Accounting for Non-detects in Satellite Retrievals: Application using CrIS Ammonia Observations

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Non-detects

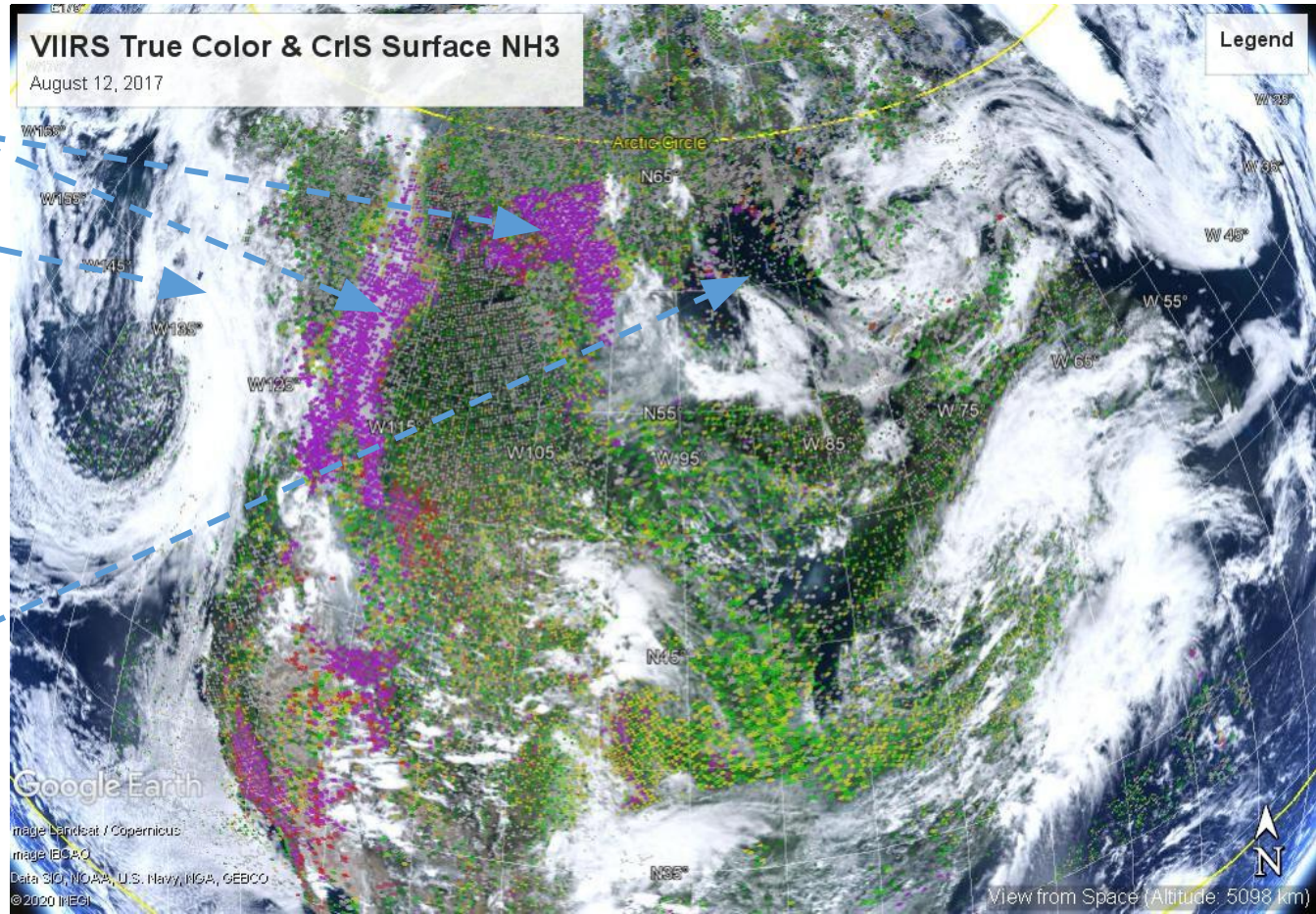
- Ammonia **atmospheric signal is relative weak** compared to the background longwave infrared signal (> 0.3%)
  - **Minimum detection limit** occurs when the signal < measurement noise (SNR<1)
  - CrIS has **excellent instrument noise** (~0.05 K), but atmospheric amounts of **ammonia can approach zero** and fall below the detection limit of the sensor.
    - Past OSSE simulations & evaluating real CrIS observations show **minimum detection limit ranges from ~0.3 to 0.8 ppbv** depending on the atmospheric state

