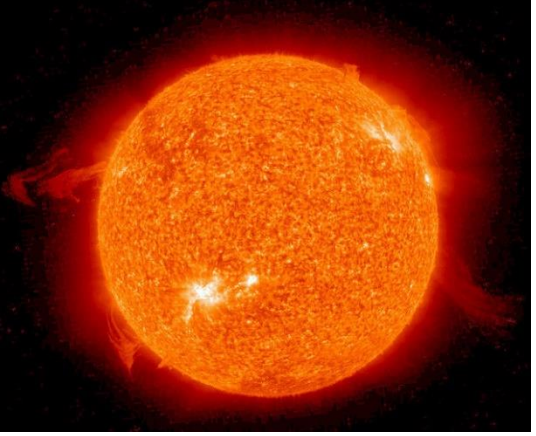

Planetary Space Weather Workshop,
Toulouse, Oct. 9-11, 2017

solar wind: 1D MHD propagation model

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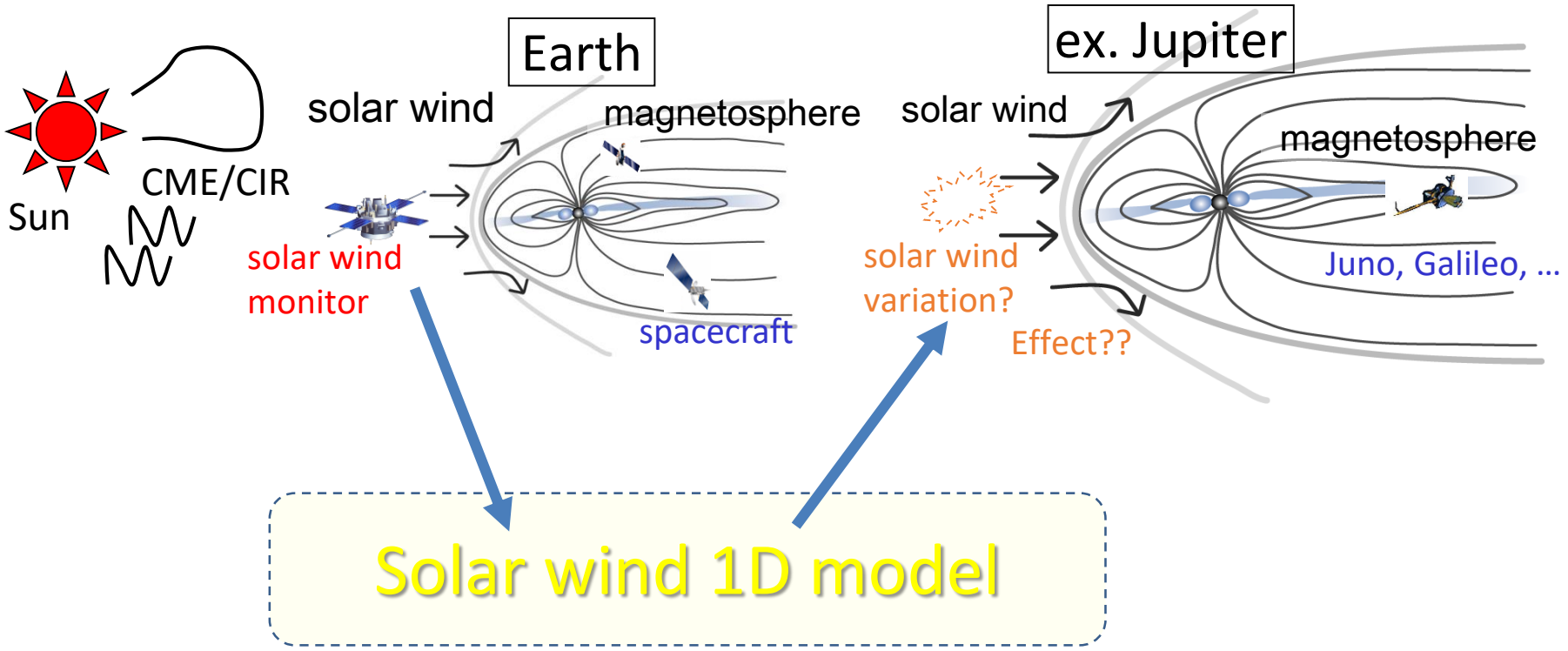
+N. Andre, V. Génot, A. P. Rouillard, E. Budnik, A. Biegun (IRAP)

Introduction: Motivation

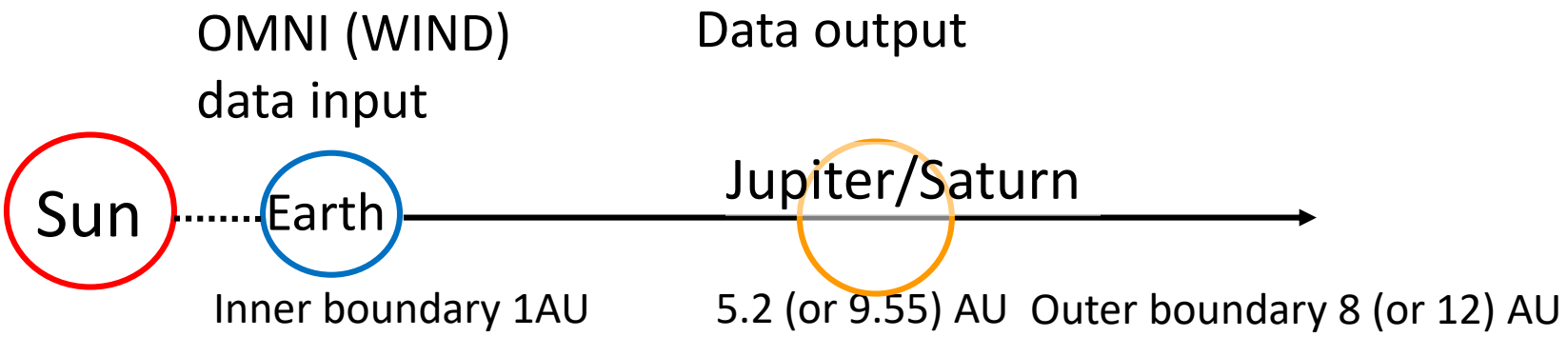
Solar wind variation is essential information for planetary physics

Problem : Lack of continuous solar wind monitor at planets

Solution : Solar wind prediction using observation at 1AU

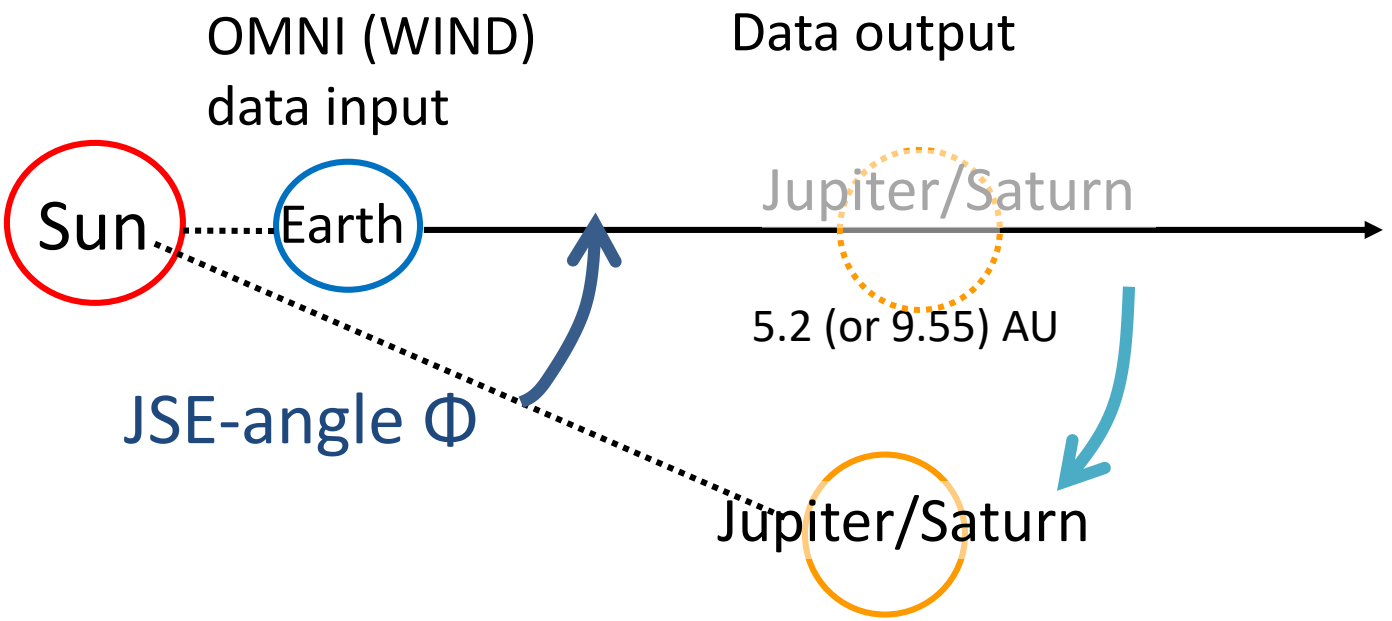


Solar wind 1D model



Spatial resolution : 0.0033AU calc. time step:60-300 sec

Solar wind 1D model



Shift the time of solar wind output data for $\Delta t = \Phi/\Omega sun$

Φ: JSE-angle between Earth's longitude at input time and Planet's longitude at output time, Ωsun: solar rotation angular velocity.

