TROPICAL/SUB-TROPICAL MESOPAUSE THERMAL STRUCTURE FROM ARECIBO, PR (18.35°N, 66.75°W) AND MAUI, HI (20.7°N, 156.3°W)

Jonathan S. Friedman[(1)] and Xinzhao Chu[(2)]

[(1)] *NAIC Arecibo Observatory, HC-03 Box 53995, Arecibo, PR 00612, USA, E-mail: jonathan@naic.edu*
[(2)] *University of Colorado, CIRES, 216 UCB, Boulder, CO 80309, USA, E-mail:Xinzhao.Chu@Colorado.edu*

ABSTRACT

Nocturnal temperature measurements from resonance fluorescence Doppler lidar observations at Arecibo, Puerto Rico (18.35°N) and Maui, Hawaii (20.7°N) during 2002–2006 have produced climatologies from geographically similar sites, separated by 2.35° in latitude and 89.55° in longitude. The seasonal variability of the mesopause altitude above Arecibo is tropical, i.e. always winter, whereas above Maui it is mid-latitude-like, low in summer and high in winter. Semi-diurnal tidal analysis for July shows very similar results for the two sites, although the 12-h forcing is considerably smaller at Arecibo in the region of the low mesopause, 85–90 km.

1. INTRODUCTION

Observational studies over the past decade have clearly resolved that the global mesopause structure exists in only one of two states, and that the coldest temperatures exist in the midsummer polar mesopause below 90 km [e.g. 1]. This low summer mesopause altitude extends through mid-latitudes for 2-3 months around the solstice, while in the summer tropics and throughout the winter hemisphere the mesopause altitude is high (~100 km). To date, there are quite limited observations from tropical / subtropical latitudes. Among these results are: 1) Rayleigh lidar studies from Mauna Loa, HI (19.5 N) [2]; 2) the nocturnal climatology published for Arecibo (18.35°N) [3]; 3) the nocturnal climatology comparison between Maui (20.7°N) and Starfire, NM (35°N) [4]; 4) the climatology work done for Tenerife, in the Canary Islands (28°N) [5]; and 5) a ship-borne lidar that traversed the tropical region in June 1996 and recorded the winter-to-summer state transition between 23° and 24° N latitude [6]. In only the last of these was there any identification of the transition latitude.

In this paper, observations from two resonance fluorescence Doppler lidars, taken between January 2002 and January 2006, are combined in a study of mesospheric temperatures at two locations near the tropical / sub-tropical boundary. One site is the US Air Force space surveillance site on Haleakala, Maui, HI (20.7°N, 156.3°W) where the University of Illinois Na wind/temperature lidar was located for the Maui-MALT campaign [7]; the other is the Arecibo Observatory (18.35°N, 66.75°W) where a K temperature lidar operates [3]. Herein we present results on the mesopause-region climatologies for Maui and Arecibo. We focus on the mid-summer period in order to study the phase change between winter and summer states of the mesopause.

2. MESOPAUSE SEASONAL VARIABILITY

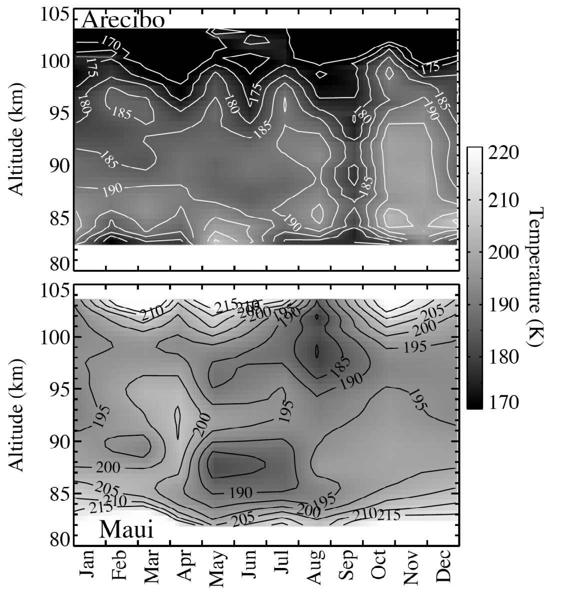

Fig. 1. Seasonal temperature climatologies for Arecibo (above) and Maui (below) using monthly average profiles. The Arecibo plot includes 12 months of data, and the Maui plot is interpolated from 7 months' data.

