7.3 METEOROLOGICAL AND OCEANIC INSTRUMENTATION AT SPACEPORT FLORIDA – OPPORTUNITIES FOR COASTAL RESEARCH

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1. INTRODUCTION

The east central coast of Florida has a collection of unique and dense meteorological and oceanographic sensors. Data from these instruments are routinely saved and thus represent a special resource for coastal atmospheric and oceanic research. This is especially true for thunderstorm prediction and convective processes, since central Florida is ‘Lightning Alley’ for the U.S. This is an area extremely rich in atmospheric boundary layer interactions and subsequent thunderstorm formation during the summer. Likewise, the nearby coastal waters are dynamically complex. The Gulf Stream flows nearby and can cause large horizontal sea-surface and vertical sea-to-air temperature gradients that vary in complex patterns over space and time with large meteorological and biological impacts. Researchers interested in using these data should contact the corresponding author to arrange access, receive advice on the strengths and weaknesses of the data, and to possibly coordinate mutually beneficial operational research.

2. BACKGROUND

The 45th Weather Squadron is the US Air Force unit providing comprehensive weather services to America’s space program at Spaceport Florida, which includes the US Air Force Cape Canaveral Air Force Station (CCAFS) and Kennedy Space Center (KSC) (Boyd et al., 1993). The meteorological sensors used by 45th Weather Squadron are perhaps the most unique and dense suite of weather sensors in operational meteorology (Harms et al., 2003). These sensors are needed because of the unique weather requirements for space launch and the subtle weather in east central Florida. In addition, the Florida Institute of Technology operates some meteorological and oceanographic sensors as part of their research and educational programs. Finally, a few other weather and oceanographic sensors near this area are operated by the National Data Buoy Center. The 45 WS has identified many areas where operational research could improve weather service to America’s space program (Roeder and Harms, 2000).

2.1 Complex Space Launch Weather Requirements

Weather has a large impact on many aspects of space launch, including: launch operations ground processing operations in preparation for launch, post-launch, various special missions, and routine 24/7 weather watch and warning responsibilities.

During launch countdowns, the 45 WS forecasts and evaluates the Lightning Launch Commit Criteria (LCC) and User LCC (Hazen et al., 1995). The Lightning LCC are a set of complex rules to avoid rocket-triggered lightning (Roeder et al., 1999). All US Air Force and NASA space launches use the same Lightning LCC.

The User LCC are limits for three weather categories: 1) near surface winds so the rocket can safely clear the launch tower, 2) ceiling and visibility for optical tracking of the rocket before acquisition of radar tracking, and 3) temperature for mechanical integrity of the rocket. As its name implies, the User LCC vary between launch vehicle programs, and different configurations of vehicles in the same program. The Space Shuttle also has Flight Rules that apply only to that program and covers the time between clearing the launch tower and wheels stopping on landing. These Flight Rules are forecast and evaluated by the National Weather Service Spaceflight Meteorology Group located at Johnson Space Center in Houston, TX (Brody, 1997).

Weather also affects four aspects of launch that are evaluated by agencies other than the 45 WS, though 45 WS advises them on weather observations and forecasts. The first launch aspect is ‘LOADS’, which refers to the aerodynamic loading on the rocket as it counter-steers against the upper-level winds to stay on the desired trajectory. If the actual winds differ too much from the planned winds, the rocket could destroy itself. The LOADS community of aeronautical engineers continually analyzes the observed winds and vehicle impact to prevent this from happening. Range Safety evaluates the second, third, and fourth aspects of launch: ‘Toxic Dispersion’, ‘BLAST’, and ‘Debris’ (Boyd et al., 1999). Toxic dispersion from nominal and catastrophic launches is analyzed to ensure the on-base and nearby civilian populations will not exceed allowable toxic exposure limits. ‘BLAST’ analyzes the likelihood of windows in nearby towns being broken and causing a safety hazard if a rocket explodes (Boyd et al., 2000). The ‘Debris’ program considers if parts of the rocket from a nominal or catastrophic launch would fall outside of the allowed impact areas.

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Weather also has a large impact on the over 5,000 ground processing operations done each year in preparation for space launches (Boyd et al., 1995). Major ground processing operations include vehicle rollouts to the launch pads, stacking and destacking rocket segments, transporting and mounting and demounting payloads, large crane operations, etc. Minor operations can be as simple as corrosion maintenance on the launch pads. Many of these processing operations are outside and must be curtailed under certain weather conditions. Weather can cause costly delays in launch preparation, with some processing operations having such restrictive weather limits that weeks of delay can occur.

