NOAA Technical Memorandum ERL ETL-296

DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

AERIAL VIDEO OF SMOKE-MARKED WIND SHIFTS CAUSED BY OCEAN INTERNAL WAVES

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1. Introduction

On August 25, 1998, an experiment was conducted off the coast of Oregon for the purpose of corroborating previously measured wind shifts at the ocean surface caused by the passage of solitary, ocean internal waves (IWs) in the same general area (Otto, et.al., 1998). In that experiment, undertaken in Sept. 1995, the wind-shifts were measured by anemometers placed on the research vessel, *FLIP* during the Coastal Ocean Probe Experiment (COPE) (Kropfli and Clifford, 1996). In the 1998 experiment reported here, smoke floats were dropped onto the surface in the field of the internal waves from a low flying, Coast Guard Helicopter based at Astoria, OR. Video was simultaneously taken through a belly window of a Cessna 177 flying at 3000 m above the surface. The location of the two separate experiments is shown in Fig. 1.

A total of four smoke floats were dropped and approximately 10 minutes of useful video was obtained. The arrival of a low stratus cloud deck prevented a longer time period of video from being taken. During the video, an offshore rock remained within the video field of view. This allowed absolute positions and surface velocities of the floats to be established from the video. This, in turn, allowed us to estimate the absolute phase speeds and surface currents of the internal waves. As a result we were able to confirm that the observed directional shifts of the smoke were not due to apparent wind shifts caused by the surface motion of the floats. The smoke trails revealed relative wind shifts ranging up to 30 degrees, consistent with the earlier 1995 observations.

2. Experimental Conditions

The experiment took place during new-moon tides on August 25, 1998 between 23:00 and 24:00 UTC. The closest ocean meteorological buoy to the experiment site was NOAA Buoy # 46029 on the Columbia River bar (see Fig. 1). At 24:00 UTC on the 25th, the wind was 310 degrees at 3 m/s with gusts to 4 m/s. The wave height and average wave period were 0.9 m and 6.2 s, respectively. The air temperature and water temperature were both 17.2 degrees C.

The video was taken along transects made perpendicular to the observed internal-wave wavefronts during and after the smoke-float deployment. The observation altitude was 3000 m.

