Configuration of PIPS for Thermal Stress Calculations

James K. Lewis
Scientific Solutions, Inc., PO Box 1029, Kalaheo, HI 96741
Tel.: (808) 651-7740, Fax: (808) 332-5120, Email: ocnphys@aloha.net

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LONG-TERM GOALS

Provide a dynamically based means for predicting under-ice noise variations due to thermally-induced fracturing in pack ice. Incorporate this forecasting technology into the next generation Polar Ice Prediction System, PIPS 3.0 (PIPS3).

OBJECTIVES

We have undertaken an assessment of incorporating the thermomechanics of pack ice (Lewis, 1998) to allow PIPS3 to predict under-ice noise variations (Stein et al., 2000). The objectives of this year's work are the initial modifications of the PIPS3 thermodynamics (Bitz and Lipscomb, 1999) to include aspects of thermomechanics and quantifying the impact of truncation error for the larger time steps and vertical discritization of the PIPS3 and ice salinity profiles that are allowed to vary in space and time.

APPROACH

A version of PIPS3 was configured to be forced by conditions observed during CEAREX. The forcing was constant over the domain, and temperature variations were considered only at the center of the grid to isolate the thermodynamics from boundary processes, ridging, and ice divergence effects. The model was run with a 20 minute time step and high resolution for the layers of ice in the vertical. As a result, the truncation error (Roache, 1972) in the finite difference equation should be relatively small. These model results were taken as a baseline with which to compare other simulations.

Additional simulations were performed utilizing a two hour time step and different numbers of ice levels in the vertical. In addition, the Bitz-Lipscomb thermodynamic code was modified to allow for ice salinities that vary in the vertical with time (Lewis, 1998). All simulation results were compared to the baseline simulation to quantify the impact of various factors.

WORK COMPLETED

Some results of the first simulation are shown in Figs. 1 and 2. The vertical progression of thermal waves through the ice results in oscillating temperatures throughout the Category 2 ice and down to ~1.4 m in the Category 5 ice. The variation of the overall thickness of the Category 5 ice (top panel, Fig. 2) has a distinct oscillation between days 287 and 302.

The simulation was executed again using a time step of 2 hours (Fig. 3). The most dramatic impact is the disappearance of the Category 2 ice half way through the simulation. In effect, the larger time step introduces an error of ~50% in predicting the existence of Category 2 ice. A follow-on simulation with

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14. ABSTRACT
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a 20 minute time step but with the PIPS3 standard of only 2 vertical levels for the Category 2 ice resulted in the predicted existence of Category 2 ice during the entire simulation, similar to Fig. 1.

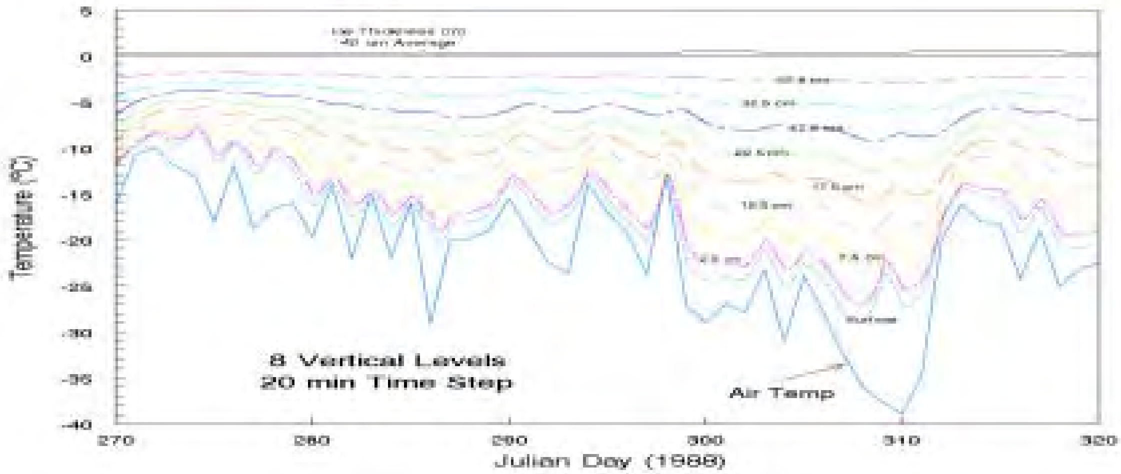

Fig. 1. Predicted ice temperature and thickness variations for Category 2 ice, no snow cover, 2minute time step, and 8 levels in the vertical.

