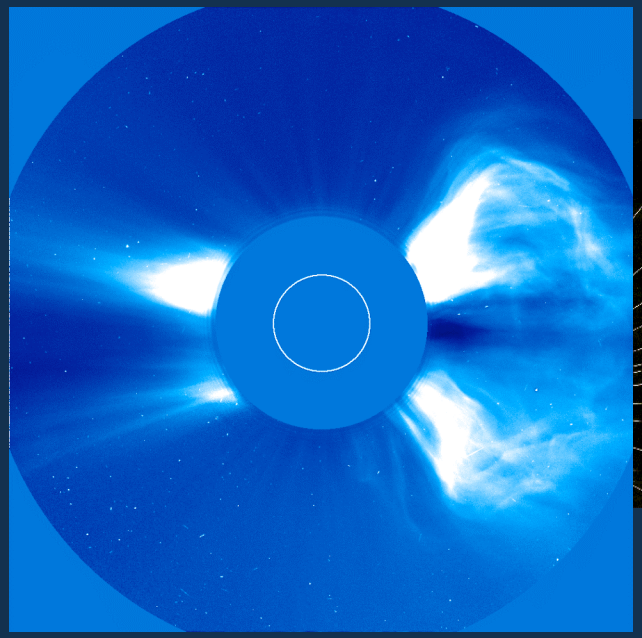
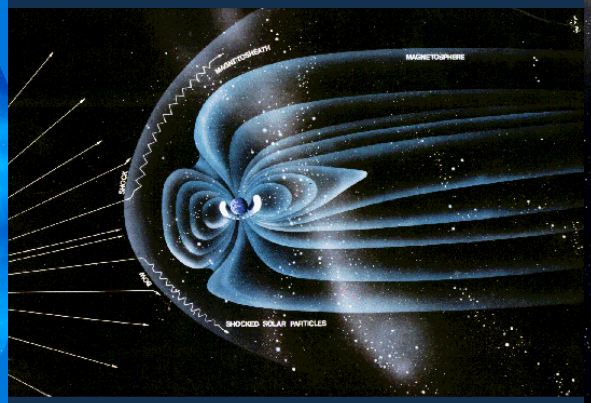
Geomagnetic Activity and GPS Anomalies at High Latitudes





Adam Jacobs

Mentor: Rob Steenburgh

NOAA SWPC

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Motivation

- Alaska's citizens use GPS for many daily activities
- Solar and Geomagnetic activity effect the accuracy of GPS
- GPS customers wonder when they can and can't rely on GPS positioning (some situations are life threatening)
- Is there a strong correlation or predictable relationship?
- If so--we want to eventually be able to forecast GPS disruption (timing/magnitude) given certain levels of geomagnetic activity

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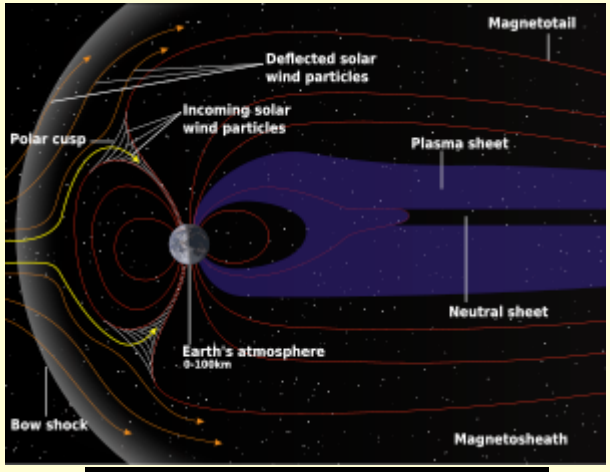
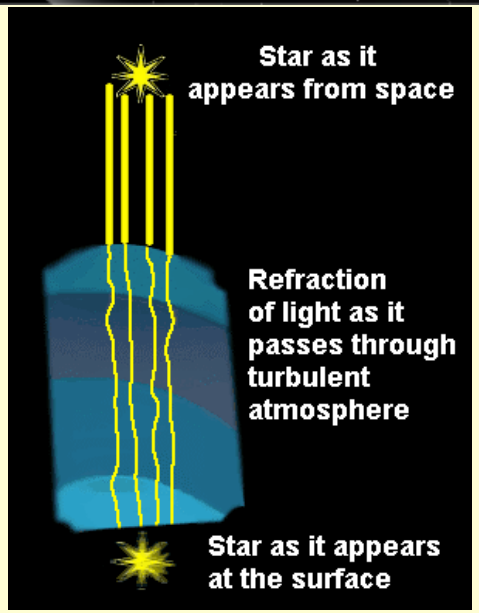
Scintillation

- Solar wind and CMEs cause perturbations in the Earth's magnetic field
- These perturbations in turn cause particle precipitation and complex structure to develop in the ionosphere—especially at high latitudes (top pic)
- Large gradients in TEC—bubbles and blobs—disrupt GPS signals (bottom pic)
- Irregularities cause diffraction and refraction of the GPS signal which in turn cause phase shifts and amplitude variability respectively
- Scintillation refers to observed rapid changes amplitude and phase





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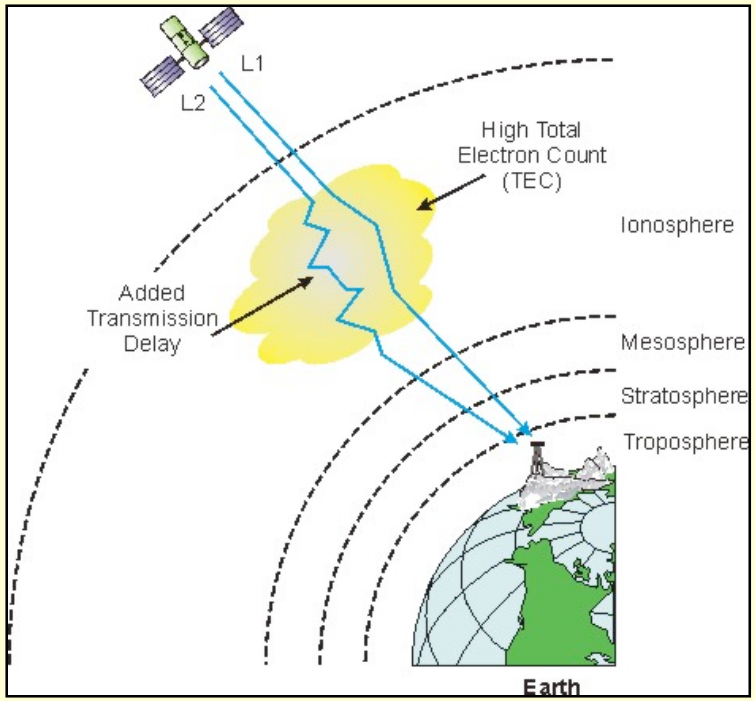
GPS Positioning Errors

- The perturbed ionosphere can cause unpredictable variations in Total Electron Content
- These variations can cause complex signal group (pseudorange) delay
- Pseudorange—the apparent distance between the reference station and a satellite using the time for the signal to get there
- Triangulation of pseudoranges are used to get the distance



