An Energy-Diagnostics Intercomparison of Coupled Ice-Ocean Arctic Models

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Outline

1. Theory
2. Data
3. Results
   - Annual statistics
   - Seasonal statistics
4. Conclusions

Basic quantities

$$KE = \frac{1}{2}\int_V \rho \mathbf{c}^2 dV \tag{1}$$

$$PE = \int_V \rho g z dV \tag{2}$$

$$APE = PE - \int_V \rho_r g z_r dV \simeq -\frac{1}{2}\int_V g(\rho - \tilde{\rho})^2 \left(\frac{\partial \widetilde{\rho}_\phi}{\partial z}\right)^{-1} dV \tag{3}$$

Balance of KE & APE

$$\frac{\partial KE}{\partial t} + ADV(KE) = G(KE) + C(APE, KE) + C(IE, KE) - D(KE) \tag{4}$$

$$\frac{\partial APE}{\partial t} + ADV(APE) = G(APE) - C(APE, KE) - D(APE) \tag{5}$$

$$ADV(E) = \int_S E\mathbf{c} \cdot \mathbf{n} dS \tag{6}$$

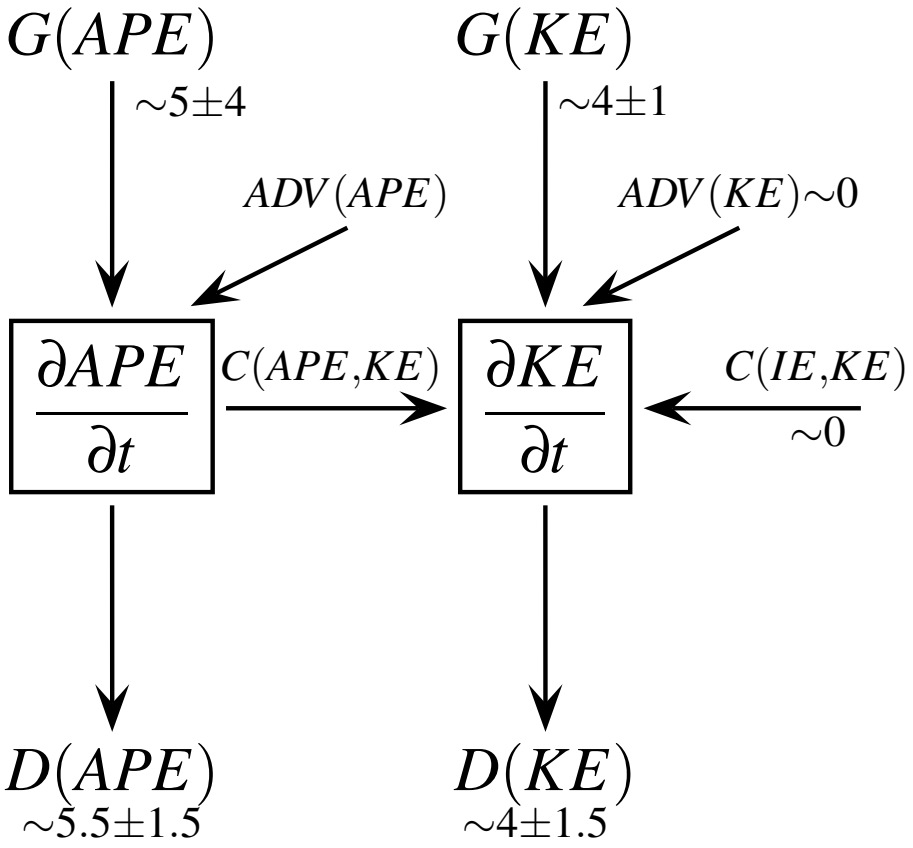
$$C(APE, KE) = -g \int_V (\rho - \tilde{\rho}) w dV \tag{7}$$

- Long term mean

$$\overline{G(KE)} = -\overline{ADV(KE)} + \overline{D(KE)} - \overline{C(APE, KE)} \tag{8}$$

$$\overline{G(APE)} = -\overline{ADV(APE)} + \overline{D(APE)} + \overline{C(APE, KE)} \tag{9}$$

$APE \leftrightarrow KE$ diagram



A schematic energy diagram describing the potential and kinetic energy flow components in the ocean. Arrows indicate the positive direction of the flow. Estimates in mWm^{-2} derived from *Oort et al. (1994)* for the northern hemisphere.

