From estimated Sun BT to the SMOS Sun Flux Prototype

2nd Workshop on SMOS for Space Weather
University of Alcala

Deimos Romania: Gabriel Graur, Suzana Vladescu
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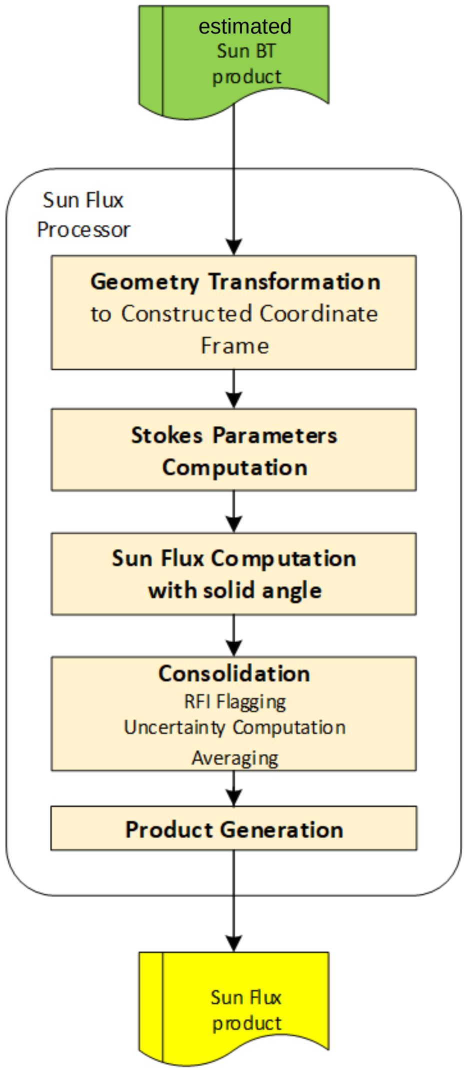
Objectives

- **Generate the first set of prototype SMOS Solar Flux products** based on SMOS v724 L1A inputs, using a dedicated estimated Sun BT
- **Disseminate** results to the space weather and solar science users
- **Gather feedback** from community
- Consider **future improvements** based on potential **future uses**.

From estimated Sun BT to the SMOS Sun Flux Prototype
SMOS Sun Flux Processing Chain



❑ Sun Flux Steps:

- Geometry Transformation
- Stokes Parameters Computation
- Sun Flux Computation
- Consolidation
- Product Generation
- Validation

From estimated Sun BT to the SMOS Sun Flux Prototype Geometry Transformation

- **Steps:**
  - **Computation** of the polarization **(Sun BT) vector**
  - **Finding** the orientation of the **Sun rotation axis** in the **J2000 reference system**
  - **Calculation** of the **solar disk frame** coordinates in **J2000**, at a given time
  - **Rotation** of the **BFP** (best fit plane) **polarization** vector to the **computed frame**, using the **Mueller Matrix**

- **The Computed Frame is:**
  - Y – axis oriented with the projection of the **Sun North Pole** direction on the plane **perpendicular** to the **Earth - Sun vector**;
  - Z – axis oriented **towards the Earth**;
  - X – axis is computed using the **Cartesian rule**

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Stokes Parameters Computation

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- **Polarimetry reference:**
  - **Positive Q**: parallel to solar rotation axis
  - **Positive U**: 45º counter clockwise
  - **Positive V**: clockwise

- **Rotated Sun BT ($T_{HH}, T_{HV}, T_{VH}, T_{VV}$) to Stokes Parameters ($I, Q, U, V$):**
  - **Stokes I**
  - **Stokes Q**
  - **Stokes U**
  - **Stokes V**

$$I = T_{VV} + T_{HH}$$

$$Q = T_{VV} - T_{HH}$$

$$U = -2 \cdot Re(T_{HV})$$

$$V = -2 \cdot Im(T_{HV})$$

- Having the **Stokes parameters** in Kelvin, they can be converted to **SFU** using the following formula:

$$F_s = k_b T_d \Omega_s \lambda^{-2} \ \ [W\mathrm{m}^{-2}\mathrm{Hz}^{-1}]$$

Where:

- F_s is the **Sun flux** in SFU
- k_B is the **Boltzmann constant** in units of $J \cdot K^{-1}$
- T_d is the **Stokes parameter** in Kelvin
- λ is the **SMOS wavelength** in meters
- The **solid angle**, Ω_s, in rad^2, is calculated using the neighbor pixels position in the grid

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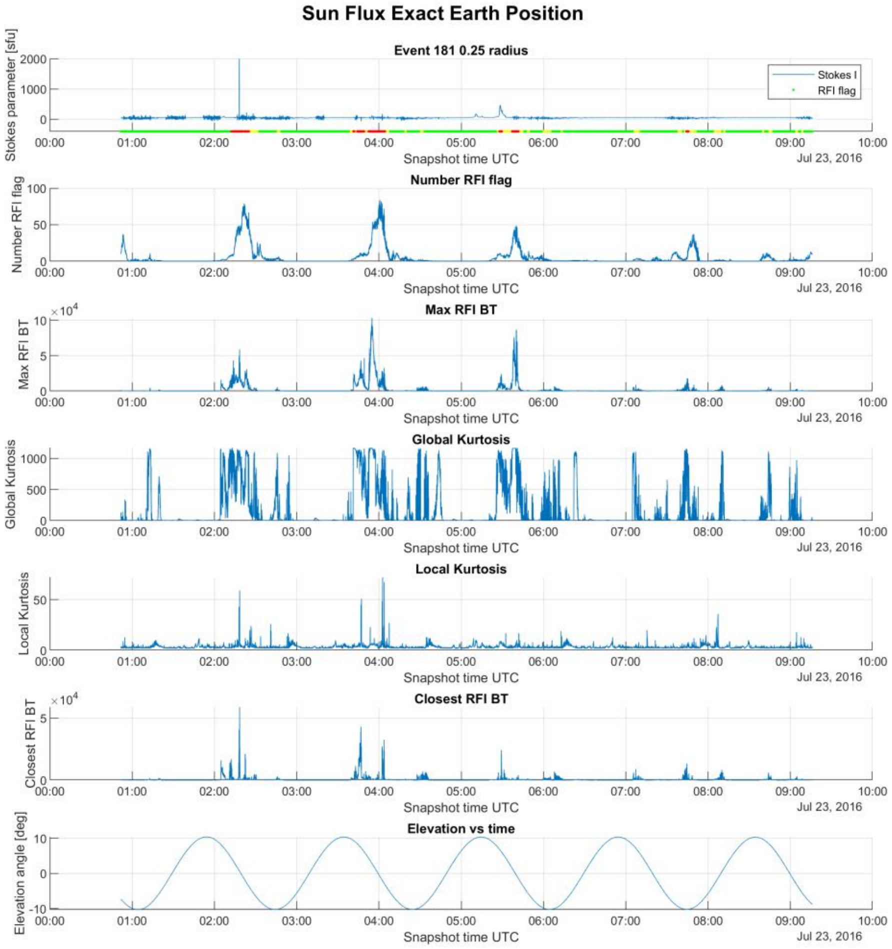
RFI flagging

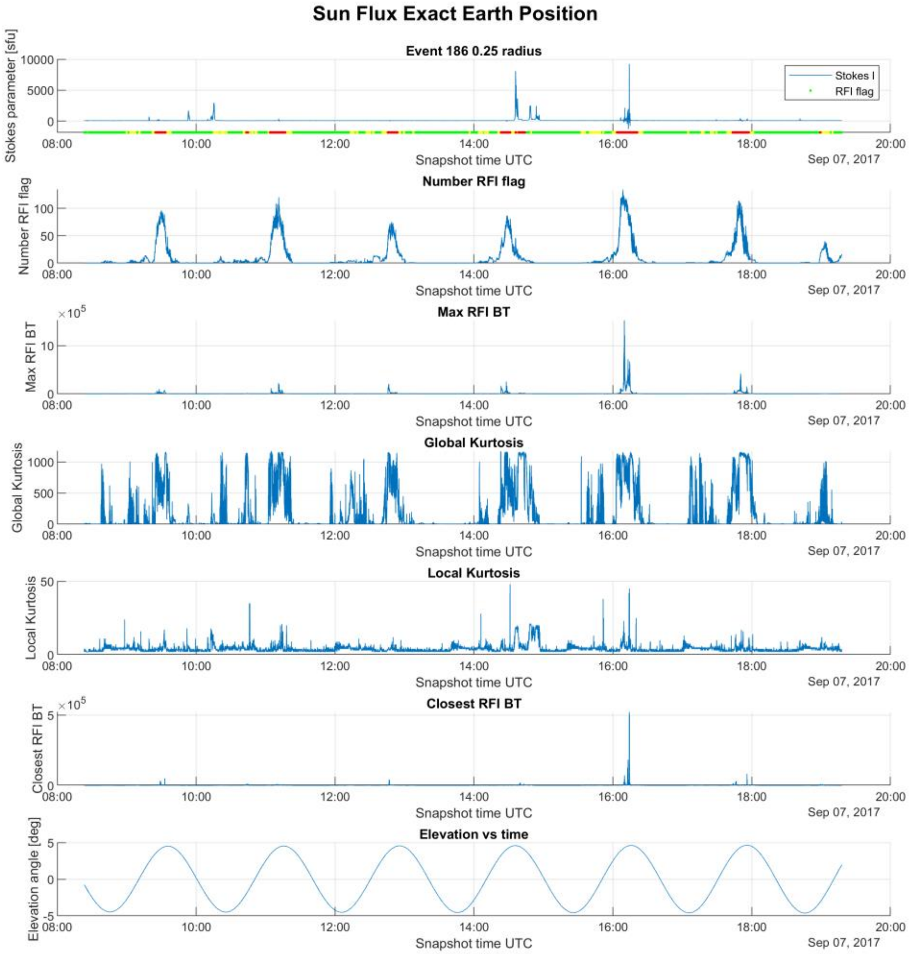
- The user will know if there was any **disturbance** to the data and its **severity**
- RFI Flagging algorithm: 3 different thresholds used to define **1 unified RFI flag** – **LOW/MODERATE/HIGH**
- **Calculation based on the following parameters**: the Sun position relative to its tails, Sun Alias position inside the hexagon relative to the closest RFI sources, and information about the magnitude of the maximum RFI sources on the snapshot and closest RFI sources

RFI Contamination Flag

- **Three levels available**: LOW, MODERATE, HIGH (marked as green, yellow respectively red in the plots)
- If the flag is **LOW**, then we don’t have contamination at all, or we had contamination in the vicinity of the Sun (or on its tails) with **weak sources** (BT < 1000K)
- If the flag is **MODERATE** then we had contamination with **moderate sources** (1000K < BT < 10000K)
- If the flag is **HIGH** then we had contamination with **strong sources** (BT > 10000K).

❑ RFI Contamination Flag (LOW – green, MODERATE – yellow, HIGH – red)





❑ 2 events showing the composition of the unified RFI flag

Uncertainty calculation

- **Expected uncertainty:**
  - Uncertainty calculation algorithm: **Polynomial function** depending on the elevation angle
  - The function was estimated using the **standard deviation** of the flux of **preselected data**
  - The **selected data** includes precomputed Sun Flux for **mid-December** products (in mid-December the Sun has a maximum elevation angle in the SMOS antenna frame) for **10 consecutive years**

- **Real-time uncertainty (energy method)**
  - **Uncertainty calculation** using the SNR (Signal to Noise Ratio) of the **energies**
  - The **energies SNR** for a certain polarization, calculated as:

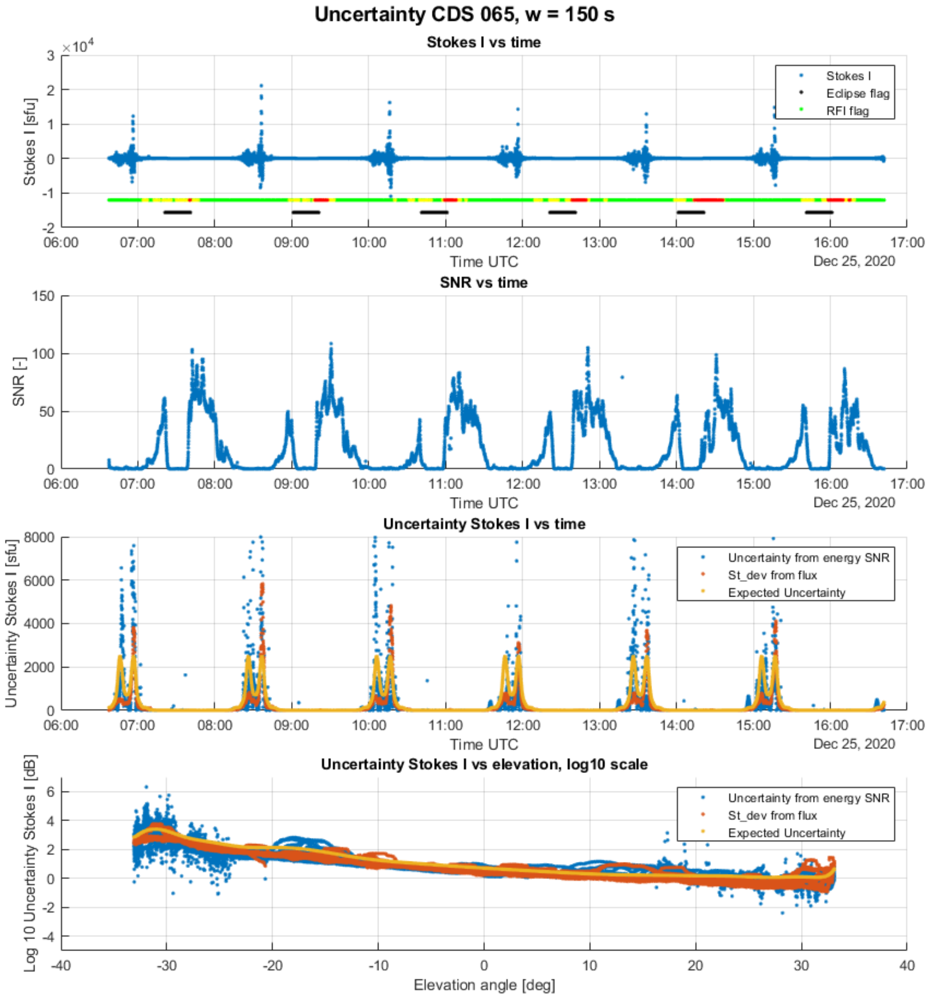
$$SNR(pol) = \frac{SE(pol) - BE(pol)}{2 * \sigma(BE(pol))}$$

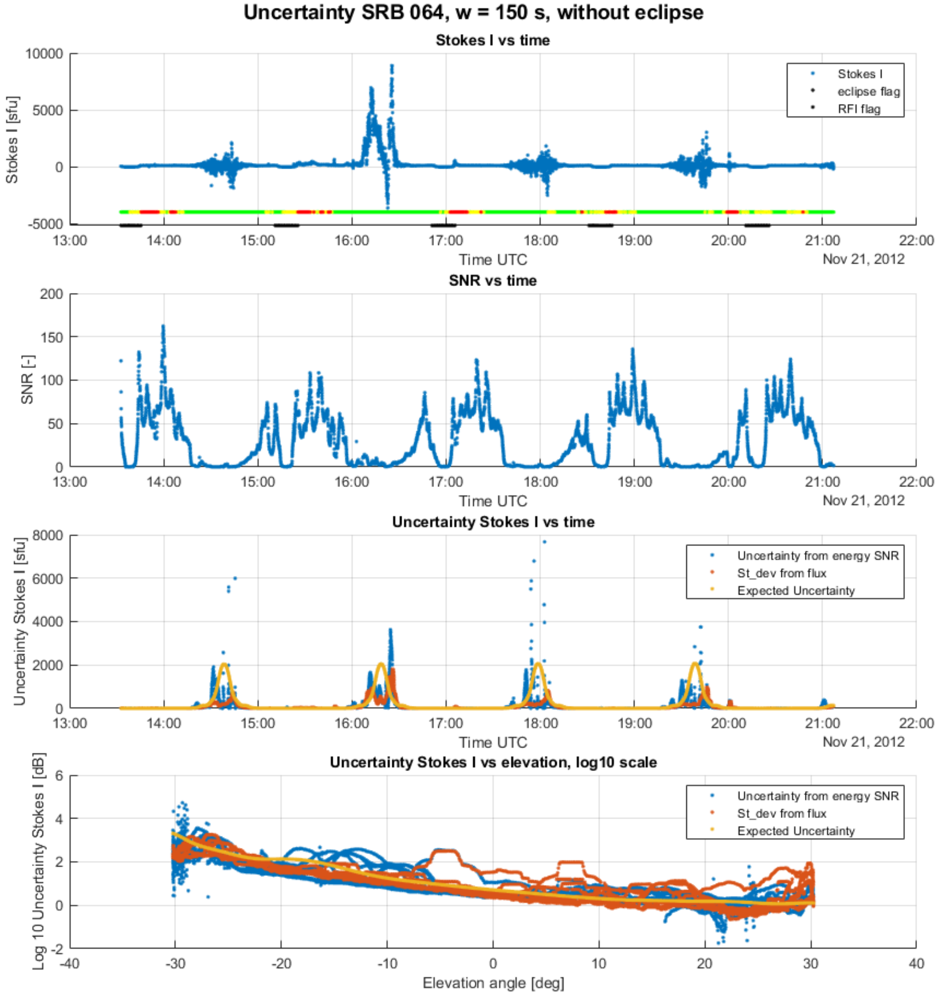
SE – Sun Energy; BE – Background Energy

  - **Uncertainty** estimated as U = μ(Stokes I) / SNR(Stokes I), where μ is the **local mean** of the Stokes I flux
- Uncertainties from both methods are **matching** each other (second method is provided to validate the first)

From estimated Sun BT to the SMOS Sun Flux Prototype Consolidation - Uncertainty calculation

❑ Energy SNR and uncertainty comparation





❑ Energy SNR and uncertainty comparation – quiet Sun interval (a) vs Solar burst (b)

