A Column-based Multi-platform Assessment of Atmospheric River Events Observed in Complex Terrain During the NASA GPM OLYMPEX Field Campaign

Stephanie M. Wingo
NASA Postdoctoral Program/USRA
Stephanie.M.Wingo@nasa.gov

Walt Petersen and Patrick Gatlin
NASA MSFC

And Colleagues:
Alexis Hunzinger[2], Jason Pippitt[3], Charanjit Pabla[4], David Marks[4], David Wolff[5], and Ali Tokay[6]
[2]PNNL, [3]SSAI/GSFC, [4]SSAI/WFF, [5]NASA WFF, [6]UMBC/GSFC

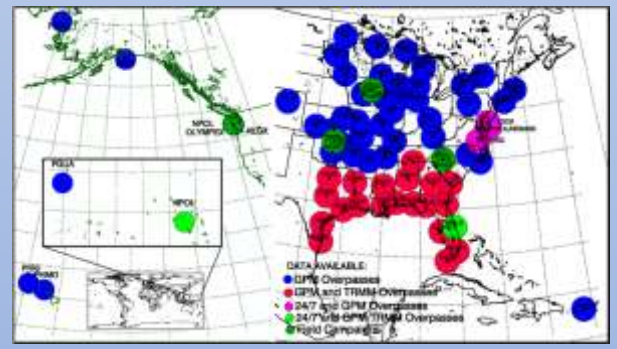
American Geophysical Union • 2018 Fall Meeting • Washington, D.C. • H52C-02

Image: Steven Sander

GPM/GV Field Efforts: Platform Diversity

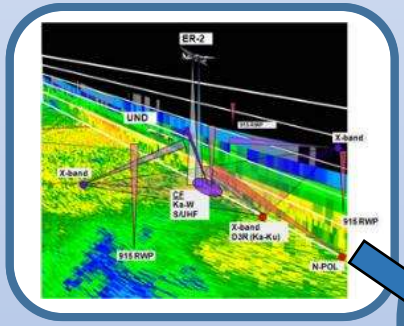
- GPM Core Observatory
  - Dual-frequency Precipitation Radar (DPR)
    Ka-/Ku-band (35.5/13.6 GHz, 125/245 km swaths)
  - GPM Microwave Imager (GMI)
    13-channels 10-183 GHz (885 km swath)
- Constellation Partners (JAXA, NOAA, DOD, EUMETSAT, CNES, ISRO)
- Multi-agency Field Campaigns
  - Meteorology/geography/topography
- **Research need:** single, integrative framework to "build" the atmospheric column with targeted, multi-sensor data

+ other partner observing networks



System for Integrating Multi-platform data to Build the Atmospheric column (SIMBA)

- Synthesizes concomitant GPM GV precipitation observations to single 3-D grid
- Modules support various data platforms and format types
  - Ground-based scanning, profiling radars
    - NPOL, 88D, D3R, DOW, MRR
  - Point measurements: gauges, disdrometers
    - Tipping bucket, Pluvio, Parsivel, 2DVD
  - GPM Satellite (DPR, GMI)
  - Soundings
  - MRMS QPE
- Attributes preserve info from native files

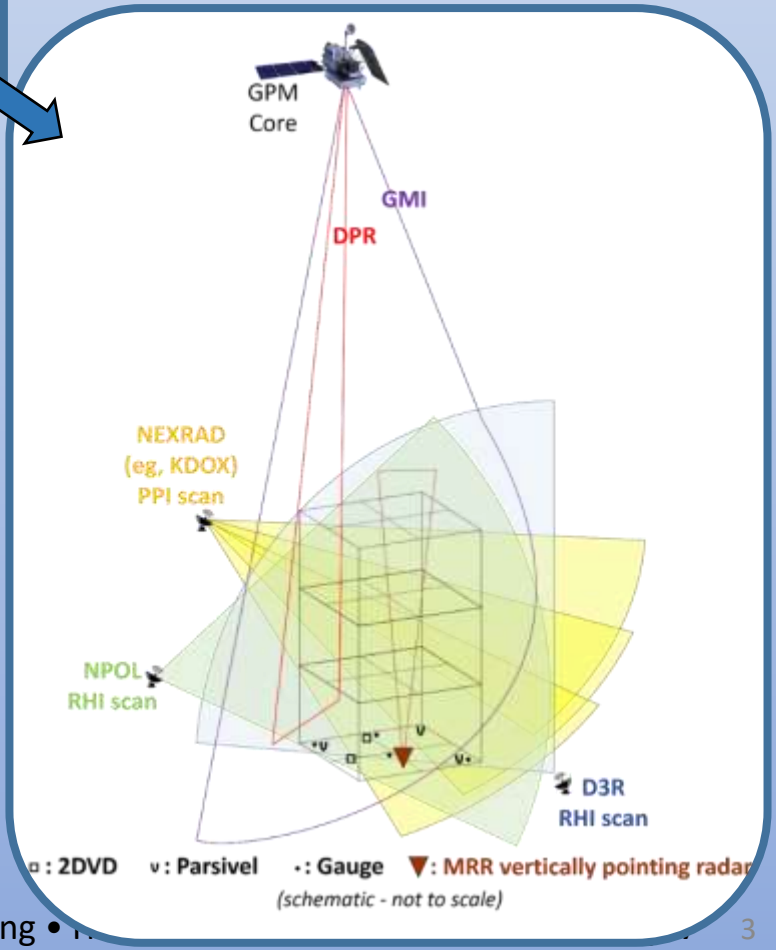


Define Column: grid center location, horizontal and vertical extent, spacing

Platform-specific Modules: read in native data formats, process gridding and/or interpolation as needed to set coincident observations into single, 3D column grid

SIMBA Column Data File: Write all available observations to a **common 3D grid in NetCDF** format. Attributes maintain key properties of original data (exact locations, operation modes, algorithm versions, etc.)

SIMBA enables more efficient precipitation science by fusing GPM GV data to a common grid



System for Inte
Build the Atmo

- Synthesizes concomitan
precipitation observatio
- Modul
and for
  - Gro
prof
    -
  - Poir
gau
    -
  - GPM
  - Sou
  - MRMS QPE
- Attributes preserve info
from native files

SIMBA Development & Initial Applications published earlier this year in the *Journal of Atmospheric and Oceanic Technology,* as part of AMS's GPM Special Collection

VOLUME 35 JOURNAL OF ATMOSPHERIC AND OCEANIC TECHNOLOGY JULY 2018

SPECIAL
Global Precipitation Measurement (GPM)
COLLECTION

The System for Integrating Multiplatform Data to Build the Atmospheric Column (SIMBA) Precipitation Observation Fusion Framework

STEPHANIE M. WINGO
NASA Marshall Space Flight Center, and Universities Space Research Association, Huntsville, Alabama

WALTER A. PETERSEN AND PATRICK N. GATLIN
NASA Marshall Space Flight Center, Huntsville, Alabama

CHARANJIT S. PABLA AND DAVID A. MARKS
Science Systems and Applications, Inc., and NASA Wallops Flight Facility, Wallops Island, Virginia

DAVID B. WOLFF
NASA Wallops Flight Facility, Wallops Island, Virginia

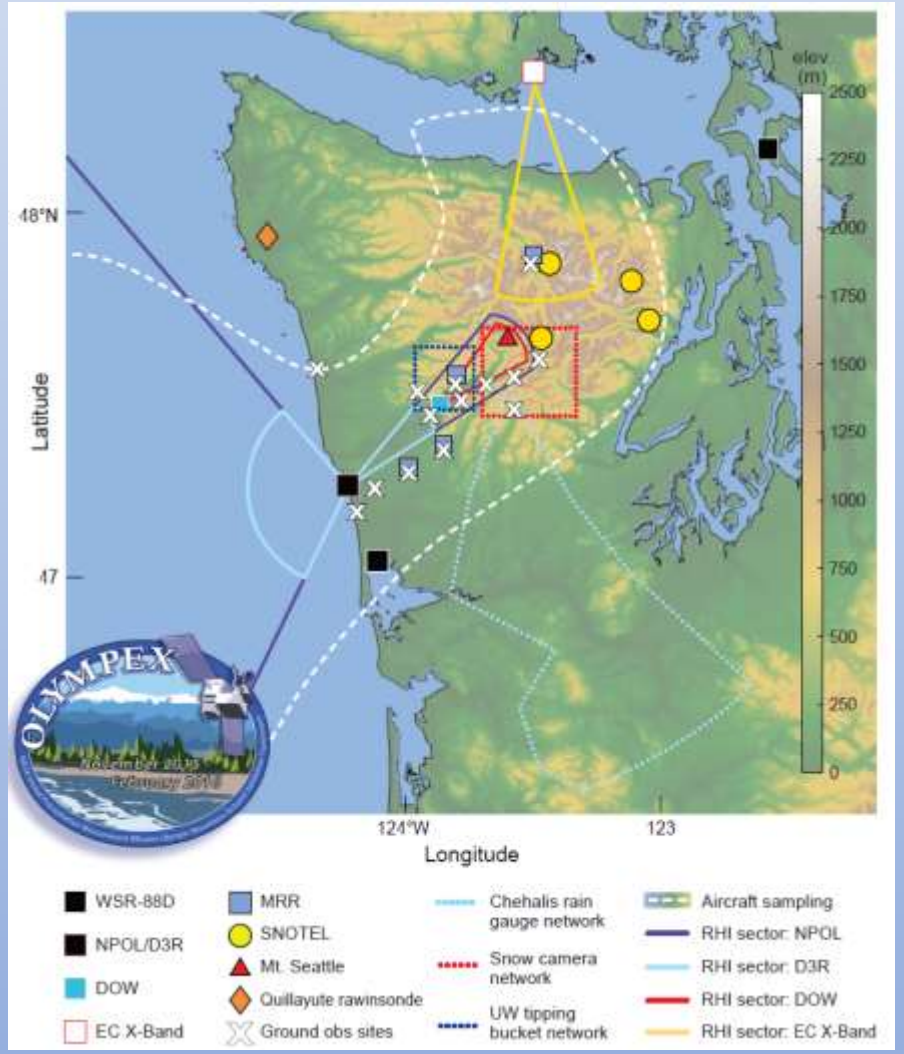
(Manuscript received 31 October 2017, in final form 6 April 2018)

ABSTRACT

Researchers now have the benefit of an unprecedented suite of space- and ground-based sensors that provide multidimensional and multiparameter precipitation information. Motivated by NASA's Global Precipitation Measurement (GPM) mission and ground validation objectives, the System for Integrating Multiplatform Data to Build the Atmospheric Column (SIMBA) has been developed as a unique multisensor precipitation data fusion tool to unify field observations recorded in a variety of formats and coordinate systems into a common reference frame. Through platform-specific modules, SIMBA processes data from native coordinates and resolutions only to the extent required to set them into a user-defined three-dimensional grid. At present, the system supports several ground-based scanning research radars, NWS NEXRAD radars, profiling Micro Rain Radars (MRRs), multiple disdrometers and rain gauges, soundings, the GPM Microwave Imager and Dual-Frequency Precipitation Radar on board the *Core Observatory* satellite, and Multi-Radar Multi-Sensor system quantitative precipitation estimates. SIMBA generates a new atmospheric column data product that contains a concomitant set of all available data from the supported platforms within the user-specified grid defining the column area in the versatile netCDF format. Key parameters for each data source are preserved as attributes. SIMBA provides a streamlined framework for initial research tasks, facilitating more efficient precipitation science. We demonstrate the utility of SIMBA for investigations, such as assessing spatial precipitation variability at subpixel scales and appraising satellite sensor algorithm representation of vertical precipitation structure for GPM *Core Observatory* overpass cases collected in the NASA Wallops Precipitation Science Research Facility and the GPM Olympic Mountain Experiment (OLYMPEX) ground validation field campaign in Washington State.

