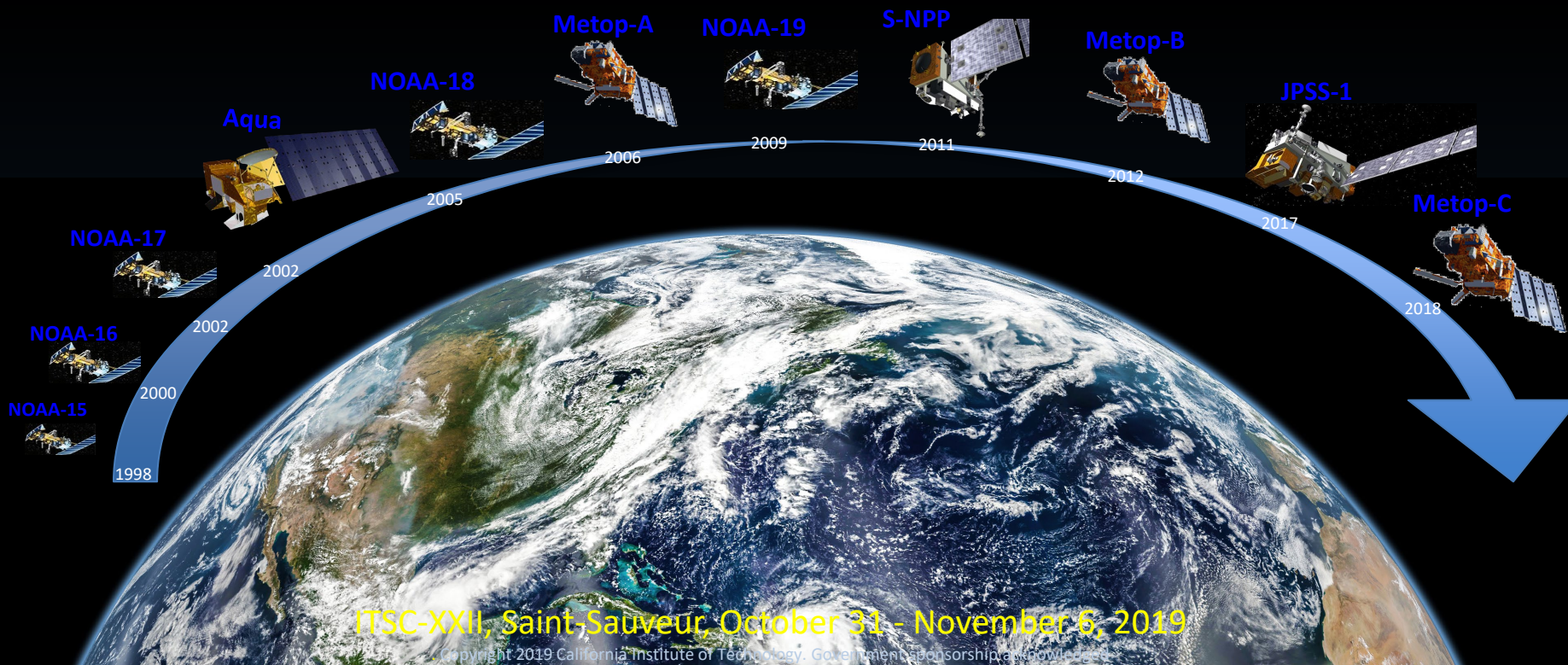


The New NASA Multi-mission Microwave Sounder Retrieval System

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Focus on the troposphere

- “Moist thermodynamics”: water vapor is the key variable
- Water cycle in the atmosphere: water vapor, clouds, precipitation
- Atmospheric processes controlling weather and climate; severe storms

Illuminated by tropospheric sounders & related sources

- IR sounders: AIRS, CrIS, IASI etc.; MW sounders: AMSU, ATMS etc.
- CYGNSS, GPSRO, GPS-met, raobs, buoys, aircraft

Some science questions

- *How do small-scale and rapid weather processes interact with the large-scale thermodynamic environment and the climate?*
- *How do weather and climate processes intersect?*
- *How well do climate models compare to observations, and how can we use global satellite observations to improve the models?*
- *How can we use long term observations to understand climate processes?*
- *How can we use microwave observations to extend the weather and climate regimes of models?*

Developed the first hyperspectral IR sounder: AIRS on Aqua

- Successor to NOAA's HIRS
- Major improvement in capabilities
- Significant weather forecast improvements & atmospheric research

Microwave sounders: Use new technology developed for NOAA

- AMSU-A + HSB \approx AMSU-A + AMSU-B

Post-Aqua: Develop joint “bridging mission” Aqua to NOAA: S-NPP

- NASA: New MW-sounder \rightarrow ATMS
- NOAA: New IR-sounder \rightarrow CrIS
- These sensors intended for future NOAA op'l satellites \rightarrow JPSS

Question: Can we use operational sounders for research?

