



GEOS Constituent Data Assimilation Beyond Aura MLS: Assimilating NASA SAGE III/ISS Profiles of Stratospheric Water Vapor

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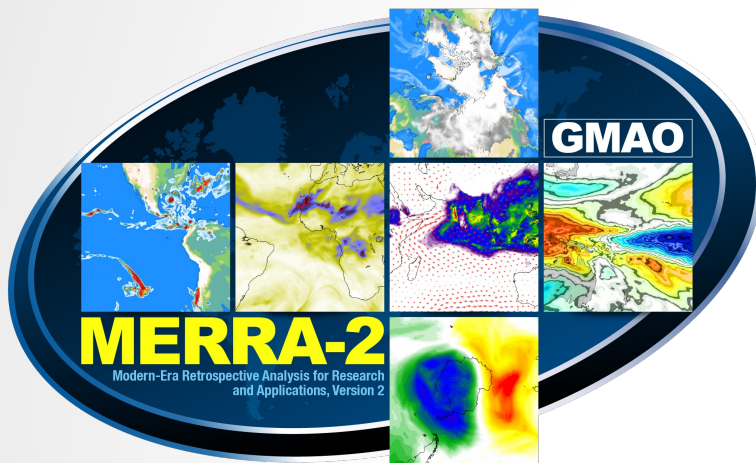
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³Science Systems Association, Inc (SSAI)

NASA's GMAO Reanalyses

MERRA-2

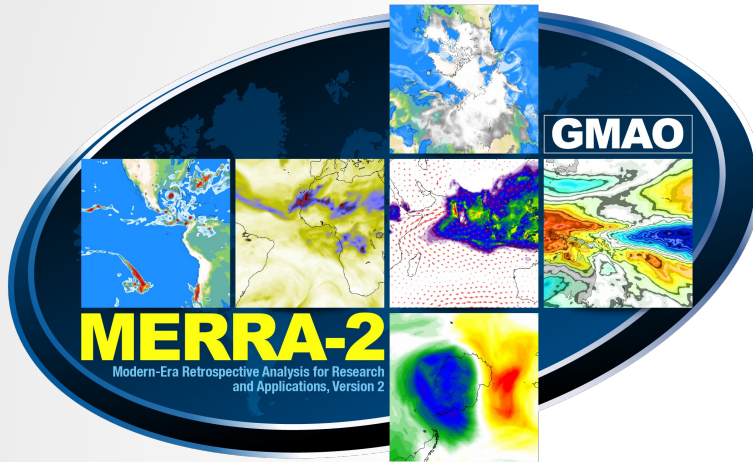


Gelaro et al., J. Climate (2017)
DOI: [10.1175/JCLI-D-16-0758.1](https://doi.org/10.1175/JCLI-D-16-0758.1)

- High resolution global data set
 - 50 km horizontal
 - 0.5° lat x 0.625° long
 - 72 levels up to 0.01 hPa
- Available since 1980
- GEOS data assimilation system

NASA's GMAO Reanalyses

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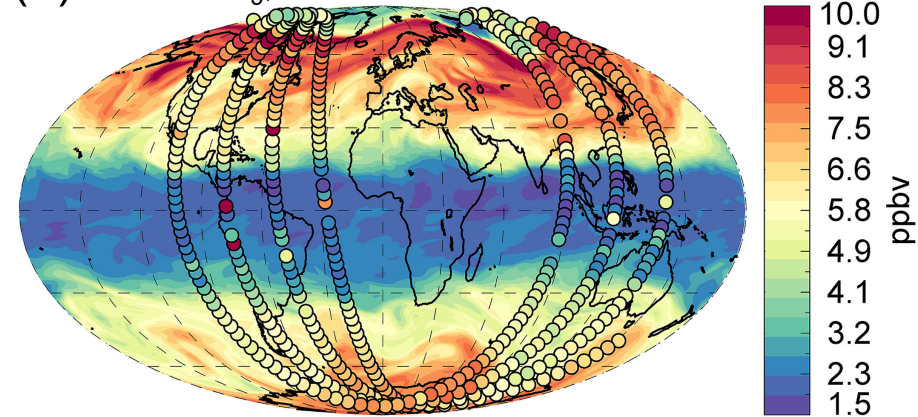


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M2-SCREAM

(b) HNO₃, 2011-03-18 : 18 UTC



Wargan et al., ESS (2023).
DOI: [10.1029/2022EA002632](https://doi.org/10.1029/2022EA002632)

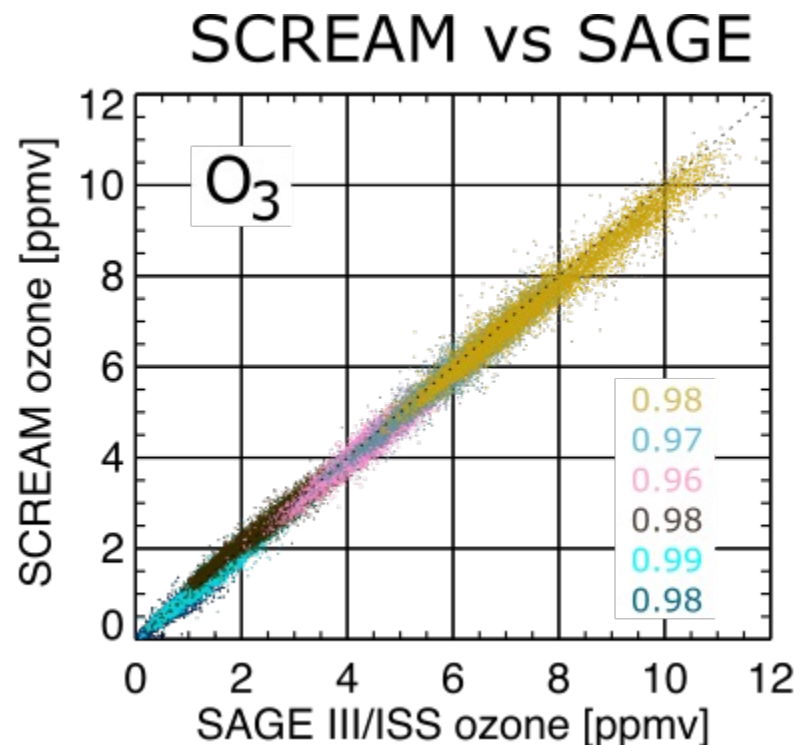
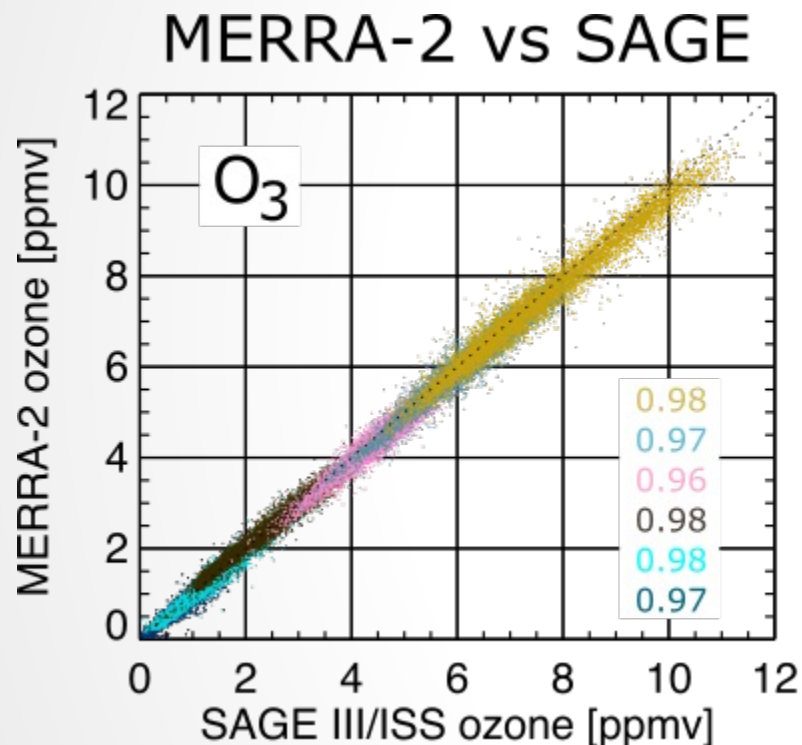
- ❑ Assimilating **MLS v4.2 ozone**, **H₂O**, **HCl**, **HNO₃**, & **N₂O** and **OMI total ozone** using CoDAS
- ❑ Constrained by assimilated meteorology from MERRA-2
- ❑ GEOS coupled to “StratChem” stratospheric-only chemistry mechanism
- ❑ Period: September 2004 – Present

Constituent Data Assimilation System “CoDAS”

- Designed to be tracer agnostic: can assimilate any type of retrieved constituent observations with an averaging kernel or at a point

Motivation

It is essential for trend and climate analysis to have consistent well-constrained data products such as reanalyses



