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COOLING TOWER PLUME BEHAVIOUR OBSERVED BY FIXED AND AIRBORNE CINE CAMERAS, NEAR GOESGEN

by

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Résumé

Une campagne spéciale de mesures et d'observations a été organisée du 12 juin au 6 juillet 1980 aux alentours du réfrigérant atmosphérique (2000 MWth) de la centrale nucléaire de Gösgen. L'objectif est d'obtenir des données sur le comportement du panache de vapeur condensée, lors des situations météorologiques instables. Une caméra aéroportée, fixée sous un ballon captif à 1000 m sur sol, a observé l'ascension d'une parcelle de panache condensé, entre le sol et le niveau des nuages moyens (à env. 2000 m/sol). Le même dispositif a permis de suivre le développement de stratocumulus castellanus dans le sillage du panache. D'autres caméras ont observé, à partir du sol, l'interaction du panache avec les nuages naturels. Ce processus a provoqué, le 27 mai 1980, le déclenchement d'un petit orage au-dessus du réfrigérant. Les films sont documentés par les sondages microaérologiques et les observations météorologiques relevées aux alentours de la centrale.

Zusammenfassung

Eine spezielle Mess- und Beobachtungskampagne wurde zwischen dem 12. Juni und 6. Juli 1980 in der Umgebung des Kühlturms (2000 MWth) des Kernkraftwerks Gösgen durchgeführt. Das Ziel ist, Daten über das Verhalten des Kühlturmschwadens während instabilen Wetterlagen zu erhalten. Eine unter einem Fesselballon befestigte Kamera verfolgte auf einer Höhe von 1000 m über Boden einen Teil der Dampffahne zwischen dem Boden und der Basis der mittelhohen Wolken (ca 2000 m/Boden). Die gleiche Ausrüstung hat es erlaubt, die Entwicklung von Haufenschichtwolken (Stratocumulus castellanus) im Lee des Dampfschwadens festzuhalten. Andere Kameras beobachteten, vom Boden aus, die Vermischung des Dampfschwadens mit den natürlichen Wolken. Dieser Prozess hat, am 27. Mai 1980, die Auslösung eines kleinen Gewitters über dem Kühlturm verursacht. Die Filme sind durch mikroaerologische Sondierungen und meteorologische Beobachtungen in der Umgebung des Kernkraftwerkes dokumentiert.

Riassunto

Una campagna speciale di misure e di osservazioni é stata organizzata dal 12 giugno al 6 luglio 1980 nelle vicinanze della torre di raffredamento (2000 MWterm) della centrale nucleare di Goesgen. Lo scopo é di ottenere dati sul comportamento della nuvola di vapore condensato durante le situazioni meteorologiche instabili. Una cinepresa aeroportata, fissata sotto un pallone frenato a 1000 metri dal suolo, ha seguito l'ascensione di una particella di nuvola di vapore condensato fra il suolo e il livello medio delle nuvole (situato a circa 2000 metri dal suolo). Lo stesso dispositivo ha permesso di seguire lo sviluppo di stratocumulus castellanus nella scia della nuvola di vapore. Altre cineprese hanno osservato dal suolo, l'interazione della nuvola di vapore con le nuvole naturali. Questo processo ha provocato, il 27 maggio 1980, la formazione di un piccolo temporale sulla torre di raffredamento. I film sono documentati da sondaggi microaerologici e da osservazioni meteorologiche rilevate nelle vicinanze della centrale.

Abstract

A special measurements and observations campaign has been organized from May 12th to June 6th near the cooling tower (2000 MWth) of the nuclear power plant of Goesgen, in Switzerland. The purpose is to obtain data on behaviour of the visible condensed water vapour plume in unstable meteorological situations. An airborne camera, attached under a tethered balloon 1000 m above ground, follows the ascent of condensed plume parcels from the ground to the middle cloud level (about 2000 m/ground) and, another day, the development of stratocumulus castellanus in the wake of the plume. Other cameras observe, from the ground, the interaction of the plume with natural clouds and, on May 27th, the triggering of a small thunderstorm above the cooling tower. These films are documented by microaerological soundings and meteorological observations around the power plant.

