Development of the Ca II K-line Index

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Outline

- Definition of different Ca II K plage and plage+active network index time series.
- The Mount Wilson Solar Photographic Archive (MW-SPA).
- Comparison of the various Ca II K index time series.
- Comparison of the Ca II K index time series with the international sunspot number time series.

Importance of Ca II K observations

- They provide an important measure of solar magnetic activity. In particular, solar magnetic plages and network are easily observed in this strong chromospheric line, at 393.37 nm.
- Plages account for roughly one-half of the Sun’s total magnetic flux and for most of the Sun’s variability in UV flux.
- Ca II K observations started at the beginning of the 20th century at several observatories. These archives are of great importance for studies of the solar magnetism on time scales longer than the activity cycle.

Ca II K index and SSN Time series

- MWO-UCLA: 8/1915 - 7/1985
- MWO-UCLA extended using proxies: 8/1915 - present
- MWO-Tlatov: 8/1915 - 7/1985
- MWO-Apn (extended using proxies): 2/1916 - 4/1999
- Kodaikanal: 1907 - 1999
- International sunspot number: 1745 - present

Essential literature

- Foukal et al.: 2009, *A Century of Solar Ca II Measurements and Their Implication for Solar UV Driving of Climate*, Solar Physics 255, 229-238.
- Tlatov et al.: 2009, *A New Method of Calibration of Photographic Plates from Three Historic Data Sets*, Solar Physics 255, 239-251.
- Ermolli et al.: 2009, *Comparison Among Ca II K Spectroheliogram Time Series with an Application to Solar Activity Studies*, The Astrophysical Journal 698, 1000-1009.
- Bertello et al.: 2010, *The Mount Wilson Ca II K Plage Index Time Series*, Solar Physics 264, 31-44.

Ca II K plage indices

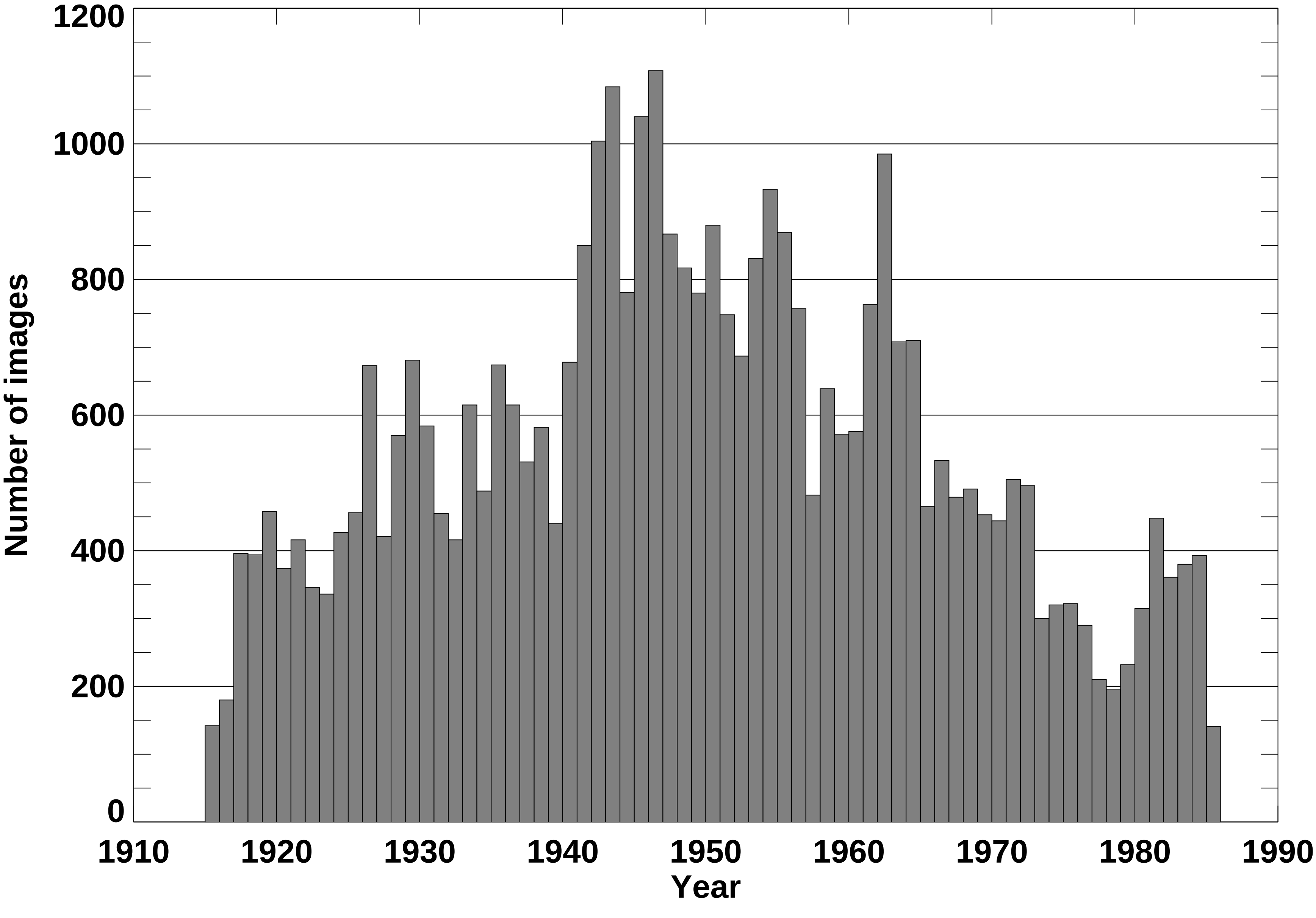
- MWO-UCLA: The index is derived from the properties of the intensity-ratio distribution of pixels across the image. The time series is extended using the MPSI as a proxy.
- MWO-Tlatov: The index is defined as the fraction of the solar hemisphere occupied by the chromospheric plages at any given time.
- MWO-Apn: The index is defined as the percentage of the solar disk covered by plages + active network. The original time series was extended using NSO/SP data.
- Kodaikanal (KKL): Same as MWO-Tlatov.
- Spectral bandpass (centered on K3): $\sim$0.35 Å for MWO observations, and $\sim$0.5 Å for KKL and NSO/SP observations.

The MW-SPA

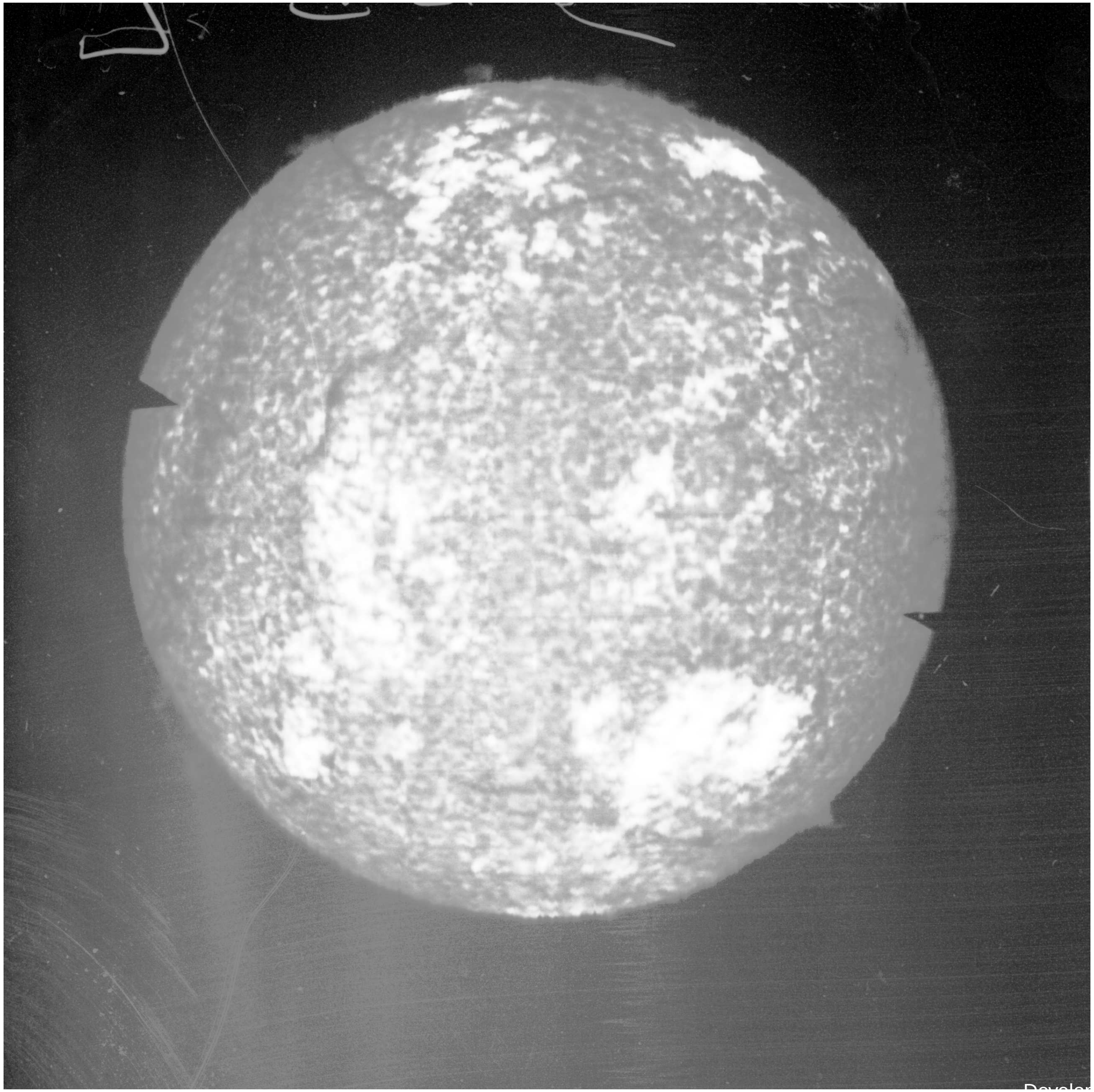
Starting in 1915 spectroheliograms in the light of the Ca II K line were taken twice per day at the Mount Wilson Solar Observatory. About the same time "white light" direct images were taken once per day.

- Approximately 45,000 images in the light of the Ca II K line, acquired from August 1915 to July 1985.
- Approximately 30,000 broad-band images (white light) acquired over the same time period.
- The spectroheliograms were first digitized by Foukal (1996) using a 512-pixel format, 8-bit camera.
- The same images were re-digitized (starting in 2003) at UCLA using a higher resolution (3000$\times$3000), 12-bit digitizer. Data from this reduction, including original log-book parameters of observation time and scan format, are available on-line.

Distribution of MWO Ca II K images



Ca II K: June 12, 1958



MWO-UCLA: Preliminary analysis

- Solar images are extracted and identified with original logbook parameters.
- The images were initially digitized with 12 bits of significant precision and up to 3000$\times$3000 spatial pixels, but then reduced in size and saved as FITS (16 bits, $\sim 866 \times 866$) files containing individual images.
- Small-scale dust and pit present in the images are reduced using a Laplacian filter.
- Radii and center of the image are determined from intensity gradients.
- Image orientation is available only for a limited number of images. In general, polar marks and cross-correlation methods can be used to determine the roll angle.

