

On the mortality of morning glories

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The Gulf of Carpentaria morning glory has been simulated with a coarse resolution three-dimensional mesoscale (Pielke) model with orography. The simulation is surprisingly good. It predicts (as observed) that the glory should propagate with little attenuation during the night hours, although there is no westerly thermal wind in the model. Its evidence is clear that the glory marks the onset of a bore rather than a finite-length long wave; and it shows with little doubt that the glory dissipates rapidly, at least with cloudless conditions, under the influence of solar heating over land, and is not likely to be responsible for the pressure waves observed at Tennant Creek, far inland to the west.

Introduction

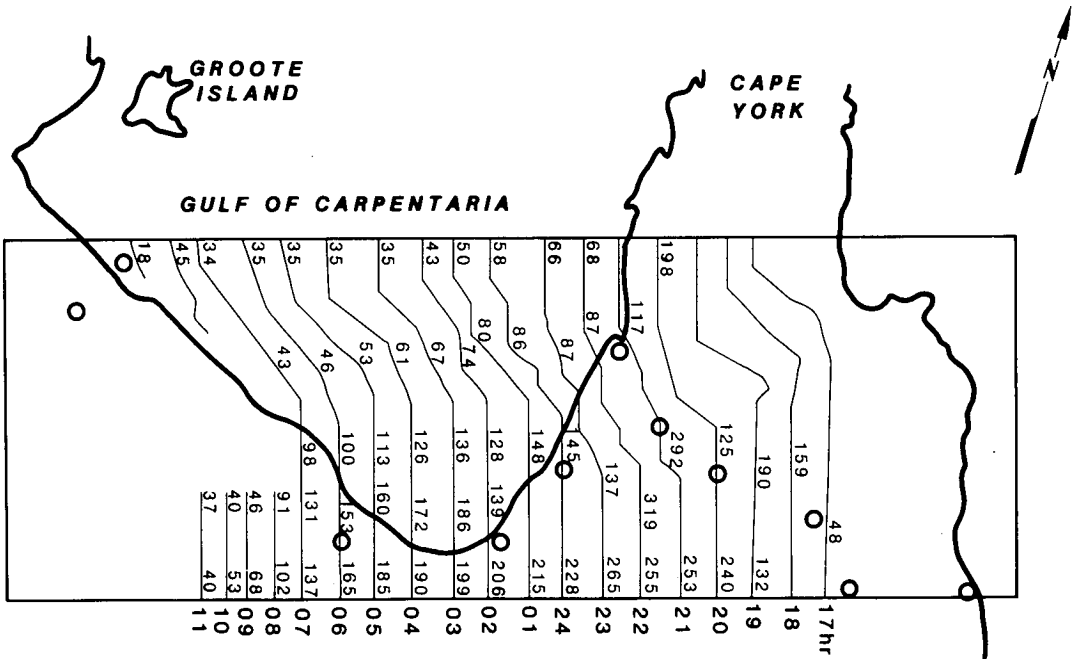
Through observations and two and three-dimensional modelling we have learnt a good deal about the origin and properties of the easterly or northeasterly morning glory in the Dunbar-Macaroni-Karumba-Burketown area of north Queensland. (For the location of these places see Fig. 1.) Recently Christie (1989) presented a detailed theoretical treatment (for idealised stratifications) of non-linear waves in the lower atmosphere, much of which is relevant to a proper description and understanding of the morning glory. However, the general case (and many variations are found in nature), with arbitrary shear and stratification, cannot be encompassed by any known theoretical approaches and must be treated numerically. The numerical work of Noonan and Smith (1985) was unable to satisfactorily reconcile observation and theory, and a more recent attempt by Clarke (1989a), using all available morning glory observations, fared no better. Crook (1986, 1988) has demonstrated that the glory should become rapidly attenuated unless at least one of three atmospheric features is present to preserve it against upward energy loss due to wave radiation.

