# Validation for Solar Wind Prediction from Models Installed at the CCMC

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*Thanks to Model Providers and CCMC Staff*

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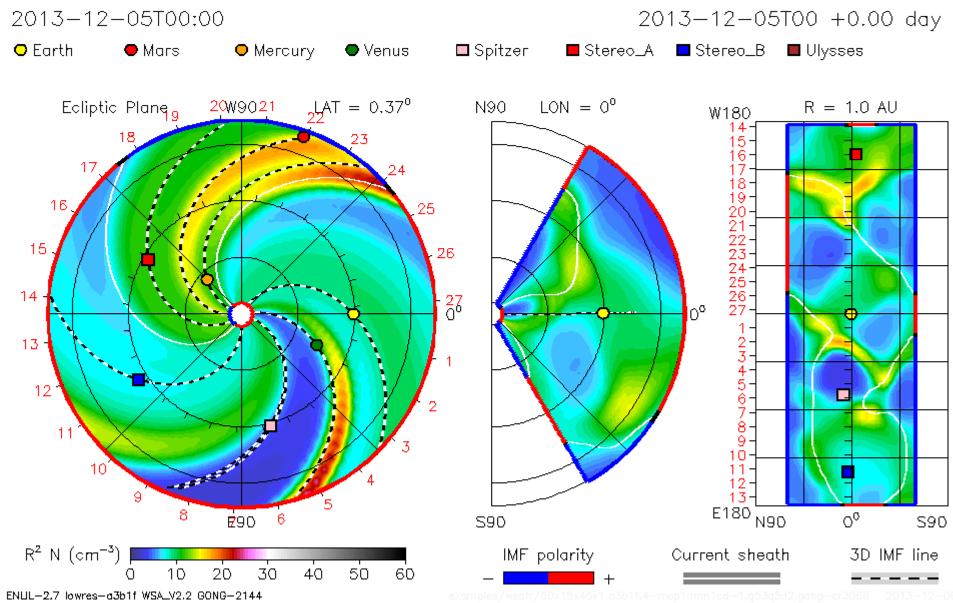
# Solar Wind Prediction Is Used by Space Weather Forecasters




*Courtesy of CCMC*

- Background solar wind and IMF sector boundary can affect the CME propagation and distort the embedded flux-rope topology
- The prediction of ambient solar wind is related to getting the right shock parameters, which are needed in SEP acceleration models
- Slow-to-fast stream interactions can trigger geomagnetic storms, disturb thermosphere, and affect Low Earth Orbit (LEO) satellite orbits
- Alfvén waves within the fast wind drive a series of particle injections → affect the evolution of the outer radiation belt

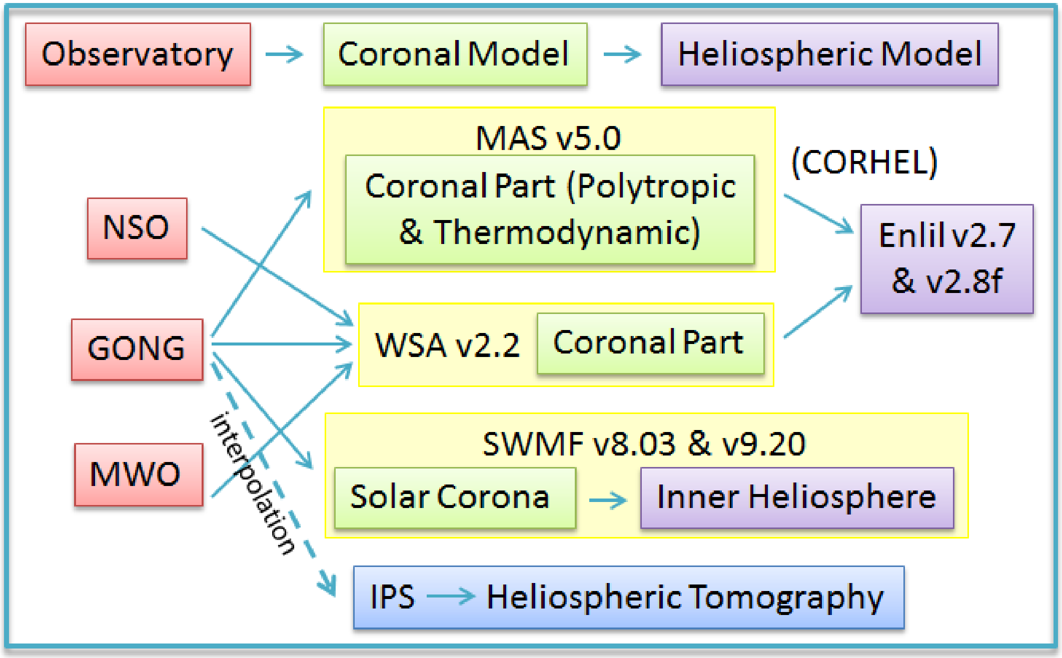
# Model Validation Effort

- Each modeling team has made numerous validation efforts, including the solar magnetogram team
- There has been third party validation for quasi-steady solar wind, e.g., *Owen et al*. (2005, 2008); *Lee et al*. (2009); *MacNeice et al*. (2009a, 2009b); *Jian et al*. (2011)
- There is not enough inter-comparison between more models and follow-up of model upgrades

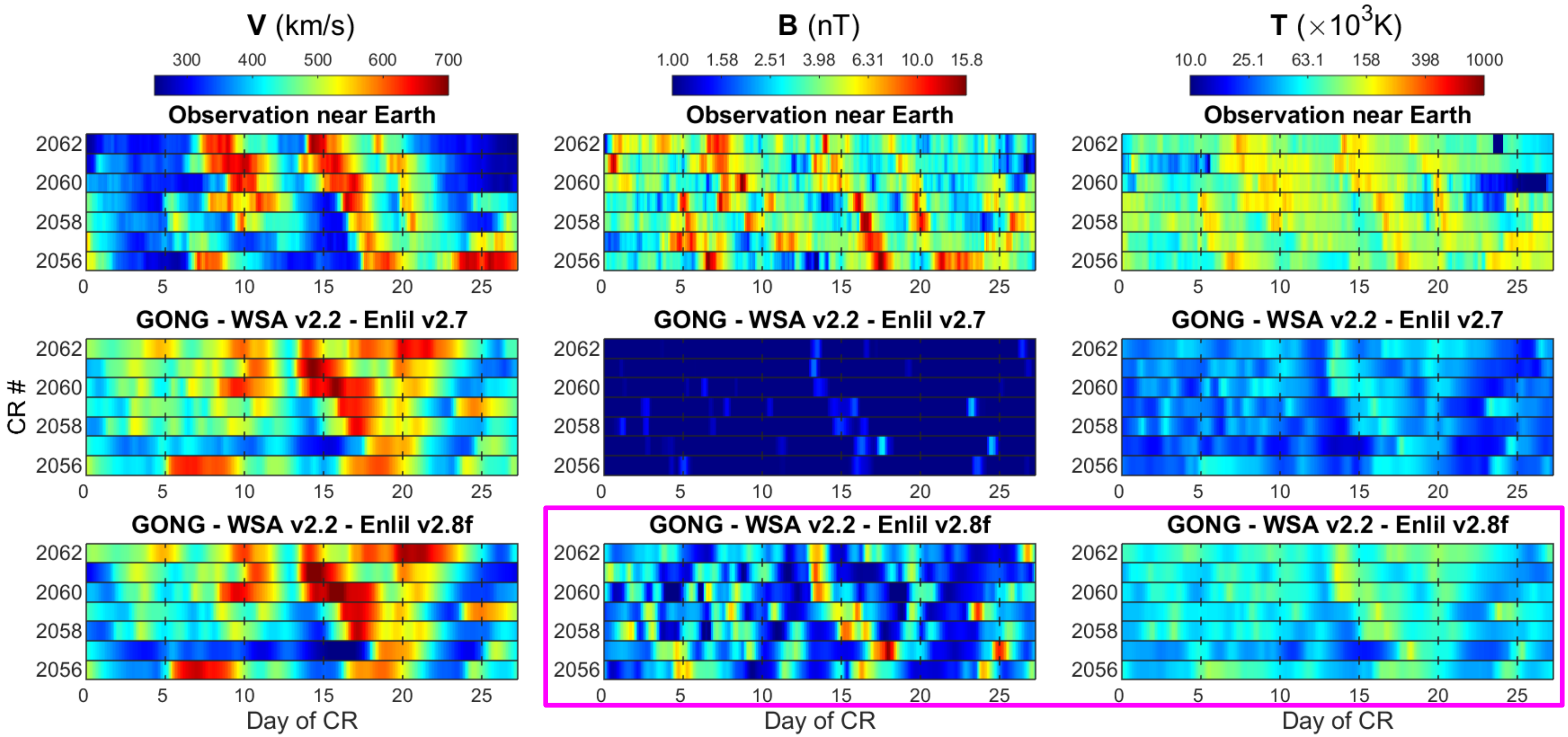
Carrington-rotation (CR) synoptic maps are used for runs of quasi-steady solar wind

GONG: Global Oscillation Network Group
NSO: National Solar Observatory at Kitt Peak
MWO: Mount Wilson Observatory

**MAS: MHD-Around-a-Sphere model**
**WSA: Wang-Sheeley-Arge model**
**SWMF: Space Weather Modeling Framework**
**IPS: Interplanetary Scintillation**



