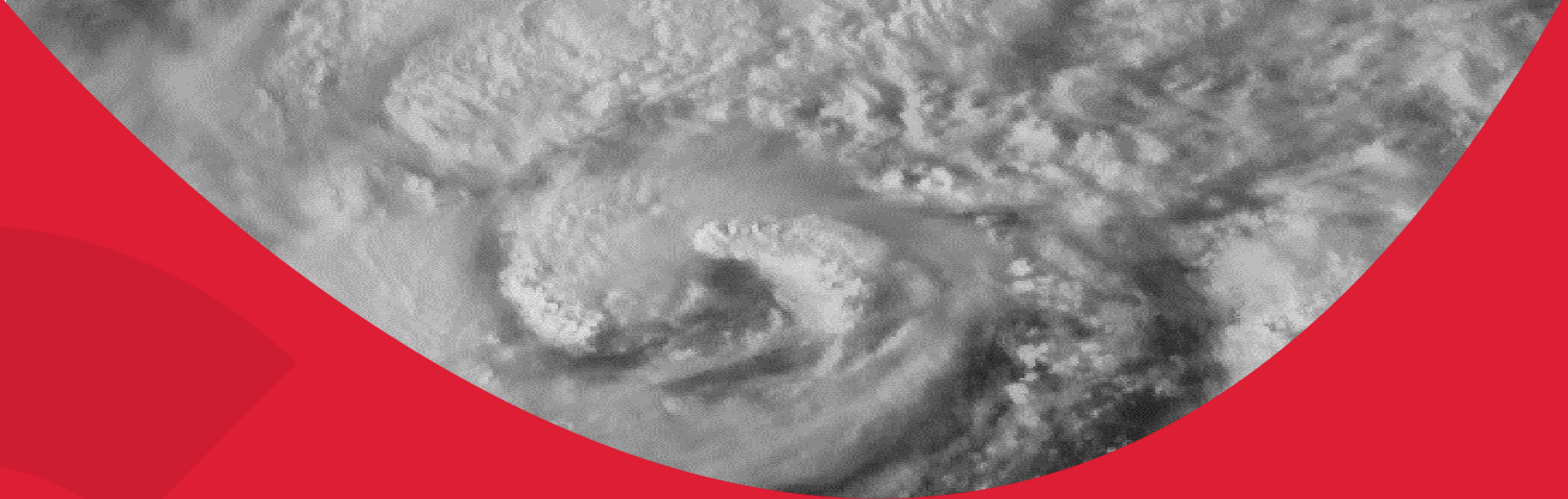

CICLONES SUBTROPICALES, TRANSICIONES TROPICALES Y EXTRATROPICALES

Autor: Juan Jesús González Alemán

Fecha de la presentación: 01/09/2022

EMBAJADA DE ESPAÑA EN GUATEMALA

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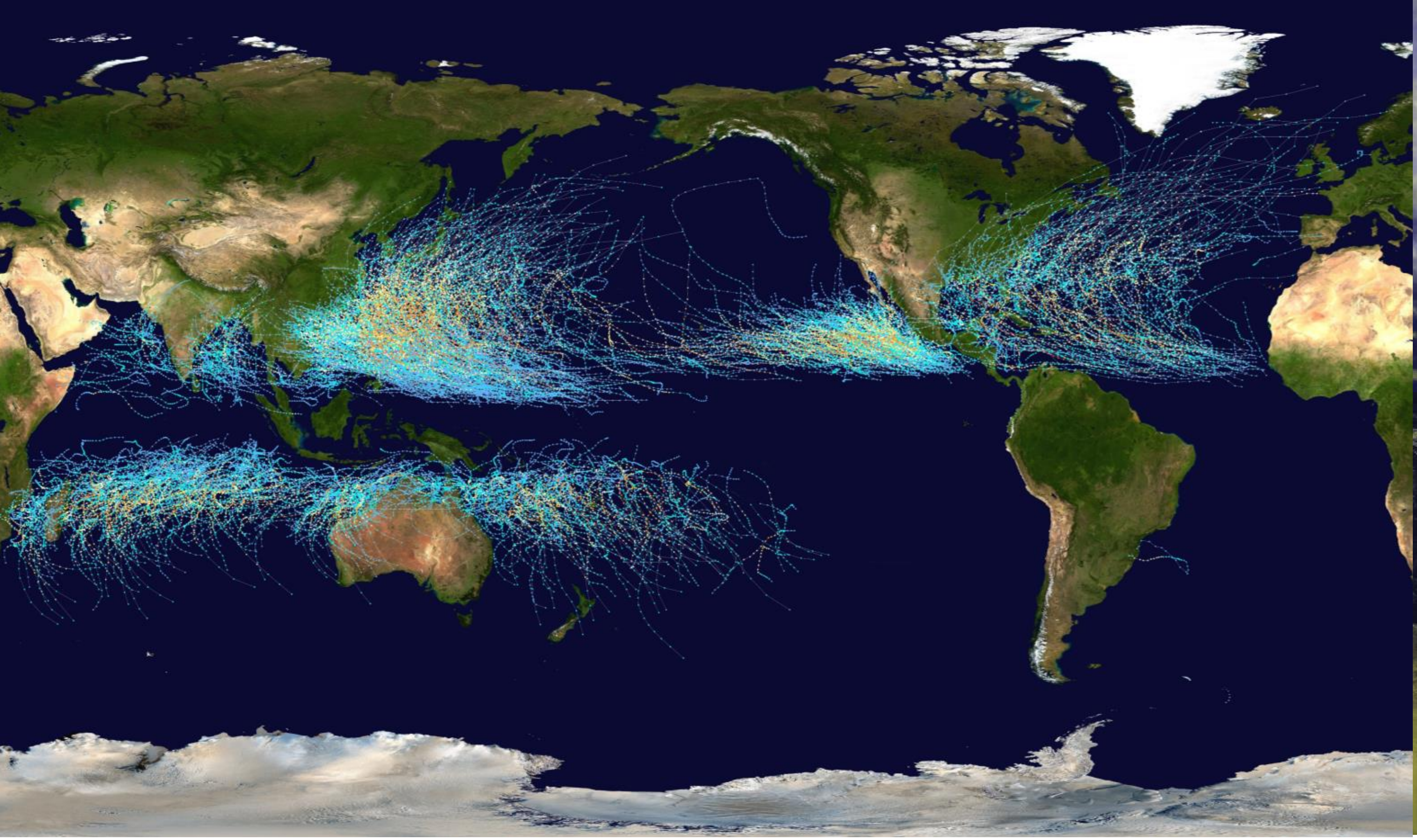

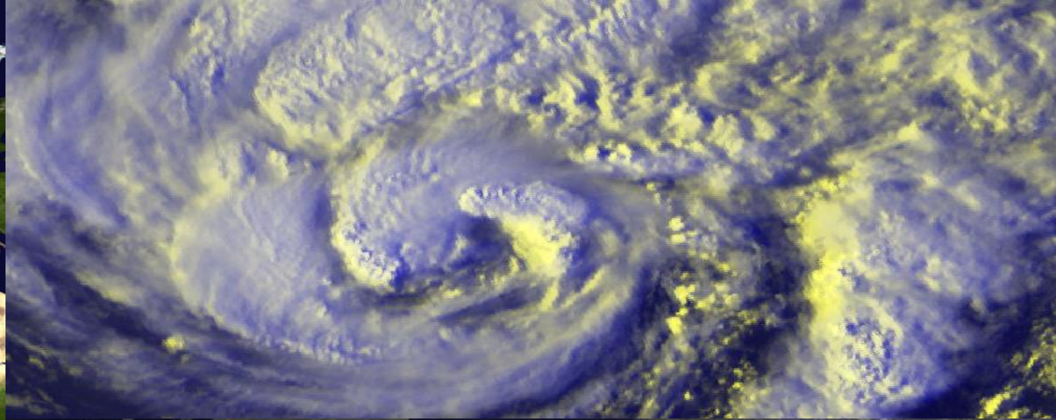

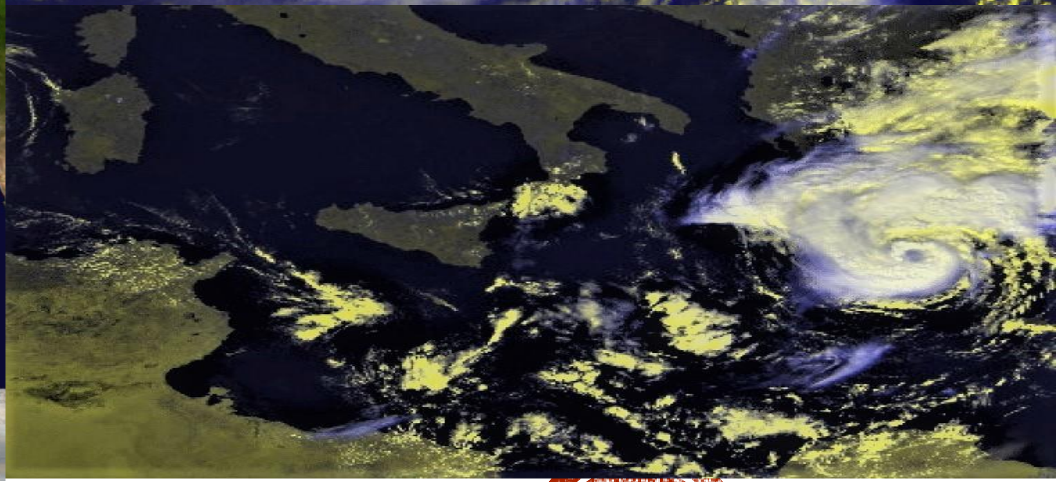

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VICEPRESIDENCIA CUARTA DEL GOBIERNO
MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA Y EL RETO DEMOGRÁFICO

AEMet
Agencia Estatal de Meteorología

METEOROLOGÍA TROPICAL:
CICLONES CON CARACTERÍSTICAS TROPICALES

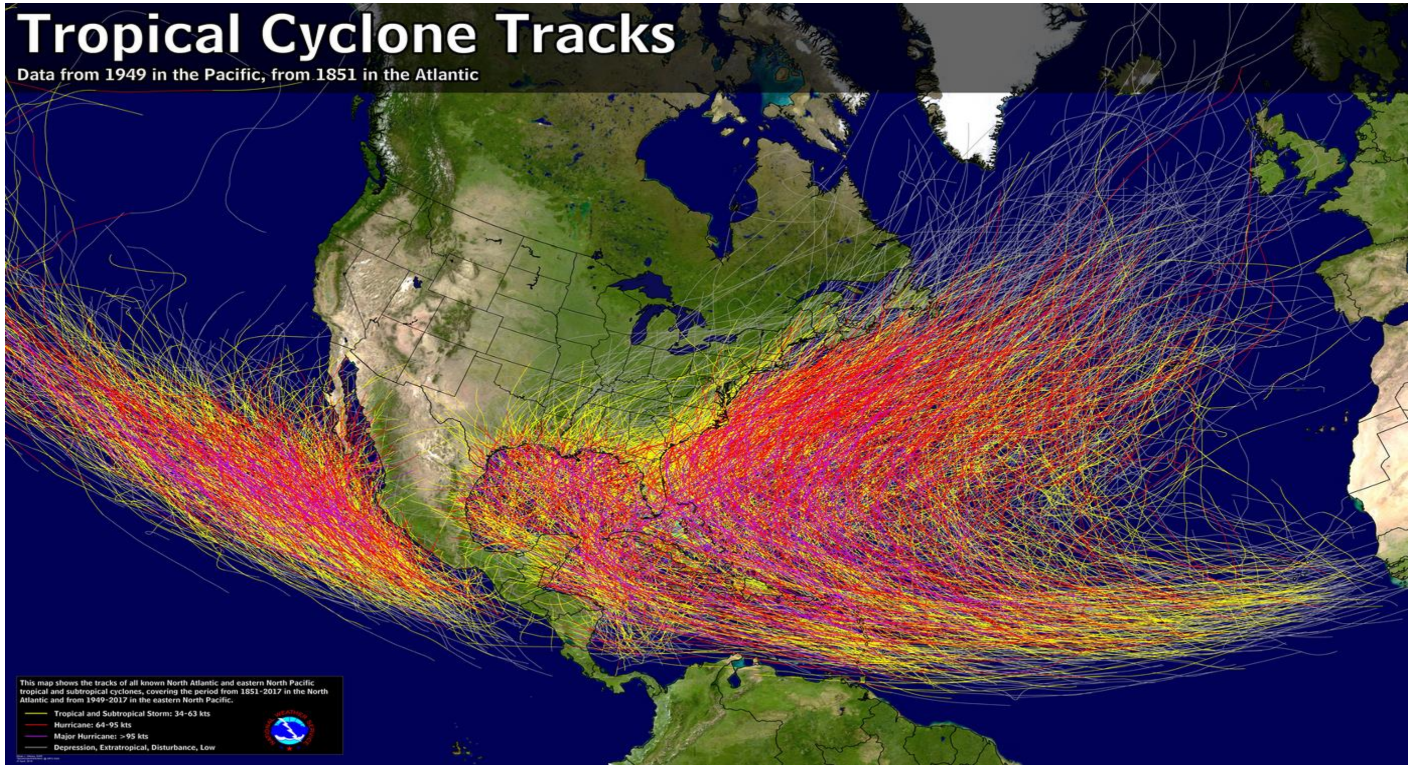
Juan Jesús González Alemán

Doctor en Física y Meteorólogo Superior del Estado

Área de Modelización. Departamento de Desarrollo y Aplicaciones

INTRODUCCIÓN

- Durante los últimos 15 años, se han detectado casos de ciclones tropicales o con características tropicales, que han afectado a la cuenca oriental Atlántico Norte (Alex, Ophelia, Pablo, Theta, etc..) e incluso con impacto en las Islas Canarias (Delta) y en la península Ibérica (Vince, Leslie) cuando según la climatología de ciclones tropicales no es lo normal.



INTRODUCCIÓN

- Vince (2005) fue el primer huracán formado en una zona atlántica cercana a la península, siendo el primer ciclón tropical en alcanzar tierras europeas desde que el Centro Nacional de Huracanes (NHC) empieza a registrarlos en 1851, época en la que el periodo de observación instrumental comienza a ser fiable. Aunque a partir de 1966 es cuando es más comparable con la actual (satélites). Aunque Pablo (2019) lo ha superado.

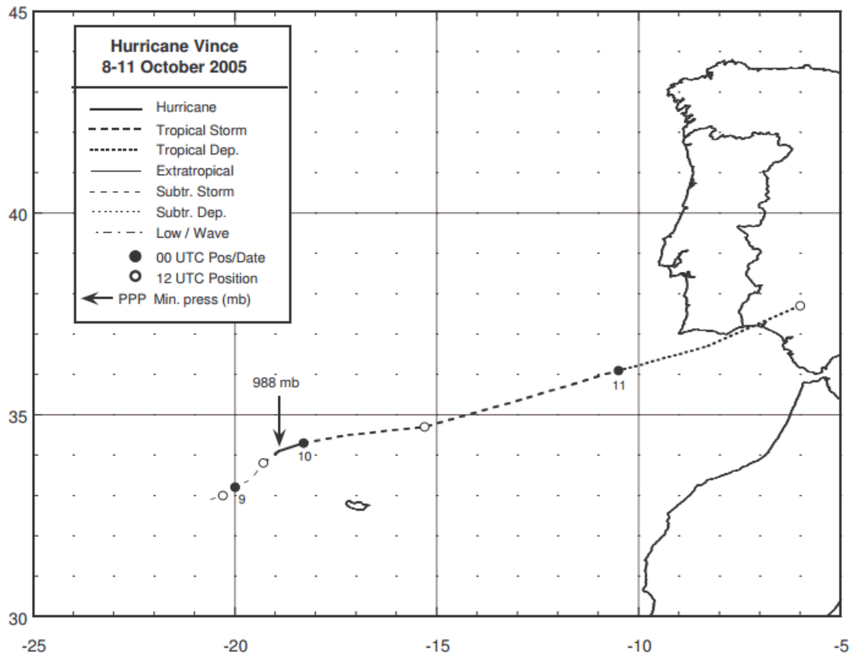
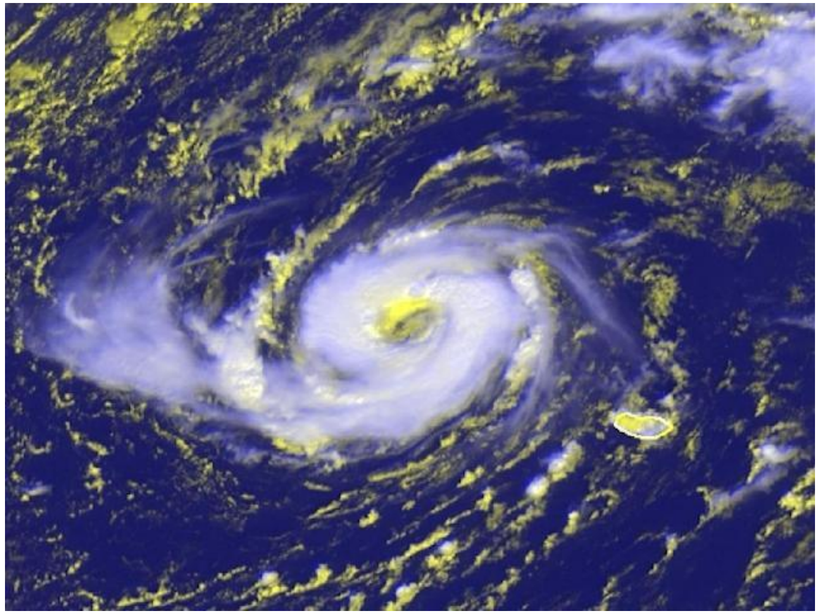
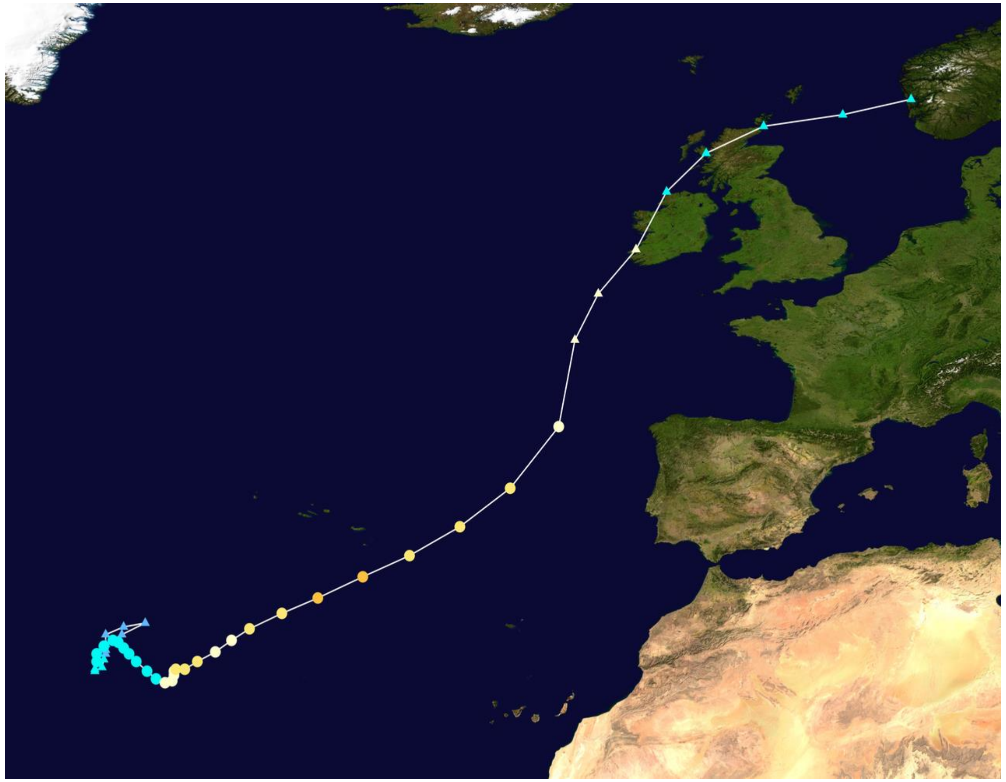


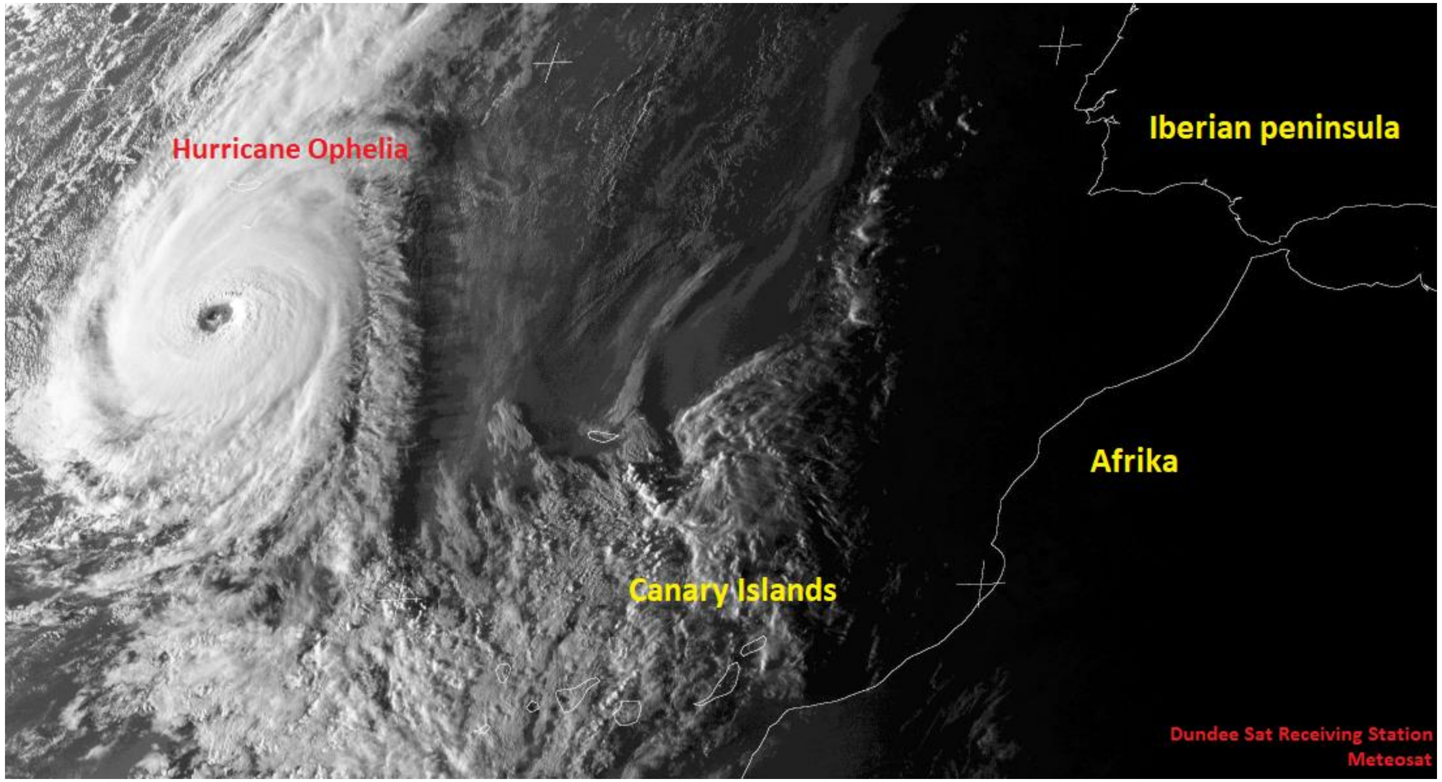
Figure 1. Best track positions for Hurricane Vince, 8-11 October 2005.



INTRODUCCIÓN

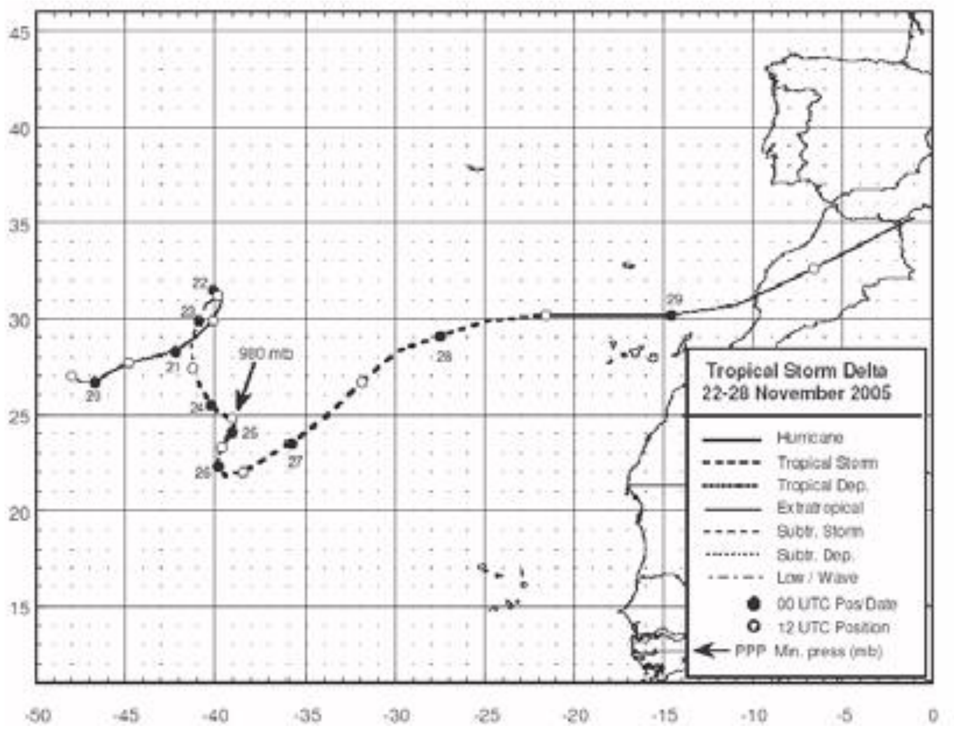
- Huracán Ofelia (2017): el primer huracán "major" de categoría 3 documentado tan al este en el Atlántico Norte.

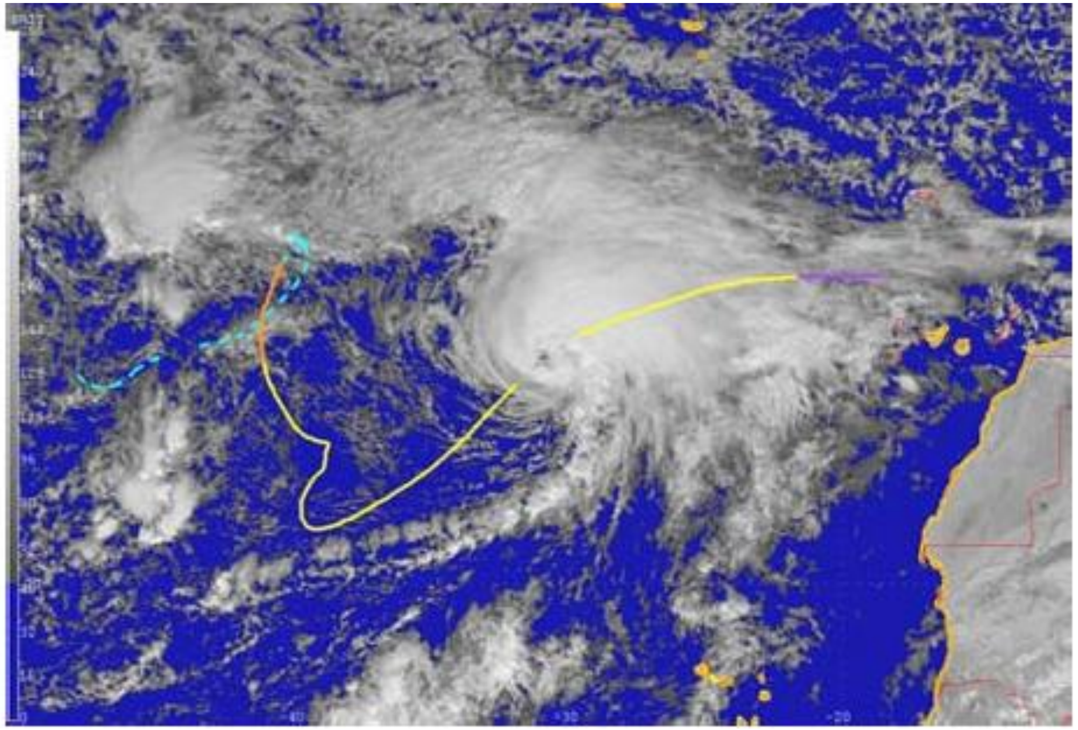




INTRODUCCIÓN

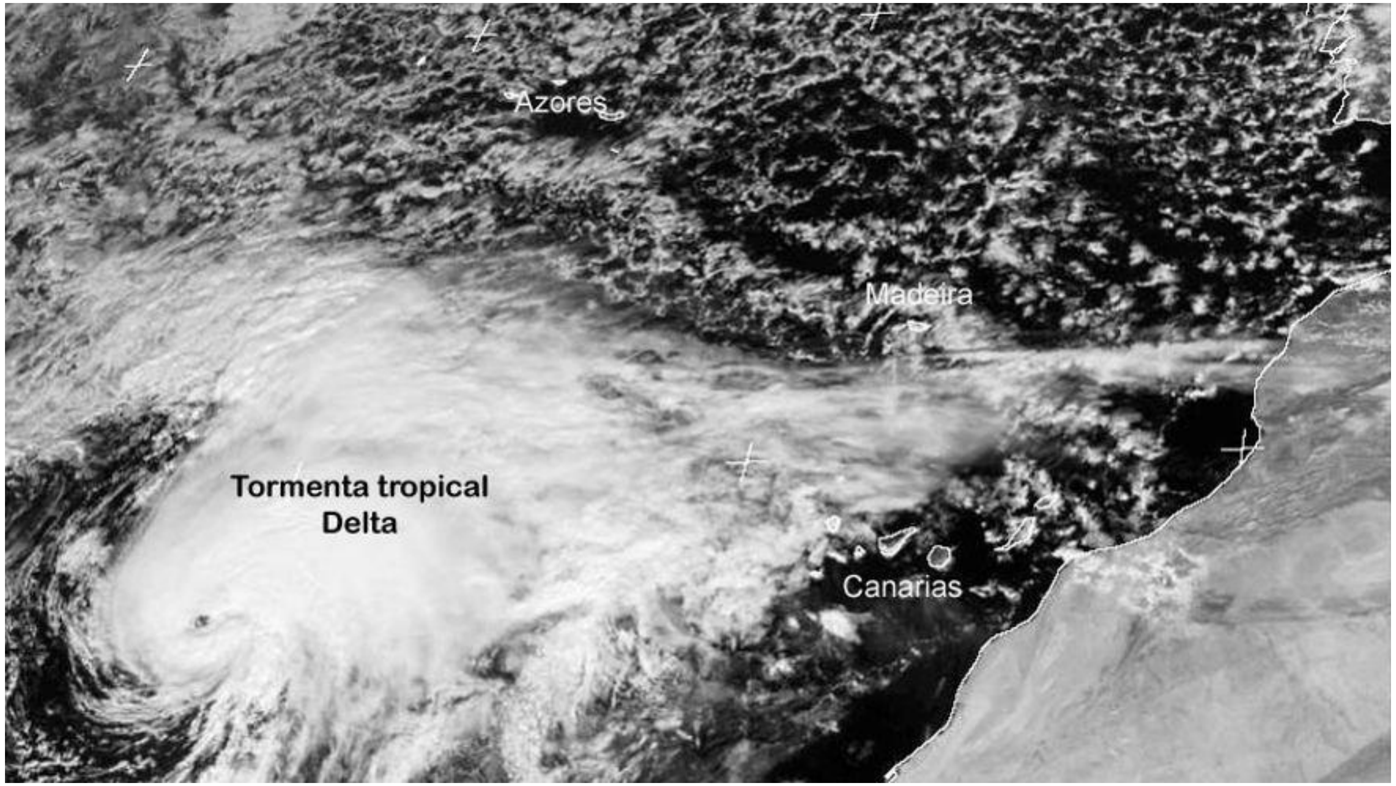
- Tormenta Tropical Delta (2005): primera transición tropical en la que Canarias se ve afectada según los registros (1851 – **1966 – 2021**)

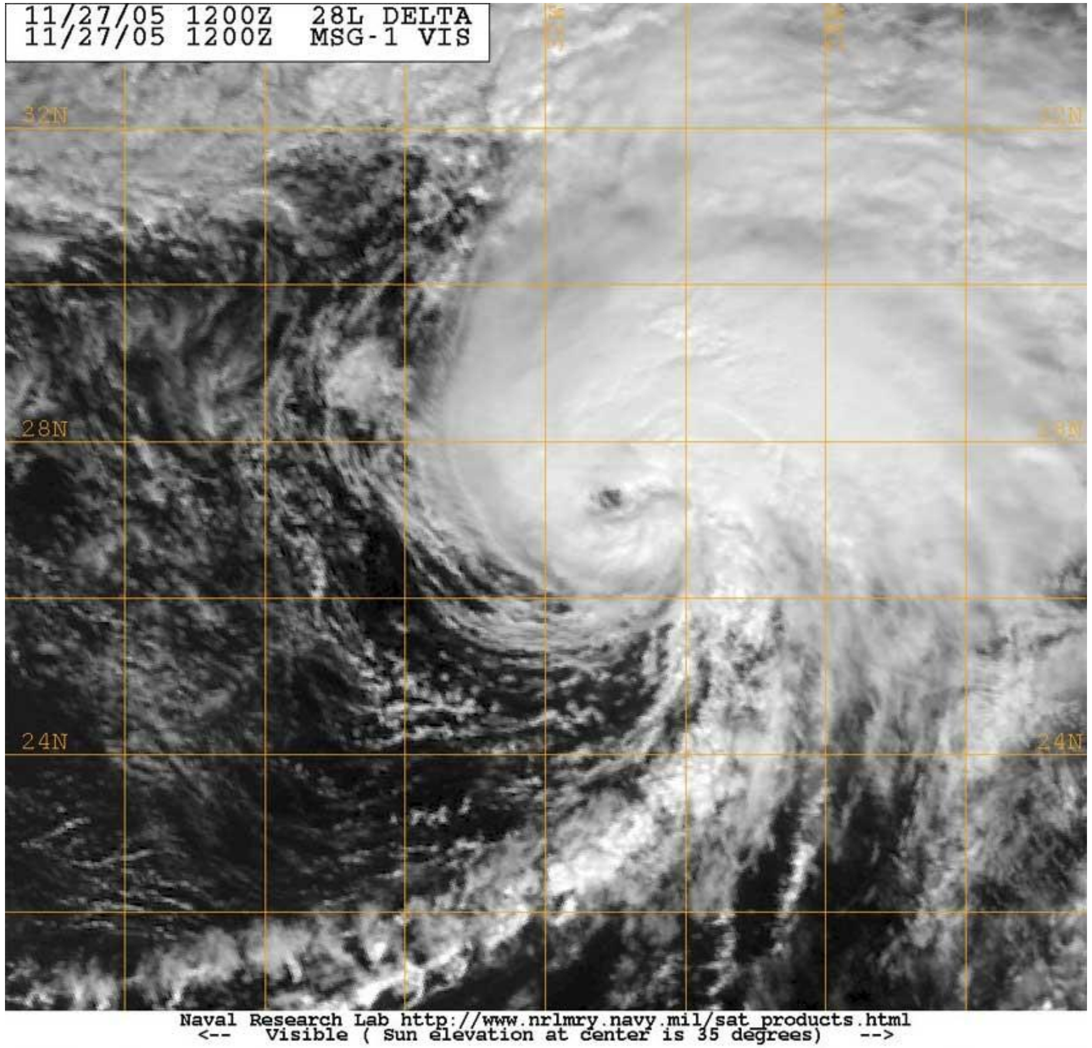




INTRODUCCIÓN

- Tormenta Tropical Delta (2005):

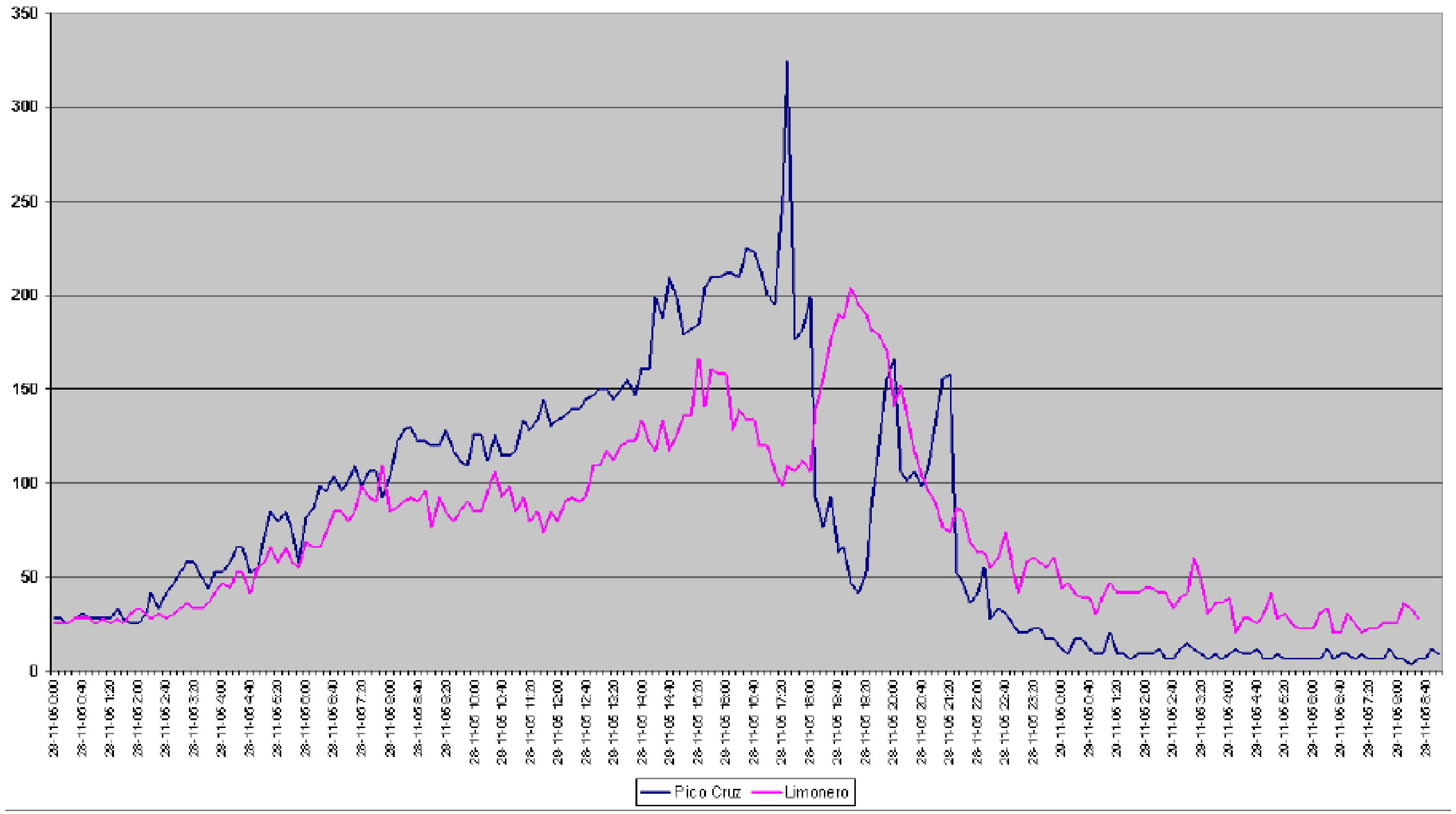




INTRODUCCIÓN

- Tormenta Tropical Delta (2005):

Rachas máximas (km/h)



INTRODUCCIÓN

- Tormenta Tropical Delta (2005):

Estudio de la tormenta tropical "Delta"

Los días 28 y 29 de noviembre del 2005 la tormenta tropical "Delta" afectó a las islas Canarias con vientos que llegaron a alcanzar los 150 km por hora en las costas y cercanos a los 250 en zonas altas de la isla de Tenerife.