Assumption: Solar wind structure is conserved during solar rotation

→This model has limitation on ①short-time variation or ②CME, and ③effect of off-equatorial structure

This model directly refers to solar wind observation

1D MHD

$$\frac{\partial}{\partial t}(\rho S) + \frac{\partial}{\partial x}(\rho v_x S) = 0 \tag{1}$$

$$\frac{\partial}{\partial t}(\rho v_x S) + \frac{\partial}{\partial x}\left[\left(\rho v_x^2 + p + \frac{B^2}{8\pi} - \frac{B_x^2}{4\pi}\right)S\right] = \rho\left[g_x + \left(v_y^2 - \frac{B_y^2}{4\pi\rho}\right)\frac{1}{R}\frac{dR}{dx}\right]S + \left(p + \frac{B^2}{8\pi}\right)\frac{dS}{dx} \tag{2}$$

$$\frac{\partial}{\partial t}(\rho v_y R S) + \frac{\partial}{\partial x}\left[\left(\rho v_x v_y - \frac{B_x B_y}{4\pi}\right)RS\right] = 0 \tag{3}$$

$$\frac{\partial}{\partial x}(B_x S) = 0 \tag{4}$$

$$\frac{\partial}{\partial t}\left(\frac{B_y S}{R}\right) - \frac{\partial}{\partial x}\left(\frac{(-v_x B_y + v_y B_x)S}{R}\right) = 0 \tag{5}$$

$$\frac{\partial}{\partial t}\left[\left(\frac{1}{2}\rho v^2 + \frac{p}{\gamma - 1} + \frac{B^2}{8\pi}\right)S\right] + \frac{\partial}{\partial x}\left[\left\{v_x\left(\frac{1}{2}\rho v^2 + \frac{\gamma p}{\gamma - 1}\right) - \frac{1}{4\pi}\left(B_y(-v_x B_y + v_y B_x)\right)\right\}S\right] = \rho g_x v_x S, \tag{6}$$

div **B**=0

1D → dBx/dx =0

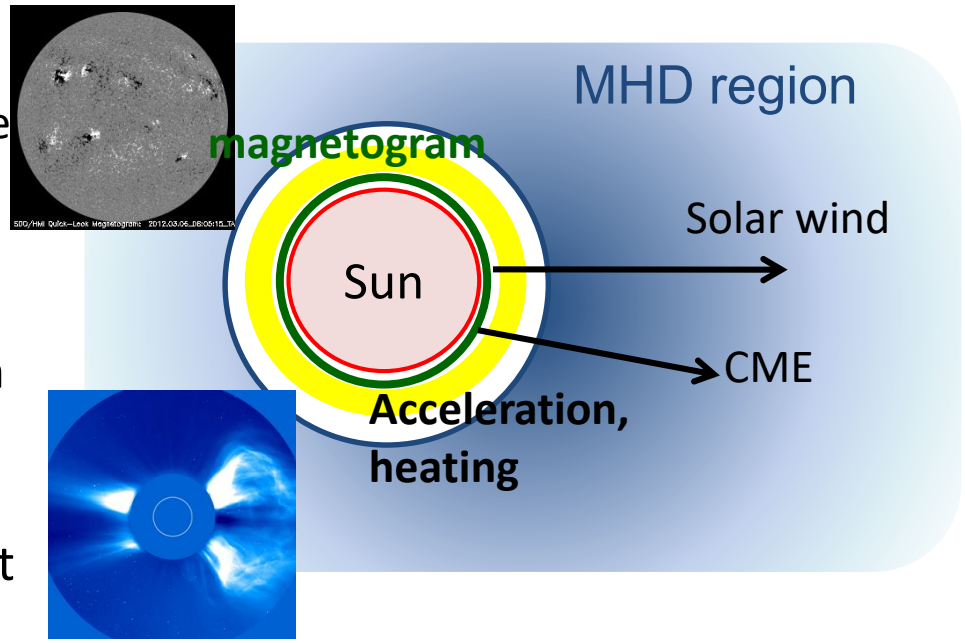
→ Bx∝1/x2

We assume small Bx @1AU (~0.001 nT).

This does not affect a lot on plasma parameters (ρ, V, |B|).

cf. Solar wind 3D model

Empirical-obs.-referred model:
ex.ENLIL [Odstrcil et al.], SUSANOO [Shiota et al. 2014]



<u>Input parameter @～25 Rsun</u>
Solar surface magnetic field observation
+Empirical model [e.g., Arge and Pizzo, 2001]
(B→ V, T, N)
+Coronagraph observation → CME input

Empirical model is used for conversion

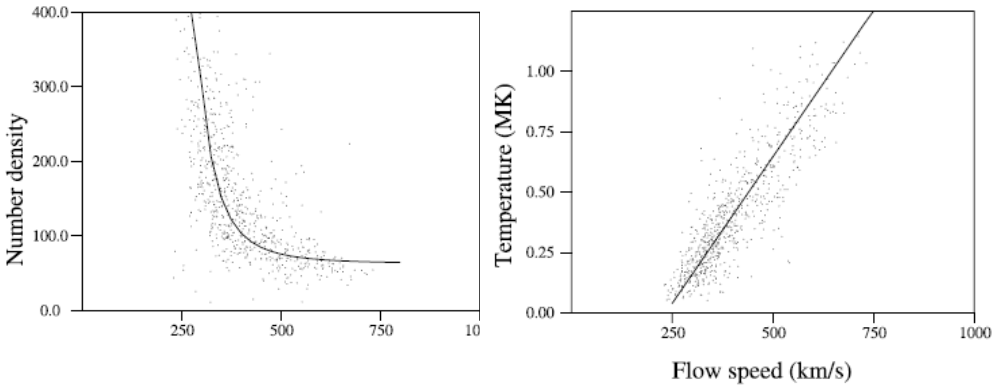


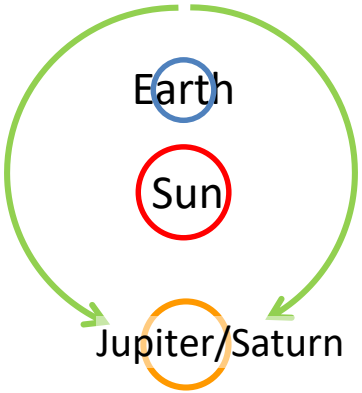
Fig. V-N @50R_{sun}, V-T relation taken by Helios observation [Hayashi et al., 2003]

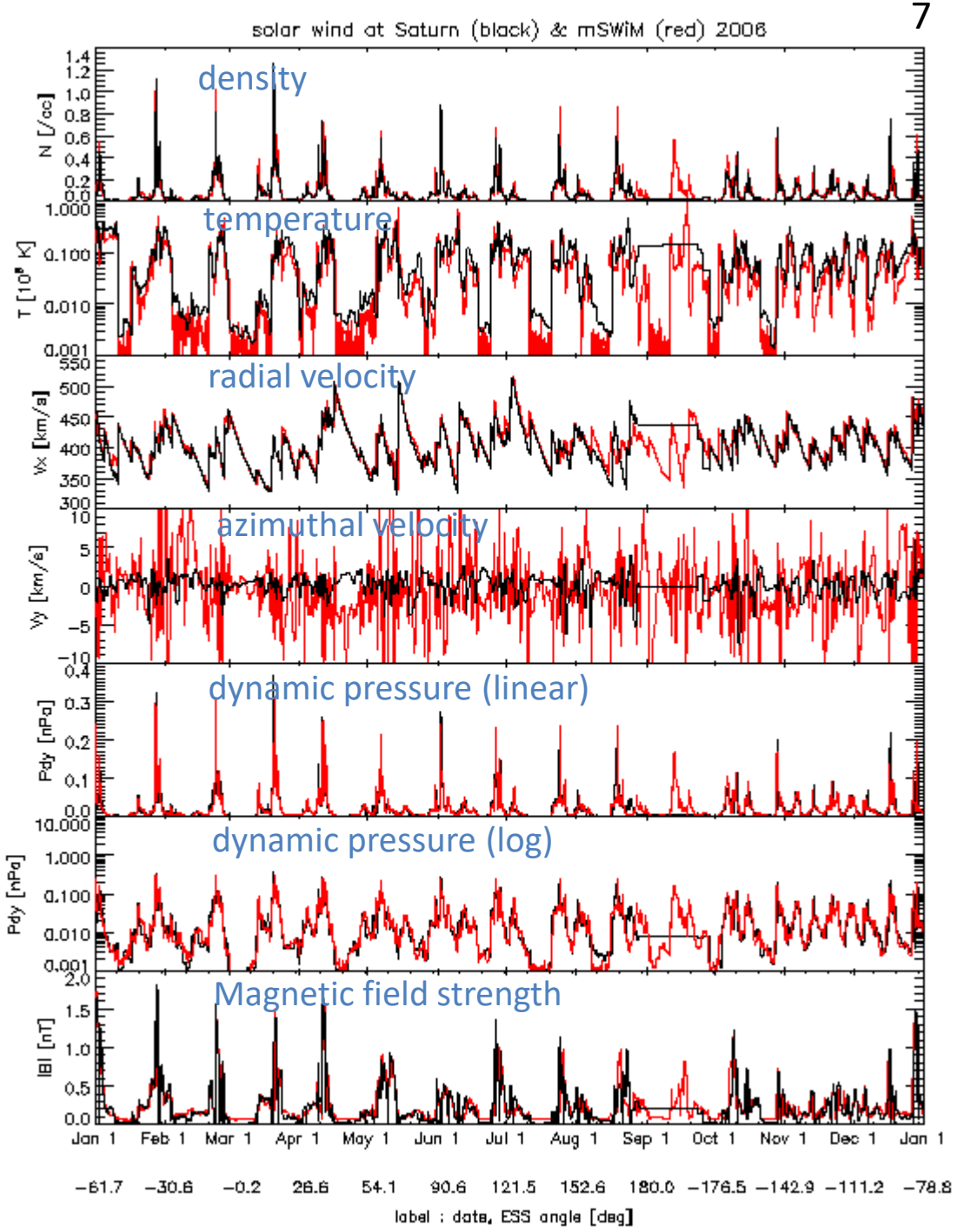
Comparison with mSWiM

Our model [Tao et al., 2005]
(1D, 2-component)
we do not consider ϕ~180, Vz, Bz
whose accuracies are not good

