Julian J Schanze

Earth & Space Research, Seattle, WA

A First Evaluation of Aquarius Sea Surface Density

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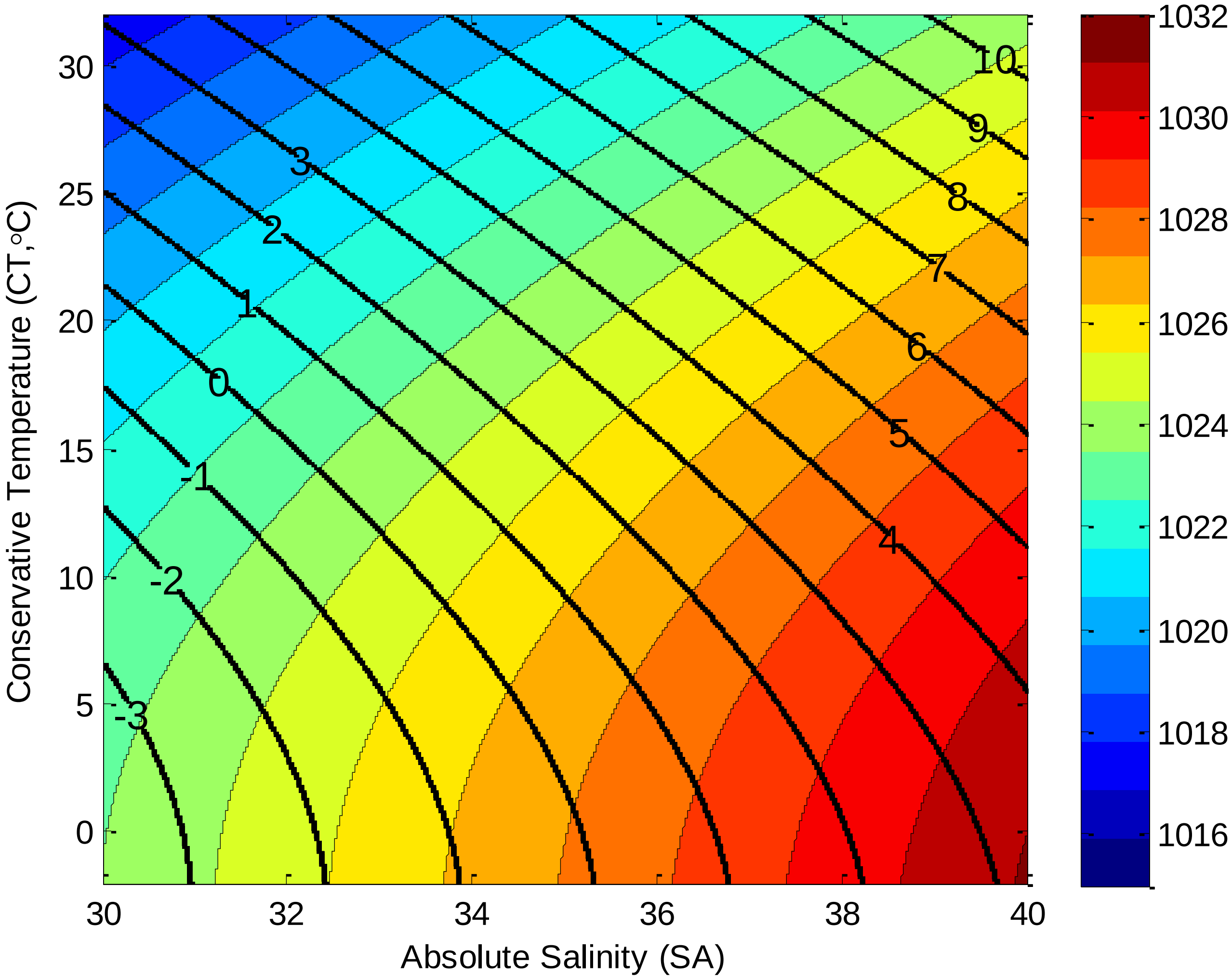
Outline

- 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

Equation of State – TEOS10



- Density: Cold/Salty (+) haline - thermal
- Spiciness: hot/salty (+) haline + thermal
- Components α and β:

$$\alpha = -\frac{1}{\rho_0} \cdot \frac{\partial \rho}{\partial \theta}\bigg|_{S,p}$$

$$\beta = \frac{1}{\rho_0} \cdot \frac{\partial \rho}{\partial S}\bigg|_{\theta,p}$$

Density: $\rho = \rho_0 \cdot (1 + \beta \cdot SSS - \alpha \cdot SST)$ Spice: $\tau = \tau_0 \cdot (1 + \beta \cdot SSS + \alpha \cdot SST)$

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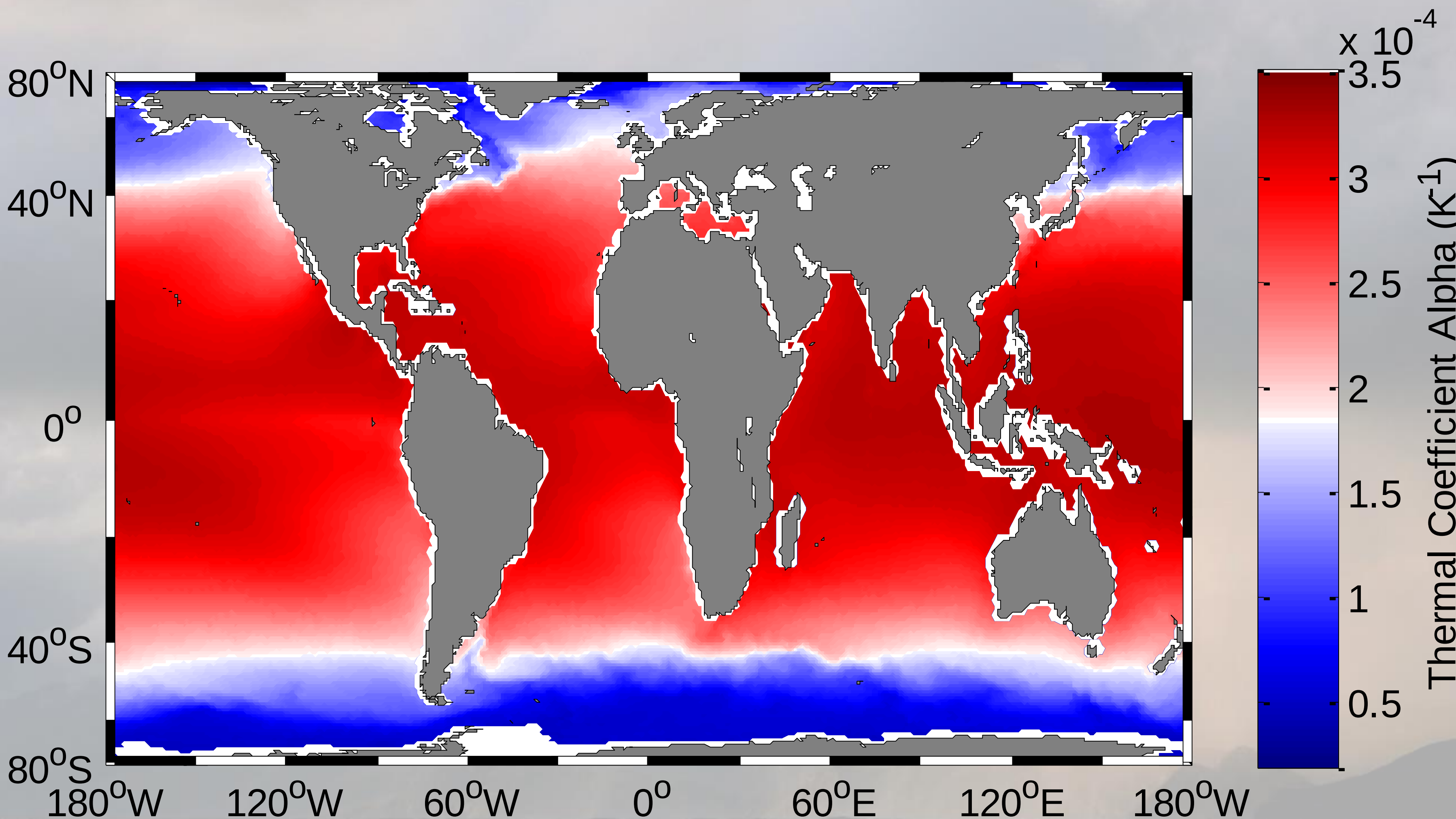
Alpha (Thermal Coefficient, TEOS-10)



