# CHARACTERISTICS OF NORTH ATLANTIC SUBTROPICAL STORMS

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## 1. Introduction

The lifecycle evolution of subtropical storms has been debated in the academic and forecast communities for the last several decades, but only one paper has addressed forecasts of Atlantic subtropical storms specifically (Hebert and Poteat, 1975). Recently, Roth (2002) compiled a 51-year database of North Atlantic subtropical storm candidates, which includes ambiguous cyclone types forming in a range of environments. Processes similar to those involved in the evolution of subtropical storms have been observed in all tropical basins, and the Mediterranean and the Great Lakes. Common to all of these are the presence of an upper cold cored cyclonic feature, cut-off from the upper westerlies, over relatively warm water.

A climatology of subtropical storms for the period 1957-2002 is reviewed, revealing the large scale environmental conditions necessary for subtropical cyclogenesis. A short survey (1999-2004) of NCEP GFS analyses of North Atlantic subtropical cyclones is also presented here, focussing on the synoptic to mesoscale features associated with subtropical storms. Storm-centred composites of atmospheric fields and synoptic anomalies reveal that subtropical storms are hybrid cyclones with upper tropospheric cold and near-surface warm cyclonic circulations, consistent with thermal wind balance considerations. The three necessary (but insufficient) conditions for baroclinic instability are satisfied during the initial stages of the lifecycle evolution of subtropical storms, supporting the idea that baroclinic processes are necessary for the development of these systems. Transitions from baroclinic to tropical cyclone have been observed and documented by Davis and Bosart (2003), and have been attributed to a diabatic reduction of vertical shear. The necessity of vertical shear in the initial cyclogenesis phase of the system's evolution sets it apart from other tropical cyclogenesis types.

Some landfalling subtropical storms (e.g Karen 2001) have been observed to have the same surface impacts as weak hurricanes (Stewart, 2001). In light of this, in 2002 the US National Hurricane Center began naming subtropical storms from the same list as tropical cyclones, and issuing similar advisories. Despite this recognition of the impacts of subtropical storms on the public, there is still disagreement between forecasters as to the criteria for subtropical cyclogenesis.

## 2. Methods

An automated cyclone tracking algorithm is used to reveal North Atlantic cyclones in the ECMWF 1957-2002 reanalyses (ERA40) fields. The Cyclone Phase Space (CPS) of Hart (2003) is used to filter the cyclones for persistent hybrid structure, which is defined as cold upper and warm lower cyclonic features, present for at least 36 hours in the reanalyses. We are only interested in cyclones that may produce damaging or disrupting winds, so the dataset is also partitioned by culling those storms which do not reach subtropical storm status (with wind speeds exceeding 17ms$^{-1}$). We remove the possibility of including tropical storms undergoing extratropical transition with similar hybrid structures, by filtering out storms which had a deep warm core CPS signature prior to the hybrid structure. The final dataset is examined to determine a temporal and geographical domain of likely subtropical storm activity. North Atlantic maps of vertical wind shear, sea surface temperature (SST), Potential Intensity (Emanuel, 1986) and Eady baroclinic wave growth (Hart and Evans, 2001) are produced to discover which basin-scale conditions are conducive to subtropical cyclogenesis in the ERA40 reanalyses.

The same exercise is applied to GFS operational analyses for the period 1999-2004, in order to produce a more recent dataset. During this period, 18 storms are selected by using satellite imagery, surface analyses, observations, radiosonde ascents and model analysis fields. Storm-centred composites are generated to identify the smaller scale features (meso-α-scale to synoptic scale) associated with subtropical cyclogenesis.

## 3. Results and Discussion

Synoptic case studies indicate that North Atlantic subtropical storms have hybrid (cold upper, warm near-surface) cyclonic circulations. A climatology and resulting composites reveal that warm season storms with these characteristics form ahead of an upper trough with associated vertical wind shear typically exceeding 10 ms$^{-1}$, over SSTs as cold as 23°C, such as Ana, in April 2003.

Subtropical storms are spawned as baroclinic developments in the presence of positive low level vorticity over relatively warm sea surface temperatures.

The schematic in Figure 1(a) represents the initial baroclinic cyclogenesis; solid grey lines are surface isobars, with an L at the position of the central low pressure. Solid black arrows are upper streamlines, for example the 300 hPa flow. Surface fronts and wind barbs are marked in the conventional manner, and shading indicates the continuous cirrus shield associated with ascent. The dashed line is the upper trough axis. In (b), the upper trough has cut off and the surface occlusion has become detached, with its associated cloud shield, from the main baroclinic zone. At stage (b), the system has become a subtropical cyclone. The near-surface feature has become distinctly more barotropic in nature, and the upper feature has cut off from the westerlies as a cold low, indicated by the X.

