Using Unsupervised Machine Learning to Resolve Bow Shock Crossings

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Goal & Source Data

Goal

• Machine Learning is becoming ever the more prominent in space physics
  o Mostly supervised – but not so much unsupervised learning

• Recent results in *Innocenti* 2021 using unsupervised methods (Self-Organizing Maps + KMeans) on classifying simulated magnetospheric regions emboldens more widespread use.
  o Next step: Using similar idea on observations?

Source Data

• Combination of THEMIS’s ESA-reduced (~3 s), ESA-full (~90 s), and the on-board computed moments (MOM, ~3 s) for all spacecraft (A, B, C, D, E) from March 2007 to end of 2020 at 1-min resolution.

• Use a Gaussian Mixture Model to separate *dayside* magnetosphere based on plasma parameters:
  o $B$ [nT], $V_{\text{ion}}$ [km/s], $\log T_{\text{ion}}$ [eV], $\log n_{\text{ion}}$ [#/cc]

• Constrain data to dayside ($X_{\text{GSE}} \geq 0$) and remove close-in magnetosphere (require $|B| \leq 200$ nT)
Clustering Results – Data Example

• Can then view clustered data in relation to various parameters

• At right is clustered THEMIS-C data from 14 Aug 2008 (Day 510) to 13 Sept 2008 (Day 540)

Right contour (Bow Shock):
Simple hyperbola - $25 R_E / (1 + 0.8*\cos(\phi))$

Left contour (Magnetopause):
Shue 1998 with parameters $B_z = 0.15 \text{ nT}$, $D_p = 3.5 \text{ nPa}$
Summary

• We demonstrated how a GMM can successfully partition plasma regions in the dayside magnetosphere using moments and magnetic field data.
• These crossings can be used as the basis for developing an empirical bow shock model

Future Work:

• Extending the unsupervised model to other dayside s/c (MMS, Cluster, etc)
• Can use the same model to also build catalogue of magnetopause crossings

Main Takeaway:
Unsupervised methods can be used to classify magnetosphere plasma regions

References:

