Lost at Sea: Hurricane Force Wind Fields and the North Pacific Ocean Environment

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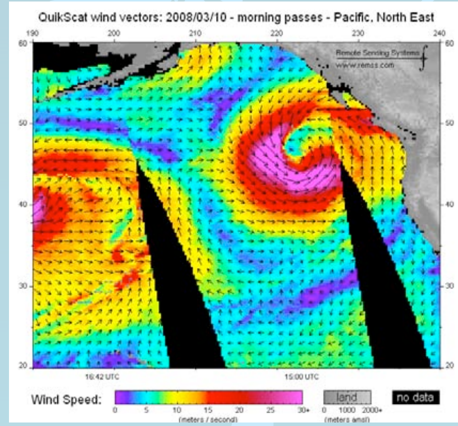
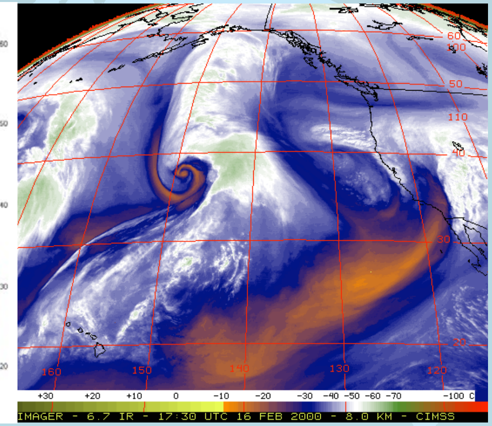




Unidata Policy Committee Meeting 5/15/2012
Steven Businger, University of Hawaii at Manoa
This research is supported by ONR

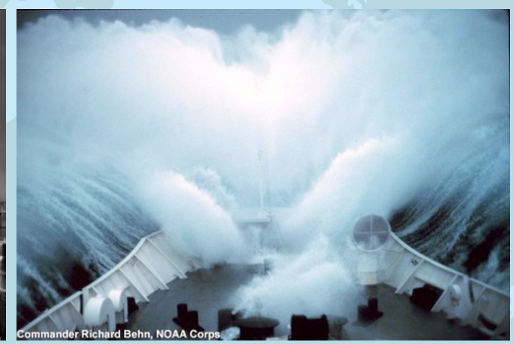
Hurricane Force (HF) Wind Fields

Outline

- Motivation – Lost at Sea
- Background: Nature of Ocean Hazard and Explosive Cyclogenesis
- Impacts of HF Wind Fields on the West Coast and Hawaii
- Climatology of HF Wind Fields over North Pacific Ocean
- Evaluation of GFS and WWIII Performance
- Conclusions
- Future Work

Motivation

to help raise awareness of the hazards created by hurricane force winds in extratropical cyclones and their relationship with extreme open-ocean and coastal sea states in the North Pacific.


Commander Richard Behn, NOAA Corps

Lost at Sea

"One large ship sinks every week on average worldwide, but the cause is never studied to the same detail as an air crash. It simply gets put down to 'bad weather.'" Dr. Wolfgang Rosenthal, lead scientist for the MaWave Project convened in 2000 to investigate the disappearance of ships.

"Severe weather has sunk more than 200 supertankers and container ships exceeding 200 metres in length during the last two decades. Rogue waves are believed to be the major cause in many such cases". A press release by the European Space Agency in 2004

Lost at Sea

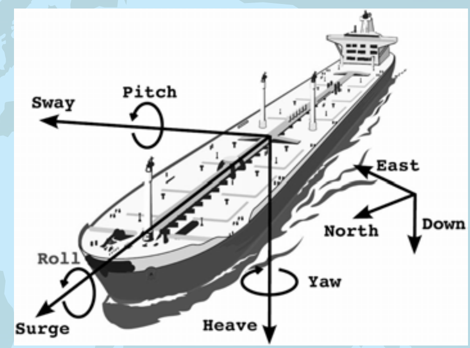
- Every hour, on average, one large shipping container is falling overboard never to be seen again.
- ~10,000 of these large containers are lost at sea each year.

Possible Causes of the Losses

- Rouge Waves – (aka freak waves) – waves whose height is more than twice the significant wave height (SWH), which is defined as the mean of the largest third of waves in a wave record.
- Rogue waves occur where physical factors such as **extreme wind fields** and strong currents cause waves to merge to create a single exceptionally large wave.
- Synchronous rolling – takes place because of resonance between the natural period of roll of the ship & the natural period of the oscillation of the waves. The rolling will gradually increase to high capsizing values.
- Parametric roll – occurs when natural roll period is between 1.8 to 2.1 times the encounter period (normally associated with the pitching period)

*Stability Analysis of Parametric Roll Resonance. B.J.H. van Laarhoven DCT 2009.062

Parametric Roll



The cruise ship Voyager in Cyclone Valentina (Mediterranean Sea), on February 14th 2005.

The larger the flare on container ships the more likely is the parametric roll occurrence and wider the range of resonance.

It requires a group of waves above a threshold or critical height for parametric roll to be initiated and sustained. The threshold depends on hull size and shape.

Parametric Roll

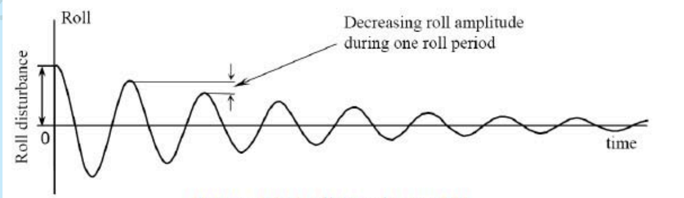


Figure 2.4: Roll in calm sea [2]

