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Gabor Analysis of the intraseasonal oceanic variability simulated in the tropical Pacific Ocean by a regional coupled model

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ABSTRACT

Intraseasonal oceanic variability simulated by an ocean-atmosphere general circulation model restricted to the tropical Pacific is studied using a newly developed method combining a Gabor analysis together with Hayashi's method. This analysis, applied to both the thermocline depth and zonal surface current, reveals strong equatorial Kelvin wave activity dominated by the first and second baroclinic modes. A strong interannual variability of this wave activity is also detected associated to the ENSO cycle, underlying the implication of such equatorial oceanic waves in the triggering, development, and termination of El Niño and La Niña events. Thanks to this new statistical technique, which is particularly effective when applied to time and amplitude modulated signals, two main periods emerge in the equatorial Kelvin wave activity. The first one is near 150 days and is associated with zonal wave number 1; it corresponds to the classical intraseasonal oceanic Kelvin wave activity, and indicates the predominance of the second baroclinic mode. The other, characterised by periods ranging from 40 to 75 days and by a zonal wave number 2, reveals pulses of strong activity of the first baroclinic mode.

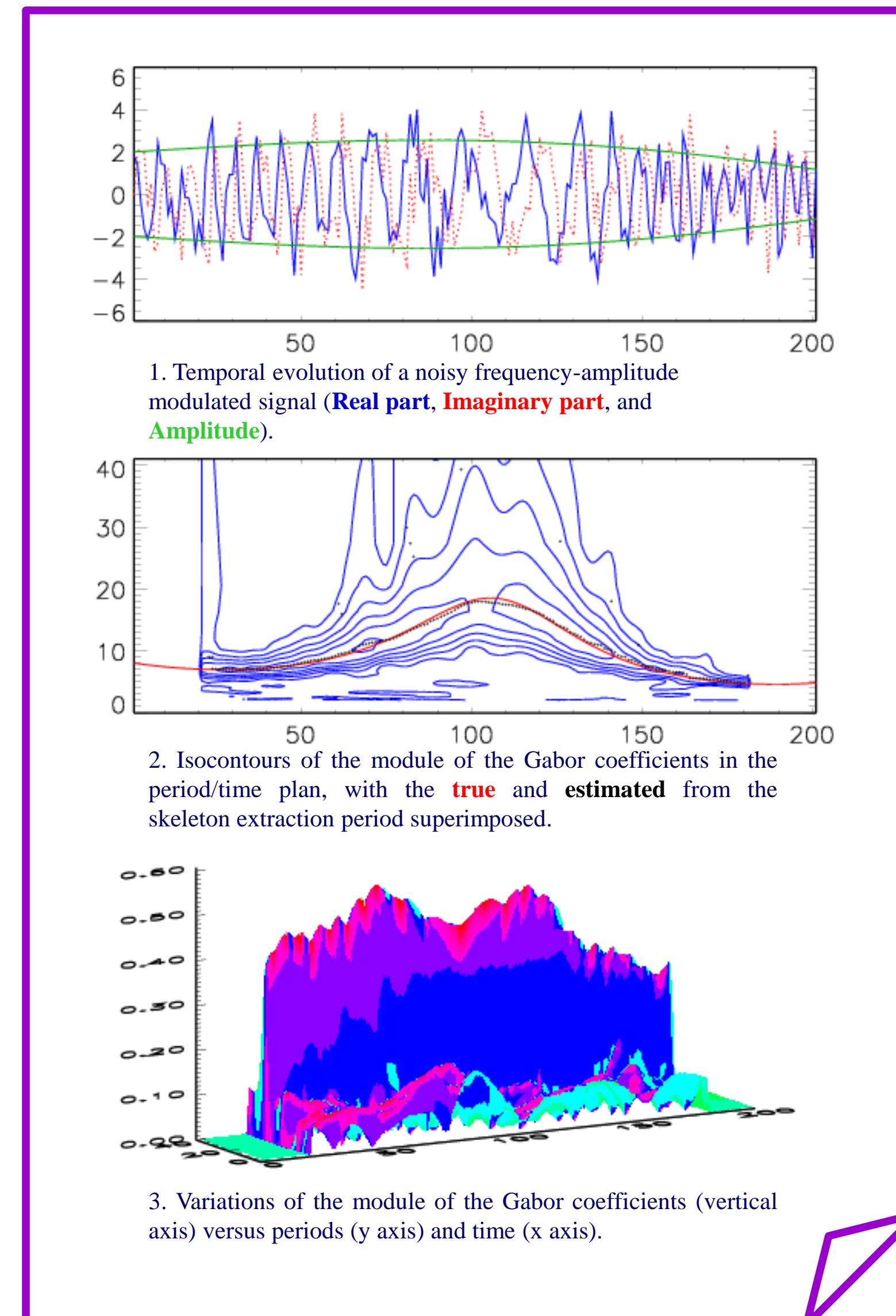
A NEW METHOD

to analyse frequency-amplitude modulated signals

Description of the method

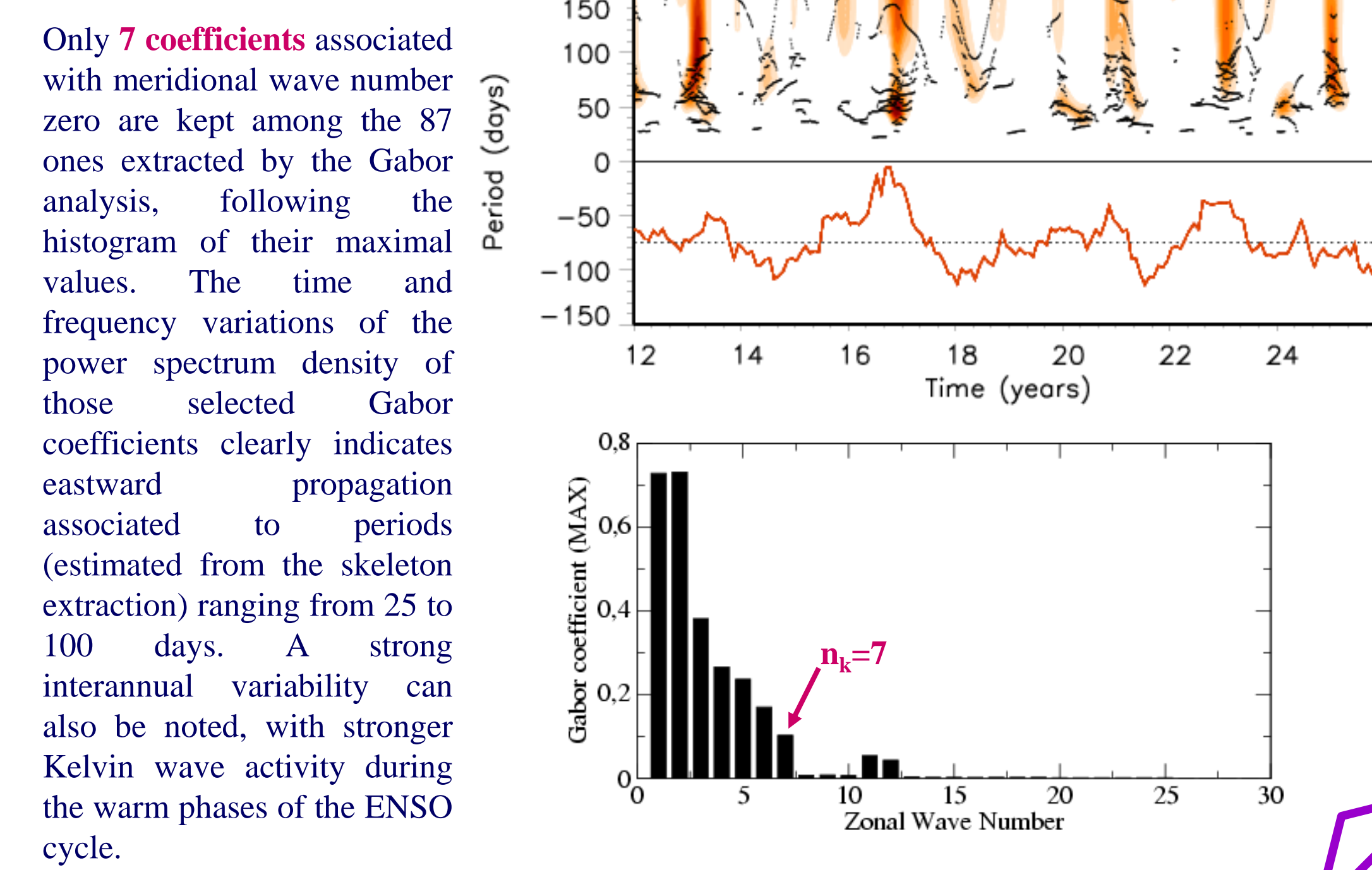
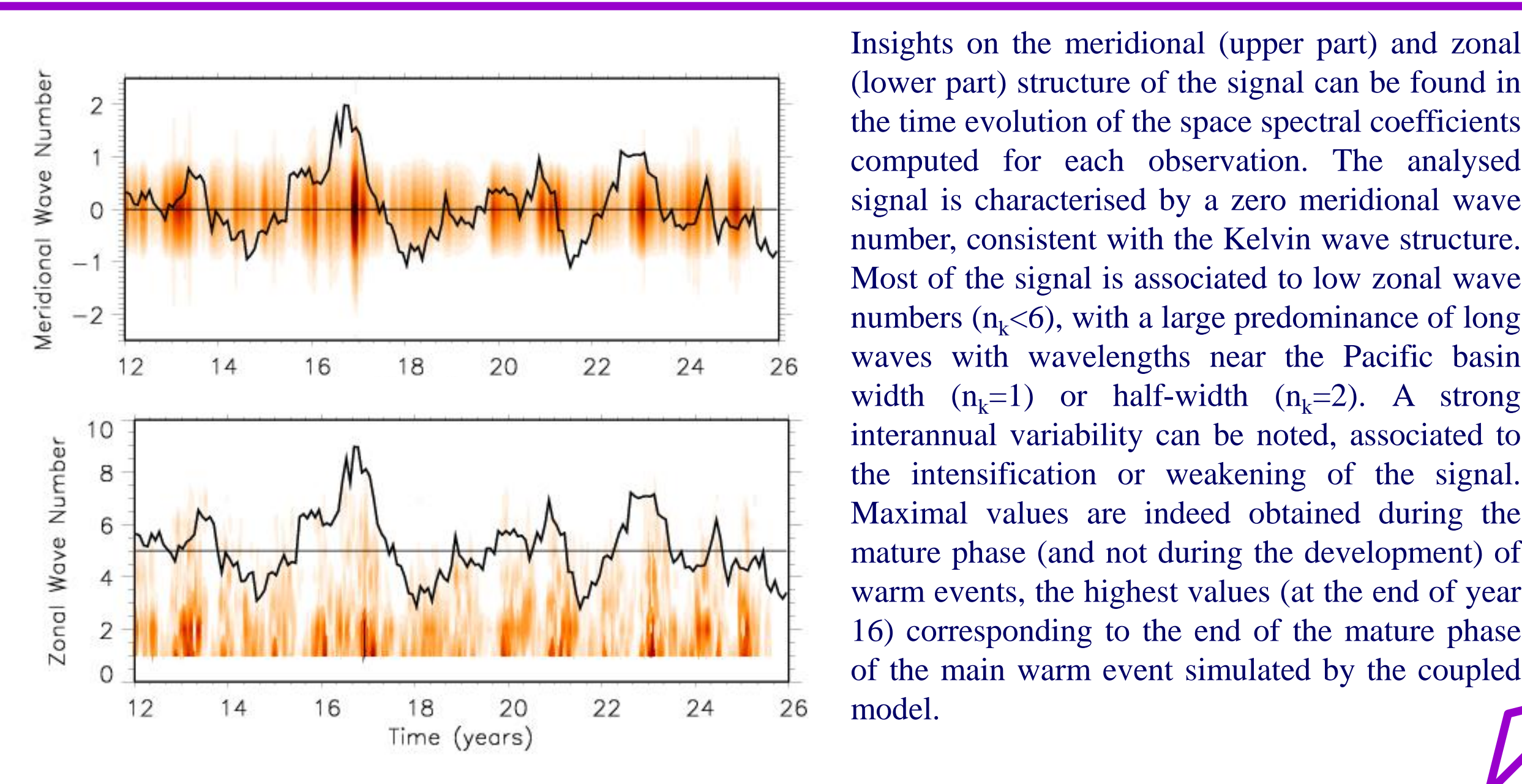
This method, which is particularly relevant for studying frequency-amplitude modulated signals, is based on Gabor Analysis (Torresani, 1995) and includes complementary diagnostics. The methodology used here can be split in 5 steps :

