Statistics of thermal convection structures in atmospheric boundary layer based upon acoustic sounding data

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Overview

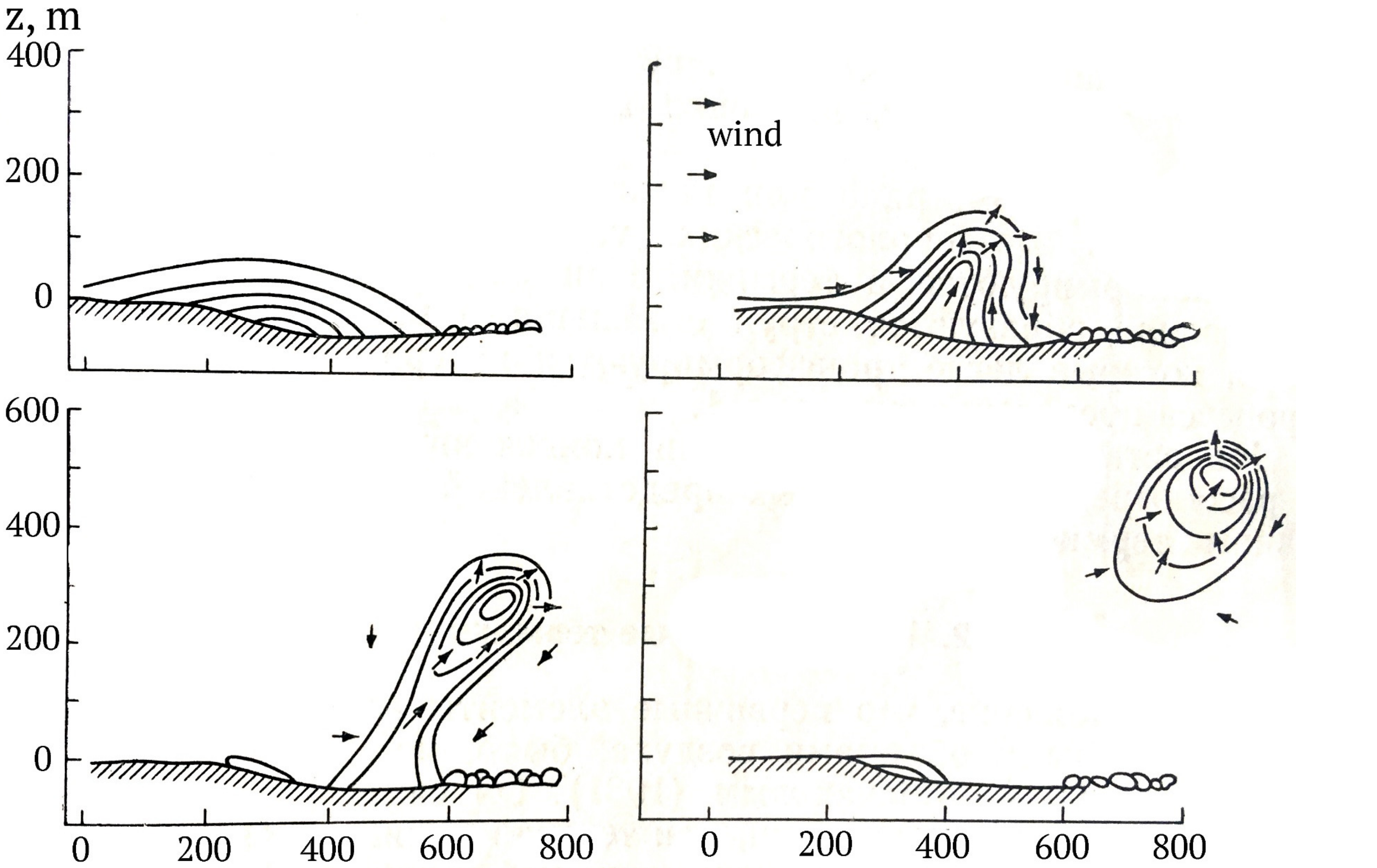
- Definition and Motivation
- Apparatus
- Method
- Cpp code
- Results
- Summary and conclusions
- Prospects

Thermal convective structures (thermals)

- It is observed that the fluid comes away from the heated boundary in lumps, which are called *thermals*
- Thermals will normally behave like each other except in so far as they are born different (ideal case – isolated from each other, in "Bubble theory", for instance)
- But they mix with the surroundings as they advance, and they grow bigger thereby. After a time therefore, most of the fluid of which a thermal is composed was originally motionless in the surroundings and most of the momentum and vorticity it possesses will have been generated by the buoyancy forces since its birth
- The condition for buoyant convection to occur atmospheric thermals: adiabatic lapse rate (decrease of temperature with height), thermal sources over land, thermals over the sea, thermals over the desert: dust devils, thermals in a valley: heating a stable lay and other