- NOAA's focus is on short-term weather prediction
- Continuity & consistency over long periods is secondary
- Calibration changes can cause discontinuities
- Algorithm changes can cause discontinuities
- Historical data are typically not reprocessed after such changes
- *All of these are hindrances to use in climate research*

NASA formed science team to address this question

- 2011-2014
- Team analyzed quality of S-NPP instruments and algorithms

Assessment report delivered in 2013

- Conclusion #1: Instrument quality is adequate
- Conclusion #2: NOAA algorithms are *not* adequate
- Conclusion #3: NOAA data processing/handling is *not* adequate

Recommendations formed the basis for next solicitation

- Develop new retrieval algorithms for all S-NPP/JPSS instruments
- Set up NASA data processing and product distribution/archiving

Subsequent sounder science team

- Instrument-level (L1b = SDR) responsibility assigned by NASA
 - CrIS: U. Wisconsin
 - ATMS: JPL
- Several competing retrieval (L2 = EDR) algorithm developments ensued
- Ultimately culminated in a “down-select” through ROSES’17
 - One CrIMSS algorithm → “CLIMCAPS” (C. Barnet)
 - One ATMS algorithm → “RAMSES” (B. Lambrigtsen)
- Algorithms are delivered to “Sounder-SIPS” at JPL for assessment
- Operationalized code delivered to GES/DISC DAAC for processing

Retrieval Algorithm for Microwave Sounders in Earth Science

- Initially funded under ROSES'13/NPP (2014-2017)
- Continued under ROSES'17/TASNPP (2018-2021)

Development path

Two approaches pursued:

- Aqua AMSU/HSB system adapted for S-NPP/ATMS (Fishbein) – RAMSES-I
- New development (Schreier)

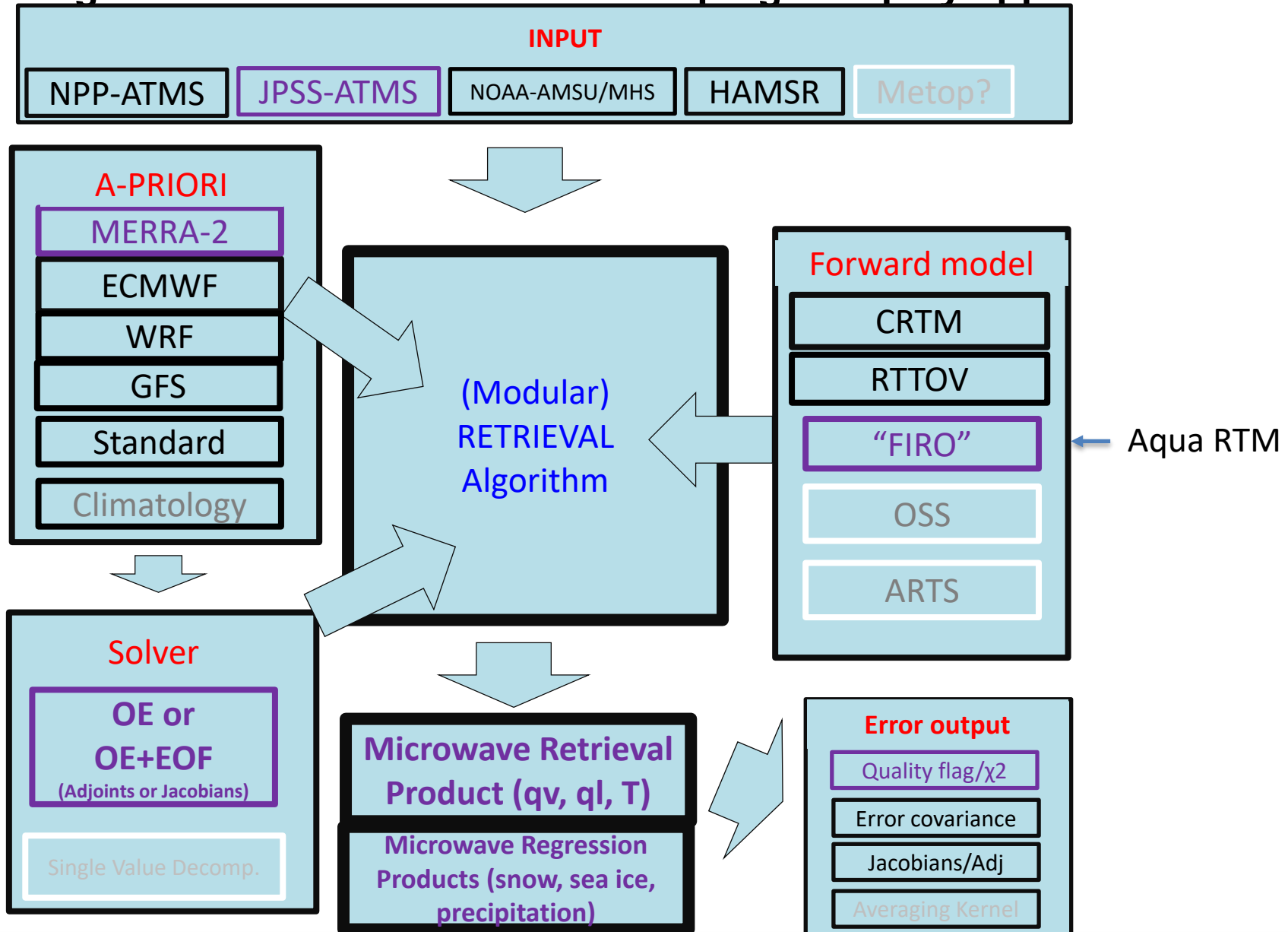
Eventual merger:

- Aqua RTM (“MitRTA”) + new development for the rest – RAMSES-II

Current status

- Baseline version delivered to Sounder-SIPS in July 2019 for testing
- Preliminary tests successful
- SIPS expects to deliver to GES DISC in October 2019

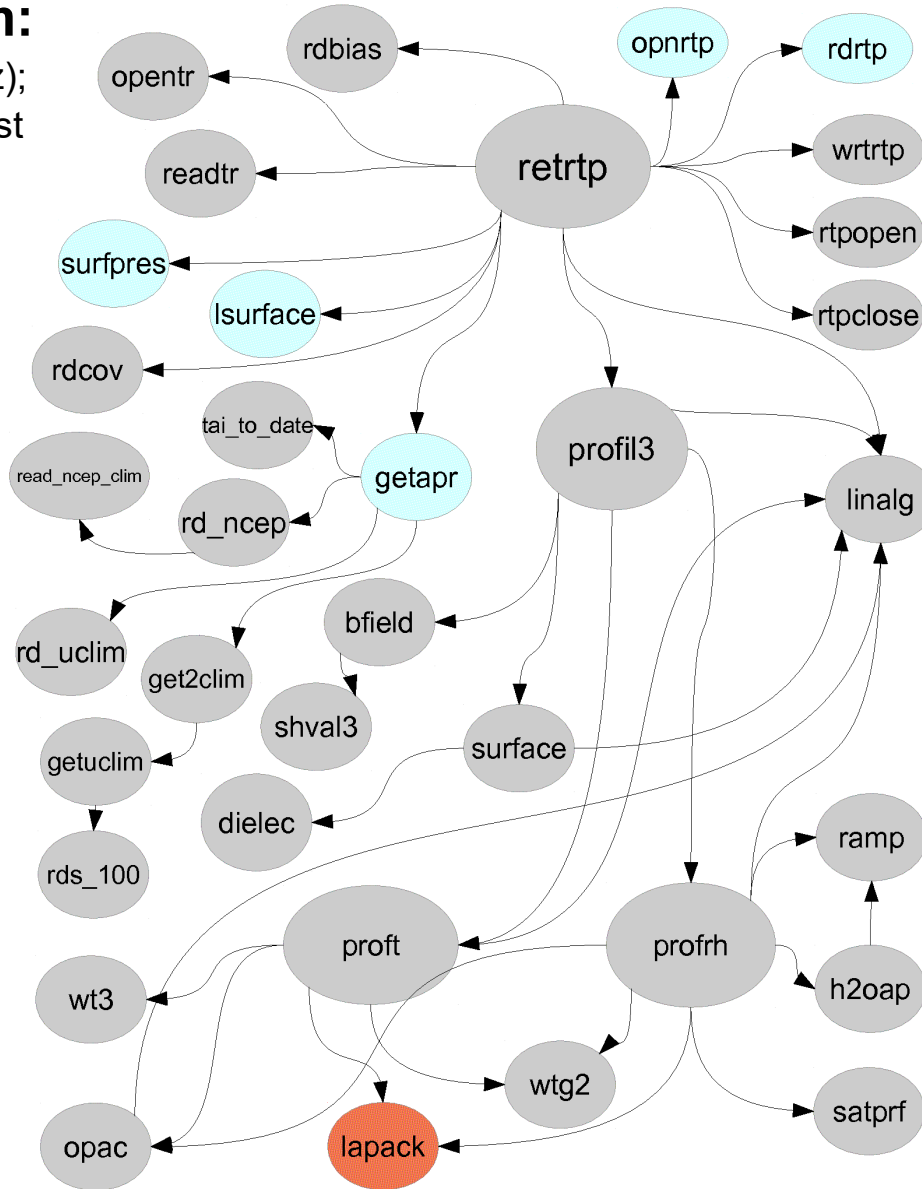
Algorithm testbed allows modular plug-and-play approach



Baseline system:

Aqua RTM (Rosenkranz);
Very accurate & very fast

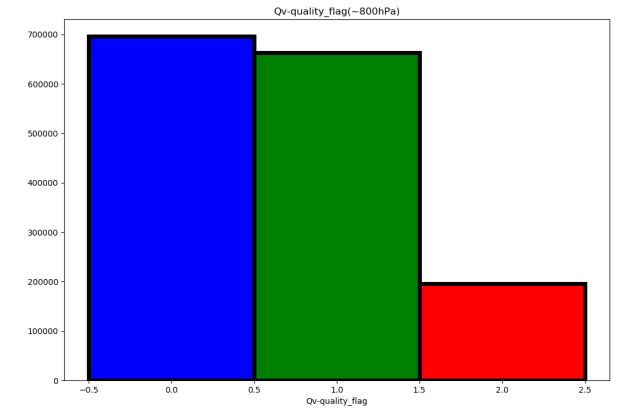
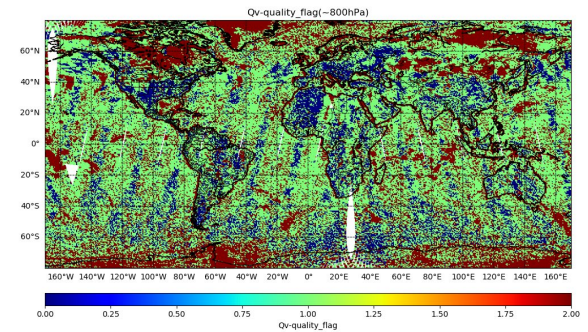
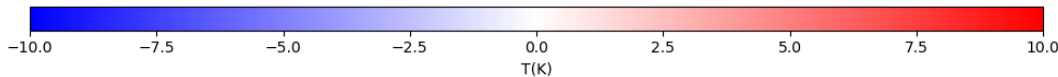
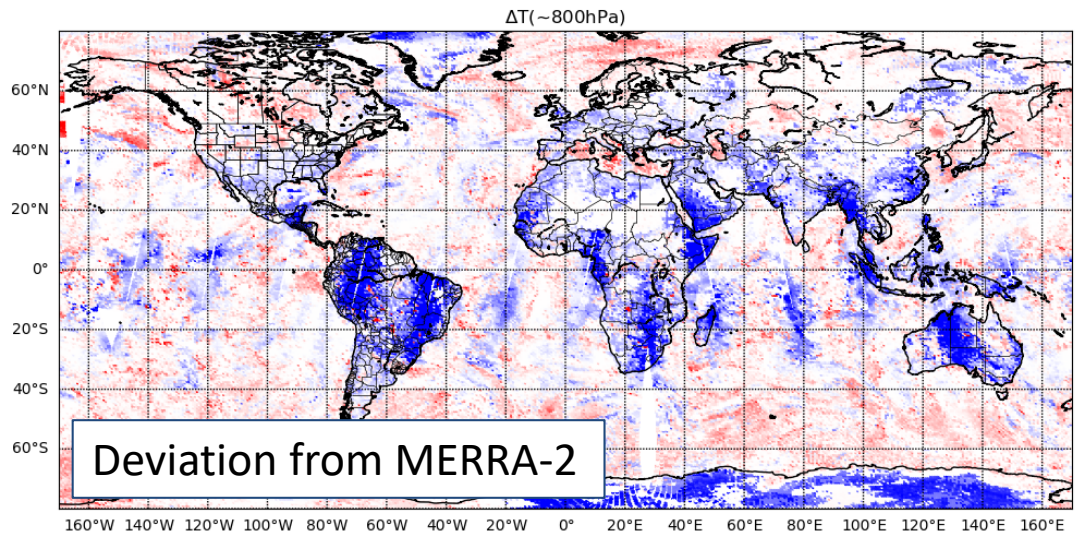
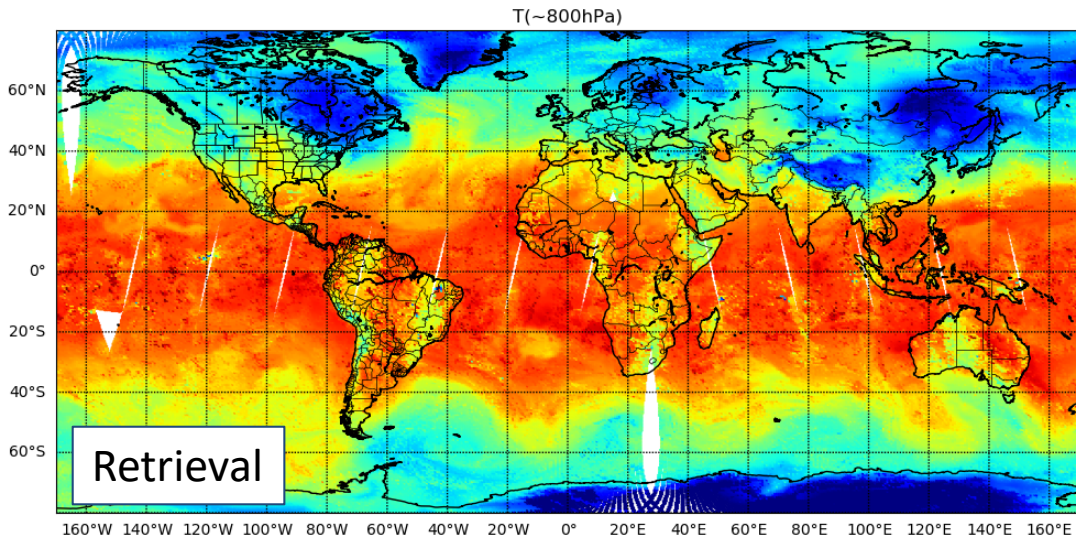
“MitRTA”