Weather can also have a major impact on post-launch operations. The best example is the at-sea recovery of the solid rocket booster motors after a Space Shuttle launch. Wind, wave height, and wave periodicity can make recovery unsafe, leading to a delay or scrub of a Shuttle launch.

The 45 WS also supports various special missions. These missions include transport of oversized components on large weather-sensitive aircraft such as the Super Guppy, transport of large components on barges across the Gulf of Mexico and along the east Florida coast, and practice astronaut rescue exercises. Another unique special mission is the Space Shuttle Ferry Flight, which is considered aviation's most weather-sensitive flight operation. A second aircraft, usually an U.S. Air Force C-141, flies 20 minutes in front of the modified 747 with the Space Shuttle on top, primarily to serve as a weather-scout aircraft. Personnel from 45 WS fly on this aircraft to provide continuous weather service.

Weather also has a significant impact on personnel safety and resource protection. The 45 WS is responsible for a large suite of weather watches, warnings, and advisories to protect over 25,000 people and over $17 billion in facilities, not including launch vehicles and payloads. Lightning is the most frequent weather threat, with an average of over 1,200 lightning advisories per year. The 45 WS is responsible for lightning advisories at 13 areas, consisting of circles with a 5 NM radii safety buffer centered on operationally significant sites: ten areas with considerable overlap on CCAFS/KSC, one at Patrick AFB, one for military operations at Melbourne airport, and one for a satellite processing facility at Titusville (Figure 1). A Phase-1 Lightning Condition is issued for one or more of these areas if lightning is expected with a desired lead-time of 30 min. A Phase-II lightning condition is issued when lightning is imminent or occurring in one or more of these areas. One of the greatest challenges facing 45 WS is canceling these lightning advisories faster, to allow outdoor work to resume, while still maintaining safety. As you might expect with all the thunderstorm activity, convective wind warnings are also important, with an average of over 175 warnings each year. The convective wind warnings have unusually precise requirements and large desired lead-times (Table 1). The 45 WS has developed several techniques to forecast convective winds (Wheeler and Roeder, 1996).

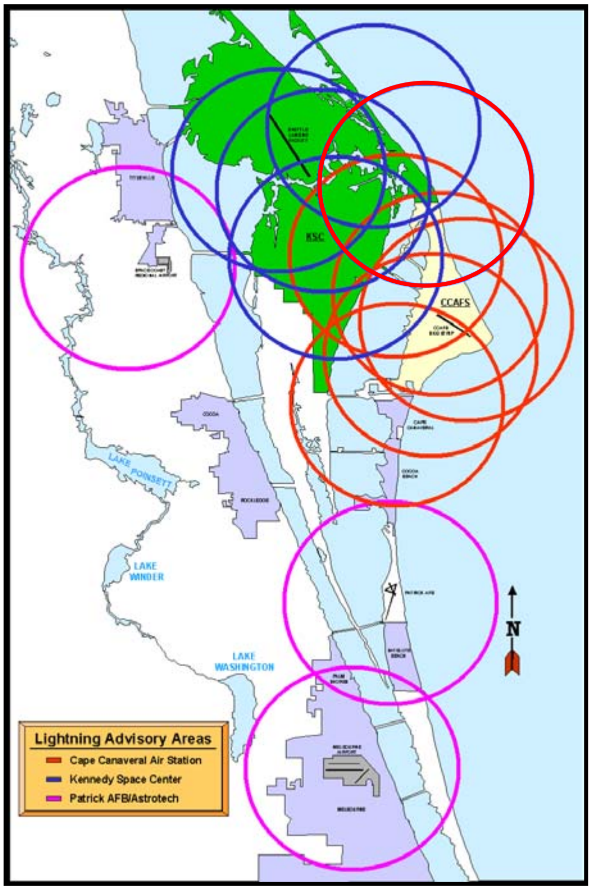

Figure 1. 45 WS Lightning Advisory Areas. Each of the thirteen circles represents a point for which 45 WS issues two-tiered lightning advisories. Each circle represents a 5 NM safety buffer around the point.

TABLE 1. 45 WS Convective wind warnings and related advisories.

