Timescales of Solar Variability

- **Solar Cycle** - months to years
  - Evolution of solar dynamo with 22-year magnetic cycle, 11-year intensity (sunspot) cycle

- **Solar Rotation** - days to months
  - Beacon effect of active regions rotating with the Sun (27-days)

- **Flares** - seconds to hours
  - Related to solar solar eruptive events due to the interaction of magnetic fields on Sun
The Solar Cycle

11-year “Sunspot” or Solar Activity Cycle

DAILY SUNSPOT AREA AVERAGED OVER INDIVIDUAL SOLAR ROTATIONS

SUNSPOT AREA IN EQUAL AREA LATITUDE STRIPS (% OF STRIP AREA)

AVERAGE DAILY SUNSPOT AREA (% OF VISIBLE HEMISPHERE)

http://solarscience.msfc.nasa.gov/
Monthly Averaged Sunspot Numbers

![Graph showing monthly averaged sunspot numbers from 1700 to 2000. Peaks and valleys indicate solar activity peaks and minima. Two dashed vertical lines mark the Dalton Minimum.](image)
Recent Sunspot Numbers

Monthly Sunspot Area

Cycle 24 Sunspot Number Prediction (June 2012)
So what are these spots anyway?

A brief detour into atomic physics…
Simple Model of Atom

Isotopes of Hydrogen, Helium, Lithium and Sodium

A photon is emitted with energy $E - hf$.

Increasing energy of orbits.

Sodium–22

Neutron  Proton  Electron

©2001 How Stuff Works
Magnetic Fields and Sunspots

P. Zeeman

G. E. Hale

G.E. Hale, June 1908

The Solar Cycl
Source of Solar Cycle

11-year sunspot cycle is really a 22-year magnetic cycle (magnetic field reverses every 11 years).

Differential rotation of Sun causes “knotting” of originally dipole-like magnetic field.

Solar Maximum: Knotting peaks ~5.5 years after “clean” start. Solar activity and output peaks.

Solar Minimum: Sun cleans itself up over next 5.5 years into a quiet, but “reversed” dipole field.
Surface magnetic fields over the solar cycle

Courtes D. Hathaway
Magnetic Butterfly Diagram
How much does the energy output of the Sun change?

- Most of the power is at visible wavelengths or longer (shape of the blackbody)
- Most of the variability is at ultraviolet wavelengths or shorter (structures in the solar atmosphere)
- So does the tail wag the dog?
The observed spectrum from the SORCE mission

Integrate over all wavelengths to get total radiative output, aka Total Solar Irradiance (TSI) or the “solar constant”
Total Solar Irradiance Observations
One way to link them is to assume the most recent is the best.

Solar Cycle $0.1\% = 1.4 \text{ W/m}^2$
4 TSI Composites: Conflicting Results

- **SOHO VIRGO PMOD** (Fröhlich) and ACRIM (Willson) composites indicate 2008 TSI is lower than 1996 level

- **SOHO VIRGO DIARAD (DeWitte)** and SORCE TIM / Model (Lean) composites indicate 2008 TSI is higher

- Uncertainty for 2008-1996 trend is about 100 ppm
TSI variability can be described as bright vs dark.
The Earth System

Earth intrinsically has an atmosphere and a magnetic field. Both of these interact with the Sun on short and long timescales.
Earth’s Atmosphere Composition & Density

Diagram showing the relationship between altitude (km) and number density, with curves for different atmospheric constituents: $O_2$, $N_2$, $O_3$. Equations indicating reactions:

- $O_2 + h\nu \rightarrow O + O$
- $O + O + M \rightarrow O_2 + M$
- $O_3 + h\nu \rightarrow O + O_2$
Solar Photons and the Atmosphere

The Solar Spectrum at top of atmosphere (similar to 5800 K blackbody spectrum)

The Solar Spectrum at the surface of the Earth
The Atmosphere and TSI

EARTH'S ENERGY BALANCE

REFLECTED SOLAR RADIATION 107 W m⁻²
REFLECTED BY CLOUDS, AEROSOL AND ATMOSPHERE 77
REFLECTED BY THE SURFACE 30

INCOMING SOLAR RADIATION 342 W m⁻²

OUTGOING LONGWAVE 235 W m⁻²
EMITTED BY THE ATMOSPHERE 165
ATMOSPHERIC WINDOW 40
GREENHOUSE GASES 324
BACK RADIATION 40

ABSORBED BY THE SURFACE 168

THERMALS 24

LATENT HEAT 24

EVAPORATION 78

SURFACE RADIATION 390
ABSORBED BY THE SURFACE 324
The SolAR Cycl

Climate Influences

- Multivariate ENSO index - weighted average of the main features contained in sea-level pressure, surface wind, surface sea and air temperature, and cloudiness in the tropical Pacific (Walter and Timlin, 1998)

- Net effect of sunspot darkening and facular brightening - model developed from observations of total solar irradiance (Lean et al. 2005)

- Optical thickness at 550 nm - compiled by Sato et al. (1993) since 1850, updated to 1999 from giss.nasa.gov and extended to the present with zero values

- Volcanic Aerosols
  - El Chichon
  - Pinatubo

- Solar Irradiance

- Anthropogenic Forcing

courtesy of Judith Lean, NRL
Combined ENSO + volcanic aerosols + solar activity + anthropogenic effects explain 85% of observed temperature variance

from Kopp & Lean 2011
Decompositions of historical and recent global surface temperatures give consistent individual natural and anthropogenic components:

**Natural components account for <15% of warming since 1890**
Does this matter?