USING DIURNAL SURFACE PRESSURE VARIATIONS TO STUDY ATMOSPHERIC CIRCULATION IN OWENS VALLEY

Yanping Li[1] , Ronald B. Smith[1] , Vanda Grubisic[2]

[1]Yale University, New Haven, CT
[2]DRI, Reno, NV
E-mail : *yanping.li@yale.edu*

Abstract: Harmonic analysis has been applied to the surface observations collected by 16 DRI AWS during T-REX project (Mar-Apr, 2006) in Owens Valley. The amplitudes and phases of the diurnal surface temperature, pressure components are calculated for quiescent/westerly days. The phase distribution shows that diurnal surface pressure component reaches its minimum around sunset, about 2 hours later than temperature maximum. The surface pressure and temperature amplitude can be used to estimate the daily mixing layer depth if the diurnal surface pressure variation is treated as the cumulative effect of the diurnal temperature variations along the whole air column. For quiescent days, the well-mixed neutral layer develops to almost ridgetop level. For westerly days, it is 500m lower since the ridgetop wind flushes out the valley and carries away part of the heating transported from the ground. WRF model 2d idealized simulations shows that the surface temperature variation is determined by ground sensible heating and eddy heat transport; while the surface pressure variation is determined by vertical advection in the valley center. With the existence of the ridgetop wind, the derived mixing layer depth becomes much lower.

Keywords: *ICAM, T-REX, Owens Valley, Harmonic analysis, Mixing depth, Energy budget*

1. INTRODUCTION:

Diurnal solar heating generates global atmospheric tide by heating the water vapor and ozone in the upper troposphere and stratosphere. In the lower troposphere, the inhomogeneous spatial heating generates local mesoscale circulations such as plateau-plain circulation (Banta, 1984), mountain-valley circulation and sea-breeze. A convenient way to monitor and classify the diurnal circulations is by separating the diurnal component from the noisy observational data through harmonic analysis (Mass et al, 1991).

The T-REX (Terrain Induced Rotor Experiment) project was held on March-April, 2006 in Owens Valley, CA (Grubisic et al., 2005). In association with the T-REX project, 16 Automated Weather Stations has been installed and maintained by Desert Research Institute. Their fine spatial (distance between stations is around 3km) and temporal resolutions (30 Seconds) are very helpful to study the extreme diurnal surface pressure signals in Owens Valley, which is also a good representative of the particular dry valleys in the Western United States.

2. OWENS VALLEY OBSERVATIONS AND MIXING DEPTH:

In our analysis, the days are categorized according to the ridge top winds (soundings from Oakland, Independence and Reno). If 700mb westerly exceeds 10m/s in 00Z (16PM LST) sounding, that day will be classified as westerly day. The calculated amplitudes and phases of the surface observations are in Figure 1. The temperature phases are around 220^o, which means that the diurnal component of surface temperature variations reaches its maximum around 2:40PM. While 90^o surface pressure phases mean that its diurnal components reach the minimum around sunset time (6PM). The amplitudes of surface pressure decrease about 20% for westerly days. According to the hydrostatic law, surface pressure approximates the integral of the whole air column in the valley and is a function of the vertical temperature profile. The surface pressure perturbation is the summation of the total temperature variations along the air column till some common pressure surface if we assume that diurnal pressure change above that level is negligible. The averaged potential temperature profile (derived from University of Leeds Independence Airport 60 days Rawinsonde Data for T-REX period) shows that the afternoon valley atmosphere is almost adiabatic. A shallow strong inversion layer about 100m forms near the ground at nighttime. The averaged sounding also shows that the valley mixing layer is about 3000m for quiescent days. For westerly days, the mixing layer top is around 2500m.

