A First Evaluation of Aquarius Sea Surface Density

Julian J Schanze
Earth & Space Research, Seattle, WA

10th Aquarius/SAC-D Science Meeting
Buenos Aires, Argentina
Outline

- Density and Spice in TEOS-10
- Density from Aquarius
  - The Thermal Component of Density
  - The Haline Component of Density
- Applications of Sea Surface Density (and Spice)
- Going Forward
- Conclusions
Part 1: Aquarius, TEOS-10, Density and Spice
Density: \( \rho = \rho_0 \cdot (1 + \beta \cdot \text{SSS} - \alpha \cdot \text{SST}) \)

Spiciness: \( \tau = \tau_0 \cdot (1 + \beta \cdot \text{SSS} + \alpha \cdot \text{SST}) \)
Alpha (Thermal Coefficient, TEOS-10)

Using Aquarius V 4.0 Salinity and Auxiliary Temperature

Note that the range of alpha is much bigger than beta
Beta (Haline Coefficient, TEOS-10)

V4 data, Note that the range of beta is much smaller than alpha
Implications for density/spice retrievals at high latitudes!
Sea Surface Density (Aq 4.0, TEOS-10)

\[ \rho = \rho_0 \times (1 + \beta \cdot SSS - \alpha \cdot SST) \]
Spiciness (now in TEOS-10 as of V3.05)

Warm/salty water is ‘spicier’ than cold/fresh water

\[ \tau = \tau_0 \times (1 + \beta \cdot SSS + \alpha \cdot SST) \]
Part 2: An Evaluation of Aquarius Density
Decomposing density into its thermal and haline components

Relative to a reference of $S_A=35$ g/kg and $\Theta=15^\circ$C (~standard seawater*)

Highlighting the contribution of Aquarius, and hence the advancement of the field through satellite SSS.

Water mass formation/transformation


*Standard Sea Water (SSW) is actually defined as $S=35$ (PSS78) and $T=15^\circ$C.
Aquarius Density (TEOS-10)

Aug 2011

Amazon, Western Boundary Currents, ITCZ/Panama
Aquarius Density (Thermal Component)

Aug 2011

Seasonal Cycle, Western Boundary Currents
Aquarius Density (Haline Component)

River outflows, ITCZ, Monsoon, High latitudes (!)
Aquarius-Argo Density

Aug 2011

Amazon, Western Boundary Currents, ITCZ/Panama
This is what Aquarius sea surface density brings to the table.
Part 3: Applications of Aquarius Density (and Spice)
Water mass formation

At low temperatures (high latitudes) alpha approaches zero (‘low thermal effect on density’)

While Aquarius has relatively low sensitivity at high latitudes, $\beta \cdot \text{SSS}$ effect dominates $\alpha \cdot \text{SST}$.

Clearly suited to study some mode water formation processes, e.g: Sub-Polar Mode Water (Talley, 1982)

Other intermediate water mass formation processes

Constraining the ocean interior through surface processes (‘power integrals’)…
Power Integrals (Stern 1965, 1969, 1975)

Assume the ocean is in steady state and stationary (mass conservation, heat conservation, salt conservation), then:

\[
\frac{1}{\rho_0 C_p} \iint_A (F_\theta) \, dA = 0
\]

\[
\frac{1}{\rho_F} \iint_A (F_S) \, dA = 0
\]

where

\[
F_\theta = -\bar{\rho_0 c_p w' \theta'} = Q_{net}
\]

\[
F_S = \bar{\rho_F S_0 (E - P - R)}
\]
Simplifying a conservation equation and using the divergence theorem (as Joyce (1980) for temperature):

\[
\frac{1}{\rho_0 C_p} \iiint_A (\theta F_\theta) dA = - \iiint_V \nabla \bar{\theta} \cdot \mathbf{u'} \cdot \theta' dV = \frac{1}{2} \iiint_V \chi_\theta dV
\]

where \( \chi_\theta = 2 \kappa_\theta \nabla^2 \theta' \)