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INTRODUCTION

The first forecasting studies on the meteorological effects of a cooling tower of 2000 MW_{th} have been carried out in Switzerland from 1972 onwards (refs. 3, 4, 6, 7, 14, 15, 16, 17, 18, 22, 23, 24, 34, 37, 38 and 39). The first numerical SAUNA model (refs. 7 and 25) of cooling tower plume simulation has been developed on the basis of existing available literature and observations carried out at Luenen (in West Germany, ref. 24). It was particularly used in obtaining an estimated statistical distribution of plume sizes emitted from a natural wet cooling tower planned to be built in Goesgen, and in forecasting the varying shadow duration on the ground (ref. 15). This numerical method has been progressively refined (KUMULUS, refs. 6 and 23) and a detailed meteorological study of the site and area around Goesgen (ref. 14) improved the input data. On the international scale a considerable growth in studies and observations of cooling towers in Europe (refs. 2, 5, 9, 10, 13, 19, 21, 27, 28, 30 and 40) and the United States (refs. 11, 12, 20, 29, 31, 36 and 41) is noted since 1974. An exhaustive analysis of the numerical models has recently been published in the U.S. (refs. 1 and 8). The first bibliography on heat releases (ref. 35), has been brought up to date. Its second edition, grouping almost 750 articles, is to be published soon (ref. 32). Since the nuclear power plant of Goesgen has come into operation in 1979, plume behaviour and its effects on the ground have been directly observed by means of three types of arrangements:

a. The continuation of site meteorological measurements, in order to assess comparisons with previous years' undisturbed values.

b. Setting-up of a network of five monitoring cameras to observe the plume behaviour and its shadow on the ground, throughout the year, at two minute intervals.

c. Organization of the first intensive measurements campaign of about one month's duration: GOM80.

Strong interactions of the plume with natural clouds, especially in unstable meteorological situations, were first filmed (see fig. 1) at Engelberg (from April 1979) and at Froburg (onwards Nov. 1979). To study these cases with greater precision, an intensive measurements campaign by the name of GOM80 (GOesgen May, 1980) is organized in close collaboration with the EIR (Swiss Federal Institute for Reactor Research, ref. 37 and 38). This campaign forms part of the CLIMOD (CLImate MODification) research programme (ref. 22) centred on the cumulating meteorological effects of already existing or projected power plants around Basle.

Plume observation campaign in unstable meteorological situation: GOM80

The intensive measurements and observations of the GOM80 are organized from May 12 - June 6 1980. These are aimed at observing the influence of unstable weather conditions on the plume and supplying valid data to be used in verifying numerical models. The study is based on the five following major sources of observations:

1. The aerological soundings at Payerne

The nearest aerological sounding station to Goesgen is situated at Payerne (100 km WSW). It provides altitude measurements needed for extending the microaerological soundings of MOBILAB taken on the site. The linking of the measurements is not always satisfactory (for example fig. 8) due to the geographical distance and time lapses of several hours between the two types of observation.

2. On site meteorological measurements

Progressively established since 1972, this network comprises at the present time seven stations (fig. 1) providing hourly measurements of temperature, humidity, wind speed and direction, precipitations and sunshine duration.

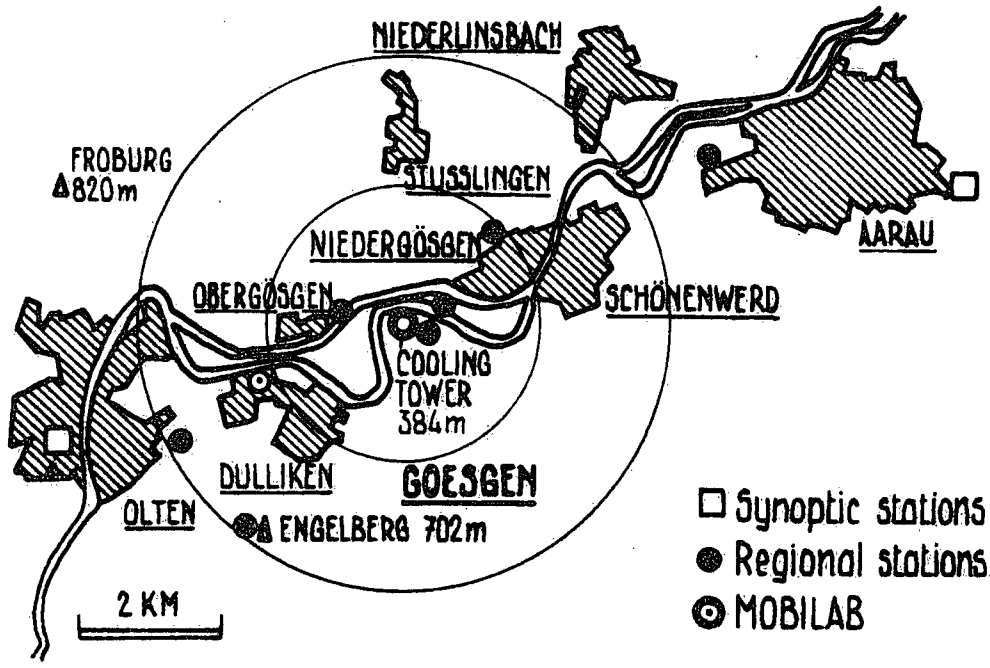

Fig. 1 Situation plan

3. Monitoring camera observations

From the start of GOM80 an automatic camera is fitted on the television transmitter at Engelberg, situated 3,8 km SWS from the cooling tower. Its favourable position, 50 m above ground, dominates the plant by 306 m. An air-conditioned case protects the super 8 cine-camera against severe weather conditions. A clock positioned in the field of view insures correct timing of the pictures taken every two minutes. The camera is switched off at night to save film, thus giving an eight-day autonomy.

