Explicit Resolution of

Mountain Wave Turb

Using the Standard Deviation of the

HRRR Vertical Velocity Field

Southwest Aviation Weather Safety Workshop X
April 21, 2023

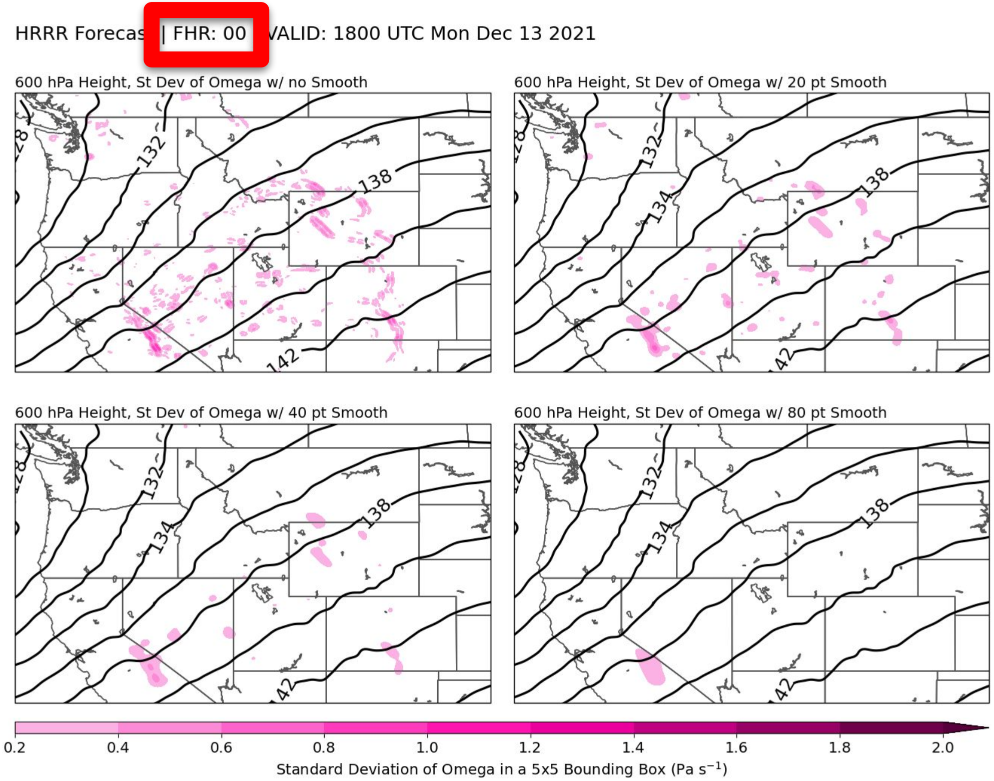
Motivation

- Mountain waves are a significant hazard to aviation and threat to aviation safety
- Traditional diagnostic methods are tedious and time consuming
  - Rely on plotting ridge top acceleration and **implying** severity from there
  - Require examining numerous model soundings and/or cross sections to assess static stability, presence of a critical level, etc.
- Can mountain waves be **explicitly** resolved in a way that makes anticipating **severe turb** (rather than moderate or less) easier?

The Experiment

- Use the HRRR
  - Finest-scale NWP model readily available
- Look at **standard deviation** of the omega field within a bounding box, plotted spatially
- Use the 1-hour forecast to allow model time to spin up waves
- Smooth the final product

Analysis vs 1-Hr Forecast



No smoothing

20-point smoothing

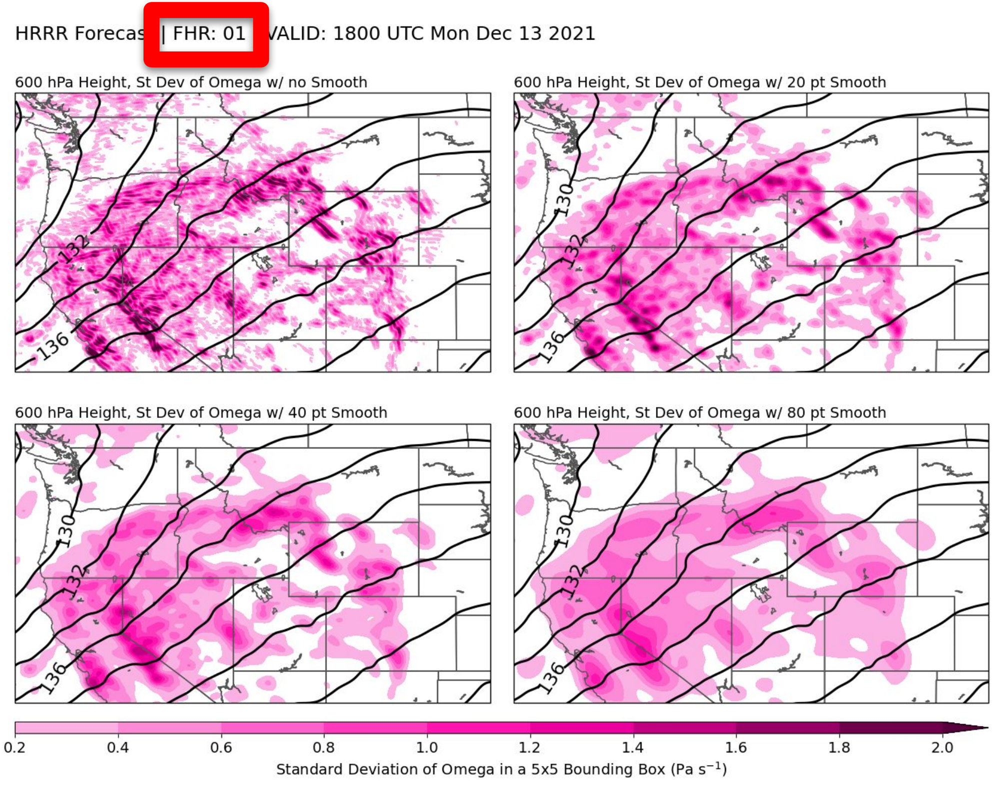
40-point smoothing

80-point smoothing

Analysis vs 1-Hr Forecast

No smoothing

20-point smoothing



40-point smoothing

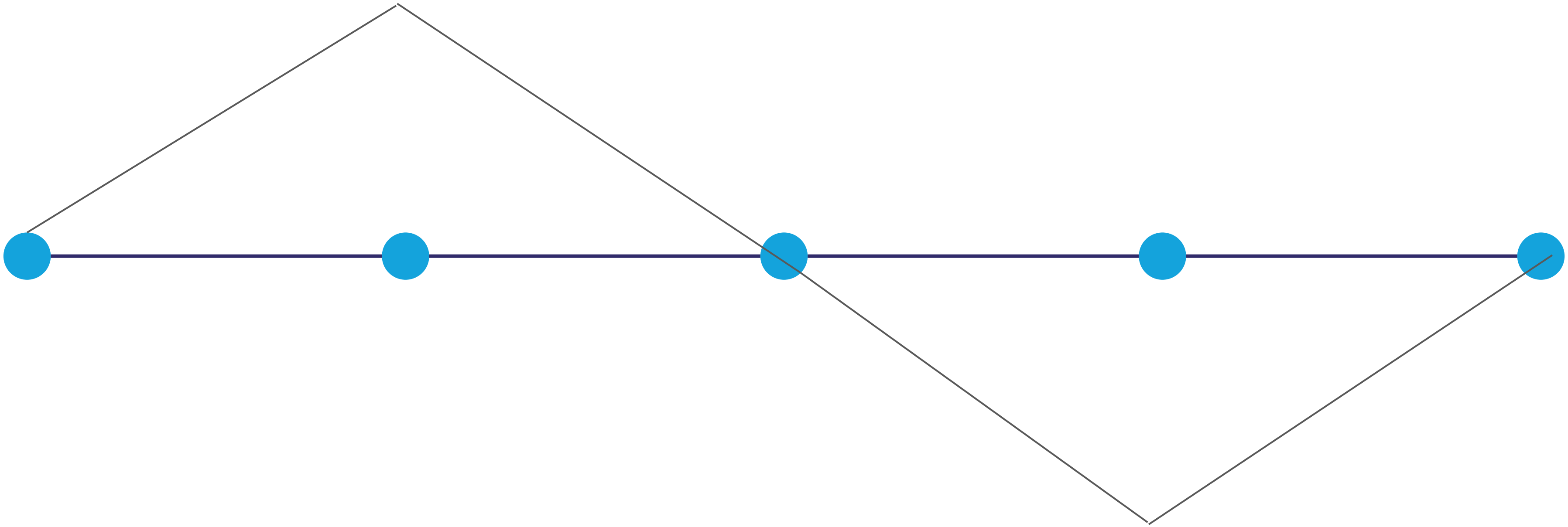
80-point smoothing

Bounding Box Size

- 5x5
  - 2 grid points in all directions in addition to centroid
  - Smallest box that can capture a wave
  - Would a bigger box be better?