- The **CrIS non-signal FOV** without a detectable ammonia signal (SNR < 1) are **identified, but not accounted for** the current Version 1.5 CrIS Level 2 or Level 3 NH3 product (they are just skipped).
  - This can result in **gridded average values (e.g. Level 3) being bias high** in regions or periods of very low or mixed (elevated and low) concentrations.

CrIS v1.5 surface retrieval example: August 12, 2017

Smoke

Clouds



Regions with sparse NH3 obs.

- Example of **non-detects** over large water body of Hudson Bay
- If most days are below the detection limit, mixed in with a couple of days with smoke passing over one might get an average value biased high over the region

CrIS ammonia cloud detection algorithm (CACDA)

- A **non-signal (SNR<1)** CrIS FOV is mainly a result of either:
  - **Non-detects** : the lower boundary layer atmospheric state (mainly a function of surface ammonia concentrations) being below the detection limit
  - **Clouds**: thicker clouds of which the sensor cannot “see” the ammonia below them
    - NH3 anthropogenic emissions are near the surface
      - short boundary layer lifetime (~hrs), so concentrations are close to the surface

- In order to **separate out the non-signal** CrIS FOV due to clouds from non-detects we have **generate a CrIS NH3 Cloud Flag**
  - Note: if there is no retrieval performed (due to no signal) then no cloud flag value is put in CrIS NH3 dataset

- The **CrIS Cloud Flag algorithm** is built from the newly available **U. Wisconsin CIMG** product that provides a **VIIRS cloud product on the CrIS FOV**, plus an added capacity by ECCC to handle **smoke plumes**
  - Note: there are ~200 VIIRS pixels (750 m) in a CrIS FOV (14 km)