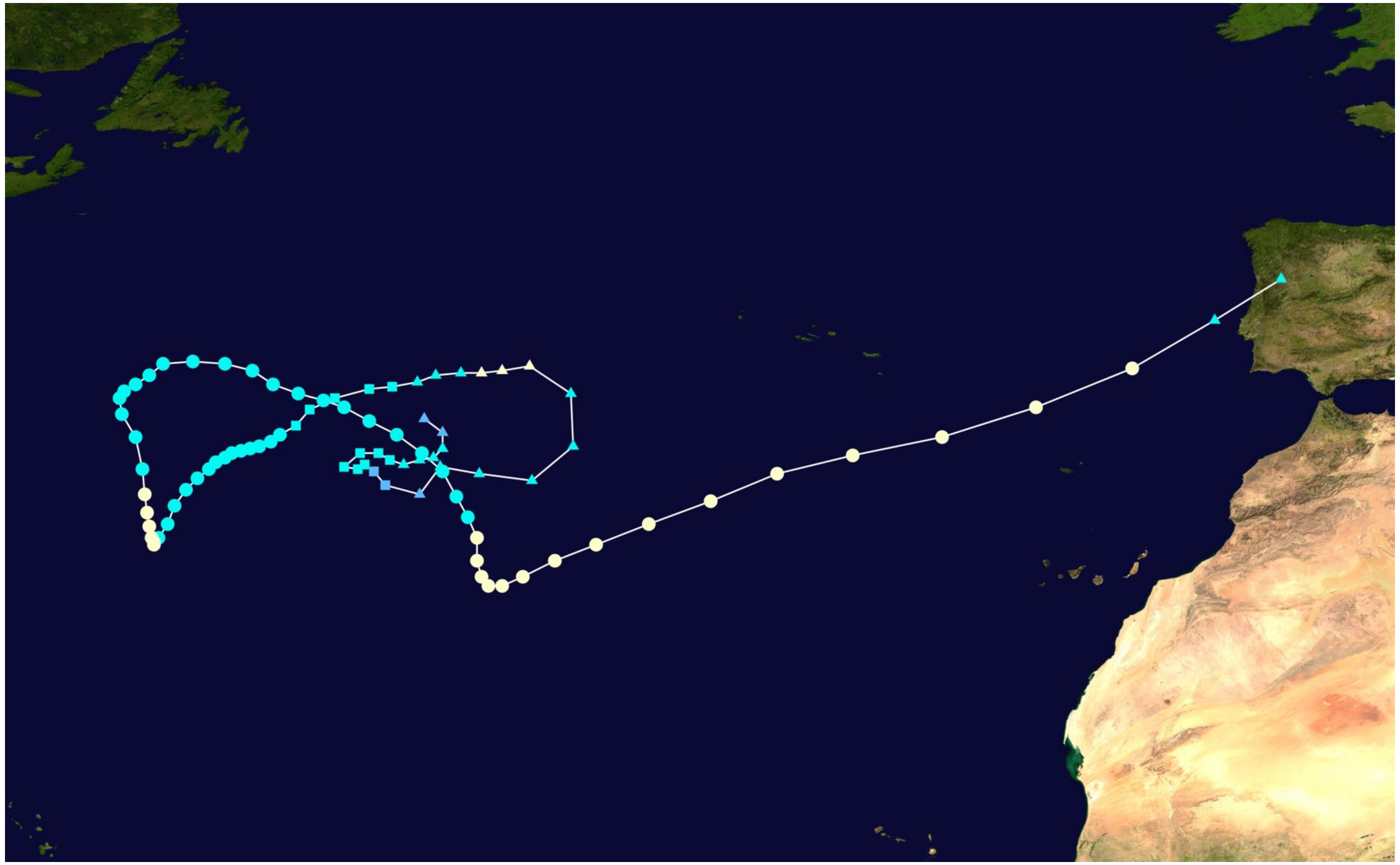
El INM publica su informe final sobre la tormenta tropical "Delta". Los días 28 y 29 de noviembre del año 2005 la tormenta tropical "Delta" afectó a las islas Canarias con vientos que llegaron a alcanzar los 150 km por hora en las costas y cercanos a los 250 en zonas altas de la isla de Tenerife. El fenómeno fue pronosticado y vigilado continuamente por el INM que también elaboró de modo inmediato un primer informe técnico. Como ya se hacía constar en el mismo, la complejidad de la situación, la necesidad de estudiar un gran número de datos y el interés en llevar a cabo diversas simulaciones mediante modelos numéricos aconsejaban realizar un estudio más profundo.

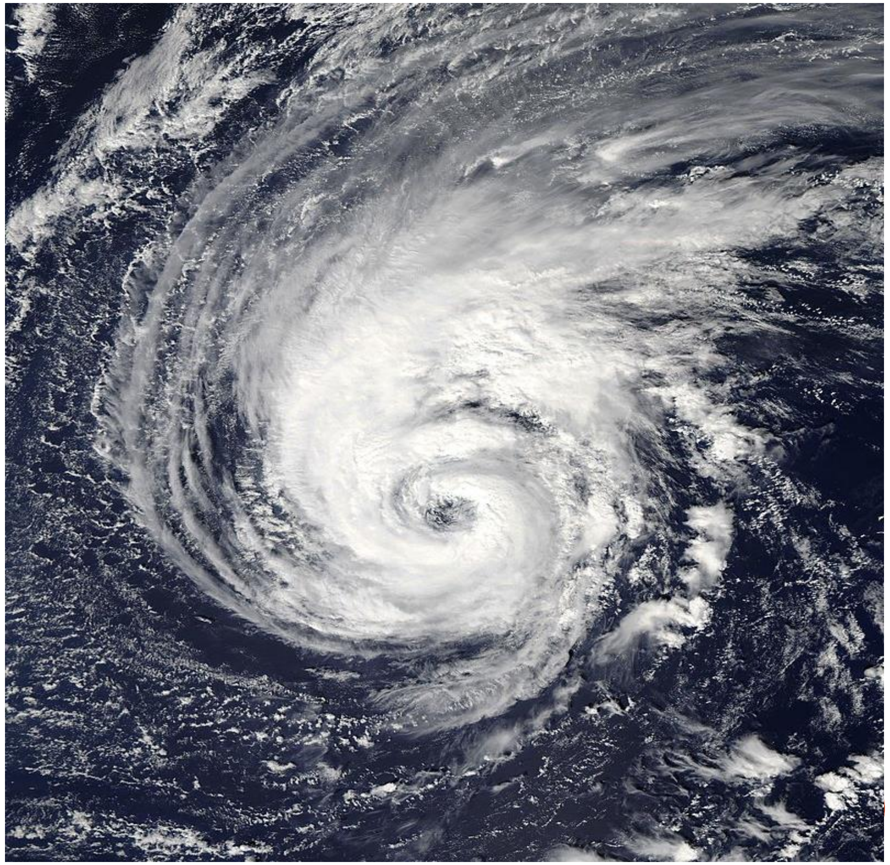
Autores :

Francisco Martín León, Coordinador
Cristo J. Alejo Herrera, Centro Meteorológico Territorial de Canarias Oriental
Juan José de Bustos Seguela, Observatorio Atmosférico de Izaña
Francisco Javier Calvo Sánchez, Área de Modelización
Ismael San Ambrosio Beirán, Servicio de Técnicas de Análisis y Predicción
José María Sánchez-Laulhé Ollero, Centro Meteorológico Territorial de Andalucía Oriental y Melilla
Daniel Santos Muñoz, Área de Modelización

INTRODUCCIÓN

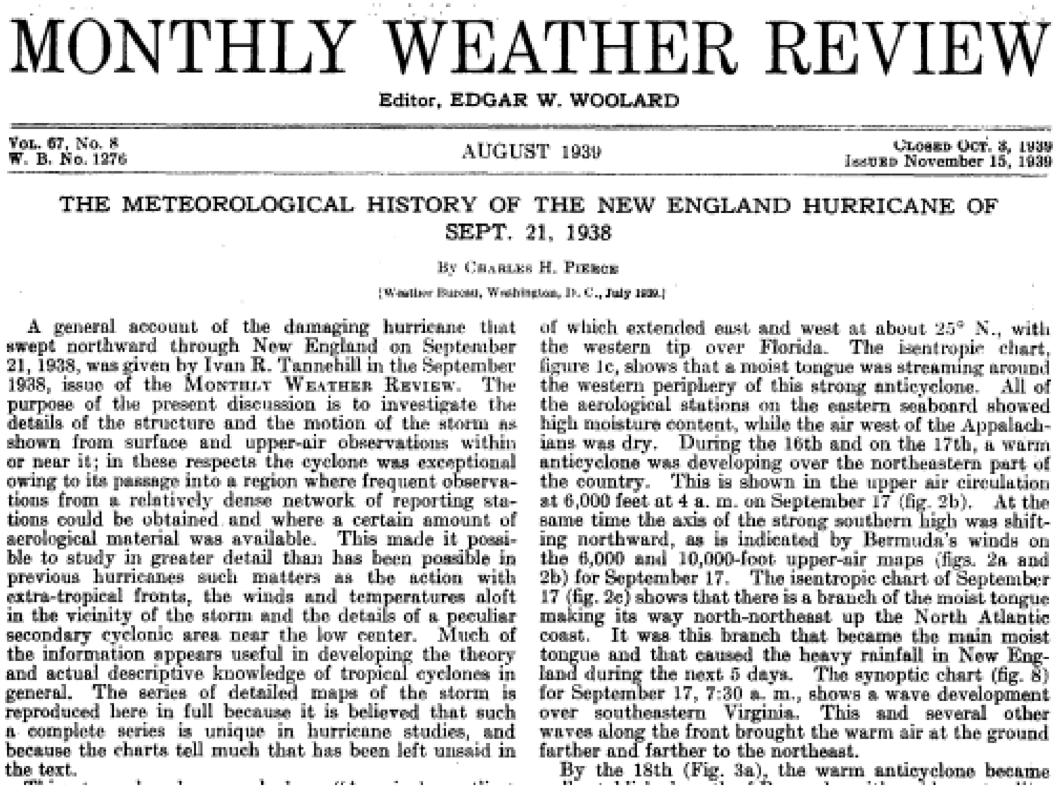
- Huracán Leslie (2005): el ciclón de origen tropical más fuerte en impactar la peninsula ibérica. Hasta 100-150 km de la costa fue tropical.





INTRODUCCIÓN

- Probablemente, el primer autor que demostró la posibilidad de que un ciclón tropical pudiese fusionarse con una zona baroclina y perder sus características tropicales para convertirse en extratropical fue Pierce (1939), en su estudio del Huracán de Nueva Inglaterra de 1938.



MONTHLY WEATHER REVIEW

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THE METEOROLOGICAL HISTORY OF THE NEW ENGLAND HURRICANE OF SEPT. 21, 1938

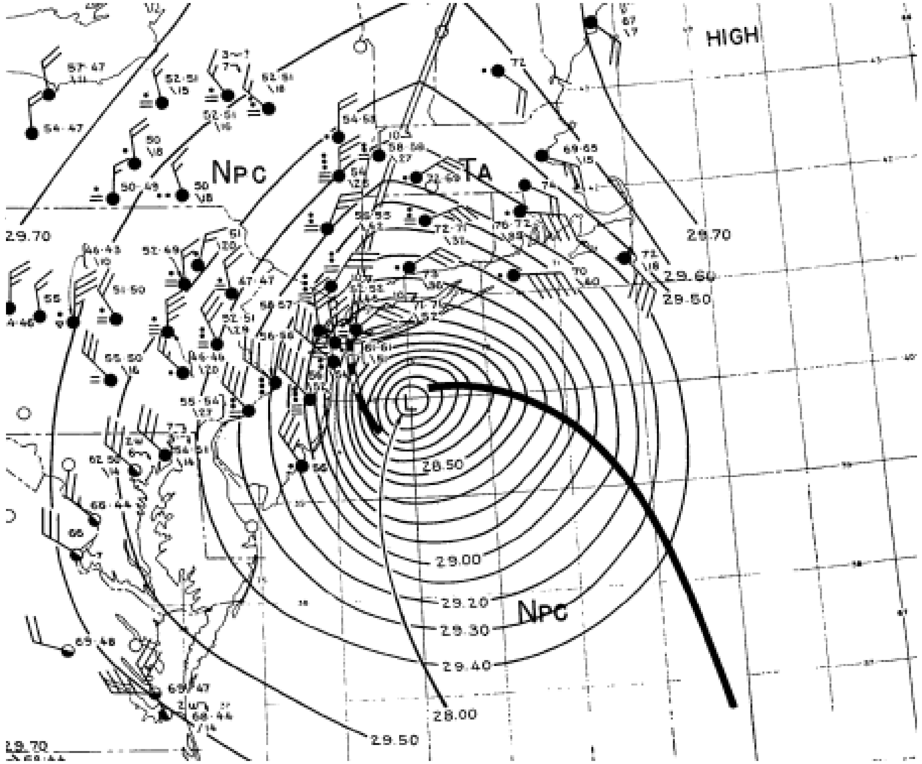
By Charles H. Pierce

[Weather Bureau, Washington, D. C., July 1939.]

A general account of the damaging hurricane that swept northward through New England on September 21, 1938, was given by Ivan R. Tannehill in the September 1938, issue of the Monthly Weather Review. The purpose of the present discussion is to investigate the details of the structure and the motion of the storm as shown from surface and upper-air observations within or near it; in these respects the cyclone was exceptional owing to its passage into a region where frequent observations from a relatively dense network of reporting stations could be obtained and where a certain amount of aerological material was available. This made it possible to study in greater detail than has been possible in previous hurricanes such matters as the action with extra-tropical fronts, the winds and temperatures aloft in the vicinity of the storm and the details of a peculiar secondary cyclonic area near the low center. Much of the information appears useful in developing the theory and actual descriptive knowledge of tropical cyclones in general. The series of detailed maps of the storm is reproduced here in full because it is believed that such a complete series is unique in hurricane studies, and because the charts tell much that has been left unsaid in the text.

of which extended east and west at about 25° N., with the western tip over Florida. The isentropic chart, figure 1c, shows that a moist tongue was streaming around the western periphery of this strong anticyclone. All of the aerological stations on the eastern seaboard showed high moisture content, while the air west of the Appalachians was dry. During the 16th and on the 17th, a warm anticyclone was developing over the northeastern part of the country. This is shown in the upper air circulation at 6,000 feet at 4 a. m. on September 17 (fig. 2b). At the same time the axis of the strong southern high was shifting northward, as is indicated by Bermuda's winds on the 6,000 and 10,000-foot upper-air maps (figs. 2a and 2b) for September 17. The isentropic chart of September 17 (fig. 2c) shows that there is a branch of the moist tongue making its way north-northeast up the North Atlantic coast. It was this branch that became the main moist tongue and that caused the heavy rainfall in New England during the next 5 days. The synoptic chart (fig. 8) for September 17, 7:30 a. m., shows a wave development over southeastern Virginia. This and several other waves along the front brought the warm air at the ground farther and farther to the northeast.

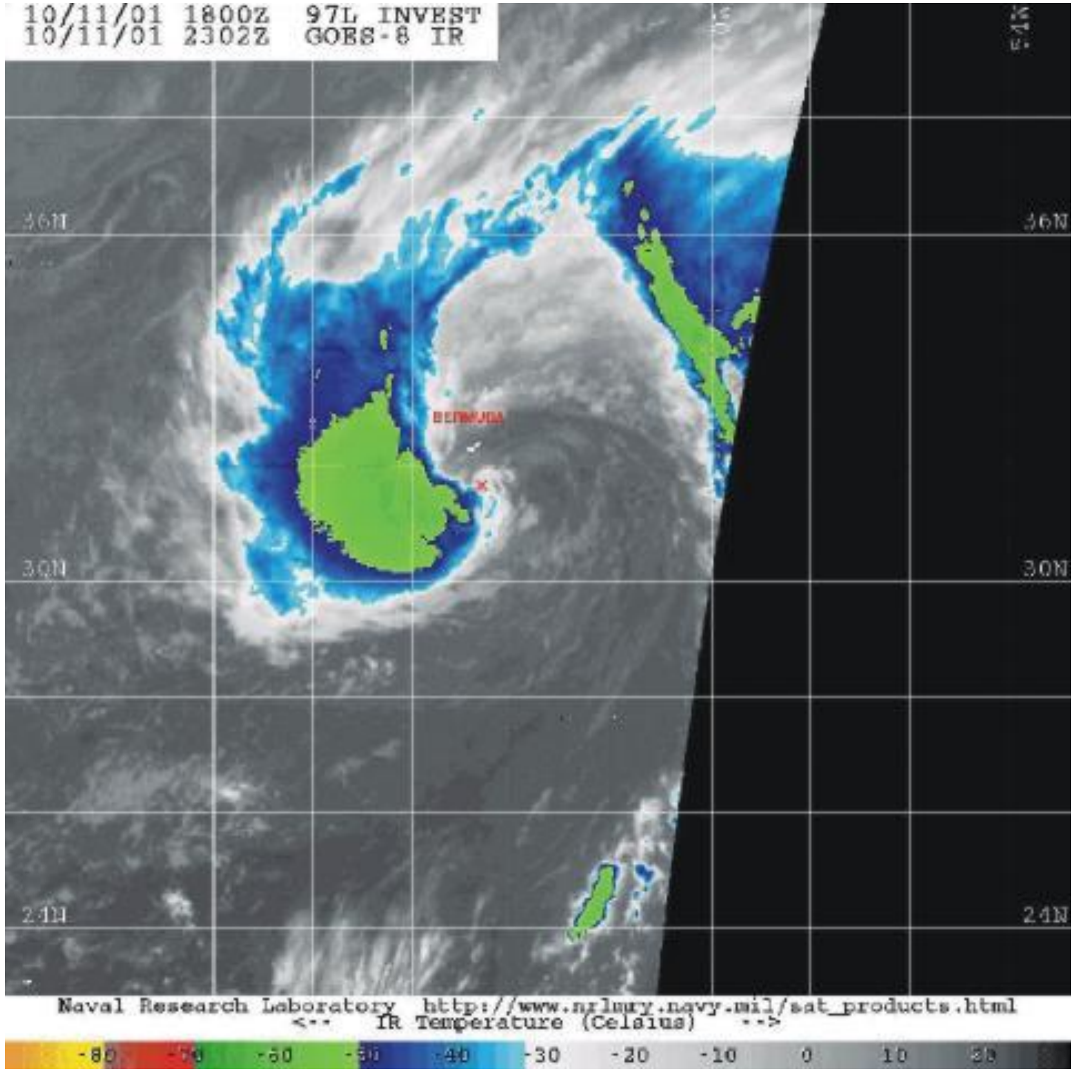
By the 18th (Fig. 3a), the warm anticyclone became

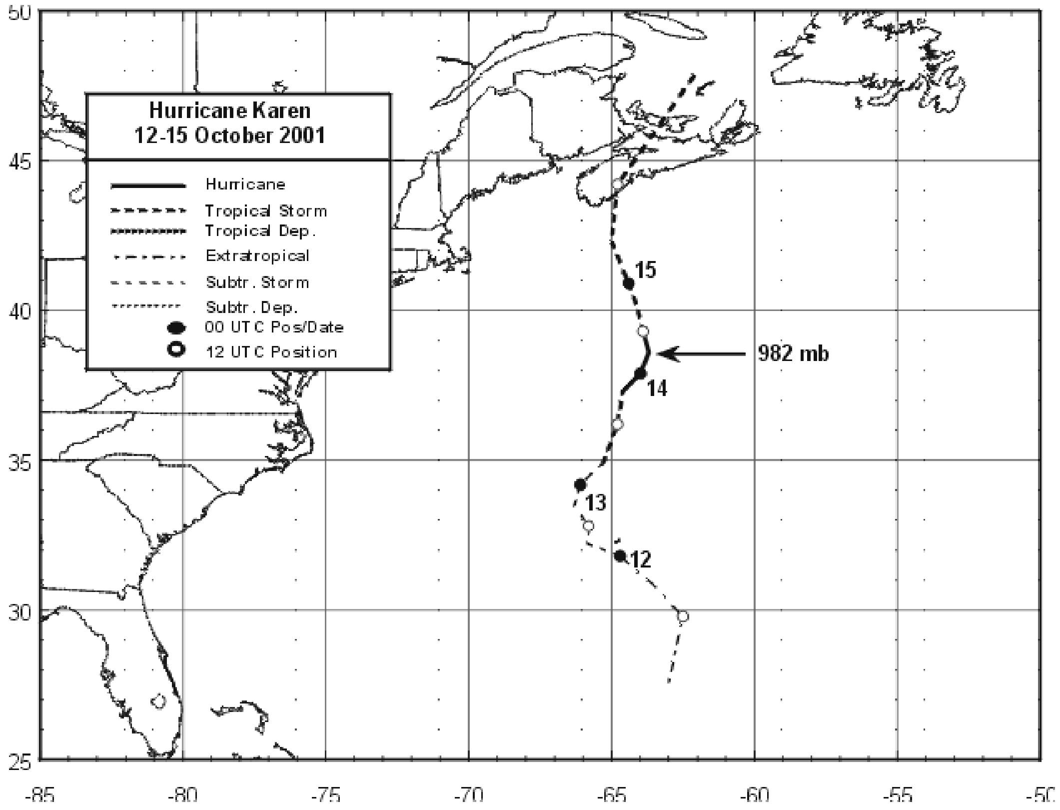


INTRODUCCIÓN

- Durante los años 60 y 70, los predictores en USA veían como ciertos ciclones parecían tener características tropicales y extratropicales, obteniendo su energía conjuntamente de los contrastes de temperatura de las masas de aire y de la convección organizada.
- Algunos evolucionaban a ciclones completamente tropicales mientras que otros conservaban características mezcladas durante toda su vida y con frecuencia tenían un origen no tropical, formándose en sistemas frontales bajo vaguadas o depresiones cerradas en altura.
- En 1972, se les dio su propia categoría después de varios años de debates y el NHC empezó a dar avisos de ciclones subtropicales a la navegación marítima para advertir de su peligrosidad.
- Pero fue en 2002 cuando realmente el NHC prestó atención a los ciclones subtropicales empezando a emitir avisos similares a los de ciclón tropical introduciéndolos incluso en la lista de nombres. Esto surgió tras verse como algunos impactos en tierra de ciclones subtropicales (p. ej. Karen (2001)) eran similares a los debido a ciertos huracanes cat. 1 o 2.

INTRODUCCIÓN





INTRODUCCIÓN

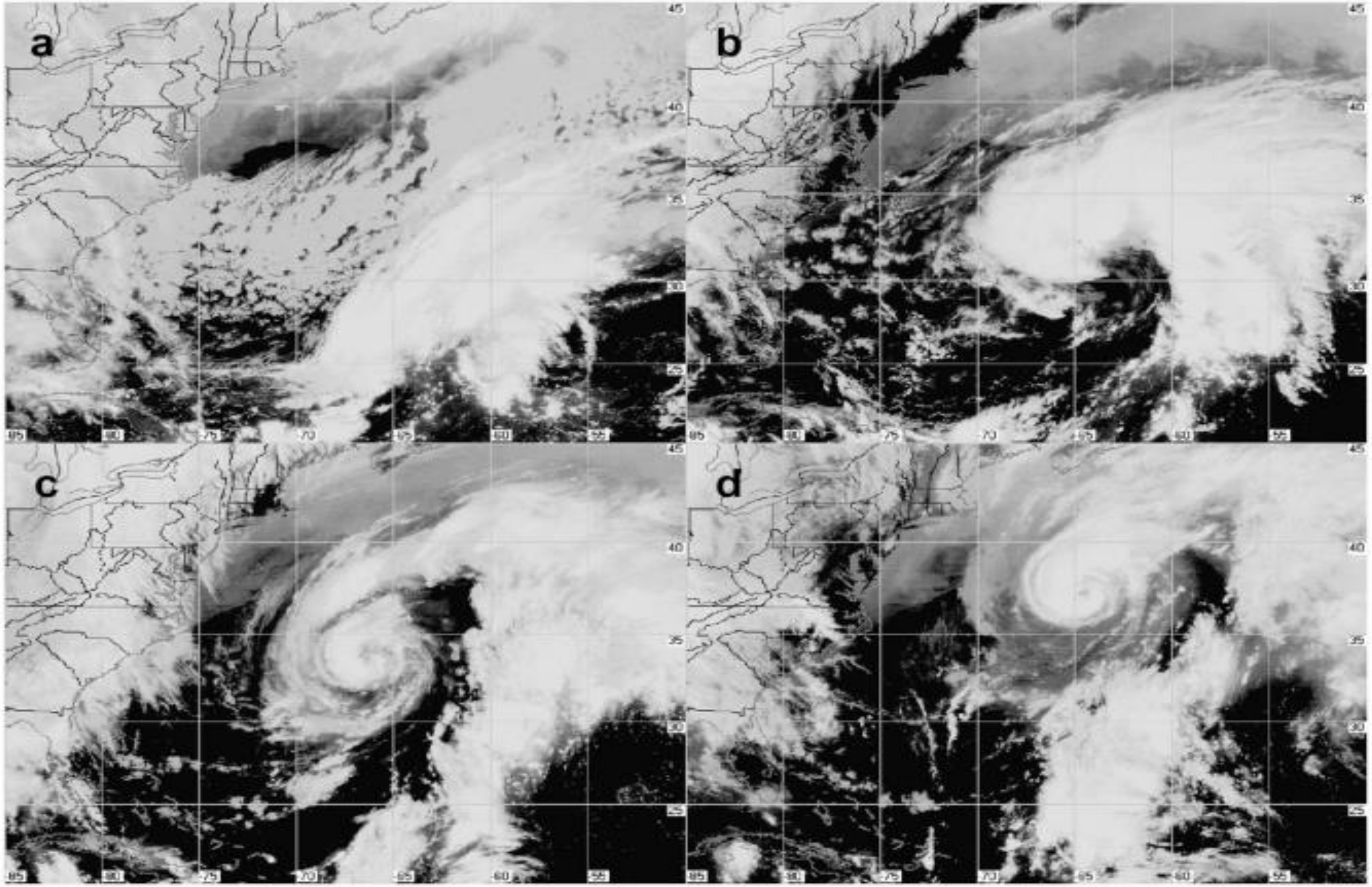


FIG. 3. Infrared imagery from GOES east of Hurricane Karen (2001) at the following times: (a) 1800 UTC 10 Oct, (b) 1800 UTC 11 Oct, (c) 1800 UTC 12 Oct, and (d) 1800 UTC 13 Oct 2001.

INTRODUCCIÓN

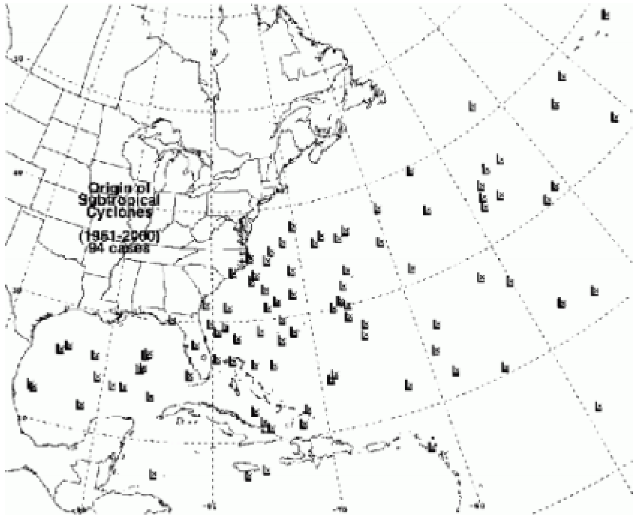
- La definición operativa de los ciclones subtropicales (STC) (publicada por el US National Weather Service (2007)) es la siguiente:
  - "Un sistema de bajas presiones no frontal que posee características tanto tropicales como extratropicales. Este sistema típicamente consta de una baja fría en niveles altos con una circulación extendida hasta la capa superficial con vientos máximos sostenidos a una distancia de 100 millas (≈ 160,9 km) o más con respecto al centro. En comparación con los ciclones tropicales, este tipo de sistemas tienen una zona relativamente amplia de vientos máximos que está localizada lejos del centro con una distribución del viento y de la convección menos simétrica. Si el viento máximo sostenido (1 minut2o de media) en la superficie es igual o mayor de 34 nudos (≈ 17,5 m/s) entonces se les designa tormenta subtropical.
- Sin embargo, esta definición no refleja la complejidad que ofrece este tipo de ciclones para ser clasificados.
- Por ejemplo, existen ciclones que efectivamente tienden hacia una estructura de núcleo cálido con convección central, aún cuando las observaciones de superficie muestran que las estructuras frontales no se han disipado y, por tanto, serían muy frontales para emitir un aviso en el NHC (nótese que se especifica que no debe ser frontal).

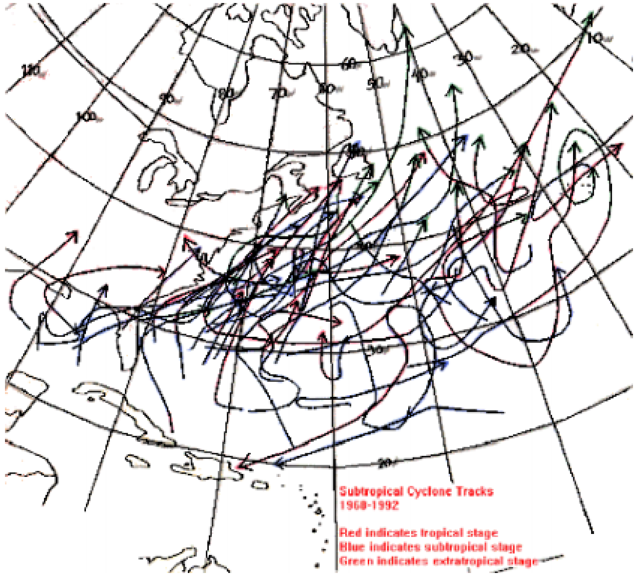
INTRODUCCIÓN

- Roth (2002) fue quien empezó a investigar con mayor profundidad los ciclones subtropicales, proponiendo dos tipos de sistema para categorizarlos.
- **Tipo A**: **bajas frías de escala sinóptica** con una circulación en superficie que tiene vientos máximos de, al menos, fuerza de galerna en un radio de 100 millas o mayor desde el centro.
- **Tipo B**: **circulaciones mesoescalares** (de menos de 50 millas de radio) que giran a lo largo de frentes en disipación y tienen máximos de vientos de, al menos, fuerza de galerna en un radio de 30 millas o menos desde el centro.

A FIFTY YEAR HISTORY OF SUBTROPICAL CYCLONES

David Mark Roth
Hydrometeorological Prediction Center, Camp Springs, MD





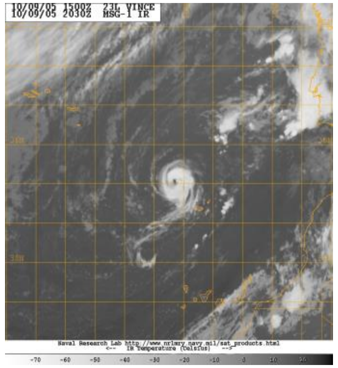
INTRODUCCIÓN

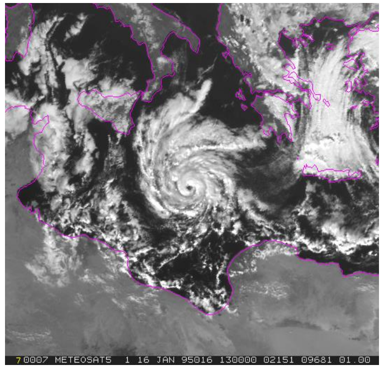
- ¿Por qué es interesante e importante estudiar este tipo de ciclones?

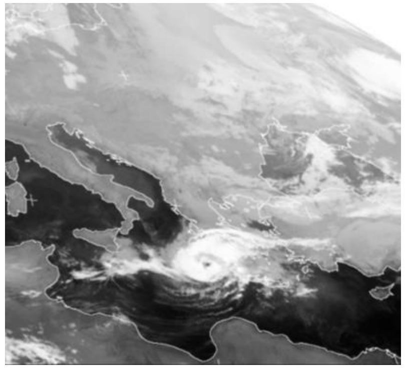
  - La **controversia** que existe en su definición.
  - Su **escasa bibliografía y conocimiento** ya que antes no se pensaba que representaran un peligro de cara al impacto social. Aunque en los últimos 10 años ha aumentado considerablemente.
  - ¿Relación con el cambio climático?
  - La **baja predictibilidad** que muestran en los modelos numéricos de predicción del tiempo y por tanto en las predicciones en general. La evolución de la estructura híbrida con frecuencia es consecuencia de un tira y afloja entre los forzamiento que buscan dominar en la evolución del sistema.
  - Su **potencialidad para convertirse en tormentas tropicales y/o huracanes**, y dejar efectos muy graves de vientos, lluvias, etc…
  - Incremento de las herramientas disponibles para estudiarlos.

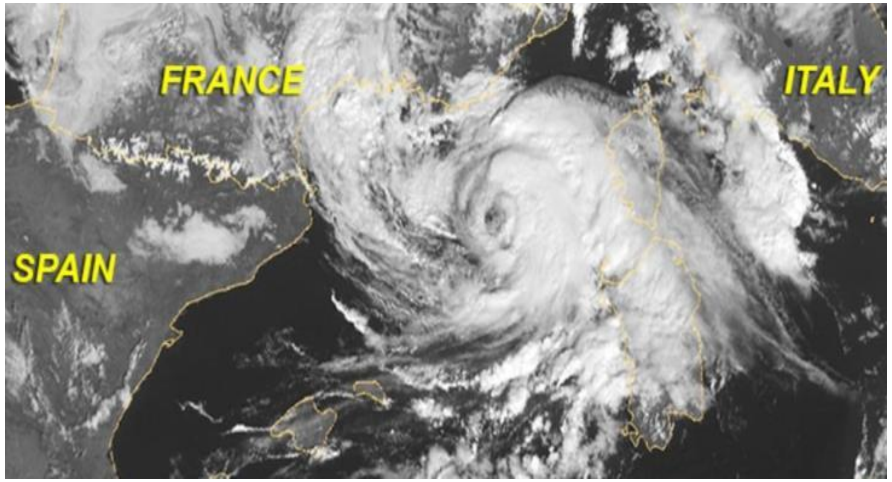
INTRODUCCIÓN

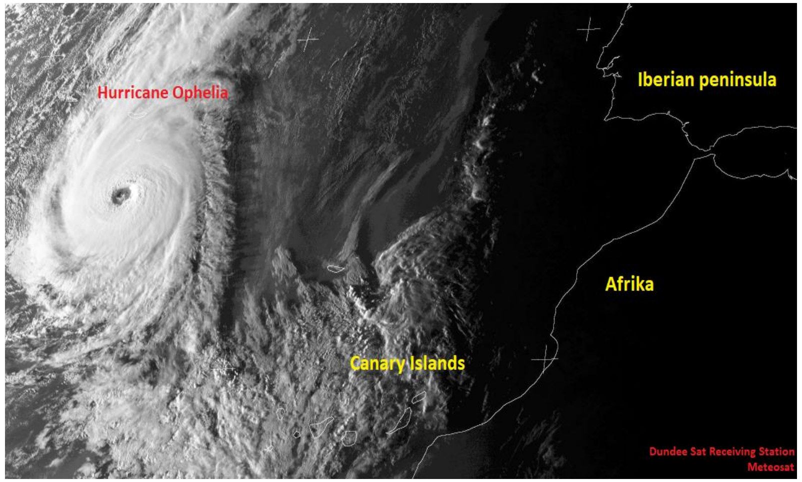
- Ejemplos de casos que han evolucionado a estructura tropicales más robustas:
  - Tropical Storm Delta (2005)
  - Hurricane Vince (2005)
  - Hurricane Alex (2016)
  - Hurricane Ophelia (2017)
  - Medicane 1995
  - Medicane Rolf (2011)
  - Medicane Zorbas (2018)
  - Medicane Ianos (2020)





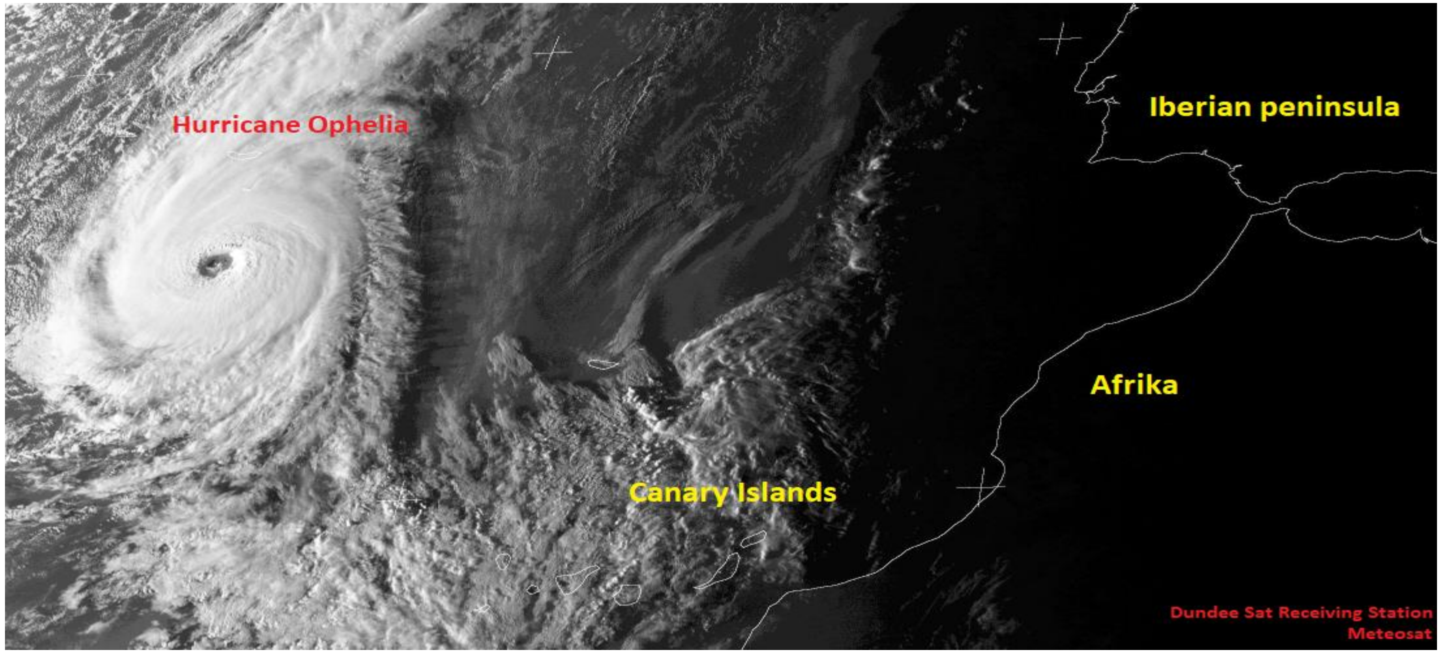






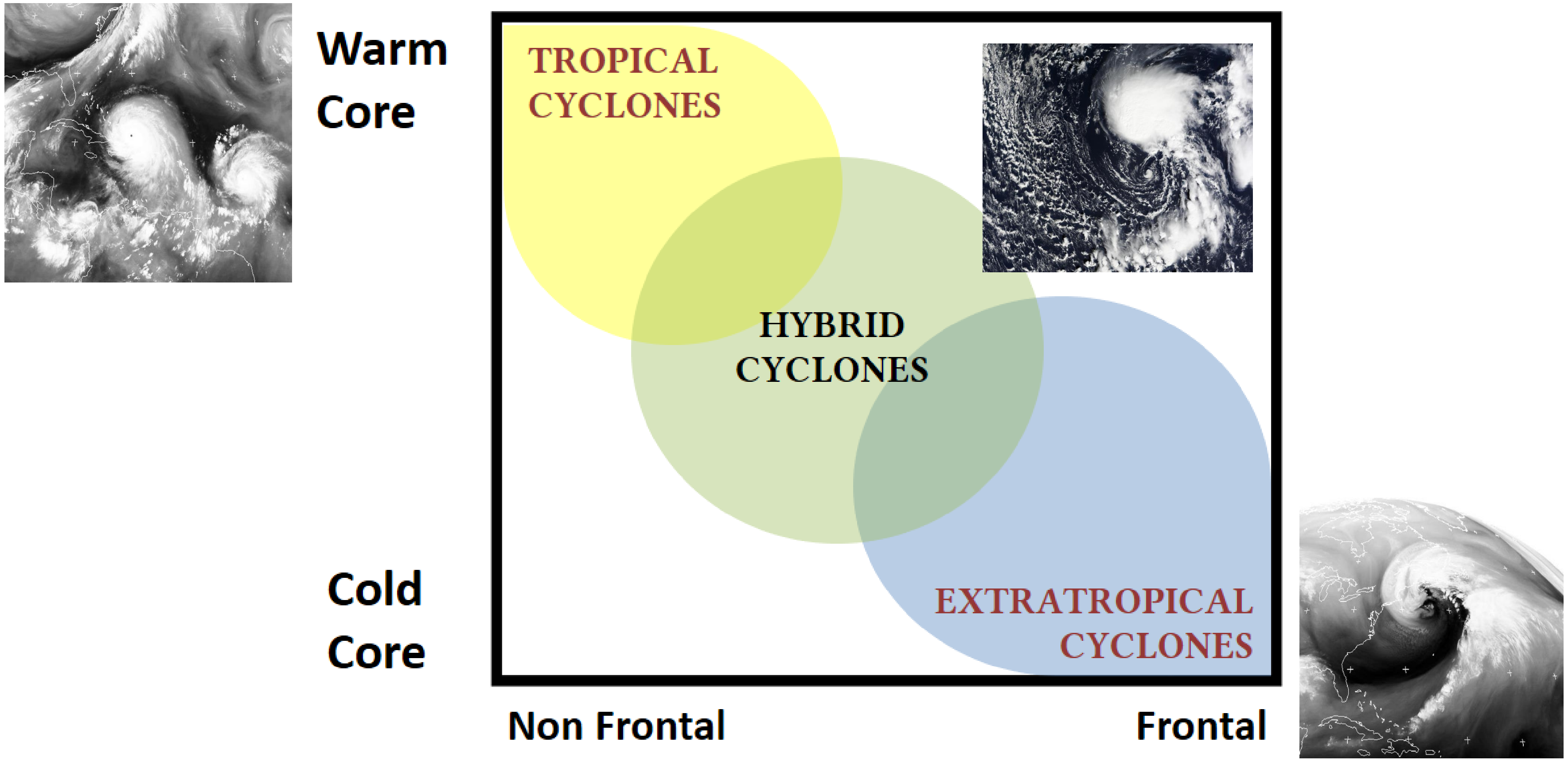
INTRODUCCIÓN

- De hecho, con respecto a lo último, el primer huracán de categoría 3 documentado tan al este en el Atlántico Norte (Huracán Ofelia) fue motivado por la transición que sufrió un ciclón subtropical cuando en 2004 rompió las reglas que se habían establecido para la formación de potentes ciclones tropicales, dejando atónitos a los expertos en huracanes.
- Además, Delta, Vince y Leslie fueron ciclones subtropicales antes de convertirse en ciclones tropicales y afectar peligrosamente a tierras españolas.



