Mixing for the ocean surface boundary layer and WAVEWATCH III model

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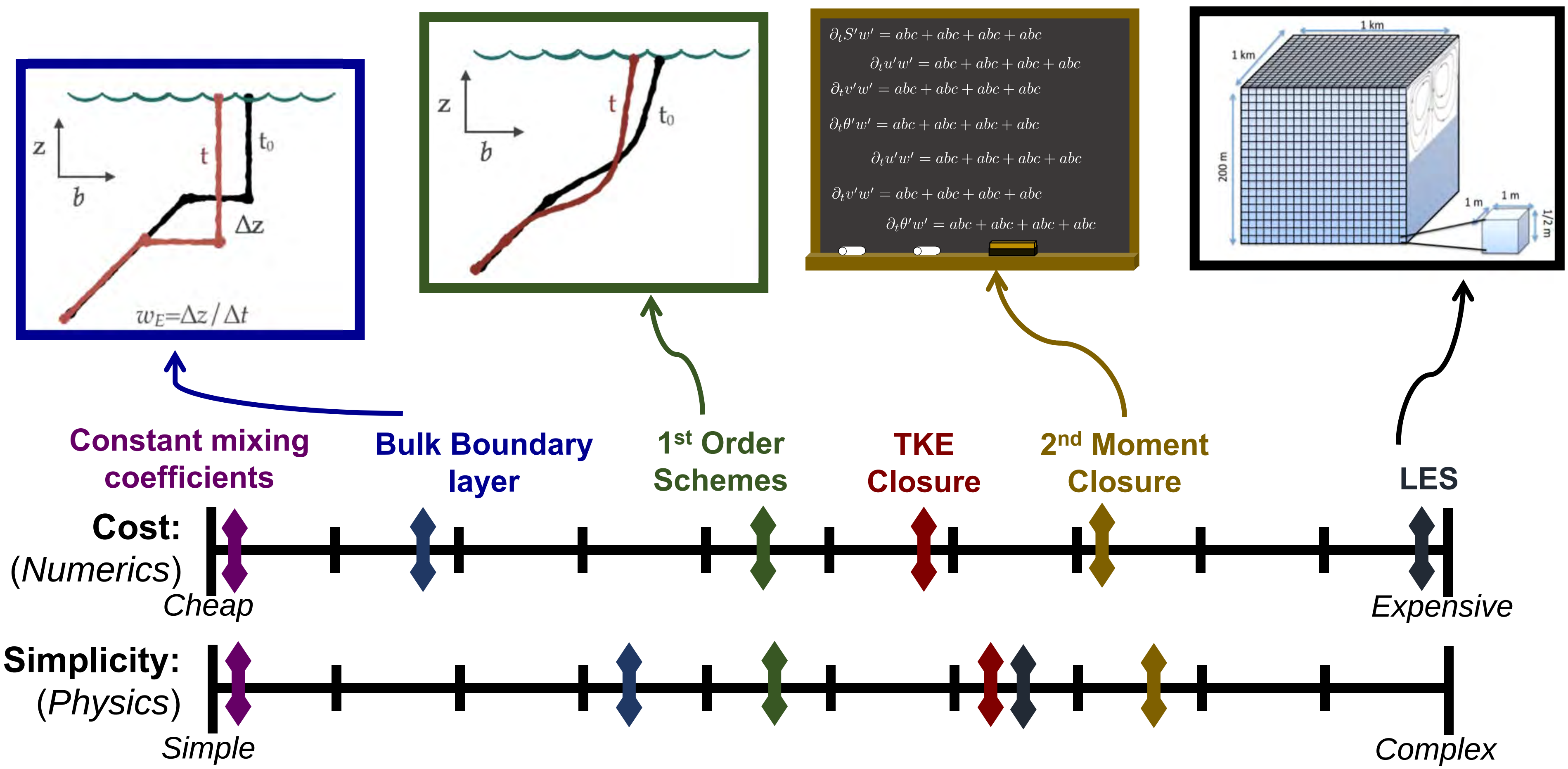
Introduction