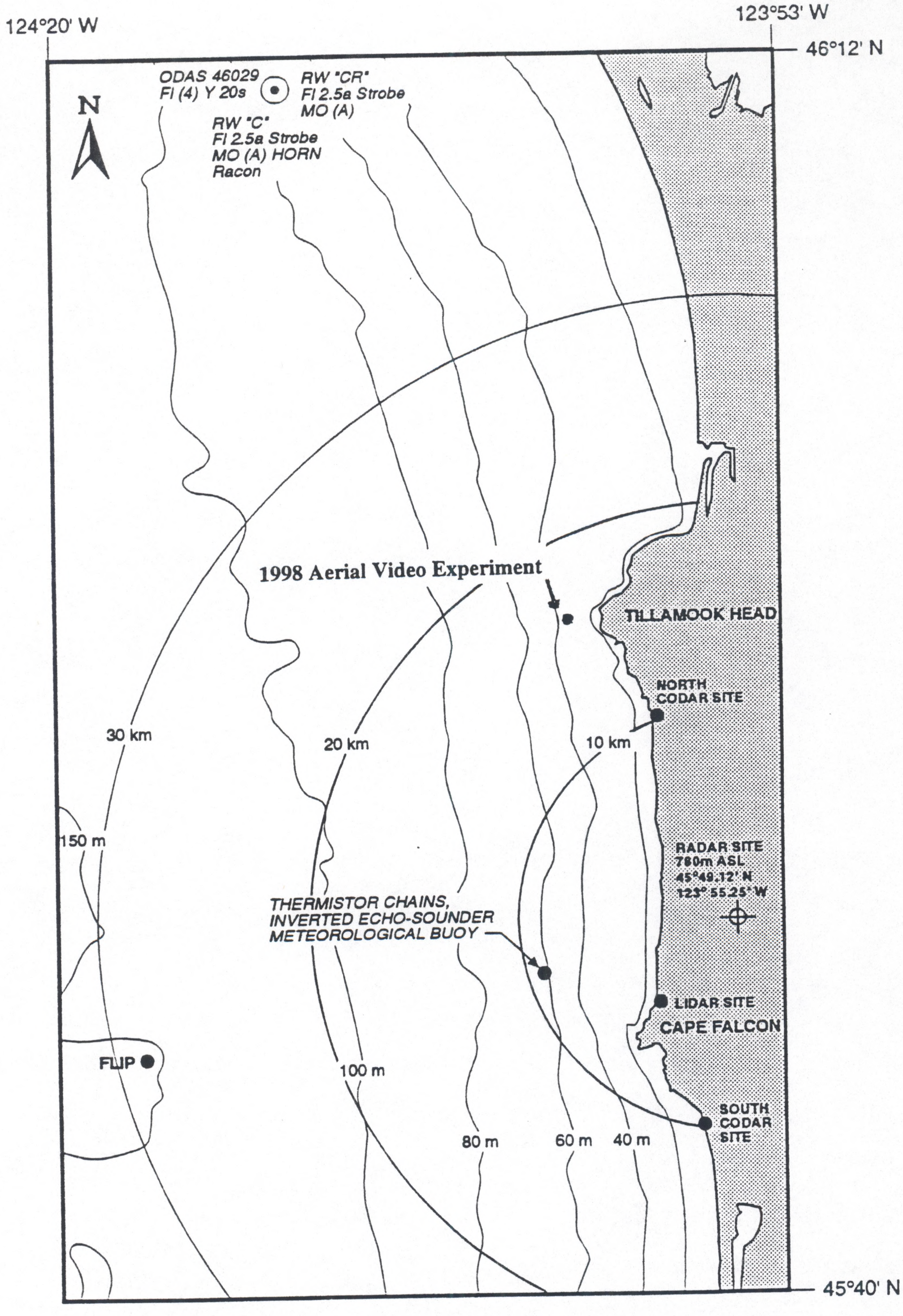

Fig. 1. Map showing the location of the original COPE instrumentation and the site of the aerial video experiment described in this report.

The video camera used a 6 mm focal length lens projecting onto a 0.85 cm CCD array. This corresponds to a scaling of 26.2 m/mm on the individually processed video frames.

3. Experimental Results

The four video frames selected for measurements are shown in Fig. 2. The smoke floats are numbered beginning with the furthest from the rock, which is the white spot near the smoke trail visible in all of the images. Other white features are low clouds. The first frame (Fig. 2a) is taken at a time before the last two floats (# 1 and # 4) were deployed and shows the IW wavefronts most clearly. The video frames of Fig. 2a and 2b show the clearest example of the internal wave-induced windshift. The smoke trail from float #2 is seen to shift from an orientation parallel to the IW wavefront to an orientation of near 30 degrees to the wavefront as the wavefront passes under it. It can be seen from Figs. 2b, and 2c that the smoke direction from float #1, deployed well ahead of the IW packet, remains relatively constant in a direction nearly parallel to the wavefronts.

In order to examine the possibility that the indicated wind shift might be an *apparent* wind shift caused by the surface-current induced motion of the floats, the position of the floats were plotted as a function of time in Fig. 3. The position plotted is the y-coordinate of the source of the smoke, using the rock as the origin and the IW wavefront as the x-axis. Also shown on the plot is the y-coordinate of the leading IW wave-front. The trajectories shown are not easily interpreted, especially considering the motion indicated for reference float #1 outside the IW packet. However, the phase speed of the IW front is ~ 0.3 m/s, which is reasonable. The largest relative motion indicated between floats #2 and #3 is also only ~ 0.3 m/s. With a background wind from the NOAA buoy reported as 3 m/s, this maximum relative motion could only account for at most ~ 7 degrees of the ~ 30-degrees relative wind shift indicated by the smoke trails.

