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**TEOS-10, Density, Spice and Aquarius:  
*An Overview***

Aquarius Calibration-Validation Workshop, Santa Rosa, CA

March 31, 2015



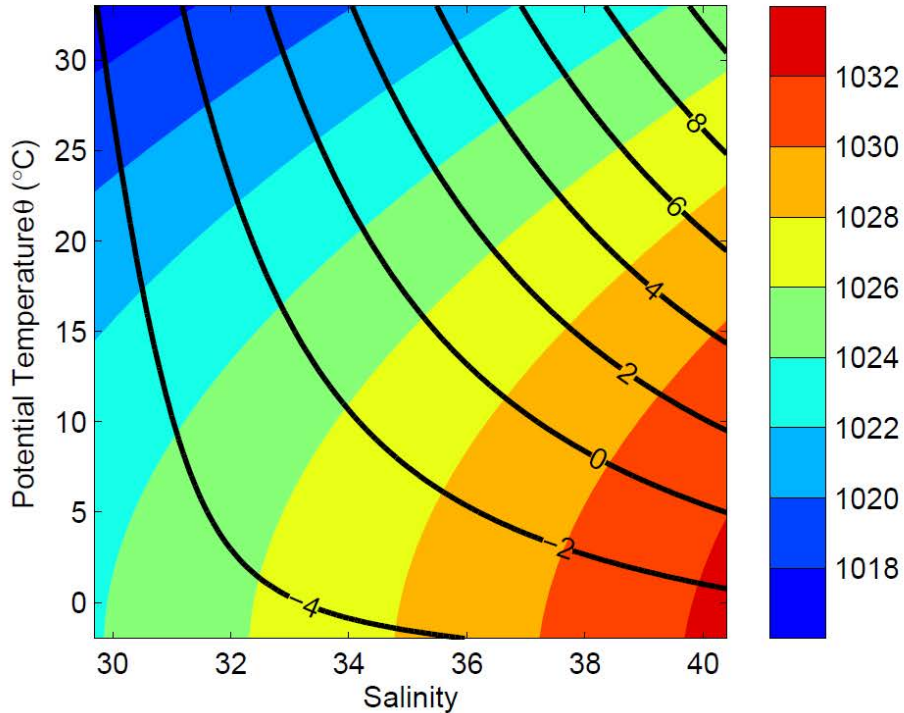
- What is TEOS-10?
- What is spice/spicity?
- Why change the definitions of temperature and salinity?
- Illustrations of density and spice from Aquarius
- Effects of temperature adjustment on density and spice
- Conclusions

*Part 1: TEOS-10, Density  
and Spice*

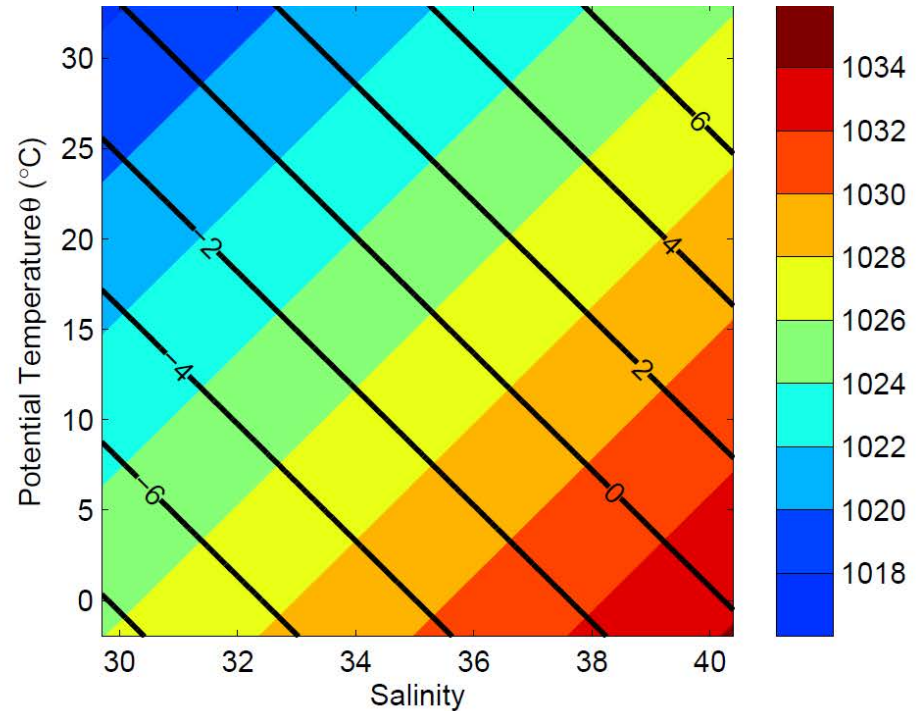


# Equation of State

Non-linear density and spice



$$\rho = \rho_0(1 - \alpha(\theta - \theta_0) + \beta(S - S_0))$$



➤ Spicy = hot/salty, perpendicular to density

➤ Coefficients  $\alpha$  and  $\beta$ :  $\alpha = -\frac{1}{\rho_0} \cdot \frac{\partial \rho}{\partial \theta} \Big|_{S,p}$      $\beta = \frac{1}{\rho_0} \cdot \frac{\partial \rho}{\partial S} \Big|_{\theta,p}$



# I *TEOS-10: Background*

- Existing functions to compute derived variables in the ocean were inconsistent (EOS-80) and IPTS-68
- This is addressed in the Thermodynamic Equation of State 2010 (TEOS-10)
- Conservative Temperature  $T_{\Theta}$  (actually conservative, unlike potential temperature, but not recommended for air-sea fluxes)
- Absolute Salinity  $S_A$  with units of g/kg (true mass fraction)
- Now adopted by all major standardization bodies



# I *TEOS-10: Background*

- Does it matter for Aquarius?
- The changes between PSS-78 (salinity in EOS-80) and TEOS-10  $S_A$  are non-trivial
- All 'archival' salinity data submissions will remain in PSS-78
- However, all publications should use  $S_A$  !
- Absolute Salinity uses Preformed Salinity (standard seawater scaled by chlorinity) plus a correction factor based on silicic acid.
- Differences as large as 0.2 g/kg



