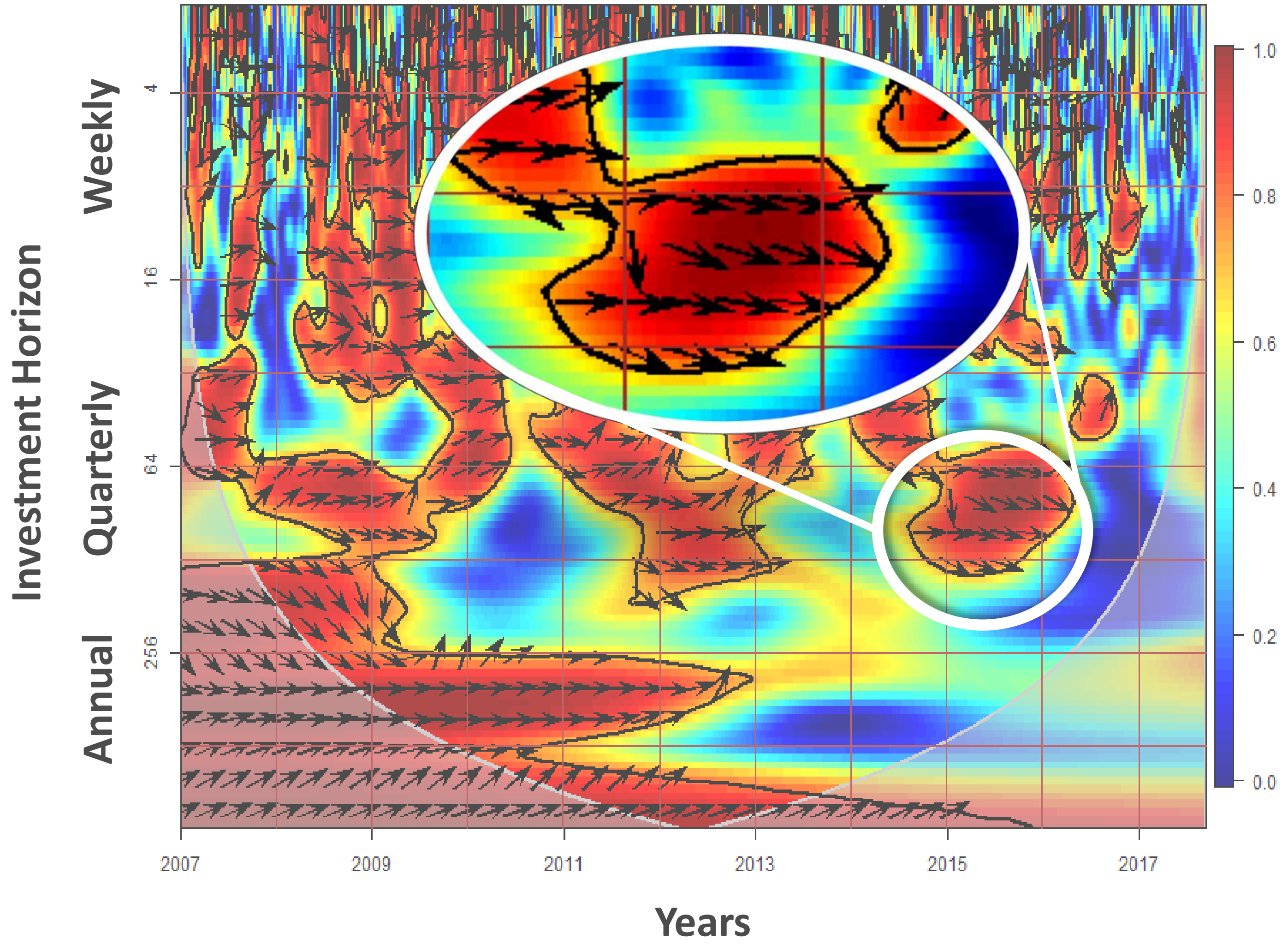
Water and Energy Univariate Visualization





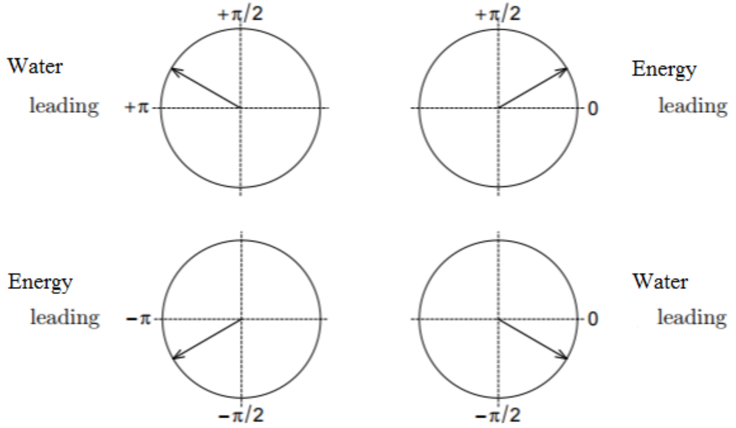
- The regions identified can be seen as the components that carry **most of the behavioral weight**.
- **Determining and translating these scales** to relevant time domain periods is useful in seeking future applications.

