Waves and Langmuir Mixing in Climate Models

Presented by Adrean Webb, with

Baylor Fox-Kemper, Ramsey Harcourt, Mark Hemer, Tony Craig, & others contributing.

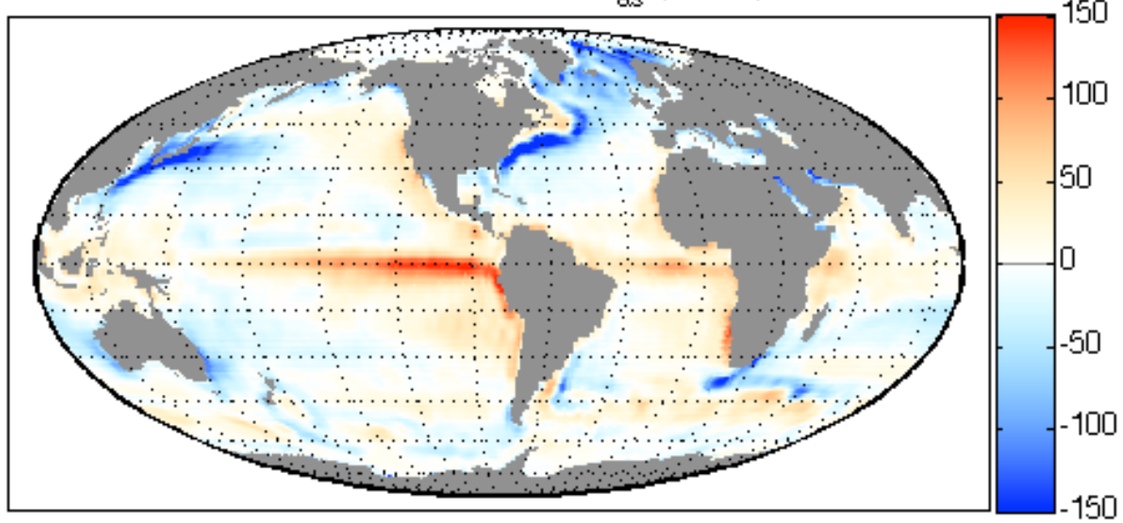
S.C. Bates, B. Fox-Kemper, S.R. Jayne, W.G. Large, S. Stevenson, and S.G. Yeager. Mean biases, variability, and trends in air-sea fluxes and SST in the CCSM4. Journal of Climate, 25(22):7781-7801, November 2012.

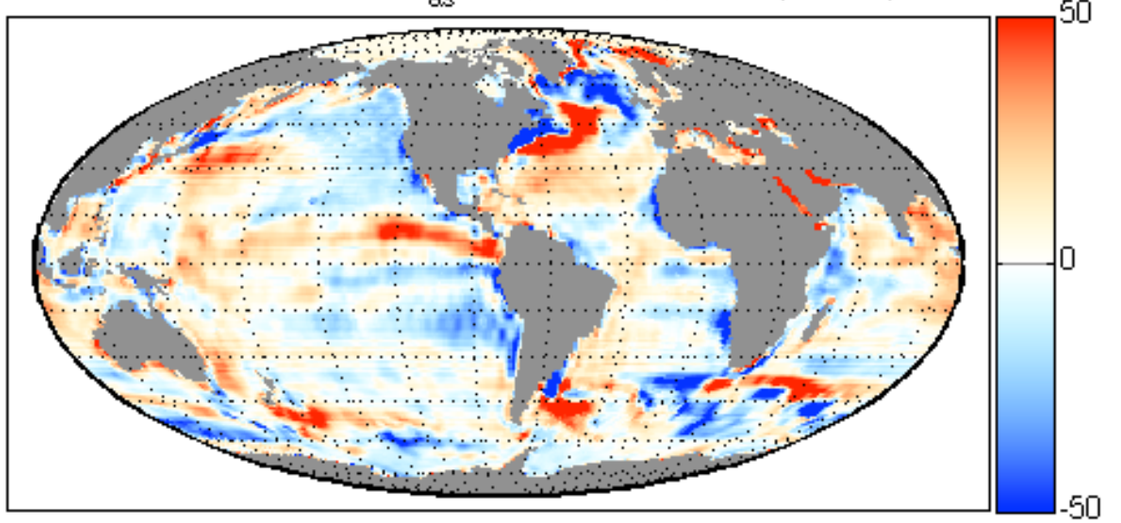
Significant Air-Sea Heat Flux Errors vs. Data (Large & Yeager 09)