4. Microaerological soundings

The MOBILAB (MOBile LABoratory) comprises a radio-receiver, a chain of data acquisitions and a couple of tethered balloons each fitted with a microaerological sonde. The soundings can reach a height of 1000 m to 1500 m above ground providing detailed measurements of pressure, temperature, humidity, wind speed and direction. The two propellers of low inertia placed at more or less 30 degrees of the sonde's horizontal axis give, after computation, the horizontal and vertical components of the atmospheric turbulence profile (ref. 33).

5. Airborne camera observations

To follow phenomena difficult to observe from the ground, a tethered balloon is especially equipped to carry an airborne super 8 cine-camera 1000 m above ground (fig. 2). An initial microaerological sounding gives the wind direction at this height. The camera is then manually orientated at the best possible angle to film the cooling tower plume from that level.

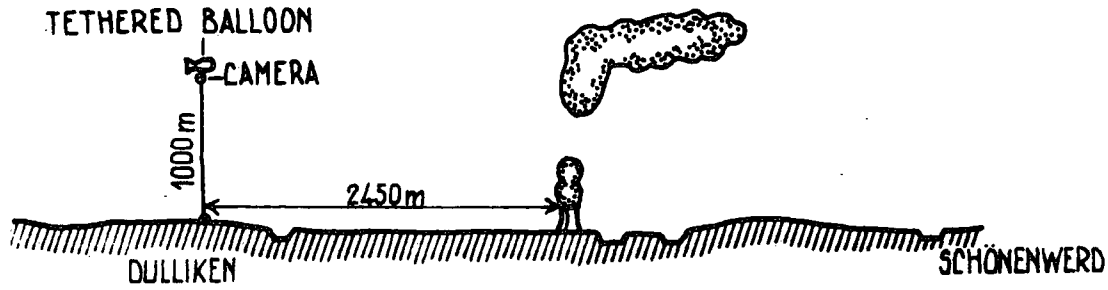

Fig. 2 Airborne camera

At a rate of one picture per second the autonomy of the airborne camera totals 54 minutes. The direction of the balloon is often modified by atmospheric turbulences, thus disturbing the stability of the picture during projection. This is why these sequences are analysed picture by picture by means of video equipment. The most significant ones are picked out and redrawn on a projection table (see figs. 3, 5 and 7). The hours, minutes and seconds of each picture are read on a clock placed in the camera's field of view. Note that the exagerated contrast between the plume and natural clouds on the drawing is deliberate. In reality there is often only little difference in shape and colour. A clear distinction of the cooling tower responsibility in artificial cloud formation is to be found by following the trajectory of plume particles.

Statistical and technical data on GOM80

1. Aerological soundings

The full aerological soundings (pressure, temperature, humidity, wind-speed and direction) at Payerne are carried out twice daily (00h and 12h GMT), each grouping 1600 data, i.e. 100.000 data per month.

2. On site meteorological measurements

The hourly routine meteorological measurements of Goesgen provide about 16.400 data per month (22 sensors amongst 7 stations).

3. Films

The majority of the 46 super 8 films made in one month are in slow motion. The 150.000 pictures taken represent about 939 hours of plume observation.

4. Microaerological MOBILAB soundings

During GOM80, 50 soundings are registered on the site of Dulliken and 5 simultaneously at Niedergoesgen, totalling 30.000 data.

5. Data assimilation

Meteorological measurements and soundings have been assimilated, verified and memorized into data files on PDP 11/20 and PDP 11/60 computers (Digital Equipment Corporation) at Payerne.

6. Film assimilation

Films have been copied on video recorder (U-matic system) and treated by an editing system (JVC CR 8200 E and JVC CR 6600 E) kindly put at our disposal by KKG company (Goesgen-Daeniken nuclear power plant).

Artificial feeding of altocumulus

The first of the three plume cases, presented here for detailed analysis is observed on May 14th 1980 between 14h and 15h by means of an airborne camera held by a tethered balloon at 1000 m above ground. Pictures A1, A2, A3 and A4 of figure 3 show the ascent of a part of the plume remaining in sight from the cooling tower to the level of altocumulus, estimated at over 1500 m above ground. The dotted lines denote the growth and lifting of the remaining visible part of the plume into the shape of a horizontal disk. The following sequence (A5, A6, A7 and A8) observed from 1452h to 1455h closely resembles the first set of pictures. The more accentuated condensing process creates a small cumulus which finally brings about an artificial increase of cloud cover. Viewing the film in greater detail, this phenomenon is continuously detectable and causes a local increase of cloud cover (from 5/8 to 7/8). Such observations cannot be detected on routine camera films, whose two minute sampling time is too low to follow an event of five minutes' duration. Only a higher rate camera can rule out ambiguity in the detection of artificial increase of natural cloud. The MOBILAB sounding (fig. 4) ending at 1321h, is extended by the aerological sounding launched at 1045h. The mean temperature gradient in the first 1000 m is near a dry adiabatic, thus corresponding with an unstable situation. This fact is confirmed by ascending wind components (fig. 4) in almost the entire measurements layer. The growing gap between dew point and the temperature above 1800 m indicates a dry sheet, which fits with the top level of cloud.

