Using Remote Sensing Data to Improve Geographic Assessments of UV-B Radiation from a Sparse Ground Monitoring Network

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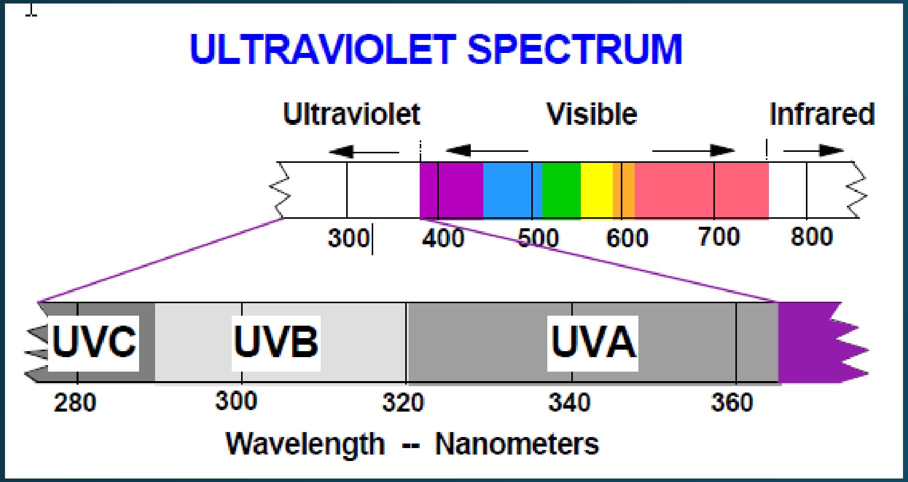
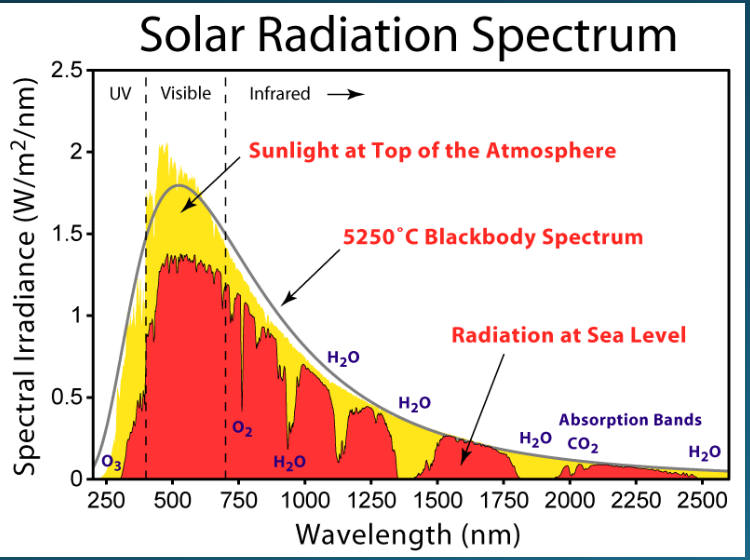
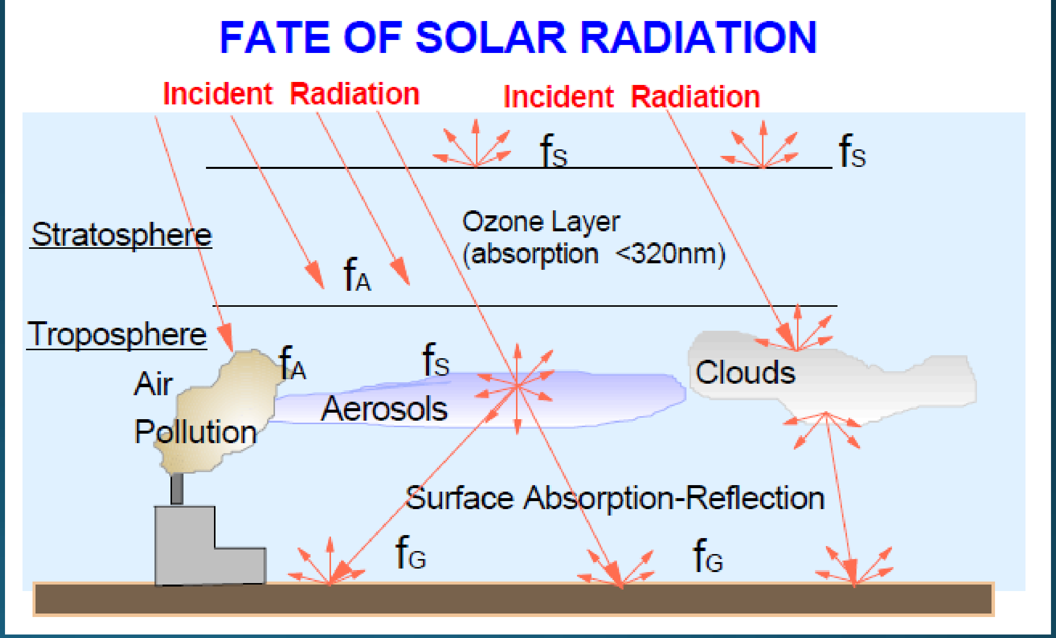
Goals

- Produce a data product that allows users to acquire time series of the distribution of UV-B radiation across the continental USA, based upon measurements from the UVMRP.
- Provide data in a format that is GIS ready.
- Users will be able to use the data product to produce time series of UV-B at any location.
- The data product will be useful for characterizing the UV-B climate, in terms of basic statistics (eg. mean, min, max, std), geographic distributions, and temporal changes at daily, weekly, seasonal, and annual time scales.

UV Radiation







Current Status of the Stratospheric Ozone Layer

From: UNEP 2014 - Environmental Effects of Ozone Depletion and Its Interaction with Climate Change

- Due to the Montreal Protocol, atmospheric abundance of most controlled ozone-depleting substances (ODSs) is decreasing. There are several indications that the global ozone layer is beginning to recover from ODS-induced depletion.

- As a result of the success of the Montreal Protocol in limiting ozone depletion, changes in UV-B irradiance measured at many sites since the mid-1990s are due largely to factors other than ozone. Positive trends of UV radiation observed after the mid-1990s over northern mid-latitudes are mainly due to decreases in clouds and aerosols.

- Large short-term increases in UV-B irradiance have been measured at some locations in response to episodic decreases of ozone at high latitudes.

- Future levels of UV-B irradiance at high latitudes will be determined by the recovery of stratospheric ozone and by changes in clouds and reflectivity of the Earth's surface.

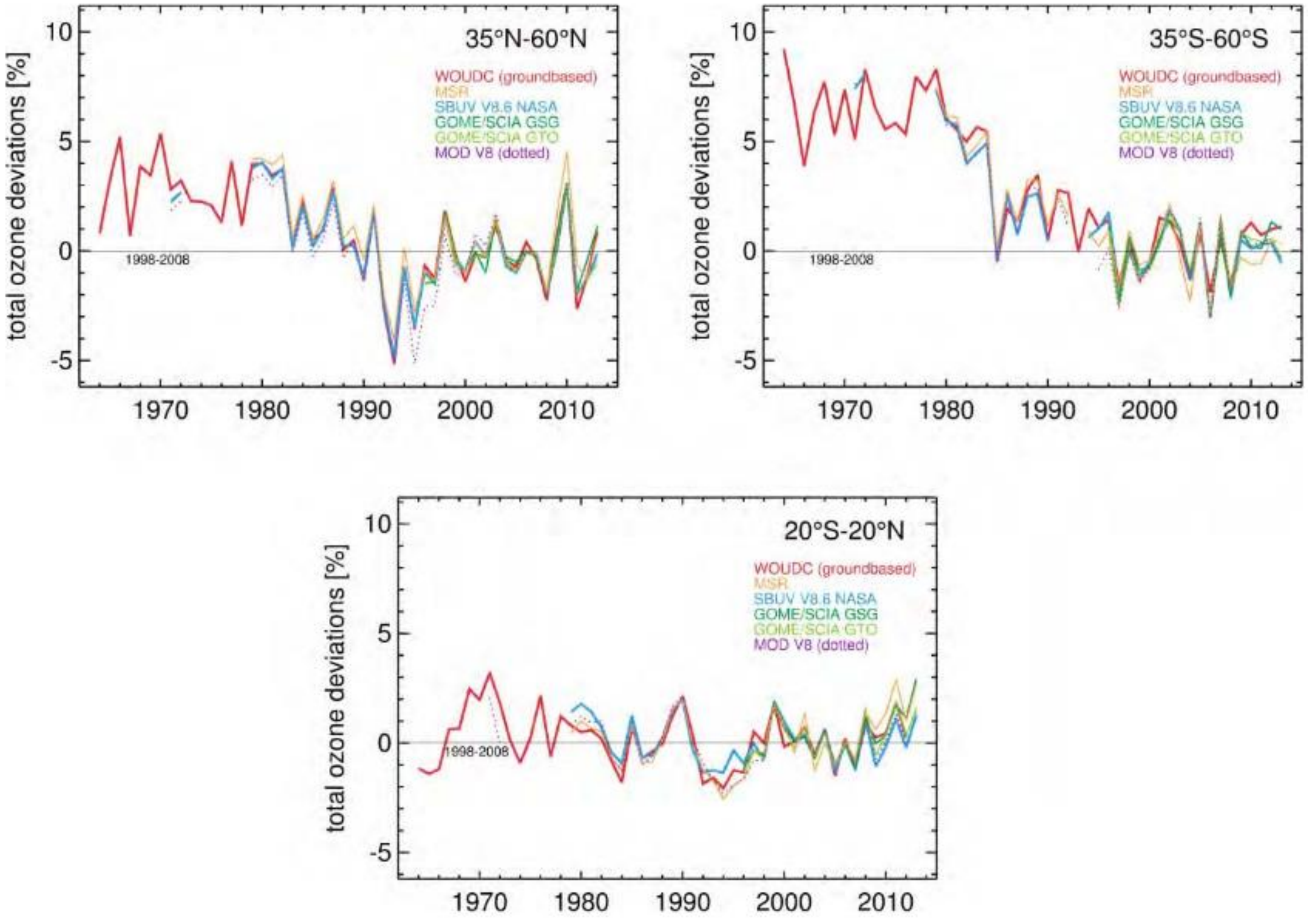


Fig 1. Total column ozone annual mean deviations relative to the 1998-2008 mean for different latitude bands as derived from different ground- and space-based datasets. Adapted from WMO 2015[265]

Effects of UV-B Radiation on Terrestrial Ecosystems

From: UNEP 2014 - Environmental Effects of Ozone Depletion and Its Interaction with Climate Change: Effects on Terrestrial Ecosystems

- The effects of UV-B radiation on plants are influenced by various abiotic and biotic factors in ways that can have both positive and negative consequences on plant productivity and functioning of ecosystem.

- Exposure to UV-B radiation can promote plant hardiness, and enhance plant resistance to herbivores and pathogens. It can also improve the quality, and increase or decrease the yields of agricultural and horticultural products, with subsequent implications for food security.

