Advances in Airborne Radio Occultation and Contributions to the Atmospheric Rivers Reconnaissance Program 2021

Jennifer S. Haase, jhaase@ucsd.edu

Bing Cao, Michael Murphy, F. Martin Ralph, Minghua Zheng,

Luca Delle Monache, Jack Parrish, Anna Wilson

SCRIPPS INSTITUTION OF OCEANOGRAPHY

UC San Diego

NSF

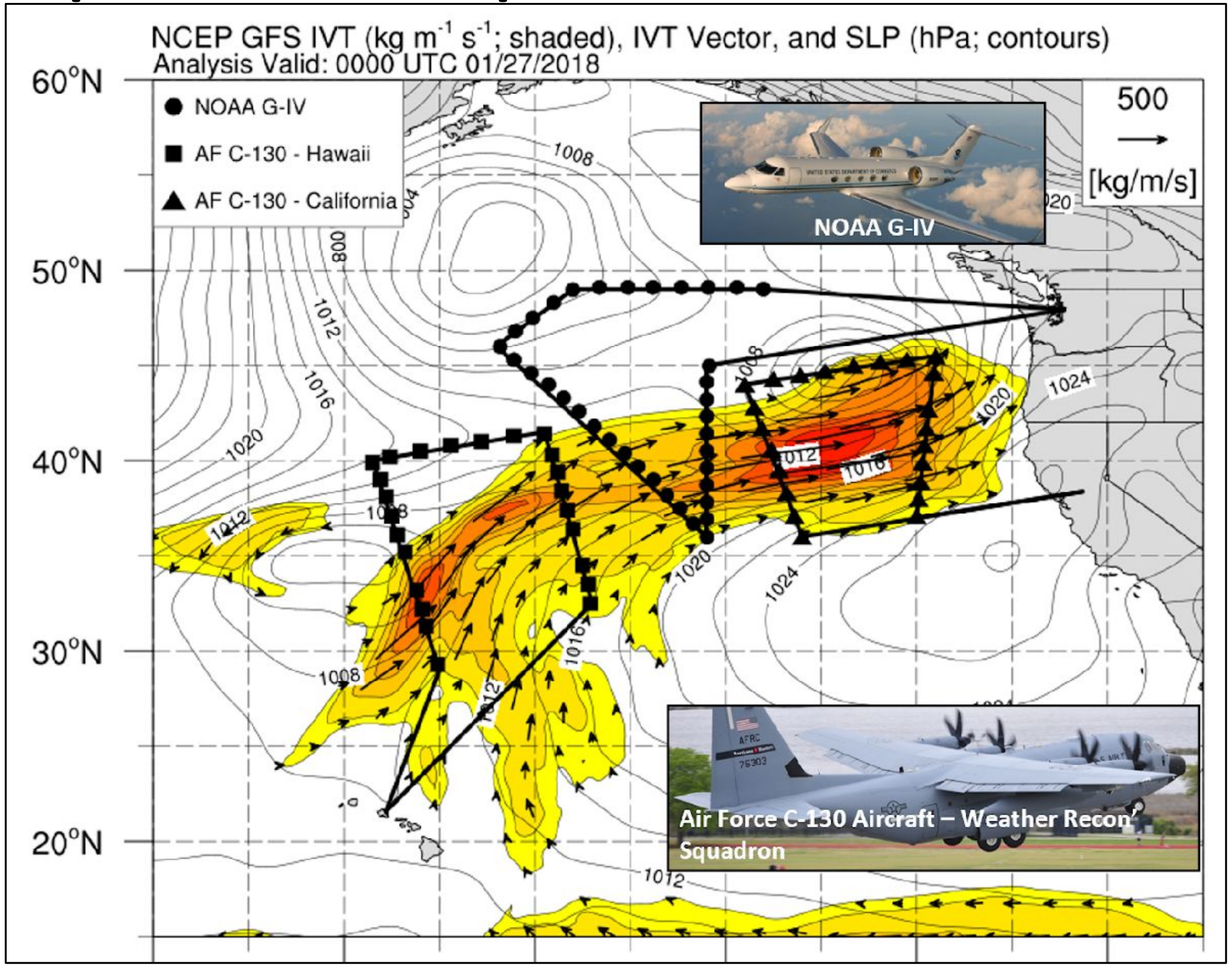
NOAA

CW3E

Office of Naval Research Science & Technology

Atmospheric River Reconnaissance (AR Recon) – a research and operations partnership

- Landfalling AR storms associated with extratropical cyclones account for 84% of the flood damage in western US and 50% of the winter precipitation.
- AR Recon is supported by the Army Corps of Engineers and the California Department of Water Resources, because of the importance of AR forecasting to flood management and reservoir operations linked to water resources management.
- AR Recon collects supplemental offshore observations, with the NOAA GIV and AF C-130 aircraft, to improve initial conditions in NWP models, by targeting sensitive areas identified using adjoint and ensemble model techniques.



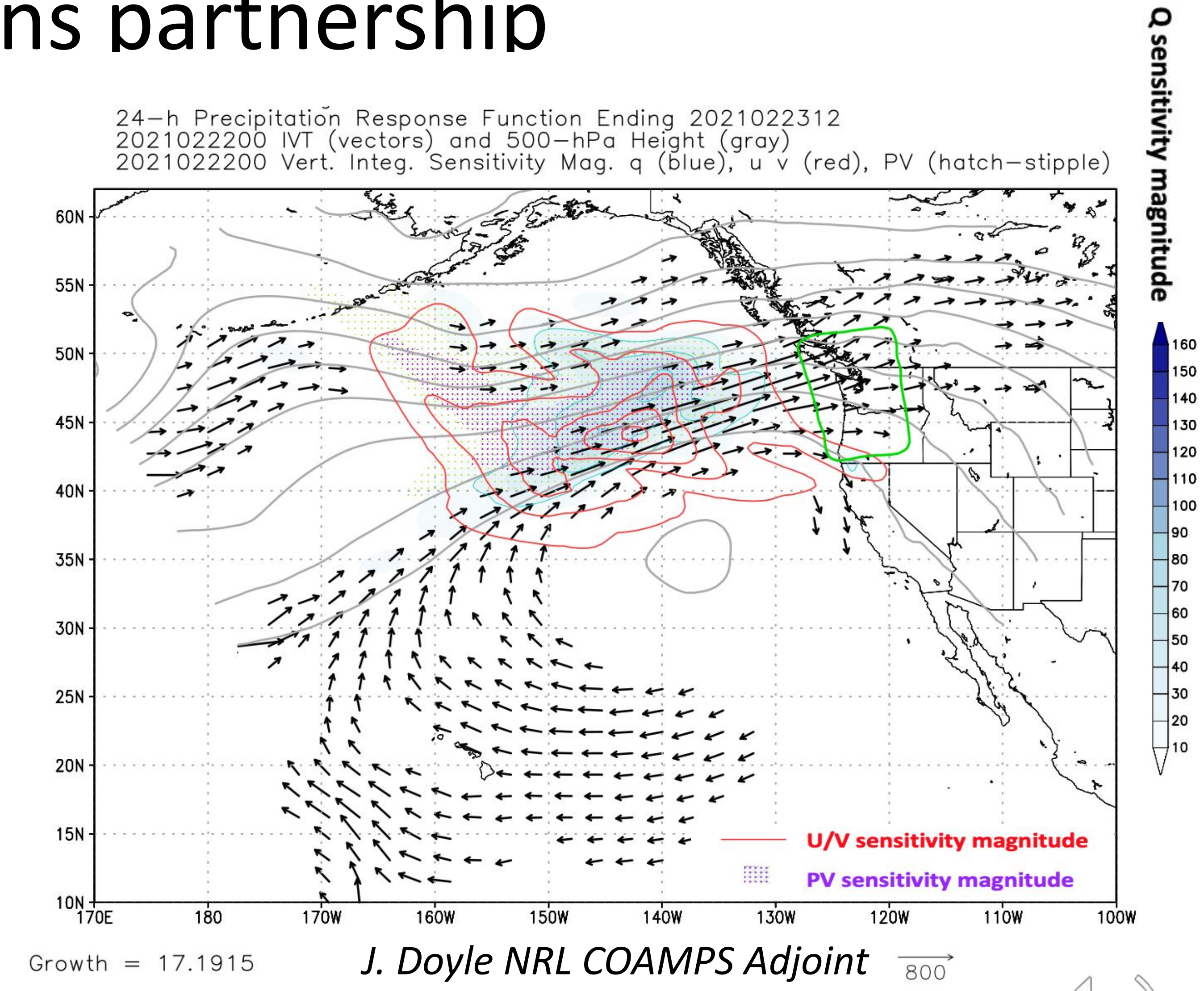
Key Sponsors: US Army Corps of Engineers; CA Department of Water Resources