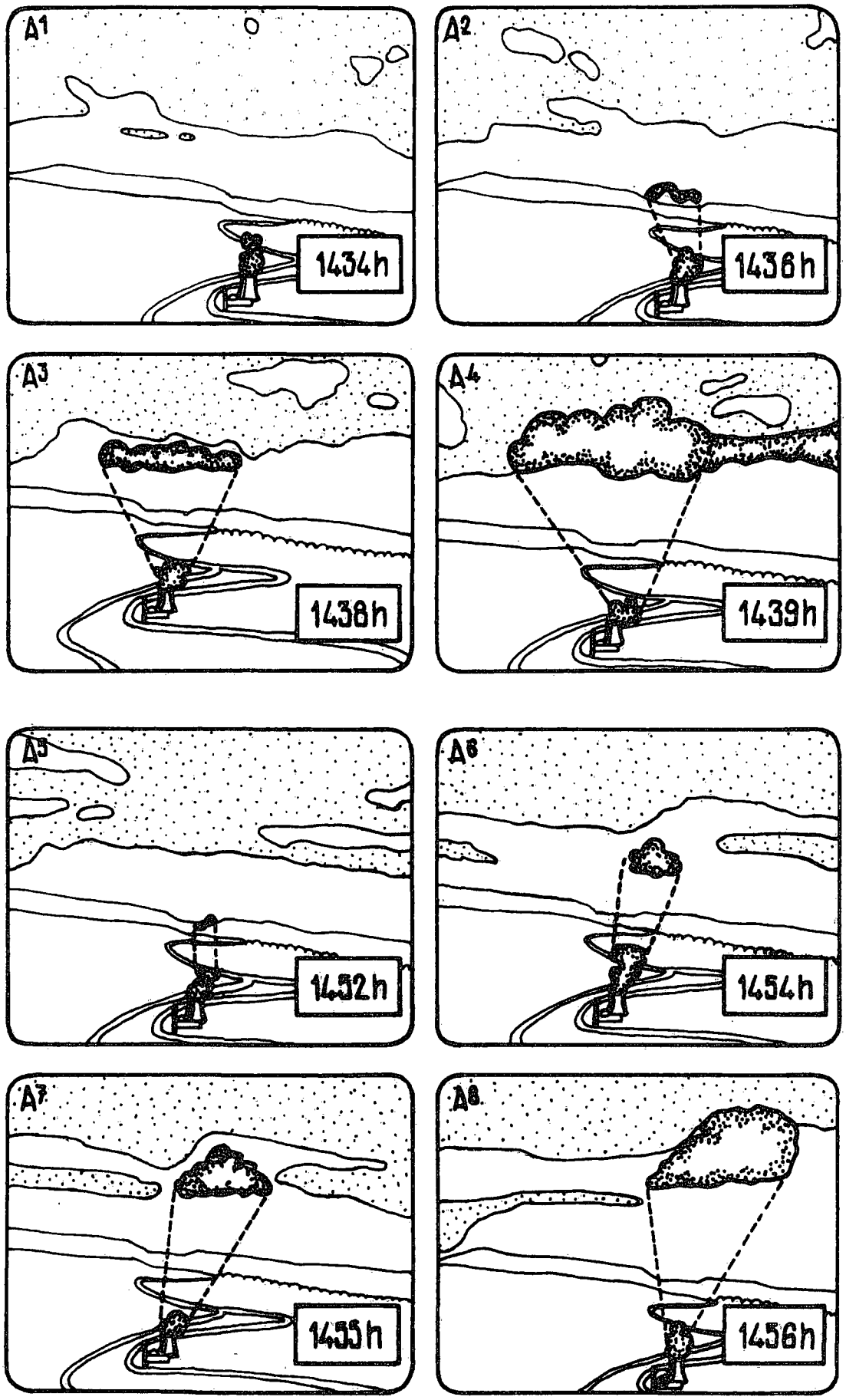

Fig. 3 Artificial feeding of altocumulus, May 14th 1980

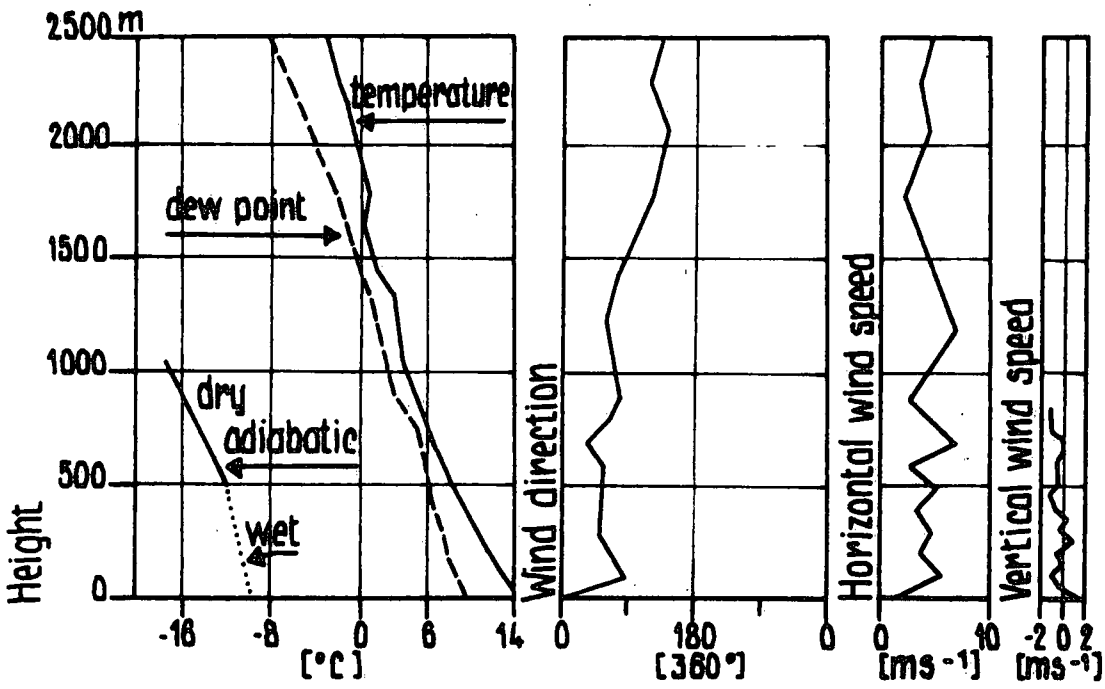

Fig. 4 MOBILAB sounding, May 14th 1980, 1258h to 1351h extended by the aerological sounding of Payerne, 1045h

Formation of castellanus in the plume's wake

The 2nd case analysed is observed on 2nd June 1980 from 1715h to 1800h. The camera placed 900 m above ground follows the plume's development in an unstable air layer. At the beginning of the sequence (fig. 5, B1) the plume is still disjointed. Then (B2) it remains visible up to its stabilisation level, estimated between 1000 m and 1200 m above ground. About 1730h (B3) the plume spreads and thickens, sometimes interacting with natural stratocumulus coming into the vicinity. Small cumulus towers grow up inside, giving the plume a stratocumulus castellanus aspect (B4, B5), typical of unstable meteorological conditions. At the ultimate stage of development (B6), the cumulus at the tail of the plume reaches an appreciable size, taking the perspective factor into account.

