Evaluation of Multiple Coronal and Heliospheric Models Installed at the CCMC

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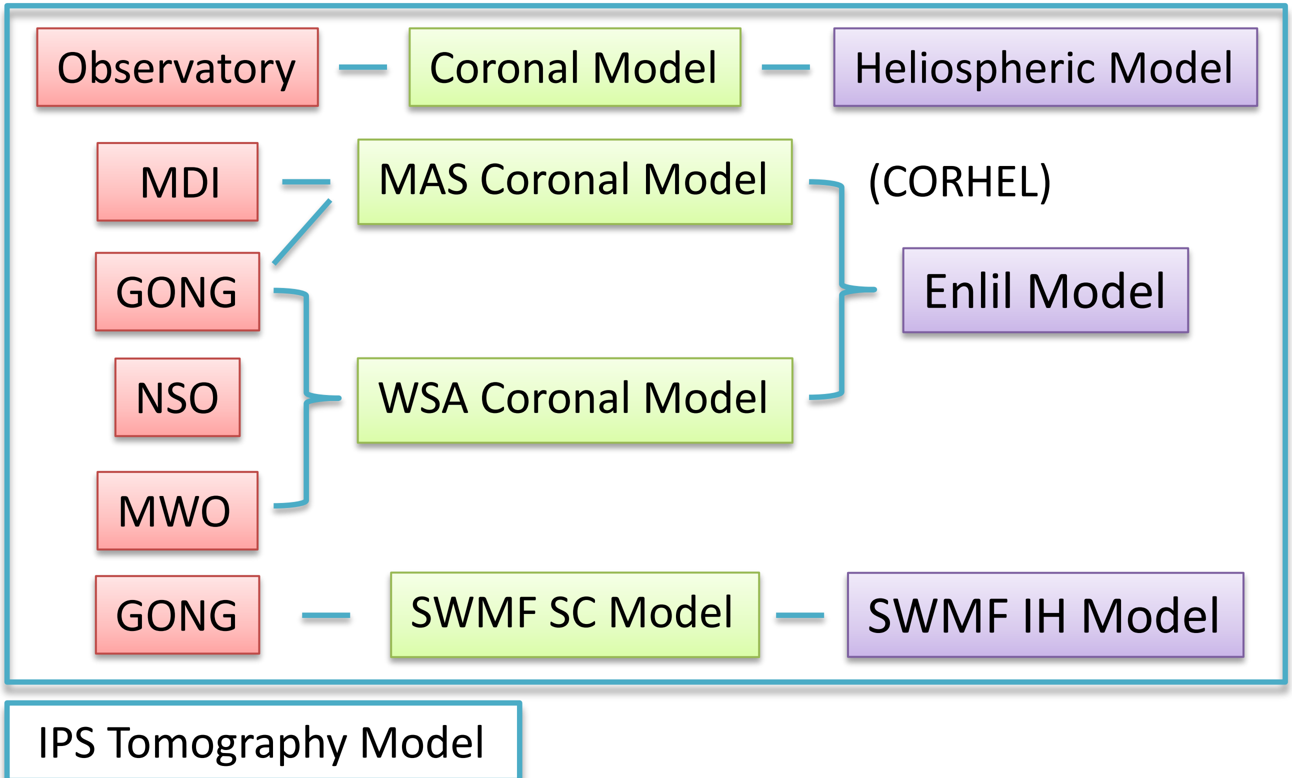
Introduction



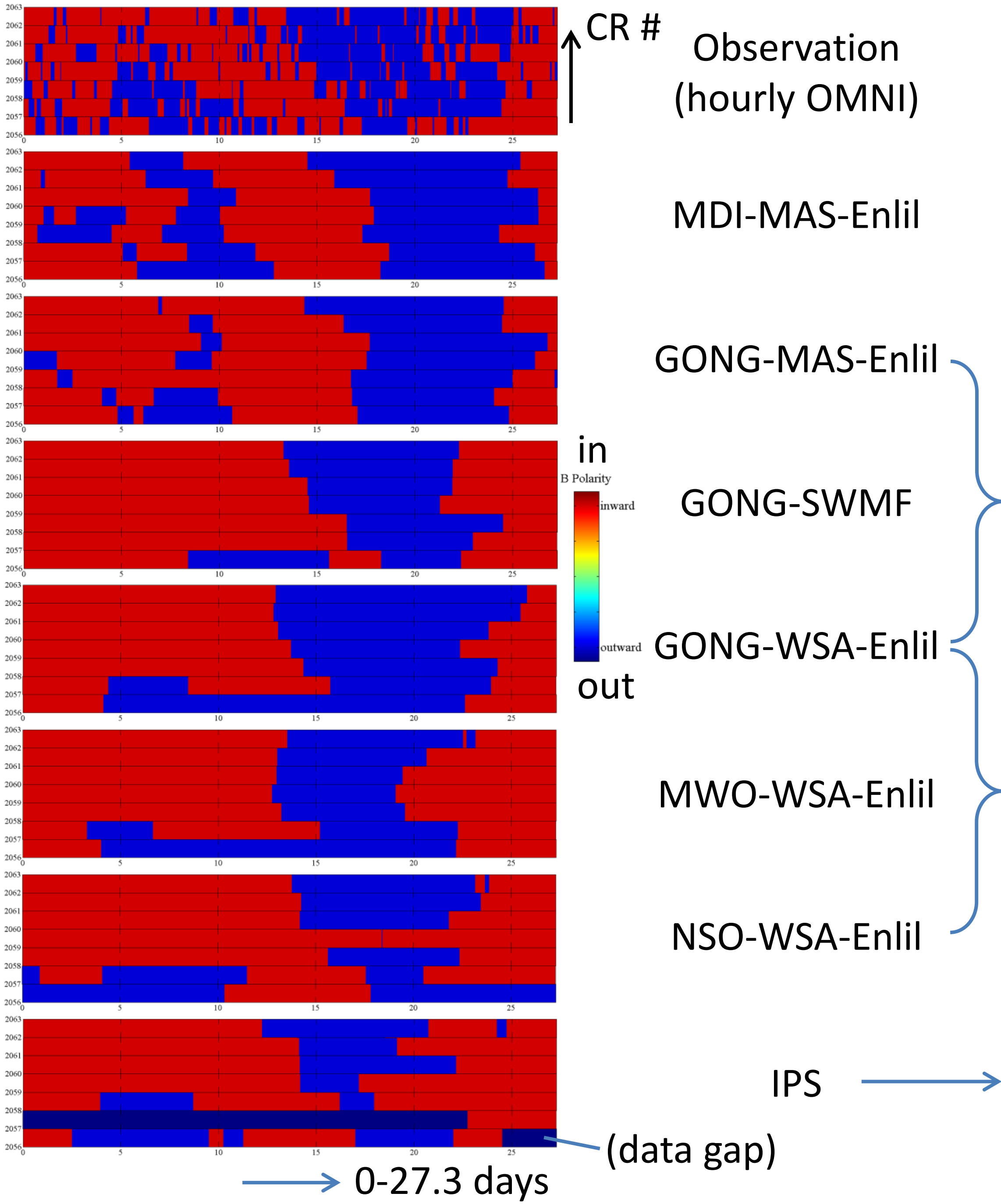
- Carrington-rotation synoptic maps of photospheric magnetograms from
  - Mount. Wilson Observatory (MWO)
  - National Solar Observatory (NSO) at Kitt Peak
  - Global Oscillation Network Group (GONG) of NSO
  - Michelson Doppler Imager (MDI) on board SOHO spacecraft

- Models
  - WSA coronal + Enlil v2.7
  - COROna-HELiosphere (CORHEL) v4.7.0, MAS coronal + Enlil are used in this module
  - Solar coronal (SC) and inner heliospheric (IH) parts of the Space Weather Modeling Framework (SWMF) v8.03
  - Interplanetary Scintillation (IPS) Tomography model

Introduction (cont.)

