

The 1997/1998 El Niño

by Gerrit Burgers and Geert Jan van Oldenborgh

The 1997/1998 El Niño: a record event. • El Niño, out of the remote vastness of the tropical Pacific Ocean, connects many seemingly unrelated events all over the world and even makes them predictable to some extent. This has captured the imagination of the public. Seldom has a meteorological phenomenon attracted so much attention as the El Niño of 1997/1998. It has not always been like this. The previous very strong El Niño was in 1982/1983. In September 1982, a group of scientists met in Princeton to discuss the El Niño phenomenon. They were unaware of the fact that one of the strongest El Niño's ever was developing. Only months later, after the peak of the El Niño, people realised something extraordinary had happened. This was completely different during the 1997/1998 El Niño. Early 1997 several of the centres that issue El Niño forecasts were observing signs that an El Niño might be imminent. During the month of May, the spectacular onset of the El Niño could be followed real-time on the Internet. By July it was clear that it would be of extraordinary strength. El Niño was a central issue at the World Meteorological Organisation (WMO) meeting in August, and forecasts for unusual and possibly catastrophic weather were issued to the public. The message came home. Television crews and journalists jumped on the subject, and soon millions of people were following the development of the 1997/1998 El Niño.

Measures of El Niño • El Niño's last for about a year, and occur irregularly with a spacing of about three to seven years. They are characterised by warmer than usual surface water along the equator in the eastern Pacific Ocean and weaker than usual trade winds in the equatorial Pacific. El Niño's

cause the precipitation region around New-Guinea to shift towards the central Pacific. A convenient crude measure for the strength of the trade winds is the Southern Oscillation Index (SOI), the normalised pressure difference between Tahiti and Darwin: if the SOI is low, then there is less wind blowing from Tahiti to Darwin, and that means weaker trade winds. The NINO3 index measures the deviation from normal of the sea surface temperature in the

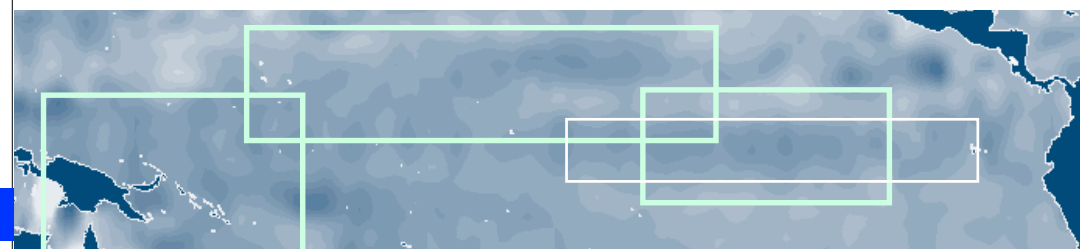
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eastern Pacific. The irregular behaviour of the NINO3 index and the SOI since 1865 is shown in Figure 1. During an El Niño, the NINO3 index is high, and the SOI is low. The NINO3 index and the SOI are two indicators of the same phenomenon, El Niño - Southern Oscillation (ENSO).

Ocean-atmosphere interactions in the tropical Pacific • The origins of ENSO only become clear if one analyses how the atmosphere and the ocean interact and influence each other¹⁾. Along the equator, the trade winds blow warm surface water westward in the direction of Asia, where it piles up. In the east, near South America, the water is replaced with cold water from below. This causes a temperature difference between the west (Australia and Asia) and the east (the Americas) of the Pacific. Air rises more over warm water than over cold water. Where air rises and cools as it enters higher altitudes, the water vapour in the air condenses and it rains: that is why it rains much more over the warm western Pacific near Asia than over the cold eastern Pacific near Peru and Equador. Also, the rising air in the west draws in more air, and this is partly responsible for the strength of the trade winds.