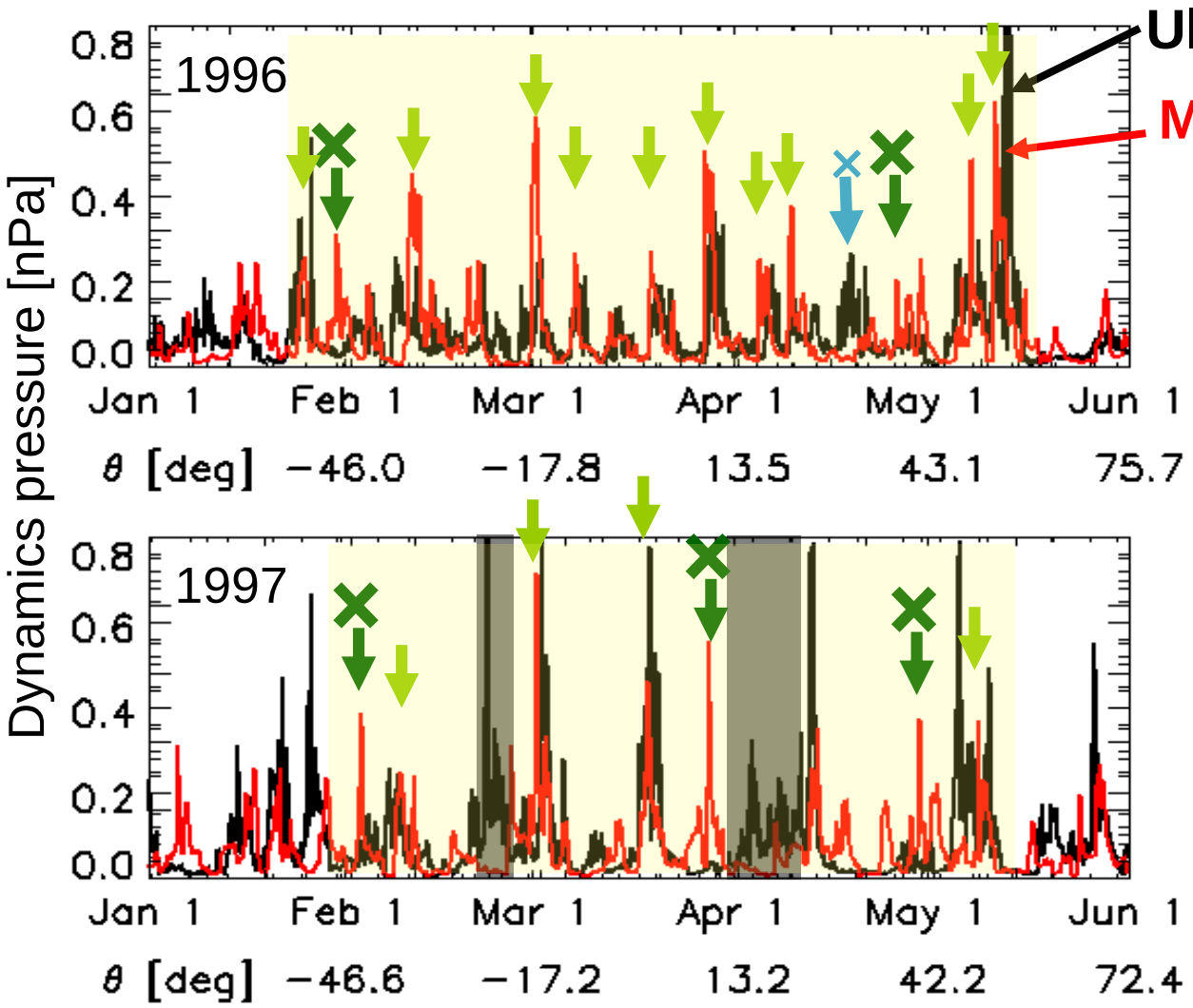
Michigan's mSWiM
[Zieger and Hansen, 2009]
(1D, 3-component) +Vz, Bz

→These results match well.





Caution of the model usage



	Obs.○	Obs.×
Model○	Hits 14	False 5
Model×	Miss 1	--

Caution!

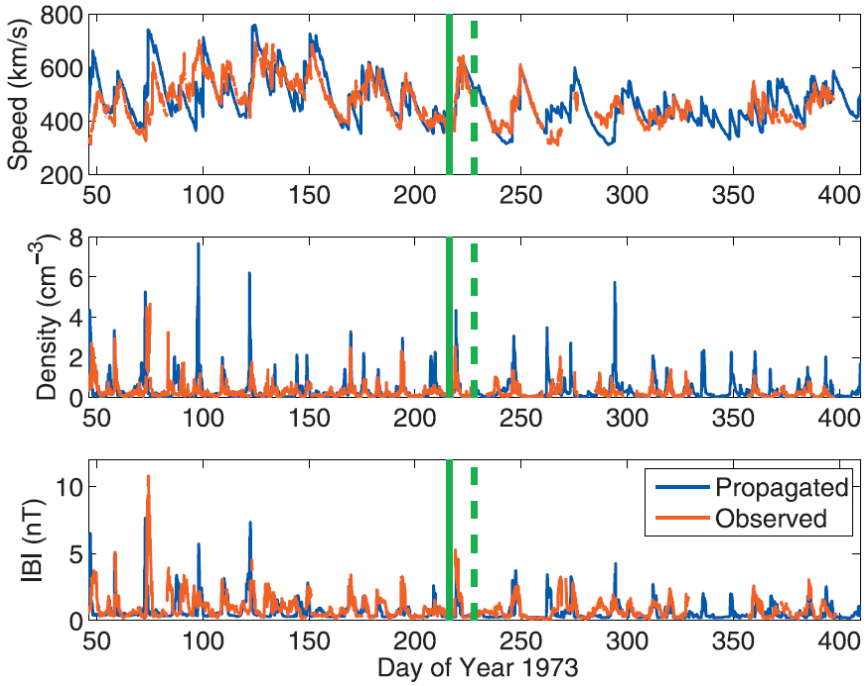
How much events of the model is correct?
(Probability Of Detection)
=(Hits)/{(Hits)+(False)}
=14/(14+5)=73.6%

Recurrence Ratio Dependence

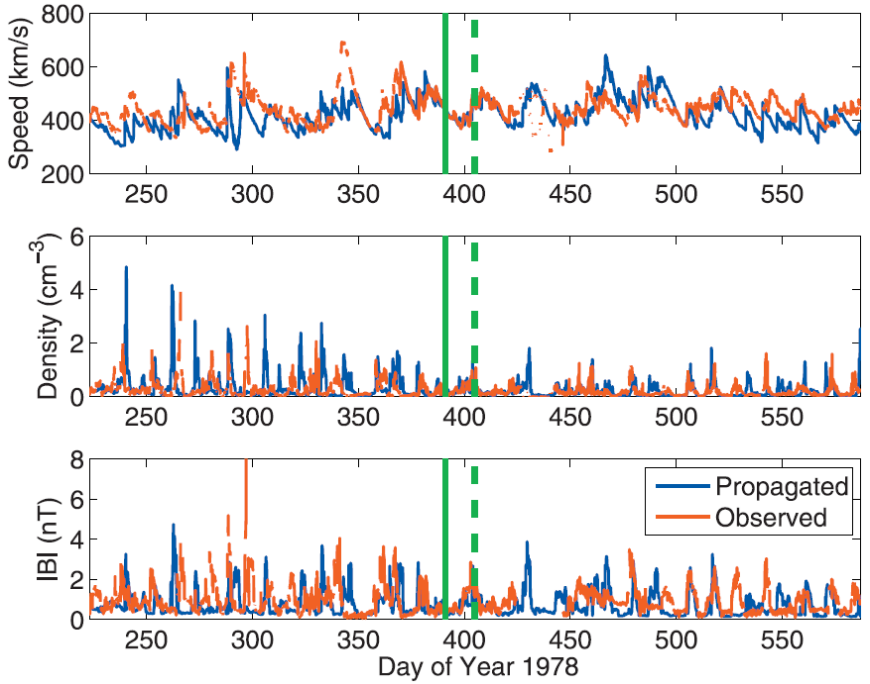
Recurrence ratio: Correlation coefficient of solar wind speed in 27-day period and that from 27-day before.