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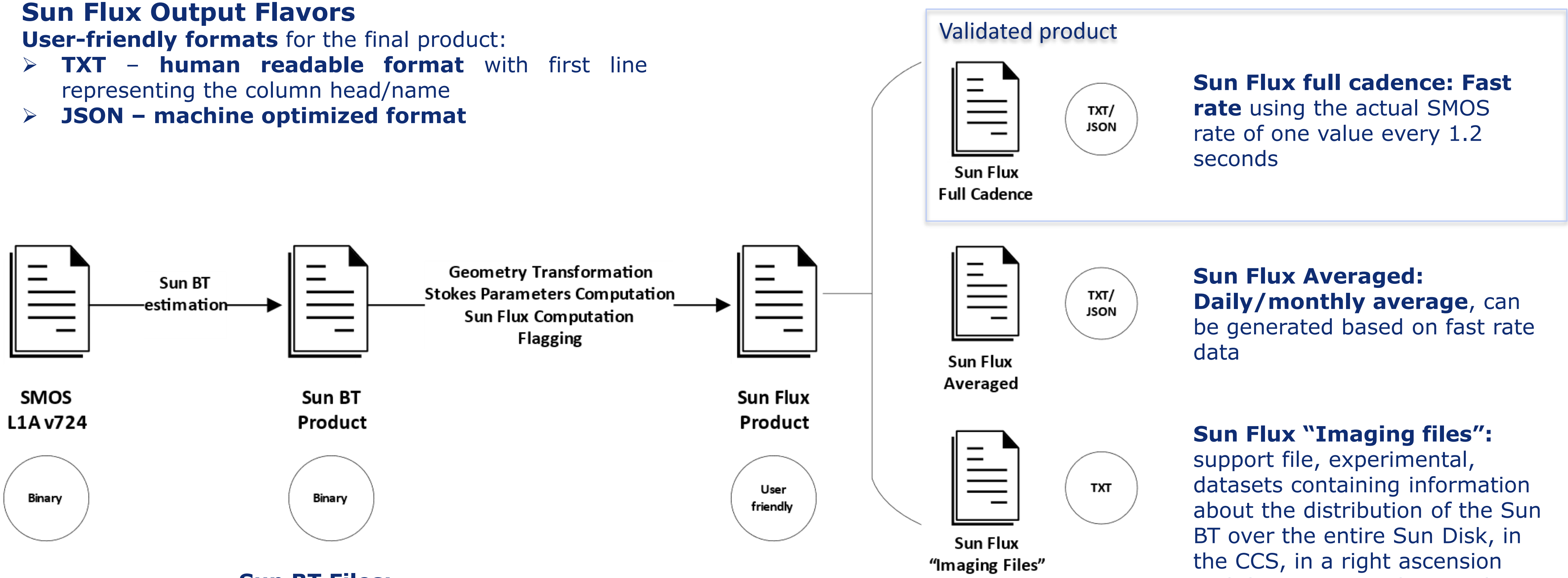
Sun Flux Output Flavors

User-friendly formats for the final product:

- **TXT – human readable format** with first line representing the column head/name
- **JSON – machine optimized format**



Sun Flux full cadence: Fast rate using the actual SMOS rate of one value every 1.2 seconds

Sun Flux Averaged: Daily/monthly average, can be generated based on fast rate data

Sun Flux "Imaging files": support file, experimental, datasets containing information about the distribution of the Sun BT over the entire Sun Disk, in the CCS, in a right ascension and declination grid, at each time stamp.

Sun BT Files:
Fast rate Sun BT estimation product

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Main Prototype Product

- **Sun Flux Product, for fast rate** = Sun Flux calculated data for each snapshot, using the actual SMOS rate of one value every 1.2 second, in the rotated frame
- Dedicated user product
- Main project product, generated for selected test datasets and validated
- With RFI Flagging
- With Uncertainty calculation
- Linear polarization removed in the final product due to the seasonal variation observed in the data, will be kept only for testing purposes

Sun Flux Field	Field Description
SUN_FLUX_Sample_Counter	Number of SUN_FLUX_Sample data set record structures
Snapshot_Time	UTC time at which the HV polarization was taken, in the format YYYY-MM-DD hh:mm:ss.s
Solar_Flux_Earth_Stokes_I	Solar flux on Earth for Stokes I, in SFU
Solar_Flux_Earth_Stokes_V	Solar flux on Earth for Stokes V, in SFU
Solar_Flux_1AU_Stokes_I	Solar flux on at 1AU from the Sun for Stokes I, in SFU
Solar_Flux_Earth_Stokes_V	Solar flux on Earth for Stokes V, in SFU
Solar_Flux_Uncertainty	Uncertainty calculated using the uncertainty function, depending on elevation angle, in SFU
Elevation_Angle	The elevation angle (in degrees) of the Sun relative to SMOS. The elevation angle is considered to be 0 at the transition, negative in the back and positive in front of SMOS.
RFI_flag	RFI flag defined as stop light with possible values: LOW/MODERATE/HIGH
Eclipse_flag	Eclipse flag defined as "true" when the Sun is eclipsed by Earth, and "false" when not

From estimated Sun BT to the SMOS Sun Flux Prototype
Sun Flux Product, avg

- ❑ **Sun Flux Product, averaged dataset**

= Sun Flux data, for the daily and monthly datasets, averaged, where averaging is proposed to be weighted, where the weight is defined by the uncertainty field.

