Explosive development of winter storm Xynthia over the Southeastern North Atlantic Ocean

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Response to anonymous Referee #1

We thank the anonymous referee for the comments which have highlighted parts of our manuscript requiring further clarification. In our responses, all section, page and line numbers refer to the NHESSD document. The text in italics corresponds to the reviewer's comments.

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General Ideas

Scientific Significance: Good
Scientific Quality: Fair
Presentation Quality: Good

This paper reinforces previous studies on cyclogenesis and, in particular, the contribution of the subtropical zones in some explosive developments. The case of Xynthia was especially painful and harmful to some countries of Western European. The work is well structured and organized, providing relevant ideas in the development of extratropical cyclone and ciclógenesis with an important subtropical component. Due to these characteristics, it is worth being published in the journal.

General comments and suggestions

Xynthia. The name of storm must be explained. This is a non official name taking into account at the European NWS (National Weather Service) but very popular in the media.

We agree with the reviewer that we should include a sentence explaining the naming of pressure systems. Xynthia was the name given by the Institute of Meteorology of the Freie Universität Berlin, which has named all pressure systems in Central Europe since 1954 (http://www.met.fu-berlin.de/adopt-avortex/historie/). These names are used by the German Weather Service and other governmental and non-governmental institutions in Europe.

This information is also to be added into the new version of the manuscript.

Xynthia suffered an explosive cyclognesis process at low latitudes. It may be useful to devote specifically some lines to this topic in the paper.

We agree with the reviewer that Xynthia's explosive cyclogenesis occurs at a relatively low latitude, while most of such events are typical of mid-to-high latitudes. This is now specifically mentioned in the manuscript, together with the full definition of explosive cyclogenesis and assessment of Xynthia's maximum deepening rate within this context (on section 3.3, page 451, line 21).

…"below 975 hPa. The concept of explosive cyclogenesis was first introduced by Bergeron (1954), referring to rapidly developing storms with a drop in central pressure of at least 24 hPa in 24 hours. Since this critical deepening rate concerned lows developing at high latitudes, typically around 60°N, the threshold was later generalized by Sanders and Gyakum (1980) to all extra-tropical cyclones, through the introduction of a geostrophic adjustment factor to any latitude φ (sin 60° / sin φ). Xynthia develops at relatively low latitudes, which is uncommon for this type of phenomena (e.g., Trigo 2006). The pressure drop of about 20 hPa during the first 18 hours of maximum deepening occurs at an average latitude of 37.5°N, which corresponds to an equivalent rate of 28.5 hPa at 60°N. The system underwent further intensification during the next hours, being therefore well within the explosive cyclogenesis classification. After this very fast developing stage, the warm sector already covered half of the Iberian Peninsula"…

SST abbreviation may be explained when it appears in the first time.

The use of the SST abbreviation is clarified in the new version of the manuscript.

1 Introduction

Comments

High values of EPT (equivalent potential temperature) at low levels tend to reduce the static stability across the troposphere and, so to reinforce the interaction between low level cyclone and high level systems, both of them leading cyclogenesis: the cyclogenesis processes and interactions are more effective than normal conditions when static stability is low.

We agree with the reviewer's comment. We have made an effort to clarify this point in the introduction.

2 Data and Methodology

Comments

Mimic_TPW products may be considered for those days (, see section 3.4). Subtropical irruption of humidity tongue or atmospheric river:*

ftp://ftp.ssec.wisc.edu/pub/mimic_tpw/animations/natl/2010/20100226T000000anim72.gif

ftp://ftp.ssec.wisc.edu/pub/mimic_tpw/animations/natl/2010/

> We are grateful to the reviewer for pointing us this dataset that is useful for this manuscript and other studies. We have introduced as auxiliary material the movie of Total Precipitation Water starting on 00:00 UTC of the 26th February 2010 (and ending at 24.00 UTC of the 28th).

448 20. The sentence of the text is not clear: "This is a typical feature for Northern Hemisphere cyclones…." All types of cyclone? Subtropical/hybrid cyclones? Extratropical cyclones and ciclógenesis?