Energetics of the Polar Ocean Model

- Surface is mixture of sea–ice and open water
- APE and KE forcing fluxes dependent on C_{ice} :

$$
\begin{aligned}
G(KE) &= C_{ice} < \tau_i \cdot \mathbf{u}_o > && (10)\\
&\quad +(1-C_{ice}) < \tau_o \cdot \mathbf{u}_o > && (11)\\
\tau_i &= \rho_w C_w |\mathbf{u}_i - \mathbf{u}_o| (\mathbf{u}_i - \mathbf{u}_o) && (12)\\
\tau_o &= \rho_a C_a |\mathbf{u}_a| \mathbf{u}_a && (13)\\
G(APE) &\propto \frac{\partial \rho}{\partial t} \propto f_H(\frac{\partial T}{\partial t}) + f_L(\frac{\partial S}{\partial t}) && (14)
\end{aligned}
$$

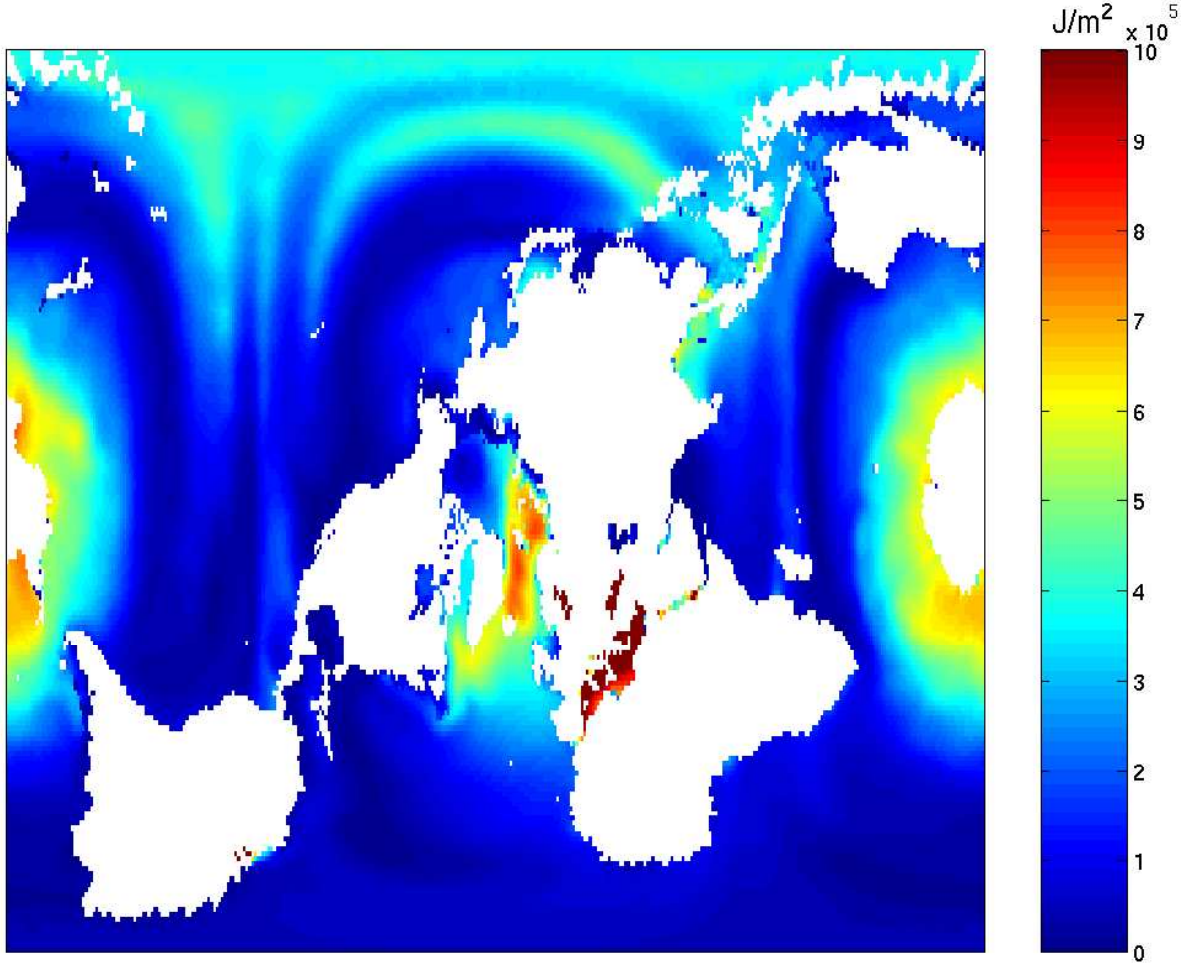
Data descriptors

Model	Ocean Model	δx	vertical dims.	Ice Dyn.
AWI	MOM	$1/4^\circ$	z-coord., 33 levels	VP
GSFC	POM	$0.9^\circ \times 0.7^\circ$	σ-coord., 20 levels	gener. visc.
IOS	MOM	$1/2^\circ$	z-coord., 29 levels	VP
NYU	MICOM	$1/2^\circ$	ρ-coord., 11 layers	cav. fluid
RAS	Finite element	1°	z-coord., 16 levels	VP
UW	MOM	40 km	z-coord., 21 levels	VP
PHC	Climatology	1°	z-coord., 32 levels	

All data are monthly averages and interpolated to the common grid.
AOMIP Live Access Server: `http://hamish.cims.nyu.edu/las/`.

