

American Meteorological Society

Frank D. Marks Jr. Symposium



31 March 2026, San Diego, CA

FOREWORD

After more than 40 years of federal service, NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML) is thrilled to partner with American Meteorological Society to dedicate the Frank D. Marks Jr. Symposium to celebrate the career of Frank Marks. Dr. Marks' contributions to meteorology and hurricane research have left an indelible impact on the field, making him a true NOAA legend. Marks began his career at AOML in July 1980 as a Research Meteorologist and quickly became a key member of the Hurricane Research Division (HRD).

Marks led the way as mission manager for the NOAA High Altitude Jet procurement, leading to the addition of the Gulfstream-IV (G-IV) to the Hurricane Hunters fleet. Building on his foundational work with the NOAA fleet, he spearheaded the development and operation of Tail Doppler Radar systems aboard the P-3 Orion and G-IV aircraft, significantly enhancing meteorologist's ability to analyze and understand storm structures. Marks also contributed to the real-time transfer of Tail Doppler Radar data from aircraft to ground stations via satellite, an innovation integrated into operational forecast models to improve intensity forecasts. His leadership extended to more than 400 missions, over 500 eye penetrations of tropical cyclones, and more than 150 peer reviewed papers, which greatly advanced scientific understanding and improved hurricane forecasting and preparedness.

In 2003, Marks was appointed Director of the Hurricane Research Division and served in this role until 2023. Additionally, he assumed the role of Research Lead for NOAA's Hurricane Forecast Improvement Program in 2007, where he focused on improving hurricane intensity and track forecasts by more than 50%. His strategic vision and dedication were crucial in overseeing innovative research that includes machine learning, small uncrewed aerial systems, and using social science to improve products. He is also a leader in the tropical cyclone research community, both inside and outside of NOAA. Marks has served on editorial boards, science advisory committees, service assessment team, as well as mentoring meteorologists and students. Dr. Marks has always made time to communicate the science to the public and to stakeholders.

His contributions to remote sensing and hurricane research did not go unrecognized; Marks' contributions have earned him numerous prestigious awards, including the U.S. Department of Commerce Gold, Silver, and Bronze Medals, the American Meteorological Society's Verner E. Suomi Award, the NOAA Distinguished Career Award, and the 2021 AMS Joanne Simpson Tropical Meteorology Research Award.

Thanks to all the mentors, colleagues, collaborators, postdocs, and students that are joining this symposium in celebration of Marks' remarkable career, his accomplishments, his service to the nation, and his continued commitment to people and advancing hurricane research!!

Molly Baringer

AOML Acting Director

Serendipity: An Autobiography from the Career Perspective

By Frank D. Marks Jr.

Early Years

I grew up in the New York Hudson Valley, halfway between Yorktown Heights and Peekskill on the river, about 50 miles north of New York City in the late 1950s and early 1960s. It was mainly a rural area, but there was some suburbia growing in the area during that time. My mom was a nurse, and my dad was a butcher at the local supermarket chain. We had a nice place to live, and it was very pleasant in the summer. A lot of people from New York City moved up to spend the summer in our area, and I was fortunate to meet a lot of different folks. New York City was an hour's train ride away, and it was a great place to visit, but I was glad I didn't live there.



I was the oldest child with four younger sisters. I was always interested in science. I remember Flipper on TV, and I got hooked on marine biology, which always intrigued me. When I was about 12 years old, I was a paperboy riding my bike around to deliver papers to different people's houses. One of the places happened to be the home of a science teacher in the local high school and middle school, named Jim Witt. He had these white boxes on his front yard, and one day when I went to pick up my pay, I asked what those boxes were for. He told me that they were Thompson screens that contain meteorological instruments to measure the temperature, humidity, and pressure. I thought that was really interesting. Jim told me he was a science teacher at the high school, where they had a weather club and if I was interested I could join the weather club even in middle school. I joined the weather club when I started middle school in 1965, over 60 years ago.

Jim was a weather enthusiast with a master's degree in meteorology from New York University (NYU). He had numerous connections with professors at NYU and people at the National Weather Service (NWS) office in New York City. He set up the equipment in the weather club so that it was hands-on for students. We had licenses for a circuit A (surface) and circuit C (upper air) teletypes, and he taught us how to decode, plot, and analyze the different types of observations on weather maps he got from the NWS office. He also taught us how to make forecasts. He was a real weather buff, and he was passing his interest and enthusiasm on to us. I went all through high school with Jim and the weather club, and we passed that enthusiasm on to each new group of classmates.



Jim was an incredible guy. He even found a radar that the Air Force was going to surplus and convinced them to give the radar to us, getting the license to put it on the roof of the high school. Jim inspired a number of us to go on to have careers in meteorology. Greg Tripoli went on to become a professor and chair of the department at the University of Wisconsin, Jordan Alpert, who worked on the Global Forecast System (GFS) at NWS, Jim Hack, who worked on the climate model at National Center for Atmospheric Research (NCAR) and eventually led the model development activities at the Oak Ridge National Laboratory, and Mike Steinberg, who became a vice president at Accuweather.

By the time I graduated high school, I'd been active in meteorology for six years and knew how to analyze

observations and forecasts, and I decided I wanted to be a meteorologist. I applied to a number of schools that the American Meteorological Society (AMS) listed as having undergraduate meteorology programs. My family didn't have a lot of money, so I was looking for a college that would give me a full scholarship. I ended up at a small liberal arts college in New Hampshire called Belknap College that had about 700 students.

Undergraduate Education

Belknap was in the Lake District in Central New Hampshire, and had a great meteorology program. They had three professors, all with at least master's degrees, and one had a doctorate from MIT under the Air Force Institute Technology Program. It had great meteorology classes and labs, plus all the basic math and physics support classes, like calculus and linear algebra.

While I was there, I helped form a student AMS chapter. I was a big fan of AMS, having used their resources to identify colleges that offered meteorology degrees. I worked with AMS to get the student chapter started and get the students to join AMS. We participated in the national weather competitions, where we tried to make forecasts for different cities.

I finished all of the meteorology classes Belknap offered by my junior year. One of my meteorology professors, Dr. Bob Derrickson, and the president of the college, Dr. Bill Widger, who had both received their PhDs in meteorology at MIT, encouraged me to apply to graduate school. They both encouraged me to apply to MIT. They offered to write letters of recommendation for me.

Graduate Education

I applied to a number of universities for graduate school. I received an early acceptance to Colorado State (CSU) to work with Prof. Elmar Reiter, but my fiancé and her family were from the Boston area. After I received the offer from CSU, my fiancée and I planned to get married before moving to Colorado. While I was visiting them in the Boston area, I got a call from MIT. It was from Prof. Jim Austin, who informed me that they were considering me for a student fellowship in the meteorology department.

After Prof. Austin called me, I had to decide between the two fellowship offers, one from CSU and one from MIT. That evening at a family gathering, my fiancée told her family that I had an offer from MIT. Her grandfather said I had to go to MIT because he didn't want his granddaughter to leave Boston. My fate to MIT was sealed. My major professor became Dr. Pauline "Polly" Austin, and I was going to do my graduate work at the radar lab on the 18th floor of the Green Building. I followed Bob Houze as Polly's graduate student. The first thing Polly did was she gave me Bob's thesis and all his notes from his PhD.



My best mentor at MIT was Spiros "Speed" Geotis, who was the radar engineer for the radar lab. He was what I would call a "Renaissance man". He was a mentor in many ways, and I really enjoyed working in the radar lab. It was a blast, and I was able to interact with a number of electrical engineering students who worked with Speed on the radar electronics and developing minicomputer systems to control and record digital radar data. Speed taught me a lot, especially going into the field. He always said, when you're in the field, do what the natives do, don't try and act like an American, understand and live the culture.



As a first-year graduate student, I was taking prerequisite math courses and the introduction to dynamic meteorology course taught by Prof. Norm Phillips. Everything you wanted to know about meteorology without

Coriolis Force playing any role. At the beginning of the course, Norm gave us the syllabus, all the homework problems, everything but the midterm and the final in a mimeographed notebook. There was a timetable given for what was covered each class. Norm would go through the sections of the course notes in order, and every week there would be a homework assignment on that section.

I remember sitting in Norm's course listening to his lecture, and I noticed that he would finish one set of notes, and if no one asked any questions, he would just start the next section. He kept going and going. Dean Duffy was the TA for him at the time. I asked Dean what was the deal with Norm moving through each section and not keeping to the schedule in the syllabus. "He doesn't stop," I said, "it's hard to keep up." Dean said "you folks are not asking questions. If you don't ask him a question, he's just going to keep going." So we got a little wise. I spread the word to the other students in the class that we need to ask questions to slow this guy down. Otherwise, I will say that Norm was a phenomenal teacher, his lectures were excellent.

GATE

Serendipity struck during the first year at MIT. I was riding the elevator up to the 18th floor one day, and I noticed a flyer hanging in the elevator that said the University Corporation for Atmospheric Research (UCAR) was looking for graduate students to apply to go to Africa for three months during the summer of 1974 to be part of the Global Atmospheric Research Program (GARP) Atlantic Tropical Experiment (GATE). They were looking for graduate students to work on land in Dakar, Senegal, or on ships out in the Atlantic. The students would get a stipend, and all the travel and accommodations would be paid for. I applied, and was selected. The idea was the students would go on the ships and get experience in the field.

I went to Africa for three months, and I never got on a ship. I was an alternate sitting in Dakar, Senegal, for three months doing odd jobs, everything from hanging the flags of every country participating in the experiment on the wall the first week, to plotting charts, and eventually interpreting ship-borne radar imagery for flight mission planning.

It was a fascinating eye-opener for me. I was serendipitously lucky to be there for such a huge experiment. The experiment had 23 ships and seven airplanes involved. The ships were set up in an array about the size of the grid boxes in the global model at the time. They were arrayed in telescoping nests, and they all had boundary layer balloons flying off of them. It was just a fascinating thing to be a part of and to meet everyone who was involved with tropical meteorology, from Jim Sadler to Dick Reed to Krishnamurti.

I worked for Profs. Alan Betts and Dave Rodenhuis in their analysis group. We were analyzing balloon soundings to evaluate the accuracy of US systems versus the systems used by other nations. The US was using a new technique developed at the National Center for Atmospheric Research (NCAR) that used the Omega navigation radio signals to track the balloons with height, while all the other countries were using radar transponders to track the balloons.

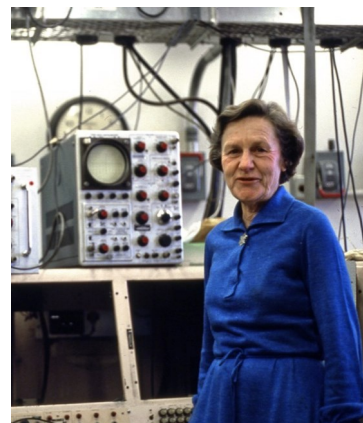
I remember heated arguments about the accuracy of the US soundings, resulting in an adjustment to the ship positions in the telescoping array to put a Russian ship together with a US ship in the center of the array as a stopgap precaution. I even remember Prof. Vern Suomi getting up in one of these meetings and saying, "We should stop using the radars to map the rain and use the radars to track the balloons." It was fascinating, as a student, I was sitting in the background and listening to all this.

My job was to plot the soundings from the two ships in the center of the array using Omega and transponder tracking, analyze the difference, and provide analysis for input to the big meetings about how to mitigate



the issue. It was interesting and really taught me a lot about field work, international experiments in particular because every briefing had to be in French, English, and Russian. There was a big contingent of Russians. The French were there because Senegal was a former French colony.

My MIT advisor, Dr. Pauline Austin, was also there advising the flight scientists on potential targets of interest using radar data from the Quadra, which was a Canadian Coast Guard cutter that had a weather radar onboard. They were sending images from the radar to Dakar via facsimile every hour. When Dr. Austin left after the first month, she told the flight planning folks that I could help them. It turned out that my first chance to do that was to work with Dr. Ed Zipser around flight planning. Ed wanted me to advise him on where to fly to get some convection. I used my best judgement to advise Ed on where he should fly. The aircraft went out where I suggested and Ed came back and said to me that the area I sent them to had nothing but stratiform rain.



My next job became analyzing all the radar facsimiles to improve targeting for flights. I had to figure out a way to digitize the hourly facsimile images. I devised a way to make a grid on some acetate and then count up the parts of the grid with echoes and classify them as convective or stratiform rain. Surprisingly, we found a semi-diurnal tide variability modulating the radar observations such that when they were flying, it was a diurnal minimum, and that's why there's all the stratiform rain.

GATE was an interesting experience. I got to meet people like Drs. Bob and Joanne Simpson, Dick Reed, Krishnamurti, Jim Sadler, Colin Ramage, Ed Zipser, and of course, Bob Burpee, who was there running the forecasting team, and who eventually became my boss at NOAA. Those connections served me well throughout my career. It was enjoyable and certainly eye-opening, for the beginning of my career. It was my introduction to tropical meteorology.

Masters Thesis

When I came back from GATE, I had to finish up my master's thesis that was on the snow enhancement along the New England coastal front and the rain-snow line between Providence, Rhode Island, and Boston. I used the radar at MIT to document the precipitation enhancement and sounding data to document the vertical thermal stratification along the coastal front boundary. I worked with Dr. Fred Sanders at MIT and Dr. Lance Bosart at SUNY Albany, who was the master of the coastal front at the time. I remember going out to Albany and visiting Lance and getting tutored by him on the coastal front characteristics.

Dr. John Young was visiting MIT my second year. I first met John in GATE. He was teaching Prof. Ed Lorenz's dynamics 2 course while Ed was on sabbatical. As part of the course, he invited us to go over to Prof. Richard "Dick" Lindzen's evening seminar series. Dick was at Harvard at that time. Once a month on Thursday evenings during the spring semester, Dick would invite experts involved with tropical meteorology (e.g., Prof. Bill Gray, Dr. Joanne Simpson, Prof. Alan Betts, etc.) to come to Harvard and present a seminar and interact with his students. I was fortunate enough to attend a number of these seminars.

Dick always took the other side of an argument, just to make a point, so, he would invite people in to have a very dynamic and stimulating discussion with the students sitting there and learning this kind of Socratic method of grilling each other. Dick was certainly a fascinating character. That was how I got to meet a bunch of his students, Lloyd Shapiro, Ed Schneider, and K. K. Tung.

At the end of my second year, we had qualifier exams which I was nervous for. For the qualifier, I had to prepare a thesis proposal, take a four-day open-book problem set, and sit through an oral exam with my thesis

committee where they could ask me anything related to my MIT courses, the four-day problem set, or my thesis proposal. My thesis committee was Profs. Peter Stone, Jim Austin, Fred Sanders, and Henry Houghton.

I picked the GATE data for my thesis proposal, particularly the African Waves, how they developed, and what drove them. For the four-day problem set, Prof. Stone gave me this interesting question about the stability of a low-level easterly jet stream just north of the Equator in a dry or moist atmosphere. I had four days to prepare my analysis based on my knowledge and references I could draw on. After I turned that in, I had the oral exam.

The night before my oral exam, my wife and I got held up while we were coming back from dinner. The next day, I got into the oral exam with my committee. I walked in, and Prof. Jim Austin broke the ice by asking me to tell him about the hold-up. After that, I was cruising. I was scared of how I would do like most grad students—I am going to be grilled, and then all of a sudden, it isn't that hard. I passed the qualifier.

