A Hypothesis for the Redevelopment of Warm-Core Cyclones over Northern Australia*

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ABSTRACT

Tropical cyclones moving inland over northern Australia are occasionally observed to reintensify, even in the absence of well-defined extratropical systems. Unlike cases of classical extratropical rejuvenation, such reintensifying storms retain their warm-core structure, often redeveloping such features as eyes. It is here hypothesized that the intensification or reintensification of these systems, christened *agukabams*, is made possible by large vertical heat fluxes from a deep layer of very hot, sandy soil that has been wetted by the first rains of the approaching systems, significantly increasing its thermal diffusivity. To test this hypothesis, simulations are performed with a simple tropical cyclone model coupled to a one-dimensional soil model. These simulations suggest that warm-core cyclones can indeed intensify when the underlying soil is sufficiently warm and wet and are maintained by heat transfer from the soil. The simulations also suggest that when the storms are sufficiently isolated from their oceanic source of moisture, the rainfall they produce is insufficient to keep the soil wet enough to transfer significant quantities of heat, and the storms then decay rapidly.

1. Introduction

Tropical cyclones are known to be powered by large heat fluxes from the underlying ocean (Kleinschmidt 1951), and therefore rapidly decay as they move inland, with an exponential time constant of around 10 h (Kaplan and DeMaria 1995). Exceptions are known to occur, however, when landfalling tropical cyclones interact strongly with extratropical systems (Hart and Evans 2001; Jones et al. 2003) or when they move over warm, swampy terrain (Shen et al. 2002). In the latter case, there can be enough heat flux from the swamp to appreciably slow the decay of the storms.

Another interesting exception occurs with some tropical cyclones making landfall over northern Australia. Even in the absence of appreciable extratropical interactions, and although the underlying soil is desert sand, some of these storms are observed to reintensify, often reacquiring classical inner-core structure, including eyes. This mysterious reinvigoration of tropical cyclones and depressions while over land is the focus of our study. Because such redeveloped warm-core cyclones are apparently nearly unique to remote desert areas of northern Australia, we here call them "agukabams," from the aboriginal word roots "agu," meaning land, and "kabam," meaning storm. Here we present an overview of one such event and go on to examine the hypothesis that warm-core cyclones may intensify and be maintained over sandy soils that are sufficiently hot and whose thermal conductivity is sufficiently enhanced after being moistened by the first rains of the storm. We use a simple tropical cyclone model coupled to a soil model as a preliminary attempt to examine this hypothesis.

An overview of a particular agukabam is presented in section 2, followed in section 3 by a description of an

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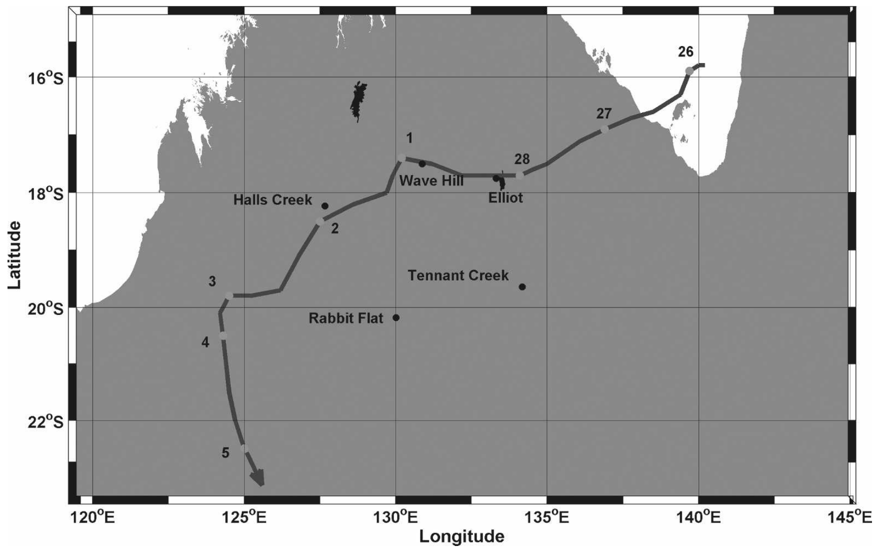

FIG. 1. Track of Abigail following landfall on the southern Gulf of Carpentaria coastline from 1100 UTC 27 Feb 2001 (271100 UTC on map) to 0632 UTC 3 Mar 2001 (030632 UTC on map).

idealized model and its sensitivity to soil parameters, storm movement, and rainfall. An attempt to simulate the observed agukabam is also presented. A summary is provided in section 4.

2. Agukabam Abigail

Tropical Cyclone Abigail made landfall on the southern coast of the Gulf of Carpentaria around 1200 UTC 26 February 2001 with an estimated maximum sustained 10-min mean wind speed of 33 m s^{-1}. It then weakened while moving in a general westward direction but later reintensified over land. Here we document two cycles of apparent reintensification as the storm progressed over land (Fig. 1). A more detailed description of Abigail may be found in the online supplement to this paper (http://dx.doi.org/10.1175/2008MWR2409.s1).

Abigail passed to the north of Elliot early on 28 February; a time series of observations is shown in Fig. 2a. In the three hourly 2330 UTC 27 February synoptic observation at Elliot, southwesterly winds averaging 15 m s^{-1} were reported with a mean sea level pressure (MSLP) of 993.4 hPa, near the time of a local diurnal pressure maximum. Heavy rain was observed, with 53 mm falling in the previous 12 h, most of which fell in the final 3 h. Three hours later, while the center of Abigail was just to the north, the station reported southeasterlies at 10 m s^{-1} with the pressure steady at 993.4 hPa. In this 3-h period, 61 mm of rain was recorded. The lowest MSLP of 992.8 hPa was recorded at 0500 UTC 28 February with easterly winds at 8 m s^{-1}, indicating that by this time Abigail was positioned to the northwest. In summary, while near Elliot Abigail had a central pressure of around 990 hPa with probable gale force winds near the center.