Water and Energy Bivariate Visualization - WSC



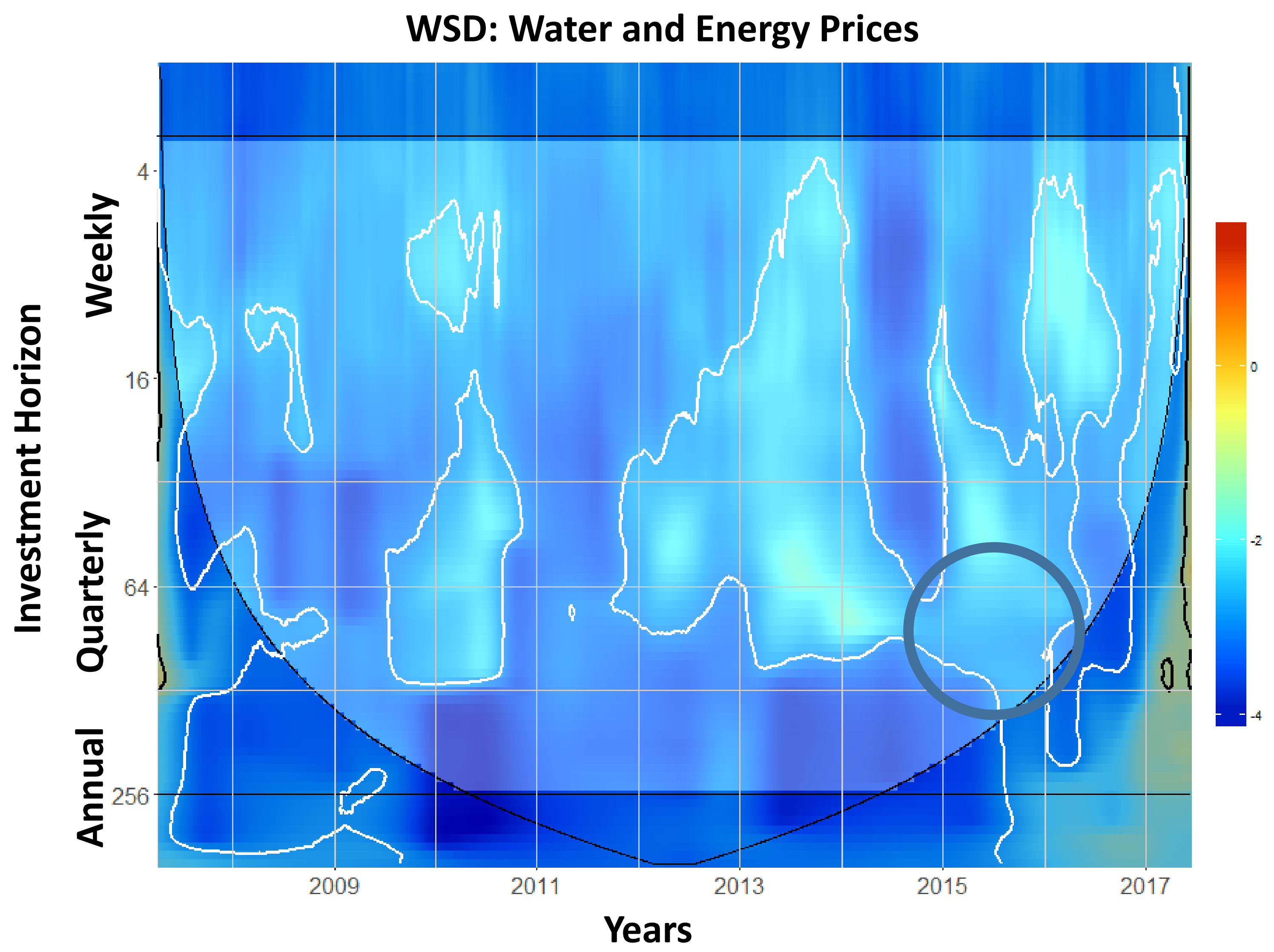
Wavelet Squared Coherence (WSC)

- Easily defines scale specific **local linear correlations** in regions of statistical significant comovement.
- The **arrows** are an indication of phase movement (leading-lagging relationship).



A phase difference of zero indicates comovement

Water and Energy Bivariate Visualization - WSD



Windowed Scalogram Difference (WSD)

- Gives **greater flexibility** in allowing the change of window size depending on which scale is of interest
- Demonstrates the **degree of similarity between the series**.
- Instrumental in distinguishing between **behavior impacted by external factors** versus behaviors identified due to **dynamic interactions**.

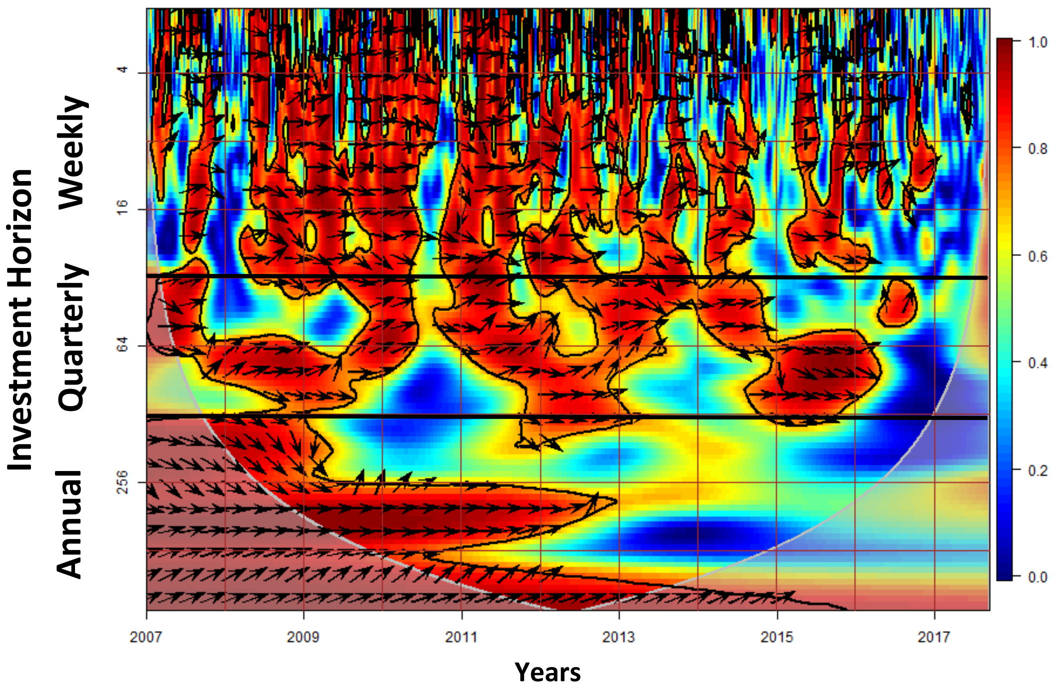
Interpretation: Investment Horizons

Understanding the **investment horizon** and interaction between commodities are important for practitioners to consider in the **design of investment models**.