Future versions:
 Account for scattering;
 Modified Aqua-RTM or CRTM

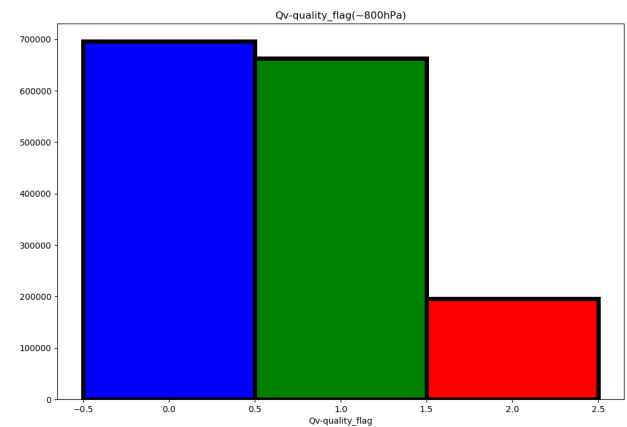
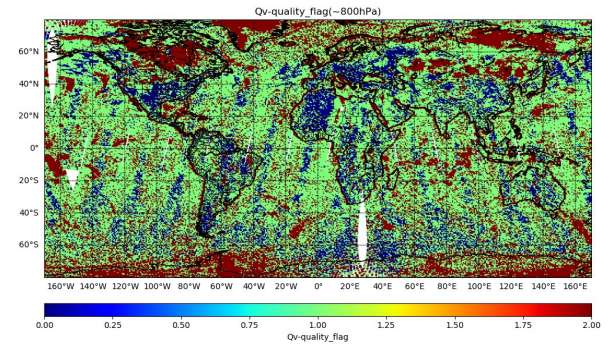
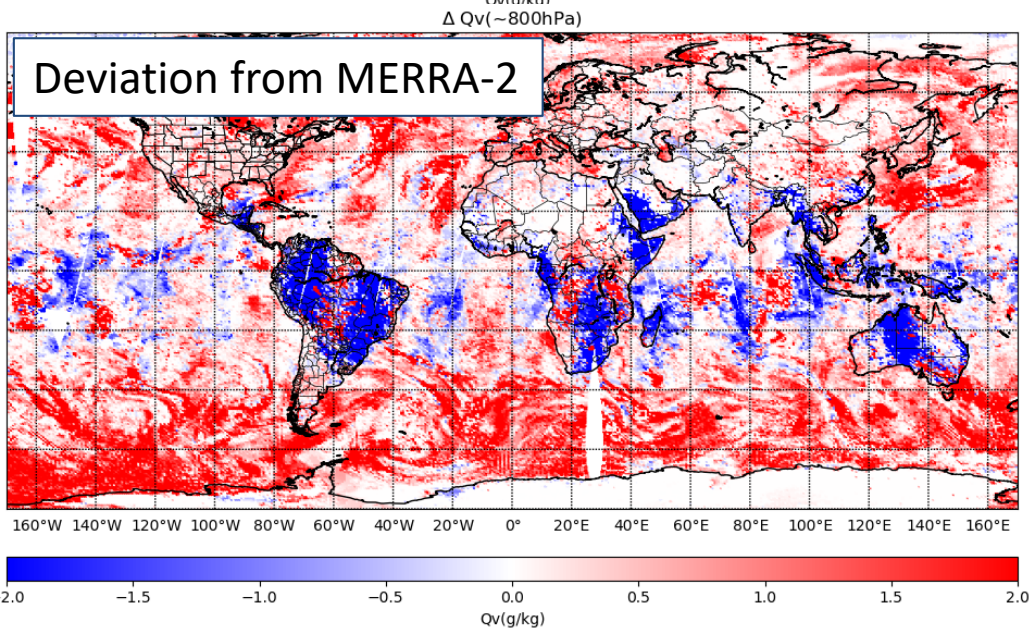
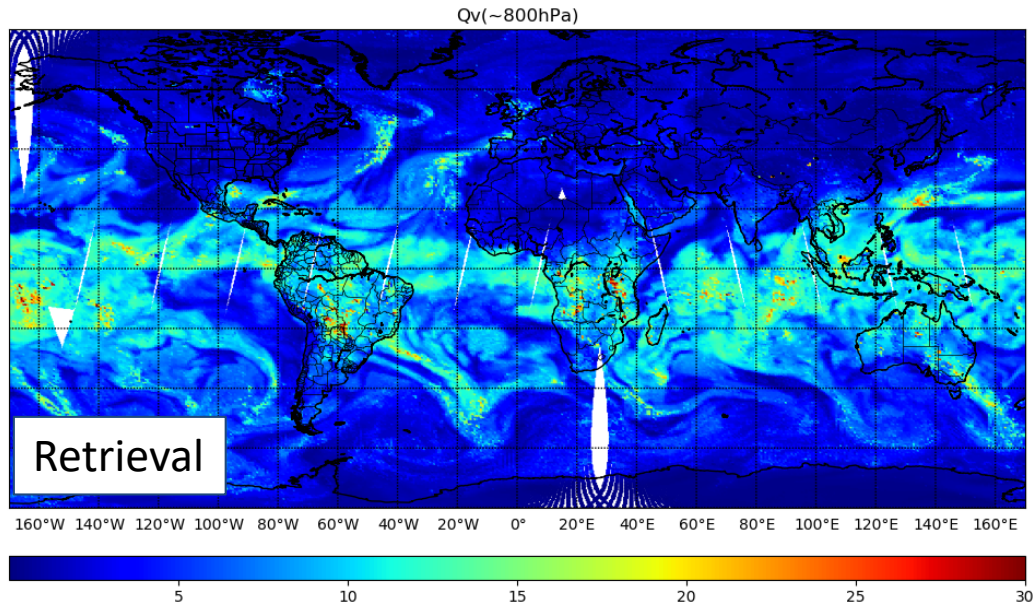
S-NPP/ATMS
 A priori: MERRA-2
 RTM: MitRTA

