Case study of a mesospheric wall wave event

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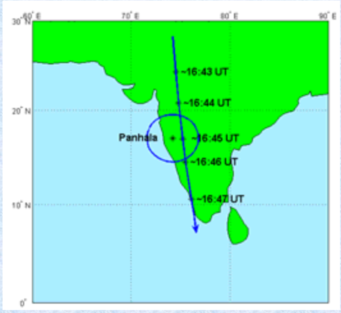
Abstract

Intense frontal features associated with gravity waves accompanying intensity variations in the airglow images were observed in the past and explained on the basis of mesospheric bore theory or wall wave theory. Most of such observational features were explained as mesospheric bores while wall wave interpretations are rare. On the night of Februay 2, 2008, airglow imaging observations made from Panhala (17ºN, 74.2ºE) showed signature of an intense gravity wave in OH, Na and OI green line emissions. Observations revealed passage of four frontal systems separated by ~325 km with an approximate time gap of ~100 minutes between passage of alternate bright and dark features. The intensity variations were nearly in phase between OH and Na images while out of phase with OI green line images. The first three fronts had horizontal extent covering entire field of view while the fourth one was relatively weaker and curved. The bright fronts (in OH and Na) showed evolution of phase locked trailing wave crests with ~15 to 25 km wavelength while the dark fronts (in OH and Na) were devoid of such features. The alternating bright and dark phases of the fronts appear to indicate the crests and troughs of a long period large amplitude gravity wave which might have given rise to evolution of short scale phase locked crests in certain occasions. Thus, this observation suggests possible generation of bores by means of wall wave perturbations. In this work we have discussed the characteristics of the event with background wind data from co-located MF radar and snapshot temperature measurements made by SABER instrument on board TIMED satellite. Also discussion on the probable source of the observed wave is made.

Schematic



Data and Analysis

✓All-sky imaging observations were carried out from Low latitude Indian station Panhala (17.0ºN; 74.2ºE) with ~2 nm bandwidth filters for OI greenline, sodium and background (at 572.3 nm) emissions, and a broad band filter covering 705 – 928 nm with a notch at ~865 nm for OH Meinel bands.

✓Images were flat-fielded, subtracted with long period average image and projected in to distance coordinates [*Garcia et al., 1997; Narayanan et al., 2009*]

✓An MF radar (operating frequency 1.98 MHz) located 20 km south of Panhala has provided useful wind information at every 2 km vertical spacing from 90 to 98 kms. There is no significant altitude variation between winds of 90 to 98 kms and hence their average is considered as background wind.

✓Snapshot temperature measurements made by SABER/TIMED over the locations shown in schematic are utilized to infer the temperature structure of the mesopause region during earlier hours of observation. The ~0.4 km vertically sampled raw data is subjected to 2km averaging at 1 km sliding intervals.

✓To access probable source of the observed wave event, visible (0.4 – 0.7 µm) and IR (10.5 – 12.5) images taken by Kalpana satellite are used.

✓Wind filtering effects up to about stratopause height are inferred with the UKMO assimilated wind.