Olympic Mountains Experiment (OLYMPEX)

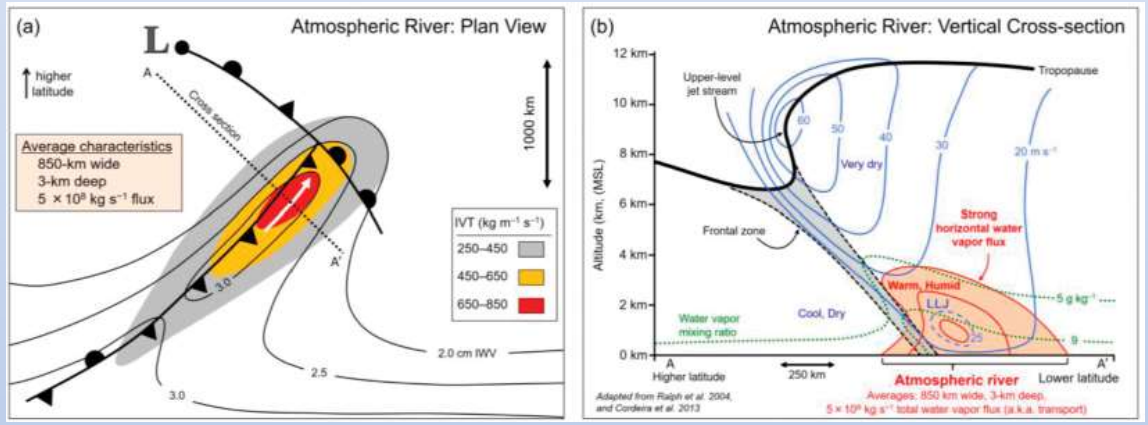
- Land & topographic influence on Pacific frontal system precipitation evolution
- Impacts of terrain (and precip behavior in terrain) on satellite measurements
- Remote sensing & in-situ observations
  - Ground-based:
    - NPOL, D3R, DOW, MRRs, 88Ds
    - Disdrometers, gauges, particle imaging
  - Aircraft-based:
    - NASA DC-8, ER-2: dropsondes, GPM Core analog
    - UND Citation: microphysics probes
    - Aerosol Clouds Ecosystems (ACE) Radar Definition Experiment (RADEX)
  - Satellite-based:
    - 2nd post-launch field campaign for DPR/GMI



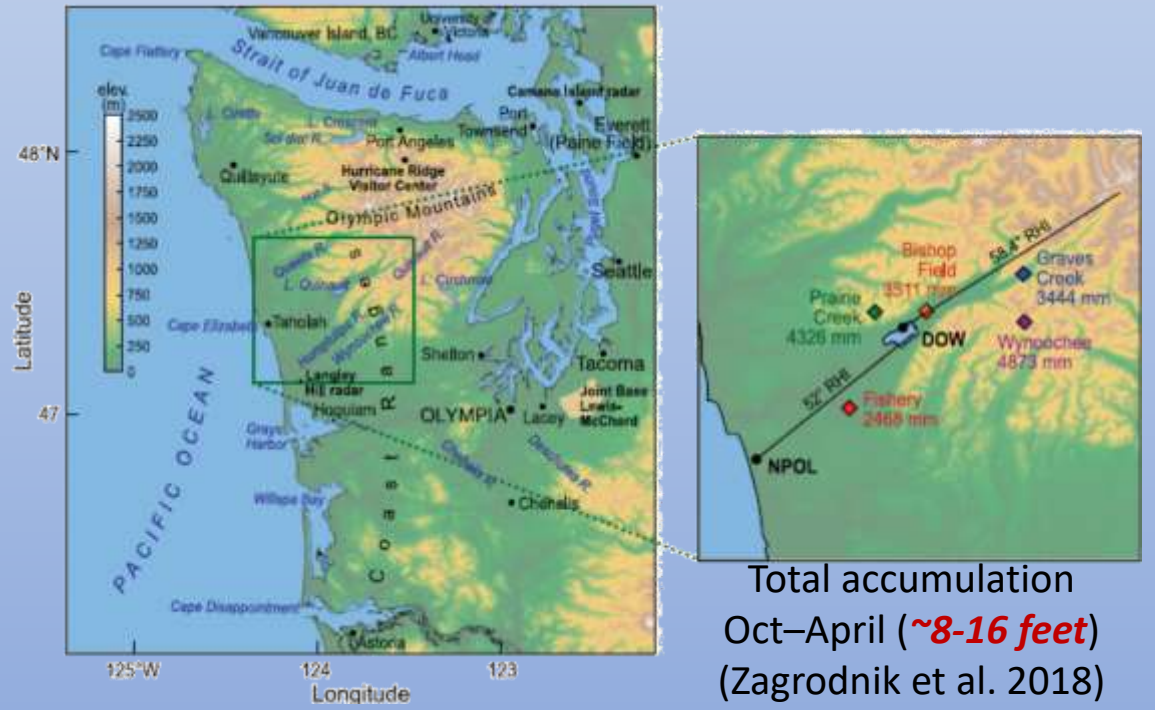
Petersen et al. 2016, Houze et al. 2017

Atmospheric Rivers

- Moisture plume, copious precipitation totals
  - > 2x fresh water as Amazon River
- Warm sector, flow orientation
  - Unblocked flow at terrain
- Orographic precipitation process modification
  - Seeder-feeder mechanism
  - Warm (non-brightband) rain
  - Riming via supercooled water
- Several ARs during OLYMPEX
  - Event totals: hundreds of mm



Horizontal & vertical AR structure schematics (Ralph et al. 2018)

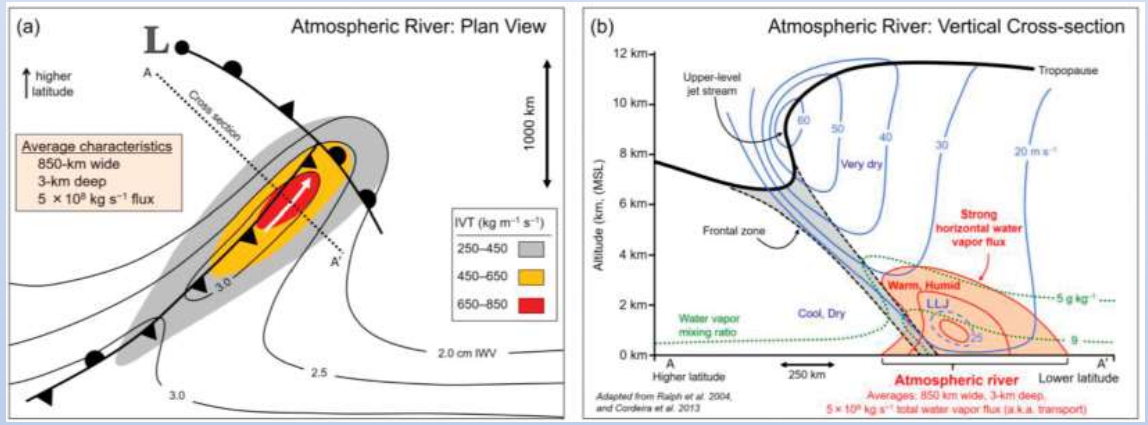


Total accumulation Oct–April (***~8-16 feet***) (Zagrodnik et al. 2018)

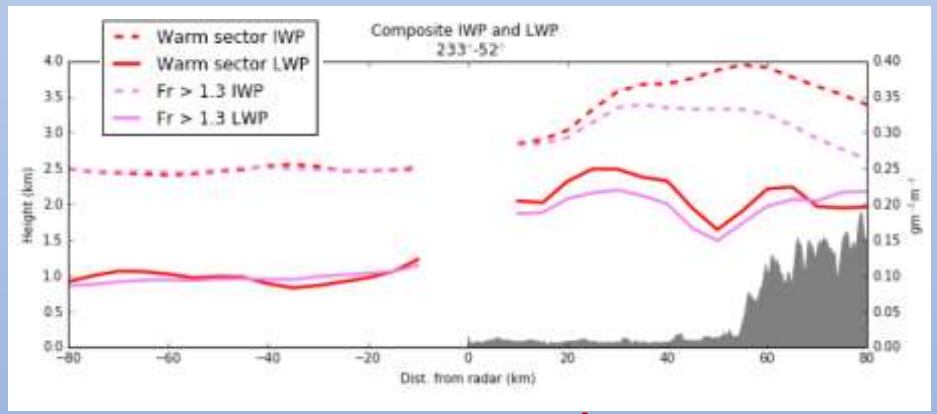
Zhu & Newell 1998, Yuter & Houze 2003, White et al. 2003, Ralph et al 2004, Martner et al. 2008, Minder et al. 2008, Ralph et al. 2018, Zagrodnik et al. 2018, Hunzinger 2018

Atmospheric Rivers

- Moisture plume, copious precipitation totals
  - > 2x fresh water as Amazon River
- Warm sector, flow orientation
  - Unblocked flow at terrain
- Orographic precipitation process modification
  - Seeder-feeder mechanism
  - Warm (non-brightband) rain
  - Riming via supercooled water
- Several ARs during OLYMPEX
  - Event totals: hundreds of mm



Horizontal & vertical AR structure schematics (Ralph et al. 2018)



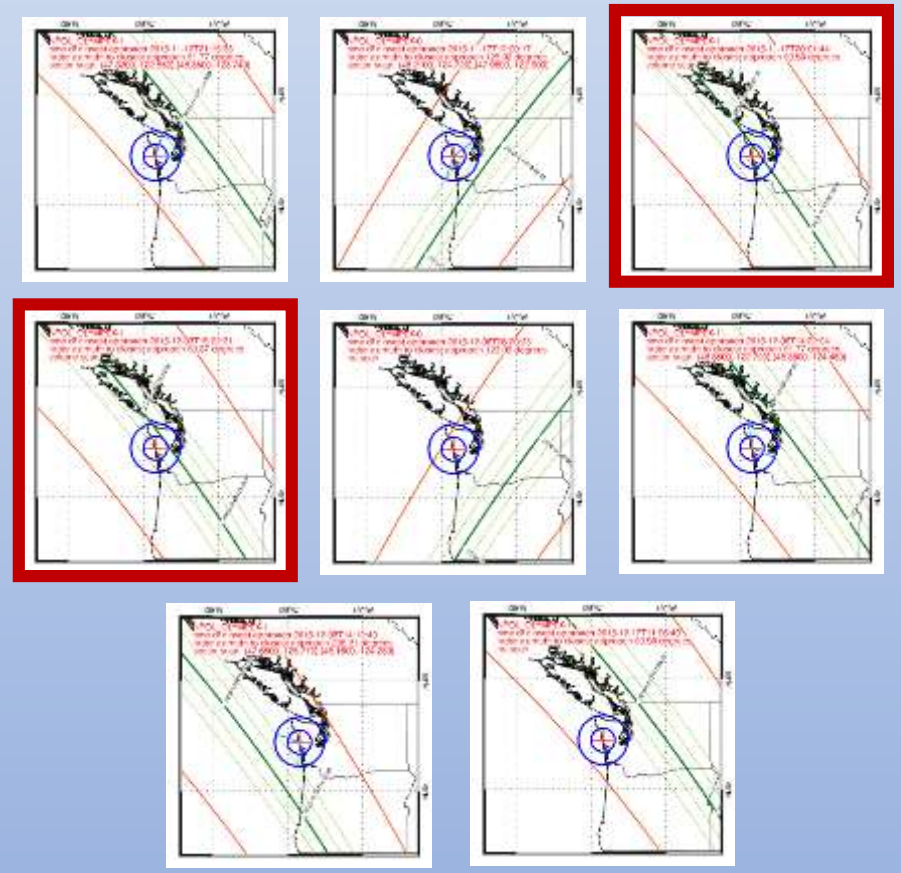
Land & topography **impact ice/liquid** precipitation processes – most pronounced in **unblocked/large Froude and warm sector** flow regimes (Petersen, Hunzinger, Gatlin 2018; *Poster H43F-2493*)