- Solar UV radiation has the potential to contribute to climate change via its stimulation of emissions of carbon monoxide, carbon dioxide, methane, and other volatile organic compounds from plants, plant litter and soil surfaces

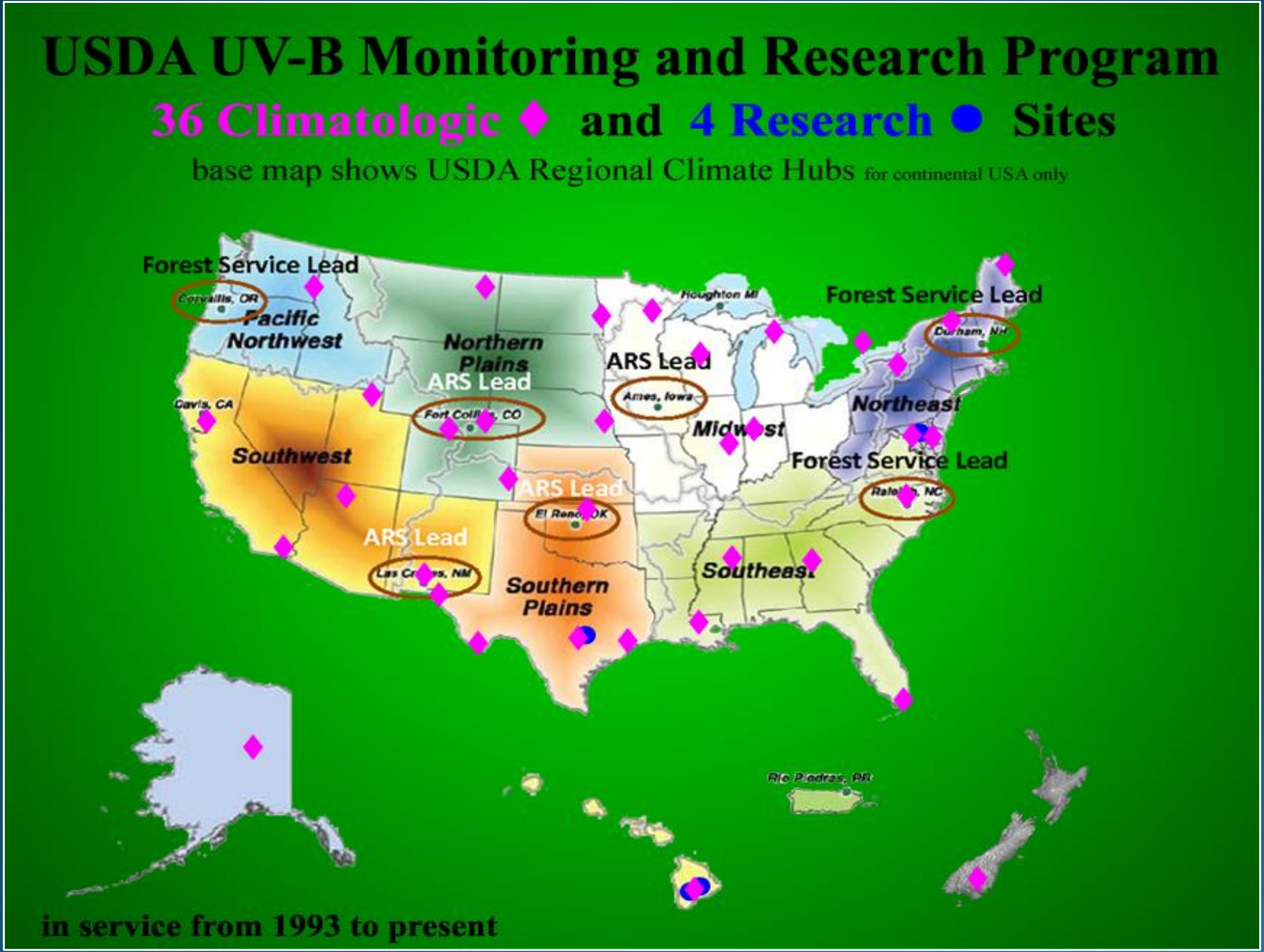
- While UV-B radiation does not penetrate into soil to any significant depth, it can affect a number of belowground processes through alterations in aboveground plant parts, microorganisms, and plant litter.

The UV-B Monitoring and Research Program (UVMRP)

- Funded by USDA since 1993, with the aim of providing information to the agricultural community and others about the climatological and geographic distribution of UV-B irradiance, which has potentially damaging effects on agricultural crops, forests, and rangelands
- Headquartered at Colorado State University, the UVMRP operates a national network of 36 UV monitoring stations across the co-terminus USA, as well as sites in Alaska, Hawaii, and New Zealand.

Data Collection Network

This Program is the only network providing nationwide surface monitoring of ultraviolet-B (UV-B) irradiance.

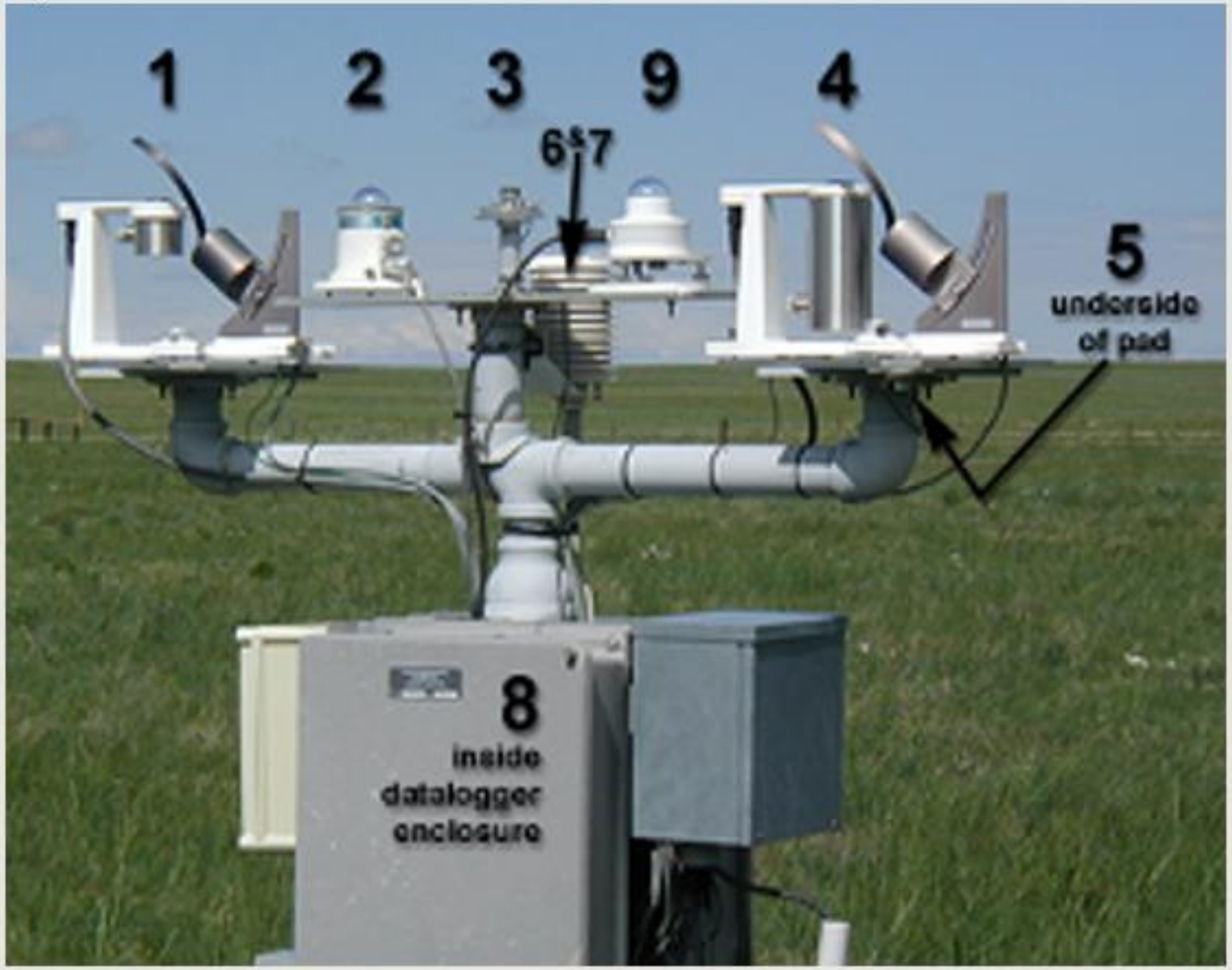


The network spans 27 states in the USA plus one Canadian province and the south island of New Zealand.

18 different eco-regions are represented by 40 network sites.

The network has been in operation since 1993.

Monitoring Network Instrumentation



Detailed Instrument Information

- Ultraviolet Multifilter Rotating Shadowband Radiometer
- Photosynthetically Active Radiation Sensor
- Broadband UVB-1 Pyranometer
- Visible Multifilter Rotating Shadowband Radiometer
- Air Temperature and Relative Humidity Sensor
- Barometric Pressure Sensor
- Downward Looking Photometer
- UV-A biometer

UVMRP Data Products

Spectral Irradiance Data Download

- In Situ calibrated
- MLO calibrated
- Historical Lamp calibrated

Weighted Irradiance Data Download

- Erythemal
- PAR

Derived Products Download

- UV Index
- Synthetic Spectra
- Instantaneous Optical Depths
- Average Optical Depths
- UV Irradiance Estimator

Climatology Products

- Daily Sums
- Hourly Sums
- US Merged Irradiance Statistics
- Sums US Contour Maps

Instrument Characteristics Download

- Filter Function Corrections
- Angular Cosine Corrections
- Langley Voltage Offsets
- Serial Number Deployment History
- Site Location Deployment History

Anciliary Measurements Download

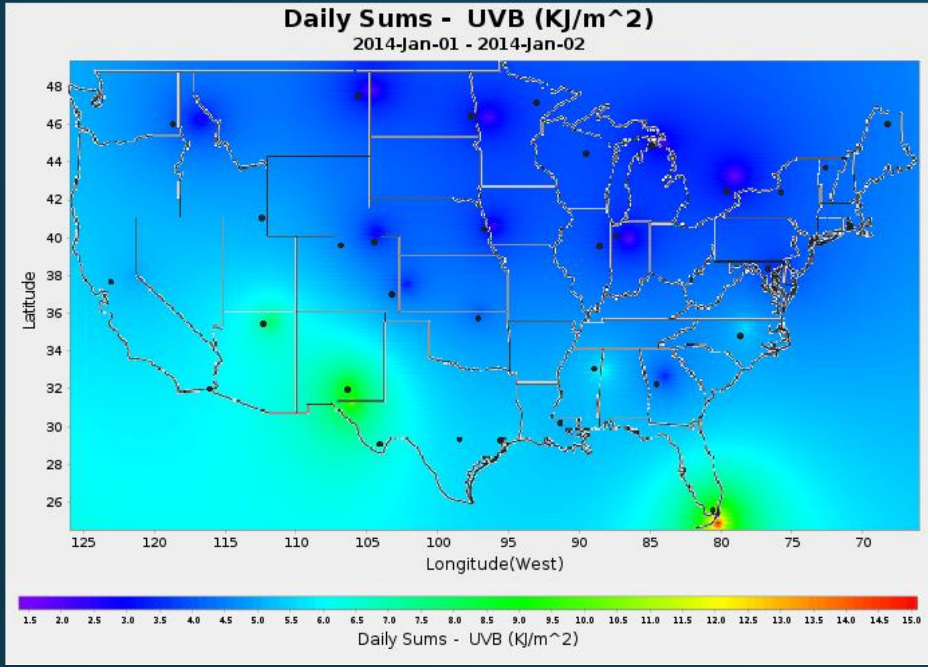
- Internal Head Temperature
- Air Temp, Humidity, Reflective Solar Irradiance
- Barometer
- Electronic Offset(Bias)
- Cosine Corrected Voltages
- UVA (uncalibrated)

