Boulder TINa Layers (100–150 km) Detected by High-Sensitivity Na Lidar and Their Relationship to Tidal Winds and TIDs

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Introduction

This study presents the first lidar observations of regular occurrences of mid-latitude thermosphere-ionosphere Na (TINa) layers over Boulder (40.13°N, 105.24°W), Colorado.

The meteoric metal layers are of great interest scientifically because:

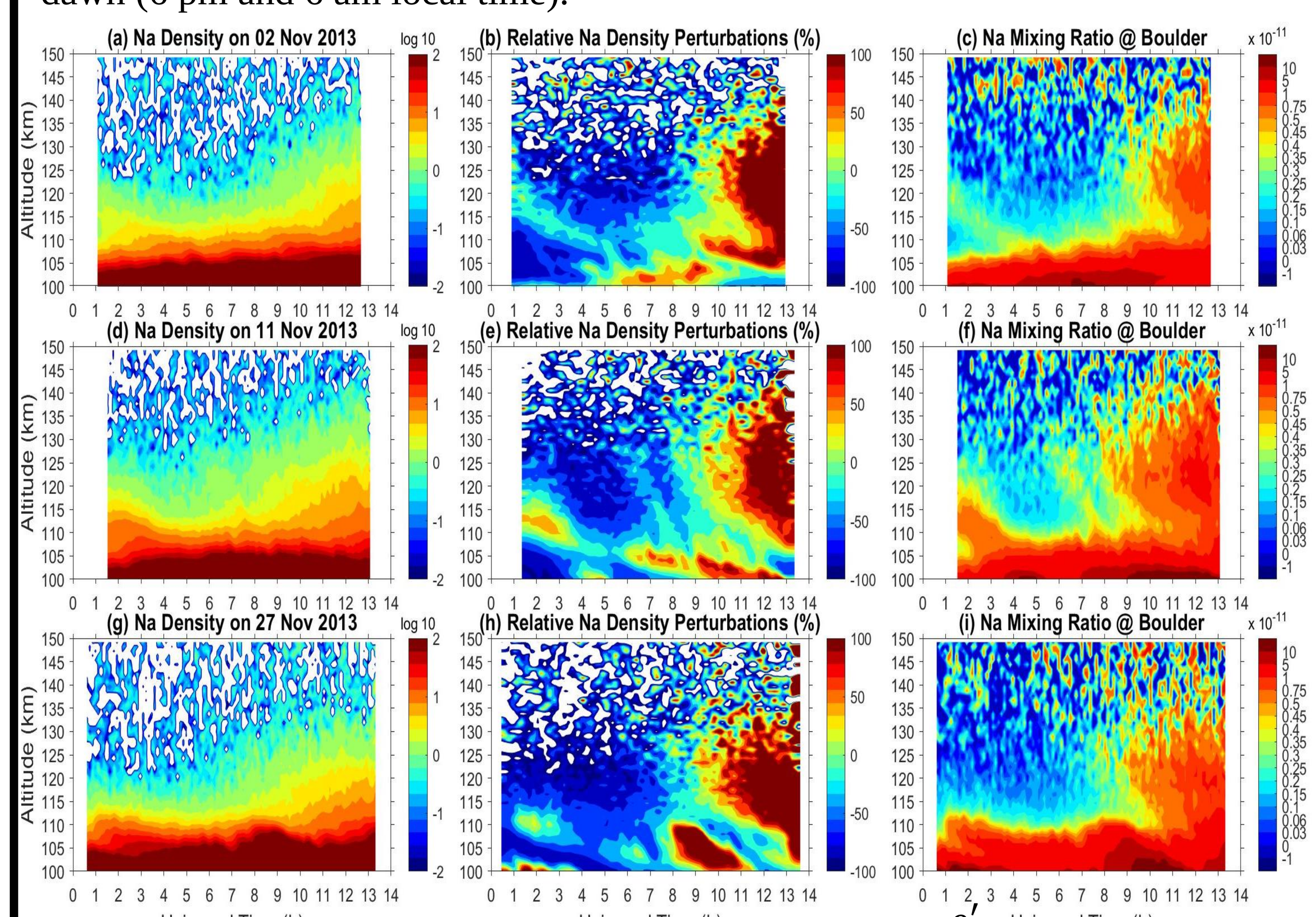
1. They are excellent tracers for profiling temperatures and winds along with various waves in the mesosphere and thermosphere.
2. They are a natural laboratory for exploring upper atmospheric composition, chemistry, dynamics, energetics, and electrodynamics.
3. They provide information on cosmic dust input flux, entry velocity, and composition in terrestrial and other planetary atmospheres.

