Wave forecasting from R/V Sikuliaq cruise Sep 30 – Nov 10

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WAM, WAVEWATCH III™, SWAN

- "Third Generation" Wave model
- Origins in "WAM Group".
  - Community effort, Hasselmann, Komen, et al.
- No *a priori* assumptions about spectral shape
- Phase-averaged (wave action density)
- Kinematics
  - Effects of currents (straining, refraction)
  - Effects of bathymetry (shoaling, refraction, etc.)
  - Great circle propagation
  - Others (varies by model)
- Dynamics
  - Generation of energy via wind
  - Wave dissipation via steepness-limited breaking
  - Nonlinear interactions
  - Others (varies by model)

WAVEWATCH III

inputs

- Allowed as non-stationary and non-uniform:
  - Wind at 10 m, air-sea ΔT
  - Water level
  - Currents
  - Ice concentration, thickness, and rheology
  - Icebergs
  - Mud thickness and rheology
  - Boundary forcing
- Allowed as non-uniform
  - Bathymetry

Highlighted: minimum req. for Beaufort/Chukchi model

User settings:

- Calibration parameters
- Bottom friction coefficient
- Bottom roughness spectrum

outputs

- Directional (2d) spectrum, Non-directional (1d, frequency) spectrum, Significant wave height, Mean wave length, Mean wave direction, …
- Peak period, Stokes transport, Stokes surface drift, Stokes spectrum, Charnock parameter , Infragravity waveheight, peak direction, mean wave period Tm02, mean wave period Tm01, mean wave period Tm0-1
- Parameters for wave partitions (swell 1, swell 2, etc.)Friction velocity, Energy flux to ocean, Energy flux to atmosphere, Momentum flux to ocean, Momentum flux to atmosphere, whitecap coverage, whitecap thickness, mean breaking height, radiation stress, Bernoulli head, Mean square slope, spectral level at tail, …

Spectral Description of Conservation of Energy used in WAVEWATCH-III

$$\frac{\partial N}{\partial t} + \nabla \cdot \vec{c} N = \frac{S}{\sigma}$$

In deep water, $S = S_{in} + S_{ds} + S_{nl4}$

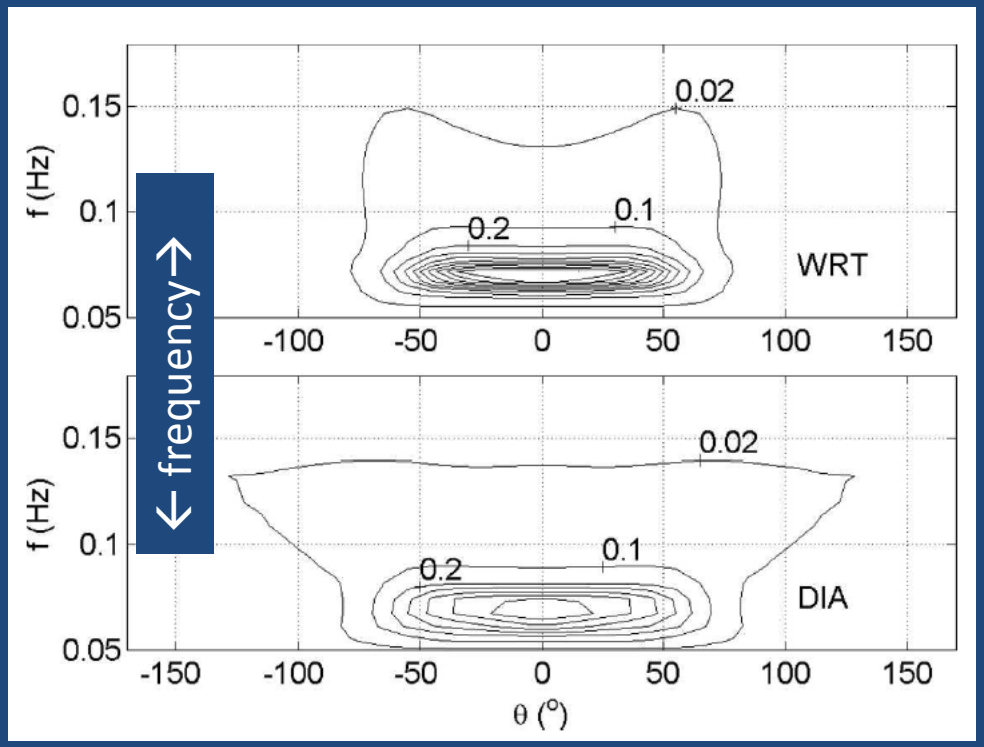
c = propagation speed
k = wave number
σ = relative radian wave frequency
θ = wave direction

