Review of the manuscript "TEOS-10 and the Climatic Relevance of Ocean-Atmosphere Interaction" by Rainer Feistel

This is an important manuscript that should certainly be published. Much of it is a review, and this is well written and is needed, given the large number of papers that have appeared on ocean, ice and air thermodynamics in the past 20 years. This review is also very appropriately submitted to *Ocean Science* since many of the recent papers on ocean thermodynamics have been published in *Ocean Science*.

There is an emphasis in the Abstract and Introduction on the alarming and unexplained global warming of 2023-2024. In the context of an academic review paper on ocean thermodynamics I think that this might be overdone and might make the review seem a bit dated when read in say 10 years' time. I recommend playing this down somewhat by delaying its discussion so that, while this issue is still there to gain the reader's attention, it does not distract from what is essentially a scholarly work.

Despite the theory of thermodynamics being 150 years old, it fell to the author, Rainer Feistel, to accurately derive the melting enthalpy and evaporation enthalpy (the so-called latent heats associated with these phase changes). These formulae were published by Rainer in his 2010 paper in Ocean Science, but since these papers are quite hard to penetrate for the uninitiated, the beauty of Rainer's derivations have been largely unappreciated. The enthalpy of evaporation is derived again in this review as Eqs. (23) and a careful reader can now follow and appreciate all the steps involved.

The review places a lot of emphasis on what thermodynamics alone can say about the causes of the increasing ocean heat content. This part of the review reflect recent research by Rainer Feistel, often published in conjunction with Olaf Hellmuth, which points out if the common assumption of the relative humidity of the atmosphere being constant was just a little in error, then there are rather large consequences for the rate of evaporation, and hence for what is typically meant by the "acceleration of the hydrologic cycle". The inclusion of this material in the review will give this idea much needed exposure to both the observational and the climate modelling community. This part of the review then extends into the trends in global-averaged cloudiness. I think that these topics which explain what thermodynamic theory says about evaporation at the air-sea interface, need to be understood by many more climate scientists, and I am very glad to see them appear in this review paper.

I identify one small part of this manuscript that I think is wrong and should be deleted, namely the part around Eq. (5). I will now describe this before then going on to list rather minor typographical things that might be corrected. Lines 290-307 of the manuscript discuss what is currently used (since TEOS-10) as the definition of ocean heat content (OHC). But then, between lines 308-323 a possible alternative definition of heat content is discussed, namely the one described by Eqn. (5). It is these lines 308-323, and Eq. (5), that I think should be deleted, because Eq. (5) does not describe a quantity that changes only due to the air-sea flux of heat, even for a very shallow ocean. To be specific, let us consider an ocean that is very shallow. In this case the TEOS-10 definition of heat content, Eq. (4), is exact in the sense that its increase or decrease is equal to the area-integrated air-sea flux of heat (air-sea enthalpy flux) [apart from the extra interior Joule heating caused by the dissipation of turbulent kinetic energy]. This is true even though the ocean is being subject to mixing and advection processes continually. Hence, we may speak of the definition Eq. (4) of OHC as being "conservative". However, this is not the case of the variable described by Eq. (5). Rather, this variable is "non-conservative", because even in the absence of any air-sea fluxes anywhere, lateral mixing of different "reference water parcels", each of which have zero entropy, but which have a variety of salinities, will result in an increase in entropy. This increase in entropy of the mixed "reference parcels" would require heat to come from the real seawater parcels in order to bring the "reference water parcels" back to zero entropy. This effect is not trivial. Looking at Figure A.16.1 of the TEOS-10 Manual (IOC et al (2010)), consider the mixing of two fluid parcels that both have zero entropy. To be specific, consider two fluid parcels both at zero Conservative Temperature and zero entropy, but one with Absolute Salinity just slightly greater than zero and the other with S_SO. When equal masses of these two fluid parcels are subject to interior ocean mixing, the well-mixed fluid will have the average Absolute Salinity and the average Conservative Temperature (which is zero) but will have a non-zero entropy (about 0.2K worth of entropy in temperature equivalent units). It is this non-conservative mixing of entropy, even when the entropy of the whole "reference state ocean" has zero entropy, that causes the non-conservation of Eq. (5) and hence invalidates it from being considered as a viable choice for "heat content".

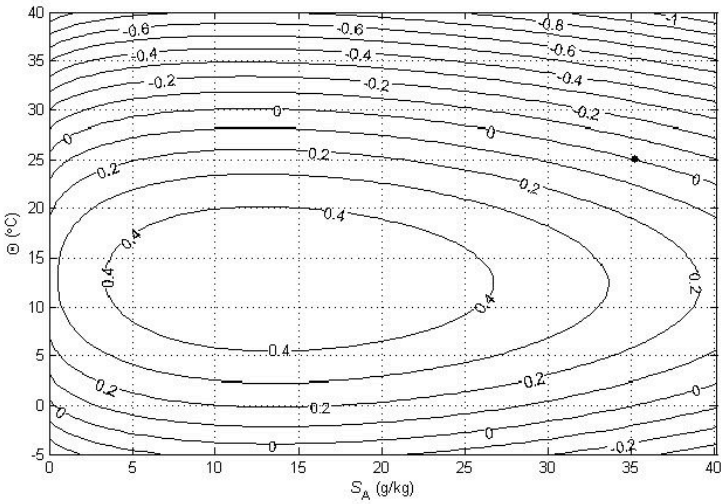

Figure A.16.1. Contours (in °C) of a variable which illustrates the non-conservative production of entropy η in the ocean.

