Minimizing Reanalysis Jumps Due to New Observing Systems

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The overall purpose of this research is to find a solution to minimize the “climate jumps” associated with observing system changes.
MERRA

- **MERRA**: NASA’s Modern Era Retrospective-analysis for Research and Applications (1979-present). It utilizes GEOS5-DAS to produce a long-term synthesis. **SSM/I**: Special Sensor Microwave/Imager. Using a unified, physically based algorithm to simultaneously retrieve ocean wind speed (at 10 meters), atmospheric water vapor, cloud liquid water, and rain rate. The SSM/I channels are sensitive to water vapor, cloud, precipitation and surface parameters, rather than temperature.
II. Reanalysis System and Data

- **MERRA**
  - MERRA: NASA’s Modern Era Retrospective-analysis for Research and Applications (1979-present). It utilizes GEOS5-DAS to produce a long-term synthesis. With emphasis on exactly closing the water and energy budgets, MERRA surpasses other latest reanalyses in assimilating time series of global monthly mean precipitation (Rienecker et al, 2011).
  - SSM/I: Special Sensor Microwave/Imager. using a unified, physically based algorithm to simultaneously retrieve ocean wind speed (at 10 meters), atmospheric water vapor, cloud liquid water, and rain rate. The SSM/I channels are sensitive to water vapor, cloud, precipitation and surface parameters, rather than temperature.

- **SPEEDY – LETKF**
  - simpler and computationally efficient
  - Rawinsonde and AIRS (Dr. Kang)

<table>
<thead>
<tr>
<th>Rawinsonde</th>
<th>U, V, T, and Q 00Z and 12Z</th>
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</thead>
<tbody>
<tr>
<td>AIRS</td>
<td>T and Q, 6 hourly</td>
</tr>
<tr>
<td>Ps</td>
<td>3x3, 6 hourly</td>
</tr>
</tbody>
</table>
II. Reanalysis System and Data

Fig 2. A schematic of the IAU implementation in GEOS-5 (Rienecker et al, 2011)

\[
\frac{dZ}{dt}_{total} = \frac{dZ}{dt}_{dyn} + \frac{dZ}{dt}_{phy} + \frac{dZ}{dt}_{ana} \quad Eq(1)
\]

**analysis tendency from IAU:** \[\frac{dZ}{dt}_{ana} = \frac{\text{analysis increment}}{6hr}\]

- **GEOS5** incorporated Incremental Analysis Update procedure (IAU, Bloom et al. 1996) to minimize the 6-hourly shock from the observation input (Kennedy et al. 2011).
III. Proposed Hypotheses

- By comparing MERRA data and an experiment without SSM/I observations (named noSSMI hereafter), we can obtain the bias between MERRA and noSSMI due to the introduction of this new observing system.

- Based on this bias information, corrections would be made on MERRA data before the introduction of the new observing system, so as to adjust the earlier period data to match with the later period data.

- In this study, we aim to make the correction in the IAU process.

- The correction terms will be derived from the bias of analysis increment between the original MERRA data and the noSSMI.
We will test our methodology, inspired by Danforth et al (2007), to solve the SSM/I introduced “climate jump” in MERRA product.

Danforth et al (2007) compared model data with a reference to generate a forcing term, and then added it to the model tendency equation. The model was run again with new tendency equation, and much reduced the bias.

Following this method, if MERRA was considered as reference, noSSMI would represent the biased model.
IV. Methodology

- The correction is defined as the bias of analysis increment between MERRA and noSSMI, for any combination of moisture, temperature, and wind states (Fig 3), which is a 2yr-long 6-hourly dataset.
IV. Methodology

- The sampling error in the correction is reduced as follows:
  1) dataset is averaged at the same time within a year. Then, a 1yr-long 6-hourly dataset is achieved.
  2) A Fourier analysis is applied to this 1-yr time series. The results show that the correction term can be well represented by combining its annual mean, semi-annual (6-month), and seasonal (3-month) oscillations (Fig 5).
IV. Methodology

- This difference contains seasonal variability that we want to keep, and weather variability that we want to filter out because it is sampling noise.
- The sampling error in the correction is reduced as follows: A Fourier analysis is applied to the 365-day 6-hourly correction time series. The results show that the correction term can be well represented by combining its annual mean, semi-annual (6-month), and seasonal (3-month) oscillations (Fig 6).

- After Fourier filter, the correction data is imported to IAU produced analysis increment every six hour, at corresponding time within a year, to test whether this correction can force noSSMI to approach MERRA. If successful, we can apply this correction to the period before SSM/I was introduced.
IV. Methodology

- Challenges: interrelationship between the variables influenced by SSM/I

![Zonal mean diff in JJA](image)

**Fig 4.** Specific humidity and temperature zonal mean difference with or without SSM/I observation (Chen. et al, 2012).

- Fig 4 shows the zonal mean differences in JJA between MERRA and the noSSMI experiment.
- Similar sign for moisture and its increment but different sigh for T and its increment.
IV. Methodology

- **Experiment scenarios.** Since moisture has dominant effect, we will begin with specific humidity correction.

