Wave-ice interaction in the Marginal Ice Zone: toward a wave-ocean-ice coupled modeling system

W. Erick Rogers, Pamela Posey
Oceanography Division
Naval Research Laboratory
erick.rogers@nrlssc.navy.mil ; (228) 688-4727

Program
Sea State and Boundary Layer Physics of the Emerging Arctic Ocean DRI

Program manager
Dr. Martin Jeffries

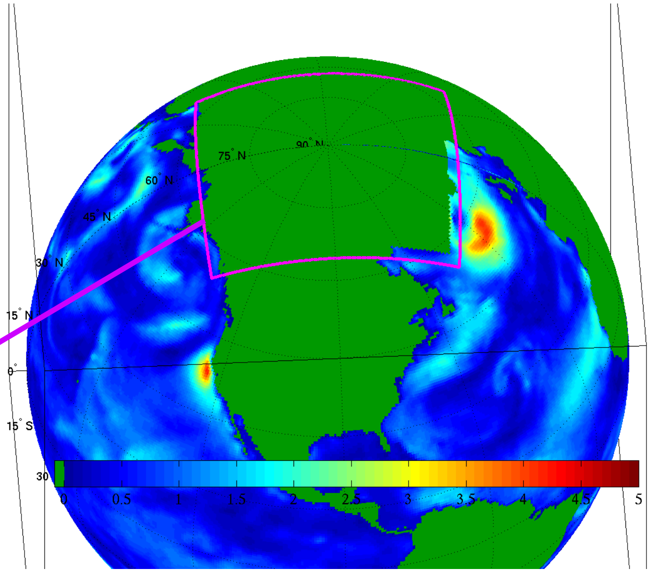
12/6/2012

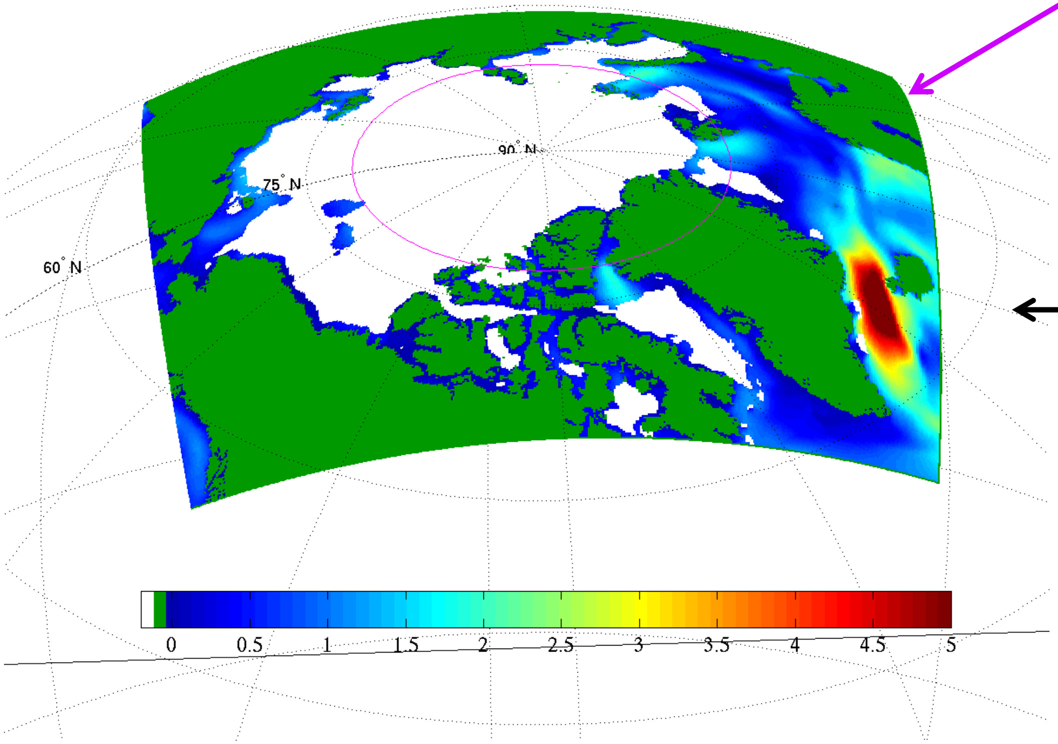
Key features

- WAVEWATCH III™
  - large-scale phase-averaged wave model
  - at FNMOC since 2000, transitioned to NAVOCEANO in 2012
- coupled model system
- wave model dynamics
- collaborations

