Interpretation and Application of Microwave Imagery and Scatterometry

2020 RA-IV WMO Tropical Meteorology Course
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Outline

• Overview of basic principles/availability of microwave sensors

• Orbital characteristics

• Single frequency channels

• Color composite images

• Scatterometry

• Exercise

* Acknowledgements to COMET, NRL, and FNMOC for many of the images shown here
Advantages of Microwave Images?

Hurricane Delta, 22Z 5 October
Max winds ~65 kt, just prior to RI
Passive sensors (SSM/I, SSMIS, AMSU, AMSR2, etc.) measure emitted microwave energy from 19 to 200 GHz.

Emissivities are directly related to \textit{brightness temperatures} ($T_b$):

- scattering effects by ice
- emission by light precipitation
- emission/absorption by cloud liquid water and rain droplets

Microwave window channel $T_b$ can be used to quantify these emissivities.

Image courtesy COMET
Overview of Remote Sensing Basics

- 85-GHz images → primary signature is \textit{lowered} $T_b$ caused by \textit{ice scattering} and \textit{cloud and rain droplets} within deep convection and precipitating anvil clouds.
Overview of Remote Sensing Basics

- 37-GHz images → primary signature is elevated $T_b$ because of minor emission from liquid hydrometeors near or below the freezing level.

Image courtesy COMET
Remote Sensing Satellites - Orbits

- Geostationary (GEO) satellites
  - Orbit at 35,800 km altitude over same spot on the equator
  - Good for continuous monitoring on a large scale
  - Good for visible and infrared, not good for microwave
  - Good for passive, not good for active

- Low earth orbit (LEO) satellites
  - Good for microwave (active and passive), visible, and infrared
  - Lower altitude orbit, but not over same spot on earth
  - Limited spatial coverage (narrow swaths of data)
  - Views each area only twice per day “snapshots” (except near poles)
  - Depending on orbital configuration, can cover nearly entire globe each day
• LEO satellites are not continuously in view of data receiving stations
• They can only download data when in range of those stations, which leads to delays in data transmission and processing by a couple of hours for most cases.
Measuring Electromagnetic Energy

- **Passive Instruments:**
  - Receive radiation leaving the earth-atmosphere system
  - Measure solar radiation reflected by earth/atmosphere targets (visible light)
  - Measure emitted and scattered infrared radiation
  - Measure microwave radiation resulting from emission and scattering

- **Active Instruments:**
  - Send out pulses of radiation, usually at microwave frequencies
  - Measure radiation returned to the sensor
  - Examples
    - Surface-based and airborne radars
    - Satellite scatterometers
Key Characteristics of Microwave Radiation

- **Water surfaces** (e.g., oceans) have low emissivity (~0.4-0.5) and appear “cold” at microwave frequencies
- **Land** surfaces have a much greater emissivity (~0.9)
- **Raindrops** have high emissivity and are “warmer”; they contrast against a “colder” ocean background
- Higher frequency (shorter wavelength) microwaves (~85 GHz) are scattered by ice particles in precipitating clouds, reducing radiation reaching the satellite (these regions also look “cold”)
Current/Operational Microwave Imagers and Sounders

- AMSU-A/B: 6 satellites (NOAA 18/19) and European MetOP-A/B
- SSM/I: 1 DMSP satellite (F-15)
- SSMIS: 3 DMSP satellites (F-16, F-17, F-18)
- GMI–GPM: JAXA/NASA
- AMSR2-GCOM W1: Japan (JAXA)
- WindSat: Navy NRL Coriolis (37-GHz Only)
- ATMS: NASA
- SAR: NASA
Orbital and Scan Characteristics
GEO vs. LEO Orbital Altitude Comparison

Geostationary Satellite
35,800 km altitude

mean distance to moon = 384,400 km

17.4°

Polar Orbiting Satellite
850 km altitude

earth radius = 6,370 km

typical shuttle orbit = 225 – 250 km
Hubble Space Telescope = 600 km

Image courtesy of http://www.nrlmry.navy.mil
Sun-Synchronous Daily Orbital Path

~12 hr to observe the entire Earth
Same location twice daily (ascending/descending)
Cross Track Scan Strategy

- **Advantage**: Larger coverage swath relative to conical scan

- **Disadvantage**: Resolution varies across the swath (coarser resolution at swath edge relative to nadir)
Cross Track Scan Strategy

AMSU Scanning Geometry and Resolution
Cross Track Scan Strategy

Note degradation in resolution at edge of scan compared to nadir

Images courtesy COMET
Conical Scan Strategy

- Advantage: Resolution remains constant because scan footprints are the same size throughout the entire swath.

