High latitude skin temperatures

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Overview

- Motivation – To provide accurate Sea-Surface Temperatures (SSTs) in the Arctic to study the Arctic Amplification of Climate Change.
- Background.
- Problems with deriving SST_{skin} from satellites.
- Assessing accuracies of satellite-derived SST_{skin}.
- Radiometers and Saildrones.
- Issues with the Arctic Atmosphere.
- Future prospects.

Human contributions to CO_2

Svante Arrhenius

- Showed that burning coal increased atmospheric CO_2 will lead to heating at the surface.
- Argued that the Arctic would be the first area to reveal the effects of CO_2 induced climate change.
- Predicted doubling CO_2 would lead to an average increase in global surface temperatures within 2x of current estimates.

THE

LONDON, EDINBURGH, AND DUBLIN

PHILOSOPHICAL MAGAZINE

AND

JOURNAL OF SCIENCE.

[FIFTH SERIES.]

APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* By Prof. SVANTE ARRHENIUS *.

I. *Introduction : Observations of* Langley *on Atmospherical Absorption.*

A GREAT deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndall † in particular has pointed out the enormous importance of this question. To him it was chiefly the diurnal and annual variations of the temperature that were lessened by this circumstance. Another side of the question, that has long attracted the attention of physicists, is this : Is the mean temperature of the ground in any way influenced by the presence of heat-absorbing gases in the atmosphere? Fourier‡ maintained that the atmosphere acts like the glass of a hot-house, because it lets through the light rays of the sun but retains the dark rays from the ground. This idea was elaborated by Pouillet § ; and Langley was by some of his researches led to the view, that " the temperature of the earth under direct sunshine, even though our atmosphere were present as now, would probably fall to −200° C., if that atmosphere did not possess the quality of selective

* Extract from a paper presented to the Royal Swedish Academy of Sciences, 11th December, 1895. Communicated by the Author.
† 'Heat a Mode of Motion,' 2nd ed. p. 405 (Lond., 1865).
‡ *Mém. de l'Ac. R. d. Sci. de l'Inst. de France*, t. vii. 1827.
§ *Comptes rendus*, t. vii. p. 41 (1838).

Phil. Mag. S. 5. Vol. 41. No. 251. *April* 1896. S

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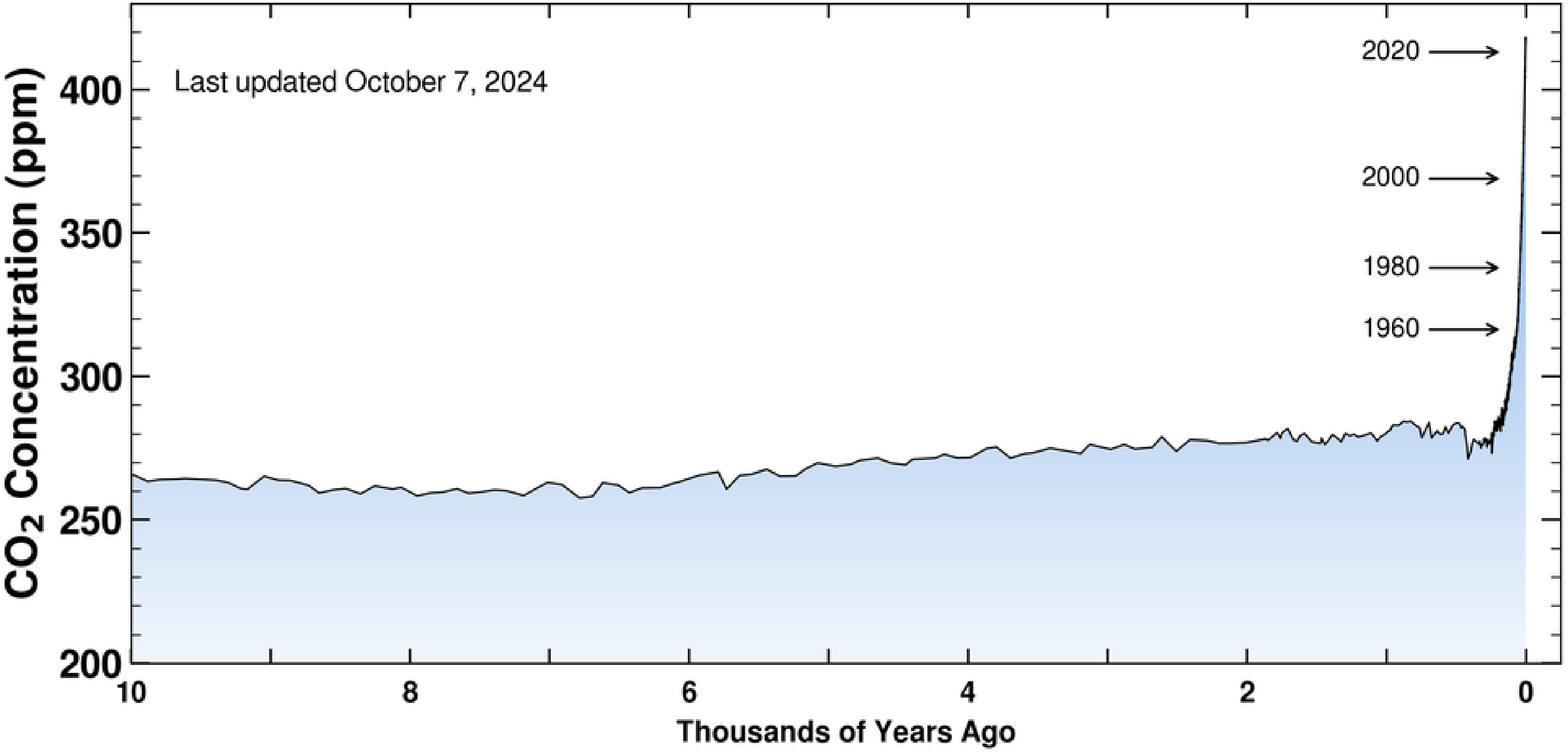
Background - greenhouse gases

Charles David Keeling

- Began taking daily measurements of atmospheric CO_2 on the summit of Mauna Loa in March 1958.
- Measurements continue, led by Ralf Keeling.
- Now augmented by NOAA measurements.



