16th International Winds Workshop, 8-12 May 2023

ADVANCES IN STEREO WINDS

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8 May 2023

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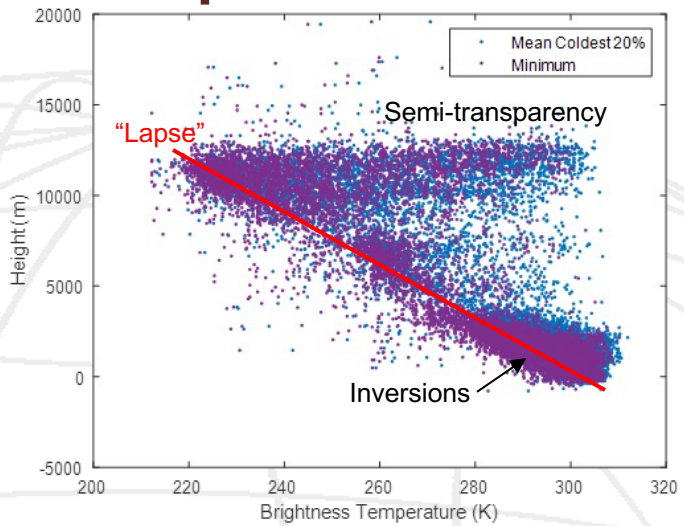
Science at work

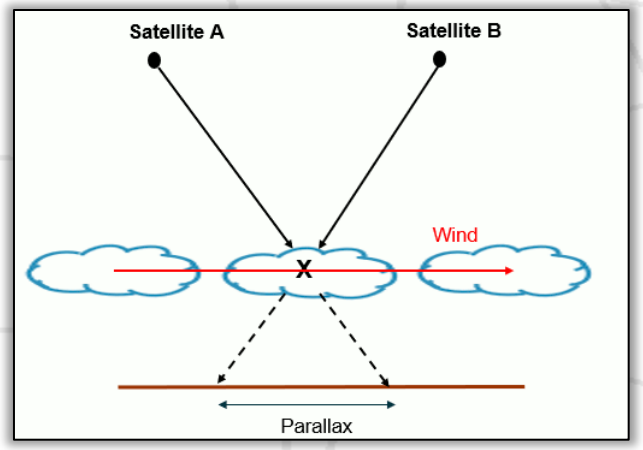
Overview

- NOAA & NASA “3D Winds” collaborations 2018-present
  - GEO-GEO Stereo (GOES, Himawari, Meteosat, ***GK2A***)
  - GEO-LEO Stereo GEO+(MISR, MODIS, VIIRS, ***Tandem VIIRS***) ***New***
  - Multi-LEO (MODIS, VIIRS, ***SLSTR***)
- Progress at NOAA towards Operational Stereo Winds
- Development of Multi-LEO Stereo for Polar Winds
- Applications and Validation

Stereo Winds Concept

- Stereo-Winds Method
  - Tracers are tracked over time from multiple platforms or look directions
  - Joint retrieval interprets apparent shifts in tracer location (“Disparities”) as a wind with its height
- Benefits
  - Direct and presumably more accurate height assignments vs. IR methods with modeled thermodynamics
  - NWP model independence
  - Complementary with LiDAR to provide 3D information with wide coverage at one (few) layer(s)
- Old idea made possible by modern Image Navigation and Registration (INR)





Hasler, A.F. Stereographic Observations from Geosynchronous Satellites: An Important New Tool for the Atmospheric Sciences. 1981, 62, 194-212, doi:10.1175/1520-0477(1981)062<0194:Sofgsa>2.0.Co;2

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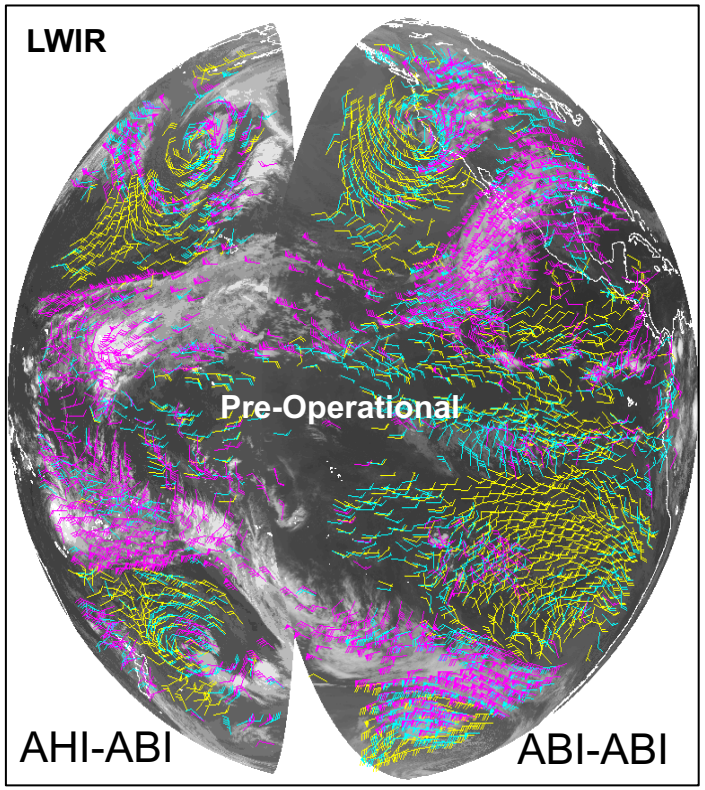
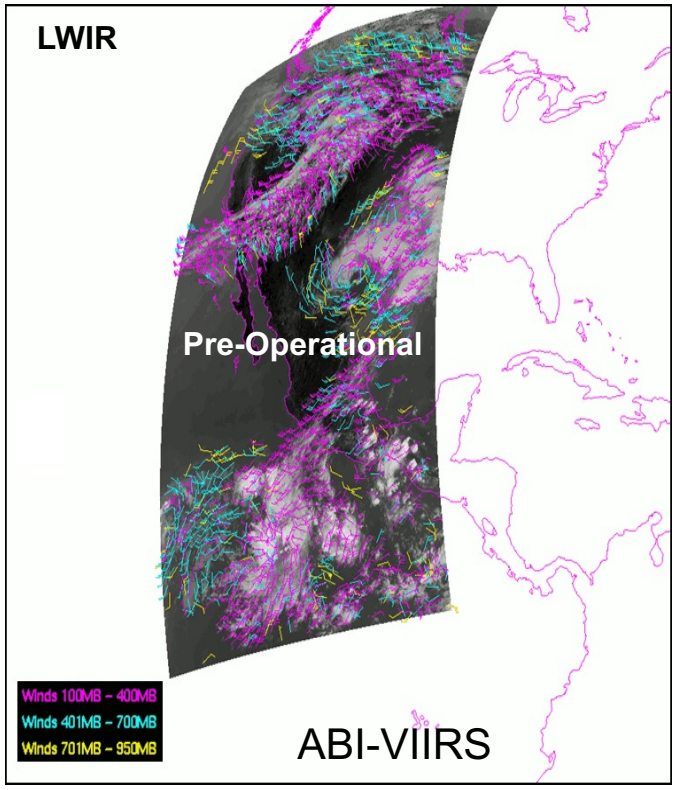
Existing Stereo-Wind Product Types

