



NATIONAL TRANSPORTATION SAFETY BOARD
Office of Aviation Safety
Washington, D.C.

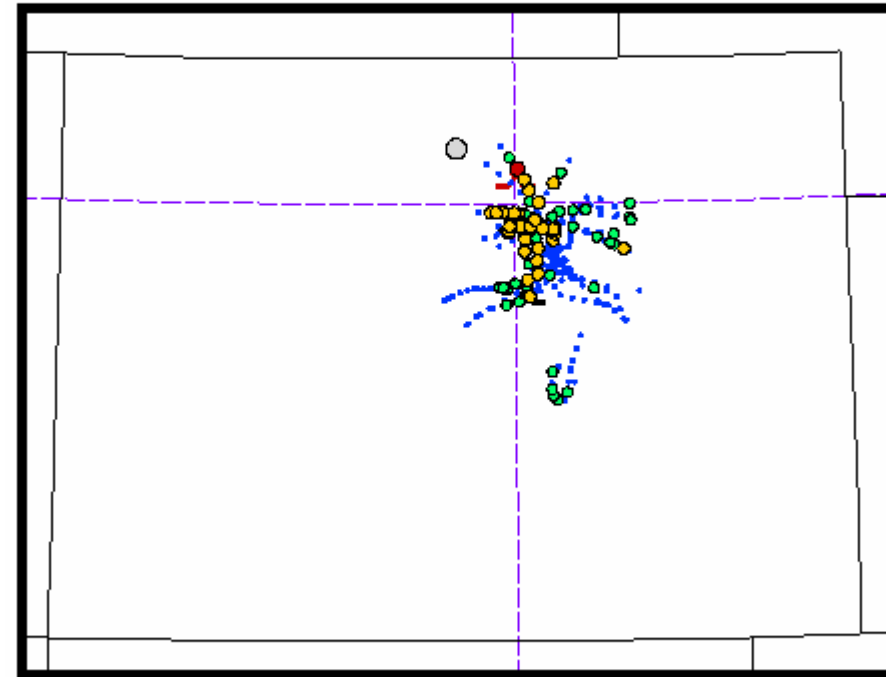
CEN22FA035 – Estes Park, Colorado

Attachment 3 – National Center for Atmospheric Research (NCAR) numerical model and Graphic Turbulence Guidance (GTG) on November 16, 2021

11/16/2021 0136 UTC turbulence case near Estes Park, CO near 9000 ft MSL

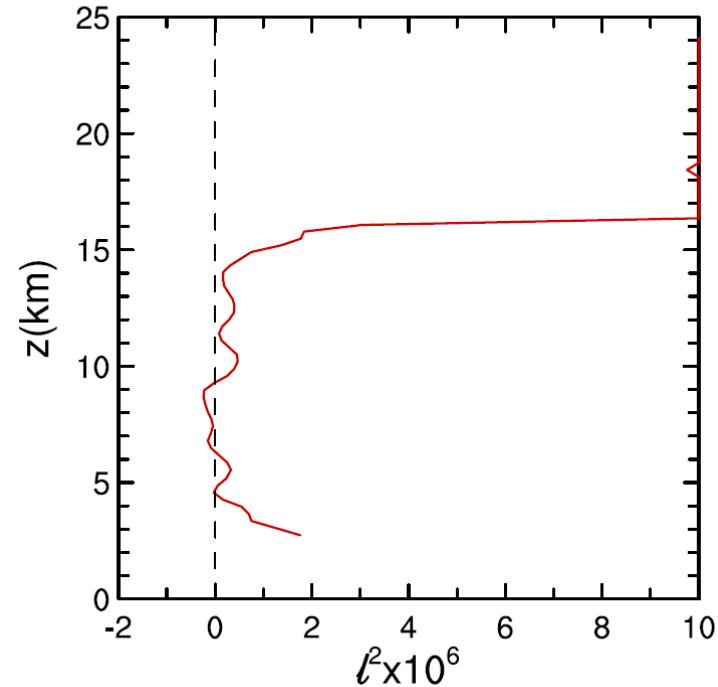
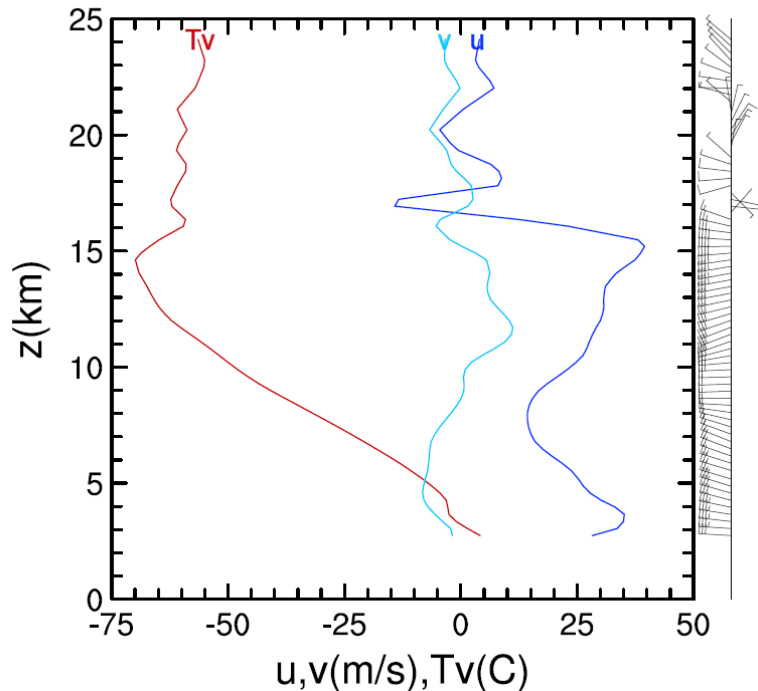
turb reports 17 nov 2021 EST 0000 to 0300 UTC 08-FEB-22
flight levels(11) - 0. to 20000.
EDR circles, yellow .22-.34 (MOD), red .34-1.0 (SEV)
nobs_000438 nmods_0038 nsogs_003 nmmts_000

- Some elevated low-level PIREPs and in situ EDR to the south, mainly going in and out of DIA (right)
- Executed HRRR NWP model to examine waves and turbulence as inferred from GTG4 (Under development)
 - 1-hr and 2-hr forecast valid at 0100 UTC, 8000,9000,10000 MSL
 - Showed low level trapped lee waves with wavelength ~ 24 km in the vicinity of the accident location
 - Rotor could have been present but HRRR horizontal grid spacing was too coarse to actually resolve it
- Operational GTG3 output showed similar results, with EDR forecast at the accident location in the 0.4-0.5 EDR range (both CAT and MWT)



11/16/2021 0136 UTC turbulence case near Estes Park, CO near 9000 ft MSL

- Sounding constructed from nearest HRRR horizontal grid point to accident
- Vertical structure of atmospheric environment conducive to low-level trapped lee waves (left)
 - Wind increasing with height up to 3-4 km
 - Temperature inversion near mountain top
- Strong low-level westerly component encourages waves
- Scorer parameter (right) decreases with height becoming negative at ~ 5 km so wave trapping expected below that level