4. Conclusion

These experimental results seem to corroborate the previous COPE observations that the passage of an IW wavefront can produce a local windshift of up to ~ 30 degrees. The video images also clearly indicate the positional dependence of the wind-shift direction. In both this

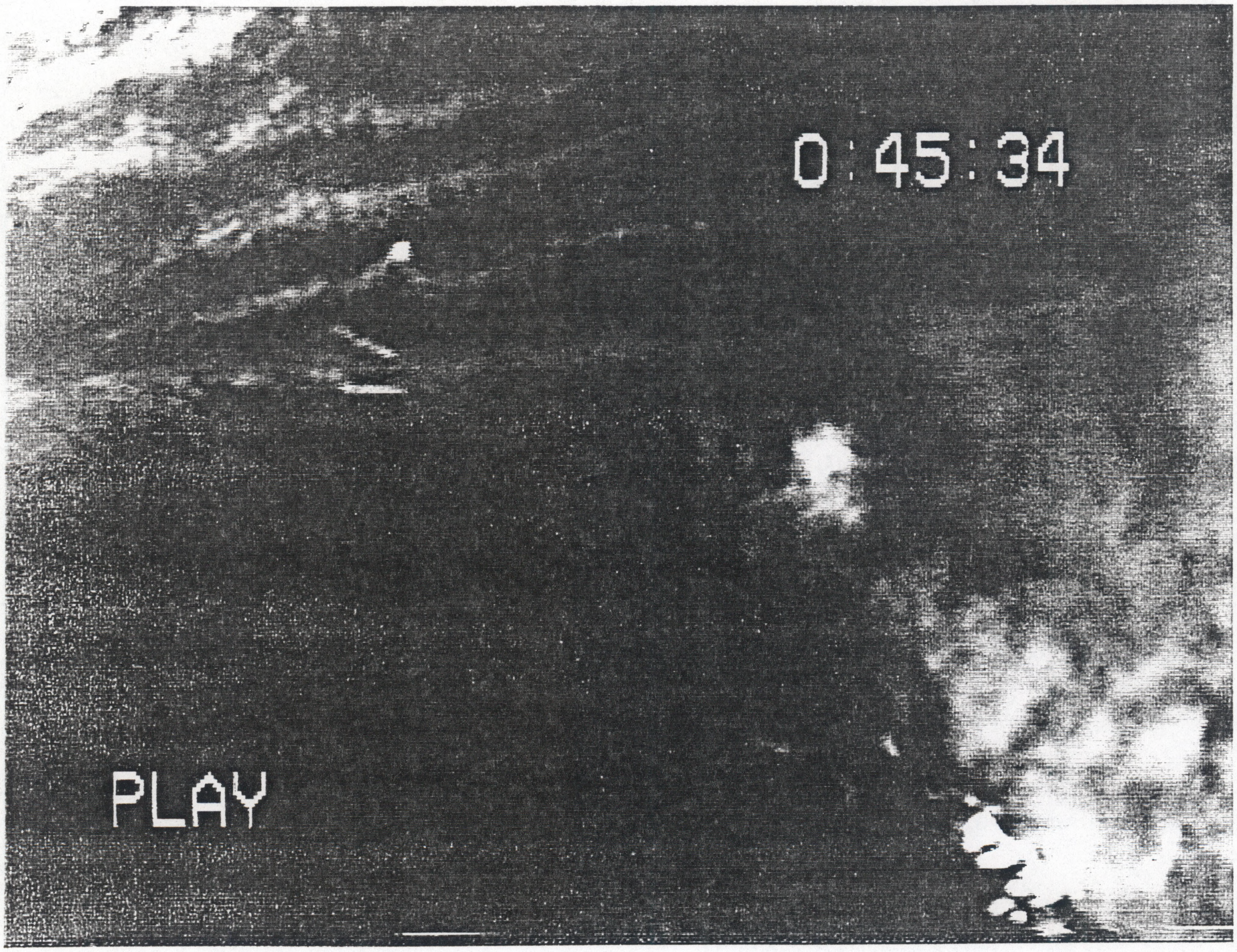

Fig. 2a. First video frame selected for measurements.