Quality flag values:



S-NPP/ATMS
 A priori: MERRA-2
 RTM: MitRTA

Quality flag values:



Perform full testing & validation

- AIRS/Sounder-SIPS science analysis team

Update algorithm & software → V2

- Implement scattering (post-V2)

Process all ATMS data

- S-NPP, JPSS-1; from start of each mission
- Reprocessed after major algorithm updates

Generate long time series

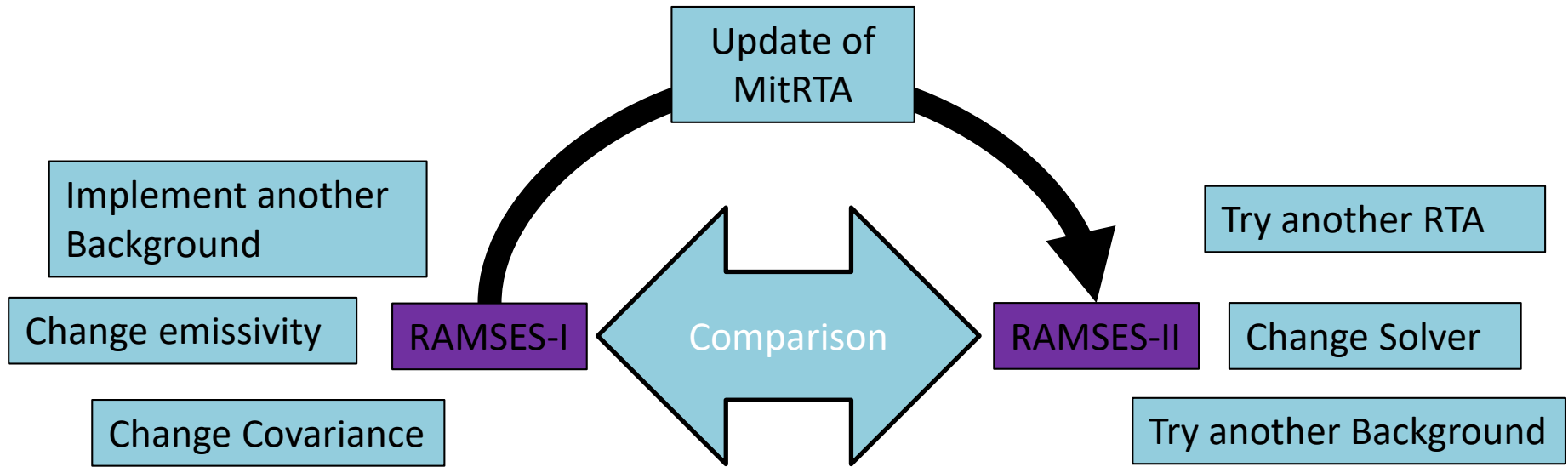
RAMSES will be implemented for all AMSU & ATMS systems

- 1998-2005+: AMSU-A/AMSU-B (NOAA-15/16/17)
- 2002-2014: AMSU-A/HSB (Aqua)
- 2005-2011+: AMSU-A/MHS (NOAA-18/19)
- 2006-present: AMSU-A/MHS (Metop-A/B/C)
- 2011-present: ATMS (S-NPP, JPSS-1/2/3/4) ← **Funded baseline**

