11.3 TERRAIN-INDUCED ROTOR EXPERIMENT (T-REX)

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1. INTRODUCTION

Rotors, low-level horizontal vortices that form downstream of and parallel to the mountain crest, can pose severe aeronautical hazards and have been cited as contributing to numerous aircraft upsets and accidents involving commercial, military and civilian aviation (Carney et al. 1988). Rotor circulations can also be important for the lifting and transport of aerosols and chemical and biological contaminants (Raloff 2001). Despite their considerable impact on human activity, rotors have until recently received relatively little theoretical attention (Kuettner 1959, Doyle and Durran 2002, Hertenstein and Kuettner 2002, Vosper and Mobbs 2002) and almost no modern observational study. One reason that so little is known about rotor intensity is that it is very hard to measure the flow within a rotor. Rotors are dangerous and difficult to sample using in situ aircraft measurements, and they are intermittent phenomena that are too small in spatial scale to be routinely sampled by conventional observing networks.

T-REX is a response to these challenges. The experiment is envisioned as a two phase effort. Phase I, taking place in 2003–2005, consists of a ground-based observing program, and a number of numerical, theoretical and climatological studies. Phase II, the hallmark of which is a major field experiment featuring the latest advances in remote sensors and an airborne observing program, is planned for February–April 2006.

2. FIELD SITE: OWENS VALLEY

The proposed fieldwork in Phase I and Phase II of T-REX will be carried out near the town of Independence in Owens Valley, just east of the southern Sierra Nevada. The southern Sierra Nevada, which contains the highest peak in the contiguous United States (Mount Whitney; 4,418 m), is the tallest, steepest, quasi-two dimensional barrier in the lower 48 states. The Owens Valley itself is a narrow feature approximately 150 km long and 15-30 km wide (Fig. 1). The average elevation change between the Sierra crest and the valley floor is roughly 3,000 m.

The Owens Valley was the site of the Sierra Wave Project, which was a U.S.-Air-Force-funded study of mountain waves also involving a two-phase field experiment: the first phase in the winter of 1951-52 and the second phase in the spring of 1955. A comprehensive overview of the synoptic situations favorable for wave and rotor activity and a description of a dozen case studies documented during this project appear in Holmboe and Klieforth (1957).

3. PHASE I

Phase I of T-REX has been designed to establish quantitative characteristics of the rotor behavior including the location and the frequency distribution of the rotor-inducing mountain-wave events in Owens Valley. This phase of the experiment has already received funding from NSF (US). The ground-based observing program in Phase I is led by the Desert Research Institute (DRI; PI Grubišić), in collaboration with the University of Washington (UW; PI Durran), Naval Research Laboratory (NRL; Doyle) and the National Center for Atmospheric Research (NCAR; Kuettner). The University of Leeds (U Leeds; PI Mobbs) is seeking funding from NERC (UK). An integral part of Phase I are also theoretical/numerical studies of rotor flow dynamics with mesoscale and microscale models. In addition to the above institutions, the Colorado Research Associates (CoRA; PI Hertenstein) in collaboration with NCAR (Kuettner) is involved also in the numerical modeling effort. Climatological study of mountain wave events using satellite data (Grubišić and Cardon 2002) is tied closely with the