Background

Progress in 6.4: WW3 extended to allow two-way nesting between global grid and curvilinear Arctic grid





Results within the Arctic grid.

masked areas are denoted as either

• land (green)

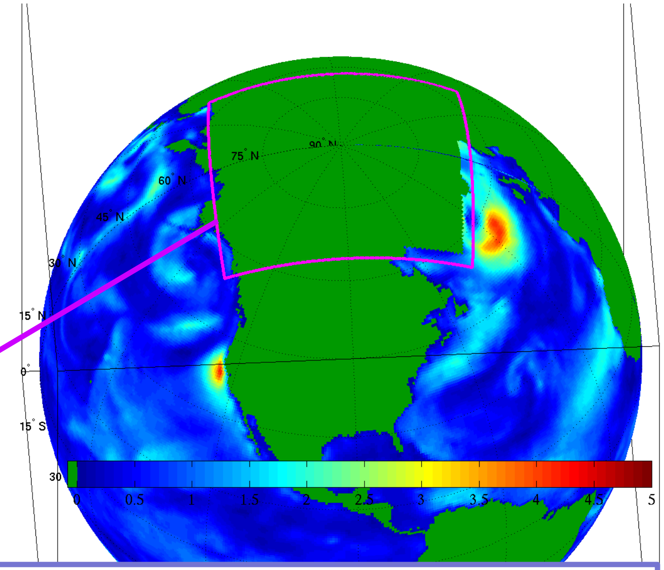
• or ice with concentration of 0.75 or greater (white).

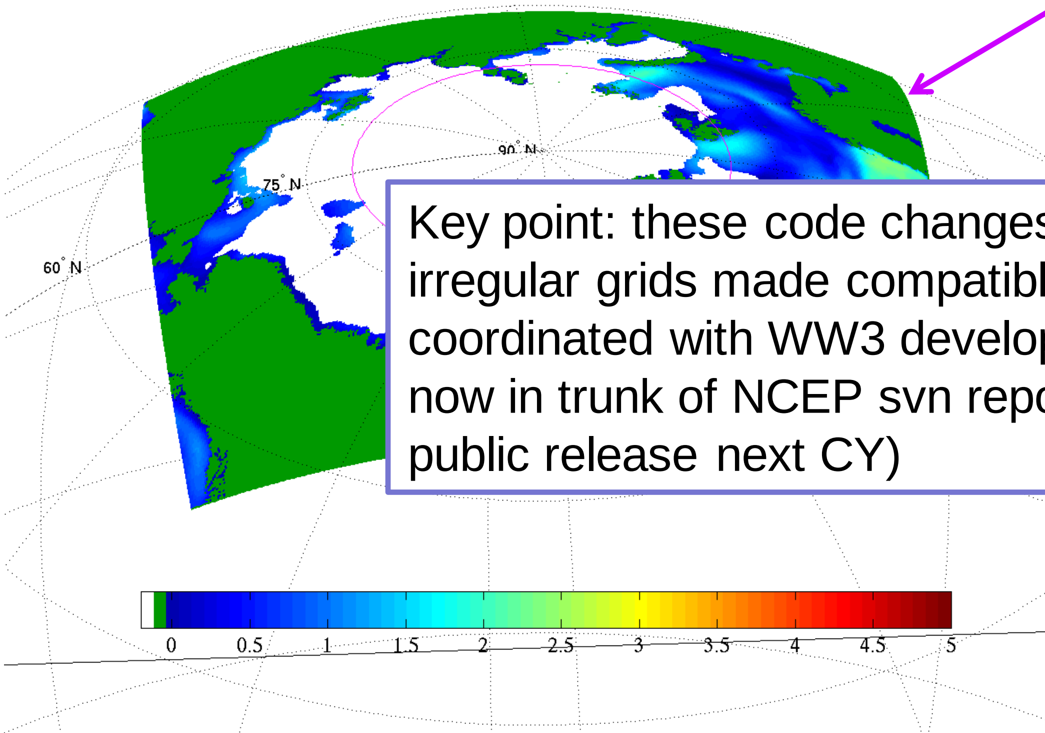
magenta line indicates 78 deg N, which is the upper limit of the operational global WW3 at FNMOC.