The next station Abigail came close to was Wave Hill, passing to its north, with its closest approach at 1700 UTC 28 February when the MSLP at Wave Hill was 987.5 hPa. The distribution of rainfall at about this time was quite asymmetric (Fig. 3). A time series of observations is shown in Fig. 2b. Winds at the time were east-northeasterly, averaging 10 m s^{-1}. Based on banding in satellite imagery (assuming that its interpretation for agukabams is similar to that for tropical cyclones over the sea) and mean sea level pressure readings, we estimate the central pressure as being below 985 hPa when Abigail passed near Wave Hill. This is equivalent to over-the-ocean 10-min peak wind speeds of 25 m s^{-1}, according to the wind–pressure relationship used in the Northern Territories by the Australian Bureau of Meteorology. A Dvorak Enhanced Infrared (EIR) satellite image at 0332 UTC 1 March (see online supplement) shows that the cyclone subsequently formed an eye. EIR eye analyses gave a T4.0[1] that is equivalent to over-the-ocean 10-min wind speeds of 30 m s^{-1} or a central pressure of 975 hPa (Velden et al. 2006).

This was probably the peak intensity for Abigail over this intensification cycle; after this, the eye feature evident in satellite imagery became less well defined.

[1] See Velden et al. (2006) for a definition of T numbers.

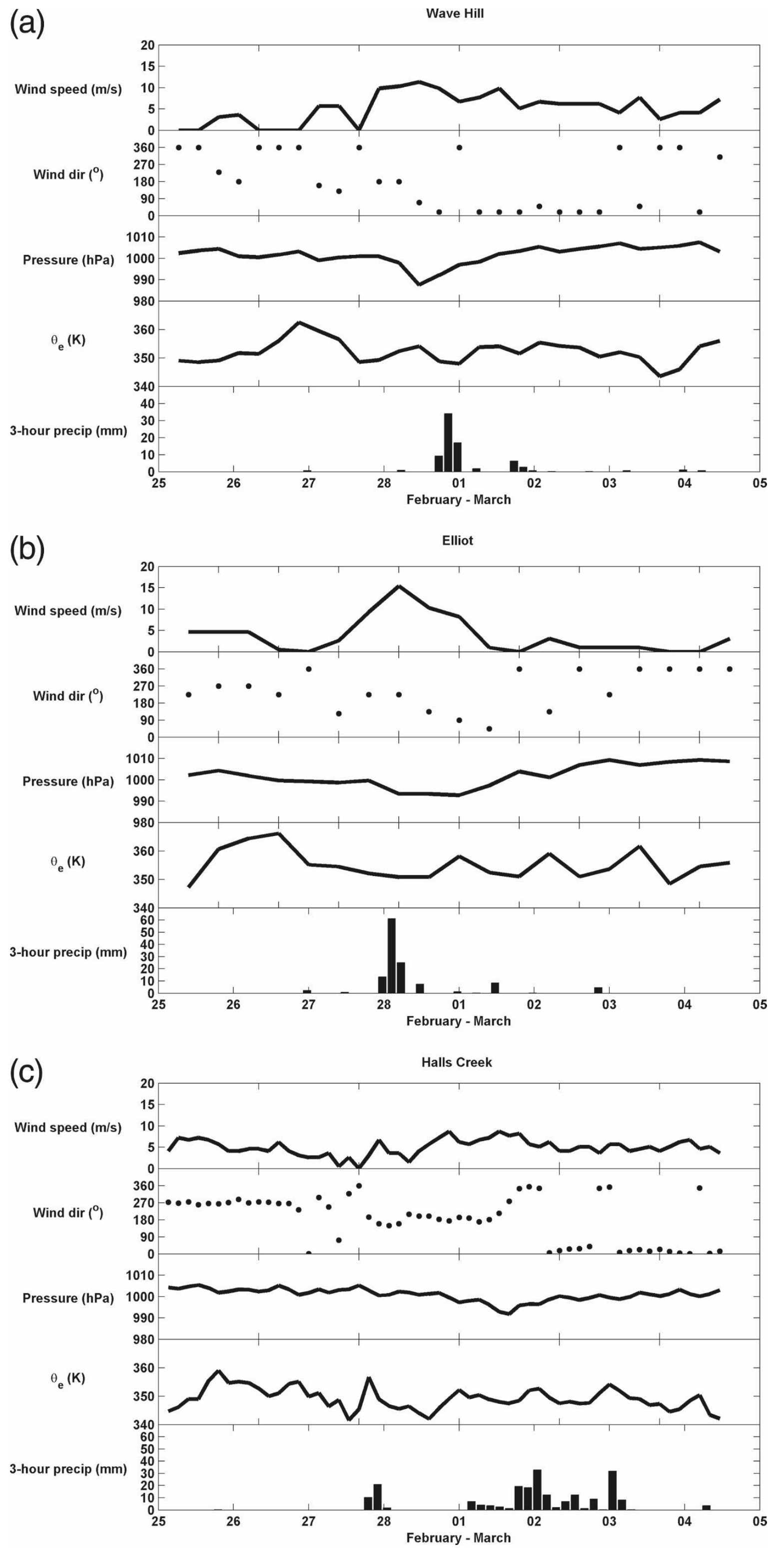

FIG. 2. Time series of meteorological observations at (a) Elliott, (b) Wave Hill, and (c) Halls Creek. Each panel shows, from top to bottom, wind direction, wind speed, sea level pressure, relative humidity, and rainfall. Wind direction is indicated by dots.

