Time-varying Map of the Global Solar Wind Speed

Computational Physics PH 662
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Solar Wind

- Solar winds are charged particles (electrons and protons) streaming from the solar corona.
- The stream of particles are able to move outward from the Sun’s atmosphere, overcoming gravity, due to their high kinetic energies.
- The particles have variation in temperature, density and velocity.

Solar Wind Measurements

Solar Wind measuring techniques:

- Close to the Earth's orbit (~1AU), in-situ measurements provide solar wind properties.
- Scattering techniques provide indirect estimates of the solar wind properties.

Scattering Technique

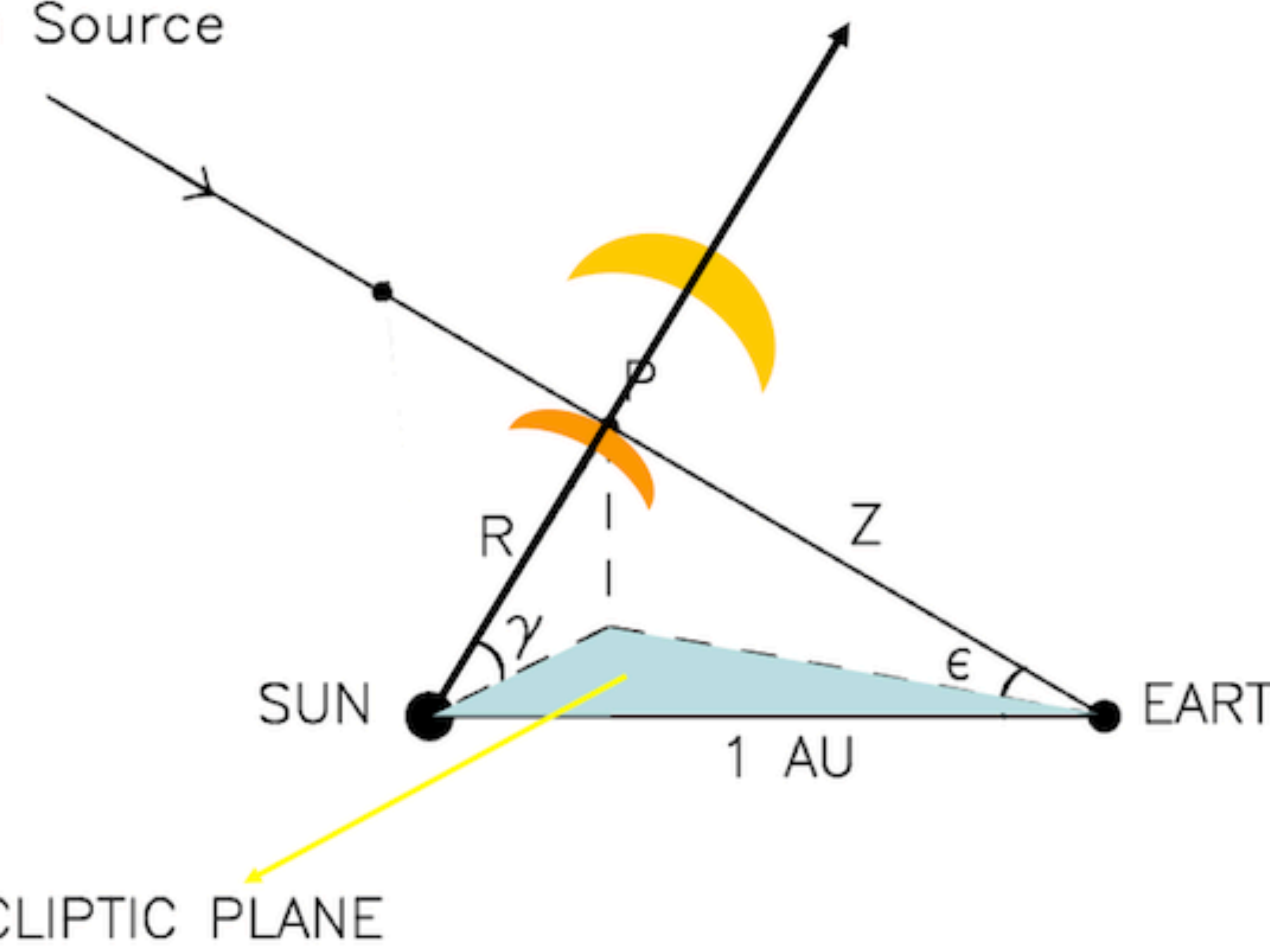
The scattering technique is useful to obtain a 3-D view of the heliosphere at various distances, all latitudes and also obtain long-term & large-scale structure of the solar wind.