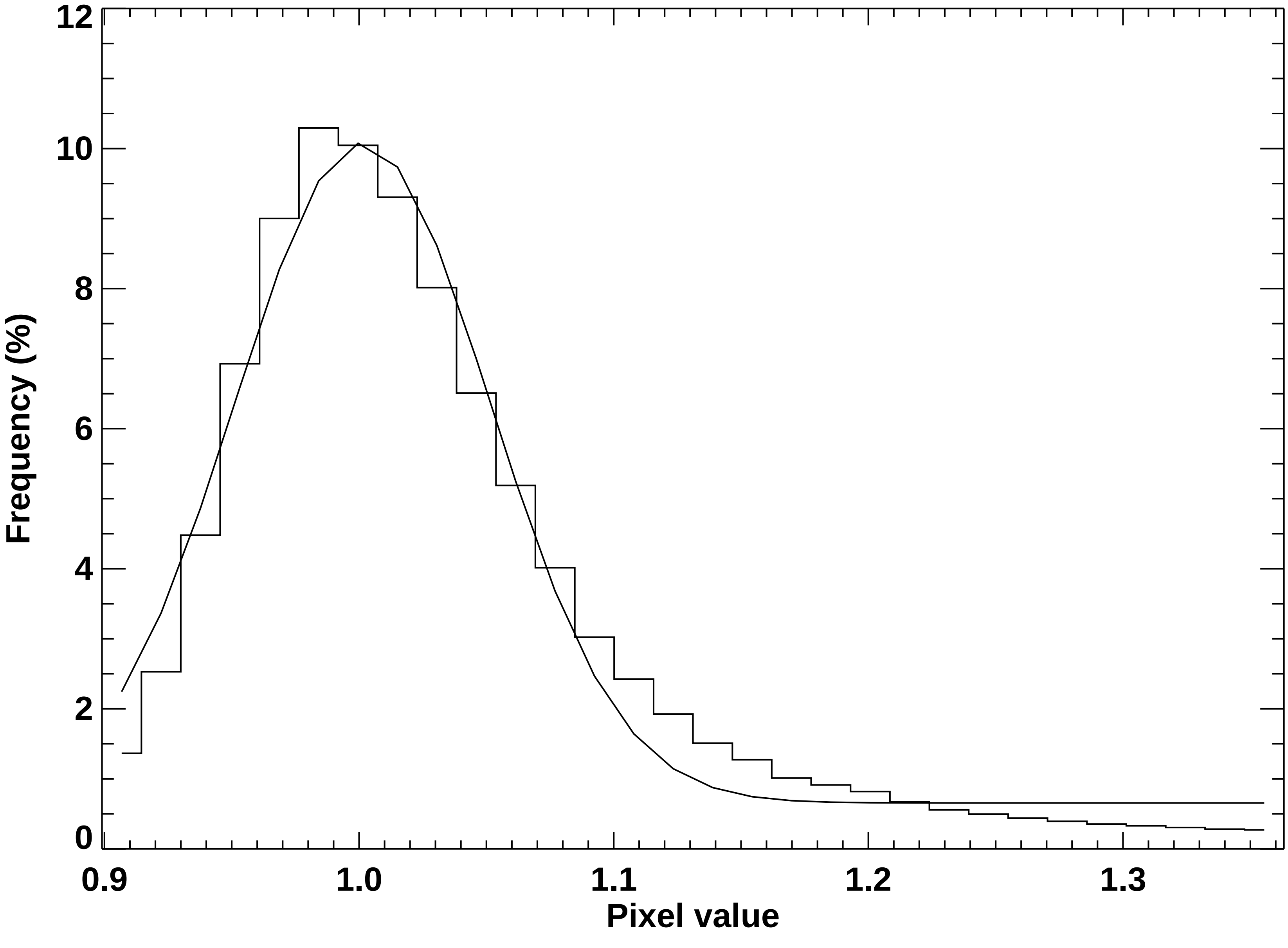
The UCLA Ca II K index

1. Each image is flat-fielded using a median filter.
2. A histogram is calculated using all pixels located within 0.99 solar radii from the center of the (flat-fielded) image.
3. A four-parameter Gaussian function is used to model this distribution:

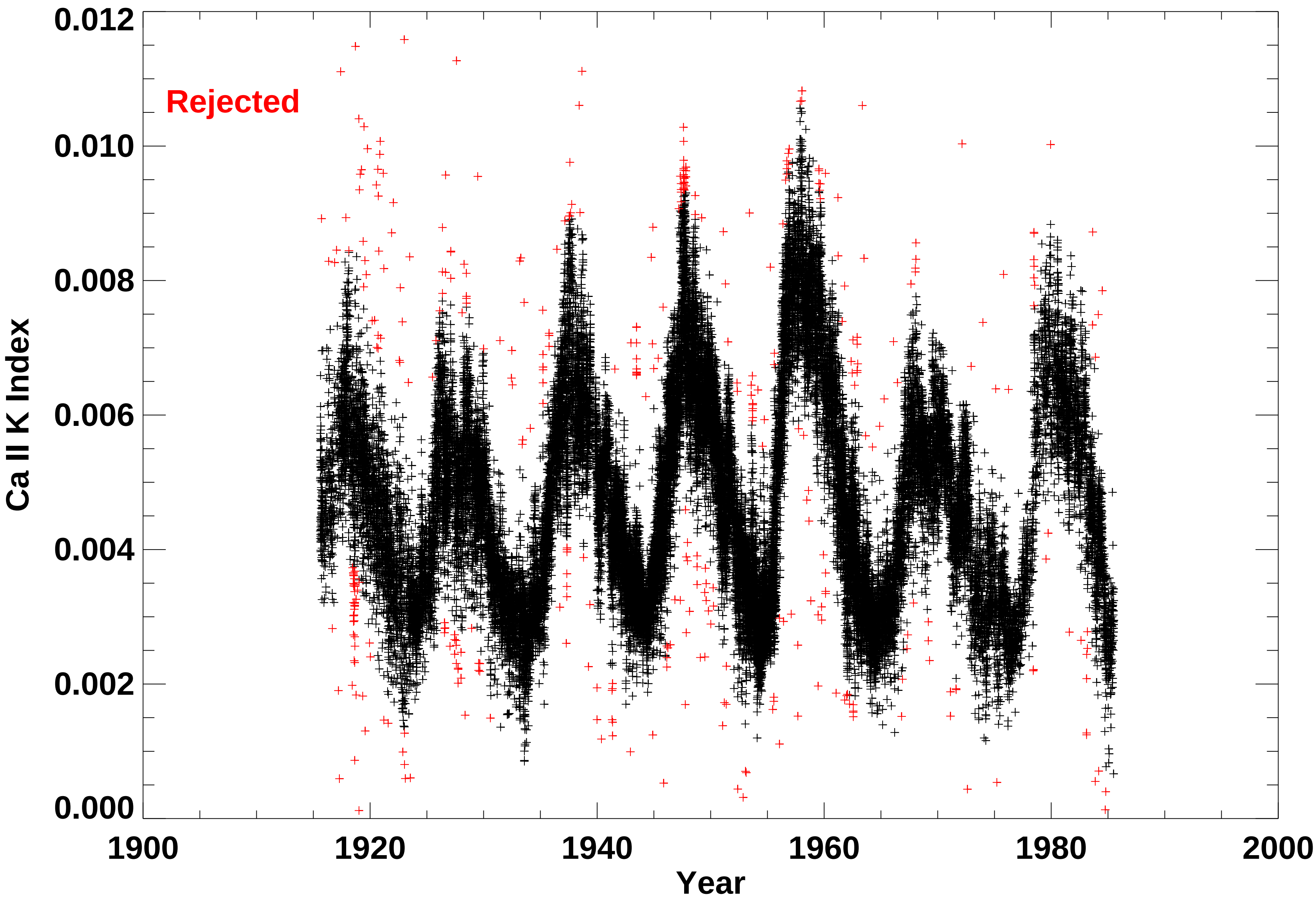
   $$y(x) = A \exp(-u^2/2) + B,$$

   where $u = (x - x_\mathrm{c})/\sigma$, x is the bin value, y is the fractional number of pixels in the solar disk with value x, σ and x_c are the width and the center of the distribution, respectively ($x_\mathrm{c} \approx 1$).
4. The constant baseline B is defined as the Ca II K index.
5. The parameter σ is related to the plage contrast.

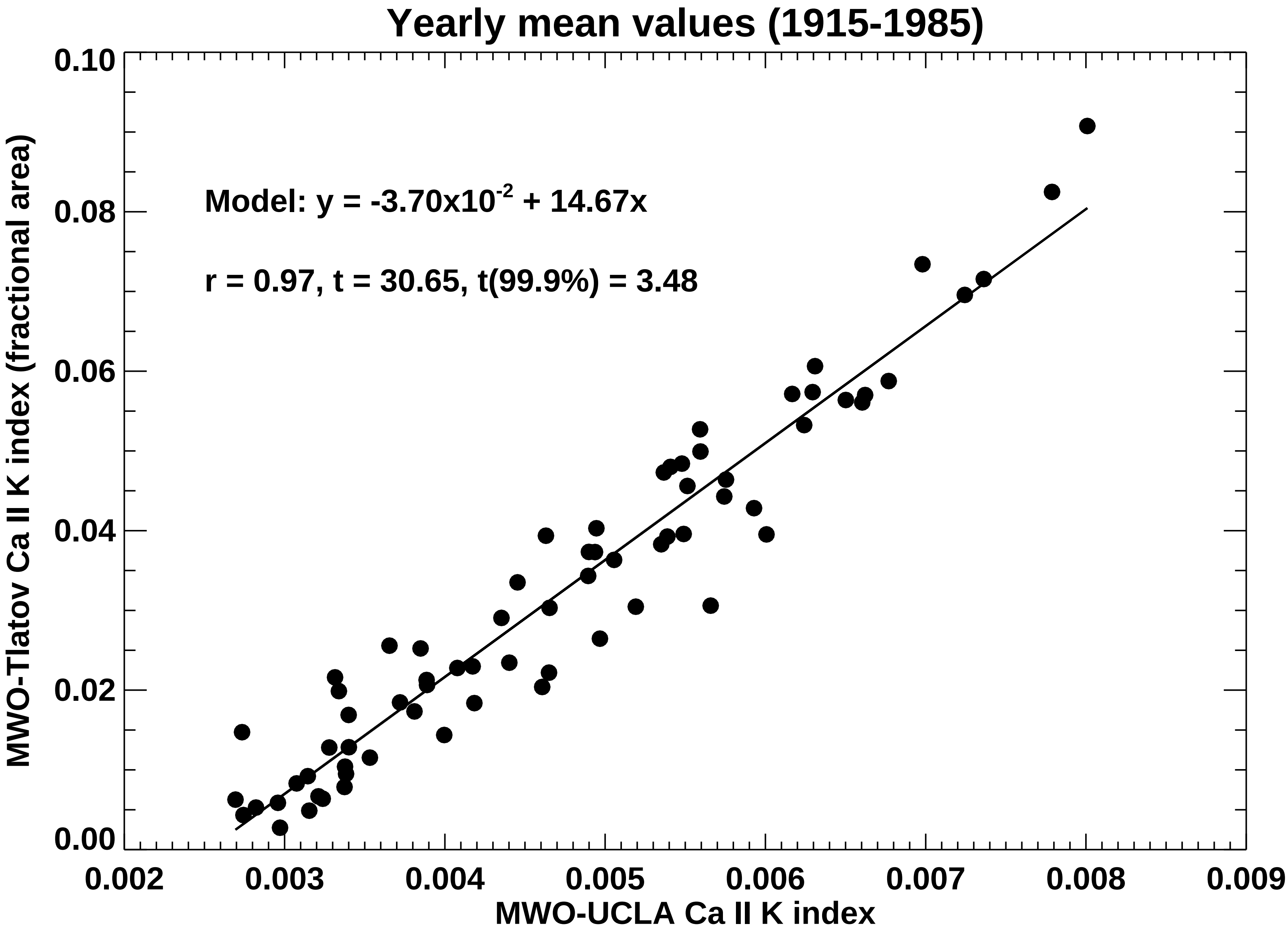
Intensity-ratio distribution (7/2/1970)