If, for one reason or another, the trade winds slacken, the water piled-up in the west will slosh back towards South-America. This heats the eastern Pacific and the temperature difference between east and west will diminish. In turn, when the difference in temperature becomes smaller, the trade winds will loose strength. In this way there is a circle of causes and effects that can reinforce each other: weaker trade winds give a smaller temperature difference, this gives weaker trade winds and so on. During the 1997/1998 El Niño, the change in sea surface temperature was extreme. In Figure 2 the sea surface temperature in the tropical Pacific of December 1997 is compared to the temperature of December 1998. At some places in the eastern Pacific, the difference was more than seven degrees Celsius.

Of course, this circular reasoning is not a complete picture. It explains why such vast deviations from normal can exist, but does not inform us about the duration of El Niño's nor about the frequency of their occurrence.



Disentangling the mechanisms

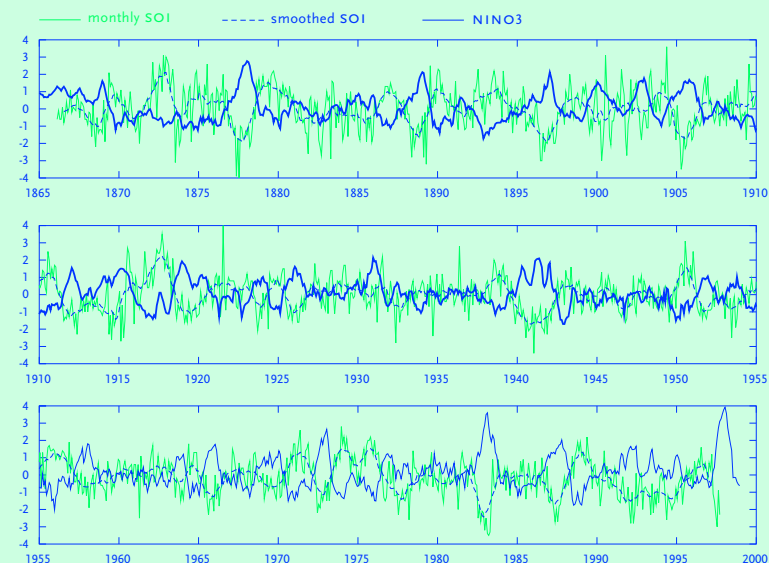


Figure 1. Two indicators of El Niño conditions, the NINO3 index and the Southern Oscillation Index (SOI), over the period 1865–1998. El Niño conditions are characterised by a high NINO3 index, and a low SOI. The NINO3 index is the deviation of the sea surface temperature with respect to normal conditions over the area 5°S–5°N, 150°W–90°W, and the SOI is the normalised sea-level pressure difference between Tahiti and Darwin. SOI made available by P.D. Jones, Climate Research Unit, University of East Anglia (UK). The NINO3 data were analysed on the basis of historical ship observations by Alexey Kaplan (Palisades, NY, USA).

The images without captions show the development of the 1997/1998 El Niño as observed by the ERS-2 (Earth Remote Sensing) satellite. They show the triggering in April 1997, the onset in June 1997, the peak in December 1997 and the following La Niña in August 1998. The white box in these images denotes the NINO3 region. Images provided by DEOS (Delft Institute for Earth-Oriented Space Research).

We know that these time scales are set by the ocean. The atmosphere adjusts relatively fast to changes in the ocean, within a month or so. However, the ocean takes much longer to adjust. Along the equator, a reaction of the ocean takes about two months to cross the Pacific from west to east, and about six months to cross it from east to west. Incidentally, for ocean standards this is very fast, and only possible around the equator. Eventually, it is the dynamics of the ocean that determines the time scale of El Niño.