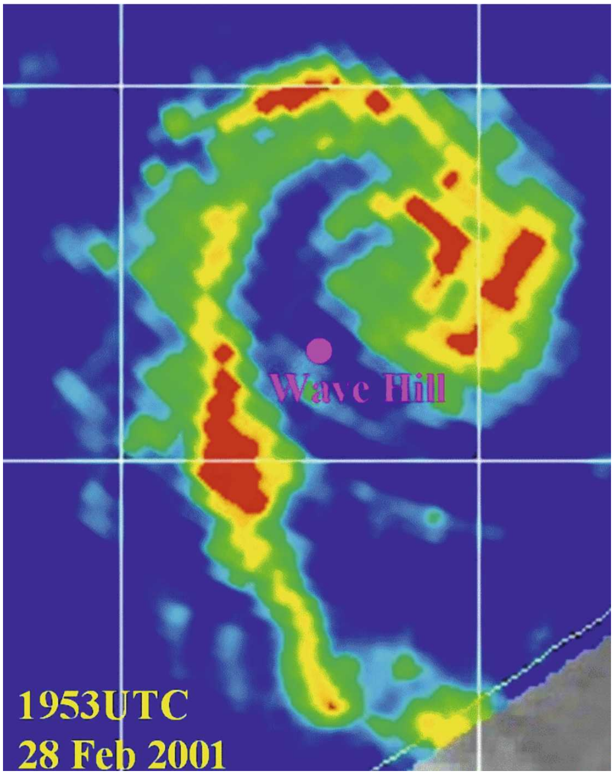

FIG. 3. TRMM Microwave Imager (TMI) 85-GHz image (horizontally polarized) showing Abigail approaching Wave Hill from the east.

Abigail then approached the Halls Creek Meteorological Station, and the radar at this site (not shown) recorded the formation of a clear eye at 1710 UTC 1 March, just 55 km to the east. A sequence of radar images (Fig. 4) shows that the structure of Abigail at this time was similar to that of a mature oceanic tropical cyclone. The cyclone was closest to the station at 2200 UTC 1 March when the station MSLP was 991.8 hPa, midway between the diurnal pressure minimum at 0300 LST and the maximum at 0900 LST. A time series of observations is shown in Fig. 2c. The wind at the station was westerly, averaging 8 m s^{-1}, with a maximum wind gust of 21 m s^{-1} from the north-northwest. Halls Creek had recorded 50 mm of rain at this time, which had commenced to fall about 21 h before, with the heaviest rain 6 h earlier. As the cyclone moved away from the station, 116 mm was recorded up to 0500 UTC 3 March, again indicating a continued asymmetric distribution of rain.

A series of 85-GHz Special Sensor Microwave Imager (SSM/I) images show the continued presence of an eye after Abigail passed Halls Creek, consistent with reintensification of the cyclone. A higher-resolution Tropical Rainfall Measuring Mission (TRMM) 85-GHz image (Fig. 5) at 1903 UTC 2 March shows a well-developed eye pattern similar to that which would normally be observed over the ocean.

EIR images between 0003 UTC and 0332 UTC 3 March show a clear eye, resulting in a Dvorak analysis of T4.5. By 0632 UTC 3 March the eye pattern had weakened to a T3.5. Thereafter, the storm continued to weaken.

It should be remarked that Abigail followed a track similar to that of Agukabams Winsome and Wylva that occurred 2–3 weeks before Abigail. These earlier cyclones produced copious rainfall that led to flooding in some places. As discussed in section 3, this probably affected the soil moisture profiles that later influenced Abigail.

Abigail is an example of a class of tropical cyclones that were observed to reintensify over northern Australia; we will present other cases in future work. We now turn to an examination of our central hypothesis, that such reintensification is made possible by large heat fluxes from a deep layer of soil whose thermal diffusivity is enhanced by the first rains of the system.

3. Simulations using a simple, coupled soil–atmosphere model

As a preliminary step toward quantifying the effect of soil heat fluxes on desert cyclones, we employ a modified version of the Coupled Hurricane Intensity Prediction System (CHIPS) described in detail in Emanuel et al. (2004). The original version of this model is an axisymmetric atmospheric model phrased in angular momentum coordinates, in which the flow is approximated as being in hydrostatic and gradient balance, while convection along angular momentum surfaces is parameterized using the boundary layer quasi-equilibrium approximation (Raymond 1995). The atmospheric model is coupled to a simple model of the upper ocean, consisting of a string of one-dimensional column models set out along the track of the storm, each of which allows the upper ocean to mix vertically using a bulk Richardson number closure. Landfall is simulated by setting the surface enthalpy flux coefficient to a value that diminishes with land elevation (Emanuel et al. 2004). The model only predicts intensity, and a track must be specified.