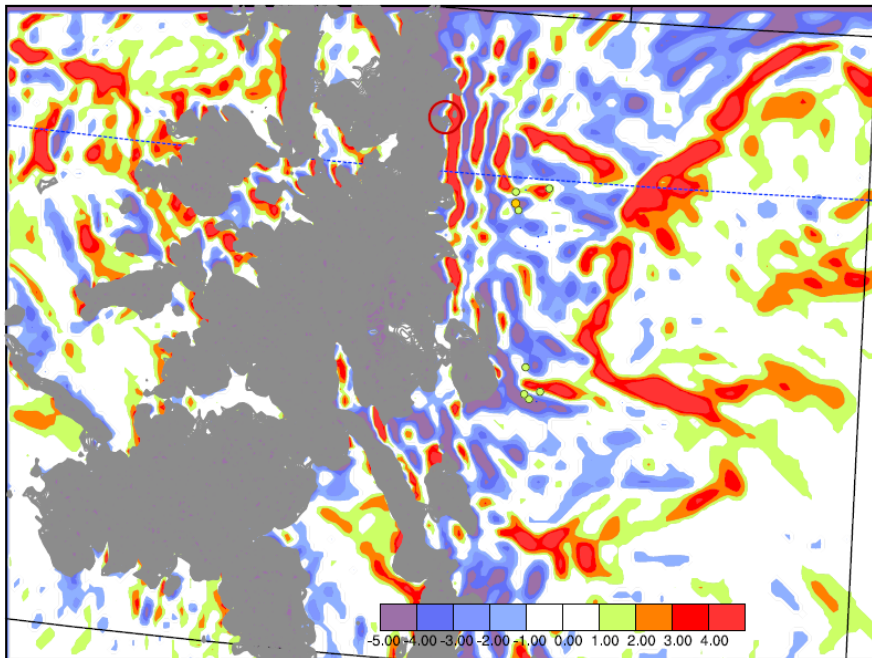


11/16/2021 0136 UTC turbulence case near Estes Park, CO near 9000 ft MSL

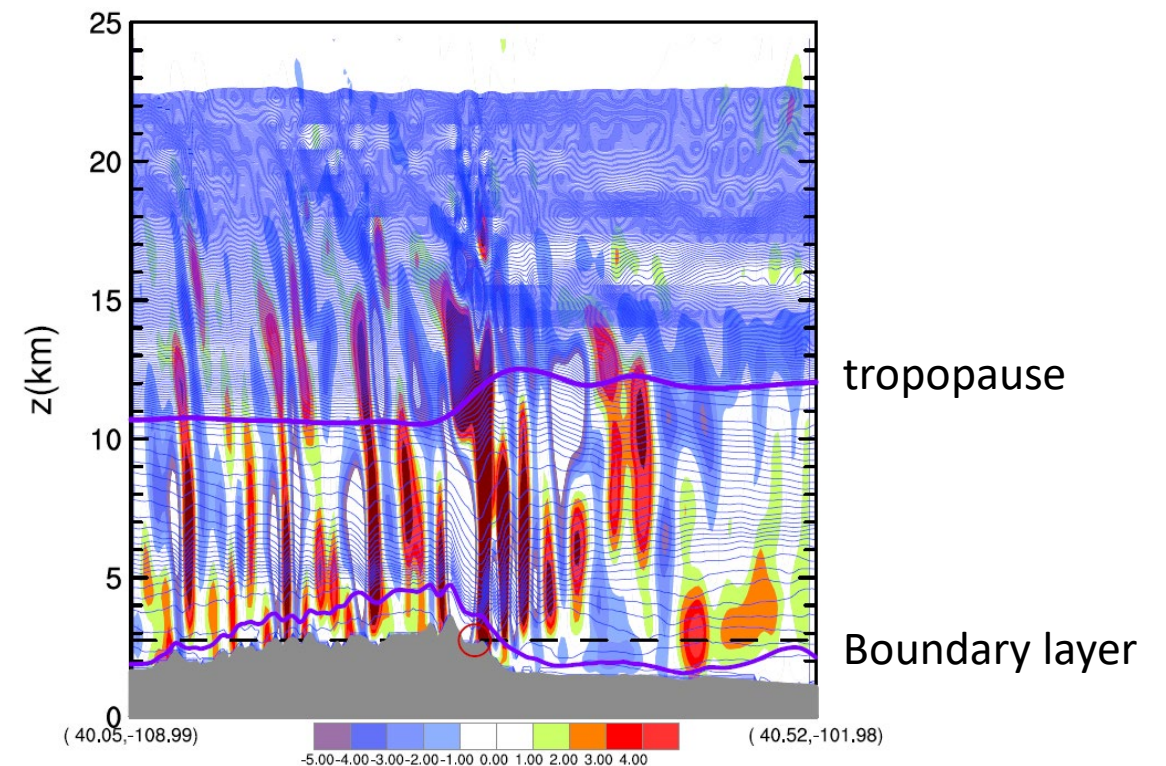
- W field (red positive, blue negative) from HRRR at 9km MSL shows trapped waves at low levels ~ 24 km wavelength
- Accident location at red circle

Z=9km

grey=terrain $ht \geq 9\text{km}$

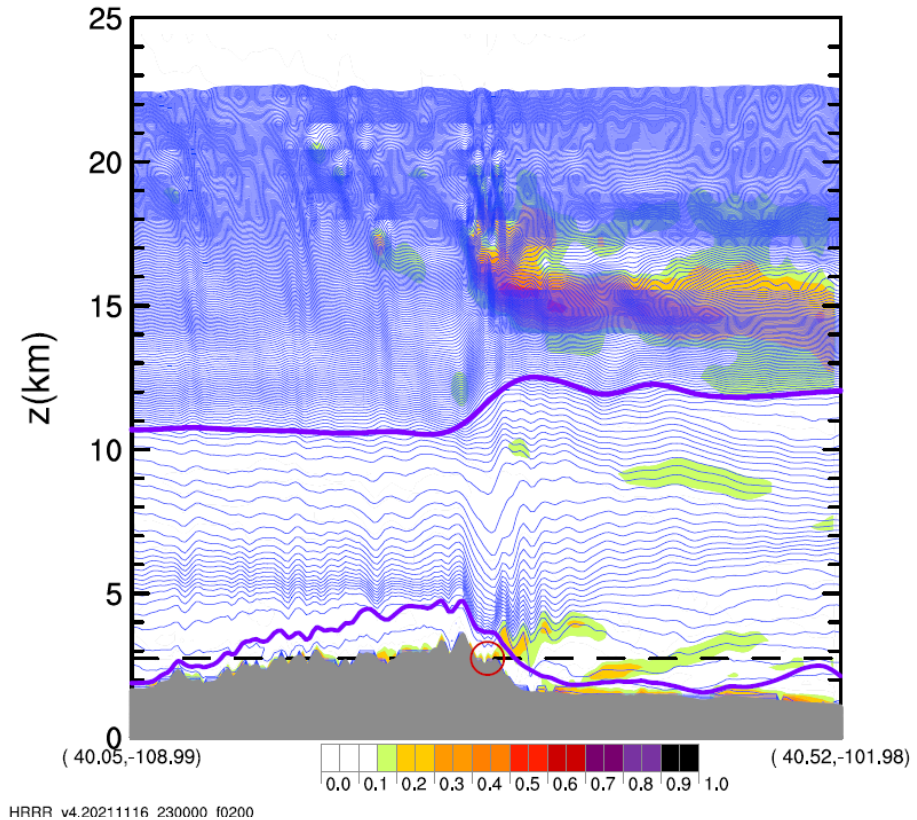


West-east vertical cross section at lat=40.33N
grey=terrain, light lines are isentropes



11/16/2021 0136 UTC turbulence case near Estes Park, CO near 9000 ft MSL

- Waves in isentropes $\sim$ streamlines near accident location between $z \sim 3$ -6 km
- Horizontal vorticity $\sim$ vertical wind shear
 - Enhanced vorticity in vicinity of accident could indicate the presence of a rotor
 - But insufficient resolution to actually resolve rotors

