EMPIRICAL ORTHOGONAL FUNCTION (EOF) ANALYSIS

& THERMOSPHERIC NITRIC OXIDE FLUX

SIERRA FLYNN[1], DELORES KNIPP[1], TOMOKO MATSUO[1], MARTIN MLYNCZAK[2], LINDA HUNT[3]

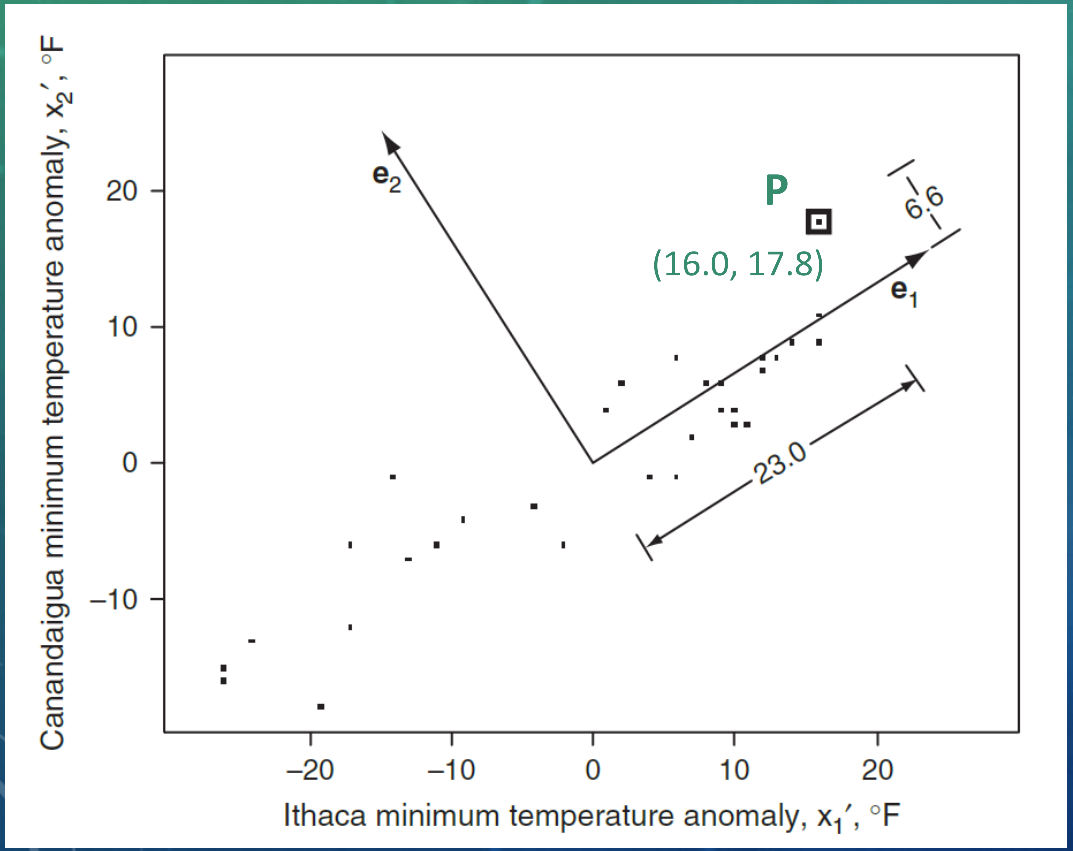
[1]CU BOULDER AEROSPACE ENGINEERING SCIENCES (AES), [2]NASA LANGLEY RESEARCH CENTER, [3]SCIENCE SYSTEMS AND APPLICATIONS, INC.

