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Acoustic Sounder Study of Sea Breeze in Southwest Monsoon Season

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Acoustic sounder echo patterns obtained at Visakhapatnam during periods of sea breeze in the month of July 1980 (monsoon month) are presented and discussed in the light of the prevailing weather conditions and surface meteorological data obtained from the antenna site. Sea breeze occurrence in July is occasional, unlike daily occurrence in summer, because of the dominant gradient flow from west to east due to the prevailing southwest monsoon. A large increase in the intensity and height of backscattered echoes was observed at the onset of sea breeze indicating the thermally inhomogeneous and turbulent nature of the air just behind the moving sea breeze front. The increase in the depth of the sea breeze as shown by the acoustic records was mirrored in hygrograms.

1 Introduction

Sea breeze is a dynamical response to the differential heating of land and sea by the sun. Sea breeze is purely a local phenomenon, and its growing and decaying pattern is different at different areas because of the differences of latitude, sea temperature, topography and other circumstances. Even at the same place, the sea breeze pattern varies considerably from day to day[1]. Considering the basic mechanism of sea breeze, one can safely state that the sea breeze becomes stronger with the amount of land heating or insolation. However, strong general wind has some influence on the sea breeze[2]. The onset time of sea breeze will be later under offshore gradient flow than in calm conditions. Under onshore gradient flow the land heating is suppressed and hence the sea breeze is recognized only as a little increase of the onshore gradient flow.

Visakhapatnam (lat., 17.7°N; long., 83.3°E) is situated on the eastcoast of the Indian Peninsula. Presented here are the acoustic sounder echo patterns obtained at Visakhapatnam during periods of sea breeze in the month of July 1980 (monsoon month). While studying the seasonal and diurnal variations of the surface wind characteristics at Visakhapatnam, Agarwala[3] has stated that the summer months (February-May) are most favourable for the sea breeze at Visakhapatnam. Later, Ramanadham and Subbaramayya[4] and Purnachandra Rao *et al.*[1] have reported some of the characteristics of the sea breeze at Visakhapatnam, the former basing their findings on pilot balloon data and the latter on acoustic sounder data. But all these studies were carried out during the premonsoon period only. However, during the monsoon season (June-September) the prevailing winds over the peninsula are from west to east and the effect of sea breeze at a station on the east coast would reveal itself by a sudden change in the wind direction from west to anywhere between southeast and south-southwest depending on the locality and terrain features. At Visakhapatnam, this change in the wind flow from offshore to onshore has brought a sudden change in the acoustic echo pattern because the transition from land breeze to sea breeze results in a sudden change of stability[5]. On many occasions a large burst of strong scattering extending to heights of 200-400 m was observed at the onset. The acoustic sounder was also able to show the decay time of the sea breeze circulation by reestablishing the intermittent scattering regions which appeared before the onset or by perturbing the existing echo structure. Many other characteristics of the sea breeze as deduced from acoustic records are presented and discussed. Surface meteorological data obtained from the antenna site on days of sea breeze have also been presented.

2 Operation of the Acoustic Sounder and Its Location

Acoustic sounder (or sodar) is a continuous and automatic remote sensing method of qualitative assessment of temperature/turbulence microstructure in the atmosphere. Scattered acoustic power also contains quantitative information on the thermal structure of the atmosphere. In the latest studies, the temperature structure parameter C_T^2 has been successfully estimated quantitatively[6]. If the Doppler technique is used, one or more wind components can be obtained depending on the design of the system[7-9]. However, the present study done by recording the backscattered acoustic energy on a facsimile-type recorder is qualtitative in nature.

2.1 Brief Description of Monostatic System

This system operates on a backscatter principle very similar to that of a radar. In a monostatic system, acoustic backscattering is caused by small scale (~10 cm) temperature inhomogeneities which are produced by turbulence in regions of larger scale potential temperature gradients[10]. A pulse of sound is transmitted vertically into the atmosphere and the amount of sound scattered back to the antenna is measured as a function of height. Received signals, after proper amplification, are displayed on a facsimile-type recorder, with darker areas marking the times and heights of strong acoustic backscattering. This system has been operated with 100 msec toneburst of 1600 Hz repeating every 18 sec with a peak power of 100 W (electrical) and probing range of 1 km.