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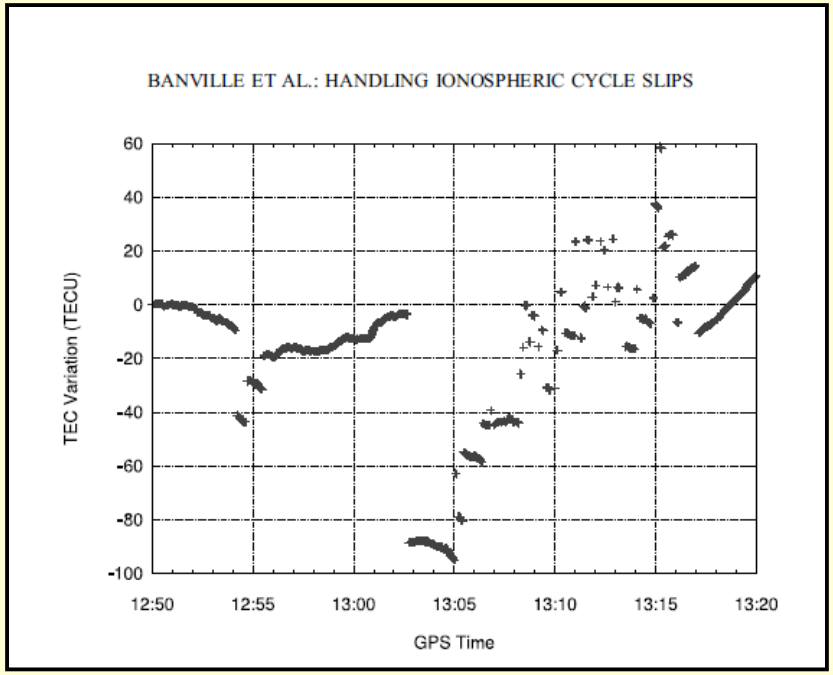
GPS Cycle Slips

- Occur as a result of phase shifts
- When the phase shift exceeds the bandwidth of a receiver's phase lock loop (PLL) the receiver loses lock
- The duration of loss of lock determines the number of cycles that will slip by unrecorded(hence cycle-slips)
- There are several relatively successful correction methods for cycle slips including polynomial fitting



Numerous cycle slips in the GPS observations create jumps in the time series.
(Banville et. al. 2010—Radio Science)

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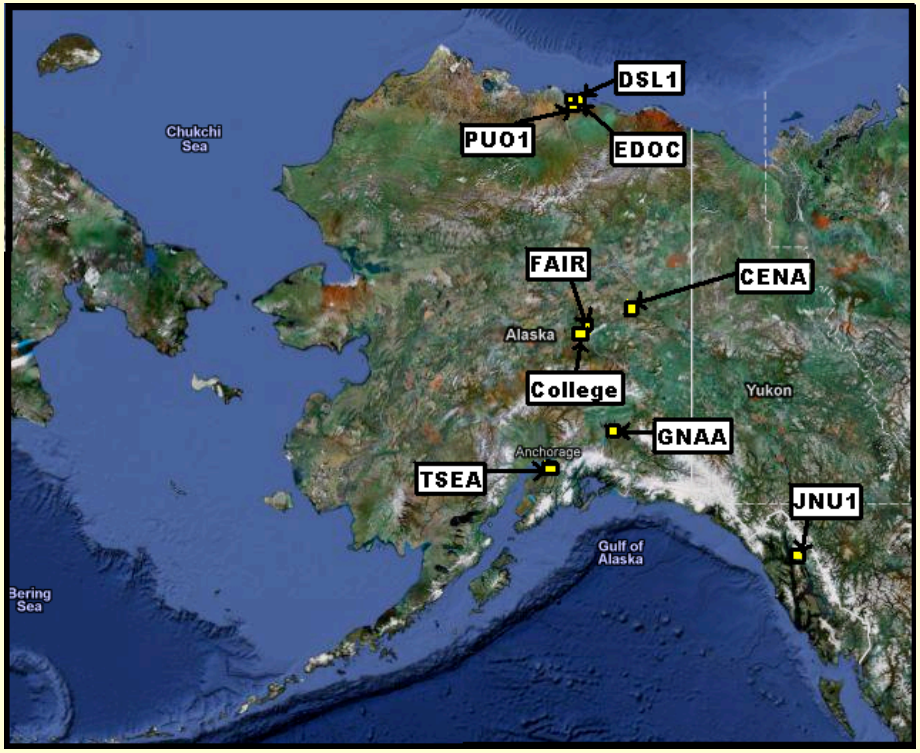
GPS Data Used

- Chose eight Alaska GPS reference stations
- Various latitudes to check for latitude dependence in GPS errors
- Stations are part of the Nation Geodetic Survey (NGS) Continuously Operating Reference Stations (CORS) network



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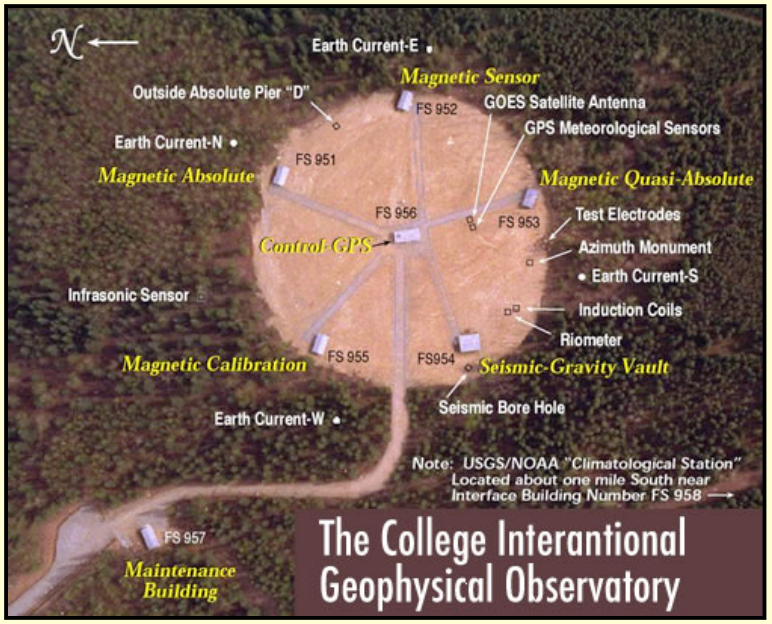
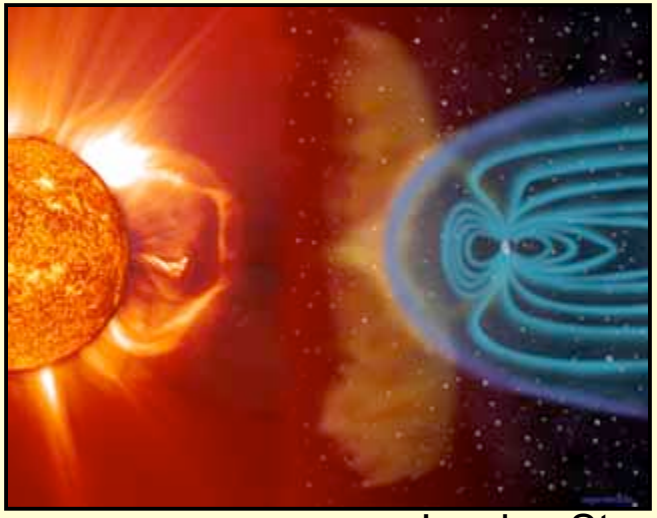
Geomagnetic Data Used

- Used daily A-index data and 3-hourly K-index data from College, AK
- K-index—represents the maximum fluctuations in the horizontal mag. Field components relative to a quiet day, during a three hour interval
- A-index—daily average of the eight “equivalent three hourly” (a-index) values which have been converted nonlinearly from the K-index values





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Data Processing

- Started with the daily number of cycle slips from all eight GPS stations and the A-index at College for 2003 and 2008 (quiet and active years)
- Examined the temporal and spatial relationships between the two data sets and calculated correlation coefficients
- Moved to GPS positioning errors (daily max and median) and compared these data sets to the A-index
- Created histograms of position errors
- Explored higher granularity data (Fairbanks only), specifically College K-index and three hourly medians for GPS positioning errors
- Examined relationships, correlations, cross-correlations, distributions, and seasonal variability (looked at specific events)

