Advisor

Global impact of El Niño and La Niña

Implications for financial markets

Commissioned for the Lighthill Risk Network

Date: May 2011

Authors: Dr. Mike Davey, Dr. Matt Huddleston, Dr. Anca Brookshaw

Global impact of El Niño and La Niña

Executive summary

Extreme weather events, often associated with significant physical and financial impacts, can vary greatly from year to year due to prevailing climatic conditions such as El Niño and La Niña. El Niño and La Niña are terms for two types of related major climatic events originating in the tropical Pacific, that recur every few years as part of a naturally-occurring cycle. Each has impacts extending worldwide, and the associated changes in regional weather can have severe consequences.

El Niño and La Niña change the risk of damaging events including storms and floods, by altering the atmospheric conditions that influence their occurrence. The highly active 2010 Atlantic hurricane season was associated with the onset of a La Niña event, which was well-predicted several months in advance. The influence of the El Niño – La Niña cycle extends well beyond Atlantic hurricanes however: the La Niña event also contributed to events such as the estimated $5.5bn flooding of Queensland Australia in 2010/11, with significant impacts on property and wider financial markets. The swings in risks can be understood in terms of physical processes, and some of them can be anticipated.

Weather extremes occur in various places every year, regardless of the state of El Niño or La Niña. The importance of El Niño and La Niña events is two-fold: they shift the risks of damaging hazards in recognisable ways and they are predictable about 6 months in advance.

The effects of El Niño and La Niña and the related shifts in climate risk may be described and explored through analyses of historical impacts and through state-of-the-art numerical climate models. The latter are also used to produce detailed long-range meteorological predictions that include the interplay of many climate processes.

The aim of this paper is to define and describe the cycle of El Niño and La Niña episodes and their worldwide impacts most relevant to the finance industry, highlighting in particular severe rainfall and tropical storm aspects.

THE LIGHTHILL RISK NETWORK

The Lighthill Risk Network is an all encompassing and inclusive organisation with the specific aim to facilitate and enhance knowledge exchange and transfer into business from academic, government and commercial experts at the forefront of risk-related research.

It is a cost effective not-for-profit organisation funded by 4 core members from the industry – Aon Benfield, Catlin, The Corporation of Lloyd's, Guy Carpenter - and supported by a number of other industry organisations and bodies including the ABI, CII and the Actuarial Profession. It is managed by a core team of professionals from (re)insurance, science and engineering.

27 Old Gloucester Street, London WC1N 3AX, United Kingdom

T +44 (0) 20 7357 2616   F +44 (0) 20 7357 1460   e office@lighthillrisknetwork.org   www.lighthillrisknetwork.org

Contents

Description of the phenomena and their impacts on weather

What are El Niño and La Niña?

El Niño and La Niña are terms for climatic events originating in the tropical Pacific that recur every few years as part of a naturally-occurring cycle. Each has meteorological effects extending worldwide, and the associated changes in regional weather can have severe consequences: the extensive floods in Queensland, Colombia and Southern Africa at the end of 2010 and the beginning of 2011, and the very active 2010 Atlantic hurricane season, are examples of weather and climate anomalies exacerbated by prevailing La Niña conditions.

From past experience, the regions/seasons most likely to be affected by the cycle can be identified. As opposite phases of the cycle, El Niño and La Niña events tend to have opposite effects.

Although the average (or typical) historical impacts of El Niño and La Niña can be mapped, individual events differ in details such as timing and magnitude. Moreover they constitute just one (albeit very important) influence on climate risk. Because of this the typical response to El Niño or La Niña should not be seen as inevitable. Rather, El Niño and La Niña events should be regarded as shifting the odds in favour of the typical response which may, for example, increase risk of heavy rainfall and consequent damage in a particular region/season of interest.

The changes in risks can be estimated and quantified from historical data. Moreover, as the cycle is predictable months in advance, and as sophisticated numerical climate models can represent the interplay of various influential factors in the ocean-land-atmosphere system, including climate change effects, the odds can be refined beyond just using past experience – leading to improved risk assessments for decision making.

El Niño, La Niña and the Southern Oscillation

El Niño and La Niña events arise in the tropical Pacific, where strong and extensive interactions between the ocean and atmosphere can lead to warmer or cooler than usual ocean conditions that last several months. These are associated with widespread changes in the climate system and can lead to significant socio-economic impacts affecting infrastructure, agriculture, health and energy sectors for example.

The name 'El Niño' nowadays is widely used specifically for the anomalous warming of the sea surface temperature that occurs every few years, typically concentrated in the east-central equatorial Pacific (see diagram in figure 1). 'La Niña' is the term adopted for episodes of cooler-than-normal sea surface temperature in the tropical Pacific that in many ways are opposite to El Niño.

