# *Interplanetary Shock Detection and Geomagnetic Storm Evolution*

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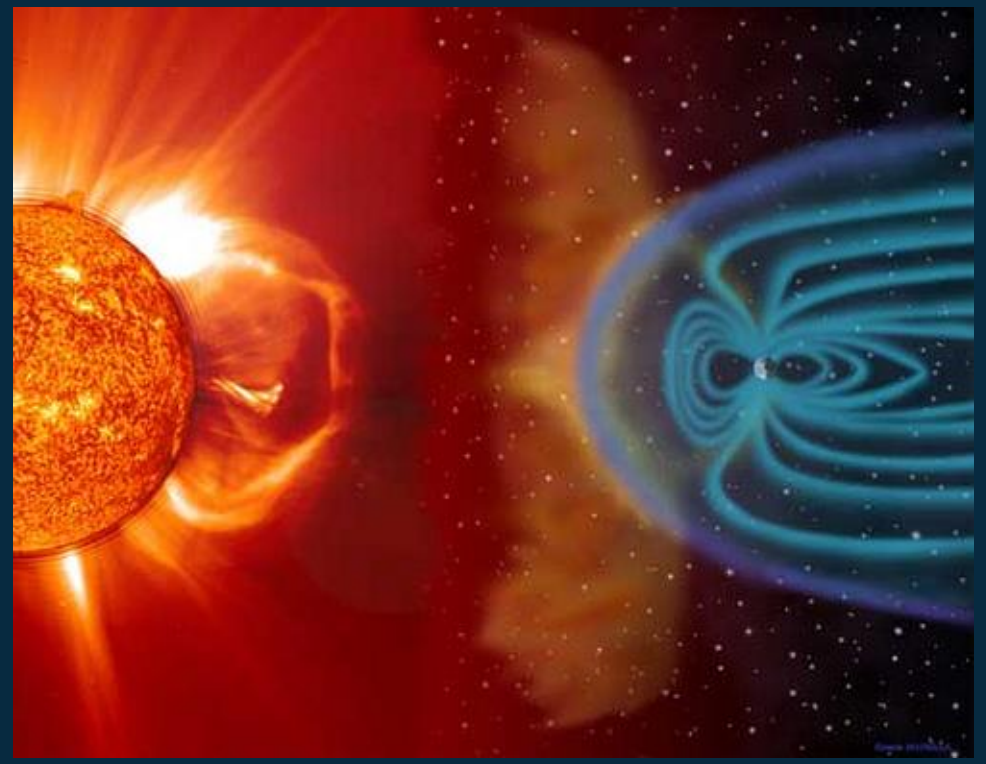
# Goal

- Increase accuracy of 3 hourly $K_P$ forecast
  - Important for: warning power companies, airlines…etc
  - Spacecraft operations (tracking, drag, orientation)