LOCATION	CRITERIA	DESIRED LEAD-TIME
KSC (surface-300 Ft)	≥ 35 Kt	30 min
	≥ 50 Kt	60 min
	≥ 60 Kt	60 min
CCAFS (surface-200 Ft)	≥ 35 Kt	30 min
	≥ 50 Kt	60 min
Patrick AFB (surface)	≥ 35 Kt	30 min
	≥ 50 Kt	60 min
	Gust Spread ≥ 20 Kt	Observed
	LLWS < 2,000 Ft	Observed
MELBOURNE (surface)	≥ 50 Kt	Observed

2.2 *Subtle Local Weather*

The intricate weather support requirements for CCAFS/KSC are complicated by the subtle weather in central Florida. Clearly the most important weather phenomenon is thunderstorms and associated hazards. The generation of these thunderstorms is dominated by many weak interacting boundaries. During the summer, the synoptic drivers in central Florida are so weak that other driving mechanisms, which would be secondary or even tertiary elsewhere, can dominate local thunderstorm formation. The sea breezes from both the Atlantic Ocean and Gulf of Mexico often migrate across the peninsula and interact with each other, depending on the gradient flow. The position of the subtropical ridge is fundamental, with seven main flow regimes (Lericos et al., 2002). If the subtropical ridge is south of the area, the resulting westerly gradient flow will hinder the inland penetration of the east coast sea breeze front and accelerate the west coast sea breeze across the peninsula. This yields the largest lightning flash densities on the east side of the state, after the approaching thunderstorms have gathered strength from surface heating all day and as the west coast sea breeze front collides with the east coast sea breeze front. Also, significant local river breezes form between the Indian River, Banana River, the barrier island, and Merritt Island. Indeed, numerical modeling shows that the vertical motion from the Indian River Breeze is as strong as the East Coast Sea Breeze itself (Rao et al., 1999). There are many other boundaries and boundary interactions which contribute to local thunderstorm formation, such as: convective outflows, horizontal convective rolls, lake breezes, cloud shadow temperature discontinuities, soil moisture temperature discontinuities, washed out frontal zones/shear lines, etc. Easterly waves and weak extra-tropical short waves also complicate the local weather.

The local land/water distribution creates a complex frictional and stability environment. This complicates forecasting wintertime peak winds at the launch pads.

2.3 *Dynamic Local Oceanography*

Likewise, the nearby coastal waters are dynamically complex. The most important feature is the nearby Gulf Stream. This important current can cause large sea-surface temperature gradients and large air-sea temperature differences that can vary in complex patterns over space and time, and have large meteorological and biological impacts. The Gulf Stream also meanders, changing its offshore distance by as much as 50 km and forming numerous eddies. Figure 2 shows typical Gulf Stream sea surface temperatures and complex flow pattern off Florida.

In addition, the complex interleaving of fresh and salt water, wetlands, and land surfaces in the area creates boundary conditions that vary spatially and temporally. Mesoscale Coupled Land-Air-Sea System (M-CLASS) modeling has been proposed by Florida Institute of Technology, and others, as necessary to improve coastal weather and oceanographic forecasts.

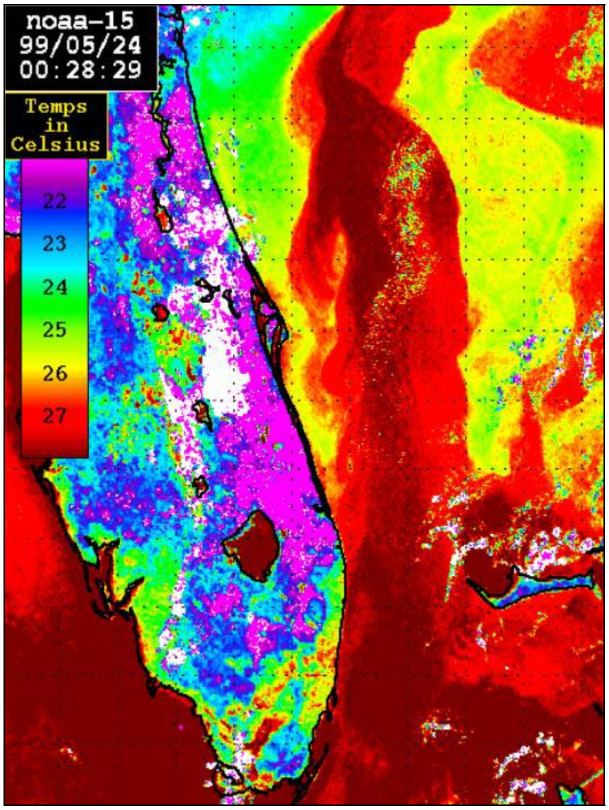

Figure 2. Typical Gulf Stream temperatures, temperature gradients, and complex flow patterns off the Florida coast.

