# Implementation of form drag into the ocean – sea ice model NEMO-SI³, calibration of input parameters with ICESat-2 surface heights, and its impact on sea ice and ocean circulation

*David Schroeder[1], Danny Feltham[1], Kyle Duncan[2] & Sinead Farrell[2]*

[1] Centre for Polar Observation and Modelling, Department of Meteorology, University of Reading, UK
[2] Departments of Geographical Sciences and Atmospheric & Oceanic Science, University of Maryland, U.S.A.

**Email: D.Schroeder@reading.ac.uk**

## 1. Motivation

- Efficiency of air-sea momentum depends on top and bottom sea ice surface roughness which varies with ice types and conditions.
- Most climate models apply constants or at best a parameterization based on ice concentration.
- Current climate models generally overestimate sea ice drift speed (see Fig. 1).
- Understanding how future sea ice reduction will impact momentum transfer from the atmosphere into the ocean requires realistic representation in climate sea ice models.

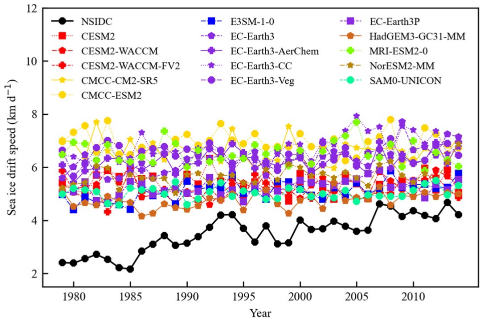



**Figure 1: Pan-Arctic averaged sea ice drift speed comparison between NSIDC-Pathfinder and fifteen CMIP6 models (1979–2014) [from Wang et al., 2023].**

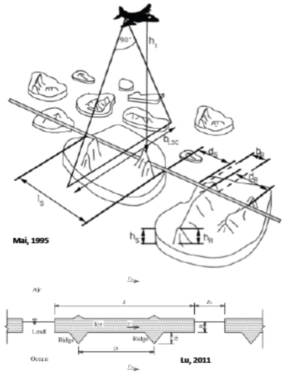
## 2. Form drag parameterization

- Tsamados et al. (2014) drag scheme implemented into SI³ (see Fig. 2 for illustration).
- Total neutral atmospheric form drag computed as a sum of form drag from sails, form drag from floe edges, form drag from melt pond edges, and a reduced skin drag due to a sheltering effect.
- Total neutral oceanic form drag computed as a sum of form drag from keels, form drag from floe edges, and a reduced skin drag due to a sheltering effect.

## 3. Model simulations

3 NEMOv5.0beta + SI³ global ocean – sea-ice simulations on course grid (ORCA2, ~80km in Arctic) with JRA55 atmospheric forcing (Tsujino et al., 2018) from 2000 to 2021:

- NEMO-SI³ default (with constant atmospheric transfer coefficient for momentum $CDN_{ia}$ =1.4 x $10^{-3}$ and ocean: $CDN_{io}$ = 5 x $10^{-3}$)
- NEMO-SI³ FORM with form drag parameterization
- NEMO-SI³ FORM-ITD with modified form drag parameterization based on ice thickness distribution




**Important parameters of the model (in parenthesis notation of schematics) :**

- L : floe size (ls)
- A : ice concentration

Atmosphere :

- Hf : freeboard (hs)
- Hr : ridge height (hr)
- Dr : distance between ridges (dr)
- Df : distance between floes (ds)
- Lp : pond size (not shown)
- Hp : elevation of ice surface relative to pond surface (not shown)

Ocean

- Hd : floe draft (D)
- Hk : ridge keel height (Hr)
- Dk : distance between keels (Dr)

**Figure 2: Illustration of the from drag parameterization from Tsamados et al. (2014) based on Lüpkes et al. (2012), Lu et al. (2011) and Mai et al. (1995).**

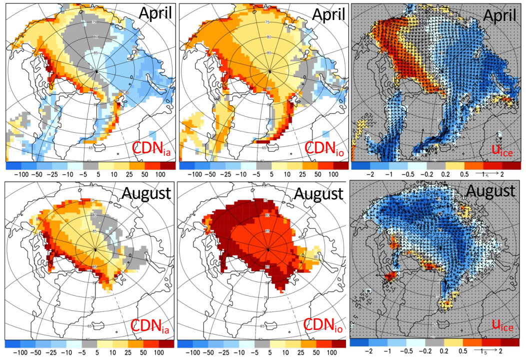



**Figure 3: Relative change of transfer coefficients for momentum in % and ice drift in cm/s (Form minus default) for April and August (Climatology from 2000 to 2021).**

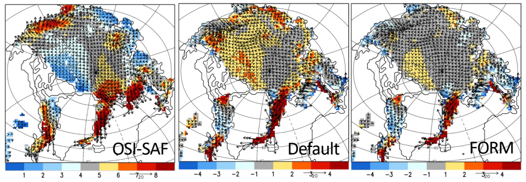



**Figure 4: Mean ice drift tansport in cm/s for 2021: OSI-SAF, NEMO-SI³ default minus OSI-SAF, and NEMO-SI³ FORM minus OSI-SAF.**