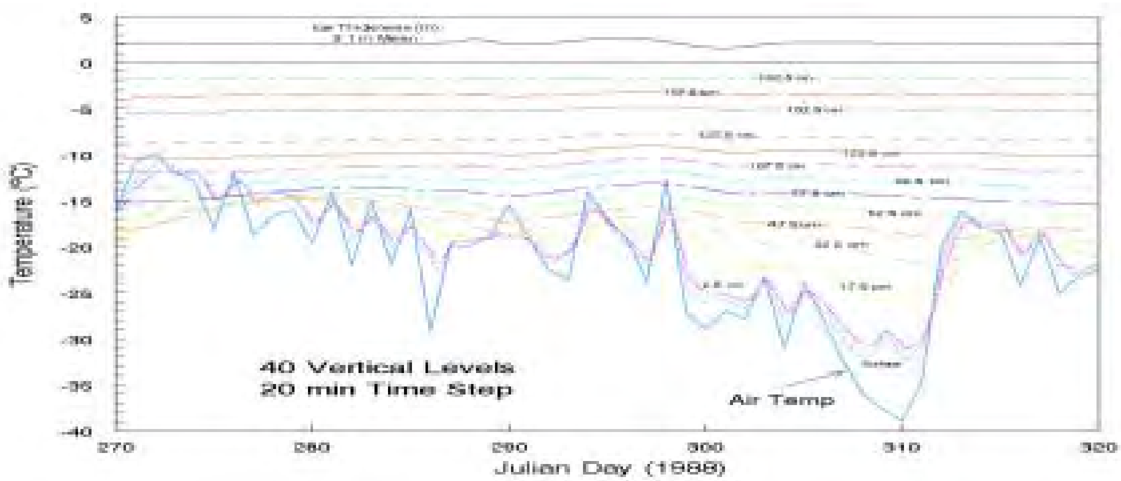

Fig. 2. Predicted ice temperature and thickness variations for Category 5 ice, no snow cover,20minute time step, and 40 levels in the vertical.

The influence of the larger time step on the Category 5 ice can be seen in the prediction of the mean thickness. In Fig. 2, the variations are quite distinct, with a mean of 2.1 m and a standard deviation of 0.20 m. But for the simulation with a 2 hour time step, the predicted thickness is practically constant, ~2.1 m, with a standard deviation of only 0.02 m. The mean temperature of the ice at ~1.5 m is only –4.8^{o}C as opposed the colder mean of –5.2^{o}C for the simulation with a 20 minute time step.

An option for varying salinity was incorporated into the PIPS3 code (Lewis, 1998), with an input flag designating whether this option is to be exercised for a given simulation. The processes governing salinity as a function of depth are a) salinity uptake at the ice/ocean interface, b) brine expulsion for cooling ice, and c) gravity drainage through brine channels. The impacts of salinity uptake, expulsion, and drainage are shown in Fig. 4. The predicted salinities are considerably different from the default PIPS3 0-3.2 ppt profiles. A salinity of 6-7 ppt for the lower layers of the thinner ice categories can translate to increased values of specific heat by a factor 2-3 over that of a salinity of 3.2 ppt.

