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

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# Outline

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

# Approach

# Impact of Observations

The question is: Impact on What?

On assimilation cycle:

*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.

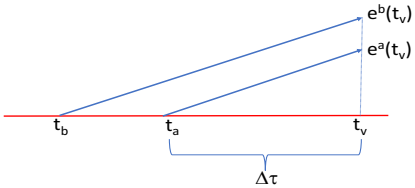
On forecast quality:

*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)

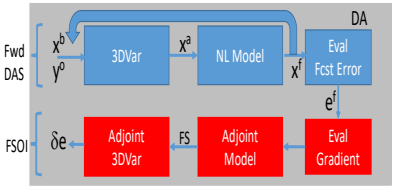



- MERRA-2 follows typical DA cycling in top row of schematic to the right.
- FSOI for MERRA-2 follows bottom row of schematic to the right.
- FSOI approach used in this works is Trémolet (2008) extension of Langland & Baker (2004).

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 **T** is defined by the coefficients of a linear total (moist) energy operator whose vertical weights asymptote to zero above 10 hPa.



# 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 ($1^o$) |
| 1 Jan 1982- 31 Dec 2002 | NOAA OISST daily ($1/4^o$; AVHRR) |
| 1 Jan 2003- 31 Mar 2006 | NOAA OISST daily ($1/4^o$; AVHRR, AMSR-E) |
| 1 Apr 2006- present | OSTIA daily ($1/20^o$) |

- 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

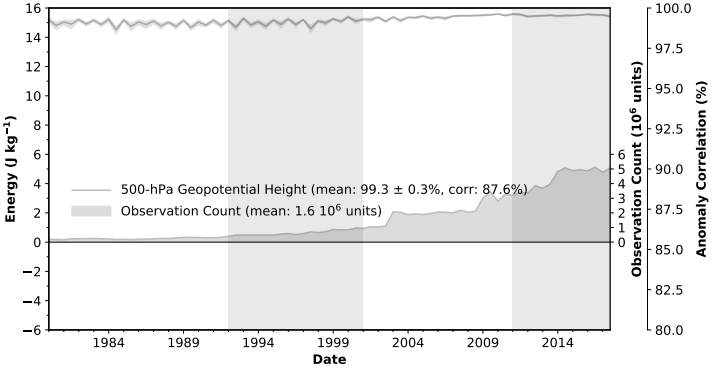
## Assimilation Strategies

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

Note: Forecasts are not a product of MERRA-2

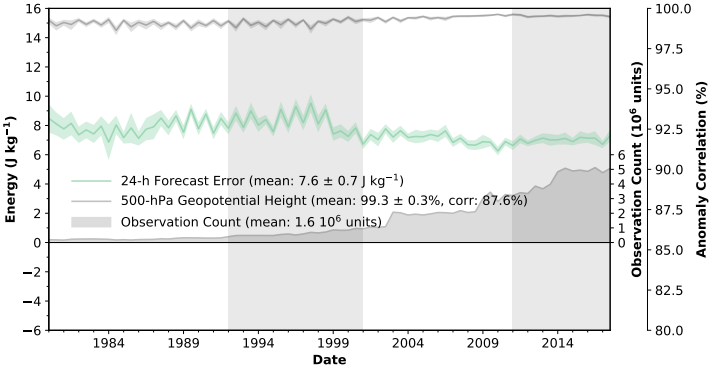
# Forecast Error Reductions due to Assimilation

# Typical Skill Evaluation: Day-1 H500 AC



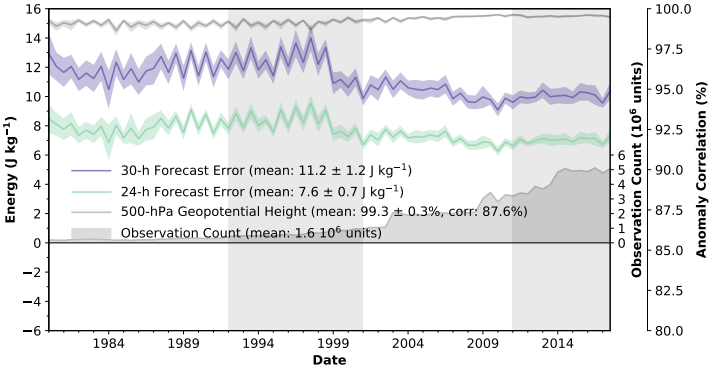

*Single variable, single level anomaly correlation seems to corroborate that over time, the increased volume and coverage of observations leads to improved forecast quality (self-evaluation).*

# More encompassing (tropospheric) metric



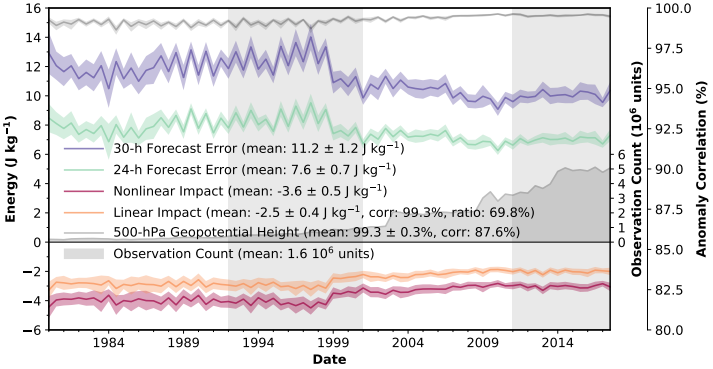

*A more encompassing metric suggests 24-hr forecast errors to evolve less smoothly than suggested by traditional evaluation.*