- We evaluate the performance of the above coronal and heliospheric models available at the CCMC, during Carrington rotations (CRs) 2056-2062 (May – Oct 2007), surrounding the Ulysses' 3rd perihelion pass at 1.4 AU in August 2007
- Synoptic map of photospheric magnetograms: 1^{o} resolution ≈ 1.8 hours
- Enlil standalone module
  - WSA coronal to 21.5 Rs: 2.5^{o} resolution
  - Enlil model to 2 AU, the grid is $1024 \times 120 \times 360 \approx 0.42$ Rs $\times 1^{o} \times 1^{o}$
- CORHEL module
  - MAS polytropic coronal model to 30 Rs: $101 \times 101 \times 128 \approx 0.3$Rs $\times 1.8^{o} \times 2.8^{o}$
  - Enlil model to 2 AU: $320 \times 60 \times 180 \approx 1.25$ Rs $\times 2^{o} \times 2^{o}$
  - The model using MDI can run up to 1.14 AU, with no output at Ulysses trajectory
- SWMF
  - 1-16 Rs: the smallest cell is 0.023 Rs
  - 16-400 Rs: the smallest cell is 0.39 Rs, and increases to 6.25 Rs at the boundaries
  - Most of the Ulysses trajectory: a resolution of 3.125 Rs
- IPS
  - 6-hour time resolution in output
  - It can provide radial and tangential field components but not total field or Tp

Earth Orbit: Magnetic Field Sector



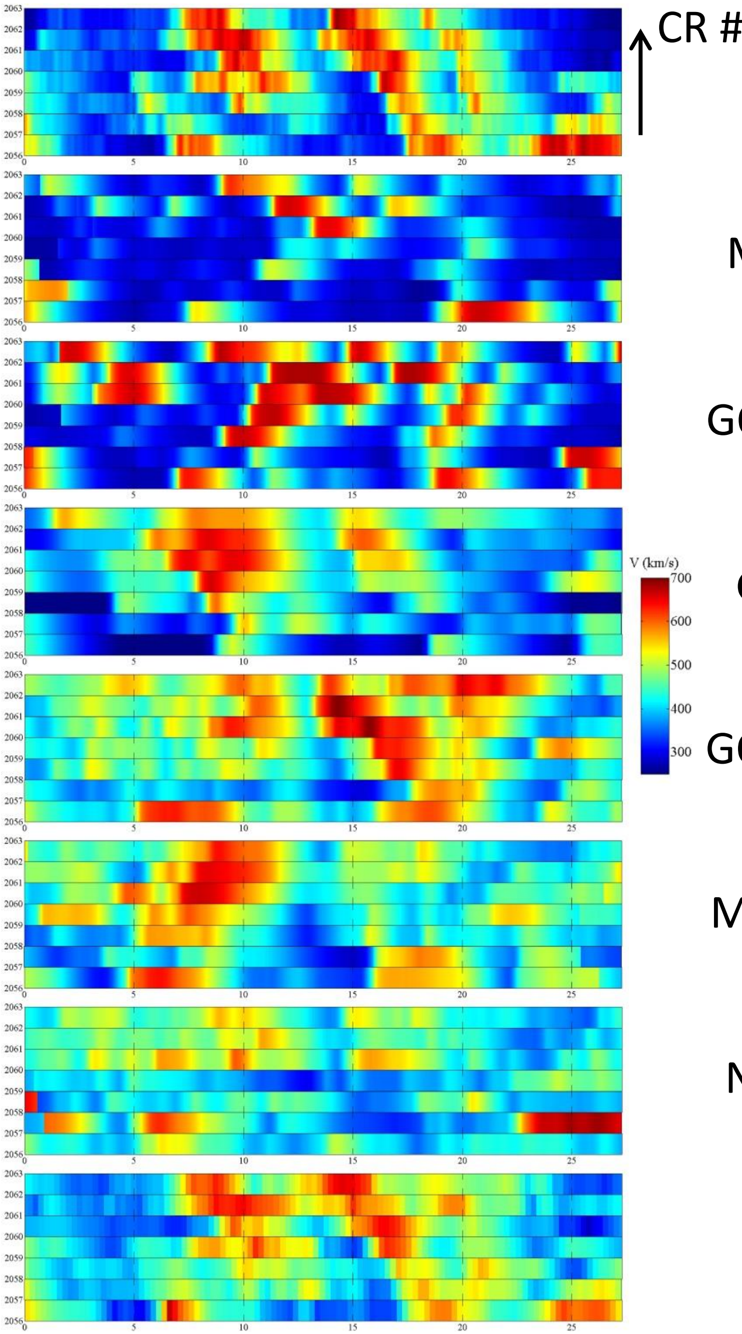
To predict the geomagnetic activity, it is crucial to predict the IMF polarity

Using the same magnetogram, the MAS-Enlil model matches with the observation best

For the same model, the simulated field polarity using GONG matches with the observation relatively better. Other runs can be off by 3 days

IPS implements NSO magnetogram to get the field. The sector duration differs from observation somewhat

Earth Orbit: Solar Wind Speed V (250-700 km/s)



Observation

MDI-MAS-Enlil

GONG-MAS-Enlil

GONG-SWMF

GONG-WSA-Enlil

MWO-WSA-Enlil

NSO-WSA-Enlil

IPS

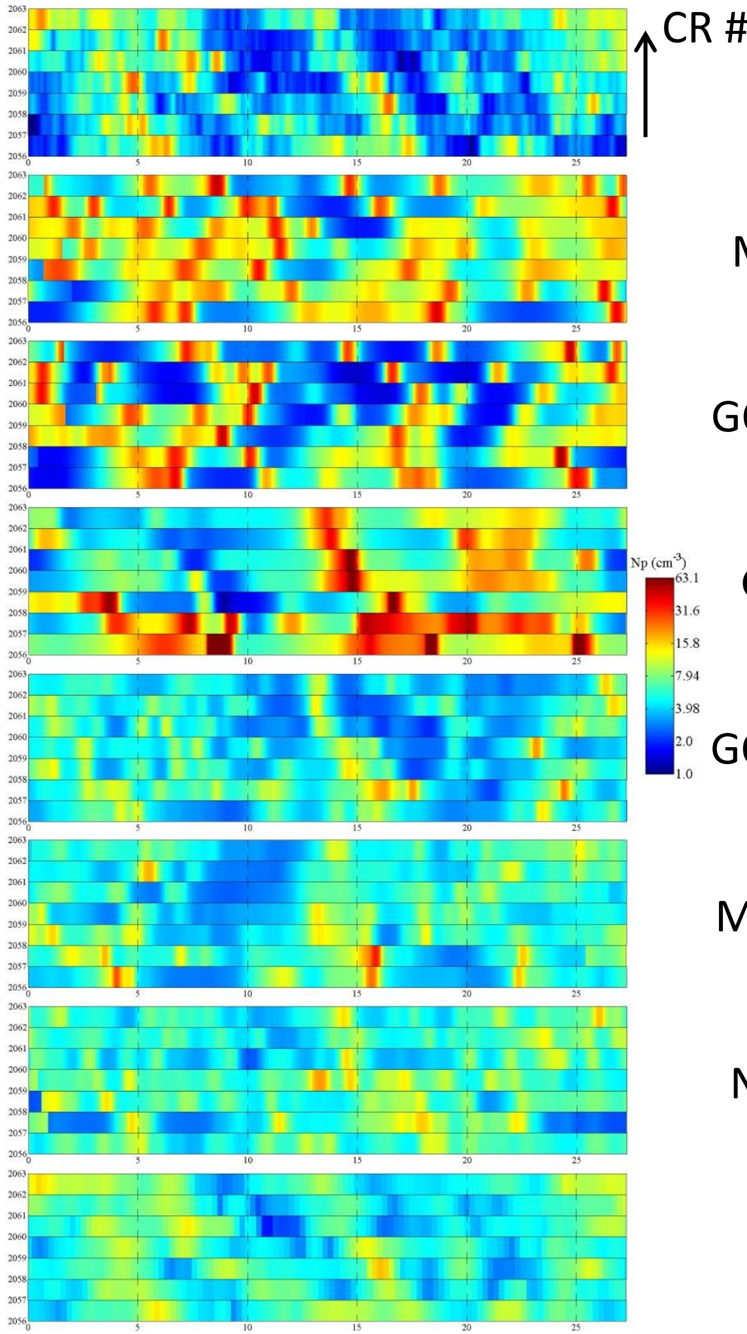
For the same model, the simulated solar wind using **MDI** is **slower** than the one using GONG