Center for Western Weather and Water Extremes

AR Recon PI: F. Martin Ralph (UCSD/SIO/CW3E)
Co-PI: Vijay Tallapragada (NOAA/NWS)

Atmospheric River Reconnaissance (AR Recon) – a research and operations partnership

- Landfalling AR storms associated with extratropical cyclones account for 84% of the flood damage in western US and 50% of the winter precipitation.
- AR Recon is supported by the Army Corps of Engineers and the California Department of Water Resources, because of the importance of AR forecasting to flood management and reservoir operations linked to water resources management.
- AR Recon collects supplemental offshore observations to improve initial conditions in NWP models, by targeting sensitive areas identified using adjoint and ensemble model techniques.



J. Doyle NRL COAMPS Adjoint

Key Sponsors: US Army Corps of Engineers; CA Department of Water Resources

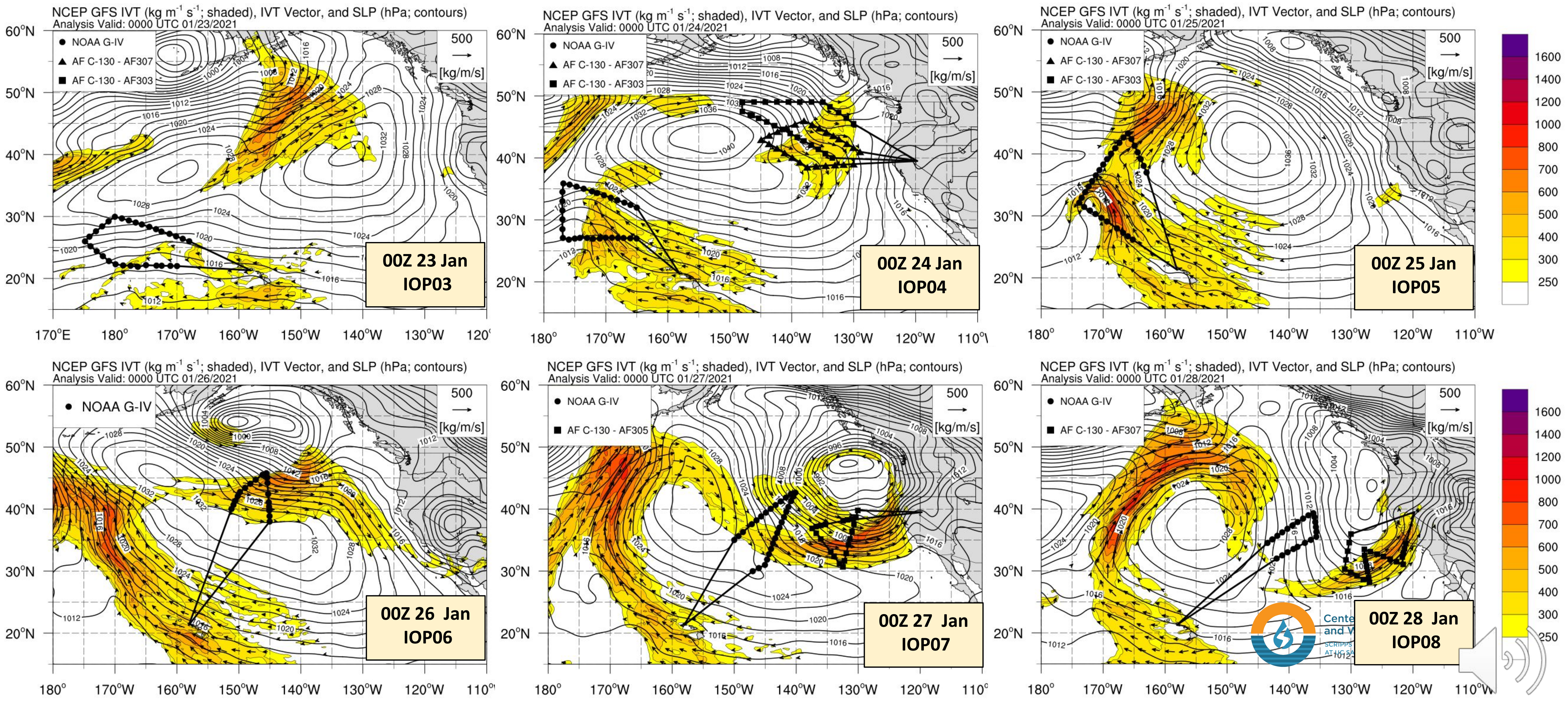
Center for Western Weather and Water Extremes

The Guardian, 6 Feb 21

Monterey County Weekly, 21 Aug 21

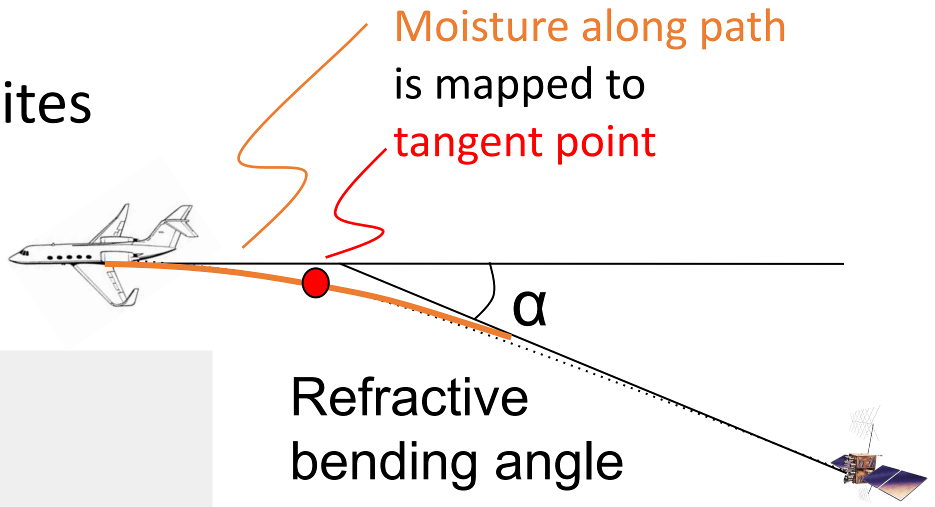
- AR Recon supports water management decisions by allowing better optimization of water storage in reservoirs and forecasts of Sierra Nevada snow pack.
- The effort in 2021 was even more critical given the impacts of flooding on wildfire burn scars.
- Example Atmospheric River event 27-29 Jan 2021
- Big Sur Coast > 220 mm (8.7”) rainfall in 24 hours

