Implementation of the Robert Filter in POP

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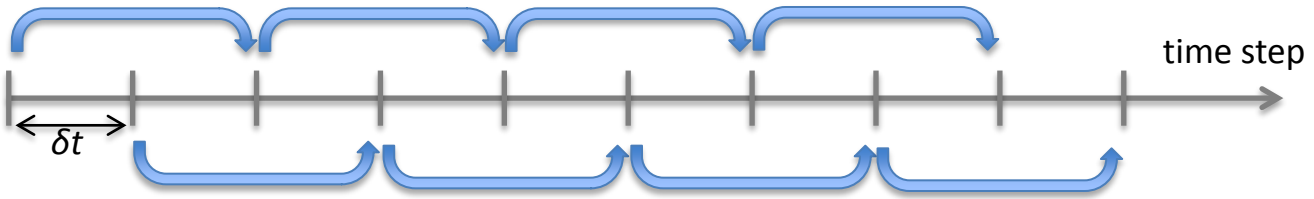
Outline

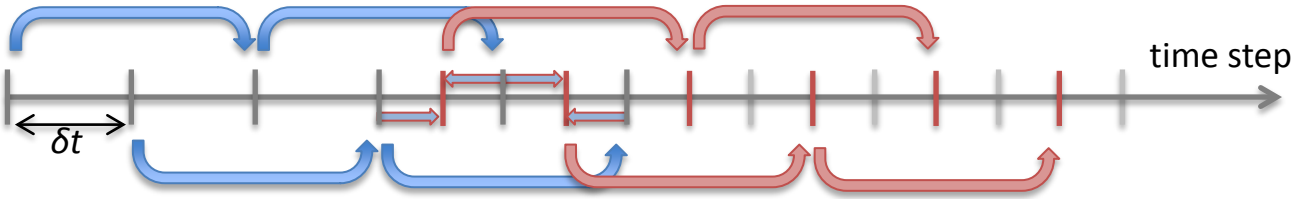
- Why do we need something different?
- Formulation of the filter
- Implementation in POP
- Results
  - Ocean only
  - Fully coupled
- What's left to do?

Leapfrog Timestepping

- 2nd order, easy to implement
- Even/odd step decoupling is unstable



- POP solution: Average even/odd solutions every N steps



Why Change?

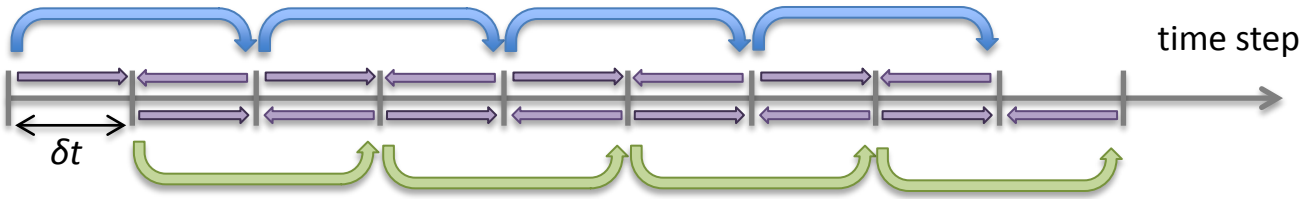
- Averaging steps worked fine for ocean-only work when the time important time boundaries when associated with data output
- For CESM, coupling interval has become definitive time segment
  - Always at least 2 averaging steps/coupling interval
  - Still ok with daily coupling
    - (23,2) (full,half) steps/day for x1
  - Too frequent with higher frequency coupling
    - (18,6) (full,half) steps/day for x1 and 4-hour coupling

What are possible options?

- 2 time level scheme
  - Pro: very versatile
  - Con: large amount of code redesign
- Robert-Asselin filter
  - Pro: keep leapfrog scheme (fewer code mods)
  - Con: keep leapfrog scheme

Robert Filter

- Do a little averaging every timestep (weak temporal diffusion)



- Formally first order, but is “quasi 2nd order” since only a little every timestep

Formulation

example: POP temperature equation

penetrative shortwave

advection + diffusion

$$(1+\xi^{n+1})T^{n+1} = (1+\xi^{n-1})T^{n-1} + 2\delta t(F^n + Q^n_{sw}(z) + Q^n_{ice} + A + D)$$