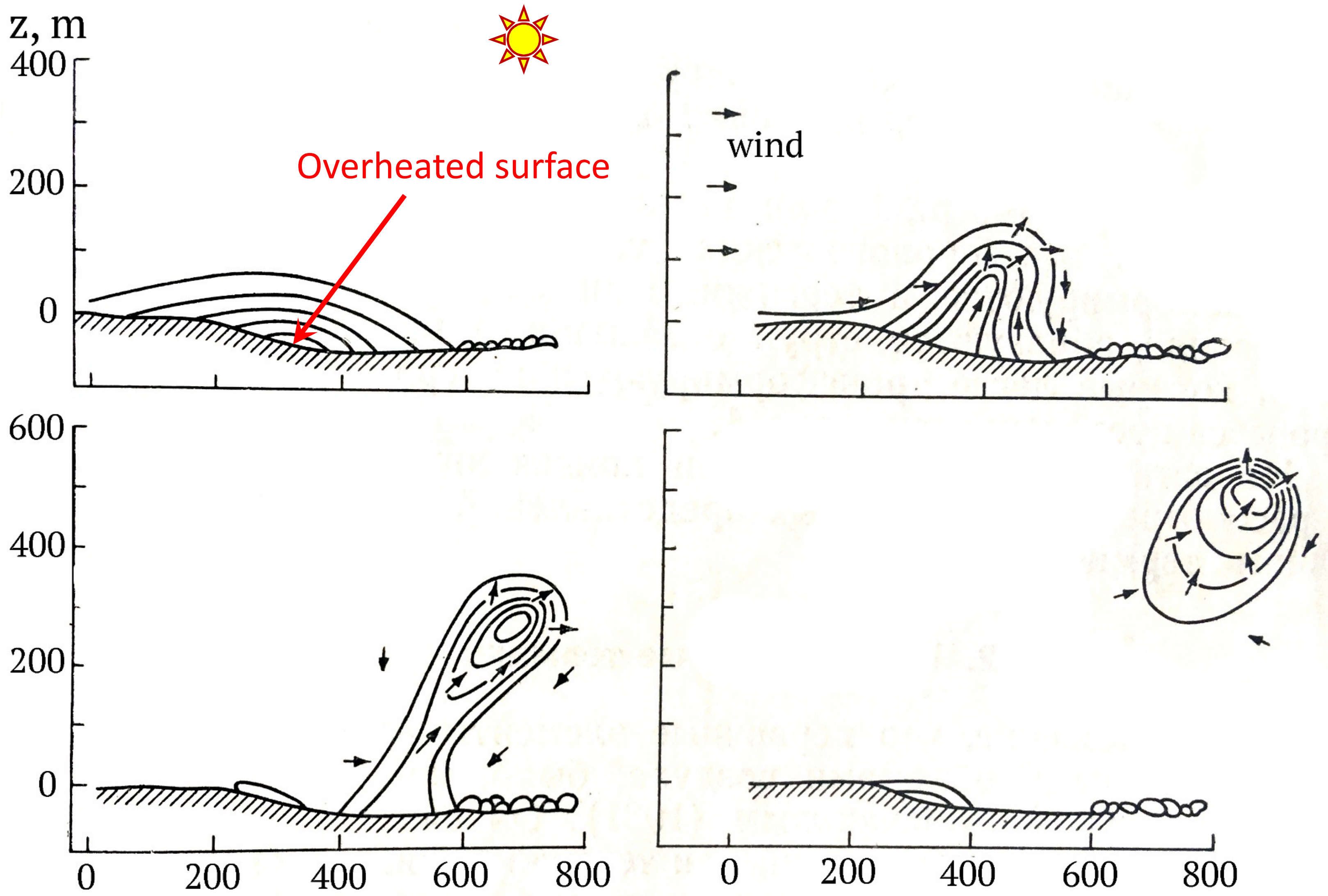
(Scorer R.S., 1958, 1978; Andreev V. & Stanchev S., 1975)

Simple thermal generation and rising scheme (Woodward, 1960)



When cloud is formed we can normally see thermals in the atmosphere

Simple thermal generation and rising scheme (Woodward, 1960)



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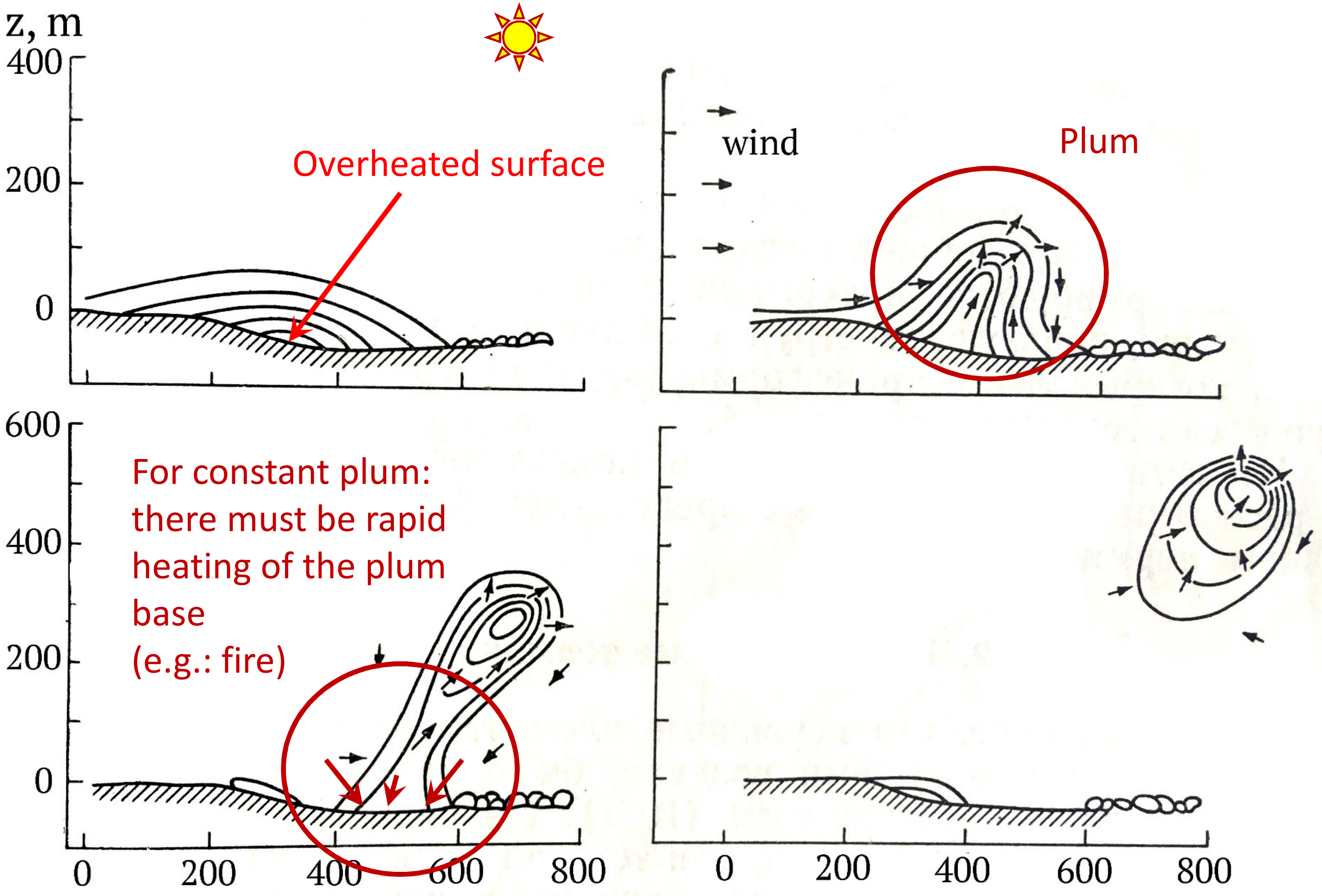

