Progress in the Synergistic Use of High Resolution Imager with Infrared and Microwave sounders for NWP and Geophysical Retrievals

Changyong Cao, Mark Liu, and Yong Chen

NOAA/NESDIS/Center for Satellite Applications and Research

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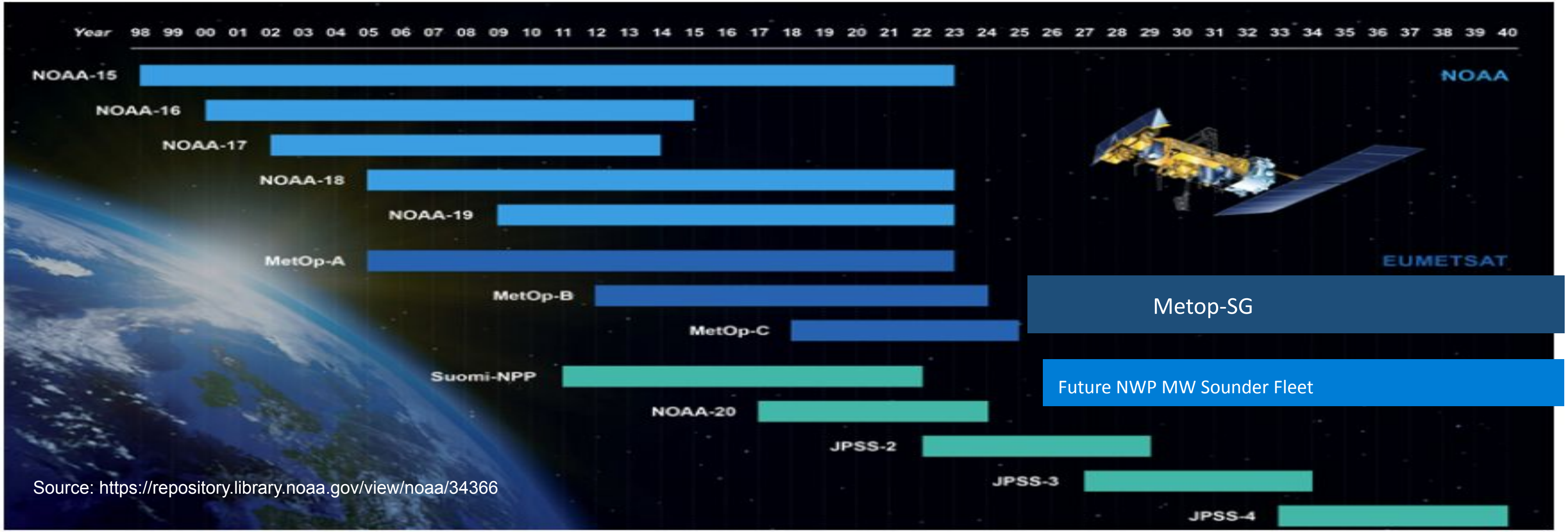
Polar Weather Satellite Missions



- Paradigm change from integrated observing system (MW, IR, Imager) to disaggregated constellations, and implications
- Future NOAA GeoXO/GXS (Schmit presentation Friday);
- Future NOAA LEO/NEON/QuickSounder(Iturbide-Sanchez, EUMETSAT presentation next week)

Background

- Spectral identification of clear channels (McNally & Watts, 2003)

- Combined use of AIRS and MODIS data was initiated about 20 years ago (Li et al. 2004)

  - Cloud fraction within IR Sounder FOV
  - Additional information from higher resolution infrared images within sounder FOV
  - Subpixel cloud characterization for the infrared sounder

- AIRS in Data Assimilation (Susskind et al. 2006)

- Use of Imager with hyperspectral sounder for cloud detection(IASI/AVHRR, Eresmaa, 2013)

- Combined use of ATMS and CrIS (AIRS algorithm/NUCAPS, Barnet et al. ATBD 2021)