Wave energy propagates in both directions across the boundaries between the regional grid shown here and the global grid. The grids run simultaneously within the same machine executable.

Background

Progress in 6.4: WW3 extended to allow two-way nesting between global grid and curvilinear Arctic grid





Key point: these code changes by NRL (irregular grids added, irregular grids made compatible with multi-grid feature) were coordinated with WW3 development group. Code changes are now in trunk of NCEP svn repository (development version, for public release next CY)

greater (white).

magenta line indicates 78 deg N, which is the upper limit of the operational global WW3 at FNMOC.

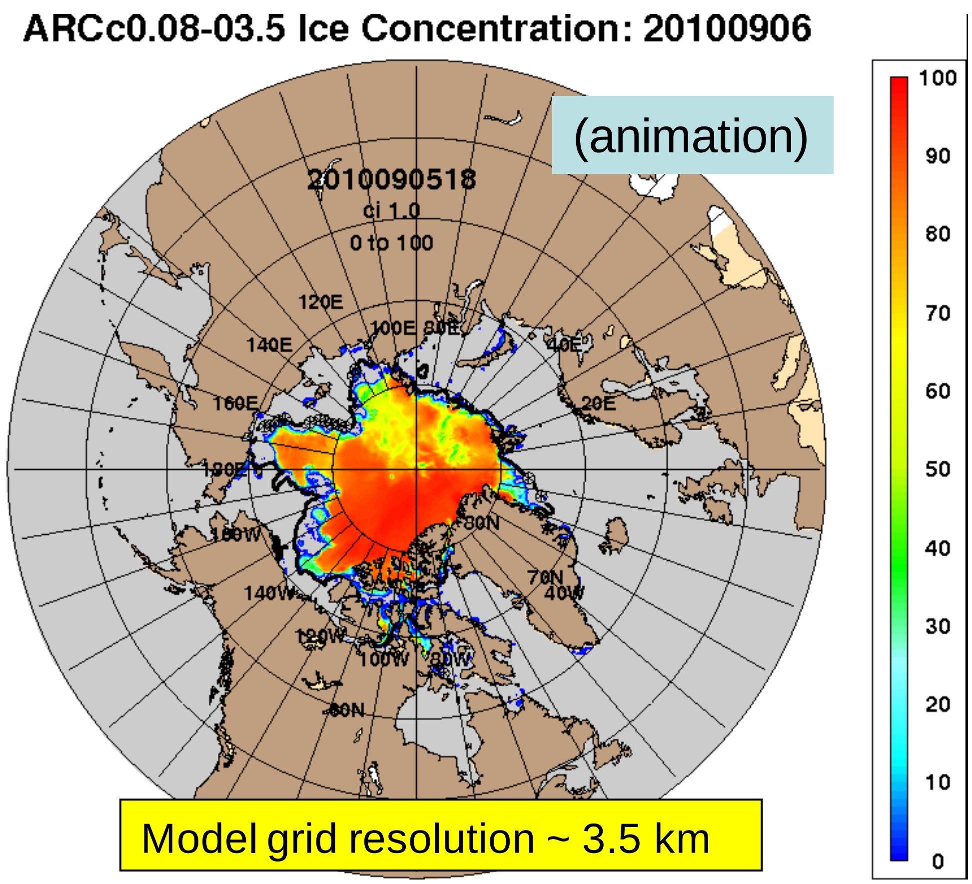
Wave energy propagates in both directions across the boundaries between the regional grid shown here and the global grid. The grids run simultaneously within the same machine executable.

1/12° Arctic Cap Nowcast/Forecast System (ACNFS)

- ACNFS consists of 3 state-of-the-art components :

- Ice Model : Community Ice CodE (CICE)
- Ocean Model: HYbrid Coordinate Ocean Model (HYCOM)
- Data assimilation: Navy Coupled Ocean Data Assimilation (NCODA)

- ACNFS uses boundary conditions from global HYCOM model



Black line denotes independent ice edge analysis from National Ice Center (NIC). Animation spans Sept 2010 – Aug 2011.