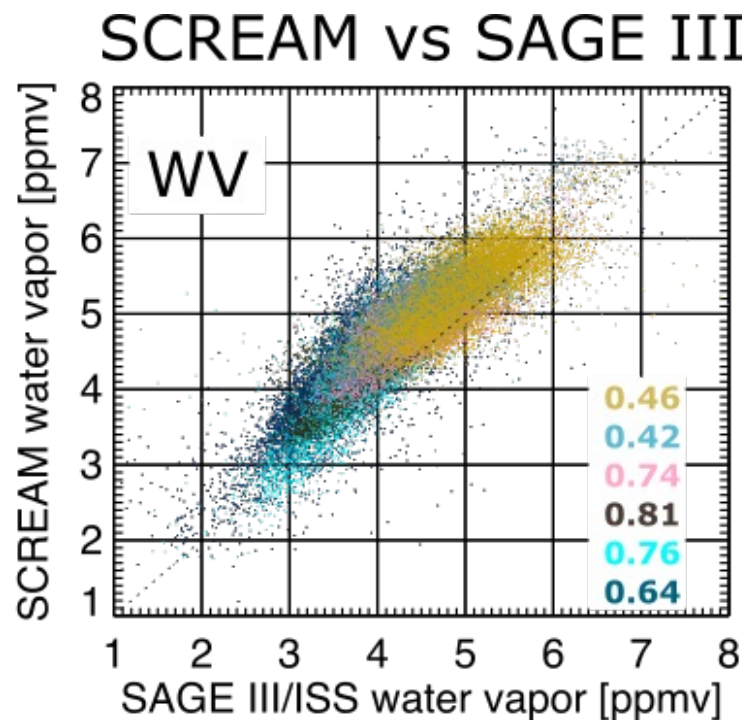
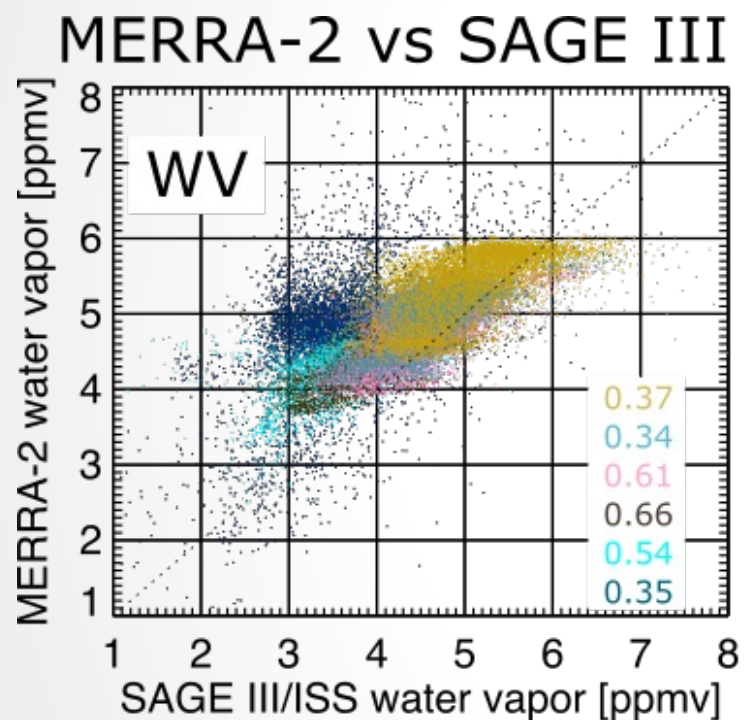
10 hPa
20 hPa
30 hPa
50 hPa
70 hPa
100 hPa

Correlation
coefficients
per level in
each inset

1. Despite differences in the complexity of stratospheric ozone chemistry, the analyzed ozone in both reanalyses have near perfect correlation with co-located 2018 SAGE III/ISS ozone.

Motivation

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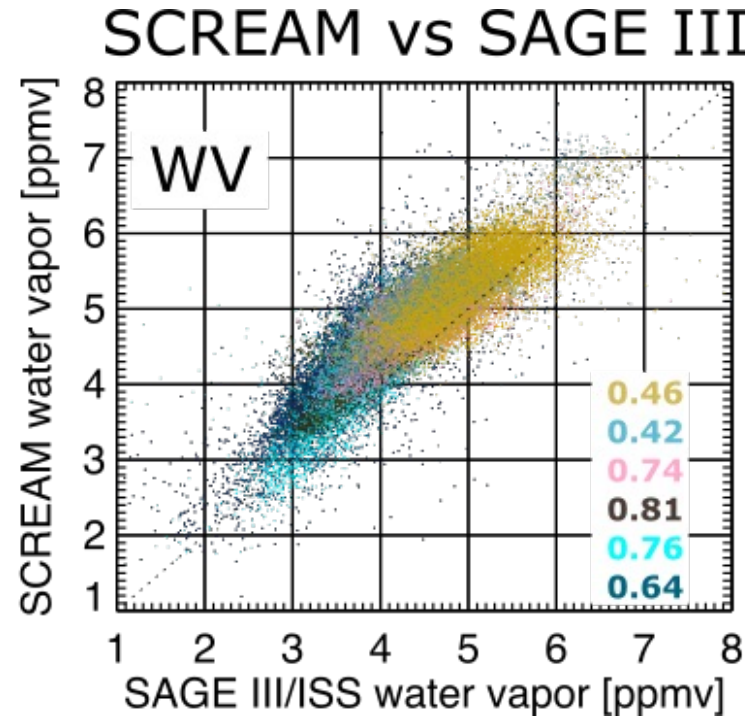
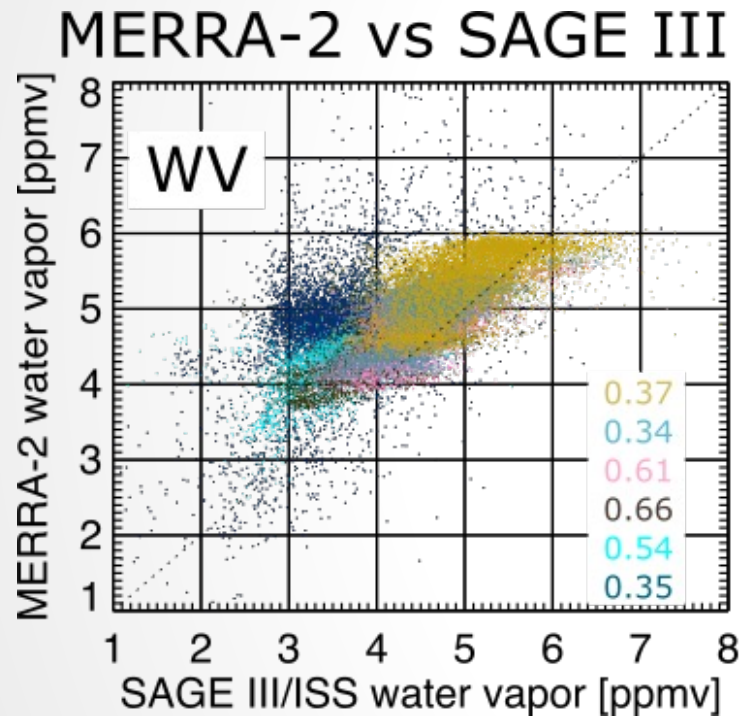
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Correlation coefficients per level in each inset

2. Reanalysis stratospheric water vapor (“WV”) historically poor without an observational constraint (see Davis et al., 2017)

Motivation

It is essential for trend and climate analysis to have consistent well-constrained data products such as reanalyses



Will the assimilation of SAGE III/ISS profiles of water vapor lead to high quality stratospheric [re]analysis products?

2. Reanalysis stratospheric water vapor (“WV”) historically poor without an observational constraint (see Davis et al., 2017)

GEOS CoDAS Experiments

Same set up as M2-SCREAM

- ❑ Constrained by assimilated meteorology from MERRA-2
- ❑ GEOS “StratChem” stratospheric-only chemistry
- ❑ Period: Initialized July 1, 2017