Scattering phenomena includes:

- Intensity scintillation
- Angular scattering
- Spectral broadening

Interplanetary Scintillation

- Radio waves from distant compact sources are scattered by density irregularities in the solar wind, producing diffraction pattern.
- The motion of the irregularities converts the pattern into temporal intensity fluctuations, which are observed as interplanetary scintillations (IPS).



Source
P
R
Z
γ
ε
SUN
EART
1 AU
CLIPTIC PLANE

The measurable quantity in the IPS observations is the temporal variations of the intensity of the scintillating radio source as a function of time, I(t).

It yields:

- Solar wind speed
- Density turbulence level
- Temporal spectrum
- Angular diameter of the source

Scintillation Index (m)

$$\Delta I = I(t) - \langle I(t) \rangle$$

$$m = \left(\frac{\text{rms of intensity fluctuations}}{\text{mean intensity of the source}} \right)$$

$$= \left\{ \frac{\langle \Delta I(t)^2 \rangle}{\langle I \rangle^2} \right\}^{1/2}$$

By using the Fourier Transform, the scintillation intensity is transformed into power components (depending on observation frequencies).

The transformed power lines of the spectrum are applied to calculate the velocity and density of solar wind.

Power spectrum from Fourier transform

$$\rho(r,t) = \langle \Delta I(r_o, t_o)\, \Delta I(r_o + r, t_o + t) \rangle$$

$$P_I = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \rho(0,t) \exp(-i2\pi\, f t) dt$$

Area under the temporal power spectrum is given by

$$m^2 = \frac{1}{\langle I \rangle^2} \left[\int_{-\infty}^{+\infty} P_I(f) df \right]$$

Solar wind speed is estimated from the cross-correlation analysis of the IPS measurements.

