RESPONDING TO A RISING TIDE

Coastal Storm Hazards for Cape Cod

Bob Thompson
National Weather Service Taunton, MA
COASTAL STORMS

• Types of coastal storms
  – Tropical Cyclones (e.g. hurricanes)
    • Hurricane Bob – August 19, 1991
  – Extratropical Cyclones (e.g. nor’easters)
    • Perfect Storm – October 30, 1991

• Impacts from Hurricanes and Nor’easters

• National Weather Service Resources

• Concluding Thoughts
NEW ENGLAND HURRICANES

Low Frequency, High Impact!

- Category 3 hurricanes
  - Great Colonial Hurricane of 1635
  - Hurricane of 1815
  - Hurricane of 1869
  - Great New England hurricane of 1938
  - Carol in 1954
- Strong Category 2 hurricane
  - Great Atlantic Hurricane of 1944
  - Edna in 1954
- Last land-falling hurricane
  - Bob in August 1991
A Preparedness Challenge

- No Category 3 hurricanes have made landfall in southern New England since 1954
  - And no hurricane at all since 1991
- Buildup in coastal population and infrastructure presents a high risk for life and property
- Most New Englanders have not experienced a worst case scenario and many no hurricane at all!
  - Inexperienced population!
Category 5 – Winds > 155 mph
Category 4 – Winds 131-155 mph
Category 3 – Winds 111-130 mph
Category 2 – Winds 96-110 mph
Category 1 – Winds 74-95 mph

Destructive potential of wind increases by the square of the wind speed!
Storm surge not closely correlated with hurricane category

Saffir-Simpson Scale
Hurricanes Come in Different Flavors

• 1938 or Carol Type Hurricanes
  – Most dangerous
  – Fast and furious

• Sandy Type Hybrid
  – May have tropical core but behaves like very severe nor’easter

• A Brusher - Earl or Edouard Type Hurricane
  – Brushes by coast
  – May be too close for comfort
  – Primary impacts may be rip currents and erosion
Jet Stream Interaction
Tropical Cyclones Impacting New England

Point at which New Englanders need to take action!
Key on approach of first tropical storm force squalls – not the eye!
Hurricane Impacts

- Wind
- Flooding Rains
- Coastal Flooding from Storm Surge and Waves
History can be a Guide to Our Future!

Wind

1938 Hurricane damage in Keene, NH

Gusts to 60 mph during Bob

1938 Hurricane took down over a billion trees in New England
- 91 million in just Windham County in northeast Connecticut
History can be a Guide to Our Future!

Flooding Rain

1938 Hurricane – Flooding in Winchendon

Tropical Storm Diane in 1955
Flash Flooding on route 44 in Putnam, CT

Tropical Storm Irene – Flash Flooding along the Deerfield River (and Conway Street) in Buckland

Photo: J. Brown
History can be a Guide to Our Future!

Flooding from Storm Surge

1938 Hurricane – 13 foot surge

Near worst case for Narragansett and Buzzards Bays

Hurricane Bob (1991) – 6 foot surge
Storm Surge for Category 3 Hurricane moving NNE at 50 mph
Storm Surge At Low Tide

Timing of Storm Critical!
Storm Surge At High Tide

Timing of Storm Critical!
New Developments from National Hurricane Center

- **Storm Surge Warnings**
  - Explicit Storm Surge Warning
    - versus implicit by a Hurricane Warning
  - Recommended by social scientists

- **Inundation mapping**
  - Visualization of inundation possible from a specific storm
  - Represents plausible worst case scenario (10% exceedance)
  - **Depicts where risk too high not to take action**
  - Does not incorporate wave runup/overwash
  - Currently only for tropical cyclones
Why is forecasting hard?
Hurricane Joaquin
115 PM EDT Wednesday September 30, 2015
Why is forecasting hard?

