

# CHARACTERIZING PLANETARY WAVE SIGNATURES IN THE IONOSPHERE

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Haystack Research Experience for Undergraduates  
2012

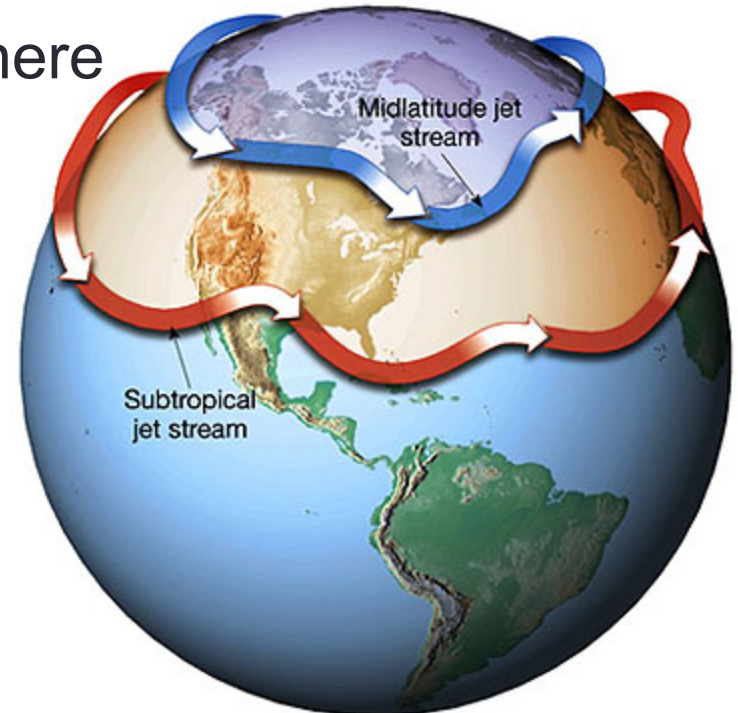


# Outline

- Physics: Planetary Waves
- Data and derivation
- Analysis and Results
  - Geophysical Drivers
  - Fourier Decomposition
  - Multi-wave fitting

# What are Planetary Waves?

- Global-scale waves that wrap around the entire Earth
- Involved in energy transfer between atmospheric regions
- Resonant structures across an entire slice of latitude
- Seen in Stratosphere and Ionosphere
- Resonances in wave 0-4 patterns
- Periods between 2 and 20 days
- Seen in various measurements:
  - Ionization
  - Temperature
  - Winds



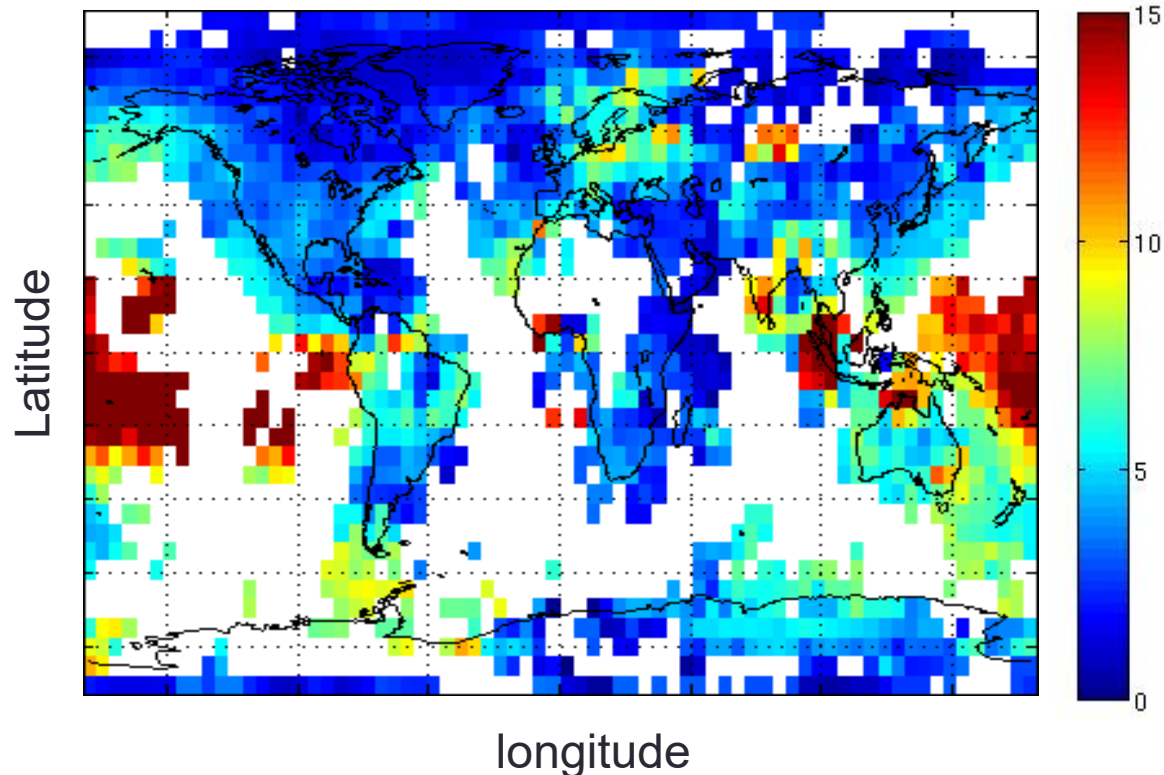
The Jet Stream-  
an example of a driver of PW

# What am I working with?

- Goal of project
  - Investigating planetary wave signatures in upper atmosphere
- Global TEC measurements from GPS network
  - TEC == Total Electron Content

- Massive data set
  - From 2003 to 2010
  - 1x1x5 minute binning
  - ~350GB of data
  - Imported from Madrigal