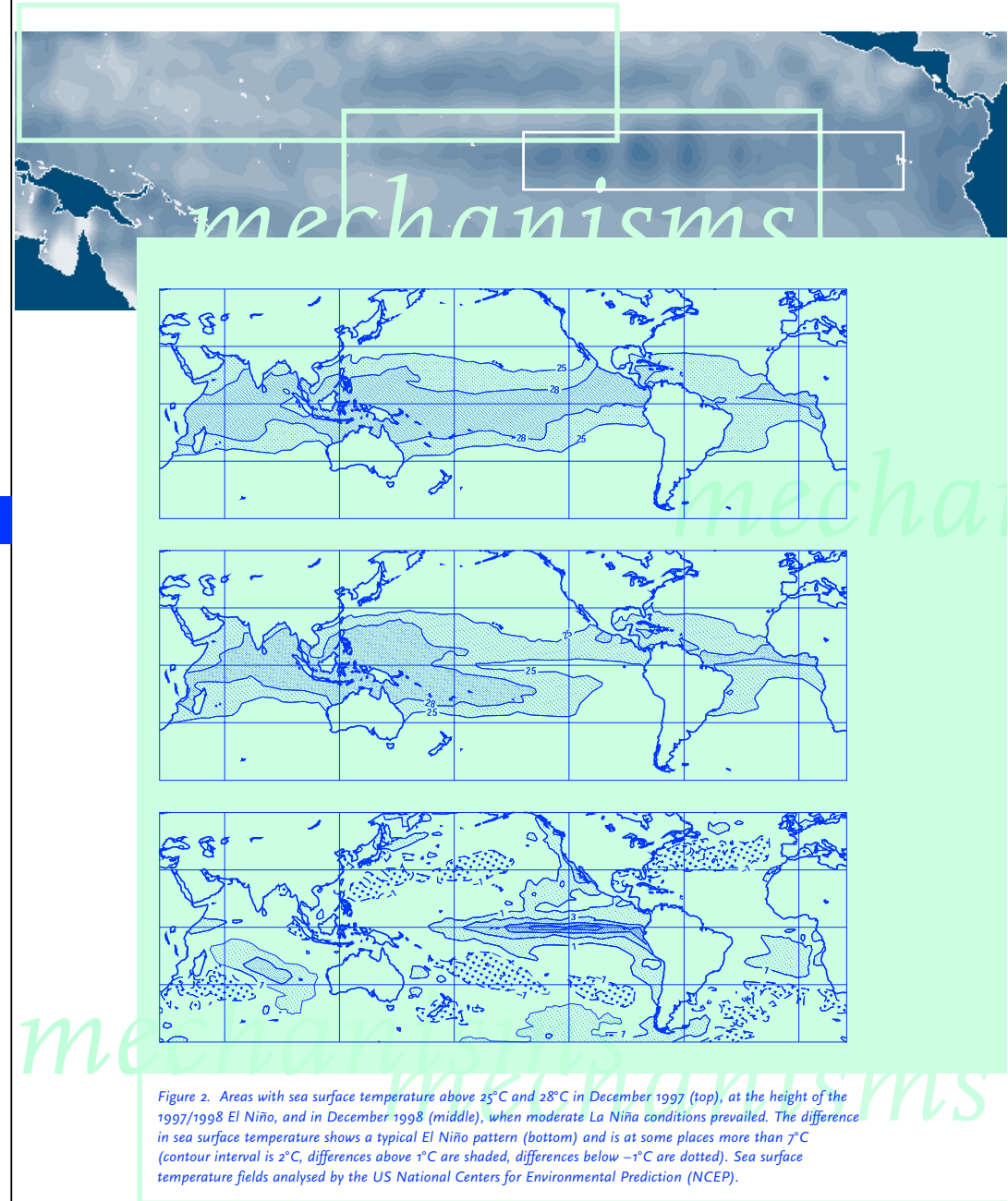
Signals propagating over the tropical Ocean • The signals in the ocean are most pronounced in the thickness of the warm surface layer of the ocean that covers the cold water of the deep ocean. As mentioned before, usually this layer is thicker and warmer in the western Pacific than in the eastern Pacific. The boundary between the warm surface layer and the deep cold water varies in depth from about 200m in the west to about 50 m in the east and is called the thermocline. In the east, where cold water surfaces, there is a strong connection between the depth of the thermocline and the surface temperature of the water. Westerly winds in the western Pacific cause a local

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deepening of the thermocline. The reaction of the ocean is to propagate the deeper thermocline to the east, causing the temperature there to rise. The response of the wind to the higher-than-normal surface temperature is strongest around the dateline (180° longitude), and makes the thermocline even deeper there, resulting in the positive feedback discussed before.