CURRENT CHALLENGES & GOALS
IN GEOSPACE SYSTEMS SCIENCE

Understanding data	**Presenting** data	**Preparing** data
• Large data sets • Multivariate • Highly correlated • Various sources • Sparse in space and time	• Physical insight • Straightforward • Raising awareness • Aesthetically pleasing • Inspiring interests	• Compressing data • Removing noise • Encouraging collaboration • Learning through data mining • Applying predictive modeling

PROPOSED METHOD
EMPIRICAL ORTHOGONAL FUNCTION (EOF) ANALYSIS

- Based on eigenvector-eigenvalue decomposition, e.g.:



(Wilks, 2006)

- Remove the mean of this 2-D data set of minimum temperatures.
- Then, it can be represented as an orthonormal pair of **eigenvectors:**
  - $\mathbf{e}_1$ points in the direction of the most variation (96.8%!)
  - **Eigenvalues** represent the % variance explained by their eigenvector
- Point P can then be defined as a linear combination of these orthonormal eigenvectors:

$$P = 23.0\mathbf{e}_1 + 6.6\mathbf{e}_2 \approx 23.0\mathbf{e}_1$$

PROPOSED METHOD
EMPIRICAL ORTHOGONAL FUNCTION (EOF) ANALYSIS

- EOF Analysis: based on eigenvector-eigenvalue decomposition, but multivariate and time-dependent
- Reduce data set into its mean and its variability using an empirical, non-linear regression-based technique
- Describe the variability empirically using *n* orthogonal **eigenmodes** (spatial, time-invariant maps, or **EOFs**) and their **eigenvalues** (variability in time, or **EOF coefficient**):

$$\boldsymbol{y}'(\theta, \varphi, t) \approx \boldsymbol{\Psi\alpha} = \sum_{i=1}^{n} \alpha_i(t)\Psi_i(\theta, \varphi)$$