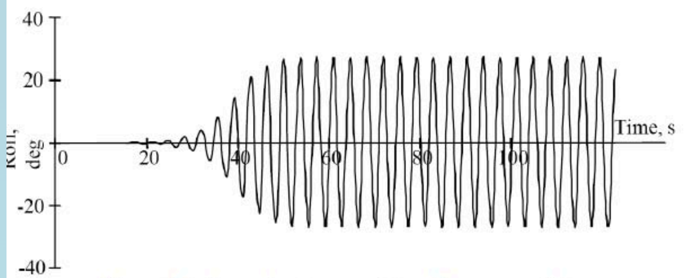
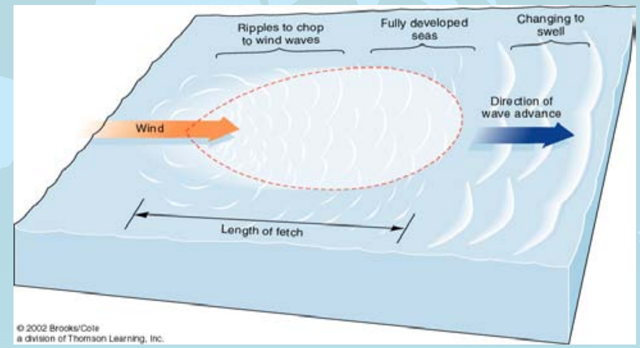


Figure 2.5: Example of parametric roll resonance [2]

Factors Affecting Wind Wave Development

The following factors control the size of wind waves:

1. Wind strength
2. Wind duration
3. Fetch - the uninterrupted distance over which the wind blows without changing direction.
4. Air-sea temperature difference
5. Ocean depth



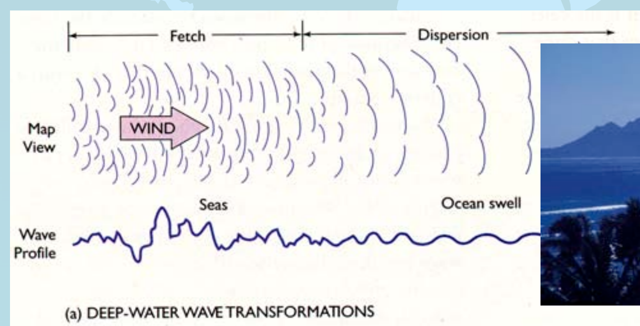
Wave Steepness and Ship Hazard

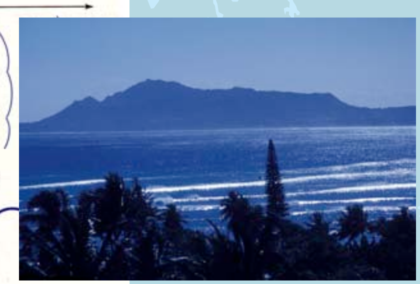
- Wave steepness= Wave Height/ Wave Length
- Young waves are steeper than older waves
- Steep waves pose significant risk to marine vessels en route
- The wave steepness in 60% of the global ship accidents ranged from .03 to .04.

Swell and Wave Lifecycle

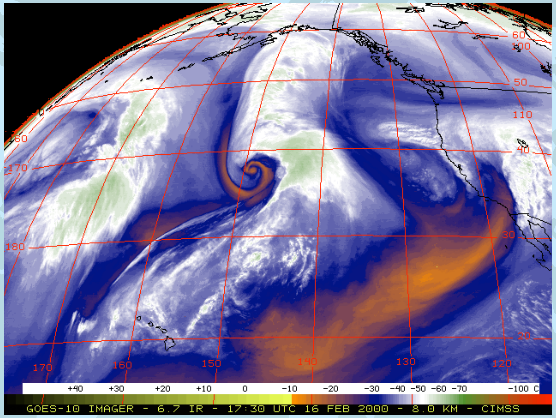
Three things happen to large waves when they leave the storm region.

1. Dissipation – internal friction
2. Dispersion – $C = (gL/2\Pi)^{1/2}$
3. Angular spreading – broad fetches favored





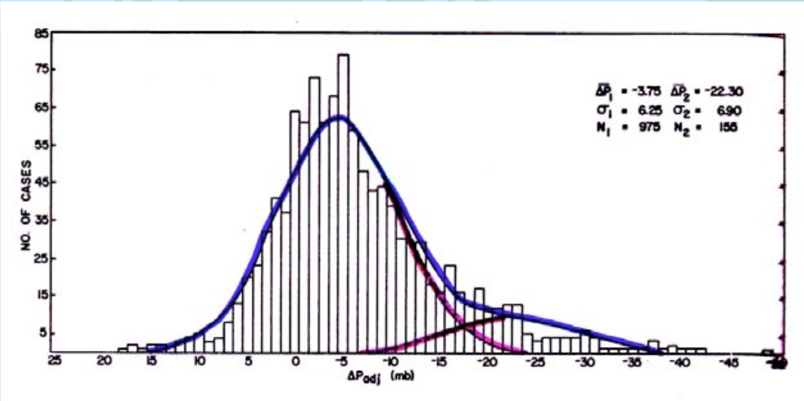
Background: Explosive Cyclogenesis



>80% of storms that produce hurricane force winds undergo a period of explosive cyclogenesis (aka “**bombs**”).

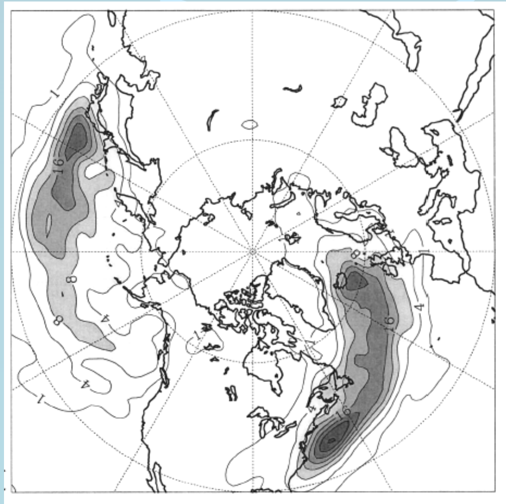
A bomb is defined as a midlatitude cyclone that deepens 1 mb/hr for 24 hours (at 60˚N equivalent).

