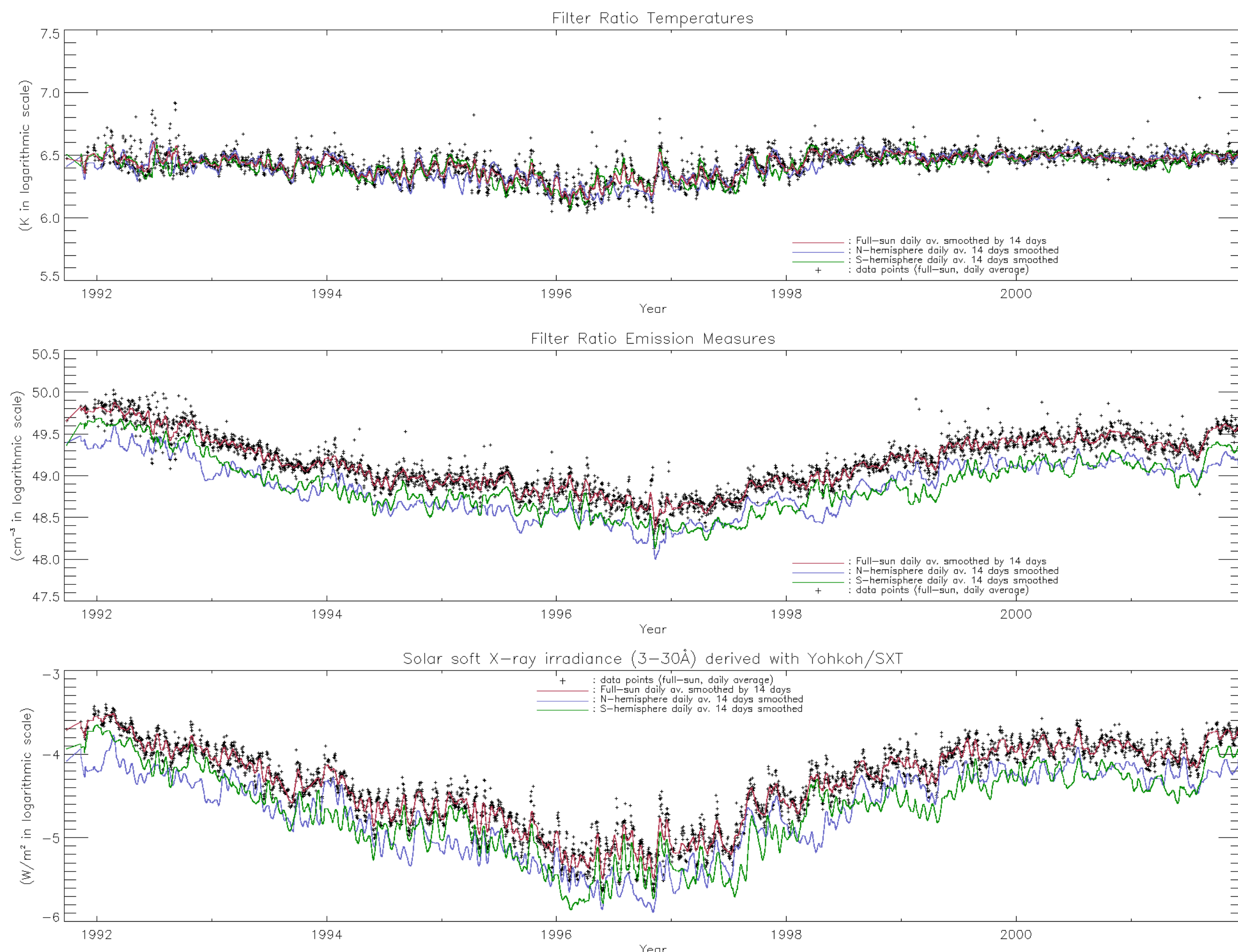