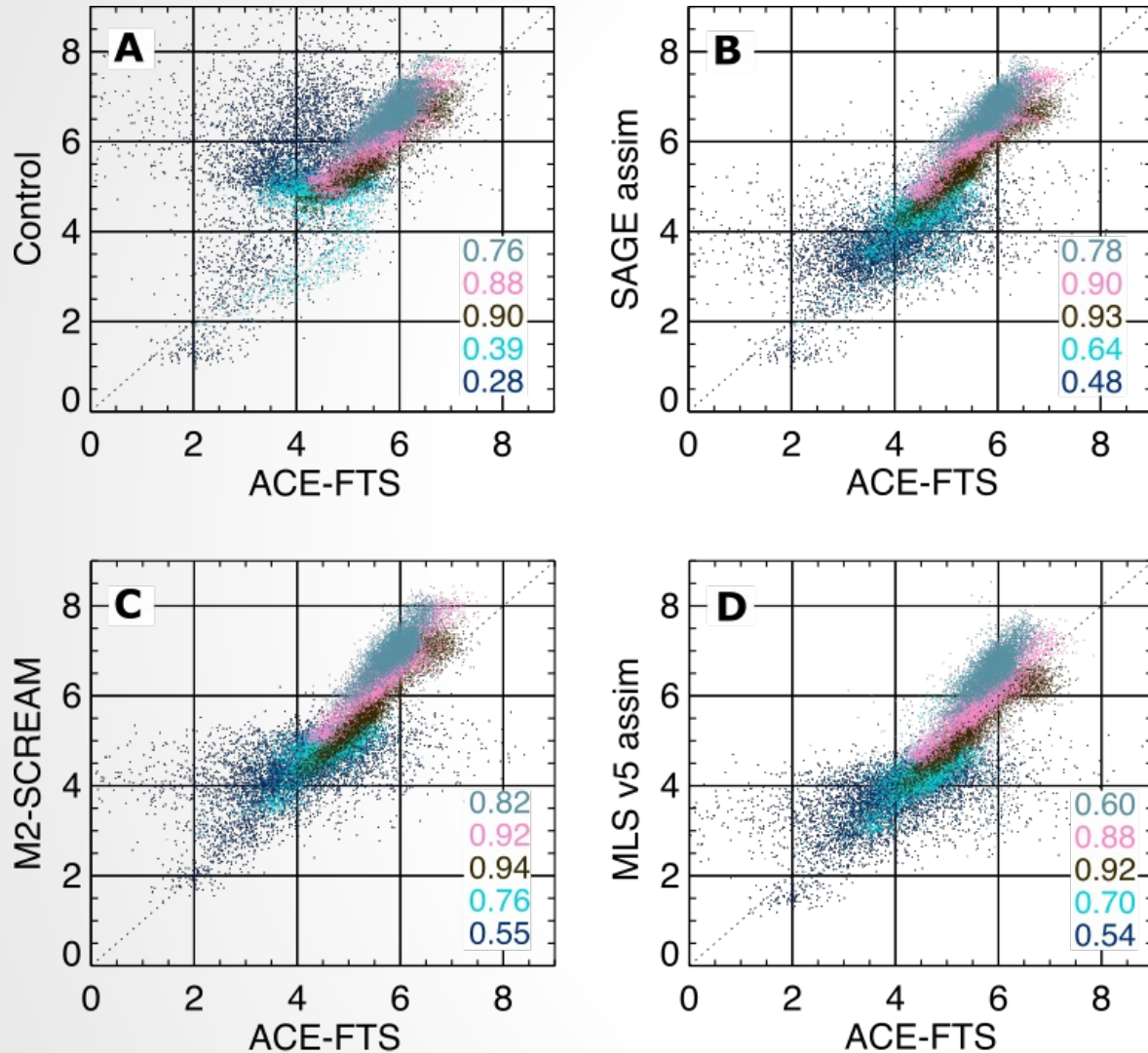
Experiments running:

1. **Control: Chemistry only (no CoDAS)**
2. **SAGE-only post-Aura: SAGE water vapor**
3. **Aura: MLS v5 profiles and OMI total column ozone (same as M2-SCREAM but with v5 MLS)**



<https://www.nccs.nasa.gov/systems>

Validation of SAGE assim compared to ACE-FTS and MLS



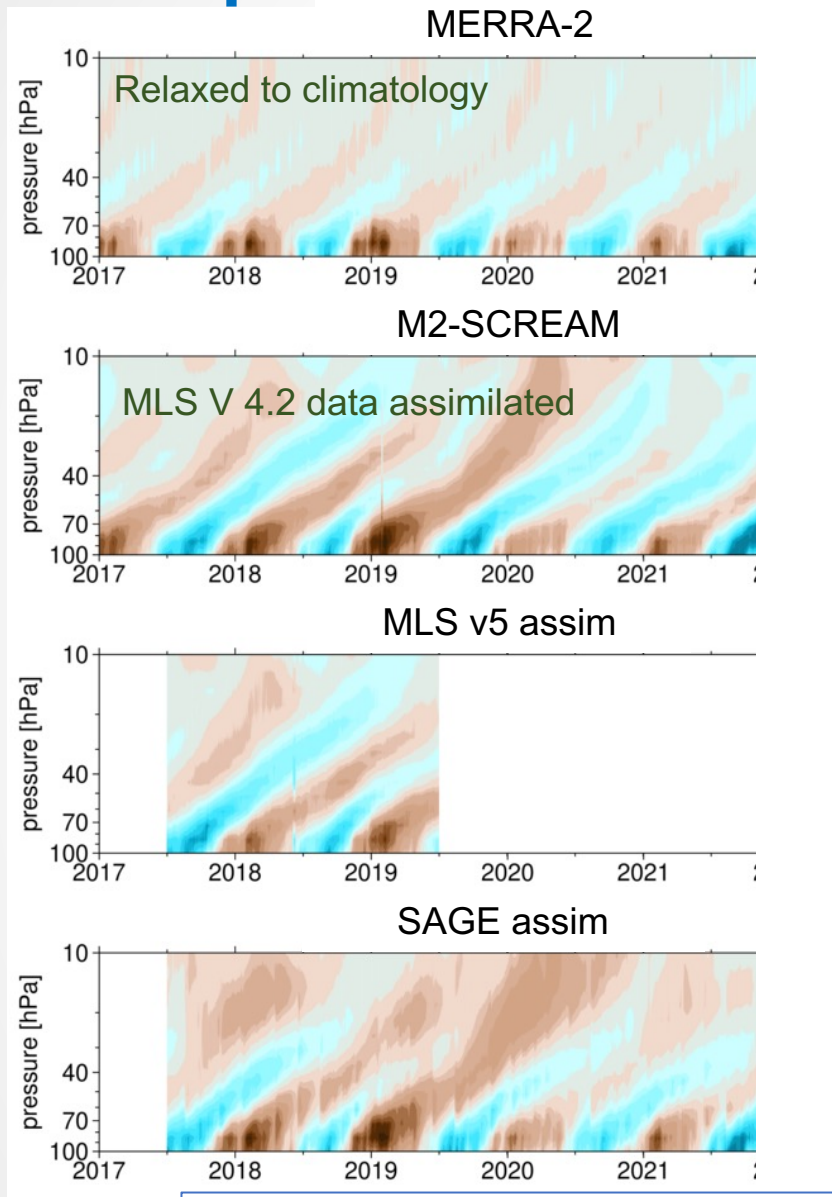
1500 K 1000 K 800 K 500 K 400 K

Comparison of 2018 ACE-FTS water vapor profiles

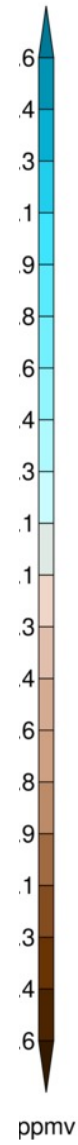
- Data constraints improves on the agreement with ACE-FTS, especially in lower stratosphere (400 to 500 K)
- SAGE assimilation (**B**) general agreement to co-located ACE-FTS measurements (400 to 1500 K)
- SAGE assimilation (**B**) falls somewhere between M2-SCREAM (**C**) and MLS v5 assim (**D**)

(Knowland et al., in prep)

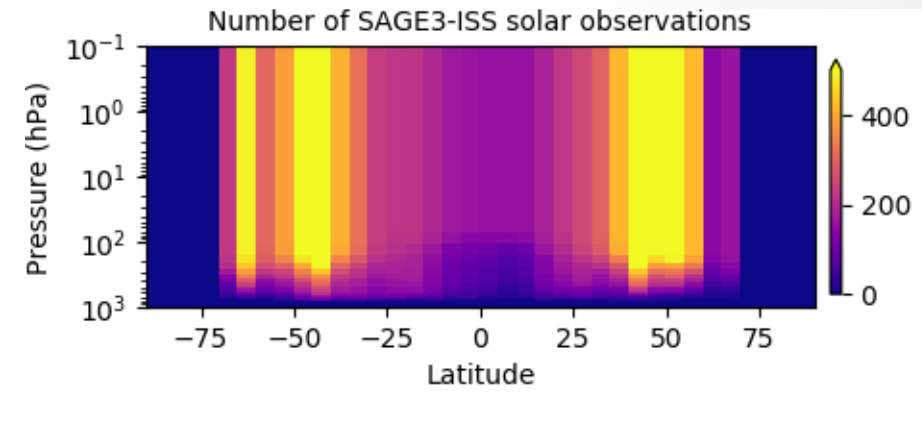
Tropical Tape Recorder: SAGE III/ISS CoDAS