(I will talk more about these "traditional" source functions at end of presentation if time allows)

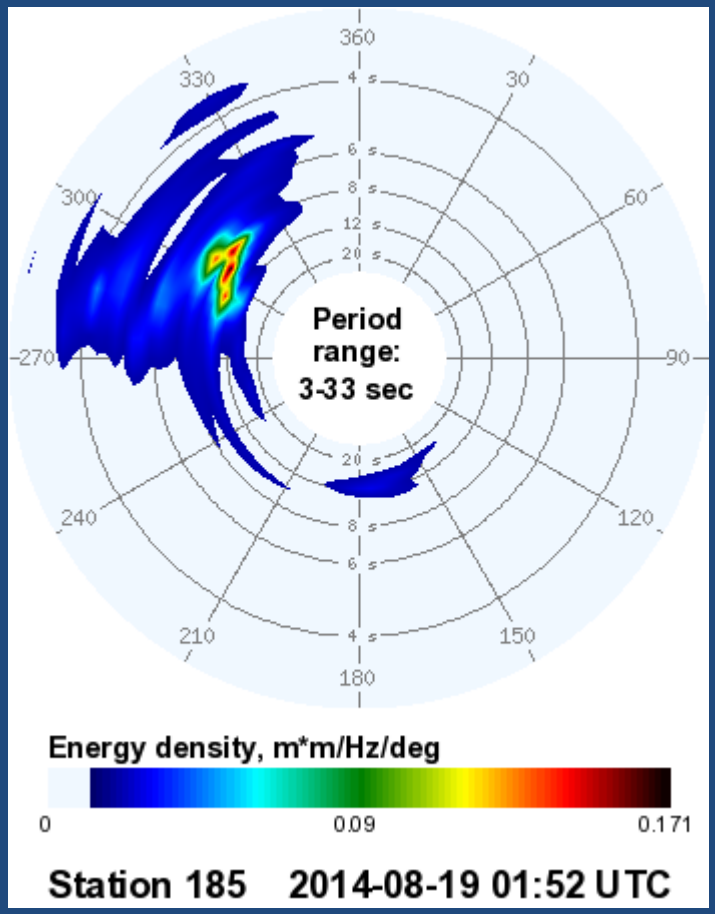
$N = N(k, \theta, \vec{x}, t)$ [spectral density, the variable that is being solved for]

$S = S(k, \theta, \vec{x}, t)$ [spectral description of source/sink terms]

The wave spectrum



← Direction →



N(k,θ) or N(f,θ)

New source functions for ice

In deep water, $S = S_{in} + S_{ds} + S_{nl4}$

$$S_{ds} = S_{br} + S_{bot} + S_{ice}$$

new

New source terms have conservative and non-conservative components.