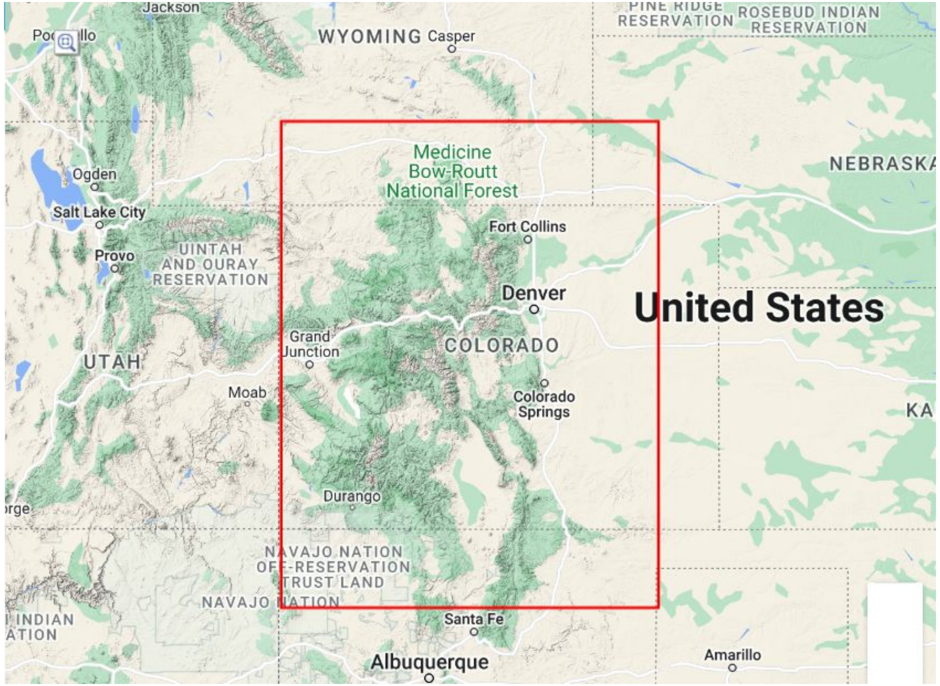
(I'm not a modeler please don't ask me technical modeling questions!)

4 Δx to Resolve a Wave



PIREP Data

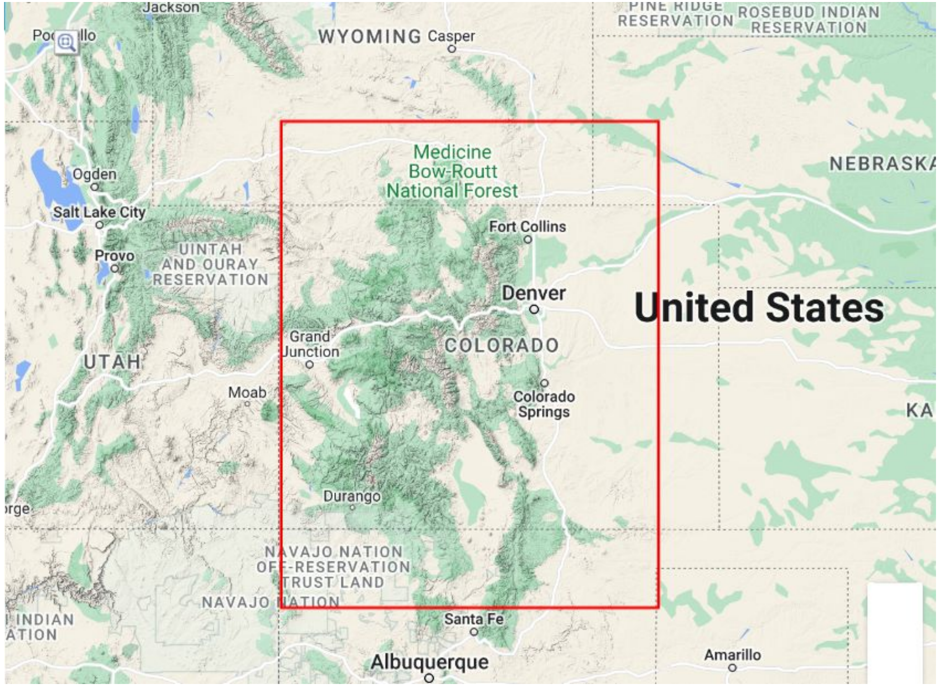
- ❑ Pulled all DJF PIREPs from Jan 2015 - Dec 2022
- ❑ Subsetted to a study area over the Rockies
- ❑ Looked at only Turb PIREPs, leaving **27,350** PIREPs
    - ❑ 2993 featured “MTN WAVE” in the REPORT string



Special thanks to IEM

PIREP Data

- Combined LGT-MOD with LGT, and MOD-SEV with SEV, to make the lengths slightly more equal
  - Way more MODs than any other intensity
- Any “MTN WAVE” PIREPs without an intensity given were manually assigned one
  - +/- 15 kts <u>or</u> gain/loss 350 ft → MOD
  - +/- 25 kts <u>or</u> gain/loss 600 ft → SEV



HRRR Data

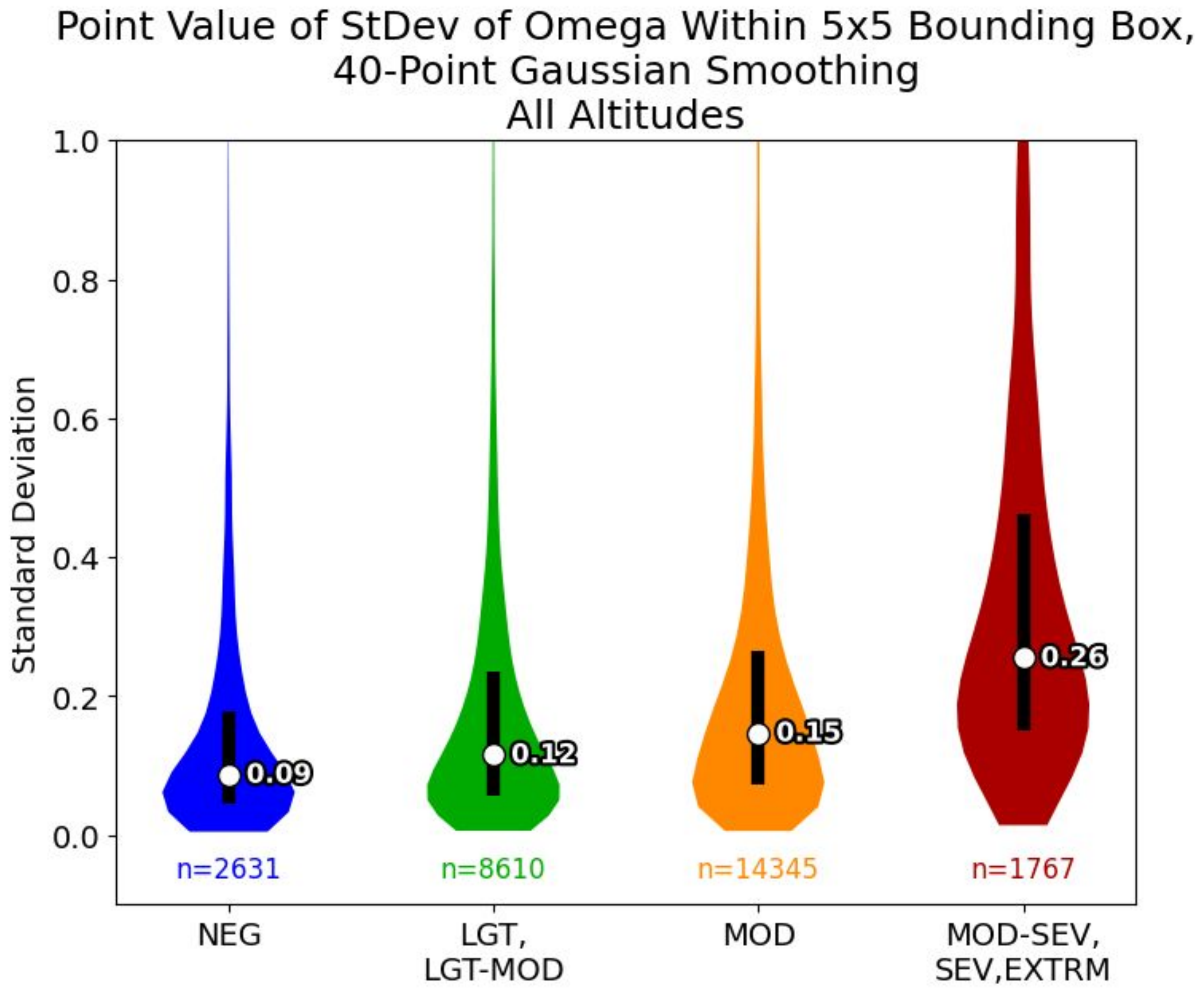
- 1-hour forecast at closest time to time of PIREP, i.e.
  - PIREP at 1925z → HRRR valid at 1900z (18z run F01)
  - PIREP at 1935z → HRRR valid at 2000z (19z run F01)
- StDev value calculated for bounding box around grid point closest to PIREP location