Fig. 1 shows the seasonal thermal structures of the mesopause region measured at Arecibo and Maui. The Maui data are from January, March, April, May, July, August and October, and are interpolated to 12 months before the contour plot is made. Data are analyzed by composing monthly mean nights and from those calculating a nocturnal average temperature for each height. The temporal extent of the data ranges from 9 hours in May–June to 12 hours in December–January, and the altitude ranges are cut off at 82 and 103 km because outside that range either the statistics are poor or, on the top side, temperatures are mostly measured during sporadic events and do not represent nocturnal averages.

The Arecibo data were recorded between December 2003 and January 2006 and include 94 nights and 667 hours. There is a minimum of four nights and 27 hours in May and a maximum of 14 nights and 108 hours in April. For Maui, there are data for 7 months between January 2002 and March 2005, containing a total of 34 nights and 241 hours. A minimum of three nights and 12 hours occurs in March, while the maximum quantity of data occurs in July, with 7 nights and 47 hours.

In Fig. 2 are May (— - -) and July (— -) monthly mean temperature profiles for Maui. These show temperature minima between 87 and 88 km, thus it appears that the phase change from the winter to the summer state occurs at Maui, while it is merely hinted at in June (– –) over Arecibo. Arecibo nocturnal mean temperature profiles for individual June nights are plotted in Fig. 3. Except for one case, the mean mesopause is high. The one night with a low mesopause altitude, 15 June 2004, constitutes 7 hours averaged, but low K density above 98 km precludes the definitive assignment of a low mesopause altitude. Altitudes of temperature minima in Fig. 3 are indicated with diamonds. These may not be mesopause altitudes, as, in all but one case, there are colder temperatures higher, but they show that for four of five cases lower temperatures occur near or above 95 km.

Several monthly average temperature profiles for Arecibo contain a mesopause that is near or above the top altitude, which is manifest in the temperature contours in Fig. 1. We see from Fig. 2 that this is true even for July (····), but apparently not for May (—) or June (– –). The summer profiles each have inversions near 90 km and secondary minima at 87 km, although

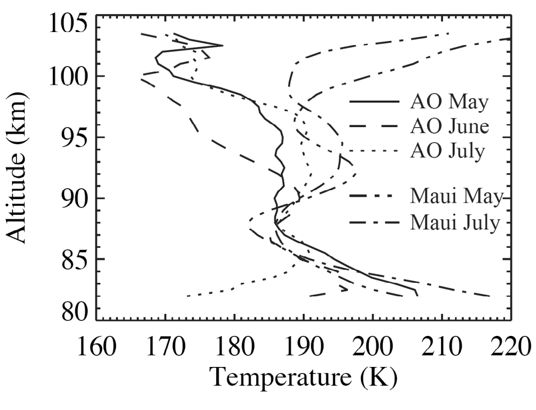

Fig. 2. Monthly mean profiles for May–July for Arecibo and Maui. For Arecibo, May is the solid line, June is dashes, and July is dotted, while for Maui May is dash-dot-dot and July is dash-dot.

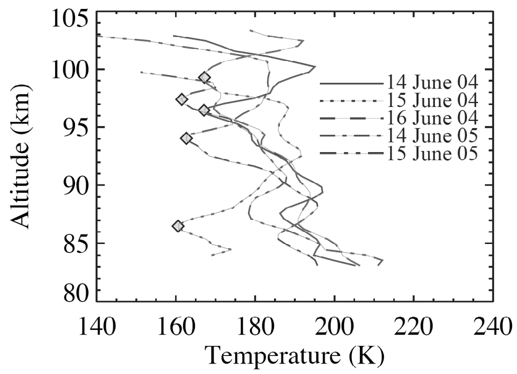

Fig. 3. June nightly mean temperature profiles for Arecibo. There are three 2004 nights: 14 (solid), 15 (short dash), and 16 (long dash), and two 2005 nights: 14 (dash-dot), and 15 (dash-dot-dot). Each curve has a grey thin line to guide the eye. The diamond symbols indicate local minima, but these may not be indicative of the mean mesopause altitude. In all cases except that of 16 June 2004 the temperature appears to still be falling at the top of the metal layer.

the 87 km temperature is, on average, warmer than the ~100 km temperature.

What is apparent in these results is a latitude boundary in the transition between the winter and the summer mesopause state. The transition occurs at Maui but not at Arecibo. In the next section we will look at this in a comparison of July 12-h tidal results.