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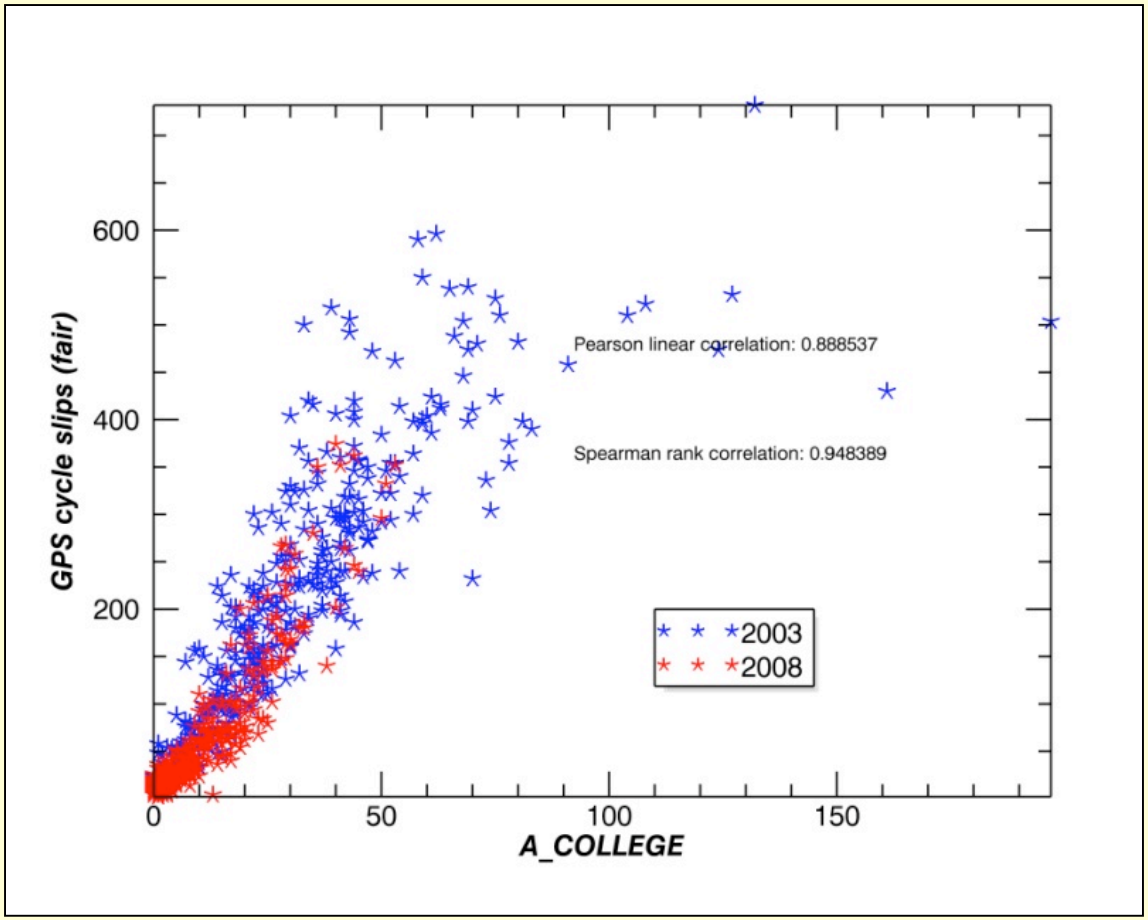
Fairbanks Cycle Slip Correlation



- Daily cycle slip count and College A-index data
- Note excellent correlation
- Also note the lack of separation between 2003 and 2008

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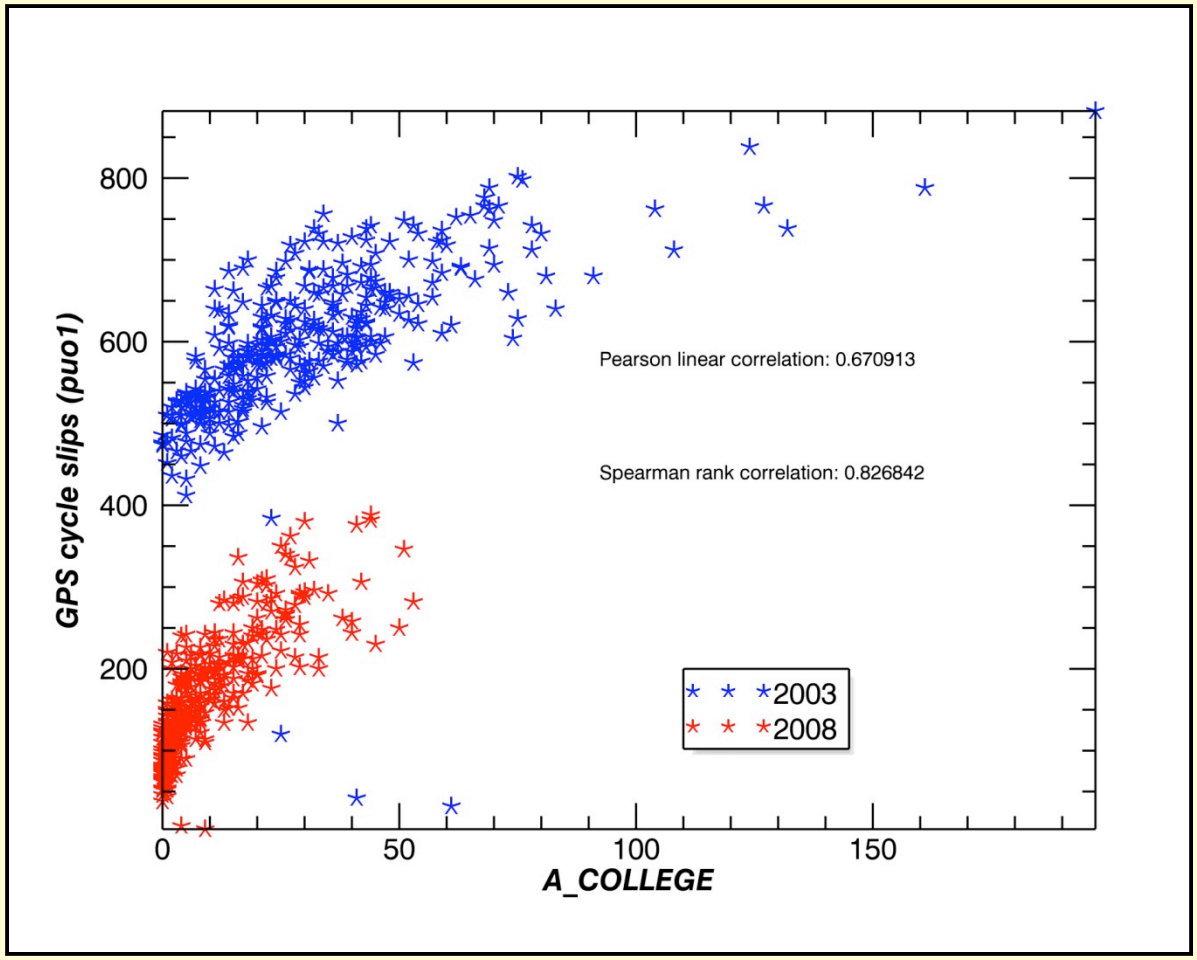
PUO1 Cycle Slip Correlation