Using the same magnetogram, the SWMF and WSA-Enlil models have better timing; the slow wind from WSA-Enlil model is generally 100 km/s faster than observed; the run using MAS generates higher-speed fast wind than using WSA model

For the same model, the simulated solar wind using GONG matches with the observation best; fast wind simulated using NSO is too slow

IPS results match with the observation best

Earth Orbit: Solar Wind Density Np (1-63.1 cm^{-3})



Observation

MDI-MAS-Enlil

GONG-MAS-Enlil

GONG-SWMF

GONG-WSA-Enlil

MWO-WSA-Enlil

NSO-WSA-Enlil

IPS

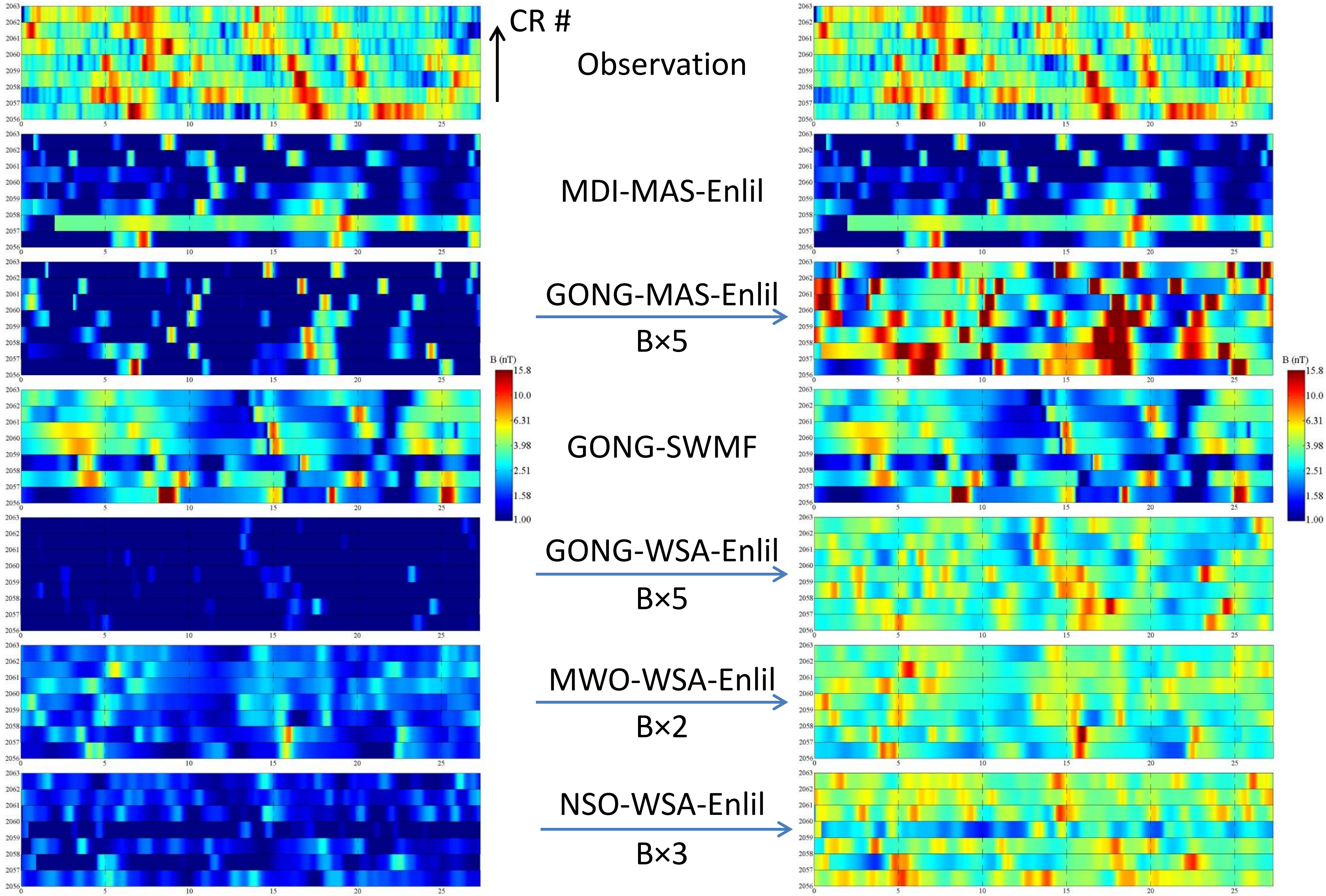
The Np compression from MAS-Enlil model is typically too high

Using the same magnetogram, the Np compression from MAS-Enlil and SWMF models are higher than observed. The density variation in solar wind from WSA-Enlil model is insufficient

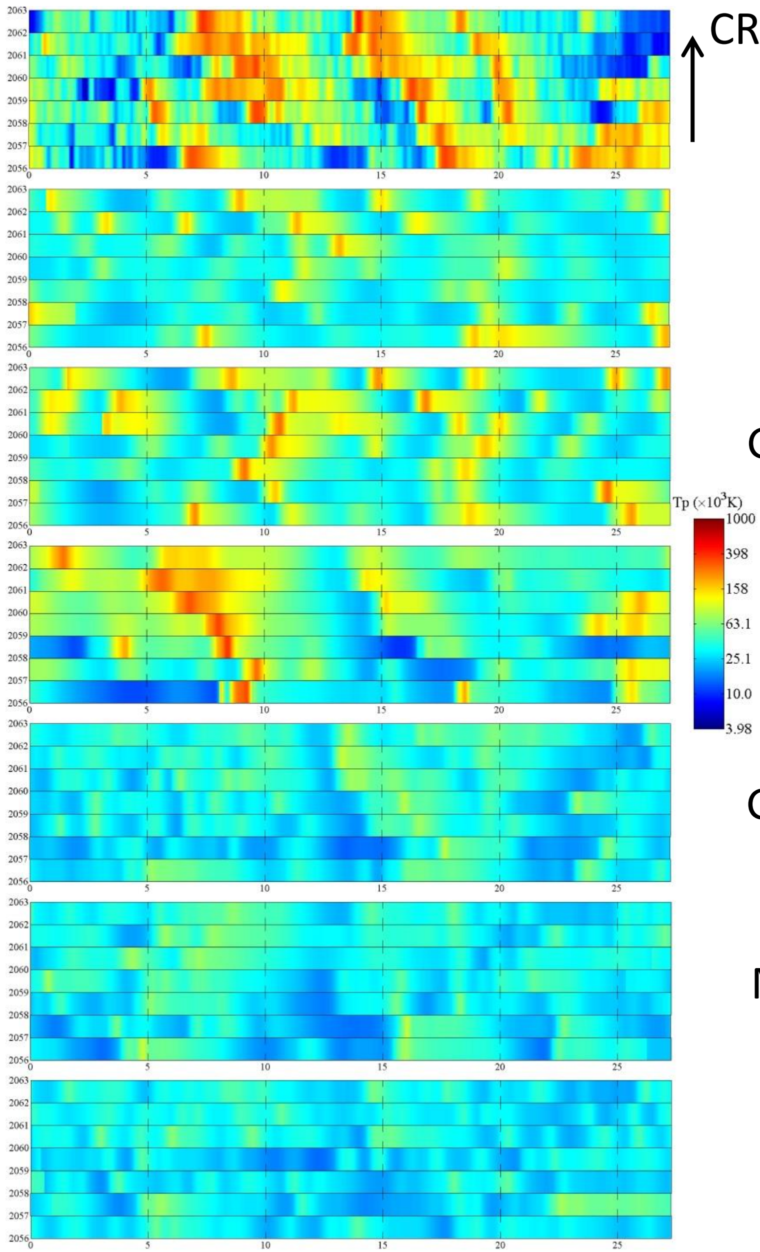
For the same model, the simulated Np using GONG matches with the observation relatively better

