

Report of Diurnal Variability Working Group

C Merchant (Chair), School of GeoSciences, University of Edinburgh, UK

Overview and context

As Chair of the DVWG, I must express up front my thanks to all who have contributed to the work of the group since the GHRSSST meeting in Melbourne in 2007.

The driver from the point of view of GHRSSST for research into DV in is the need to estimate real geophysical biases between different types of ‘sea surface temperature’ (SST) observations (skin ↔ subskin ↔ at depth ↔ foundation):

- to permit high temporal resolution SST analyses (resolve diurnal cycle)
- to maximise data use in operational systems (e.g, daytime observations)
- to combine different observations properly (infrared, microwave, in situ), e.g., in analysis of daily foundation temperature

More broadly, air-sea interaction in the long term can be modified by sub-daily near-surface variability¹, and so there is a fundamental contribution to be made to understanding the atmosphere-ocean system.

The amplitudes and dependencies of the average diurnal cycle in SST (as observed from space with a particular spatial resolution, ~25 km) are illustrated in Figure 1. Large diurnal excursions in SST occur when winds are light and insolation strong. On average, there is a classic shape to the daily cycle, with warming from shortly after dawn until a peak around 14h or 15h, followed by a slower decline. Near-surface ocean turbulence models forced with time-resolved insolation and constant winds typically reproduce this classic shape. Where winds are observed co-incidently with SSTs (such as with microwave imagers), the expected (mean) diurnal increment in SST (“dSST”) can readily be estimated, either from parameterisations of empirical data² or a look-up table.

However, it is not a case of “problem solved”: here are some of the complications.

1. The dSST is not in reality a unique function of wind and top-of-atmosphere insolation; it depends primarily on the history of heating (all net surface heat fluxes) and of wind speed from dawn to the time of observation. (Implicit here is the concept that the dSST is defined relative to the -- somewhat elusive -- “foundation SST”, the temperature prior to diurnal stratification on which the diurnal warm layer builds during the day.) Moreover, other factors exert a more subtle influence on dSST: any persistence of near-surface stratification from the previous day, the temperature and salinity of the water, the optical attenuation coefficient of the water, the short-term gustiness of the wind, and mixing from wave motions of non-local origin.
2. The dSST is resolution dependent. Infrared observations at 1 to 5 km resolution reveal structures not evident in microwave measurements at 25 km resolution. Point measurements from in situ radiometry or profilers point to three-dimensional aspects of diurnal warm layer formation with corresponding variability in dSST at horizontal scales $\ll 1$ km.
3. Empirical fits and look-up tables of dSST to instantaneous wind field estimates tend to underestimate dSST at low wind speeds. This partly arises through the asymmetric errors in wind estimates at low wind speeds coupled with the highly non-linear relationship between dSST and wind; the other contributing effect is that the fact that the instantaneous wind is low, it is more likely than not to have been higher (and thus tending to reduce dSST) earlier in the day.
4. Many SST observations do not have a contemporaneous wind estimate. Winds from numerical weather prediction (NWP) are an alternative source, but suffer from complex errors, such as there correctly being a minimum in the forecast wind field, but this being in the wrong location,

sometimes by hundreds of km. Moreover, global NWP fields are typically available at 6 hourly synoptic times and at ~100 km resolution, and do not therefore resolve either the time or space scales relevant to some major diurnal warming events.