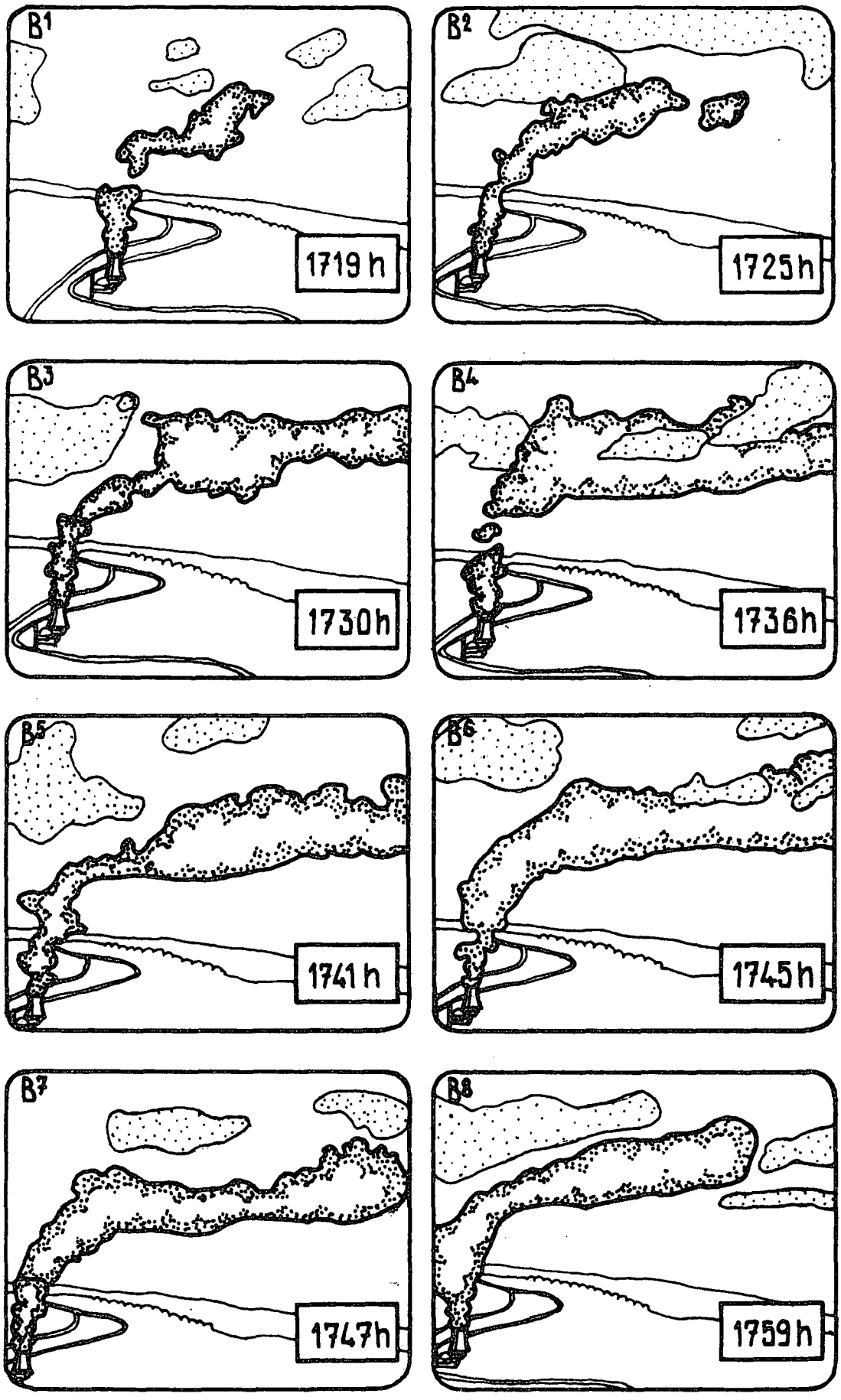

Fig. 5 Formation of castellanus in the plume's wake, June 2nd 1980

At the end of the sequence, the general situation becomes more stabilised (B7, B8). The MOBILAB sounding (Fig. 6) of 1646h is characterized by essentially ascending vertical wind components. The most unstable thermal gradient, measured at 1100h over Payerne, is situated between 1000 m and 1200 m. Favourable conditions are prevailing in this relatively humid layer for noticeable plume development which, over 1300 m, is limited owing to greater gradient stability and lower humidity.

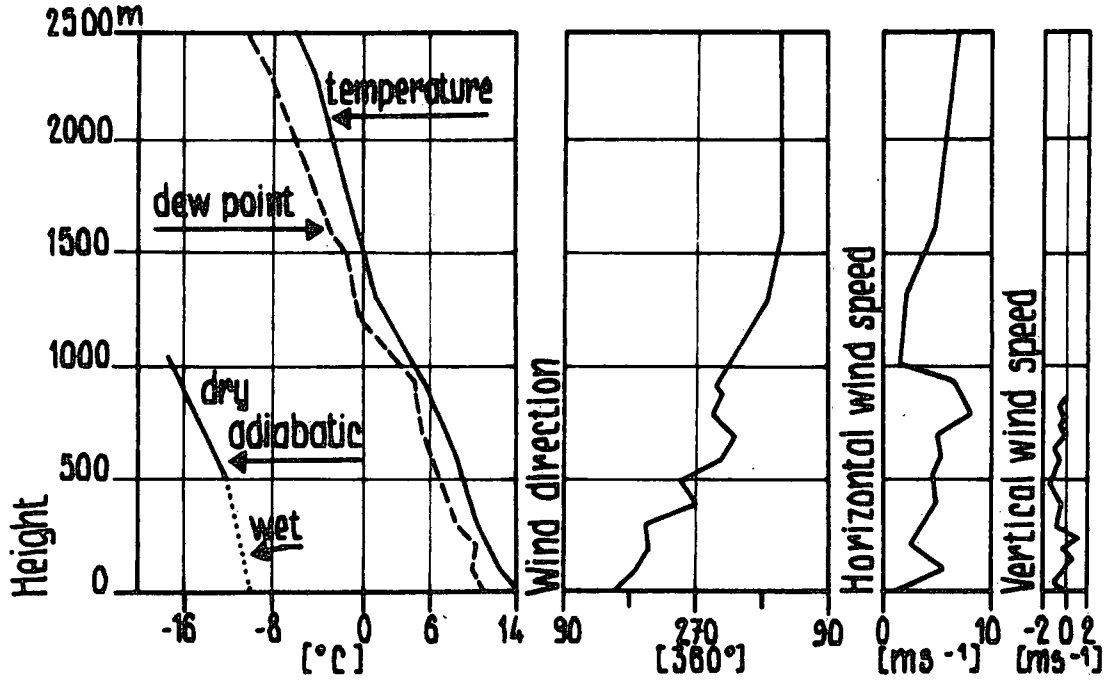

Fig. 6 MOBILAB sounding, June 2nd 1980, 1621h to 1646h extended by the aerological sounding of Payerne, 1045h