- Combined use of MODIS/VIIRS cloud products with ATMS in tropical cyclone studies (Han et al, 2016)

- VIIRS radiance cluster in CrIS BUFR (Wang et al. 2023, EUMETSAT conference)

- Collocated VIIRS radiance and ATMS for all-sky radiance assimilation (Zhu et al. 2016 https://doi.org/10.1175/MWR-D-15-0445.1; Liu et al, 2021)

IR Imager vs. Sounder observations (better spatial resolution)

- The probability of a complete cloud free sounder (such as CrIS or ATMS) FOV is very low
- Algorithms perform retrievals or assimilation in cloud free and partially cloudy scenes
- In partially cloudy IR sounder FOVs, cloud cleared radiance can be retrieved only if there exists a subpixel level cloud information
- Imager (such as VIIRS) radiance can be used to identify cloud inhomogeneity within sounder FOV and therefore to calculate the percentage of clear pixels (cloud fraction)
- IR imager adds more information to sounder observations

Methodologies

Assumptions:

- Sounders have low spatial resolution; thus Imagers provide cloud fraction information within sounder FOV
- Microwave sounders penetrates clouds, while infrared images detects clouds
- The combined use of MW and IR image adds benefits

Two methods:

Method 1: Use of Imager Cloud Products (fraction, height) to collocated with IR sounder

Examples: Han et al. 2016: Use of percent cloudy pixels within sounder FOV

Method 2: Use of Image IR radiances to collocate with IR sounder

Example: Wang et al. 2023: use of VIIRS radiance cluster within CrIS FOV

Combined use of IR Imager with IR Sounder in Data Assimilation

ECMWF Experience:

- IASI/AVHRR implementation in Level 1C data (Cayla, 2001)
- Cloud fraction from imager helps quality control in DA (Eresmaa, 2014)
- Distinguish homogeneous clouds (Farouk et al, 2019)
- Significant impact: reduction in counts assimilated with higher quality (Burrows, 2022)

Geostationary Imager and Sounder:

- AGRI/GIIRS (Gong et al. 2024, IEEE TGARS)
- Future missions: MTG, Himawari-10, and GeoXO/GXS

JPSS:

- Collocated VIIRS “cloud products” with CrIS (impacts not as significant as expected, Jungs)
- VIIRS “radiance cluster” implementation (Wang, 2022)

VIIRS radiance cluster collocated with CrIS FOV

The Algorithm (Wang et al. 2022):

- Traditional K-Mean cluster unsupervised classification algorithm (Lloyd 1957) applied to all VIIRS IR channels

- 7 clusters per band, with mean, std, coverage per cluster

- Implemented in NOAA CrIS BUFR as of Feb. 2024.

Preliminary Impact assessments by ECMWF

Very positive feedback from ECMWF (Chris Burrows, 2022)

- Assimilation results consistent with that of IASI/AVHRR
- IASI/AVHRR assimilation has very positive impacts on DA
- Expect positive impacts from CrIS/VIIRS radiance cluster BUFR data
- However, more impact assessments are needed