The system is situated in the Andhra University campus, Visakhapatnam. The antenna site is roughly 1 km away from the coastline and nearly 40 m above the mean sea level. The sea coast at Visakhapatnam is oriented nearly in the southwest-northeast direction with Bay of Bengal to the east.

3 Results and Discussion

Examination of the acoustic sounder records for the month of July 1980 revealed evidence of a sea breeze circulation on 7 days. Although the 7 episodes observed had some similar characteristics, each one was unique by itself. Figs. 1-3 show echosonde records pertaining to the development and decay of the sea breeze circulation for three days, viz. 14, 15 and 17 July 1980.

Most of the days in July were rainy and cloudy due to the prevailing southwest monsoon. However, sea breeze did occur on days of moderate cloud cover, light gradient flow and moderate surface heating by the sun.

Also shown in Figs. 1-3 are thermograms and hygrograms obtained on days of sea breeze from the Meteorological Observatory situated very close to the antenna system. Three hourly surface observations (0000, 0300, 0600, ... GMT hrs)) giving prevailing weather conditions, wind and cloud (amount and type) are shown on records in international symbols. Hourly wind data during the period 0600-1900 hrs LT which are available are also shown. It may be mentioned that anemograph is not available at the observatory.

3.1 Sodar Record of 14 July 1980

Shown in Fig. 1(top) is the acoustic sounder record obtained from 0810 hrs on 14 July 1980 to 0040 hrs LT on 15 July 1980. About four to five octa cloud cover, mostly middle and high type, was observed during morning hours. Due to this, the intermittent scattering regions, characteristic of convective plume activity

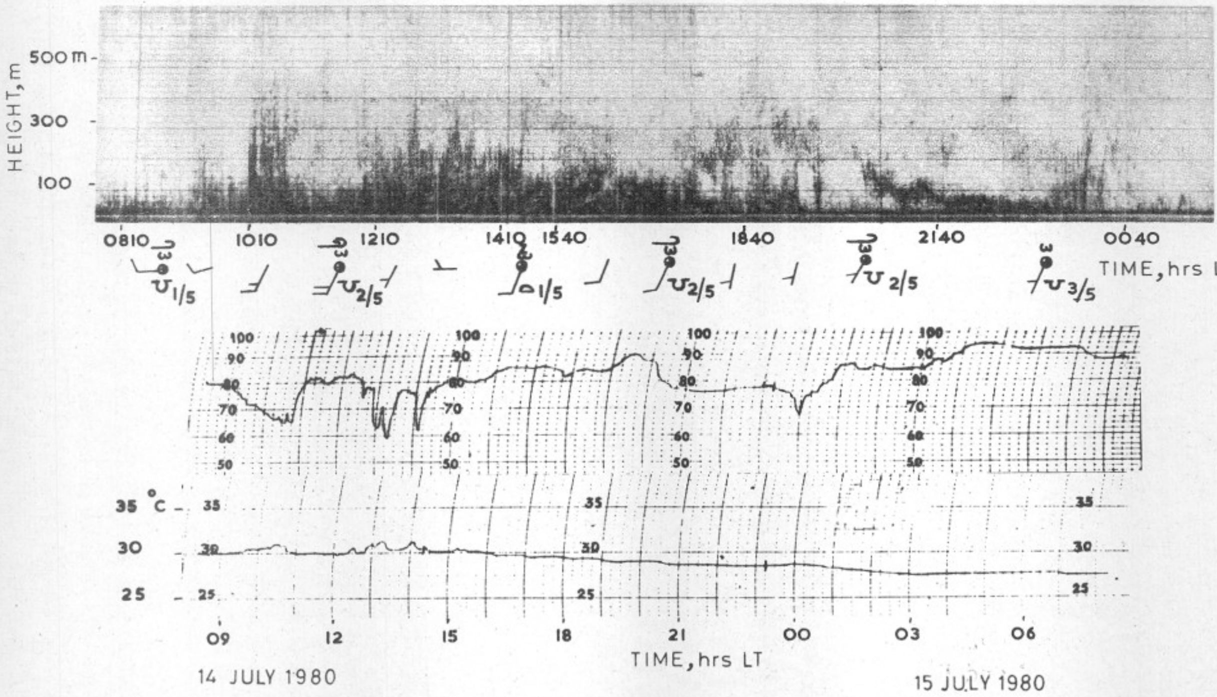

Fig. 1—Acoustic sounder record of 14 July 1980 showing the sea breeze related returns (Also shown are the hygro and thermograms obtained from the antenna site.)

