THERMOSONDE AND RADIOSONDE DATA FROM THE
T-REX CAMPAIGN

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1. INTRODUCTION

The Air Force Research Laboratory was a participant in the T-REX Campaign[1,2] from 20 March 2006 through 6 April 2006, which included IOPs 6 through 9. The purpose of this report is to describe the data that are available on the UCAR EOL web site. Further description and other data requests should be made to the corresponding author.

The objective of the AF participation was to study higher altitude mountain waves and associated turbulence. Optical turbulence was measured using the balloon-borne thermosonde instrument, which includes a radiosonde. Those radiosondes and other radiosondes that were launched without a thermosonde were used to study the atmospheric wave properties. The instruments were launched from the windward side of the Sierra Nevada Mountains near Three Rivers California.

The AFRL thermosonde[3] estimates the optical turbulence profile by measuring a 1m horizontal temperature structure function as it ascends through the atmosphere 110m below a large weather balloon. The temperature differences are sensed by two 3.45µm diameter tungsten wires which are legs of a Wheatstone bridge detecting the temperature differences as small as 0.001K. Onboard instrumentation computes a 4 to 8 second running root-mean-square of the difference, which is transmitted to the ground station as spare channel data along with the met data from the attached RS-80GE radiosonde. The temperature structure function is converted to the temperature structure constant assuming that the turbulence follows Kolmogorov[4] behavior and using Obukhov[5] and Yaglom's[6] deduction for passive scalars. The radiosonde data is then used to convert the temperature structure constant to the structure constant for the index of refraction, C_n^2. For radiation near the visible spectrum, and when the moisture contribution can be ignored (everywhere except in immediate proximity to a body of water) it is customary to use the formula[7]:

$$C_n^2 = \left(a_d\left(\lambda\right) \frac{P}{T^2} \right)^2 C_T^2$$

where $a_d\left(\lambda\right)$=70x10^{-8} K/Pa for visible and near-infrared wavelengths.

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Eighteen thermosondes were launched with their radiosondes, 17 of which had usable C_n^2 data, and 22 additional radiosondes were launched, often in poor weather conditions, and 8 had usable data. Rawinsonde data from all launches is being used to detect mountain wave parameters to include variance in ascent rate, horizontal wind velocity, and potential temperature. Where possible, the optical turbulence strength will be tested for correlation with the wave parameters. In addition, there will be comparisons to various numerical model forecasts and possibly to other measurements in the T-REX Campaign.

2. THE CAMPAIGN

The Three Rivers location was chosen to attempt to have the balloons and sampling the waves and turbulence at reasonably high altitude over the Sierra Nevada mountains. The Three Rivers site would be upwind of the mountain during the west-southwest flows that could generate mountain waves, and for those winds, the balloons should cross the Owens Valley near the T-REX instrument sites for maximum support of the other research teams. Three Rivers is located by the star in the lower left hand corner of the map in Figure 1. The actual balloon launch site was the Ash Mountain Helibase near the Ash Mountain Entrance to the Sequoia National Park, an 8 mile drive from Three Rivers. The launch area is shown in Figure 2, looking toward the north. The coordinates of the launch site are: Lat. 36.48720N, Long. 118.84048W, Alt. 503m.

Air Force participation was limited to about three weeks. We selected the period from late March through early April to achieve maximum overlap with the aircraft measurements, since the BAE146 from the UK Natural Environmental Research Council was joining the NSF/NCAR HIAPER Gulfstream V and the University of Wyoming King Air 200T during that period.

The radiosondes were Vaisala[8] RS-80-15GE. When the radiosonde was part of the thermosonde payload, an ozone interface card was added (OIF11). Two Vaisala DigiCORA® ground stations were used: the MW15 and the MW21. The latter exhibited occasional noisy signals, and finally failed near the end of the campaign. The ground station output included listing of time (s), pressure (hPa), temperature(deg C), and relative humidity (%) every ~1.4s for the MW15, and about every 2s for the MW21. For thermosondes, the temperature structure function information is received as "counts" in additional columns to these files. The GPS wind data comes down every 2s for the MW15 and every 0.5s for the MW21 in a file that shows the time (min + s), altitude (km), temperature (deg C), humidity (%), wind speed (m/s) and wind direction (deg).

