WEATHER CLIMATE WATER

WORLD METEOROLOGICAL ORGANIZATION

Food and Agriculture Organization of the United Nations

Weather and Desert Locusts

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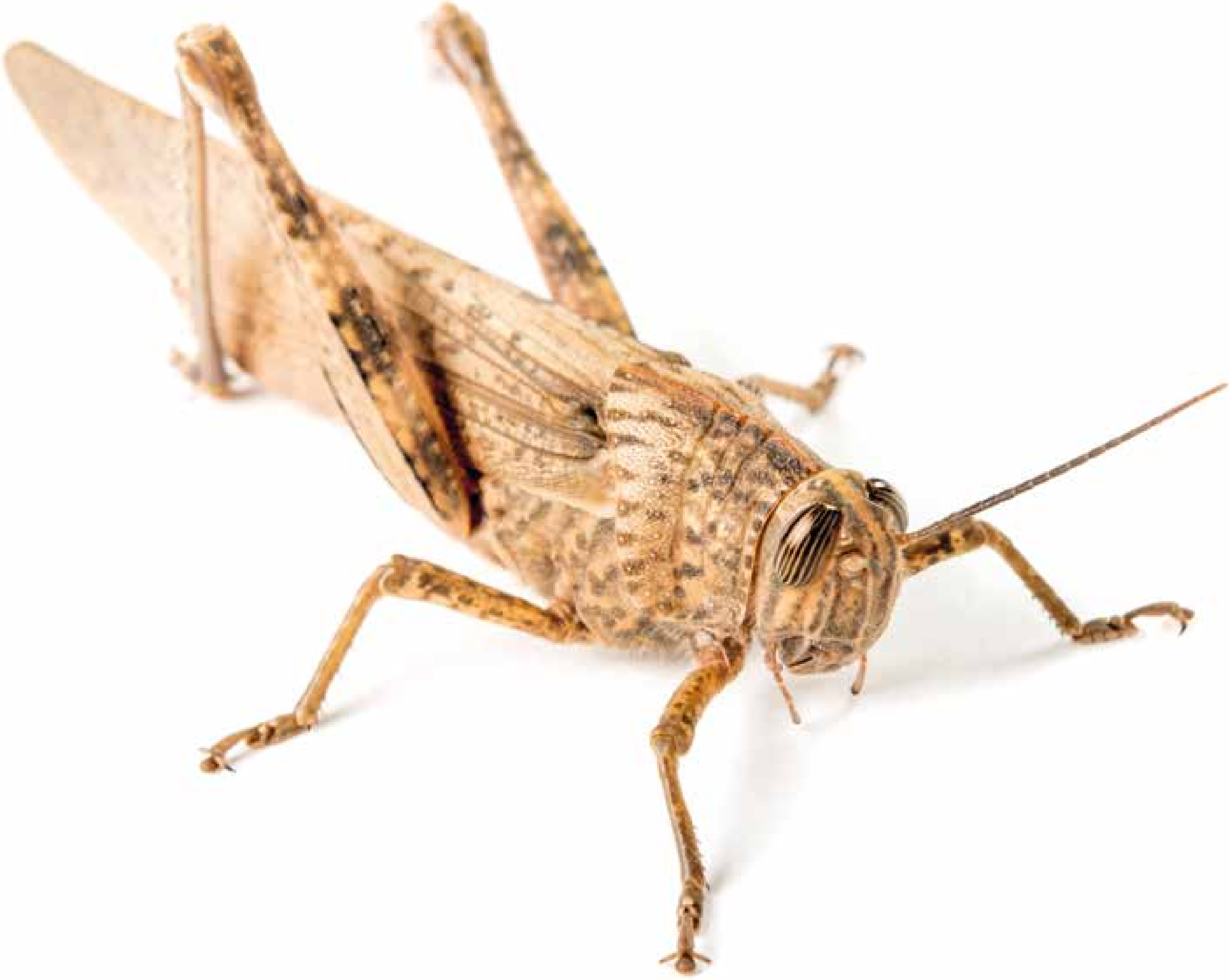

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FOREWORD

Desert Locust plagues can be an important contributing factor to famines and a threat to food security in many regions of the world. The Desert Locust plague of 1986–1989 and subsequent upsurges during the past two decades demonstrate the continuing capacity of this historic pest to threaten agriculture and livelihoods over large parts of Africa, the Near East and South-West Asia. In 2004–2005, a major upsurge caused significant crop losses in West Africa, with a negative impact on food security in the region. These events emphasize the need to strengthen and maintain a permanent system of well-organized surveys in areas that have recently received rains or been flooded, supported by a control capability to treat Desert Locust hopper bands and adult swarms efficiently in an environmentally safe and cost-effective manner.

The events of the 1986–1989 plague showed that, in many instances, the existing strategy of preventive control did not function well, for reasons which included the inexperience of the field survey teams and campaign organizers, lack of understanding of ultra-low volume spraying, insufficient or inappropriate resources and the inaccessibility of some important breeding areas. These reasons were compounded by the general tendency to allow survey and control capacity in locust-affected countries to deteriorate during locust recession periods. Given the certainty that there will be future Desert Locust upsurges, the Food and Agriculture Organization of the United Nations (FAO) produced a series of guidelines and standard operating procedures primarily for use by national and international organizations and institutions involved in Desert Locust surveys and control.

The infrequency and brevity of locust plagues is welcome. However, long locust recession periods may be a source of problems. When a new campaign is needed, few national locust staff and even fewer pilots are likely to have campaign experience. Manpower and equipment resources on hand may have been diverted and, hence, are not available, or are insufficient, to run a campaign. Morale is likely to be low after a decade or more with only rare seasonal activity of any significance. Inexperienced staff from outside the national locust unit are likely to be deployed and every available sprayer used, whether suitable or not. Furthermore, lack of funds, bureaucratic rigidity and poor security in locust-affected countries can easily hamper a timely and effective response. When there is an upsurge, pesticide and aircraft are often supplied far in excess of what can be deployed currently, even by a well-trained, well-organized unit.

Furthermore, while the possible effects of climate change on Desert Locust are still under study, depending on the region, policymakers may have to prepare for longer locust seasons. This calls for strengthening international collaboration to better study the behavioural patterns of Desert Locusts in relation to changing meteorological and climatic conditions and to adapt control and preparedness plans.

FAO and the World Meteorological Organization (WMO) collaboration on Desert Locusts started in 1951, when the WMO Technical Assistance Mission for Desert Locust Control was established. Major movements of swarms were hypothesized to take place downwind, towards and within zones of convergent surface windflow. In 1981, meteorologists participated for the first time in the meeting of the FAO Commission for Controlling the Desert Locust in North-West Africa that was held in Algiers, 14–19 March 1981 (WMO, 1992). As the relationship between meteorological conditions and locust activity had been known for many years, the basis for cooperation with National Meteorological and Hydrological Services (NMHSs) was thereby established. Meteorologists from WMO Members have since been involved in national Desert Locust programmes and in joint action by WMO and FAO.

FAO is the lead agency in Desert Locust monitoring and control and runs the Desert Locust Information Service (DLIS). All locust-affected countries transmit locust and environmental data, as well as survey and control results, to DLIS for analysis, in conjunction with weather and habitat data and satellite imagery, in order to assess the current locust situation, provide forecasts of up to six weeks, and issue early warnings. FAO routinely prepares monthly locust bulletins and periodic updates forecasting the scale, location and timing of locust migration and breeding on a country-by-country basis. This information constitutes the early warning system operated by DLIS to alert countries and donors about the development of plagues. DLIS disseminates information by e-mail, the Locust Watch website (http://www.fao.org/ag/locusts) and social media.

In cooperation with affected countries, FAO undertakes field assessment missions and coordinates survey and control operations, as well as assistance during locust emergencies. To address the deterioration of survey and control capacity during recession periods, FAO has given high priority to a special programme, the Emergency Prevention System for Transboundary Animal and Plant Pests and Diseases to strengthen national capacities.

As the authoritative voice on weather, water and climate of the United Nations system, WMO provides valuable assistance to FAO to ensure that WMO Members and their NMHSs provide near-real-time meteorological data and forecasts for locust-affected countries. WMO also maintains a Meteorological Information for Locust Control web page on the site of the World AgroMeteorological Information Service (WAMIS). WAMIS is a centralized web server that disseminates agrometeorological products issued by WMO Members (http://www.wamis.org/locust/index.php).

The complex and serious nature of Desert Locust plagues demands that countries that are invaded and those that are threatened by them to work together across borders to find the best form of locust control. Desert Locust control is indeed an international responsibility, because locusts breed and move over wide areas so that events in one country rapidly affect events in others. Together, WMO and FAO have been helping to improve coordination and planning for potential locust outbreaks and control actions.

Petteri Taalas
Secretary-General, WMO

José Graziano da Silva
Director-General, FAO

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INTRODUCTION

This publication is mainly intended to be used as a general reference guide for use by staff of National Locust Control Centres (NLCCs) and NMHSs of locust-affected countries. It may also be useful for anyone wanting to know more about Desert Locust and associated meteorological phenomena. The publication contains basic information on the biology and behaviour of Desert Locust, a history of locust events, weather factors that influence locust development and how to use weather information. The reader is encouraged to consult the following websites for more information:

FAO Locust Watch

http://www.fao.org/ag/locusts/en/info/info/index.html

WMO Meteorological Information for Locust Control

http://www.wamis.org/locust/index.php

DESERT LOCUSTS

Overview

Locusts are members of the grasshopper family *Acrididae*, which includes most short-horned grasshoppers. Locusts differ from grasshoppers because they have the ability to change their behaviour and physiology, in particular their morphology (colour and shape), in response to changes in density, when meteorological conditions are favourable. Adult locusts can form swarms that may contain millions or billions of individuals that behave as a coherent unit (Figure 1). The non-flying hopper (or nymphal) stage can form cohesive masses that are called hopper bands.

Desert Locusts (*Schistocerca gregaria*) are always present somewhere in the deserts between Mauritania and India. When numbers are low, they behave as individuals (solitarious phase); when high, they behave as a single mass (gregarious phase). Colour and shape are an indication of how they been behaving but may not be a reliable guide as to how they will behave in the future.

When plentiful rain falls and annual green vegetation develops, Desert Locusts can increase rapidly in number and, within a month or two, start to concentrate and become gregarious. Unless checked, this can lead to the formation of small groups or bands of wingless hoppers and small groups or swarms of winged adults. This is called an outbreak and usually occurs within an area of about 5 000 km^2 (100 km by 50 km).

An outbreak or contemporaneous outbreaks that are not controlled can evolve into an upsurge if widespread or unusually heavy rain falls in adjacent areas, creating favourable breeding conditions. An upsurge generally affects an entire region and occurs after several successive seasons of breeding and further hopper-band and adult-swarm formation takes place.

Figure 1. Desert Locust (a) hopper, (b) hopper band, (c) adult and (d) swarm. Hoppers are the wingless juvenile stage, while adults can fly and reproduce. Under optimal conditions, hoppers can form bands and adults can form swarms.

If an upsurge is not controlled and ecological conditions remain favourable for breeding, locust populations continue to increase in number and size, and the majority of locusts behave as gregarious bands or swarms, then a plague can develop. A major plague exists when two or more regions are affected simultaneously.

Although outbreaks are common, only a few lead to upsurges. Similarly, few upsurges lead to plagues. The last major plague was in 1986–1989 and the last major upsurge, or regional plague, was in 2003–2005. Upsurges and plagues do not occur overnight; they take many months to develop. During plagues, Desert Locusts may spread over an area of some 29 million km^2, extending over or into parts of some 60 countries.

The Desert Locust has the potential to damage the livelihoods of one tenth of the world's population. Recent increases in cultivated areas on the edges of deserts in northern Africa, the Near East and South-West Asia make the Desert Locust a threat to the livelihood, income and food source of local populations. Swarms are often tens of square kilometres in size. A swarm of 1 km^2 eats the same amount of food in one day as 35 000 people. A swarm the size of Bamako (Mali) or Niamey (Niger) can consume what half the population of either country would eat in a single day.

The Desert Locust plague of 1986–1989, the subsequent upsurges in the 1990s and the regional plague in 2003–2005, drew the world's attention to the threat they pose to the food security of the affected countries, especially in the developing world. This situation calls for an integrated approach to understanding the conditions that lead to the locust build-up and their migration so that effective solutions can be developed for controlling damage.

Locust control is complicated by several factors:

(a) The swarm is highly mobile, migrating from 50 to more than 100 km in a day;
(b) The total invasion period frequently occurs in a relatively brief time, sometimes as short as a month but rarely longer than three months;

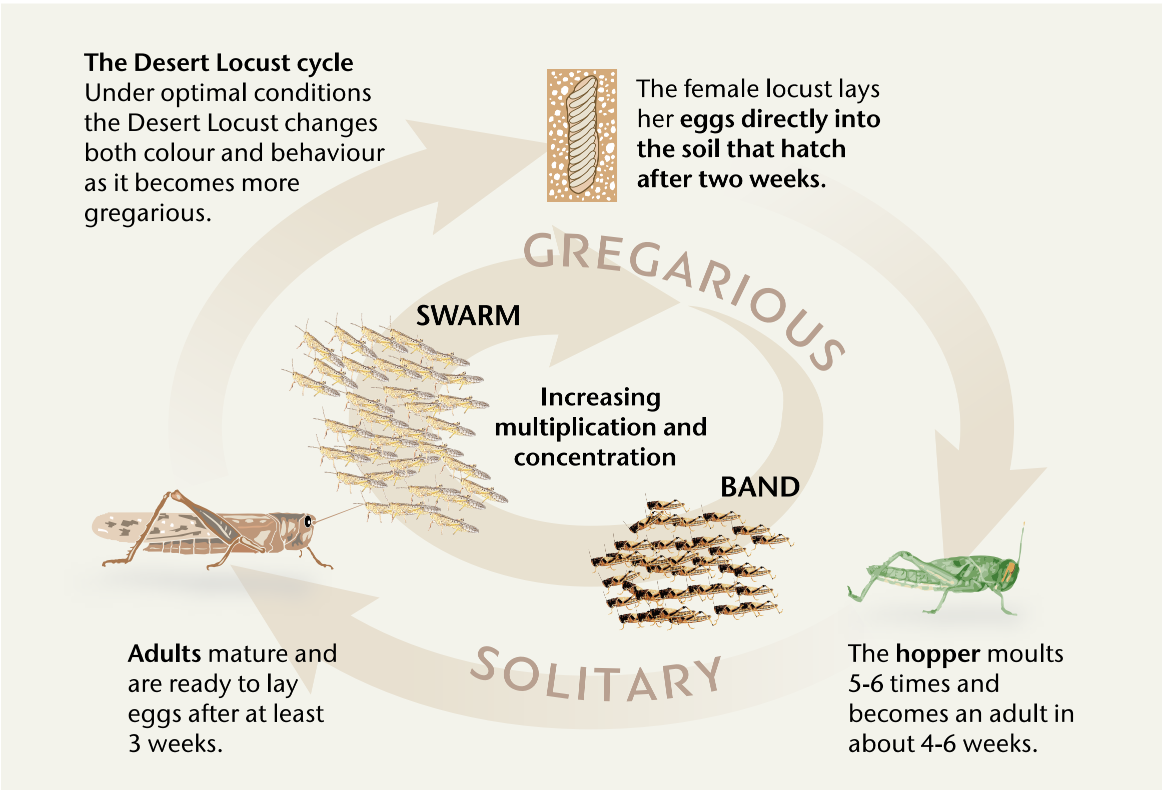


Figure 2. Desert Locust life cycle. The lifetime of a Desert Locust is about three months but this can be extended to up to six months under cold conditions.

(c) The swarms are unevenly distributed in time, so that very large swarms may be available for only a few days, followed by relatively long periods when none is present;
(d) Swarms are variable in size and can extend up to thousands of hectares;
(e) Campaign experience, funds and supplies are often lacking in locust-affected countries because of the irregular occurrence of locust upsurges and plagues.

Life cycle

A Desert Locust lives about three to five months, although this is extremely variable and depends mostly on weather and ecological conditions. The life cycle comprises three stages: egg, hopper (nymph) and adult (Figure 2). Eggs hatch in about two weeks, depending on temperature (the range is 10–65 days). Hoppers shed their skins five or six times, each time growing in size. This process is called moulting and the stage between moults is referred to as an instar. Hoppers develop over a period of about 30-40 days; adults mature in about three weeks to nine months but more frequently from two to four months, depending on environmental conditions, mainly temperature. If conditions are dry and cool, adults may remain immature for six months. Adults do not moult and therefore do not grow in size but gradually increase in weight. An adult locust can eat its own body weight every day, about 2.5 g. Adults that can fly are initially sexually immature, but eventually become sexually mature and can copulate and lay eggs. Solitary individuals always remain somewhere in the desert, ready to mate when conditions are favourable.

