# The Impact of Extreme Weather Events on Food Security

Tom Beer

**Abstract**

To meteorologists, food security is dominated by the impacts of weather and climate on food systems, but the link between the atmosphere and food security is more complex. Extreme weather events, the exemplar of which are tropical cyclones, impact directly on agriculture, but they also impact on the logistical distribution of food and can thus disrupt the food supply chain, especially in urban areas. A holistic approach is required to understand the phenomena, to forecast outcomes and to predict their societal consequences. In the Food Security recommendations of the Rio + 20 Forum on Science, Technology and Innovation for Sustainable Development, it states that it is important "To understand fully how to measure, assess and reduce the impacts of production on the natural environment including climate change, recognising that different measures of impact (e.g. water, land, biodiversity, carbon and other greenhouse gases) may trade-off against each other…". The International Union of Geodesy and Geophysics (IUGG), through its Union Commission on Climatic and Environmental Change (CCEC), led a consortium of international scientific unions to examine weather, climate and food security as well as to look at the interaction of food security and geophysical phenomena.

**Keywords**

Extremes · Disasters · Natural hazards · Food · Food security

## Introduction

To meteorologists and climatologists, food security is dominated by the impacts of weather and climate on food systems, and the meteorological

T. Beer (✉)
IUGG Commission on Climatic and Environmental Change, Potsdam, Germany
e-mail: tom.beer@safesystemsolutions.com.au

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community has primarily focussed on food production and its disruption during extreme weather events. Extreme weather events, the exemplar of which are tropical cyclones, impact directly not only on agriculture but also on the logistical distribution of food. A pluri-disciplinary approach is required to understand the phenomena, to forecast catastrophic events such as tropical cyclones and to predict their societal consequences, given that past experience indicates that the social consequences of a tropical cyclone in the developed world, disastrous though they may be, are less disastrous than the social consequences of an equivalent disaster in the developing world.

In the Food Security recommendations of the Rio + 20 Forum on Science, Technology and Innovation for Sustainable Development, held as a preparatory scientific meeting to the 2012 UN Conference on Sustainable Development, one of the recommendations states that scientists need "To understand fully how to measure, assess and reduce the impacts of production on the natural environment including climate change, recognising that different measures of impact (e.g. water, land, biodiversity, carbon and other greenhouse gases) may trade-off against each other…".

## Safety and Security

Within the risk assessment community, most attention has been paid to issues related to defining risk, evaluating risk and treating risk along with substantial academic investigation related to the concept of uncertainty and how this relates to risk.

Far less attention has been devoted to the epistemological issue of what, exactly, is the antonym of risk. If pressed, most risk analysts would probably say that safety is the opposite of risk, but if then queried about security would consider that safety and security are synonymous.

Australia has an enviable safety record. The national airline, Qantas, has the best safety record of any international airline. The Australian State of Victoria was the first jurisdiction in the world to legislate compulsory seat belts in automobiles. It is compulsory to wear helmets when riding horses, motorcycles or bicycles. When dealing with food, food security is seen as being a much wider concept with food safety being just one small part of food security—as may be seen by examination of Fig. 1.

If we use the Beer and Ziolkowski (1995) definition of risk as: The risk during a given time is the union of a set of likelihoods and a set of consequences of the scenarios under consideration; then risk minimisation of extreme weather events must consist of reducing the consequence. Safety and security relate to minimising the consequences. Developed countries, with greater resources to apply to recovery, rehabilitation and rebuilding, are better able to minimise the consequences than developing countries.