$\frac{SSH}{dz_k}\delta_{1,k}$

surface heat flux

sea ice formation

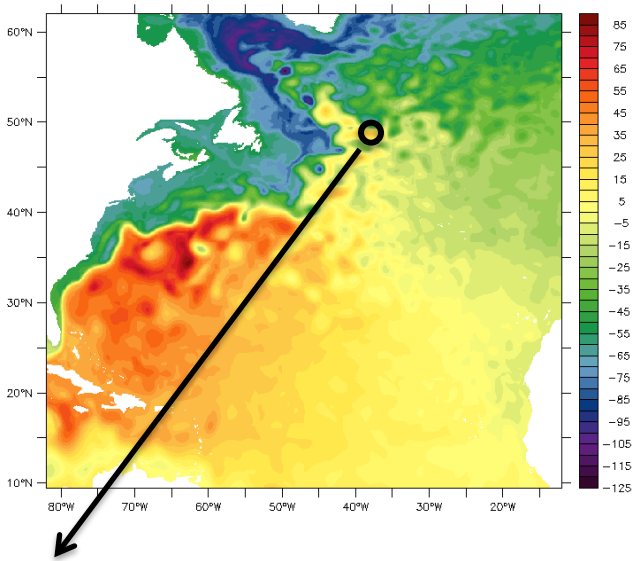
Robert Filter

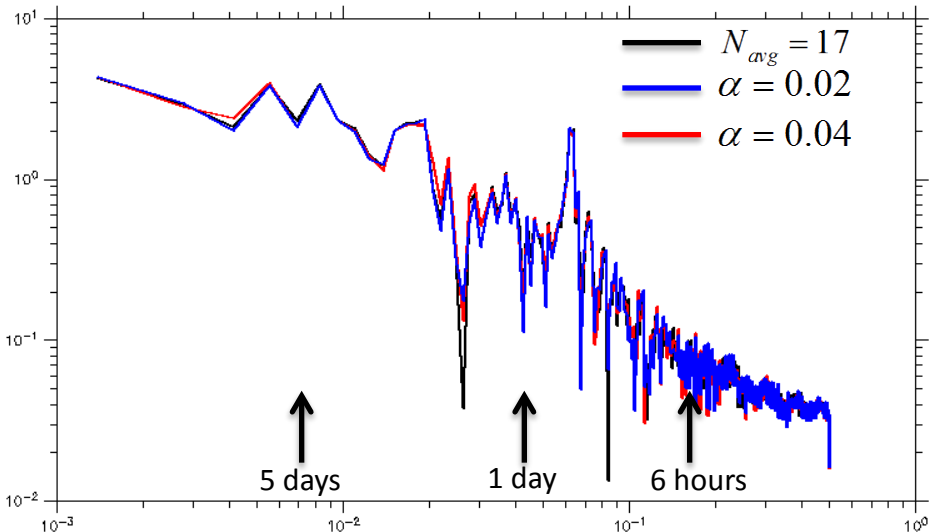
$$(1+\hat{\xi}^n)\hat{T}^n = (1+\xi^n)T^n + \alpha\left[(1+\xi^{n+1})T^{n+1} - 2(1+\xi^n)T^n + (1+\hat{\xi}^{n-1})\hat{T}^{n-1}\right]$$

α □ *1*

Ocean-Only Results

- Too diffusive?
  - 1/10 North Atlantic with
  - 6-hour “Normal Year”
  - 7 minute timestep
  - 30 day run, 1 hour sampling





Spectrum of U (cyc/hour)

Coupling Problem

- Robert filter not able to conserve both globally and locally (Griffies etal)
- Leclair and Madec (2009) to the rescue
  - Split n-level forcing to n-1/2, n+1/2
  - Modify filter to account for this
  - Can achieve both local and global conservation

Modified Formulation

Temperature equation

$$(1+\xi^{n+1})T^{n+1} = (1+\xi^{n-1})T^{n-1} + \delta t(F^{n-1/2} + Q_{sw}^{n-1/2} + Q_{ice}^{n-1/2}) + \delta t(F^{n+1/2} + Q_{sw}^{n+1/2} + Q_{ice}^{n+1/2}) + 2\delta t(A + D)$$

Robert Filter

$$(1+\hat{\xi}^{n})\hat{T}^{n} = (1+\xi^{n})T^{n} + \alpha\left[(1+\xi^{n+1})T^{n+1} - 2(1+\xi^{n})T^{n} + (1+\hat{\xi}^{n-1})\hat{T}^{n-1}\right] + \alpha\delta t(F^{n-1/2} + Q_{sw}^{n-1/2} + Q_{ice}^{n-1/2}) - \alpha\delta t(F^{n+1/2} + Q_{sw}^{n+1/2} + Q_{ice}^{n+1/2})$$