Spectral Description of Conservation of Energy used in WAVEWATCH-III model

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

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

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

$$S_{ds} = S_{br} + S_{bot} + \underbrace{S_{ice}}_{\text{proposed}}$$

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

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

Background: existing methods for representation of effect of ice on waves

<u>Existing ice representation in WW3: Grid cell transparency scheme</u>: In WW3, the attenuation and scattering of waves by ice floes have been implemented as a sub-grid transmission/blocking procedure (Tolman, Ocean Modeling, 2003), based on user-specified ice concentration values. It is implemented as a propagation feature (kinematics, LHS of gov. eq.), rather than as a source/sink term (dynamics, RHS of gov. eq.). Result: resolution has a non-physical impact on attenuation. Also, dependence of the attenuation on wavelength is not allowed.

<u>Justification</u>: Operationally, only ice concentration is available, which permits only crude methods.

However, there are modest improvements that can be made, even with only ice concentration available, and most importantly, we can improve physics in the model in anticipation of future operational inputs (e.g. floe size distributions, floe thickness).

$$k = k_r + ik_i$$

$$S_{ice} / E = -2C_g k_i$$

- k_r enters the model via the dynamics as shown here
- k_r enters the model via the C and C_g calculations on the left-hand side of the governing equation.
- code changes non-trivial
- fundamentals are straightforward
  - ➢ e.g. Rogers and Holland (2009 and subsequent unpublished work) modified a similar model, SWAN (Booij et al. 1999) to include the effects of a viscous mud layer using the same approach

“no-cost” components

- WW3 interface
- Basin-scale hindcasts
- Limited sensitivity analysis
- Add waves to Arctic Cap system (conditional)

Main components of proposal

- extended sensitivity analysis with additional theoretical models
- real part of wavenumber
- baseline sub-regional hindcasts
- deterministic modeling
- breakup investigations
- implement in coupled modeling system (test with sub-regional grid)

Out-year components

- inversion
- non-dissipative scattering
- detailed study of process interaction (positive feedbacks, etc.)

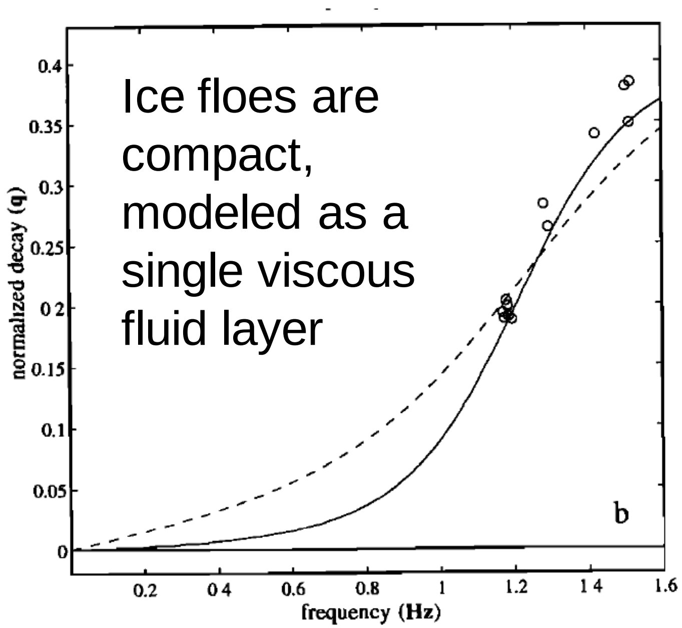


Figure 1. Comparison of laboratory to model predictions for experiment 1; see Table 1 for parameter description. On each panel the dashed curve shows the Stokes/Lamb one-layer model results for $\hat{\nu}_1 = 1.5\times10^4$; the solid curve shows the Keller two-layer results for $\hat{\nu}_2 = 2.5\times10^4$. The circles give our laboratory data; the vertical bars show the 95% confidence limits. (a) Normalized wavenumber $\hat{k}$ versus f, (b) normalized wave decay coefficient $\hat{q}$ versus f.