Very little has been done to determine the ultimate fate of the glory, and surmises have been made that it is responsible for some of the nocturnal pressure waves observed at Warramunga (Christie et al. 1978, 1979) near Tennant Creek, some 600 km to the west-southwest of Burketown. The glory was said, by the pioneer investigator Deering in 1937, to have occasionally been seen, in the last stages of dissipation, as far west as Borroloola, 390 km west-northwest of Burketown; we have a picture (Clarke 1972) said to be of a glory passing Turtle Island in the Sir Edward Pellew Group, near the coast northeast of Borroloola.

Numerical experiments

The present study is based on the use of the three-dimensional Colorado State University model (McNider and Pielke 1981), with detailed orography and conditions appropriate to mid-October, to simulate the glory. The grid used had 20 points in the vertical, the highest above 9 km, and a horizontal net at 20 km intervals over a strip of land and sea, including the southern part of the Gulf of Carpentaria, with an inner area measuring

Fig. 1 Map showing the inner area for the simulation of the morning glory (truncated seaward). The lines labelled with hour of the day at the bottom indicate the locations of isobaric maxima corresponding to the modelled glory, which is not traceable beyond about 1100 h on the second day. The numbers appearing vertically on these lines represent vertical velocities at 1150 m in mm s^{-1} associated with the tendency maximum. The circles locate from left: Borroloola, Turtle Island, Burketown, Karumba, Macaroni, Kowanyama, Dunbar, Highbury, Wrotham Park, Chillagoe and Cairns, which featured in morning glory research.



1360 by 400 km. This area extends from 400 km out in the Coral Sea to Borroloola and beyond, and is oriented with its long axis normal to the east coast of Cape York Peninsula. Initialisation at 0300 h local time was with geostrophic winds, uniform in three dimensions, of respectively 5 and 7 m s^{-1} normal to this east coast, and with vertical temperature and humidity profiles as measured at Macaroni on 10 October 1981. Noonan and Smith (1987) have already used this model, but without orography, to model part of this area, with a uniform initial geostrophic wind of 5 m s^{-1} .

The model, despite its coarse grid, produces a reasonably satisfactory analogue of the glory, and this has been used to provide insight into several aspects of the morning glory, including the effects on it of solar heating after it passes inland from the vicinity of Burketown.

Results of the simulations

The simulations were credible from most points of view, producing a vigorous line disturbance propagating at precisely 40 km h^{-1} (11.1 m s^{-1}) when u_g , the onshore geostrophic wind, is 5 m s^{-1} , and 12.1 m s^{-1} when $u_g=7 \text{ m s}^{-1}$. A second line disturbance, moving slowly towards east-northeast inland of the west coast of the Peninsula, as found by the author's two-dimensional model (Clarke 1984, Figs 11 and 12) is also observed, with vertical velocities of up to 0.05 m s^{-1} at midnight, but it gradually weakens during the night and is of almost negligible amplitude by 0500 h. When $u_g=7 \text{ m s}^{-1}$ this second line is still traceable but less pronounced. The morning glory produced when $u_g=5 \text{ m s}^{-1}$ is more credible than with $u_g=7 \text{ m s}^{-1}$, which computes a glory arriving at Burketown at 0420 h. This is not

unknown, but the arrival time of 0600 h predicted when $u_g = 5 \text{ m s}^{-1}$ is much more commonly observed.

There are some difficulties in pinpointing the glory in the model, partly because of the poor resolution, and partly because of the irregular terrain, which produces vertical velocity fields other than those produced by the analogue glory. The most reliable indicator for the glory is found to be the surface pressure tendency, determined in these experiments over a period of 20 minutes. A tendency maximum coincides closely over a flat surface with a maximum in the vertical velocity at a height of a kilometre or more above the surface.