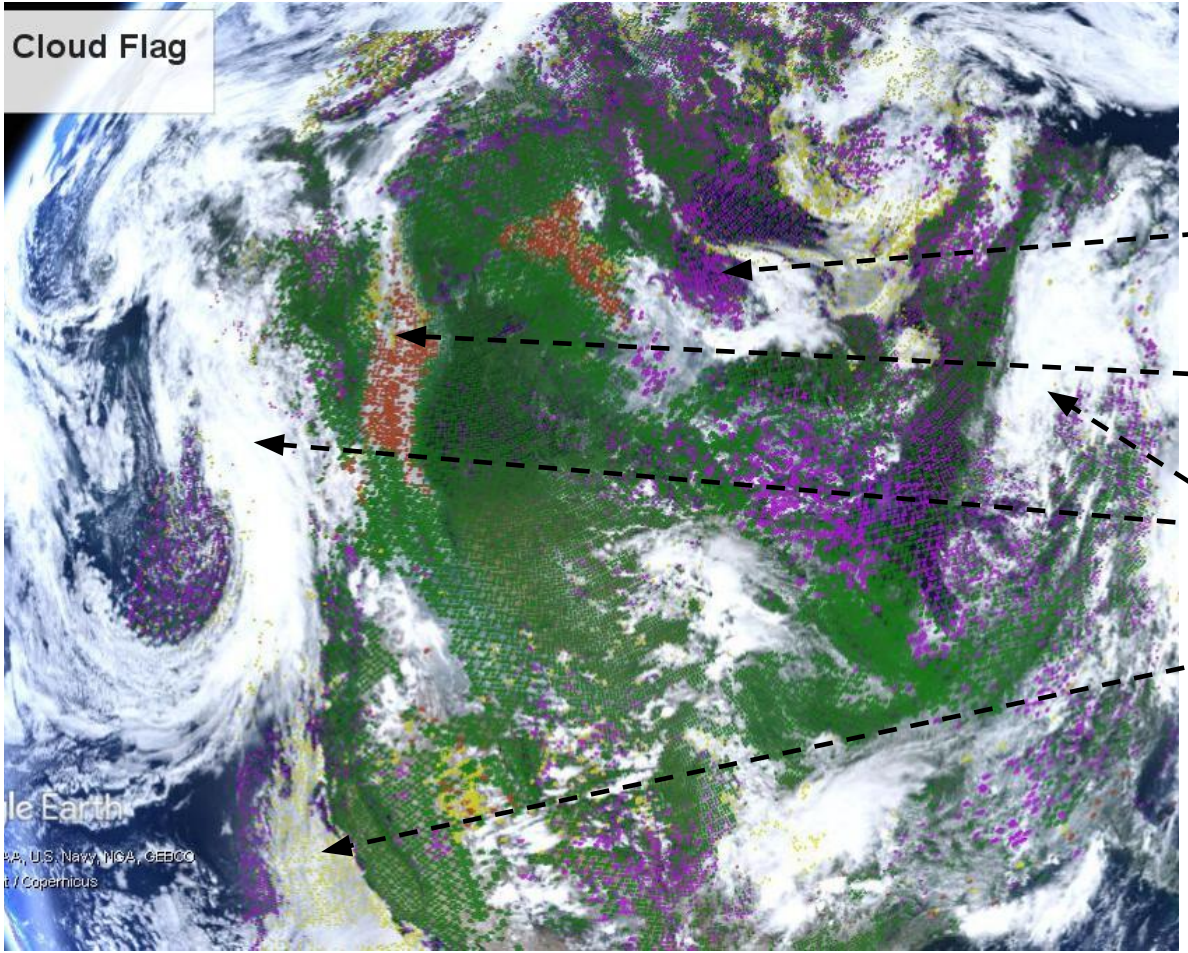
CrIS ammonia cloud detection algorithm (CACDA)

The CACDA derived cloud flag is constructed based on:

1. CIMG cloud fraction in CrIS FOV < 0.25 then clear
2. CIMG cloud fraction in CrIS FOV > 0.25 and < 0.9 then:
   a. If LW BT difference between clear and cloudy pixels averages < 25K then clear
   b. Else flagged as cloudy
3. CIMG cloud fraction in CrIS FOV > 0.9 then cloudy
4. If CACDA identifies a cloud in steps above, but the estimated CrIS NH3 SNR > 5 then the CrIS FOV is flagged as smoke
   - CACDA using VIIRS CIMG product can flag thick smoke plumes as clouds
   - Use the **upwelling longwave radiation signal from NH3** to flag cloud pixels as smoke
     - Caution: this is not a indicator of ALL smoke pixels. Only for CrIS FOV in which retrievals were performed, and identified as clouds by the the first three steps of the CACDA, and then identified as smoke in step 4. There are retrievals in smoke are not identified as clouds by CACDA.

Cloud Flag	Descriptor	Comment
-1	No cloud information	Corresponding VIIRS cloud information was missing.
0	Clear retrieval	Retrieval under cloud-free conditions.
1	Cloudy retrieval	Retrieval was performed that was identified by VIIRS as a containing cloud.
2	Smoke cloud	CrIS FOV that were initially identified by VIIRS as cloudy, but are smoke plumes.
3	Survival non-detect	Survival data for cloud-free CrIS FOV below the detection limit of sensor.
Note: Cloudy pixels with no signal are not retrieved or included in dataset		