Cross-correlation at a time lag Δt between two time series of intensity data

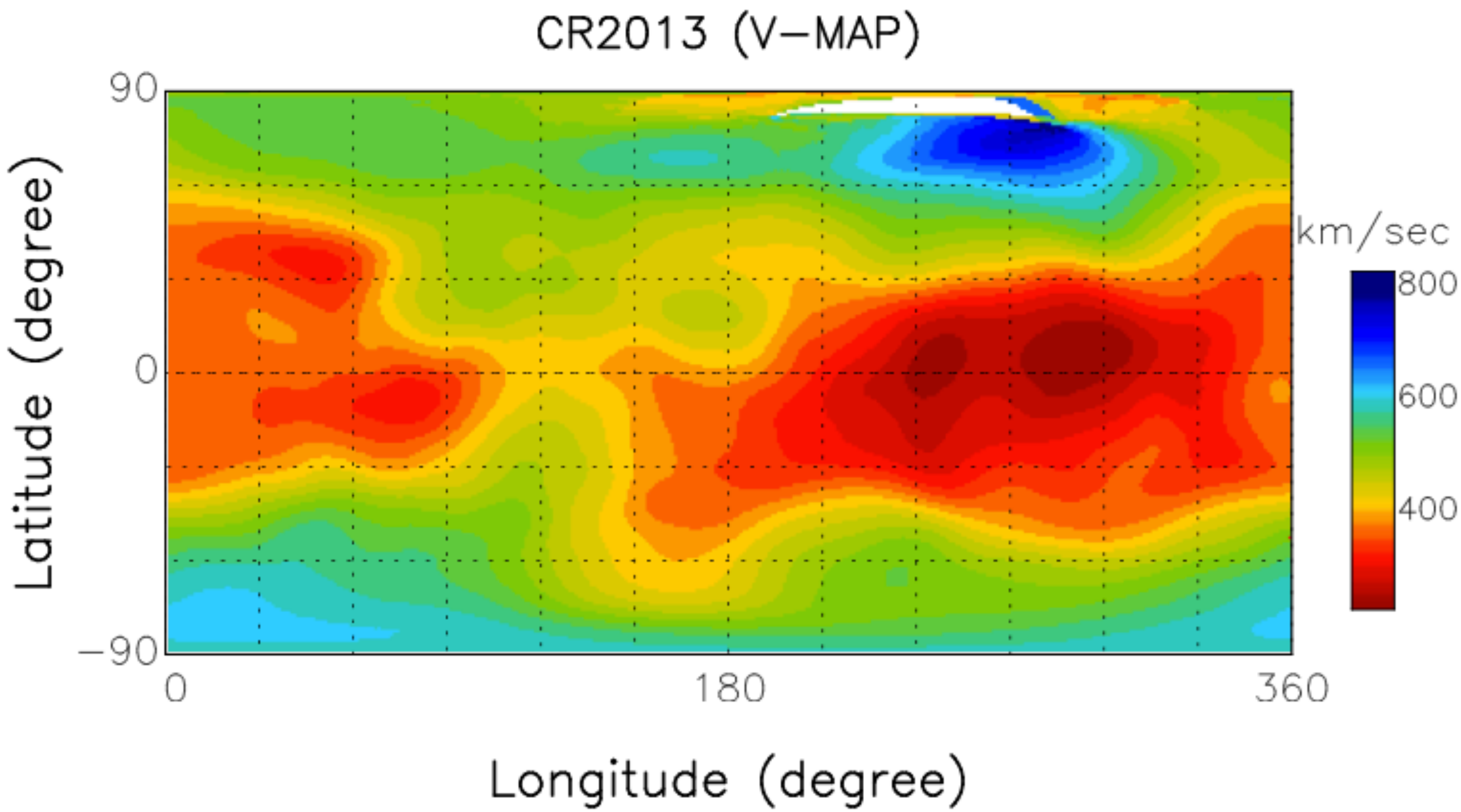
$$C(r, \Delta t) = \langle T(r_o, t)\, I(r_o + r, t + \Delta t)\rangle / \langle I^2 \rangle$$

- To find the regions of solar wind streaming near the Sun, reverse mapping technique is used.
- The measured solar wind is mapped back to a source surface. This requires constant and radial solar wind flow.
- With an assumption that solar wind speed is constant, the value is assigned to a 2-D coordinate system representing Carrington helio latitude and longitudes.