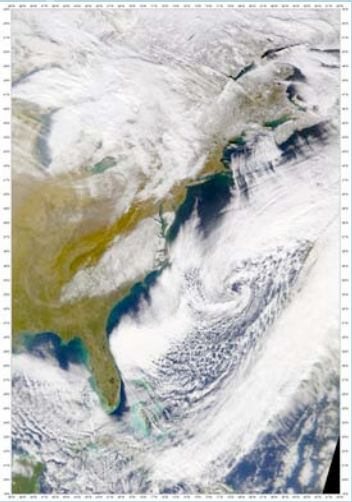
Distribution of Pressure Falls in Bombs



Distribution of pressure falls in 24 hours
(Sanders and Gyakum 1980)

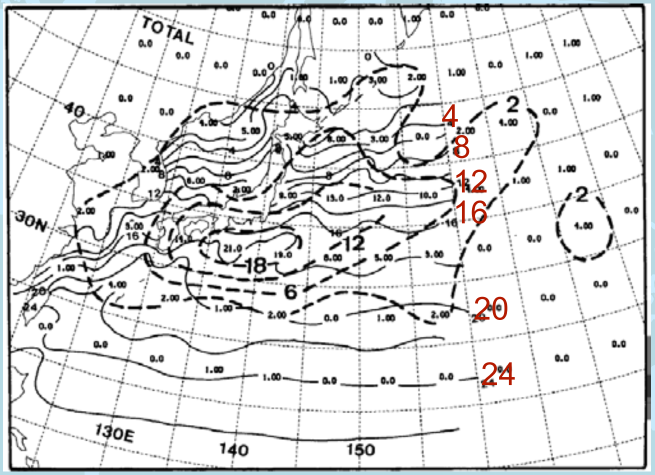
Distribution of Bombs





Explosive cyclone density [contour interval 4×10^{-5} explosive cyclones (°lat^{-2}), 1979-1999 (From Lim and Simmonds 2002).

SST and Distribution of Bombs



Distribution of bomb events in the North Pacific Ocean 1974-1984 with SST (Chen and Fu 1997).

Surface Sensible Heat Fluxes

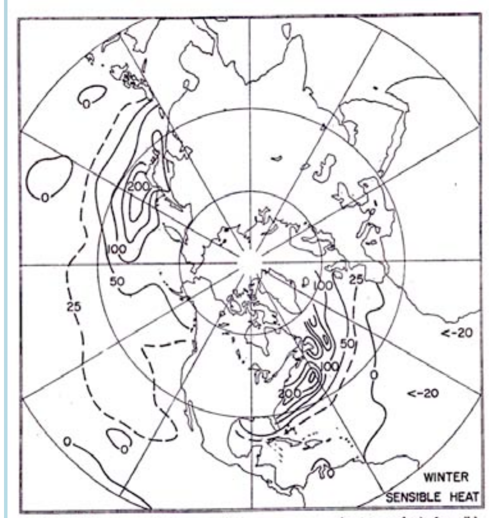
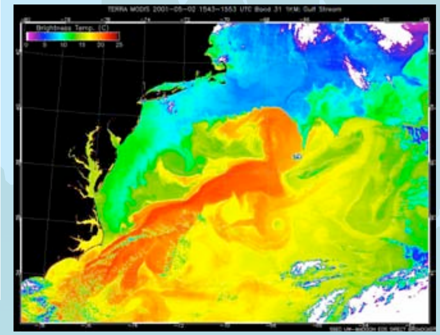
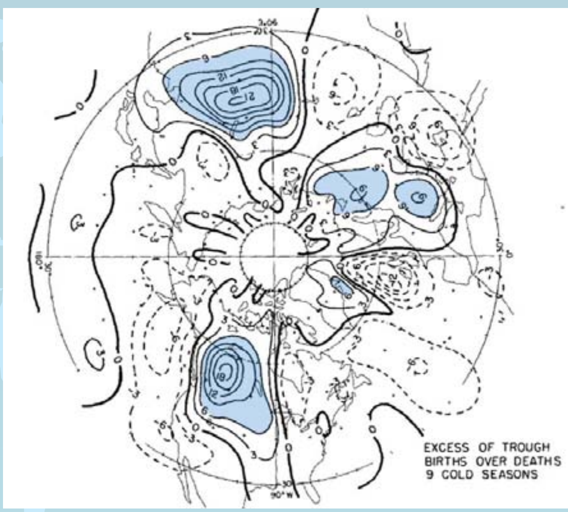


Fig. 20.3.5. Mean amount (in gram calories per square centimeter per day) of sensible heat exchanged between the sea and the atmosphere in winter. (*After Jacobs* [7].)



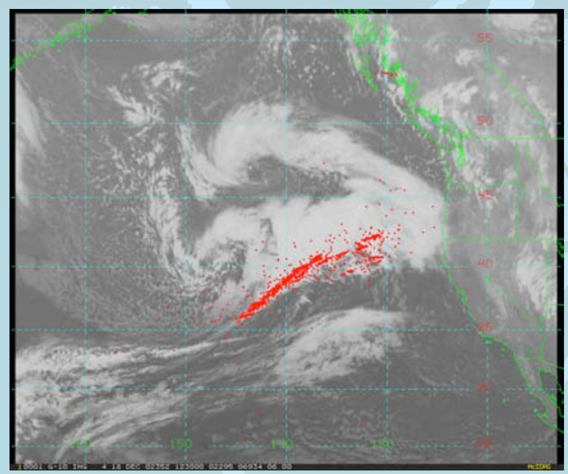
Distribution of sensible-heat fluxes

Genesis of Shortwaves – PVA

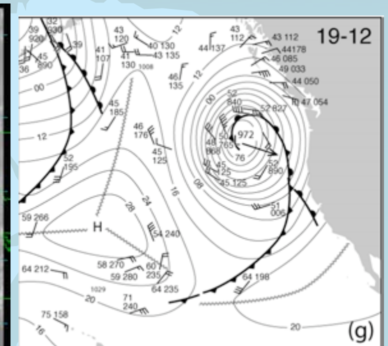


Short waves aloft provide strong mid-tropospheric quasi-geostrophic forcing where needed.

Deep Convection in HF Storms



Northeast Pacific Storm 18-20 December 2002
was under forecast by more than 10 mb by NCEP.