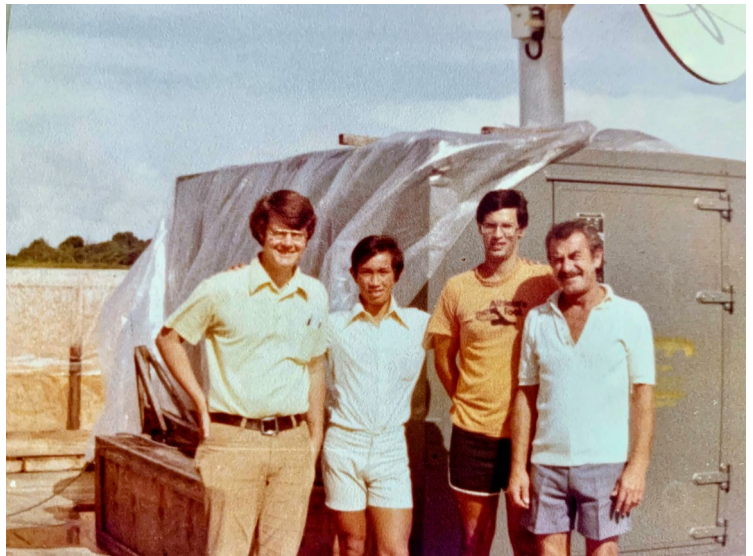
I was so afraid I wasn't going to pass that I set up a plan B applying for a job at NOAA in Washington, DC to work on the GATE data. When they offered me the job, I had only one condition: I wanted to go back to MIT after a year with the data I worked on for my doctoral thesis, which both NOAA and my thesis committee agreed on my plan.

At NOAA, I worked for Drs. Gene Rasmussen and Mike Hudlow in the Center for Environmental Data Analysis, they processed all the GATE data. I took the job for a year, met a lot of interesting folks there who were trying to get their PhDs while working full time, and realized that it was probably smart to go back to MIT after a year.

Doctoral Thesis

My oldest daughter was born when we moved back to Boston and I managed to keep working on my thesis, which was on the possibility of inertial instability along easterly jet streaks that came off Africa along the leading edge of the Saharan Air Layer. I worked with the data from the ship soundings, ship radars, and geostationary satellite imagery to define cloud and radar characteristics that accompanied the easterly jet streaks. I was able to develop a theory that these jet streaks could be a result of inertial instability caused by changes in potential vorticity as they exited the convectively neutral structure over the desert and were undercut by the stable thermal structure over the cooler coastal waters off Senegal.

Along the way, I spent six weeks in the Island of Northern Borneo, Malaysia during January 1978, for the Winter Monsoon Experiment (W-MONEX), recording radar data on the North Coast of Borneo with the MIT portable radar system. I got to interact with the NOAA P-3 airborne radars for the first



time. Bob Houze and Peter Webster were in charge of the flight missions. When they would fly in precipitation systems near Borneo, we would be making observations with the ground radar to compare to the airborne radars. This was my first chance to interact with the NOAA P-3 airborne radar systems. That's also where I met Jerry Meehl and John Gamache. Jerry and John were also students in W-MONEX. Jerry did the radiosonde balloons, and John and I did the radar.

When I went back to MIT from the W-MONEX, Fred Sanders became my advisor, and I was wrapping up my thesis. Bob Burpee came to MIT as a visiting faculty member. He asked me if I'd be interested in working for NOAA in Miami, FL. I said definitely. He set up a chance for me to go down to Miami and give a seminar. I went down to what was then the National Hurricane Research Laboratory (NHRL) in the late 1979. I gave a seminar, and Stan Rosenthal, who was the director at the time, invited me to his office and told me he'd like to offer me a job. "I thought to myself" here was an opportunity that allowed me to fly in airplanes into storms, collect data, analyze the data, and write papers. This is a field program heaven. Count me in!

After the Miami visit, Burpee really pushed the buttons to get my thesis done so I could get to Miami. I worked my tail off, completed my thesis, too late for graduation in June 1980. Fred Sanders had asked me to do a computation. Like many students who get to that point in their PhD, they're thinking: "Okay, that's a good idea, but I'm not going to do it right now. I'll do it when I write the paper." Time came for my thesis defense and everything seemed to go well. I was sitting in the hall waiting to hear if I passed. Fred came in and told me I passed, but he would not sign my thesis until I did the computation he requested. I told him that I was moving my family to Miami now, but I would come back and finish it. Remembered, this was 1981, no PCs. All the computations were done on a big IBM mainframe.

One of the interesting parts about my PhD thesis was that I did it all digitally. Being in the radar lab, a lot of the students from Electrical Engineering worked in the lab. One of the students suggested that I did my thesis digitally. He helped me acquire a CRT with an acoustic coupler and keyboard, which I set up in our bedroom. Every night I put my daughter to bed, and then I'd take over the phone, and hook up to the computer over at the MIT Artificial Intelligence (AI) lab, and type in my thesis. I ended up with my PhD thesis on a 9-track tape. I actually printed up my thesis on an AI Lab laser printer where I could lay out all the equations and everything using TROF, which was a predecessor to LaTeX.

Unfortunately, the calculation that Sanders wanted me to complete had to be done on the IBM mainframe. Therefore, I had to go back to MIT after I got my family settled in Miami. I went back for two weeks, and my wife stayed with my in-laws who loved to have my wife and their granddaughter visit. After two weeks of hard work, I completed the computation and handed it into Fred. Fred agreed to sign my thesis which is why my graduation date was actually January 1981, even though I was done at the end of July 1980.

NOAA Hurricane Research

We returned to Miami in early August just as Hurricane Allen was developing. I was able to go on my first hurricane mission on August 5, 1980, about a week after we returned to Miami. It was quite the experience and my wife said it looked like I was walking on clouds when I returned home. I was officially hooked!

I arrived at NHRL at the same time as Steve Lord. Steve was a student of Arakawa at UCLA who worked on cumulus parameterization and numerical models. I knew Steve from our interactions through analysis of the GATE data sets and their utility in refining cumulus parameterizations. I also knew Wayne Schubert, another Arakawa's former students, from GATE. Wayne was visiting NHRL the first year Steve and I arrived. Also at NHRL when I arrived was Lloyd Shapiro. Lloyd was a student of Dick Lindzen's at Harvard during my MIT tenure, and I got to know him through attending Dick Lindzen's seminar series.

During the first 4 years I was at NHRL, we had a car-pool that included Steve Lord (numerical modeler), Hugh Willoughby (theoretician), Dave Jorgensen, Peter Black, and myself (all observationalists). We would meet at one of our homes in the morning and drive 20-30 minutes into Coral Gables. Every day



we'd have a science discussion going back and forth from the office. I learned so much in those carpool discussions. It was fantastic and a lot of fun. I really miss those trips back and forth to work.

I was brought in to work with the airborne radars. NHRL was looking for somebody with radar meteorological experience to work with the aircraft radars. I brought a lot of the experience and research tools I developed while at MIT, to ensure that the P-3 radars were calibrated properly and that we could access the data in a quantitative digital manner.

The radars were purchased when the planes were built, which I feel was an extremely innovative approach to observing hurricanes away from land while they were still out far from the coast. They turned out to be amazing platforms for just that purpose. The first work I did was a study on the radar structure of Hurricane Allen, the first storm I flew into, because we really didn't have a good characterization of the storm's three-dimensional radar structure out at sea away from land and how it evolved.

My office mate, Dave Jorgenson, had done research using the three NOAA planes (two P-3s and a C-130) flying into the storm at three different altitudes to get a characterization of the storm's vertical structure. Flying the aircraft in this manner into the storm was like trying to find the seeds in an apple by poking a pin into it and hoping you hit an apple seed. Whereas, with the radar, we could get a three-dimensional CAT scan of the structure. Therefore, taking on the airborne radar analysis of these storms was just a perfect marriage for me. Without the radar on the plane, we wouldn't have a chance to see the structure inside the eye unless the storm passed over a land-based radar. These were targeted observations versus waiting for something to happen.

In those days, NOAA had the WSR-57 radars, which were the weather service radar that was put up in the 1950s. These ground-based radars were at NWS stations, and none of them were digitized. We worked with Dale Sirmans at National Severe Storm Laboratory (NSSL) to develop a digitizer for the WSR-57 radar data. We paired the digitizer with a portable mini-computer and a tape drive in a small shipping box that we could take to any WSR-57 to record the data so that we'd have it for analysis as the storm made landfall.

Folks at NHRL had recorded radar data for Hurricanes David and Frederic in 1979. We partnered with the NWS Training Center to record the data, and I helped analyze that in my first year at NHRL. We made movies to study storm evolution during landfall. At MIT, I developed a way to contour the radar observations in a plan view using line printer output to use different characters to get the gradations, like an @, -, or + to represent different reflectivity levels so you could draw contours on it. We would make these printouts and photographs on 35-mm film to make a movie of the radar evolution at landfall. When the movie was completed, we showed it at a NHRL seminar. Vic Ooyama, one of the most accomplished numerical modelers of hurricanes, thought it was the greatest thing since sliced bread because it showed him what a hurricane really looked like and how it evolved.

Vic Ooyama was a phenomenal scientist, and every paper he wrote was a major contribution to hurricane science. I remember reading his 1964 and 1969 papers as an MIT graduate student on simulating hurricanes in three dimensions. That paper became a classic on modeling tropical cyclones. Vic was so interesting to talk to, and he was interested in observations. After a seminar on the Alicia Doppler radar analysis, Vic came to my office to ask a lot of questions, saying he needed to know more about this.

At the time, one of my interests was to use the radar observations to better characterize the storm rainfall and its evolution. How much rain does a hurricane produce? We didn't have quantitative estimates. Sure, rain gauges provided some useful estimates, but they were spotty. Another major question was what the rain bands looked like, and what role they played in the storm's evolution. A third issue that came up was the concept of eyewalls within eyewalls, or secondary eyewall formation after our flights into Hurricanes David and Allen presented us with their appearance in the ground-based and airborne radar observations.

Hugh Willoughby and I worked on the rainband structure and secondary eyewall issues, writing a speculative paper describing something we dubbed the rainband complex with a principal rain band and the evolution of secondary eye walls. The idea was that another eye wall would form outside the principal eyewall and would be surrounded by other rainbands enclosed around the principal rain band. Putting these concepts together was eventually what killed the Project STORMFURY. We demonstrated that the project hypothesis of seeding rainbands outside the eyewall to form a larger eyewall was already happening without any intervention by seeding. Storms were forming outer eye walls, contracting them, and choking off the inner eye wall.

Hurricane Field Program

One of the things I think the public should know is that we've been doing this field program every year since the creation of NHRP in 1956. We have access to the NOAA aircraft every summer, and we go out and fly in hurricanes. They're very rare events, 10-12 missions per year. People have asked me for years, don't you know everything about hurricanes by now? My response is hurricanes are like people. If you see a hundred people, does that allow you to know everything about people? Probably not.

I've flown in over a hundred storms over my 45 years at HRD. I've been in and out of the hurricane eye over 500 times (By 2024, I had total 528 eye penetrations and ranked in No. 7 all time and No.2 in active scientists), and that's not even counting the weak systems that I've flown into. I actually enjoy flying into the weaker systems because I've learned things in the weaker storms that are helping National Hurricane Center (NHC) predict the genesis of hurricanes.



I have often used the field program as a leadership tool for my staff, rotating members of the staff as field program director. The field program director has to really be able to juggle a lot of interests. They must learn how to make decisions and live with the consequences, because there's not a right and wrong, just decision and consequence. Our field program plan each year lays out the research objectives and outlines a strategy to collect the data needed. However, Mother Nature doesn't always behave the way you want. So you roll with the punches and hope for the best.

The field program director doesn't only organize what we want to do. They also have to interact with our partners in NOAA: the Aircraft Operations Center, who manage and operate the aircraft and all the equipment on it; and the NWS, whom we provide the data to. Most seasons, they also have to interact with universities, NASA, or NSF collaborators, so it serves as a great leadership tool.

I'm motivated by the fact that flying into these storms has multiple benefits. We want to get the data off the plane and to the ground to help warn people, protecting lives and property. I think that my staff work their tails off because they have this belief that the information that we're providing is important. I would say the air crews are the same way. They go out there recognizing that they're doing this for the good of others, not just themselves.

I still get excited to fly into storms and am blessed that I have been in the field for so many years and doing field work. To me, sitting at a desk and writing papers and doing analysis is equally enjoyable. The beauty of the atmospheric sciences and oceanographic sciences in some ways is that you're out in the environment. You could have a representation or characterization of the storm on a computer screen but there's nothing

like getting out in the environment.

If you don't like turbulence, it's probably not your bag. But if you like roller coasters, you'd be fine on hurricane flights. It's very safe, safer than driving your car to the airport. There's nothing like breaking out into the eye and seeing Mother Nature in all her glory. The thing about flying into a hurricane is you go from the most wonderful weather into the worst weather you can imagine in a very short time, and you do that repeatedly. People ask me, "isn't it dangerous?" I describe a hurricane flight much like Winston Churchill's quote about war, it's "95% boredom and 5% sheer terror."

I encourage my numerical modeling partners to come on a flight so they can see what it takes to get the information that they need. Almost all of them step away from it with a different perspective. It's one thing to model something and think that if I change the diffusion, or the grid length, or this parameterization that it makes a difference. Then you go out and you see the real thing and you realize it's not that simple. I don't think there's been a flight I haven't learned something from.

The things you can see and the things you learn are incredible every time you go out there because they're rare events. I always describe them like people: They have a life cycle—They start out small; They're skinny; They get a little fatter; They go through evolution, lose some weight, gain some weight, and then they die. They're all different. They all have unique structures because they're in a four-dimensional fluid that's evolving. Timing in that evolution is so important because where the storm is in time and space is so critical to how it's going to evolve.

Airborne Doppler Radar

Besides the research questions, we were always using the field program to test new instrumentation all the time. In my second year at NHRL, we started working with Doppler radar technology on the aircraft. We worked with colleagues at NCAR and NSSL to Dopplerize the tail radar on the P-3 so that we could get Doppler velocity as well as reflectivity from the airborne radar systems. Dave Jorgenson and I were testing this new Doppler radar recording system. We started trying to get Doppler data sets in hurricanes and winter storms, but initially we had problems with the tape recorders dropping bits. Eventually we were successful during a winter storm mission off the coast of Washington state in early 1982.



Then the first tropical cyclone airborne Doppler radar data set was collected in strengthening tropical storm Debbie in the 1982 hurricane season that Bob Houze and I worked on. That started my real close collaboration with Bob. We analyzed the Debbie observation, and then in 1983 we managed to get a Doppler data set in Hurricane Alicia. That was the first time we'd gotten airborne Doppler radar observations in a hurricane that showed the three-dimensional structure of the storm, allowing us to not only characterize the radius-height structure but also characterize asymmetries in that structure. Prior to those observations, we couldn't say anything about the asymmetric structure of these storms. We were able to not only document the radius-height symmetric structure but also characterize the asymmetries and even the vortex tilt with height.

That was followed by airborne Doppler radar observations made in Hurricane Norbert in 1984 that started to highlight the importance of Doppler radar as a tool to look at the structure and evolution of hurricanes, as well as input into numerical models to improve the forecast. The collaboration with Bob Houze and his students was incredible. It changed the way we characterized the structure of tropical cyclones and its interactions with the changing environment. It set the stage for my career's pursuit of ensuring that the airborne

Doppler observations would be available to the operational, as well as, the research community to improve forecast guidance, something I'm very proud of today.