https://keelingcurve.ucsd.edu/

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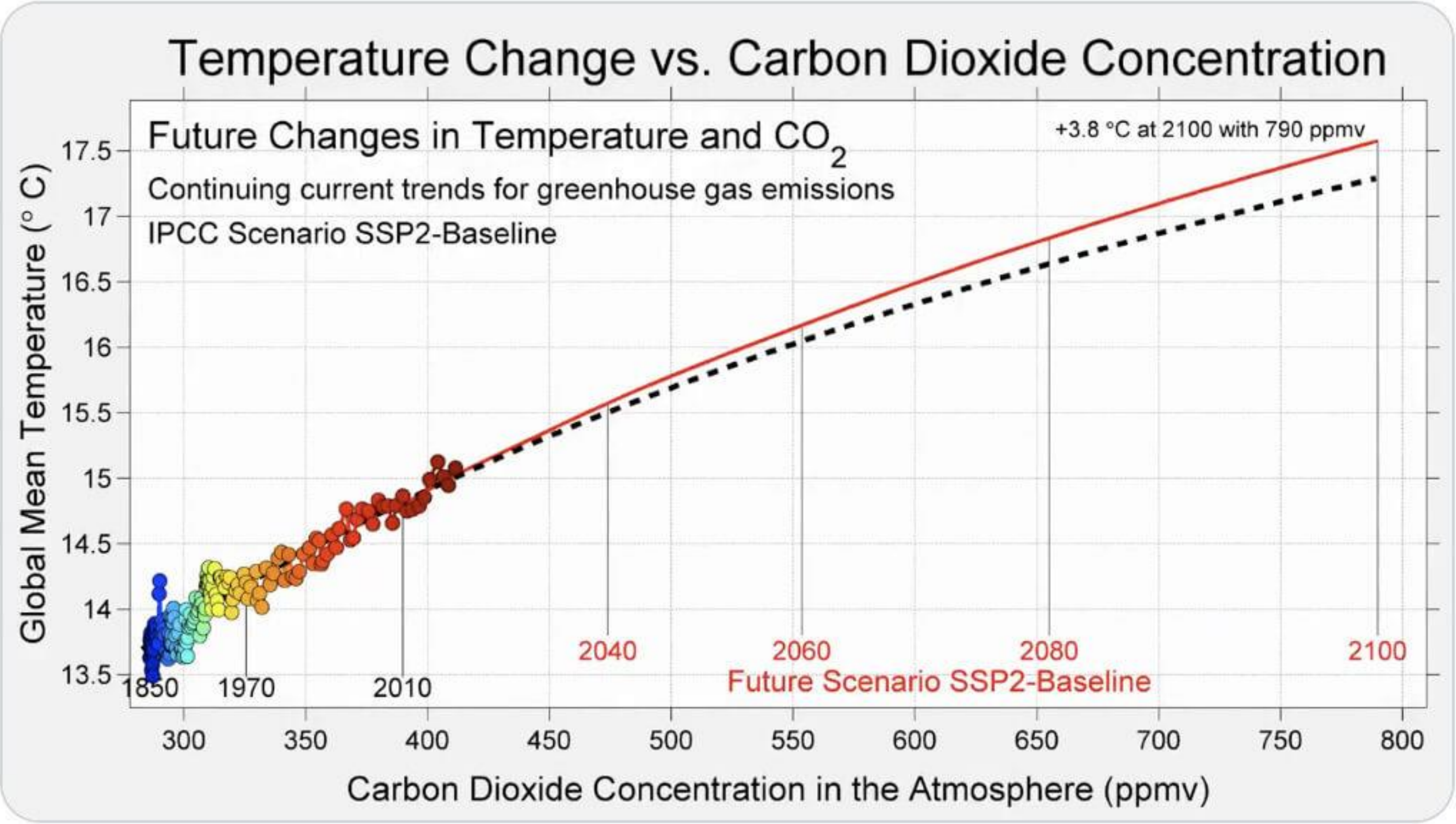
Temperature and CO_2 Changes.

- Has global surface temperature increased?
- Is it related to CO_2?

https://berkeleyearth.org/



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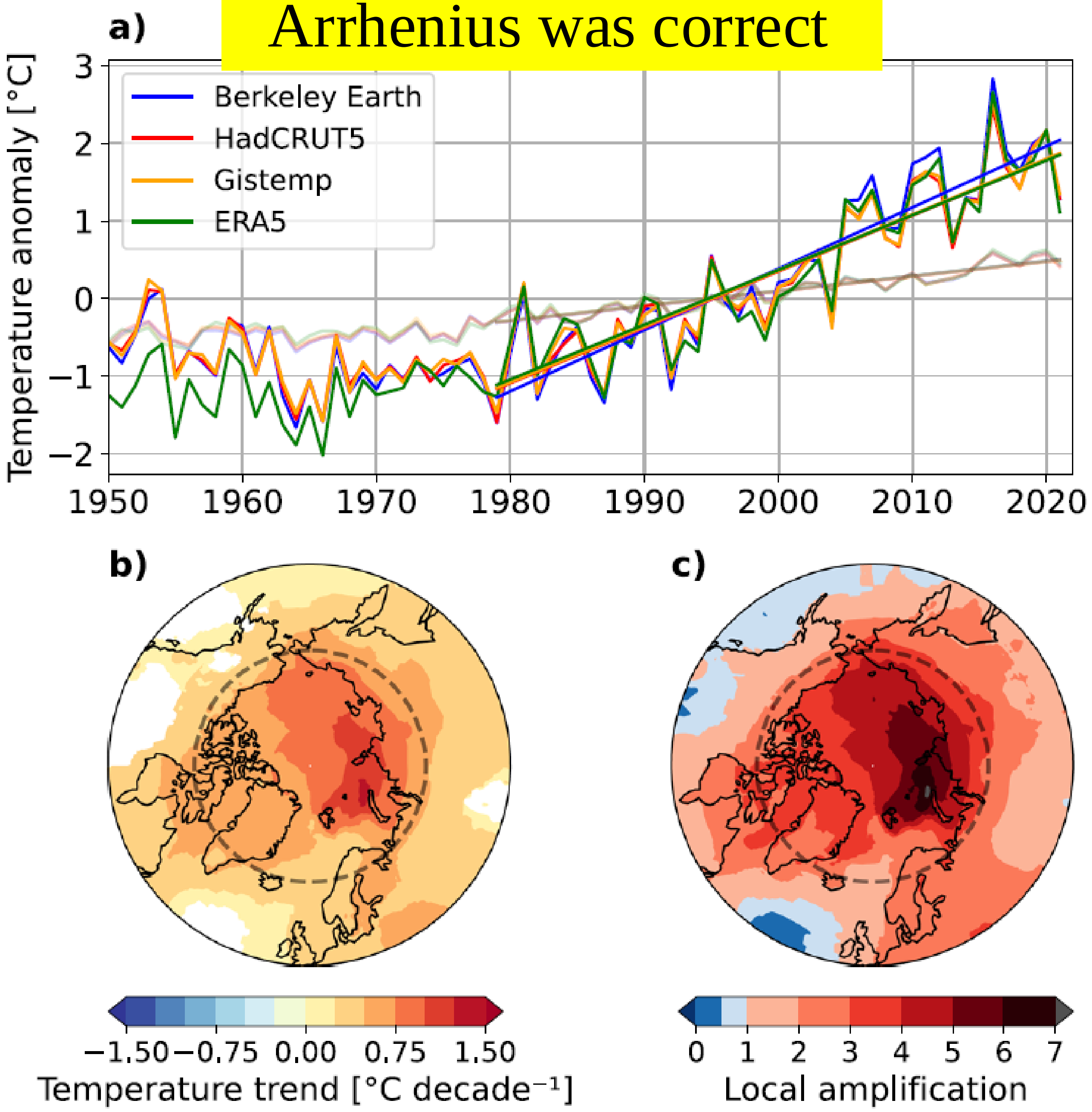
Arctic Surface Temperatures

Arrhenius was correct



Annual mean temperature evolution in the Arctic.

a) Annual mean temperature anomalies in the Arctic (66.5°–90°N) (dark) and globally (light) during 1950–2021 derived from the various observational datasets. Temperature anomalies have been calculated relative to the standard 30-year period of 1981–2010. Shown are also the linear temperature trends for 1979–2021.

b) Annual mean temperature trends for the period 1979–2021, derived from the average of the observational datasets.

c) Local amplification ratio calculated for the period 1979–2021, derived from the average of the observational datasets.