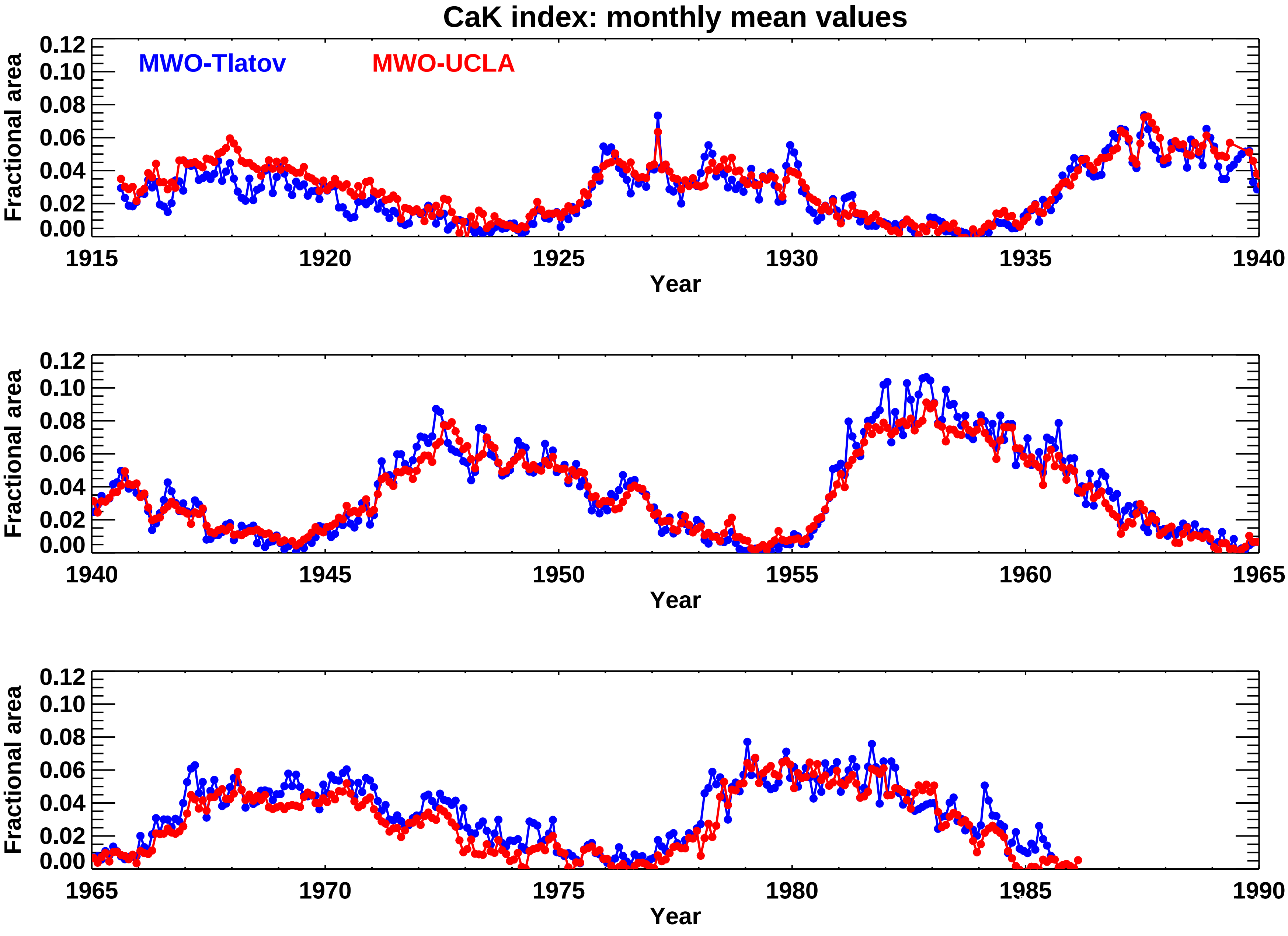
MWO-UCLA: Computed index



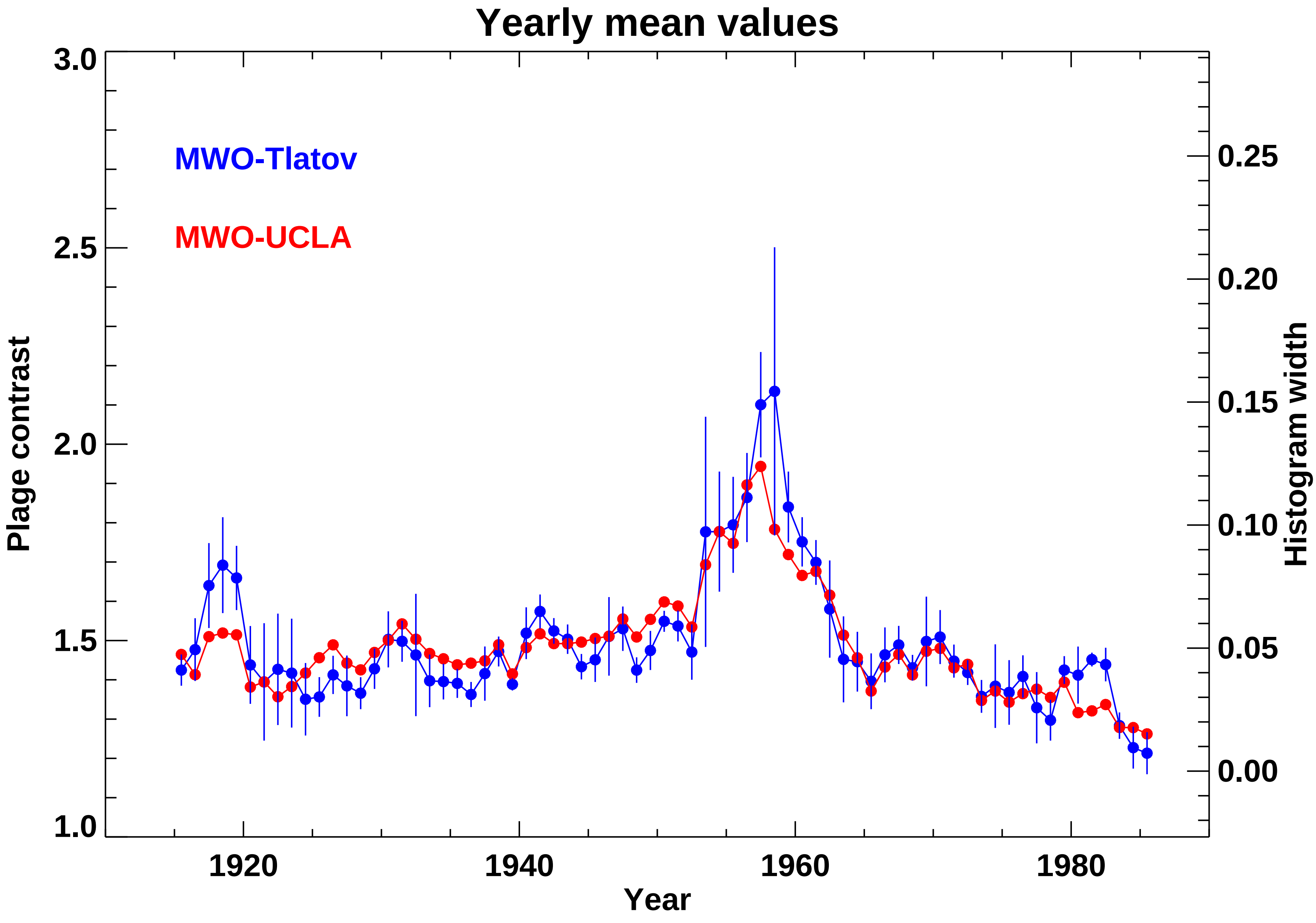
Rescaling the MWO-UCLA time series



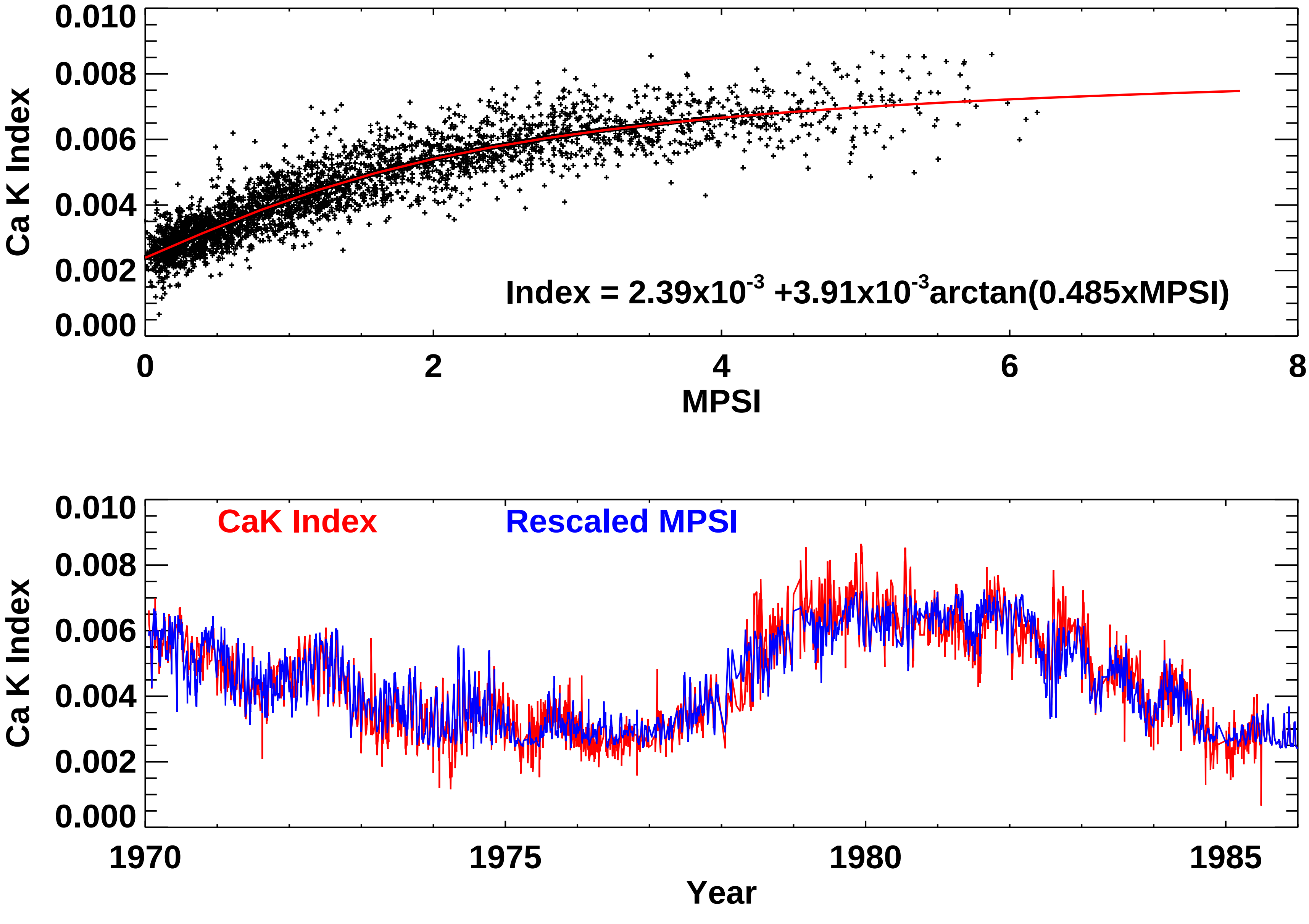
MWO-UCLA vs. MWO-Tlatov



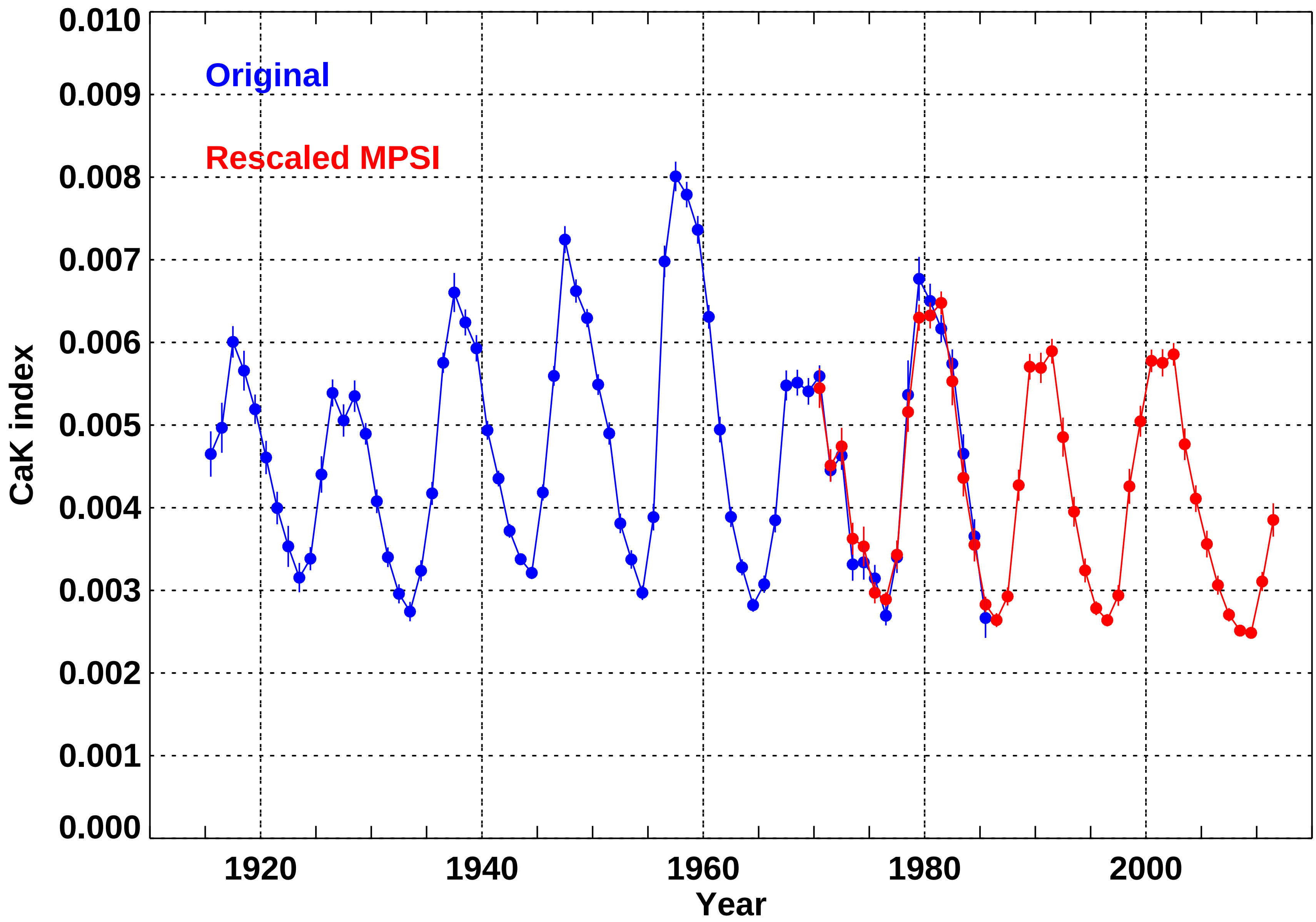
Plage contrast comparison



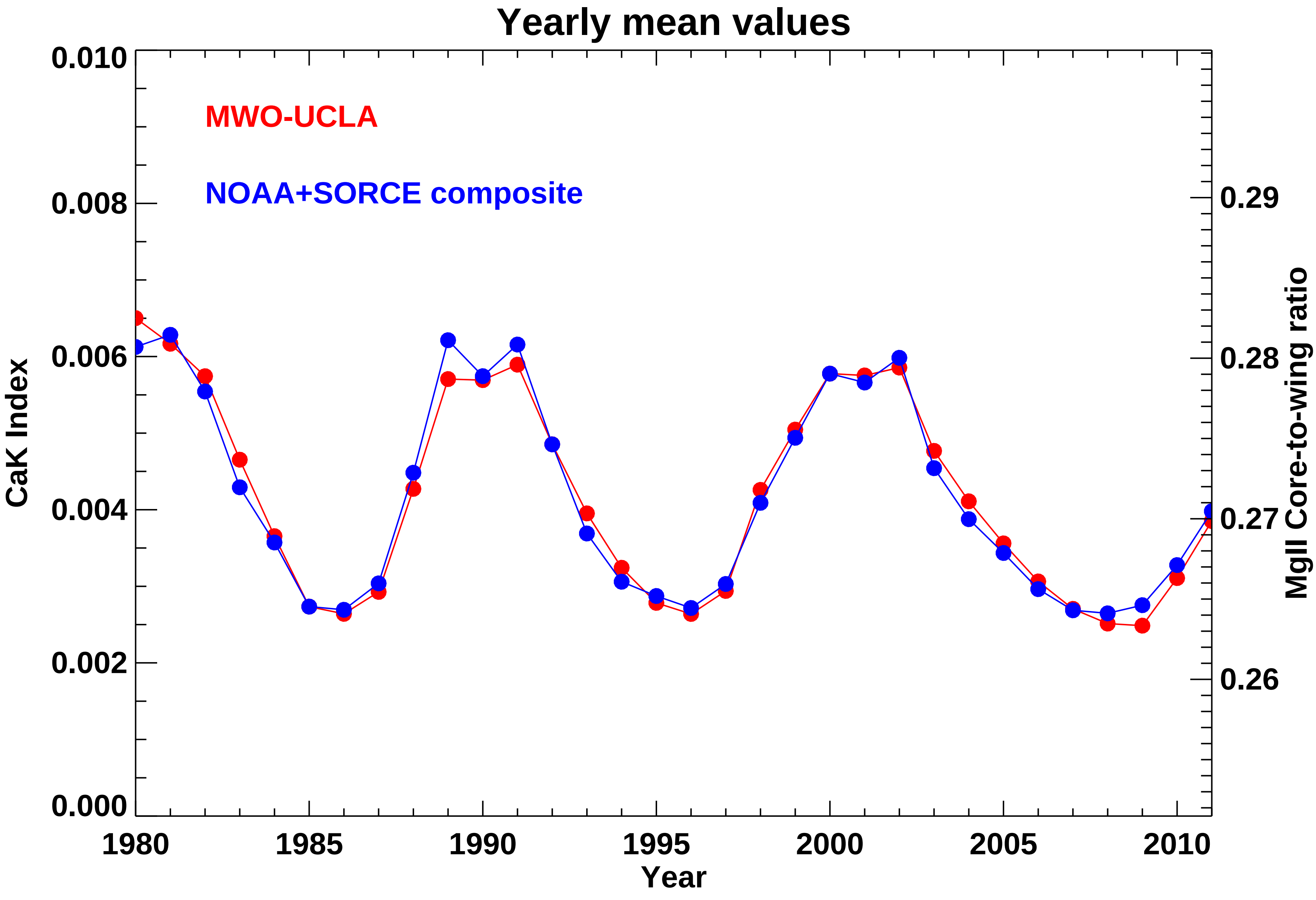
MWO-UCLA Ca II K index vs. MPSI



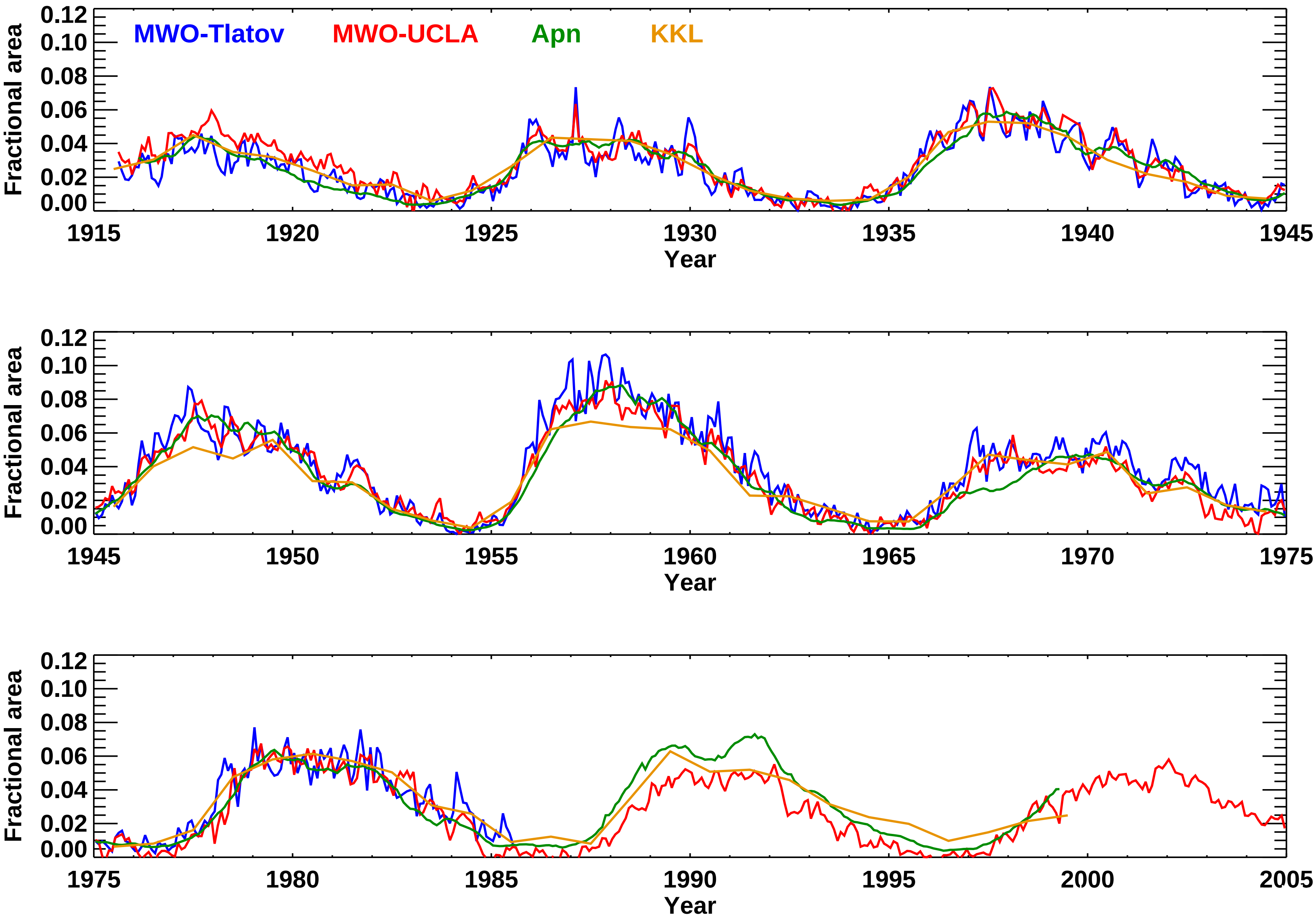
