Assessing the Impact of Observations in a multi-year Reanalysis (MERRA-2)

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Extracted from Diniz & Todling (2019), QJRMS, *sub-judice.*

Approach

Impact of Observations

The question is: Impact on What?

<u>On assimilation cycle:</u>

Evaluation of observation residual statistics (Mean and RMS of O-B and O-A)

but variety of units gets in the way of getting an overall assessment. Alternatively:

*Degrees of Freedom for Signal (DFS) - Tr(**HK**)*

essentially provides an assessment of the consistency of the prescribed statistics wrt the actual.

<u>On forecast quality:</u>

Evaluates observations contribution to reducing forecast errors.

Approach: Forecast Sensitivities-based Observation Impact (FSOI), with caveats:

- Reliance on a norm (forecast error metric);
- Reliance on (tangent) linear validity;
- Dependence on reliability of adjoint of both forward model and analysis component.

# Forecast Sensitivity-based Observation Impact (FSOI)
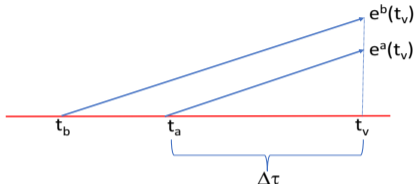
Forecast error:

$$e^s(t_v|t_0) = < [\mathbf{x}^f(t_v|t_0) - \mathbf{x}^v(t_v)]^T \, \mathbf{T} \, [\mathbf{x}^f(t_v|t_0) - \mathbf{x}^v(t_v)] >$$

where $\mathbf{T}$ is defined by the coefficients of a linear total (moist) energy operator whose vertical weights asymptote to zero above 10 hPa.

- MERRA-2 follows typical DA cycling in top row of schematic to the right.
- FSOI for MERRA-2 follows bottom row of schematic to the right.
- FSOI approach used in this works is Trémolet (2008) extension of Langland & Baker (2004).
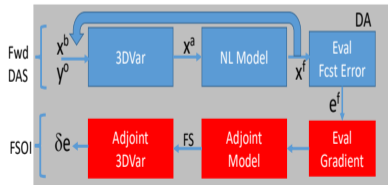
MERRA-2

Components the MERRA-2 Atmospheric System

Atmospheric GCM

- Fully ESMF-compliant
- Resolution: 50 km, 72 hybrid pressure levels
- Hydrostatic cubed-sphere dynamical core
- RAS-Bacmeister convective physics
- Chou-Suarez radiation scheme
- Koster et al. catchment land-surface model
- Lock et al. turbulence physics
- Interactive ozone
- Interactive GOCART aerosols
- Prescribed SST & Sea Ice:

1 Jan 1980- 1 Dec 1981	CMIP midmonth (1°)
1 Jan 1982- 31 Dec 2002	NOAA OISST daily (1/4°; AVHRR)
1 Jan 2003- 31 Mar 2006	NOAA OISST daily (1/4°; AVHRR, AMSR-E)
1 Apr 2006- present	OSTIA daily (1/20°)

- MERRA-Land precipitation correction (low-mid lats)

Meteorological Analysis: GSI

- 3DVAR FGAT
- TLNMC balance
- JCSDA CRTM (clear sky radiances)
- BiCG minimization (2 middle loops)
- Dry-mass conservation constraint

Aerosol Analysis: PSAS
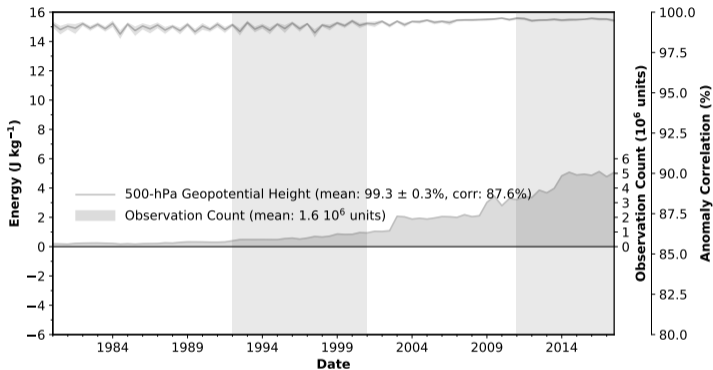
- 3DVAR applied to AOD

