Exam composition: 50-60% multiple choice or history matching; 40-40% short essay, draw and explain, or problems. Covers: lectures 19-29. You will have about an hour. We will begin promptly at 11:00 and end a bit after noon. Bring pencils and a scientific calculator.

Waves (LEC 20)

1. Definitions:
    a. Sea: Waves excited locally by the wind
    b. Swell: Waves excited elsewhere
    c. Wavelength: Distance from crest-to-crest
    d. Period: Time between crests or toughs
    e. Height: Vertical distance from trough to crest
    f. Phase speed = Wavelength/Period
2. Deep-water waves
    a. Water moves in circular orbits
    b. Converges ahead of troughs and diverges behind crests
    c. "Dispersive"---longer waves move faster than short ones
3. Shallow-water waves
    a. Water moves back and forth horizontally
    b. Waves in shallow water move faster than waves in not-so-shallow water
    c. "Nondispersive" ---all wavelengths move with the same speed provided that the water is shallow
    d. Near shore, wave slowing in shallow water focus energy on promontories and away from bays
4. Waves grow as the wind pushes on their backs and pulls at their fronts
    a. Fastest growing move with 1/6 of wind speed
    b. Limited by Fetch or Duration in many cases
    c. Fully arisen sea---max possible for a given wind speed
5. Waves break when their steepness (H/L) > 1/7
6. Waves are higher in the hazardous semicircle because winds are stronger and because the waves move with the hurricane, and conversely in the navigable semicircle.
7. Long-period swell is a harbinger of hurricanes

Storm Surge (LEC 21)

1. Factors in storm-induced sea-level rise
    a. Inverted barometer effect
    b. Wave run up
    c. <u>Wind stress forces the ocean over the land</u> (dominant)
2. High surge favored by
    a. Strong wind blowing over long distance (ie large as well as strong storm)
    b. Shallow water offshore
    c. Lack of barriers like dunes or wetlands
3. SLOSH Model
    a. Based upon wind stress and inverted barometer
    b. Requires accurate topography and bathymetry
    c. One-size fits all evacuation zones based upon recognizable landmarks
4. ADCIRC Model: more sophisticated finite-element model
5. New Orleans in Katrina of 2005
    a. Long warning time, 80% evacuation
    b. Levees designed for CAT 3 (Betsy of 1965)

   c. Failed below design threshold

The 1940s & 1950s (LEC22)

1. "Surprise" Hurricane of 1943 (25-29JUL) hit Galveston, TX as a CAT 1 with little warning, first flight into a TC
2. Great Hurricane of '44 (9-16SEP).
   a. Cape Verde storm, replay of '38 storm
   b. Affected Cape Hatteras and struck southern New England as CAT3
   c. Sank 5 Navy & Coast Guard ships, drowning 356 sailors, but killed only 46 ashore… attributed to first use of aircraft reconnaissance
3. Typhoon "COBRA" (17-18DEC44)
   a. Hit US 3rd Fleet (TF38), under ADM Halsey
   b. Refueling and rearming after Lete Gulf (Philippines) invasion
   c. CFT Meteorologist interpreted N wind as cold front
   d. Fleet steamed west then south into Typhoon's path
   e. Three destroyers sunk, 790 sailors lost
   f. Extensive damage to other ships, especially aircraft carriers
4. Havana-Tampa (Pinar del Rio) Hurricane (12-23 OCT44)
   a. Formed in Caribbean, passed over western Cuba to landfall hear Sarasota
   b. Devastating in Pinar del Rio and Havana provinces
   c. First radar observation and first rawinsonde ascent in the eye
5. Richmond Field: Blimp base destroyed by CAT3 hurricane 15SEP45. Site of present Maimi METRO ZOO

Rain (LEC 23)

1. Redfield-Reid applied to rainfall: Pattern moves with storm center, but does not change rapidly
2. Low-level convergence feeds moisture into the storm
3. Rising motion causes condensation
4. Convective (heavy, brief) and stratiform (light, long lasting) rain
5. Cloud processes
   a. Warm rain and role of ice,
   b. Conversion of suspended cloud water into precipitation
6. TC precipitation efficiency enhanced by low evaporation in TCs
7. Kraft's rule R (in) = 100/C(kt)
8. Radar: Microwave beams reflected by raindrops, not snow or cloud
9. Z-R relationship between reflectivity and rain rate
10. Airborne radar and spaceborne radar (TRMM)
11. Orographic (upslope) rainfall can be very heavy in landfalling storms
12. Hurricane Mitch (1998) drowned ~11,000 in Guatemala and Honduras after weakening from CAT 5 to CAT 1at landfall, TS inland
13. Freshwater flooding caused 60% of hurricane-related deaths 1970-2004 (pre Katrina)