Zhu & Newell 1998, Yuter & Houze 2003, White et al. 2003, Ralph et al 2004, Martner et al. 2008, Minder et al. 2008, Ralph et al. 2018, Zagrodnik et al. 2018, Hunzinger 2018

Integrating GV Obs in SIMBA for OLYMPEX ARs

- SIMBA column files generated for 5 locations up terrain for OLYMPEX AR events:
  - 13 Nov 03-00 UTC (20%)
  - 17 Nov 10-21UTC (10%)
  - 3 Dec 14-00 UTC (10%)
  - 6-7 Dec 00-02 UTC (25%)
  - 8-9 Dec 13-10 UTC (20%)
  - 17 Dec 08-00 UTC (15%)
- Column grids:
  - 10 x 10 x 8 km extent
    - 5 km means
  - 500 x 500 x 250 m spacing
  - 5 min centered on NPOL
- Column sites:
  - 20 km SW of NPOL (O)
  - 12.5 km NE of NPOL (A)
  - Fishery (B), Neilton (C), Bishop (D)
    - MRR field sites

8 GPM OPs
2 with DPR
WS / Fr>1.3



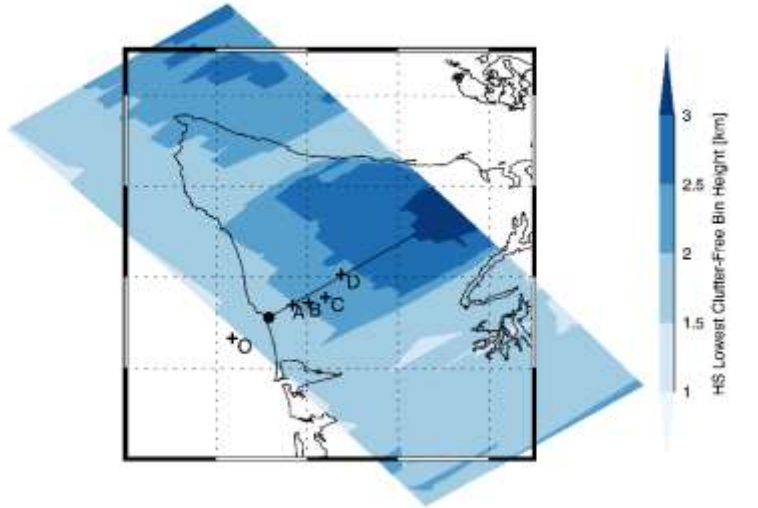
- NPOL RHI compositing: Z, D_M, RR (Chen et al. 2017)
- GPM V05A: GPROF, GMI, 2ADPR, 2BCMB

Integrating GV Obs in SIMBA for OLYMPEX ARs

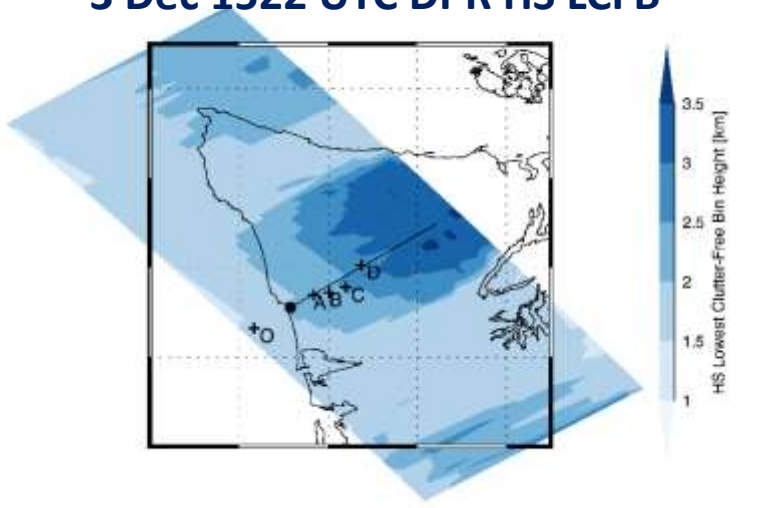
- SIMBA column files generated for 5 locations up terrain for OLYMPEX AR events:
  - 13 Nov 03-00 UTC (20%)
  - 17 Nov 10-21UTC (10%)
  - 3 Dec 14-00 UTC (10%)
  - 6-7 Dec 00-02 UTC (25%)
  - 8-9 Dec 13-10 UTC (20%)
  - 17 Dec 08-00 UTC (15%)
- Column grids:
  - 10 x 10 x 8 km extent
    - 5 km means
  - 500 x 500 x 250 m spacing
  - 5 min centered on NPOL
- Column sites:
  - 20 km SW of NPOL (O)
  - 12.5 km NE of NPOL (A)
  - Fishery (B), Neilton (C), Bishop (D)
    - MRR field sites
- NPOL RHI compositing: Z, D_M, RR (Chen et al. 2017)
- GPM V05A: GPROF, GMI, 2ADPR, 2BCMB

Complex terrain introduces complex challenges to observations, especially space-based