From Rantanen, M., Karpechko, A.Y., Lipponen, A., Nordling, K., Hyvärinen, O., Ruosteenoja, K., Vihma, T., & Laaksonen, A. (2022). The Arctic has warmed nearly four times faster than the globe since 1979. Communications Earth & Environment 3, 168. 10.1038/s43247-022-00498-3

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Visible and Infrared Imagers on Satellites

Natural-color mosaic of data taken by MODIS on *Terra* on July 11, 2011.

https://visibleearth.nasa.gov/images/51396/sunny-skies-over-arctic-sea-ice

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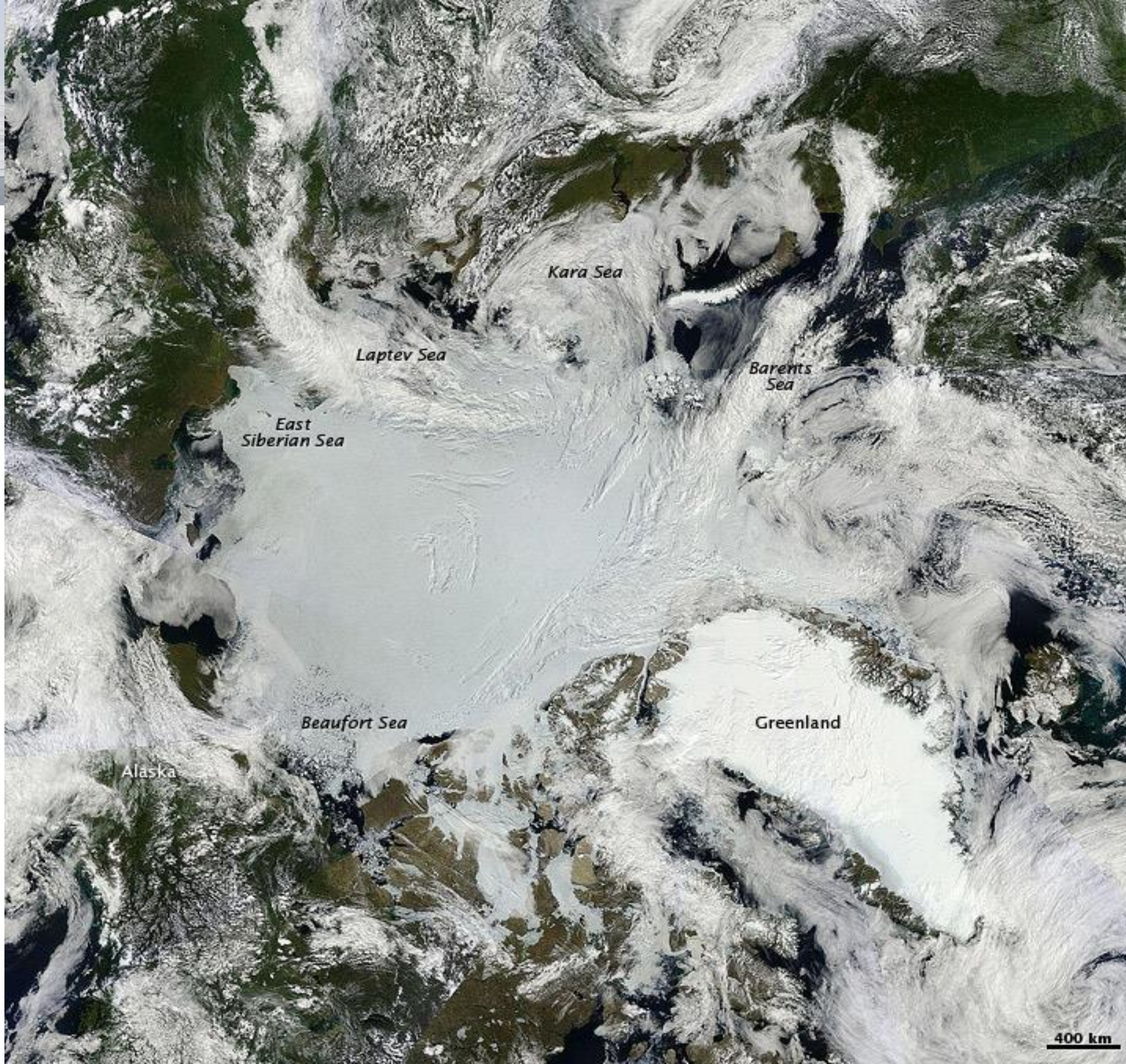
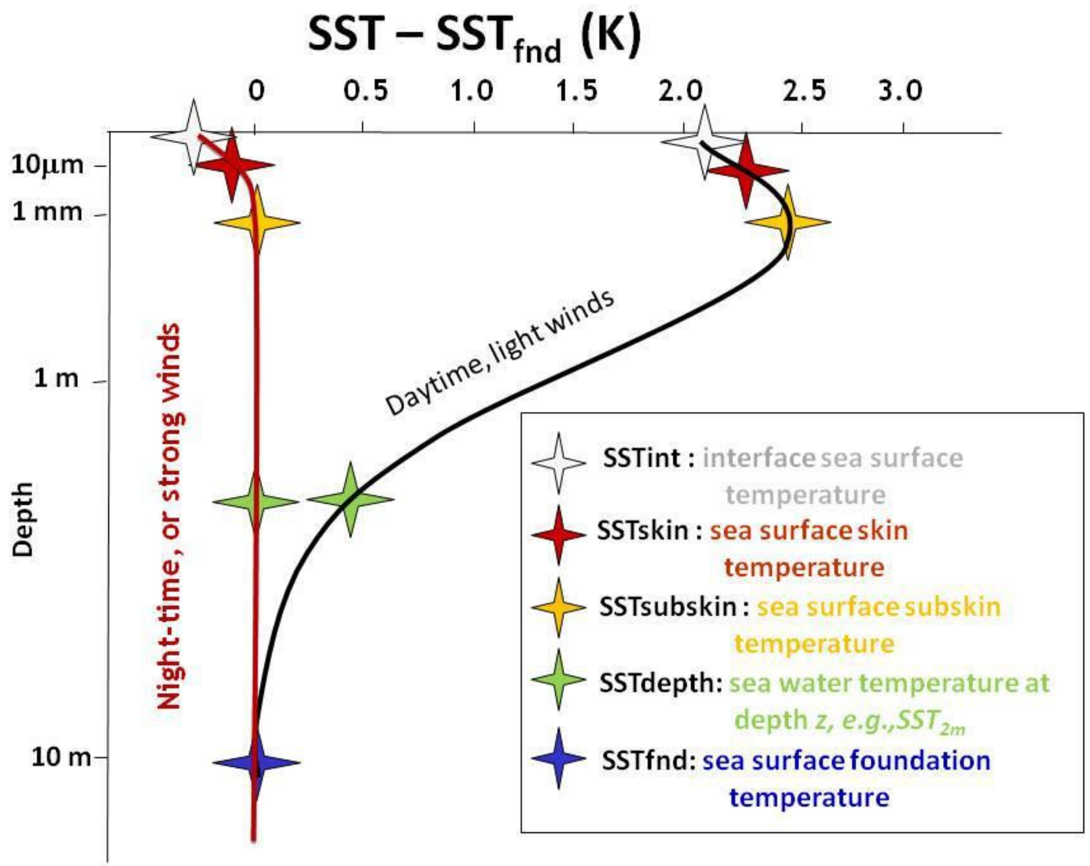
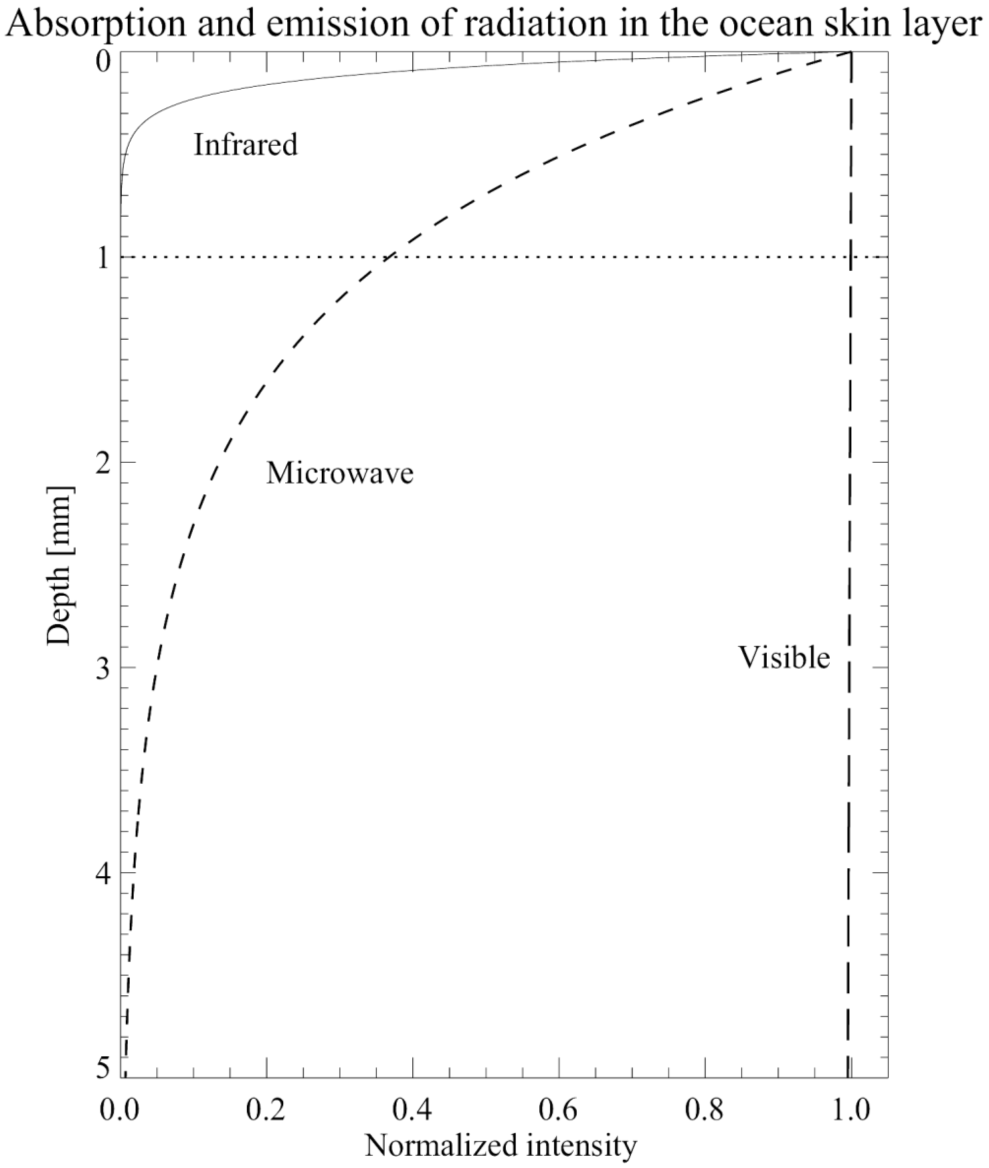