Infrared vs. Microwave Sounder Observations

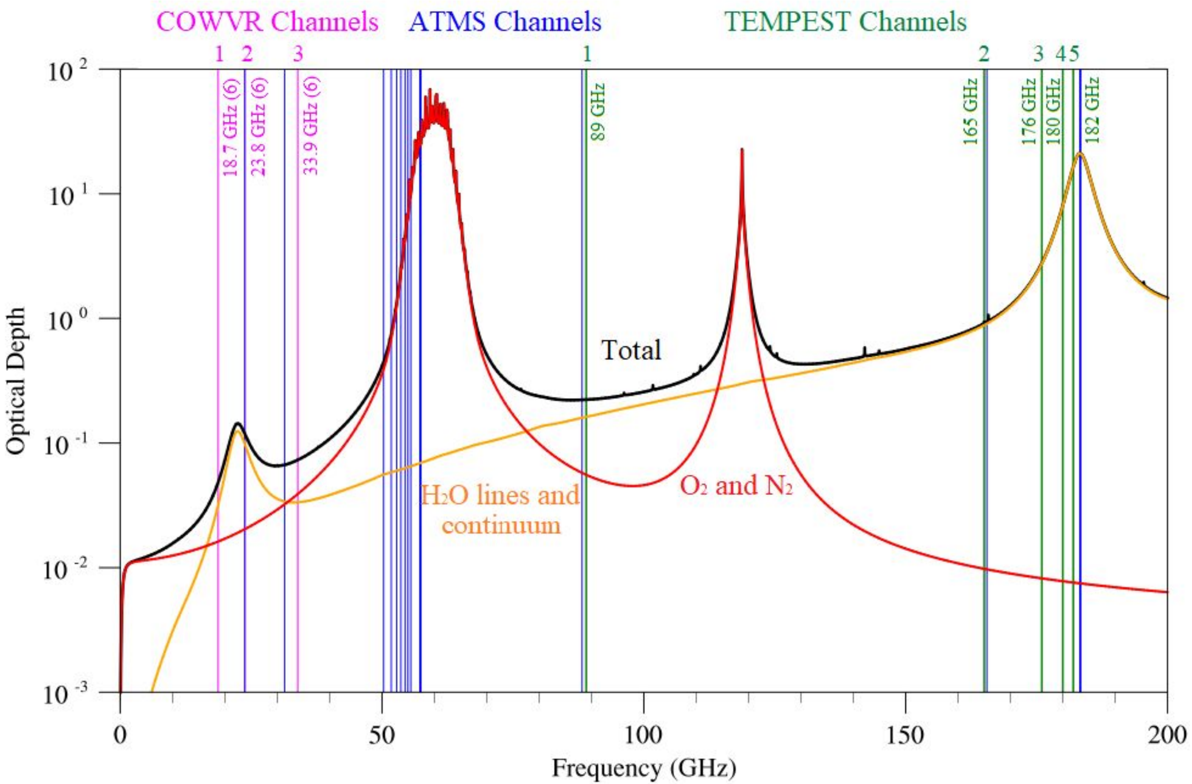
In comparison to imager product (such as VIIRS cloud height and cloud fraction) mapped to infrared sounder (such as CrIS FOV), the ATMS-VIIRS radiance combination have more advantages:

- The VIIRS cloud product with CrIS are for better clear-sky pixel identification while VIIRS radiances with ATMS may lead to **better all-weather radiance assimilation**.
- VIIRS infrared spectral information for CrIS is redundant while VIIRS infrared radiances to ATMS are independent and complementary.
- VIIRS cloud fraction can be very useful because it's control variable in DA currently
  - Recognizing cloud fractions are different between optical and microwave observations
- ATMS FOV is much larger than that of CrIS, thus a complete clear FOV is very rare.