The propagation of a deeper thermocline anomaly to the east during the 1997/1998 El Niño can be seen in Figure 3. This shows the development of sub-surface temperatures along the equator during the onset of the 1997/1998 El Niño. While the signal reached the surface only at the end of April, already since March warm water could be seen moving eastwards below the surface.

So during the onset of an El Niño, the thermocline gets deeper than normal in the east, but this also contains the germ of its own demise, because wind by itself does not heat the ocean. The warm water is drawn from areas to the north and south of the equator. The thermocline becomes shallower in those off-equatorial regions. Eventually, the shallow parts in the thermocline move back to the equator. Probably, reflections at the western coast are important in this process. Next, the shallow regions in the west travel eastward along the equator, and overcome the positive feedback of the wind anomalies. Eventually, the thermocline in the east is shallower than normal



and a state develops which is known as La Niña, with colder than normal surface waters in the east, and stronger than normal trade winds. This mechanism, which consists of a quasi-instantaneous positive feedback followed by a delayed negative feedback, is known as the delayed-action oscillator mechanism. Reflections at the eastern coast are less important: the earth's rotation enables a large fraction of the warm water to flow along the American coasts towards the poles. However, it should be noted that the details of the evolution of an El Niño are much more complicated than the simple picture sketched above. The demise of the 1997/1998 is shown in Figure 4. It took half a year for the NINO3 index to drop to zero from its maximum value in December 1997.

Tracing the origin of El Niño • ENSO oscillations are quite erratic. The 1997/1998 El Niño was an extremely strong one, while the five preceding years were relatively quiet. Some periods, like the eighties of both the nineteenth and twentieth century, are characterised by large, almost smooth, swings. At other times El Niño is jumpy from one season to the next.

Probably, a large part of the irregularity is caused by 'noise', i.e., by atmospheric and oceanic influences which are independent of ENSO. A very simple model, a stochastically forced linear oscillator, can already simulate many aspects of ENSO index timeseries²⁾. ENSO forecasts made on the basis of the stochastic oscillator clearly outperform persistence and climatology forecasts. However, it is a long-standing controversy how large the role of 'noise' is for ENSO, because the ENSO system might be chaotic and part of the

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irregularity might be intrinsic. At KNMI, in an effort to contribute to the solution of this controversy, a 'sensitivity' model for the NINO3 index has been developed³⁾. With this model, the sensitivity of the ENSO situation with respect to what happens months earlier can be investigated. Results⁴⁾ show that the onset of the 1997/1998 El Niño has mainly been triggered by two large 'windburst' events in the western Pacific, see Figure 5, the first one in the beginning of March 1997, and the second one at the end of March 1997. We do not yet understand why the windbursts were so prominently present in 1996/1997 and virtually absent in the year before. The activity seems to be unrelated to the ENSO situation. A second factor determining the strength of last year's El Niño was the strong pile-up of warm water in the western Pacific during the preceding years. Disentangling the importance of these and other mechanisms is currently the subject of much research.