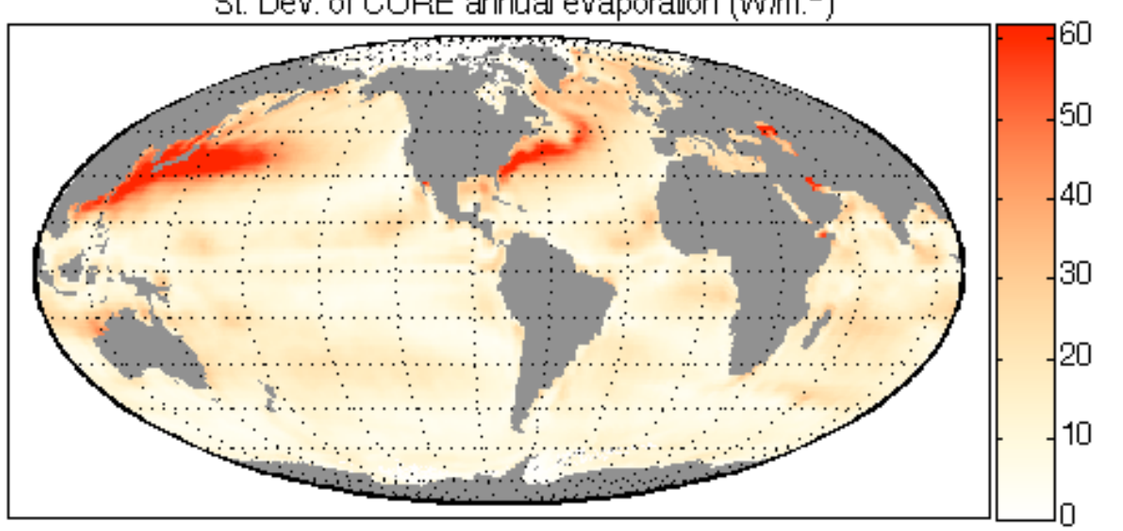
Mean

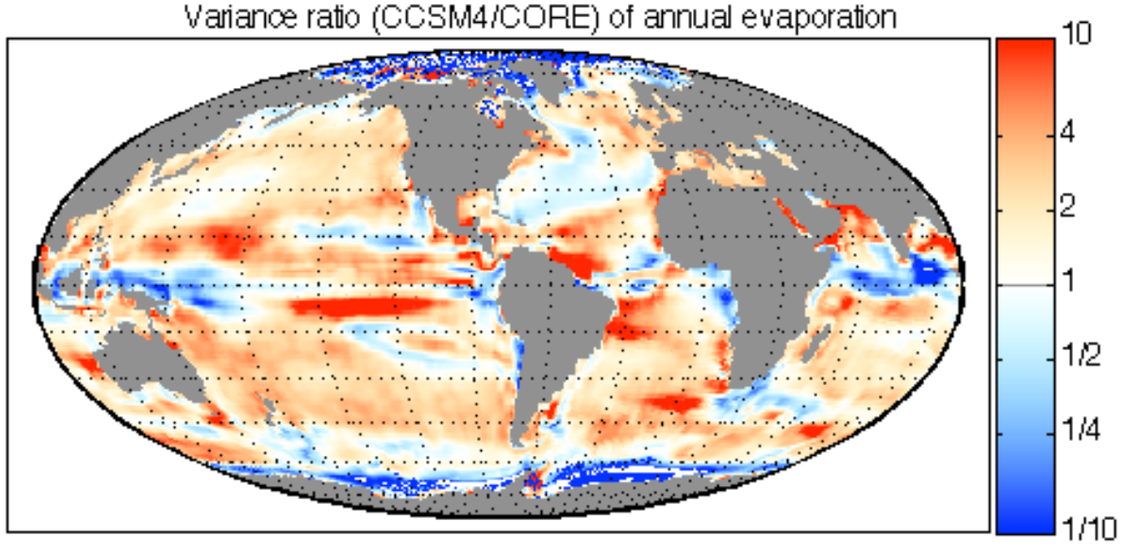
Annual 9–15mo

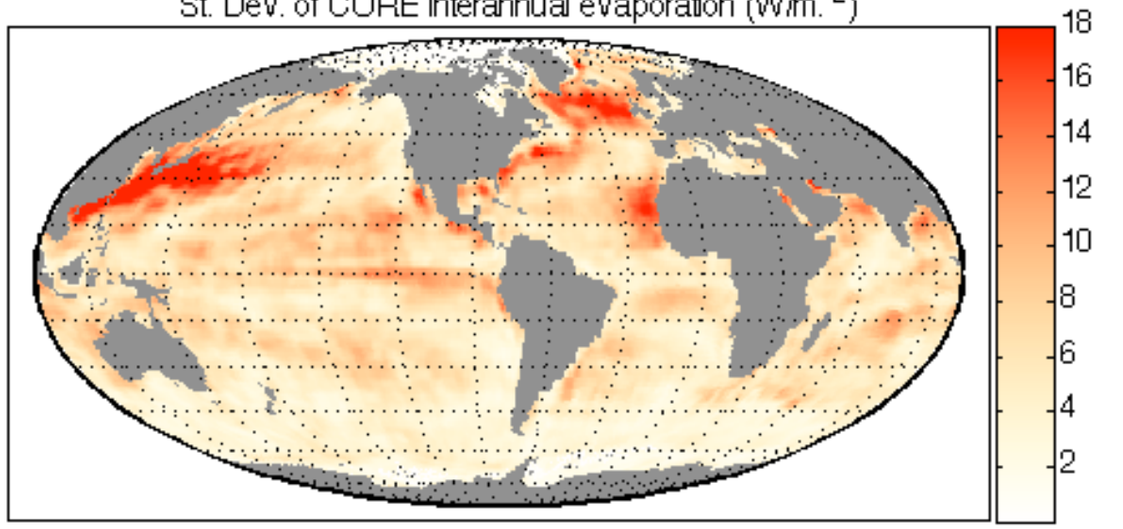
Interannual 2–7yr

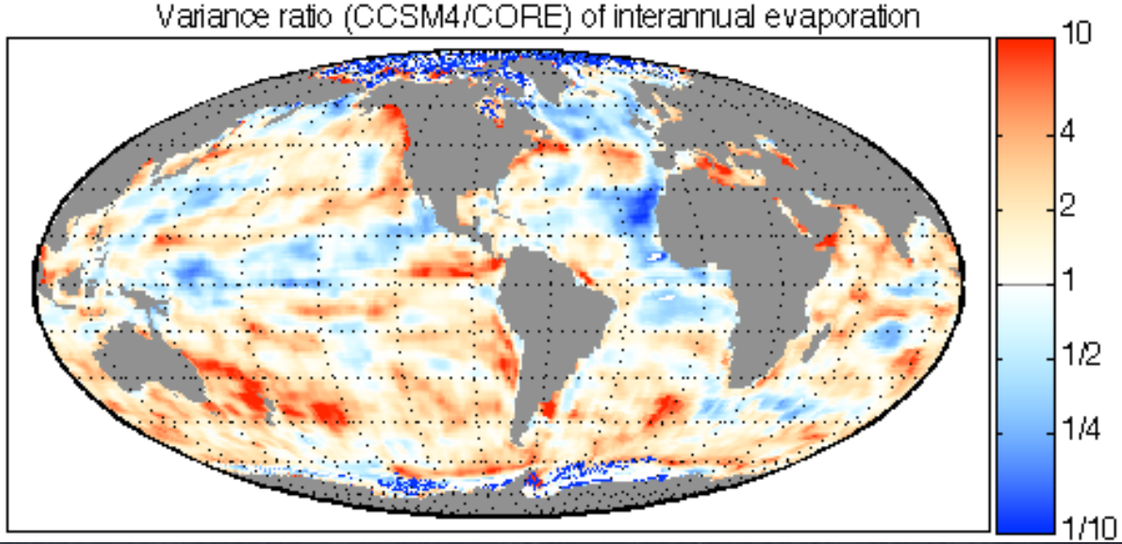












The Character of the Langmuir Scale

- Near-surface
- Langmuir Cells & Langmuir Turb.
- Ro>>1
- Ri<1: Nonhydro
- 10-100m
- 10s to mins
- w, u=O(10cm/s)
- Stokes drift
- Eqns: Craik-Leibovich
- Params: McWilliams & Sullivan, 2000, etc.

Image: Leibovich, 83

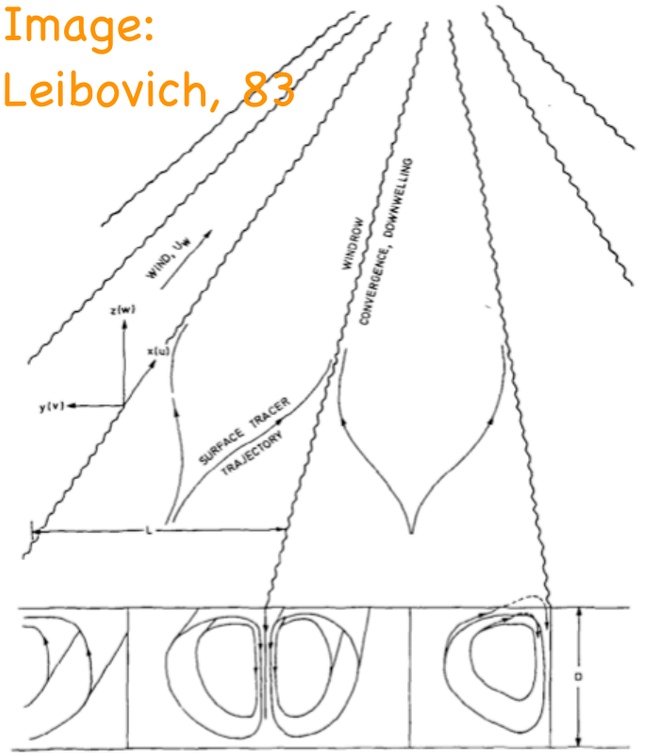


Figure 1a Illustration of Langmuir circulations showing notation used in this review and surface and subsurface motions.

Image: Quickbird, Deepwater Horizon Oil Spill

Importance for Climate Research

There is a persistent, shallow mixed layer bias in the Southern Ocean in global climate models (GCM): Langmuir turbulence missing???

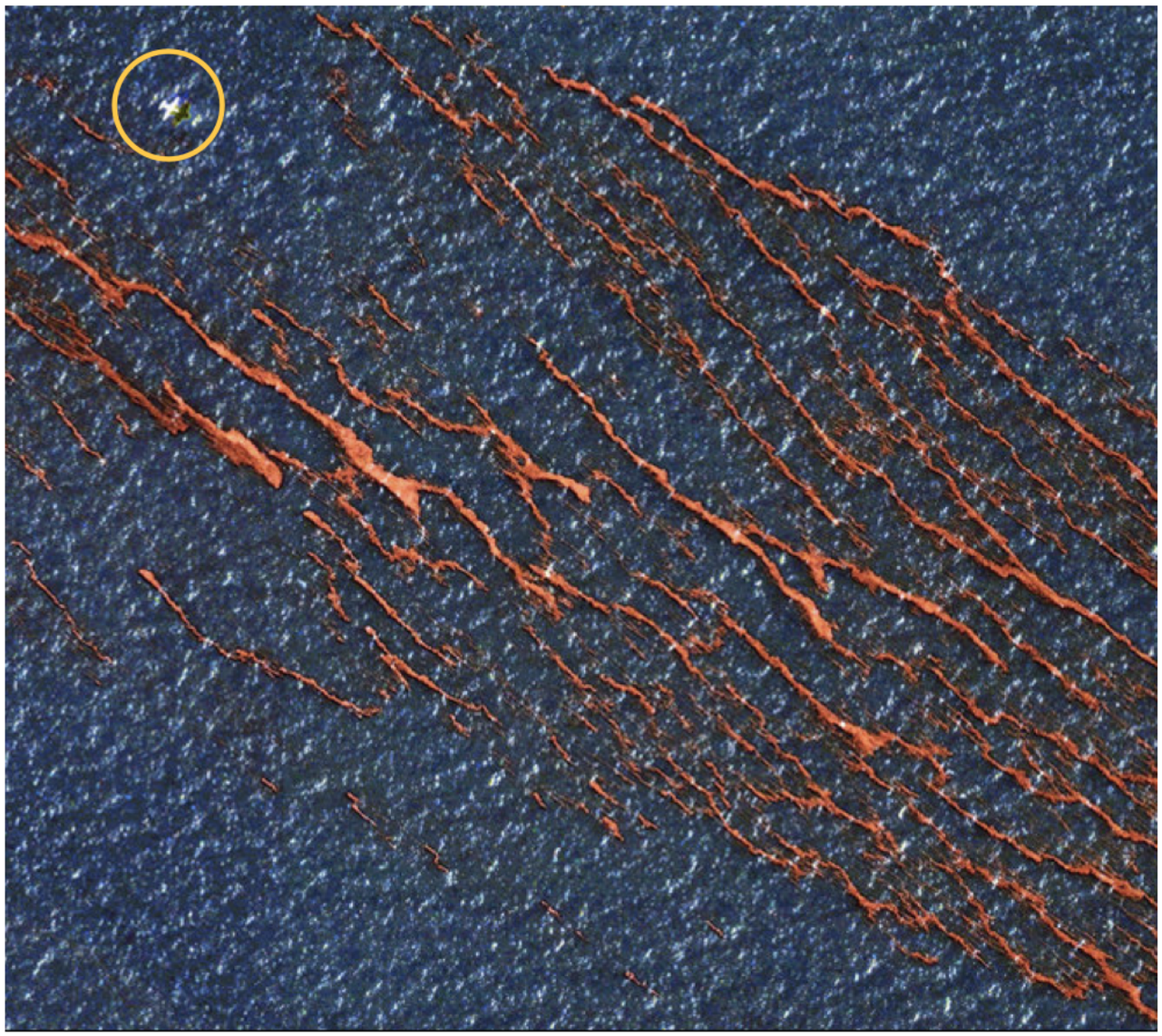


Figure: Satellite observations from the Deepwater Horizon oil spill of Langmuir turbulence (Quickbird)

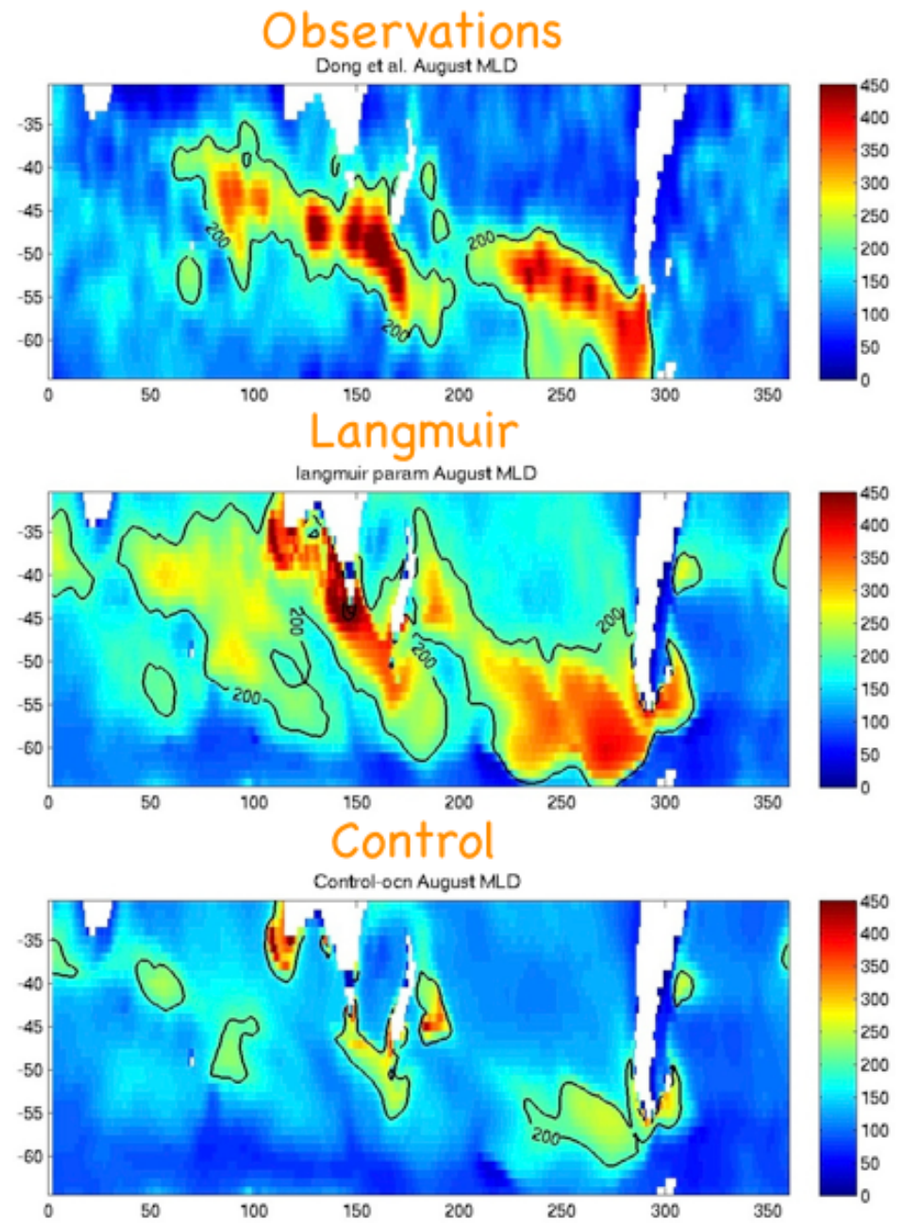


Figure: Mixed layer depth bias is reduced in NCAR CCSM 3.5 model runs (Peacock and Danabasoglu)