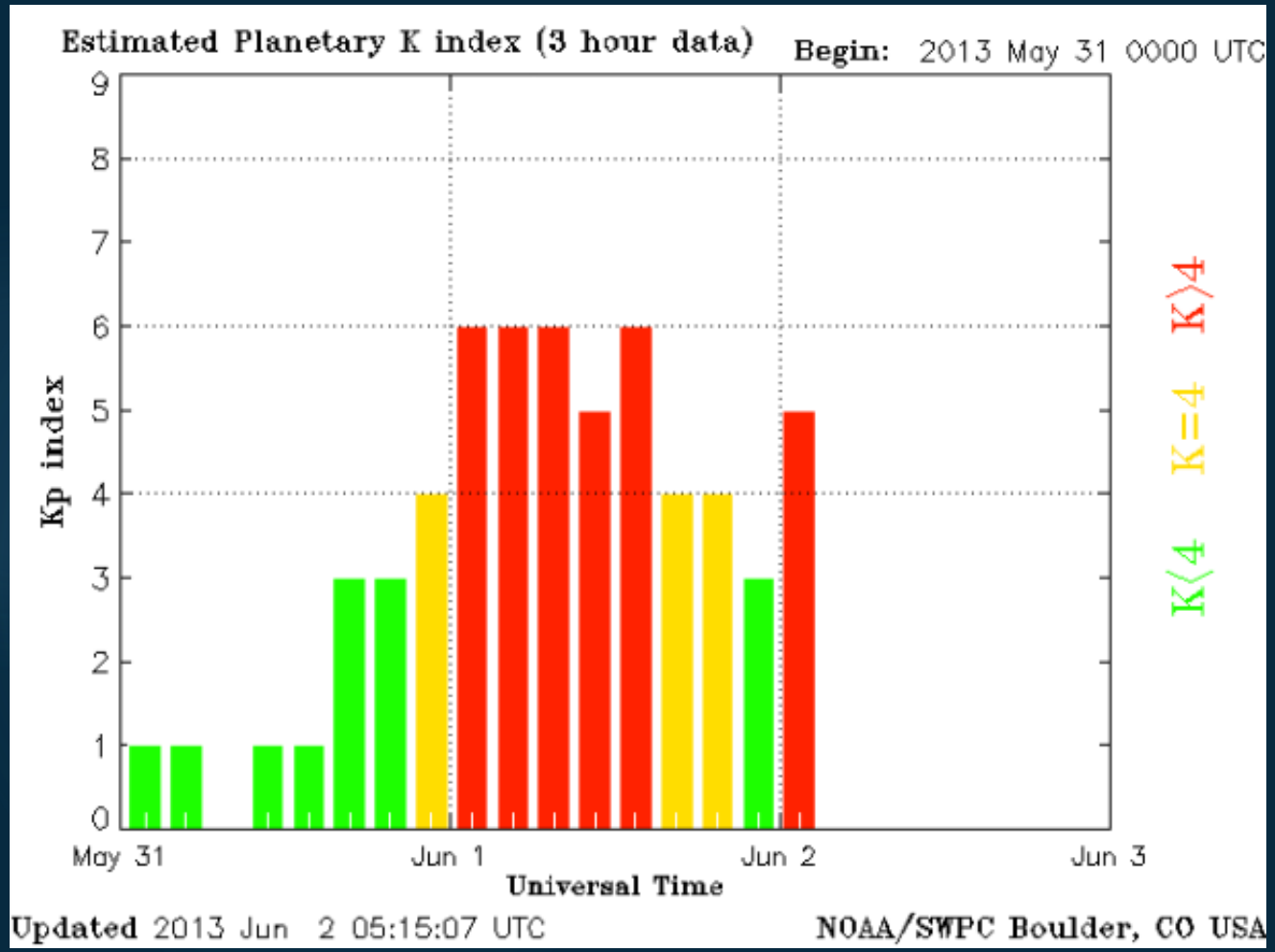
# Introduction

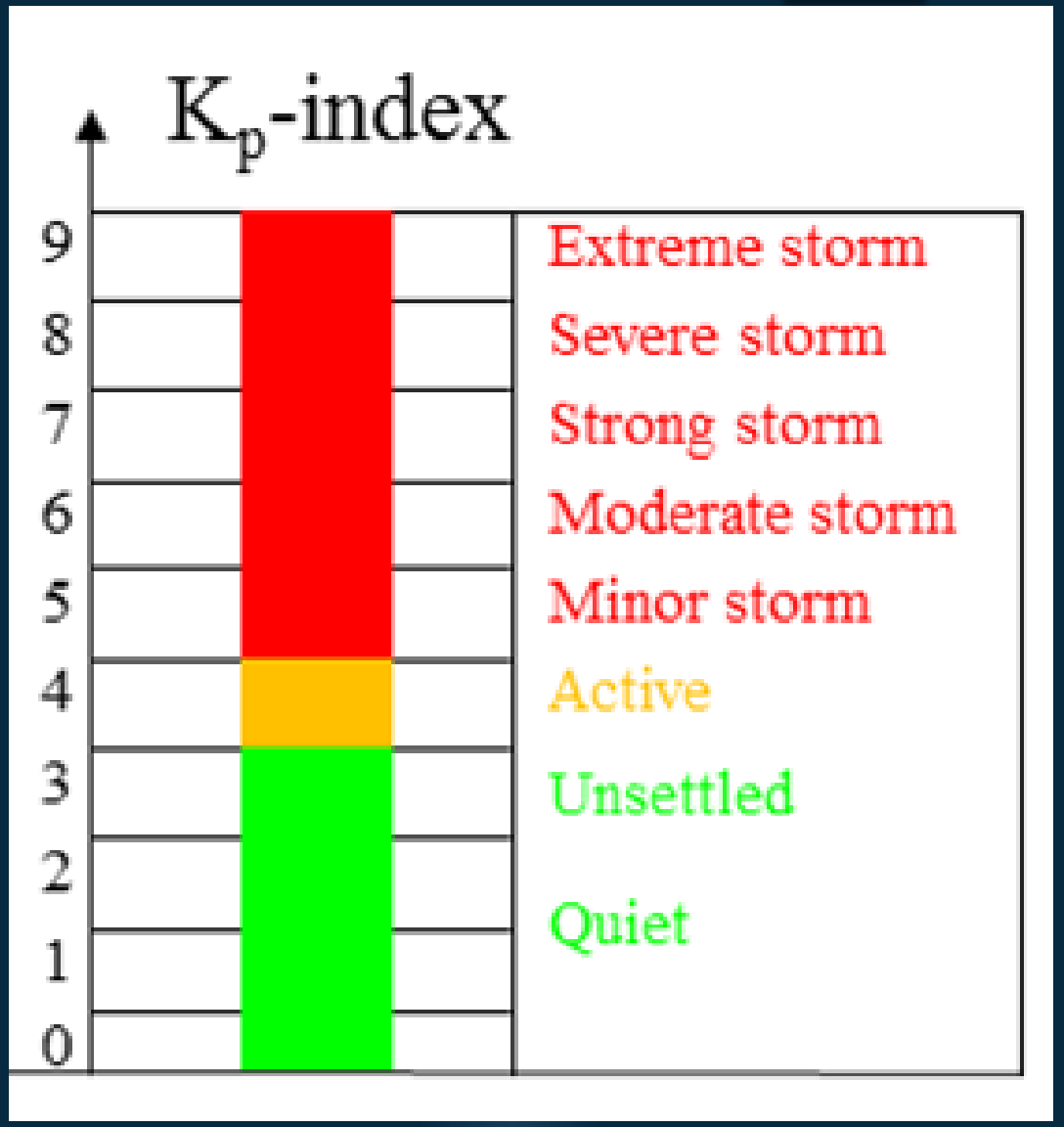
- Primary focus on CMEs and K-index
- Shock detection at ACE
- Time from detection to G-scale thresholds



# K-Index

- Two types: $K_b$ and $K_P$



# G-Scale

## NOAA Space Weather Scales

| Category | | Effect | Physical measure | Average Frequency (1 cycle = 11 years) |
|---|---|---|---|---|
| Scale | Descriptor | Duration of event will influence severity of effects | | |
| **Geomagnetic Storms** | | | Kp values* determined every 3 hours | Number of storm events when Kp level was met; (number of storm days) |
| G 5 | Extreme | Power systems: widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. Spacecraft operations: may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. Other systems: pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.).** | Kp=9 | 4 per cycle (4 days per cycle) |
| G 4 | Severe | Power systems: possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. Spacecraft operations: may experience surface charging and tracking problems, corrections may be needed for orientation problems. Other systems: induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.).** | Kp=8 | 100 per cycle (60 days per cycle) |
| G 3 | Strong | Power systems: voltage corrections may be required, false alarms triggered on some protection devices. Spacecraft operations: surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. Other systems: intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.).** | Kp=7 | 200 per cycle (130 days per cycle) |
| G 2 | Moderate | Power systems: high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. Spacecraft operations: corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. Other systems: HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.).** | Kp=6 | 600 per cycle (360 days per cycle) |
| G 1 | Minor | Power systems: weak power grid fluctuations can occur. Spacecraft operations: minor impact on satellite operations possible. Other systems: migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine).** | Kp=5 | 1700 per cycle (900 days per cycle) |

* Based on this measure, but other physical measures are also considered.

** For specific locations around the globe, use geomagnetic latitude to determine likely sightings (see www.swpc.noaa.gov/Aurora)

# Methods

- 2 Shock tables:
  - Cash - manually compiled
  - Smith (Vorotnikov) – automated shock detection algorithm
- K-based alerts from SWPC
- Elapsed time using Octave
- Limited to 24 hours

# Assumptions/Considerations

- No distinction between $K_b$ or $K_p$
- Origin of shocks is undetermined
- Post-March 2002
- Limits

  "Old": K=5: 10h K=6: 15h K=7-9: 24h

  "New": K=5-9: 24h

# Results

## Smith Tables

### Old

Elapsed Time from Shock to Kp Level (hours) using Smith et.al.