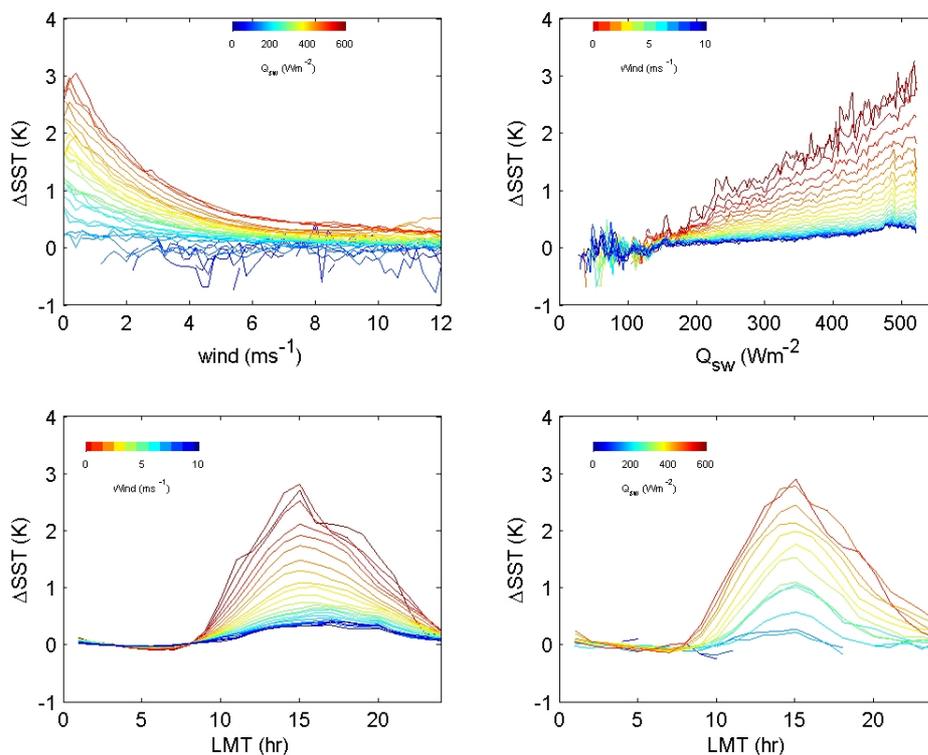


Figure 1. Amplitudes and dependencies of diurnal cycles in SST, analysed² by local mean solar time (LMT), top-of-atmosphere insolation (Q_{sw}) and wind speed, from averaging large volumes of data from a microwave imager aboard an asynchronous satellite.

At the Melbourne 2007 meeting of GHRSSST, the DVWG raised the question, in its break-out session, about how best to conceive of delivering usable dSST estimates to be associated with SSTs, within the GHRSSST systems of provider/RDAC/GDAC. At the working group meetings since, a clearer direction of travel has emerged, to be described below.

DVWG3 – Edinburgh, September 2007

The third working group meeting was hosted at Edinburgh, 19-21 September 2007, and involved the following participants: Sandra Castro, Gary Wick, Andrew Harris, Samantha Lavender, Dave Poulter, Chris Jeffrey, Helen Kettle, Owen Embury, John Stark, Karsten Fennig, Mark Filipiak, Pierre le Borgne and Chris Merchant. As usual, this list represents a mix of the core² active membership of the WG and of local interested parties who wished to participate. Working group meetings are always “open” affairs in that sense.

I won't summarize the whole meeting, just the some themes and activities that emerged from the event.

At the Edinburgh meeting, the “ALADIN+” data set contents were reviewed and finalized, and research using the data set started in earnest. This is a data set of high NWP fields resolution (Meteo-France's ALADIN model, 1 hourly, 0.1° spatially), married on a common grid with SEVIRI SSTs and fluxes, microwave SSTs and winds, ECMWF meteorology, AVHRR SSTs (when available, at higher resolution) and GlobColour fields of sea surface optical properties. The period covered is April to September 2006; the area covers the Western Mediterranean, Bay of Biscay and Irish and North Seas. Published results³ using the ALADIN+ data have identified (1) an effect of ocean colour on the spatial distribution of dSST

in the North Sea, and (2) orographic influences on the wind field that in turn affect the spatial distribution of dSST in the W Mediterranean – see Figure 2. Peak dSSTs in excess of 6 K were shown to be rare but readily observable from space in this area, with a $1:10^4$ mean likelihood of occurring at a given place per day (from April to September). Point in situ observations will be unlikely to observe these “extreme” >6 K dSSTs: one would have to cruise the area for 50 summers on average to observe one occurring. Moreover, on the assumption that the statistical distribution of the ALADIN wind field are reasonably realistic, we demonstrated that instantaneous winds cannot predict extreme dSSTs because the minimum wind speed of 0 m/s occurs too frequently. Persistently low winds over several hours from about 9h can, however, account for the dSST extremes.