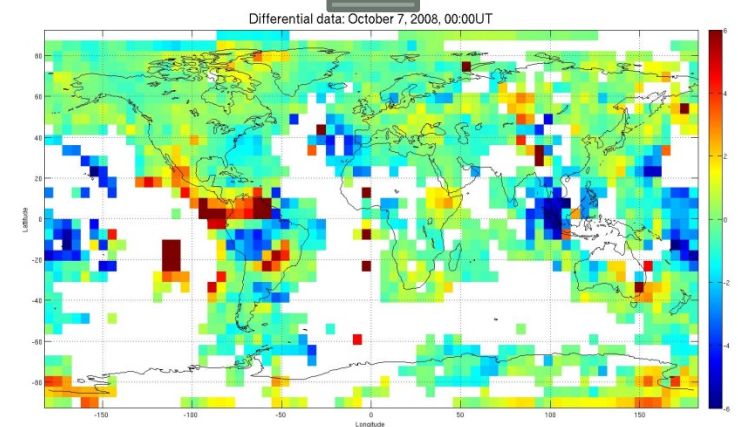
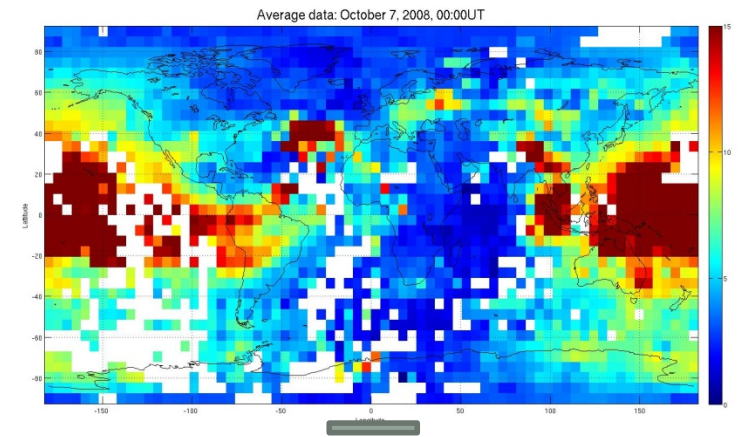
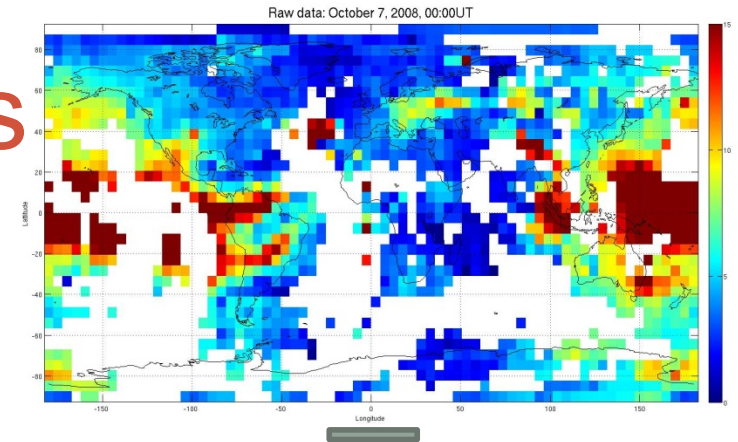
TEC data starting Jan 4, 2008