Using Aquarius V 4.0 Salinity and Auxiliary Temperature

Note that the range of alpha is much bigger than beta

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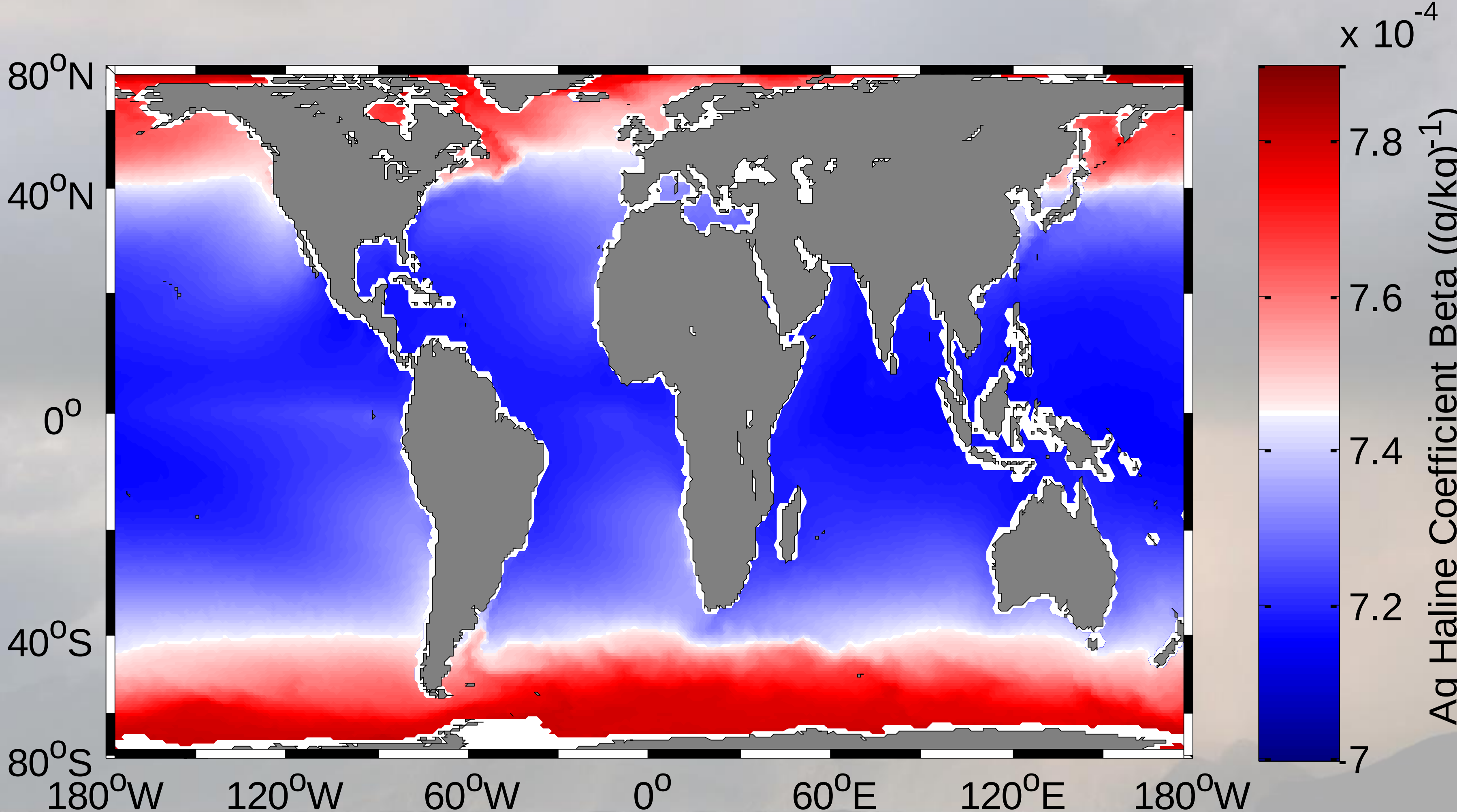
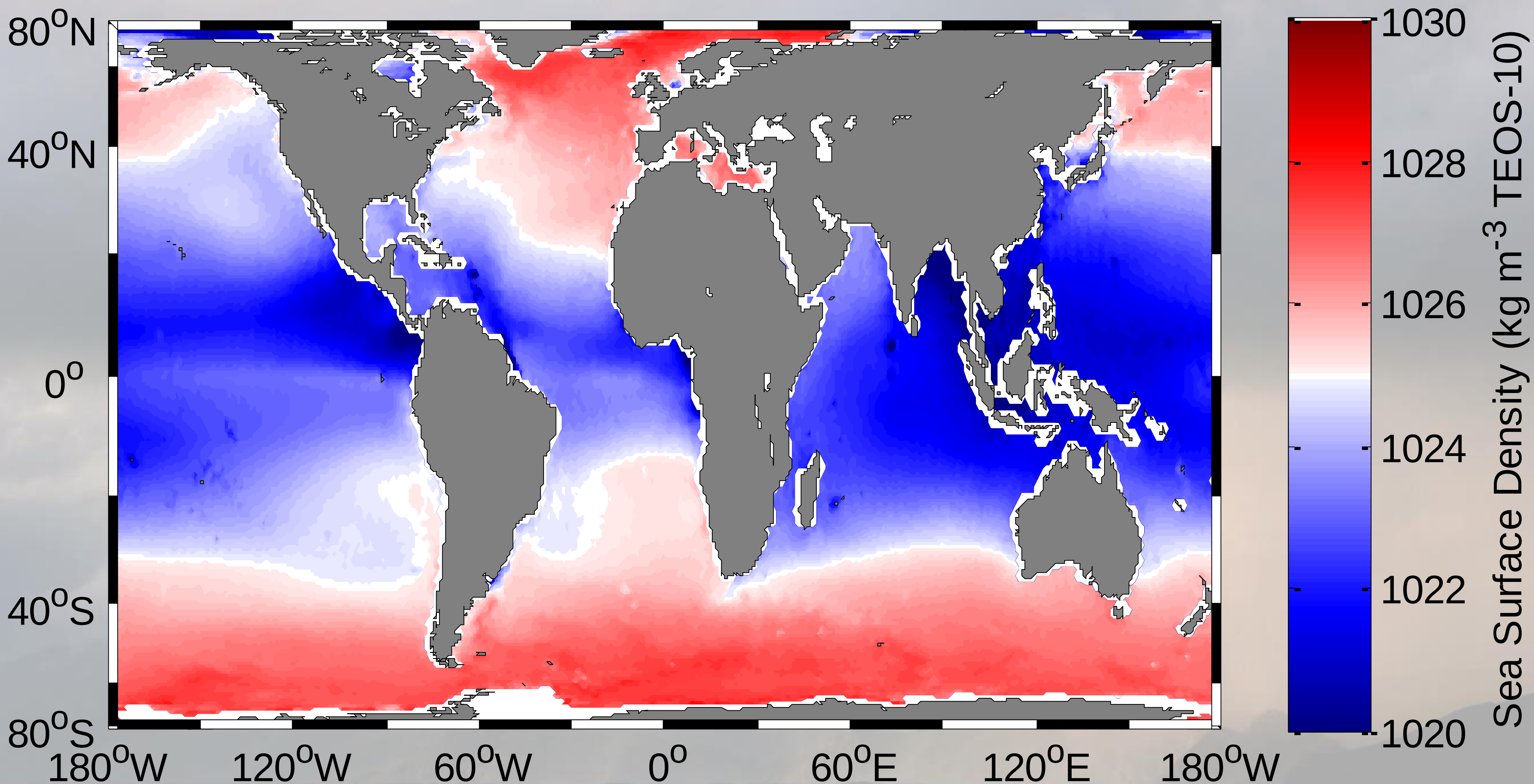
Beta (Haline Coefficient, TEOS-10)