GEO-GEO



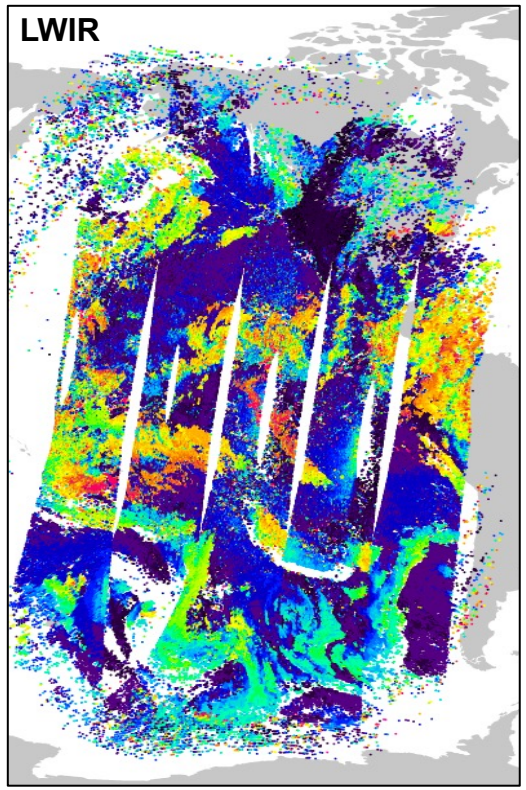
Pathfinder GEO-GEO Stereo Winds Product

GEO-LEO

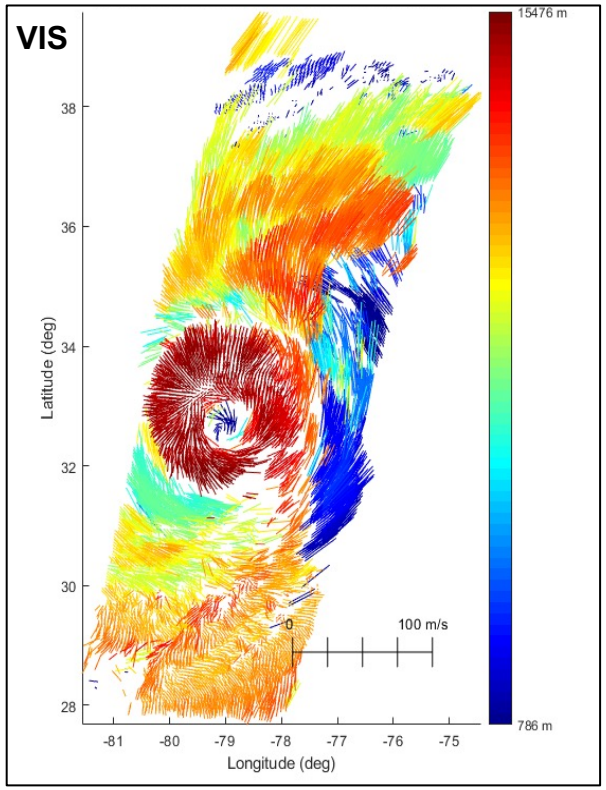


Pathfinder GEO-LEO Stereo Winds Product

GEO-LEO Multi-Angle



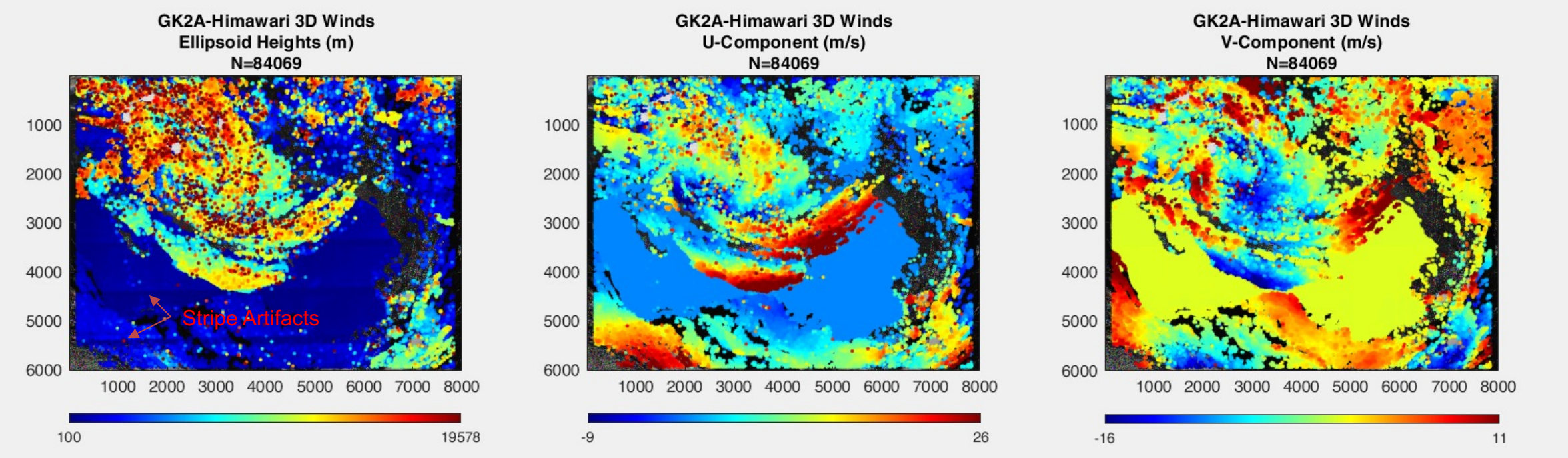
Multi-Orbit GOES-MODIS/Terra Daytime



GOES-MISR Multi-Angle Dorian Mesoscale

GK2A/AMI Overlapping Himawari/AHI

Example of Australian Region of Interest: B03 @ 0.5 km



Very useful to study smoke plumes from wildfires

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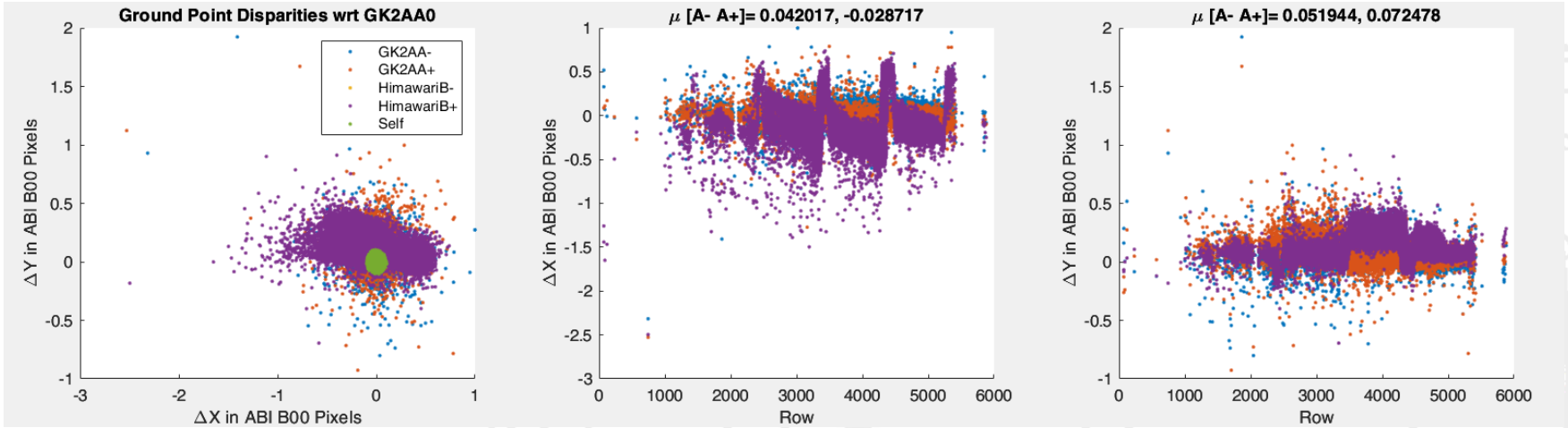
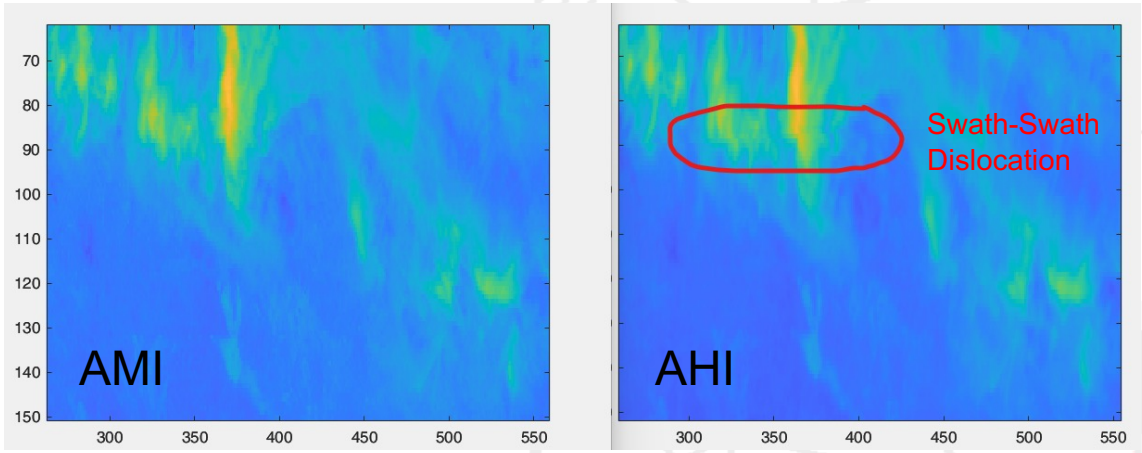
AMI-AHI Ground Sites





Small longitude difference of 12.5° makes this paring susceptible to small and subtle INR errors

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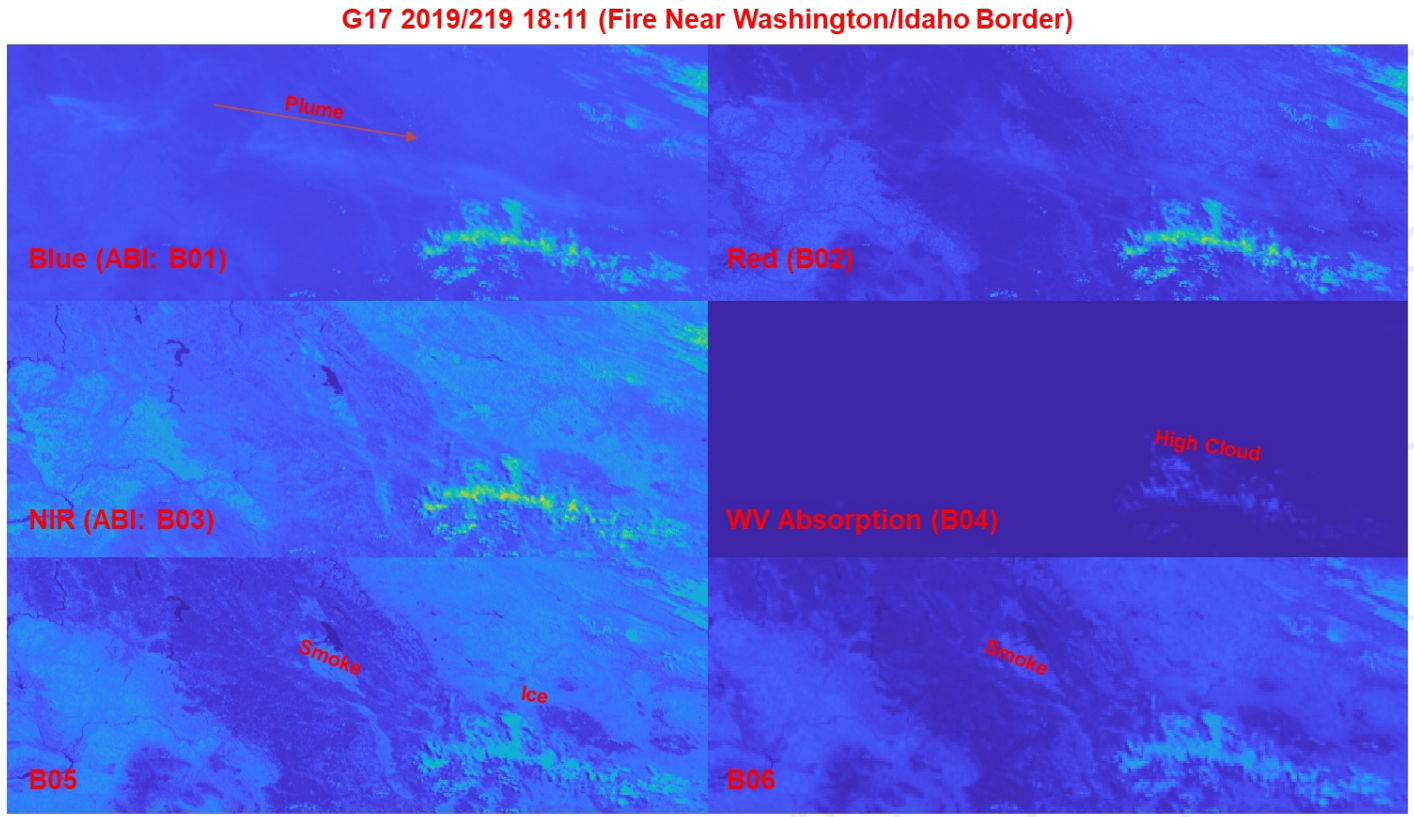
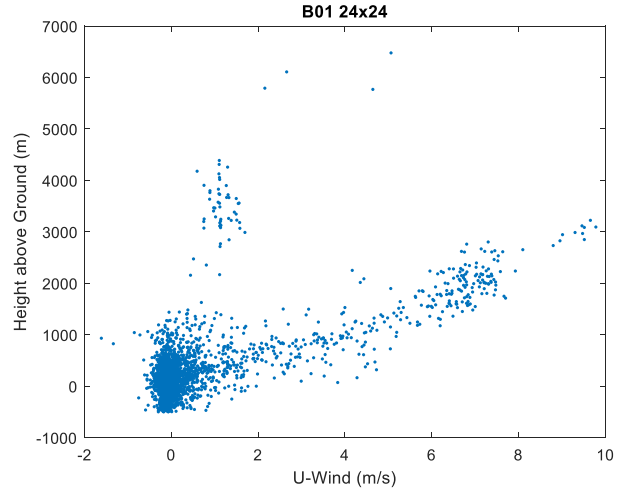
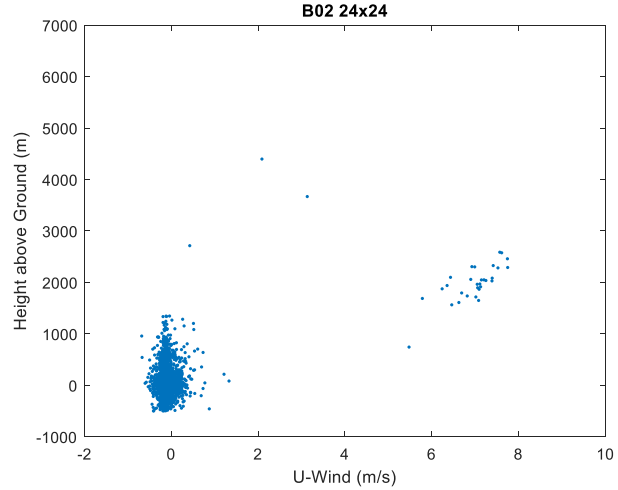
Smoke vs. Cloud Advection







Multiband approach discriminates smoke from clouds

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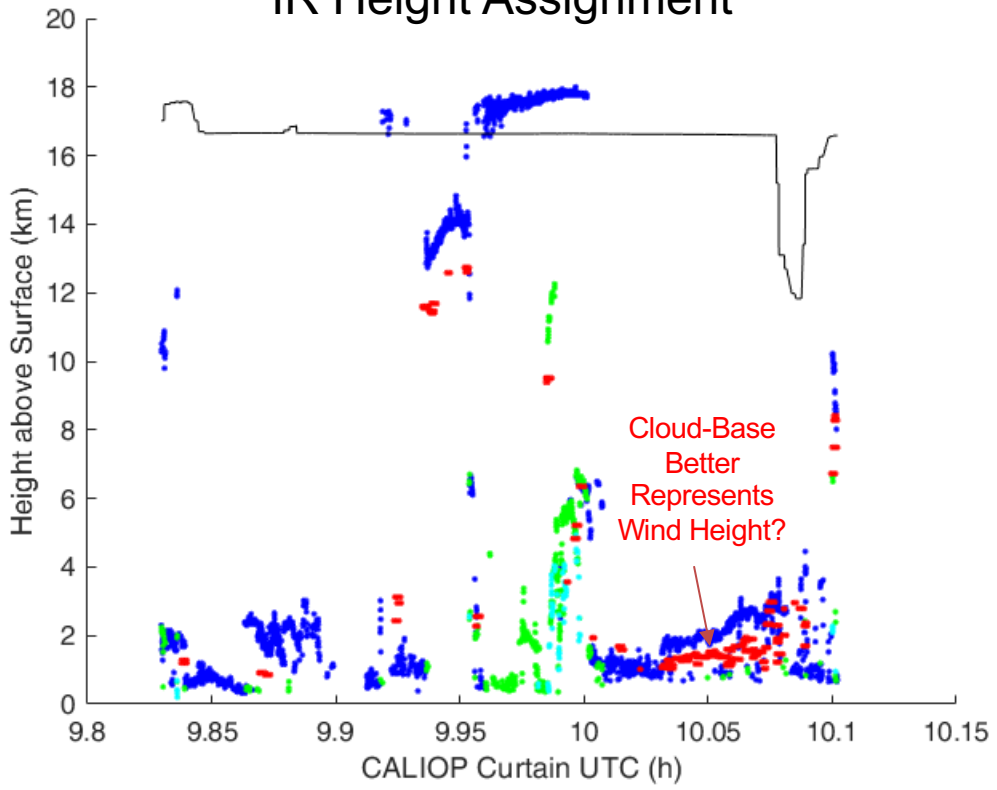
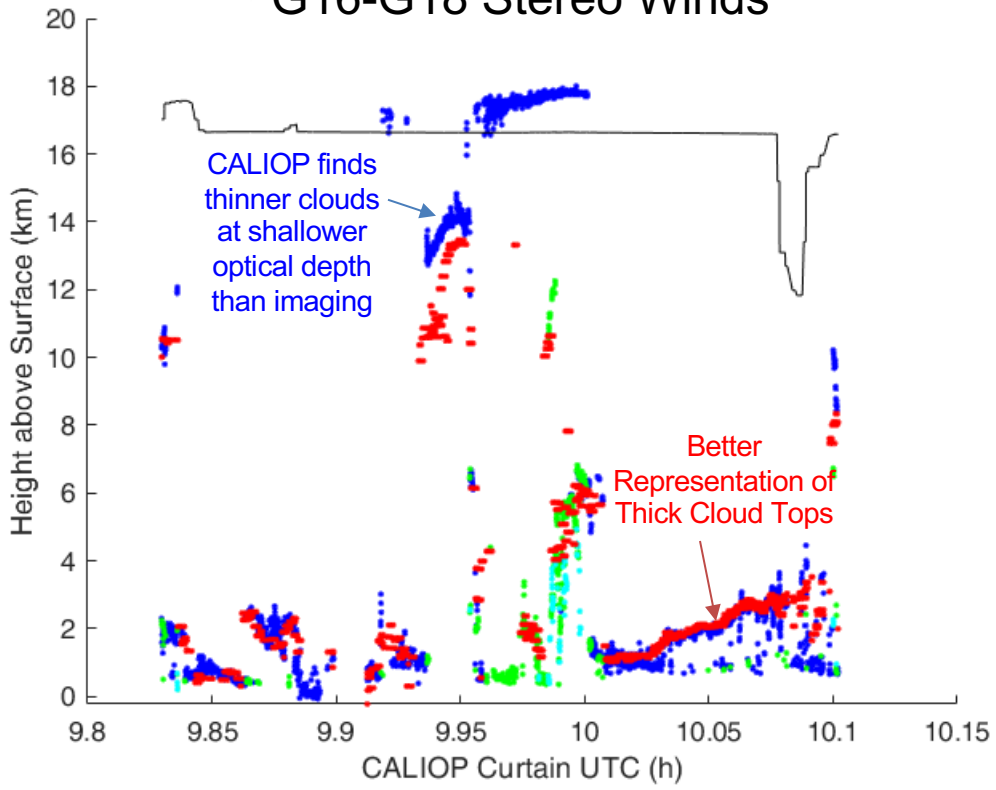
GEO-GEO CALIOP Validation