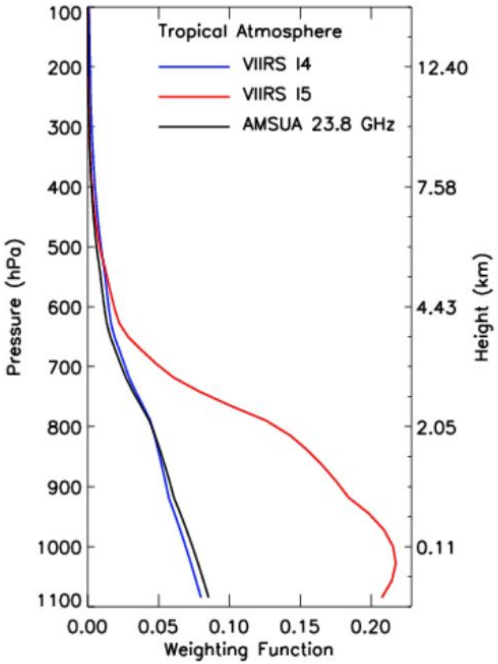
Microwave Sounding Channels

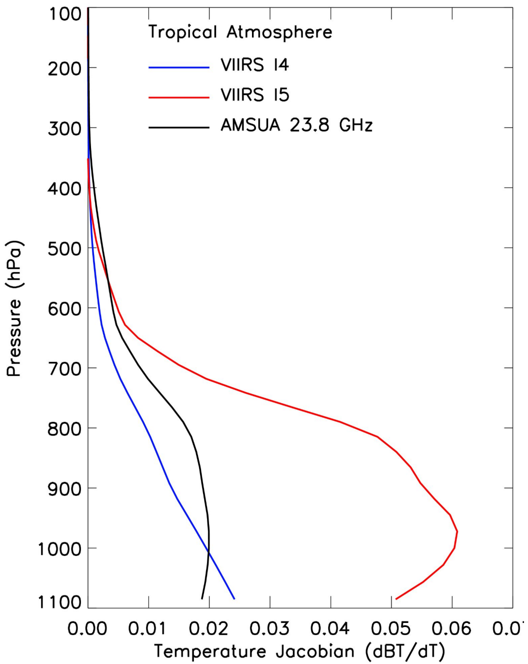
"Window" channel at 23.8GHz

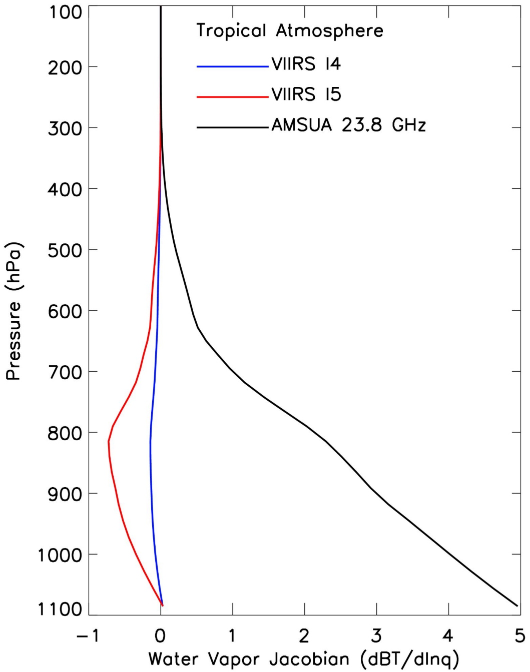
RFI concerns



Comparison of Weighting Function and Jacobian (Over Ocean)



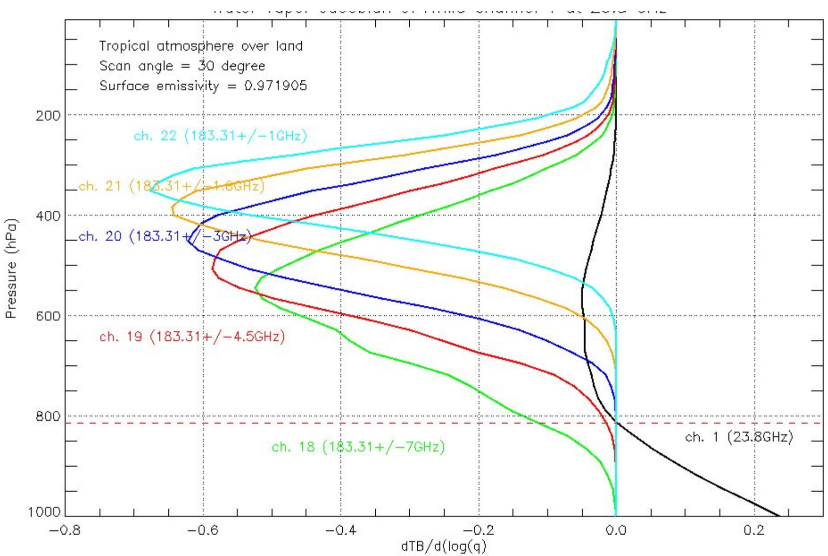




IR 3.7um channel has similar weighting function to MW 23.8GHz, but very different Jacobian to Water Vapor; IR 3.7um channel measures surface temperature much more accurately.