VIIRS true colour image with cloud flag overlay



Cloud Flag	Descriptor
-1	No cloud information
0	Clear retrieval
1	Cloudy retrieval
2	Smoke cloud
3	Survival non-detect

- **Non-detects** over non-source regions
  - e.g. Hudson Bay
- Approach developed to identify **smoke pixels** that VIIRS identified as clouds
- Retrievals during cloudy periods
  - Retrievals are generally not performed in thick clouds (no NH3 spectral signal)
  - Some thin cloud conditions where retrievals are performed

Non-detect algorithm

- **In-situ data was used to generate "survival" data** that can be used to represent ammonia concentrations under CrIS non-detect conditions

- Ideally, we would like to use continuous in-situ surface **ammonia observations in non-source regions at the CrIS overpass time**
  - Very few continuous observations are made in non-source regions
  - Currently using limited number of available stations
    - Will incorporate more as they become available
  - Can also use the continuous observations to investigate the instantaneous overpass times vs integrated averages
    - See if the integrated stations (e.g. bi-weekly AMoN) can be used
      - Maybe with an adjustment for diurnal variability, etc.
      - Or independent evaluation the pre and post inclusion of survival data

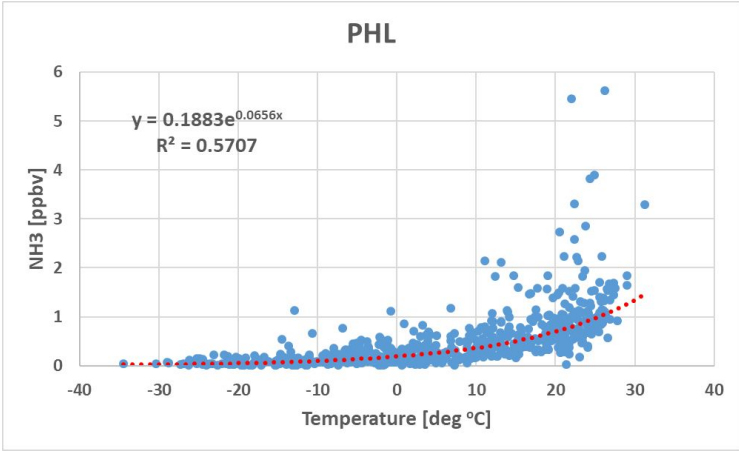
Non-detect values derived from continuous in-situ surface ammonia observations as a function of temperature (Exponential Fit)

Look up table (LUT)

Bin Size (Temperature oC)	Median Average
[-35 -30]	0.0
[-30 -25]	0.0
[-25 -20]	0.0423
[-20 -15]	0.0732
[-15 -10]	0.0959
[-10 -5]	0.1705
[-5 0]	0.1720
[0 5]	0.2244
[5 10]	0.2666
[10 15]	0.3863
[15 20]	0.4649
>20	0.4649*
*Just used same value for warmer temperature	