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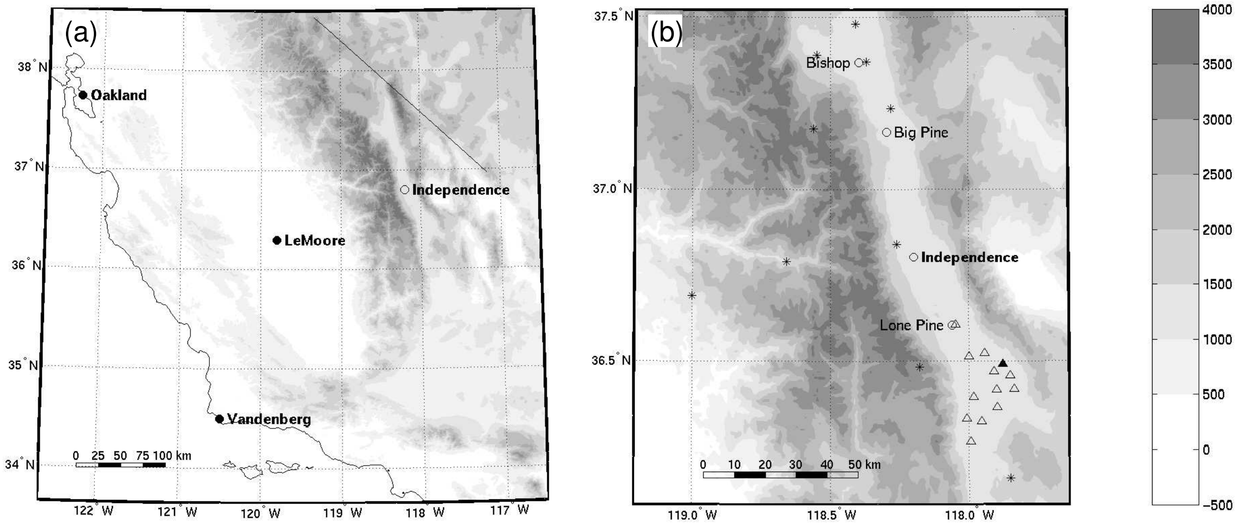


Figure 1: (a) Topographic map of the central and southern California. The town of Independence is located in the Owens Valley; Oakland, Vandenberg and Lemoore are locations from which radiosondes will be launched. (b) An enlargement of the Owens Valley and the southern Sierra Nevada showing the GBUAPCD network of stations (△) and other existing surface stations (∗). The GBUAPCD wind profiler is indicated by the solid triangle.

ground-based observing program.

The core of the ground-based instrumentation in Phase I consists of a network of 32 automatic weather stations (AWS) to be installed by DRI (16 stations) and U Leeds (16 stations) in the central portion of Owens Valley near Independence (Fig. 2). All 32 AWS will measure winds at 10 m, temperature and humidity at 2 m, and will be equipped with microbarographs. The DRI AWS will have a telemetry system to allow remote transmission of temporally averaged data to the central repository at DRI to allow near real-time data access.

In addition to the AWS, the planned ground-based instrumentation in the Owens Valley includes three 15 m turbulence towers set up to record raw turbulence data and provide momentum and heat fluxes (U Leeds), three sodars (U Leeds), a sun-photometer (NRL), video cameras, and two Integrated Sounding Systems (ISS) (DRI & NCAR). The latter will be deployed during a two-month Intensive Observation Period (IOP) in March–April 2004. Each ISS consists of a 915 MHz windprofiler, balloon-borne radiosonde sounding system, an automatic weather station, and a Radio Acoustic Sounding System (RASS). Additional surface measurements in and around Owens Valley are available from the Bureau of Land Management (BLM) and the US Forest Service RAWS (remote automatic weather stations), Caltech's Owens Valley Radio Observatory (OVRO) near Big Pine, and a network of surface meteorological sites near (dry) Owens Lake in the south part of Owens Valley maintained by the Great Basin Unified Air Pollution Control District (GBUAPCD).

Given the importance of documenting the upstream thermodynamic and kinematic flow structure for interpreting the mountain wave response, substantial effort has been made to obtain adequate upwind upper-air sounding data. The NWS regular sounding stations closest to the area of interest and upwind of the Sierra Nevada are located in Oakland, CA and at Vandenberg AFB, CA (Fig. 1). During Phase I, supplemental upstream soundings will be carried out at the Naval Air Station (NAS) Lemoore (675 m ASL) in the San Joaquin Valley, which lies upwind of the area of interest under southwesterly winds (Fig. 1). During the IOP in March–April 2004, NCAR mobile GPS/Loran Atmospheric Sounding System (GLASS) will be deployed on the western slope of the Sierra Nevada to augment the LeMoore sounding in order to obtain a more complete depiction of the properties of the mean cross-mountain flow.