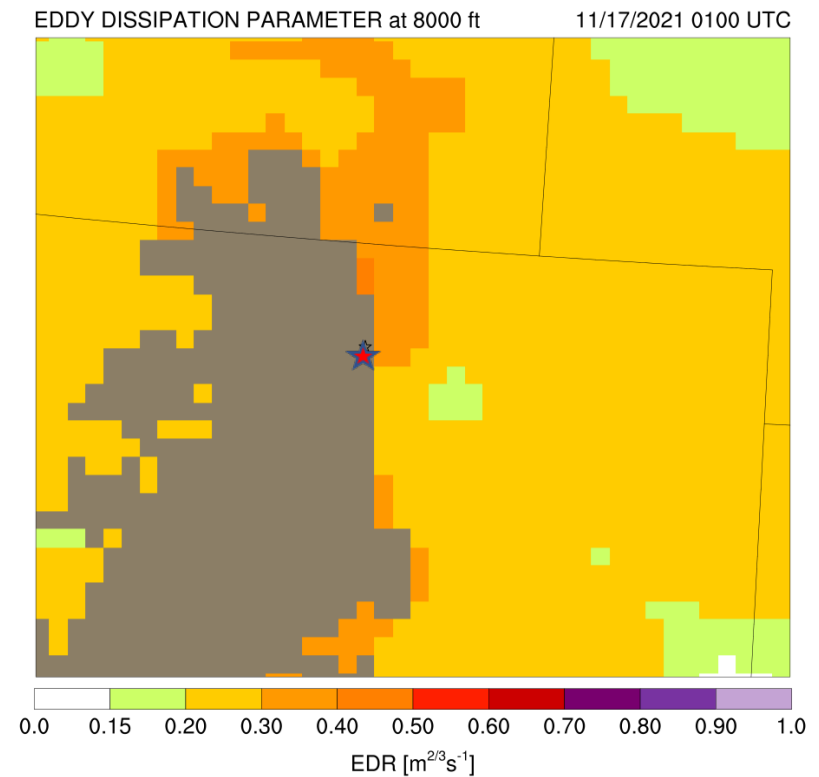
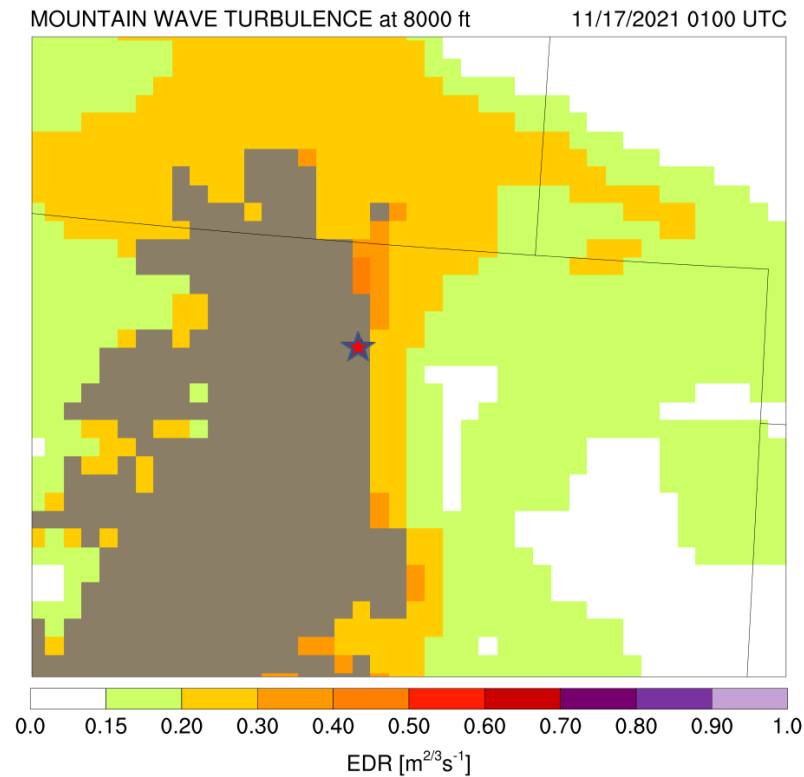
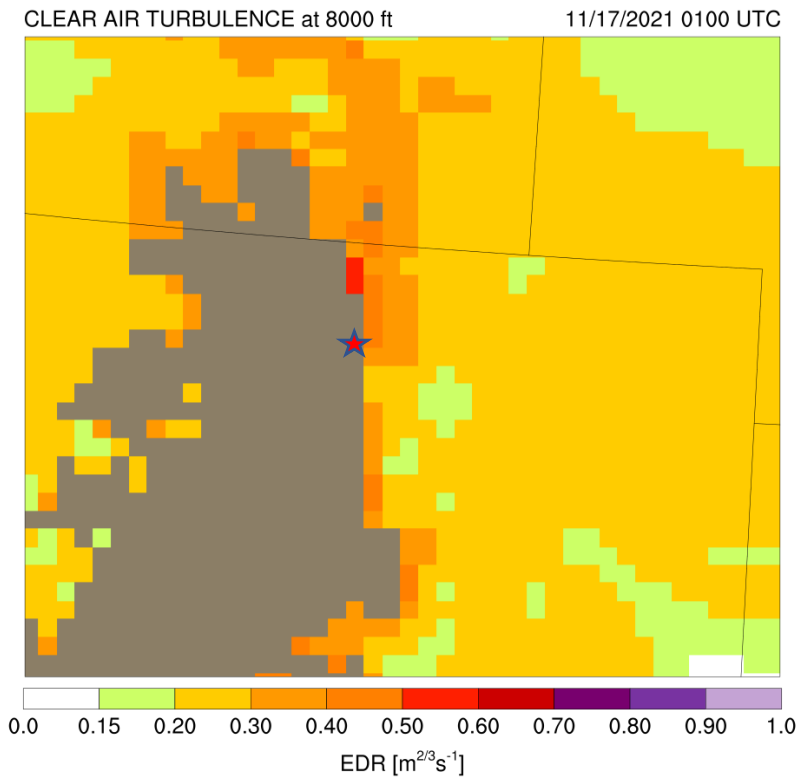


Contours of VWS (arbitrary)