- Disadvantage: Narrower coverage swath relative to cross-track scan.
Conical Scan Strategy

Resolution remains constant across swath

Images courtesy COMET
Imagery Characteristics and Applications
85-GHZ Imagery Interpretation

- Imagery can penetrate through clouds and reveal internal storm structure.
- Imagery is better at locating tropical cyclone centers than conventional visible and infrared.
- Land appears warm relative to water surfaces.
- Water surfaces and deep convection appear relatively cold (due to scattering from ice).
- Imagery can not always see low-level circulations associated primarily with low-level clouds.
- Offers higher spatial resolution than imagery at lower microwave frequencies.
37-GHZ Imagery Interpretation

- Precipitating clouds and land surface appear **warm**
- **Cold** features: sea surface only
- Imagery highlights low-level cloud features and storm structure
- Imagery identifies cirrus-covered eyes and gives a ‘true’ low-level center instead of a mid/upper-level center (as in 85-91 GHz imagery)
Advantages of Using 85-GHz and 37-GHz Imagery for TC Analysis

• In a sense, “sees” through clouds
• Identification of circulation center (critical step in initiating TC advisories)
• Acquire positioning of TCs in difficult situations (especially in early stages of development and at night)
• View of convective rain bands that is directly related to intensification of the TC
• Monitoring structural changes such as eyewall formation and eyewall replacement cycles
Effects of Resolution

- Comparison of 36/37-GHz color composite imagery over TS Philippe from AMSR-E (left) and SSMIS (right) at 0432 UTC and 0830 UTC 28 September 2011, respectively – Images courtesy FNMOC TC webpage

- Higher resolution of AMSR-E makes center location much easier to find relative to lower-resolution SSMIS
Effects of Resolution

- Resolution differences also affect the ability to resolve low to mid-level eyewall structure

Comparison of 36/37-GHz color composite imagery over Hurricane Maria from AMSR-E (left) and SSMIS (right) at 1739 UTC and 2018 UTC 15 September 2011, respectively – Images courtesy FNMOC TC webpage
Importance of Center Location

- Locating the center is critical for the initial motion, initializing model guidance, and assessing the organization and intensity of the cyclone.

- Dvorak estimates are very sensitive to incorrect center locations at certain stages of development, especially for sheared systems and systems with embedded centers in infrared imagery.

Tropical Storm Rosa – 9 November 2006

There is a large difference in the Dvorak intensity estimate if the center is located in the deep convection or exposed well to the west.
Parallax Error in Center Fixing

• Satellite-derived position error exists, potentially up to 20 km (~10.8 n mi) from actual position

• Occurs due to conical viewing angle and/or viewing geometry of the satellite

• Higher parallax error in 85-GHz images since scattering hydrometeors produce a signature much higher in the eyewall at 85 GHz than at 37 GHz
85-GHz Parallax

- Ice Crystals (85 GHz)
- Raindrops (37 GHz)

Effective Level of hydrometeors

10-12 km

Release of latent heat

Warm ocean

Moist air

500-2000 km

X

Y

85 GHz Parallax
37-GHz Parallax

- Ice Crystals (85 GHz)
- Raindrops (37 GHz)

Effective Level of hydrometeors

37 GHz Parallallax

30
Eye Size Example
Always use the lowest frequency, which corresponds to the lowest altitude, for center positioning in order to avoid parallax error.
Example of dense ice as coldest $T_b$
**Color Composite Imagery**

- Color composite images combine PCT with V and H polarizations to remove ambiguities between convection and the sea surface.

  - **85 color composite** - PCT (red), V (blue), H (green)
    - Deep convection (red)
    - Low-level clouds, water vapor, warm precipitation (blue-green)
    - Relatively cloud-free (gray or black)

  - **37 color composite** - PCT (red), V (green), H (blue)
    - Deep Convection/intense ice scattering (pink)
    - Rain/clouds (cyan)
    - Sea surface (green)
• 37-GHz PCT (37H/37V composite) depicts weak Cu lines surrounding the LLCC
• 85-GHz PCT fails to define the weaker Cu lines and indicates that the center may be further south
Access to Online Microwave Imagery
NRL Tropical Cyclone Webpage
https://www.nrlmry.navy.mil/TC.html
Try to position in the rain-free dry area—out of the convection
Positioning in Microwave Imagery

Look for convective free darker areas
Anticipating the location of the LLCC based on vertical wind shear creating asymmetry in the deep convection pattern helps, **BUT** it can **not always** be used as an absolute as this case clearly indicates.
Positioning in Microwave Imagery

Look for low cloud curvature
Where is the center?
37 GHz Example

Well-defined low-level eye
21/2346Z Reconnaissance Aircraft Position
16.6N 60.2W
Low-level recon center position at 21/2346Z
Low-level recon center position at 21/2346Z

mid-level eye or 'sucker hole'?
Less than 2h later, a new low-level center/eye developed beneath the mid-level eye; pressure decreased 10 mb.
Hernan near peak intensity
9 Aug 2008
Hernan Eyewall Replacement Cycle 24 h later
10 Aug 2008
Precursor Structure Before Rapid Intensification

- A closed low-level ring of convection in 37-GHz imagery can be a precursor signal to rapid intensification *IF* other environmental factors (e.g., vertical wind shear) are favorable.