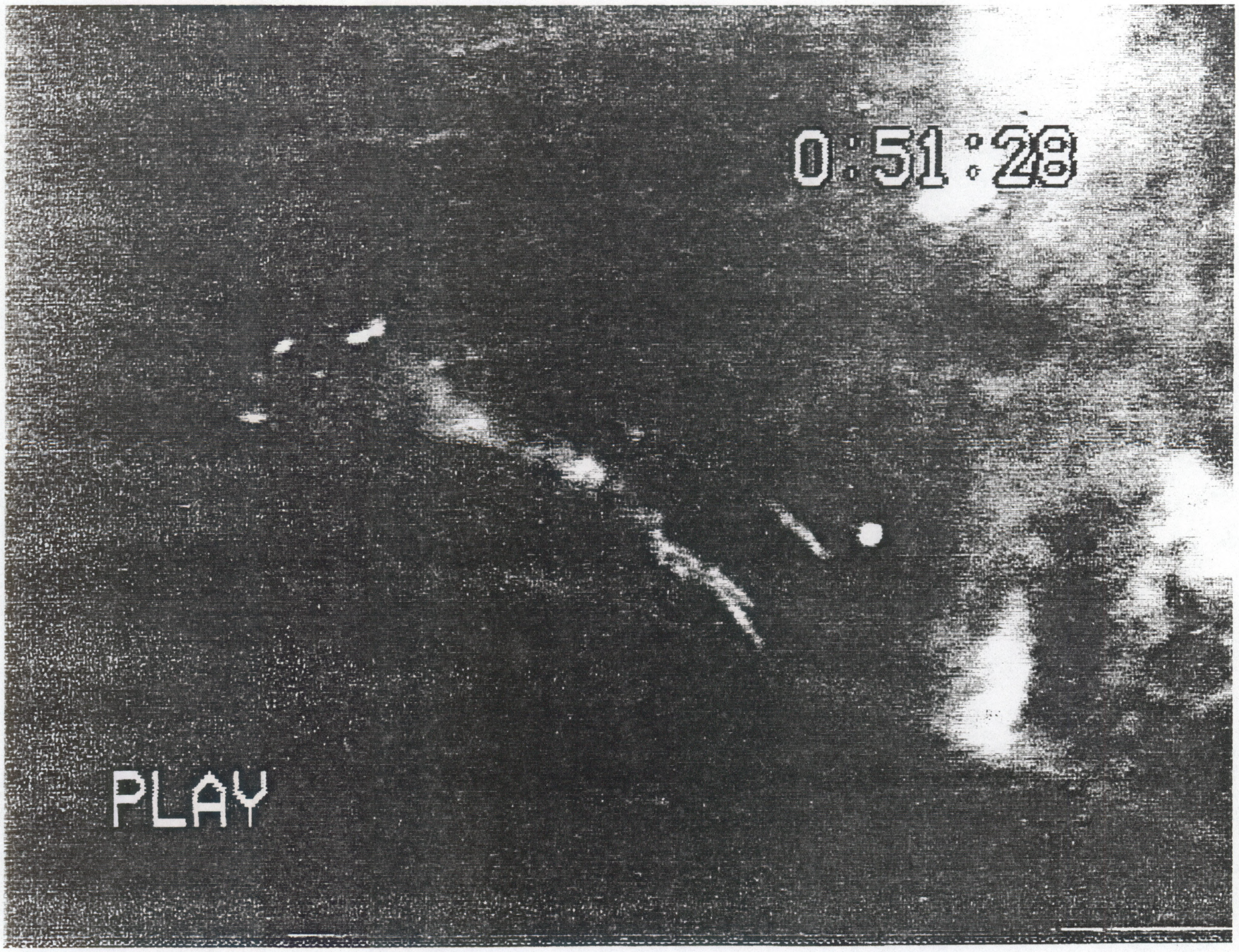

Fig. 2b. Second video frame selected for measurements.

