First Discovery of Regular Occurrence of Mid-Latitude Thermosphere-Ionosphere Na (TINa) Layers Observed with High-Sensitivity Na Doppler Lidar and New Data Processing Techniques over Boulder

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12. Measurements in the stratosphere, mesosphere and thermosphere

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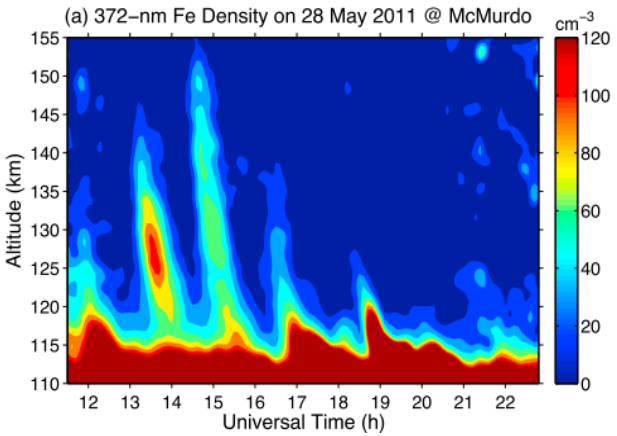
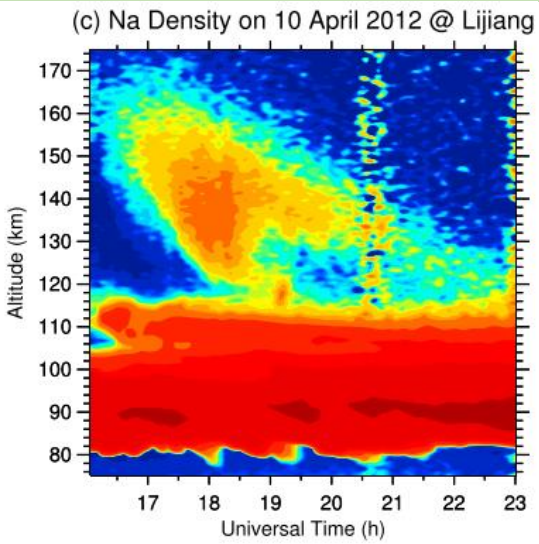
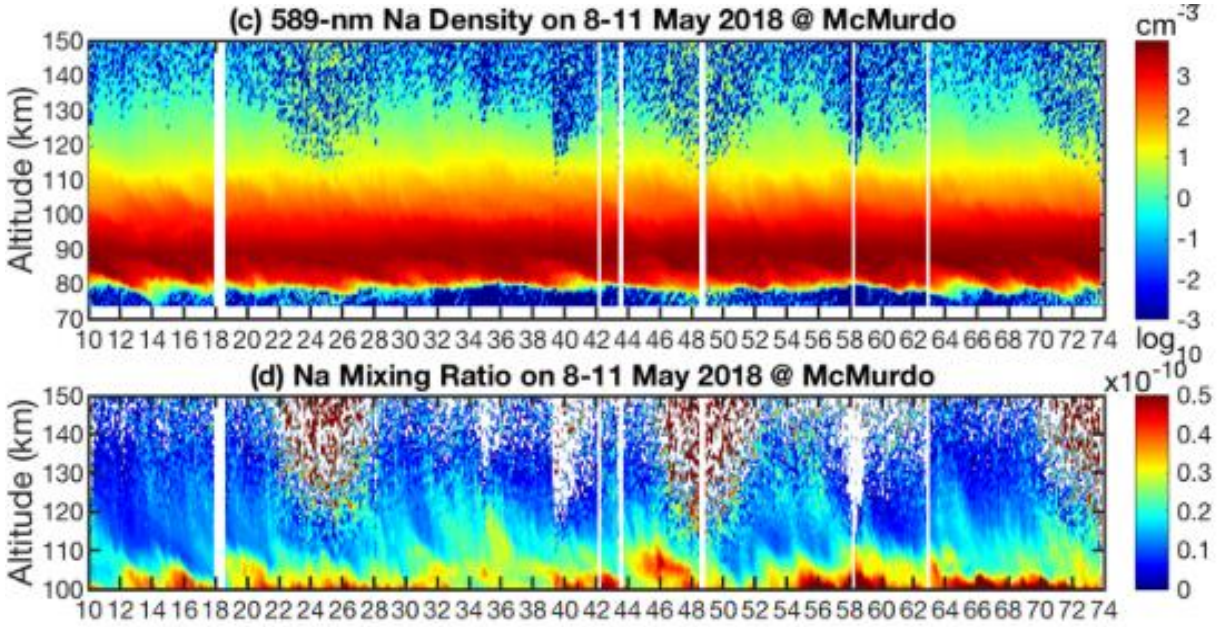
Introduction to thermosphere-ionosphere metal (TIMt) layers