## Sendai Framework and IRDR

The Sendai Framework for Disaster Risk Reduction 2015–2030 was adopted at the Third UN World Conference on Disaster Risk Reduction in Sendai, Japan, on 18 March 2015. It aims to achieve a substantial reduction of disaster risk and losses in lives, livelihoods and

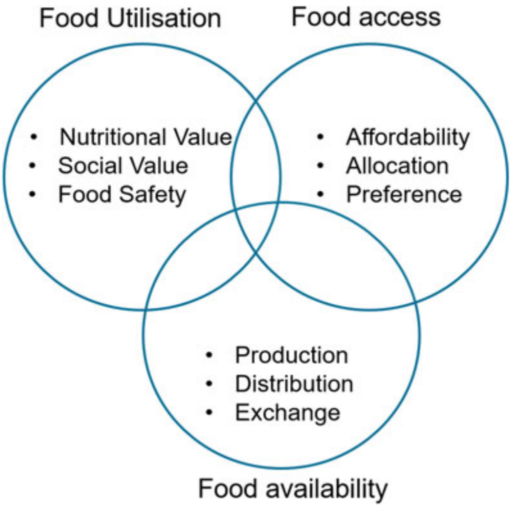

**Fig. 1** The research programme future earth envisages food security as being composed of three components—utilisation, access and availability

health and a substantial reduction of losses in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries over the next 15 years.

The Framework outlines seven targets and four priorities for action to prevent new and reduce existing disaster risks: (i) Understanding disaster risk; (ii) Strengthening disaster risk governance to manage disaster risk; (iii) Investing in disaster reduction for resilience and; (iv) Enhancing disaster preparedness for effective response, and to "Build Back Better" in recovery, rehabilitation and reconstruction.

The overall expectation is that the scientific community, through the international research programme Integrated Research on Disaster Risk (IRDR), will provide the underpinnings for the first and the last actions of the Sendai Framework. This expectation arises because the three research objectives of IRDR are:

| | |
|---|---|
| Objective 1 | Characterisation of hazards, vulnerability and risk. |
| Objective 2 | Understanding decision-making in complex and changing risk contexts. |
| Objective 3 | Reducing risk and curbing losses through knowledge-based actions. |

## Rural and Urban Vulnerability to Weather Events

Meteorological variability and extreme weather conditions have increased in frequency in the last century (Porter and Semenov 2005). Figure 2 shows the number of climatological, meteorological, hydrological, geological and biological disasters recorded in the EMDAT database of disaster trends from 1980 to 2016. Extreme and variable weather conditions, such as stronger and more irregular precipitation or increased temperature, lead to significant declines in crop yields and crop stability (Lansigan et al. 2000; Olesen and Bindi 2002; Wollenweber et al. 2003). Unfortunately, despite the extreme impacts of extreme weather conditions on agroecosystems and the broad implications for food supply and production, weather variability and weather extremes are rarely studied outside of rural agroecosystems. Specifically, there is a large gap in research on weather effects, and especially the effects of extreme effects such as tropical storms on local urban food production. This is of particular concern given that urban landscapes frequently exhibit more extreme weather impacts than rural areas due to increased impervious land cover.

A number of environmental changes have already come with urbanisation that affect the agronomic conditions necessary for food production (Pickett et al. 2001; Kaye et al. 2006) including changes in patterns of water availability, nutrient supply, soil degradation and pest pressure, affecting crop growth in urban areas (Eriksen-Hamel and Danso 2010). Extreme weather events add another layer of complexity affecting local production. However, urban agriculture systems may provide services that help regulate weather impacts. For example, many private and community gardens provide storm attenuation services to the urban landscape by decreasing the amount of impervious surface in cities. In German cities, allotment gardens used on green belts have been shown to facilitate drainage and reduce local flooding from storm events by allowing for a greater infiltration potential of precipitation (Drescher et al. 2006). In contrast, hard paving increases impervious surfaces, and in Leeds, United Kingdom (UK), increased hard paving in residential front gardens has been linked to more frequent and severe local flooding (Perry and Nawaz 2008).

