An Example of Hurricane Tracking and Forecasting with a Global Analysis-Forecasting System

W. A. Heckley[1], M. J. Miller[1], and A. K. Betts[2]

Abstract

The tracking of Hurricane Elena by the ECMWF operational analysis system is compared with reported positions from reconnaissance aircraft and coastal radar. An example forecast is shown for the operational model and also for an experimental version of the model. A strong sensitivity to the parameterization of deep cumulus convection is found.

1. Introduction

According to Case (1986) the erratic, five-day track of Hurricane Elena, so close to the shore, resulted in perhaps the most-extensive evacuation in the history of the United States of America—nearly a million people were involved. Due to Elena's changing threat, nearly half of the Gulf coastline was put under hurricane warning by the National Weather Service at one time or another.

Elena can be traced in the European Centre for Medium Range Weather Forecasts (ECMWF) operational analyses from an origin as a wave that formed in the region immediately downstream of the African Hoggar mountains (Reed et al. 1986) on 20 August 1985. The wave moved rapidly across the Atlantic. On 26 August, Elena first appeared in the public advisories, issued by the National Hurricane Center (NHC) in the United States, as a strong tropical wave about 250-n mi east of the Leeward Islands. Elena was classified as a tropical depression on 27 August and as a tropical storm on 28 August. Elena's track from 00 UTC 28 August to 06 UTC 4 September is shown in Fig. 1. Positions (six hourly), central pressures (hPa), and maximum wind speeds (knots) are courtesy of the NHC. On 29 August Elena was classified as a hurricane, at which time sustained winds of 75 kt were reported and Elena was moving on a west-northwest course through the Gulf towards New Orleans. During 30 August the steering currents weakened and Elena moved first northward, then slowly to the northeast, towards the west coast of Florida. On 31 August Elena started to move directly east and came to within 55 n mi of Cedar Key, Florida. On 1 September Elena strengthened to a major hurricane with sustained winds of 110 kt and began to move northwest again. By 23 UTC that day, Elena became a severe hurricane with winds of 125 kt. The eye reached the Mississippi coastline at 13 UTC 2 September.

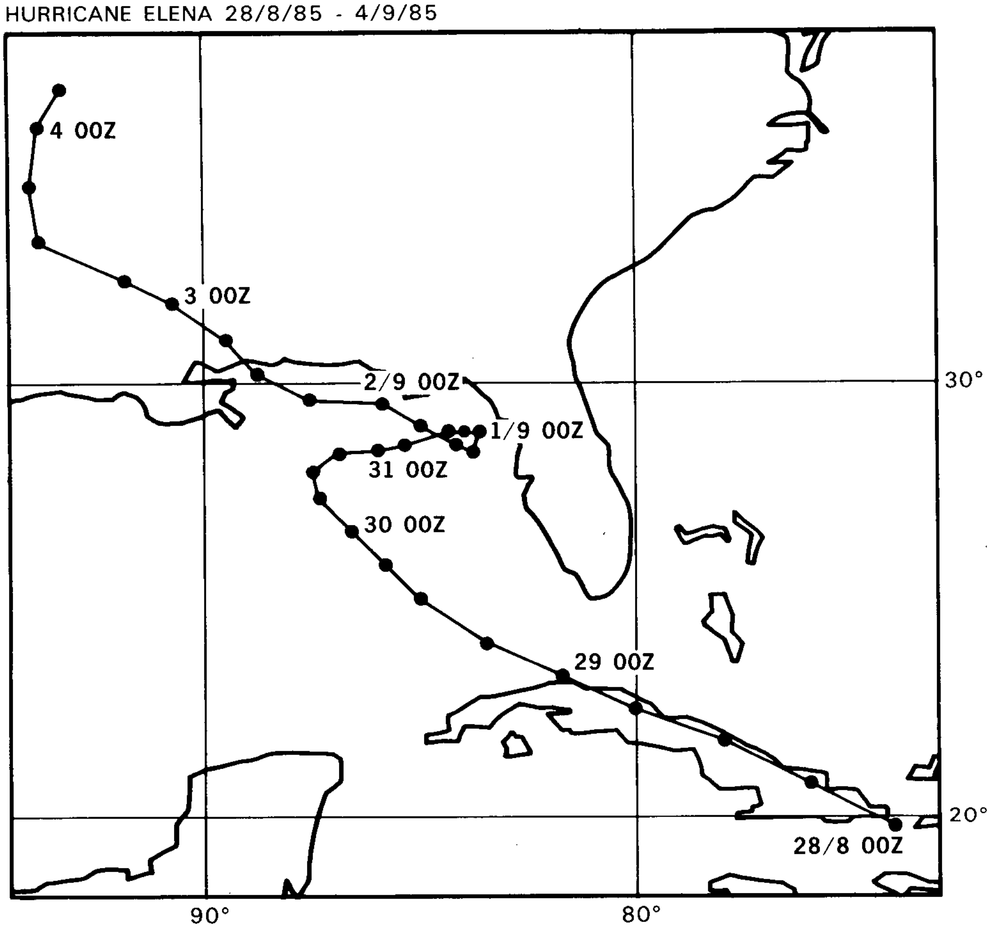
This is an interesting case for study because of Elena's intensity, and the complex nature of the steering flow in which it was embedded made prediction of the track especially difficult. Section two illustrates the ability of an operational analysis system to track hurricanes. Section three illustrates the sensitivity of forecasts to model physics, which in certain cases (such as the one shown here) can be dramatic. It should be emphasized that this case has been chosen to illustrate the extreme sensitivity that can occur and not to illustrate "typical" sensitivity.