Resonance fluorescence lidar is an effective tool for studying meteoric metal layers in the upper atmosphere. The main layer of metal atoms (75–105 km) have been observed from the ground for nearly a century, but neutral metal layers in the thermosphere were not discovered until Chu, Yu, et al. (2011) reported the first lidar observations of thermosphere-ionosphere Fe layers from Antarctica. Since then, thermosphere-ionosphere metal (TIMt) layers have been reported from high to low latitudes, including Fe, Na and K layers.

Observations of TINa layers (100–150 km) have opened a new door to advance understanding of fundamental processes in the space-atmosphere interaction region, especially in the E–F regions where measurements of the neutral atmosphere are scarce and plasma-neutral interactions are rich.

Boulder TINa dusk and dawn layers

TINa layers (~0.1–1 cm^{-3}) up to 150 km detected by high-sensitivity Na lidar exhibit dusk and dawn layers with downward phase. Note that 7 UT corresponds to midnight in Boulder, while 1 and 13 UT correspond to dusk and dawn (6 pm and 6 am local time).



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

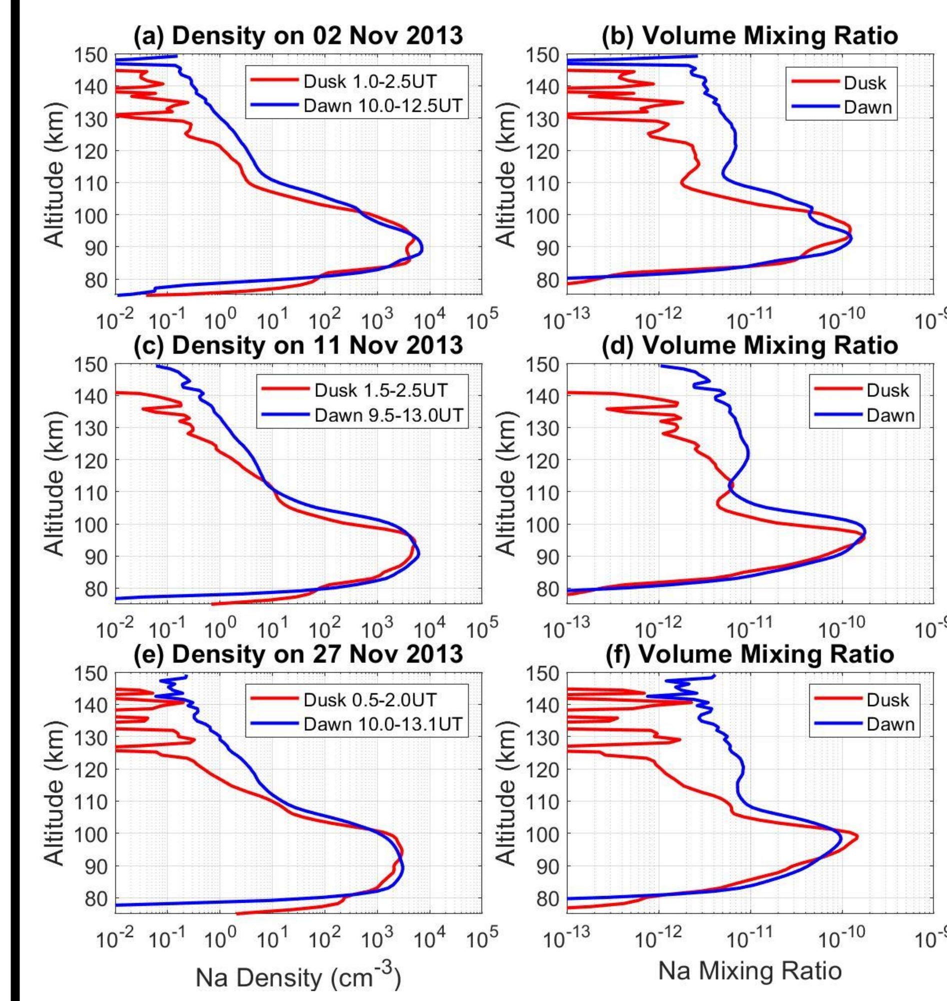
ρ'_{Na} = Na density - nighttime average Na density profile