<table>
<thead>
<tr>
<th>Experiment name</th>
<th>Correction applied</th>
</tr>
</thead>
<tbody>
<tr>
<td>add_Q</td>
<td>Specific humidity</td>
</tr>
<tr>
<td>add_2Q</td>
<td>2*Specific humidity</td>
</tr>
<tr>
<td>add_Q&amp;T</td>
<td>Specific humidity and temperature</td>
</tr>
<tr>
<td>add_2Q&amp;2T</td>
<td>2<em>Specific humidity and 2</em>temperature</td>
</tr>
<tr>
<td>add_U&amp;V&amp;T&amp;Q</td>
<td>Specific humidity, temperature, U wind, and V wind</td>
</tr>
</tbody>
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Fig 5. Specific humidity (Q) correction and its Fourier transform truncations.

- The limited Fourier series truncation that we used to reduce sampling errors was sufficient to represent well the observed mean AI difference between MERRA and noSSMI.
- This was also true for the other variables of the analysis, namely T, U, and V (not shown).
• 1987 July – November Total Precipitable Water (TQV)

Fig 6. Daily TQV global mean, July – Nov 1987. Q correction only

- add_Q&T, add_U&V&T&Q results are close to add_Q (not shown)
- add_2Q&2T is close to add_2Q (not shown)
Fig 7. Daily Total Precipitable Water bias, 1987 Sep-Nov mean

- MERRA - noSSMI
- Add_Q - noSSMI
- Add_2Q - noSSMI
• 1987 July – November Total Precipitation

Fig 8. Daily precipitation global mean, July – November 1987
Q correction only
Fig 9. Daily precipitation bias, 1987 Sep-Nov mean
1987 September – November, Specific Humidity

- MERRA – noSSMI
- add_Q – noSSMI
- add_2Q - noSSMI

Fig 10. Qv, 1987 Sep-Nov mean.
• 1987 September – November, Temperature

Fig 11. Temperature, 1987 Sep-Nov mean.
• 1987 September – November, Zonal Wind

Fig 12. U wind, 1987 Sep-Nov mean.
1987 September – November, Meridional Wind

MERRA – noSSMI

add_Q – noSSMI

add_2Q - noSSMI

Fig 13. V wind, 1987 Sep-Nov mean.
So far, the main result we have obtained is that correcting the noSSMI reanalysis with the difference between the MERRA and noSSMI analysis increments is only partially successful because it is too weak.

In fact, doubling the Q correction gives results that are much closer to the original MERRA.

We pose the hypothesis that this is because the difference between the analysis increments is not just due to the assimilation of SSMI, but to the accumulation of these increments from the past, which evolve with nonlinear interactions between different variables during the training period.
Alternatively, the proper correction should be obtained by comparing AIs between 1) MERRA (exp_MERRA), and 2) an analysis started from MERRA every 6 hours but withholding the SSM/I observation (exp_MnoSSMI).

We hypothesize that the 6-hr AI difference caused by withholding SSM/I doesn’t contain accumulated error from the past, and there is no nonlinear interactions between different variables within SSM/I.

![Schematic on 6-hourly correction definition in MERRA system](image)

\[
\text{correction} = \frac{\text{AI difference}}{\text{exp}_\text{MERRA}} = \left(\frac{\text{AI}_{\text{MERRA}}}{\text{exp}_\text{MERRA}} - \frac{\text{AI}_{\text{MnoSSMI}}}{\text{exp}_\text{MERRA}}\right)
\]

Fig 14. Schematic on 6-hourly correction definition in MERRA system
However, restarting every 6hr is operationally unfeasible for MERRA. We will test the technique with the SPEEDY-LETKF, using the system developed by Dr. Kang.

- The corrections in U, V, T, Q, and Ps states are added to exp_R model tendency equation.
Fig 16. SPEEDY-LETKF SpHu 1982Apr mean
Fig 17. SPEEDY-LETKF Temperature  1982Apr mean
Fig 18. SPEEDY-LETKF SpHu 1982Nov mean
Fig 19. SPEEDY-LETKF Temperature 1982Nov mean
The present research studies the discontinuity in the time evolution of MERRA associated with observing system, SSM/I, change. The overall purpose is to find a solution to minimize such discontinuities.

MERRA utilizes the NASA GEOS5-DAS, which is incorporated with Incremental Analysis Update (IAU) procedure. IAU distributes AIs evenly over assimilation cycle as an additional forcing term in model’s tendency equation. So, making correction in IAU process is the same as changing model tendency.
This method is only partially successful because it is too weak. One explanation is that, this method doesn’t take nonlinear interactions between different variables of SSM/I into account. The nonlinear interaction impacts would accumulate during the whole training period and introduce errors not just due to assimilation of SSM/I.

Considering computational feasibility, we will use SPEEDY-LETKF system, developed by Dr. Kang, to test our hypothesis that, the proper correction should be obtained by comparing AIs between one analysis, and another experiment restarting from this analysis while withholding certain observation systems every 6 hour.
VI. Conclusions (cont.)

![Graph showing time steps and analysis increments](image)

**Correction** = $A_{MERRA} - A_{noSSMI}$

**Time steps during training period, typically 6 hour window**

$t-1$  
$t$  
$t+1$  

$exp_{MERRA}$

$Exp_{MnoSSMI}$, starting from MERRA but withholding SSMI

$correction = \frac{AI_{difference}}{} = A_{MERRA} - A_{MnoSSMI}$
The ICTP AGCM (nicknamed **SPEEDY**, for "Simplified Parameterizations, privitivE-Equation DYnamics") is based on a spectral dynamical core developed at the Geophysical Fluid Dynamics Laboratory. It is a hydrostatic, $\sigma$-coordinate, spectral-transform model in the vorticity-divergence form, with semi-implicit treatment of gravity waves.