CME arrival-time validation of real-time WSA-ENLIL+Cone simulations at the CCMC/SWRC

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METHODOLOGY

➤ Validation results of the WSA-ENLIL+Cone model running in real-time at the CCMC/SWRC and archived in DONKI.

➤ Compare model predicted CME arrival-times to in-situ ICME shock observations near Earth, STEREO-A & B, March 2010 - present (simulations of 2,700 CMEs).

➤ Report hit, miss, false alarm, and correct rejection statistics

➤ For hits, compute bias and average absolute arrival time error and dependence of errors on CME input parameters

➤ Determine impact of multi-spacecraft observations on the CME parameters used to initialize the model

➤ before and after the STEREO B communication loss (since September 2014) & STEREO-A side-lobe operations (August 2014-December 2015)
VALIDATION PROCESS

➤ The quality of model operation is evaluated by comparing the model output to the observed CME arrival time.
  ➤ Referencing ICME catalogues (Lan Jian, Teresa Nieves, Richardson & Cane, ISEST, HELCATS)
  ➤ DONKI database
  ➤ Analysis of in situ data (ACE, WIND, STEREO)

➤ Complications:
  ➤ Observed arrival is weak
  ➤ Hybrid SIR and CME event
  ➤ CME arrival with uncertain source.
## Contingency Table & Skill Scores

- **Success Ratio**: $\frac{H}{(H+FA)}$
  - fraction of predicted arrivals that were correct; perfect score = 1
- **False Alarm Ratio**: $\frac{FA}{(H+FA)}$
  - fraction of predicted arrivals that were incorrect; perfect score = 0
- **Accuracy**: $\frac{(H+CR)}{Total}$
  - fraction of correct forecasts; perfect score = 1
- **Bias Score**: $\frac{(H+FA)}{(H+M)}$
  - ratio of predicted arrivals to observed arrivals; under forecast <1; perfect score = 1; over forecast >1
- **Probability of Detection (hit rate)**: $\frac{H}{(H+M)}$
  - fraction of observed events that were predicted; perfect score = 1

<table>
<thead>
<tr>
<th></th>
<th>Observed Arrival</th>
<th>No Observed Arrival</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Predicted Arrival</strong></td>
<td>Hit (H)</td>
<td>False Alarm (FA)</td>
</tr>
<tr>
<td><strong>No Predicted Arrival</strong></td>
<td>Miss (M)</td>
<td>Correct Rejection (CR)</td>
</tr>
</tbody>
</table>
### HITS, FALSE ALARMS, MISSES & CORRECT REJECTIONS

<table>
<thead>
<tr>
<th></th>
<th>Earth</th>
<th>STEREO-A</th>
<th>STEREO-B</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hits</strong></td>
<td>128</td>
<td>105</td>
<td>58</td>
<td>291</td>
</tr>
<tr>
<td><strong>False Alarms</strong></td>
<td>112</td>
<td>85</td>
<td>53</td>
<td>250</td>
</tr>
<tr>
<td><strong>Misses</strong></td>
<td>109</td>
<td>&gt;108</td>
<td>&gt;71</td>
<td>&gt;288</td>
</tr>
<tr>
<td><strong>Correct Rejections</strong></td>
<td>1114</td>
<td>1195</td>
<td>848</td>
<td>3157</td>
</tr>
</tbody>
</table>

#### Success and False Alarm Ratios

<table>
<thead>
<tr>
<th>Success Ratio</th>
<th>False Alarm Ratio</th>
<th>Accuracy</th>
<th>Hit Rate (POD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Success Rate</td>
<td></td>
<td>Bias Score</td>
<td></td>
</tr>
</tbody>
</table>

- **Earth**
- **STEREO-A**
- **STEREO-B**
- **All**
CME ARRIVAL TIME PREDICTION ERRORS

Average Absolute Error at Earth, STEREO A & B

Average Absolute Arrival Time Error (hrs.)

- March 2010 - Present (all runs)
- Mar 2010 - Sep 2014 (3 spacecraft)
- Oct 2014 - Dec 2015 (2 spacecraft-STA sidelobe)
- Jan - Dec 2016 (2 spacecraft)

Earth
STEREO-A
STEREO-B
All

36 hits
291
237
18 hits
CME ARRIVAL TIME ERROR DISTRIBUTION

Occurrence

CME arrival time prediction error (hours)

Earth
STEREO-A
STEREO-B
All
CME arrival time error compared to input speed

Input CME radial speed (km/s)

CME arrival time error compared to input speed

Input CME radial speed (km/s)
**Kp Range Prediction Skill Scores**

*Is the observed Kp$_{max}$ within the predicted Kp range?*

- **March 2010 - Present** (all runs)
- **Mar 2010 - Sep 2014** (3 spacecraft)
- **Oct 2014 - Dec 2015** (2 spacecraft: STA sidelobe)
- **Jan - Dec 2016** (2 spacecraft)

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**Kp skill scores varying with threshold**

*Using threshold varying contingency tables for observed and predicted Kp$_{max}$*

- **Success Ratio**
- **False Alarm Ratio**
- **Bias Score**
- **Hit Rate (POD)**

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**Skill Score**

- **Kp**
- **Kp$_{max}$ threshold**
Error in predicting $K_{p_{\text{max}}}$ varied by threshold

$K_{p_{\text{max}}}$ errors computed for hits in threshold varying contingency tables

Mean Error (ME)
Mean Absolute Error (MAE)
RMSE
CONCLUSIONS

- Simulations of 2,700 CMEs (March 2010 - present), 291 observed arrivals:
  - CME arrival time average absolute error at all locations = 10 hours
- Preliminary validation of the period post-September 2014 (without STEREO B and reduced STEREO A coverage) shows a reduction in skill of 2.3 hours (36 observed arrivals)
  - multi-view coronagraph observations have a quantitative impact on CME arrival time forecast accuracy (support for L5 need)
- Sources of CME arrival time error:
  - input CME parameters
  - ambient solar wind prediction (and magnetogram limitations/uncertainties)
  - input model ambient parameters
  - model assumptions - CME has no flux-rope field
FUTURE WORK

➤ Introduce quality factors for observed arrivals and identifying candidate CMEs

➤ Look at other locations (MESSENGER, Mars)

➤ Winslow et al. (2015) MESSENGER ICME catalogue