Caveats

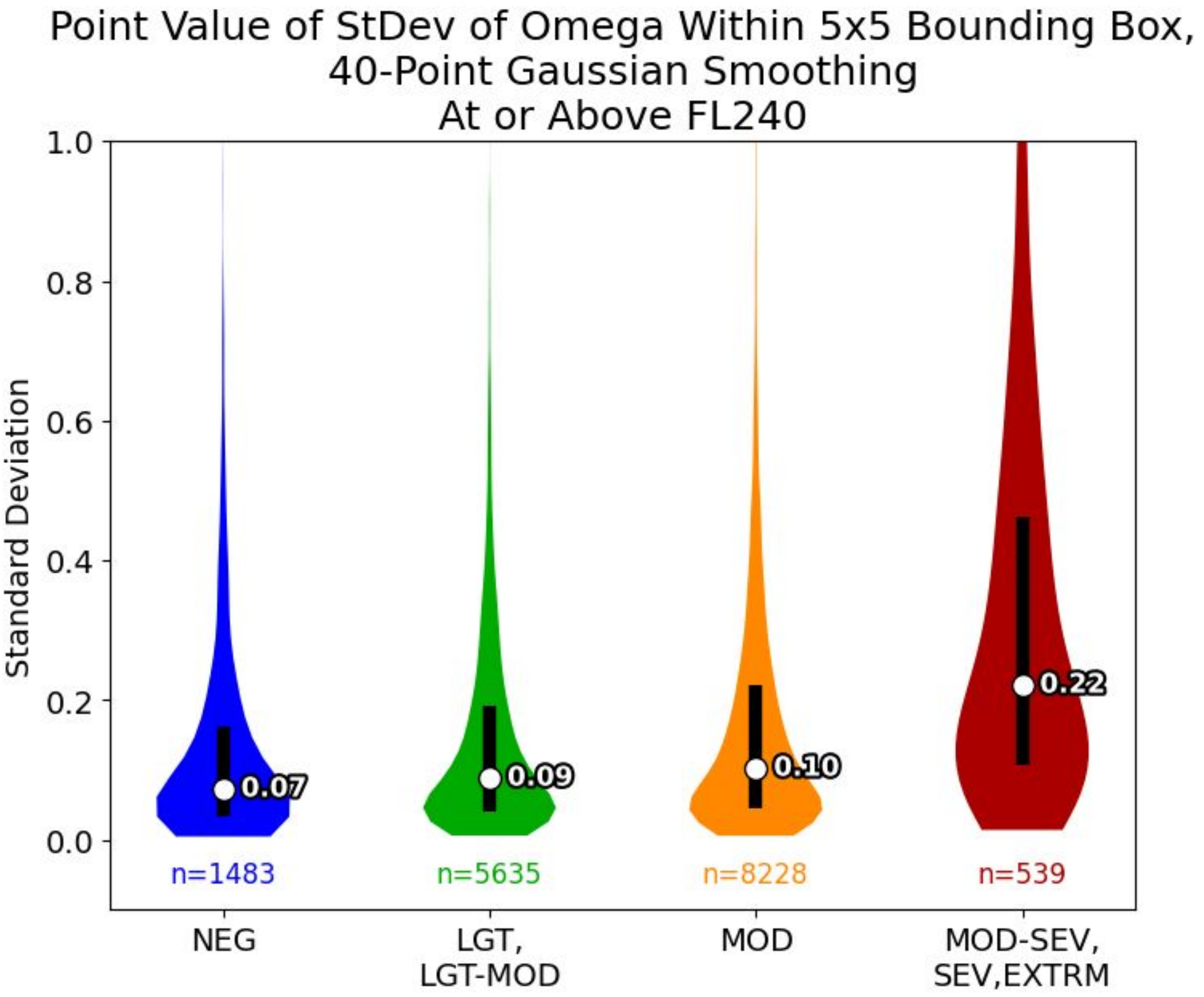
- PIREP data is messy!
  - Lots of duplicates and incorrect locations
- Not all turb over CO is from mountain waves
  - But most mountain wave turb is just reported as turb rather than MTN WAVE

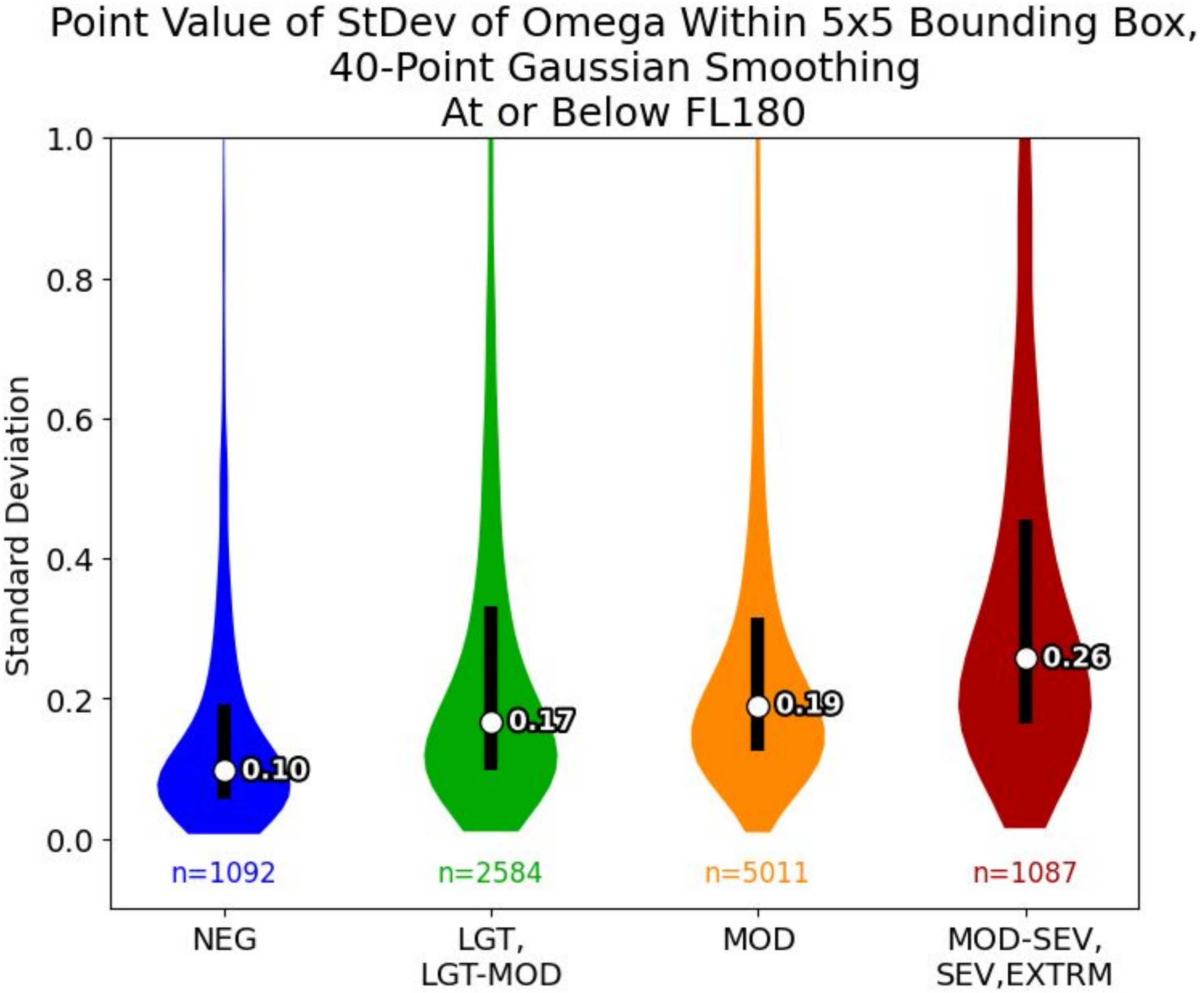
Smoothing

- All plots will show results for using the **40-point** Gaussian smoothing
- Results largely similar regardless of degree of smoothing but 40-point showed most difference (lowest p-value) between MODs and SEVs

