The solar spectrum for space weather and space climate applications

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Outline

- Why measure the solar spectrum?
- Why the solar spectrum is hard to measure?
- Strategies for space weather
The solar spectrum

Composite made out of observations (2003-2010)

spectral irradiance [mW/m²/nm]

wavelength $\lambda$ [nm]

altitude [km]

solar spectral irradiance

black body @ 5777 K
The solar spectrum

Composite made out of observations (2003-2010)

Solar spectral irradiance

Variability (over 11 years)
The solar spectrum

Composite made out of observations (2003-2010)

- Spectral irradiance [mW/m²/nm]
- Relative variability [%]
- Altitude [km]
- Wavelength $\lambda$ [nm]

- XUV
- EUV
- UV
- VIS
- IR

Solar spectral irradiance

Variability (over 11 years)

Altitude of strongest absorption
Definitions

SSI = solar spectral irradiance
- spectrally-resolved [W m\(^{-2}\) nm\(^{-1}\)]
- integrated over the full Sun

TSI = total solar irradiance
- integrated over all wavelengths [W m\(^{-2}\)]
- the TSI is an ECV (essential climate variable)

\[ TSI(t) = \int_{0}^{\infty} SSI(\lambda, t) \, d\lambda \]
Some observations

- Soft X-ray flux (0.1-1 nm)
- EUV flux (10-121 nm)
- MUV flux (200-300 nm)
- Total Solar Irradiance (TSI)
- impact: neutral density @ 250 km
Some observations (zoom)

- X-ray flux (0.1-1 nm)
- EUV flux (10-121 nm)
- MUV flux (200-300 nm)
- Total Solar Irradiance (TSI)
- Impact: neutral density @ 250 km
Main impacts (in a nutshell)

**EUV & Soft X-ray**
- ionisation, dissociation, etc
- strong and immediate impact on upper atmosphere (heating, density increase, composition changes)

**UV**
- photolysis
- ozone production and destruction in middle atmosphere (< 240 nm)

**Visible and infrared**
- direct heating of ground, oceans and troposphere
- low variability = no significant short-term impact
User needs: what timescale?

- **Months-years**
  - climate studies (solar forcing for high-top models)
  - radiometrically accurate reconstructions

- **Hours-days**
  - specification of the thermosphere-ionosphere
  - orbitography (satellite drag), radio communication (optimal band selection), positioning (e.g. drilling)

- **Seconds-Hours**
  - specification of the thermosphere-ionosphere (flares)
  - radio communication, positioning (e.g. aviation, defence)
Issues with the SSI/TSI
Issues with the SSI/TSI

- Instrument degrade in space = no long-term monitoring
  - radiometrically calibrated observations are very challenging
  - instrument lifetime = a few years

- Sparse coverage in time/wavelength
  - full spectrum measured since 2003 only
  - continuous monitoring not guaranteed (including for the TSI)

We’re still very far from a continuous monitoring of the SSI
Sparse coverage

spectral coverage by different instruments
Instruments disagree
Present use of TSI/SSI in space weather
Soft X-ray band

- Only spectral band that is available for operational use
- Measured continuously since 1986 by GOES
  - 2 wavelengths, 1 sec. cadence
  - available in near real-time from NOAA/SWPC

![GOES X-ray Flux (1-minute data)](image)
No continuous observation

Solar proxies are used instead

- 10.7 cm radio flux \((f_{10.7} \text{ index})\) measured at Penticton (Canada)
- available daily in near real-time from NOAA/SWPC since 1947
UV & Visible bands

- No continuous observation

- Solar proxies are used instead
  - core-to-wing ratio of the MgII line at 280 nm (MgII index) for the UV
Models for reconstructing the TSI/SSI
Different needs

- **Climate modelling**
  - *need*: high radiometric accuracy (science-grade models)
  - hindcast
  - mainly rely on solar proxies (sunspots, magnetograms...)

- **Thermosphere-Ionosphere specification (flareless)**
  - *need*: compensate for the lack of observations + predict (3-30 days ahead)
  - nowcast and forecast
  - mainly rely on solar proxies (f10.7, magnetograms, ...)

- **Thermosphere-Ionosphere specification (flares)**
  - *need*: compensate for the lack of observations
  - hindcast and nowcast
  - mainly rely on soft X-ray observations

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**Several models:**
(SATIRE, NRLSSI, SRPM, COSI, ...)

**2 models:**
s2k (USA), soteria (F)

**1 model:**
FISM (USA)

All models are empirical / semi-empirical
Soteria model provides the SSI in near real-time
- uses solar magnetograms as input (SDO/HMI satellite)
- 30-day forecast possible by modelling the surface magnetic field with a surface flux transport model
The main difficulties we encounter are:

- **transition to operations**: now considering CLS (Collecte Localisation Satellites) to host this service.

- **validation**: have a realistic idea of what the quality of the data is

- **long-term support**: very limited possibilities...
To conclude
Conclusions 1/2

- Soft X-ray / EUV / UV observations are important for various space weather applications.

- But most observations do not meet the needs of space weather services.
  - SSI monitoring is NOT a priority for space agencies (except soft X-ray by NOAA).
  - Major lack of observations $\implies$ proxies are widely used instead.
    - *Un tiens vaut mieux que deux tu l’auras / A bird in the hand is worth two in the bush*.
  - but proxies are poor substitutes for a radiometrically correct SSI.

Users have stayed away from direct observations because of their lack of continuity / stability.
Conclusions 2/2

- Nowcasting: models supplement the lack of observations
  - monitoring the SSI is today possible

- Prediction: demand for spacecraft operations and radio communication
  - flares cannot be predicted
  - SSI can be predicted (3-30 days ahead) by using surface magnetic field model to determine future evolution of surface magnetic field.