## 4. Results

- Form drag parameterization introduces noticeable spatial and temporal variability of neutral 10-m atmosphere-ice and ocean-ice drag in NEMO-SI³ (see Fig. 3).
- Big impact on ice drift (20-30% reduction, Fig.3) and ocean current (not shown); ice transport much closer to observed ice drift (EUMETSAT Ocean and Sea Ice Satellite Application Facility OSI-SAF [Lavergne and Down, 2023] Fig. 4).
- But how realistic are input variables for form drag parameterization?
- Comparison with surface topography data set which has been derived from the ICESat-2 ATL03 global geolocated photon height data product [Duncan and Farrell, 2022] shows poor agreement: Ridges in NEMO-SI³ FORM too high and too frequent (see Fig. 5).

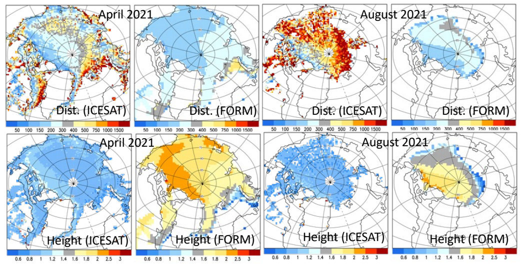



**Figure 5: Comparison of ridge height and distance in m between ICESat-2 and NEMO-SI³ FORM for April and August 2021.**

## 4. Results (cont'd)

- Potential uncertainties of simulated sea ice thickness seem not to be key reason for mismatch; distance between keels from ICESat well correlated to fraction of upper end in ice thickness distribution ITD (Fig. 6).
- Applying ITD to parameterize volume of ridged ice enables to derive realistic ice ridge distributions.
- Resulting transfer coefficients lower than in original form drag parameterization (Fig. 7), but improvements in ice drift comparable (Fig. 8).

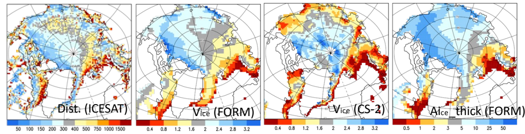



**Figure 6: Comparison of ICESat-2 ridge distance in m with ice volume in m from NEMO-SI³ FORM and Cryosat-2 and fraction of ice thicker than 2.85m in % (NEMO-SI³ FORM) for April 2021.**

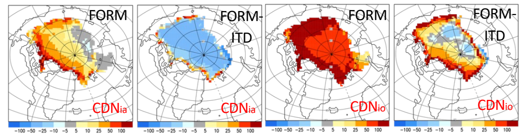



**Figure 7: : Relative change of transfer coefficients for momentum in %: FORM vs default for August 2021**

## 5. Conclusions

- Form drag parameterization implemented in NEMOv5beta.
- Form drag has the potential to overcome the consistent issue of climate models overestimating the Arctic sea ice drift speed.
- ICESAT-2 based estimates of surface properties indicate that existing parameterizations of height and distance of pressure ridges are not realistic, and modifications affect transfer coefficients strongly.

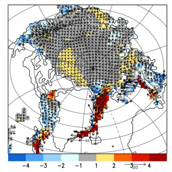


**Figure 8: As Fig. 4, but for FORM-ITD.**

References:
Duncan, K., & Farrell, S. L. (2022). Determining variability in Arctic sea ice pressure ridge topography with ICESat-2. Geophysical Research Letters, 49, e2022GL100272. https://doi.org/10.1029/2022GL100272.
Lavergne, T. and E. Down (2023). A climate data record of year-round global sea-ice drift from the EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI SAF), Earth Syst. Sci. Data, 15, 5807–5834, https://doi.org/10.5194/essd-15-5807-2023.
Lu, P., Z. Li, B. Cheng, and M. Leppranta, 2011: A parameterization of the ice–ocean drag coefficient. *J. Geophys. Res.,* **116,** C07019, doi:10.1029/2010JC006878.
Lüpkes, C., V. M. Gryanik, J. Hartmann, and E. L Andreas (2012), A parametrization, based on sea ice morphology, ofthe neutral atmospheric drag coefficients for weather prediction and climate models,J. Geophys. Res.,117, D13112, doi:10.1029/2012JD017630.
Mai, S., C. Wamser, and C. Kottmeier, 1996: Geometric and aerodynamic roughness of sea ice. *Bound.-Layer Meteor.*, **77**, 233–248, doi:10.1007/BF00123526.
Tsamados, M., Feltham, D., Schroeder, D., Flocco, D., Farell, S., Kurtz, N., Laxon, S. and Bacon, S. (2014) Impact of variable atmospheric and oceanic form drag on simulations of Arctic sea ice. Journal of Physical Oceanography, 44 (5). pp. 1329-1353. ISSN 0022-3670 doi: 10.1175/JPO-D-13-0215.1
Tsujino, H., et al. (2018): JRA-55 based surface dataset for driving ocean–sea-ice models (JRA55-do), Ocean Model., 130, 9–139, https://doi.org/10.1016/j.ocemod.2018.07.002.