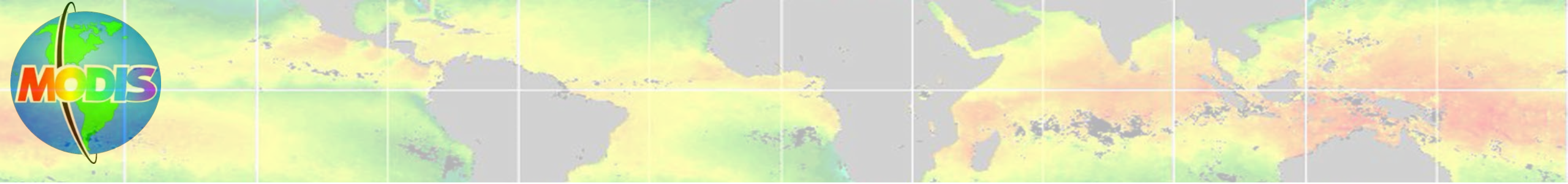

Studies of Arctic diurnal variability in skin sea surface temperature from MODIS enabled by the orbital drift of *Terra* and *Aqua*.

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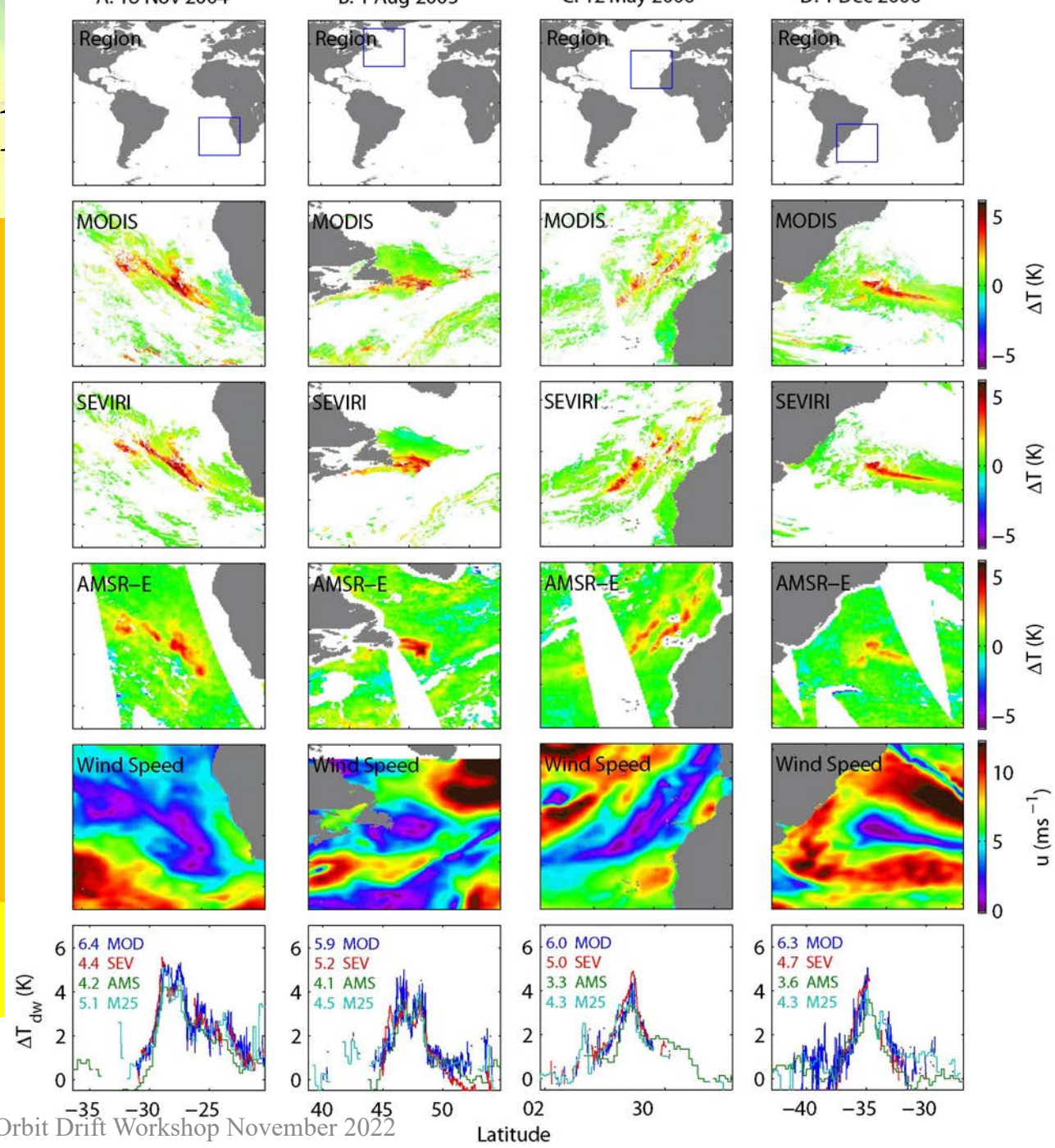
Large amplitude diurnal heating is identified in independent satellite data.