INTRODUCCIÓN

- Cyclones with tropical characteristics (hybrids) share features of both baroclinic and diabatic cyclones. In the continuum between the theoretical extremes of cyclones.

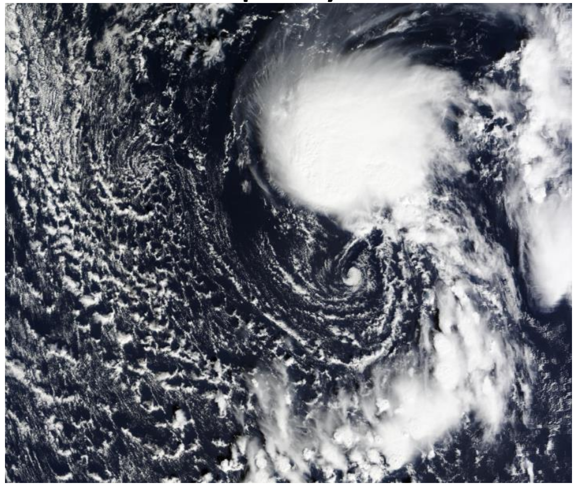


INTRODUCCIÓN

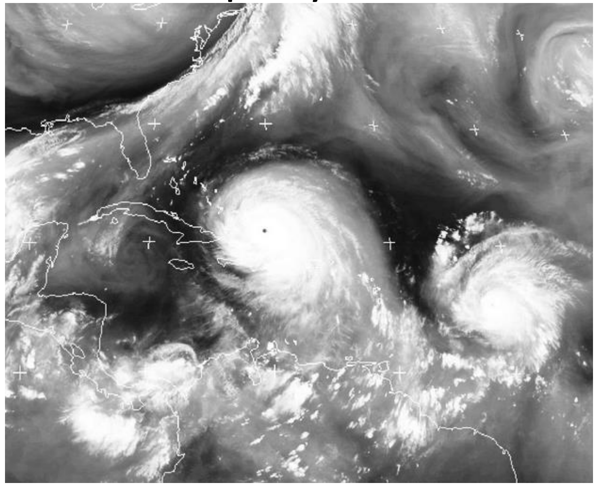
- **Extratropical cyclones** form from baroclinic sources, explained by quasi-geostrophic theory.
- **Tropical cyclones** formation is still under controversy, but baroclinic sources are not important. Diabatic heating and surface fluxes play a key role.
- In **hybrid cyclones**, both mechanisms can play a role. The relative importance of each one is what defines their structure. Examples: warm seclusions, subtropical cyclones, tropical and extratropical transitions, and medicanes.

Extratropical cyclone

Subtropical cyclone



Tropical cyclone



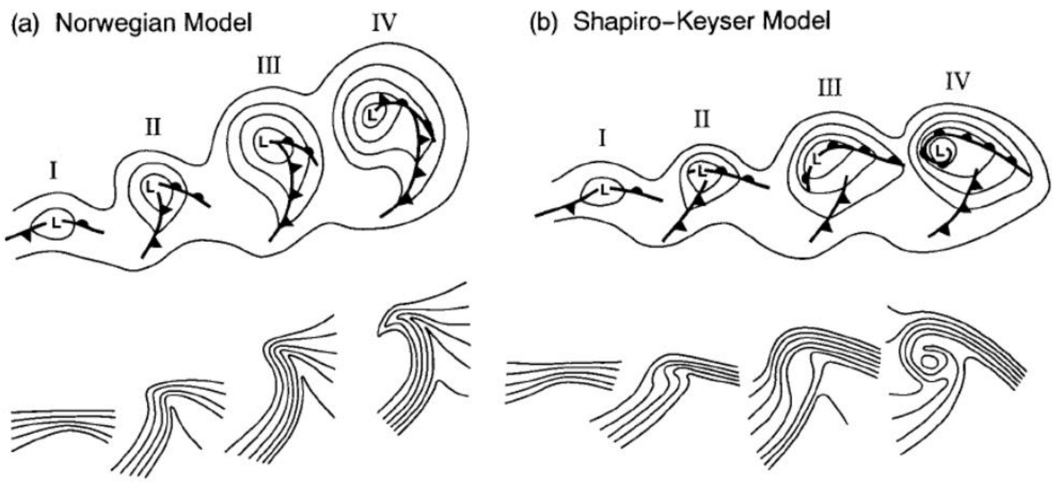
INTRODUCCIÓN

- Warm seclusions:

  - Alternative way of development from the Norwegian model in mature stages of extratropical cyclones; Shapiro-Keyser model.
  - Characterised by the seclusion of warm air (from the warm region) in the centre of the low. Formation of T-bone and warm bent-back front
  - Associated with high damage, especially in winds (sting jet).

Fronts and sea level pressure -->

Lower-levels thermal field -->

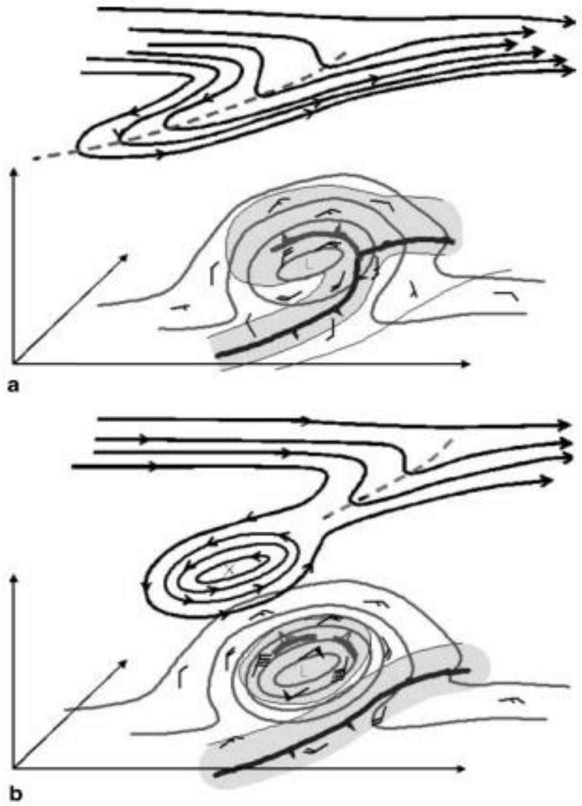


INTRODUCCIÓN

- Subtropical cyclones:

  - Tend to form when an upper-level trough move over a baroclinic zone over the subtropics and diabatic heating becomes important.

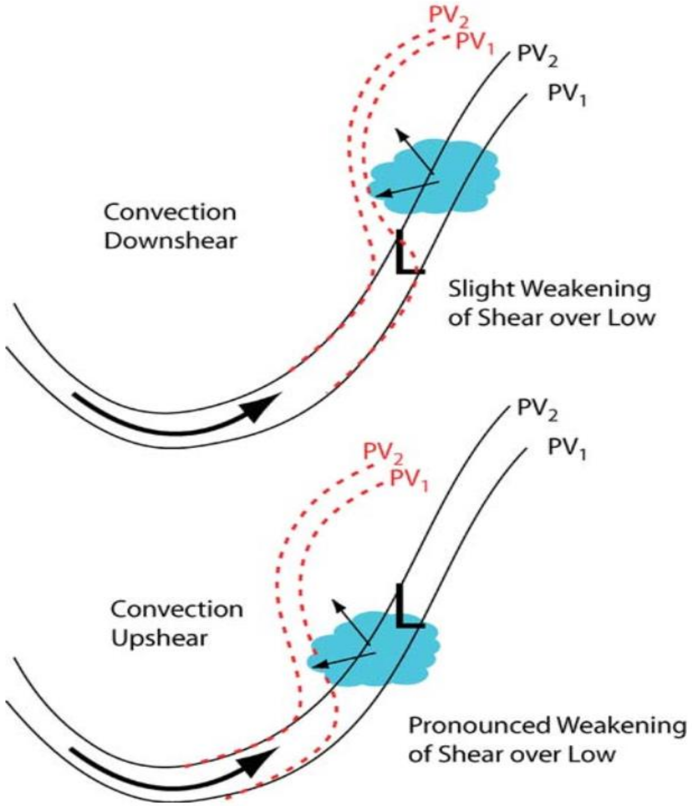
  - The initially baroclinic cyclone occludes and frontal structures disappear from the centre, but convective processes begin to increase.



Guishard et al. (2007)

INTRODUCCIÓN

- Tropical transitions:
  - The same process as in subtropical cyclones but convection is more efficient in changing the structure of the initially baroclinic cyclone.
  - Convection upstream of the cyclone has been found as determinant, by decreasing wind shear over the cyclone and making it more favourable for further development.
  - It is more likely when sea surface temperatures are relatively high (surface heat fluxes)

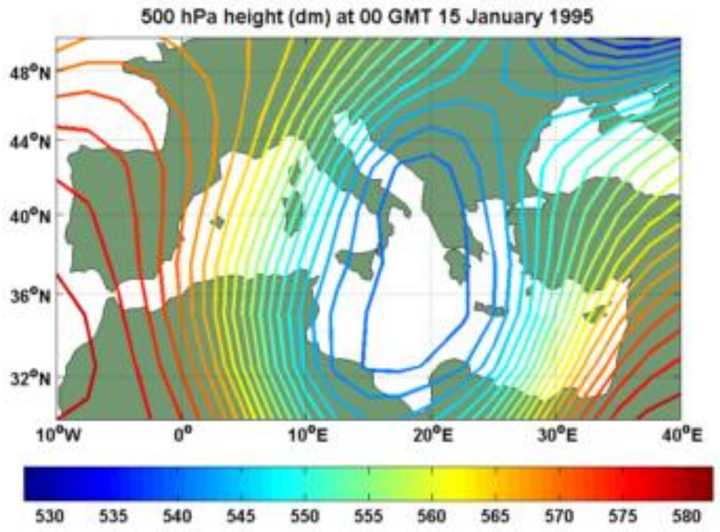


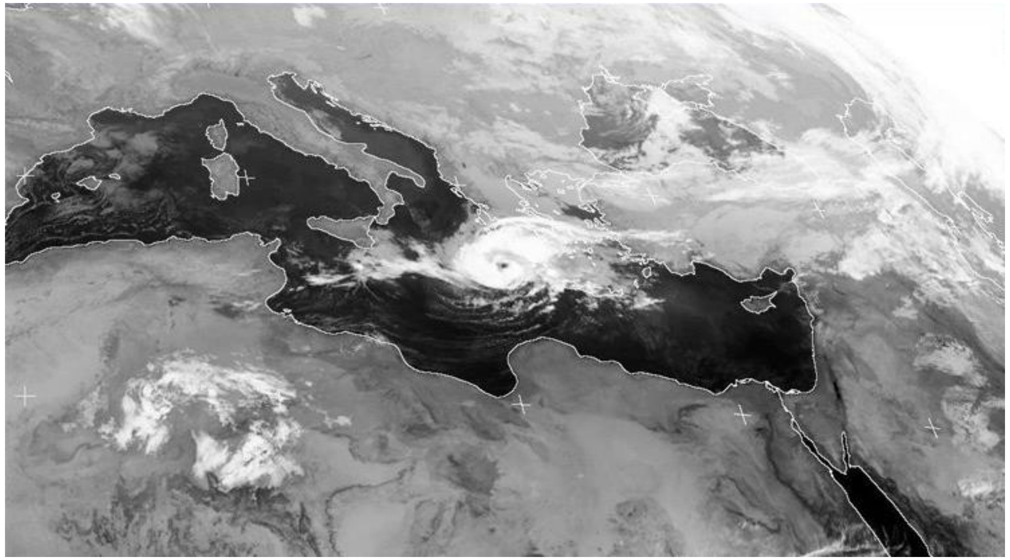
Davis and Bosart (2004)

INTRODUCCIÓN

- Medicanes:

  - Could be considered as a kind of subtropical cyclones over the Mediterranean Sea, with some of them undergoing tropical transition.
  - Tend to form when a upper level cutoff low reaches the Mediterranean Sea in a favourable environment.
  - If surface fluxes gain more importance, they can acquire fully tropical structures.





CONTENIDO

Ciclones con características tropicales e híbridos:

- **Hora 1:**
  - Características meteorológicas y climáticas de los ciclones subtropicales.
- **Hora 2:**
  - Características meteorológicas y climáticas de las transiciones tropicales y extratropicales.
- **Hora 3:**
  - Impacto del cambio climático en los ciclones tropicales.

- **Hora 1:**
  - Características meteorológicas y climáticas de los ciclones subtropicales.

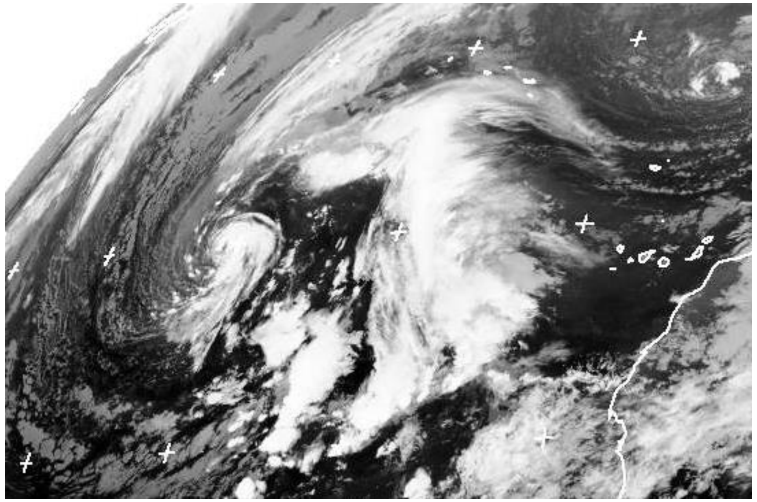
METEOROLOGÍA TROPICAL:
CICLONES CON CARACTERÍSTICAS TROPICALES

Juan Jesús González Alemán
Doctor en Física y Meteorólogo Superior del Estado.
Área de Modelización. Departamento de Desarrollo y Aplicaciones (SSCCs)

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

2. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LOS CICLONES SUBTROPICALES

- A typical case of a hybrid cyclone in the North Atlantic is a subtropical cyclone (STC; Evans and Guishard, 2009; Guishard et al., 2009).
- STCs develop from both tropical (diabatic) and extratropical (quasi-geostrophic) processes. This combination causes the cy-clone to bear a hybrid thermal structure in its core, consisting of a positive thermal anomaly at low levels (typically from 900 to 600 hPa) and a negative thermal anomaly at upper levels (600-300 hPa).
- Through thermal wind arguments, a weak wind speed signature at midlevels is expected as a result.
- Apart from the North Atlantic, STCs have been also studied in other regions such as the South Atlantic (Evans and Braun, 2012; Gozzo et al., 2014), central Pacific (Otkin and Martin, 2004), and Tasman Sea (Holland et al., 1987; Browning and Goodwin, 2013).



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- STCs typically are a subsequent stage of an incipient low which is formed through QG processes: They begin to develop low-level warm core due to diabatic processes from deep convection, and frontal structures tend to disappear.
- STCs differ from ordinary baroclinic cyclones in that they develop in environments with little low-level baroclinicity in conjunction with diabatic processes.
- STCs develop in environments where positive vorticity is present in lower levels (originate from baroclinic processes) in conjunction with environments with low static stability.
- This kind of interaction is similar to that observed during extratropical and tropical transitions, but often occur during a period of time that is long enough while midlatitude westerlies are not affecting it.

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- STCs typically have only a weak lower-tropospheric warm-core structure because there is the lack of sustained convection near the cyclone core.
- This displacement of convection from the cyclone center is often due to the existence of a weak frontal structure within the cyclone, forced by mesoscale ascent away from the center.
- A large radius of maximum winds is associated with these cyclones, which is more typical of extratropical cyclones than of tropical cyclones. The transformation of a subtropical cyclone into a fully tropical cyclone only occurs if convection near the cyclone core is developed and maintained.
- Satellite imagery can be used to diagnose this conversion, although it can be difficult to forecast since the evolution within numerical models is often subtle and poorly characterized using conventional analyses.
- This is because the development of a full-tropospheric warm core implies that the potential cyclone intensity change, being more governed by convective processes, resulting in a more complex predictability with substantially more amplitude than was the case prior to warm core transition.

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- As the research focus on STCs is recent, there are still some inconsistencies regarding their definition. From an operational point of view, the National Hurricane Centre (NHC) consider these cyclones as (NHC, 2018):
  - "*A non-frontal low-pressure system that has characteristics of both tropical and extratropical cyclones. Like tropical cyclones, they are non-frontal, synoptic-scale cyclones that originate over tropical or subtropical waters, and have a closed surface wind circulation about a well-defined center. In addition, they have organized moderate to deep convection, but lack a central dense overcast. Unlike tropical cyclones, subtropical cyclones derive a significant proportion of their energy from baroclinic sources, and are generally cold-core in the upper troposphere, often being associated with an upper-level low or trough. In comparison to tropical cyclones, these systems generally have a radius of maximum winds occurring relatively far from the center (usually greater than 60 n mi), and generally have a less symmetric wind field and distribution of convection*".
- If the subtropical cyclone has maximum sustained surface wind speed (using the U.S. 1-minute average) of 33 kt (38 mph or 62 km/hr) or less it is called subtropical depression. Subtropical Storm is reserved for a subtropical cyclone in which the maximum sustained surface wind speed (using the U.S. 1-minute average) is 34 kt (39 mph or 63 km/hr) or more.

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- However, in the academic context, the definition of STC does not focus on fronts. Instead, the focus is on its hybrid structure.
- Based on the definition proposed by Guishard et al. (2009), for a cyclone to be subtropical it must: "attain gale-force winds (17 m s-1) on the 925-hPa surface at some time during its life cycle; exhibit a hybrid structure, determined by the CPS (Hart 2003) criteria of -VTL > -10 and -VTU < -10; persist in its hybrid form for at least 36 h; attain gales in the 20°–40°N latitude band; and become subtropical (i.e., attain hybrid structure) within 24 h if identified first as a purely cold- or warm-cored system".

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- When this definition is contrasted with the operational STC datasets (Guishard et al., 2009):
  - STCs contribute to 12% of tropical cyclones (TC) in the current NHC-HURDAT database
  - This is equivalent to about 1 in 8 genesis events from an incipient STC disturbance.
  - 144 STCs identified that are not presently in HURDAT and a reclassification (as not STCs) of 65 existing storms in HURDAT.
  - 197 out of 597 storms (33%) in the combined database are STCs.
- An additional class of hybrid storm is that of a 'frontal hybrid' (Beven, personal communication) that is characterized by organized moist convection in the presence of surface frontal zones, but this hasn't been further developed.
- The socioeconomic impact of these cyclones could be similar to that of tropical storms.
- Despite their low frequency of occurrence, STCs pose a significant challenge to weather forecasters due to the high economical losses and security damage associated to them.
- They cause important warm-season forecasting problems for subtropical locations such as Bermuda and the southeastern United States because they can rapidly acquire of gale-force winds close to land.

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- They are also often associated with poor forecast. Finer scale processes like convective processes and turbulent fluxes, which are still not resolved in typical global operational forecast models, are critical to subtropical and tropical cyclogenesis.
- On the other hand, forecast tracks and intensity of typical extratropical cyclones tend to be more accurate, due to more robust steering patterns in the mid-latitudes and predominance of synoptic processes governing it.
- Hence, development of extratropical cyclones is easier to forecast than subtropical cyclogenesis. In this context, the transition to subtropical cyclones is also less predictable as it is a convective-related phenomenon.
- Once a storm reaches its subtropical phase, the strength of the surface cyclone will mainly depend on the organization of the convection. 4
- Thus, it could be stated that the same difficulty arises when forecasting intensity change in a subtropical storm as in a tropical storm.
- As long as global forecast models increase their resolution and include better representation of finer scale processes, forecast of subtropical cyclones will improve.

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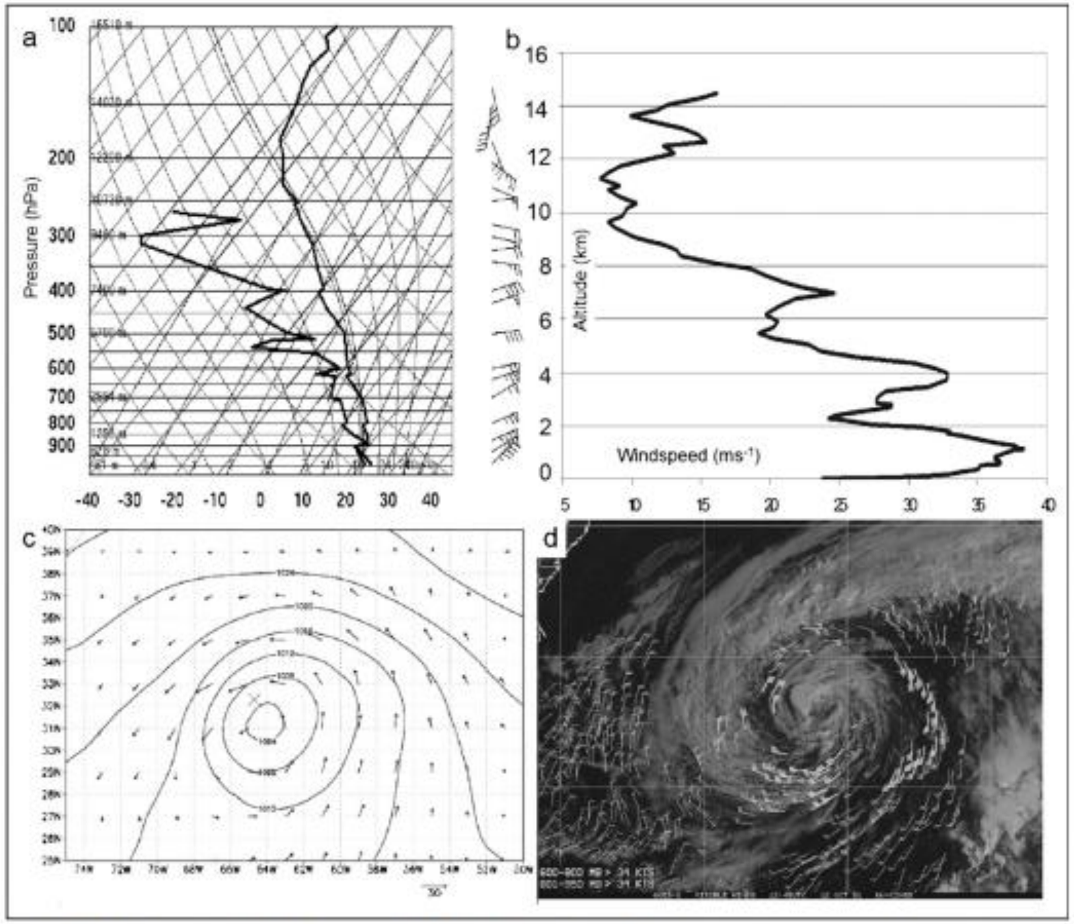

FIG. 1. Observations taken at 0000 UTC 12 Oct 2001 during the landfall approach of pre-Hurricane Karen. (a) Radiosonde ascent from Bermuda International Airport, (b) wind profile (plot and data from the University of Wyoming), (c) GFS analysis of sea level isobars and 700-hPa wind vectors, and (d) cloud vector winds overlaid on the visible *Geostationary Operational Environmental Satellite-8* (*GOES-8*) satellite imagery for 1245 UTC 12 Oct 2001. [Satellite data source: University of Wisconsin—Madison Cooperative Institute for Meteorological Satellite Studies (UW-CIMSS).]

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- Debido a la constatación de que el impacto social de estos ciclones puede llegar a ser similar a la de una tormenta tropical o incluso al de un huracán, últimamente se les ha prestado mayor interés, aumentándose las investigaciones sobre estos fenómenos.
- Aunque la frecuencia de ocurrencia es relativamente pequeña, estos sistemas son un reto significativo para los predictores de los servicios de meteorología por ser causantes de grandes daños económicos y de seguridad en las personas

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Evans and Guishard (2009):

Atlantic Subtropical Storms. Part I: Diagnostic Criteria and Composite Analysis

JENNI L. EVANS AND MARK P. GUISHARD*

Department of Meteorology, The Pennsylvania State University, University Park, Pennsylvania

(Manuscript received 29 November 2007, in final form 14 January 2009)

Criterios de identificación:

- El sistema ha de alcanzar o superar el valor de **vientos con fuerza de galerna**, esto es, los 17 m/s (10 minutos de promedio) en el nivel de los 925 hPa vientos sostenidos durante al menos 36 h. El momento en el que se alcanzan los 17 m/s se define como el instante de la formación del STC.
- Mostrar una **estructura híbrida** en los diagramas de fase durante al menos 36 h. Esta estructura híbrida ha de identificarse en los diagramas de fase imponiendo el criterio $-|V_T^L| > -10$ y $-|V_T^U| < -10$.
- El ciclón debe no haber sido identificado con una estructura de núcleo puramente frío o puramente cálido durante más de 24 horas antes de alcanzar la estructura híbrida.
- Sólo se han de tener en cuenta los ciclones formados sobre el océano y situados entre 20°N y los 40°N de latitud.

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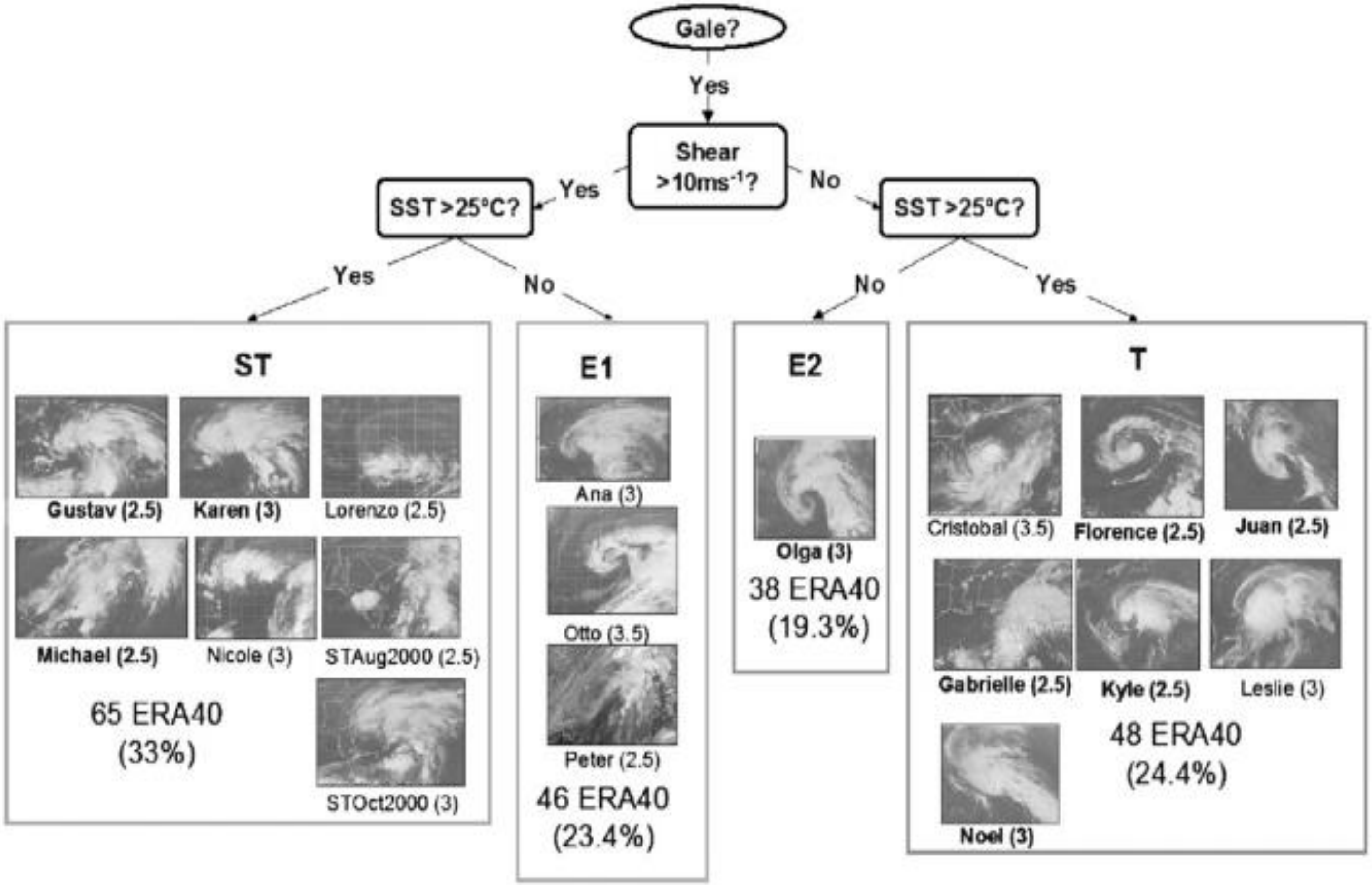

FIG. 9. Partition of the 18 ST cases based upon characteristics of their synoptic environment at genesis. ST class numbers (Hebert and Poteat 1975) are printed in parentheses and correspond to the following storm intensities: 2.5, 18–21 m s^{-1}; 3.0, 23–26 m s^{-1}; 3.5, 28–34 m s^{-1}.

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- Guishard et al. (2009):

Atlantic Subtropical Storms. Part II: Climatology

MARK P. GUISHARD* AND JENNI L. EVANS

Department of Meteorology, The Pennsylvania State University, University Park, Pennsylvania

ROBERT E. HART

Department of Meteorology, The Florida State University, Tallahassee, Florida

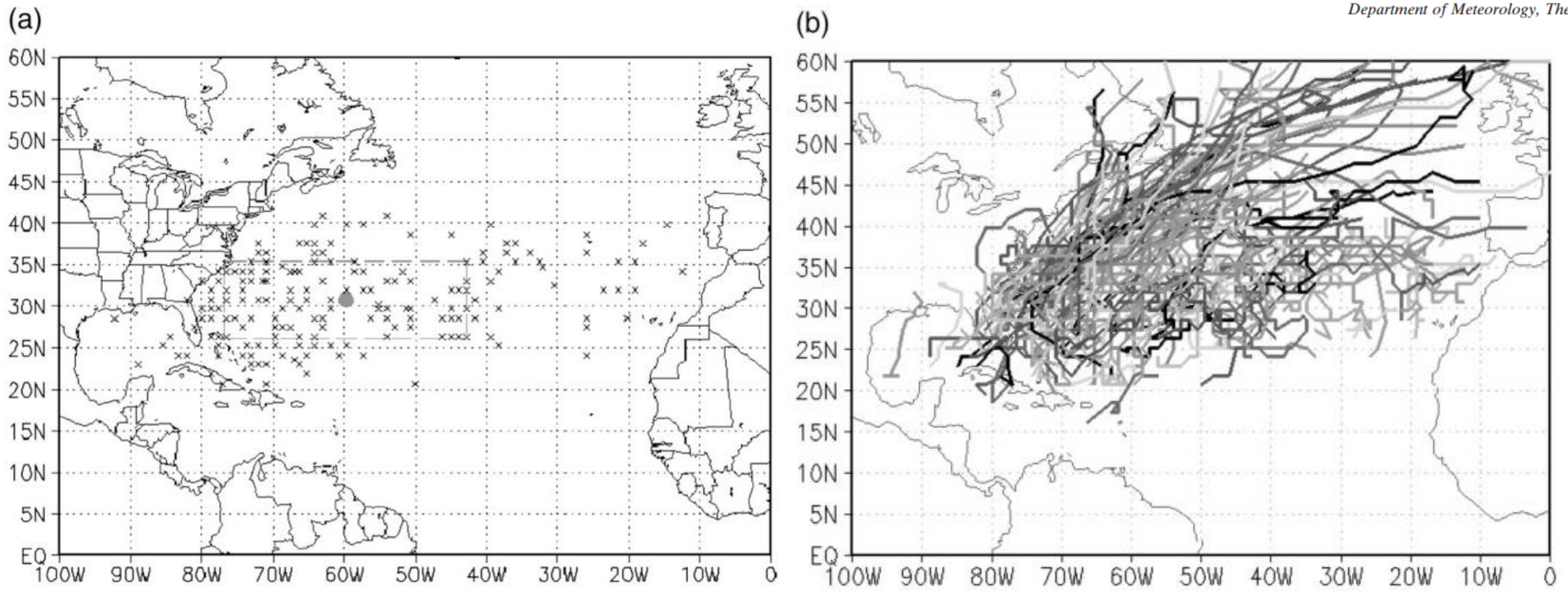

FIG. 5. Geographic distribution of Atlantic ST in the ERA-40 climatology: (a) genesis location (onset of gale-force winds) and (b) tracks. The black dot in (a) indicates the average position of all 197 ERA-40 subtropical storms at the onset of gale-force winds and the dashed-line box encloses the area within one standard deviation from this mean location.

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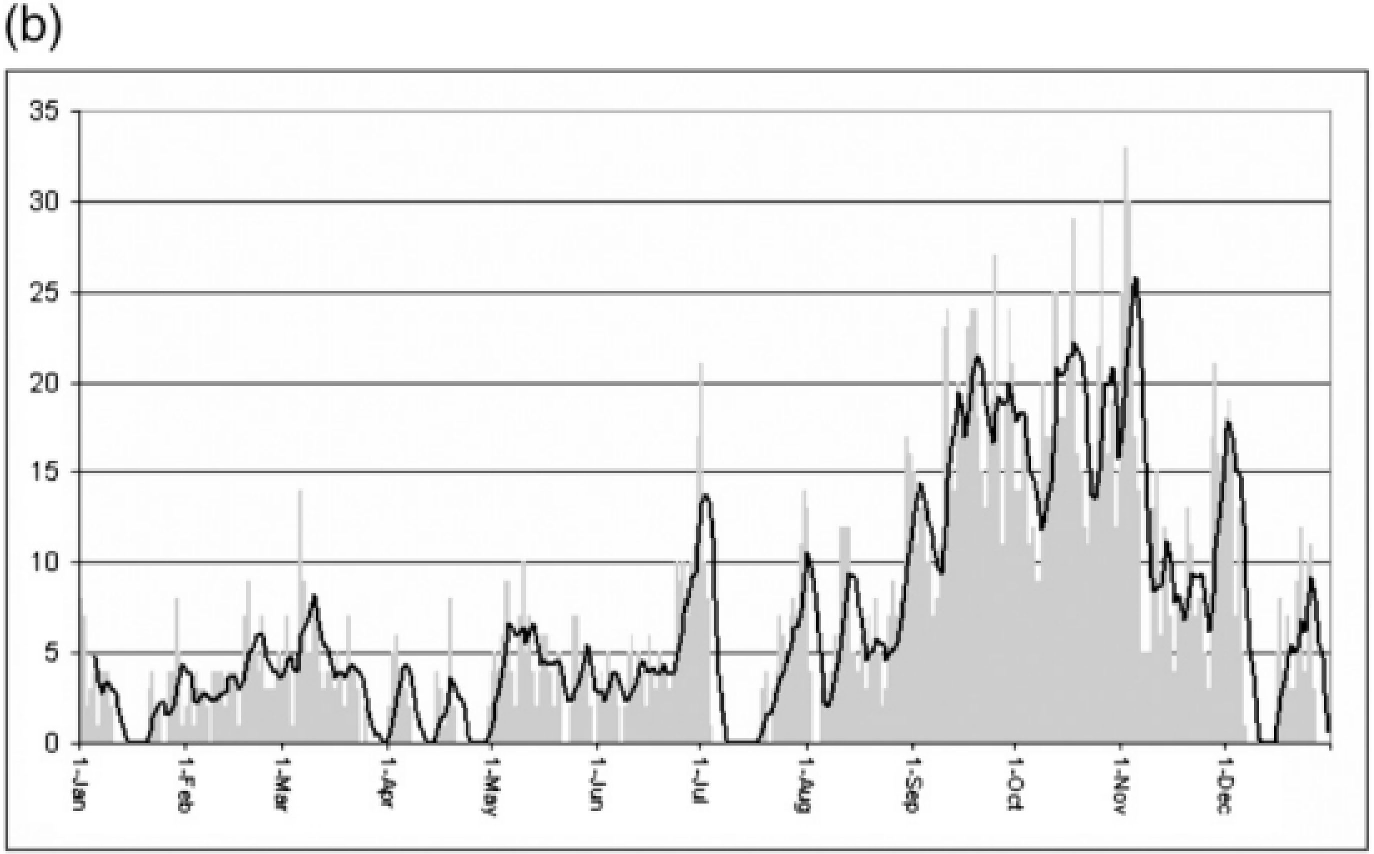

FIG. 6. Temporal distribution of ST occurrence: (a) Year vs month gridded plot of occurrence of subtropical storms. Monthly and annual histogram distributions are plotted below and to the left of the main plot, respectively. (b) Daily distribution of all ST occurrences in the 45-yr dataset (histogram) and 5-day running average (black line).

