Retrieval of Growing Sea Ice Thickness from Infrared Remote Sensing Observations

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The first Visible/Infrared Imager Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership (S-NPP) platform was launched in October 2011. VIIRS is a 22-channel scanning radiometer which provides observations in the wavelength range from the visible to infrared. The nominal spatial resolution is 375 m (including infrared) for imagery resolution spectral bands and 750 m for moderate resolution spectral bands.

Along with a large number of other land surface, ocean, atmosphere and cryosphere products, VIIRS observations are used to routinely map and monitor the global distribution of new and young sea ice. This presentation considers the algorithm proposed to estimate the VIIRS ice thickness and estimates its results. Sea ice growth model is named Ice Age Model (IAM) because initially it was proposed to calculate Ice Age (thickness) on the basis of the VIIRS observations.

Traditionally, one-dimensional energy balance models are applied to estimate ice thickness. The equation includes the heat fluxes of different origination: radiation, turbulent fluxes, ice heat conductivity and is considered applicable to describe ice growth. This study compares Ice Age Model (IAM) with One-dimensional Thermodynamic Ice Model (OTIM). These two methods created completely independently by different groups of authors have many similar features and their direct comparison could serve as a very general estimate of errors in calculations of sea ice growth.

Both models use different realizations of the same energy balance equation describing the processes of the vertical heat exchange between ice covered ocean and the atmosphere and ice thickness could be calculated for a variety of conditions (Figure 1) as a function of the difference between surface and air temperature for different air temperatures included in the legends. A general conclusions of the comparison is that the difference between results of IAM and OTIM algorithms in the case under consideration is acceptable.

However if the air and surface temperatures are not in agreement, the errors in ice thickness could be very large. Therefore the two significant modifications of the ice growth model were developed and are described as follows below.

Firstly, we developed the enhanced model of ice growth based on air temperature and including surface temperature as an unknown internal parameter of the model. The VIIRS Ice Age algorithm bases its calculations only on air temperature having surface temperature as an internal parameter of a model. It means that air and surface temperature are always in agreement.

Secondly, the parameterization of snow on ice was also significantly modified since snow depth is a source of significant errors. The calculations of ice thickness are very sensitive to the depth of snow, because of the relatively low thermal conductivity of snow. It was previously determined that snow on ice leads to more than 60% uncertainty in ice thickness retrieval and that it is necessary to get accurate estimates of snow depth.

Snow depth on ice in the VIIRS Ice Age retrieval is modeled as a function of local snowfall rate and the time of ice grow. Because snow accumulation on ice influences the temperature of upper snow surface it works as a negative feedback modifying surface temperature and suppressing errors in ice thickness calculations.

The equation, defining ice growth as a function of air temperature and snow accumulation is our basis to create a Snow Depth / Ice Thickness LUT that contains predicted snow depth. The improved quality of information on snow depth accumulated on sea ice is a very notable step to a higher level of support users by the information on ice thickness (age).

A principal difference between the OTIM model and currently used VIIRS AIM algorithm to estimate ice age is very significant. The former bases its calculations on supposedly available information on surface and air temperature and is very sensitive to the changes in the difference between air and surface temperatures. The latter uses only air temperature (Figure 2).

Current efforts are focused on the heat flux not included in the original thermal balance equation and on a better account for ice salinity and conductivity as well as a specific heat of ice formation to account for existing discrepancies.

It is important to emphasize that retrieval of ice thickness (age) should draw more attention, because the "techniques provide an unprecedented opportunity to monitor the cryosphere routinely with relatively high spatial and temporal resolutions."

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Wang, X., J. R. Key, and Y. Liu (2010), A thermodynamic model for estimating sea and lake ice thickness with optical satellite data, J. Geophys. Res., 115, C12035.