Hurricane Joaquin

Wed Sept. 30 AM models

Wed Sept. 30 PM models
Joaquin Forecasts from Two Main Stream Global Models

90 hour forecast from
- GFS Model
- ECMWF Model
Major Hurricane Joaquin:
Category 4 (130 mph sustained)
NHC Atlantic Track Error Trends

Error Reduction since 1990:

- 72 h: 67%
- 48 h: 65%
- 24 h: 58%
Sometimes, the clouds will telegraph their Intentions…
Anatomy of a Major Nor’easter

• Upper level wind energy
• Sharp lower level temperature gradient
The Basics

• Astronomical tide amplitude (Spring Tide?)
• Onshore wind speed
• Wind fetch (distance over water)
• Duration of strong winds headed toward shore
• Angle of wave train to shoreline
• Storm motion with respect to shoreline
• Size of wind field
• Wave period
  – Long period waves potentially more damaging
ASTRONOMICAL TIDES

• Spring Tide
  – During full and new moons
  – Moon and sun gravitational forces in alignment

• Neap Tide
  – Quarter moon phases
  – Moon and sun gravitational forces offsetting
Storm Surge and Wave Heights

Determined by:
- Wind Speed
- Wind Fetch
- Wind Duration

Hurricanes and Nor’easters both impact coastline with storm surge and waves

Coastal flooding and erosion result from storm surge on top of the astronomical tide and wave action on top of the storm tide.

Timing of the maximum storm surge is an important issue for those locations (e.g. New England) that have large tidal ranges.

**Storm Tide** (Total Still Water Level) = **Astronomical Tide + Storm Surge**

Waves contribute the following:
- Add to water level behind barrier beach via *overwash* (from wave runup)
- Cause damage to structures (sea walls, docks, homes, etc.) via *wave battery*
- Scour and transport beach sand via *erosion*
Timing Matters!

January 27, 2015 High Tide at Boston

Storm Surge at max storm tide = 3.35 feet (3.12 feet at time of actual astronomical high tide)

Max storm surge = 4.78 feet (approx. 30 minutes after time of low tide)
WHAT IF...

• The storm was about 6 hours faster and peak surge occurred at high tide:
  – $10.5 + 4.78 = \text{storm tide of 15.28 feet MLLW}$
  – Just above record water level of 15.1 feet MLLW set during the 1978 Blizzard

• The storm occurred the week before when we had a 12 foot MLLW astronomical tide:
  – Potential storm tide near 16.8 feet (would bring us to unchartered territory)
And WAVES MATTER!

Overwash

Splashover

Rule of thumb:
Along exposed coast, overwash and splashover can become important when waves about 10 miles offshore reach 20 feet or more
Wave Overwash

Elevation of top of staff gage is EL 16.6 which is approx level of ic

2/11/2013 9:37:14 AM
And Erosion Can Be a Big Issue

Misquamicut Beach – Westerly, RI (2 days after Sandy)
Wave Run-up

- Experimental program to help understand and forecast wave impact
  - Empirical technique being applied to “hot spots”

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These are the individual output parameters

- $R_{2\%}$: 4.19, 1.28
- $R_{\text{Swash}}$: 3.19, 0.97
- $R_{\text{Setup}}$: 1.00, 0.30

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NOTE: During times when the area is under a Tropical Storm/Hurricane Watch or Warning, the storm tide or total water level forecast will reflect a plausible worst case scenario (versus the usual most likely scenario).
Coastal Flood Threat and Inundation Mapping

Inundation Extent at 12ft MLLW

Scituate
High Tide
Day/Time: 02/04 AM
(Time rounded to nearest hour)

Astro Tide 8.6 ft
  + Surge -0.1 to 0.9 ft
Total Water Level 8.5 to 9.5 ft
  + Waves 3-4 ft
Flood Category NONE

View Hourly Graph of TWL forecast

NOTE: During times when the area is under a Tropical Storm/Hurricane Watch or Warning, the storm tide or total water level forecast will reflect a plausible worst case scenario (versus the usual most likely scenario).
COASTAL FLOOD HEADLINES
Extratropical Storms (e.g. Nor’easters)