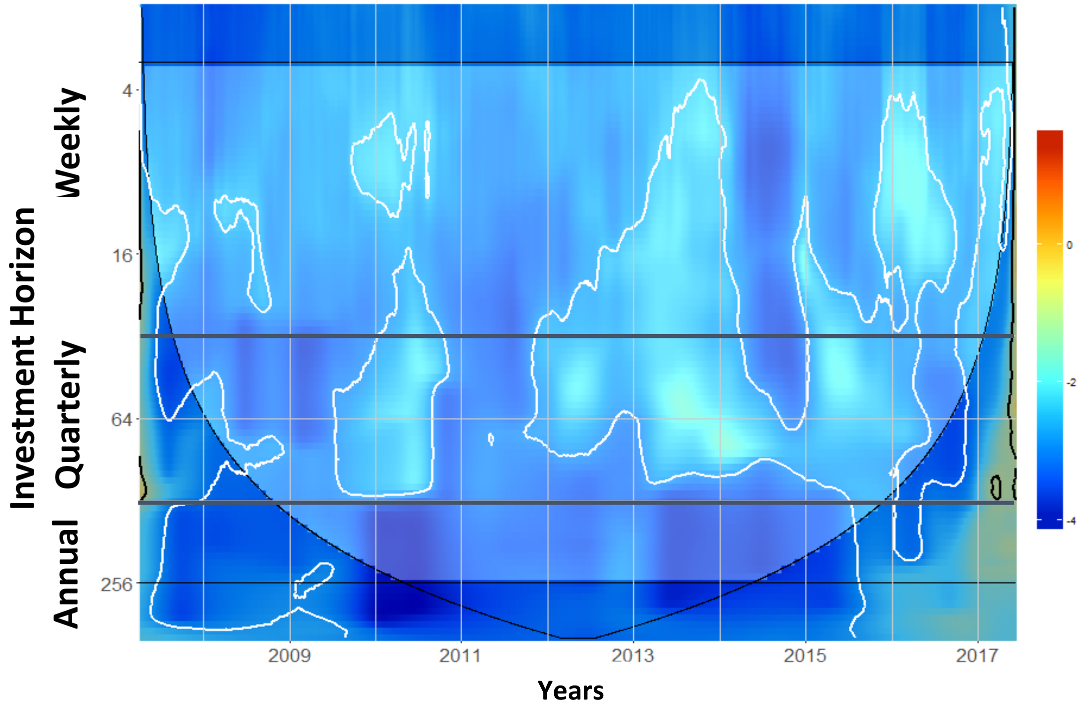
- The **CWT** we see a potential investment opportunity for **quarterly** (32-128 days) **investment horizon**; these time series quarterly contribution to the overall behavior of the series has medium to high power.

- The WSC and WSD clearly indicate the **dynamic relationship** during the **quarterly range** (32-128 days).

WSC: Water and Energy Prices



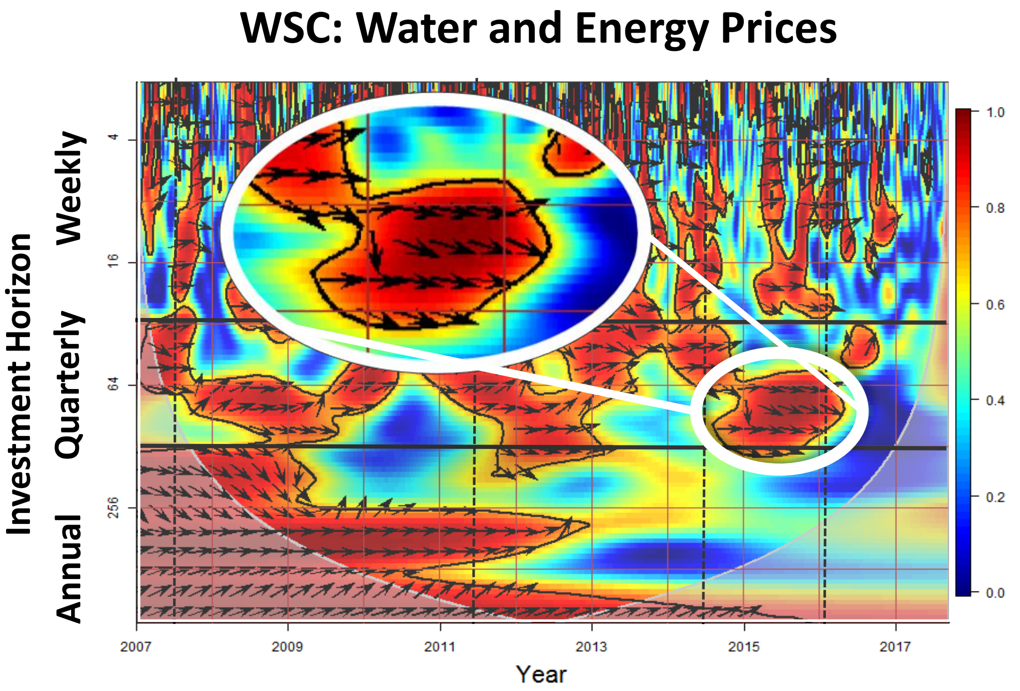
WSD: Water and Energy Prices

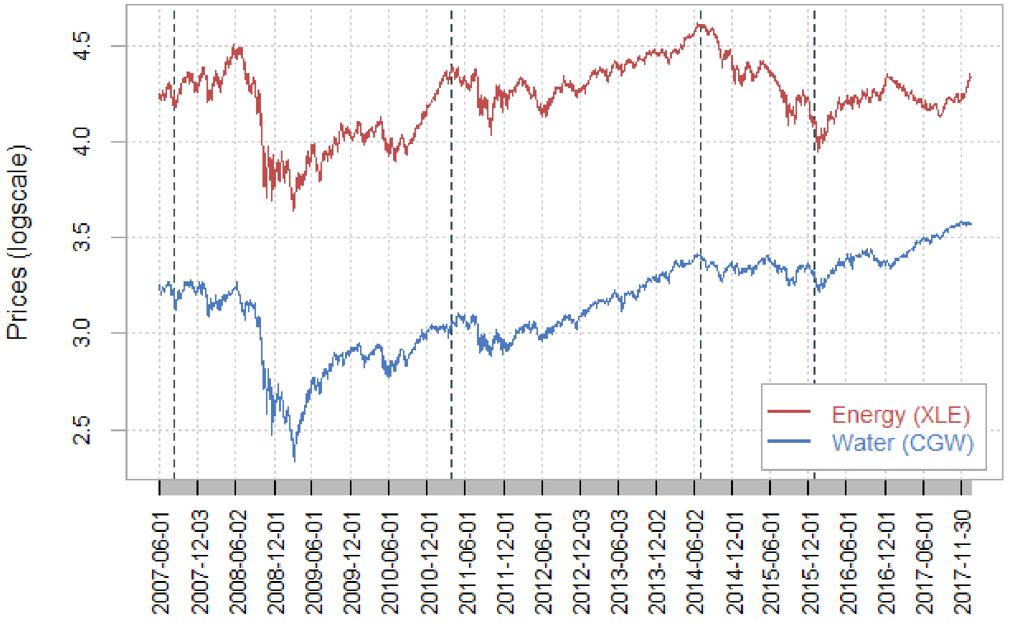


Interpretation: Economic Behavior

The WSC also allows us to look at the water-energy **phase behaviors** for two events.