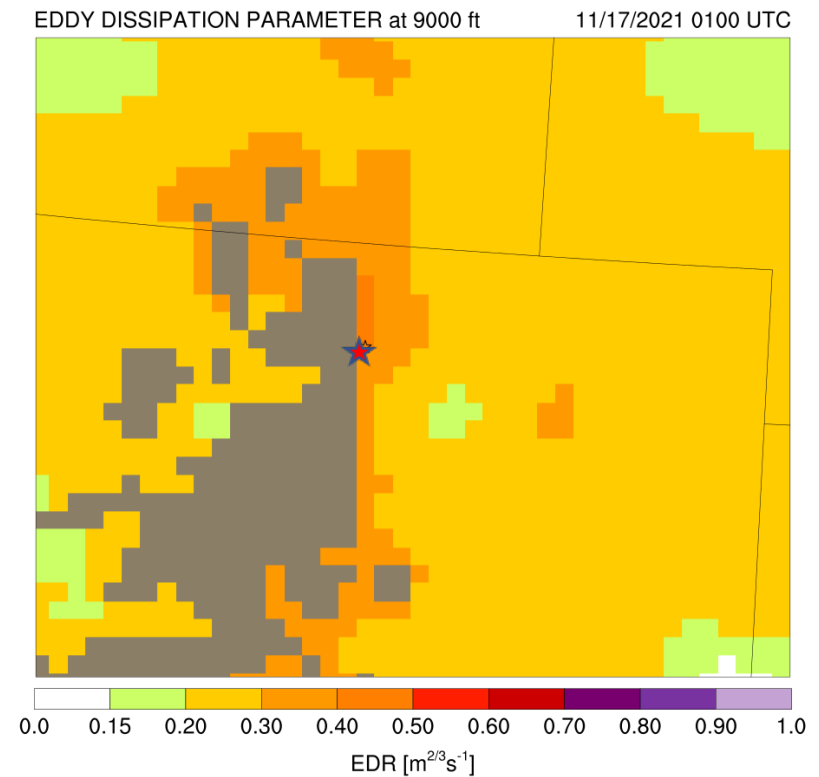
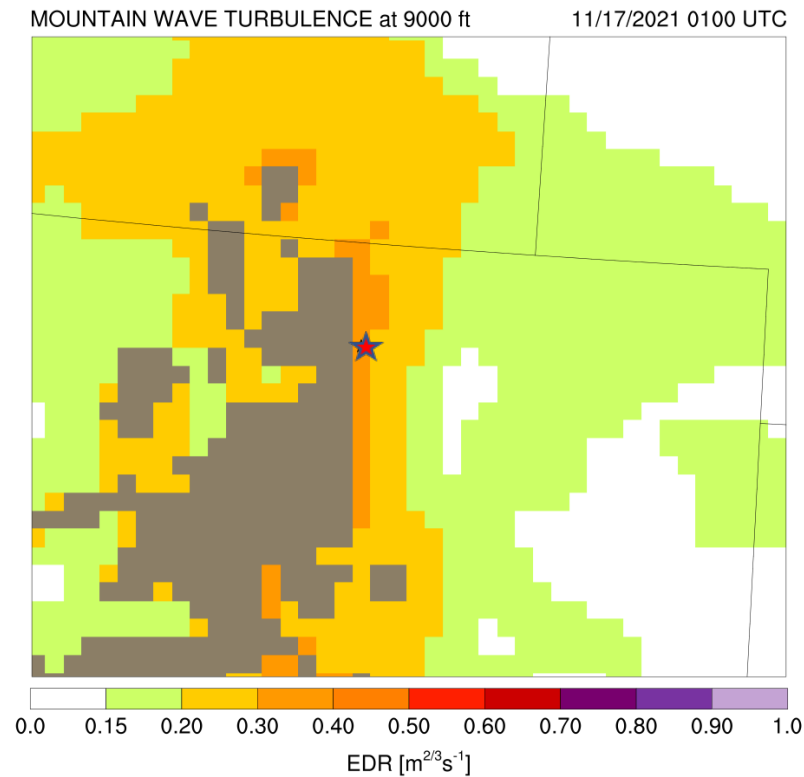
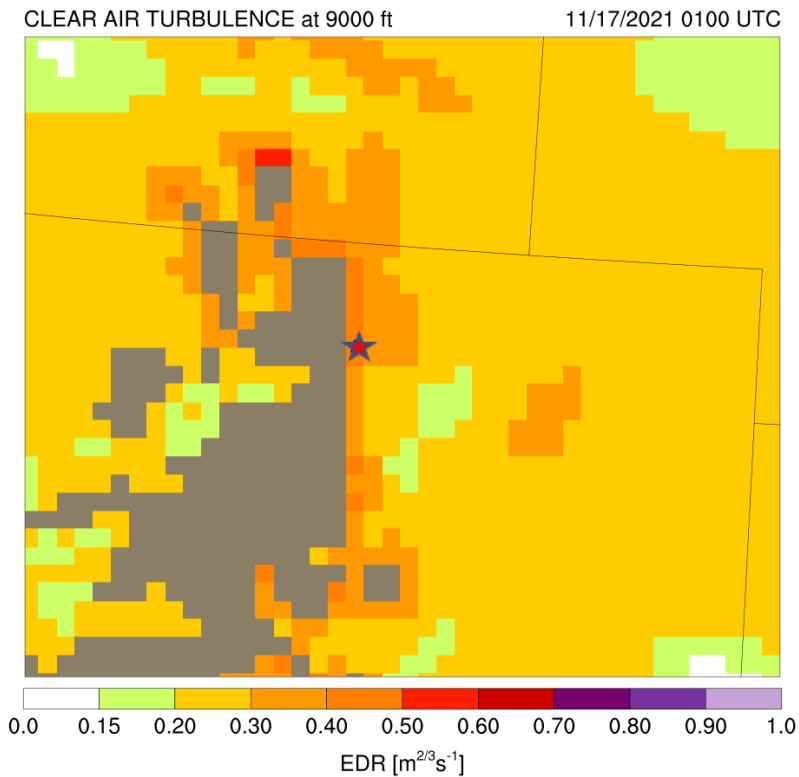
Operational GTG3 output

- Showing 1 hour forecasts valid at 0100 and 0200 UTC on 20211117.
 - Plan view plots for 8,000 9,000 10,000 ft.
 - Accident location shown as a star
 - West-East Vertical cross section through accident location

