Overview of Bering/Chukchi Sea Wave States for Selected Severe Storms

Abstract # A33B-0147

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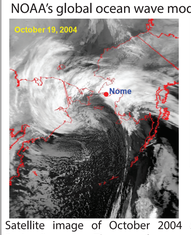
Abstract

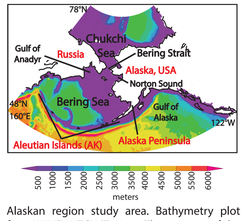
Strong storms are regular features over the ocean west of Alaska. These systems often loiter, generating moderate to severe marine states which can exhibit persistence, maximizing damage and hazard potential. This analysis presents the wave states associated with selected storms over the Bering and Chukchi Seas. These include the damaging events of October 2004, September 2005, and November 2009, along with a strong event from September 2011 that exhibited north winds. For each event a brief synoptic overview is presented followed by consideration of the resultant wave state, including parameters such as wave steepness. Wave data come from NOAA's WAVEWATCH III operational global ocean wave model, implemented locally on the Arctic Region Supercomputing Center at University of Alaska Fairbanks. Comparison with observational data gathered by a wave buoy, funded by the US Environmental Protection Agency/NOAA and deployed in 2011, is also undertaken.

Introduction

Strong storms over the Bering and Chukchi Seas are common occurrences with the potential to cause significant impacts and damage to the Alaskan coastal region. These storm systems often stall over the ocean creating severe wave states and increasing hazard potential. The associated strong winds and high waves can result in coastal flooding, erosion, and structural damage amounting to millions of dollars. A major Bering Sea storm in October 2004 resulted in high winds of approximately 50-80 mph (22-36 m/s), storm surges up to 3.6 meters (12 feet), and an estimated $20 million of damage with the majority of damage sustained in the coastal village of Nome, AK. This research analyzes the wave states in the Bering and Chukchi Seas associated with this severe October 2004 storm along with major storms in September 2005, November 2009, and September 2011. Wave states in the Alaskan region are analyzed using NOAA's global ocean wave model WAVEWATCH III.



Satellite image of October 2004 Bering Sea storm. The coastal village of Nome, AK is indicated.



Alaskan region study area. Bathymetry plot from WAVEWATCH III. Note: The majority of the Aleutian Islands are unresolved in the model.

Global Ocean Wave Model: NOAA's WAVEWATCH III

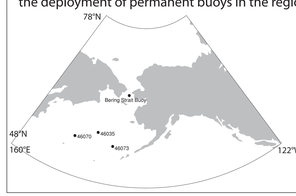
WAVEWATCH III version 3.14 (WW3) is a full-spectral third-generation wind-wave model developed at the Marine Modeling and Analysis Branch of the Environmental Modeling Center of the National Centers for Environmental Prediction. Governing equations include refraction of the wave field due to variations in mean water depth, wave growth and decay due to wind action, nonlinear resonant interactions, dissipation, bottom friction, and dynamically updated ice coverage.

WW3 grid resolution for the Alaskan region is 0.25°x0.50°. 10-meter wind and sea ice input data is from the Global Forecast System (GFS) with 1°x1° resolution and are updated every 6 and 24 hours, respectively. Within WW3, sea ice with a concentration less than 50% is considered open water while sea ice with a concentration greater than 50% is treated as 'land' with no wave energy transferred. Model runs begin with calm ocean conditions and a ~10 day spin-up is necessary to develop realistic wave heights.

WW3 is run on the Penguin Computing Cluster at the Arctic Region Supercomputing Center at the University of Alaska Fairbanks.

Bering Sea Buoys

WAVEWATCH III significant wave height output are compared against observed wave heights at Bering Sea buoys 46070, 46035, and 46073 depending on buoy data availability and proximity to storm center. Buoy data is obtained from NOAA's National Data Buoy Center. Additional observed wave height data is provided by a buoy deployed in the Bering Strait during the summer of 2011. This Bering Strait buoy was sponsored by the US Environmental Protection Agency and NOAA. No observed wave height data is available in the Chukchi Sea due to sea ice preventing the deployment of permanent buoys in the region.