Implementation in CESM

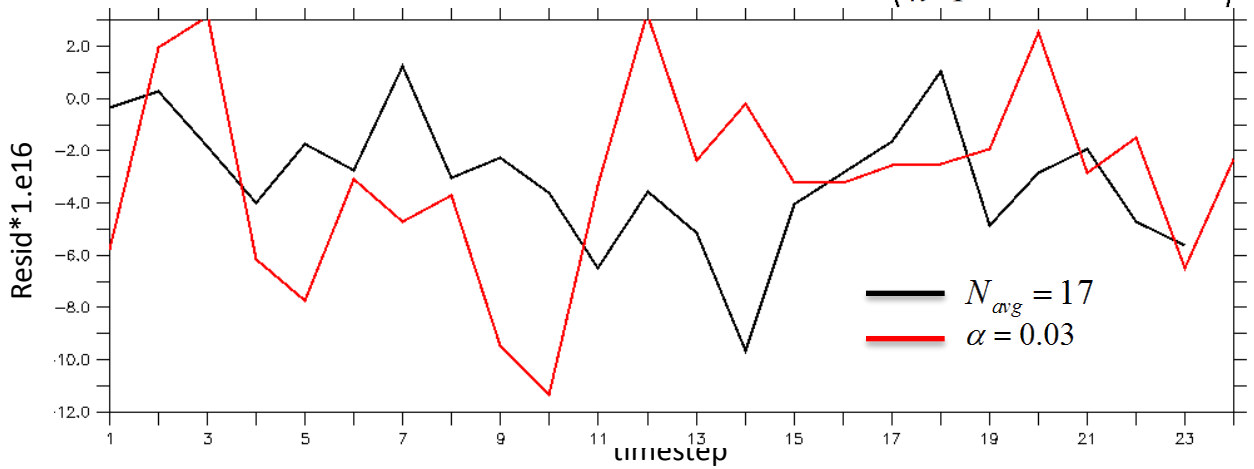
- Focus on fully coupled (B1850)
- 2 time levels for surface forcing
  - Latent, sensible, longwave constant over coupling interval
  - Shortwave can change every timestep
  - Shortwave needs extra 3D array
  - Ice formation only on last timestep of coupling interval
  - Extra restart fields

Coupled Results

- F09_g_B1850, CESM_1.1.beta08
- Daily coupling
- 4 year "startup" runs
  - averaging timestep every 17 steps (default)
  - Robert filter, $\alpha = 0.03$
  - Robert filter, $\alpha = 0.02$
  - averaging timestep every 9 steps

Ocean Temperature Residual

$$Resid_T(N) = \langle T(N) \rangle - \langle T(0) \rangle + \left\langle \sum_{n=1}^{N} Source(n) \right\rangle$$