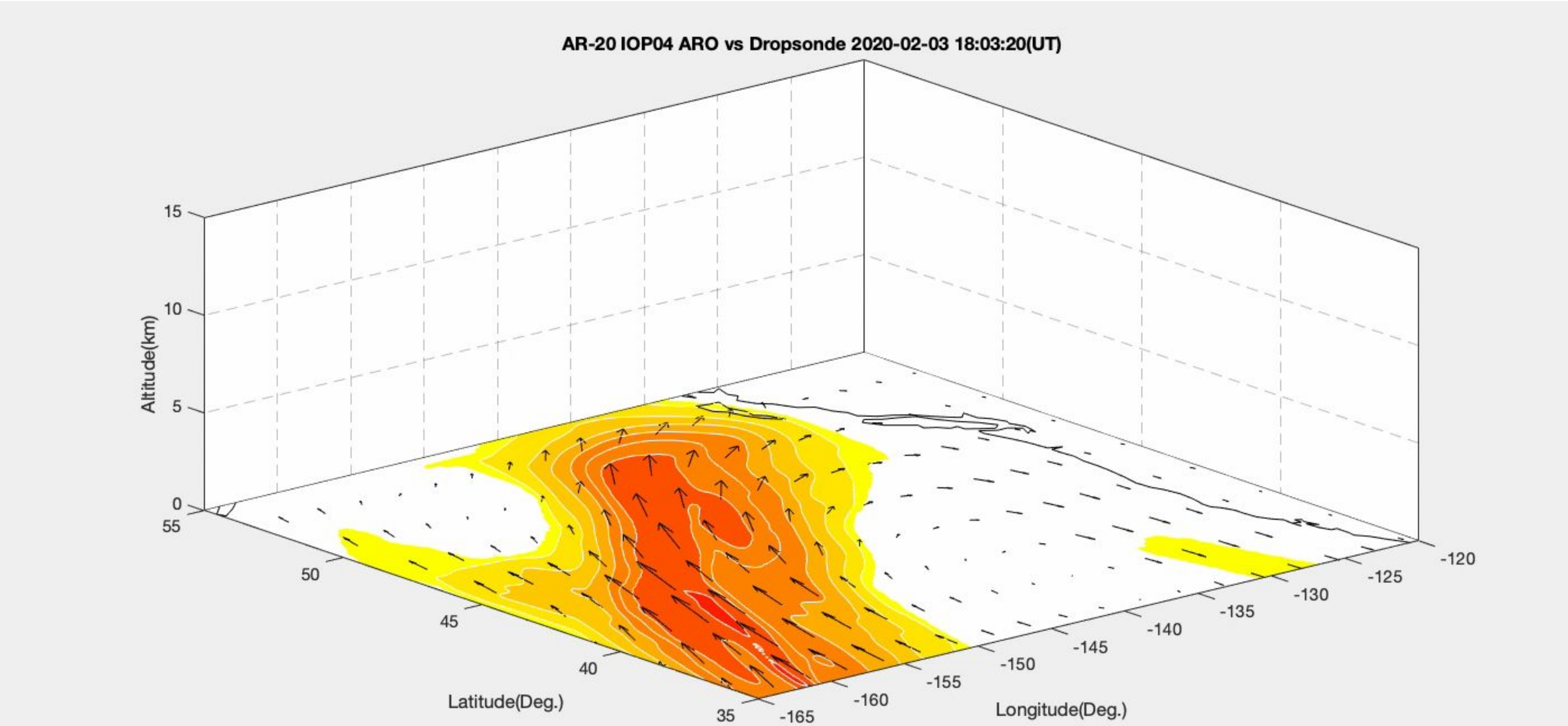
AR Recon 2021 Sequence 1 (23-28 Jan 2021)



Airborne GNSS Radio Occultation

- •Side-looking GNSS receiver tracks setting and rising satellites
- •Nearly horizontal raypaths experience refractive delay





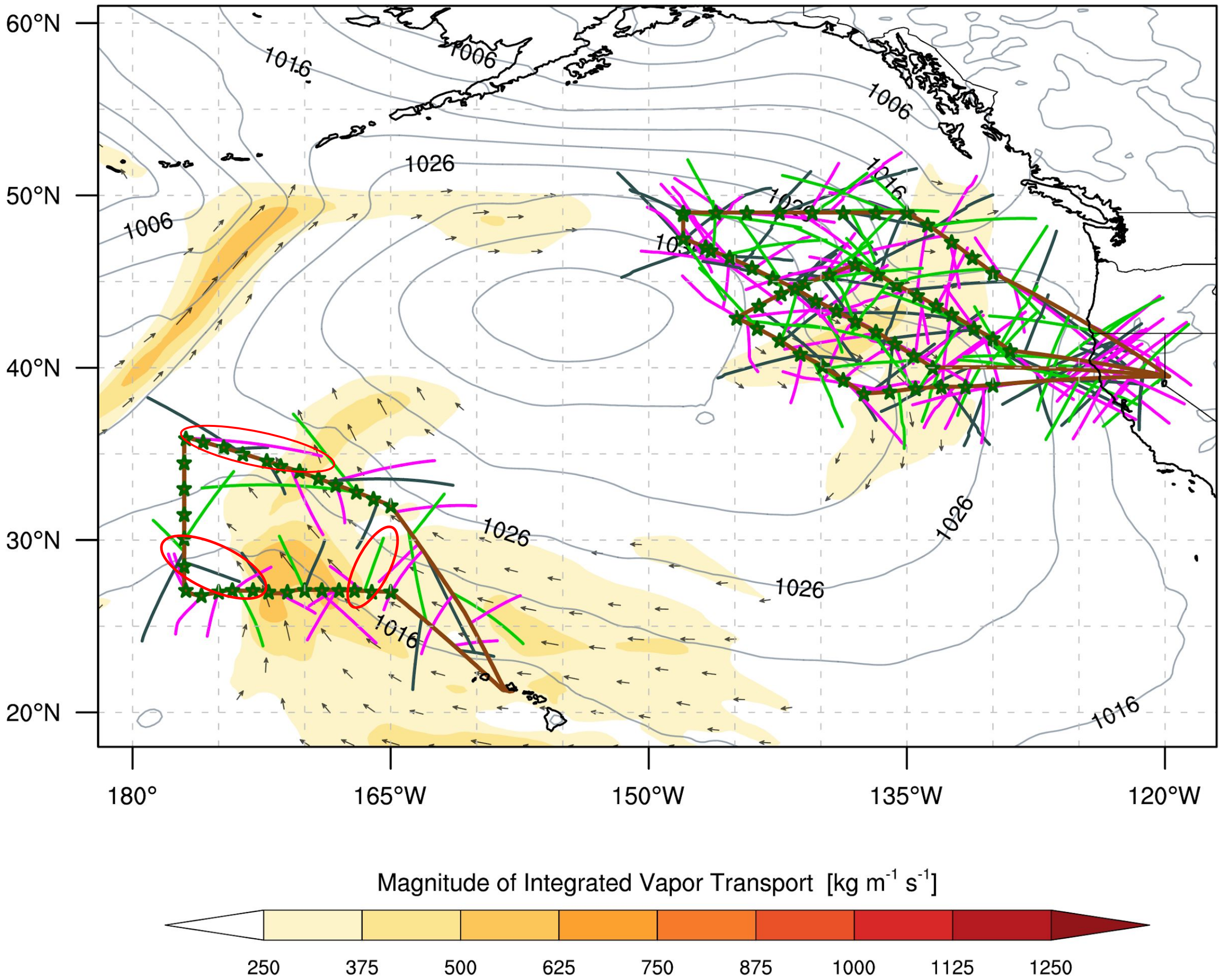
Contours are integrated vapor transport and vectors are direction of transport.