## Extreme Weather in Australia

Australia's major natural hazards are hydro-meteorological in nature. An Australian poet characterised Australia as a land "of droughts and flooding rains". The droughts make the countryside prone to wildfires known in Australia as bushfires—and the rains, as the poet emphasises, lead to floods. For the purpose of this paper, we will consider drought to be an extreme climatic event, rather than an extreme

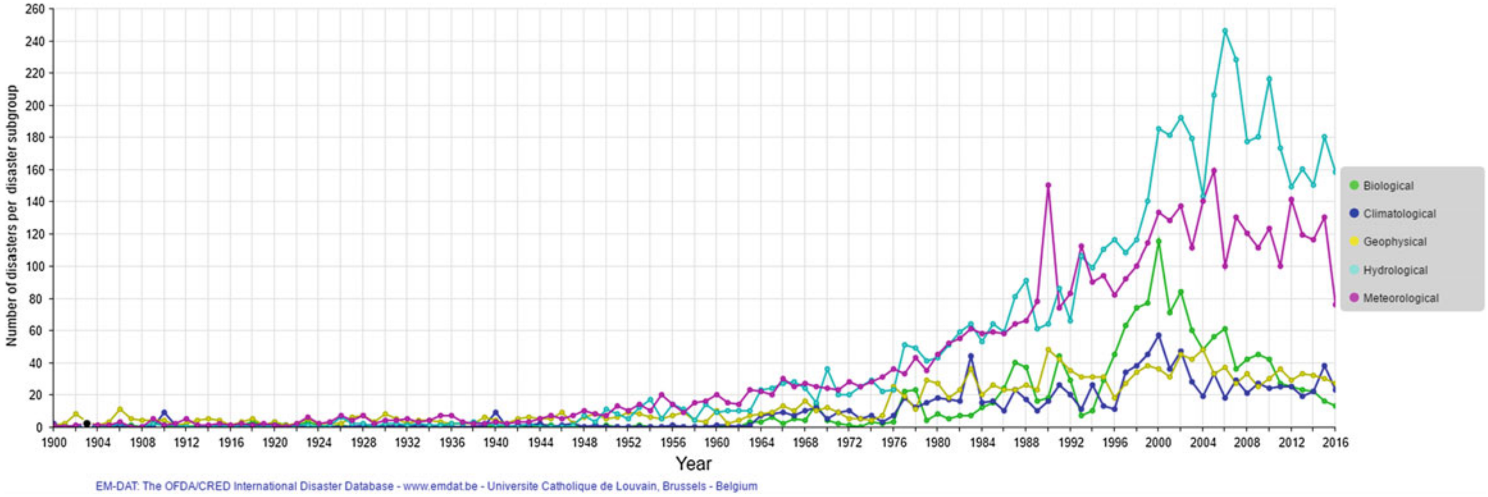

**Fig. 2** Number of climatological, meteorological, hydrological, geological and biological disasters recorded in the EMDAT database of disaster trends. Source: D. Guha-Sapir, R. Below, Ph. Hoyois - EM-DAT: The CRED/OFDA International Disaster Database–www.emdat.be–Université Catholique de Louvain–Brussels–Belgium)

**Table 1** Modified Saffir–Simpson tropical cyclone scale used by the Australian Bureau of Meteorology

| Category | Wind description | Wind speed (km/h) | Typical effects |
|---|---|---|---|
| 1 | Gales | 118–125 | Minimal house damage. Damage to some crops, trees and caravans. Boats may drag moorings |
| 2 | Destructive winds | 125–164 | Minor house damage. Significant damage to signs, trees and caravans. Heavy damage to some crops. Risk of power failure. Small boats may break moorings |
| 3 | Very destructive winds | 164–224 | Some roof and structural damage. Some caravans destroyed. Power failure likely |
| 4 | Very destructive winds | 225–279 | Significant roofing and structural damage. Many caravans destroyed and blown away. Dangerous airborne debris. Widespread power failures |
| 5 | Extremely destructive winds | >280 | Extremely dangerous with widespread destruction |

weather event, and thus outside the scope of the discussion.

Rather than engage in a general discussion on flooding and its myriad causes, this chapter will consider only tropical cyclones and their consequences—one of which is flooding due to the extreme precipitation during a tropical cyclone. Other consequences of tropical cyclones are a decrease in atmospheric pressure that causes sea level rise in coastal locations and thus exacerbates coastal flooding. In addition, the extreme winds associated with a tropical cyclone can remove rooves and cause damage by slamming unanchored objects into people, houses and buildings. At coastal locations, the extreme winds will also drive large waves that batter the coast, erode shorelines and cause damage to buildings.

