Numerical Investigation on tidal and gravity waves contribution to the summer time Na density variations in mid latitude E region

Xuguang Cai[1,2] Tao Yuan[1,2] Vince Eccles[3]

1 Center of Atmosphere and Space Science

2 Physics department USU

3 Space Environment Coporation,Logan,Utah,USA

Abstract

In this paper, we investigate the tidal and gravity waves effects on the summer time (June) Na density variations in mid-latitude E region (95-130 km) by running an one-dimensional numeric model. The model simulates the Na ion-molecular chemistry within a background atmosphere modulated by tidal and gravity waves. The neutral atmosphere is generated in a unique hybrid model that combines HAMMONA (Schmidt et al., 2006) and CTMT (Oberheide et al., 2011) models. In order to investigate the extreme large tide amplitude effects, we run the model with 1x and 5x CTMT tide amplitude, respectively. Then we compare our simulated result with the observed average full-diurnal cycle Na density by USU Na Lidar. The comparison reveals that the results below 100 km are similar, while the results above 100 km are very different. The gravity wave is also added on the 1x tidal condition to test how gravity wave propagation and saturation influencing Na density. In addition, we also run the model to test the effect of transports, chemistry and eddy diffusion. We find that vertical wind transport contributes the most to the Na structure in E region. Above 100 km, the Na ion-molecular chemistry, combined with photo-chemistry, mainly works to decrease Na density, while the eddy diffusion also modulates the Na density temporally and spatially.

1. Introduction

The mechanisms that drive the summer time Na density variations in lower E region is still not understood after decades of experimental observations and model developments.

Here we investigate how Na is influenced by tide/gravity waves by running classic Na chemistry model [Plane 2004] with dynamic modifications

2. Numeric Framework

$$\frac{\partial N_M}{\partial t} = S_M + P_M - L_M - \nabla \bullet \left(N_M \vec{v} \right)$$

Following Plane et al [2004], we set the changing rates of all other species to zero, except those for Na, Na^+ and $NaHCO_3$.

For diffusion, only vertical direction is included

For neutral transport

$$v_n = u - k_{zz}\left(\frac{1}{H} + \frac{1}{T}\nabla T + \frac{1}{N_M}\nabla N_M\right) - D_M\left(\frac{1}{H_M} + \frac{1}{T}\nabla T + \frac{1}{N_M}\nabla N_M\right)$$

$$D_M = \frac{kT}{m_M\left(v_{in} + v_{nn}\right)}$$ **Banks and Kockarts, [1973]**

For ion transport, from Schunk and Nagy, [2009]

$$\nabla p - nmG - en\left(v_i \times B\right) = -nm\nu_{in}\left(v_i - u\right)$$

$$B = B\left(0, \cos I, -\sin I\right)$$

Vertical transport: flux-corrected algorithm and diffusion

Horizontal transport: $v_x \frac{dN_M}{dx} + N_M \frac{dv_x}{dx} + v_y \frac{dN_M}{dy} + N_M \frac{dv_y}{dy}$ **No diffusion**

