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Investigating the Features of Desert Areas on the Climate of Boundary Layer

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Abstract: In 1904, Prandtl represented the concept of boundary layer, boundary layer of atmosphere is called to the area of atmosphere that is located just after Earth's surface in which great turbulence is observed in vertical transfer of heat, humidity and air displacement than troposphere. Air flow higher than earth's surface can be as thin and turbulent layers. Since, horizontal wind velocity on the surface is zero, velocity is increasing by altitude immediately. In thin (non-turbulent) layers of flow, no considerable mixing is performed in slide layers of air. Mixing heat, steam and moving inside boundary layer, creates a separated effect on vertical profile of temperature, steam and wind velocity. In the layers close to earth's surface, turbulence of heat, humidity and movement are under the influence of their distance from surface elements like stones, plants and corns. Near to sea shore, there is a cold boundary layer, its depth is changing during day, strong weather inversion separates cold sea boundary layer and above hot weather. In the average distance of 60 km from shore, there is a strong daytime signal in relation with heating and cooling of surface. Also, weak inversion between 825-850 m bar can be observed. In farthest distances from shore about 130 km, the depth of boundary layer is high during day and no sign of inversion exists. Therefore, an upstream ocean cold flow can have great impact on the structure of boundary layer.

Key words: Boundary layer, desert, turbulence, sea, weak

INTRODUCTION

Characteristic of flow field is a function of object's form. Whatever the geometry of surface is simpler (like sphere or cylinder) complexities of flow field are also smaller. The nature of flow on objects is severely dependent on the value of Reynolds number whether it is $Re<1$ or $Re>1$.

In external flows in which the size of object is medium and characteristic length is about $0.01<l<10$ m and upstream velocity is about $0.01<U<100$ m sec^{-1} and the fluid's viscosity is not great (like climate) Reynolds number is about $10<Re<10^9$ and therefore inertia is dominant. According rule of thumb in flows with $Re>100$, inertia effects is dominant and for $Re<1$, viscosity effects are dominant.

For example, in slow precipitation of pollution in lakes because of particle's small diameter and low speed of precipitation, Reynolds number is small and viscosity effects are dominant. Also for the objects that move inside oil with high viscosity, Reynolds number is small because of large value of μ.

In 1904, Prandtl represented the concept of boundary layer and thereby an important relationship was created between ideal fluid flow and real fluid flow. For the fluids that have relatively small viscosity, the impact of internal friction is considerable only in a thin area of environment that constitutes fluid boundary and therefore, flow must be considered as ideal out of this thin layer near to solid boundaries.

When movement is commenced in a fluid that has very low viscosity, flow is non-rotational in the first moment. Since fluid has zero velocity near boundaries with respect to boundaries, velocity gradient from boundaries to fluid flow is great. Velocity gradient in a real fluid is started near to shear boundary forces and decreases flow velocity with respect to boundary. The layer of fluid that its velocity is under the impact of boundary cutting is called boundary layer. Velocity in boundary layer symmetrically tends to velocity of main flow. Boundary layer in the end of upstream flow of flow lines is very thin even in steady state. When this layer is moving, continuous performance of shear stress tends to stop additional particles of fluid and consequently primary thickness increases by adding distance than upstream flow. Also, the fluid is subjected to pressure gradient in the intended layer which is calculated by the help of potential flow. The result will be momentum decrease (inverse pressure gradient) if the pressure in downstream flow is great. Flow out of boundary layer may cause entering momentum to layer. For upstream boundaries of flat surface, boundary layer is started as slow boundary layer in which fluid particles are moving in steady and smooth layers. By the increase of the thickness of slow boundary layer, layer's instability is increased and finally it is turned into turbulent boundary layer in which fluid particles are moving in random paths; though their velocity is decreased because of viscosity in border. When boundary layer is turbulent, yet a very thin layer exists in the vicinity of border that has slow moving which is called slow sub-layer. There are different definitions for thickness of boundary layer. The most fundamental definition refers to main flow displacement because of decreasing the speed of fluid particles in boundary area (Gamo, 1996).

MATERIALS AND METHODS

Boundary layer of atmosphere: Boundary layer of atmosphere refers to an area of atmosphere that is located exactly above earth's surface where great turbulence is observed in vertical transfer of heat, humidity and air displacement than troposphere. Its depth can be considered from several hundred meters to more than several kilometers.