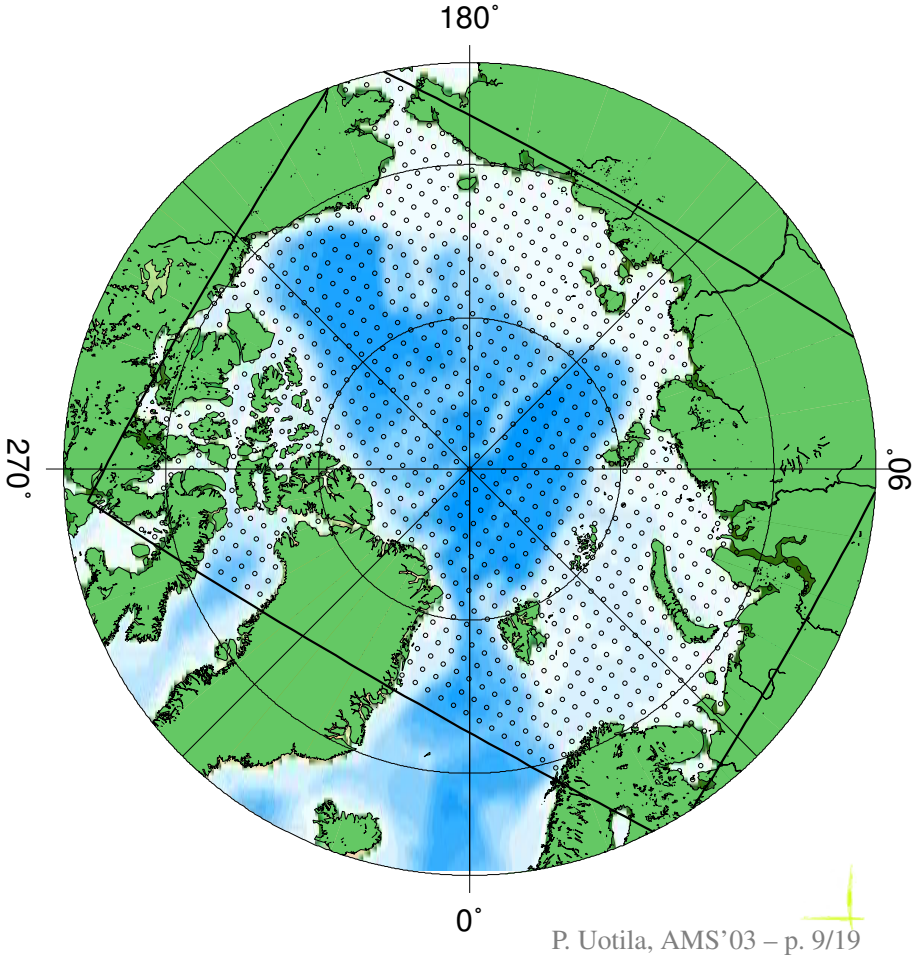
Global APE from PHC

Vertically integrated annual average oceanic APE density field based on the Polar science center Hydrographic Climatology (PHC) v. 2.1. from http://psc.apl.washington.edu/Climatology.html



Study area

The common intercomparison area for all models is outlined by the rectangular box. That area is represented by a latitude-longitude grid with 1° spatial resolution and has rotated latitude-longitude coordinates with respect to true geographical latitude-longitude coordinates. It is referred as the AOMIP grid.



Annual statistics

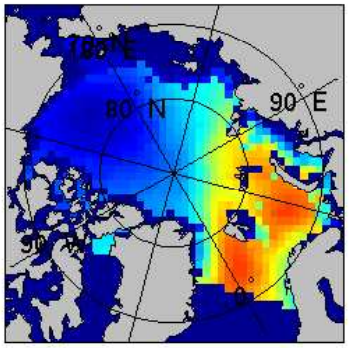
	PE $10^{10}\mathrm{Jm}^{-2}$	APE $10^{5}\mathrm{Jm}^{-2}$	KE Jm^{-2}	C mWm^{-2}	$\int_S < APE > < \mathbf{v} > dS$ mWm^{-2}