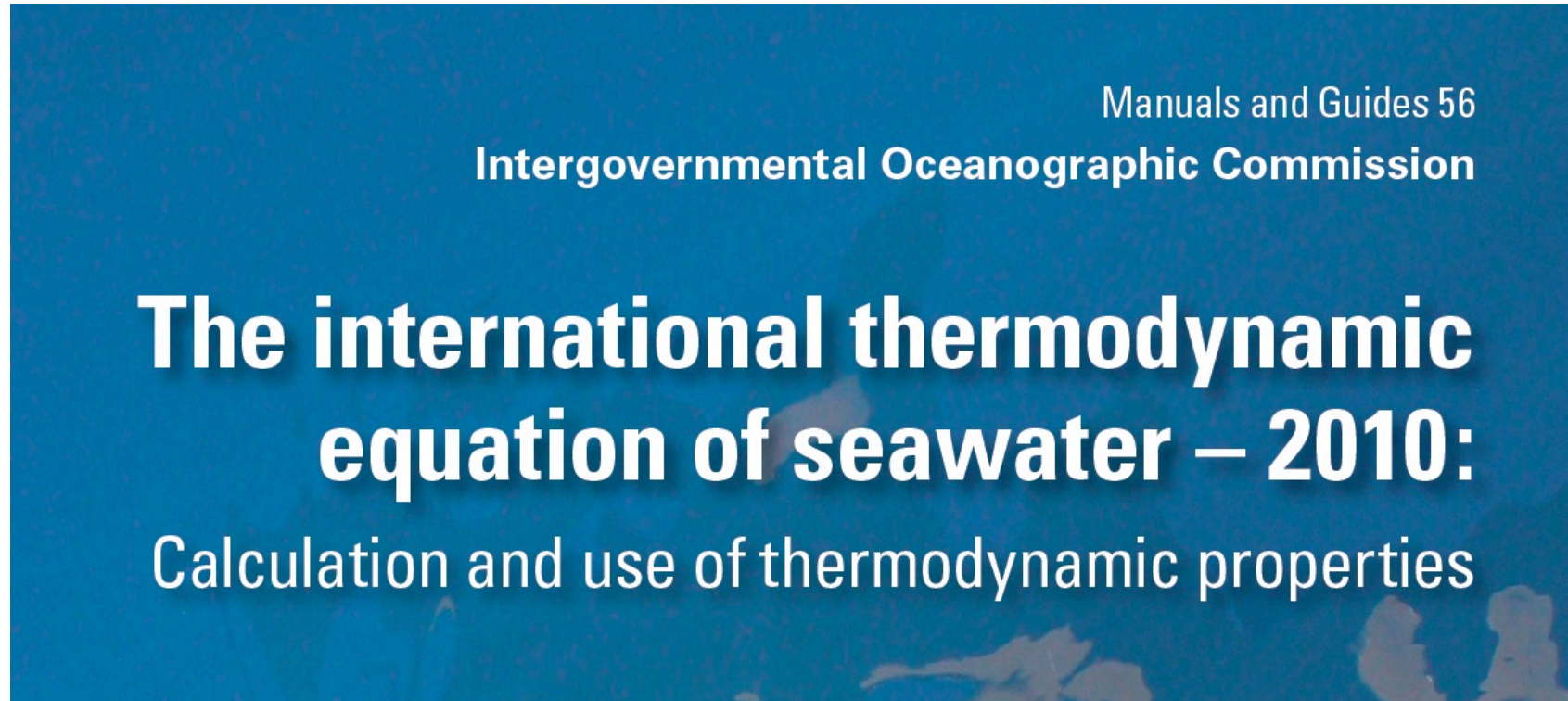
# TEOS-10: Background

- *“For the first time the influence of the spatially varying composition of seawater can systematically be taken into account through the use of Absolute Salinity.”*
- *“In the open ocean, this has a non-trivial effect on the horizontal density gradient computed from the equation of state, and thereby on the ocean velocities and heat transports calculated via the “thermal wind” relation.”*



# TEOS-10: Background

- TEOS-10 resources: The TEOS-10 Manual (200+ pages)



- ...but there are more user-friendly resources:

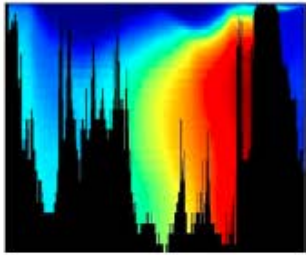




# TEOS-10: Background

- TEOS-10 resources:

## TEOS-10 PRIMER



What every oceanographer needs to know about TEOS-10  
(The TEOS-10 Primer)

Rich Pawlowicz<sup>1</sup>

Oct 2010, last updated April 2013 (v8)

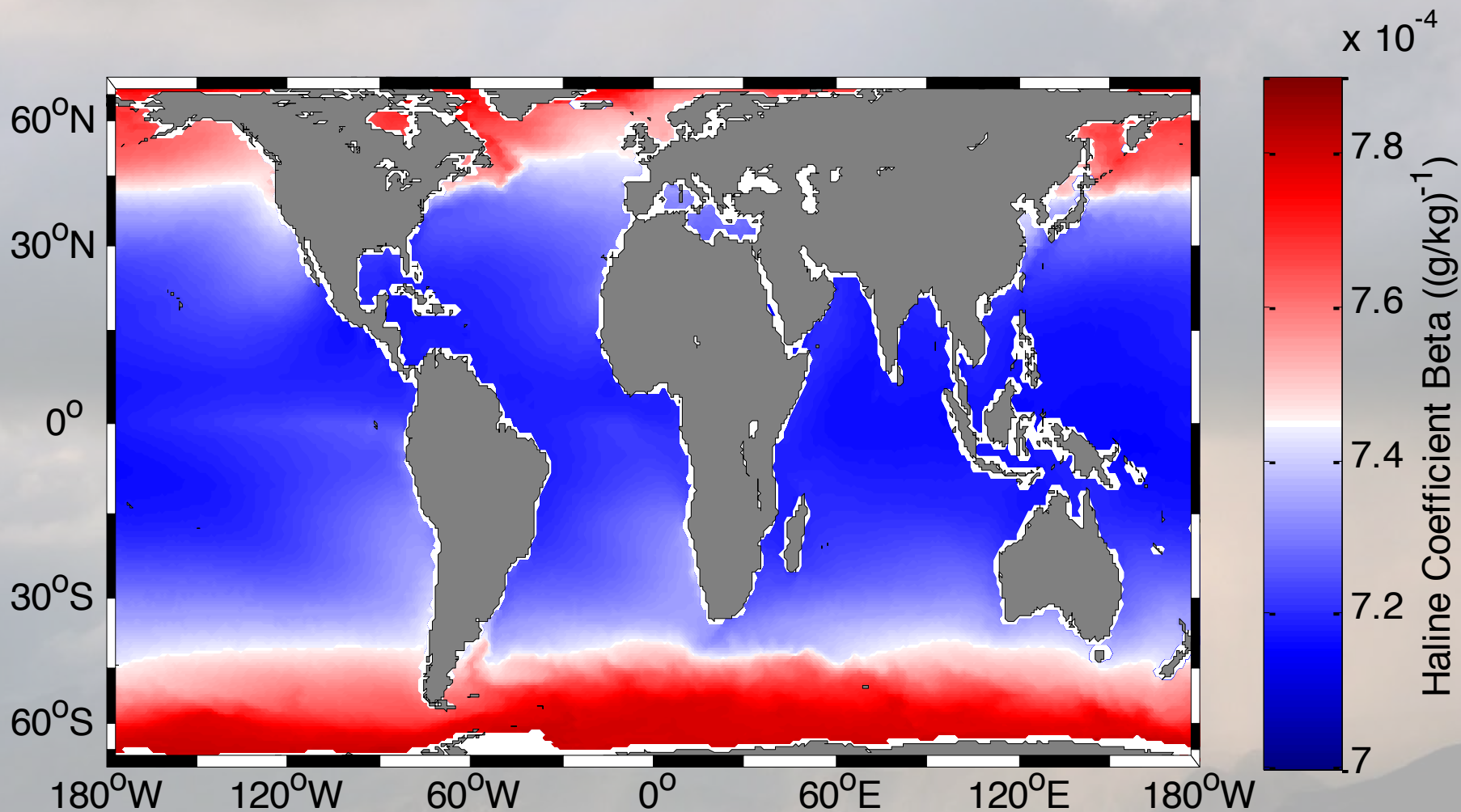
- The Gibbs SeaWater (GSW) Toolbox for TEOS-10 is available for MATLAB, Fortran, C, Java...
- Easy (enough) to use