2. Tracking of Elena

The ECMWF analysis system is a global, three-dimensional, multivariate analysis that is based on a form of statistical optimal interpolation (Lorenc, 1981) of surface pressure, wind, and geopotential at sixteen standard-pressure levels, and a univariate analysis of layer precipitable-water content. The analyzed fields are expressed in terms of a series of spherical-harmonic coefficients. A triangular truncation is applied at wave number 106, which corresponds approximately to a lowest resolved wavelength of 380 km, which in terms of a grid-point model would correspond to about a 190-km grid. The approach is four dimensional in the sense that a six-hour forecast from the previous analysis, using the full forecast model, is used to provide a first-guess field for the subsequent analysis. A more-detailed description of the analysis may be found in Bengtsson et al. (1982) and in Shaw et al. (1984). Information on the smallest scales will come almost exclusively from the (approximately 190-km) resolution of the forecast model used to provide the first-guess fields. The resolution that is actually "analyzed" is more on the order of 1000 km (Daley, 1983), which is defined partly by the data density and partly by the breadth of the statistical-correlation functions used to "spread" the observational data.

Clearly, the ECMWF global-analysis system will be unable to resolve, much less analyze, in detail, the structure of a hurricane, but it should be able to describe the large-scale flow associated with the hurricane (given sufficient observations) and also to track the system. Although high-resolution data were obtained by the reconnaissance flights into and around Elena, none of this data was used in the ECMWF analyses. The ECMWF analyzed track of the vortex center from 12 UTC on 29 August through 12 UTC on 3 September is shown in Fig. 2a, and the reported track from the NHC is reproduced in Fig. 2b. Considering the effective resolution of the analysis the vortex center is generally well located by the

[1] European Centre for Medium Range Weather Forecasts, Reading, U.K.
[2] West Pawlet, VT 05775.



		WIND SPEED (kt)	CENTRAL PRESSURE hPa
08/28			
	00Z	30	1,012
	06Z	30	1,010
	12Z	30	1,008
	18Z	45	1,006
08/29			
	00Z	50	1,004
	06Z	55	1,000
	12Z	65	994
	18Z	70	990
08/30			
	00Z	75	986
	06Z	80	980
	12Z	90	974
	18Z	90	978
08/31			
	00Z	90	977
	06Z	90	976
	12Z	90	975
	18Z	90	974
09/1			
	00Z	95	971
	06Z	100	965
	12Z	105	961
	18Z	110	954
09/2			
	00Z	110	953
	06Z	105	957
	12Z	100	959
	18Z	60	990
09/3			
	00Z	45	1,000
	06Z	30	1,004
	12Z	25	1,006
	18Z	25	1,008
09/4			
	00Z	20	1,010
	06Z	20	1,010

FIG. 1. Track of the Hurricane Elena from 00 UTC 28 August, 1985 through 06 UTC 4 September, 1985. Position is recorded every 6 hours. Also plotted is the reported central pressure in hPa and the reported maximum wind speed in knots (Position, pressure, and wind information courtesy of the National Hurricane Center, Coral Gables, Florida, U.S.A.).

global analysis. The analyzed 850-hPa wind fields for 12 GMT 31 August and 12 UTC 2 September are shown in Fig. 3. Although the very strong reported winds are not captured, the analysis shows a well-defined hurricane circulation that is located well with respect to that observed. (For discussion of the ability of the ECMWF system to analyze and track easterly wave disturbances the reader is referred to Reed et al. [1986].)

3. Forecasts of Elena

The ECMWF operational forecast model has a spectral representation of variables in the horizontal with resolution of 106 waves (triangular truncation). A finite-difference representation is used in the vertical, with 16 levels on hybrid, sigma-pressure, coordinate surfaces. A description of the adiabatic formulation of the model may be found in Jarraud et al. (1985). The model has a comprehensive parameterization of diabatic processes including surface-layer fluxes, free-atmosphere turbulent fluxes, deep-cumulus convection, shallow (nonprecipitating) cumulus convection, large-scale precipitation, radiation, cloud cover, cloud-radiation interaction, computed surface temperature, soil moisture, and snow cover. Details of the model parameterizations may be found in Tiedtke et al. (1979); Tiedtke and Slingo (1985); Slingo (1986); and Ritter (1985). An assessment of the performance and systematic errors of the ECMWF model in the tropics may be found in Heckley (1985).