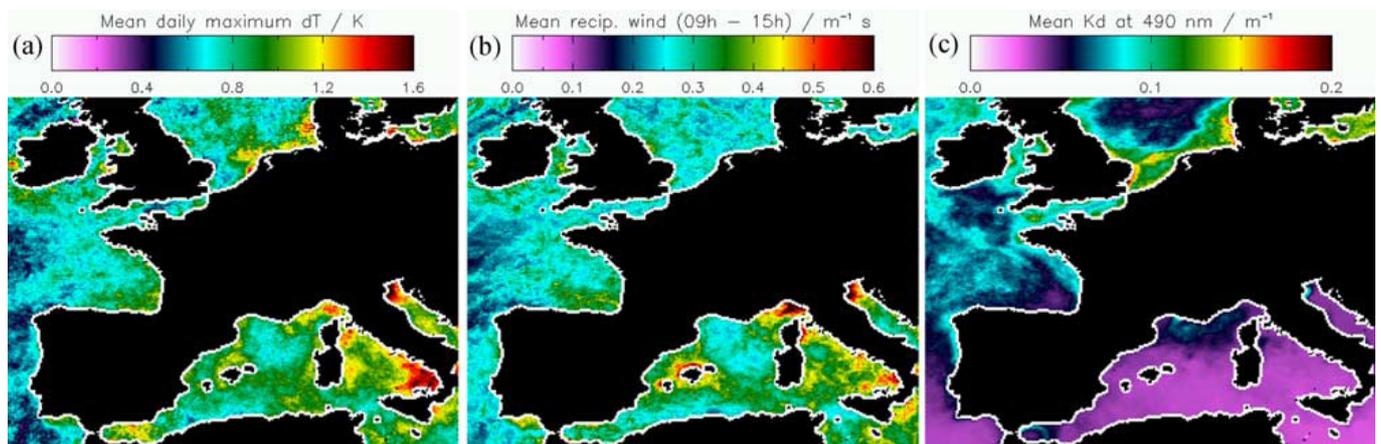


Figure 2 (a) Mean of the daily maximum of the diurnal cycle in sea surface temperature over the study area and period. (b) Aladin 0.1_ resolution wind field, represented by the mean of the reciprocal of the wind speed between 0900 and 1500 h UTC. (c) Mean of the diffuse attenuation coefficient at 490 nm. From [3].

The question was raised in the meeting as to whether the SEVIRI based SSTs derived in the ALADIN+ data set could be biased in their amplitude. The worry was that the peak dSSTs reported above may be exaggerated by some retrieval artefact. Embury undertook a radiative transfer simulation study during the meeting that showed that, apart from at the extreme limb of the satellite view, exaggeration of dSST in day-night differences of SEVIRI were very unlikely. In fact, in most cases, the SEVIRI retrieval algorithm has a sensitivity to dSST of between 0.8 and 1.0, implying the true dSST amplitude may be underestimated in the ALADIN+ data set.

The group debated at length what should be our strategy for supporting L2P producers to generate a dSST (with error) to associate with their SST fields. We concluded that a centralized capability within the GHRSSST system will be required. The concept proposed is a facility that allows producers to obtain (for the nearest hour to the observation time) either a dSST estimate, or any of the auxiliary parameters they require to create a dSST estimate and which they may not be able to source locally. This conclusion was driven by the likelihood that the complexity of the dSST estimation problem will require a relatively complex solution.

DVWG4 – Orlando, March 2008

The fourth working group meeting met over the weekend prior to the Oceanography and Limnology meeting in Orlando⁴, on the 1-2 March. In addition, during the conference, a well-attended session on broader aspects of diurnal variability in the ocean was held, and an evening open working group meeting (with refreshments) on the 4 March attracted several interested parties and GHRSSST “regulars”. In attendance for at least part of the weekend workshop were Sandra Castro, Gary Wick, Andrew Harris, Samantha Lavender, Dave Poulter, Chris Jeffrey, Helen Kettle, Owen Embury, John Stark, Mark Filipiak, Pierre le Borgne, Gary Corlett, Chelle Gentemann, Peter Minnett, Craig Donlon, Ken Casey, Helen Beggs, Fred Wimmer and Chris Merchant. Again, I present here only a sample of the work discussed and developed during this working group meeting.

Stark and Beggs showed the results of foundation SST analysis experiments in which a look up table for dSST was used to increase the daytime flow of observations (because fewer low-wind-speed SSTs were excluded from the analysis). Broadly, in both cases, the impact on analysis residuals was neutral using initial techniques, partly because the additional data tended to arise from locations where night-time observations already existed. Discussion generated many ideas for refined experiments.