Now for the small suggested changes.

Line 12. Replace "Here, history and properties ..." with "Here, the history and properties ..."

Lines 22-27. I discourage the inclusion of religion in scientific papers. First, the bible is not a scientific book, nor is it scientifically correct since its discussion of the arrival of humans on earth (in its first chapter) contradicts the known science of evolution. Second, scientific papers should be able to be read by authors of all religions without them encountering quotes which somehow endorses the basic textbook of one religion. Hence, I think that biblical quotes, just like quotes from the textbooks of any religion, should not be allowed in *Ocean Science*. Please delete these lines.

Line 48. "and is apparently even counting." I'm not sure what this means. Is it a typo?

Line 73. Replace "85% result from" with "85% results from"

Lines 202-203. Surely the water which IAPWS-95 describes is not Standard Mean Ocean Seawater.

Line 201 and in hundreds of places throughout the paper, Absolute Salinity and Conservative Temperature are used without their upper-case letters. This goes against what IOC et al. (2010) and Valladares, J., Fennel, W., and Morozov, E.G (2011) and Spall et al (2013) [see below] dictate. I think the field should stick with the upper-case letters, simply because there are many different possible definitions of absolute salinity and of conservative temperature, but there is only one definition (each) of Absolute Salinity and Conservative Temperature. Having said that, I have no problem with skipping on the subscript A in the symbol for Absolute Salinity if an author wishes to do so.

Line 244. Replace "thereof" with "thereby"

Line 272. Replace "entered of left" with "entered or left"

Line 335. Replace "suggests its" with "suggests a"

Line 397. Replace "eq. (e4.6)" with "eq. (12)"

Line 447. Replace "equating" with "equalling"

Line 654. Replace "hen-and-egg" with "chicken-and-egg" [since this is the more common expression in English].

Line 688. Should "minor rest" be "minor residual"?

Line 706. I think here T_0 is being used as a general reference temperature, rather than 273.15K. If so, perhaps the subscript could be changed.

Line 811. "but are, expectedly, also the". I'm not sure what this means. Please reword.

Lines 816-817. Replace "mainly focussed on ocean modelling," with "mainly focussed on ocean observations and modelling,"

Line 857. Is "Feistel et al. 2008" really "Feistel et al. 2008a"?

Line 896. Replace "derived thereof" with "derived therefrom"

Line 909. Replace “To the total energy E of the sample,” with “To the internal energy U of the sample,”

Line 911. Replace E with U in this and subsequent equations. IOC et al (2010) has used U and u for internal energy (extensive and intensive), and this review paper should do the same.

Line 957. Replace “(extensive) energy E” with “extensive internal energy U”

Line 974, equation (B.10) has a sign error. The last term should be added, not subtracted.

Line 974, equation (B.10). The things that are held constant during the differentiation in the last term in this equation are not correct. They should be the same as the corresponding term in the next equation. Eq. (B.11).

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EDITORIAL

In 2010, the Intergovernmental Oceanographic Commission (IOC; Chairman Javier Valladares), with the endorsement of the Scientific Committee on Oceanic Research (SCOR; President Wolfgang Fennel) and the International Association for the Physical Sciences of the Oceans (IAPSO; President Eugene G. Morozov), adopted the International Thermodynamic Equation Of Seawater—2010 (TEOS-10) as the official description of seawater and ice properties in marine science, to replace the 1980 International Equation of State of Seawater (EOS-80). The commission has urged all oceanographers to use the new TEOS-10 algorithms and variables to report their work. The TEOS-10 computer software, the official TEOS-10 manual, and other background and explanatory documents are available online (http://www.TEOS-10.org). The advantages of TEOS-10 relative to EOS-80 and guidelines on its usage are contained in those documents.

A prominent part of TEOS-10 is the adoption of a quantity referred to in the standard as “Absolute Salinity” (abbreviated in the standard as “S_A”) to describe the salinity of seawater. An associated quantity, which replaces potential temperature θ and accurately describes the heat content per unit mass of seawater, is referred to in the standard as “Conservative Temperature” (“Θ”). The leading uppercase letters in these two terms are a defined and integral part of the printed and approved TEOS-10 standard, as is the roman font for the subscripted A in the Absolute Salinity symbol. To foster proper usage of the TEOS-10 standard and to minimize confusion in the community, the American Meteorological Society (AMS) Publications Department and the field editorial staff of the *Journal of Physical Oceanography* (*JPO*) have opted, for these specific terms, to make an exception to the long-practiced AMS scientific-journal style rules that prohibit capitalization of variable names and stipulate that single-character subscripts will be typeset in italic font. This style policy will take effect with the publication in this issue of *JPO* of the article by Graham and McDougall titled “Quantifying the nonconservative production of Conservative Temperature, potential temperature, and entropy” and will be applied to all AMS journals from that point forward. Prior to now and since its introduction in McDougall’s 2003 *JPO* paper, Conservative Temperature had been typeset as “conservative temperature” in AMS journals.

It is hoped that these revisions to our editorial style will help to promote usage of the TEOS-10 standard in the scientific community and will encourage continuing publication of state-of-the-art physical oceanographic research in the AMS journals.

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