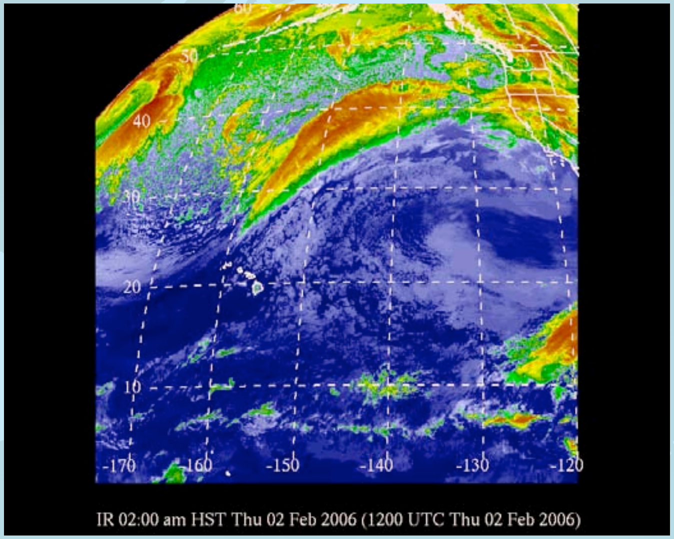
Surface analysis
Valid 1200 UTC
19 December 2002

Pessi, A. T., and S. Businger, 2009: Mon. Wea. Rev., 137, 3177-3195.

West Coast Windstorms

SEATTLE - 2/4/06

Hurricane force winds cut power to nearly 200,000 homes and businesses in Western Washington on Saturday, forced the closure of the floating bridge on Lake Washington for the first time in nearly seven years, and resulted in at least one fatality when a tree fell on a car.



West Coast Windstorms

SEATTLE - 12/15/06

Fierce winds cut power to nearly 800,000 homes and businesses in Western Washington on Friday. This home in Redmond had ten fallen trees on it when the winds died down.