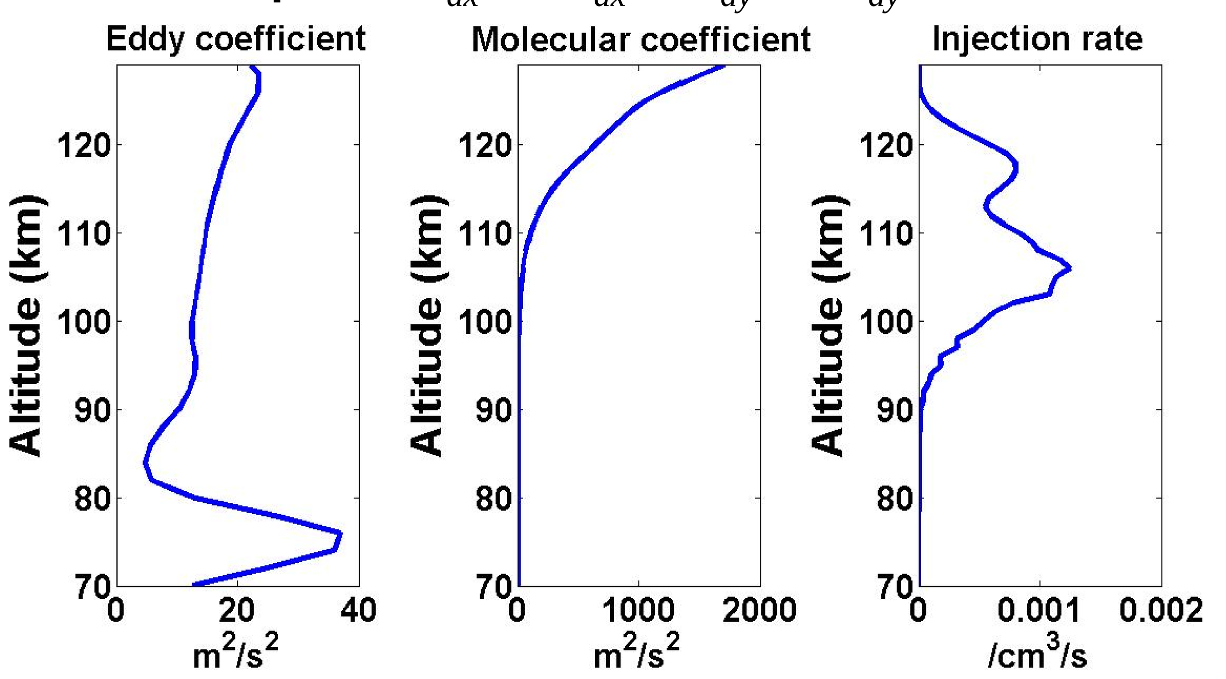

Figure.1 left) Eddy diffusion coefficient, middle) Molecular diffusion coefficient and right) injection rate