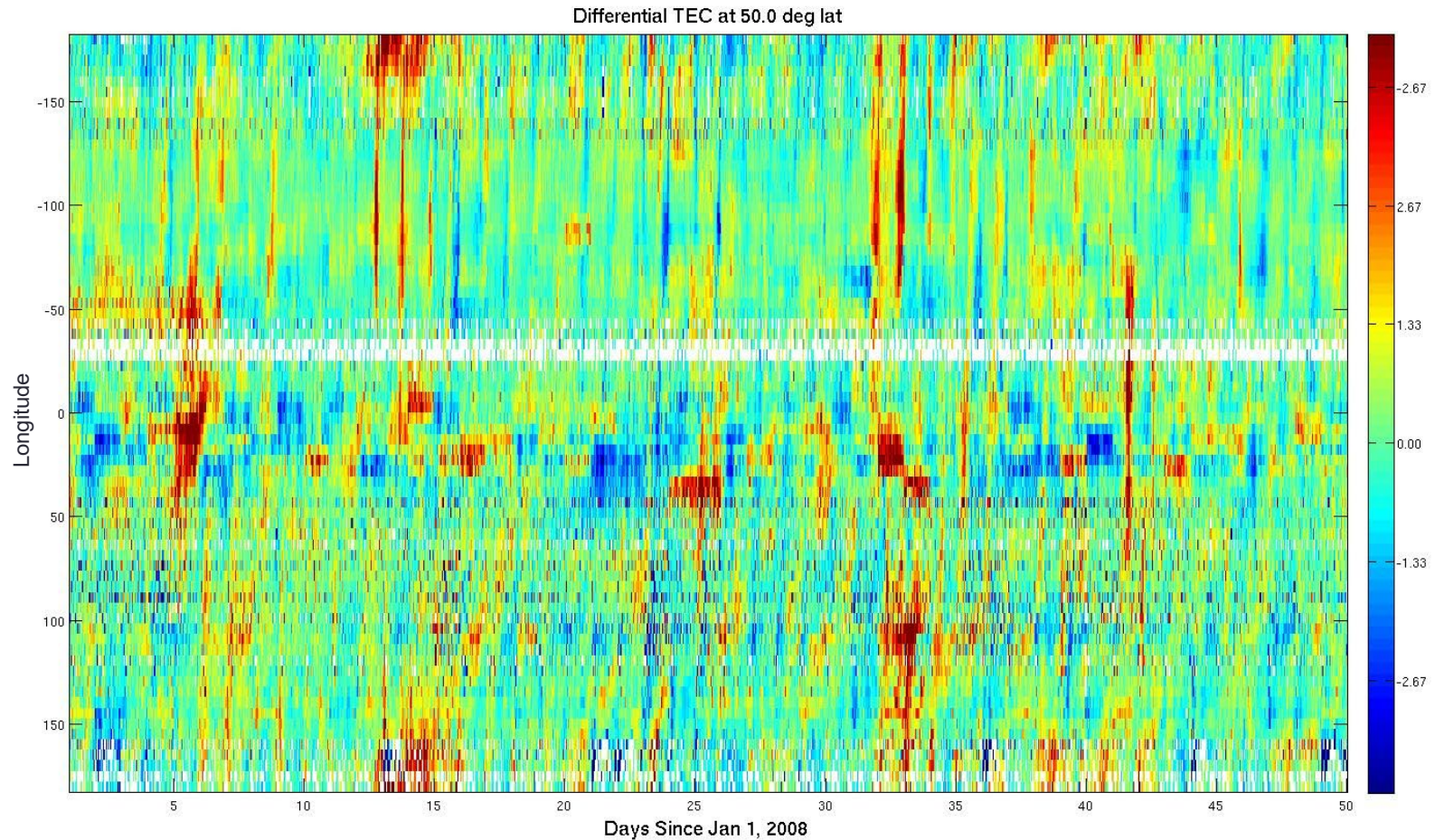
# Created Data Products

- Data Formatting
  - .MAT file type
  - 5 degree by 5 degree by 1 hour bins.
  - ~60% coverage
- 27 day moving average
- Differential TEC
- Have 5 final data types
  - Easy-to-access
  - In both .dat and .mat format
- Coordinate Conversions
  - From [ lat long Utime ]
  - To [ lat long localtime]
  - To [ lat localtime Utime]
  - To [ geomagnetic, Utime]

Out  
Ave  
Diff  
Per  
Smooth



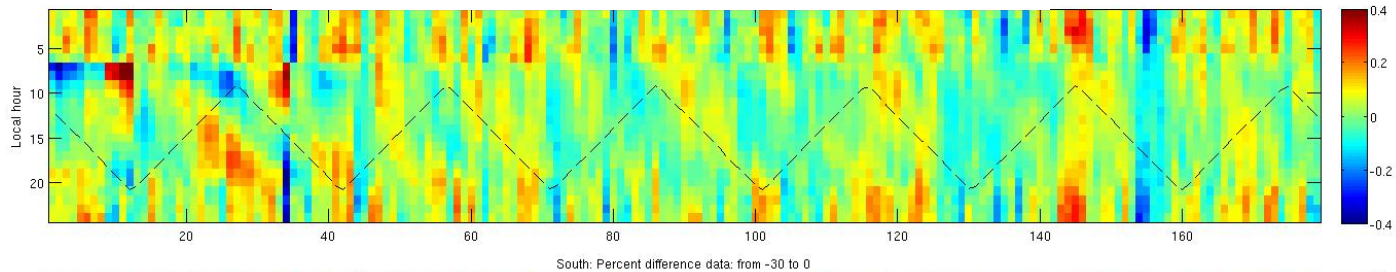
# A different Visualization: Differential Data



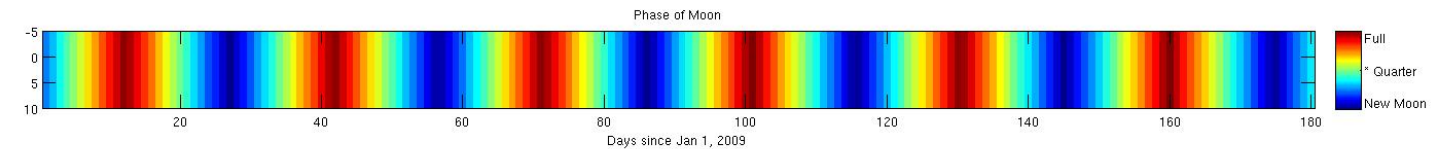
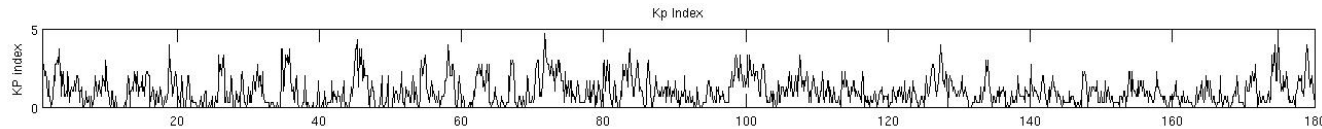
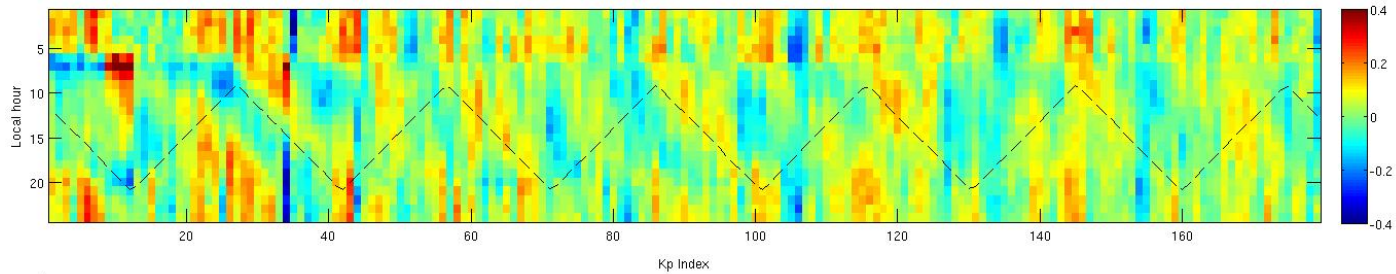
# Geophysical Drivers: Moon