From Gentemann, C. L., P. J. Minnett, P. LeBorgne, and C. J. Merchant, 2008: Multi-satellite measurements of large diurnal warming events. *Geophysical Research Letters*, 35, L22602. doi:10.1029/2008GL035730

warming events. *Geophysical Research Letters*, **35**: L22602. doi:10.1029/2008GL035730



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Consequences of Neglect

- Failure to account for diurnal heating leads to significant errors in estimates of air-sea heat, momentum and gas exchanges and local heat and water budgets.
- Marullo et al. (2016) used one year of geostationary satellite SST measurements of the Mediterranean Sea and found neglecting diurnal heating leads to large errors in the surface heat budget: annual mean error was 4 Wm^{-2}, and nearly double in summer.
- Marullo et al. (2016) also found that neglecting diurnal heating led to errors in the Mediterranean Sea water budget and consequently uncertainties in the estimates of its water mass formation and thermohaline circulation.
- The correct depiction of diurnal heating is also important for proper representation of air-sea exchanges of heat, moisture, and momentum in numerical weather prediction and climate models, and in air-sea exchanges of gases including CO_2.
- Imaging radiometers on geostationary satellites provide good measurements to study diurnal heating at mid- and low-latitudes, but not at high latitudes.

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Marullo, S., Minnett, P.J., Santoleri, R., & Tonani, M. (2016). The diurnal cycle of sea-surface temperature and estimation of the heat budget of the Mediterranean Sea. *Journal of Geophysical Research: Oceans 121*. 10.1002/2016jc012192

MODIS Arctic SST_{skin} Retrievals.

- R2016 MODIS SST retrievals showed larger errors at high latitudes.
- Improved algorithms used in R2019 reprocessing increased accuracy.
- MODIS SSTs are now more suited to high latitude research. This is important given Arctic Amplification of climate change and the role of temperature feedbacks.

QL = 0	N	R2016				R2019			
		Mean	Median	STD	RSD	Mean	Median	STD	RSD
Night	31604	-0.535	-0.495	0.536	0.441	-0.163	-0.134	0.467	0.395
Day	17195	-0.383	-0.315	0.590	0.419	-0.033	0.010	0.515	0.402
Night & Day	48799	-0.482	-0.430	0.560	0.448	-0.117	-0.087	0.489	0.405

SST_{skin} error statistics compared to buoy measurements

Distribution of Aqua best quality SST matchups with drifting buoy measurements from 2013 to 2017. From Jia, C., & Minnett, P.J. (2020). High latitude sea surface temperatures derived from MODIS infrared measurements. Remote Sensing of Environment 251, 112094. https://doi.org/10.1016/j.rse.2020.112094