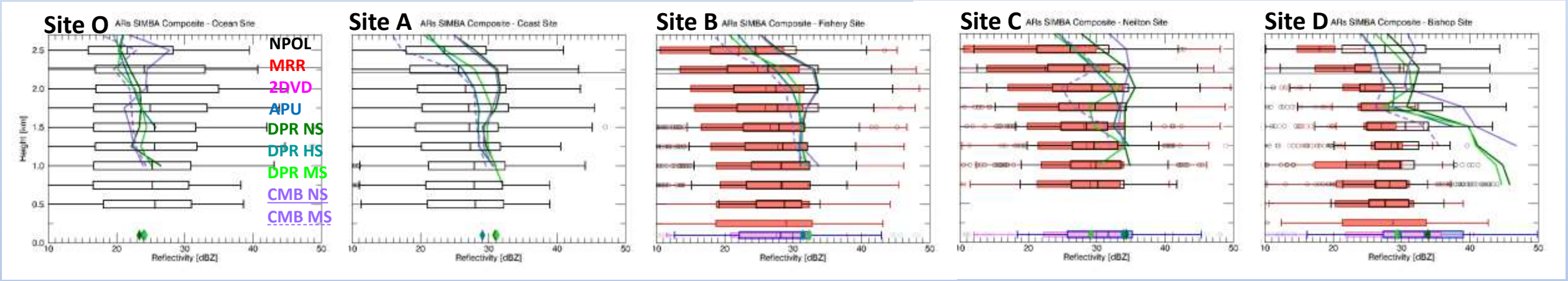
17 Nov 2001 UTC DPR HS LCFB



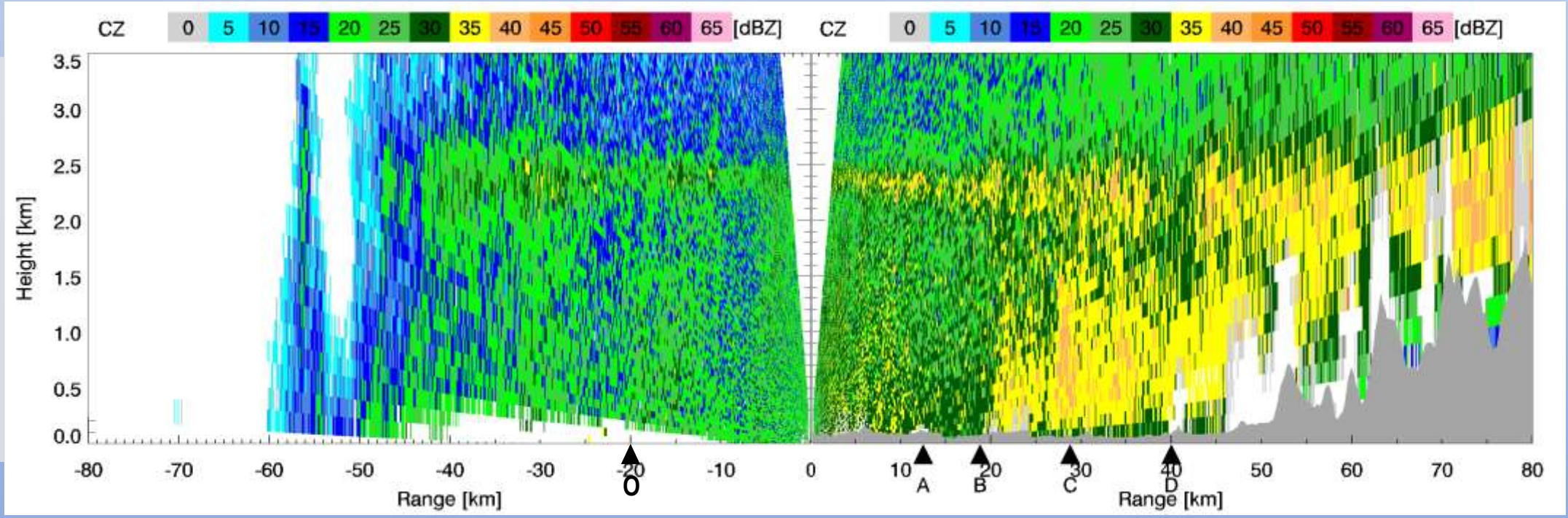
3 Dec 1522 UTC DPR HS LCFB



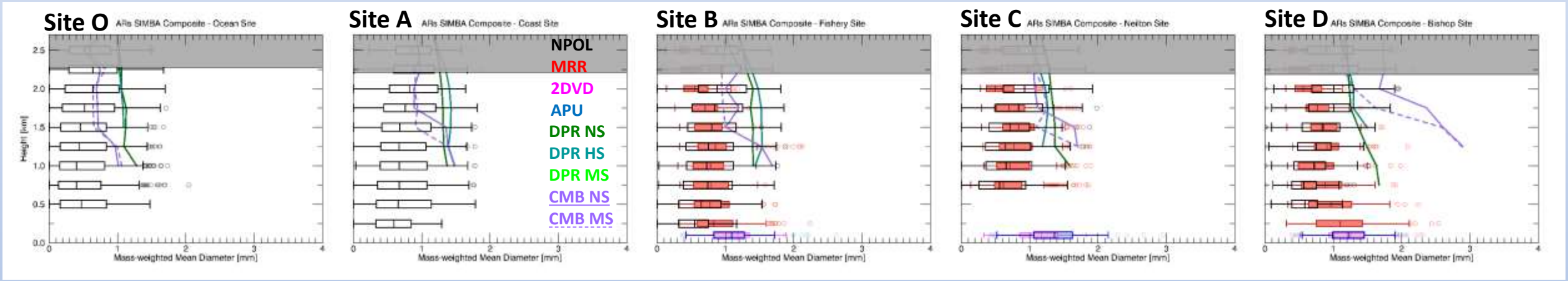
ARs Composite: Reflectivity



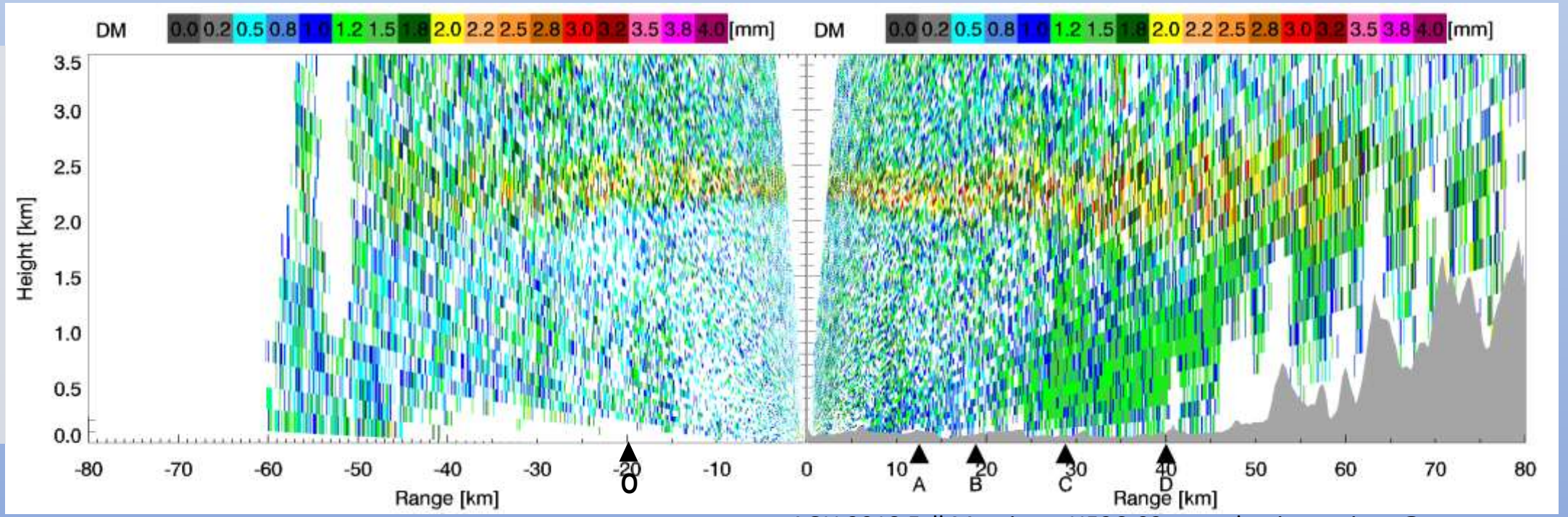
- Large spread – multiple events
- As approach terrain barrier:
  - DPR vs. CMB more different
  - GPM vs. ground obs



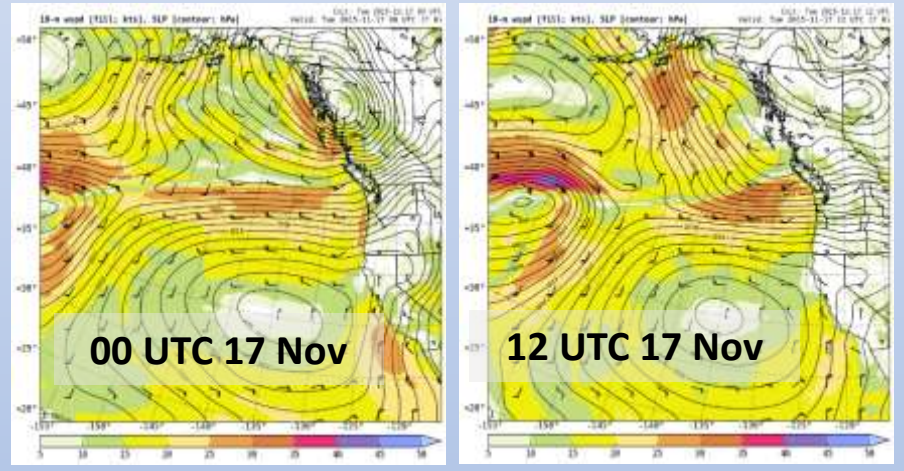
ARs Composite: D_M



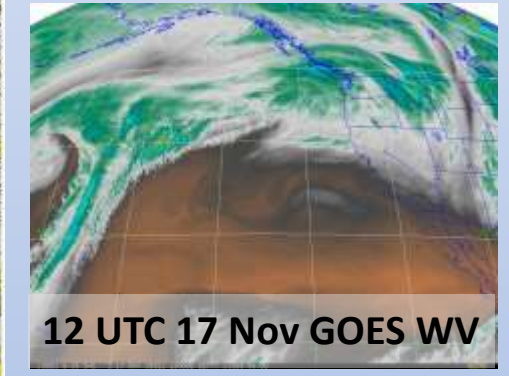
- **MRR** - below 0°C, drop size enhancement
- **DPR** vs. **CMB** as approach terrain barrier
- **MRR** vs. **NPOL** at inland sites