The Australian public is concerned both with the occurrence of tropical cyclones in the immediate future and seeks forecasts in the longer term about the distribution, landfall location and intensity of tropical cyclones. The rainfall in the Australian tropics is due to the effects of the monsoonal wet season, augmented by the extra rainfall from the occasional tropical cyclone. Though tropical cyclones themselves can produce strong winds, storm surges and floods, the combination of a particularly severe wet-season and a tropical cyclone can intensify the disaster and amplify the consequences.

## Tropical Cyclones

On 25 December 1974, Tropical Cyclone Tracy[1] destroyed virtually all of the northern Australian city of Darwin causing the deaths of 71 people (49 on land and 22 at sea) and the evacuation of 75% of the city's residents. This event shocked the Australian public and encouraged the serious scientific study of Australian tropical cyclones.

This was not the first time that Darwin had been severely damaged by a tropical cyclone: In both January 1897 and March 1937 the city was badly damaged, but only after Tracy was more attention given to building codes and other social aspects of disaster planning. Darwin was rebuilt and is now a thriving city of 128,100 people as at June 2011.

The Bureau of Meteorology[2] provides a database of past tropical cyclones, histories of tropical cyclones and a library of individual cyclone reports. Australian Tropical Cyclones[3] are classified according to the modified Saffir–Simpson scale shown in Table 1, with Category 1 tropical cyclones having winds below 42 m/s but above 33 m/s, which is the minimum wind speed needed for a tropical storm to be classified

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[1] http://www.bom.gov.au/cyclone/history/pdf/tracy.pdf.

[2] http://www.bom.gov.au/cyclone/history/index.shtml.

[3] http://www.bom.gov.au/cyclone/about/intensity.shtml.

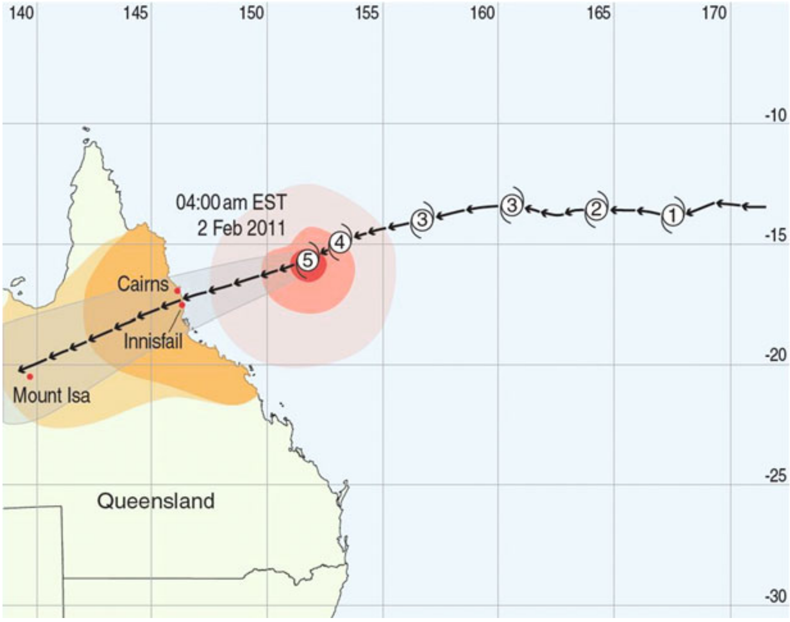

**Fig. 3** Forecast track of TC Yasi as at 4am on 2 February 2011. Subsequent analysis downgraded the intensity from Category 5 at 4am to Category 4 though the same analysis indicates that TC Yasi became Category 5 at 4pm, just before landfall (Reproduced by permission of Bureau of Meteorology, © 2017 Commonwealth of Australia)

as a tropical cyclone. Category 5 tropical cyclones are the most intense and will cause catastrophic damage to structures.

There are, on average, approximately 12 tropical cyclones per year that are identified as occurring within the Australian region. Of these about 40% (~5) make landfall over the Australian continent. Tropical cyclones and tropical storms provide a large proportion of rainfall in tropical Australia that ranges from 40% in tropical Queensland to 60% in tropical Western Australia (Lavender and Abbs 2013). Tropical cyclone climatologies for Australia have been used to determine the tropical cyclone hazard.