3. Tide and Gravity Waves

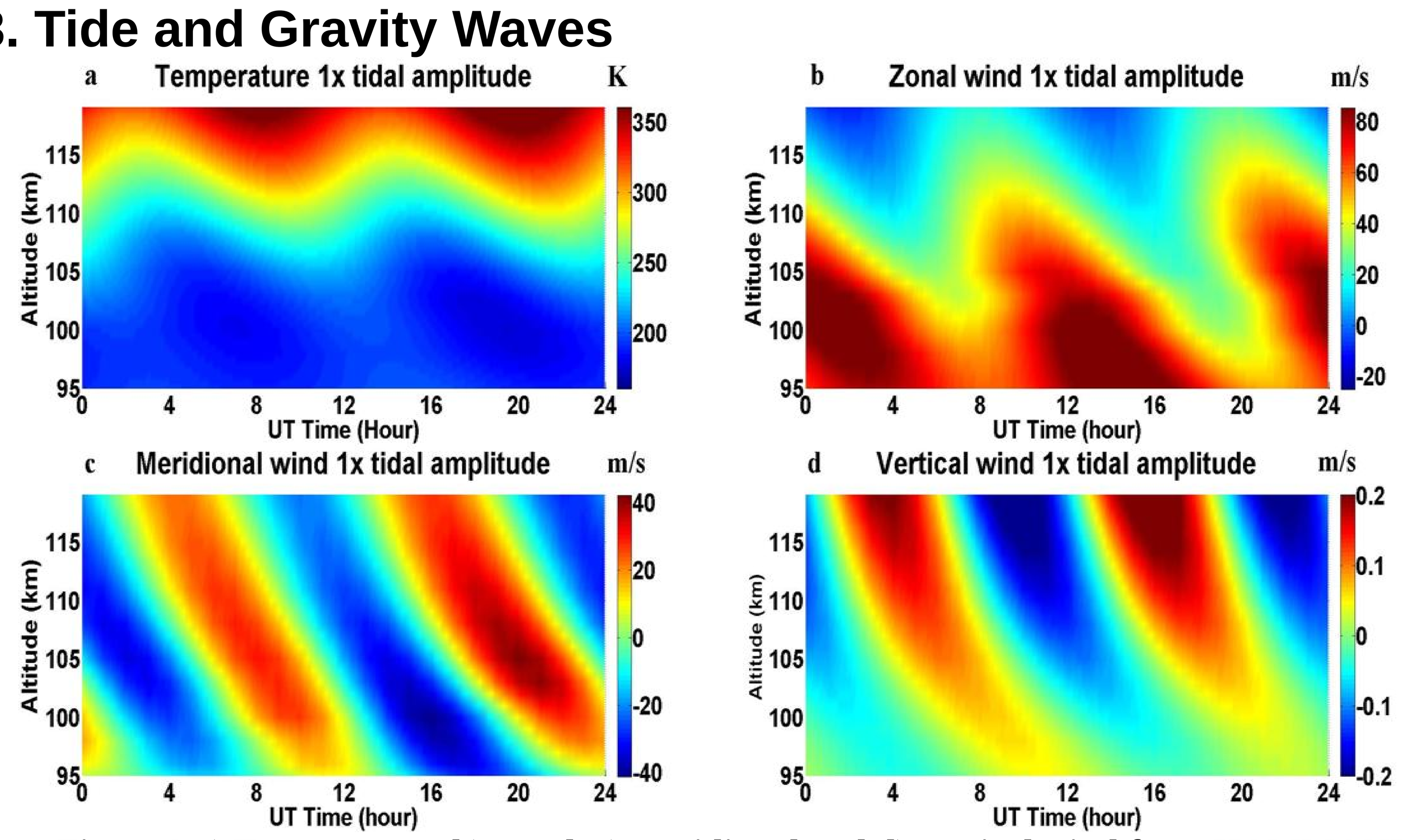

Figure.2 a) Temperature, b) zonal, c) meridional and d) vertical wind from HAMMONIA and CTMT

For gravity waves, middle frequency gravity wave dispersion relationship [Fritts and Alexander, 2003] is used

$$m = \frac{N}{\bar{u} - c}$$

$$w' = A\exp((z - z_0)/2H) \bullet \cos\left(k_H x + m\left(z - z_0\right) - k_H ct\right)$$

$$T' = -i * u_H' * N * \bar{T}/g \qquad u_H' = -mw'/k_H$$

Only consider convective instability, when GW amplitude is large enough to cause $N^2 < 0$, then it becomes saturated and enhances the background eddy diffusion [Fritts, 1984]

$$w' = w_s'\exp(-mi(z - z_0)) \qquad mi = \frac{1}{2H} - \frac{3}{2}\frac{\partial\bar{u}/\partial z}{\bar{u} - c}$$

$$k_{zz} = \frac{k(u - c)^4}{N^3}\left(\frac{1}{2H} - \frac{3}{2}\frac{\partial\bar{u}/\partial z}{\left(\bar{u} - c\right)}\right)$$