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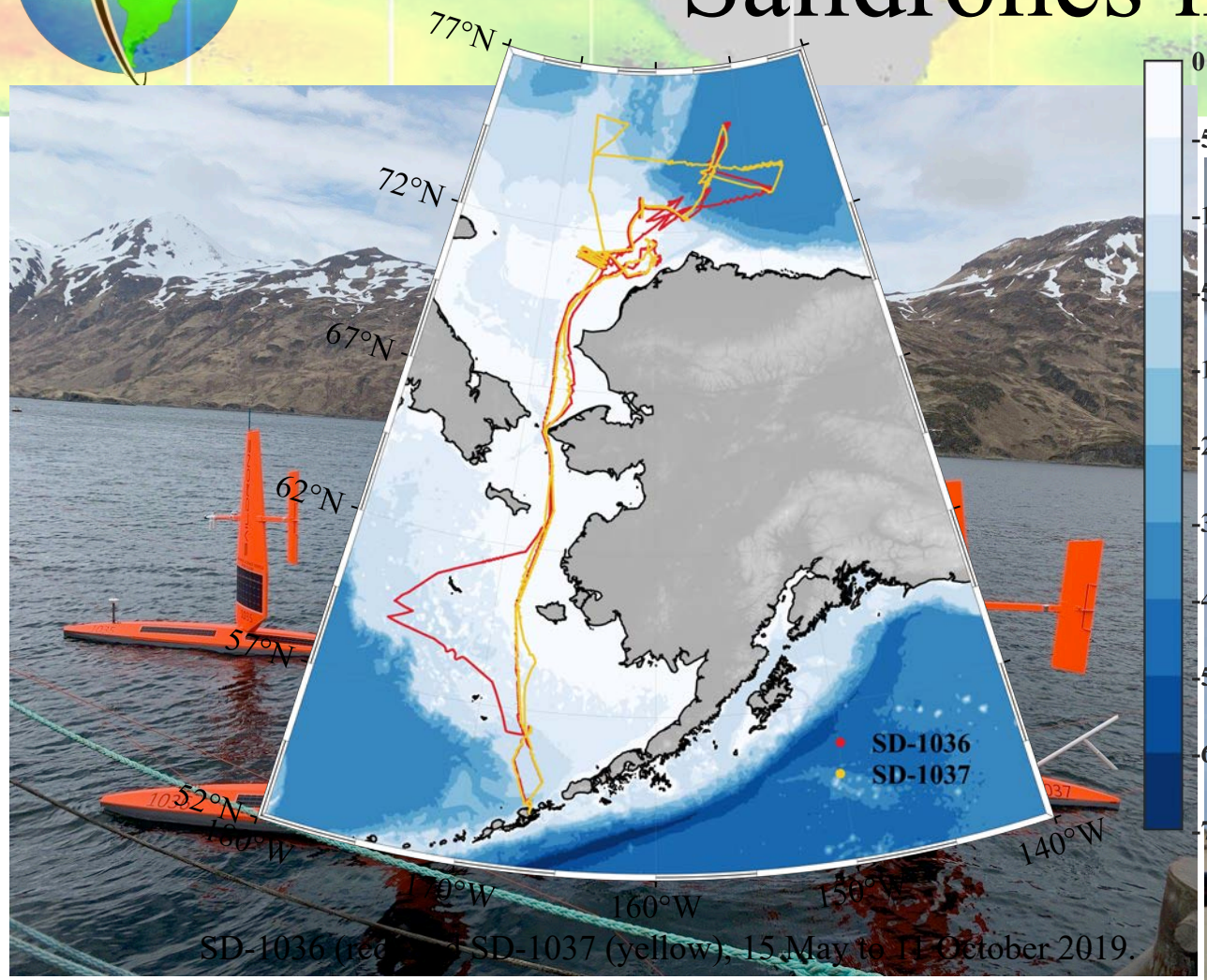
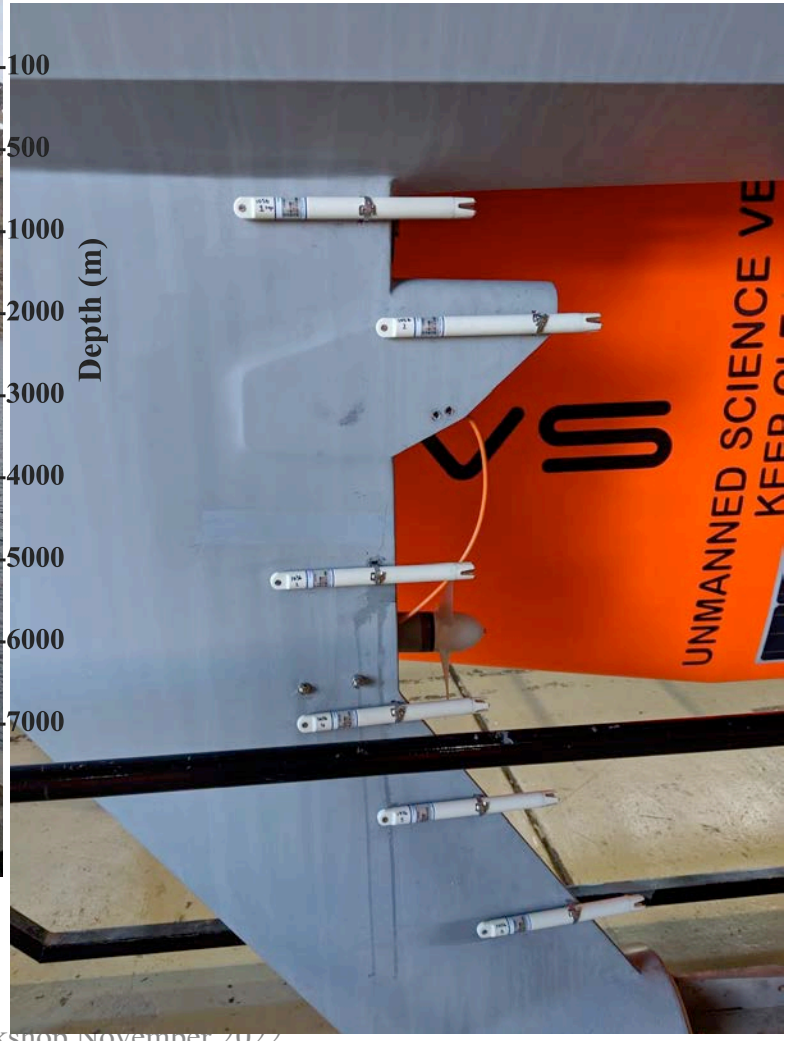
Saildrones in the Arctic



SD-1036 (red) and SD-1037 (yellow), 15 May to 11 October 2019.