We adapt the CHIPS model to the present problem by coupling the atmospheric component to a simple model of soil heat transfer. We regard this modified model as a tool for performing a preliminary test of the hypothesis that heat transfer through wet, sandy soils may be enough to sustain a warm-core cyclone of subhurricane intensity. If the results are encouraging, this

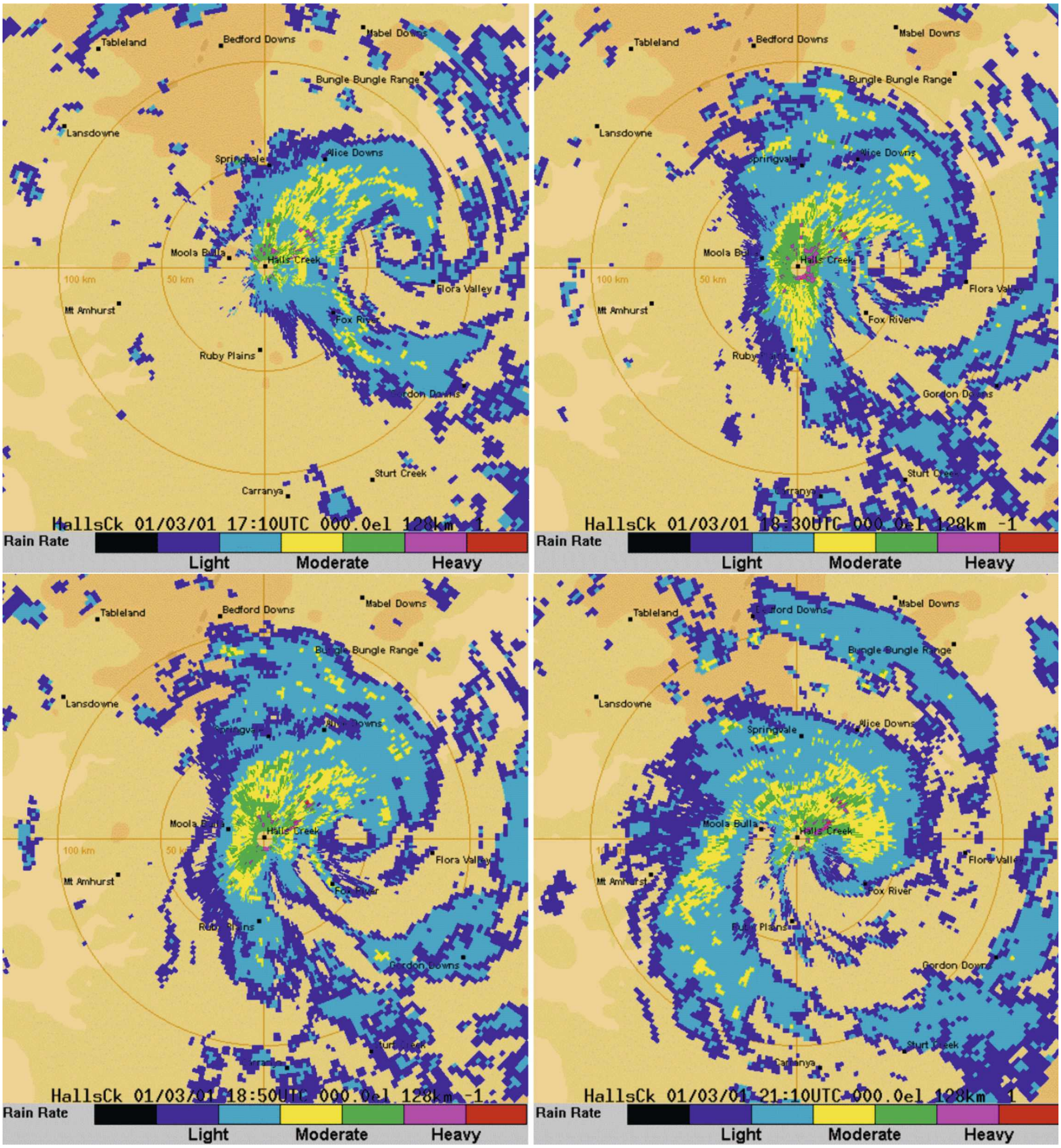

FIG. 4. Radar images of Tropical Cyclone Abigail from the radar at Halls Creek Meteorological Office from 1710 to 2110 UTC 1 Mar 2001.

would warrant attempts to simulate such storms using models with more complete physics.

As with the ocean model, our soil model consists of a string of one-dimensional columns arranged along the track of the cyclone. In the coordinate system of the model, which is moving with the cyclone, the properties of each column are advected rearward along the storm track. Each column integrates a heat equation (Flerchinger and Saxton 1989) of the form

$$\frac{\partial T_{\text{soil}}}{\partial t} = \frac{\partial}{\partial z}\left(\kappa \frac{\partial T_{\text{soil}}}{\partial z}\right) - I\frac{\partial T_{\text{soil}}}{\partial z}, \tag{1}$$

where T_{soil} is the soil temperature, κ is the thermal diffusivity, and I is the product of the hydraulic con-

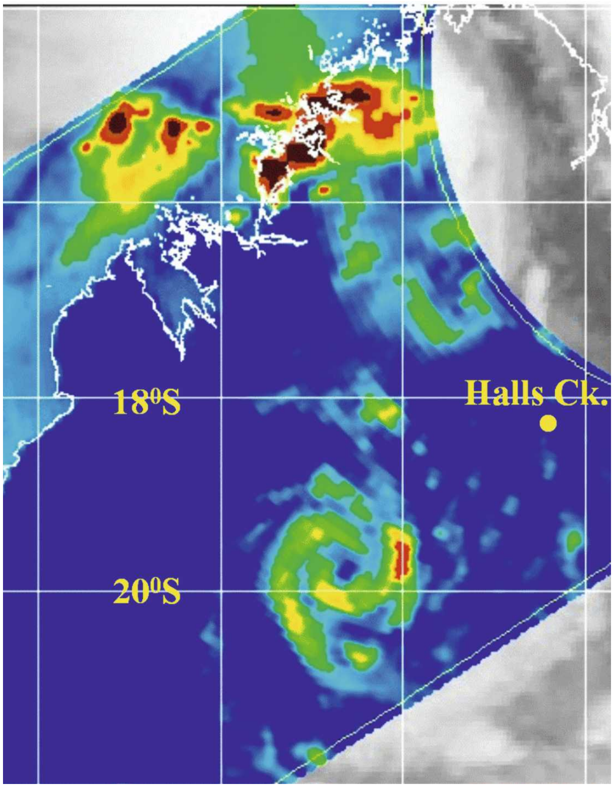

FIG. 5. TRMM 85-GHz (horizontally polarized) microwave image 1903 UTC 2 Mar 2001.