4. PHASE II

Phase II of T-REX, with a field program of substantially larger scope, is planned for early spring 2006. Results of Phase I will provide essential scientific guidance in planning for the second phase of the experiment. Core objectives of Phase II of T-REX are the rotor flow dynamics including rotor/wave

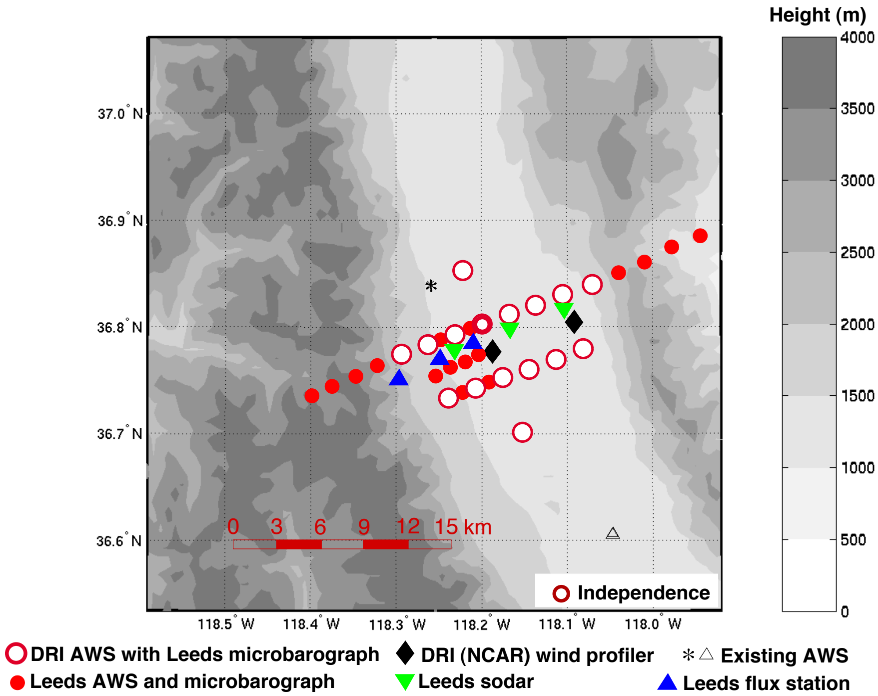


Figure 2: Topographic map of the Owens Valley surrounding Independence showing the Phase I array of surface stations, microbarographs, sodars, and flux stations. The site plan also shows windprofilers that will be deployed in the Intensive Observation Period (IOP) in March-April 2004.

interaction, topospheric and stratospheric gravity-wave breaking, sensitivity of mountain-scale flow to upstream and downstream conditions, numerical predictability of mountain-wave/rotor flows, and the aviation safety aspects under rotor flow conditions. Supporting objectives identified so far include orographic precipitation mechanisms, rotor/wave climatology, stratospheric/tropospheric exchange, phase transition in lee wave clouds, and "layering" of humidity upstream of and within lenticular clouds.

The emphasis with Phase II instrumentation is on enhanced ground-based remote sensing systems and research aircraft. Among the latest advances in remote sensing instrumentation planned for this experiment for documenting rotors and rotor substructures are dual Doppler lidar and K-band radar arrays to be located in Owens Valley. The research aircraft requirements to study the airflow between ground and 55,000 ft are illustrated in Fig. 3. They may also include gliders as well as unmanned platforms.

5. SUMMARY

We have presented a short overview of Phase I and Phase II of T-REX, a new international initiative to study mountain-wave/rotor flows, and low- and upper-level turbulence in airflow over complex terrain. T-REX is planned as a two-phase effort with Phase I in 2003–2005, and Phase II in 2006.

Acknowledgments. This effort was supported in part by the National Science Foundation (NSF), Division of Atmospheric Sciences, Grant ATM–0242886.