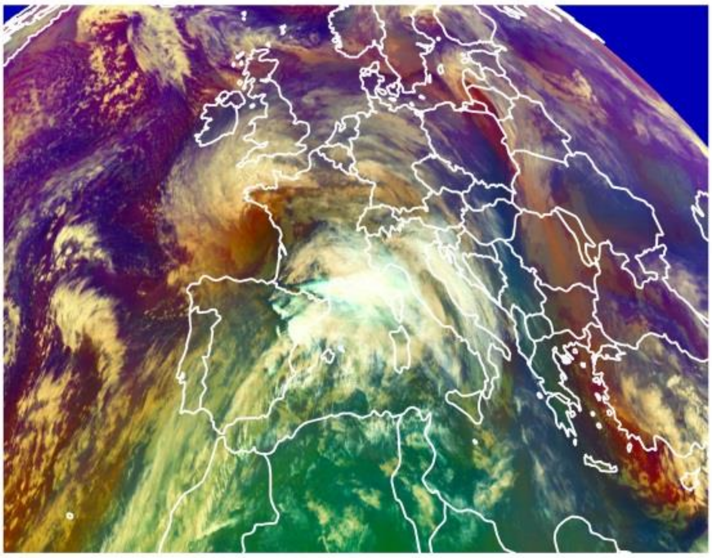
> We agree that this sentence could be misleading. The sentence now reads "This is a typical feature for Northern Hemisphere extratropical cyclones"…

3 Results

3.3 General suggestion: Eumetrain/eport/archive web page allows and provides the combination of IR/WV/VIS imagery and ECMWF fields, so it is possible to improve the figure 5.

http://eumetrain.org/eport/archive_euro.html?width=1280&height=1024

> We were aware of Eumetrain site. Unfortunately there is no data there prior to September 2010. The combination of WV (centred at 6.2 µm and 7.3 µm), ozone (9.7 µm) and thermal IR (10.8 µm) SEVIRI/MSG channels into the so-called air mass RGB composite (EUMETRain) was performed by the authors and is now included in the new Fig. 5. The Meteosat air mass composite shows high/mid-level in white/pinkish colour, while dry stratospheric air is revealed in reddish colours. The figure below is now shown as Fig.5d and the caption was updated.



"Composite image (often referred to as "air mass RGB") obtained with the following Meteosat channels for 28 Feb 2010 close to 00 UTC: water vapour (6.2 µm and 7.3 µm), ozone (9.7 µm) and thermal infrared (10.8 µm)."

453 5. Comments

The concept of WCB, warm conveyor belt is not clear when it is explained in the text. The cloud band observing IR imagery is just only one significant part of the WCB. There are zones, forming de WCB, but they are not detected by IR channels. WCB is formed by cloud, moisture zones, etc.

The descending dry air from aloft must be explain using WV channels rather than IR imagery.

The authors agree with the reviewer. The IR image was replaced by an air mass composite (please see reply to previous comment), which enhances areas with different moisture contents, temperatures and cloud heights. As detailed in the text, Fig. 5d shows a cloud band with increasing cloud top heights from south-west to north-east as would be expected along the rising relatively warm and wet air within the warm conveyor belt. Encircling the cyclone centre from the southern tip towards the direction of the movement, a region without clouds, and appearing in reddish colour indicating dry air/ low tropopause in this type of composite image, is noticeable upon the satellite image over the Bay of Biscay. On section 3.3, page 453, lines 5 to 11, text is to be replaced by the following:

"Figure 5d shows a composite image, often referred to as "air mass RGB" (http://oiswww.eumetsat.org/IPPS/html/MSG/RGB/AIRMASS/), obtained with the following Meteosat for 28 Feb 2010 close to 00 UTC. This composite makes use of water vapour (6.2 µm and 7.3 µm), ozone (9.7 µm) and one thermal infrared (10.8 µm) channels, enhancing differences in temperature, moisture and cloud height: high/mid-level appear white/pinkish, while dry stratospheric air is revealed in reddish colours. This figure shows the cloud structure of the cyclone just before making landfall. A band of clouds stretching from the NA towards the Mediterranean and running parallel to the cold front may be assigned to the warm conveyor belt of the cyclone system. Figure 5d shows increasing cloud top heights from south-west to north-east as would be expected along the rising relatively warm and wet air within the warm conveyor belt. The cold conveyor belt bends back around the cyclone centre at the north-western edge. Encircling the cyclone centre from the southern tip towards the direction of the movement, a region without clouds, and appearing in reddish colour indicating dry air/ low tropopause in this type of composite image, is noticeable upon the satellite image over the Bay of Biscay. This may be explained"…

*3.4 Moisture and TPW (Total Precipitation Water). See * en 2*

May this technique (based on E-P field) be used with subtropical/hybrid cyclones?

As far as we know, there is no limitation to the application of this technique to all categories of cyclones. Different research groups are currently engaged in this type of applications to various phenomena.

455 20 Is there any evidence or consideration about SST anomaly origin??