[Chu et al., 2011]
@ McMurdo (77.83°S)



[Gao et al., 2015]
@ Lijiang (21.6°N)

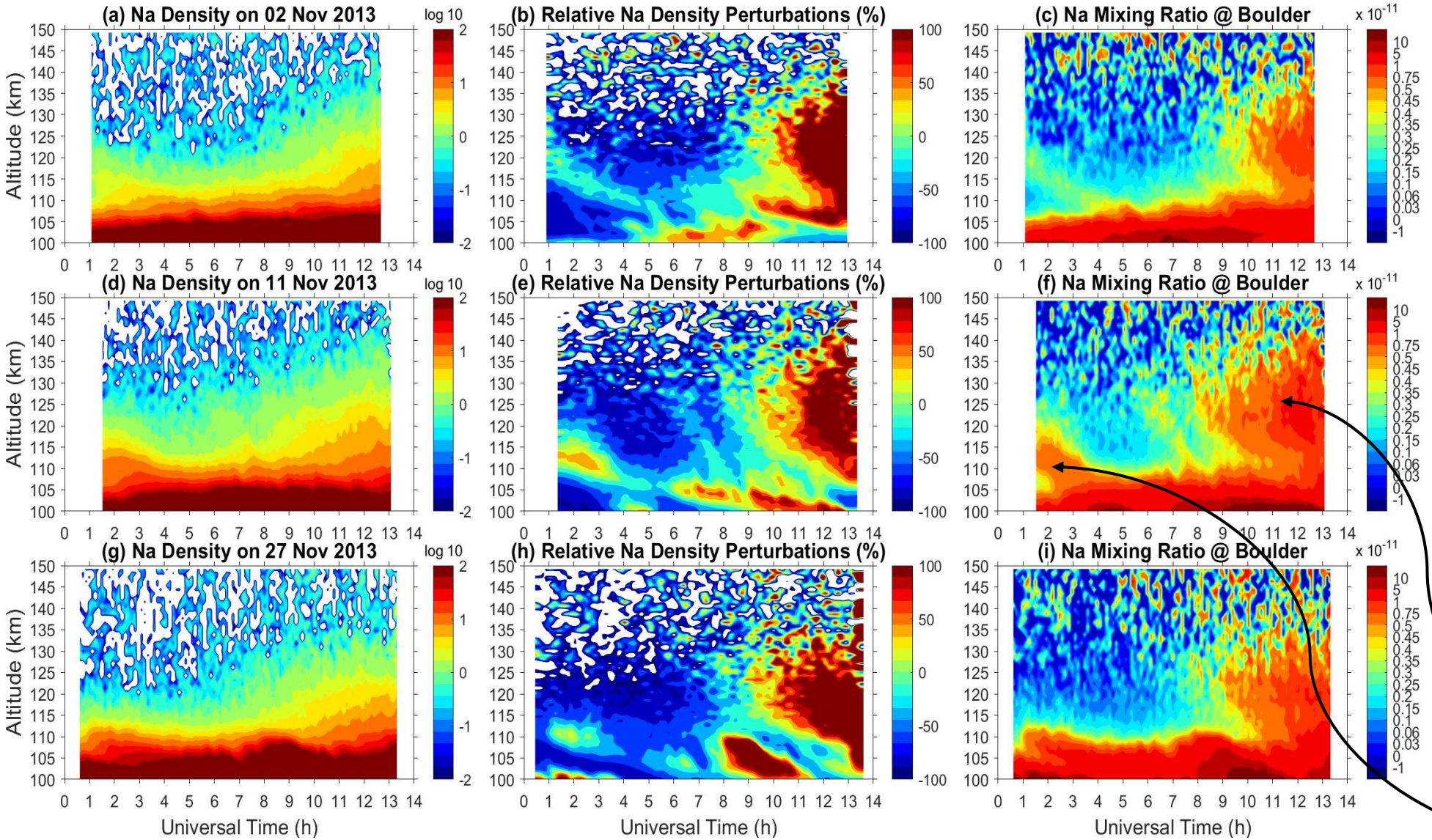


[Chu et al., 2020] @ McMurdo (77.83°S)

- Thermosphere-ionosphere metal (TIMt) layers
- First discovered 10 years ago in Antarctica
- **Occur irregularly at high and low latitudes as well as midlatitudes based on previous obs.**
- TIMt layer extends the ground-based lidar observations into the space, i.e., in the E to lower F regions (~100 to 200 km altitude) where measurements of the neutral atmosphere are scarce but plasma-neutral interactions are rich.

Nearly 30 years of lidar observations at mid-latitudes showed only intermittent occurrence of TINa layers in the 100–200 km from a few locations. Then in 2021, the first discovery of regularly occurring mid-latitude TINa layers was made over Boulder with the combination of **high detection sensitivity** of lidars and **creative data processing techniques (volume mixing ratio calculations)**. [Chu, Chen, et al., GRL, 2021]

