A Multi-Layer Mixed-Layer Ocean Model

Coupled with GSFC fvGCM

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Code 913, NASA/GSFC, 2004

- A modular global multi-layer mixed-layer ocean (MLO) model was developed and coupled to the GSFC fvGCM. The core physics is based on Gaspar (JPO, 1998).

- The vertical and horizontal resolutions of the MLO model can be easily changed for different applications. Currently a 30-layer MLO has been coupled to the fvGCM 2x2.5L55. The MLO model extends down to 1000 meter, with varying layer thickness. If the ocean is shallower than 50 m, it is treated as a 50m slab ocean.

Input Required by MLO at Surface:

- Net downward Solar Radiation
- Net upward Longwave Radiation
- Sensible heat flux
- Latent heat flux
- precipitation
- Evaporation
- Wind stresses

Mixed-Layer Physics:

Three prognostics:

temperature, salinity, and mixed-layer depth

- Temperature is controlled by: surface heat fluxes, heat flux corrections, penetrating solar radiation, entrainment of water from ocean below mixed layer, convective adjustment, vertical diffusion.

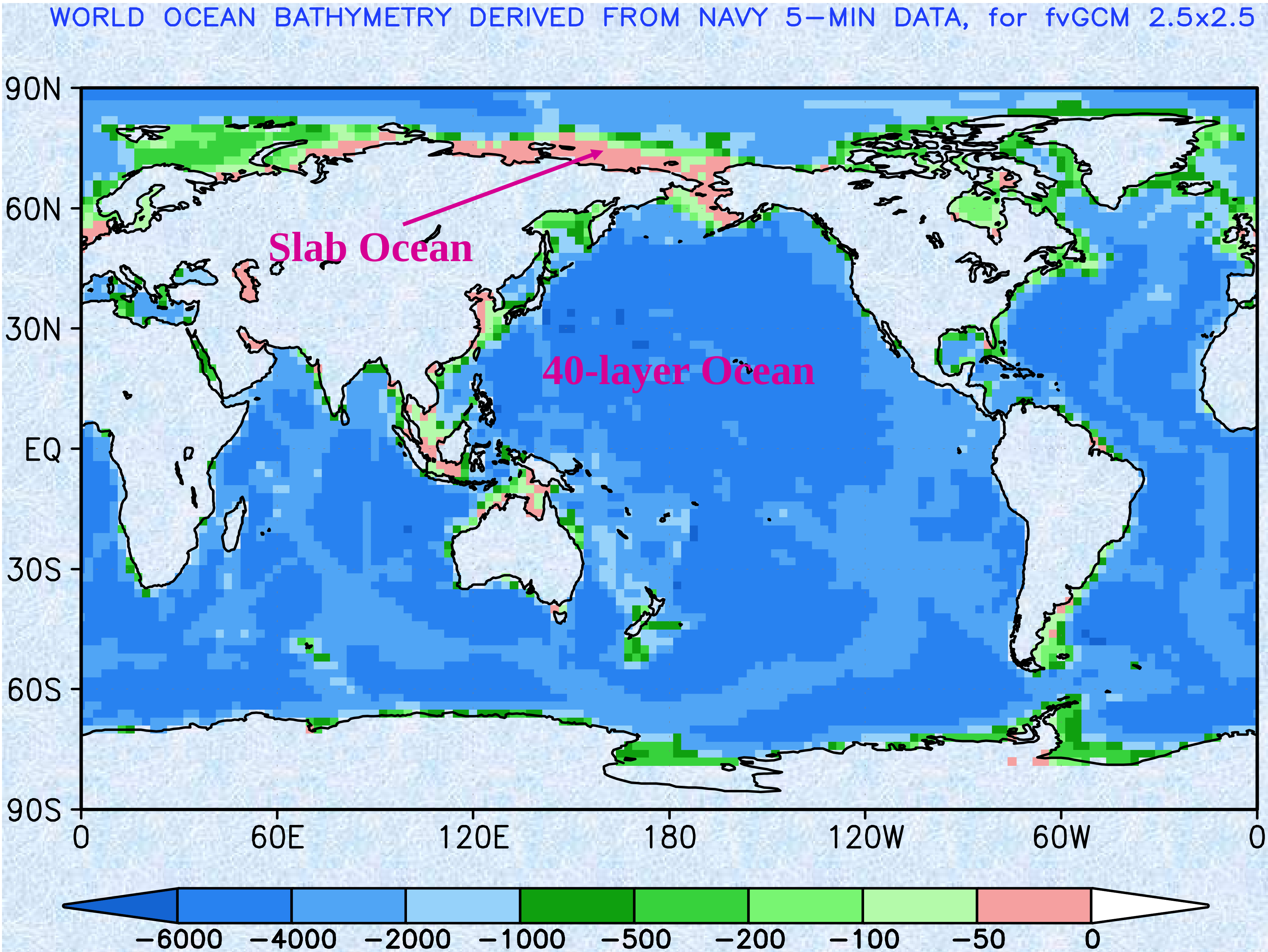
- Salinity is controlled by freshwater flux, water flux corrections, entrainment, convective adjustment, and vertical diffusion.

- Mixed-Layer Depth: by Niiler & Kraus (1977) closure, determined by wind stress, water/bouyancy flux, heat flux, turbulent dissipation rate, and turbulent kinetic energy.