A satellite sees the central dense overcast, that big cloud shield that covers the inner core, but it does not see into the eyewall and rainbands. Because we flew in the storm and the radars could see the structure and evolution of the hurricane under what the satellites could observe, we worked very closely with the folks at National Environmental Satellite and Data Information Systems (NESDIS), Cooperative Institute for Research in the Atmosphere (CIRA), and Cooperative Institute for Meteorological Satellite Studies (CIMSS) who were doing all the satellite research on hurricanes. Those groups were close collaborators, using our airborne flight level and Doppler radar data to help improve the satellite estimates. It's been a great collaboration.

Non-hurricane Field Experiments

In the late 1980s and the early 1990s HRD was involved in a number of non-hurricane field experiments utilizing our knowledge and expertise with the NOAA P-3 aircraft and its unique instrumentation. I was able to participate in these field projects in a number of capacities bringing my expertise in the use of the unique instrumentation of the NOAA P-3 aircraft, particularly the airborne Doppler radar.

In the summer of 1985 HRD was involved in the Preliminary Regional Experiment for STORM (PRE-STORM), a U.S. Weather Research Program (USWRP) STormscale Operational and Research Meteorology (STORM) sponsored experiment in Oklahoma and Kansas to investigate the structure and dynamics of Mesoscale Convective Systems (MCSs). The focus of the experiment was to use NOAA P-3s and portable Doppler Radars to improve the forecast of the occurrence, strength, movement, duration, rainfall, and potential for severe weather of MCSs. I was involved in helping to set up and monitor the HRD portable ground-based radar recorders at the WSR-57 in Wichita, KS, while the P-3s were based in Oklahoma City, OK. During one of my visits to University of Oklahoma to work on a paper with my friend Prof. Howie Bluestein based on observations of the eye of Hurricane Diana (1984), I was able to go on a P-3 mission into an MCS with Ed Zipser and my former office mate Dave Jorgensen. I also had to go to Wichita to fix an issue with the HRD portable radar recorders and interacted with one of Bob Houze's students, Ed Rappaport, who was monitoring the portable recorder.

In the winter of 1986 a number of us were involved in the Genesis of Atlantic Lows Experiment (GALE) based out of Raleigh, NC utilizing the NOAA P-3s and our portable ground-based radar recording systems to study mesoscale and air-sea interaction processes in East Coast winter storms, with particular emphasis on their contributions to cyclogenesis. The radar recorders were set up at 2-3 WSR-57 radar sites in North Carolina and Virginia, while the P-3s were used to collect tail Doppler radar and dropsonde observation off the Mid-Atlantic Coast during intensive observing periods. During that experiment I benefited from interactions with my friends Profs. Lance Bosart and Kerry Emanuel. I was fortunate to meet and interact with Kerry's students, Chun-Chieh Wu, John Neilsen, and Peter Neilley.



In the winter of 1987 HRD was involved in the Equatorial Mesoscale EXperiment (EMEX) based in Darwin Australia that was designed to test one main hypothesis, that the net diabatic heating associated with the near equatorial convective cloud systems is the strongest in the upper troposphere. We utilized the NOAA P-3 airborne Doppler radars to map the vertical air motions and other kinematic properties of tropical mesoscale convective-cloud systems. EMEX was conducted over the tropical oceanic area north of Australia during the Southern Hemisphere (austral) summer, and was organized to coincide with two other major experimental programs being conducted in the region at the same time. The Australian Monsoon Experiment (AMEX) was a program of enhanced upper-air soundings and radar data collection in northern Australia providing an

excellent synoptic context for the convective and mesoscale measurements obtained in EMEX. The NASA Stratosphere-Troposphere Exchange Program (STEP) was conducted to obtain high-level aircraft measurements of trace chemicals, radiation, and other quantities above tropical convection in the region with the aim of understanding tropospheric-stratospheric interaction. My good friend and colleague Bob Houze and Dr. Peter Webster, whom I worked with during Winter MONEX, were leading the EMEX effort. I was fortunate to interact with a number of friends and colleagues, including Drs. Gary Barnes, Bill Frank, Greg Holland, Roger Smith, Graham Stevens, and Ed Zipser. I also was able to interact with a number of Houze's students, in particular Mike Biggerstaff, Dean Churchill, and Brian Mapes.

In July 1991 HRD and I were involved in two field experiments with the NOAA P-3 aircraft: the Convection and Precipitation/Electrification Experiment (CaPE) based at Cape Canaveral Florida; and the Tropical Experiment in Mexico (TEXMEX) based in Acapulco, Mexico. The CaPE experiment was a NASA, NSF and NCAR program to identify the relationships among kinematic, microphysical, and electric field properties within thunderstorms using observations collected by ground-based Doppler radars, aircraft, and electric field mills around the Kennedy Space Center. One NOAA P-3 was utilized to make airborne Doppler radar, microphysics and electric field observations within the thunderstorms, while the other aircraft sampled the boundary layer structure surrounding the thunderstorm. A secondary objective for the NOAA P-3 was to test a new tail Doppler radar antenna designed by France's Centre de Recherches en Physique de L'Environnement Terrestre et Planetaire (CRPE) that contained two phased array antennas mounted back to back enabling complete dual-Doppler coverage along the flight track. This antenna was a prototype for the NCAR Electra Doppler Radar (ELDORA) system. During the CAPE missions we collaborated with our NCAR, NASA, and university colleagues Drs. Gary Barnes, Roger Wakimoto, Jim Willson, Wen-Chau Lee, as well as, Drs. Jacques Testud and Frank Roux from CRPE on the new antenna evaluation.



During the same period in 1991 HRD and I were involved in TEXMEX missions utilizing the second P-3 to make airborne Doppler radar and dropsonde observations into disturbed areas over the eastern Pacific and measuring the atmosphere in the lower layers to examine the thermal and humidity structure of the near surface layer of the atmosphere in an attempt to relate elevated levels of high equivalent potential temperature air to tropical cyclogenesis. The P-3 tracked these disturbances until they were out of range or formed into organized tropical cyclones. During the TEXMEX missions we collaborated with Profs. Kerry Emanuel, Dave Raymond, Joe Zehnder, and a number of their students, particularly Marja Bister and Luis Farfan.

In the winter of 1992-93, I was involved in the Tropical Ocean – Global Atmosphere (TOGA) Coupled Ocean Atmosphere Response Experiment (COARE) based in Honiara, Guadalcanal in the Solomon Islands. TOGA COARE was the third largest international atmospheric field program, behind MONEX and GATE. The premise of the experiment was that the dynamic adjustment of the ocean in the tropics is far more rapid than at higher latitudes and, therefore, more closely in tune with the atmosphere. To gain a clear understanding of global climate change, the El Niño–Southern Oscillation (ENSO) phenomenon, and the intra-seasonal variability of the coupled atmosphere-ocean system, it was clear that a better specification of the coupling of the ocean and the atmosphere was required. An observational program was designed similar to the type used in the GATE Program (1974), where the consistency of in situ aircraft measurements were checked by the surrounding upper-air network, which provided estimates of gross budgets of moisture, heat, and momentum. Once

again I was fortunate to interact with a number of friends and colleagues, including Drs. Gary Barnes, Carl Friehe, Bob Houze, Dave Jorgensen, Peggy LeMone, Jim Moore, Dave Rogers, Brad Smull, and Ed Zipser. I also was able to interact with a number of Bob Houze's post docs and students, in particular Shuyi Chen, Brian Mapes, Sandy Yuter, and Chidong Zhang.

Tropical Rainfall Measurement Mission (TRMM)

Working with NASA collaborators during TOGA COARE I found out that they were interested in aircraft radar observations in tropical cyclones because they were planning to launch a satellite mission with an active radar system that could observe global rainfall, the Tropical Rain Measurement Mission (TRMM). NASA wanted to fly in a tropical cyclone because it would provide the whole spectrum of weather and precipitation from blue sky to the heaviest precipitation you can imagine as you fly into the core. These storms are also compact, enabling an aircraft to sample it and to observe the variability of precipitation, which is what TRMM was after. The TRMM satellite was launched in November 1997 and in 1998, we organized a joint experiment with NASA, the 3rd Convection and Moisture Experiment (CAMEX-3) to coincide with the annual HRD field program to collect radar and microphysics observations using the NOAA P-3s and NASA DC-8 missions as a means to calibrate the TRMM satellite rain estimates.



After that experiment, I was invited to a number of NASA sponsored conferences to discuss the observations collected from the NOAA aircraft radar systems. The first one I went to was a TRMM meeting in Paris that was focused on a review of what TRMM observed during the first year or so of operation. I went to this meeting in Paris and they started showing images from TRMM, and the first thing I noticed was images of a tropical cyclone. I said, huh, TRMM sees tropical cyclones and that image looked pretty interesting. Then another speaker got up and also showed an image of a tropical cyclone in his talk and I thought, oh, must be the same storm. No, it wasn't. It's another one. The next five or six talks also showed images of tropical cyclones, and I thought to myself, oh my god here's a tool that can observe tropical cyclones globally.

About a month later I ended up going to give a seminar at NASA, and after the talk, I went to see the TRMM chief scientist, Dr. Joanne Simpson, who I first met in GATE in 1974. She was an incredible scientist, one of the first women PhDs in meteorology, a pioneer in our field. Whenever I spoke to her about my tropical cyclone research she's always enthusiastic. I walked into her office, and I said, Joanne, you know, at these TRMM meetings, I was seeing a lot of tropical cyclones in the TRMM imagery. She responded excitedly, Oh, yeah, TRMM sees a lot of tropical cyclones. I said, "is anybody looking at them?" She said no, we need somebody to do that. I asked her that if I could get a grad student through my affiliation with the University of Miami and she would be interested in us looking at the TRMM tropical cyclones. She became really excited and said we should definitely do that. She said I needed to write a proposal to get a student. I said, okay.

The Joanne Simpson Tropical Meteorology Research Award



THE JOANNE SIMPSON
TROPICAL METEOROLOGY
RESEARCH AWARD
Frank Marks, Jr.



I went back to Miami and contacted my colleague, Prof. Shuyi Chen at University of Miami, and I told her that I could get a student for her to work on TRMM. She said sure, she would be definitely interested in getting a student to do that. So we went through a couple applicants and we found this young man, Manuel Lonfat, who was just perfect for the task and we brought him on to study the TRMM data. We wrote the proposal to NASA and managed to get a full proposal funded. The net result of that research was to use the TRMM observations of global tropical cyclones to derive a global climatology of tropical cyclone rainfall. Over the first three years the TRMM satellite observed 700 tropical systems of which ~250 were hurricanes that we used to develop this rainfall climatology. I think that it is still the best climatology I know of to characterize tropical cyclone rainfall. Manuel completed his PhD working on the TRMM rainfall climatology. It was incredible. And it was just serendipity again, walking into somebody's office and saying, hey, anybody looking at this, just having that curiosity. It's unbelievable.

Hurricane Hugo

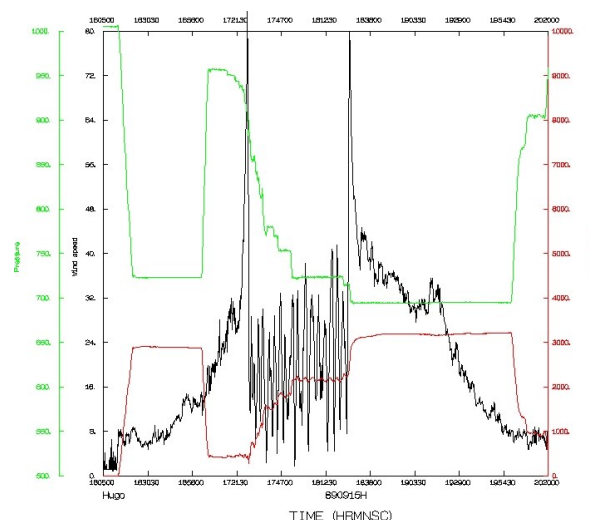
The thing about flying into a hurricane is you go from the most wonderful weather into the worst weather you can imagine in a very short time, and you do that repeatedly. People ask me, isn't it dangerous? I describe a hurricane flight much like Winston Churchill's quote about war, it's 95% boredom and 5% sheer terror.

The storm that made that clear to me was Hurricane Hugo in 1989. We were flying the two P-3s out of Barbados. The plan for the mission was one P-3 would map out the inner structure of the storm, the inner 100 kilometers or so, while the other P-3 mapped the immediate environment of the storm with dropsondes around the periphery. We tried to do this experiment for about two years to no avail as either the storm or an aircraft issue caused us to cancel the attempts but we were determined to try to do this experiment. On this attempt we made a tactical error. We altered the plan such that we would begin the mission with the inner core mapping at low altitude, 1500 feet into the storm. Our tactical error was moving this part of the pattern first, instead of nearer the end of the mission after we already reconnoitered the storm to make sure that it was safe to fly at low altitude.

It turned out the storm was a lot stronger than we anticipated, deepening rapidly for the six hours between our briefing and arriving at the storm. The wind speeds ramped up to 150 miles an hour. As we approached the storm the lower fuselage radar presentation suggested that this was a better organized storm than we'd thought. There was a small eye about 10 or 12 miles across and surrounded by very intense reflectivity.

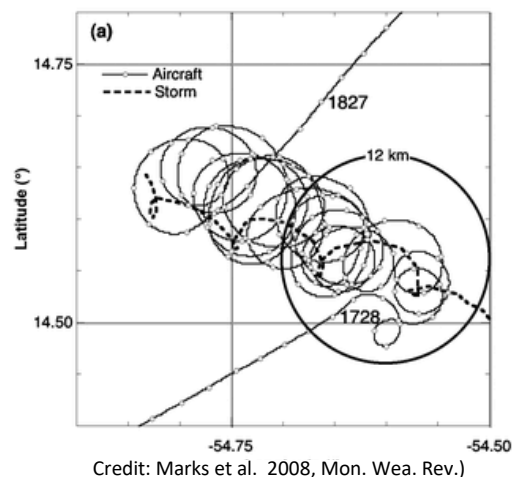
That is when Murphy hit us. The lower fuselage radar went down and we circled outside the storm to fix it. After 10-15 minutes the radar was back up and we continued our pattern at 1500 feet. As we're approaching the storm I was thinking this could be a rough penetration at 1500 feet, and I suggested to the pilots that if it got too rough we could climb up to 5,000 or 10,000 feet altitude if they wanted to. They said OK and decided to continue the penetration.

We ended up penetrating the most intense part of the eyewall. Within 30 seconds we hit three updrafts above 10 meters per second separated by two downdrafts of 10 meters per second and each one of the updrafts got stronger. At the end of the last updraft, just as we were breaking into the eye, somebody in the back of the plane says there's a flame coming out of engine number three. That is something you don't ever want to hear on an aircraft, particularly



as you break into the eyewall at low altitude. We were forced to shut down engine number three and almost all of the instruments so we could dump fuel to lighten the aircraft. We were in this magnificent giant stadium of clouds stretching up to 10-12 miles high, but nobody was looking at it. All we were looking at was the sea below us and trying to decide what to do next. I was sitting in the cockpit with the 2 pilots and a flight engineer, and we were focused on staying out of the eyewall. Our only option was to turn into the bad engine, and lose some lift. We decided to do a short loop to the right to get clear of the eyewall, and then start looping left to maintain lift while we assessed the situation. In the middle of the short loop to the right we lost lift and descended to about 1200 feet before we could turn to the left and start climbing in the eye. A number of the folks in the back were really anxious about our descent, thinking the worst. It wasn't until later that they realized it was a controlled descent.

We circled in the eye for about an hour, slowly climbing up to about 2500 feet and cleaning up the inside of the aircraft. An Air Force plane came into the eye and flew by our aircraft to make sure there



https://www.aoml.noaa.gov/hurricane_blog/25th-anniversary-of-a-hairy-hop-into-hurricane-hugo/

was no physical damage they could see. The other P-3 broke off their pattern and came into the eye to escort us out of the eye and back to Barbados.