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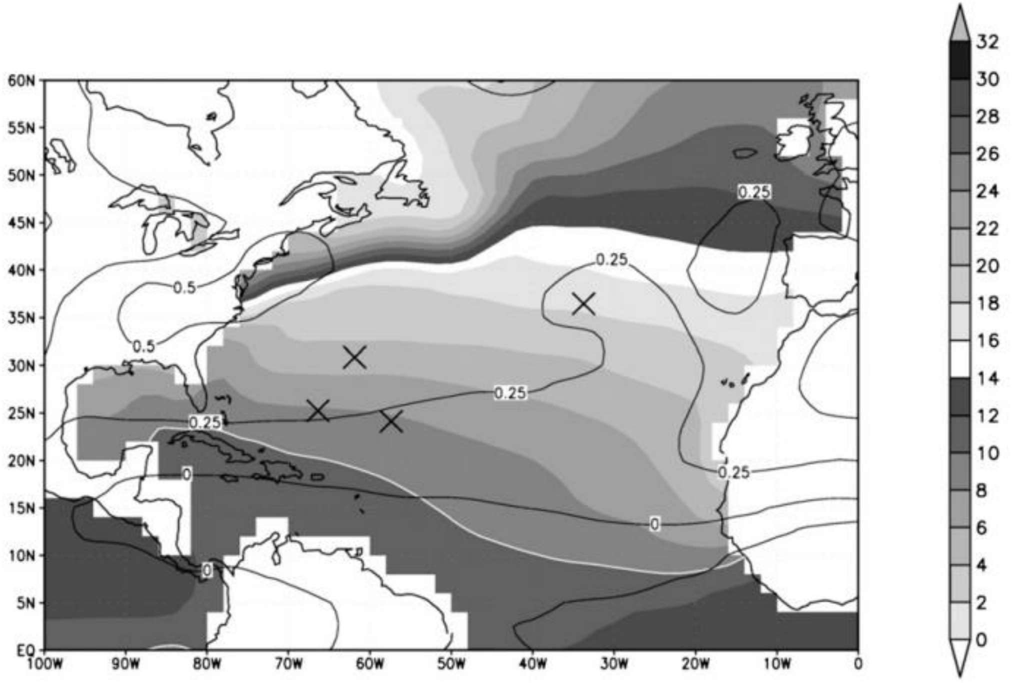

FIG. 12. April long-term mean NCEP–NCAR Reanalysis composite Eady baroclinic growth rate (contoured; day^{-1}) and SST (shaded; °C). The crosses indicate the April positions of ST storm (gale) onset.

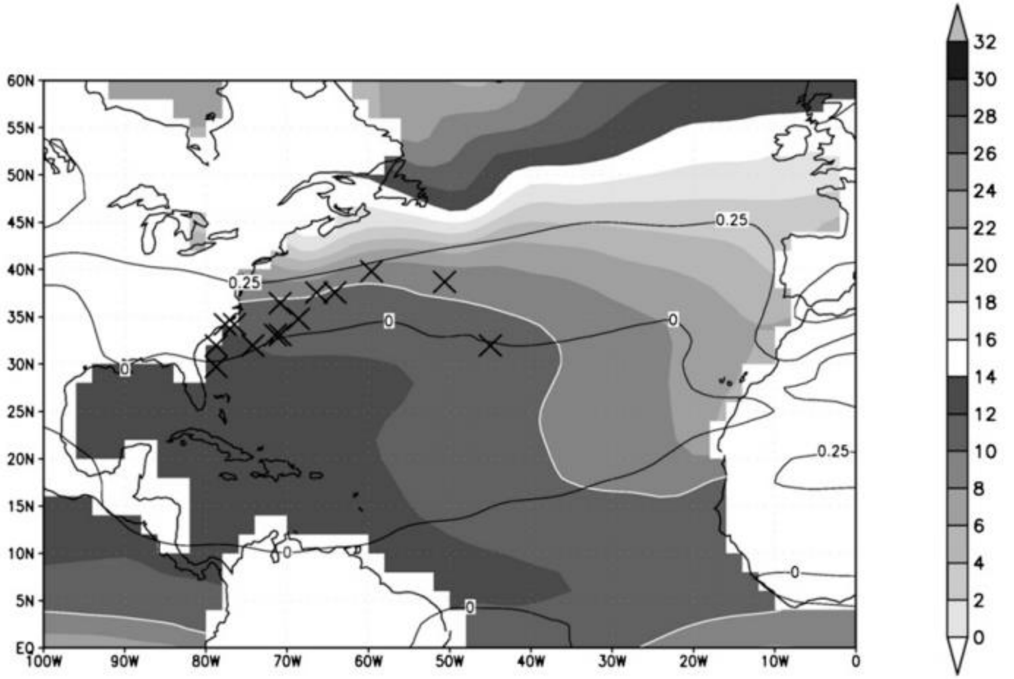

FIG. 13. As in Fig. 12, but for August.

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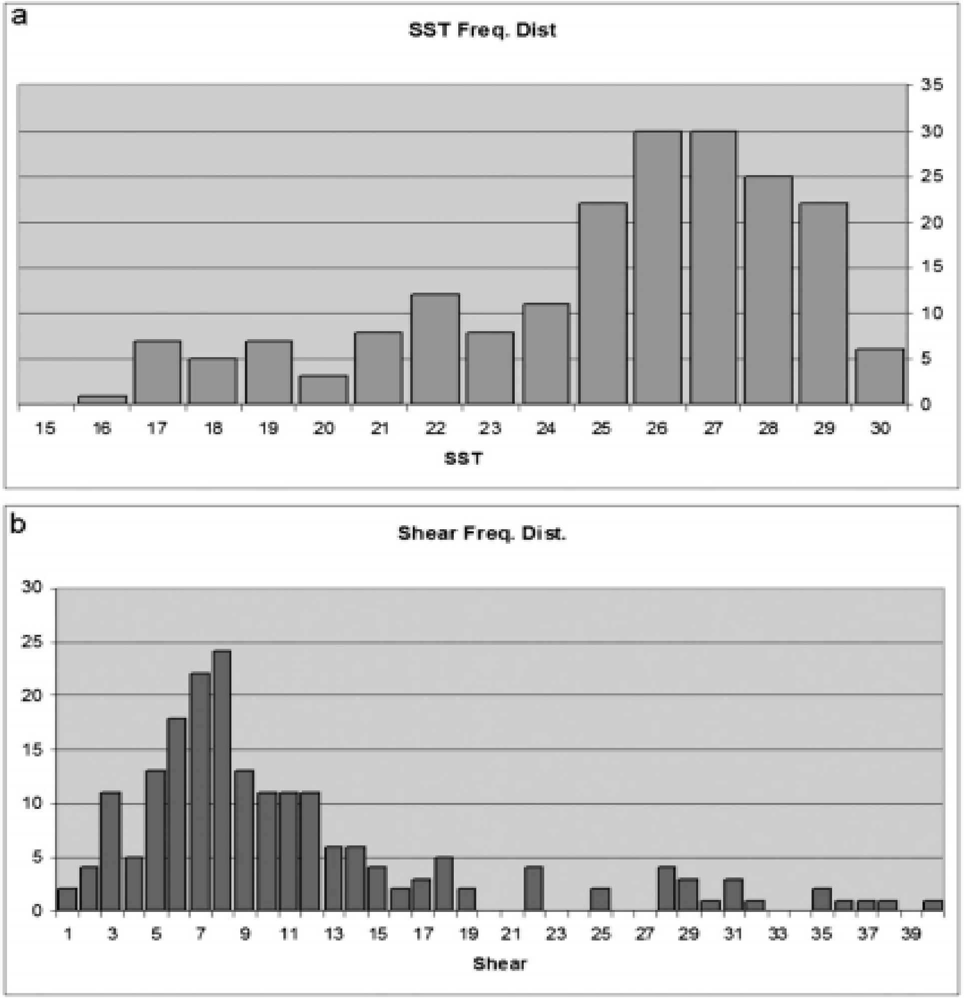

FIG. 8. Frequency distribution of the numbers of ERA-40 storms sorted by (a) SST (°C) and (b) 925–200-hPa vertical wind shear (m s^{-1} over the 725-hPa layer).

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- Guishard et al. (2009):

TABLE 2. Comparison of the necessary conditions for subtropical cyclogenesis determined in this study against those required for tropical cyclogenesis.

Subtropical cyclone (ST)	Tropical cyclone (TC)
Dynamic conditions	
Upper trough (nontrivial deep layer shear)	Weak deep layer shear
Positive low-level relative vorticity	Positive low-level relative vorticity
Latitudes 20°–40°N (Coriolis parameter is large compared with tropical genesis)	Latitudes 10°–20°N (Goldenberg and Shapiro 1996)
Thermodynamic conditions	
Near-neutral stability in the free troposphere. Facilitated by warm SST and cold upper temperatures. Deep convection possible with forced ascent.	Ability to sustain deep convection. Facilitated by warm SST and saturation in the boundary layer.
Anomalously high lower-tropospheric moisture (cf. long-term monthly average).	Anomalously high lower-tropospheric moisture (cf. long-term monthly average).

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- González-Alemán et al. (2015):

15 April 2015 GONZÁLEZ-ALEMÁN ET AL. 3331

Classification and Synoptic Analysis of Subtropical Cyclones within the Northeastern Atlantic Ocean*

Juan J. González-Alemán and Francisco Valero

Departamento de Física de la Tierra, Astronomía y Astrofísica II, Universidad Complutense de Madrid, Madrid, Spain

Francisco Martín-León

Agencia Estatal de Meteorología, Madrid, Spain

Jenni L. Evans

Department of Meteorology, The Pennsylvania State University, University Park, Pennsylvania

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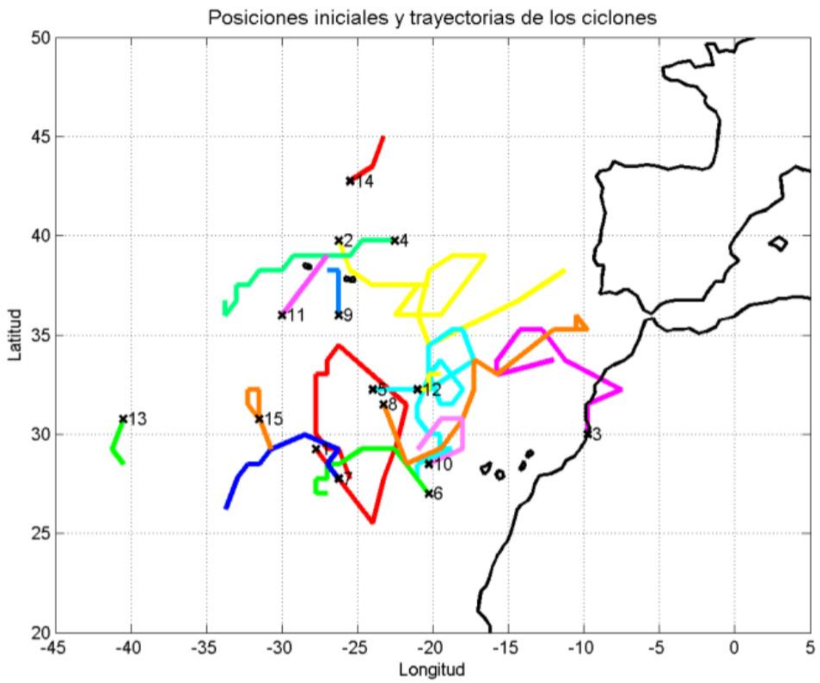

Fig. 1: Posiciones iniciales y trayectorias de los ciclones subtropicales identificados en la cuenca este del Atlántico Norte durante el periodo 1979-2011. Las cruces indican la posición del ciclón en el momento (t_0) en el que es identificado como ciclón subtropical.

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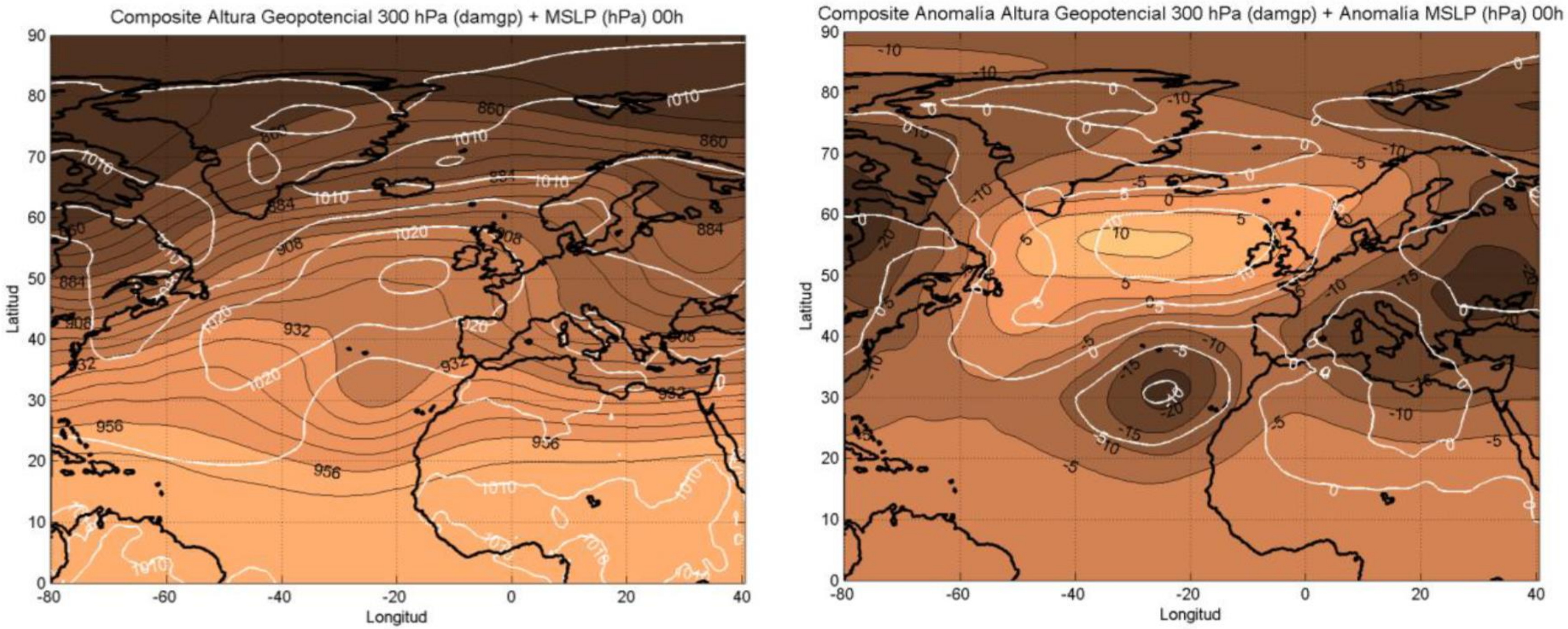

Fig. 2: a) Izquierda: Mapa compuesto de la altura geopotencial en 300 hPa (dam) (coloreado) y de la MSLP (hPa) (isolíneas blancas) en t_0 para los 15 STCs. b) Derecha: Ídem pero con mapa compuesto anómalo (respecto a la climatología).

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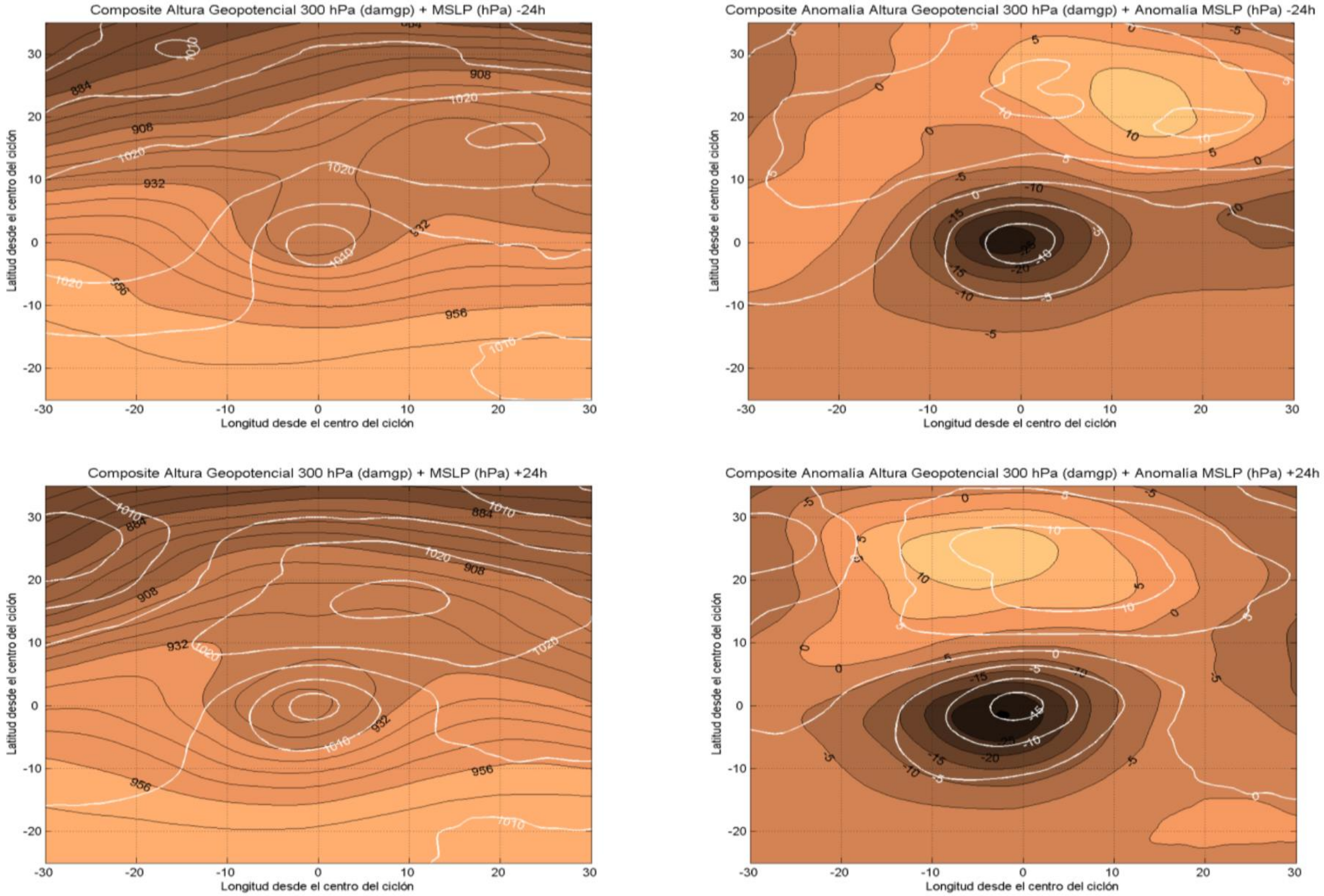

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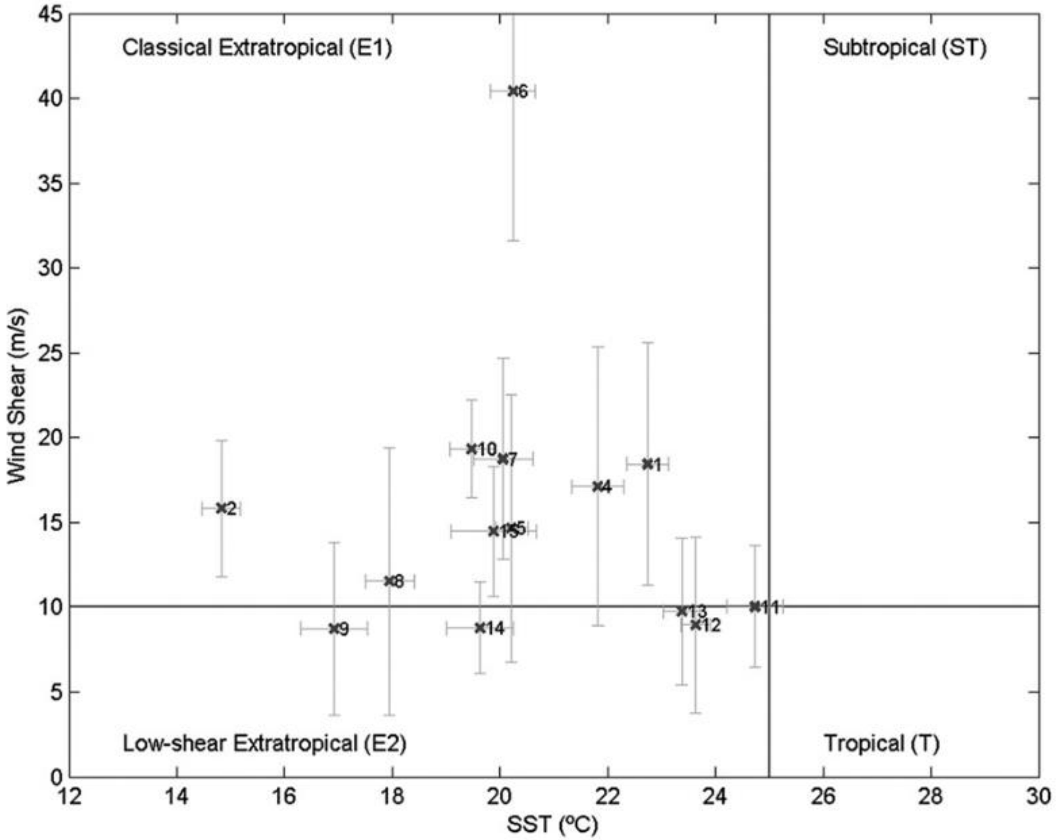

FIG. 6. Partition of the 14 STC cases based upon characteristics of their synoptic environment at genesis time (t_0). Number is associated with the name of the cyclone. Uncertainty bars indicate the standard deviation.

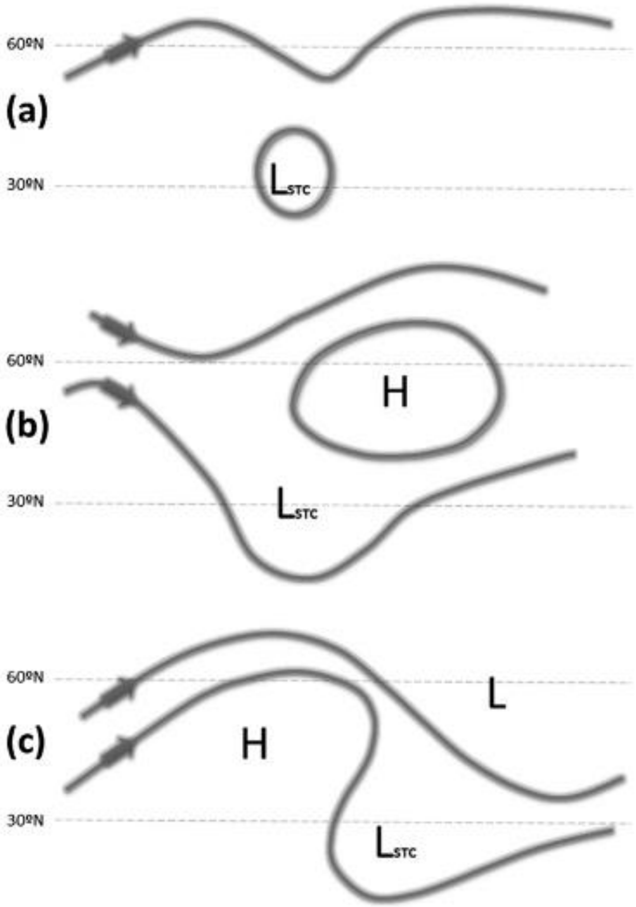

FIG. 7. Conceptual models of geopotential height at 300-hPa patterns at the formation of the cyclones (t_0): (a) cutoff/isolation, (b) bifurcation, and (c) prolongation. The arrows indicate the approximately sense of the flow at 300 hPa; H denotes a region of high pressure and L denotes a region of low pressure, where the subscript STC denotes the subtropical cyclone.

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- Ciclogénesis subtropical:

  - Tal y como habíamos visto anteriormente con las dos clases de ciclogénesis en la atmósfera, también podemos hablar de ciclogénesis subtropical como un proceso por el cual se genera un ciclón subtropical.

  - Sin embargo, este proceso está mucho menos investigado y desarrollado y, por ello, se describe a continuación una idealización.

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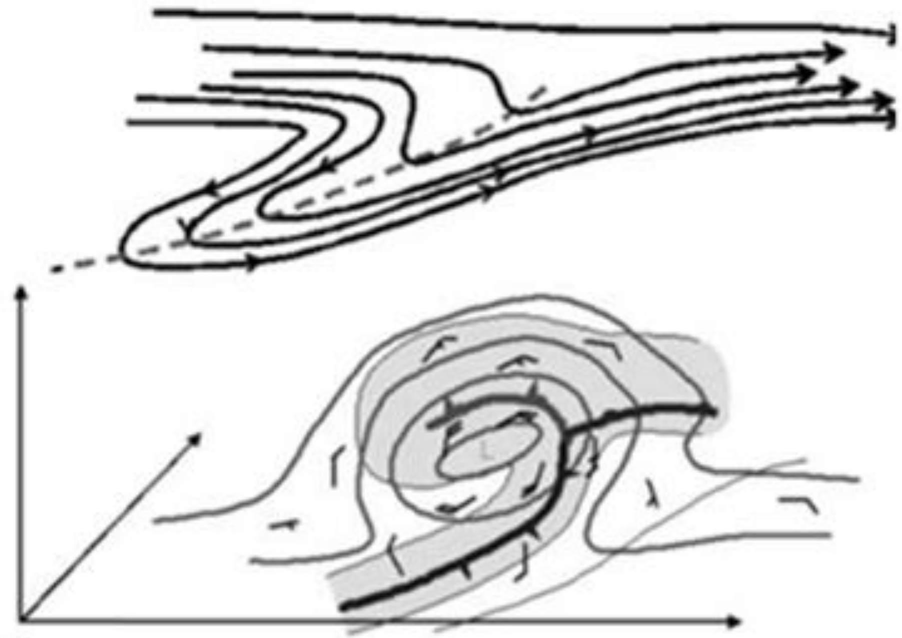
- Ciclogénesis subtropical:
  - En la figura se representa la ciclogénesis baroclina inicial con una vaguada integrada en la circulación del oeste aportando forzamiento QG y formando una baja en superficie con sus frentes asociados. Esta vaguada comienza a presentar signos de descolgamiento, que se producirá a través de una ruptura de onda de Rossby (RWB).



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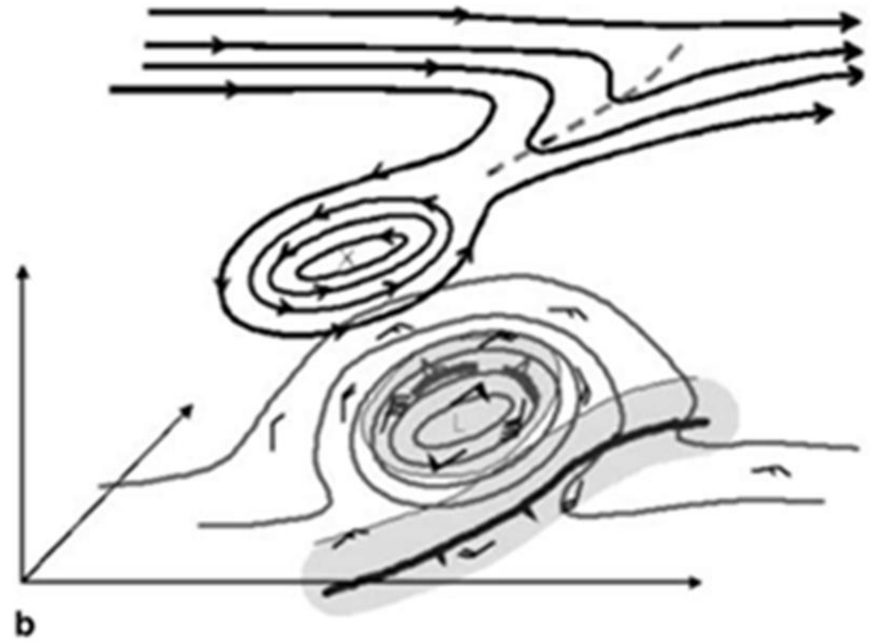
- Ciclogénesis subtropical:
  - En la figura se muestra como la vaguada en altura se ha aislado de la circulación conjuntamente con la baja en superficie, que se ocluye con su escudo nuboso asociado, procedente de la zona baroclina principal.
  - El desarrollo de la convección debido al núcleo frio en altura en un entorno cada vez menos baroclino es lo que crea el núcleo cálido en niveles bajos formando una estructura híbrida con características de ciclón subtropical.



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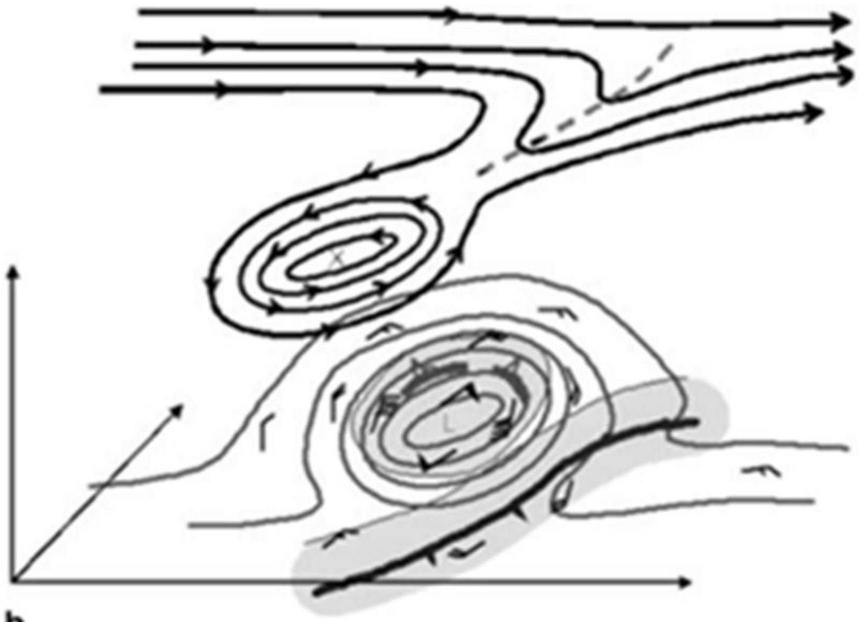
- Ciclogénesis subtropical:
  - Una vez aislado, la separación entre el ciclón y su chorro de niveles altos primario incrementa la probabilidad de una transición tropical.
  - Finalmente, si el núcleo es cálido, conduce al desarrollo vertical del ciclón tropical con convección extendida completamente alrededor de la baja presión y de flujo anticiclónico de salida de aire en altura.



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- Ciclogénesis subtropical:
  - La estructura híbrida permanece evidente hasta que la convección erosiona el máximo de vorticidad potencial en altura (si es capaz de hacerlo) hasta el punto de que el núcleo cálido en niveles bajos domina y el ciclón se vuelve de naturaleza más tropical.
  - De no ser así, el ciclón podría adquirir características más extratropicales si la convección no se sostiene, por ejemplo, debido a una SST fría o a intrusiones de aire seco.
  - Si este es el caso, la baja fría en altura puede extenderse hacia abajo impulsando una circulación menos intensa en niveles bajos de lo que ocurriría en un huracán.
  - Si esta baja fría permanece aislada puede rellenarse en cuestión de días.

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DETECCIÓN DE UN CICLÓN SUBTROPICAL

Título :	Detección de un ciclón subtropical
Autor :	González-Alemán, Juan J.; Valero Rodríguez, Francisco; Martín León, Francisco
Palabras clave :	Ciclón subtropical; Evolución sinóptica; Imágenes de satélite; Cizalladura vertical; Vorticidad
Fecha de publicación :	2015
Editor:	Agencia Estatal de Meteorología
Citación :	Calendario meteorológico. 2016, p. 299-306
Resumen :	En este trabajo se analiza el ciclo de vida de lo que debería haber sido una típica borrasca de invierno que suele afectar a la cuenca atlántica nororiental. Sin embargo, dicha baja comenzó a adquirir características tropicales, lo que le lleva a ser identificada como ciclón subtropical. Con esta descripción se detalla una metodología para identificar este tipo de fenómenos. En ella se utilizan una serie de herramientas y campos meteorológicos que demuestran ser útiles para realzar las características de los ciclones subtropicales. Estos fenómenos han cobrado importancia durante los últimos años y han centrado la atención de la comunidad científica por llevar asociados fenómenos meteorológicos extremos de gran impacto en la sociedad y por su potencial para convertirse en tormentas tropicales o huracanes. Uno de los problemas a los que se enfrenta un meteorólogo o predictor operativo en nuestra cuenca, es el de diferenciar este tipo de ciclones con los ciclones extratropicales o típicas borrascas de invierno.
Patrocinador:	Este trabajo ha sido realizado gracias al proyecto de investigación CGL2011-25327 del MINECO.
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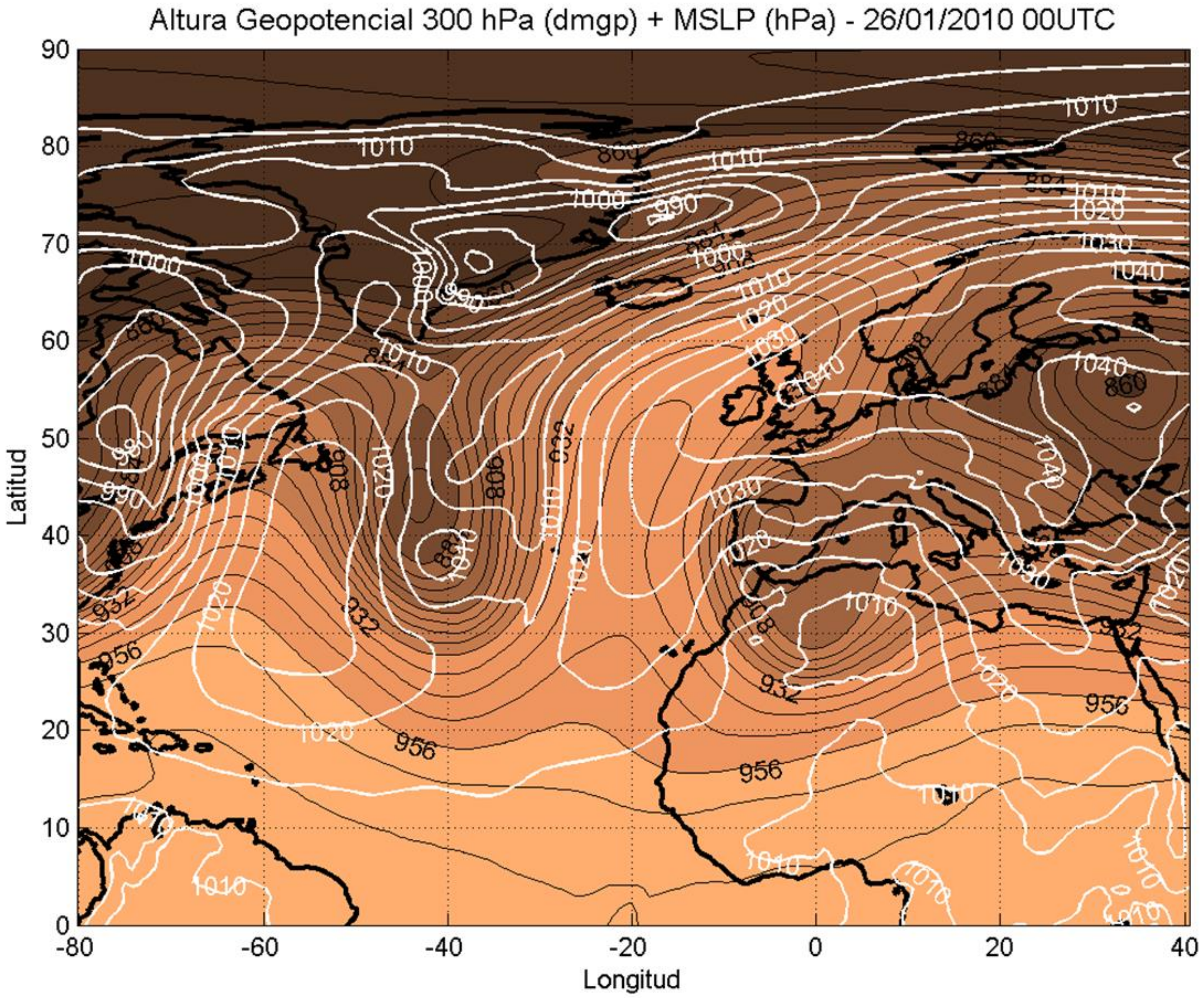
Historia sinóptica



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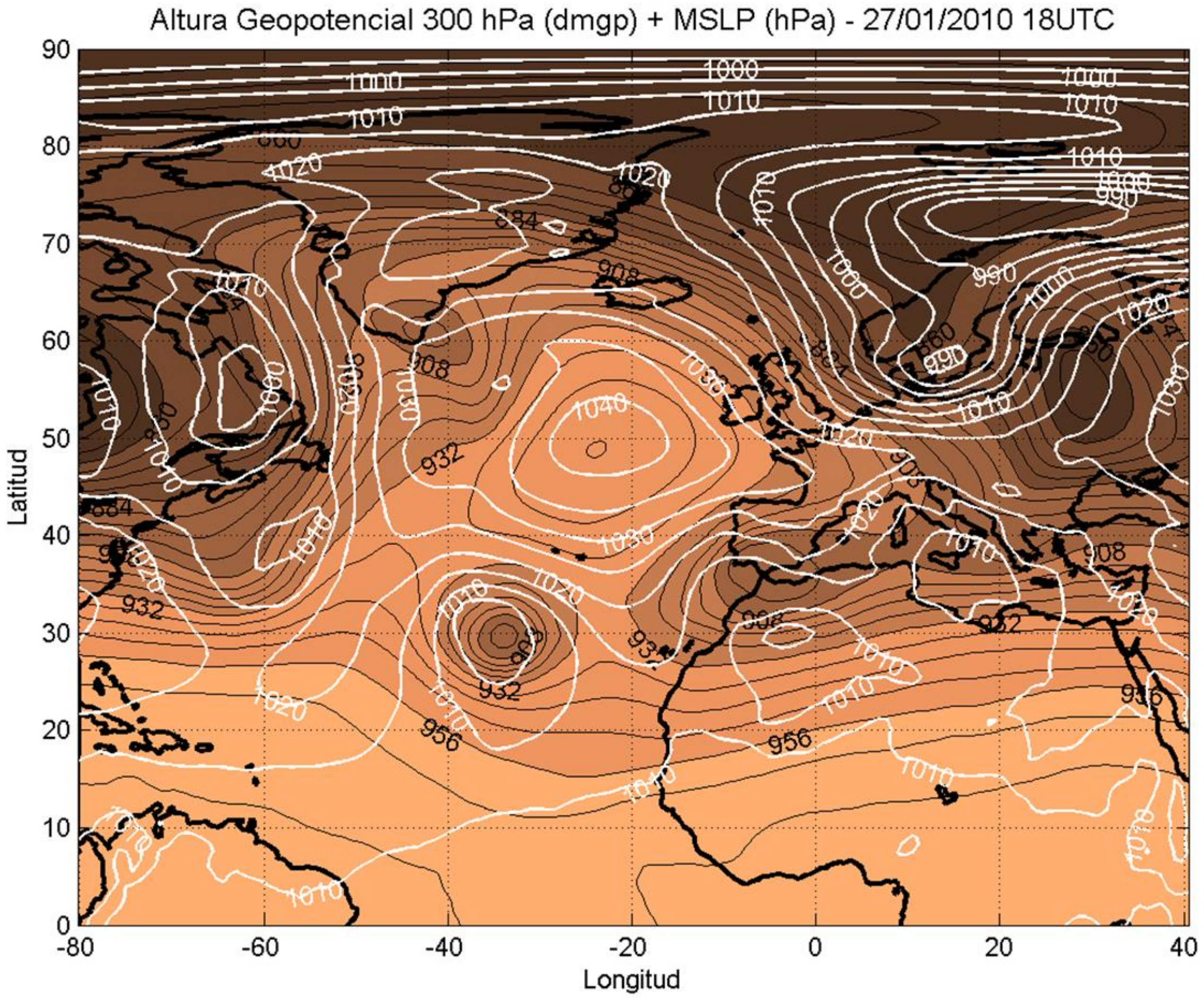