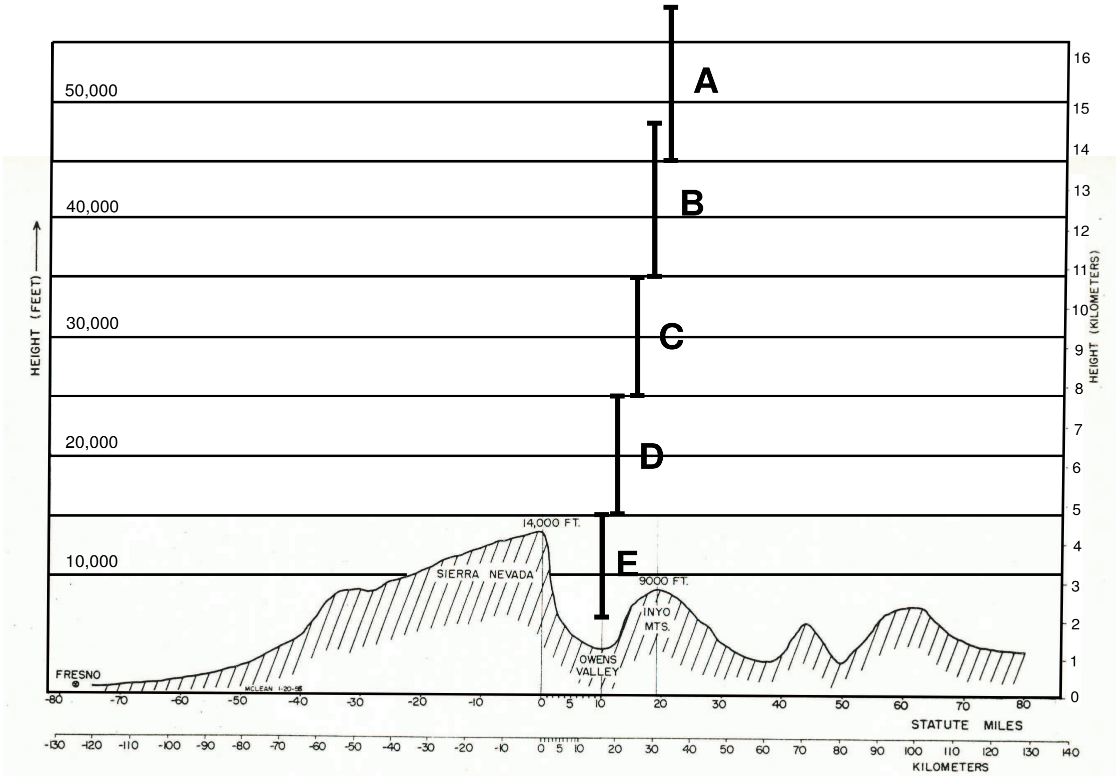
6. REFERENCES

Carney, T.Q., A. J. Bedard Jr., J. M. Brown, J. McGinley, T. Lindholm, M.J. Kraus, 1988: *Hazardous Mountain Winds and Their Visual Indicators.* US Dept of Transportation, FAA, Washington, D.C. Publication AC 00-57.

Doyle, J. D., and D. R. Durran, 2002: The dynamics of mountain-wave induced rotors. *J. Atmos. Sci.*, **59**, 186-201.

Grubišić, V., and S. Cardon, 2002: Climatology of the Sierra Nevada mountain-wave clouds. *Proceedings. AMS 10th Conference on Mountain Meteorology*, Amer. Meteor. Soc., 392–393.

Hertenstein, R., F., and J. P. Kuettner, 2002: Simulations of rotors using steep lee-slope topography. *Proceedings. 10th Conference on Mountain Meteorology.* Amer. Meteor. Soc., 330–333.



A = B-57 (NASA)
B = Hiaper/Gulfstream (NSF/NCAR)
C = FAAM (BAc146; UK)
D = P-3/Eldora (Navy); Kingair (NSF/U Wyoming)
E = Motorglider

Figure 3: Vertical cross-section over the Sierra Nevada, Inyo Mountains and Owens Valley showing vertical ranges of aircraft planned in Phase II of T-REX.

Holmboe, J. and H. Klieforth, 1957: Investigation of mountain lee waves and the air flow over the Sierra Nevada. Final Report. Department of Meteorology, UCLA, Contract AF 19(604)-728, pp. 283.

Kuettner, J. P., 1959: The rotor flow in the lee of mountains. GRD Research Notes, No. 6, AFCRC-TN-58-626, ASTIA Document No. AD-208862, pp. 20.

Raloff, J., 2001: Dust, Part 2: Ill winds. *Science News*, **160**, No. 14, p. 218.

Vosper, S. B., and S. D. Mobbs, 2002: Numerical simulations of lee-wave rotors. *Proceedings. 10th Conference on Mountain Meteorology.* Amer. Meteor. Soc., 334–336.