The only thing that bothered me later was that we didn't turn the airborne Doppler radar back on as we were orbiting in the eye. However, the flight-level observations from that mission were incredible. It is probably the only example of a category five storm penetration with winds over 180 knot winds, and a greater than 40 kt updraft on record. The analysis of those observations was a labor of love, and I was elated when we finally got it published. I think it's fueled a lot of research ideas, like improving the HWRF model, and a number of studies of turbulent processes in hurricanes because that type of data is priceless. You can't get that type of data anymore because nobody's crazy enough to fly that low through category five anymore. We've tried different ways to do it since using uncrewed aerial and surface vehicles. However, we know experience makes good decisions, but you need to make mistakes to get experience. Our experience is based on those mistakes.

Operational Interactions

Interactions with NHC the first 20 years of my career were not as productive as I hoped. Their focus was communicating to the public what they needed to know to protect life and property, not necessarily to tell the detailed meteorological information. As scientists, we were intimately interested in the details, and all they focused on was the need to work with the preparedness folks who get these forecasts and make them wanted to do was to get the basics across to the public. They used everything they could get, and they used it to their ability to make a forecast.

The first NHC director I interacted with was Neil Frank. NHC was just struggling to do track forecasts when I started in 1980. Intensity forecasts were not the main priority. None of the track or intensity guidance was for more than two or three days out. There was a lot of changes going on, and I think Neil was smart when he focused on the need to work with the preparedness folks who get these forecasts and make them understand the potential impacts of a hazard like a hurricane.

The second NHC director I interacted with was Bob Sheets. Having been at NHRL for a number of years and running the hurricane field program, Bob knew what we did and the potential the research could have for operations. Bob would use anything we would give him, but he had his own ideas about how to use the data we provided. Our relationship with him was sometimes different in terms of research priorities. He definitely understood the benefits of the aircraft observations, like the dropsondes, on improved track prediction, which directly led to him proposing NOAA purchase a high-altitude aircraft for operational use - the G-IV.

After Bob Sheets stepped down as director in 1994, my former NHRL boss, Bob Burpee, became the NHC director. Working with Bob was easy as he led the field program from 1981-1992 and had been the HRD director from 1993-1995. Bob had championed many of the HRD research activities, particularly the synoptic-flow experiments that dramatically improved track predictions. He was a natural to step into the NHC director position. Unfortunately for Bob, beginning in 1995, hurricane activities in the Atlantic basin picked up dramatically, leading to increased pressure on NHC and less time for Bob to focus on transitioning our research to operations.

After Bob stepped down in 1997, Jerry Jarrell served as the NHC director until 2000. In 2000, Max Mayfield became the NHC director. Max was an old friend, and he really understood what we were doing and the potential value of the improvements we were making with the aircraft observations, particularly the stepped frequency microwave radiometer



(SFMR). That was a distinct transition in the attitude of the operational folks at NHC that Max initiated and is still true today. In fact, one of their division heads recently said to me that if NHC were a corporate entity, NHC would do a hostile takeover of HRD. It was that change over the decades, from “we just need the aircraft observations” to “we need your help.” That was fascinating to watch.



Getting the data back to NHC in real time was a challenge when I first started. All the data we collected was on magnetic tape, and we'd come off the plane with an armload of tapes. We'd take them back to the lab, and maybe two years later, we would get some meaningful result. So all NHC was seeing from our observations was just a minimal stream of observations that we could send back.

That changed in 2000 when I worked with Kevin Kelleher at NSSL to test broadband satellite communication on the P-3 to get more observations to NHC faster. Up until then, the only way we got data back from the P-3s to NHC was through an old geostationary satellite communication link that was 100 baud. The test worked great. It was costly at the time, but it worked so well that we put satellite receivers on the P-3s and G-IV and started being able to have larger and larger bandwidth transmission.

Now we have excellent satellite communication from P-3 and the data arrives at NHC and Environmental Modeling Center (EMC) within minutes after we collect it, including the Doppler analysis. The plane-to-ground data pipeline now is phenomenal. In my opinion, that's one of the many reasons why NHC is demanding more data from the NOAA aircraft.

Mentoring

One of my great joys while at HRD was working with students and postdocs who came to do an internship at the laboratory for a summer or a few years. They are always so enthusiastic and full of energy. I always looked for ways they could meld their experience and skills into the hurricane research arena, bringing a

diversity of new ideas that we could tap into. I always felt that they didn't need to have hurricane research experience, that we could teach them. I always looked to see how I could learn from their experiences and research ideas, and I believe I learned as much from them as they did from working with me and the rest of the HRD staff. The most memorable ones were Gus Alaka, Michael Bell, Dan Cecil, Xiaomin Chen, Levi Cowan, Jason Dunion, Pavlos Kollias, Wen-Chau Lee, Manuel Lonfat, Mike Montgomery, Shirley Murillo, Krishna Kishore Osuri, Sai Prashanth, Jon Poterjoy, Thiago Quirino, Paul Reasor, Rob Rogers, Frank Roux, Jason Sippel, Alka Tiwari, Jun Zhang, Xuejin Zhang, to name a few.



There are two things I learned in my research that I always stressed with students and postdocs. One, how do you define a center? Knowing where the storm is located is the most important characterization of the storm. If they say, "It's where the horizontal wind is zero," I say, "But at what altitude? The center location can change with height. What about the pressure center?"

How does wind shear impact the center definition? The second thing I mention is the track, or how that center location changes in time. There are 86,400 seconds in 24 hours. If you have a one-meter-per-second error in the motion of the storm, you will be off by 86.4 kilometers in 24 hours. That's about 50 nautical miles, currently our average 24-hour track error. That tells us that we're pretty darn good already at deducing the storm location. But how do we get down below that 86.4-kilometer error in 24 hours? That error compounds every 24 hours, adding to our forecast error spread.

HRD Director

After running the field program for nine years, I realized I wasn't getting a lot of research done, and HRD had a lot of young scientists doing great research with the data we collected. So, in 2002, after Hugh Willoughby stepped down as HRD director, the AOML director at the time, Kristina Katsaros asked me if I was interested in being the next director. She said I had a choice to make whether I wanted to drive the bus or to ride on the bus. She told me that if I don't want to drive the bus, somebody else is going to drive it, and you will need to do what they say. That made up my mind, and I applied for the HRD director position.

I became HRD Director in 2003, and I retired on August 1, 2023. Twenty years later, I think I probably didn't get into the ditch too many times driving the bus, but I got in the ditch a few times. It's been a great ride. I have a fantastic staff, a key thing you learn about when you're a director. When you're a researcher, it's about you, and then when you become a professor like you are or will be, it's about your group, colleagues, and collaborators. It's the same thing when you're a director of a division of scientists. It's about how I can facilitate them to be as productive as possible, how I can make opportunities for them like I had, how I can make it safe to interact and do all the things that I have to do to make it happen.



Working for the government is like being on a roller coaster every year. We start with zero dollars in our budget on October 1st. If we're lucky, we get guaranteed support the first few months to pay our staff, and then we hope for a budget to sustain the progress over the remainder of the year. Over the last few years, it's been a struggle, but we deal with it. I always looked at it like a roller coaster because you start with nothing, and then all of a sudden in June, you have money to spend

before September 30th when your budget has to be zero again.

It's an interesting way to work. Luckily, we have great collaborations with the University of Miami's cooperative institute that supports roughly half of our staff. That is great because you get to bring on great young people to work with. The struggle is you've got government employees and university employees. How do you juggle their wants and needs when your partner is in charge of them and you're in charge of yours, and you have to work together. That's always a challenge, but we've been fortunate to have great directors at the cooperative institute, and it's been a phenomenal collaboration.

When I started as director, I had a very young staff in the early stages of their careers. A number of our older staff went over to NHC, or went up to NWS offices in Washington. So we had to build an infrastructure to support their growth. Now, they're all at the point in their careers where any one of them could become HRD director. They have the science and leadership skillsets, and learned how to deal with others. It's a very different mindset. You learn that people matter. It's the gray matter between the ears, not the equipment that moves science forward.

Flying into storms is something I love to do. Now when I go, I'm going with younger staff who haven't had experience flying in storms. I'm trying to show them how to take advantage of a hundred-million-dollar aircraft with all the equipment on it. Be responsible. Learn how to execute, how to manage your time. You want to make the best use of that resource. It's a phenomenal resource.

There were times when I would have loved to be in the air, like in Katrina or Rita. But I decided I had other things to worry about, like getting new wings for P-3s. That's what I was doing when Hurricane Sandy was forming in 2012. I was up in Washington with NOAA leadership discussing the need to re-wing the P-3s to get the airborne Doppler radar and dropsonde data into the models to make the forecast better. I was trying to convince them that we needed to spend a hundred million dollars on new wings for the P-3s. Then Sandy happened. There was a disaster supplemental that provided the money for the new wings. Then we found out the Navy had spare P-3 wings already. We were able to get them for three million dollars and give the hundred million back.

Hurricane Forecast Improvement Project/Program (HFIP)

The idea behind HFIP began while I was in Guadalcanal with the P-3s in 1992-1993 during TOGA-COARE. My colleague, Rit Carbone, approached me with a proposition. He told me he was taking on a new position working for the US Weather Research Program (USWRP) to put together a research plan. He asked me if a research plan was needed to address hurricane issues and if I would be interested in spearheading it. I said definitely.

In 1997, Rit contacted me about leading a USWRP prospective development team (PDT) on hurricanes at landfall. I said sure. I pulled together a lot of my colleagues to develop a plan. We met at FSU in Tallahassee and spent three days drafting a plan that was published in the Bulletin of the AMS as the report of PDT-5 Hurricanes at Landfall. The plan laid out what observations and research needed to be done to address hurricane impacts at landfall, from wind, rain, surge, and severe weather. From that, we backed out the science objectives.

The report provided an impetus for us to put together a UCAR/ASP summer colloquium on hurricanes at landfall in 1998. I worked with Wen-Chau Lee and Bob Gall to organize the workshop. We spent one week in Boulder and one week in Miami. Our hope was to spin up



the new talents we needed to tackle the PDT-5 objectives through the students and postdocs attending the colloquium. We had a great group of young graduate students and postdocs, a number of whom are now the leaders in hurricane operations and research, such as Parks Camp, Dan Cecil, Jennifer Collins, Sytske Drury, Jason Dunion, Matt Eastin, Bob Hart, Daniel Jacob, Sharan Majumdar, Rebecca Morss, Shirley Murillo, Kevin Petty, Greg Postel, Paul Reasor, Rob Rogers, and John Schroeder to name a few.

We also put together a USWRP-sponsored workshop, wrote a summary report, and an implementation plan for USWRP and NOAA. Unfortunately, the only thing NOAA pushed forward from the implementation plan was the formation of the Joint Hurricane Testbed.

When I became HRD director in 2003, I felt we needed to bring the USWRP Hurricane at Landfall plan to fruition. I kept pushing it. Coincidentally, five storms hit Florida in 2004 hurricane season, Hurricanes Katrina, Rita, and Wilma made landfall in 2005. The NOAA Administrator at the time put a working group together to make recommendations on how NOAA could do better forecasting intensity of storms as well as track them. That working group was phenomenal. They prepared a report with 34 recommendations on what NOAA should do to improve hurricane intensity forecasts.

I volunteered to help develop a plan to address all 34 recommendations, and that plan became the Hurricane Forecast Improvement Project (HFIP) in 2007. The HFIP plan was focused on developing the best hurricane forecast model, but I didn't know much about models. However, HRD had good people who could help. The operational numerical models used to predict hurricanes at the time was the Hurricane Weather Research and Forecast (HWRF) model. HWRF was built on the Weather Research and Forecasting (WRF) developed by the research community and run through NCAR. HWRF used a different model core developed at the NWS and



2007 HFIP management team (Upper row: Fred Toepfer, Bob Gall, Rick Spinrad, and Jack Hayes; Low row : Louis Uccellini, Scott Rayder, Ed Rappaport, and Frank Marks)

was not readily available to the research community. So there was a lot of friction going on at that time between the NWS and the research community over the best way forward. NWS adapted WRF to run on their high-performance computers using a different dynamical core that ran faster than the NCAR version so that it could produce a product in ninety minutes every six hours. How to develop a research infrastructure to accelerate the new hurricane model development became the struggle. Could HWRF be made available to run on research high-performance computers, making NWS code with the dynamical core and physics available to the research community to use? The alternative was to replace HWRF with some flavor of WRF, which was open source to the research community. This proved to be HFIP's first hurdle. We had to develop a strategy to help us decide which path to take.

We asked NHC to give us 69 cases to use for a test. We had the first HFIP workshop, inviting a number of the research and operational hurricane modelers. We proposed to provide the 69 cases to anybody who wanted to run their model and produce results over the next year using whatever configuration they wanted. We judged all volunteered simulations for the 69 cases on a level playing field using the statistics package NHC ran for all the models they used. When we met a year later to talk about it, the results of the test suggested that it didn't matter which model we chose to use as they were all not so good. I even remember the hurricane specialist who selected the 69 cases got up and said if he'd known all the models were this bad, he would have given us easier cases. Given the test results, we decided to focus our efforts on improving HWRF.

HFIP started with HRD support in 2008 and received the first NWS budget in 2009 through a presidential supplemental after Hurricanes Gustav and Ike made significant U.S. landfalls in 2008. We used the support to start our path down the road of building an infrastructure and capacity to do this kind of accelerated research. Our goals were to improve forecast guidance for track and intensity by 50% in 10 years and by 20% in five years. We were given roughly twenty million dollars a year to do that, of which four or five million dollars went to building the infrastructure for the high-performance computing needed. We set up a high-performance computer complex at a NOAA laboratory in Boulder and we converted all the HWRF code so it could run on any computer infrastructure available. We used the Developmental Testbed Center, which was a joint effort between NOAA and NCAR, to support the infrastructure and to train researchers to use HWRF. We held annual workshops on how to use the model. I told my boss, Bob Atlas, that we couldn't have HFIP without HRD involvement. He agreed, and we told NWS that AOML was committing HRD's base resources to HFIP to focus on the research aspects of the plan. I became the research lead, and Bob Gall and Fred Toepfer were the project and development leads. Ed Rappaport, the NHC deputy director, was the operational lead. Some of the research was externally funded by the NWS HFIP support, primarily for collaborators we brought to the table.



HRD had access to the NOAA aircraft and researchers who developed and ran HWRF. We started working closely with the NWS/EMC, who maintained HWRF and developed the infrastructure and manpower capacity to actually do the work we set out to do.

I'd say the key to HFIP was that we had clear operational goals that NWS and NHC wanted us to do. It wasn't like we're going to study secondary eyewall replacement cycles or to study rain bands. How do we improve the track? How do we improve the intensity? Of course, you've got to do all those other things that get there because you have to make sure the model does them with some fidelity.

So that's where the observations came in. The observations became the key because EMC and GFDL were not observationalists. They didn't have their roots in the data. They trusted the best track information for their evaluations of the model. However, the Best Track is just the best estimate NHC can put together with the limited observations they used. We worked hard together to change the developmental mindset to work as a team rather than modelers doing the modeling and we do the observations and we'll figure it out. We actually merged the teams together and focused them on specific projects and brought our collaborators in-to funding opportunities.

My best collaborator story is about Prof. Fuqing Zhang. Fuqing was a colleague who I had met in the mid-early 2000s when he was at Texas A&M. He picked my brain about how to use Doppler radar to initialize hurricane models. He was a data assimilation expert with a great bunch of students and he wanted to know how we could use the airborne Doppler radar to improve the initial analysis for the model.