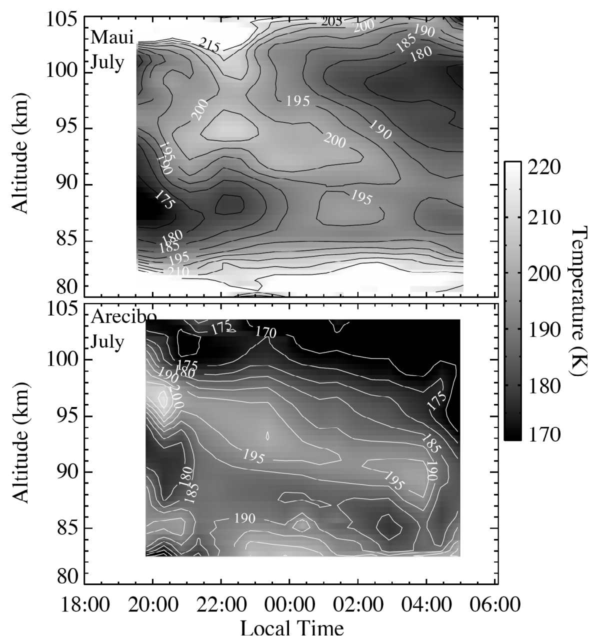

Fig 4. Composite mean night thermal structure for Maui (upper) and Arecibo (lower).

3. TIDAL STRUCTURE

In Fig. 4 we show composite mean night temperature contours for July over Maui (upper) and Arecibo (lower). July is chosen as the midsummer representation because there are no June observations for Maui, and both sites have much more data for July than for May. The Arecibo composite night is built from 48 hours over seven nights in 2004–05, while that for Maui comes from 47 hours over seven nights in 2002–03. The amplitudes and phases of a 12-h fit to these modulations are shown in Fig. 5. We chose to fit a 12-hour temporal modulation at each altitude for both sites because this is the clearest wave apparent from both sites in Fig. 4. This choice can be problematic due to under-sampling, as there are insufficient data to unequivocally determine what the principle contributions to the modulation are. However, the 12-h fit can be statistically justified for even slightly under 12 hours of data [8], and continuous multi-day observations of mesopause temperatures from Tenerife (28.3°N, 17.5°W) show a dominant semi-diurnal tide, which supports our approach [9].

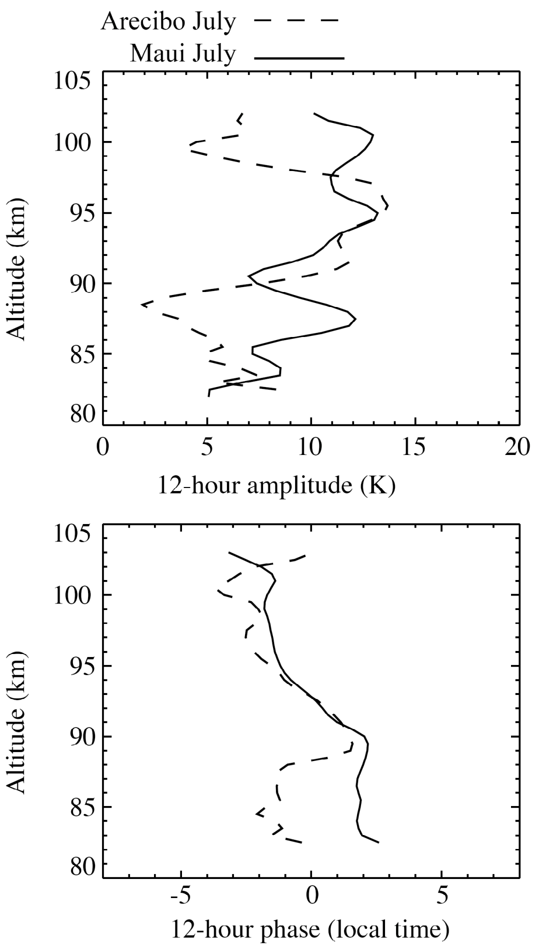

Fig. 5. Amplitude and phase plots for a 12-hour modulation fit to the temperature variability seen in Fig. 4. Arecibo July is the dashed line and Maui July is the solid line.