Near Simultaneous with CALIPSO Overpass: Marine Clouds

IR Height Assignment



G16-G18 Stereo Winds



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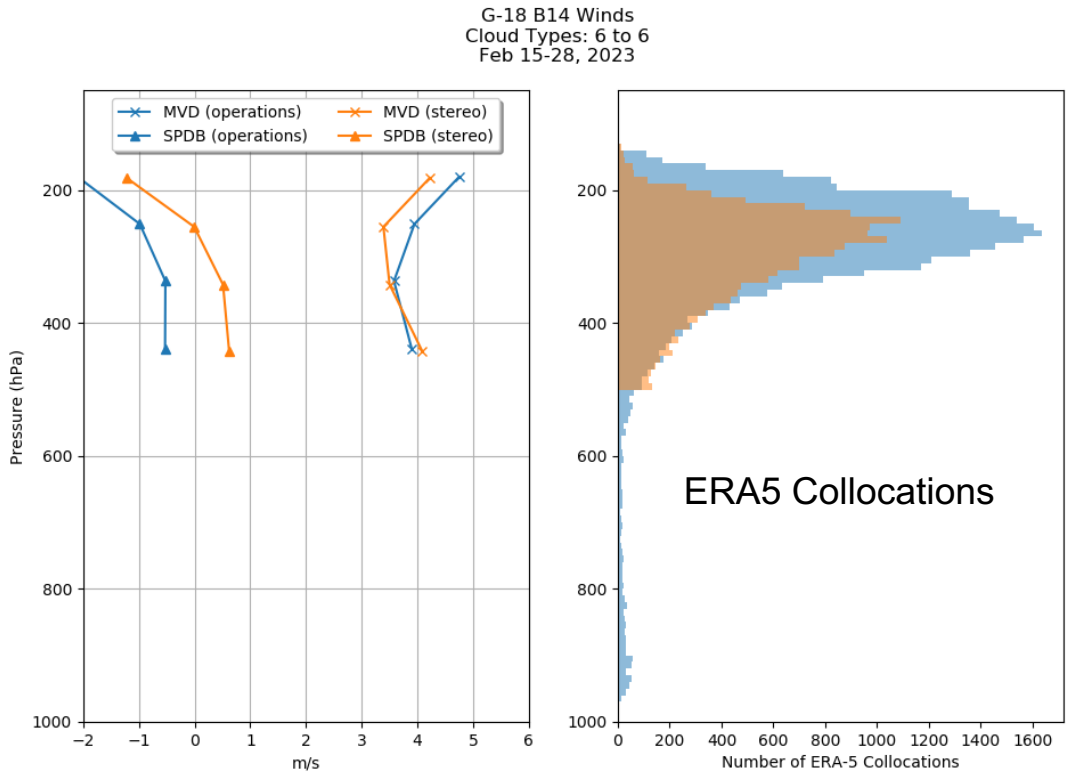
Comparative Height Assignments

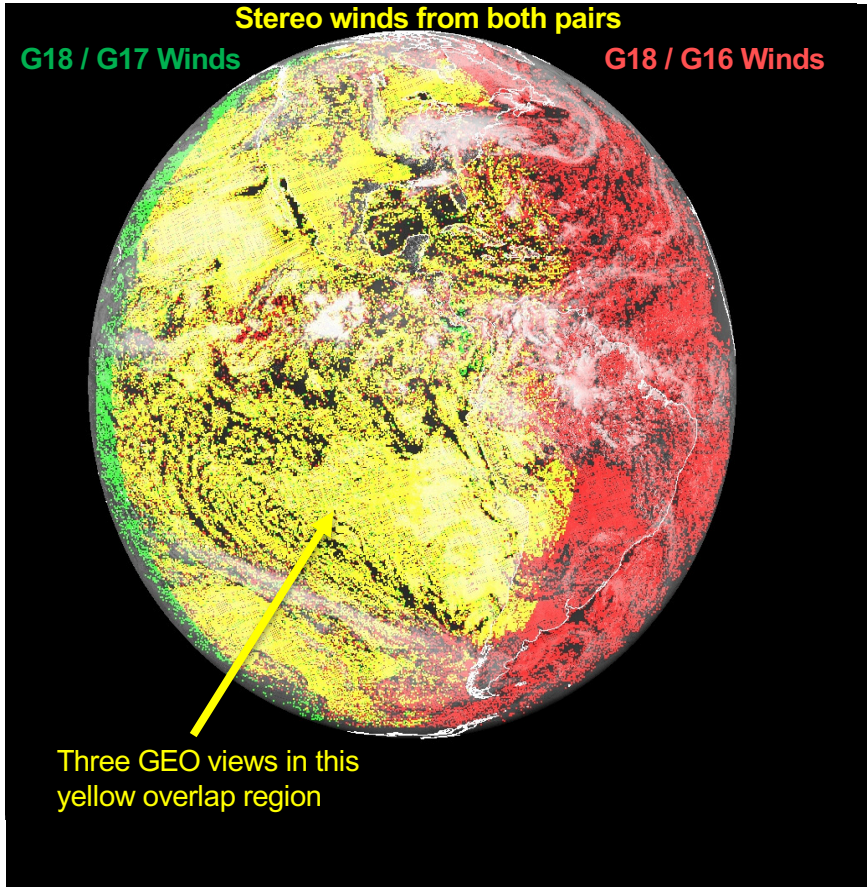
- Stereo methods seem to have the clearest benefit for higher-level winds
- Situation is more nuanced at lower levels where cloud base may be the better marker for wind height in marine environments
  - Collocated reanalysis winds seem not as well aligned with stereo ones in these cases (more work to be done)
- Observation points to having both height assignments available in Operational products



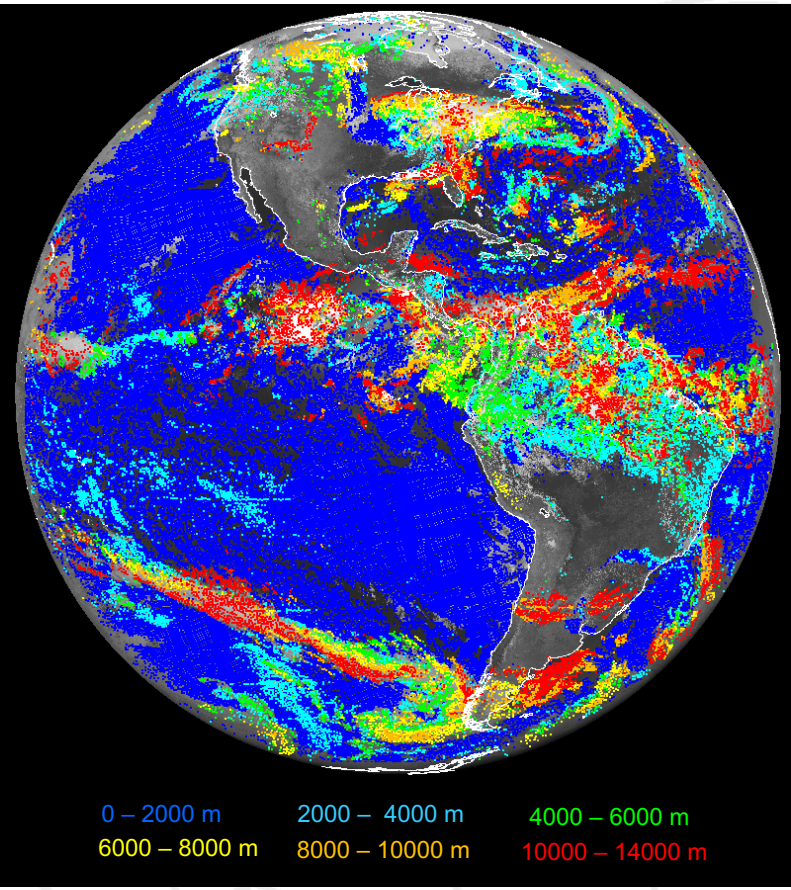
Hasler AF, Skillman WC, Shenk WE, Steranka J. In situ aircraft verification of the quality of satellite cloud winds over oceanic regions. Journal of Applied Meteorology and Climatology. 1979 Nov;18(11):1481-9.

Filling in the GEO Ring

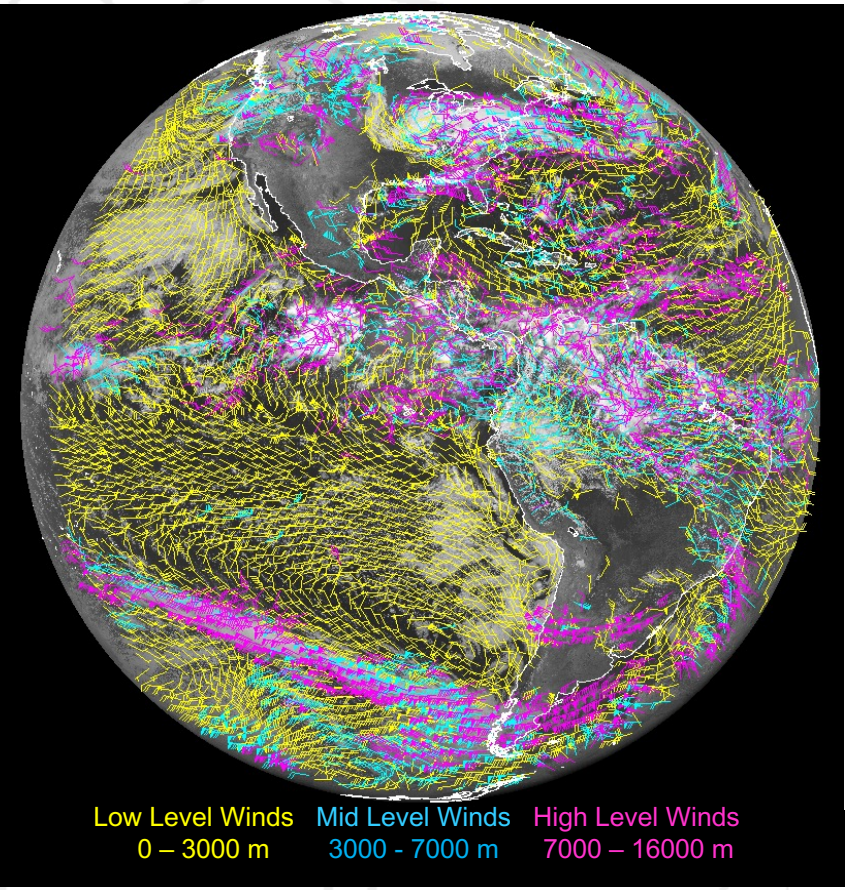
Overlapping Coverage



Retrieved Ellipsoid Height (m)



Retrieved Stereo Winds (Band 2)



G17: -137.2° G18: -89.5° G16: -75.2°

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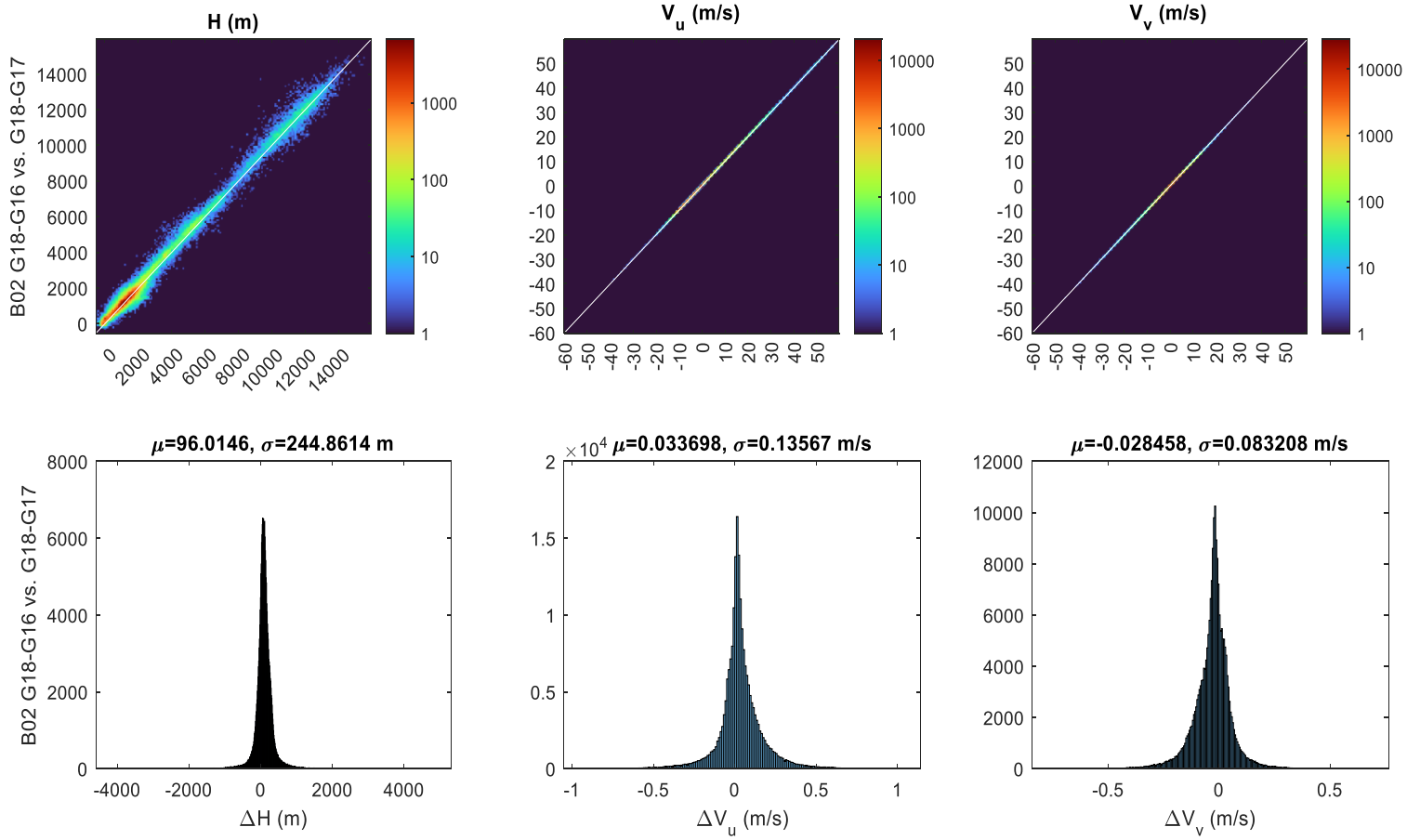
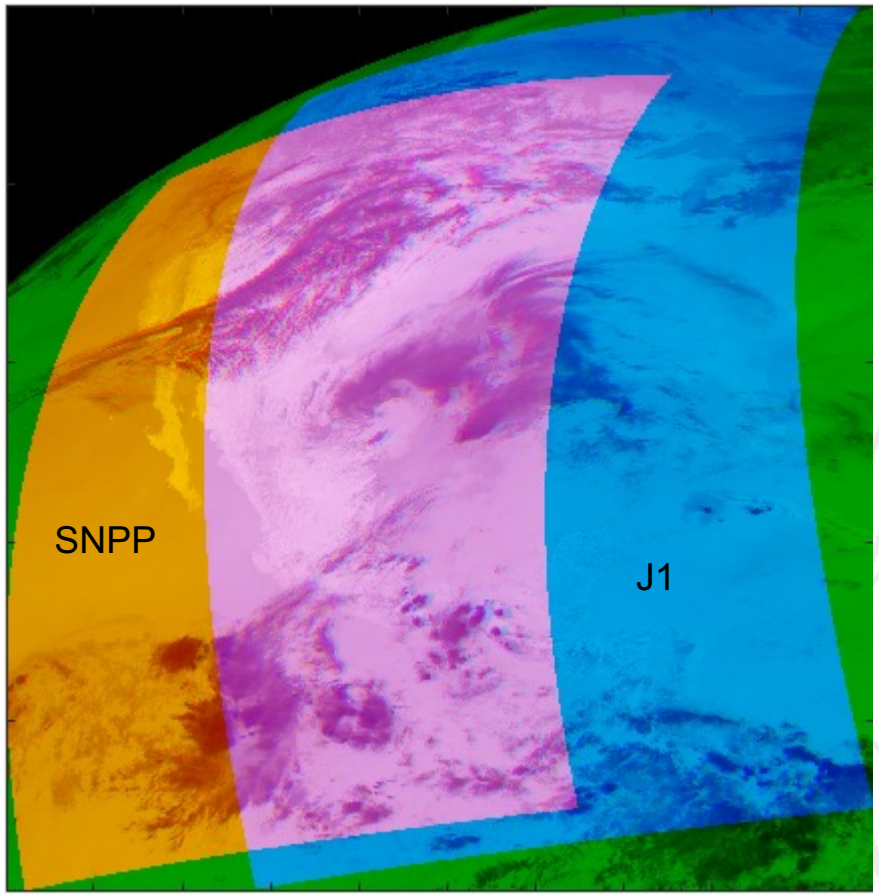
Consistency between G18-X Pairings