3. Local Meteorological And Oceanic Sensors

The 45 WS has a large suite of weather sensors to conduct their weather support mission (Harms et al, 1998). This suite of sensors may be the most dense and most unique in all of operational meteorology. A brief list of these weather systems is provided in Table 2. The geographical distribution of most of the weather sensors is shown in Figure 3. Most of these data are saved and are available for climatological analysis for improved forecasting.

The Florida Institute of Technology also operates some meteorological and oceanographic sensors at two sites about 25 and 35 miles south of Spaceport Florida. These sensors are listed in Table 3 and their positions are shown in Figure 4.

The National Data Buoy Center operates three nearby data buoys and three nearby Coastal-Marine Automated Network (C-MAN) stations. These sensors are listed in Table 4 with locations shown in Figure 4.

Numerous other sensors are also available (Case et al., 2002). These include traditional weather sensors like the Automated Surface Observation Site at the Melbourne Airport and non-traditional sensors like the Aircraft Communications Addressing and Reporting System (ACARS) and a GPS Precipitable Water sensor at Cape Canaveral. In addition, a surprising amount of non-traditional data from private industry also exists.

TABLE 2. List of local weather sensors used by 45 WS. Most of these data are saved and are available for after the fact study.

SENSOR	NO.	COMMENTS
BOUNDARY LAYER		
Weather Towers	44	30 x 40 Km Area, 2 to 150 m, Wind, Temperature, Humidity
915 MHz DRWP/RASS	5	Wind (0.12-3 Km), 5 Min Virtual Temperature (0.12-2.5 Km), 15 Min
Mini-Sodars (Projected 2005)	8	Wind (15m-150 m, every 5 m), 1 min
Surface Observer	2	KSC, Patrick AFB (contractor)
Rain Gauges	33	Most collocated at field mill sites (see LPLWS)
UPPER AIR		
Automated Meteo. Profiling System (AMPS) (Low-Res)	1	GPS-tracked RAOB (asynoptic times)
Automated Meteo. Profiling System (High-Resolution)	1	GPS-tracked Jimsphere (High precision wind balloon, countdowns only)
Rocketsonde (Not After 2000)	1	20-90 Km, Limited launches
50 MHz DRWP	1	Winds (2.0-19.0 Km), 112 Gates (150 m spacing), 5 Min refresh rate
LIGHTNING		
Lightning Detection And Ranging (LDAR)	7	Detects all lightning types, Depicts 3-D structure
Launch Pad Lightning Warning System (LPLWS)	31	Surface electric field, Detects all lightning types (poor location accuracy)
Cloud to Ground Lightning Surveillance System (CGLSS)	6	Improved Accuracy with Combined Technology (IMPACT) sensors
NLDN *	105	Commercial data source
A. D. Little	1	Detects all lightning types in range bins
RADAR		
WSR-74C/IRIS	1	5 cm, 2.5 Min Volume Scan, Customized Products
WSR-88D *	1	NWS/Melbourne

* Not a local weather sensor, but is included for its importance in operational research or for completeness.

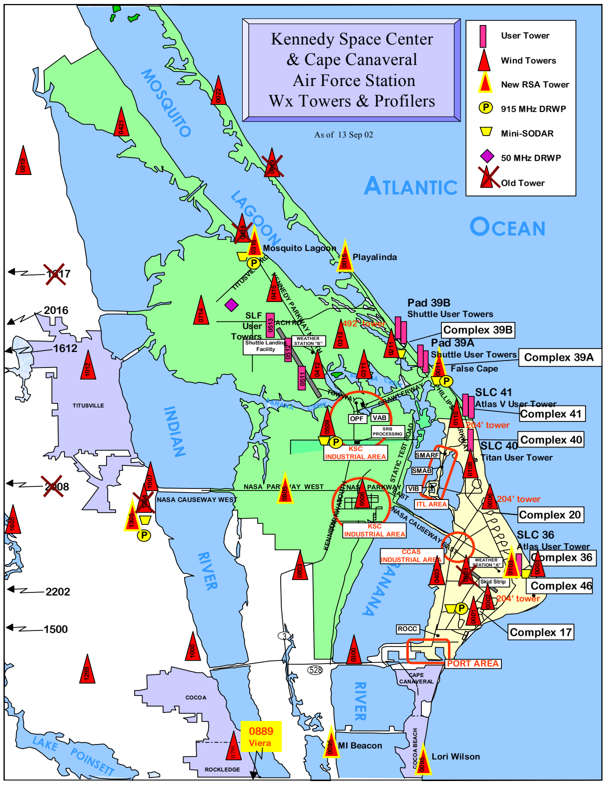

Figure 3. Locations of most of 45 WS weather sensors.