- During the **2008 financial crisis** at the **quarterly range** (32-128 days) **energy is leading water**, however, for the **market year range** (250-500 days) these series are mostly comoving.
    - In our paper we point out that this **comovement is a result of the market impact** where energy and the S&P500 series are mostly in-phase and the degree of similarity according to the WSD is significant.
- In contrast, during the **2014/2015 global oil glut**, water and energy are in-phase with **water leading energy prices** during this quarterly investment horizon.





Why do I care and why should you care?

Economic Impact

Social Impact

Investments
and
Future Developments

Policy

Water Management Cost

Investments and Future Developments

- Exploration of the water-energy nexus using non-stationary financial instruments in the time-scale domain
  - Investment decisions made under the **umbrella of portfolio investment theory** to determine the optimal risk-return trade-off in the two commodities
- Techniques can also be useful to consider **further development** of time-varying structure
  - E.g. The dynamic comparison between known economic complements across different time horizons.

Acknowledgement and Questions

- **Dr. Vicente J. Bolos** and **Dr. Rafael Benitez** who supplied the R code for the WSD and with whom we are collaborating to **build a comprehensive wavelet package** for **economics and finance applications.**

- This material is based upon work supported by the **Ken Kennedy Institute for Information Technology 2016/17 Shell Graduate Fellowship** and the **National Science Foundation Graduate Research Fellowship Program** under Grant No. (DGE# 1450681).

Any Questions?

Open up your Laptop – lets leaRn together

References

[Bolos et al., 2017] Bolos, V. J., Bentez, R., Ferrer, R., and Jammazi, R. (2017). The windowed scalogram difference: A novel wavelet tool for comparing time series. Applied Mathematics and Computation, 312:49-65.

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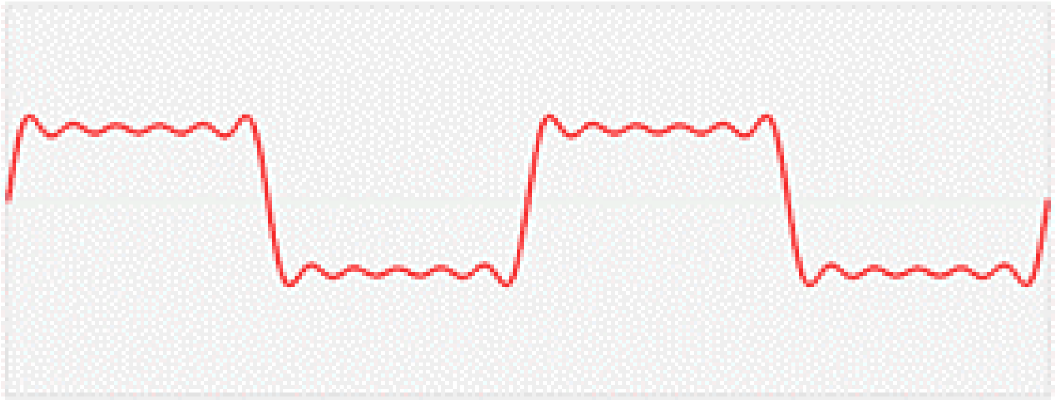
Appendix