- Starting point:** a spectral analysis is performed in the space domain of the 2D field, i.e. space spectral coefficients (depending on the zonal and meridional wave numbers sampled by the Fourier transform) are computed for each observation.
- Selection:** taking into account the huge size of the resulting file gathering all the space spectral coefficients, only the most significant ones are selected for further analysis.
- Gabor Analysis:** A time-frequency analysis of the spatial spectral coefficients is then performed, using a Gabor analysis, i.e. a Fourier transform with a Gaussian sliding window, which provides the localization of the periods in time. This third step consists of computing the Fourier transform of the windowed signal, while sliding continuously over the whole available sample. Note that the choice of a Gabor analysis (instead of a classical Wavelet analysis) is purely due to step (4), as the Gabor analysis allows us to stay in the same framework as Hayashi (1977, 1979, 1982). Note also that the width of the window to be used (T_w) is directly connected to the maximal value of the periods to be retrieved with confidence (T_{max}):
$$T_w = 2 T_{max} + 1$$
- Havashi's partition:** The Hayashi's (1977, 1979) partition into standing and travelling parts is then performed, for all the space-time power spectra associated to the selected space spectral coefficients.
- Additional diagnostics:** Various tools are available in order to perform complementary diagnostics and facilitate physical interpretation, such as :
 - *) **skeleton extraction** of the Gabor transform (to get the instantaneous frequencies), using, following Torresani (1995) the stationarity properties of the Gabor coefficients phase;
 - **) **cluster analysis** of the local spectra, in order to display the time evolution of the dispersion relationship.