- Atmospheric humidity is a function of refractive delay

$$N = (n-1)\cdot 10^6 = k_1 \frac{P_d}{T} + k_2 \frac{e}{T} + k_3 \frac{e}{T^2}$$

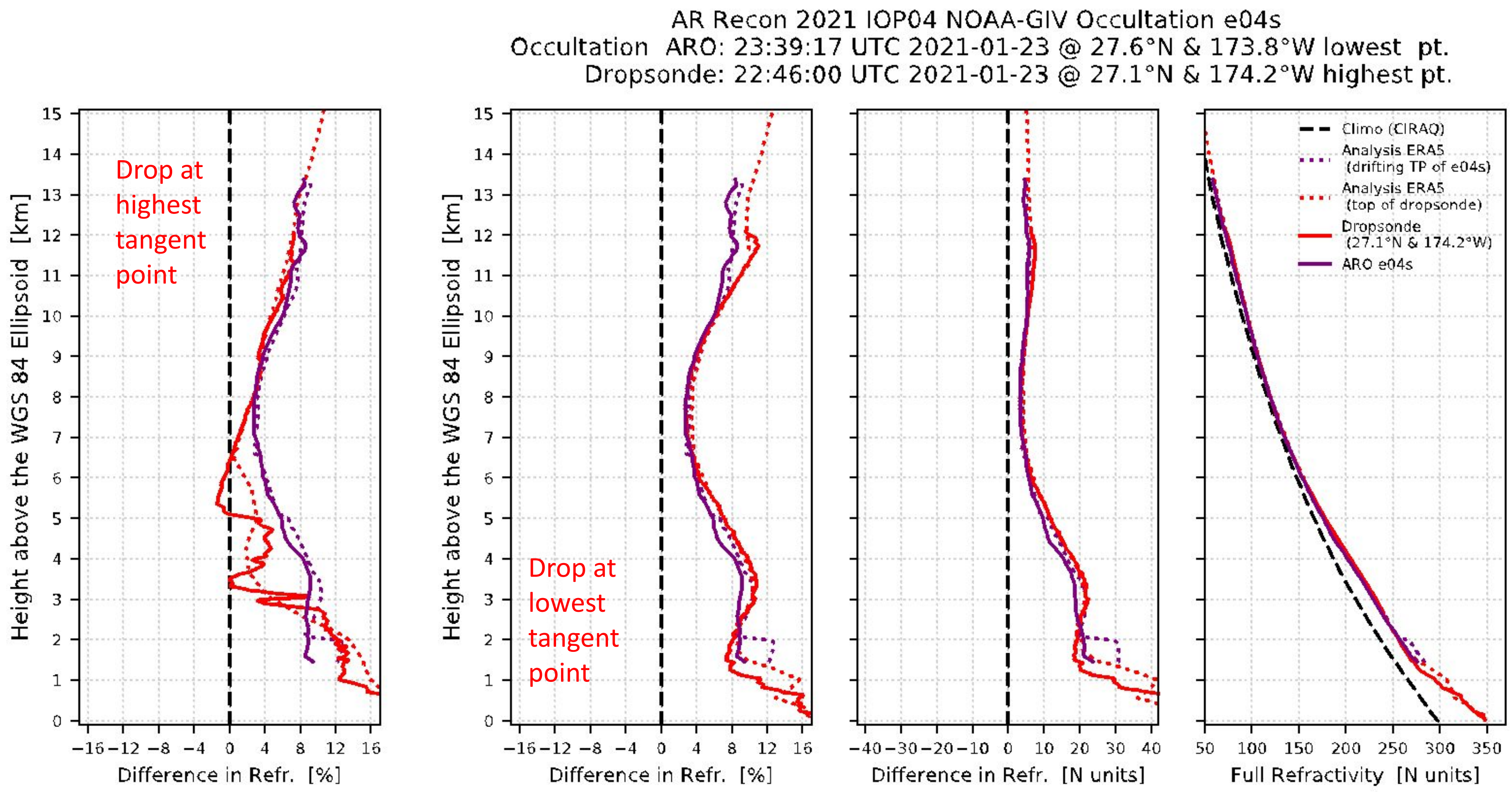
Haase et al., 2014, GRL.

AR Recon 2021 – 00Z 24 Jan IOP04



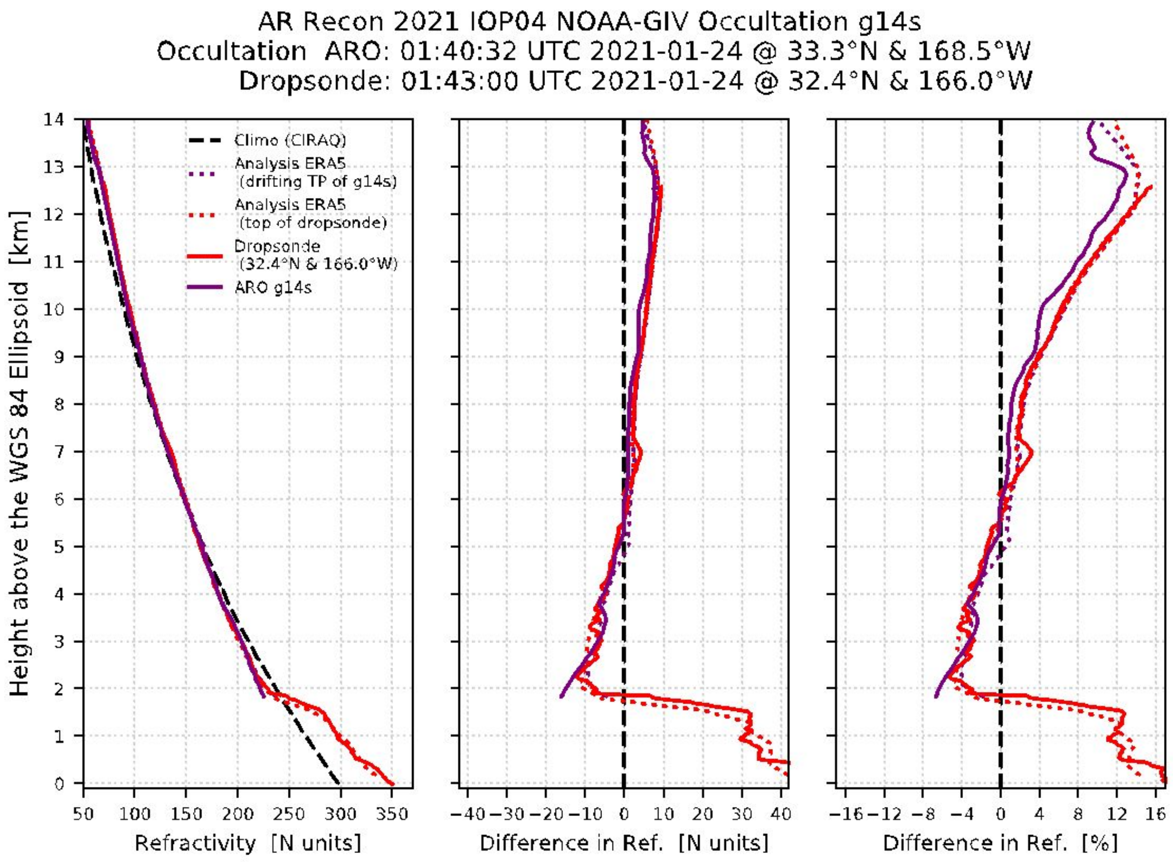
- NOAA G-IV out of Hawaii was tasked with sampling a region of tropical moisture export where a developing subtropical low pressure system would introduce significant uncertainty into the 3-day forecast
  - 44 occultations retrieved from GLONASS, GPS, Galileo
  - 14 reached lower than 3 km
- Hypothetical coverage evaluating potential deployment on C-130s tasked with sampling a moderate landfalling AR feature
  - 126 additional occultations expected from all constellations