$$S_{ice} = S_{ice,c} + S_{ice,nc}$$

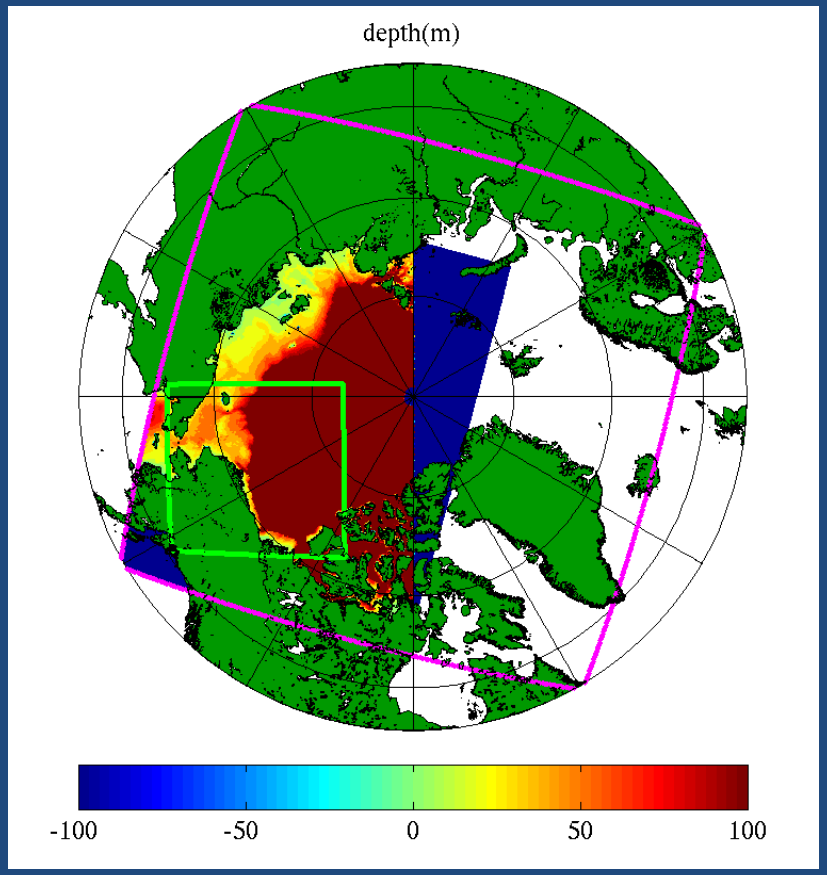
Example: "IC3" (S_{ice} routine, category 3), treats ice as a viscoelastic layer and requires as user-input the "effective" rheological parameters, e.g. effective viscosity: intended to allow many different ice types simultaneously.

On-ship wave forecasting

- Laptop (late model Linux/MacOS): 4 cores
- 2 grids (15 km and 10 km, nested)
- 6 day forecast: ~ 45 minutes per grid
- Run 0 to 2 times daily (most often 1/day)
- Briefed at daily POD meetings, following Ola's weather brief
- Supplemented by shoreside wave forecasts
  - ECMWF (entire cruise)
  - NRL-Stennis 5 km WW3 (until Oct 10)

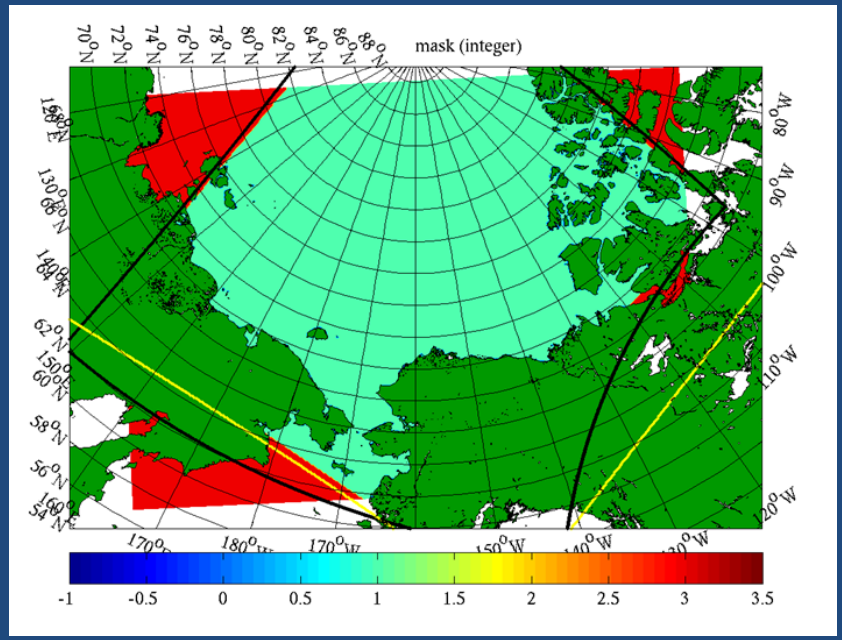
Outer WW3 grid

- 15 km Grid Resolution
  - 223x286x31x36
  - Polar Stereographic projection
- FNMOC forcing
  - 2/day. 12Z forcing ready ~noon SKQ time, on U. Victoria ftp site via NRLSSC cron job
  - Winds: NAVGEM (0.5 deg)
  - Ice concentration: SSMI analysis (0.5 deg)
- 34 run cycles during cruise
- Crude ice physics

