First Characterization of Pre-Dawn Thermosphere-Ionosphere Na (TINa) Layers and Their Correlations with Sunrise Time Using 7 Years of Lidar Data over Boulder

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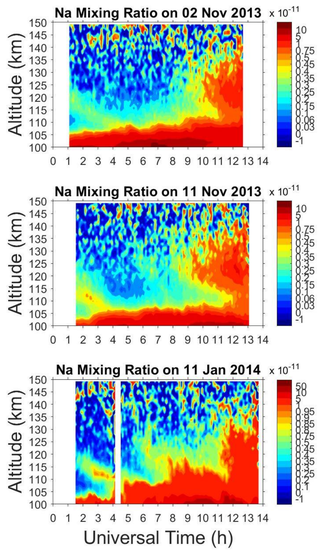
Abstract: We report a new discovery—the positive correlation of thermosphere-ionosphere Na (TINa) layers with sunrise time using 7 years of high-sensitivity lidar observations over Boulder (40.13°N, 105.24°W). Despite their tenuous densities, the University of Colorado Boulder STAR lidar observations reveal pre-dawn TINa layers have nearly 100% occurrence rate (160 out of 164 nights of observations). These TINa layers provide tracers to study plasma-neutral coupling in the E to lower F region.

First Discovery: TINa Regular Occurrence

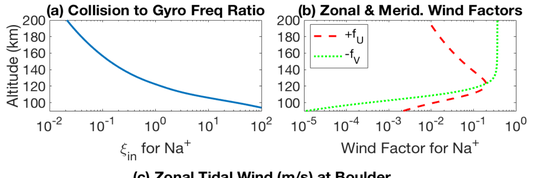


Thermosphere-ionosphere metal (TIMt) layers provide tracers to study fundamental processes in the space-atmosphere interaction region, especially in the E–F regions where measurements of neutrals are scarce but plasma-neutral interactions are rich (Chu et al., 2020).

Nearly 50 years of lidar observations showed only irregular occurrence of TINa layers from a few locations. Then in 2021, the first discovery of regularly occurring mid-latitude TINa layers was made over Boulder, enabled by the combination of **high detection sensitivity** of lidars and creative data processing techniques (**volume mixing ratio** calculations). Boulder TINa layers are studied further in this report.

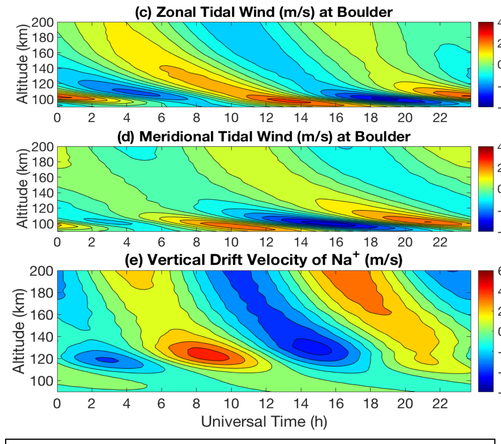
[Chu, Chen, et al., GRL, 2021]

Proposed Formation Mechanism



ξ: ratio of ion-neutral collision freq. to gyro freq. of Na^+

θ_D: dip angle



$$f_U = \frac{\xi cos\theta_D}{1+\xi^2}$$

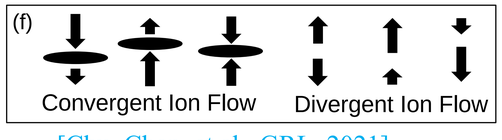
$$f_V = -\frac{\sin(2\theta_D)}{2(1+\xi^2)}$$