15°S-15°N average water vapor anomalies

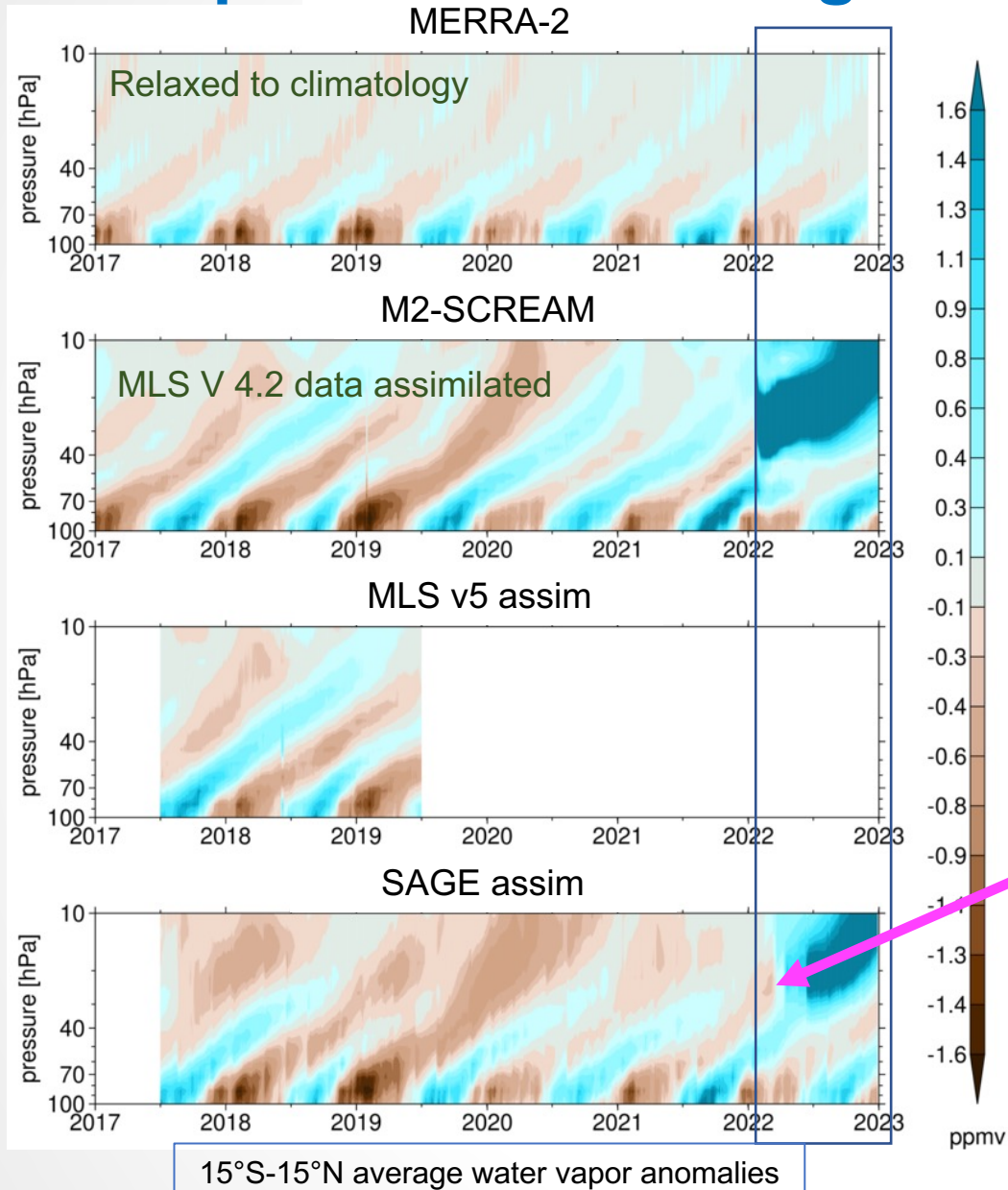


- ✓ SAGE assim similar Tropical Tape Recorder patterns seen for the MLS assimilations.
- SAGE assim is not as smooth as M2-SCREAM and MLS v5 assim likely due to the frequency of tropical observations assimilated



(Knowland et al., in prep)

Tropical Tape Recorder: Honga Tunga Eruption



✓ SAGE assim similar Tropical Tape Recorder patterns seen for the MLS assimilations.

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How well can SAGE assim capture the Honga Tunga Eruption?

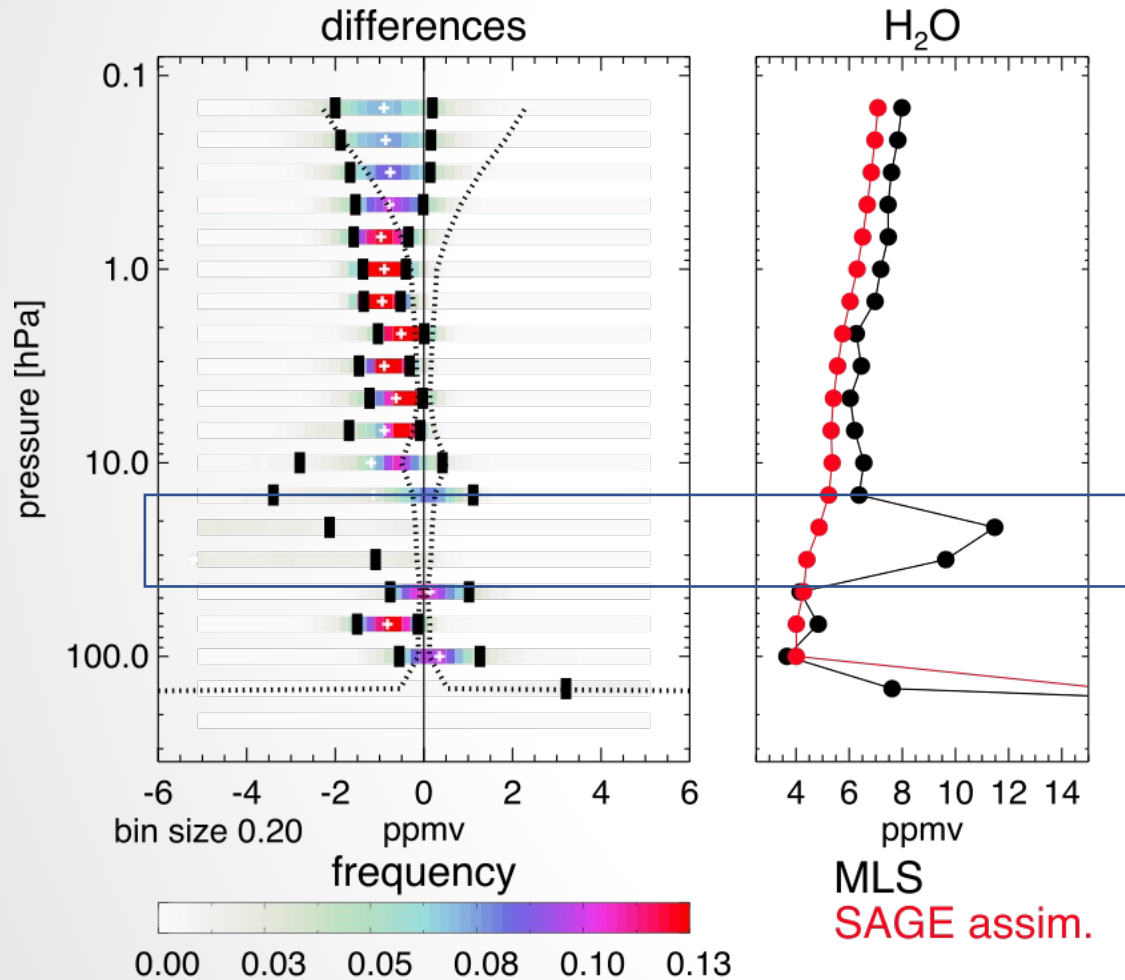
➤ Takes a few months but the signal is picked up. *But why the delay?*

(Knowland et al., in prep)

Monthly Statistics comparing SAGE assimilation to MLS v4.2 for March 2022



March 2022

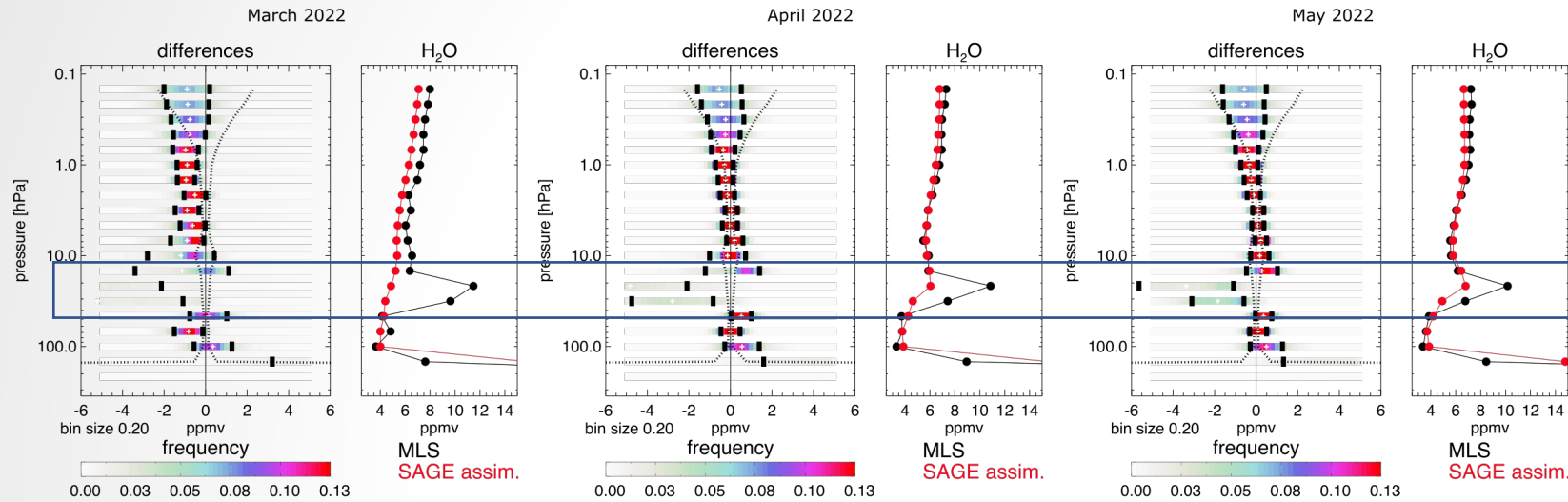


MLS observations compared to **SAGE assimilation** sampled at MLS pressure levels.