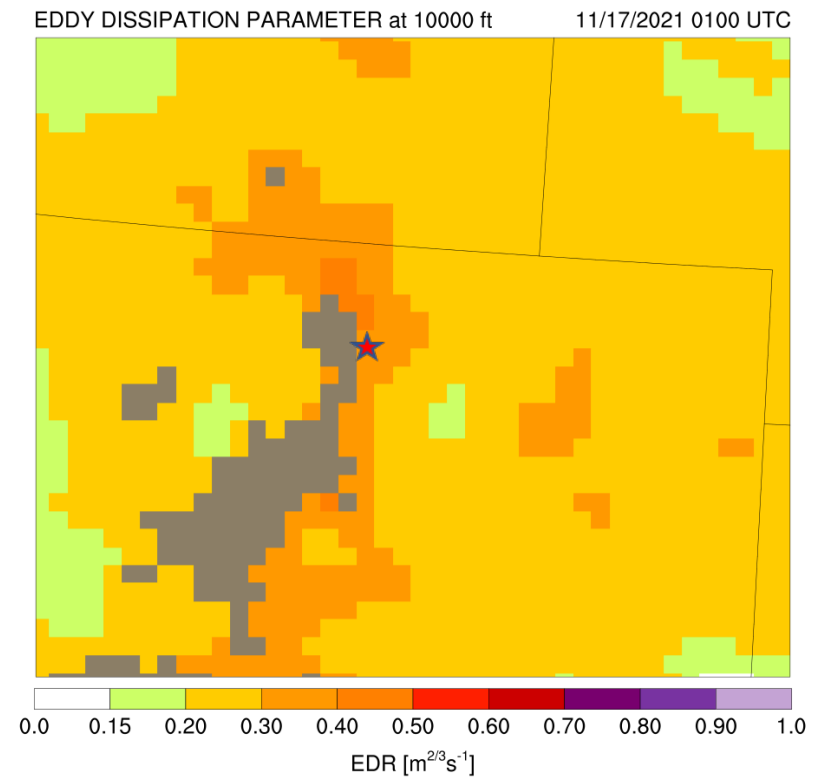
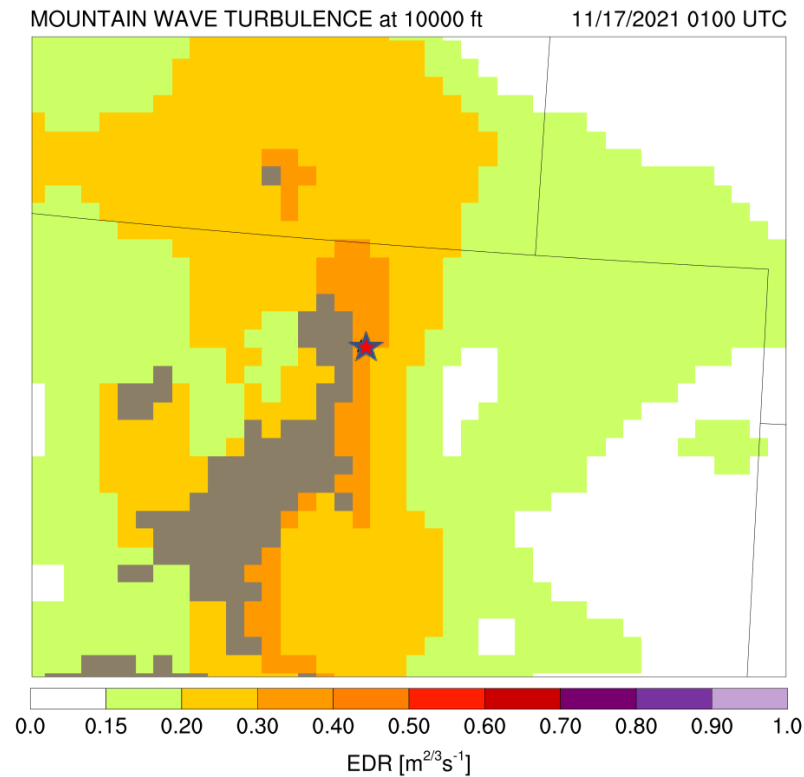
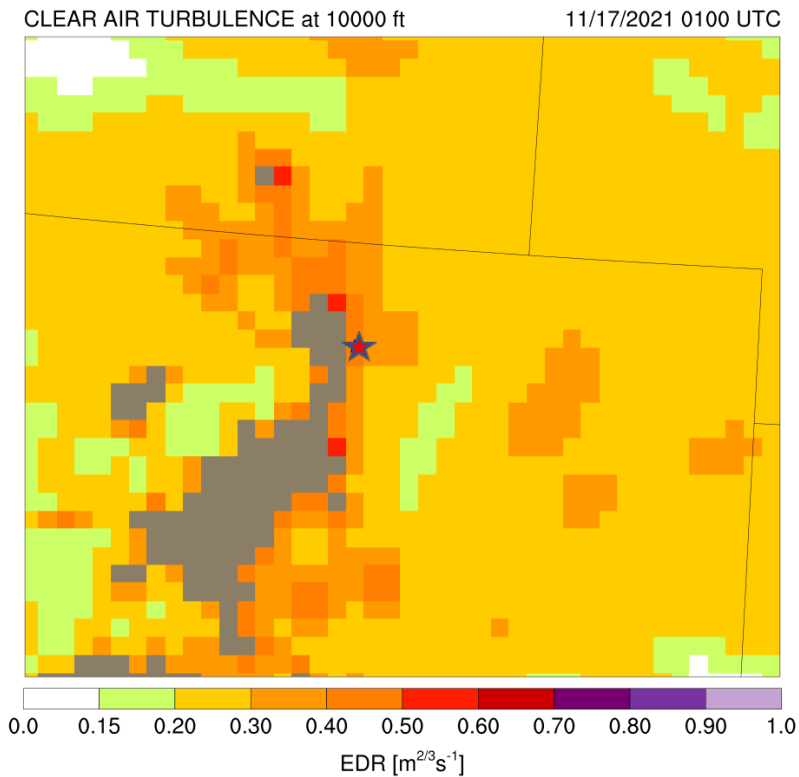
GTG3 1hr forecasts valid at 0100 UTC on 11/17/2021 at 8,000 ft: CAT, MTW, COMB



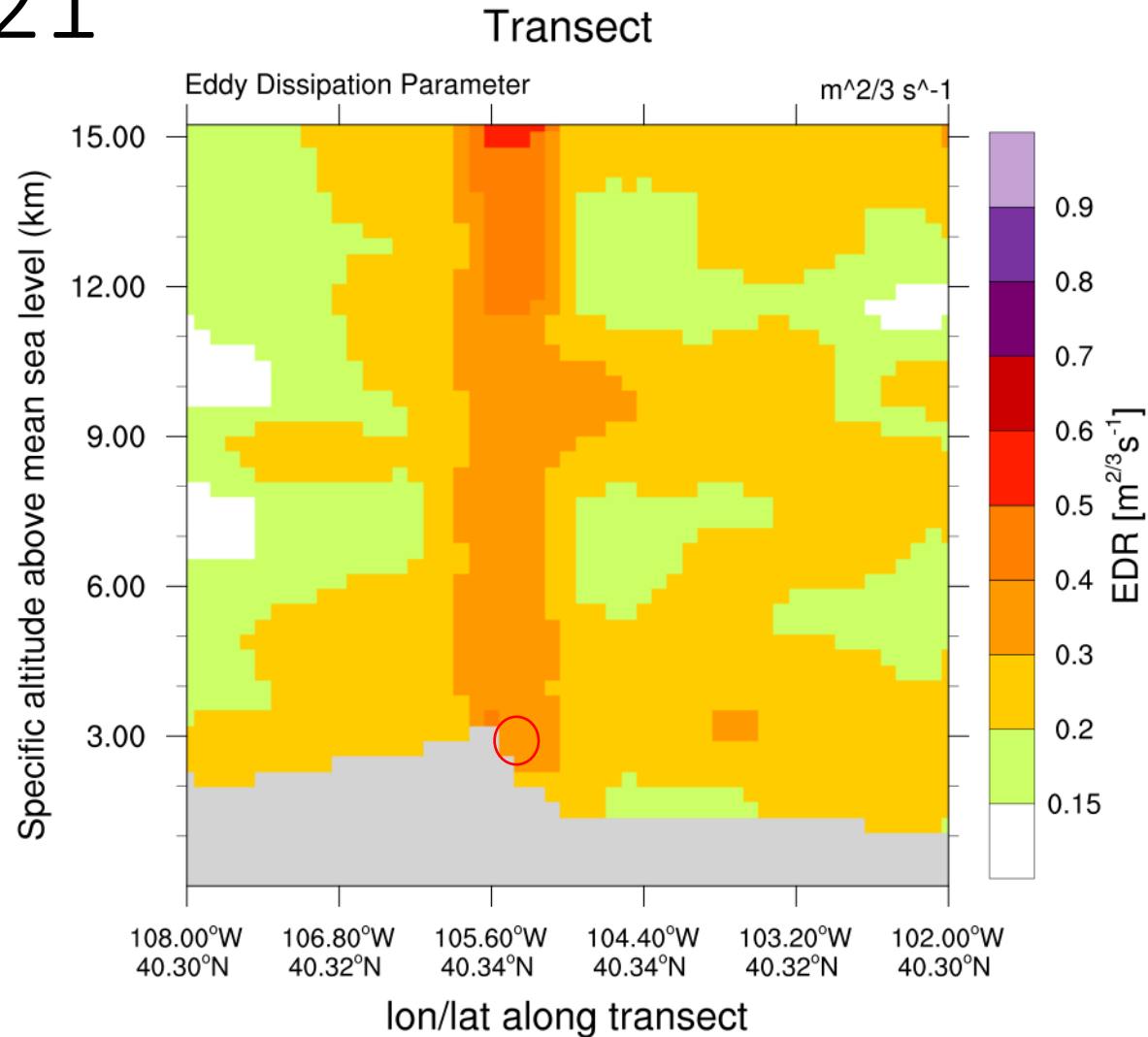
GTG3 1hr forecasts valid at 0100 UTC on 11/17/2021 at 9,000 ft: CAT, MTW, COMB