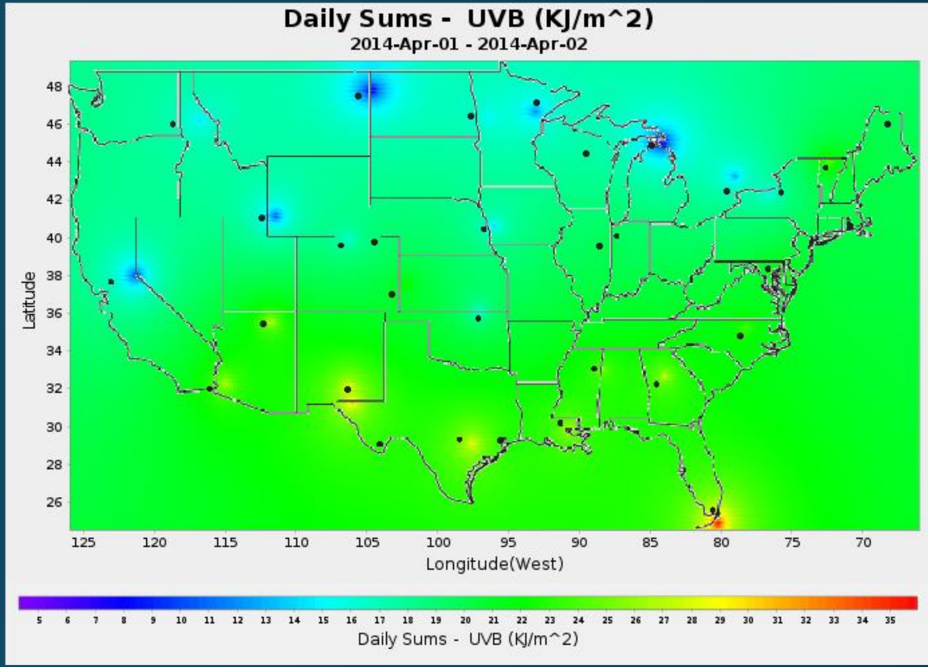
The Need for this Research

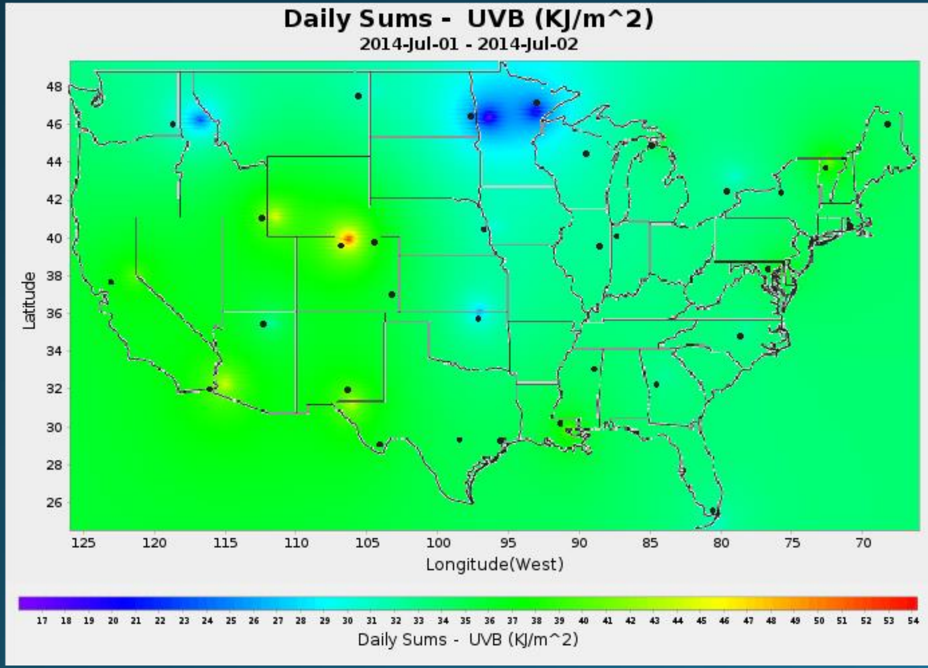
The UVMRP monitoring network is relatively sparse, and it is difficult to provide realistic interpolations for areas located between stations.

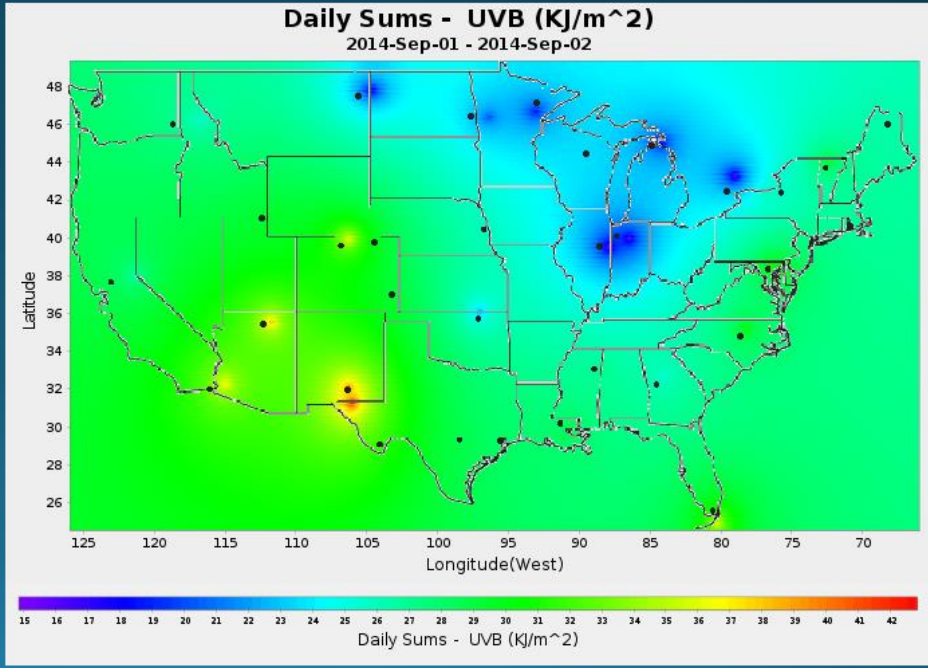
Simple interpolation techniques produce characteristic “bulls-eye” patterns across the USA.

Therefore there was a need to develop a more realistic approach to predicting geographic distributions of UV-B.


Daily Sums - UVB (KJ/m^2)
2014-Jan-01 - 2014-Jan-02
Latitude
48 46 44 42 40 38 36 34 32 30 28 26
125 120 115 110 105 100 95 90 85 80 75 70
Longitude(West)
1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0 10.5 11.0 11.5 12.0 12.5 13.0 13.5 14.0 14.5 15.0
Daily Sums - UVB (KJ/m^2)


Daily Sums - UVB (KJ/m^2)
2014-Apr-01 - 2014-Apr-02
Latitude
48 46 44 42 40 38 36 34 32 30 28 26
125 120 115 110 105 100 95 90 85 80 75 70
Longitude(West)
5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35
Daily Sums - UVB (KJ/m^2)


Daily Sums - UVB (KJ/m^2)
2014-Jul-01 - 2014-Jul-02
Latitude
48 46 44 42 40 38 36 34 32 30 28 26
125 120 115 110 105 100 95 90 85 80 75 70
Longitude(West)
17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54
Daily Sums - UVB (KJ/m^2)


Daily Sums - UVB (KJ/m^2)
2014-Sep-01 - 2014-Sep-02
Latitude
48 46 44 42 40 38 36 34 32 30 28 26
125 120 115 110 105 100 95 90 85 80 75 70
Longitude(West)
15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42
Daily Sums - UVB (KJ/m^2)

Approach

- Use satellite data to improve spatial interpolations based upon UVMRP data
- Download data from the NASA Mirador site
- Reformat, process, and structure the data with a series of custom computer programs
- Use GIS and image processing software to produce derived data products, and to carry out a variety of analyses and visualizations

The UVMRP Data Products

- Data from the monitoring instruments are acquired at 3-minute intervals. The UVMRP processes these into hourly sums of several radiation variables including UVB, UVA, erythemal (skin damage) spectral weighted dose, and Flint and Caldwell plant damage spectral weighted doses.
- A computer program was developed to produce data files of day-long sums (KJ/day), and mid-day, morning and afternoon dose rates (W/m^2) of each of these variables for 2006-2014. These data files are used as input to the spatial interpolation program.

The Satellite Data

- The Ozone Monitoring Instrument (OMI) is a nadir-viewing near-UV/Visible spectrometer on board NASA's Aura satellite, which is the atmospheric chemistry mission of the NASA EOS.
- Aura was launched in 2004.
- Aura flies in formation about 15 minutes behind Aqua, both orbiting the earth in a polar Sun-synchronous pattern providing global daily coverage. Scenes are taken at solar noon.
- The OMI was developed by scientists in the Netherlands and Finland.

The Satellite Data (continued)

- The OMI mission measures the status of the Earth's tropospheric ozone layer, as well as concentrations of aerosols and trace gases, all of which impact the amount of UV-B radiation at the Earth's surface.
- A variety of derived data products are produced including ozone, top of atmosphere and surface UV-B in four wave bands, UV-A, cloud cover, and erythemal dose.
- Data processed to different levels are available, from raw data to quality-filtered and spatially aggregated.

The Satellite Data (continued)

- Nadir ground pixel size of 13x12km, swath width of at least 725km
- Level 2 data are orbital swaths of 13x24 km^2 pixels
- Level 2G data are resampled to grids of 0.25 x 0.25 degree pixels
- Level 3 products use the best data to create 0.25 x 0.25, 0.5 x 0.5 and 1 x 1 degree grids.
- On this project we used the Level 3 1 x 1 degree gridded data of surface UV-B (OMUVBd).
- Data are can be downloaded from the NASA Mirador site at the Goddard Space Flight Center.

Data Processing Steps

- The data are hdf5 files, contained within NetCDF files.
- Use GDAL (Geospatial Data Abstraction Library) to translate from HDF5 to IDRISI .rst format.
  - This involved writing a program that produces DOS command line batch files then running the batch files.
- Import the .rst files into Terrset (formerly IDRISI)
- Create and run a Terrset macro (in Idrisi Macro Language) to resample the data to geographic coordinates (from simple row and column numbers), on a lat-long grid covering the USA.
- The data products are organized into folders and subfolders according to years, level of processing, and data types.
- Step-by-step instruction sheets (tutorials) were created.
- Graduate student interns (funded by ColoradoView) carried out the downloading and data processing and learned much about basics of acquiring and initial processing of remote sensing data.
- Each year resulted in over 18,000 files of 90MB produced (times 10 years). The final lat-long data set amounted to >5900 files, and 2920 raster grids per year (8 bands x 365 days).

Data Processing Steps (Continued)

- A computer program was developed that computes total UVB, Flint weighted, Caldwell weighted, and erythemal weighted UV-B from OMI data in four wavelengths (305, 310, 324, and 380 nm).
  - This program uses a reference solar spectrum (radiance by nm) to estimate spectrum-wide UVB from radiances at the four wavelengths.
- Another program was developed to temporally composite the daily data to weekly data.

The Interpolation and Data-Fusion Program

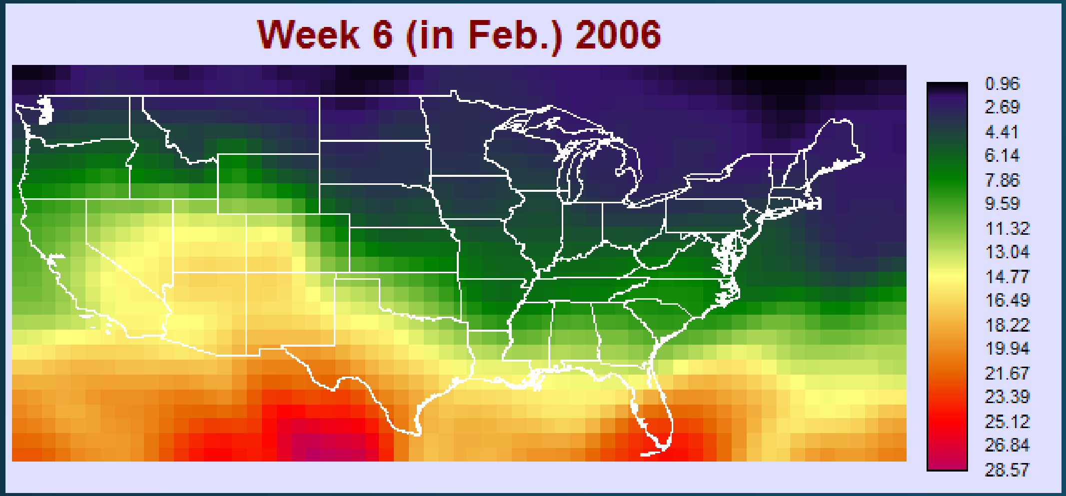
- Based on an algorithm that was originally developed compute precipitation maps as part of a spatially explicit ecosystem model in the late 1980's.
- The algorithm was implemented as a stand-alone program in the 1990's to create precipitation and snow depth maps for Yellowstone National Park. It is still used for that purpose.
- The key idea is that precipitation is often correlated with elevation and the algorithm adjusts for elevation differences between any point on the landscape and the weather stations.
- A regression equation is developed within the program, relating precipitation or snow water to elevation, based upon the station data for each grid-cell. The slope of the regression line, which is mm H2O per m elevation difference, is used to correct for elevation differences between any location and any observation station.
- Once the station data in a local region around a grid-cell are brought to the elevation of the grid-cell, they are used in spatial interpolation. Inverse distance weighting or Gaussian distance weighting can be used.