- SAGE assimilation water vapor is generally lower compared to MLS v4.2
- Mean zonal average water vapor in MLS has water vapor peak at 20 hPa of about 11.5 ppmv
- SAGE assimilation in March 2022 misses this feature.

(Knowland et al., in prep)

Monthly Statistics comparing observations and SAGE assimilation for March – May 2022



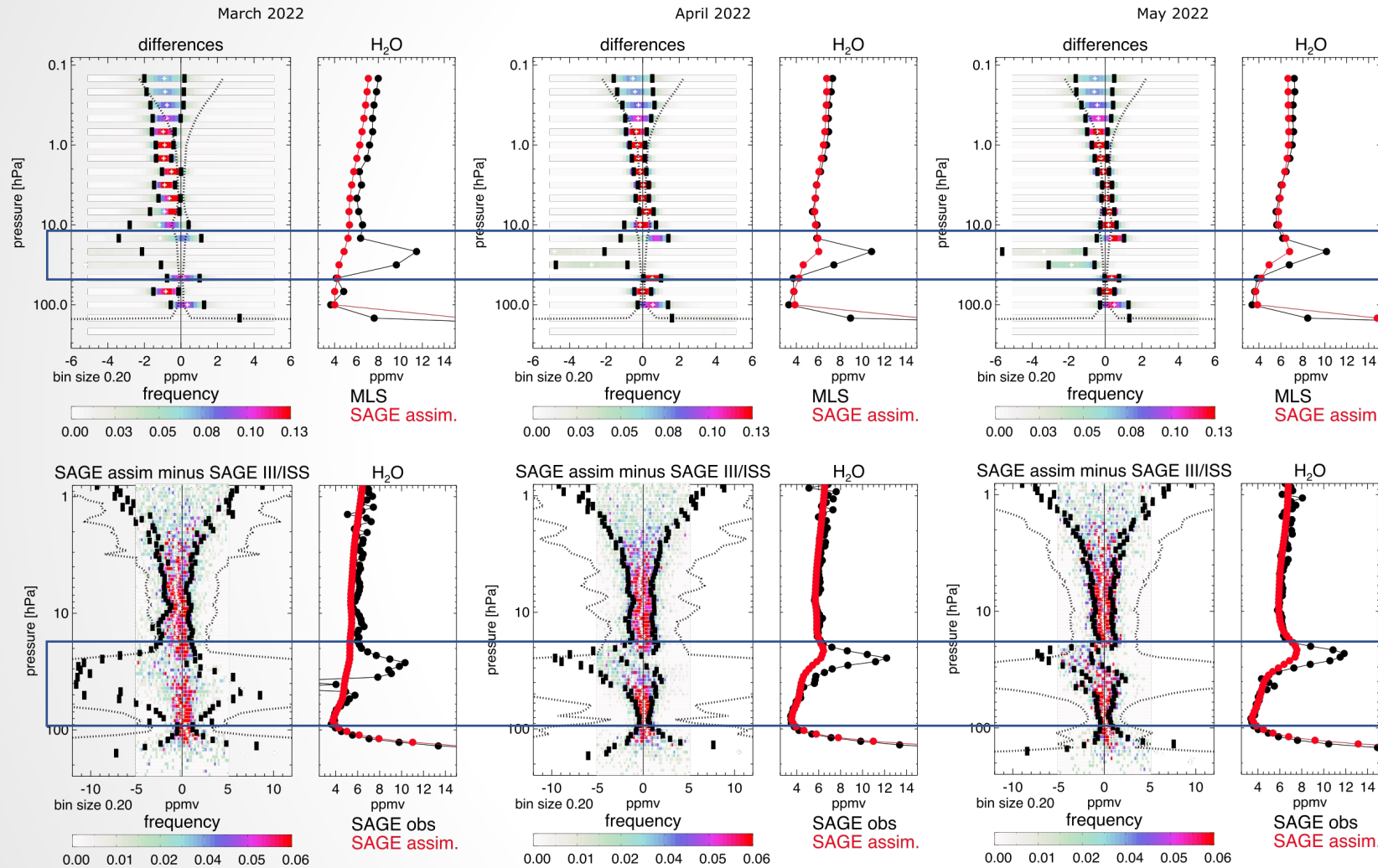
MLS observations compared to **SAGE assimilation** sampled at MLS pressure levels.

- Large differences (assim minus obs) between 20-40 hPa.

Over the three months, the enhanced water vapor plume in **SAGE assim** is increasing (7 ppm in May), while the MLS peak decreases from about 12 to 10.5 ppm

(Knowland et al., in prep)

Monthly Statistics comparing observations and SAGE assimilation for March – May 2022



SAGE observations compared to SAGE assim on SAGE pressure levels.

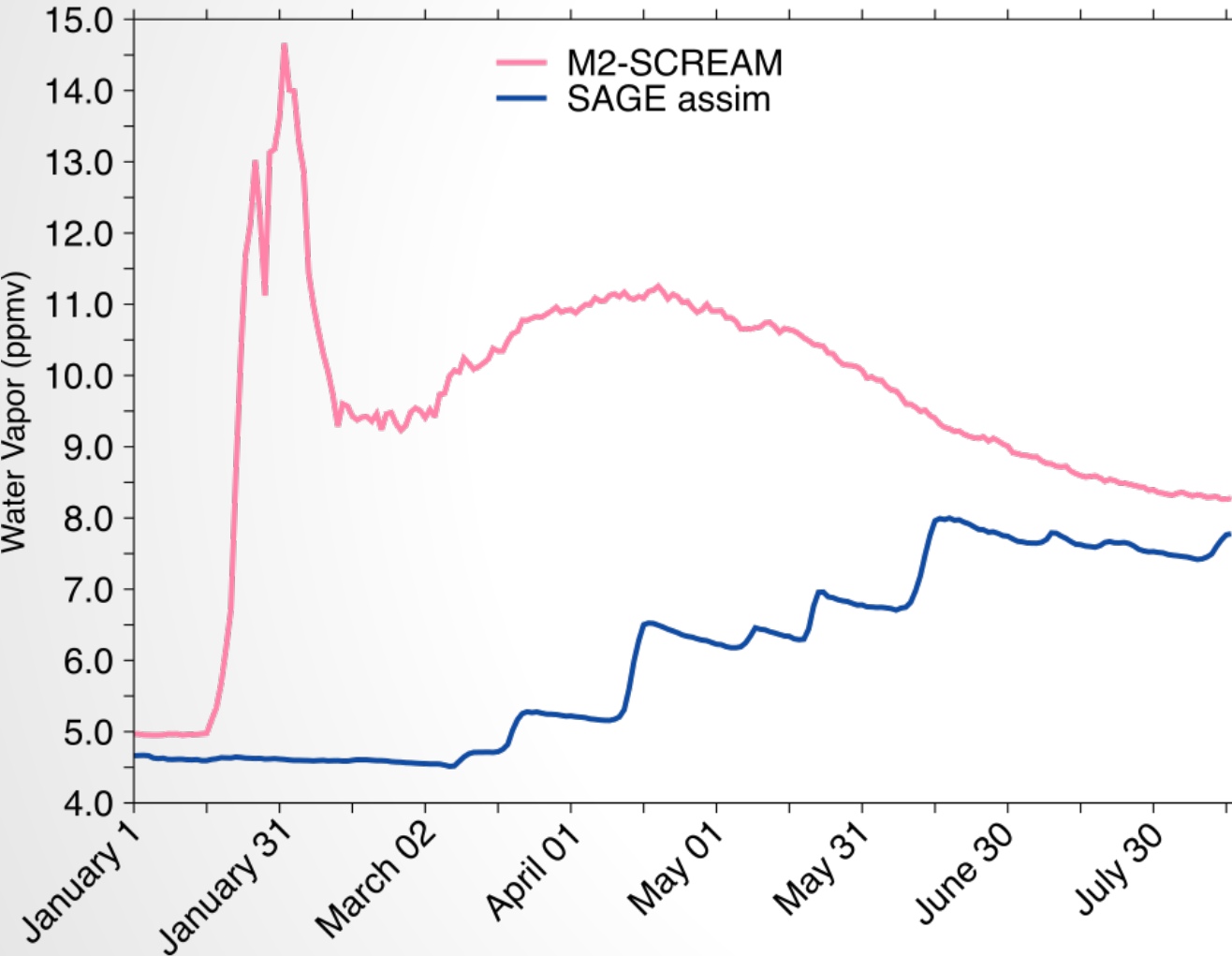
SAGE and MLS profiles agree well (black lines) but the assimilation system does not trust the observations given the large error estimates 20-70 hPa (dotted lines left panels, bottom).