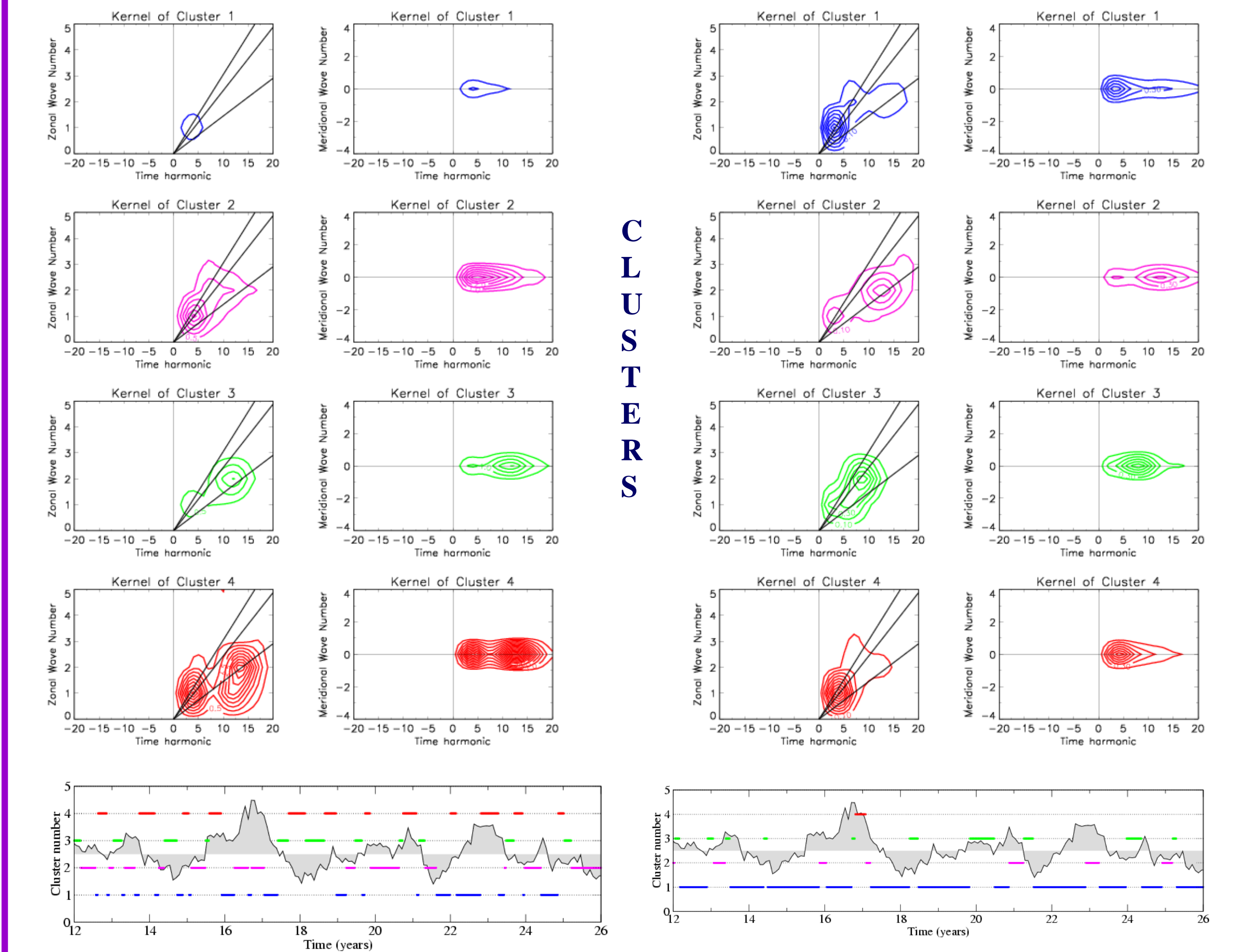
KELVIN WAVE ACTIVITY IN RELATION WITH ENSO as simulated by a coupled model for the tropical Pacific