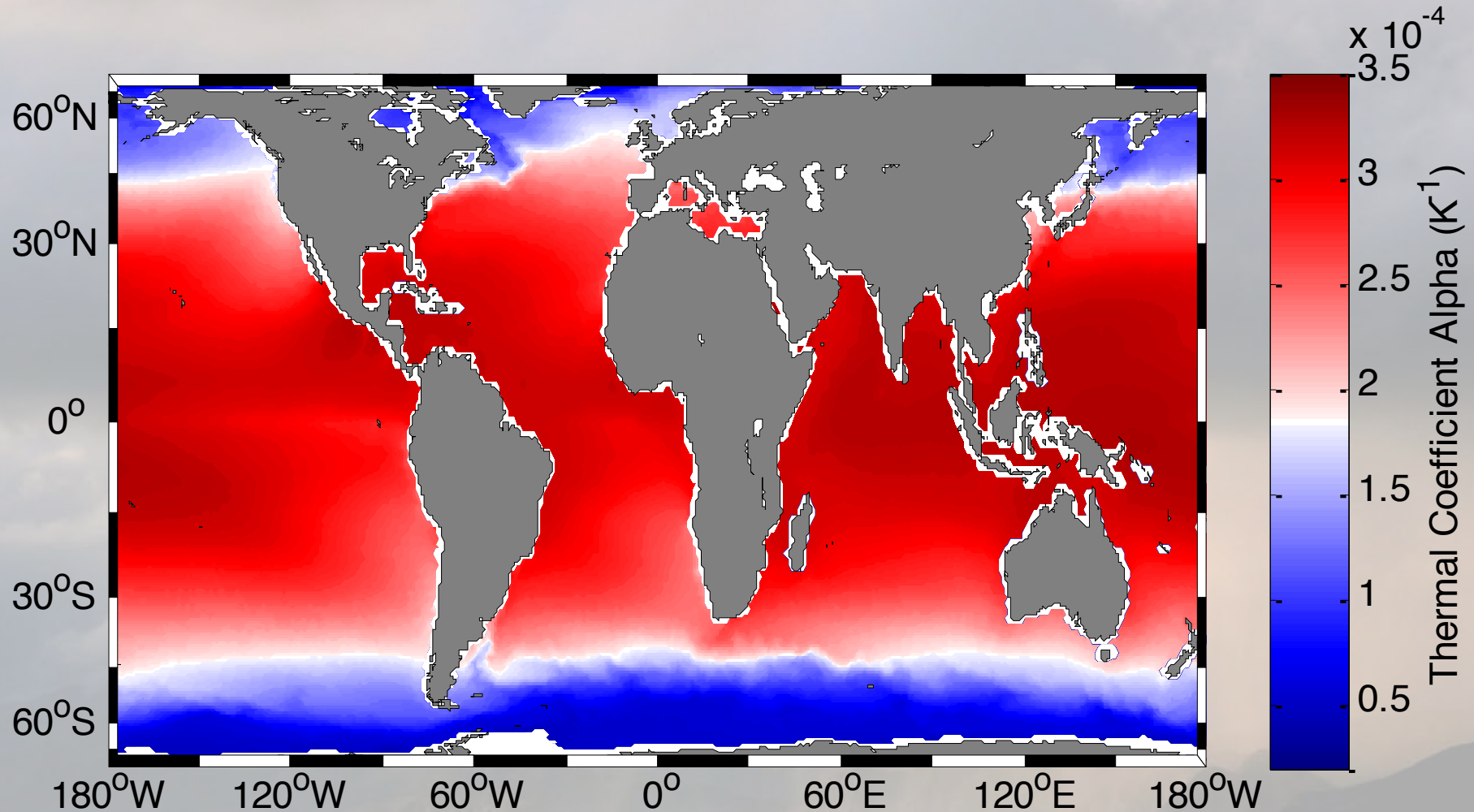
*Part 2: Derived Variables  
from Aquarius V3.0*



