Temperature and Water Vapor Profiles over Northeast Arkansas

Bryant N. Fong[1] and J. Tillman Kennon[2]
Arkansas State University, State University, AR 72467, USA

Ed Roberts[3]
Pottsville High School, Pottsville, AR 728558, USA

Arkansas BalloonSAT is an educational outreach and research program at Arkansas State University. Balloon-borne Anasonde instruments measured temperature and water vapor as relative humidity, converted to absolute humidity with temperature, for the past three years. Measurements using BalloonSAT match other balloon-borne studies and provide a supplement and cost-effective alternative to satellites and unmanned aerial vehicles measurements. Statospheric water vapor concentrations were found to vary with seasons with water vapor lowest in the winter and greatest in the summer. Temperature measurements followed standard atmospheric profile measurements with a negative lapse rate in troposphere and positive lapse rate in stratosphere with a temperature inversion at the tropopause.

I. Introduction

THE BalloonSAT program at Arkansas State engages mid-level and secondary students in project based learning applying engineering based practices with student created payload boxes and experiments. The program has grown to accommodate high altitude research in addition to educational outreach.[1] Weather balloons carry payload boxes to study physical and chemical properties throughout the atmospheric air column. High altitude weather balloons provide a low cost alternative and supplement to unmanned aerial vehicles and satellite measurements. Weather balloons and unmanned aerial vehicles are generally more sensitive to local atmospheric processes than satellites. Satellites are ideal for global studies, but must be complemented by non-satellite measurements to verify analyses. Airborne measurements in conjunction with satellites can calibrate instruments and identify subtle long-term changes.[2]

Studies point to an increase in the importance of stratospheric water vapor as an indicator of global temperature changes. A 10% decrease in lower-stratospheric water vapor was found to counteract 25% of the global temperature increase from 2001 -2005. Monitoring trends in water vapor content in the stratosphere is important to create accurate climate change detection and prediction.[3] As atmospheric temperature rise, more water is evaporated from the surface. Water vapor concentrations can be higher when with warmer air temperatures because the air is able to "hold" more water. Higher concentrations of water vapor can absorb more thermal IR energy radiated from the Earth which further warms the atmosphere. This creates a positive feedback loop with warmer temperatures holding more water. Water vapor contributes approximately 60% of the warming effect.[4] Carbon dioxide is a highlighted greenhouse gas agent because changes in water vapor concentration are result of natural climate feedbacks rather than industrialization.

In this study, temperature and water vapor profiles and seasonal variation at select altitudes are analyzed. These measurements are important to identify current atmospheric patterns and their possible global climate change implications.

[1] Department of Chemistry and Physics, PO Box 60, State University, AR, 72467
[2] Associate Chair of Science Education, Department of Chemistry and Physics, PO Box 60, State University, AR 72467
[3] Secondary Science Teacher, Pottsville High School, 7000 Hwy 247, Pottsville, AR 72858

II. Methods/Materials

Arkansas BalloonSAT launches use 1600g latex weather balloons with 5.5 kg (12 lbs.) of atmospheric monitoring instruments and high altitude experiments. These instruments include Anasonde-4 (Anasphere) which measure temperature, water vapor as relative humidity (RH), and pressure profiles throughout ascent and descent of the balloon flight. RH measurements were converted to absolute humidity given temperature for accurate interpretation and comparison to other studies. Atmospheric profiles were created by matching the measurement to altitudes via timestamps.

Typical balloon flights elapsed 90-120 minutes, reaching up to 26 km (100,000 ft). At higher altitudes, the balloon expands due to the pressure difference between the Earth's surface and at high altitudes. Payload boxes are secured to a balloon and parachute with a 100 pound test polyester line passed through each box. Attached underneath the balloon is a parachute to slow descent of payloads after balloon bursts. HAM radios transmit real-time GPS and altitude data to aid in balloon recovery. Data was collected across three years with 10 balloon flights. On each flight, data was collected at 15 second intervals, with data points on graphs made at one minute averages, equating to measurements every 0.55 km.

III. Results and Discussion

Temperature and water vapor as absolute humidity and measurements were taken during ascent. Measurements during descent mirror those of ascent, but have a larger error due to the rapid descent of the balloon.