• Coastal Flood Watch
  – Potential for moderate or greater coastal flooding
  – Generally 36 to 48 hours lead time

• Coastal Flood Warning
  – Moderate or major coastal flooding likely/expected
  – Generally 24 to 36 hours lead time

• Coastal Flood Advisory
  – Minor coastal flooding likely/expected
  – Generally 24 to 36 hours lead time
HEADLINE CRITERIA

- Minor – Coastal Flood Advisory
- Moderate or Major = Coastal Flood Warning
Coastal flood impacts appearing in TWLBOX are a function of water level and waves (derived from staff experience and local studies)

### Scituate

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Product Example

COASTAL HAZARD MESSAGE
NATIONAL WEATHER SERVICE TAINTON MA
443 RM EST FRI FEB 8 2013

...COASTAL FLOOD WARNING FOR THE MASSACHUSETTS EAST FACING COASTLINE AROUND THE TIME OF THIS EVENINGS AND SATURDAY MORNINGS HIGH TIDES...

A powerful coastal storm will produce moderate coastal flooding this evening and moderate to major coastal flooding Saturday morning along with severe erosion in some spots. Very large waves on top of an above normal tide will likely cause a number of vulnerable shore roads to become impassable for a while...and may cause damage to homes along the immediate shoreline from Hull to Sandwich during the Saturday morning high tide. Very large breakers crashing onto the shoreline may make it unsafe to remain in some exposed ocean front homes.

MAZ007-013-016-019-022>024-080548-
/-O.CON.EBOK.CP.W.0001.149209T.01007-130209T1700Z/
EASTERN ESSEX MA-EASTERN SUFFOLK MA-EASTERN NORTFOLK MA-
EASTERN PLYMOUTH MA-BARNSTABLE MA-DUKES MA-NANTUCKET MA-
443 RM EST FRI FEB 8 2013

...COASTAL FLOOD WARNING REMAINING IN EFFECT FROM 8 PM THIS EVENING TO MON. EST SATURDAY...

* LOCATION...EAST FACING COASTLINE OF MASSACHUSETTS

* COASTAL FLOODING...MODERATE COASTAL FLOODING IS LIKELY FOR THIS EVENINGS HIGH TIDE AND MODERATE TO MAJOR COASTAL FLOODING IS LIKELY FOR THE SATURDAY MORNING HIGH TIDE...WITH THE MOST SEVERE IMPACT EXPECTED ALONG EAST AND NORTH FACING SHORELINES SOUTH OF BOSTON.

* TIMING...THIS EVENING AND SATURDAY MORNING HIGH TIDES

* IMPACTS...A NUMBER OF SHORE ROADS WILL LIKELY BECOME IMPASSABLE FOR A TIME FRIDAY EVENING...COASTAL FLOODING AROUND THE SATURDAY MORNING HIGH TIDE WILL LIKELY CAUSE NUMEROUS SHORE ROADS TO BECOME IMPASSABLE AND PUT SOME STRUCTURES AT RISK ALONG THE IMMEDIATE SHORE. ESPECIALLY THOSE VULNERABLE LOCATIONS SOUTH OF BOSTON. ESPECIALLY THOSE VULNERABLE LOCATIONS SOUTH OF BOSTON FROM HULL TO SANDWICH. SEVERE BEACH EROSION WILL ALSO OCCUR IN SOME LOCATIONS...ESPECIALLY DURING THE SATURDAY MORNING HIGH TIDE. THE PRIMARY CONCERN WITH THE SATURDAY MORNING HIGH TIDE WILL BE VERY LARGE BREAKERS CRASHING...INTO THE SHORELINE.