4. Simulation Results

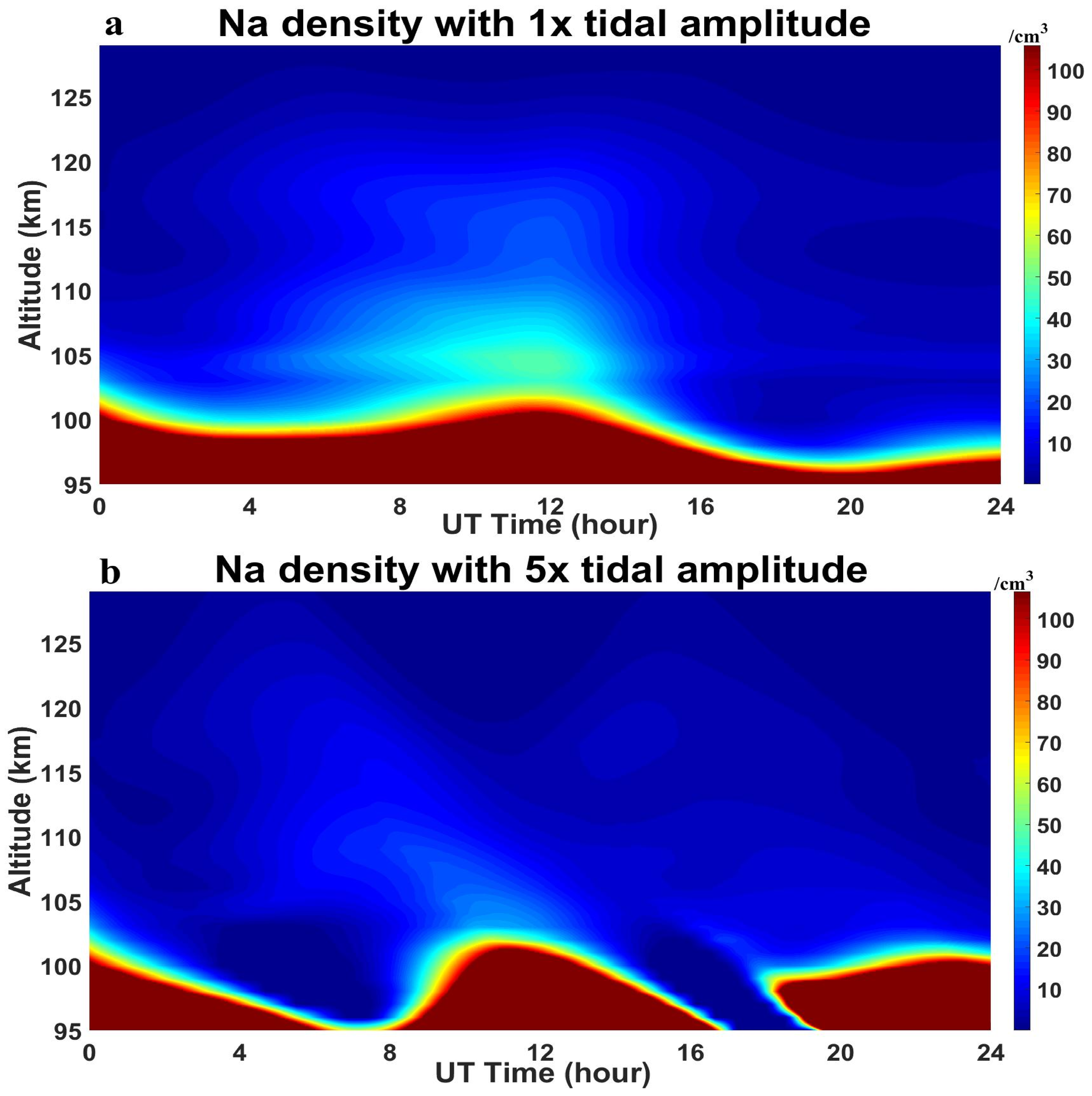

Figure. 3 Na density with a) 1x and b) 5x tidal amplitude

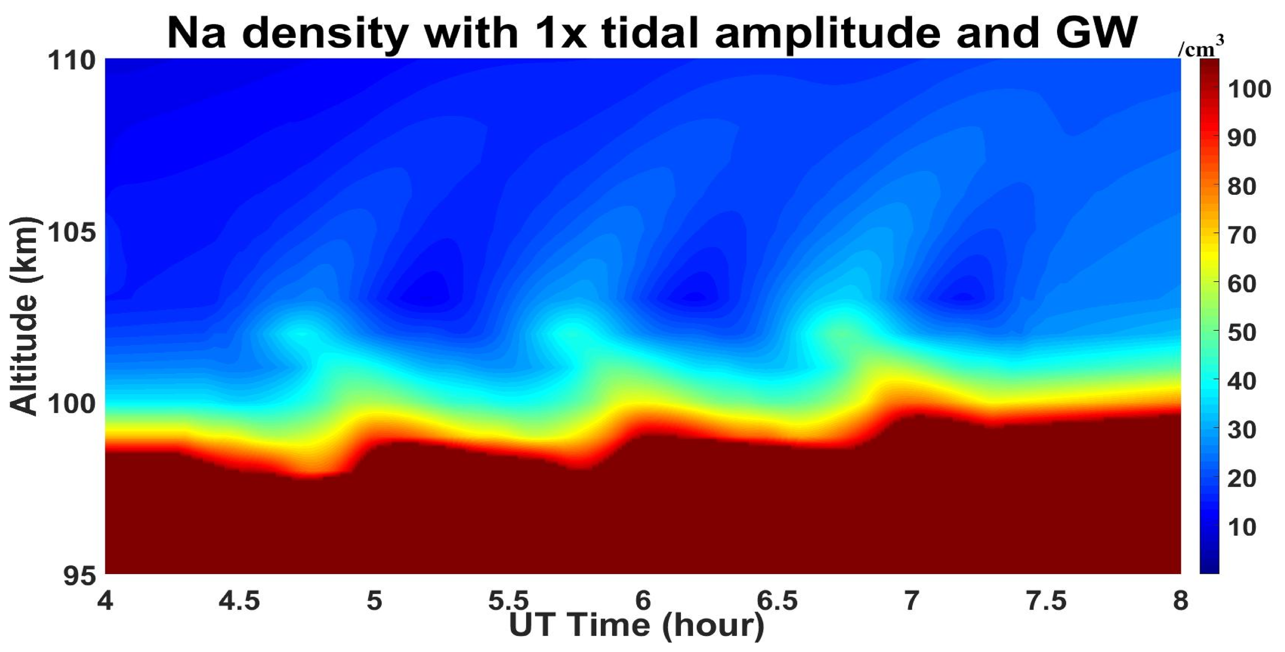

Figure. 4 Na density with 1x tidal amplitude and gravity wave

GW: 1-hour 80m/s horizontal phase speed, continue for 3-hour, north direction, saturated above 103km, with largest amplitude 0.78 m/s in vertical wind.