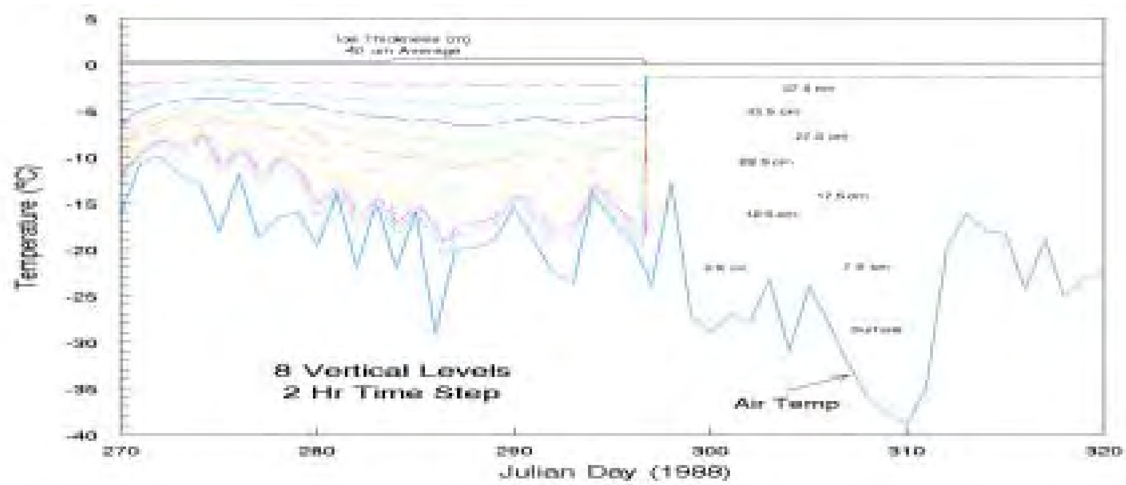

Fig. 3. Predicted ice temperature and thickness variations for Category 2 ice, no snow cover, 2 hour time step, and 8 levels in the vertical.

RESULTS

Our primary goal is to determine how to include in PIPS3 the capability to predict under ice noise resulting from thermally-induced fracturing of the ice pack. Accomplishing this goal includes an assessment of the ability of the Bitz-Lipscomb thermodynamics formulation to predict temperature oscillations (which translates to oscillations in the stress state of the ice pack) as well as the inclusion of the thermomechanics presented in Lewis (1998).

Results strongly indicate that the time step of the thermodynamics must be in the order of 20 minutes to provide reasonably accurate predictions. Since the ice dynamics and thermodynamics are not explicitly coupled, some form of mode splitting can be utilized to allow the ice-ocean dynamics components of PIPS3 to execute with a larger time step while the ice thermodynamics runs with a smaller time step. The concern is the increased computer time for the thermodynamics. However, in most previous models, it has been assumed that the time step of the model was small enough that the specific heat at the current time level is a good approximation of the specific heat at the future time level. In the Bitz and Lipscomb scheme, this assumption is not made, and the model iterates the calculation of the vertical temperature profile at each time step to obtain the specific heat at the future time level. As a result, the scheme is a truly energy-conserving model. But by using larger time steps, numerical diffusion becomes significant, and thermal energy becomes less well conserved.