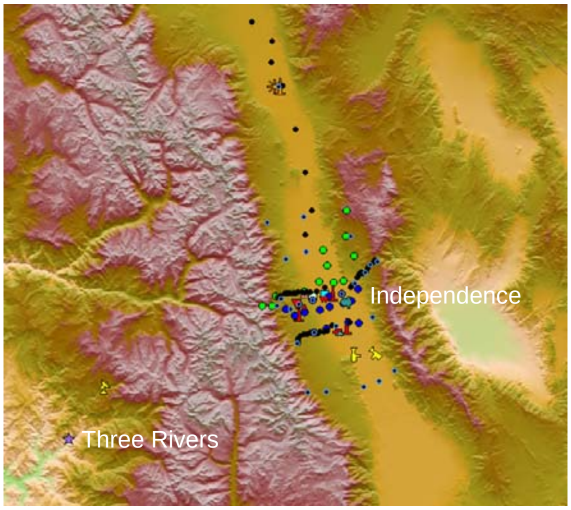

Figure 1. Color relief map of the central portion of Owens Valley California from the T-REX web site. The Sierra Nevada mountains are the darkest purple ridge running from the northwest corner to the bottom central area. The Balloons were launched near Three Rivers, located by a purple star in the lower left of the map.

Figure 2. Radiosonde ready for launch near helium tanks on the northern edge of the Ash Mountain Helibase. The ridge shown behind the balloon frequently blocked radio signals from radiosondes that began their flight heading northward.

3. Flights

The campaign period was marked by an abundance of bad weather that interfered with data collection. Rainfall reached record and near-record levels. The fine wire temperature sensors of the thermosonde are susceptible to breakage in heavy rain and ice, which reduced the number of thermosonde flights. Many radiosonde-only flights suffered early terminations due to broken balloons. In addition, attempts to launch two balloons at the same time was

Table 1: T-REX flights. T/S is for thermosonde flights, R/S for radiosonde flights, green denotes good data for most of a 30km flight, yellow is at least part of the flight has good data, red is not enough usable data to analyze.

Launch Date Time (UTC)	Flight ID	Radiosonde or thermosonde	Ground Station	Result
3/21/06 2:15	T-REX001	R/S	MW-21	
3/21/06 2:20	T-REX002	R/S	MW-15	
3/22/06 2:13	T-REX003	R/S	MW-21	
3/22/06 2:07	T-REX004	T/S	MW-15	
3/23/06 2:18	T-REX005	T/S	MW-21	
3/23/06 2:19	T-REX006	T/S	MW-15	
3/25/06 5:50	T-REX007	T/S	MW-15	
3/25/06 5:59	T-REX008	R/S	MW-21	
3/25/06 7:53	T-REX009	T/S	MW-15	
3/25/06 8:00	T-REX010	R/S	MW-21	
3/25/06 9:47	T-REX011	T/S	MW-15	
3/25/06 9:57	T-REX012	T/S	MW-21	
3/26/06 1:33	T-REX013	R/S	MW-15	
3/26/06 3:06	T-REX014	R/S	MW-15,21	
3/28/06 2:11	T_REX015	T/S	MW-15	
3/28/06 2:17	T-REX016	R/S	MW-21	
3/28/06 3:47	T-REX017	T/S	MW-15	
3/28/06 3:53	T-REX018	R/S	MW-21	
3/31/06 0:48	T-REX019	T/S	MW-15	
3/31/06 0:54	T-REX020	R/S	MW-21	
3/31/06 2:52	T-REX021	T/S	MW-15	
3/31/06 2:58	T-REX022	R/S	MW-21	
3/31/06 4:35	T-REX023	T/S	MW-15	
3/31/06 4:49	T-REX024	T/S	MW-21	
4/1/06 7:50	T-REX025	R/S	MW-15	
4/1/06 10:04	T-REX026	R/S	MW-15	
4/1/06 11:50	T-REX027	R/S	MW-15,21	
4/1/06 13:41	T-REX028	R/S	MW-15	
4/3/06 0:02	T-REX029	T/S	MW-15	
4/3/06 0:11	T-REX030	R/S	MW-21	
4/3/06 1:51	T-REX031	T/S	MW-15	
4/3/06 1:57	T-REX032	R/S	MW-21	
4/3/06 3:44	T-REX033	R/S	MW-15	
4/3/06 5:42	T-REX034	R/S	MW-15	
4/4/06 17:41	T-REX035	R/S	MW-15	
4/4/06 18:40	T-REX036	R/S	MW-15	
4/4/06 20:52	T-REX037	R/S	MW-15	
4/5/06 23:44	T-REX038	R/S	MW-15	
4/6/06 1:40	T-REX039	T/S	MW-15	
4/6/06 3:27	T-REX040	T/S	MW-15	
4/6/06 5:14	T-REX041	T/S	MW-15	