- Strong Correlation
- Excellent separation in years

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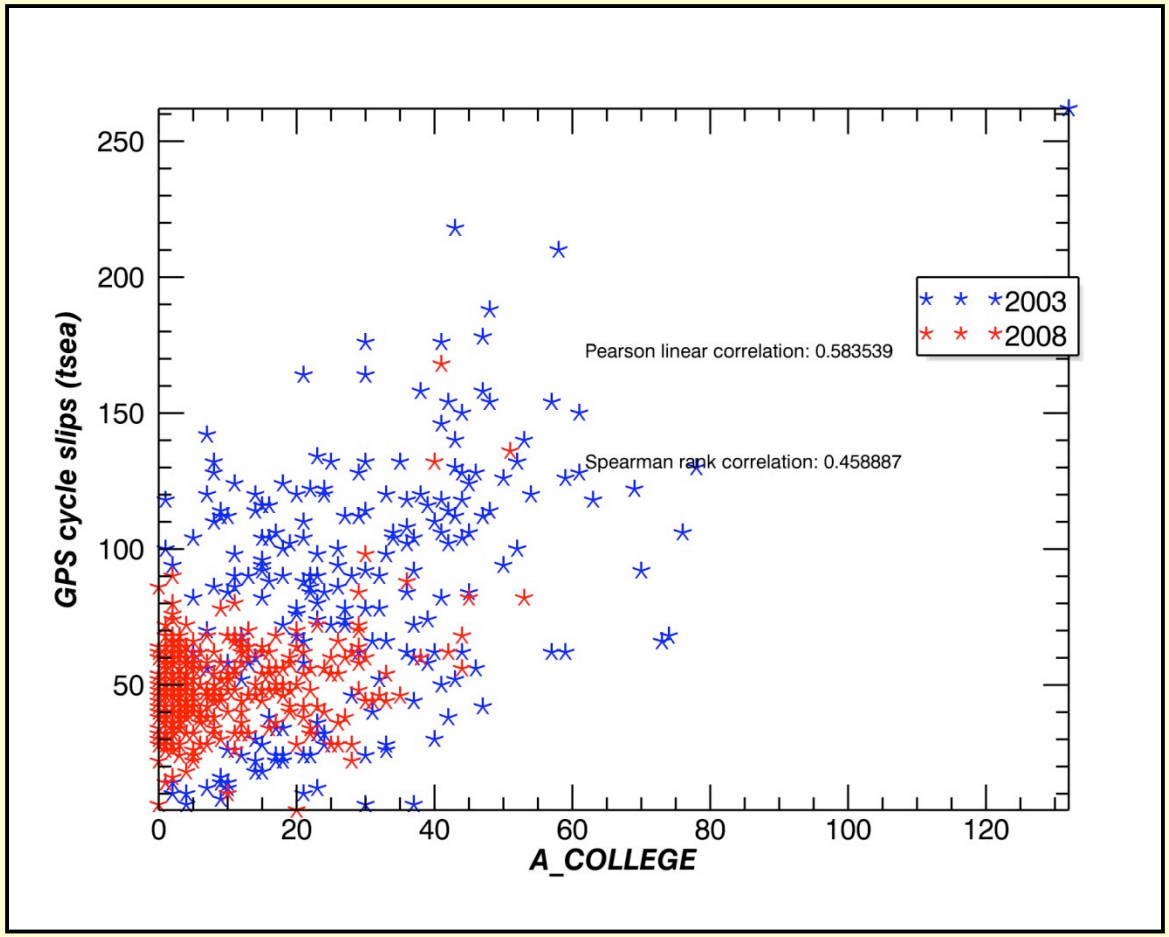
TSEA Cycle Slip Correlation