# Beta (Haline Coefficient, TEOS-10)

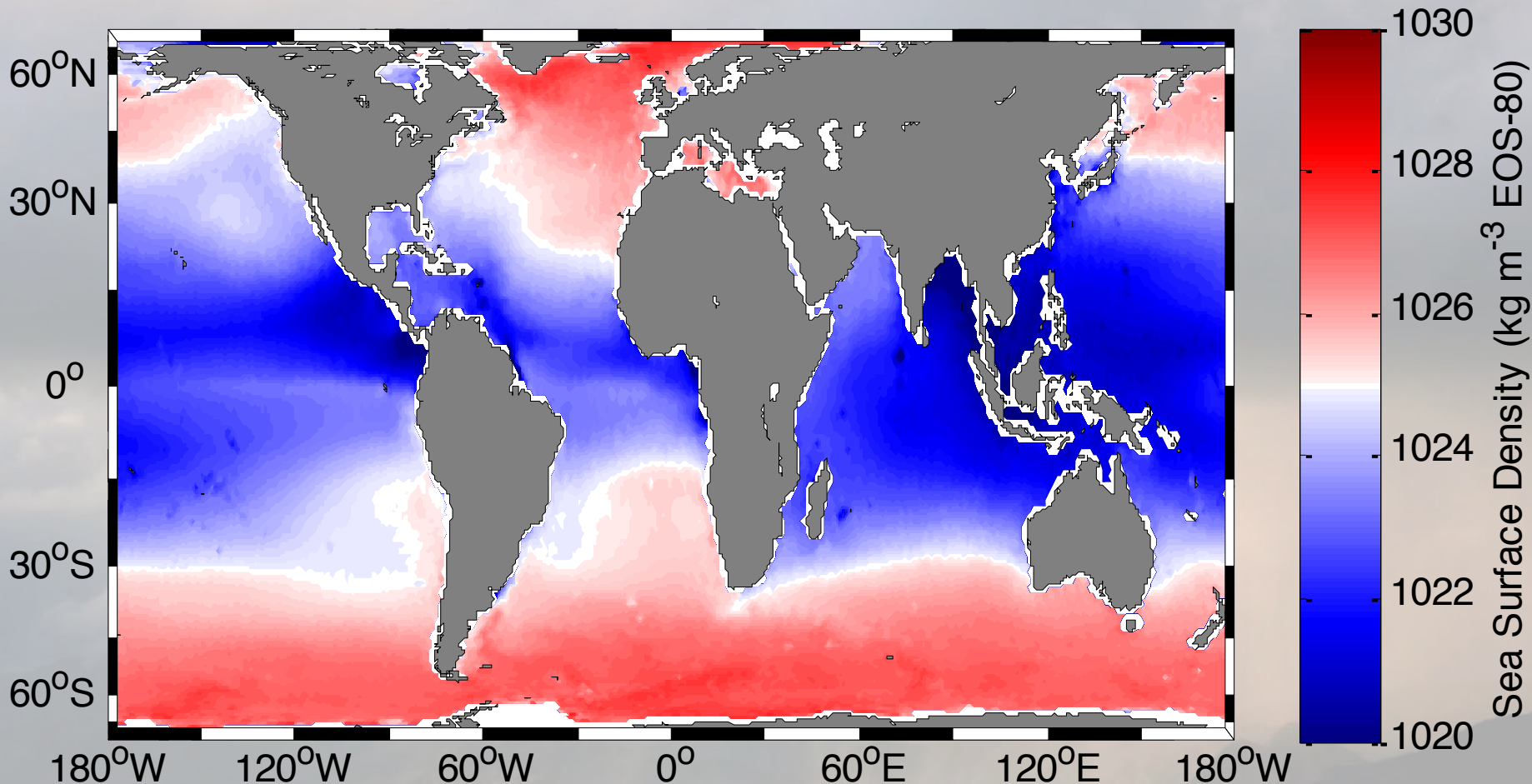


# *Alpha (Thermal Coefficient, TEOS-10)*



II

# Sea Surface Density (Aq 3.0 EOS-80)

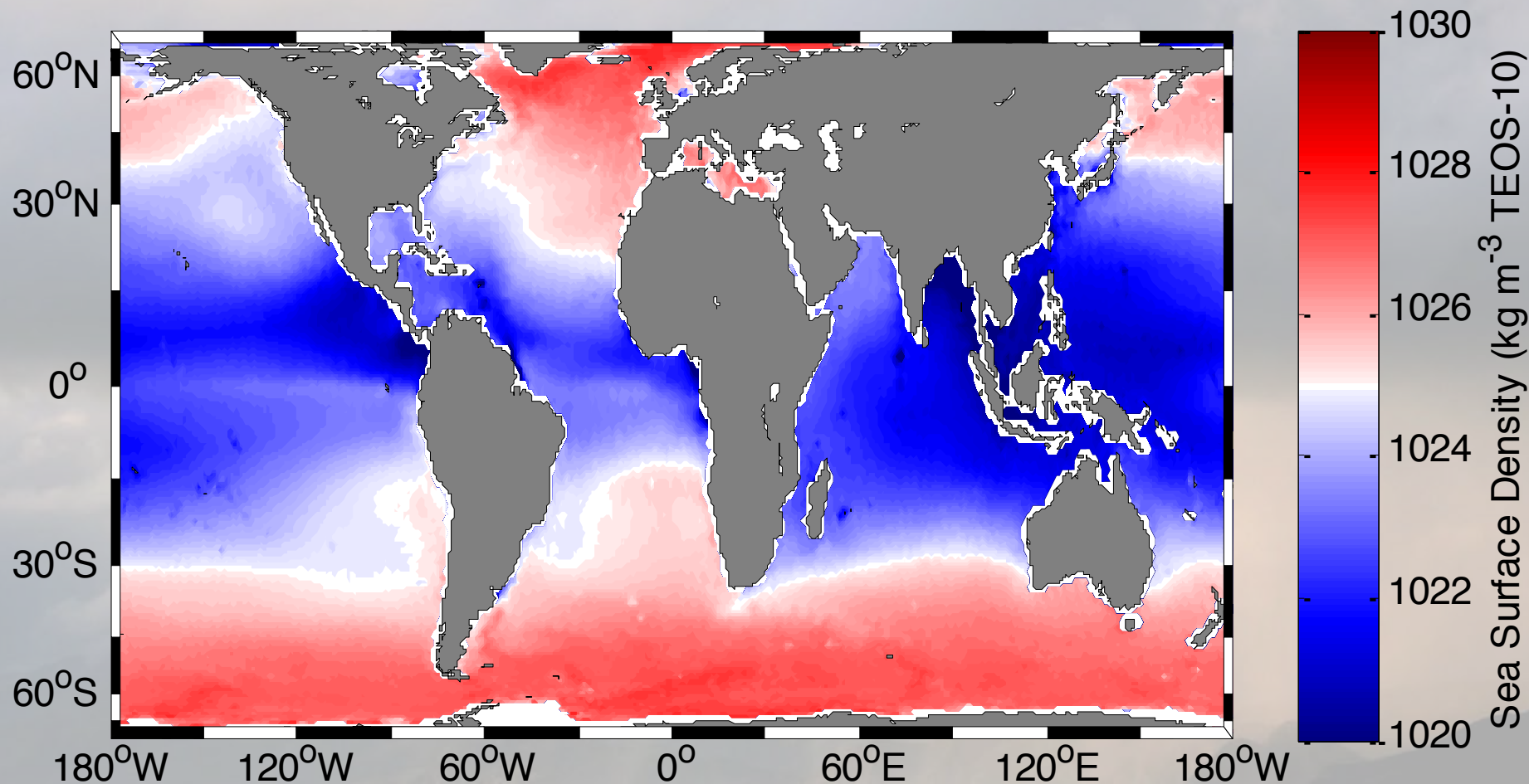


$$\text{Rho} = \text{rho}_0 * (\text{beta} * \text{SSS} - \text{alpha} * \text{SST})$$