Unique Characteristics of the Water Vapor Jacobian for the 23.8 GHz channel

- The 23.8 GHz channel water vapor absorption was not well understood in the past (often referred to as 'Window Channel'.
- This channel has a positive response to water vapor in the planetary boundary layer (PBL <800 hPa), compared to all other channels which have little response there.
- On the other hand, this channel has a negative response to water vapor in the mid/up troposphere.
- As a result, the "total column" response to water vapor appears to be much reduced, but its unique response to low troposphere has great potential and requires further exploration.

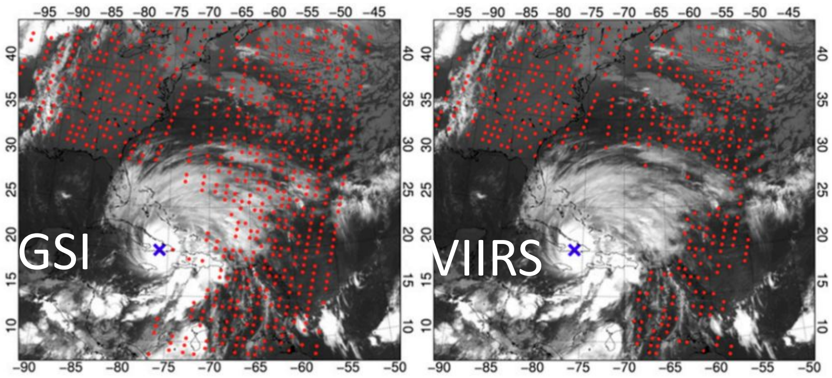


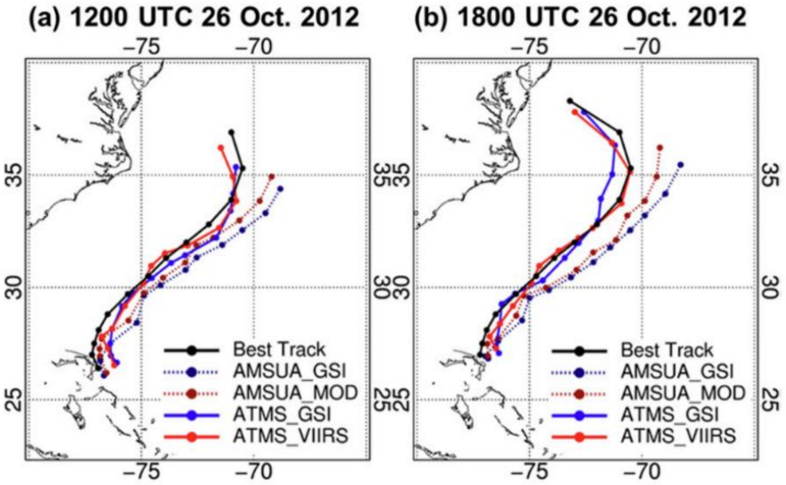
Comparison of Water Vapor Jacobian of the 23.8 GHz vs other channels shows the importance of the 23.8 channel in measuring water vapor in the PBL.

Liu, Q, et al. 2021, Remote Sensing, Vol. 13, No. 3.

The Use of VIIRS Cloud Product for Hurricane Tracking

- Han et al. (2016) studied the impact of VIIRS cloud detection in ATMS assimilation for Hurricane Sandy
- Shown very positive impacts:
  - Improved forecast by 0–38 km for the track and 0–3 hPa for SLP(Sea Level Pressure)
  - Optimal cloud fraction (CF) experimented (60-90%)
- ATMS/VIIRS outperforms AMSU/MODIS (lack of water vapor channels)





Courtesy of Han et al. 2016

Synergistic use of VIIRS with ATMS

Experiments (in progress)