Residual after mean subtracted

Time-varying amplitude of EOF_i

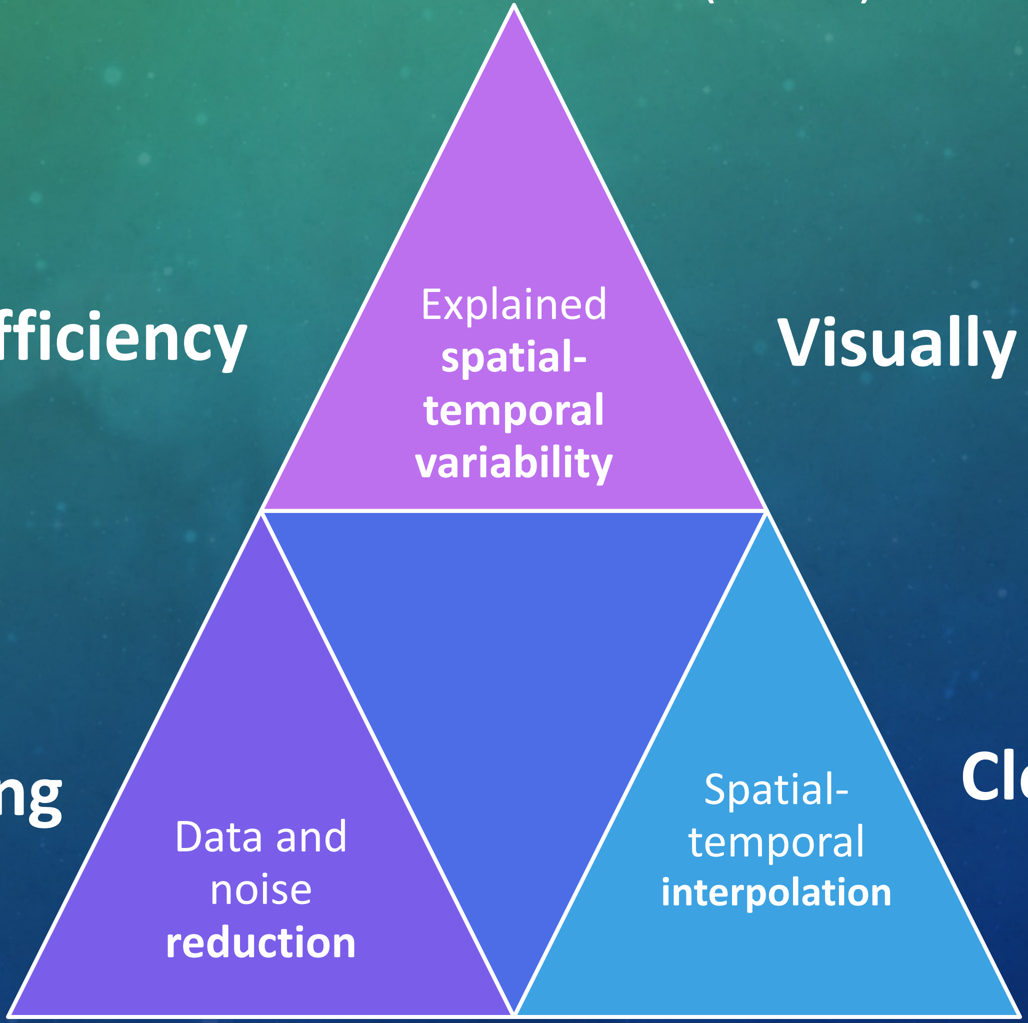
EOF_i in spatial coordinates

(Matsuo & Forbes, 2010)

ACCOMPLISHMENTS
EMPIRICAL ORTHOGONAL FUNCTION (EOF) ANALYSIS

Computational efficiency

Visually understandable



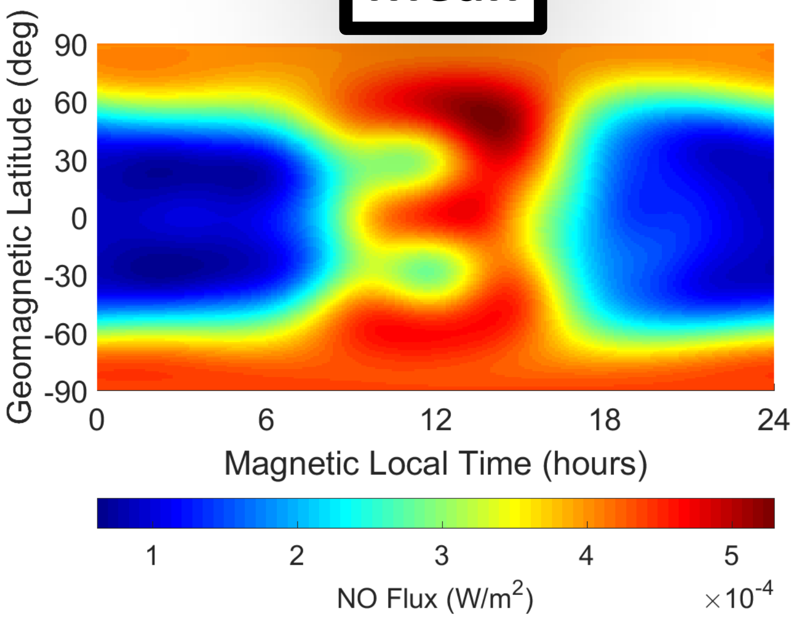
Predictive modeling

Clean & simple model

APPLICATIONS: EOFS
THERMOSPHERIC NITRIC OXIDE FLUX

$$\boldsymbol{y}'(\theta,\varphi,t) \approx \sum_{i=1}^{n} \alpha_i(t)\Psi_i(\theta,\varphi)$$