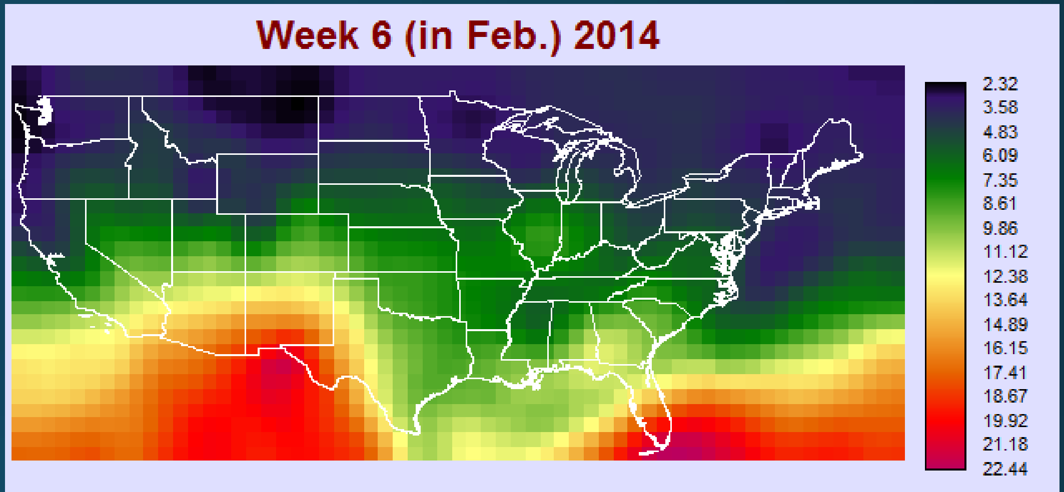
The Interpolation and Data-Fusion Program (continued)

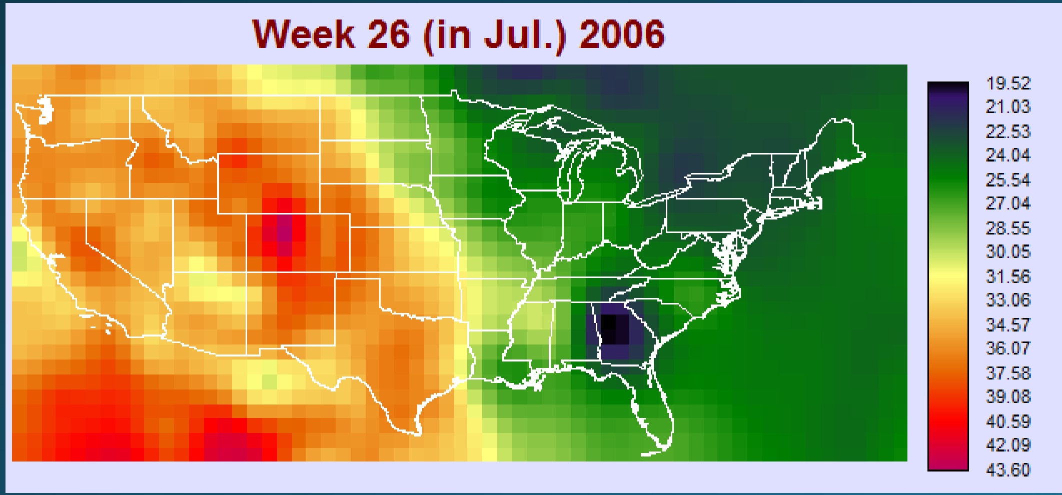
- The same idea is used to interpolate UV-B data. Instead of using elevation as a basis for correcting station data, it uses the OMI remote sensing grids.
  - Regressions of the station data against the OMI data are performed.
  - The weekly OMI grids are used as a basis for estimating weekly or daily UV-B maps from the daily or weekly UVMRP monitoring network data.
  - The resulting data set consists of time-series maps for total daily dose, morning, mid-day, and afternoon dose rates, and Flint, Caldwell, and Erythemal weighted daily doses.
- Importantly, if we use inverse distance weighting, the resulting map data will almost exactly agree with the station data in the pixels where the stations are located.