PHC, global	6.0	2.2			
PHC, arctic	3.9	3.3			
AWI[1]	3.7	3.7	110	2.0±0.1	−0.9
GSFC	3.4	3.6	230	8.4±1.0	0.7
IOS	3.3		150		
NYU[2]	3.7	12.0	28	-0.9±0.2	−0.6
RAS	3.7	2.5	83	-5.0±1.3	1.0
UW[3]	3.4	2.0	125	-2.8±0.3	0.3

Annual mean (μ), deviation ($\sigma = \sqrt{\sum \sigma_i^2}/N$). [1]SSS restoring.

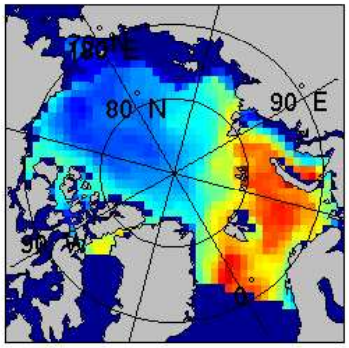
[2]Apparently unrealistic sea–ice distribution. [3]SSS and SST restoring.

APE vertical integrals

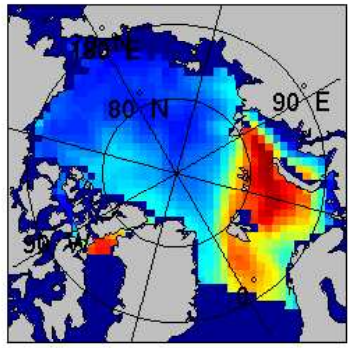
a) PHC



b) AWI

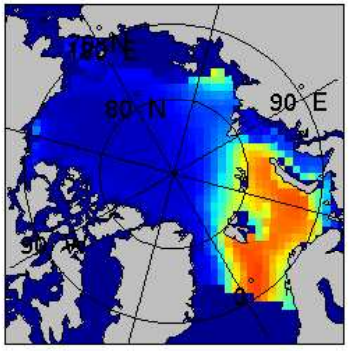


c) GSFC

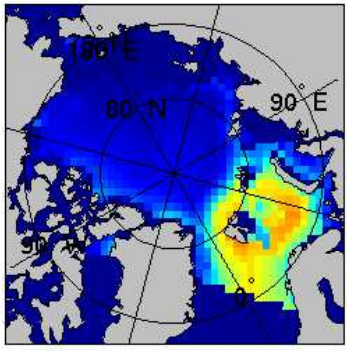


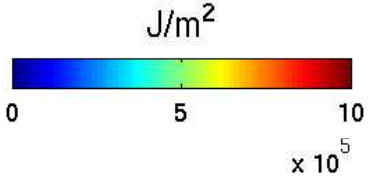
Annual average fields for 1978.