- In the case shown here, Patricia strengthened an incredible 90 kt from 60 kt to 150 kt in only 24 hours!
Satellite Ocean Surface Vector Winds

Image courtesy EUMETSAT
Scatterometry Basics

- Scatterometer → **ACTIVE** microwave imager

- Microwave energy is sensitive to small-scale roughness of the ocean surface that is generated by surface winds

- By viewing the same patch of ocean from several angles, it is possible to derive wind speed and direction

Images courtesy COMET
Advanced Scatterometer (ASCAT)

Satellites: MetOp-1, -2, -3
Launched: 2006, 2012, 2018
Operator: EUMETSAT

Sensor: Microwave radar
Channel: 5.25 GHz (C-band)
Swath: Two 550-km swaths; 670 km nadir gap
Advanced Scatterometer (ASCAT)

- 25- and 50-km ASCAT wind vector products available online: https://manati.orbit.nesdis.noaa.gov/datasets/ASCATData.php

**Benefits**
- Long-term, operational scatterometer series
- C-band scatterometer is less susceptible to rain contamination than legacy Ku-band instruments
- High-quality data for TC wind speed/radii analysis

**Limitations**
- Gaps over the tropics reduce spatial coverage, and swaths may miss features of interest
- Spatial sampling/resolution leads to a low wind speed bias for stronger TCs
- Directional ambiguity
Scatterometer Ambiguity

- Wind direction is derived by determining the angle that is most likely consistent with the backscattered energy.

- The best fit usually matches the true wind direction.

- But what if it doesn’t?
  - Look at ambiguities to view other possible directions and identify the most likely solution.

Images courtesy COMET
Ambiguity Analysis

• ASCAT ambiguities can be used to help assess appropriate wind directions and improve the center fix for developing TCs
Access to Scatterometer Data

https://manati.orbit.nesdis.noaa.gov/datasets/ASCATData.php

Hurricane Laura
26 Aug 2020
Other Scatterometer Data

Satellites: SCATSat-1 (2016)
Operator: Indian Space Research Organization (ISRO)

Processed data available through NOAA:
https://manati.orbit.nesdis.noaa.gov/datasets/SSCATData.php

Sensor: Microwave radar
Channel: 13.5 GHz (Ku-band)
Swath: 1800 km

Note: Ku-band more sensitive to rain contamination, which can lead to overestimated winds

Note: Unavailable since 28 Feb 2021 due to an instrument anomaly

Image courtesy ISRO
Other Scatterometer Data

**Satellites:** HY-2B (2018), -2C (2020)

**Operator:** Chinese National Satellite Ocean Application Service (NSOAS)

Processed data available through EUMETSAT:
https://scatterometer.knmi.nl/

**Sensor:** Microwave radar

**Channel:** 13.3 GHz (Ku-band)

**Swath:** 1300 km

**Note:** Ku-band more sensitive to rain contamination, which can lead to overestimated winds
Applications: TC Genesis

- Used as justification to initiate advisories on TD Four-E (later TS Douglas) and set initial intensity at 30 kt

TROPICAL DEPRESSION FOUR-E DISCUSSION NUMBER 1
NWS TPC/NATIONAL HURRICANE CENTER MIAMI FL EP042008
800 PM PDT TUE JUL 01 2008

ASCAT DATA AT AROUND 16Z SHOWED THAT THE LOW PRESSURE AREA SOUTHWEST OF MANZANILLO MEXICO HAD A BROAD CENTER ELONGATED NORTH-NORTHWEST TO SOUTH-SOUTHEAST. SINCE THAT TIME...SATELLITE IMAGERY INDICATES THAT THE CIRCULATION AND ASSOCIATED SHOWER ACTIVITY HAS SOMEWHAT CONSOLIDATED AT THE SOUTHERN END OF THE ELONGATION. BASED ON THIS...ADVISORIES ARE INITIATED ON TROPICAL DEPRESSION FOUR-E. THE INITIAL INTENSITY IS 30 KT IN AGREEMENT WITH SATELLITE INTENSITY ESTIMATES FROM TAFB AND SAB...AS WELL AS THE OBSERVED WINDS IN THE EARLIER ASCAT DATA.

THE ASCAT DATA SHOWED 25-30 KT WINDS IN A BAND THAT IS CURRENTLY ABOUT 200 N MI FROM THE CENTER IN THE NORTHEASTERN QUADRANT. WHILE THE CENTER OF THE CYCLONE IS EXPECTED TO REMAIN WELL OFFSHORE...
• Reduced ASCAT rain contamination and prevalence of 3\textsuperscript{rd} and 4\textsuperscript{th} ambiguities in areas of low winds can help make center fixing easier.
Applications: TC Intensity Analysis

• **Reminder:** ASCAT cannot be used to determine the peak intensity of stronger tropical storms or hurricanes
Applications: Cyclone Phase Transition

Tropical Storm Epsilon
Applications: Extratropical Transition
Applications: Marine Surface Analysis

- Surface troughs/tropical waves
- Orientation of the surface ridge axis
- Extratropical cyclones and fronts
Questions?