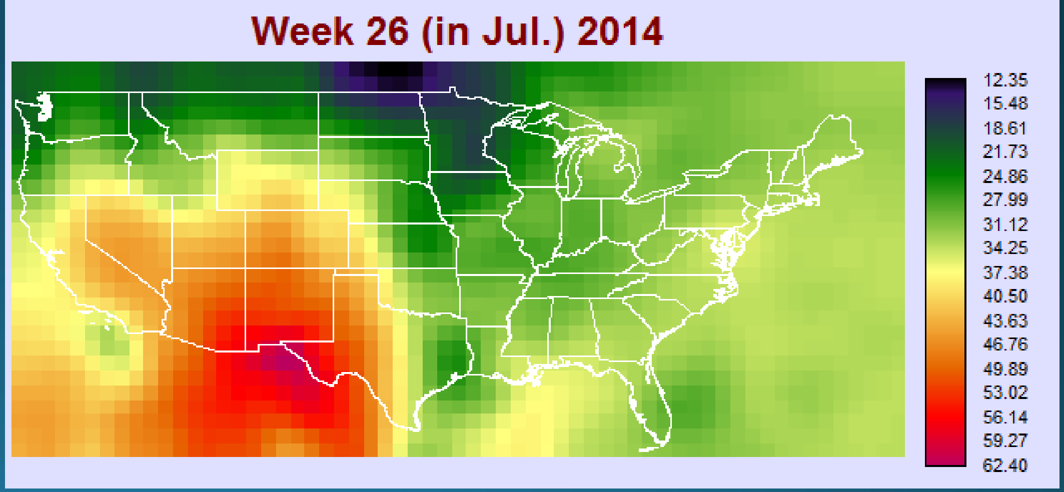
Example Outputs – Weekly UVB Maps

Units are KJ/m²/day



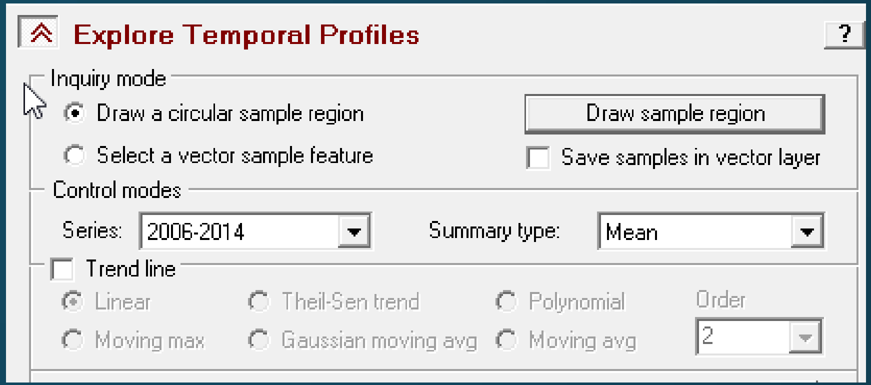


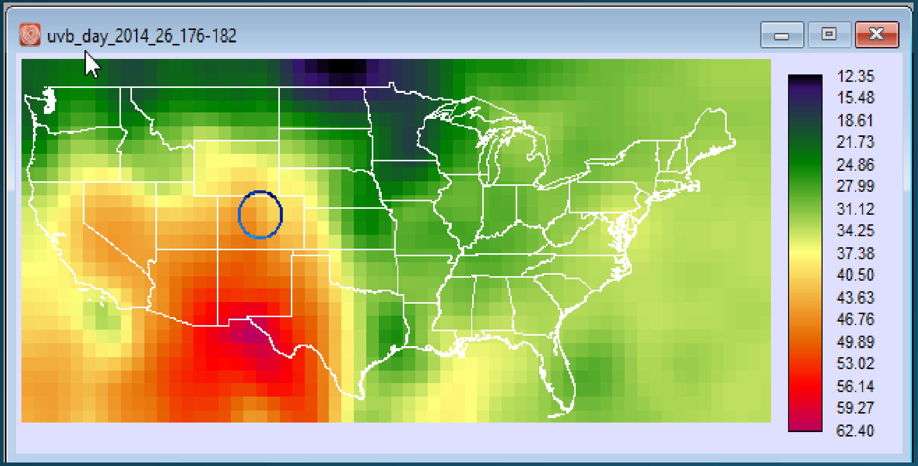


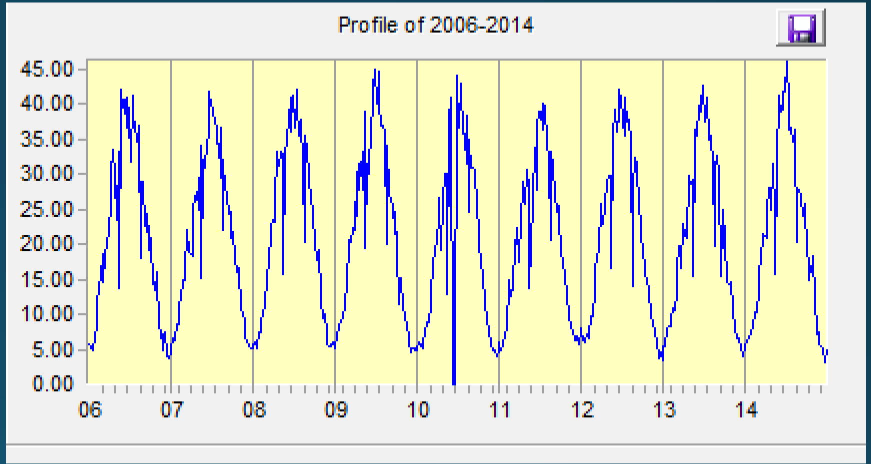


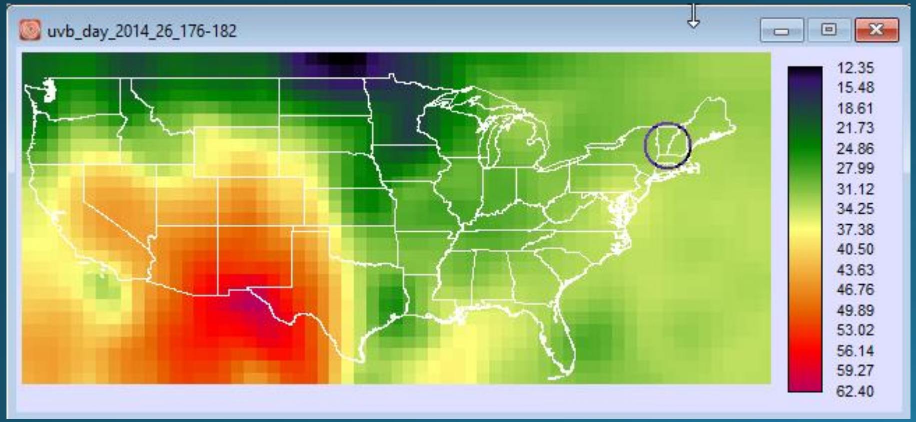
Temporal Profiles for Selected Areas

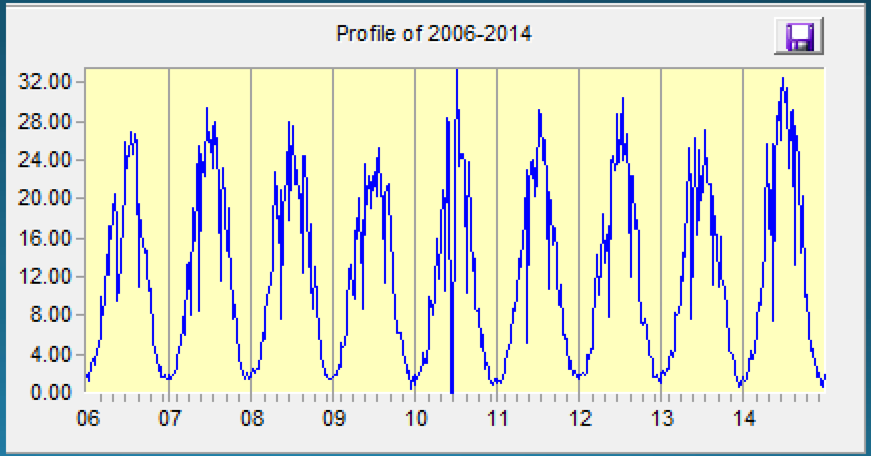
Example for Two Areas







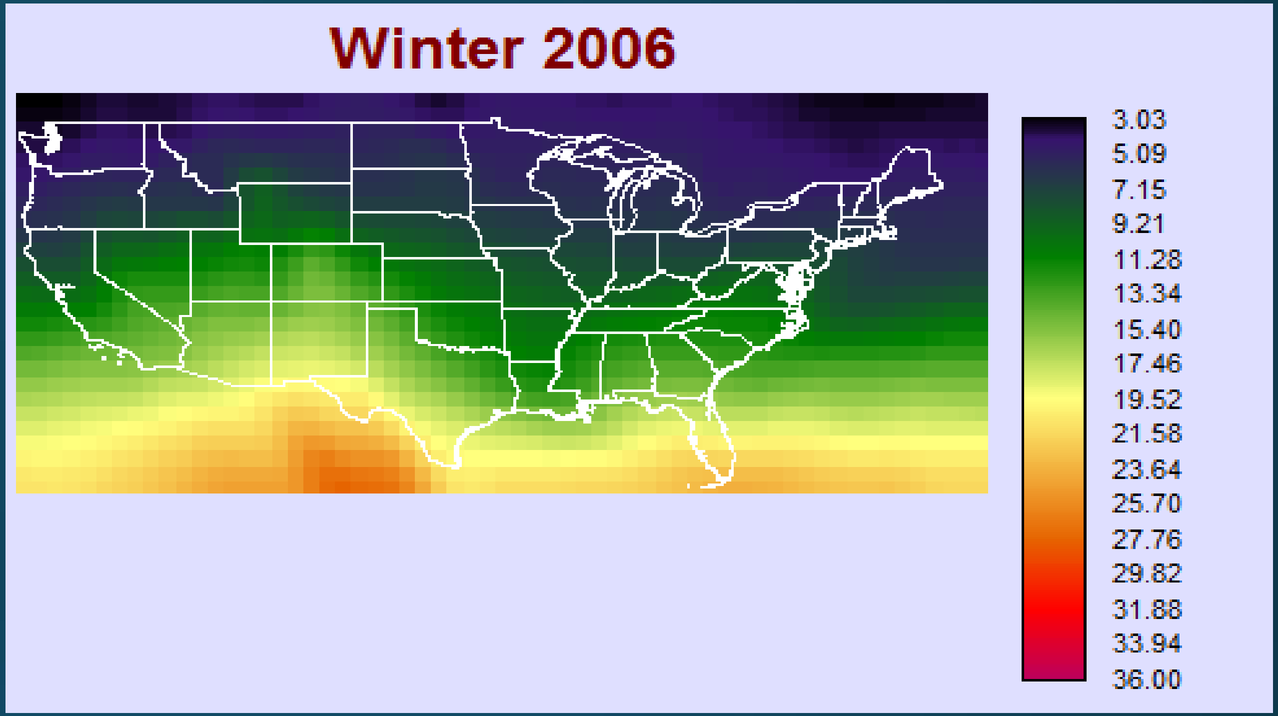


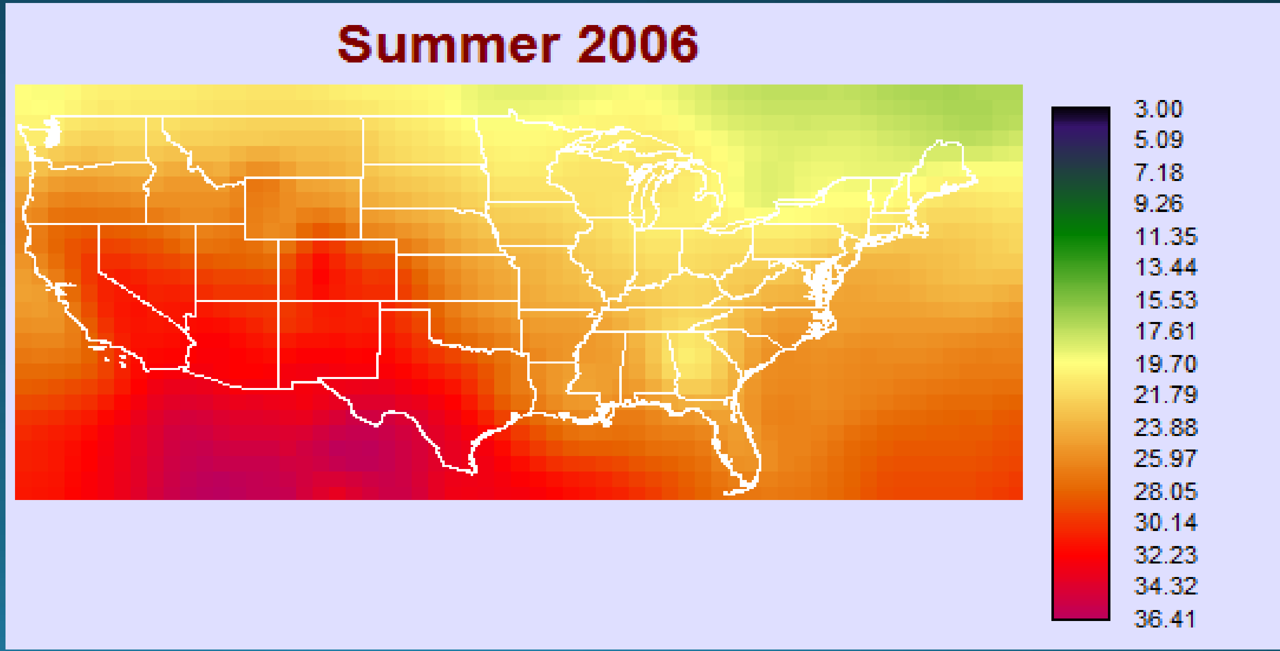


Season Maps

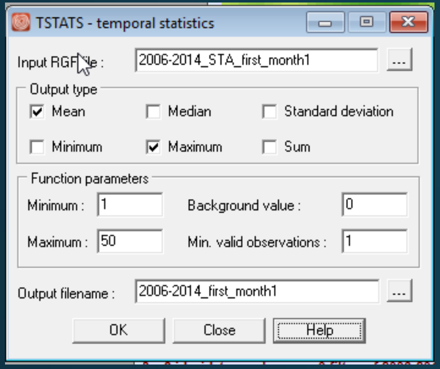
Created using an IML

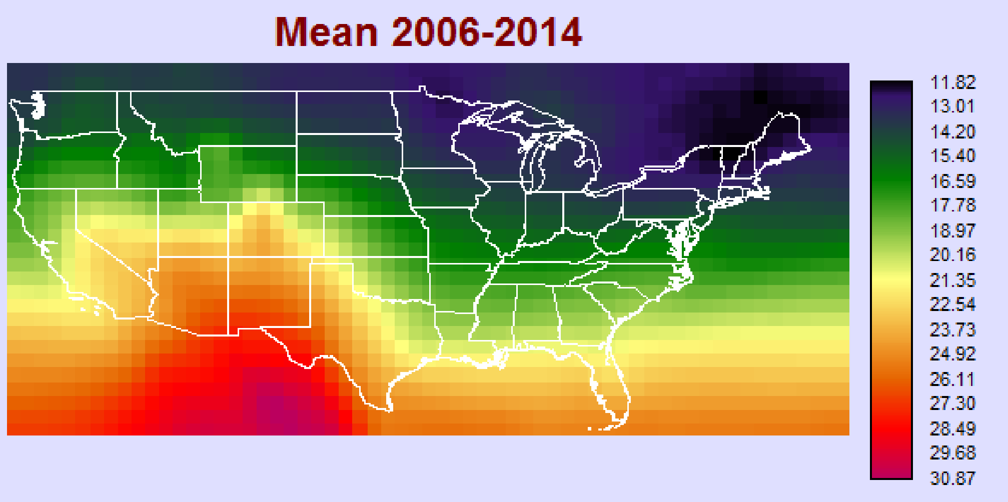
```
overlay x 1*uvb_day_2006_14_092-098*uvb_day_2006_15_099-105*temp1
overlay x 1*temp1*uvb_day_2006_16_106-112*temp2
overlay x 1*temp2*uvb_day_2006_17_113-119*temp1
overlay x 1*temp1*uvb_day_2006_18_120-126*temp2
overlay x 1*temp2*uvb_day_2006_19_127-133*temp1
overlay x 1*temp1*uvb_day_2006_20_134-140*temp2
overlay x 1*temp2*uvb_day_2006_21_141-147*temp1
overlay x 1*temp1*uvb_day_2006_22_148-154*temp2
overlay x 1*temp2*uvb_day_2006_23_155-161*temp1
overlay x 1*temp1*uvb_day_2006_24_162-168*temp2
overlay x 1*temp2*uvb_day_2006_25_169-175*temp1
overlay x 1*temp1*uvb_day_2006_26_176-182*temp2
scalar x temp2*uvb_day_2006_sprn*4*13
```