Physics Below Mixed Layer

Vertical diffusion, convection adjustment, penetration of solar radiation

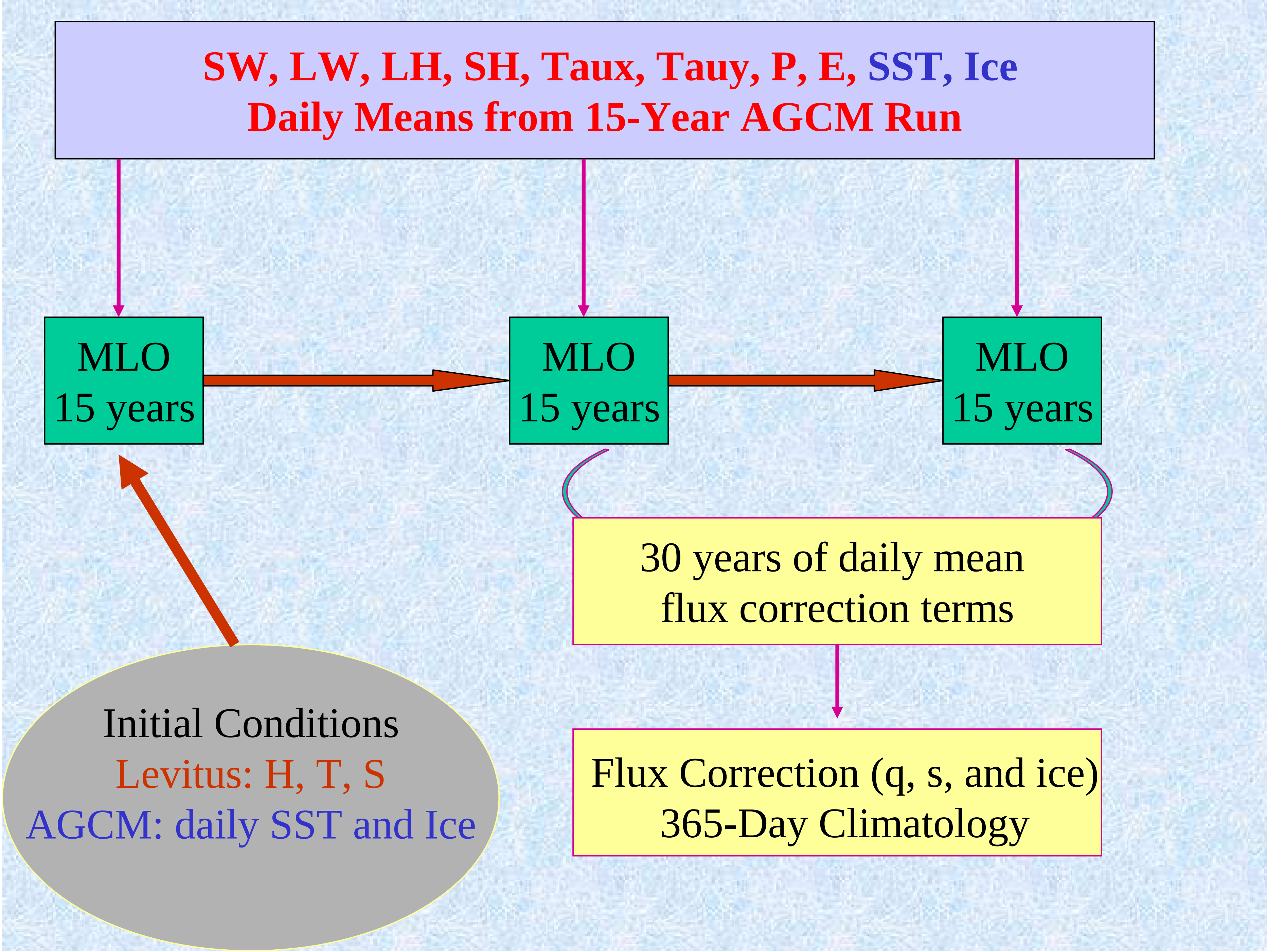
No horizontal and vertical advection. temperature and salinity are damped to observed climatology at a 10-year time scale.


WORLD OCEAN BATHYMETRY DERIVED FROM NAVY 5-MIN DATA, for fvGCM 2.5x2.5
Slab Ocean
40-layer Ocean
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
-6000
-4000
-2000
-1000
-500
-200
-100
-50
0

Flux Correction Calculation

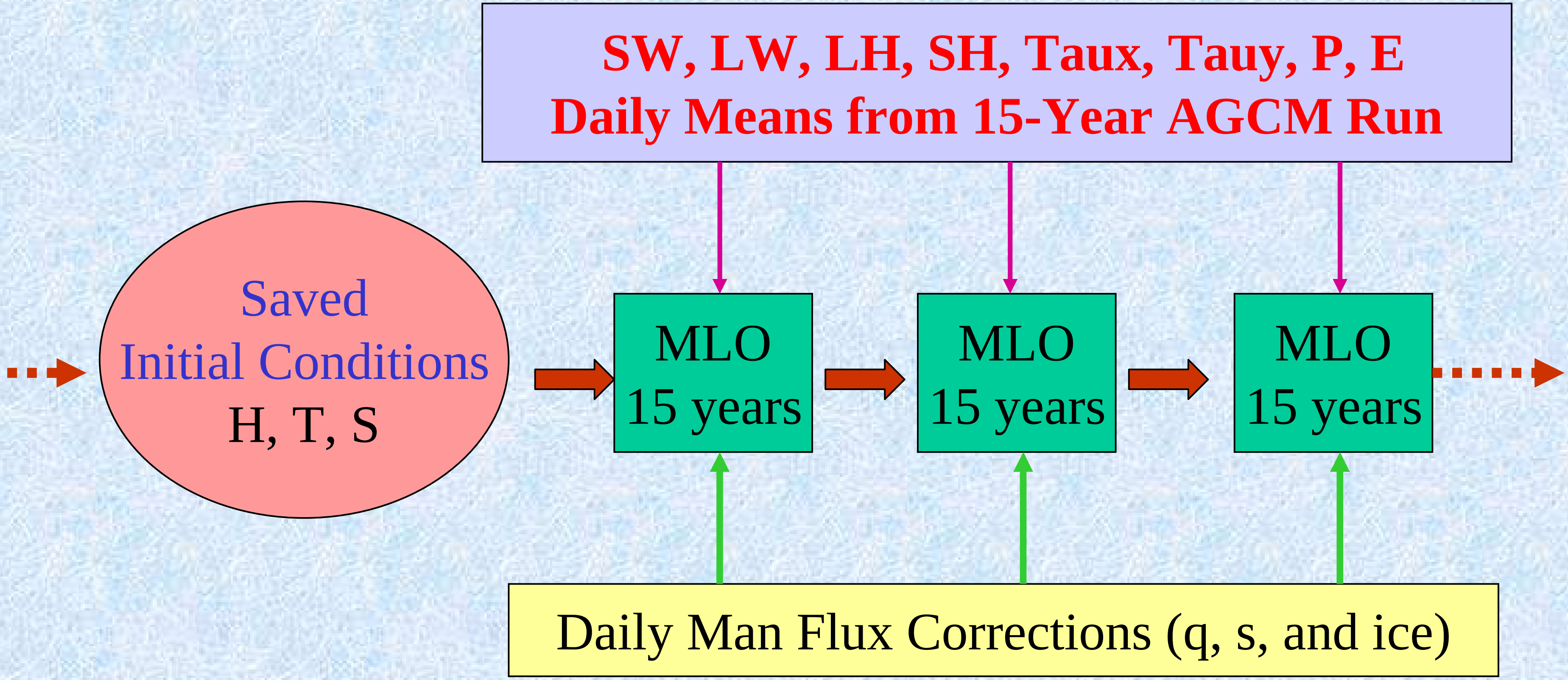
- Why: the MLO has no ocean dynamics. Flux correction terms (heat and salinity) are used to compensate dynamical transport and ERRORS in AGCM forcing data.