[Zieger and Hansen, 2008]

High Recurrence Ratio (0.50)



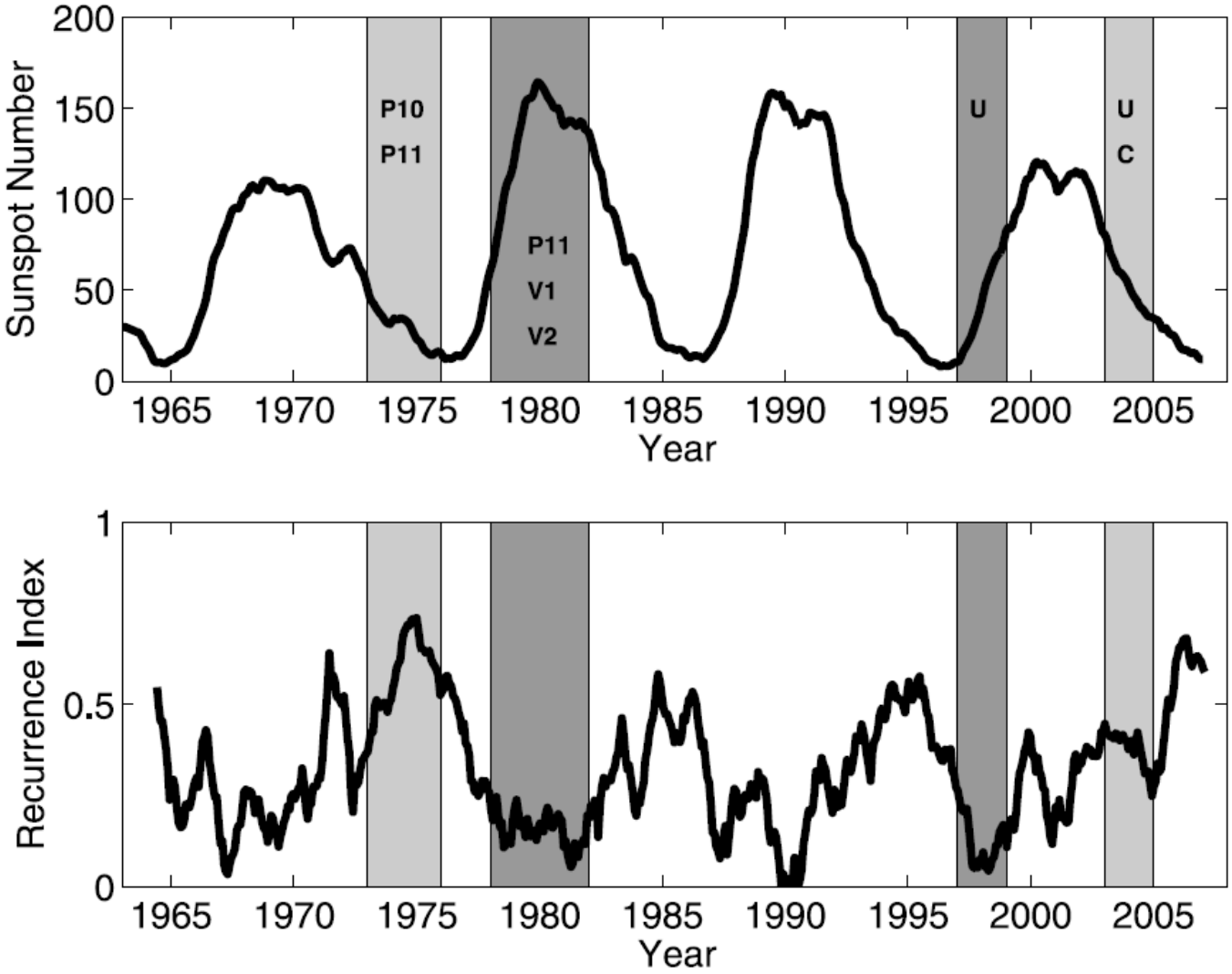
Low Recurrence Ratio (0.17)



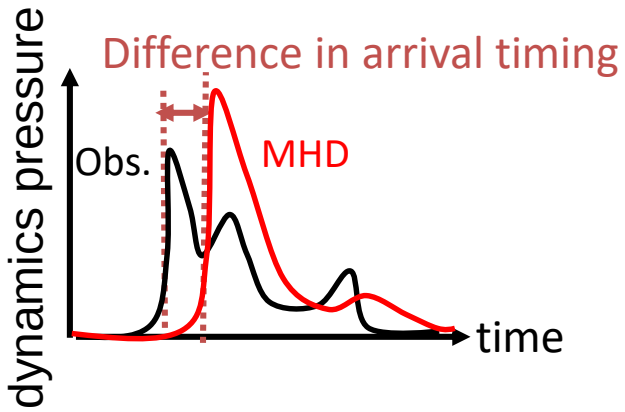
Since 1D model assumes solar wind structure is conserved during solar rotation, model prediction accuracy is good when the recurrence ratio is high.

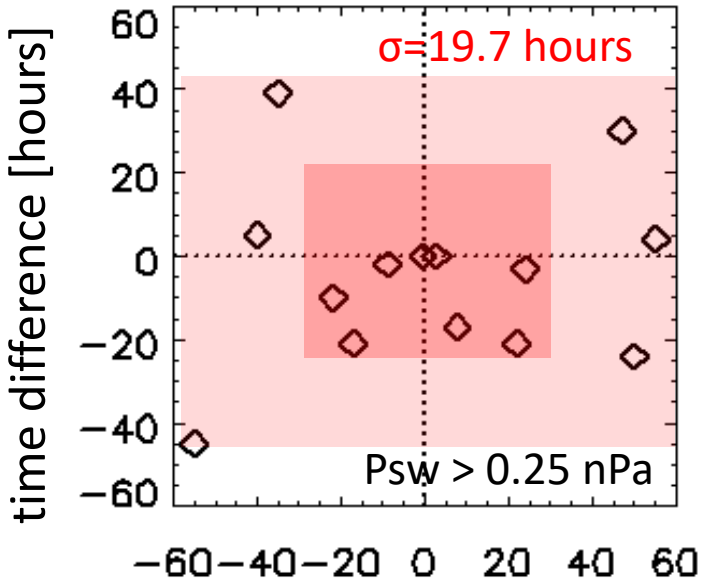
Recurrence ratio

[Zieger and Hansen, 2008]



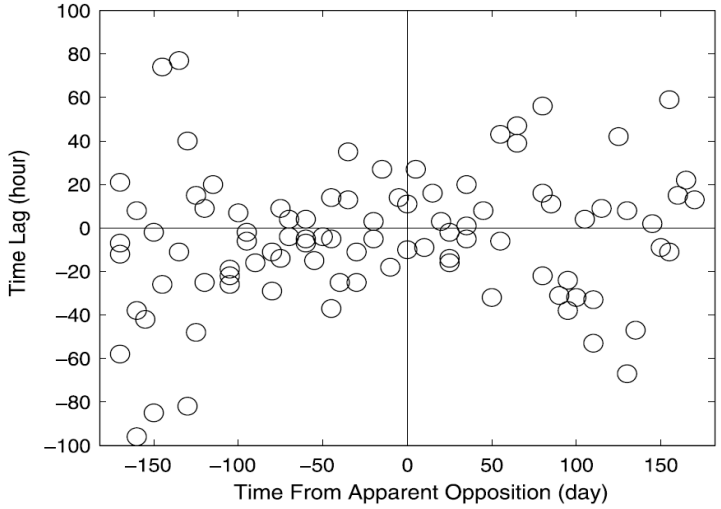
SW1D model evaluation: arrival time



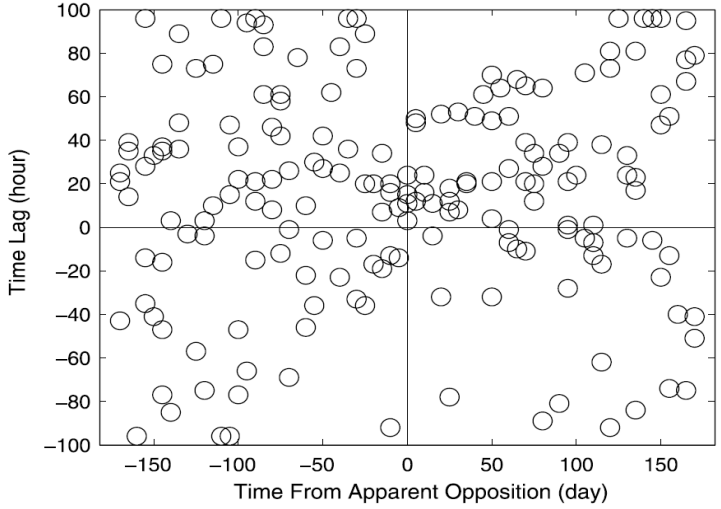


[Tao et al., 2005]

High recurrence case (>0.4)