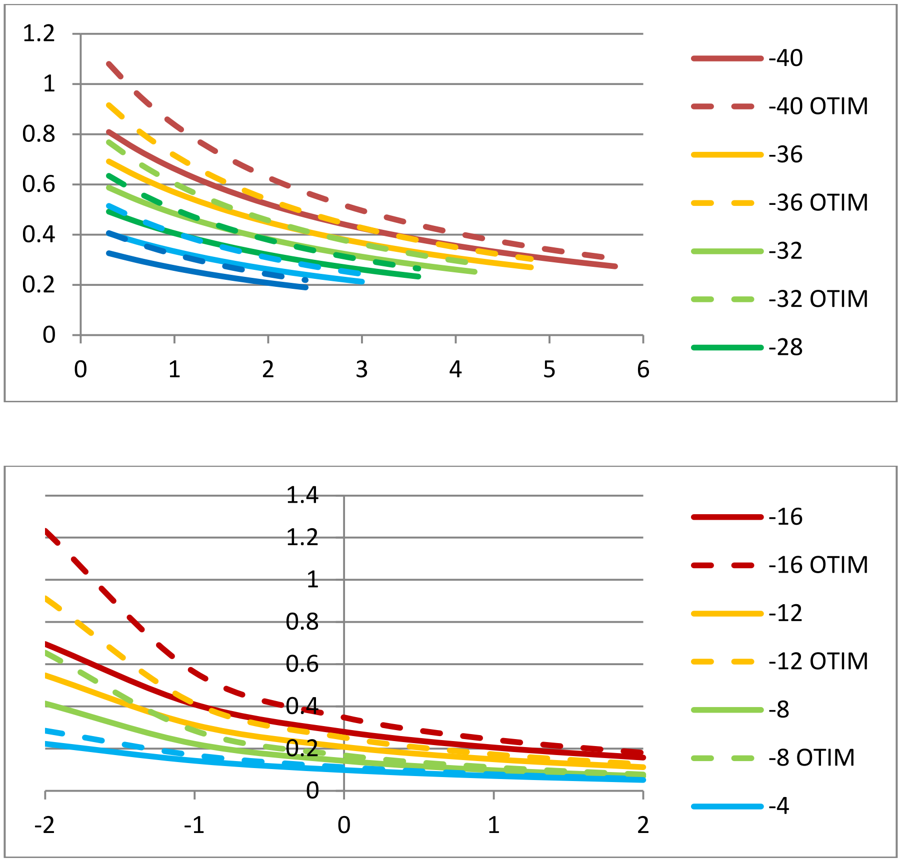

Fig. 1. Thickness versus the difference between surface and air temperatures for different air temperatures

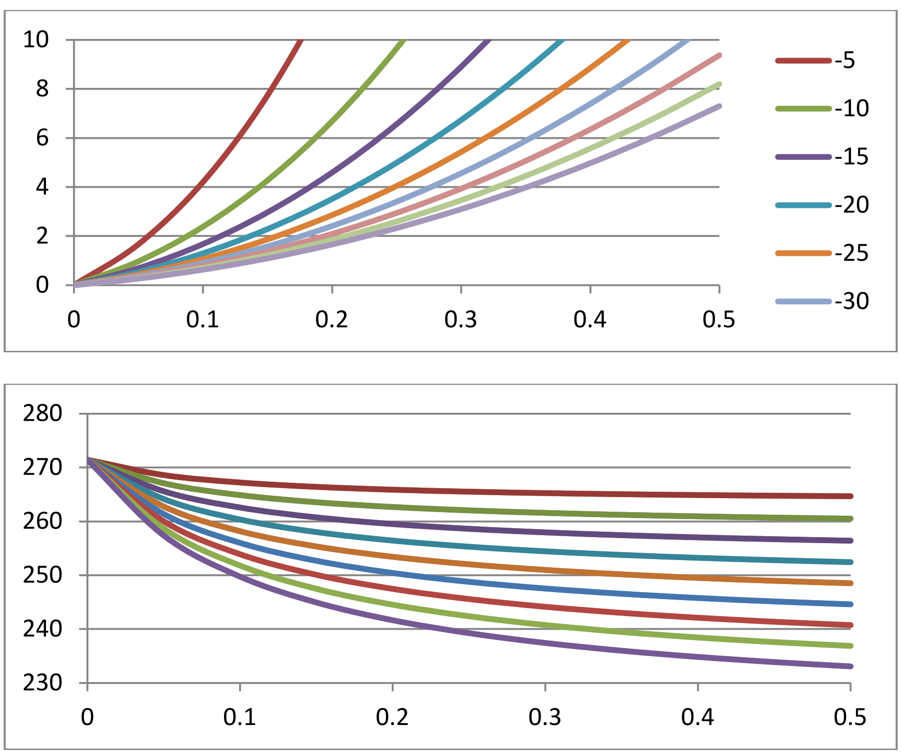

Fig. 2 Time in days (top) and surface temperature (bottom) versus ice thickness for different air temperatures