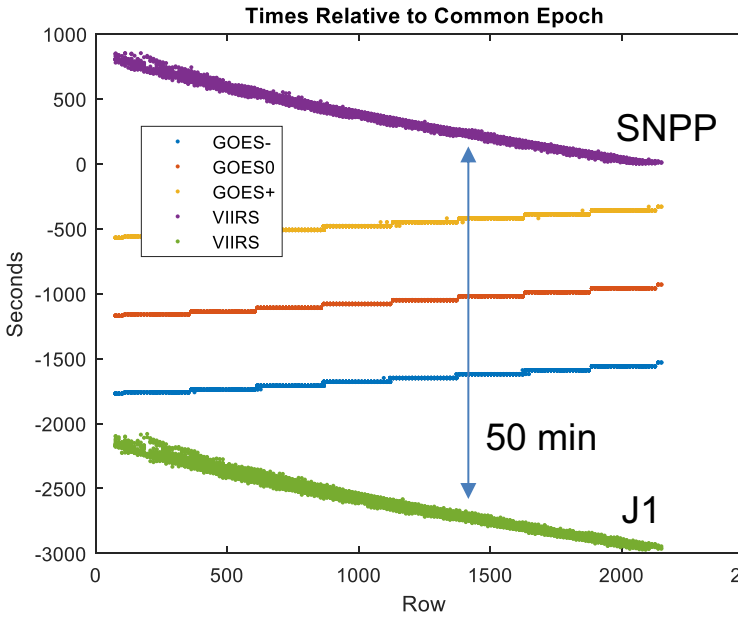
Breadth and Consistency shows Strength/Benefit of Stereo with a full GEO Ring

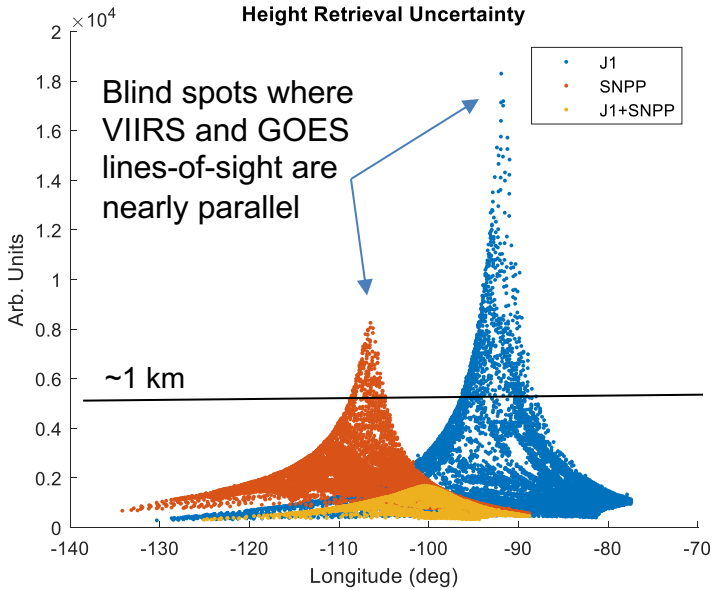
Single & Tandem VIIRS

VIIRS over GOES



- 2xVIIRS mitigates stereo blind spots in the triple overlap
- Single-VIIRS coverage extends breadth of product





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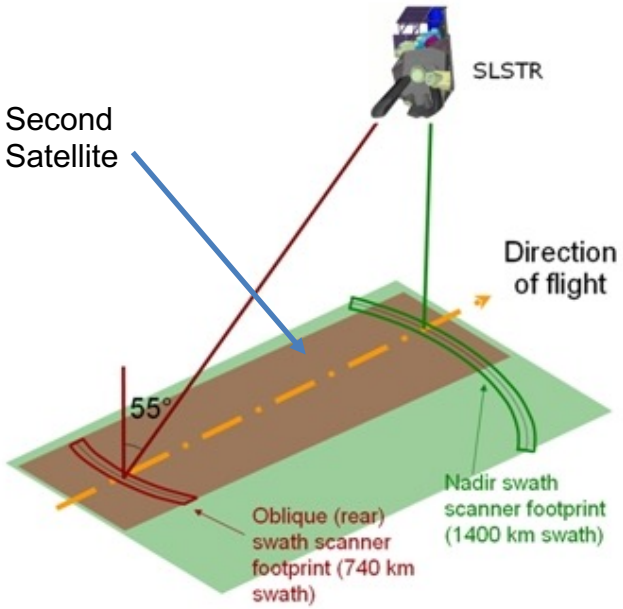
Polar Stereo w/ MODIS & SLSTR

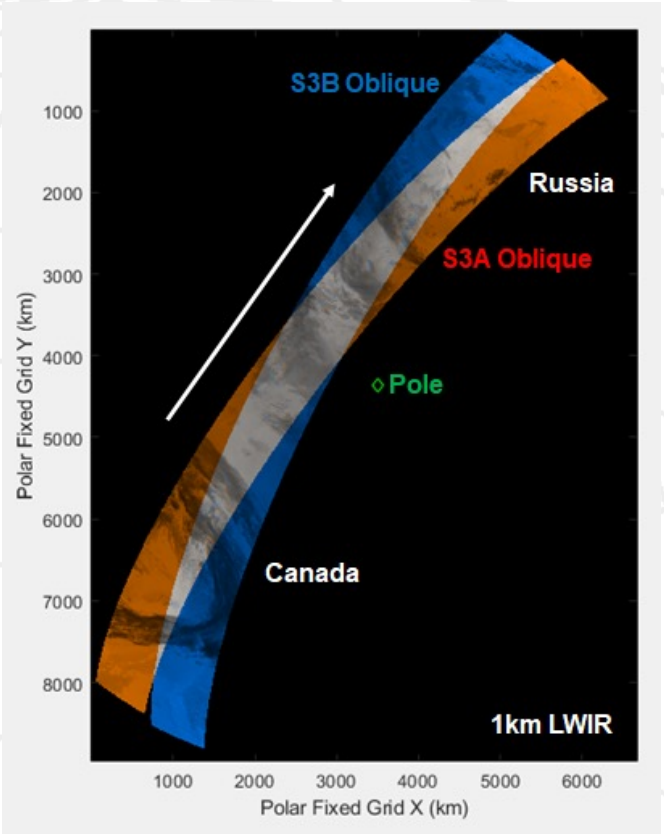
Multi-Angle Sensing Solves "Stereo Blind Spot" or *Astereopsis* Problem.



- Sentinel-3A/B and Terra form a train.
- Sentinel-3 and Terra time phasing beats due to different orbital periods.

2-Satellite Tandem w/ Global Coverage

2-Satellite Tandem w/ Polar Coverage



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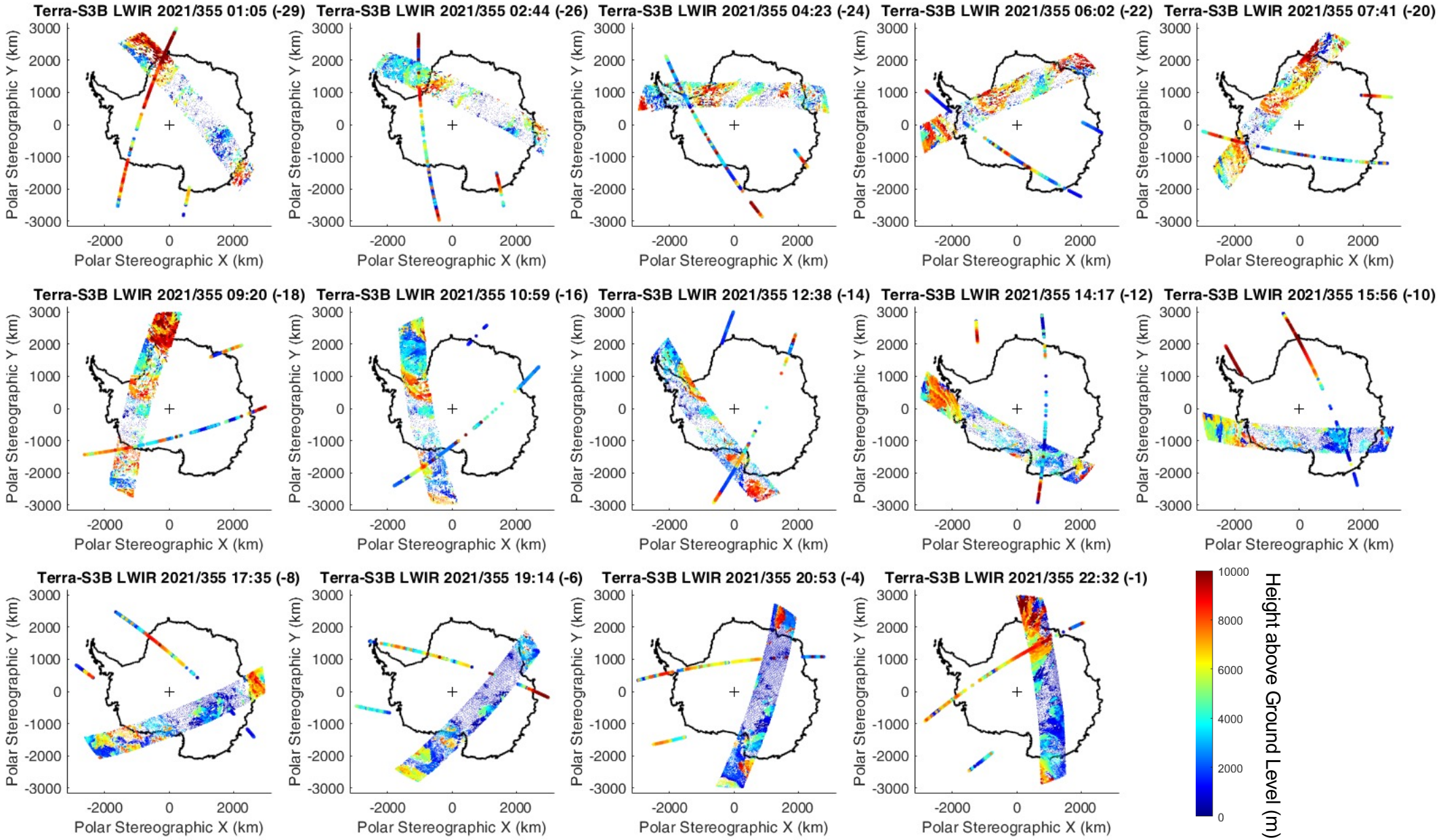
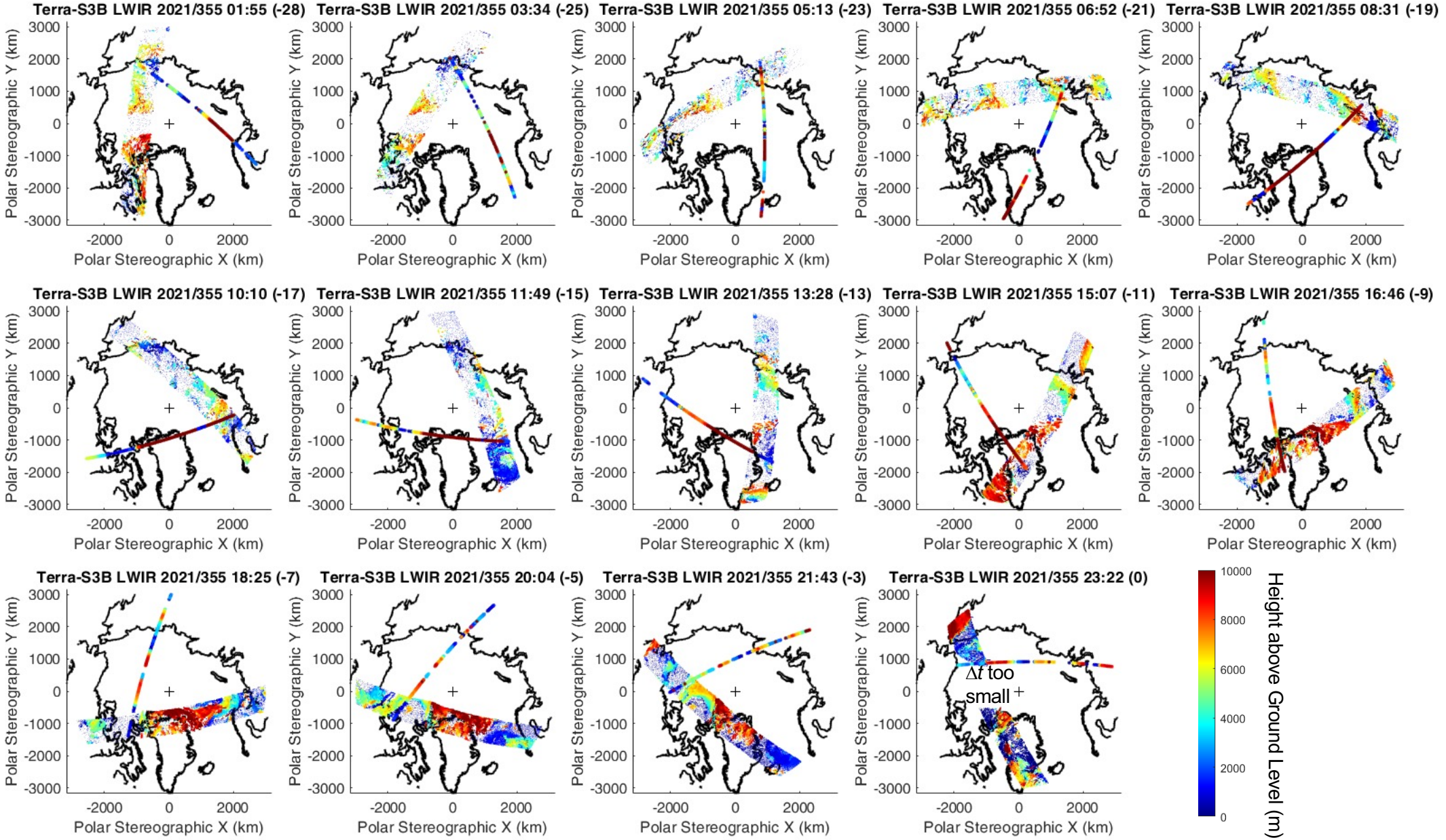
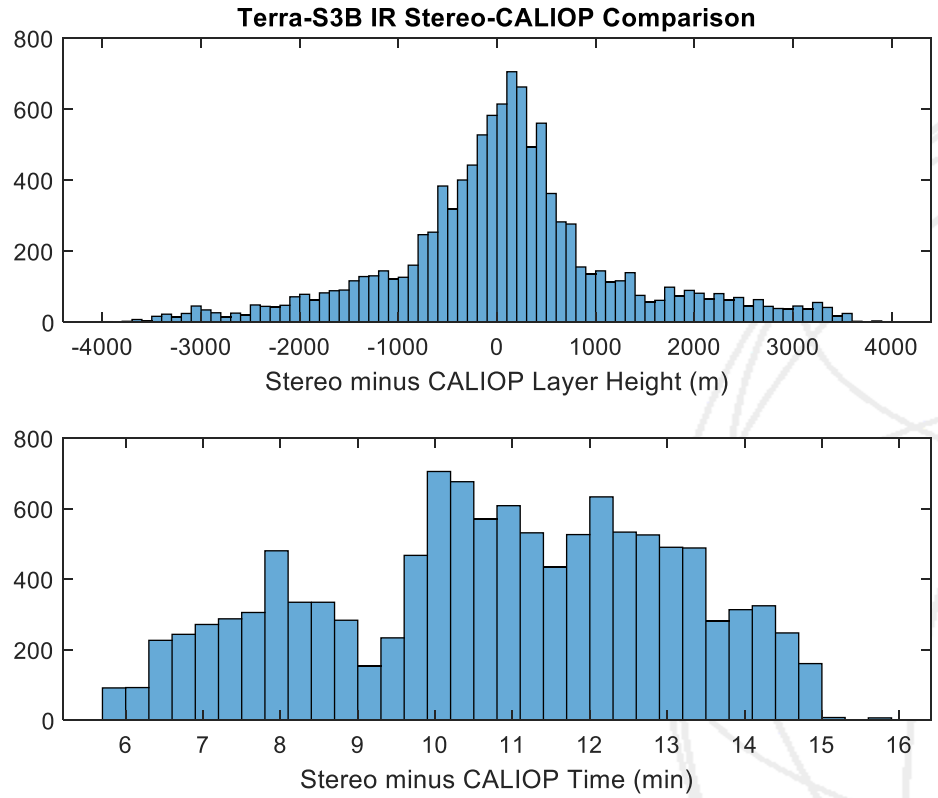
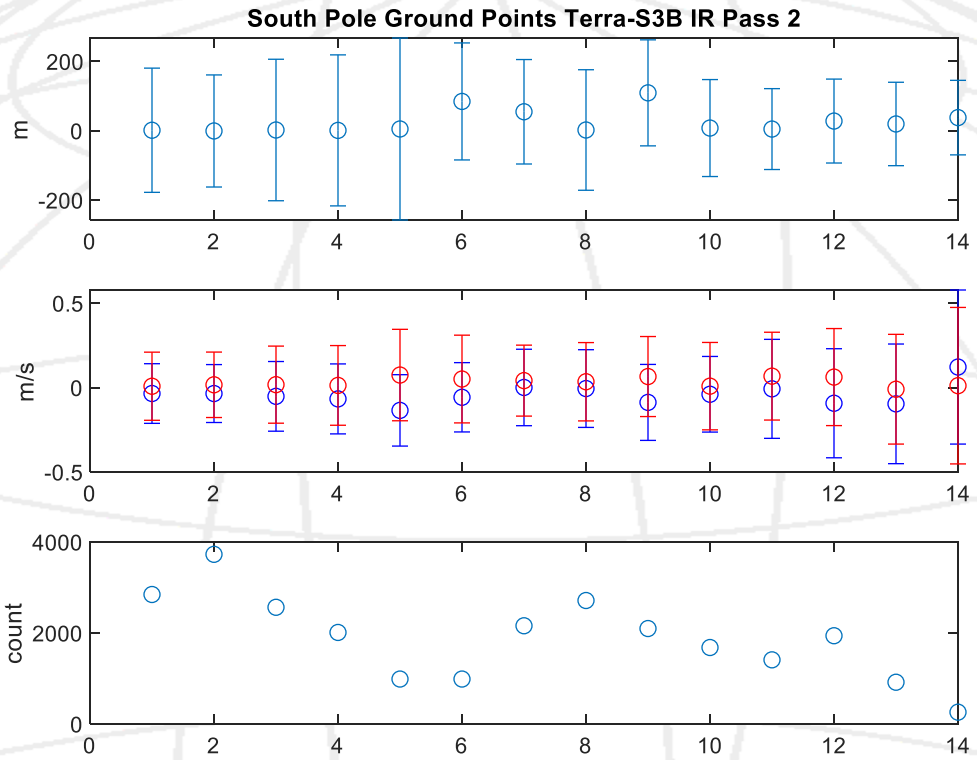