The 1950s & 1960s (LEC 24)

1. Wartime (1941-45) developments
   a. Aircraft reconnaissance
   b. Reflectivity Radar
   c. Upper air observations
   d. Former military meteorologists enter the field

2. Future NHC moves to Miami in 1943, Grady Norton in Charge
3. Two hurricane hits on Miami in 1947, extensive flooding in West Dade
4. Compact, CAT3 Hurricane King tracks N over Dade & Broward Counties in 1950
5. Naming of storms:
    a. Military phonetic (ABLE, BAKER, CHARLIE, DOG, EASY, FOX…) in 1950
    b. Women's names 1953
    c. Men & Women's in 1978, English, Spanish, and Creole
6. Six hurricane affect mid-Atlantic states in 1954 & 1955
7. Navy P-2 lost in Janet of 1955 in the Caribbean
8. East-coast storms motivated establishment of NHRP and deployment of WSR-57 radar
9. Grady Norton died of a stroke during Hazel of 1954, succeeded by Gordon Dunn
10. Audrey of 1957 killed ~390 in Cameron Parish LA. Good forecasts, poor communications
11. Donna of 1960 affected E Coast from Florida to Maine, killed 354 total, but only 50 US
12. Satellites:
    a. Tyros (polar orbit, NOAA), launched in1960
    b. SMS (geosynchronous, GOES) 1974
13. Betsy of 1965 killed 76 in US
    a. Affected S. Florida & LA (CAT 3).
    b. Betsy's track was like Andrew's & Katrina's
    c. Became the design storm for New Orleans Levees

Hurricane Flying (LEC 25)

1. LTCOL Duckworth flies into the "Surprise" Hurricane of 1944
2. The 1944 disasters motivated establishing military reconnaissance
3. NOAA's Aircraft Operations Center currently flies 2 WP-3Ds and a Gulfstream IV (G-4)
    a. NOAA's Hurricane Research Division uses these airplanes to study hurricanes and other tropical weather
    b. They also do some routine reconnaissance
    c. The P-3's focus on hurricane structure, intensity, and tynamics
    d. The G-4's primary mission is to fly around hurricanes to improve specification of the steering flow and improve track forecasts (by about 20%)
4. Air Force (Reserve) flies WC-130J's for routine reconnaissance
5. Penetration strategy
    a. Maintain attitude and airspeed
    b. Fly perpendicular to the wind into storm center
6. Kinds of aircraft data
    a. Flight-level data
    b. Reflectivity radar.
    c. Doppler radar & wind.
    d. Microphsyics.
    e. Atmospheric soundings & track predictions
    f. Oceanic soundings & intensity

Remote Sensing (LEC 26)

1. Satellite types
    a. Polar orbiting: low orbits (~850 km), pass overhead twice a day, first was TIROS in 1960, current are NOAA Satellites
    b. Geostationary: High orbits (~34000 km), remain over a fixed point, first was SMS in 1974, current are GOES Satellites.

2. The Dvorak technique uses scene types and measurements from satellite imagery to estimate the strength of a tropical cyclone.
    a. T-numbers that typically increase by one each day after reaching T2
    b. Estimates combine "modeled" (MET) with "data" DT
    c. T-numbers range from T0 to T8
    d. > T 2.5 = Tropical Storm (40 mph)
    e. > T 4 = Hurricane (75 mph)
    f. > T 5.5 = Major Hurricane (111 mph)
3. Be able to recognize four basic scene types plus one
    a. Curved band pattern, TD to CAT 1 (T1-T4.5)
    b. Shear pattern, TD to TS (T1.5 to T3.5)
    c. Banding eye, CAT 1 (T4 to T 4.5)
    d. CDO pattern, TS to CAT 2 (T2.5 to T5)
    e. Eye pattern, CAT1 to CAT 5 (T4.5 to T 8)
4. Digital and Objective Dvorak get E numbers from IR temperature differences between eye and CDO
5. Microwave imagers like SSMI & AVHRR see cold rain against warm sea. Radar-like images
6. Airborne Scatterometer measures wind speed and direction by radar reflected from the surface
7. Airborne Stepped-Frequency Microwave Radiometer is a passive instrument that senses wind speed (but not direction) and rain rate by looking at microwave radiation emitted from the sea surface and rain between flight level and the sea.
8. Spaceborne Scatterometers—QuickSCAT & ERS-2—measure wind speed and direction from satellites. It has limitations in terms of maximum wind speed and sensor footprint.