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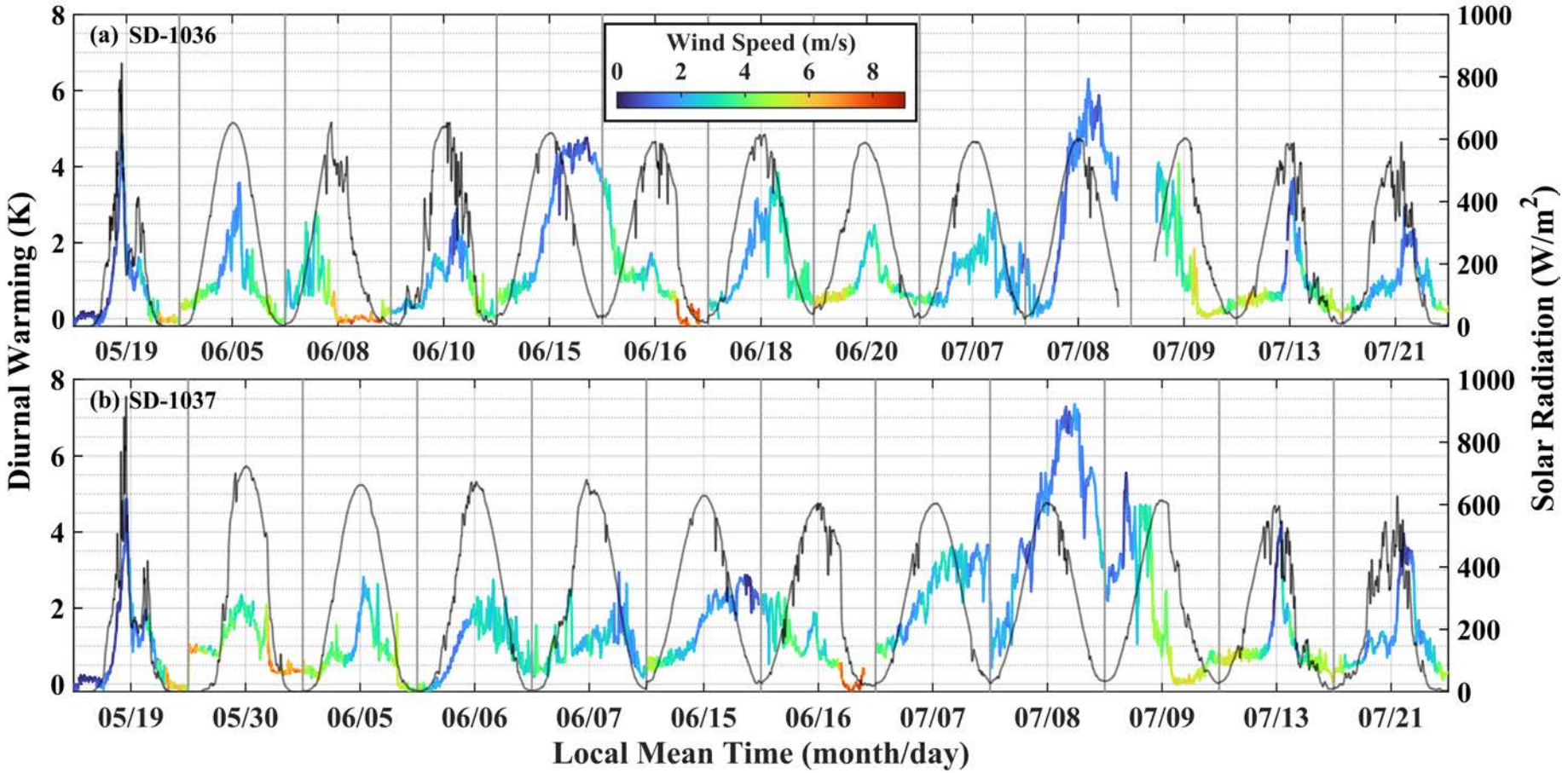
Measured Diurnal Heating

Examples of diurnal warming (SST_{skin} – $SST_{1.71m}$), 5-min intervals in 24 hours (colored by wind speed) and solar radiation (black line), as a function of local mean time (LMT) for days with warming > 2 K. (a) SD-1036 and (b) SD-1037. The vertical lines separate each day.



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Jia, C., & Minnett, P.J. (2022). Significant Diurnal Warming Events Observed by Saildrone at High Latitudes. *Journal of Geophysical Research Submitted*. https://doi.org/10.1002/essoar.10512612.1

Arctic Diurnal Heating

Diurnal warming 19 May 2019.

(a) Surface diurnal warming (black) and wind speed (blue) The background is colored by insolation.

(b) Temperatures relative to $SST_{-1.71\ m}$ (background); time series of SST_{skin}, T_{air}, and subsurface SSTs.