Eggs

Laying

Eggs are usually laid in areas of bare sandy soil and require previous rainfall. Generally, the female will not lay unless the soil is moist at about 5–10 cm below the surface. In soft sandy soils, females have been known to lay when moisture is found only at depths below 12 cm. Before laying, the female will often probe the soil, inserting the tip of her abdomen to determine if there is enough moisture.

The female lays eggs in batches called pods. The eggs look like rice grains and are arranged like a miniature hand of bananas. The pods contain fewer than 80 eggs in the gregarious phase and typically between 90 and 160 in the solitarious phase. Swarms often lay egg pods in dense groups, with tens and even hundreds of pods per square metre. Laying occurs in only a small number of the apparently suitable sites. This behaviour, as well as an agent added to the egg pod foam when adult females are crowded, will help induce gregarization of the next generation.

The number of egg pods a female lays depends on how long it takes for her to develop a pod and how long she lives. An average of two pods per female is the norm. Because of natural mortality, not all the eggs hatch and, of those that do, not all reach the adult stage. In optimal temperature and habitat conditions, a single female can produce up to 16–20 viable locusts in a single generation.

Development and incubation

The Desert Locust nearly always lays her eggs in soil that is wet enough to allow the eggs to absorb sufficient moisture to complete their development. If eggs are laid in dry soil, they desiccate (dry out) unless rain falls soon afterwards. The rate of development is exclusively a function of the soil temperature at pod depth (Figure 3). There is a reasonably good relationship between soil temperature and screen (air) temperature so rates of egg development can be predicted satisfactorily from air temperatures and even from long-term mean values since temperatures do not vary greatly between years for a given place and time of year in most of the breeding areas. However, there can be exceptions to this, notably during the winter, when the weather may be unusually warm, allowing development to continue.

Mortality

The proportion of eggs that survive to hatching varies widely according to habitat conditions and the presence of egg parasites and predators. While eggs can dry up, especially if exposed by wind, and can also be destroyed by persistent flooding, such events are uncommon. High mortality may occur if soil temperatures are above 35°C. Estimates of total losses vary from about 5% to 65%.

Hoppers

Hoppers immediately moult until the first instar. They then pass through five instars (sometimes six in the solitary phase), shedding a skin (moulting) between each. The development from eggs into hoppers (wingless larvae or nymphs) is a function of temperature. The hopper development period decreases with increasing daily air temperature from 24°C to 32°C (Figure 4). The correlation with air temperature is less clear than with eggs because the hoppers can control their body temperature to a considerable extent by basking or seeking shade.

When solitarious hoppers increase in number, their behaviour changes, they become concentrated and can form groups. Grouping often occurs in open, less uniform, habitats, where there are patches of relatively dense vegetation separated by large areas of bare soil.

Bands

As hoppers continue to concentrate, they become more gregarious and the groups fuse to form bands. During warm and sunny days, hopper bands follow a pattern of behaviour alternating between roosting and marching throughout the day. On overcast days, bands usually do not move very far. For example, measurements for predominantly fourth instar bands range from about 200 m to 1 700 m in a day. If the vegetation is very dry, bands may continue moving at night in search of green vegetation. The band usually maintains a constant direction during a day; even a major obstruction is not always sufficient to change its path. The heading is often, but not always, downwind.

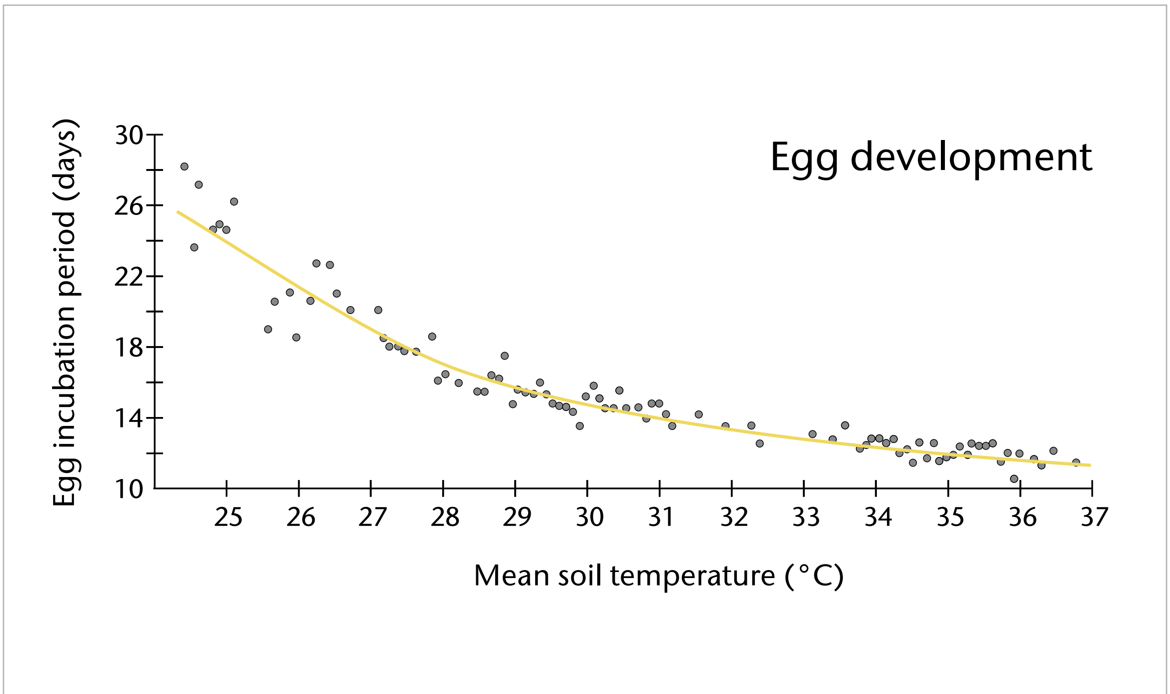


Figure 3. Relationship between egg development and temperature.
Eggs will hatch sooner under warmer conditions.

Adults

After the final moult the new adult has soft wings that must dry and harden before it can fly; this can take up to 10 days. Once able to fly, solitarious adults migrate at night when the temperature is above 20–22°C and the wind is less than 7 m/s (13.6 knots). They usually take off about 20 minutes after sunset and can fly for up to 10 hours, usually flying for only a few hours at a time. Individuals have been detected by radar up to heights of 1 800 m.

Swarms

The first swarms form several kilometres downwind from the main laying area and spend the night roosting in vegetation. At sunrise, they descend to the ground and warm up by basking in the sun. By mid-morning, swarms take off and will often continue flying until just before sunset when they land and feed. If the weather is unusually hot, swarms may settle at midday before flying off again in the afternoon. Swarms can occur as low-flying sheets (stratiform) or may pile high in the air (cumuliform), with the top level as much as 1 500 m above the ground. Stratiform swarms are flat, usually tens of metres deep, and often occur during cool, overcast weather or in the late afternoon. Cumuliform swarms are associated with convective updrafts on hot afternoons, especially common during the warmer and drier months of the year.

Like aircraft, locusts land and take off into wind. By mid-morning – or earlier, if the temperature is warm enough for sustained flight – the entire swarm takes to the air. Sustained flight is rare if

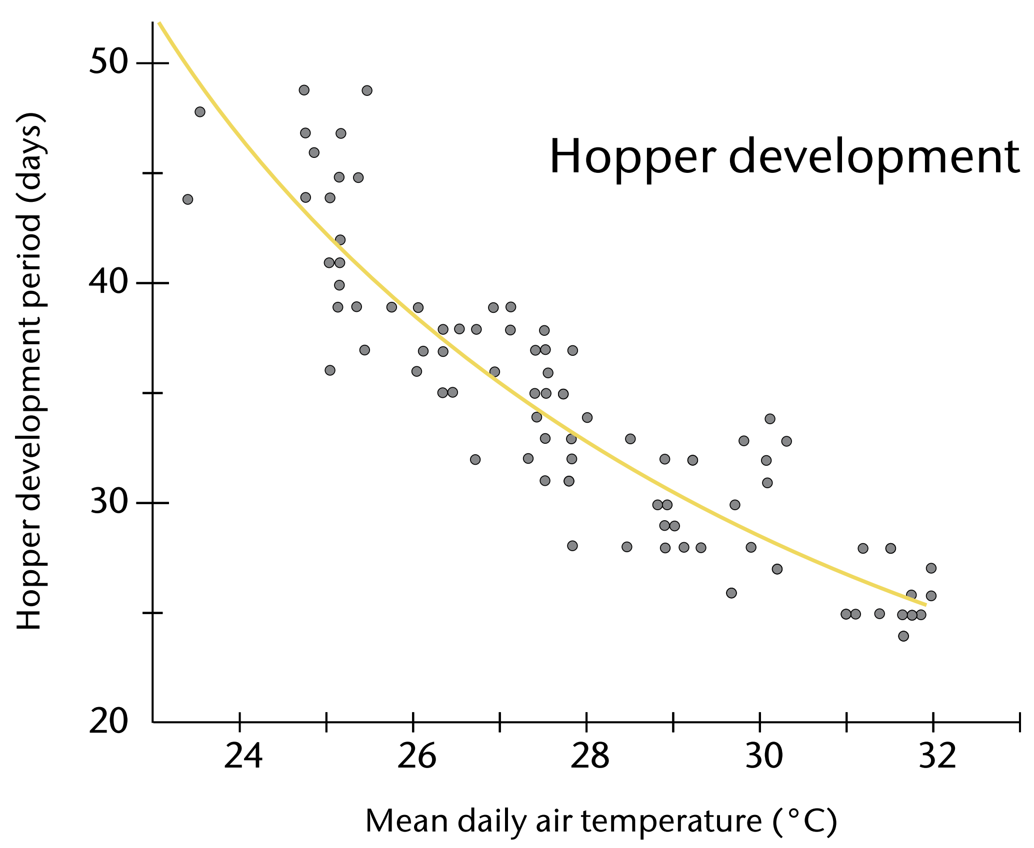


Figure 4. Relationship between hopper development and air temperature. The warmer the temperature, the faster hoppers will mature and become adults.

temperatures are below about 20°C. This lower limiting temperature is higher under overcast conditions (about 23°C).

Swarms may fly up to nine or 10 hours in a day, moving downwind, although mature swarms may sometimes move a short distance upwind if the wind is light. Swarms may be towed along by winds aloft or they may be held back by winds near the surface which are usually slower and often blow from a different direction. Although locusts within a swarm may be oriented in different directions, the overall result is a downwind displacement. A swarm is usually displaced at slightly less than the wind speed and may easily move 100 km or more in a day. It is not clear with cumuliform swarms which wind level determines displacement. Swarms start to settle about an hour before sunset as convection dies away. Very high airborne densities can occur during this period. With many swarms, a considerable proportion of the locusts spend some of the time on the ground, so the swarm nearly always moves at less than the wind speed. In the absence of wind, locusts fly at about 3–4 m/s (5.8–7.8 knots).

Downwind displacement tends to bring locusts into an area during the season when rain is most likely, for example, the Sahel of West Africa and the Sudan in the summer and the Red Sea coast in the winter. Once rain falls, locusts will mature and breed. By the time the new generation of adults is capable of sustained flight, the seasonal wind pattern may well have changed and breeding conditions become poor. The locusts will then migrate rapidly, often over very great distances, to another area.

Movements often take place during periods of particular winds, rather than coinciding with the prevailing windflow. Locust adults and swarms do not always fly with the prevailing winds but instead wait for specific types of winds to occur. For example, in West Africa in autumn, the prevailing winds are from the north. Swarms will not move south with these winds. Instead, they move northwards across the Sahara during the few days in which there are southerly winds associated with an atmospheric depression (generally low-pressure systems, indicated by an “L” on an air-pressure map) over the western Mediterranean. This is because the southerly winds are warmer than the northerly ones.

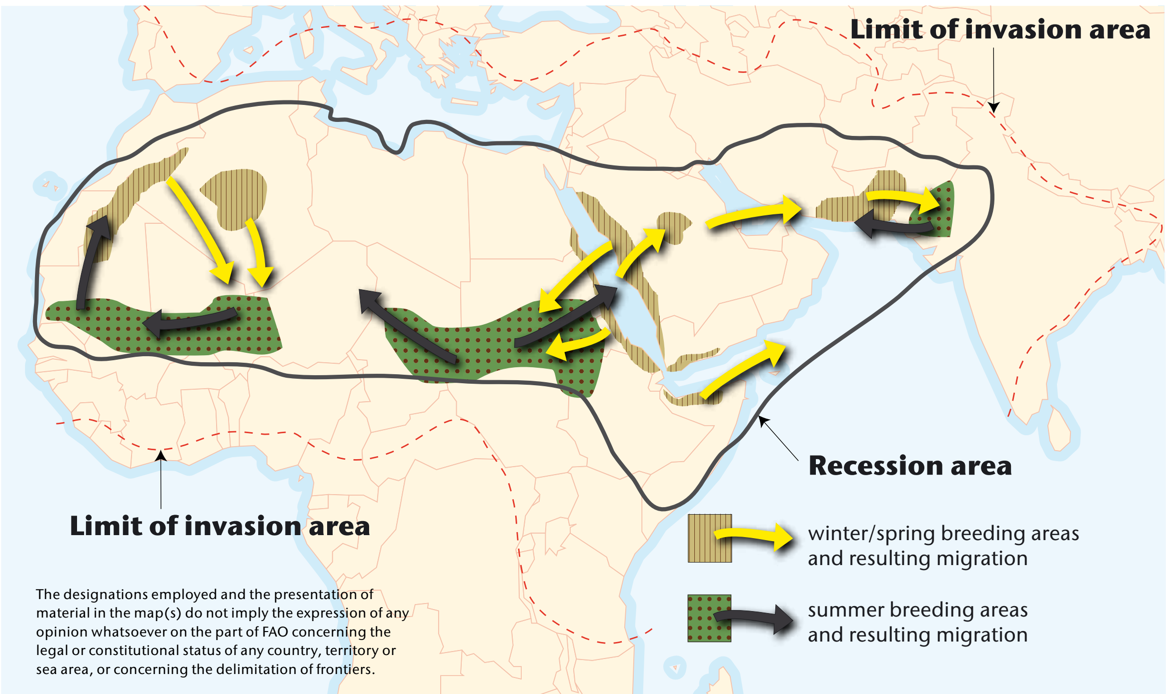


Figure 5. Desert Locust recession area. The Desert Locust recession area covers about 16 million km^2 from West Africa to western India. The invasion area extends to the north, south and east of the recession area, covering some 30 million km^2 – approximately four times the size of the USA.

Similarly, adults and swarms leave the summer breeding areas in the interior of Sudan in the autumn and move north-east towards to the Red Sea coast. In order to achieve this, they wait for the prevailing north-easterly winds to be interrupted by south-westerly winds, which may be warmer and more humid. In order for swarms to migrate from the interior of Arabia to central Sudan at the beginning of summer, locusts in the Red Sea area can fly only on the rare days with cross-sea upper-level winds, and even then the swarms appear to select a particular height at which to fly.

Swarm densities vary considerably. The generally accepted figure for an average medium-density settled (resting on the ground) swarm is about 50 million locusts/km^2 (50 locusts/m^2) across a range varying from 20 million km^2 to 150 million/km^2. Swarms generally spread out when flying, typically covering between two and three times the area they occupy when roosting in the sun or feeding. Volume densities of flying swarms can be as high as 10 locusts per m^3. About half the swarms exceed 50 km^2 in size.

Affected areas

During calm periods, Desert Locust infestations are usually present somewhere within about 16 million km^2 of desert in 25 countries between West Africa and India (Figure 5). During plagues, the number of countries and the size of the potentially affected area doubles, representing about 20% of the Earth's land mass. Within the recession area, that is, the normal area occupied during calm periods, locusts move with the winds. These bring them into particular zones during the summer (the Sahel and the Indo-Pakistan desert) and during the winter/spring (North-West Africa, along the Red Sea, in Baluchistan (Pakistan) and the Islamic Republic of Iran). If heavy rain falls in successive seasonal breeding areas, the locusts will gregarize and, unless prevented by control, drought, or migration to unsuitable habitats, plagues can develop. Rainfall over 25 mm in two consecutive months is usually assumed to be enough for locust breeding and development.