# More encompassing (tropospheric) metric




*This becomes more evident at 30 hours into the forecast.*

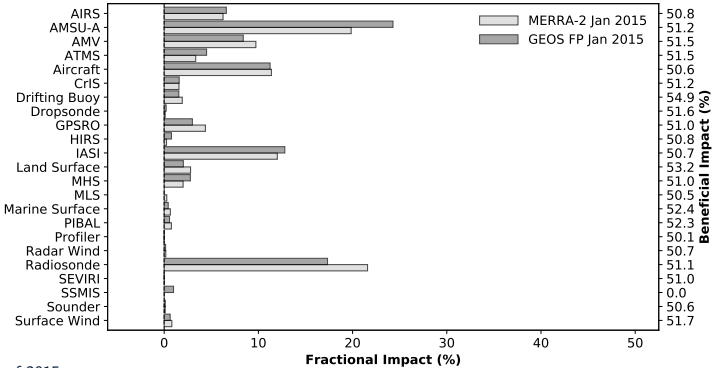
# Impact of assimilating observations: NL error reduction & FSOI




*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

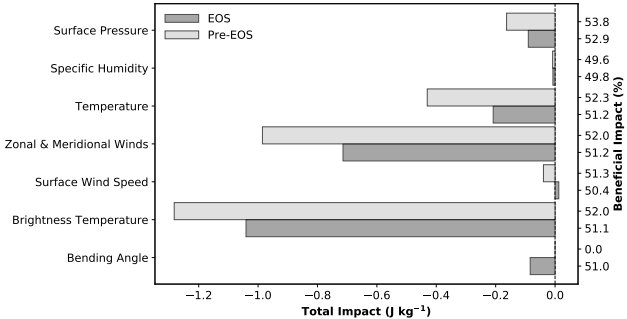
# FSOI: MERRA-2 vs GMAO Near-Real-Time (FP) System




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.

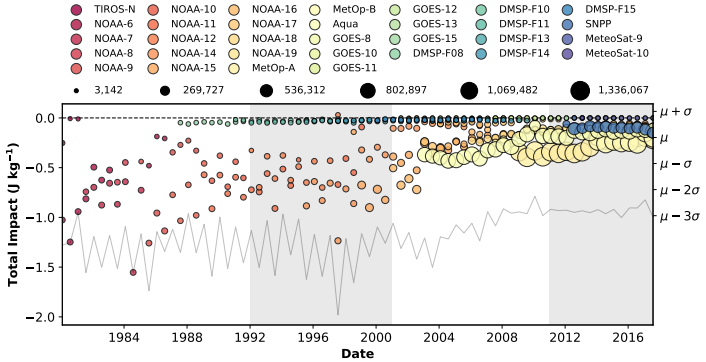
# MERRA-2 FSOI: Assessment by Data Type




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.

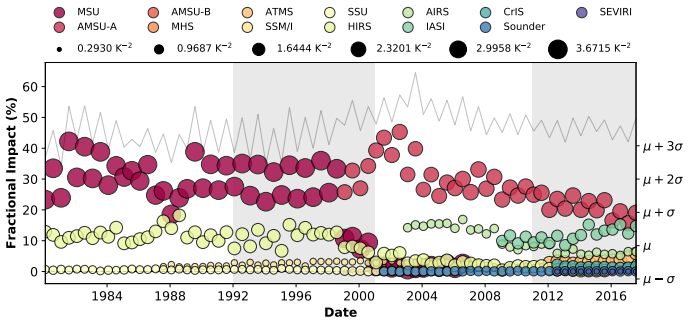
→ From 1980 to about 2002 the NOAA platforms dominate the impacts;

→ 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.

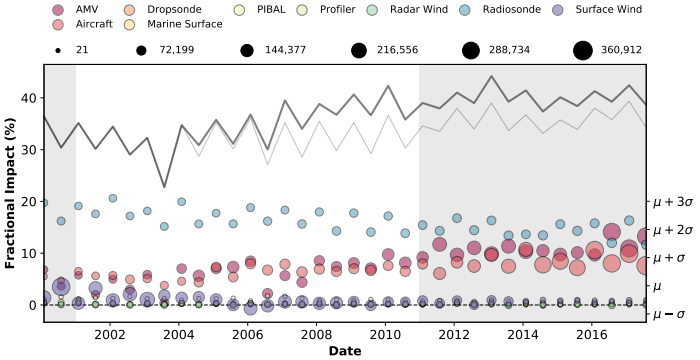
→ As other advanced instruments are introduced, such as hyperspectral IR, the fractional impact of AMSU-A diminishes.

→ 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:

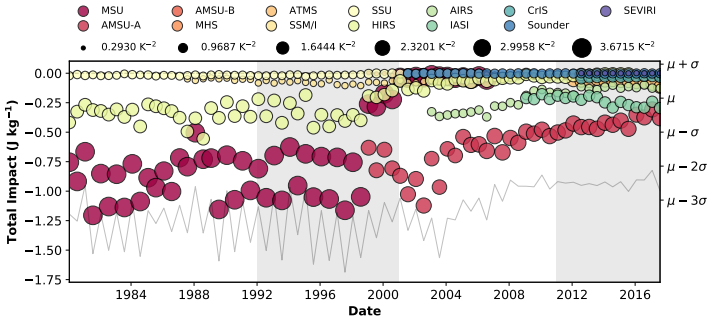
- Relatively abrupt reduction of impact from the end of the 1990's to the modern era.
- Reduction directly associated with abrupt forecast error reduction across same period.
- From the early 2000's onwards the fractional impact of satellite radiances is taken away by increased AMV, Aircraft and GPSRO 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.