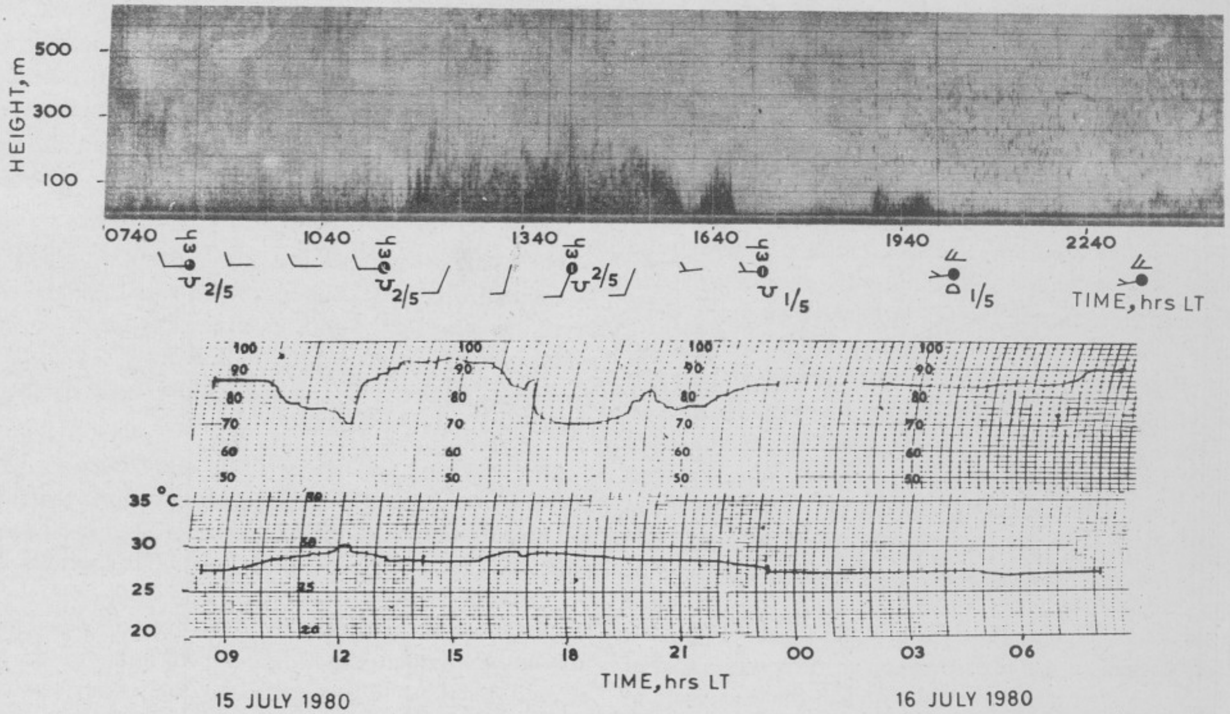

Fig. 2—Same as Fig. 1 but for 15 July 1980

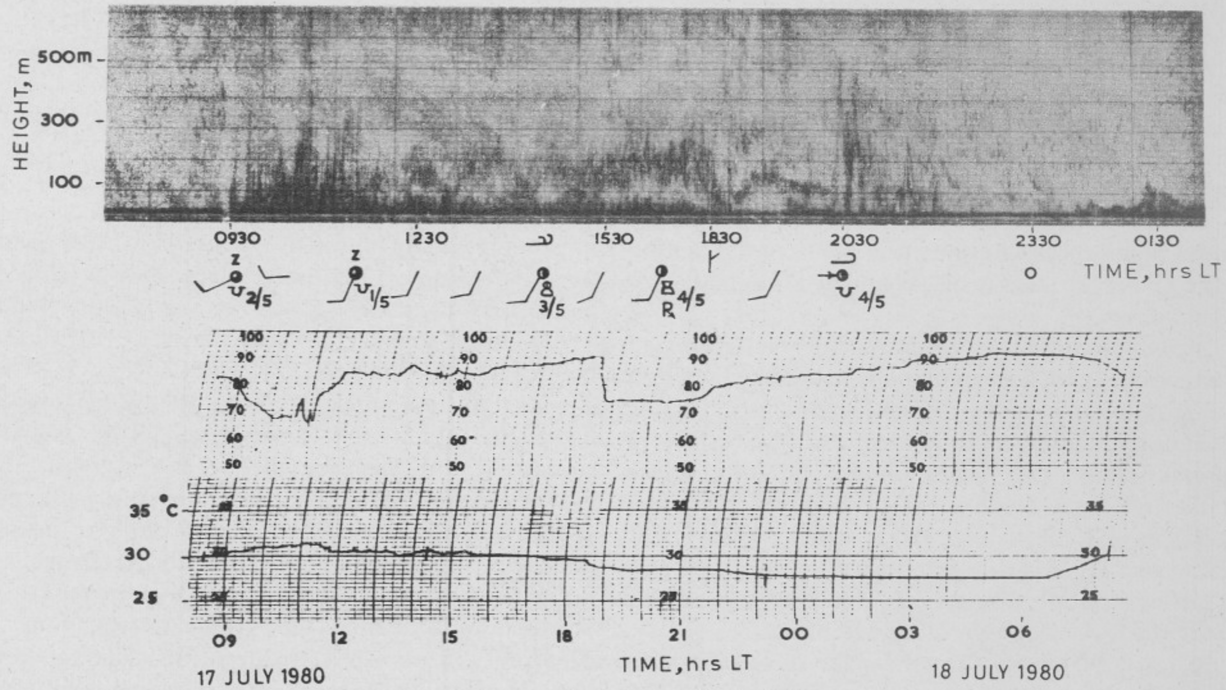

Fig. 3—Same as Fig. 1 but for 17 July 1980

associated with a low level superadiabatic (unstable) layer[11], were weak and extended only up to 200 m until 0930 hrs LT unlike those in May which extended up to 500 m. These intermittent scattering regions are also called spike echoes because they appear as vertical intermittent spikes or 'grass' rising from the ground[12]. These conditions prevailed up to around 1000 hrs LT, after which the echo pattern has suddenly changed. If there is no sea breeze, these plumes continue to appear on the record throughout the daytime with a maximum frequency of occurrence around noon when surface heating is most intense and they gradually die out during the afternoon as the heating of the earth's surface by insolation decreases.

At about 1010 hrs LT a sudden enhancement of echo heights and intensity of backscattering extending to nearly 350 m height was observed. This echo structure has persisted for about 35 min after which the scattering is confined to below 100 m till 1200 hrs LT. It is thought that this enhanced backscattering is due to strong vertical motions along the sea breeze front. Glider observations also indicate upward speeds of the order of 10 m/sec in this region at a height[13] of about 1 km. In his theoretical model, Estoque[14] also found strongest vertical motions along the sea breeze front. During this episode the fall in relative humidity (RH) was arrested and two small jumps in RH were noticed at 1025 and 1035 hrs