Achieve continuity & consistency

- Reprocess all data after algorithm or calibration changes
- Option 1: Each platform/instrument processed independently
- Option 2: Apply bias adjustments to equalize all platform/instrument series
- *Baseline approach is Option 1*

Algorithm testbed enables easy upgrade path



Planned upgrades:

- Account for scattering → Retrievals in presence of precipitation
 - Based on system developed for aircraft sounder "HAMSR"
- Implement for AMSU
 - Time series can be extended

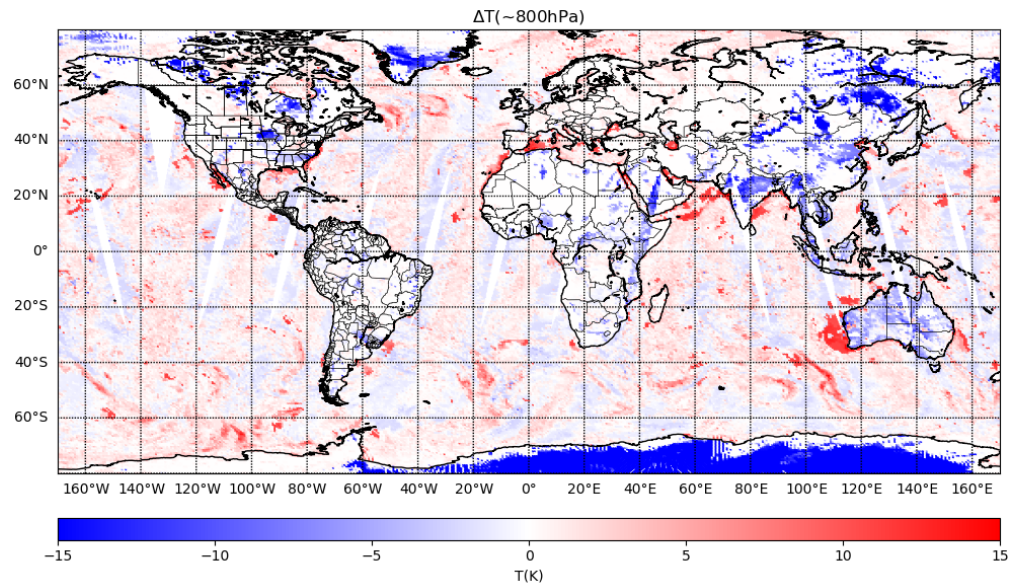
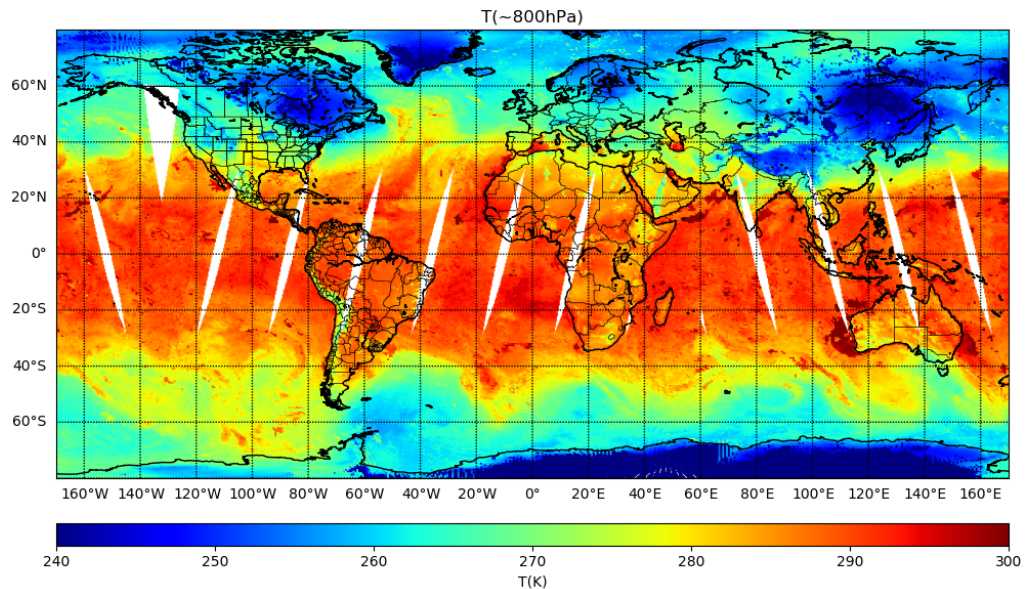
Example: AMSU-A/MHS (NOAA-19)

- AMSU interpolated to MHS
- A-priori: ECMWF
- RTA: CRTM
- Scattering accounted for

Shown:

- Temperature at 800 mb
- Deviation from ECMWF

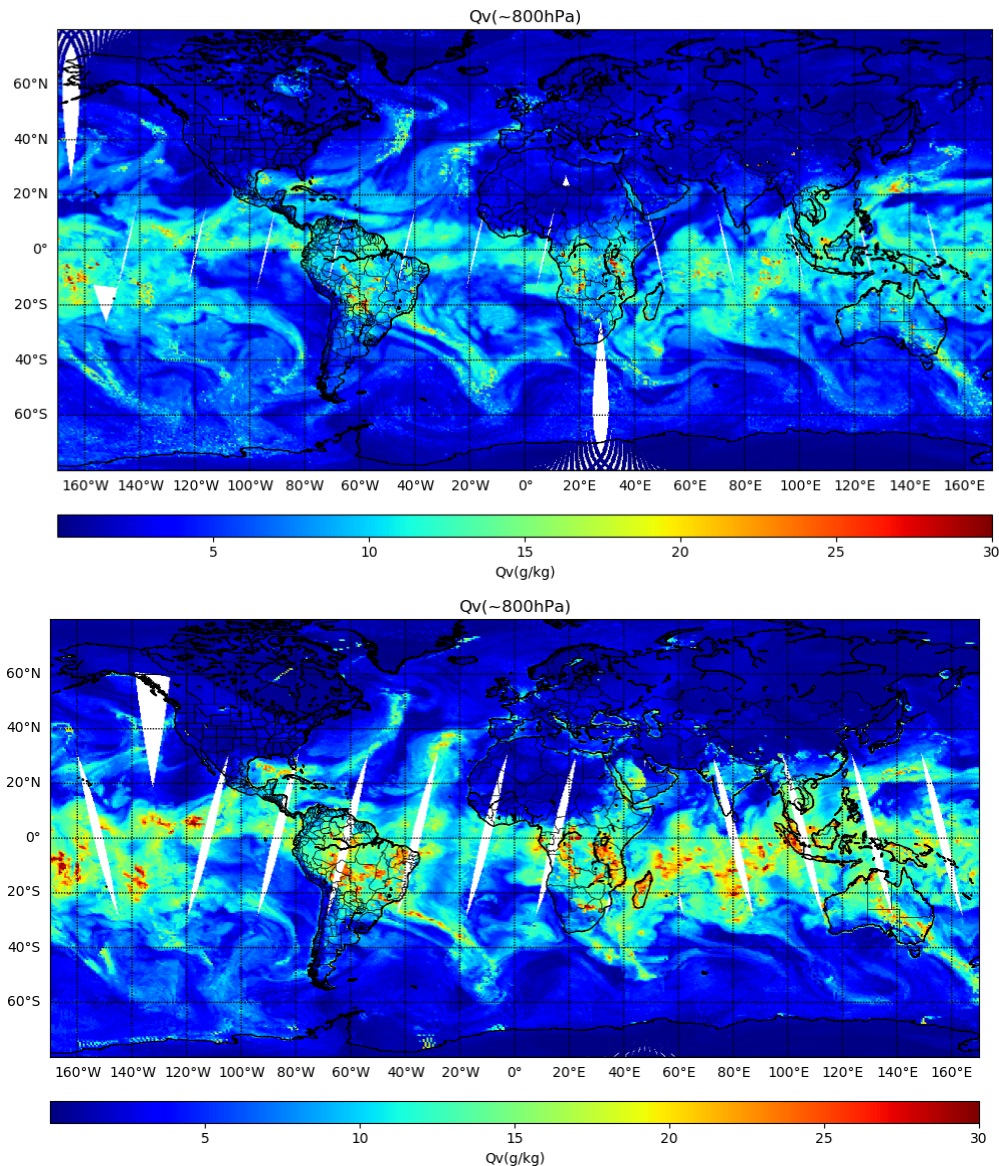
Conclusion: Valid retrievals
even in precipitating areas



Example: ATMS vs. AMSU and
scattering vs. non-scattering
Shown: Water vapor @ 800 mb

- Top: SNPP/ATMS
 - RTM: MitRTA
 - Apriori: MERRA-2
 - Scattering: No
- Bottom: NOAA-19/AMSU
 - RTM: CRTM
 - Apriori: ECMWF
 - Scattering: Yes

Conclusion: Scattering reveals
additional structures



RAMSES will produce “climate quality” soundings

- From microwave sounders: All-weather T, q, etc.
- Quality instruments from 1998: Long time series possible
- Quality instruments beyond 2030: Continuation of time series

Clear upgrade path

- Algorithm testbed: Easy testing of new components
- Scattering to be included: Retrievals in precipitation & convection
 - This has already been implemented for aircraft sounder

Enabling international collaboration

- RAMSES can be implemented for a variety of MW sounders
 - US sounders
 - European sounders
 - Japanese sounders
- Comparisons with other retrieval systems can be used to address biases
- Supports international climate research

Future of microwave sounding look bright

- Continuation of operational microwave sounders seems assured
- Growing interest in geostationary microwave sounders
- Synergy with infrared sounders, imagers & radar