Steam Devils Over a Hot Springs Pool

ROGER F. REINKING

Boundary Layer Dynamics Group, Environmental Research Laboratories, NOAA, Boulder, CO 80303

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ABSTRACT

Small but well-organized steam devils were observed forming and propagating over a swimming pool fed by hot springs. The steam devils are described and compared to similar vortices observed in various environs.

Natural hot springs feed two large swimming pools at a lodge in Glenwood Springs, Colorado. While soaking in the hotter of the two pools one evening (24 September 1977), I watched steam devils rise and whirl across the waters in abundance. The air was calm, dry and pleasantly cool (~18°C). The water temperature was 39–40°C. The surface area of the hot pool is approximately 720 m^2. Water evaporating from the pool was condensing as steam that rose and drifted in random plumes less than a meter high over the entire surface. The wind shear was minimal, and ordinary mixing apparently was too inefficient to transfer sensible and latent heat from the surface as fast as it was being released. One can hypothesize that the steam devils formed to expedite the transfer and aid the tendency toward equilibrium. Roughly, one to three steam devils formed each minute, but sometimes four or five simultaneously meandered over the pool, dissipating mainly from the bottom up only as they encountered cool, dry concrete at the pool's edge. At other times, drift of the air increased slightly and normal diffusion and mixing were enhanced, so the vortices were not required to aid the energy transport, and were possibly suppressed by still weak but increased wind shear.

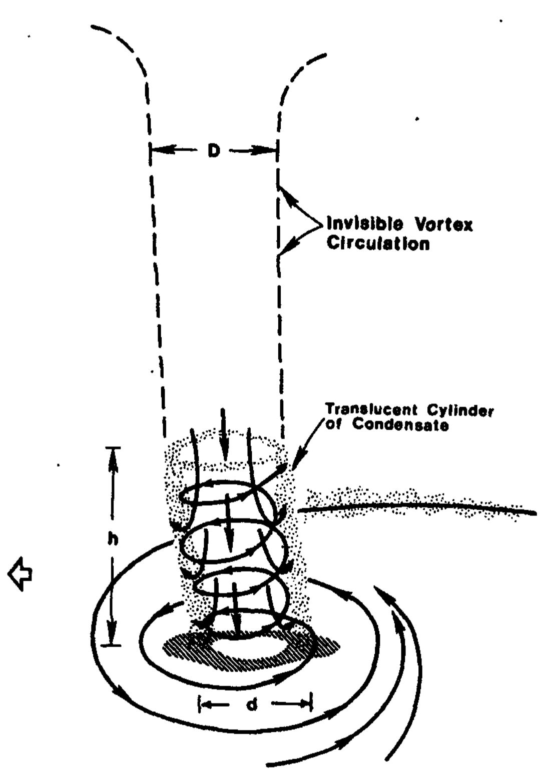

FIG. 1. Envisioned structural flow model of the observed steam devils.

The second pool is much larger (~3125 m^2) but 7–9°C cooler. Steam rising from this pool was relatively light, disorganized and somewhat less dense than that in the photograph of the pool presented by Weaver (1977). Heat transfer across the surface-to-air temperature lapse of about 14°C over this pool was insufficient to cause steam devils, whereas the 21°C lapse over the hotter pool was suitable. Thus, the limiting temperature conditions were within this range.

The steam devils were tight circulations with well-defined translucent walls at maturity. Beginning as "steam whirls" (Holle, 1977) these vortices organized after only 1–3 s to form fairly rapidly rotating, crooked or bent columns, each with a remarkably uniform diameter. Waves generated by swimmers, or the lack of sufficiently strong circulations, apparently prevented any obvious development of a dark spot or spiral circulation on the water surface beneath the individual steam devils. Ignoring this point and the lack of any connection with an overhead cloud, the envisioned total circulation of the devils could be likened in form to Golden's (1974) model of the well-developed dark spot stage in the life cycle of waterspouts. Thus, the model shown in Fig. 1 seems to be appropriate. In each steam devil, no spreading of the vortex with height was apparent (i.e., the diameter D well above the base was about the same as the base diameter d, at least in the visible portion of the vortex, such that $D \approx d \approx 5\text{–}15\ cm$). Using h to refer to the height of the visible column, $h \approx 1\text{–}2\ m$; thus, $h \gg d$. The spiraling motion in the visible wall of each vortex was

TABLE 1. Observed features of various steam devils.