New version of IPS reproduces Np much better than the previous version; the small Np variation could be due to its low cadence

Earth Orbit: Interplanetary Magnetic Field B (1-15.8 nT)



Earth Orbit: Solar Wind Temperature Tp (3.98-1000 kK)



CR #

Observation

MDI-MAS-Enlil

GONG-MAS-Enlil

GONG-SWMF

GONG-WSA-Enlil

MWO-WSA-Enlil

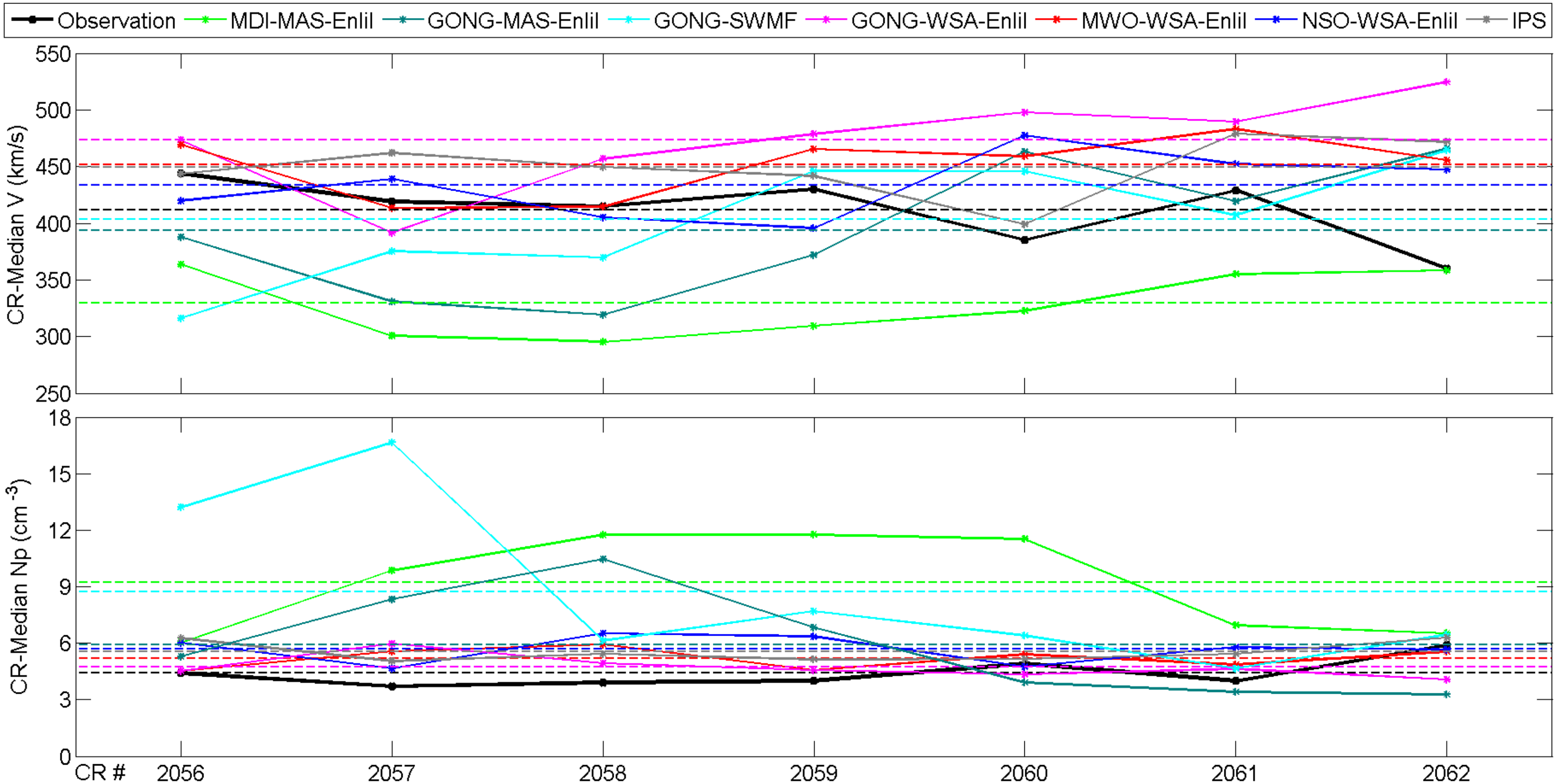
NSO-WSA-Enlil

Tp from the MAS-Enlil model using GONG matches with the observation better

Using the same magnetogram, Tp from the SWMF model matches with the observation best, the next is MAS-Enlil model. The Tp variation in solar wind from the WSA-Enlil model is insufficient

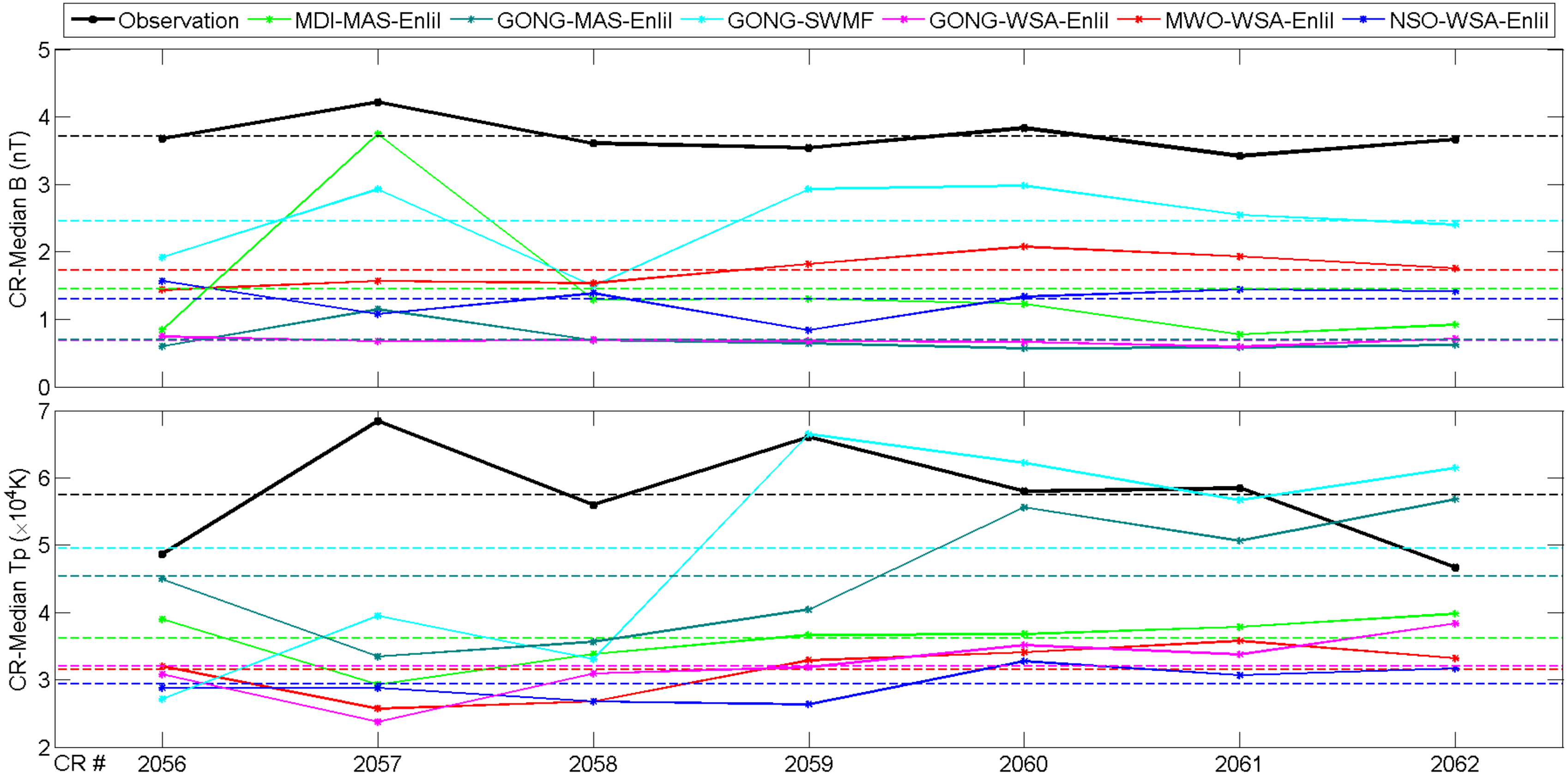
The WSA-Enlil model needs more heating in the solar wind