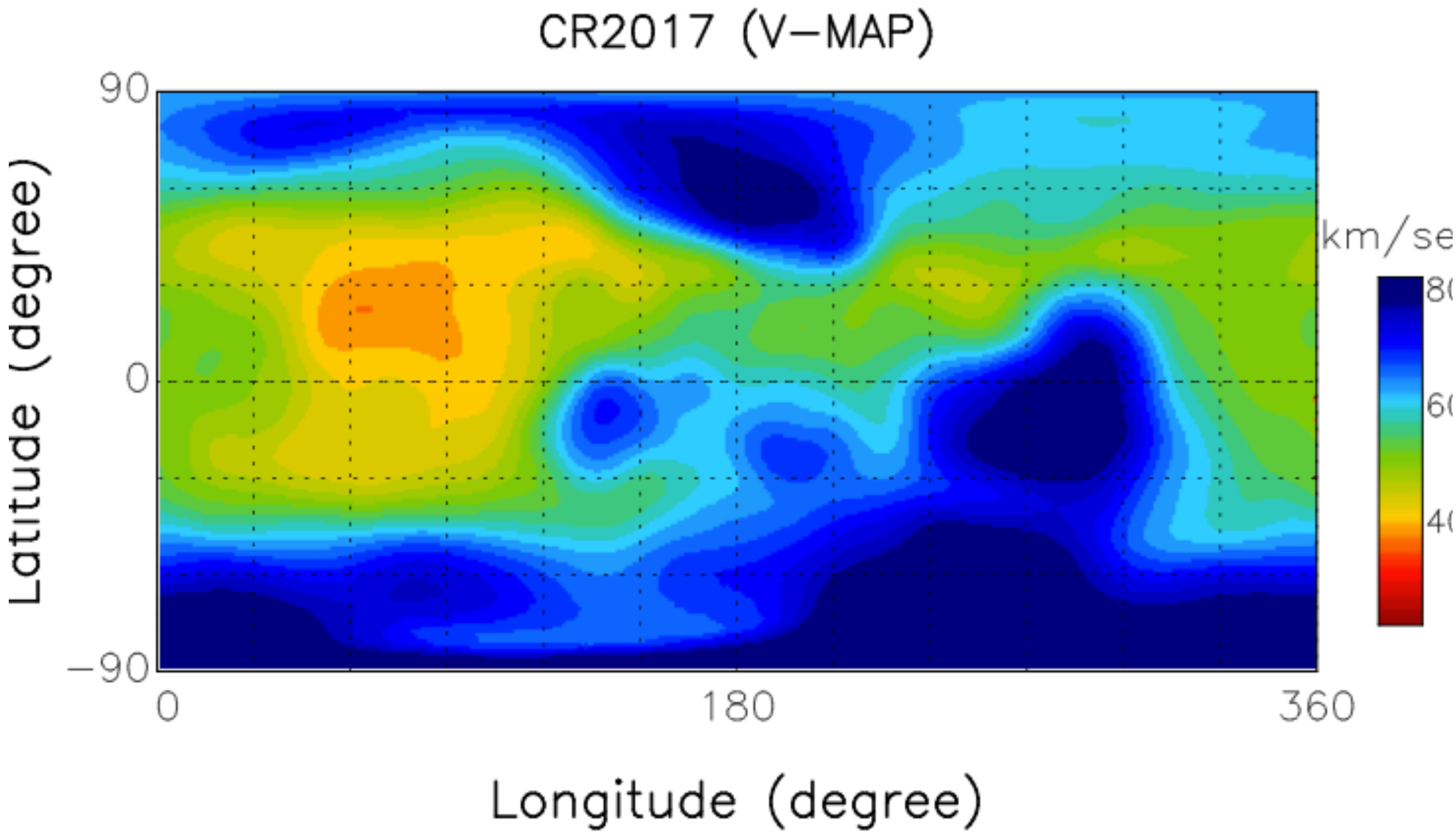
Time-varying velocity map

- Compute the coordinates of the point that lies closest to the Sun on the line that connects the Earth with the source (P-point).
- Trace backward/forward from each P-point to a source point on a Sun- centered spherical surface of certain radius R by radially projecting the P-point onto the reference sphere and then tracing backward or forward (in the longitudinal direction) to the appropriate spot on the sphere.