NOAA WAVEWATCH III Details

Third-Generation Model:

- Creates and evolves wave spectra in a coupled spatial-spectral domain
- Uses structured grids (lat-lon, polar)
- Includes extensive physics and parameterizations

Deficiencies for Climate Use:

- Computationally expensive
  - 5-D problem with $6-50 \times 10^6$ unknowns and nonlinear source terms
- Spatial and spectral singularities at poles
  - Difficult to model polar-ice-free climate scenarios

WAVEWATCH III Benchmarking

Lat-lon grids: G3: $2.4^\circ \times 3^\circ$, G4: $3.2^\circ \times 4^\circ$

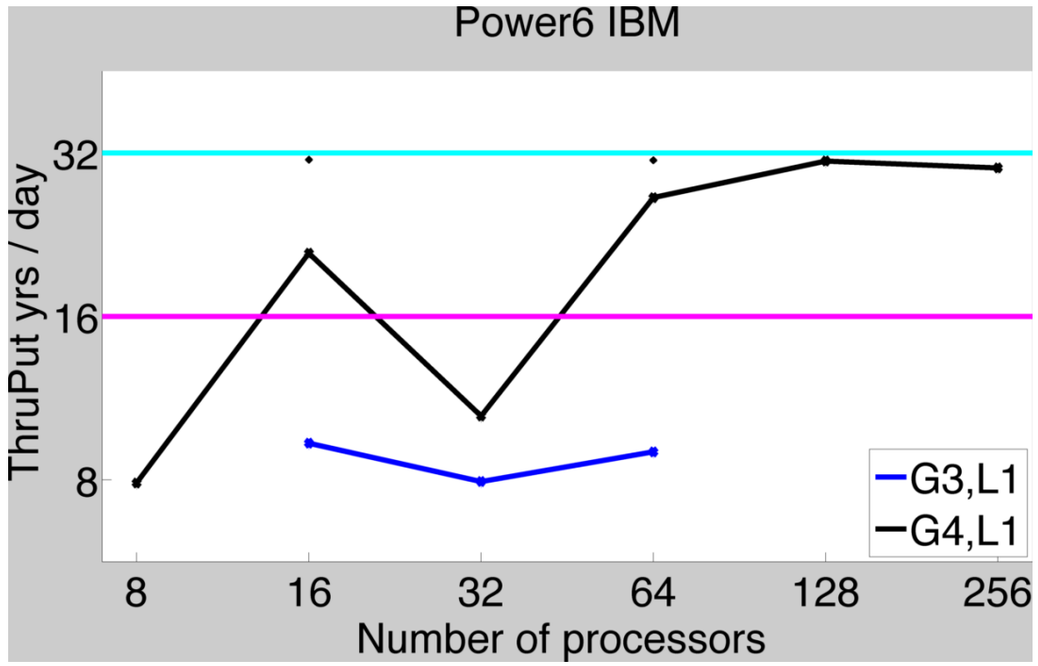
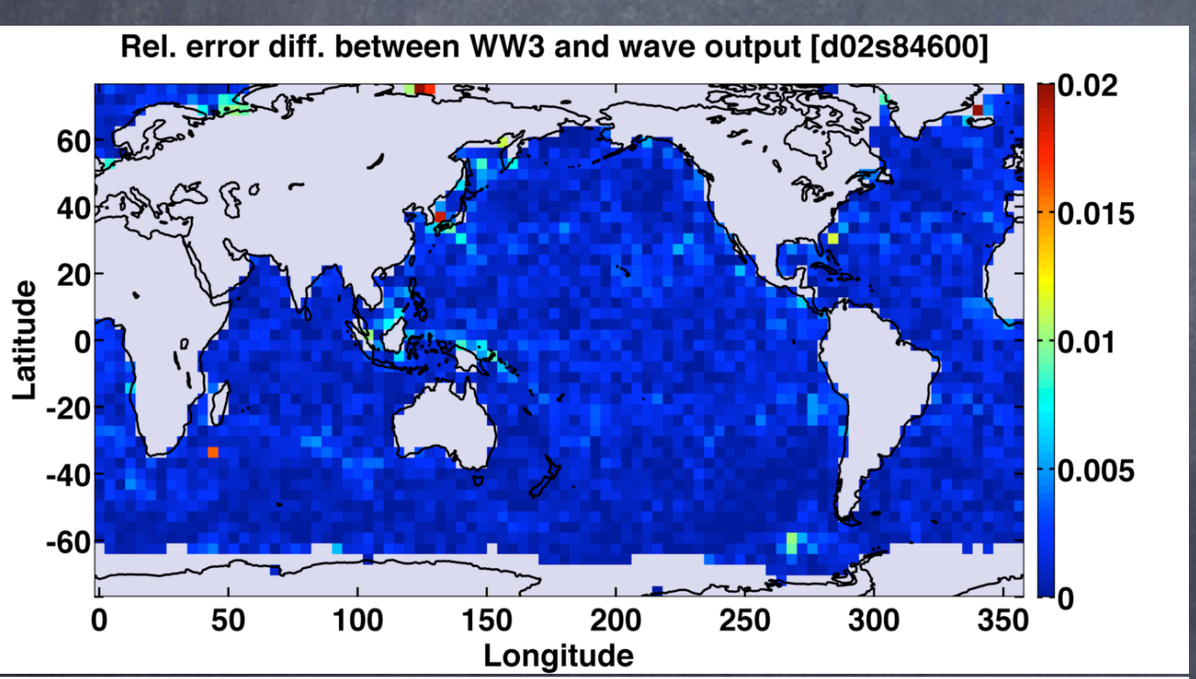


Figure: Grid performance with benchmarking targets for coupling to NCAR CESM on Bluefire

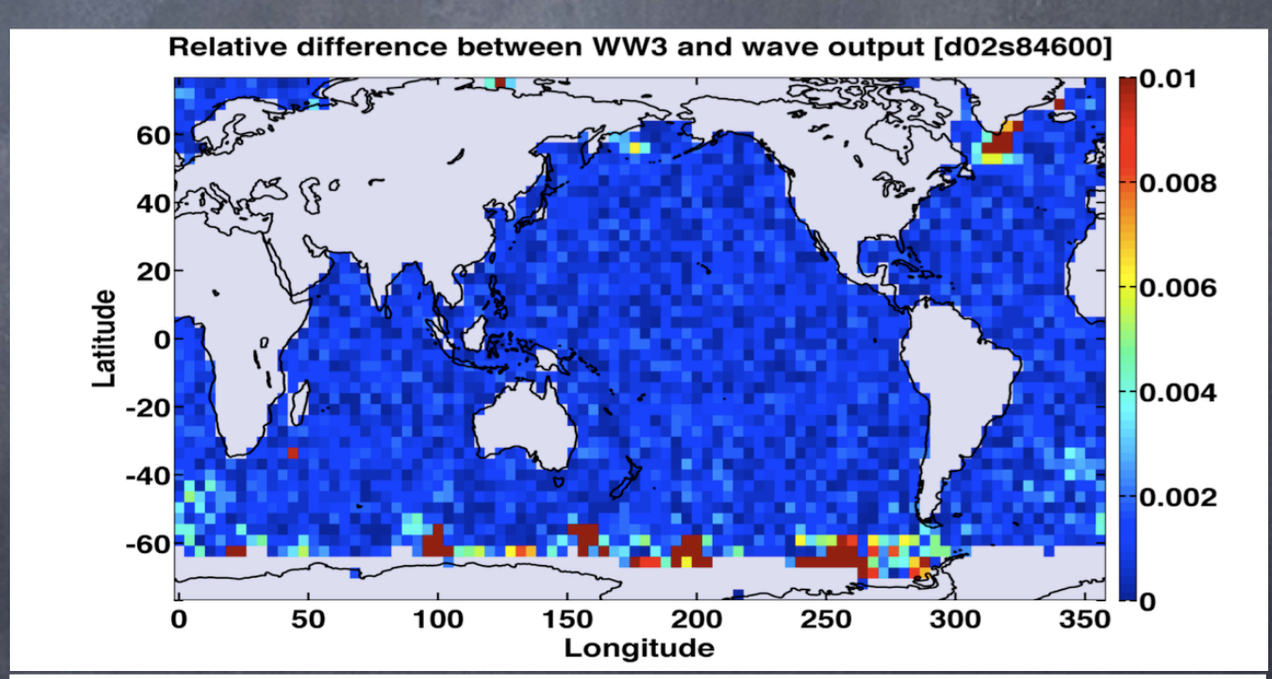
WAVEWATCH III is Coupled into CESM (T. Craig implementing as dev. head)

Coupled Wave Model Details:

- Uses a 30 min time step on an [0:4:356] x [-75.2:3.2:75.2] grid
- Coupled on a 30 min delay from the atmospheric model
- Wave spectrum is initialized using atm. forcings (instead of calm conditions)



Hs errors (relative norm) after 1 day are within 1% between models using U10 and ice concentrations. Errors are mostly due to a loss of precision from WW3 ascii output (used for comparison only).