In 2008, Fuqing decided to leave Texas A&M to move to the Pennsylvania State University (Penn State), and he spent the month of July in Miami during his transition. Right at the beginning of his visit, I got a call from Fred Toepfer, who was the HFIP project manager at the time. He found out that NSF has a new computer

coming online in Texas called the Texas Advanced Computer Complex (TACC), and they wanted HFIP to test it out to see what it can do. NSF was willing to provide NOAA and HFIP a million CPU hours on TACC over 6 months to test our hurricane models. He asked me to provide a list of objectives we could tackle with the TACC resources. When Fuqing walked into HRD, I told him that we just received a million CPU hours on TACC. I asked him to think of some ways we could use those resources to improve model forecasts. Fuqing said we could use the resources to run 100 high-resolution hurricane model ensembles to look at predictability improvements. I told Fred what we thought we could use the resource for, and he approved the idea.

Fuqing's original idea for coming to HRD for a month was how to get the airborne Doppler data automatically off the plane and into the hurricane model. He was already working with HRD staff on automating the air-



borne Doppler radar data quality control and processing to get it through the satellite communications pipeline to the ground. Fuqing was familiar with and ran a WRF ensemble model to improve the data assimilation for his hurricane work, and it was already available on TACC. So we altered the tests on TACC to focus on running the WRF hurricane model with Fuqing's data assimilation system to use any airborne Doppler radar data we could get to TACC to evaluate the utility of that data to improve the WRF hurricane model forecast guidance.

By the time Fuqing left HRD four weeks later, we had a working prototype of the data transmission and assimilation ready for when the next storm occurred. In mid-August, tropical storm Fay approached and made landfall in Florida. We were able to control the airborne Doppler radar data quality and process it automatically through the satellite communications pipeline. Fuqing had the WRF hurricane model and data assimilation system tested and running on TACC and was able to produce a forecast. A few weeks later, Hurricane Gustav entered the Gulf of Mexico headed for the panhandle of Florida. This time Fuqing flew on the P-3 with us, and we got the airborne Doppler radar through to TACC in almost real-time, producing model guidance.

Two weeks later, Hurricane Ike passed into the Gulf and was headed right at Texas. As you can imagine, the TACC folks were freaking out because here's a storm heading right at Texas. They're in Austin, but it's headed at Texas. Having Fuqing's model running on TACC in near real-time using the P-3 airborne Doppler radar data NOAA was collecting in the storm was a real coup for Fuqing, HFIP, and TACC. We produced model output that they could visualize at TACC. Needless to say, Fuqing never had to ask TACC for any CPU time after that because it made such a press opportunity for TACC that, to this day, I still get notices from TACC about new developments and opportunities for collaboration.

The amazing thing about Fuqing was that he stuck with it. He was a professor and researcher at Penn State. He was teaching and advising students, and yet he was working his tail off with HRD, HFIP, and NOAA. He was running his model in real time on the HFIP-developed high-performance computing infrastructure that HFIP set up in Boulder. He told me that the one thing he learned was that doing operations is hard. You can't fail. Everything has to work every six hours. He told me he learned so much from that experience.

Fuqing passed that on to his students, and a lot of his students are working in HRD and EMC and are still working within HFIP. It's been an interesting transition from research to operations and how that works. It's just been so fortuitous to know people who have helped make this happen. HFIP is a success because of them, not because of me.

At the end of 10 years, we were able to continue HFIP thanks to the Weather Forecasting and Research Improvement Act in 2017 that directed NOAA to continue HFIP. We're in our second 10-year window that is focused on the implementation of the new-generation operational hurricane model, the Hurricane Analysis and Forecast System (HAFS).

Conclusion

NOAA and HFIP are pushing to make communicating the risks from impacts better. One of the things that the Weather Act instructed HFIP to address is communication of uncertainty of the risk of hazards. So we're now partnering with social, behavioral, and economic researchers, just like the climate community is, to try and figure out how to best communicate the risks from the natural hazards.

I live in hurricane alley. I've been on the ground in a number of storms. I went through Andrew in 1992 and had damage to my home. I have family along the west coast of Florida. I know what the impacts are. So that's always in the back of your mind. How bad is it going to be?

I always say that climate is local. My climate is different from the climate in New York City. My impacts are going to be different. Right now, climate science is focused on the big picture. We're starting to try to figure out how to scale it down to local impacts. That's why I feel climate is so important, but making sure that we can deal with the local impacts is also important. That's where I think we're going in NOAA in the future, getting down to the local level. How to deal with the uncertainty of it. How do you deal with that?

I feel I accomplished something in my career that I think is useful and beneficial to the country and the society. To go from plotting circuit A and circuit C on the little maps in our high school classroom to where I am today, it blows my mind to look back at the arc of it all. It's certainly been enjoyable most of the time. Certainly, I've forgotten all the bad stuff. It's been a joyful struggle. I've been fortunate to stand on the

shoulders of giants, the Austin's, Bosart's, Burpee's, Emanuel's, Carbone's, Gray's, Houze's, Ooyama's, Reed's, Rosenthal's, Sanders', Simpsons', Zipser's, and more.

When I talk with people about my career, I just say I was in the right place at the right time. I was lucky. I'm a firm believer in serendipity, that you make your luck. I always tell students and postdocs that you need to take chances. Don't be afraid to take a chance. You never know what's going to happen. It's an opportunity to push yourself to stretch yourself to learn something new. Sure, there was a lot of anxiety going on in between all those different wonderful things that happened to me in my career. Life is full of twists and turns, and you just have to kind of go along for the ride. What I'm trying to say is while I was doing it, it just seemed like one continuous race from one thing to the next.



Curriculum Vita

Frank D. Marks, Jr.

Education:

Belknap College	Meteorology	B.S.	1973
Massachusetts Institute of Technology	Meteorology	M.S.	1975
Massachusetts Institute of Technology	Meteorology	Sc.D.	1981

Professional Experience:

Meteorologist	7/1975 to 7/1976
Center for Experiment Design and Data Analysis	
NOAA/Environmental Data Service, Washington, DC	
Research Meteorologist	7/1980 to present
Director of NOAA/AOML/Hurricane Research Division	2/2003 to 7/2023

Field Program Experience:

1980-present	NOAA Hurricane Field Program (>360 missions in tropical cyclones)
1993-2002	HFP Director
1992-93	TOGA COARE (Solomon Islands)
1991	Convection and Precipitation Experiment (Florida)
1991	Tropical Experiment in Mexico (Acapulco, Mexico)
1987	Equatorial Mesoscale Experiment (Australia)
1986	Genesis of Atlantic Lows Experiment (North Carolina)
1985	Preliminary Regional Experiment for STORM-Central (Kansas)
1978-79	Winter Monsoon Experiment (Malaysia)
1974	GATE (Africa)

Honors and Awards:

2022	National Tropical Weather Conference William M. Gray Award
2021	AMS Joanne Simpson Tropical Meteorology Research Award
2018	NOAA/OAR Dr. Daniel L. Albritton Outstanding Science Communicator Award
2015	U.S. Department of Commerce Gold Medal for developing and implementing the high-resolution HWRF model (group)
2014	AMS Banner I. Miller Award (with Fuqing Zhang, Yonghui Weng, and John Gamache)
2012	NOAA Administrator's Award for outstanding management of the G-IV Tail Doppler Radar (group)
2011	2010 NOAA/OAR Outstanding Scientific Paper Award for Weather and Water
2011	AMS Verner E. Suomi Award
2010	NOAA Distinguished Career Award
2008	NOAA Research Employee of the Year
2007	NOAA Bronze Medal for Hurricane Research Division Performance during Hurricanes Rita and Katrina (group)
2005	NOAA Administrator's Award for establishing and administering the Joint Hurricane Testbed (group)
2005	OFCM Richard H. Hagemeyer Award at the 59 th Interdepartmental Hurricane Conference
2005	USWRP Joint Hurricane Testbed Outstanding Contributor Award
2003	NOAA Diversity Council Spectrum Achievement Award for Managers
2001	NOAA TECH 2002 award for best wireless application for development of satellite-cell based WLAN for NOAA WP-3D aircraft (group award)
1997	US Department of Commerce Silver Medal for performance as the Research Mission Manager for the NOAA High Altitude Jet procurement

- 1992 US Department of Commerce Gold Medal for Hurricane Research Division's Performance in Hurricane Andrew (group award)
- 1989 Distinguished Authorship Award, NOAA, Environmental Research Laboratories

AMS Activities:

- 2026-2027 Member, AMS STAC Committee on Tropical Meteorology and Tropical Cyclones
- 2025-2026 Member, AMS Oceanographic Research Awards Committee
- 2020-2023 Member, AMS Atmospheric Research Awards Committee (chair 2022-2023)
- 2013-2016 Councilor, American Meteorological Society
- 2000-present Fellow, American Meteorological Society
- 1984-1991 Committee on Radar Meteorology, American Meteorological Society (Chairman 1987-1991)
- 1980-present member, Greater Miami Chapter of the American Meteorological Society (secretary 1981, chairman 1982)
- 1973-present member, American Meteorological Society
- 1971-1973 student member, American Meteorological Society

Professional Activities:

- 2022-present Member, Sigma Xi
- 2021-present Member, American Association for the Advancement of Science (AAAS)
- 2020-2022 Editorial Committee, MAUSAM, Quarterly Journal of Meteorology, Hydrology, and Geophysics
- 2015-present Editorial Board, Tropical Cyclone Research and Review
- 2015-2020 NCAR EOL Airborne Phased Array Radar (APAR) Advisory Committee
- 2011-2012 NOAA Service Assessment Team for Hurricane Irene 2011, (Co-lead)
- 2010-2012 Review Team for NASA Earth Venture–1 Investigation: Hurricane and Severe Storm Sentinel (HS3)
- 2008-2017 Working Group for Tropical Cyclone Research (WG/TCR) for the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM), (Co-chairman)
- 2007-present NOAA Hurricane Forecast Improvement Program, (Research Lead)
- 2006 Guest Associate Editor, Special Issue on CAMEX, Journal of Atmospheric Science
- 2005-2007 Tropical Cyclone Joint Action Group (TC/JAG) for the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM), (Co-chairman)
- 2005-2014 NCAR EOL External Advisory Committee
- 2004 NOAA/National Weather Service Executive Leadership Seminar
- 2003-2012 NOAA G-IV tail Doppler radar procurement, (Research Mission Manager)
- 2001-2005 USWRP Joint Hurricane Testbed Steering Committee
- 1999-2008 NASA TRMM (Precipitation) Science Team
- 1999 Committee for NASA/GSFC Mesoscale Atmospheric Processes Branch
- 1998 UCAR Advanced Study Program (ASP) Summer Colloquium on Hurricanes at Landfall (co-organizer)
- 1997 USWRP Landfalling Hurricanes Workshop Organizing Team (Co-Chairman)
- 1996 USWRP Prospectus Development Team #5: Landfalling tropical cyclones, (Co-Chairman)
- 1996-2001 North American Atmospheric Observing System (NAOS), Test and Evaluation Working Group
- 1996 NSF Review panel for NCAR's Atmospheric Technology Division, (Chairman)
- 1995 Committee of Visitors, Review of the NSF Division of Atmospheric Sciences' Lower Atmospheric Research Section
- 1993-1997 NOAA mid-size jet procurement, (Research Mission Manager)
- 1992-1994 Observing Facility Advisory Panel, NCAR/ATD (Chairman 1994)

Significant Publications

Marks, F. D., P. G. Black, M. T. Montgomery, and R. W. Burpee, 2008: Structure of the eye and eyewall of Hurricane Hugo (1989). *Mon. Wea. Rev.*, 136, 1237-1259.

Marks, F. D., and L. K. Shay, 1998: Landfalling tropical cyclones: Forecast problems and associated research opportunities. Report of the Fifth Prospectus Development Team to the U.S. Weather Research Program. *Bull. Amer. Meteor. Soc.*, 79, 305-323.

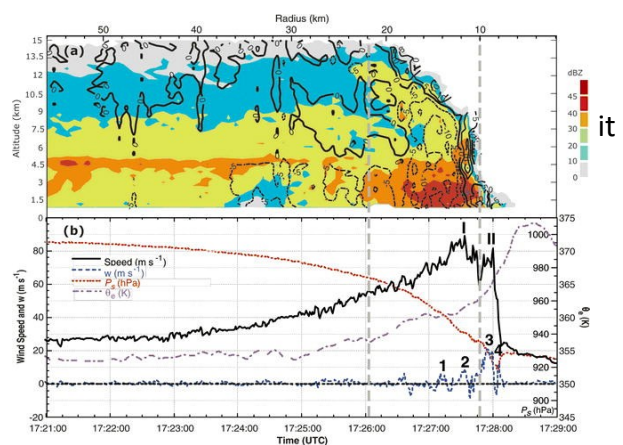
Marks, F. D., R. A. Houze, and J. F. Gamache, 1992: Dual-Aircraft investigation of the inner core of Hurricane Norbert: Part I: Kinematic structure. *J. Atmos. Sci.*, 49, 919-942.

Marks, F. D., and R. A. Houze, 1987: Inner core structure of Hurricane Alicia from airborne Doppler radar observations. *J. Atmos. Sci.*, 44, 1296-1317.

Marks, F. D., and R. A. Houze, 1984: Airborne Doppler radar observations in Hurricane Debby. *Bull. Amer. Meteor. Soc.*, 65, 569-582.

(Frank D. Marks had authored or co-authored 157 scientific articles so far and still counting.)