These episodes alternate in an irregular inter-annual cycle called the ENSO cycle. 'ENSO' stands for 'El Niño Southern Oscillation', where 'Southern Oscillation' is the historical term for atmospheric changes in the tropical Pacific that accompany both El Niño and La Niña episodes in the ocean. The name 'ENSO' is a reminder that close interaction between the atmosphere and ocean is an essential part of the process. While the global climate system contains many processes, ENSO is by far the dominant feature on inter-annual timescales.

The ENSO cycle is illustrated in figure 1 by a time-series of the monthly sea surface temperature anomalies in a region of the central equatorial Pacific. This 'Niño3' region is one of several used to monitor changes in the tropical Pacific. Definitions vary, but as a guide the El Niño and La Niña episodes occur when anomalies in this region are larger than about 0.5°C in magnitude. According to this indicator, the 2010/11 La Niña was substantial but not record-breaking. Note also the large positive anomalies associated with the 1997/98 El Niño – an El Niño of similar strength has not occurred since. This time-series demonstrates that events occur irregularly with various sizes and durations. The ENSO cycle is a natural climate phenomenon; proxy evidence (e.g. coral growth rate measurements) indicates that ENSO has been going on for thousands of years.

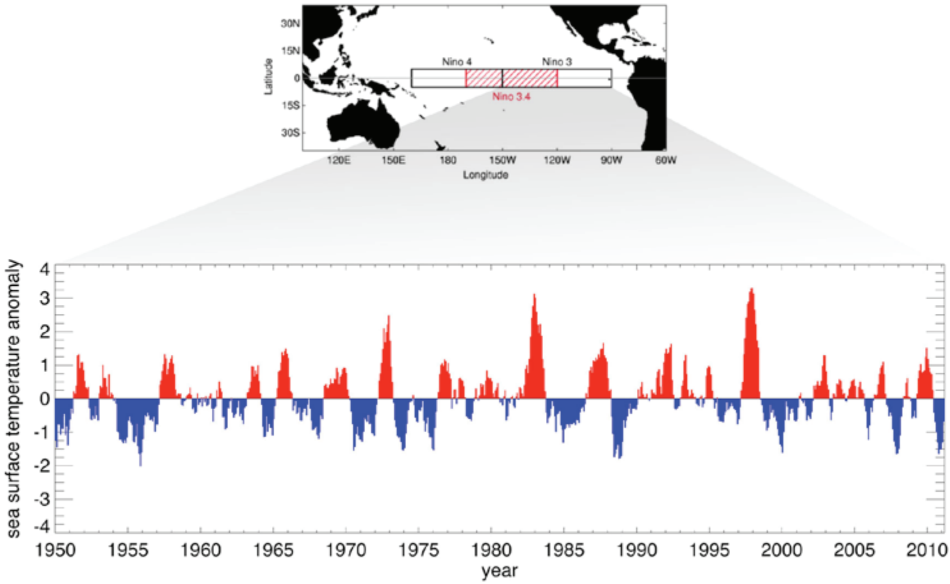


Figure 1: *Time-series of monthly sea surface temperature anomalies in the Niño3 region (5ºN-5ºS, 150ºW-90ºW) relative to the long-term average. Red indicates temperature warmer than usual, blue colder than usual. Niño3 and some other standard regions used to monitor ENSO are indicated on the map. Data are from the Met Office HadISST sea surface temperature dataset.*

What causes El Niño and La Niña events?

The cycle is the consequence of slow feedbacks in the ocean-atmosphere system acting alongside the strong air-sea interaction processes in the tropics that allow the growth of small disturbances to the large-scale ocean state.

Normally the equatorial Pacific Ocean has a pool of relatively warm water in the upper ocean in the west and a shallower layer of relatively cool water in the east, maintained by and in balance with easterly surface winds. The well-mixed upper ocean layer (a few tens of metres deep) lies above a thin 'thermocline' layer, with cold water below.

An El Niño event can start in several ways, usually with the sea surface temperature raised slightly in the central/east Pacific. This may be, for example, through the action of 'westerly windbursts' (short-lived storm-like events in the West Pacific) that disturb the 'balance' maintained by easterly winds, or through slow evolution of the ocean thermocline – rather like water sloshing in a bathtub on a grand scale – as a consequence of a previous event. The increased sea surface temperature influences the atmospheric winds, which in turn influence the upper ocean and the thermocline such that the sea surface temperature is increased further – a positive feedback. When conditions are favourable, this feedback generates an El Niño event.