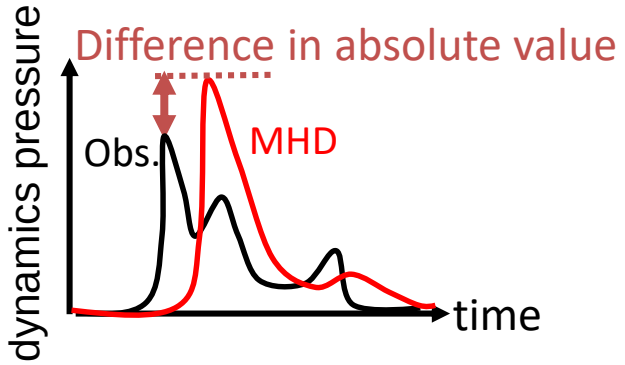


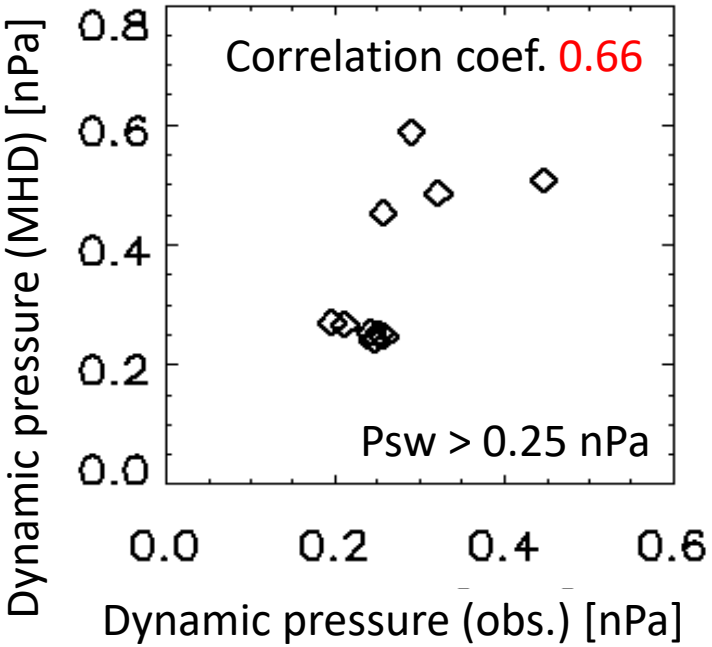
Low recurrence case (<0.4)



[Zieger and Hansen, 2009]

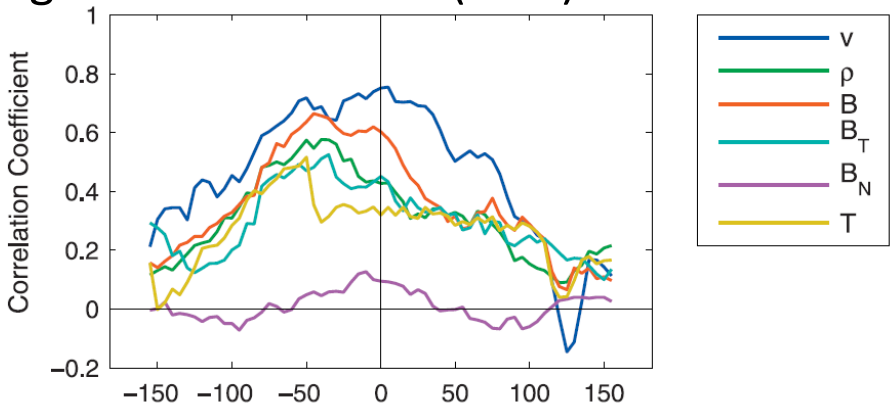
SW1D model evaluation: value



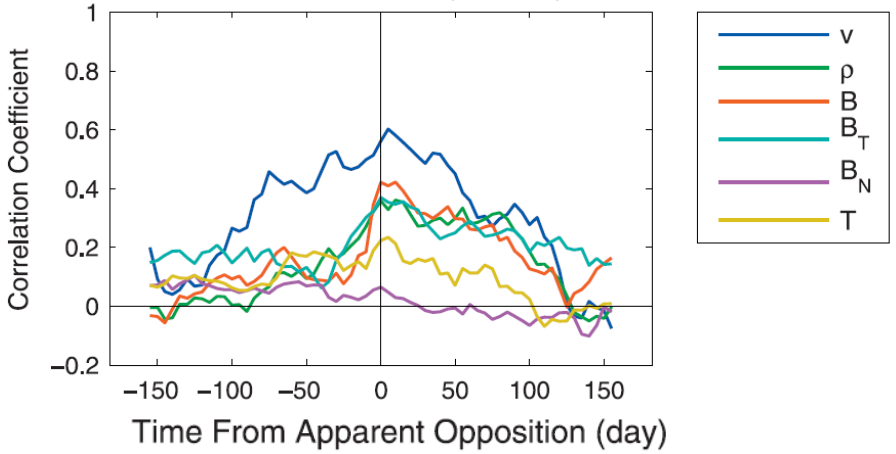


[Tao et al., 2005]

High recurrence case (>0.4)



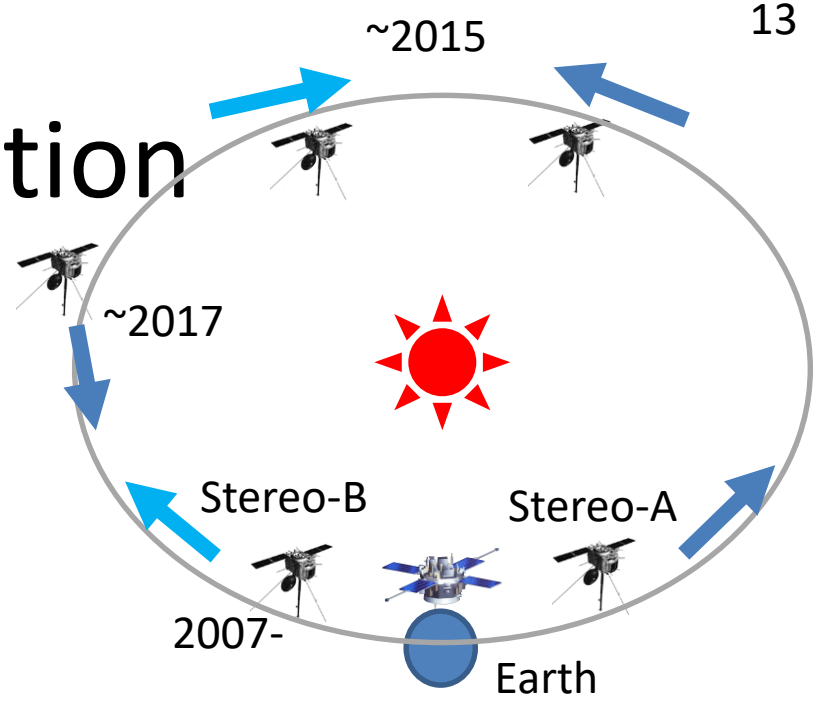
Low recurrence case (<0.4)

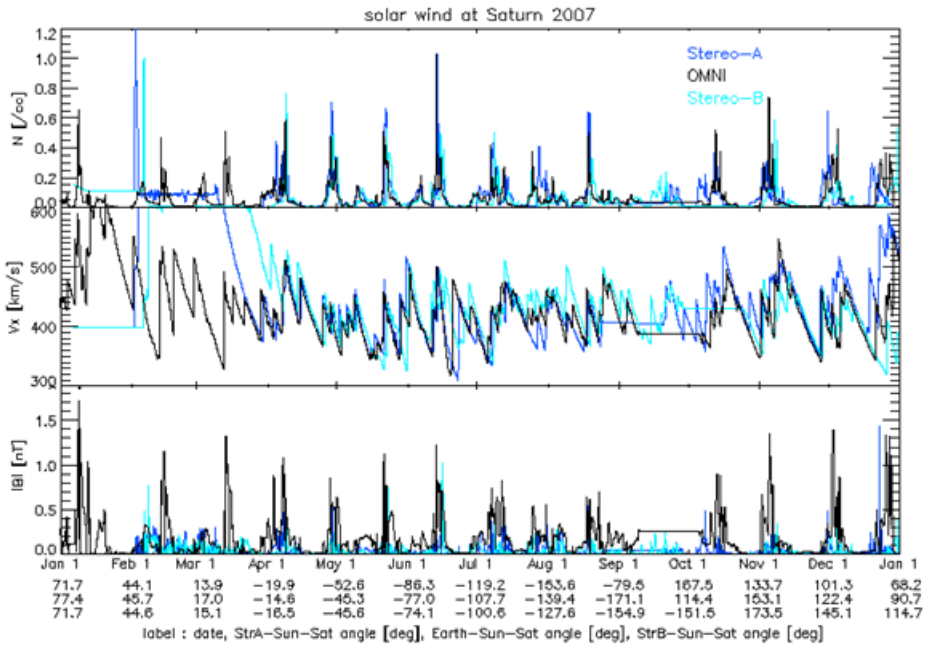


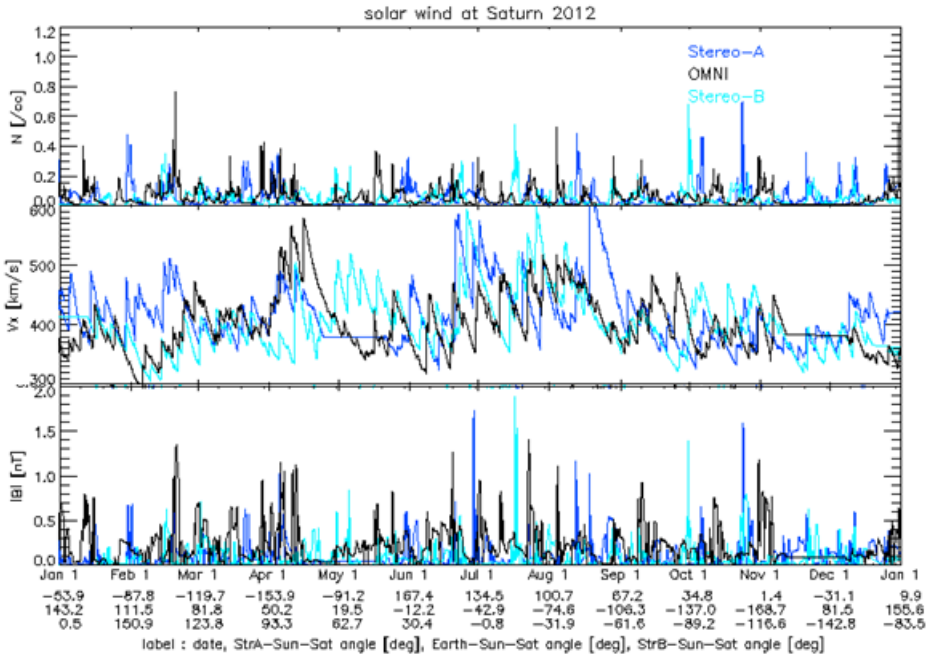
[Zieger and Hansen, 2009]

Stereo input simulation

We can input solar wind at any places.
For example, Stereo-A/B observe solar wind at different heliospheric longitude.
→ This covers different periods.