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)



$$\rho = \rho_0 * (1 + \beta \cdot SSS - \alpha \cdot SST)$$

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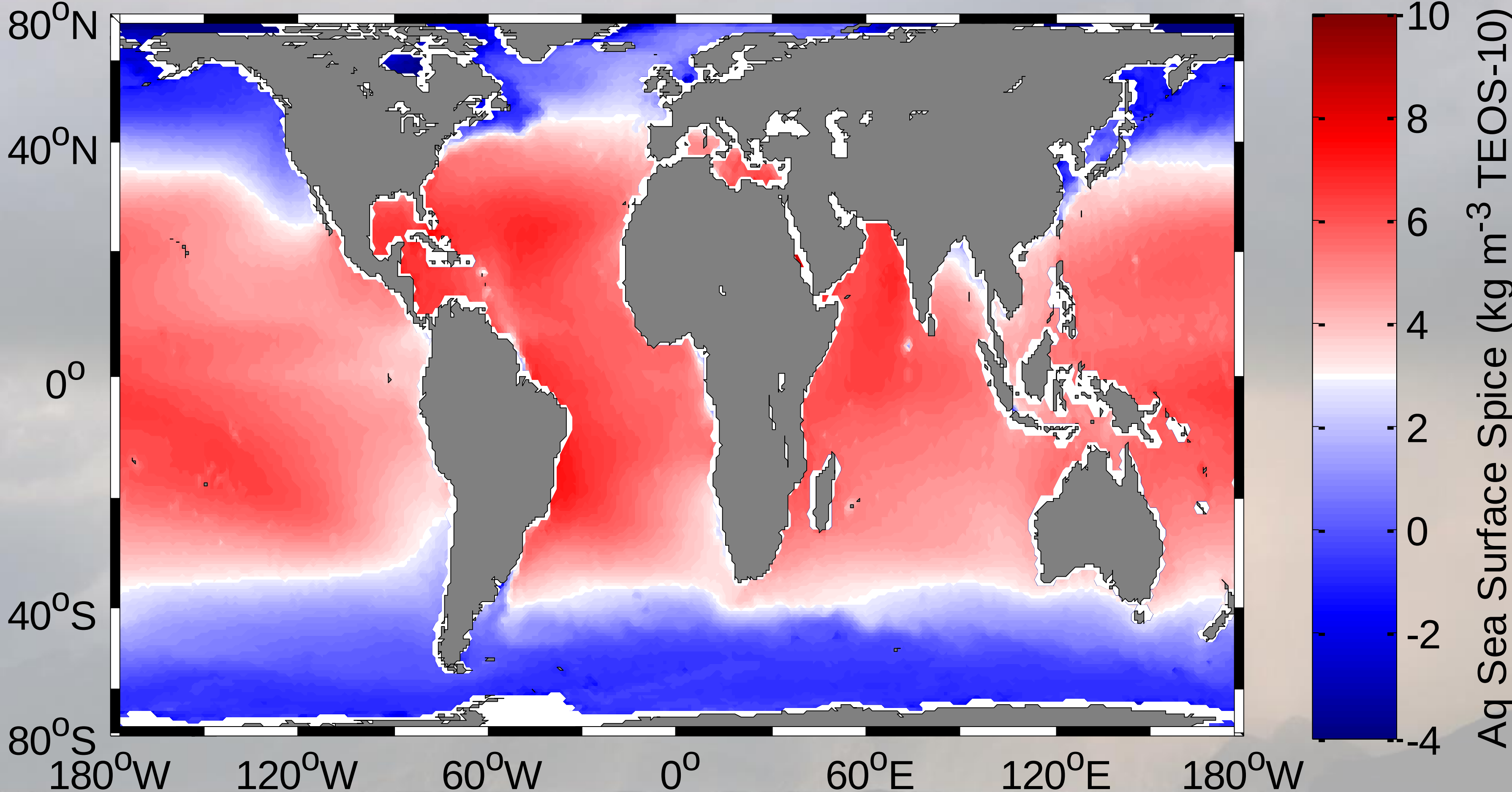
Spiciness (now in TEOS-10 as of V3.05)

Warm/salty water is 'spicier' than cold/fresh water



$$\tau = \tau_0 * (1 + \beta\cdot SSS + \alpha\cdot SST)$$

Part 2: An Evaluation of Aquarius Density

II

Decomposing Density

- Decomposing density into its thermal and haline components
- Relative to a reference of S_A=35 g/kg and Θ=15°C (~standard seawater*)
- Highlighting the contribution of Aquarius, and hence the advancement of the field through satellite SSS.
- Water mass formation/transformation
- Constraint for interior processes (Stern (1975), Joyce (1980), Schneider & Bhatt (2000), Schanze (2013), Bryan (2015), Schanze & Schmitt (2015) …)

*Standard Sea Water (SSW) is actually defined as S=35 (PSS78) and T=15°C.