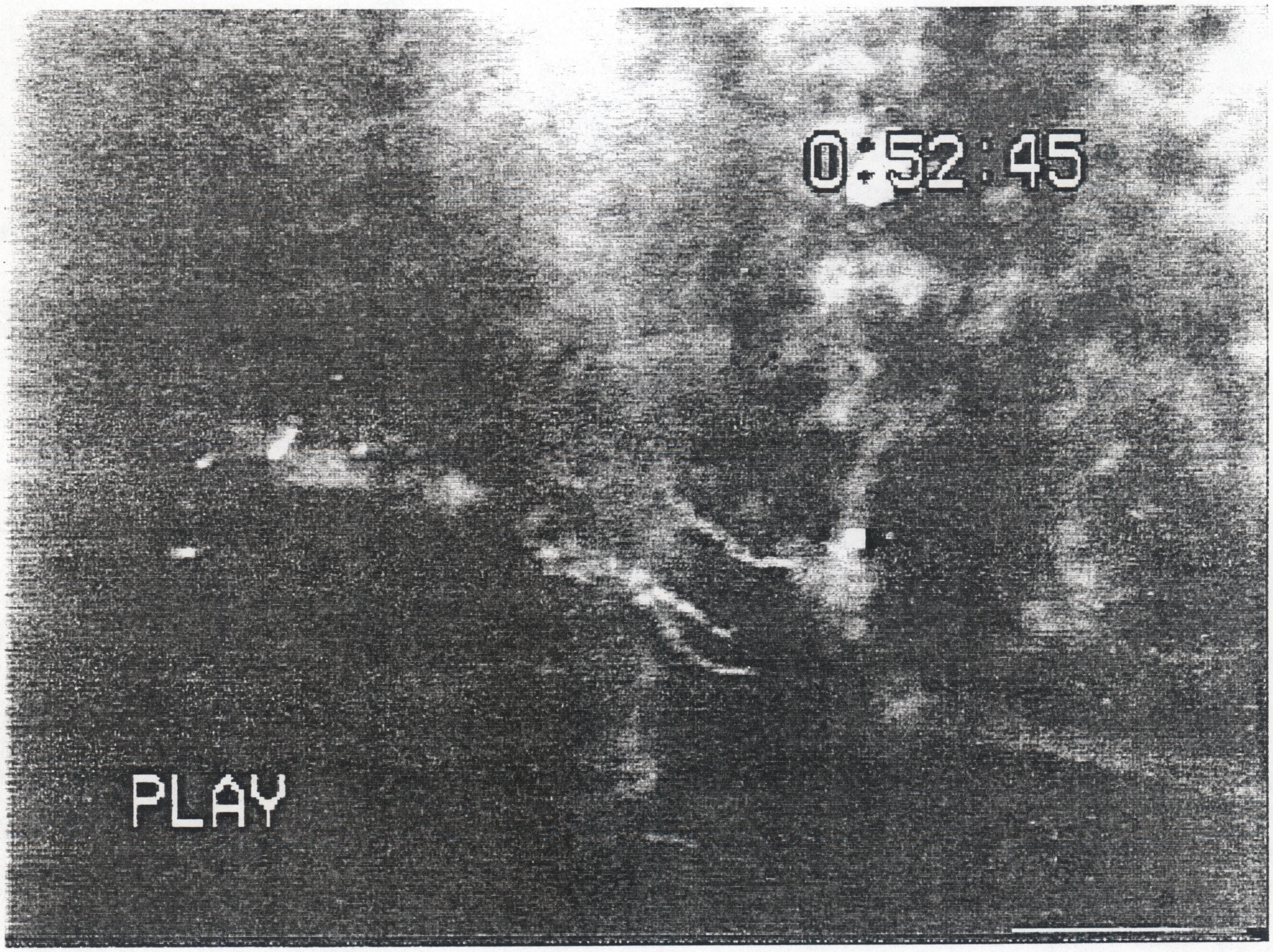

Fig. 2c. Third video frame selected for measurements.