Kb and Kp: 03/2002-12/2014

| K-Index | Mean | Median | Minimum | Maximum | Standard Deviation | Number of Cases |
|---|---|---|---|---|---|---|
| 5 | 3 | 2 | 0 | 9 | 2 | 53 |
| 6 | 4 | 3 | 0 | 14 | 3 | 42 |
| 7 | 6 | 4 | 0 | 23 | 6 | 20 |
| 8 | 6 | 5 | 1 | 13 | 4 | 9 |
| 9 | 5 | 6 | 2 | 6 | 0 | 3 |

Kb: 03/2002-12/2011

| K-Index | Mean | Median | Minimum | Maximum | Standard Deviation | Number of Cases |
|---|---|---|---|---|---|---|
| 5 | 3 | 3 | 0 | 9 | 2 | 49 |
| 6 | 4 | 3 | 0 | 13 | 3 | 38 |
| 7 | 6 | 4 | 0 | 23 | 6 | 18 |
| 8 | 6 | 6 | 1 | 13 | 4 | 8 |
| 9 | 5 | 6 | 2 | 6 | 2 | 3 |

Kp: Post 12/2011

| K-Index | Mean | Median | Minimum | Maximum | Standard Deviation | Number of Cases |
|---|---|---|---|---|---|---|
| 5 | 2 | 2 | 0 | 6 | 2 | 4 |
| 6 | 5 | 3 | 2 | 14 | 5 | 4 |
| 7 | 6 | 6 | 4 | 7 | 1 | 2 |
| 8 | N/A | N/A | N/A | N/A | N/A | 0 |
| 9 | N/A | N/A | N/A | N/A | N/A | 0 |

### New

Elapsed Time from Shock to Kp Level (hours) using Smith et.al.

Kb and Kp: 03/2002-12/2014

| K-Index | Mean | Median | Minimum | Maximum | Standard Deviation | Number of Cases |
|---|---|---|---|---|---|---|
| 5 | 7 | 5 | 0 | 23 | 7 | 78 |
| 6 | 7 | 5 | 0 | 23 | 7 | 54 |
| 7 | 6 | 4 | 0 | 23 | 6 | 20 |
| 8 | 6 | 5 | 1 | 13 | 4 | 9 |
| 9 | 5 | 6 | 2 | 6 | 2 | 3 |

Kb: 03/2002-12/2011

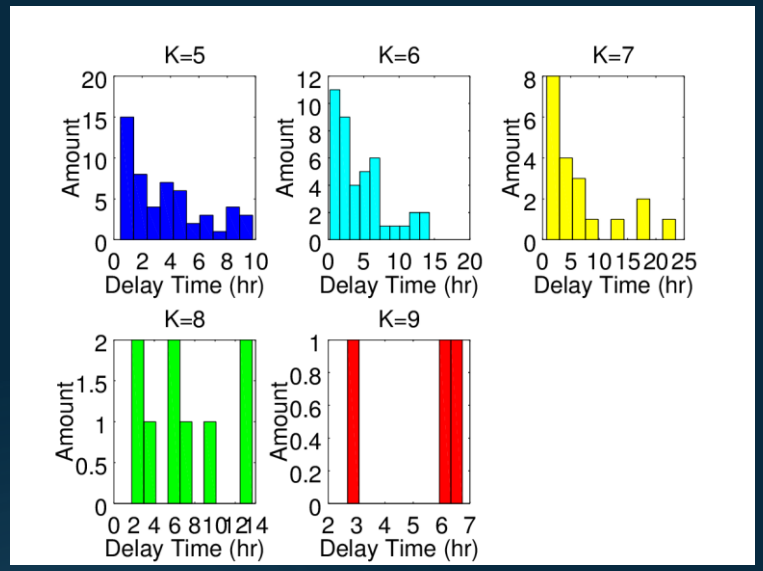
| K-Index | Mean | Median | Minimum | Maximum | Standard Deviation | Number of Cases |
|---|---|---|---|---|---|---|
| 5 | 7 | 5 | 0 | 23 | 7 | 71 |
| 6 | 7 | 5 | 0 | 23 | 7 | 49 |
| 7 | 6 | 4 | 0 | 23 | 6 | 18 |
| 8 | 6 | 6 | 1 | 13 | 4 | 8 |
| 9 | 5 | 6 | 2 | 6 | 2 | 3 |

Kp: Post 12/2011

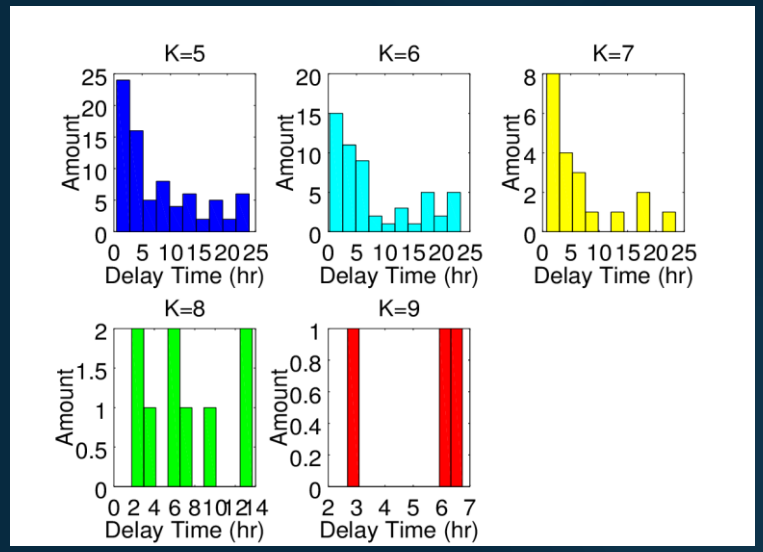
| K-Index | Mean | Median | Minimum | Maximum | Standard Deviation | Number of Cases |
|---|---|---|---|---|---|---|
| 5 | 7 | 4 | 0 | 17 | 7 | 6 |
| 6 | 8 | 3 | 2 | 17 | 6 | 5 |
| 7 | 6 | 6 | 4 | 7 | 1 | 2 |
| 8 | N/A | N/A | N/A | N/A | N/A | 0 |
| 9 | N/A | N/A | N/A | N/A | N/A | 0 |