5. Comparison between observation and simulation

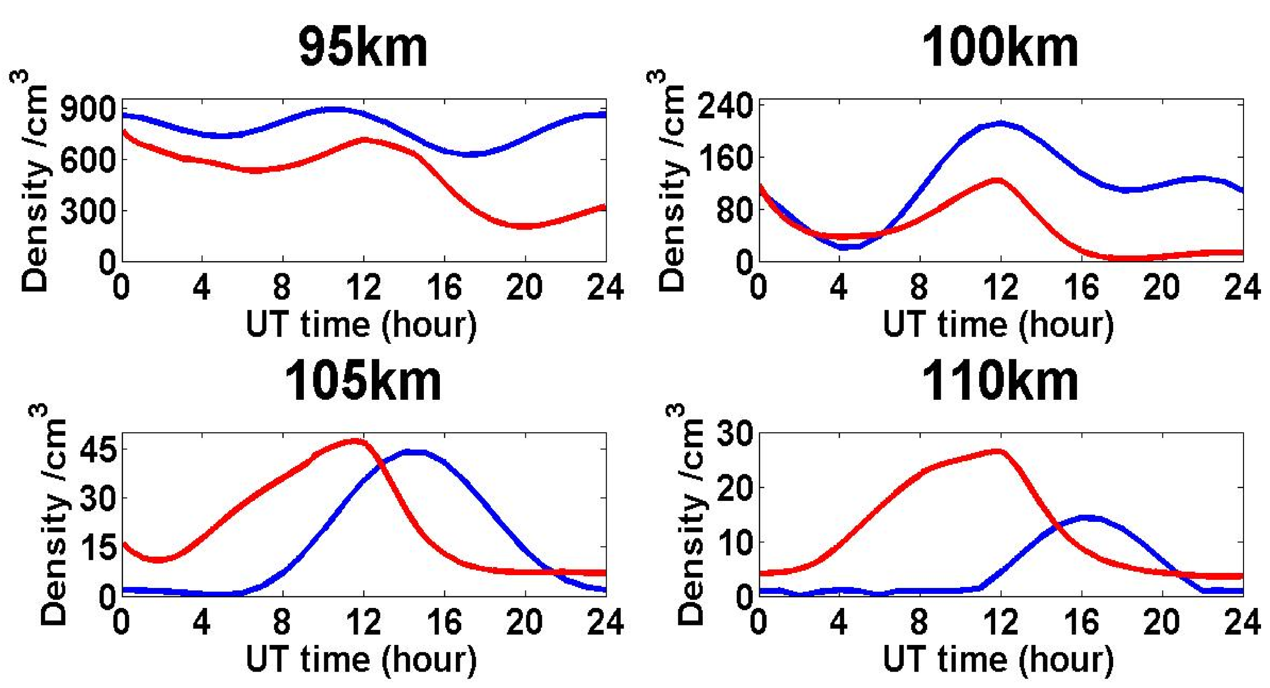

Figure 5 Comparison of Na density of observation and a) 1x and 5x) simulation at 95km, 100km, 105km and 110km