GTG3 1hr forecasts valid at 0100 UTC on 11/17/2021 at 10,000 ft: CAT, MTW, COMB

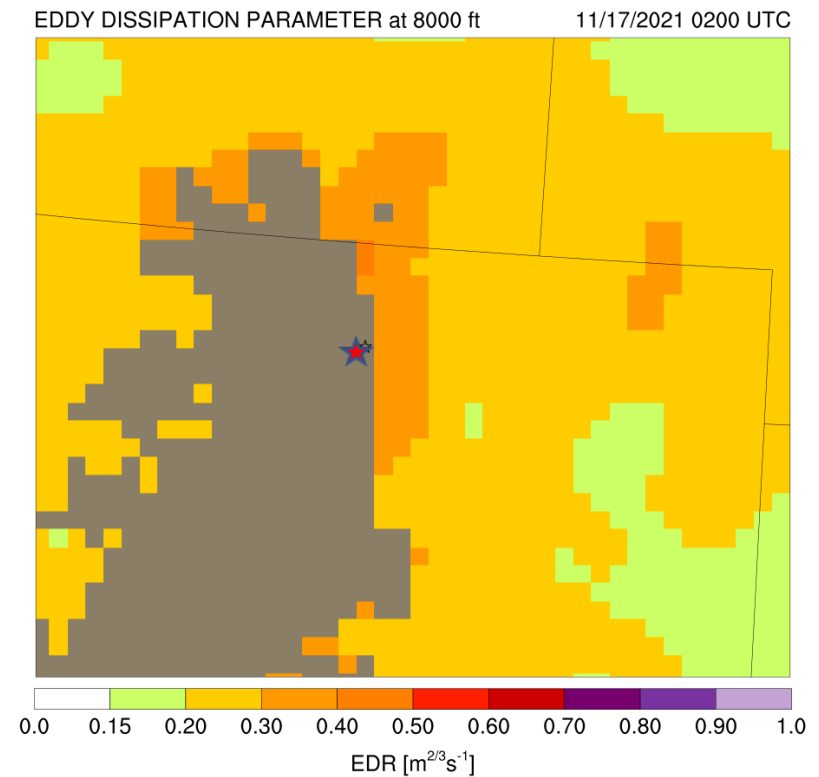
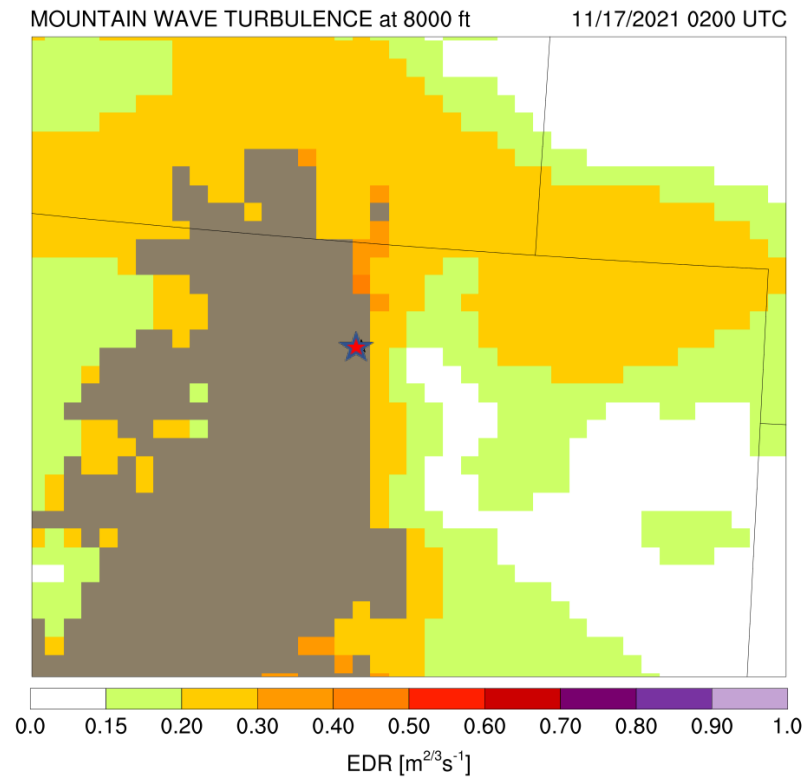
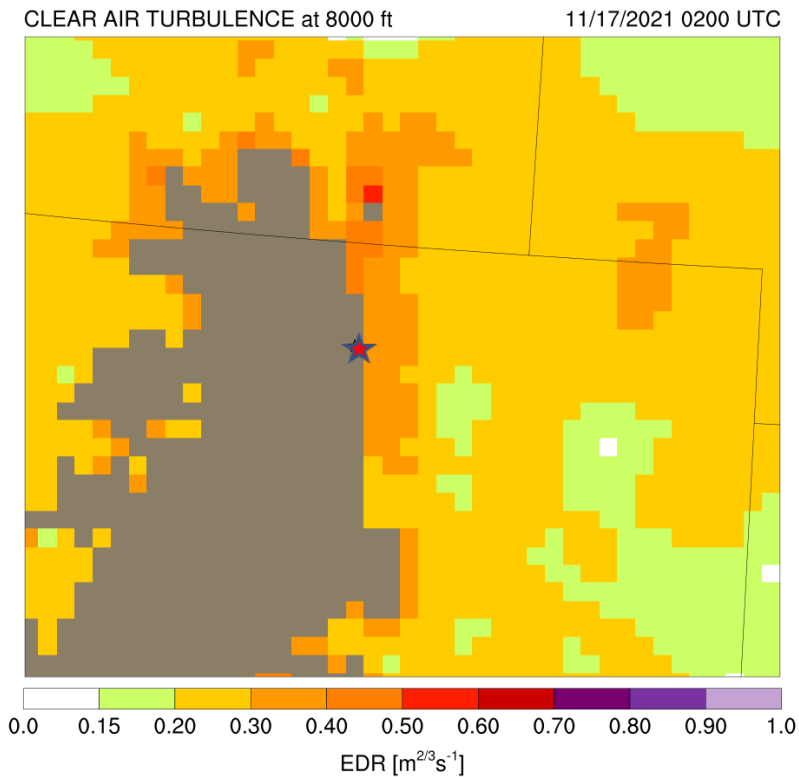