# Smith Histograms: Post-2002

## Old

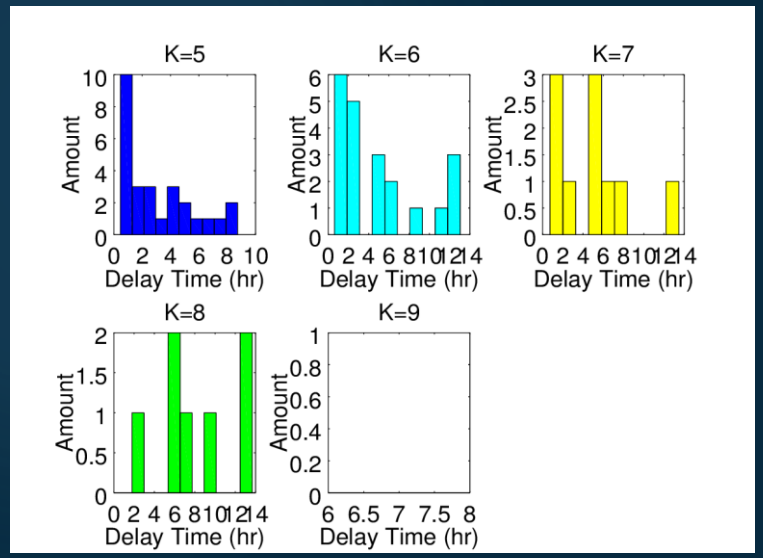



## New

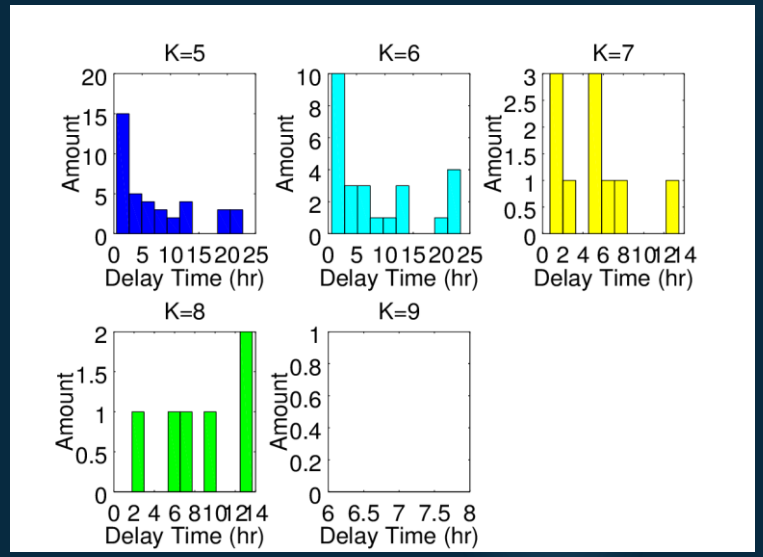



# Cash Histograms: Post-2002

## Old

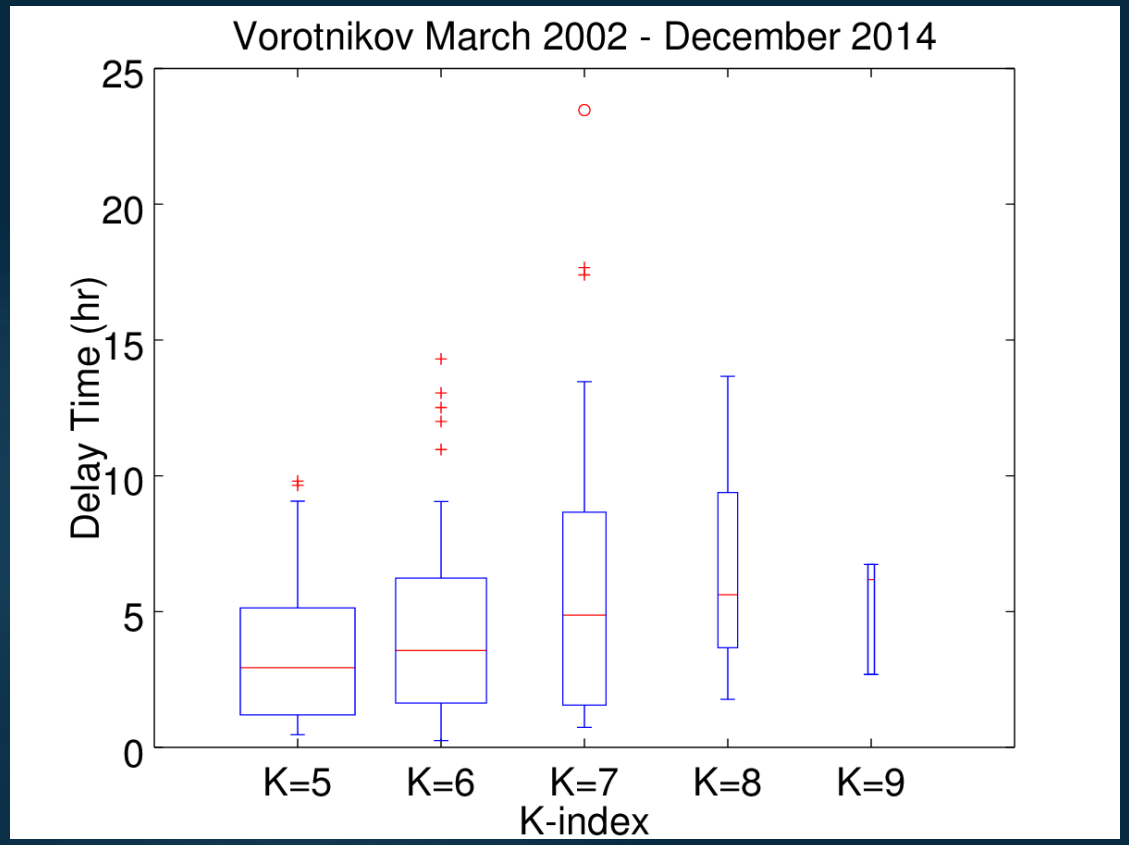