# Enlil Model v2.7 versus v2.8



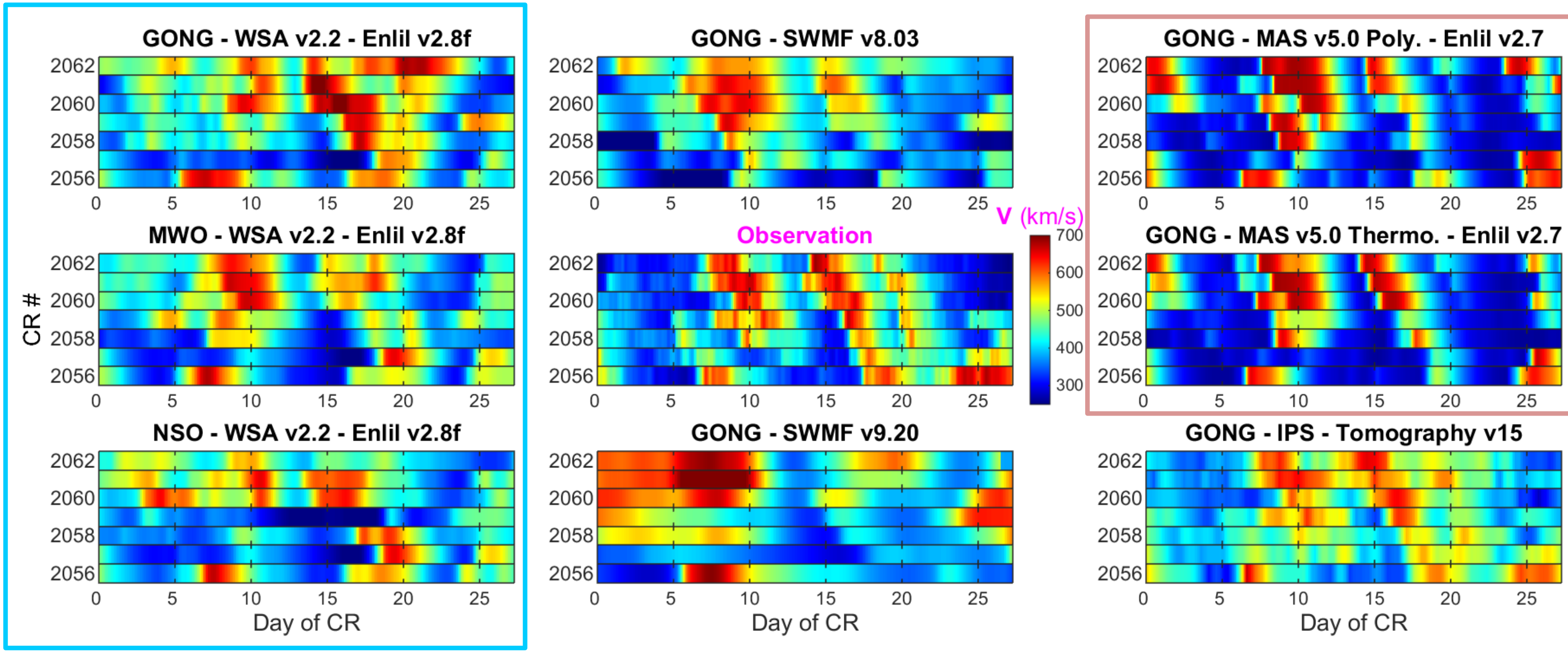

- Enlil v2.8 became available for Runs on Request (RoR) at CCMC in late 2015, and it is coupled with WSA coronal model v2.2
- The Enlil model coupled with MAS coronal model is still v2.7
- With the **increased magnetic field scaling factor and added heating**, the new version of Enlil produces stronger IMF and higher solar wind temperature, which are closer to observations

# Validation Framework

- We choose CR 2056 – 2062 (May – Nov 2007) to study
  1. GONG magnetograms became available in Sept. 2006
  2. Late declining phase of a solar cycle, with only one weak CME
  3. Ulysses had a fast latitudinal scan
- Grid resolutions are different among models. We use the highest resolution available at CCMC. The coarsest time scale from simulation is ~**5h**, so 5h moving averaging is applied to OMNI and Ulysses hourly data
- Performance metrics for solar wind simulation
  1. Visual comparison
  2. Mean square error for time series of solar wind parameters (without & with normalization)
  3. Model/observation ratio
  4. Correlation between model and observation
  5. Capturing IMF sectors
  6. Capturing slow-to-fast stream interaction regions

Ulysses {
  7. Capturing the latitudinal variations of solar wind
  8. Statistics of solar wind at low latitudes and mid-to-high latitudes (not shown here)