Plume behaviour in stormy weather

The 3rd case observed late in the afternoon of June 27th 1980 has already been studied by the EIR (refs. 37 and 38). In our study, the eight drawings (fig. 7) come from a film (1 picture every 3 seconds) taken at Dulliken (2.45 km WSW of the cooling tower), facilitating a more detailed investigation. During the

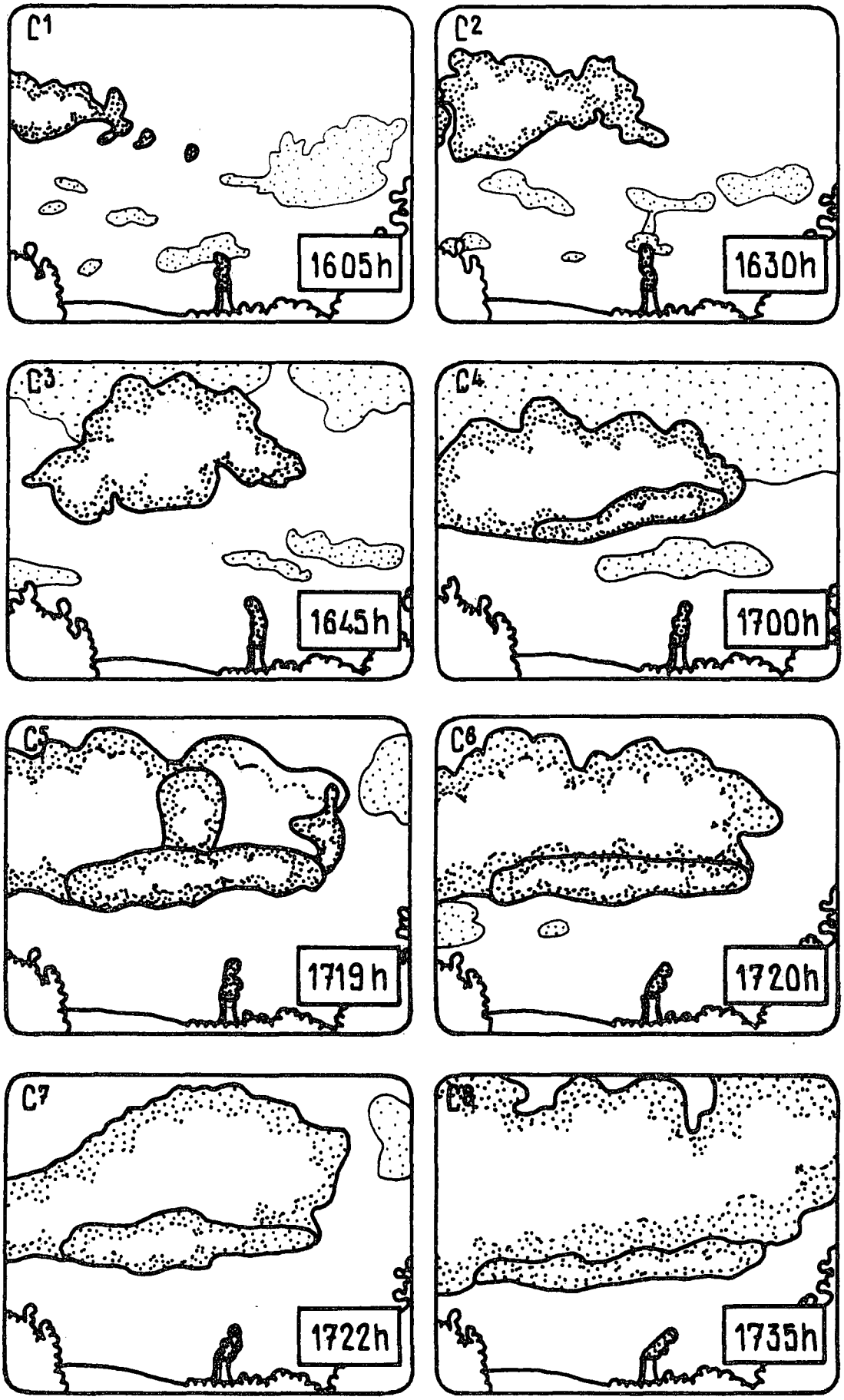

Fig. 7 Plume behaviour in stormy weather, May 27th 1980

afternoon, the plume is split in two parts (C1, C2). The first lifts vertically, 300 m to 400 m over the tower, and the second, more voluminous, strongly resembling natural convective clouds, maintains its position over the plant. From 1635h it develops noticeably in size creating a horizontal base (C4) typical of active cumulus. Fed by the heat release, the cloud continues to grow considerably (C5, C6, C7). The connection between tower and cloud is finally severed by a strong level NE wind. The cumulus carries on its own life independently amongst other smaller natural convective formations. A small thunderstorm (some lightning flashes less than 3 km away) breaks out at 1815h. It is very probably associated with the cumulus triggered off by the power station. Later (from 1930h) other more violent thunderstorms, of natural origin, are observed in the region. The MOBILAB sounding of 1647h (fig. 8) gives the detailed thermodynamic profile up to 1186 m above ground. At this level, the connection with the 1045h sounding of Payerne is unsatisfactory and the next sounding (2245h) is used. A jump of 3.1 ^{o}C in temperature at the joining level prohibits, in this particular case, unrestrictive use of measurements from Payerne. The mean thermal gradient remains unstable up to 2000 m and the humidity deficit diminishes with altitude. Under these conditions strong convections are likely to arise.