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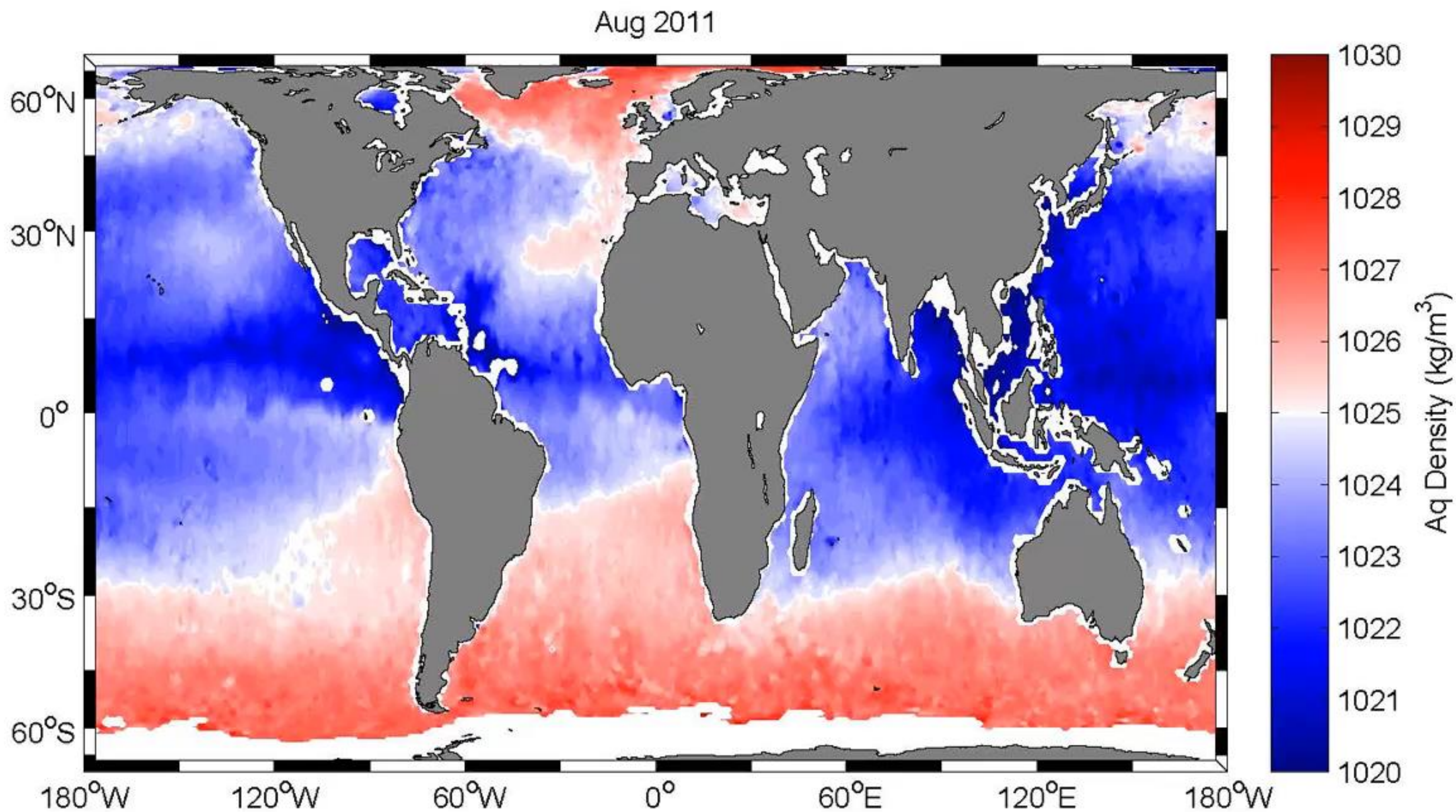
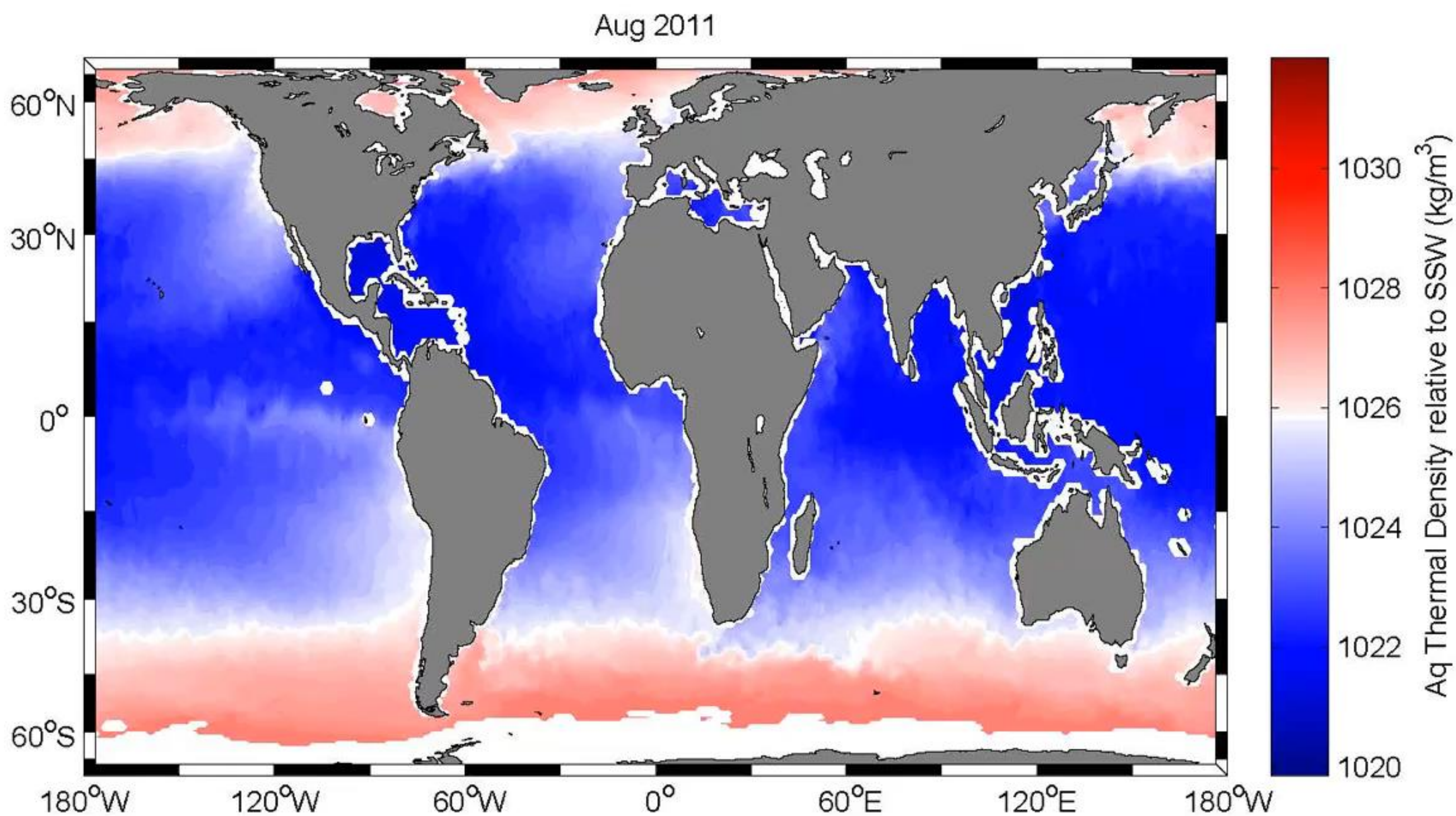
Aquarius Density (TEOS-10)



Amazon, Western Boundary Currents, ITCZ/Panama

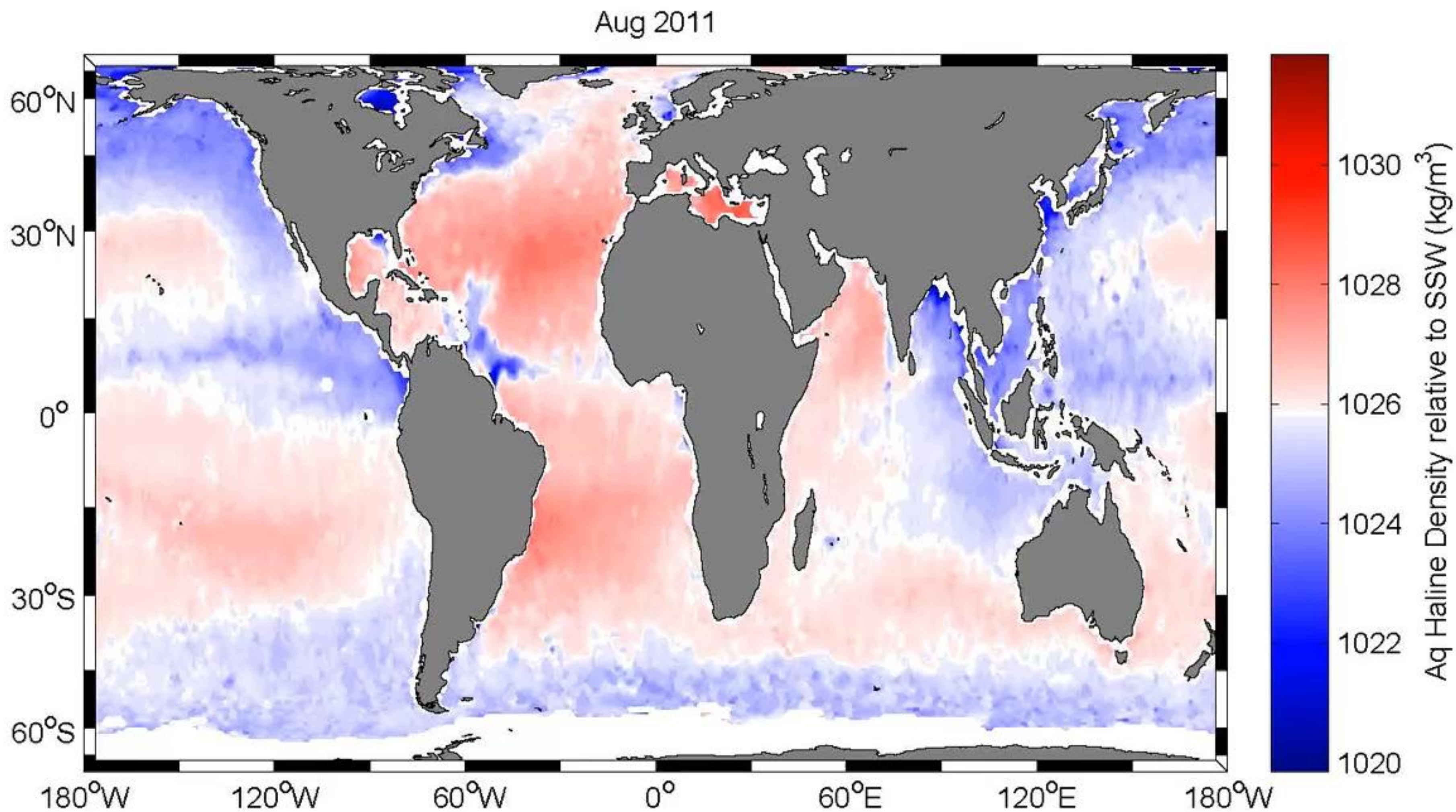
II Aquarius Density (Thermal Component)