Thermal Skin Effect





SST_{skin} is the temperature that controls air-sea exchanges.
SST_{skin} is the temperature that gives rise to the signal measured by satellite radiometers.

Minnett, P.J., & Kaiser-Weiss, A.K. (2012). Group for High Resolutio Sea-Surface Temperature Discussion Document: Near-Surface Ocean Temperature Gradients, (7 pp.) Available https://zenodo.org/record/470033

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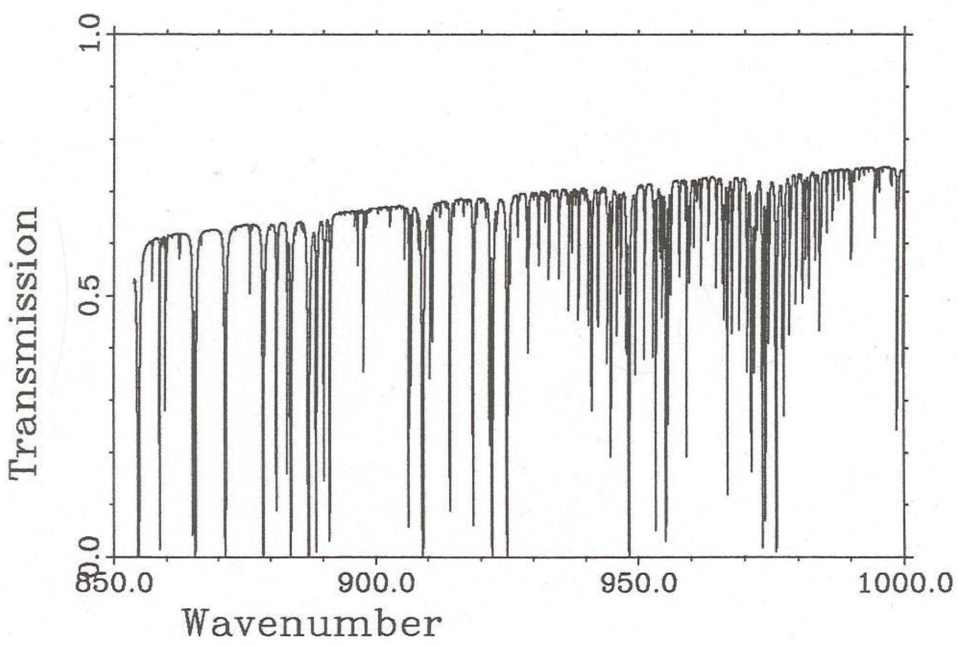
Problems with Deriving SST_{skin} from Satellites