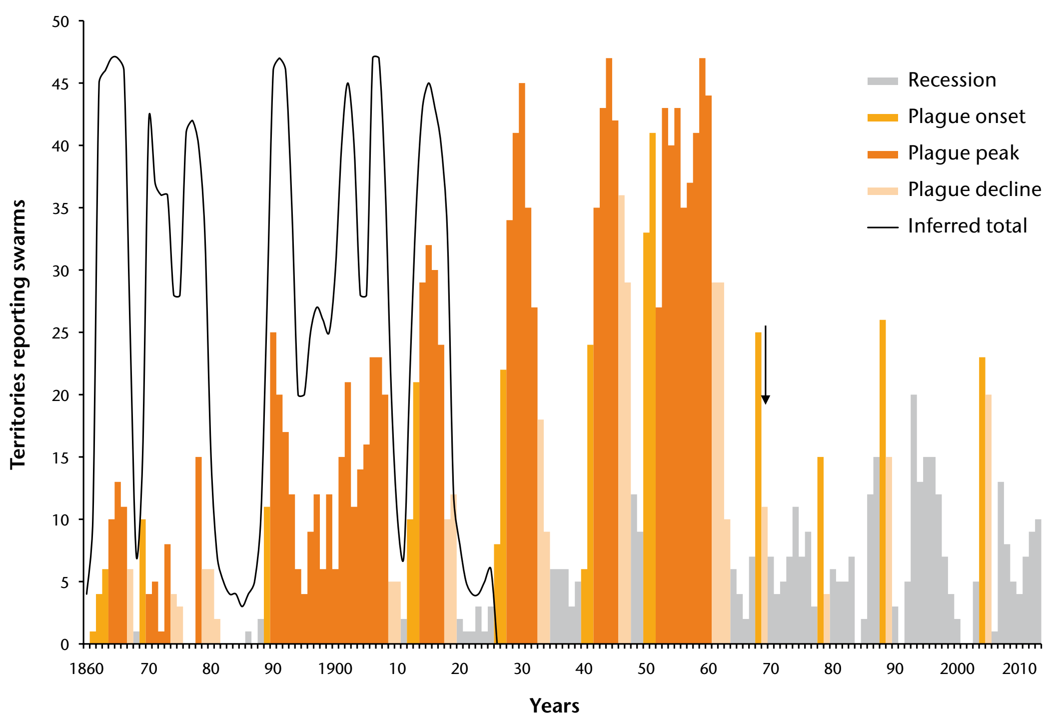


Figure 6. Desert Locust plagues in the past. There have been numerous plagues (orange bars) in the past with calm periods (recessions) in between (grey bars). Since the 1960s, the frequency and duration of Desert Locust plagues have declined, probably due to preventive control.

Individual locusts are not a threat to humans and crops. Only after gregarization and the formation of bands and swarms are locusts a serious threat to food security of the human population.

Locust migration

If the answer to all the following questions is "yes", there is a good possibility that the adults or swarms will migrate:

(a) Can the locusts fly?
(b) Is the temperature warm enough?
(c) Is the wind not very strong?
(d) Are ecological conditions dry where the locusts are now?

Plagues and upsurges

Desert Locust plagues have been reported since Phaoronic times in ancient Egypt. There is no evidence that they occur after a specific number of years (Figure 6). During the last century, plagues occurred in 1926–1934, 1940–1948, 1949–1963, 1967–1969, 1986–1989 and 2003–2005 (Table 1). Recent major upsurges were reported in 1992–1994, 1996–1998 and 2003. Locust outbreaks can develop suddenly and unexpectedly in remote, inaccessible areas or in the absence of regular surveys and incomplete data. Recent developments in satellite techniques to monitor rainfall and vegetation have made it easier to detect potential areas of significant locust activity that may require survey and control.

Table 1. Historical Desert Locust recessions, declines, upsurges and plagues

Recessions	Upsurges	Plagues	Declines
---	---	1861–1867	---
1868	---	1869–1881	---
1882–1888	---	1889–1910	---
1911	1912	1912–1919	1917–1919
1920–1925	1925–1926	1926–1934	1932–1934
1935–1939	1940–1941	1940–1948	1946–1948
1948	1949–1950	1949–1963	1961–1963
1964–1967	1967–1968	1968	1969
1969–1972	1972–1974	---	---
1975–1976	1977–1980	---	---
1981–1985	1985	1986–1988	1988–1989
1990–1992	1992–1994	---	---
1995	1996–1998	---	---
1999–2002	2003	2003–2005	2005
2006–			

Source: Updated from Symmons and Cressman (2001):
FAO Desert Locust Guidelines, Chapter 1 – Biology and behaviour, p. 37.

WEATHER

Weather and Desert Locust biology

All the different phases in the life cycle of a locust require ideal meteorological conditions for it to develop and cause the widespread damage that is often associated with locust plagues. Meteorological data are important for both assessing the current locust situation and forecasting its development (Table 2). Data, such as temperature, pressure and wind, are usually available from NMHSs and should be used.

Information on meteorological and ecological parameters such as rainfall, soil moisture, soil and air temperatures, surface and boundary winds, synoptic-scale patterns and the convective state of the atmosphere are needed to understand and forecast swarm movement and the various developmental stages. These stages include egg-laying, egg development, hopper development, moulting, hardening of the wings, adult maturity, rate of movement of hopper bands and adult swarms, and transition from the solitarious phase to the gregarious phase.

Rainfall data can be used to identify which areas may become suitable for breeding or where green vegetation and locusts may be present. Temperature data can be used for estimating the development rate of eggs and hoppers, as well as indicating whether it is warm enough for adults to take off and fly. Wind and large-scale (synoptic) data are useful during periods when adults or swarms are likely to be migrating or to estimate if there is an invasion threat from a neighbouring country.

During recessions, the most important variables to monitor are rainfall, vegetation and soil moisture. During outbreaks, upsurges and plagues, more environmental conditions play a role (Table 2). Access to information on rainfall, vegetation quantity, soil moisture, temperature and wind direction can be valuable in making accurate predictions and is essential for assessing the potential for locust movement and the planning of control operations.

Rainfall

Rainfall data consist of rainfall location, date and amount to date. Because of the sparse coverage of the measurement network and the variable nature of rainfall, such data can be inaccurate or

Table 2. Useful meteorological information in detection/prediction of outbreaks, upsurges and plagues and in planning control operations during different stages of Desert Locust development

	Data	Actual	Forecast	Use	Stage
Rainfall	Total	Daily Dekadal Monthly	+1 day +10 day +30 day Seasonal	Breeding Migration	Outbreaks Plagues Recessions
Temperature	Min/max	Daily Dekadal Monthly	+1 day +10 day +30 day Seasonal	Maturation Migration	Upsurges Plagues Outbreaks
Wind	Direction Speed Height	12 h		Migration	Plagues

missing altogether. A rough estimate can often be obtained by asking locals during a survey. Rainfall estimates can also be derived from satellite observations. The date and quantity of the first rains of the season are useful. The occurrence of the last rainfall can sometimes be estimated by observing to what depth the soil is moist. Sometimes it may not be possible to find out the exact date or amount of rain, but a rough indication can still be useful. When relying on local surveys, it is important to remember that different people have different concepts of rainfall quantity. Some may say heavy while others may say light for the same rainfall. In general, light rainfall is defined as up to 20 mm, moderate from 21 mm to 50 mm and heavy as more than 50 mm. Also, rainfall quantity (how much rain fell?) may be confused with intensity (how hard did it rain within a given period of time?). The latter has no predictive power, however. Predictions of rain, obtained from NMHSs, can be useful in estimating plague and individual locust development.

Eggs require moist soil conditions after laying as they need to absorb moisture to complete their development. They can be destroyed by flooding if extreme rainfall occurs after the laying takes place.

Hopper development from the first instar to fledging (the final moult from the wingless fifth or sixth instar to winged adult) indirectly requires rainy conditions, since the hoppers require edible vegetation for survival.

Adults start to mature when they arrive in an area that received significant rains recently. After fledging, the hardening of the soft wings of the locust is stimulated by rainfall.

Temperature

Egg development in the female depends on air temperature. Temperatures below 15°C are unfavourable. The rate of development of the laid eggs is a function of the soil temperature at the depth where the eggs are laid. Under conditions of high temperatures, egg development is more rapid. Egg mortality may occur when soil temperatures are above 35°C.

Hopper development is also a function of temperature. The hopper development period decreases with increasing daily air temperature from 24°C to 32°C. Band movement is stimulated by air temperature. On warm, sunny days, the bands march throughout the day while, on overcast days, they do not move very far. Exceptionally high night temperatures can also facilitate some movement.

Adults take off in temperatures above 20°C–22°C and fly with the wind (i.e. downwind). The migration of solitary adults occurs at night, usually 20 minutes after sunset, when the air temperature is above 20°C–22°C and the wind is less than 7 m/s (13.6 knots). Sustained flights require warm temperatures. Under temperatures < 20°C, sustained flights are rare.

Swarms usually take off about 2–3 hours after sunrise. In sunny conditions, they can take off in temperatures of at least 15°C–17°C. Under cloudy conditions, take-off occurs when temperatures reach 23°C–26°C. Under cooler conditions, take-off can be delayed to some 4–6 hours after sunrise. Locusts generally will not take off if winds are greater than 6–7 m/s (11.7–13.6 knots).

Wind

Wind is the main transportation mechanism of locusts and also concentrates them by convergence. In certain parts of the locust area in certain seasons, winds are regular in speed and direction. These areas and winds can be recognized by using local climatological knowledge and hence the spatial distribution of direction and speed of swarm movements. Air brought into strong frontal systems and circulation of cyclones from the surrounding countries may collect locusts from any scattered solitarious populations, as well as survivors from multiple swarming populations. The associated widespread and scattered rains may provide suitable breeding conditions for rapid multiplication of these immigrants, causing an unexpected outbreak if local locust teams are not informed and surveys not conducted.

Eggs can dry up if exposed to wind.

Hopper band movement is usually downwind.

Adult migration occurs at night when the air temperature is above 20°C–22°C and the wind is less than 7 m/s (13.6 knots). The direction of the flight is downwind. The take-off wind speed of swarms is usually < 6 m/s (11.7 knots). Swarms land about an hour before sunset as convection dies away.

Swarms move under the influence of large-scale weather patterns on a synoptic scale. The structure of swarms depends on weather conditions, governed by convective winds and low-pressure systems. Cool, overcast weather favours stratiform swarms, while convective updrafts on hot afternoons promote cumuliform swarms. Thus, swarms are usually stratiform in the morning and become cumuliform in the heat of the day, when convection takes place from the hot ground.

Seasonal changes in mean windflow bring locusts into specific zones. At the beginning of summer, the locusts move southwards from North-West Africa into the northern Sahel; in the autumn, they move northwards again. However, locusts do favour warmer winds associated with atmospheric depressions and, in such cases, the movement need not follow the prevailing winds in a given season.

Furthermore, wind speed is used to estimate the size of warms flying overhead. This can be done with a simple formula: time (s) x width (m) x wind speed (m/s) = size of swarm (m). This estimation has to be used with caution as it may overestimate the swarm size, but it can provide valuable information on the extent and severity of upsurges and plagues.

It is hard to estimate the direction of a swarm movement from observations made inside it. Even when a swarm passes directly over an observer and the direction of the upper parts of the swarm are recorded as it approaches and recedes, uncertainties remain of the position relative to the rest of the swarm. This is true for both the observer and the swarm, since often the observer cannot be sure that successive sightings are of the same swarm. A single ground observer can rarely do more than establish the general sense of displacement of a travelling swarm.

Weather and locust control operations

For locust control, as well as swarm movement, it is important to know the weather conditions and windfields because these affect the concentration of potential control targets and the suitability of conditions to carry out effective spraying. In planning Desert Locust surveys, the following principles should be borne in mind (WMO, 1991):

(a) Locust populations move downwind;
(b) The hotter the wind, the greater the distance travelled per day;
(c) Highly turbulent (and correspondingly hot) winds disperse populations (reduce their area density);
(d) Downwind movement eventually brings locusts into zones of wind convergence, where they accumulate;
(e) As opposed to steady wind conditions, where turbulence disperses populations, convergent winds have been shown to concentrate populations at least to the order of 10 000-fold;
(f) Locust populations are trapped in zones of wind convergence and participate in the diurnal and daily cycle of movement of such zones. In some places and seasons, these movements are relatively small and the locust population is correspondingly relatively stationary;
(g) Waiting for locusts to concentrate and form high-density populations is the most important strategy for efficient and economic control of locusts, so that the concentrating effect of zones of convergence must be utilized in control techniques.

In addition to their influence on locust development and migration, weather conditions are also important in locust control operations (Table 3).

Desert Locust control relies on conventional chemical insecticides that work mainly by direct contact action (droplets land on the locusts) and sometimes by secondary contact action (locusts touch the droplets on the vegetation) or stomach action (locusts eat the sprayed vegetation). Insecticides are usually neurotoxic, i.e. they kill the locust by interfering with its nervous system. The applied pesticide should be evenly spread over the target swarm either by hand, from a vehicle or by aircraft. An even distribution is accomplished by adjusting the size of the droplets to the wind speed and the location of application to the wind direction.

Spraying should take place under very specific meteorological conditions to ensure maximal effects on locust populations. The best time for spraying is usually in the morning between 8 a.m. and 11 a.m. and after 4 p.m. Effective spraying may be possible before 8 a.m. if the wind is strong enough. It may also be possible to spray effectively between 11 a.m. and 4 p.m. if it is either cloudy and relatively cool (less than about 30°C) or if there is a steady wind of more than 4 m/s (7.8 knots) that will tend to prevent convection.

Wind must be present when spraying because it is needed to spread or drift the spray over the target area. If there is no wind, the operator could be contaminated because the spray is not being carried away from him/her. There should be a steady wind of at least 2 m/s (3.9 knots) measured at a height of 2 m (a distinct breeze felt on the face). Spraying at wind speeds above 10 m/s (19.4 knots) (recognizable because dust and leaves are blown around) should be avoided, since it is not easy to predict where the spray will be deposited.

Spraying is done at right angles to the wind direction. If carried out in up- and downwind directions, the result will be a large overdose on a very narrow strip of the target area and, possibly, poisoning of the operator during downwind spraying. During application, wind direction should also be monitored since: (a) if the wind drops or becomes very strong (more than 10 m/s (19.4 knots)), spraying has to be stopped and can only continue when the right conditions occur again; and (b) if the wind direction changes by more than 45°, spraying should recommence from the new downwind edge, over the remaining unsprayed area.

It can be more efficient or necessary to spray swarms while they are flying using aircraft, if available, rather than using ground vehicles. The target swarms may be sprayed while they are on the ground, around the roost site, or while they are in full flight. Both stratiform swarms (low-flying up to heights of 100 m) and cumuliform swarms (flying up to heights of 1 000 m or more) may be sprayed. The swarm density is usually greatest in areas of convective winds, thus the highest success rate of locust control is achieved when spraying under these conditions. The advantage of spraying flying swarms is that flying locusts collect droplets efficiently since they are moving quickly (about 3 m/s (5.8 knots)) and their wings are beating faster.

Temperature differences between the hot ground and the air are the drivers for convection and wind. Convection occurs when the Sun rises high in the sky and heats up the ground. It usually occurs on hot afternoons but may also occur in the late morning, especially if there is little wind. Locusts should never be sprayed when there is strong convection, because spray droplets may be carried outside the target area.

Rainfall predictions are needed to time the control operations, since rain may wash off the insecticide from the vegetation. Spraying should not take place if rain is falling or seems likely to fall soon.

Weather and Desert Locust plagues and upsurges

The majority of Desert Locust upsurges and plagues develop as a result of unusual meteorological conditions such as those associated with cyclones and other extreme weather events that lead to heavy rainfall, which, in turn, causes ecological conditions to become extremely favourable for locust breeding. Plague declines are often attributed to the combined effects of control operations and unfavourable environmental conditions.