CR-Median V and Np at Earth Orbit: Observation vs. Models



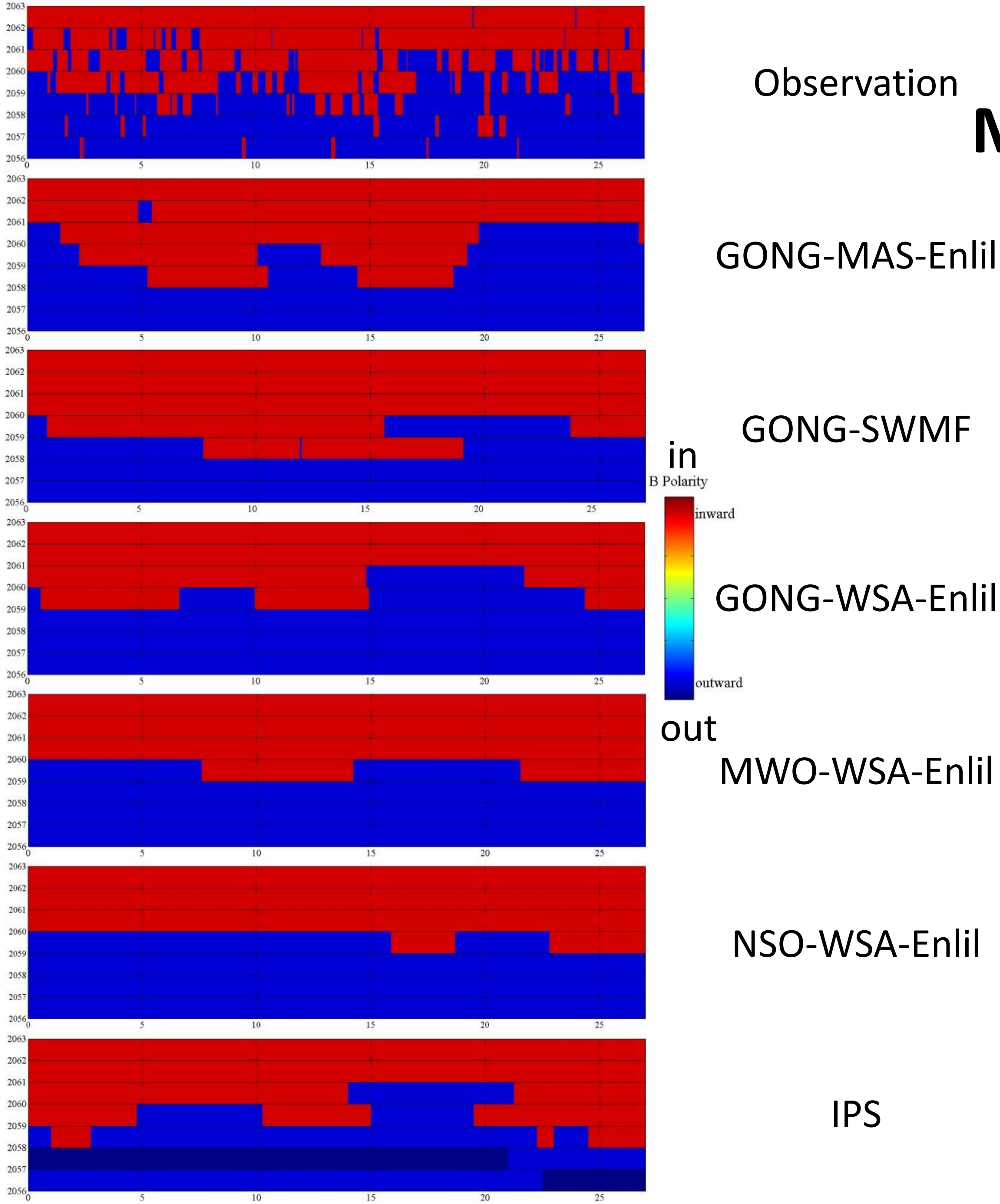
- ✓ Over all 7 CRs, the IPS model matches with the observed CR-median V best, while the MDI-MAS-Enlil model disagrees most
- ✓ Over all 7 CRs, all the models tend to overestimate Np. The MDI-MAS-Enlil and GONG-SWMF models have biggest offset in some CRs

CR-Median B and Tp at Earth Orbit: Observation vs. Models



- ✓ All the models underestimate B. The GONG-SWMF model matches with the observations most while the GONG-WSA-Enlil model underestimates B most
- ✓ Most time, all the models underestimate Tp. The GONG-SWMF and GONG-MAS-Enlil models match with the observations relatively better