•Worst case out of the eight stations

•This station is located at a lower latitude than stronger cases

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Fair TS 2003

2003 Zoom

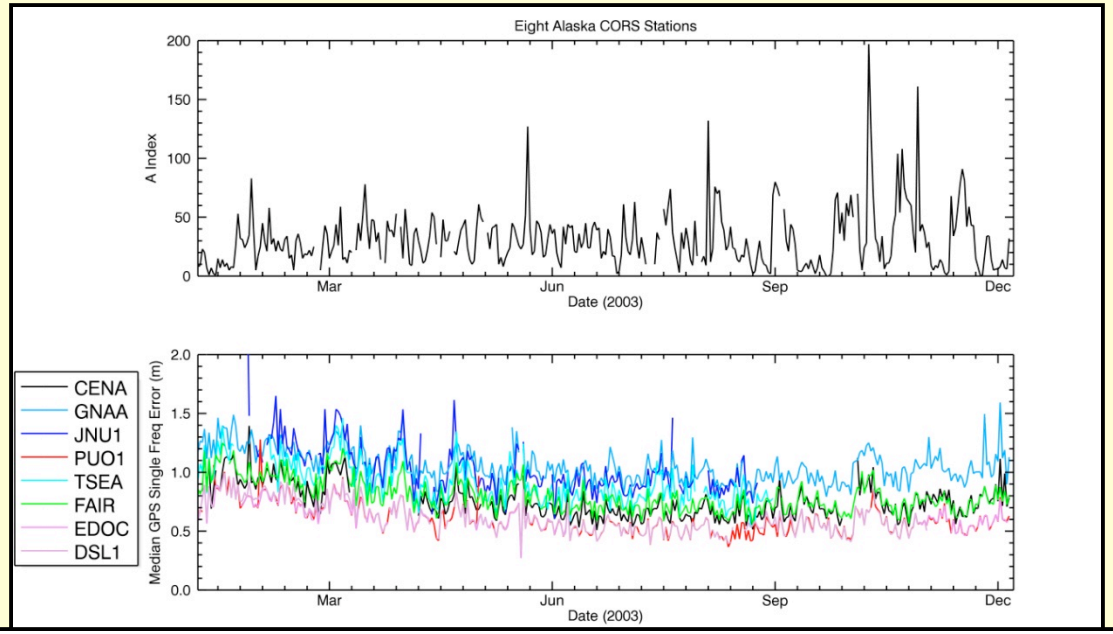
Fair TS 2008

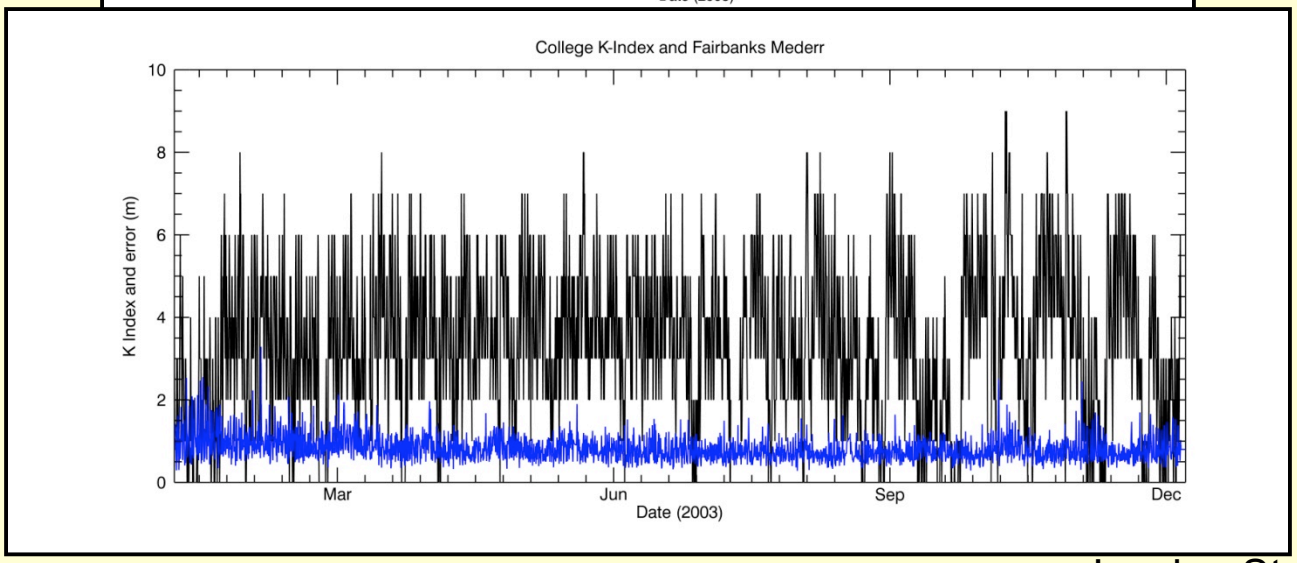
2008 Zoom

Fair Corr. 1

Fair Corr. 2

Fairbanks 2003 Time Series





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Fair TS 2003

2003 Zoom

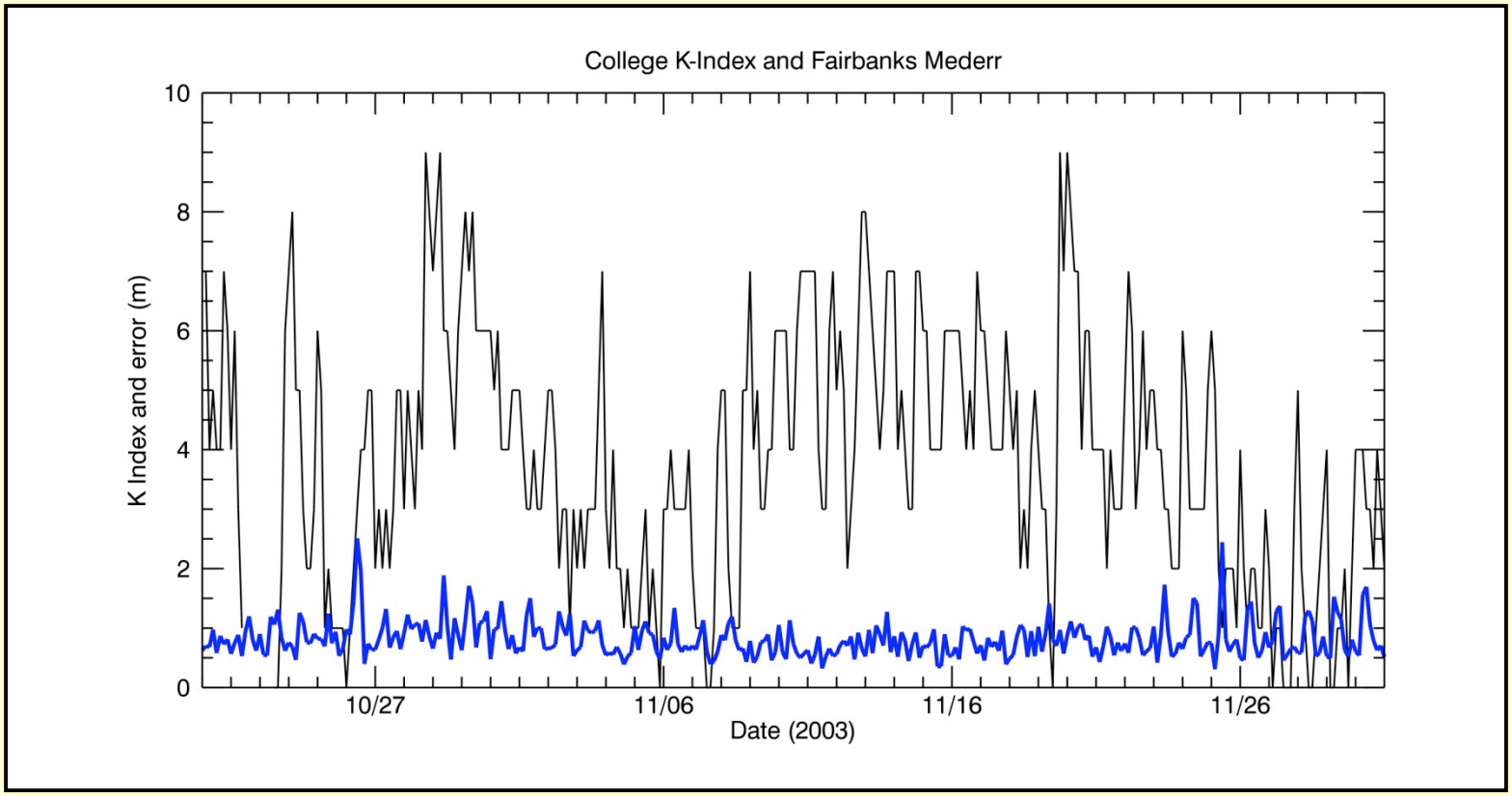
Fair TS 2008

2008 Zoom

Fair Corr. 1

Fair Corr. 2

Fairbanks 2003 Zoom In



- There doesn't seem to be an obvious direct or lagged correlation in this data.

