Python Programming for Data Processing and Climate Analysis

Jules Kouatchou and Hamid Oloso

Jules.Kouatchou@nasa.gov and Amidu.o.Oloso@nasa.gov

Goddard Space Flight Center
Software System Support Office
Code 610.3

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Training Objectives

We want to introduce:

- **Basic concepts of Python programming**
- **Array manipulations**
- **Handling of files**
- **2D visualization**
- EOFs

Special Topics

Based on the feedback we have received so far, we plan to have a hand-on presentation on the following topic(s):

F2Py:

- Python interface to Fortran
- Date: April 29, 2013 at 1:30pm

iPython Notebook:

- A web-based interactive computational environment
- Tentative Date: TBD

Obtaining the Material

Slides for this session of the training are available from:

https://modelingguru.nasa.gov/docs/DOC-2322

You can obtain materials presented here on *discover* at

/discover/nobackup/jkouatch/pythonTrainingGSFC.tar.gz

After you untar the above file, you will obtain the directory *pythonTrainingGSFC/* that contains:

```
Examples/
Slides/
```

Settings on *discover*

To use the Python distribution:

```
module load other/comp/gcc-4.5-sp1
module load lib/mkl-10.1.2.024
module load other/SIVO-PyD/spd_1.9.0_gcc-4.5-sp1
```

To use uvcdat:

```
module load other/uvcdat-1.2-gcc-4.7.1
```

What Will be Covered Today

1. Basic Introduction to EOF
2. Data Source & EOFs with NCL
3. Two Approaches for Doing EOFs
    - CDAT
    - Numpy

Useful Links on EOFs

- **EOF Analysis by Cygnus Research International**, http://www.cygres.com/OcnPageE/Glosry/OcnEof1E.html
- **Time Series Tutorial Notes** by Jin-Yi Yu, http://www.ess.uci.edu/~yu/class/ess210b/lecture.5.EOF.all.pdf

What is EOFs Analysis?

- Empirical Orthogonal Function (EOF) analysis attempts to find a relatively small number of independent variables (predictors; factors) which convey as much of the original information as possible without redundancy.
- EOF analysis can be used to explore the structure of the variability within a data set in a objective way, and to analyze relationships within a set of variables.
- EOF analysis is also called principal component analysis or factor analysis.

What Does EFO Analysis Do?

Uses a set of orthogonal functions (EOFs) to represent a time series in the following way

$$Z(x, y, t) = \sum_{k=1}^{N} P_k(t) \times E_k(x, y)$$

- $Z(x, y, t)$ is the original time series as a function of time (t) and space (x, y).
- $E_k(x, y)$ show the the spatial structures (x, y) of the major factors that can account for the temporal variations of Z.
- $P_k(t)$ is the principal component that tells you how the amplitude of each EOF varies with time.

What Does EOF Analysis Provides?

1. A set of EOF **loading patterns** (eigenvectors)
2. A set of corresponding **amplitudes** (temporal scores)
3. A set of corresponding **variances accounted for** (eigenvalues)

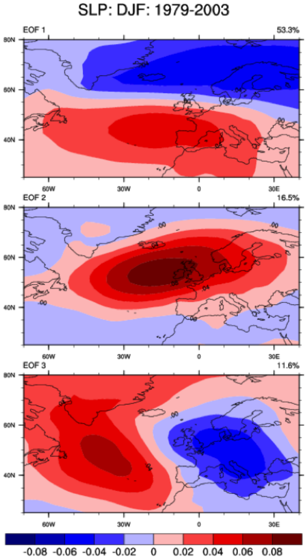
Data

- We use Sea Level Pressure from NCEP/NCAR Reanalysis 1
- Monthly means from 1948 to present
- 2.5×2.5 grid resolution
- Global data

Verification

- We can use NCAR Command Language (NCL) to perform EOF calcilations.
- Show good demonstration of typical steps (data sub-setting, seasonal time averaging, plotting of EOFs, etc)
- For plots: `http://www.ncl.ucar.edu/Applications/eof.shtml`
- For source code: `http://www.ncl.ucar.edu/Applications/Scripts/eof_1.ncl`

NCL: Seasonal SLP Plot



What is eof2?