1. Daily mean fluxes saved from a 15-year simulation of the fvGCM b55 are used to force the MLO30.
2. For each time step (one day), MLO initial SST and ice fraction are set to the daily mean AGCM output; S1 are set to Levitus daily climatology.
3. At the end of each time step, T1, S1 and ice fraction are compared to their initial values to compute daily mean flux corrections of heat, salinity and ice fraction.


SW, LW, LH, SH, Taux, Tauy, P, E, SST, Ice
Daily Means from 15-Year AGCM Run
MLO
15 years
MLO
15 years
MLO
15 years
30 years of daily mean
flux correction terms
Initial Conditions
Levitus: H, T, S
AGCM: daily SST and Ice
Flux Correction (q, s, and ice)
365-Day Climatology

MLO Offline Simulation --"Hindcast"

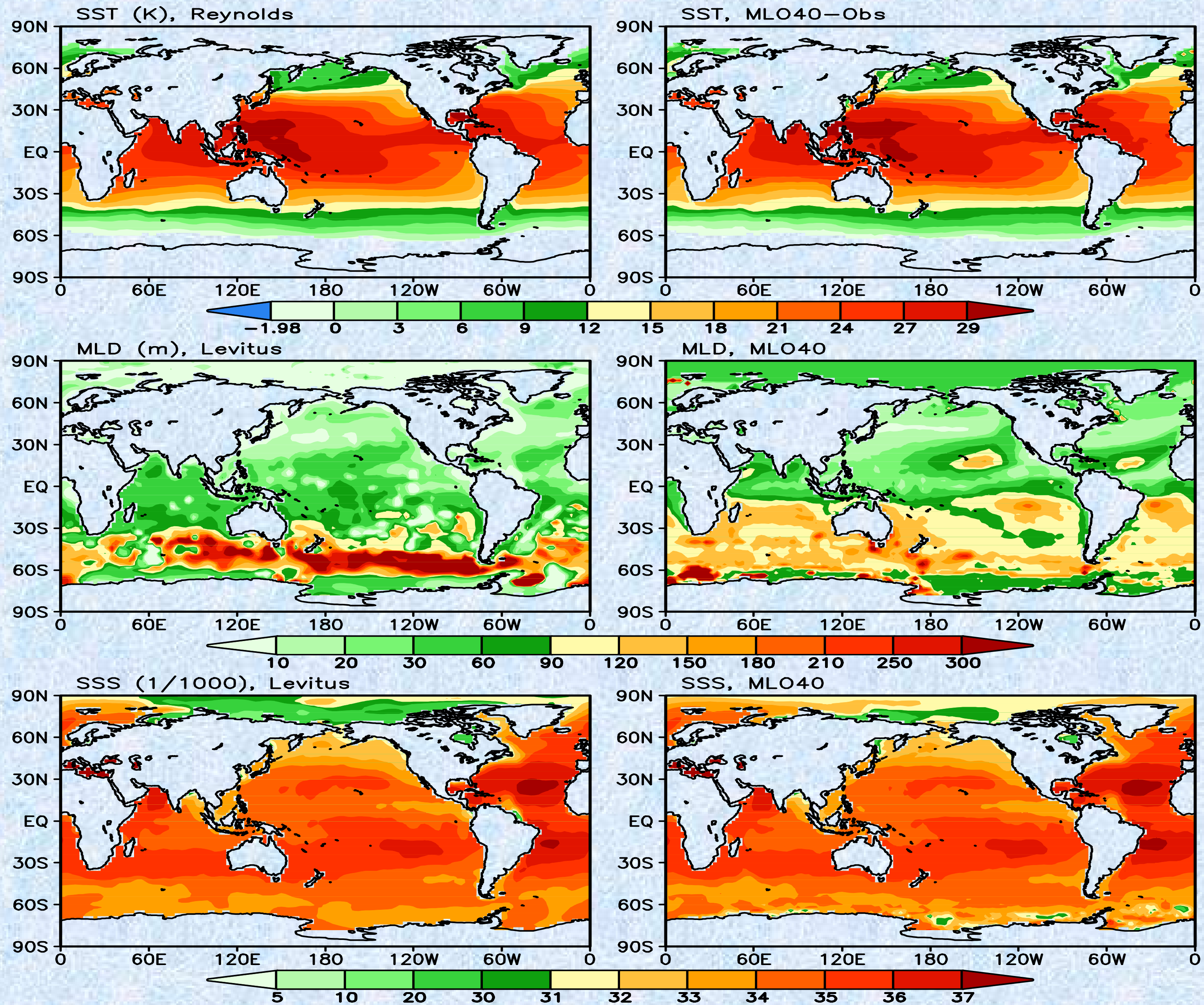
Now: SST and SSS are predicted without insertion of observation