Bering Sea Buoy 46070: 55.083°N 175.270°E

Bering Sea Buoy 46035: 57.067°N 177.750°W

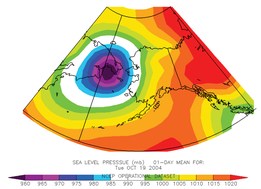
Bering Sea Buoy 46073: 55.011°N 171.981°W

Bering Strait Buoy: 65.000°N 168.750°W

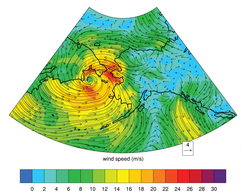
October 2004 Storm

Storm Dates: 18-24 October 2004

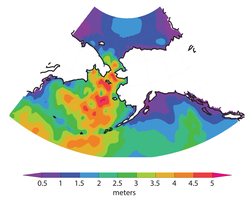
A low pressure system moved north over the central Aleutian Islands into the Bering Sea on the evening of 17 October 2004. By the evening of the 18th, the storm had deeped with central pressure decreasing from 978 mb to 941 mb and was centered over the Gulf of Anadyr. Although the storm began to weaken on the 19th and central pressure increased to 980 mb on the 20th, the system loitered over the general area for the next few days. The storm produced winds of 50-80 mph and storm surge up to 12 feet. The resulting damage across coastal western Alaska was estimated at $20 million with Nome, AK sustaining the majority of the damage. Regional damage included coastal flooding, structural damage to residential and commerical buildings, roadway damage, seawall and jetty damage in the harbour, and minor damage to the village's water treatment system. Impacts and damage estimates from National Weather Service post-storm assessment.



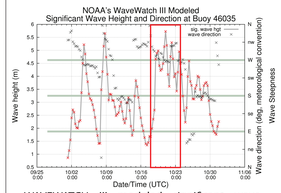
Mean sea level pressure on 19 October 2004. Low pressure system is located over the Gulf of Anadyr and has just begun to weaken. Figure from NOAA's Earth System Research Laboratory, Physical Sciences Division.



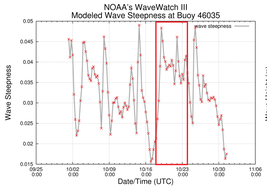
GFS 10-meter wind field at 19 October 2004 00Z utilized by WAVEWATCH III. Westerly winds are observed over the Bering Sea, easterly winds over the Chukchi Sea, and southerly winds impact much of western Alaska.



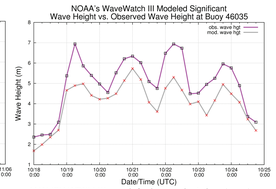
WAVEWATCH III modeled significant wave heights at 19 October 2004 00Z. Maximum wave heights of 4.5-5.5 meters are located in the center of the Bering Sea.



WAVEWATCH III modeled significant wave heights and direction at Buoy 46035 (central Bering Sea). Storm dates are highlighted.



WAVEWATCH III modeled wave steepness (wave height to wave length ratio) at Buoy 46035 (central Bering Sea). Storm dates are highlighted.

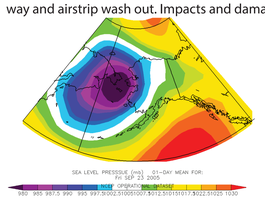


WAVEWATCH III modeled wave heights (gray) vs. observed wave heights (purple) at Buoy 46035 (central Bering Sea) for the storm dates.

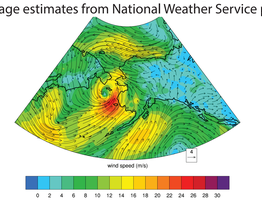
September 2005 Storm

Storm Dates: 21-26 September 2005

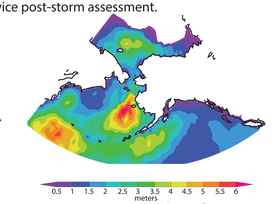
A low pressure system moved north over the eastern Bering Sea on 22 September 2005. Early on the 23th, the storm strengthened to a central pressure of 966 mb and was located over the Bering Strait. The system then stalled over the northern Bering Sea for approximately 3 days. The storm produced wind gusts of ~65 mph in coastal regions of Norton Sound and southern Chukchi Sea. Aided by the already elevated sea levels due to a weaker storm the day earlier, 9 foot storm surges and 10-15 foot wind-waves were observed in the northern Bering Sea in addition to 4 foot storm surges and 5-10 foot wind-waves in the southern Chukchi Sea. The resulting damage along the coasts of Norton Sound and the southern Chukchi Sea was estimated at roughly $2 million. Regional damage included coastal flooding, up to 30 feet of beach erosion, minor structural damage to residential and commerical buildings, and roadway and airstrip wash out. Impacts and damage estimates from National Weather Service post-storm assessment.