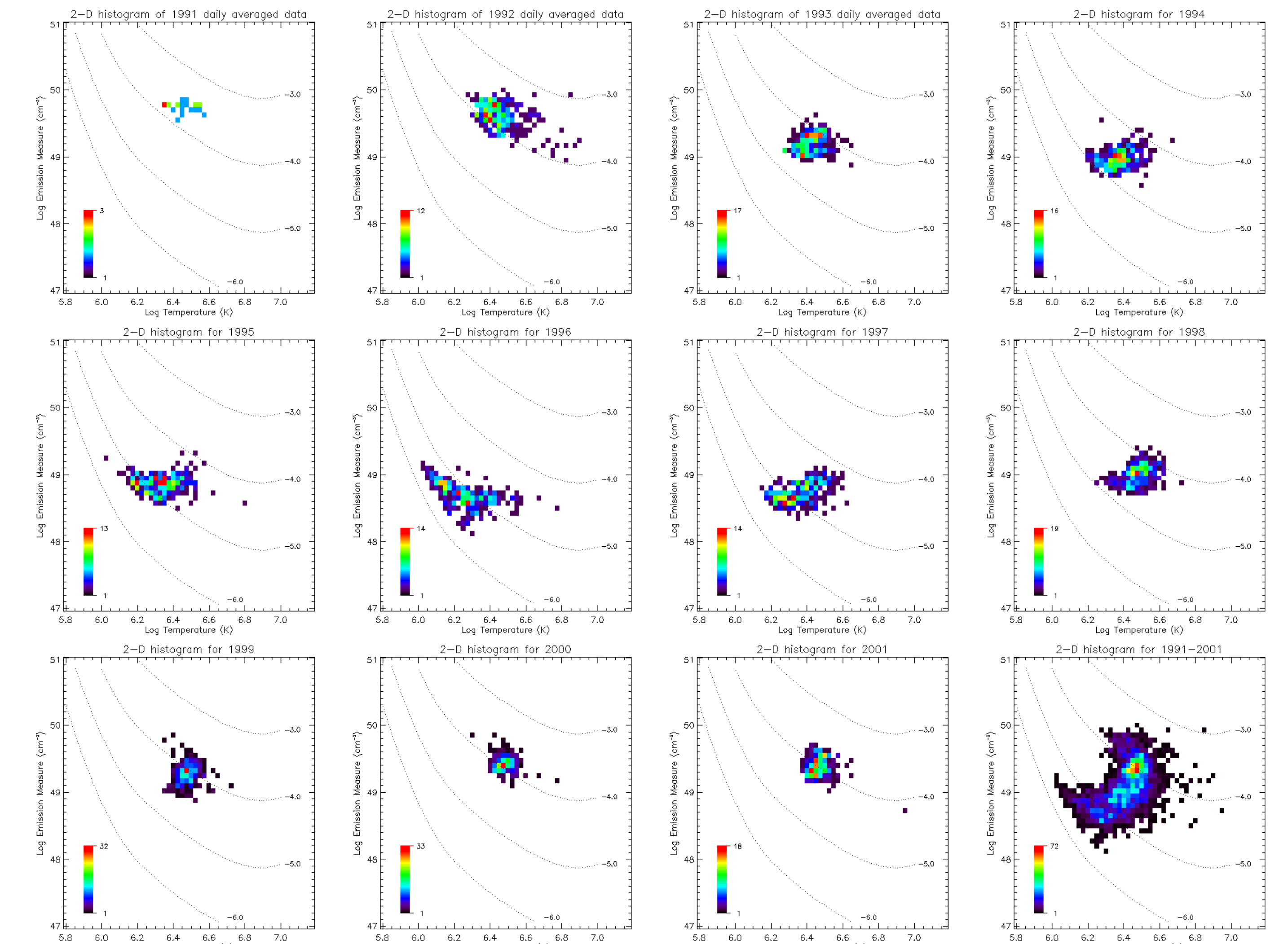