- Python package for performing EOF analysis on spatial-temporal data sets
- Suitable for large data sets
- Transparent handling of missing values
- Work both within a CDAT environment or as a stand-alone package
- Provides two interfaces (supporting the same sets of operations) for EOF analysis:
  1. **Numpy** arrays
  2. **cdms2** variables (which preserves metadata)
- For more information: http://ajdawson.github.com/eof2/

eof2 Solver

- Uses SVD
- Expects as input a spatial-temporal field represented a an array (Numpy array or cdms2 variable) of two or more dimensions.
- Internally, any missing values in the array are identified and removed.
- The EOF solution is computed when an instance of **eof2.Eof** (for cdms2) or **eof2.EofSolver** (for Numpy) is initialized.

Main eof2 Functions

Here are some functions associated with the solver:

```
eofs:                Array with the ordered EOFs along
                     the first dimension
eofsAsCorrelation: EOFs scaled as the correlation of
                     the PCs with the original field.
eofsAsCovariance:  EOFs scaled as the covariance of
                     the PCs with the original field.
eigenvalues:         Eigenvalues (decreasing variances)
                     associated with each EOF
pcs:                 Principal component time series (PCs).
                     Array where the columns are the ordered PCs
```

How to Use eof2?

```
from eof2 import Eof
#from eof2 import EofSolver
...
# Initialize and Eof object.
# Square-root of cosine of latitude weights are used.
solver = Eof(myData, weights='coslat')

#coslat = np.cos (np. deg2rad ( lats ))
#wgts = np. sqrt ( coslat )[... , np. newaxis ]
#solver = EofSolver (myData , weights = wgts )

# Retrieve the first two EOFs.
eofs = solver.eofs(neofs=2)

# Retrieve the eigenvalues
eigenVals = solver.eigenvalues()
```

What is CDAT?

- CDAT: Climate Data Analysis Tools
- Software "glued" under the Python framework
- CDAT packages use:
  - cdms2 - Climate Data Management System (file I/O, variables, types, metadata, grids)
  - cdutil - Climate Data Specific Utilities (spatial and temporal averages, custom seasons, climatologies)
  - vcs - Visualization and Control System (manages graphical window: picture template, graphical methods, data)

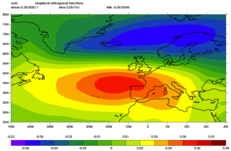
CDAT: Reading Data and Calculations

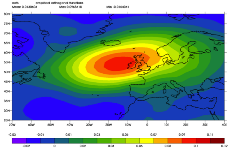
```
f = cdms2.open('slp.mon.mean.nc  )
slp = f('slp', time=('1979','2003'), \
            latitude=(85,20), longitude=(-70,40))
f.close()

# Put time point at the beginning instead of middle of m
cdutil.setTimeBoundsMonthly(slp)

# Extract Dec-Jan-Feb seasons
djfslp = cdutil.DJF(slp)

coslat = np.cos(np.deg2rad(slp.getLatitude()[:]))
wgts = np.sqrt(coslat)[..., np.newaxis]

slpsolver = Eof(djfslp, weights=wgts)
eofs = slpsolver.eofs(neofs=3)
eigenvalueVec = slpsolver.eigenvalues()
```

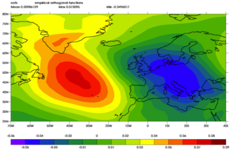
CDAT: Looking at the Results

```
print eigenvalueVec()
print 100*eigenvalueVec()[0:3]/fsum(eigenvalueVec())

# Initialise a VCS canvas for plotting
p = vcs.init()

t=p.createtemplate('new')
t.scale(0.5)

# Plot the first EOF
p.plot(eofs[0],'default','isofill')
```

CDAT: Seasonal SLP Plot







How Do We Do EOF?