A La Niña event can arise similarly. El Niño and La Niña events are self-limiting, evolving in such a way that the equatorial sea surface temperatures gradually return to normal and the event ends after several months. Often the system overshoots, to start the opposite phase of the cycle rather than just return to neutral conditions.

What are the impacts on global weather?

During ENSO events the changes in sea surface temperature cause (and are influenced by) changes in atmospheric circulation (i.e. wind and pressure patterns) and in temperature and rainfall. Through atmospheric dynamics, these atmospheric changes extend well beyond the tropical Pacific region. The Atlantic and Indian oceans are also affected, which further extends and prolongs the impacts.

The effects vary considerably with location: for example, during an El Niño event the eastward shift of rainfall in the west Pacific region tends to cause rainfall deficits in the Philippines, Indonesia, and Australia, while central Pacific islands experience excess rainfall.

By averaging conditions experienced during many past events maps can be made that give an impression of their main effects: some such schematic maps for rainfall tendencies are provided in figure 2. However, each individual event is different (e.g. in severity and timing), and impacts are also modified by the state of the climate at the time: even the sign of the anomaly (excess or deficient rainfall for example) may vary from one event to another for particular locations. More detailed analyses provide quantitative information about the probability of various outcomes (levels of severity) for specific regions, conditioned by the occurrence of an ENSO event.

In any individual year the observed climate anomaly over a region may be a complex combination of many factors, of which El Niño is just one. These other factors will include local sea surface temperatures, other modes of natural climate variation e.g. in the north Atlantic or stratosphere, volcanic eruptions and solar variations. While ENSO may be the leading cause of variation in extreme precipitation globally, explaining 15%–20% of precipitation extremes, 80% of the variability is due to the combined influence of other factors (Goddard et al. 2006). This also suggests why any one event cannot be solely attributed to one driving factor (cf. attribution of individual extreme events to increases in greenhouse gases) and attribution is necessarily in a risk-based framework.

Predictions of the effects of an ENSO event that is initiating or in progress are best based on forecasts that take into account all known details of the recent and present state of the climate system, rather than using ‘typical’ impact maps. Currently this is only possible in numerical global climate models.

The schematic maps in figure 2 are intended to indicate mostly mainland and seasonal tendencies. They do not provide information about severity or robustness. Changes in the risk of short-lived extreme weather events may differ, though broadly increases in short-lived rainfall extremes are associated with a tendency for wetter seasonal conditions (Kenyon and Hegerl 2010). Currently few such analyses are available, and there is a need for more extensive research on weather tendencies and also on their economic effects for a range of sectors.

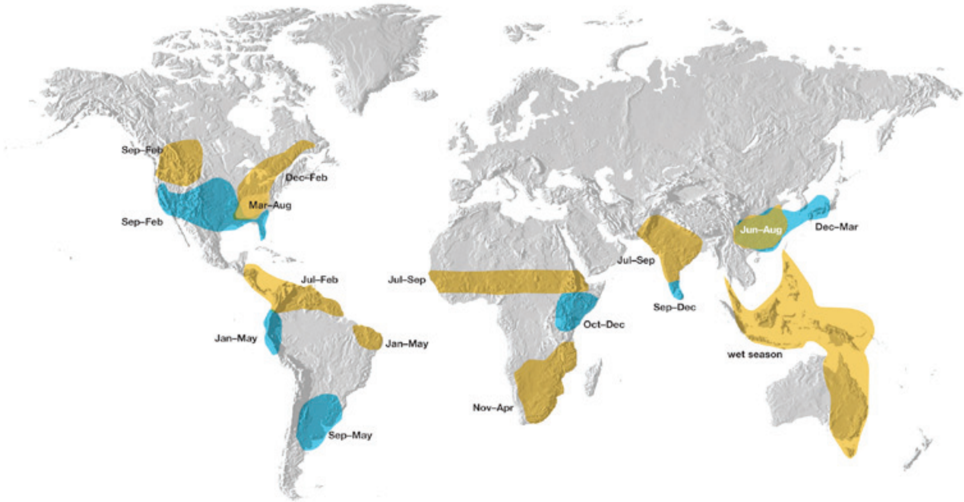
The occurrence of both wetter and drier regions on each map reflects the tendency of ENSO events to displace rainfall patterns geographically as well as enhance or decrease local precipitation. Effects are more robust around the Pacific and in tropical regions.

Along with changes in rainfall, the ENSO cycle also substantially affects other weather conditions such as temperature, with regional and seasonal variations. The focus here is on rainfall and tropical storms, as these have more impact on property and related financial sectors.

