Diagnosing and Calibrating the Multi Century Sunspot Number Series-

Space Climate Symposium 2022

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Introduction

- The **Sunspot Number** introduced by **Prof .Rudolf Wolf** is a collection of historical **sunspot observations constructed in 1850** + a time series built in real time since then
- The ***k- factors:***

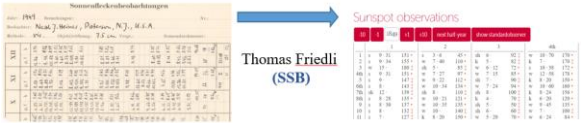
- After first attempt of Sunspot Number recalibration which resulted in **SN Version 2** in **July, 2015 (Clette et al., 2016),** inconsistencies still remain.
- GOAL : Reconstruction Instead of ~~Recalibration~~

Data

- In 1843, Professor **Rudolf Wolf** founded a **journal** called the **"Mittheilungen der Natur-forschenden Gesellschaft** in Berne" where he published yearbooks with all of his findings, including sunspot observations as far back as Galileo (Wolf, 1861).

ID	DATE	GROUPS	SUNSPOTS	WOLF
14219	1861-01-03	4	9	49
14220	1861-01-06	4	5	45
14221	1861-01-18	2	3	23
14222	1861-01-19	2	3	23
14223	1861-01-23	4	8	48
14224	1861-01-26	4	13	53
16767	1861-02-05	3	6	36
16768	1861-02-06	3	9	39
16769	1861-02-07	1	1	11
16770	1861-02-15	6	16	76
16771	1861-02-16	7	16	86

- Recounted Datasets from original drawings of important historical observers. For example: Recounts of Schwabe data by Arlt et al, 2011, Recounts from Carrington's drawings by Tom Teague, etc…..
- Wolf's own handwritten records on loose (unbinded) pages were recovered at the ETH Library in Zürich in 2015. We call them the "Source Books" and they were digitized by Thomas Friedli (Friedli, 2016) on the period from 1849 to 1877. Some of the data Wolf recorded in his Source Books he did not use, and thus might not have had them printed in the *Mittheilungen.*