Assimilation Strategies

- 6-hour cycling
- Meteorology: 3D-IAU with Dry-Mass Constraint
- Aerosols: Local Displacement Ensemble Update

Note: Forecasts are not a product of MERRA-2

Forecast Error Reductions due to Assimilation

Typical Skill Evaluation: Day-1 H500 AC

Single variable, single level anomaly correlation seems to corroborate that over time, the increased volume and coverage of observations leads to improved forecast quality (self-evaluation).
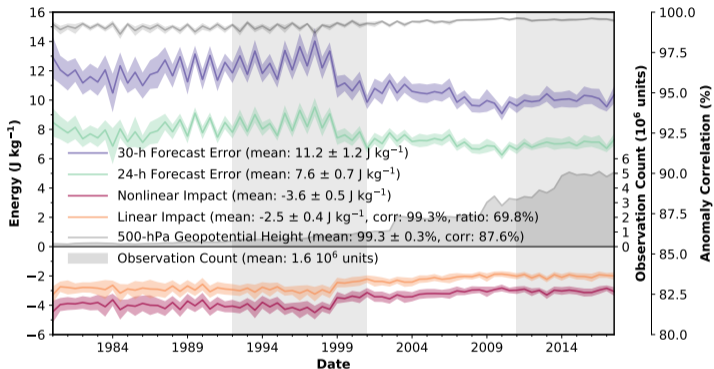
More encompassing (tropospheric) metric
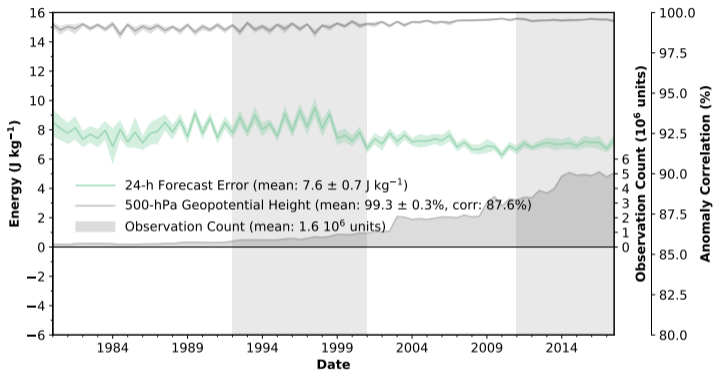
A more encompassing metric suggests 24-hr forecast errors to evolve less smoothly than suggested by traditional evaluation.

More encompassing (tropospheric) metric
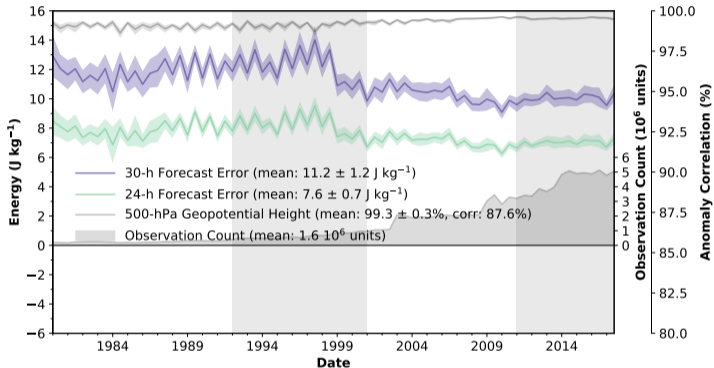
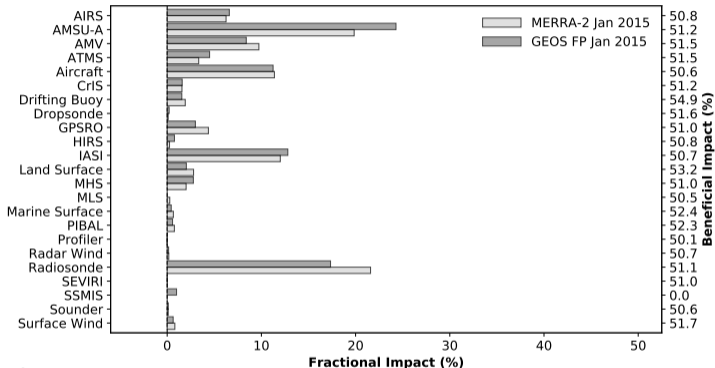*This becomes more evident at 30 hours into the forecast.*

Impact of assimilating observations: NL error reduction & FSOI

Nonlinear (NL) error reduction serves as proxy for adjoint-derived FSOI, the latter having the advantage of being breakable into different subcomponents of the observing system.