We use:

- netCDF4: to read the dataset
- Numpy: to manipulate arrays
- eof2: for EOF calculations
- Matplotlib/Basemap: for plotting

Numpy: Reading the Data

```
ncin = Dataset('slp.mon.mean.nc', 'r')

lons = ncin.variables['lon']
lats = ncin.variables['lat']
time = ncin.variables['time']

slp = ncin.variables['slp']
```

Numpy: Temporal Subsetting

```
# get the "unit" of variable time
timeUnit = time.getncattr('units')

# extract the numbers in time coordinate of the
# time range of interest (January  1979 to January 2003)
dateNum1 = date2num(datetime(1979,1,1,0,0),
                    units=timeUnit)
dateNum2 = date2num(datetime(2003,1,1,0,0),
                    units=timeUnit)

# obtain the time coordinate indices of time range of in
dateIndex1 = np.where(time[:] == dateNum1)[0][0]
dateIndex2 = np.where(time[:] == dateNum2)[0][0]

# generate a date index array for time coordinate
# indices in time range of ineterest
dateIndex = np.arange(dateIndex1,dateIndex2+1)
```

Numpy: Spatial Subsetting

```
# Realign SLP so that longitude goes from -180 to 180
slpShift = np.zeros((slp.shape[0],slp.shape[1],
                     slp.shape[2]),dtype=np.float32)
for i in range(slp.shape[0]):
    slpShift[i,:,:],lonShift =
          shiftgrid(180.,slp[i,:,:],lon[:],start=False)

# Subsetting and Resersing latitudes
latIndex = np. nonzero (( lat [::-1]>= 25 ) & \
                        (lat [::-1]<= 80 ))[0]
# Subsetting longitudes
lonIndex = np. nonzero (( lonShift >= -70 ) & \
                        (lonShift <=40 ))[0]

# extract the desired data subset for analysis
slpSubset=slpShift[:,::-1,:][dateIndex[0]:dateIndex[-1]+
                    latIndex[0]:latIndex[-1]+1,lonIndex]
```

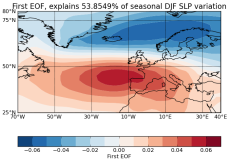
Numpy: Seasonal Climatology

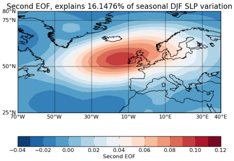
```
# Compute Dec-Jan-Feb seasonal climatology
slpDJF = np.zeros((25,latIndex.shape[0],
                  lonIndex.shape[0]),dtype=np.float32)
slpDJF[0,:,:] = (slpSubset[0,:,:]*31.+
          slpSubset[1,:,:]*28.)/(31.+28.)  # first seaso
for i in range(1,24):
   if np.mod(i,4) == 1:      # leap year
      slpDJF[i,:,:] = ((slpSubset[12.*i-1.,:,:] + \
      slpSubset[12.*i,:,:])*31. + \
      slpSubset[12.*i+1.,:,:]*29.) / (31.+31.+29.)
   else:                     # non leap year
      slpDJF[i,:,:] = ((slpSubset[12.*i-1.,:,:] +
          slpSubset[12.*i,:,:])*31. +
          slpSubset[12.*i+1.,:,:]*28.) / (31.+31.+28.)

slpDJF[24,:,:] = (slpSubset[-2,:,:]+
                    slpSubset[-1,:,:])*31./62.
```

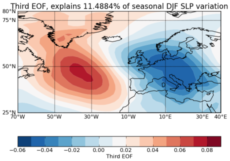
Numpy: EOF Solver

```
#---------------------------------------------
# Create an EOF solver to do the EOF analysis.
# Square-root of cosine of latitude weights are
# applied before the computation of EOFs.
#---------------------------------------------
coslat = np.cos(np.deg2rad(lat[::-1][latIndex]))
wgts = np.sqrt(coslat)[..., np.newaxis]
solver = EofSolver(slpDJF, weights=wgts)

# extract eignevalues
eigenValues = solver.eigenvalues()

# compute % contribution of each EOF
percentContrib = eigenValues*100./np.sum(eigenValues)

# compute the first three leading EOFs (EOFs 0, 1 and 2)
eofs = solver.eofs(neofs=3)
```