Disentangling

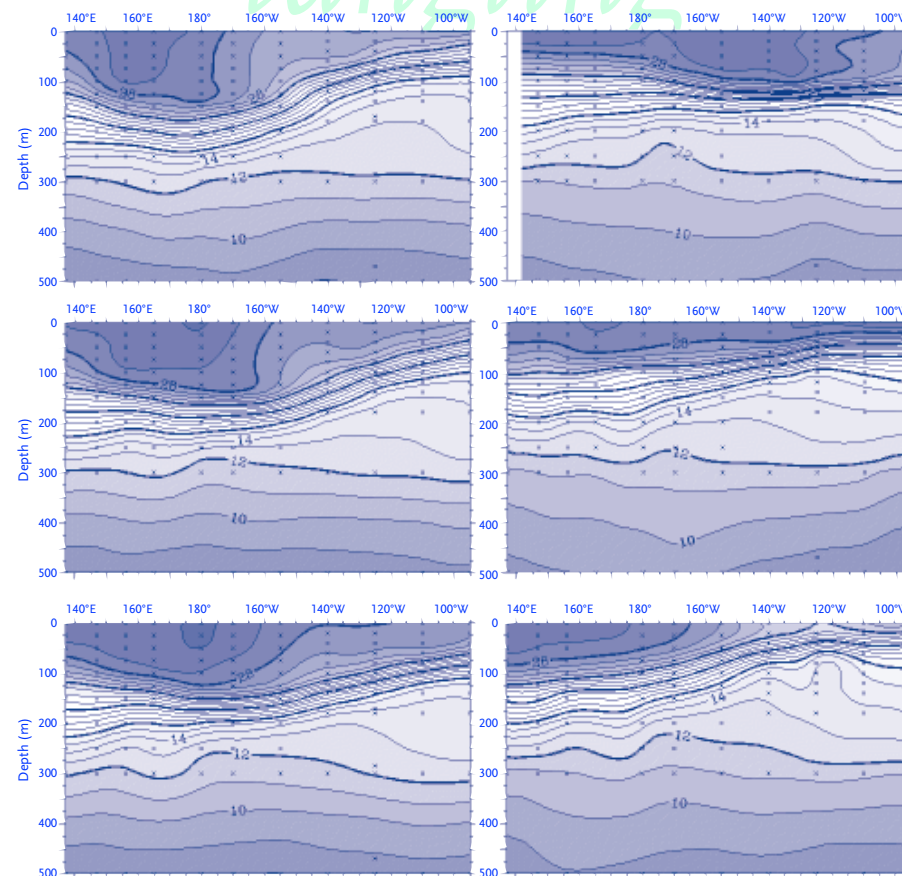


Figure 3. Sub-surface temperatures along the equator during the onset of the 1997/1998 El Niño. The plots are for March 1997 (top), April 1997 (middle) and May 1997 (bottom). A large warm sub-surface temperature signal can be seen propagating from west to east, depressing the thermocline in the east in May 1997. Sub-surface temperature fields measured by buoys of the Tropical Atmosphere Ocean (TAO) array and analysed by the US Pacific Mooring Experiment Laboratory (PMEL).

Figure 4. Sub-surface temperatures along the equator during the demise of the 1997/1998 El Niño. The plots are for December 1997 (top), March 1998 (middle) and May 1998 (bottom). It can be clearly seen that at the height of the El Niño in December 1997, already cold water was looming below the surface in the west. It took half a year before cold water reached the surface in June 1998. Sub-surface temperature fields measured by buoys of the Tropical Atmosphere Ocean (TAO) array and analysed by the US Pacific Mooring Experiment Laboratory (PMEL).

La Niña, El Niño's little sister • The opposite phase of El Niño is called La Niña. Close to the coast of South America, the surface warming of an El Niño can be much stronger than the cooling of a La Niña: that is why Peruvian fisherman discovered El Niño and not La Niña. More precisely formulated, the distribution of sea surface temperature anomalies is skewed

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towards higher temperatures, i.e., weak positive anomalies are less probable than weak negative anomalies, while strong positive anomalies are more probable than strong negative anomalies. To some extent, this skewness towards positive values can be seen in the NINO3 index as well. How this changes if one goes from the eastern to the western Pacific as well as the tendency of the distribution to have multiple maxima has been investigated quantitatively⁵⁾. It appears that in the central Pacific, El Niño and La Niña can have the same strength. So far, the pattern of varying skewness is hard to simulate for models of ENSO.