First discovery: regular occurrence of thermosphere-ionosphere Na (TINa) layers



1) Tenuous layer ~0.1–1 cm^{-3} @ 150–130 km

2) up to 150 km

3) downward phase progression

4) Semidiurnal tidal phase

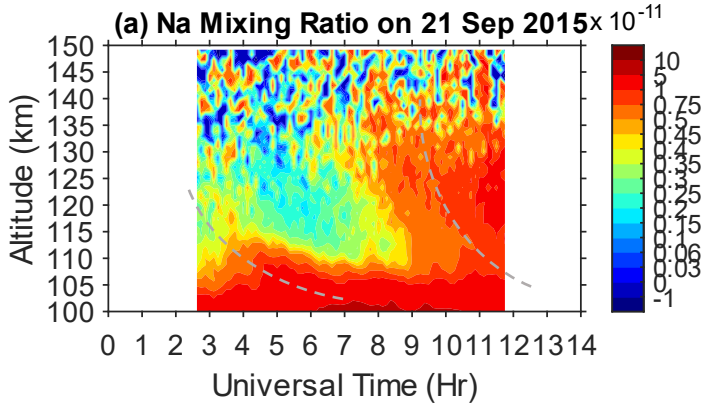
Dawn layer

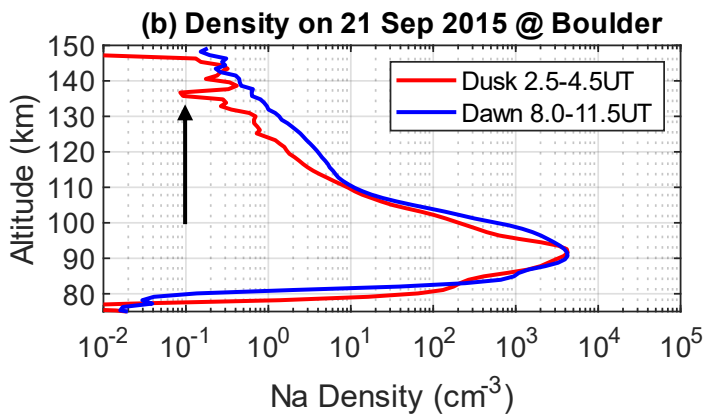
Dusk layer

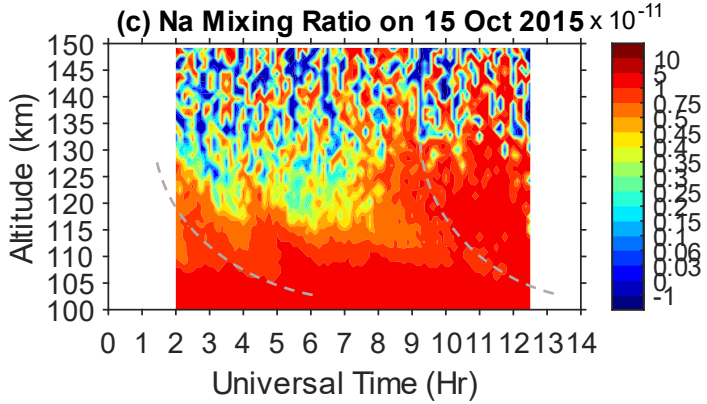