Numpy: Seasonal SLP Plot







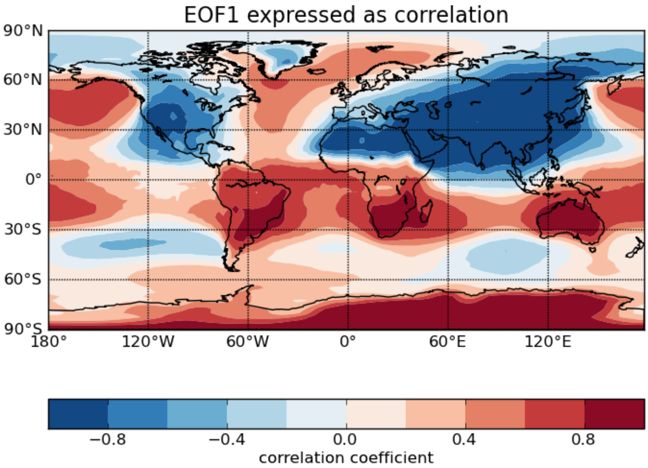
Numpy: Reading the Data Global Data

```
ncin = Dataset('slp.mon.mean.nc', 'r')

lons = ncin.variables['lon'][:]
lats = ncin.variables['lat'][:]
time = ncin.variables['time'][:]

slp = ncin.variables['slp'][:]

ncin.close()
```

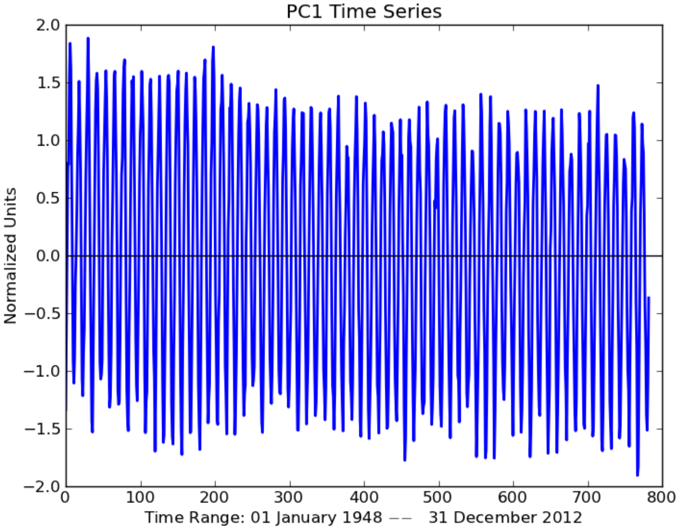
Numpy: EOF Solver

```
#-----------------------------------------------------
# Create an EOF solver to do the EOF analysis.
# Square-root of cosine of latitude weights are
# applied before the computation of EOFs.
#-----------------------------------------------------
coslat = np.cos(np.deg2rad(lats))
wgts = np.sqrt(coslat)[..., np.newaxis]
solver = EofSolver(slp, weights=wgts)

#-----------------------------------------------------------
# Retrieve the leading EOF, expressed as the
# correlation between the leading PC time series and
# the input SLP at each grid point, and the leading
# PC time series itself.
#-----------------------------------------------------------
eof1 = solver.eofsAsCorrelation(neofs=1)
pc1 = solver.pcs(npcs=1, pcscaling=1)
```

Numpy: SLP EOF1 Expressed as Correlation



Numpy: SLP PC1 Time Series



References I

- Johnny Wei-Bing Lin, *A Hands-On Introduction to Using Python in the Atmospheric and Oceanic Sciences*, `http://www.johnny-lin.com/pyintro`, 2012.
- Hans Petter Langtangen, *A Primer on Scientific Programming with Python*, Springer, 2009.
- Drew McCormack, *Scientific Scripting with Python*, 2009.
- Sandro Tosi, *Matplotlib for Python Developers*, 2009.
- A. Hannachi, I. T. Jolliffe and D. B. Stephenson, Empirical orthogonal functions and related techniques in atmospheric science: A review, *Int. J. Climatol.* **27**: 1119–1152 (2007).