Focus: Improving representation of air-sea interface physics in GFDL's climate models

- Developed an **energetic Planetary Boundary Layer (ePBL)** ocean surface mixing framework for climate simulation
- Used a process level approach to introduce **Langmuir turbulence** to ePBL, reducing bias in ocean vertical mixing
- Examining wave coupled models at **GFDL** and **NCEP** to enhance NOAA weather and climate simulation capabilities

Upper Ocean Mixing For Climate Models

- Parameterized mixing schemes should be **efficient** & **robust**
- **ePBL** uses **1st order** approach trained with **2nd moment** & **LES** results



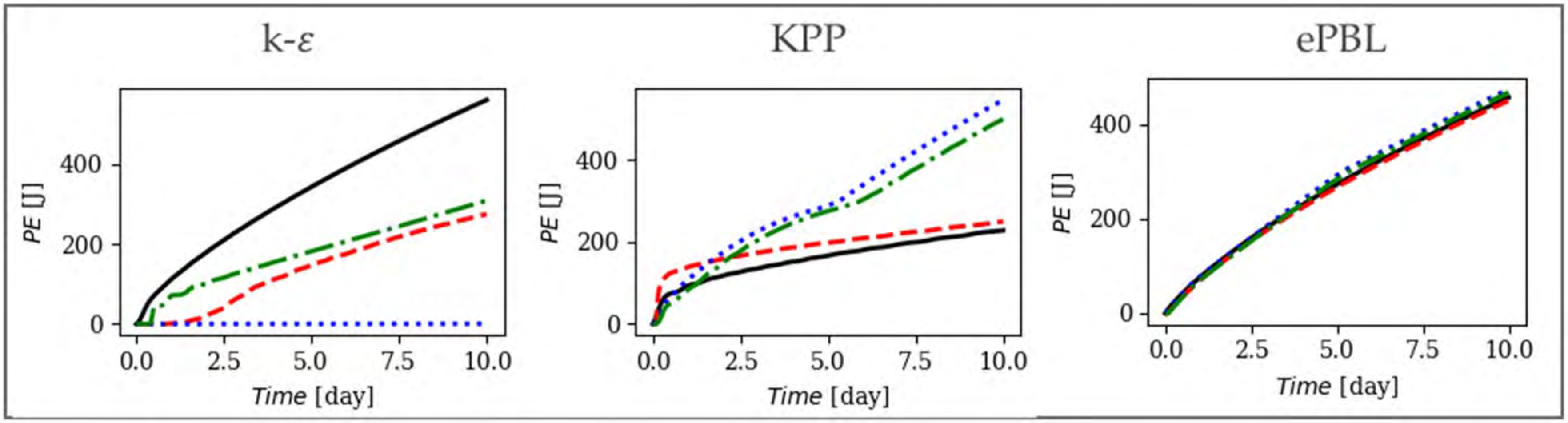
ePBL: Implicit Numerics

ePBL uses an **implicit**, **non-local energetic** mixing constraint

Why? Robust to numeric constraints (grid & time step)