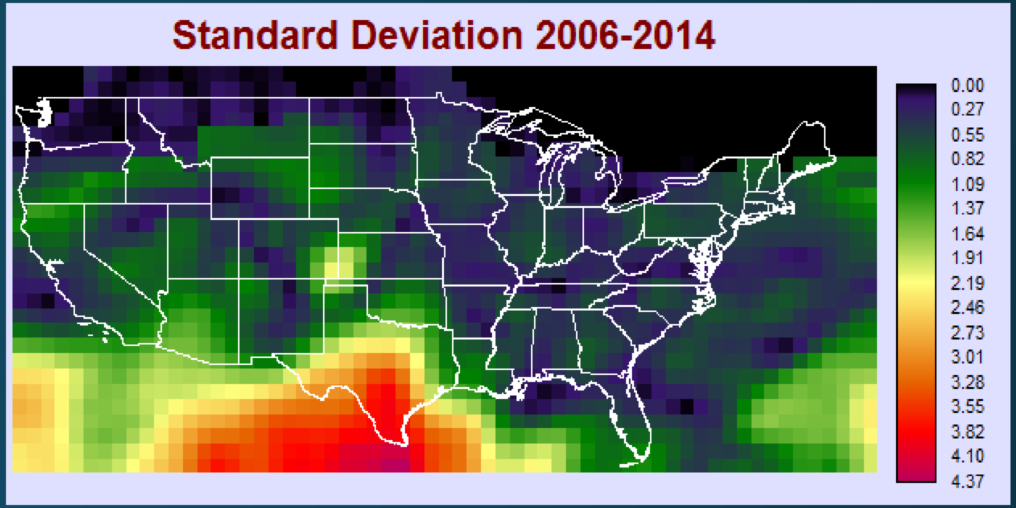


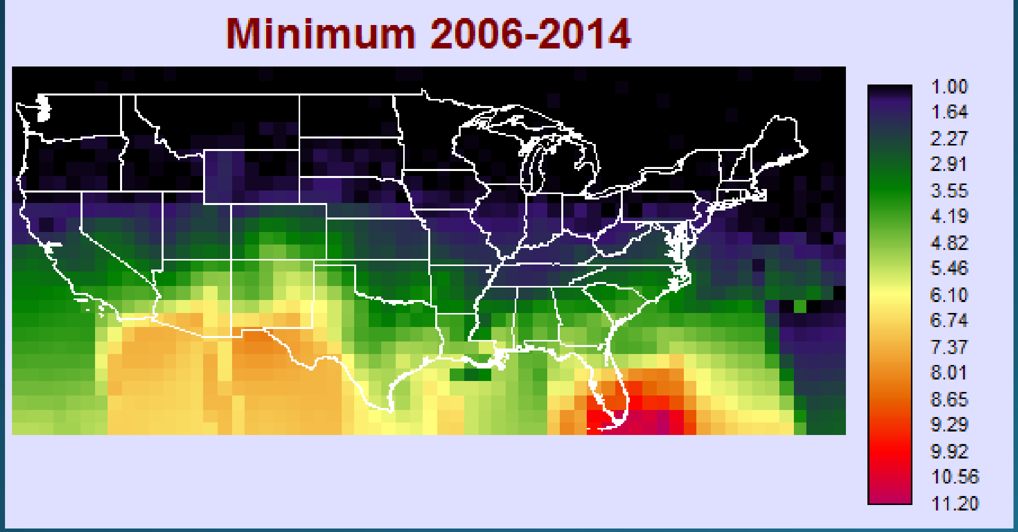


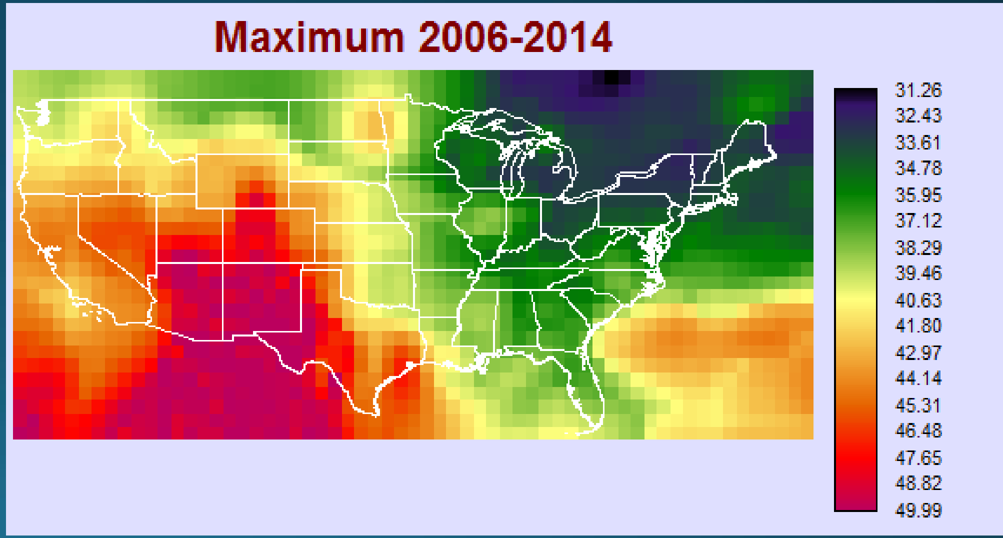
Temporal Statistics



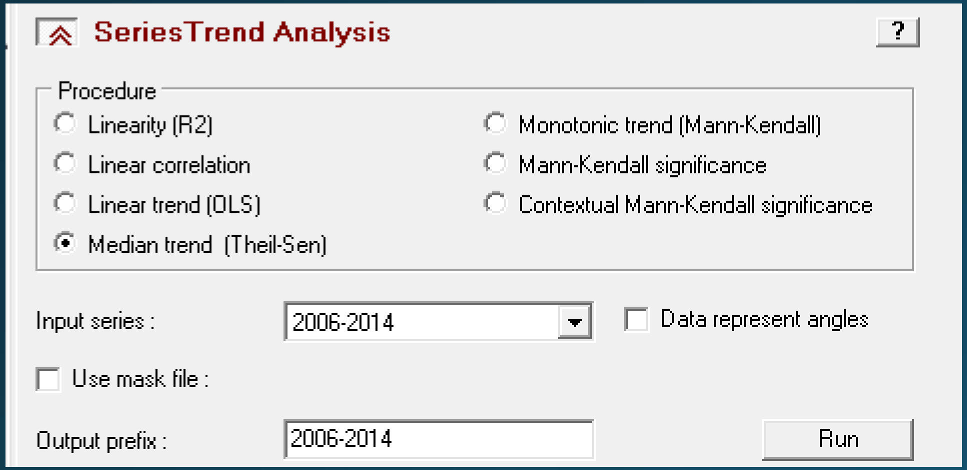




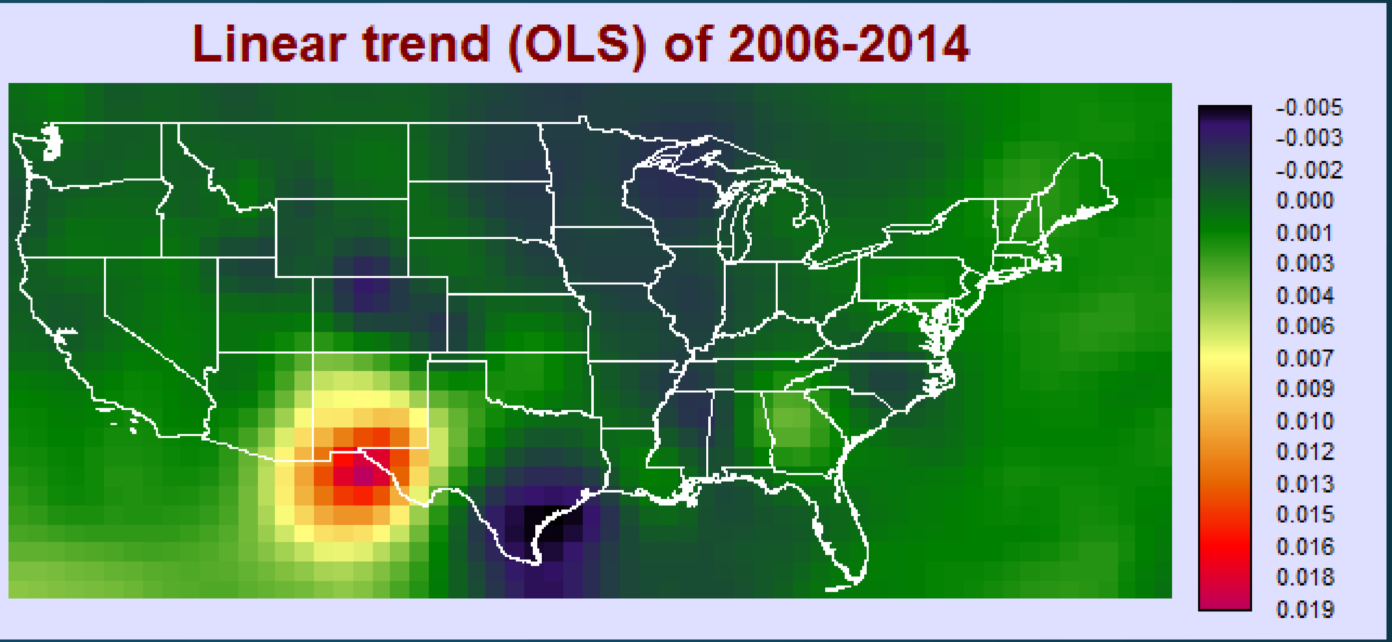




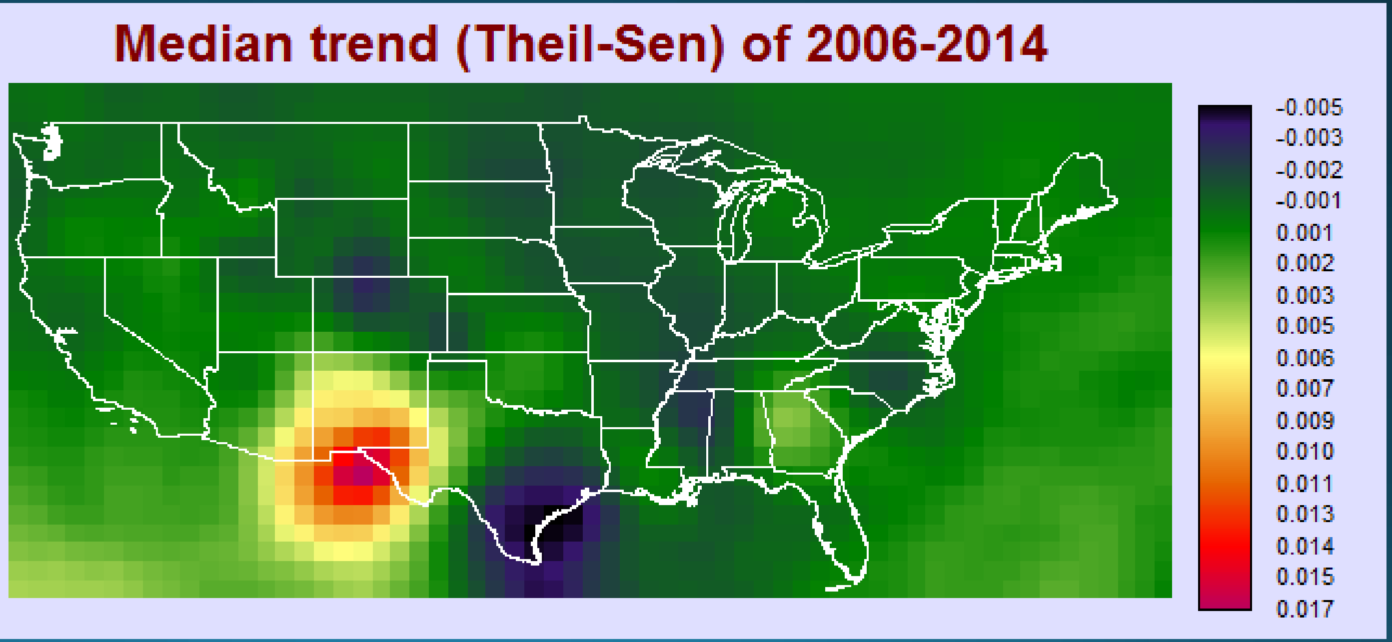
Trend Maps



SeriesTrend Analysis
?
Procedure
Linearity (R2)
Linear correlation
Linear trend (OLS)
Median trend (Theil-Sen)
Monotonic trend (Mann-Kendall)
Mann-Kendall significance
Contextual Mann-Kendall significance
Input series :
2006-2014
Data represent angles
Use mask file :
Output prefix :
2006-2014
Run



