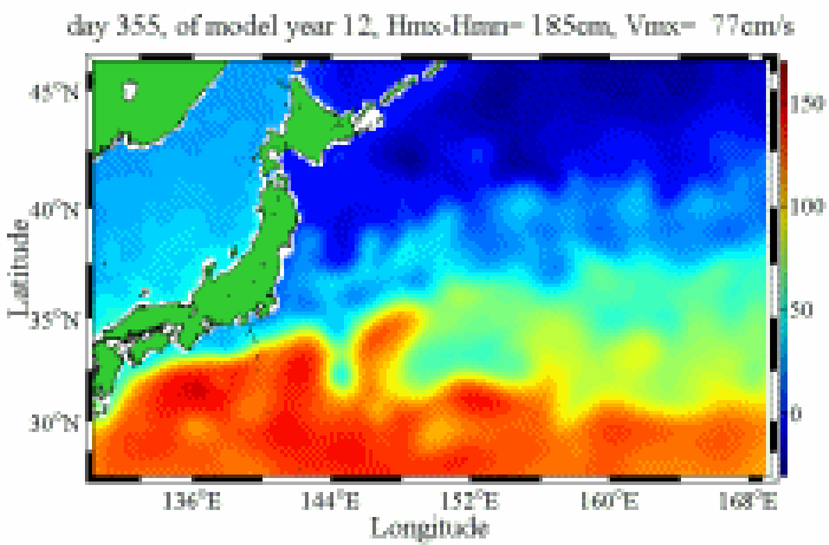
Development of a 1/16° Eddy-resolving Global Ocean Simulation within an Earth System Model Framework

An international collaborative effort for Multi-scale Ocean Circulation System (MUSOC)



Yu-Heng Tseng, Luc Vandenbulcke, Chih-Chieh Young, Wen-ien Yu, Rui Caldeira, Mu-hua Chien, Yu-Chiao Liang

Objectives

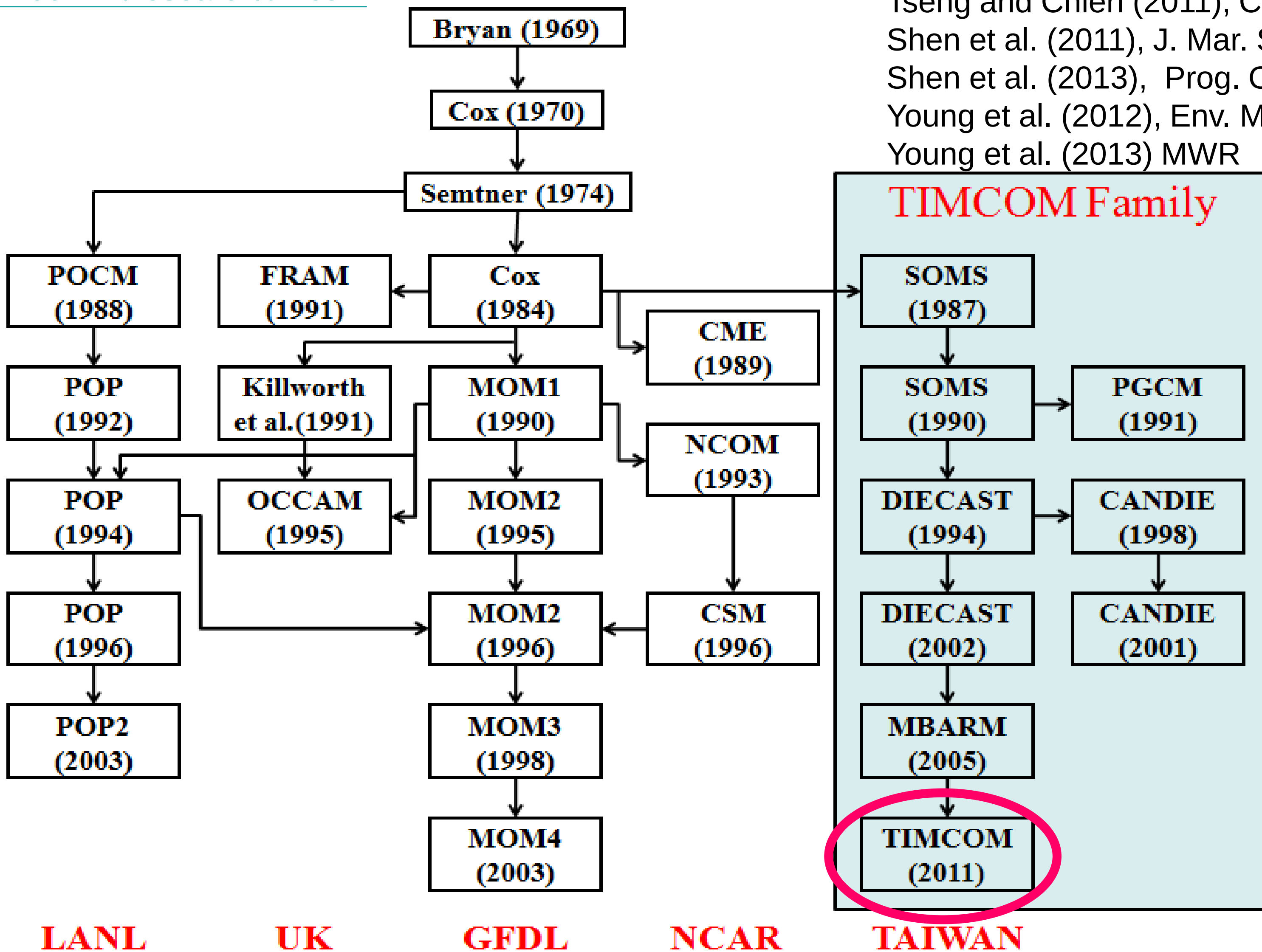
- Build and redesign a new ocean community model to resolve multi-scale dynamics with the most efficient two-way coupling in high accuracy
- Provide a scalable high-resolution global ocean circulation model (targeting at 1/60) for global ocean climate study in an Earth System Model Framework
- Operational and forecast capability while maintaining the simplest system structure
- International collaborative effort

Name or institution	Funder	Notes
Community Earth System Model/NCAR	NSF-DOE	Most extensive global modeling effort; couples atmosphere, ocean, and land
Geophysical Fluid Dynamics Laboratory	NOAA	Major model includes Princeton University contributions
National Centers For Environmental Prediction	NOAA	Focus on short- to medium-term weather prediction
Goddard Institute for Space Studies	NASA	Emphasis on global and regional climate sensitivity
Goddard Earth Observing System	NASA	Earth system model informed by space observations
Proposed DOE Model	*DOE*	*Would focus on higher resolution modeling*

