

Spatial and Temporal Variabilities of Mesospheric Concentric Gravity Waves Revealed with a Space Borne Visible Spectroscopic Instrument

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Abstract

This thesis focuses on the spatial and temporal variability of concentric gravity waves (CGWs) in the mesopause region based on the O₂ A-band (762 nm) nightglow data obtained with IMAP/VISI. Atmospheric gravity waves (AGWs) have been studied intensively because of their major role in the atmospheric dynamics, such as transporting energy and momentum and interaction to the mean wind and thermal structure of the middle atmosphere. CGWs are one of the most distinct features of gravity waves, which show a direct coupling between lower and upper atmosphere. The past studies have revealed the general properties of CGWs, such as launching mechanism and effect of the background wind profile. However, these are mostly based on a single event, which give only local information. Thus, a statistical approach with space-based observations is ideal since they cover wider area globally and can measure atmospheric gravity waves without cloud obscuration.

For the data analysis, we used the airglow data measured with the Visible and near-Infrared Spectral Imager (VISI) of the IMAP mission on the International Space Station (ISS). IMAP/VISI was operated from October 2012 until August 2015 in the nightside hemisphere with geographical latitude range of $\pm 51^\circ$, measuring mainly three different airglow emissions of OI at 630 nm, the OH Meinel band at 730 nm and the O₂ (0-0) A-band at 762 nm at an altitude of ~ 400 km with the typical spatial resolution of 16 – 50 km.

The present study of CGWs is divided into two parts; the first part is a case study using the coordinated observations of IMAP/VISI and ground-based all-sky imager at Rikubetsu, and the second part is a statistical study on the global distribution and seasonal variability of CGW. Here we examined a partial CGWs case observed in northeastward of Japan on October 18, 2012. IMAP/VISI measured an arc-like shaped; partial CGWs pattern around the mesopause (~ 95 km) in the O₂ 762-nm airglow emission at 1204 UT. The maximum radius of CGWs was $\sim 1400 - 1500$ km. Similar patterns were also observed by the all-sky imager at Rikubetsu (43.5°N , 143.8°E) in OI 557.7-nm and OH-band airglow emissions from $\sim 1100-1200$ UT. Horizontal wavelengths of the observed small-scale gravity waves are ~ 50 km (OH-band and OI 557.7-nm) and ~ 67 km (O₂ 762-nm). From MTSAT and TRMM data the source is suggested to be a deep convective activity over Honshu island (33°N , 136°) which likely to be related to a typhoon in the south of Japan. Background winds and temperature on the propagation mechanism were analyzed with MERRA, Wakkanai MF Radar and SABER data. Using atmospheric temperature profiles, we conclude that this long-distance propagation of the waves could be caused by thermal duct in the middle atmosphere in the altitude range of 45 to 110 km. The zonal and meridional wind profiles could produce the arc-like shaped CGWs in which the wind filtering effect plays a role on the suppression of wave propagation in the particular direction.

We also conducted a statistical study using 235 CGWs events obtained from 3 years data of IMAP/VISI to clarify the spatial and temporal variability of CGWs in the mesopause. We found the horizontal wavelength ranging from 40 to 250 km and maximum radius of 200 to 3000 km, clearly demonstrating the fact that the small-scale gravity waves can travel for a long distance up to 3000 km. The zonally averaged latitudinal distribution of the CGWs occurrence maximized at mid-latitudes (40°N and 40°S) and minimized at low latitudes (10°S). It is interesting to note that more events were found in the summer hemisphere mid-latitudes, with a rapid transition between northern and southern hemisphere around the equinoxes. Occurrence probability of the CGWs was significantly high during non-solstice months (February-May and August–November) than solstice months (June-July and December-January), suggesting that they are able to survive breaking and critical level absorption in the middle atmosphere to reach the mesopause region more often during these periods. Information regarding localized regions of high CGW activities seen in the global map and the seasonal variability are useful for the future mesospheric and upper atmospheric studies.

別 紙

論文審査の結果の要旨

地球超高層大気と下層大気は、大気重力波等によりエネルギー上下結合することが知られているが、その因果関係や伝搬過程はよくわかっていない。本研究は、国際宇宙ステーション（ISS）に搭載された可視近赤外分光装置（VISI）観測データを用いて、中間圏界面（高度 95km）付近に存在する酸素原子 A-band(762 nm)大気光発光強度分布を求め、メソスケール大気重力波の水平分布を導出した。特に、大気重力波による上下結合の因果関係が明瞭とみなすことができる同心状大気光現象（CGW）に着目し、世界で初めて詳細なイベント解析ならびに統計解析を実施した。

イベント解析では、CGW を引き起こす大気重力波の上下結合過程を明らかにするために、2012年10月18日11UT付近に北海道東方で発生したアーク状CGWについて、ISS/VISIに加えて複数衛星と地上光学・レーダー同時観測データを用いて調べた。CGWの同心構造から決定された中心とTRIM・MTSAT衛星による対流圏降雨・対流活動の対応関係から、このソースは本州上空の活発な対流領域であることが示唆された。また、このソースとCGWとの距離は約1400 km 離れているが、この伝搬について稚内 MF レーダーや客観解析（MERRA）データならびに SABER 衛星データを用いて解析し、高度 45-110 km に存在したサーマルダクト効果で長距離伝搬が可能となったと解釈された。

さらに、大気重力波による上下結合のグローバルな時空間変動特性を明らかにするため、2013年から約3年間に観測された235例のCGWについて統計解析を行った。この結果、CGW構造の水平波長が40-250 km、半径が200-3000 km であること、また、発生頻度は中緯度に多く低緯度に少ないことが分かった。さらに、発生頻度は夏半球で高くなるものの、そのピークは夏至よりも2-3ヶ月前倒しし、北半球の場合は2-3月、南半球の場合は8-11月であることが示された。この事実について、GAIAモデルの風向・風速と温度分布を用いて、大気重力波の中層大気伝搬時におけるフィルター効果や破波について定量評価した。

この研究は、従来観測が難しかった中間圏現象について新たな知見をもたらし、また将来地球・惑星探査機光学観測にも示唆を与えるものである。また、査読付き論文も2件（うち1件は査読中）の成果が出ている。以上から、セプティ・ペルウィタサリは自立して研究活動を行うに必要な高度の研究能力と学識を有することを示している。したがって、セプティ・ペルウィタサリ提出の博士論文は、博士（理学）の学位論文として合格と認める。