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

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

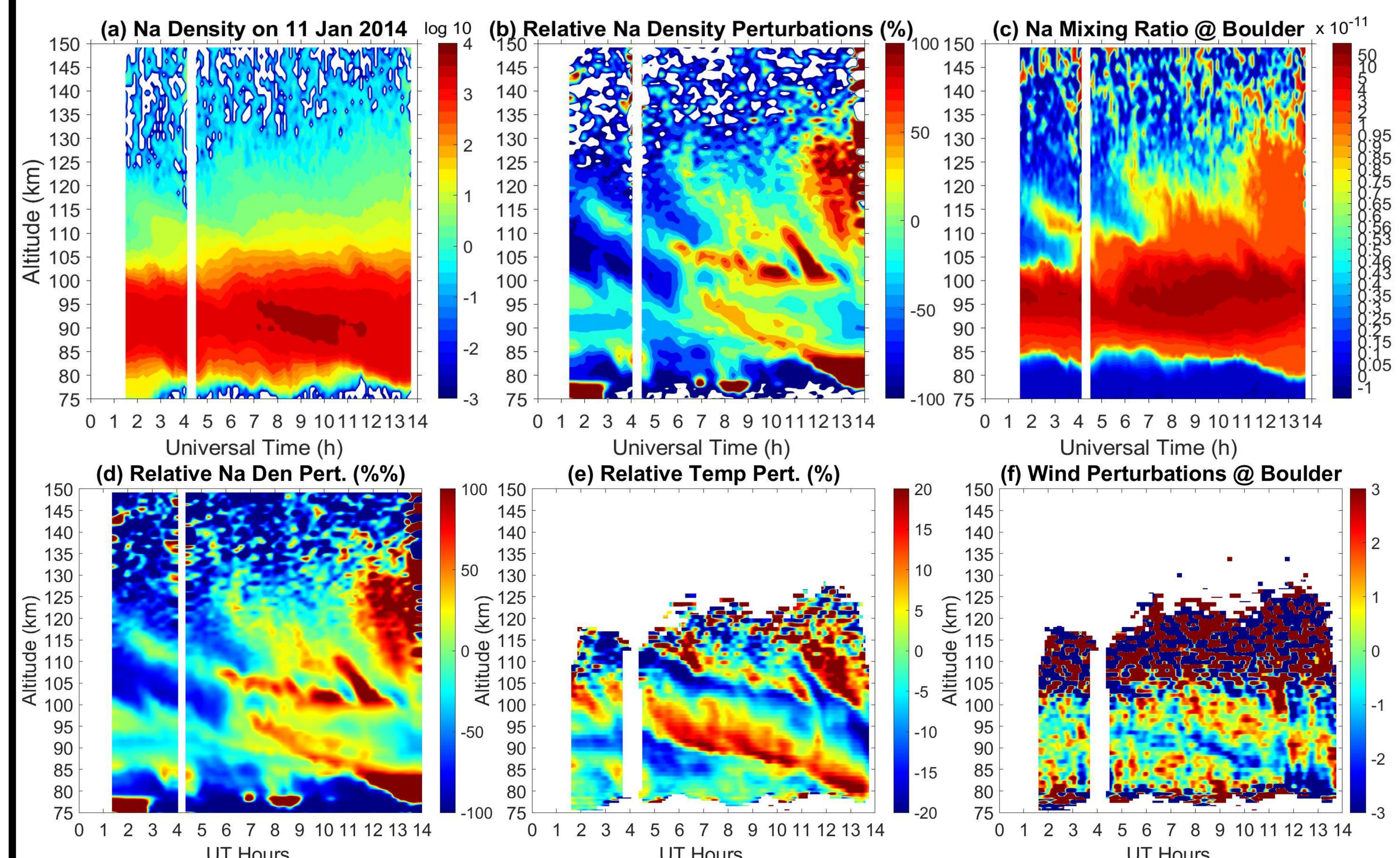
- The TINa dawn layer exhibits ascending features in the envelope of Na total density (e.g., Figure (a)) from 8–9 to ~12UT but descending features in the maximum mixing ratio (e.g., Figure (f)) from ~140–150 km at ~10–11UT to ~120–110 km at ~12–13UT.
- Dawn layer is observed every night if observation time is sufficient.
- The TINa dusk layer begins to descend from ~125–120 km to ~110 km at 1 UT and merges with the main metal layer near 4 UT.
- **Between dusk and dawn layers, some midnights (e.g., 11 Nov 2013) show a third layer, while other nights (e.g., 2 Nov 2013) do not appear.**