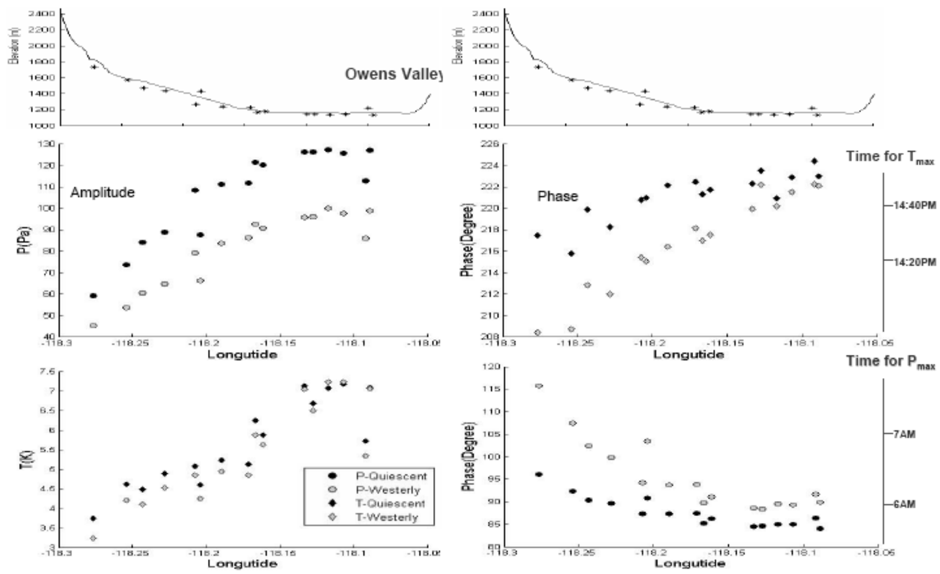

Figure 1: The diurnal components amplitude and phase of the surface pressure and temperature perturbations for stations across Owens Valley.

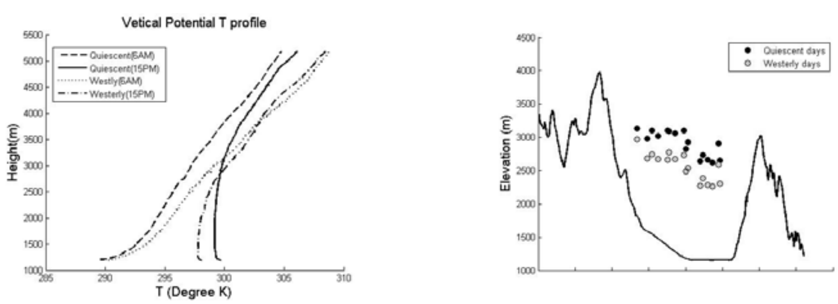

Figure 2: Left: Averaged vertical potential temperature profile in Owens Valley derived from Sounding data. Right: The estimated daytime maximum mixing layer depth (H) for 16 DRI AWS in Owens Valley for T-REX project period.

A simple estimation of the mixing layer depth could be: $H = \frac{2\bar{T}}{\bar{\rho} g} \cdot \frac{|\hat{P}|}{|\hat{T}|}$ $\cdot \left|\hat{P}\right|, \left|\hat{T}\right|$ here are the of the diurnal component amplitude of surface pressure and temperature variations. $\bar{\rho}$, $\bar{T}$ are column averaged air density and temperature. The defined H here can also be used as an index of the flushing effect caused by ridgetop wind, since $|\hat{T}|$ is mainly determined by the incoming solar radiation, but pressure is sensitive to upper level wind. The intrusion of ridgetop wind into the valley, especially during daytime, will affect the adiabatic descending mechanism, and carry away and flush out the heat and prevent the mixing layer buildup. Figure 2 shows the estimated H for Owens Valley from the observations. For quiescent days, the daytime maximum mixing layer reaches almost ridgetop level. For westerly days, the mixing layer height is about 500 meters lower. It is consistent with the mixing layer heights derived from the averaged sounding data.