AR2021 Observations: Galileo



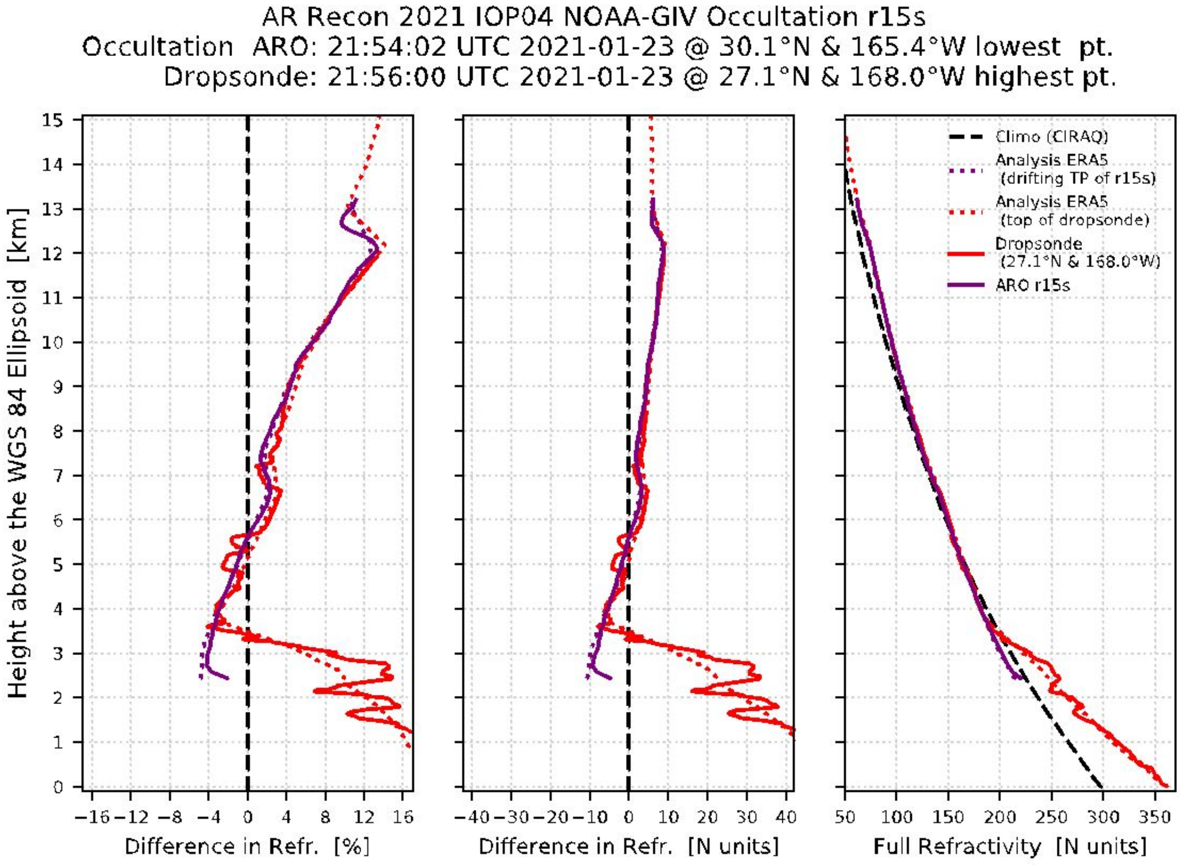
- Galileo occultation
- 400 km tangent point drift matches with several different dropsondes

AR2021 Observations: GPS



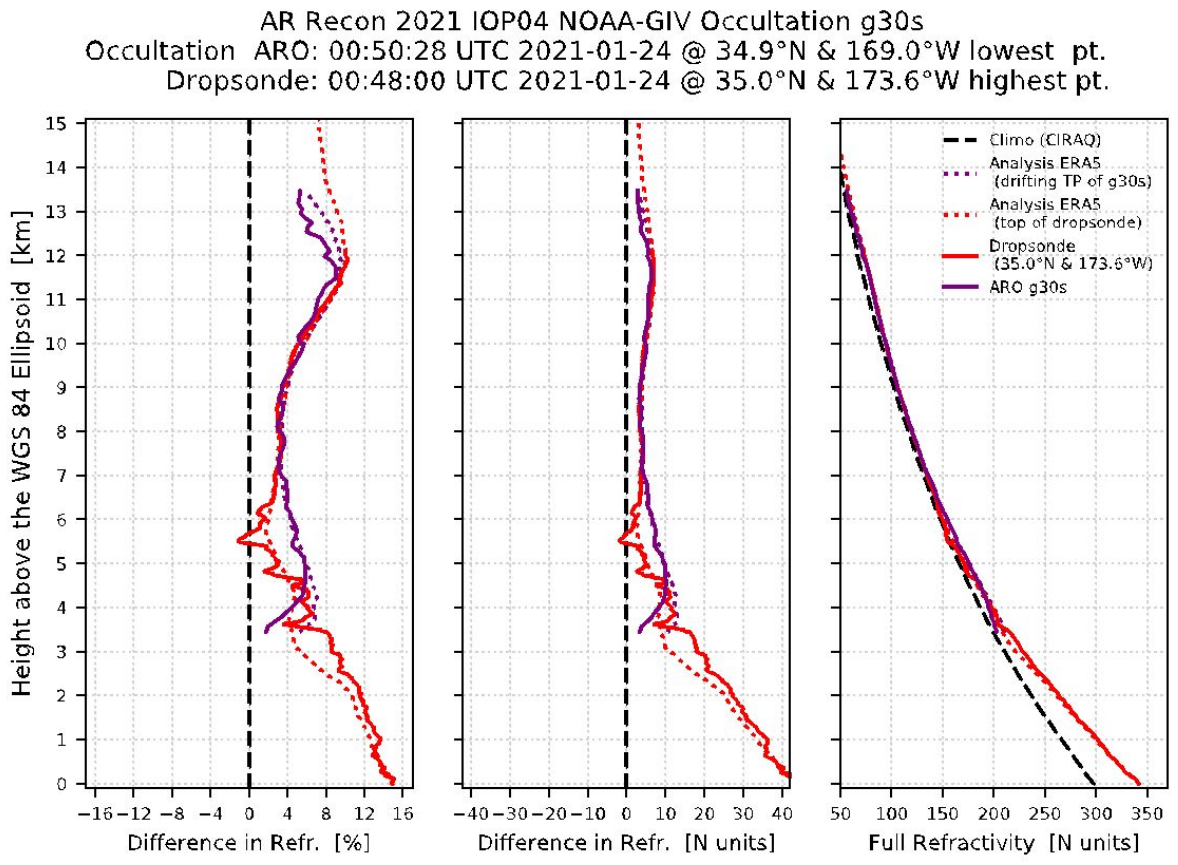
- GPS occultation
- Many extend just to the top of the boundary layer
- They give a very sensitive indication of the boundary layer height.

AR2021 Observations: GLONASS



- GLONASS occultation
- Sharp gradient of moisture is higher as moisture is lifted in this area of tropical convection.
- The ARO profile shows this moisture height varies by 1 km over distances of 200 km (separation between dropsonde and ARO)