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Fair TS 2003

2003 Zoom

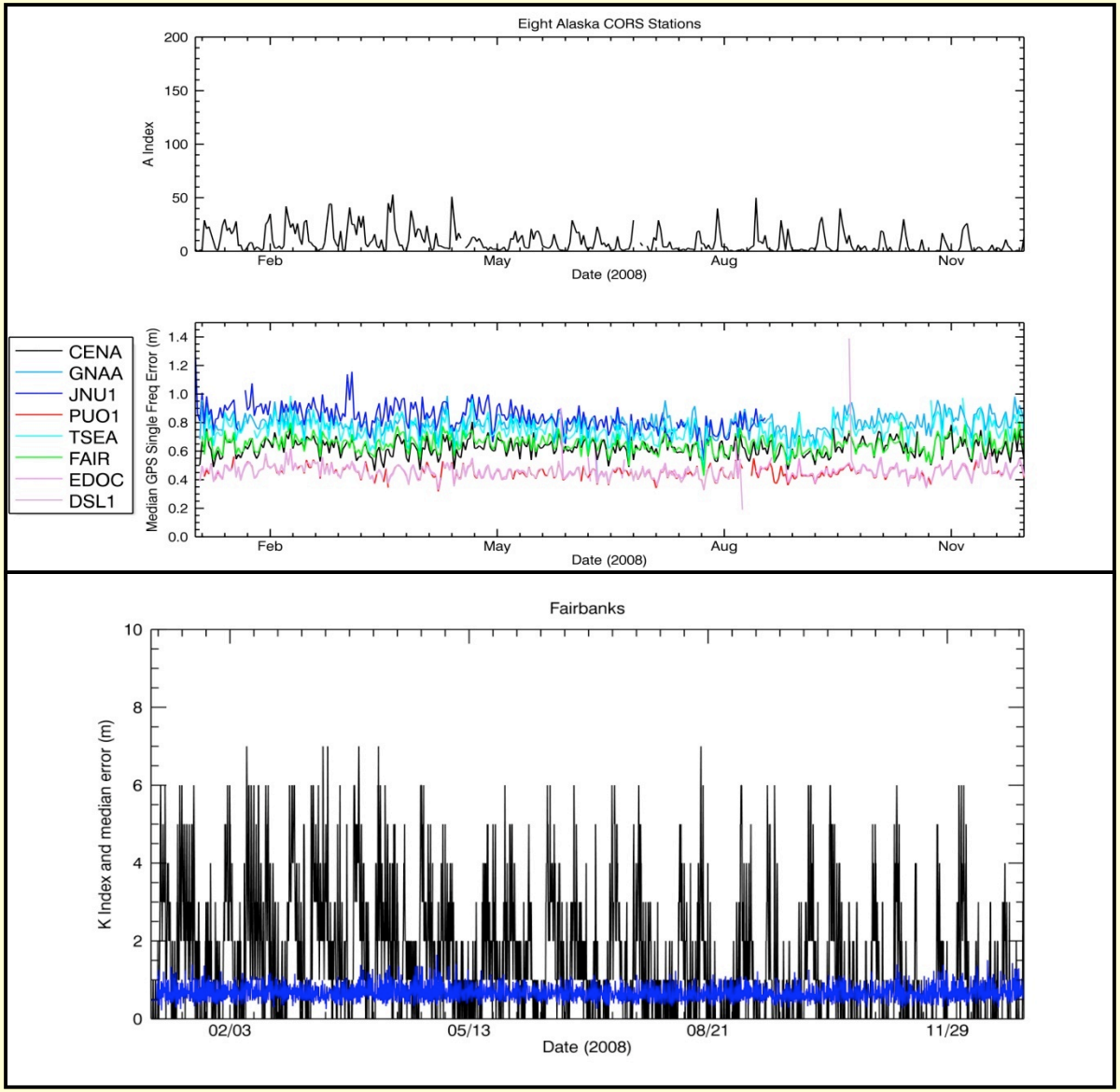
Fair TS 2008

2008 Zoom

Fair Corr. 1

Fair Corr. 2

Fairbanks 2008 Time Series



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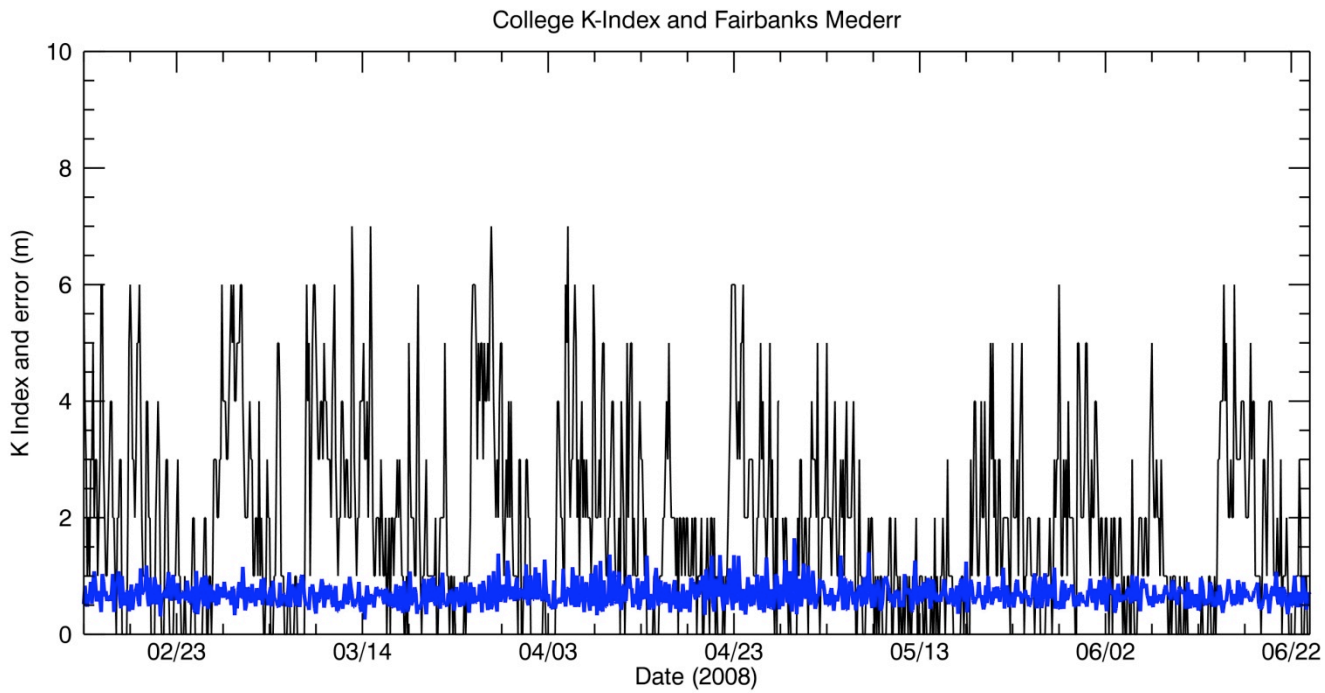
Fairbanks 2008 Zoom In



- Again there are no obvious correlations in 2008
- Interesting ~5-day periodic structure to GPS errors though

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2008 Zoom

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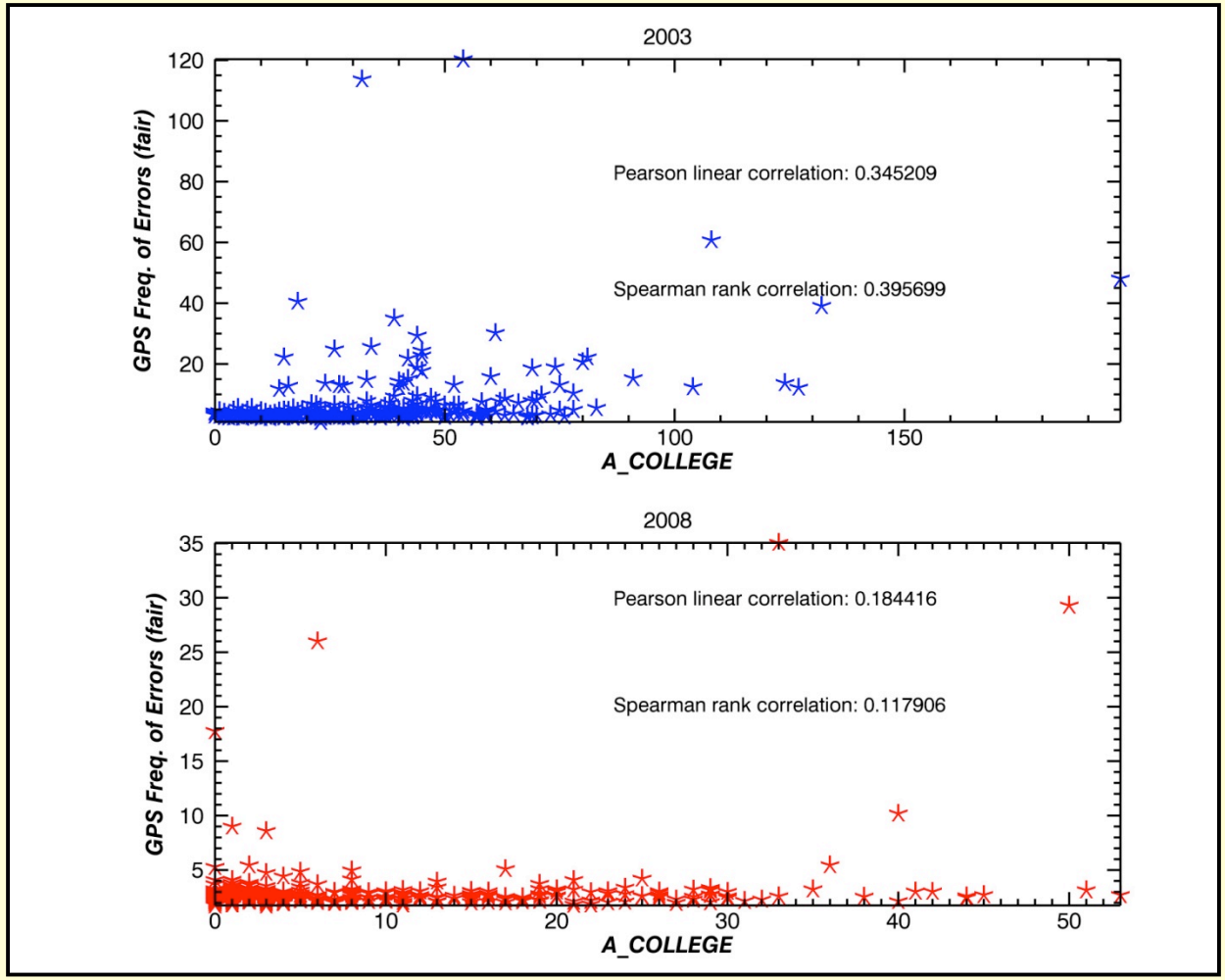
Fairbanks Daily Max Error Correlation