FSOI for MERRA-2

FSOI: MERRA-2 vs GMAO Near-Real-Time (FP) System

In the particular January of 2015:

- Overall impacts from MERRA-2 do not differ substantially from those of GMAO near-real-time (FP) system.
- The dominant observing systems in the FSOI sense are Radiosondes and AMSU-A.
- In this particular January, GMAO FP relies more on AMSU-A followed by Radiosondes; MERRA-2 is the reverse.
- In MERRA-2, slightly more than 50% of each observation class contributes positively to reduce 24 hour forecast errors.

MERRA-2 FSOI: Assessment by Data Type
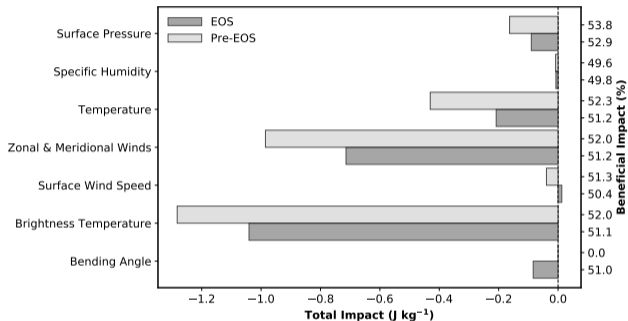
Evaluation is split into pre-EOS and EOS eras:

- As seen from time-series of total FSOI, observations have larger impact on forecasts in the pre-EOS era.

- Brightness Temperature observations have the largest impact in both eras, followed by Wind and Temperature observations.

- In the modern era, the impact of GPSRO is comparable to that of all surface pressure observations combined.

# MERRA-2 FSOI: Radiance Assessment by Platform
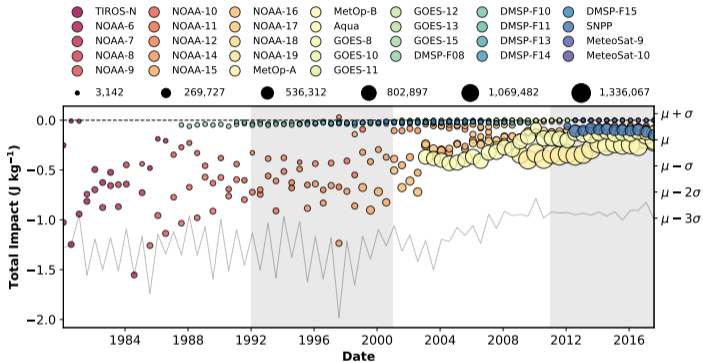
Total Impact of Radiance-providing Platforms (bubbles), with total impact of all radiance (grey curve), revealing that:
→ Considerable seasonal dependence is noticed on impact, though it is largely reduced in recent years.
→ From 1980 to about 2002 the NOAA platforms dominate the impacts;
→ From 2002 to about 2008 the Aqua platform takes over as providing largest impacts;
→ From 2008 onwards the MetOp platforms dominate.

Note: size of bubbles proportional to monthly average observation count.

# MERRA-2 FSOI: Radiance Assessment by Instrument Type
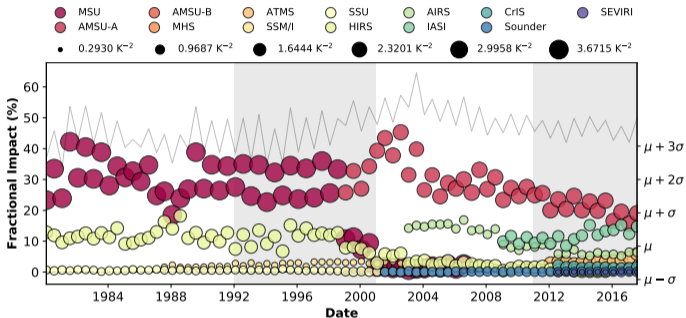
Fractional Impact of Radiance instruments (bubbles) and fractional impact of all radiance (grey curve) reveals that:

→ Between 40% to as much as 60% of all radiance observations contribute to reduce errors in the 24-hr forecasts.