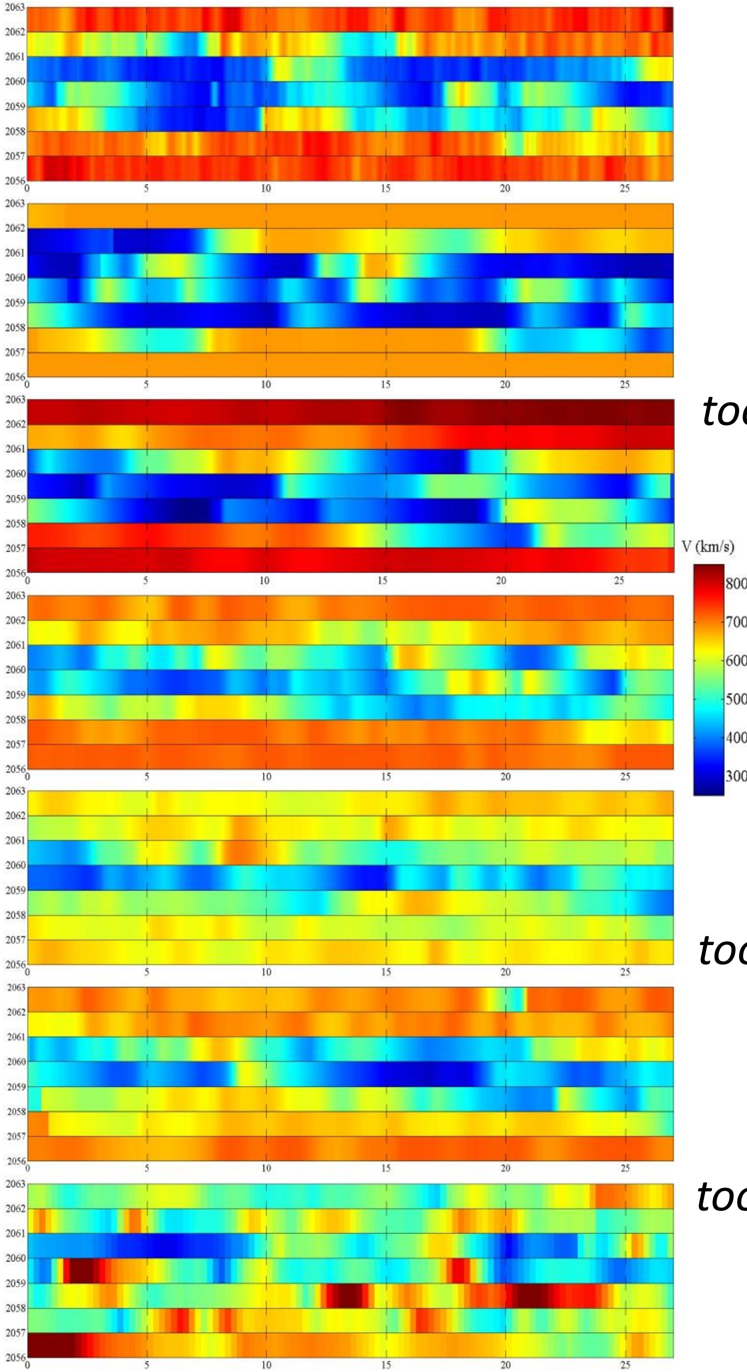
Ulysses Orbit: Magnetic Field Sector



- Excluding the short excursions, the sector changes happen in CRs 2059-2060 → the latitudinal span of the heliospheric current sheet (HCS): -16° to 22°
- The latitudinal span of HCS from the GONG-MAS-Enlil, GONG-WSA-Enlil and IPS models match with observation relatively well
- Because the resolutions of magnetograms and simulation grids are low, all the models cannot capture short changes of field polarity

Ulysses Orbit: Solar Wind Speed V (250–850 km/s)

Covering ±60° in heliographic latitude



Observation

GONG-MAS-Enlil

too fast

GONG-SWMF

GONG-WSA-Enlil

Using the same magnetogram, the high-latitude fast wind is too fast from the SWMF model, and slow by 100 km/s in the other two models

MWO-WSA-Enlil

too slow

NSO-WSA-Enlil

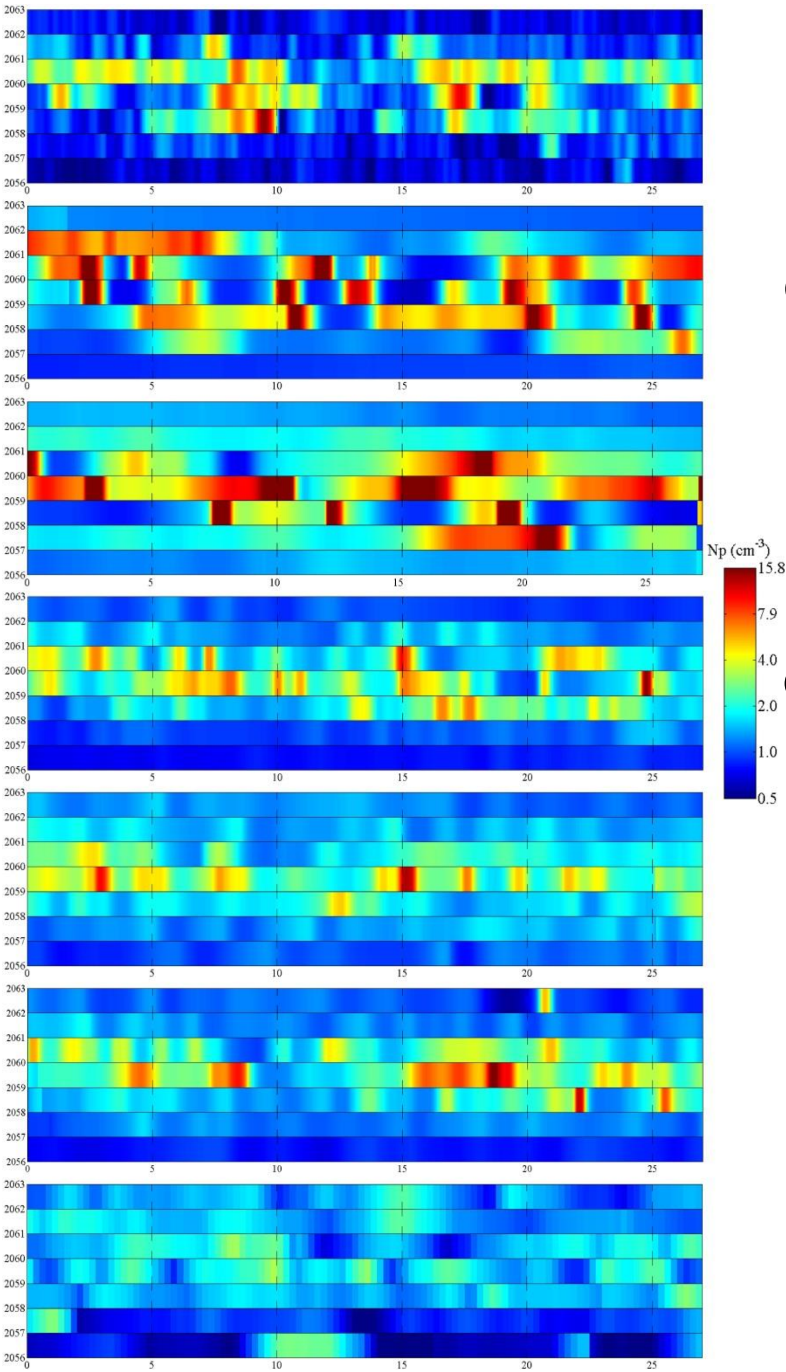
For the same model, the simulated V using GONG matches with observations better, and the high-latitude fast wind from the model using MWO is too slow

too slow

IPS

The high-latitude fast wind from IPS is too slow

Ulysses Orbit: Solar Wind Density Np ($0.5 – 15.8\ cm^{-3}$)