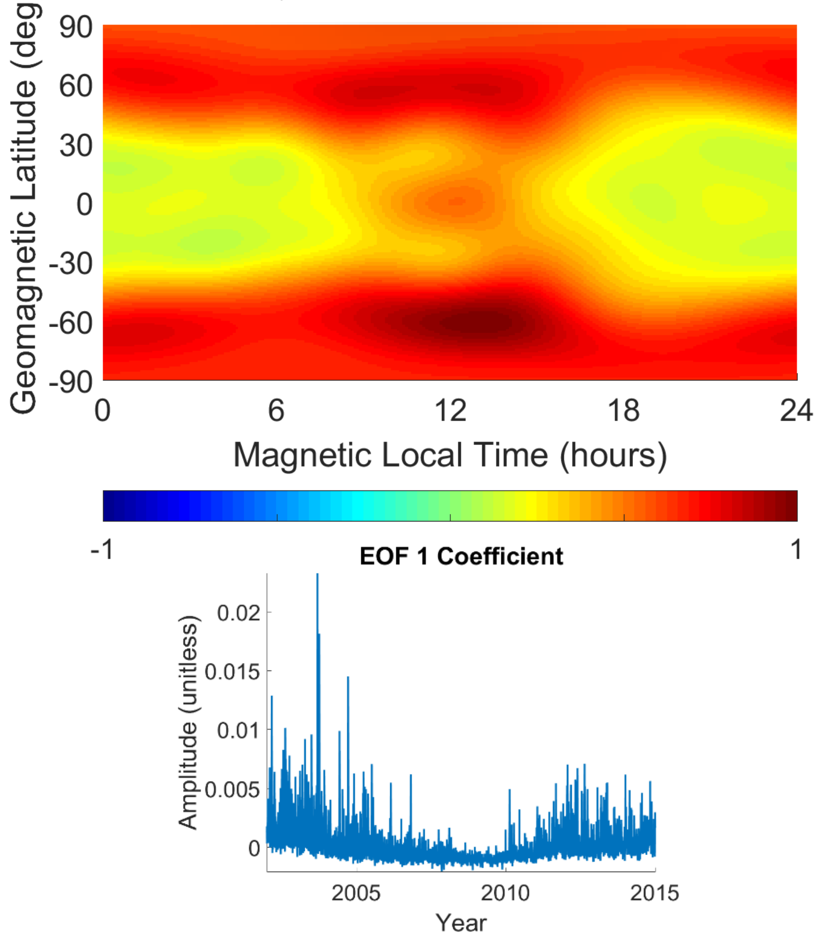
Mean



(Does not vary in time)