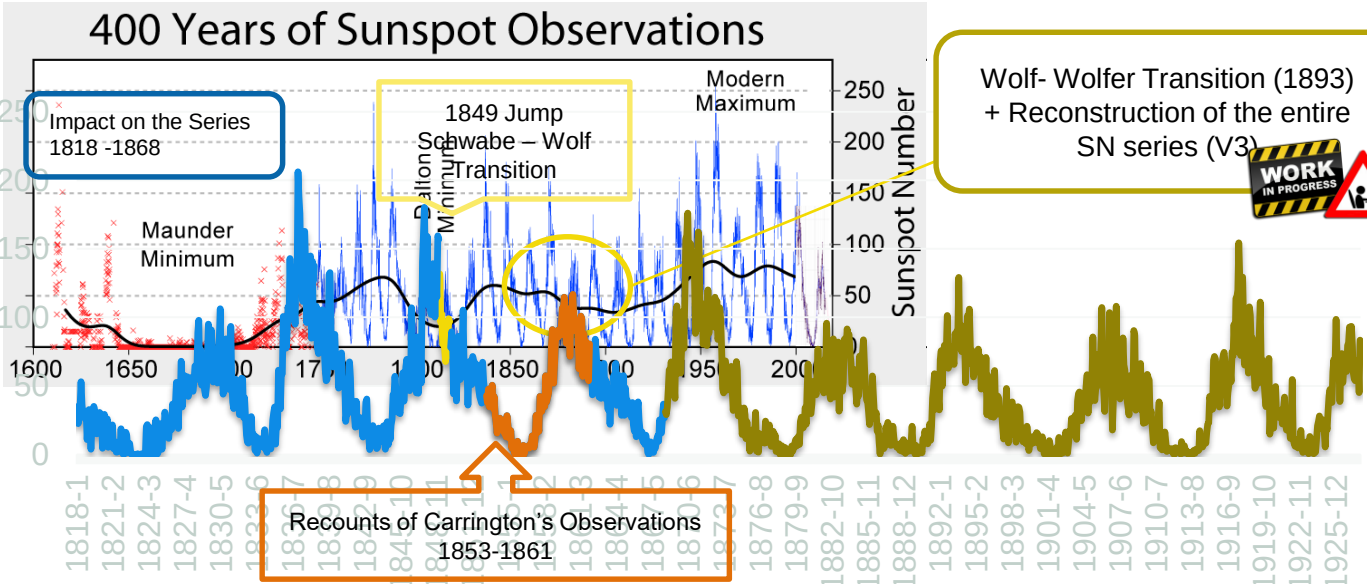


Why Reconstruction?

- A homogeneous Sunspot number series is necessary to study the evolution of long-term solar activity and its impact on the Earth.
- Sunspot Number series plays an active role in the accurate determination of the total solar irradiance models.
- No consistent error Bars in the existing versions.
- Hence, more robust SN series, more robust prediction models

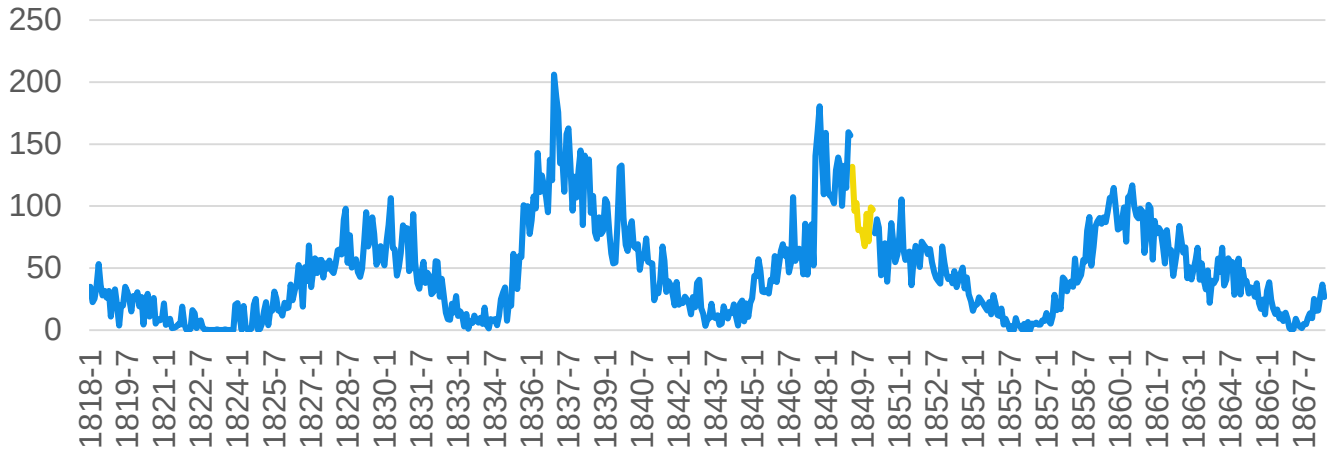
Carrasco, V.: 2022, A revised collection of sunspot group numbers: Context and future improvements.Technical report, Copernicus Meetings. [carrasco2022revised],
Lean, J.L.: 2018, Estimating Solar Irradiance Since 850 CE. Earth and Space Science 5(4), 133. DOI. ADS. [2018E&SS....5..133L]

Overview



Hoyt, D. V., and K. H. Schatten (1998a). "Group sunspot numbers: A new solar activity reconstruction. Part 1.". Solar Physics 179: 189-219.