GTG3 1hr forecasts valid at 0100 UTC on 11/17/2021

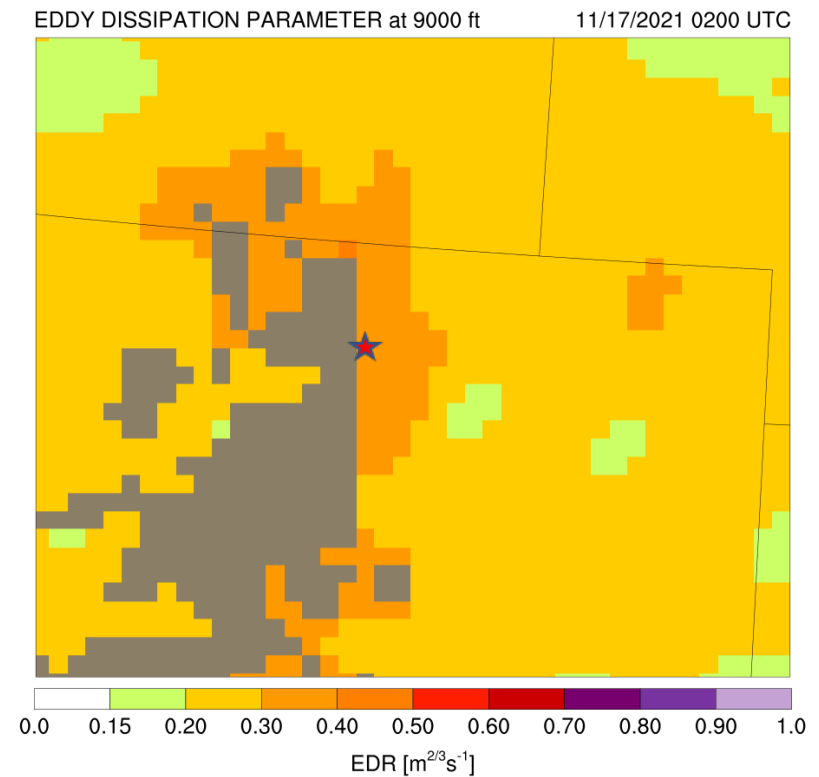
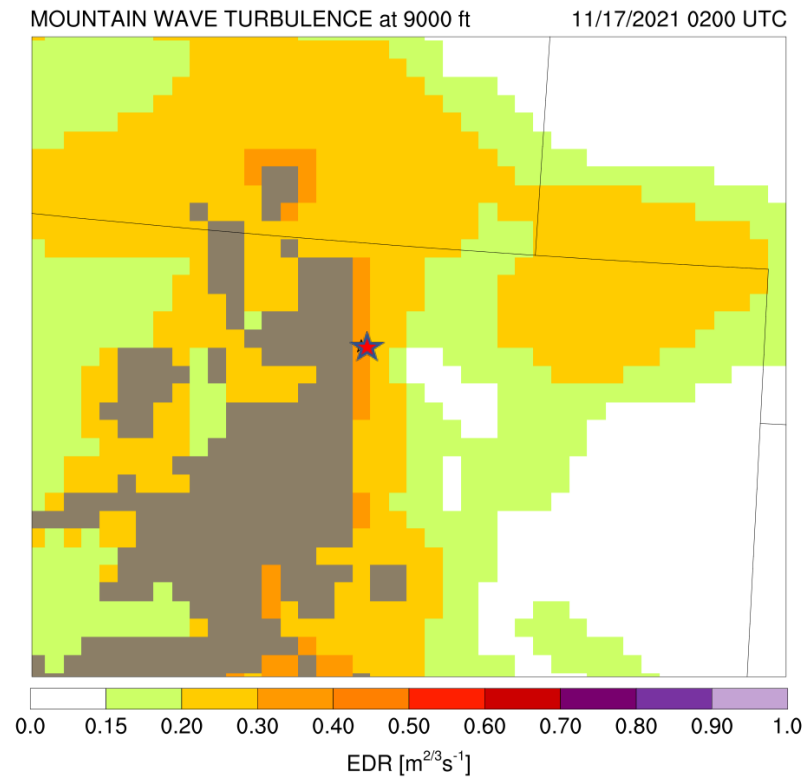
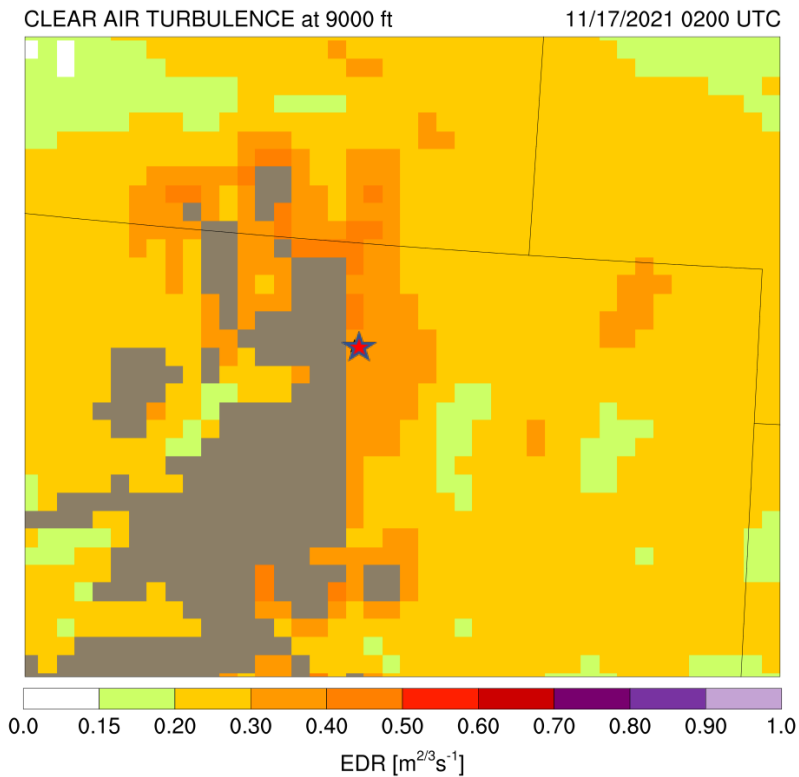