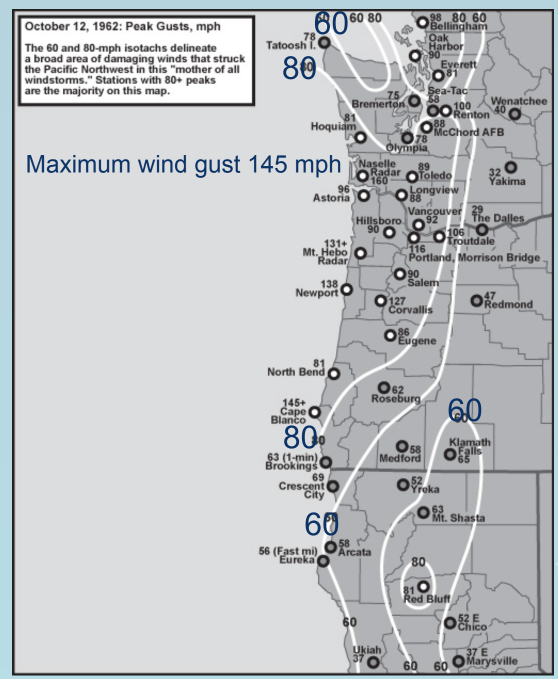
Mother of all NW Windstorms

Columbus Day Storm of 1962

Mother of all NW Windstorms

Columbus Day Storm of 1962

Maximum wind gust 145 mph



NW Windstorms and Bridges

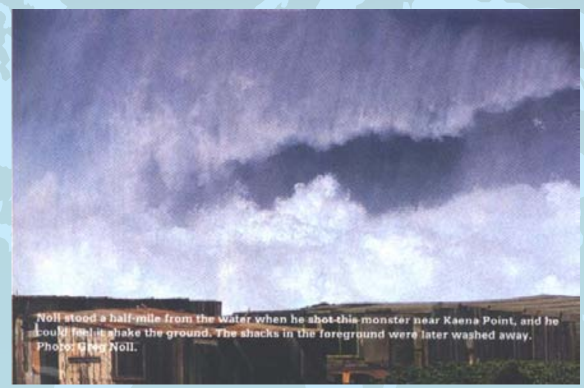
Hood Canal Bridge sinks on 13 Feb. 1979

NW Windstorms and Bridges

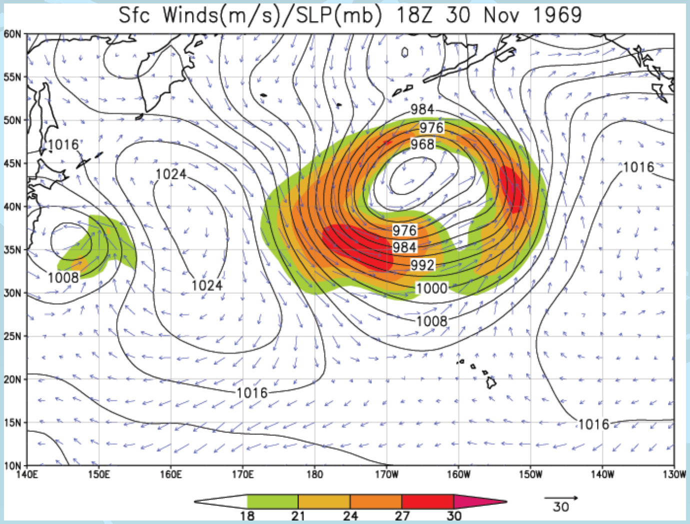
Tacoma Narrows Bridge 7 November 1940

Hawaii: Two Epic Wave Events

1969 Wave Damage on Oahu

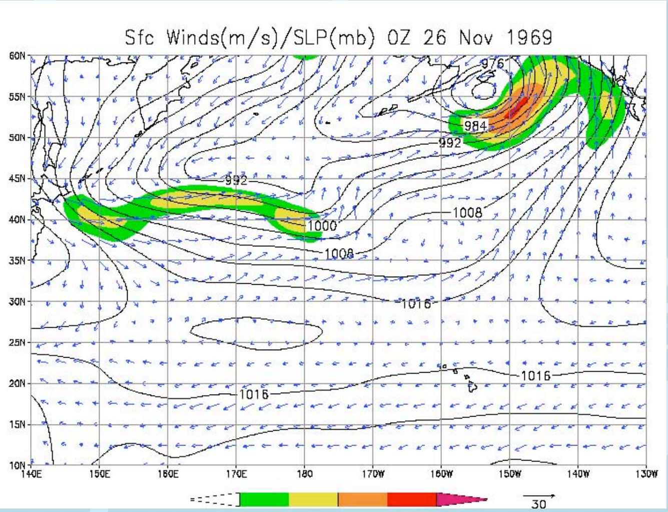


HF Storm of December 1969



NCAR/NCEP Reanalysis Data for 8 AM 30 November 1969

Animation of SLP Analyses Dec. 1969

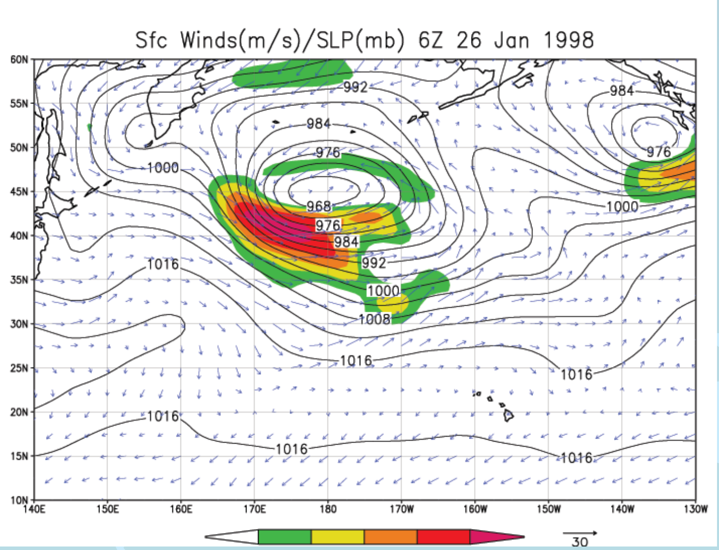


A *captured fetch* occurs when the swell travel at the same speed as the storm, so that high winds remain over the swell region.

HF Storm Jan. 1998

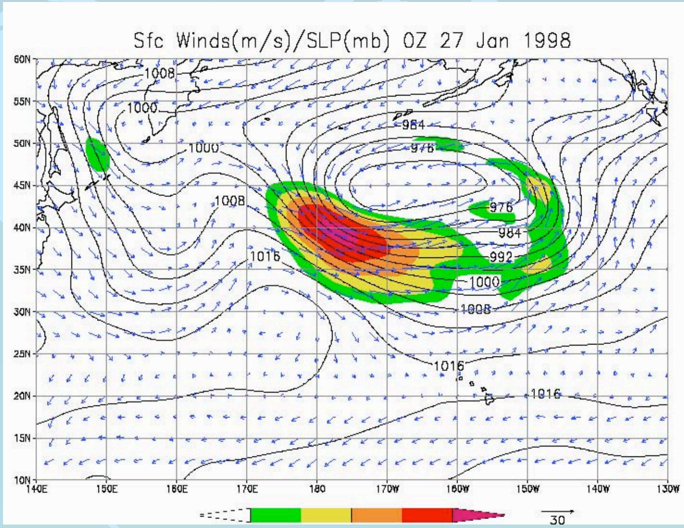
Photos by S. Businger

HF Surface Winds on 26 January 1998



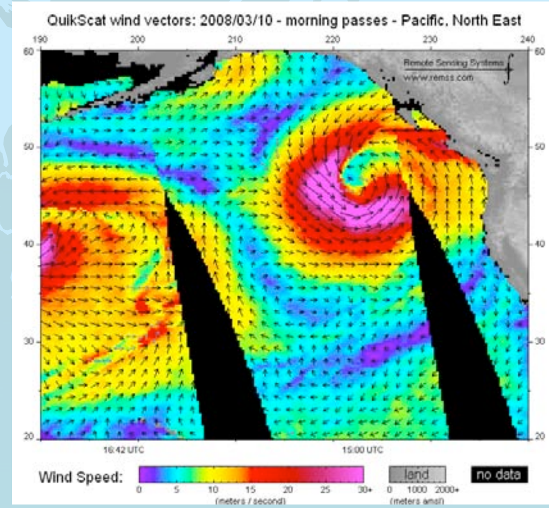
NCAR/NCEP Reanalysis Data for 8 PM 25 January 1998

Animation of SLP Analyses Jan. 1998



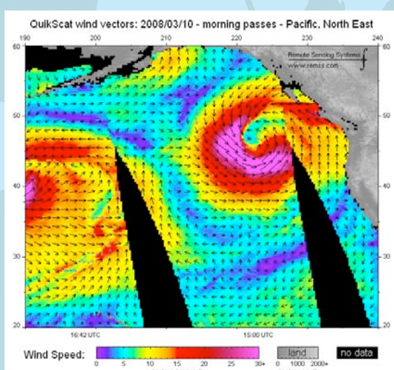
Note the captured fetch that again occurred in this case.

HF Wind Fields: Data and Methods



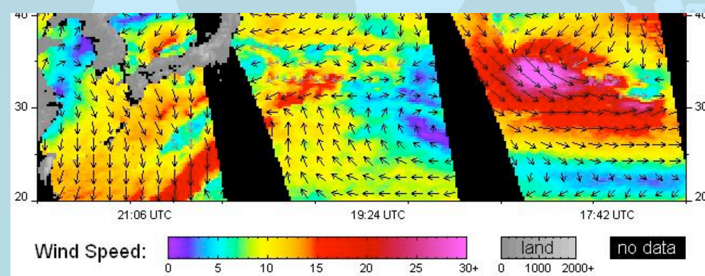
QuikSCAT

- QuikSCAT was launched in 1999 and failed in November 2009. Instrument sends microwave pulse, backscatter observation estimates wind speed through surface roughness. Data has ~25 km resolution.
- QuikSCAT can measure wind speeds up to 30 m s^{-1} (near hurricance force) with an accuracy of ±2 m s^{-1} (Shirtliffe, 1999). OPC forecasters routinely observe QuikSCAT winds in excess of 32.9 m s^{-1}.