Seasonal Cycle, Western Boundary Currents

II

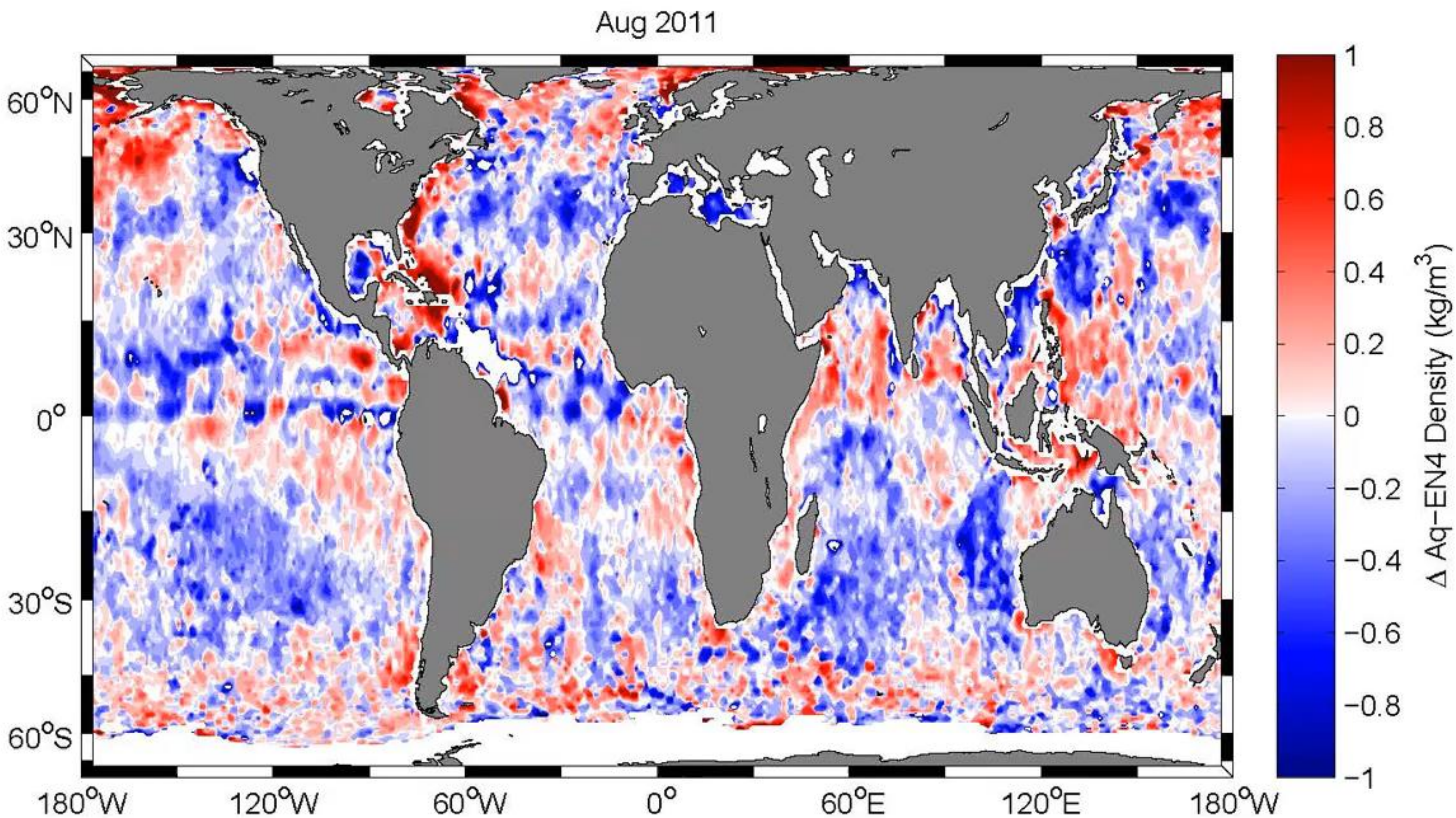
Aquarius Density (Haline Component)



River outflows, ITCZ, Monsoon, High latitudes (!)