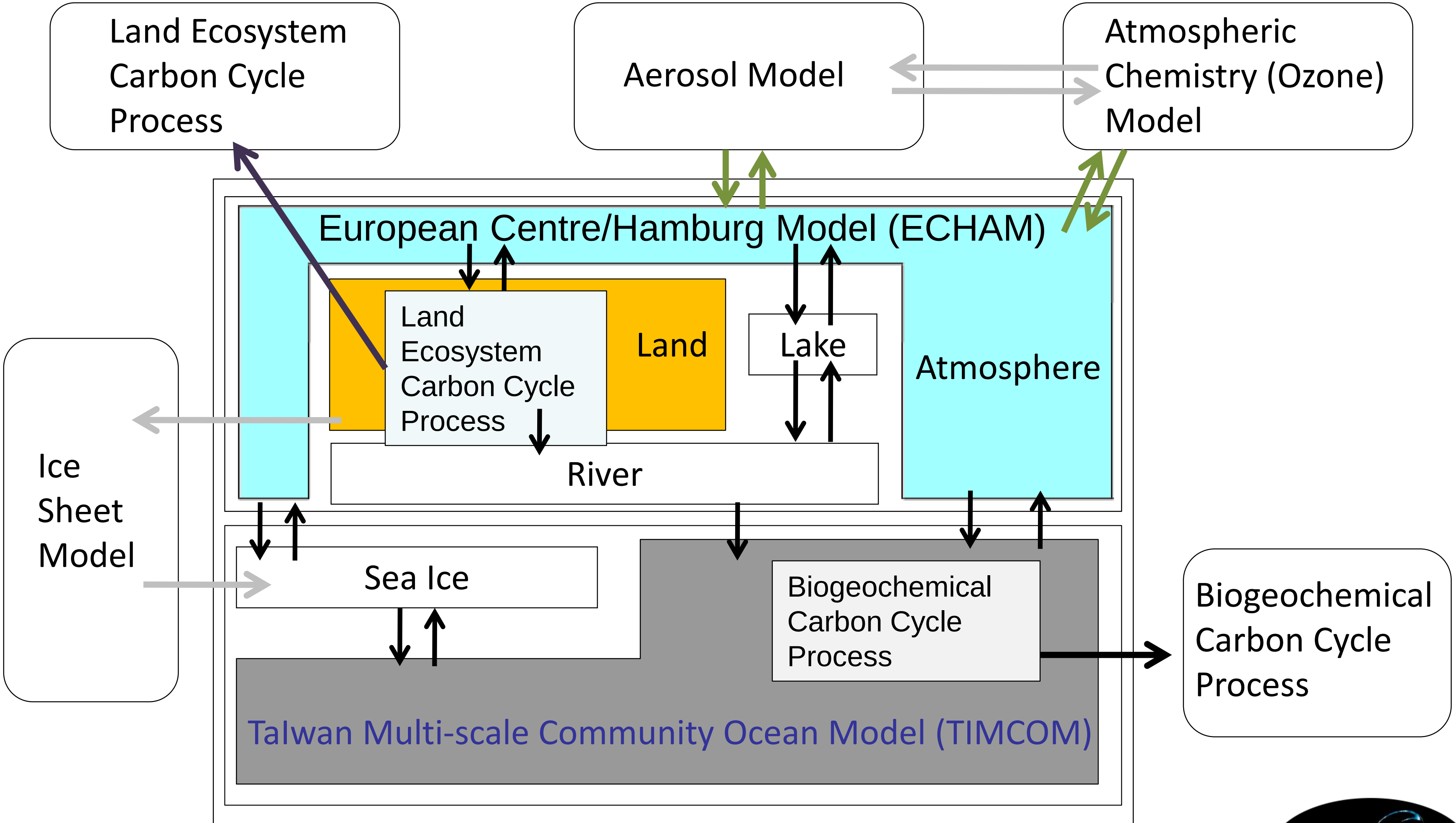
Multi-Scale Ocean Circulation System (PD-TIMCOM)

http://140.112.66.144/research/timcom

Tseng et al. (2012), Prog. Ocean
Tseng and Chien (2011), Comp. Fluids
Shen et al. (2011), J. Mar. Sys.
Shen et al. (2013), Prog. Ocean
Young et al. (2012), Env. Modell. Soft.
Young et al. (2013) MWR