The analysis of the oceanic Kelvin wave activity was performed using both the thermocline depth (estimated from the depth of the 20°C isotherm) and the surface zonal current. Please note that only the results relative to thermocline depth are displayed here. This study relies on the use of 15 years of pentadal data (i.e. 1095 observations) of thermocline depth in the equatorial wave guide (between 2°S and 2°N). A preliminary treatment was applied (1) to isolate the symmetric part (with respect to the equator) of the signal, and then (2) to filter the signal in order to only keep the part corresponding to eastward propagation. The half width of the Gaussian window (corresponding to the maximal period to be retrieved with confidence) was taken equal to 30 observations (150 days), which excludes signals linked to the seasonal cycle while keeping the whole intraseasonal variability.



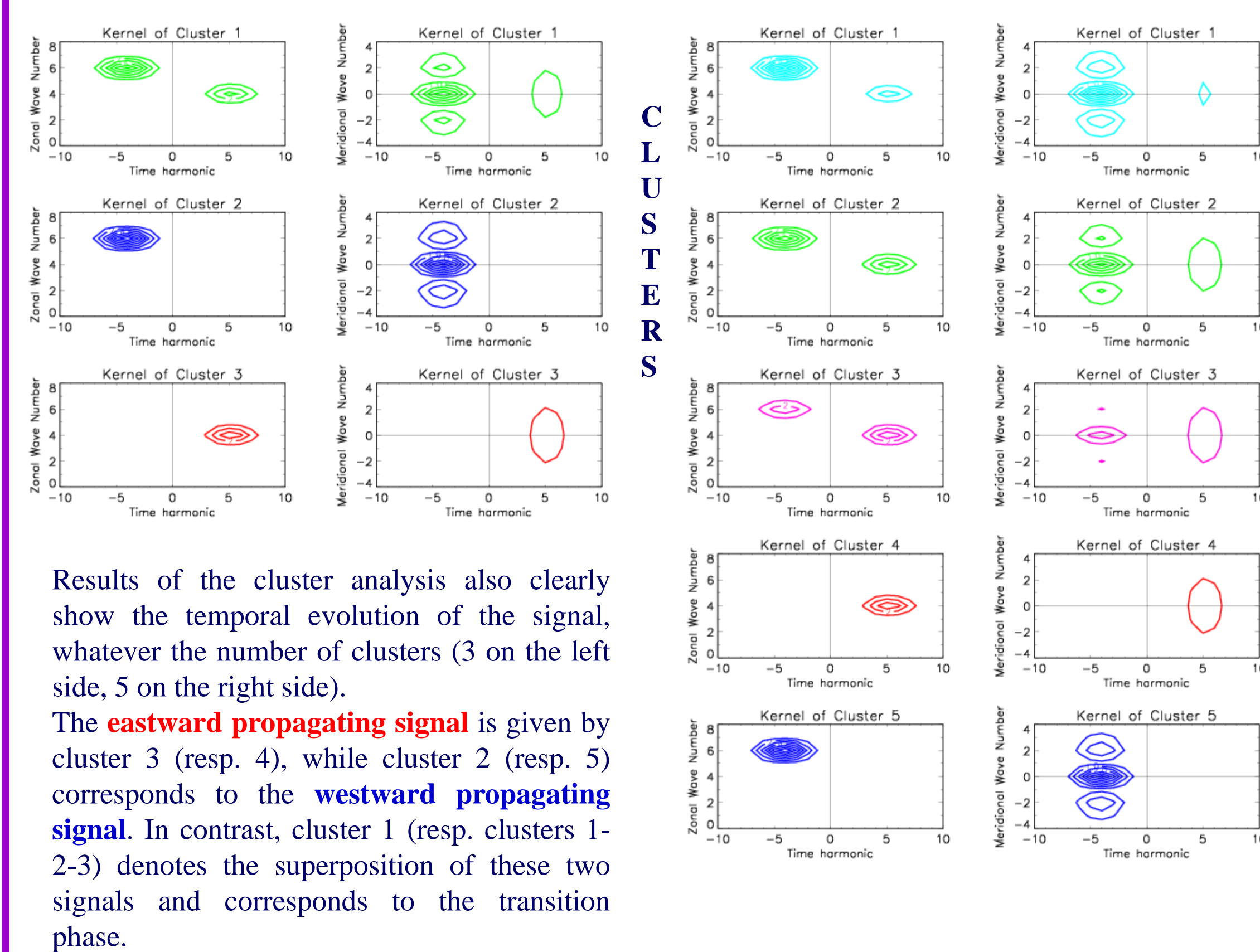
Temporal evolution of the oceanic Kelvin wave activity