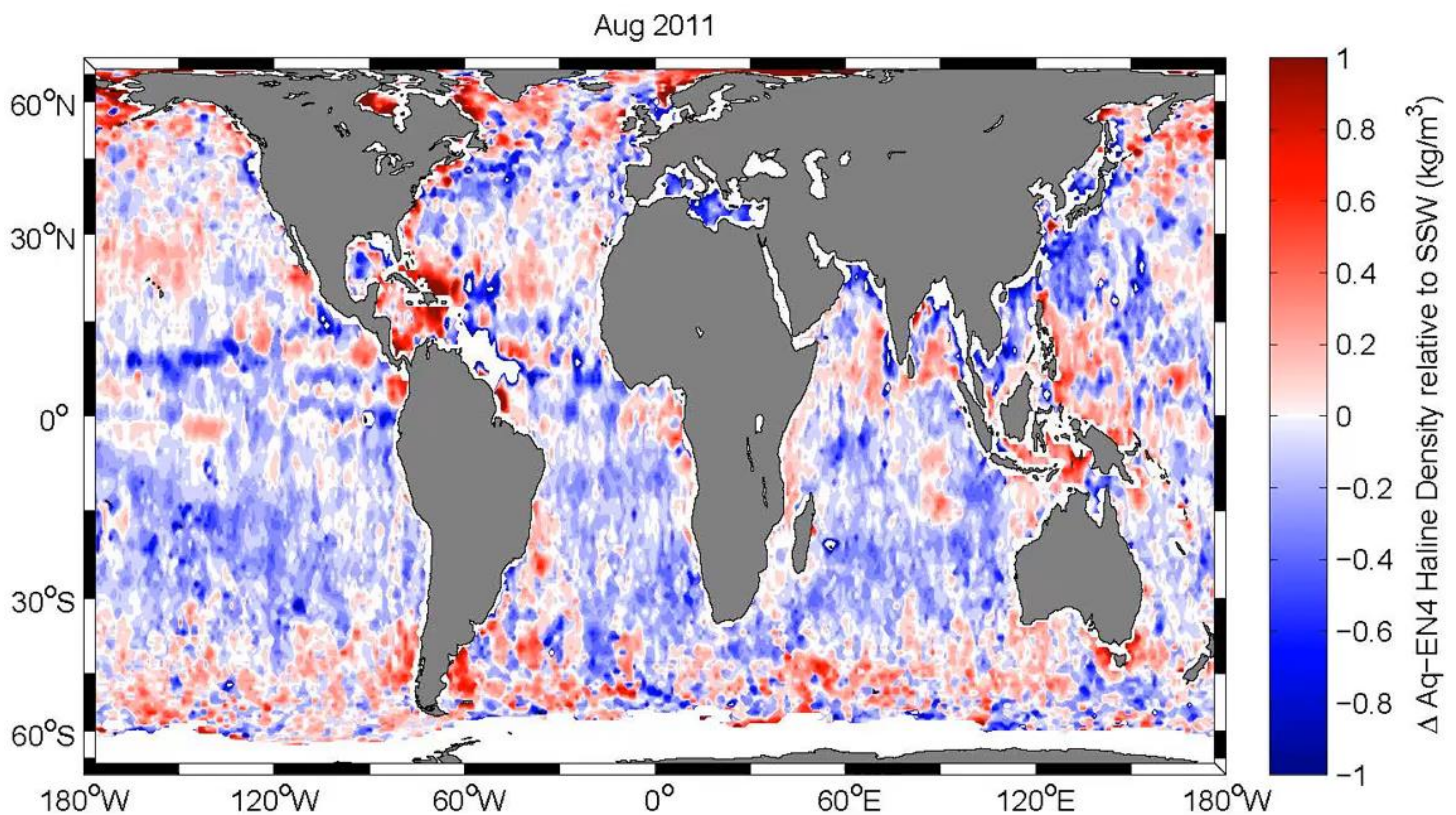
II

Δ Aquarius-Argo Density



Amazon, Western Boundary Currents, ITCZ/Panama

II Δ Aq-Argo Haline Density



This is what Aquarius sea surface density brings to the table

Part 3: Applications of Aquarius Density (and Spice)

III Applications of Surface Density & 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, $\beta \cdot SSS$ effect dominates $\alpha \cdot SST$.
  - 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’)…

III

Power Integrals

- Power Integrals (Stern 1965, 1969, 1975)
- Assume the ocean is in steady state and stationary (mass conservation, heat conservation, salt conservation), then:

$$\frac{1}{\rho_0 C_p} \oiint_A (\overline{F_\theta})\,dA = 0$$

$$\frac{1}{\rho_F} \oiint_A (\overline{F_S})\,dA = 0$$

where

$$F_\theta = -\overline{\rho_0 c_p}\,\overline{w'\theta'} = Q_{net}$$

$$F_S = \overline{\rho_F}\,\overline{S_0}(\overline{E - P - R})$$

Power Integrals

- Simplifying a conservation equation and using the divergence theorem (as Joyce (1980) for temperature)

$$\frac{1}{\rho_0 C_p} \oiint_A (\bar{\theta}\overline{F_\theta})dA = -\iiint_V \nabla\bar{\theta}\cdot\overline{\mathbf{u}'\cdot\theta'}dV = \tfrac{1}{2}\iiint_V \chi_\theta dV$$

- 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)…

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Power Integrals

- Isopycnal gradients cancel in the density equation

$$\frac{1}{2}\iiint_V \chi_\rho dV = -\oint\!\!\oint_A [(\alpha\bar{\theta} - \beta\bar{S})(\alpha\overline{w'\theta'} - \beta\overline{w'S'})]dA$$

$$= -\iiint_V [(\alpha\boldsymbol{\nabla}_d\bar{\theta} - \beta\boldsymbol{\nabla}_d\bar{S}) \cdot (\alpha\overline{\theta'\mathbf{u}'_d} - \beta\overline{S'\mathbf{u}'_d})]dV$$

- Diapycnal gradients cancel in the spice equation

$$\frac{1}{2}\iiint_V \chi_\tau dV = -\oint\!\!\oint_A [(\alpha\bar{\theta} + \beta\bar{S})(\alpha\overline{w'\theta'} + \beta\overline{w'S'})]dA$$

$$= -\iiint_V [(\alpha\boldsymbol{\nabla}_i\bar{\theta} + \beta\boldsymbol{\nabla}_i\bar{S}) \cdot (\alpha\overline{\theta'\mathbf{u}'_i} + \beta\overline{S'\mathbf{u}'_i})]dV$$

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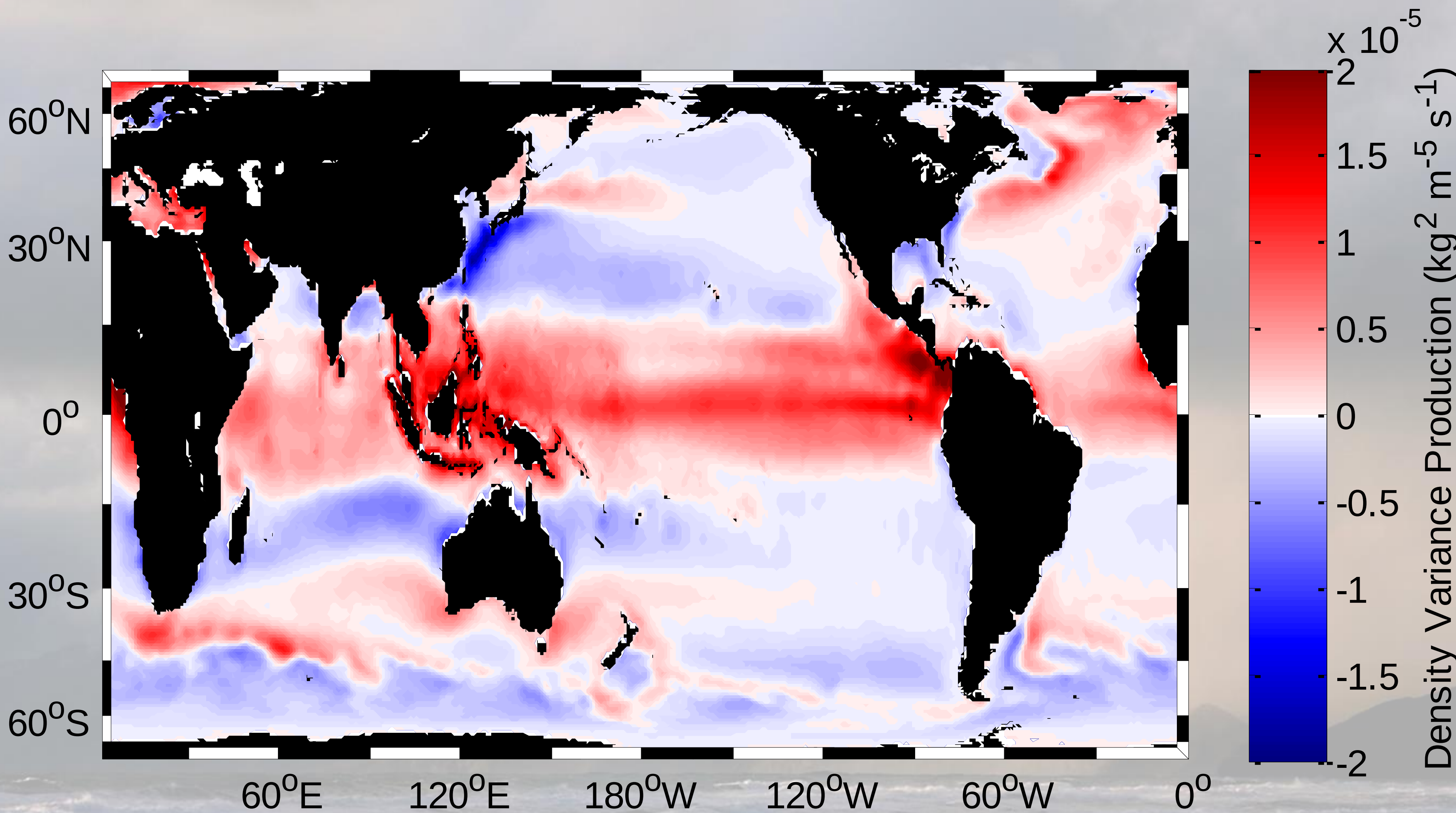
Power Integrals