DESIGNATION	WIND	UNDERLYING SURFACE	SURFACE VS AIR TEMPERATURE	VORTEX SHAPE / ORGANIZATION	VISIBLE VORTEX DIMENSIONS	LIFETIME	ROTATION RATE
STEAM DEVILS (THIS ARTICLE)	CALM, LIGHT AND VARIABLE DRIFT	HOT POOL	$T_S - T_A \simeq 21°C$ (RH ≃ 30%)	CROOKED COLUMNS OF UNIFORM DIAMETERS, TIGHTLY ORGANIZED LIKE WATERSPOUTS; THIN WALLS, CLEAR CORES	h ≃ 1-2 M d,D ≃ 5-15 CM	0.2-1 MIN	MODERATE TO RAPID (ROUGHLY 1-2 ROTATIONS PER SECOND)
COLUMNAR VAPOR DRIFT (HORTON, 1933)	ALMOST STILL	WARM POND	$T_S - T_A \simeq 5\text{-}6°C$ (RH ≃ 96%)	QUITE REGULAR COLUMNS	h ≃ 0.5-2 M d,D ≃ 10-25 CM	1-2 MIN	SLOW
STEAM COLUMNS (BRYSON, 1955)	CALM	MOIST, SUNLIT PLOWED SOIL	$T_S \gg T_A$	INVERTED, HYPERBOLIC FUNNELS; CIRCULAR CROSS-SECTIONS, SHARP-EDGED, NO ENTRAINMENT ABOVE SURFACE	h ≃ 2 M INFLOW DIA ≃ 1-10 M D << INFLOW DIA	-----	RAPID
STEAM DEVILS (HOLLE, 1977)	VERY LIGHT COLD AIR DRAINAGE	HOT GEYSER POOLS AND VICINITY	$T_S \simeq 40\text{-}95°C \gg T_A$	FUNNEL FORCED FROM BELOW, DECREASING IN INTENSITY WITH HEIGHT; MODERATELY ORGANIZED AND TURBULENT, CLEAR CORE; SIMILAR TO DUST DEVIL	h ≃ 2-8 M; 30 M MAX d,D ≃ 26-80 CM; 1 M MAX	TYPICALLY 0.5 MIN MAXIMUM 1.5 MIN	1 ROTATION/5 SECONDS (SLOW)
FOG DEVILS (MORIARTY, 1977)	CALM OR LIGHT BREEZE	SUNLIT, DEW-COVERED, GRASS AND PLOWED GROUND	$T_S \gg T_A$	LIKE A DUST DEVIL, LOOSELY ORGANIZED	h ≃ 75 M	6-7 MIN	-----
STEAM DEVILS (LYONS AND PEASE, 1972)	STRONG WIND (≃ 10 M s^{-1}, GUSTS TO 20 M s^{-1})	LAKE MICHIGAN OVERLAIN BY STEAM FOG	$T_S - T_A \simeq 22°C$	FINGERS OR COLUMNS, MORE SIMILAR TO DUST DEVILS THAN WATERSPOUTS (I.E., LESS ORGANIZED)	h - LAKE SURFACE TO CLOUD BASE d,D ≃ 50-200 M	3-4 MIN	SLOW

smooth, rather than turbulent as in the steam devils photographed by Holle (1977). Inflow was apparently minimal beyond a few centimeters above the surface, as for steam devils observed by Bryson (1955). In proportion to the size of the circulation, this is also true for mature waterspouts (Golden, 1974).

The steam devils observed over the pool could also be likened to dust devils, such as those described by Sinclair (1973), in that the two types of vortices occurred over warm surfaces with no overhead cloud present; however, contrary to the nature of the steam devils, the dust devils occurred in a relatively windy environment and exhibited radial inflow at all levels except in the upper portion.

Steam devils, called by various names, have been observed over warm ponds on cool, calm mornings (Horton, 1933); over moist, dark soil heated by the morning sun (Bryson, 1955; Moriarty, 1977); over Lake Michigan during arctic outbreaks (e.g., Lyons and Pease, 1972); and over hot pools of a geyser basin (Holle, 1977). Some key features of these various vortices are compared in Table 1. The obvious common denominator is the underlying heat and moisture source that is significantly warmer than the air.

The steam devils observed over Lake Michigan are set well apart from the others by their dimensions which compared to those of waterspouts, and by their association with strong winds and clouds overhead. Their dynamics were clearly more complicated than in the other cases.

The remainder of the cases cited occurred when the air was quite calm. Whereas a surface-to-air temperature gradient near 20°C was required for steam devils to form over the hot springs, and roughly this or a larger gradient was necessary over the geyser pools, only a 5–6°C difference was required in the case cited by Horton (1933). The combination of these observations suggests that a smaller temperature gradient is required when the air is closer to completely calm. A tendency toward stronger vortex organization during very calm conditions is also suggested. A continuum of possible vortex dimensions is apparent; and vortex lifetime is loosely correlated with size at maturity. The sizes of individual vortices may change during their lifetimes, especially during developing and dissipating stages. However, this is not recorded by the other observers, nor was it obvious during the visible portions of the lifetimes of the steam devils over the hot springs pool.

Hot pools such as those in Glenwood Springs could provide unique, readily accessible laboratories for examining the dynamics and thermodynamics of steam devils and related vortices.

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