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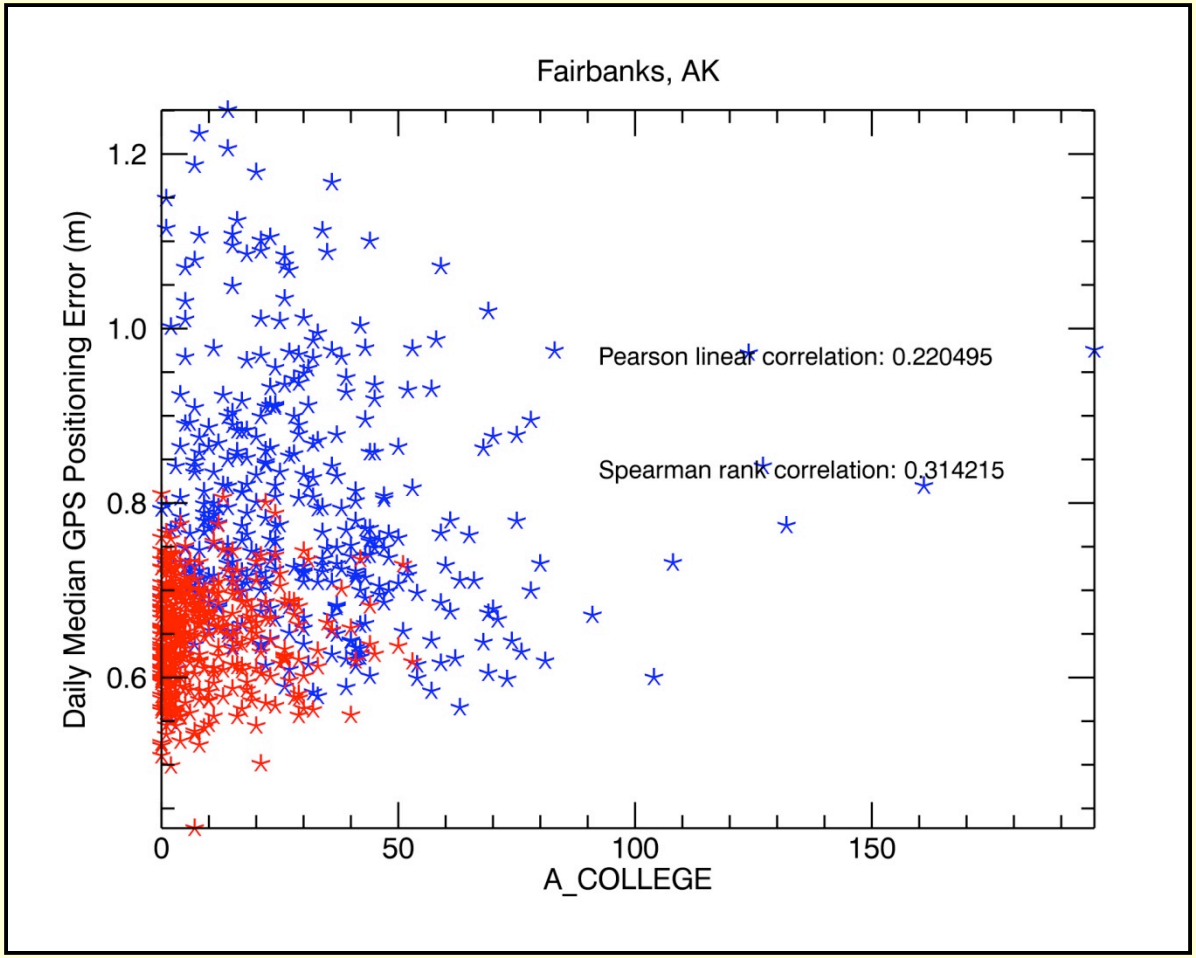
Fairbanks Daily Median Error Correlation



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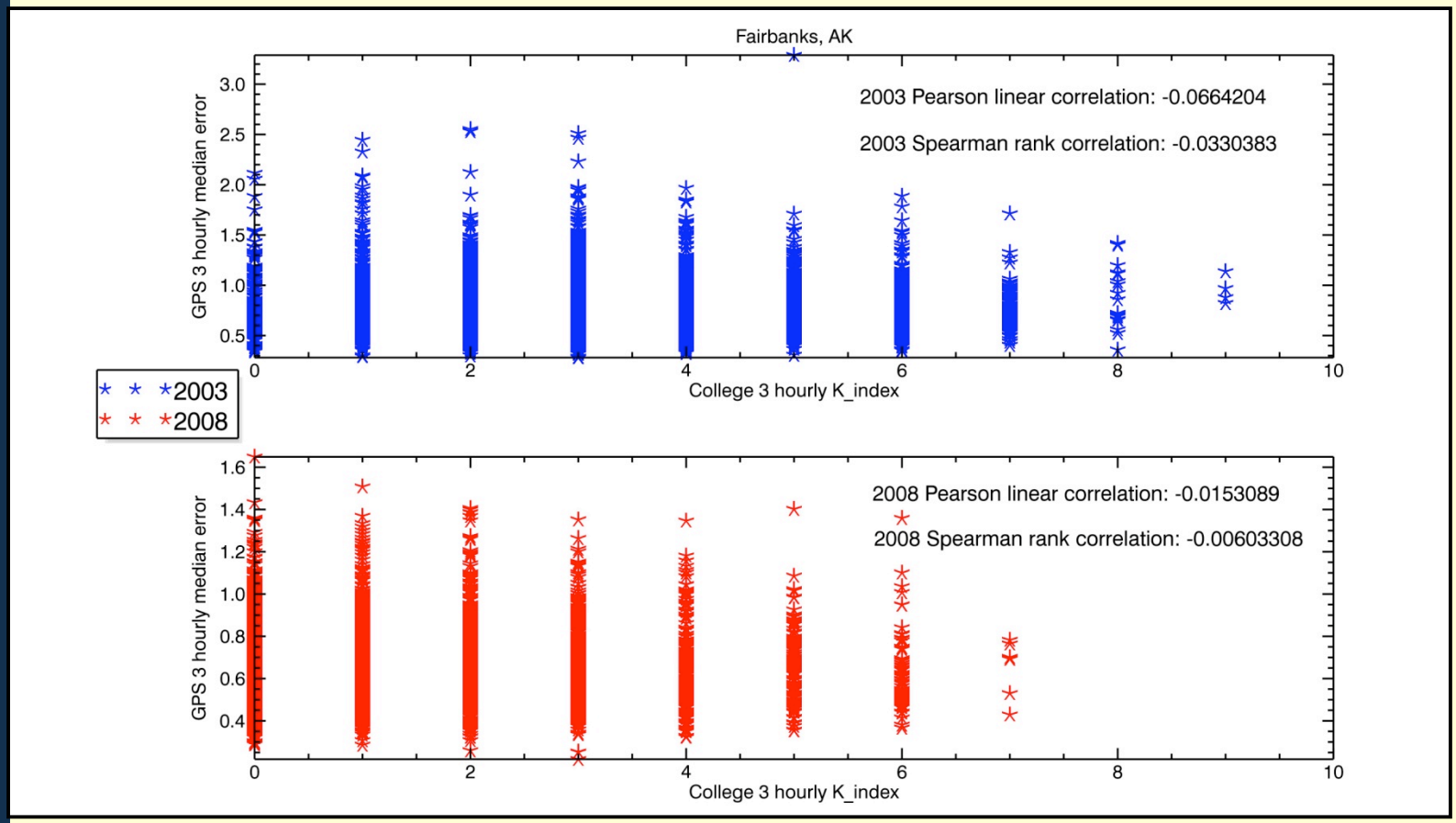
Fairbanks 3-hourly Median Error Correlation