Quantification of dusk/dawn layers



- Na density profiles, and the volume mixing ratio profiles are plotted in log-10 scales for the dusk and dawn layers.
- The density profiles of dawn layers show a turning point around 110 km, above and below which the slopes are different. Correspondingly, the volume mixing ratio exhibits a broad peak above ~110 km.
- Dusk layers exhibit a narrower mixing ratio peak above its density slope turning point that is usually several kms lower than that of the dawn layers.
- **Such increased mixing ratios provide strong evidence for in-situ production of Na above the turning point (~105–110 km) for both the dusk and dawn layers.**

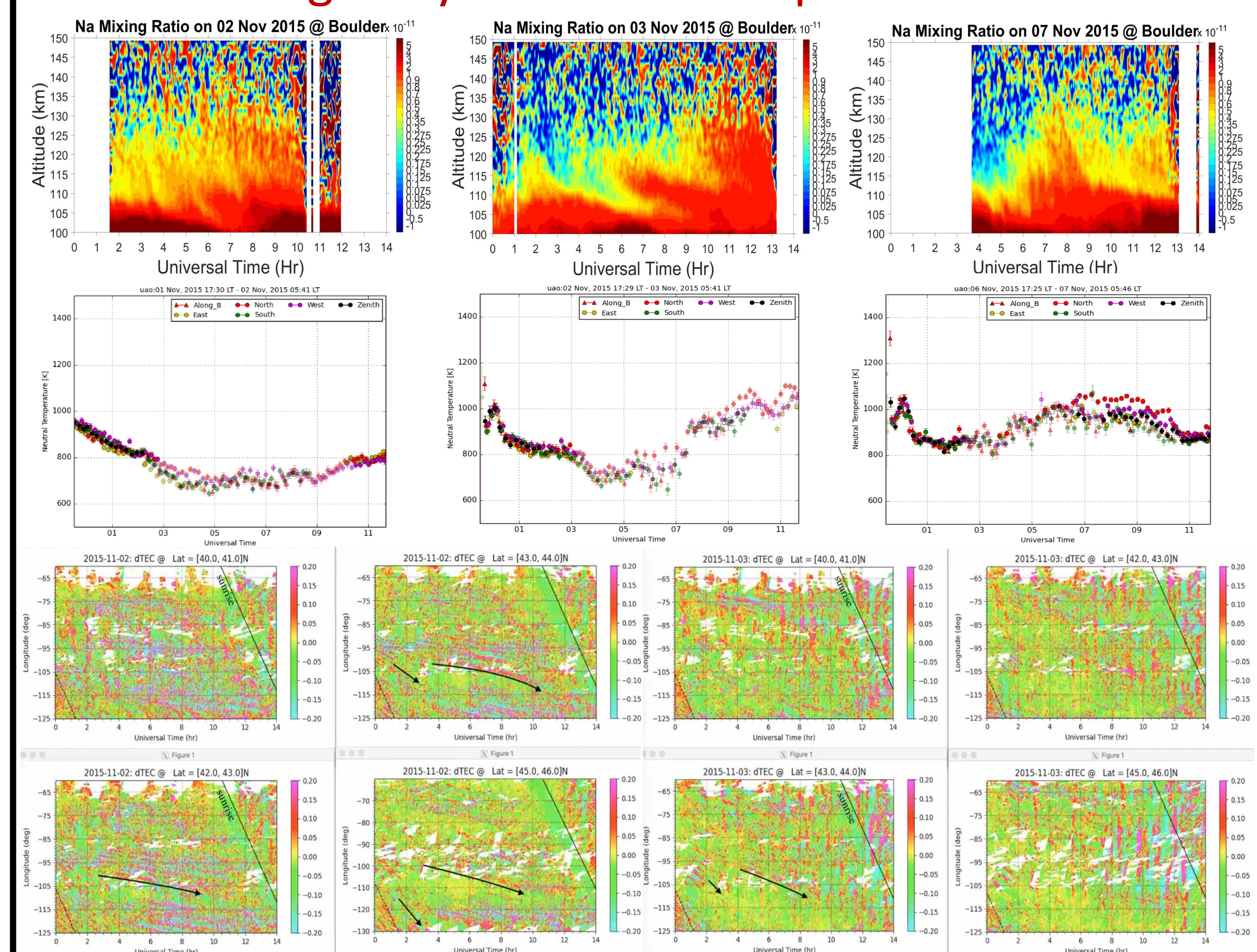
TINa dusk/dawn layers' relationship to tidal winds