Boundary layer and turbulence: Air flow above earth surface can be as thin and turbulent layers. Since the velocity of vertical wind on surface is zero, velocity is increased by altitude immediately. In thin (non-turbulent) layers of flow, no considerable mixing is formed in slide layers of air. The only mixing that is occurred is via exchange between layers. Molecules are entered from a slower layer near to earth to a faster layer in higher surface; slower velocity of molecule causes the decrease of velocity in upper layer. Similarly, faster molecule in moving towards down, affected by the tension of lower layers, causes the increase of beneath layer velocity. The movement of steam molecule between layers causes the pure transfer of humidity from wet layers to dry layers; and the heat from molecule's kinetic energy also is exchanged because of molecule's exchange between layers (Rutllant and Ulriksen, 1979).

In turbulent flow because of the twist in air mixture between layers, mixing is much more severe than molecular mixing in slow flow. For example, since the amount of steam in surface vicinity is decreased by altitude, in air movement of turbulent twist, steam is higher in upper section than lower section. Turbulence is created via floating and also via vertical shear of horizontal wind. During day, sun heat from lowest layer of atmosphere causes establishing the relation with earth's surface which causes the increase of floating air's pack. The increase of this pack causes more mixing of lower atmosphere. Vertical depth of this turbulent mixing during day defines boundary layer (convection). During night, the atmosphere near to surface is cooled and the energy source for floating is removed. No new turbulent energy exists in this stable boundary layer near to earth. In this state, the mixing factor is vertical shear in horizontal wind; unless in the cases that horizontal wind is very strong, this boundary layer is much less deep during night.

Difference between night turbulence that is created only from wind shear solely and turbulence during day that is created from both floating movement and wind shear. Both curves are change with time of wind vertical tendency in 29 m AGL, based on BIVANE measurement that lower curve shows horizontal changes in night turbulence with relatively small amplitude and high frequency which results in vertical shear from horizontal wind. This curve shows high frequency diversity during day in a low frequency change with a 15-60s period. Other changes during day are in relation with vertical twist of floating air movement (Priestley, 1959).

The structure of turbulent boundary layer: Mixing heat, steam and movement inside boundary layer creates a separated impact on vertical profile of temperature, steam and wind velocity. Changes in wind velocity and steam with altitude when it is mixed appropriately in boundary layer, is relatively uniform. Nevertheless, air packs are non-saturated that are transported up and down by turbulence and are mixed. Thermo dynamic processes that occur are adiabatic. Thus, vertical characteristics of temperature for mixed dry air which changes adiabatic are recognized as a "neutral effect" in characteristics of temperature. In these conditions, temperature is changed uniformly with altitude (Driese and Reiners, 1997).

Proper mixed profiles and turbulence from different meteorology variables penetrate upward gradually during heating cycle of day. The profiles of vertical structure of temperature in a few times during day heating cycle which is measured in Great Basin Desert. Heat during day causes the increase of the depth of temperature potential layer. In night, cooling of lower atmosphere layer creates temperature inversion.

RESULTS AND DISCUSSION

Aerodynamic roughness and vertical wind characteristics: In the layers near to earth surface, turbulence of heat, humidity and movement is affected by their distance from surface elements like stones, plants and corns. Generally, uneven surfaces cause more severe turbulence. Turbulence effect on vertical wind in surface layer is caused by a parameter named roughness length (z_0). Equation 1 shows it specifically (strong convective mixture):

Table 1: Estimation of aerodynamic roughness length in desert (U-Unknown) (Desert meteorology)

Surface type	Value (cm)	Location	Reference
Bare sand (1 mm diameter)	0.001	u	Bagnold (1935)
	0.018	Peruvian desert	Stearns
	0.030	u	Oke (1987)
	0.070	u	Stull
Moving sand	0.300	u	Rasmussen
Bare, smooth playa	0.010	u	Sullivan (1987)
Sand with small desert shrubs	0.173	u	Greeley and Iverson
Very Rough lava	1.000	Mojave desert	Greeley and Iverson
Sand with small desert shrubs	0.105	Sonoran desert	Lee
Smooth desert	0.030	u	Deacon
Dry lake bed	0.003	Mojave desert	Vehrencamp
Smooth mud flats	0.001	u	Deacon
Stones (7 cm diameter)	0.028	Peruvian desert	Stearns

$$U = \frac{U_*}{k}\ln\frac{z}{z_0} \quad (1)$$

Where:

U = Mean wind velocity in altitude z
u_* = Friction velocity
k = Von Karman constant which its value is equal to 0.35-0.40
z = The altitude higher than earth's surface

Friction velocity shows the velocity of atmosphere movement on earth's surface and/or friction stress. Surface layer in which this equation is satisfied is withing 50-100 m of mixed layer and displacement of heat, humidity and movement is partly turbulent. If $z = z_0$ in relation 1, then U = zero.