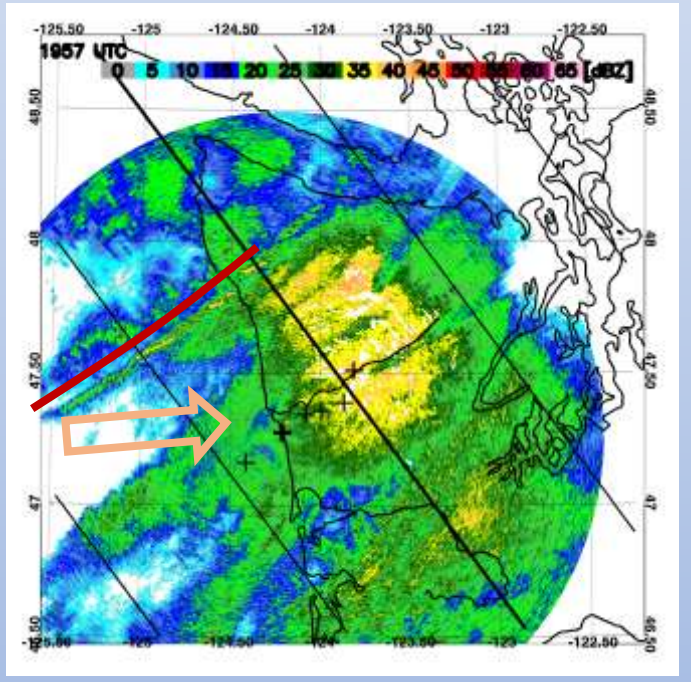


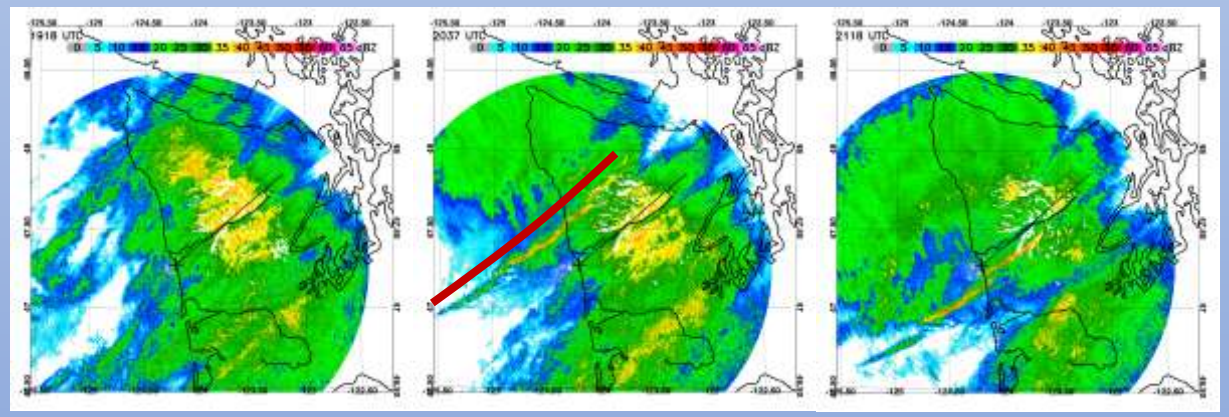
OLYMPEX AR Event: 17 November 2015



UW WRF+GFS Analyses: 10 m winds & SLP



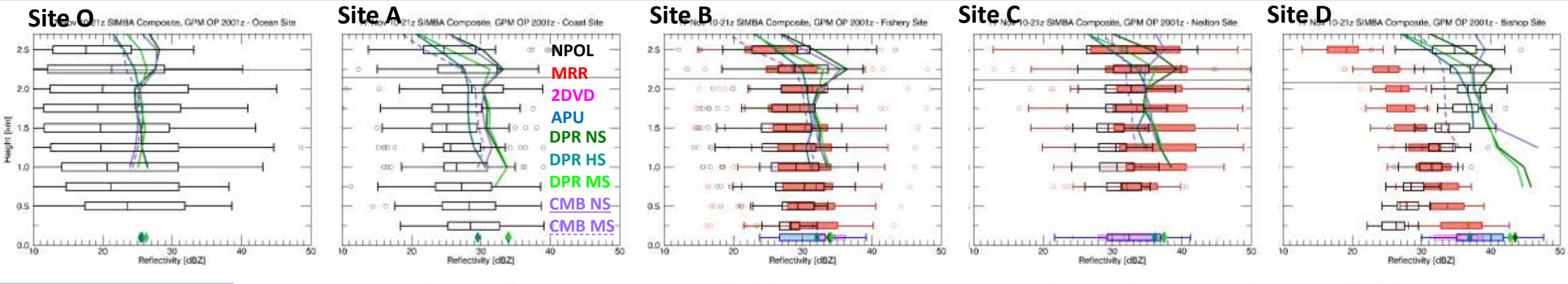




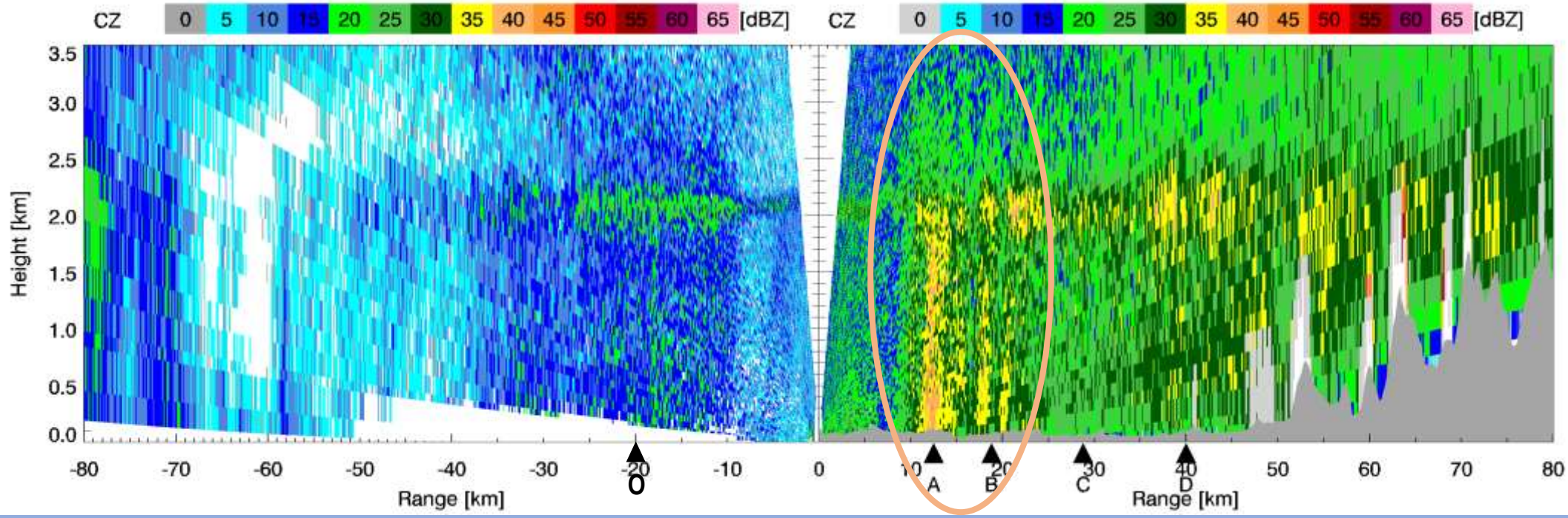
NPOL 1.5° Z

- ***Westerly flow,*** banner atmospheric river event
- Prominent stratiform, some embedded cells
- **200+ mm/24 h** in QRV (up to 60 mm leeward)
- **GPM DPR OP @ 2001**
- Later: FROPA/NCFR, into elongated sections as passed over land

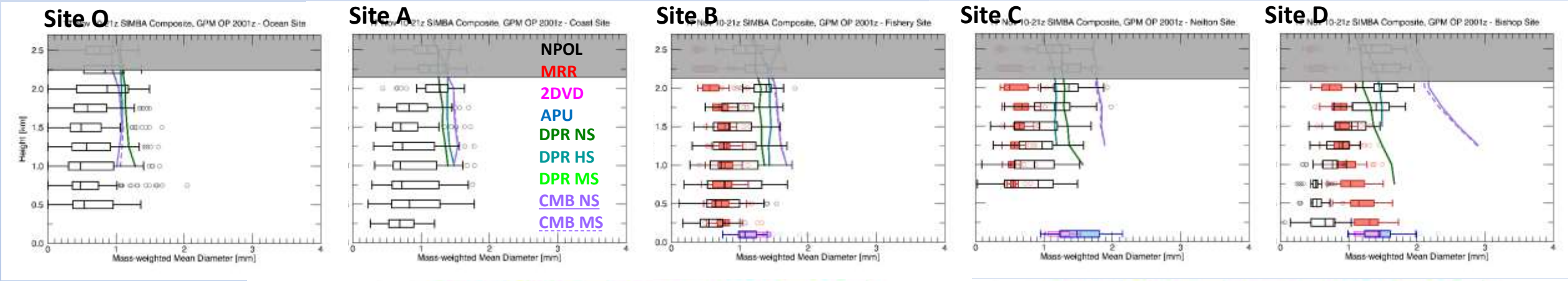
17 November: 10-21 UTC Composite Z



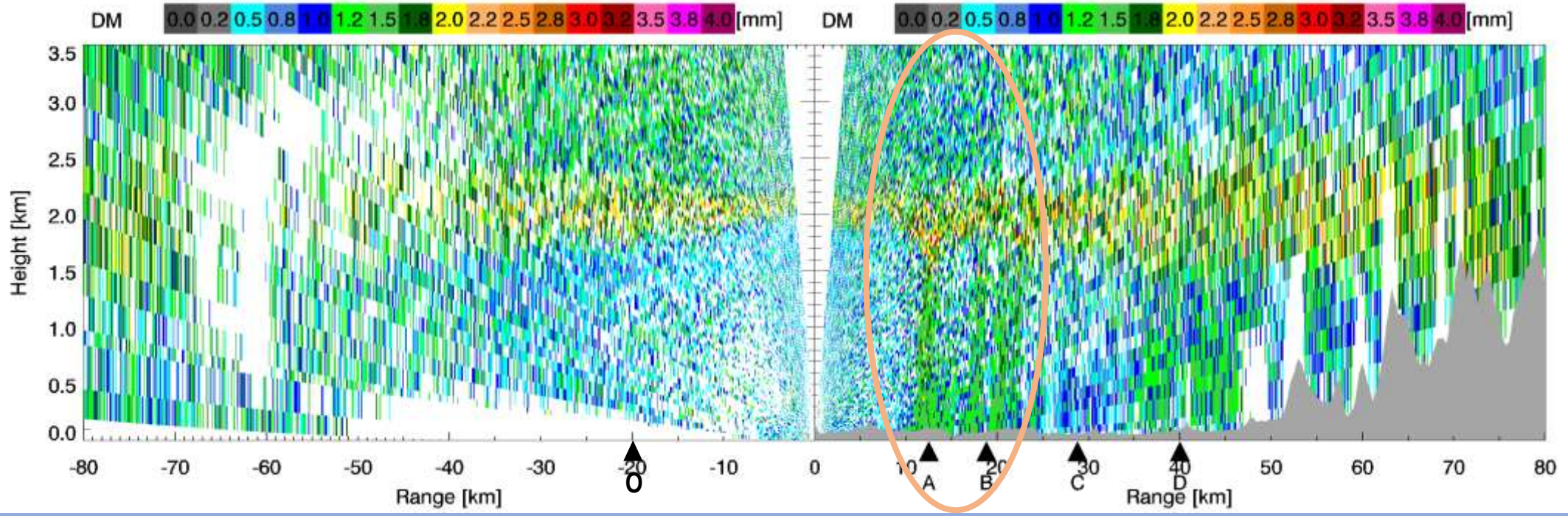
- Distinct preferred regions of enhancement ahead of terrain barrier
- **DPR** & **CMB** profiles more different in valley
- **MRR** vs. **NPOL**



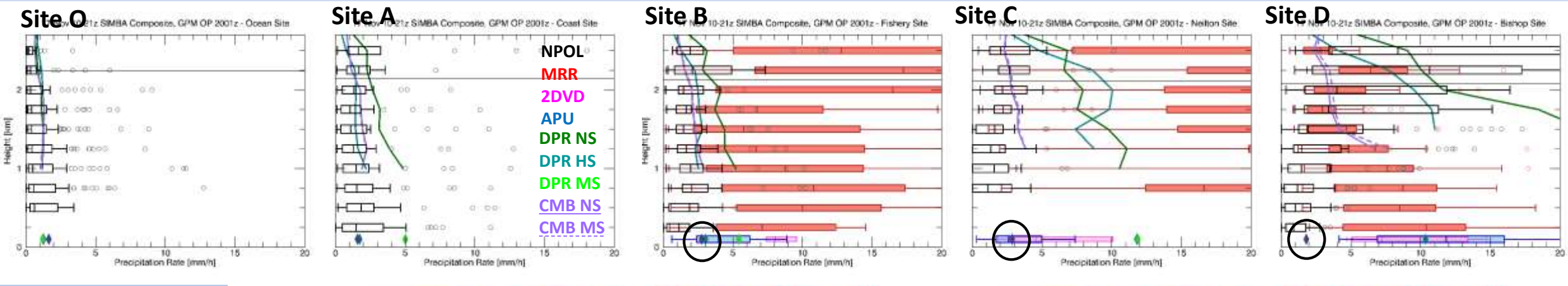
17 November: 10-21 UTC Composite D_M



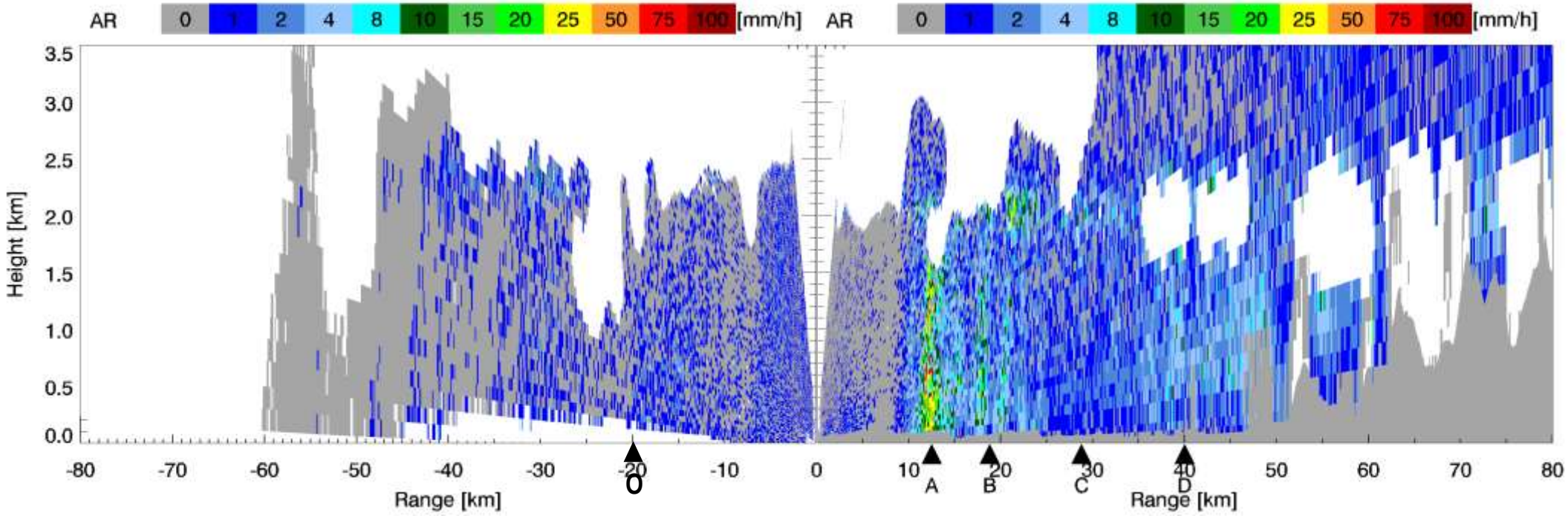
- Distinct preferred regions of enhancement
- Satellite profiles more different in valley-**DPR**, **CMB** overestimate
- **MRR** vs. **NPOL**