LT, respectively. The final steep rise in RH of about 15% was noticed only at 1045 hrs LT which marks the onset of sustained sea breeze at the antenna site. This time has coincided with the time when the large scattering prevailing from 1010 hrs LT on the sounder record was suppressed.

The height of the surface-based scattering region was not uniform from 1200 hrs LT, but showed large variations. The fluctuations are due to the temporary withdrawal of sea breeze which in turn reestablished the thermal plumelike activity such as that seen around 1250 hrs LT in Fig. 1. This contention is supported by hygrogram and thermogram records which showed a sudden fall in RH and a rise in air temperature (Fig. 1 bottom). Thus it clearly shows that the sea breeze was not steady but was intermittent. The oscillatory behaviour of sea breeze between 1250 and 1410 hrs LT was due to the prevailing westerlies and changes in cloud amount. This is in agreement with Wexler's[2] statement that sometimes the sea breeze and gradient wind will appear intermittently at a coastal station throughout an afternoon seemingly in a battle for dominance.

From about 1430 hrs LT, the surface-based scattering region has more or less maintained uniform height except for some minor fluctuations indicating that during this time the sea breeze was not oscillatory if not steady. The height of the scattering region increased from around 100 m between 1050 and 1200 hrs LT to nearly 150 m after 1430 hrs LT. Mention may be made here that the wind speed also decreased during this period. This may indicate the decrease in the strength of the sea breeze.

