Forecasting secular variation using accelerated core surface flows

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Magnetic Field variation

- CHAOS-5 main field variation
- RMS differences (to degree 13):

<table>
<thead>
<tr>
<th>Years</th>
<th>Total RMS difference [nT]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005 – 2000</td>
<td>382</td>
</tr>
<tr>
<td>2010 – 2005</td>
<td>400</td>
</tr>
<tr>
<td>2015 – 2010</td>
<td>440</td>
</tr>
</tbody>
</table>
IGRF and WMM series

- Secular variation forecasts from:
  - IGRF-9, 10 and 11 (to degree 13)
  - WMM2000, WMM2005, WMM2010 (to degree 12)

<table>
<thead>
<tr>
<th>Year</th>
<th>IGRF SV</th>
<th>WMM SV</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>79</td>
<td>98</td>
</tr>
<tr>
<td>2010</td>
<td>109</td>
<td>122</td>
</tr>
<tr>
<td>2015</td>
<td>84</td>
<td>104</td>
</tr>
</tbody>
</table>
Can we improve on this?

- IGRF-12 SV candidate submissions
  - Instantaneous SV extrapolations
  - Data assimilation into geodynamo models
  - Core Flow / Accelerated core flows

- Look at forecasts from core flows derived from SV and SA
  - Flows from inversion of SV only
  - Flows from inversion of SV and SA
  - Flows with steady acceleration from SV and SA
Assumptions

• Frozen flux approximation
  • No diffusion assumed

• Solve for toroidal and poloidal flow and accelerations
  • Compute flow and accelerations to degree 14
  • Bloxham ‘strong’ norm damping above degree 8
  • Slightly damped to impose geostrophic flow

• Use SV and SA from ~160 observatory and 648 ‘virtual observatory’ satellite data

• Solve flow and acceleration models in six sets of years:
Example models [2007 - 2010]

Constant Flow
Forecasting

- Start at year e.g. 2005 or 2010
  - Compute MF coeffs from model (e.g. CHAOS-5)
  - Use core flow and/or acceleration to compute instantaneous SV and SA for timestep (i.e. 1 month)
- Add to MF, update Gaunt/Elsasser matrices
- Compute RMS difference
- Repeat ..
- Can also compute hindcasts
Flow model (2010-2015)

SV only

SV and SA
Flow model with acceleration (2010-2015)

<table>
<thead>
<tr>
<th>RMS Diff [nT] at 2015.0</th>
<th>SV only</th>
<th>SV and SA</th>
<th>SF with accel</th>
<th>IGRF-11</th>
<th>WMM2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001-2007</td>
<td>113</td>
<td>111</td>
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<tr>
<td>2001-2010</td>
<td>85</td>
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<td>107</td>
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<tr>
<td>2005-2010</td>
<td>80</td>
<td>79</td>
<td>85</td>
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<td>104</td>
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<tr>
<td>2007-2010</td>
<td>77</td>
<td>85</td>
<td>75</td>
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</table>
Flow model (2005-2010)

SV only

SV and SA

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Flow model with acceleration (2005-2010)

<table>
<thead>
<tr>
<th>RMS Diff [nT] at 2010.0</th>
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<th>SF with accel</th>
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<th>WMM2010</th>
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<td>109</td>
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Improvements over previous generations?
Conclusions

• Usually able capture > 75% of the field change

• Jerks/accelerations are significant for goodness of forecast

• Core flows using 3-5 years of data are best

• *Slightly better to somewhat better* than standard instantaneous SV extrapolation