e) RAI



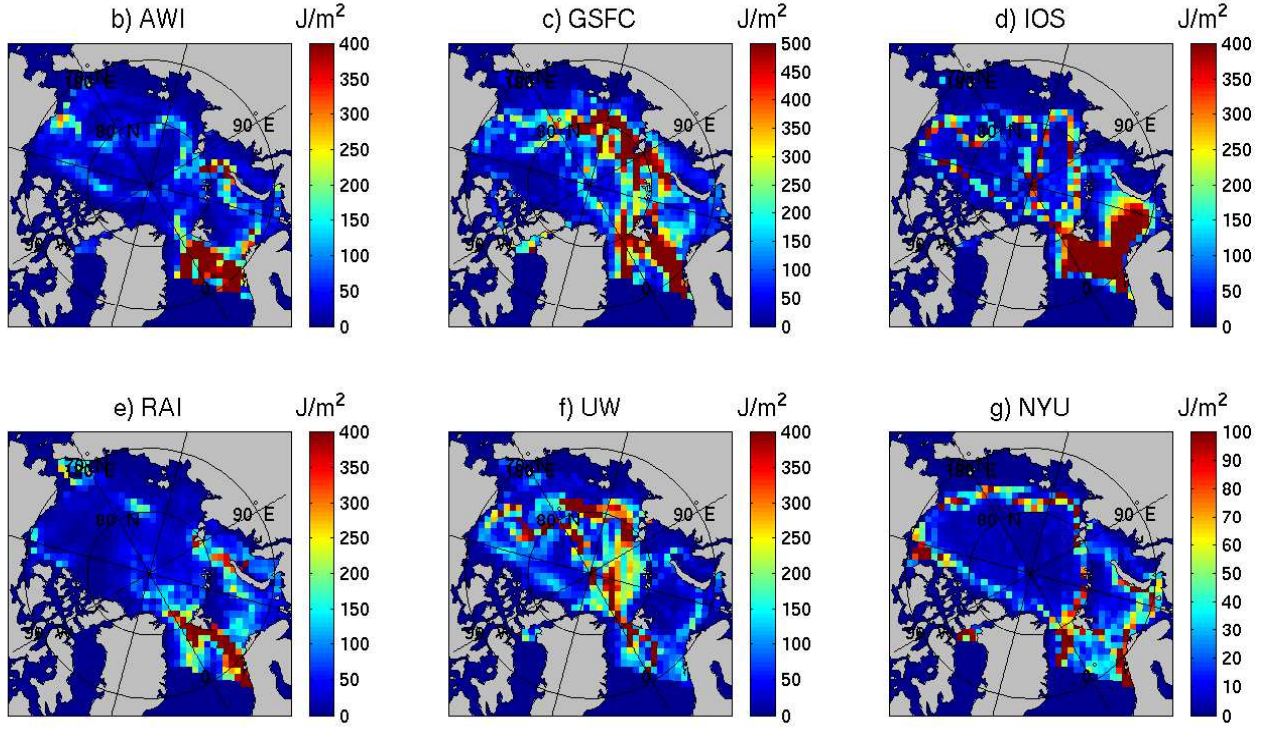
f) UW





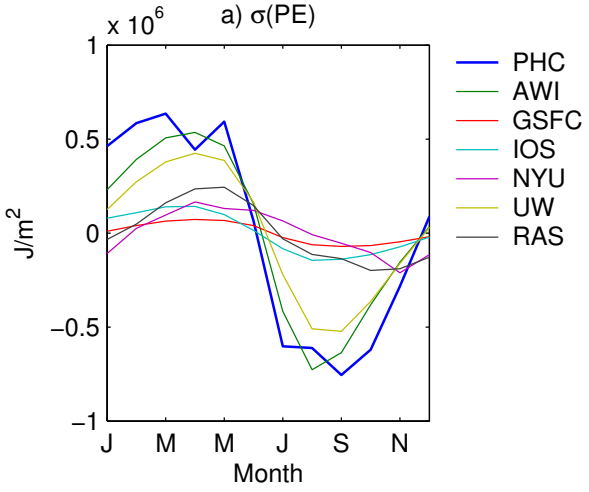
KE vertical integrals

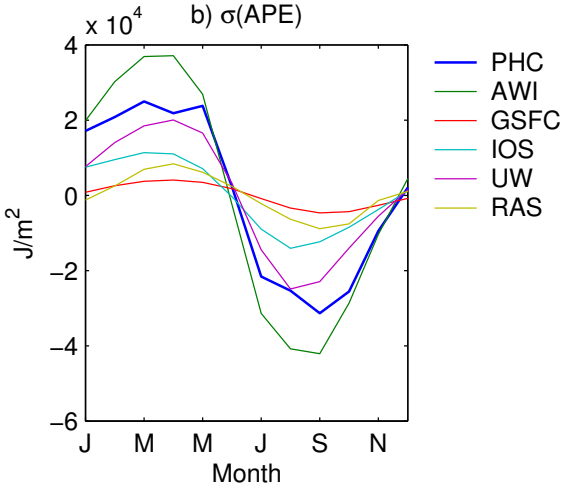