Table 3. Relevant conditions, control applications and example products

Stage	Relevant conditions	Control applications	Example products
Egg (10–65 days)	Laying when soil is moist 0 cm–15 cm (rainfall > 25 mm/month for 2 months) Soil temperature range for egg viability 15°C–35°C Egg development rate increases with temperature Air temperature range of 20°C–35°C for egg and hopper development Eggs die if flooded or exposed to wind or high soil temperatures (>35°C)	Planning survey and control operations Identification of areas suitable for breeding Estimation of rate of egg development	Maps of estimated 10-day precipitation and soil moisture
Hopper (24–95 days; average 36 days)	Rain needed for annual vegetation for food and shelter Development period decreases as air temperature increases from 24°C to 32°C. In the early morning and late afternoon, hoppers bask on plant tops or the ground; at midday, they take shelter inside plants. Bands march on warm, sunny days; bands do not move on overcast days. Band movement is usually downwind.	Planning survey and control operations Identification of areas of green vegetation Estimation of rate of hopper development Control operations against gregarizing hopper groups and bands	Maps of estimated 10-day precipitation 10-day dynamic greenness and dryness maps 10-day Normalized Difference Vegetation Index (NDVI) maps
Adult (2.5–5 months)	Adults mature from 3 weeks to 9 months (2–4 months is average). Mature rapidly in areas receiving recent significant rains; mature slowly in low temperatures or dry habitats. Take-off 20 minutes after sunset above 20°C–22°C and wind < 7 m/s (13.6 knots) Fly downwind during the night at heights up to 1 800 m (generally < 400 m) with ground speed of 25–65 km/h for up to 10 hours (2-hour average) Sustained flights are rare < 20°C.	Planning survey and control operations Identification of areas of green vegetation Estimation of rate of adult development Estimation of displacement rate and direction Control operations against gregarizing adult groups	Maps of estimated 10-day precipitation Daily wind maps and forecasts 10-day dynamic greenness and dryness maps 10-day NDVI maps
Swarm	Bask to warm up in the sun from sunrise to mid-morning. Take off about 2–3 hours after sunrise in warm weather (4–6 hours after sunrise in cool weather) and wind < 6 m/s (11.7 knots). Take off in sunny conditions at least 15°C–17°C; in cloudy conditions at 23°C–26°C. Fly downwind during the day at heights up to 1 700 m with ground speed of 1.5–16 km/h until 2 hours before sunset or 0.5 hours after sunset. Will not take off in winds > 10 m/s (19.4 knots).	Planning survey and control operations Identification of areas of green vegetation Estimation of rate of adult development Estimation of displacement rate and direction Control operations against swarms	Maps of estimated 10-day precipitation Daily wind maps and forecasts 10-day dynamic greenness and dryness maps 10-day NDVI maps

Plague of 1986–1989

The last major Desert Locust plague occurred from 1986 to 1989 and affected 43 countries. It arose from widespread heavy rains that fell in Western Sahara in the late summer of 1986. The plague finally ended in 1989 because of control operations and unusual winds that blew swarms across the Atlantic Ocean.

Upsurge of 2003–2005

Four local outbreaks developed simultaneously and independently in the autumn of 2003 in north-west Mauritania, northern Mali, Niger and north-east Sudan as a result of good rainfall and breeding during the summer. Two days of unusually heavy rains occurred in October 2003 from Senegal to Morocco, during which some areas in Western Sahara received more than 100 mm of rain compared to an annual precipitation of about 1 mm (Figure 7). Environmental conditions remained favourable for the next six months and Desert Locusts increased rapidly. During the summer of 2004, large numbers of swarms from North-West Africa invaded the Sahel in West Africa and quickly moved into crops. By then, the threat of a locust plague emerged, creating one of the most dangerous situations since 1989. As the year progressed, the swarms migrated over the continent, causing devastation. In November 2004, they appeared in northern Egypt, Jordan and Israel for the first time in 50 years. Lack of rain and cold temperatures in the winter breeding area of North-West Africa in early 2005 slowed down the development of the locusts and allowed national locust control teams to break the breeding and migration cycle. Ground and aerial operations in more than 20 countries treated nearly 130 000 km² of locust infestations. It took two years and more than US$ 400 million to bring the regional plague to an end.

Upsurge of 1996–1998

A regional upsurge affected countries along both sides of the Red Sea from June 1996 to the summer of 1998. It developed as a result of a cyclone in June 1996 and heavy rains in November. Locust infestations were primarily concentrated in Saudi Arabia and, to a lesser extent, Egypt, Eritrea, Ethiopia, northern Somalia, Sudan and Yemen. Large-scale control operations treated more than 700 000 ha and brought the upsurge to an end by the summer of 1998.

Figure 7. Heavy rains in Western Sahara. Two days of unusually heavy and widespread rains in Western Sahara in 2003 allowed ecological conditions to be favourable for breeding for the next six months, giving rise to a Desert Locust upsurge in West and North-West Africa.

Outbreaks of 2006–2015

Due to unusually heavy and/or widespread rains, Desert Locust outbreaks occur almost every year in part of the recession area. Recent outbreaks took place in:

- Eritrea (December 2006–March 2007)
- Yemen (May–September 2007)
- Western Sahara (September 2008)
- Yemen (March–June 2009
- Northern Somalia (March–June 2009)
- Mauritania (October–December 2009)
- India/Pakistan (October–November 2010)
- Mauritania (October 2010–May 2011)
- Sudan (October 2010–May 2011)
- Libya/Algeria (January–May 2012)
- Sudan (September 2012–April 2013)
- Sudan/Eritrea/Yemen/Saudi Arabia (August 201–March 2014)
- Northern Somalia (January–March 2014)
- Sudan/Eritrea/Saudi Arabia (October 2014–March 2015)
- Mauritania/southern Morocco (November 2015–May 2016)

The unusually heavy rains encountered before an outbreak can cause severe flooding in the normally arid desert. Within minutes, runoff can trickle down and fill up the normally dry wadis, making them difficult to cross (Figure 8). Within hours, large areas of the desert can be under water. Once the floodwaters recede, the moist sand will be covered by a rarely seen green carpet of annual vegetation – the perfect habitat for Desert Locust breeding.

Importance of weather information and conditions for Desert Locust control

The behaviour of the Desert Locust is directly influenced by meteorological parameters, such as rainfall, temperature and winds arising from convergence, monsoons, position of storms and depressions and the fluctuations in the position of seasonal convergence zones such as the Inter-Tropical Convergence Zone (ITCZ) and Red Sea Convergence Zone. Accurate

Figure 8. A ground team during a typical Desert Locust survey. Unusually heavy rains in 2007 made it increasingly difficult to move in the already remote and rough locust-breeding areas in the interior of Yemen. Yet ground teams are essential in trying to determine the extent of the current problem and in guiding aerial control operations.

meteorological information is crucial for understanding locust population dynamics, outbreaks, upsurges and plagues and for the undertaking of survey and control operations (Table 4). A basic understanding of meteorology is useful when trying to analyse weather data in order to predict locust developments. In countries threatened by a locust invasion, it is important for meteorologists to have some knowledge of locust behaviour and for locust officers to have a basic understanding of the influence of weather on breeding and migration.

The NMHSs in locust-affected countries monitor and forecast meteorological elements such as precipitation, temperature, humidity and wind speed and direction. These elements are crucial to forecasting locust breeding, maturation, migration and survival. Climatology (long-term climate information) is an important element in strategic planning during recessions and in advance of control operations. Climatology can provide the long-term mean weather and deviations – unusually heavy rainstorms, for example – since it indicates the weather most likely to be encountered. For more immediate actions, such as control operations, observations of actual weather and weather forecasts are needed. Ideally, three types of information should be available, namely: climate, actual weather and forecasts.

Locust control services can make use of meteorological information for planning survey and control operations and for forecasting locust breeding and migration, for example:

(a) Where breeding is likely to occur;
(b) When the next generation is likely to be flying;
(c) Where and when that generation is likely to reach areas at risk of invasion;
(d) Effects of weather on logistics of survey and control – the moving of staff and materials, as well as ground and aerial control operations against hoppers and swarms.

In general, locust movements take place in the temporary spell of warm winds ahead of cold fronts. These depressions firstly bring the winds which make the movement possible and, secondly, the rain necessary for making conditions suitable for breeding. Locusts are blown from areas of divergence towards areas of convergence, which can be related to the position of the ITCZ. Rainey (1951) was the first to discover the marked association between the occurrence of locust swarms and the ITCZ. While the ITCZ does not change dramatically from day to day, meteorologists should study its movements on a weekly to 10-day basis in order to provide assistance to national locust surveys and control teams in the area and for upsurge prevention.

The differences in how data are collected and reported at the national and international levels and the sparse coverage of meteorological data can be the cause of inaccurate forecasts and false security. Rainfall, for example, is interpolated between observing stations, giving the impression of precise knowledge, while the variable nature of rain can cause great differences in its spatial distribution. Experience has demonstrated that a major gap remains in the identification of clear and useful guidelines on the exact nature of meteorological products that must be provided at regular intervals.

Specific meteorological parameters are needed by NLCCs, as expressed at regional training workshops for locust-affected countries on meteorological information for locust monitoring and control, based on the type, frequency, format and whether it is an invasion (I – outbreaks, upsurges, or plague) or a recession (R) period (see Table 4).

Interpreting weather maps

While environmental conditions, especially rainfall, are important for locust development and breeding, wind and other atmospheric disturbances are most important for flying swarms. Locust swarm movements are influenced by large-scale weather patterns and smaller-scale wind motions. Locust swarms flying in a given area will tend to accumulate along any line of convergence in the windfield, atmospheric fronts separating warm and cold airmasses. These lines of convergence, such as the ITCZ or the sea-breeze front, consequently restrict the movement of a swarm. The movement of these front lines is usually accompanied by heavy rains, while the winds blow in the direction of the fronts.

Table 4. Various meteorological parameters needed by National Locust Control Centres with station names, geographic coordinates, date and weather data in standard format (R = recession, I = invasion)

Parameter	Specifics	Period	Frequency	Format
Rainfall	Observed, estimated	R/I	Daily, dekadal, monthly	Tables, georeferenced digital maps, analyses
	Daily forecast	I	One-day forecast	Georeferenced digital map
	Heavy rain forecast	R/I	6-day forecast	Georeferenced digital map
	60 day cumulative	R/I	Monthly	Georeferenced digital map
	Seasonal forecast	R/I	Monthly	Georeferenced digital map
Wind	Ground to 2 000+ m	I	Observed 1–7 day forecast	Tables, maps
	Warning	I	Dekadal	Bulletin
ITCZ position		R/I	Daily, dekadal, one-day forecast	Georeferenced digital maps, analysis
Temperature	min/max/avg	I	Daily, one-day forecast	Tables, georeferenced digital maps
Weather warnings		R/I		Bulletin
NDVI	1 km or less resolution	R/I	Dekadal	Georeferenced digital map
Dynamic green/dry vegetation	250 m or less resolution	R/I	Dekadal	Georeferenced digital map
Soil moisture	0–15 cm	R/I	Dekadal	Georeferenced digital map
Soil temperature	0–15 cm	R/I	Dekadal	Georeferenced digital map

Mesoscale atmospheric circulation affecting locust swarms (WMO, 1965) are:

(a) Thermals: masses of buoyant air rising through lower temperature surroundings. A thermal is formed over places where the temperature is higher than in the nearby areas under weak wind conditions. Locusts may be carried upwards by convection, for example, in regions of convergence. Thermals are typically strongest during the afternoon, when the solar heating of the ground is highest;

(b) Winds and turbulence: anabatic wind blows up a steep slope or mountainside, driven by heating of the slope through solar radiation during the afternoon. Anabatic flow may continue up a downwind slope against the direction of the general wind, forming an eddy where convergence towards the point of separation takes place. Eddies always have the effect of aggregating, not dispersing, swarms of locusts.

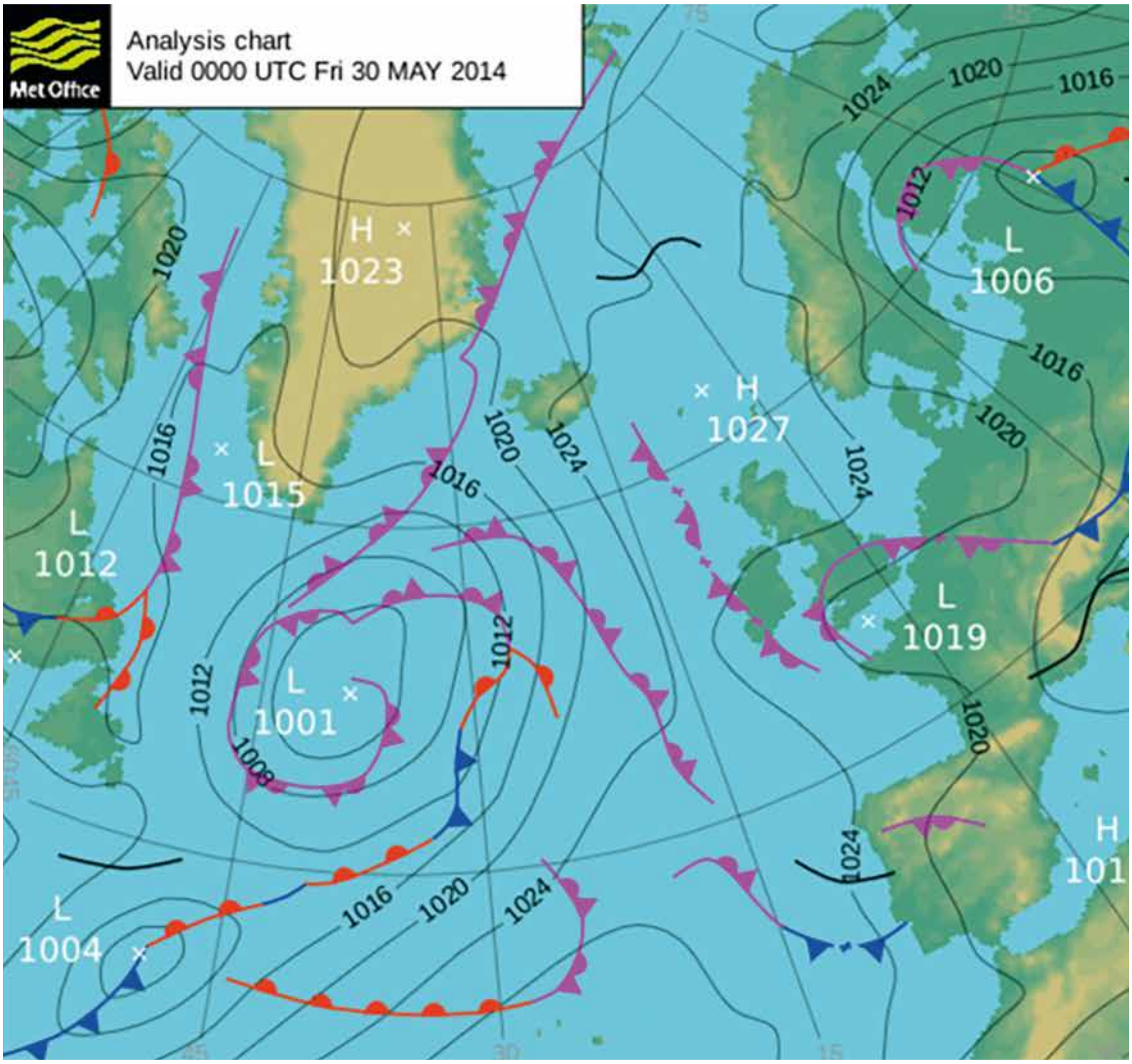
The most reliable method for analysing and predicting the movement of locust swarms is to construct trajectories of the airstreams in which they are present. Trajectories give position as a function of time for unsteady motion, as opposed to streamlines which presuppose a steady state in time. A streamline analysis is a series of arrows oriented parallel to the wind, showing wind motion. Streamlines are drawn from wind speeds; for use in locust forecasts, a surface weather map or the streamlines at 850 hPa (mb), which is roughly 1 500 m above sea level, are the most useful.

Weather maps

Weather maps provide a visual representation of the current or forecast weather conditions.

They can be based on satellite and radar images, recordings from instruments at weather stations, and computer analysis. The most common weather map is a surface analysis, based on pressure systems at mean sea-level pressure.

On a surface analysis weather map, high- and low-pressure centres are marked "H" and "L" (Figure 9). The lines around these highs and lows are called isobars. "Iso" means "equal" and "bar" is a unit of pressure. An isobar therefore means equal pressure. The closer the isobars are together, the stronger the pressure gradient. The pressure gradient is the difference in pressure between high- and low-pressure areas. The wind speed is directly proportional to the pressure gradient. Hence, the strongest winds are in the areas where the pressure gradient is the greatest. The wind direction is designated by the direction it is coming from: a west wind therefore comes from the west and blows towards the east.