Results From MLO40 Offline/Hindcast Run

30-Year Simulation Forced by fvGCM Fluxes

Observations Simulations July



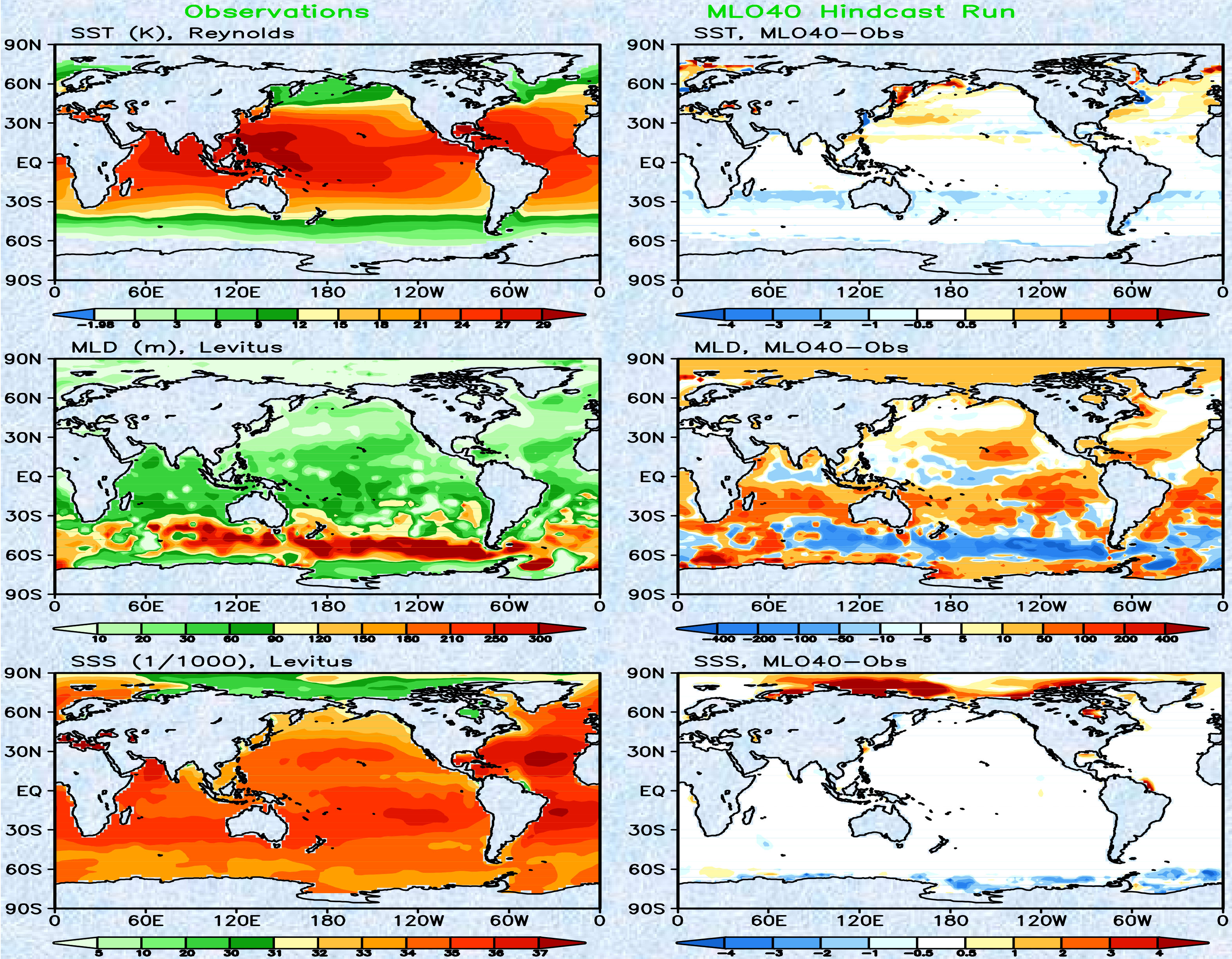
SST

MLD

SSS

July

Obs | MLO40 - Obs

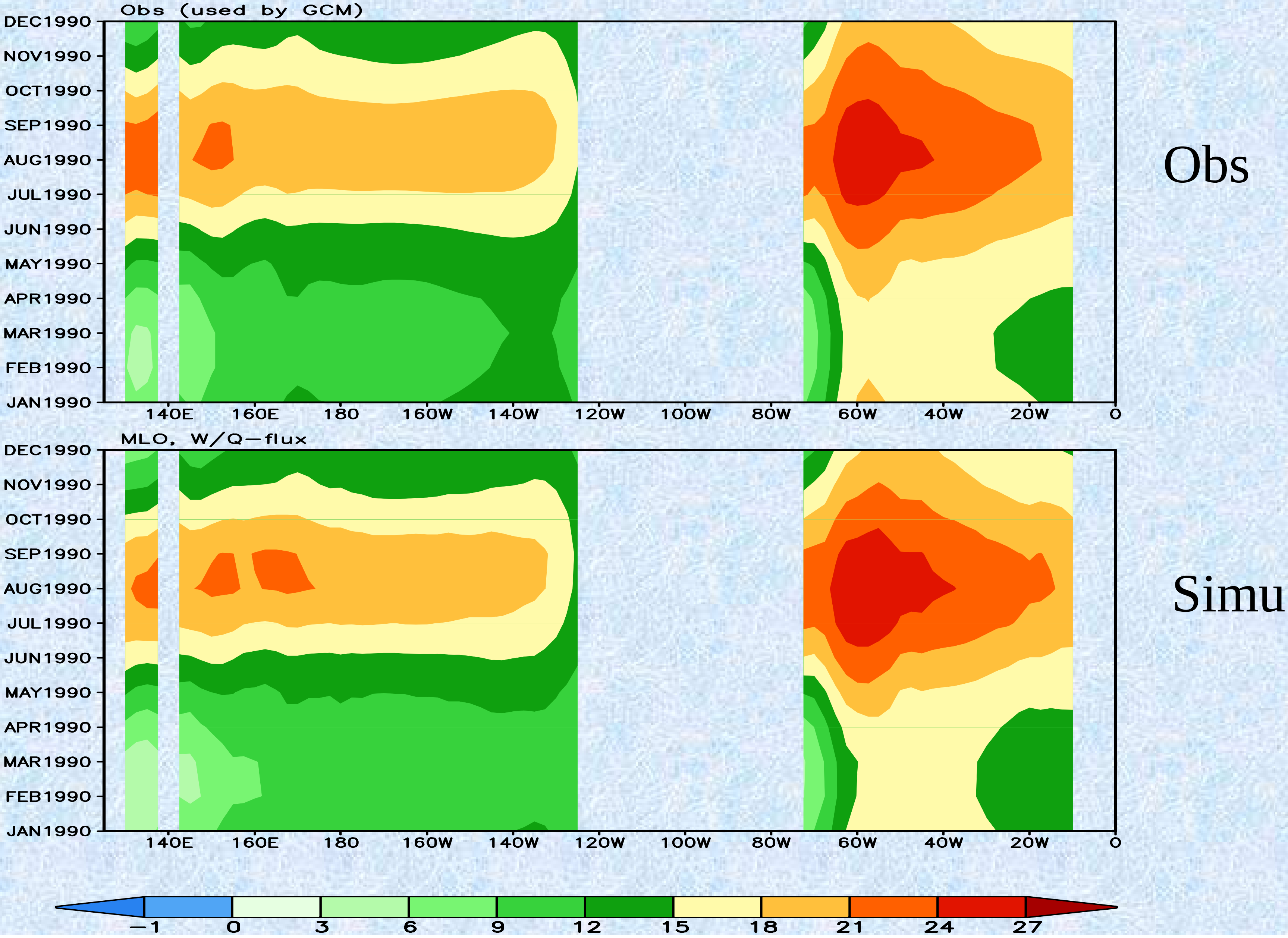


SST

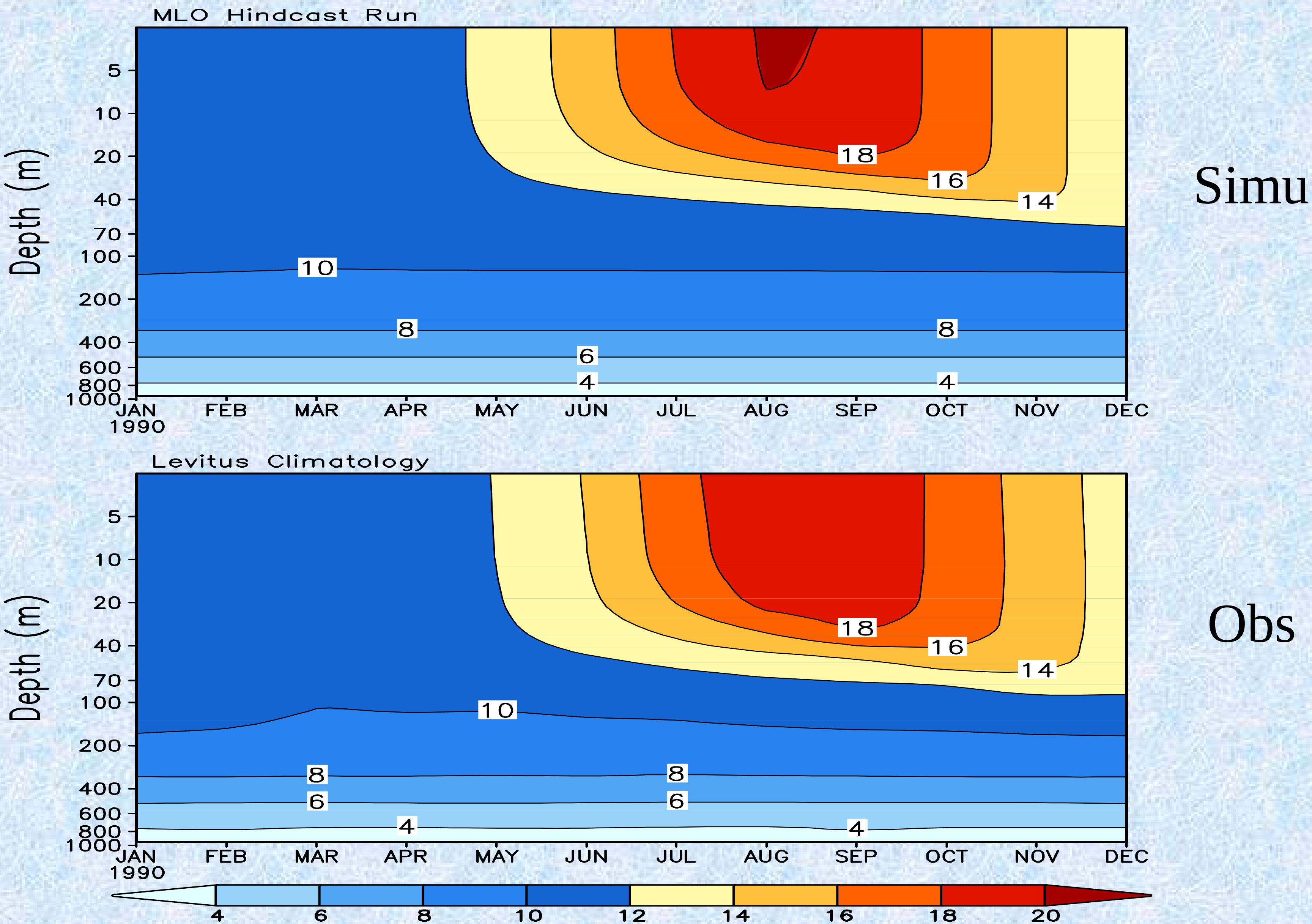
MLD

SSS

Annual Cycle of SST at 40N



Mean Ocean Temperature over (150E-150W, 30N-50N)



MLO Comparison

We shall call the aforementioned GSFC MLO as "New MLO". It will be compared to a 31-layer MLO model developed by Michael Alexander at CDC/NOAA.

Both the “Alexander MLO” and the “New MLO” are based on the theoretical framework of Gaspar [1988]. The major differences between the two lie in the numerical methods used to compute mixed-layer retreat, vertical diffusion, convective adjustment, and the treatment of energy conservation when the mixed layer deepens or shoals.

$$A_p = C_{p3}(h)u_*^3 - C_{p1}(h)hB(h) = 0$$

1. Mixed-Layer Retreat

   According to Gaspar [1988], when mixed-layer entrainment velocity is negative, mixed layer retreats. New mixed-layer depth is determined by solving the above equation, which is a very complex function, including products of exponential and integral terms of h.

Alexander MLO uses *Newton-Raphson* method to obtain new h. It needs to compute d(*Ap*)/d(*h*) for many times to obtain the solution. Furthermore, to use Newton-Ralphson *Ap* must be a smooth function. This condition is not always satisfied.

New MLO uses an alternate approach, the so-called *stepwise-truncation* method, to solve the equation without computing d(*Ap*)/d(*h*) . It is faster and more accurate.

$$ {dT_k}/{dt} = \nu \, {\partial^2 T}/{\partial z^2} $$

2. Vertical Diffusion of Temperature and Salinity

Alexander MLO uses Crank-Nicholson method with non-uniform vertical grid. The entire mixed layer is treated as one layer.

New MLO uses classical implicit finite difference, together with inverse substitution to solve the tri-diagonal matrix. The variable is first projected onto uniform vertical gird, then integrated back to non-uniform gird after diffusion computation. The mixed layer is divided into many layers during calculation to avoid sharp jumps at the bottom of the mixed layer.

3. Convective Adjustment

For New MLO, more straightforward code was developed to compute temperature and salinity adjustments when the stratification is unstable.