3. WRF 2D IDEALIZED SIMULATIONS:

WRF idealized numerical simulations are employed to study the quiescent diurnal valley circulation without/with the shadow effect or with the existence of ridgetop westerly. The idealized valley is constructed by two bell shaped mountains. The computational domain is 100km in x direction (across valley) with spatial resolution 250m. The domain extends to 16km in the vertical direction with 200 equally spaced grid points and a 5km Rayleigh Damping layer near the top. The open boundary condition is chosen for x direction and periodic condition for y direction to represent an infinite long valley. The 3rd order Runge-Kutta scheme and 1.5 order TKE closure sub-grid model are used. Heating is applied at ground with $Q_{\mathbf{max}}$ = 200 Wm^{-2} at noon and $Q_{\mathbf{min}}$ = -34 Wm^{-2} at midnight, with a sinusoidal shape during the day to represent the incoming shortwave radiation and nearly constant at night to represent the longwave radiation cooling. The initial dry sounding is derived from the averaged 4AM Reno sounding in April. The model is integrated for 2 days. The first 24 hours are used as a spin-up for the system.

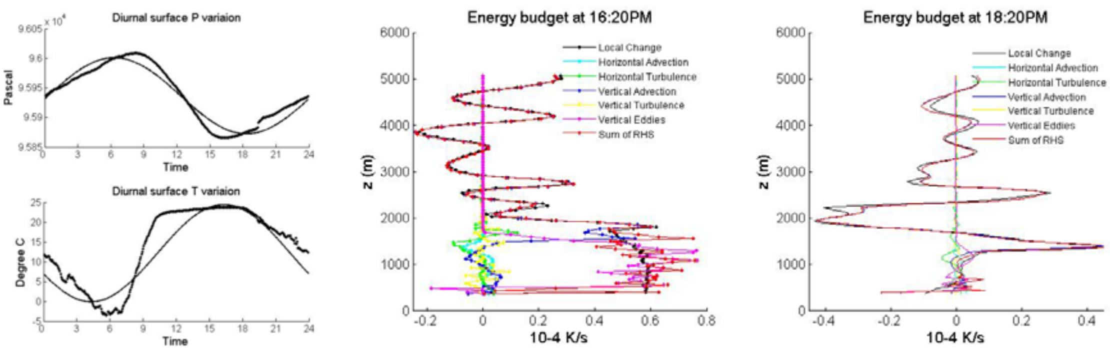

Figure 3: WRF simulations for the quiescent day without shadow effect: diurnal surface temperature and pressure variations at the valley center and their diurnal component; the vertical heating budget at 4:20PM and 6:20PM for the valley center.

The diurnal surface temperature and pressure variations at the valley center are shown here with their diurnal components. The phase for surface pressure is 94^o, which refers to 18:20PM for diurnal surface pressure minimum. The phase for surface temperature is 244^o, which refers to 16:20PM for diurnal surface temperature maximum. Although there's difference between the phases calculated from the observations and the idealized WRF simulations, but the existence of time lag between surface pressure minimum and surface temperature maximum are consistent.

The energy budget is calculated to study the valley heating mechanisms. In the energy equation $\frac{\partial \theta}{\partial t} = \dot{Q} - \bar{u}\frac{\partial \bar{\theta}}{\partial x} - u'\frac{\partial \theta'}{\partial x} - \bar{w}\frac{\partial \bar{\theta}}{\partial z} - \frac{\partial (w'\theta')}{\partial z} + \frac{\partial}{\partial t}\left[K_v\left(\frac{\partial \theta'}{\partial z} - \gamma\right)\right]$, $\frac{\partial \theta}{\partial t}$ is the local temperature change, $-\bar{u}\frac{\partial \bar{\theta}}{\partial x}$ and $-\bar{w}\frac{\partial \bar{\theta}}{\partial z}$ are the heat transport through horizontal and vertical advection, $-u'\frac{\partial \theta'}{\partial x}$ and $-\frac{\partial (w'\theta')}{\partial z}$ are the heat transport through horizontal and vertical turbulence with resolved eddies. $\frac{\partial}{\partial t}\left[K_v\left(\frac{\partial \theta'}{\partial z} - \gamma\right)\right]$ is the vertical heat transport through the unresolved eddies. $\dot{Q} = 0$ is everywhere except at the ground.

For the lower part of the valley, local heating is mainly contributed by the unsolved eddies. For the upper part, local heating is mainly contributed by the vertical advection. At 4:20PM, diurnal surface temperature component reaches its maximum, $\frac{\partial \theta}{\partial t}$ is zero at ground but still positive in the valley center. At time 6:20PM, the vertical descending still warms up the upper part of the valley, with $\frac{\partial \theta}{\partial t}$ still positive at the valley upper part but negative near the ground, and $\int_{z=0}^{z=H} \frac{\partial \theta}{\partial t} dz = 0$. Surface pressure variations actually reflect the temperature variation in the upper part of the valley.