Low Latitudes: (+/-) 0.0 – 25.0 deg

N Hemisphere

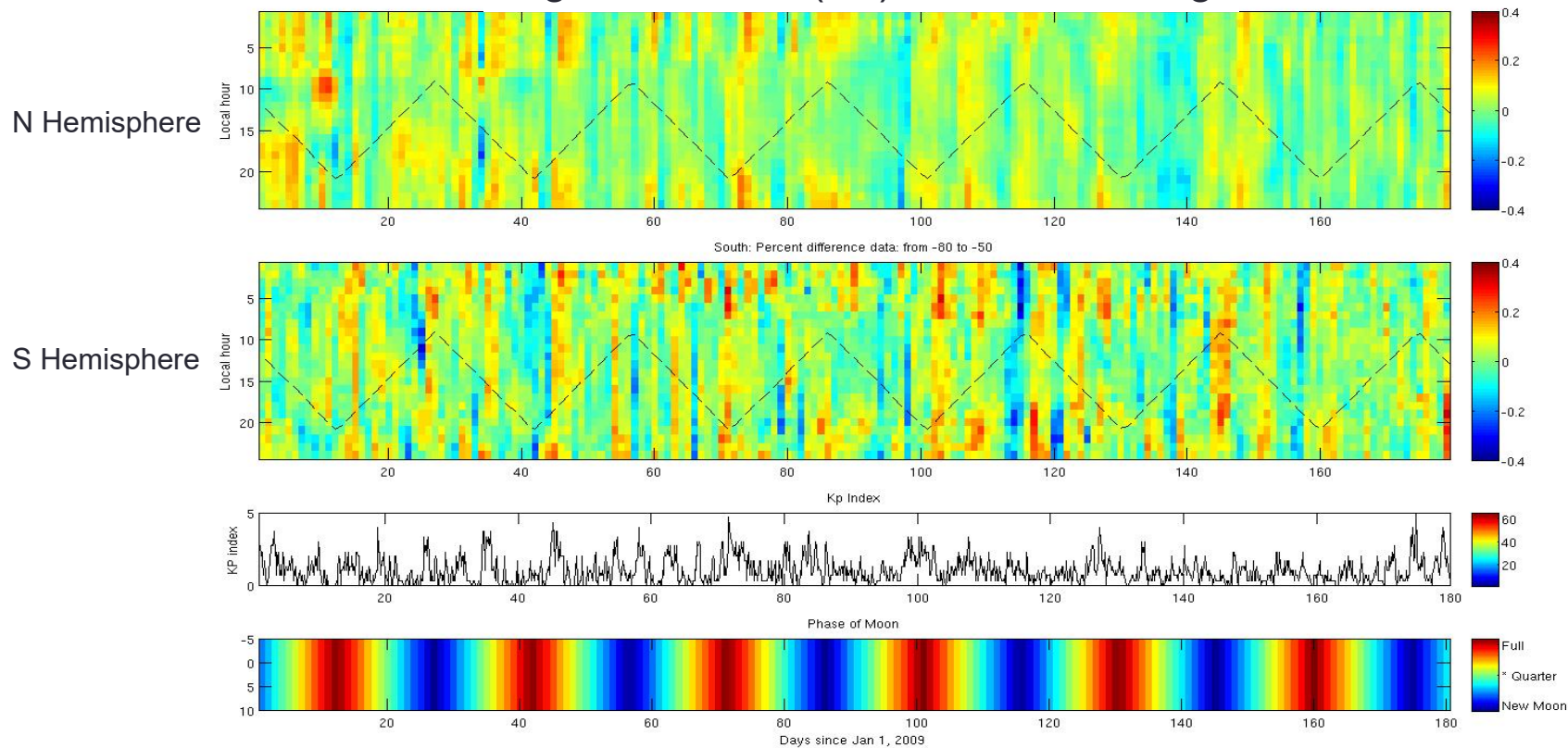


S Hemisphere



# Geophysical Drivers: Kp

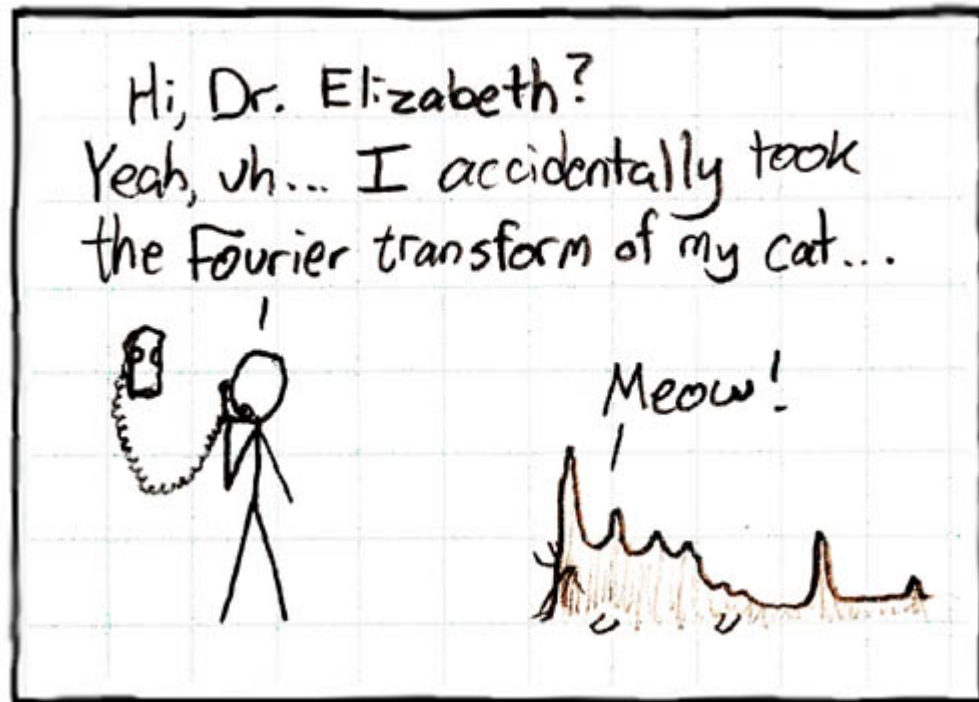
High Latitudes: (+/-) 50.0 – 75.0 deg



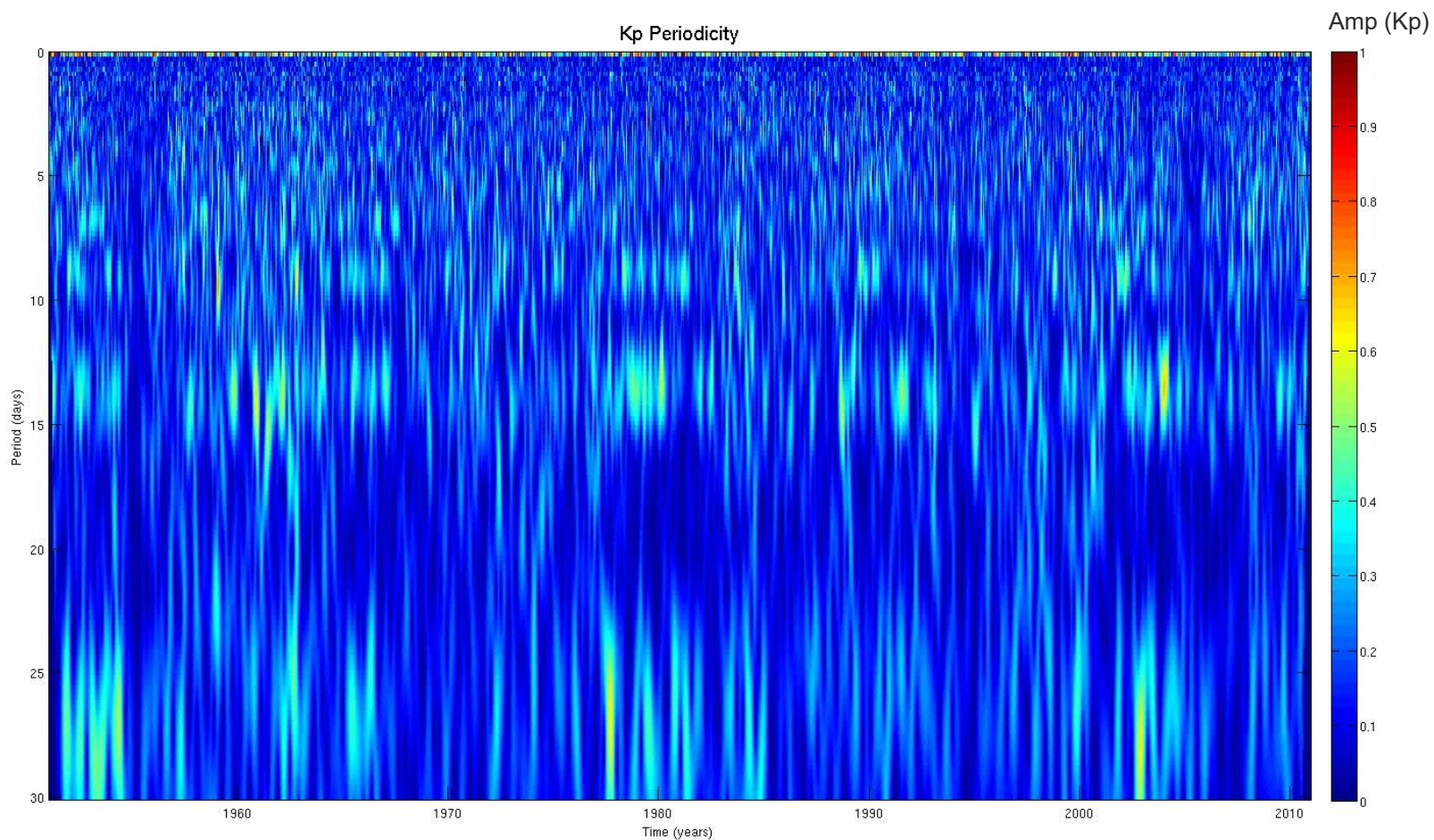