In the European region, far from the Pacific centre of action, the effects are less pronounced, and there is considerable variability in the observed conditions. Recent research (Bell et al. 2009) has led to better understanding of the processes linking ENSO and Europe and the conditions under which significant effects may occur.

Note that there are also various “flavours” of El Niño – including the so called *central Pacific* or *modoki* type events. Understanding the different types of El Niño and their specific impacts will allow improved prediction of risk.

During El Niño



During La Niña

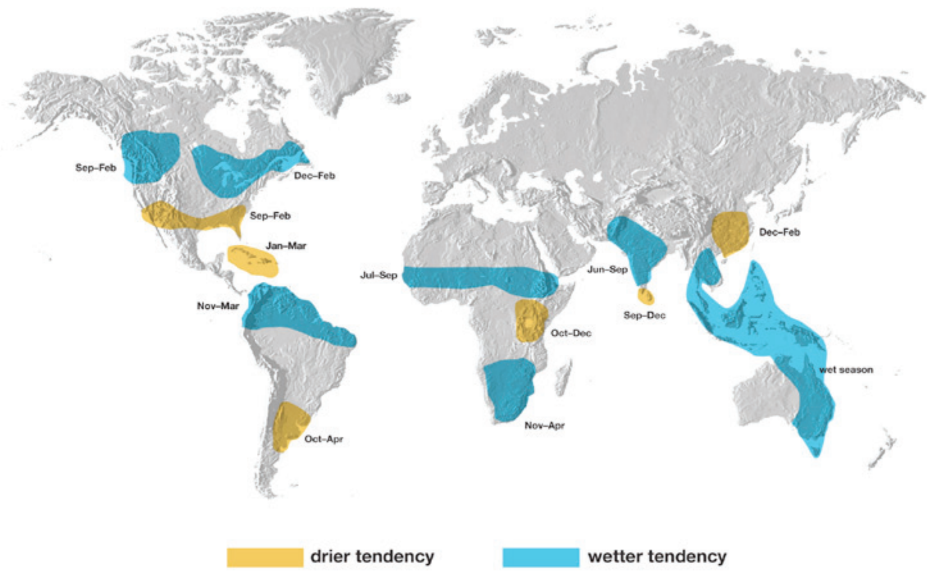


Figure 2: *Schematic maps indicative of typical rainfall tendencies during an El Niño event (top) or a La Niña event (bottom). Precise geographical detail is not implied. Periods of the year when the tendencies are more evident are indicated on the highlighted areas. (Overlap of signals for several parts of the year may arise occasionally, in places – with implications for the appearance of the colours in the figure).*

Impacts on the financial industry

The changes in regional temperature, rainfall and wind patterns in the tropics and extra-tropics affect the financial industry through direct impacts – for example, on property damage, agriculture (especially crops), forestry (e.g. fire damage in dry conditions), transport infrastructure – and also through changes in financial markets. For property insurance, the most significant changes are associated with damage caused by flooding or storms, and these aspects are emphasised below.

Wind storm activity and El Niño and La Niña

There is a well-known connection between ENSO and the numbers of **North Atlantic tropical storms** in the hurricane season, with a pronounced tendency for fewer during El Niño and more during La Niña events. The reason is that the changes in atmospheric circulation and in humidity in the tropical Atlantic as a consequence of El Niño make it more difficult for storms to develop.

In the 2010 season the developing La Niña conditions were a strong contributing factor to the observed near-record (joint second highest) number of 19 named tropical storms, as anticipated by various long-range forecast systems. However insured losses were relatively low: with the influence of prevailing Atlantic conditions on the storm tracks only one (Bonnie) made landfall in the USA.

ENSO has a strong influence on intense hurricanes: there are on average twice as many during La Niña events as during El Niño (Camargo et al. 2010). The probability of landfalling Atlantic hurricanes in various USA states, Caribbean and Gulf regions is altered by ENSO: e.g. landfall on the USA eastern seaboard is more likely in La Niña years, and reduced during El Niño events.

The ENSO cycle influences tropical cyclone numbers in other regions. For example, in the **West Pacific** (northern and southern hemisphere) there tend to be more cyclones during a La Niña event and fewer during El Niño, whereas in the northeastern tropical Pacific (the origin of hurricanes that impact the Mexican and Central American Pacific coasts) there tend to be more strong hurricanes during El Niño. Indeed in the 2010 season there was a record low number of named storms and hurricanes in the eastern North Pacific.

The atmospheric circulation changes include shifts in the mid-latitude jet streams and **storm tracks** in both hemispheres. For example, during El Niño winter storm tracks over the western USA tend to shift southward from their usual location, bringing unusually wet weather into **California** with accompanying elevated flood and mudslide risks.