Impacts of El Niño, even in the Netherlands • The large region of very warm sea surface temperature with ascending air around Indonesia and the western Pacific is of primary importance for the planetary atmospheric circulation and the redistribution over the Earth of heat from solar radiation. It is not surprising, then, that changes and shifts of this region have pronounced effects on the weather all over the globe.

Of course, the strongest effects are on countries around the equatorial Pacific Ocean. As an example, in Figure 6, the NINO3.4 index is shown together with years with very large forest fires in Indonesia. Almost always, years with very large forest fires are years with a large NINO3.4 index in summer. At the other side of the Pacific, in deserts in Peru near the Pacific coast where most years it does not rain at all, El Niño's cause heavy rain. Early 1998, a lake of 15000 km² appeared in the desert. Other countries that are strongly affected by El Niño include Australia, Uganda, Uruguay and the United States.

In Europe the impact of El Niño is in general rather small. A relatively large effect is that in El Niño years after 1950 there is a high probability of heavy rain in the south of the Iberian peninsula in autumn. What caused the change around 1950 is not known.

That does not mean there is no effect of El Niño at all in the Netherlands. A significant relation has been found⁶⁾ between the winter NINO3 index and the spring rainfall in the Netherlands, see Figure 7. If there is a strong El Niño in winter, it is very likely that the following spring will be

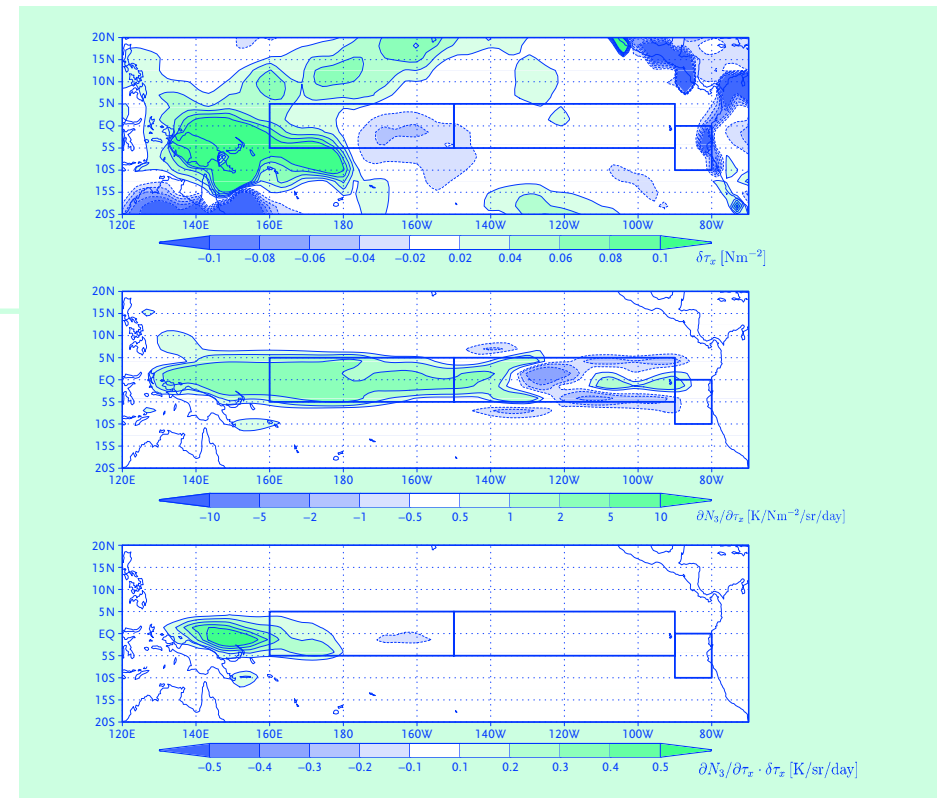
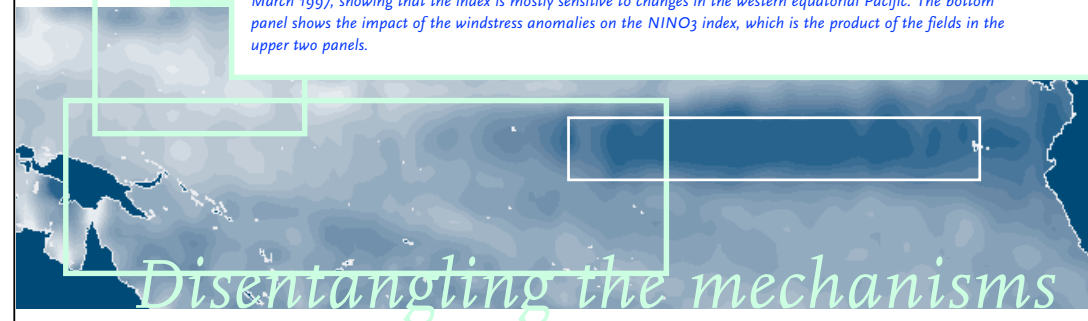