ductivity and the soil porosity, divided by the product of soil heat capacity and density; it is a measure of the downward flux of water through the soil. The first term in (1) represents thermal diffusion through the soil, while the last term represents heat transport by the percolation of rainwater downward through the soil. It can be important here as we are simulating circumstances in which heavy rain often falls on very hot, dry soil, and the downward infiltration of water occurs on a time scale not very different from the time interval between the onset of precipitation and the passage of the storm center. For saturated sand, the typical time scale for the penetration of water down to 20-cm depth is of order a day or two. In our simulations, the soil vertical temperature gradient is usually negative, so this percolation term usually acts to cool the soil.

In keeping with the spirit of simplicity in this initial effort, we take the thermal diffusivity κ to be independent of depth, and treat I as a constant provided that the soil moisture exceeds a threshold value, and zero otherwise. We solve (1) on a finite-difference grid with 100 layers, extending from the surface down to 2 m. The initial condition is a horizontally and vertically uniform soil temperature, T_{s0}, and this same value constitutes the lower boundary condition of the model. We solve the finite-difference form of (1) in all but the topmost layer; for this layer we solve the following:

$$\delta z C_s \rho_s \frac{\partial T_1}{\partial t} = C_s \rho_s \kappa \frac{T_2 - T_1}{\delta z} - C_k \rho_a |\mathbf{V}|(k_0^* - k_b) - \rho_l P C_l (T_1 - T_{\text{rain}}) + \dot{Q}_{\text{rad}}, \tag{2}$$

where δz is the depth of the uppermost soil layer; T_1 is the temperature of this layer; T_2 is the temperature of the second soil layer; C_s is the heat capacity per unit mass of the soil; ρ_s is its density; C_k is the surface enthalpy transfer coefficient; ρ_a is the surface air density; $|\mathbf{V}|$ is the surface (10 m) wind speed; k_0^* and k_b are the enthalpy of air in equilibrium with the soil surface, and the actual enthalpy of the air at 10 m, respectively; ρ_l is the density of liquid water; C_l is the heat capacity per unit mass of liquid water; P is the rate of precipitation (m s^{-1}); T_{rain} is the temperature of rain as it reaches the surface; and $\dot{Q}_{\text{rad}}$ is the radiative heating of the soil. The three terms on the right of (2) represent, respectively, upward heat diffusion from the subsurface soil, turbulent heat exchange with the overlying atmosphere, including evaporative cooling, and direct cooling of the surface by rain. We take $\dot{Q}_{\text{rad}}$ to be a constant whose value gives zero net tendency in (2) when there is no precipitation, the soil temperature is equal to its initial value, and the wind speed is representative of unperturbed conditions. In solving (2), we approximate T_{rain} by the wet-bulb temperature of the air at 10 m, while the wind speed, boundary layer enthalpy, and precipitation rate are supplied from the atmospheric model. The solution of (2) constitutes the upper boundary condition for the solution of (1). The finite-difference form of the system composed of (1) and (2) rigorously conserves energy.

The system composed of (1) and (2) allows for soil cooling by surface enthalpy flux, surface cooling by the flux of relatively cold rain drops, interior soil cooling by downward percolation of relatively cold water, and upper soil heating by upward diffusion of heat from the interior soil. The wind speed and boundary layer enthalpy needed to drive the soil model using (2) are supplied directly from CHIPS. While CHIPS does not explicitly produce precipitation, here we calculate it by multiplying the convective updraft mass flux by the boundary layer specific humidity and by the model's (variable) precipitation efficiency. The boundary layer specific humidity is estimated, for this purpose, by using the surface saturation specific humidity and an assumed relative humidity of 80%.

The soils of the Northern Territory of Australia con-

TABLE 1. Thermal and hydraulic properties of wet and dry sand (Campbell and Norman 1998).

	Density (kg m^{-3})	Thermal diffusivity (10^{-7} m^2 s^{-1})	Heat capacity (J Kg^{-1} K^{-1})	Hydraulic conductivity (m s^{-1})	Porosity
Dry sand	1600	2.8	800	—	—
Wet sand	2100	10	1600	0.3	0.1

sist mostly of sands and massive earths[2] (McKenzie et al. 2004). These surfaces are sparsely covered with vegetation and tend to have low albedos, as the sands are high in iron with a red appearance. The thermal conductivity of sand rises rapidly with soil moisture, reaching a limiting value after relatively little precipitation. Because of this, and to avoid solving a soil moisture equation, we approximate the soil as being either completely dry or saturated, depending on whether or not a threshold amount of precipitation has occurred at a particular soil column, and determine the thermal hydraulic conductivity accordingly. While no doubt crude, this should capture the essence of the steplike dependence of thermal conductivity on soil moisture. We use tabulated values of soil properties (heat capacity, density, diffusivity, hydraulic conductivity, and porosity) for wet and dry sand, as given in Table 1. We assume that the initial soil moisture is below the threshold we used for high thermal conductivity, even though two storms that occurred within 2–3 weeks of Abigail produced soil moisture anomalies that may have persisted until the time of Abigail.[3]

As with sea surface temperature perturbations in CHIPS, the soil surface temperature anomalies are used to calculate the surface enthalpy fluxes [the second term on the right of (2), but with the sign reversed]. These affect the model primarily in the region of maximum winds, where they have a perceptible effect of storm intensity in that model. Also, the drag coefficient over land used here is double the standard value over water.