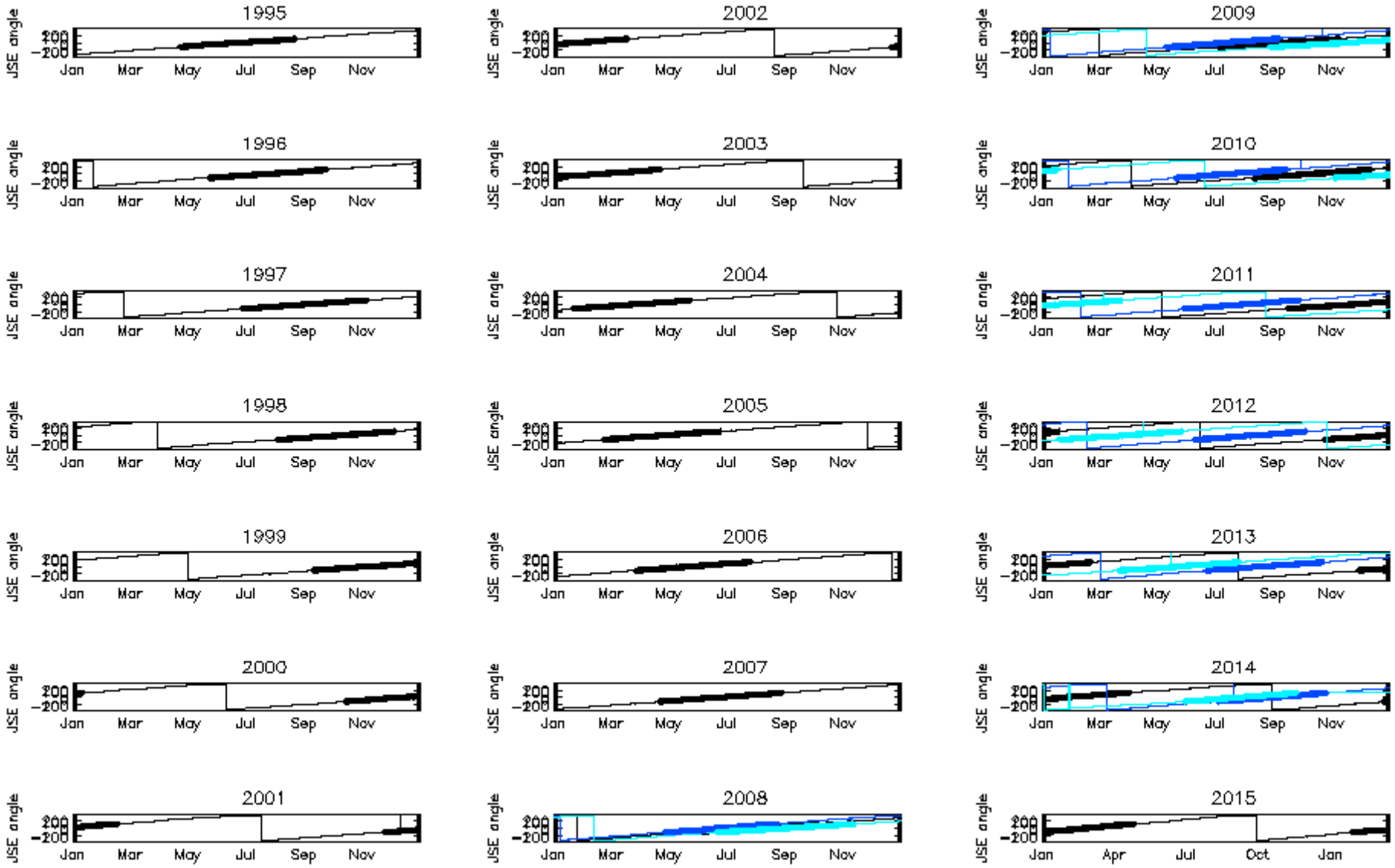






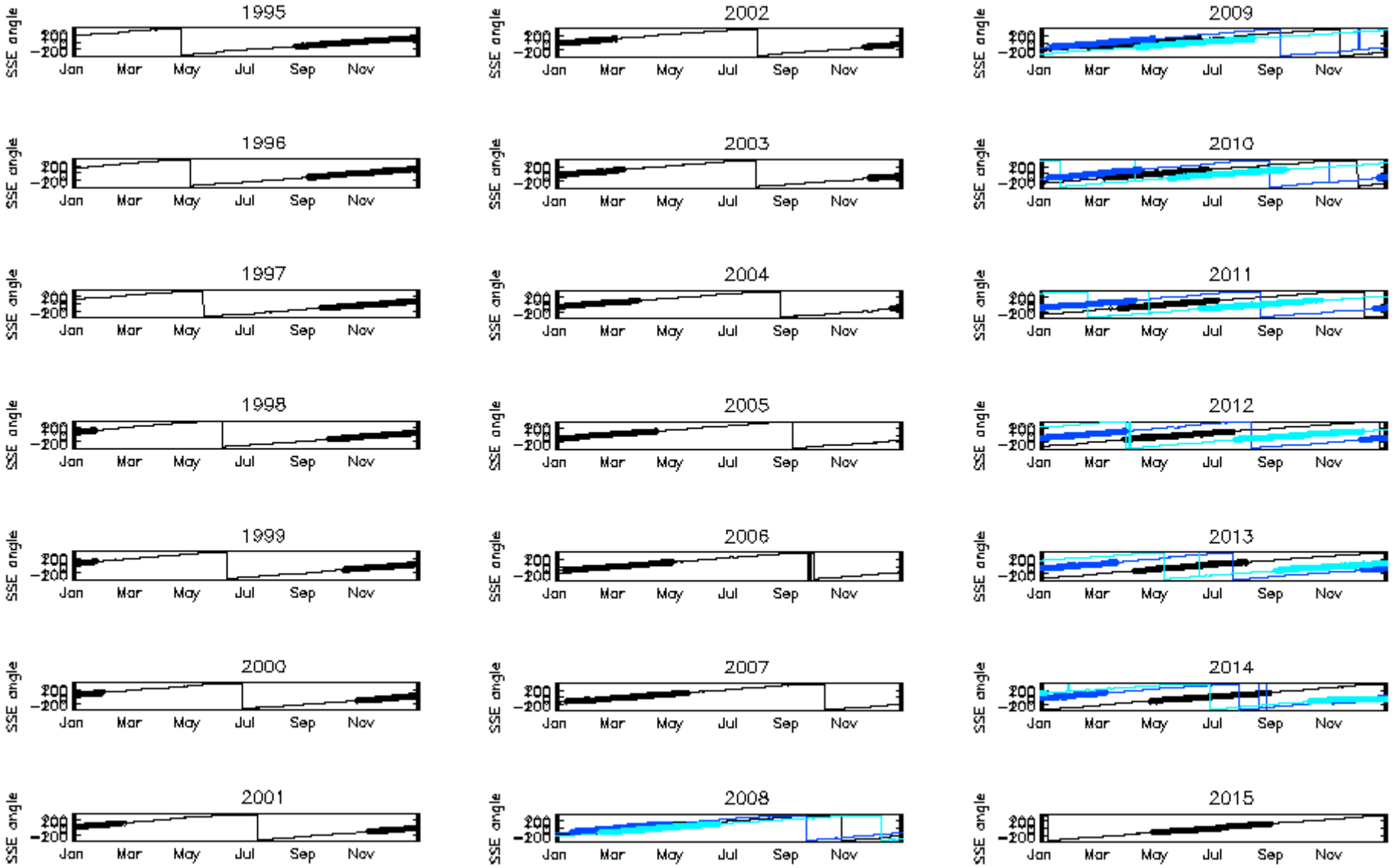
Thick line: |angle|<60 deg.

Jupiter-Sun-Earth angle



Thick line: |angle|<60 deg.