# SOLAR CYCLE VARIATION OF CORONAL TEMPERATURES AND EMISSION MEASURES (1991-2001) OBSERVED WITH YOHKOH SOFT X-RAY TELESCOPE.

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**Fig. 1:** [top plot] Daily averaged filter-ratio temperatures derived from the full-Sun integrated signals (red line) of the thin-Al and Al/Mg/Mn filter pairs of Yohkoh/SXT. The blue and green lines were calculated using the integrated signals of Northern- and Southern-hemispheric corona, respectively. [middle plot] Daily averaged filter-ratio emission measures associated with the temperatures in the above. [bottom plot] Soft X-ray irradiance calculated for the wavelength range of 3-30Å.



**Fig. 2:** 2-D histograms of daily averaged filter-ratio temperatures and emission measures from the full-Sun integrated signals, for the year 1991 to 2001 and 1991-2000. The bin size of the histogram along the Te- and EM-axes in log scale is 0.025 (K) and 0.075 ( $\text{cm}^{-3}$ ) respectively. The dot curves indicate the pairs of Te and EM that gives the same irradiance values; -3.0, -4.0, -5.0 and -6.0  $\text{W/m}^2$  (in log scale), respectively from upper-right to lower-left in each plot.

## Summary

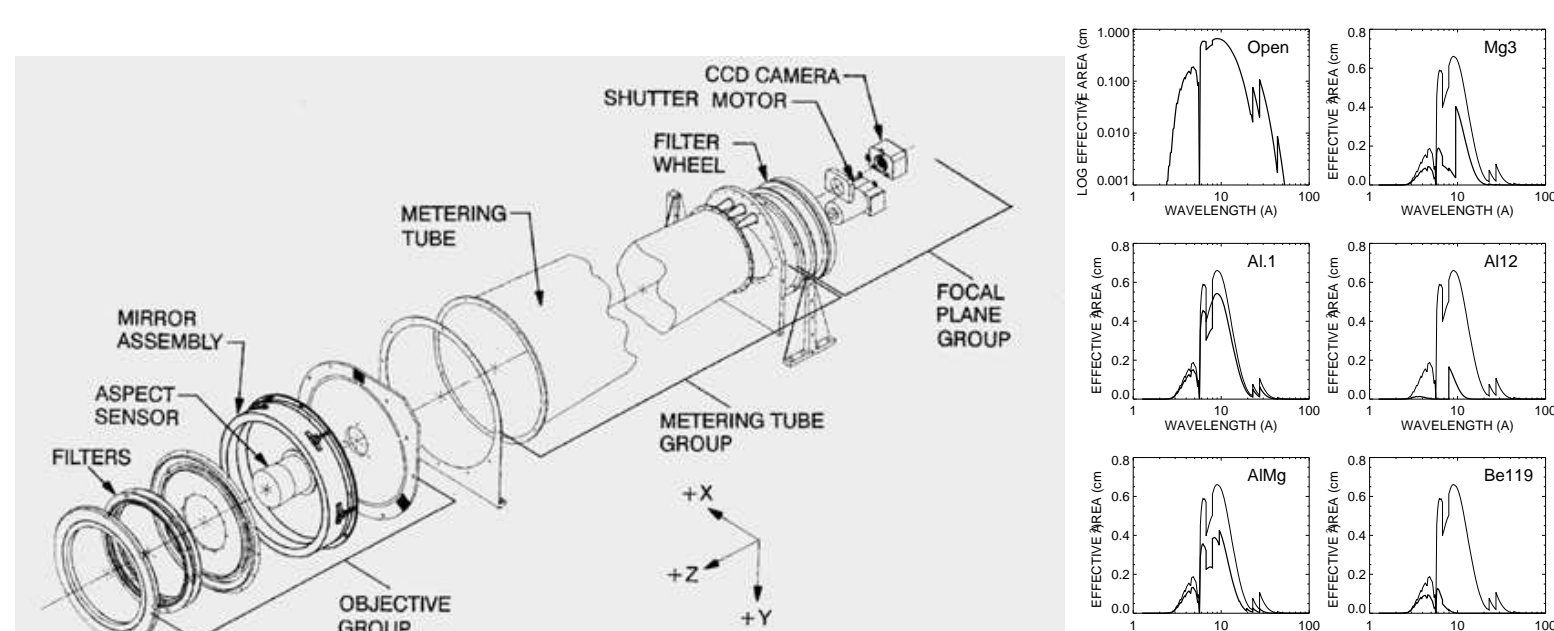
The soft X-ray telescope (SXT) aboard the Yohkoh satellite is a grazing-incidence telescope which observed the Sun for a nearly whole solar cycle (Cycle 22 max through Cycle 23 max). Like Hinode/XRT, SXT was equipped several broadband X-ray analysis filters, which were designed to diagnose coronal temperatures (Te) and emission measures (EM) through the filter ratio technique.