CHIPS contains a parameterization of wind shear effects on tropical cyclone intensity, but here we omit this for the sake of simplicity. Since shear is always a negative effect in CHIPS intensity forecasts, omitting it will tend to produce an upper bound on what is realistically achievable in its depiction of a tropical cyclone–like development. Thus we expect our model to overpredict storm intensity, all other things being equal. In essence, we seek the maximum plausible effect that soil heat transfer might have on desert storms, in order to determine whether a more complete model investigation is warranted.

a. Idealized simulations

We performed a limited number of idealized simulations in which the storm is initialized over land and moves at a constant speed over initially horizontally homogeneous soil. The boundary layer enthalpy is specified to be consistent with air at 27°C with a humidity of 80%, but in the framework of the CHIPS model this could as well represent different combinations of temperature and humidity that yield the same enthalpy (e.g., a temperature of 35°C and a humidity of 10%.). The tropopause temperature is set to −85°C, consistent with summertime soundings in northern Australia. The model is initialized with a warm-core vortex with maximum winds of 17 m s^{-1} at a radius of 80 km from the center, and decaying to zero wind at a radius of 500 km.

Even with such a simple model, there is a potentially large parameter space to explore, and we find significant sensitivity to initial vortex size and translation speed, and to the various soil properties such as thermal diffusivity. Figure 6 shows the results of a set of simulations with soil parameters as in Table 1 and with varying initial soil temperature, for storms with an initial radius of maximum winds of 80 km and moving at 13 km h^{-1}. Except in the case of the highest initial soil temperature, the storms initially decay and only later reamplify. Examination of the model fields shows that the initial decay is owing to insufficient time since the model initialization for the soil to moisten and heat to diffuse upward through it to provide a high surface enthalpy flux in the storm core. There is clearly a large sensitivity to the initial soil temperature, with intensification beginning sooner and continuing longer for higher soil temperatures. Figure 7 shows a similar sensitivity to the coefficient of thermal diffusivity of wet sand (the value for dry sand is held fixed), although there is little sensitivity of the timing of the intensification. The bottom curve of Fig. 7 is for a thermal diffusivity typical of dry sand, showing the importance of soil wetting in enhancing the surface heat flux. Increasing translation velocity also increases storm intensity, as

[2] Massive earths have texture profiles in which the clay content increases gradually with depth from sandy loam/clay at the surface to light or medium clay subsoils.

[3] We are grateful to R. McTaggart-Cowan for pointing this out.

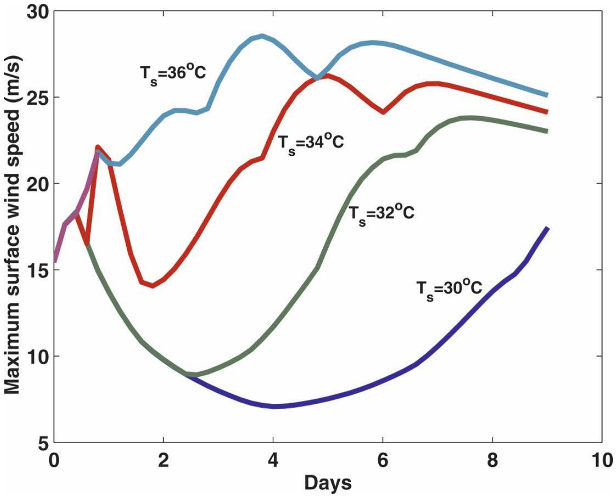

FIG. 6. Evolution with time of the maximum wind speed in warm-core cyclones over land, as simulated with CHIPS coupled to a simple soil model. In these idealized simulations, the model is initialized with a warm-core vortex with maximum winds of 17 m s^{-1}, with an initial intensification rate shown by the violet curve, and the storm center is assumed to be translating at 13 km h^{-1}. Each curve represents a different initial soil temperature.

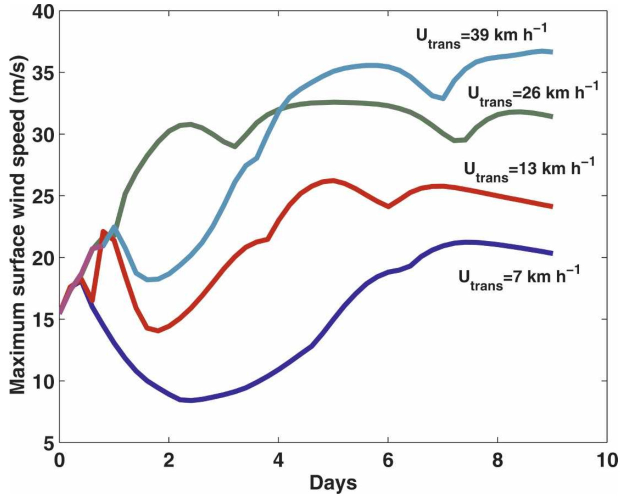

FIG. 8. As in Fig. 6, but varying the translation speed of the vortex. The initial soil temperature in each of these simulations is 34°C.

shown in Fig. 8, though part of this increase is the direct effect of adding a fraction (60%) of the translation speed to the storm-relative wind speed in the CHIPS model. Faster-moving storms are less effective in depleting the heat stored in the soil. Note that, in reality, high translation speeds are likely to be accompanied by larger vertical shear, which has not been accounted for here.