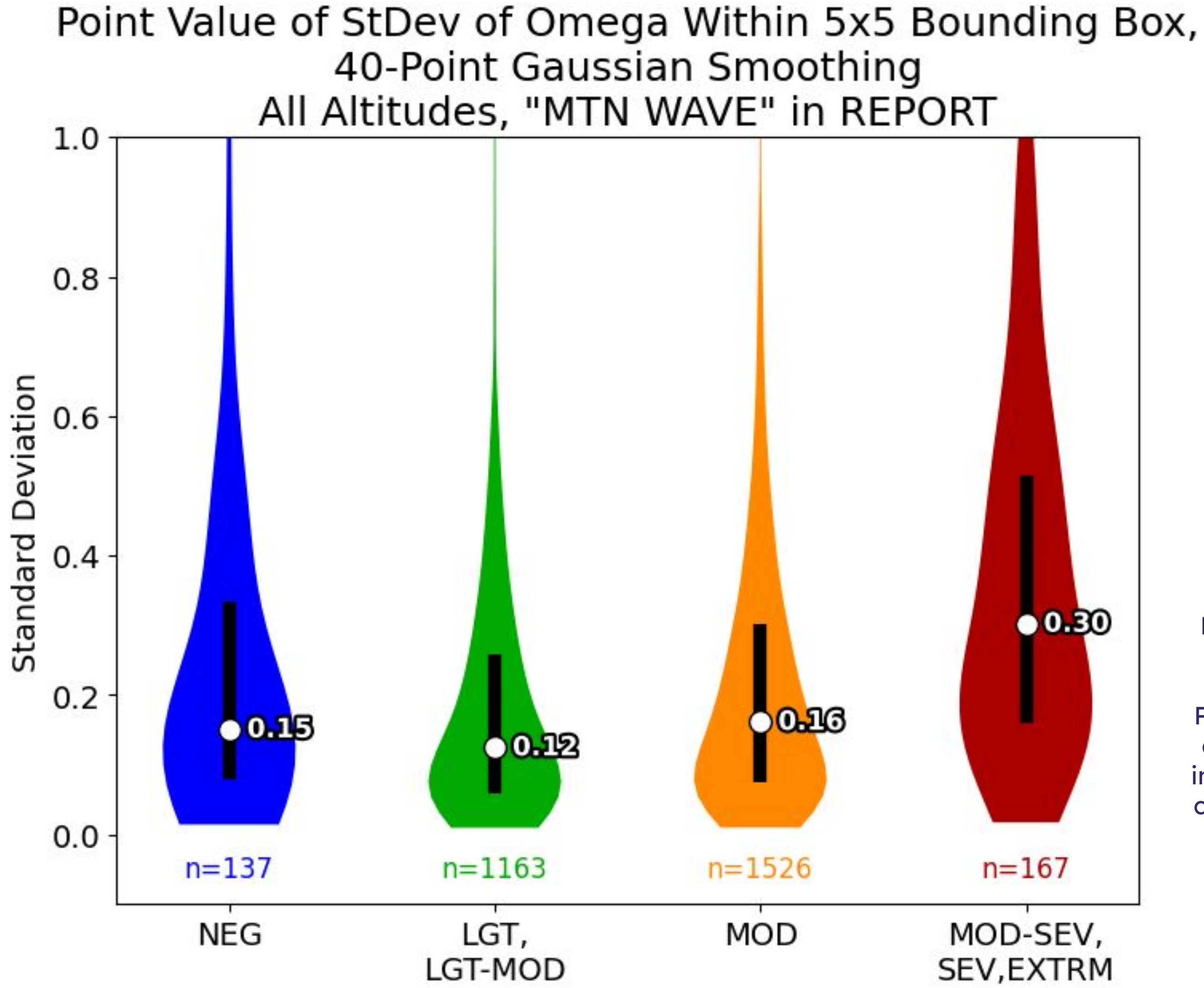


Point Value of StDev of Omega Within 5x5 Bounding Box,
40-Point Gaussian Smoothing
All Altitudes
Standard Deviation
1.0
0.8
0.6
0.4
0.2
0.0
0.09
0.12
0.15
0.26
n=2631
n=8610
n=14345
n=1767
NEG
LGT,
LGT-MOD
MOD
MOD-SEV,
SEV,EXTRM


Point Value of StDev of Omega Within 5x5 Bounding Box,
40-Point Gaussian Smoothing
At or Above FL240
Standard Deviation
1.0
0.8
0.6
0.4
0.2
0.0
0.07
0.09
0.10
0.22
n=1483
n=5635
n=8228
n=539
NEG
LGT,
LGT-MOD
MOD
MOD-SEV,
SEV,EXTRM



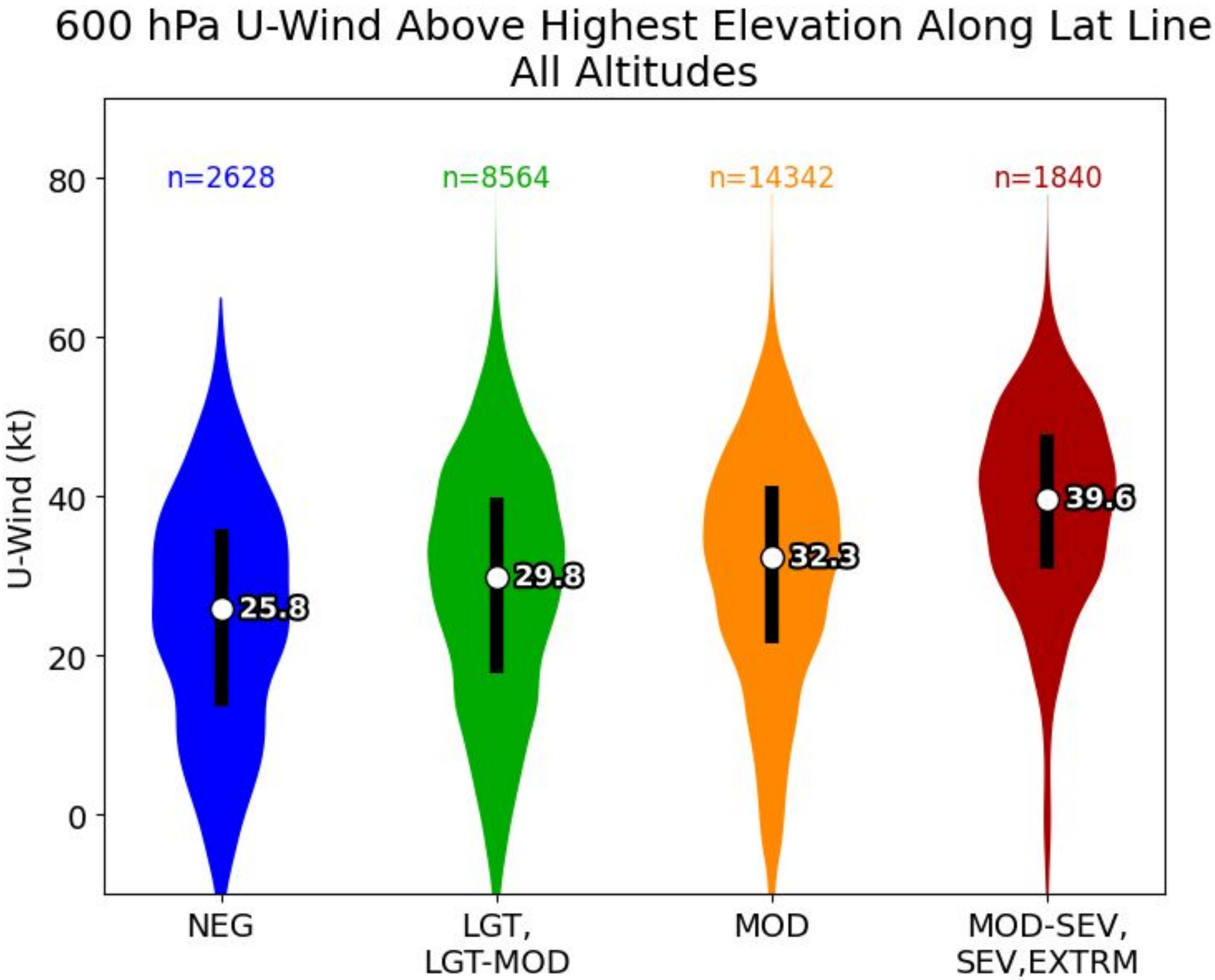
Point Value of StDev of Omega Within 5x5 Bounding Box,
40-Point Gaussian Smoothing
At or Below FL180
Standard Deviation
1.0
0.8
0.6
0.4
0.2
0.0
0.10
0.17
0.19
0.26
n=1092
n=2584
n=5011
n=1087
NEG
LGT,
LGT-MOD
MOD
MOD-SEV,
SEV,EXTRM