Direct Recombination

$Na^+ + e^- \rightarrow Na + h\nu$

Dissociative Recombination

$Na^+ \cdot X + e^- \rightarrow Na + X$
$(X = O, N_2, CO_2)$

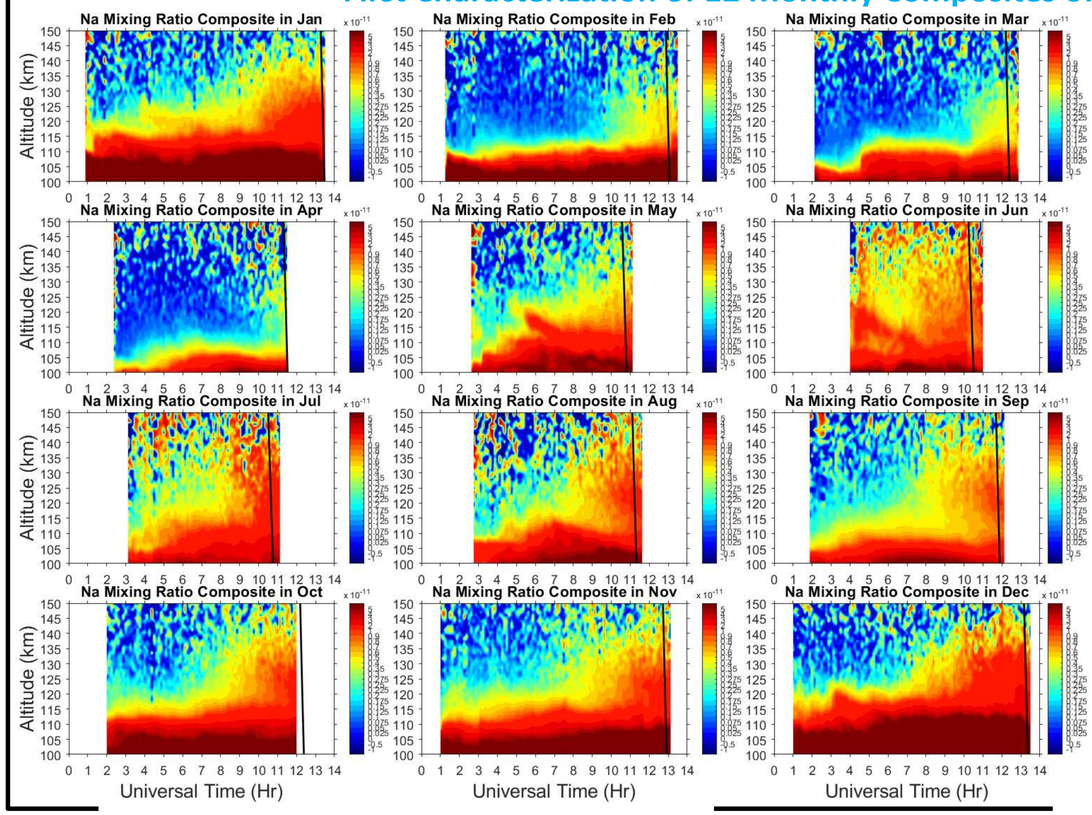


[Chu, Chen, et al., GRL, 2021]

Vertical drift velocity of $TINa^+$ calculated with ICON HME tidal winds (Immel et al., 2018; Cullens et al., 2020) shows convergent flow phases aligned well with Boulder TINa.

This work was supported by grants of NSF/AGS-1452351, AGS-2029162, OPP-1443726 and NASA 80NSSC21K1776.