For **Europe**, wind storm tracks are more strongly related to another regional climate phenomenon called the North Atlantic Oscillation (NAO), which represents fluctuations in the gradient in atmospheric pressure between the Azores and Iceland. A positive NAO phase leads to more extreme wind storms in northern Europe. La Niña and NAO are not independent however, as La Niña tends to drive positive winter NAO, and an enhanced effect is possible during La Niña years. El Niño favours negative winter NAO, and thus colder temperatures in Northern Europe in late winter. The physical mechanism linking ENSO and Europe is gradually being uncovered with the stratosphere now thought to play an important role in conveying the ENSO influence.

Flooding – Queensland, Australia

One of the regions strongly affected during the 2010/11 La Niña episode was the state of Queensland in Australia. Losses of $5.5bn have been estimated, including major sugar cane crop ruin (Queensland is a major world supplier), disruption of coal mining and wheat transport activities and extensive property damage. The rainy season is November to March, and heavy rains caused extensive flooding and damage, exacerbated by an unusually strong tropical cyclone hitting the region: the La Niña event and high sea surface temperatures in the Coral Sea created conditions favourable to the above normal rains.

It is instructive to look at the relationship between seasonal rainfall and the ENSO cycle as illustrated in figure. 3**.**

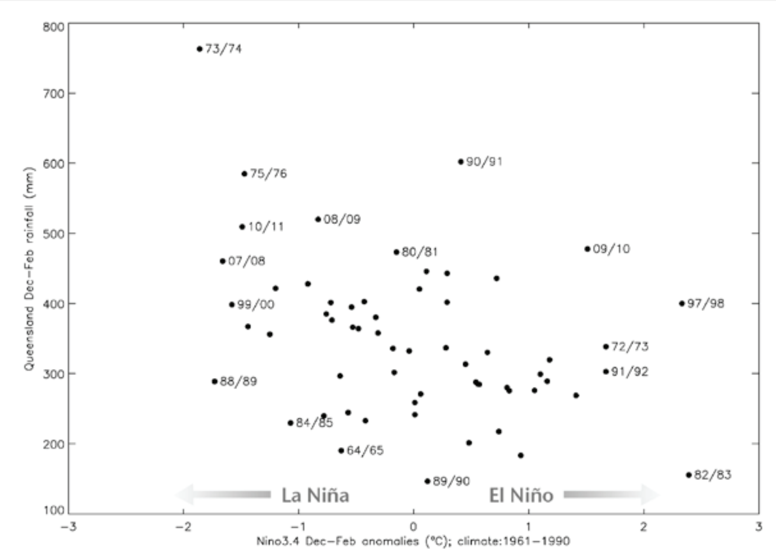


Figure 3: *December-January-February rainfall amounts in Queensland and sea surface temperature anomalies in region Niño3.4 (see map in figure 1), for 1950/51 to 2010/11 seasons. (Data source: rainfall – Australian Bureau of Meteorology; Niño3.4 index – HadISST)*

It may be seen that rainfall is above normal in most (but not all) La Niña events and below average, mostly, during El Niño events (i.e. ENSO events shift the odds visibly). Examples drawn from individual years are given below.

The exceptionally heavy rains in 1973/74 that devastated the sugar cane industry occurred in a strong La Niña, conversely exceptionally dry conditions in 1982/83 prevailed in a very strong El Niño event.

However, extreme events can also arise without strong ENSO, as in 1990/91 and 1989/90, so the absence of a prominent ENSO event does not guarantee 'near-normal' conditions. Conversely, active ENSO seasons do not guarantee corresponding 'typical ENSO' rainfall changes: note low rainfall in the 1988/89 La Niña, relatively high rainfall in the 2009/10 El Niño, and rains near-average in the very strong 1997/98 El Niño.

From diagrams such as that of figure 3 the risks associated with ENSO can be quantified by constructing rainfall probabilities conditional on ENSO state. The risks can be refined by using information about prevailing conditions and outlooks.

Events impacting financial industry

The best-documented impacts are those associated with the very strong El Niño event in 1997/98, which was followed by an extended La Niña episode covering the next two years. While these impacts were unusually large, they give an idea of the range of consequences – and they may occur again.

Impacts include:

- California: heavy storms in December 1997 until February 1998 generated 3 times normal rainfall. Losses from wind and flood in the 1997/98 El Niño were $1.1bn (Changnon 2000).

- USA: agriculture sector losses from the 1997/98 El Niño were estimated at $1.5-$1.7bn, whilst estimated1998-99 La Niña event losses range from $2.2 to $6.5bn (Adams et al 1999).