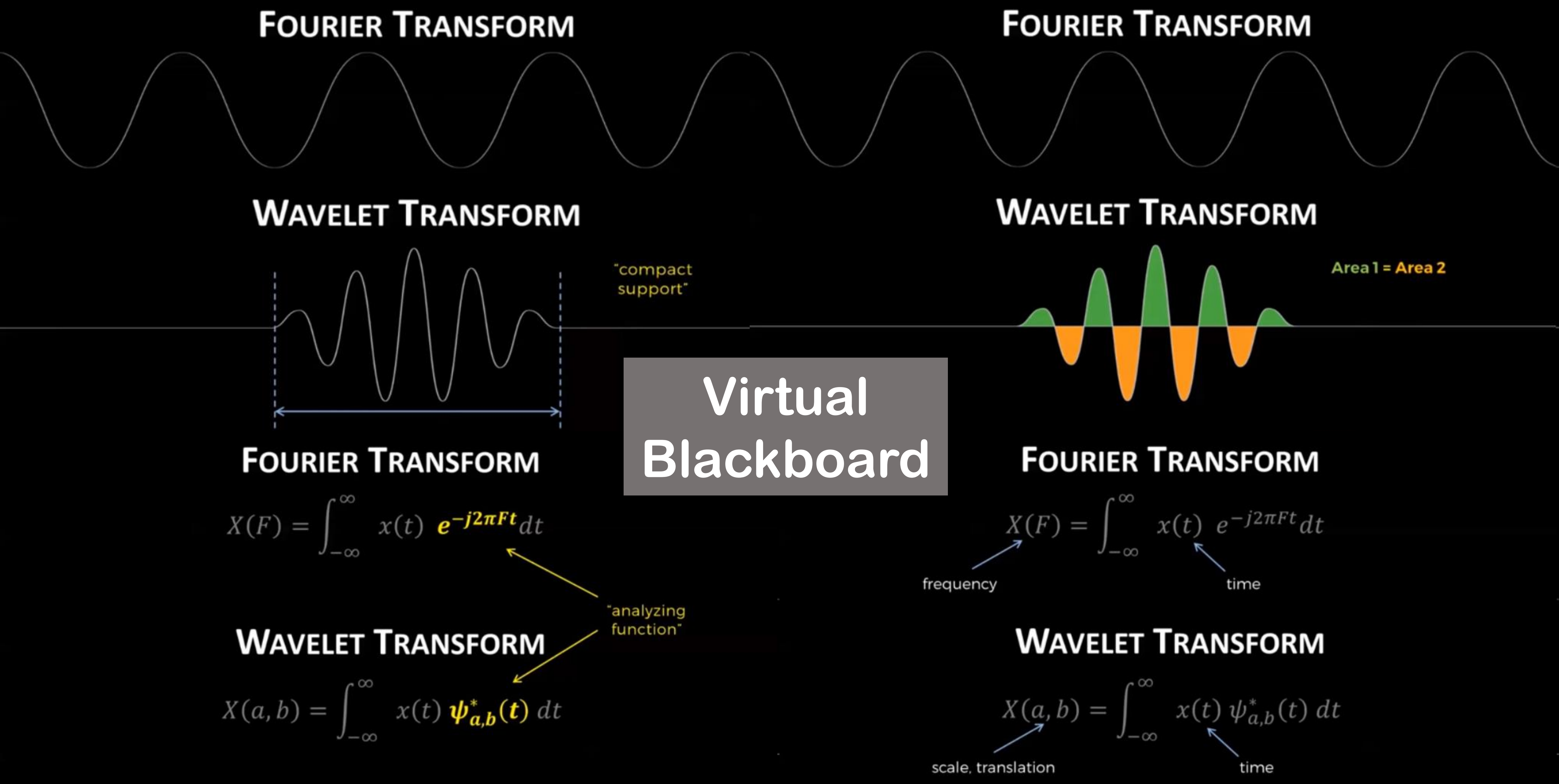
Easy Introduction to Fourier Analysis



Source: Wiki

Video: Easy Introduction to Wavelets

See next two Slides

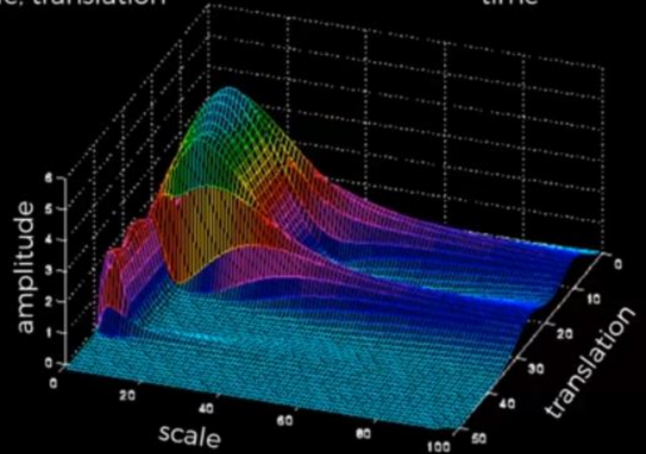

FOURIER TRANSFORM
WAVELET TRANSFORM
"compact support"
FOURIER TRANSFORM
$X(F) = \int_{-\infty}^{\infty} x(t)\; e^{-j2\pi Ft} dt$
"analyzing function"
WAVELET TRANSFORM
$X(a,b) = \int_{-\infty}^{\infty} x(t)\, \psi^*_{a,b}(t)\, dt$
Virtual Blackboard
FOURIER TRANSFORM
WAVELET TRANSFORM
Area 1 = Area 2
FOURIER TRANSFORM
$X(F) = \int_{-\infty}^{\infty} x(t)\; e^{-j2\pi Ft} dt$
frequency
time
WAVELET TRANSFORM
$X(a,b) = \int_{-\infty}^{\infty} x(t)\, \psi^*_{a,b}(t)\, dt$
scale, translation
time