Figure 5. The effect of the March 1997 westerly windburst on the NINO3 index in early June 1998. The top panel shows the windstress anomaly field for the week centred on 11 March 1997 with a clear westerly windburst in the western Pacific. The middle panel shows the sensitivity of the June NINO3 index for windstress anomalies in March 1997, showing that the index is mostly sensitive to changes in the western equatorial Pacific. The bottom panel shows the impact of the windstress anomalies on the NINO3 index, which is the product of the fields in the upper two panels.



Disentangling the mechanisms

wet. Over Europe, the effect is found in a belt from southern England eastwards into Asia. The delay in the relation suggests that south-east Asian temperature anomalies may act as intermediate variables.

Following and forecasting El Niño • Nowadays El Niño is monitored quite well. A special array of buoys in the equatorial Pacific measures winds, and temperatures down to some 300 m depth. It is this array that makes it possible to follow sub-surface temperature anomalies as shown in Figures 3 and 4. Satellites measure sea surface temperature, surface winds and sea level all over the globe. Sea level is a measure for the mean temperature of the ocean and thus of the depth of the thermocline, because sea water expands when heated - in which case the sea level rises. Current techniques and models are able to predict El Niño about six to twelve months in advance.

Seasonal climate forecasts • Because El Niño is related to abnormal weather phenomena in places all over the world, El Niño research has opened up the possibility of seasonal climate forecasts. Such forecasts can be used in deciding what crops to grow and whether to take preventive measures for countering El Niño effects, such as clearing drainage systems, etc. Compared to ordinary weather forecasts there are differences. The first, and most obvious, is that the forecasts are not so much concerned with specific weather events such as storms and heat waves at a particular day, but with general characteristics of a month or season, such as mean temperature, precipitation or cloudiness. The second is that, even more than ordinary weather forecasts, seasonal forecasts are always probabilistic, e.g., a forecast could be that 'there is a 75% probability that it will be a wet summer' or 'the probability that a hurricane will hit that area is three times smaller than usual'. It should be kept in mind that whether such information is of any value to a user, depends entirely on the specific needs of the user.

Seasonal predictability varies from place to place and from time to time. Obviously, seasonal climate forecasts are more skillful in the tropics where the effects of El Niño are more pronounced than in mid-latitudes. The skill also depends on the season. El Niño behaves in such a way that it is much more easy to predict what January will look like from July conditions than to predict what July will look like from January conditions. Moreover, once a strong El Niño has set in, it is relatively easy to forecast its evolution, simply because the signal to noise ratio (of El Niño related phenomena to phenomena that have no relationship with El Niño) is larger.