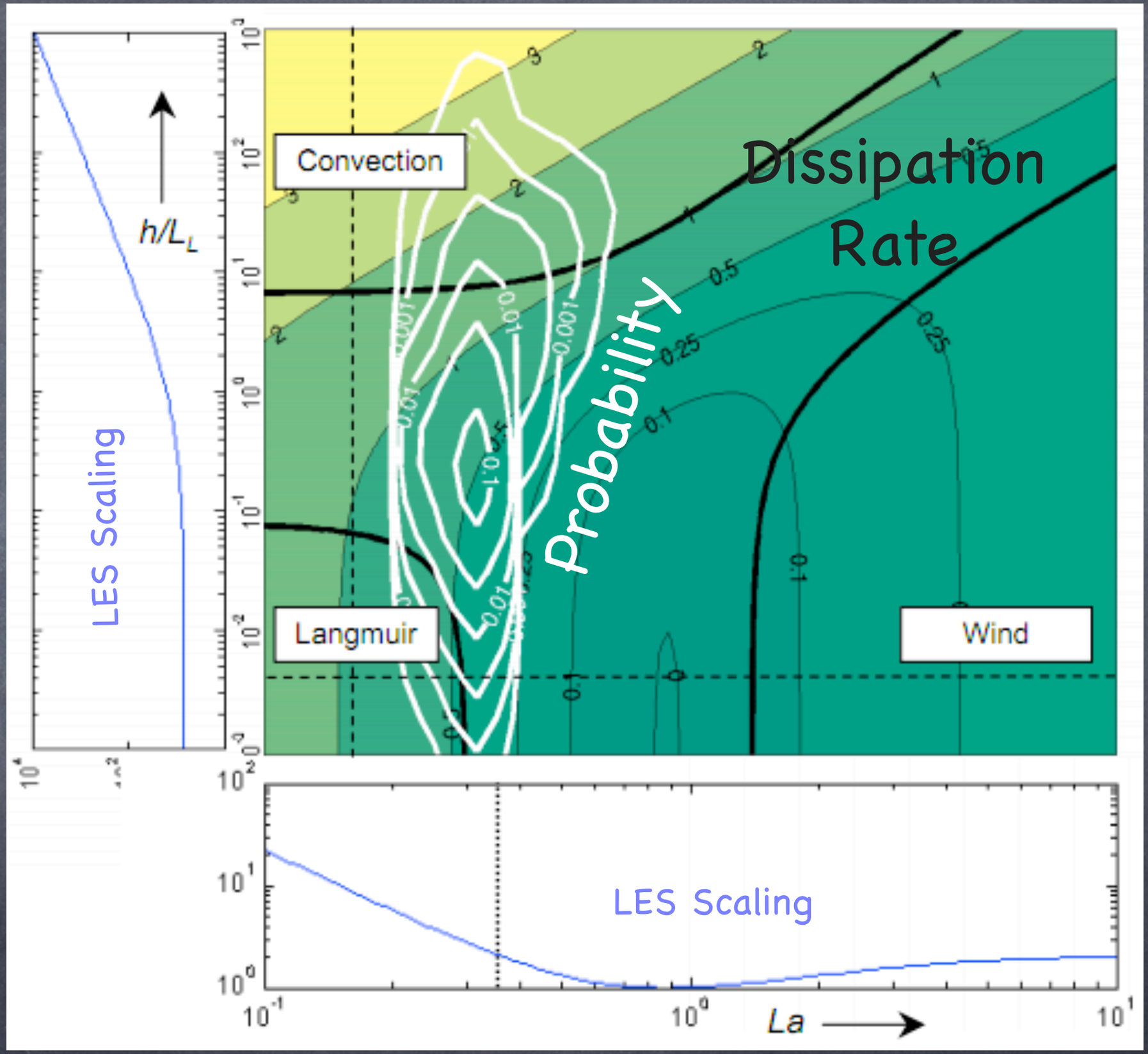
Model is sensitive to boundary changes. Large Hs errors resulted from using slightly different ice concentrations after 1 day (concentrations were updated on a different time frequency).

Offline: Tests of potential importance of Langmuir

- 1) Data Diagnosis with LES Scalings of (Grant)
  - Waves frequently an important energy source vs. other energy sources (winds, convection) based on LES-derived scalings
    - S.E. Belcher, A.A.L.M. Grant, K. E.Hanley, B. Fox-Kemper, L. Van Roekel, P.P. Sullivan, W.G. Large, A. Brown, A. Hines, D. Calvert, A. Rutgersson, H. Petterson, J. Bidlot, P.A.E.M. Janssen, and J.A. Polton. A global perspective on Langmuir turbulence in the ocean surface boundary layer. Geophysical Research Letters, 39(18):L18605, 9pp, 2012.
- 2) Mixing up ARGO profiles with Harcourt's Second-Moment Closure mixing scheme
  - Including wave effects leads to substantial deepening over winds & fluxes only ("Normal-year Forcing")

Data + LES, Southern Ocean mixing energy: Langmuir (Stokes-drift-driven) and Convective

Thus, neglect wave-driven mixing in the Southern Ocean is at your own risk!

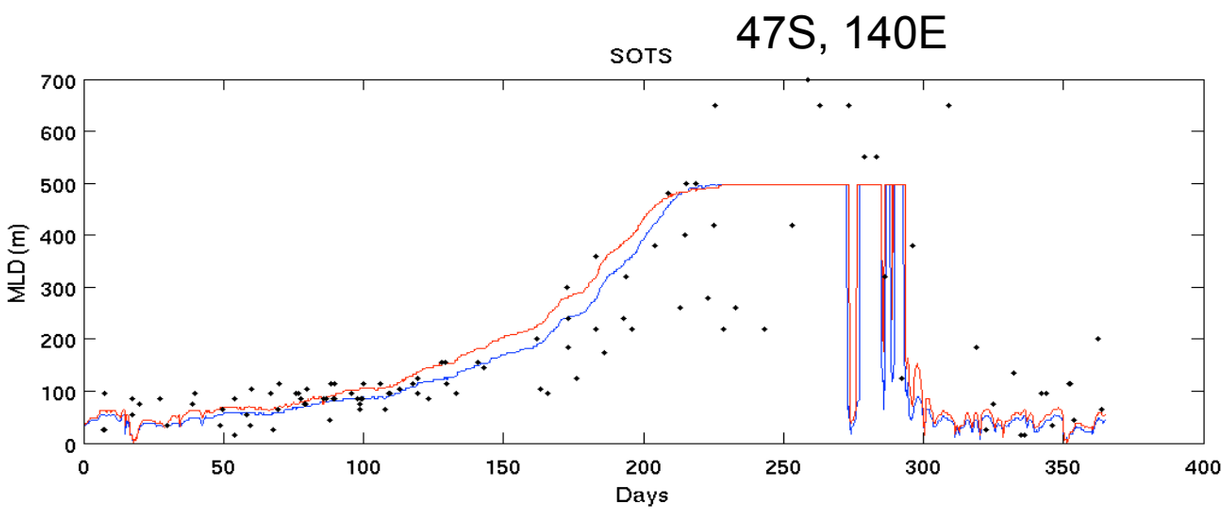


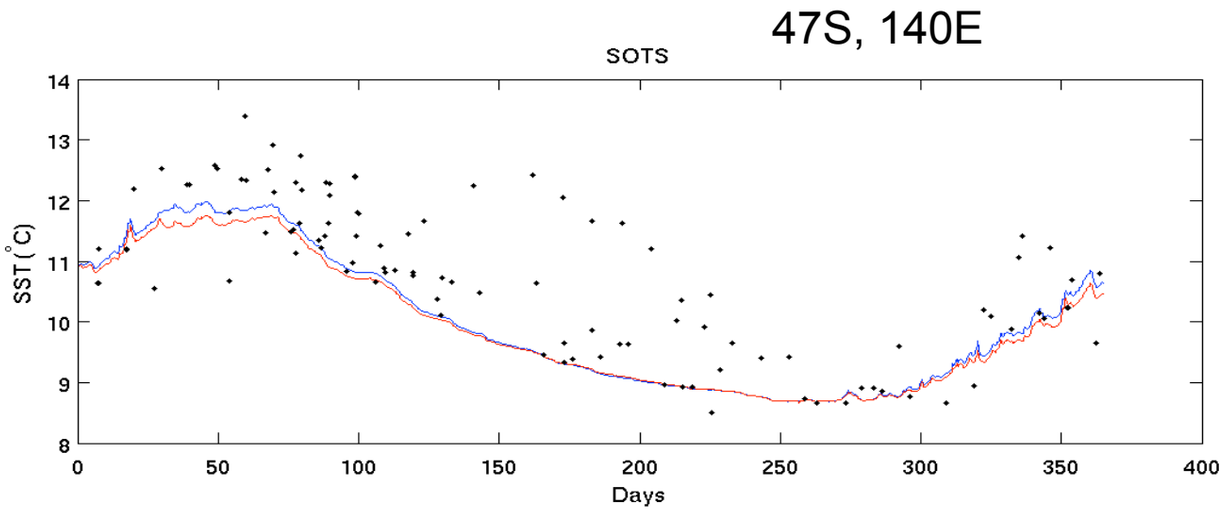
S.E. Belcher, A.A.L.M. Grant, K.E. Hanley, B. Fox-Kemper, L. Van Roekel, P.P. Sullivan, W.G. Large, A. Brown, A. Hines, D. Calvert, A. Rutgersson, H. Petterson, J. Bidlot, P.A.E.M. Janssen, and J.A. Polton. A global perspective on Langmuir turbulence in the ocean surface boundary layer. *Geophysical Research Letters*, 2012.

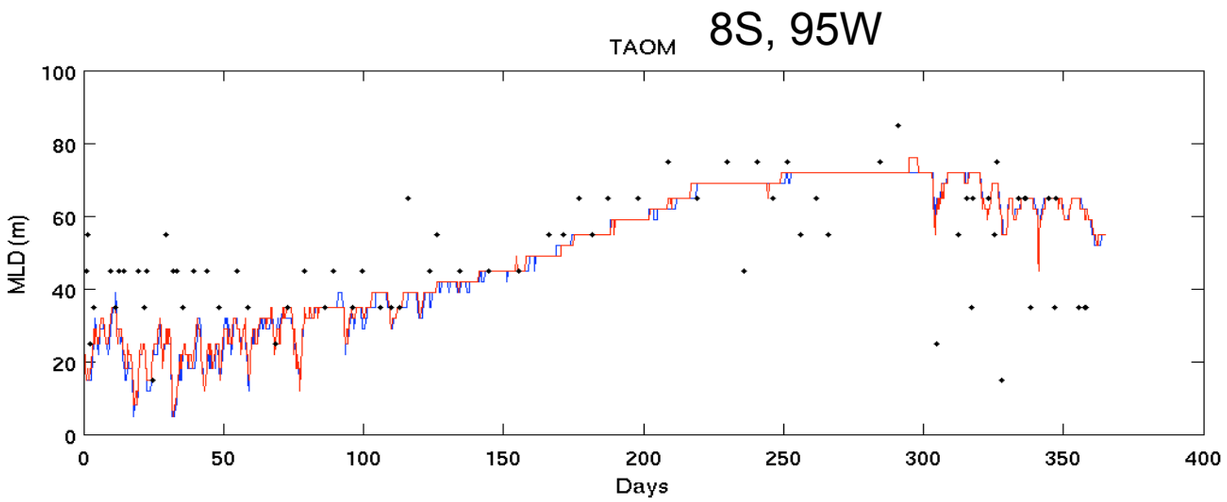
Harcourt (2013 JPO) SMC Model:

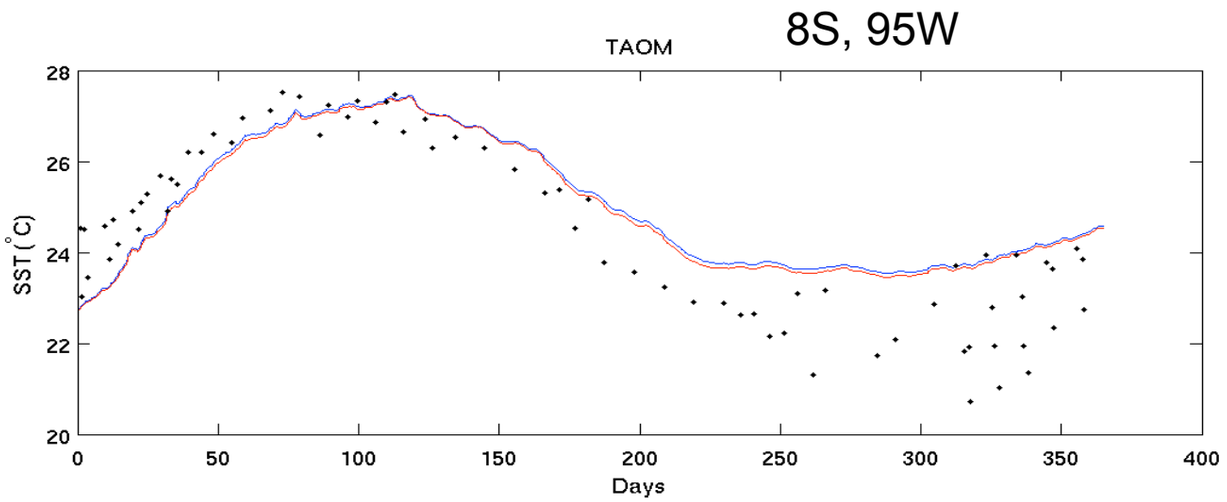
- Expands on implementation of Langmuir mixing of Kantha & Clayson.
- Allows waves to affect eddy scale as well as eddy energy sources.
- Was run for 1-year, using "Normal Year" and matching WaveWatch-III waves. ARGO profiles near summer solstice chosen as initial condition.
- Pure 1D mixing vs. solar & fluxes only -- No ocean circulation or eddy restratification, etc.

