NOAA ROSES Semi-Annual Report

Reporting Period: September 2021 – February 2022 (3rd report)

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Project Title: Use of modern geostationary data to improve a global diurnal warming model for multi-satellite data fusion

Executive Summary (1 paragraph max)

Our previously reported validation results indicated that fairly substantial (although not physically unreasonable) tuning of empirical turbulence model parameters was required to obtain good results. These findings led us to consider revisiting the band definitions for in-water absorption. We have now performed rigorous calculations, using high resolution spectroscopic information, to ensure matching between atmospheric and in-water effects. Preliminary evaluation of the new parameterization has been performed, using our combined approach of comparisons to geostationary SSTs as well as oceanographic cruise data. This shows that our new radiance-weighted in-water absorption component permits a substantially more realistic distribution of diurnal warming on the basin-scale as observed by GOES-16. Meanwhile, high quality cruise validation now shows an overestimate of warming when using the previous turbulence model tunings – a result that is not unexpected. The impact of cloud on spectral band weights have also been calculated and, particularly for the case of water cloud, demonstrate drastic reduction in near-IR components that are responsible for the shallowest heating. All these findings all serve to underscore the critical importance of pursuing thorough calculation of the source heating terms, with subsequent turbulence model tunings via both large-scale and detailed validation. All validations datasets and modelling outputs continue to be made available to the community via web and FTP.

Progress toward FY21 Milestones and Relevant Findings (with any Figs)

Our previous modeling focused exclusively on the effect of clear-sky atmospheric effects on the incident shortwave radiation. The primary reason for this was that this aspect has almost entirely been neglected in comparison to fairly extensive modeling of variations in in-water absorption, particularly due to the presence of biological matter (chlorophyll, CDOM, etc.). In order to preserve compatibility with prior work on in-water absorption, we retained the 9-band absorption of Paulson & Simpson (1981), which itself can be traced back to Defant (1961). However, the tables in Defant find their origin in works that, in some cases, date back more than a century. Thus, it was deemed appropriate to recalculate the in-water absorption based on more modern complex refractive index information. The most useful source for this appears to be Segelstein (1981), which is a rigorous Kramers-Kronig analysis of a variety of data sources. The relatively high resolution of the Segelstein data makes accurate interpolation onto the 1 cm-1 grid of the Modtran atmospheric calculations quite straightforward. While a “simple” band-averaging might be considered adequate, it was decided to perform a case-by-case convolution of the downward radiance calculations all

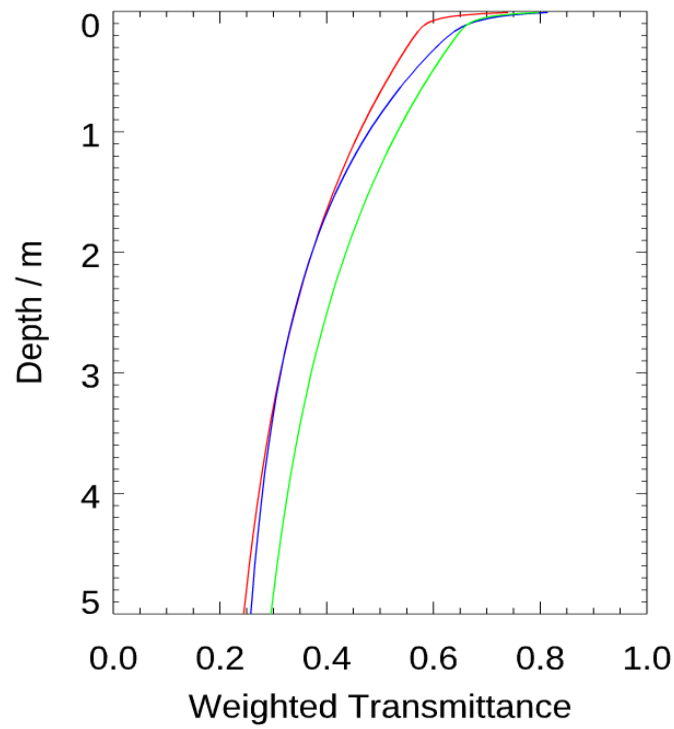


Figure 1. *Fraction of incident solar radiation as a function of depth. The original Defant is shown in red; our previous solar parameterization in green, and the latest parameterization in blue.*

1,358 atmospheric profiles, in order to properly account for (*i.e.* weight) in-band variations in heating. Thus, we now have tables of water vapor and solar zenith angle dependent in-water variations in 1/e depths, along with those for band Planck-weights. However, the straightforward average of flux-weighted 1/*e* depths actually accounts for the majority of the variation, and the residual effects of water vapor and view angle are fairly modest. The biggest change in in-water absorption occurs in the 2nd band, with the 1/*e* depth decreasing from ~2.3 m to ~1.4 m. Since this band has the highest Planck weight (approaching 40% of the total solar flux), the impact on the in-water heating profile is substantial. Figure 1 shows the contrast between the original Defant scheme, where ~40% of incoming solar radiation is absorbed in the top ~10 cm, the less intense near-surface absorption of our initial parameterization, and the latest version, which is more of an intermediate absorption profile. To reiterate – this is not an intentional "blend" of the two schemes, but rather the outcome of our much more detailed calculations for in-water absorption.