Extended MWO-UCLA Ca II K series



Mg II core-to-wing



Ca K index time series

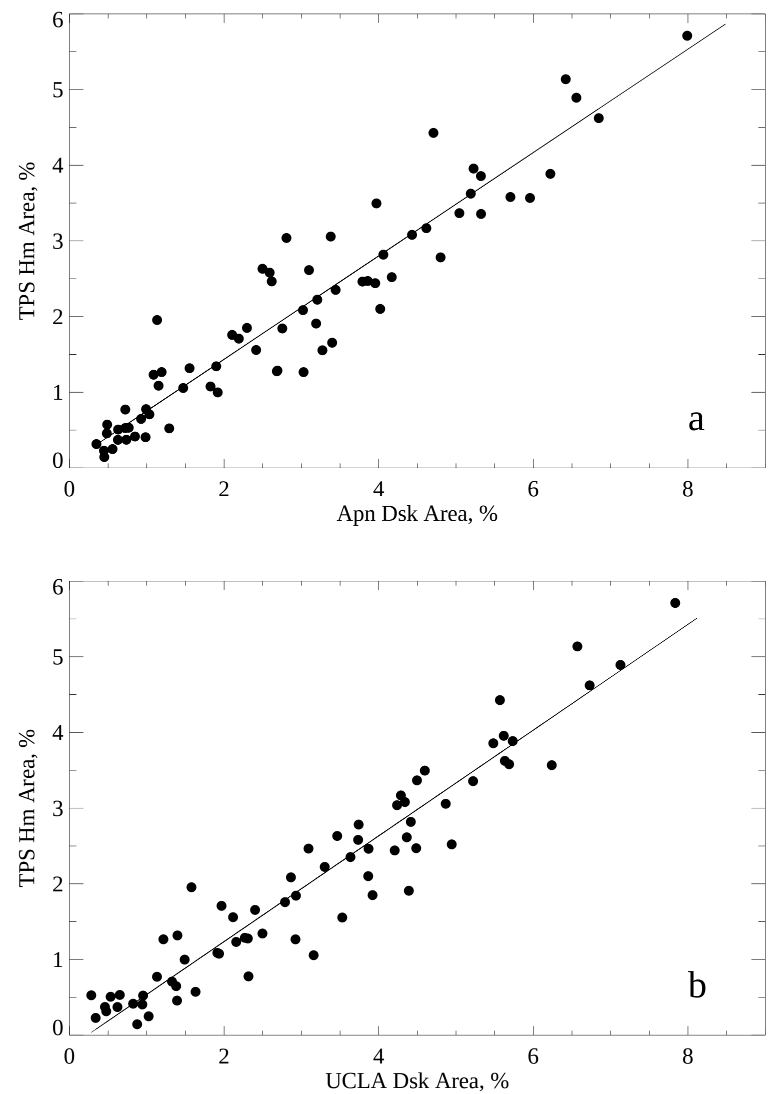


Ca K index: Correlation matrix

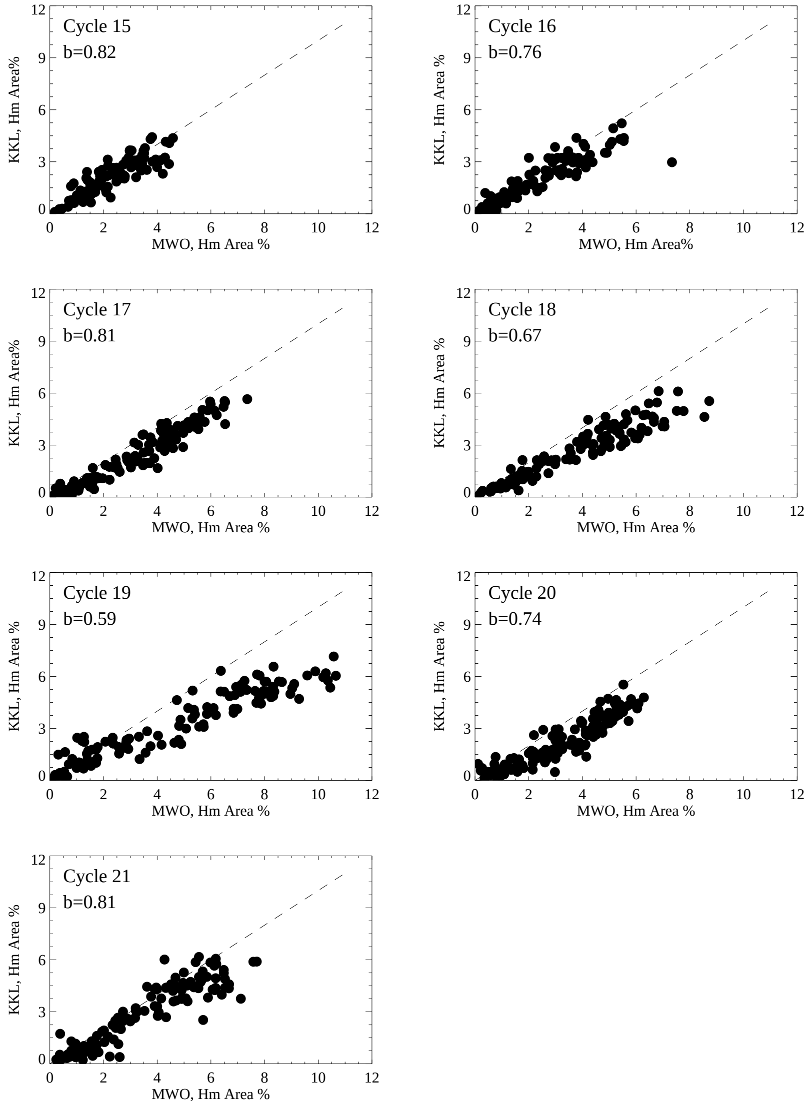
The correlation matrix has been computed using the yearly mean values of each time series from 1916 to 1985.

	Tlatov	UCLA	Apn	KKL
Tlatov	1	0.966	0.969	0.959
UCLA	0.966	1	0.972	0.964
Apn	0.969	0.972	1	0.943
KKL	0.959	0.964	0.943	1