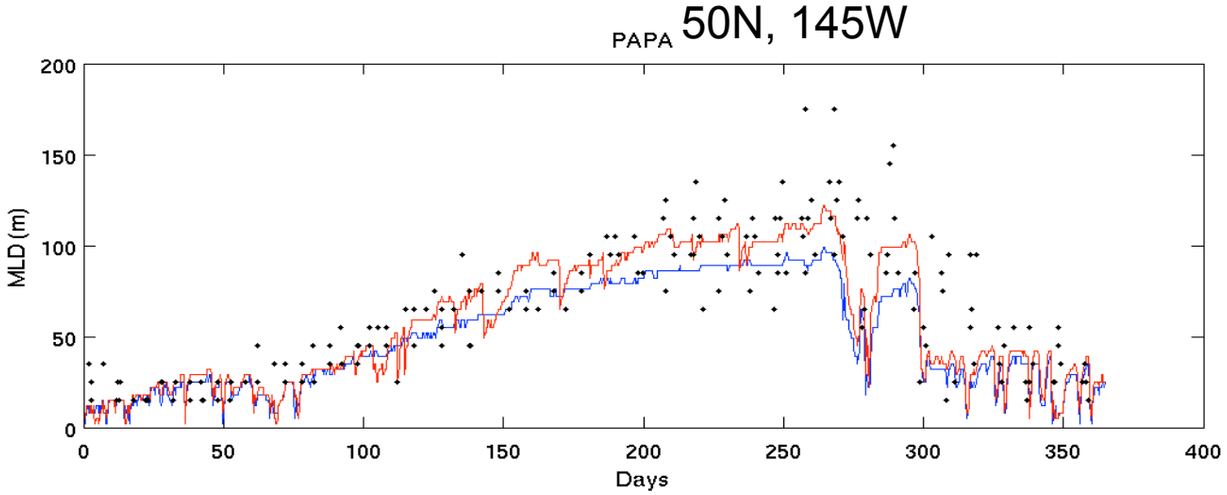
Harcourt--Evolving Mixed Layer Depth Results (Simulated by M. Hemer, CSIRO)

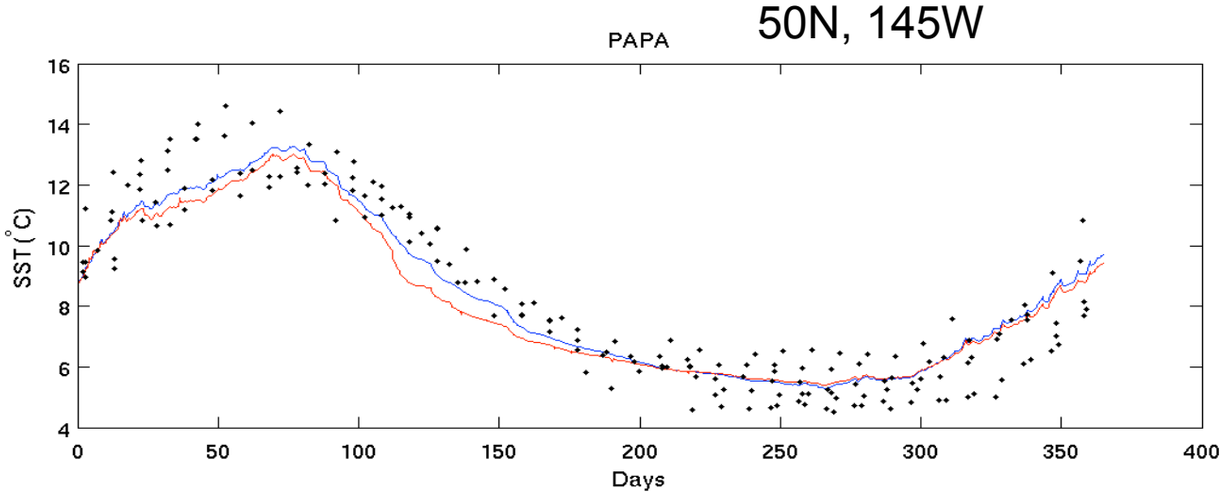










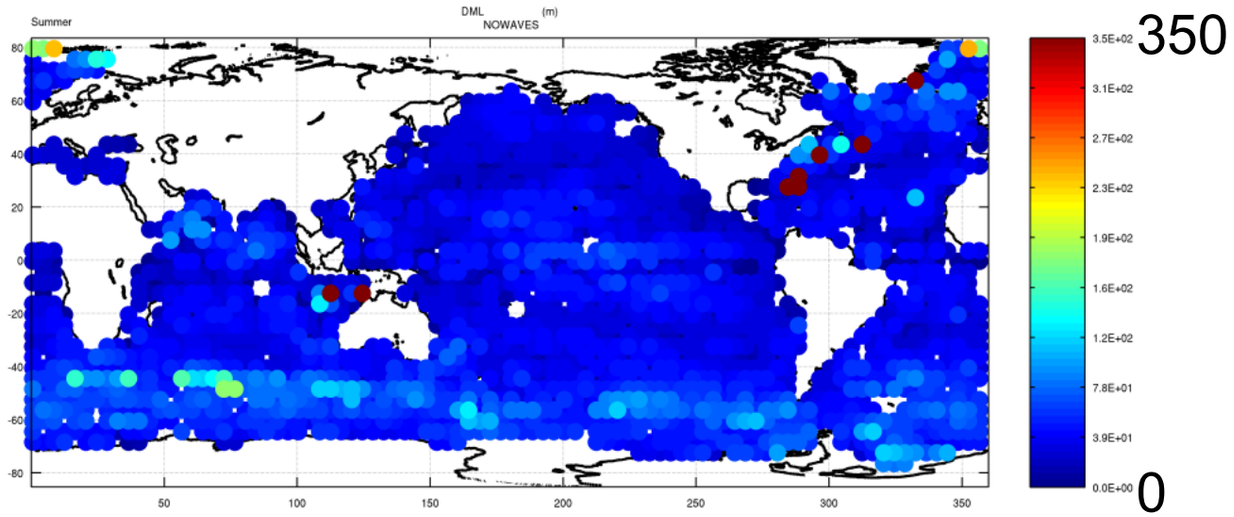


NO WAVES WAVES Nearby ARGO PROFILES (dots)

90 days after initial profile:

Cooling equinox

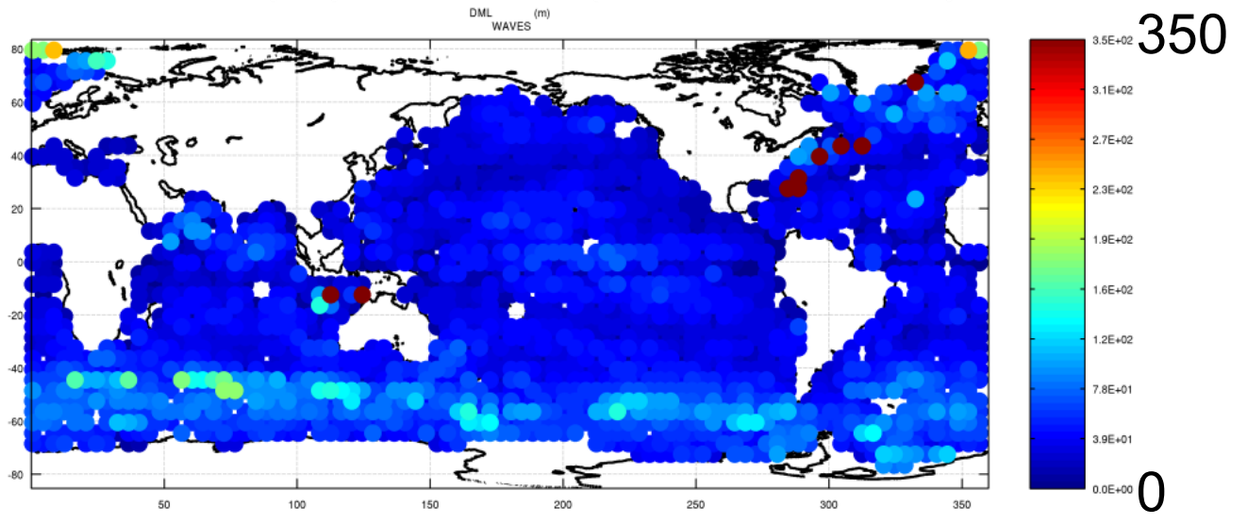
DML (m): No waves (Us = 0, Hs = 0)



350

0

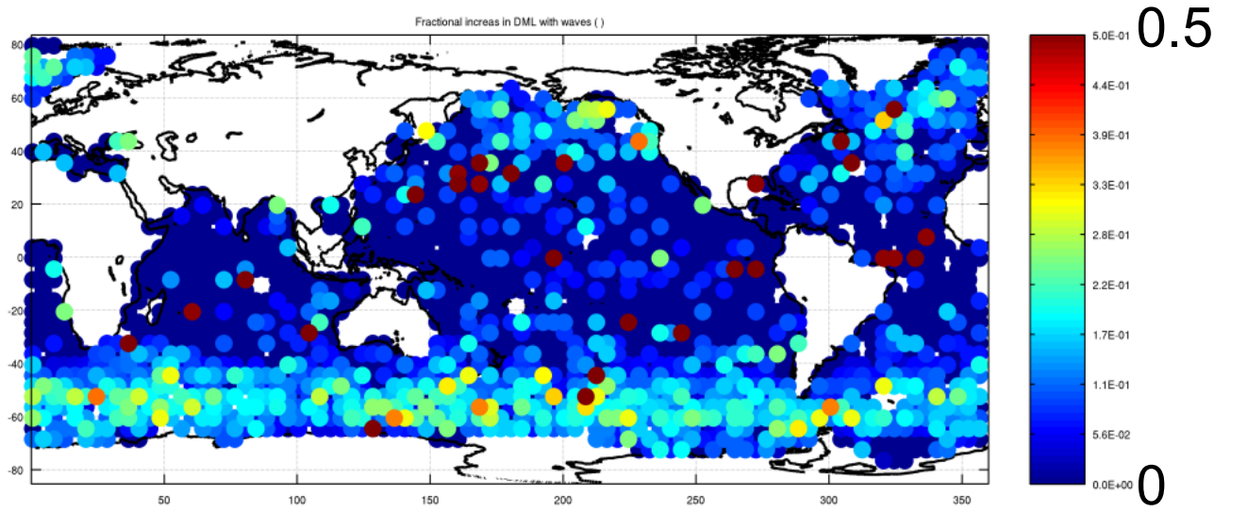
DML (m): Waves (CORE-WW3)