# 1.1 Visual Comparison: Solar Wind Speed at Earth Orbit

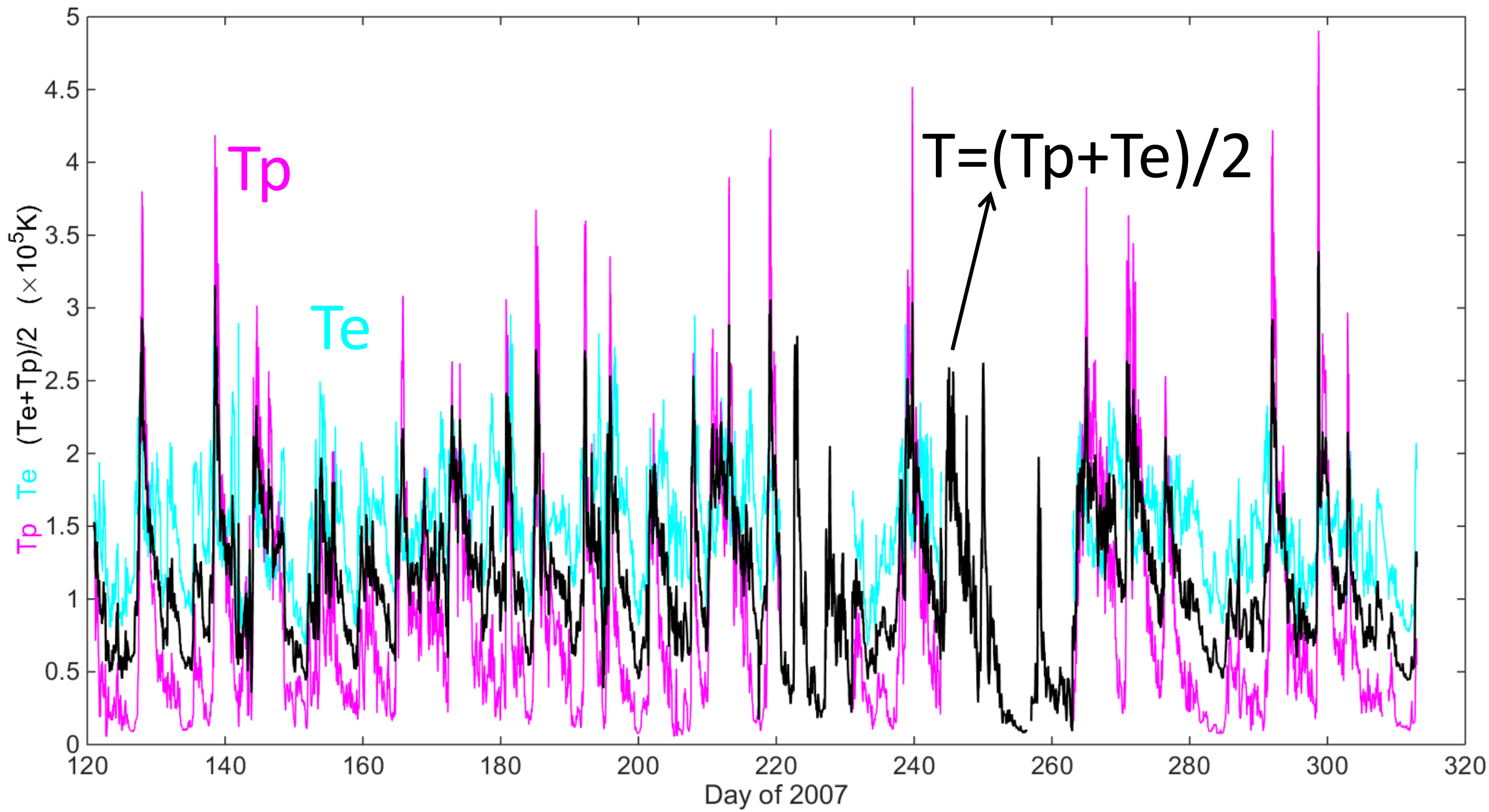



*After Jian et al. (2015)*

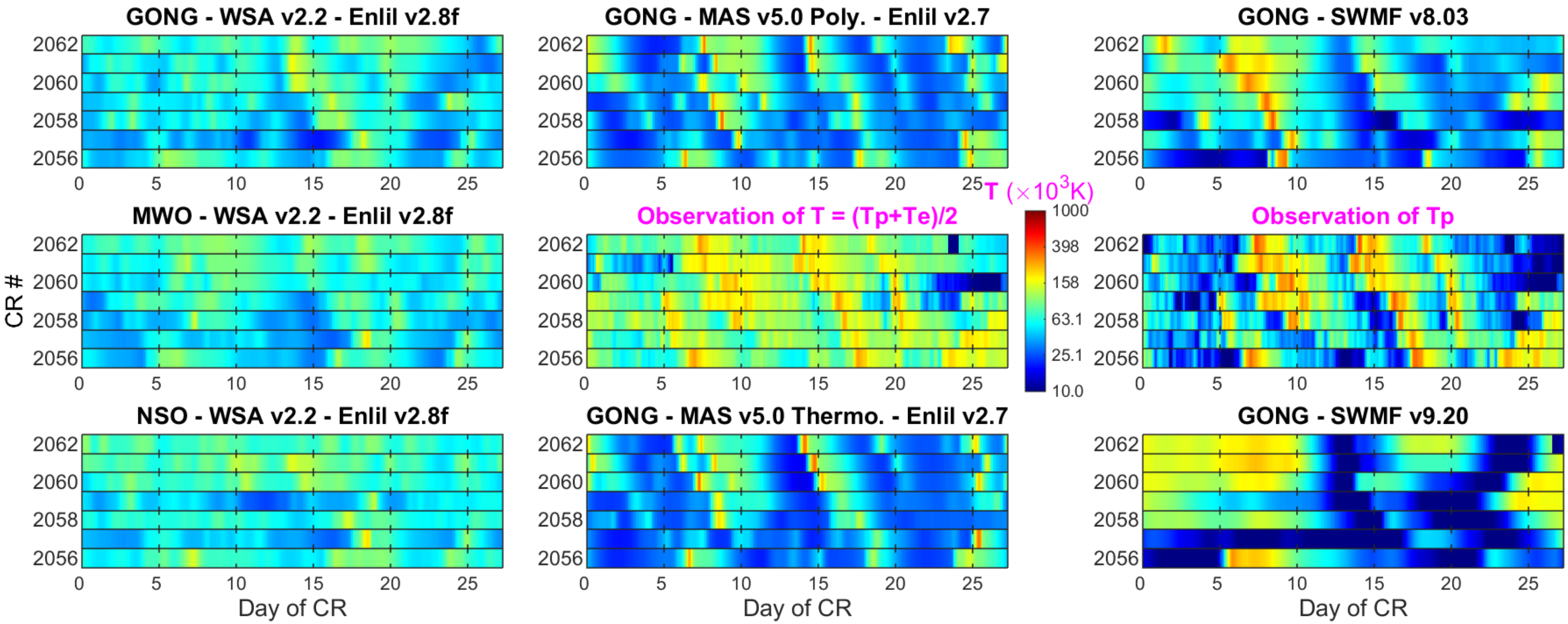
**Large variability from simulation results**

- WSA v2.2 – Enlil v2.8 model using magnetograms from different sources: GONG, MWO, NSO
- Multiple models using the same GONG magnetogram

# Solar Wind Temperature at 1 AU



# 1.2 Visual Comparison: Solar Wind Temperature at Earth Orbit



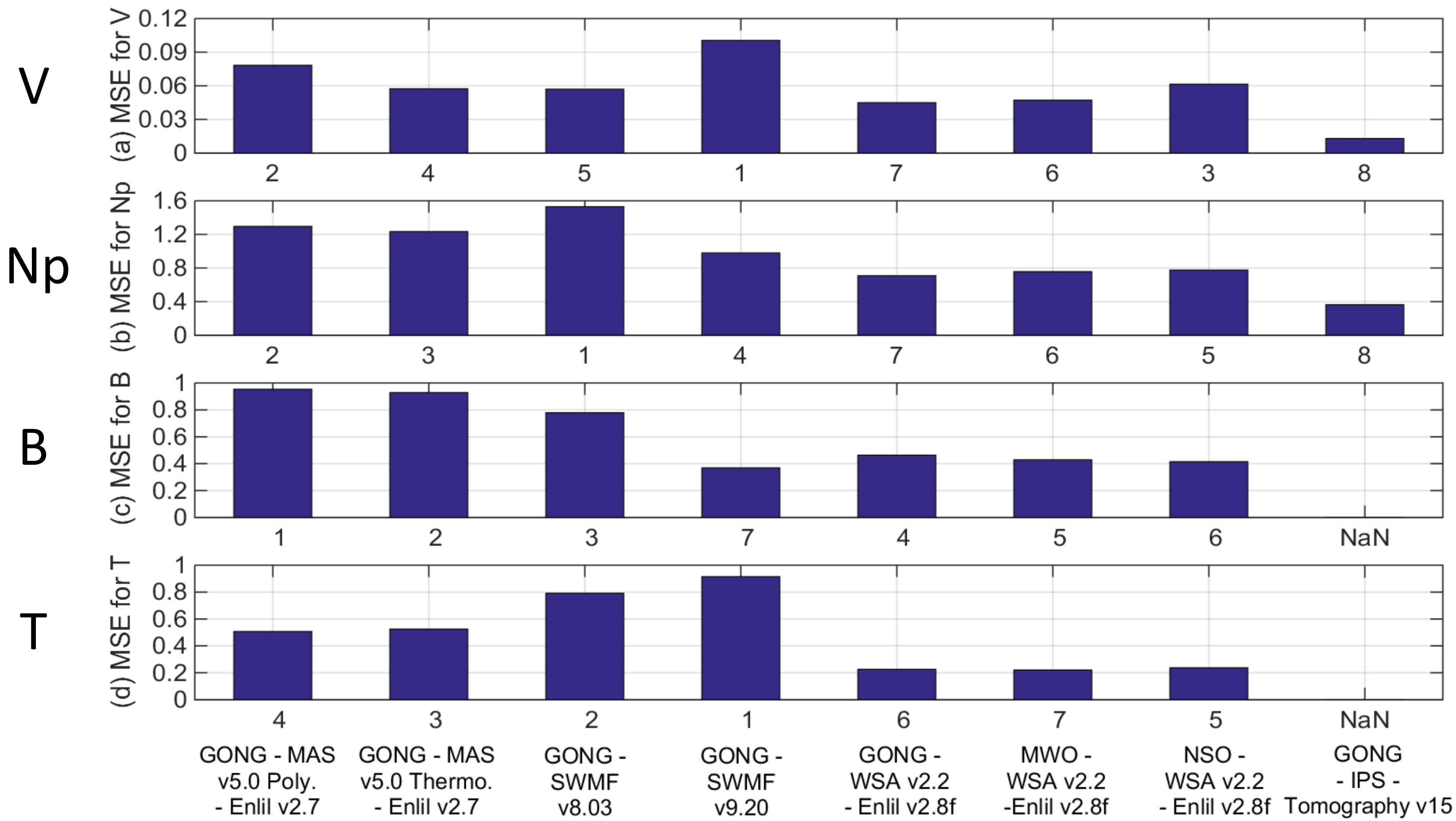

- Enlil model only produces one temperature, so mean temperature of protons and electrons are used for comparison
- SWMF produces separate ion and electron temperatures, so its results are compared with proton temperature
- IPS tomography does not output solar wind temperature or IMF intensity

# 2. Validation for Time Series of Normalized Solar Wind Parameters

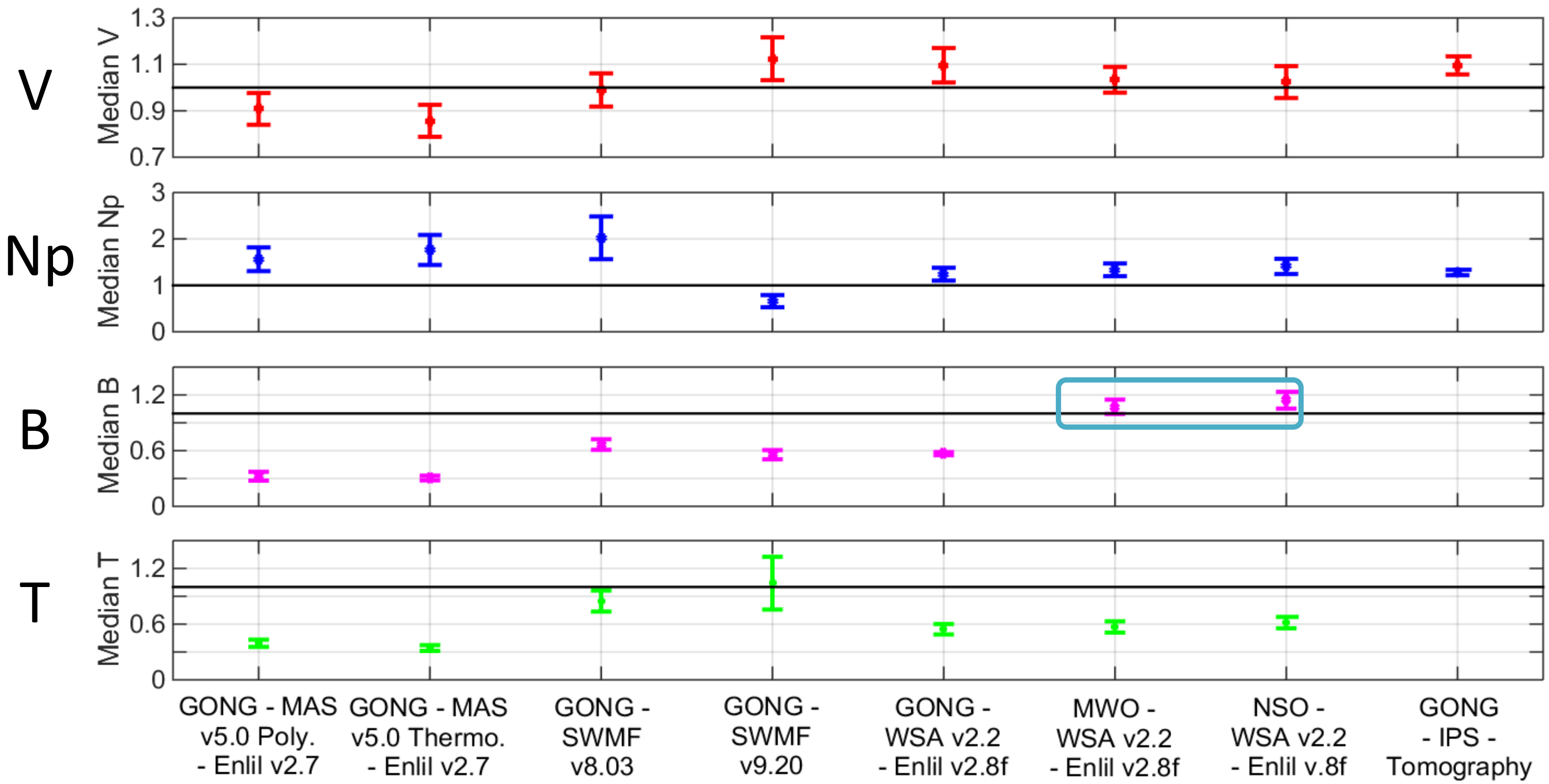
Mean square error (MSE) for parameter $x$: MSE = $\frac{1}{n}\sum_{t=1}^{n}(x_t - x'_t)^2$