6. Test

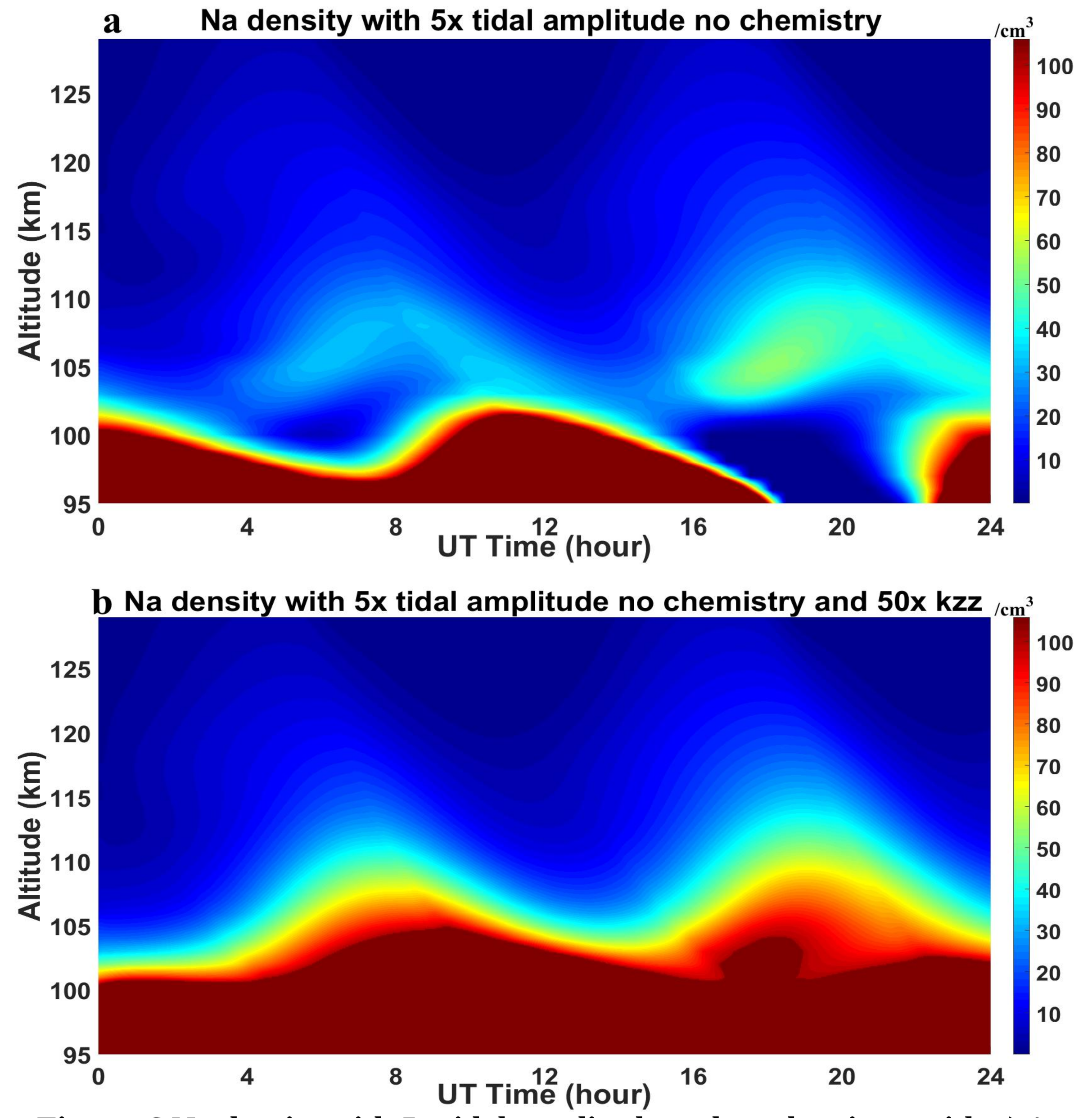

Figure. 6 Na density with 5x tidal amplitude and no chemistry with a) 1x and b) 50x eddy coefficient