Wavelet Transform

$$X(a,b) = \int_{-\infty}^{\infty} x(t)\,\psi^*_{a,b}(t)\,dt$$

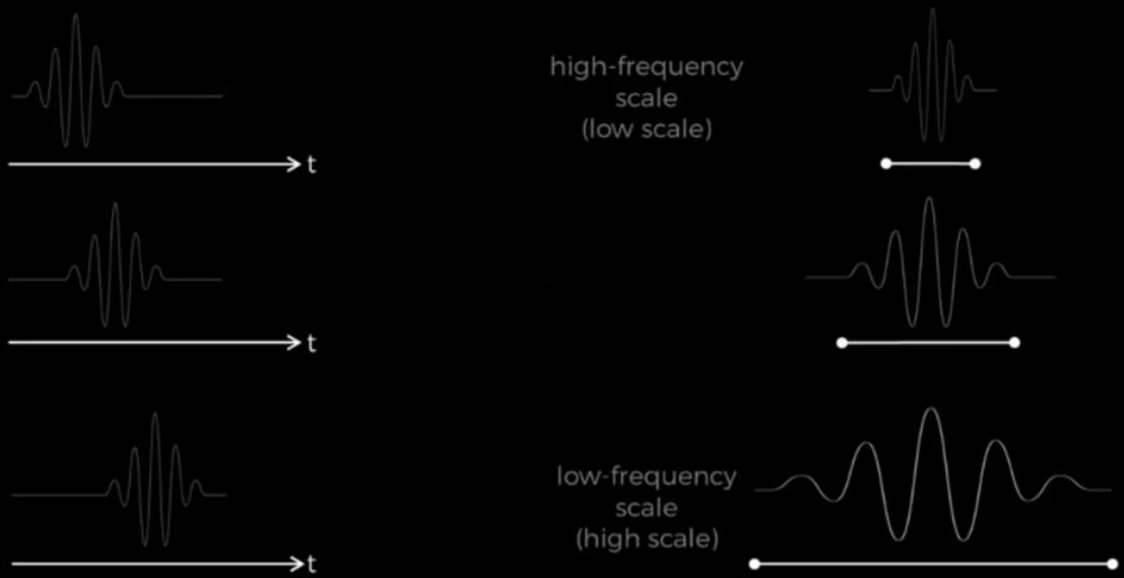
scale, translation

time

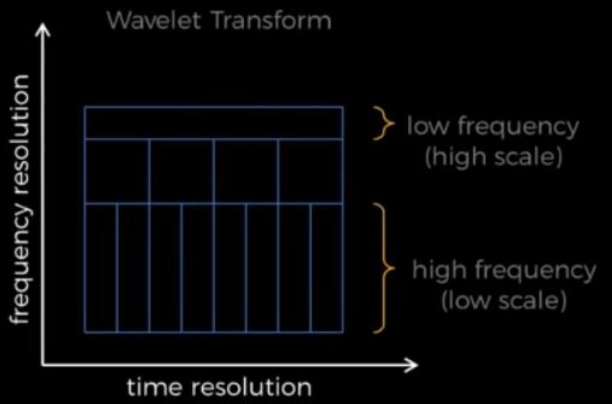


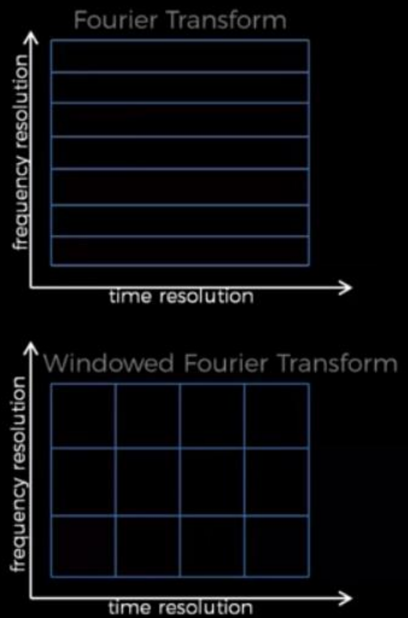
Credit: Rowan University

Translation and Scale



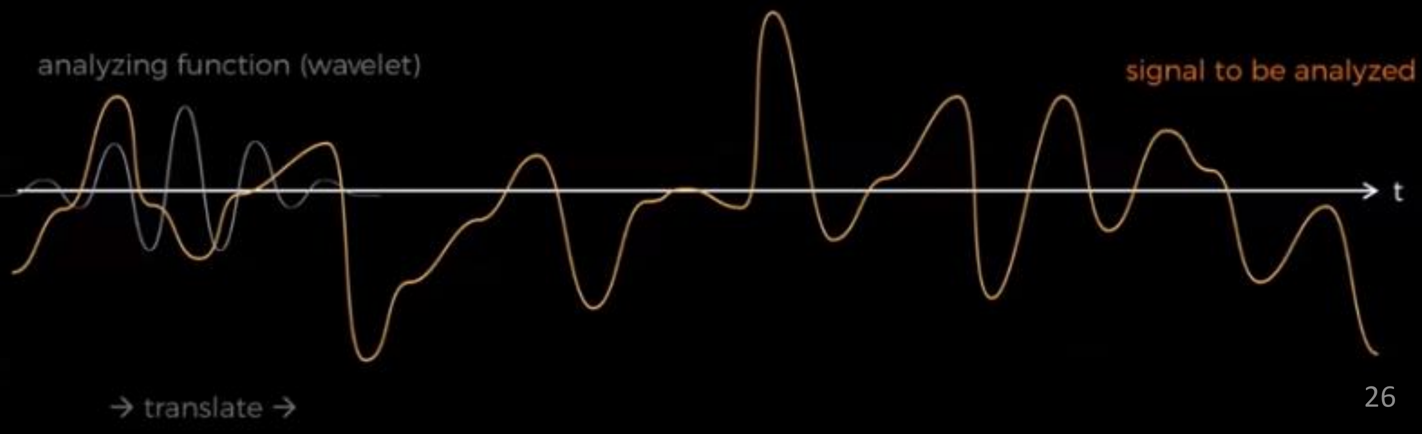
Resolution





Correlation

$$X(a,b) = \int_{-\infty}^{\infty} x(t)\,\psi^*_{a,b}(t)\,dt$$



Mathematics

$$\Psi^M(t) = \pi^{-\frac{1}{4}} e^{-\frac{1}{2}t^2} e^{i\omega_0 t}.$$

Mother Wavelet - Morlet

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right),$$

Wavelet Transform

$$W_x(a,b) = \langle x, \psi_{a,b} \rangle = \int_{\mathbb{R}} x(t) \psi^*_{a,b}(t)\, dt,$$

Wavelet Coefficient

$$W_{x,y}(a,b) = W_x(a,b) W^*_y(a,b),$$

Cross wavelet Transform

$$WSC(a,b) = \frac{|S(a^{-1}W_{xy}(a,b))|^2}{S(a^{-1}|W_x(a,b)|^2) S(a^{-1}|W_y(a,b)|^2)}.$$

Wavelet Squared Coherence

$$Phase(a,b) = Arg(W_x(a,b)) = tan^{-1}\left(\frac{\Im(W_x(a,b))}{\Re(W_x(a,b))}\right),$$

$$\phi_{x,y} = tan^{-1}\left(\frac{\Im(S(a^{-1}W_{x,y}(a,b)))}{\Re(S(a^{-1}W_{x,y}(a,b)))}\right).$$

Windowed Scalogram Difference

Windowed Scalogram

$$WSD_{\tau,r}(t,k) = \left(\int_{k-r}^{k+r} \left(\frac{WS_\tau(t,k) - WS'_\tau(t,k)}{WS_\tau(t,k)}\right)^2 dk\right)^{\frac{1}{2}},$$

$$WS_\tau(t,k) = \left(\int_{t-\tau}^{t+\tau} |W_x(a, 2^k)|^2 da\right)^{\frac{1}{2}}.$$

Why do I care and why should you care?

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Policy

- As fracking expands in the United States and oil prices stay relatively low, the **use of aqueous-drilling fluids** will increase due to low cost and limited environmental impact
  - Between **2000 and 2014** the average amount of water used to drill a well has increased **from 177,000 gallons to 5.1 million gallons per well**

- As **newer technology** becomes available to drill deeper into the ground the volume of water needed will place tremendous amounts of stress on the water availability of the global water basins
  - Even though the amount of water needed for fracking is less than that needed for farming and cooling it **can still strain water supply in areas where water is limited**.

- As water becomes an **increasingly scarce commodity**, discussions of the water-energy nexus policy reform is starting to be addressed alongside the food-energy nexus discussion.

  - **The quantification for the dynamic relationship can contribute to the validity of these discussions**.

Water Management Cost

- During the past year, there have been increased discussions in the Texas Permian Basin suggesting that the **future of upstream energy water management cost** reduction is **water commoditization or a water price index**.

- The **water management market makes up about $20 billion** and most of this money is spent on water logistics.

  - The creation of a **marketplace for water** would allow water services to be accurately priced based on the demand and supply of the market.
  - However, creating this marketplace could potentially **lead to various conflicts regarding rights to water resources**.

If this marketplace should exist or not is a matter of discussion, but as we have shown there is a **quantifiable dynamic relationship** between water and energy commodities that **could potentially reduce water management cost in the energy industry**.