Solar wind parameter is normalized by its average in each CR before validation

Results are very different from the ones without normalization

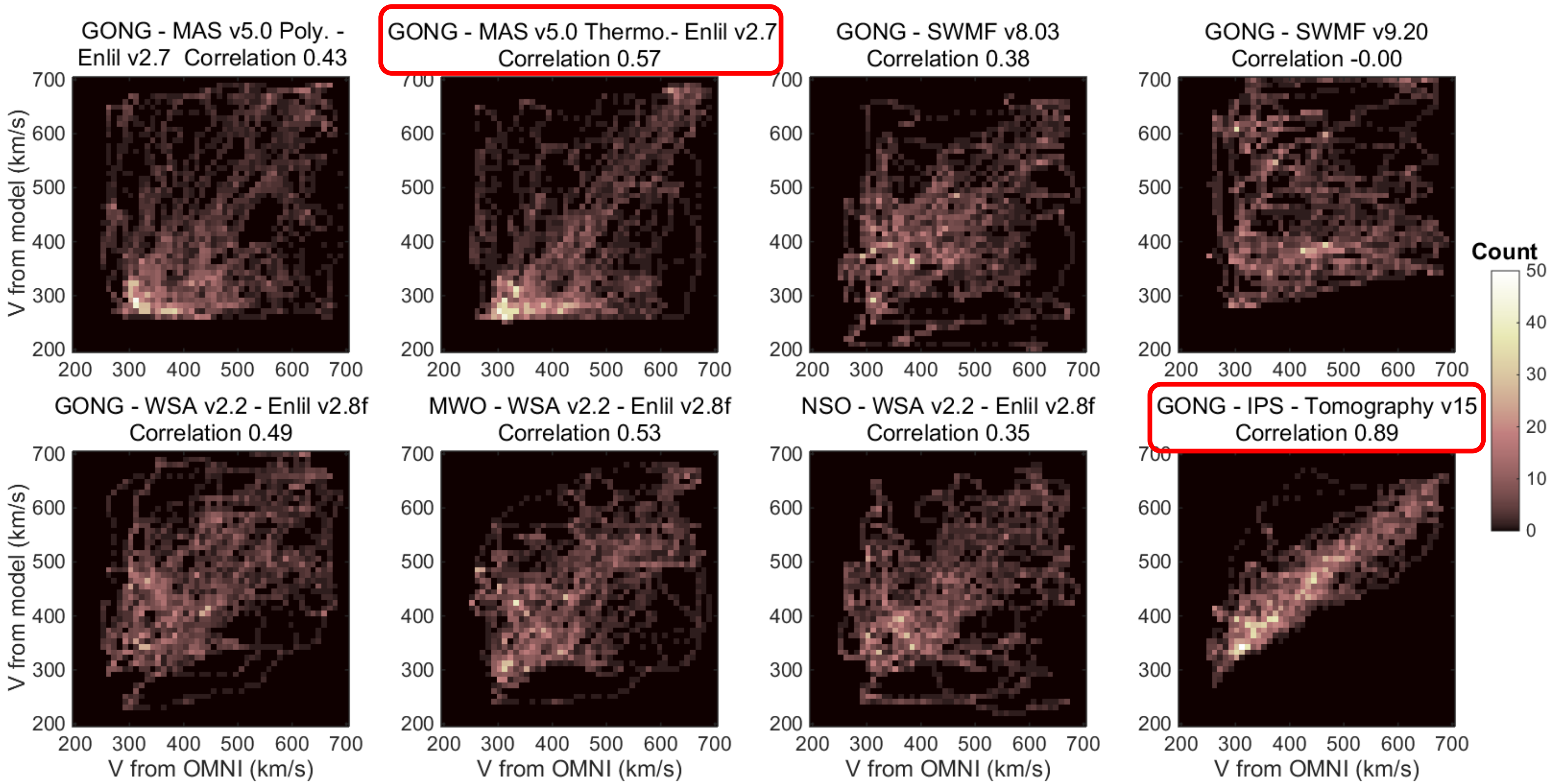


# 3. Model/Observation Ratios of Solar Wind Parameters



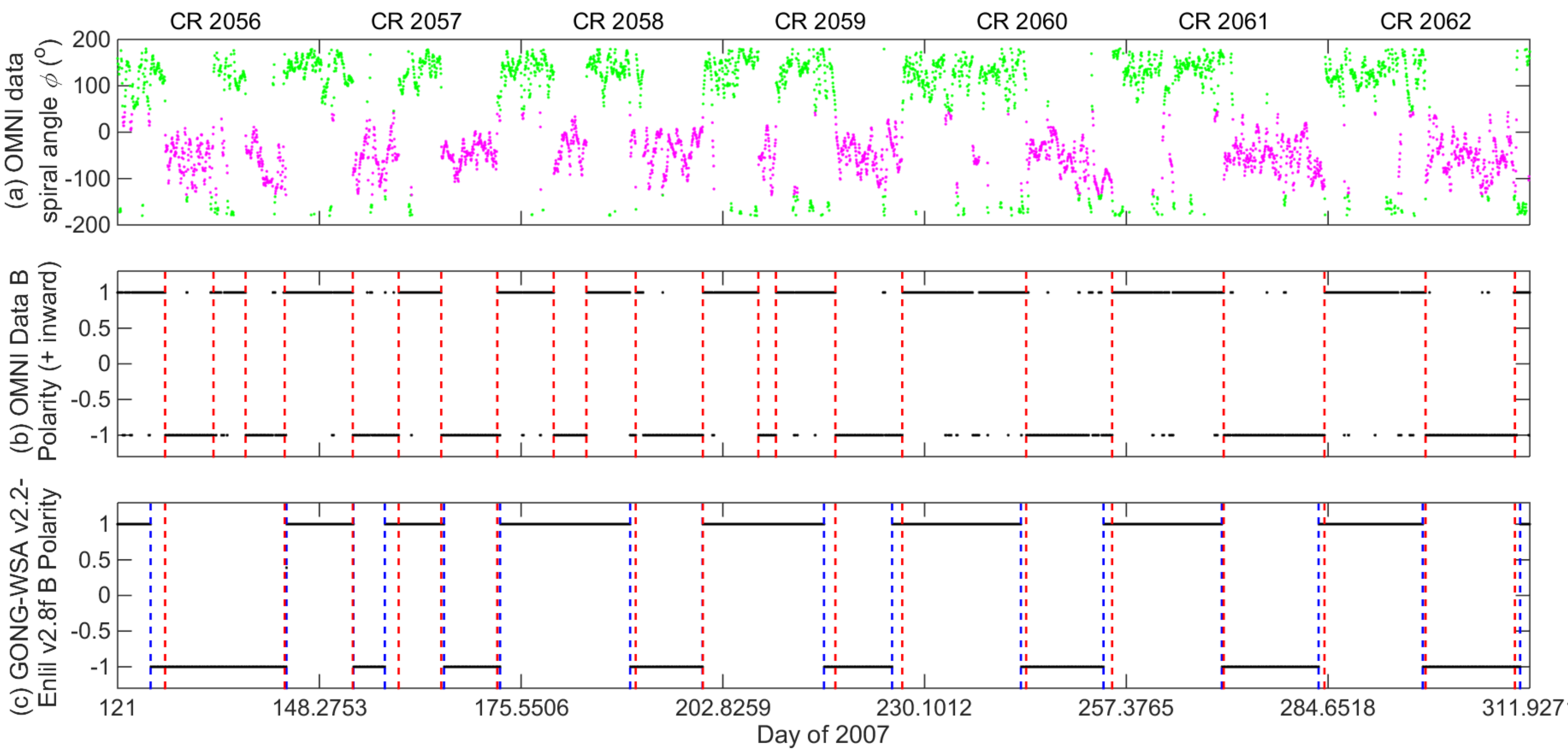

- Statistics are from seven CRs and done for minimum and maximum of each parameter too. They provide error bars for solar wind prediction
- Solar wind speed is the best modeled parameter, within ±20%
- The estimation of median B is improved in WSA v2.2 - Enlil v2.8

# 4. Correlation between Model and Observation: Solar Wind Speed




The model performance does not always agree with the MSE results!

