ments in question are the simultaneous charge and size measurements shown in Figs. 12 and 14 of Christian et al. (1980) and Fig. 8 of Gaskell et al. (1978). We examine again the possibility that these coincidence measurements are of particles which have interacted with the propeller.

All the coincidences presented in Christian et al. (1980) are for particles of diameter $\geq 1$ mm which are therefore not suspect. Figure 8 of Gaskell et al. (1978) has 11 coincidences with $d = 0.5 \pm 0.3$ mm. The other eighteen are for larger particles. These eleven events comprise a small proportion of the total number of coincidences recorded, and when regard is given to the predominance of liquid precipitation, and the small estimated increase in flux, then it seems that at most one or two could be due to propeller interference. We therefore feel that the major conclusions of the paper are unaffected.


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1. INTRODUCTION

Johns et al. (1981) presented a numerical model and simulated the storm surge of November 1977 on the east coast of India. The results from their numerical model imply that major storm surges occurred over a 1200 km stretch from Pondicherry to Contai (Fig. 1). They mentioned that the results of their model agreed with observations but they did not present any observations.

Johns et al. gave the results of their model at five locations: Pondicherry, Kavali, Divi,

![Figure 1. Vulnerability of the east coast of India to storm surges.](image)

Blackened area: major surges (5 m or greater)
Shaded area: intermediate surges (2 to 5 m)
Dotted area: minor surges (less than 2 m)
(modified from Rao 1968).
Vishakhapatnam and Contai. The output from their model showed surges up to several metres' amplitude at these stations. Some arguments are presented below to suggest that the storm surge was extremely local and occurred at the most along a 30 km stretch which included Divi. Thus, whereas the results of Johns et al. are probably correct for Divi, their results for the other four locations are erroneous. They pointed out that the storm surge amplitudes at Kavali and Contai were very sensitive to the boundary conditions used in their numerical models.

2. Observational evidence

While I have no actual tide gauge data to present here, a summary of all available direct and indirect observational evidence points clearly to the extreme localization of the storm surge under study. My native town (Rambhotlapalem, see Fig. 2) is only about 30 km from Divi. In 1978 I visited India and spent about 6 weeks visiting all the places affected by this storm surge. I speak the local language 'Telugu' and have read everything I can find that was written in the press. I also read summaries of the reports (printed in the press) prepared by the federal, state and municipal governments, various national and international relief agencies etc. In addition, I talked with dozens of people who were residents of these areas. Based on all this information, I sketched in Fig. 2 the area

![Detailed map of the Andhra coast. The blackened area shows the region affected by the surge. The area encompassed by the dotted line is the region affected by the cyclone.](image)

affected by the storm surge.

It can be seen from Fig. 2 that Masulipatnam is just barely affected. I estimated from water marks on buildings here that the surge amplitude was under 2 m. All evidence points to a surge of about 4 to 5 m at Divi. At Nizampatnam and Rambhotlapalem there was no trace of any surge.

In Fig. 2 I also show the area affected by the cyclone itself (mainly house roofs blown off and trees uprooted or broken by the strong winds). I discussed my findings with the Director General
of the India Meteorological Department and the directors of the regional meteorological centres at Calcutta, Madras and Delhi. All of them agreed that the storm surge was extremely local. The results of the survey team from the Andhra University's Department of Meteorology and Oceanography (based at Vishakhapatnam) arrived at the same conclusion (as reported in the press).

Further support for these arguments comes from historical evidence. Figure 1 based on a study by Rao (1968) using all available past data classified the east coast of India from a storm surge point of view. Again it can be seen that in the area comprising Divi and Masulipatnam major storm surges have occurred in the past, as well as in two zones south and north of it.

Next we will briefly discuss the probability of a major storm surge at the five locations considered by Johns et al. Contai lies in a zone of major surges and if the storm track passes close to Contai, disastrous surges can occur there. However, there was no evidence to suggest that there was any surge associated with the 1977 Andhra cyclone which made a landfall near Chirala (Fig. 2) about 800 km to the south of Contai.

Vishakhapatnam lies in a zone of minor or insignificant surges. Past experience shows (Murty 1983) that even when the storm track passes near Vishakhapatnam, only minor surges (few cm amplitude) occur there. No surge was registered by the tide gauge there (reported in the press).

Divi lies in a zone of major surges and although there was no tide gauge, all the evidence points to a major surge of 4 to 5 m amplitude (over 10000 people killed). The results of Johns et al. are correct for Divi.

