

# ENSO forecast using a wavelet-based decomposition

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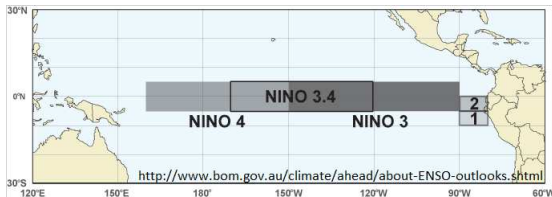
- 1 Introduction: El Niño Southern Oscillation
- 2 Wavelet-based mode decomposition
- 3 Results with the Niño 3.4 index
  - Decomposition and reconstruction of the Niño 3.4 index
  - Forecast of the Niño 3.4 index
  - Assessment through hindcasts
- 4 Conclusions

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## Analyzed data

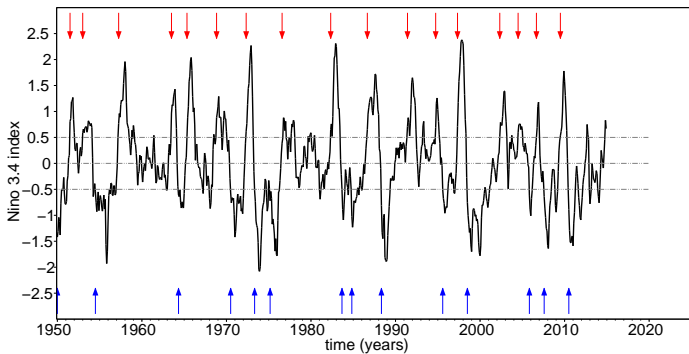
- Analyzed data: Niño 3.4 time series, i.e. monthly-sampled sea surface temperature anomalies in the Equatorial Pacific Ocean from Jan 1950 to Dec 2014 (<http://www.cpc.ncep.noaa.gov/>).



- El Niño event: SST anomaly above  $+0.5^{\circ}\text{C}$  during 5 consecutive months.
- La Niña event: SST anomaly below  $-0.5^{\circ}\text{C}$  during 5 consecutive months.

## El Niño/La Niña events

## ● Niño 3.4 index:



● 17 El Niño events.

● 14 La Niña events.

## Teleconnections

- Flooding in the West coast of South America
- Droughts in Asia and Australia
- Fish kills or shifts in locations and types of fish, having economic impacts in Peru and Chile
- Impact on snowfalls and monsoons, drier/hotter/wetter/cooler than normal conditions
- Impact on hurricanes/typhoons occurrences
- Links with famines, increase in mosquito-borne diseases (malaria, dengue, ...), civil conflicts
- ...

→ Importance of predicting El Niño/La Niña events.

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## Wavelet transform and spectrum

- The wavelet used in this study is the function

$$\psi(t) = \frac{\exp(i\Omega t)}{2\sqrt{2\pi}} \exp\left(-\frac{(2\Omega t + \pi)^2}{8\Omega^2}\right) \left(\exp\left(\frac{\pi t}{\Omega}\right) + 1\right),$$

with  $\Omega = \pi\sqrt{2/\ln 2}$ , which is similar to the Morlet wavelet ([3]).

- The wavelet transform of the signal is computed as:

$$Wf(a, t) = \int f(x) \bar{\psi}\left(\frac{x-t}{a}\right) \frac{dx}{a},$$

where  $\bar{\psi}$  is the complex conjugate of  $\psi$ ,  $t \in \mathbb{R}$  stands for the location/time parameter and  $a > 0$  denotes the scale parameter.

- The wavelet spectrum is computed as:

$$\Lambda(a) = E |Wf(a, \cdot)|$$

where  $E$  denotes the mean over time.



## Reconstruction and forecast

- We look for the scales  $a_1, \dots, a_J$  for which the wavelet spectrum  $\Lambda$  reaches a maximum.
- A good approximation of  $f$  is given by

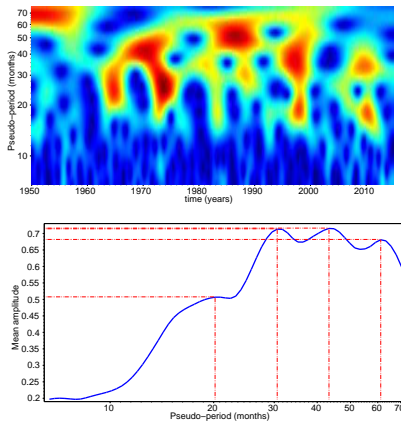
$$f(t) \approx \sum_{j=1}^J |Wf(a_j, t)| \cos(\arg Wf(a_j, t)).$$

- Since  $\cos(\arg Wf(a_j, t))$  roughly corresponds to a cosine with a period proportional to  $a_j$ , forecasts of the reconstructed signal can be obtained with smooth extrapolations (using Lagrange polynomials) of the amplitudes  $|Wf(a_j, t)|$ .