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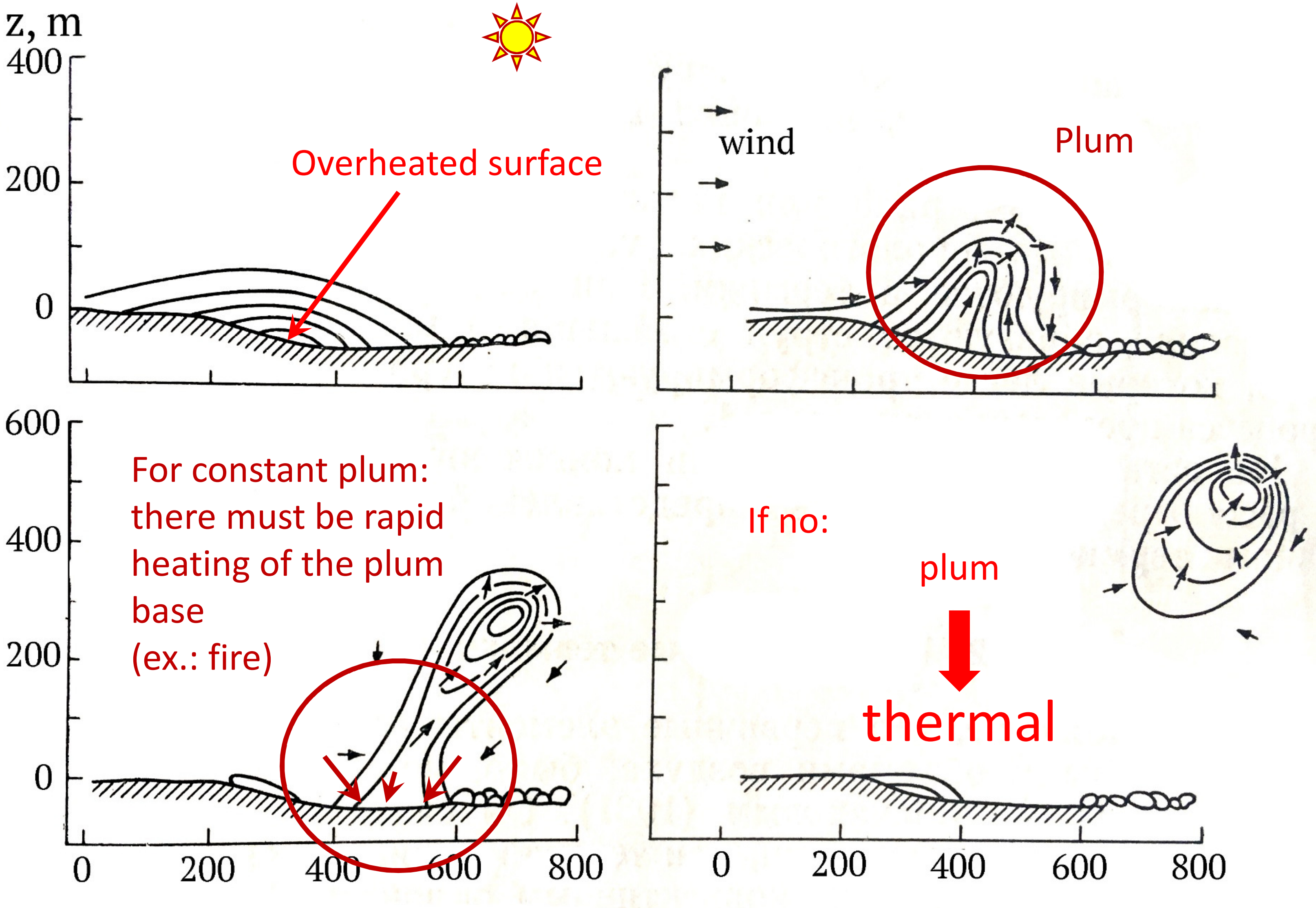
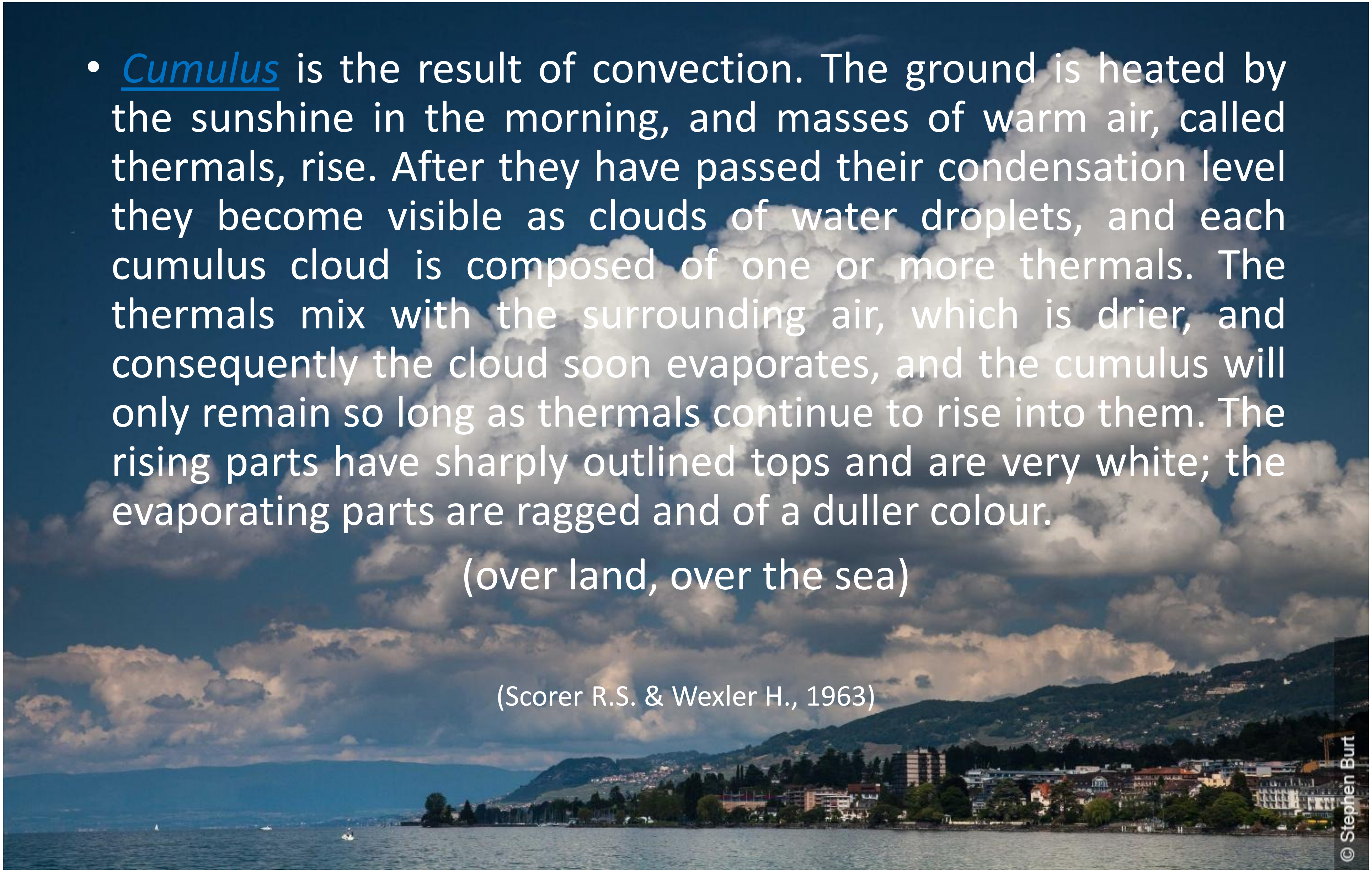