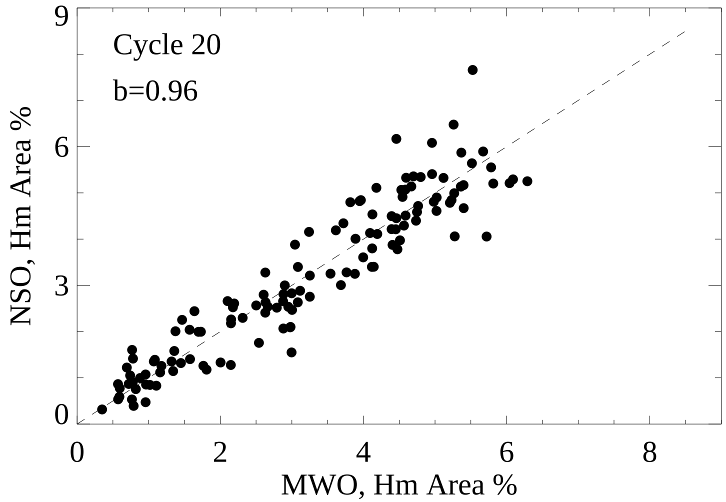
Ca II K index: Correlations

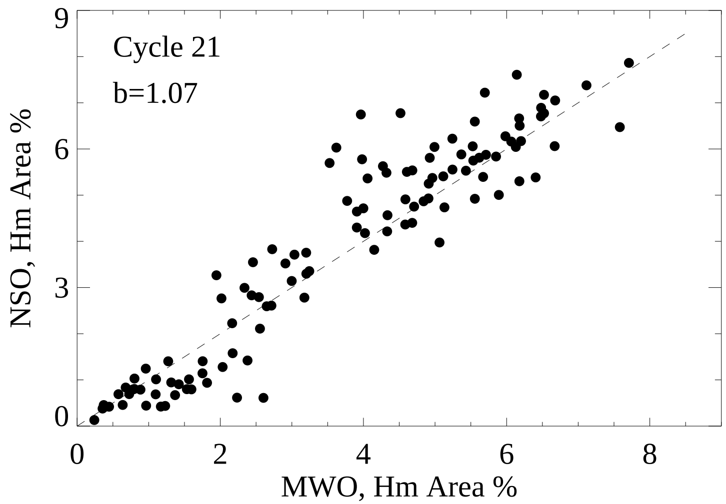


Correlations by solar cycles

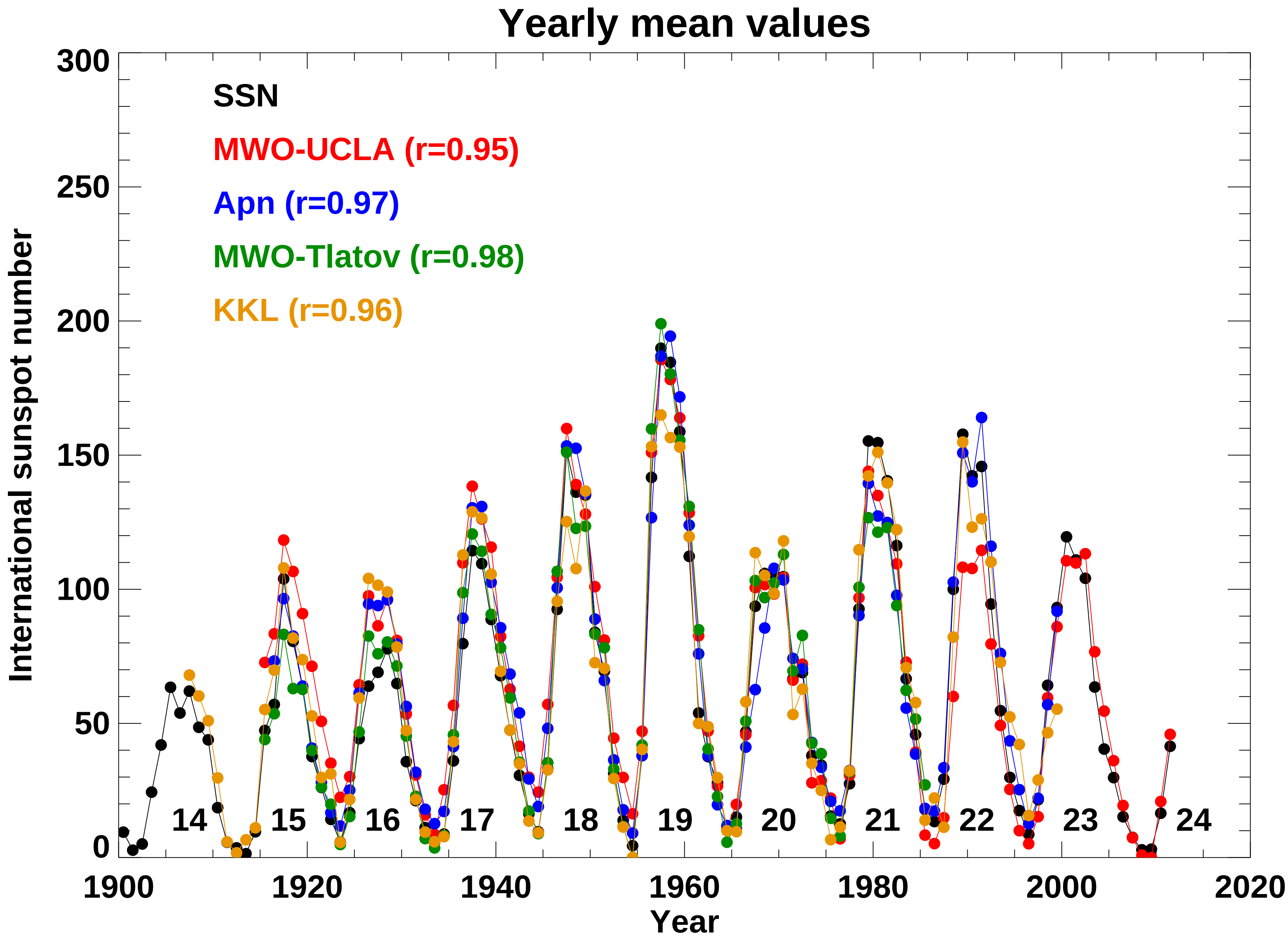


MWO-Tlatov vs. NSO/SP

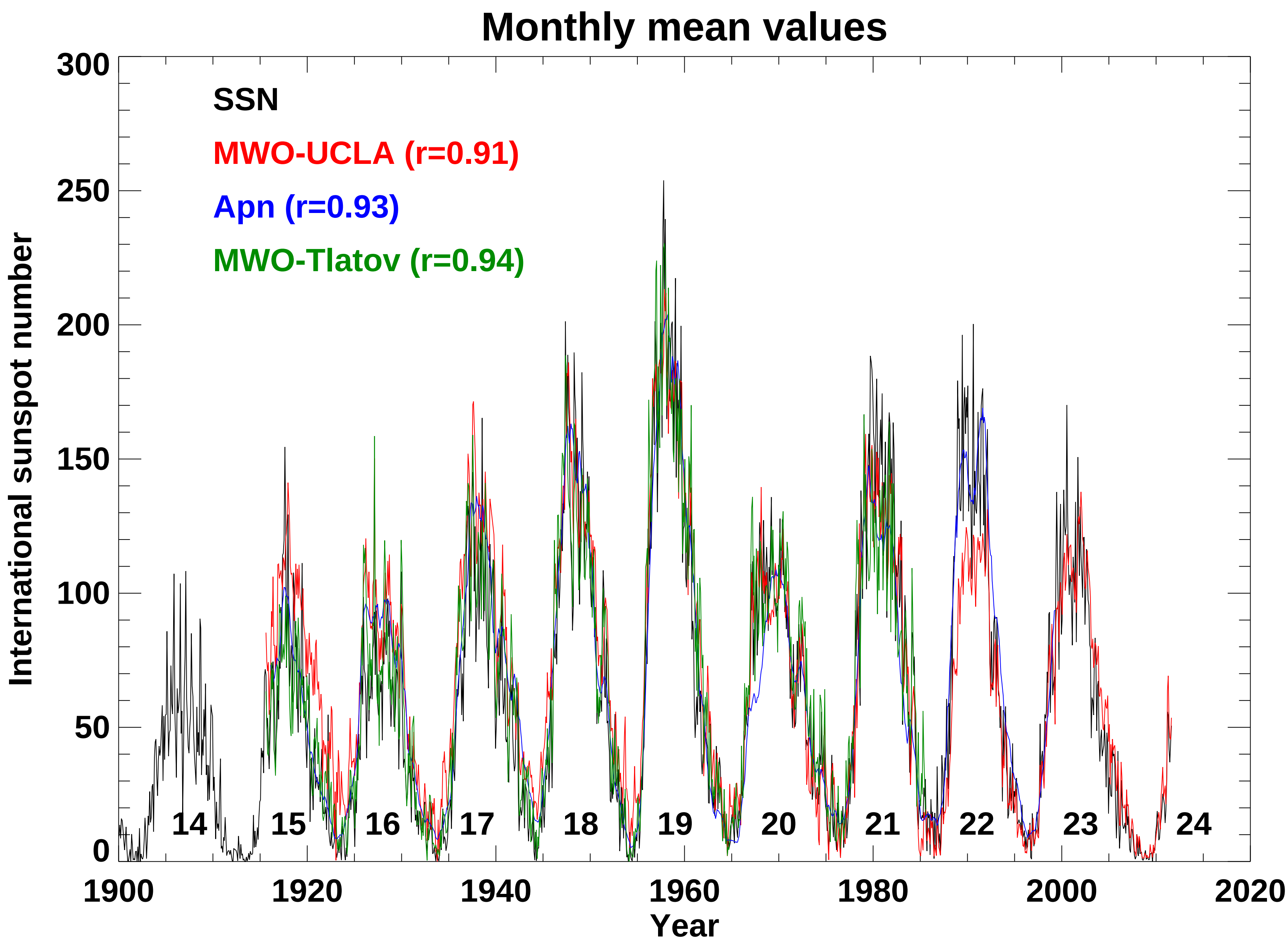




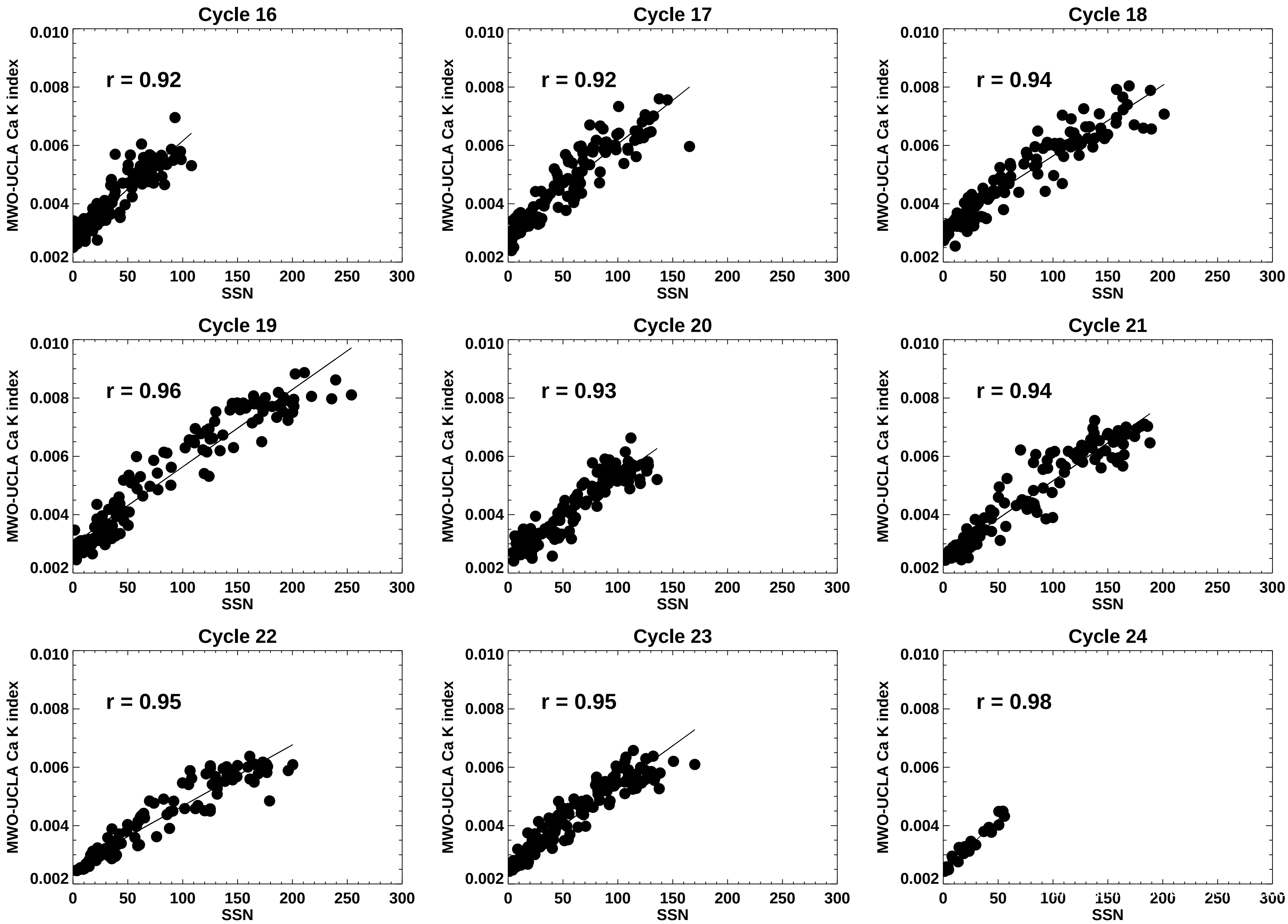
Ca K index vs. SSN series - 1



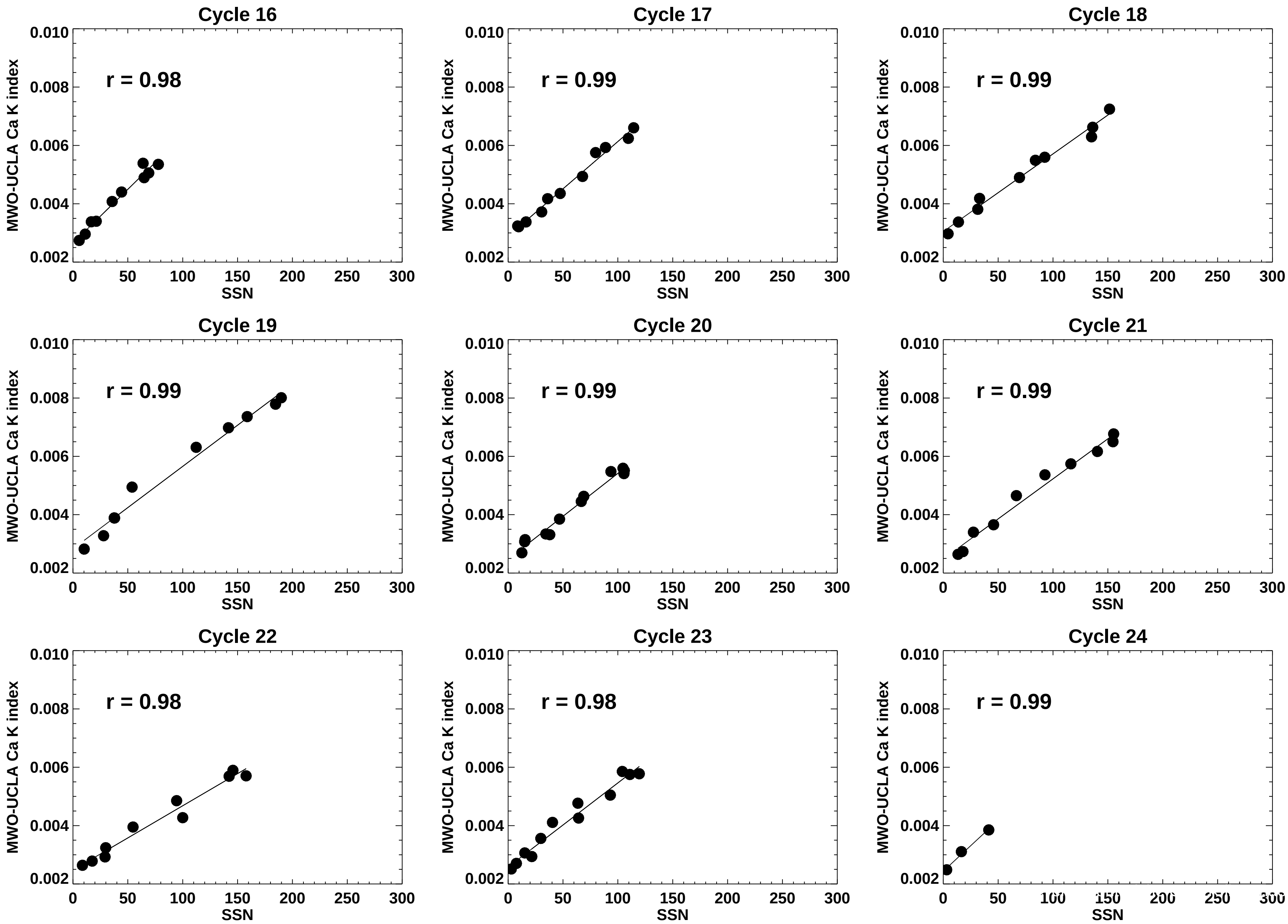
Ca K index vs. SSN series - 2



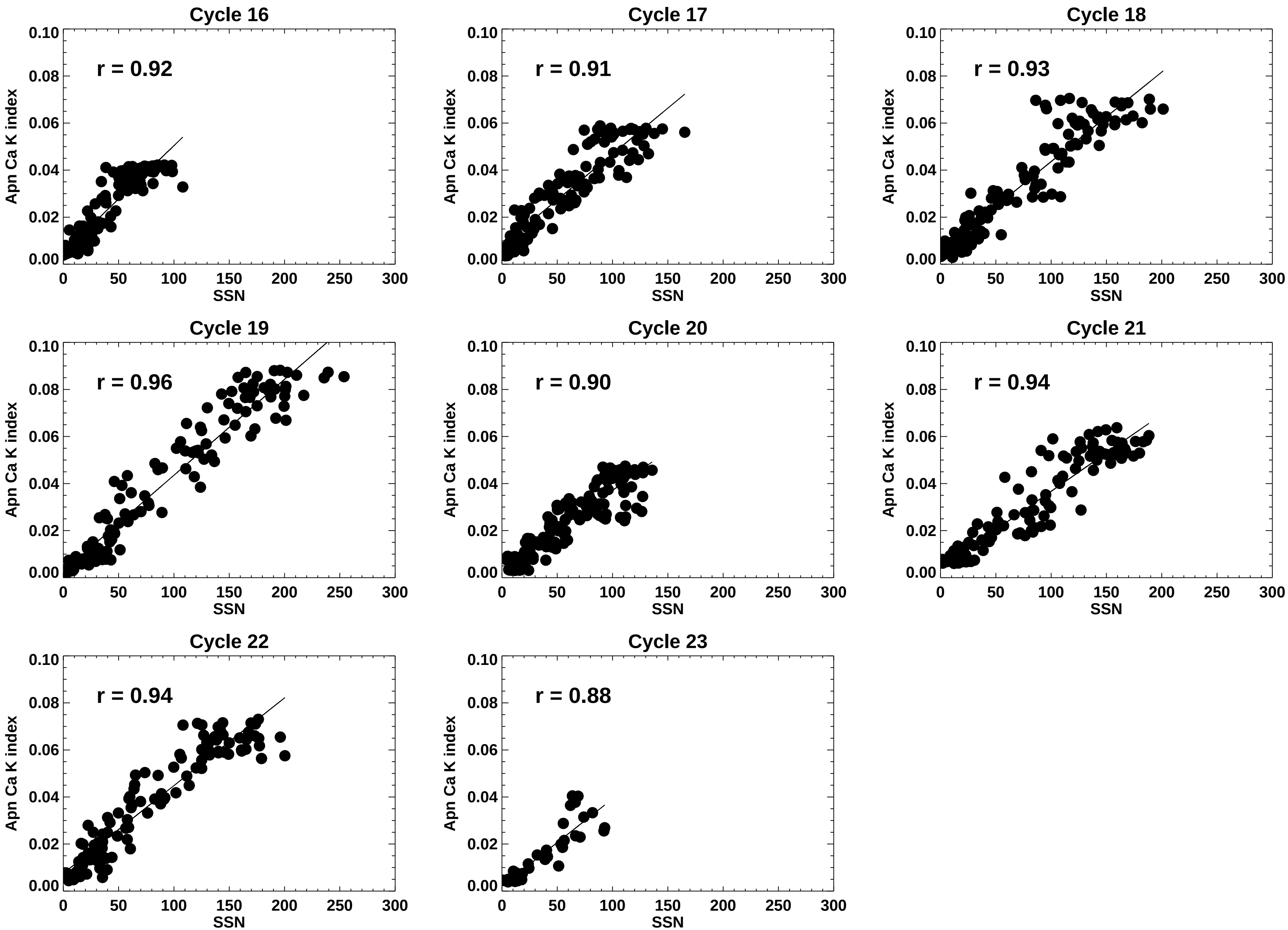
$r_{SSN,UCLA}$ cycle by cycle - 1



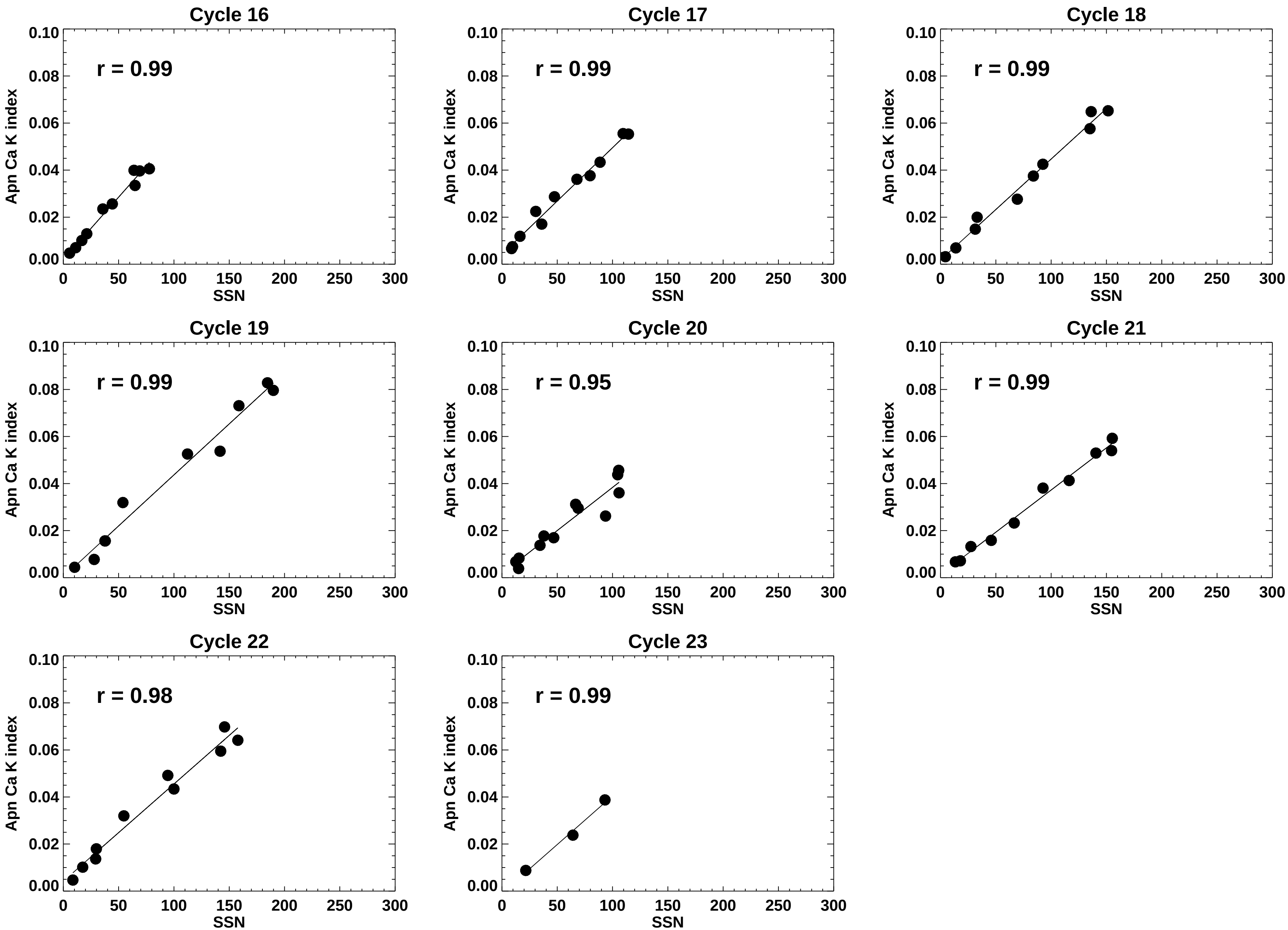