- Kenya: The strong El Niño event of 1997/98 caused damages in Kenya estimated at 11% of GDP (over three months). Over 90% of the calculated flood losses were associated with transport, infrastructure damage and water supply and sanitation. Conversely, La Niña caused drought damage to the extent of 16% of GDP in each of 1998/99 and 1999/00 financial years.

- Indonesia: a drought in 1997/98 reduced the normal August to September rainfall substantially, leading to widespread fires and failure of the coffee crop with a poor quality harvest.

- Ecuador: severe floods in January to February 1998 led to $2bn of total loss damage to property.

- The impacts of ENSO-reduced rainfall and drought can enhance fire risk in many locations around the globe including parts of USA, Brazil, Australia, Borneo and Indonesia. Forest and bush fires can lead to property damage, business interruption and loss of livestock. For example, Australia's El Nino-related *Ash Wednesday* of 1983 killed 300 000 sheep and cattle, destroyed 2539 homes and killed 75 people.

In some regions the 'expected' impacts do not arise: in 1997 the Indian monsoon rains were near normal, and in Australia timely rains occurred to avert drastic crop losses through drought conditions.

Opportunities arising from El Niño

Not all of the impacts are negative, and the counterside of enhanced extremes hazards in some areas is that other areas can have reduced chances of extremes. With regard to commodities, although some regions suffered heavy losses, others benefited from higher prices and more favourable production conditions. Clearly the periodic reduction of risk offers economic and societal benefits that, if known in advance, could be exploited. For example, in the USA the 1997/98 El Niño generated national savings from reduced heating costs estimated at $6.7bn and overall net economic benefits of approximately $15bn (Changnon, 1999).

Legal implications

Significant flooding in 2010 in Colombia has lead to a collective lawsuit filed against the government. In spite of receiving meteorological warnings of months of heavy rain, the government is accused of inaction to protect life and property.

The issue of El Niño / La Niña predictability has been raised relating to discussions on the *force majeure* clause that is standard in many contracts. If El Niño and La Niña mean that extreme events are significantly predictable to either party in a contract, there is a rationale that the events are then not beyond expectation. The discussion has especially focused on commodities, where production interruption can have significant impact on price.

Headline events from the 2010/11 La Niña period

Weather extremes occur in various places every year, regardless of the state of ENSO. The importance of ENSO is two-fold: it shifts the odds in recognisable ways, and it is predictable. (Goddard et al, 2005, 2006). While it is difficult to attribute individual events to ENSO, an analysis can be made on recent events that do or do not 'fit' the general pattern:

- Queensland: extensive floods and widespread damage in January 2011, following above normal rainfall in late 2010 (rainy season), exacerbated by tropical cyclone Yasi. This event was very likely associated with La Niña, as above-normal rainfall is a typical tendency in this region.

- Colombia: extensive, widespread flooding in the last part of 2010 leading to around 400000 homes destroyed and widespread crop damage. The excess rainfall was typical of La Niña and was forecast ahead of time, although the management of a dam has also been cited as contributing to the flooding.

- Southern Africa: damaging floods in December 2010-January 2011, affecting South Africa, Mozambique, Zimbabwe (e.g. South Africa property damage ~$50m, extensive crop damage and 8 of 9 provinces declared disaster areas). This is typical of La Niña's influence.

- USA Pacific Northwest region: heavy rain and snowfall in early 2011, which are consistent with La Niña influence.

- Sri Lanka: damaging floods in January 2011. These were not typical of the La Niña tendency in this region, but possibly a consequence of La Niña's typical (wet) influence on Indonesia extending further westward than 'usual' in this particular event.

- Brazil: June 2010 floods in coastal northeastern Brazil (Alagoas and Pernambuco states) caused substantial damage, with thousands made homeless. However these were not likely to be due to La Niña as they were highly localised and occurred during the transition of El Niño to La Niña.

- Brazil: January 2011 damaging floods and mudslides in the state of Rio de Janeiro (south-central coastal Brazil) leading to one of the worst such events in Brazilian history with at least 900 deaths. These occurred due to very heavy rainfall in a 24-hour period but were not likely to be a La Niña effect as they were highly localised and the region is well to the south of the area where La Niña has a wetter tendency in South America.

Managing the risks: long-range prediction

Predicting El Niño and La Niña

With the aid of modern technology, nowadays ENSO is closely observed with arrays of moored buoys in the tropical Pacific Ocean, satellite data and atmospheric measurements. Much of the network of observational data has been established since the mid-1980s and has allowed greater understanding of the mechanics of the El Niño phenomenon and significant advances in long-range prediction.