Terra-S3B LWIR 2021/355 01:05 (-29)
Terra-S3B LWIR 2021/355 02:44 (-26)
Terra-S3B LWIR 2021/355 04:23 (-24)
Terra-S3B LWIR 2021/355 06:02 (-22)
Terra-S3B LWIR 2021/355 07:41 (-20)
Terra-S3B LWIR 2021/355 09:20 (-18)
Terra-S3B LWIR 2021/355 10:59 (-16)
Terra-S3B LWIR 2021/355 12:38 (-14)
Terra-S3B LWIR 2021/355 14:17 (-12)
Terra-S3B LWIR 2021/355 15:56 (-10)
Terra-S3B LWIR 2021/355 17:35 (-8)
Terra-S3B LWIR 2021/355 19:14 (-6)
Terra-S3B LWIR 2021/355 20:53 (-4)
Terra-S3B LWIR 2021/355 22:32 (-1)
Polar Stereographic Y (km)
Polar Stereographic X (km)
3000
2000
1000
0
-1000
-2000
-3000
-2000
0
2000
Height above Ground Level (m)
10000
8000
6000
4000
2000
0


Terra-S3B LWIR 2021/355 01:55 (-28)
Terra-S3B LWIR 2021/355 03:34 (-25)
Terra-S3B LWIR 2021/355 05:13 (-23)
Terra-S3B LWIR 2021/355 06:52 (-21)
Terra-S3B LWIR 2021/355 08:31 (-19)
Terra-S3B LWIR 2021/355 10:10 (-17)
Terra-S3B LWIR 2021/355 11:49 (-15)
Terra-S3B LWIR 2021/355 13:28 (-13)
Terra-S3B LWIR 2021/355 15:07 (-11)
Terra-S3B LWIR 2021/355 16:46 (-9)
Terra-S3B LWIR 2021/355 18:25 (-7)
Terra-S3B LWIR 2021/355 20:04 (-5)
Terra-S3B LWIR 2021/355 21:43 (-3)
Terra-S3B LWIR 2021/355 23:22 (0)
Δt too small
Polar Stereographic Y (km)
Polar Stereographic X (km)
Height above Ground Level (m)

CALIOP & Ground-Point Validations





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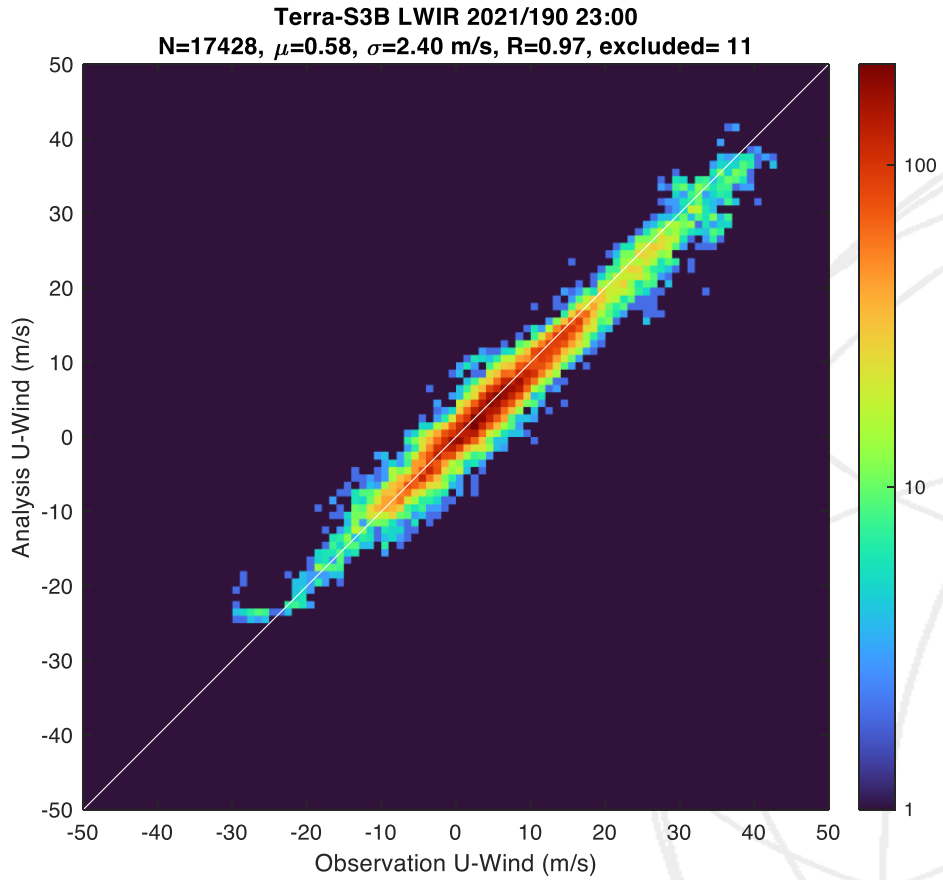
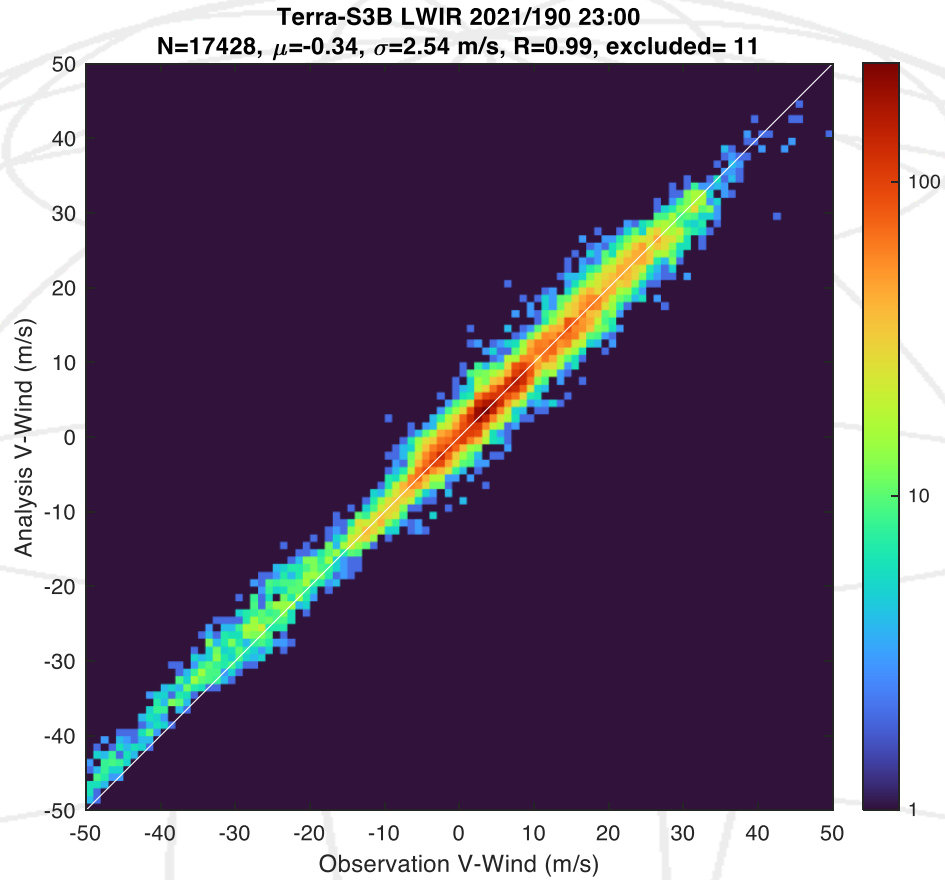
Polar Wind & ERA5 Collocations





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Summary

- The portfolio of Stereo Winds has grown
- Work at NOAA aims for Stereo Winds to be an Operational Product
  - GEO-GEO (GEO = GOES, Himawari)
  - GEO-VIIRS
- The whole globe can now be covered in Stereo
  - GEO-GEO
  - GEO-LEO
  - Polar Multi-LEO
- Future Directions
  - GOES-METEOSAT/FCI
  - Constellation Concepts (e.g., CMIS – Low-Cost Multi-angle IR Imager)

Related Stereo IWWG Presentations

- Jaime Daniels: “Status of Development of Atmospheric Motion Vectors (AMV) Capabilities at NOAA”
- Michael Kelly: “A New Capability for Monitoring Multi-Level Tropospheric Winds”
- Dong Wu: “Diurnal Variations of 3D-Wind Cloud Height and Winds From Hurricanes and PBL”
- Rebecca Stone: “Evaluation of Dual Geostationary Stereo Winds in NAVGEM”
- Akos Horváth: “Local Horizontal Wind Perturbations Caused By the Hunga Tonga-Hunga Ha’apai Eruption of 15 January 2022”
- Ad Stoffelen: “ESA Earth Explorer 10 Harmony”
- Kevin Maschhoff: “Synergies Obtained from Combined Observations of MISTiC Winds, CMIS, and NGRx in a Micro-Satellite Constellation”

IWWG16

BACKUP SLIDES

Our Stereo Winds Bibliography

Carr J.L., Wu D.L., Friberg M.D., Summers T.C. “Multi-LEO Satellite Stereo Winds,” Remote Sensing. **2023** https://doi.org/10.3390/rs15082154

Carr, J.L., Wu, D.L., Daniels, J., Friberg, M.D., Bresky, W., Madani, H. “GEO-GEO Stereo-Tracking of Atmospheric Motion Vectors (AMVs) from the Geostationary Ring,” Remote Sensing, **2020** https://doi.org/10.3390/rs12223779

Carr, J.L.; Daniels, J.; Wu, D.L.; Bresky, W.; Tan, B. “A Demonstration of Three-Satellite Stereo Winds,” Remote Sensing, **2022** https://doi.org/10.3390/rs14215290

Carr, J.L., Wu, D.L., Wolfe, R.E., Madani, H., Lin, G., Tan, B. “Joint 3D-Wind Retrievals with Stereoscopic Views from MODIS and GOES,” Remote Sensing, **2019** https://doi.org/10.3390/rs11182100

Carr, J.L., Wu, D.L., Kelly, Kelly, M.A., Gong, J. “MISR-GOES 3D Winds: Implications for Future LEO-GEO and LEO-LEO Winds,” Remote Sensing, **2018** https://doi.org/10.3390/rs10121885

Hasler, A.F. Stereographic Observations from Geosynchronous Satellites: An Important New Tool for the Atmospheric Sciences. **1981**, 62, 194-212, doi:10.1175/1520-0477(1981)062<0194:Sofgsa>2.0.Co;2.

