

GENESIS STAGE EXPERIMENT  
*Science Description*

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**Experiment/Module:** Favorable Air Mass (FAM)

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**Requirements:** Pre-genesis disturbances (pre-TDs), including NHC-designated “Invests”

**Plain Language Description:** Although the ingredients for tropical cyclone formation have been well-documented for decades, it is still difficult to predict which disturbances will develop and which ones will not. A big factor in this uncertainty is the favorability of the air mass ahead of, and interacting with, the disturbance. This experiment proposes to collect observations of mid-level humidity and winds to assess the favorability of the disturbance’s environment for tropical cyclogenesis. These aircraft observations may also provide helpful guidance for the expanded use of satellite observations in the absence of aircraft observations.

**Genesis Stage Science Objective(s) Addressed:**

The overarching objective is to investigate if a pre-genesis disturbance has matured into a TC, including the organization of convection and the development of a closed low-level circulation.

- 1) To investigate the favorability in both dynamics (e.g., vertical wind shear) and thermodynamics (e.g., moisture, stability) for tropical cyclogenesis in the environment near a pre-TD, especially the downstream environment [*APHEX Goal 3*].

**Motivation:** The environment near a pre-TD is critical to the favorability for tropical cyclogenesis to occur. The probability of cyclogenesis for a given pre-TD, such as an African easterly wave, is dependent upon thermodynamics (e.g., moisture, relative humidity) and dynamics (e.g., vertical wind shear) in the adjacent air mass(es). Increased observations of lower- and mid-tropospheric humidity in the near-disturbance environment would shed light upon critical moisture thresholds important (or necessary) for tropical cyclogenesis and would help correct moisture biases in numerical weather prediction models. The downstream environment is most important for cyclogenesis predictions because that is the environment that a pre-TD moves into.

**Background:** As early as the 1930s, westward propagating disturbances in the lower troposphere were identified as seed circulations for most TCs in the North Atlantic Ocean (Dunn 1940). The origins of these pre-genesis disturbances, or pre-tropical depressions (pre-TDs), were traced back to North Africa and are now known as African easterly waves (AEWs; Riehl 1945). About 70% of all TCs and, more impressively, 85% of major hurricanes in the North Atlantic Ocean have been found to initiate from AEWs (Landsea 1993). On average, sixty AEWs exit the West African coast each year. However, determining which of these AEWs will develop into TCs has proven to be a forecasting challenge. For example, over 50% of TC genesis events in the Atlantic main development region predicted by the Global Forecast System (GFS) from 2004–2011 were false alarms (Halperin et al. 2013).

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Recent research has shed some light on the relationship between AEWs and TC genesis in the North Atlantic Ocean. The AEW-relative flow around an incipient disturbance has been hypothesized to be an important factor in protecting the disturbance from environmental intrusions, and thus creating or maintaining a favorable environment for TC genesis to occur (Dunkerton et al. 2009). Brammer and Thorncroft (2015) have shown that, as AEWs leave West Africa, the troughs are sensitive to the low-level environment to their west and northwest. Although the vortex at 700 hPa typically has a closed circulation in the wave-relative reference frame, the AEW troughs are still cold-core in the lower troposphere and, therefore, there is relative westerly flow under the vortex and through the lower levels of the trough. In a composite analysis, significant differences in the moisture of the low-level environment to the northwest of the troughs were found between developing and non-developing waves. Favorable developing waves had significantly higher moisture content in the lower troposphere to the northwest of the trough as they exited the West African coast compared to favorable non-developing waves. Trajectory analysis for all the waves revealed that as the AEWs transition over the West African coast the troughs are typically open to the environment ahead and to the northwest of the trough. For developing waves this means that moist air (e.g., moist tropical sounding, Dunion 2011) is ingested into the lower levels of the system, while for non-developing waves dry air (e.g., SAL or mid-latitude dry air intrusion soundings) is ingested. At this stage in the AEW life cycle, moisture differences may be fundamental in determining whether a favorable wave will develop or not.

The depth and the integrity of the closed circulation around the pre-genesis disturbance is an important consideration for providing a convectively favorable environment for TC genesis. Freismuth et al. (2016) argue that the vortex of ex-Gaston (2010) was susceptible to dry air above the vortex maxima, which hindered deep convection and led to a weakening of the vortex. In addition, nondeveloping disturbance AL90 (2014) encountered lower tropospheric dry air to its west and northwest, which was ingested by the disturbance and was likely a major contributor in the failed genesis. Brammer and Thorncroft (2017) showed that as AEWs leave the West African coast there is an increase in air parcel trajectories reaching the AEW circulation from low-levels to northwest of the trough circulation. Although the AEW troughs typically possess closed circulations at 700–600 hPa as they leave the West African coast, the circulation can remain open to the environment both above and below the 700–600-hPa layer. As AEWs propagate across the North Atlantic, the troughs are more likely to exhibit closed circulations at low-levels due to either increased vorticity within the trough or the changing background shear profile over the central Atlantic. It was therefore hypothesized that AEWs are especially sensitive to the low-level environment to the west and northwest of the trough during the first three days after leaving the West African coast. Since AEWs typically propagate at  $7.5 \text{ m s}^{-1}$  over the Atlantic (Kiladis et al. 2006), these waves are typically located near  $35^\circ\text{W}$  after three days.