With the shadow effect, western slope will get incoming sensible heating ahead of eastern slope. Around sunrise/sunset time, there will be strong wind cross the valley due to the asymmetric heating. With the effect of ridgetop westerly, the daytime vertical descending in the valley center will be modified by the synoptic wind. Compared with those derived from the observation in Owens Valley, the WRF idealized 2d simulation also shows that the ridgetop westerly makes the amplitude of both surface pressure and temperature smaller, with the calculated mixing depth H=2000m for quiescent days, and 1700m for ridgetop westerly days.

4. CONCLUSIONS:

The amplitude and phase distributions of the diurnal component of surface temperature, pressure are calculated and categorized as quiescent and westerly days according to the ridge top westerly. The amplitude and phase of surface temperature are similar for two classes while the pressure amplitude and phase differ markedly. For quiescent days, the diurnal component of surface pressure reaches its minimum around 18PM LST around sunset, while surface temperature reaches its maximum around 14:30PM LST. Since the surface pressure is the integral of the column air mass above the surface, which, in turn, depends on the temperature distribution along the column, so the mixing layer depth (H) is estimated by the ratio of pressure to temperature amplitudes. H can also be used as an index of the ridgetop wind flushing effect, because the ridge top wind can flush out the valley and carry away the heat transported from the ground. The mixing boundary layer becomes lower than that of the undisturbed days.

WRF 2 dimensional simulations have been applied to study the effect of the shadow and ridgetop wind. Without the shadow and ridgetop wind, valley circulation is symmetric. The diurnal component of the surface temperate variation reaches its maximum around 4:20PM but pressure variation reaches its minimum about 2 hour later. The vertical energy budget shows that the diurnal surface temperature variation is determined by the incoming sensible heating and the eddy heat transport. But the dominant factor for diurnal surface pressure variation is the vertical advection. In the late afternoon, although the temperature at and near the ground start to decrease, the descending in the upper part of the valley still warms up the atmosphere there, thus the surface pressure keeps decreasing until after sunset. With the shadow effect, a strong cross-valley wind will form around sunrise/sunset time. With the existence of the ridgetop westerly, the amplitude of the diurnal surface pressure and temperature become smaller compared with that of the quiescent day. And the derived mixing layer depth is 300m lower for westerly case.

***Acknowledgements**: This research was supported by the National Science Foundation, Division of Atmospheric Sciences (ATM-0531212).*

REFERENCES

Banta, R.M. 1984: Daytime Boundary-Layer evolution over mountainous terrain. Part I: Observations of the dry circulations. *Mon. Wea. Rev.*, **112**, 340-356.

Chapman, S., and R. S. Lindzen, 1970: Atmospheric Tides. D. Reidel, 200pp.

De Wekker S. F. J., S. Zhong, J. D. Fast, and C. D. Whiteman, 1998: A numerical study of the thermally driven plain-to-basin wind over idealized basin topographies. *J. Appl. Meteor.*, **37**, 606-622.

Grubisic V., J. D. Doyle, J. P. Kuettner, G. S. Poulos, and C. D. Whiteman, 2005: T-REX: Terrain-Induced Rotor Experiment. *Science overview document and experiment design.*

Mass, C. F., W. J. Steenburgh and D. A. Schultz, 1991: Diurnal surface-pressure variations over the continential United states and the influence of sea level reduction. *Mon. Wea. Rev.*, **119**, 2814-2830.

Rampanelli G., D. Zardi and R. Rotunno, 2004: Mechanisms of Up-Valley winds. *J. Atmos. Sci.*, **61**, 3097-3111.

Whiteman, C.D., 1990: Observations of thermally developed wind systems in mountainous terrain. *Atmospheric Processes over Complex Terrain*, Meteor. Monogr., No. 45, Amer. Meteor. Soc., 5-42.