We used the full-Sun integrated intensities of the two thin filters (the thin-Al and Al/Mg/Mn filters) from SXT to calculate coronal temperatures and emission measures for the whole mission, based on recently re-calibrated SXT response functions and a recent atomic database (CHIANTI ver. 8.0). Our calculation assumed so-called 'hybrid' elemental abundances. By assuming traditional coronal abundances, Te showed no significant difference, while EM resulted in 30 to 45% lower values.

We next applied the filter ratio method to the images instead of integrated signals, to derive solar cycle variation of the EM of cool (less than 1.5MK), medium (1.5 to 2.5MK) and hot (more than 2.5MK) temperature component of coronal plasma. It turned out that the medium and hot components show similar sunspot-cycle variation as the soft X-ray irradiance. The cool component, on the contrary, keeps flat in descending and rising phase of the activity cycle and shows enhancement at the minimum phase. The total emission measure of the hot component in the descending phase of activity cycle (1992 - 1996) is significantly lower than that of medium component, while in the ascending phase (1998 - 2001) the amount of hot component is comparable with that of medium component. It also turned out that the EM weighted average of the spatially resolved temperatures are generally 20 to 30% lower than those derived from the integrated signals, and that the total of spatially resolved EMs are accordingly 1.5 to 2 times higher than the values from the integrated signals.

## 1. Yohkoh/SXT and the YLA

- Yohkoh (Japanese word for 'sunshine') is a Japan/US/UK mission for high-energy solar physics (1991-2001). See Fig. 3. Yohkoh/SXT is the predecessor of Hinode/XRT.
- SXT (Soft X-ray Telescope) is a grazing incidence telescope on-board the Yohkoh satellite to form X-ray images in the 3 - 45Å range on a 1024x1024 CCD.
- All usable dataset from the Yohkoh mission (from raw level to highly calibrated) are accessible from the Yohkoh Legacy data Archive (YLA) at <http://www.solar.physics.montana.edu/ylegacy>.
- Most recent correction of the SXT response functions considering the diminishing X-ray sensitivity experienced during the first 15 months of the mission (Acton 2018) was implemented.

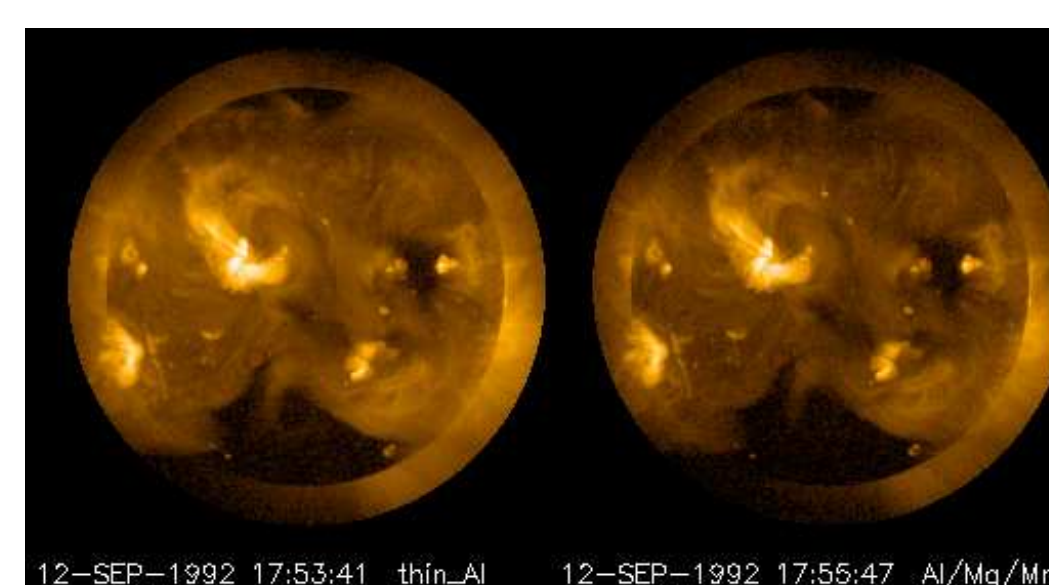


**Fig. 3:** Yohkoh/SXT assembly and spectral response of X-ray analysis filters (from Tsuneta et al., 1991).

## 2. Data processing

The Yohkoh Legacy data Archive (YLA) provides the mission-long SXT full-sun composite images as SXT level\_2 data. Data were processed with the following steps.