UK Met Office

Figure 9. Map showing weather fronts and high- and low-pressure systems

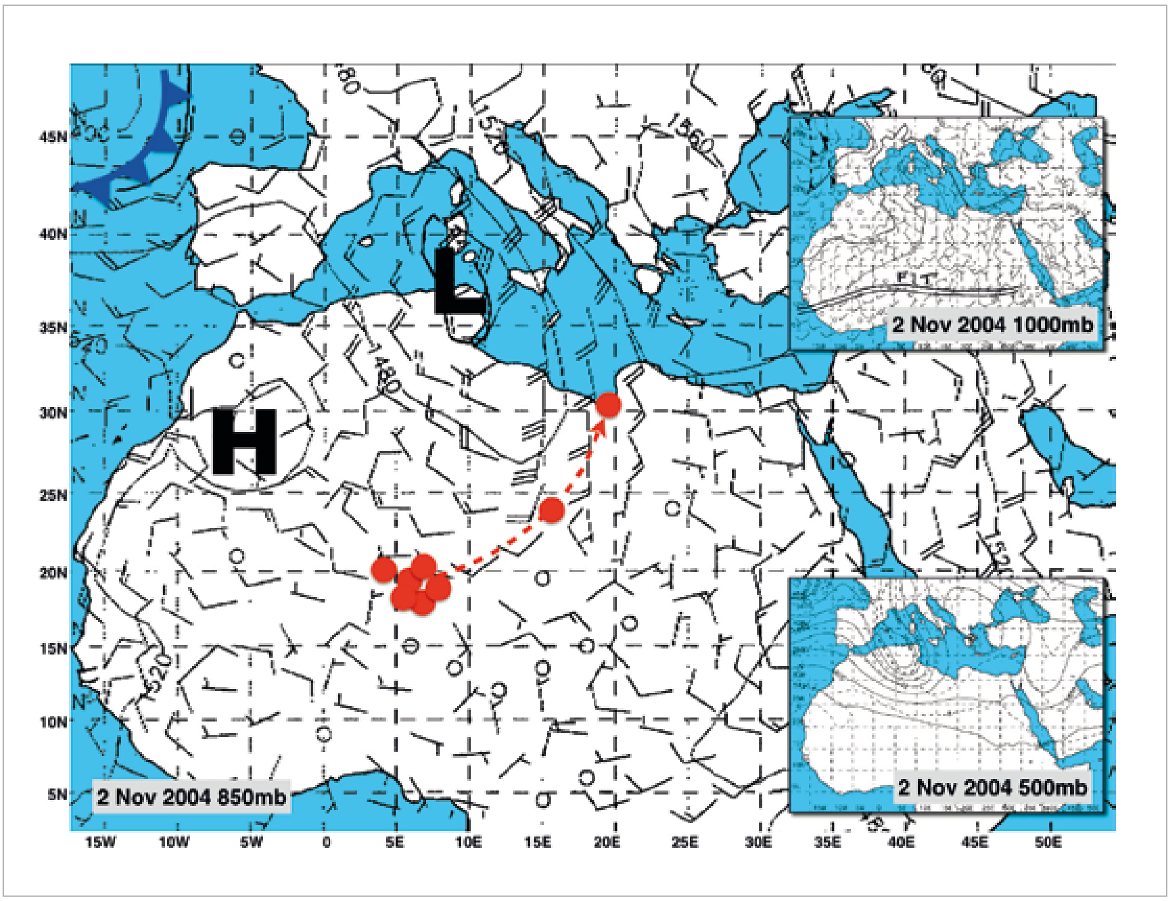
Weather fronts indicate the boundary or transition zone between two airmasses and they have an important impact upon the weather. For example, one airmass may be warm and moist and the other may be cold and dry. These differences produce a reaction in a zone known as a front. As a front approaches a location, one can expect a change in the weather once the front passes over the location.

Across the frontal boundary, there can be a large change in temperature, as warm air comes into contact with cooler air. The difference in temperature across the front can indicate its strength. For example, if very cold air comes into contact with warm tropical air, the front can be classified as a strong or intense front. If, on the other hand, there is little difference in temperature between the two airmasses, the front may be classified as weak (UK Met Office, 2015).

Streamline analysis

In the mid-latitudes, the isobars – lines of equal or constant pressure – found on a weather map are closely related to wind direction and speed. In the equatorial regions there is almost no pressure gradient and a pressure-based weather map has very few lines. Streamlines (based on wind speeds) and sometimes isotachs (contours of wind speed often drawn at the 300 hPa and 200 hPa level) are therefore used to illustrate the windfield. A streamline analysis is a series of lines with arrows oriented parallel to the wind, showing wind motion (Figure 10).

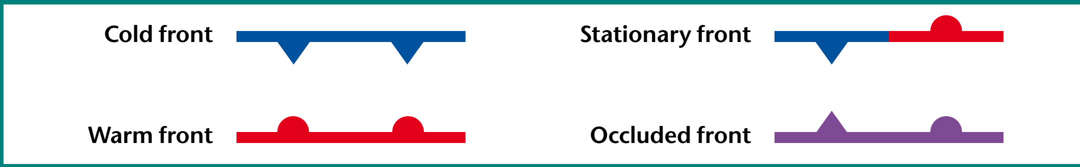
On weather maps, features such as lines of convergence become apparent and can be used in forecasting Desert Locust movement. For use in locust forecasts, a surface weather map or the



Météo-France

Figure 10. Use of weather maps. Desert Locust swarms (red dots) formed at the end of summer 2004 in the northern Sahel of Mali and Niger. Some of these swarms moved in warm, moist southerly winds associated with an eastward-moving low-pressure system over the central Mediterranean that carried them to the Libyan coast and then east to Egypt where one swarm flew over Cairo on 17 November, nearly 50 years to the day when the last swarm was seen in the capital.

Box 1. Weather fronts: symbols used on weather maps



Cold front (symbolized on a weather map as a line with triangles). Cold fronts are typically coloured blue. Cold fronts are associated with heavy rainfall and high wind speeds. The direction in which the triangles point is the direction in which the cold front is moving and this means that cold air is advancing and pushing warmer air underneath. This is because the cold air is heavier – more dense – than the warm air. Cold air is thus replacing warm air at the surface.

Warm front (symbolized on a weather map as a line with semicircles). Warm fronts are typically coloured red. The edges of the semicircles indicate the direction of movement of the warm air, which means that warm air is advancing and rising up over cold air. This is because warm air is lighter – less dense – than cold air. Warm air is replacing cooler air at the surface. A warm front typically brings a gradual increase in rainfall as the front approaches, followed by prompt clearing and warming after the front passes.

Stationary front (symbolized on a weather map as a line with semi-circles bordering one side and triangles along the opposite side, indicating that the front is not moving in any direction). Stationary fronts can bring long, continuous rainy periods that linger for extended periods of time in one area.

Occluded front (symbolized on a weather map as a line with both semicircles and triangles). Occluded fronts are typically coloured purple. They are slightly more complex than cold or warm fronts. Occluded means hidden and an occlusion occurs when the cold front catches up with the warm front. The warm air is then lifted up from the surface, and is therefore hidden. An occlusion can be thought of as having the characteristics of both warm and cold fronts.

streamlines at 850 hPa, which is approximately 1 500 m, are the most useful (see Figure 11). The process of convergence is an essential factor in the production of precipitation, while divergence is commonly associated with fair weather. Much of the process of weather forecasting may in fact be considered as the recognition and characterization of areas of convergence and divergence (WMO, 1963).

Low-pressure systems, also known as cyclones, are located in minima in the pressure field. Rotation is inward and counterclockwise in the northern hemisphere, due to the Coriolis force. Near a cyclone, weather shows increased cloudiness, increased winds, increased temperatures and upward motion in the atmosphere, leading to an increased chance of precipitation. Tropical cyclones and winter storms are intense examples of low pressure. Over land, low-pressure systems are indicative of hot weather during the summer.

High-pressure systems, also known as anticyclones, rotate outward and clockwise in the northern hemisphere. Under high-pressure systems at the surface, sinking motion leads to skies that are clearer, winds that are lighter and a reduced chance of precipitation. There is normally a greater range between high and low temperature due to the drier airmass present. If high pressure persists, air pollution can build up due to pollutants trapped near the surface.

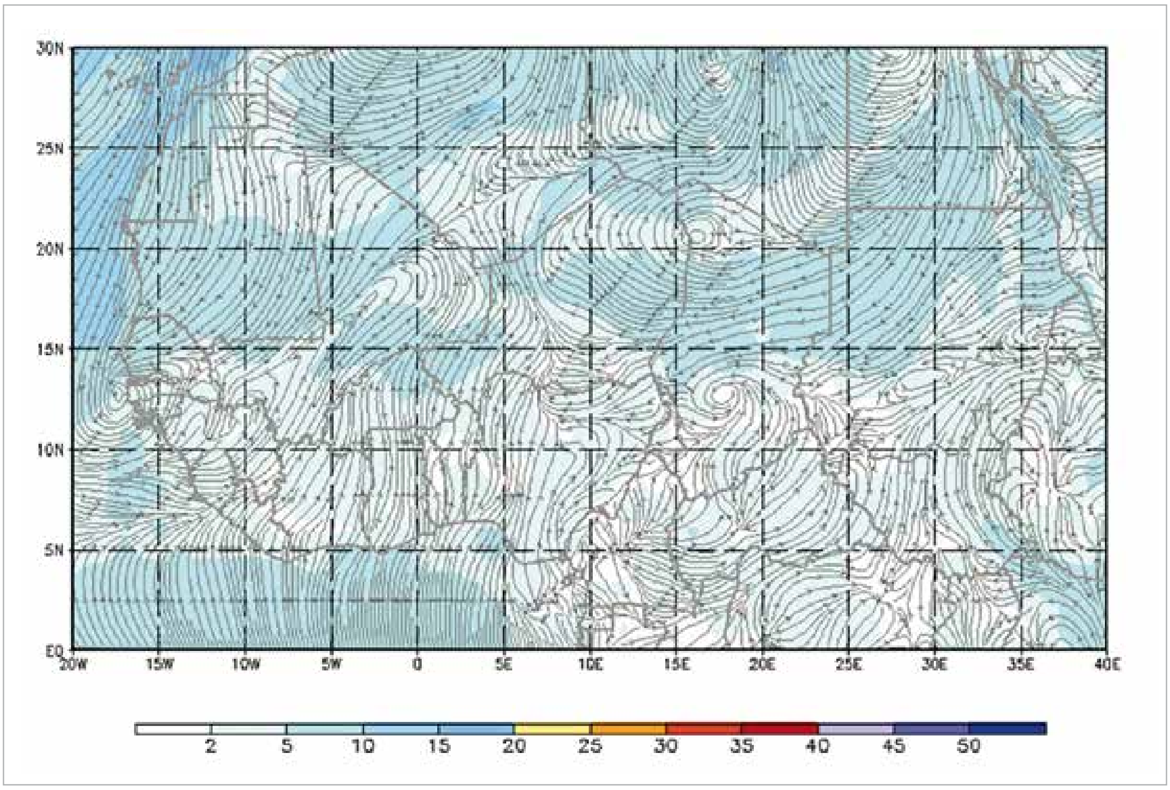


Figure 11. Map of streamline analysis. On streamline charts, low-pressure systems (including tropical cyclones) appear as inflowing anticlockwise circulation in the northern hemisphere. High-pressure systems appear as outflowing clockwise circulation. The exact location of locust swarms can be assessed by combining a streamline analysis map with the mean windfields. This gives information on both the direction and speed at which the swarms are moving.

Box 2. Wind maps

Wind intensity can be interpreted by observing the half and full lines, called pennants, on wind barbs. The wind barb points towards the wind direction with its pennants, thus into the direction from where the wind is coming (Figure 12). The information for wind speed is given in metres per second or knots*. Wind speed is obtained by adding up the number of pennants on the wind barb:

- A full black pennant or triangle is 50 knots (25.5 m/s);
- A full line on the wind barb is 10 knots (5.1 m/s);
- A half line is 5 knots (2.5 m/s).

Wind blowing from the west at 75 knots | Wind blowing from the north-east at 25 knots | Wind blowing from the south at 5 knots | Calm winds

*1 knot = 1 nautical mile/h = 1.15 mile/h = 0.51 m/s = 1.85 km/h

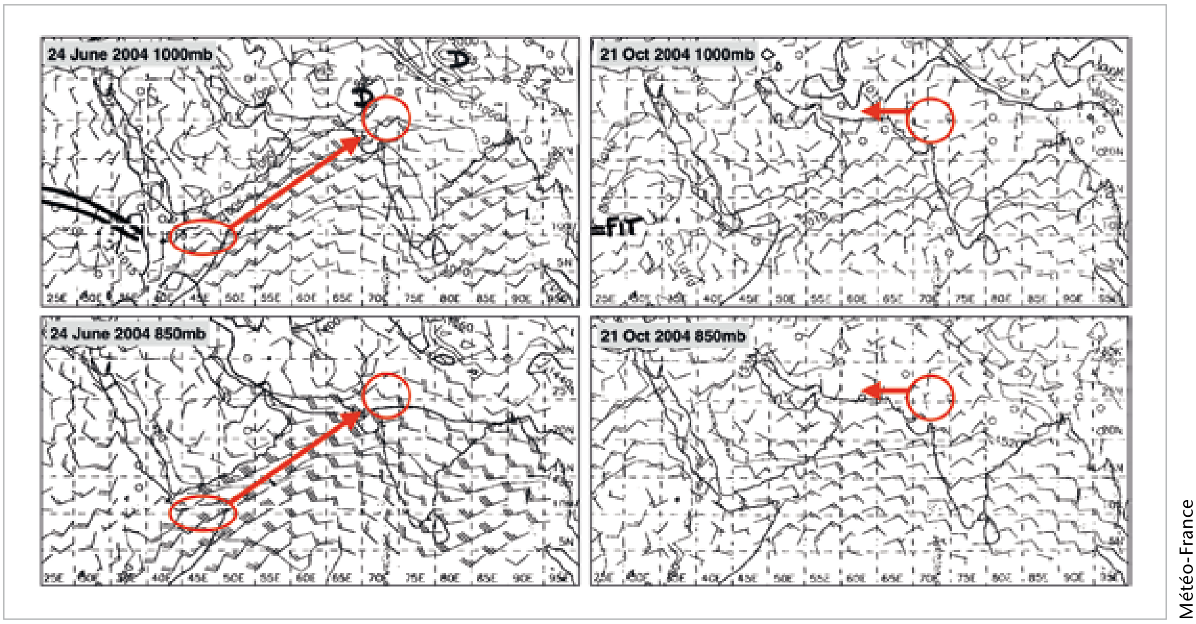


Figure 12. Use of synoptic charts showing wind direction and speed. Seasonal wind patterns contribute to rainfall and affect Desert Locust breeding and migration. In May, south-westerly monsoon winds become established over the Horn of Africa that can carry spring-bred adults from northern Somalia to the Indo-Pakistan border areas, where breeding can occur from July to September (red circles and arrow). By mid-October, this windflow reverts to the prevailing north-easterlies. Consequently, summer-bred adults often move towards western Pakistan during the autumn (red circle and arrow).

Interpreting rainfall-analysis maps

Rain is the liquid form of precipitation that results from the condensation of atmospheric water vapour into drops of water, larger than 0.5 mm in diameter, that fall from a cloud and make it to the surface. Two processes, possibly acting together, can lead to air becoming saturated and resulting in rainfall: cooling of the air or addition of water vapour. Rain is the primary source of freshwater for most areas of the world, providing suitable conditions for diverse ecosystems, natural vegetation and crop irrigation. Rainfall is measured through the use of raingauges at meteorological stations operated by NMHSs. Rainfall amounts are also estimated actively by weather radar and passively by weather satellites. For synoptic purposes, rain showers are classified as “slight”, “moderate”, “heavy”, or “violent” for rates of accumulation of about 0–2 mm/h, 2–10 mm/h, 10–50 mm/h, or > 50 mm/h, respectively (UK Met Office, 2007).

The movement of the ITCZ brings rainy seasons to savannah climates. However, rainfall in desert areas is highly variable and may not always be reported because of the sparse observational network and data coverage. Any area where substantial rain has fallen at the right season must be regarded as a possible site for locust breeding. When rain occurs in the right quantity at the right time, some solitarious locusts usually appear to take advantage of the conditions. Therefore, the estimation of the occurrence of rain is the main concern during recessions. On the other hand, the seasonally infested areas during plagues normally receive enough rain for successful breeding. The forecasting of swarm migration therefore becomes the critical activity.