As can be seen from Fig. 1, Elena underwent two distinct periods of growth. The first intensification began at about 00 UTC 29 August when the hurricane moved rapidly on a northwest course through the Gulf of Mexico, and the second began about 18 UTC 31 August, when the hurricane turned and again began to move rapidly on a northwest course. Between these two periods of intensification, the hurricane weakened slightly, or grew very little, and drifted slowly eastward. The period chosen for experimentation is from 12 UTC 31 August, which is immediately prior to the turning and second intensification of the hurricane. This should present an especially difficult forecasting problem because both the turning and intensification aspects need to be predicted.

a. The forecasts

The track of the hurricane as predicted by the operational ECMWF global-forecast model is shown in Fig. 2c. The

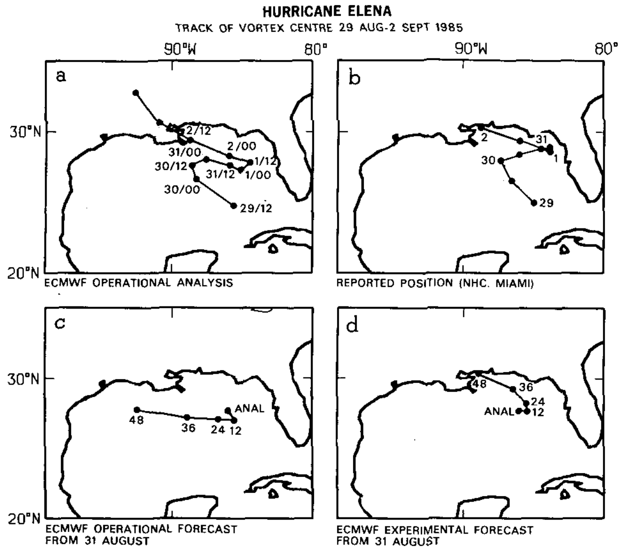


FIG. 2. Track of the Hurricane Elena 12 UTC 31 August 1985 through 12 UTC 2 September 1985. Position is recorded every 12 hours. a) ECMWF operational analysis. b) Reported position (NHC, as Fig. 1). c) ECMWF operational forecast from 12 UTC 31 August 31. d) ECMWF experimental forecast from 12 UTC 31 August.

model correctly predicts the movement of the hurricane towards the southwest, but instead of turning to the northeast, it tracks to the west. The associated wind field for the 48-hour forecast from 12 UTC 31 August is shown in Fig. 3c.

In the experimental forecast shown in Fig. 2d the hurricane is correctly predicted to turn to the northwest and the predicted landfall on 2 September is at precisely the reported position. Given that this is a 48-hour forecast of a difficult situation it is quite remarkable. The associated 850-hPa wind field (Fig. 3d) for this 48-hour forecast is almost identical to the verifying analysis (Fig. 3b). The experimental forecast started from the same analysis and used the same model except for the parameterization of cumulus convection.

b. Parameterization of cumulus convection

The operational model parameterizes deep convection using a version of Kuo's scheme (Kuo, 1974; Tiedtke et al., 1979; Tiedtke and Slingo, 1985). The moisture convergence is par titioned using a parameter $b = (1 - R)^3$ where R is the environmental relative humidity. A fraction, $1 - b$, of the moisture convergence is precipitated, and a fraction, b, is used to moisten the atmosphere, Shallow convection in the operational scheme is parameterized using a diffusive scheme (Tiedtke, 1986) whenever a cloud top is found, but there is no net moisture convergence.

The experimental forecast (Fig. 3c) included a cumulus parameterization based on lagged adjustment towards computed reference profiles for deep and shallow convection (Betts, 1986; Betts and Miller, 1986). An adjustment time of 1 h was used. The reference profiles are designed to represent a quasi-equilibrium structure for deep convection, and a mixing-line reference process (Betts, 1985) for shallow nonprecipitating convection.

To determine whether the differences between the forecast intensification or track are caused by the differences in the shallow- or deep-convection parameterizations, the experiment was repeated using the lagged-adjustment scheme for shallow convection and the Kuo-type parameterization scheme for deep-cumulus convection. This forecast also failed to capture the intensification of the hurricane, and produced a track similar to that of the operational forecast. This is reasonable as the deep convection is the primary source of latent-heat release, which is the direct cause of amplification. We are further investigating the characteristics of the convection-adjustment scheme.