Three partners in the DVWG are planning experimental hourly analyses of ocean surface diurnal variability within the next two years. These new products will benefit from the significant progress (recent and ongoing) in physical (Castro, Wick, Gentemann) and novel statistical (Filipiak, Merchant) models of diurnal warming. In particular: Wick presented progress on modifying a Kantha-Clayson class model by blending a background convective mixing term across a wind speed boundary of 2 m/s, which then showed excellent reconciliation with cruise data; Gentemann reported on plans for releasing the POSH model (described at GHRSS8, Melbourne); Merchant showed a statistical model for dSST in the ALADIN+ domain which captures the full range of dSST up to >6 K, being based on the persistence of low winds rather than instantaneous winds.

Highlights of the concluding open session of the working group included some new results derived during the working group meeting:

Gentemann showed comparisons between 6 models of diurnal variability applied to a test day (17th July 2006, ALADIN+ domain) in comparison with SEVIRI-inferred dSST, see Figure 3 for example.

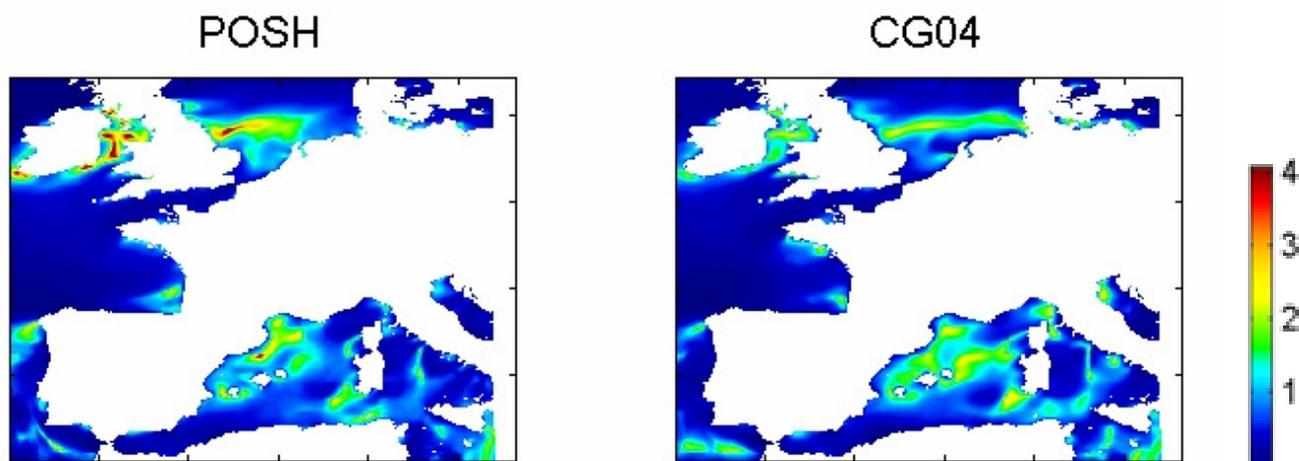


Figure 3. Comparisons of modelled dSST at 12h UTC, 17/7/6. Comparison of fast model (POSH) with statistical model (Gentemann, 2004). In common with most statistical models CG04 underestimates peak warming (yellow = 3°C warming) compared to the POSH model, which, with peak warming in excess of 4°C is more realistic compared to the matching SEVIRI observation (see Figure 4 for observed dSST values).

Merchant discussed steps towards hourly analysis of dSST, by blending observations and models. He presented an example (Figure 4) developed during the workshop in which prior ECMWF wind field was blended with a wind field inferred from the diurnal warming from SEVIRI (where available, by inverting the statistical dSST model). This created a spatially complete dSST analysis (observation-model synthesis) for every hour, and showed that the original ECMWF winds were unrealistically high in some places. While very experimental, this does suggest that L4 or even near-real-time analysis of hourly dSST is a real possibility. A challenge will be to extend the technique to more observation-sparse situations.

