Diagnosing Sea Ice in the Unified Forecast System (UFS)

Neil Barton¹, Robert Grumbine¹, Dmitry Dukhovskoy¹, Philip Pegion², Avichal Mehra¹

¹NOAA/ NWS/ NCEP/ EMC, ²NOAA/ OAR/ PSL

2023 UIFCW, July 28th, 2023
## Acknowledgement to UFS Coupled Prototype Active Developers

### Atmospheric Physics

**NCEP/EMC:** Shrinivas Moorthi, Jongil Han, Michael Barlage, Helin Wei, Anning Cheng, Bing Fu, Wei Li, Ruiyu Sun, Rongqian Yang, Qingfu Liu, Weizhong Zheng, Sajal Kar, Alexei Belochitski, Yihua Wu, Eric Sinsky, Bo Yang, Hong Guang, Xu Li, Fanglin Yang  
**ESRL/GSL:** Dom Heinzeller, Shan Sun, Michael Toy, Ben Green, Tanya Smirnova, Joseph Olson  
**ESRL/PSL:** Philip Pegion, Lisa Bengtsson, Clara Draper, Jian-Wen Bao, Songyou Hong, Dustin Swales  
**DTC:** Weiwei Li, Ligia Bernardet  
**Catholic University of America:** Valery Yudin

### Coupled Model Component Development

**NCEP/EMC:** Jessica Meixner, Jiande Wang, Lydia Stefanova, Shrinivas Moorthi, Jun Wang, Denise Worthen, Robert Grumbine, Bing Fu, Ali Abdolali, Bin Li, Minsuk Ji, Matthew Masarik, Walter Kolczynski, George Gayno, Yuejian Zhu, Neil Barton, Arun Chawla, Avichal Mehra  
**ESRL/GSL:** Shan Sun, Ben Green  
**ESRL/PSL:** Phillip Pegion, Lisa Bengtsson  
**GFDL:** Brandon Reichl, Alistair Adcroft, Robert Halberg, Stephen Griffies, Rusty Benson, Marshall Ward, Matthew Harrison  
**NCAR:** Rocky Dunlap, Mariana Vertenstein, Alper Altuntas, Gustavo Marques, Gokhan Danabasoglu, Keith Lindsay  
**NRL/ESMF:** Gerhard Theurich  
**GMU:** Cristina Stan, Ben Cash, Jim Kinter, Lawrence Marx  
**FSU:** Eric Chassignet, Alan Wallcraft, Alexandra Bozec  
**NASA:** Akella Santha  
**Univ. Alaska:** Katherine Hedstrom  
**U. Mich.:** Christiane Jablonowski  
**Univ. Victoria:** Andrew Shao

### Atmospheric Composition

**NCEP/EMC:** Raffaele Montuoro, Li Pan, Partha Bhattacharjee, Walter Kolczynski, Jeff McQueen, Ivanka Stajner  
**ARL:** Barry Baker, Patrick Campbell, Rick Saylor  
**ESRL/GSL:** Li (Kate) Zhang, Shan Sun, Georg Grell  
**CSL:** Siyuan Wang, Jian He, Stuart McKeen, Gregory Frost  
**NESDIS/STAR:** Xiaoyang Zhang, Ethan Hughes, Shobha Kondragunta

### Coupled Model Evaluation

**NCEP/EMC:** Lydia Stefanova, Jiande Wang, Partha Bhattacharjee, Sulagna Ray, Wei Li, Michael Barlage, Weizhong Zheng, Robert Grumbine, Huug van den Dool, Avichal Mehra  
**CPC:** Wanqiu Wang, Yanyun Liu, Jieshun Zhu  
**ESRL/PSL:** Zachary Lawrence, Amy Solomon, Maria Gehne, Chris Cox  
**GMU:** Cristina Stan, V. Krishnamurthy, Eunkyo Seo
Sea Ice Modeling in UFS

UFS Driver

Atmosphere: UFS ATM
- FV3 dycore
- CCPP Physics
- NOAH-MP

Ocean: MOM6

Mediator: CMEPS

Aerosols: GOCART

Waves: WAVEWATCH III

Ice: CICE6

CICE6
- Department of Energy Based Model
  - Los Alamos National Laboratory (LANL)
- CICE consortium
  - DOE, NSF, US Naval Research Lab, NASA, NOAA, DMI, Environment Canada, iPAN
- ¼ degree tripolar grid (same as ocean)
- 5 thickness categories
- Mushy thermodynamics
- B-grid
- JEDI-SOCA (Sea-Ice Ocean and Coupled Analysis) for initialization (sea ice concentration, sea ice thickness, snow thickness)
CICE Coupling