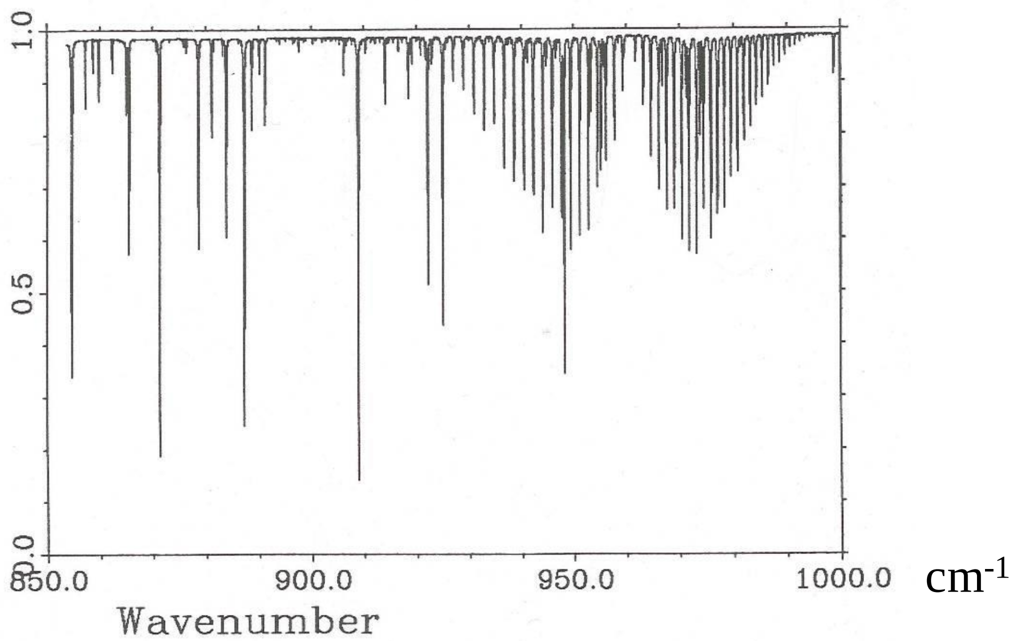
- High resolution imaging satellite instruments measure radiance at several wavelengths in the visible and infrared at the top of the atmosphere.
- We need SST_{skin} at the bottom of the atmosphere.
- To derive SST_{skin}, we must remove cloudy measurements and correct for the effects of the intervening cloud-free atmosphere, done by taking measurements at two infrared wavelengths. But
  - Generally cloudy
  - Atmosphere is dry and cold, an extreme in the global conditions.

High Resolution Atmospheric Transmissivity

Moist summer mid-latitude atmosphere



Dry Arctic atmosphere



Transmission spectra calculated for a moist summer mid-latitude atmosphere, and a very dry Arctic atmosphere.

See Minnett, P.J., et al. (2019). Half a century of satellite remote sensing of sea-surface temperature. Remote Sensing of Environment 233, 111366. https://doi.org/10.1016/j.rse.2019.111366

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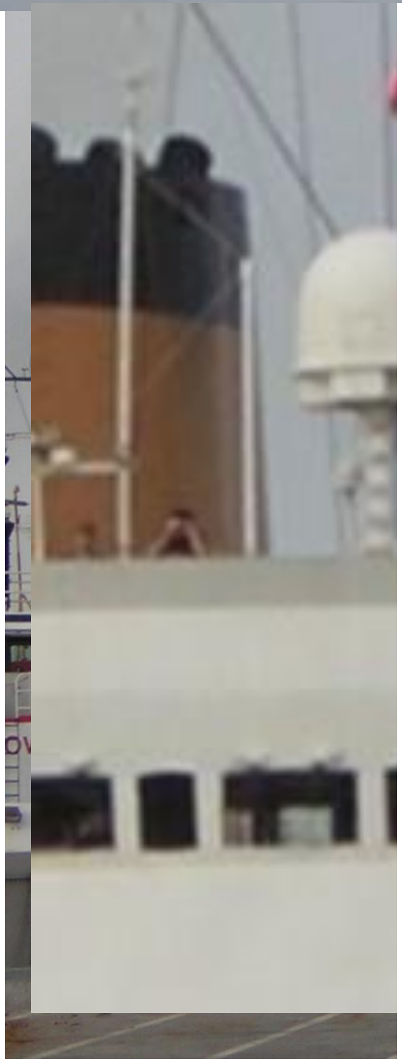
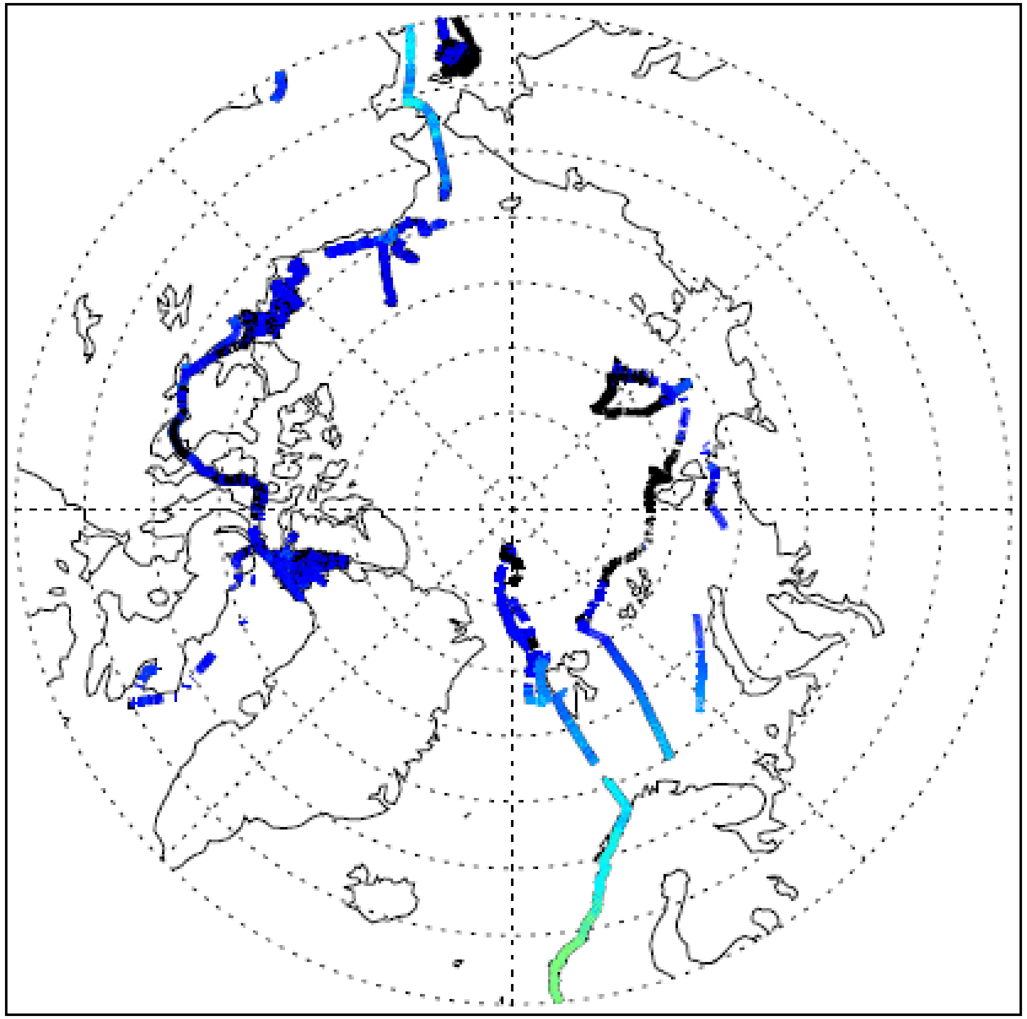
IR radiometers near the sea-surface