4. Misc

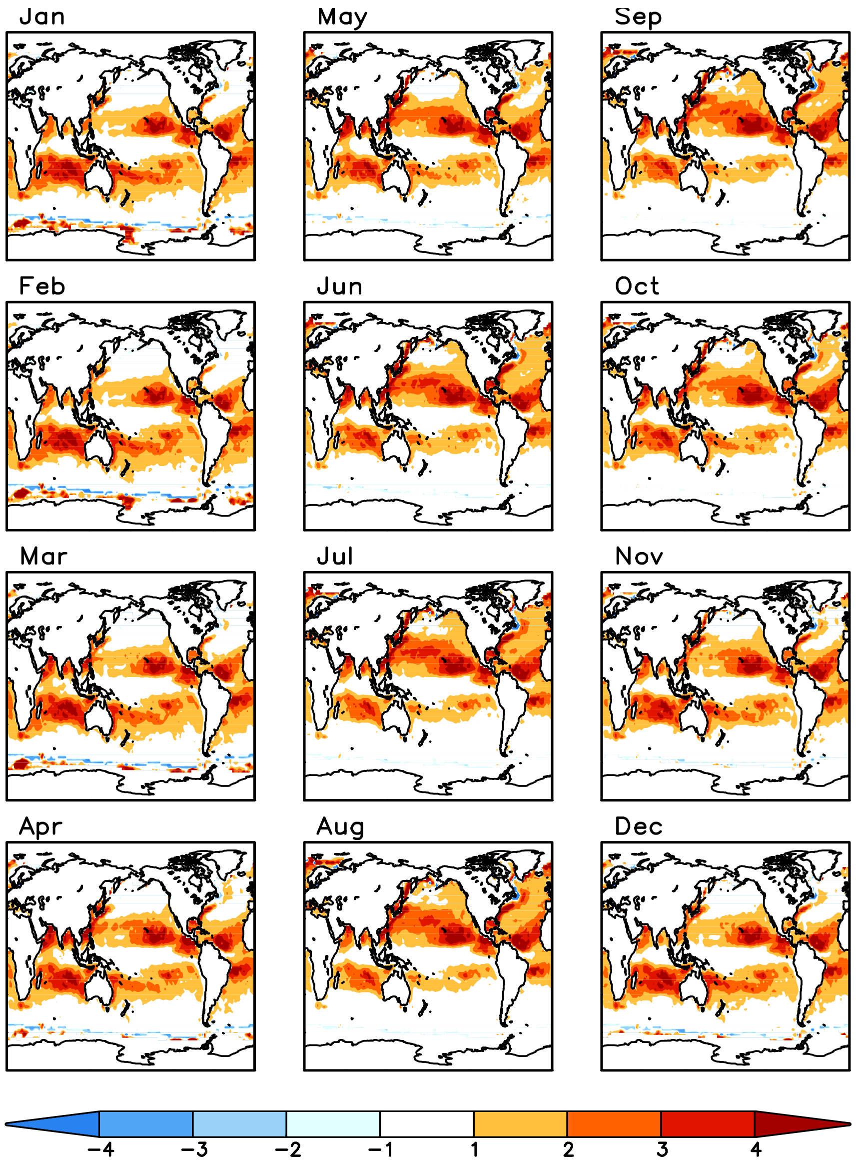
- The New MLO has 30 layers with slightly different vertical structure from the Alexander 31-layer MLO;
- The New MLO uses Fortran 90 standard with dynamical arrays and online documentation;
- When mixed layer deepens or retreats, new mixed-layer temperature and salinity are computed with mass weighting;
- The model is computationally efficient, and easy to be coupled to any AGCM for its modular structure

Offline Hind-cast Comparison between Alexander MLO and New MLO

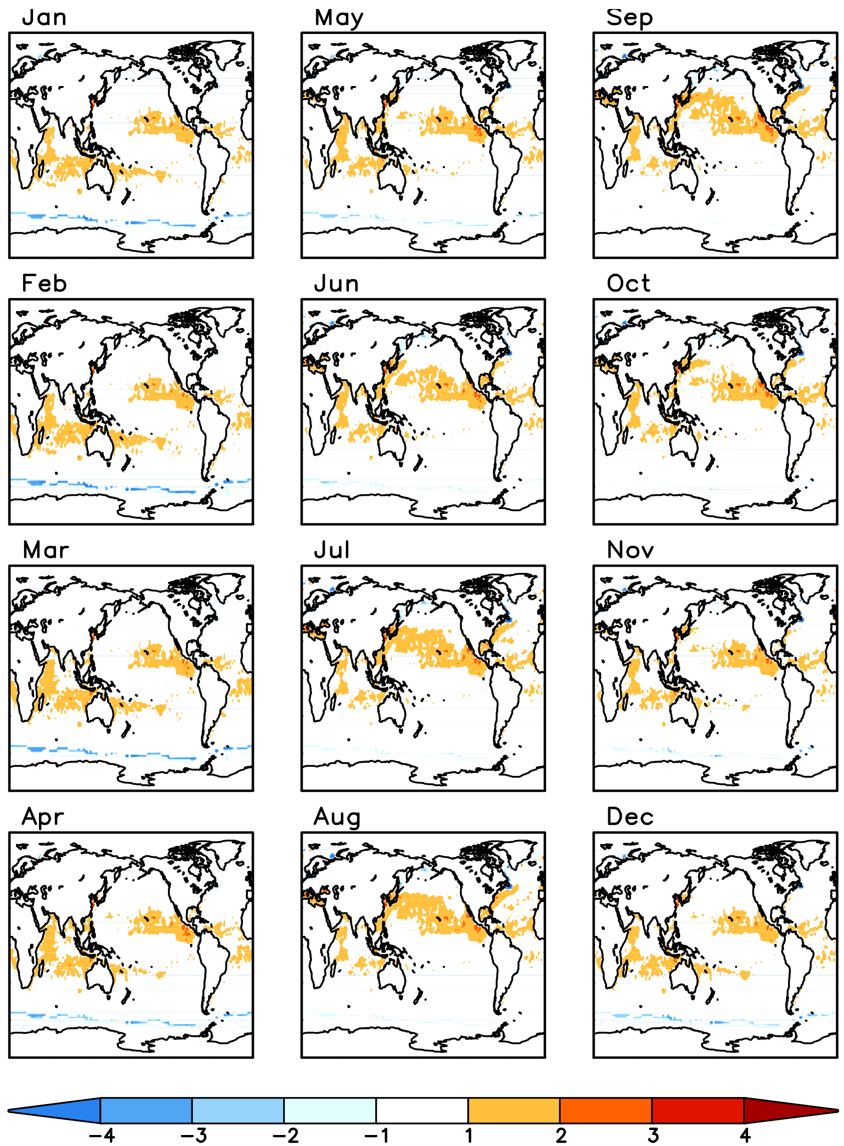
- The two MLO models are trained by surface fluxes from the fvGCM (30 years) and NSIPP GCM (40 years) forced by climatological SSTs. Heat and salt flux corrections were derived for each MLO model to represent dynamical advections.