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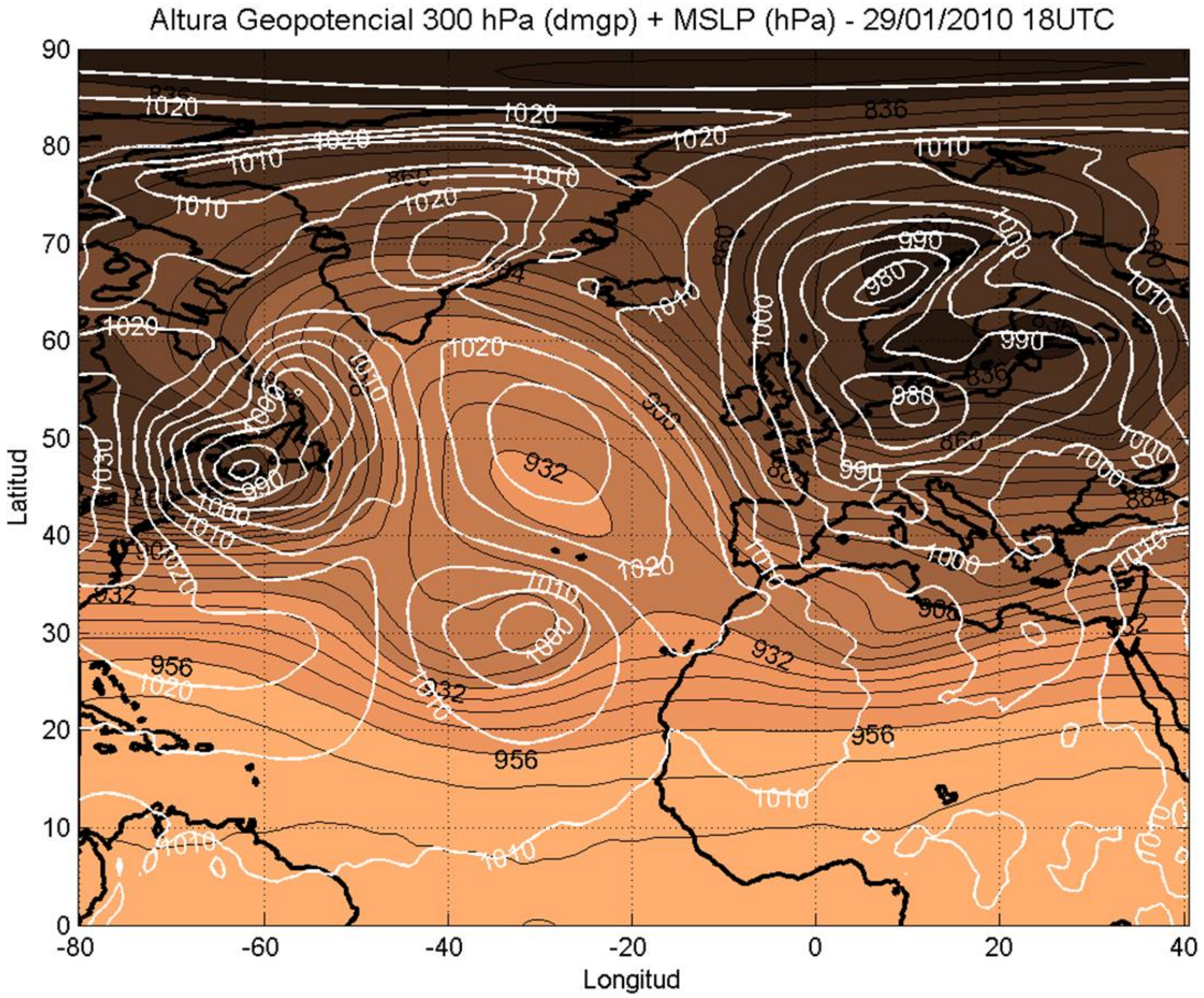

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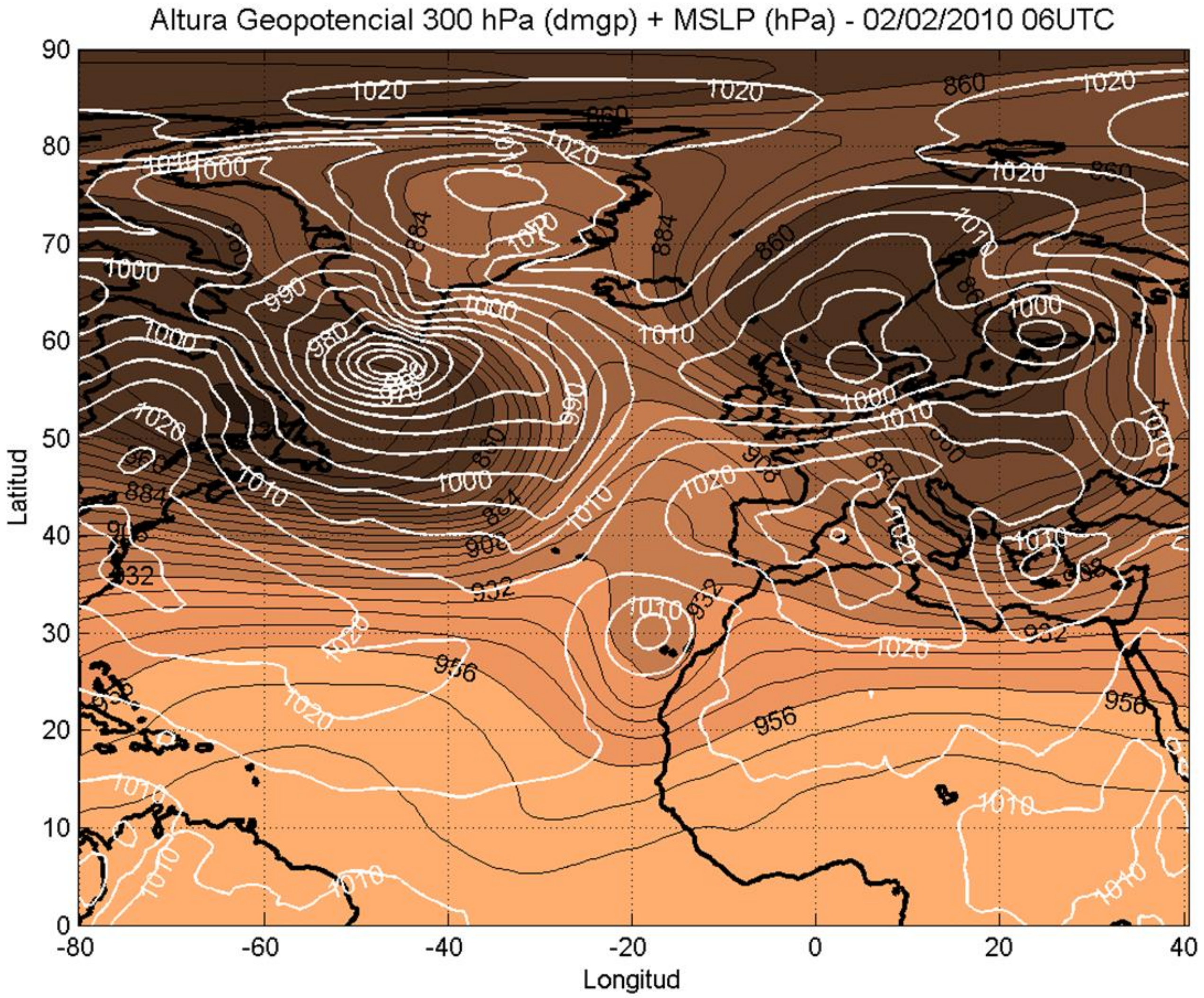

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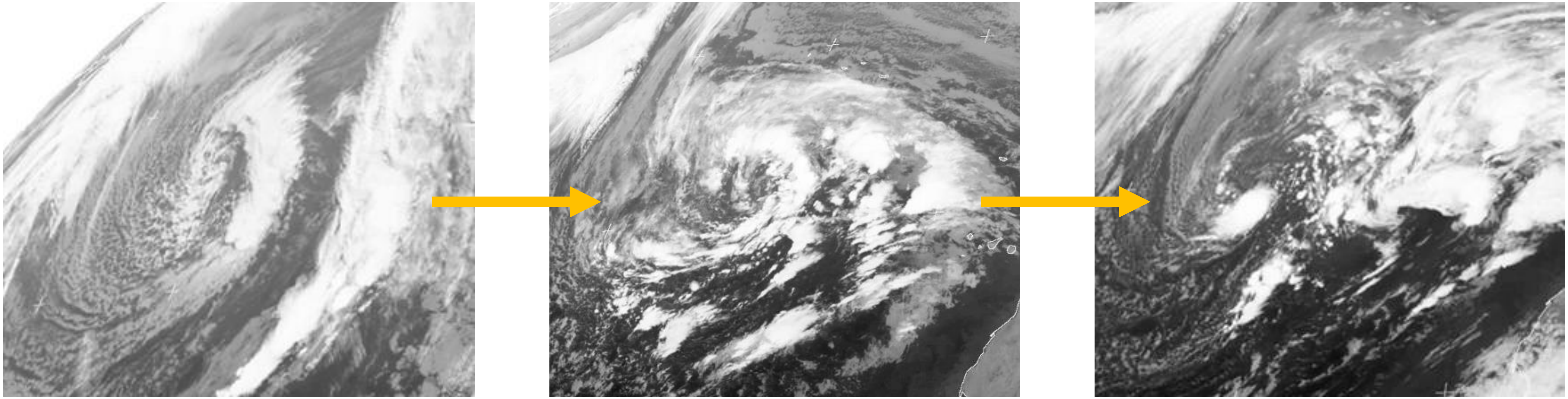

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2. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LOS CICLONES SUBTROPICALES

Técnica Hebert & Poteat

A SATELLITE CLASSIFICATION TECHNIQUE

FOR SUBTROPICAL CYCLONES

Paul H. Hebert, NHC, Miami, Florida
Kenneth O. Poteat, NESS, SFSS, Miami, Florida

Scientific Services Division
Southern Region
Fort Worth, Texas
July, 1975

ABSTRACT: The Dvorak (1973) technique for estimating the intensity of tropical (T) cyclones from satellite pictures is frequently inapplicable for subtropical (ST) cyclones. A new technique which gives not only the intensity but also the type (tropical, subtropical) of cyclone has been derived, using guidelines similar to the Dvorak scheme, so that the two systems will intermesh when cyclones change type. These guidelines were evaluated by Miami Satellite Field Services Station (SFSS) meteorologists for a data sample of 32 cases (27 subtropical) for the period May-November 1968-74. Results indicate mean absolute wind errors comparable to those using the Dvorak technique, as well as a successful meshing of the two techniques, and the ability to distinguish between the two types of cyclones.

UNITED STATES DEPARTMENT OF COMMERCE
Rogers C. B. Morton, Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Robert M. White, Administrator

National Weather Service
George P. Cressman, Director

Objetivos

- Ser capaz de **distinguir los ciclones** subtropicales de los tropicales en sus etapas de formación mediante imágenes de satélite IR

- Ser capaz de **estimar la intensidad** de los ciclones subtropicales.

- Tener un criterio con el que se pudiera **entrelazar con la técnica Dvorak** para el momento en el que se conviertan en tropicales.

NO.	DATE	ORIGIN	MAXIMUM SUSTAINED WIND (KNOTS)	MINIMUM SEA LEVEL PRESSURE (MILLIBARS)
1	9/ 9-11/68	B-2	50	1000
2	9/14-23/68	B-1	70	980
3	9/23-29/68	B-2	50	1001
4	6/16-19/69	B-2	40	1000
5	8/24-27/69	B-1	50	999
6	9/21-25/69	B-1	50	995
7	9/24-28/69	A	35	1005
8	9/29-10/1/69	B-2	50	996
9	10/28-31/69	B-1	50	995
10	10/30-11/6/69	A	60	992
11	8/10-12/70	B-2	45	995
12	10/12-17/70	B-2	60	991
13	10/20-28/70	B-1	60	992
14	7/ 4- 7/71	B-1	35	1005
15	9/16-19/71	B-1	40	1001
16	10/17-20/71	B-2	50	997
17	5/23-28/72	B-2	60	1001
18	8/22-27/72	B-1	60	992
19	9/18-21/72	B-1	60	990
20	11/ 1- 4/72	A	40	998
21	5/ 2- 6/73	B-2	35	1005
22	7/29-8/1/73	B-2	40	1005
23	10/ 7-11/73	B-2	75	995
24	10/23-27/73	B-2	50	985
25	7/14-19/74	B-1	45	1005
26	8/ 9-15/74	B-1	50	992
27	10/ 4- 8/74	B-1	45	1005

Table 1. Dates, origins (see page 6 for definition), estimated maximum winds

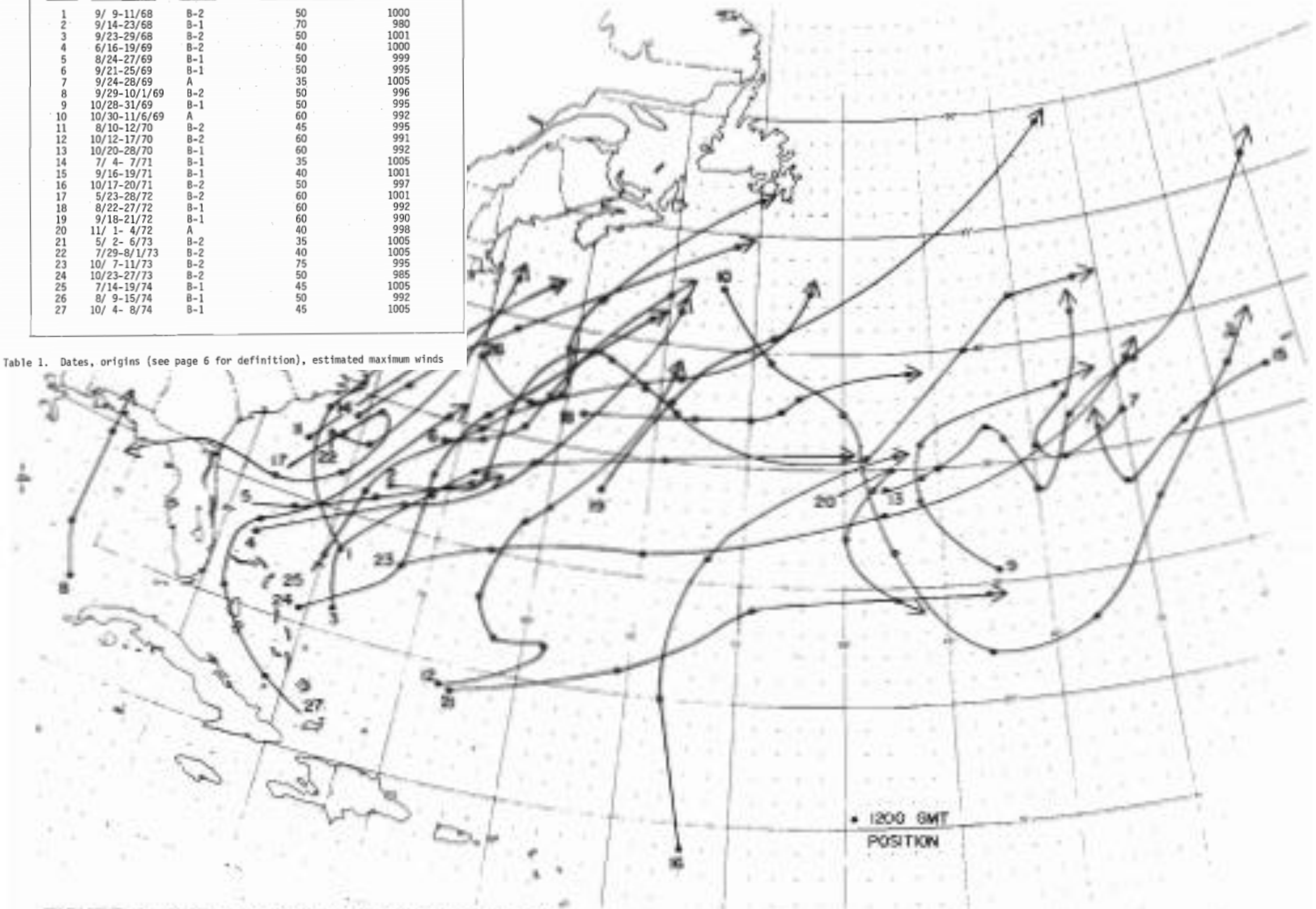


FIGURE I. SUBTROPICAL STORMS 1968-1974.

Determinación del tipo de ciclón

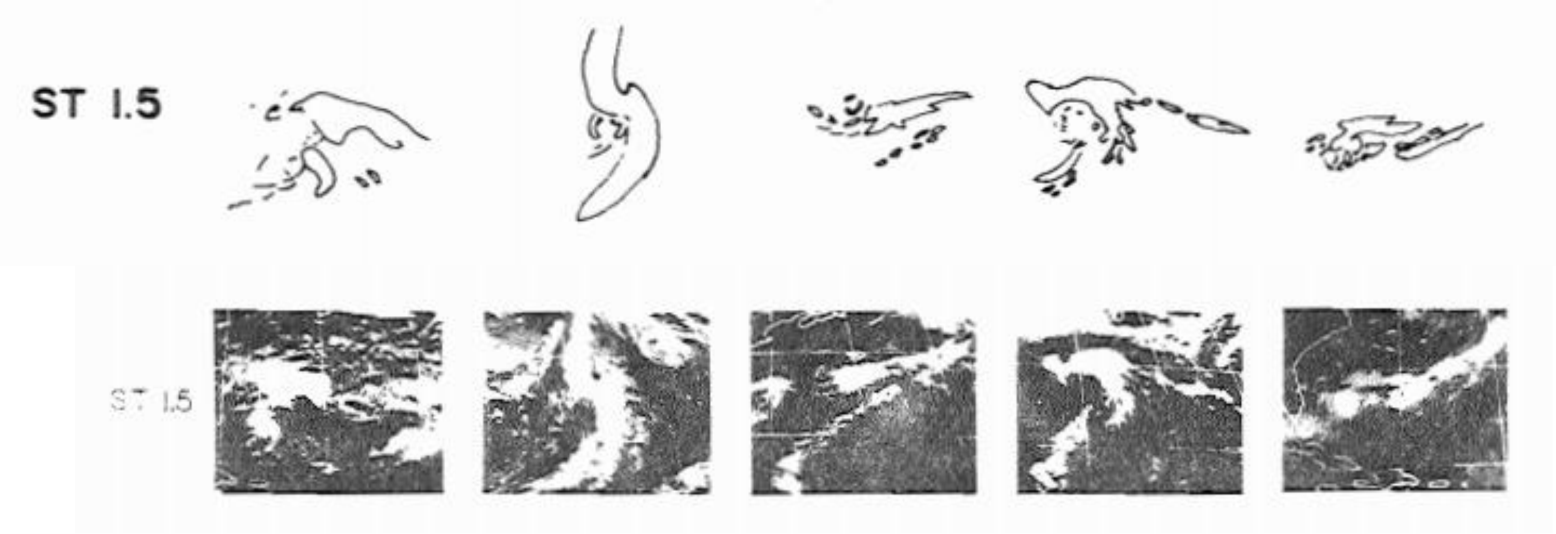
	Subtropical	**Tropical**
Convección principal	Hacia el polo y este del centro	Hacia el ecuador y este del centro
Tamaño del sistema de nubes	Anchura de 15º o más	Anchura normalmente inferior a 10º
Interacción con el ambiente	El sistema de nubes convectivas permanece conectados con otros sistemas sinópticos (excepto algunas depresiones aisladas)	El sistema de nubes se aísla

Estimación de la intensidad

ST 1.5 (13-16 m/s):

Centro de circulación en niveles bajos entre **0,5º y 2º de latitud** desde la **convección pobremente organizada** (no necesariamente densa).

Para bajas frías, la **convección puede no estar conectada** a otros sistemas y existe un área pequeña (< 3º) de convección profunda cerca del centro.

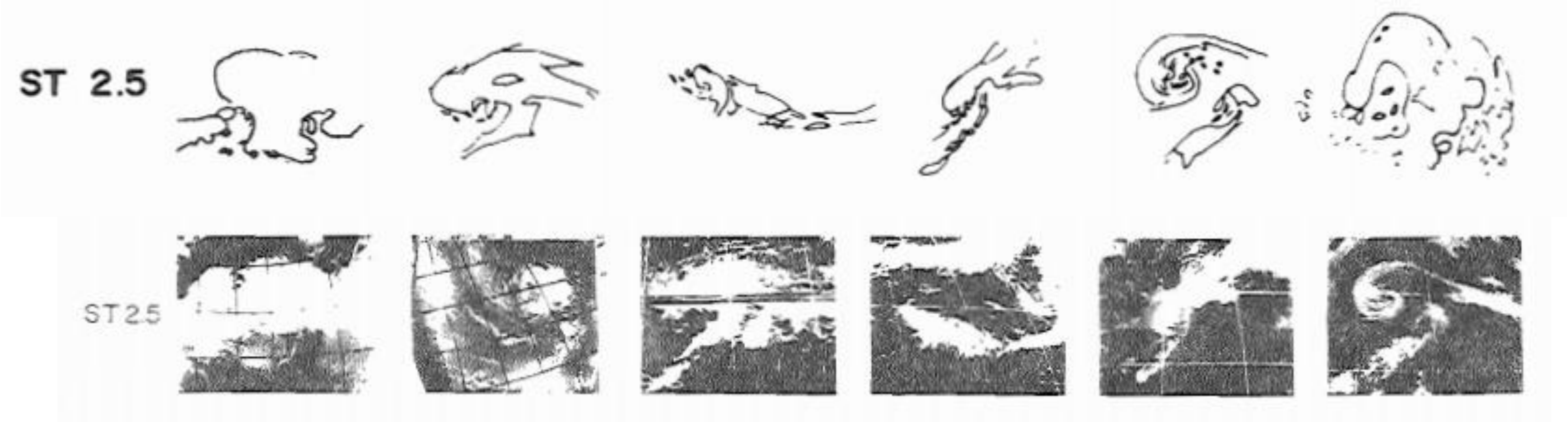


Estimación de la intensidad

ST 2.5 (18-21 m/s):

Centro de circulación en niveles bajos entre **0,5º y 2º de latitud** desde la **convección profunda,** que se ha incrementado con mayor curvatura que los días previos (no necesariamente densa).

Bandas convectivas exteriores a 5º-10º al este del centro y posiblemente otras bandas convectivas a 2º-4º al noroeste del centro.

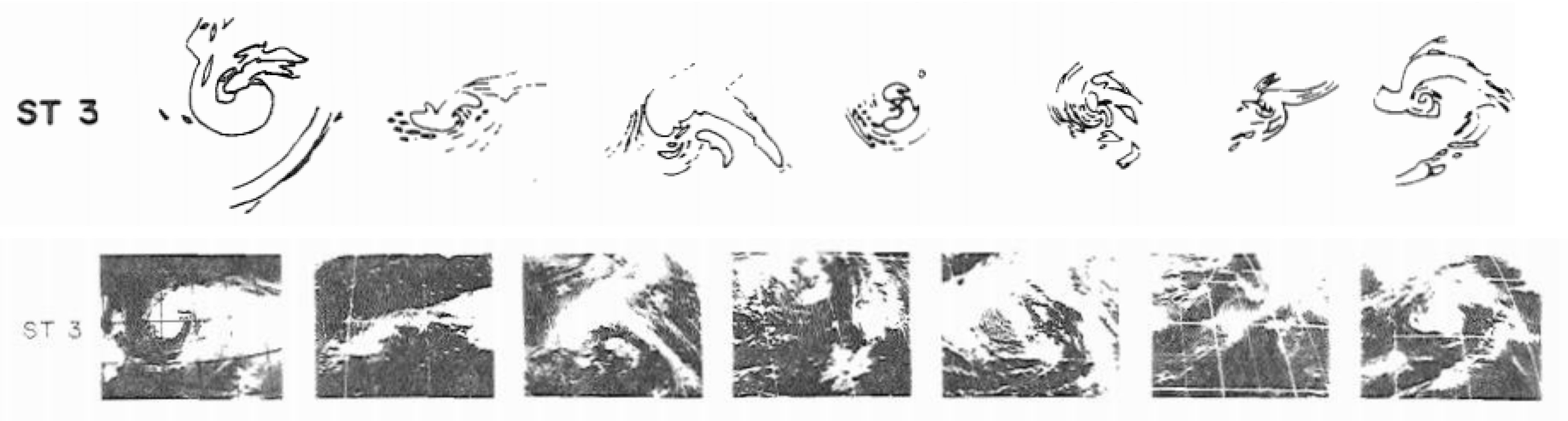


Estimación de la intensidad

ST 3.0 (23-26 m/s):

Mismo criterio que el anterior pero con **mayor curvatura y convección mejor organizada** que los días anteriores. La cobertura de nubes puede volverse densa.

Evidencias de bandas nubosas cerca del centro (<1º latitud).



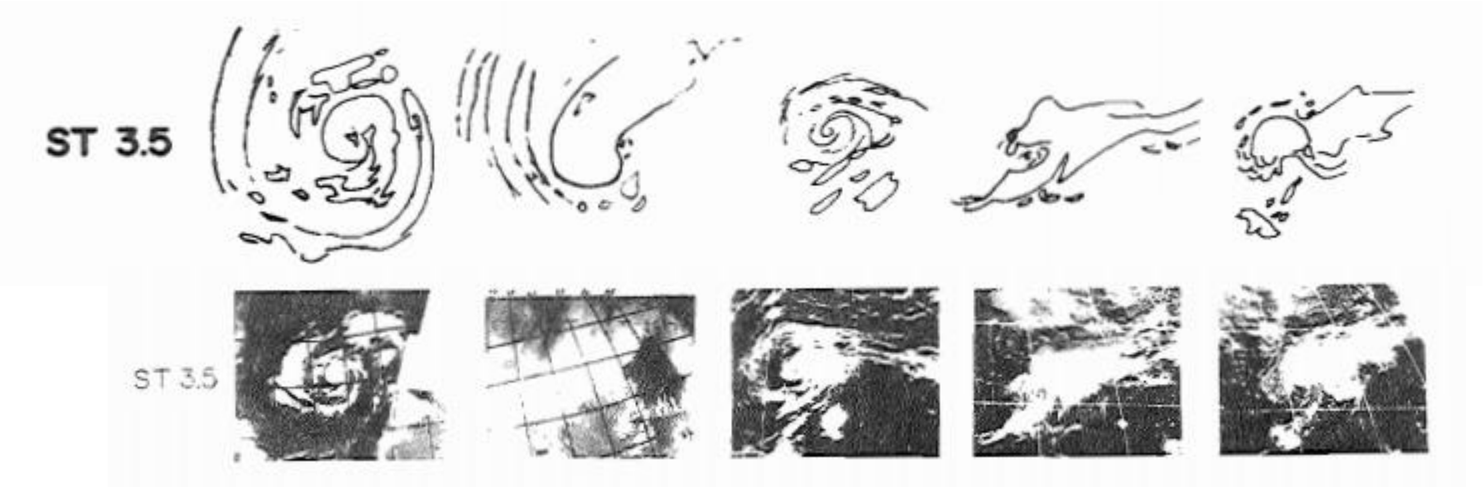
Estimación de la intensidad

ST 3.5 (28-34 m/s):

Convección profunda (frecuentemente con cobertura de nubes densa sin ser central) en bandas a 1-3º de latitudes respecto del centro.

Bandas convectivas exteriores a 5º-10º al este del centro posiblemente más débiles que días anteriores, pero pueden formarse nuevas bandas convectivas a 5º-10º al oeste del centro.

Para sistemas que se mueven rápidamente hacia el este, puede existir únicamente una cobertura de nubes densa (>3º latitud) entorno a 2º-4º al este del centro.



Comparación con la técnica Dvorak

Similitudes:

- Uso de la cobertura nubosa convectiva.
- Uso de la distancia entre el centro de la circulación y la cobertura nubosa.
- Los números de ST elegidos corresponden a los números de la intensidad observada de modo que convergen con los números T de la técnica Dvorak cuando el sistema se vuelve tropical.

Diferencias:

- Considera el ambiente para determinar el tipo.
- No puede tener un centro bajo una cobertura nubosa densa.
- No requiere una cobertura nubosa densa.
- No requiere bandas nubosas.
- Uso de la curvatura de las características convectivas para todos los números de ST en ausencia de bandas.
- La estimación de la intensidad está sujeta a rangos de la velocidad del viento

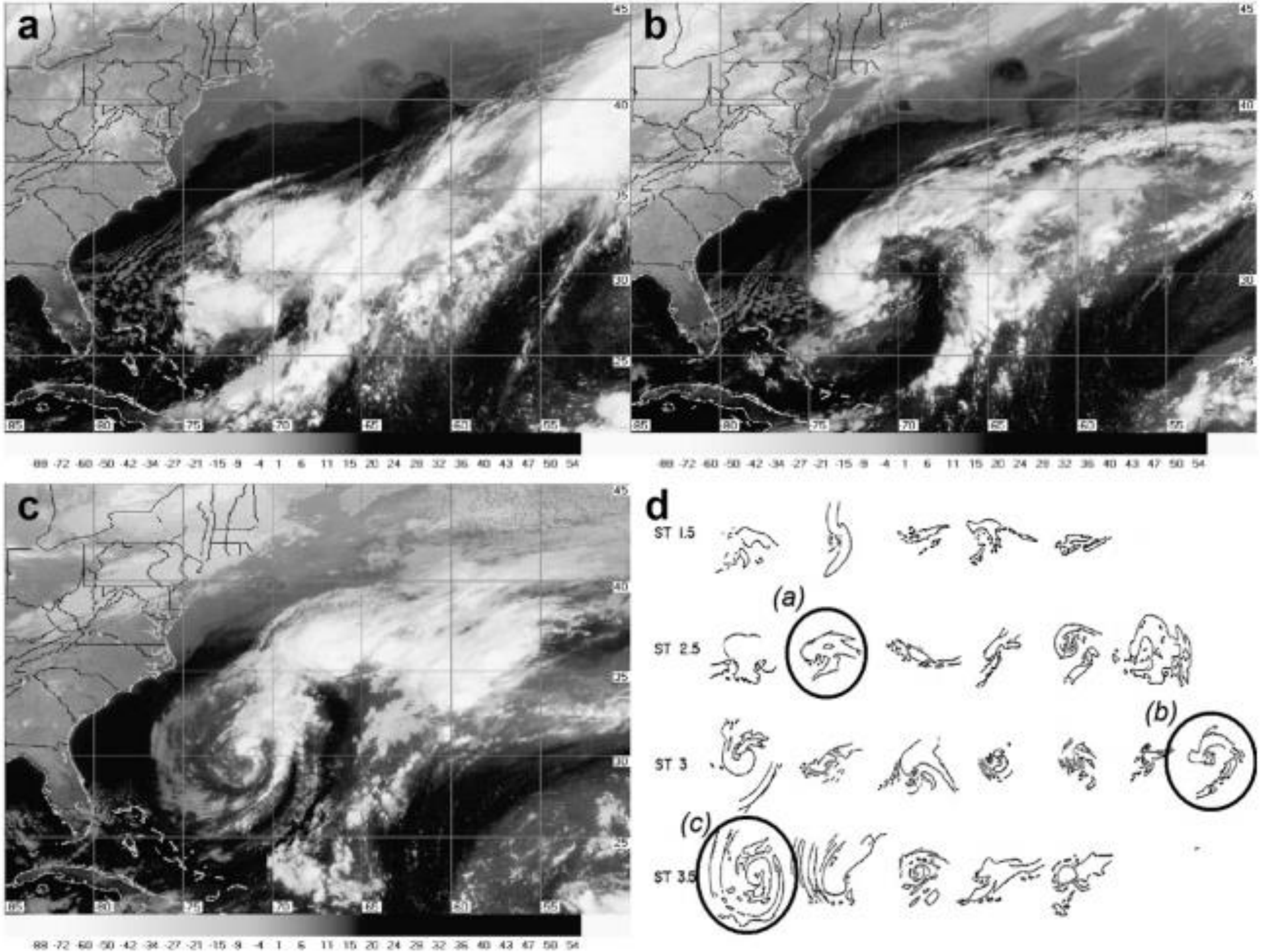


FIG. 1. Infrared (channel 2; 0.725–1.0 μm) satellite imagery for the Northwest Atlantic on (a) 1200 UTC 14 Oct, (b) 1200 UTC 15 Oct, and (c) 1200 UTC 16 Oct 2000. (d) HP75 satellite signatures for ST. Cloud patterns typical of the signatures in (a)–(c) are identified in (d). These support the intensification of Michael (2000) through the time period highlighted.

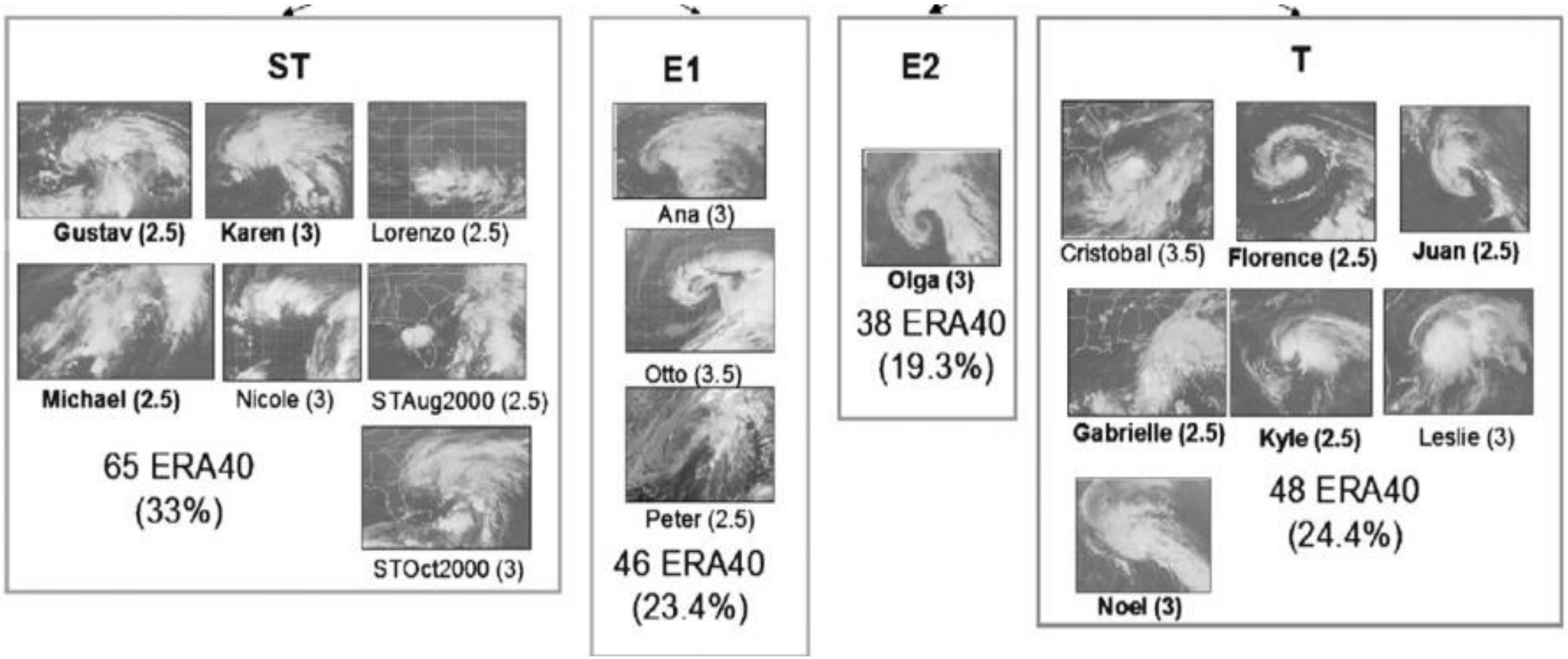
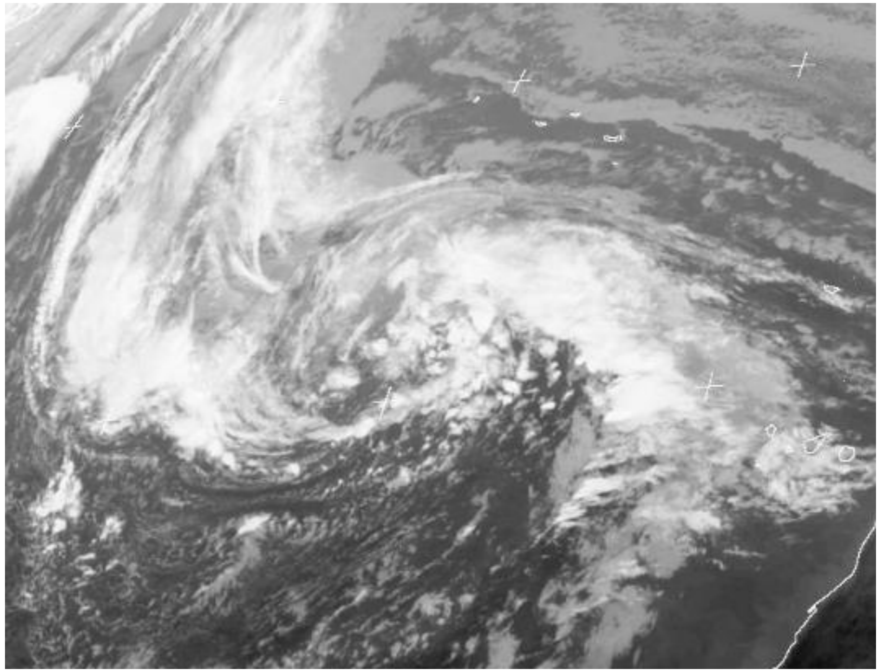
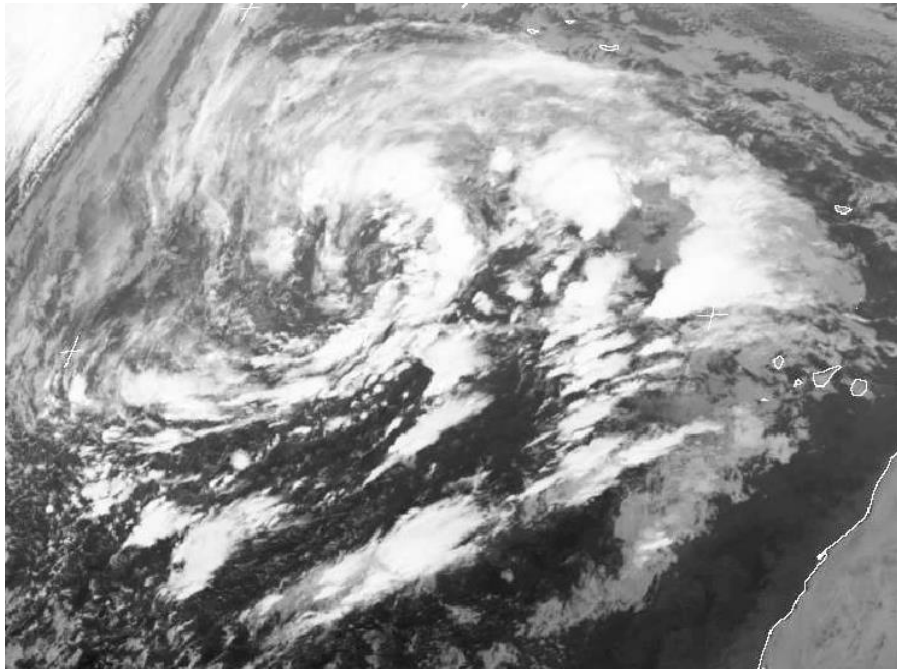


FIGURE 4. SCHEMATICS OF ST NUMBER PATTERNS





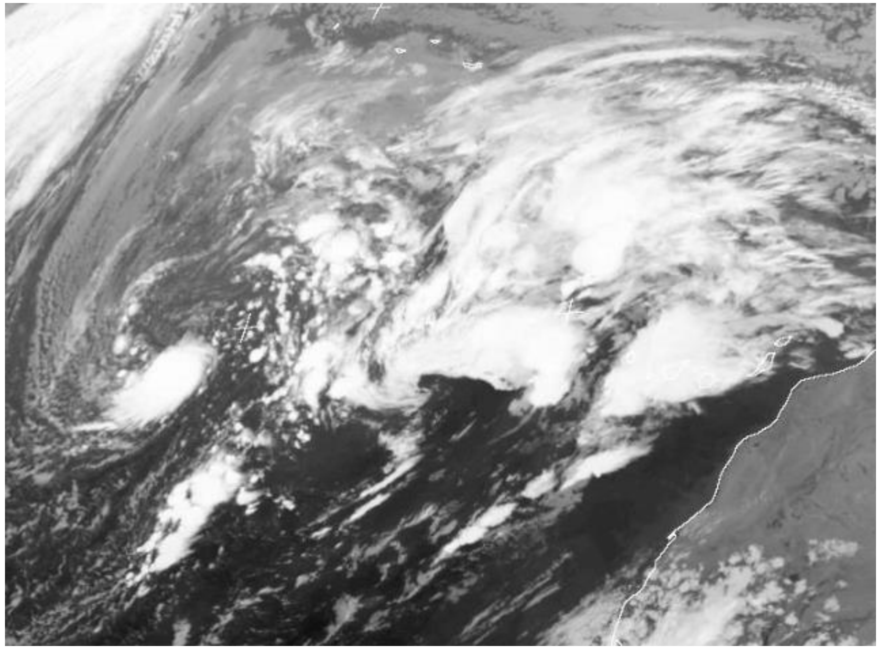


FIGURE 4. SCHEMATICS OF ST NUMBER PATTERNS

- **Hora 2:**
  - Características meteorológicas y climáticas de las transiciones tropicales y extratropicales.