1-d Wind-driven Simulations $\tau = 0.25\ \mathrm{N/m^2}$

$f = 2\Omega \sin(60)\ \mathrm{s^{-1}}$

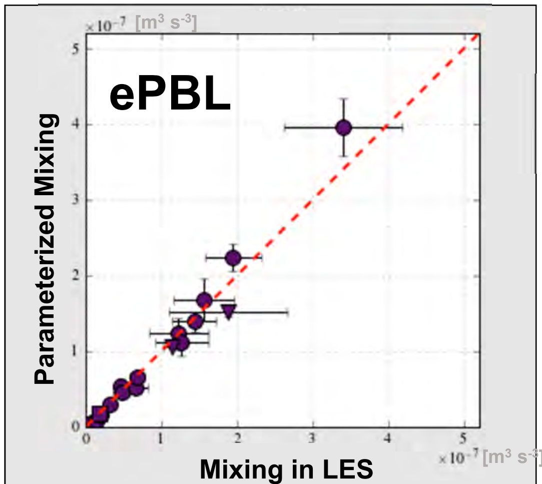


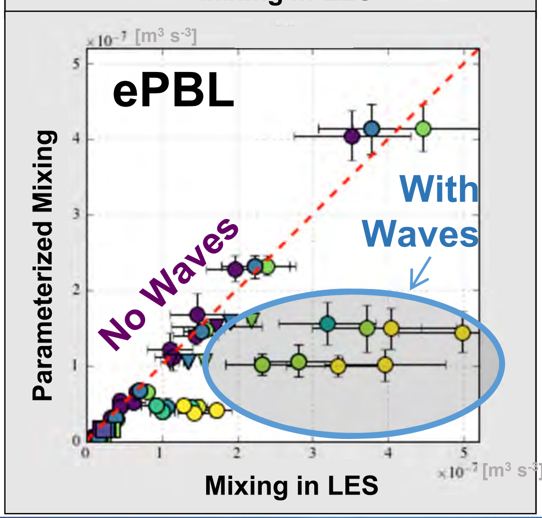
Rodi, 1987 *Large et al., 1994* *Reichl and Hallberg, 2018, OM*

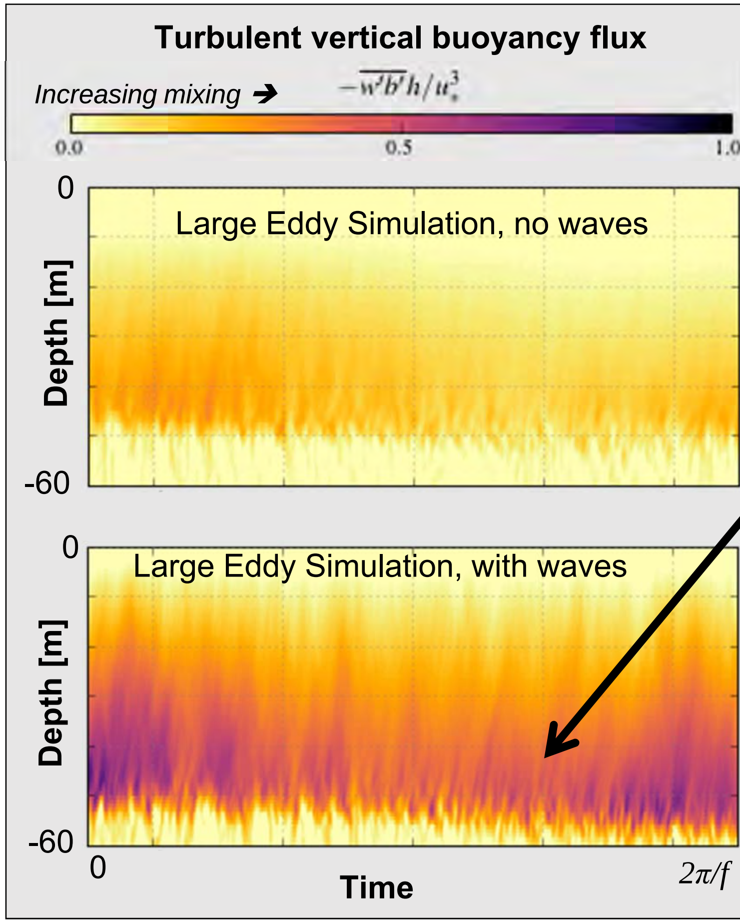
ΔZ = 1 m, ΔT = 30 s **ΔZ = 20 m, ΔT = 30 s** **ΔZ = 1 m, ΔT = 7200 s** **ΔZ = 20 m, ΔT = 7200 s**