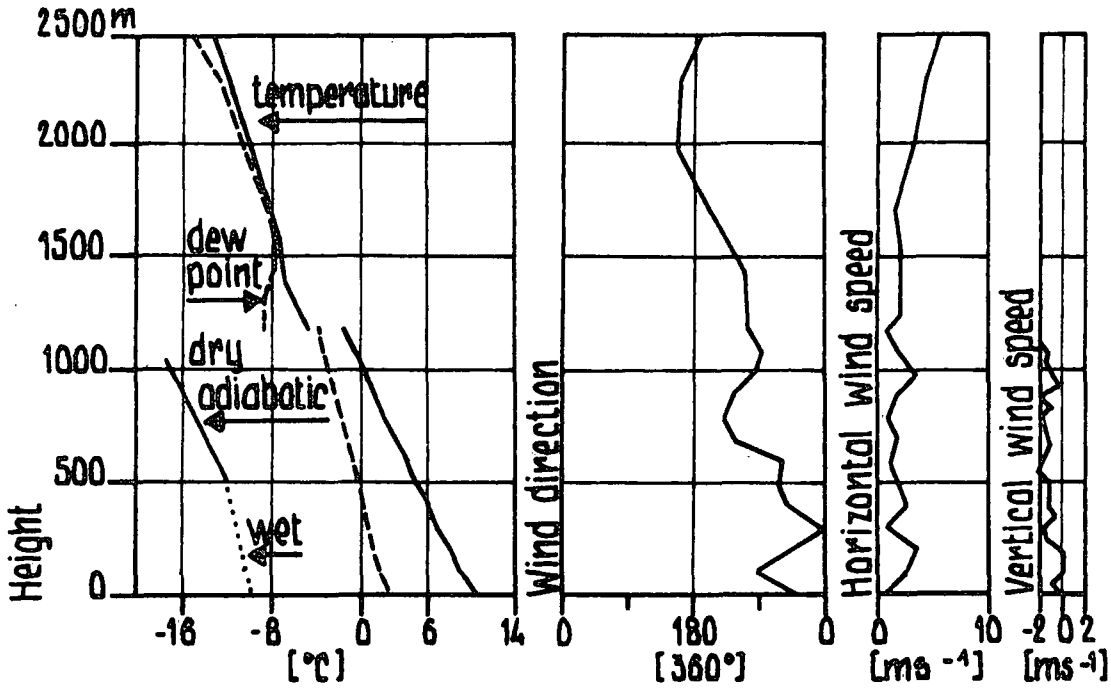

Fig. 8 MOBILAB sounding, May 27th 1980, 1623h to 1647h extended by aerological sounding of Payerne, 2246h

CONCLUSIONS

The 50 microaerological soundings carried out during the GOM80 campaign and the 939 hours of cinematographical plume observations constitute a collection of data, especially suitable for validating numerical models in unstable meteorological conditions.

The observation of the feeding of altocumuli reveals a transfer of energy (enthalpy) from the cooling tower to natural clouds at a height of more than 1500 m above ground, resulting in a local increase of cloud cover and reducing the sunshine duration at ground level.

In an unstable layer in altitude, the wake of the plume can become active and stimulate stratocumulus castellanus formation.

When general conditions are unstable, the plume may trigger off a convective formation over the cooling tower likely to evolve into a small premature thunderstorm which seems to be less severe (ref. 29) than a completely natural process.

The individual cases analysed above only prove the existence of the observed phenomena, but do not give any statistical information on their frequency. Several years' observation, by means of a five camera network currently in operation, will provide the real time distribution of the different plume behaviours and of its shade duration on the ground.

ACKNOWLEDGEMENTS

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