UFS Driver

Atmosphere
- SSTs
  - LW up, T\text{skin}, Latent Heat, Sensible Heat, Momentum, Snow Volume, Ice Fraction, Ice Volume, Albedo
- Surface Roughness

Ocean
- Latent Heat, Sensible Heat, LW (net and down), SW (dir and diff)
  - Rain Rate, Snow Rate, T, Q, U, V, P, Height
- Basal heat flux, basal freshwater flux, basal salinity flux, basal stress, basal SW
- Stokes Drift

Sea Ice
- SSTs, Slope, SSS, SSU, SSV, Freezing/Melting Potential
- Rain Rate, Snow Rate, T, Q, U, V, P, Height

Waves
- U 10m, V 10m
- Ice Fraction
- SSU, SSV

Mediator
Sea Ice Results from Prototype 8

Forecast Setup:
- Every 1st and 15th day from April 2011 to March 2018
- 35 Day Forecasts
- Prototype Testing Runs

Initial Conditions:
- CICE: CPC analysis (CSIS) (Liu et al. 2019)
- MOM6: CPC 3DVAR
- FV3: GEFS Reanalysis

Observations:
- Sea Ice Concentrations/Extent
  - NASA A-Team Sea Ice Thickness
Northern Hemisphere Comparison
NH Sea Ice Extent

- Sea Ice Extent
  - Area with > 15% sea ice
NH Sea Ice Extent

- Negative bias in Sea Ice extent
- Negative bias in initial conditions
- Greater negative biases during summer melt months
  - More rapid melt
Southern Hemisphere Comparison
SH Sea Ice Extent

- SH sea ice extent biases are larger than NH biases.
- P8 SH sea ice extent is mostly greater than observations except during seasons melt period.
- Larger differences in initial sea ice compared to observations when comparing to NH
Sensitivity to Physics

- P8 is result of constant development of the UFS
- Each prototype had multiple changes that results in difficulties when isolating the cause of change
- Limited HPC resources to test individual changes
- However, GSL re-ran P8 with the old GFDL physics for analysis
- Hypothesis: Thompson microphysics can represent the clouds in the Arctic more accurately, in particular with respect to low-level mixed-phases clouds, which leads to a better representation of surface radiation, and then sea ice.

<table>
<thead>
<tr>
<th>Thompson Microphysics</th>
<th>GFDL Microphysics</th>
</tr>
</thead>
<tbody>
<tr>
<td>P8</td>
<td>previous prototypes of UFS (ops since 2019)</td>
</tr>
<tr>
<td>double microphysics (mixing ratio and droplet size)</td>
<td>single moment microphysics (mixing ratio)</td>
</tr>
</tbody>
</table>

*Runs completed by NOAA/ OAR/ GSL Ben Green and Shan Sun*
Overall, there are not large differences between NH sea extent with the changes in microphysics. However, Thompson microphysics systematically produces more sea ice in the NH winter months.
NH Sea Ice Extent

Feb

Sep
NH September: Sensitivity to Physics

Thompson (P8) minus GFDL

- Higher low cloud cover cloud occurs in Thompson microphysics compared to the GFDL microphysics.
- Differences in clouds start early in the forecast
NH February: Sensitivity to Physics

Thompson (P8) minus GFDL

- Higher low cloud cover occurs in Thompson microphysics compared to the GFDL microphysics.
Comparison to CFSv2

- Raw, uncorrected model results
- P8 sea ice extent biases are much smaller than CFSv2 biases in Northern and Southern Hemisphere
- Recalibration needed for biases corrections for S2S UFS runs
Conclusions

- Initial look at large scale sea ice in the global UFS runs
- Sea ice extent in NH is reasonable
- Larger biases occur in the SH compared to the NH.
  - The initial sea ice in SH summer season should be examined in greater detail
- The switch to Thompson microphysics slightly alters the sea ice extent predictions
  - In particular, NH winter sea ice is greater with Thompson microphysics and results in closer agreement to observations
  - Corresponding with higher low-cloud fractions. However, more analysis of cloud properties is needed
- Shorter Term Updates:
  - Ensembles
  - Initialization in weakly coupled DA system
- Longer Term Updates/testing:
  - C-Grid
  - Meltponds, aerosols
Thank You!

neil.barton@noaa.gov
Sea Ice Thickness Comparison

- Week 1 average of Sea ice thickness
- Initialized from CPC analysis
  - Biases similar to initialization 
  
  Collow et al. (2019)
- Overall decent agreement for no assimilation of thickness
- Higher sea ice thickness values north of Canada in the model compared to observations