*Approximate
accident location
shown by red circle

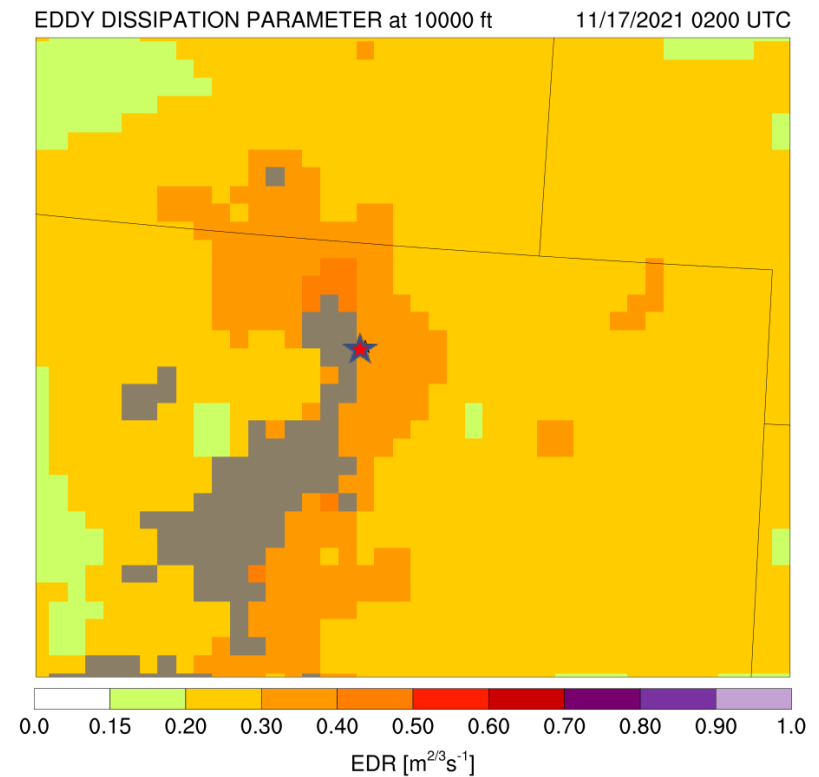
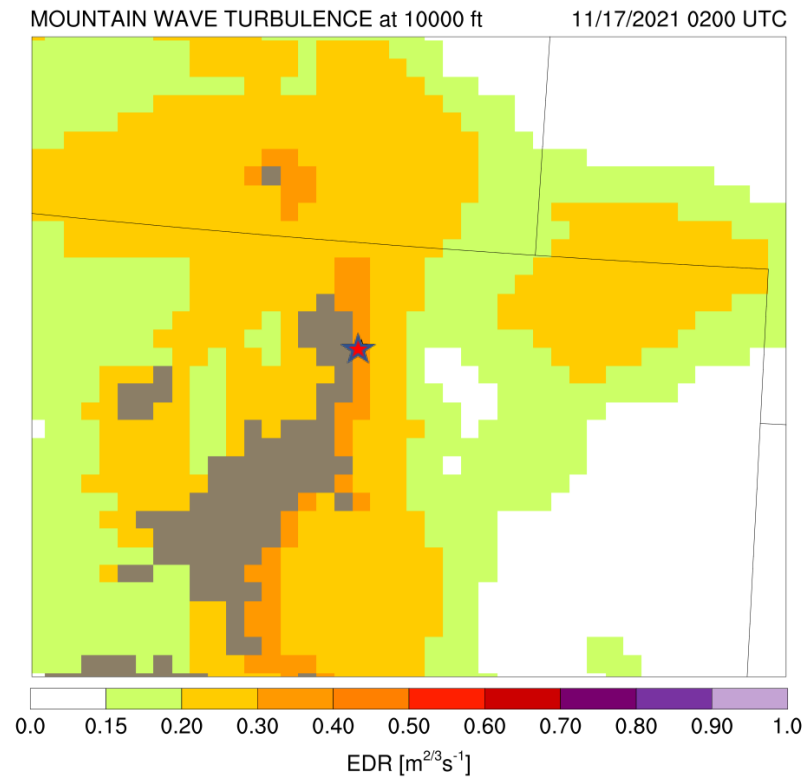
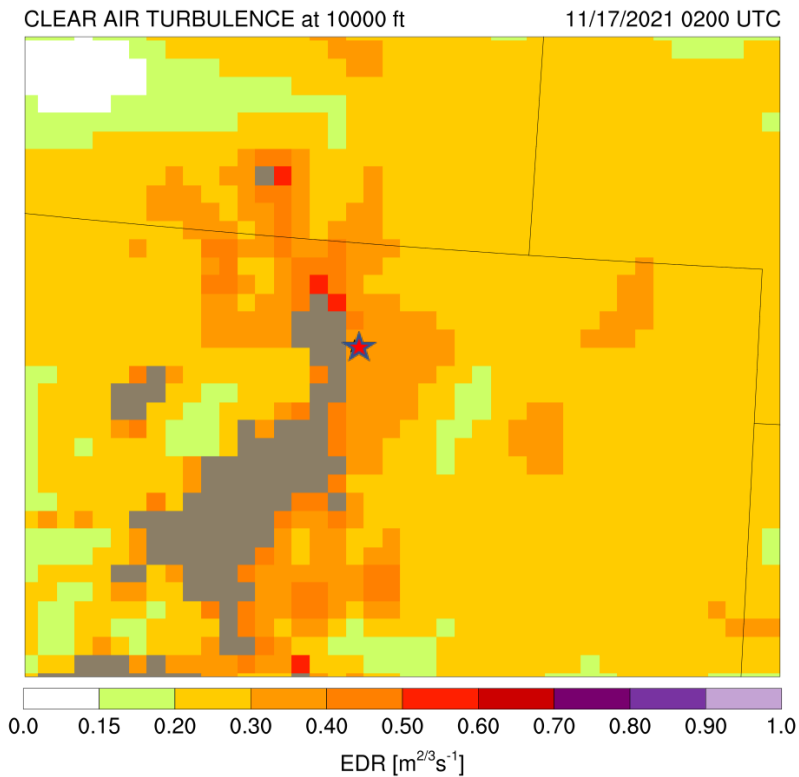
GTG3 1hr forecasts valid at 0200 UTC on 11/17/2021 at 8,000 ft: CAT, MTW, COMB



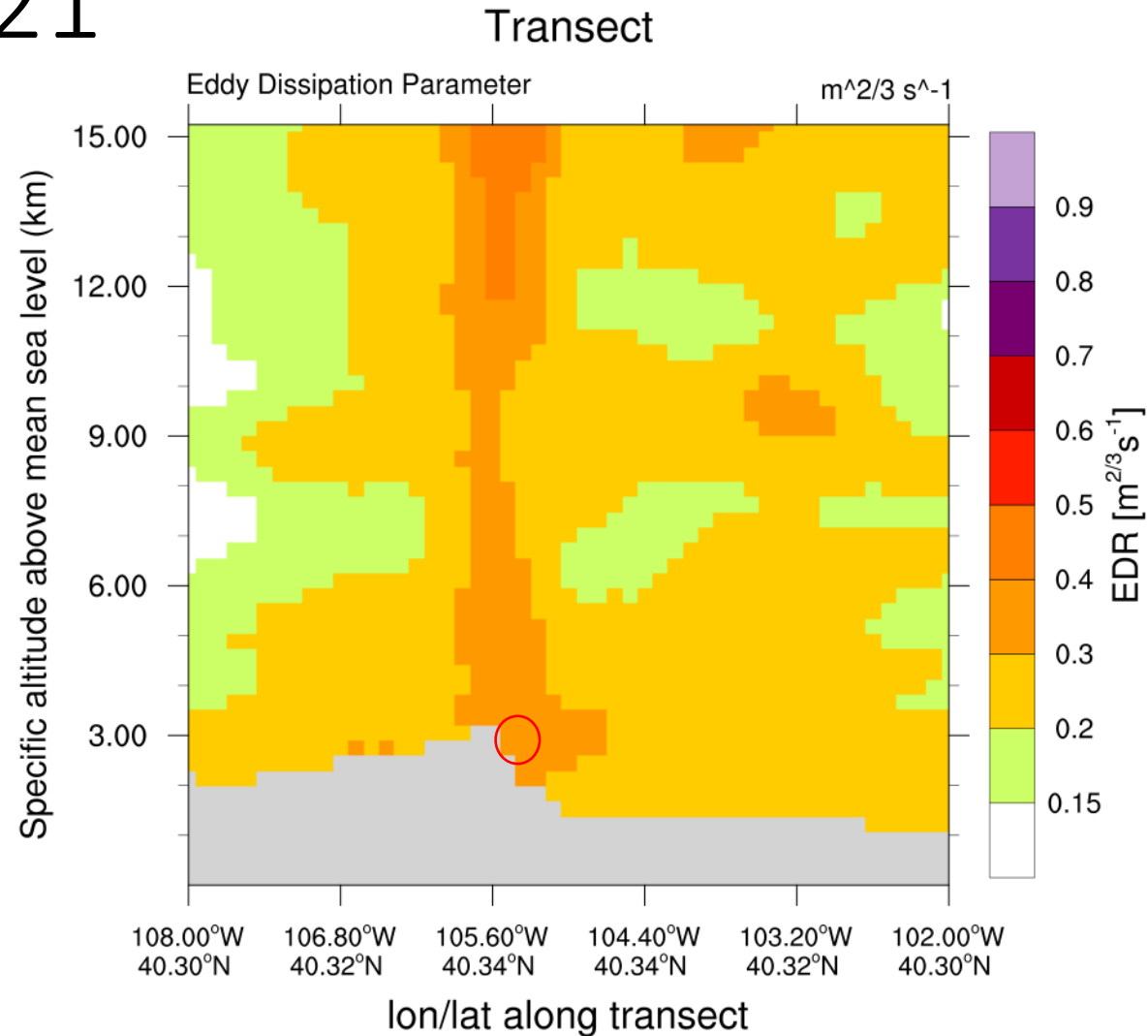
GTG3 1hr forecasts valid at 0200 UTC on 11/17/2021 at 9,000 ft: CAT, MTW, COMB



GTG3 1hr forecasts valid at 0200 UTC on 11/17/2021 at 10,000 ft: CAT, MTW, COMB



GTG3 1hr forecasts valid at 0200 UTC on 11/17/2021



*Approximate
accident location
shown by red circle