1. Find pairs of thin-Al and Al/Mg/Mn filter images taken close in time ( $< 10$  min. apart) and review for quality check.
2. Collect coronal intensities within 1.2Rs to obtain full-sun integrated signal pairs from each pair of images.
3. Derive filter-ratio temperature and emission measure from each signal pairs
4. Isothermal coronal spectra is calculated from the derived temperatures and emission measures, using CHIANTI atomic DB and software (ver. 8.0.7).
5. Integrate obtained spectrum over SXT's effective spectral range (3-30Å) to derive coronal irradiance in the unit of  $\text{W/m}^2$ .



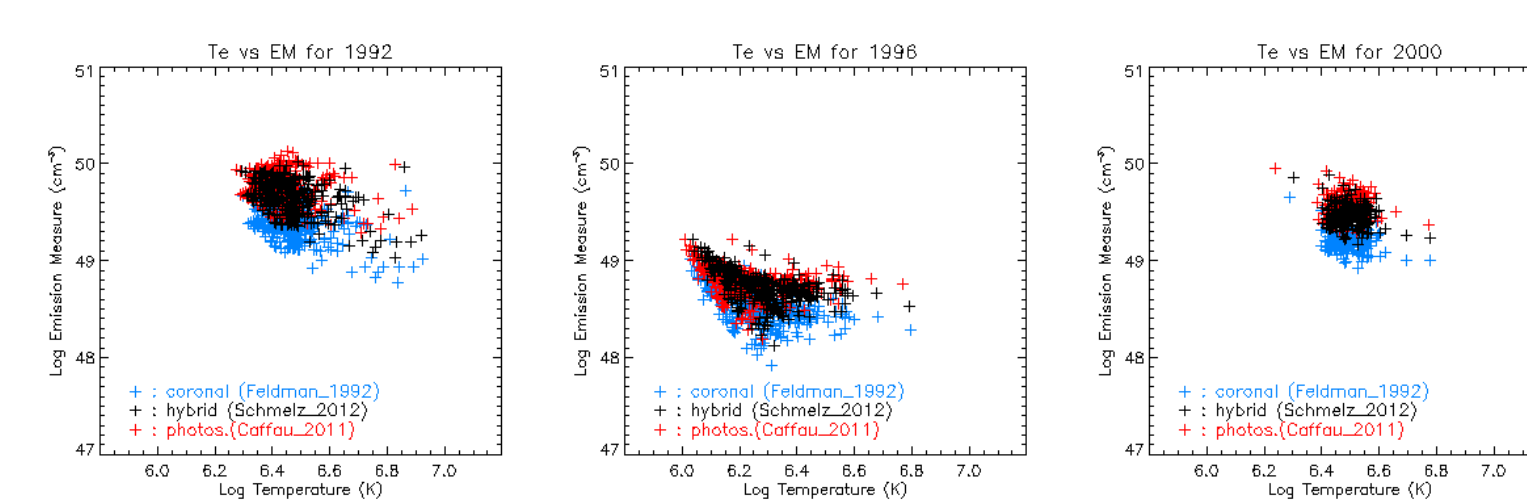
**Fig. 4:** Example of thin-Al and Al/MgMn filter image pair. The areas outside 1.2Rs are masked.