Observation

GONG-MAS-Enlil

GONG-SWMF

GONG-WSA-Enlil

MWO-WSA-Enlil

NSO-WSA-Enlil

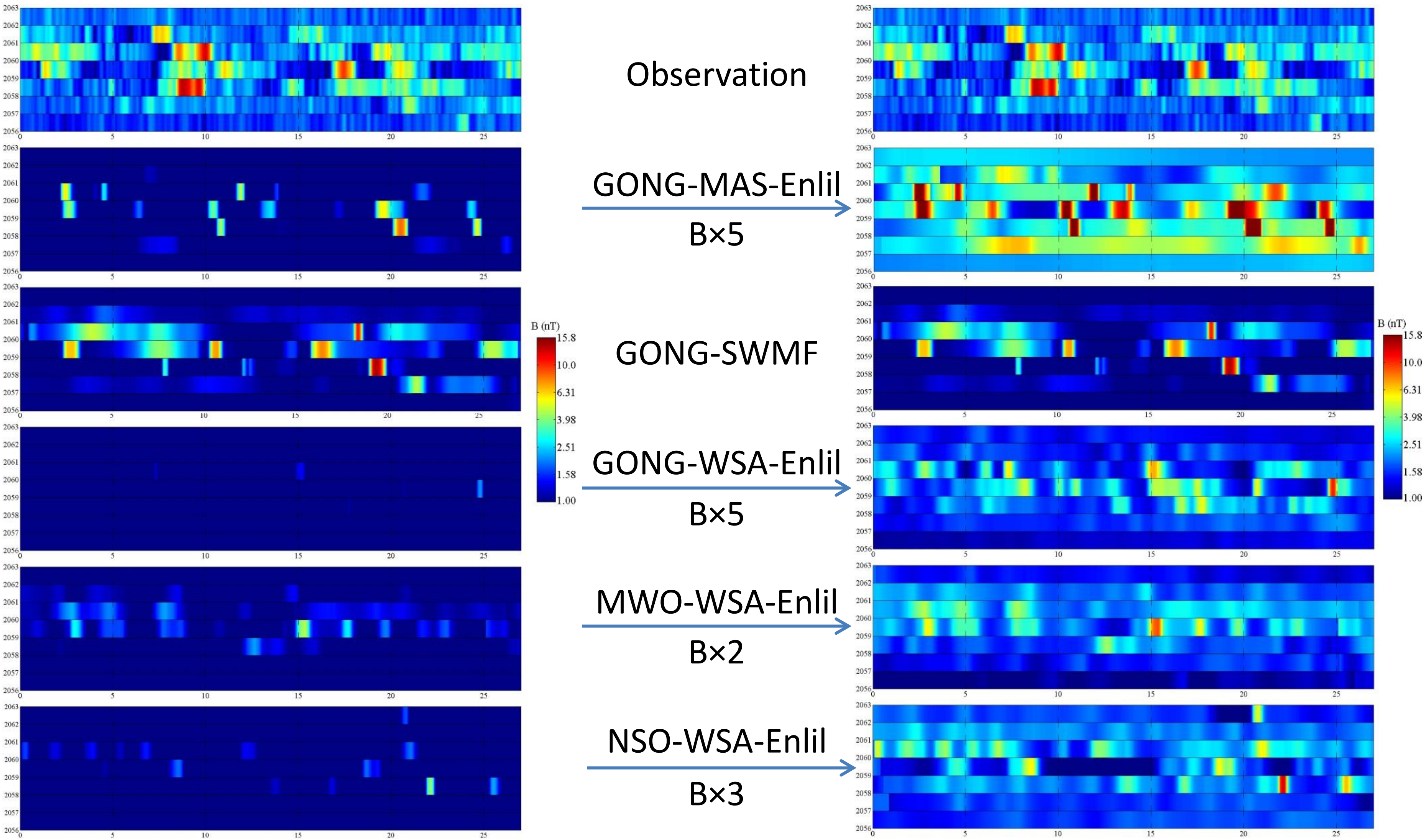
IPS

Using the same magnetogram, the Np in middle latitudes from the SWMF model is a little higher than observed.

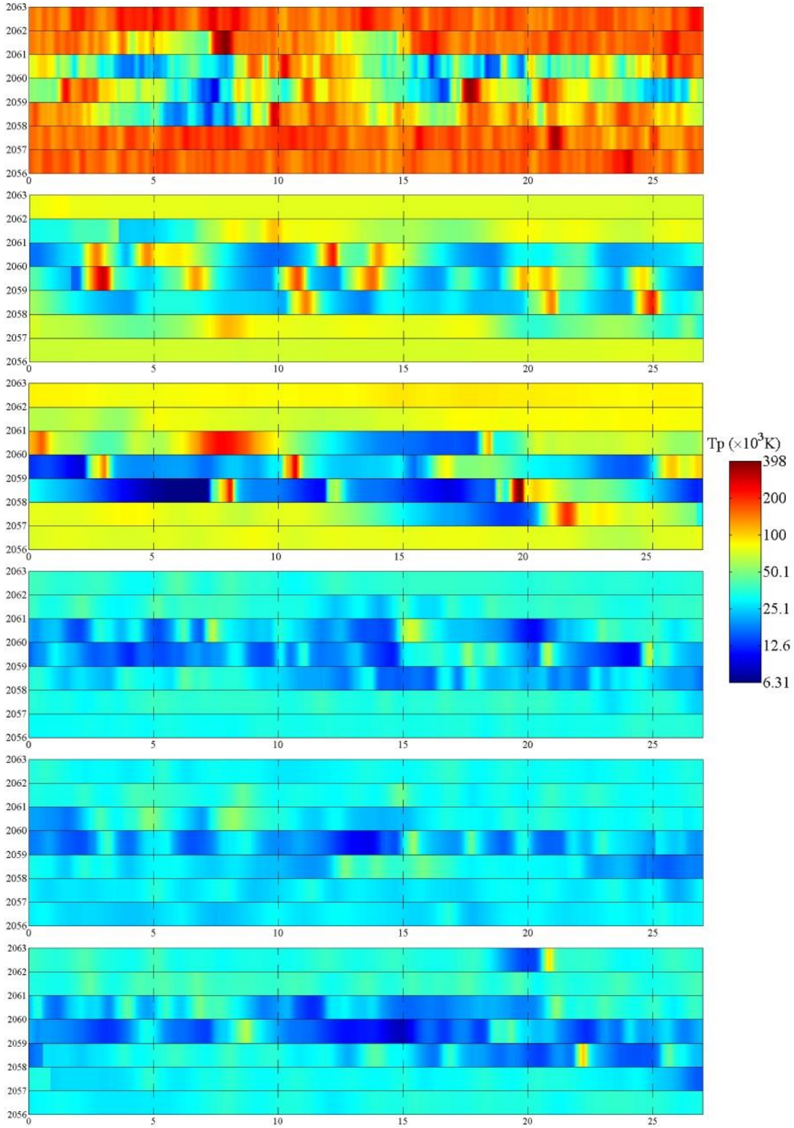
Np from the WSA-Enlil model using different magnetograms are similar

Np from IPS has N-S asymmetry. IPS produces more moderately dense regions at high latitudes

Earth Orbit: Interplanetary Magnetic Field B (1-15.8 nT)



Ulysses Orbit: Solar Wind Temperature Tp (6.31-398 kK)