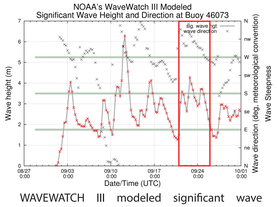
Mean sea level pressure on 23 September 2005. Low pressure system is located just south of the Bering Strait and is near peak strength. Figure from NOAA's Earth System Research Laboratory, Physical Sciences Division.



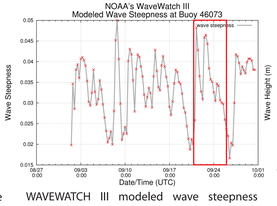
GFS 10-meter wind field at 23 September 2005 00Z utilized by WAVEWATCH III. Southwesterly winds are observed over the Bering Sea, easterly winds over the Chukchi Sea, and southerly winds impacting much of western Alaska.



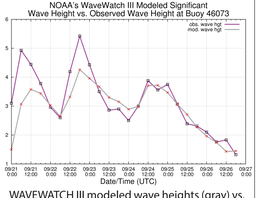
WAVEWATCH III modeled significant wave heights at 23 September 2005 00Z. Maximum wave heights of ~5.5 meters are located in southeast Bering Sea. Note: Sea ice in the Arctic is represented in white.



WAVEWATCH III modeled significant wave heights and direction at Buoy 46073 (southeast Bering Sea). Storm dates are highlighted.



WAVEWATCH III modeled wave steepness (wave height to wave length ratio) at Buoy 46073 (southeast Bering Sea). Storm dates are highlighted.

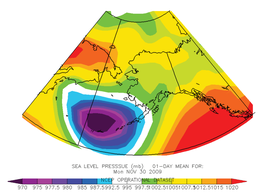


WAVEWATCH III modeled wave heights (gray) vs. observed wave heights (purple) at Buoy 46073 (southeast Bering Sea) for storm dates.

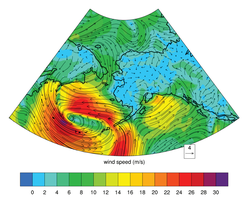
November 2009 Storm

Storm Dates: 27 November 2009 - 4 December 2009

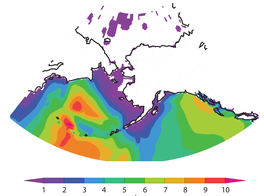
A low pressure system moved east-northeast over the southern Bering Sea November 29 - December 2, 2009. The storm reached peak strength on 30 November 2009 with a central pressure of approximately 960 mb and was centered over the south central Bering Sea. The storm produced high winds of 60-80 mph with peak gusts around 100 mph. The associated high surf across the Aleutian Islands and Alaska Peninsula resulted in coastal flooding. The storm also produced heavy snow and blizzard conditions across the Bering Sea coastal region. The National Weather Service does not have damage estimate records for this storm. Impacts report from National Weather Service post-storm assessment.



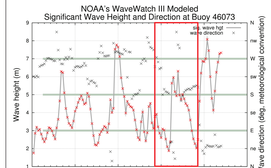
Mean sea level pressure on 30 November 2009. Low pressure system is located over south central Bering Sea and is near peak strength. Figure from NOAA's Earth System Research Laboratory, Physical Sciences Division.



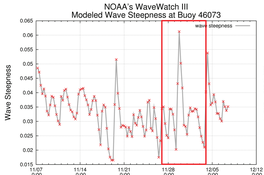
GFS 10-meter wind field at 30 November 2009 00Z utilized by WAVEWATCH III. Westerly winds are observed along the Aleutian Islands while easterly winds are observed over much of the Bering Sea.



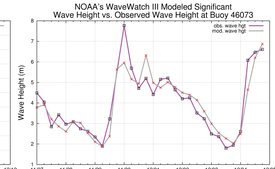
WAVEWATCH III modeled significant wave heights at 30 November 2009 00Z. Maximum wave heights of 9-10 meters are located in west and southwest Bering Sea. Note: There is extensive sea ice, represented in white, in the Arctic, Chukchi Sea, and in the Norton Sound regions.



WAVEWATCH III modeled significant wave heights and direction at Buoy 46073 (southeast Bering Sea). Storm dates are highlighted.



WAVEWATCH III modeled wave steepness (wave height to wave length ratio) at Buoy 46073 (southeast Bering Sea). Storm dates are highlighted.