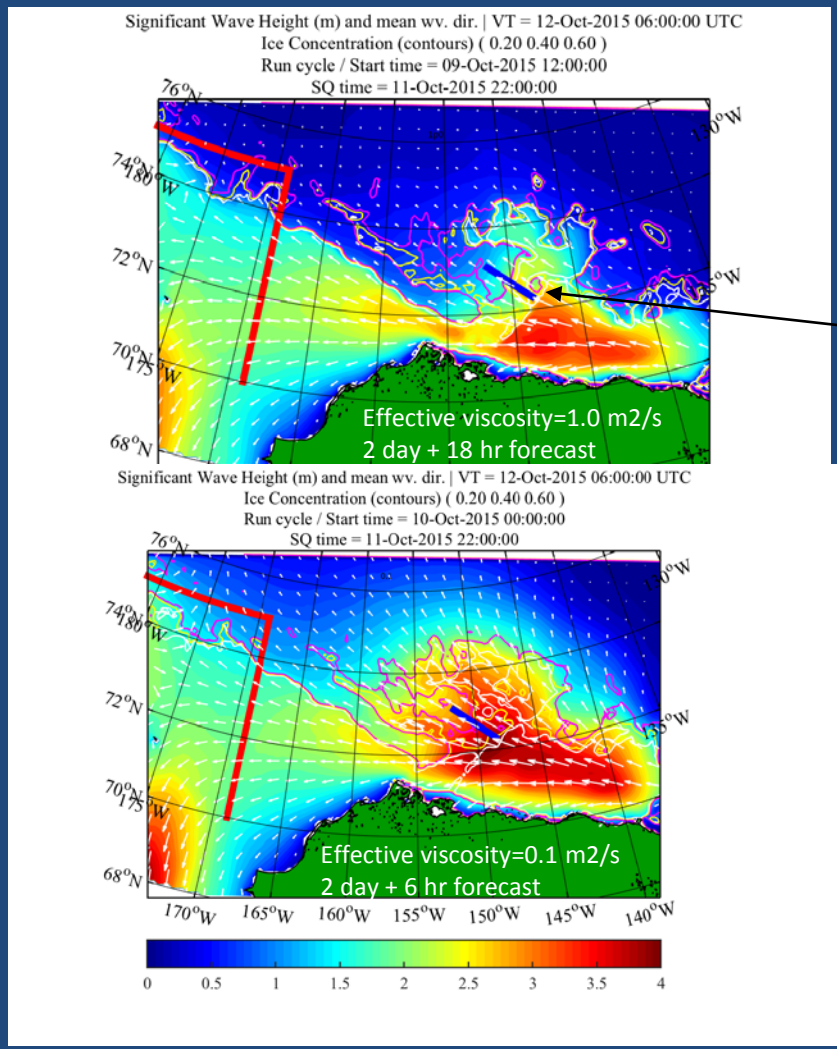


Inner WW3 grid

- 10 km Grid Resolution
  - 231x121x31x36
  - Irregular grid based on great circles
- Ice concentration, ice thickness: NRL 2 km CICE
  - 1/day : 0Z file available ~0300 SKQ time
- New physics for wave damping by ice (visco-elastic model)
- Otherwise similar to outer grid
- 24 run cycles during cruise



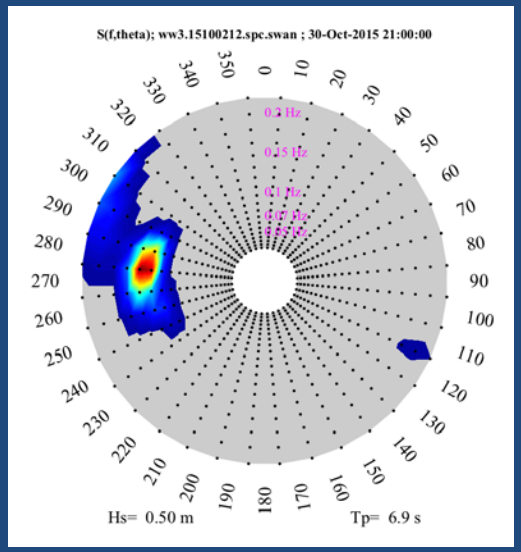
Example forecasts (grid 2)