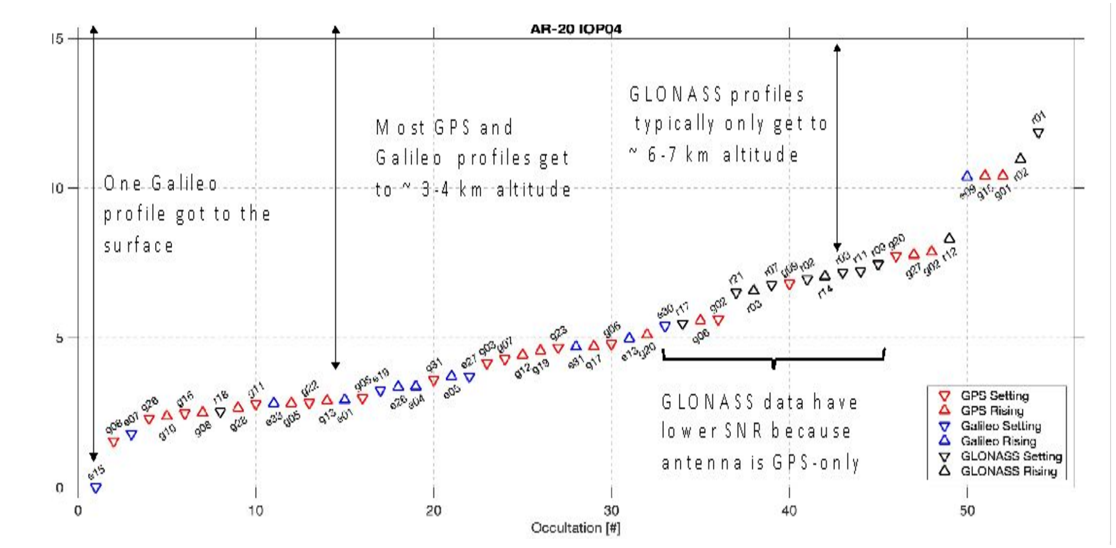
AR2021 Observations: GPS



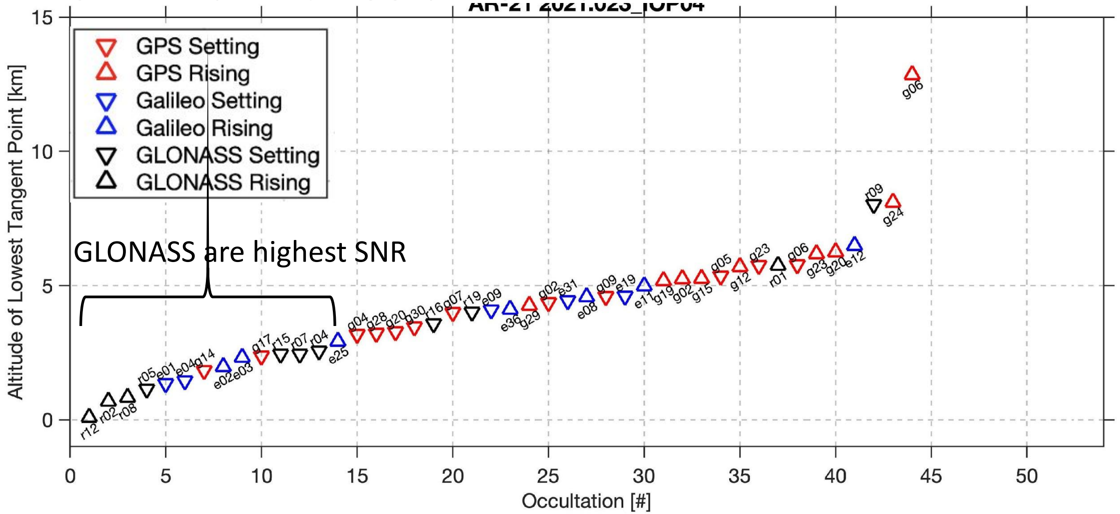
- GPS occultation
- Tend to terminate higher than GLONASS, perhaps because of lower SNR for GPS L2

Improved SNR with multi-GNSS antenna in 2021

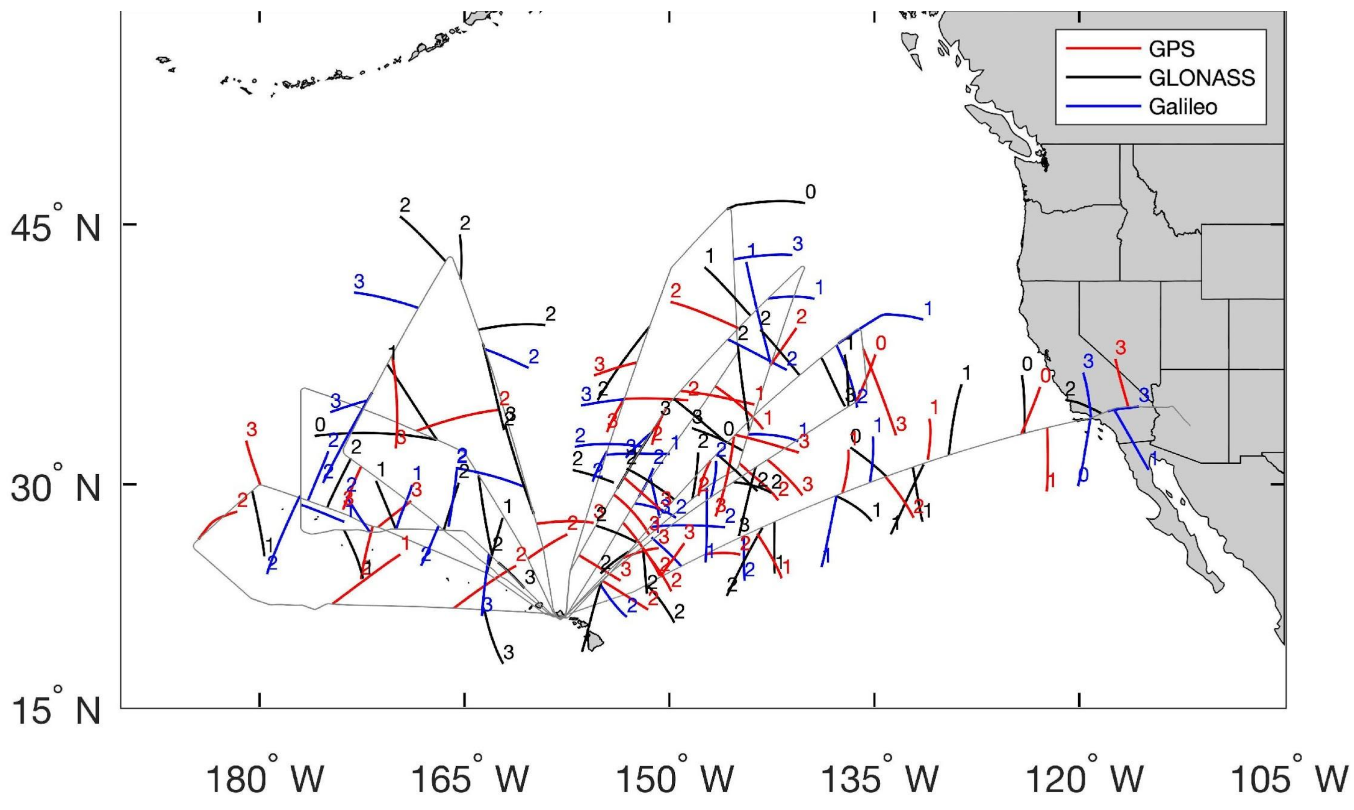
- 2020 GPS only antenna



- 2021 Multi-GNSS antenna



First 7 flights from 2021, profiles with lowest height < 3 km.



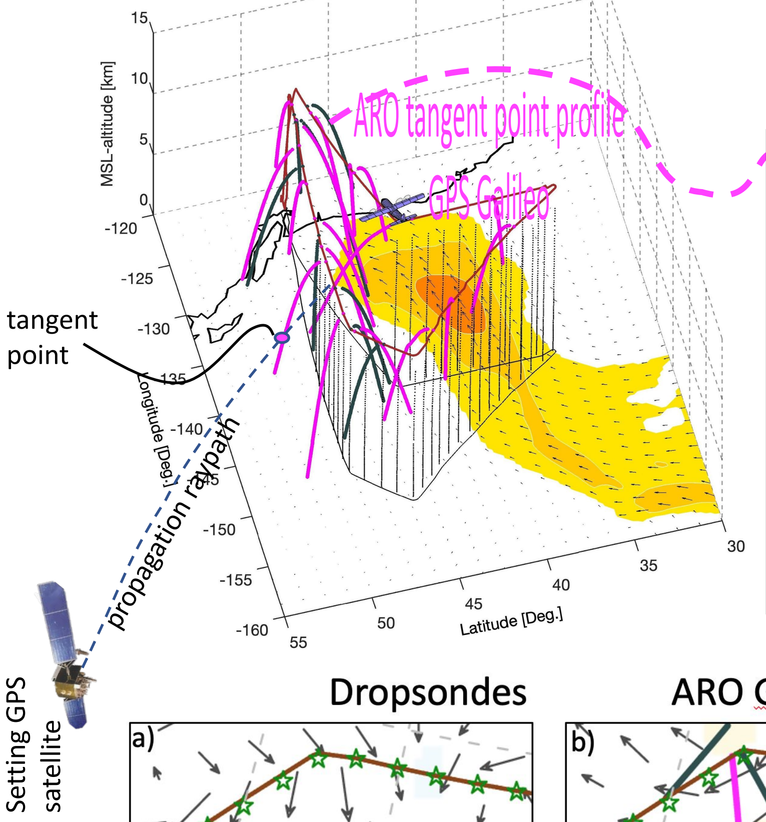
Typical recovery is ~45 profiles per flight.
In the 6 flight sequence, 271 occultation profiles were retreived.
101 profiles extended below 3 km.
These supplement the 131 dropsondes released below the flight track.