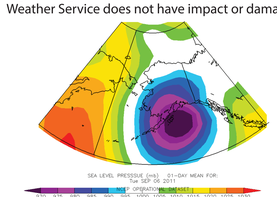


WAVEWATCH III modeled wave heights (gray) vs. observed wave heights (purple) at Buoy 46073 (southeast Bering Sea) for the storm dates.

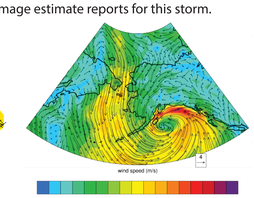
September 2011 Storm

Storm Dates: 5-9 September 2011

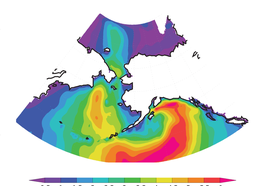
A low pressure system loitered over the Alaska Peninsula region September 5-8, 2011. The storm reached peak strength on 6 September 2011 with a central pressure of approximately 960 mb while centered just southeast of the Alaska Peninsula. The storm produced high wind gusts of 65-70 mph along the Aleutian Islands and wind-wave heights up to 4.5 meters within the Bering Sea. The National Weather Service does not have impact or damage estimate reports for this storm.



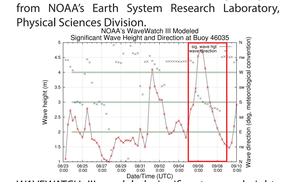
Mean sea level pressure on 6 September 2011. Low pressure system is located just southeast of the Alaska Peninsula and is near peak strength. Figure from NOAA's Earth System Research Laboratory, Physical Sciences Division.



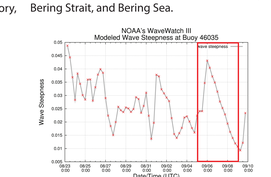
GFS 10-meter wind field at 6 September 2011 00Z utilized by WAVEWATCH III. Northerly winds are observed over the Chukchi Sea, Bering Strait, and Bering Sea.



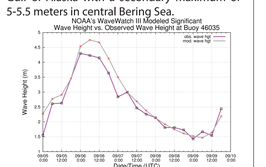
WAVEWATCH III modeled significant wave heights at 6 September 2011 00Z. Maximum wave heights of 6+ meters are located in the Gulf of Alaska with a secondary maximum of 5-5.5 meters in central Bering Sea.



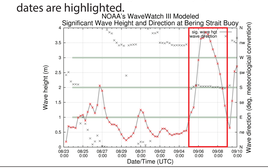
WAVEWATCH III modeled significant wave heights and direction at Buoy 46035 in central Bering Sea (above) and at Bering Strait Buoy (below). Storm dates are highlighted.

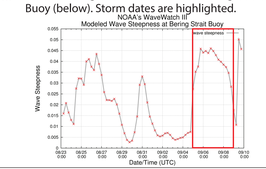


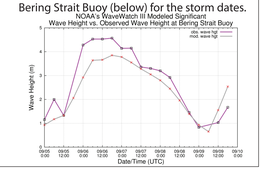
WAVEWATCH III modeled wave steepness (wave height to wave length ratio) at Buoy 46035 in central Bering Sea (above) and at Bering Strait Buoy (below). Storm dates are highlighted.



WAVEWATCH III modeled wave heights (gray) vs. observed wave heights (purple) at Buoy 46035 in central Bering Sea (above) and at Bering Strait Buoy (below) for the storm dates.







Results

October 2004 Storm:

- With the system loitering over the Gulf of Anadyr region, there is a rapid onset and slow decline of large, steep wind-waves, typical of stalled storms, in the Bering and Chukchi Seas.
- WW3 modeled significant wave heights of ~5-5.5 meters persist throughout the storm dates within the Bering Sea while significant wave heights reach ~3.5-4 meters at the storm peak (Oct. 19) in the Chukchi Sea.
- At Buoy 46035 (central Bering Sea), WW3 underestimates wave heights by approximately 0.5-2 meters during the storm dates.

September 2005 Storm:

- With the system stalled over the northern Bering Sea, there is rapid onset of large, steep wind-waves in the Bering and Chukchi Seas. The wind-waves experience a slow decline in height and steepness until the system stops loitering, resulting in an abrupt decline.
- WW3 modeled significant wave heights greater than ~3.5 meters persist throughout the storm dates within the Bering Sea and reach ~6 meters at the storm peak (Sept. 23). Significant wave heights in the Chukchi Sea reach ~2-3 meters throughout the storm dates.
- At Buoys 46073 (southeast Bering Sea) and 46035 (central Bering Sea, data not presented), WW3 underestimates peak wave heights by ~1 meter during the storm dates.