Study -I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1845-1
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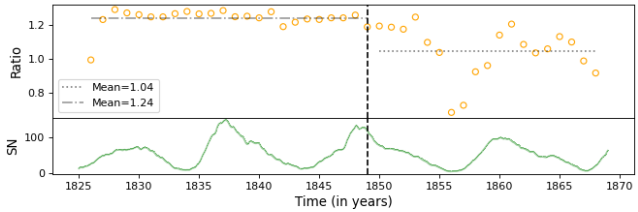
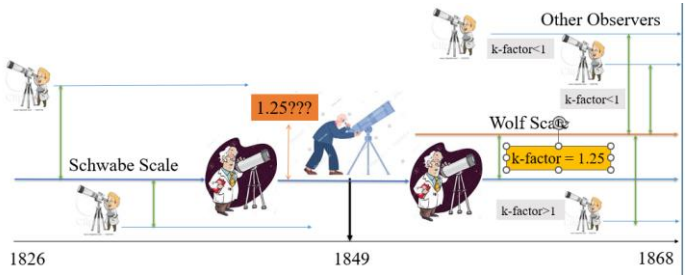
1848-1
1849-7
1851-1
1852-7
1854-1
1855-7
1857-1
1858-7
1860-1
1861-7
1863-1
1864-7
1866-1
1867-7

Schwabe – Wolf Scale Transition

- **~ 20% jump in SN series** was reported in 1849 by various studies such as Leussu et al, 2013, Senthamizh et al. 2015
- **Schwabe's *k-factor*** was calculated based on **observations from 1849-1868** when **Wolf used** them to **fill gaps** in his own series. Therefore, it remained **controversial** if this **same k-factor** was suitable for Schwabe's observations for the period **1826-1848** when he was the **primary observer** (Friedli, 2016).





1826-1848 → The **early Schwabe data** was **recounted** by Wolf himself in 1859, **therefore *k-factor* ~ 1**

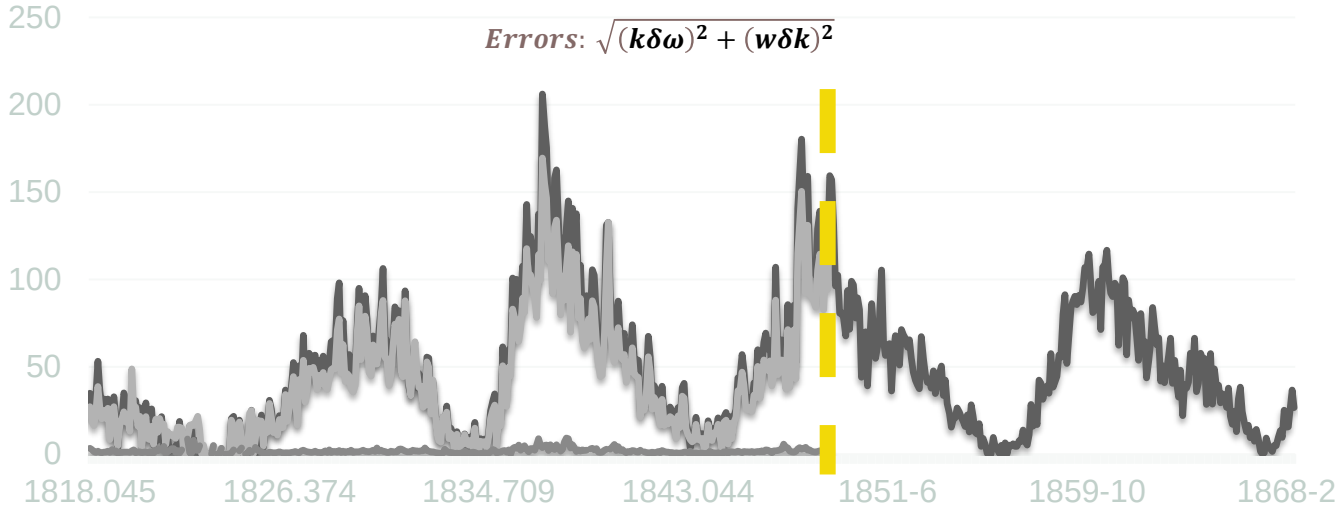
1848-1868 → The **later part** was added **"in real time"** from **Schwabe's correspondence , therefore k-factor ~ 1.25.**