7 UT—Midnight

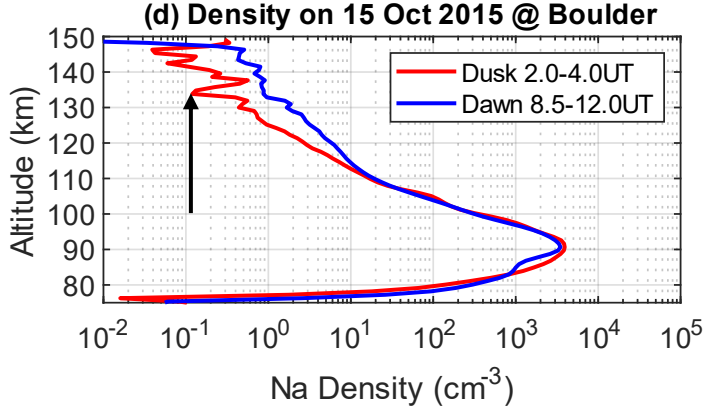
[Chu, X., Chen, Y., et al.: Mid-latitude thermosphere-ionosphere Na layers observed with high-sensitivity Na Doppler lidar over Boulder. Geophys. Res. Lett., 48(11), 1–10 (2021).]

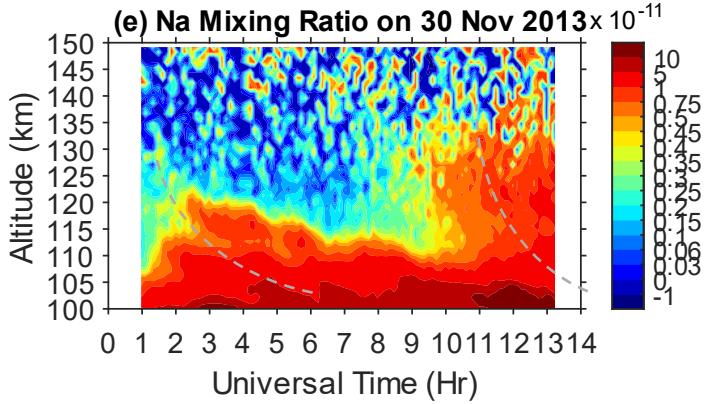
Quantification of Boulder dusk/dawn layers (high detection sensitivity is necessary)