- Clear sky only (different definitions in MW and IR)
- Cloud product (cloud fraction, and cloud height);
- Determine surface temperature more accurately with IR, and then help estimating MW emissivity
- How VIIRS radiance can improve MiRS retrieval accuracy

Data assimilation (long term goal)

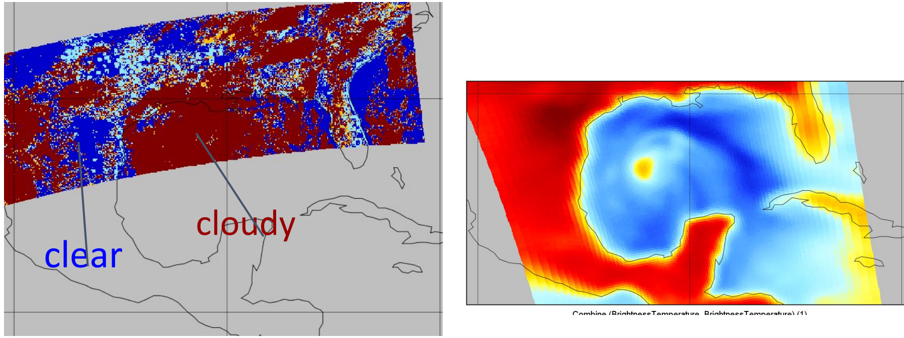
DA experiments

Hurricane Beryl Observations

- ATMS vs. VIIRS

Use of VIIRS Cloud Product with ATMS

- Definition of cloudiness is different in MW vs. IR
- MW not sensitive to as many types of clouds as VIIRS
- Can the VIIRS cloud info be useful for MW retrievals?

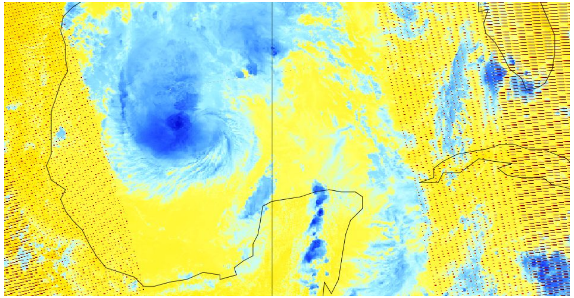


MiRS clear pixel 82%; VIIRS clear pixels 30-60% depending on % clear within ATMS FOV (Zhou 2024)

Use of VIIRS Radiance with ATMS

- More useful information than cloud products
- Collocating within MW FOV
- Unsupervised vs. supervised classification
- Better classification algorithm
- Use of AI/ML
  - Autoencoder
  - CNN/RNN/GAN
  - AI PCA

VIIRS Pixels inside 1 ATMS FOV



IR channel radiance provides more info

Summary

- ECMWF has demonstrated significant impact of IR image for hyperspectral sounder in direct radiance assimilation for NWP for more than a decade
- NOAA NESDIS has implemented the VIIRS radiance cluster in CrIS BUFR data, in addition to the VIIRS cloud products, although experiments are still needed to demonstrate the impacts for NWP
- Next step is to explore the impact of IR imager radiance for Microwave retrievals and DA, following previous positive but very limited studies with VIIRS cloud products
- The focus will be on the synergistic use of VIIRS and ATMS radiance data including BUFR data generation
- We welcome feedbacks and collaboration (such as DA collaboration partners)

References

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Han, Hyojin et al., 2016, Microwave Sounder Cloud Detection Using a Collocated High-Resolution Imager and Its Impact on Radiance Assimilation in Tropical Cyclone Forecasts, Monthly Weather Review, 144(10), 3937-3959, https://doi.org/10.1175/mwr-d-15-0300.1

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Wang, L., L. Zhou, H. Sun, B. Yan, S. Kalluri, and M. Goldberg, 2022: VIIRS Radiance Cluster Analysis within CrIS Supporting NWP Data Assimilation, 2022 EUMETSAT Meteorological Satellite Conference, Brussels, 19-23 September 2022

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