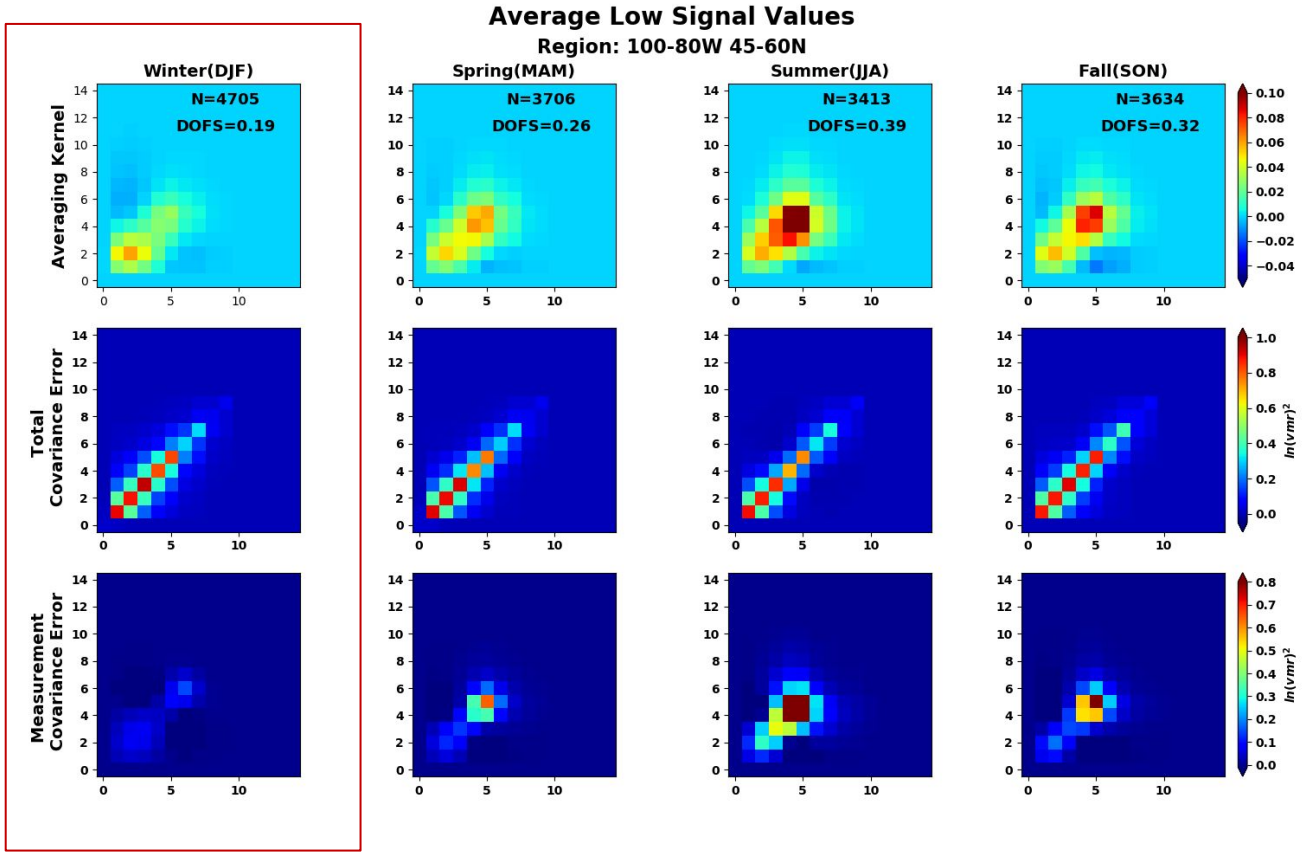
Median Average: Average of median values at CTR, OLF and PHL sites

Exponential Fit based on PHL station only



- Generating a fit from multiple stations at once can be challenging, LUT approach might be better
  - Can investigate further the fit if needed
- Having a more refined estimate for the survival data might not have a huge impact, likely biggest gain it just accounting for them
  - Sensitivity test to bracket the issue shown later
    - [nothing, estimated ND value, insert zeros]

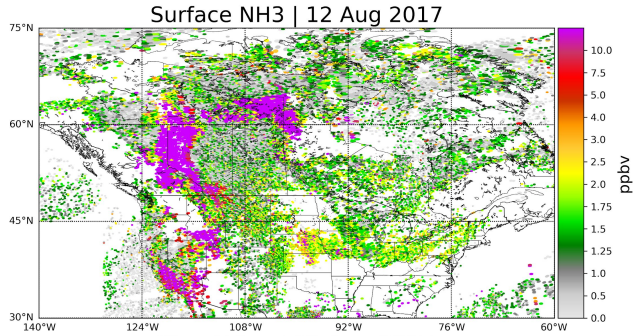
Representative non-detect matrix values derived from CrIS retrievals with low-signal (|SNR|<1.01)



- Average of retrieval output matrices very close to the CrIS detection limit (|SNR|<1.01) to be inserted into the CrIS NH3 profile with the non-detect values.
- For the product we selected the winter.