## New

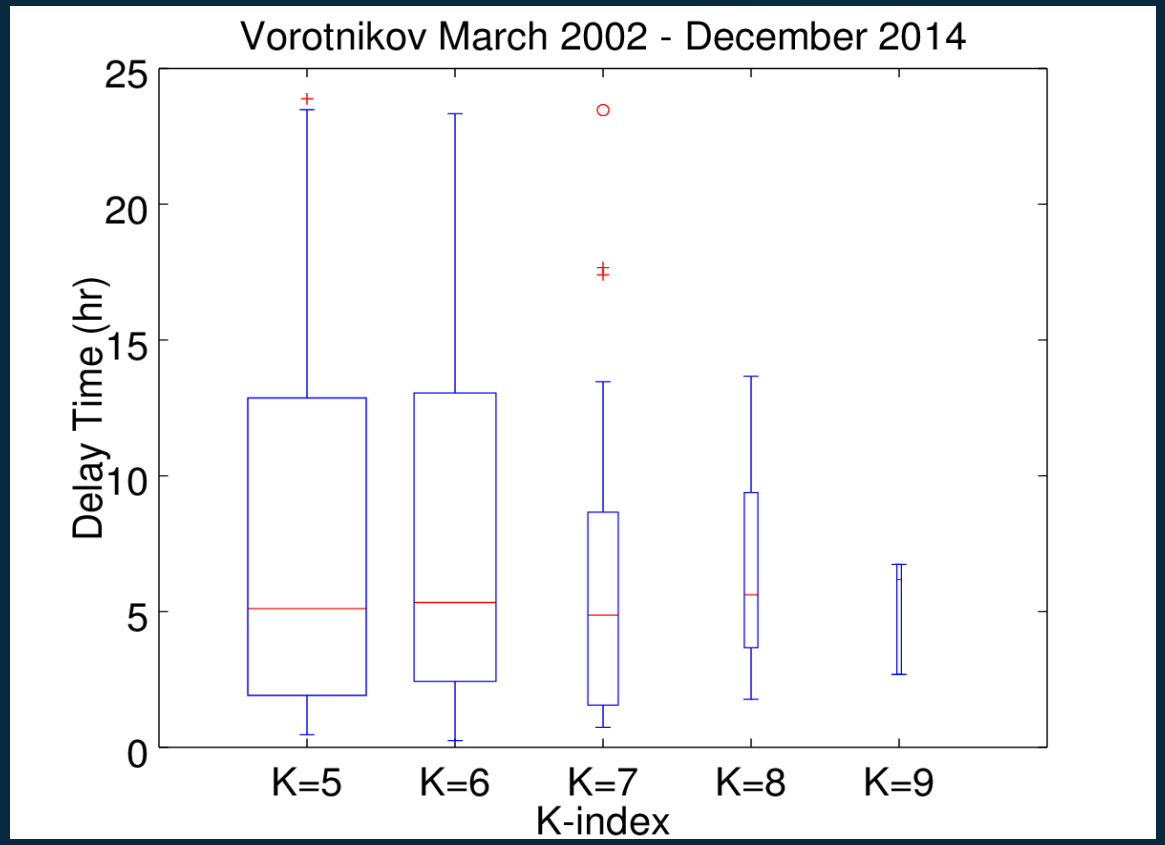


# Smith Boxplots: Post-2002

## Old

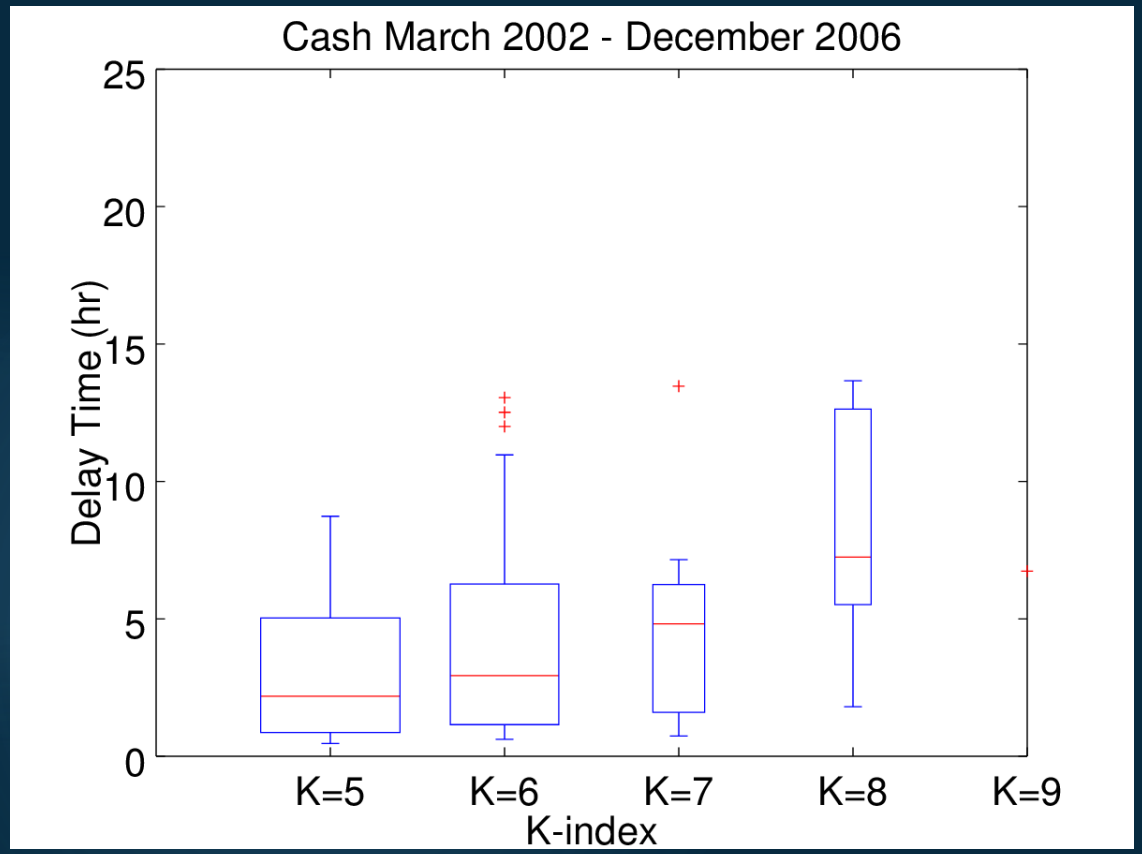



## New

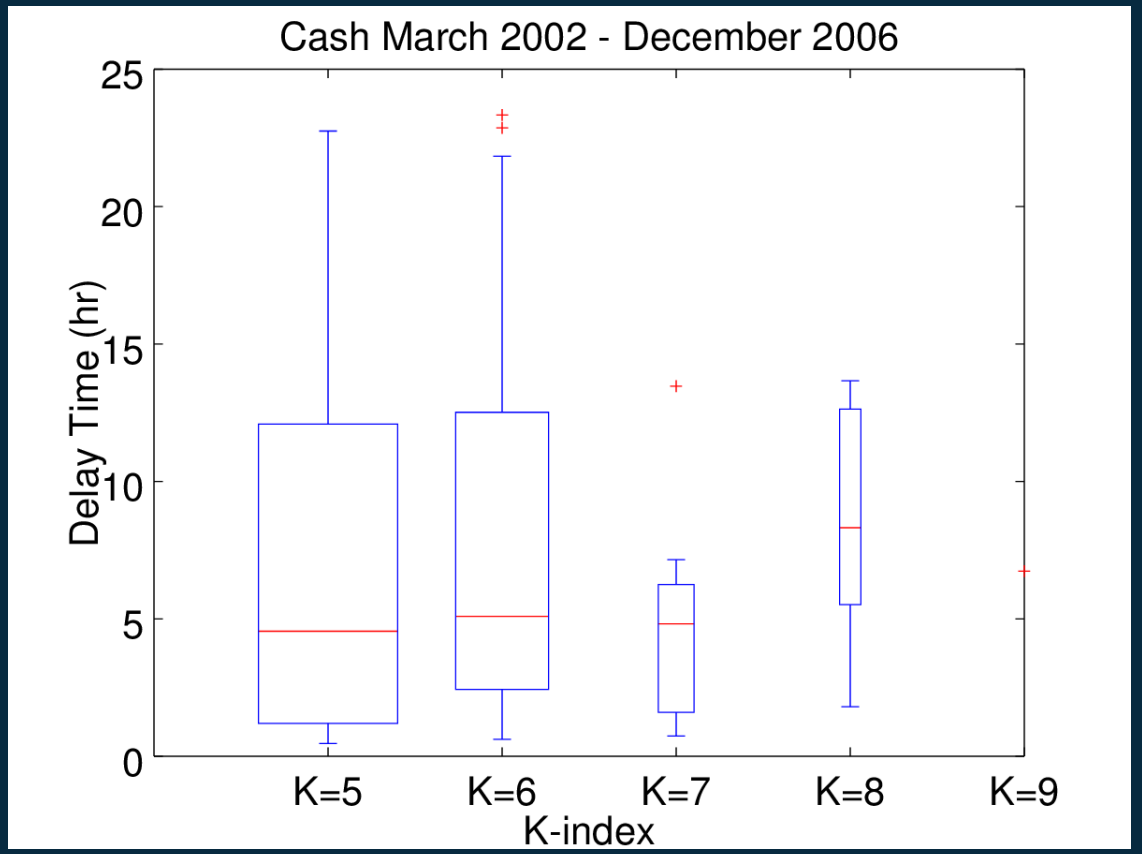