350

0

Fractional increase in DML with waves



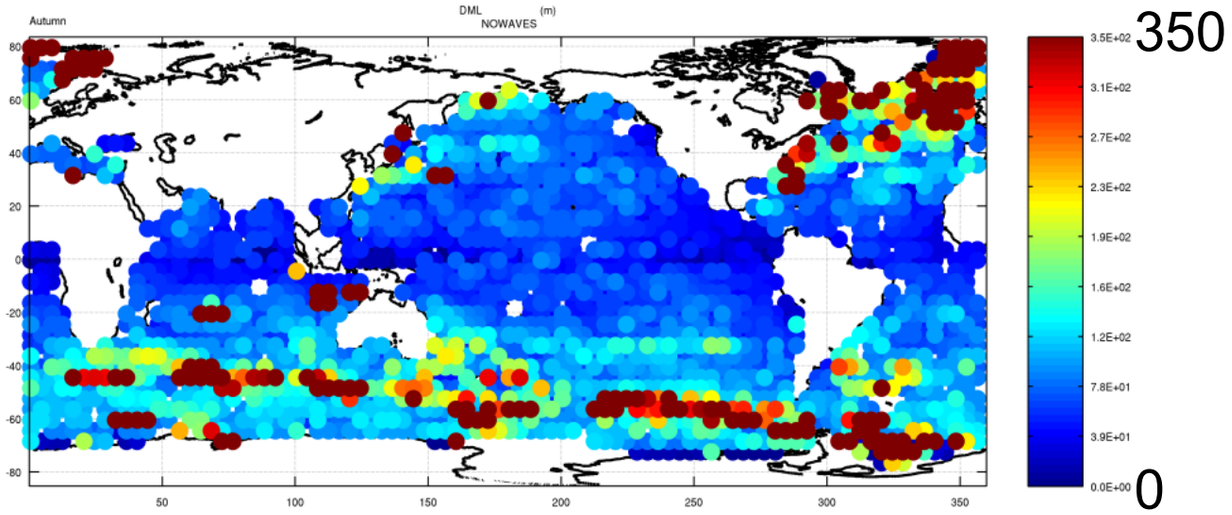
0.5

0

180 days after initial profile:

Winter solstice

DML (m): No waves (Us = 0, Hs = 0)



350

0

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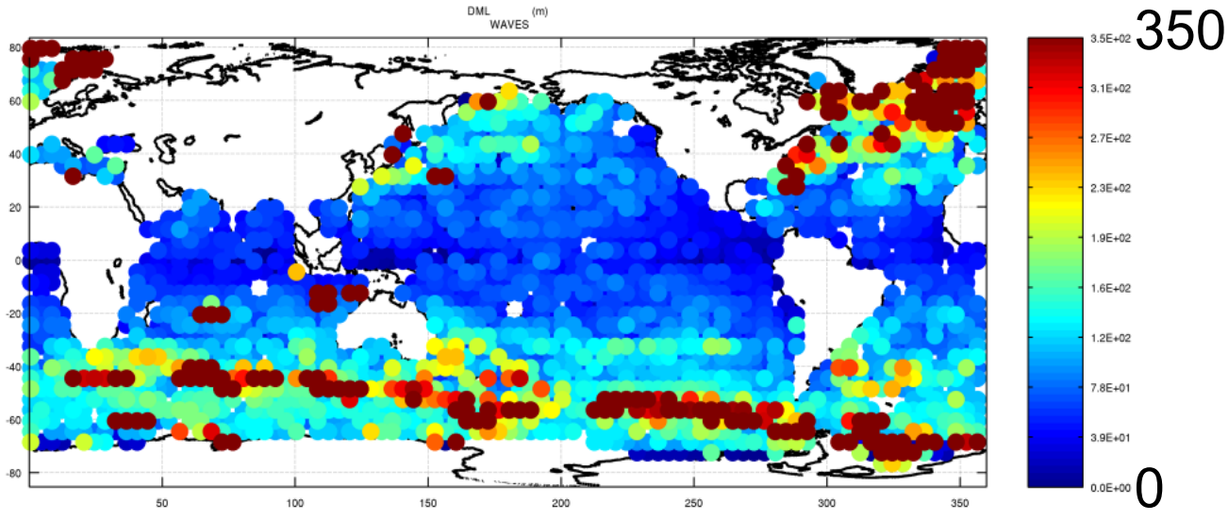
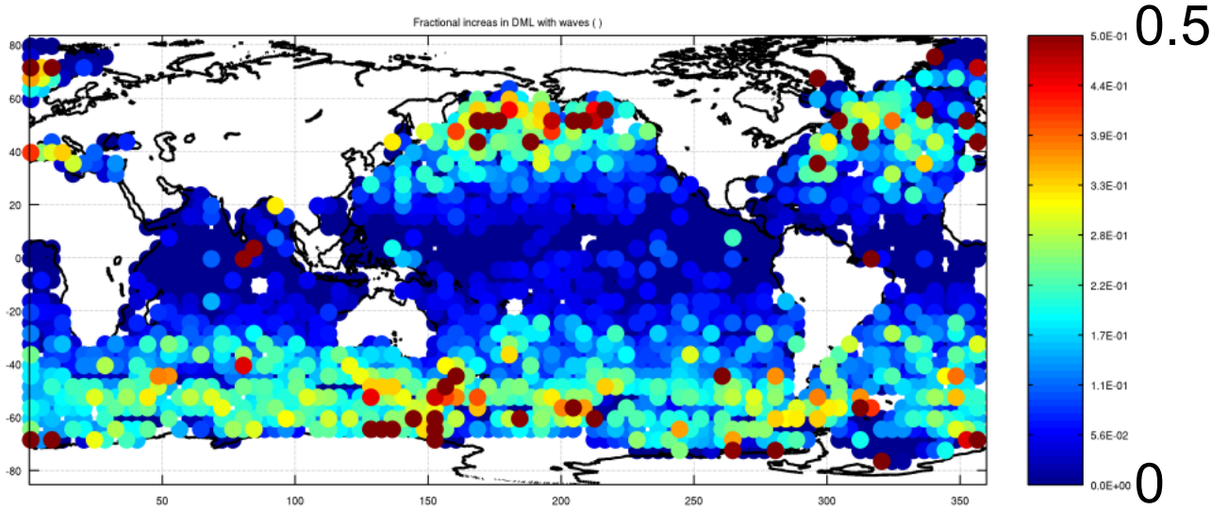


350

0

Fractional increase in DML with waves



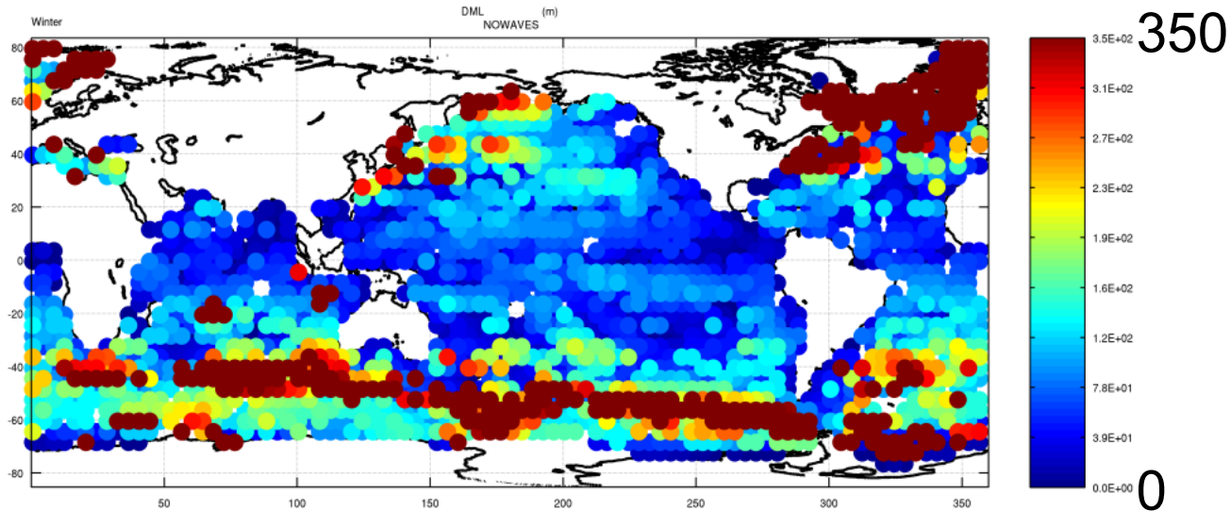
0.5

0

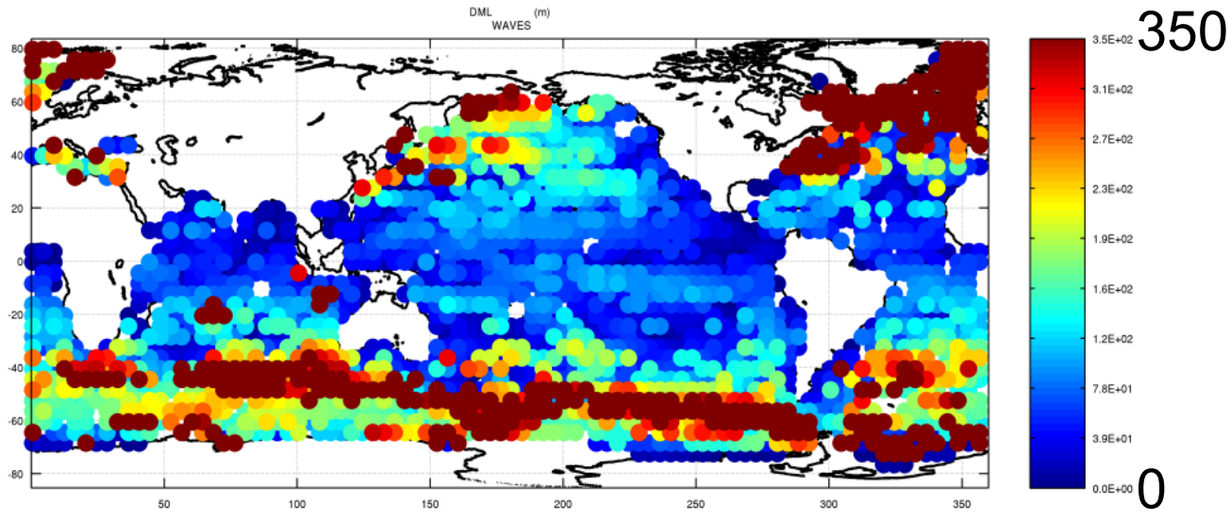
270 days after initial profile:

Warming equinox

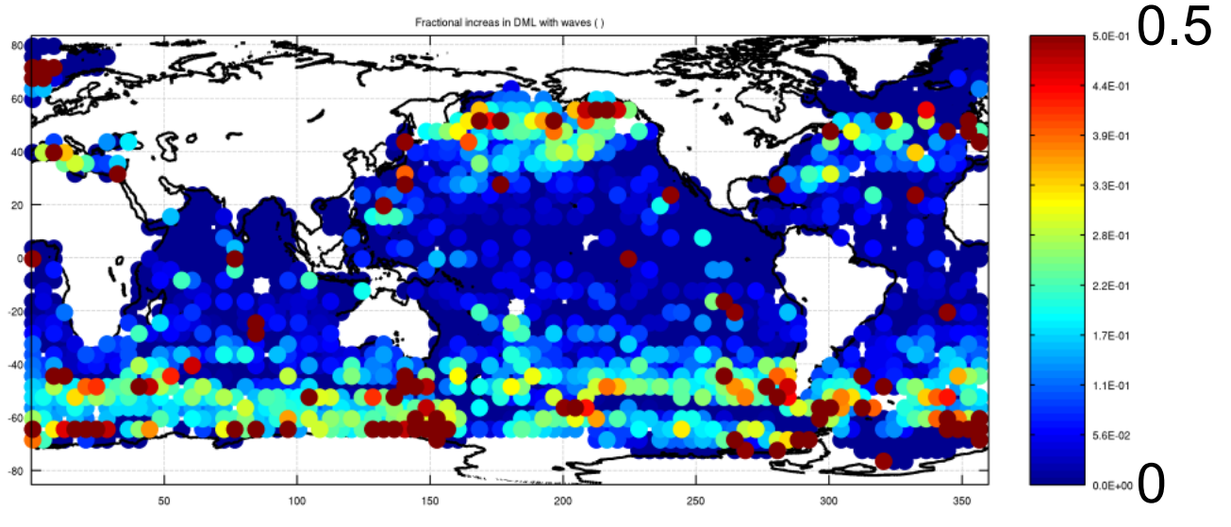
DML (m): No waves (Us = 0, Hs = 0)



DML (m): Waves (CORE-WW3)



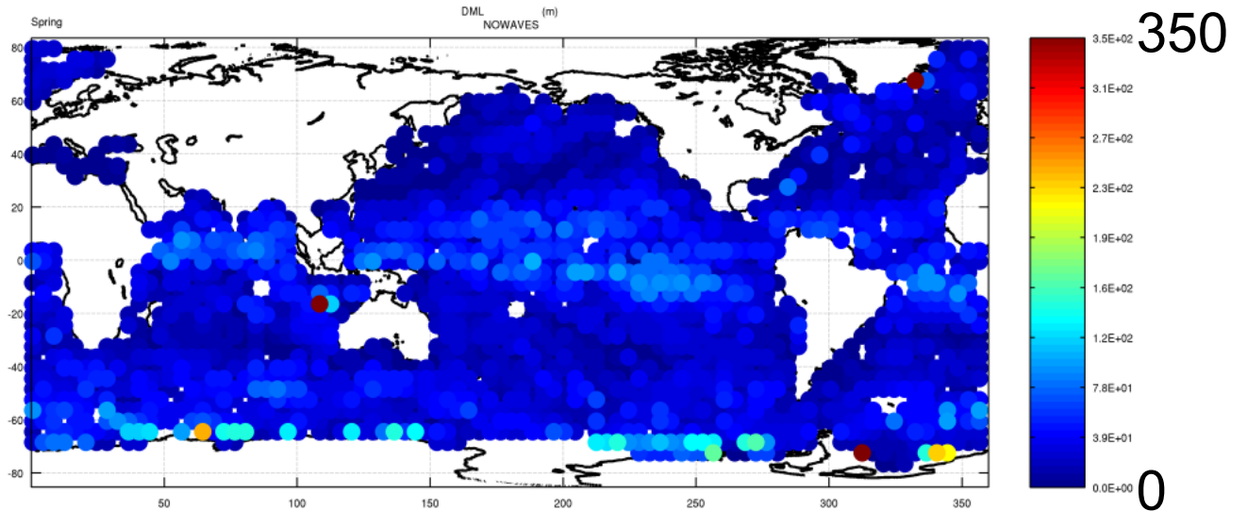
Fractional increase in DML with waves



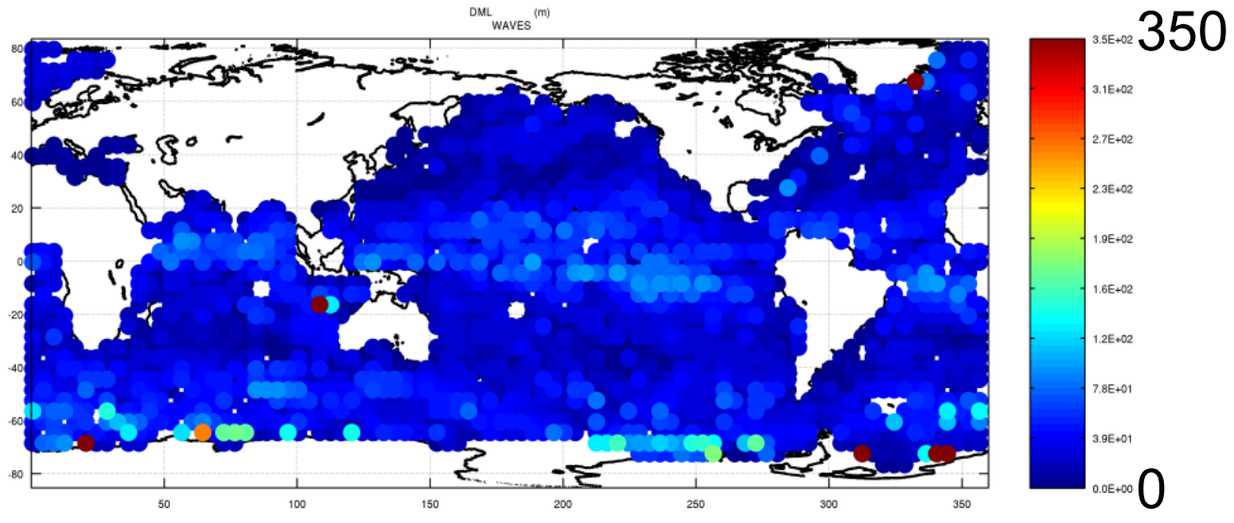
360 days after initial profile:

Summer solstice

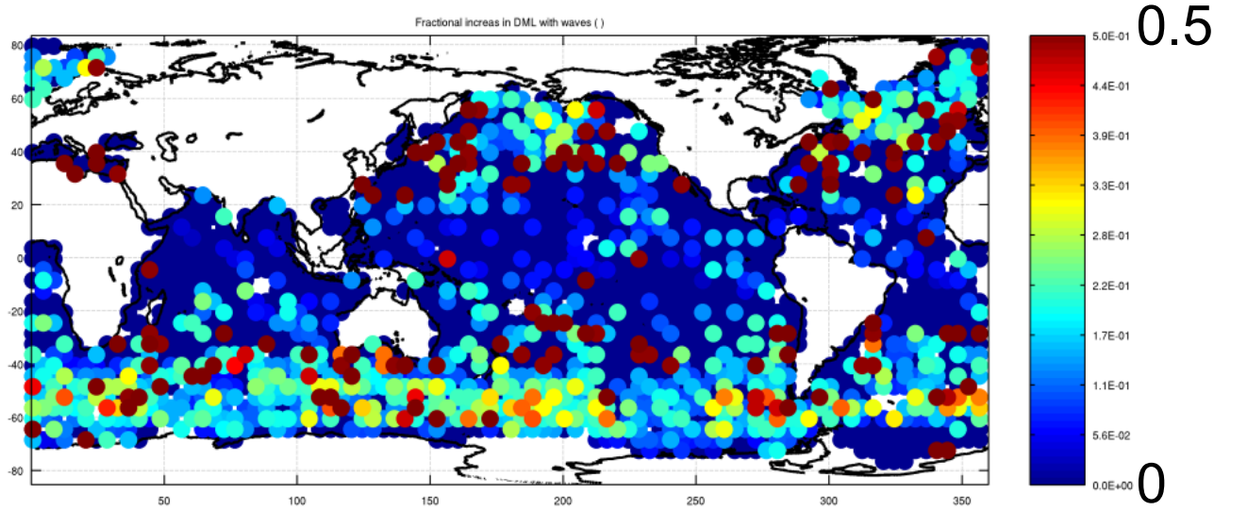
DML (m): No waves (Us = 0, Hs = 0)



DML (m): Waves (CORE-WW3)



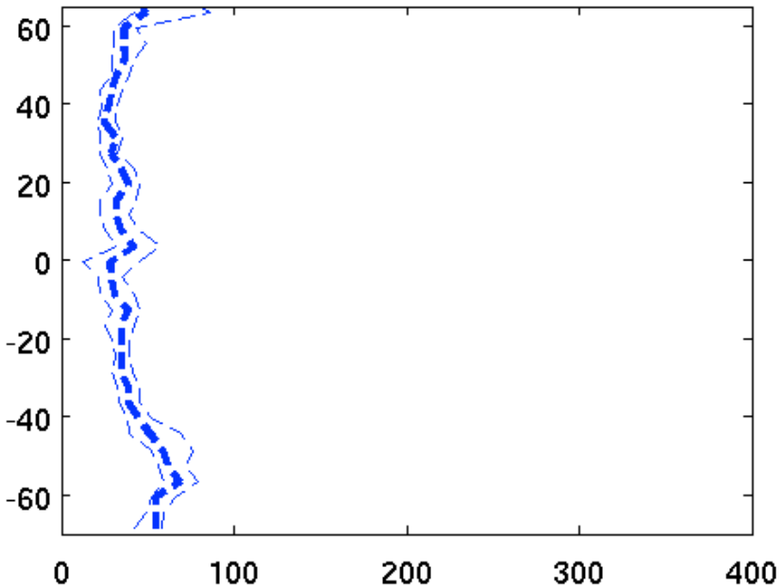
Fractional increase in DML with waves



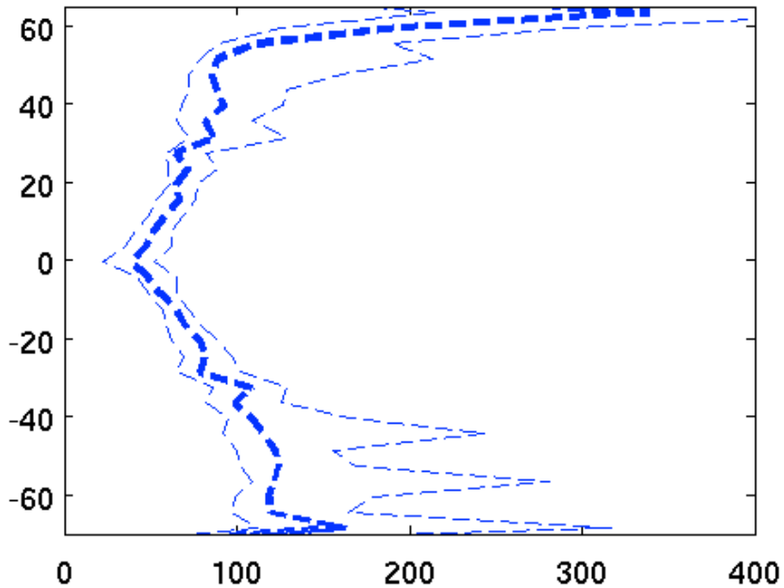
Zonal Median Mixed Layer Depth (and inter-quartile range)