METEOROLOGÍA TROPICAL:
CICLONES CON CARACTERÍSTICAS TROPICALES

Juan Jesús González Alemán
Doctor en Física y Meteorólogo Superior del Estado.
Área de Modelización. Departamento de Desarrollo y Aplicaciones (SSCCs)

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES TROPICALES

- Conceptual diagram of classification of different types of cyclones from the early work of Beven (1997).
- This diagram is useful for outlining a simple conceptual idea; the existence of a continuum in the spectrum of observed cyclone types.

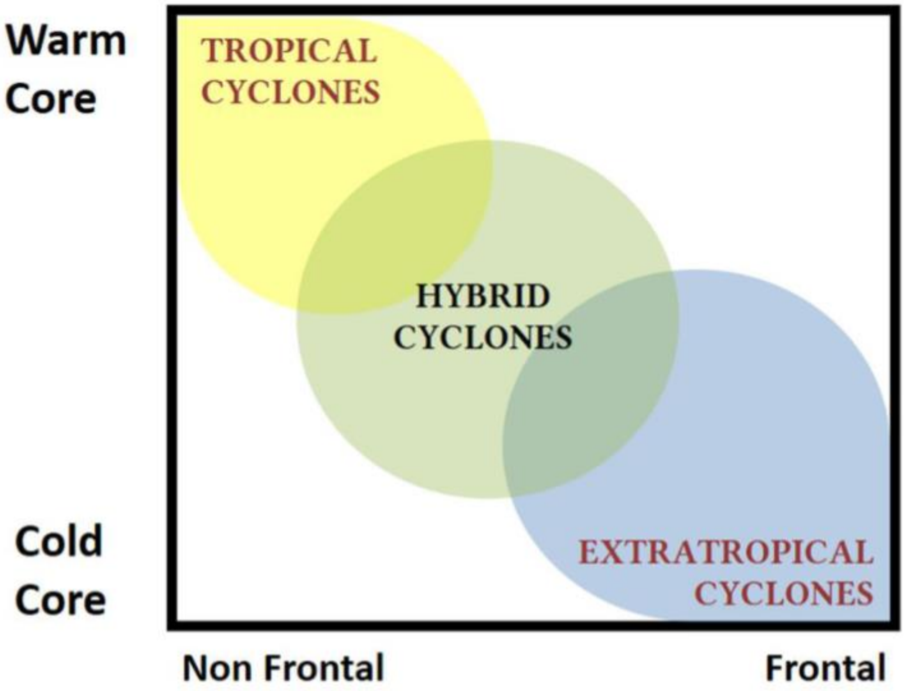
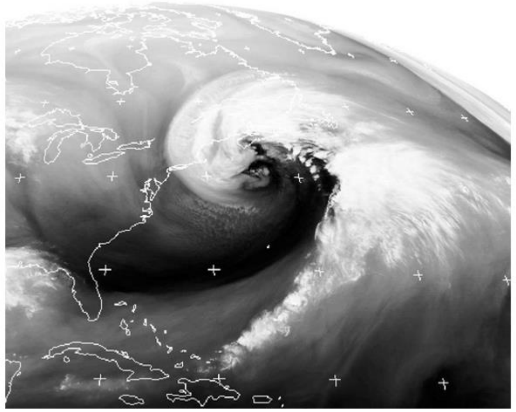
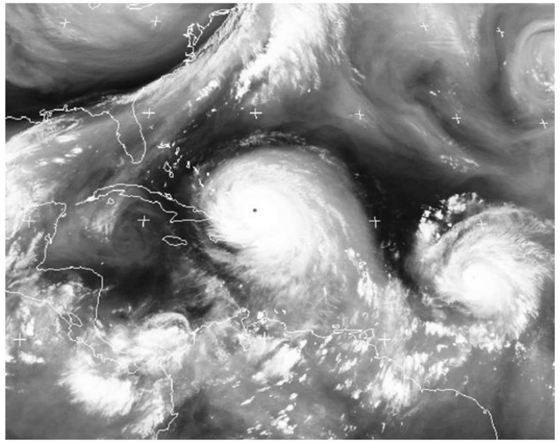


Figure 5. Schematic classification of atmospheric cyclones based on their thermal and frontal nature. Adapted from Beven (1997).





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1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES TROPICALES

- From such an idea arises the concept of transition, since there is no physical constraint in the free atmosphere to prevent one given type of cyclone from transforming into other different type one or from having hybrid characteristics.
- The structure and energy source of tropical cyclones is completely different from those of extratropical cyclones.
- Past works had already dedicated thoughts to the fundamentals of the idea many decades ago. From this viewpoint, the tropical and extratropical transitions are two possible cases of transition occurring in the atmosphere, leading from one extreme to another in the spectrum, while they often show characteristics of hybrid cyclones.
- Transitions are frequently associated with extreme weather development, with the associated social and biological impacts being of very significant concern (Pezza 2008).

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES TROPICALES

- Tropical transition (TT) is the process by which a cold-core cyclone loses its asymmetrical nature and gradually acquires characteristics typical of warm-core symmetrical tropical cyclones, ending up as a pure tropical cyclone. In addition, deep warm-core polar lows or medicanes are formed through this mechanism. The process by which a baroclinic, vertically sheared, extratropical cyclone is transformed into a warm-core, vertically stacked tropical cyclone.
- TTs have received much attention during the last decade since Davis and Bosart (2004) defined this process.
- Tropical cyclones are not phenomena exclusive of the tropics. Influential studies of Palmén (1948), Gray (1968), and DeMaria et al. (2001) showed that the environmental conditions deemed favorable for tropical cyclogenesis are frequently observed at tropical latitudes. However, environmental conditions can become favorable for tropical cyclogenesis in locations out of the tropics.
- A global climatology of tropical cyclogenesis (McTaggart-Cowan et al., 2013) showed that the majority of tropical cyclones which form poleward of 25°N (25°S) in the Northern (Southern) Hemisphere during 1948-2010 developed nearby an upper-tropospheric disturbance in a baroclinic environment.

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES TROPICALES

- The frequency of formation of those tropical cyclones varied across and between individual ocean basins. This is likely associated to the frequency of upper-level disturbances reaching these regions from the midlatitudes (Wernli and Sprenger, 2007).
- Bentley et al. (2017) farther developed this association and found that STCs that undergo TT could be separated into one of three categories based on the upper-tropospheric features associated with their formation: 1) cutoff lows, 2) meridional troughs, and 3) zonal troughs.
- While forecasters have been aware of this mechanism of tropical cyclogenesis for some time (Guishard, 2006), it is only recently that the frequency of occurrence of such genesis has been documented for the North Atlantic (Davis and Bosart 2003, 2004; Bentley et al., 2016).

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES TROPICALES

- Tropical cyclone development from baroclinic origin is preceded by diabatically enhanced turbulent momentum fluxes that act to homogenize the wind profile leading to rapid vertical wind shear decrease.
- The vertical potential vorticity (PV) redistribution due to convection results in upper-level PV depletion within the environment of the developing tropical cyclone (e.g., Hulme and Martin, 2009a,b; Galarneau, 2010).
- The TT (Davis and Bosart, 2003, 2004) process describes a TC developing from a cyclone formed in the presence of an upper-tropospheric disturbance in a purely baroclinic environment at the very first moment.
- While the TT is ongoing, the initial extratropical cyclone often exhibits some characteristics reminiscent of an evolving marine extratropical cyclone in the Shapiro-Keyser model (i.e. bent-back warm front and warm seclusion; Shapiro and Keyser, 1990; Neiman and Shapiro, 1993; Schultz et al., 1998; Hulme and Martin, 2009a,b; Cordeira and Bosart, 2011, Bentley and Metz, 2016).

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

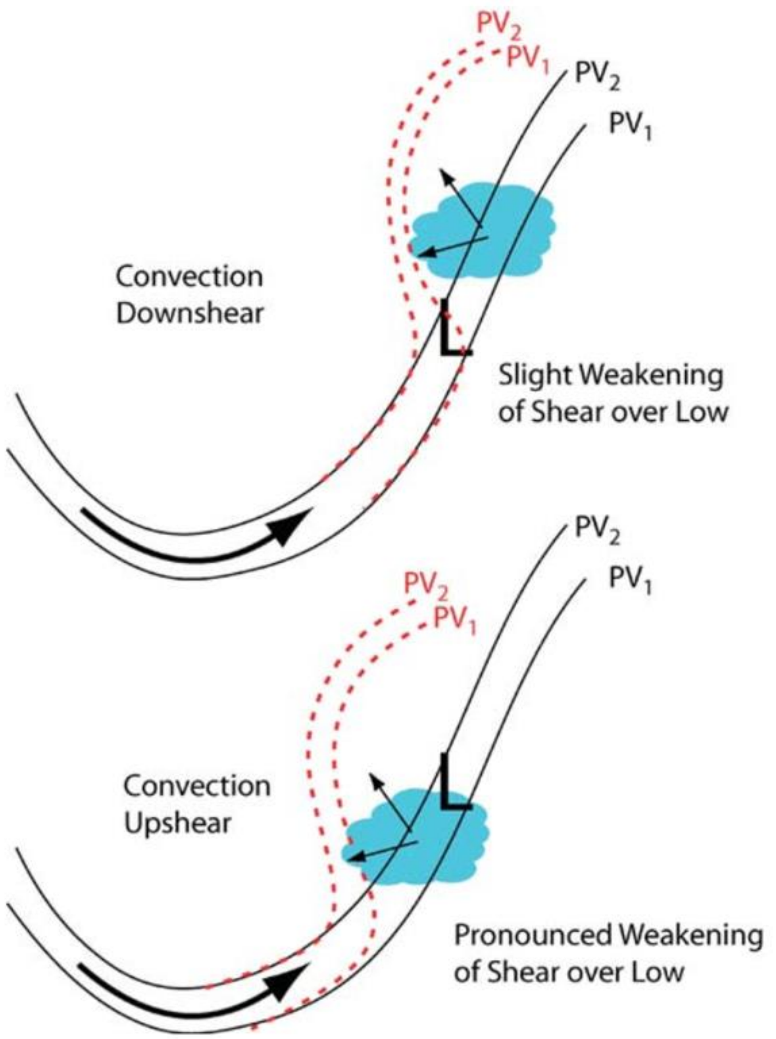
1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES TROPICALES

- During the first stages of the process, a region of upward motion is produced by vertical wind shear in a baroclinic environment (quasigeostrophic forcing; Suctcliffe, 1947; Trenberth, 1978), which in turn focuses deep moist convection and diabatic heating.
- Later on, a vertical transport of PV and momentum redistributes PV due to differential diabatic heating released by deep convection (e.g., Hoskins et al., 1985; Davis and Emanuel, 1991; Raymond, 1992; Stoelinga, 1996; Campa and Wernli, 2012).
- This in conjunction with the divergent outflow in the upper troposphere provokes a reduction in vertical wind shear, i.e., the initially baroclinic environment becomes more barotropic.
- The initial trough or upper-level low supporting the baroclinic cyclogenesis weakens and the system start to acquire a warm-core structure through latent heat release.
- This subsequently causes an environment setup that favors and/or allows an intensification of the stacked surface cyclone through air-sea interaction processes (Emanuel, 1987; Davis and Bosart, 2004; Bentley and Metz, 2016).
- During the transformation period, the system often has structure of STCs, which could indicate us that STCs are in reality cyclones in a never-ending TT process.

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES TROPICALES

- This bent-back idea was further supported by Hulme and Martin (2009a,b), who noted the presence of convection to the west and southwest of the surface cyclone in TT events (SEC cases).
- This occurred at the time of frontogenesis and upper-level PV deformation, which suggests that diabatic heating contributes significantly to the TT process consistently with its role in extratropical occlusion (Posselt and Martin, 2004).
- Far from improving the distinction of TTs, they also argued that their results support the idea of TTs being a substantially similar process as the occlusion process in ordinary marine extratropical cyclones, with the key distinctions being that the convection is stronger, and the initial upper-level feature is weaker in TTs.
- Therefore, TTs of SEC precursors follows the canonical midlatitude cyclone life cycle, where upshear convection favors or induces the TT by organizing processes.
- Due to the important role played by convection, it is suggested that TT is encouraged whenever extratropical occlusion occurs over relatively high SSTs.



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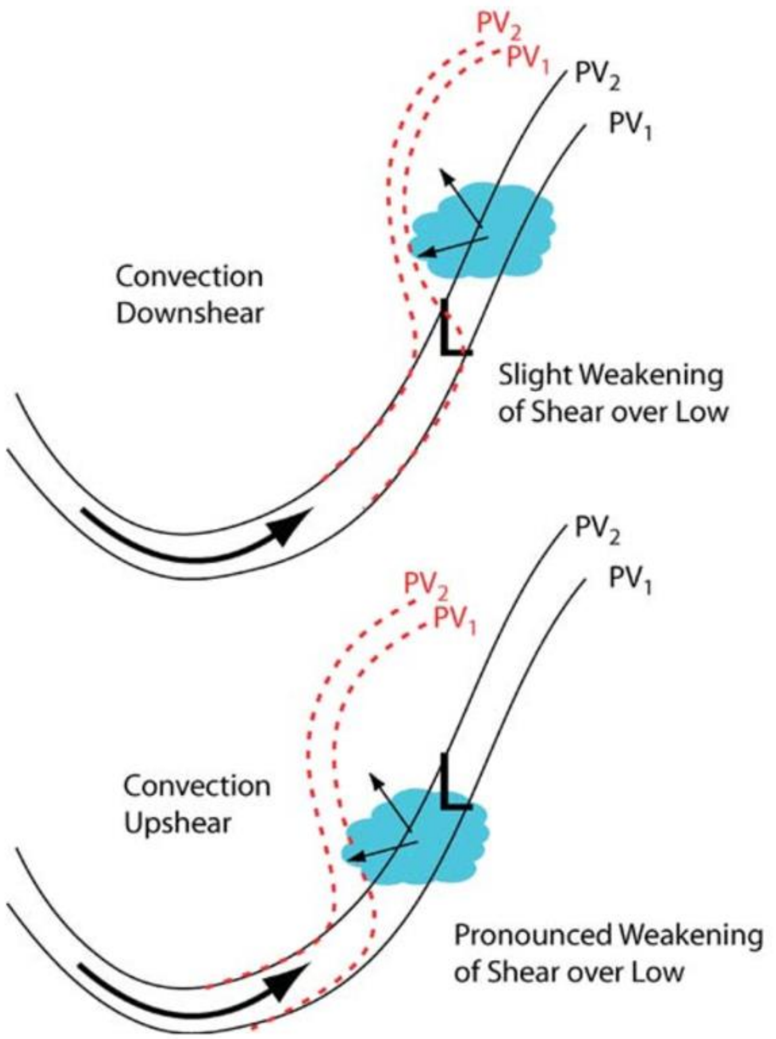
- Davis and Bosart (2004) indicated that the occlusion process in cyclones undergoing TT is distinct because it is driven by diabatic heating and advection arising from its secondary circulation, whereas the classical occlusion in pure extratropical cyclones is driven by quasi-horizontal advection by the swirling flow around the cyclone.
- They also separated TT cases based on the amplitude and structure of the precursor disturbance: strong extratropical cyclone (SEC) and weak extratropical cyclone (WEC). The distinguishing factor between these archetypes is that in SEC cases, extratropical cyclogenesis produces a surface cyclone already capable of WISHE (Emanuel, 1987), whereas in WEC cases, the baroclinic cyclone is an organizing agent for convection which is later fed by WISHE.
- They also mention the possibility of the bent-back structure associated with occlusion occurring prior to TT, with enhanced rainfall upshear from the surface low (the upshear direction based on a synoptic-scale average).
- This is particularly efficient for eliminating the vertical shear over the cyclone center (displacing upper-level PV gradients through upper-level PV dilution due to latent heat release, as shown by the conceptual model in Figure 13.



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- The formation of a warm-core in oceanic extratropical cyclones has been mainly linked to air-sea interactions (more importantly sensible heat fluxes) (e.g., Bosart and Bartlo, 1991; Neiman and Shapiro, 1993; Cordeira and Bosart, 2011).
- Cordeira and Bosart (2011) showed, through Lagrangian trajectory analysis, that the warm seclusion and subsequent TT process of the "Perfect Storm" (1991) in the northwestern North Atlantic was associated with the isolation of air parcels near the cyclone center. These air parcels were warmed in the lower troposphere via sensible heating from the underlying relatively warm Gulf Stream.
- Studies have revealed that tropical cyclones resulting from the TT process occur over SSTs below the traditional threshold of 26.5°C for tropical cyclogenesis (e.g. Palmén, 1948; Gray, 1968). For instance, Mauk and Hobgood (2012) highlighted the potential for tropical cyclogenesis in the northeastern Atlantic to occur over relatively cold SSTs, in environments characterized by reduced stability.
- Indeed, McTaggart-Cowan et al. (2015) proposed a revision of the SST threshold for tropical development in baroclinic environments characterized by the presence of an upper-tropospheric disturbance.
- This feature could lower the height of the dynamic tropopause and steepens the stability lapse rates, which facilitates the development of deep convection that catalyzes TT.
- These kinds of development were noted with the advent of satellite imagery, although they are not frequent due to the difficulty for the climatological atmosphere to set up a synoptic pattern introducing an extratropical cyclone over sufficiently warm sea surface temperatures and low wind shear.

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES TROPICALES

REVISITING THE 26.5°C SEA SURFACE TEMPERATURE THRESHOLD FOR TROPICAL CYCLONE DEVELOPMENT

BY RON MCTAGGART-COWAN, EMILY L. DAVIES, JONATHAN G. FAIRMAN JR., THOMAS J. GALARNEAU JR., AND DAVID M. SCHULTZ

A measure of tropospheric depth and bulk convective stability replaces the traditional sea surface temperature–based threshold as a necessary ingredient for tropical cyclogenesis from baroclinic precursors.

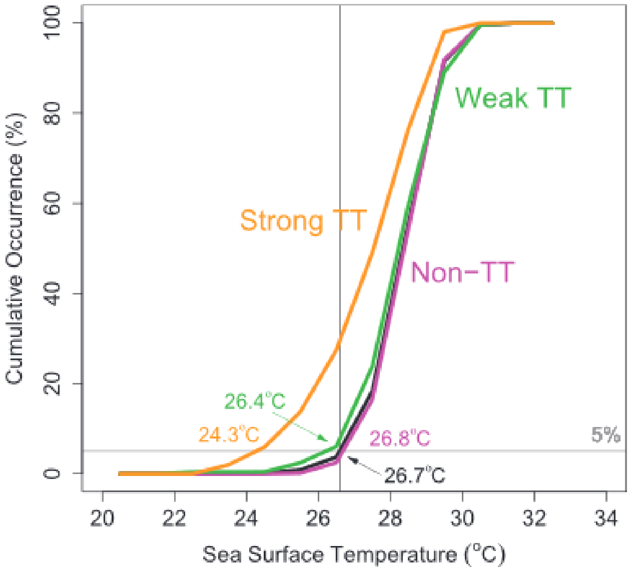


FIG. 6. Pathway-dependent cumulative distribution functions of development SST. Binning is performed at 1°C intervals as described for Fig. 1, and it is plotted using different line colors for individual pathways as labeled (black for the cumulative distribution of all events). The 5th percentile line is plotted in gray, with the values of its intersection point with the cumulative distribution functions annotated in the appropriate color for the pathway. The 26.5°C threshold is identified with a thin vertical line.

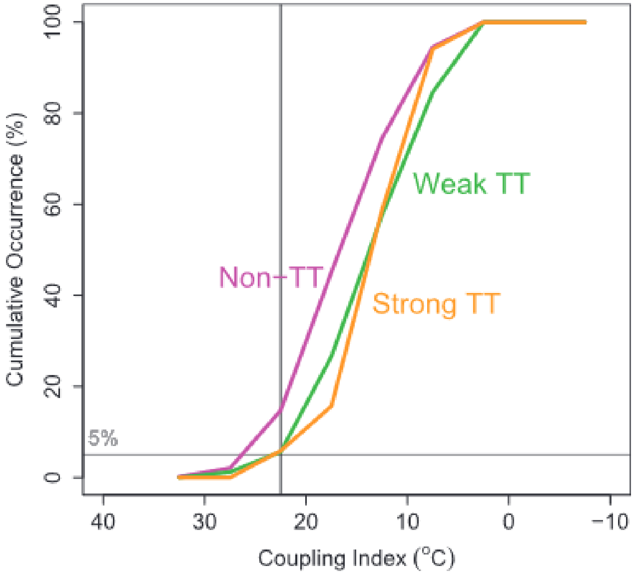


FIG. 8. Pathway-dependent cumulative distribution functions of development-time coupling index in the environment plotted as in Fig. 6, except for coupling index binning performed at 5°C intervals from −10° to 40°C. The 22.5°C threshold is identified with a thin vertical line.

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES TROPICALES

- The TCs forming via TT have been documented in many basins where tropical cyclogenesis events climatologically occur, such as the western North Atlantic (e.g., Moore and Davis, 1951; Bosart and Bartlo 1991; Bracken and Bosart, 2000; Davis and Bosart, 2001; McTaggart-Cowan et al., 2006a; Evans and Guishard, 2009; Guishard et al., 2009; Hulme and Martin, 2009a,b), the western North Pacific (e.g., Wang et al., 2008), and the western South Pacific (e.g., Garde et al., 2010; Pezza et al., 2014).

- On the other hand, they have also been shown to form in basins where tropical cyclogenesis events are extremely rare, including the eastern North Atlantic (e.g., Case, 1990; Franklin, 2006; Beven, 2006; Blake, 2016), eastern North Pacific (Bentley and Metz, 2016), the western South Atlantic (e.g., Pezza and Simmonds, 2005; McTaggart- Cowan et al., 2006b; Evans and Braun, 2012; Gozzo et al., 2014), and the Mediterranean Sea (medicanes or Mediterranean tropical-like cyclones)

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES TROPICALES

- Despite subtropical transitions not addressed in the literature, they could be considered as part of the tropical transition process, specifically the first stage when the cyclone starts to acquire tropical characteristics.
- Once the subtropical transition is completed, the cyclone would have subtropical structure and could continue its tropical transition to a tropical cyclone, remain subtropical until the end or die as a weak extratropical cyclone.
- To sum up, it could be said that subtropical cyclones are unfinished tropical transitions, or in other words, subtropical cyclones are extratropical cyclones which start their transition into tropical cyclones but never achieve a final stage of a pure tropical cyclone.

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES TROPICALES

- Hulme and Martin (2009):
  - Six recent tropical transitions of strong extratropical precursors in the subtropical North Atlantic are compared to better understand the manner by which some of the canonical structures and dynamical processes of extratropical cyclones serve to precondition the cyclone for transition.
  - All six transitions resulted from the interaction between a surface baroclinic zone and an upper-level trough. During the extratropical cyclogenesis of each storm, a period of intense near surface frontogenesis along a bent-back warm front occurred to the northwest of each sea level pressure minimum.
  - Within the resultant circulation, diabatic redistribution of potential vorticity (PV) promoted the growth of a low-level PV maximum near the western end of the warm front. Concurrently, the upper-level PV anomaly associated with each trough was deformed into the treble clef structure characteristic of extratropical occlusion.
  - Thus, by the end of the transitioning process and just prior to its becoming fully tropical, each cyclone was directly beneath a weakened upper-level trough in a column with weak vertical shear and weak thermal contrasts.
  - The presence of convection to the west and southwest of the surface cyclone at the time of frontogenesis and upper-level PV deformation suggests that diabatic heating contributes significantly to the process of tropical transition in a manner that is consistent with its role in extratropical occlusion.
  - Thus, it is suggested that tropical transition is encouraged whenever extratropical occlusion occurs over a sufficiently warm ocean surface.

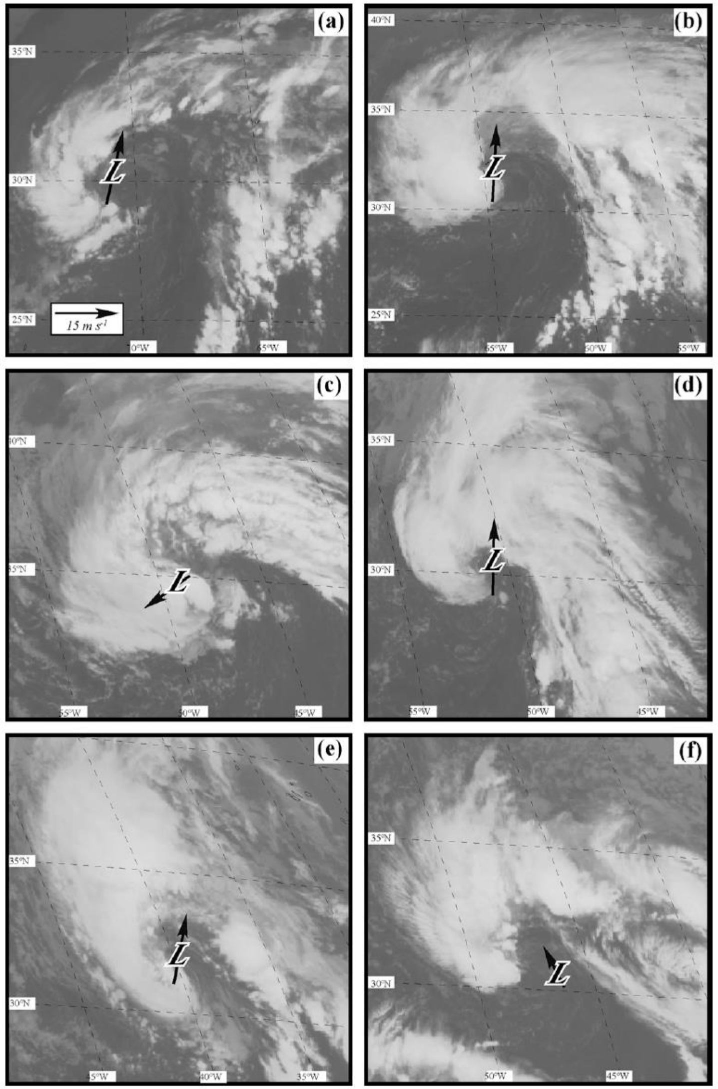


FIG. 9. Infrared satellite images from (a) 1115 UTC 15 Oct 2000 (Michael), (b) 2215 UTC 11 Oct 2001 (Karen), (c) 0915 UTC 3 Nov 2001 (Noel), (d) 0815 UTC 23 Nov 2001 (Olga), (e) 0415 UTC 22 Nov 2005 (Delta), and (f) 1115 UTC 28 Nov 2005 (Epsilon). Thick black arrow in (a)–(f) indicates the direction and magnitude of the 200–900-hPa vertical shear over the cyclone center determined as in Table 2.

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES TROPICALES

- Galarneau et al. (2015):
  - Tropical cyclone (TC) development near upper-level potential vorticity (PV) streamers in the North Atlantic is studied from synoptic climatology, composite, and case study perspectives. Midlatitude anticyclonic wave breaking is instrumental in driving PV streamers into subtropical and tropical latitudes, in particular near the time-mean midocean trough identified previously as the tropical upper-tropospheric trough.
  - Twelve TCs developed within one Rossby radius of PV streamers in the North Atlantic from June through November 2004–08.
  - This study uses composite analysis in the disturbance-relative framework to compare the structural and thermodynamic evolution for developing and non-developing cases.

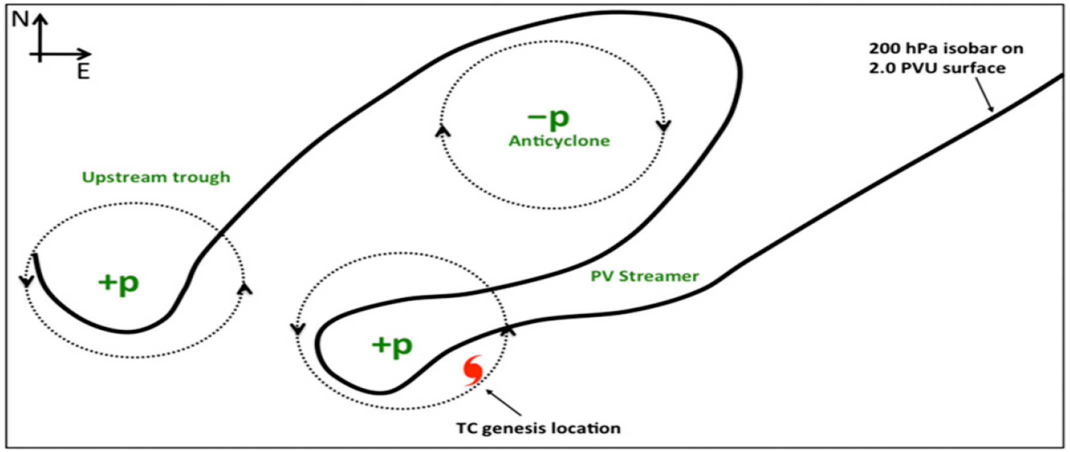


FIG. 1. Schematic illustration of AWB on the DT. The 200-hPa isobar on the DT is marked by a black solid contour at $t - 0$ h. Circulations associated with pressure anomalies are indicated by dotted circles with arrows. Positive pressure anomalies ($+p$) are equivalent to positive PV anomalies, and negative pressure anomalies ($-p$) correspond to negative PV anomalies. The preferred location for TC development is marked by the red hurricane symbol.

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES TROPICALES

- Galarneau et al. (2015)
  - The results show that incipient tropical disturbances are embedded in an environment characterized by 850–200-hPa westerly vertical wind shear and mid- and upper-level quasigeostrophic ascent associated with the PV streamer, with minor differences between developing and nondeveloping cases.
  - The key difference in synoptic scale flow between developing and nondeveloping cases is the strength of the anticyclone north of the incipient tropical disturbance. The developing cases are marked by a stronger near-surface pressure gradient and attendant easterly flow north of the vortex, which drives enhanced surface latent heat fluxes and westward (upshear) water vapor transport.
  - This evolution in water vapor facilitates an upshear propagation of convection, and the diabatically influenced divergent outflow erodes the PV streamer aloft by negative advection of PV by the divergent wind.
  - This result suggests that the PV streamer plays a secondary role in TC development, with the structure and intensity of the synoptic-scale anticyclone north of the incipient vortex playing a primary role.

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES TROPICALES

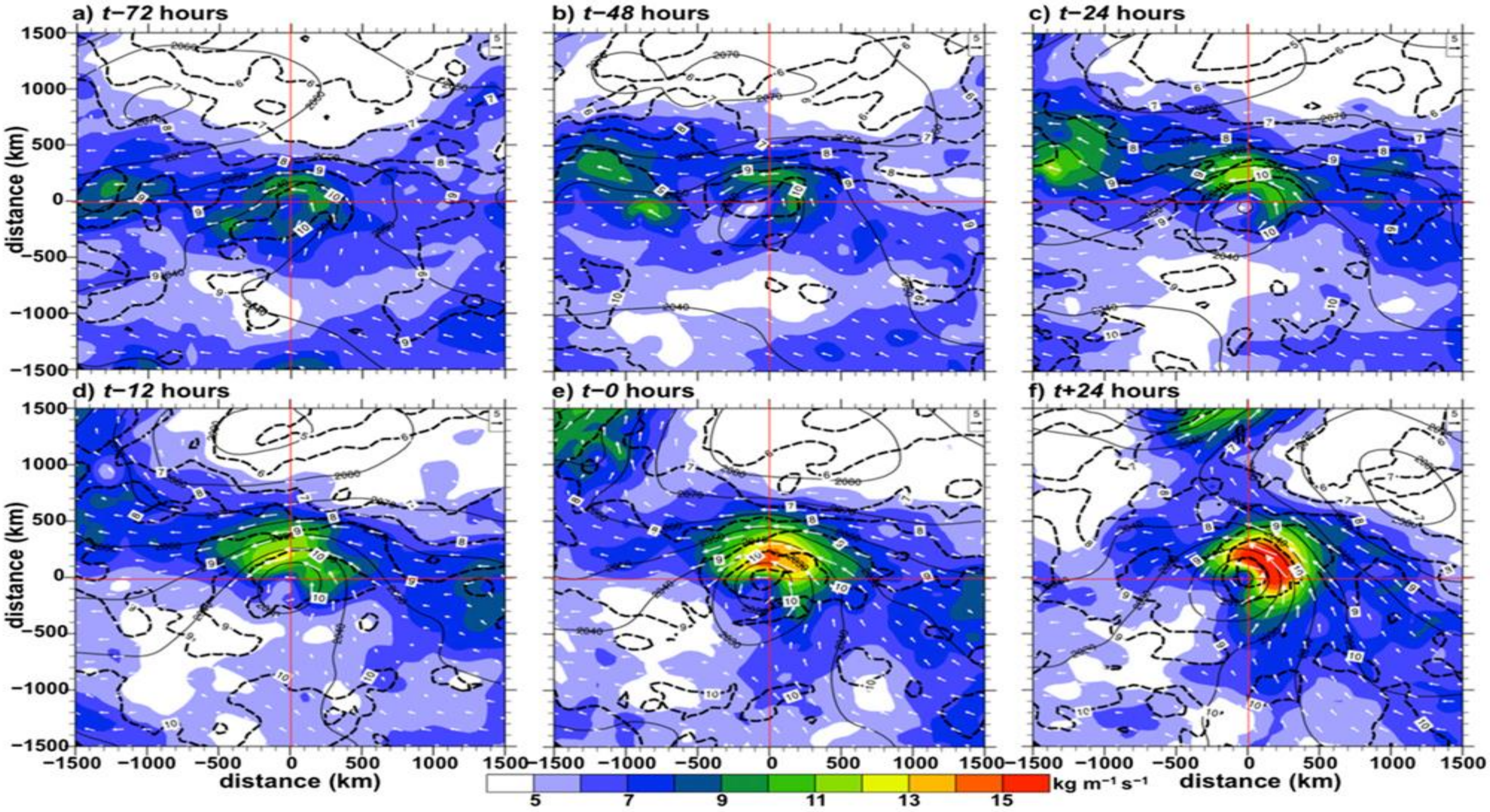


FIG. 18. Disturbance-relative composite-mean 800-hPa geopotential height (solid contours every 10 m), 900–700-hPa layer-mean water vapor mixing ratio (dashed contours every 1 g kg^{-1}), and 900–700-hPa IVT (arrows with magnitude shaded according to the color bar; kg m^{-1} s^{-1}) for the developing cases at time (a) $t - 72$, (b) $t - 48$, (c) $t - 24$, (d) $t - 12$, (e) $t - 0$, and (f) $t + 24$ h.

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES TROPICALES

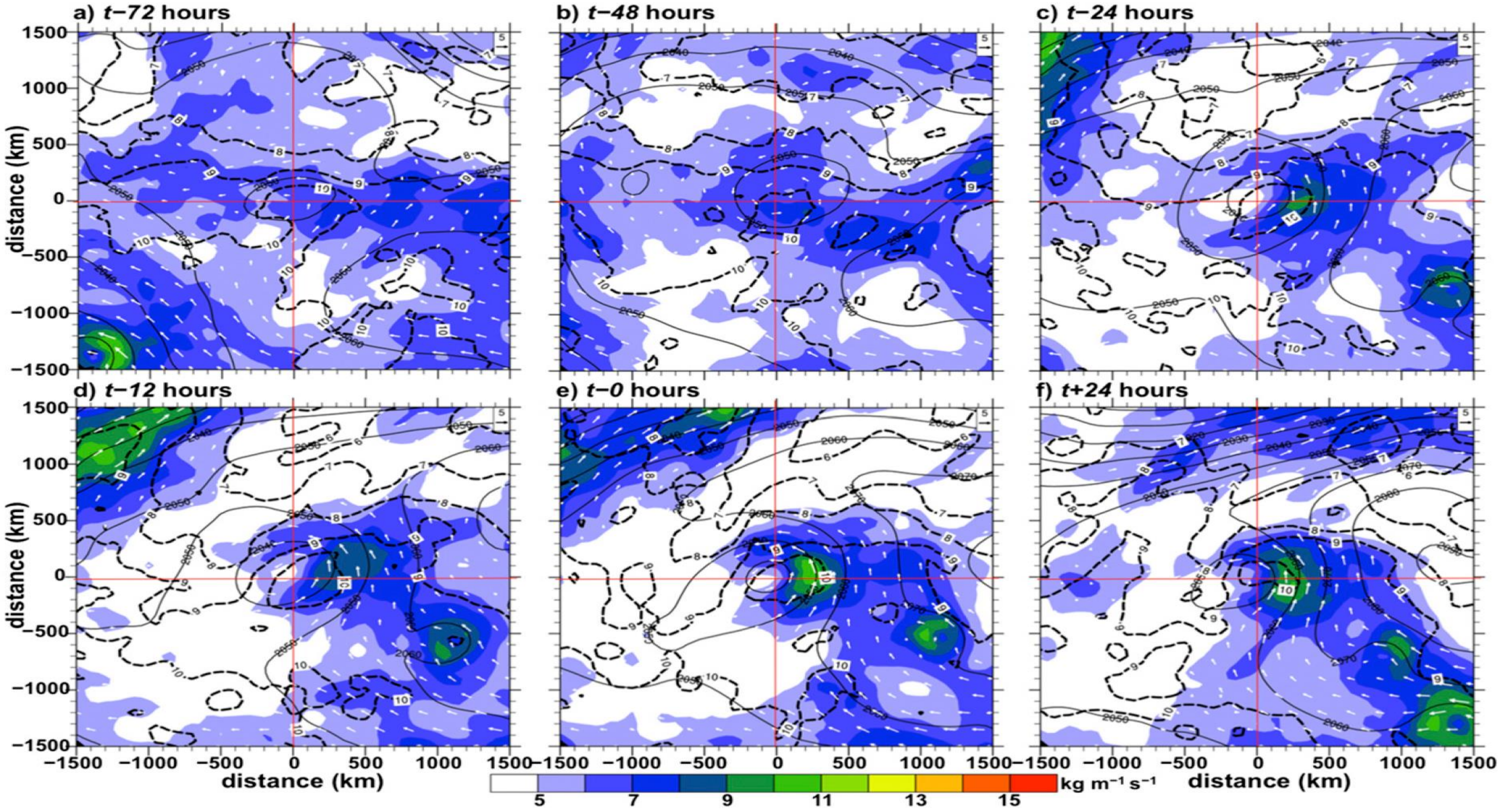
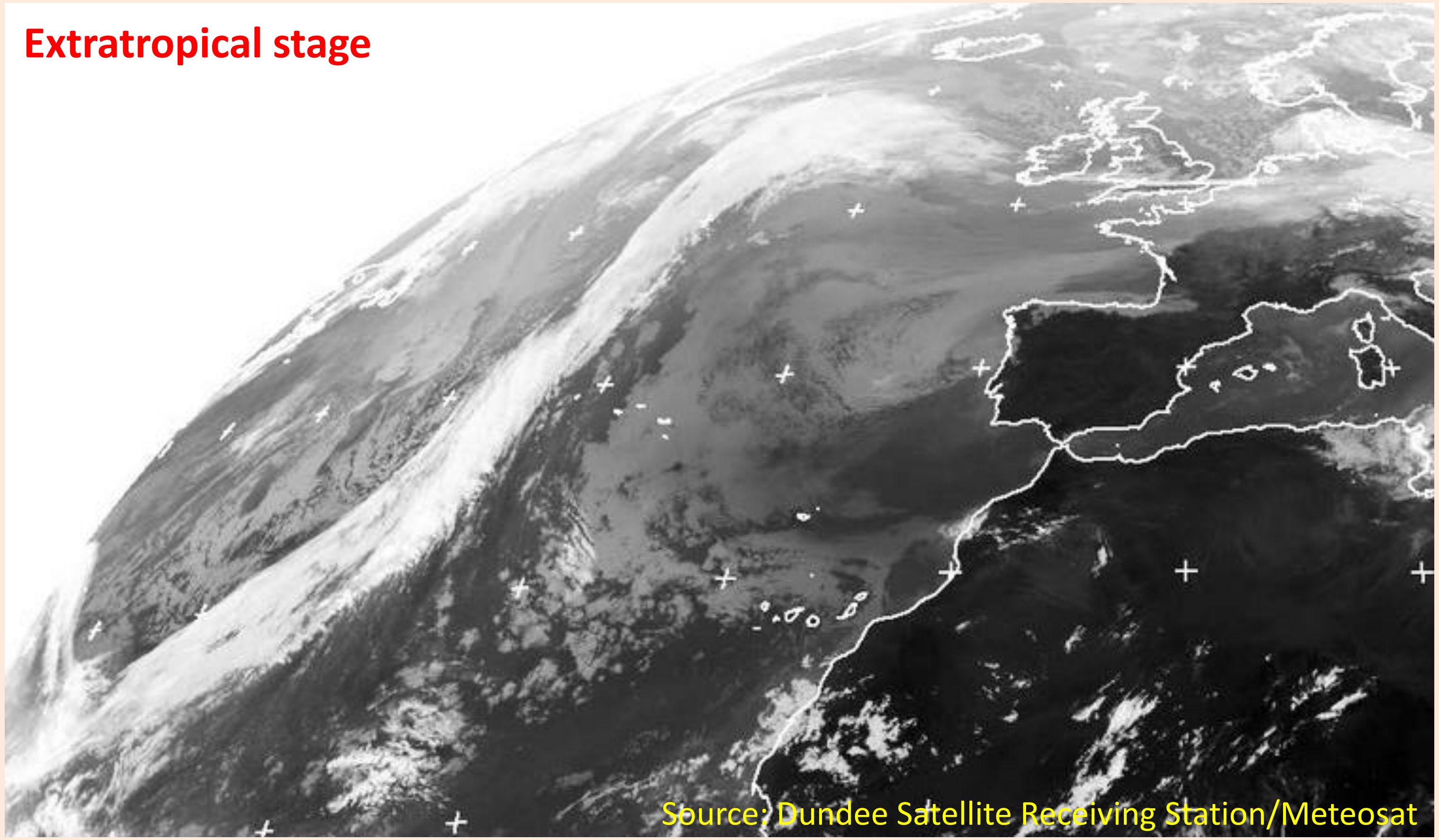


FIG. 19. As in Fig. 18, but for the nondeveloping cases.