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 104, NO. C4, PAGES 7837–7840, APRIL 15, 1999

Comparison of laboratory data with a viscous two-layer model of wave propagation in grease ice

Karl Newyear[1] and Seelye Martin
School of Oceanography, University of Washington, Seattle

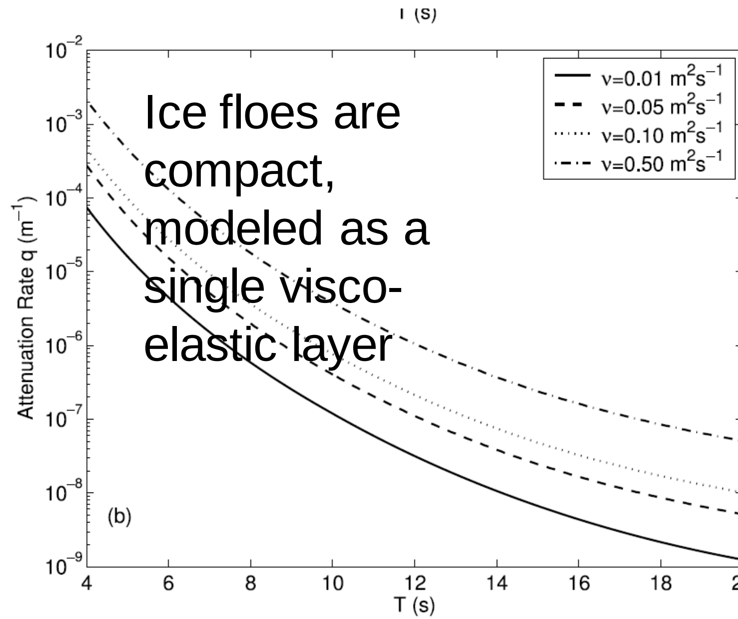


Figure 4. Viscous layer model for long waves. (a) Normalized wave number κ versus wave period $T(s)$ for the dominant wave mode and (b) attenuation rate $q(m^{-1})$ versus wave period $T(s)$ for the dominant wave mode. Parameters used are as follows: h = 0.5 m, H = 100 m, G = 0.

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, C06024, doi:10.1029/2009JC005591, 2010

Gravity waves propagating into an ice-covered ocean: A viscoelastic model

Ruixue Wang[1,2] and Hayley H. Shen[2]

Ice floes are compact, dissipation from turbulence at ice/water interface

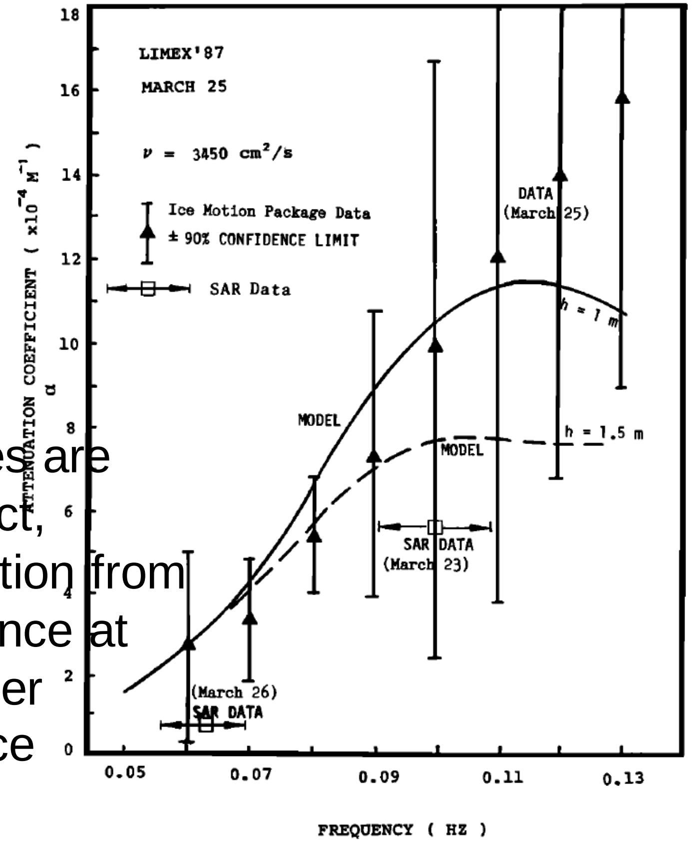


Fig. 11. Model-data comparisons for the wave attenuation coefficient as a function of wave frequency f