II

# Sea Surface Density (Aq 3.0 TEOS-10)

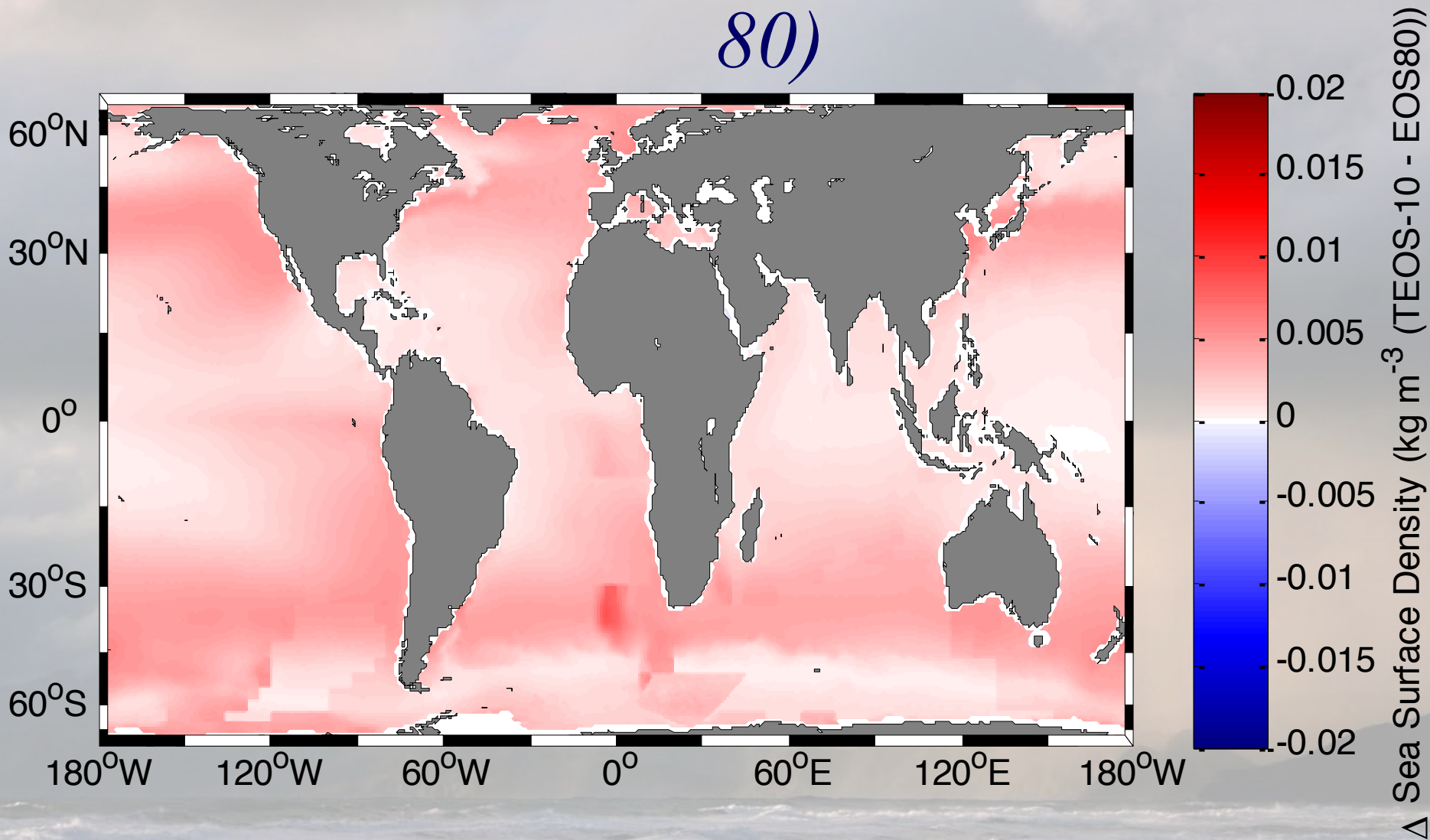


$$\text{Rho} = \text{rho}_0 * (1 + \text{beta} * \text{SSS} - \text{alpha} * \text{SST})$$