Saturn-Sun-Earth angle



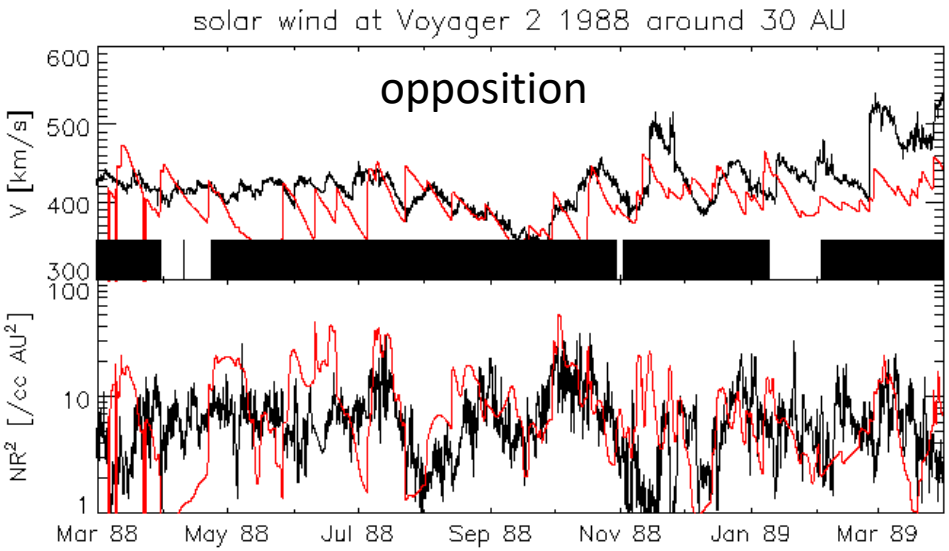
Solar wind at Uranus/Neptune

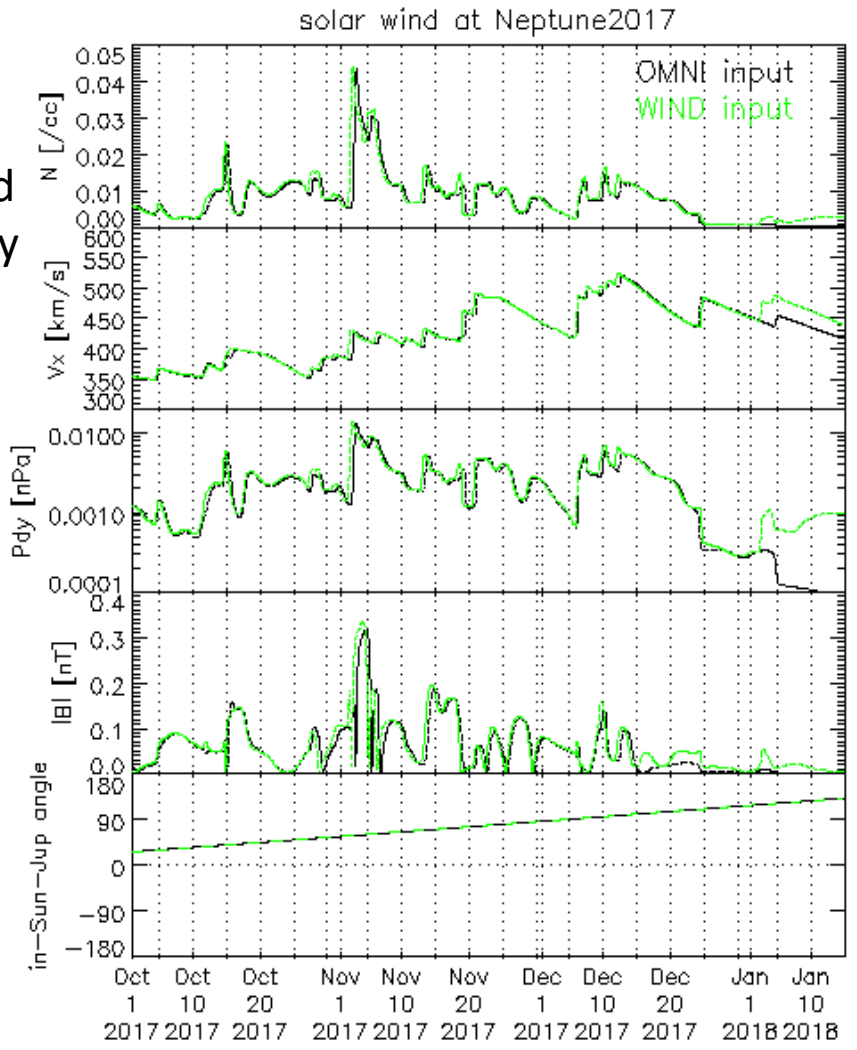
Earth : OMNI

>10AU Interaction with Interstellar H

Uranus: ~20AU
Neptune: ~30 AU

In 2014 and 2017, we got Hubble Space Telescope time to observe Uranus aurora when the solar wind shock arrival is predicted by the model (PI: Lamy).
→ We are trying for Neptune





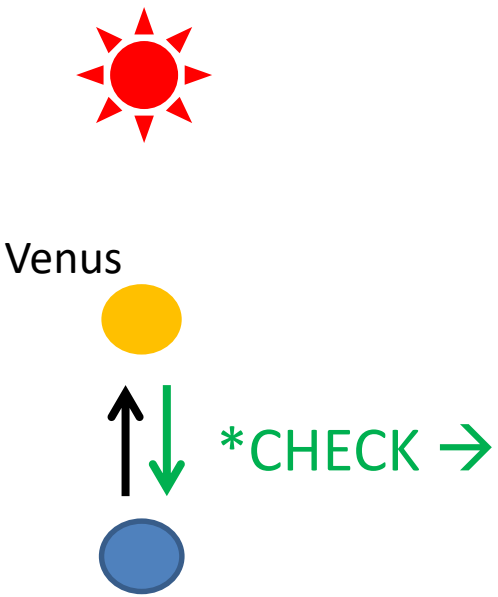
SW prediction on Oct 5

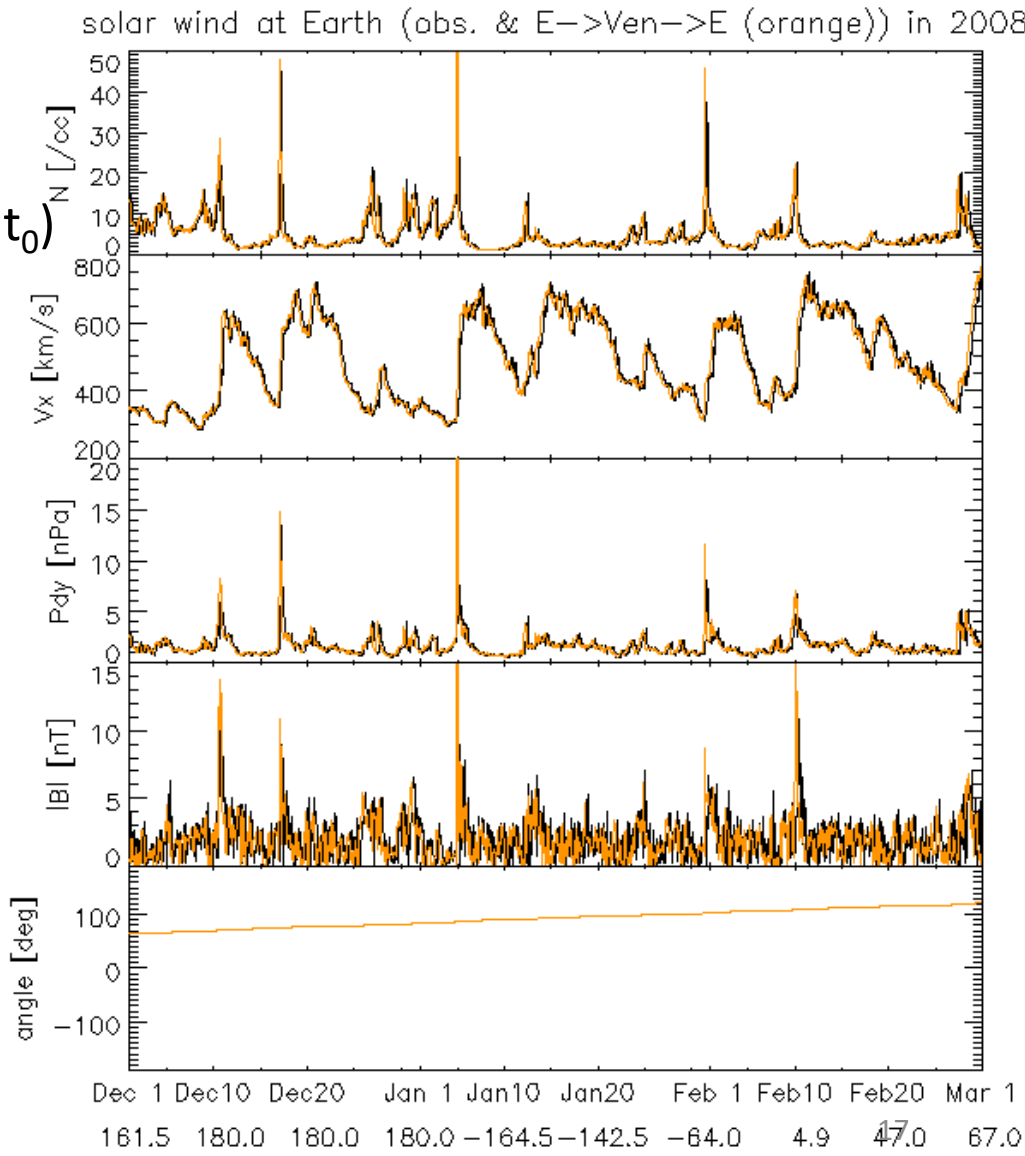
Solar wind at Venus

Method:

1) Time reversal of Input data
(input order $t=t_1$, $t_1-\Delta t$, $t_1-2\Delta t$, …, $t_0+\Delta t$, t_0)