“On 15 September 1989, one of NOAA’s WP-3D research aircraft, N42RF [lower aircraft (LA)], penetrated the eyewall of Hurricane Hugo. The aircraft had an engine fail in severe turbulence while passing the radius of maximum wind and before entering the eye at 450-m altitude. After the aircraft returned to controlled flight within the 7-km radius eye, gained altitude gradually as it orbited in the eye. Observations taken during this period provide an updated model of the inner-core structure of an intense hurricane and suggest that LA penetrated an intense cyclonic vorticity maximum adjacent to the strongest convection in the eyewall [eyewall vorticity maximum (EVM)]. This EVM was distinct from the vortex-scale cyclonic circulation observed to orbit within the eye three times during the 1 h that LA circled in the eye. At the time, Hugo had been deepening rapidly for 12 h. The maximum flight-level tangential wind was 89 m s^{-1} at a radius of 12.5 km; however, the primary vortex peak tangential wind, derived from a 100-s filter of the flight-level data, was estimated to be 70 m s^{-1} , also at 12.5-km radius.” (Credit: Marks et al. 2008, *Mon. Wea. Rev.*)



Podcasts

Deep Convection (2023): Episode 10 - Frank Marks doi: <https://lnns.co/k9seiYtM7nA>

Weatherbrains (2022): Episode 864: Just Kids Solving Laplacian doi: <https://weatherbrains.com/?p=10065>

ideaXme (2020): Hurricanes: Evolution, Risk Reduction, Tracking and Simulation doi: <https://radioideaxme.com/2020/11/06/hurricanes-evolution-risk-reduction-tracking-and-advanced-science-of-hurricane-simulation/>

Design Safe Radio (2017): Episode 20 - Legends Of Hurricane Hunting Part 2 doi: <https://podcasts.apple.com/us/podcast/episode-20-legends-of-hurricane-hunting-part-2/id1267927535?i=1000397358405>

Design Safe Radio (2017): Episode 19 - Legendary Hurricane Hunter Frank Marks doi: <https://podcasts.apple.com/us/podcast/episode-19-legendary-hurricane-hunter-frank-marks/id1267927535?i=1000396786674>

AMS Annual Meeting (2011): Frank Marks: 2011 Verner E. Suomi Award doi: <https://youtu.be/zvvHurXKfoA?feature=shared>

Weatherbrains (2008): Episode 139: Dr. Marks Marks the Spot doi: <https://weatherbrains.com/?p=110>

PhD Student Theses committees:

Alka Tiwari (Keith Cherkauer), Purdue University, 2024
Jie Chen (Dan Chavas), Purdue University, 2021
George Bartuska (Lloyd Fernald), Orlando University, 2021
Sai Prashanth Bhalachandran (Dan Chavas), Purdue University, 2018
Jason Dunion (Chris Thorncroft), University of Albany, SUNY, 2016
Alanka Sravani (S. S. V. S. Rama Krishna), Andhra University, 2016
Krishna Kishore Osuri (S. S. V. S. Rama Krishna), Andhra University, 2012
Thiago Quirino, (Miroslav Kubat), University of Miami/ECE, 2012
Aurelie Bouchard (Jacques Testud), University Paris VI - Pierre et Marie Curie, 2007
Eyad Atallah (Lance Bosart), University of Albany, SUNY, 2006
Sylvie Lorsolo (John Schroeder), Texas Tech University, 2006
Manuel Lonfat (Shuyi Chen), University of Miami/RSMAS, 2004
Stephane Oury (Jacques Testud), University Paris VII - Denis Diderot, 2000
Pavlos Kollias (Bruce Albrecht), University of Miami/RSMAS, 2000
Paul Reasor (Michael Montgomery), Colorado State University, 2000
Daniel Cecil (Ed Zipser), Texas A&M University, 2000
Sam Houston (Gary Barnes), University of Hawaii, 1999
Nicolas Viltard (Jacques Testud), University Paris VII - Denis Diderot, 1995

MS Student Theses committees:

Ashvin Namboodiri (Brian Soden), University of Miami/RSMAS, 2023
Andrew Wyatt Smith (Shuyi Chen), University of Miami/RSMAS, 2016
Mike Jankulak (Mei-Ling Shyu), University of Miami/ECE, 2012
Monica Laureano (Dev Niyogi), Purdue University, 2009
Peter Kozich (Shuyi Chen), University of Miami/RSMAS, 2007
Shirley Murillo (Gary Barnes), University of Hawaii, 2006
John Cangialosi (Shuyi Chen), University of Miami/RSMAS, 2006
Michael Bell (Wen-Chau Lee), Colorado State University, 2006
William Maxham (Paul Ruscher), Florida State University, 2004
Guojun Gu (Shuyi Chen), University of Miami/RSMAS, 1998
Chris Samsury (Ed Zipser), Texas A&M University, 1992

Post docs:

Lakemariam Worku, 2020
Levi Cowan, 2020
Xiaomin Chen, 2017
Jonathan Poterjoy, 2016
Hua Chen, 2009
Sylvie Lorsolo, 2009
Jun Zhang, 2008
Alex Fierro, 2008
Paul Reasor, 2000
Nick Viltard, 1996
Frank Roux, 1991
Wen-Chau Lee, 1989

1.1 Uncle Frank and Airborne Dual-Doppler Radar

Robert A. Houze
Univ. of Washington, Seattle, WA

Frank Marks and I came out of Polly Austin's MIT Weather Radar Project in the early 1970s. We participated in GATE (1974), taking the first shipborne digital radar data in the tropics, leading to a quantitative understanding of the role of mesoscale convective systems (MCSs) in tropical oceanic rainfall. In 1978, we designed a radar field project in Winter MONEX that led to knowledge of how MCSs affect the diurnal cycle of convection over the Maritime Continent. In the mid 1980s, we pioneered airborne dual-Doppler radar measurements in Tropical Storm Debby (1982), Hurricane Alicia (1983), Hurricane Norbert (1984). Those flights led to papers on the dynamics, microphysics of hurricanes. Frank and I spent so much time together writing those papers that he became known to my daughters as "Uncle Frank." In 1987, we brought the NOAA P3 dual-Doppler system to the EMEX project to document MCSs in the Australian Monsoon. In 1991, we obtained airborne dual Doppler observations in the CaPE project. Those data led to statistics of the air motions in Florida sea breeze convection using two-dimensional probability distributions (known colloquially as CFADs). In 1992, we brought two NOAA P3 dual Doppler systems to the Solomon Islands and documented the vertical profiles of divergence and overall airflow patterns in MCSs over the western tropical Pacific warm pool. Those data revolutionized the concept of how MCSs feedback to the large-scale environment via conservation of potential vorticity. In the early 2000s, Frank helped Shuyi Chen and me design the RAINEX project, which obtained dual-Doppler radar data in Hurricanes, Katrina, Rita, and Ophelia in 2005. Those flights led to fresh insight into hurricane rainbands and eyewall replacement.



1.2 Application of the Rotating Convection Paradigm to the Problem of a Tropical Cyclone In a Uniform Environmental Flow

Michael T. Montgomery, R. Smith, and J. Persing
NPS, Monterey, CA

Over the last decade Roger Smith and I have developed a robust conceptual model of tropical cyclone evolution. The model is based on fundamental physical principles and unrestricted to axially-symmetric dynamics of convective rings. It is unrestricted also to ad-hoc geometric assumptions with tacit sources of cyclonic absolute angular momentum. In this talk I will summarize some of our recent work with John Persing that re-examines the dynamics of tropical cyclone intensification in a uniform flow. This problem is a critical benchmark because it represents a natural first step towards an improved dynamical understanding of the asymmetric and symmetric spin-up dynamics within an environmental flow with deep vertical-shear.

Complementing an earlier study by Thomsen et al., a comparison of the simulated updraft structure with that predicted by Shapiro's asymmetric boundary layer theory for a translating vortex suggests strongly that, while the surface moisture fluxes



act to maintain deep convection in the near-core region of the moving vortex, the asymmetric pattern of this convection is primarily frictionally controlled rather than by surface enthalpy fluxes. An analysis of three idealized, three-dimensional, numerical simulations with and without a uniform flow has revealed a number of interesting and important differences in the evolution of the simulated vortex. Several analysis techniques are presented and interpreted including a comparison of ventilation diagnostics for the simulations, the role of eddy processes, and a novel sector partitioning method that serves to extend the classical axisymmetric spin-up ideas to an intrinsically asymmetric flow. The latter analysis highlights asymmetric features of the spin-up process in which the storm-relative tangential velocity is amplified in the main updraught sector by the strong inward flux of absolute vorticity in the lower troposphere there. This vorticity is subsequently transported into the remaining sectors by the tangential circulation, where there is a weak outward vorticity flux that alone would lead to spin down. This geometrical feature broadly explains why there is a weaker spin up rate in the presence of storm translation.

Time permitting, some implications of this work will be discussed.

1.3 - Future Direction For Hurricane Research

Frank D. Marks Jr. and Ghassan Alaka Jr.
AOML, Miami, FL

In response to the 2017 Weather Research and Forecasting Innovation Act NOAA developed a plan detailing the specific research, development, and technology transfer activities to address the Act's three main objectives: 1) improving the prediction of intensity and track of TCs; 2) improving the forecast and communication of surges from TCs; and 3) incorporating risk communication research to create more effective watch and warning products. The plan outlined the key research strategies to improve tropical cyclone (TC) forecast guidance. However, the current forecast products, metrics, and verification fall short of those needed to meet the goals outlined in the plan. Future TC research objectives must focus on resiliency from TCs by addressing impacts from hurricanes (e.g., wind, surge, inland flooding, severe weather) and incorporate risk communication research to create more effective TC products. More research is needed to improve probabilistic hazard guidance by utilizing machine learning to consider uncertainty of track, intensity, and structure for each storm. Finally, there is a need to support social and behavioral science research to improve the communication of risk and uncertainty for emergency managers and the public through more effective TC products. Future research opportunities should transform TC hazard guidance by blending social and behavioral science with physical science research and development.



5D.1 An Overview of NOAA's Hurricane Field Program: 2025 Review & Priorities for 2026 and Beyond

Ghassan J. Alaka Jr., J. A. Sippel, J. P. Dunion, and H. Holbach
NOAA/AOML/HRD, Miami, FL

NOAA's Hurricane Field Program (HFP), which supports the "Advancing the Prediction of Hurricanes Experiment (APHEX)", has been gathering observations of tropical cyclones (TCs) for over 40 years. The program is a multi-agency collaboration in NOAA between the Hurricane Research Division (HRD) at the Atlantic Oceanographic and Meteorological Laboratory, the Aircraft Operations Center (AOC) at the Office of Marine and Aviation Operations, and the National Weather Service (NWS), particularly the National Hurricane Center and the Environmental Modeling Center. HRD spearheads the effort, AOC operates WP-3D and Gulfstream IV-SP Hurricane Hunter aircraft, and NWS uses the data to issue operational TC forecasts. The fundamental goals of APHEX aim to improve TC forecasts through an integrated approach: 1) by collecting observations that span the entire TC life cycle, 2) by developing measurement strategies and technologies, and 3) by improving understanding of physical processes. APHEX goals are achieved by analyzing aircraft observations, utilizing this data for initializing and evaluating forecast models, and developing novel observing systems to address observational gaps and maximize data impacts.



This presentation will comprehensively review HFP's activities during the 2025 hurricane season, highlighting recent advancements and contributions toward an enhanced understanding and prediction of TCs. Specifically, we will discuss how NOAA APHEX addressed high-priority forecast challenges, summarize recent collaborative initiatives, detail advancements in observing systems and the assimilation of aircraft data into operational models, and emphasize pivotal progress in comprehending TC processes, particularly those important to predict rapid intensification. The discussion will conclude by evaluating NOAA APHEX strategic priorities for the 2026 hurricane season and beyond.

5D.2 Title: North Pacific (“Rock Star”) Tropical Cyclone Lionrock (2016) Revisited: The Many “Flavors” of a Long-lived North Pacific Tropical Cyclone

Lance F. Bosart
University at Albany, Albany, NY

Four tropical cyclones (TCs; Kompasu, Mindulle, Lionrock and TD-14W) developed from cyclonic vortices embedded in a broad monsoon gyre located over the subtropical western North Pacific in mid-August 2016. TC Lionrock was especially noteworthy because: (1) it was an intense cyclone that formed on 19–20 August southeast of Japan via the tropical transition (TT) process, a pathway that is less common in the western North Pacific as compared to the North Atlantic basin, and (2) the storm underwent multiple interactions with TCs Mindulle, Kompasu, and TD-14W that had a significant impact on its track. TC Lionrock subsequently moved south-westward well east of Taiwan as it engaged in a “Fujiwhara-like” cyclonic rotation with TCs Kompasu and Mindulle, as well as TD-14W farther to the east.

TC Lionrock’s ET was noteworthy because the storm made a TC Sandy (2012)-like “left hook” towards Japan as it underwent ET. TC Lionrock’s ET culminated in multiple extreme rainfall events that included a predecessor rain event (PRE) and devastating flooding over parts of eastern Asia in late August 2016. TC Lionrock’s remarkable life cycle from its initial formation by the TT process to its concluding strong ET and accompanying “left hook” toward Japan presents several science opportunities. These opportunities include: (1) investigating the structure and evolution of monsoon gyre formation and the resulting multiple TC interactions within this gyre, (2) documenting the ET of TC Lionrock and its role in observed extreme precipitation events including the aforementioned PRE over eastern Asia, and (3) determining the cumulative downstream impacts of multiple TC-TC, TC-gyre, and TC-baroclinic trough interactions that culminated in the strong ET of TC Lionrock.



5D.3 Dual-Doppler Analysis of Tropical Cyclones at AOML/HRD

John Gamache and P. D. Reasor
AOML/HRD, Miami, FL

Dr. Marks began working at HRD shortly before airborne Doppler radar analyses were done in tropical cyclones. Thanks to his and others' guidance in the development of a series of improvements in the airborne Doppler radar(s) on the NOAA WP-3D and G-IV aircraft, we at the AOML Hurricane Research Division were able to produce three-dimensional (3D) analyses of winds, beginning with Hurricane Debby in 1982, and much improved ones since. A vertical cross-section of vertical wind was developed for Hurricane Alicia in 1983, and those analyses have evolved now to cross-sections of all three wind components.

Since 1982, the data collection and analysis have evolved. During early flights until around 1990, the radar swept in vertical scans in a plane normal to the flight track. The 3D wind analyses required two radar observations plus the mass-continuity constraint. Thus, to obtain analyses, the WP-3D would fly two (generally) orthogonal flight legs, and then with the mass-continuity equation a 3D wind field was produced. This method of obtaining winds was known as the pseudo-dual Doppler method. The solution was an iterative process starting with the assumption of zero vertical wind. There were two issues with the resulting analyses. The iterative solutions became unstable in regions where a Doppler observation had an earth elevation angle greater than 45 or less than -45 degrees. The method also had to assume no evolution in the wind field during the flight pattern, which could be on the order of a half to full hour. A single translation velocity of the entire observed region was included in the composite.

After 1990, the antenna was often run in a mode known as fore/aft (F/AST) scanning. The radar would scan in alternating cones that were 20 degrees fore and aft of the plane normal to the aircraft fuselage. At the Battan Memorial 40th AMS radar conference in Boston in 1987, as ELDORA (Electra Doppler radar) was being developed, and in the resulting book *Radar in Meteorology* (David Atlas, Editor), a community consensus was developed that F/AST scanning at 20 degrees would produce the best compromise between the needs for Doppler-radial angle directional independence and smaller temporal evolution. The method was first tested on a NOAA WP-3D aircraft in Hurricane Gustav in 1990 using the physically steered radar that pointed alternately fore and aft. In 1991, a dual-plate antenna was installed on one of the WP-3D aircraft, and a single transmitter was switched between the two fore and aft antennas. This switching continued until two solid-state transmitters were installed in 2017 on a NOAA P3, and from then transmission was occurring out of both antennas simultaneously. A pair of fore/aft traveling wave tube transmitters were accepted for use on the NOAA G-IV aircraft in 2012, and later were replaced by solid-state transmitters. Throughout all these developments, Frank Marks was consulted as they were developed, and continues to be a resource as further developments are made to NOAA airborne radars.

Concurrently with the radar developments above, analysis methods have continued to improve. Because of the need to remove data with earth elevation angles above 45 degrees, many of the winds in small eyewalls were eliminated with the older synthesis method. In 1994, Gamache, in consultation with Dr. Wen-Chau Lee, began exploring a fully 3D least-squares solution of the wind field. This would allow high-vertical-incidence radials to be included, permitting a more complete depiction of eyewall winds. After testing, HRD used this method to produce 3D Cartesian wind fields.

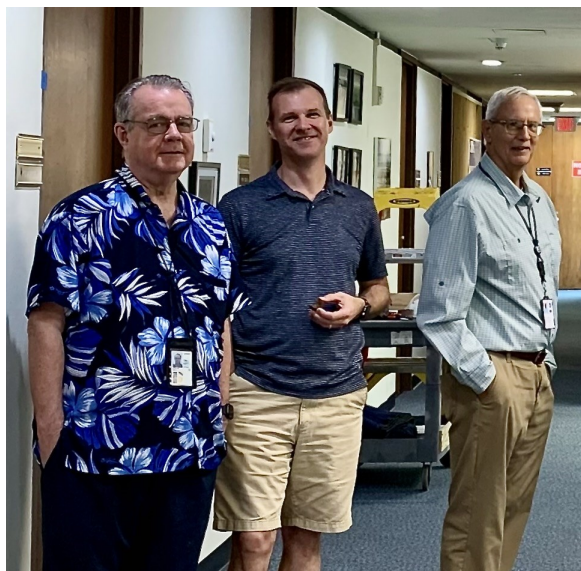
The de-aliasing of Doppler winds during the 1980s was done by first interpolating all the data. This required each radial observation at a grid point to be within a Nyquist velocity of the first one interpolated to that grid point. Then the 3D grid was de-aliased by context with the surrounding grid points. Eventually, HRD began using the SOLO method, developed at NCAR by Richard Oye, to de-alias and quality control (QC) each sweep

of the radars separately, which produced a generally more reliable wind field. This manual editing of sweeps meant that for a single one-hour pass of the aircraft through a storm, it would take several weeks to produce a set of satisfactory sweeps.