II

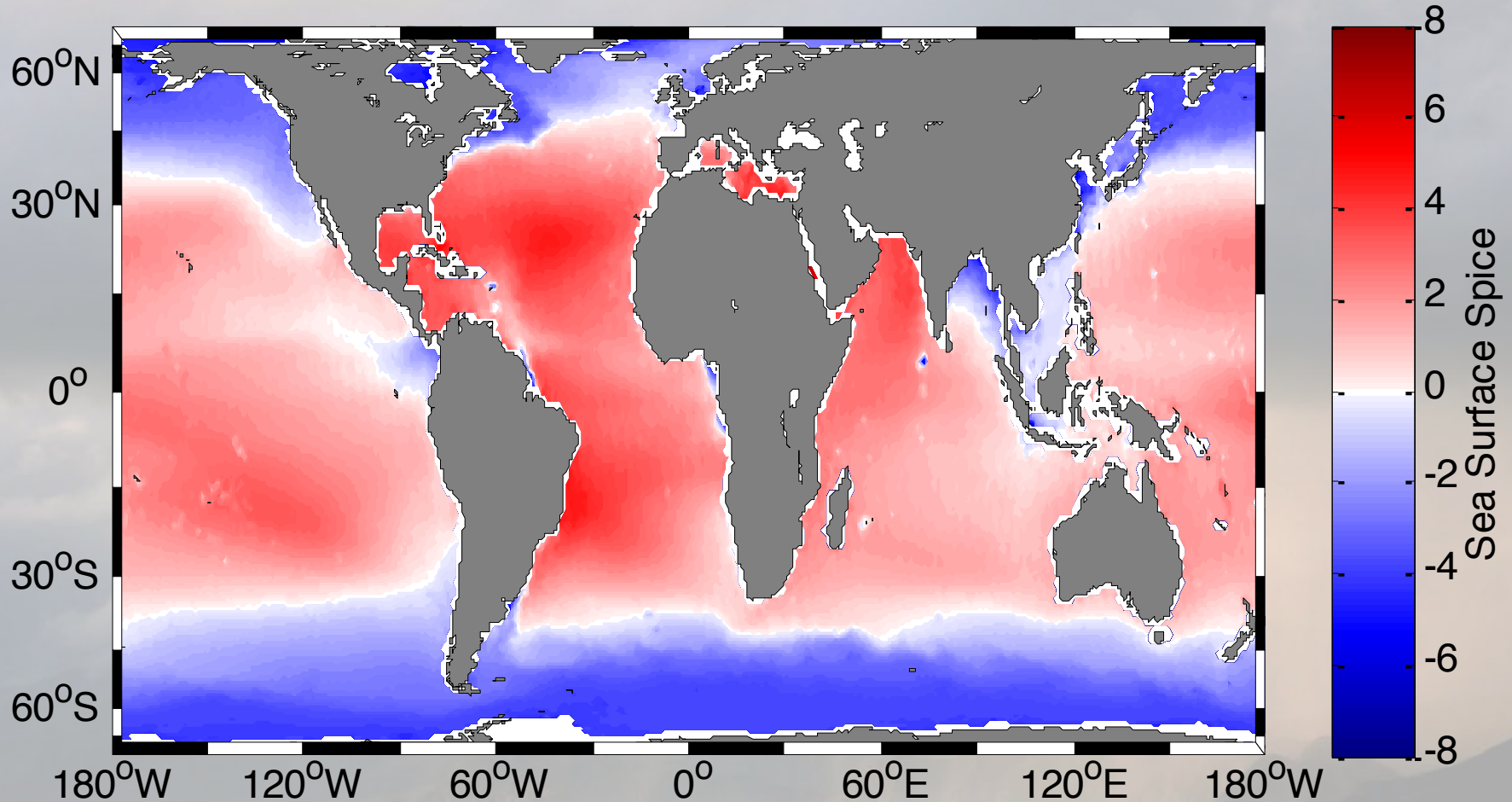
# Sea Surface Density (TEOS-10 – EOS-80)



Difference is very small at the surface of the ocean  
This makes SSD a 'robust' derived variable



# Spice (Rui-Xin Huang 'Spicity')



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

$$\text{Tau} = \text{tau}_0 * (1 + \text{beta} * \text{SSS} + \text{alpha} * \text{SST})$$





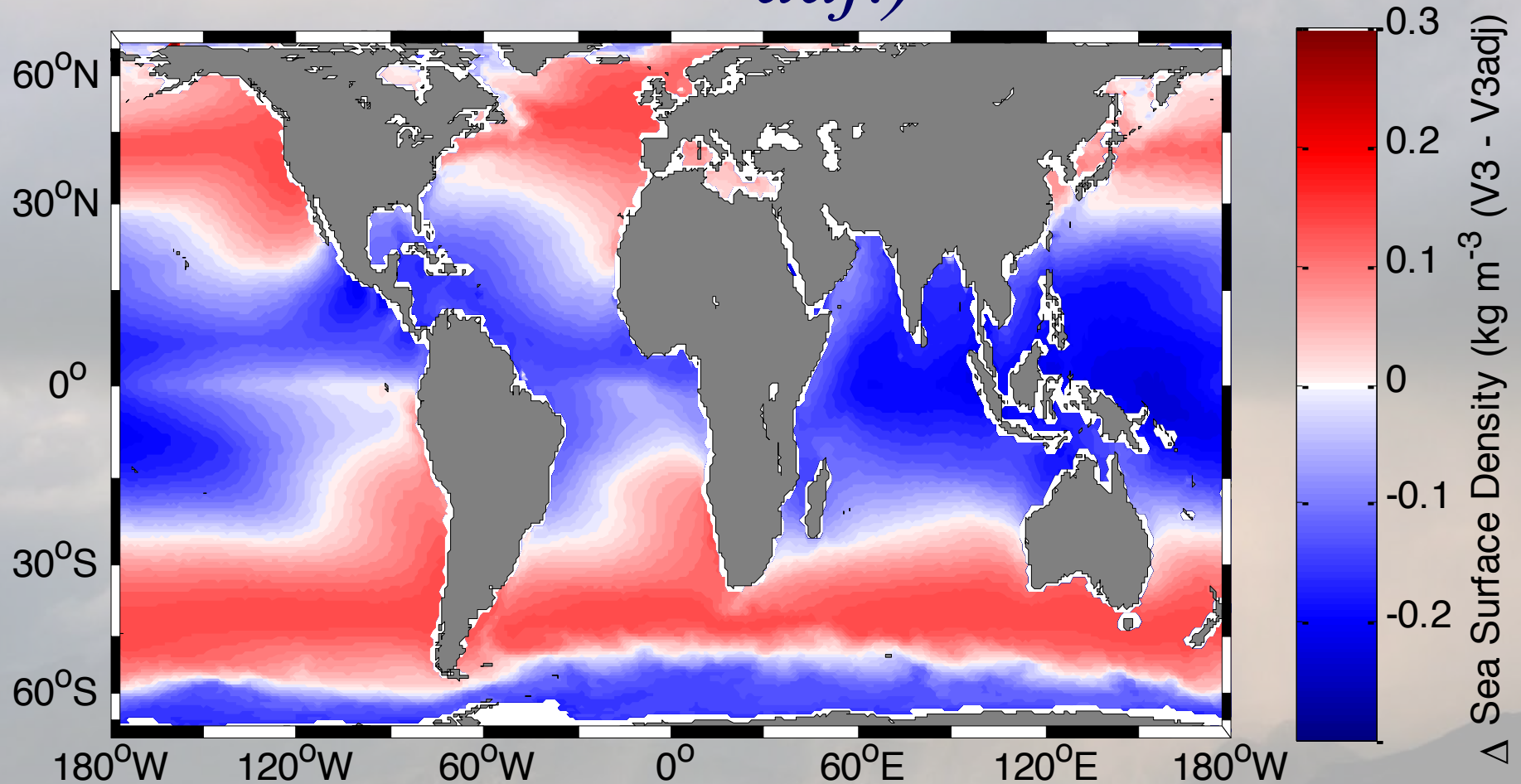
# *Sea Surface Density*

- Does it make sense to provide density with Aquarius?
- What about spice?
- Useful for budgets, air-sea fluxes (density, spice injection), currents and other computations in physical oceanography
- Next: What are the effects of the temperature adjustment to Aquarius? (and hence approximately the differences between 3.0 and 3.4)