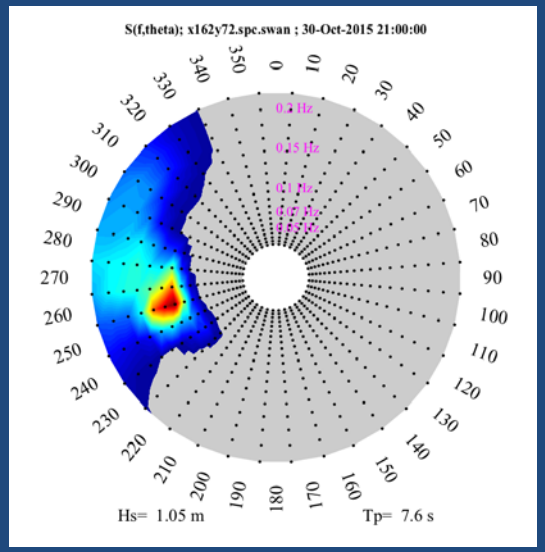


These are new (de-cluttered) plots made from the original output files created on the ship (i.e. actual forecasts). Thus comparable to plots used in POD brief.

CICE ice edge was superb in this case.

Example forecasts (wave spectra)





Two forecasts of directional spectrum for the western component of an overlapping double swell event (from west and southwest) which may have contributed significantly to the retreat of the ice near the Racetrack Oct. 30 to Nov. 1. Left panel: Briefed at Oct 25 POD meeting, for AWAC position, 159.0W 72.6N. Right panel: Briefed at Oct 30 POD meeting, for 162.0W 72.0N. Both plots are for Oct 30, 21Z.

General Impressions (1/2)

- On-ship forecasting
  - Disadvantage: computer hardware
  - Advantages:
    - respond immediately to requests
    - improve model & model presentation day-to-day according to feedback
    - utilize other science team expertise in realtime
    - (not to mention post-cruise science benefits)
- Wave predictions:
  - Period and direction tended to be well predicted
  - SWH
    - outside ice, on-ice waves: good prediction
    - outside ice, off-ice winds: so-so
    - Inside ice: so-so

General Impressions (2/2)

- FNMOC COAMPS: winds anemic, not used after Oct 10
- FNMOC NAVGEM: winds generally good (or very good), though ECMWF was often ~1 day earlier in terms of seeing future wind events
- FNMOC SSMI analysis: under-predicts ice (known problem with passive microwave radiometer)
- NRL 2 km CICE: very good until ~October 20. After that, over-predicted ice.
- Science team was most interested in
  - SAR images of ice
  - Atm. forecast
  - Wave forecast (which ingests atm. and ice forecast)
- Reinforced belief that accurate ice (ice edge, conc., thickness) are essential for accurate wave forecast