# Cash Boxplots: Post-2002

## Old




## New



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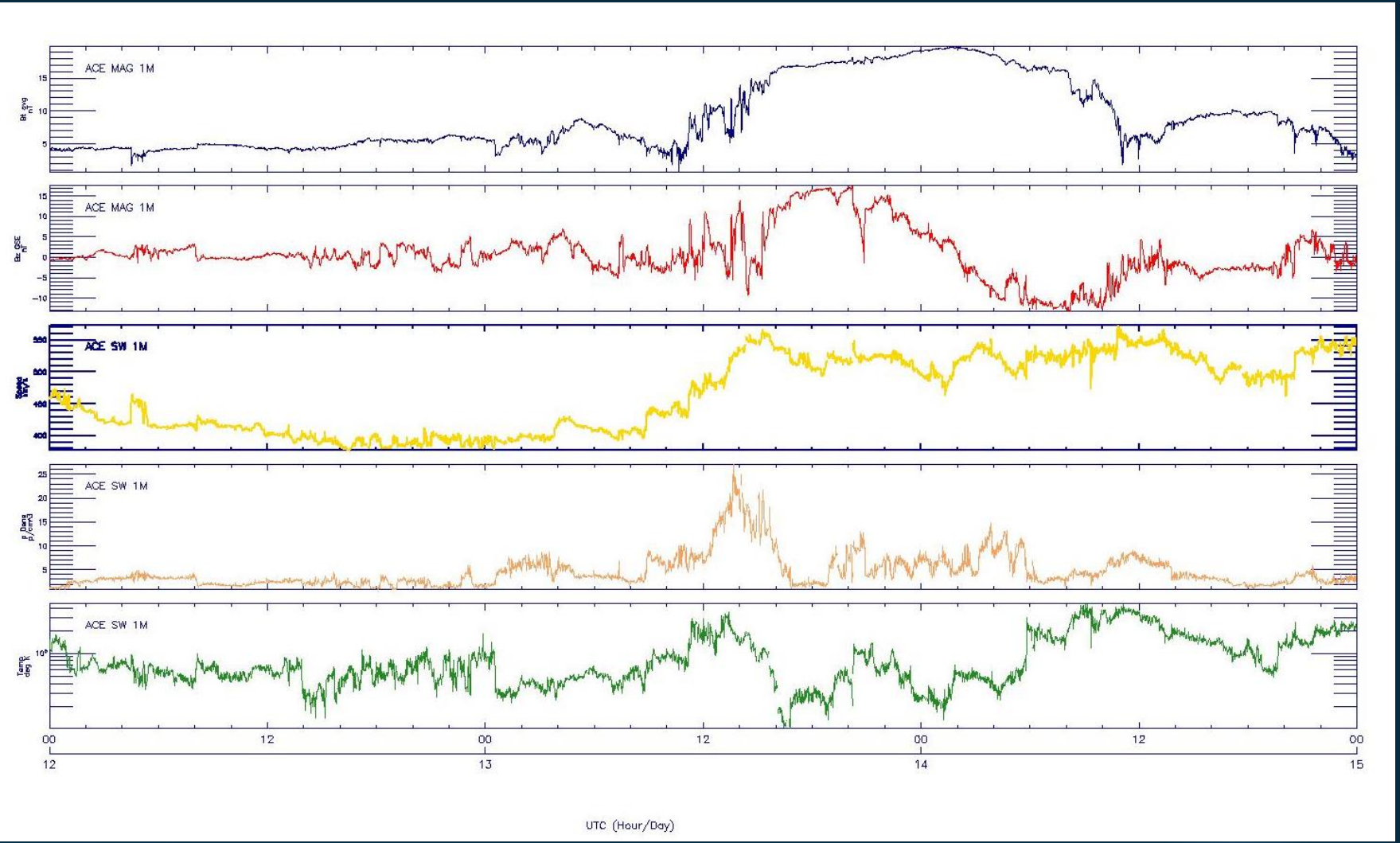
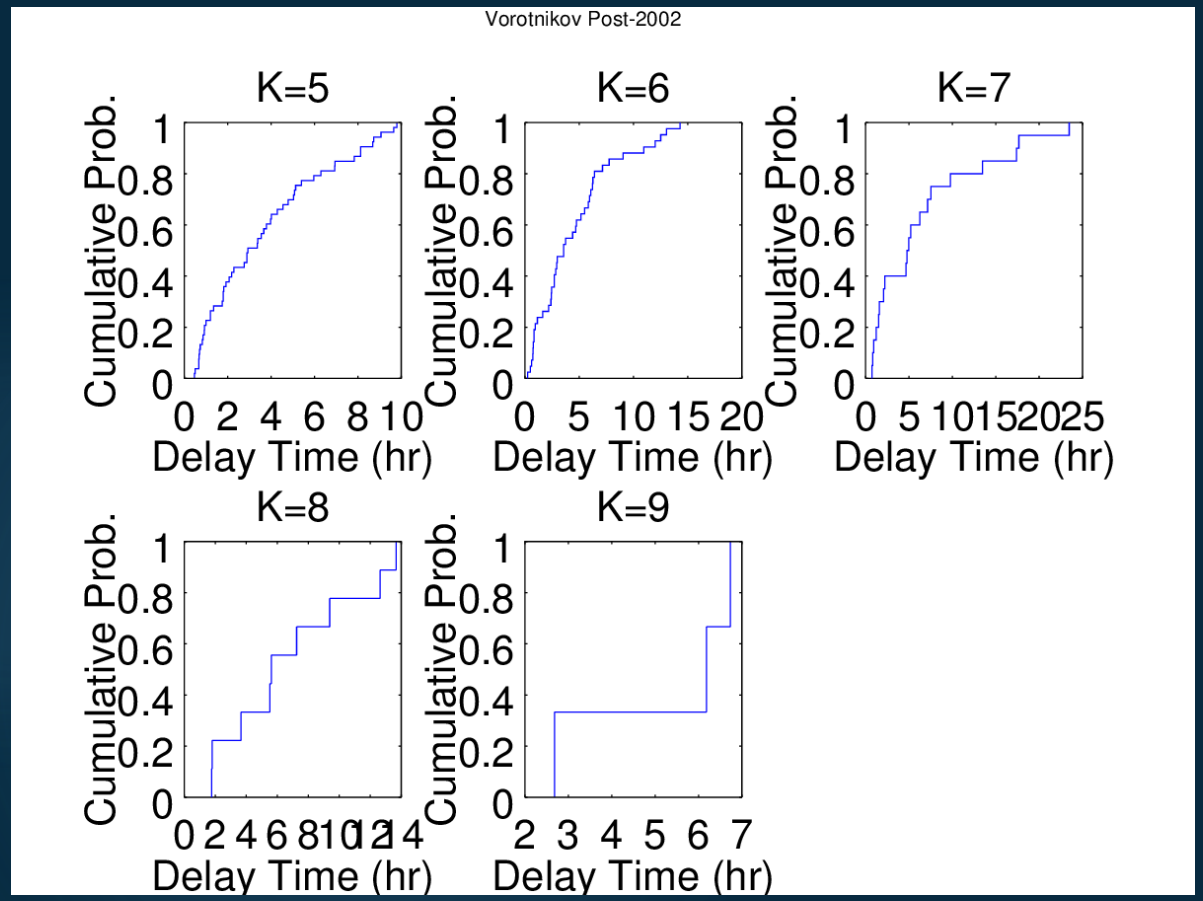