- 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

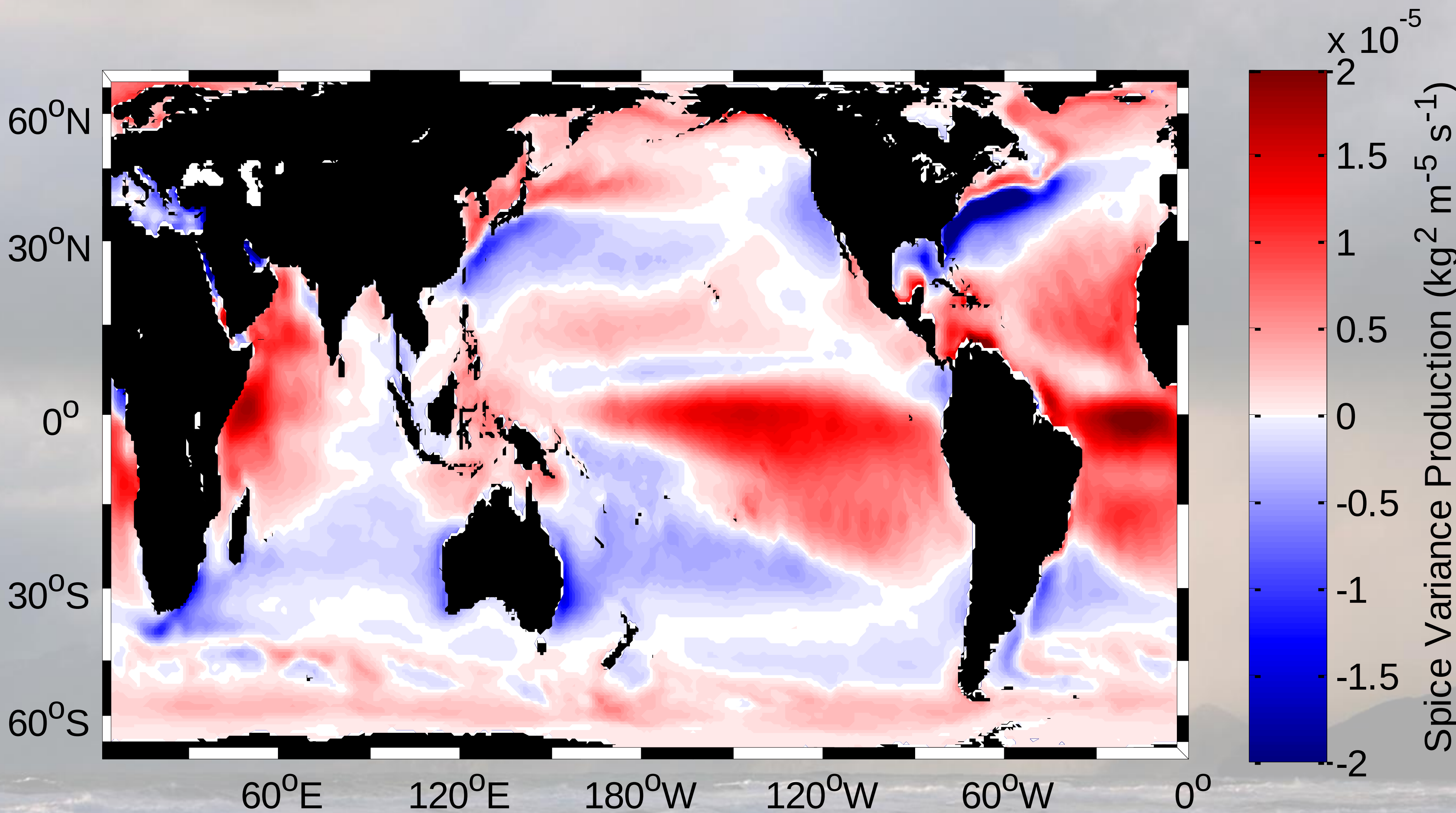
III



Aquarius SSS, OISST, OAFlux E and Qnet, GPCP P

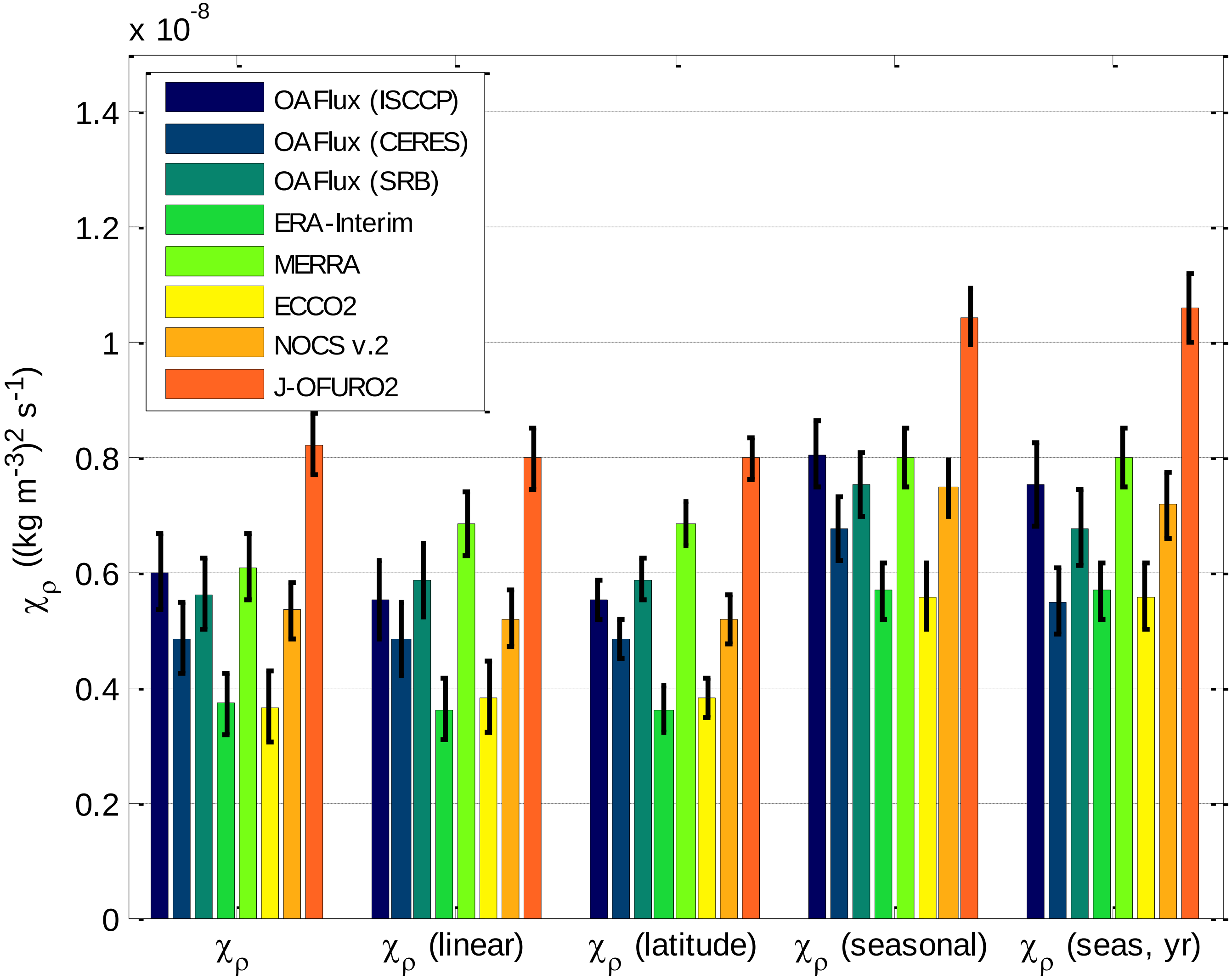
III

Spice Variance Production



Aquarius SSS, OISST, OAFlux E and Qnet, GPCP P

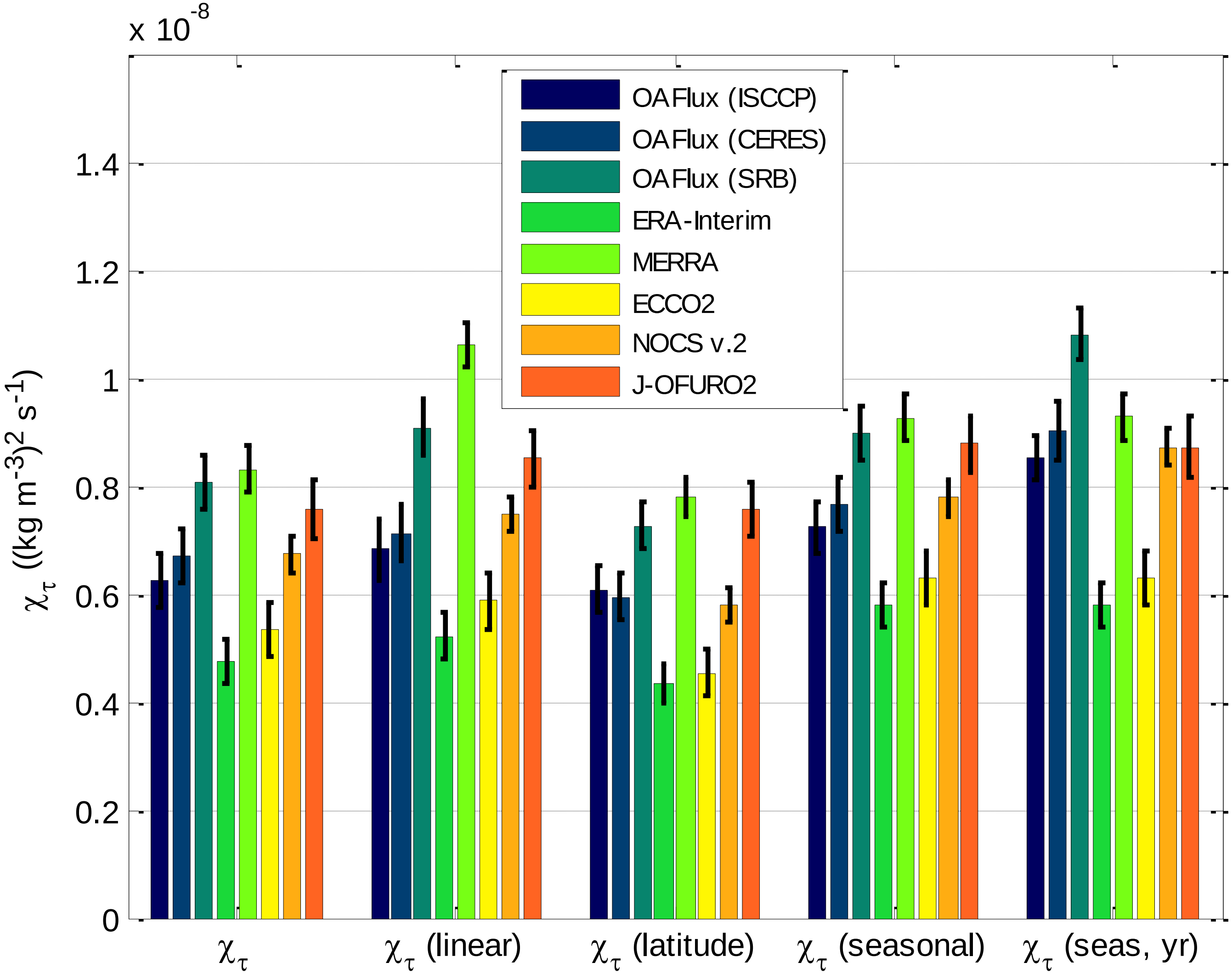
III Density/Diapycnal Dissipation Estimates



- Scale height H=600m.
- Units are $(kg\ m^{-3})^2\ s^{-1}$, same as spice
- Range of results from $3\text{-}11\times10^{-9}$ $(kg\ m^{-3})^2\ s^{-1}$

Note: Color bars are different Q_{net} datasets, Black range is E-P

III Spice/Isopycnal Dissipation Estimates

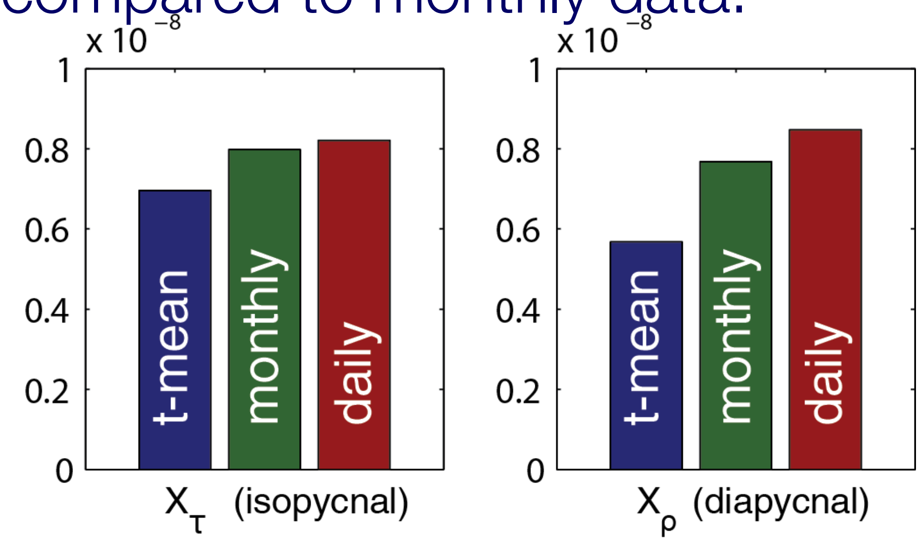


- Units are $(kg\ m^{-3})^2\ s^{-1}$ same as density
- Range of results $5\text{-}11 \times 10^{-9}$ $(kg\ m^{-3})^2\ s^{-1}$
- Close to equipartition

Note: Color bars are different Q_{net} datasets, Black range is E-P

III From Monthly to Daily

- OISST daily and OAFlux v3 for Q_{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, χ_ρ (diapycnal) increases by 10% χ_τ (isopycnal) increases by 3% compared to monthly data.
- Implications:
  - Space scales
  - Local vs global
  - Covariance!



Dissipation Conclusions

- Density dissipation estimate is ~6×10^{-9} (kg m^{-3})^2 s^{-1}
- Spice dissipation estimate is ~7×10^{-9} (kg m^{-3})^2 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

IV

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)

V

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?
- Local isohaline/isothermal/isopycnal/isospice budgets *a la* Walin (1982) – in preparation

Thank You!

Questions?