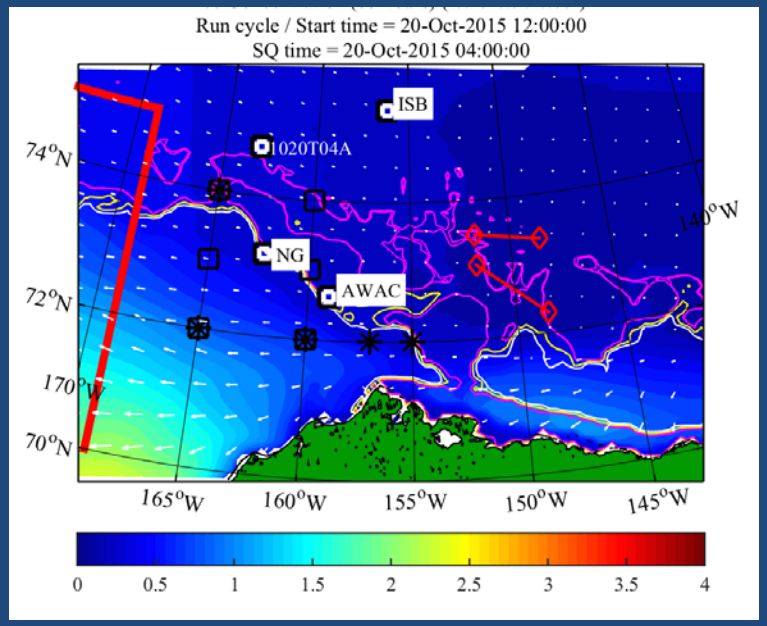
Recommendations

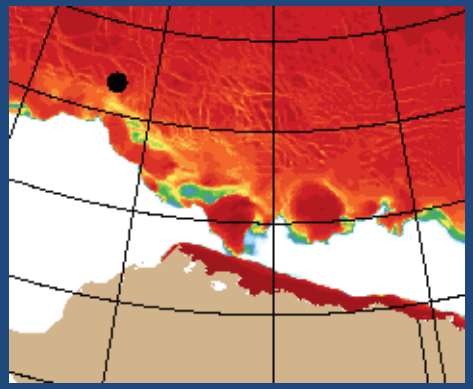
Should be provided to wave forecaster (gridded):

- CICE analysis (not just nowcast/forecast)
- L3 satellite products, e.g. AMSR2, SMOS
- Further information on ice, e.g. rigid sheet ice vs. vs. loose floes vs. loose pancakes
  - Two categories at minimum (rigid vs. loose)

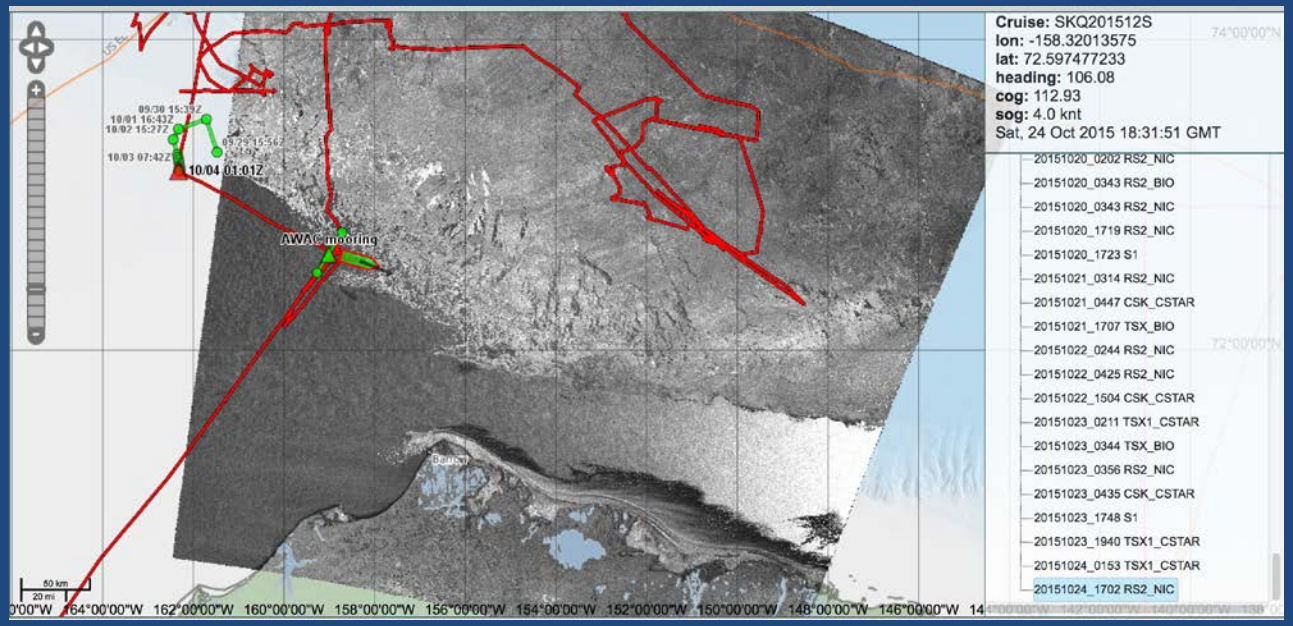
Calculating fetch for use with parametric wave model

(ice edge in gridded products were not accurate enough for use in WW3, off-ice wind case)





Wave model forcing: “gap” closed Oct 20



SAR: “gap” still open Oct 24