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 96, NO. C3, PAGES 4605–4621, MARCH 15, 1991

Wave Propagation in the Marginal Ice Zone: Model Prediction and Comparisons With Buoy and Synthetic Aperture Radar Da

Antony K. Liu

Oceans and Ice Branch, NASA Goddard Space Flight Center, Greenbelt, Maryland

Benjamin Holt

Jet Propulsion Laboratory, California Institute of Technology, Pasadena

Paris W. Vachon

Canada Centre for Remote Sensing, Ottawa

Ice floes are not colliding, dissipation from scattering from floes

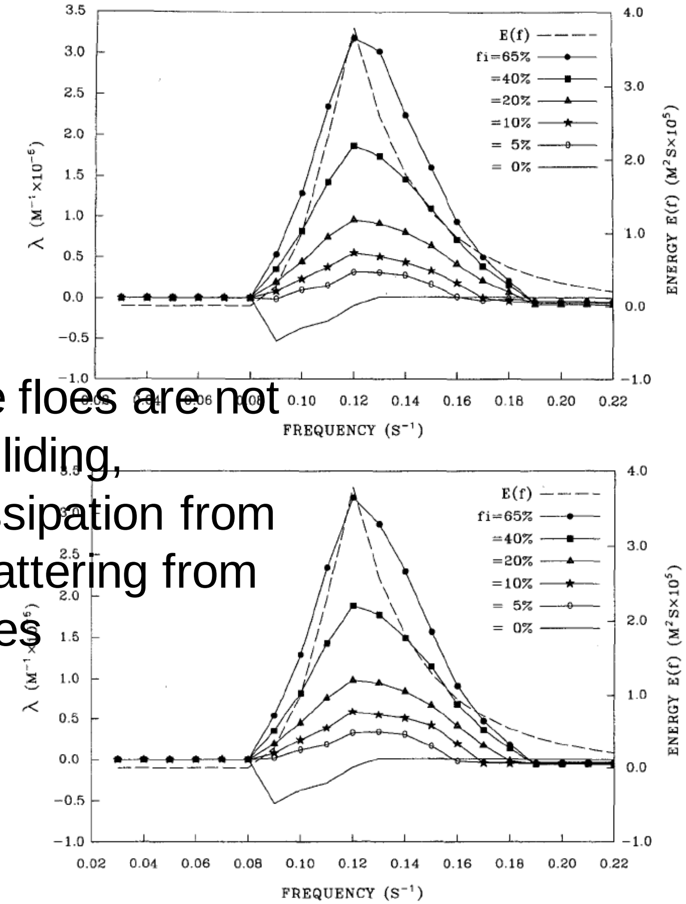


FIG. 3. Wave attenuation λ as a function of frequency f and ice cover concentration fi. The energy impinging on the MIZ is given by $E(f)$ assuming (a) 20-m floe diameter and 1.5-m floe thickness, (b) 20-m floe diameter and 3.0-m floe thickness and (c) 15-m floe diameter and 1.5-m thickness.

Air–Ice–Ocean Momentum Exchange. Part I: Energy Transfer between Waves and Ice Floes