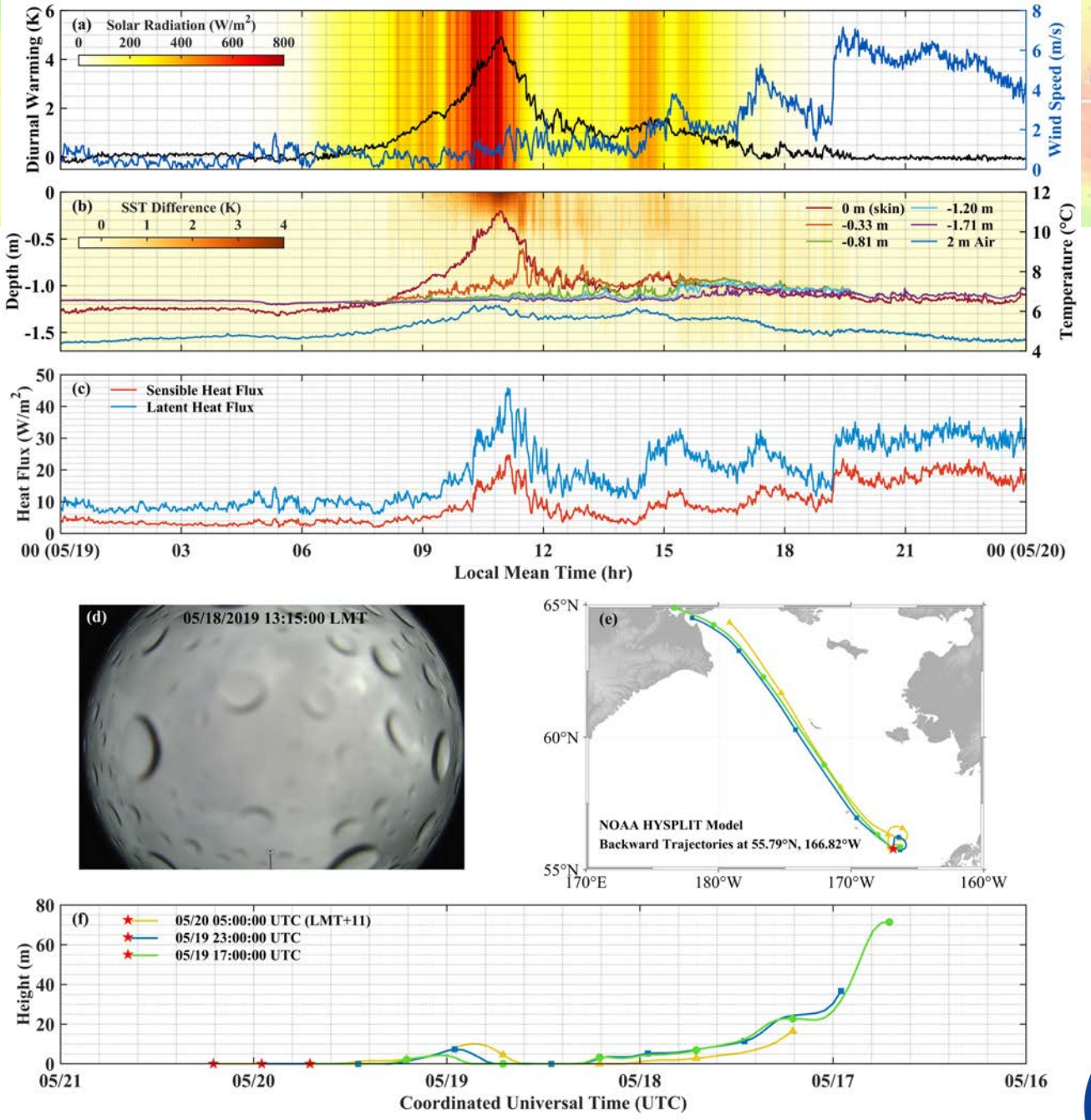
(c) Calculated sensible and latent heat fluxes at the surface (positive upward).

(d) Up-looking image at 13:15 LMT, 18 May 2019, indicating rainfall.

(e) Backward atmospheric trajectories at three times during the warming event are modeled by NOAA HYSPLIT. The red star represents the start location.

(f) The height of air along each trajectory output from HYSPLIT.

Image courtesy Saildrone Inc. Used with express permission.