In order to highlight the temporal evolution of the spectral characteristics of the eastward propagating signals, two cluster analyses have been performed using the local spectra isolated by the Gabor analysis. The results of such a classification using 4 classes is given by two sorts of plots: the first one gathers the four corresponding local spectra displayed as a function of the zonal (resp. meridional) wave number, while the second one illustrates their occurrence during the 15 years of the study.

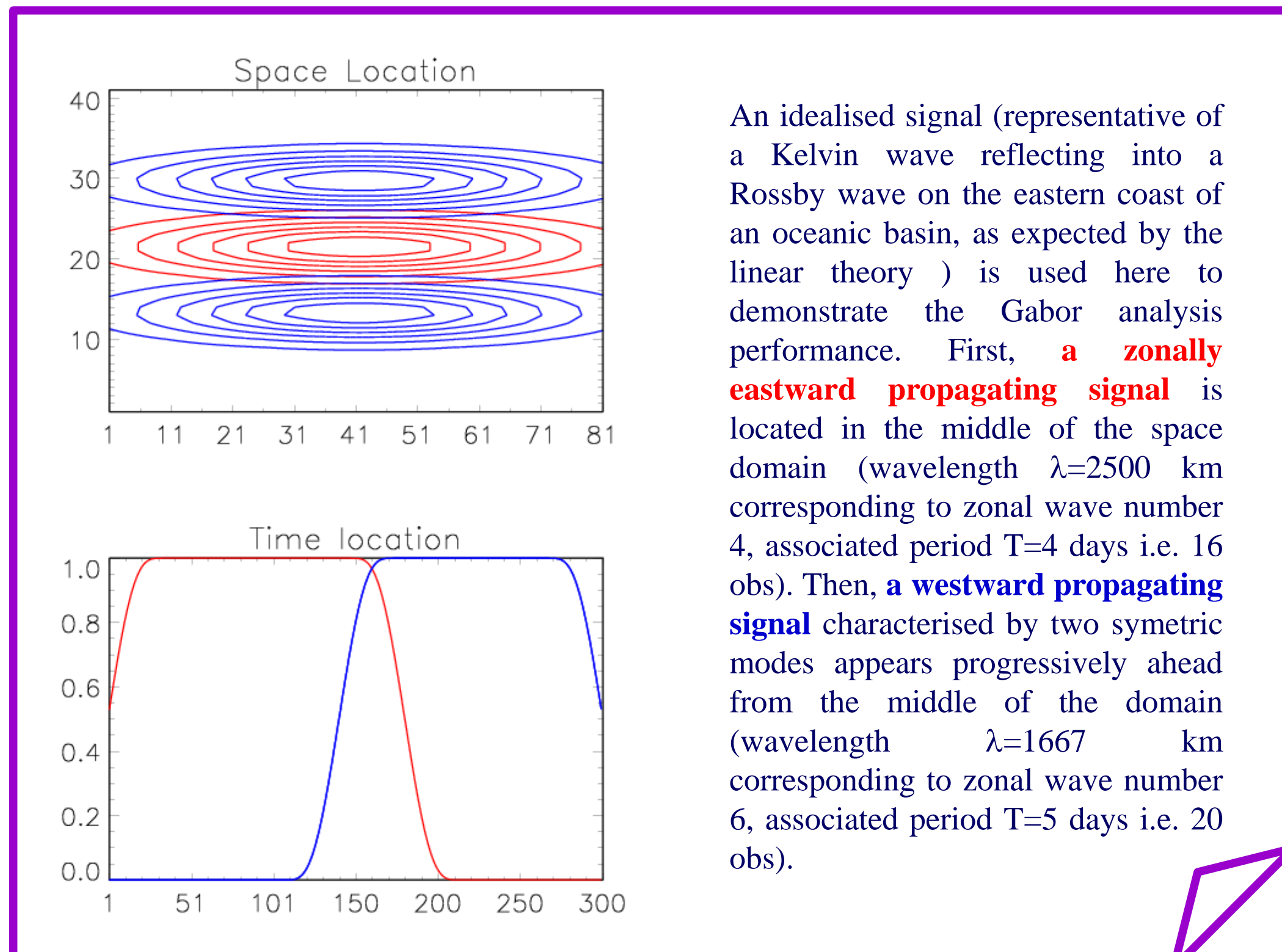
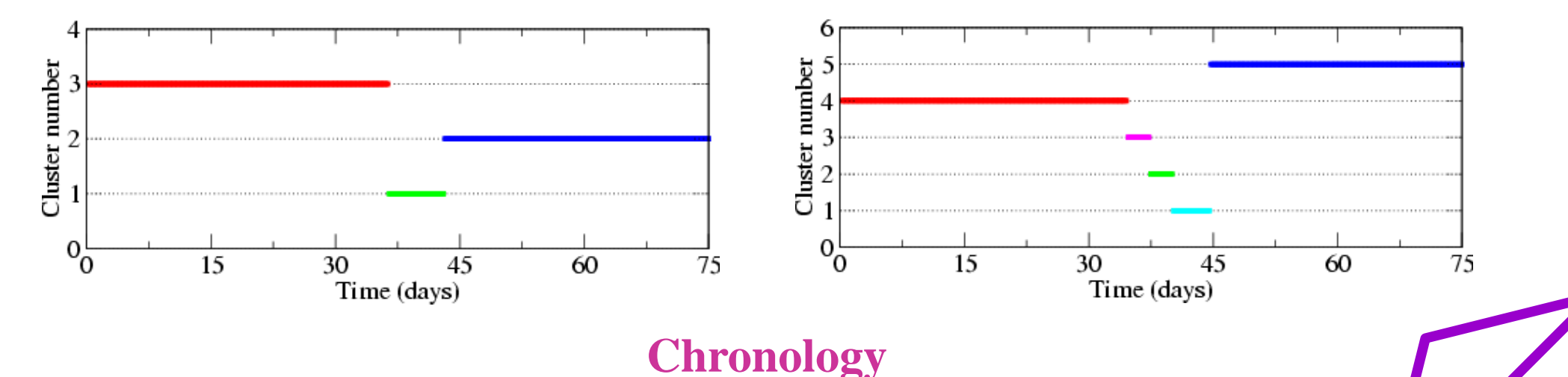