TABLE 3. List of weather and oceanographic sensors used by the Florida Institute of Technology. Most of these data operate continuously, are routinely saved and are available for after the fact study.

SENSOR	NO.	COMMENTS
SEBASTIAN INLET NORTH JETTY (27.86 N, 80.45 W)		
Automated Weather Station	1	Temperature, Dew Point, Wind, Surface Pressure
Tide Gauge	1	None
Wave Gauge	1	Directional spectrum
FLORIDA INSTUTUTE OF TECHNOLOGY (28.07 N, 80.16W)		
GPS Precipitable Water	1	Precipitable Water, Surface Pressure, Temperature, Relative Humidity
Wind Station	1	Winds
Research devices from which related weather data can be inferred	Variable	E.g., Solar Panels, Irradiance Meter, Wind Turbines, etc.

New sensors are also being planned for Florida. For example, the Florida Department of Transportation is installing a network of about 50 GPS-Precipitable Water sensors across Florida.

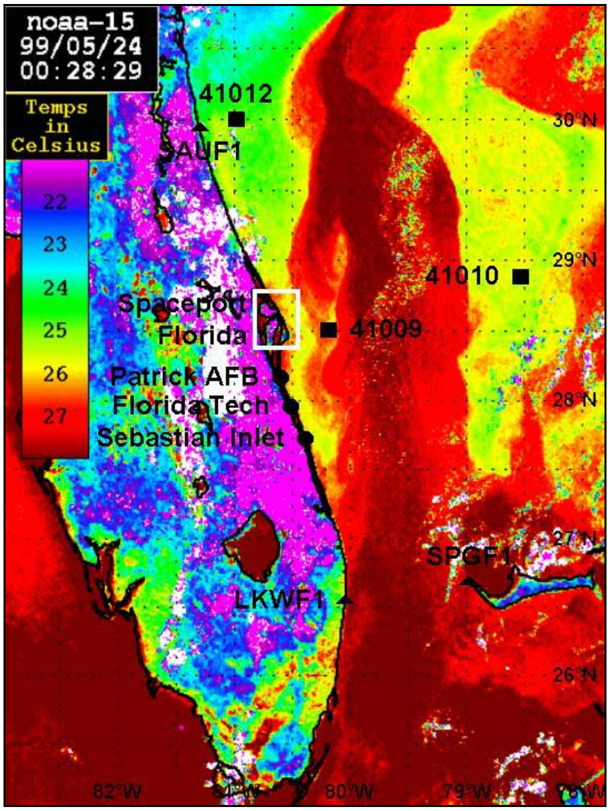

Figure 4. Locations of the nearby meteorological and oceanographic sensors used by the Florida Institute of Technology and the National Data Buoy Sensors.

TABLE 4. List of nearby weather and oceanographic sensors from the National Data Buoy Center.

SENSOR	LOCATION	COMMENTS
	BUOYS	
Station 41009 Canaveral	28.50 N, 80.18 W	Air Temperature, Anemometer, Barometer, Sea Temperature
Station 41010 Canaveral East	28.89 N, 78.52 W	Same As Above
Station 41012 St. Augustine	30.00 N, 80.50 W	Same As Above
	C-MAN STATIONS	
Station SAUF1 St. Augustine, FL	29.86 N, 81.26 W	Air Temperature, Anemometer, Barometer
Station LKWF1 Lake Worth, FL	26.61 N, 80.03 W	Same As Above
Station SPGF1 Settlement Point, Grand Bahamas Island	26.70 N, 79.00 W	Same As above
	Site specific details available at www.ndbc.noaa.gov	

Websites for the 45th Weather Squadron, Florida Institute of Technology, and the National Data Buoy Center are listed in Table 5.

TABLE 5. Websites for the organizations discussed in this article.