2) Reversal of radial velocity (inner propagation, Vr -> -Vr)

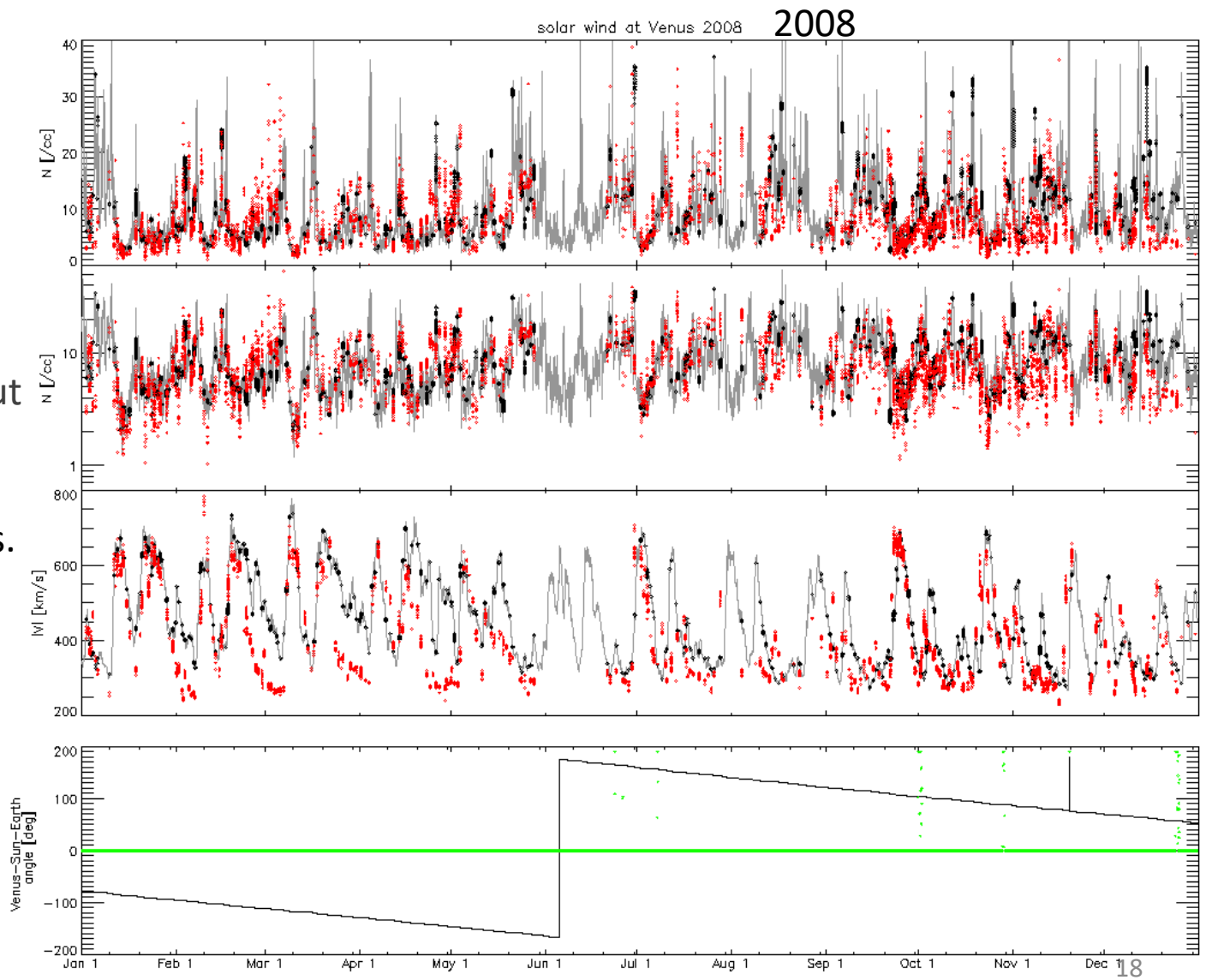




Solar wind at Venus: comparison with VEX

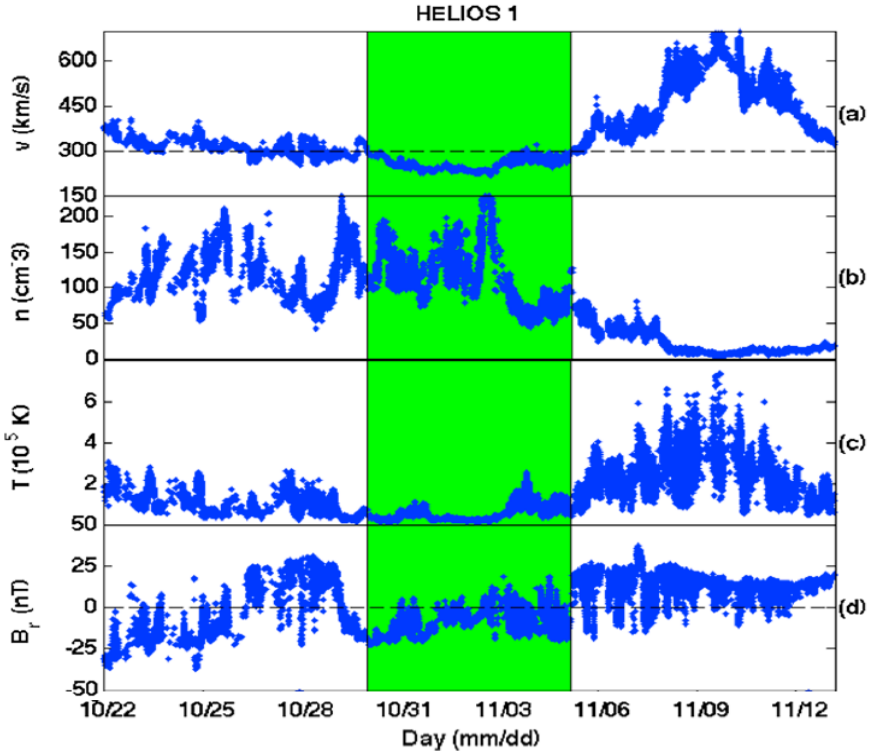
VEX/ASPARA-4/IMA
"Quality value" >0.95 period is shown as red points.
Thanks to Andrei Fedorov (IRAP)

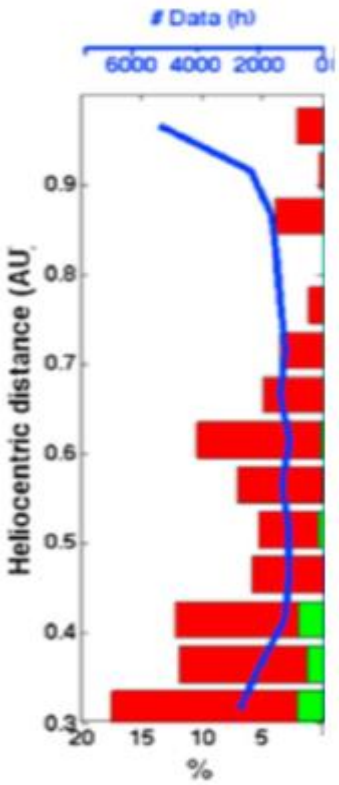
Gray lines model output
Black points are model output simultaneous with obs.



Solar wind propagation from Helios

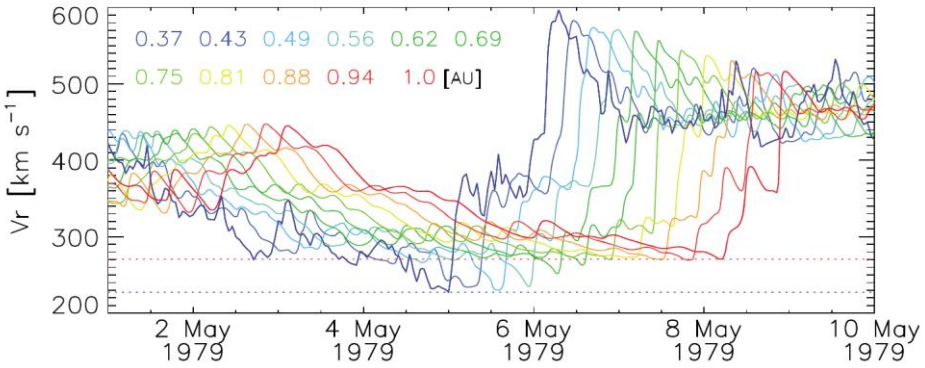
Very slow solar wind (VSSW) <300 km/s





<300 km/s

<250 km/s



[Sanchez-Diaz et al., 2016JGR]
Larger occurrence of VSSW for smaller radial distance from the Sun is observed by Helios (0.3-1 AU)

Solar wind model shows gradient of dynamic pressure is the main component to accelerate VSSW.

Summary

Solar wind models provide predictions of solar wind variation with better accuracy while there are some limitations

(miss/false events, errors in propagation timing and absolute values)

→Recommended usage: dynamic pressure, density, velocity, and |B| (or By) for the angle between input and output < 60 deg., statistically as much as possible

Several types of model run are possible:

Spacecraft -> Spacecraft, Spacecraft -> Planets

inward and outward calculation

Forecast Usage using:

(Jupiter: 2 weeks, Saturn >2 weeks, Uranus: >6weeks…)

Our model outputs are updating in AMDA archive

http://amda.cdpp.eu/

OMNI → Jupiter/Saturn/Mars/Rosetta

+request to my for other applications

Model validation using threat score is under going.