SCRIPPS INSTITUTION OF OCEANOGRAPHY

Airborne Radio Occultation on the NOAA G-IV

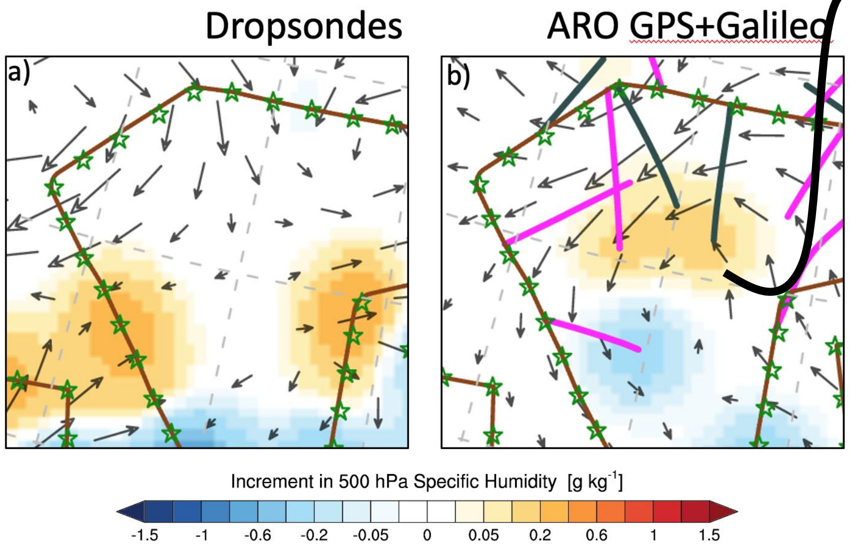
Results from AR Recon 2018

Haase et al., JGR – Atmospheres, 2021, submitted



ARO retrieves a profile of refractivity values at the midpoints of the raypaths each time a GNSS satellite sets.

The refractivity
$N \sim k_1\, p/T + k_2\, e/T^2$
which is the native variable sensed by ARO,
reveals distinguishing characteristics of the dynamic tropopause,
AR low-level jet,
and boundary layer.



ARO modifies the moisture field in areas not sampled by the dropsondes.

The challenge is to observe deeper into the boundary layer with a GNSS signal recorder and open-loop tracking.

ARO deployment during AR Recon
- leveraging support from NASA, NOAA, NSF, ONR


NSF/NASA Dual-pol side-looking antenna

NSF ROC2 occultation receiver

Septentrio Asterxu phase tracking receiver

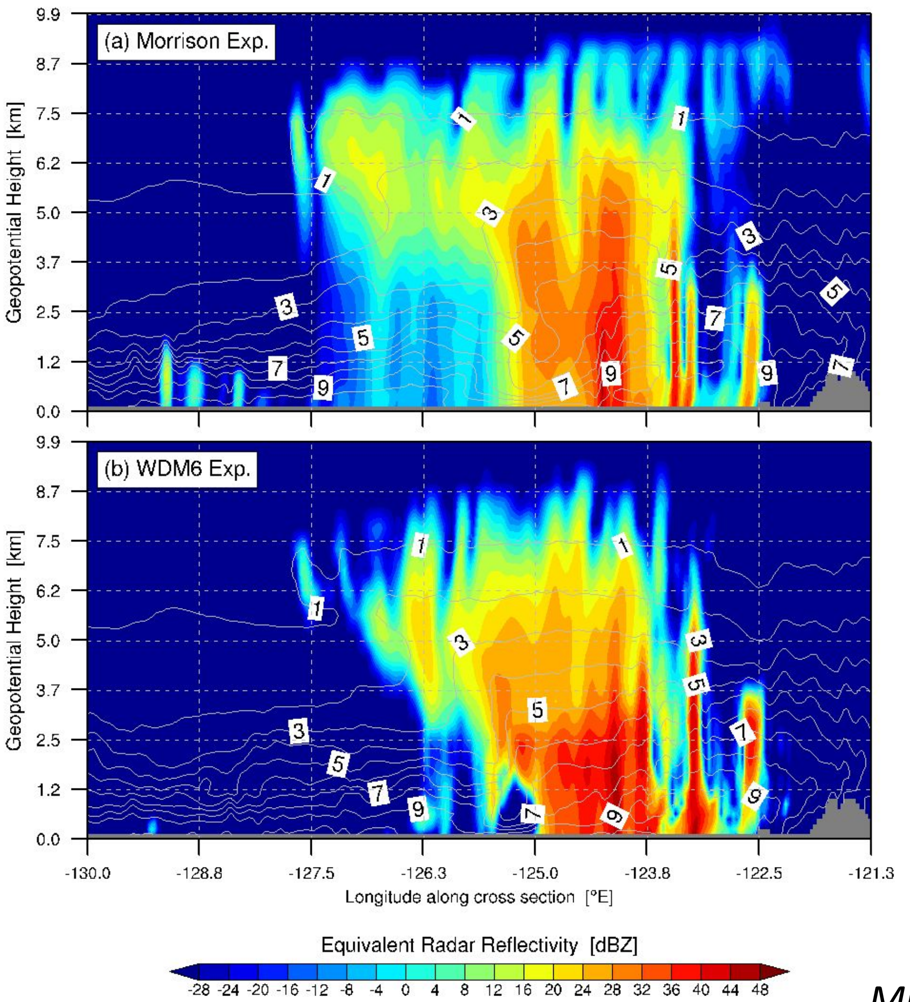
New NOAA multi-GNSS L-band antenna

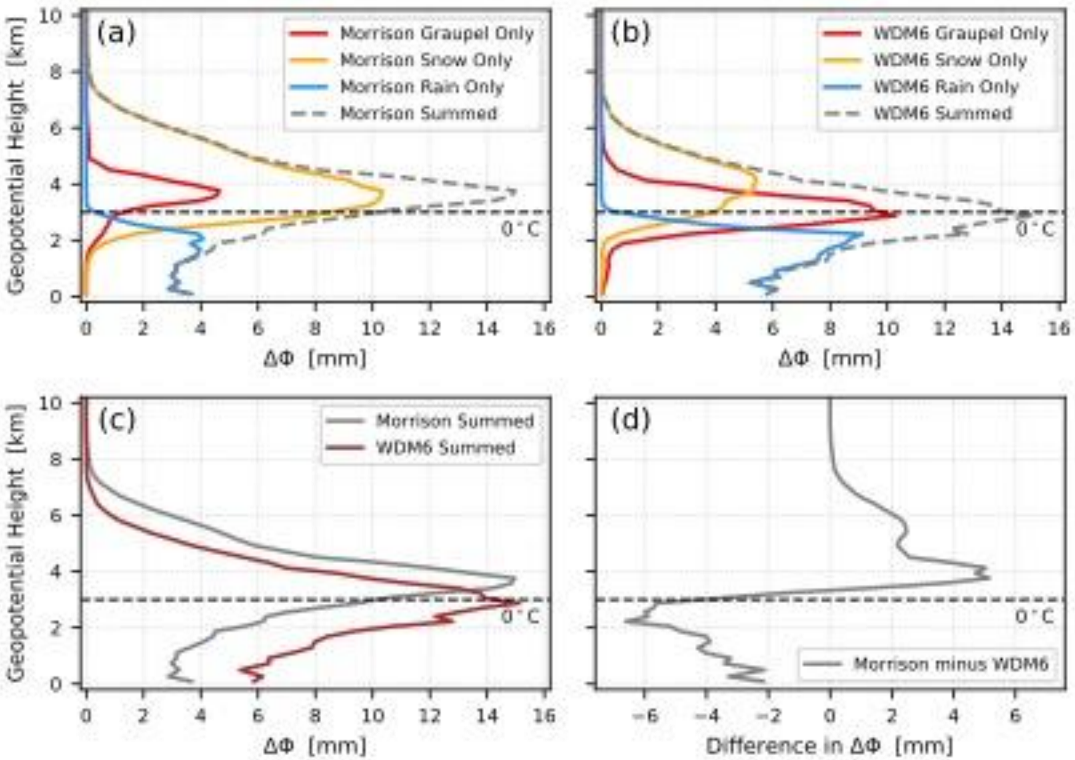
ONR Spirent GNSS signal recorder

NOAA Grav-D real-time GNSS/IMU positioning system

H-V polarimetric observations of hydrometeors

Simulations show the performance of different microphysical parameterizations can be distinguished from polarimetric observations. Largest signal is at ice/rain transition.