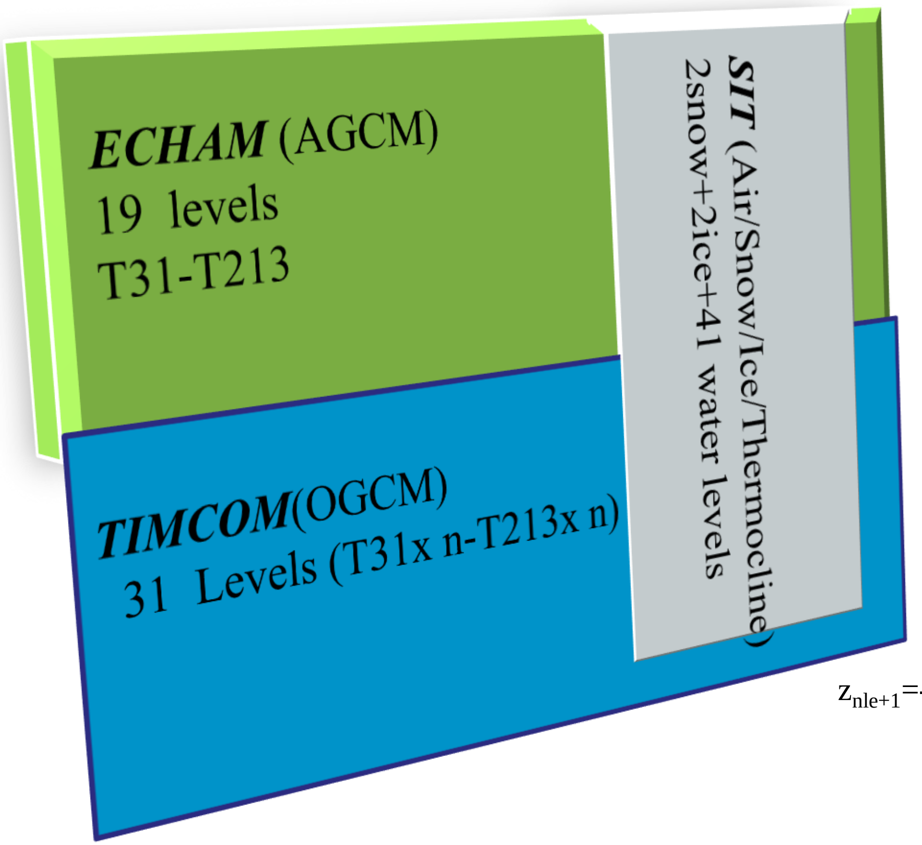


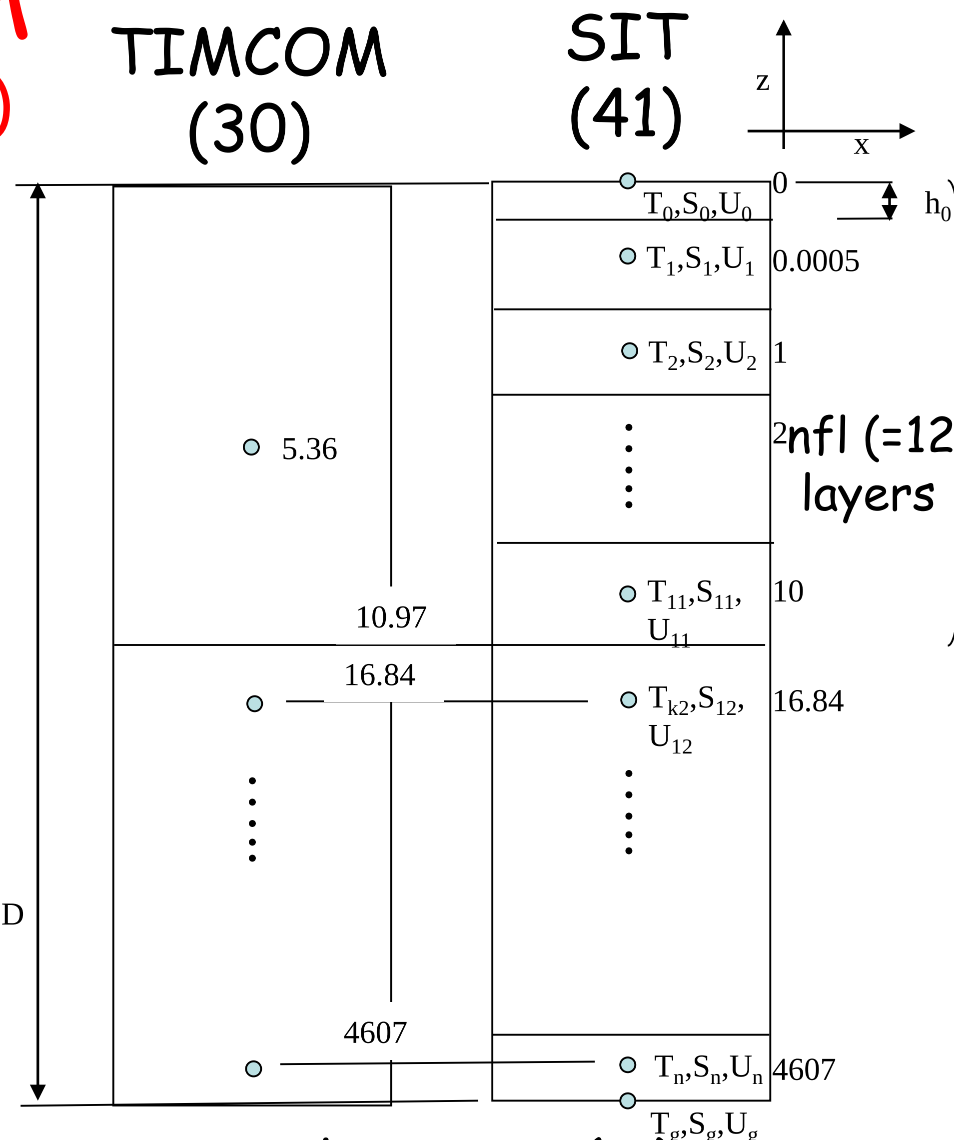
ECHAM/Taiwan Earth System Model




MUSOC
Multi-Scale Ocean Circulation system
MUSOC is a new community ocean circulation model with a number of outstanding features, most prominently a (i) Highly accurate and low-dissipative numerical scheme; (ii) Efficient and accurate Error Vector Propagation (EVP) solver and (iii) Flux-conserved grid coupling algorithm, allowing for multi-scale set-ups (iv) Modular (F90) organization.
RAIA.DA implementations:
✓ Operational forecast
✓ Ensemble capabilities
✓ Standard netcdf input and outputs
✓ Arbitrary atmospheric forcing
✓ User-friendly input files
The present workshop aims at:
1. Help users create / modify existing configurations
2. Solve a number of stability issues: i) domain boundaries; ii) interfaces, iii) long-term: iv) hot-restart
3. Implement non-hydrostatic config.
4. Lagrangian (offline) toolkit
5. Establish future developments
INVITED SPEAKERS:
➢ David Dietrich (USA)
➢ Yu-heng Tseng (USA)
➢ Pierrick Penven (France)
➢ Mao-lin Shen (Norway)
➢ Luc Vandenbulcke (Portugal)
➢ Iria Sala (Portugal)
➢ Rui Caldeira (Portugal)
Funchal, 11-14 August, 2014
ciimar
MARIE CURIE ACTIONS
ciimar madeira

ECHAM/TWESM
(ECHAM5/SIT/TIMCOM)

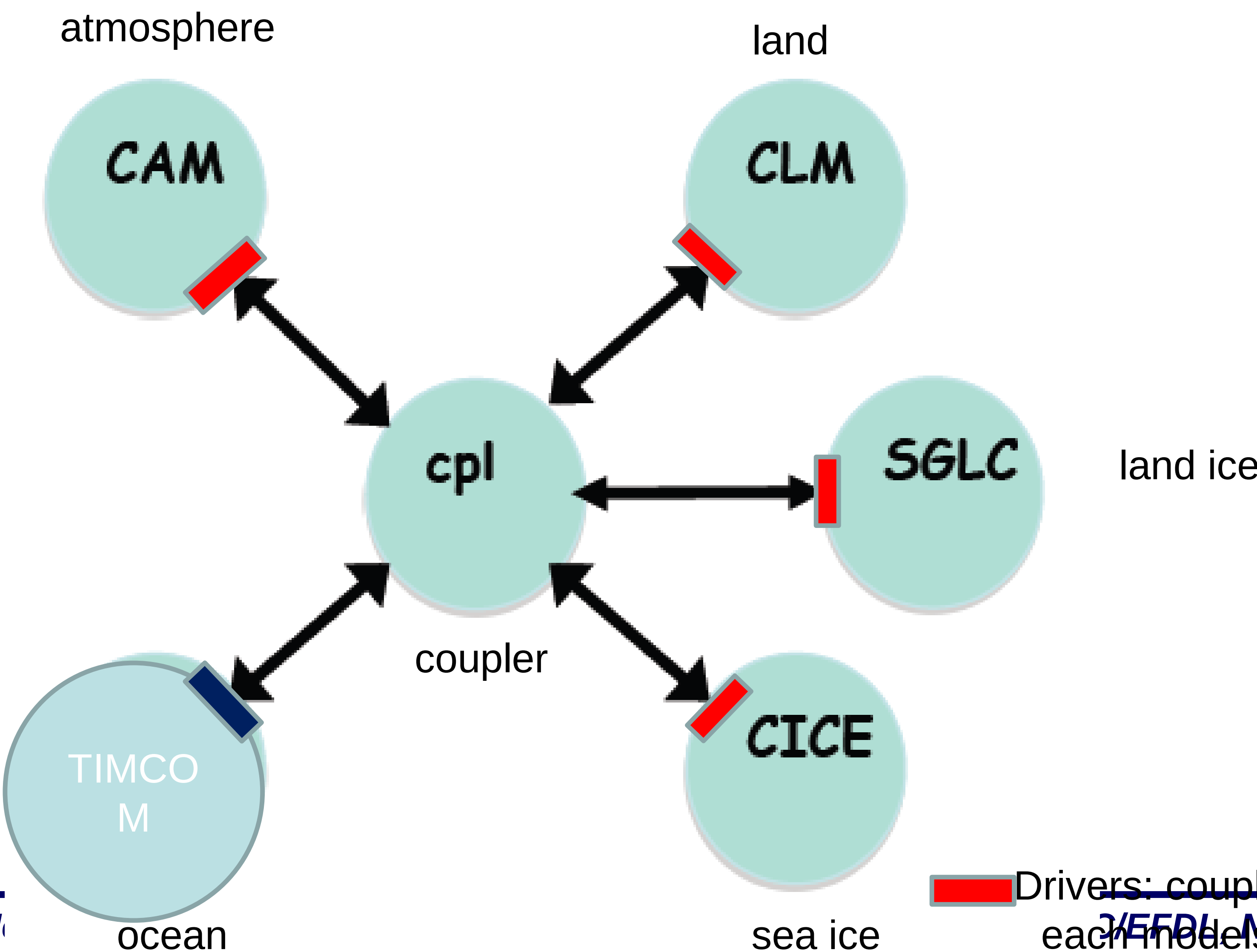




grid system (m)

- Improved MJO
- Better diurnal cycle
- Improved cool-skin simulation (Tu and Tsuang, 2005)