Precipitation forecasts are normally given for synoptic hours such as 0000, 0600, 1200 and 1800 GMT or can be extended into a multi-day forecast. They give the expected amount of precipitation accumulated over a specified time period over a specified area. Currently, forecasts are based on small-scale atmospheric weather models, which can be verified through use of raingauge measurements, weather-radar estimates, or a combination of both. Raingauge measurements are point data, whereas model estimates provide averages in space. Raingauge observations can be gridded into areal averages for comparison with outputs from the grids of the forecast models. Another technique, weather-radar estimates of rainfall, can be used outright or corrected using raingauge observations. Within six to seven hours of the time of the radar image, radar-imagery forecasting techniques show higher skill than model forecasts. On longer timescales, seasonal probabilistic forecasts can be used.

Satellites and models

Measurements and estimation of the movement of a swarm are almost impossible from observations made inside it, even when a swarm passes directly over an observer. A single ground observer can rarely hope to do more than establish the general sense of direction of a travelling swarm. Unfortunately, satellites currently available for civilian use cannot directly detect individual locusts or locust swarms on an operational basis. Some highly sophisticated satellites used by the military and forthcoming civilian satellites could potentially detect locust swarms but these images are not yet available. Current satellites can provide continuous estimates of rain-producing clouds and ecological conditions, such as vegetation development, which are important factors for monitoring Desert Locust habitats and forecasting locust development.

Rainfall estimates

Rainfall estimates for the entire Earth are derived from passive microwave and infrared satellite data at high spatial and temporal resolution based on the Climate Prediction Center MORPHing (CMORPH) algorithm, developed by the US National Oceanic and Atmospheric Administration (NOAA). In locust monitoring, the processed 24-hour cumulative estimates, as well as dekadal (10-day) and monthly estimates of rainfall, are usually used on a 0.25° latitude/longitude grid. Satellite-derived estimates are preferred instead of purely model-derived estimates because the former are better indicators of the spatial distribution of rain (where it has rained) while the latter are more appropriate for rainfall quantity (how much it has rained). It is more important to have

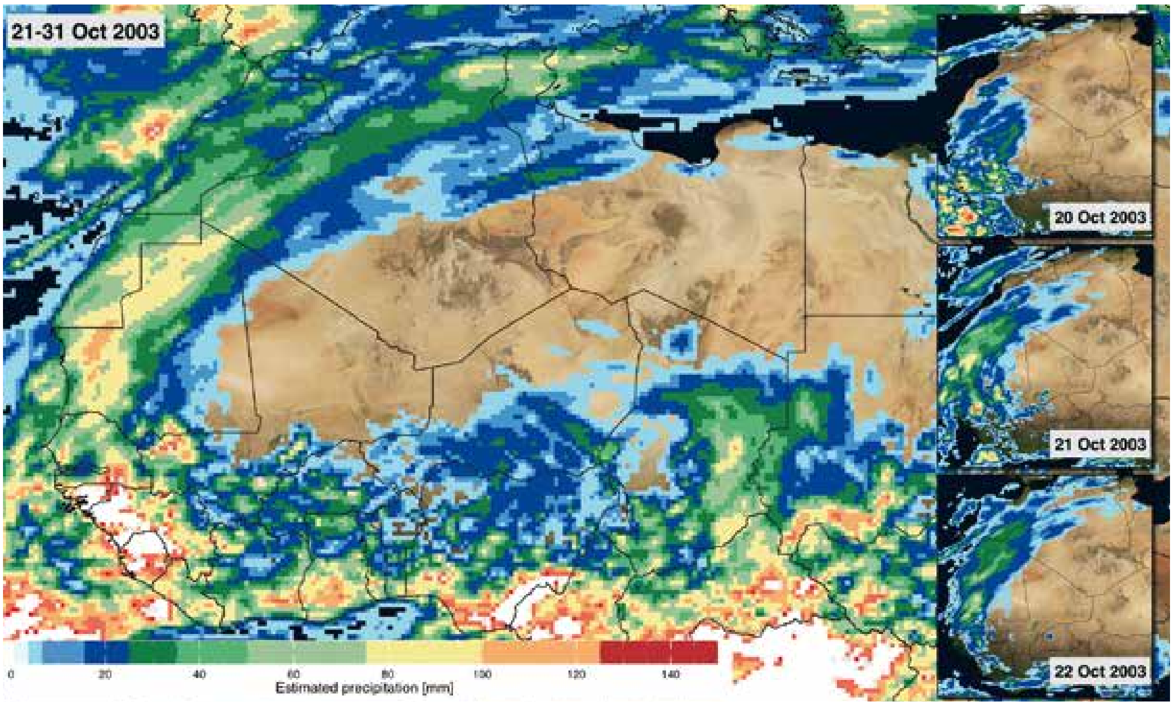


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Figure 13. Use of satellite-derived rainfall estimates for monitoring habitat conditions. Unusually heavy rains fell over a widespread area, extending from Senegal to the Atlas Mountains in Morocco, 20–22 October 2003. Some areas of north-west Mauritania and Western Sahara received more than twice their average annual rainfall, causing severe flooding (see Figure 7). Once floodwaters receded, breeding conditions remained favourable for more than six months, leading to an upsurge that took two years and US$ 500 million to bring under control.

a rough idea of where it has rained so as to help guide survey teams, rather than knowing exactly how much it has rained.

Rainfall-analysis maps can be issued for different periods, the most common being daily, dekadal and monthly (Figure 13). The rainfall amount is divided into classes indicated with different colours on the map. The legend and colours for every map may change with the highest amount of rainfall predicted for that period, as different amounts may require the classes to be adjusted. The maps are used to identify areas where at least 20 mm of rain may have fallen, which can cause soil to become moist and thus allow locusts to breed and annual vegetation to become green for their survival and development.

Vegetation estimates

Satellite sensors can provide information on vegetation status such as vegetation greenness, percentage of vegetation cover and vegetation moisture content. Even though these sensors are specifically designed for vegetation monitoring, it has become clear that it is difficult to detect the sparse vegetation in the desert and asses its quality. For example, vegetation that appears to be dry to the satellite sensor can be sufficiently green for Desert Locust survival and breeding. Analysis of cumulative images and individual channels provides a more accurate estimation of ecological conditions in Desert Locust habitats that should be verified with survey results, whenever possible.

There is ongoing research and collaboration between FAO DLIS, universities and research institutes. Satellite vegetation (MODIS) images are made available every 16 days to locust-affected countries. MODIS-derived products, such as dynamic greenness and dryness maps, show changes over time in vegetation conditions every 10 days at a spatial resolution of 250 m (Figure 14). The Sentinel 3 satellite offers resolutions as high as 10 m. Locust-affected countries use these products operationally to monitor vegetation greenness and to help guide national survey teams to potential areas of green vegetation where Desert Locusts may be present, while DLIS uses them for assessing breeding conditions and forecasting subsequent developments.

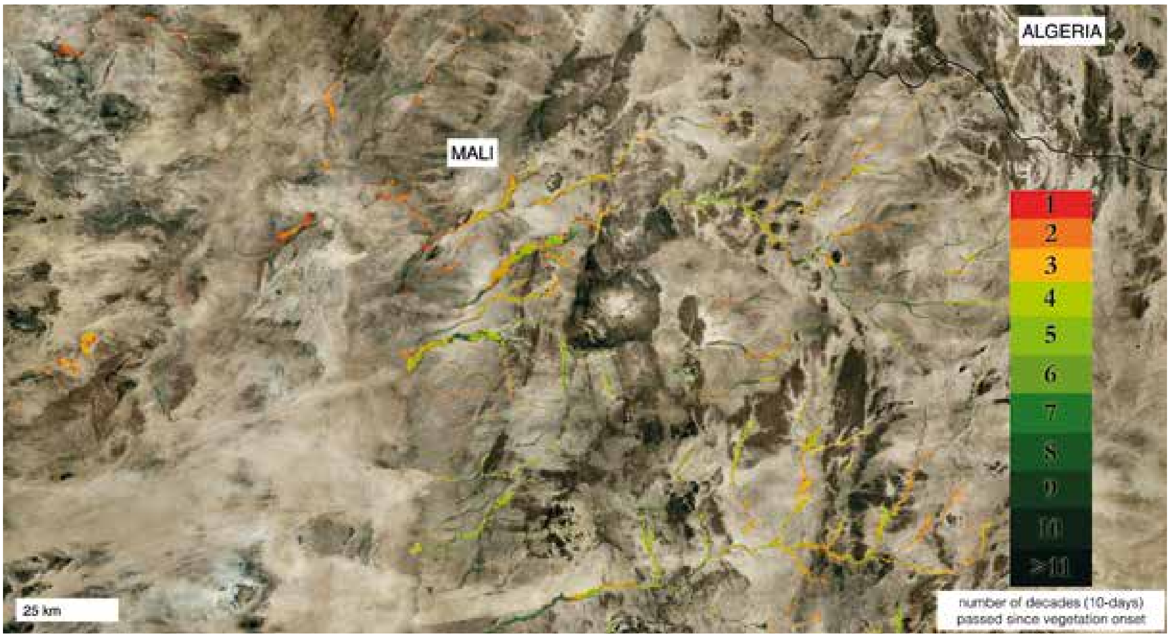

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Figure 14. Use of MODIS-derived products to monitor vegetation. Seasonal rains during summer 2015 caused annual vegetation to become green in northern Mali. The MODIS-derived dynamic greenness map for 11-20 September 2015 indicates that green vegetation first appeared in early July, while recent rains in the western portion of the area caused new areas to become green. Greenness maps help survey teams to prioritize areas to check for locusts.

This information is incorporated in the monthly FAO Desert Locust Bulletin, which gives information on potentially affected countries in desert and semi-desert areas of northern Africa, the Near East and South-West Asia for planning survey and control operations (FAO, 2016).

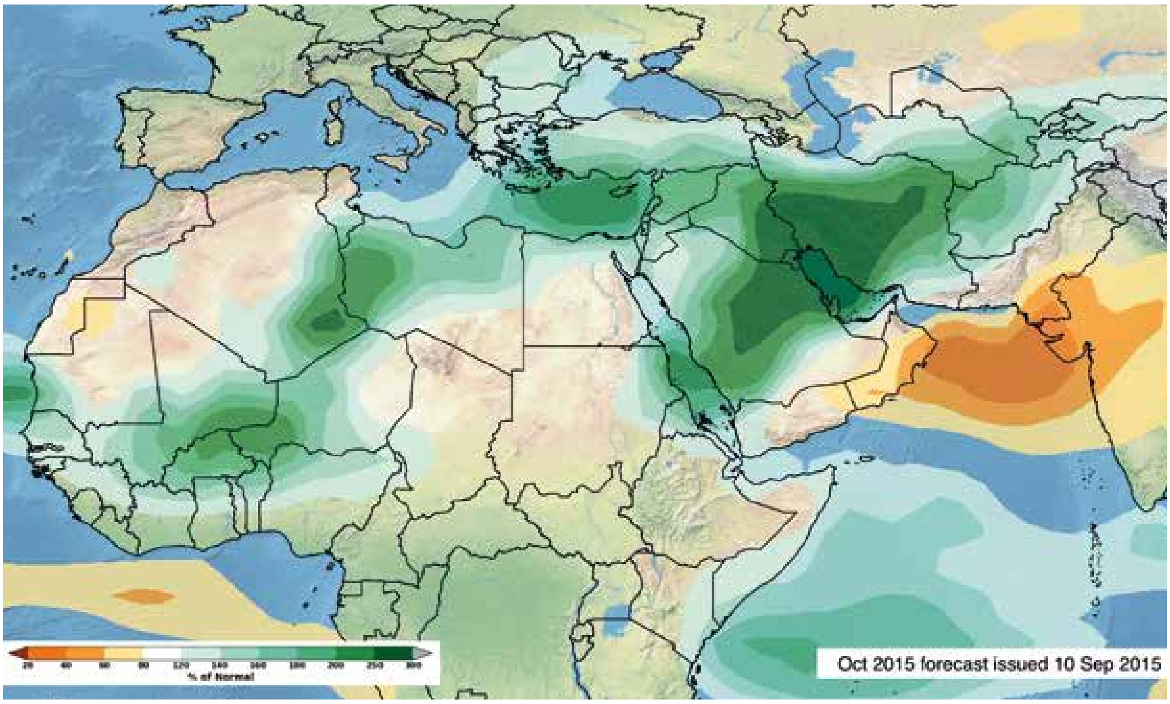
Soil moisture content

Research is underway to use remote-sensing imagery to monitor soil moisture on an operational basis. This could help to identify areas that are potentially favourable for Desert Locust egg-laying.

Seasonal weather predictions

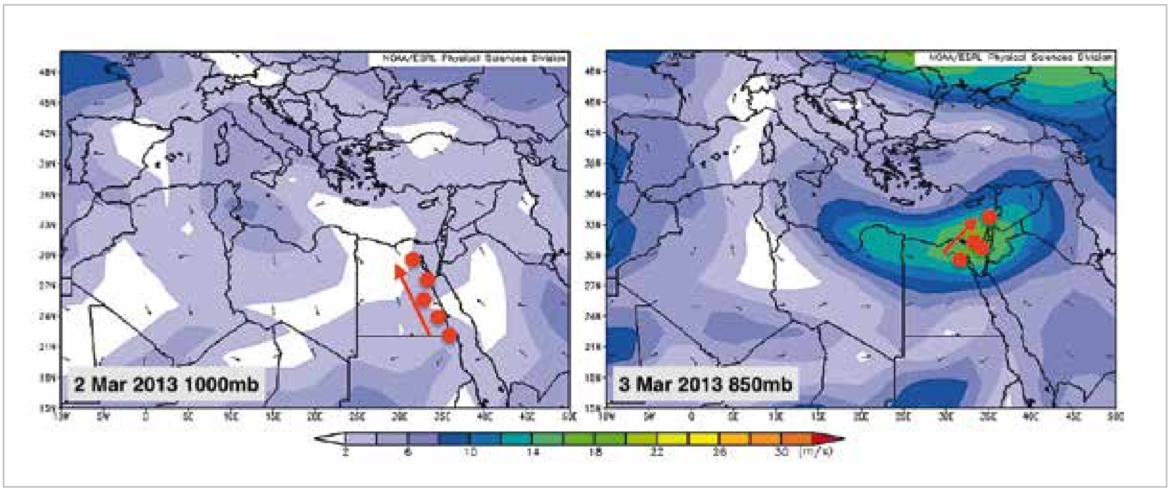
Since 2005, FAO's DLIS has been using seasonal forecasts from the World Climate Service (WCS) that predict rainfall and temperature anomalies six months in advance in the Desert Locust recession area (Figure 15). These products are supplemented by subseasonal forecasts to predict rainfall and temperature anomalies for the next 2–4 weeks. The WCS forecasts are based in part on the seasonal ensemble forecast products of the European Centre for Medium-Range Weather Forecasts, an international centre in Reading, United Kingdom, supported by 25 European States. Probabilistic seasonal forecasts are computed from ensembles of computer models that simulate the motions and energy transfers in the atmosphere and ocean and then do several runs to include the range of uncertainties in observations and in the numerical models with slightly different initial conditions. The probabilities are then computed from the distribution of individual forecasts within the ensemble.

These forecasts are being used by DLIS on an operational basis but with caution. They are partially incorporated into the locust forecasts that appear in the monthly FAO Desert Locust Bulletin, updates and other advice provided by DLIS to locust-affected countries and the international community.