Horváth, Á., Bresky, W., Daniels, J., Vogelzang, J., Stoffelen, A., Carr, J.L., Wu, D.L., C. Seethala, C., Günther, T., Buehler S.A. “Evolution of an atmospheric Kármán vortex street from high-resolution satellite winds: Guadalupe Island case study,” Journal of Geophysical Research: Atmospheres, **2020** https://doi.org/10.1029/2019JD032121

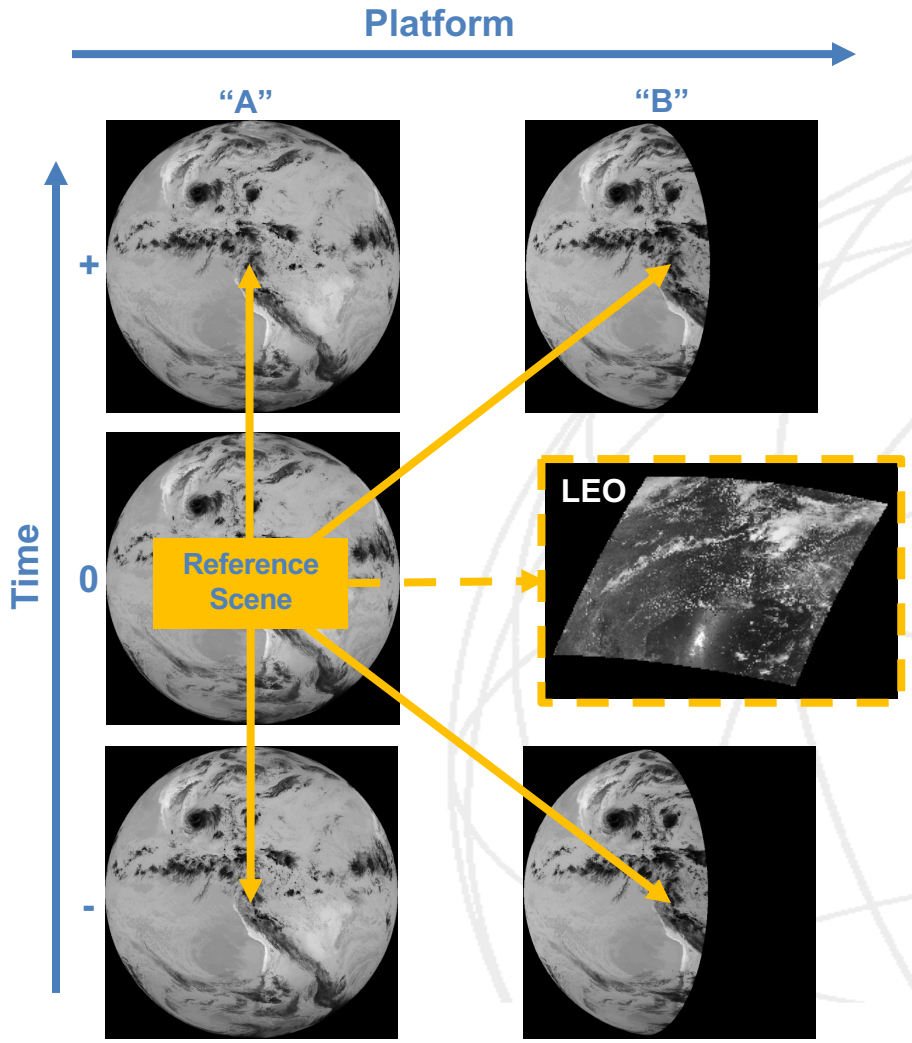
Horváth, Á., Carr, J. L., Girina, O. A., Wu, D. L., Bril, A. A., Mazurov, A. A., Melnikov, D. V., Hoshyaripour, G. A., Buehler, S. A. “Geometric estimation of volcanic eruption column height from GOES-R near-limb imagery – Part 1: Methodology,” Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2021-155, **2021**.

Horváth, Á., Girina, O. A., Carr, J. L., Wu, D. L., Bril, A. A., Mazurov, A. A., Melnikov, D. V., Hoshyaripour, G. A., Buehler, S. A. “Geometric estimation of volcanic eruption column height from GOES-R near-limb imagery – Part 2: Case studies,” Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2021-156, **2021**.

Carr, J. L., Horváth, Á., Wu, D. L., Friberg, M. D., “Stereo plume height and motion retrievals for the record-setting Hunga Tonga-Hunga Ha'apai eruption of 15 January 2022”, with Geophysical Research Letters, 49, e2022GL098131. https://doi.org/10.1029/2022GL098131, **2022**.

Horváth, Á., Carr, J. L., Wu, D. L., Bruckert, J., Hoshyaripour, G. A., Buehler, S. A., “Measurement report: Plume heights of the April 2021 La Soufrière eruptions from GOES-17 side views and GOES-16–MODIS stereo views”, Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2022-253, **2022**.

Universal Stereo Method



- Remap "B" satellite into geometry of "A" satellite; common configurations:
  - Triplet GEO + Doublet GEO
  - Triplet GEO + Single MODIS/VIIRS
  - Multi-Angle MISR + Triplet GEO
- Measure disparities of features matched to Reference Scene
  - Same Platform = Motion
  - Cross Platform = Parallax + Motion
- Tag or model match times relative to Reference Scene
- Jointly retrieve motion vector and height for templates or nested tracks
- Quality Filter

Synchronized Observations Not Needed

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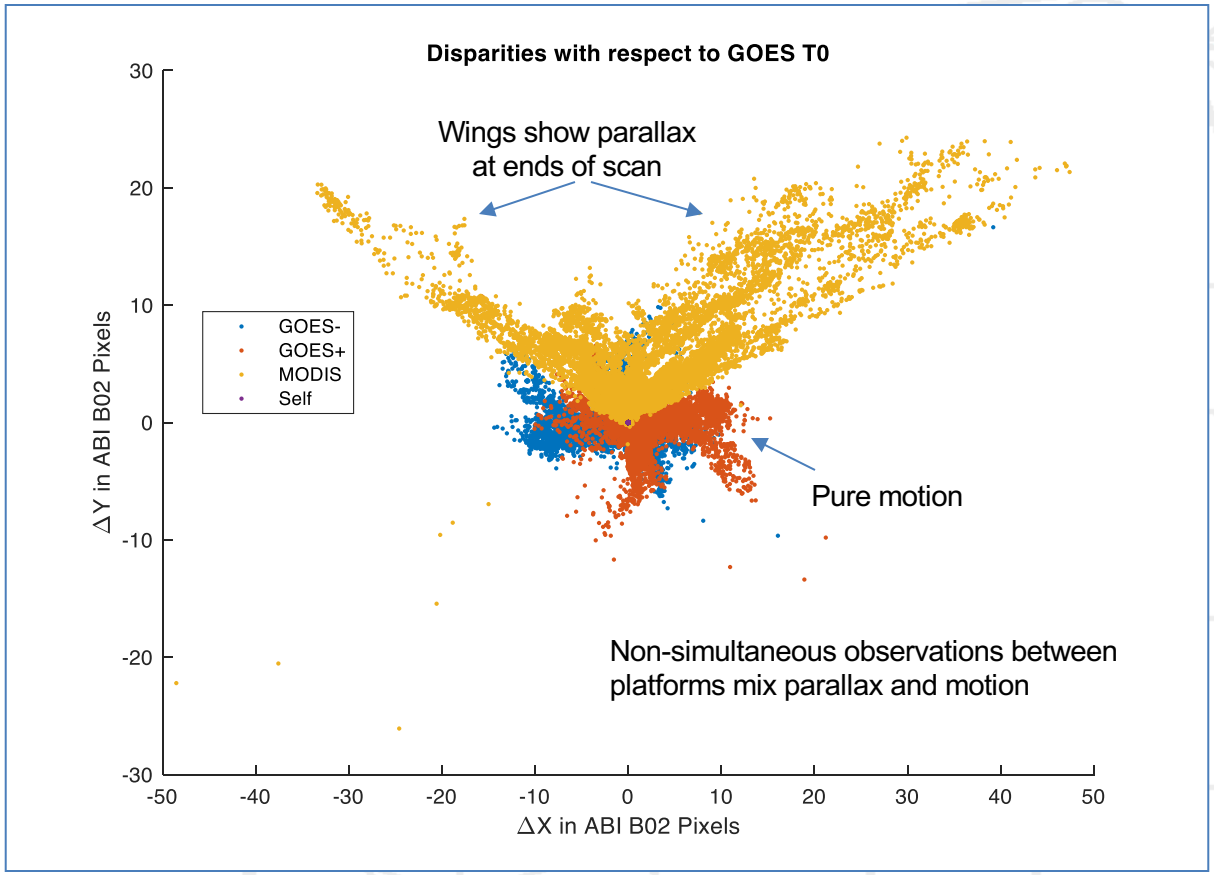
Disparities



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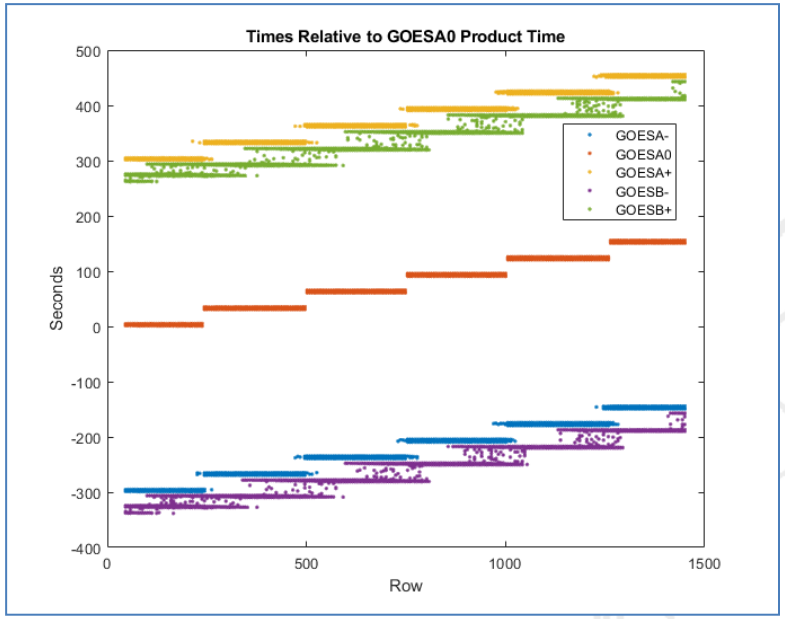
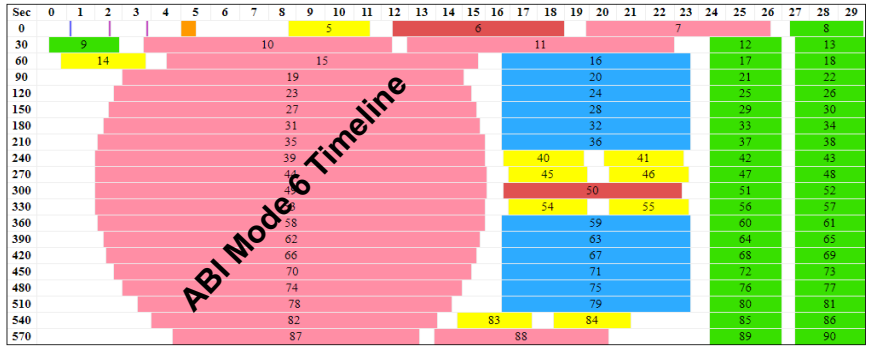
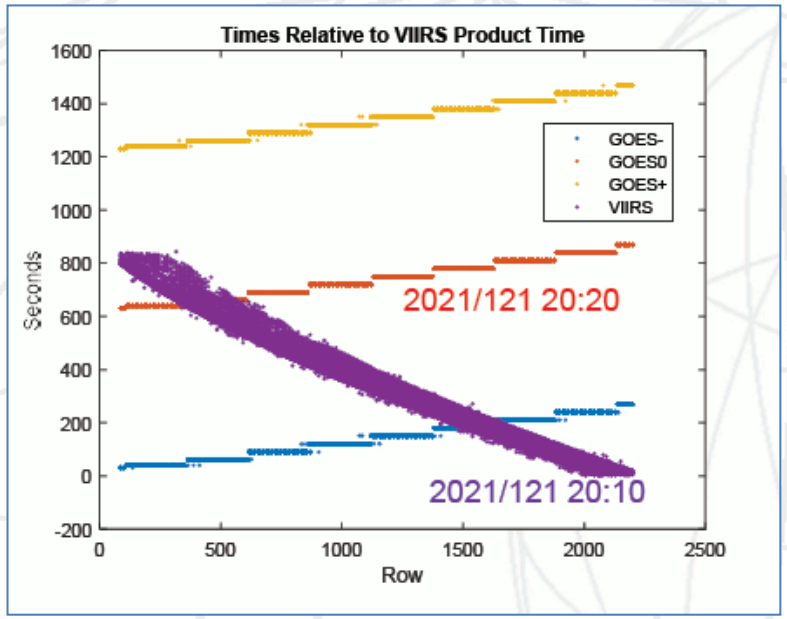
Time Tagging & Modeling