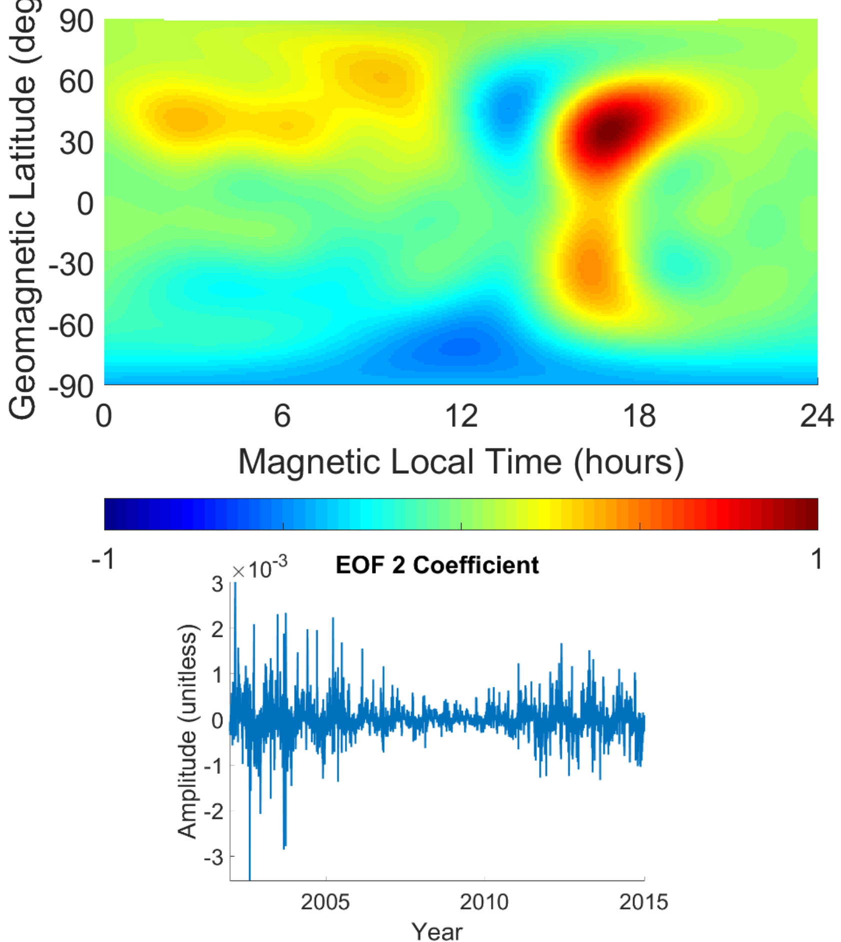
EOF 1

69.1% of the total variance



EOF 2

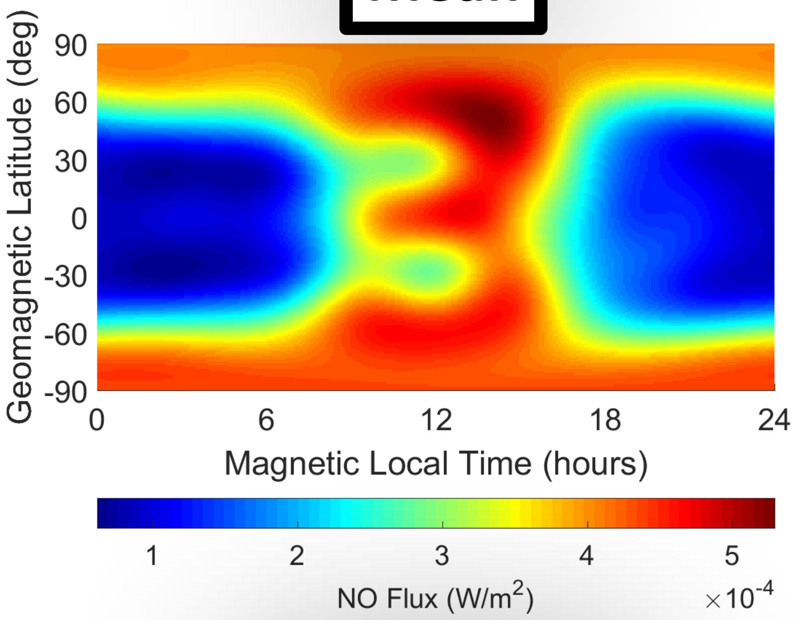
7.1% of the total variance



APPLICATIONS: CORRELATION ANALYSIS
THERMOSPHERIC NITRIC OXIDE FLUX

$$y'(\theta,\varphi,t) \approx \sum_{i=1}^{n} \alpha_i(t)\Psi_i(\theta,\varphi)$$