**Goal(s):** To investigate the favorability in both dynamics (e.g., vertical wind shear) and thermodynamics (e.g., moisture, relative humidity) for tropical cyclogenesis in the environment near a pre-tropical depression, especially the downstream environment.

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**Hypotheses:**

1. Environmental air downstream from a pre-TD (or AEW trough axis) is ingested before the low-level circulation is closed.
2. Environmental relative humidity to the west and northwest of a pre-TD is critical to the development of that disturbance.
3. Environmental vertical wind shear in the vicinity of a pre-TD is critical to the development of that disturbance.
4. Dry air associated with the Saharan Air Layer (SAL) inhibits or delays genesis of pre-TDs.
5. Dynamical models (e.g., GFS) are consistently too moist in the inflow layer to the west of a pre-TD, resulting in genesis false alarms.

**Objectives:**

1. Collect aircraft observations of thermodynamics and dynamics in the air mass surrounding and ahead of a pre-TD.
2. Consecutive missions are recommended to observe the evolution of the observations over time and how that pertains to the (non-)development of a pre-TD.

**Aircraft Pattern/Module Descriptions (see *Flight Pattern* document for more detailed information):**

**G-IV Pattern #1:** Sample the environment to the west of an easterly wave, especially if dry air is detected in that region. Sample when the easterly wave is forecast to develop in reliable computer models or is showing signs of development in observations. Standard Lawnmower pattern should be used to set up a grid of observations and dropsondes, with drops every 150 n mi (280 km). The most likely orientation of the lawnmower pattern will be to the West or Northwest of the tropical disturbance/cyclone. To maximize the usefulness of the data, a minimum of two lawnmower legs should be flown. In some situations, the same box could be flown twice to maximize data coverage in a more specific region.

**P-3 Pattern #1:** G-IV Pattern #1 (described above) can be modified to accommodate the P-3. Flight level should be 15–20 kft to maximize the altitude of dropsonde data. P-3 missions will likely start later than G-IV missions due to the greater range of the G-IV, especially if the disturbance is in the Atlantic Main Development Region.

**Links to Other Genesis Stage Experiments/Modules:** This experiment is ideally suited to include sampling of the disturbance itself, including the vorticity maximum and precipitation properties identified from the TDR, and thus the PREFORM experiment (also part of the Genesis Stage). Of course, special consideration must be given to the length of the flight and the distance of the disturbance from the takeoff/landing airport(s). It may be especially fruitful to evaluate the

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relative humidity in the environment ahead of a disturbance and consequently investigate the precipitation properties within the disturbance itself. The FAM observing strategy is ideally flown in support of the Impact of Targeted Observations on Forecasts, especially the 2022 ITOFS – East Atlantic (ITOFS-East) experiment (description below) that will be flown from the Cabo Verde Islands.

**ITOFS-East:** The overarching objective of ITOFS-East is to fly the NOAA G-IV to collect rare measurements of tropical disturbances and tropical cyclones in their very early stages of development, farther east than any NOAA hurricane reconnaissance aircraft has ever flown. Operating from Cabo Verde, G-IV research missions will provide an opportunity to sample an AEW as it emerges from the West African coast. AEWs (as a pre-cursor to a TC) accounts for about 60% of the tropical storms and non-major hurricanes and 85% of the major hurricanes in the Atlantic, and is therefore a high priority target for ITOFS-East. The three goals of ITOFS-East are:

1. Examining the operational impact of in-situ observations in the normally data sparse eastern and central North Atlantic through real-time monitoring of AEWs and the early stages of TCs, and assessing how those observations may improve model and National Hurricane Center (NHC) short- and long-term forecasts of TC formation;
2. Understanding the structural aspects of AEWs, such as the SAL and African easterly jet (AEJ), that make them favorable or unfavorable for possible development in the western North Atlantic;
3. Evaluating the accuracy of experimental (e.g., NASA TROPICS) and operational (e.g., from GOES, NOAA-20, Suomi-NPP) satellite product guidance in the region against collected G-IV observations (collaboration with the 2022 HFP Experiments: *Evaluation of Tropical Cyclone Environment Using Satellite Soundings Experiment* and *TROPICS Satellite Validation Module*).

In addition to the research opportunities ITOFS-East offers, NOAA NHC is interested in:

- Accessing GPS dropwindsonde and tail Doppler radar observations in the central and eastern North Atlantic to capture the early lifecycle stages of tropical disturbances and tropical cyclones, especially those that pose a threat to land areas in the central and western part of the Atlantic basin, including the CONUS, Puerto Rico, and the U.S. Virgin Islands.
- Testing strategies for sampling tropical disturbances and tropical cyclones farther east and earlier in their lifecycles. These efforts will help address strategies for future requirements and capabilities, including NOAA NHC 7-day tropical cyclone forecasts and the enhanced range capabilities of the anticipated G550 aircraft.