→ A rise in fractional impact is observed from the mid-90's to the early 2000's.

→ MW observations dominate fractional FSOI (as they do the radiance impact itself).

→ AMSU-A shows the largest fractional contribution to FSOI in its initial years.

→ As other advanced instruments are introduced, such as hyperspectral IR, the fractional impact of AMSU-A diminishes.

→ Fractional radiance FSOI is seen to steadily decrease from early 2000's to the present.

Note: size of bubbles proportional to estimate of overall weight given by analysis.

MERRA-2 FSOI: Who moved my cheese?

Which observing system is taking away the fractional impact of radiance?
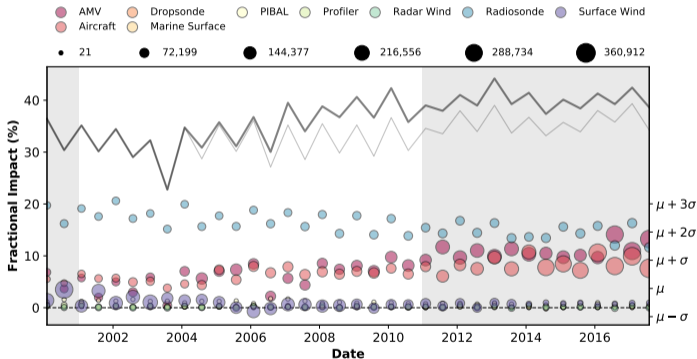
Fractional Impact of all source of Wind observations:
→ Rise in assimilation of AMV's and Aircraft observations is seen to be taking it away from radiances.
→ Contribution from GPSRO ranges from the 5% when introduced to about 10% at the peak of COSMIC.

Note: Grey curve is for total fractional impact of Wind observations; heavy black curve adds GPSRO to that.

Closing Remarks

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The impact of observations on short-range forecasts from MERRA-2 reveals:

- Relatively abrupt reduction of impact from the end of the 1990's to the modern era.
- Reduction directly associated with abrupt forecast error reduction across same period.
- From the early 2000's onwards the fractional impact of satellite radiances is taken away by increased AMV, Aircraft and GPSRO observations.
- In the modern era, the impact of GPSRO is comparable to that of all surface observations.
- In MERRA-2, the impact from Heritage IR instruments is found to be comparable to impact from Hyperspectral instruments (not shown; could do better using latter).

Further ongoing investigation:

- DFS evaluation for MERRA-2
- Comparison with ERA5-verified forecasts.

MERRA-2 FSOI: Radiance Assessment by Instrument Type
Backup Slide
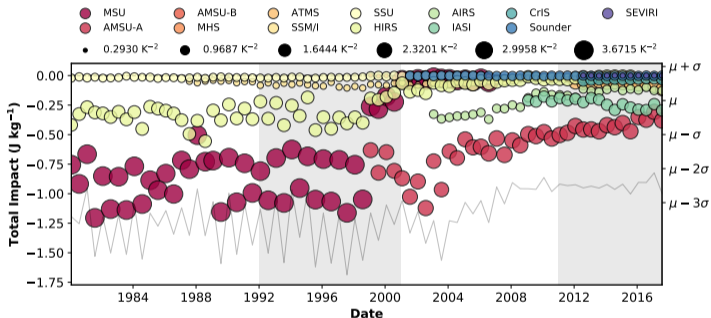
Impact of Radiance instruments (bubbles), with impact of all radiance (grey curve), reveals that:

→ MW dominates the impact from radiance observations.

→ IR instruments follow as next largest contributors.

→ Impact from Heritage IR instruments is comparable to impact from hyperspectral ones, suggesting more could be done to extra better information from the latter (e.g., correlated channels).

Note: size of bubbles proportional to estimate of overall weight given by analysis.