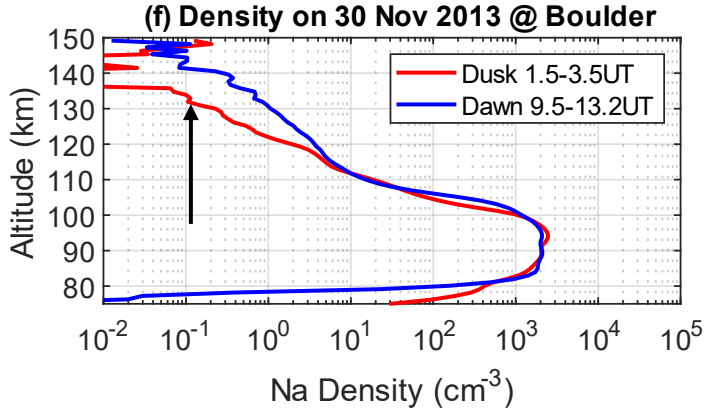






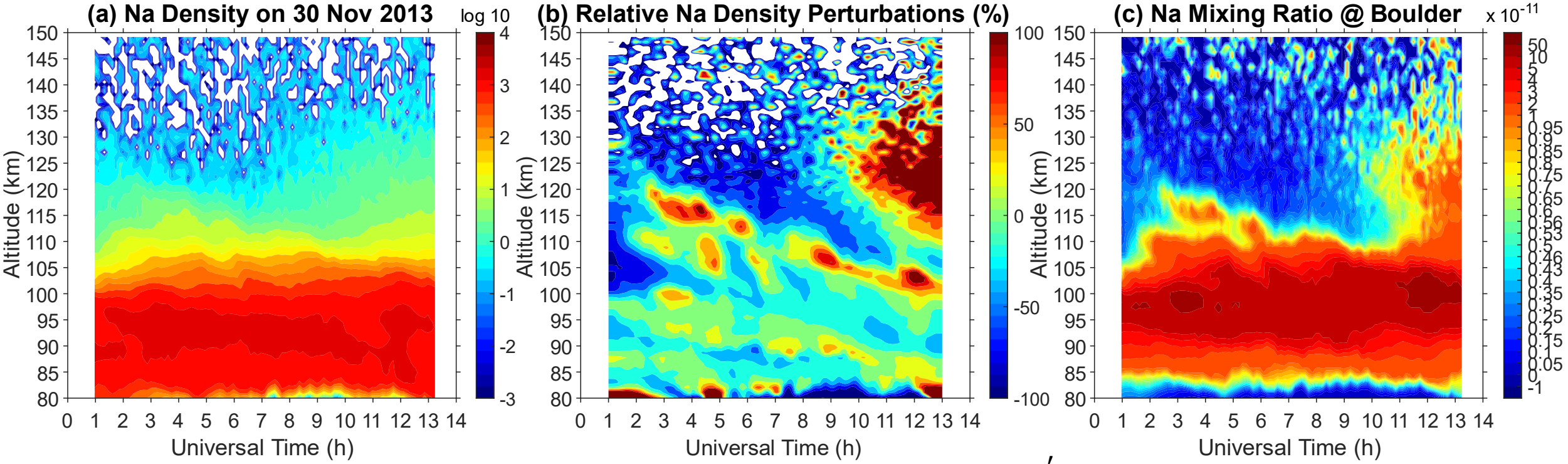






- Dawn/dusk TINa layers occur in various months and years besides those six cases shown in Chu, Chen, et al., 2021.
- Na density profiles (Figure b, d, f) are plotted in log-10 scales for the dusk and dawn layers from three different observations.
- From density profiles, above ~130 km, the detection limit with Na density of high-sensitivity lidar is about 0.1 cm^{-3} .
- The density profiles of dawn/dusk layers show a turning point around 110 km, above and below which the slopes are different.
- Such different slopes provide strong evidence for in-situ production of Na above the turning point (~105–110 km) for both the dusk and dawn layers.

Why mixing ratio calculation is important to the first discovery of regular occurrence of TINa