## 3. Analysis and results

### 3.1 Dependence on elemental abundances

Recently Brooks et al.(2017) reported that the FIP bias (ratio of coronal to photospheric abundances) of the global corona highly correlates with the F10.7cm radio flux and thus solar magnetic activity. It is therefore useful to compare the results obtained by assuming different type of elemental abundances. We made a comparison among the following three elemental abundance sets provided by CHIANTI atomic database:

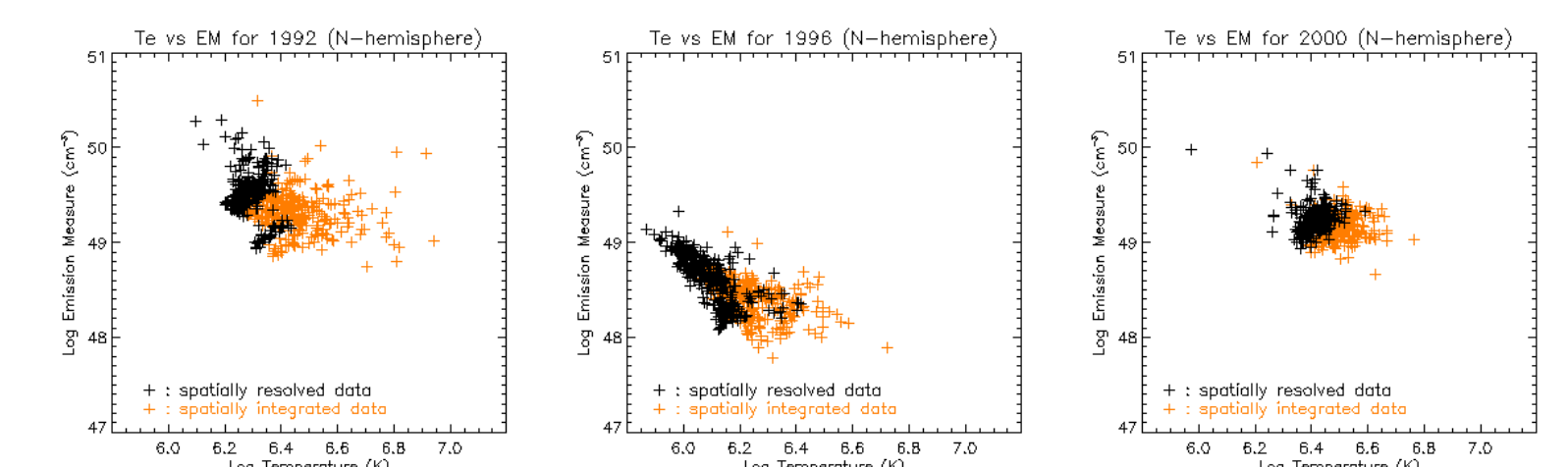
1. sun.coronal.2012.schmelz.ext.abund : Assumed by default in this study. The latest version of hybrid abundance set based on Schmelz et al. (2012).
2. sun.coronal.1992.feldman.ext.abund : Traditional coronal abundance set based on Feldman et al. (1992).
3. sun.photospheric.2011.caffau.abund : The latest version of photospheric abundance set based on Caffau et al. (2011).