My guess here is that the NEGs are contaminated by PIREPs that should be classified at a higher intensity but didn't get caught by my intensity assignment scheme

Compared to Just Wind

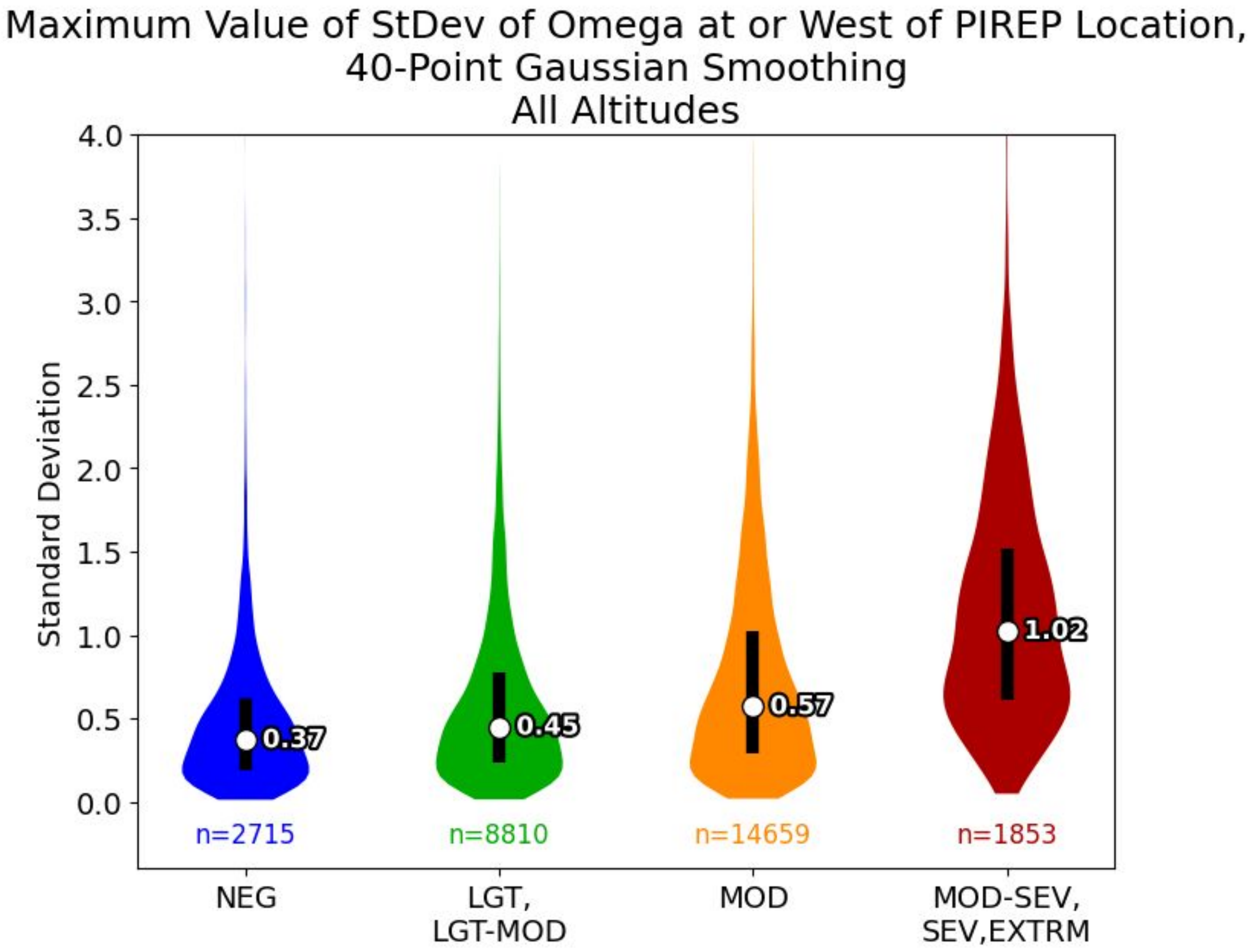
- Same plots but looking at 600 hPa (~FL140) **u component** of wind
  - Making an assumption that u wind represents the cross-barrier component
  - Looked at wind value over highest terrain grid point **upstream** (west) of PIREP location
  - Used RAP instead of HRRR
    - 13 km grid spacing should tamp down noise, closer to what we look at in ops (NAM upscaled to 32 km)
- Not perfect but needed something that could be calculated systematically for 27,350 PIREPs
- Should be a good approximation of "ridge top flow"