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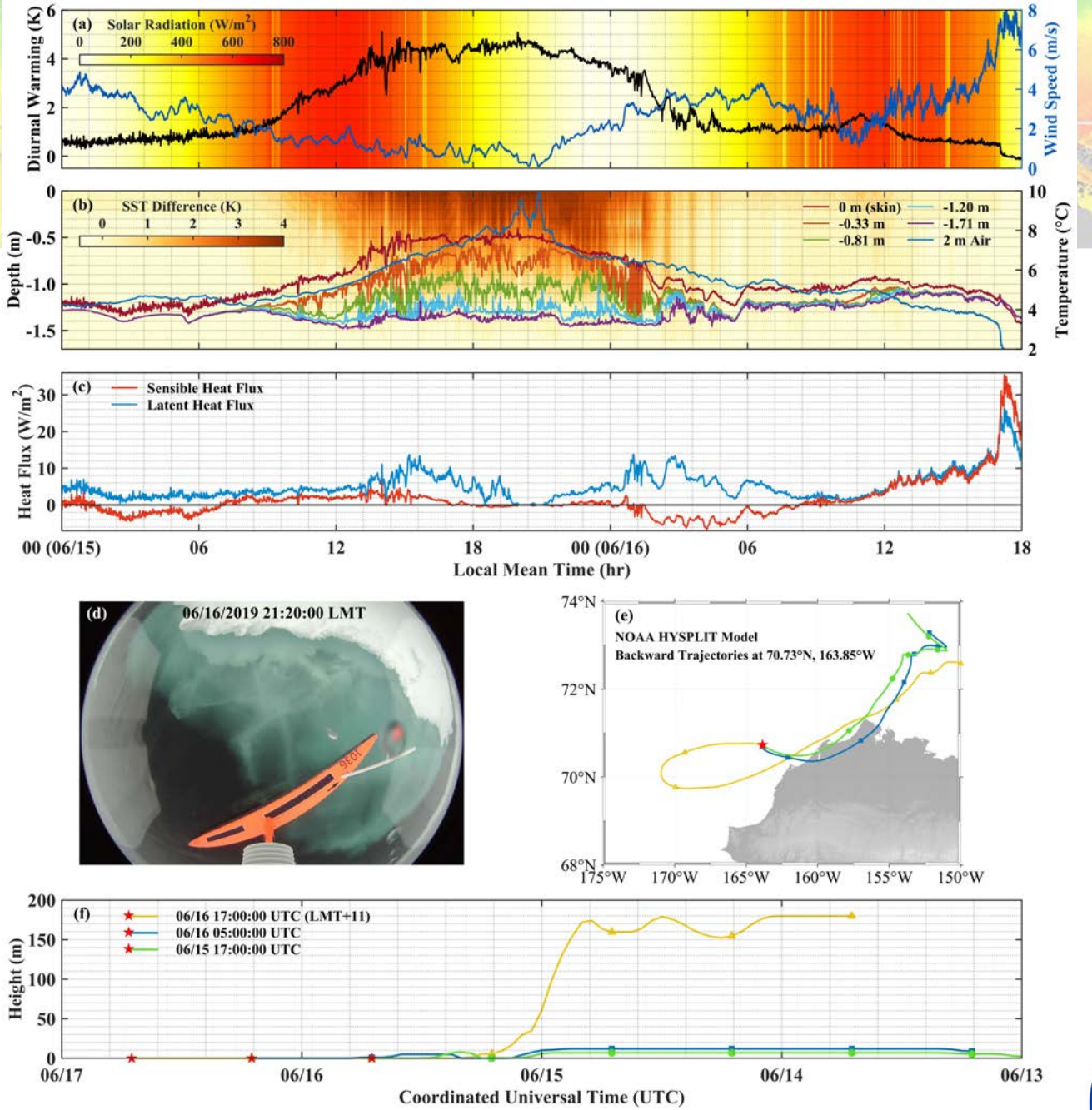
Jia, C., & Minnett, P.J. (2022).

Arctic Diurnal Heating

As before, but for the diurnal warming on 15-16 June 2019.

Down-looking camera image shows proximity to melting sea ice. As with precipitation, sea-ice melt introduces a surface low salinity layer that can stabilize the near-surface water enhancing the likelihood of reduced vertical mixing and facilitating diurnal heating.



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Jia, C., & Minnett, P.J. (2022).

Arctic Diurnal Heating

As before, but for the diurnal warming on 7-8 July 2019.

Side-looking camera image shows diurnal heating can occur without precipitation or sea-ice melt.