Down-gradient flux of properties due to stirring/mixing

Same for salinity, density, spice

Splitting all gradients into isopycnal (i) and diapycnal (d)…
I

Power Integrals

- Isopycnal gradients cancel in the density equation

\[
\frac{1}{2} \iiint_V \chi_\rho dV = - \iint_A \left[ (\alpha \bar{\theta} - \beta \bar{S}) (\alpha \bar{w'} \bar{\theta'} - \beta \bar{w'} \bar{S'}) \right] dA \\
= - \iiint_V \left[ (\alpha \nabla \bar{d} \bar{\theta} - \beta \nabla \bar{d} \bar{S}) \cdot (\alpha \bar{w'} \bar{d} \bar{\theta'} - \beta \bar{w'} \bar{d} \bar{S'}) \right] dV
\]

- Diapycnal gradients cancel in the spice equation

\[
\frac{1}{2} \iiint_V \chi_\tau dV = - \iint_A \left[ (\alpha \bar{\theta} + \beta \bar{S}) (\alpha \bar{w'} \bar{\theta'} + \beta \bar{w'} \bar{S'}) \right] dA \\
= - \iiint_V \left[ (\alpha \nabla \bar{d} \bar{\theta} + \beta \nabla \bar{d} \bar{S}) \cdot (\alpha \bar{w'} \bar{d} \bar{\theta'} + \beta \bar{w'} \bar{d} \bar{S'}) \right] dV
\]
Density equation relates surface forcing to diapycnal dissipation

Spice equation relates surface forcing to isopycnal dissipation

This means we can estimate the relative magnitude of isopycnal to diapycnal dissipation (~mixing) in the ocean.
Density Variance Production

Aquarius SSS, OISST, OAFlux E and Qnet, GPCP P
Density/Diapycnal Dissipation Estimates

- Scale height \( H = 600 \text{m} \).
- Units are \((\text{kg m}^{-3})^2 \text{s}^{-1}\), same as spice
- Range of results from \(3 - 11 \times 10^{-9} \ (\text{kg m}^{-3})^2 \text{s}^{-1}\)

Note: Color bars are different \( Q_{\text{net}} \) datasets, Black range is E-P
Spice/Isopycnal Dissipation Estimates

- Units are \((\text{kg m}^{-3})^2 \text{s}^{-1}\) same as density
- Range of results \(5-11 \times 10^{-9}\) \((\text{kg m}^{-3})^2 \text{s}^{-1}\)
- Close to equipartition

Note: Color bars are different \(Q_{\text{net}}\) datasets, Black range is E-P
From Monthly to Daily

- OISST daily and OAFlux v3 for $Q_{\text{net}}$ (2008-2009) for thermal component
- Aquarius V4 Weekly (interpolated to daily) and GPCP Daily v1.2 for haline component (2012-2013)

- Using daily data, $X_{\rho}$ (diapycnal) increases by 10% $X_{\tau}$ (isopycnal) increases by 3% compared to monthly data.

- Implications:
  - Space scales
  - Local vs global
  - Covariance!
Density dissipation estimate is $\sim 6 \times 10^{-9} \text{ (kg m}^{-3})^2 \text{ s}^{-1}$

Spice dissipation estimate is $\sim 7 \times 10^{-9} \text{ (kg m}^{-3})^2 \text{ s}^{-1}$

Suggests approximate equipartition between isopycnal and diapycnal mixing, could be a useful constraint in models

Horizontal scales are much larger than vertical scales

Use of daily data suggests greater importance of local diapycnal dissipation
Part 4: Conclusions and The Future
Conclusions

- Operational sea surface density (and soon spiciness in V5) products from Aquarius and SMOS.

- Significant temporal and spatial improvements over Argo

- Implications for water mass formation and transformation

- By combining surface fluxes with surface parameters, we can diagnose interior ocean processes (Schanze, 2013, Schanze & Schmitt, 2015, ongoing research)
The Future

- V4 currently provides TEOS-10 density from Aquarius

- V5 is planned to provide Spiciness as well (now part of TEOS-10 since version 3.05)

- Continuity of measurements using SMOS/SMAP

- Assimilation into Ocean State Estimates?

Thank You!

Questions?