# Fourier Decomposition

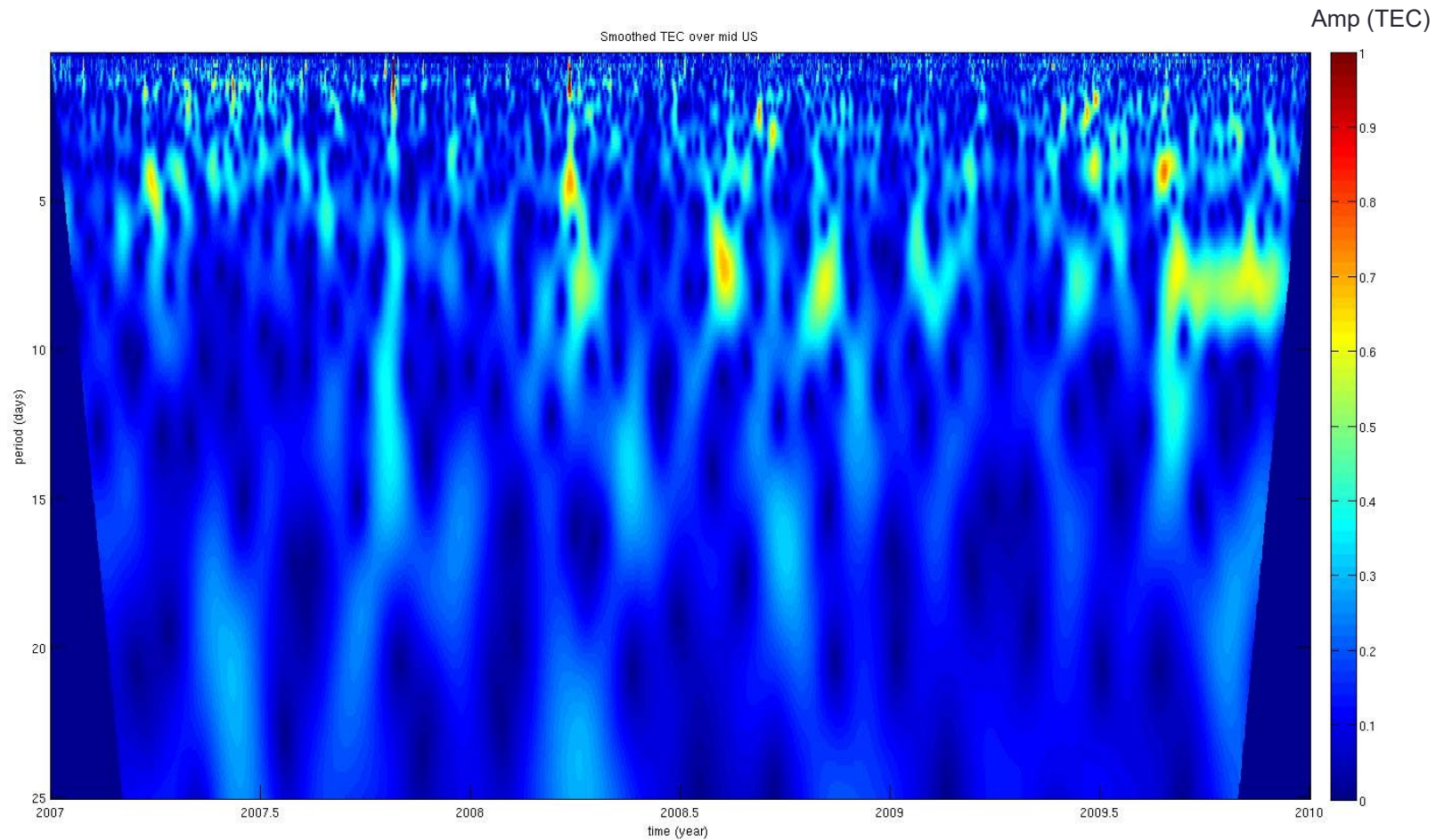
- Take sub-portions of data and Fourier transform it
- Gives evolution of wave amplitude through time
- This method Applicable to any 1D signal (and cats?)