Full range (75–150 km) contours of Na density, relative density perturbation, volume mixing ratio, relative temperature perturbation and wind perturbations on 11 January 2014 over Boulder (40.13ºN, 105.24ºW).

- **Dawn/dusk layers are likely to be correlated with semidiurnal tides over Boulder because of the downward-progression phase speeds.**
- Vertical phase speed roughly estimated by tracking the maximum mixing ratio is ~10 km/h, translating to ~2.7 m/s, which is a typical semidiurnal tidal phase speed from 130–150 km (Friedman et al., 2013). The dusk layer is narrower in time span and has a slower vertical phase speed of ~1.3 m/s, which is consistent with average semidiurnal tidal phase speed from 105 to 120 km (Friedman et al., 2013).
- **Three different layers occur overnight on 11 Jan 2014 including TINa dusk, dawn and midnight layers.**
- As shown in relative temperature perturbations and wind perturbations, the terdiurnal tide wave structure found is likely related to the midnight layers.

TINa midnight layers' relationship to MTM and TIDs



Na volume mixing ratio plotted in uneven color scales; neutral temperature obtained from UIUC's Fabry-Perot Interferometer website and dTEC image observed by GPS satellites above Boulder (40.13ºN, 105.24ºW).

- Occasional **midnight layers can be related to strong TIDs** (Traveling Ionospheric Disturbance) observed in TEC (Total Electron Content).
- Midnight TINa layer often occurs simultaneously with the **neutral midnight temperature maximum (MTM)**.

✓ TEC measurements show there is a mesoscale TID propagating in the zonal direction on 02 and 03 Nov 2015 when the midnight TINa layer occurs. The slow westward trending TID signal shown in TEC plots are likely to correlated with electric dynamics (plasma instability).

✓ MTM can be related to the midnight TINa layer because both TINa layers and thermospheric temperature are maximized near midnight. The MTM happening from 5 to 8 UT on 03 Nov 2015 perfectly corresponds to the TINa layer descending from ~125–120 km to ~110 km around midnight. More evidently, strong MTM makes temperature increase after 5 UT on 07 Nov 2015 while midnight layers reach high altitude.

Conclusions

New discoveries of Boulder TINa layer interactions with tidal winds, MTM and TIDs provide a great opportunity to study the plasma-neutral coupling and fill some data gaps of ICON mission. Boulder TINA layers indicate that thermospheric metal layers are likely a global phenomenon, providing potential tracers for exploring the properties of the space atmosphere integration region, especially around altitudes of 100–200 km.

1. TINa layers (~0.1–1 cm^{-3}) up to 150 km detected by high-sensitivity Na lidar exhibit dusk and dawn layers with downward phase.
2. Increased Na mixing ratios provide strong evidence for in-situ production of Na above the turning point (~105–110 km) for both the dusk and dawn layers.
3. Dawn/dusk layers are likely to be correlated with semidiurnal tides, while terdiurnal tides are likely the cause of midnight layers.
4. Midnight layers can be related to strong TIDs and MTM.