When cloud is formed we can normally see thermals in the atmosphere

Convective clouds connected with thermals



- *Cumulus* is the result of convection. The ground is heated by the sunshine in the morning, and masses of warm air, called thermals, rise. After they have passed their condensation level they become visible as clouds of water droplets, and each cumulus cloud is composed of one or more thermals. The thermals mix with the surrounding air, which is drier, and consequently the cloud soon evaporates, and the cumulus will only remain so long as thermals continue to rise into them. The rising parts have sharply outlined tops and are very white; the evaporating parts are ragged and of a duller colour.

(over land, over the sea)

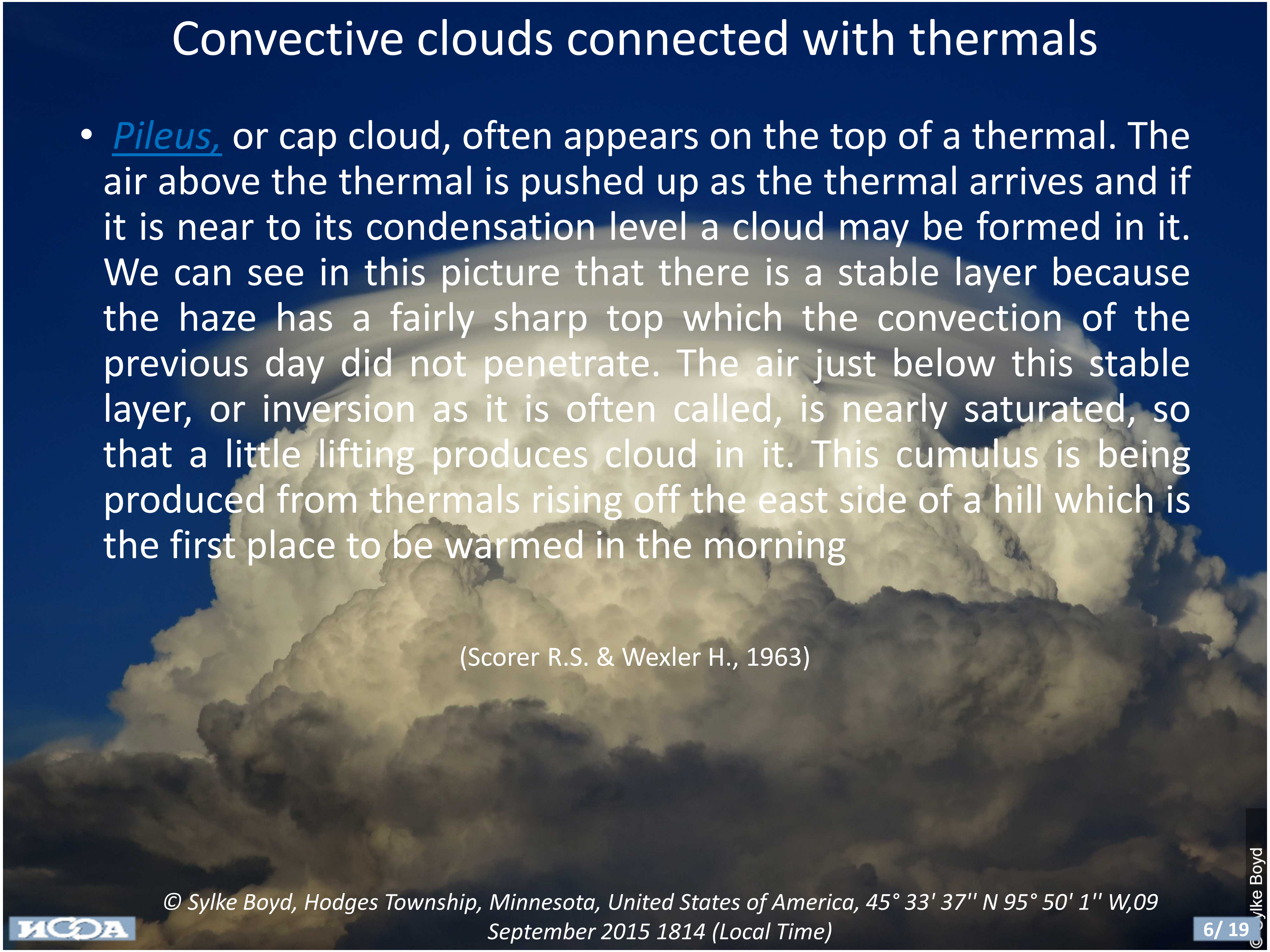
(Scorer R.S. & Wexler H., 1963)