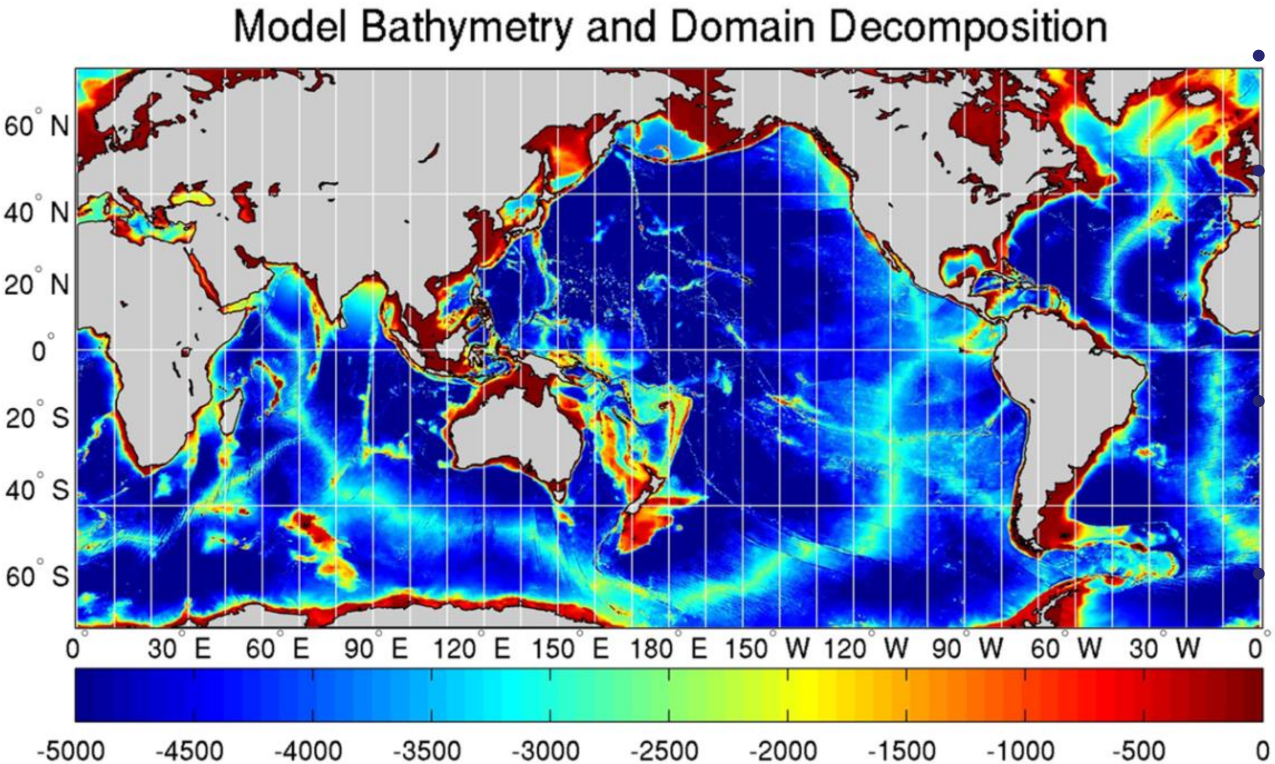
CESM framework--Drivers



Drivers: coupler i...
each models/co...

Tseng and Chien (2011)

Parallel Domain-Decomposed Taiwan Multi-Scale Community Model (PD-TIMCOM)



- Bathymetry from 1-min Etopo1
- Pacanowski and Philander Vertical mixing (1982) and Smagorinsky horizontal mixing (1993).
- Initial Temperature and Salinity from NOAA WOA 09.
- Surface wind forcing from Hellerman and Rosenstein (1983)

- 1/16°and 1/4° horizontal resolution, latitudes covers from 72°S to 72°N. with 51 linear exponential levels vertically. (1440x792x51)
- Primitive, hydrostatic equation
- Fourth-order numerics combined Arakawa A and C-grid (1977)
- Rid-lid approx. and Free surface are used (Yang et al., in preparation)

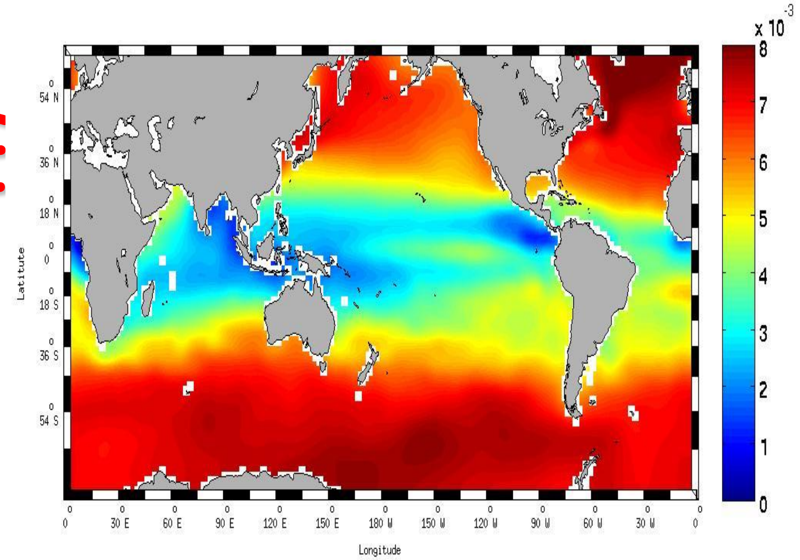
EQUATION OF STATE

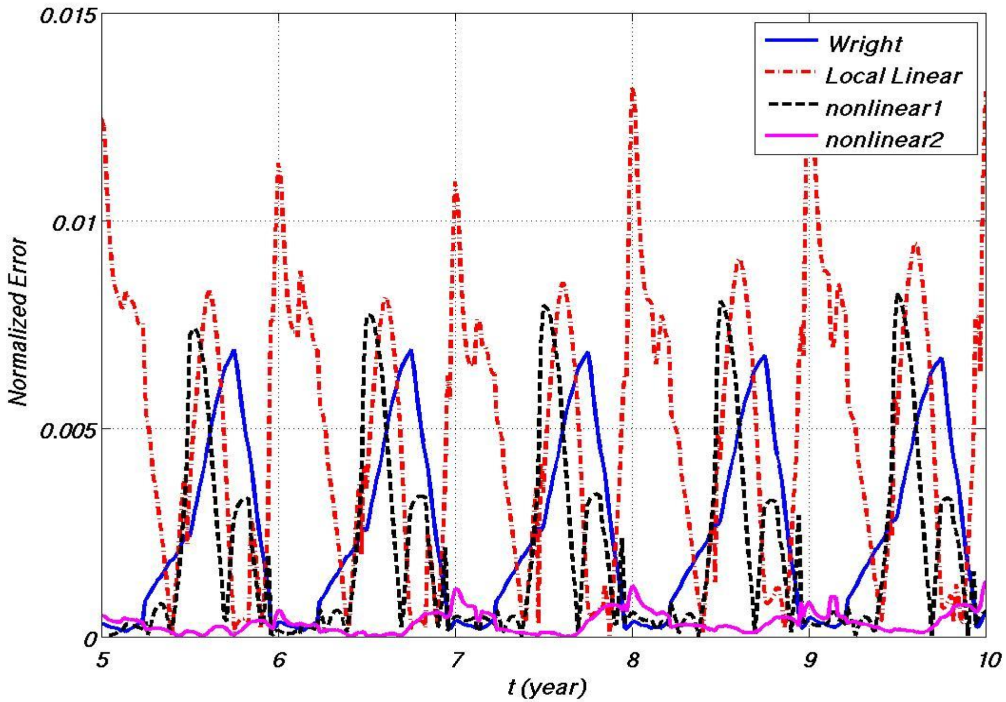
Wright's: $(\alpha-\alpha_0)(p+p_0)=\lambda \Rightarrow \rho=\dfrac{p+p_0}{\lambda+\alpha_0(p+p_0)}$

Polynomial fit:

$$D(t,s,p)=C_0+\left(C_t+C_{tt}t+C_{ts}s\right)t+C_s s$$

[Sanderson et al., 2001]





- *UNESCO*: standard solution.
- Error is normalized.
- Largest error of *Wright's* in autumn.
- Largest error of *Local Linear* in winter.
- Largest error of *nonlinear1* in summer.
- Largest error of *nonlinear2* in winter.