GEO-GEO — "Sat A" GOES-16 (CONUS) / "Sat B" GOES-17 (FD)





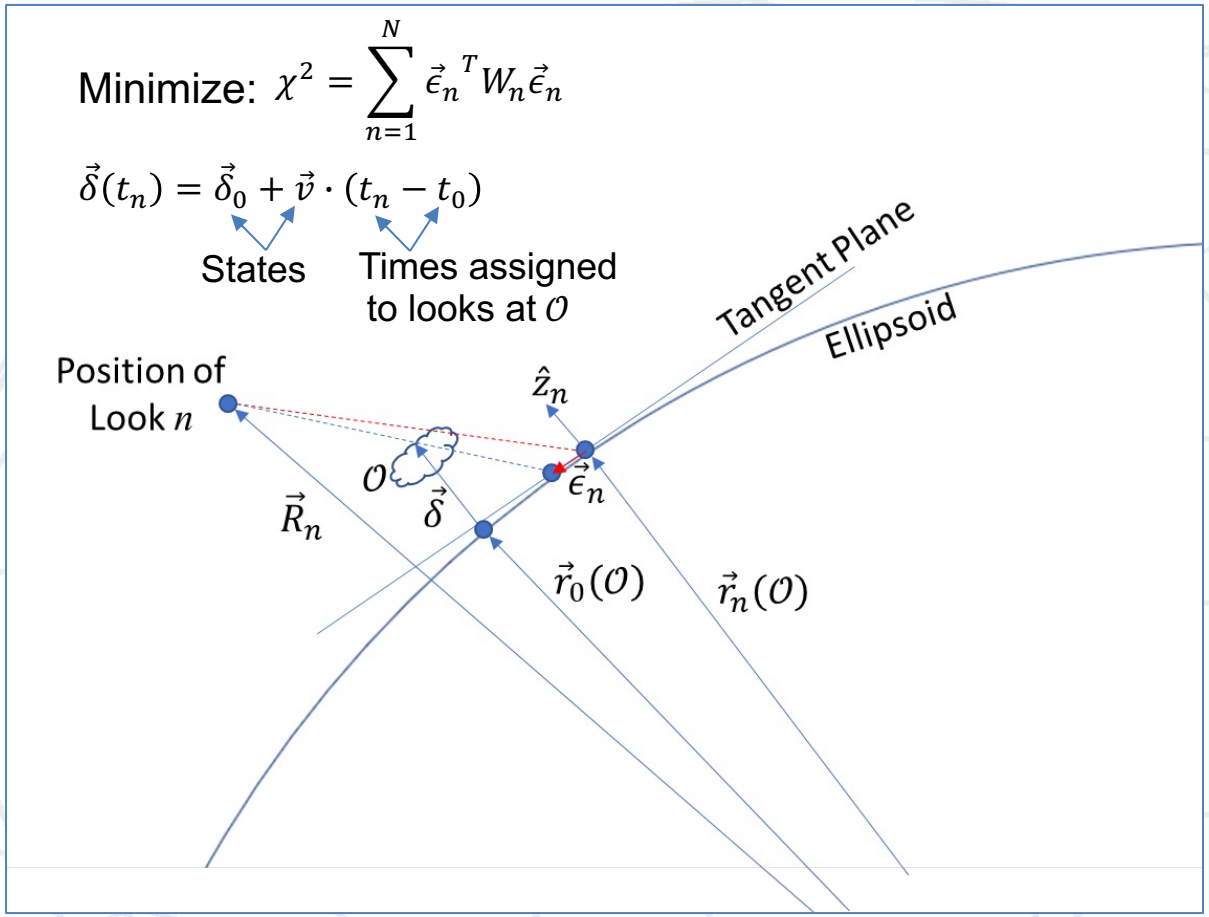
GEO-LEO — "Sat A" GOES-17 (FD) / "Sat B" SNPP (Single VIIRS)



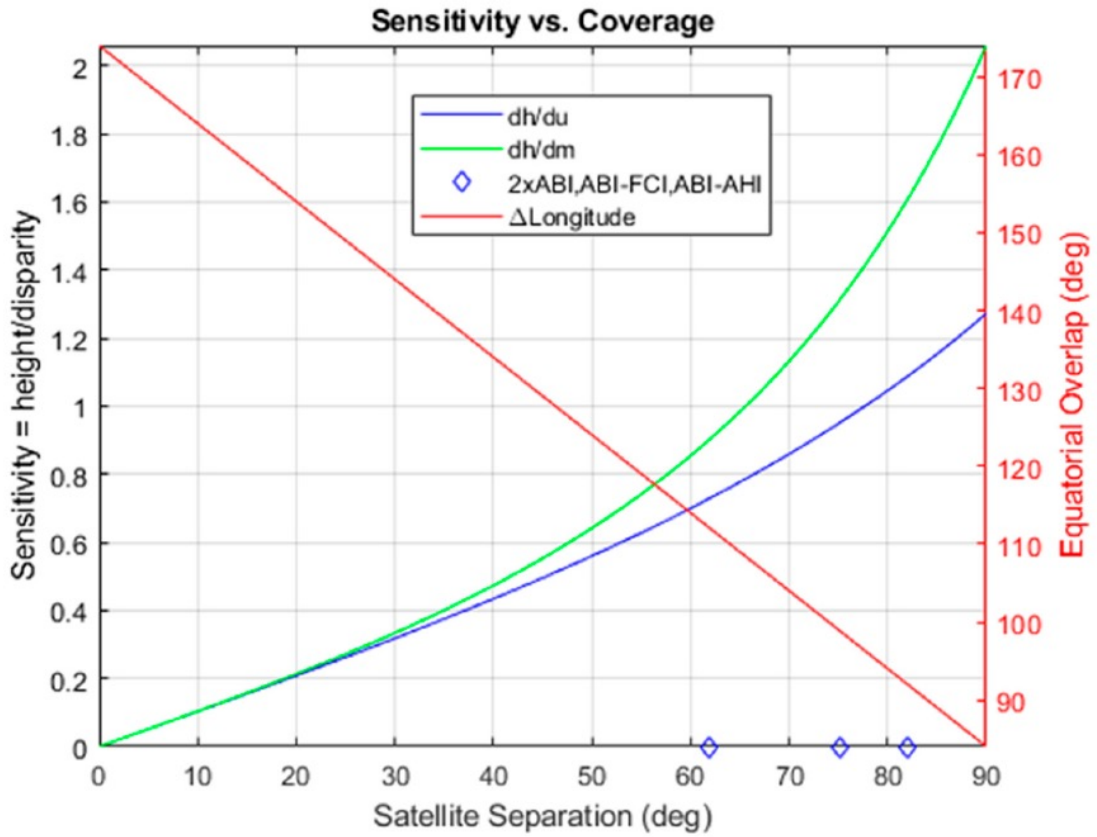
- GOES Times Modeled from Timeline and Swath Pattern
- Other Satellites include Time in their Level-1 Products

Retrieval Model

- Reference Scene ($n = 0$)
- Solve for 5 states at each site; $\vec{\epsilon}_n$ is a function of
  - 3 positions ($\vec{\delta}_0$)
  - U & V winds
- Minimization of χ^2 with N looks determines 5 states if $2(N-1) > 5$
- Covariance matrix indicates uncertainties in retrieved states
- Retrieval residuals indicate if disparities conform with model & therefore the quality of retrieved states (typical residuals < 1 pixel)



Stereo Coverage-Sensitivity by Longitude



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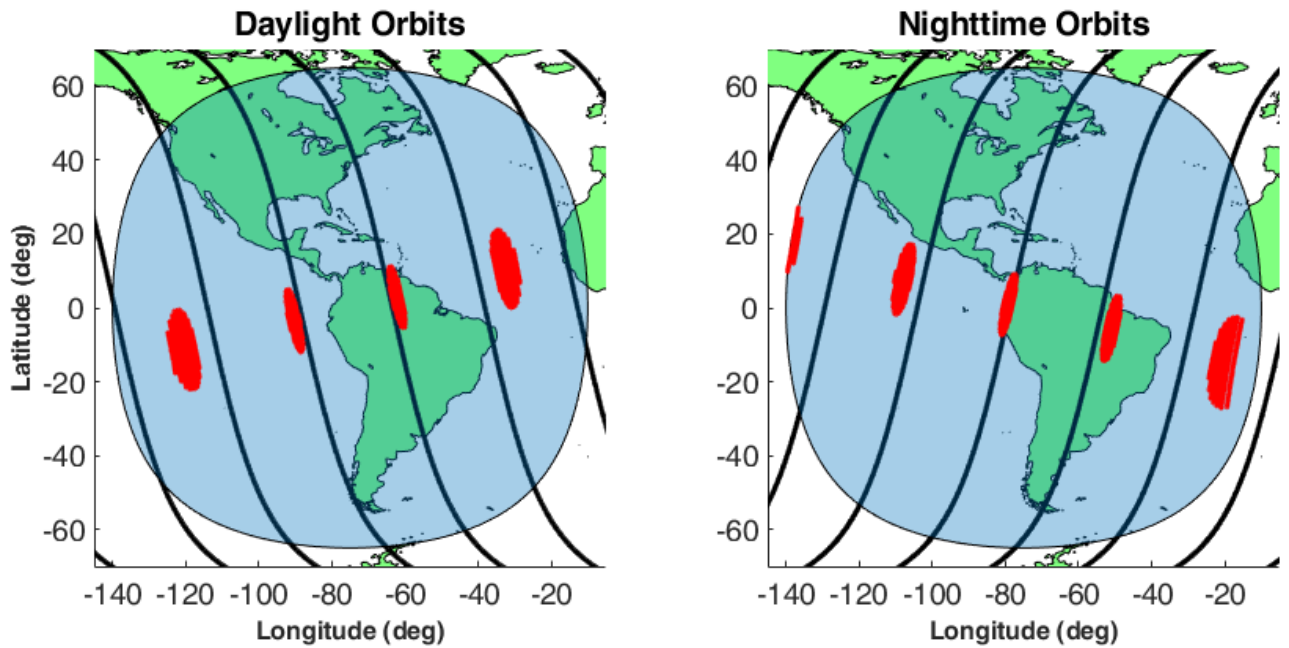
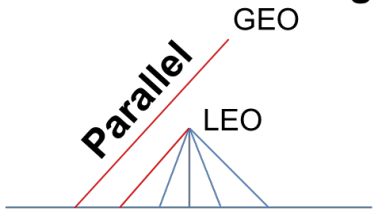
GEO-LEO Stereo Blind Spots