W. Perrie and Y. Hu

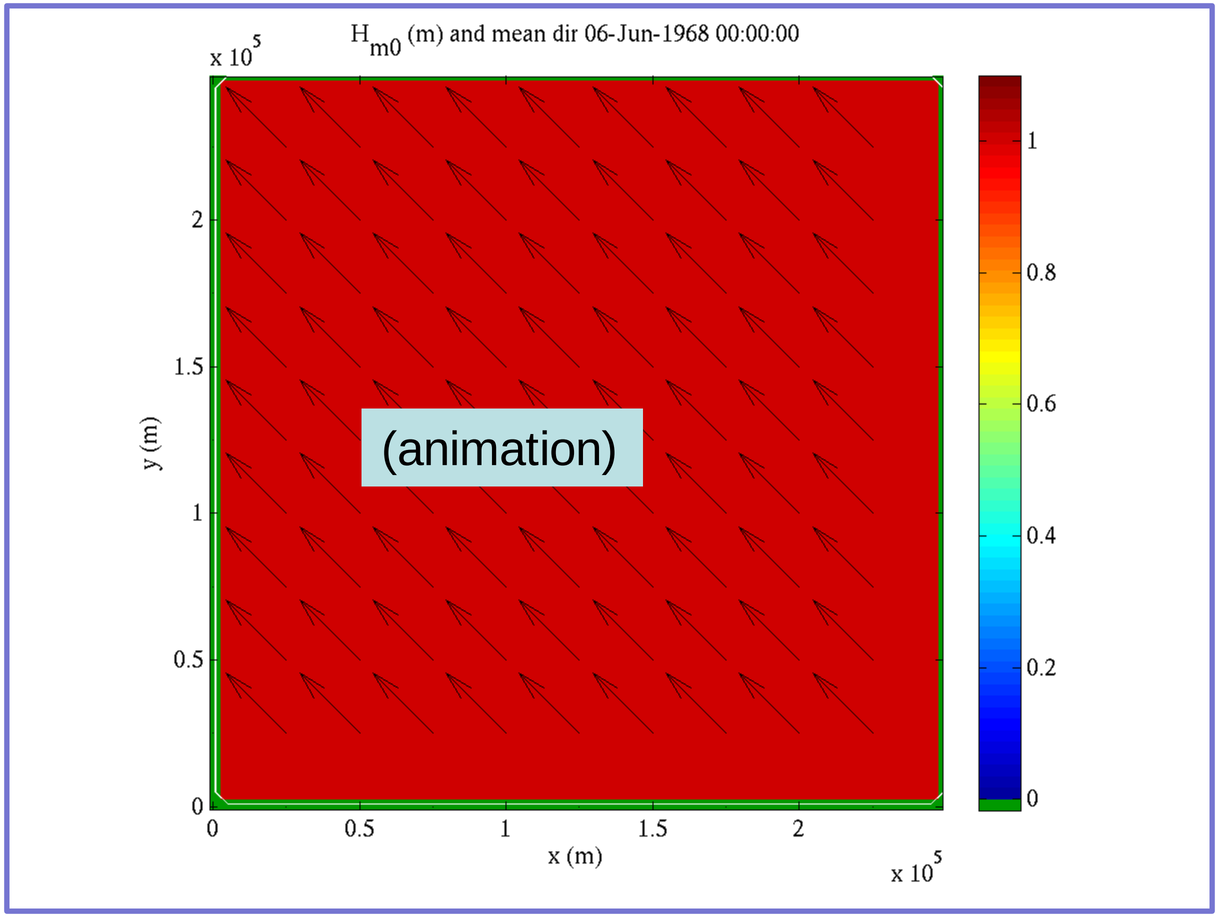
Physical and Chemical Sciences, Scotia–Fundy Region, Department of Fisheries and Oceans, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada

(Manuscript received 20 December 1994, in final form 18 October 1995)