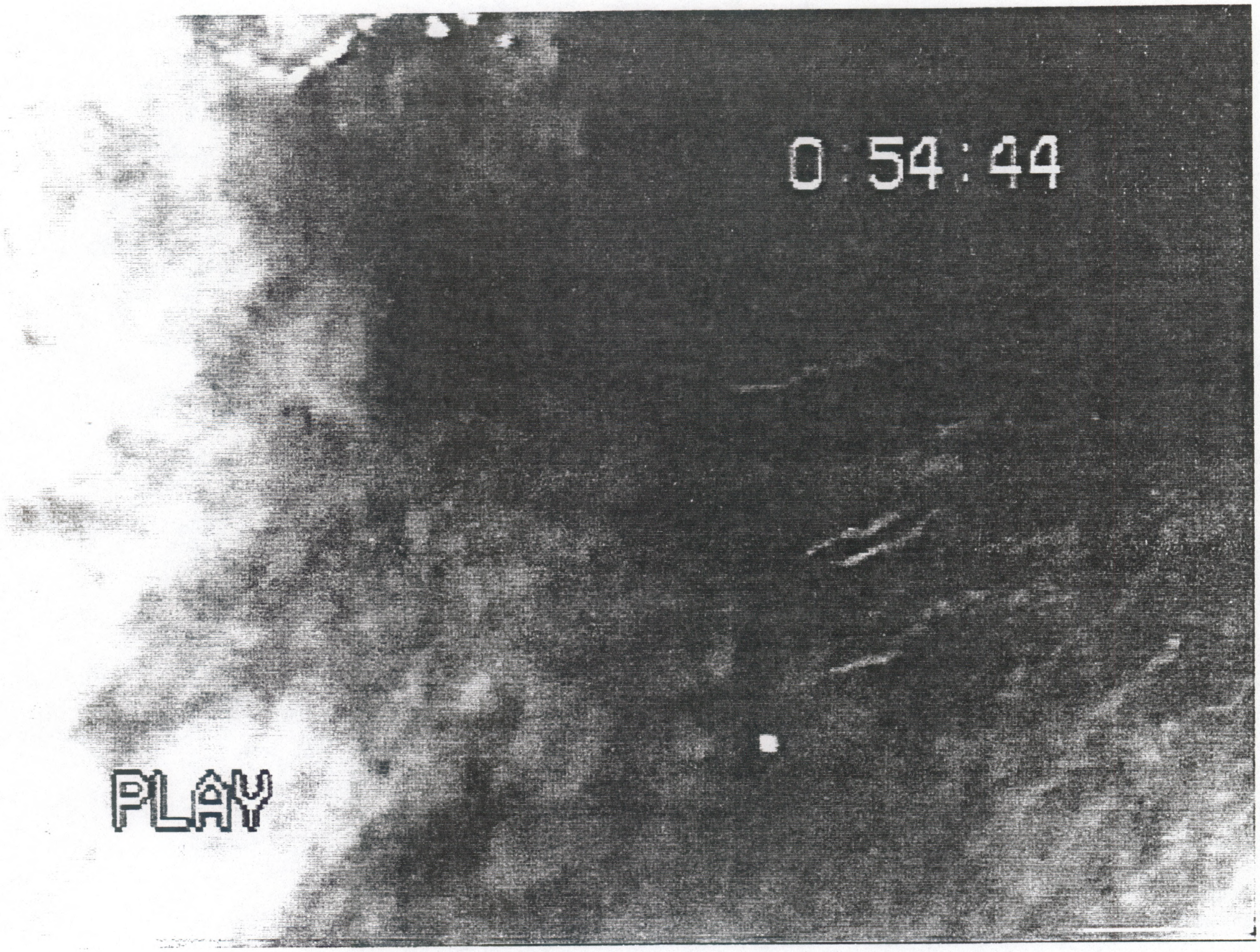

Fig. 2d. Fourth video frame selected for measurements.