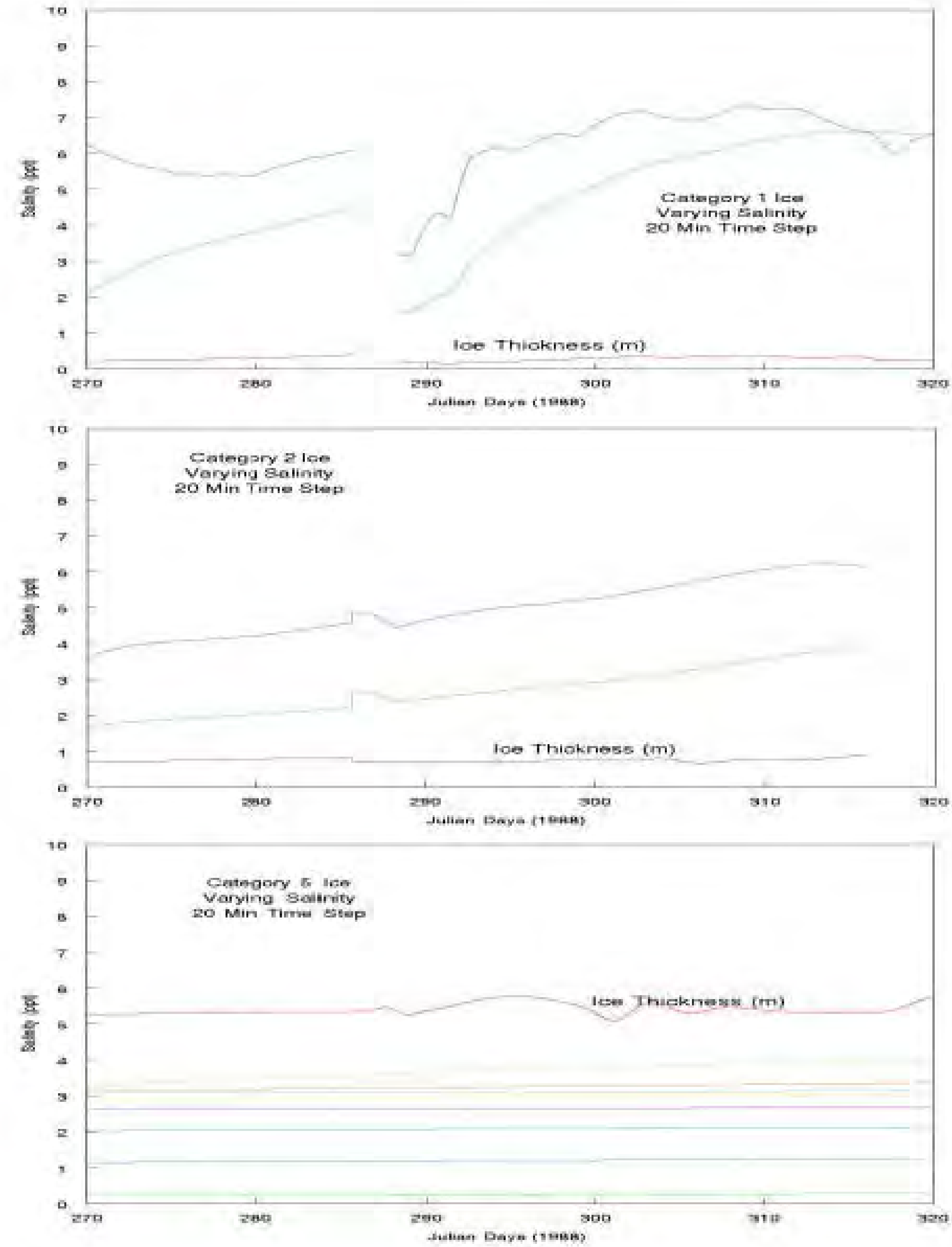

Fig. 4. Predicted salinity profiles for Category 1, 2, and 5 ice thicknesses. Typically, higher salinities are associated with levels that are deeper in the ice.

To overcome this problem, it is recommended that the Bitz-Lipscomb code be modified to have the ability to bypass the iteration process and execute with a smaller time step (small numerical diffusion), assuming that the specific heat at the current time level is a good approximation of the specific heat at the future time level.

Increasing the number of vertical levels for the Category 5 and Category 4 ice can enhance PIPS3 accuracy. The problem is the ability to accurately resolve temperature gradients within the top 20-25 cm of the ice. Additional vertical levels in the Category 4 and 5 ice will increase computational requirements. But it is the thicker ice that has the greatest impact on operational scenarios, so additional computational requirements may be warranted. It is recommended that at least 12 vertical levels be utilized for the Category 5 ice, and perhaps10 levels for Category 4 ice.

Simulations that include salt uptake and discharge indicate that time-varying salinity profiles will have a noticeable impact on PIPS3's prediction. The greatest impact will be on the thinner, more rapidly growing ice thickness categories. For thicker ice categories, the use of a set salinity profile may be reasonable but with somewhat larger values of salinity at the bottom of the ice. But we note that summer-time brine expulsion and melting at the ice-ocean interface could significantly modify the bottom salinities of thicker ice, resulting in less saline conditions during the fall when freeze-up conditions begin. In any case, it is recommended that the PIPS3 thermodynamics have the capability to calculate time-varying ice salinity profiles, with a flag to indicate whether the salinity calculations are to be performed or not for a give simulation.

IMPACT/APPLICATIONS

The impact of this work will be a more accurate prediction capability for PIPS3. It will also mean the need for somewhat more computational capabilities at fleet centers for the calculation of ice salinities. The modifications made to the Bitz-Lipscomb thermodynamics during this project can be readily incorporated into the PIPS3 software. Thus, little impact is expected for software modifications.

TRANSITIONS

These results are ready for transition to NRL for 64 testing. We are waiting to hear from NRL.

RELATED PROJECTS

None

REFERENCES

Bitz C. M., and W. H. Lipscomb, 1999: An energy-conserving thermodynamic model of sea ice. *J. Geophys. Res*., 104(C7), 15669-15677.

Lewis, J. K., 1998: Thermomechanics of pack ice. *J. Geophys. Res*., 103(C10), 21868-21882.

Lewis, 2000: An assessment of incorporating thermomechanics formulations into PIPS 3.0. A Report to the Office of Naval Research. Scientific Solutions, Inc., PO Box 1029, Kalaheo, HI 96741, 27 pp.

Roache, P. J., 1972: *Computation Fluid Dynamics*, Hermosa Publishers, 446 pp.

Stein, P. J., J. K. Lewis, J. C. Parinella, and J. C. Euerle, 2000: Under-ice noise resulting from thermally-induced fracturing of the arctic ice pack: theory and a test case application. *J. Geophys. Res.*, 105(C4), 8813-8826.