- Various IR radiometers have been mounted on ships to provide SST_{skin} data to compare with satellite retrievals.
- Provide a “like-with-like” comparison, avoiding variable effects of diurnal heating and the thermal skin layer that introduce differences with subsurface temperatures.
- Ship-satellite comparisons are used to refine the atmospheric correction algorithms and assess the accuracy of the derived SST_{skin}.
- But these ships rarely go into the Arctic.

M-AERI on Icebreakers

- Marine-Atmospheric Emitted Radiance Interferometer (M-AERI) have been mounted on several icebreakers for a few high latitude deployments.
- M-AERI on USCGC *Polar Sea*, 2006.
- M-AERI is large, heavy and costly.
- A smaller, cheaper, but accurate instrument is needed.





M-AERI Arctic cruises 1998 - 2008.

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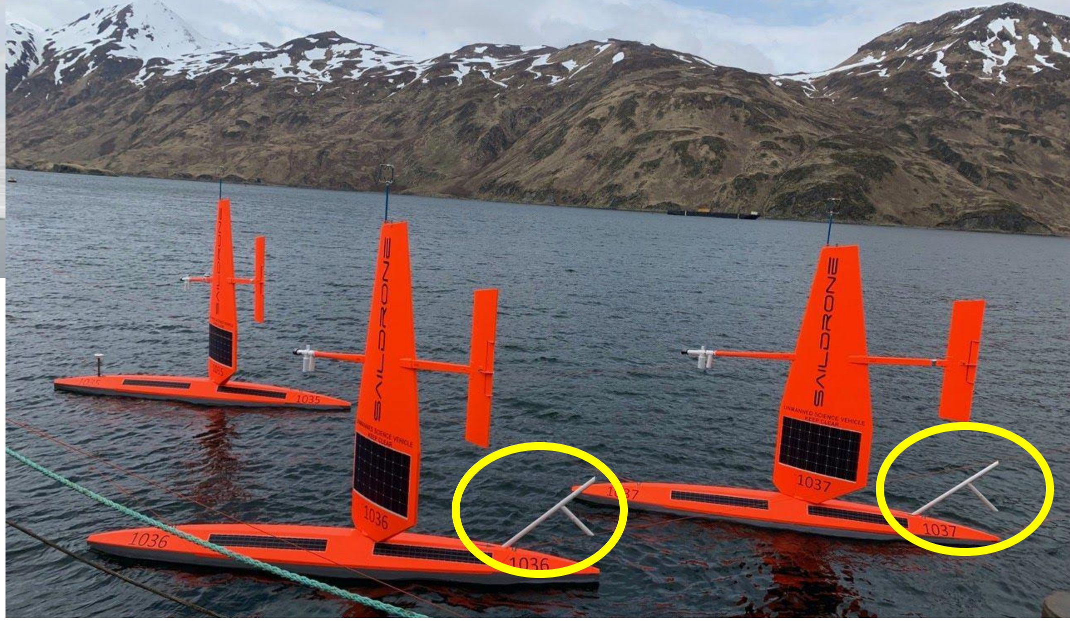
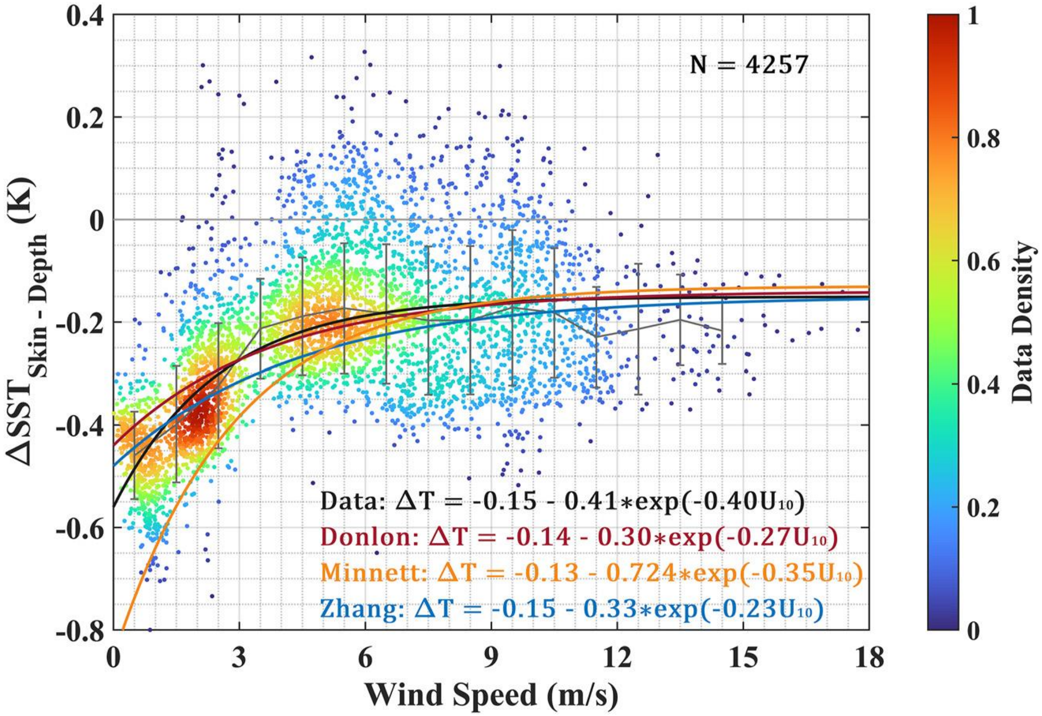
SST_{skin} from Saildrones.



- Saildrones are autonomous surface vehicles that carry a range of oceanographic and meteorological instruments.
- Two Saildrones (SD1036, SD 1037) were deployed for 150-day cruises in the Pacific Sector of the Arctic in 2019. Each carried a pair of Heitronics radiometers for the derivation of SST_{skin}.
- After careful qc, the uncertainty in SST_{skin} is 0.12 K.
- Wind speed dependence of skin effect is "in family."