© Stephen Burt, Montreux, Switzerland, 46° 25' 18'' N 6° 55' 25'' E, 29 May 2014 0932 (Local Time)

Convective clouds connected with thermals

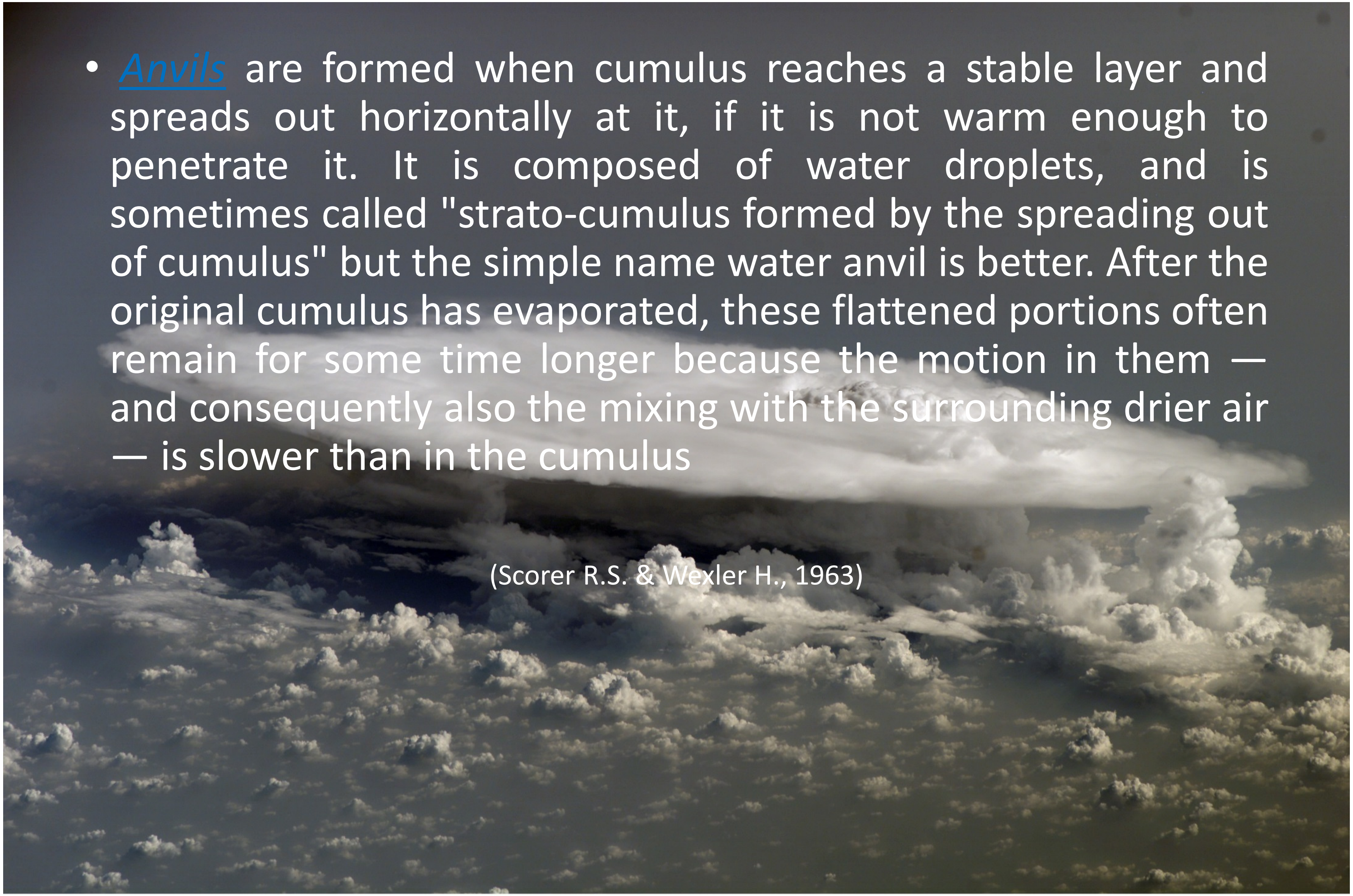
- *Pileus,* or cap cloud, often appears on the top of a thermal. The air above the thermal is pushed up as the thermal arrives and if it is near to its condensation level a cloud may be formed in it. We can see in this picture that there is a stable layer because the haze has a fairly sharp top which the convection of the previous day did not penetrate. The air just below this stable layer, or inversion as it is often called, is nearly saturated, so that a little lifting produces cloud in it. This cumulus is being produced from thermals rising off the east side of a hill which is the first place to be warmed in the morning

(Scorer R.S. & Wexler H., 1963)



© Sylke Boyd, Hodges Township, Minnesota, United States of America, 45° 33' 37'' N 95° 50' 1'' W,09 September 2015 1814 (Local Time)

Convective clouds connected with thermals



- *Anvils* are formed when cumulus reaches a stable layer and spreads out horizontally at it, if it is not warm enough to penetrate it. It is composed of water droplets, and is sometimes called "strato-cumulus formed by the spreading out of cumulus" but the simple name water anvil is better. After the original cumulus has evaporated, these flattened portions often remain for some time longer because the motion in them — and consequently also the mixing with the surrounding drier air — is slower than in the cumulus

(Scorer R.S. & Wexler H., 1963)

Convective clouds connected with thermals

(Scorer R.S. & Wexler H., 1963)

- *Artifical thermals* may be produced by a sufficiently large artificial source of heat
- and others.