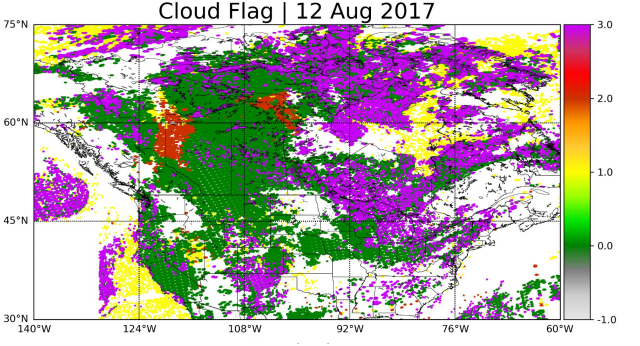
Single day

V 1.5



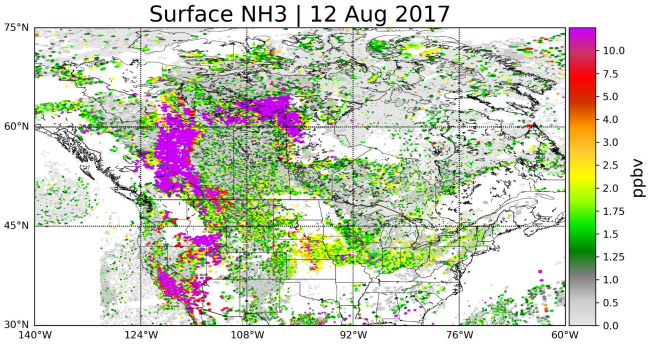
- **Current version that does not take into account non-detects.**
- **Does not perform retrievals with no atmospheric ammonia signal**
  - Thick clouds
  - Non-detects

Cloud Flag



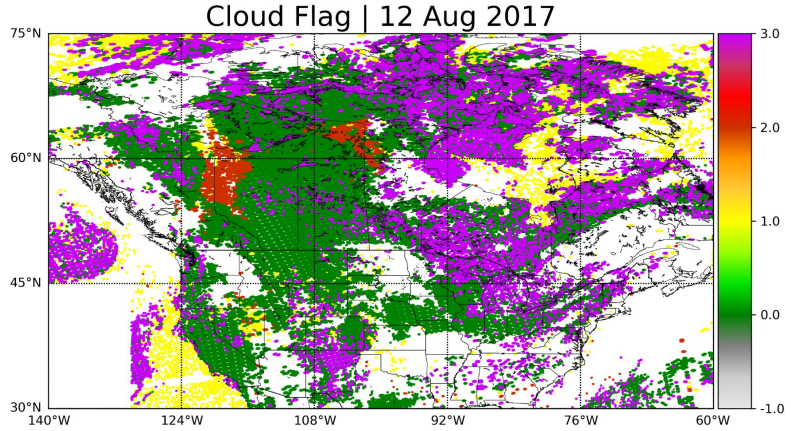
Cloud Flag	Descriptor
-1	No cloud information
0	Clear retrieval
1	Cloudy retrieval
2	Smoke cloud
3	Survival non-detect