Leussu, R., Usoskin, I.G., Arlt, R., Mursula, K.: 2013, Inconsistency of the Wolf sunspot number seriesaround 1848. Astron. Astrophys. 559, A28. DOI. ADS. [2013A&A...559A..28L]

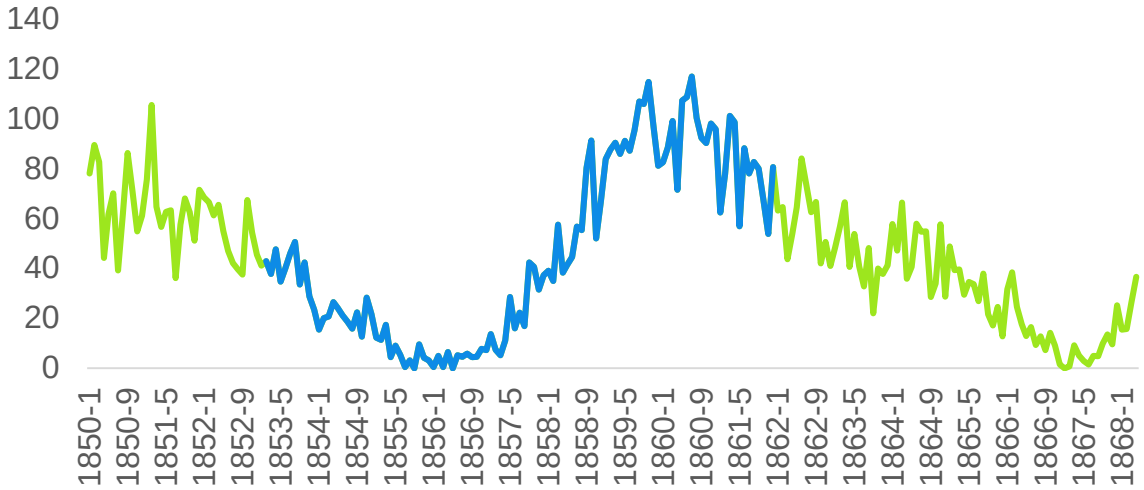
Senthamizh Pavai, V., Arlt, R., Dasi-Espuig, M., Krivova, N.A., Solanki, S.K.: 2015, Sunspot areas and tilt angles for solar cycles 7-10. Astron. Astrophys. 584, A73. DOI. ADS. [2015A&A...584A..73S]

SN V2.1- Reconstruction

- After a thorough investigation, we find there is no impact on this jump after 1849.



Study II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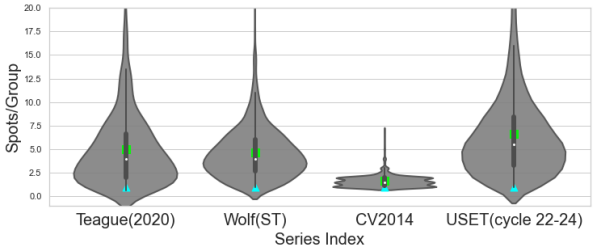
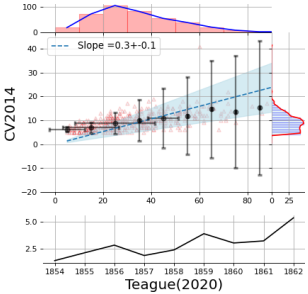
1862-1
1862-9
1863-5
1864-1
1864-9
1865-5
1866-1
1866-9
1867-5
1868-1