Papers. Motivation

- Theory of convective plumes: Zeldovich, 1937; Batchelor, 1954; Morton, Taylor, Turner, 1956; Sounders, 1957; Squires, Turner, 1962…
- Turbulent convective plumes: Vulfson, 1961
- Isolated thermals - observations, data treatment, models, laboratory experiments: Ludlam, Scorer, 1953, 1957 (Bubble theory); Woodward, 1959; Malkus, Witt, 1959; Lilly, 1962, Ogura, 1962…

“ **–** ”:

- Data scattering of empirical constants
- Complexity of aircraft investigation → use acoustic sounding data
- In studying thermal convection structures a large number of theoretical physico-mathematical model has been created. Numerical solution of the thermohydrodynamics equations are difficult for calculating, analysis and understanding the results. An exact analytic solution are found only in some case studies
- Consequently, the statistic methods retain its relevance and significance and continue to develop (Petenko I. & Bezverkhnii V., 1999). The Maxwell distribution for ensemble of the thermal convection structures was received (Vulfson A. & Borodin O., 2016)

Apparatus

- A longwave LATAN-3M sodar with a vertical resolution of 20 m, a pulse emission interval of 5 s, an altitude range of 400–600 m, and a basic carrier frequency of 2 kHz was used to receive the profiles of the wind velocity components and the vertical length of the ascending convection stream, 2007
- A longwave LATAN-3M sodar with a vertical resolution of 10 m, a pulse emission interval of 3 s, an altitude range of 350 m, and a basic carrier frequency of 3 kHz was used to receive the profiles of the wind velocity components and the vertical length of the ascending convection stream, 2016

Apparatus

- From sodar echograms and vertical velocity patterns it is easy to visually identify thermal convective coherent structures (Brown and Hall, 1979; Neff and Coulter, 1986). A few earlier papers (Hall et al., 1975; Moulsley et al., 1985; Taconet and Weill, 1982; Greenhut and Mastrantonio, 1989) have presented some of the results of sodar studies of the convective plumes and have identified some typical features of the behaviour of thermal turbulence and vertical velocity in the CBL. Plume-shaped areas of high temperature fluctuations revealed from sodar echograms usually correlate well with upward flow
- Consider the data obtained during periods shortly after midday when convection is fully developed and steady

(Petenko I. & Bezverkhnii V., 1999)

Method

- The new method of acoustic sounding data treatment for getting thermal convection structures in the atmospheric boundary layer has been received and put to an evaluation test. Results obtained in the experiments of the A.M. Obukhov Institute of atmospheric physics RAS over arid-steppe zones in southern Russia. The observed semi-desert areas were located near the Komsomolsky settlement in Kalmykia Republic (the Caspian lowland).

- The structures have been studied under different wind and temperature conditions over July of years 2007, 2016. A rectangular filter has used for averaging the original data of the horizontal and vertical wind-velocity components. The averaging interval has been empirically chosen and, in this case, amounted to 10 min. At such values, the spatiotemporal velocity-field structure was adequately reproduced.

Assumptions

- From Hall et al. (1975), it should be noted that detection of thermals from the vertical velocity only with a value of $w > w_{th}$ (where w_{th} is a threshold value of about 0.2–0.6 m/s, as suggested by Taconet and Weill (1982)) is only valid for most intense thermals.
- The evaluation of the horizontal scale for thermals under different wind conditions is of interest. Unfortunately, from single-point observations, we can get only a rough approximation using Taylor's hypothesis to convert the temporal scale τ to the spatial one by $l = \bar{u}\tau$, where $\bar{u}$ is the mean wind speed
- The estimation of l-value from a single-point observation gives the lower limit, because a threedimensional convective element passes through this point, not necessary by its central part

(Petenko I. & Bezverkhnii V., 1999)

Method. Cpp code

- Accounting results are represented by the example of 100m – level for 2007 and layer averaged mean value of vertical velocity for 2016 with the averaging parameter 1min.

- The program detected episodes of the above-limit values of a vertical velocity at which convection structures arouse hypothetically. As the limit a few alternatives were used in this work: 0.3 m/s, 0.6 m/s and 1.2 m/s. The duration of over-limit vertical velocity, maximum velocity in this interval and space scale along the X-, and Y-axis have been calculated. It is assumed that convective structures move progressively during any relatively small time step with some averaged velocity. In such a value the spatial distribution of velocity field and its time variations have been reproduced favourably.

Method. Part of Cpp code

```
int main()
{
// … {initialization}
 for (i=1; i<=gran; i++)
 {
 m=0;
 SX=0.0;
 SY=0.0;
 jSum=0;
 for (j=(11*3600/3); j<=(17*3600/3); j++)
 {
 SX2=0.0;
 SY2=0.0;
 for (k=0; k<=Nusr1; k++)
 {
 SX2=SX2+PromX[i][k+j];
 SY2=SY2+PromY[i][k+j];
 }
 AvePromX[i][j]=SX2/Nusr;
 AvePromY[i][j]=SY2/Nusr;
 if (PromZ[i][j]>1.2)
 {
 if (PromZ[i][j]>PromZ[i][j-1])
 {
 SZMax=PromZ[i][j];
 }
 jSum=jSum+1;
 SX=SX+AvePromX[i][j];
 SY=SY+AvePromY[i][j];
 fprintf(ResultVelocityFile, "%f\t", PromZ[i][j]);
 }
 if ((PromZ[i][j]<=1.2) && (PromZ[i][j-1]>1.2) &&
(j!=(11*3600/5)))
 {
 m=m+1;
 Hresult=i*H;
 deltaX=(SX/jSum)*(jSum/Usr);
 deltaY=(SY/jSum)*(jSum/Usr);
 deltaL=sqrt (pow (deltaX, 2) + pow (deltaY, 2));
 fprintf(ResultFile, "%i\t %f\t %f\t %f\t %f\t %f\t %f\t", m,
Hresult, (jSum/Usr), SZMax, deltaX, deltaY, deltaL);
 fprintf(ResultFile, "\n");
 fprintf(ResultVelocityFile, "\n");
 SX=0.0;
 SY=0.0;
 jSum=0;
 }
 }
 }
//…{closing procedures}
}
```