A. Temperature Measurements

The temperature readings of BalloonSAT correlate with other atmospheric temperature studies with a negative lapse rate in the troposphere (0-15 km) and a positive lapse rate in the stratosphere (15-30 km) as a function of altitude (Fig.1). The troposphere and stratosphere layer heights vary seasonally and latitudinal and are identified with a temperature inversion. The tropopause identifies the upper boundary of the troposphere, thus the boundary region between the troposphere and stratosphere.[5–8]

The negative lapse rate in the troposphere is due to a decrease in the convection heat with higher altitudes. BalloonSAT tropospheric lapse rate measurements (-4.2° C/km) are comparable to the U.S. standard lapse rate (-6.5° C/km).[9] While the positive lapse rate in the stratosphere is a result of the reaction between ozone and UV radiation that forms oxygen and heat. More ozone reactions create a higher temperature.[7] Ozone has the highest concentration at 20-25 km measured by ground based laser radar.[10] The weather balloons reach into the middle of the ozone layer and not above, so a temperature increase is observed. The temperature lapse rate throughout the air column during descent mirrored those of ascent.

No seasonal variations in atmospheric temperature at 10 km were observed (Fig. 2). Measurements taken during autumn and winter months are highlighted in grey. The tropospheric temperature in autumn winter was lower in 2013, but higher in 2014 compared to spring and summer 2014. BalloonSAT measurements match satellites satellite-borne Microwave Sounding Unit (MSU) which found a +0.1 to +0.04K temperature increase in the lower troposphere over the past decade, or +0.004 K increase per year.[11] BalloonSAT measurements show a +0.0013K increase per year at 10 km, similar to satellite measurements considering error.

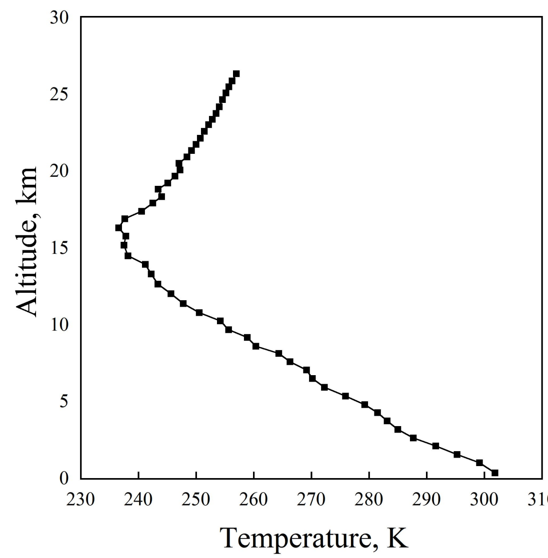

Figure 1. Vertical profile of NE Arkansas atmosphere using Anasonde sensors

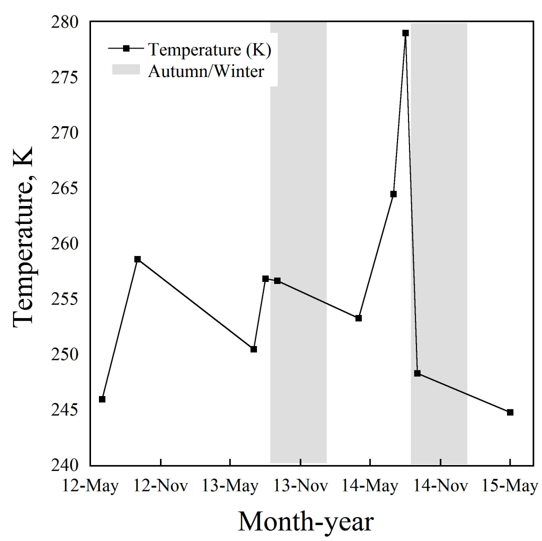

Figure 2. Seasonal temperature variation at 10 km in NE Arkansas lower troposphere