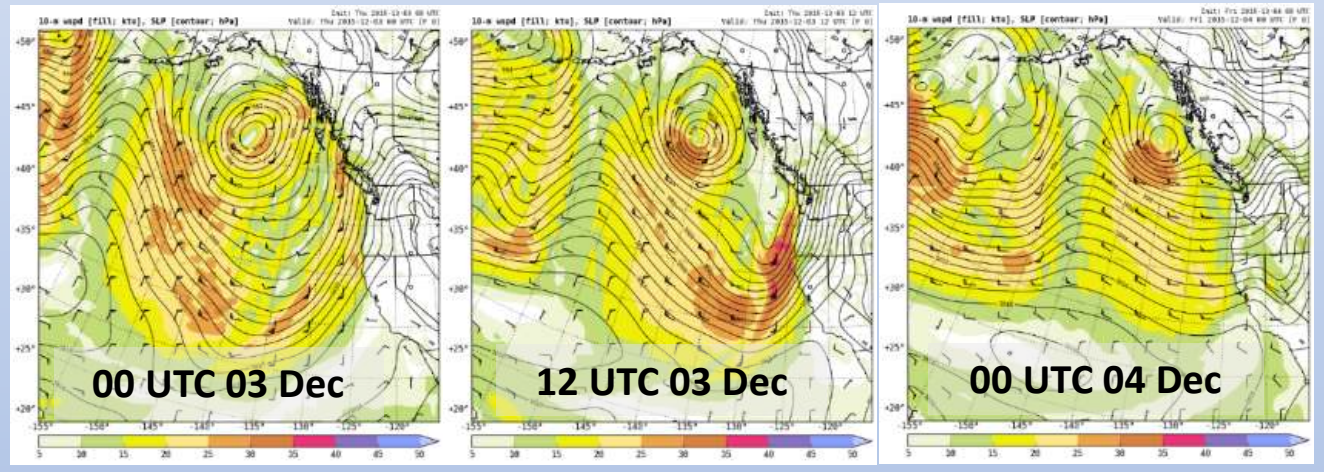
17 November: 10-21 UTC Composite RR



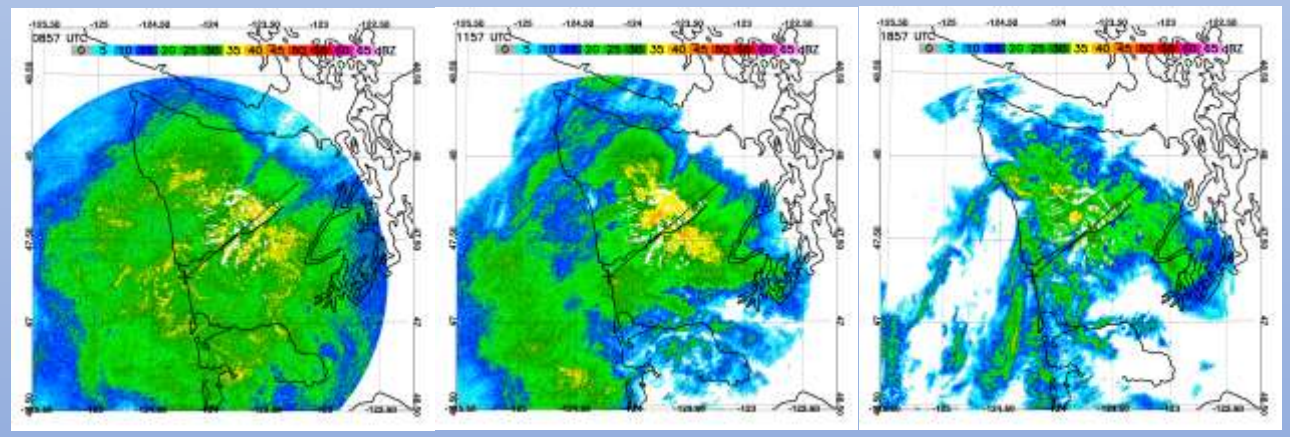
- Initial inland enhancement region most prominent (Z)
- Satellite, MRR issues in valley
- MRR vs. **NPOL**, **MRR** + disdos.
- **GPROF** underestimates



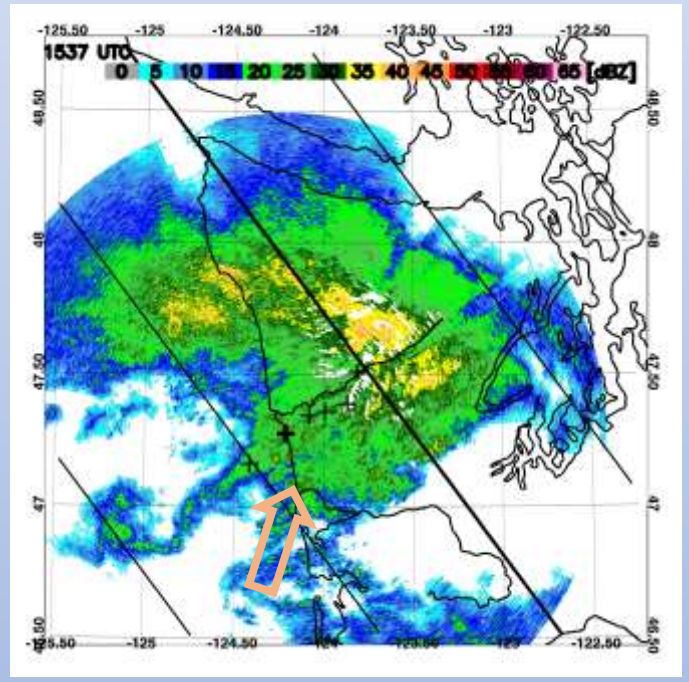
OLYMPEX AR Event: 3 December 2015



UW WRF+GFS Analyses: 10 m winds & SLP

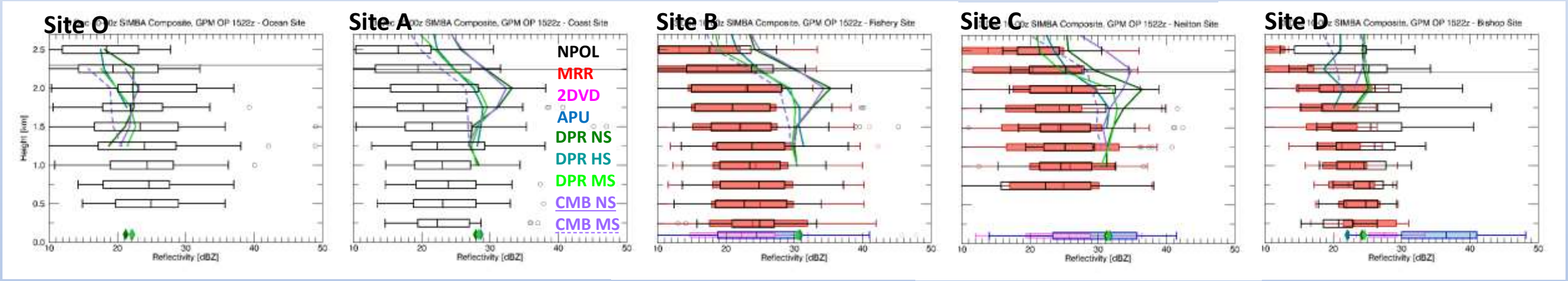


NPOL 1.5° Z

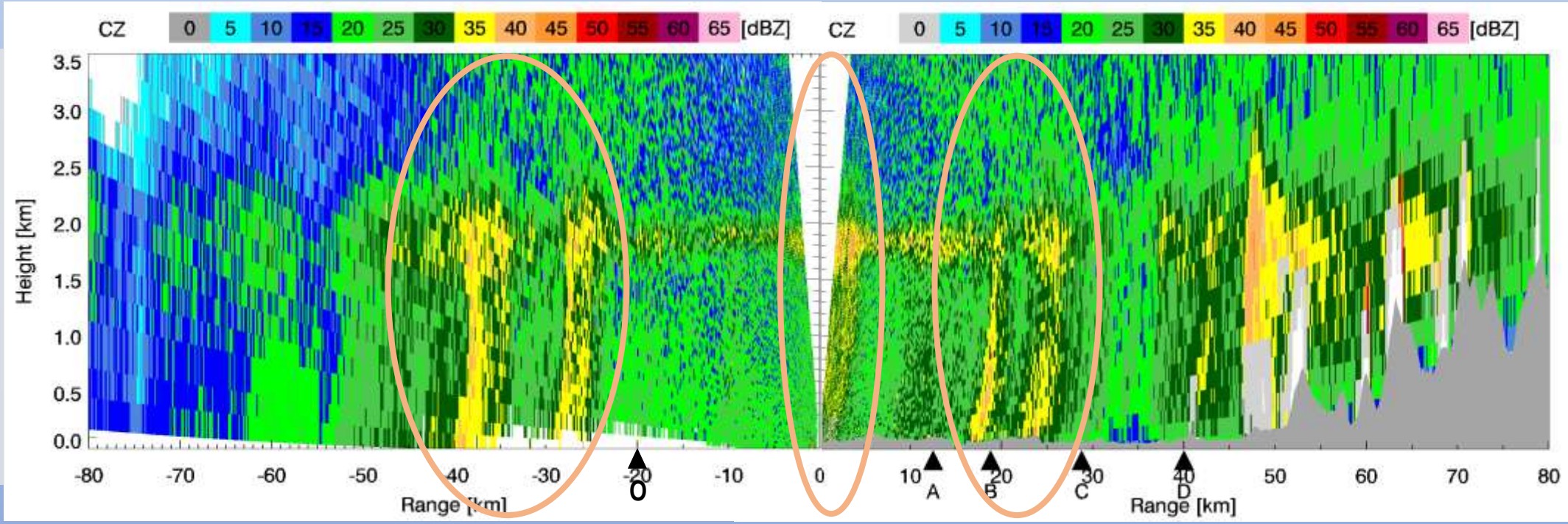


- Evolving system with shortwave trough
- ***Southerly component to flow***
- Early: Widespread stratiform, variability
- **GPM Core OP @ 1523**
- Ideal triple aircraft coordination
- Later: front-like shallow echo line with wind shift