The ENSO cycle is predictable a few seasons ahead and is the most skilfully predicted large-scale climate phenomenon on the seasonal to inter-annual timescale. Skill generally decreases as the lead time increases. Forecasts made during northern hemisphere late winter and spring are often less skilful than at other times of the year – this is sometimes referred to as the 'spring predictability barrier'.

ENSO forecasts are made routinely by a number of prediction centres around the world. Some forecasts come from global prediction systems – complex numerical models which incorporate a wide range of dynamical and physical processes. There are also forecasts specifically for ENSO which are based on statistical relationships of key historical ocean and atmosphere data (see, at the end of the report, details on websites hosting live forecast information).

The Met Office GloSea (Global Seasonal) dynamical prediction system is based on the latest version of the Hadley Centre climate model. The forecast model is run several times each month, sampling uncertainty in the initial forecast conditions and model processes. The resulting forecast 'ensemble' allows the probability of occurrence of events to be estimated.

An example of the forecast model predicting the transition from El Niño towards La Niña conditions in 2010 is shown below.

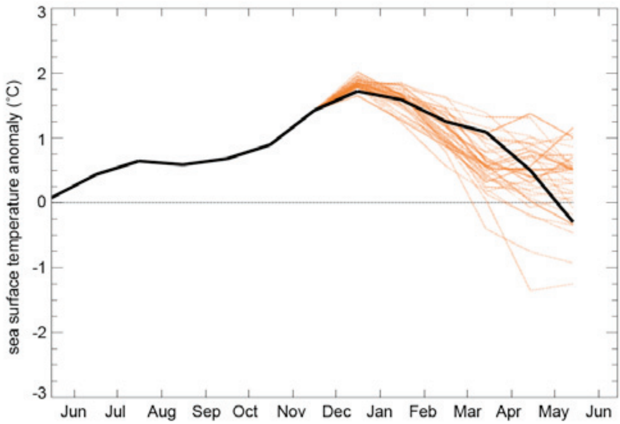


Figure 4: *Forecast plume (red lines) of central Pacific sea surface temperature (Niño 3.4 region) initialised from December 2009, with observations (black line) for comparison. Only observations before December 2009 were used in making the forecast. The forecast is from the Met Office seasonal forecasting system GloSea4.*

The World Meteorological Organization (WMO) issues an El Niño/La Niña Update several times each year, based on contributions from the leading centres around the world.

Long-range prediction of regional climate variations

Even in areas that are strongly impacted by El Niño and La Niña events, regional climate forecasts and climate risk assessments for forthcoming seasons should not be based solely on ENSO indications as many climate extremes develop independently of El Niño and La Niña, the tendencies associated with ENSO are modified by other factors, and the type of ENSO can vary.

Statistically-based regional forecasts typically combine predictive information from a few relevant factors, such as the ENSO state and local sea surface temperatures, and rely on past observed relationships. The most advanced forecasting systems are dynamical ocean–atmosphere–land surface numerical models that represent a large range of physical processes (including those that produce gradual climate change) and make use of large amounts of observational data to initialise the forecasts. Several prediction centres now operate such systems and routinely issue long-range outlooks with global coverage.

The WMO has established a system of Global Producing Centres of long-range forecasts – of which one is the UK Met Office – that provide outlooks based on advanced forecasting systems. Several real-time regional rainfall forecasts are regularly produced through consensus discussion forums known as Regional Climate Outlook Forums (RCOFs – see, at the end of the report, details on websites with supplementary information).

Long-range forecasts are already used operationally in several sectors: a significant example is the sugar cane industry, in Queensland, where they inform a range of decisions related to planting, harvesting, milling and marketing activities. However, the potential for use of long-range forecasting information in risk management is not yet fully realised in many sectors.

Outlook – May 2011

At the time of writing (May 2011) near-neutral conditions are favoured for the remainder of 2011, but development of El Niño or return of La Niña cannot be ruled out as uncertainty is currently relatively high. Outlooks issued in the next few months should provide firmer indications of expected ENSO evolution.

Future research and the impacts of greenhouse gases

The science of the El Niño Southern Oscillation started with work on the analysis of patterns in atmospheric conditions in the 1920s by Sir Gilbert Walker, and these were linked to the oceanic oscillations by Professor Jacob Bjerknes in the 1960s. Today, comprehensive numerical models are used to simulate ENSO and can be used to explore the detailed physical mechanisms which drive it. There are still many unanswered aspects relating to the topic however, and some of them are surprisingly fundamental.