# Sea Surface Density (Aq 3.0 – Aq 3.0 adj.)

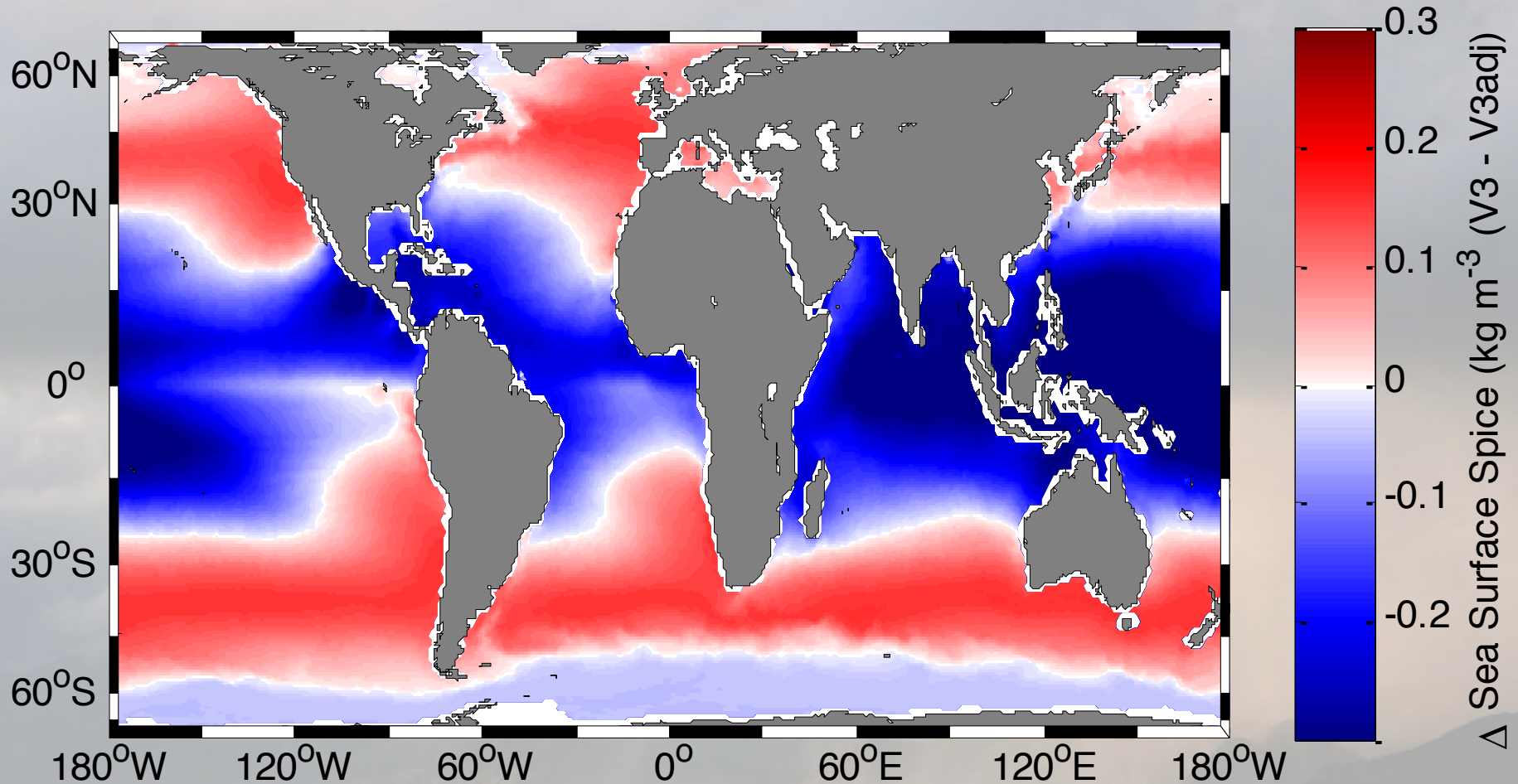


TEOS-10, Significant effect on density





# *Sea Surface Spice (Aq 3.0 – Aq 3.0 adj.)*



Rui Xin Huang 'Spicity' definition, Significant effect on spice  
Most noticeable in low latitudes



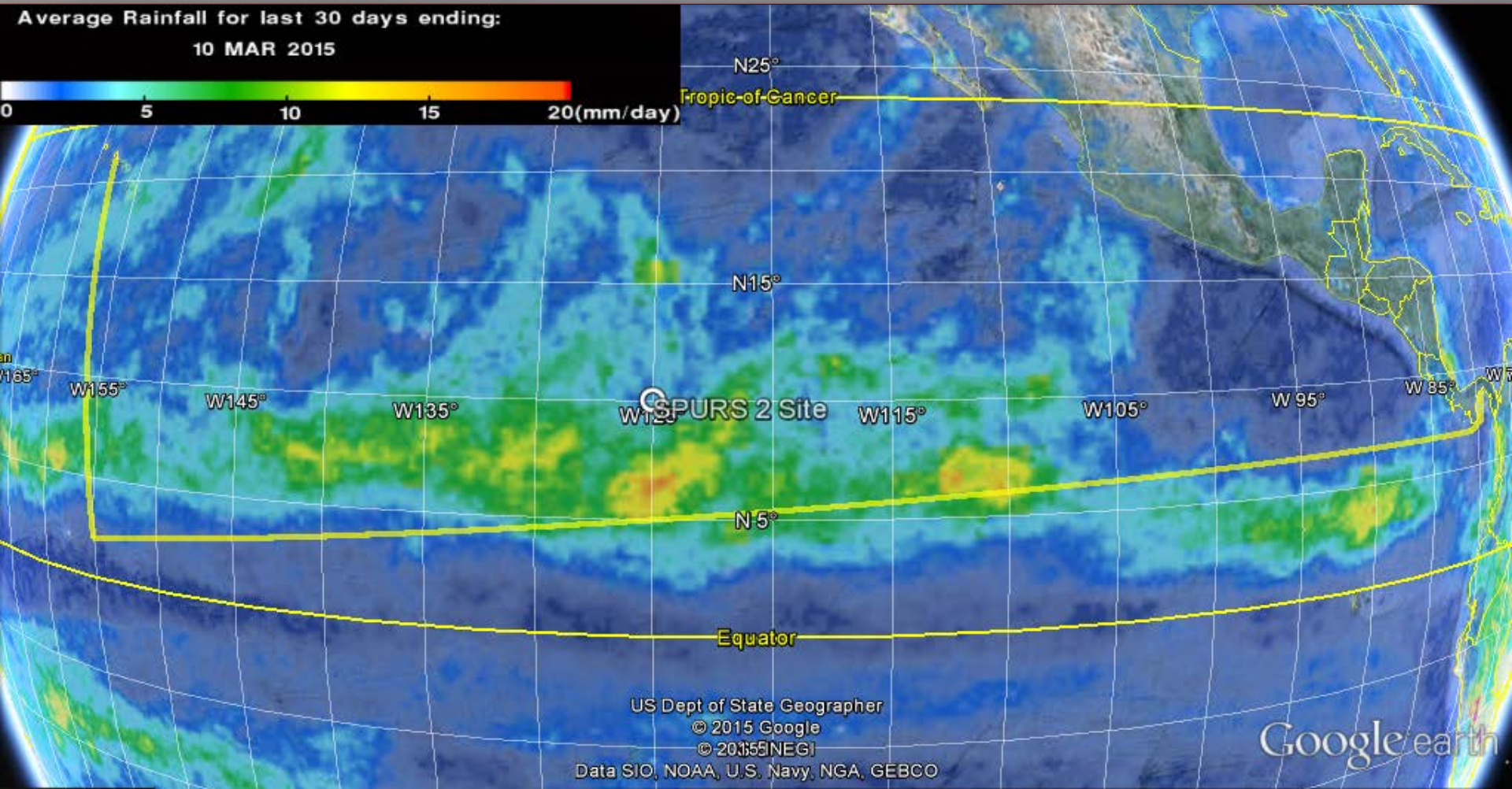
*Addendum: Shipborne Cal-  
Val Efforts*