RAW-FILTER

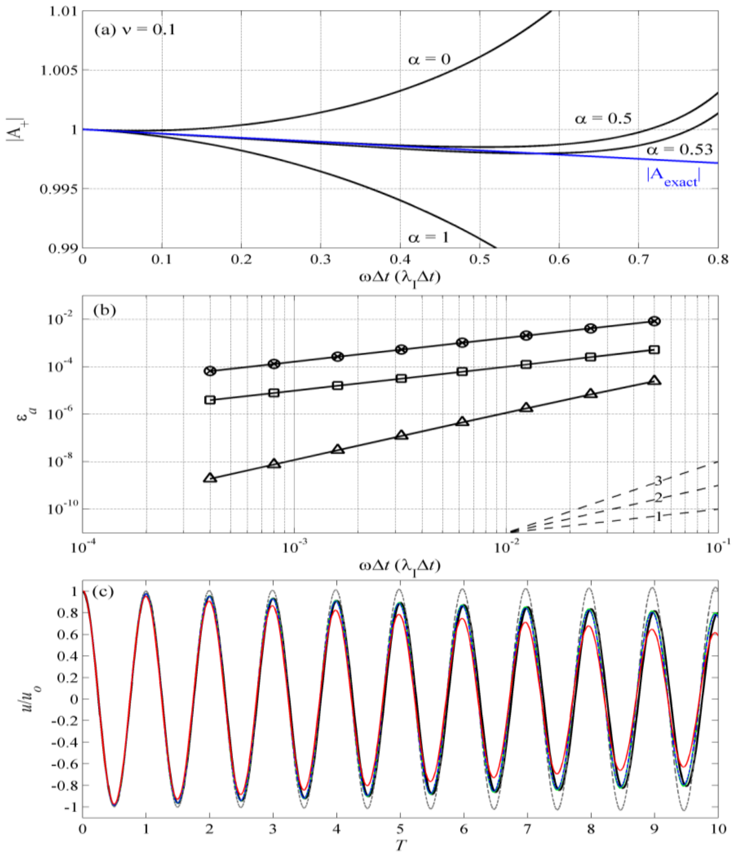
- 3rd-order accuracy in Amp.
- reduce time-splitting instability.
- easy to implement.
- low computational cost.

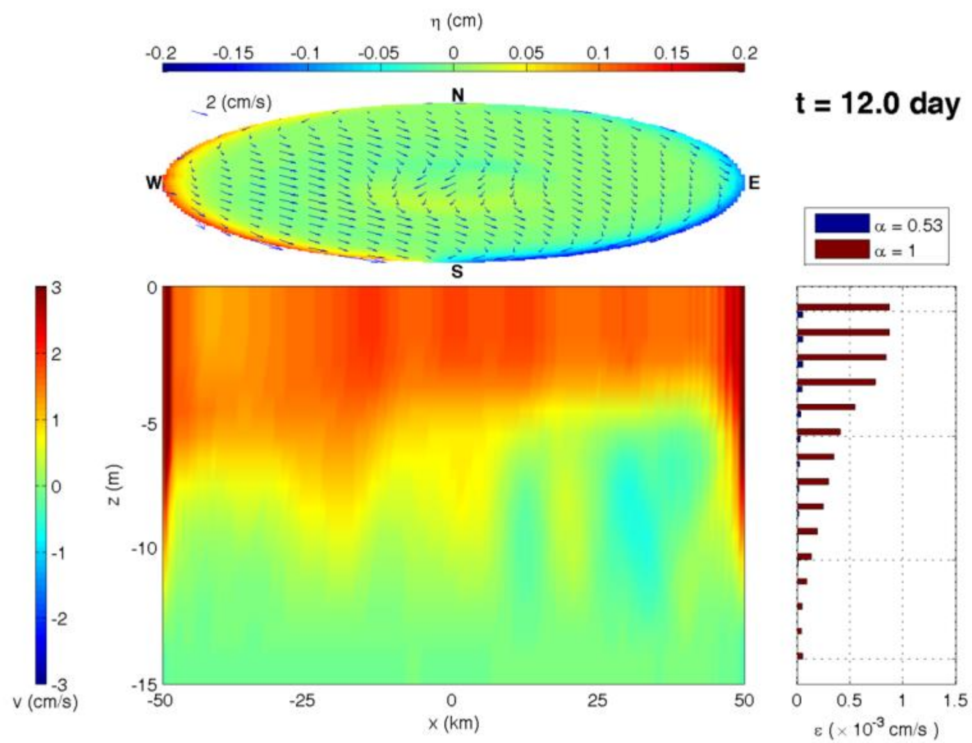
Young et al. (MWR in press)

$$\overline{\overline{F}}(t)=\overline{F}(t)+\frac{\nu\alpha}{2}\left[\overline{\overline{F}}(t-\Delta t)-2\overline{F}(t)+F(t+\Delta t)\right]$$

$$\overline{F}(t+\Delta t)=F(t+\Delta t)-\frac{\nu(1-\alpha)}{2}\left[\overline{\overline{F}}(t-\Delta t)-2\overline{F}(t)+F(t+\Delta t)\right]$$

- $0.05 < \nu < 0.2$
- $\alpha = 0.53$
- $\nu = 0$ -> *Leap-frog*
- $\alpha = 1$ -> *RA-Filter* [Williams, 2009]





Coastal trapping Kevin wave

Numerical Experiments

1. 50 years TIMCOM 1/4° global simulation with WOA (2009) and HR (1984) wind forcing (rerun).
2. 50 years TIMCOM 1/4° global simulation with WOA09 and Scatterometer Climatology of Ocean Winds (SCOW, 2008) wind forcing (rerun).
3. 2004-2010 TIMCOM 1/4° global hindcast with NOGAPS daily forcing (in prep.).
4. 1960-2010 TIMCOM 1/4° global hindcast with ECMWF monthly forcing (in prep.).

5. 30 years TIMCOM 1/16° global simulation with Levitus (1994) and HR (1984) wind forcing (in proc.).
6. 30 years TIMCOM 1/16° degree global simulation with WOA09 and Scatterometer Climatology of Ocean Winds (SCOW, 2008) wind forcing (in prep.).
7. 2004-2010 TIMCOM 1/16° degree global hindcast with NOGAPS daily forcing (in prep.).
8. 1960-2010 TIMCOM 1/16° degree global hindcast with ECMWF monthly forcing (in prep.).