(Knowland et al., in prep)

SAGE assimilation: Impact of the number of obs and the obs error on the analyzed water vapor



Mean zonal analyzed water vapor at 20 hPa between 30°S-Equator



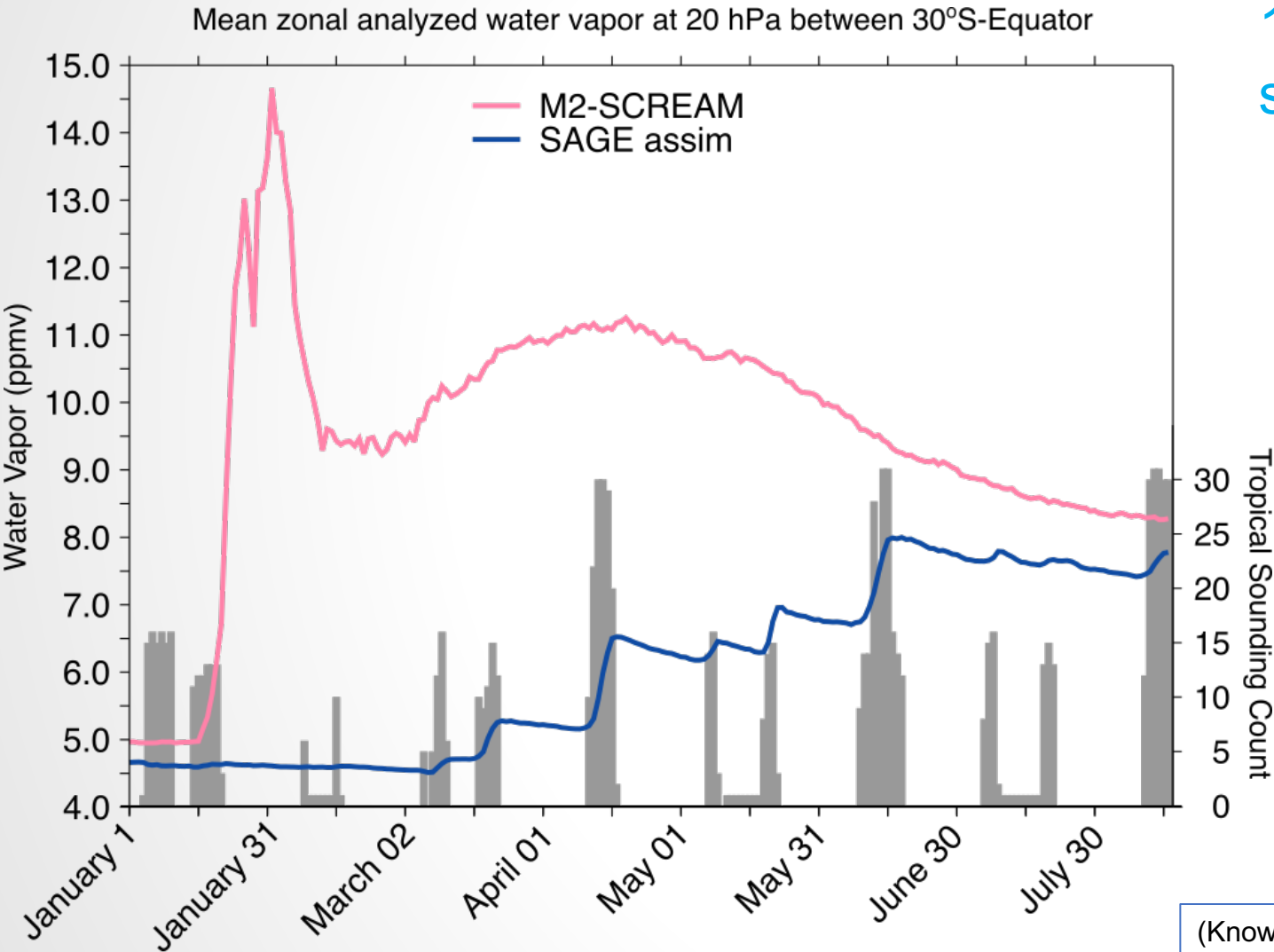
Hongka Tunga erupted January 15, 2022.

- Response in M2-SCREAM took a few days before the max mean zonal water vapor reached nearly 15 ppmv
- SAGE assimilation remained as background concentrations till early March

What is leading to the SAGE incremental increases in water vapor from March through June?

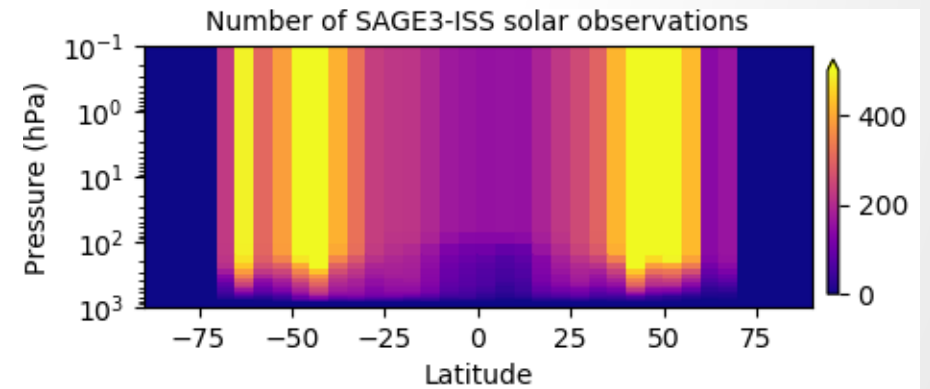
(Knowland et al., in prep)

CoDAS SAGE III/ISS: Impact of the number of obs and the obs error on the analyzed water vapor



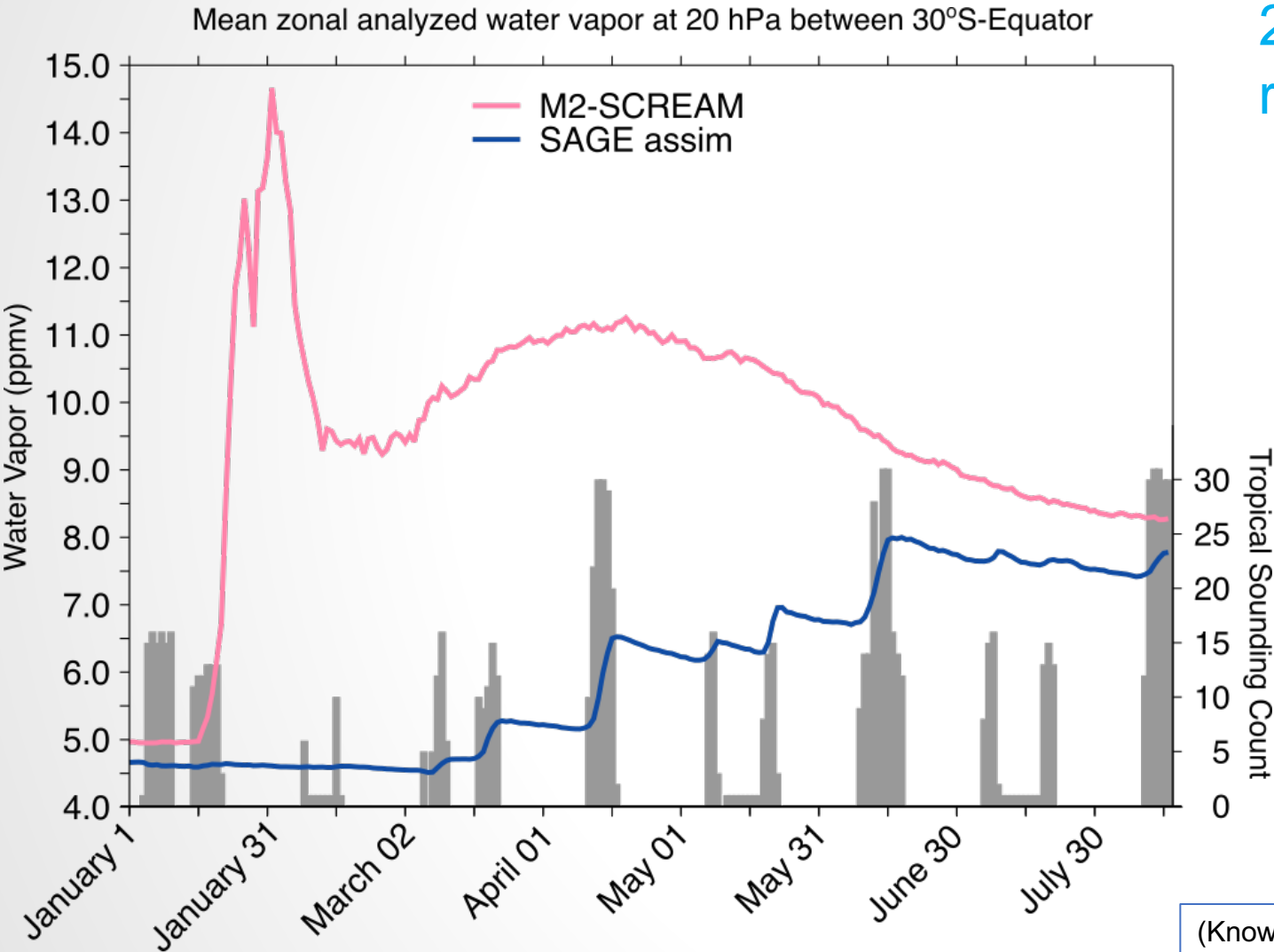
1. Were there enough tropical soundings at the time of the eruption?