thwarted by a ground station that did not work properly at the start of the campaign, and completely failed later in the campaign. There were also instances of loss of signal from mountain obstruction of signal. That being said, the campaign was certainly a success in that there were many successful thermosonde flights, some showing very high levels of turbulence. In addition, there were several flights showing evidence of strong gravity waves. The flight data acquisition results are summarized in Table 1.

4. Data Reduction

The "raw" ground station files are often corrupted by noise, dropouts, and obviously incorrect information. Various in-house utility programs are used to process the files, including removing obviously incorrect data. In some cases, gaps in a particular variable might be filled by interpolating between the nearest reliable data points. The processing program recomputes the altitude by using the more accurate, variable gravitational acceleration and the hypsometric equations. Time is then used to assign the proper altitude for the wind data. The temperature structure function is determined using calibration data and conversion equations. These data are then output into the ".win" file listing the altitude (km), wind speed (m/s) and direction (deg). All other thermosonde data are output in the ".txt" file, giving altitude (km), pressure (hPa), temperature (deg C), relative humidity (%), and C_n^2 ($m^{-(2/3)}$). For the radiosonde data alone, a .txt and .win are also provided, without the C_n^2 column.

The processing program computes the vertical ascent rate using the time rate of change of pressure and the hydrostatic equations. This rate is output in a file with many other parameters of minor interest. It has been well documented that any excursions in ascent rate above 0.5m/s difference from a constant or slowly varying rate can be attributed to vertical wind velocity[9]. This is after obvious instrument errors are corrected. If the variation is oscillatory, the variations can be attributed to the presence of gravity waves. Since many T-REX experimenters are interested in the inferred vertical velocity of the air, the ascent data were further analyzed using signal processing techniques. The objective was to determine the mean ascent rate and variations about the mean. For the stratosphere, mean quantities were determined using a low pass filter with a pass band of 1/(5km) and a stop band at 1/(2km) spatial frequency. In order to get the fluctuating components within the spatial frequencies of the apparent gravity waves, the data were high passed with a stop band and pass band of 1/(5km) and 1/(3.2km) respectively. Next, the resulting signal was low pass filtered with a pass band and stop band of 1/(400m) and 1/(348m) respectively. The filtering was accomplished using non-causal, zero-phase digital filters[10]. The rise rate data are in the files labeled "t-rex0XX_RR.txt". The columns are: altitude (km), ascent velocity (m/s), mean ascent velocity (m/s) and variations about the mean (m/s).

5. Some Results

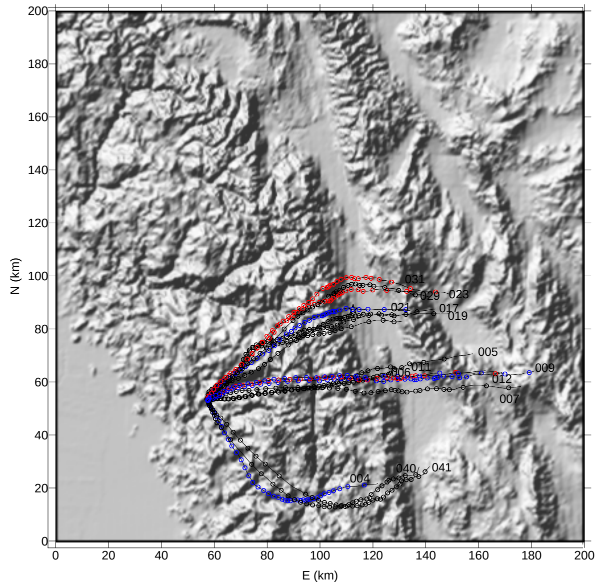

Figure 3: Trajectories of the T-REX thermosonde flights. The first group headed nearly eastward over the Sierra Nevadas and the Owens Valley. The second group headed northerly, the third more southerly.