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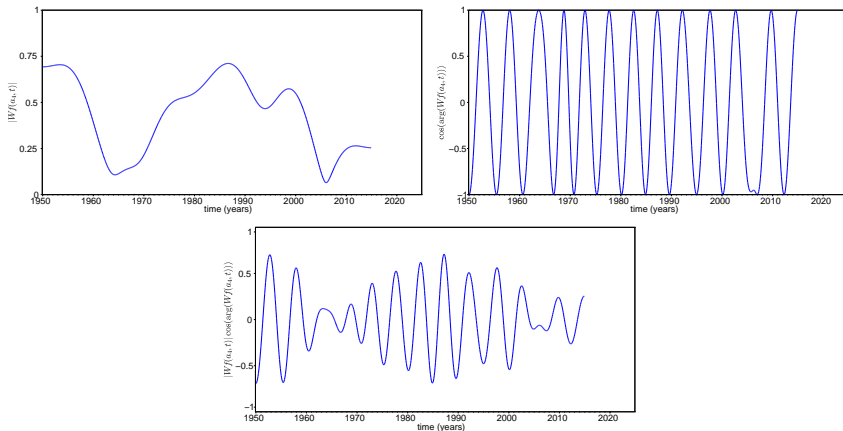
## Wavelet transform and spectrum



Top: Modulus of the wavelet transform of the signal (values range from 0 (dark blue) to 1.2 (dark red)). Bottom: Associated wavelet spectrum. Four peaks are detected, corresponding to periods of about 21, 31, 43 and 61 months.

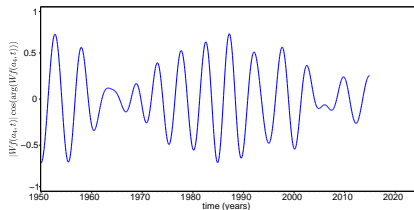
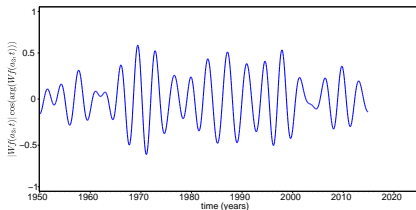
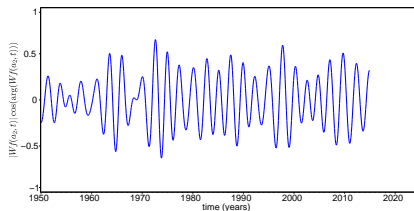
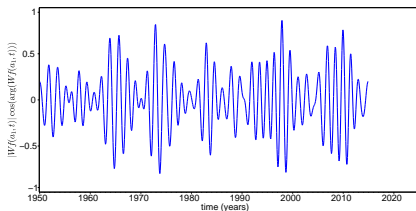
## Extraction of the components

Example: extraction of the 4th component (61 months-period).



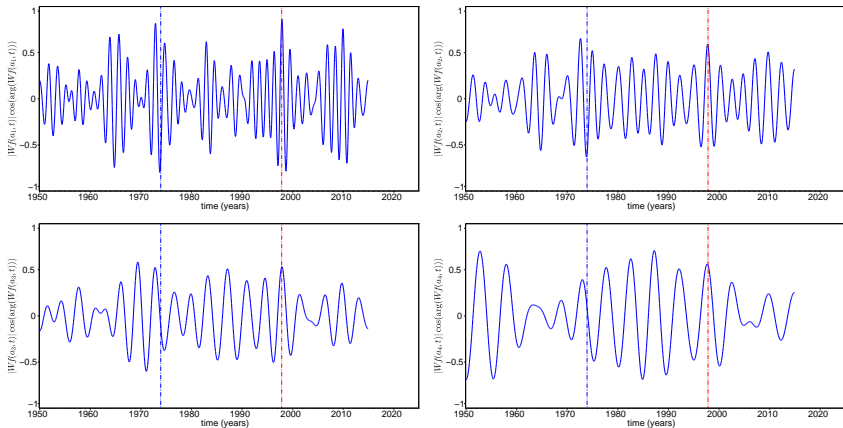
Top: amplitude  $|Wf(a_4, t)|$  (left) and oscillatory part  $\cos(\arg Wf(a_4, t))$  (right).  
 Bottom: the 4th component  $|Wf(a_4, t)| \cos(\arg Wf(a_4, t))$ .