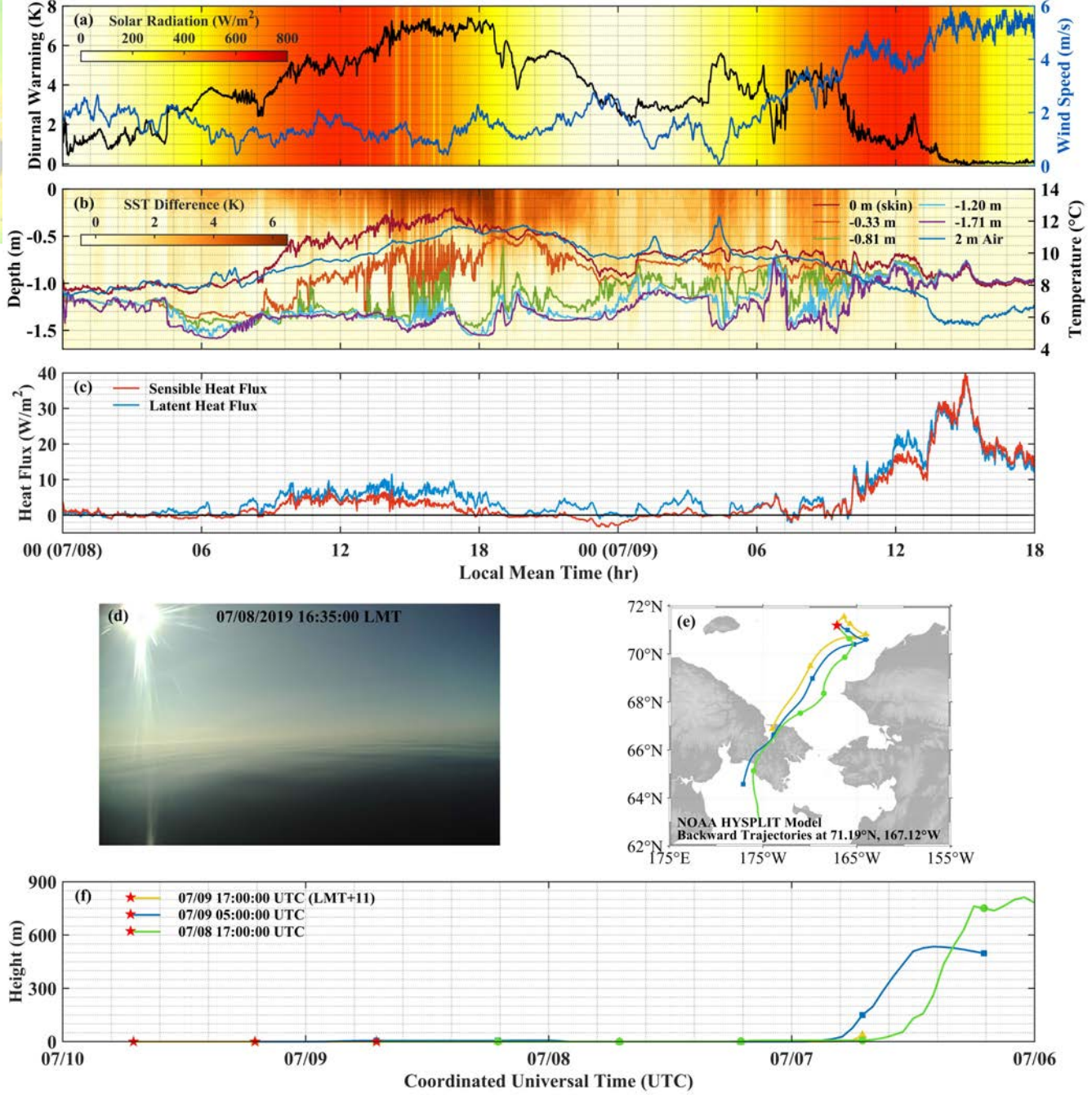

Image courtesy Saildrone Inc. Used with express permission.

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Jia, C., & Minnett, P.J. (2022).

Diurnal Heating Statistics

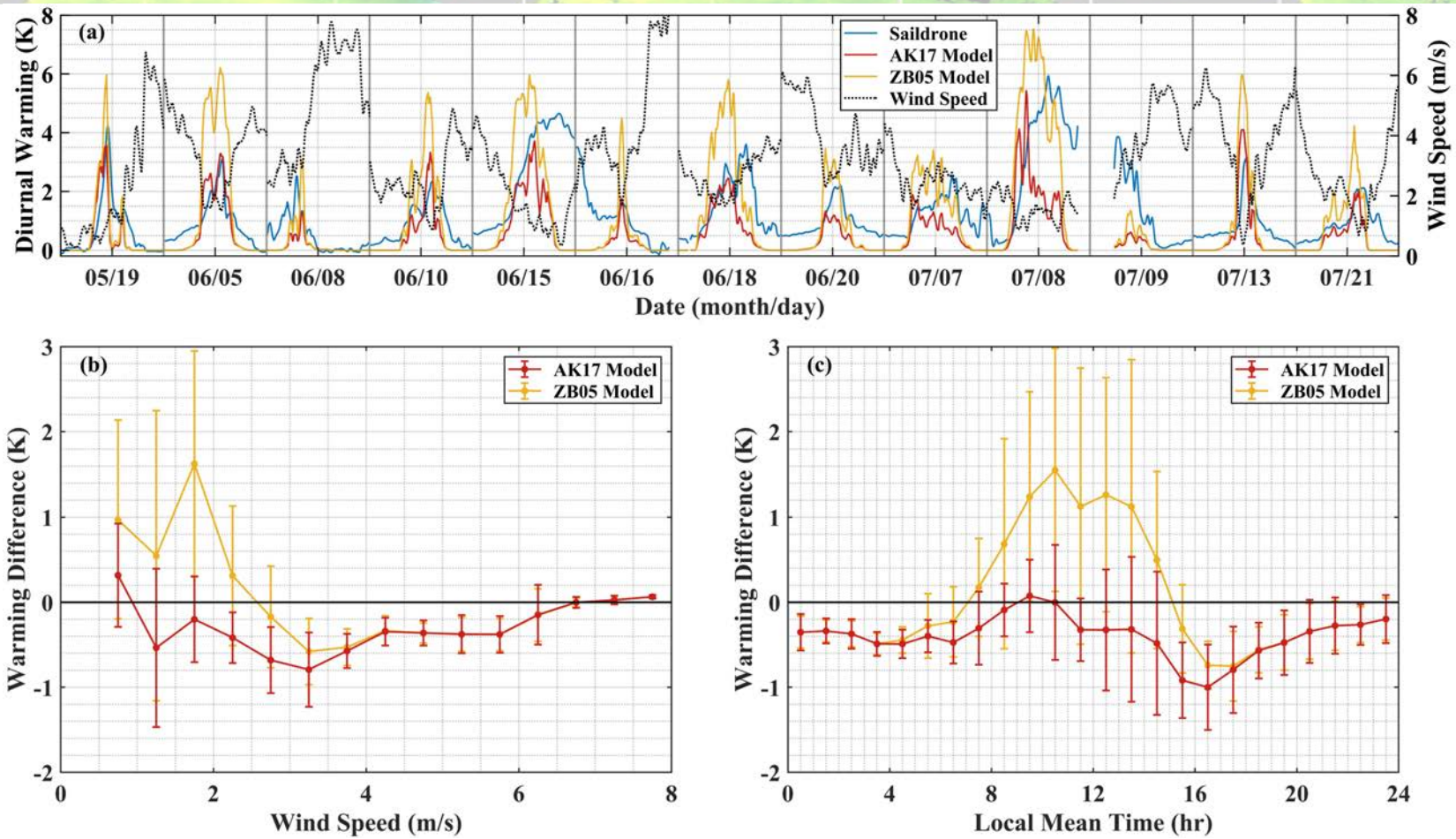
Occurrence of daily maximum diurnal warming (SST_{skin}-$SST_{1.71m}$) measured by SD-1036 and SD-1037.