El Niño research is an international effort. In Europe, operational seasonal forecasts are made by one international centre, the ECMWF (European Centre for Medium-Range Weather Forecasts). Contributing to improving this system is an important aim of El Niño research at KNMI. At KNMI, modules have been developed for the ECMWF ocean circulation model that can better represent the structure of the upper ocean ⁷⁾. Also, new methods are developed

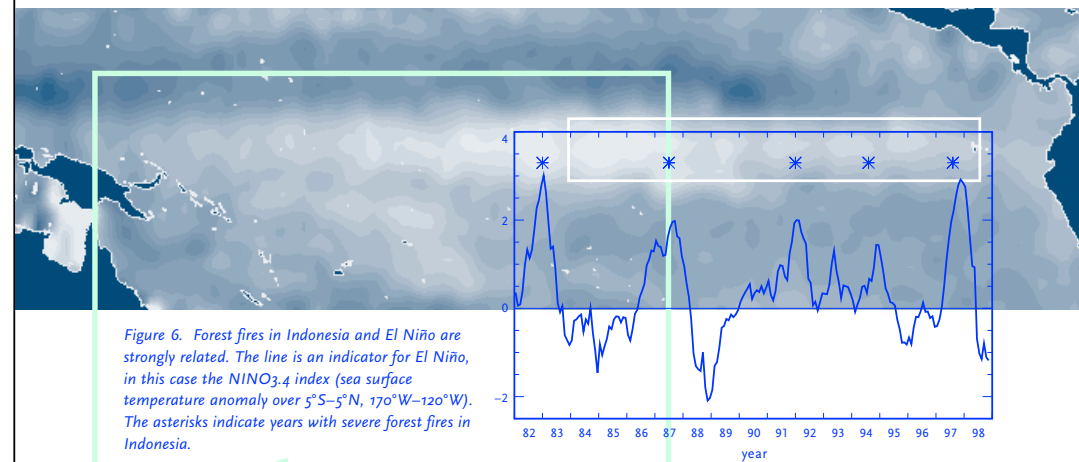


Figure 6. Forest fires in Indonesia and El Niño are strongly related. The line is an indicator for El Niño, in this case the NINO3.4 index (sea surface temperature anomaly over 5°S–5°N, 170°W–120°W). The asterisks indicate years with severe forest fires in Indonesia.

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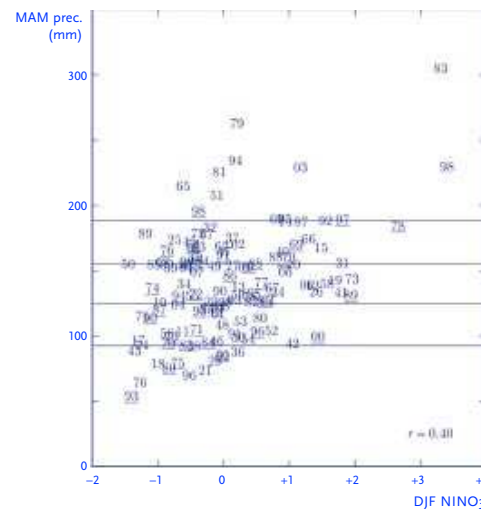


Figure 7. Scatter plot of spring precipitation in the Netherlands against the value of the NINO3 index (sea surface temperature anomaly over 5°S–5°N, 150°W–90°W) in the preceding winter, over the period 1857–1998. Underscored numbers refer to the 19th century, the horizontal lines denote the 10%, 33%, 67% and 90% percentiles of spring precipitation. The correlation between the variables is 0.40.

that aim at optimally incorporating the information from observations in the forecast model, and at giving an estimate of the uncertainty in the forecast.

Thanks to the collaborative effort in observations, theory and modelling of El Niño, useful forecasts can now be made of this capricious phenomenon. In turn, El Niño imposes some order on the chaotic weather over large parts of the globe, bringing the century-old dream of seasonal forecasts closer to reality.

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