Current status

http://140.112.66.144/wiki/index.php/Timcom_Wiki

- Focus mainly on the MEDINA and GLOBAL configurations
- For historical (climatological) studies of processes along the interface between Mediterranean Sea and Atlantic Ocean: promising (we see Meddies) but slow (not parallelized yet)
- For operational forecasts: being implemented now (not very much manpower to do it, so it's taking some time)
  - Doesn't really need parallel version for it (ensemble runs are parallel by themselves)

Recent additions

- Enhanced data input capacity (free-format ascii files, can read scalars, vectors, or load from netcdf files)
- Numbered models : input and output (000 to 999) for future ensemble runs
- Basic river runoff influences
- More flexible nudging configuration (incl. 3D coeffs.)
- Support for real time atmospheric forcing instead of climatological time: the model keeps track of the "modified julian day" (days after 18/november/1858).
  Thus years have their exact number of days rather than 12*30=360 days

Recent additions

Surface fluxes for heat, momentum and freshwater

- Fluxes computed from atmospheric fields using bulk formulae (based on code from GETM model)

or

- Fluxes read from netcdf files

The module is initialized, data is read from netcdf files and interpolated in space during the model startup; and interpolated in time during model integration

Tested with data from NCEP, ECMWF and CORE-2

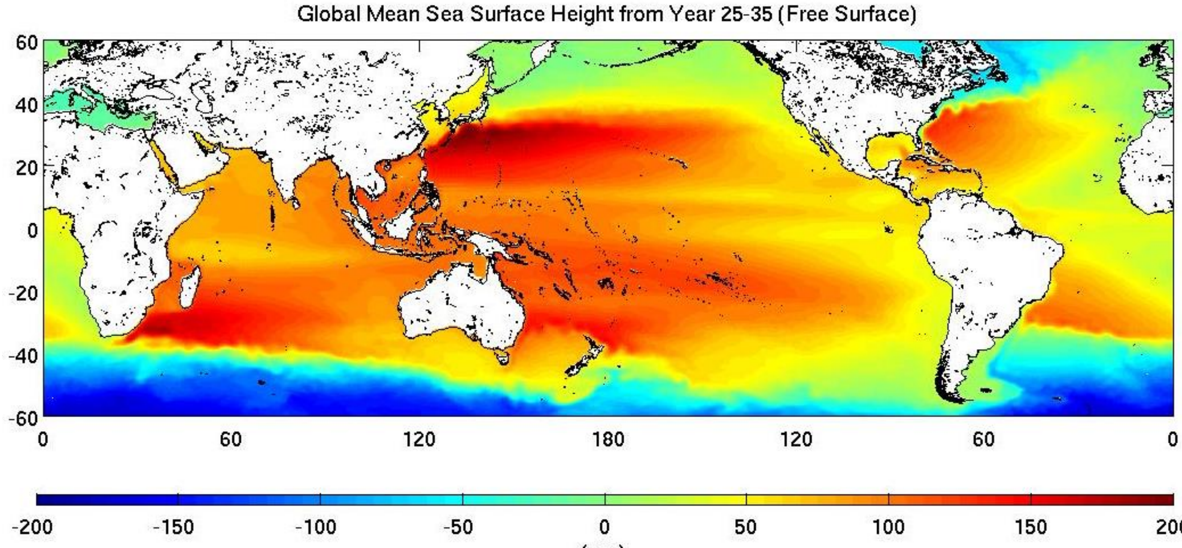
Data assimilation

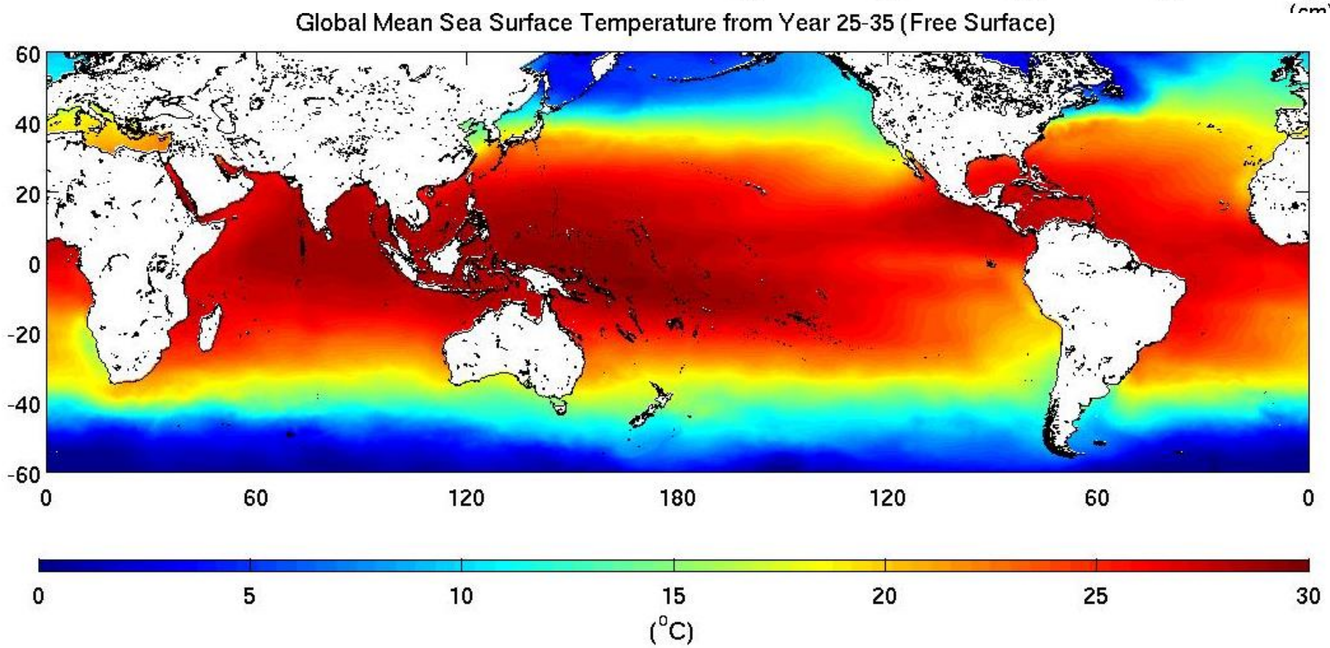
- Data assimilation independent from TimCOM
- Bash scripts alternatively run the model and the data assimilation code
- The data assimilation code modifies the TimCOM restart file
- The data assimilation code we plan to use is OAK

(modb.oce.ulg.ac.be/mediawiki/index.php/Ocean_Assimilation_Kit)

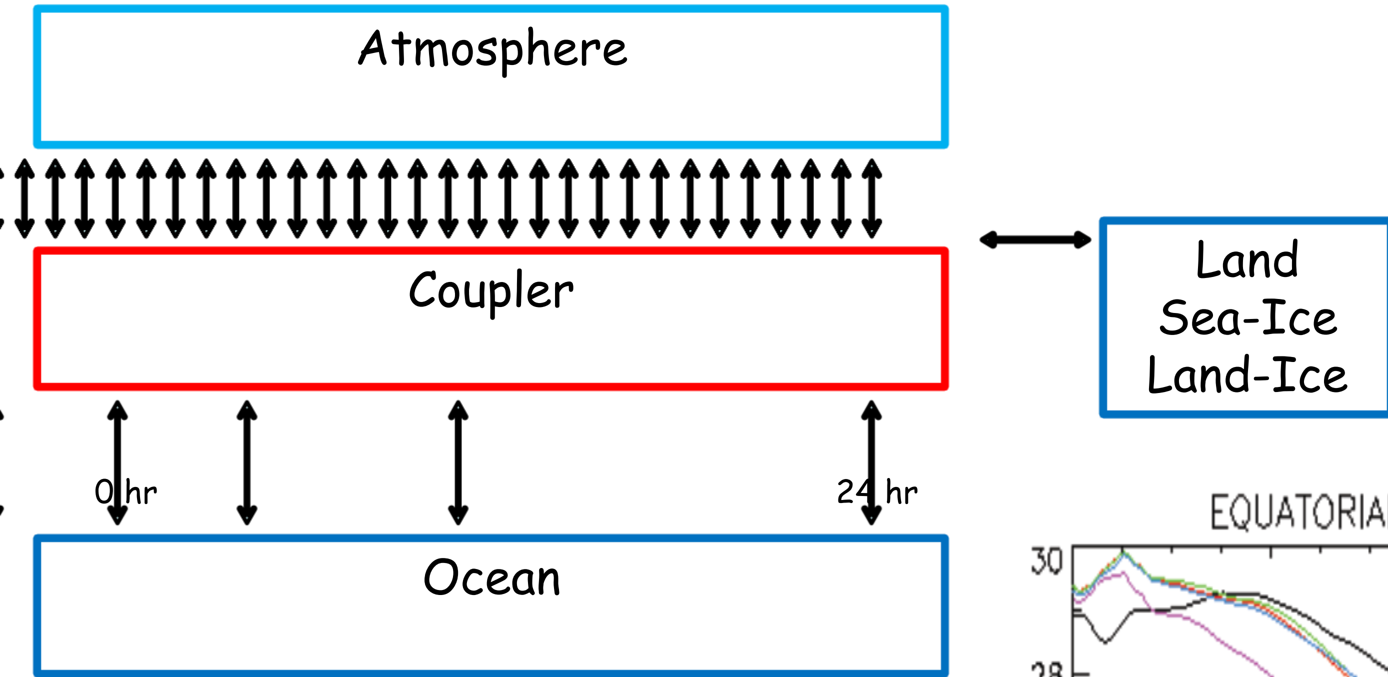
multi-grid, multi-variate, 3D, reduced-rank Kalman filter. The state-vector error covariance matrix can be obtained from a historical run ("fixed-base SEEK filter") or from an ensemble (EnKF)