Richard Carrington-The spot count discrepancy

- **Bridge observer when Rudolf Wolf switched telescopes**
- **Carrington's data in Mittheilungen:**
  - Group Number and sunspot area (1854-1860)
  - Group number and sunspot count (1859-1860)
- **Original Catalog** - 4900 sunspot counts and area observations: published by **Casas and Vaquero, 2014** (1853-1861) - CV2014
- **Recount of Richard Carrington's original data** (1853-1861) by **Tom Teague (UK)**





- CV2014 is a **position catalog**
- Chose the sunspots for an ideal placement of the "crosswire" to keep track of the groups - had fewer choices of spots during minima

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A Modern Reconstruction of Richard Carrington's Observations (1853–1861)

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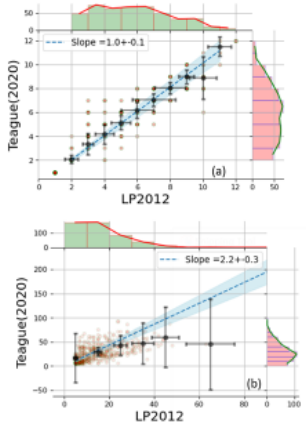
Abstract

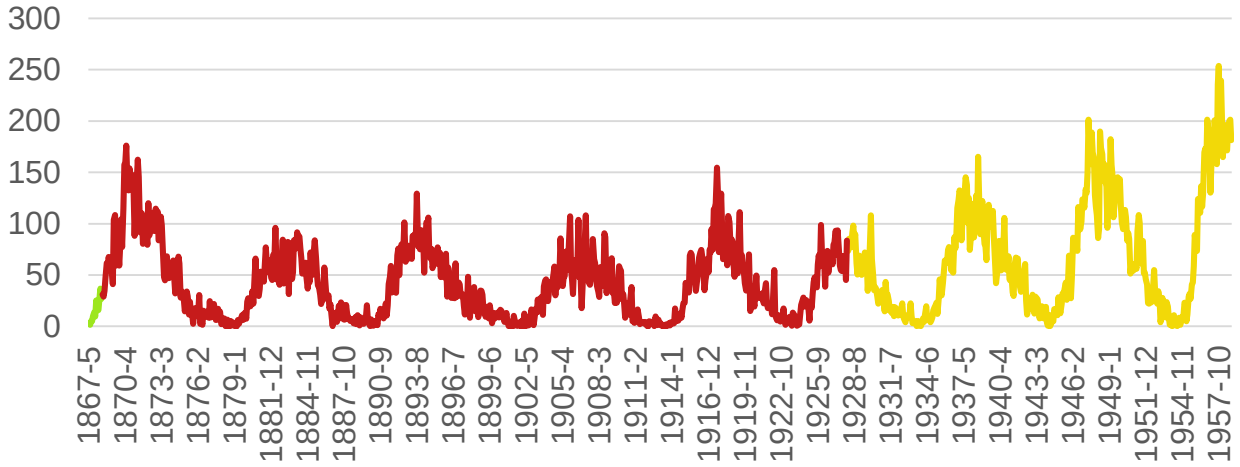
The focus of this article is a re-count of Richard Carrington's original sunspot observations from his book drawings (Carrington in Observations of the Spots on the Sun from November 9, 1853, to March 24, 1861 Made at Redhill, Williams and Norgate, London, 1863) by an observer from the World Data Center-SILSO (WDC-SILSO, http://www.sidc.be/silso/home) network, Thomas H. Teague (UK). This modern re-count will enable the recomputation of the entire Sunspot Number series in a way Carrington's original counts (Casas and Vaquero in Solar Phys. **289**(1), 79, 2014) did not. Here we present comparison studies of the new re-counted series with contemporary observations, new data extracted from the Journals of the Zürich Observatory and other sources of Carrington's own observations and conclude that Carrington's group counting is very close to the modern way of counting while his method for counting individual spots lags significantly behind modern counts. We also test the quality and robustness of the new recount with methods developed in Mathieu et al. (Astrophys. J. **886**(1), 7, 2019).