- Likely not in that key time following the eruption through January and February.
- Solar observations are limited when there are high solar beta angles ($|\beta| > 60^\circ$).



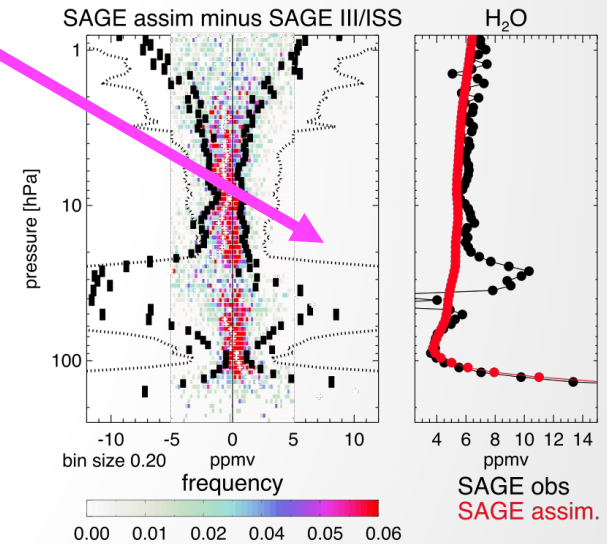
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CoDAS SAGE III/ISS: Impact of the number of obs and the obs error on the analyzed water vapor



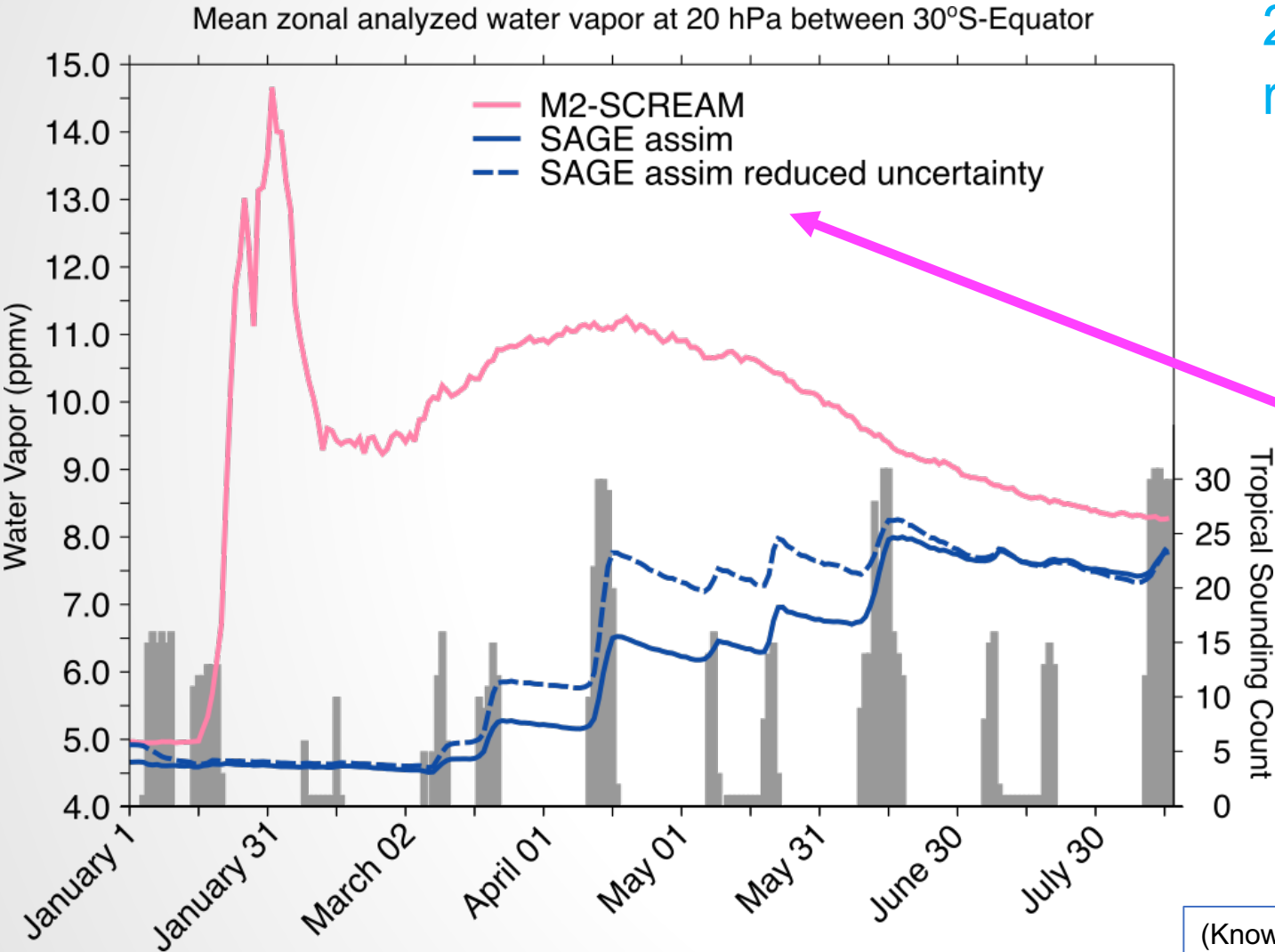
2. SAGE observations were high in this region, what happened in the DAS?

The assimilation system does not weight the observations given the large error estimates 20-70 hPa



(Knowland et al., in prep)