Early progress with WW3, S_{ice} and related i/o

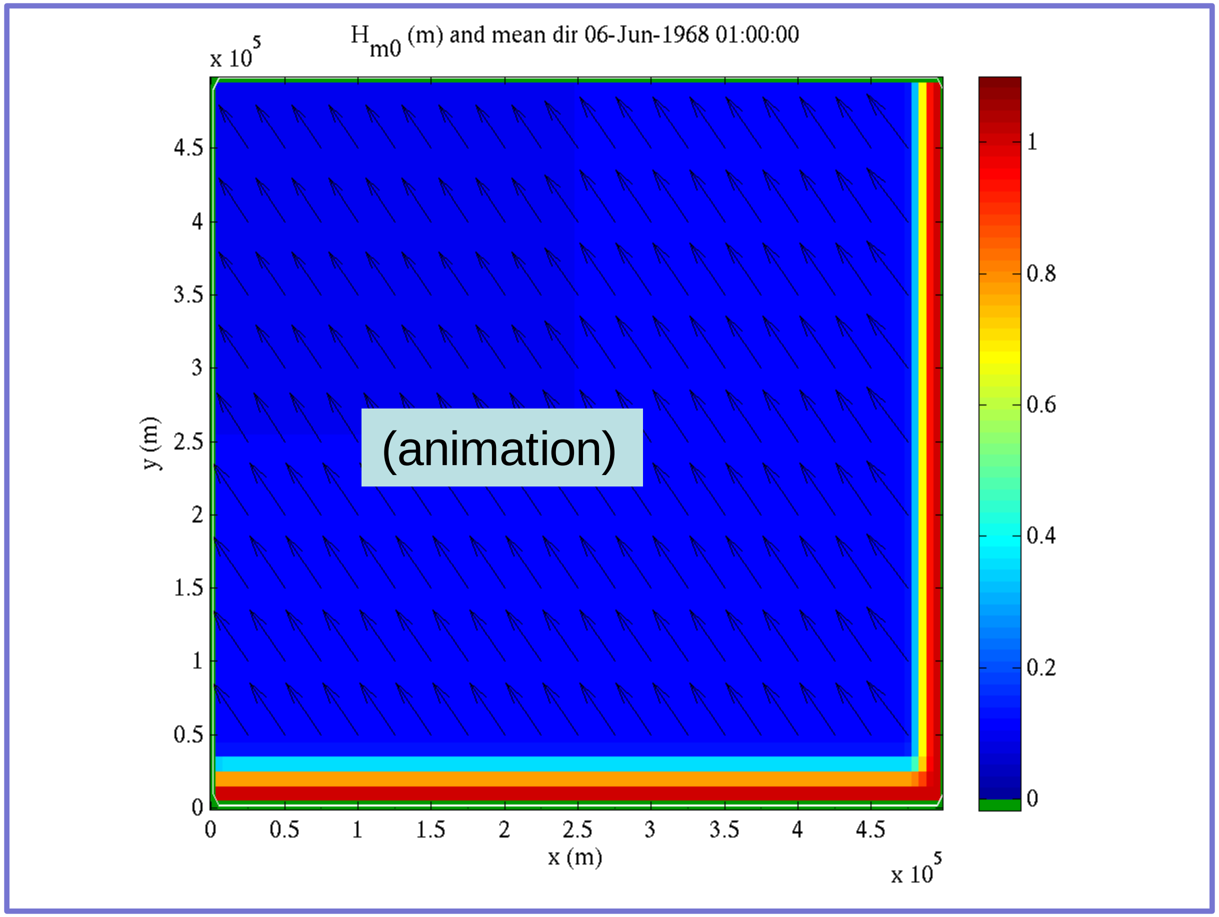
- input:
  - up to 5 ice-related parameters can be read in (8, conditionally)
  - does not include variables that already existed (concentration, ΔT, currents, water depth)
  - might include water temperature, salinity, ice thickness, effective viscosity, floe size information, parameters for elasticity/plasticity
  - can be non-stationary, non-uniform
- S_{ice} routine: Liu et al. (JGR 1991) implemented for testing

Demonstration of early progress with WW3, S_{ice} and related i/o



- k_i prescribed
- ice appears in NW corner, swell reacts
- ice disappears, swell fills in
- demo of nonstationary, non-uniform ice field

Demonstration of early progress with WW3, S_{ice} and related i/o



- k_i is not prescribed, but calculated using Liu et al. source function
- ice thickness, eddy viscosity parameter prescribed

Further discussion of WW3, S_{ice} and related i/o

- the 5 to 8 ice-related parameters need not be physical quantities
- they might be describing $k_i(f)$ based on computations made outside WW3 using physical quantities, e.g. $k_i(f)=a0+a1*f+a2*f^2+a3*f^3+a4*f^4$
- some theoretical models require difficult complex root-finding procedures which may be more efficient outside WW3
- Matlab curve-fitting methods could be useful

Key Collaborations

- Theoretical modeling
  - Visco-elastic modeling
  - Discrete ice-floe modeling
- Remote sensing (ice and waves)
- In situ observations

Key points (in closing)

- Numerical obstacles and coding (1st phase) have been addressed
- Work on S_{ice} starting CY2012
  - no shortage of theoretical models to use
  - challenge is to:
    - select appropriate model
    - provide necessary inputs