Kavali lies in a zone of intermediate surges. Had the storm track passed south of Kavali, probably a major surge could have resulted there. As it happened in this case, Kavali was on the left side of the storm track. There is observational evidence (Murty 1983) that in the northern hemisphere in the majority of cases major surges occur to the right of the storm track. In the region surrounding Kavali there are vast beaches and low lying areas and thousands of villagers live near the coast. Any major surge here would have not escaped notice.

Pondicherry lies in a zone of minor surges. It also was to the left side of the storm track. There could not have been a major surge at Pondicherry without a significant surge at Madras whose tide gauge showed none.

3. Conclusions

Arguments are presented to indicate that the storm surge associated with the November 1977 Andhra cyclone on the east coast of India was extremely local and occurred on a coastal stretch not exceeding 30 km in length (and not along a 1200 km stretch). The results of Johns et al. are correct for Divi but erroneous for Pondicherry, Kavali, Vishakhapatnam and Contai.

Acknowledgments

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References


Reply to Comments by T. S. Murty
By B. Johns

Dr Murty, as a result of enquiries made locally in India, compares observational evidence on the surge generated by the 1977 Andhra cyclone with results from our numerical models (Johns et al., 1981).
Firstly, in connection with a specific, and most insistently made, point, Dr Murty draws attention to our computed high surge response at Contai. In reply to this, it is necessary to reference the comments that we make in our article in the final paragraphs at the bottom of p. 929. Here, we state quite clearly that this computed feature is of doubtful real significance and proceed to give reasons as to why our model should lead to such a result. As suggested at the foot of p. 929 (and since confirmed by us in a series of further experiments), the computed response at Contai is spurious and is a consequence of an over-representation of the wind-speed, as implied by (34), for \( r > R \). We have found that on modifying (34) so as to reduce the speed in the far wind field to a more realistic value, the computed surge responses at Contai, Vishakapatnam and Pondicherry are reduced to relatively insignificant values whilst leaving that at Divi essentially unchanged. Further information on this is given by Dube et al. (1981).

Dr Murty recognizes that his observational data is obtained indirectly and that it does not carry the same weight as that monitored by a tide gauge. This is, of course, inevitable in a region with such a sparse network of gauges. However, in order that the indirectly obtained data be at all convincing, it is necessary to be more precise with regard to its quantitative presentation. Dr Murty states that the surge amplitude at Masulipatnam was under 2 m – this being estimated from water marks on buildings. Before this information is useful, it is necessary to know the height of the footing of the building above mean sea-level. Is the footing at mean sea-level (in which case it would be subject to flooding by tides) or is it 1 m or 2 m above mean sea-level? Perhaps Dr Murty has already compensated for this in quoting a surge amplitude of 2 m but this is not made clear. It is important to note that our computed elevations are heights above an effective equilibrium sea-level. Clearly, when interpreting this indirectly obtained data, such considerations are important. Thus, the essence of our reply is that indirectly obtained surge elevations are obtained from evidence of flooding and, if the land is sufficiently elevated to prevent this, no evidence of a surge will be forthcoming. In this connection, it is noteworthy that the Divi region is characterized by a low-lying island situated at the mouth of a river and is particularly susceptible to flooding. It seems probable that flooding at Divi was a consequence of surge penetration into the river with the lateral spreading of water over adjacent regions.

Further comments on the dynamics of surge development are appropriate here. The view that the maximum surge, in the northern hemisphere, occurs to the right of the position of landfall is generally true only when the storm impinges normally on a long straight coastline. This was not so in the case of the Andhra cyclone and we have recently obtained evidence from our numerical models that the main dynamical response consists of a coastally-trapped wave travelling northwards along the Andhra coast. The local amplitude of this is predominantly determined by the local bathymetry and coastal topography and is not a sole consequence of local wind-stress forcing. Whilst our result concerning the occurrence of the maximum computed surge elevation at Kavali was unexpected (and we recognize that a change in the local bathymetric specification might conceivably change this result), it cannot be rejected out of hand on the basis of dynamical reasoning.

In conclusion, Dr Murty is concerned that our numerical models lead to a high surge affecting a substantial length of coastline. In reply to this, we reference the case of the surge generated by Hurricane Carla in 1961 in the Gulf of Mexico. In this, surge elevations exceeding 1 m were monitored by tide gauges from Texas to the coast of Louisiana – a distance of over 800 km. In many respects, this hurricane was similar to the 1977 Andhra cyclone in that the radius of maximum wind at the time of landfall was about 70 km. There appears to be no clear reason as to why there should be any substantial difference in the dynamical scale of the surge response forced by these similar atmospheric phenomena.

References