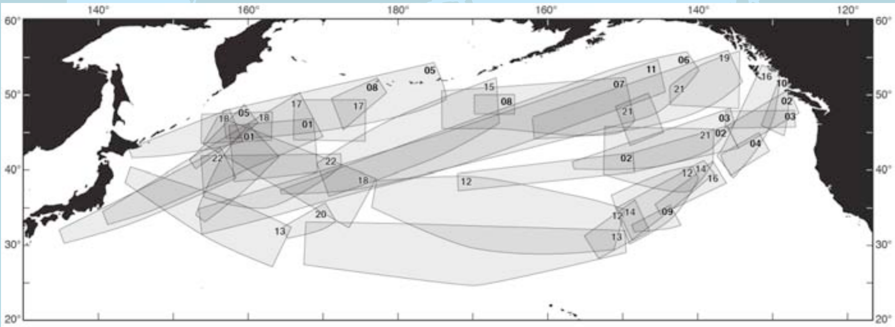
HF Wind Fields: Data and Methods

- Used QuikSCAT data to isolate cases of hurricane force winds in winter storms for 2003-2008, and constructed a climatology of ocean fetches (v>35 kt) associated with these storms.
- Compared maxima in QuikSCAT winds to maxima in GFS analyses.
- Selected cases where threshold conditions (7.5 m estimated breaker height) were measured at a buoy, and compared observations of the significant wave height and dominant period at buoys against Wavewatch III (WW3) output.