- ❑ proposed format, not fully validated

Sun Flux Field	Field Description
SUN_FLUX_Sample_Counter	Number of SUN_FLUX_Sample data set record structures
Average_Type	Type of the average. Can be "daily" or "monthly"
Time_Period	Time period over which the average was taken. Depending on the Average_Type, Time_Period is in the format YYYY-MM-DD for daily averaging or YYYY-MM for monthly averaging
Solar_Flux_Earth_Stokes_I	Averaged Solar flux on Earth for Stokes I, in SFU
Solar_Flux_Earth_Stokes_V	Averaged Solar flux on Earth for Stokes V, in SFU
Solar_Flux_1AU_Stokes_I	Averaged Solar flux on at 1AU from the Sun for Stokes I, in SFU
Solar_Flux_1AU_Stokes_V	Averaged Solar flux on at 1AU from the Sun for Stokes V, in SFU
Elevation_Angle	The maximum absolute elevation angle (in degrees) of the Sun relative to SMOS antenna plane during the day/month. The elevation angle is considered to be 0 at the transition, negative in the back and positive in front of SMOS.

From estimated Sun BT to the SMOS Sun Flux Prototype Experimental imaging file

- **Sun Flux Support File, image dataset**

= image data file containing the estimated rotated Sun BT to the Sun frame written for the oversampled grid. Defined as a file containing all necessary data to generate image files

- Was generated as support file for implementation of prototype
- Can be generated on demand for specific cases (big data file)
- Not released, currently experimental but with potential for investigation/refining

General target requirements:

- **polarization state:** provided as Stokes parameters
- **reference for polarimetry:** fixed position and looking towards the Sun
- **reference for linear polarization**: Q: parallel to solar rotation axis, Positive U: 45º counterclockwise
- **reference for circular polarization**: Positive V: clockwise
- **units of the solar radio signal:** Solar flux units (SFU) – absolute flux on Earth + flux at 1AU from the Sun
- **calibration of the data:** Measurements must be self-consistent
- **radio-frequency interferences (RFIs) and other structures of non-solar origin:** Non-solar structures and RFIs must be corrected or clearly flagged. Solar radio burst should not trigger the RFI flagging
- **frequency of data sampling:** For the fastest sampling data: The file should contain a constant sampling rate of at least one value every 10 seconds.
- **data file format (non-real time):** At least two options: one optimized for machines (e.g., JSON), and other easy to read by humans (e.g., ASCII or CSV).

From estimated Sun BT to the SMOS Sun Flux Prototype Product Requirements (II)

Real-Time target requirements:

- **radio-frequency interferences (RFIs) and other structures of non-solar origin:** Only non-solar structures and RFIs that are clearly weaker than important radio bursts (around 400 sfu or 5·105 K) are admissible. Solar radio burst should not trigger the RFI flagging.
- **frequency of new data releases**: A frequency of one data release every 3 hours is admissible for the fastest sampling data (1.2s). Daily and monthly averaged data to be released on a daily and monthly basis, respectively.
- **maximum duration of periods without data:** As short as permitted by the SMOS service requirements. When possible no longer than 20 minutes.
- **time interval in each file:** For the fastest sampling data (1.2s): Up-to-date file containing data from the last 24 hours. For daily and monthly averaged data: Up-to-date file containing all the available data until the last day and month, respectively.
- **data file format**: Universal, small size, and optimized for machines (e.g., JSON files).

Thank you

With Contributions from the **SMOS FLARES Team**:

Consuelo Cid Tortuero, **Manuel Flores Soriano** – University of Alcala
Ali Khazaal - RDIS conseils
José Barbosa – Research and Development in Aerospace

www.elecnor-deimos.com

From estimated Sun BT to the SMOS Sun Flux Prototype Survey

Survey link: https://tinyurl.com/sunFlux