The impact of our new in-water absorption has been evaluated using both high-quality cruise data and NWP fluxes on the basin-scale. Comparisons of model predictions using our

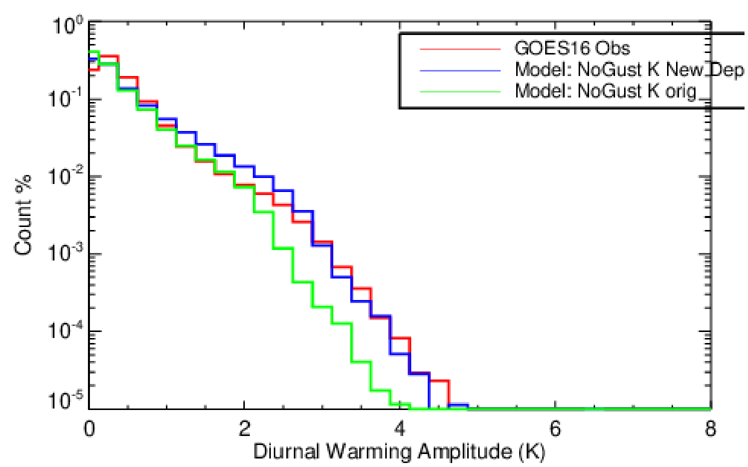


Figure 2. *Comparison of probability density functions for GOES-16 observed diurnal warming (red) and modeled warmings using previous (green) and new (blue) in-water absorption.*

previous and new insolation schemes against GOES-16 ABI observed diurnal warming are shown in Figure 2. The underestimation of the most extreme diurnal warming events is no longer present illustrating that the revised model is now able to successfully reproduce greater warming. There is evidence that the more moderate warmings (which are more prevalent – note the logarithmic scale) are now slightly overestimated relative to the satellite data, but the model tunings have not yet been optimized for the new insolation parameterization.

This is further borne out by comparisons using the more detailed DYNAMO cruise data (see Figure 3). The results below are shown for equivalent model configurations using the (left) first version of the refined absorption model and (right) the revised version with modified depth scales. Significantly increased diurnal warming is simulated with the revised version. The model was highly modified to turn off all wave effects to produce the initial results on the left and several of these modifications will no longer be required to produce favorable results using the revised version. This is a good illustration of the challenges in this work – model behavior is dependent on physics in the first instance, but (especially with turbulence modeling) there are unmodeled components that are parameterized, and the parameterizations are tunable (highly so in some instances, such as "background mixing", which can be varied by at least 2 orders of magnitude). Thus, as physics is improved, tunings need to be continually revisited.