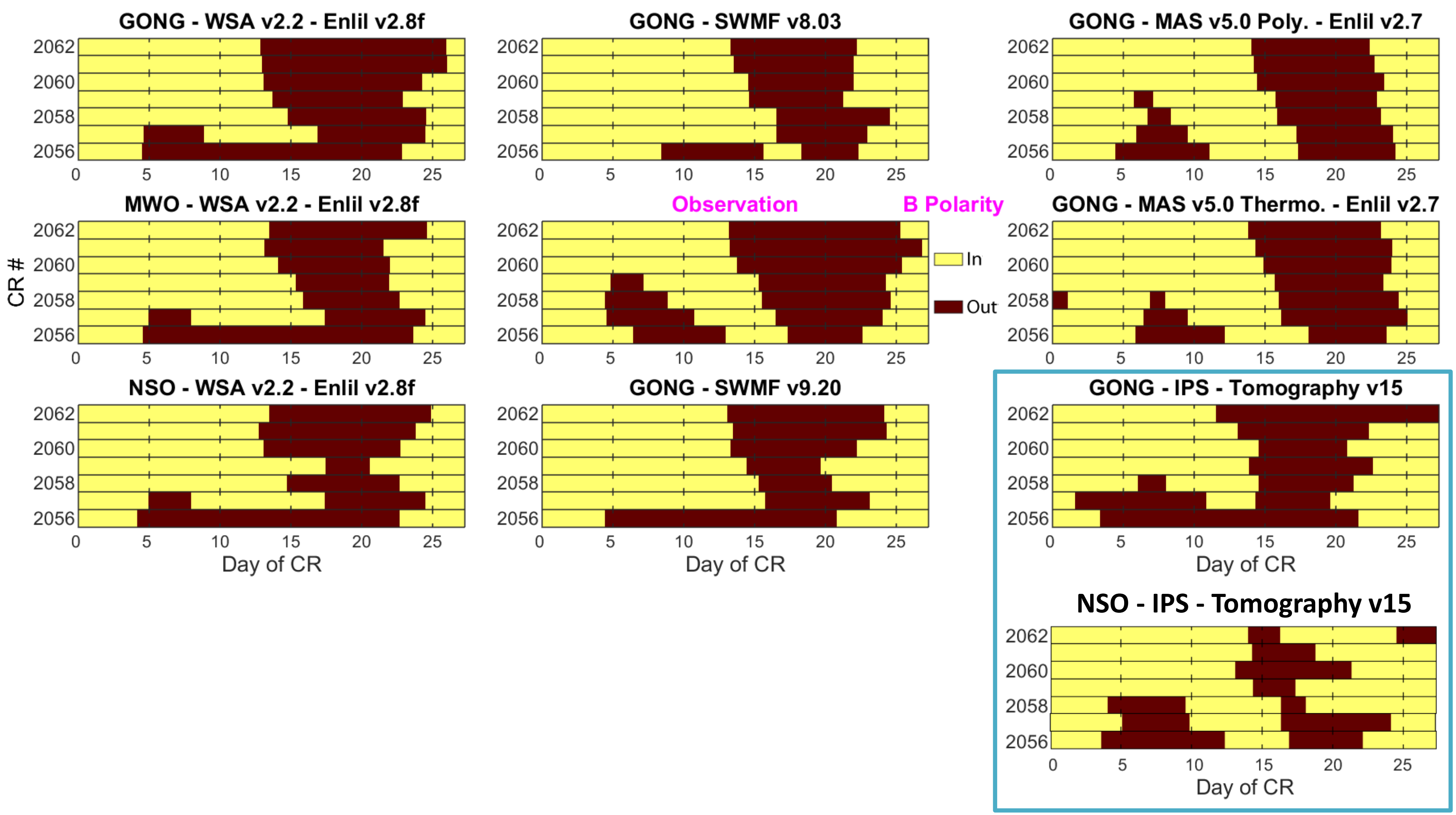
# 5.1 Identification of IMF Sector



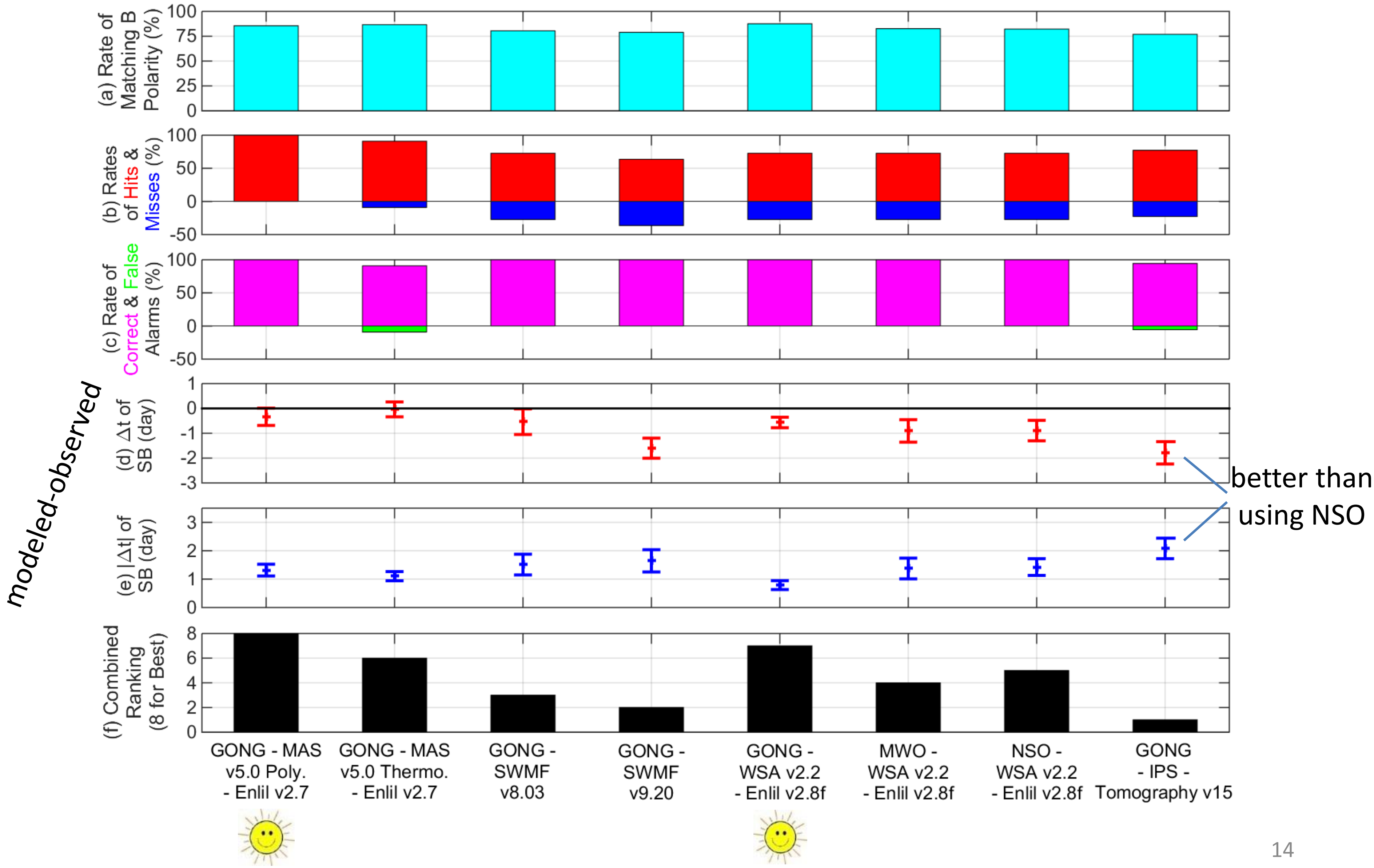

Red/blue dashed line: sector boundary (SB) from observation/simulation

- Parker spiral angle is used to determine the magnetic field inward/outward polarity in observation and IPS-Tomography data
- Magnetic field polarity is an output parameter from models
- Apply a 6-step algorithm to eliminate short excursions (≤ 1 day) from the main magnetic field sectors

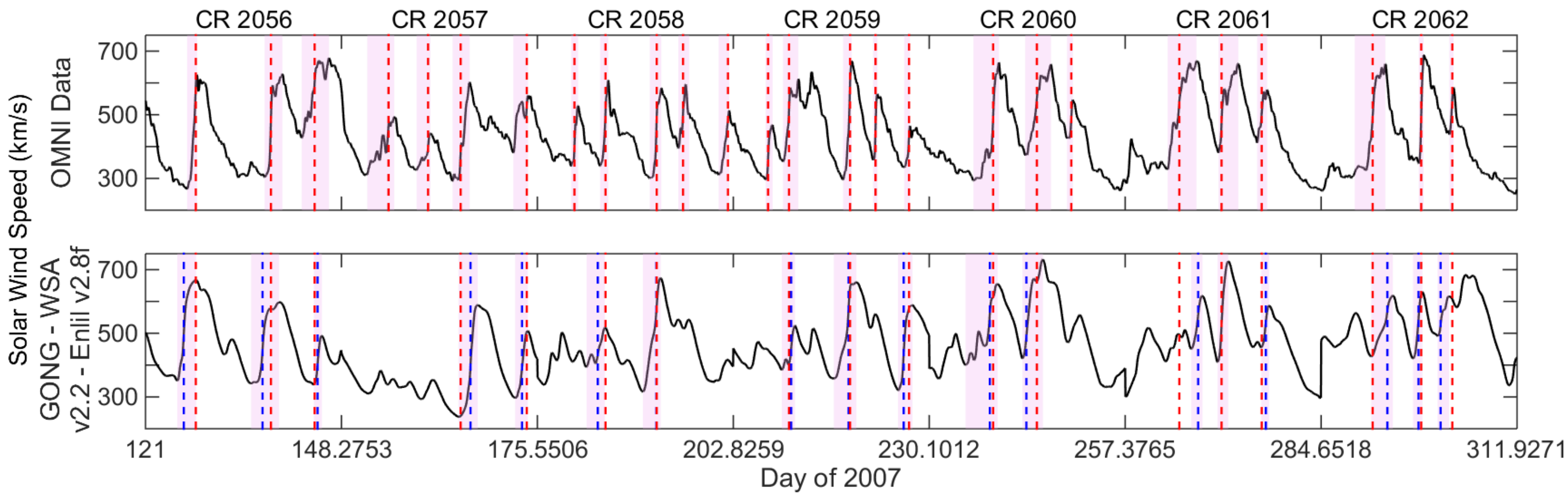
# 5.2 Distribution of IMF Sectors at Earth Orbit