Day time

Averaging procedure

Threshold

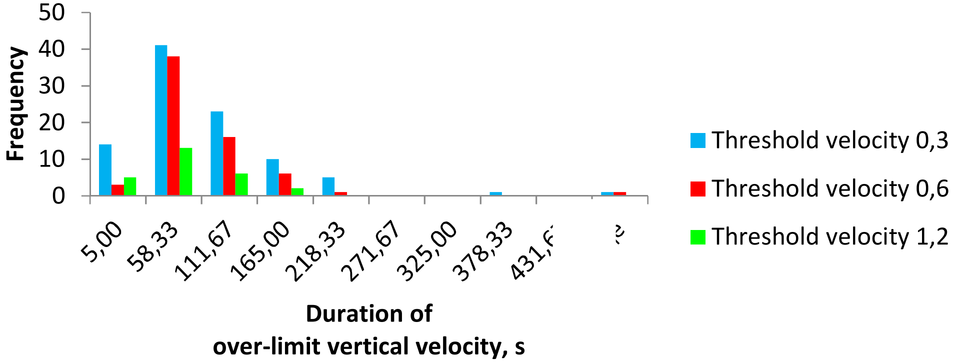
Maximum velocity

Space scale along the X-, and Y-axis

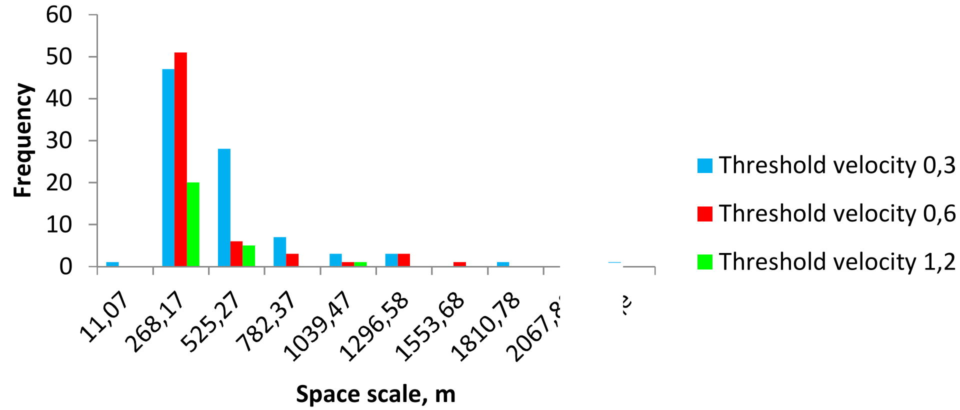
Duration of over-limit vertical velocity

Results

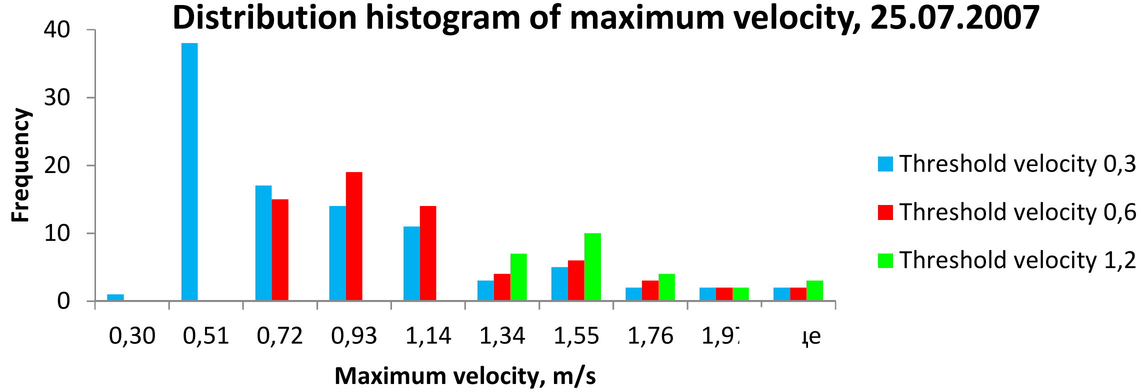
Distribution histogram of Duration of over-limit vertical velocity, 25.07.2007



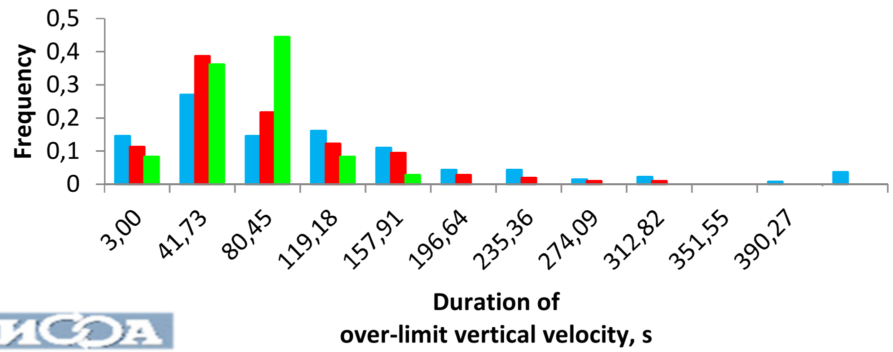
Distribution histogram of space scale, 25.07.2007