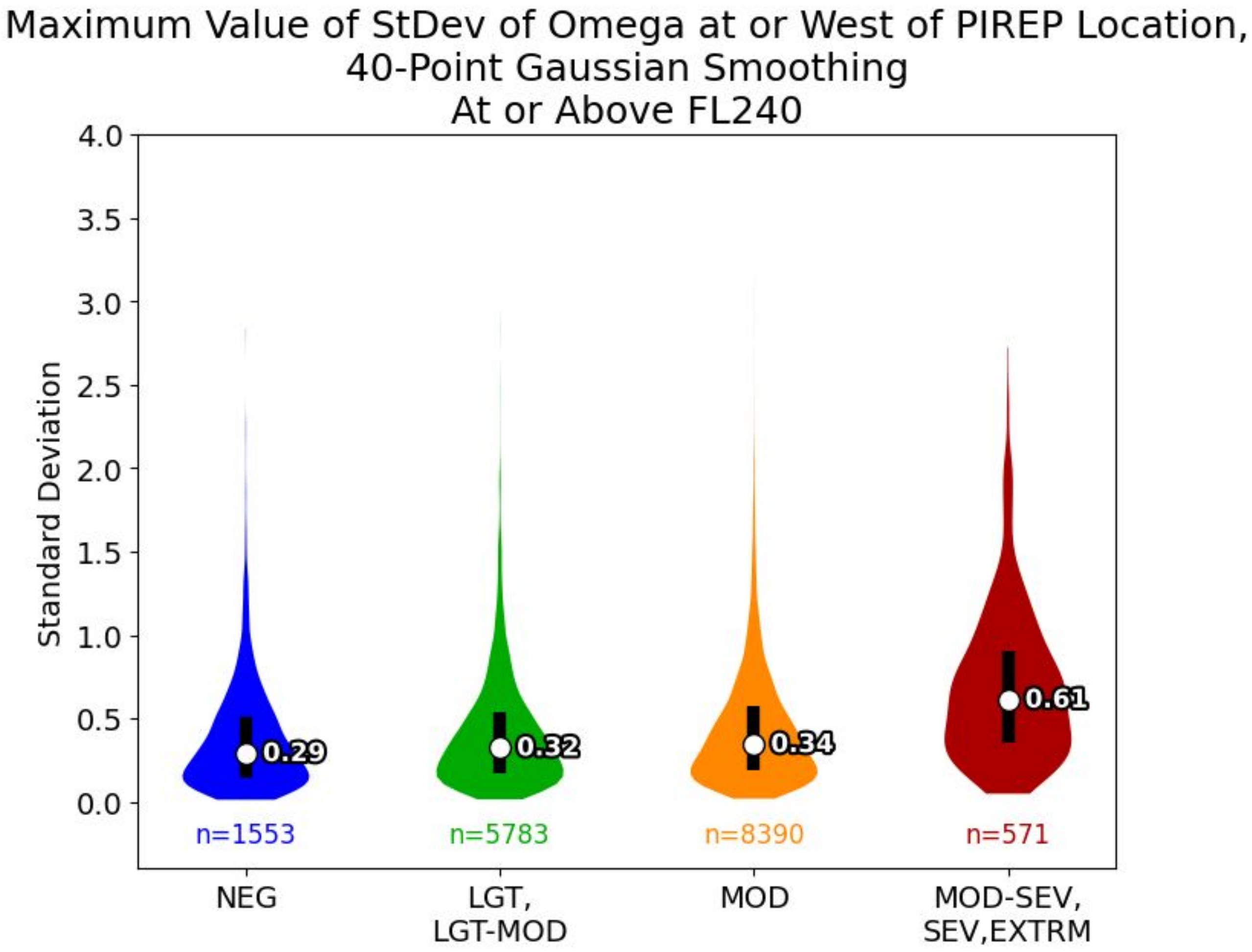


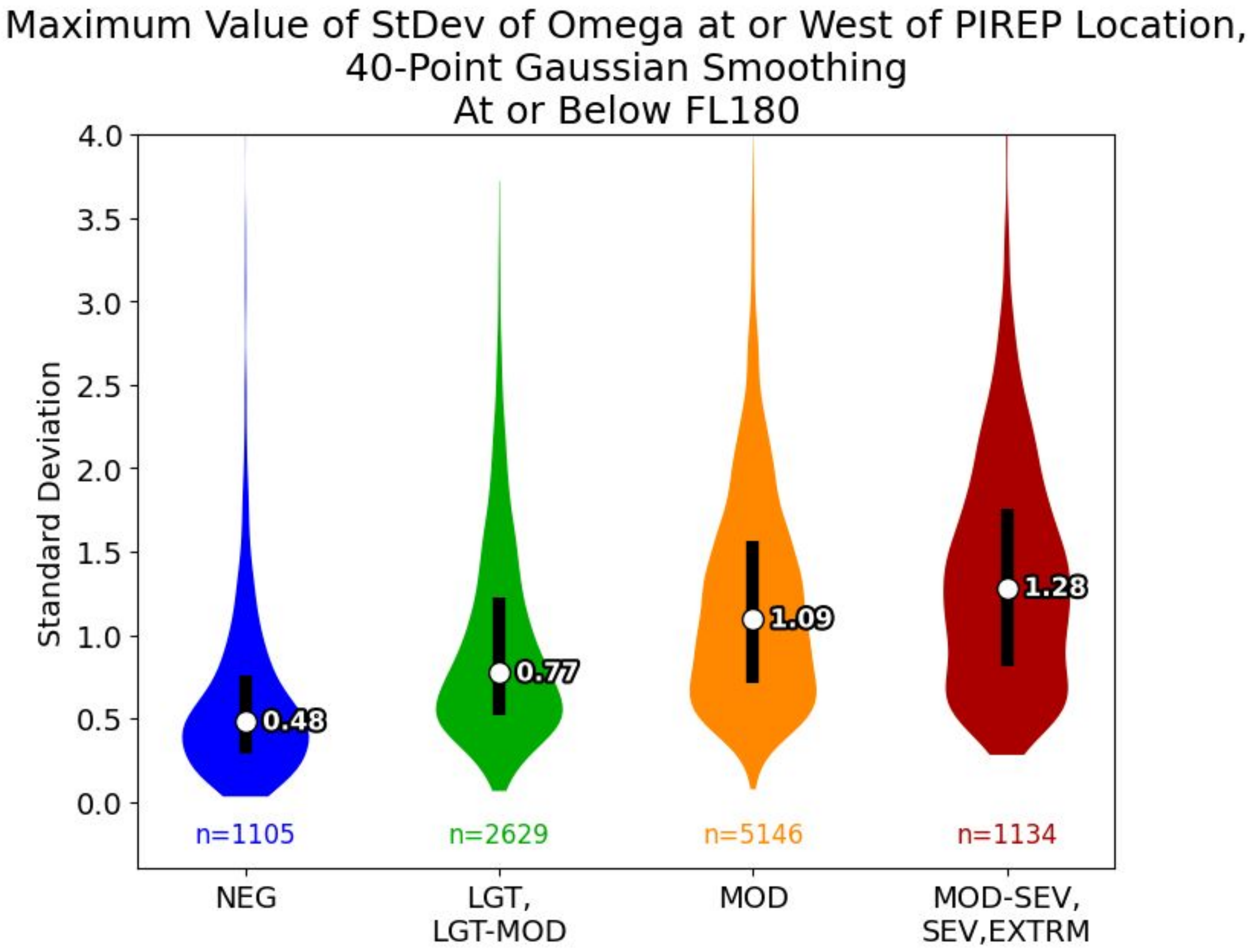
600 hPa U-Wind Above Highest Elevation Along Lat Line
All Altitudes
U-Wind (kt)
80
60
40
20
0
n=2628
n=8564
n=14342
n=1840
25.8
29.8
32.3
39.6
NEG
LGT,
LGT-MOD
MOD
MOD-SEV,
SEV,EXTRM

Data Analysis

- All variables for all turb intensities have a long positive tail
- NEG, LGT, and MOD show a trend, but biggest difference by far is between MOD and SEV
  - Which is what we want!
- Visually more separation in interquartile ranges with StDev Omega than with just ridge-top flow
- However, values seemed low…
- What about the **maximum value** at or west of the PIREP location?
  - Looked at 2 grid points north/south/east, and all grid points west to edge of domain


Maximum Value of StDev of Omega at or West of PIREP Location,
40-Point Gaussian Smoothing
All Altitudes
Standard Deviation
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.37
0.45
0.57
1.02
n=2715
n=8810
n=14659
n=1853
NEG
LGT,
LGT-MOD
MOD
MOD-SEV,
SEV,EXTRM


Maximum Value of StDev of Omega at or West of PIREP Location,
40-Point Gaussian Smoothing
At or Above FL240
Standard Deviation
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.29
0.32
0.34
0.61
n=1553
n=5783
n=8390
n=571
NEG
LGT,
LGT-MOD
MOD
MOD-SEV,
SEV,EXTRM


Maximum Value of StDev of Omega at or West of PIREP Location,
40-Point Gaussian Smoothing
At or Below FL180
Standard Deviation
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.48
0.77
1.09
1.28
n=1105
n=2629
n=5146
n=1134
NEG
LGT,
LGT-MOD
MOD
MOD-SEV,
SEV,EXTRM

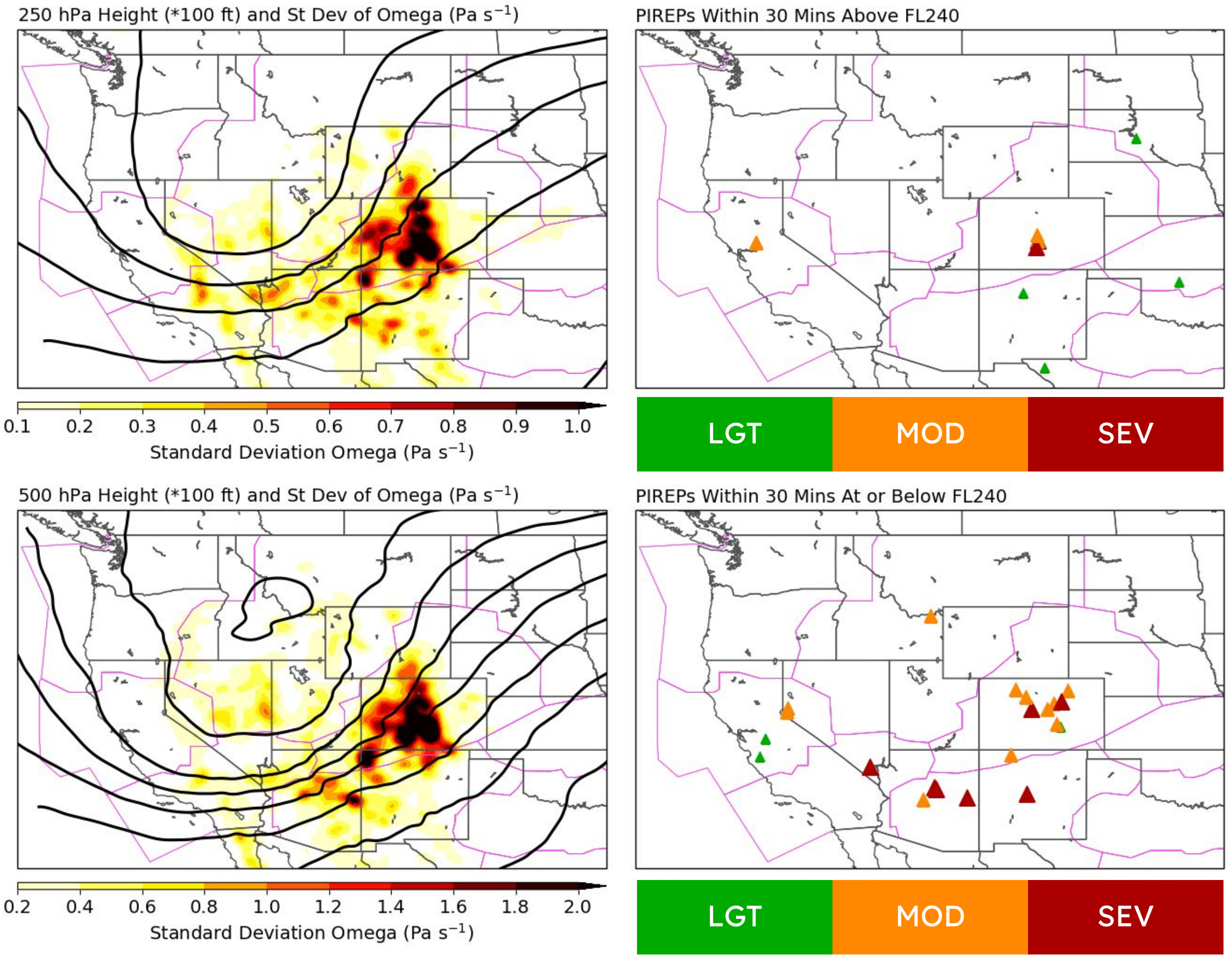
Final Data Analysis

- Enhanced separation between MODs and SEVs overall with max upstream values relative to at-point values
- Lower values at higher altitudes
  - HRRR probably (likely) not resolving tropopause wave breaking well
  - Want to use different thresholds for high vs low altitudes
- MOD-SEV separation is somewhat reduced for low altitudes, but LGT-MOD separation increases
  - Ryan's Hypothesis: light aircraft reporting SEV at low altitudes mixed with airliners reporting MOD
  - Higher proportion of SEVs in low altitudes vs high altitudes