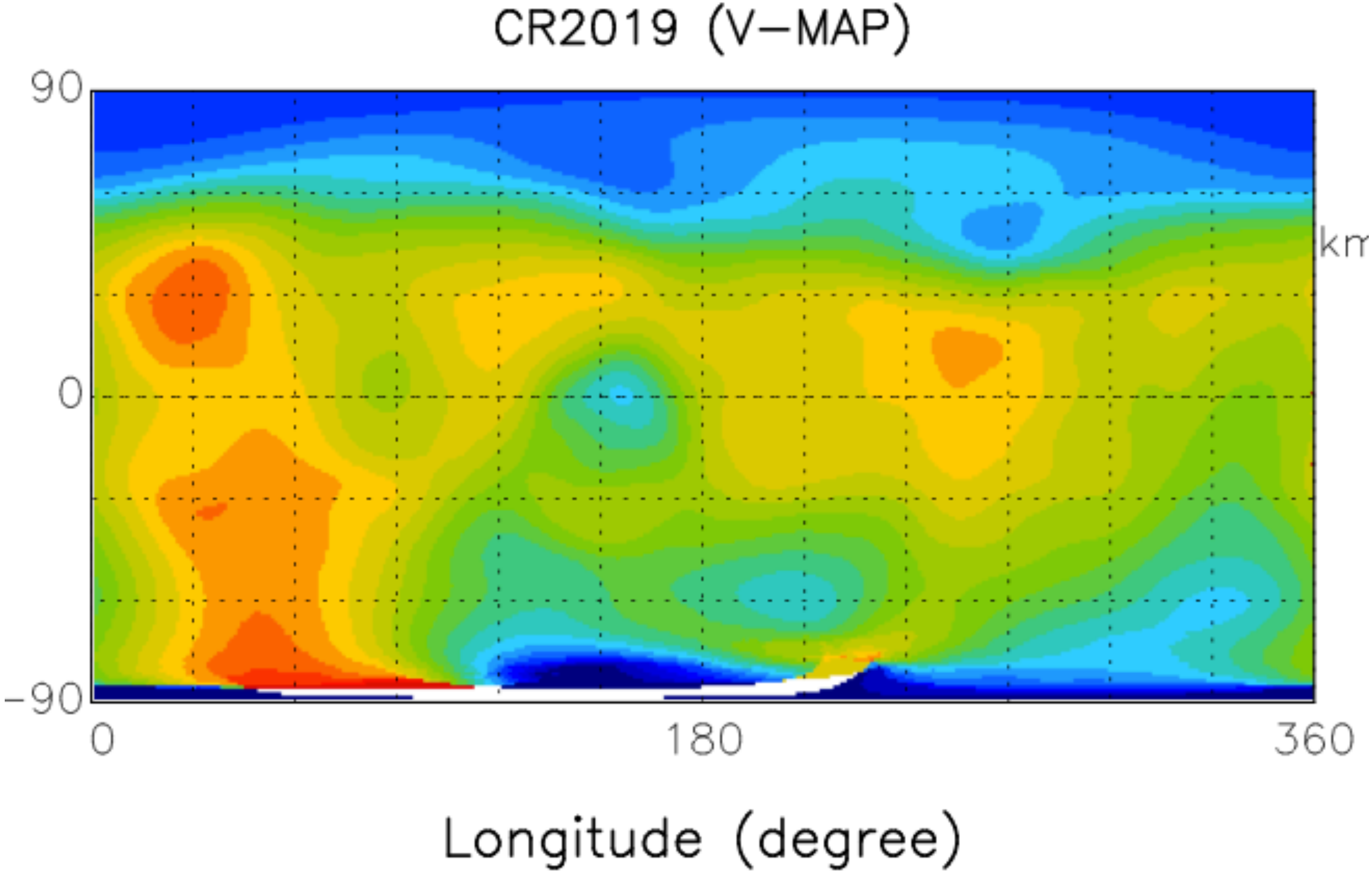
Result



CR2013 (V–MAP)
90
0
−90
Latitude (degree)
0
180
360
Longitude (degree)
km/sec
800
600
400



CR2017 (V-MAP)
90
0
−90
Latitude (degree)
0
180
360
Longitude (degree)
km/se
80
60
40



CR2019 (V-MAP)
90
0
-90
0
180
360
km
Longitude (degree)

The obtained results are the synoptic velocity maps using the IPS measurements for the Carrington rotations 2013, 2017 and 2019.

When analyzed for many consecutive Carrington rotations, the solar wind speed over many years or for an entire solar cycle can be studied.