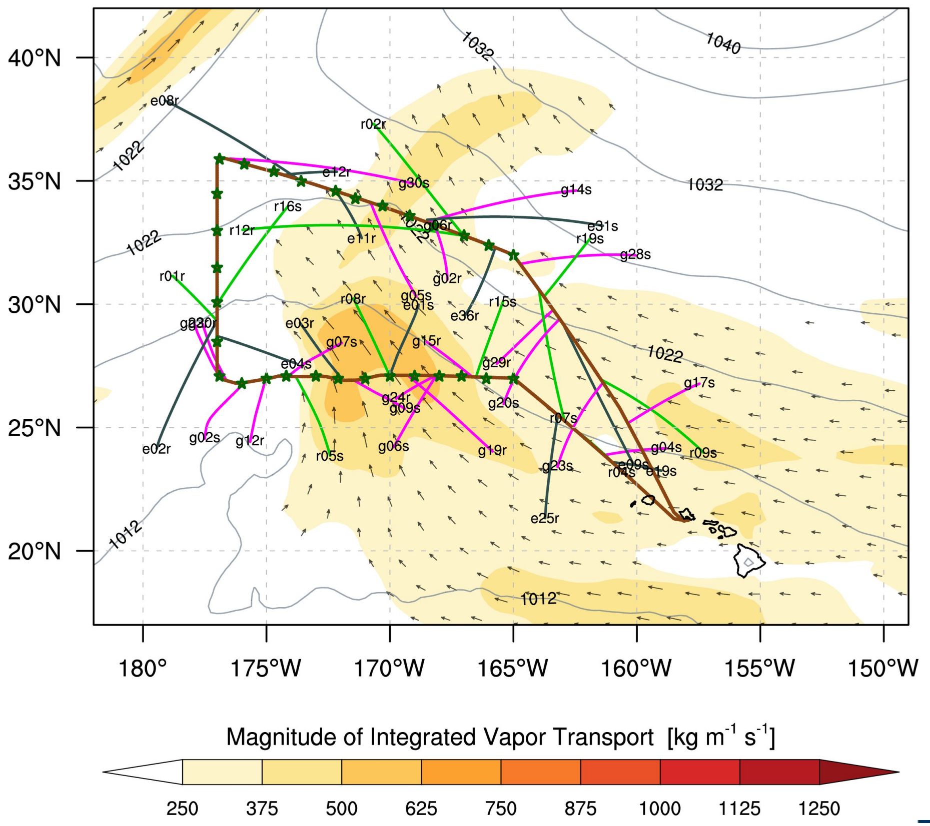


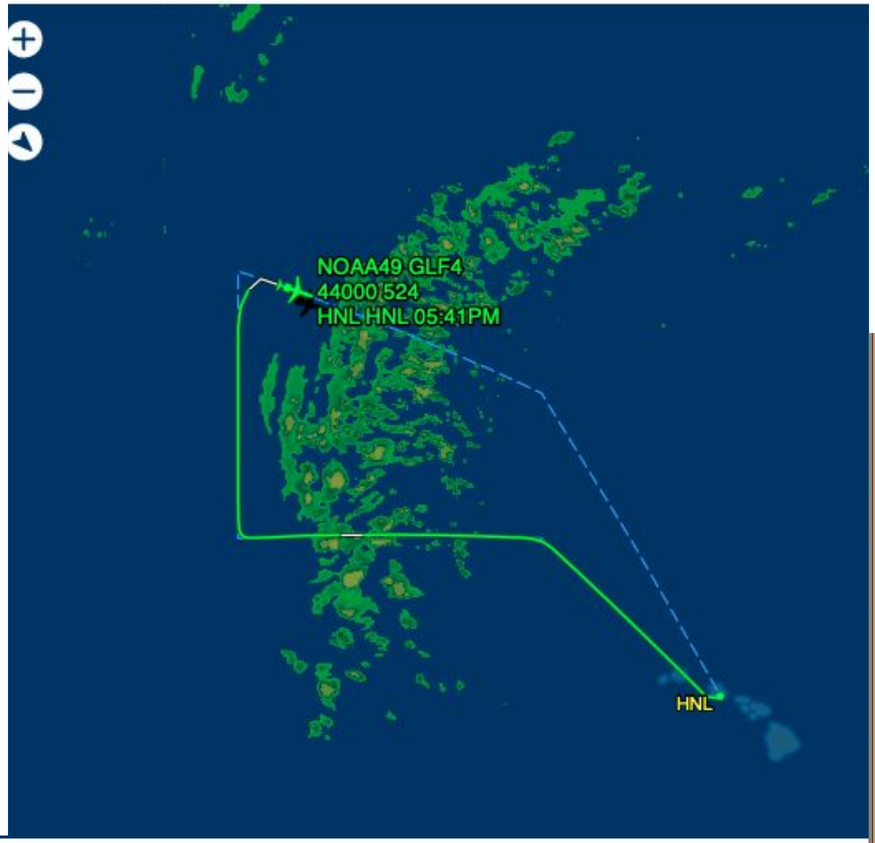


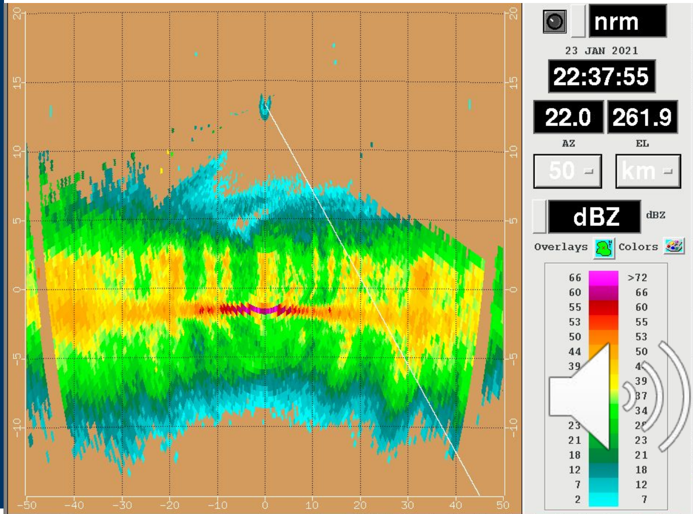
Murphy et al., The potential for discriminating microphysical processes in numerical weather forecasts using airborne polarimetric radio occultations, Remote Sensing, *2019*

H-V polarimetric observations of hydrometeors

- 3 Channel Spirent recorded top antenna and H/V signals from a side antenna
- Several good events with moderate convective activity
- G-IV Tail Doppler Radar observed the same events







Summary

- AR Recon field campaign in 2018, 2019, 2020, 2021
- Increasing number of flights 6, 3, 17, 29
- Advances: multi-GNSS antenna, real-time GNSS/IMU precise positioning, GNSS recorder for open loop tracking, and H/V polarimetric measurements of hydrometeors
- Consistently retrieving ~45 profiles per flight with ~1/3 extending below 3 km.
- Future scientific investigations:
  - Data impact in areas of sensitivity
  - Resolving areas of latent heat release and convection in core of AR
  - Analysis of open-loop and H/V Pol observations