Figure 1: All-sky images illustrating the fronts of the wall wave

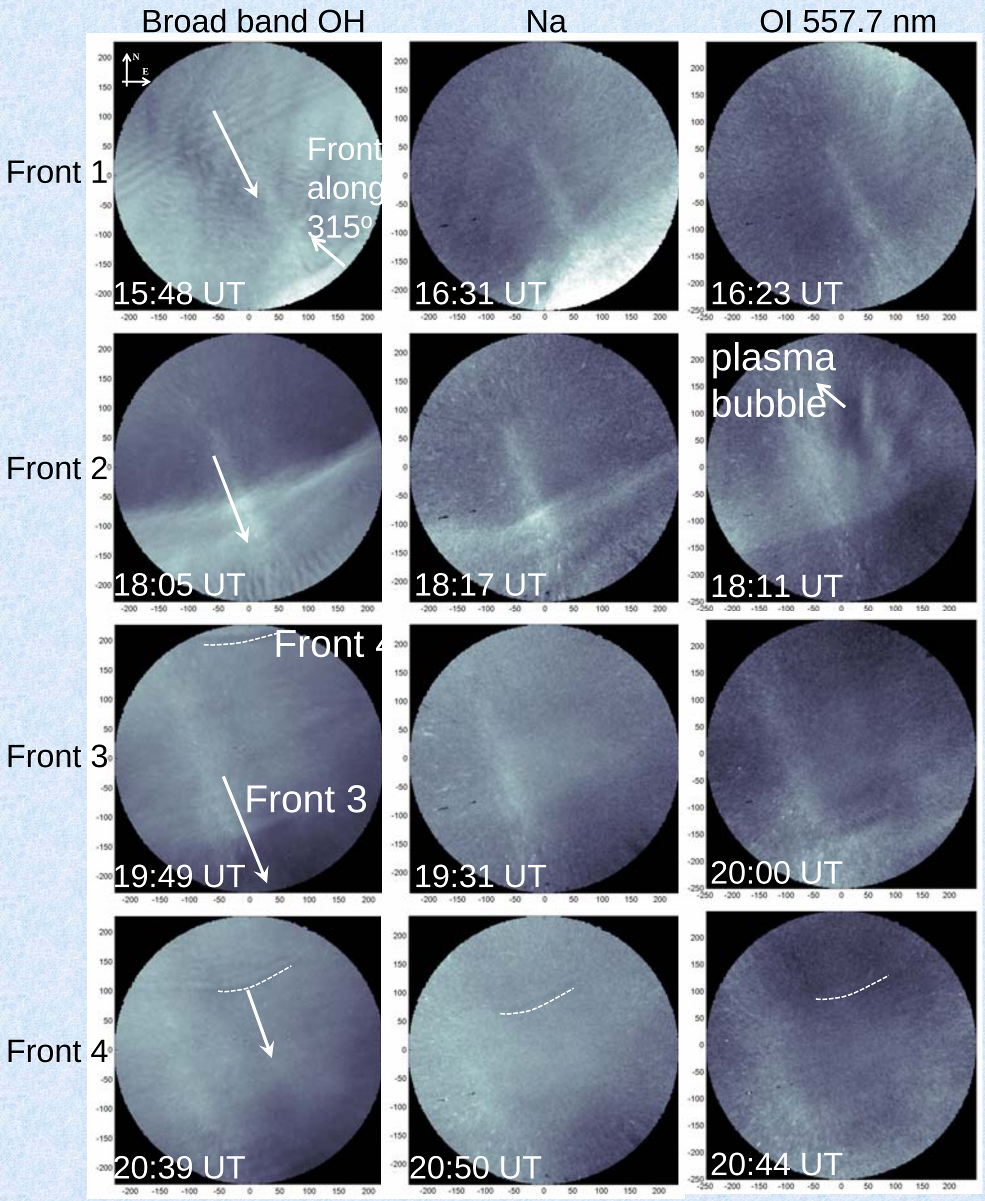


Figure 2: Background wind and temperature

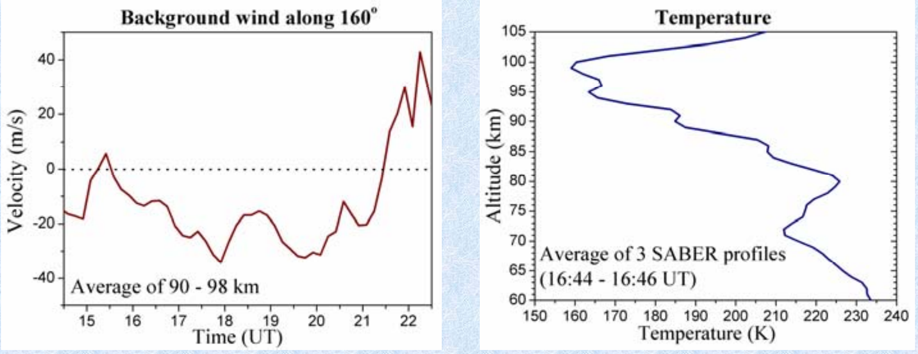


Figure 3: Probable source

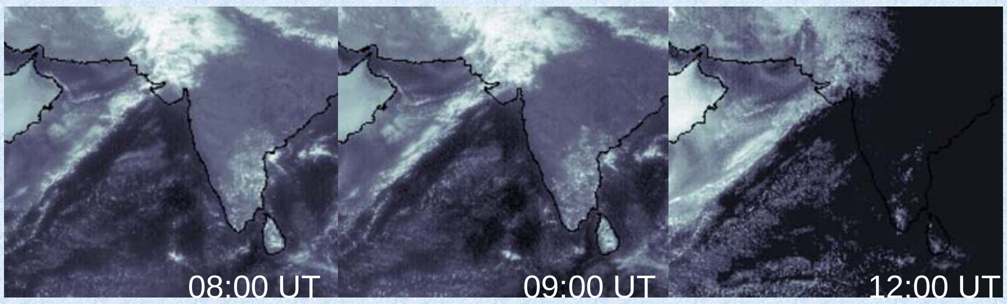
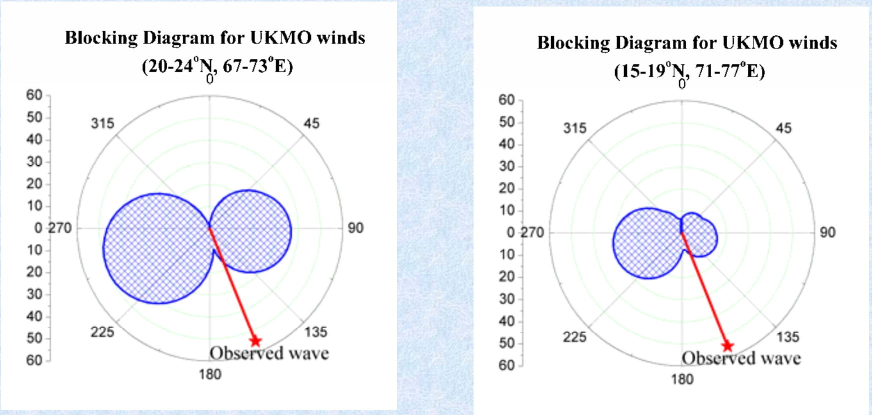