- Offline hind-casts were performed forced by 30-yr fvGCM and 40-yr NSIPP GCM fluxes and flux corrections. We compare here results from the two MLO models.

Offline Hindcast, fvGCM, Monthly Mean SST Bias

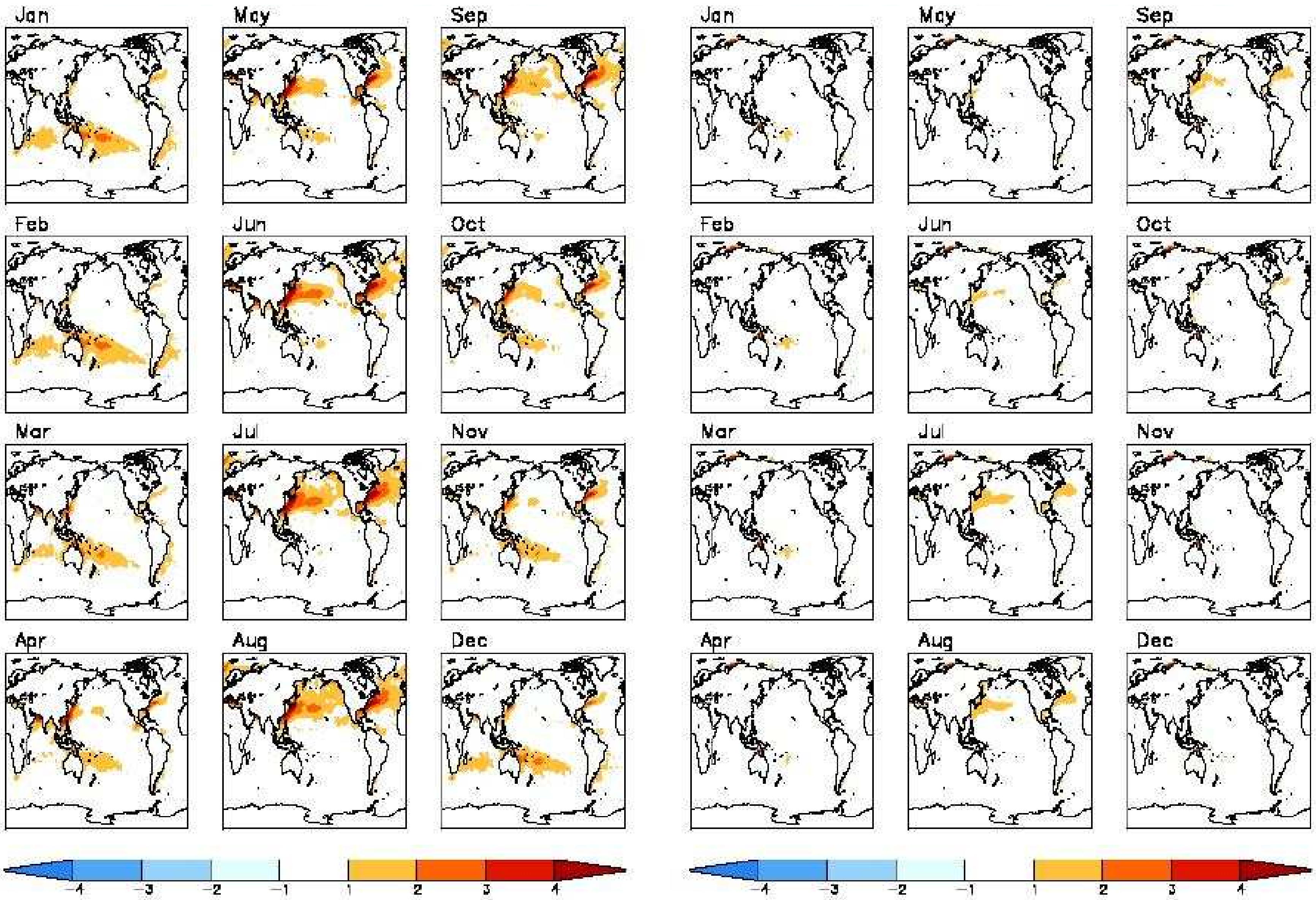


Alexander MLO



New MLO

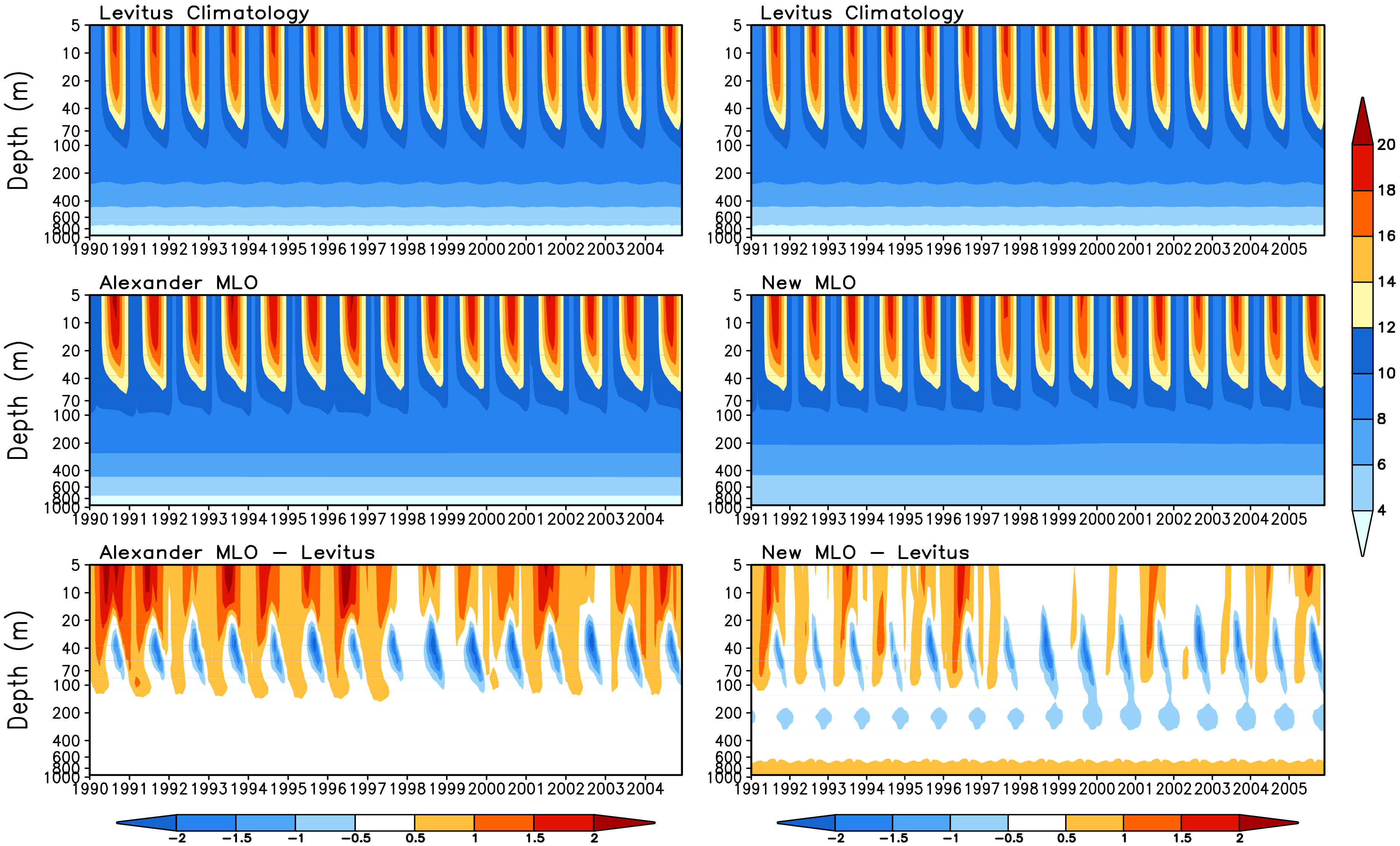
Offline Hindcast, NSIPP GCM, Monthly Mean SST Bias