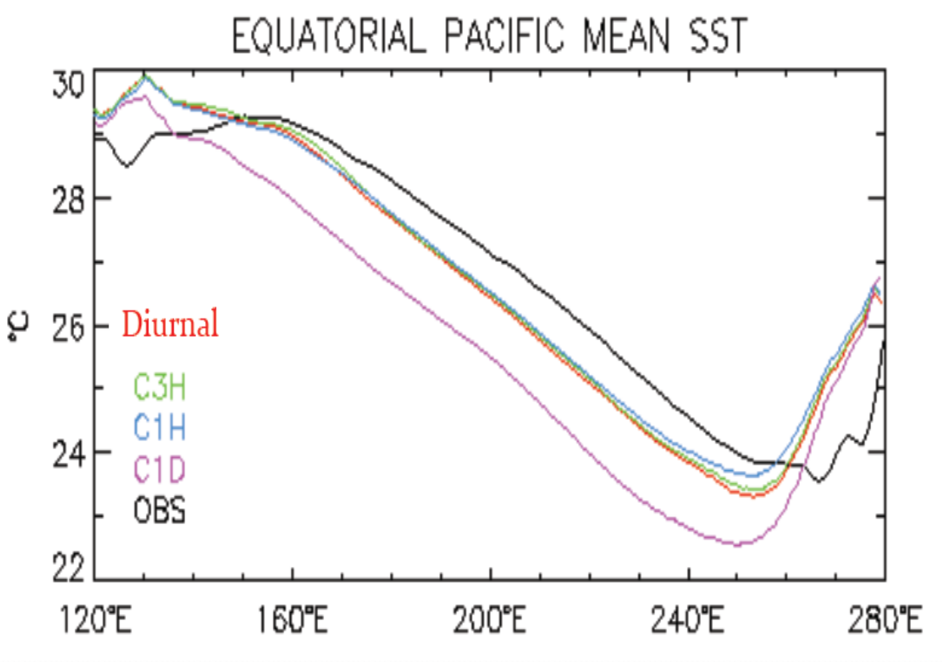
Mean SSH and SST



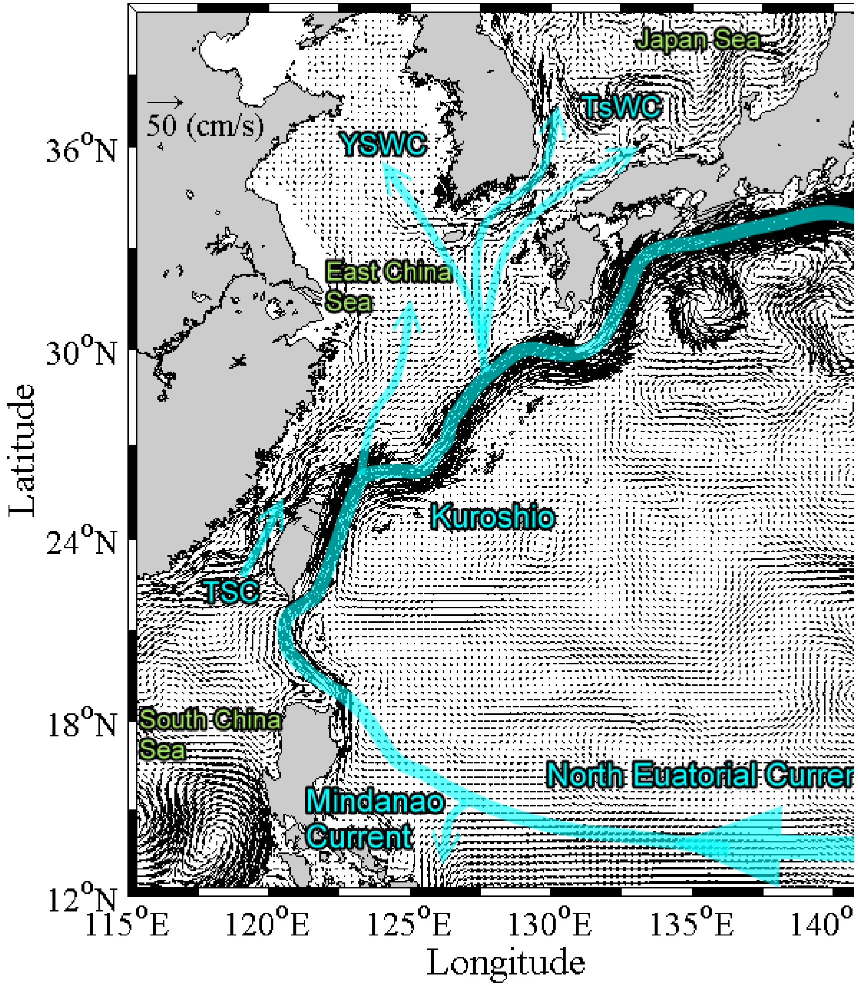


Future Plans

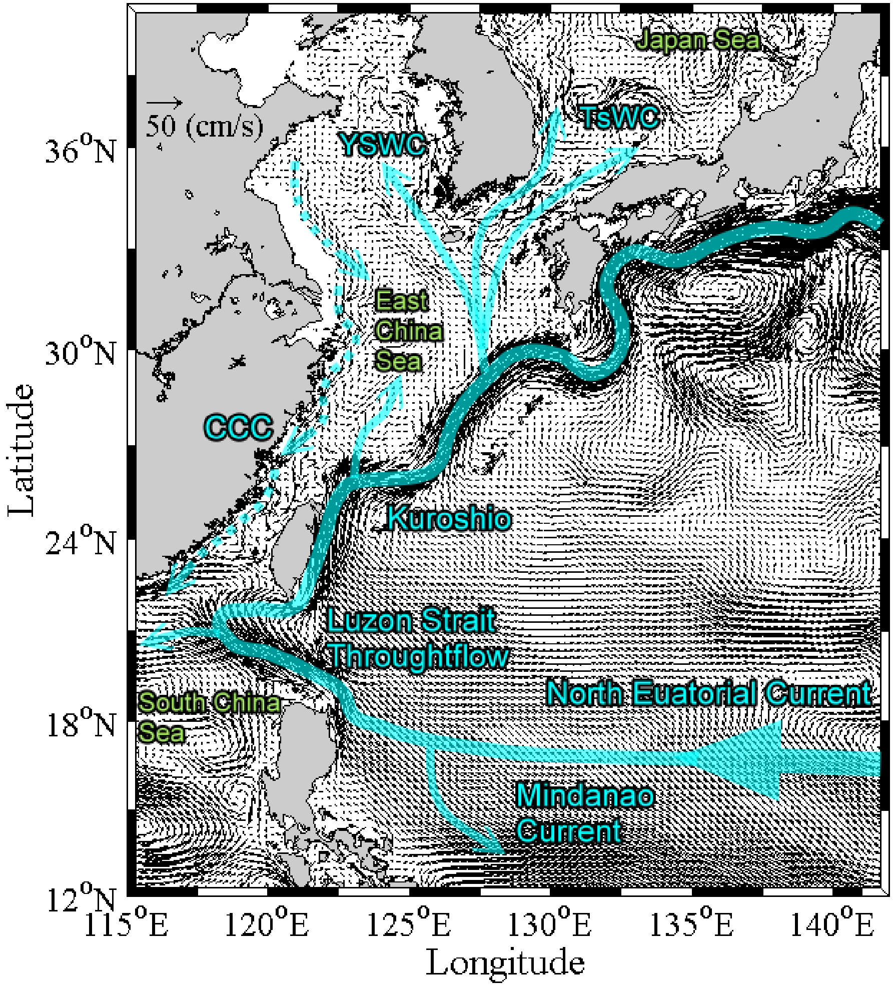




General seasonal circulation pattern-DUPOM

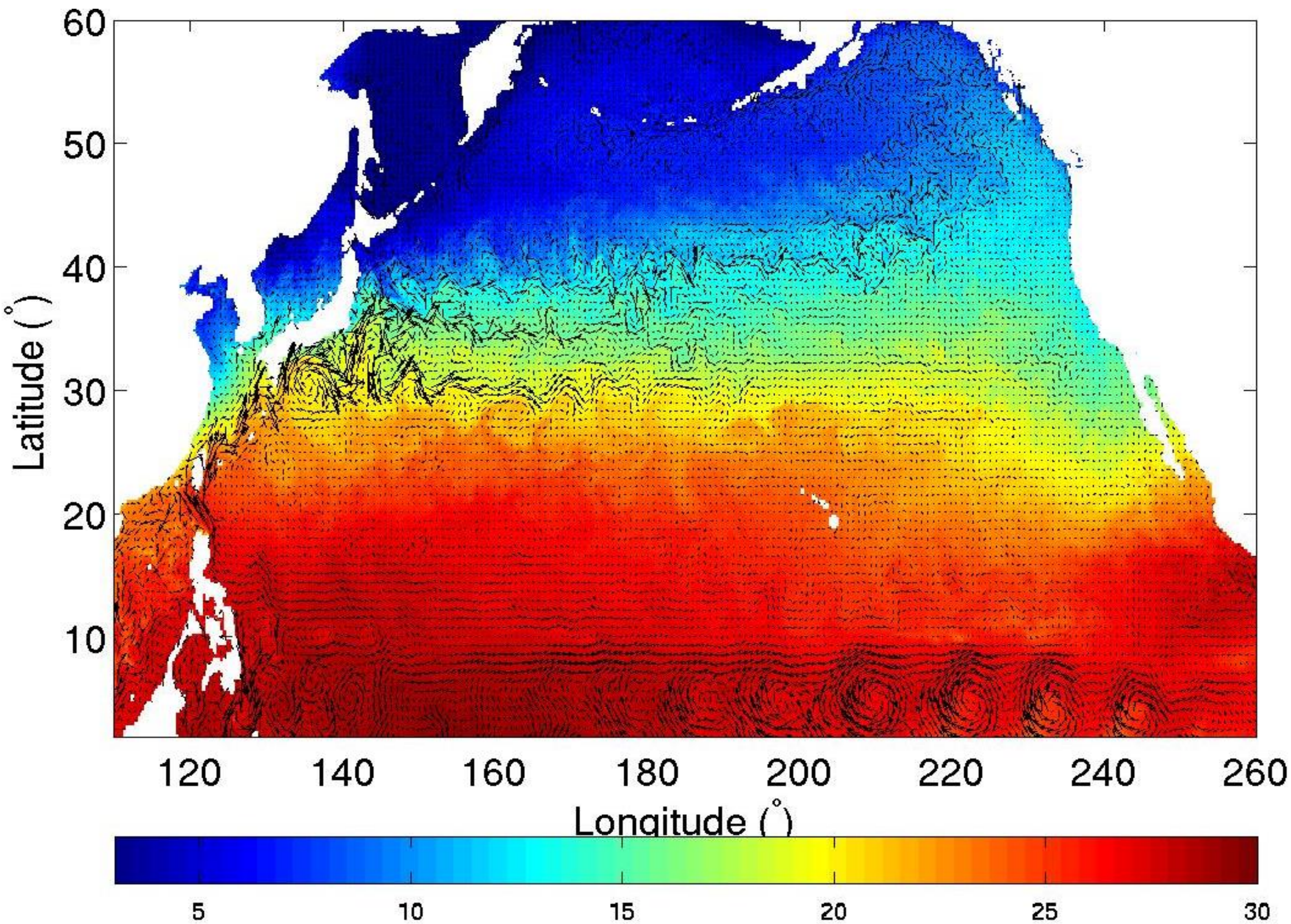


Summer



Winter

1/4° x 1/4° global resolution (domain 1442x720x26)



North Pacific temperature and velocity field (day 5, Year 49)

Governing Equations

λ: the longitudinal variable
ϕ: the latitudinal variable
z: the vertical variable

Continuity eqn. $$\frac{1}{R\cos\phi}\left(\frac{\partial u}{\partial\lambda}+\frac{\partial(v\cos\phi)}{\partial\phi}\right)+\frac{\partial\omega}{\partial z}=0$$

Momentum eqn.
$$\frac{\partial u}{\partial t}=-\mathcal{L}u+\left(f+\frac{u\tan\phi}{R}\right)v-\frac{1}{\rho_0 R\cos\phi}\frac{\partial p}{\partial\lambda}+D_m u+\frac{\partial}{\partial z}\left(A_u\frac{\partial u}{\partial z}\right)$$
$$\frac{\partial v}{\partial t}=-\mathcal{L}v-\left(f+\frac{u\tan\phi}{R}\right)u-\frac{1}{\rho_0 R}\frac{\partial p}{\partial\phi}+D_m v+\frac{\partial}{\partial z}\left(A_v\frac{\partial u}{\partial z}\right)$$

Conservation eqn. for temperature and salinity
$$\frac{\partial T}{\partial t}=-\mathcal{L}T+D_h T+\frac{\partial}{\partial z}\left(K_T\frac{\partial T}{\partial z}\right)$$

Eqn. of State
$$\rho=\rho(S,T,p)$$

Hydrostatic Eqn. $$\frac{\partial p}{\partial z}=-(\rho-\bar{\rho})g$$

$$D_{m(h)}=\frac{A_{m(h)}}{R^2}\left(\frac{1}{\cos^2\phi}\frac{\partial^2}{\partial\lambda^2}-\tan\phi\frac{\partial}{\partial\phi}+\frac{\partial^2}{\partial\phi^2}\right)\qquad \mathcal{L}=\frac{u}{R\cos\phi}\frac{\partial}{\partial\lambda}+\frac{v}{R}\frac{\partial}{\partial\phi}+\omega\frac{\partial}{\partial z}$$