November 2009 Storm:

- With the storm moving across the Aleutian Islands, there is rapid onset and relatively rapid decline of large, steep wind-waves in the Bering Sea. The continued movement of the system prevents sustained large, steep wind-waves.
- WW3 modeled significant wave heights greater than ~4 meters persist throughout the storm dates within the southern Bering Sea while significant wave heights reach ~9 meters at the storm peak (Nov. 30). There is extensive sea ice in the Chukchi Sea preventing wave development in the region.
- At Buoy 46073 (southeast Bering Sea), WW3 underestimates wave height by ~2 meters at the peak of the storm but overestimates a secondary peak in wave height by ~1 meter during the storm dates.

September 2011 Storm:

- With the storm loitering over the Alaska Peninsula, there is rapid onset of large steep wind-waves within the Bering Sea. The decline of these wind-waves becoming increasingly rapid as the system meanders around the Alaska Peninsula region. Wind-waves in the Chukchi Sea experience rapid onset and decline of large, steep wind-waves.
- WW3 modeled significant wave heights of ~4-5 meters persist throughout the storm dates within the Bering Sea while significant wave heights reach ~4 meters at the storm peak (Sept. 6) in the Chukchi Sea.
- WW3 underestimates peak wave heights by ~0.5-1 meters at Buoy 46070 (southwest Bering Sea, data not presented) and the Bering Strait Buoy while overestimating peak wave heights by ~0.5 meters at Buoy 46035 (central Bering Sea) during the storm dates.

Conclusions

- Storm systems located in the northern Bering Sea, Bering Strait, and Chukchi Sea regions generally produce westerly winds over the Bering Sea, easterly winds over the Chukchi Sea, and southerly winds impacting western Alaska. These storms can produce large, steep wind-waves in both the Bering and Chukchi Seas (peak wave heights in the Bering Sea) that have the potential to cause significant damage to coastal regions in western Alaska. Stalled and loitering systems, such as the October 2004 and September 2005 storms, cause these wind-waves to have rapid onsets and slow declines, increasing wave heights and hazard potential.
- Storm systems located over the Aleutian Islands generally produce easterly winds over much of the Bering Sea and westerly winds impacting the island chain. These storms can produce significant wave heights in the Bering Sea which have the potential to cause coastal flooding and damage along the Aleutian Islands. Storms that do not loiter, such as the November 2009 storm, produce large, steep wind-waves which have rapid onsets and relatively rapid declines.
- Storm systems located over the Alaska Peninsula generally produce northerly winds over the Chukchi Sea, Bering Strait, and Bering Sea. These storms can produce large, steep wind-waves in both the Chukchi and Bering Seas. Even with the system loitering and/or slowly meandering around in the general region of the Alaska Peninsula, wind-waves have rapid onset and decline, with the speed of decline increasing with latitude.
- Overall, WAVEWATCH III underestimates wave heights within the Bering Sea and Bering Strait during all three types of storms. WW3 has particular difficulty in reconstructing peak wave heights and when the storm centers move over the immediate area.

Future Work

- Run sensitivity tests and tune WAVEWATCH III for the Alaskan region (e.g. increase drag coefficient to allow larger wind-waves to develop and reducing underestimation).
- Run WW3 with nested grids (include 1/16° x 1/8° Alaskan coastal grid) allowing the Aleutian Islands to be resolved and wave states in the region to be more realistic.
- Complete storm model runs with different wind and ice data for comparison against GFS-driven model runs.

References

- Tolman, 2009: User manual and system documentation of WAVEWATCH III version 3.14. NOAA/NWS/NCEP/MMAB Technical Note 276, 194 pp + Appendices.
- National Weather Service, Environmental Modeling Center, WAVEWATCH III Model: http://polar.ncep.noaa.gov/waves/wavewatch/wavewatch.shtml
- WAVEWATCH III source code distributed as public domain software.
- Global Forecast System 10-meter wind and sea ice data obtained from NOAA National Operational Model Archive & Distribution System: http://nomads.ncdc.noaa.gov/
- Bering Sea buoy data obtained from NOAA National Data Buoy Center: http://www.ndbc.noaa.gov/

Acknowledgements

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