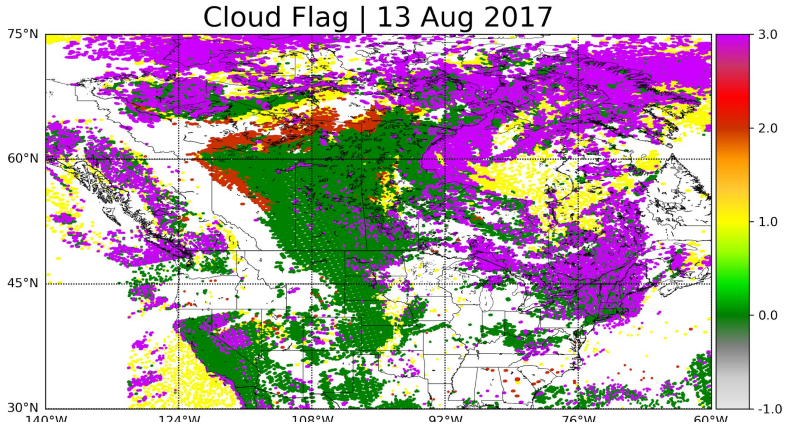
V 1.6

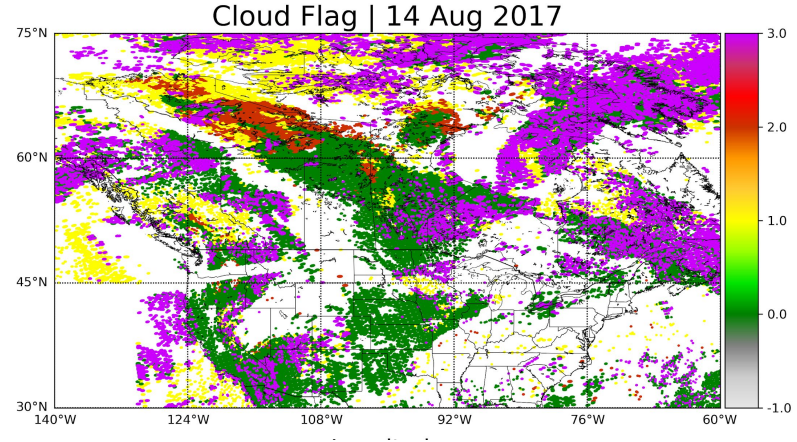


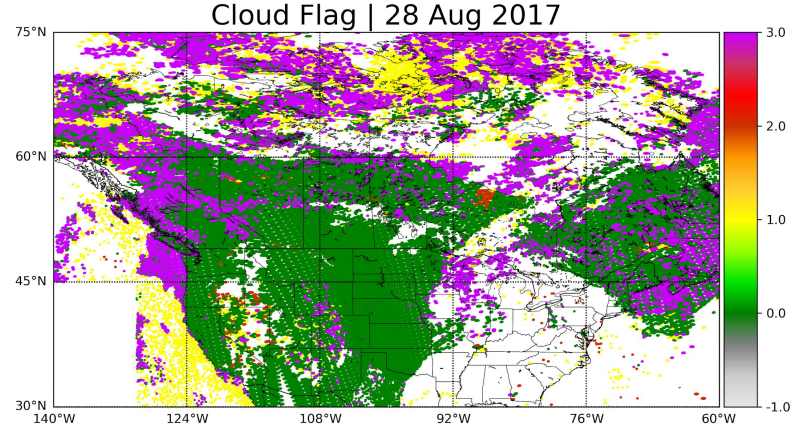
- **Does not perform retrievals with no atmospheric ammonia signal**
  - **<u>Accounts for non-detects</u>** (post-processing step)
  - Does not account for thick clouds with no NH3 signal
  - Can QC around retrievals performed that identified as containing clouds (cloud_flag=1)
    - Thin clouds
    - NOT APPLIED HERE