Jia, C., Minnett, P.J., Szczodrak, M., & Izaguirre, M. (2023). High Latitude Sea Surface Skin Temperatures Derived From Saildrone Infrared Measurements. *IEEE Transactions on Geoscience and Remote Sensing*, *61*, 1-14

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Saildrone MODIS Accuracy Assessment

	MODIS on *Aqua*			MODIS on *Terra*		
	SD-1036	SD-1037	Total	SD-1036	SD-1037	Total
Mean	-0.073	-0.468	-0.263	-0.076	-0.490	-0.291
Median	-0.036	-0.352	-0.214	-0.021	-0.379	-0.207
STD	0.727	0.701	0.741	0.649	0.752	0.734
RSD	0.656	0.588	0.669	0.551	0.565	0.559
RMS	0.730	0.842	0.786	0.653	0.897	0.789
R	0.943	0.947	0.948	0.956	0.945	0.947
Num	411	380	791	409	444	853

When Saildrones were close together, statistics are essentially the same.
So, differences related to spatial separation?

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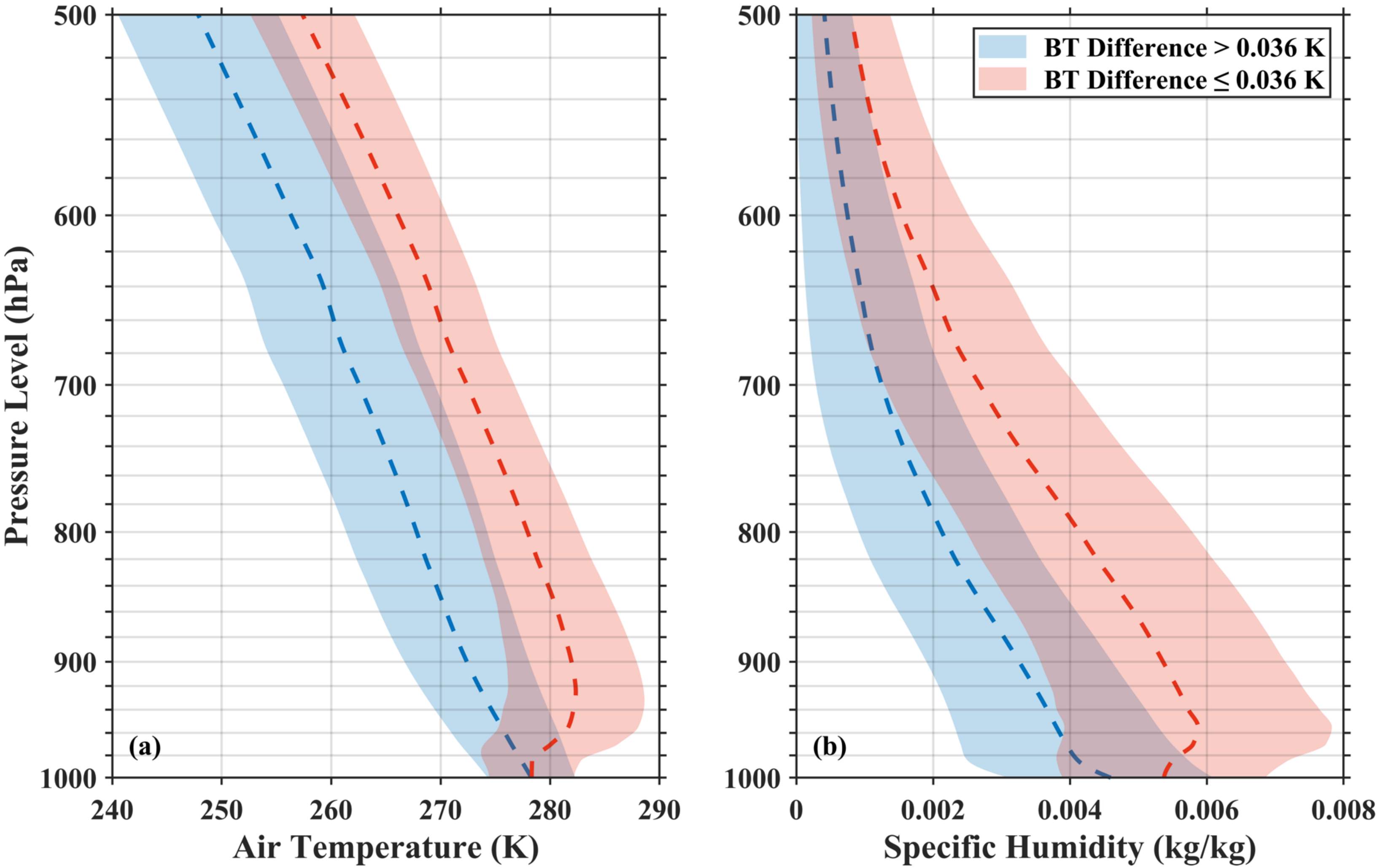
Degraded SST_{skin} accuracy and inversions

MERRA-2 atmospheric profiles for *Aqua* MODIS-buoy positions, north of 60ºN.

(a) air temperature

(b) specific humidity

Mean (dashed line) ± 1 STD (envelope) for ΔBT > 0.036 K (normal; blue) and ΔBT ≤ 0.036 K (anomalous; red).



Jia, C., Minnett, P.J., & Szczodrak, M. (2024). Characteristics of R2019 Processing of MODIS Sea Surface Temperature at High Latitudes. *Remote Sensing 16*, 4102. 2072-4292

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Effects of Inversions

- Are the effects of inversions in the Saildrone data restricted to this area in the summer of 2019?

  Answer is no.

- Are inversions common throughout the Arctic?

  Answer is yes.

- Do inversions and their effects have spatial and seasonal variations?

  Answer is probably.

To find the answers:

- **More SST_{skin} data in the Arctic.**
- **Ideally from icebreakers which can launch radiosondes**.

Radiometers on R/V *Sikuliaq*

Heitronics Radiometers on the R/V *Sikuliaq*

Ethan Roth
Science Operations Manager, R/V *Sikuliaq*

Bud Foran
Heitronics Inc.

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Conclusions and Outlook

- Understanding Arctic Amplification requires better satellite retrievals of SST_{skin}, requiring better atmospheric correction algorithms.
- More SST_{skin} and atmospheric profile measurements are needed.
- Radiometers, such as those on some Saildrones and on the R/V *Sikuliaq* offer a very cost-effective way of providing these data.

Acknowledgments

- Funding from NASA.
- Many members of my research group.
- Colleagues at several institutions.
- Bud Foran, Heitronics.
- Ethan Roth, R/V *Sikuliaq*.