ORG.	WEBSITE
45th Weather Squadron	https://www.patrick.af.mil/45og/45ws
Florida Institute of Technology	www.fit.edu
National Data Buoy Center	www.ndbc.noaa.gov

4. SUMMARY

Many factors combine to make east central Florida an outstanding location for research in meteorology and oceanography. The saved data from the unique and dense weather and oceanic sensors at Spaceport Florida, Florida Institute of Technology, National Data Buoy Center, and other sources, are available to researchers. A superabundance of thunderstorms is usually produced during the summer and is triggered by a large number of subtle boundary interactions. The space program has many complex weather requirements that provide the opportunity for mutually beneficial operational research.

REFERENCES

Boyd, B. F., D. E. Harms, P. N. Rosati, C. R. Parks, and K. B. Overbeck, 2000: Weather Support To Range Safety For Forecasting Atmospheric Sonic Propagation, *9th Conference on Aviation, Range, and Aerospace Meteorology*, 11-15 Sep 00, 432-437

____, B. F., D. E. Harms, M. E. Fitzpatrick, R. P. Stout, P. N. Rosati, D. D. Berlinrut, C. R. Parks, and K. B. Overbeck 1999: Weather Support To Range Safety, *Joint Army Navy NASA Air Force Safety & Environmental Protection Subcommittee*, CPIA Pub. 687, Vol. I, 26-30 Apr 99, 59-69

____, W. Roeder, J. Lorens, D. Hazen, and J. Weems, 1995: Weather Support to Pre-launch Operations at the Eastern Range and Kennedy Space Center, *6th Conference on Aviation Weather Systems*, 15-20 Jan 95, 135-140

____, J. T. Madura, and M. E. Adams, 1993: Meteorological Support to the United States Air Force and NASA at the Eastern Range and Kennedy Space Center, Paper 93-0753, *AIAA 31st Aerospace Sciences Meeting & Exhibit*, 11-14 Jan, pp 11

Brody, F. C., 1997: Operations of the National Weather Service Spaceflight Meteorology Group, *AIAA 35th Aerospace Sciences Meeting and Exhibit,* Paper 97-0181, 6-10 Jan 97, pp 8

Case, J. L., J. Manobianco, T. D. Oram, T. Garner, P. F. Blottman, and S. M. Spratt, 2002: Local Data Integration Over East-Central Florida Using The ARPS Data Analysis System, *Weather and Forecasting*, 17, Feb 02, 3-26

Harms, D. E., B. F. Boyd, F. C. Flinn, J. T. Madura, T. L. Wilfong, and P. R. Conant, 2003: Weather Systems Upgrades to Support Space Launch at the Eastern Range and the Kennedy Space Center, *12th Symposium on Meteorological Observations and Instrumentation*, 9-13 Feb 03, pp 9

____, D. E., B. F. Boyd, R. M. Lucci, and M. W. Maier, 1998: Weather Systems Supporting Launch Operations at the Eastern Range. *AIAA 36th Aerospace Sciences Meeting and Exhibit*, Paper 98-0744, 12-15 Jan 98, pp 11

Hazen D., W. P. Roeder, B. F. Boyd, J. Lorens, and T. Wilde, 1995: Weather Impact On Launch Operations At The Eastern Range And Kennedy Space Center, *6th Conference On Aviation Weather Systems*, 15-20 Jan 95, 270-275

Lericos, T. P, H. E. Fuelberg, A. I. Watson, and R. L. Holle, 2002: Warm Season Lightning Distributions Over The Florida Peninsula As Related To Synoptic Patterns, *Weather And Forecasting*, Vol. 17, No. 1, 83-98

Rao, P.A., H.E. Fuelberg, and K.K. Droegemeier, 1999: High Resolution Modeling Of The Cape Canaveral Land/Water Circulations And Associated Features, *Monthly Weather Review*, 127, Aug 99, 1808-1821

Roeder, W. P., and D. E. Harms, 2000: Using Climatology to Improve Weather Forecasting for America's Space Program, *12th Conference On Applied Climatology*, 8-11 May 00, 66-69

____, J. E. Sardonia, S. C. Jacobs, M. S. Hinson, D. E. Harms, and J. T. Madura, 1999: Avoiding Triggered Lightning Threat To Space Launch From The Eastern Range/Kennedy Space Center, *8th Conference on Aviation Range, and Aerospace Meteorology*, 10-15 Jan 99, 120-124

Wheeler, M., and W. P. Roeder, 1996: Forecasting Wet Microburst On The Central Florida Atlantic Coast in Support of the United States Space Program. *18th Conference on Severe Local Storms*, 19-23 Feb 96, 654-658