Final Remarks

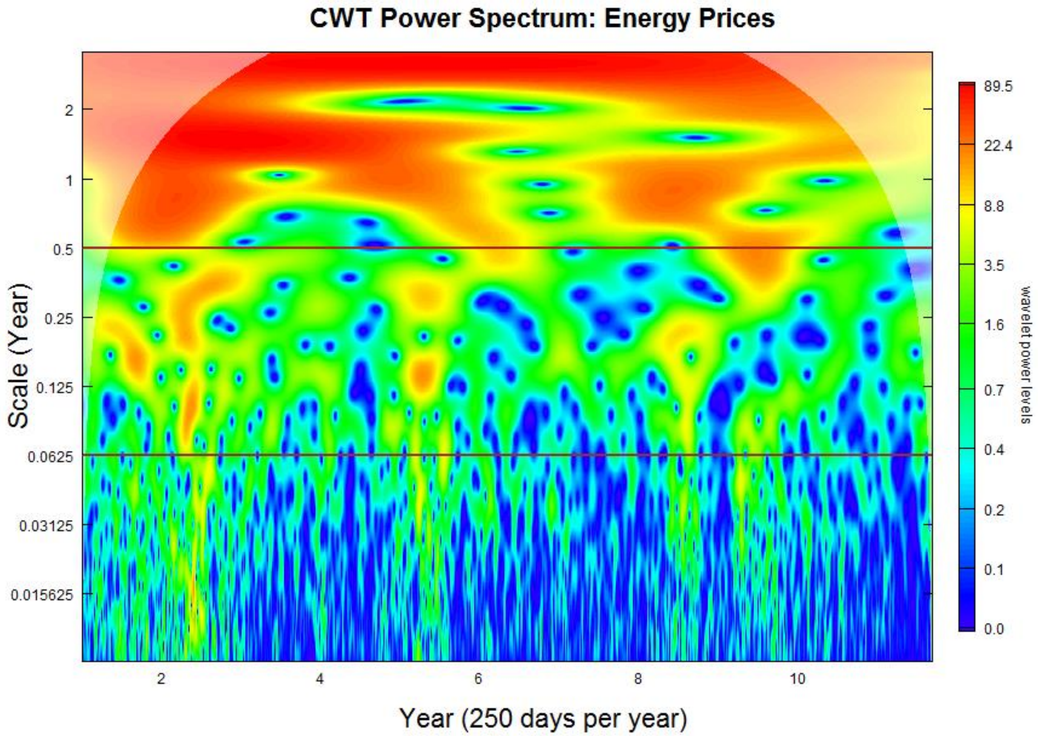
- **Correctly identifying the dynamic interactions of water and energy commodities** not only creates:
    - A vehicle to **improve upon** current investment strategies within the United States
    - It could also impact decisions and **policy processes** within countries that have high water stress

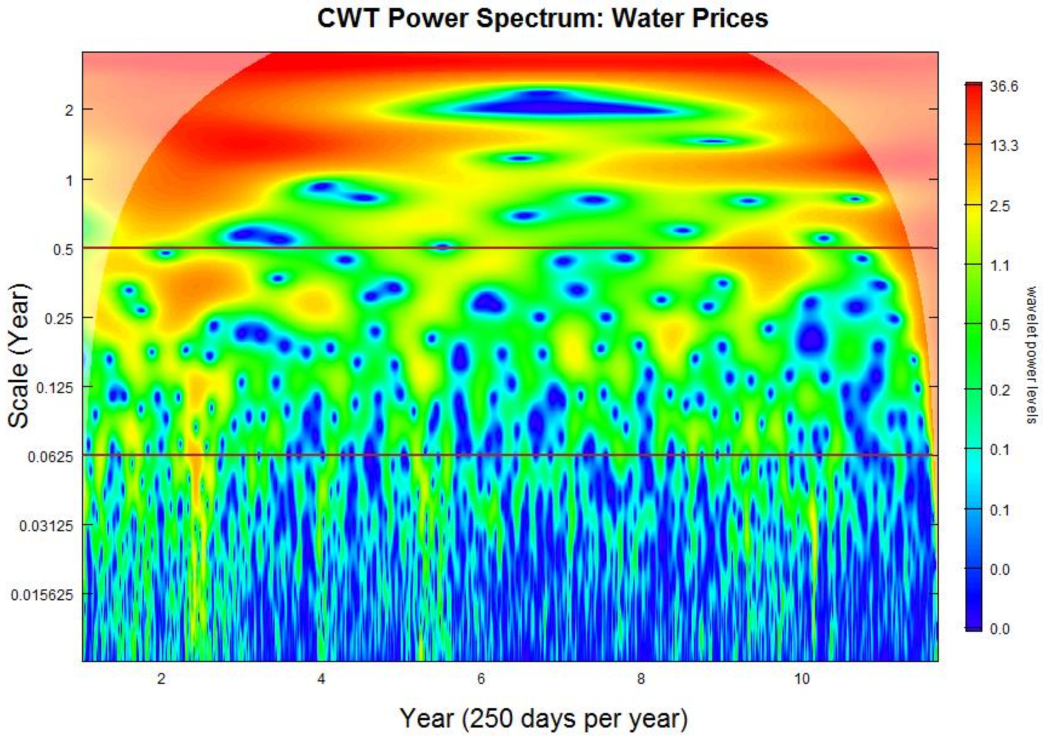
The **UN forecast for 2035** indicates that **energy and water consumption will increase by 35 and 85 percent**, respectively, and the **withdrawal of water for energy use would increase by 20 percent.**

Our research speaks directly to ***this important global challenge*** of the next two decades by helping investment planners and risk managers make better decisions on **how to allocate water to maximize energy returns while preserving potable water sources.**