Alexander MLO

New MLO

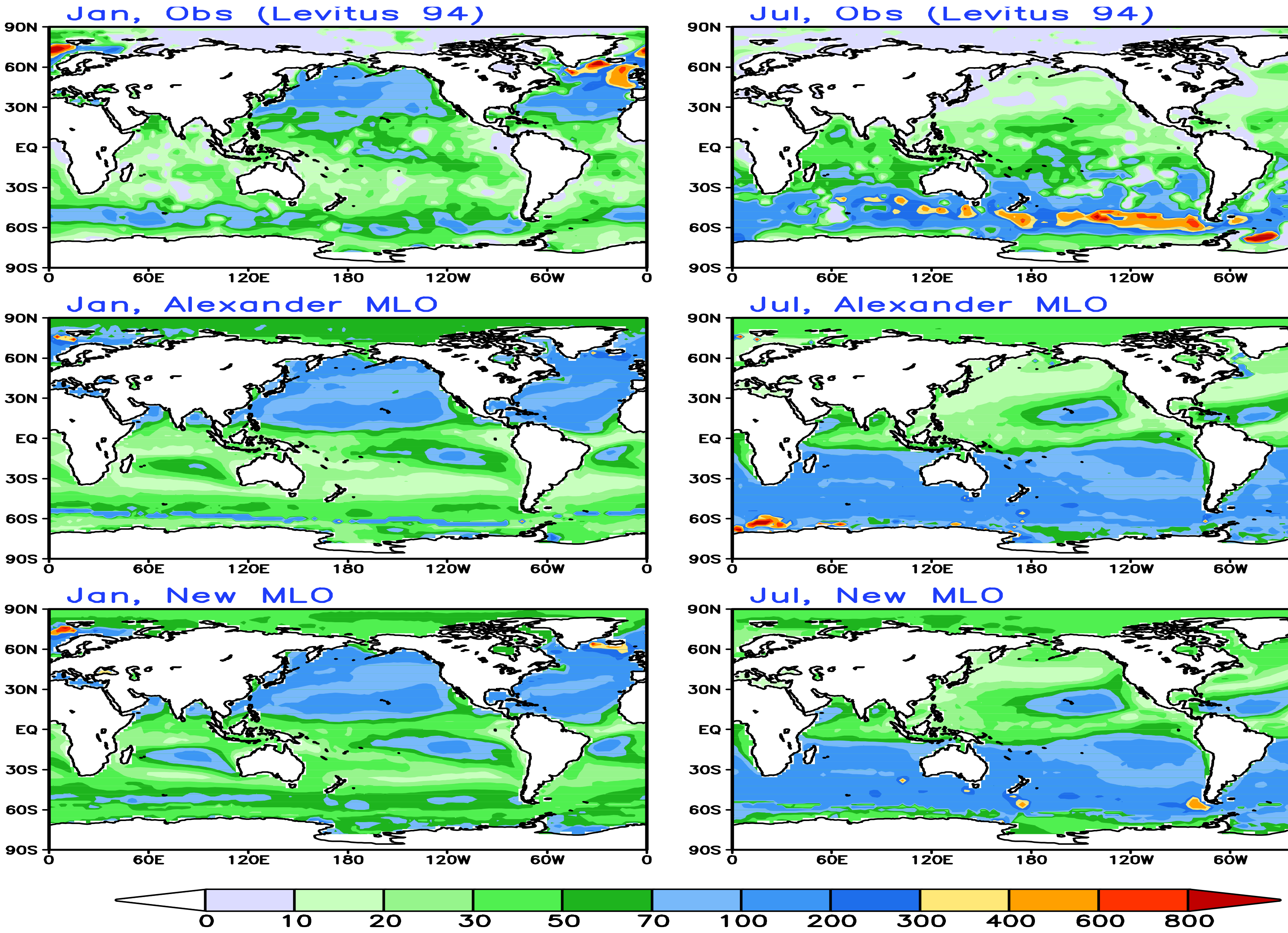
Offline Hindcast, fvGCM
North Pacific SSTs [30N-55N, 150E-150W]



Alexander MLO

New MLO

Offline Hindcast, fvGCM, Mixed-Layer Depth



Users of the GSFC MLO

- Fanglin Yang and K.-M. Lau at GSFC, coupled to fvGCM/McRAS to study aerosol forcing on climate.
- Hailan Wang and K.-M. Lau at GSFC, coupled to NSIPP1 GCM to study mid-latitude air-sea interaction.
- David DeWitt at IRI Columbia University, applied for ENSO forecast.