NO WAVES

90 days after initial profile:
Cooling equinox

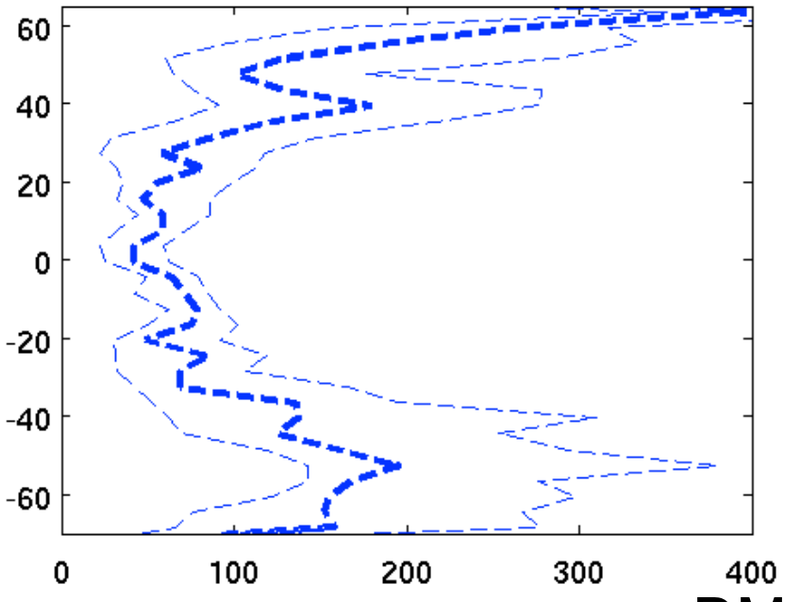


180 days after initial profile:
Cold solstice

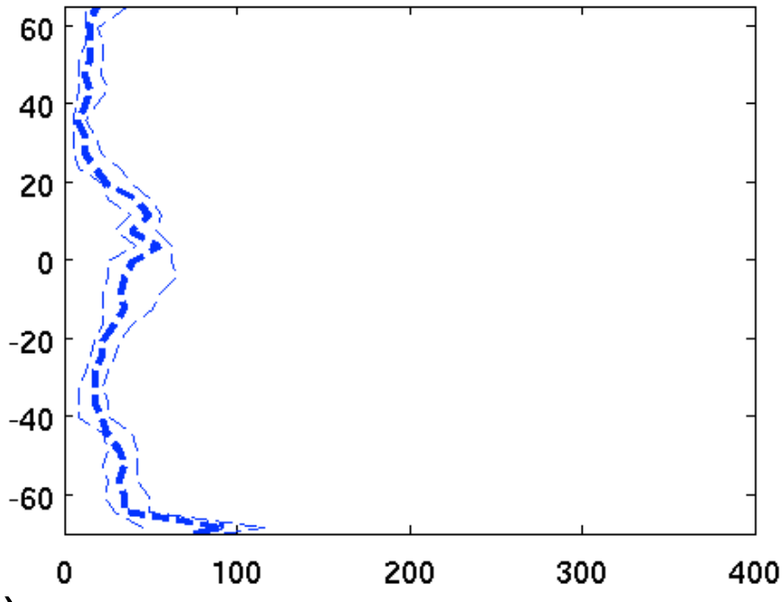


Latitude

270 days after initial profile:
Warming equinox



360 days after initial profile:
Warm solstice



DML (m)

Zonal Median Mixed Layer Depth (and inter-quartile range)

NO WAVES
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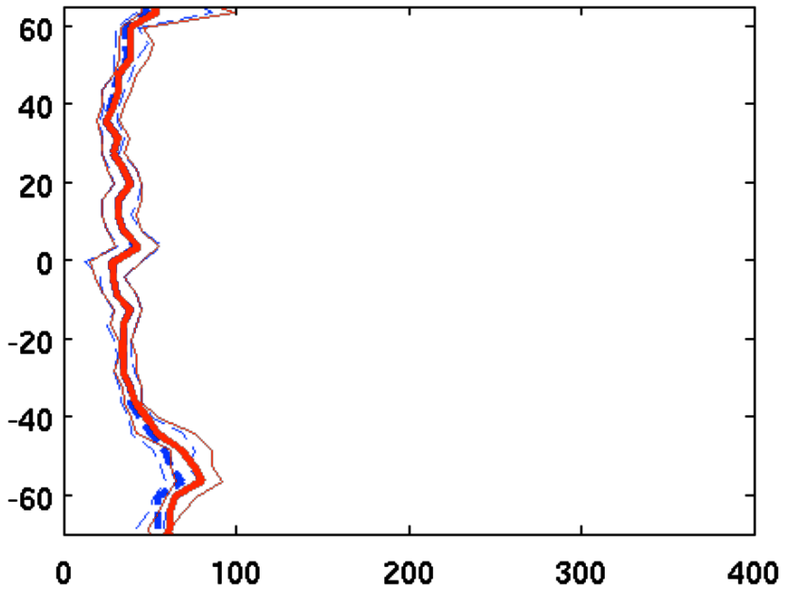
Cooling equinox



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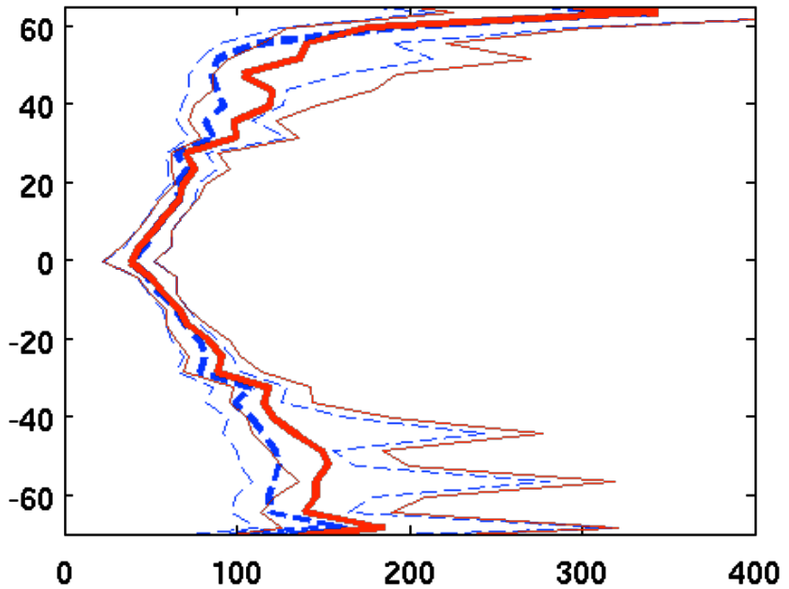

Latitude

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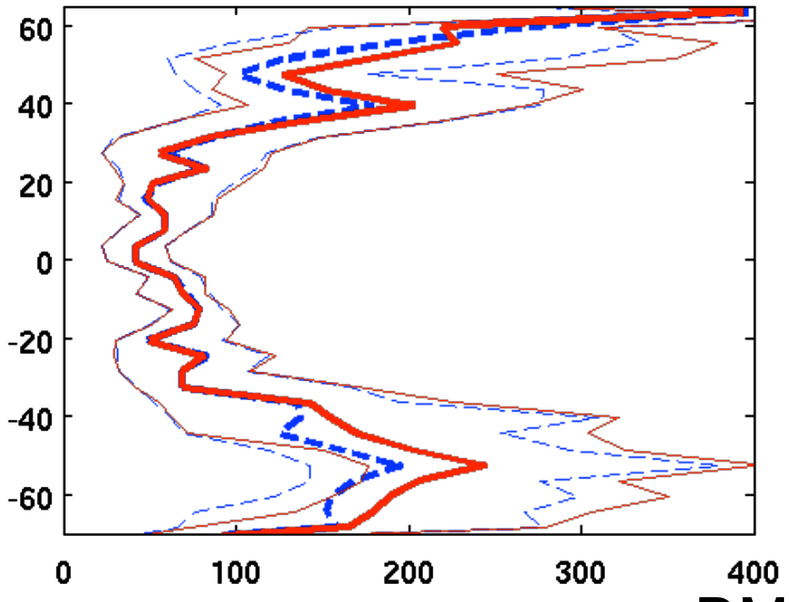
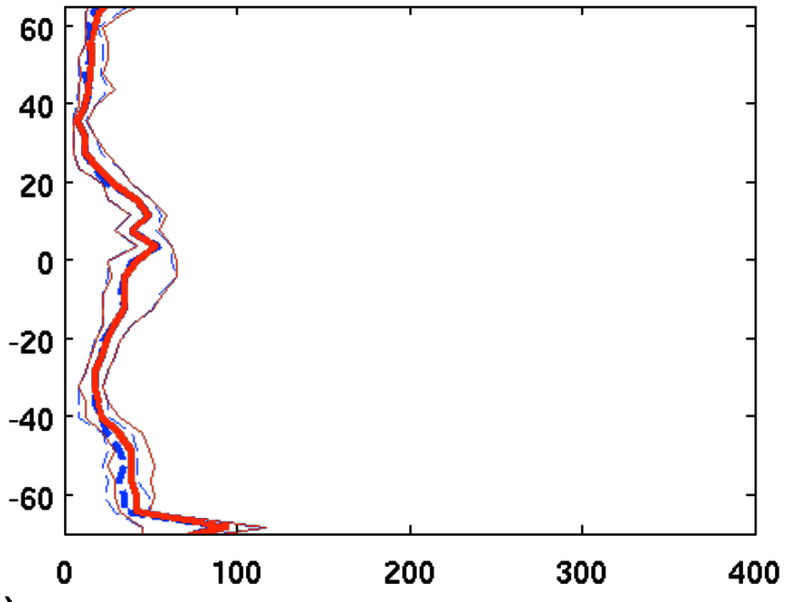
Warming equinox



360 days after initial profile:
Warm solstice



DML (m)

Conclusions:

- Pieces are in place to include Langmuir mixing in CESM.
  - Prognostic waves or "data waves"
  - Mixing scalings
- A variety of Langmuir mixing scalings estimate a nontrivial effect
- Impact biggest in the Southern Ocean and North Atlantic & Pacific. Winter deepening & spring recovery.
- 1 step forward... 2 steps backward? Not the same regions as submesoscale restratification, but similar magnitude.