# Smith CDF Plots: Post-2002

## Old

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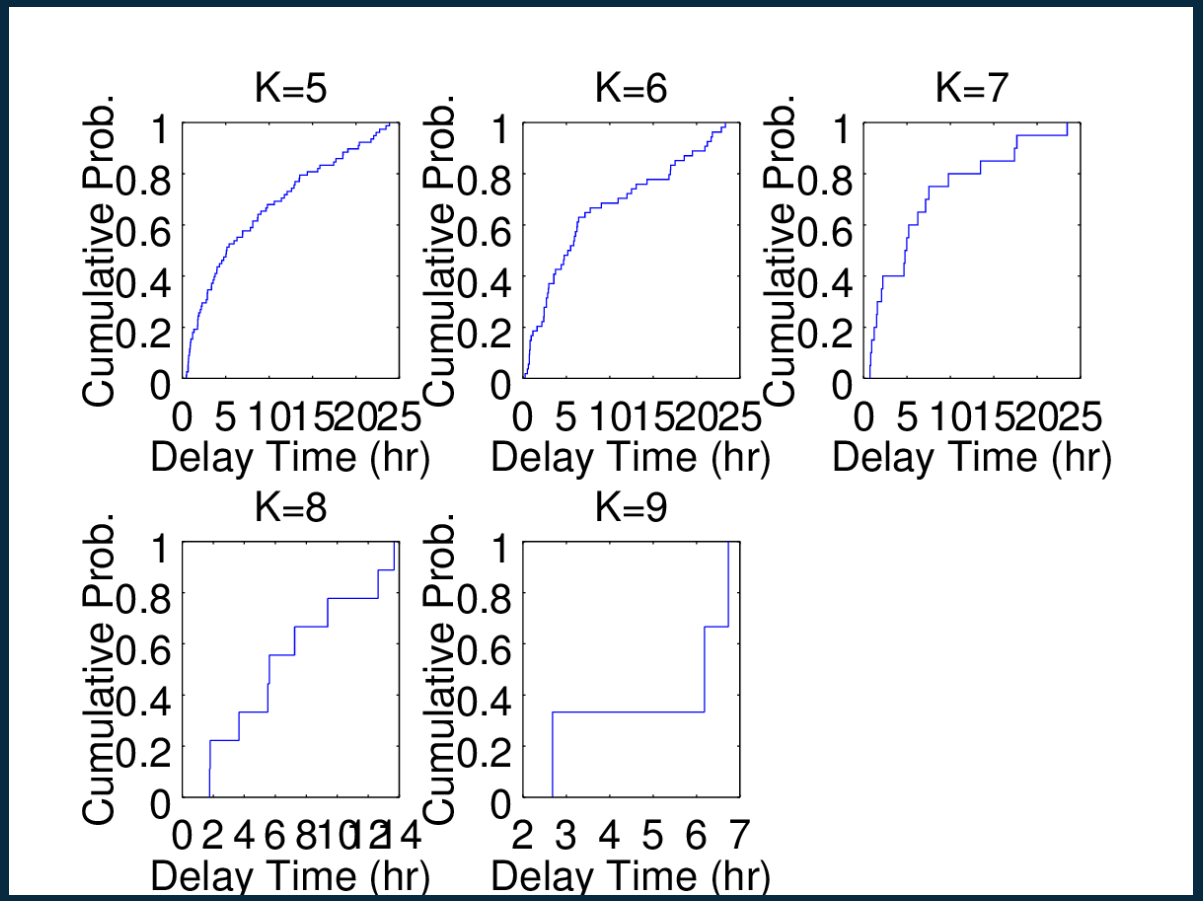
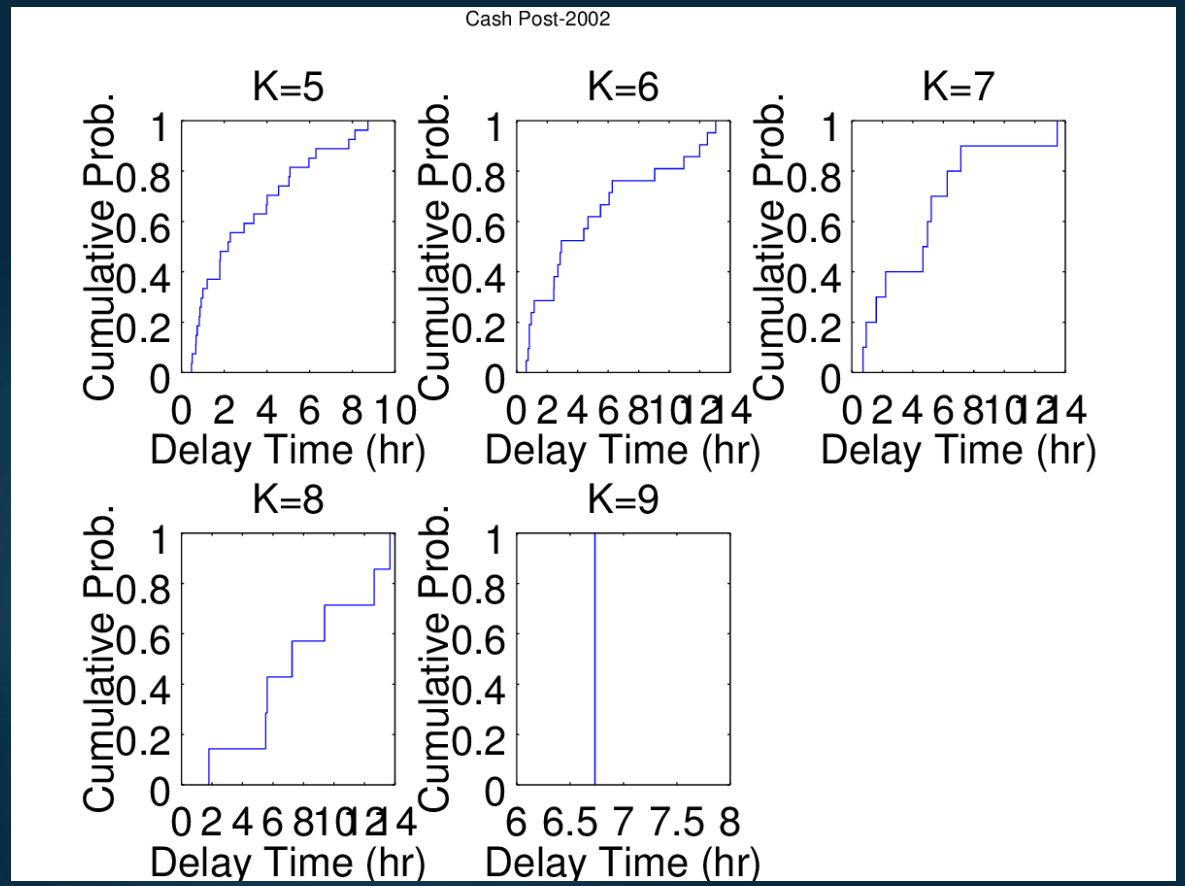
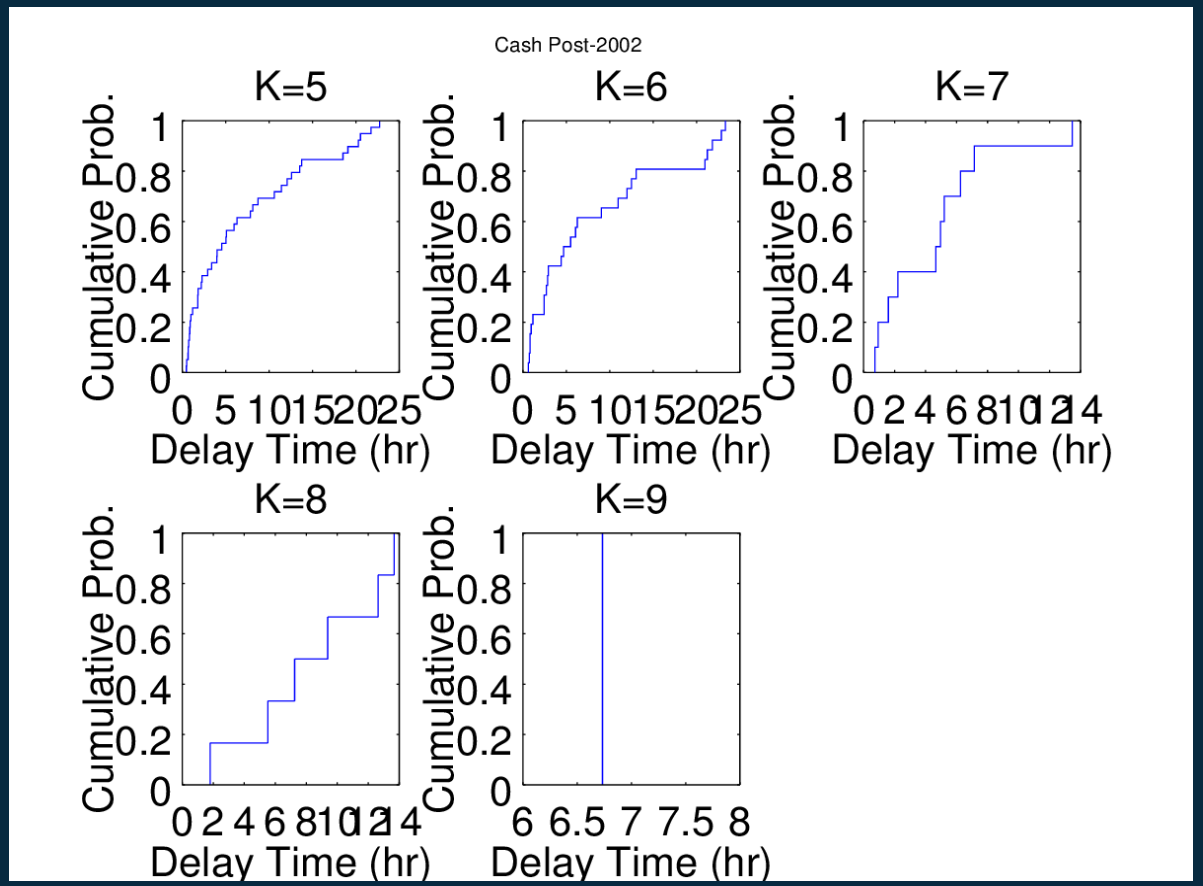


# Cash CDF Plots: Post-2002

## Old




## New



# Conclusions

- $K_b$ and $K_p$ are similar
- Shorter times more likely
- Median times from 2 to 6 hours
- Possible coronal holes in expanded data set

Next Steps:

- Separate CMEs from coronal holes
  - Evaluate individually

# References and Acknowledgements


- *Cash, M. D., J. S. Wrobel, K. C. Cosentino, and A. A. Reinard (2014), Characterizing interplanetary shocks for development and optimization of an automated solar wind shock detection algorithm, J. Geophys. Res. Space Physics, 119, 4210–4222, doi:10.1002/2014JA019800.*

- *Vorotnikov, V. S., C. W. Smith, Q. Hu, A. Szabo, R. M. Skoug, and C. M. S. Cohen (2008), Automated shock detection and analysis algorithm for space weather application, Space Weather, 6, S03002, doi:10.1029/2007SW000358.*



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