First Characterization of 12 Monthly Composites of TINa Dawn Layers

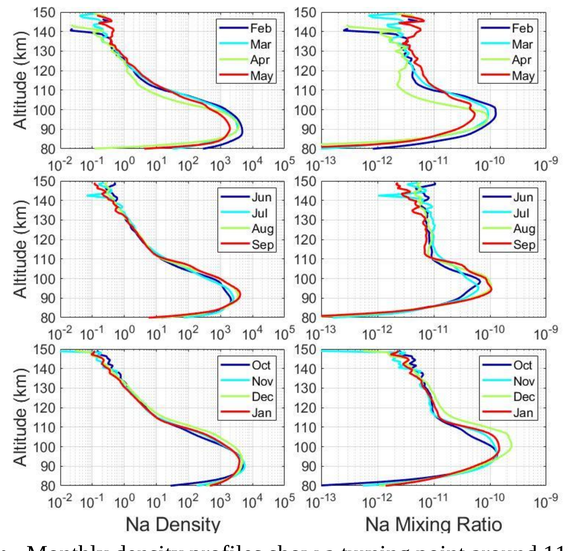


- ❖ With the nearly 100% occurrence rate (160 out of 164 nights of observations), the regular occurrence of pre-dawn TINa layers can be decisively confirmed at mid-latitudes.
- ❖ Based on the regularly occurring Boulder TINa dawn layers, the TINa mixing ratio composite contours are calculated in 12 different months from 7 years of lidar data.
- ❖ That is, averaging Na mixing ratio in the same local time (LT) and at the same altitude bin within the same month.
- ❖ **Downward phase progression** can be seen clearly each month before dawn, descending from ~150 km to 110 km, which decisively confirms that some coherent structures play important roles in the layer formation.
- ❖ Such pre-dawn TINa layers appear to be **positively correlated with sunrise time**. Black solid lines in those plots are the sunlit altitudes at sunrise.

Peak phase time of pre-dawn TINa layers versus sunrise time are shown below for different altitudes. Seasonal variations of peak phase time show strong positive correlation with sunrise time through all 12 months of a year.

Does such discovery mean that tidal wind phase at midlatitudes also has seasonal variations following the sunrise time?

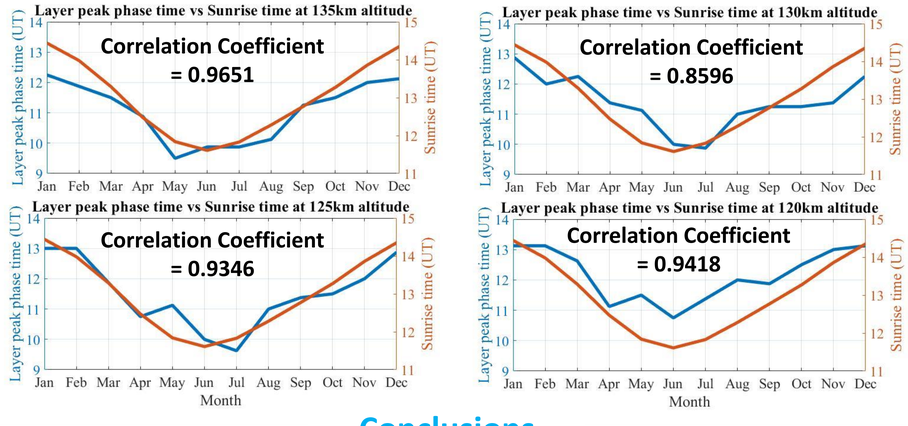
Quantification of TINa Dawn Layers



Monthly-mean Na density and volume mixing ratio profiles are plotted in log-10 scales for all qualified dawn layer cases through all 12 months.

- Monthly density profiles show a turning point around 110 km, while monthly mixing ratio profiles exhibit a broad peak above ~110 km.
- Monthly mean results from 7 years of lidar data provide strong evidence for in-situ production of Na above the turning point (~105–110 km) for dawn layers.

TINa Correlation with Sunrise Time



Conclusions

1. Monthly composite contours show clear downward phase progression of the pre-dawn TINa layers through all 12 months of a year at this mid-latitude site, which decisively demonstrates the regular occurrence of Boulder pre-dawn TINa layers.
2. Nearly 100% occurrence rate and positive correlation with sunrise time suggest periodic factors dominating pre-dawn TINa formation, e.g., tidal winds or E-field.
3. Such TINa layers provide a unique tracer to probe the neutral atmosphere and its coupling with plasma in the E to lower F regions.