## Extraction of the components



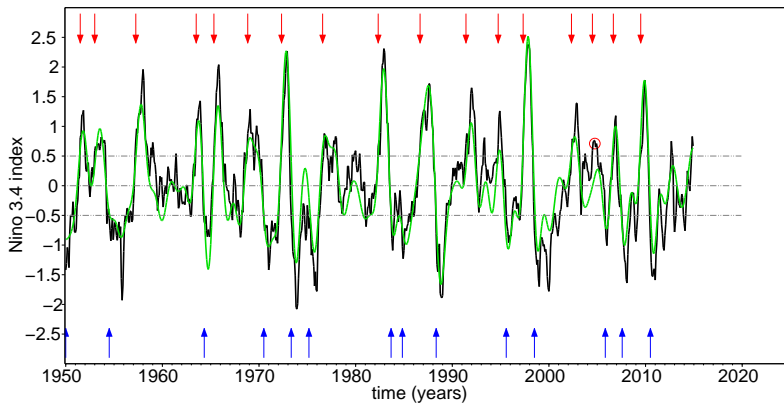
From top to bottom, from left to right: components extracted associated to periods of 21, 31, 43, 61 months.

## Extraction of the components



Red: occurrence of the strongest El Niño event. Blue: occurrence of the strongest La Niña event.

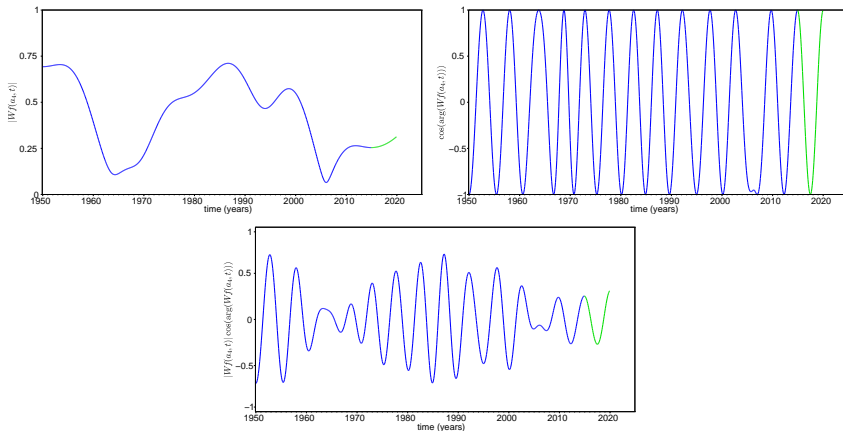
# Reconstruction of the Niño 3.4 index



- RMSE =  $0.366^{\circ}\text{C}$  and correlation = 0.894.
- 30/31 (96.7%) of El Niño/La Niña events recovered.

## Extrapolation of the components

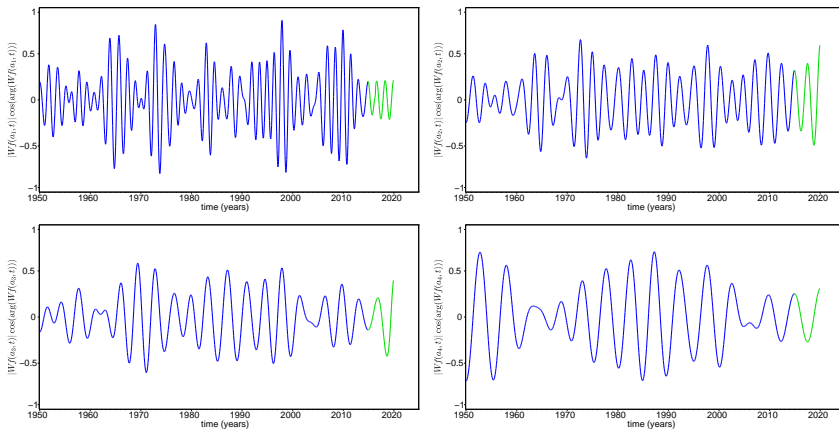
Example: forecast of the 4th component (61 months-period).