	< 1 K	1 - 2 K	2 - 3 K	3 - 4 K	4 - 5 K	> 5 K	Days > 1 K	Days of Data*
SD-1036	42	17	12	3	3	2	37	79
SD-1037	64	32	8	4	2	2	54	112

*Excludes days when SST_{skin} retrievals were contaminated by rainfall or ice in the sea view. Later in the deployments, the radiometers were shut down due to power limitations.

Model comparisons

Diurnal warming from SD-1036 (blue), simulated by AK17 (red) and ZB05 (yellow); 10 m wind speeds (black). Model-Saildrone diurnal warming as *f*(wind) (b) and *f*(LMT) (c) as mean and robust standard deviation of the differences at 0.5 ms^{-1} and 1 hr intervals.



AK17 - Akella, S., Todling, R., & Suarez, M. (2017). Assimilation for skin SST in the NASA GEOS atmospheric data assimilation system. *Q. J. Roy. Met. Soc. 143*, 1032-1046. doi:10.1002/qj.2988

ZB05 - Zeng, X., & Beljaars, A. (2005). A prognostic scheme of sea surface skin temperature for modeling and data assimilation. Geophysical Research Letters 32, L14605. doi:10.1029/2005GL023030

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Conclusions

- Based on recent Saildrone measurements, diurnal heating at high latitudes is frequent and can reach large amplitudes.
- Areas are beyond sampling of geostationary imagers.
- Swath overlap of MODIS (and other imaging radiometers on polar orbiters) can provide good diurnal sampling at high latitudes.
- Accuracies of R2019 SST_{skin} retrievals from MODIS on Terra and Aqua are sufficient to resolve these signals.
- Current models used at GMAO and ECMWF do not simulate measurements to good accuracy.

Studies of Arctic diurnal variability in skin SST from MODIS enabled by the orbital drift of *Terra* and *Aqua*.

How widespread is diurnal heating at high latitudes?	Don't know.
How frequent is diurnal heating at high latitudes?	Don't know.
Is there a difference between Atlantic and Pacific Sectors of the Arctic?	Don't know.
How does diurnal heating influence air-sea exchanges in the Arctic?	Don't know.
How does diurnal heating influence thermal feedbacks in the Arctic?	Don't know.
Can upper ocean models replicate diurnal heating in the Arctic?	No.
Would more data help improve upper ocean models' ability to replicate diurnal heating in the Arctic?	Yes.
Can measurements from MODIS in drifting orbits contribute to studies?	Yes.

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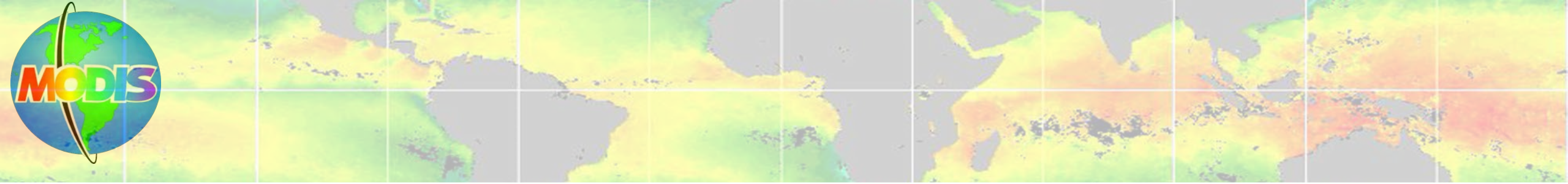

Thank you for your attention.

Questions, comments?