The first one (left part of the plot) is performed on the signal as it stands, i.e. without any normalisation. Clusters 1 and 2 are both associated with zonal wave number 1 and time harmonic 4 (corresponding to a period near 150 days); both denote the occurrence of the second baroclinic mode of Kelvin waves. In contrast, clusters 3 and 4 can be interpreted as the first baroclinic mode of Kelvin waves : both are associated with zonal wave number 2 and time harmonic 12 and 14, respectively (i.e. periods near 50 and 42 days, respectively). The second one (right part of the plot) is performed using results of the Gabor analysis normalised by the total energy, in order to highlight changes in the structure (and not in the intensity) of the propagating waves. Clusters 1 and 4 appear as very similar to cluster 2 issued from the first classification, denoting the occurrence of the second baroclinic mode with zonal wave number 1 and a period near 150 days. Cluster 2 is mainly associated with zonal wave number 2 and periods ranging from 40 to 60 days, corresponding to the first baroclinic mode of Kelvin waves (previously described by clusters 3 and 4 in the first classification). Last, cluster 3 (associated with zonal wave number 2 and period near 75 days) denote the occurrence of higher frequency Kelvin first baroclinic mode.

Results of the cluster analysis



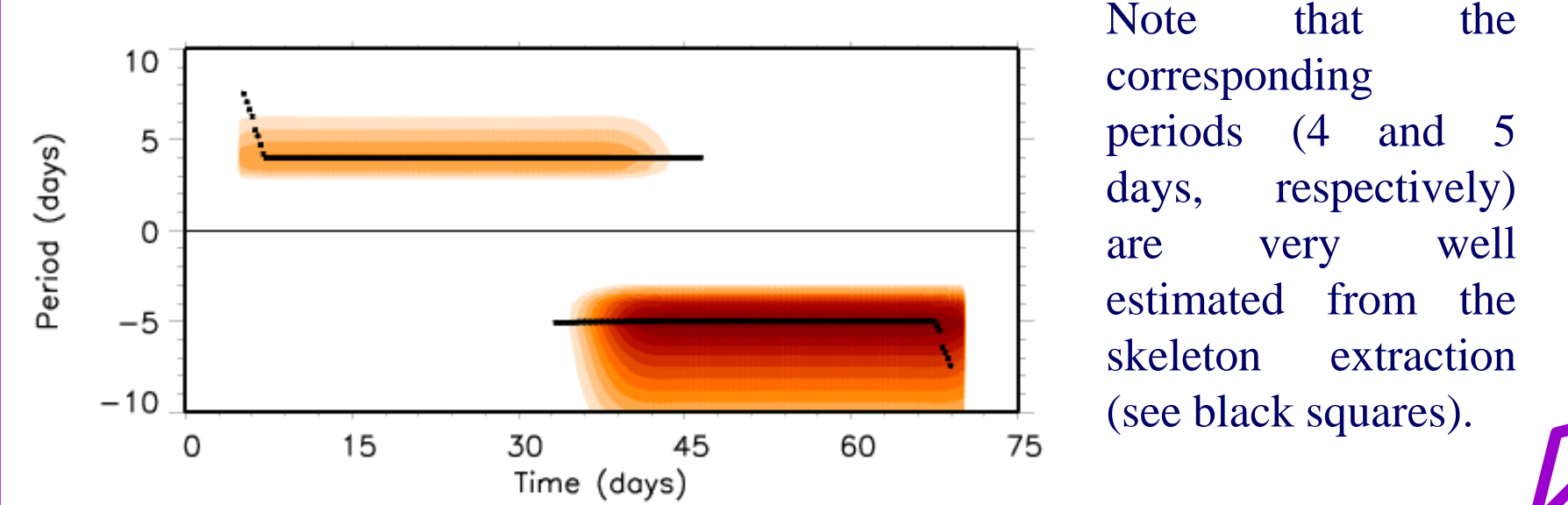
Results of the cluster analysis also clearly show the temporal evolution of the signal, whatever the number of clusters (3 on the left side, 5 on the right side). The eastward propagating signal is given by cluster 3 (resp. 4), while cluster 2 (resp. 5) corresponds to the westward propagating signal. In contrast, cluster 1 (resp. clusters 1-2-3) denotes the superposition of these two signals and corresponds to the transition phase.



An idealised signal (representative of a Kelvin wave reflecting into a Rossby wave on the eastern coast of an oceanic basin, as expected by the linear theory) is used here to demonstrate the Gabor analysis performance. First, a zonally eastward propagating signal is located in the middle of the space domain (wavelength $\lambda = 2500$ km corresponding to zonal wave number 4, associated period $T = 4$ days i.e. 16 obs). Then, a westward propagating signal characterised by two symmetric modes appears progressively ahead from the middle of the domain (wavelength $\lambda = 1667$ km corresponding to zonal wave number 6, associated period $T = 5$ days i.e. 20 obs).

Application to an idealised signal

The time and frequency variations of the power spectrum density of the Gabor transform clearly indicate two types of propagation, with the eastward signal appearing first in the upper part of the plot (prograde part of the signal corresponding to positive periods), and the westward signal (retrograde part corresponding to negative periods, lower part of the plot) replacing it progressively in the second time interval.



CONCLUSION

This new method constitutes a very useful tool for the study of frequency and amplitude modulated signals, as it can provide :

1. The evolution of the period of the signal with time,
2. The temporal evolution of the local spectra, giving insights on the temporal evolution of the dispersion relationship,
3. A simple way to separate (following Hayashi's work) the propagative from the stationary part of the signal
4. And, as a consequence, a useful way to filter spatially and temporally a signal, with, the potential of filtering the eastward from the westward propagating part (or in contrast, the stationary part).

Its application to oceanic signals issued from a coupled ocean-atmosphere simulation highlights the occurrence of intraseasonal Kelvin wave activity during the ENSO cycle, and provides a precise description of the main baroclinic modes involved, with the associated zonal wave numbers and periods.

Much work is still to be done, for example:

1. The improvement of the skeleton extraction algorithm,
2. The improvement of the method used to separate the propagative from the stationary part of the signal,
3. The extension of the Gabor analysis to the space domain,
4. The use of wavelet analysis instead of Gabor analysis, which would allow us to deal with signals with very rapid or abrupt characteristic variations.

References

- Hayashi, Y., 1977: On the coherence between progressive and retrogressive waves and a partition of space time power spectra into standing and traveling parts. *J. Appl. Meteor.*, 16, 368-373.
- Hayashi, Y., 1979: A generalized method of resolving transient disturbances into standing and traveling waves by space-time spectral analysis. *J. Atmos. Sci.*, 36, 1017-1029.
- Hayashi, Y., 1982: Space-time spectral analysis and its applications to atmospheric waves. *J. Meteor. Soc. Japan*, 60, 156-171.
- Torresani, B., 1995: Analyse continue par ondelettes. Savoir Actuels, Interédition/CNRS Editions, pp239.