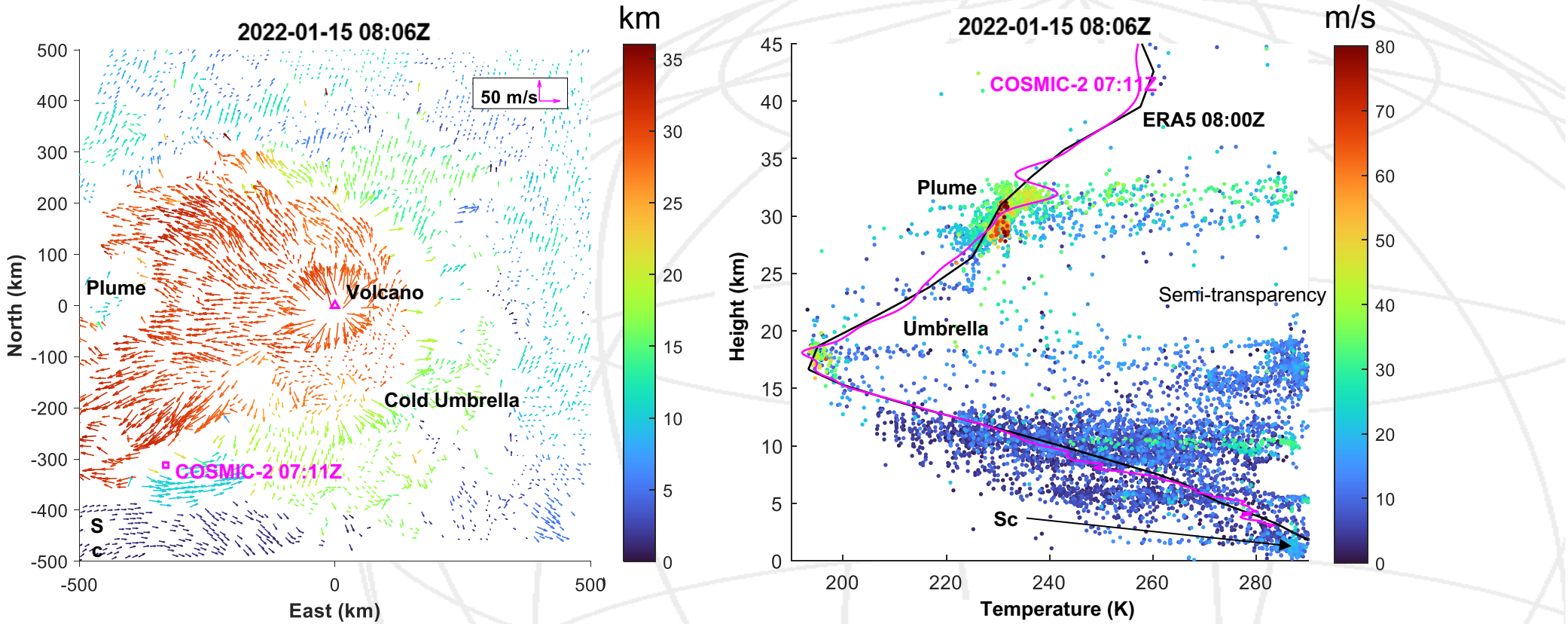
GOES-JPSS Stereo Blind Spots



Singular Geometry:
Cannot retrieve height



G17-Himawari :Hunga Tonga



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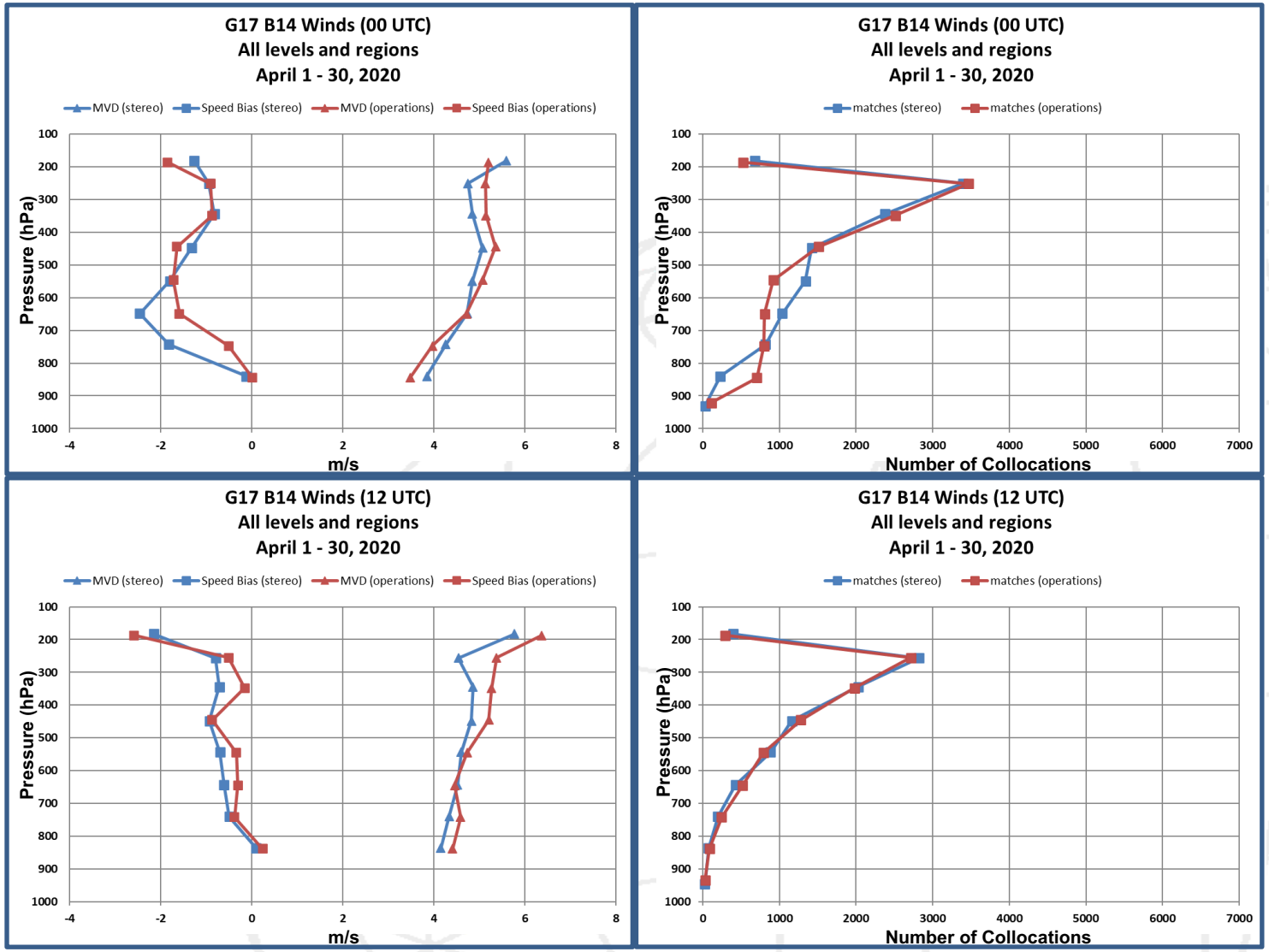
Rawinsonde Collocations



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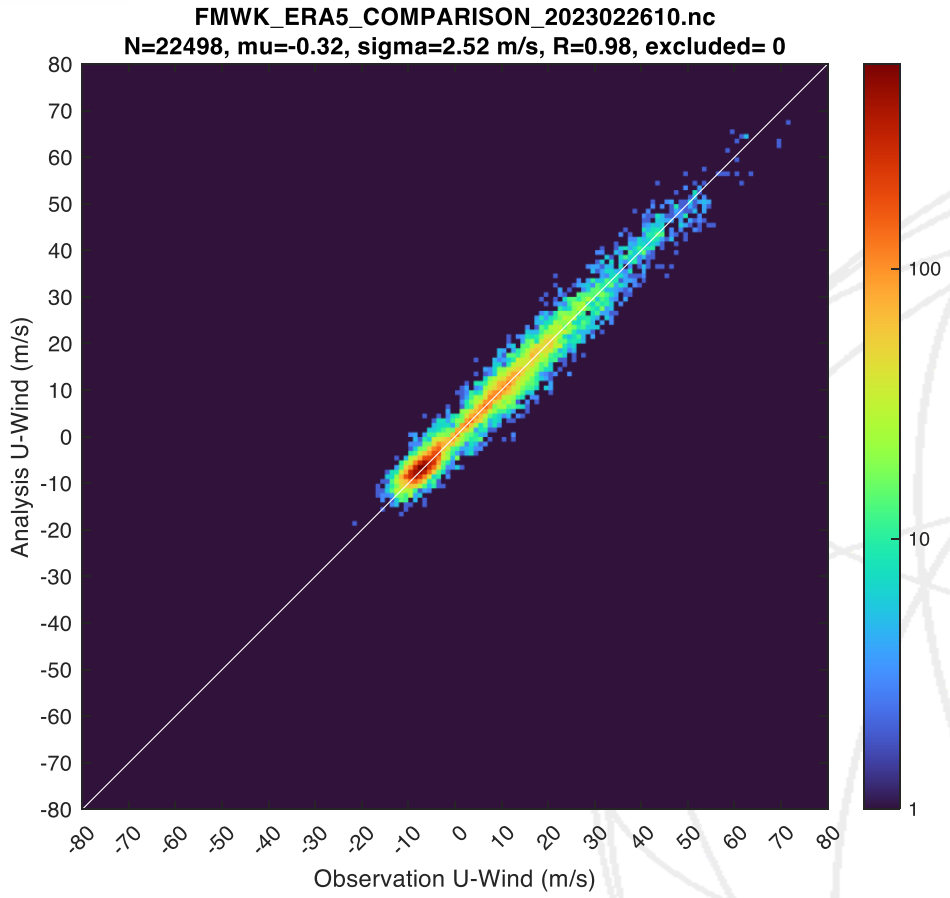
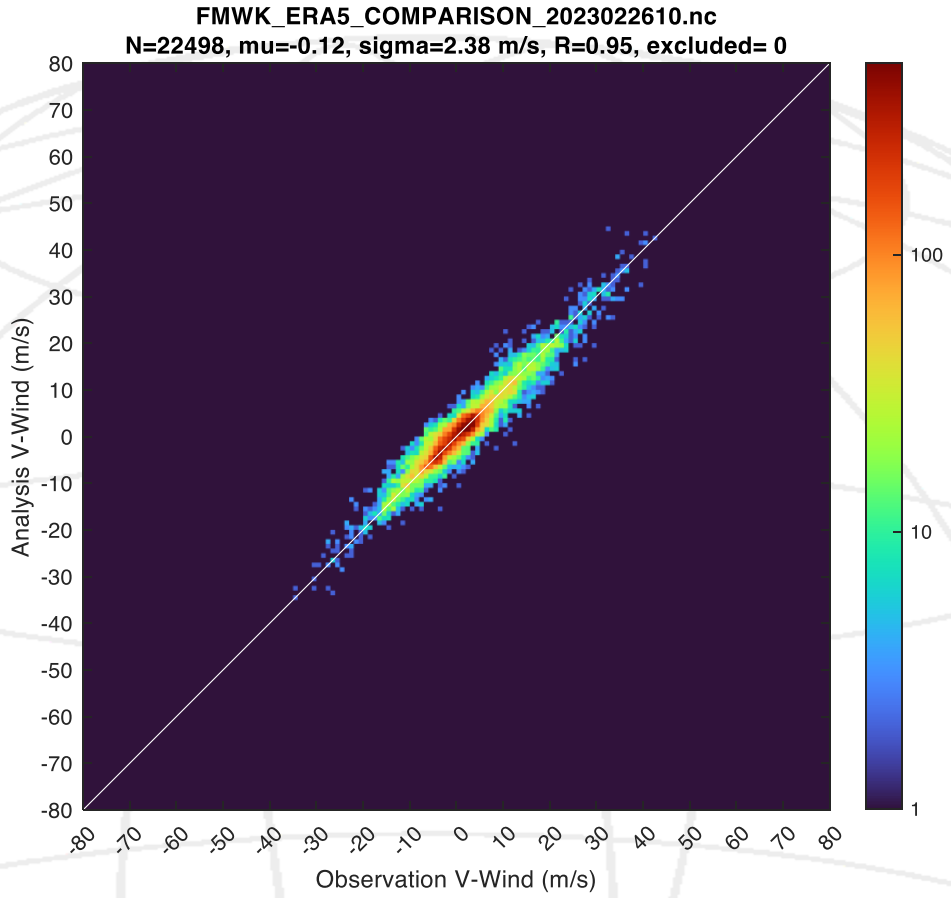
Collocations with ERA5 Winds





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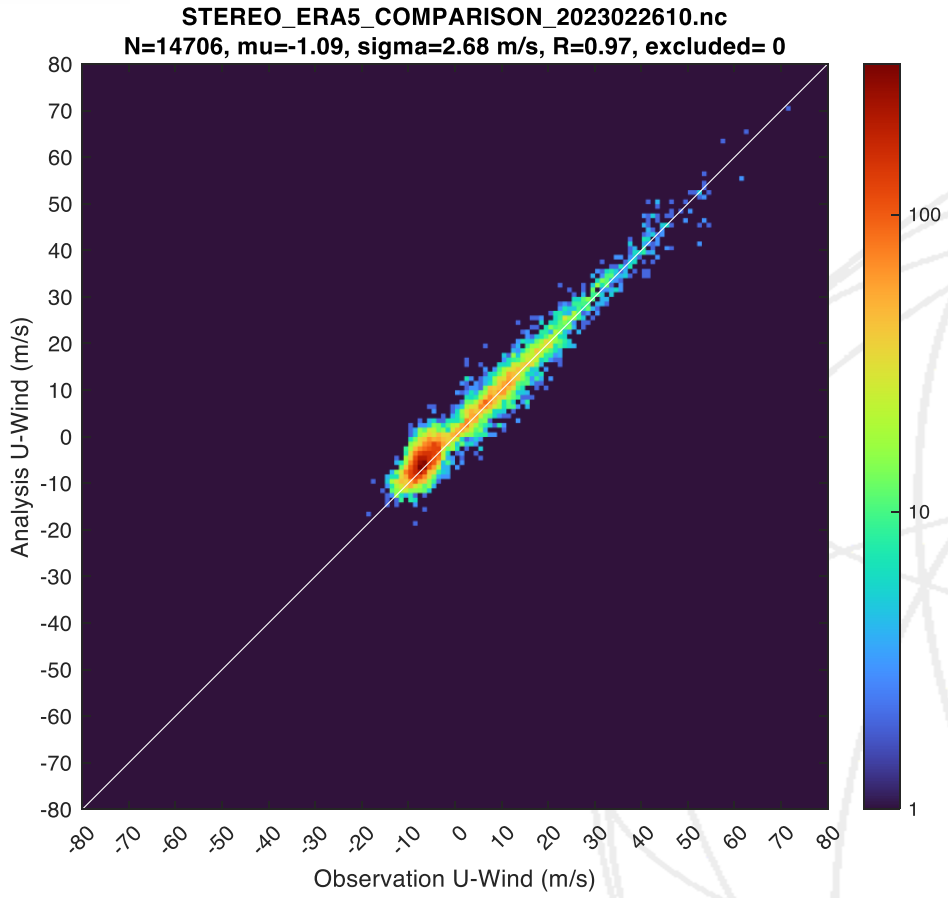
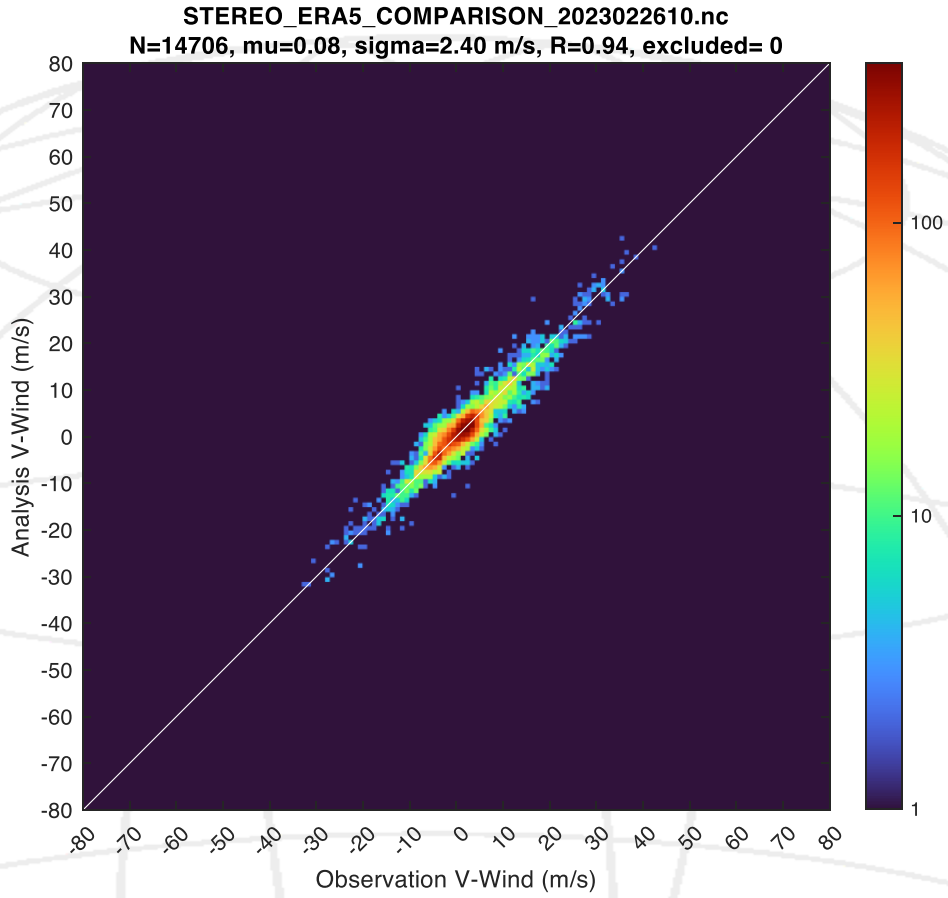
Collocations with ERA5 Winds





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