Example

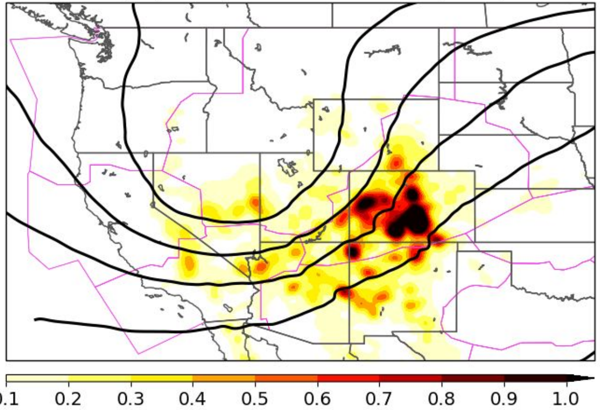
- November 9, 2022

HRRR Forecast | FHR: 01 | VALID: 1900 UTC Wed Nov 09 2022

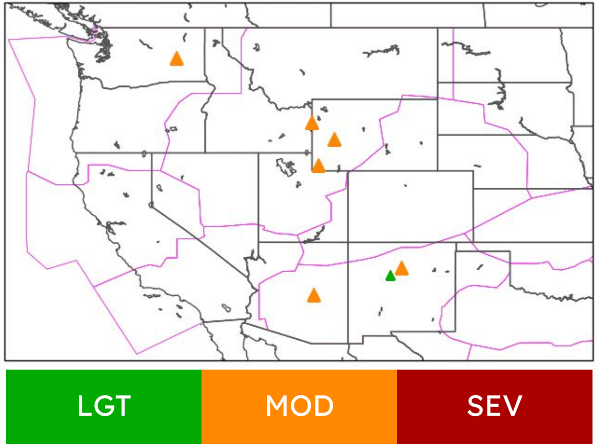


HRRR Forecast | FHR: 01 | VALID: 2000 UTC Wed Nov 09 2022

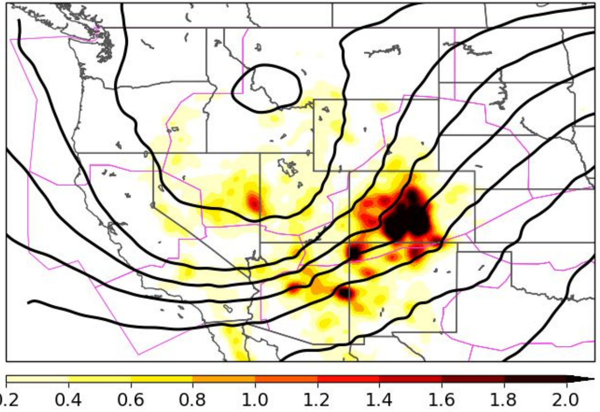
250 hPa Height (*100 ft) and St Dev of Omega (Pa s^{-1})



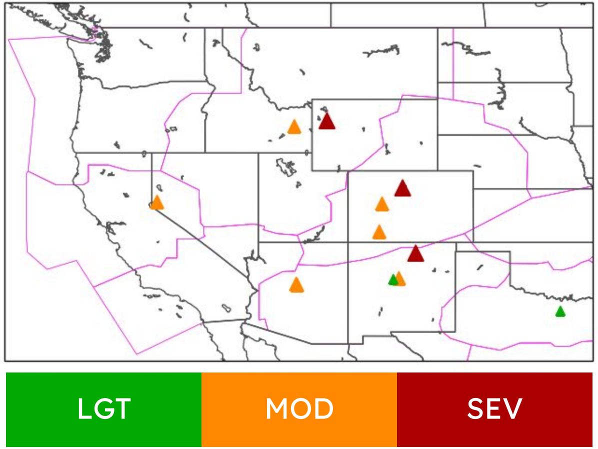
PIREPs Within 30 Mins Above FL240



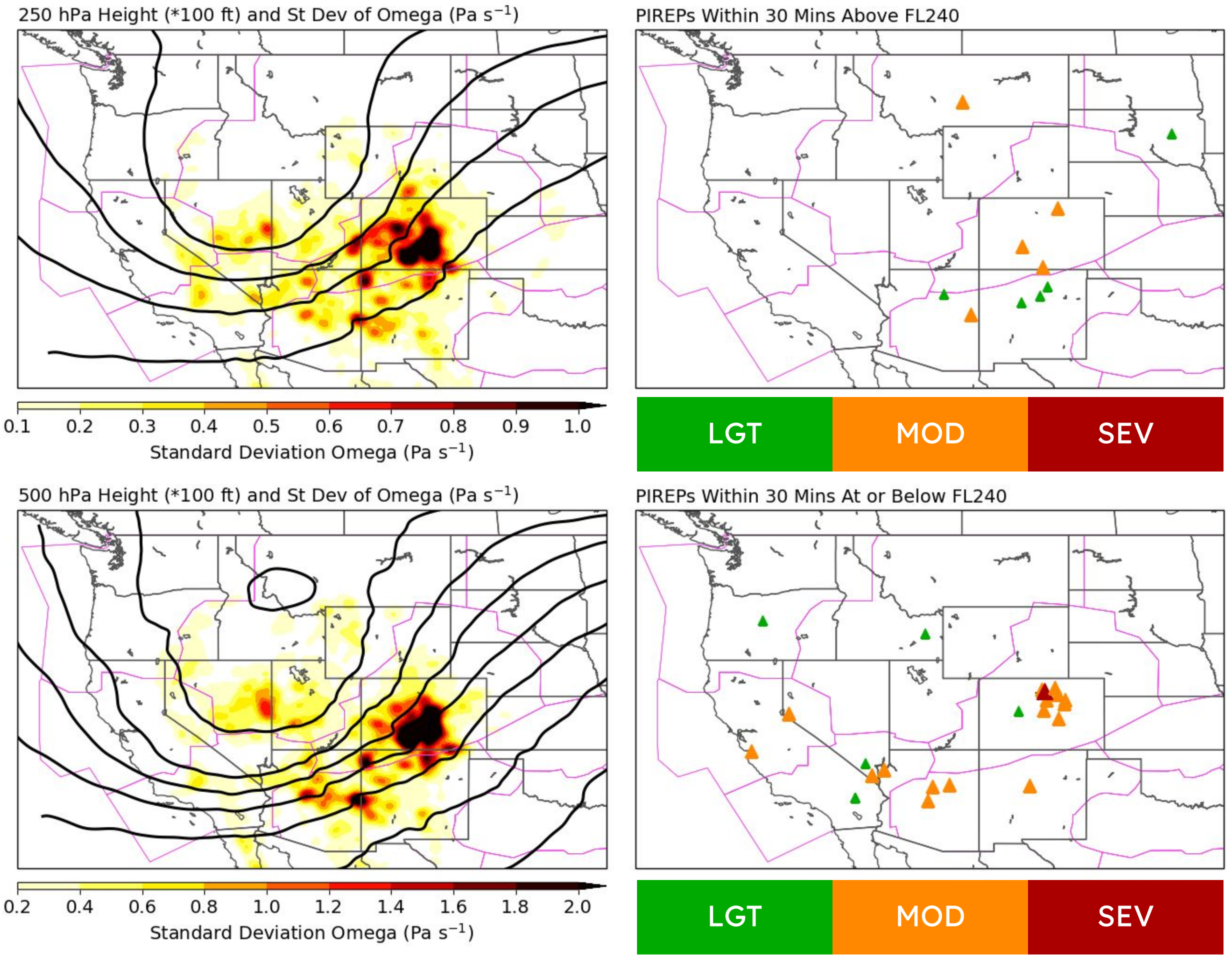
500 hPa Height (*100 ft) and St Dev of Omega (Pa s^{-1})



