

## Reply

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We appreciate Mr. Neumann's interest and comments on our paper. We are presently making similar rawinsonde observations (as reported in this paper for the west Pacific) in the west Atlantic. Initial indications show the west Atlantic results to be very similar to those of the west Pacific. We are presently increasing our rawinsonde data sample in each ocean to 20 years in the hope of obtaining more accurate steering relationships for selective cyclone classes.

Yes, most of our motion results at the present time are diagnostic. The statement referred to is perhaps overly optimistic at this time, and more clarification should have been made. What was intended was the possible future increased confidence and possible better forecast skill which might be obtained for the 20–25% or so of tropical cyclones which follow atypical tracks. If the cyclone motion-steering flow concepts could be better documented as regards level, horizontal extent of surrounding circulation, etc., for all cyclone classes, some degree of future improvement in cyclone forecasts might be forthcoming. This would require that the steering current be much more accurately measured than at present through special aircraft flights.

There are a variety of ways one might perform new research on cyclone motion and surrounding wind relationships with rawinsonde data sets. We are planning to selectively examine the steering flow relationships (in a statistical sense) for unusually tracked cyclones, right and left turning versus straight moving storms, intensifying versus filling cyclones, etc. If there should prove to be a time lag of 12–24 h in response of the cyclone center motion to outer wind-height changes, then some forecasting skill increase might be expected through more accurate monitoring of the outer fields with aircraft coverage. I am confident that improved knowledge on this subject is possible through judicious rawinsonde compositing of selectively chosen cyclone motion classes. It was with regard to the future use of rawinsonde data that we expressed the opinion that new operational forecasting schemes "might" be developed.

In a companion paper by George and Gray (1977) we used these same compositing techniques to show that west Pacific cyclone recurvature is best specified 12–60 h prior to recurvature by 200 mb wind-height fields 8–20° northwest to northeast of the cyclone center. The 700–500 mb level from which recurvature is usually forecast

shows smaller and less relevant differences between these two classes of cyclones. We are told that this observation of using 200 mb level data has influenced to some degree the present JTWC (Guam) forecasting of recurvature.

We are aware of the lack of significant improvement in tropical cyclone forecast skill in recent years despite development of new forecast techniques. These limitations are likely due to the following:

- 1) Lack of improvement in the measurement of middle-level flow patterns which best steer the cyclone. Rawinsonde networks have not been improved in recent years. Satellite-derived winds are available only at lower and upper tropospheric levels. Also, fewer middle-level winds are available from prop aircraft now that most commercial air traffic is accomplished at upper tropospheric levels.

- 2) The new forecast techniques have had to often use individual time period height-geostrophic winds from rawinsonde-void regions. These data are of questionable quality. The newer forecast verifications of steering current can be no more reliable than the older schemes. By contrast, our rawinsonde compositing does not use space interpolated pressure-height data.

We disagree with Mr. Neumann that the availability of continuous satellite viewing of tropical cyclones has downgraded the relative predictive potential of the steering current. Satellite data cannot well determine surrounding cyclone middle-level wind-heights and steering currents. Recent attempts at utilization of satellite cloud information for improved cyclone track prediction has not been encouraging. That present and past motion correlates best with cyclone future motion is likely a result of the following:

- 1) The majority of time most cyclones move with uniform direction and speed. In these situations no special techniques beyond extrapolation-climatology are required to make satisfactory forecasts. As most of the significant forecast error occurs in one-quarter of the situations when atypical movement occurs, signifi-

cant improvement to forecasting is likely to occur only with an improved handling of these atypical situations. As these situations represents only the minority of cases, present and past track information of the majority of well-behaved cases will statistically dominate over the atypical situations and give (for the atypical movement cases) a false sense of parameter relevance. Past and present position with climatology does not lead to satisfactory forecasts in the 20-25% of cases of atypical motion. Hurricane Anita of 1977 is an example.

- 2) In the verification of individual forecasts accurate middle-level (~500-700 mb) steering flow is seldom available. By contrast, accurate present and past cyclone center position usually is. Statistical testing of relevant motion parameters is thus biased against steering flow. A fair comparison has yet to be made. If really accurate middle-level steering current information were available at all times, this comparison would likely be significantly more favorable for steering, especially in those situations when the cyclone does not follow a typical track.

Cyclone motion and steering current relationships will likely have to be well documented for the difficult to forecast atypical motion cases (at least in the statistical sense) before the costs of special middle-level aircraft flights can be justified. Our future research will attempt to determine if such documentation can be made. There is the possibility that forecasts based on accurate and current surrounding steering flow may (in the difficult atypical motion situations) be superior to the present forecast schemes which are usually severely limited by accurate steering flow information.

#### REFERENCES

- George, J. E., and W. M. Gray, 1976: Tropical cyclone motion and surrounding parameter relationships. *J. Appl. Meteor.*, **15**, 1252-1264.
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