# Salinity Snake 2.0 Shakedown

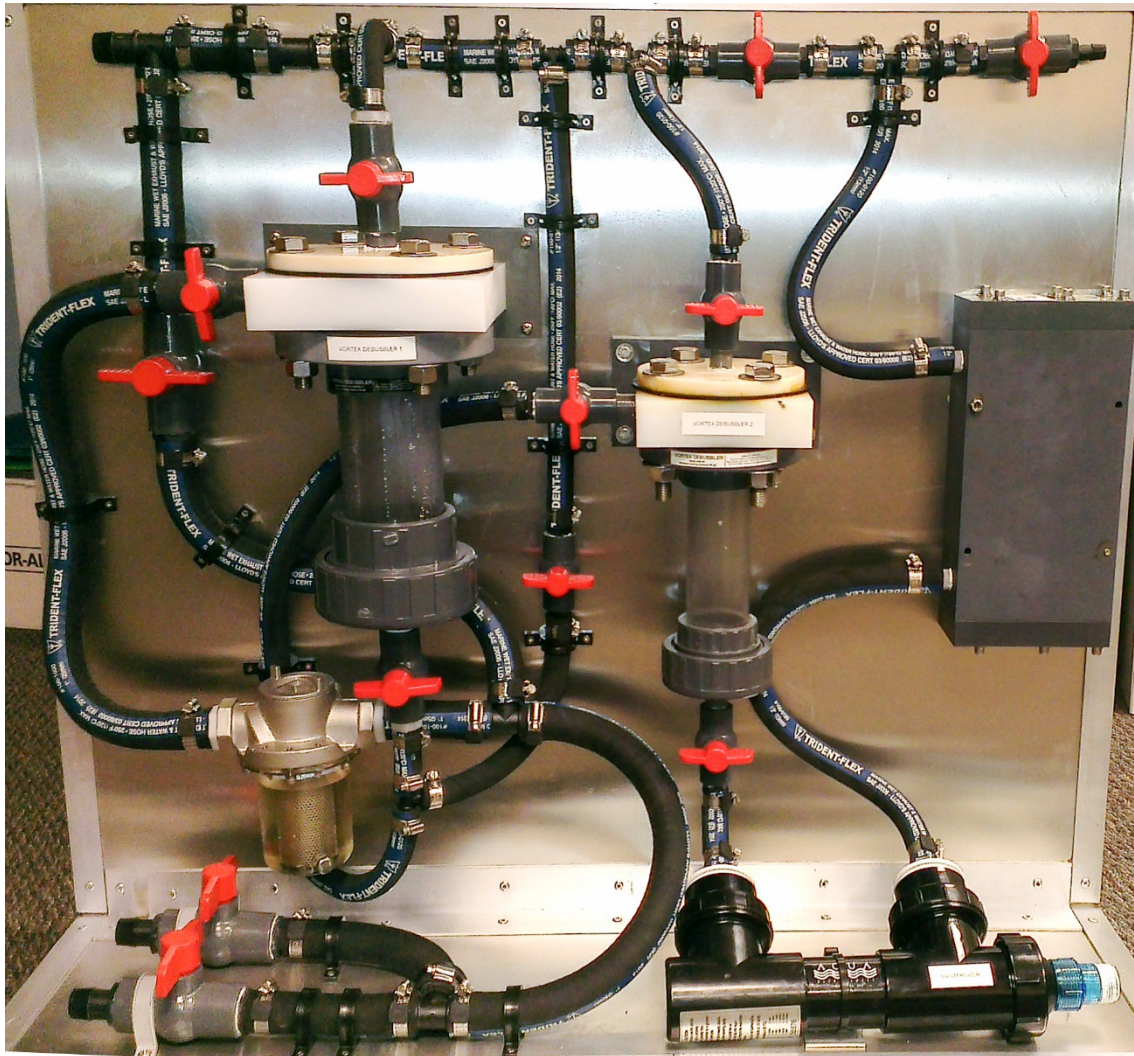
Average Rainfall for last 30 days ending:  
10 MAR 2015

0 5 10 15 20(mm/day)



➤ Test on NOAA R/V Okeanos Explorer in May/June 2015

# Salinity Snake 2.0 Shakedown



- Underway profiling of surface salinity during SPURS-2
- Improved shipboard apparatus (shown), ancillary data (in-situ temperature & pressure, met data)
- Improved boom configuration (30ft total, adjustable)

# Conclusions

- TEOS-10 was officially adopted by the Intergovernmental Oceanographic Commission (IOC), International Association for the Physical Sciences of the Oceans (IAPSO) and the Scientific Committee on Oceanic Research (SCOR)
- Should be used for all publications
- Not needed for archival
- Density and spice are useful derived quantities
- Does it make sense to integrate this into the Aquarius product? If so, at which level?



*Thank You!*

*Questions*