Cloud flag for other days around Aug 12, 2017





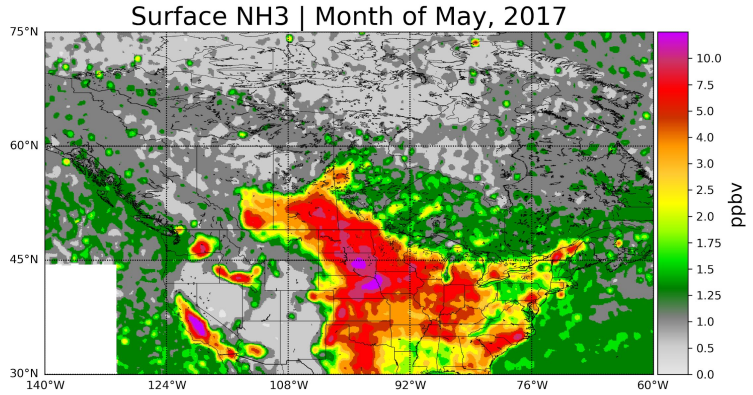


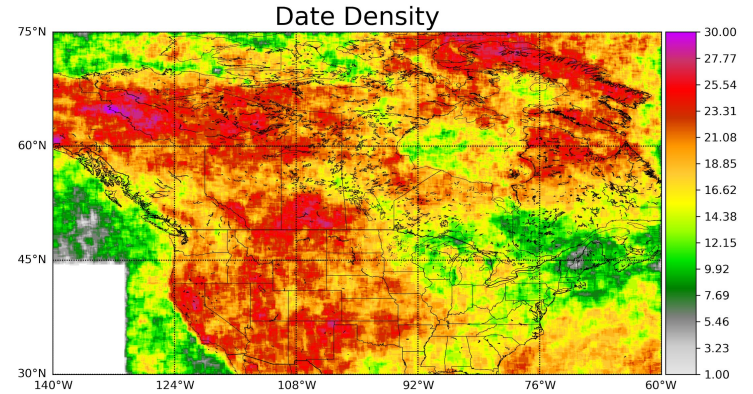


Magenta are the non-detects being added in.

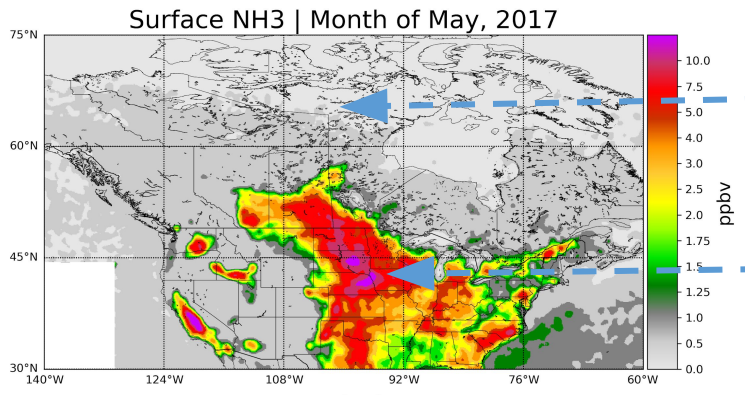
Gridded and averaged results (Level 3): May 2017

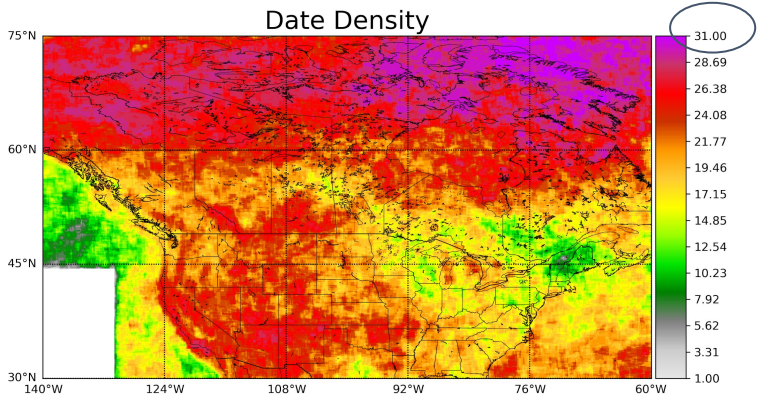
V 1.5





V 1.6





Accounting for non-detects:

- **reduces the high bias in non-source regions (e.g. Northern latitudes & oceans)**
- **No significant impact on source regions**

Daily data density count

- **↑ non-source regions where there would be more non-detects**
- **Remained almost the same in source regions**
- **Polar-orbiter has more overlapping near poles**