SCITUATE

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NOTE: During times when the area is under a Tropical Storm/Hurricane Watch or Warning, the storm tide or total water level forecast will reflect a plausible worst case scenario (versus the usual most likely scenario).
HAZARDOUS WEATHER OUTLOOK (HWO)

• Issued every early morning
• Potential hazardous weather out to 7 days
• May be your first clue of a local concern!
• Threat evolution
  – May not appear too ominous at first (especially if time period is greater than 5 days)
    • But let that be your signal for higher situational awareness
  – Monitor evolution of threat with time (e.g. increasing or decreasing threat)
• Check HWO daily to maintain situational awareness
AREA FORECAST DISCUSSION (AFD)

• Explains the rationale behind the warning and forecast decisions (i.e., the “why” of the forecast)
• Favorite product for many broadcast meteorologists
• Confidence level and degree of uncertainty
• May indicate alternative scenarios possible
• A way to get inside our heads
Area Forecast Discussion

Friday morning March 18, 2016

LONG TERM /SATURDAY NIGHT THROUGH THURSDAY/...

HIGHLIGHTS FOR LATE SEASON WINTER STORM POTENTIAL SUN PM/MON AM:

* SIGNIFICANT WINTER STORM STILL POSSIBLE FOR AT LEAST PART OF THE REGION
* LOW CONFIDENCE ON BEST CHANCE FOR SIGNIFICANT SNOWFALL
* WESTERN TRACK: SIGNIFICANT SNOW POTENTIAL ACROSS INTERIOR WITH DRY SLOT/PTYPE ISSUES ON THE COASTAL PLAIN
* EASTERN TRACK: LIGHTER SNOWFALL ACROSS THE INTERIOR WHILE SIGNIFICANT SNOW POTENTIAL OCCURS ACROSS EASTERN MA/RI

DETAILS...

SUNDAY INTO MONDAY....

A FAIRLY COLD AIRMASS WILL BE IN PLACE FOR LATE MARCH EARLY SUNDAY MORNING WITH HIGH PRESSURE ACROSS EASTERN CANADA. AT THE SAME TIME...A POTENT CLOSED UPPER LEVEL DISTURBANCE WILL BE APPROACHING FROM THE WEST AND INTERACT WITH NORTHERN STREAM ENERGY. THE STRENGTH AND TIMING OF THE ENERGY WILL DETERMINE THE STRENGTH/TRACK OF THE STORM WHERE HEAVIEST SNOWFALL OCCURS.

NORMALLY AS YOU GET CLOSER TO AN EVENT CONFIDENCE IN A GIVEN SCENARIO INCREASES...BUT THE OVERNIGHT MODEL RUNS ACTUALLY DID THE OPPOSITE. NOW THAT DOES OCCASIONALLY HAPPEN...PARTICULARLY WHEN THE MAIN EVENT IS STILL OUTSIDE 72 HOURS IN THE MODEL WORLD.

TO SUMMARIZE...THE EARLIER 12Z INTERNATIONAL MODELS SHOWED A RAPIDLY INTENSIFYING LOW PRESSURE SYSTEM PASSING NEAR THE CAPS/ISLANDS. THIS SCENARIO WOULD BRING A LARGE SWATH OF 6 TO 12+ INCHES OF SNOW ACROSS INTERIOR MA AND NORTHERN CT WITH THE HELP OF A POTENT BACKBENT MID LEVEL WARM FRONT....WHILE MUCH OF EASTERN MA/RI WOULD RECEIVE A FRONT END THUMP OF HEAVY SNOW AND THEN HAVE DRY SLOT/PTYPE ISSUES. STRONG WIND GUSTS OF 40 TO 55 MPH WILL ALSO BE A CONCERN FOR A TIME ALONG THE COAST. MEANWHILE...THE 12Z AMERICAN MODELS SHOWED A WEAKER AND MORE PROGRESSIVE LOW PRESSURE SYSTEM CONFINING MOST OF THE SIGNIFICANT SNOW TO EASTERN MA/RI WITH LIGHTER SHOWS BACK INTO THE INTERIOR.