Keywords Sun · Sunspots · Sunspot number

Carrington - Bhattacharya (2021)



Study III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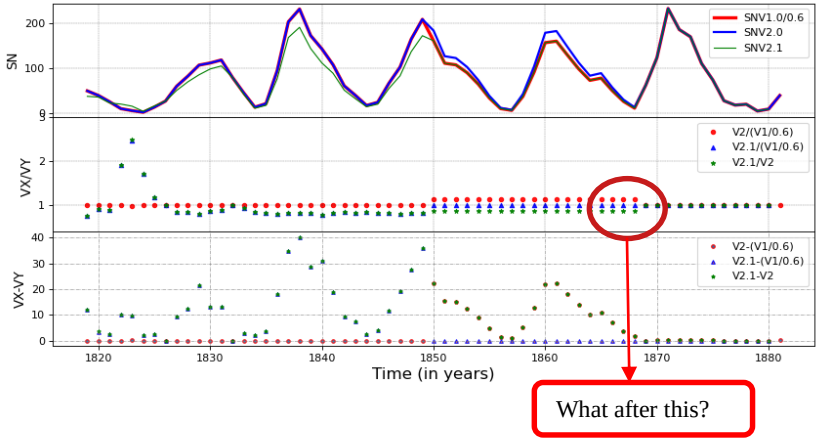
Wolf – Wolfer Transition

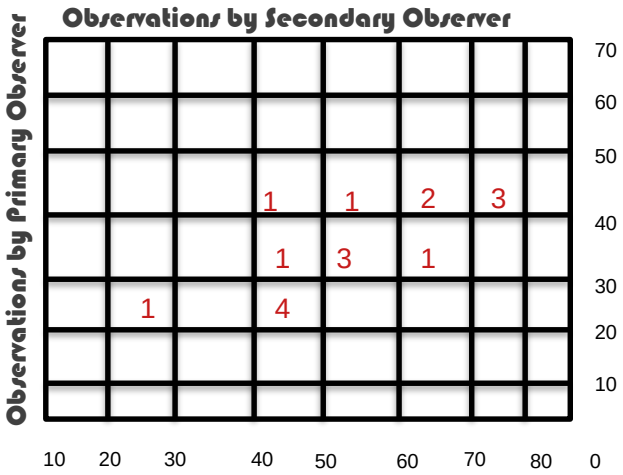


- Wolf and Wolfer both are important backbones in several reconstructions
- SN V2 stops at 1868
- Studies like Usoskin et al.,2016 shows the relation is not linear.

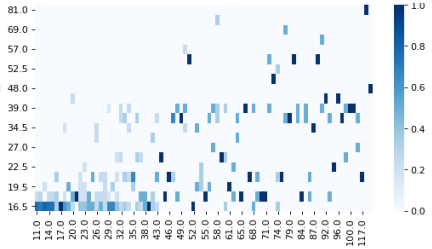
Beyond k-factors

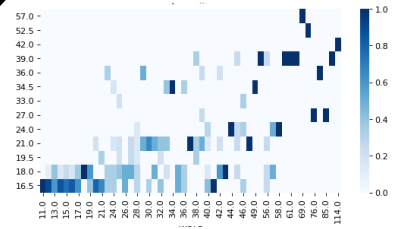
WORK IN PROGRESS

- Method by **Chatzistergos et al., 2017**



After dividing each column by their sum





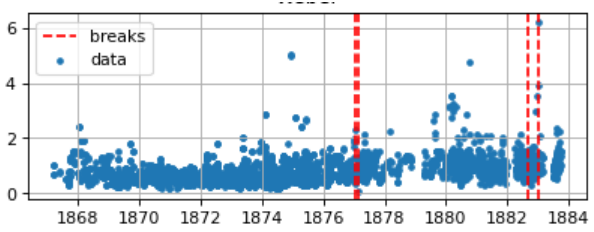
Pros and Cons

- Pro:

No assumption of Linearity

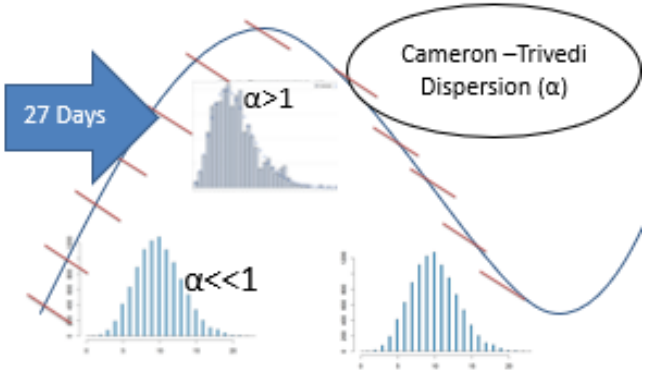
- Con:

Change of observation techniques remain undetected



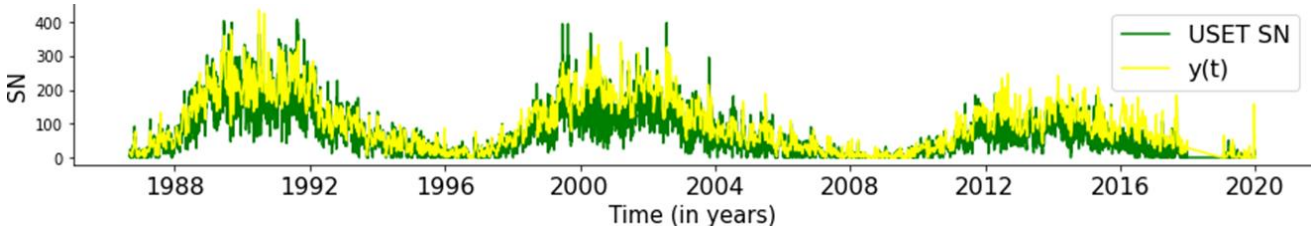
Change in variance detection.

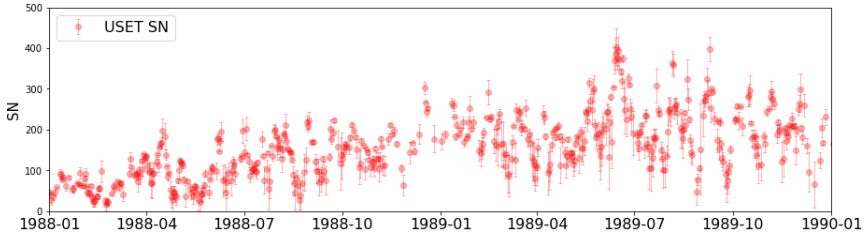
Error Determination

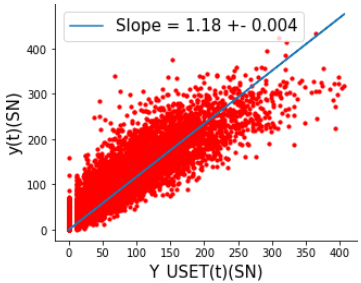


- Explanatory Variable: Time
- Overdispersed Count data: Sunspot Data

Model Fit







- USET Observes **18% more** SN compared to predicted values.
- In accordance with Mathieu et al,2019 where **USET has 0.8 k-factor (= ~20% more SN than network mean)**

Future Work

- Merge to obtain SNV3 (2023)
- Extend beyond 1928
  - ETH Zurich data recovered and in process of digitization (1945-1985)
- Daily SN prior 1818
  - Data are being recovered daily and some of them have already been digitized
- Error Determination for sparse data (2023)
- FARSUN (2023-2026)

Thank You!