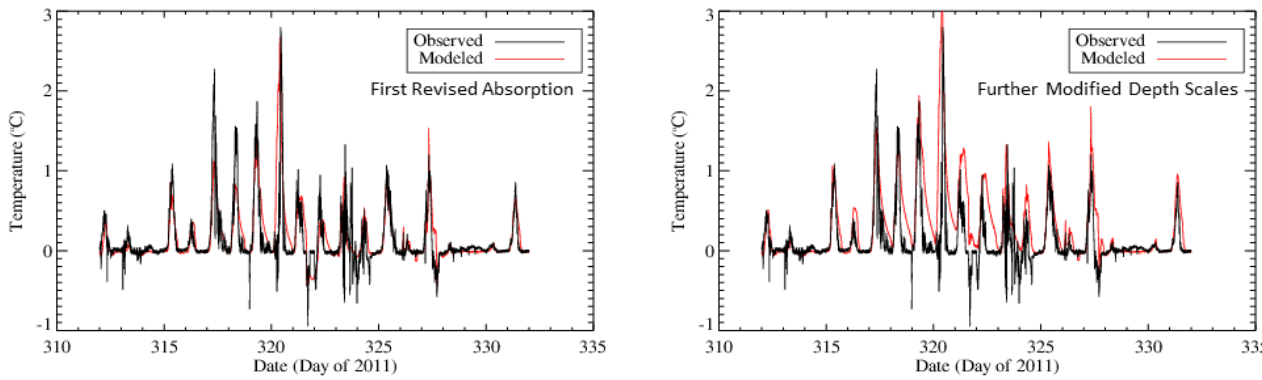
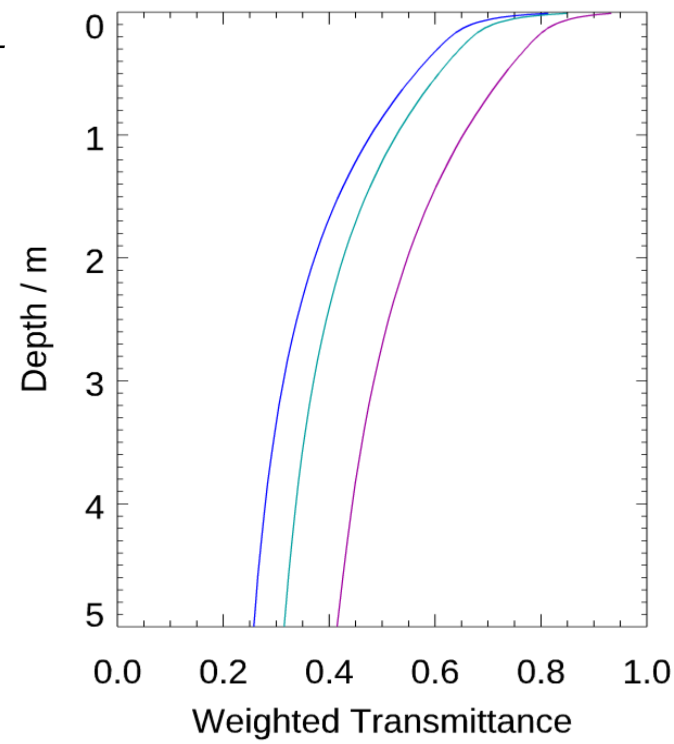


Figure 3. *Testing of the previous (left-hand panel) and new in-water absorption schemes using cruise data from DYNAMO experiment and the previous "optimized" model configuration. Note the larger warmings in the modeled results for the new in-water absorption cf. observations.*

Regarding improved physics, the other primary consideration for atmospheric effects is the presence of cloud. Although cloud fraction will reduce the shortwave flux, this is already taken care of in the NWP fluxes. The question that concerns us is the possible impact on the calculated Planck weights. We have performed Modtran calculations that include standard cloud prescriptions (two water cloud types, one ice cloud type). The simple Isaacs 2-stream approach utilized for clear-sky calculations proved inadequate for multiple-scattering in cloud, thus we adopted 8-stream DISORT. This increased the calculation time by about 2 orders of magnitude, thus representative subsets of the data were used to perform an initial assessment. As might be anticipated, the water clouds in particular greatly reduce the near-IR components (*i.e.* the most strongly absorbed in-water bands), while ice clouds have a less dramatic effect (see Figure 4). The implication is that near-surface heating rates under less than clear skies may be substantially reduced. This could explain the increased prevalence of moderate warming *cf.* observations that is observed in Figure 2. However, the calculations are not particularly usable in their current form because the optical depths of the default cloud types are rather large (~30-40 @0.55 μm), and the reduction in total shortwave flux is inevitably very substantial, to the point where almost no diurnal warming would be expected.

Figure 4. *As for Figure 1, but with our new clear-sky parameterization in blue, the equivalent in-water transmission profile for low stratus in purple, and high cirrus cloud in teal.*



We are revising the modelling scenarios to take this into account, and make the calculations more usable in terms of the available predictors in NWP fields.

Plans for Next Reporting Period

Progress to date has very much followed the scientific method. It is encouraging that the main factors which were originally identified as likely to be important have indeed proved to be so. Our two-pronged validation and tuning approach also provided indications that certain aspects of physics which were assumed to be largely correct actually needed to be revisited, and the impact on the in-water absorption coefficients will now be included in all future parameterizations. Specific plans for the next reporting period include:

- Perform full range of calculations for ice and water cloud types using appropriate scaling of optical extinction.
- Development and testing of cloud-dependent predictors to account for cloud type and fraction
- Replace the NCEP net shortwave flux with the downward component and a detailed accounting of band-dependent surface reflection
- Addition of refraction in the heating profile to improve estimates at lower sun angles
- Incorporation and testing of the cloud-dependent parameterizations in the global model calculations
- Revisiting of model tunings (especially nonlocal mixing and background mixing terms)
- Drafting of a manuscript on the validation of the baseline model configuration and comparison with other diurnal warming models is ongoing and planned for completion by the end of the project year.
    - Corresponding abstract “Evaluation of Modeled Diurnal Warming Estimates for Use in Producing SST Analyses” by G. Wick, S. Castro, A. Harris, J. Mittaz, and E. Maturi submitted to the 23rd Group for High Resolution Sea Surface

Temperature International Science Team Meeting with presentation planned for July.

- Continue production of DW amplitude products for operational geostationary satellites