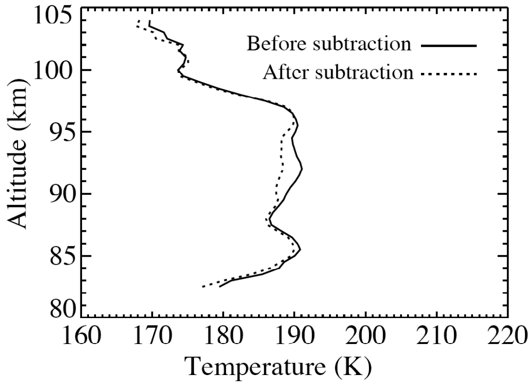

Fig. 6. The July mean temperature profile without (solid) and with (dotted) the 12-hour modulation removed.

The amplitude of the modulation between 85 and 90 km is much stronger for Maui than for Arecibo, >10 K vs. <5 K. This begs the question of whether this modulation plays a role in the low mesopause over Maui. Subtracting this modulation from the temperature data does not affect the nocturnal mean profile significantly [4]. The same is true for Arecibo, as shown in Fig. 6, where the solid line is the mean temperature profile computed from the composite night, while the dotted line is the mean profile after the 12-hour modulation is subtracted. Except that the latter is ~1 K cooler between 90 and 95 km, the profiles are essentially identical.

The fact that the phases are effectively identical above 88 km indicates that the 12-hour modulation is principally the result of a semidiurnal migrating tide. To account for difference between 85 and 90 km we suggest, but cannot at this time test, two possibilities. First would be due to the fact that the observations were carried out during different years. The Maui observations are mostly from 2002 (6 of 7 nights), just as those for Arecibo are mostly from 2004 (6 of 7 nights). To answer the question of interannual variability will require a longer time data set, which is not yet available. Second is the question of whether local effects, such as non-migrating tides, gravity waves, and gravity wave – tide interactions, may amplify the tide over Maui or partially cancel it over Arecibo. This is a topic for future investigation. It is interesting to note that over Haleakala and Tenerife the 12-hour amplitude is ~10 K throughout the profile [4, 9]. These sites are on 3000 m mountains, while Puerto Rico reaches only 1300 m, so if local effects are involved, orography is an important consideration.

4. DISCUSSION AND CONCLUSIONS

Resonance lidar temperature measurements of the thermal structure of the mesopause region over Haleakala, Maui, HI and Arecibo, PR, sites separated by only 2.35° in latitude, show distinct seasonal variations. The Maui mesopause is evidently mid-latitude in nature, while that of Arecibo is low-latitude. Assuming that longitudinal differences are far less important than latitude, which is supported by other lidar observations [2], this may narrow down the transition latitude between the winter and summer state in the northern hemisphere. If so, the latitude differs only slightly from that reported by *von Zahn et al.* [6], who found the transition between 23° and 24°. Neither observation is conclusive, as we observe at widely disparate longitudes, and the *von Zahn et al.* observations contain only one night at each latitude, but the principle that the mesopause altitude experiences a phase transition between the low and high state at the midsummer tropic is clearly supported.

We looked at composite mean nights for the two sites for the month of July. There is a clear descending modulation of the thermal structure with an approximate ½-day period. Its phase is nearly identical at both sites above 88 km, as are the amplitudes, except in the low summer mesopause range of 85–90 km, where the amplitude is much larger over Maui. The matched phases support the idea of a dominant propagating semidiurnal tide in the tropical/subtropical mesopause region temperature structure [9]. In order to determine what the source of the difference in amplitudes is, a more thorough study is needed. Means of determining gravity wave spectra and of differentiating the non-migrating tidal forcing are required. Models could then help to determine the influence of these on the local structure. In addition to recording data at both sites during the same periods, rather than during separate years, it is necessary to completely elucidate the contributions to this 12-hour modulation, which will help reveal other modulations, both tidal and non-tidal. This will require both sites to monitor temperatures during the day. Such observations at Tenerife have shown that semi-diurnal tides dominate the modulation in sub-tropics, and the amplitudes measured there compare well with those of Maui [4, 9].

Arecibo is in the process implementing daylight capabilities to the K lidar, and these should be fully active later this year (see Friedman, J. S., "The Arecibo potassium lidar daylight receiver" in this volume). We anticipate that the University of Illinois lidar will return to Maui soon, and we urge them to provide daylight operational capability as early as possible.

ACKNOWLEDGMENTS

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