AT 00Z...THE NAM JOINED THE 12Z INTERNATIONAL MODELS SHOWING A POTENT SETUP FOR HEAVY SNOW ACROSS THE INTERIOR WITH A FRONT END THUMP FOLLOWED BY DRY SLOT/PTYPE ISSUES ON THE COASTAL PLAIN. HOWEVER...THE LATEST 00Z OPERATIONAL ECMWF WHICH HAD BEEN CONSISTENT TRENDED SIGNIFICANTLY FURTHER EAST AND_weekener. THIS WOULD CONFINE SIGNIFICANT SNOW POTENTIAL TO EASTERN MA/RI WITH A LIGHTER SNOWFALL BACK INTO THE INTERIOR. ECMWF ENSEMBLES ALSO TRENDED FURTHER EAST...BUT THERE WAS STILL A LARGE SPREAD WITH SOME STILL SHOWING BIG HITS ACROSS THE INTERIOR...BUT MORE ACROSS EASTERN NEW ENGLAND. AS FOR THE GFS...IT REMAINED THE WEAKEST AND FURthest EAST SOLUTION BUT ITS INDIVIDUAL ENSEMBLE MEMBERS STILL SHOWED A LARGE POTENTIAL RANGE IN POSSIBLE OUTCOMES.

SO IN A NUTSHELL...A SIGNIFICANT WINTER STORM IS STILL POSSIBLE FOR AT LEAST A PORTION OF SOUTHERN NEW ENGLAND. THE MAIN QUESTION IS WHERE DOES THIS OCCUR. A LOT OF THE 00Z GUIDANCE...BUT CERTAINLY NOT ALL OF IT SHIFTED THE POTENTIAL OF HEAVIEST SNOW ACROSS EASTERN MA/RI. HOWEVER...THE INTERIOR BY NO MEANS IS OUT OF THE WOODS AS SOME OF THE GUIDANCE STILL HAS THE FOCUS OUT IN THAT REGION. THE SPREAD IN THE ENSEMBLES AND SUBTLE TIMING DIFFERENCES IN SHORTWAVE INTERACTION TELL US IT'S TOO EARLY TO LOCK IN A SPECIFIC SCENARIO.
Looking to the Future

• Rising sea level
  – Expect more frequent coastal flooding
  – New record total water levels
  – Raises the impact stakes
STORMREADY

Boston – May 20, 2009
WeatherReady Nation Goals Include

• Accurate and timely forecasts and warnings
  • Integration of cutting edge science into operations
• Understanding of and effective response to weather information by partners/customers
  • Emphasis on Impact Decision Support Services
Impact Decision Support Services

• Supports WeatherReady Nation goal
  – Provide weather information that enables Americans to respond effectively to weather hazards and achieve high level of resilience
  – Information to enable effective decisions by officials
    • Public Safety
    • Preservation of natural and human resources

• Take on different forms
  – High Impact Storm
    • Blast emails (sometimes with Powerpoint Briefings), conference calls, Hazardous Weather Outlooks, Special Statements, social media posts, etc.
  – Special Event Support
    • Major such as July 3rd-4th Esplanade or Boston Marathon
    • Smaller but still with significant public safety risk
      – Regattas, concerts, sporting events, large flea markets, fairs, etc.
Take Away Thoughts

• Cape Cod vulnerable to both hurricanes and nor’easters
  – Hurricanes more extreme but nor’easters more frequent
  – Hurricanes usually greater threat to south side and nor’easters usually greater threat to east side

• Inexperienced population

• Warning => Risk Too High => Take Action if vulnerable

• Expect more frequent and severe coastal flooding and erosion episodes with continued sea level rise
PREPAREDNESS!

New England snowstorm indicators...

LIGHT

MILK

MODERATE

MILK

NOR'EASTER

BEER
Assess Vulnerability, Make Plan, and Act on Plan before too late!
“Natural calamity strikes at just about the time that one forgets its terror.”

-- Japanese Proverb
THANK YOU!