Hurricane Ophelia (2017)

- During the first stages of the process, a region of upward motion is produced by vertical wind shear in a baroclinic environment (quasigeostrophic forcing; Suctcliffe, 1947; Trenberth, 1978), which in turn focuses deep moist convection and diabatic heating.



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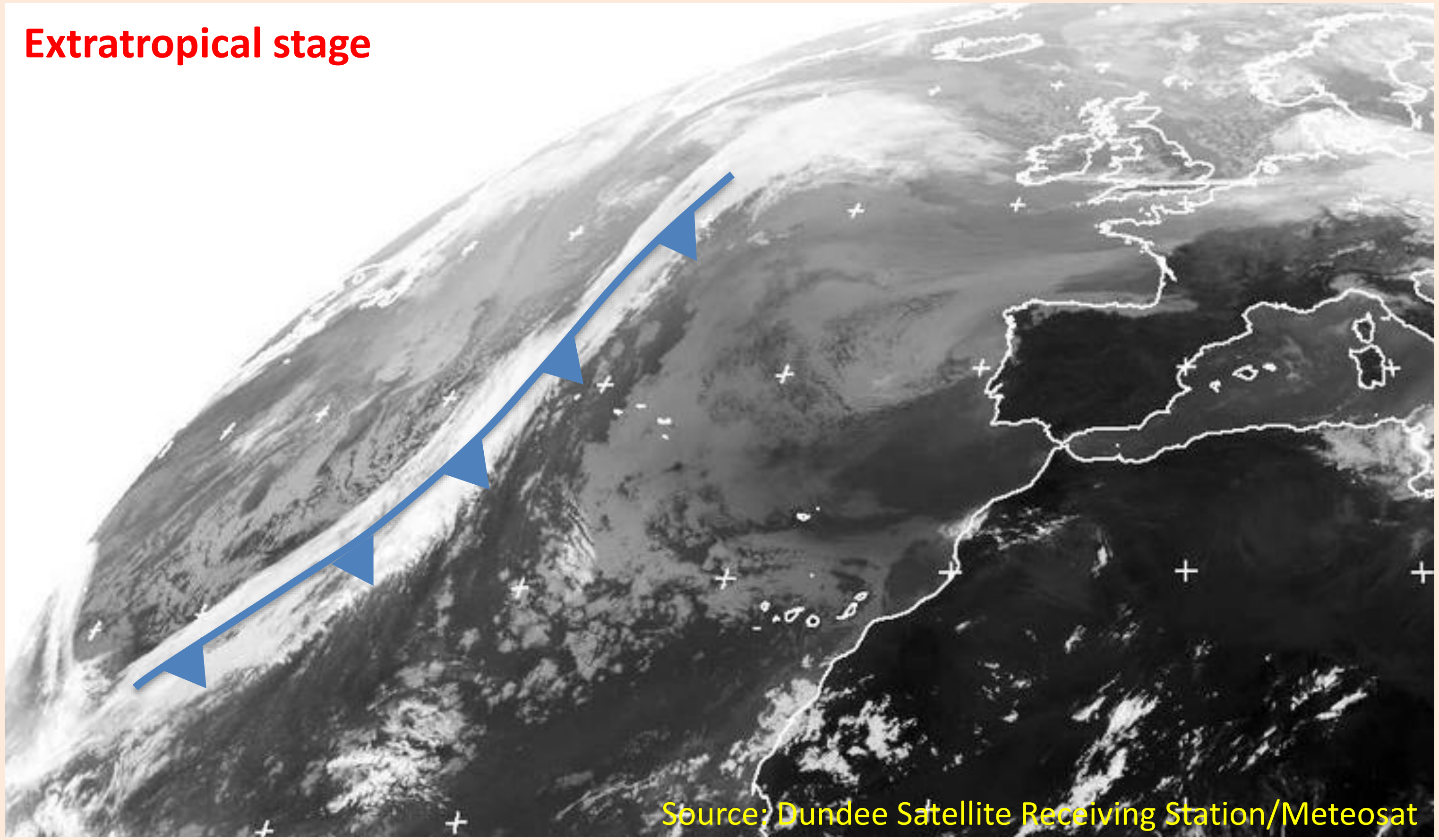
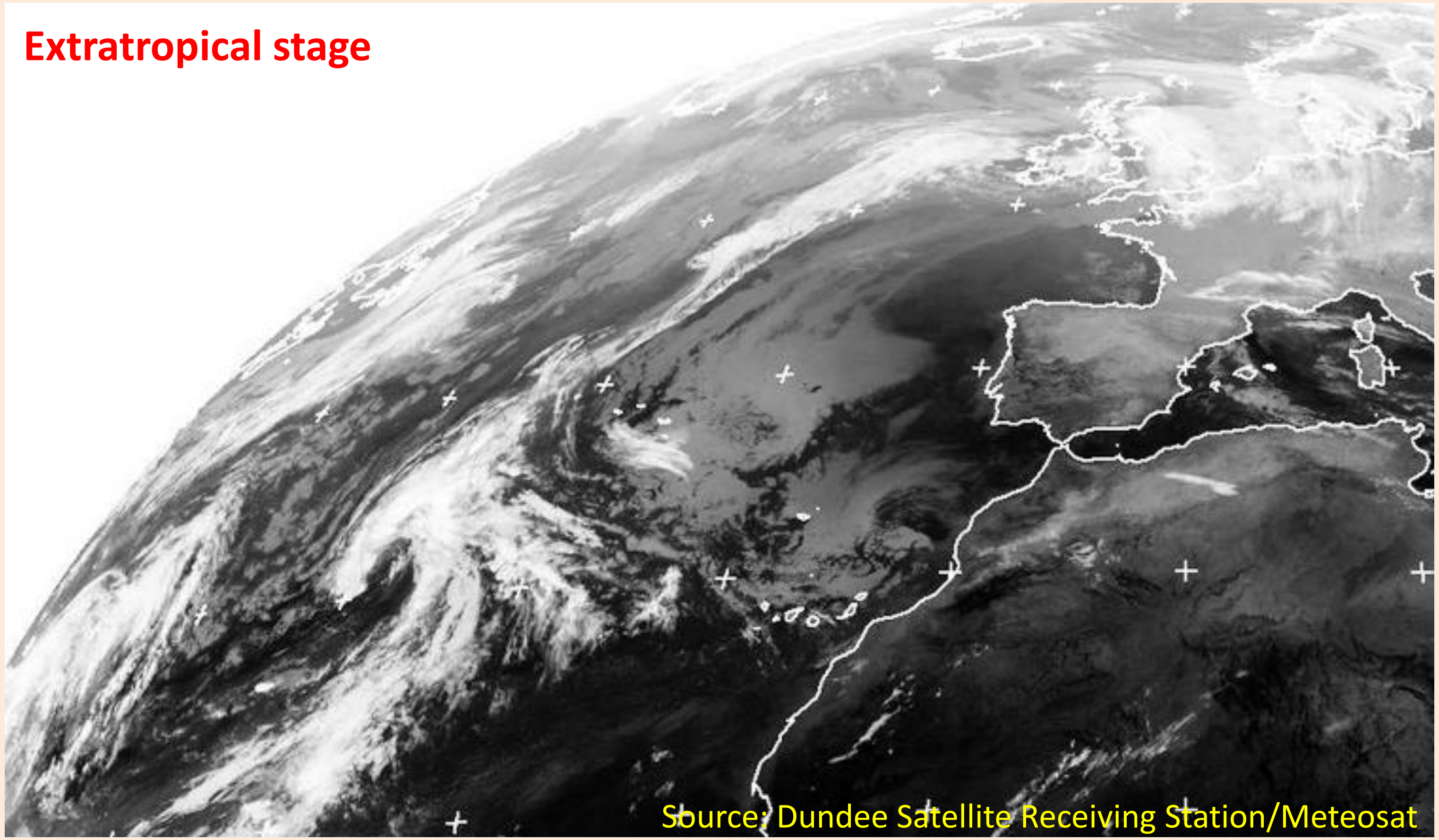


Hurricane Ophelia (2017)

- Later on, a vertical transport of PV and momentum redistributes PV due to differential diabatic heating released by deep convection (e.g., Hoskins et al., 1985; Davis and Emanuel, 1991; Raymond, 1992; Stoelinga, 1996; Campa and Wernli, 2012).



Hurricane Ophelia (2017)

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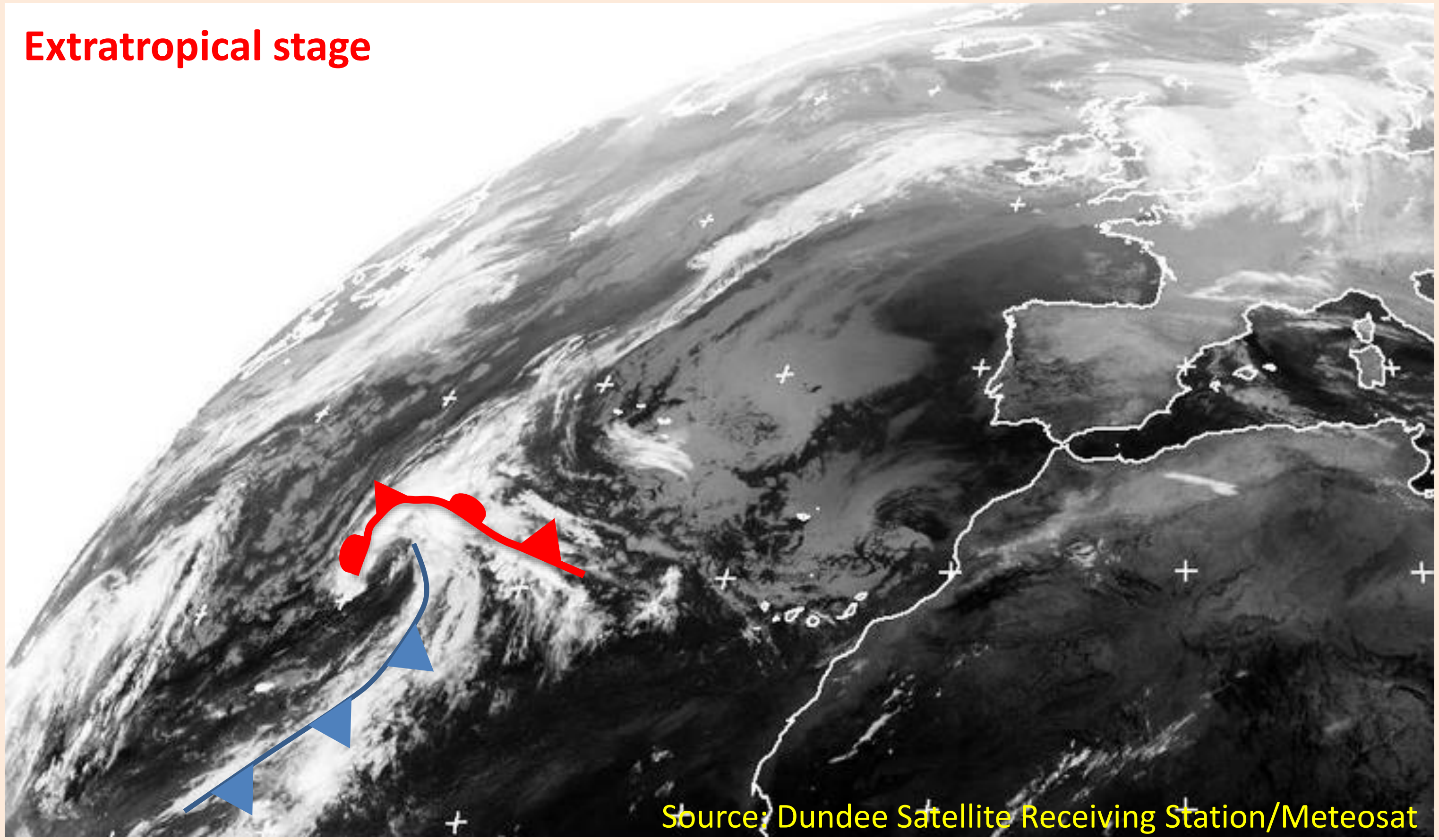
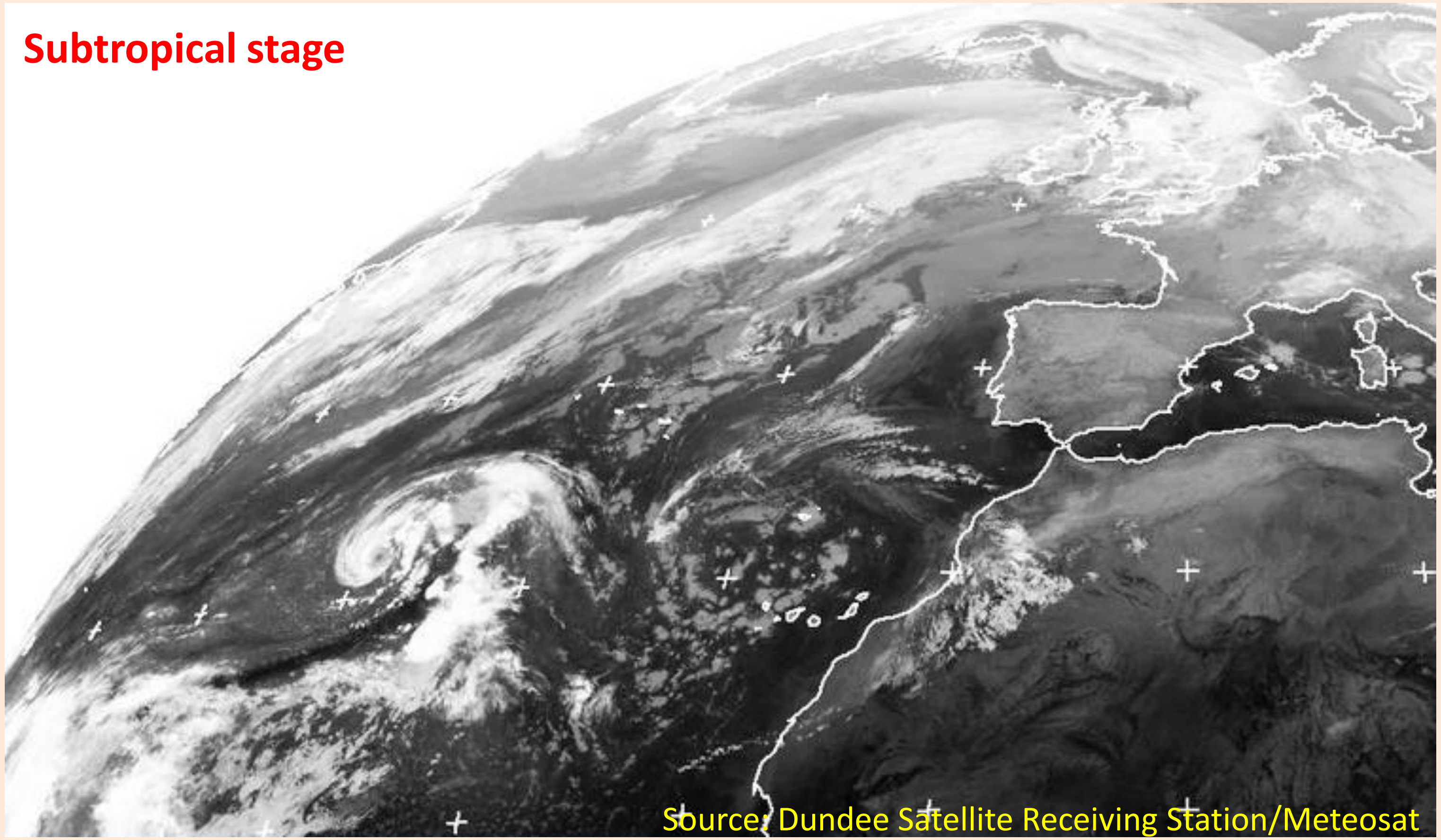


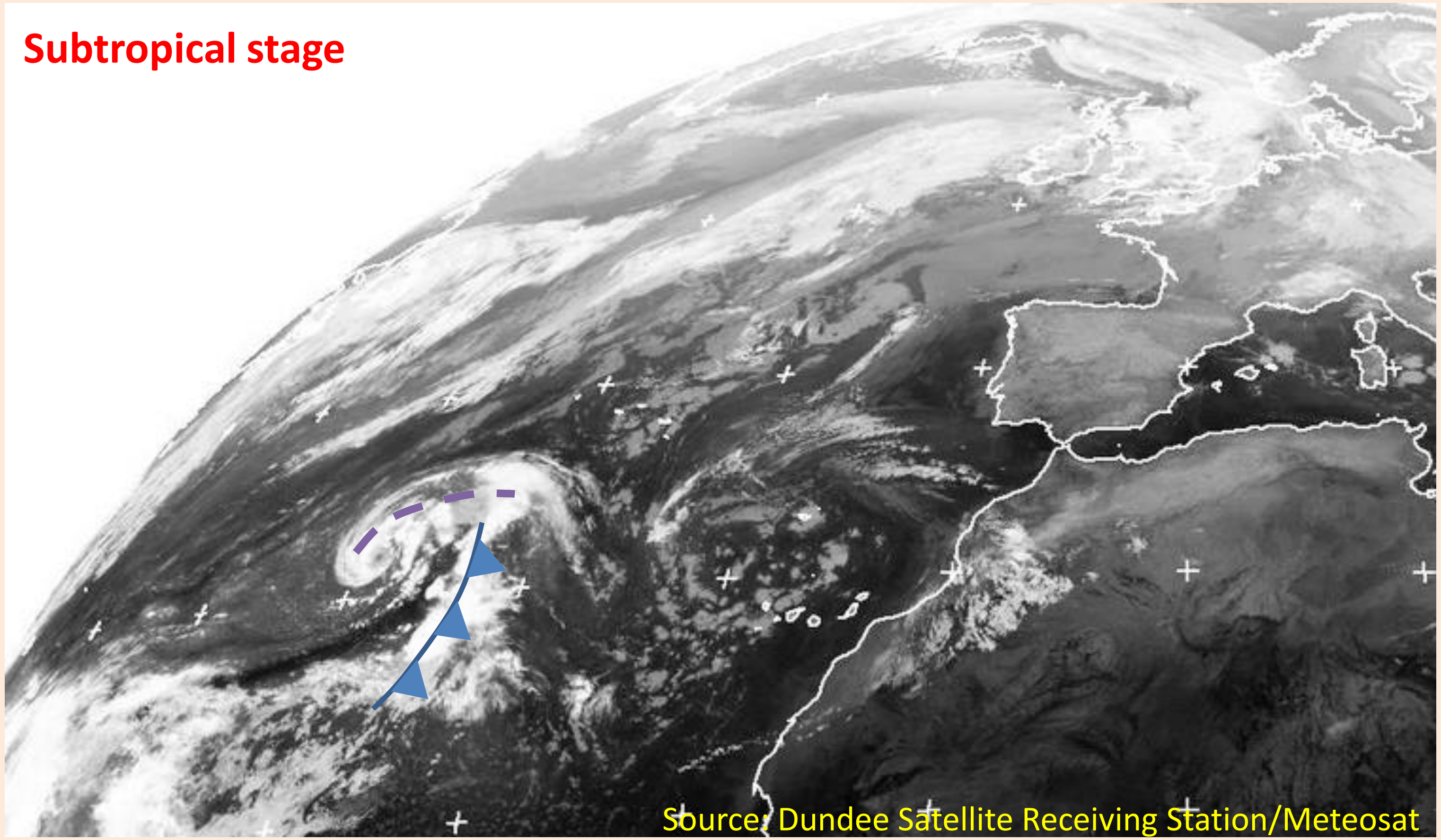
Hurricane Ophelia (2017)

- This in conjunction with the divergent outflow in the upper troposphere provokes a reduction in vertical wind shear, i.e., the initially baroclinic environment becomes more barotropic.



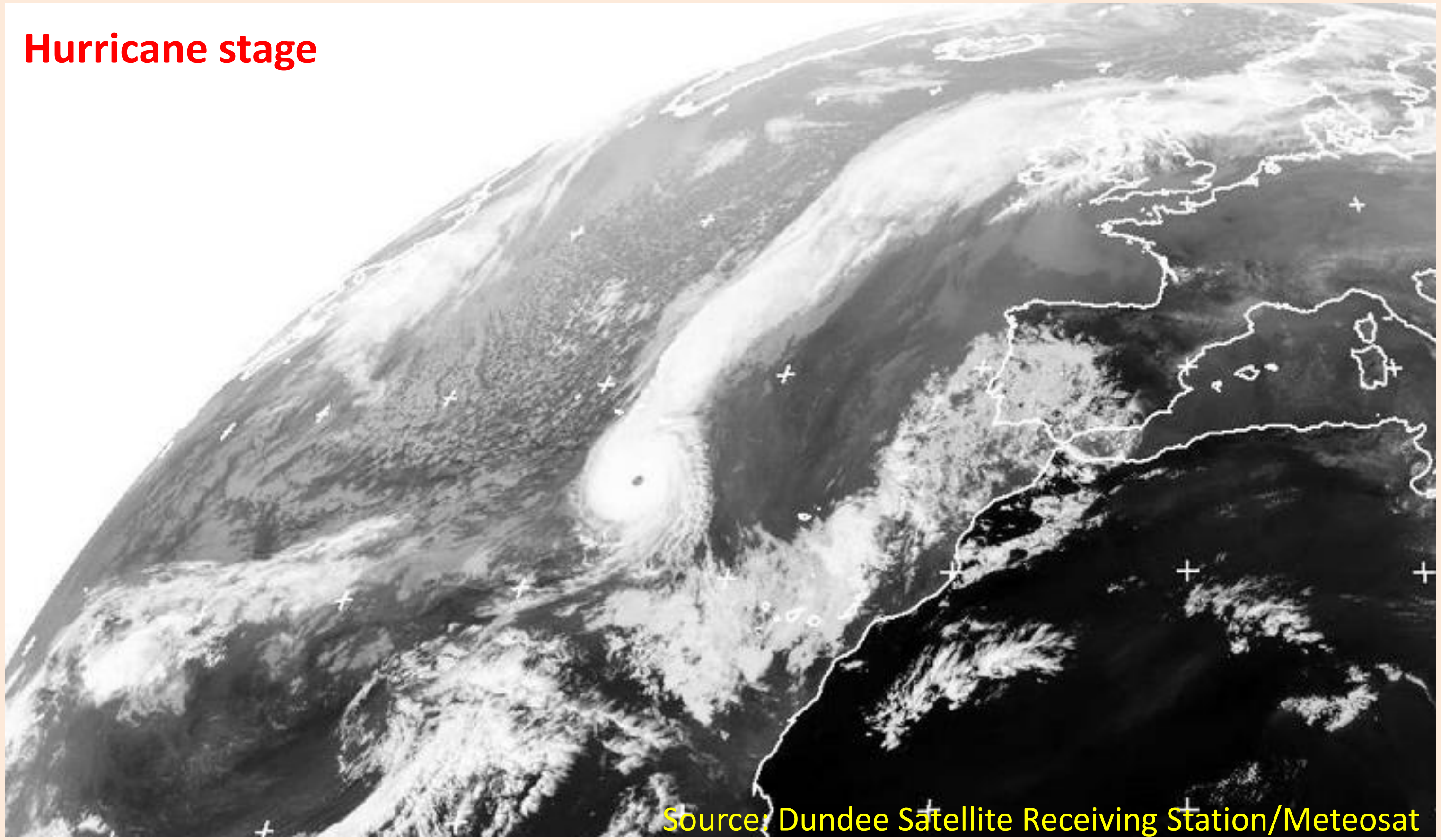
Hurricane Ophelia (2017)

- The initial trough or upper-level low supporting the baroclinic cyclogenesis weakens and the system start to acquire a warm-core structure through latent heat release.



Hurricane Ophelia (2017)

- This subsequently causes an environment setup that favors and/or allows an intensification of the stacked surface cyclone through air-sea interaction processes (Emanuel, 1987; Davis and Bosart, 2004; Bentley and Metz, 2016).



Hurricane Ophelia (2017)

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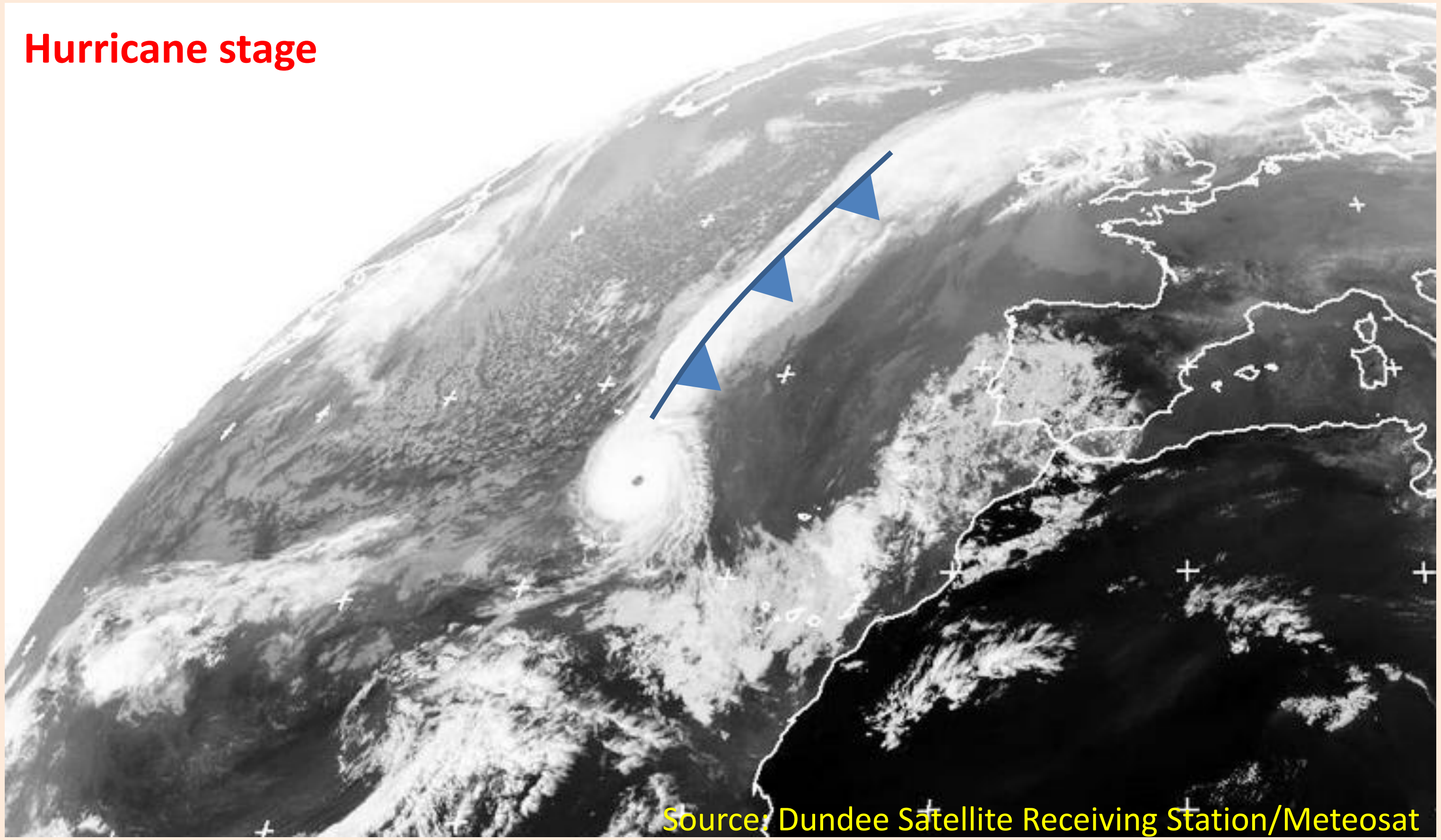
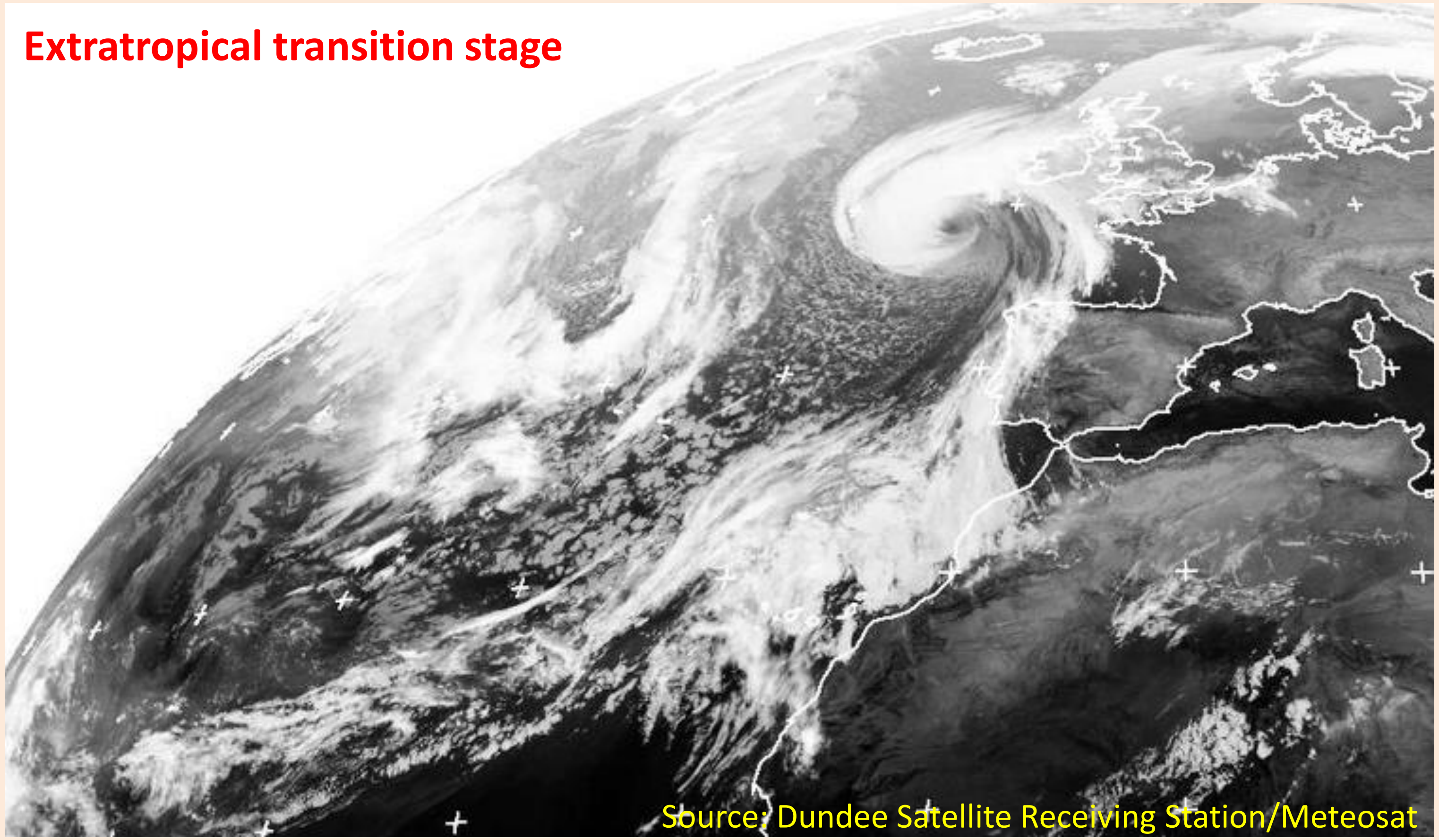


Hurricane Ophelia (2017)

- The tropical cyclone interacts with the midlatitude westerly circulation: A trough can pick up the cyclone and its accompanying baroclinic zone transforms the cyclone structure. Making it asymmetrical.