Top: amplitude (left) and oscillatory part (right). Bottom: the 4th component.  
Green parts: forecasts.

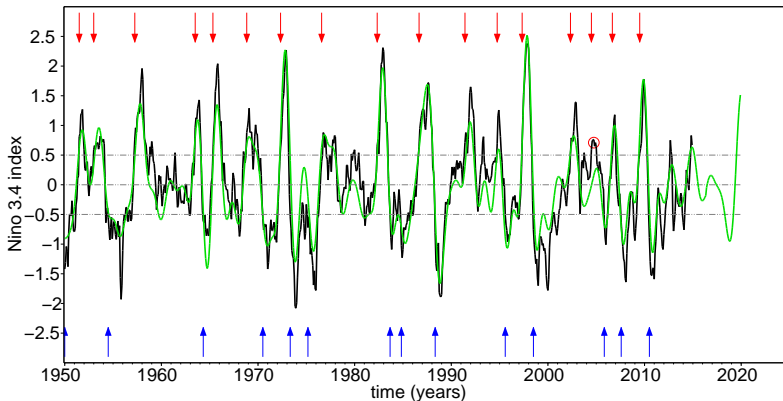


## Extrapolation of the components



From top to bottom, from left to right: components extracted associated to periods of 21, 31, 43, 61 months. Green parts: forecasts.

## Forecast of the Niño 3.4 index



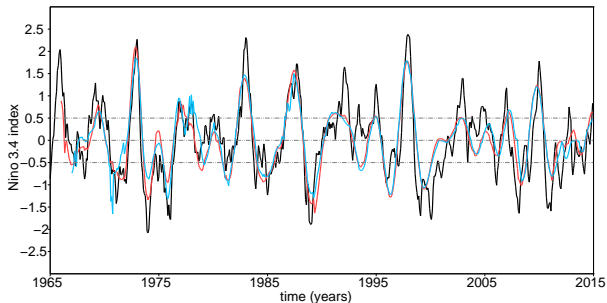
The next La Niña event should start early in 2018 and should be followed soon after by a strong El Niño event in the second semester of 2019.

## Hindcasts (running retroactive probing forecasts)

Example: 12 months hindcast starting in 1965.

- 1) Take the time series up to the time point  $t_0$  (e.g.  $t_0 = \text{Dec } 1964$ ).
- 2) Perform the decomposition and reconstruction of this signal.
- 3) Based on this particular decomposition and reconstruction, make a forecast (at least 12 months).
- 4) The 12th value of the forecast is the first value of the hindcast.
- 5) The initial condition  $t_0$  becomes  $t_0 + 1$  and steps 1 – 4 are repeated (the 12th value of the second forecast is the second value of the hindcast, etc.).
- 6) Each value of the hindcast is predicted 12 months in advance, and no data past the date the value is issued is used.

## Examples of hindcasts (12 and 24 months)

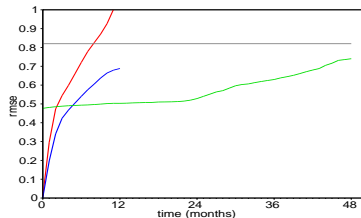
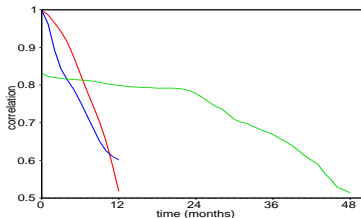


Red (resp. blue): 12 (resp. 24) months hindcast starting in 1965.

## Hindcasts: a few numbers

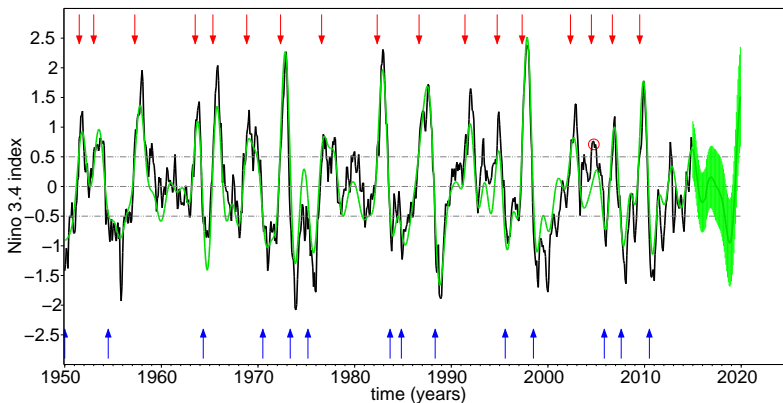
Proportion of El Niño/La Niña events accurately predicted and erroneously predicted (false positive) when using hindcasts (from 1965).

signal	predicted	false positive
12 months hindcast	92%	2
24 months hindcast	87%	2
36 months hindcast	78%	2
48 months hindcast	74%	3



Correlation/RMSE between the  $t$ -months hindcast and the signal as functions of the lead time  $t$  (green) and comparison with those of models from [2] (blue) and [7] (red).