Numerical weather prediction models have not, as yet, reached sufficiently fine resolution that they can predict the formation and subsequent strengthening and motion of a tropical cyclone. They are, however, able to identify tropical lows so that a sufficiently skilled forecaster is able to use such numerical weather prediction models, along with satellite photographs of tropical cyclone clouds that position the tropical cyclone, and thus use the two items of information to assist with forecasts of tropical cyclone tracks.

Once the tropical cyclone has made landfall, there are four particular impacts that need to be considered: strong winds; extreme rainfall; the flooding associated with the cumulative rainfall; and the short-term rise of sea level (known as storm surge).

During the severe wet-season of January–February 2011, the eastern coast of Australia was affected by three tropical cyclones: Severe Tropical Cyclone Zelia[4] from 14 to 18 January 2011, Tropical Cyclone Anthony[5] from 22 to 31 January 2011 and Severe Tropical Cyclone Yasi[6] from 30 January to 3 February 2011. Figure 3 depicts the track of Severe Tropical Cyclone Yasi. The scale shows very destructive winds in red, destructive winds in pink, and gale force winds are shaded.

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[4] http://www.bom.gov.au/cyclone/history/zelia11.shtml.

[5] http://www.bom.gov.au/cyclone/history/anthony.shtml.

[6] http://www.bom.gov.au/cyclone/history/yasi.shtml.

**Fig. 4** Motorists wait for water to subside over the Bruce Highway outside of Innisfail on 3 February 2011 in Innisfail, Australia following Cyclone Yasi which struck land as a Category 5 storm and destroyed the banana crop, as shown (AAP Image/Dave Hunt)

## Extreme Weather and Food Availability

### Production

Food production is the most visible, and the most studied, aspect of food security. Extreme events ruin crops. In the short term, hail can damage wheat; floods can ruin rice; strong winds can denude vegetation and destroy fruit crops as shown in Fig. 4. In the longer term, extreme events can be responsible for crop diseases, for silting of irrigation channels, destruction of rice terraces and injury to the personnel needed to work on food production.

### Distribution

Figure 4 also depicts the logistical disruption consequent upon a severe weather event. The Bruce Highway, shown in the photograph, is the main highway linking communities in the northern part of Queensland. Even though the photograph depicts only passenger vehicles, cutting the highway in this manner meant that trucks were also not able to deliver food supplies.

Because food consumers outnumber producers in every country (Tweeten 1999), food must be distributed to different regions or nations. Food distribution involves the storage, processing, transport, packaging and marketing of food (FAO 1997). Food-chain infrastructure and storage technologies on farms can also affect the amount of food wasted in the distribution process. Poor transport infrastructure can increase the price of supplying water and fertiliser as well as the price of moving food to national and global markets (Godfray et al. 2010).

The distribution of food by aid agencies following a disaster can lead to inequities because of the impossibility of uniform food distribution. Certain areas—those near to airfields, for example—are likely to have preferential access to the incoming food supplies.

In practice, geography is only one of the many factors involved in such distribution and allocation. Nobel Prize-winning economist Amartya Sen has observed that “there is no such thing as an apolitical food problem”. While drought and other naturally occurring events may trigger famine conditions, it is government action or inaction that determines its severity, and often even whether or not a famine will occur.

### Exchange

Around the world, few individuals or households are continuously self-reliant for food. This creates the need for a bartering, exchange or cash economy to acquire food (Gregory et al. 2005). The exchange of food requires efficient trading systems and market institutions, which can have an impact on food security (Ecker and Breisinger 2012). Per capita world food supplies are more than adequate to provide food security to all, and thus food accessibility is a greater barrier to achieving food security than is food production.

The discussion, above, on the history of Tropical Cyclone Yasi demonstrates the short to medium term disruption to food availability. In this case, the food production that was affected was only one crop—bananas. Though a blow to the local economy that led to a nationwide shortage of bananas, it did not lead to widespread hunger, famine or food shortages.