A negative NAO phase induces positive SST anomalies over this area of the subtropical North Atlantic (cf. Wanner et al., 2001, Surveys in Geophysics 22: 321–382; their Fig. 9b). Further El-Niño events are known to enhance SSTs over the subtropical North Atlantic in the following months (cf Wanner et al., 2001, their Fig. 8; Enfield and Mayer, 1997). This may also have been the case for the winter 2009/2010. We had made the option in the original submission of the paper not to include such information as the "origin" of the SST anomaly is a complete different issue and would need detailed modelling studies for demonstration of evidence. Following the reviewer's suggestion, we have added a sentence to the text stating that the SST anomaly is coherent with NAO and ENSO influence, even though we make no statement about causality.

Additionally, we have introduced a reference of a recent modelling study evaluating the influence of the SST anomaly and latent heat fluxes on the development of Xynthia (Ludwig et al., 2013, QJRMS, under revision).

456 5 Comments

Enhanced EPT at 850 hPa may increase de baroclinic processes or temperature/moisture gradients between polar-subtropical air masses, which in turn it may reinforce the cyclogenesis processes. The cold front and frontogenesis are well developed as shown IR imagery. In other words, low latitudes baroclinic processes need intense tongue of moisture and temperature to supply additional energy in explosive cases.

Thanks for the comment. We have included a sentence in the new version of the text, clarifying this idea stated by the reviewer.

4 Discussion and concluding remarks

Pag. 457 14 ".. the total number of cyclones may decrease in this region …" But, what type of cyclones: subtropical, extratropical, hybrid???

We are mentioning only extratropical cyclones. The wording was changed to make this clear. One more reference was added (Zappa et al., 2013, JCLIM, in press).

Figures and captions

Figure 1:

Source of images?

This storm has been well documented among the media and there are numerous photos in the internet, most of them without the source. In this case the figures included on Figure 1 were downloaded from a BBC website (http://news.bbc.co.uk/2/hi/in_pictures/8541808.stm).

We have included this reference in Figure's 1 legend.

Places and locations are not familiar for "basic" readers

We understand that this could be misleading. Thus the 4 sites are now identified with a number instead of a "*" on the map of Fig. 2.

"a) b).. c)" are not standard tags in this article. See figure 5 for a, b.. into a square.

We changed "a) b) … d)" to a square.

Figure 3: Where is Santander and the buoy location?

Even if we write on pg 449 ln 20 “According to data available from the Spanish Oceanographic Institute (IEO) a buoy moored 22 miles north of Santander”, we have now indicated the approximate position of the buoy with a symbol (e.g. ◊) on Fig. 2.

Figure 4: “a” and “b” do not appear in the figure and the captions.

We added “a” and “b”, both to the figures and caption.

New references to be included:

Bergeron, T., 1954. Reviews of modern meteorology-12: The problem of tropical hurricanes. Q. J. R. Meteorol. Soc., 80: 131-164.

Enfield, D.B. and Mayer, D.A. 1997. Tropical Atlantic SST variability and its relation to El Niño-Southern Oscillation, J. Geophys. Res. 102: 929-945.

Ludwig P., Pinto J.G., Reyers M., Gray S.L., 2013. The role of anomalous SST over the Southeastern North Atlantic in the explosive development of winter storm Xynthia. Quart J R Meteorol Soc (submitted)

Sanders, F. and J. R. Gyakum, 1980. Synoptic-dynamic climatology of the “bomb”. Mon. Wea. Rev., 108: 1589-1606.

Wanner H., Bronnimann S., Casty C., Gyalistras D., Luterbacher J., Schmutz C., Stephenson D.B., Xoplaki E. 2001. North Atlantic Oscillation-concepts and studies. Surv. Geophys. 22: 321-382.

Zappa, G., L.C. Shaffrey, K.I. Hodges, P.G. Sansom, and D.B. Stephenson, 2013. A multi-model assessment of future projections of North Atlantic and European extratropical cyclones in the CMIP5 climate models. J. Clim., in press, doi:10.1175/JCLI-D-12-00573.1

Note: To be corrected over the text:

Liberato et al. (2013) should be Liberato et al. (2012)

Correct reference:

Liberato, M. L. R., Ramos, A. M., Trigo, R. M., Trigo, I. F., Durán-Quesada, A. M., Nieto, R. and Gimeno, L. (2012) Moisture Sources and Large-Scale Dynamics Associated With a Flash Flood Event, in Lagrangian Modeling of the Atmosphere (eds J. Lin, D. Brunner, C. Gerbig, A. Stohl, A. Luhar and P. Webley), American Geophysical Union, Washington, D. C.. doi: 10.1029/2012GM001244