First day

Ocean Temperature Residual

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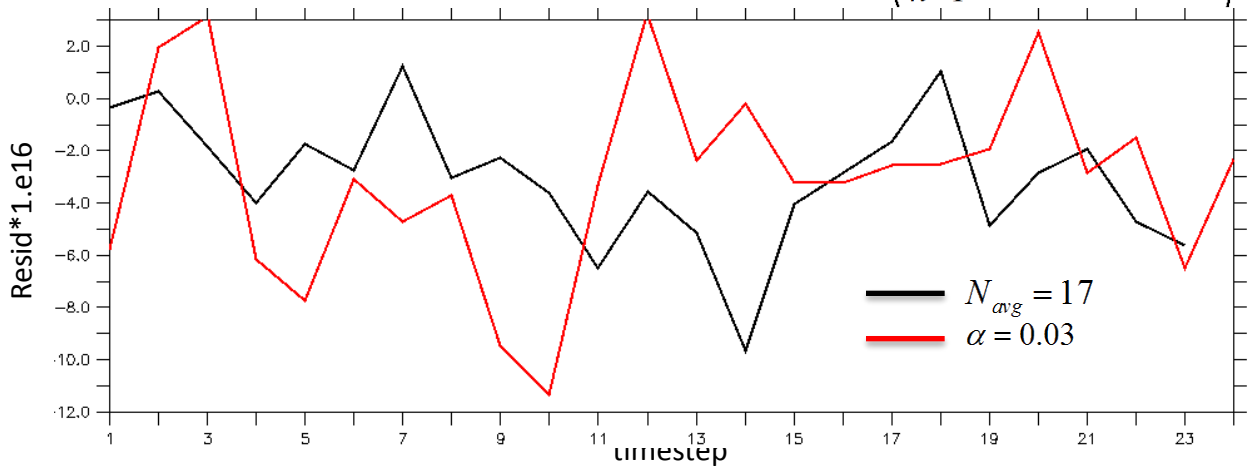
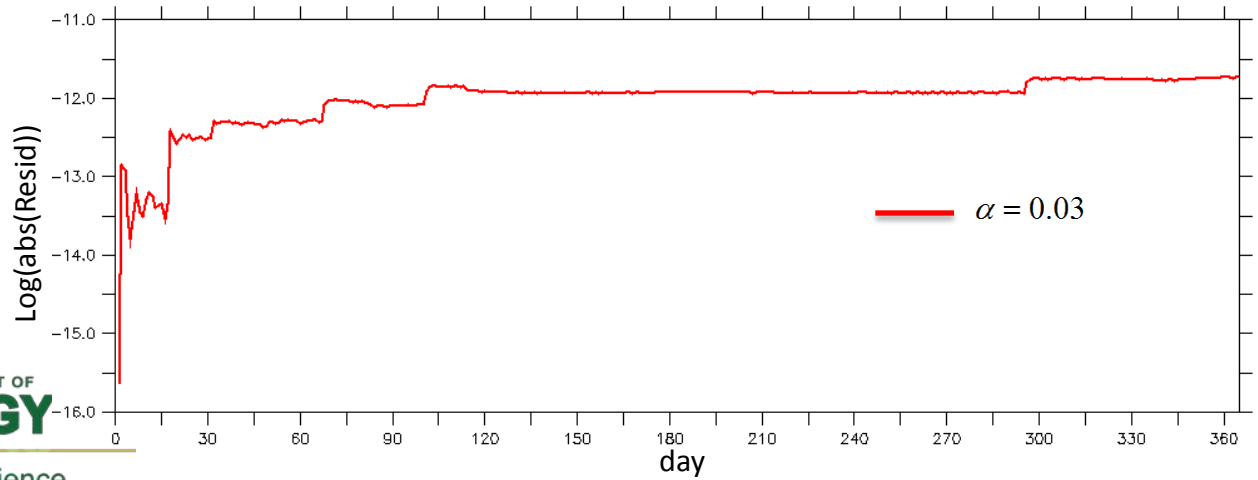
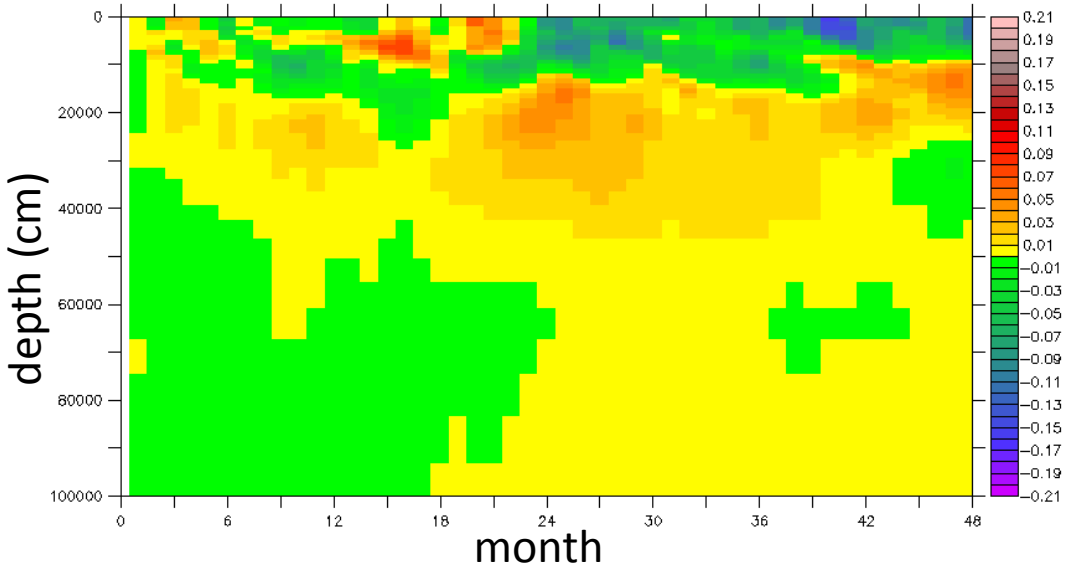