ePBL: Accurate Physics

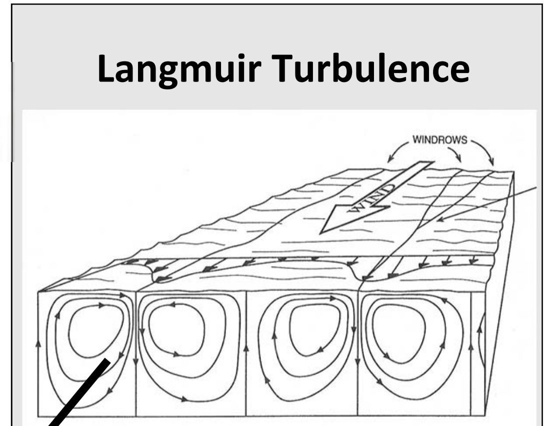
- Mixing constraints for **ePBL** validated from **Large Eddy Simulations**
- LES also used to add **wave effects** on mixing (ePBL ➔ **ePBL-LT**)



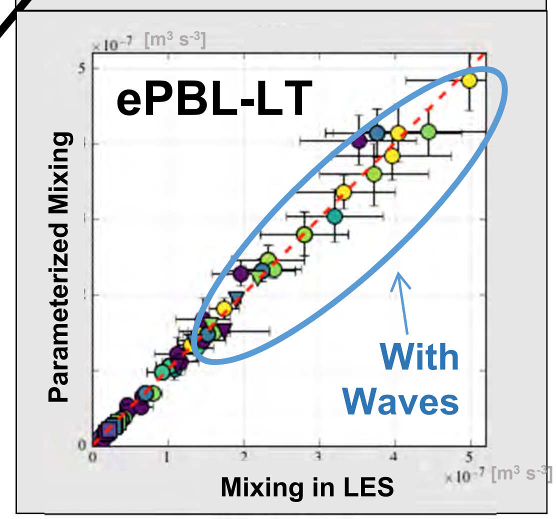




Reichl and Hallberg, 2018 OM; Reichl and Li, 2019, JPO

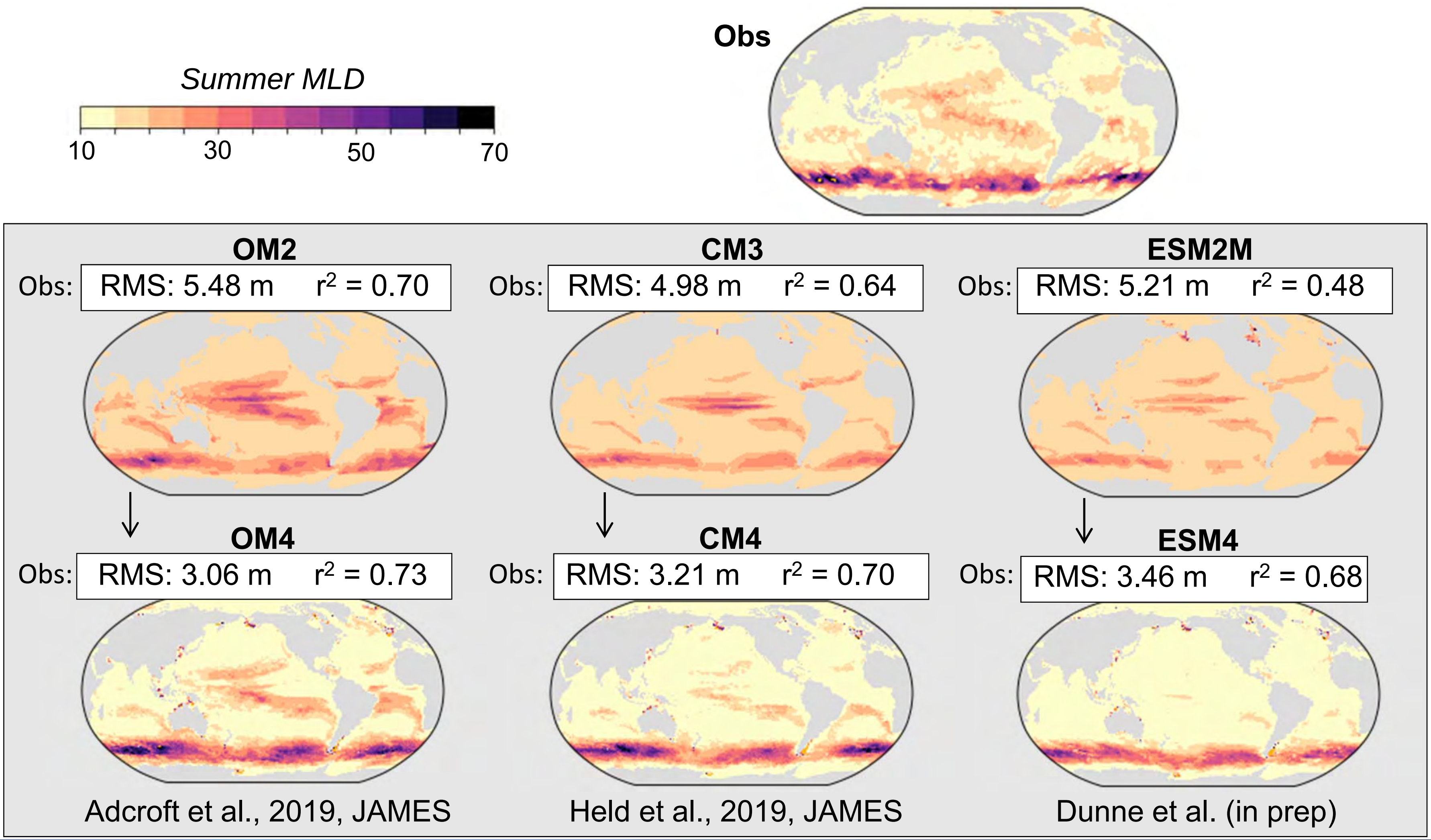


Thorpe, 2004



Ocean Mixing in GFDL Climate Models