Observation

GONG-MAS-Enlil

GONG-SWMF

GONG-WSA-Enlil

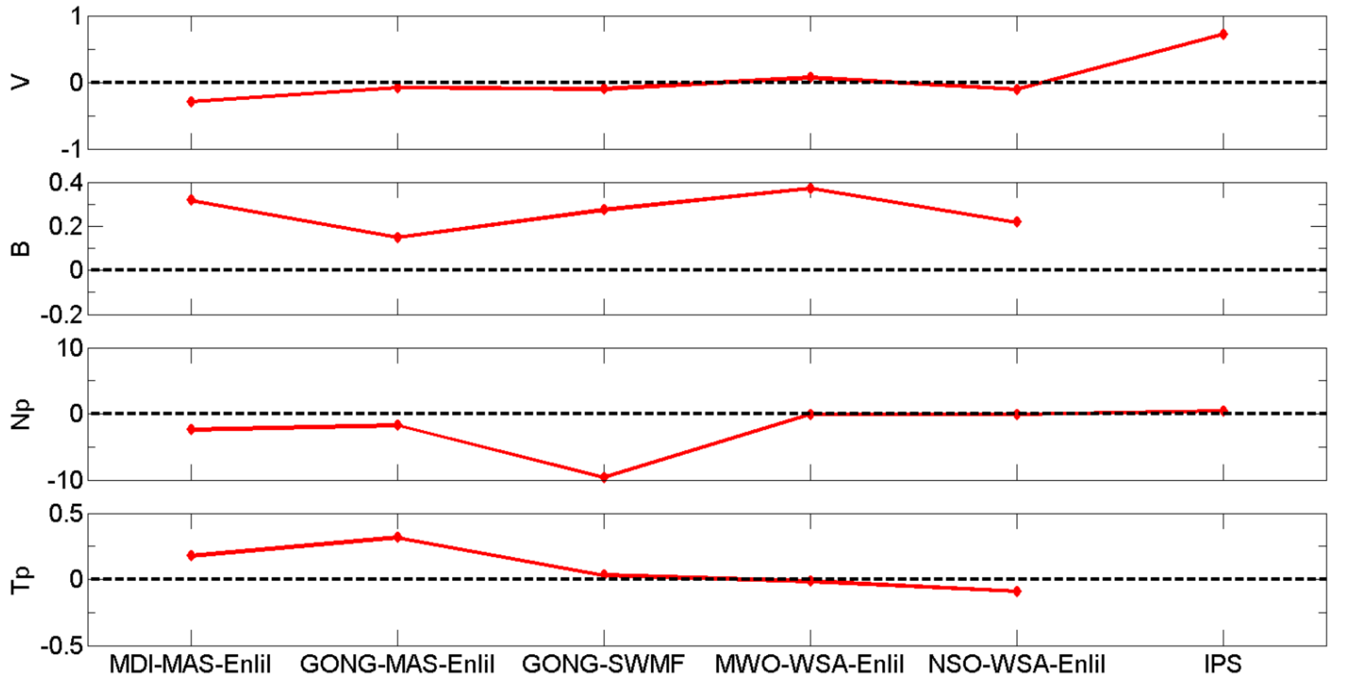
MWO-WSA-Enlil

NSO-WSA-Enlil

Using the same magnetogram, the MAS-Enlil and SWMF models can produce high Tp in fast wind at high latitudes, but need to double the Tp at least

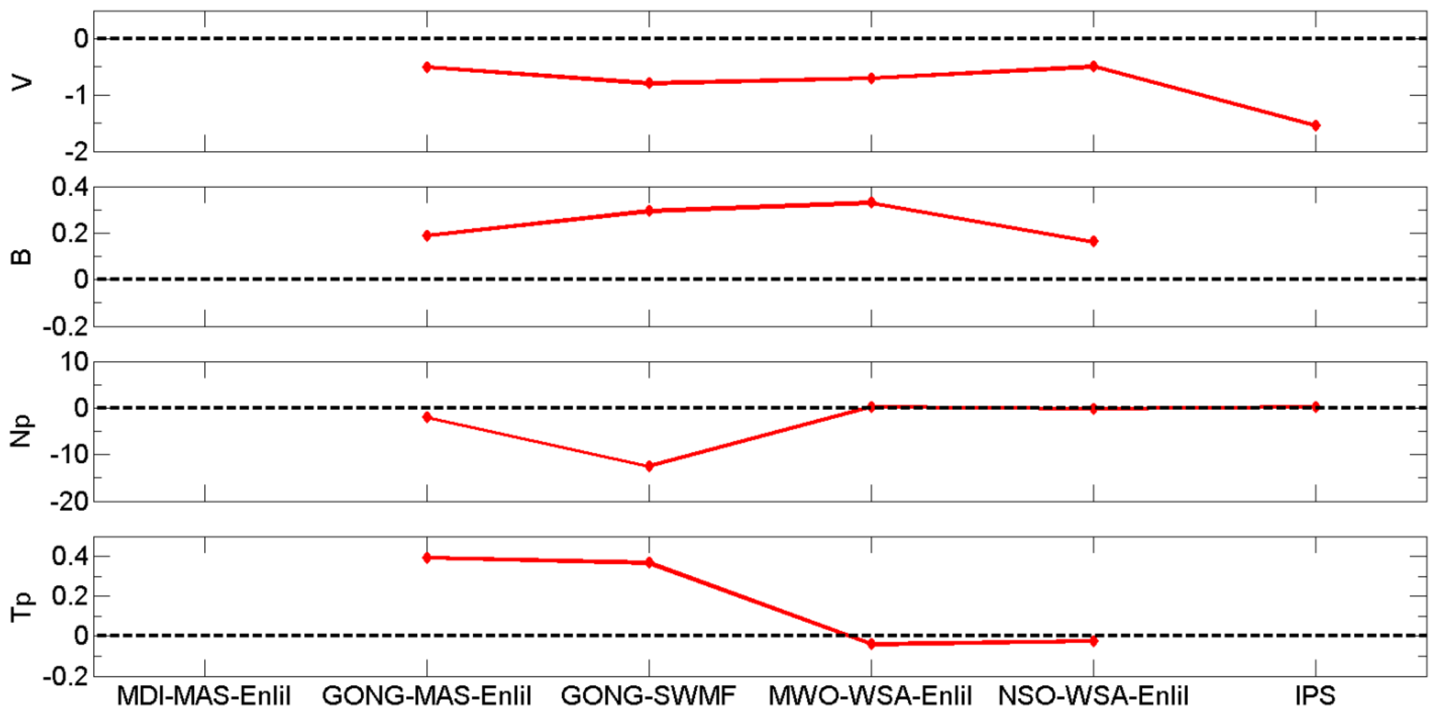
all need to increase Tp at high latitudes by a factor of 4

Skill Scores of Multiple Models at Earth



- **Mean square error (MSE)** between the observed and simulated time series of parameter x: MSE = $\frac{1}{n}\sum_{t=0}^{n}(x_t - x'_t)^2$
- Relative skill of a model using a reference model, **skill = 1-MSE/MSE$_{ref}$**
  - Skill = 0, MSE = MSE$_{ref}$, the two models perform equally
  - Skill > 0, MSE < MSE$_{ref}$, the current model works better
  - Skill < 0, MSE > MSE$_{ref}$, the reference model works better
- Because the **GONG-WSA-Enlil** model has most overlap with other models, we use it as the reference model

Skill Score of Multiple Models at Ulysses Orbit



- Because of the out boundary limit, the MDI-MAS-Enlil model cannot provide results at Ulysses currently
- The order of skill score varies from Earth to Ulysses. For instance, IPS matches well with near-Earth observation but not so well at high latitudes
- The B from GONG-WSA-Enlil model disagrees with the observation most

Summary of Model Evaluation

<table>
<tr><th>Model</th><th>Strength (Quantity)</th><th colspan="2">Weakness</th></tr>
<tr><td>MDI-MAS-Enlil</td><td>B sector at 1 AU</td><td colspan="2">Misses fast streams in 3 CRs, underestimates median V at Earth, overestimates Np compression in some CRs</td></tr>
<tr><td>GONG-MAS-Enlil</td><td>Tp at Earth and Ulysses, B sector at Earth and Ulysses</td><td colspan="2">Large time offset of V pattern, overestimates the B compression ratio at Earth</td></tr>
<tr><td>GONG-SWMF</td><td>Tp and B at Earth and Ulysses, although they still need to be increased</td><td colspan="2">Overestimates V at mid-high latitude and Np compression, mismatches B sector at Earth and Ulysses</td></tr>
<tr><td>GONG-WSA-Enlil</td><td>V, Np, and B sector at Ulysses</td><td>Underestimates B most</td><td rowspan="3">Underestimates B and Tp, insufficient Np variation at Earth</td></tr>
<tr><td>MWO-WSA-Enlil</td><td>No prominent strength</td><td>V at mid-high latitude is too slow</td></tr>
<tr><td>NSO-WSA-Enlil</td><td>No prominent strength</td><td>Misses fast streams in 2 CRs, Vmax tends to be slow, Np in fast wind is too high, matches with B sector at Ulysses least</td></tr>
<tr><td>IPS</td><td>Best fit of V at Earth</td><td colspan="2">Underestimates V at mid-high latitude, underestimates Np at low latitude and overestimates it at high latitude</td></tr>
</table>

Discussion

- What we need in order to compare apple to apple
  - CORHEL model: increase the grid scale of Enlil part
    - MDI-MAS-Enlil model: extend outer boundary to include Ulysses
  - SWMF model: add more source options of magnetograms
  - IPS: implement mangetograms from other source
- What need to improve
  - Higher resolution of photospheric magnetogram, e.g., SDO/HMI
  - Time dependent solar input from ADAPT model
  - WSA-Enlil model: increase scaling factors of B to match its operational version, and add more heating
  - To provide more quantitative assessment based on sector boundaries and fast wind