# 5.3 Capabilities of Capturing IMF Sectors



# 6.1 Prediction of Stream Interaction Region (SIR)

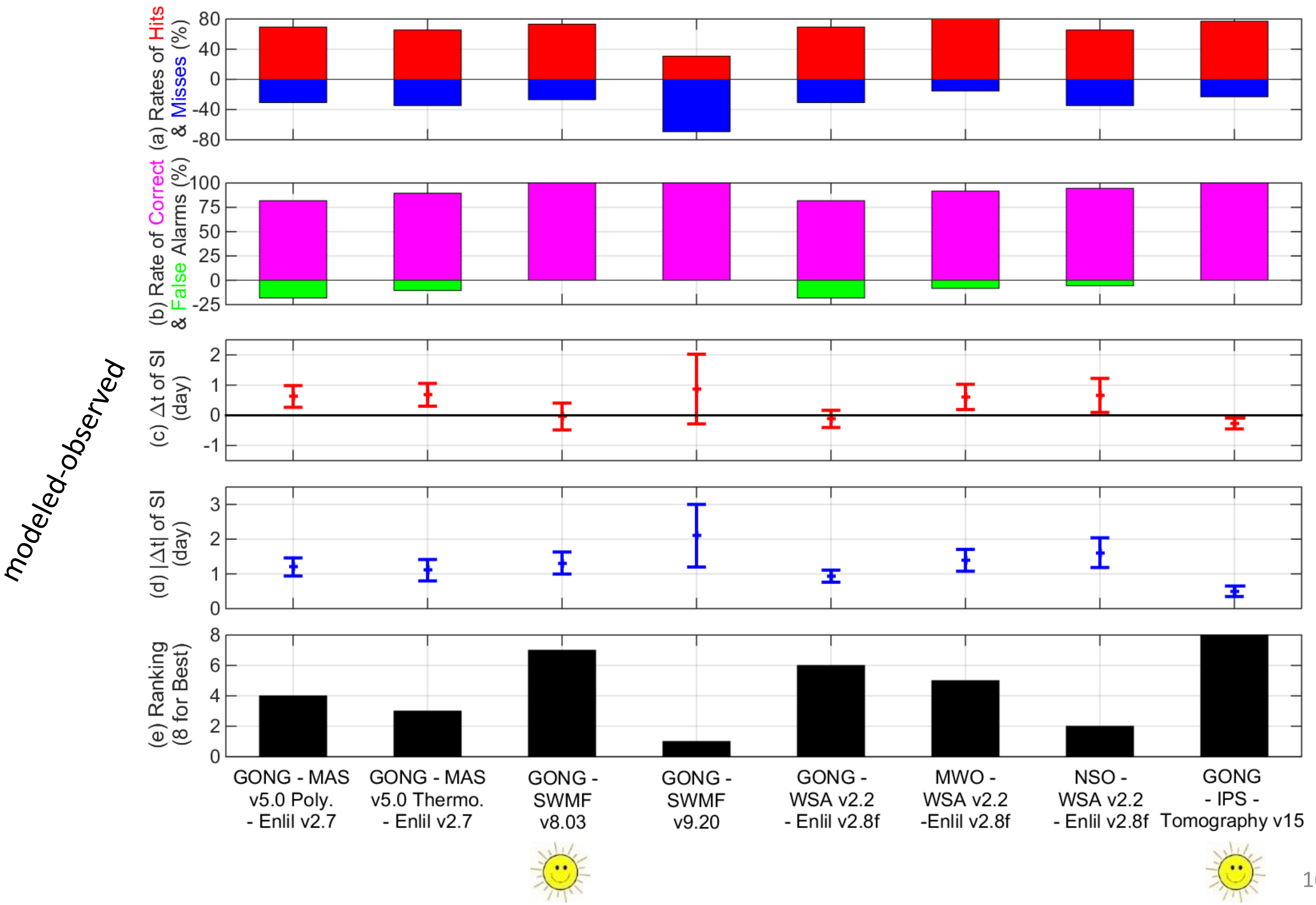



Shaded region: SIR

Red/blue dashed line: stream interface (SI) from observation/simulation

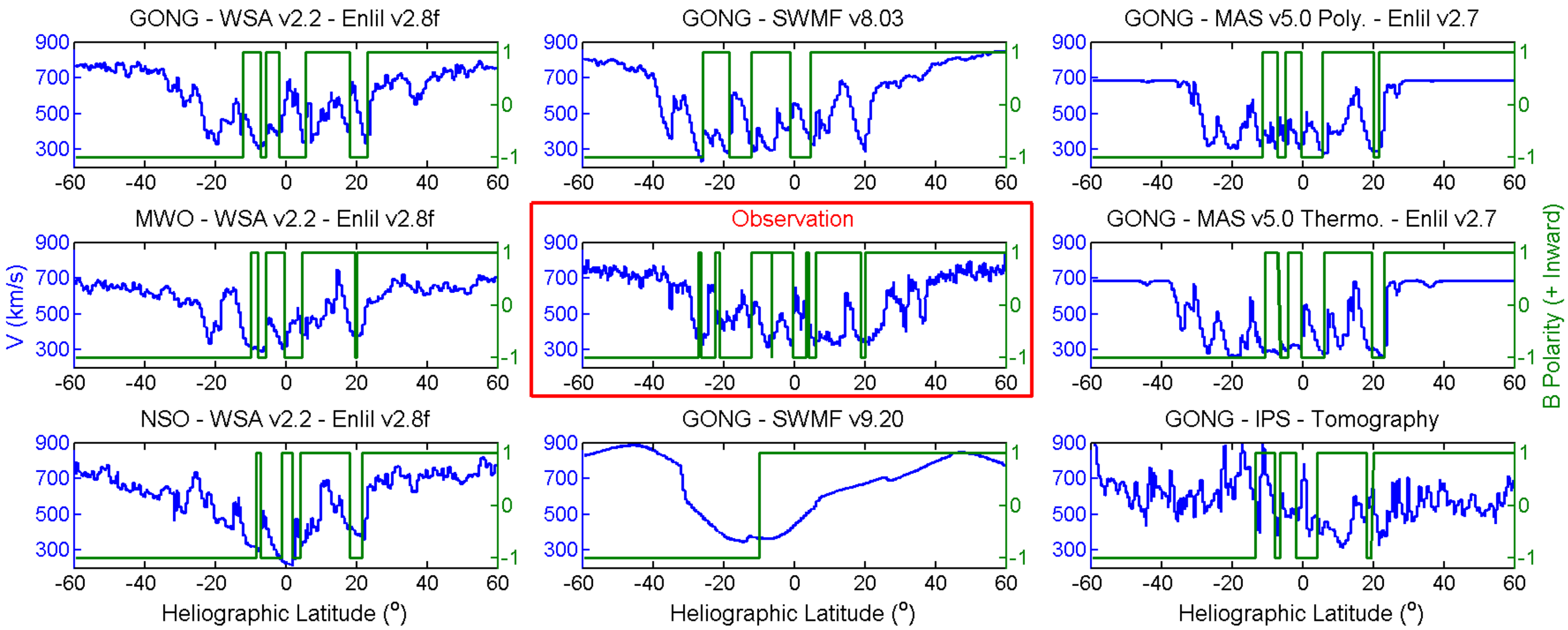
- Apply a 10-step algorithm to automatically detect SIRs using V
  - SIRs last more than half a day
  - Vmin ≤ 500 km/s, Vmax ≥ 400 km/s, speed increase ≥ 100 km/s
  - SIRs crossing two CRs are excluded
- Find the best-matching SIR and SI from observations

# 6.2 Capabilities of Capturing SIRs



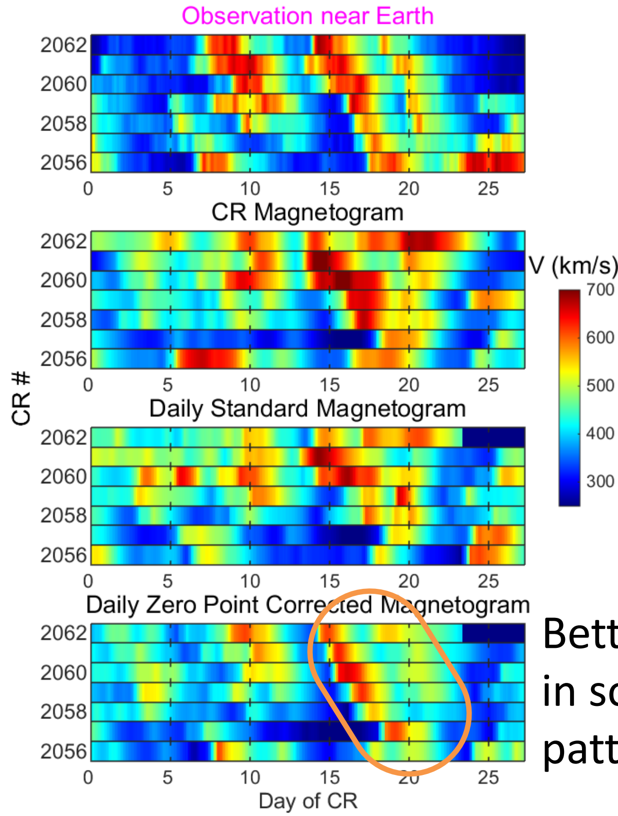
# 7. Capabilities of Capturing Latitudinal Variations of Solar Wind