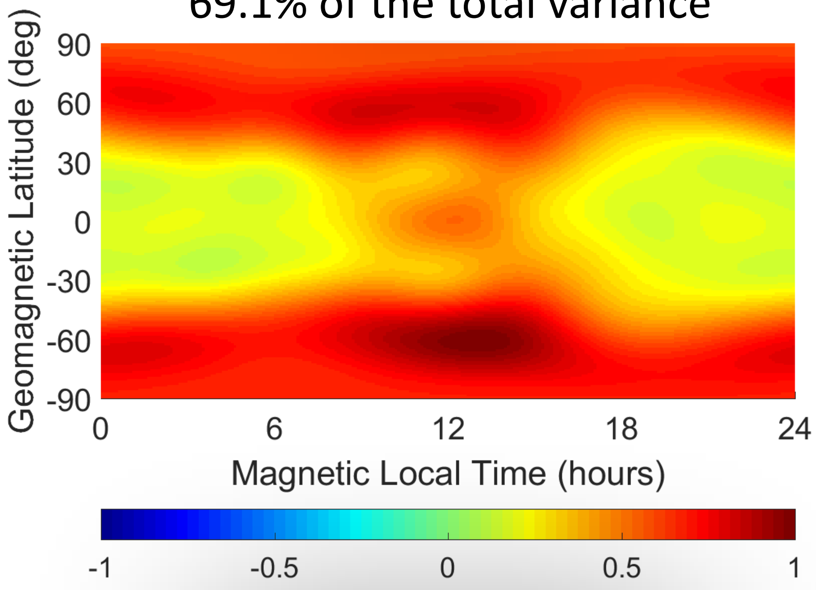
Mean



Diurnal & Auroral Drivers

EOF 1

69.1% of the total variance

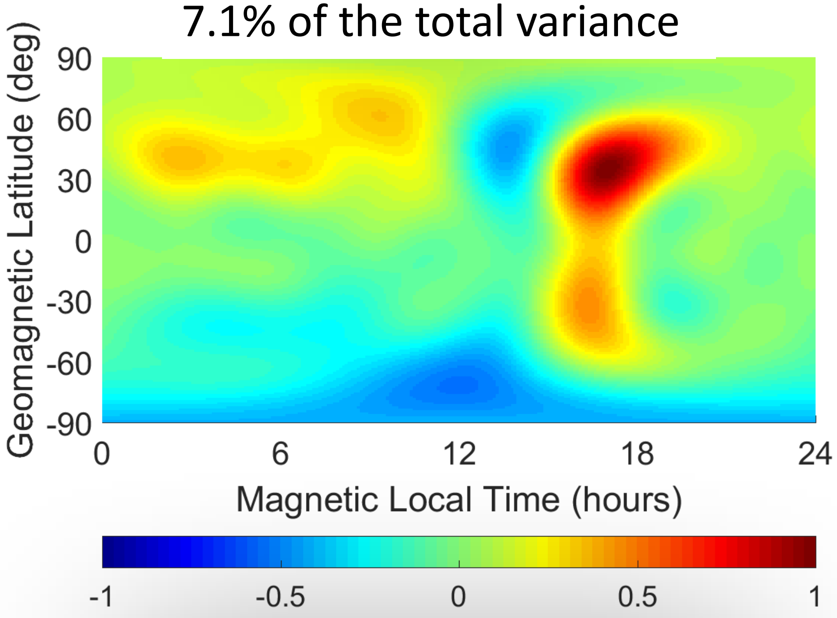


Geomagnetic & Solar Storms

Kp (R = 0.68, 10 hour lag)
F10.7 (R = 0.63, 3 day lag)

EOF 2

7.1% of the total variance



Annual & Seasonal Cycles

annual (R = 0.45, peaks @ aphelion)
seasonal (R = 0.17, peaks @ equinox)

CONCLUDING REMARKS
EMPIRICAL ORTHOGONAL FUNCTION (EOF) ANALYSIS

Reconstruct a **global NOF map** that represents **85% of the original covariance** and condenses 13 years of data into a data set that is **6% of its original size**!

↓

Correlation analysis can help determine the **primary geophysical drivers** for each EOF

↓

Further regression modeling can lead to **predictive models**

For more information, see my poster (DATA-01) tomorrow!

REFERENCES

Matsuo, T. & Forbes, J. (2010). Principal modes of thermospheric density variability: Empirical orthogonal function analysis of CHAMP 2001–2008 data. *Journal of Geophysical Research, 115(*A07309). doi:10.1029/2009JA015109.

Wilks, D. S. (2006). *Statistical Methods in the Atmospheric Sciences: Second Edition*. Burlington, MA: Elsevier Inc.