From 1750 hrs LT the echosonde record began to show the development of an elevated layer in addition to the surface-based layer. An increase in the height of the elevated layer on the acoustic record indicates an increase in the depth of the sea breeze circulation. This was also mirrored in the hygrogram with an increase of 8% in RH between 1750 and 1930 hrs LT. This is in agreement with Wexler's[2] observation that an increase in the depth of the sea breeze circulation may produce a rise in RH. The elevated layer on the echosonde record indicates the boundary between the inflowing cool marine air and warm land air above. The boundary between the two air masses, differing sharply in temperature and humidity, is generally a turbulence producing shear zone associated with a temperature inversion which, in turn, produces sharp gradients in acoustic refractive index resulting in strong backscattering of transmitted acoustic energy[15].

The termination of the sea breeze circulation could be clearly seen on the sounder record with the elevated layer reaching the ground level and cessation of the surface-based scattering around 2000 hrs LT. This has also been reflected in the hygrogram by a sudden decrease of relative humidity by 8%.

An elevated layer between 100 and 200 m height began to appear on the record shortly before 2040 hrs LT and it slowly descended to the ground level and appeared as a surface-based layer. This probably indicates that the sea breeze is persisting at higher levels even after it was removed at the surface[16]. This surface-based echo structure has been interrupted at around 2330 hrs LT which may be taken as an indication of the cessation of sea breeze. The sloping echo structure exactly at 0000 hrs LT on 15 July 1980 corresponds to the onset of land breeze. This has also been shown in the hygrogram by a sudden increase in RH. By this time the land air will be more humid than sea air due to greater nocturnal cooling of air over land.

3.2 Sodar Record of 15 July 1980

Despite six to seven octa cloud cover which consists mostly of medium and high type during the daylight hours of the day, a sea breeze circulation developed and lasted for several hours on this day (15 July 1980). The acoustic sounder detected the onset of the sea breeze at approximately 1215 hrs LT (Fig. 2). The sloping echo structure extending to the heights of 320 m at 1215 hrs LT corresponds to the frontal surface of the sea breeze circulation. When a moderate offshore motion of the air exists due to the general pressure distribution, the sea breeze starts suddenly, and temperature and humidity show abrupt changes as if a front is passing[17]. Such situation were investigated at Madras under various meteorological conditions[18]. This front consists of a sloping transition zone between two air masses differing sharply in temperature (the warm land air overlying the cool marine air) and in moisture content. Therefore, the frontal zone is an inversion of considerable slope.

The transition from land breeze to see breeze (Fig. 2) was marked by a change from convective plume structures to structures with stronger echoes and more persistence. The pattern change at the onset of the see breeze was just barely detectable under visual examination.

The hygrogram and thermogram showed a steep rise of 16% in RH and nearly 1°C drop in surface air temperature, respectively, at the onset.

The depth of the sea breeze circulation started decreasing from 180 m at 1540 hrs LT to ground level at around 1610 hrs LT. This marked the termination of the circulation which can, also be seen in the hygrogram. The RH decreased from 92% at 1545 hrs LT to 82% at 1640 hrs LT. Thereafter, the surface winds were light and turned westerly.

Again the sounder record had begun to show a surface-based echo structure from 1630 hrs LT which slowly deepened to a height of approximately 200 m around 1645 hrs LT, then started loosing its height and disappeared completely by 1700 hrs LT. During this 30-min period from 1630 to 1700 hrs LT, a thick haze layer was persisting at the antenna site and visibility was reduced.

Similar situation was recorded from 1815 hrs LT. This time it persisted up to 2030 hrs LT, i.e. for a period of 2 hr 15 min. This is also shown in hygrogram with a prominent rise in RH during this period. The surface winds turned westerly at 2030 hrs LT when the haze layer has withdrawn from the site and the scattering ceased on the acoustic record.

3.3 Sodar Record of 17 July 1980

The sea breeze detected on this day had two distinct features. The scattering from the sea breeze circulation was divided into two discrete regions, namely, a low level zone of intense scattering and an elevated scattering layer between 100 and 300 m heights. The two regions maintained their identity for nearly 6 hr. The decay of the circulation was well marked with the elevated layer reaching the ground level.