First day



First year

Globally Averaged Ocean Temperature Difference



Standard ($N_{avg} = 17$) – Robert ($\alpha = 0.03$)

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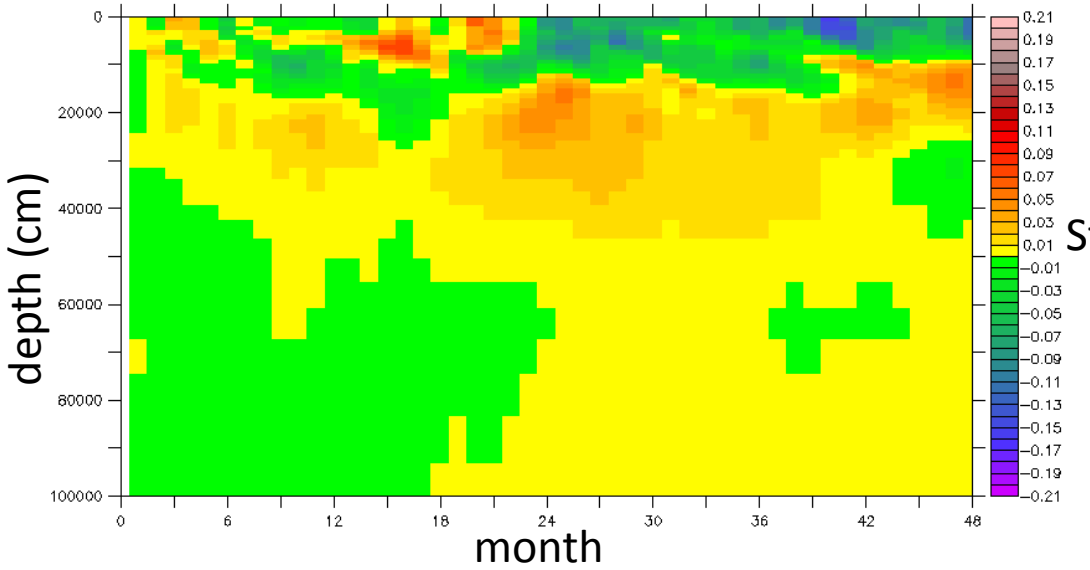

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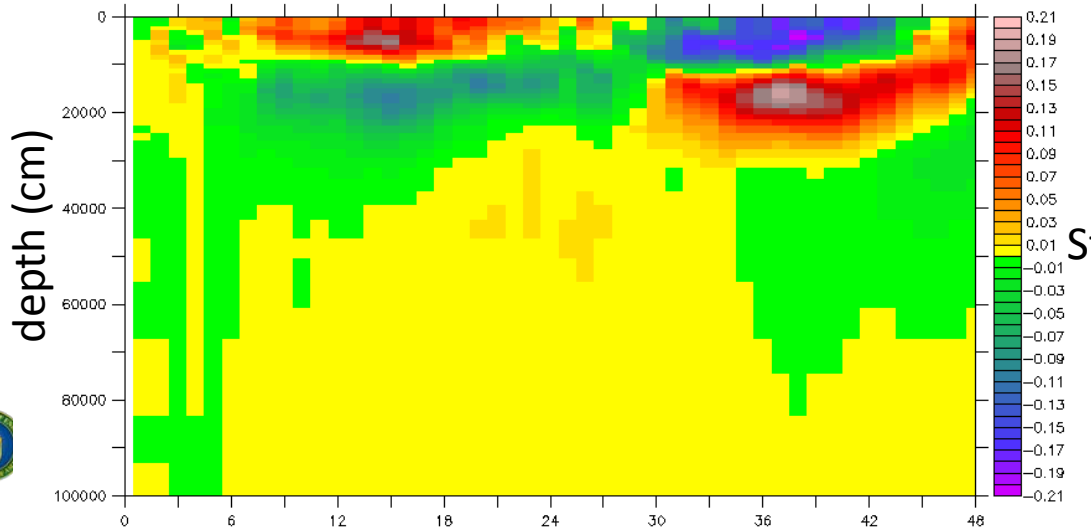