Figure 1 shows, for $u_g = 5 \text{ m s}^{-1}$ (from a direction of 073°), the location of pressure rise maxima at hourly intervals during the progression of the analogue glory at 11.1 m s^{-1} over much of the gridded area, between 1700 and 0700 h on the next day. The sharpness of the model glory and its strength, in terms of vertical velocity, vary markedly along its length, decreasing from the southern end where modelled w (vertical velocity component) at 1150 m above the surface is roughly 0.2 m s^{-1} during the night hours, to the northern part over the central Gulf where it is more diffuse and yields a maximum w of the order of only 0.05 m s^{-1} . Evidently the narrower part of the Peninsula is much less effective in producing concentrated surges than is the wider part to the south, where the glory effects are mainly focused. These model results appear to be well in accordance with the findings of Noonan and Smith (1987). Comparison of our results with the latter show that at midnight our glory is 60 to 80 km further advanced. This is the order and sign of the difference expected to result from neglecting orography. Experience of varying initial temperature structure suggests that the effect of using different initial temperature and humidity profiles is not likely to be responsible. (Noonan and Smith used measured Willis Island profiles, while the present experiment used an evening profile measured in the centre of the gridded area in a pre-glory situation. It contained a capping inversion of about 6°C at a height of about 4 km.) It will be noted that the glory (at least the stronger southern portion of it) propagates at a steady speed throughout the night and until 0700 h, without significant weakening, as has been observed in the field. Two of Crook's conditions for survival are met in the model: a strong mid-level inversion, and a low-level flow towards the disturbance (due to a fossil

sea-breeze flow from the day before). Crook's possible third condition, reversal of flow from easterly to westerly in the middle troposphere, is clearly not met in the model.

Over the Gulf the model glory propagates from east-northeast at its steady speed of about 11 m s^{-1} , being much more vigorous in the south. After daybreak it is approaching land on the southwest side of the Gulf, and sea-breeze influences are already at work in such a manner as to weaken and rapidly destroy the feeble northern extension of the glory, at about the time it should reach Turtle Island. Thus, a glory at this island is not likely under normal circumstances. Over the land south of the Gulf, after 0700 h, the glory weakens and decelerates, as shown in Fig. 2 (to 6.1 m s^{-1} for $u_g = 5$ and 8.3 m s^{-1} for $u_g = 7 \text{ m s}^{-1}$). Its pressure effects fade rapidly to less than 0.1 hPa by 1000 h. The vertical velocity at its leading edge (not shown) drops from 0.17 to about 0.02 m s^{-1} by 1000 h, and similar decreases in intensity are seen for the case when $u_g = 7 \text{ m s}^{-1}$. Pressure and vertical velocity signatures following the disturbance cannot be said from the evidence to decrease to vanishing point, but they become so weak that the glory cannot be located with any certainty after midday. Thus, morning glories at Borroloola are expected to be rare events. The effect of the onset of solar heating on the glory is quite dramatic, as can be seen by reference to Figs 3 to 6. Heating from below rapidly redistributes properties such as momentum and heat content in the vertical, destroying the structure of the disturbance, as well as enhancing momentum destruction at the ground.

If, as well as a surface inversion, a higher level inversion were participating in the wave motion, the disturbance at higher levels might not be strongly affected by the surface heating. In the morning glory situation, the surface inversion is separated from the capping inversion by a nearly neutral layer, through which the wave motions may be only minimally transmitted. The answer given by the model to the question: 'What is the fate of the morning glory after it is subjected to solar heating over land?' is unequivocal. It decays rapidly.

The glory is clearly visible in Figs 3 and 4 (at 2400 and 0300 h) as a concentrated strong convergence line, at least in the more southerly portion of the field; no such convergence line is in evidence at 0900 h (Fig. 5) in the area where the glory might be expected. Three hours of sunshine (sunrise is at 0548 h) have

Fig. 2 This shows the distance inland from the east coast of Cape York, for the coast-normal ray (073/253°) through Burketown, of the sea-breeze *cum* glory as a function of time of day. It also shows the magnitude of the pressure jump (for this purpose the surface pressure rise in an hour) accompanying the modelled glory, as a function of time of day. The decay of the pressure jump and the deceleration of the analogue glory after sunrise are clearly seen.