## Solar Wind Speed & IMF Polarity



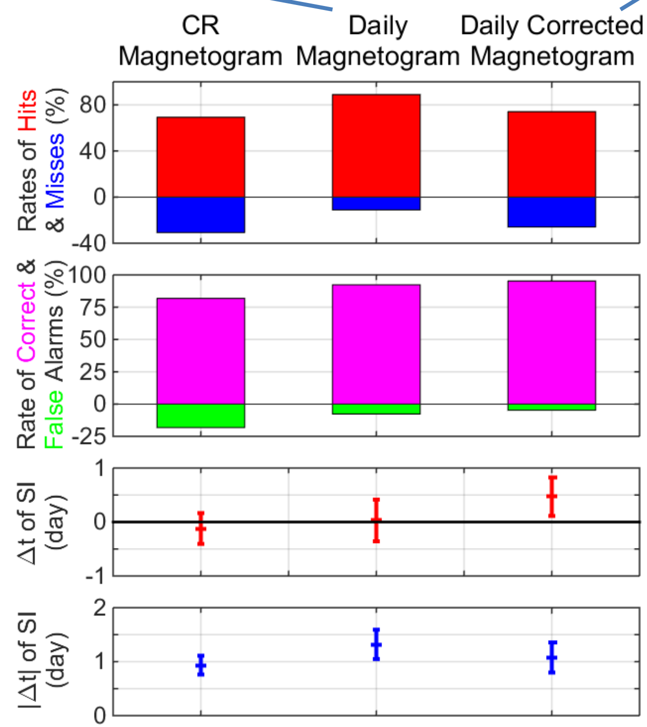

*Jian et al. (in revision, 2016)*

# WSA v2.2 – Enlil v2.8 Using Different Magnetogram Synoptic Maps from GONG – I




Better match in solar wind patterns

SIRs crossing two CRs are included



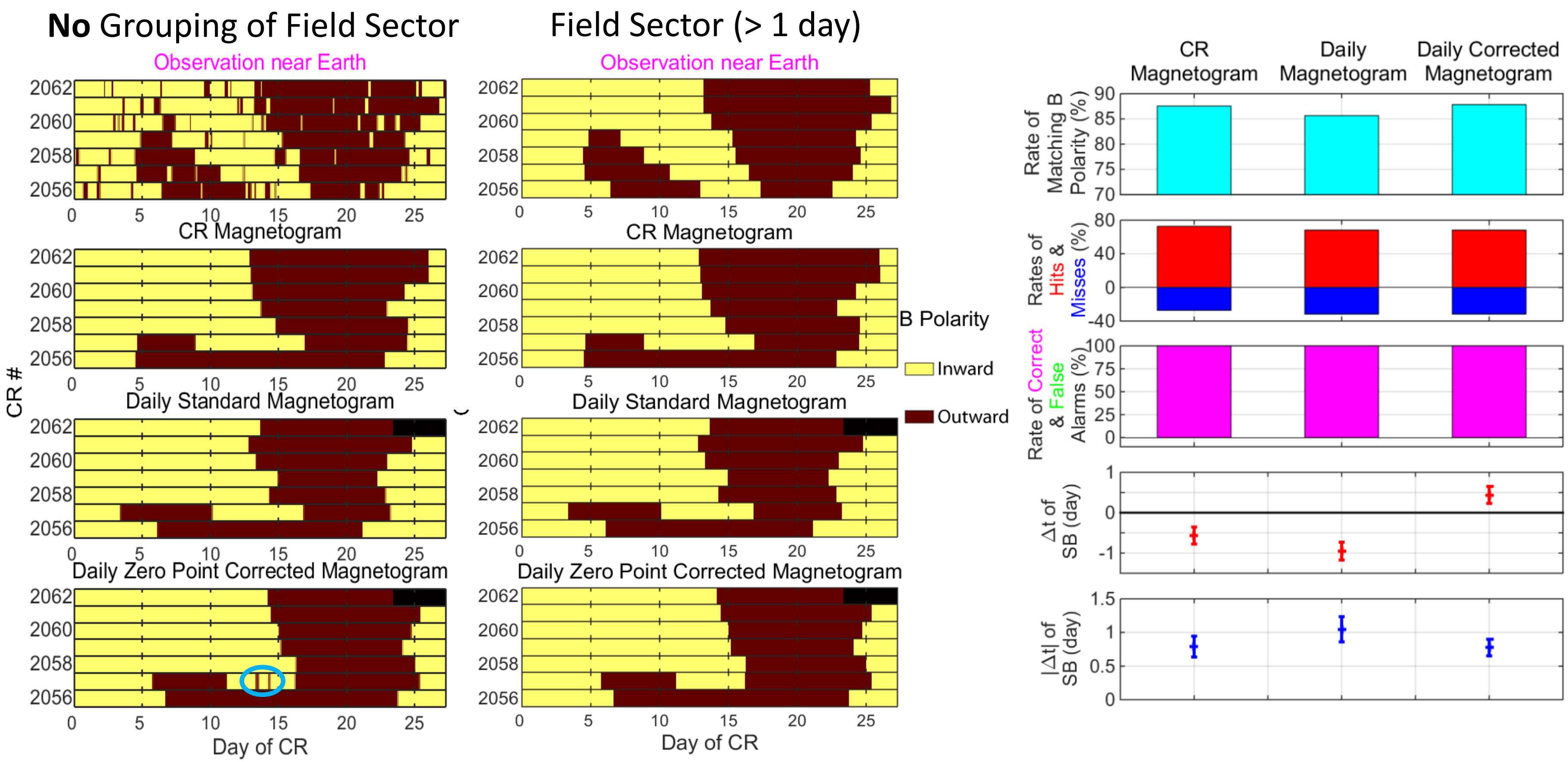

Input for WSA -Enlil model at the CCMC

Default for stationary solar wind: Integral full-rotation magnetograms

Default for CME simulation: Daily standard quick-reduce synoptic magnetograms (more frequent maps are available in GONG archive)

**Not Default**: Standard quick-reduce zero point corrected magnetograms. Fully calibrated CR maps with the correction are **unavailable**

# WSA v2.2 – Enlil v2.8 Using Different Magnetogram Synoptic Maps from GONG – II

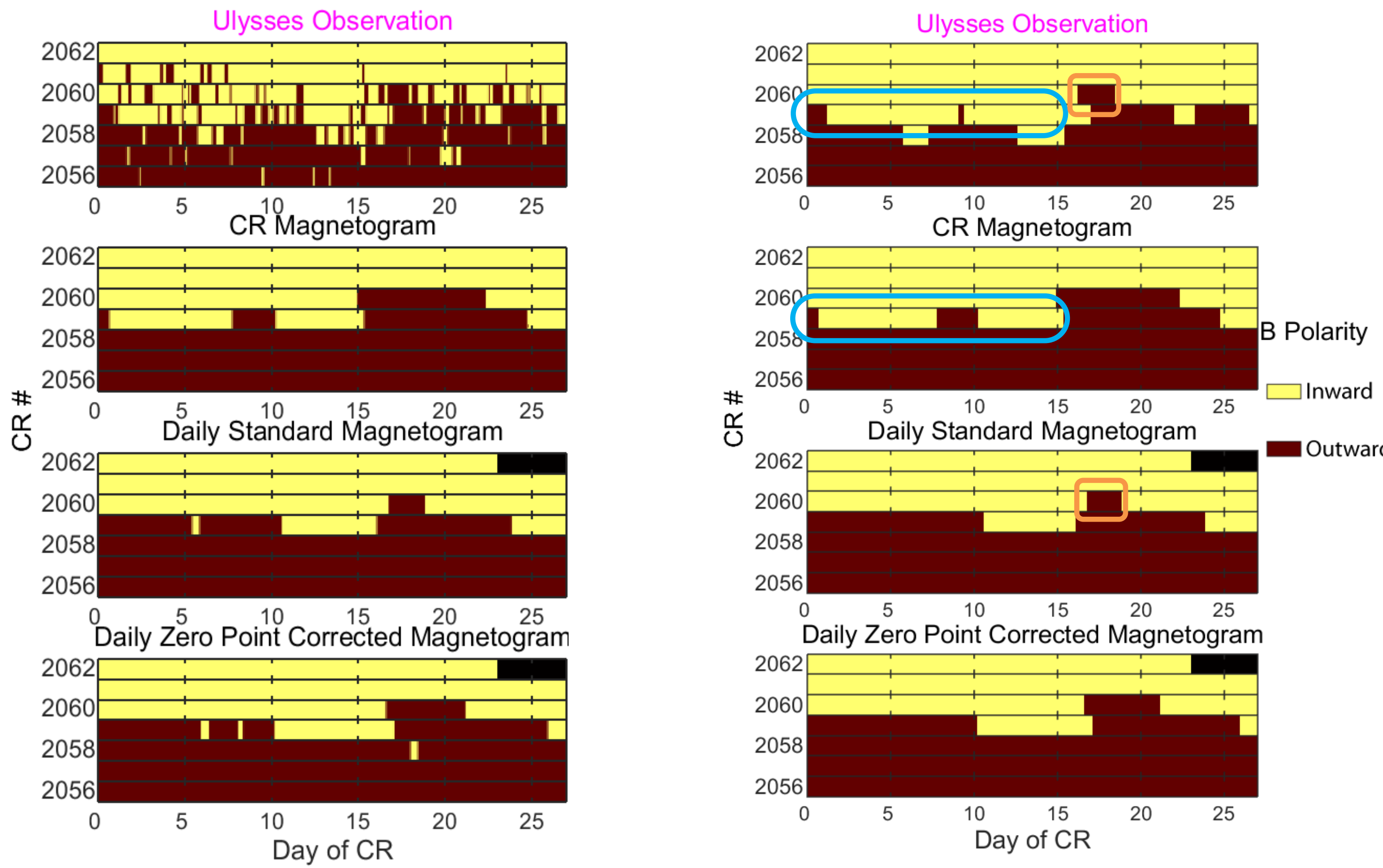



Simulations using daily magnetograms not necessarily capture more transient IMF polarity changes. Some contributing factors:

- Synoptic maps have been smoothed to a longitudinal resolution of 2.5° (~4h)
- Coarsest time resolution from Enlil model's grids is ~5h

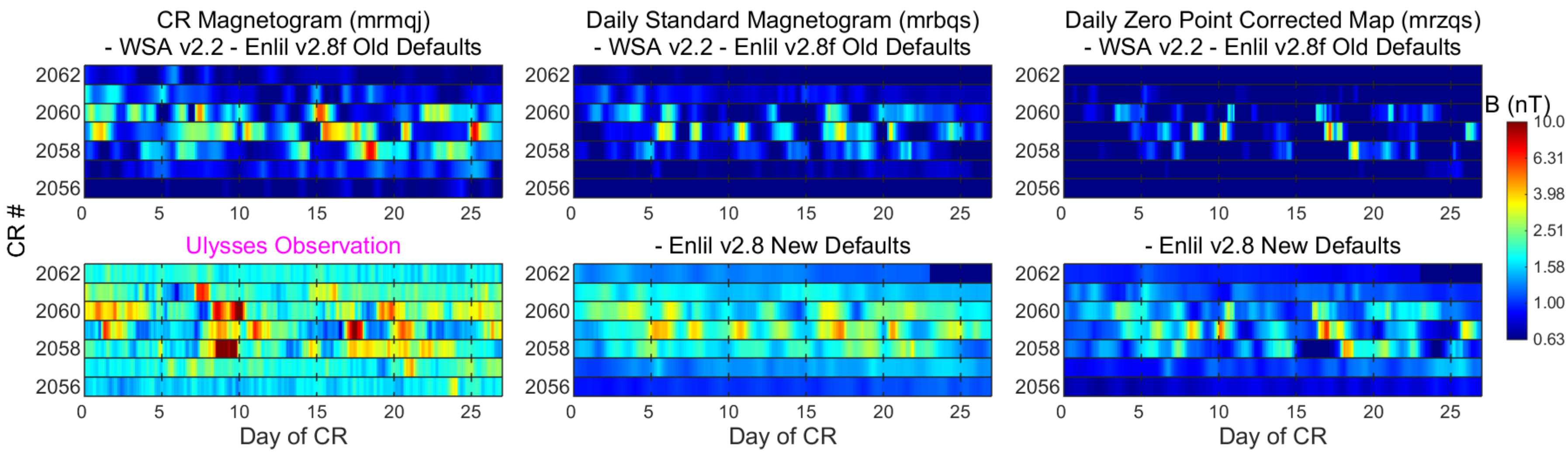
# WSA v2.2 – Enlil v2.8 Using Different Magnetogram Synoptic Maps from GONG – III

**No** Grouping of Field Sector | Field Sector (> 1 day)




No superior one between CR magnetogram and daily magnetogram for capturing IMF polarity

# WSA v2.2 – Enlil v2.8 Using Different GONG Magnetograms and Different Parameter Settings




- **More than 10 parameters** are used in setting the ambient wind conditions at Enlil's inner boundary
- They have been recently added in the WSA-Enlil result page as the **control file**
- The run results using old default setting (currently used in RoR) and new default setting (to be implemented) are similar, except in the new runs
  - Lower number density, larger discrepancy from observation, consistent with a decrease of number density at the inner boundary
  - Higher magnetic field intensity, closer to observation, consistent with the doubling of magnetic field scaling factor

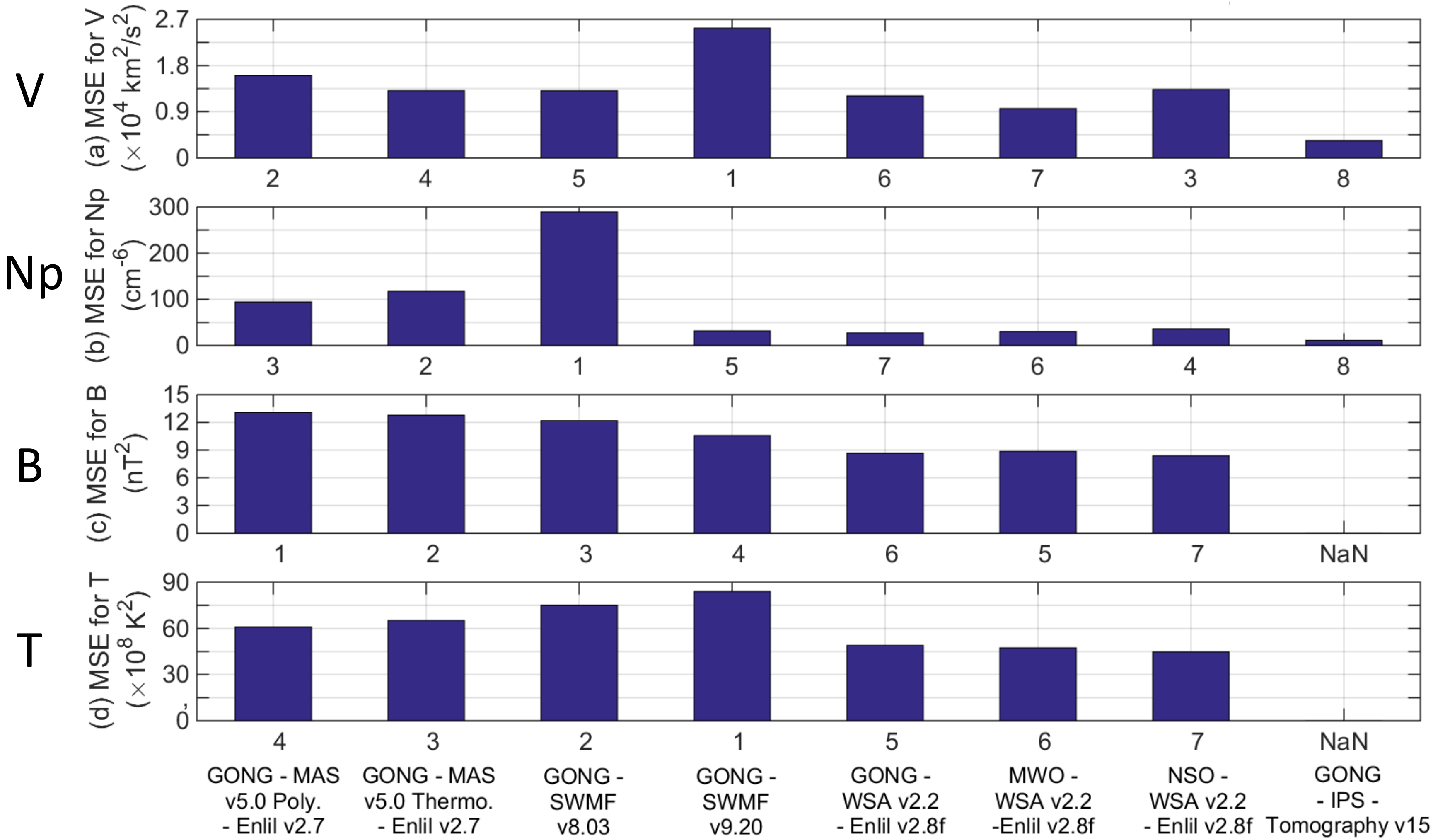
# Summary

- Comprehensive performance metrics are developed for solar wind prediction
- Eight model combinations installed at CCMC are evaluated for 2007. General strengths and weaknesses for each model are diagnosed
- All of the models make different simplifying assumptions, treating the physics in very approximate fashion in many aspects, thus the model performance is also a test of how well those assumptions can simulate the nature
- <u>It is not yet available to use the same grids for various models at CCMC</u>
- The model validation for a more active phase of solar cycle 24, a longer period, and following the magnetogram and model upgrades is needed
- SHINE session "Coronal model drivers: A fistful of maps"

# Backup

# 2.1 Validation for Time Series of Solar Wind Parameters

Mean square error (MSE) for parameter $x$: MSE = $\frac{1}{n}\sum_{t=1}^{n}(x_t - x'_t)^2$



# Ambient Wind Condition Settings of Enlil v2.8f

- Old defaults (a4b1):
  ratio of specific heats (gamma): 1.6666667
  runpar=g53q5, vfast=700., vslow=200.,
  vrfast=25., **vrslow**=100, **bfast**=300, **bscl**=2,
  **dfast**=200, **tfast**=2, **xalpha**=0.03, nbrad=1

- New defaults (a6b1):
  ratio of specific heats (gamma): 1.6666667
  runpar=g53q5, vfast=700., vslow=200.,
  vrfast=25., **vrslow**=75, **bfast**=350, **bscl**=4,
  **dfast**=125, **tfast**=1.5, **xalpha**=0.05, nbrad=1