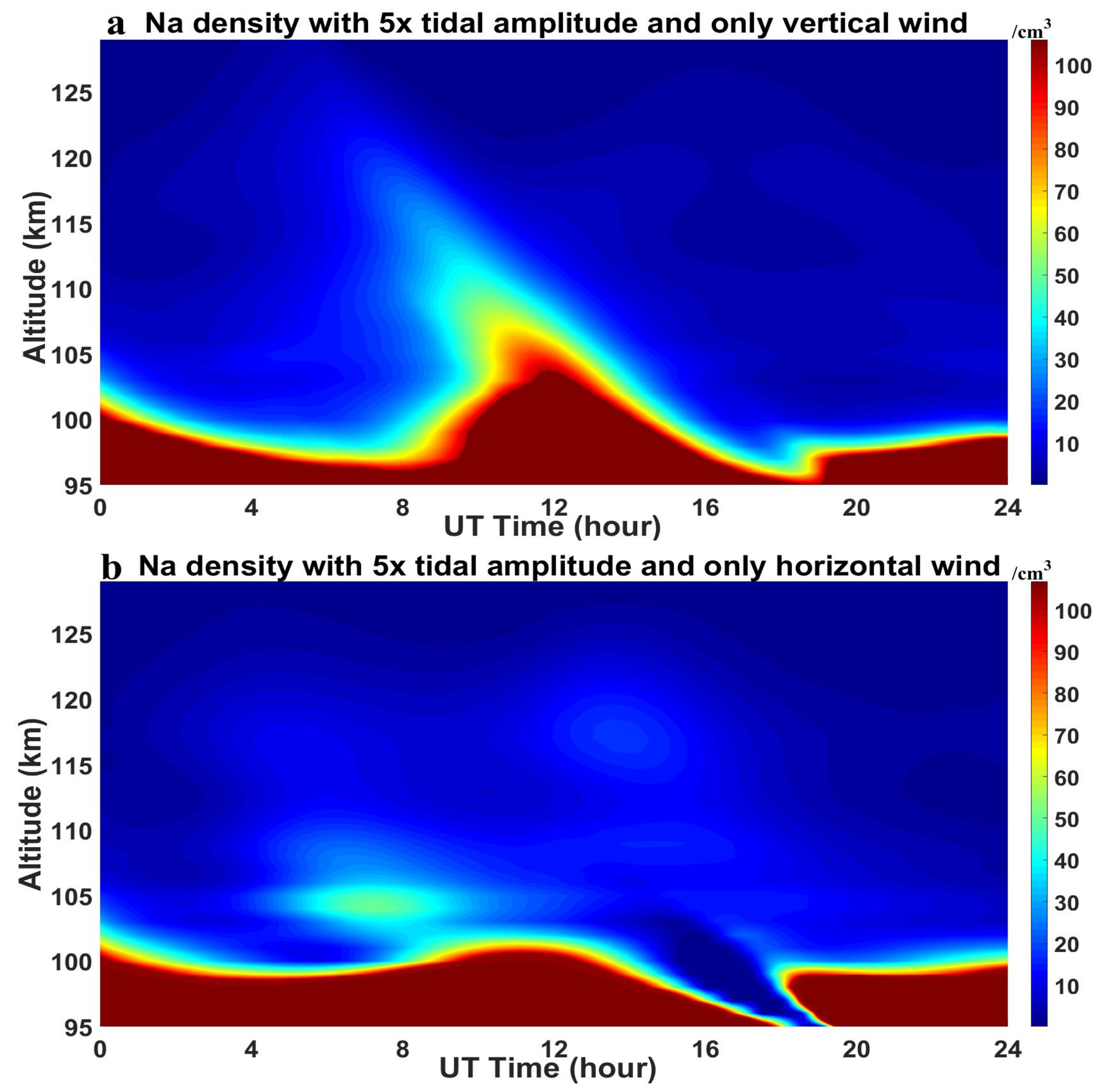

Figure. 7 Na density with 5x tidal amplitude together with a) vertical transport only and b) horizontal transport only

7. Conclusion

1. For the comparison between observation and simulation, the results agree relatively better below 105 km, while they are much different above 105 km. In the night, the observed Na above 105 km is low, which means there may exist some important mechanism that removes the Na density during night above 105 km.

2. From the simulation, the Na density structure in E region is mainly determined by both vertical transport and the horizontal transport, which is same order of magnitude. Large vertical transport can push Na up to 125 km, while large horizontal transport can only enlarge Na density below 105 km

3. Eddy diffusion coefficient can modulate the Na density structure spatially and temporally, and even inverse the Na density phase line (extreme large eddy when GW saturation). Large eddy diffusion will prevent Na atom from converging.

4. For Na chemistry, it increases Na density below 100 km, especially from 20:00 UT to 24:00 UT, but decreases Na density above 100 km.

Note: The model is not self-consistent due to the assumption of other species constant and the simplified horizontal transport.

Reference

Banks and Kockarts. (1973), *Aeronomy, part A*, Academic Press, New York.

Plane, J. M. C. (2004), A time-resolved model of the mesospheric Na layer: Constraints on the meteor input function, *Atmos. Chem. Phys.*, *4*,627–638, doi:10.5194/acp-4-627-2004.

Schunk, R.W., A.F. Nagy (2009) Ionospheres: Physics, Plasma Physics, and Chemistry Cambridge University Express, Cambridge, England.

Oberheide, J et al. (2011), Climatology of upward propagating diurnal and semidiurnal tides in the thermosphere, J. Geophy. Res.,116, A11306, doi:10.101029/2011JA016784.

Schmidt, H. et al. (2006), The HAMMONIA chemistry climate model: Sensitivity of the mesopause region to the 11-year solar cycle and CO2 doubling, J. Climate, 19, 3903-3931.