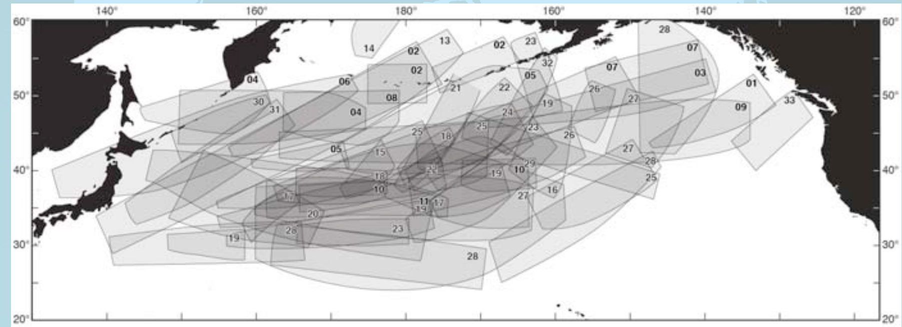
Hurricane Force Fetch Climatology

2003-2004 Winter



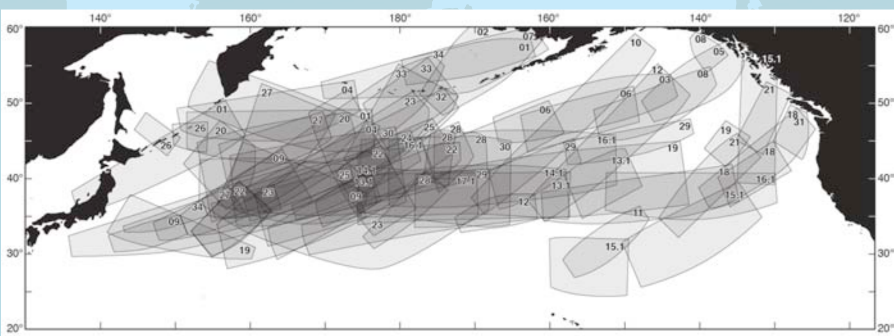
Hurricane Force Fetch Climatology

2004-2005 Winter



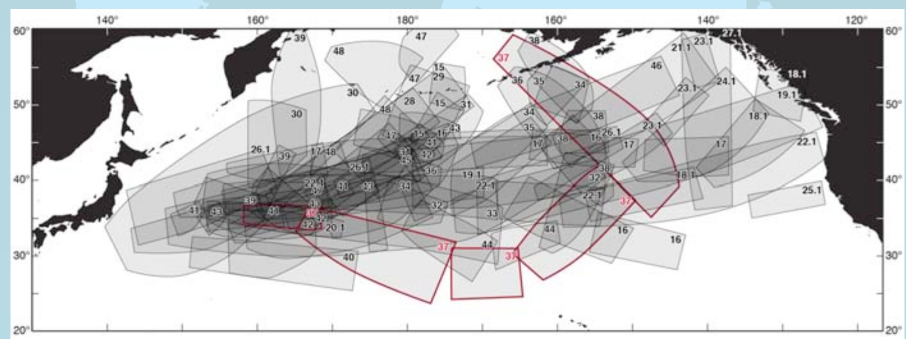
Hurricane Force Fetch Climatology

2005-2006 Winter



Hurricane Force Fetch Climatology

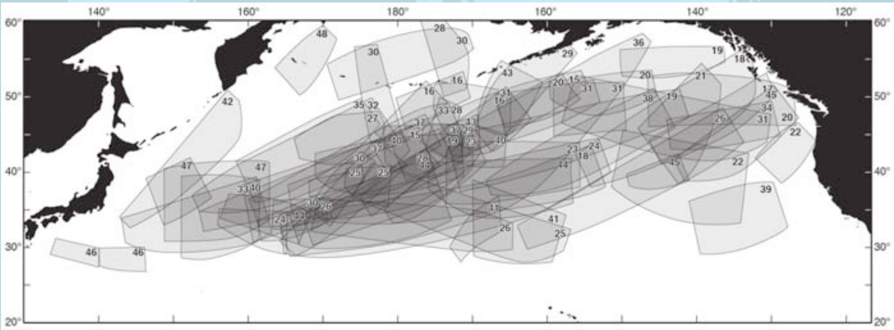
2006-2007 El Niño



HF Storm Example: 28-29 Jan. 2007

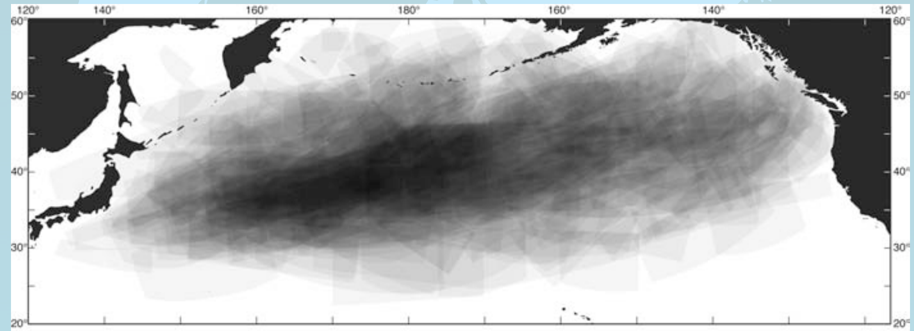
Hurricane Force Fetch Climatology

2007-2008 La Niña

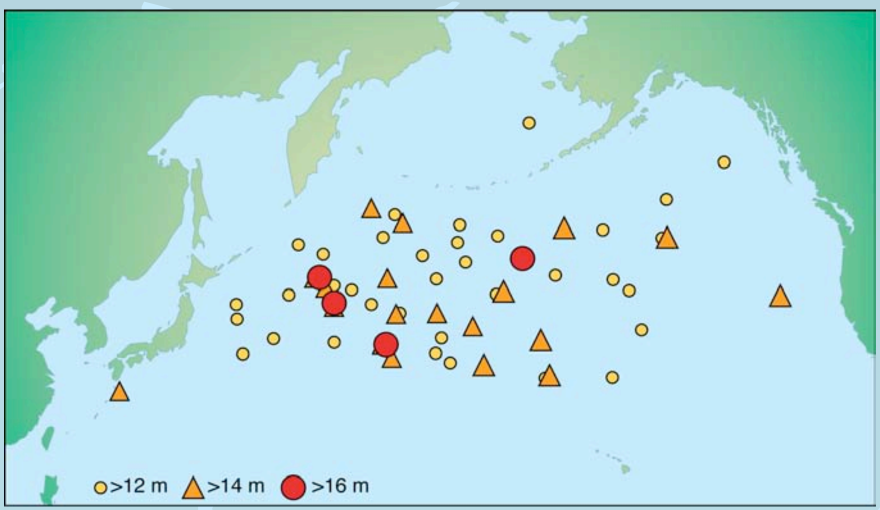


Hurricane Force Fetch Climatology

Jan 2003 through May 2008

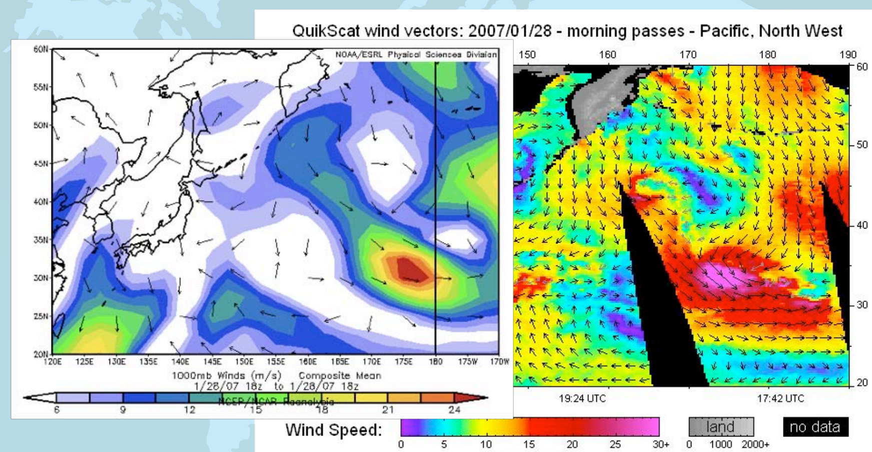


Very Extreme Sea-State Events



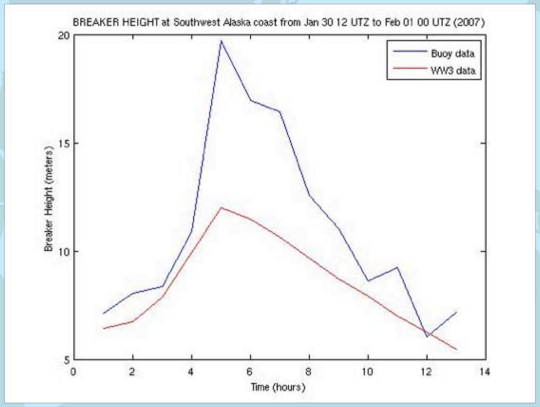
Distribution of 12+m significant wave height events as measured by the TOPEX, ENVISAT and JASON Altimeters (Cardone et al. 2005).

HF Storm Example: 28-29 Jan. 2007



QuikSCAT wind image and GFS wind analysis for same time.

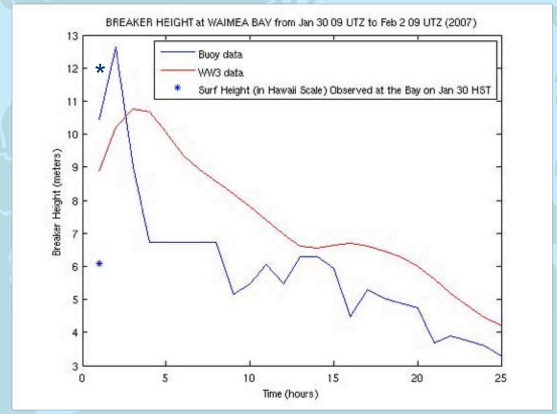
Comparison of WWIII Predicted vs Observed Breaker Heights: 1/30/2007



Breaker height = wave height x period x shoaling factor

Wave steepness reached .07 along the AK coast.