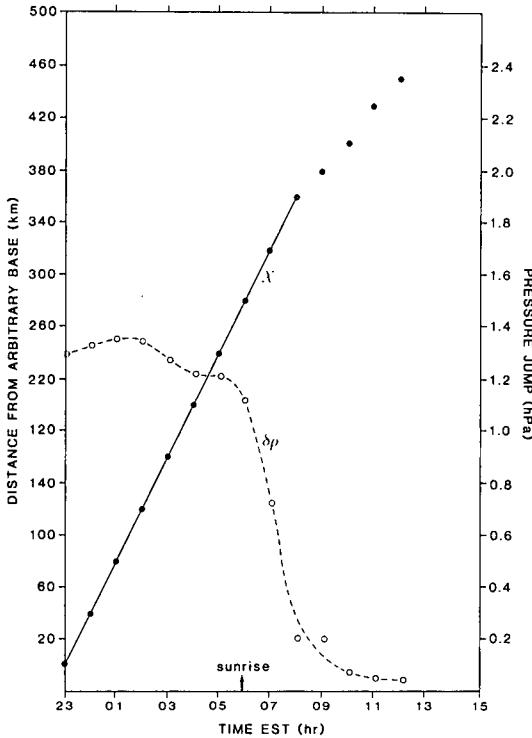


Fig. 3 Map showing wind speed and direction 100 m above the surface at 2400 h (at one-quarter of the density of the computed field). The location of the main convergence line representing the morning glory is marked. Also shown is V_g , the initially imposed geostrophic wind of 5 m s^{-1} . The circle marks Burketown.

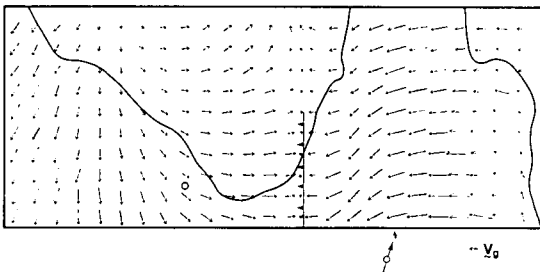


Fig. 4 As for Fig. 3, except that the time is 0600 h and the analogue glory is passing over Burketown.

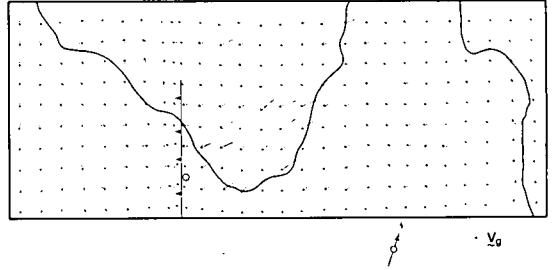


Fig. 5 As for Fig. 3, except that the time is 0900 h. There is no obvious sign of the morning glory.

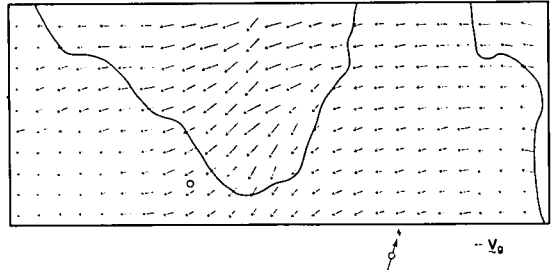
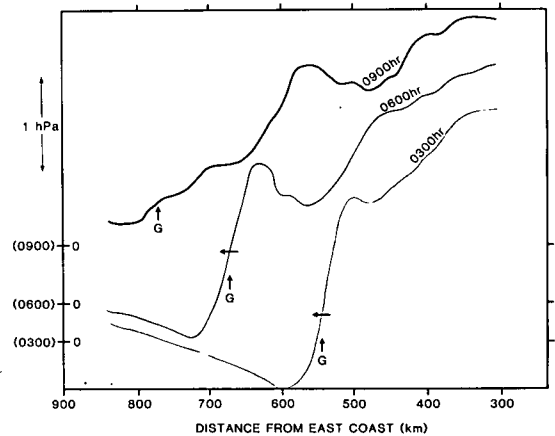


Fig. 6 The surface pressure distribution (deviation from initial) on a line oriented 073-253° through Burketown at 0300, 0600 and 0900 h. G marks the position of the glory, which at 0900 h is barely perceptible.



been sufficient to erase it. (This is not to say that morning glories cannot occur at Burketown after 0900 h. We know they can, probably with smaller effective geostrophic wind than the 5 m s^{-1} prescribed here; but at Burke-

town they will have been subjected to a relatively small amount of solar heating after coming from the waters of the Gulf.)