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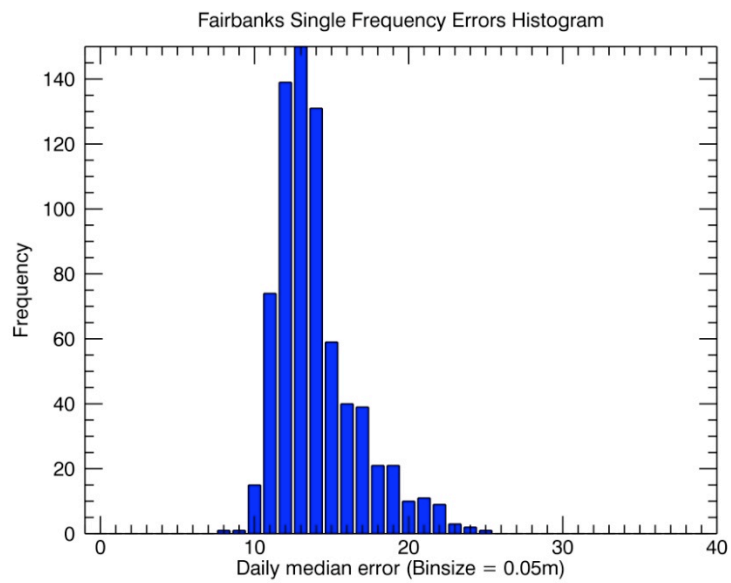
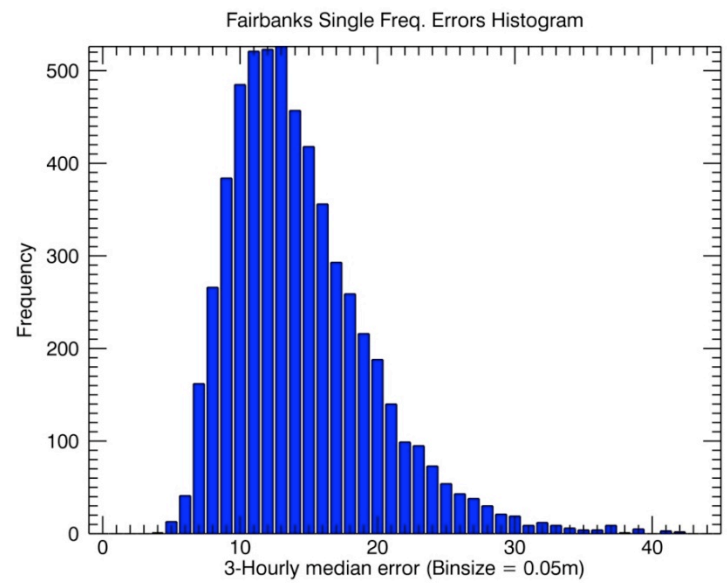
Fairbanks Histograms





- We were looking for a “circle of trust” and outer ring to subtract out noise

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Conclusions

- The daily number of GPS cycle slips in 2003 and 2008 are strongly correlated with the College daily A-index

- GPS positioning errors — inconclusive…a strong correlation with daily and 3-hourly geomagnetic indices was not found, but further investigation may yet reveal a

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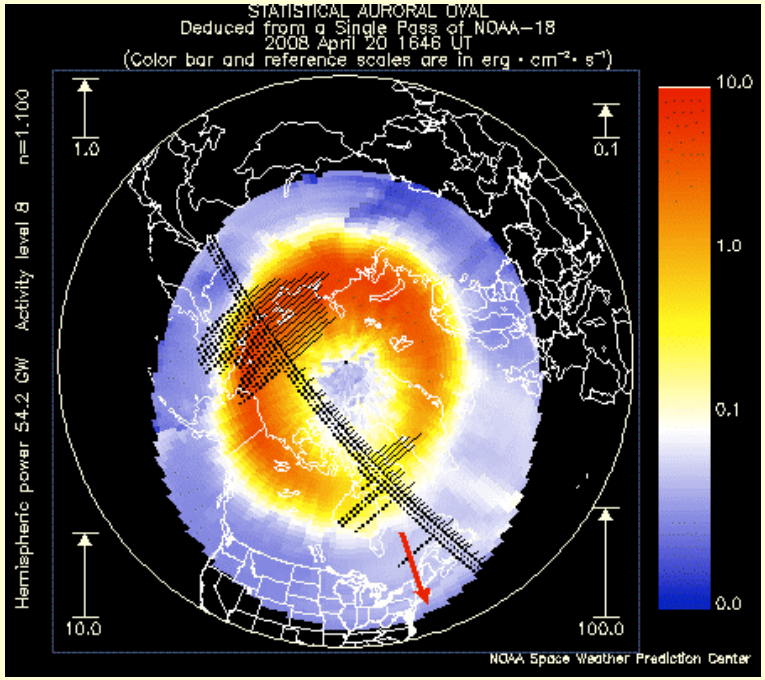
Future Work

With Current Data

- Running Average
- Weighted K-index
- Even higher granularity and interpolation
- Seasonal Analysis of Lags



With New Data

- Use of Auroral Oval Location/Intensity data (POES data)
- Include an elevation mask to eliminate multipath
- Replace (impute) missing data — when GPS really went haywire

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Acknowledgments

SWPC Project Help

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- Russel Henson
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- Erin Wood
- Robert Steenburgh

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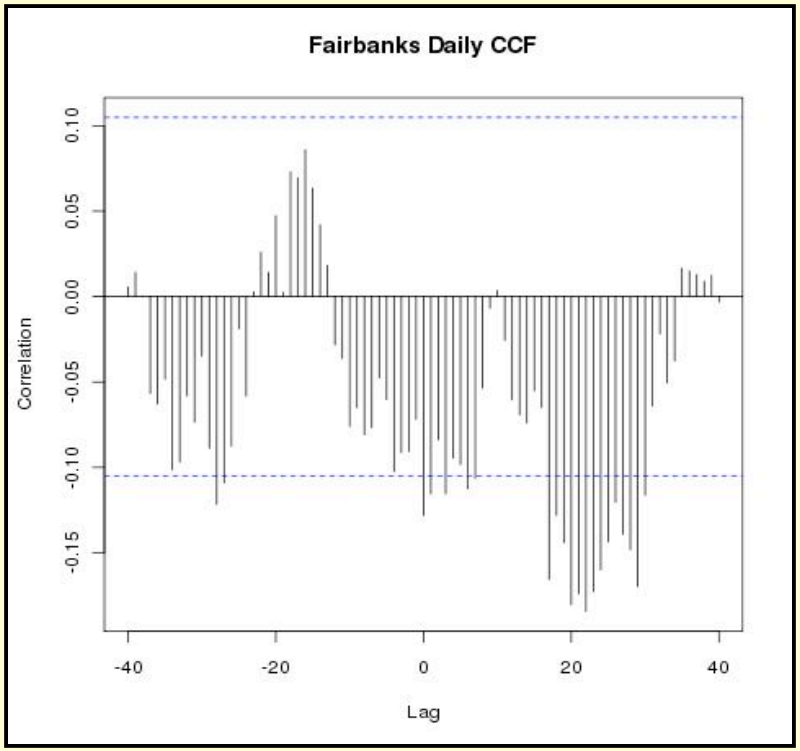
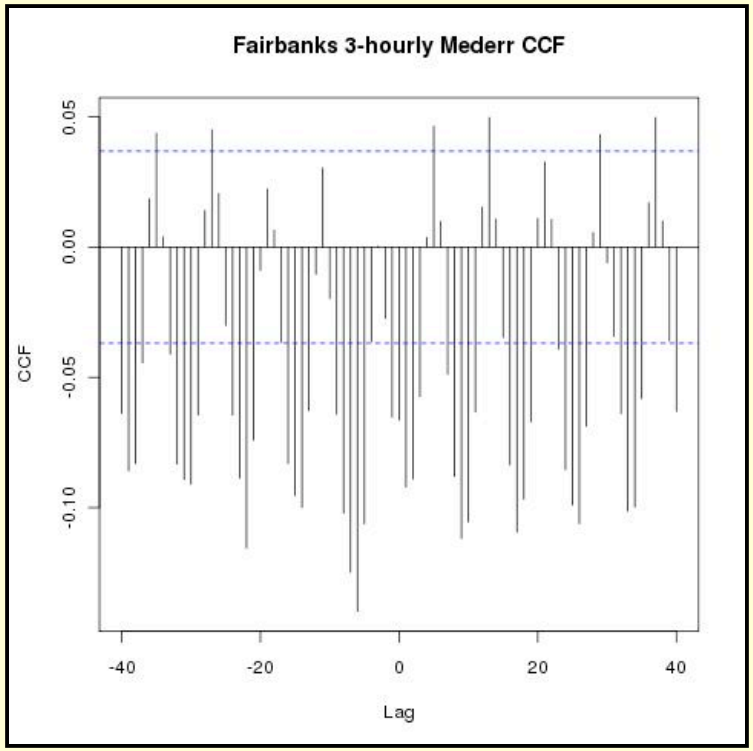
Fairbanks Lag Time Correlations



Daily Lags



3-hourly Lags