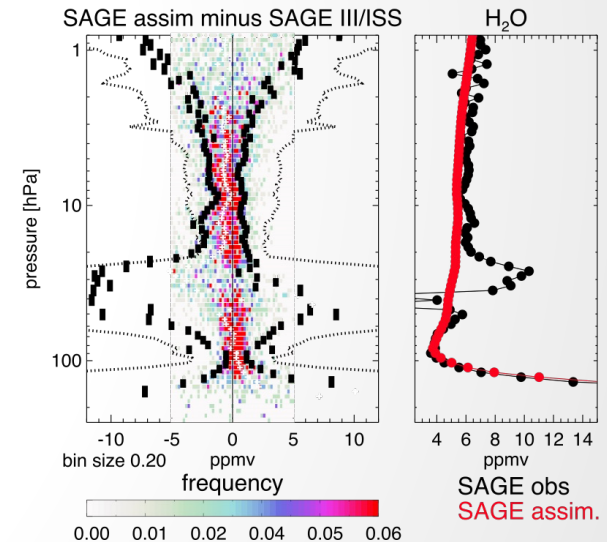
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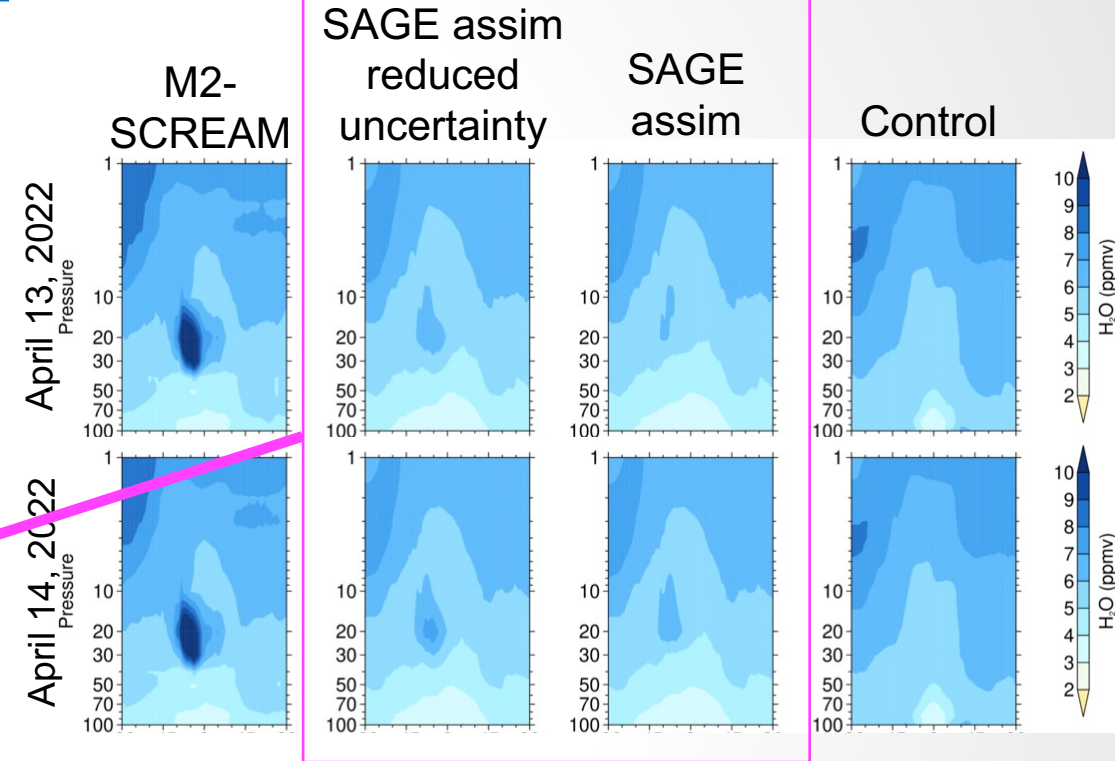
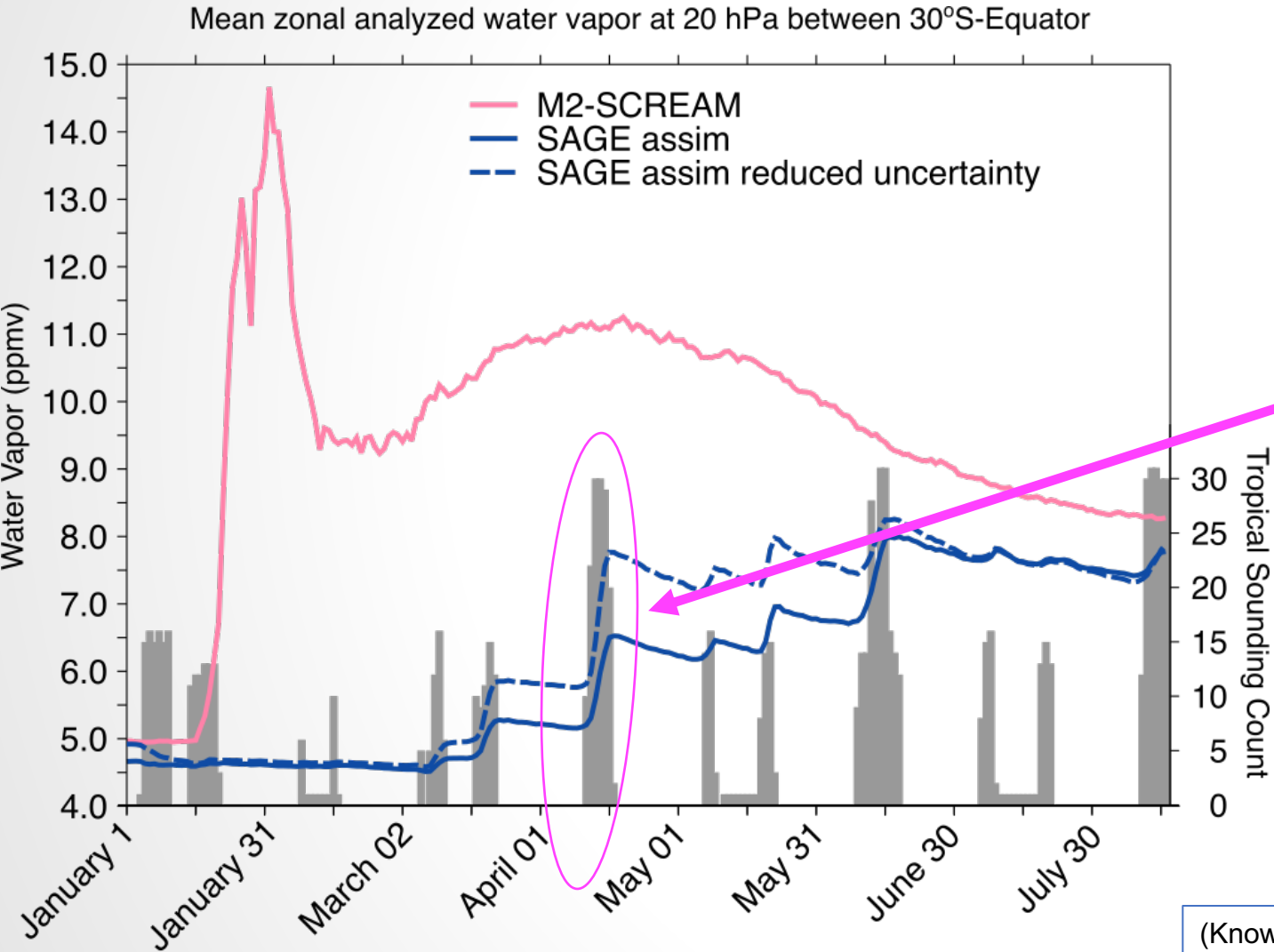
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We tested artificially reducing the errors by a factor of 10 where $a_{ext}(1020\text{ nm}) > 1000\text{ km}^{-1}$



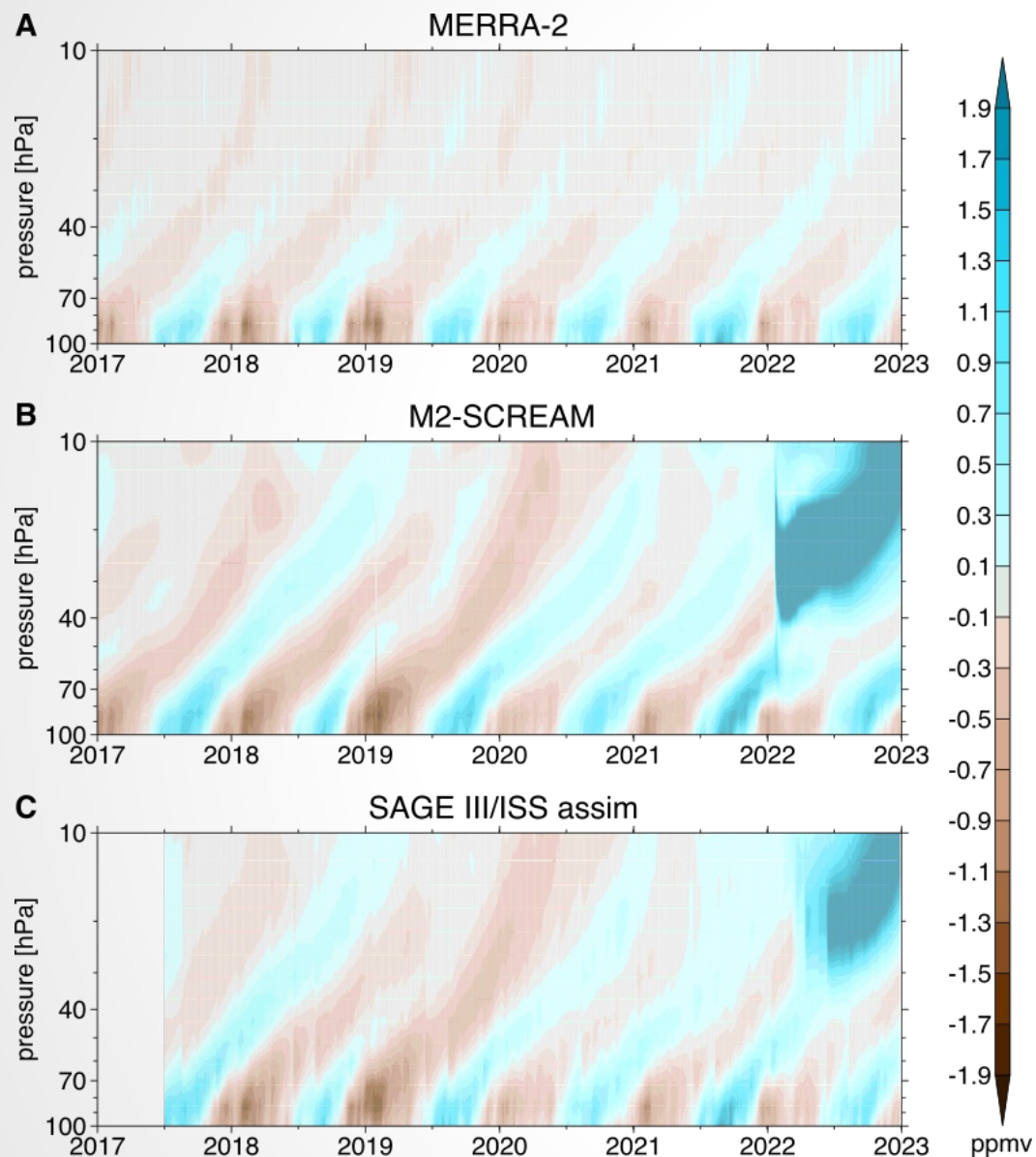
(Knowland et al., in prep)

CoDAS SAGE III/ISS: Impact of the number of obs and the obs error on the analyzed water vapor



This helps from March to June to increase the water vapor in the region of the plume; however, still underestimates compared to M2-SCREAM but better than the Control without a data constraint at all!

(Knowland et al., in prep)



Summary: Bridging the data gap with SAGE III/ISS

- There is a clear benefit to assimilating the less frequent high-resolution SAGE III/ISS water vapor observations, with the caveat that when there are few to no observations, like in the polar regions or tropics, the analysis is dominated by the underlying model
- The assimilation of SAGE water vapor (and other species) in the GEOS CoDAS framework can carry-on the trend and climate assessments after the Aura mission.

(Knowland et al., in prep)