Baroclinic Sea Surface Height for HYCOM

Following "Clarifying the Distinction Between Steric and Baroclinic Sea Surface Height" (Zaron and Ray, in preparation), which suggests using the depth average pressure as an approximation to barotropic pressure, the archv2data2d (archv2ncdf2d) utility in HYCOM-tools defines baroclinc SSH, η^b, and non-baroclinc SSH, η^{nb}, from a HYCOM 3-D archive file, as:

$$
\begin{aligned}
\eta^{nb} &= \eta - \eta^b \\
\eta^b &= \overline{\eta} + (h^d - \overline{h^d}) \\
h^d &= -\frac{1}{\eta + D} \int_{-D}^{\eta} \frac{\rho(z) - \rho_0}{\rho} z dz
\end{aligned}
$$

where

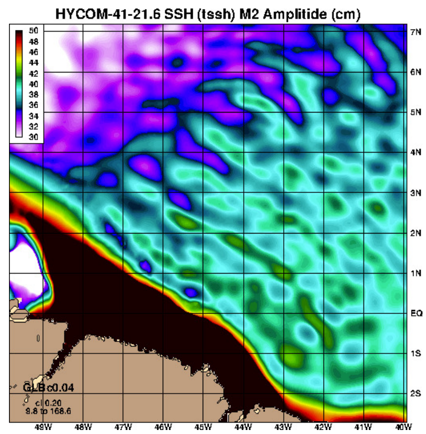
$$
\begin{aligned}
\eta &= \text{sea surface height (SSH)} \\
\eta^b &= \text{baroclinic SSH} \\
h^d &= \text{depth average pressure sea level} \\
\overline{h^d} &= \text{longterm mean depth average pressure sea level} \\
\overline{\eta} &= \text{longterm mean SSH} \\
D &= \text{rest depth} \\
\rho_0 &= \text{constant reference density} \\
\rho &= \text{depth averaged density} \\
\rho(z) &= \text{density at depth z}
\end{aligned}
$$

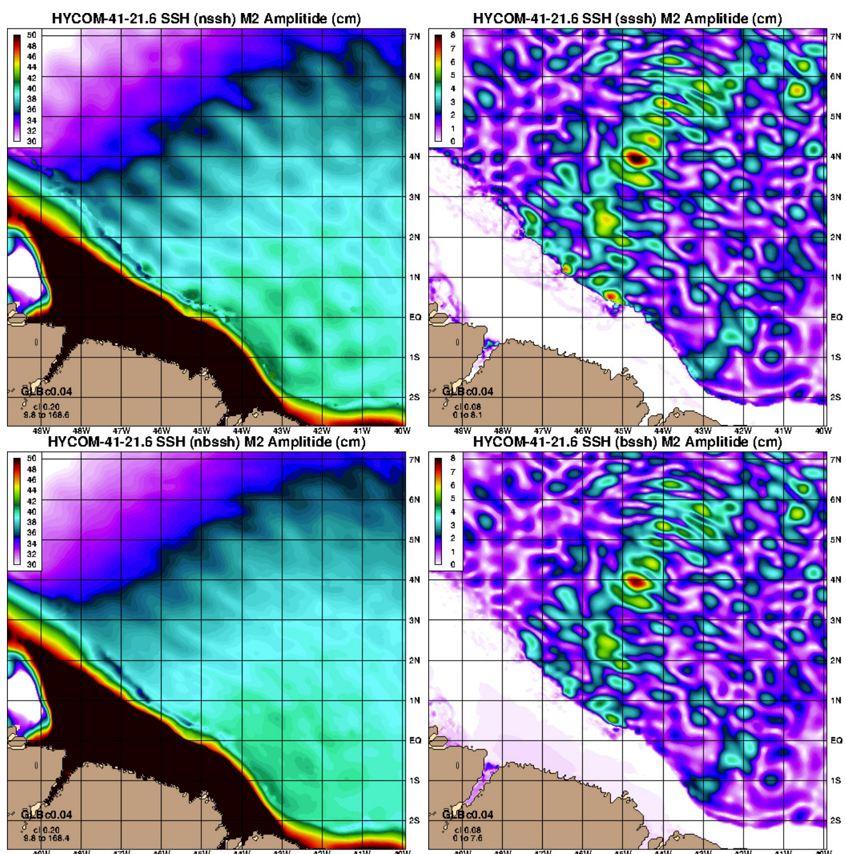
The value of ρ_0 does not matter, because it cancels in $(h^d - \overline{h^d})$. It is included because $\rho - \rho_0$ is much smaller than ρ and this improves numerical accuracy. The depth averaged density, ρ, is used in the denominator in place of ρ_0 from (Zaron and Ray) because HYCOM is not Boussinesq and because otherwise the choice of ρ_0 would change the result slightly. The longterm mean values are typically taken from a multi-year mean 3-D archive, which will have any tides averaged out, and we assume its SSH is entirely baroclinic.

The depth average pressure sea level, h^d, is based on the depth average pressure and so allows for the fact that steric changes in height are partially compensated by changes in bottom pressure. An effect that is typically between 10% and 30% of the total for features like the SSH signal from internal tides.

The limitation of archv2data2d is that it requires a 3-D archive and these are not usually written out hourly, so generating baroclinic SSH from existing cases with tides will be sub-optimal. For a 51 GB 9000 x 7055 x 41 GLBc0.08 archive file, the serial archv2data2d utility requires about 90 GB of memory and takes 230 seconds on an AMD 7H12 Rome processor and the MPI version takes 36 (56) seconds on 32 (8) cores with almost all the wall time spent reading the archive file.

As a test, hourly steric and baroclinic SSH fields where calculated for 3 days from GOFS 3.5 (0.04 degree global with tides and data assimilation). The figure below shows the M2 tidal amplitude near the Amazon from a 3-day Foreman tidal analysis for Total, Non-steric, Steric, Non-Barotropic and Barotropic SSH (tssh, nssh, sssh, nbssh, and bssh). Note that the internal tide has a maximum of 8.1 cm (Steric SSH) or 7.6 cm (Barotropoic SSH), and the external M2 tide is much larger. The split between the external and internal tides is cleaner for the Barotropic SSH. although there appears to still be some internal tide signal in non-Barotropic SSH.





To illustrate that Baroclinic SSH snapshots are similar to Steric SSH, the figure below shows Total, Non-steric, Steric, Non-Barotropic and Barotropic SSH snapshots near the Amazon at 12Z on January 2nd 2020 from GOFS 3.5. Note that the color bar extent is always 50 cm, but the mid-points are not all the same. There is a hint of internal tide leakage into the Non-Baroclinic SSH, but this is more pronounced for the Non-Steric SSH.