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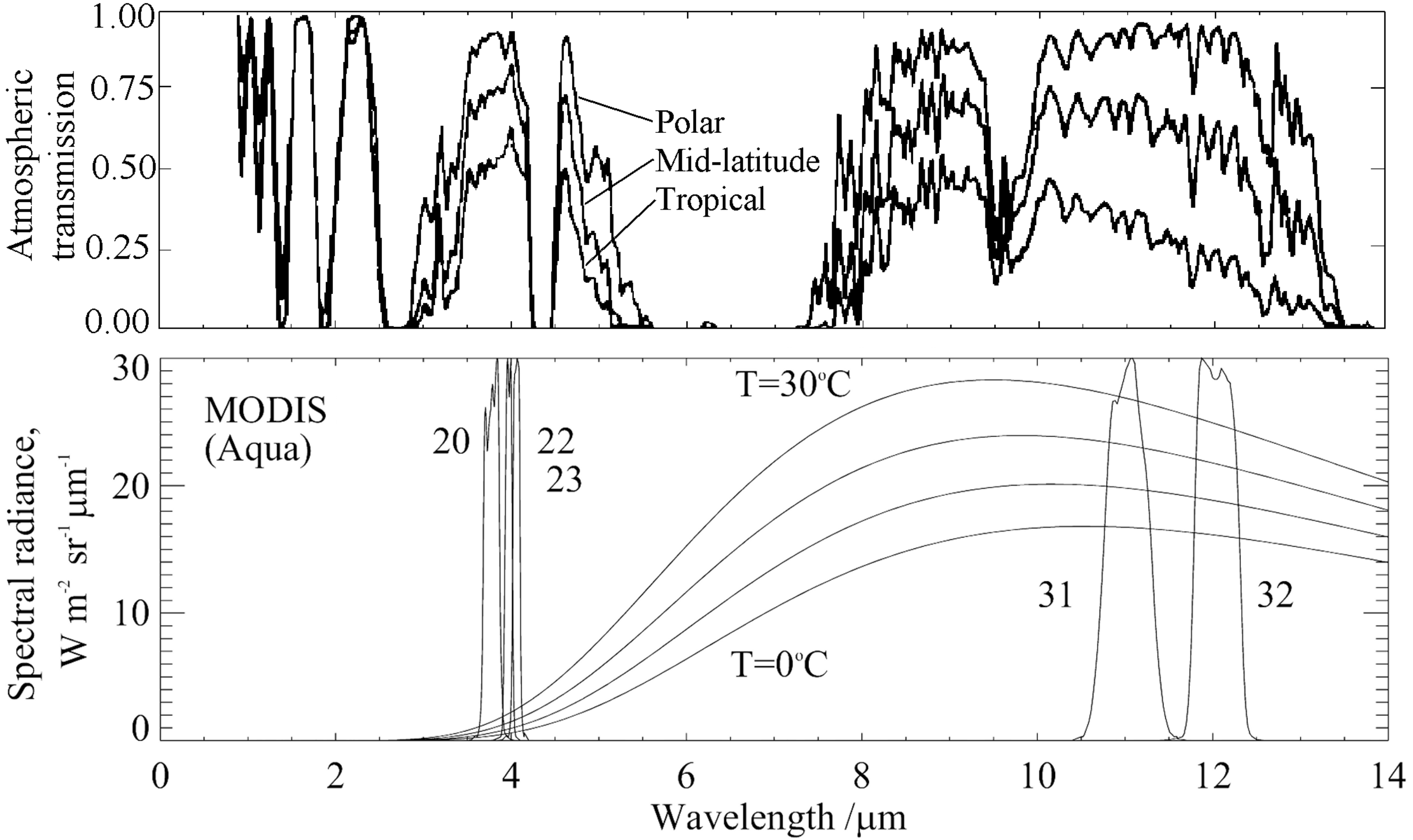
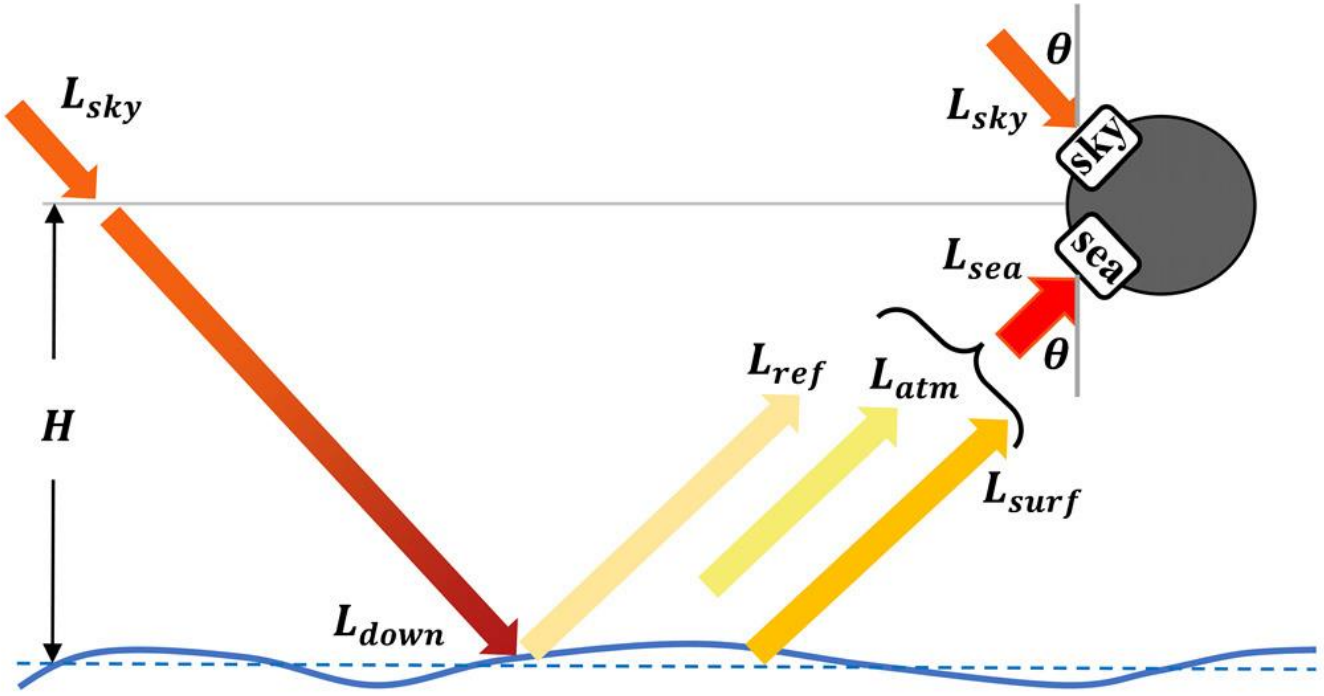
- Backup slides

Atmospheric Transmissivity



Information for correcting the effects of the atmosphere are in the differences in the derived brightness temperatures measured at wavelengths of ~11 and ~12 µm: ΔBT

At-sea radiometer measurements



L_{surf} is the emission from the sea surface at SST_{skin}.

To obtain L_{surf} from L_{sea}, corrections for L_{atm} and reflected L_{down} must be made.

For radiometers mounted close to the sea surface, $L_{atm} \approx 0$ and $L_{down} \approx L_{sky}$ which is measured.

Accurate values of reflectivity, equal to (1 – emissivity), are needed,

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- Ship-satellite comparisons are used to refine the atmospheric correction algorithms and assess the accuracy of the derived SST_{skin}.
- But these ships rarely go into the Arctic.
- New development – autonomous surface vehicles, such as Saildrones.