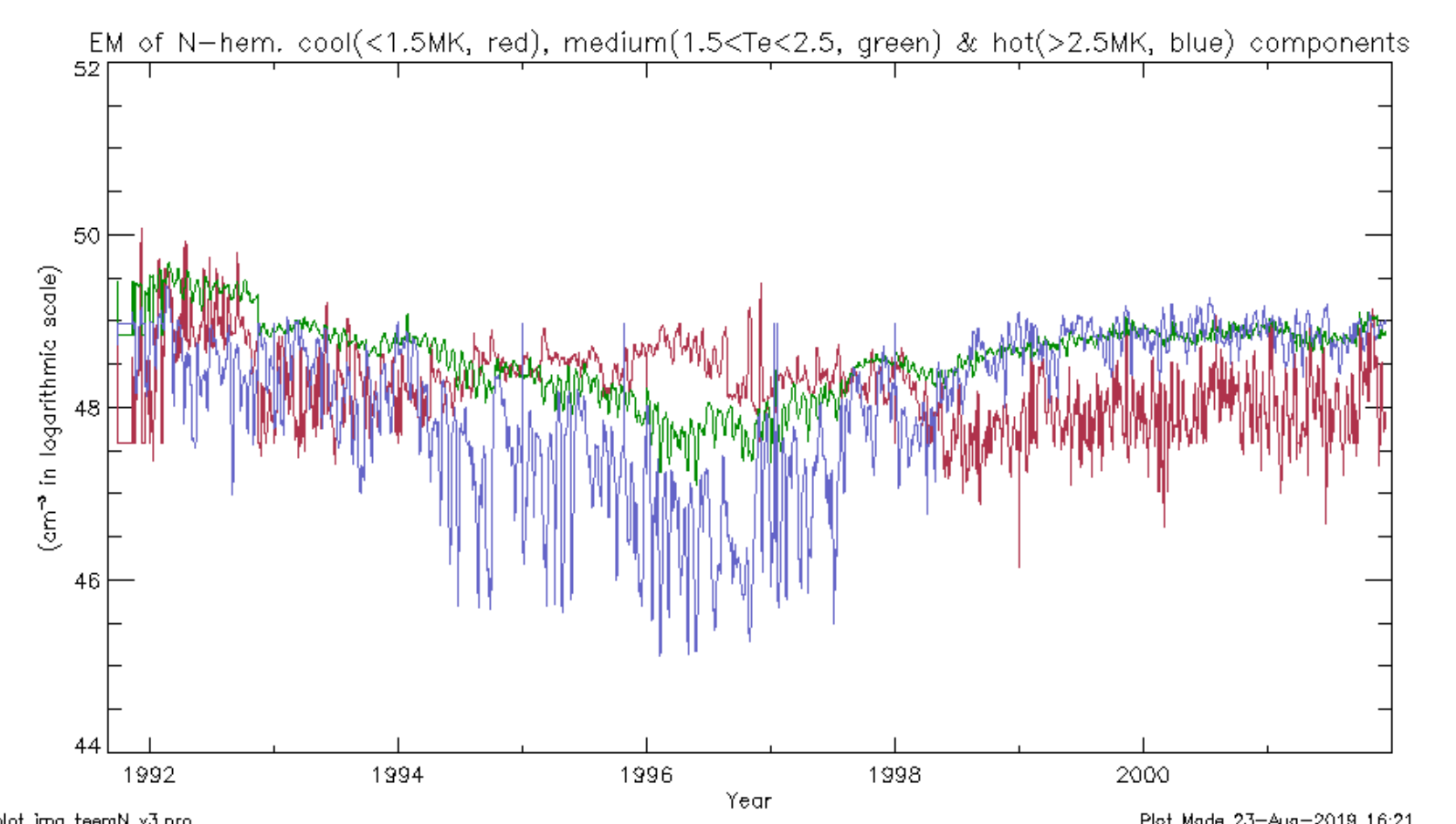
**Fig. 5:** Scatter plot of daily averaged filter-ratio temperatures and emission measures with different elemental abundance assumptions, for the sample years 1992, 1996 and 2000.

### 3.2 Spatially-resolved approach

The use of full-Sun integrated signals for the irradiance study gains photometrical advantage, but trades off the spatial information of the observed corona. To incorporate the spatial information, we tried the alternative method that applies the filter ratio method to the coronal images instead of spatially integrated signals. It is photometrically challenging, especially because SXT experienced the stray light contamination since 1992 November. We use only Northern hemisphere data for the better photometry, to avoid the Southeast part of the image where a major stray light patterns are located. For each pair of temperature and emission measure maps, we calculated the average temperature weighted by emission measures, and the total emission measure as a sum of all pixels in an emission measure map. Using these averaged temperature and the total emission measure, the irradiance (3 to 30Å) from the Northern hemispheric corona was calculated with the same method used for the integrated signals. See Summary for conclusions.



**Fig. 6:** Scatter plots of daily averaged filter-ratio temperatures and emission measures obtained from two different methods. The data points calculated from spatially resolved data (black) are compared with the data points calculated from spatially integrated signals (orange). These results are for the Northern hemisphere for the sample years, 1992 (left), 1996 (middle) and 2000 (right).



**Fig. 7:** Mission-long variation of the emission measures of cool ( $< 1.5\text{MK}$ , red), medium ( $1.5\text{--}2.5\text{MK}$ , green) and hot ( $> 2.5\text{MK}$ , blue) components of the Northern hemispheric corona. Data points were smoothed by 5-day running average.

## References

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