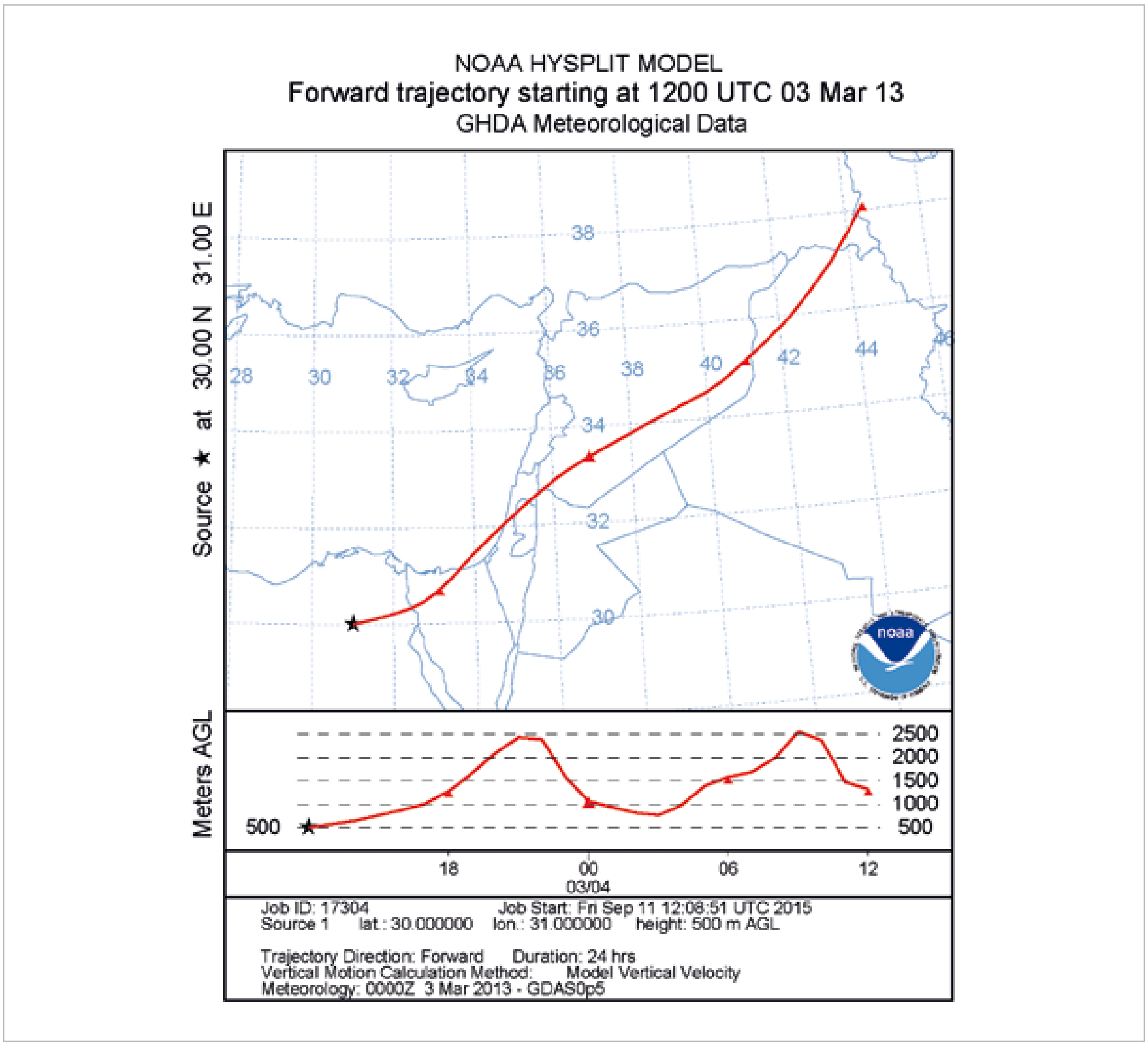
Source: World Climate Service, Prescient Weather

Figure 15. Interpretation of seasonal rainfall predictions. Up to three times the amount of normal rainfall is predicted to occur over the Persian Gulf while up to two times the normal amount could fall in parts of Algeria, Libya, Mali and Niger. Drier-than-normal conditions are estimated for western India.



National Centers for Environmental Prediction (NOAA)/National Center for Atmospheric Research reanalysis

Figure 16. Use of wind models. Small swarms (red dots) originating from winter breeding on the Red Sea coast along both sides of the Egypt/Sudan border moved northwards on warm southerly winds along the coast and adjacent hills, reaching Cairo on 2 March and then moving east to Sinai, Israel and Lebanon on the following day.



NOAA

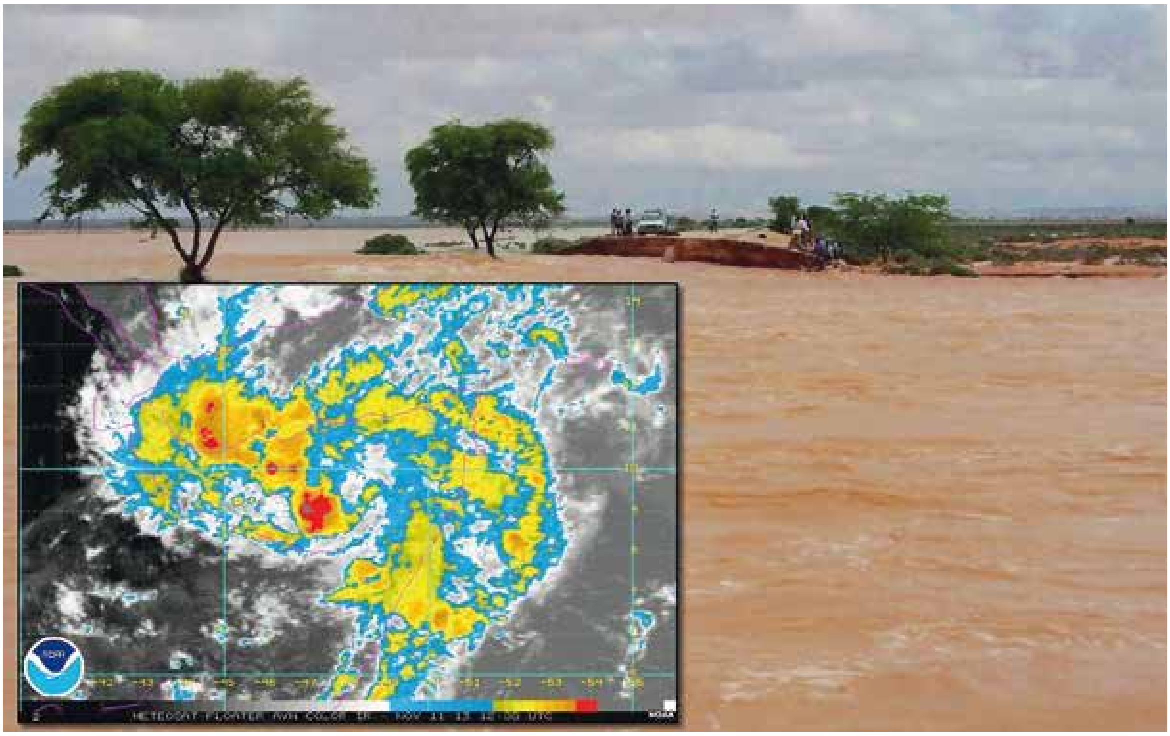
Figure 17. Use of a trajectory model to estimate Desert Locust migration. The forward trajectory of the NOAA HYSPLIT MODEL confirms the movement of small swarms and adult groups from Cairo and north-east Egypt to the Sinai, Israel and Palestine that occurred on 3 March 2013. Although a few small groups reached Lebanon, no locusts were reported further east.

Trajectory models

A trajectory model typically moves a cubic parcel of air forward or backward in time from one area to another based on temperature, pressure, and wind direction and speed data at different atmospheric levels every 6 or 12 hours (Figure 16). As locusts are passive fliers and drift with the wind, such models can be used to estimate adult and swarm movements over time and space (Figure 17). For example, if a swarm suddenly appears at a particular location, then the model can be used to understand where the swarm may have originated. Similarly, if a swarm is present in an area of drying vegetation, then the model can estimate where that swarm may move in the next 10 days.

The impacts of climate change

Climate change experts predict more extreme weather, including droughts, floods and cyclones. Whereas locust numbers decrease during droughts, locust outbreaks often follow floods and cyclones (Figure 18). Local increases in rainfall can favour breeding conditions for locusts and determine the size of feeding areas, leading to changes in plague development. An outbreak in the interior of Yemen (May–September 2007), for example, took place in an area that was thought to be more of a transit zone for Desert Locusts, rather than an important breeding ground. Because the area is extremely rugged and remote and rarely infested by locusts, external international experts, additional pesticides, some spray equipment, pesticide and fuel pumps, protective clothing and first aid kits were needed from abroad to support national control efforts and eliminate the emerging outbreak before it could destroy agricultural production and spread to other countries. In November 2015, two cyclones brought heavy rains to coastal and interior areas of southern Yemen, allowing breeding conditions to remain favourable for up to six months. These examples may be a precursor for other outbreaks and upsurges in unexpected locations, possibly linked to a changing climate.



NOAA

Figure 18. Potential impact of climate change on Desert Locust. An increase in extreme rainfall events is one effect of climate change that will impact Desert Locusts. On 11 and 12 November 2013, heavy rains of 75–300 mm associated with Tropical Cyclone 03A fell over northern Somalia. Severe flooding occurred in some areas that received more than 15 times their average annual rainfall in two days. This led to a Desert Locust outbreak that eventually spread to Djibouti and Ethiopia.

Climate change experts also predict that temperatures will continue to rise. Temperature governs the speed of locust development and swarm movement. Thus, increased temperatures associated with climate change can potentially shorten both the long maturation and incubation periods during the spring and allow an extra generation of breeding to occur in North-West Africa, the Arabian Peninsula and South-West Asia. This could increase the number of locust generations in a year in these regions and amplify overall plague risk. Changes in El Niño and La Niña events due to climate change could affect breeding during the winter in the Great Horn of Africa and during the summer in the West African Sahel.

The effects of climate change on winds are less certain. Any changes in wind speed, direction and circulation flows are expected to affect Desert Locust migration and could allow adults and swarms to reach new areas at different times of the year. Whether they will be able to become established, survive and breed in these new areas will depend on ecological, habitat and weather conditions.

Box 3. Workshop recommendations

Based on the conclusions from the Expert Meeting on Meteorological Information for Locust Control, held in Geneva, Switzerland, 18–20 October 2004, FAO and WMO decided to organize regional workshops for both the francophone and anglophone countries in North Africa and South-West Asia.

The workshops brought together experts and representatives of NMHSs and NLCCs from potential locust-threatened countries in North and East Africa, the Near East and South-West Asia. The francophone workshop was held in Niamey, Niger, 18–21 April 2005. The anglophone workshop was held in Muscat, Oman, 9–12 April 2006.

Recommendations for national NMHSs and NLCCs – Niger workshop

- NMHSs should improve the quality and transmission of existing meteorological data;
- Satellite imagery should be used to supplement current data but the issue of cost needs to be addressed;
- METEOSAT Second Generation data (1–2.5 km promised, currently <50km) should be exploited;
- Current weather data should be supplemented with secondary sources such as existing rain stations and results of Desert Locust surveys;
- Additional training should be provided to NLCC staff in the use of meteorological and remotely sensed information;
- Personnel should be exchanged between NLCCs and NMHSs; for example, an NMHS meteorologist could be placed temporarily in the NLCC during locust outbreaks;
- Information and data exchange between countries should be improved;
- A national task force should be established during locust emergencies that includes NLCCs, NMHSs, and plant protection agencies on locust-control activities. The task force should meet for daily or weekly briefings and be small enough so they can rapidly come together;
- Formal roles and frameworks to encourage discussions and briefings between NMHSs and NLCCs need to be established;
- Mechanisms need to be developed to ensure close collaboration, not only during locust emergencies, but also during recession periods;
- Logos and other means of explicit recognition should be used to actively promote the collaboration between NMHSs and NLCCs.

Recommendations for national NMHSs and NLCCs – Oman workshop

- Organize a meeting between NMHSs and NLCCs to discuss future collaboration;
- Establish a high-level formal agreement between NMHSs and NLCCs;
- Establish a joint task force between NMHSs and NLCCs;
- Establish focal points in NMHSs and NLCCs;
- Establish format and delivery of weather products;
- Encourage and establish local collaboration (encourage locust officers in towns with meteorological stations to meet the meteorological staff);
- NLCC to routinely acknowledge the assistance and data from NMHS in bulletins and other media;
- If needed, International agencies (FAO and WMO) should facilitate collaboration between NMHSs and NLCCs;
- Egypt and Oman could be considered as providers for assistance in numerical weather prediction (NWP) and satellite products to NLCCs in neighbouring countries in their respective regions;
- Organize training courses for NLCC and NMHS personnel;
- Develop basic training course for NLCCs on how to understand weather products (with WMO assistance, if needed);
- Develop standard manuals targeting NLCC personnel (with WMO assistance, if needed);
- Develop basic training course for NMHS personnel on locust issues;
- NLCCs to improve the speed and reliability of their Internet connection in order to receive and download meteorological products;
- NLCCs should approach other potential data sources and make agreements with other agencies;
- Encourage an exchange of personnel between NLCCs and NMHSs;
- Develop the NMHS facilities and capabilities to meet the information requirements of NLCCs.

Recommendations for regional and international agencies

- Prepare and distribute a FAO/WMO Desert Locust meteorology publication in Arabic, English and French;
- Prepare a joint FAO/WMO brochure on locust meteorology for decision-makers, donors and the general public;
- Provide Desert Locust meteorology training and refresher courses for NLCCs/NMHSs;
- Provide capacity-building (equipment, training) for countries not able to provide satellite and NWP products;
- Encourage applied research in Desert Locust meteorology;
- Provide training in SPOT/MODIS, WAMIS, transfer of technologies, etc.;
- Transfer the regional weather data and model output over the WMO Global Telecommunication System for better access;
- Explore the feasibility of increasing the number of real-time raingauge stations;
- Provide additional equipment to NLCCs;
- Improve the flow of information between the AGRHYMET Regional Centre and national centres;
- Make available meteorological products of improved coverage and resolution at national and regional levels.
- Organize regional workshops between NMHSs and NLCCs every few years;
- Establish links between FAO and WMO websites;

ORGANIZATIONAL CONSIDERATIONS

National Meteorological and Hydrological Services and National Locust Control Centres

As locust breeding and migration depend on the weather – specifically, rainfall, temperature and winds – and, because weather is difficult to forecast accurately in advance, Desert Locust forecasts may not be as precise as many people would wish. Forecasts are usually made by the Senior Locust Forecasting Officer at FAO in DLIS. Information Officers in the NLCCs often include forecasts in national locust situation bulletins that may affect survey and control operations in their country. The forecasts concentrate on events that are mostly likely to occur and filter those that are likely to happen only in rare circumstances. The number of active meteorological stations in a locust-affected country is likely to be limited and probably will not give a sufficiently accurate picture of conditions in all locust areas. Nevertheless, the data can provide useful estimates for planning, analysing and forecasting locust situations. NMHSs should be able to provide NLCCs with data on a daily, weekly, dekadal, fortnightly (two weeks) or monthly basis but this may require a formal agreement and may not be a free service.

Forecasts should give guidance to survey and control teams in the field on the scale, timing and location of likely changes in the locust distribution and where best to look for locusts on a monthly, weekly, daily or even hourly basis. For example, meteorology combined with knowledge of locust behaviour can determine the best time of day for locust surveys to be carried out, as solitarious locusts can be difficult to detect. These are most active when soil temperature ranges between 25°C and 30°C. In summer, therefore, survey timing is best between 7 a.m. and 11 a.m. and between 4 p.m. and 6 p.m. while, in the winter season, it is best between 9 a.m. and 3 p.m.

During recession and plague periods it is usually sufficient when daily rainfall and temperature data are supplied on a dekadal or fortnightly basis. The effectiveness of control operations depends on wind, temperature and no rainfall. Consequently, operational forecasts of these parameters would be useful for NLCCs during periods of increased locust activity. Furthermore, wind, synoptic and temperature data may be required on a daily basis when adults may be migrating or there is an invasion threat. This could be difficult to arrange at short notice, however, and thus requires agreements and good cooperation between NLCCs and NMHSs.

National Meteorological and Hydrological Services

Rainfall (recession and invasion)

The locations and quantities of rainfall that are reported should be provided in the form of georeferenced digital maps or tables (spreadsheets), including the station names, geographic coordinates and dates in a standard format. The data should either be shared by e-mail or made available over the Internet. In this way, NLCCs can incorporate the data easily into geographic information systems (GIS) for display and analysis, and include them in their bulletins and reports. The current data could be supplemented with secondary sources, such as existing rain stations and results of Desert Locust surveys. For NLCCs, it is helpful if rainfall amounts are given as deviations from the climatology, indicating if the rainfall is normal, above or below normal. Warnings should be issued after the occurrence of widespread heavy rains and runoff that might contribute to increased locust activity.

Forecasts for the coming few days can provide valuable preparation time for control teams in the field and during control operations. The rains are often associated with readily recognizable synoptic weather systems and should be predictable a few days in advance.

Temperature (invasion)

The range (minimum and maximum) of temperatures during the day and night should be provided and shared in the same manner as the rainfall data. The daily maximum temperature is used for calculating the flight duration of swarms. The daily temperature at sunset is used for estimating the possibility of take-off by non-swarming locusts before long-distance night flights.