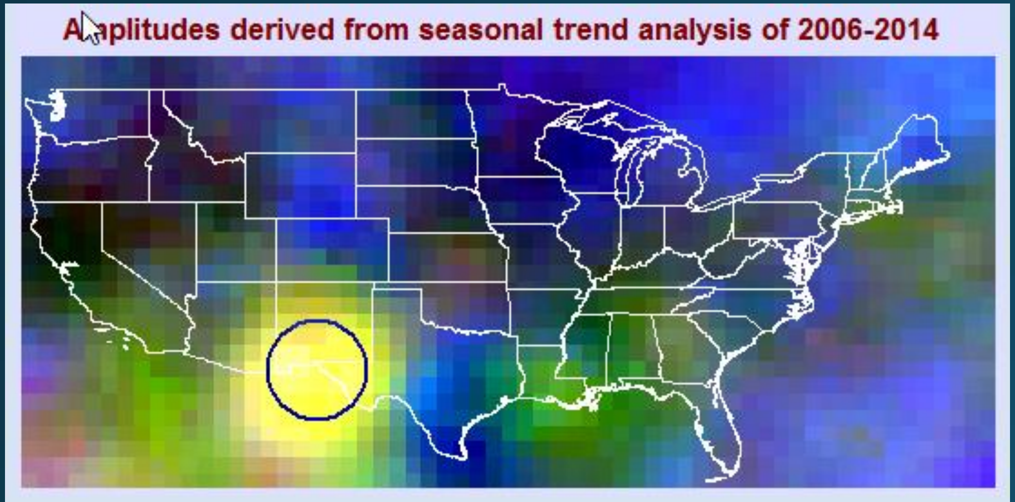
Linear trend (OLS) of 2006-2014
-0.005
-0.003
-0.002
0.000
0.001
0.003
0.004
0.006
0.007
0.009
0.010
0.012
0.013
0.015
0.016
0.018
0.019

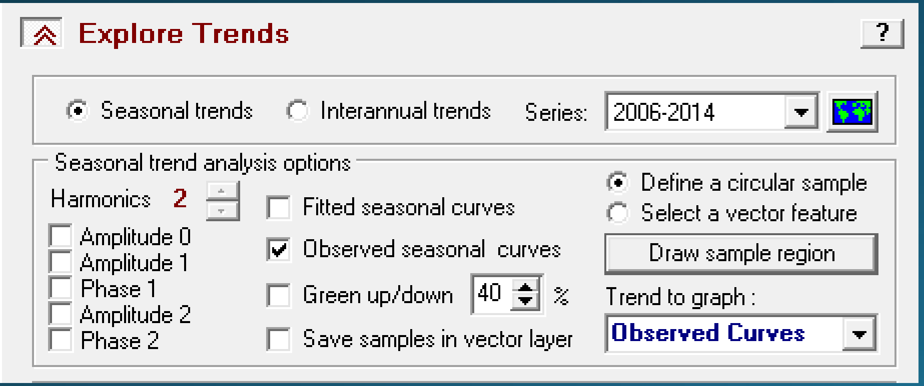


Median trend (Theil-Sen) of 2006-2014
-0.005
-0.003
-0.002
-0.001
0.001
0.002
0.003
0.005
0.006
0.007
0.009
0.010
0.011
0.013
0.014
0.015
0.017

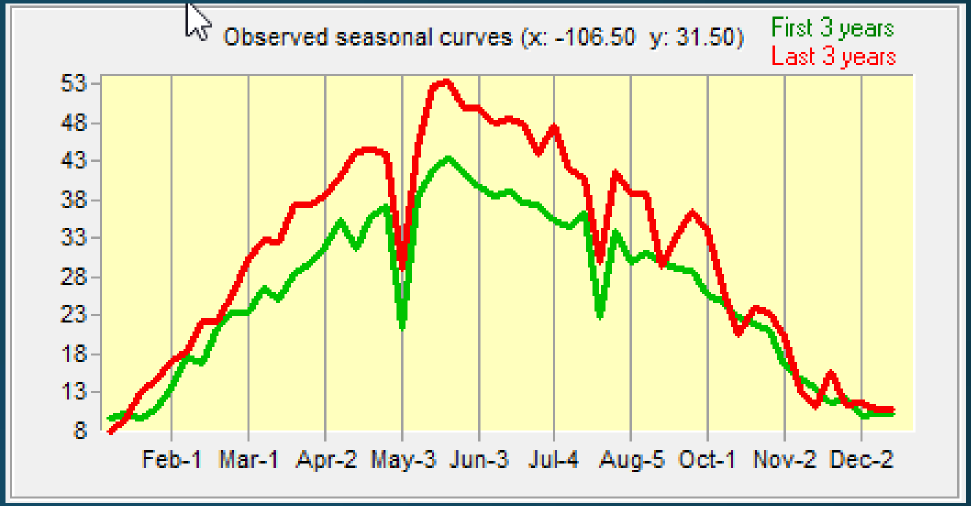
Seasonal Trend Analysis

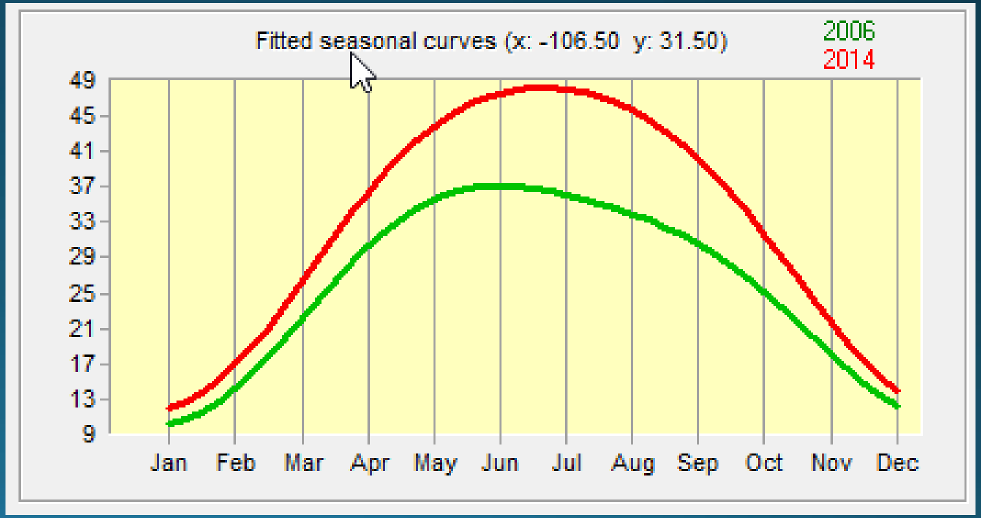
RGB image of 3 amplitudes in a harmonic regression – with a selected region





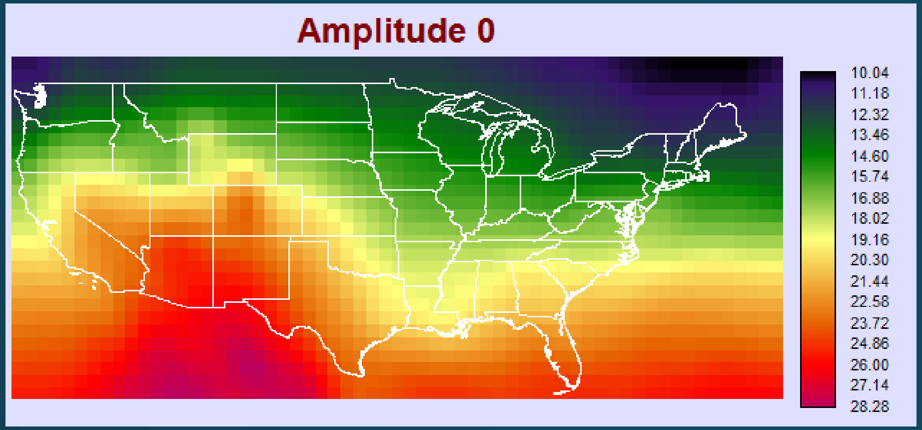
Observed and Fitted Seasonal Curves For Selected Region
First 3 Years (green), Last 3 Years (red)

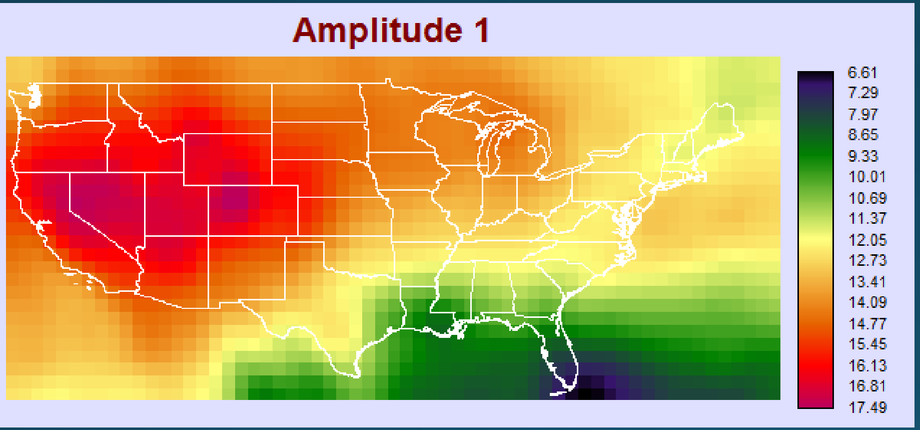


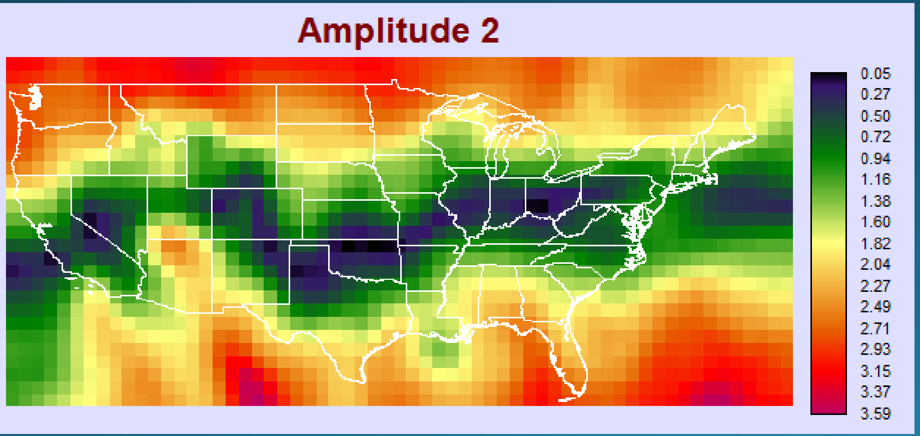


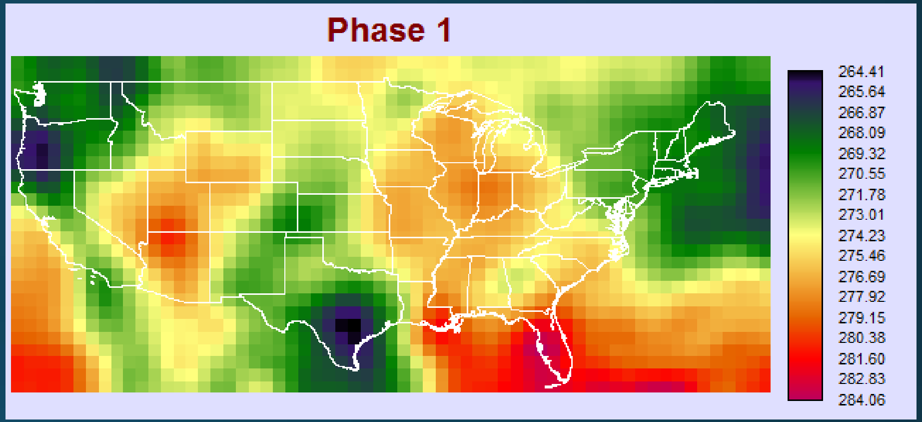
Seasonal Trend Analysis

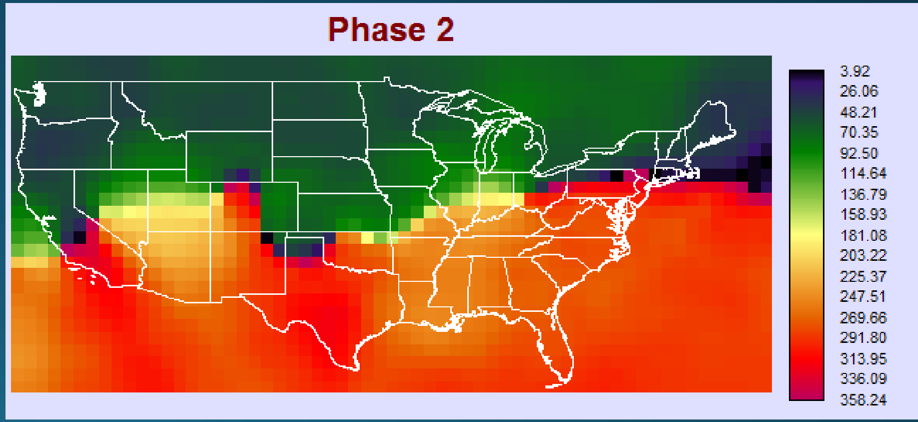
2014
Harmonic Regression
Three Amplitudes and Two Phases