In this respect, we can contrast TC Yasi with TC Winston, also a Category 5 Tropical Cyclone that affected Fiji 20–21 February 2016 (Fig. 5). News reports from 24 February 2016 stated:

> Koro Island, which lies in the Koro Sea between Fiji's two largest islands, was one of the worst-hit by Cyclone Winston on the weekend. Aid is slowly arriving on the island but resident Serepe Pela, who lives in Nasau village, said more assistance was desperately needed.
> 'They need their houses to be constructed. At present all houses were ruined by Cyclone Winston,' he said. 'And foods, currently the food security level at Nasau is 5 per cent to 10 per cent. 'Maybe by next week there will be no more food.'
> Other residents on Koro Island told local media how several people were killed by huge waves whipped up by the cyclone.

## Extreme Weather and Food Access

### Affordability

It is probably a truism to state that after a disaster, if food is available, it will be expensive. In the case of TC Yasi (Fig. 2), a major portion of the Australian banana crop was wiped out causing extreme spikes in the banana price (Fig. 6)—repeating the situation of 2006 when Tropical Cyclone Larry made landfall on 20 March 2006 and also destroyed 80–90% of Australia's banana crop. Australia is relatively free of banana pests and diseases, imposes quarantine restrictions to ensure this continues and thus does not allow bananas to be imported. Bananas were in short supply throughout Australia for the remainder of both 2011 and 2006, which increased prices across the country by 400–500%.

In developing countries, aid agencies are aware of such increases in food prices and tend to distribute food to poor areas that are unable to afford to purchase food following a disaster.

### Allocation

Food allocation may be seen as an example of food distribution, but the term "food allocation" has come to be used to describe the internal allocation of food within a household. A household's access to enough and nutritious food may not assure adequate food intake for all household members, as intra-household food allocation may not sufficiently meet the requirements of each member of the household. (Ecker and Breisinger 2012) The USDA adds that access to food must be available in socially acceptable ways, without, for example, resorting to emergency food supplies, scavenging, stealing or other coping strategies.

The application of military food distribution systems to disaster areas is a growing area of interest. The methods used by the military to feed armies in the field have obvious applications to emergency relief. Within the developed world, it is the military that has developed the logistical supply chains to feed troops in inaccessible areas and has made use of the advances in food science and technology to provide long-lasting, easy to transport, nutritious victuals. The organisation and deployment of such supplies is a political decision that is governed as much by the political relationship between a hardship area and a potential donor as it is by the urgency or the need of the recipient.

### Preference

The most recognisable way to illustrate the importance of food preference is to consider the

**Fig. 5** Location of Nakodu, the only village on Koro Island, emphasises the difficulty of providing food to an isolated rural community after a tropical cyclone. The red line that passes directly through Koro Island marks the approximate path of Tropical Cyclone Winston on 20 February 2016, (Image is reproduced with permission from the Pacific Disaster Center [PDC] http://www.pdc.org)