Warnings could be issued for (a) the occurrence of spells of temperatures markedly different from the seasonal mean, as they may indicate an increase or decrease of either development rate or flight duration; and (b) the occurrence of temperature persistently too low for locust development, as these are useful for estimating prolonged development, particularly by overwintering eggs or adults, with implications, for example, in timing the deployment of survey and control teams in the field.

Wind (invasion)

Daily maps and/or tables of the windfield are useful in estimating the directions and, in combination with estimates of flight duration, distance of daily swarm movements. The most appropriate data are a daytime surface map, at 850 hPa or 700 hPa, and a daily map of the windfield at 500 m above the ground at night for estimating direction and distance of night flight.

Warnings should be issued during the occurrence of persistent and strong coastal winds blowing from land to sea, as they may carry large numbers of locusts to islands or lead to mass drowning.

Forecasts of wind would help in determining the best spraying time in control operations. Spray is applied across winds but avoiding turbulence, so early and late in the day are usually the best times.

Other information that may be useful to NLCCs is data on soil moisture, the position of the ITCZ, NDVI and soil temperature.

National Locust Control Centres

Activities of NLCCs contribute to the fight against poverty and to the security of food supplies. Their surveillance, control and research activities often take place over exceptionally difficult terrain. To accomplish its main tasks, an NLCC:

(a) Carries out operations of surveillance and control against Desert Locust populations;
(b) Develops and implements plans for locust survey, control, environmental and health monitoring, training and research;
(c) Coordinates, follows up and evaluates Desert Locust control campaigns;
(d) Collects data on Desert Locust and environmental conditions for exchange at national, regional and international levels;
(e) Assists and advises the regional branches of the various government ministries on Desert Locust control.

Teams in the field

The number of field teams varies from year to year and from country to country, depending on the size of the locust breeding area, environmental conditions and the extent of locust infestations. In an average period of recession, 4–6 teams will survey the summer breeding area for 4–6 months and 2 or 3 teams will survey the winter-spring area for 2–4 months. In a year of invasion, however, the number of teams can rise to more than forty.

The composition of a team (personnel, vehicles, materials) varies according to the exact action to be undertaken and the level of locust activity. Teams are equipped with tools for data recording and transmission (eLocust, standard forms), navigation (compasses, maps, Global Positioning System (GPS)) and for collecting specimens (nets, containers) and weather data (anemometers, thermometers).

Mission lengths vary from a few days to several weeks, again depending on the locust situation. During a mission, a team works every day of the week and will typically travel up to 150 km per day, depending on terrain, habitat conditions and the presence of locusts. Teams stop to make observations whenever they find locust populations or green vegetation.

Gathering data

Surveys are conducted on the ground by four-wheel drive vehicles to check potentially active breeding zones, which are usually areas that have received rainfall or runoff recently. Observations are made on the habitat (type, vegetation density and state, soil moisture), rainfall, locust populations and control operations, if any, at each stop. Soil moisture is an important factor in assessing a biotope's potential for breeding and the depth of the wet layer is measured and recorded in centimetres. Detailed data are gathered on locusts (sexual maturity, appearance, behaviour, colour, density, size, activity and area infested). Density is evaluated by using foot and vehicle transects for adults and quadrant samples for hoppers, according to standard methodologies published by FAO.

The georeferenced data are immediately recorded and transmitted by satellite to NLCC headquarters using the eLocust system. Teams stay in contact with NLCC by HF radio. Data can also be recorded manually onto a standardized FAO survey and control form which is used in all locust-affected countries. During control operations, additional data are collected and recorded concerning treatment, mortality and environmental and human safety.

Box 4. The WMO Global Telecommunication System

The WMO Global Telecommunication System (GTS) is a core component of the WMO information System (WIS) collecting and distributing meteorological data from and to National Meteorological and Hydrological Services to ensure that all Members have access to all meteorological and related data, forecasts and alerts (Figure 19) (WMO, 2015). This secured communication network enables real-time exchange of information, critical for forecasting and warnings of hydrometeorological hazards.

The GTS links three main World Meteorological Centres (WMCs) (Melbourne, Moscow and Washington) and 15 Regional Telecommunication Hubs (RTHs) (Algiers, Beijing, Bracknell, Brasilia, Buenos Aires, Cairo, Dakar, Jeddah, Nairobi, New Delhi, Offenbach, Toulouse, Prague, Sofia and Tokyo). This network has the function of providing an efficient, rapid and reliable communication service by getting information to and from NMHSs via the WIS core network where the rapid global exchange of information takes place.

The six WMO Regions (Africa; Asia; South America; North America, Central America and the Caribbean; South-West Pacific; Europe) are interconnected to the Main Telecommunication Network (MTN) ensuring the collection of observational data and selective distribution, both nationally and between countries. Next to the integrated network, HF radio broadcasts and the Internet may be used for the dissemination of meteorological information.

In addition to the data received from Members, data are collected via satellite, the International Maritime Mobile Service and mobile satellites (INMARSAT). Thus, the GTS is an integrated network of surface- and satellite-based telecommunication links of point-to-point circuits and multi-point circuits, interconnecting meteorological telecommunication centres for reliable, round-the-clock data collection and distribution.

The WMO GTS, being built on high availability and dedicated circuits, is the backbone for global exchange of data and information in support of multi-hazard, multi-purpose early warning systems, including all meteorological and related data; weather, water and climate analyses and forecasts; tsunami-related information and warnings, and seismic parametric data. The GTS is complemented by other elements of the WIS that enable the systematic discovery, access and exchange of data and information of all WMO and related international programmes.

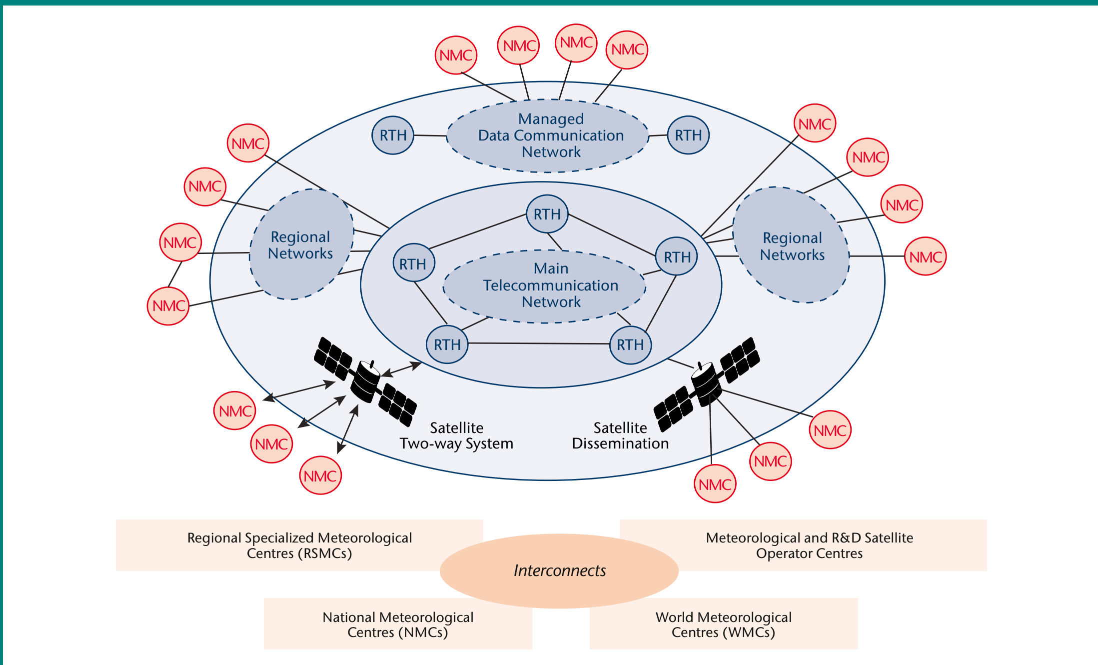


Figure 19. Structure of the Global Telecommunication System: Main Telecommunication Network, Regional Networks and National Meteorological Centres

The World Meteorological Organization and the Food and Agriculture Organization

One of the mandates of FAO is to provide information on the general locust situation to all Members and to give timely warnings and forecasts to locust-affected countries. To this end, FAO operates the centralized DLIS within the Locust Group at FAO headquarters in Rome, Italy. All locust-affected countries transmit data to FAO, where, in turn, the information is analysed in conjunction with weather and habitat data and satellite imagery in order to assess the current locust situation, provide forecasts up to six weeks in advance and issue warnings on an ad hoc basis. FAO prepares monthly bulletins and periodic updates summarizing the locust situation and forecasting the scale, timing and distribution of breeding and migration on a country-by-country basis. This information is distributed by e-mail and is available on the Internet at FAO's Locust Watch website (http://www.fao.org/ag/locusts), Facebook (http://www.facebook.com/faolocust), and Twitter (http://www.twitter.com/faolocust). All locust information is archived at FAO headquarters.

WMO provides information for locust-affected countries via the World AgroMeteorological Information Service (WAMIS). WAMIS is a centralized web server that disseminates agrometeorological products issued by WMO Members (http://www.wamis.org/). Several countries are already providing quality-controlled daily weather and agrometeorological bulletins on the WAMIS website. Locust survey and control operations are prioritized and organized, based on a combination of weather information provided by WMO and others (precipitation, temperature, humidity and wind), prior knowledge of favourable sites for breeding and anticipated directions of locust migrations.

FAO collaborates with WMO to provide training and prepare publications on various aspects of locusts.

Locust emergencies

Locust-affected countries and FAO have adopted a preventive control approach to Desert Locust management, which is based on early warning and early reaction. FAO seeks to minimize the risk of locust emergencies developing by strengthening national capacities in survey, reporting, control, training and contingency planning through its three regional locust commissions – the Commission for Controlling the Desert Locust in the Western Region, in the Central Region and in South-West Asia. FAO provides early warnings to locust-affected countries and the international community on a continual basis through its DLIS.

When a locust emergency occurs, FAO fields rapid assessment missions and coordinates emergency assistance, logistics and control operations in affected countries within existing emergency mechanisms. FAO and UN emergency funds are immediately activated to allow a quick response to an emergency and give donors sufficient time to mobilize additional resources. To achieve this, FAO maintains a regular dialogue with the international donor community. Priorities for assistance are based on daily information provided by NLCCs and plant protection services, supplemented by reports from FAO's country representatives and advice from FAO consultants in the field. Donor-funded locust control projects are developed and implemented that provide inputs including equipment, environmental monitoring and technical advice. Bilateral assistance to affected countries is monitored in order to coordinate inputs and avoiding duplication of efforts. A pesticide triangulation strategy, in which countries with excessive stocks donate pesticide to countries facing a locust emergency, helps to reduce the accumulation of obsolete pesticide stocks. Bio-pesticides are used in sensitive areas such as those near water bodies, habitations where livestock may be grazing and national parks.

Box 5. New technologies

Reconnaissance And Monitoring System of the Environment of *Schistocerca* (RAMSES)

RAMSES is an open-source, platform-independent customized GIS with a spatial database that is used by NLCCs to manage and analyse locust and environmental data, including data collected by national survey and control teams using eLocust. It helps Desert Locust officers to geographically orient field surveys, forecast breeding and migration and develop control strategies in case of emergency. It is designed to provide and support early warning by helping NLCCs to manage, analyse, and disseminate data. The RAMSES user can view daily, dekadal and monthly information about the Desert Locust: the geographical position, age, behaviour and size of a population and whether it has been controlled. The distribution of locusts can also be studied in relation to the main habitat types in a seasonal breeding area. Historical and meteorological data can be used, along with satellite imagery of vegetation and rainfall estimates to assess the potential development of a population.

RAMSES can manage all types of vector and raster data that include map-based products, different meteorological data, field observations by survey and control teams, daily rainfall station totals and satellite- and model-based rainfall estimates. The integration of satellite images within RAMSES allows NLCCs to detect potential areas of favourable habitats and to guide national survey teams.

eLocust

The collection and recording of accurate and complete data in remote desert areas and their subsequent transmission to the NLCC and use in RAMSES has been one of the main constraints in Desert Locust operations and forecasting. The FAO DLIS developed, in collaboration with Novacom (France), the eLocust system for field officers to enter and send georeferenced data in real time to the NLCC. The latest system, eLocust3, consists of a rugged 25.65 cm (10.1 inch) multi-touch android handheld tablet with a built-in GPS receiver, camera and wireless INMARSAT-based satellite connection that allows for automatic position location, georeferenced photos and real-time data transmission. The field officer can quickly enter data using the touch screen and send them from anywhere in the desert directly to the NLCC in a matter of minutes via satellite. At the NLCC, the data are automatically received, decoded, checked and imported into the RAMSES GIS for analysis. The field officer can also see his updated position in the field on a map and in relation to green vegetation as indicated by the latest remote-sensing image without the need of an Internet connection. eLocust3 also contains references and photos for the identification of locust and vegetation species in the field. It is easy to use, even for persons with limited computer skills. The regular use of eLocust3 by survey and control teams in all locust-affected countries has led to dramatic improvements in data quality and timeliness and survey efficiencies, which, in turn, contributes to better planning and early warning of Desert Locust outbreaks, upsurges and plagues.

GLOSSARY

Anabatic winds – An upslope wind; wind blowing up a hill or mountain as the result of strong heating of the slope

Atmospheric depression – An area of lower atmospheric pressure showing signs of a developing cyclonic (counterclockwise) circulation, which typically generates higher winds and rain.

Climatology – Study of the mean physical state of the atmosphere, together with its statistical variations in both space and time, as reflected in the weather's behaviour over a period of time

Convection/convective – Organized motions within a layer of air leading to the vertical transport of heat

Convergence – Winds which are flowing towards an area.

Cumuliform – Clouds or locusts which occur vertically (up and down) within the atmosphere.

Divergence – Winds which are flowing away from an area.

Egg pods – Eggs laid in batches.

Ensemble forecasts – Forecasts which are generated by many outputs of a numerical weather prediction computer model.

Gregarization – The phase of the Desert Locust when large numbers of individuals concentrate and gather together (gregarize).

Hoppers – Non-flying nymphal stage (juvenile) locusts

Hopper bands – A cohesive mass of gregarious hoppers that persists and moves as a unit, which varies in size.

Inter-Tropical Convergence Zone (ITCZ) – Narrow zone where the winds of the northern and southern hemisphere converge.

Instars – Stages of developmental between successive moults of larvae and nymphs, for example the first instar occurs between hatching from the egg and the first moult. The Desert Locust's hoppers (nymphs) pass through five or six instars (stages) before becoming adults.

Moulting – A process of shedding the old cuticle (shell) after the formation of a new one, allowing the hoppers to grow and increase in size. Moulting usually occurs five to six times during the development of a Desert Locust.

Outbreak – A marked increase in locust numbers due to concentration, multiplication and gregarization which, unless checked, can lead to the formation of hopper bands and swarms.

Plague – A period of one or more years of widespread and heavy locust infestations, the majority of which occur as bands or swarms. A plague can occur when favourable breeding conditions are present and control operations fail to stop a series of local outbreaks from developing into an upsurge that cannot be contained. A major plague exists when two or more regions are affected simultaneously.

Recession area – The area to which Desert Locust populations of low densities are confined and within which they move around. It covers some 16 million km^2 in the semi-arid or arid interior of the invasion area and extends over, or into parts of, 30 countries.

Red Sea Convergence Zone – Narrow zone where the winds converge over the Red Sea.

Settled – Desert Locusts resting on the ground

Solitarious phase – A phase of the Desert Locust where individuals live mostly separately from each other. They are usually drab coloured – brown or grey – as immature adults and pale yellow as mature adults.

Stratiform – Clouds or locusts spread out in an extensive horizontal sheet or layer in the atmosphere

Streamlines – Lines which indicate windflow in the atmosphere.

Swarms – A mass of adult locusts which contains thousands of millions of individuals behaving as a coherent unit.

Synoptic scale – The scale of the high- and low-pressure systems whose typical dimensions range approximately from 1 000 km to 2 500 km.

Thermals – A local updraft of air produced above a surface warmer than its immediate surroundings

Upsurge – A period following a recession marked initially by a very large increase in locust numbers and contemporaneous outbreaks followed by the production of two or more successive seasons of transient-to-gregarious breeding in complementary seasonal breeding areas in the same or neighbouring regions. More than one upsurge can occur at the same time but in different regions and many upsurges die out without leading to a major plague.

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