Due to the rain and heavy cloud (8 octas), the acoustic sounder system was stopped on 16 July 1980 and switched on only at 0930 hrs LT on 17 July 1980. Prior to the onset of sea breeze around 1120 hrs LT, intermittent plume structures were observed on the record (Fig. 3). Shortly after 1030 hrs LT, the sounder record showed a large increase in the intensity of scattering extending to a height of nearly 400 m as a result of the first spell of the sea breeze. This occurrence was supported by the hygrogram shown in Fig. 3. After this event, thermal plumes began to appear on the record till around 1100 hrs LT when another burst of scattering resulted with the onset of sustained sea breeze shortly after 1100 hrs LT. During the 40-min interval following the onset of sea breeze, RH increased 18% and the fall in surface air temperature was 1°C.

The elevated scattering layer reached the ground level exactly at 1830 hrs LT marking the termination of the sea breeze circulation. This has been well supported by the hygrogram with a sudden fall of 16% in RH. But this fall in RH was arrested at 1850 hrs LT. The steep fall in RH occurred along with a fall in air temperature. This is due to the downdraft from a thunderstorm to the west of the antenna site and its spread eastwards[19]. It may be mentioned that the observatory at the Visakhapatnam air port which is situated to the west of southwest of the antenna site reported a thunderstorm between 1650 and 1750 hrs LT and a strong gust of 25 kmph from a westerly direction at 1807 hrs LT. When the effect of the downdraft ceased, the sea breeze circulation revived at 1850 hrs LT with the development of an elevated layer. This fresh circulation terminated shortly after 2020 hrs LT by a perturbation that produced scattering up to heights in excess of 500 m. The source of the perturbation was not clearly known. The winds were light and changed to westerly at the start of the perturbation. The source for the vertical line echoes around 2300 hrs LT was not understood.

3.4 General Characteristics of the Observed Sea Breezes

The present study clearly shows the variability in the structure of the sea breeze in July. Despite this variability, characteristic features such as increased low level scattering and development of the elevated layer allowed the sea breeze to be detected. The meteorological data confirmed the occurrence of the sea breeze.

Out of 31 days in July 1980, sea breeze occurred on 7 days. A striking difference among the sounder records presented here is in respect of the elevated layer corresponding to the sea breeze. Out of 3 cases presented here, the elevated layer on 15 July 1980 is not discernible. The exact reason for this is not known but a sea breeze of very low depth may not produce an elevated layer because surface heating rapidly reestablishes a shallow superadiabatic layer which may extend to the full depth of sea breeze. However, to confirm this interpretation, one has to have in situ measurements. While studying the sea breeze at Melbourne (Australia), Ahmet[20] reported that some times the sea breeze appears as a surface-based echo structure on acoustic sounder records and he referred to them as not well developed sea breezes. In the remaining two cases also, the elevated layer was detected after a few hours of the onset of the sea breeze. One possible explanation for this delay in the development of the elevated layer may be due to the strong vertical motions along the sea breeze front. These vertical motions can prevent the formation of any elevated layer structure.

The height of the elevated layer in this monsoon month was within 300 m whereas in summer month (May) it reached 600 m (Ref. 1). This is obviously the result of reduced ground heating in monsoon months due to clouds and rain. The onset of the sea breeze circulation was usually preceded by plume activity.

4 Conclusion

The passage of the sea breeze in July was usually well marked by a distinct change in the character of the acoustic sounder records. The increase in the intensity of scattering and extension in the echo heights to 200-400 m at the onset indicated the turbulent and thermally inhomogeneous nature of the sea breeze front. The surface-based scattering layer extending to 100-200 m replaced 'spiky' echo features characteristic of convective plume activity. This low level scattering layer showed some variations in its height due to the oscillatory behaviour of sea breeze. The sounder record also showed haze layer which moved inland from the coast line. These interpretations are, however, based on the basic concepts of sea breeze and echosonde principles. A more convincing interpretation of the echosonde data requires more meteorological data to higher levels obtained with pilot balloon ascents, slow rising radiosonde ascents, tethered balloon systems or other in situ techniques. A beginning in this direction has already been made at Visakhapatnam and the studies are in progress.

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