ePBL helps improve simulated ocean mixed layer depth



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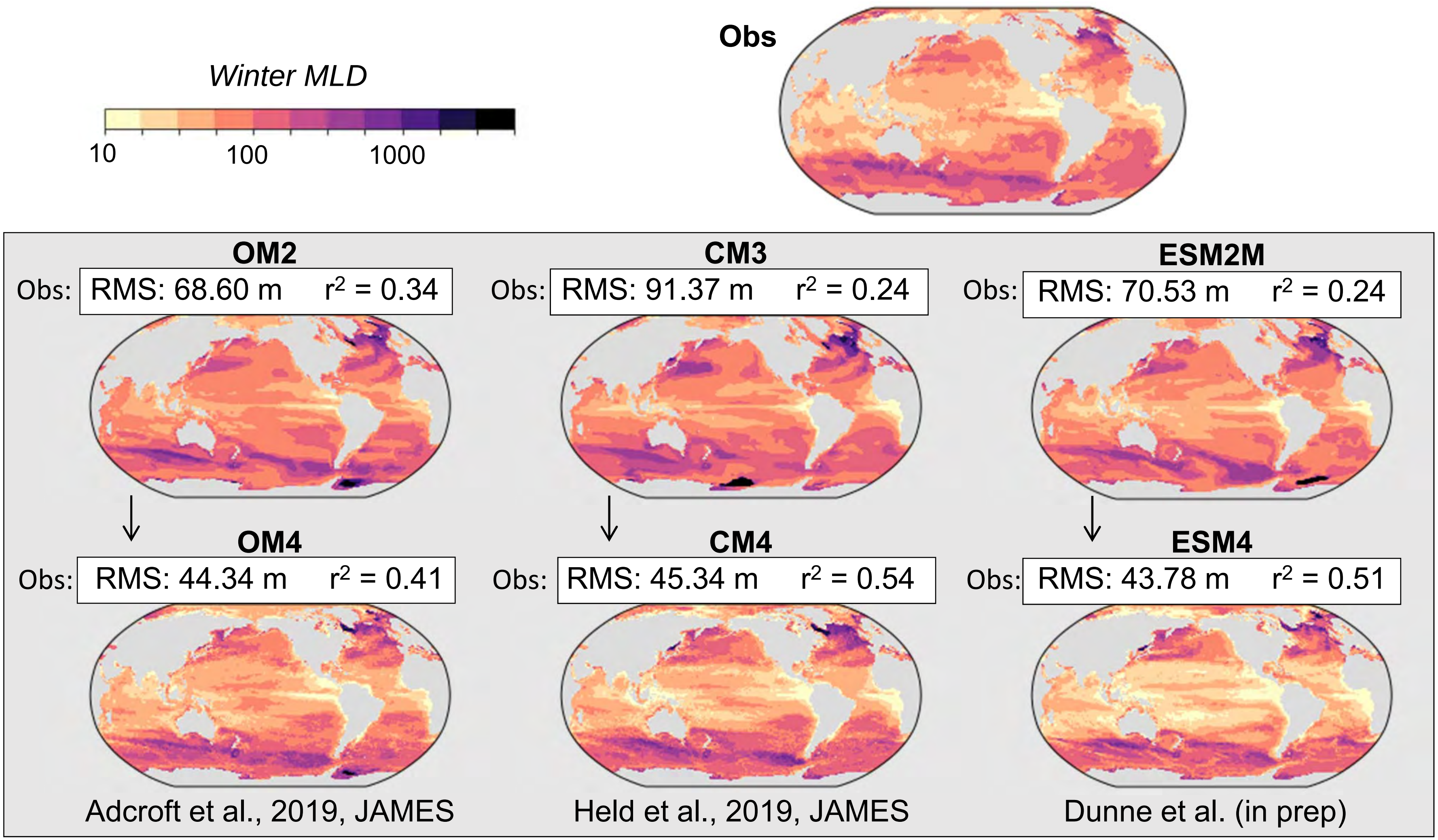
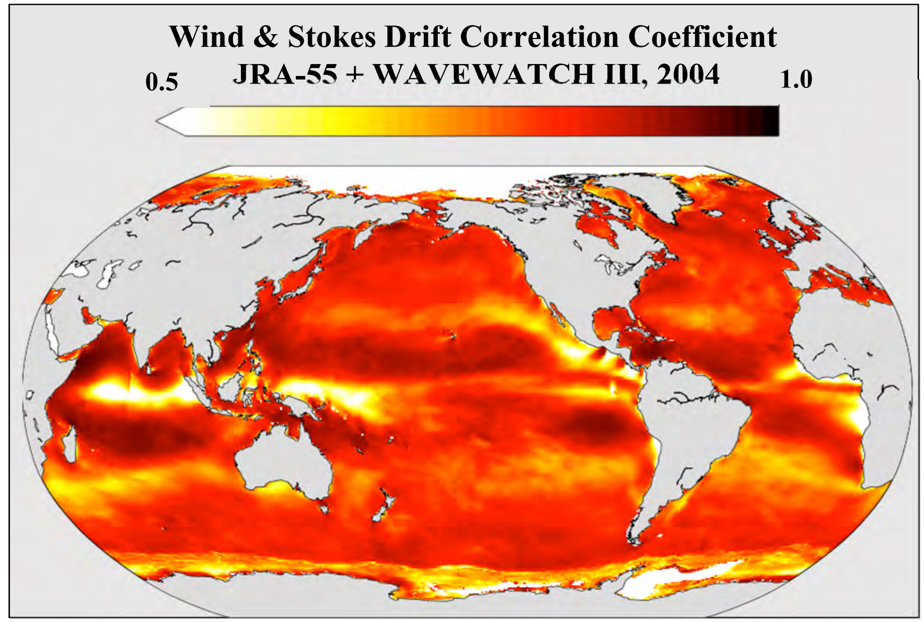
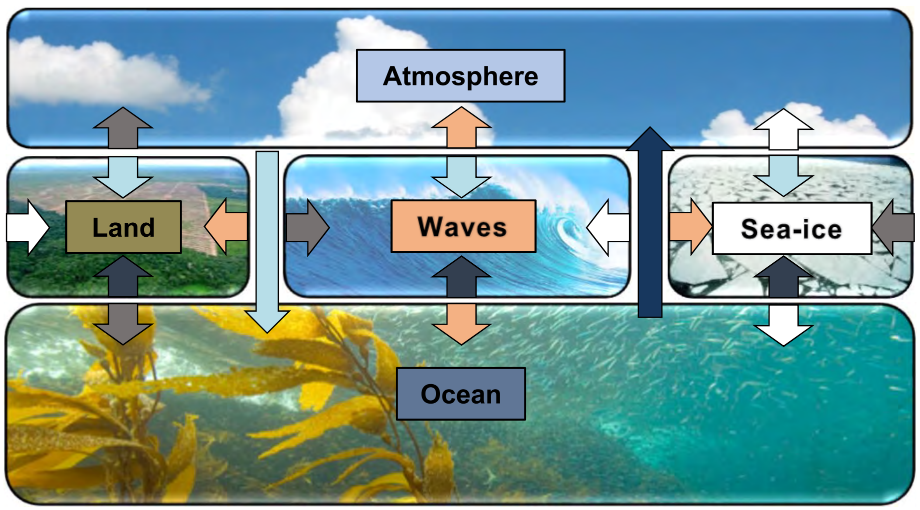