Standard ($N_{avg} = 17$) – Standard ($N_{avg} = 9$)

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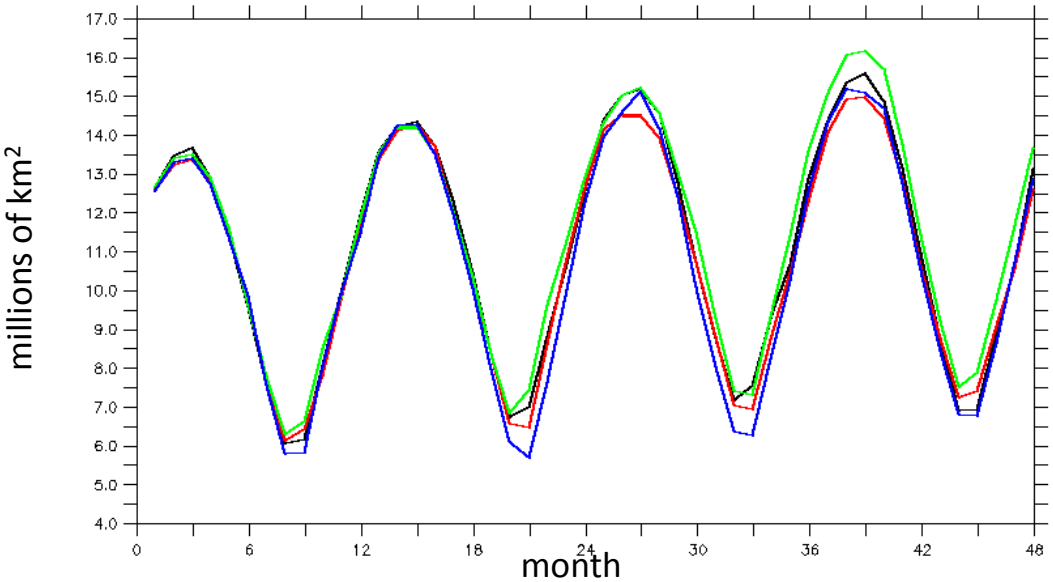
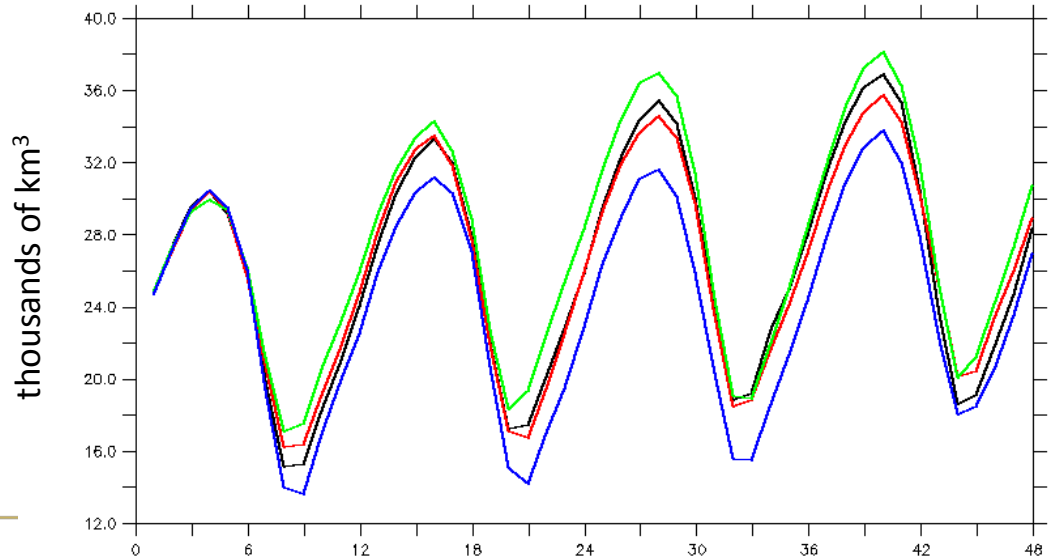
Arctic Sea Ice



Ice Area



Ice Volume

$N_{avg} = 17$

$\alpha = 0.03$

$\alpha = 0.02$

$N_{avg} = 9$

Future

- Complete robust implementation
  - Passive tracers
- More thorough testing in variety of configurations
  - Multi-century control run
- Extend to the higher order variant of Williams (2009)
  - Also filters the n+1 time level
- Make compatible with z*