- Little research has been done on the quantitative attribution of individual extreme weather and climatic events to ENSO or any other natural mode of variability.
- There have been very few analyses quantitatively linking ENSO events to property or financial losses.
- Regarding property losses, in research on the impact of Atlantic tropical storms the effects of landfalling and frequency of storms tend to be conflated in statistical analyses.
- More investigation is required into the different flavours in the El Niño / La Niña cycle and their impacts on regional weather around the globe, and into the combined influence of other modifying conditions.

Finally, numerical simulations of the future which include increases in greenhouse gases indicate that ENSO activity will continue. Individual models suggest changes in the patterns and strength of ENSO but these changes vary from model to model. There is currently no consistent indication of future changes in ENSO amplitude or frequency (IPCC 's Working Group I – 4th assessment report 2007) and more research is needed to understand the potential future impacts.

Acronyms:

ENSO	El Niño Southern Oscillation
HadISST	Hadley Centre Ice and Sea Surface Temperature dataset
NAO	North Atlantic Oscillation
GDP	Gross Domestic Product
IPCC	Intergovernmental Panel on Climate Change

Some sources of further information

Web

World Meteorological Organization – ENSO updates and Regional Climate Outlooks:
www.wmo.int

Met Office global long-range forecasts, including ENSO and tropical cyclone activity:
www.metoffice.gov.uk/research/climate/seasonal-to-decadal/long-range

Australian Bureau of Meteorology ENSO forecast summary:
www.bom.gov.au/climate/ahead/ENSO-summary.shtml

International Research Institute for Climate and Society – including ENSO forecast summaries:
www.iri.columbia.edu

Tropical Atmosphere Ocean monitoring:
www.pmel.noaa.gov/tao

Selected books

El Niño, 1997-1998: The Climate Event of the Century
Edited by Stanley A. Changnon, Oxford University Press 2000

El Niño: the weather phenomenon that changed the world
By Ross Couper-Johnston, Hodder & Stoughton 2000

Currents of change: impacts of El Niño and La Niña on climate and society
By Michael Glantz, Cambridge University Press 2001

The El Niño Southern Oscillation Phenomenon
By Edward S. Sarachik and Mark A. Cane, Cambridge University Press 2010

Selected references

Adams, R. M., C. Chi-Chung, B. McCarl and R. Weiher, 1999 The economic consequences of ENSO events for agriculture, Climate Research, Vol. 13 165-172.

Arribas, A., M. Glover, A. Maidens, K. Peterson, M. Gordon, C. MacLachlan, R. Graham, D. Fereday, J. Camp, A. A. Scaife, P. Xavier, P. McLean, A. Colman, S. Cusack, 2011. The GloSea4 ensemble prediction system for seasonal forecasting, Monthly Weather Review, in press.

Bell, C.J., L.J. Gray, A.J. Charlton-Perez, M.M. Joshi and A.A. Scaife, 2009. Stratospheric communication of El Niño teleconnections to European winter. Journal of. Climate, 22, 4083-4096.

Changnon, S.A., 1999: Impacts of 1997-98 El Niño-generated weather in the United States. Bulletin of the American Meteorological Society, 80(9), 1819-1827.

Camargo, S. J. A.H. Sobel, A.G. Barnston, and P.J. Klotzbach, 2010. The influence of natural climate variability, and seasonal forecasts of tropical cyclone activity, Chapter 11, pp. 325-360, in Global Perspectives on Tropical Cyclones, from Science to Mitigation, 2nd edition, World Scientific Series on Earth System Science in Asia, vol. 4, J.C.L. Chan and J.D. Kepert, editors, ISBN 978-981-4293-47-1

Goddard, L. and M. Dilley. 2005. El Niño: Catastrophe or opportunity. Journal of Climate, 18: 651-665.

Goddard, L. and M. Dilley, 2006. Reply to Comments on "El Niño: Catastrophe or Opportunity". Journal of Climate, 19: 6443-6445.

Kenyon, J. and G.C. Hegerl. 2010. Influence of modes of climate variability on global precipitation extremes. Journal of Climate, 23, 6248-6262.

Klotzbach, P.J. 2011. El Niño-Southern Oscillation's impact on Atlantic basin hurricanes and U.S. landfalls. Journal of Climate, 24, 1252-1263.

Note: full list of references is available on request

Note rainfall data for figure 2 is subject to copyright and was provided by the Australian Bureau of Meteorology.

Licences and further information can be obtained from the
Met Office IPR Officer, FitzRoy Road, Exeter, Devon, EX1 3PB
Email: iprmanager@metoffice.gov.uk

Met Office
FitzRoy Road, Exeter
Devon, EX1 3PB
United Kingdom

Tel: 0870 900 0100
Fax: 0870 900 5050
enquiries@metoffice.gov.uk
www.metoffice.gov.uk

Produced by the Met Office