Beginning around 2003, the Environmental Modeling Centers began expressing an interest in assimilating airborne Doppler data into its HWRF model. It would require a much faster QC method. A Joint Hurricane Testbed (JHT) project at HRD developed such a method. It was based upon setting conservative noise settings when collecting the data, and very conservative use of believable Doppler radials to produce a simple wavenumber 0 plus mean wind analysis that could then be used to initialize a Bergen-Brown along-radial de-aliasing of velocities. A more complete set of radials could then be used to construct a wavenumber 0/1 analysis, and that analysis was used to finally de-alias velocities that would be interpolated for a final 3D Cartesian synthesis. The method was tested on the aircraft in 2004, and in 2005, in Hurricane Katrina, the first analysis was sent to the Hurricane Center in real time. WP-3D airborne Doppler radials were first assimilated in 2008 into a non-operational WRF-ARW analysis in Tropical Storm Fay, then into an experimental HWRF run in Hurricane Sandy in 2012, and then into the operational HWRF runs of 2013. G-IV radials were first assimilated operationally in 2018.

The National Hurricane Center has also begun to rely on airborne Doppler analyses to improve their real-time understanding of the structure of tropical cyclones. They often refer to them in their storm discussions. The airborne Doppler radars aboard the NOAA aircraft have been an important source of data and wind analyses since the 1980s, but the automated QC developed for the JHT has made them a valued real-time, operational resource.

Another form of analysis, previously mentions, that will not be described here, using the same QC, is a higher-resolution vertical wind-profile analysis along the radial aircraft tracks into the storm center. This may be discussed during the talk.



6D.1 Deducing Tropical Cyclone Three-Dimensional Structures From Single-Doppler Radar Observations: Frank Marks' Vision in 1988

Wen-Chau Lee
NCAR, Boulder, CO

The three-dimensional (3D) tropical cyclone (TC) winds have been deduced from pseudo-dual-Doppler analysis using the NOAA WP-3D tail-Doppler radar (TDR) measurements since 1984. This elaborated process was not fully automated onboard the P3s until 2004. Adapting the convective scale vortex identifying algorithm using ground-based Doppler radar, Carbone and Marks (1988) first illustrated a brilliant concept, the Velocity Track Display (VTD), to estimate the mean tangential wind and radial wind at the flight level from single TDR observation scanning perpendicular to the flight track that can be deduced in real time. Lee et al. (1994) demonstrated that the 3D axisymmetric primary and secondary circulation of Hurricane Gloria (1985) can be deduced using the VTD technique via Fourier series decomposition of the Doppler velocity on a ring centered at the TC center, consistent with the structure derived from pseudo-Doppler analysis.

The VTD formulation was adapted for ground-based radar application, called ground-based VTD (GBVTD), to deduce TC wind structure and central pressure of landfalling TCs within the Doppler range of a coastal Doppler radar. The limitations of the VTD/GBVTD includes the inability to separate higher order wavenumber tangential and radial winds, to deduce the cross-beam mean wind component, and the geometric distortion of the vortex signature in the ground-based radar PPI scans. With these limitations in mind, GBVTD has been applied to deduce mesocyclone structures in convective storms beyond its originally intended applications. This paper will present the research progresses of the VTD/GBVTD formulation in addressing the three primary limitations stated in the last paragraph to obtain a more complete 3D vortex structures over a 30-year period, inspired by Frank Marks' original vision and his encouragement and brainstorming ideas over the years.



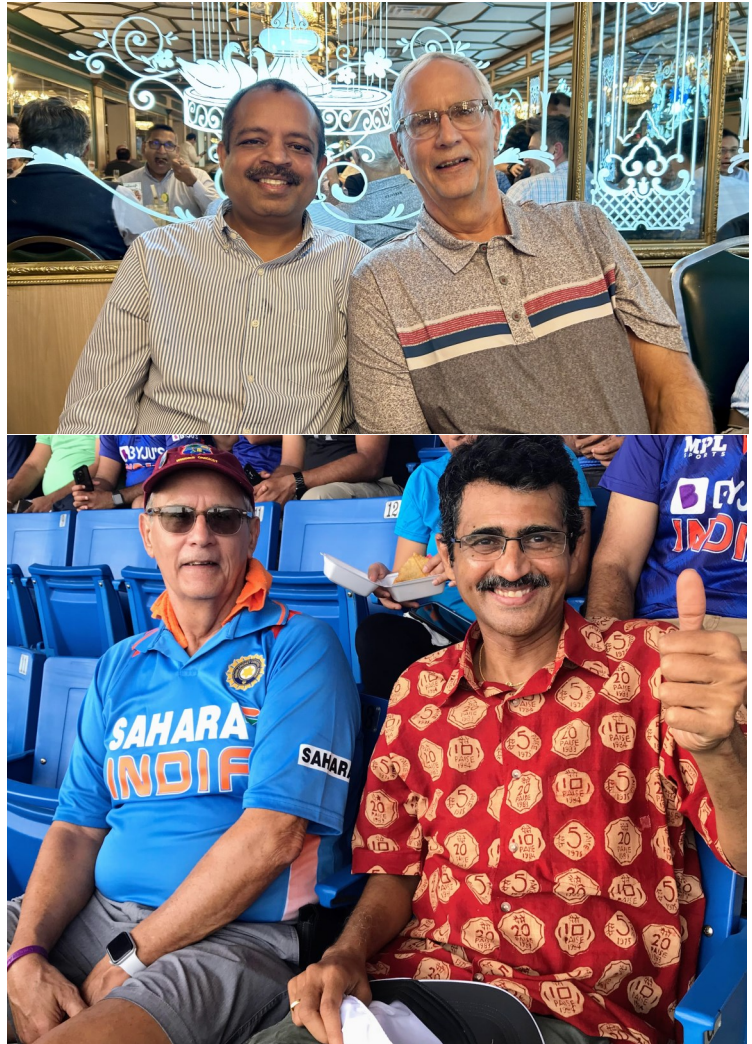
6D.2 Fifteen Years of the HFIP Real-Time Demonstration System: A Proven Pathway for Community-Driven Hurricane Modeling Innovations Transitioning to Operations

Vijay S. Tallapragada, and S. Gopalakrishnan
NOAA, College Park, MD

For over fifteen years, the HFIP Real-Time Demonstration System (HFIP-RT) has provided a sustained, real-time framework for evaluating advanced hurricane prediction capabilities—reflecting the collaborative, research-to-operations vision originally championed by HFIP Leaders Fred Toepfer, Bob Gall, Frank Marks, and Ed Rappaport. The HFIP-RT experiments are structured with a Stream 1.0/1.5/2 design that enables systematic testing emerging innovations, including high-resolution global and regional models, coupled atmosphere ocean modeling, high-resolution ensembles, and assimilation of inner-core observations using advanced DA techniques. The HFIP Program Office has coordinated these experiments each year for producing real-time multi-model regional and global products, and targeted improvements in physics, data assimilation and hurricane initialization. The success of HFIP-RT can be solely attributed to the dedicated computing resources provided to the researchers with reservations enabling near-real-time delivery of experimental products for potential use by the forecasters at the National Hurricane Center.

Many techniques first vetted in HFIP's real-time environment have since transitioned into NOAA operations, contributing to measurable gains in track and intensity forecast skill and accelerating community-driven R2O progress. The longevity and impact of the HFIP-RT Demo System underscore its unique role as a critical testbed—one that continues to unify research and operational communities and drive sustained innovation in hurricane modeling.

This presentation will highlight some of the successful outcomes of the HFIP-RT Demo System, and potential opportunities for the future advancements.



6D.3 Towards Understanding Turbulent Characteristics of the Low-Level Hurricane Eyewall

Jun A. Zhang, F. D. Marks Jr., G. Lin, J. B. Wadler, J. J. Cione,
D. H. Richter, J. Elston, and M. Z. Stachura
CIMAS/University of Miami and NOAA/AOML/HRD, Miami, FL

This study analyzes the flight-level data between 1 km height and the sea surface collected by both crewed and uncrewed aircraft that either penetrated or flew within the eyewalls of intense hurricanes. Turbulent momentum flux and turbulent kinetic energy (TKE) are estimated using the eddy correlation method. Spatial scales of turbulent eddies are estimated through both spectral and wavelet analyses. Sizes of dominant turbulent eddies and their variations with wind speed and height are quantified. Universal-shape wind spectra and cospectra are derived following the similarity theory. Contributions from turbulence-scale (100 m–2 km) and mesoscale (2–10 km) eddies to the total flux and TKE are compared. Characteristics of coherent features such as eyewall mesovortex and their impact on turbulent mixing are also examined. This study is a first attempt at estimating turbulent characteristics of the low-level eyewall using in-situ aircraft observations. The results may offer useful guidance for turbulence parameterization in hurricane forecast models.



7D.1 Structure and Dynamics of the Multi-level Secondary Circulations in Tropical Cyclones

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University of Miami, Miami, FL

The basic structure of the secondary circulation in tropical cyclones has been well known for decades, consisting of the boundary layer inflow (BLI), upward and outward motion through the eyewall, and the upper-level outflow (ULO) just below the tropopause. Numerical simulations of TCs of many types (axisymmetric, three-dimensional, idealized, and real-case) also suggest that there are frequently inflow layers just below the ULO that can be called the upper-level inflow (ULI), and occasionally an inflow layer above the ULO, that can be called the lower-stratospheric inflow (LSI). In recent years, radial wind profiles from high-altitude dropsondes have occasionally confirmed these features. We will present new analyses from the comprehensive tail Doppler radar data set known as TC-RADAR, which confirms the prevalence of the ULI, and suggests the frequent existence of an outflow layer between 6 and 9 km altitude which we call the mid-level outflow (MLO). The recent study by Wang et al. (2020, QJRM) suggested that the driving force for the LSI and ULI is a positive pressure anomaly generated in the deceleration region of the ULO. We will explore this hypothesis using a collection of real-case and idealized simulations to isolate this pressure anomaly and identify the shear-relative quadrants of the multi-level circulations in moderately sheared storms.

7D.2 Expansion of Ensemble-based Sensitivity to TC Hazard Forecasts

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Tropical cyclones are often characterized by compound hazards, including wind, storm surge, and freshwater flooding. Forecasts of these hazards can exhibit sensitivity to the structure of the storm and/or associated synoptic features, such as upstream troughs and lower-tropospheric fronts. Consequently, it can be important to have an accurate depiction of these features in a model's initial conditions; however, it can be cost-prohibitive to comprehensively observe everywhere. Consequently, it is necessary to identify optimal locations where assimilating observations into numerical forecast models could lead to the largest change in some measure of forecast outcomes, or metrics, that are related to TC-hazards. Ensemble-based sensitivity methods are an attractive way of estimating this quantity because it is computationally inexpensive and provides flexibility in terms of forecast outcomes and fields. Since 2019, the National Hurricane Center (NHC) has used ensemble-based sensitivity guidance to identify locations where the TC track forecast is sensitive to the steering flow, which in turn has been used to develop tracks for the NOAA Gulfstream IV aircraft tracks and for supplemental rawinsonde observations.

This talk describes the extension of this sensitivity technique to forecast metrics that quantify variability in the TC-related 2D wind and precipitation forecast using output from the European Centre for Medium Range Weather Forecasts (ECMWF) and Global Ensemble Forecasting System (GEFS) ensemble systems. Following a description of the automated hazard metric algorithms, Hurricane Helene and Milton's sensitivity patterns will be presented for the wind and precipitation metrics and compared to the sensitivity patterns for the track metric. Both storms exhibit similar sensitive regions for wind/precipitation metrics relative to track, but with key differences related to the definition of the metric. Finally, we will present a brief climatology of how the wind/precipitation metric variability compares to the track metric during the 2024 and 2025 seasons.

7D.3 Bridging the Modeling-Observation Divide: Frank Mark's Contributions to Hurricane Boundary Layer Research

Xiaomin Chen
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University of Alabama in Huntsville, Huntsville, AL

Throughout the advancement of hurricane science, modeling and observations have acted as two complementary engines driving progress. Few have bridged them as effectively as Frank. During his tenure as Director of NOAA/AOML's Hurricane Research Division (HRD), Frank engaged deeply with both observation and modeling teams, championing efforts to strengthen Research-to-Operations (R2O) pathways and to integrate aircraft observations with high-resolution numerical modeling. This presentation highlights Frank's leadership in initiating and guiding the development of a novel modeling framework to evaluate various planetary boundary layer (PBL) schemes under realistic hurricane conditions (Chen et al. 2021; Chen 2022). This framework, which integrates turbulence-resolving simulations with dropsonde composites from mature hurricanes, also offers an effective tool for characterizing the unique features of hurricane boundary layers relative to conventional low-wind boundary layers. Built upon this framework, a hurricane-specific PBL parameterization scheme (i.e., `tc_pbl`) was developed and is now implemented in NOAA's next-generation Hurricane Analysis and Forecast System (HAFS), contributing to improved forecasting of rapid intensification and storm structure (Chen et al. 2022; 2023; Chen and Marks 2024). Beyond his scientific accomplishments, Frank's gentle mentorship has shaped a generation of early-career scientists. His enthusiasm for radar meteorology continues to inspire ongoing boundary layer research that uses Doppler radar wind retrievals to investigate the internal boundary layers during hurricane landfalls (e.g., Leffler et al. 2025).



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7D.4 An Overview of Cloud Physics Observations in Hurricanes and Forward

Xuejin Zhang, F. D. Marks Jr., and Xin Yang
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Obtaining cloud physics processes is one the biggest challenges in order to characterize the physical processes in hurricanes. In more than four decades, NOAA's Hurricane Field Program (HFP) had strived to penetrate through the hurricane eyewall and intense convections to observe the complicate cloud physical processes. In this study, we will review the cloud physics observing instrument evolvment, observing strategies, data implications, and scientific understanding of cloud physics in hurricane environment. We will demonstrate how we can apply new technology such as machine learning to our past and future observations and obtain the physically-consistent interpretation. We will further explore the novel pathway on representing characteristics of cloud processes by this data set in order to simulate the microphysical in numerical models. Some preliminary results of microphysics simulations will be presented in this study as well.



8D.1 Development of Typhoon Forecasting Technology: Past, Present, and Future

Hui Yu

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Typhoons represent one of the most severe meteorological disasters in China, causing annual direct economic losses of tens of billions of RMB and affecting over 30 million people. Accurate forecasting of typhoon tracks, winds, and associated rainfall is fundamental for effective disaster prevention and mitigation.

This presentation reviews major milestones in the development of typhoon forecasting technology in China over the past century, tracing the evolution from cloud identification and synoptic chart analysis to statistical, statistical-dynamic, and numerical forecasting methods. These advances have led to significant, step-wise improvements in the accuracy and stability of typhoon forecasts issued by the China Meteorological Administration (CMA), with each technological transition marking a clear leap in capability.

Today, typhoon forecasting is entering a new phase focused on overcoming the challenges of predicting fine-scale structures and extending forecast lead times. Progress in physical understanding, combined with enhanced technical capacity, is expected to catalyze a new leap in forecasting technology.

