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

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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 HAMMONIA (Schmidt et al., 2006) and CTM (Oberheide et al., 2011) models. In order to investigate the extreme large tide amplitude effects, 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 Na density variations in mid-latitude E region (95-130 km) by running an one-dimensional Na ion-molecular chemistry, combined with photo-chemistry, mainly works to decrease 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
Following Plane et al [2004], we set the changing rates of all other species to zero, except those for Na, Na+ and NaHCO3.
For diffusion, only vertical direction is included
For neutral transport
\[ \frac{\partial N}{\partial t} + \nabla \cdot (v_N N) = D_N \nabla^2 N \]
For ion transport, from Schunk and Nagy, [2009]
\[ \nabla \cdot (n_i v_i) = -n_i \nabla \cdot (v_i - u) \]
\[ B = B(0, cos \lambda, -sin \lambda) \]
Vertical transport: flux-corrected algorithm and diffusion
Horizontal transport: \[ \frac{\partial N}{\partial t} + \nabla \cdot (v_N N) = \frac{\partial}{\partial z} \left( \frac{D}{\rho} \frac{\partial N}{\partial z} \right) \]

3. Tide and Gravity Waves

4. Simulation Results

4.1 Na density with 1x tidal amplitude

4.2 Na density with 5x tidal amplitude

4.3 Na density with 1x and 5x tidal amplitude together with gravity wave

5. Comparison between observation and simulation

5.1 Comparison of Na density of observation and simulation at 95km, 100km, 105km and 110km

6. Test

6.1 Na density with 5x tidal amplitude no chemistry

6.2 Na density with 5x tidal amplitude no chemistry and gravity wave

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