Hurricane Modification (LEC 27)

1. Cloud seeding with Silver Iodide (and also frozen CO_2 in the early days)
    a. Intended to freeze supercooled water
    b. Dynamic seeding caused extra buoyancy from latent heat released
    c. Mainstream science in the 1940s – 1960s
2. Hurricane modification was part of the original NHRP mission
3. Two STORMFURY Hypotheses:
    a. First, trigger symmetric instability
    b. Second, build new outer eyewall through cloud seeding
4. Tried 8 times in 4 hurricanes with apparent 50% success:
    a. Esther, 1961; Beulah, 1963; Debbie, 1969; Ginger, 1971
5. <u>Abandoned because of:</u>
    a. Too little supercooled water (Hallett-Mossup process)
    b. Naturally occurring concentric eyewall cycles
    c. Political/ Legal problems, "Not in MY ocean…"

Forecasting (Lecture 28)

1. Track: Where is it going?
    a. Steady improvement for a half century
    b. In 1990s errors were 100, 200, 300 nmi at 24, 48, 72 h lead time
    c. Now 50, 100, 150 at same lead times
    d. Now HNC forecasts to 96 & 120h (4 & 5 days)

2. Intensity: How Strong is it?
    a. A work in progress…
    b. Factors: Shear, ocean heat content, eyewall cycles, …
    c. Rapid intensification is the big challenge
    d. High-resolution (< 3 km) models show promise
3. Distributions of rainfall and winds
4. Storm surge…SLOSH
    a. One size fits all based on MEOWS
    b. Zones for any TC, nonmajor hurricanes, major hurricanes
    c. Big payoff in preventing deaths
5. Timeliness: Forecasters live and die by it
6. Guidance—i.e. numerical models. Modern forecasts are an informed consensus of model predictions.
7. Advisories—Summary of current and expected weather
    a. Forecast---Prognostication of weather elements such as wind, temperature,…
    b. Watch---Expect hurricane (or tropical storm) conditions within 48 h
    c. Warning---Expect hurricane (or tropical storm) conditions within 36 h

Camille, Agnes, and 1970 (Lectures 29)

1. Gordon Dunn retires in 1967; succeeded by Robert Simpson; then by Neil Frank in 1973
2. Camille of 1969
    a. Second recorded US CAT5
    b. Killed 259, half due to surge, half due to flash floods inland
    c. Same time as Debbie Seeding
3. Agnes of 1973
    a. Affected FL Panhandle and Mid-Atlantic States
    b. Last storm before Katrina to kill > 100 in US (122)
4. Bay of Bengal (BoB) Cyclones
    a. BoB has two cyclone seasons that peak in May and November as ITC shifts
    b. BoB is the least active TC basin, but populations are very vulnerable
5. Bohla cyclone of 1970
    a. Killed 300,000 to 500,000; led to partition of Bangladesh from Pakistan
    b. Construction of shelters since 1991 has limited mortality
    c. Cyclone Sider of 2007 (~3500 dead, 1000 missing)

Tracy and Andrew (Lecture 30)

1. Tracy hit Darwin Australia on Christmas Day 1974
    a. Killed 65; AU$ 0.8B (1974) in damage
    b. Defining cyclone Down Under
2. US lull in damaging hurricanes 1973-2003, apart from Frederick (1979) and Hugo (1989) as costal populations doubled
    a. 1985 Season: 6 US landfalls, Juan did significant damage
    b. Gilbert of 1988 established a new record MSLP, 888 mb

3. Andrew of 1992
    a. Landfall Monday morning 24 August
    b. Originally estimated as CAT 4; increased to CAT 5 in 2002
    c. Killed 26; did $27B (1992 $) in damage
    d. Defining US hurricane disaster for a time….