PIREPs Within 30 Mins At or Below FL240



HRRR Forecast | FHR: 01 | VALID: 2100 UTC Wed Nov 09 2022



Special Thanks

IEM

MetPy

Contact Info

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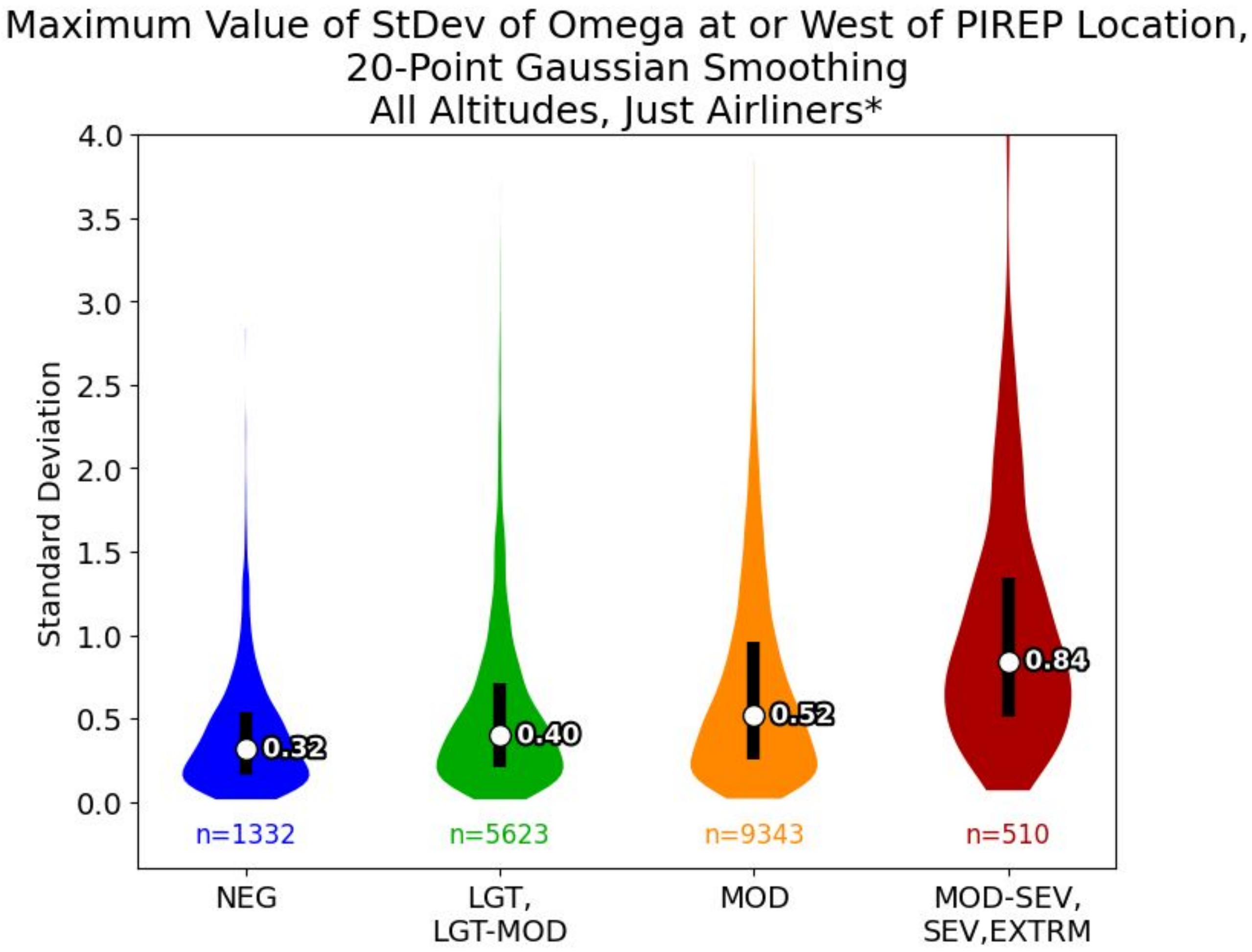
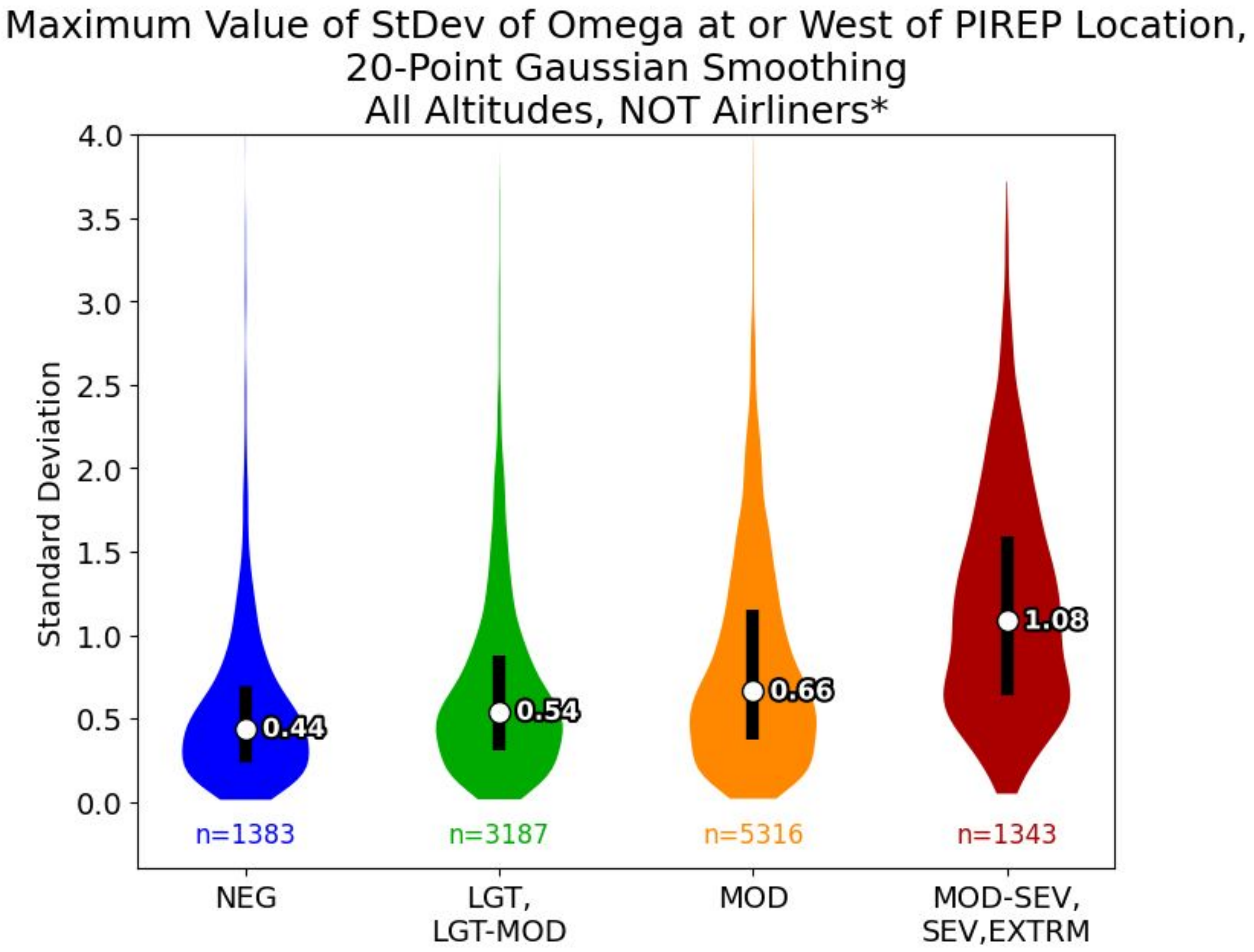
Bonus Slides


Maximum Value of StDev of Omega at or West of PIREP Location,
20-Point Gaussian Smoothing
All Altitudes, Just Airliners*
Standard Deviation
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.32
0.40
0.52
0.84
n=1332
n=5623
n=9343
n=510
NEG
LGT,
LGT-MOD
MOD
MOD-SEV,
SEV,EXTRM



Maximum Value of StDev of Omega at or West of PIREP Location,
20-Point Gaussian Smoothing
All Altitudes, NOT Airliners*
Standard Deviation
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.44
0.54
0.66
1.08
n=1383
n=3187
n=5316
n=1343
NEG
LGT,
LGT-MOD
MOD
MOD-SEV,
SEV,EXTRM