Annual average fields for 1978.

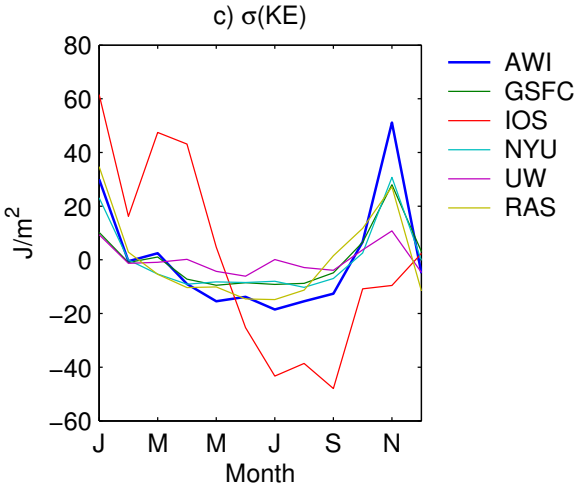


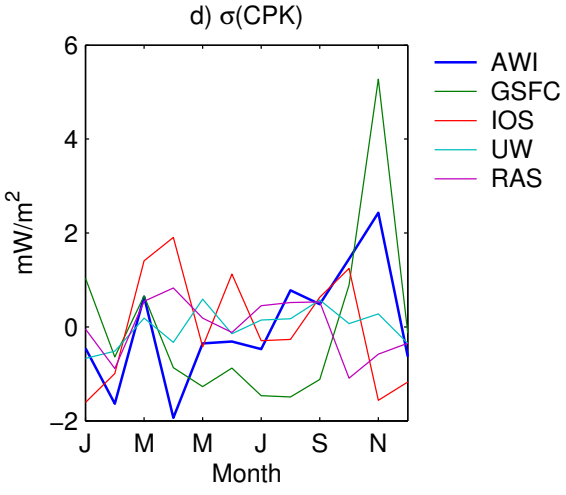
Monthly time series

Values are relative to the annual means.