Soil wetting has two effects that work in opposite directions. On the one hand, wet sand has much higher thermal diffusivity than dry sand, and this enhances heat transfer from deeper in the soil. On the other hand, rainwater may arrive at the surface with a temperature as low as the wet-bulb temperature (assumed here), and the percolation of this cold water into the soil cools it and reduces heat transfer to the overlying air. Although the rain cooling dominates initially, once a soil temperature gradient is established, upward conduction of heat occurs and eventually dominates the rain cooling. The importance of rain wetting of the soil is illustrated by a simulation (Fig. 9) in which the relative humidity of air in the boundary layer is assumed to decrease linearly in time from 80% at the time the model storm makes landfall to 0% eight days later. At the same time, the temperature is increased so as to leave the moist entropy of the boundary layer unchanged; thus there is no direct effect on the storm's energetics. This is a simple attempt to account for the fact that, as the storms move inland, they are increasingly cut off from their oceanic source of moisture. As the rainfall diminishes, it becomes insufficient to moisten the soil after about 6 days, and the maximum wind speeds rapidly diminish thereafter.

Experiments adjusting the threshold rainfall accumulation for determining the soil thermal conductivity reveal that adjustments up or down by a factor of 3 had little effect, but increasing the threshold by a factor of 5 or more delays the onset of the reintensification. The onset of rainfall in these simulations is fairly abrupt, so as long as the threshold is reached by the time the eyewall passes, the results are insensitive to the threshold.

It is clear from these simulations that the coupled model, even though it is very simple, is quite sensitive

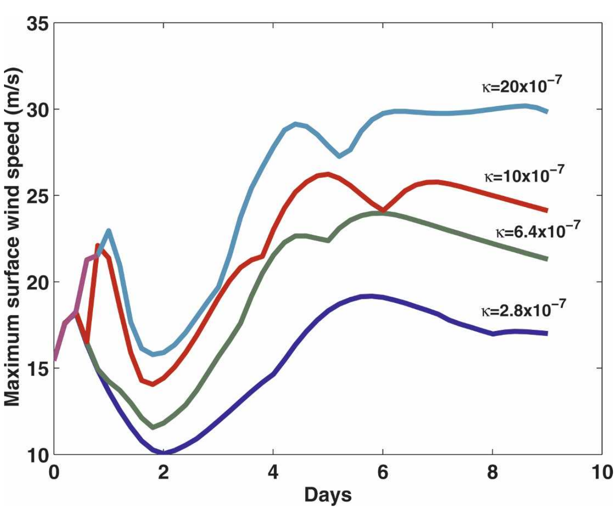

FIG. 7. As in Fig. 6, but showing the intensity evolution for different values of the assumed thermal diffusivity (m^2 s^{-1}) of wet sand, for an initial soil temperature of 34°C.

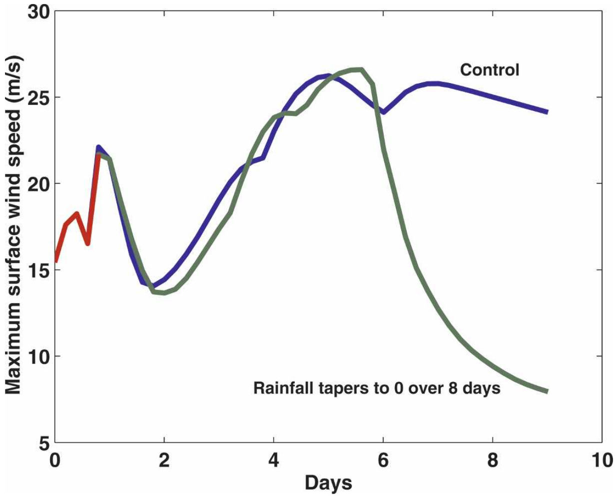

FIG. 9. Control simulation as in Fig. 6 (with an initial soil temperature of 34°C) compared with a simulation in which the boundary layer relative humidity, assumed to be 80% initially, decreases linearly to 0 over 8 days. After 6 days of simulation, there is not enough soil moisture to maintain the soil heat flux needed to sustain the storm at its previous intensity. Red curve shows the initial intensification rate.

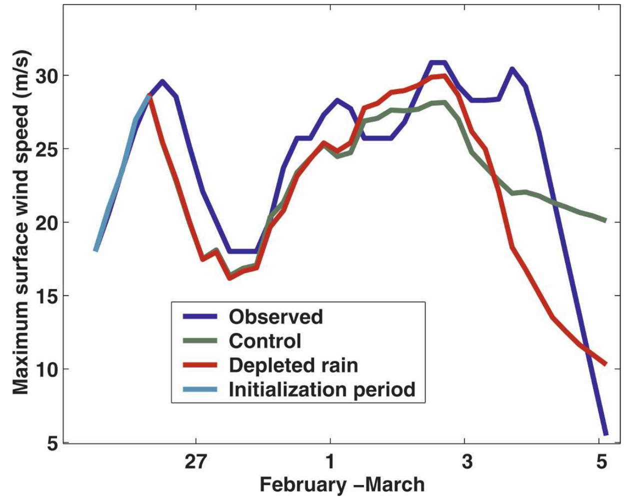

FIG. 10. CHIPS simulation of the evolution of the maximum wind speed in Abigail (green) compared with our best estimate from observations (blue). A second simulation, shown by the red curve, assumes that the boundary layer relative humidity, used only in the estimation of rainfall, decrease linearly from 80% at 0600 UTC 1 Feb to 0 at 0600 UTC 7 Feb. The aqua-colored curve shows the initialization period during which CHIPS is matched to the observations.