B. Water Vapor measurements

Seasonal averaged water vapor profiles of flights in the past three years show that most seasonal variation occurs below 12 km, within the troposphere (Fig. 3). Water vapor is at the highest concentration near the Earth's surface (0-5 km) due to surface convective currents. As the temperature of the atmosphere decreases with height, the amount of water vapor decreases because saturation vapor pressure is proportional to temperature. Overall, the lowest amount of water vapor is observed at the tropopause, the coldest temperature in a balloon flight. Water vapor does not vary as much in the stratosphere as changes in troposphere and lower stratosphere travel into the upper stratosphere via upwelling dissipate with increasing altitudes. Stratospheric water vapor is also influenced by methane oxidation which is strongest at high altitudes, falling sharply at lower altitudes. These two processes, upwelling from troposphere and contribution from methane have opposing altitude dependencies and may explain the small variation in water vapor observed.[12] BalloonSAT measurements match other balloon-borne frost point hygrometer measurements in Boulder, CO[13] and LIDAR measurements[14] water vapor profiles.

The water vapor at stratospheric altitudes (28 km) is shown in Fig. 4. Measurements taken during autumn/winter months are shaded in grey. Higher amounts of water vapor were found to occur in summer months, while lower amounts were observed in the winter months. These maxima correlate with North America monsoon seasons which transport moist troposphere air into the stratosphere via monsoonal circulations.[15] Winter loss of water vapor is due to cold stratospheric temperatures caused by the Earth's tilt that freeze water vapor creating large ice crystals that fall from the stratosphere. In the summer, those ice crystals are heated in the troposphere and travel into the stratosphere.[16]

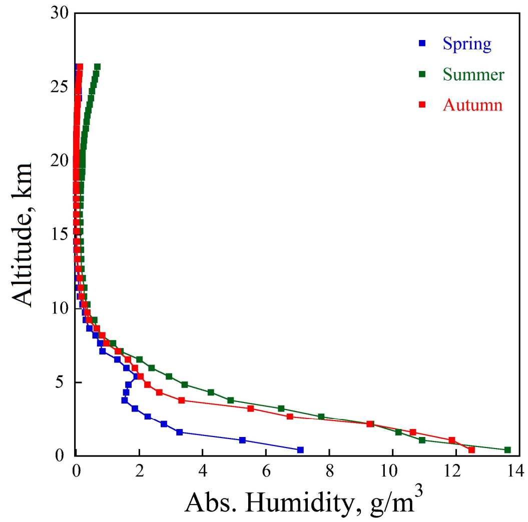

Figure 3. Seasonal water vapor profile variations observed over NE Arkansas.

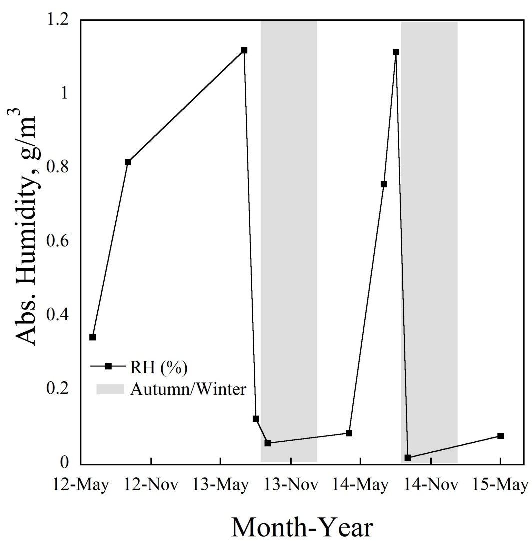

Figure 4. Seasonal stratospheric water vapor measurements observed at 27 km. Higher water vapor concentrations are observed in summer due to monsoons and tropospheric upwelling.

IV. Conclusion

Arkansas BalloonSAT measurements using Anasonde instruments were found to match other high altitude balloon and satellite studies at similar latitudes. Temperature profile measurements show a negative lapse rate in the troposphere and positive lapse rate in the stratosphere which correlates with understood atmospheric models. Temperatures are lower with higher tropospheric altitudes due to greater distance from surface convection cycles, while warmer in the stratosphere due to reactions of ozone and UV which release heat as a product. Water vapor measured as absolute humidity show high variability across seasons at altitudes below 12 km, and small variations at higher altitudes. Stratospheric water vapor measurements show higher concentrations in the summer months which correlate with North American monsoon seasons. Overall BalloonSAT proves to be an effective research program that collects atmospherically relevant data comparable to other high altitude balloon and satellite measurements.

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