## Forecast of the Niño 3.4 index



Error bars induced by the RMSE between the hindcasts and the original signal. Note that we predicted that current El Niño conditions wouldn't last long and wouldn't lead to a strong event.

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## Conclusions

- The WMD allows to decompose the Niño 3.4 index into four pseudo-periodic components (21, 31, 43, 61 months).
- The reconstruction allows to recover 30/31 El Niño/La Niña events.
- The components can be extrapolated to make a several years forecast.
- The quality of the forecast is assessed using hindcasts; most of the major events can be predicted several years in advance.
- Our method resolves the large variations of the signal and is particularly competitive for mid-term predictions.



## Conclusions








### Ideas for future work...

- Understanding the underlying mechanisms governing ENSO variability (i.e. the origin of the “pseudo-periodicities” detected in Niño 3.4).
- Checking if current models take these periods into account; if not, improving current models and forecasting procedures.
- Application to other climate indices (e.g. the North Atlantic Oscillation index where periods of  $\sim 30$ ,  $\sim 40$  and  $\sim 60$  months have also been found [4]).
- ...

Don't worry too much now... but be careful in 2018!

Thanks.

## Some references

-  K. Ashok, S.K. Behera, S.A. Rao, H. Weng, and T. Yamagata (2007)  
El Niño Modoki and its possible teleconnection.  
*J. Geophys. Res.*, 112(10.1029).
-  D. Chen, M.A. Cane, A. Kaplan, S.E. Zebiak, and D. Huang (2004)  
Predictability of El Niño over the past 148 years.  
*Nature*, 428(6984):733–736.
-  M.H. Glantz (2001)  
*Currents of Change: Impacts of El Niño and La Niña on climate society.*  
Cambridge University Press.
-  Y.G. Ham, J.S. Kug, and I.S. Kang (2009)  
Optimal initial perturbations for El Niño ensemble prediction with ensemble Kalman filter.  
*Climate dynamics*, 33(7):959–973.
-  T. Horii and K. Hanawa (2004)  
A relationship between timing of El Niño onset and subsequent evolution.  
*Geophysical research letters*, 31(6):L06304.
-  S.M. Hsiang, K.C. Meng, and M.A. Cane (2011)  
Civil conflicts are associated with the global climate.  
*Nature*, 476(7361):438–441.
-  G. Mabille and S. Nicolay (2009)  
Multi-year cycles observed in air temperature data and proxy series.  
*The European Physical Journal-Special Topics*, 174(1):135–145.

## Some references



S. Mallat (1999)  
*A Wavelet Tour of Signal Processing.*  
Academic Press.



S.J. Mason and G.M. Mimmack (2002)  
Comparison of some statistical methods of probabilistic forecasting of ENSO.  
*Journal of Climate*, 15(1):8–29.



S. Nicolay (2011)  
A wavelet-based mode decomposition.  
*Eur. Phys. J. B*, 80:223–232.



S. Nicolay, G. Mabile, X. Fettweis, and M. Erpicum (2009)  
30 and 43 months period cycles found in air temperature time series using the Morlet wavelet method.  
*Climate dynamics*, 33(7):1117–1129.



W. Wang, S. Saha, H.L. Pan, S. Nadiga, and G. White (2005)  
Simulation of ENSO in the new NCEP coupled forecast system model (CFS03).  
*Monthly Weather Review*, 133(6):1574–1593.



S.W. Yeh, J.S. Kug, B. Dewitte, M.H. Kwon, B.P. Kirtman, and F.F. Jin (2009)  
El Niño in a changing climate.  
*Nature*, 461(7263):511–514.



J. Zhu, G.Q. Zhou, R.H. Zhang, and Z. Sun (2012)  
Improving ENSO prediction in a hybrid coupled model with embedded temperature parameterisation.  
*International Journal of Climatology*, online, 2012.