Figure 4: Wind filtering up to stratopause



Observations and discussion

➢On Feb 2, 2008, four prominent frontal features were observed in succession between 15:15 – 21:15 UT in mesospheric nightglow emissions. First and third fronts possessed trailing undulations while second front did not. Fourth front was relatively weak and curved with 2 – 3 undulations that are dissipated within 1 hour and ripple features were seen afterwards.

➢The fronts appeared to possess complementary feature similar to mesospheric bores [*Taylor et al., 1995; Dewan and Picard, 1998; Smith et al., 2003*], with in phase variation between OH and Na and out of phase variation between OI greenline and the other two emissions.

➢Apart from this, the bright and dark fronts appear to pass alternatively in the individual emission images (Clearly seen in Front 2 and 3), similar to the observation of wall wave [*Swesnson et al., 1998*] by *Li et al., (2007)*.

➢The apparent phase velocity of all the four fronts were fairly close around 55 m/s.

➢The time difference between the passage of successive fronts was found to be ~97 mins yielding an approximate distance of ~320 km between them. Directly measured distance between front 3 and 4 was ~335 km.

➢The alternate appearance of bright and dark fronts could be the manifestation of opposite phases of a large scale gravity wave of wavelength ~650 km with an apparent phase speed of ~55 m/s resulting in apparent time period of ~197 minutes.

➢The background wind along the propagation direction is opposite and there was a reversal around the time of disappearance of the fourth front.

➢The snapshot temperature measurement around 22:15 UT after passage of front 1 shows a ~6km vertical perturbation feature. However, it does not appear to be related to the wall wave.

Table: Wave Parameters

	Wavelength, λ_h*	Phase velocity, *c*	Propagation angle, *φ*	Background wind, *u***	Vertical wavelength, λ_v***
Front 1	Increases from ~16 to ~ 20 km	~54 m/s	150º – 155º	-13 m/s	Vertically evanescent
Front 2	No trailing undulations	~55 m/s	163º	-31 m/s	---
Front 3	~23 km	~55 m/s	163º	-27 m/s	Vertically evanescent
Front 4	~16 km (undulations disspated)	~52 m/s	158º	-10 m/s	Vertically evanescent
Wall Wave (Comprising of fronts)	~650 km	~55m/s	~160º	-19 m/s	~25 km

* Represents wavelength of trailing undulations for Fronts 1 – 4.

** Average of 40 minutes centered on the passage of the front through zenith. For front 4, it corresponds to estimated time of passage.

*** Obtained from the dispersion relation $m^2 = N^2/(c-u)^2 - k^2 - 1/4H^2$, with buoyancy frequency N = 0.02 and scale height H = 6 km.

➢In addition to the above mentioned features, there was a front moving towards 315º between 15:40 – 16:30 UT and it collided with front 1. Afterwards, its signature was not found.

➢Kalpana satellite images show a frontal feature that is nearly parallel to the observed fronts in airglow images. Here we show features in visible images alone whereas the cloud front is also observed in IR images and was found to persist till the start of the airglow imaging observation time. Further, the front was moving towards the Southeast, nearly in the same direction as the fronts observed in airglow images, at an approximate speed of 10 m/s. Hence, the front in the cloud images might be the probable source of the observed wall wave in airglow images.

➢From UKMO assimilated winds for the day, we infer the wind filtering effects up to about stratopause heights. Average winds over a latitude-longitude bin of 4ºx6º centered over observation location and probable source region are used. In both the cases, winds up to stratopause heights (~53 km) were not sufficient enough to block the observed wave.

Summary

We have observed successive passage of four frontal systems with alternate bright and dark fronts. They are suggestive of passage of opposite phases of a large scale gravity wave. Two of the fronts (1st and 3rd) showed evolution of phase locked trailing undulations while the other two appeared to suppress trailing undulations. Possibility for presence of a strong ducting region in the upper mesosphere cannot be overlooked. In such a case, probably, the perturbations corresponding to the crest (or trough) of the gravity wave may result in increase of the duct width and it might evolve as a mesospheric bore. The perturbations resulting from the opposite phase of the gravity wave is expected to bring about decrease in the duct width and consequently trailing undulations may be suppressed. Therefore, this observation hints at the possible relationship between wall waves and bores in a manner that the latter has its source in the former. The source of this event is traced to a tropospheric cloud front.