Using machine learning to find a mapping between states of polarization and atmospheric model variables

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Solar Influences on Earth’s Space Environment

- Space weather originated by sun:
  - Flare
  - Coronal Mass Ejections

- These phenomena triggered by magnetic field
Measuring magnetic field

- Using Polarizations:
  - Produced by symmetry-breaking processes

- State of Polarization: The Stokes vector $\{I, Q, U, V\}^T$
Forward problem and Inversion problem

**Forward Modeling:**
- Atmospheric Model
  - (T, ρ, B, v...)
- Radiative Transfer
- Solve Equations
- Synthetic Spectra

**Inversion:**
- Observations
- Inverse Mapping
- Physical State
Goals

- Validating notable structures in Atmospheric model and polarized spectra
- How much diversity exist in solar atmosphere and how this varies by time
- Detecting any outlier or new structure can be found
- Ultimate goal: Finding a mapping
Methods: Clustering

Clustering:

- K-means:
  - Number of clusters
  - Tolerance

- DBSCAN:
  - Epsilon
  - Minimum points
Methods: Evaluation

- Using domain experts knowledge
  - finding familiar structures like magnetic regions and granulations
- Inertia
- Silhouette

\[ s(i) = \frac{b(i) - a(i)}{\text{Max}(b(i), a(i))} \]
Hinode data-set

- HOP 336 dataset
- 3 sets of samples: North(+37°), South(-37°), and Equator
- Features: Magnetic field (strength, inclination, azimuth, fill factor), Doppler shift, Continuum intensity
- 300 maps in total, 153 maps in North, and almost 132 million samples
Preprocessing: First Setting

- Obtaining Cos of Azimuth
- Using $B\cos(inc)$ instead of $B$ and inclination separately.
- Subtracting a regression line from each row for Doppler shift (for each map individually).
- Tried 3, 4, 5, and 10 clusters using k-means.
- Result: Centers were really close to each other and no structure found! Maybe due to local minima problem in k-means.
First Setting: Results

For K = 10 clusters
Preprocessing: Second Setting

- Using $B$ and cosine of inclination Separately
- Removing Azimuth due to noisy characteristic.
- Putting constraint over magnetic field. $|B| < 200$ G should be treated as noise:
  \[\text{SLFF} = 0, \quad B = 0, \quad \text{Inclination} = 90.\]
- Try higher number of clusters: 25, 50, 100, 150, 200
- For better visualization, we ordered the same clustering results in 3 different order: based on $B$ and CI centers
Second Setting: Results

For $K = 50$ clusters
Second Setting: Results

For $K = 50$ clusters
Second Setting: Results

- A strange artifact found when $k = 50$ clusters with a very low continuum intensity (450 compared to average of 21000)
- We used Inertia as a metric.
- This setting, improved inertia by 50x, compared to first setting: It was expected since we removed Azimuth and zeroing features related to $B < 200$ G.
Optimal number of clusters: Inertia
Optimal number of clusters: Silhouette
DBSCAN result

- Reaching to 2 clusters!
- 10% improvement in silhouette
  Compared to K-means
Future directions

- Using a grid search to find optimal parameters for DBSCAN
- Categorize our pixels/samples to two different data-set and apply clustering to them separately
- Using other clustering methods like Hierarchical methods
Thanks for your time

Encounters at the end of the world by Werner Herzog

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