$$relative\ Na\ density\ perturbations = \frac{\rho'_{Na}}{\rho^{0}_{Na}}$$

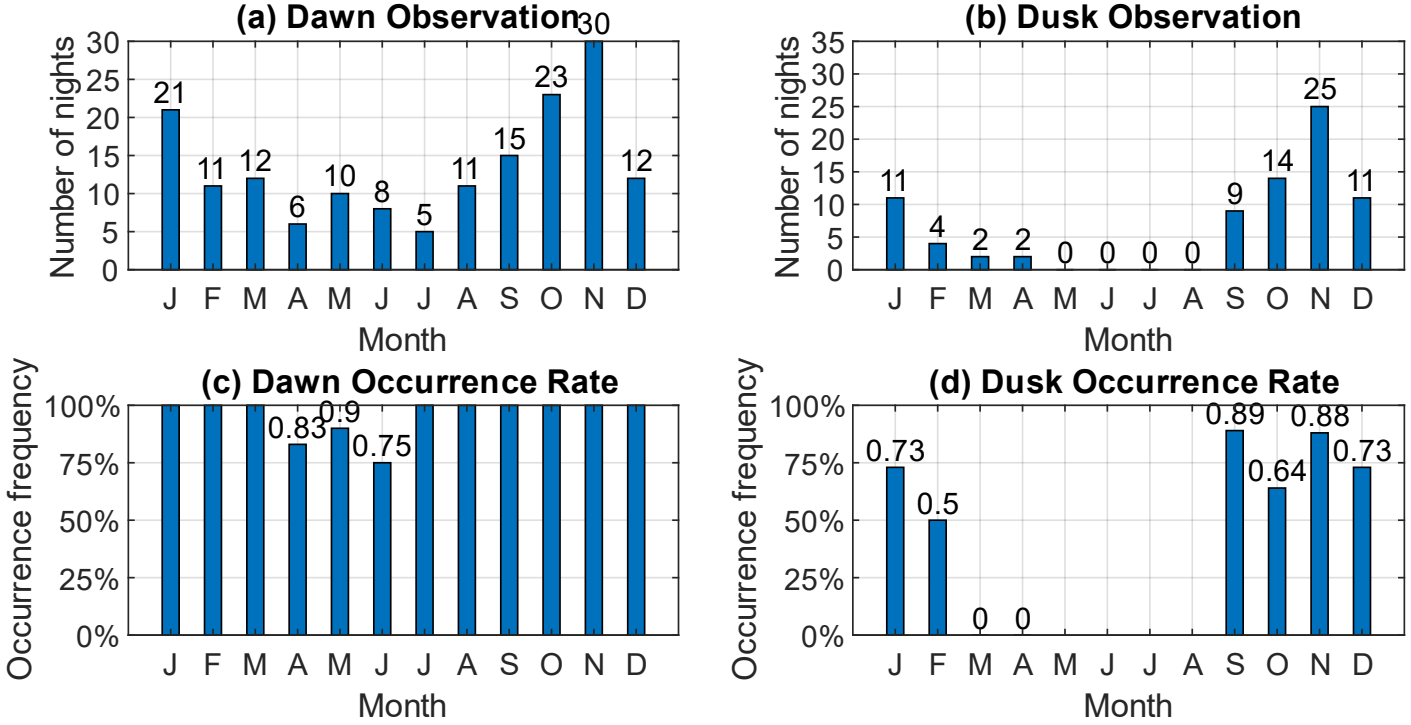
ρ'_{Na} = *Na density - nighttime average Na density profile*

ρ^{0}_{Na} = *nighttime average Na density profile*

$$Na\ volume\ mixing\ ratio = \frac{\rho_{Na}}{\rho_{atmosphere}}$$

Na volume-mixing-ratio contour (Figure (c)) makes two different layers much more clearly than the other two plots. TINa dawn layer exhibits ascending features in the Na total density (Figure (a)) from ~9 to ~13UT but descending features in the maximum mixing ratio (Figure (c)) from ~140 km at ~10–11UT to ~120–110 km at ~12–13UT.

Statistical study based on 7 years of lidar observations



7 years of lidar observations reveal Boulder TINa dawn layers with nearly **100% occurrence rate (160 out of 164 nights of observations)**, while observations also indicate that Boulder TINa dusk layers occur regularly for qualified observation nights, mainly during winter seasons **(57 out of 78 nights of observations)**.

Conclusions

1. First discovery of regular occurrence of mid-latitude thermosphere-ionosphere Na (TINa) layers (110–150 km) was made over Boulder (40.13°N, 105.24°W), Colorado.
2. Detection of tenuous Na layers (~0.1–1 cm^{-3} from 150 to 130 km) was enabled by high-sensitivity Na Doppler lidar.
3. A new data processing technique is applied to pave the way for the discovery, which is Na volume mixing ratio calculations.
4. These layers provide a natural laboratory for studying the ion-neutral coupling and act as tracers for extending the profiling of neutral wind and temperature into the E to F regions.
5. Such potentials offered by the TINa layers promote future advancement of lidar technologies for even higher detection sensitivities to enable new science endeavors.