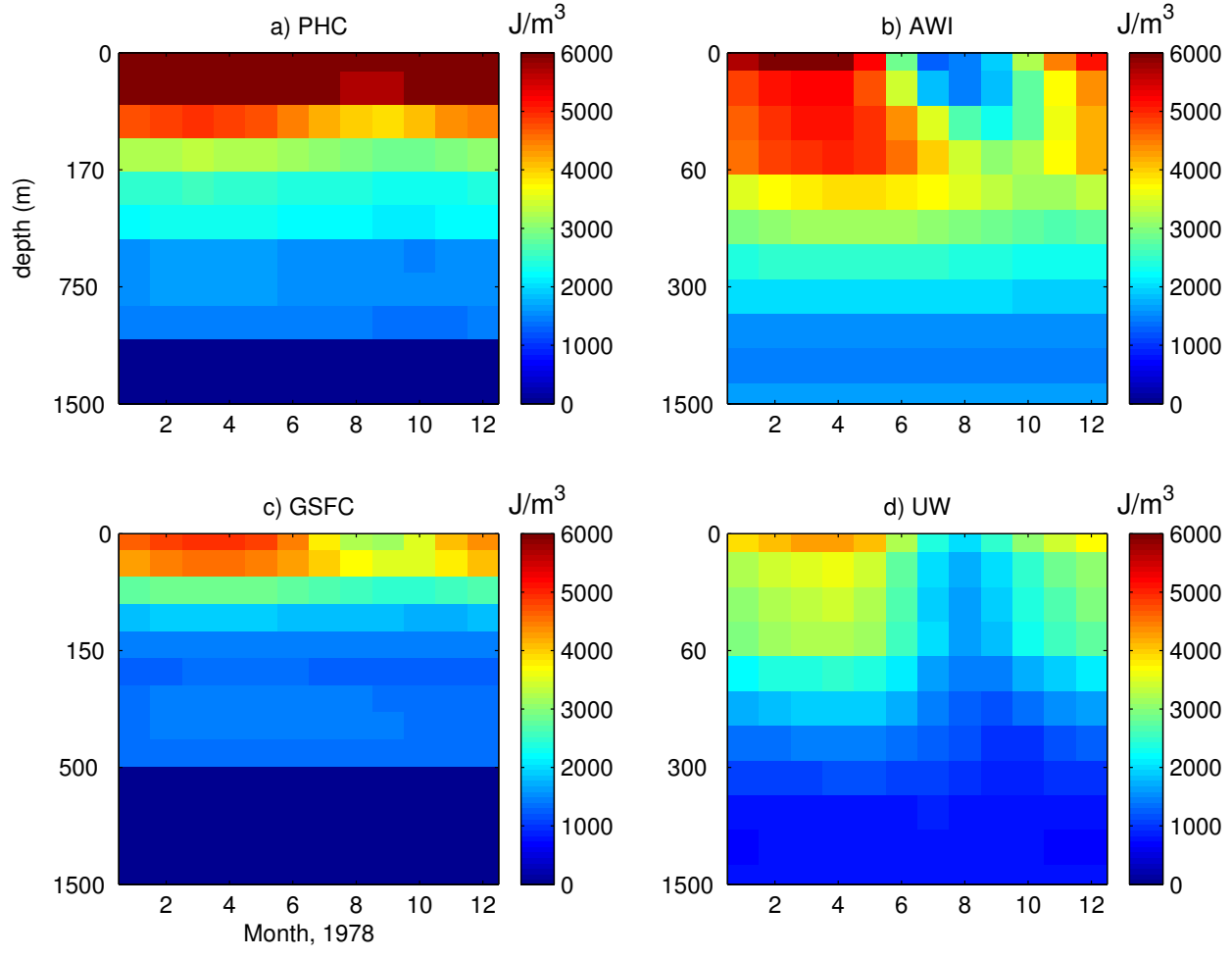






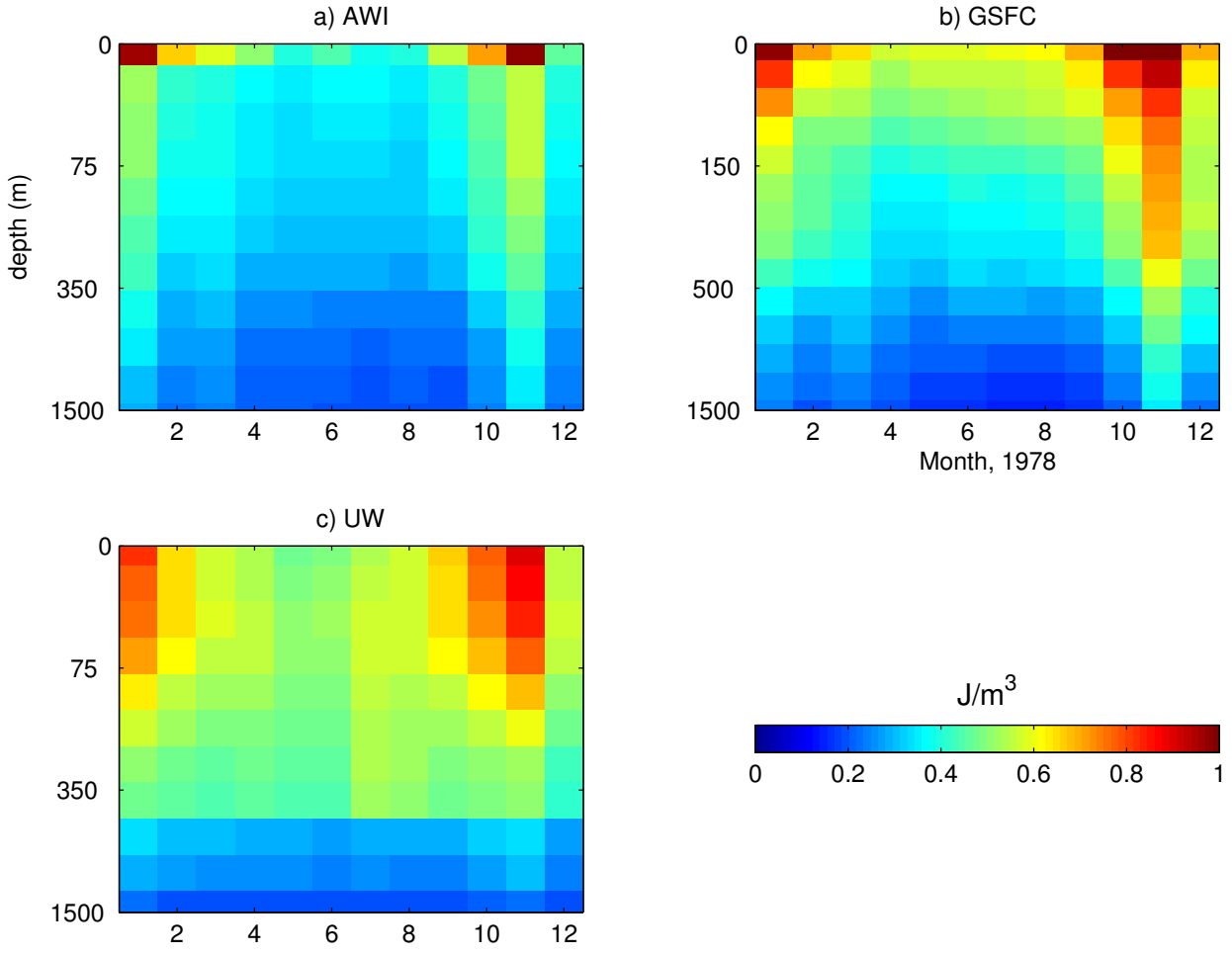
APE horizontal average

Vertical monthly section for 1978.



KE horizontal average

Vertical monthly section for 1978.



Conclusions

- New set of AOMIP experiments has been carried out: Forcing, initial and boundary conditions are uniformly defined.
- Models, however, have varying setup, e.g. SSS and SST restoring, which affects the intercomparison analysis.
- C estimates suggest that the models have different energy balance or do not resolve energy balance.
- Advection terms from monthly data are probably not reliable.
- Modeled sea–ice conditions affect the forcing of KE and APE at the ice–ocean interface and further the energetics of the underlaying ocean model.

Next:

- spinup experiment 1948 – 1979 (completed)
- analysis experiment 1979 – 2002
- 50-yr rerun with enhanced models

Participating Models

- Alfred-Wegener Institute (AWI), Germany
- NASA/Goddard Space Flight Center (GSFC)
- Institute of Ocean Sciences (IOS), Sidney, Canada
- Courant Institute, New York University (NYU)
- Russian Academy of Sciences (RAS), Moscow
- Applied Physics Laboratory, University of Washington (UW), Seattle

C vertical profile

Vertical monthly section for 1978.