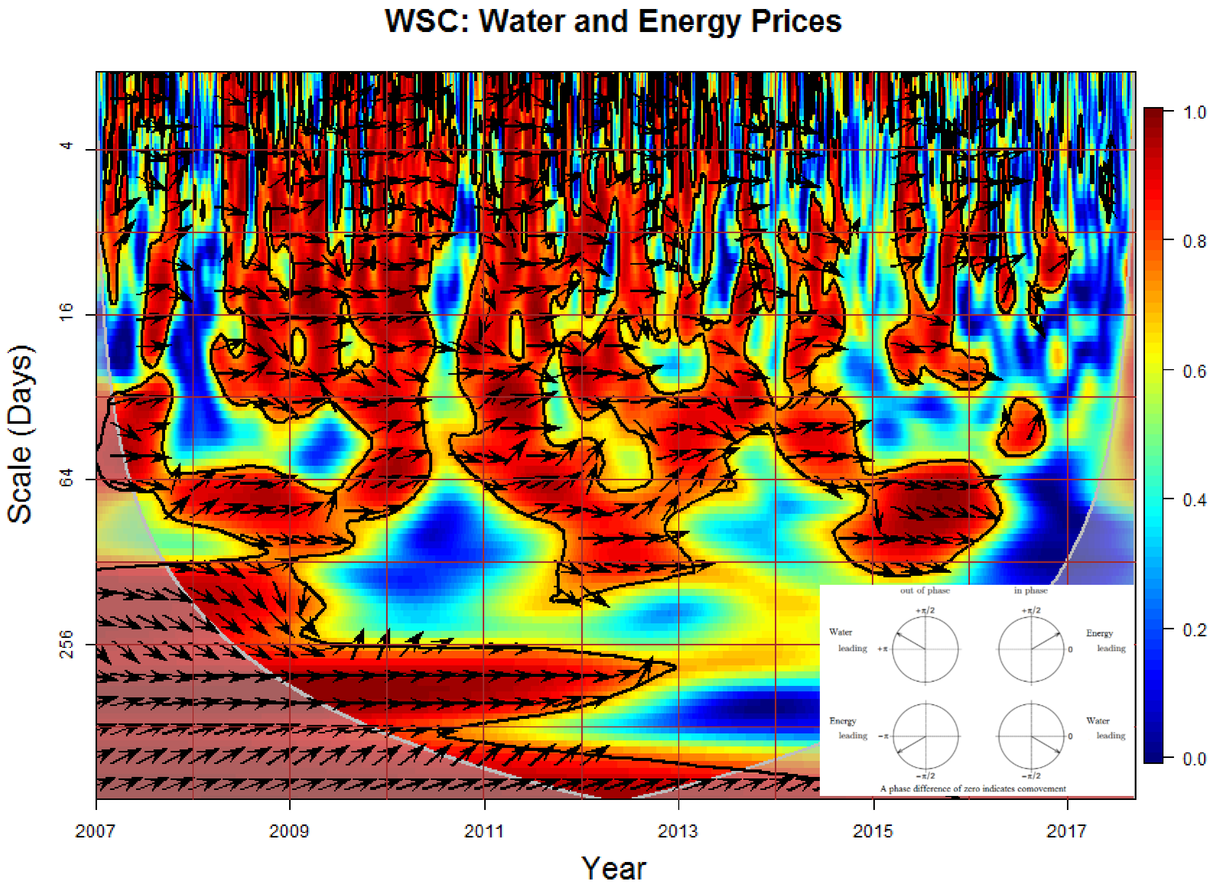
Figures from Paper

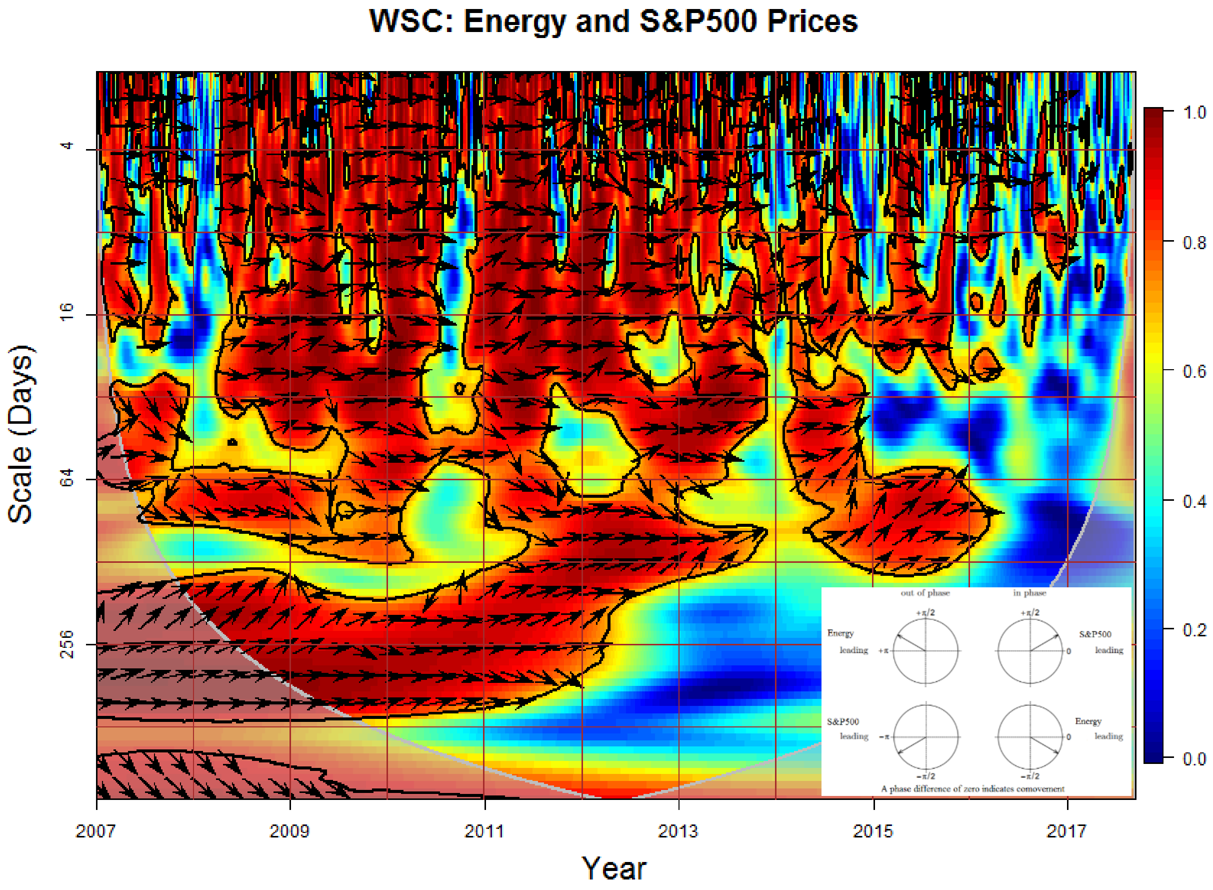
Continuous Wavelet Transforms (CWT)





Wavelet Squared Coherence (WSC)





Wavelet Scalogram Difference (WSD)