Therefore, when z_0 altitude is higher than earth surface as high as in which wind velocity goes to zero, this condition is neutral condition and is proportional to surface roughness. Since, U_* is a function of altitude in surface layer and K is a constant, the changes of U is logarithmic with increasing z.

It is clear that z_0 is linearly related to line slope U/ln (z/z_0) and intercept is z_0. U profiles with altitude are shown for stable and unstable conditions. For stable conditions, curve's direction is downward and for unstable conditions, curve direction is upward. Bagnold (1935) showed that roughness length of a flat bare sandy surface is almost 30 times of mean diameter of sand grain (almost 10^{-5}m for common sand). For tiny sand, roughness length is only a little larger than the estimated value for calm water surface (Oke, 1987). Sullivan (1987) using wind characteristics measurement estimated that roughness length of bare flat surface of Mojave Playa desert which is covered by clay is 10^{-4}m. When vegetarian exists, roughness length is larger and its obtaining is harder (Driese and Reiners, 1997; Griffiths and Soliman, 1972).

There are many studies on the area of boundary layers in agriculture with regular cultivation but there is less studies on less-homogenous natural environments. Table 1 shows the estimation of different lengths of aerodynamic roughness for desert.

Individual aspects of desert boundary layers: Boundary layers in desert have individual continent; boundary layers in their depth are different with desert in terms of temperature, dryness and dust. Generally, water shortage in bed causes the increase of surface temperature that can transfer stronger thermal flux to atmosphere and increase mixing depth. Because of low humidity of bed, evaporation and sweeting rate is low. Because of lacking vegetarian, wind velocity near to earth surface is very close to upper levels of atmosphere and bed dryness causes soil particles not to be connected; both the factors increase entrance of dust to upper layers of atmosphere.

Depth of boundary layer of afternoon (dashed lines) is in the range 4-5 km. Inversion of constant temperature above boundary layer is clear in June and August. During winter, depth of boundary layer is 1 km or less during afternoon. Night profile (continuous line) shows AGL about 2 km along with neutral layers during night in summer. Nightly layer is stable and its lowest value is 500 m AGL. As it is shown by a comparison from January and July profiles, a very big seasonal changeability exists in the depth of boundary layer and lower atmosphere stability.

Baquedano is located 60 km far from shore and shows a strong daily signal in relation to surface heating and cooling. Also, a weak inversion between 825 and 850 m bar is observed. El Loa in 130 km of inside shore has a deep boundary layer during day that doesn't show any sign of an inversion. Therefore, an upstream cold flow of ocean can highly affect the structure of boundary layer.

In West Sahara, Nouadhibou (E) is in shore of Atlantic Ocean and in Salah (F) which internally shows shore stataion with existence of constant marine air mass. In Salah, the features of neutral layer are a little more stable and exist in a depth of about 6 km AGL. When lower layers of atmosphere are subjected to southern flow penetration for a long time, hot surface causes the increase of instability. These features are shown averagely for 2 day in May in an empty region of Saudia Arabia which shows a developed deep boundary layer exists in 650 m bar with depth of 3.5 km. Humidity changes uniformly to the top of boundary layer; above it weather dryness is decreased rapidly in fall from upper troposphere (Blake *et al*., 1983).

CONCLUSION

Boundary layer of atmosphere refers to the area of atmosphere that is located just after earth's surface which has high turbulence in vertical transfer of heat, humidity and air displacement than troposphere. Boundary layers in desert have their own unique continents. Boundary layers in their depth are different in terms of temperature, dryness and dust with desert. Generally, water shortage in bed increases surface temperature which this can transfer stronger thermal flux to atmosphere and can increase the depth of mixing. Because of low humidity in bed, evaporation and sweeting rate is low. Because of lacking vegetation, wind velocity near to earth's surface is very near to higher levels of atmosphere and dryness of bed causes soil particles no to be connected; both factors cause the increase of entering dust to higher layers of atmosphere. Desert areas dependent on their distance from shore have different impacts on boundary layer. Close to shore, there is a cold boundary layer that its depth varies during day; strong weather inversion separates sea's cold boundary layer and upper hot weather. In mean distance of 60 km from shore, there is a strong daily signal in relation with surface heating and cooling. Also, a weak inversion is observed between 825 and 850 m bar. In more distance from shore, about 130 km far from shore, the depth of boundary layer is high during day and no sign of inversion exists. Therefore, an upstream oceanic cold flow can have high influence on the structure of boundary layer.

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