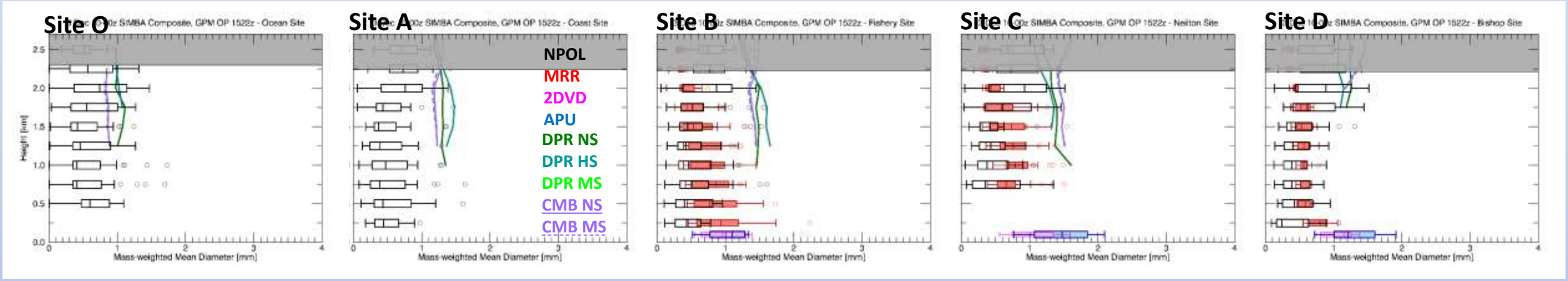
3 December: 14-00 UTC Composite Z



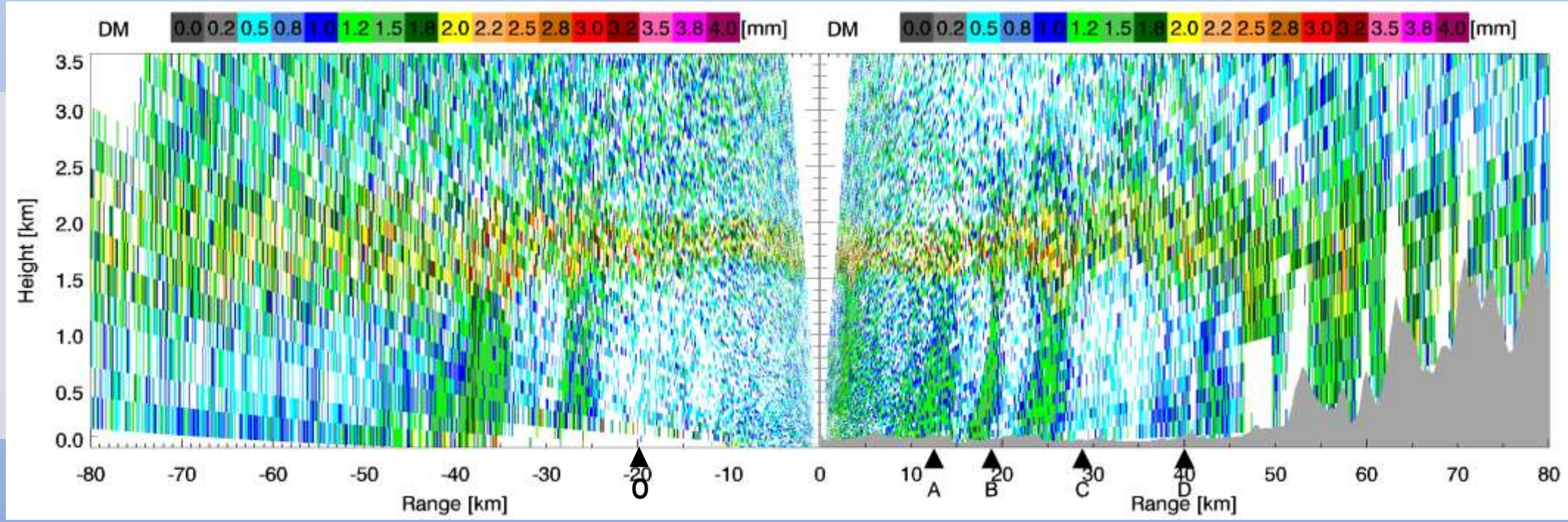
- Enhancement region locations – begin offshore
- **MRR** vs. **NPOL** – less discrepancy inland than for 17 Nov. composites
  - Flow orientation…



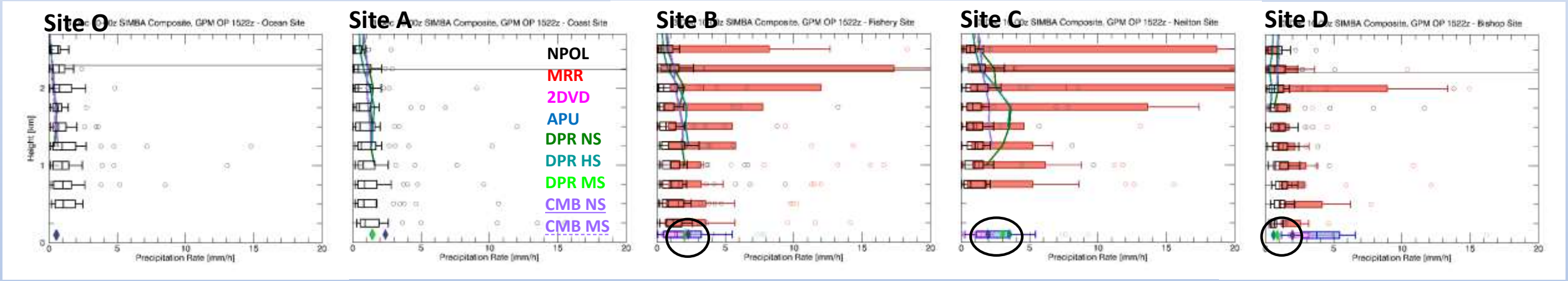
3 December: 14-00 UTC Composite D_M



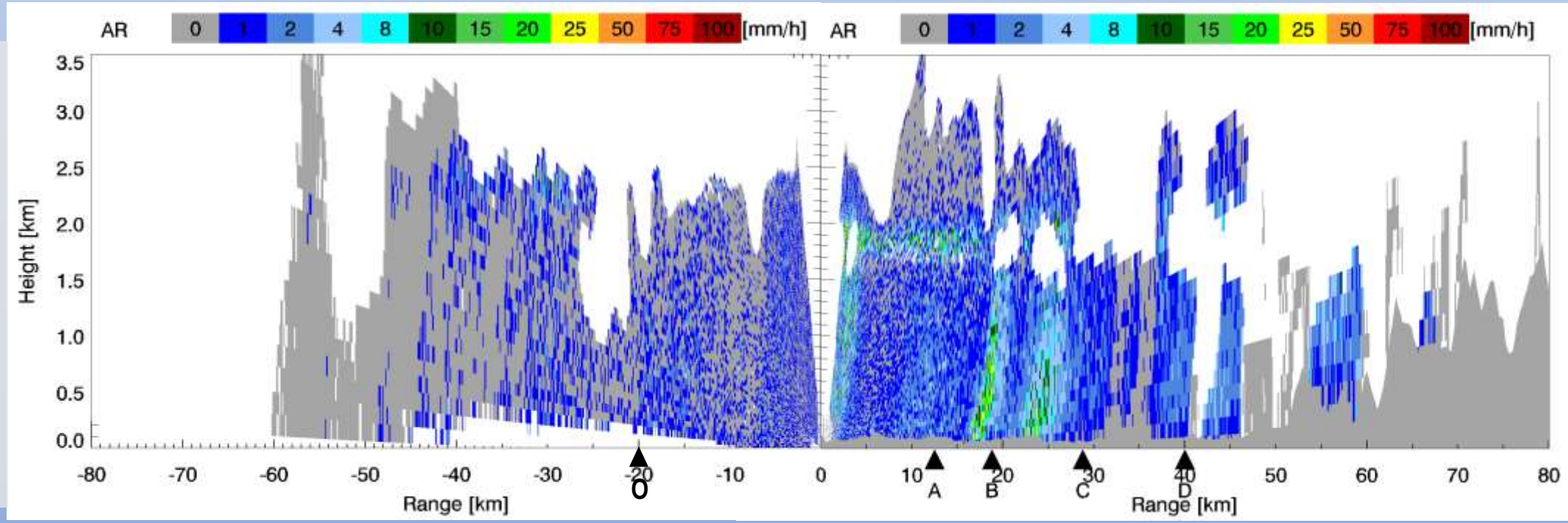
- **DPR** & **CMB** exceed ground-based IQR at all sites
- **MRR** trend opposite that of **NPOL** & nearer sfc ob values



3 December: 14-00 UTC Composite RR

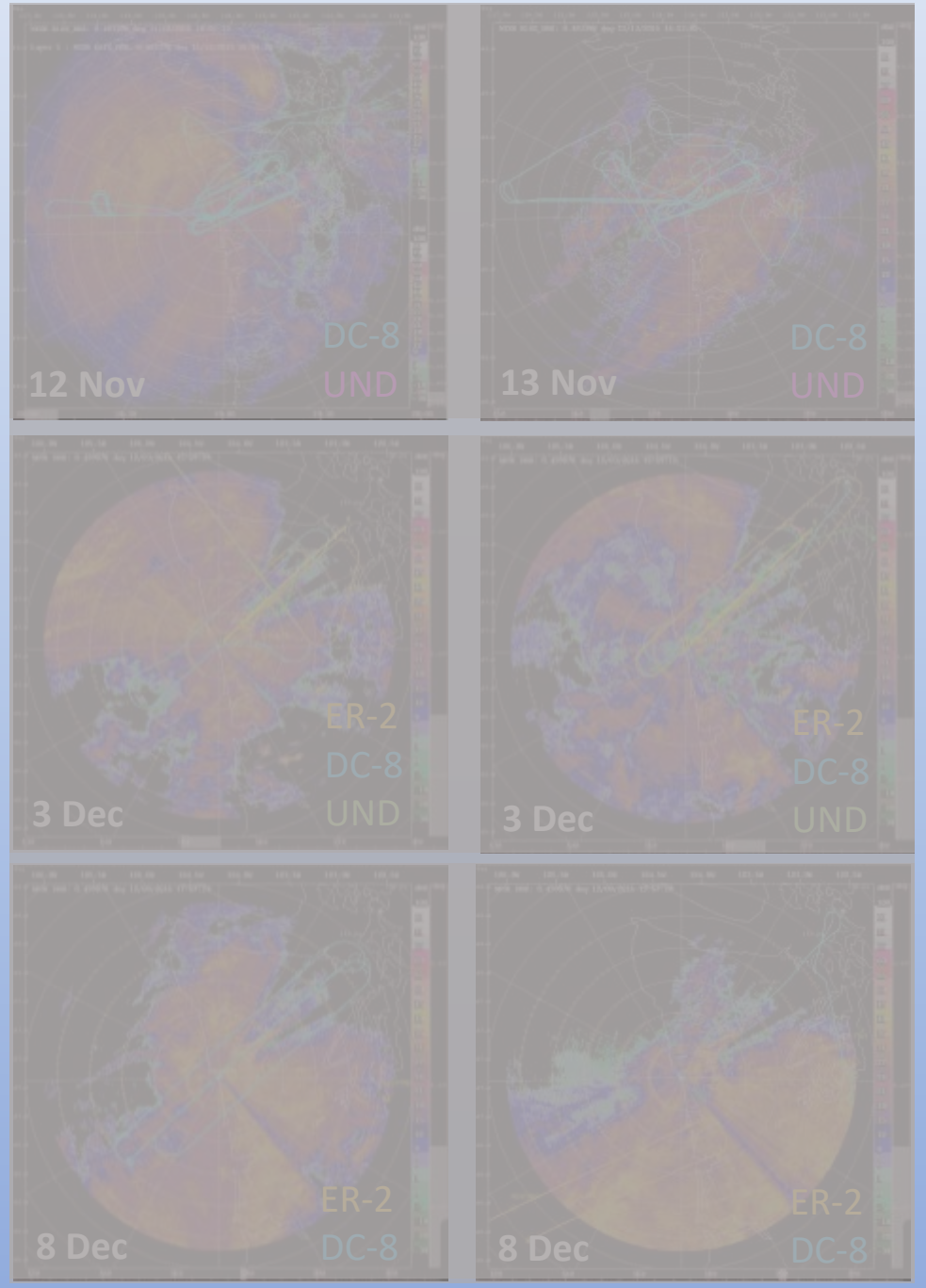


- Composite rates generally more modest, still prefer regions
- Initial inland peak largest
- **GPROF** & **DPR** sfc values underestimate as move inland



Additional perspective: Airborne Observations

- Continuing work:
  - Integrating airborne data
  - Ground-based HID + in situ
  - GPM Core + airborne “analogs”
- 12-13 Nov: Citation, DC-8
  - Legs across valley, GMI OP, NCFR
  - Variations in LWC aloft
- 3 Dec: Citation, DC-8, ER-2
  - Stacked legs/DPR OP, valley legs
  - Liquid water (including -20C)
- 8-9 Dec: DC-8, ER-2
  - Valley, GMI OP, offshore
  - Dropsondes - cross-AR structure



Summary & Continuing Work

- OLYMPEX Atmospheric Rivers: GPM overpasses, Warm Sector / Fr > 1.3
  - 6 events, over 100+h of obs, 8 GMI/2DPR Ops, 5 SIMBA sites
- *All Cases:*
  - Large variation of precipitation parameters
  - Enhancement at coast & as approach terrain barrier clear, but somewhat gradual
  - DPR aligns with ground-based observations **best over ocean**
- *17 Nov - Westerly flow case:*
  - Larger **MRR vs NPOL** discrepancy
  - More intense precipitation rates
  - Enhancement regions most prominent over land
- *3 Dec - Southerly component case*:
  - MRR & NPOL means better align
  - Generally lower precipitation rates
  - **Enhancement regions initiate offshore**

This work is supported by an appointment to the NASA Postdoctoral Program at Marshall Space Flight Center, administered by Universities Space Research Association through a contract with NASA.