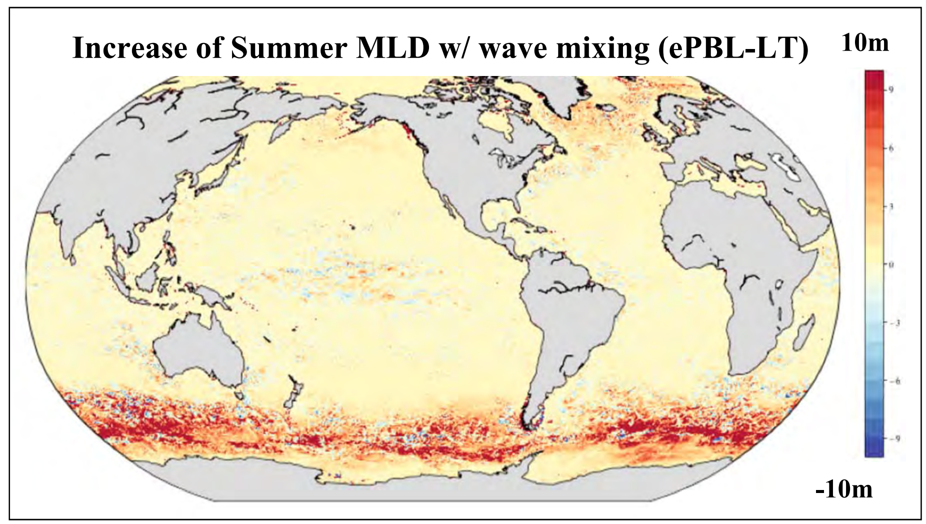
GFDL-NCEP Collaboration & WAVEWATCH III

- Ocean waves are critical component of air-sea physics
- Yet, waves are not explicitly represented routinely in models
- Wave coupled models are critical to understand their impacts in Earth System Models





Images: 1-usra.edu, 2-yale.edu, 3-mit.edu, 4- nsidc.org, 5-noaa.gov



Summary

Improved representation of upper ocean physics

- **ePBL** in GFDL "4th generation" models (OM4, CM4, ESM4)
  - **Implicit** numerics w/ **realistic** physics
  - **Wave-driven mixing** for realistic Southern Ocean
- **WAVEWATCH III** coupling for surface wave simulation

Future Work

- Apply ePBL principles continuously through water column
  - Bottom boundary layers
  - Breaking internal gravity waves
  - Internal tides
- Wave coupling
  - Improve air-sea flux parameterizations (e.g. momentum, gases [CO_2, Reichl and Deike, in revision], heat, mass)
  - Represent wave/cryosphere interactions (sea ice, icebergs)
  - Sea-state dependent sea-salt aerosols
  - Weather vs climate scale: Wave variability and extremes