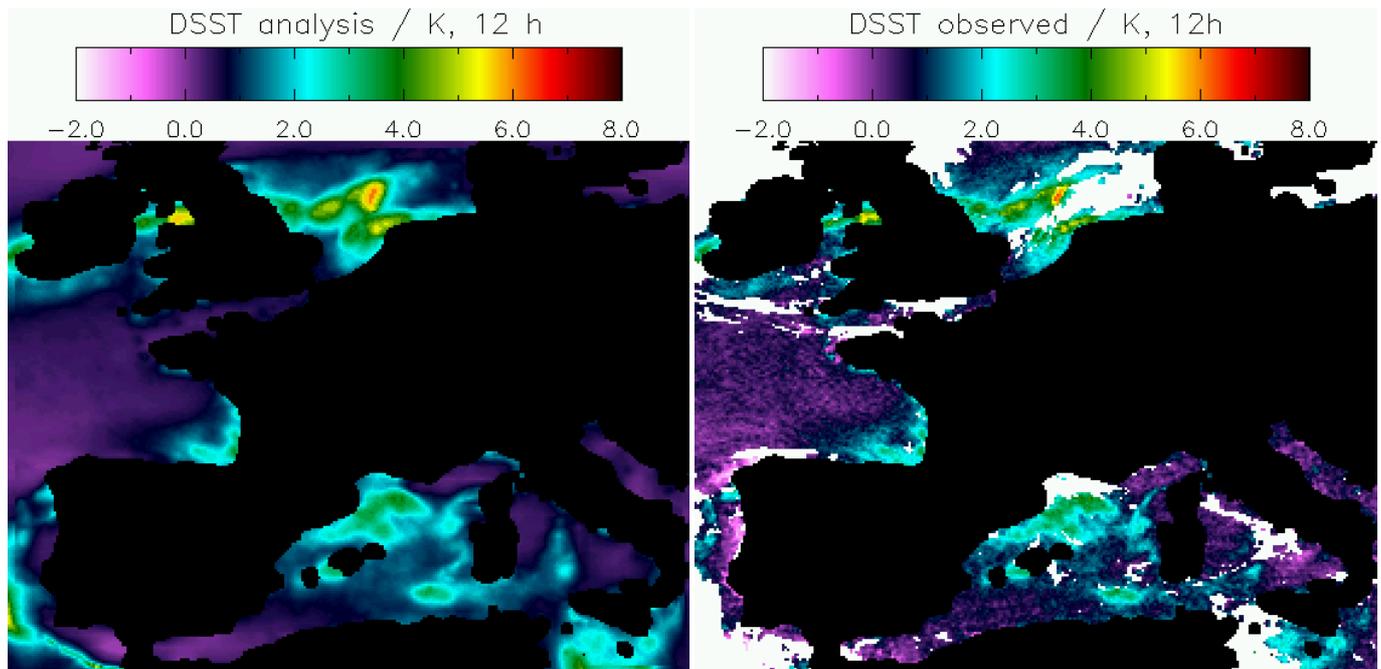


Figure 4. Spatially complete hourly dSST analysis based on an experimental blend of ECMWF and SEVIRI-dSST-derived winds. Right, corresponding SEVIRI-observed dSST for the same hour.

Poulter showed strikingly different outcomes of a diurnal warming analysis tool newly incorporated into the Diagnostic Data Set facility of GHRSSST. This clearly made the point that dSST is very different at different locations and that DDS can be used to explore that.

Beggs showed examples of why diurnal warming of the waters to the north of Australia is significant for analysis and may not be adequately understood at present. The DVWG agreed that a tropical equivalent of the ALADIN+ data set is a top priority to advance this line of research, and this is now underway. In discussion, the possibility was raised of “operationalizing” ALADIN+; this would clearly be valuable, and will be followed up in due course.

Concluding remark

The recent work on observational data sets, fast modelling of DV and hourly dSST analysis is developing the understanding and tools necessary to underpin GHRSSST needs and fundamental science. The upcoming challenge of embedding this progress in practical systems will be comparably demanding.

¹ For example: Kettle H and Merchant C J, Systematic errors in global air-sea CO₂ flux caused by temporal averaging of sea-level pressure, *Atmos. Chem. Phys.*, 5, 1459-1466, 2005.

² Gentemann, C. L., C. J. Donlon, et al. (2003). “Diurnal signals in satellite sea surface temperature measurements.” *Geophysical Research Letters* 30(3): 1140.

³ Merchant, C. J., M. J. Filipiak, P. Le Borgne, H. Roquet, E. Autret, J.-F. Piolle, and S. Lavender (2008), Diurnal warm-layer events in the western Mediterranean and European shelf seas, *Geophys. Res. Lett.*, 35, L04601, doi:10.1029/2007GL033071.

⁴ The running costs of the working group meeting were funded under the UK’s Natural Environment Research Council grant NE/D011582/1, gratefully acknowledged.