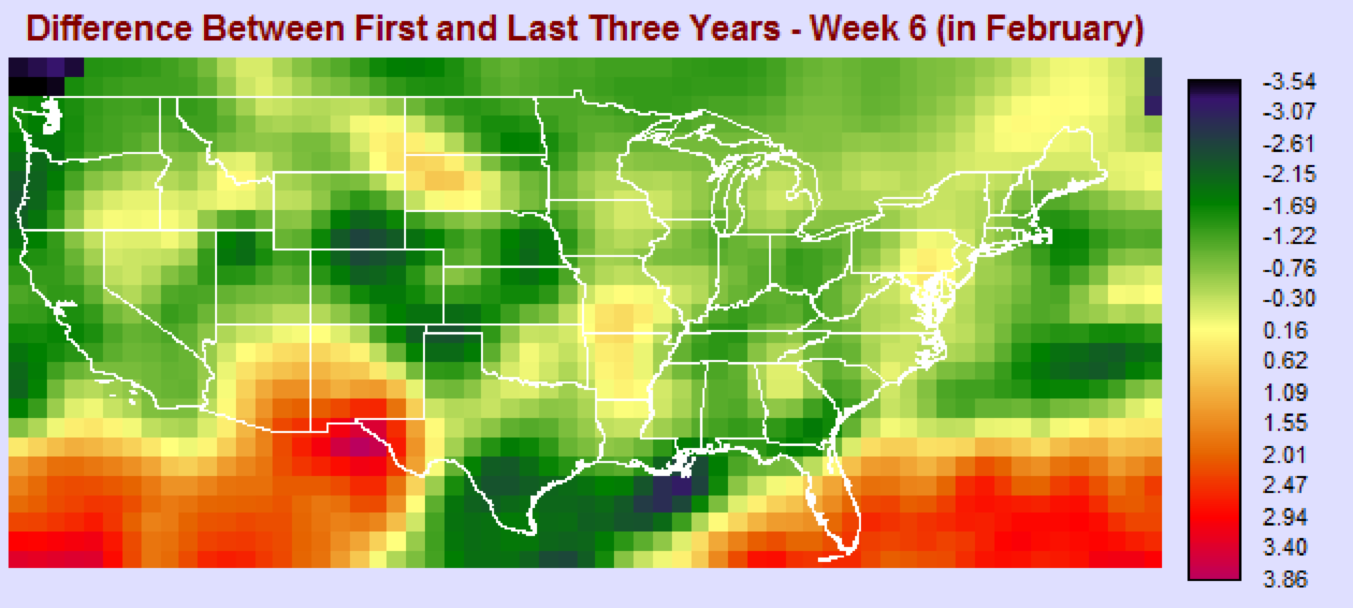


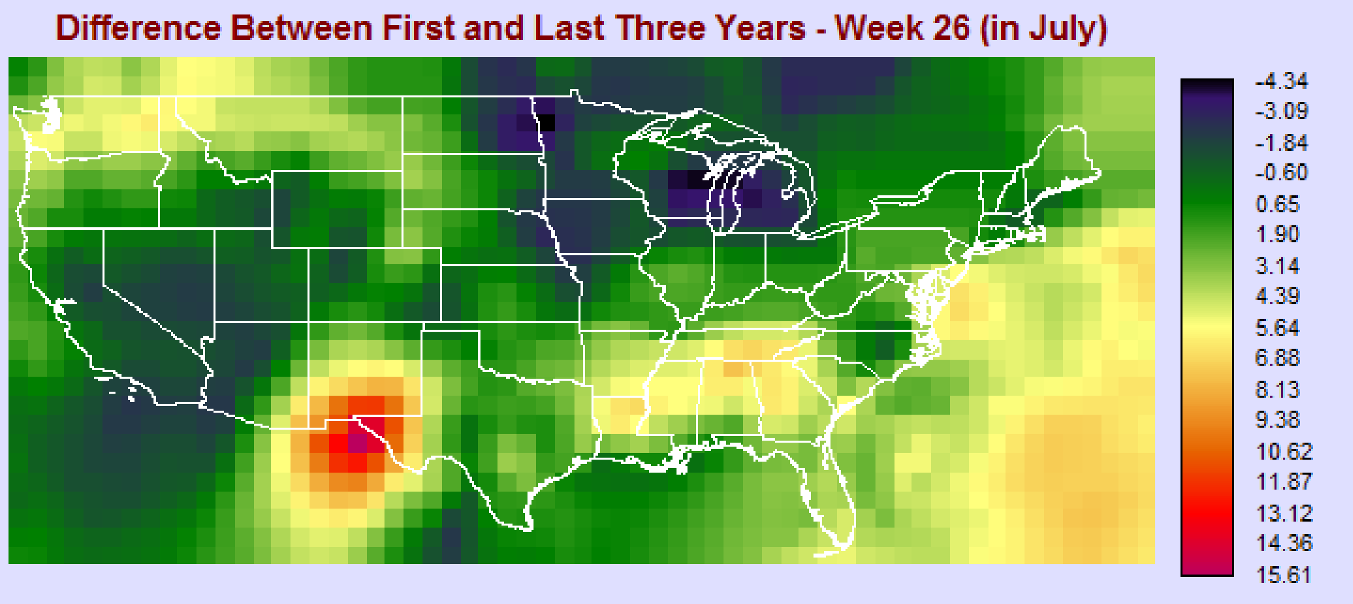




Seasonal Trend Analysis

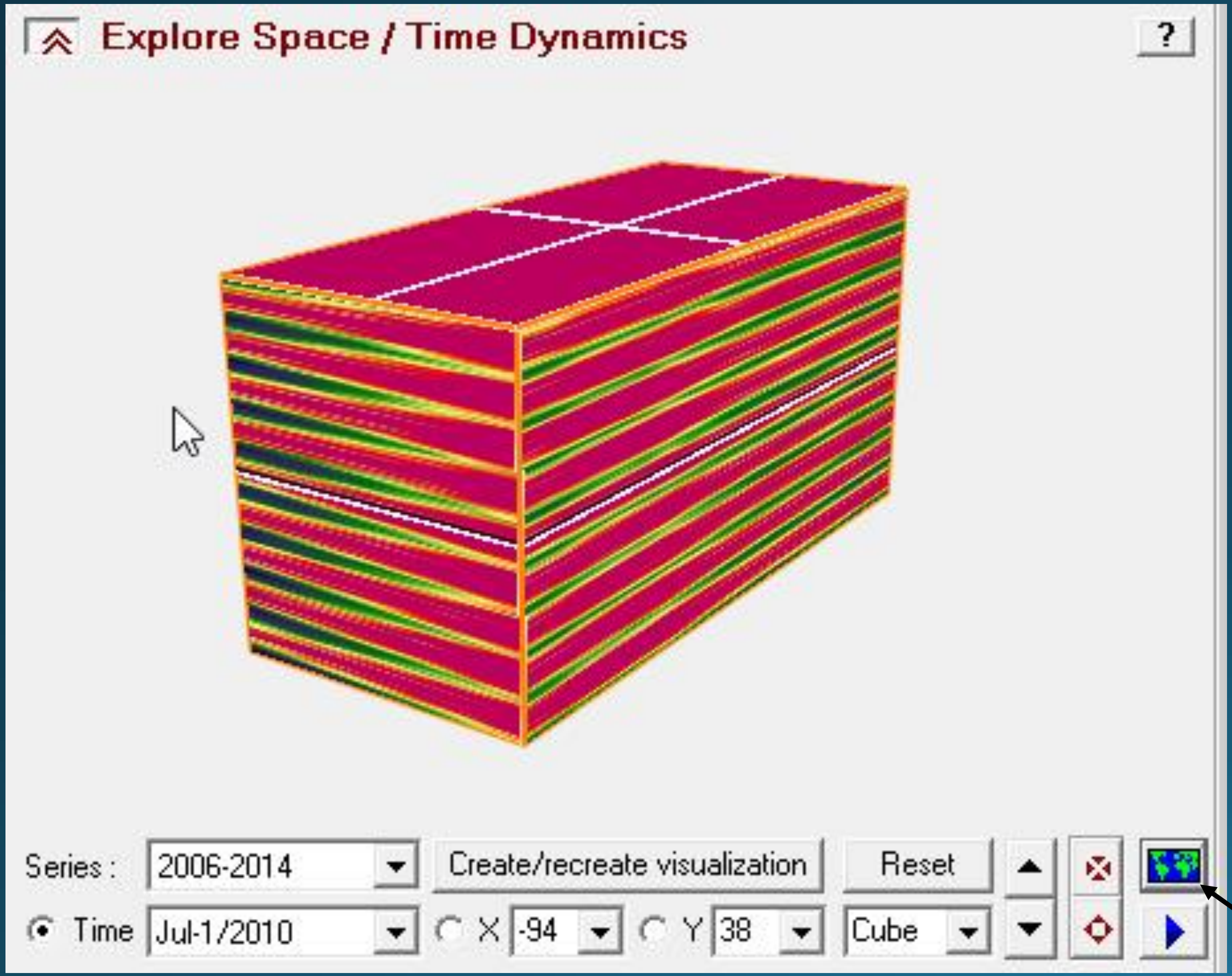
2014



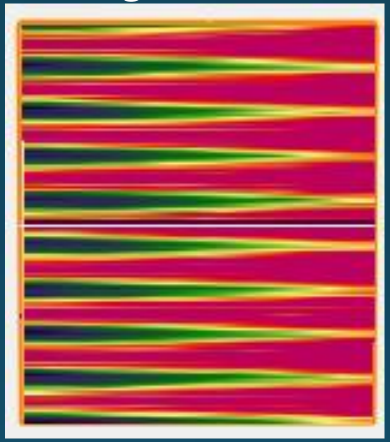


Visualization Cube for Exploring Space/Time Dynamics

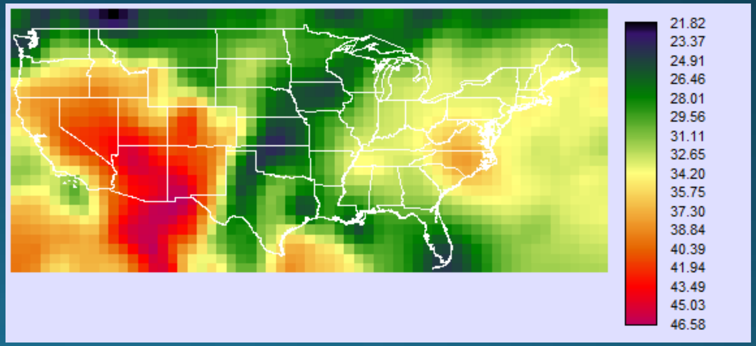
X Axis Longitude / Y Axis Latitude / Z Axis – Time



X-Lat / Y-Time
Color – UVB
Level (at a single
longitude)



X-Long / Y-Time
Color-UVB Level
(at a single latitude)



Display Map for
a Chosen Date

Future

- Hi resolution maps for Colorado
  - Account for elevation, slope, aspect
- Use of higher resolution cloud cover data, e.g. from MODIS
- Make data set available on the web
- Develop tools to carry out temporal profiling and climatological statistics at specified locations via the UVMRP web site.
- Bring dataset up to date and develop a data flow procedure for rapid production based on most recent OMI data.