Summary & Continuing Work

- OLYMPEX Atmospheric Rivers: GPM overpasses, Warm Sector / Fr > 1.3
  - 6 events, over 100+h of obs, 8 GMI/2DPR Ops, 5 SIMBA sites
- *All Cases:*
  - Large variation of precipitation parameters
  - Enhancement at coast & as approach terrain barrier clear, but somewhat gradual
  - DPR aligns with ground-based observations **best over ocean**
- *17 Nov - Westerly flow case:*
  - Larger **MRR vs NPOL** discrepancy
  - More intense precipitation rates
  - Enhancement regions most prominent over land
- *3 Dec - Southerly component case*:
  - MRR & NPOL means better align
  - Generally lower precipitation rates
  - **Enhancement regions initiate offshore**

This work is supported by an appointment to the NASA Postdoctoral Program at Marshall Space Flight Center, administered by Universities Space Research Association through a contract with NASA.

Summary & Continuing Work

- OLYMPEX Atmospheric Rivers: GPM overpasses, Warm Sector / Fr > 1.3
  - 6 events, over 100+h of obs, 8 GMI/2DPR Ops, 5 SIMBA sites
- *All Cases:*
  - Large variation of precipitation parameters
  - Enhancement at coast & as approach terrain barrier clear, but somewhat gradual
  - DPR aligns with ground-based observations **best over ocean**
- *17 Nov - Westerly flow case:*
  - Larger **MRR vs NPOL** discrepancy
  - More intense precipitation rates
  - Enhancement regions most prominent over land
- *3 Dec - Southerly component case*:
  - MRR & NPOL means better align
  - Generally lower precipitation rates
  - **Enhancement regions initiate offshore**

This work is supported by an appointment to the NASA Postdoctoral Program at Marshall Space Flight Center, administered by Universities Space Research Association through a contract with NASA.

Summary & Continuing Work

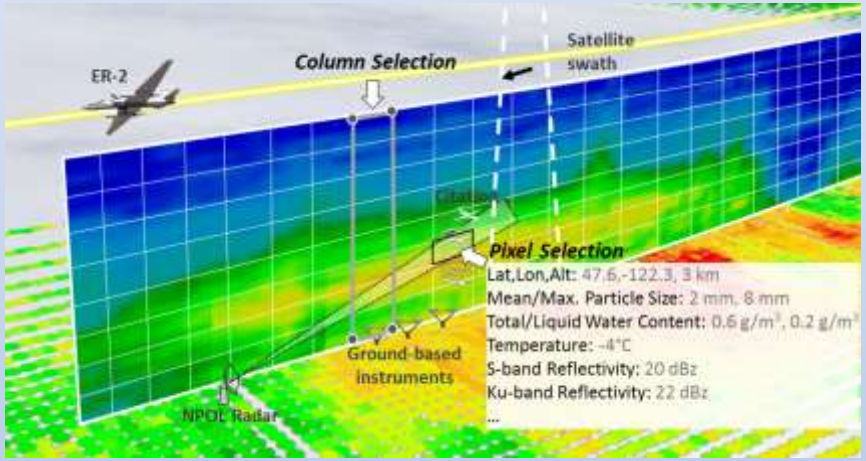
- OLYMPEX Atmospheric Rivers: GPM overpasses, Warm Sector / Fr > 1.3
  - 6 events, over 100+h of obs, 8 GMI/2DPR Ops, 5 SIMBA sites
- *All Cases:*
  - Large variation of precipitation parameters
  - Enhancement at coast & as approach terrain barrier clear, but somewhat gradual
  - DPR aligns with ground-based observations **best over ocean**
- *17 Nov - Westerly flow case:*
  - Larger **MRR vs NPOL** discrepancy
  - More intense precipitation rates
  - Enhancement regions most prominent over land
- *3 Dec - Southerly component case*:
  - MRR & NPOL means better align
  - Generally lower precipitation rates
  - **Enhancement regions initiate offshore**

- Processes, satellite-based observations involve more than below 0°C level
  - **ICE vs LIQ**, incorporating airborne data will improve analysis
  - Compositing with "analog" instruments
  - PMW & CMB **algorithm products** – impacts of ice and transition to higher terrain

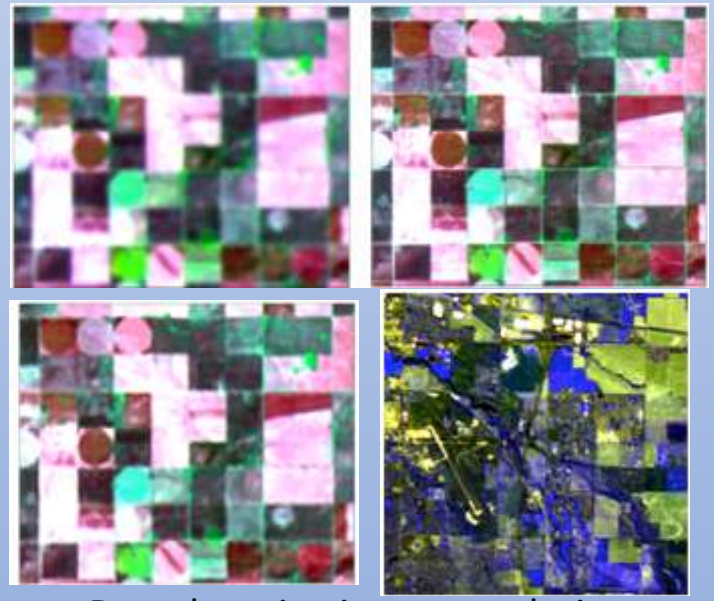
This work is supported by an appointment to the NASA Postdoctoral Program at Marshall Space Flight Center, administered by Universities Space Research Association through a contract with NASA.

Related Projects/ Ancillary Applications

- Long-term validation at WPRF
  - *Poster H43F-2470 (Thurs)*
- Visualization for Integrated Satellite, Airborne, and Ground-based data Exploration (VISAGE)
  - NASA AIST collaboration of UAH ITSC & MSFC/GHRC DAAC
  - *Poster IN51D-0609 (Fri)*
- Improving DPR spatial resolution via Machine Learning
  - Testing application of deep learning image resolution technology to satellite radar data
  - *Poster T31E-0363 (Wed)*



VISAGE concept schematic



Deep learning image resolution enhancement: input low, target high, output high res, output high res

Pabla et al. 2018; Conover et al. 2017,2018; Collins et al. 2017, Beck et al. 2018

References

Collins, C. B., and colleagues, 2017: Deep learning for multisensor image resolution enhancement. in Proceedings of the 1st Workshop on Artificial Intelligence and Deep Learning for Geographic Knowledge Discovery. ACM.

Conover, H., and colleagues, 2017: Introducing the VISAGE project- Visualization for Integrated Satellite, Airborne, and Groundbased data Exploration. 2017 Fall Meeting, New Orleans, LA, Amer. Geophys. Union.

Conover, H., T. Berendes, P. N. Gatlin, M. Maskey, A. Naeger, and S. M. Wingo, 2018: Preliminary results from the VISAGE project – Visualization for Integrated Satellite, Airborne, and Ground-based data Exploration. *Amer. Met. Soc.*, 98th Annual Meeting, Austin, TX.

Chen, H., V. Chandrasekar, and R. Bechini, 2017: An improved dual-polarization radar rainfall algorithm (DROPS2.0): Application in NASA IFloodS field campaign. *J. Hydromet.* **18**, 917-937.

Hou, A. Y., and colleagues, 2014: The Global Precipitation Measurement Mission. *Bull.. Amer. Meteor. Soc.*, **95**, 701-722.

Houze, R. A. Jr., and colleagues, 2017: The Olympic Mountains Experiment (OLYMPEX). *Bull. Amer. Meteor. Soc.,* **98***,* 2167-2188.

Hunzinger, A. H., 2018: Orographic effects on ice and liquid-phase precipitation processes during the Olympic Mountains Experiment. MS thesis, Dept. of Atmospheric Science, University of Alabama in Huntsville, 139p.

Martner, B. E., and colleagues, 2008: Raindrop size distributions and rain characteristics in California coastal rainfall for periods with and without a radar bright band. *J. Hydrometeor.*, **9**, 408-425.

Minder, J. R., and colleagues, 2008: The climatology of small-scale orographic precipitation over the Olympic Mountains: Patterns and processes. *Q. J. R. Meteorol. Soc.*, **134**, 817-839.

Petersen, W. A., and colleagues, 2016: The Olympic Mountains Experiment. *Met. Tech. Int.*, Sept 2016, 22-26.

Ralph, F. M., P. J. Neiman, and G. A. Wick, 2004: Satellite and CALJET aircraft observations of atmospheric rivers over the eastern North Pacific Ocean during the winter of 1997/98. *Mon. Wea. Rev.*, **132**, 1721-1745.

Ralph, R. M, and colleagues, 2018: Defining "Atmospheric River:" How the *Glossary of Meteorology* helped resolve a debate. *Bull. Amer. Met. Soc.*, **99**, 837-839.

Schwaller, M. R., and K. R. Morris, 2011: A ground validation network for the global precipitation measurement mission. *J. Atmos. Oceanic Technol.*, **28**, 301–319.

Skofronick-Jackson, G., and colleagues, 2017: The Global Precipitation Measurement (GPM) Mission for Science and Society. *Bull. Amer. Meteor. Soc.*, **98**, 1679-1695.

Yuter, S. E. and R. A. Houze, 2003: Microphysical modes of precipitation growth determine by S-band vertically pointing radar in orographic precipitation during MAP. *Q. J. R. Meteorol. Soc.*, **29**, 455-476.

White, A. B., and colleagues, 2003: Coastal orographic rainfall processes observed by radar during the California Land-Falling Jets Experiment. *J. Hydrometeorol.*, **4**, 264-282.

Wolff, D. B, and colleagues, 2015: GPM radar studies at NASA's Wallops Precipitation Research Facility. 37th Conf. on Radar Meteorology, Norman, OK, Amer. Meteor. Soc.

Zagrodnik, J. P., L. A. McMurdie, and R. A. Houze Jr., 2018: Stratiform precipitation processes in cyclones passing over a coastal mountain range. *J. Atmos. Sci.*, **75**, 983–1004.

Zhu, Y. and R. E. Newell, 1998: A proposed algorithm for moisture fluxes from atmospheric rivers. *Mon. Wea. Rev.*, **126**, 725-735.