$r_{SSN,UCLA}$ cycle by cycle - 2



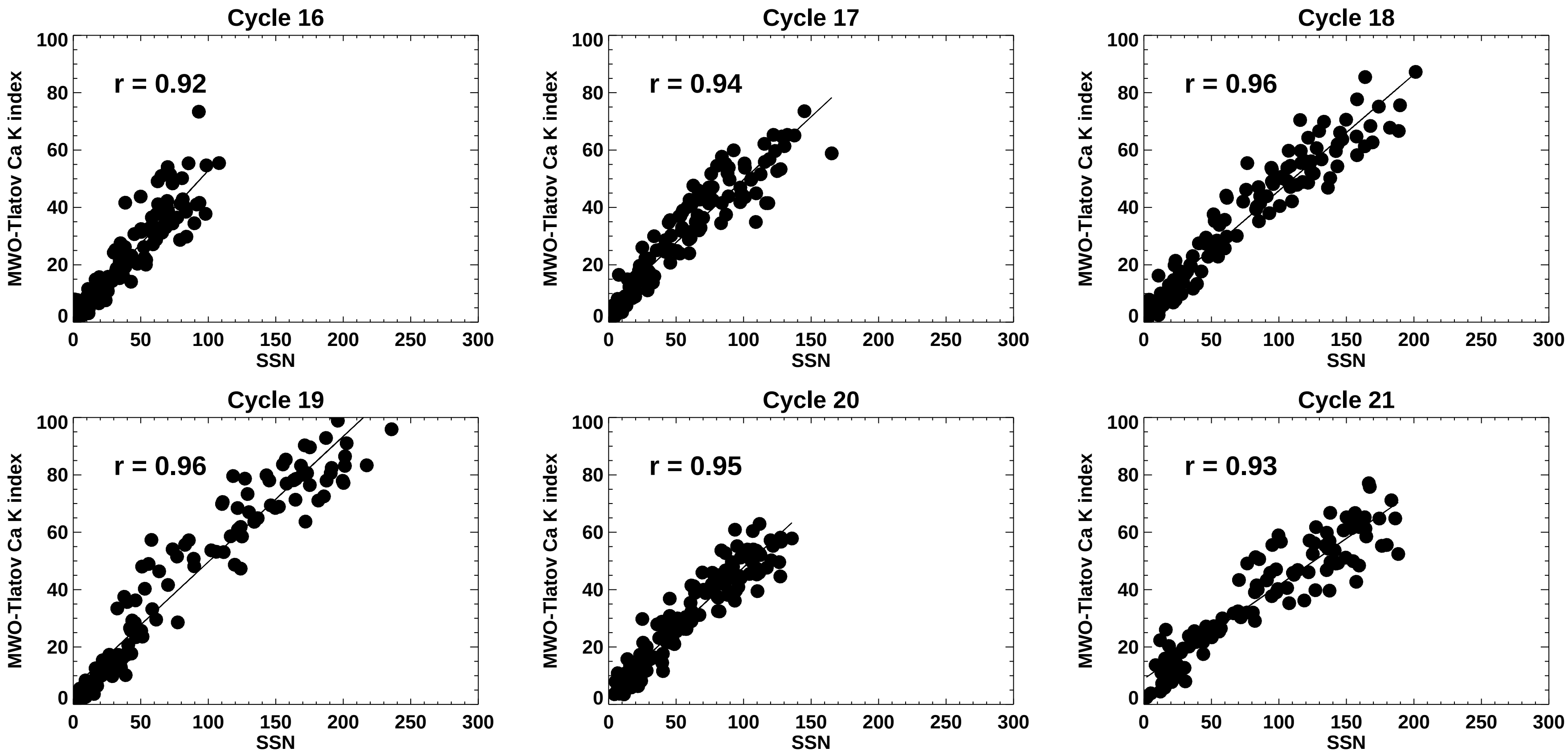
$r_{SSN,Apn}$ cycle by cycle - 1



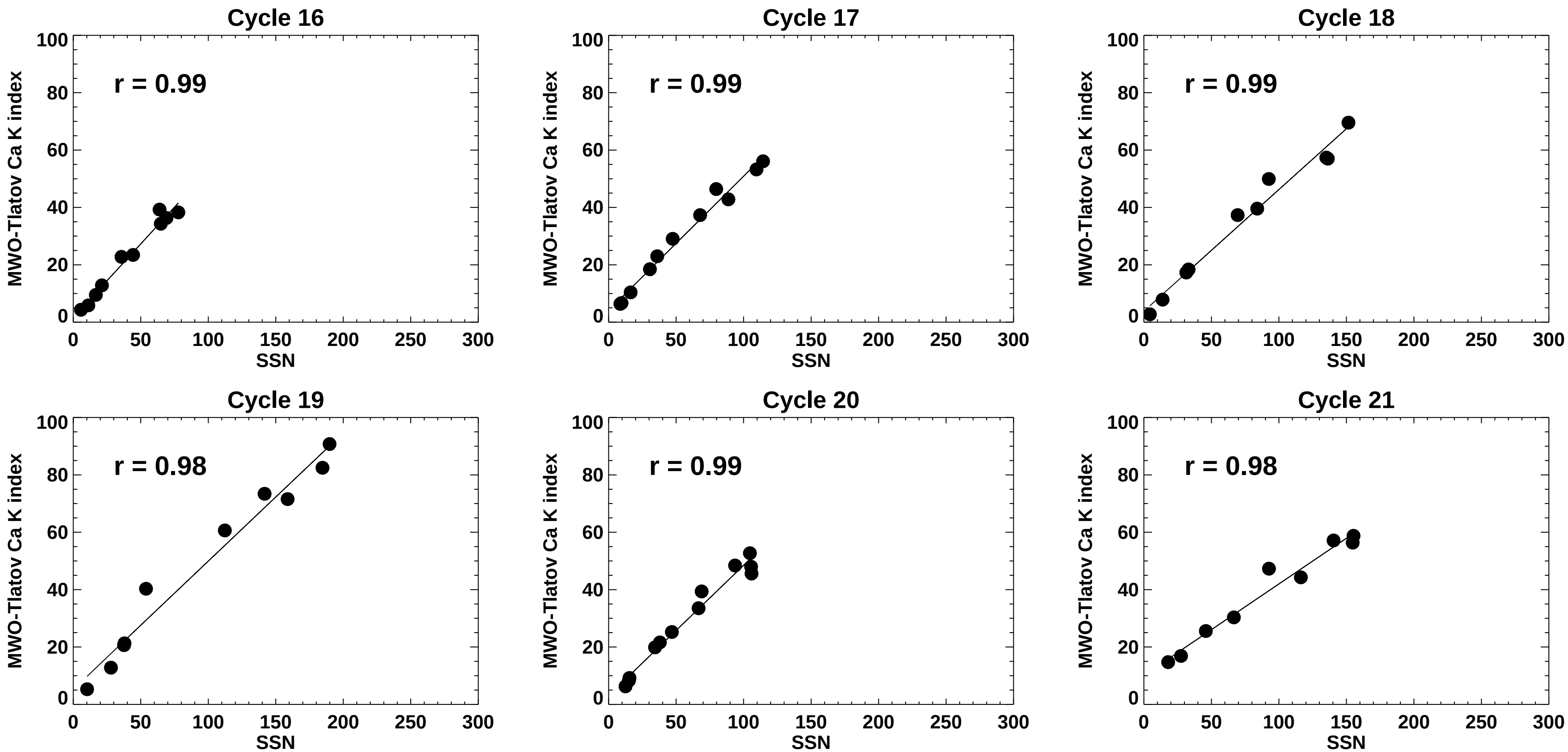
$r_{SSN,Apn}$ cycle by cycle - 2



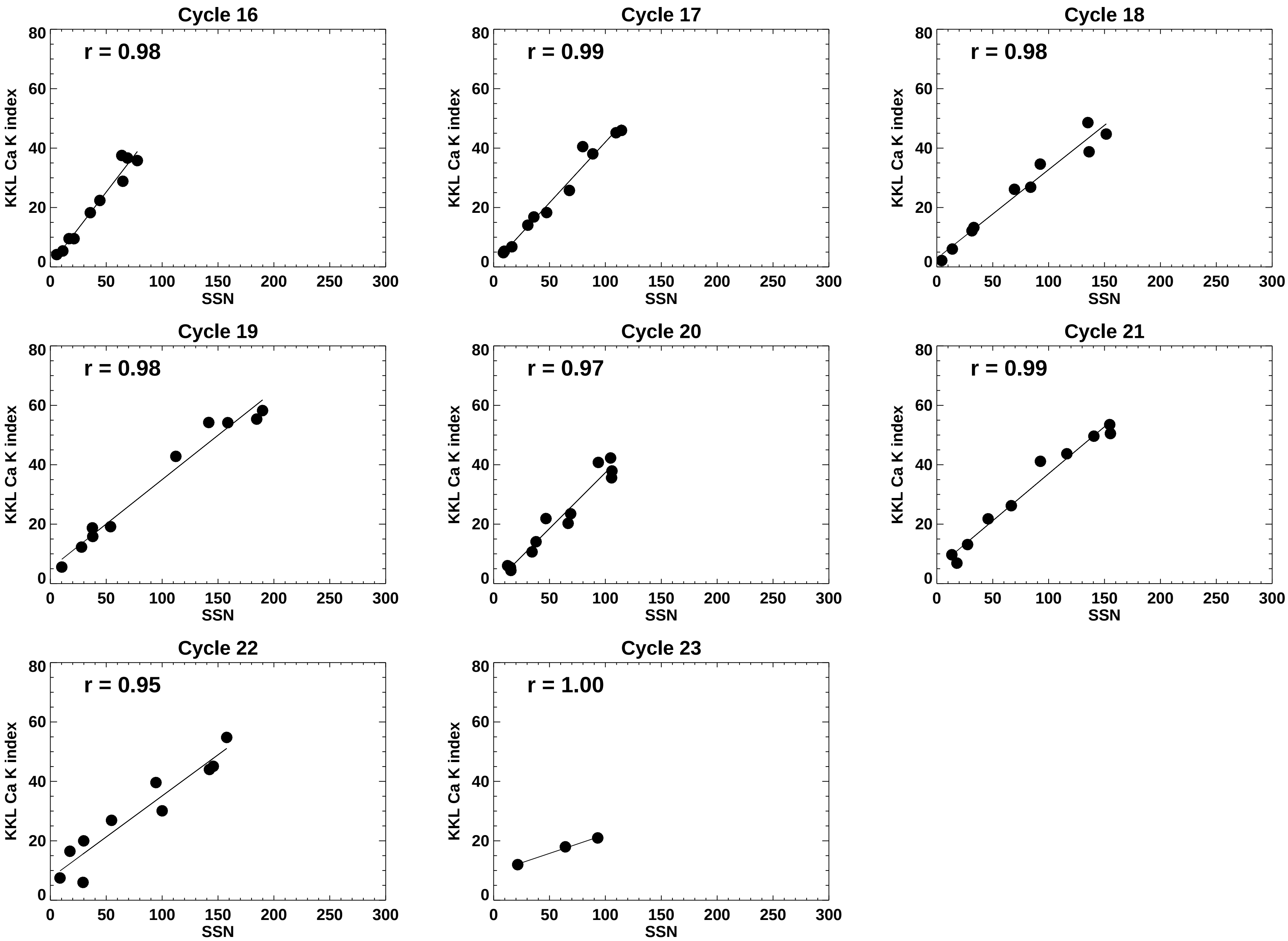
$r_{SSN,Tlatov}$ cycle by cycle - 1



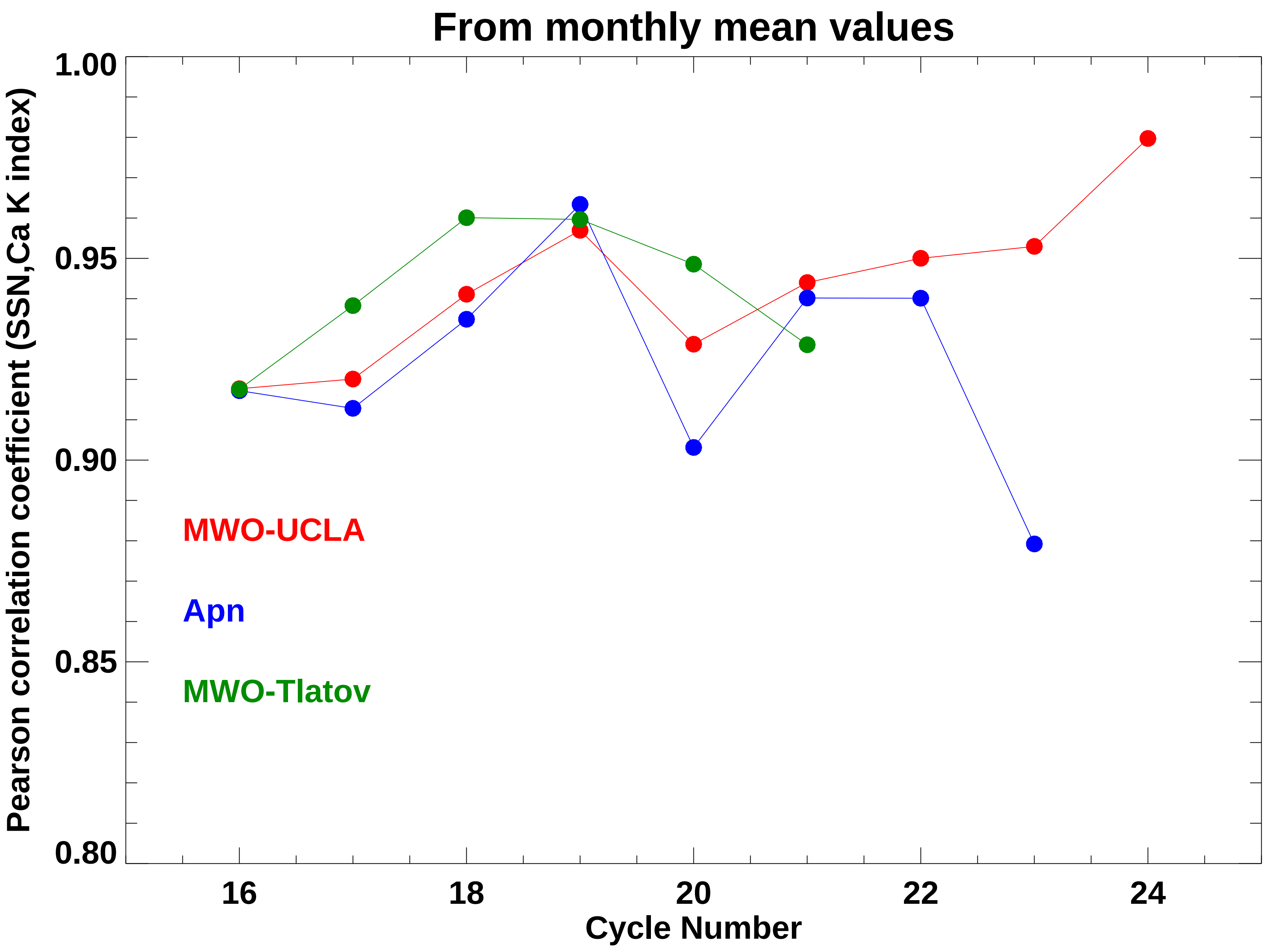
$r_{SSN,Tlatov}$ cycle by cycle - 2



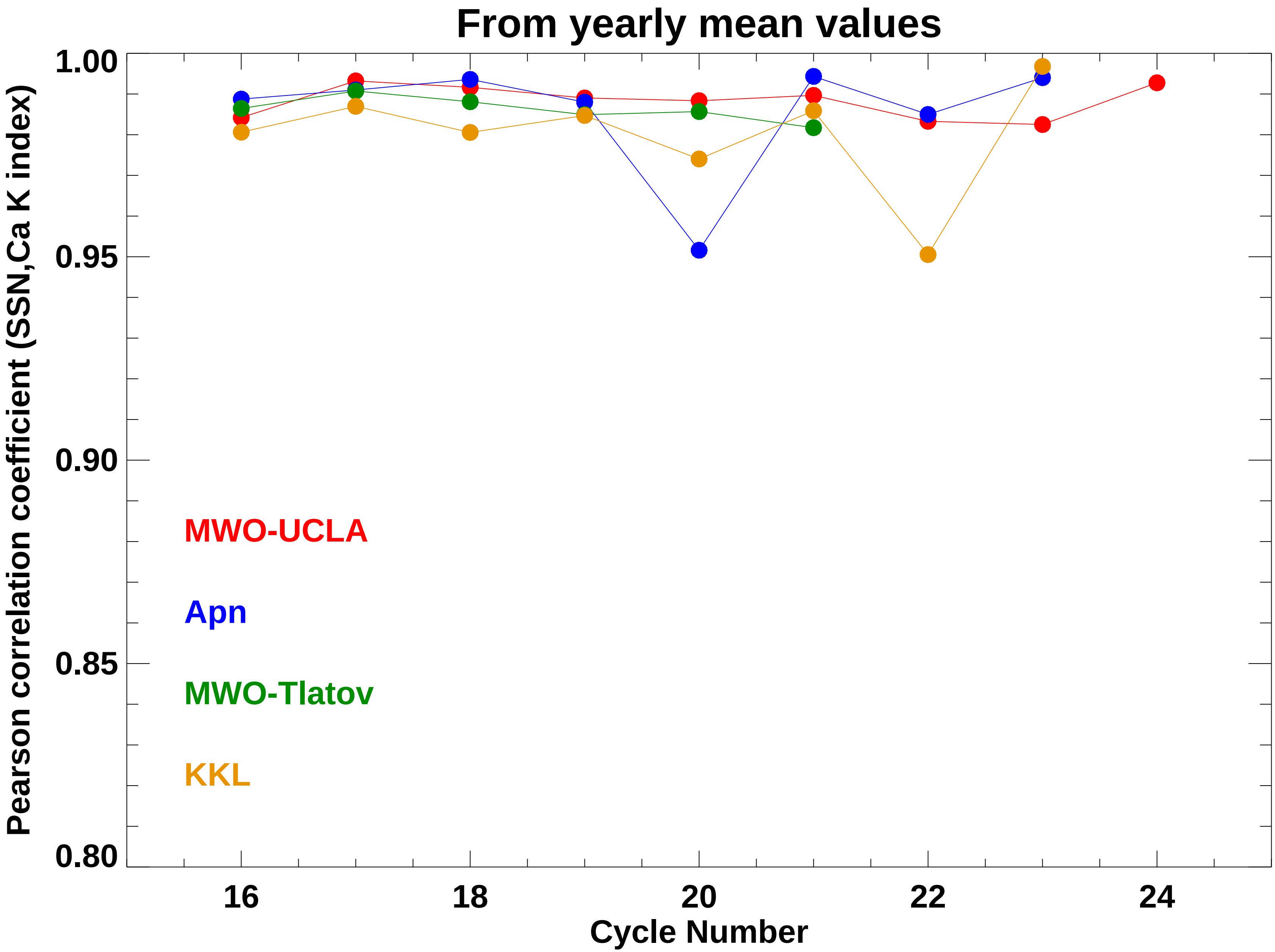
$r_{SSN,KKL}$ cycle by cycle



$r_{SSN,CaK\ index}$ time variation - 1



$r_{SSN,CaK\ index}$ time variation - 2



Main conclusions

- Overall there is a good consistency among the different annual mean values of the Ca II K plage index time series ($0.94 < r < 0.97$).
- Cycle 19 is the strongest in all Ca K time series, although the KKL amplitude is significantly lower than in the MWO data. This discrepancy is noticeable also for cycle 18.
- The Apn time series shows lower values than other indices during the 1967-1969 period.
- The amplitude of the extended MWO-UCLA time series is significantly lower than the amplitude of the extend Apn series during cycle 22.

Main conclusions (cont'd.)

- Correlations with the SSN exceed 0.95 for all the yearly mean indices, and 0.91 for the monthly mean values.
- The rescaled KKL amplitude during cycles 18 and 19 is about $\sim 10 - 15$% lower than the amplitude of the SSN.
- The largest discrepancy between the SSN and Ca K plage index time series occurs during cycle 22, when the extended MWO-UCLA show significantly lower values.
- Data calibration and rescaling are some of the factors that could potentially alter the comparison among the Ca II K and the SSN time series.