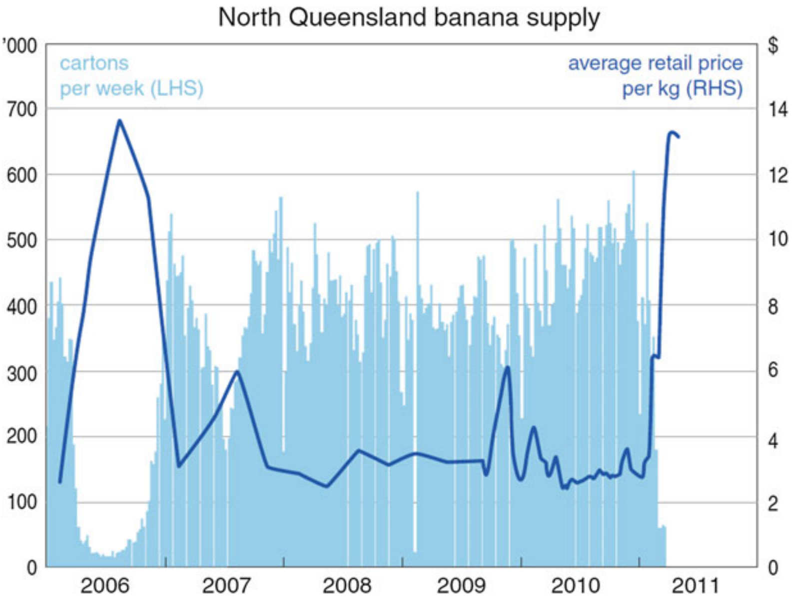

**Fig. 6** Graph of the banana supply and banana price from the north-eastern part of Australia demonstrating the sharp price rises in banana price following Tropical Cyclones Larry (*left*) and Yasi (*right*) both of which destroyed most of the Australian banana crop. (Reproduced with permission of the Reserve Bank of Australia with acknowledgement to the Australian Bureau of Statistics, Australian Banana Growers' Council Inc. and the Reserve Bank of Australia for the provision of data)

food choices that follow from religious observance. Observant Muslims and observant Jews are prohibited from eating pork. This is so well known that no aid agency would think of delivering pork-based food to an Islamic disaster area, but many societies have less well-known dietary taboos either from religious or cultural practices. Delivering wheat products to areas that normally eat rice or delivering rice to areas that normally eat wheat products may not be as appreciated as the donor would like.

## Extreme Weather and Food Utilisation

### Nutritional Value

One of the key analytical pieces of information that a meteorologist should be able to calculate is the minimum nutritional requirement for a human being. Three key parameters in this calculation are:

The Stefan–Boltzmann constant = $\sigma$ = 5.670367 $\times 10^{-8}$ W $m^{-2}$ $K^{-4}$.
The skin temperature of a human being, which we take as $T_s$ = 37 °C = 310 K.
The calorific value of food, for which we use the value of cellulose = 17 MJ/kg.
In the spirit of that wonderful book on environmental problem solving, "Consider a Spherical Cow" (Harte 1988), we shall assume a cylindrical human being that is 2 m tall and 0.25 m in radius. Using Stefan's Law, such a person emits 524 W $m^{-2}$.

Our idealised cylindrical person has a surface area of 3.5 $m^2$ and thus emits a power of 1852 W—approximately equivalent to the power of a strong bar heater—which means that there is something wrong with the calculations. If a typical person emitted 1852 W of radiation, then we would not need the electrical bar heaters used to heat rooms in winter.

More sophisticated calculations account for the fact that:

(a) the skin temperature is only 34 °C not 37 °C.
(b) long-wave radiation at the air temperature radiates into the skin offsetting the losses out.
(c) emissivity is only 0.97, as well as
(d) humans wear clothes, sweat and can thus use convection and diffusion as means to control heat loss.

The website at: http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/bodrad.html presents a more sophisticated calculator in which, accounting for an ambient temperature of 23 °C the heat loss is 232 W = 232 J/s so that over a 24 h period a naked human being, totally at rest, needs to obtain 20 MJ of energy just to balance the heat loss through the skin.

As this is the largest source of energy loss we can, in rough terms, state that a human needs to eat about 1 kg of cellulose everyday. The FAO at: http://www.fao.org/docrep/007/y5686e/y5686e08.htm estimates that the basal metabolic rate lies between 6 and 8 MJ/day, indicating that by wearing clothes we need to eat about 700 g of food less than if we were naked and stayed out in the open. Nutritionists would express this in terms of calories, or kilocalories, rather than in Joules and can provide tables of the calorific value of different foods.

There are two questions in relation to nutritional value. Is sufficient food being eaten? Is it the right kind of food? Famine stricken peasants do not get sufficient food. Obese westerners do not get the right kind. Both situations are problematic.

### Social Value

To some extent, the social value of food mirrors the food choices discussed under "preference"; except that in the case of social value, it is cultural norms rather than religious strictures that determine the preferable, acceptable or non-acceptable foods and the ways in which they can be distributed, cooked or eaten within the family and within the community.

A graphic example of the difficulties that arise when donors with different social values attempt to assist starving communities is given in the description of the Irish Potato famine in "The Great Hunger" by Woodham-Smith (1992), where it is pointed out that the well-intentioned attempts by the English to teach Irish peasants to cook cheap foods foundered because the peasants had neither pots, nor pans nor kitchens nor fuel.