Distribution histogram of maximum velocity, 25.07.2007



23.07.2016



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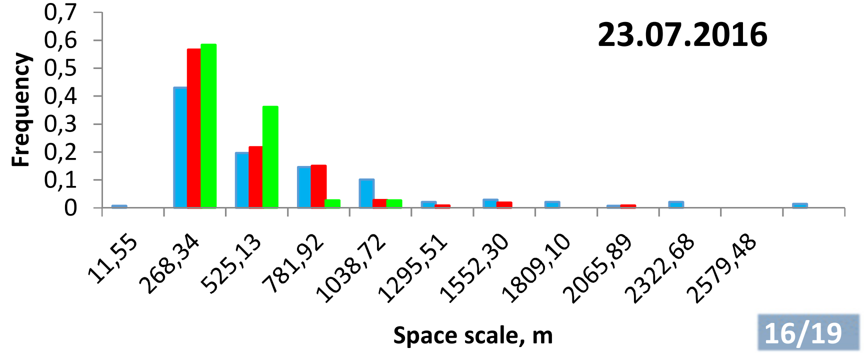


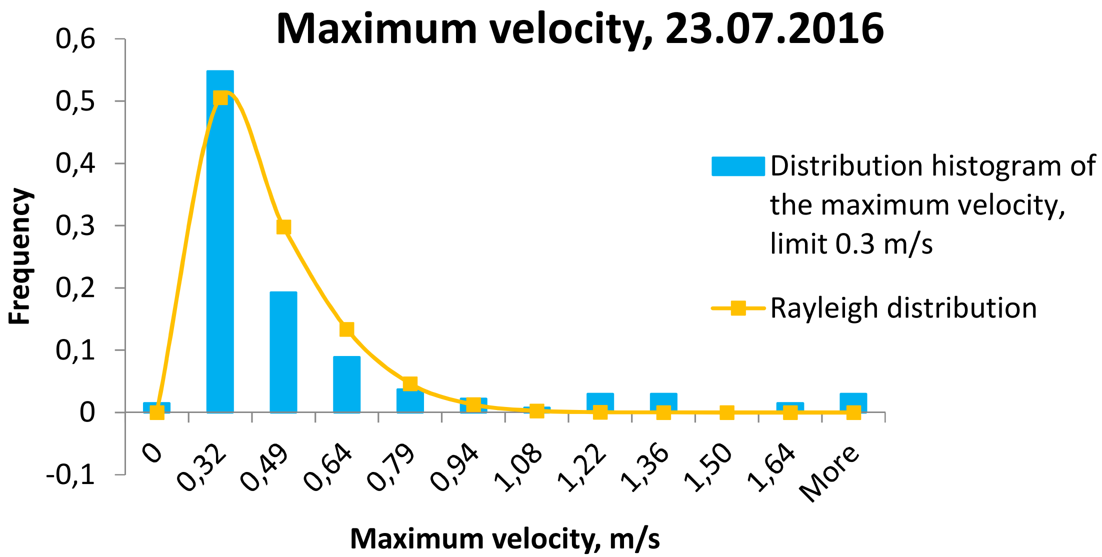
Results

- The received statistic characteristics have been similar to Rayleigh distribution :

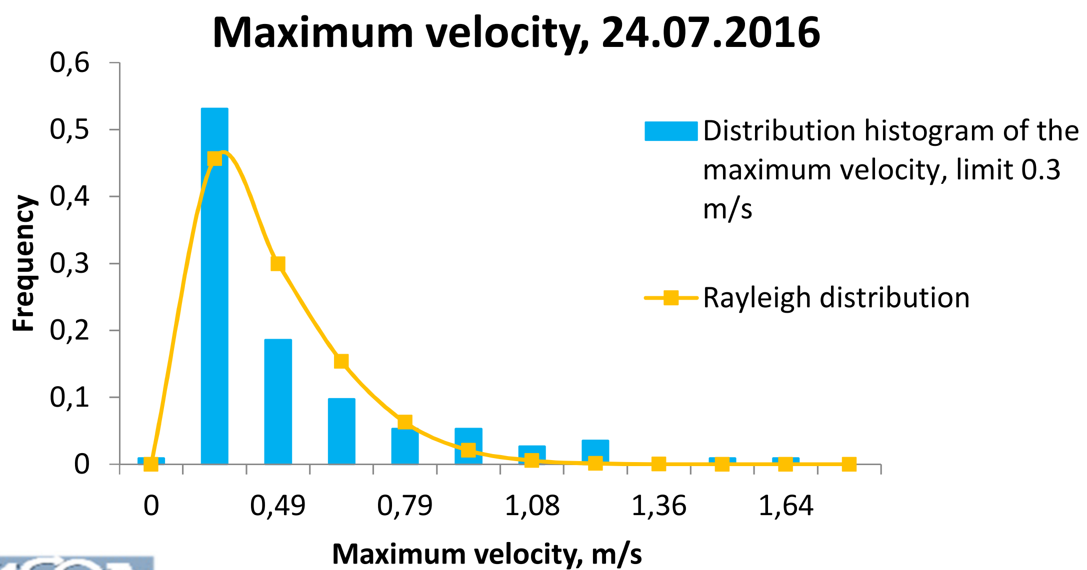
$$\rho(U) = \frac{2U}{{U_0}^2} exp\left(\frac{{U_m}^2 - U^2}{{U_0}^2}\right),$$

here ${U_0}^2 = \left[\langle U^2 \rangle - {U_m}^2\right]$, $\langle U^2 \rangle$ – root-mean-square vertical velocity of the thermal convection structures, U_m – limit for vertical velocity.

Results



Distribution histogram of the maximum velocity and Rayleigh distribution, Kalmykia, 23[d] July, 2016.



Distribution histogram of the maximum velocity and Rayleigh distribution, Kalmykia, 24[th] July, 2016.

Summary and Conclusions

- The statistic methods of thermals investigations retain its relevance and significance and continue to develop
- The received statistic characteristics have been similar to Rayleigh distribution (Such a distribution are applied for the statistics of the intensive humid-moistly convective vortices and for the height of the ocean waves also)
- This fact facilitate the forecast of thermal convection structures

- Future plans: using Kernel Density Estimation, also termed the Parzen–Rosenblatt window method, to solve data smoothing problem where inferences about the population are made, based on a finite data sample