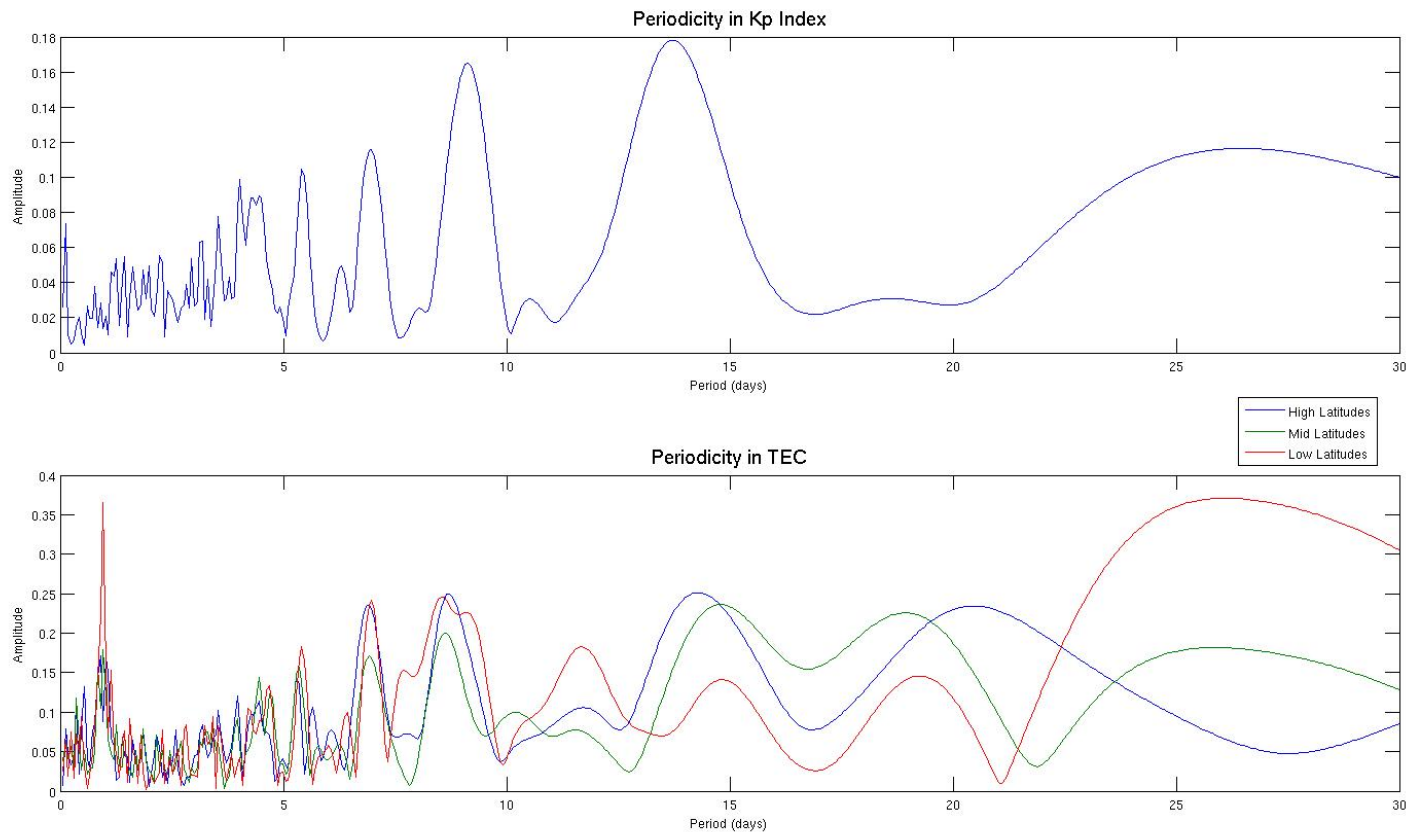
# Kp Index, from 1951 to 2011



# TEC over mid US (35.0 lat -80.0 long)



# Comparing Kp and TEC periodicity



- Kp and TEC taken as a 180-day slice starting Jan 1, 2009
- TEC taken as average over specified Latitude range and all longitude

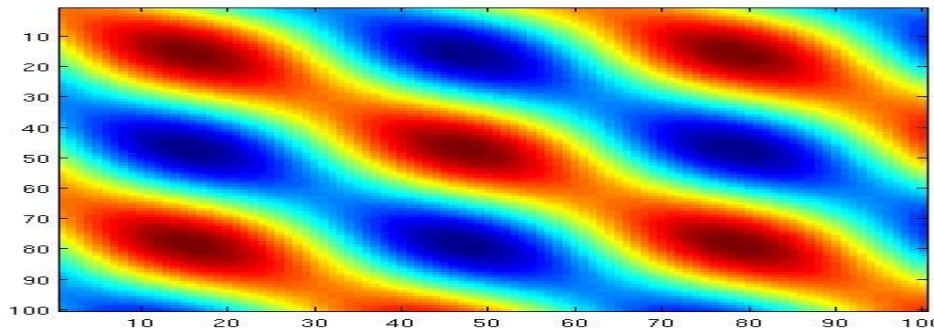