Hurricane Ophelia (2017)

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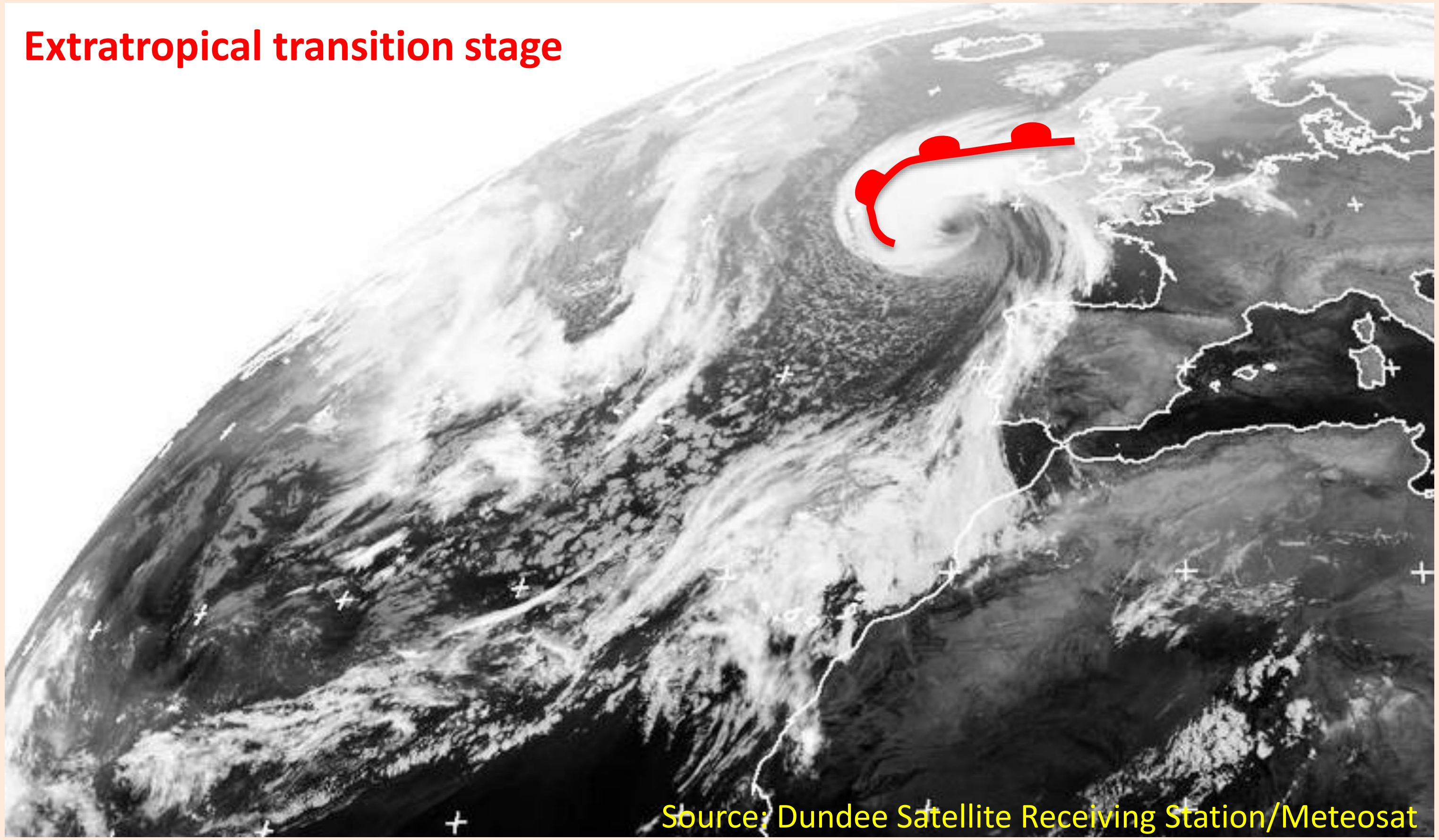
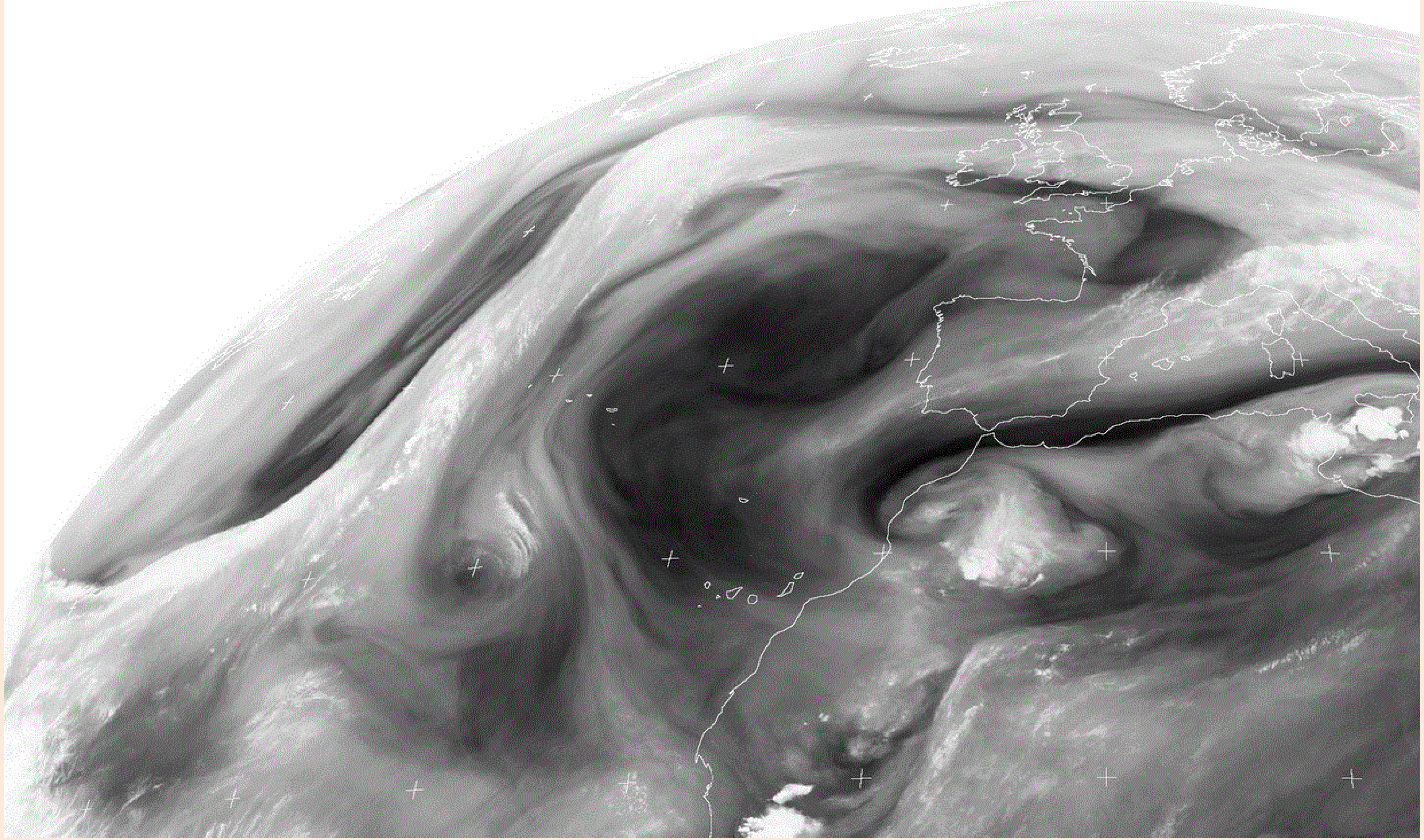


Hurricane Ophelia (2017)



2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

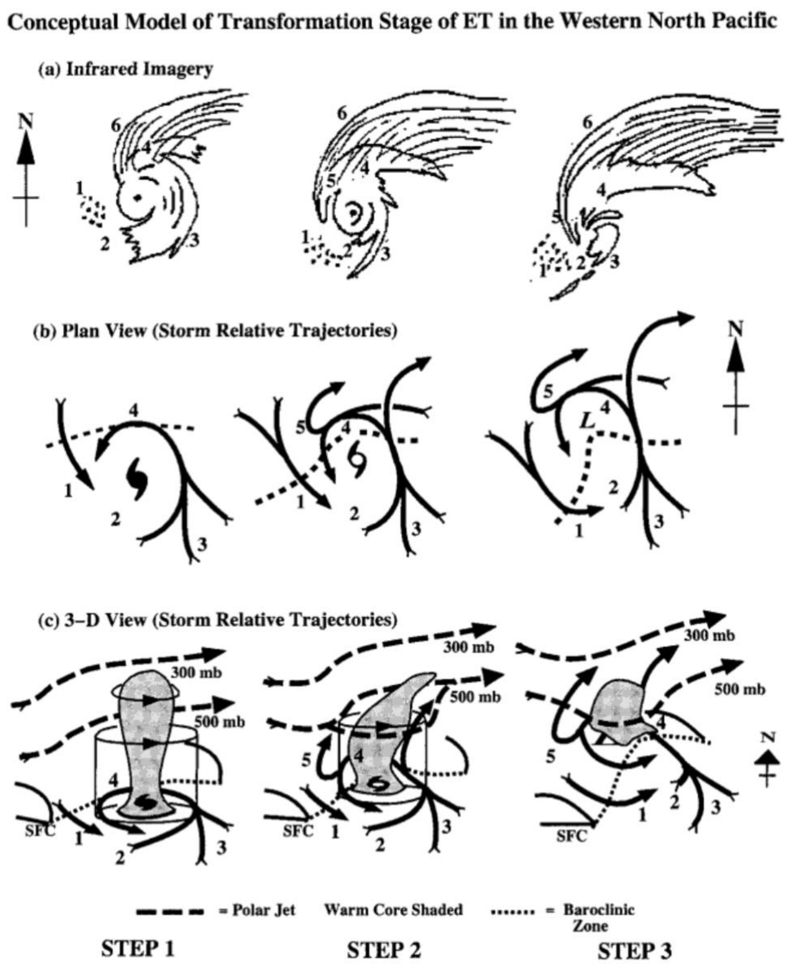
1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES EXTRATROPICALES

- It is a process by which a tropical cyclone loses its warm-core and symmetric nature and gradually acquires characteristics typical of cold-core asymmetrical cyclones, ending up as a pure extratropical cyclone.
- One of the most hazardous stages of tropical cyclones is the ET. This stage does not necessarily occur in all tropical cyclones, but it is only likely in those substantially moving northward to midlatitude regions.
- Only a subset of tropical cyclones complete ET and become fully extratropical, although even if they are only beginning their ET, they can already produce damage [e.g. Hurricane Sandy (2012)].

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES EXTRATROPICALES

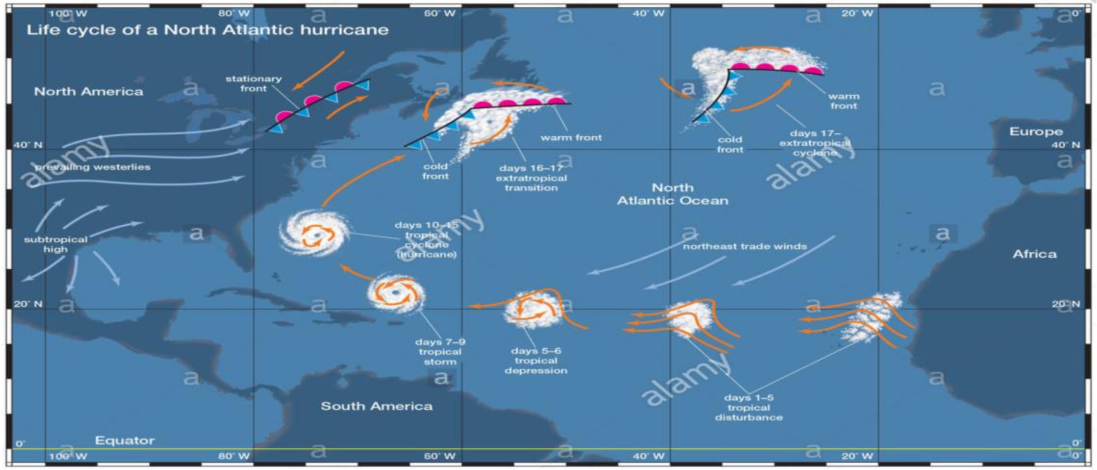
- In their ET stage, tropical cyclones are influenced by midlatitude atmospheric patterns by providing, e. g., sufficient forcing from upper-level troughs.
- When this process happens, the system gradually loses its tropical characteristics and becomes extratropical, its deep warm-core structure vanishes and becomes shallow, simultaneously being deformed in shape and less symmetric in circulation, convection, and humidity, ultimately resulting in a cold-core, asymmetric structure that includes the development of surface fronts.
- The cyclone develops a westward and poleward tilt with height. As this process progresses, convection is suppressed near the centre. This transformation during the ET process often results in an expanded area of damaging winds and heavy rainfall, which can produce extreme waves, flooding and mudslides.
- The main risk of this phase is associated with the cyclone being able of possessing hurricane-force winds extended to a wider region.
- This evolution occurs as the tropical cyclone moves poleward into an increasingly baroclinic environment, which is characterized by the aforementioned temperature and moisture gradients as well as increased vertical wind shear, reduced sea surface temperature (SST), and an increasing Coriolis parameter.
- This environmental change is detrimental for tropical cyclone development, but it can otherwise change the TC structure if baroclinic conditions are favourable.



2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES EXTRATROPICALES

- Over the North Atlantic, the most typical trajectory of tropical cyclones undergoing ET is outlined by a storm recurving over the western basin and heading northeastward.
- Therefore, the coastal Atlantic areas most likely to be impacted by a transitioning tropical cyclone are the northeastern United States and the Canadian Maritimes (1-2 storms every year) and western Europe (1 storm every 1-2 years).
- ETs involve interactions across a wide range of spatial (tropical cyclone core to baroclinic trough) and temporal (convective to synoptic) scales.
- This presents a substantial challenge to the representation of these complex dynamic and thermodynamic processes in numerical weather prediction models, while imperfect representation of the initial conditions compounds the problem.
- ETs events also often reduce downstream predictability by triggering or modifying Rossby wave train development, thereby propagating forecast uncertainty into regions far from the ET event. ETs have been also found to generate hazards downstream [e.g., Hurricane Katia (2011).



2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES EXTRATROPICALES

VOLUME 145 MONTHLY WEATHER REVIEW NOVEMBER 2017

REVIEW

The Extratropical Transition of Tropical Cyclones. Part I: Cyclone Evolution and Direct Impacts

CLARK EVANS,[a] KIMBERLY M. WOOD,[b] SIM D. ABERSON,[c] HEATHER M. ARCHAMBAULT,[d]
SHAWN M. MILRAD,[e] LANCE F. BOSART,[f] KRISTEN L. CORBOSIERO,[f] CHRISTOPHER A. DAVIS,[g]
JOÃO R. DIAS PINTO,[h] JAMES DOYLE,[i] CHRIS FOGARTY,[j] THOMAS J. GALARNEAU JR.,[k]
CHRISTIAN M. GRAMS,[l] KYLE S. GRIFFIN,[m] JOHN GYAKUM,[n] ROBERT E. HART,[o] NAOKO KITABATAKE,[p]
HILKE S. LENTINK,[q] RON MCTAGGART-COWAN,[r] WILLIAM PERRIE,[s] JULIAN F. D. QUINTING,[t]
CAROLYN A. REYNOLDS,[i] MICHAEL RIEMER,[u] ELIZABETH A. RITCHIE,[v] YUJUAN SUN,[s] AND FUQING ZHANG[w]

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES EXTRATROPICALES

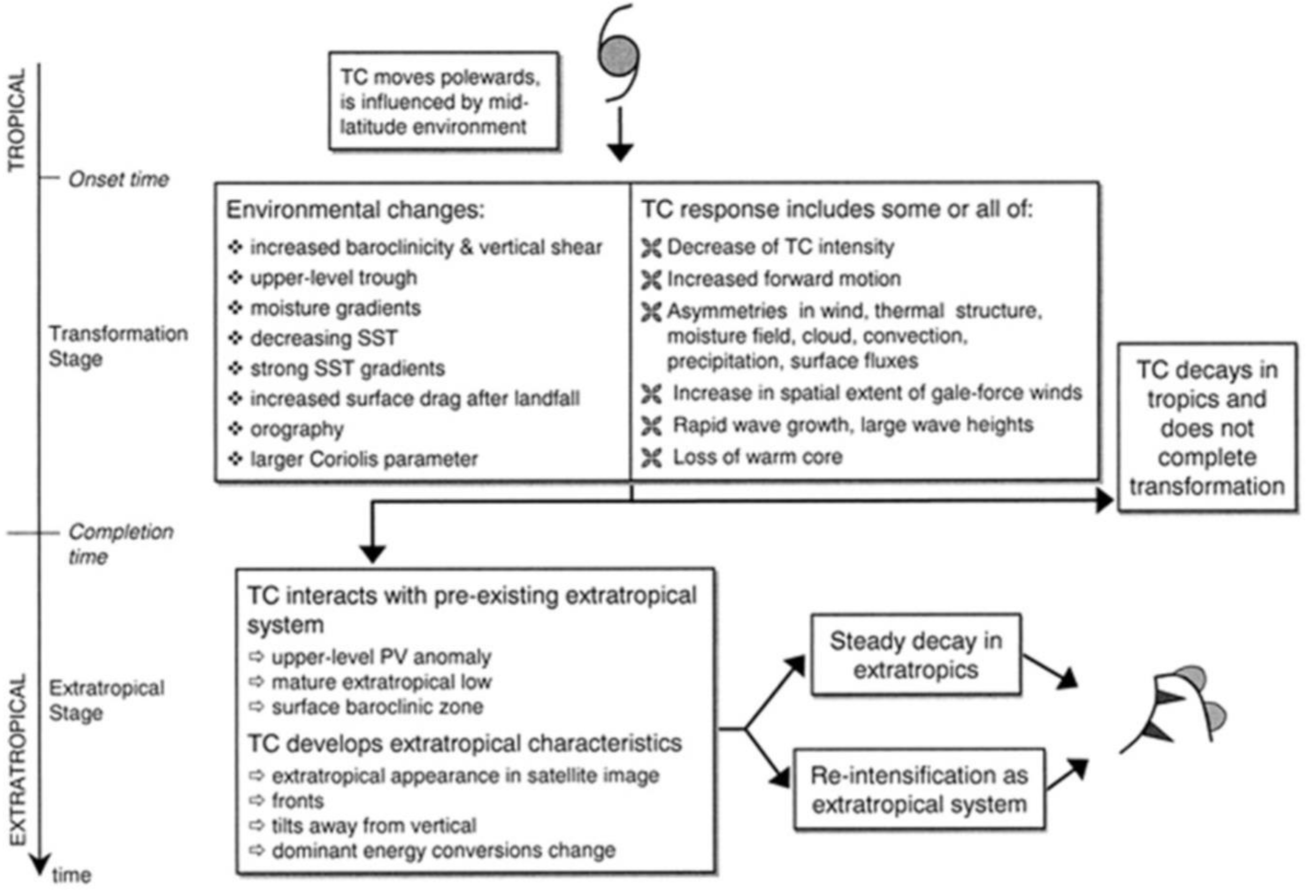


FIG. 1. A two-stage ET classification based on Klein et al. (2000). The onset and completion times correspond to the definitions of Evans and Hart (2003). The "tropical" and "extra-tropical" labels indicate approximately how the system would be regarded by an operational forecast center. Figure reproduced from Jones et al. (2003, their Fig. 11).

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES EXTRATROPICALES

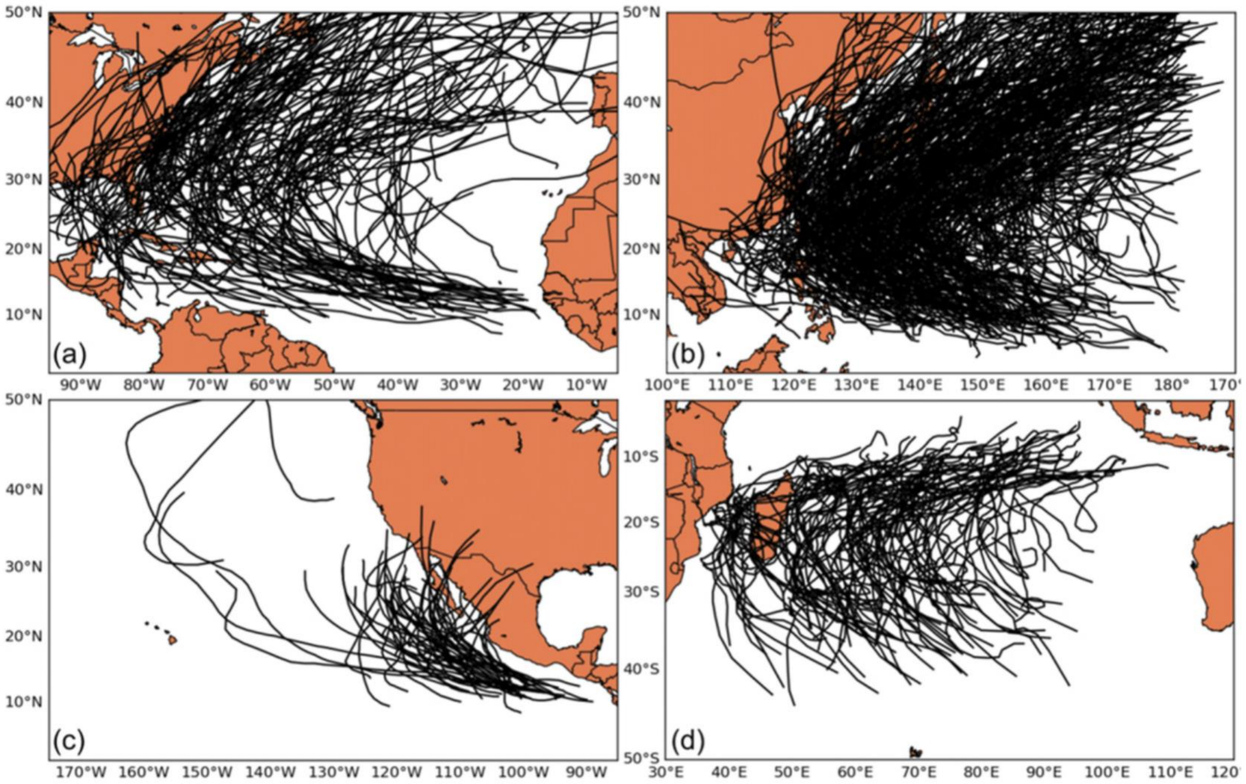


FIG. 2. Tracks of TCs that completed the transformation stage of ET for the (a) NATL [1981–2010; ET designations from HURDAT2 best track data, described in Landsea and Franklin (2013)], (b) WNP (1981–2010; ET designations from Japan Meteorological Agency best track data), (c) ENP [1971–2012; reanalysis-derived CPS ET designations by Wood and Ritchie (2014a)], and (d) SWIO [1987–2013; reanalysis-derived ET designations subjectively determined by Griffin and Bosart (2014)]. No attempt is made to account for ET classification practice differences between operational centers or the historical evolution of ET classification practices at these centers.

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES EXTRATROPICALES: IMPACTO DE LAS TRANSICIONES EXTRATROPICALES

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Research Article

The key role of diabatic processes in modifying the upper-tropospheric wave guide: a North Atlantic case-study

Christian M. Grams, Heini Wernli, Maxi Böttcher, Jana Čampa, Ulrich Corsmeier, Sarah C. Jones, Julia H. Keller, Claus-Jürgen Lenz, Lars Wiegand

First published: 17 August 2011 | https://doi.org/10.1002/qj.891 | Citations: 126

Quarterly Journal of the Royal Meteorological Society
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Research Article

The impact of Typhoon Jangmi (2008) on the midlatitude flow. Part I: Upper-level ridgebuilding and modification of the jet

Christian M. Grams, Sarah C. Jones, Christopher A. Davis, Patrick A. Harr, Martin Weissmann

First published: 21 March 2013 | https://doi.org/10.1002/qj.2091 | Citations: 41

Quarterly Journal of the Royal Meteorological Society
RMetS

Research Article

The impact of Typhoon Jangmi (2008) on the midlatitude flow. Part II: Downstream evolution

Christian M. Grams, Sarah C. Jones, Christopher A. Davis

The Extratropical Transition of Tropical Cyclones. Part II: Interaction with the Midlatitude Flow, Downstream Impacts, and Implications for Predictability

Julia H. Keller[1,2], Christian M. Grams[3,4], Michael Riemer[5], Heather M. Archambault[6], ... View More +

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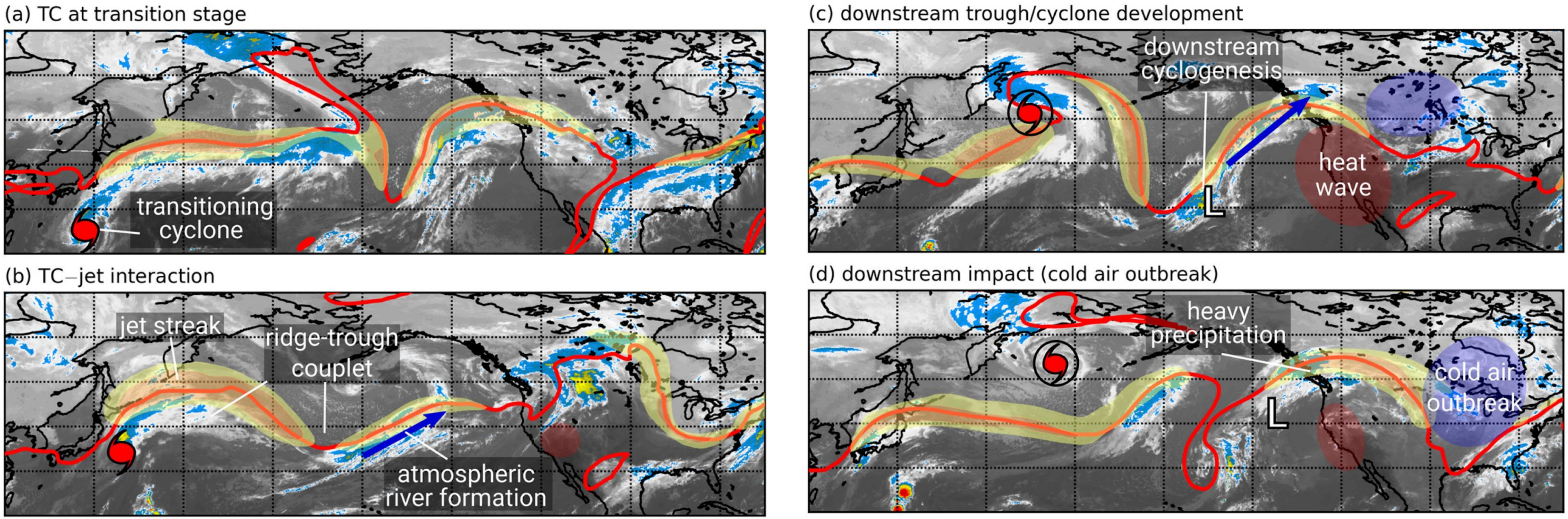
DOI: https://doi.org/10.1175/MWR-D-17-0329.1
Page(s): 1077–1106

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES EXTRATROPICALES: IMPACTO DE LAS TRANSICIONES EXTRATROPICALES

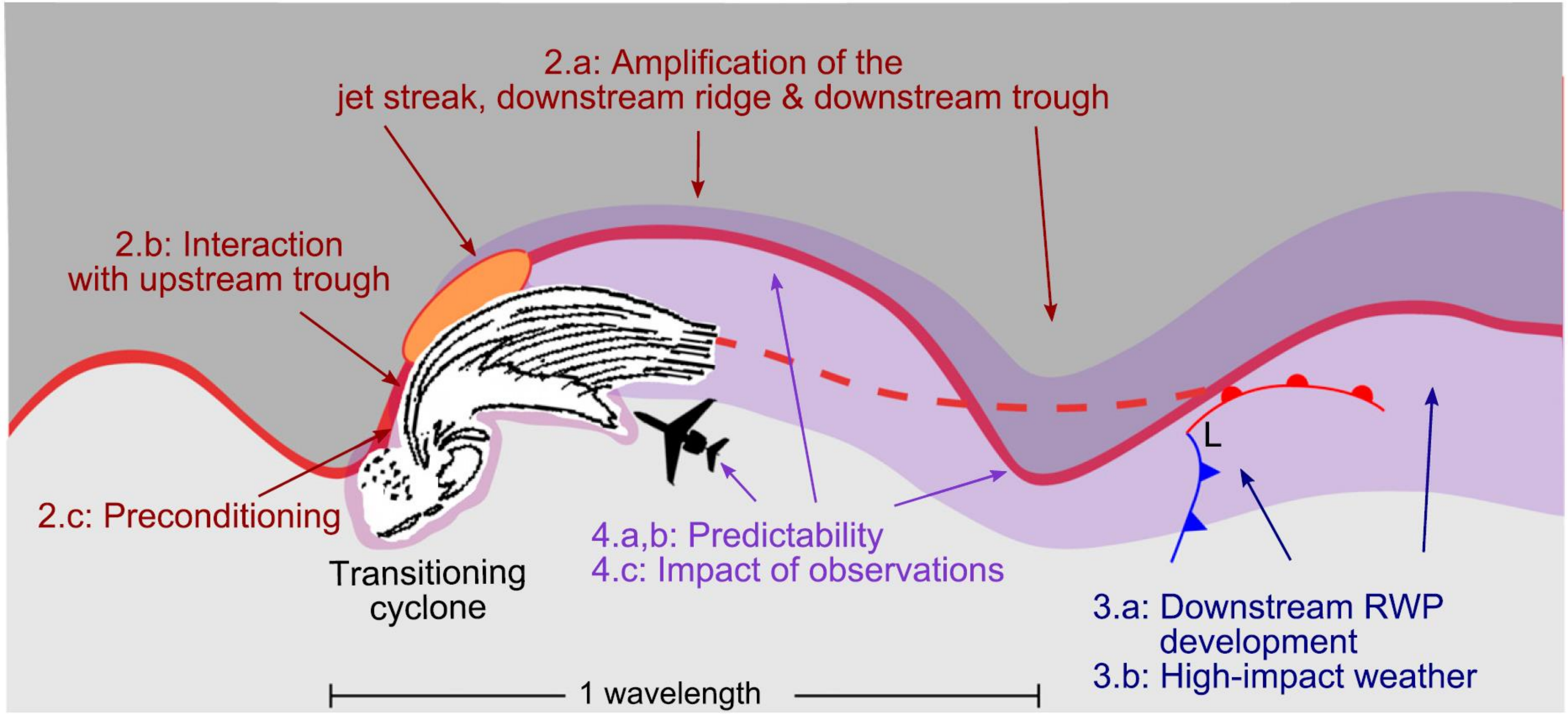
- Since 2003, it has become increasingly apparent that a forecasting challenge from extratropical transitions (ETs) is also present for the region downstream of ET because ET often leads to a basin-wide or even hemispheric reduction in the forecast skill of numerical weather prediction (NWP) models through exciting Rossby wave packets (RWPs).



2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES EXTRATROPICALES: IMPACTO DE LAS TRANSICIONES EXTRATROPICALES

- Esquema:



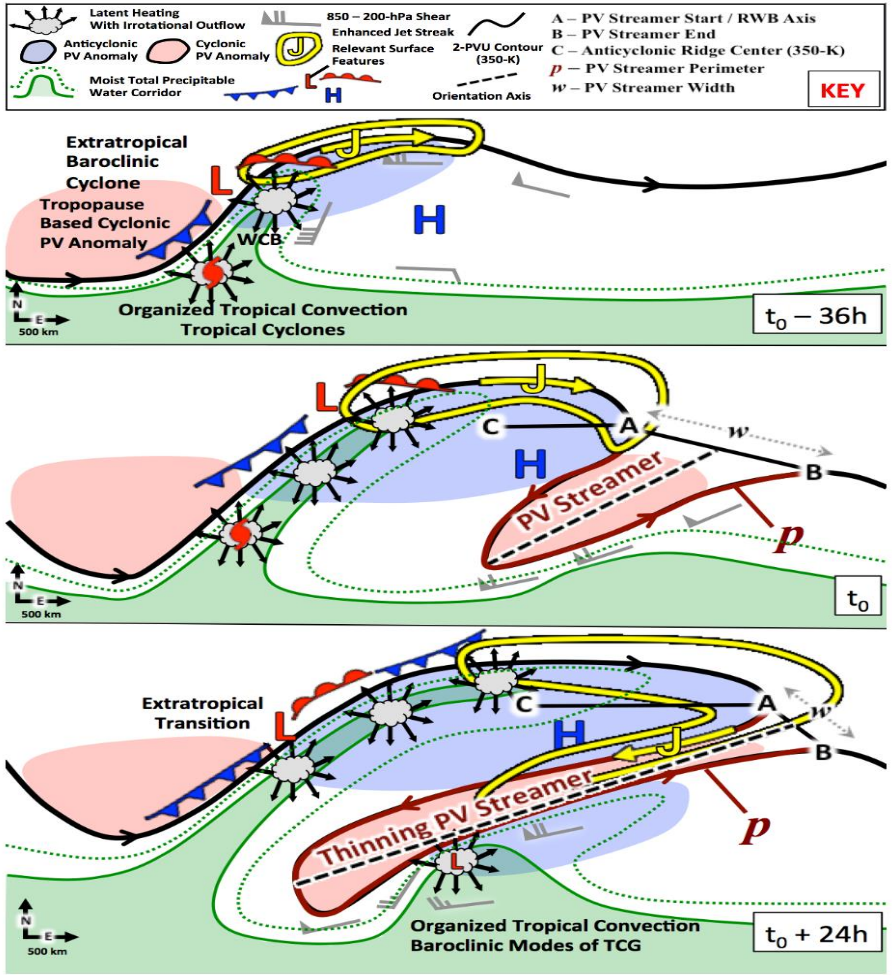
2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES EXTRATROPICALES: IMPACTO DE LAS TRANSICIONES EXTRATROPICALES

- Direct impacts on the midlatitude flow: Downstream ridge amplification, jet streak formation, and downstream trough amplification.
  - During ET, the transitioning cyclone typically exerts a direct impact on the midlatitude flow, which manifests in a modification of the jet streak and the ridge–trough couplet immediately downstream of the transitioning cyclone. Three mechanisms for this initial modification of the midlatitude flow has been proposed:
    - (1) Nonlinear-balanced circulation of the transitioning cyclone perturbs the gradient of potential vorticity (PV) associated with the midlatitude jet, thereby exciting RWPs and associated downstream development.
    - (2) Diabatic PV modification and the presence of upper-tropospheric air with anticyclonic PV originating from the TC outflow. Previous works loosely defined it but has been described to enhance downstream ridging and jet streak formation and to promote anticyclonic wave breaking. More recent work has confirmed that both mechanisms operate and has clarified their respective roles.
    - (3) A third mechanism has been identified that is arguably the most important individual process: PV advection by the upper-tropospheric divergent outflow.

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES EXTRATROPICALES: IMPACTO DE LAS TRANSICIONES EXTRATROPICALES



Philippe P. Papin: http://www.atmos.albany.edu/student/ppapin/research_phd.php

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

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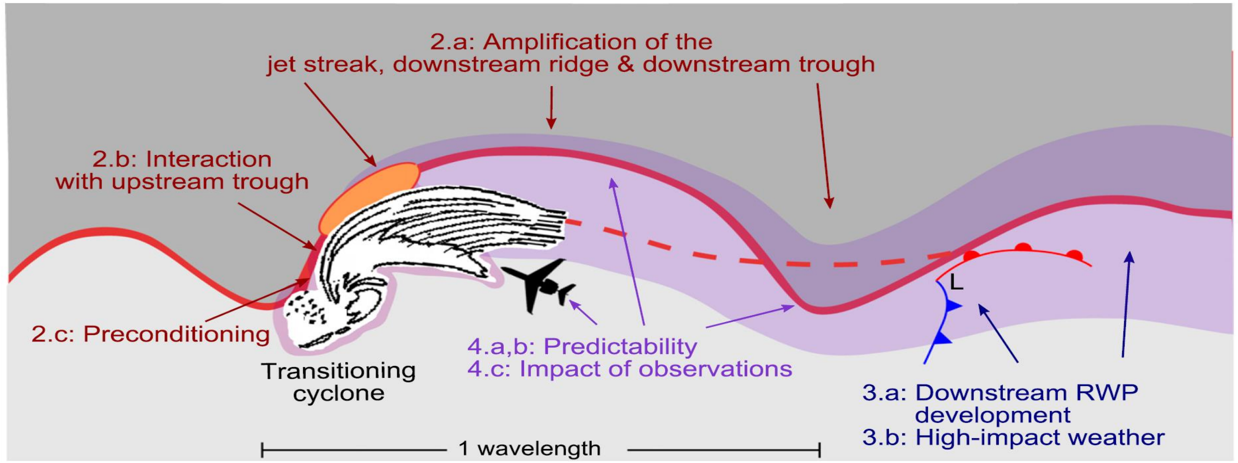
- Downstream impacts: Modification of midlatitude Rossby wave packets
  - The amplification of the first downstream ridge–trough couplet due to the processes marks the initiation or modification of a midlatitude RWP.
  - ET may excite Rossby waves on the upper tropospheric PV gradient, which will disperse downstream by the mechanisms for downstream development of unstable baroclinic waves.
  - The importance of downstream development in the context of forecasting: The main focus of previous works were on the amplification of the ridge–trough couplet directly downstream of ET. More recent work has investigated the processes that determine downstream development following the onset of ET beyond one wavelength and identified a climatological signal of RWP development downstream of ET.
  - The development of high impact weather in regions downstream of ET has been investigated more recently.



2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES EXTRATROPICALES: IMPACTO DE LAS TRANSICIONES EXTRATROPICALES

- Downstream impacts: Downstream high-impact weather
  - By triggering or amplifying midlatitude RWPs, ET may contribute to the development of high-impact weather in downstream regions.
  - The relationship between ET and downstream high impact weather exists because strongly amplified RWPs, in general, may result in blocking anticyclones, establish atmospheric conditions that are prone to strong cyclogenesis, or favour PV streamers and associated heavy precipitation.
  - These PV streamers and cutoff lows over Europe may affect the development of severe thunderstorms and heavy precipitation, the formation of Mediterranean cyclones, or the track and intensity of extratropical cyclones in the region and associated heavy precipitation. Furthermore, the PV streamers may also influence the development of subsequent North Atlantic hurricanes.

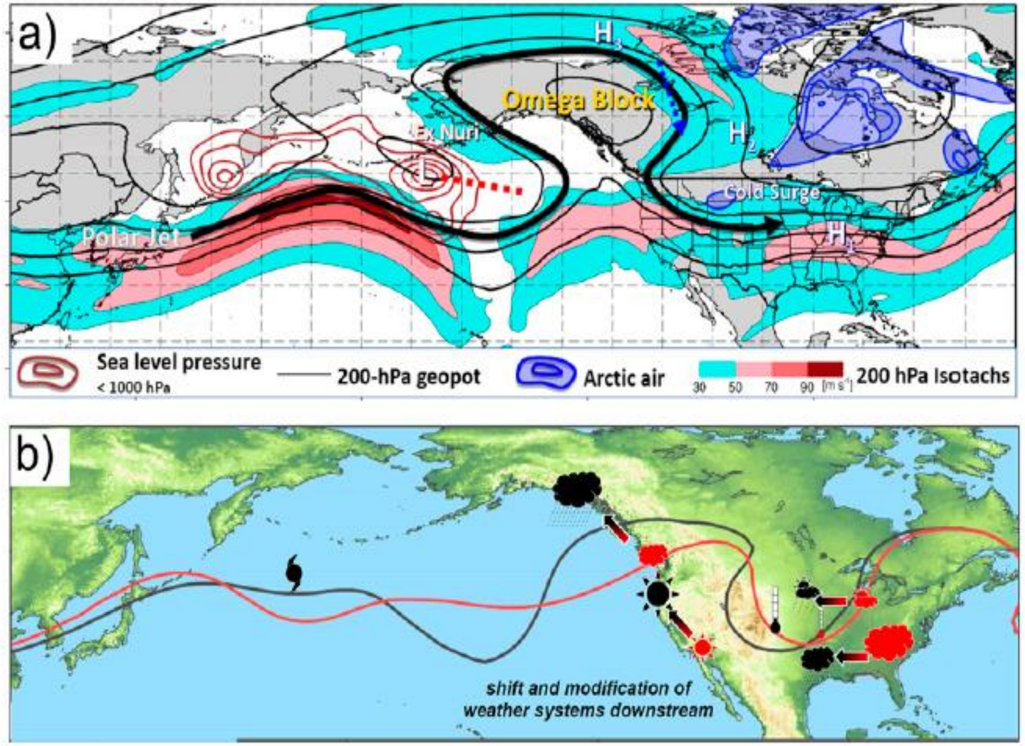


FIG. 12. (a) Illustration of omega block and high-impact weather downstream of Typhoon Nuri (2014) after Bosart et al. (2015). (b) Downstream impact of Typhoon Choi-Wan (2009), based on NWP experiments where the storm has been removed from initial conditions (Keller and Grams 2015). Black items represent midlatitude flow features in the presence of ET, and red items the evolution if ET influences were not present: 300-hPa geopotential height contour indicates upper-level waveguide (950 dam at 0000 UTC 22 Sep 2009). Arrows indicate shift of high-impact weather (precipitation, sunny and hot conditions, cold conditions) with symbol size representing magnitude.

2. CICLONES CON CARACTERÍSTICAS TROPICALES: ATLÁNTICO NORTE

1. CARACTERÍSTICAS METEOROLÓGICAS Y CLIMÁTICAS DE LAS TRANSICIONES EXTRATROPICALES: TRANSICIONES EXTRATROPICALES

- Predictability: Manifestation of midlatitude forecast uncertainty during ET
  - A first increase is found at the onset of interaction between the transitioning cyclone and the midlatitude flow in the direct vicinity of the cyclone.
  - Subsequently, the initial uncertainty then propagates farther downstream with the group velocity of the midlatitude RWP in which the uncertainty is embedded.
  - Without the development of an RWP during ET, or for short forecast lead times, forecast uncertainty remains limited to the direct vicinity of the transitioning cyclone, corroborating the essential role of the RWP in transmitting forecast uncertainty into downstream regions

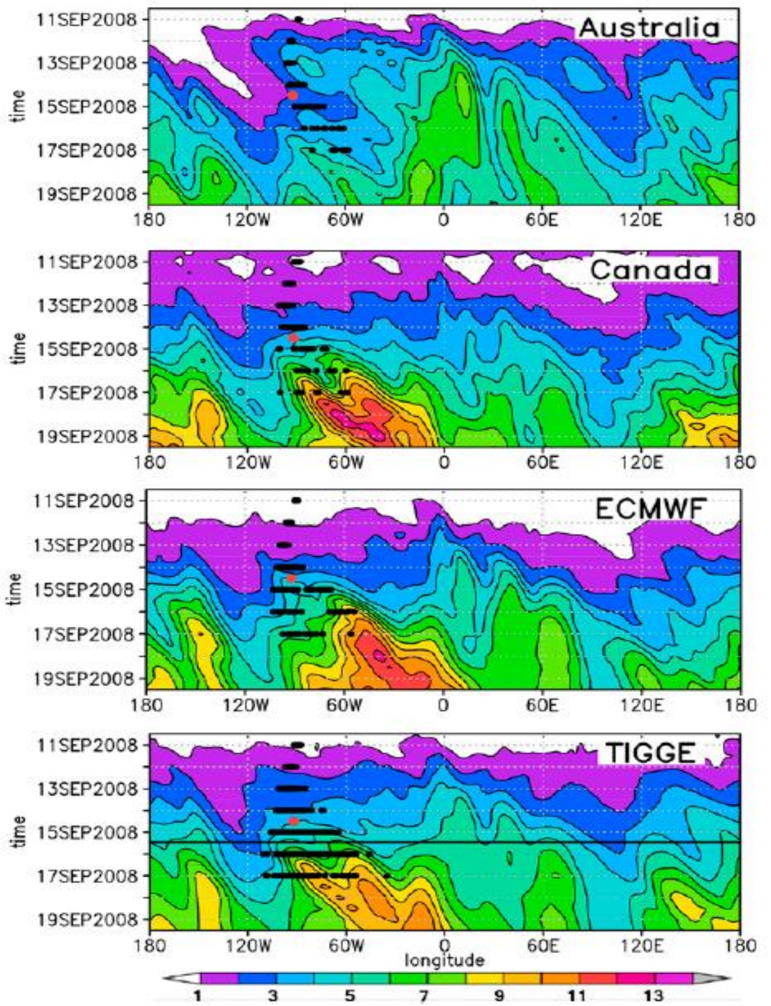


FIG. 14. Increase in standard deviation of the 500-hPa geopotential height (in dam) in the Australian, the Canadian, the ECMWF, and the TIGGE (Swinbank et al. 2016) multimodel EPS for the ET of Hurricane Ike. Forecast initialized 0000 UTC 10 Sep 2008. TC position in ensemble members is marked by the black dots, best track position at ET time by the red dot. [Figure 1 from Keller et al. (2011).]

Muchas gracias por su atención

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