Specifying the Equatorial Ionosphere using DINEOFs

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DINEOFs

• Data INterpolating Empirical Orthogonal Functions (Beckers and Rixen, 2003)

• EOFs are a data based technique to determine a limited set of orthogonal basis functions and their evolution in time that best reproduce a given data set

• Employs Singular Value Decomposition which provides a reconstructed data set with a minimum variance with original data
DINEOF Process

- Fill in data gaps with an unbiased estimate of missing values
- Perform EOF decomposition on data set
- Reconstruct data set using EOFs and update estimate of missing data values
- Repeat until EOFs on successive iterations converge

\[ X = UDV^* \]

- **X** - Data set; **U** - Spatial basis functions; **V** - Temporal basis functions; **D** - Singular Values
DINEOF Properties

- No a priori information about data is required
- Optimal number of basis functions empirically determined
- Employs a covariance array in calculation of basis functions
  - Accommodates any spatial or temporal distribution of data
  - Can incorporate measurements of different parameters
  - Relation between parameters does not have to be specified
- Global and individual reconstruction error available
Test Problem

True picture if we could measure everywhere

What is measured

Construct full picture using only partial data over multiple days

Reconstructing AVHRR Data

Continuity in time of the images is not necessary to effectuate the reconstruction. Good results can be obtained with irregularly time-distributed data. However, if the set of images is too sparse in some periods (e.g., only one or two images in summer and the rest in autumn), the reconstruction will be deteriorated by irrelevant EOFs describing the variability of a different period of the year, since the information for the former period is insufficient. To avoid this problem, the set of images contains only data from September and October.

An example of reconstruction of these three sets can be found in Fig. 8 which shows the reconstruction of the three data sets for 16 October 1995. The initial, almost clean image of 16 October is shown in Fig. 8a. The images with an additional 40%, 60% and 80% are shown in Fig. 8c.1, d.1 and e.1 respectively. Their reconstruction is shown in Fig. 8c.2, d.2 and e.2 respectively. The reconstructed image from the 40% of added clouds shows a good agreement with the original field, free of clouds, as well as the image that was covered with 60% of added clouds. The main physical features are realistically represented, such as cold temperatures south of the Po River and the warm current entering by the Strait of Otranto and following the east coast.

Fig. 8. Image of 16 October. (a) is the original image, with low cloud coverage; (b) is the difference between the reconstruction of 40% added clouds and the initial image; (c.1) is the initial image plus 40% of added clouds; (c.2) shows the reconstruction of (c.1); (d.1) is the initial image plus 60% of added clouds; (d.2) shows the reconstruction of (d.1); (e.1) is the initial image plus 60% of added clouds; (e.2) shows the reconstruction of (e.1).

Alvera-Azcarate, Ocean Modeling, 2005
Filling in Ion Drifts

- Using IVM data covering 2009 and 2010
- Drift measurements are restricted to below 550 km
- Average drifts over longitude and local time are calculated using 5 days of data, 1 hr local time bins, 30 degrees apex longitude
- Minimum of 100 samples per bin are required
DOY 255-260, 2010

Measurements

Measurements plus DINEOF Estimate
DOY 255-260, 2010
JRO Sector

![Graph showing median drift (m/s) with observed and predicted lines, and average range markers.](image)

- **Median Drift (m/s)**
- **Observed**
- **Predicted**
- **Average range**

MLT (Magnetic Local Time)
Sudden Stratospheric Warming

90°N Mean Temperature 50 hPa MERRA

HNO$_3$ = 6 ppbv, H$_2$O = 4.5 ppmv

Type I PSC
Type II PSC

HNO$_3$ = 6 ppbv, H$_2$O = 4.5 ppmv

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SSW Ion Drifts at JRO

Chau, Fejer, Goncharenko (2009)
CINDI Drifts and DINEOF Reconstruction after SSW in JRO sector

DOY 35-40, 2010

Median Drift (m/s)

Observed
Predicted
Average range
Ion Drifts over 2010

Measured Ion Drifts

Measured Drifts plus DINEOF Estimate

Median Meridonal Drift 2010

Day of Year

MLT

Ion Drift (m/s)

Median Meridonal Drift 2010

Day of Year

UTD

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Possible Improvements

• Modify DINEOF iterative process:
  – Enforce curl free condition on drifts over all local times and longitudes
    ▪ Requirement may be added to drift reconstructions as well as basis functions
  – Enforce continuity across 0,360 longitude as well as 0,24 local time

• Add more data!
  – More drift measurements
  – Space weather parameters
Cartoon Data Coverage of Ion Drifts

C/NOFS

DMSP

Longitude

Magnetic Local Time

JRO

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COSMIC and C/NOFS

- Combine measurements from both platforms to improve reconstruction
- C/NOFS - Ion Drifts in 3-dimensions as well as ion density, temperature, and composition
- COSMIC - Electron density profiles of the ionosphere
  - altitude at peak density
  - magnitude of peak density
  - thickness of ionosphere near maximum
COSMIC-2

• Measurements of ion drifts can be completely filled using bin sizes of .25 MLT and 4 degrees longitude over +/- 24 GLAT on a daily basis
• Restricting data to drifts near the magnetic equator (+/- 12 MLAT) reduces coverage to 50%
• Drifts at higher MLATs as well as GPS RO data will help constrain reconstructions at the equator
Data Products

- DINEOFs may be used to produce daily ionospheric maps
- Including lagged versions of drivers enables basis functions determination that spans multiple (m) days
- After determining the basis functions, supplying sparse data for n days, n<m, leads to a prediction for the remaining days
- Predictions require very little computation
Summary

• DINEOFs show promise in generating a more complete picture of the ionosphere given a sparse data set
  – General process that does not require a priori information about the data
  – Reconstruction procedure provides information on the error of inferred data points
  – May be used to combine multiple data sources
    ▪ Different measurement patterns are likely preferred
  – May be used for prediction
Thank you