In the schematic (b), the upper cyclone has cut off and reduced in size from synoptic to hurricane scale (mesoscale) in horizontal extent. The hybrid structure remains evident until the convection erodes the upper vorticity maximum (if it is able to do so) to the point when the lower warm core part of the system dominates, and the storm becomes more tropical in nature, as per the study of

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Davis and Bosart (2003). Ultimately, this will lead to a tropical cyclone, if the warm core extends upwards through the system's depth, with convection which has completely wrapped around the central low and an upper anticyclonic outflow.

Conversely, the cyclone may become more extratropical in character if the convection is not sustained, e.g. due to cold SST, or intrusions of dry air. If this is the case, the upper cold low may build down to the surface, leading to a less intense lower circulation that is the case in the hurricane scenario. If this cold low remains cut off, it will fill in a matter of days.

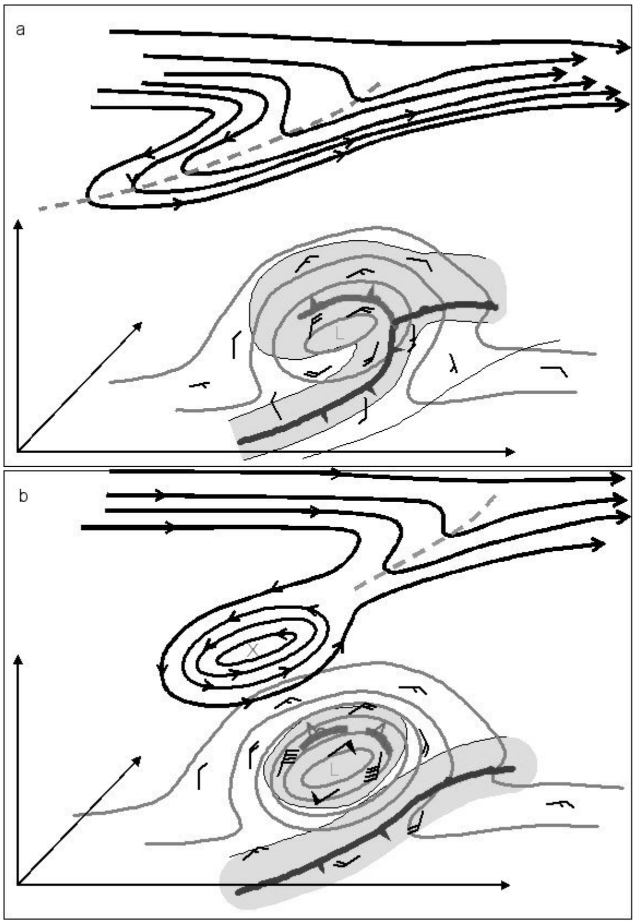


Figure 1: Conceptual schematic of subtropical cyclogenesis (see text for details).

The transition between tropical and extratropical phases of cyclones does necessitate some time spent as a hybrid cyclone. However, the nature of tropical-to-extratropical transitions is such that this time is often short (i.e. on the order of one day). Extratropical-to-tropical and subtropical-to-tropical transitions are more likely to be associated with longer periods as a hybrid cyclone. This is because the upper low associated with the incipient surface cyclone must slow its forward speed considerably in order for a warm core low to build from convective processes. Otherwise, the shear accompanying a rapidly translating upper trough or low would disrupt the condensational warming associated with the convection.

Pratt (2004) indicates that global operational model forecasts of tropical cyclogenesis are not as reliable as forecasts of baroclinic (extratropical) cyclogenesis. Often, finer scale processes than are resolved in the operational forecast models are critical to tropical cyclogenesis, most notably convective processes and turbulent fluxes. In addition, forecast tracks of extratropical cyclones tend to be more accurate, due to more robust steering patterns in the mid-latitudes. Hence, one might expect that the development of incipient baroclinic vortices are easier to forecast than tropical cyclogenesis. The transition to hybrid subtropical storm is less predictable, as it is often difficult to ascertain whether the convection will become organized.

Once a storm does reach its subtropical phase, the organization of the convection in the lower warm core will control the strength of the surface cyclone. So one might say that it is as difficult to forecast intensity change in a subtropical storm as it is for a tropical depression of tropical storm.

In pursuit of more accurate subtropical cyclogenesis and development forecasts, finer scale cloud resolving models may be beneficial, in conjunction with higher resolution global and regional numerical models.

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