## Food Safety

Under normal circumstances, developed nations have food inspection and certification systems in place to guarantee the quality and safety of the foods that are sold. In developed countries where food purchases may take place in the bazaar or market, rather than the supermarket, the assurance of food safety is tied to the reputation of the trader that sells the food.

The disruption of the logistical supply chain following a major disaster makes it more difficult to guarantee the safety of the food and infection of common organisms such as Salmonella or *E. Coli* may occur because the food that is being eaten is old, has been improperly stored or has been contaminated. In extreme disasters, the corpses of the people that have been killed may contaminate the drinking water and contamination may be transmitted by those handling these bodies.

# Discussion

## International Co-operation

The International Union of Geodesy and Geophysics (IUGG) led a consortium of international scientific unions to examine weather, climate and food security (WeatCliFS[7]) as well as to look at the interaction of food security and geophysical phenomena. A question that underpinned their effort was: *What technologies and methodologies are required to assess the vulnerability of people and places to extreme events that lead to famine.*

As a general rule in relation to disasters, a major difference between the response in developing countries and developed countries is that in developing countries fatalities dominate. In developed countries, infrastructure and property losses dominate. In relation to food issues, a major disaster in a developing country, such as a large-scale drought, wildfire or extensive flood, has the potential to lead to famine whereas an analogous disaster in a developed country will lead to price increases (Fig. 6).

## Future Earth

Future Earth, previously known as the Earth Systems Science Partnership, is a major initiative of the International Council of Science (ICSU) formed by bringing together the existing work of three interdisciplinary programmes—the International Geosphere Biosphere Programme (IGBP); the International Human Dimensions Programme (IHDP); Diversitas, an international biological programme. The World Climate Research Programme (WCRP) has also agreed to partner with Future Earth.

It was recognised that food security would be an important part of Future Earth[8] (Fig. 1), and thus Future Earth and the Consultative Group on International Agricultural Research (CGIAR) agreed that the CGIAR research programme on Climate Change, Agriculture and Food Security (CCAFS) would become one of the initial research programmes of Future Earth. Thus, it may be stated that at an international level the Weather and Food Security link, or at least the Climate and Food Security link, has been made in terms of Climate Change—Agriculture—Food Security through the work of CCAFS. Less international effort has been devoted to examining the Weather—Fisheries—Food Security link or the Weather—Supply Chain—Food Security link, which is a particular concern of the International Union of Food Science and Technology (IUFoST).

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[7] The acronym stands for Weather, Climate and food security. See http://ccec-iugg.org/sites/default/files/files/CCEC%20report2013(1).pdf.

[8] http://www.planetunderpressure2012.net/policybriefs.asp.

There is also ongoing work on weather and food security, especially the role of seasonal forecasting in improving agricultural yields (Iizumi et al. 2013) which showed that improved forecasts can be achieved worldwide if the state of ENSO, the El Nino–Southern Oscillation, is incorporated into yield forecasts. However, work by Asseng et al. (2013) indicates that a greater proportion of the uncertainty in projections of crop yields is due to variations among crop models rather than to variations among the downscaled weather or climate models.

## Conclusions

Despite the existence of the ICSU research programme Integrated Research on Disaster Risk, the science plan for IRDR (ICSU 2008) indicates that food security is not an aspect of its research mandate. Thus, the international aspects, including the urban aspects, of the agricultural disruption, economic disruption and logistical disruption to food availability, food access and food quality as a result of natural disasters remain an under-researched topic.

Climate change is affecting (and will affect) global food production and hence global food security both through changing climate and through the occurrence, possibly increased occurrence, of extreme weather events resulting from climate change. Urban agriculture plays a significant role in maintaining and improving the health of city dwellers, particularly those disadvantaged. Extreme weather effects are likely to impact more severely on urban environments with associated negative effects on food security, as has been discussed. Existing research programmes are not addressing these aspects of extreme weather effectively and deserve immediate attention.

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