# Multi-wave fitting

- Creates a least-squares 2-dimensional best fit model of the data
- Simultaneously linearly fits 30 waves to a least-squares fit

(standing) 2-day 3-day 5-day 10-day 16-day

Example data:

Wave 0  
Wave 1  
Wave 2  
Wave 3  
Wave 4



$$Z(i, j) =$$

$$1.0 * \sin(k_1 * x_i) * \sin(k_2 * y_j) +$$

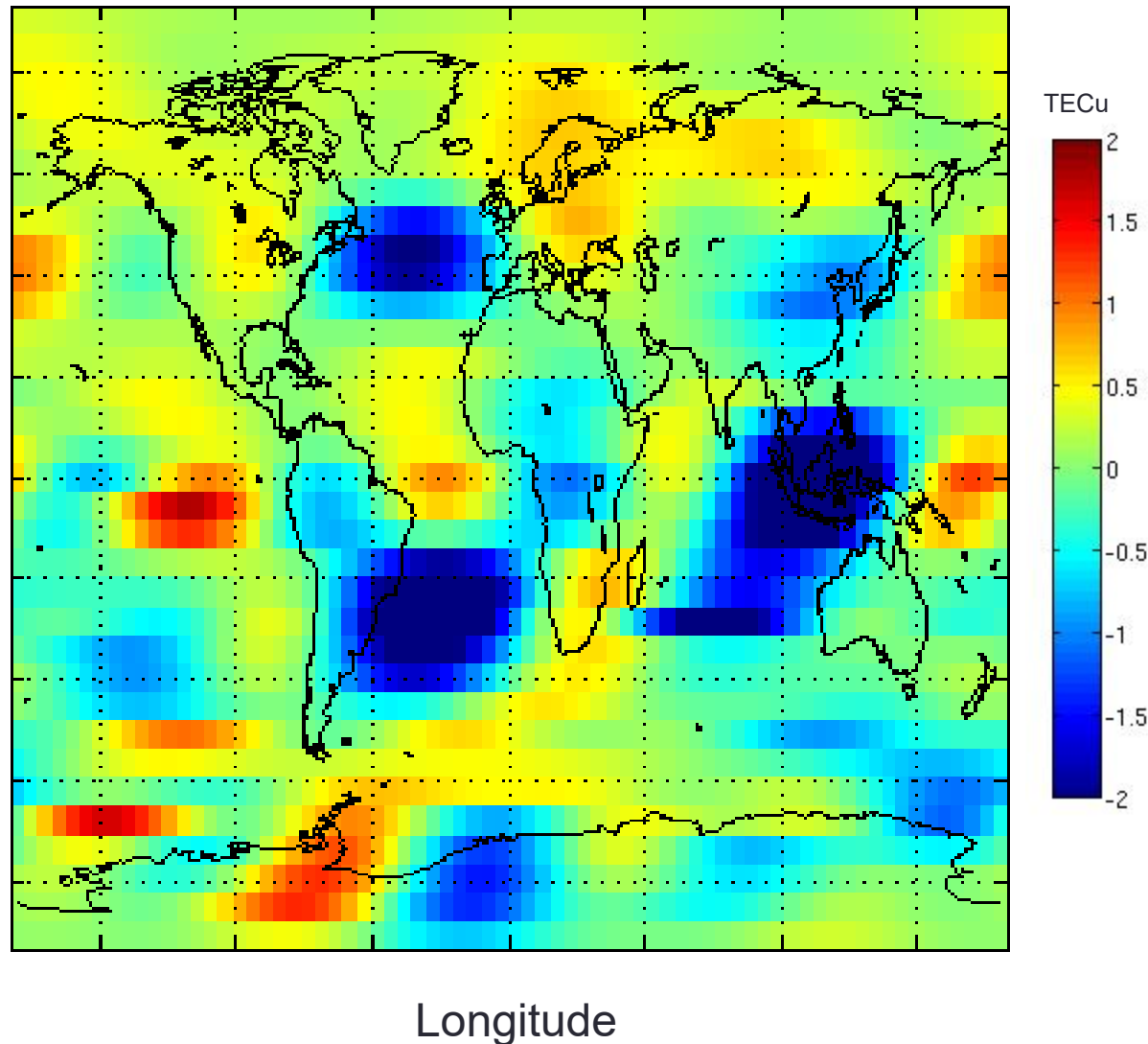
$$0.5 * \cos(k_1 * x_i) * \cos(k_2 * y_j) +$$