Figure 6 shows the computed surface pressure distribution (departure from initial) along the ray 073/253° through Burketown at 0300, 0600 and 0900 h. The pressure jumps representing the glory at the two earlier times are very well marked; that at 0900 h has virtually vanished. Considerable effort in the past has been expended to try to find from field observations at Macaroni and Burketown whether the shallow cool layer which deepens with the passage of the glory remains deeper well behind the event. The pressure traces in Fig. 6 at 0300 and 0600 h show that, according to the model, it does, although a noteworthy dip has developed behind the pressure jump at 0600 h. This answers the question posed implicitly and answered in the negative by Christie (1989): 'Is the glory a bore?' The meteorological evidence is that the glory is a bore, and not a 'finite-length wave of elevation'.

Conclusions

One feels justified in deducing from these experiments that a glory-type disturbance on a surface inversion cannot propagate, at least with such intensity as to be perceived as a wind change or a pressure signature of greater than 0.1 hPa, after several hours of solar heating. After solar heating commences, the pressure effects of the surge decrease rapidly in intensity and its vertical velocity field decays in a few hours, to the point where it can no longer be detected with certainty. There is no evidence that the disturbance is transmitted on a higher level capping inversion, as postulated by Christie et al. (1981), although the transmission of very attenuated signals cannot be ruled out. The rapid obliteration of the disturbance predicted by the numerical model is matched by observations on the 'southerly morning glory' observed at Daly Waters (NT) on 1 August 1974: it was seen to dissolve in the forenoon without leaving any traces. (Clarke 1986, Appendix.) This conclusion is also compatible with the observations of Christie et al. (1978) that no solitary wave signatures were observed during the daylight hours after 1100 h CST (GMT + 9 h) at Warramunga. It contradicts the unsubstantiated conclusion (Christie et al. 1981) that cloud lines observed in the afternoon in the Australian interior are 'the result of solitary

waves associated with the leading edge of a dissipating finite-length bore'.* It also tends to contradict the opinion of D. R. Christie (personal communication to Smith (1988, p. 281)) that 'some of the nocturnal solitary wave dominated disturbances observed in the microbarograph array at Tennant Creek . . . are remnants of north-easterly morning glories generated on the previous night'.†

According to the simulation experiments the morning glory can continue to propagate almost unattenuated from its formation before midnight until daybreak, without any wind reversal aloft. It also demonstrates that morning glory waves are, for practical purposes, at the leading edge of a bore rather than of a long finite-length wave of elevation, as considered by Christie (1989). Finally, the experiments suggest that the inclusion of orography in the model is necessary, at least for the realistic timing of morning glory events.

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* The cloud lines described, on the meteorological evidence, marked the leading edges of sharp cold fronts which were essentially gravity currents. This was certainly so for the event at about 0745 h on 25 July 1979 at Mount Isa (event A of Christie et al. 1981), for which the normal wind component at 80 m above the surface exceeded the rate of propagation of the surge for several hours after its passage. It was also accompanied by a sustained fall of at least 2°C at a height of 125 m, as can be seen by examining Clarke (1983, Fig. 14) and the relevant thermograms. The maximum temperature at Mount Isa was 5°C lower on 25 July 1979 than on the preceding day, the barogram shows the change was accompanied by a pressure jump of more than 2 hPa, and the pressure at 0745 on 25 July 1979 was the lowest for the whole week 23-30 July, marking it as a synoptic-scale event.

† It is barely possible that the morning glory might propagate into a region with a surface inversion topped by an extensive thick cloud cover extending far to the west, and that solitary waves at the leading edge of the morning glory might penetrate during the day to Tennant Creek. However, this would certainly be a rare occurrence, and could not account for an appreciable proportion of the solitary wave trains observed there. What probably can account for many of them is the sea-breeze surge mechanism, which creates a long wave of elevation (Clarke 1989b).

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