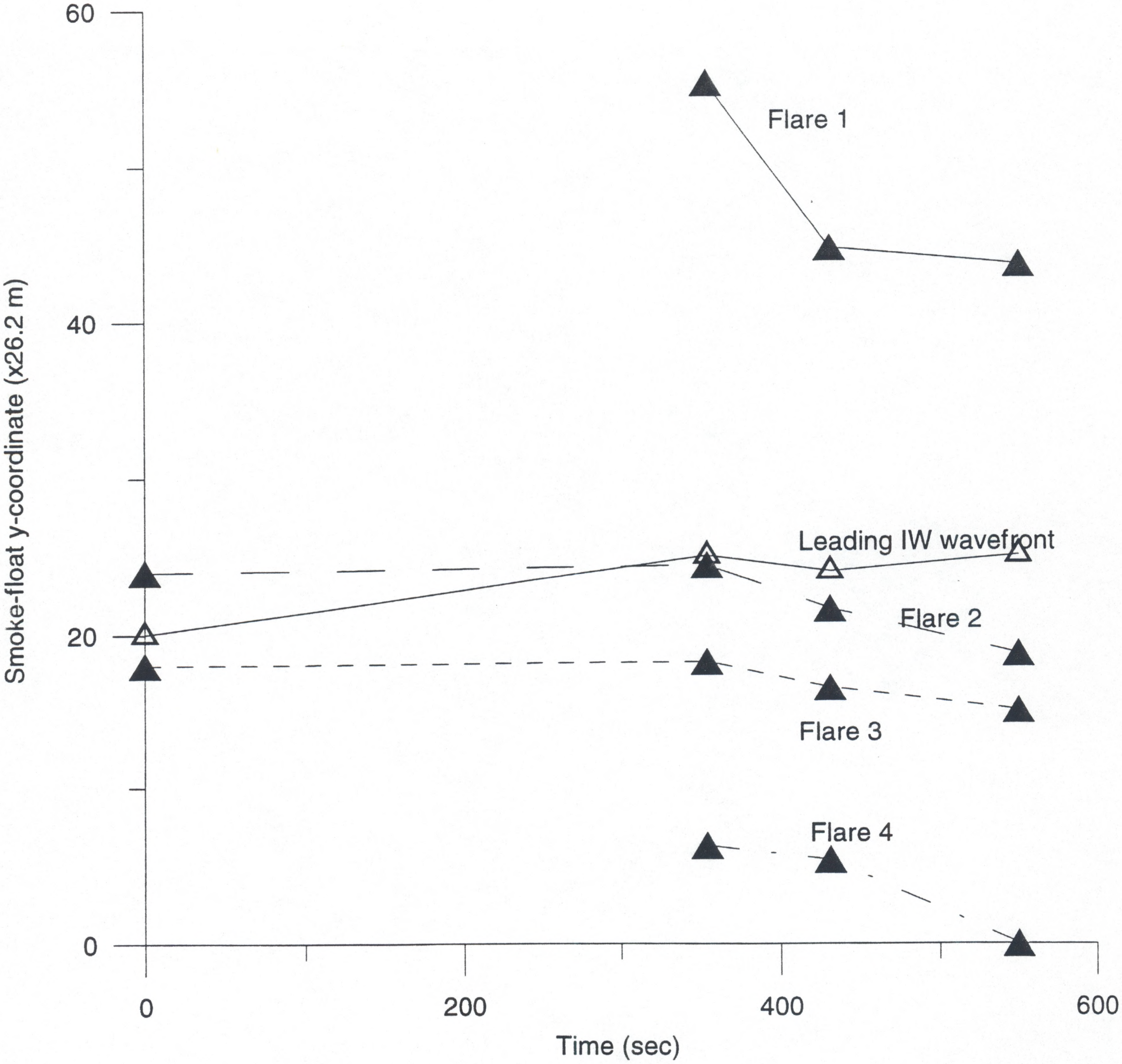

Fig. 3. Y-coordinate plots of smoke floats and leading IW wave-front vs. time.

experiment and the COPE experiment, the undisturbed, ambient wind was nearly parallel to the wavefronts, and the passage of the IW wave-front caused steerage of the wind in a direction toward the back of the IW packet.

5. References

Kropfli, R.A. and S. F. Clifford "The coastal ocean probing experiment: Further studies of air-sea interaction with remote and in-situ sensors" *Proceedings of the IGARSS Conference*, 1996.

Otto, W.D., J.E. Hare, R.J. Hill, and C.W. Fairall "The Effect of Ocean Internal Waves on the Atmospheric Surface Layer" NOAA Technical Memorandum ERL ETL-293, October, 1998.