$$0.0 * \sin(k_1 * x_i) * \cos(k_2 * y_j) +$$

$$0.0 * \cos(k_1 * x_i) * \sin(k_2 * y_j) +$$

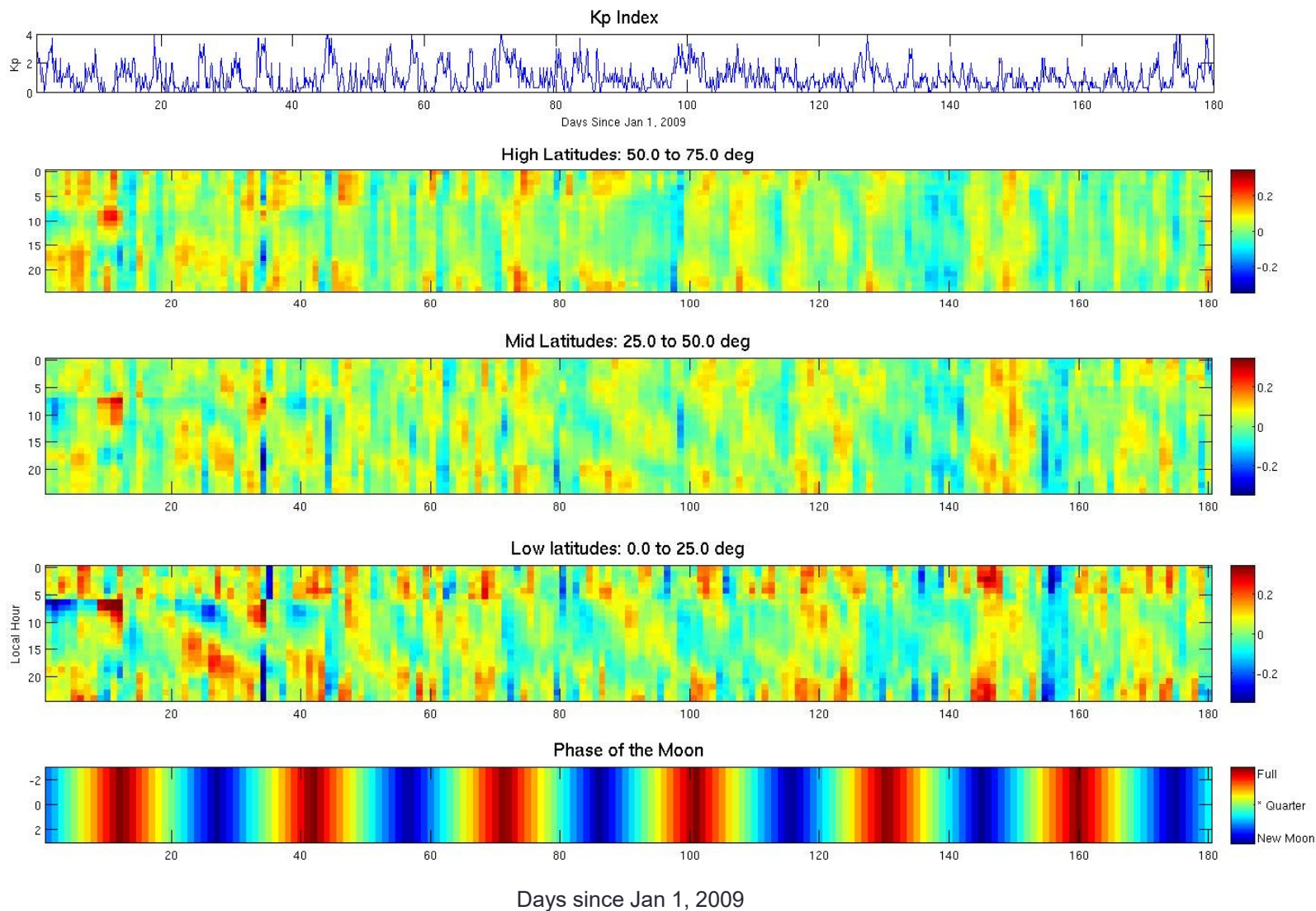
- 4 degrees of freedom for each wave differentiate between left-moving, standing, and right-moving

# Example Fitting: starting July 14, 2007



- Doesn't match data very well
- Uses overlaid fittings
  - 72 fits present
  - 280,000 semi-dependent fitting parameters
- Shows basic forms of PW activity

# Geophysical Drivers



# Results and Conclusions

- Periodicities seen in TEC data
- In TEC data there were clear signatures of forcing from Kp and the moon, dependent of Latitude
- Developed wave analysis tools for simultaneous extraction of multiple waves
- Developed useful tools for future work
  - Global dataset with coverage from 2003-2010
  - 1,000-1,500 lines polished MATLAB code



# Thanks to

- My advisors:
  - Anthea Coster
  - Larisa Goncharenko
  - Shunrong Zhang
- The Haystack Community
- Haystack
- NSF

# Questions?