to a variety of factors influencing the transfer of heat from the soil to the atmosphere. In the following, we attempt to simulate Agukabam Abigail using what little soil information is available to us.

b. *Simulations of Abigail*

The CHIPS model was initialized for this case when Abigail was still at sea, at 1200 UTC 25 February. The CHIPS initialization requires matching to the observed maximum wind over a finite time interval, which in this case we specify as 24 h. The soil temperature was initialized at 34°C based on soil temperature measurements at a small number of stations close to Abigail's track, while the soil parameters are set to their standard values as listed in Table 1. The evolution of the maximum wind speed with time is compared with our observed estimate (as described in section 2) in Fig. 10. The evolution of the maximum wind speed after landfall at approximately 1200 UTC 26 February is well simulated through about 1200 UTC 2 March, when the simulated storm begins to decay even though the observed storm maintains high intensity for another day or so.

When the storm reaches its first intensity peak over the Gulf of Carpentaria, it is close enough to land to produce high winds and heavy precipitation over the coast. This decreases the soil surface temperature through both direct and evaporative cooling, so that by the time the storm center makes landfall, the soil surface temperature is barely above the local wet-bulb temperature of the air, and there is little net heat flux. But now the reduced winds and weaker precipitation are less effective in cooling the soil further inland, and as the storm center progresses inland, it encounters warm soils. The wetting of the hot desert soil greatly enhances upward heat flux through the soil, and the cyclone is able to intensify.

Comparing predicted with observed soil temperature is problematic, because soil temperatures are observed at only a handful of stations, and given the often large inhomogeneity of soil properties, measurements at these stations may not be representative of general conditions along the storm path. In addition, our soil model is integrated only in columns directly along the storm path, thus soil temperatures away from the storm track are not predicted. Nevertheless, we attempt to compare predicted to observed soil temperature at Halls Creek, which lies very near Abigail's path (Fig. 1). Records of soil temperature to the nearest whole degree Celsius are available at four depths at 0600, 0900, 1200, and 1500 local time. We average the records at 20-cm depth at these times to produce a daily mean value; this is compared to the model-predicted value at 20-cm depth in Fig. 11. Note that both the model and the observations show a strong drop in soil temperature as Abigail passes, reflecting large flux of heat from the soil to the atmosphere. The surface flux peaks at about 190 W m^{-2} in this simulation. This is the key physical process that we believe allows storms like these to reintensify over land.

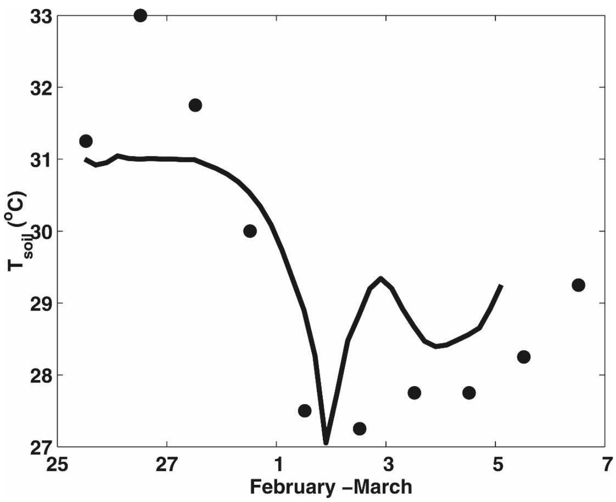

FIG. 11. Predicted (solid curve) and observed (dots) soil temperature at 20-cm depth at Halls Creek, during the passage of Agukabam Abigail in 2001.

The control simulation shown in Fig. 10 assumes, for the purpose of estimating rainfall in the CHIPS model (which does not explicitly predict rain), that the boundary layer relative humidity is always about 80%. For comparison, we also show in Fig. 10 a simulation in which the relative humidity was permitted to fall to zero linearly in time, beginning 4 days after initialization and ending 6 days later. This simulation achieves a slightly higher intensity, owing to reduced rain cooling of the soil, but decays much more rapidly when there is not enough rain to increase the thermal diffusivity of the soil.

Given the crude parameterization of soil physics used here, these results should only be taken as a guide to constructing a more complete model. But the results presented here suggest that the detailed evolutions of soil temperature and moisture can be important to the evolution of warm-core cyclones over hot land.

4. Summary

Tropical cyclones are powered by surface enthalpy fluxes and thus usually decay rapidly after landfall. But some storms are observed to reintensify after making landfall in northern Australia, even though no significant extratropical interactions are apparent. Here we argue that the hot, sandy soils of northern Australia may store enough heat and, after they are wetted by the first rains of an oncoming cyclone, may be able to diffuse heat upward rapidly enough to sustain warm-core storms of marginal hurricane intensity. Given the apparent uniqueness of such events to Australia, we call them agukabams, a word constructed from aboriginal roots. Simulations with a simple, coupled soil–atmosphere model suggest that this hypothesis may have merit, but also show that the underlying soil must be quite hot and have a large enough heat conductivity when wet to support storms of reasonable strength. The simulations also demonstrate sensitivity to such quantities as storm translation speed and atmospheric moisture availability.

We regard the simulations presented here as constituting a feasibility study that suggests that a more sophisticated modeling study be undertaken, including a much more refined soil model. High time-resolution observations of upper-soil-layer heat content during the passage of agukabams would also provide much information about heat flow to the atmosphere during these events, which in turn could be used to evaluate our working hypothesis.

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