4. Discussion

It has been shown that ECMWF global analysis-forecasting system has the potential to track the movement of hurricanes and also, in some circumstances, to correctly forecast their movement. However, a very strong sensitivity to the parameterization of cumulus convection is found for this case. Perhaps this above-normal sensitivity is due to the complicated nature of the steering flows in this case. It should not be concluded from this example that one parameterization scheme outperforms the other, as other forecast examples could be given in which the reverse would be true.

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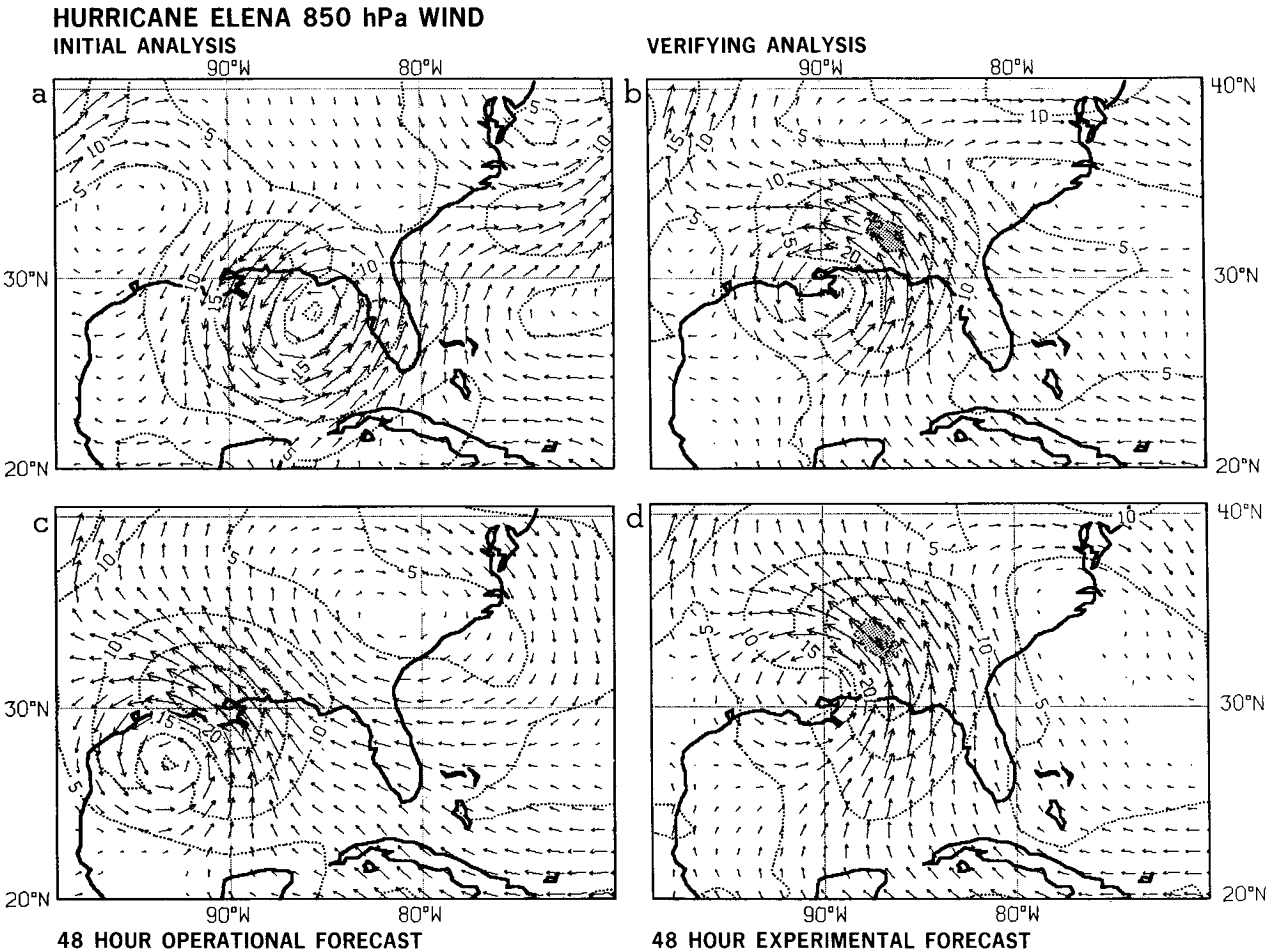

FIG. 3. 850-hPa wind field in Hurricane Elena based on a) ECMWF operational analysis 12 UTC 31 August 1985. b) ECMWF operational analysis 12 UTC 2 September 1985. c) 48 hour ECMWF operational forecast, from 12 UTC 31 August, that verifies on 12 UTC 2 September. d) as in c) except for an experimental forecast. Contour interval for wind speed is 5 $m \cdot s^{-1}$ and winds greater than 15 $m \cdot s^{-1}$ are shaded and greater than 25 $m \cdot s^{-1}$ are heavily shaded.

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