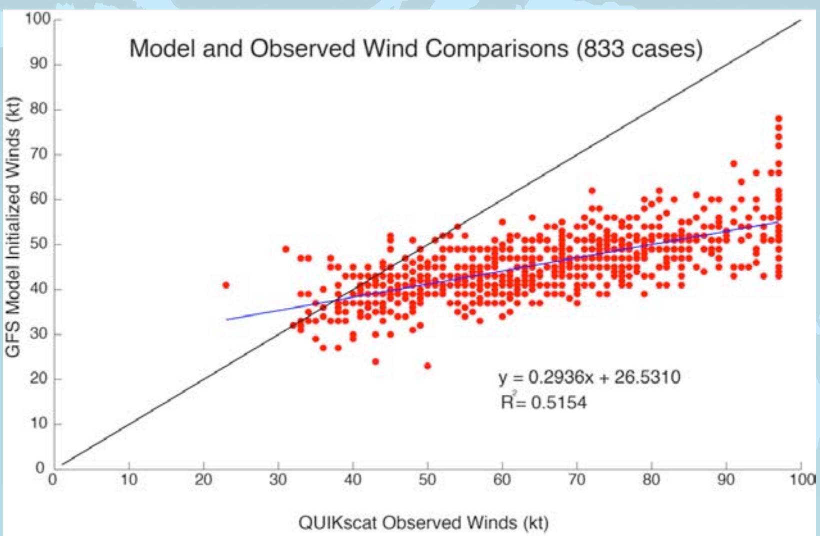
Comparison of WWIII Predicted vs Observed Breaker Heights: 1/30/2007



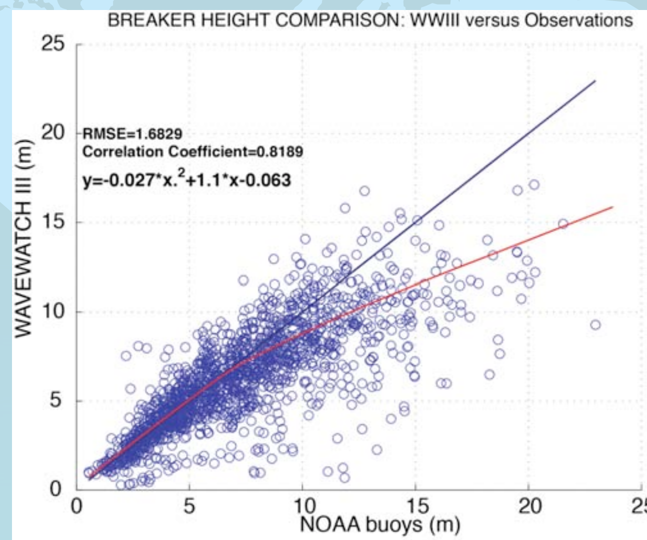
Breaker height = wave height x period x shoaling factor

Wave steepness reached .07 along the AK coast.

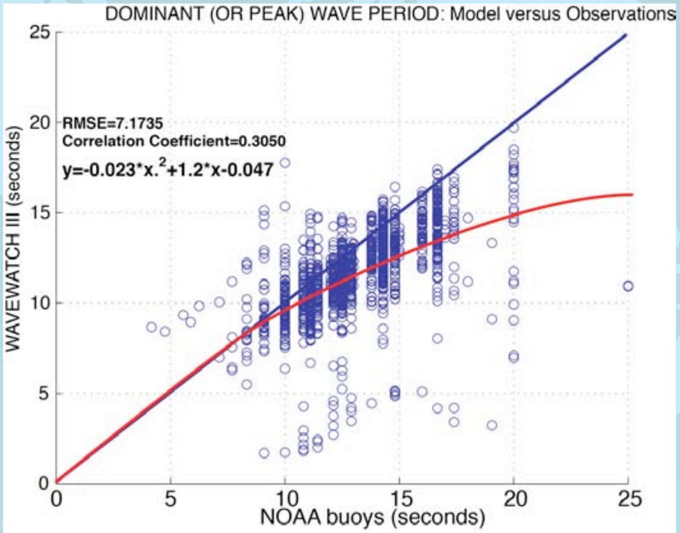
QuikSCAT vs GFS Analyses



Breaker Height Comparison: WW3 vs Buoys



Dominant Wave Period: WW3 vs Buoys



Conclusions

- Storm fetches show the location of greatest hazard and the extent of interannual variability.
- The GFS weather model analyses underestimate the strength of the winds in these strong storms when compared to QuikSCAT Satellite wind observations.
- The buoy observations show that the WWIII under forecasts large wave events over the North Pacific Ocean, consistent with the under forecast of the winds.
- WWIII wave steepness is greatest in the core of the fetches and is greater than damage threshold for ships.

Recommendations

The results of this study suggest that a replacement for QuikSCAT winds should be priority. Better data assimilation methods need to be developed to ingest satellite wind data.

Ship accidents occur when the wavelength is systematically above half the ship length. Each ship captain should therefore interpret the marine forecasts with respect to their ship type and loading state.

It would be of great benefit to have a ship's black box, i.e., a data-recording device onboard storing the information needed to improve safety of ship operations. In combination with a detailed hindcast of the sea state conditions great progress could be made.

Add fold-out stabilizing fins to ships.

Track the weight/inventory of containers to help organize their loading.

Future Work

The results of this study suggest that there is an opportunity to improve GFS and WWIII model performance.

Future work is needed to analyze the performance of the GFS and WWIII models without QuikSCAT.

Despite considerable efforts, currently there are no plans in the U.S. to launch future scatterometers. Wind data from other satellite instruments needs to be evaluated for HF storms.

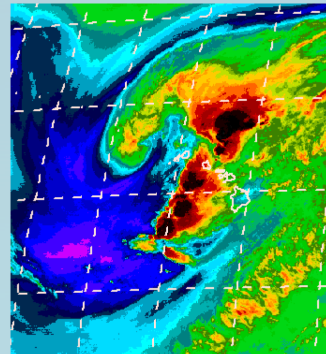
Acknowledgements

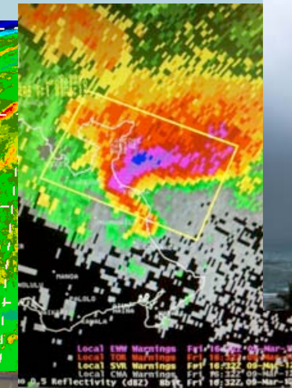
The research is supported by ONR

Thanks to Selen Yildiz for data analysis, and to Thomas Robinson and Krystina Bower for technical help.

Thanks to Joseph Sienkiewicz (NOAA) for motivating me to undertake this study.

Photo by S. Businger





Questions?

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