To address the limitations of traditional approaches, a scale-adaptive physics package (SAPP) has been developed specifically for typhoon forecasting, incorporating innovative parameterization schemes for cloud cover, convection, microphysics, turbulence, radiation, and sub-grid topographic drag. A demonstration typhoon forecasting system based on a variable-resolution global model has been established on this foundation, demonstrating excellent performance in predicting track, intensity, and associated wind and rainfall—with the highest resolution reaching 1 km in targeted areas.

Notable recent advances also include the rapid operational implementation of meteorological AI models such as Pangu, Fengwu, Fuxi, and Fengqing, which have demonstrated particular strengths in long-term typhoon track forecasting. These are complemented by the development of NWP-AI hybrid models and purely AI-based high-resolution systems, such as the Intelligent Shanghai Typhoon Model (ISTM), designed to achieve further improvements in forecasting intensity and structure.

8D.2 Tropical Cyclone Intensification: The Transition from Vortex Misalignment to Alignment

Liguang WU

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Tropical cyclone (TC) intensity forecasting remains one of the most persistent challenges in operation, particularly in the presence of vertical wind shear (VWS). A critical process governing intensification under shear is the transition from a misaligned, tilted vortex to a vertically aligned structure. This study addresses that challenge by exploring how internal vortex dynamics facilitate realignment.

Through high-resolution numerical simulations, we demonstrate that the TCvortex possesses an intrinsic resistance to vertical tilt, dynamically governed by the evolution of the balanced wavenumber-1 component. This component is closely tied to vortex Rossby wave (VRW) activity, which regulates the structure and positioning of asymmetric convection within the storm. Diabatic heating associated with enhanced convection, typically concentrated in the downwind direction, gradually promoting vertical realignment. Importantly, significant intensification commences only after the asymmetric structures attain a favorable phase relationship with the axisymmetric circulation, enabling the development of a vertically coherent vortex. These results highlight the critical role of the balanced wavenumber-1 field in controlling the timing and onset of TC intensification. Accurate initialization of these asymmetries is essential for improving intensity forecasts in sheared environments. This framework provides new insight into the coupled roles of balanced dynamics, convective asymmetries, and wave-mediated adjustment processes in tropical cyclone evolution.

8D.3 The Value of Near-Real-Time Subsurface Ocean Information for Assessing Tropical Cyclone Intensity Forecasts from HAFS

Paige Down Lavin, D. S. Trossman, D. A. Byrne, and L. J. Gramer
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Accurately modeling and forecasting tropical cyclone (TC) intensity changes, especially rapid intensification (RI) and rapid weakening (RW) events, presents a major challenge for the TC forecasting community. Historically, much of the work to improve forecasts of RI/RW has focused on enhancing forecasting models' representation of the atmosphere, with relatively little attention paid to the ocean, especially below the sea surface. However, in addition to the well-known role of sea surface temperature (SST), both RI and RW events can be strongly influenced by the heat content and stratification of the upper ocean, particularly for larger and slower-moving TCs. The danger and costs faced by coastal communities from TCs may increase as upper ocean heat content reaches new extremes, since sustained enthalpy fluxes from the ocean can increase TC intensity and precipitation amounts. Therefore, improved near-real-time information about upper ocean conditions can aid in the evaluation and potentially in the improvement of RI/RW forecasts.

At the National Oceanic and Atmospheric Administration (NOAA), a new algorithm is being developed to replace the current, operational NOAA National Environmental Satellite, Data, and Information Service (NESDIS) Satellite Ocean Heat Content Suite (SOHCS), which entered operations in 2012. The Next-Generation Enterprise Ocean Heat Content (NGE OHC) algorithm is an empirical parameterization that generates synthetic depth-resolved ocean temperature and salinity (T/S) profiles. Since these daily profiles will be generated in near-real-time using satellite altimetry, sea surface temperature (SST), and sea surface salinity (SSS) observations, they can initially be used operationally to evaluate ocean model initialization for TC forecast models such as the NOAA Hurricane Analysis and Forecast System / Modular Ocean Model 6 (HAFS/MOM6). To improve the utility of this new algorithm, upper ocean metrics of interest will be calculated from the NGE OHC profiles, including Tropical Cyclone Heat Potential (TCHP), mixed layer depth, and near-surface stratification strength. These additional parameters should improve statistical predictions of intensity (e.g., using Statistical Hurricane Intensity Prediction Scheme (SHIPS)) and enable detailed analysis of the potential oceanic contributions to RI/RW. Other important future applications of the product will be to improve the initialization of TC forecast coupled ocean models using data assimilation and to better enable observation-only upper ocean heat budget analyses.

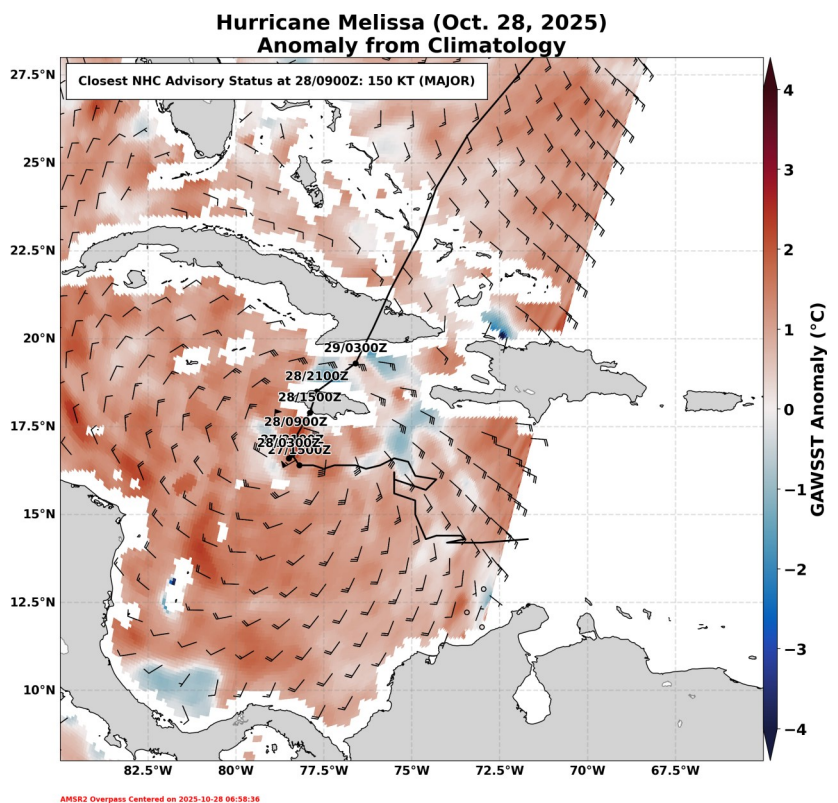
By leveraging known ocean dynamics from relatively sparse in situ T/S profiles, the NGE OHC algorithm is able to project satellite data into the interior to directly estimate subsurface T/S profiles at high vertical and horizontal resolution. We will present recently published case studies from the 2020–2022 Atlantic hurricane seasons where daily oceanic conditions from the NGE OHC are retrospectively compared with in situ Argo float observations, model initializations from HAFS/MOM6, and the SOHCS product to illustrate examples of when the pre-operational NGE OHC algorithm for the Gulf of America and Caribbean Sea could have helped to improve the model's initial ocean state in these basins. We find that many HAFS forecasts with intensity busts miss near-surface heat and barrier layers (which inhibit ocean mixing and can enhance TC intensity) found in both in situ observations and in the NGE OHC synthetic profiles. Initial results from the extended, experimental North Atlantic NGE OHC algorithm will be shown that suggest that it could be ready to be used in near-real-time by forecasters in the 2026 Atlantic hurricane season.

8D.4 Ocean Cooling Observed by AMSR2 All-Weather Sea Surface Temperature During the 2025 Atlantic Hurricane Season

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NESDIS, College Park, MD

Orbiting aboard the Japanese Aerospace Exploration Agency's (JAXA) GCOM-W1 satellite is the Advanced Microwave Scanning Radiometer-2 (AMSR2). The Ocean Surface Winds team (OSWT) of the National Oceanic and Atmospheric Administration (NOAA) has been providing a near-real-time dataset of AMSR2 observations since 2012 (<https://manati.star.nesdis.noaa.gov/datasets/GCOM2Data.php>). Since then, AMSR2 has provided global coverage every 2-days of sea surface temperature (SST) that improves observational coverage of meteorological and oceanographic phenomena, especially that of tropical cyclones (TC). The SST observations AMSR2 are capable of delivering can be crucial in understanding tropical cyclone development, but these observations typically suffer from inflated observations due to localized scattering and emission mechanisms influencing measured brightness temperature at the surface level.

Traditional analysis and retrieval algorithms of microwave radiometer SSTs disregard rain contaminated regions. These gaps are especially pronounced within TCs where changes in SST can only be observed after a storm has passed. In order to mitigate that gap, the OSWT has developed, with ongoing validation and improvement efforts, a global all-weather SST (GAWSST) algorithm using a linear combination of vertical and horizontal polarizations of the 6, 10, and 18 GHz channels to salvage these key observational regions. The GAWSST algorithm's goal is to mitigate the impact of rain on brightness temperature measurements while simultaneously preserving SST sensitivity. The GAWSST processor was utilized on all AMSR2 passes over Atlantic TCs during the 2025 season, including the record-breaking Erin and Melissa storms. Through these observations, GAWSST SST retrievals were providing a first ever look at temporary surface cooling induced by TC rain bands while also providing evidence towards deep-ocean cooling from TC-induced upwelling. Validation of this exciting new product was performed using in-situ wave drifters equipped with SST sensors. Observations from the 2025 Atlantic hurricane season and corresponding validation efforts will be presented and discussed.



M64 Observing and Defining Mid-Level Outflow (MLO) in Tropical Cyclones

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University of Miami, Miami, FL

For decades now, atmospheric scientists have had a strong understanding of the generalized flow of the secondary circulation of tropical cyclones (TCs). But observations of radial wind throughout the depth of TCs indicate that there can be outflow in the mid-levels nearly equal in strength to the outflow at the tropopause as seen from azimuthally-averaging over hundreds of cases. Analysis of the TC-RADAR database—which is comprised of 1,510 tail Doppler radar (TDR) flight passes for 436 TCs spanning 1997–2024—shows that when defining the mid-level outflow (MLO) by the value of the 95th percentile of radial wind in the height slice from 6.5 to 9.5 km, statistically significant differences of the MLO strength are associated with changes in best-track maximum wind speed (V_{max}), environmental vertical wind shear, relative humidity (RH), 24-hr intensity change, and vortex tilt between MLO and non-MLO storm cases. Vertical cross sections, contoured frequency by altitude diagrams (CFADs), and composite plots of radial wind provide indications of the structural signature of this feature, with clear indications of the MLO initializing in the downshear quadrants before spiraling outward and upward into the main outflow layer. Further analysis into the structure of the MLO and the significance of the TC characteristic differences will be conducted. Additionally, the TC-DROPS database will be explored to ensure robustness and examine atmospheric moisture variables not existing in TC-RADAR.

M97A Continued Analysis of Semi-High Resolution Surface Observations from Hurricanes Katrina and Rita (2005) at Landfall

James Robert Howard
Ponchatoula, LA

Furthering the effort to directly quantify the relationship between meteorological observations and impacts from tropical cyclones before, during, and after landfall, a team of undergraduate atmospheric science students, now degreed meteorologists, and two degreed meteorologists, one faculty and the other staff, with assistance from others in government, academia, and the general public, placed instrumented portable stations directly in the expected paths of Major Hurricanes Katrina and Rita (2005) along the Louisiana coastline prior to each tropical cyclone's arrival there. All stations were located either at the coastline or within a few kms of the coastline and were in parts of the eye and eyewall of one of the two storms. The Buras, Louisiana, station for Katrina measured a minimum pressure of 920 mb at the point of Katrina's second U.S. landfall, one of the lowest surface pressures ever recorded in the U.S. during any weather event, while being surrounded by storm surge during much of the event. The data retrieved, mostly sampled at a rate of 1 Hz, is currently undergoing analysis, particularly with respect to turbulent wind characteristics and the relationship between those characteristics and the somewhat rapidly changing upstream land and ocean structure during each event. Those changes are linked primarily to the changes in wind direction from each storm's passage and to the concomitant storm surge inundation nearby to some of the station locations. Analysis presented at the conference will include a comparison of the datasets from the two systems with respect to the different upstream structures present prior to each system's arrival and the changes to those areas that occurred during the events.

M97 A summary and update on the Tropical Cyclone Logistical Guidance for Genesis (TCLOGG) including spatiotemporal expansion, further incorporation of Machine Learning techniques, and Genesis Pathway analysis of TCLOGG performance

Robert E. Hart, D. Murphy, S. T. Barnier, and D. J. Halperin
Florida State University, Tallahassee, FL

The Tropical Cyclone Logistical Guidance for Genesis (TCLOGG) is increasingly well-calibrated guidance for forecasting TC formation that has been disseminated graphically since 2014 at <https://moe.met.fsu.edu/modelgen>. Research development for this guidance began in 2012 (coincidentally nearly the same time as the TCGI (Tropical Cyclone Genesis Index) research of Dunion et al. 2013, Brammer et al. 2022, Grogan et al. 2022) and has resulted thus far in two Ph.D. dissertations (Halperin 2015, Remondelli 2024) and five publications (Halperin et al. 2013, 2016, 2017, 2020; Halperin and Hart 2025). In 2022, the guidance was officially selected for implementation as a forecast tool within NOAA/NHC to ensure its long-term viability for forecasters within NOAA and especially NHC and CPHC. Here we discuss the updates and developments since official operational implementation and conclude with the ongoing and proposed developments for the next few years.

Expansion of the TCLOGG guidance occurred in multiple stages, increasing the skill and spatiotemporal expanse of the guidance:

2014: Initial version of multiple logistic regression probabilistic guidance through five days released using three global models (CMC, GFS, and UKMET) and a consensus probability, for the AL and EP basins.

2019: Guidance expanded to four global models (NAVGEM added) and to one week.

2022: Guidance expanded to five global models (ECMWF added) and expanded to all Global TC basins: AL, EP, IO, SH, WP.

2022: Guidance expanded to include a Most-Likely Time of Genesis metric that provides an additional timing estimate of TC formation (Remondelli et al. 2023, 2024).

Ongoing but not-yet-implemented TCLOGG development has expanded to include:

1. Testing subdivisions of larger TC basins (IO, WP, and SH) into sub-basins.
2. Ten days forecast length using a subset of the five global models that provide at least 240-hour forecast output (CMC, GFS, and ECMWF).
3. Use a subset of version 12 of an ensemble of a single global model reforecast (GEFSR; Hamill et al. 2013) through two weeks forecast length.
4. Use now widely-used machine-learning (ML) techniques (e.g., Convolutional Neural Network, Extreme Gradient Boosting [XGBoost], Recursive Feature Elimination, Random Forest Regression, and Support Vector Regression; Remondelli 2024 and numerous presentations).

Accordingly, this poster presents: a) a brief summary of the TCLOGG history; b) an update of TCLOGG training dataset verification statistics, including spatiotemporal climatology of those metrics; c) further developments and performance measures that incorporate ML methods in TCLOGG; and d) the newly begun analysis of TCLOGG forecast performance (TC genesis forecast success vs. failure distinction and physical insight) through composites of TC genesis pathways as defined by McTaggart-Cowan et al. (2008, 2013) and Wang et al. (2018). These latter two developments of (c) and (d) form the thesis research of the latest graduate students on this project, and co-authors of this poster, Murphy and Barnier.

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