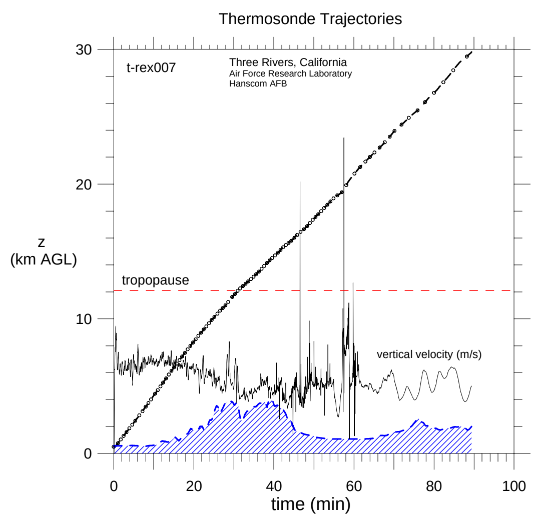

Figure 4: Terrain height (in blue), altitude (black circles) and vertical ascent velocity (black lines) versus flight time for balloon T-REX007.

The trajectories for many of the flights seemed to follow one of three branches shown in Figure 3. The first group headed nearly due east across the region, the second group headed in a more northerly trajectory, the final group headed in a more southerly direction. In Figure 4, the terrain height, instrument altitude, and ascent velocity are shown as a function of time in the flight. The very large spikes in ascent velocity are probably due to instrument error. This plot does show large excursions in ascent velocity over the Owens Valley.

An example of thermosonde results is shown in Figure 5. In the left hand frame is shown the temperature and vertical ascent rate of the instrument. The oscillation of both temperature and ascent rate, and the oscillations of wind velocity in the right hand frame are possible signatures of gravity waves. In fact, the low horizontal velocity just above 20km is indicative that the wave was nearly critical at that point[11]. In the center frame, the profile of the structure constant for index of refraction (C_n^2) is shown. The region from about 19 to 22km is very high in optical turbulence. The reference atmosphere[7], CLEAR 1, an approximately average atmospheric turbulence profile, is shown as the smooth line in the plot.

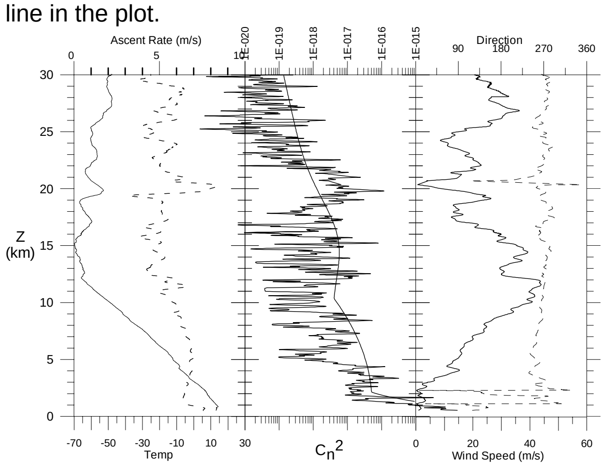

Figure 5. Output of some of the data from Flight t-rex007, launched at UTC 05:50 03/25/06. The sounding is unique in that it shows some of the highest stratospheric temperature variations that we have observed to date from 15 to 25km, as shown in the left hand panel of the chart showing temperature (solid line) and vertical ascent rate (dashed line). The structure constant for index of refraction (C_n^2) and the smoother reference atmospheric average (CLEAR1) are shown in the central panel. The C_n^2 is quite high in the altitude region from 19 to 22km. The wind speed and direction are shown in the right hand panel. The horizontal wind speed essentially stops slightly above 20km, which is a possible indicator of a gravity wave reaching critical amplitude, along with the vertical ascent rate being a maximum.

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