**Link to NASA’s Convective Processes Experiment – Cabo Verde (CPEX-CV):** In addition to ITOFS-East, FAM could be flown in coordination with CPEX-CV and the NASA DC-8 aircraft during their planned deployment period between 1–30 September. The NASA DC-8 will be flying [DAWN](#) (Doppler Aerosol Wind Lidar), [APR-3](#) (the Airborne Third Generation Precipitation Radar), HALO (High Altitude Lidar Observatory), [HAMSR](#) (High Altitude MMIC Sounding

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Radiometer), AIRO (Airborne Radio Occultation), and will be able to deploy dropsondes. The CPEX-CV science objectives include the following:

- Improve understanding of the interactions between large-scale environmental forcings (e.g., AEWs, ITCZ, SAL, mid-level AEJ) and the lifecycle and properties of convective cloud systems, including tropical cyclone precursors, in the tropical East Atlantic region;
- Observe how local kinematic (wind) and thermodynamic conditions, including the vertical structure and variability of the marine boundary layer, relate to the initiation and lifecycle of convective cloud systems and their processes (e.g., cold pools);
- Investigate how dynamical and convective processes affect size dependent Saharan dust vertical structure, long-range Saharan dust transport, and boundary layer exchange pathways.
- Assess the impact of CPEX-CV observations of atmospheric winds, thermodynamics, clouds, and aerosols on prediction of tropical Atlantic weather systems, and validate and interpret spaceborne remote sensors that provide similar measurements.

With the additional support provided by the Office of Naval Research (ONR), the NASA-NOAA-ONR field program collaboration in the East Atlantic in 2022 will be the most comprehensive effort to sample tropical weather in that region since NASA's African Monsoon Multidisciplinary Analyses (NAMMA) experiment in 2006. Flights from the DC-8 and G-IV will offer rare in-situ and remotely-sensed measurements of wind, humidity, temperature, aerosols, and clouds and precipitation in potentially developing easterly waves, in a vastly under-sampled region of the Atlantic basin, thus facilitating an opportunity to more intensively sample potential tropical cyclogenesis events than usually possible with the NOAA aircraft alone.

**Analysis Strategy:** Dropsonde profiles will be evaluated to determine the horizontal gradients and advection of environmental relative humidity. Characteristics of the dry air mass will be scrutinized, including the minimum relative humidity, the height/depth of the dry air, and the horizontal extent of the dry air. Wind analyses from dropsondes and TDR will be evaluated to determine the impact of environmental vertical wind shear on the pre-genesis disturbance. This analysis will go beyond the traditional deep layer vertical wind shear metric, taking into account the hodograph to evaluate vertical wind shear through a number of different levels. The observations collected in this experiment will be crucial to evaluation of dynamics/thermodynamics and the diagnosis of genesis false alarms in numerical weather prediction models (e.g., GFS, HWRF).

**References:**

- Brammer A., and C. D. Thorncroft, 2015: Variability and Evolution of African Easterly Wave Structures and Their Relationship with Tropical Cyclogenesis over the Eastern Atlantic. *Mon. Wea. Rev.*, **143**, 4975–4995.
- Brammer A., and C. D. Thorncroft, 2017: Spatial and Temporal Variability of the Three-Dimensional Flow around African Easterly Waves. *Mon. Wea. Rev.*, **145**, 2879–2895.

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- Dunion, J.P., 2011: Re-writing the climatology of the tropical North Atlantic and Caribbean Sea atmosphere. *J. Climate*, **24**, 893–908.
- Dunkerton, T. J., M. T. Montgomery, and Z. Wang, 2009: Tropical cyclogenesis in a tropical wave critical layer: Easterly waves. *Atmos. Chem. Phys.*, **9**, 5587–5646.
- Dunn, G. E., 1940: Cyclogenesis in the tropical Atlantic. *Bull. Amer. Meteor. Soc.*, **21**, 215–229.
- Freismuth, T. M., Rutherford, B., Boothe, M. A., and Montgomery, M. T., 2016: Why did the storm ex-Gaston (2010) fail to redevelop during the PREDICT experiment? *Atmos. Chem. Phys.*, **16**, 8511–8519.
- Halperin, D. J., H. E. Fuelberg, R. E. Hart, J. H. Cossuth, P. Sura, and R. J. Pasch, 2013: An evaluation of tropical cyclone genesis forecasts from global numerical models. *Wea. Forecasting*, **28**, 1423–1445, doi:10.1175/WAF-D-13-00008.1
- Landsea, C. W., 1993: A climatology of intense (or major) Atlantic hurricanes. *Mon. Wea. Rev.*, **121**, 1703–1713.
- Riehl, H., 1945: "Waves in the easterlies and the polar front in the tropics" Misc. Rep. No. 17, Department of Meteorology, University of Chicago, 79 pp.