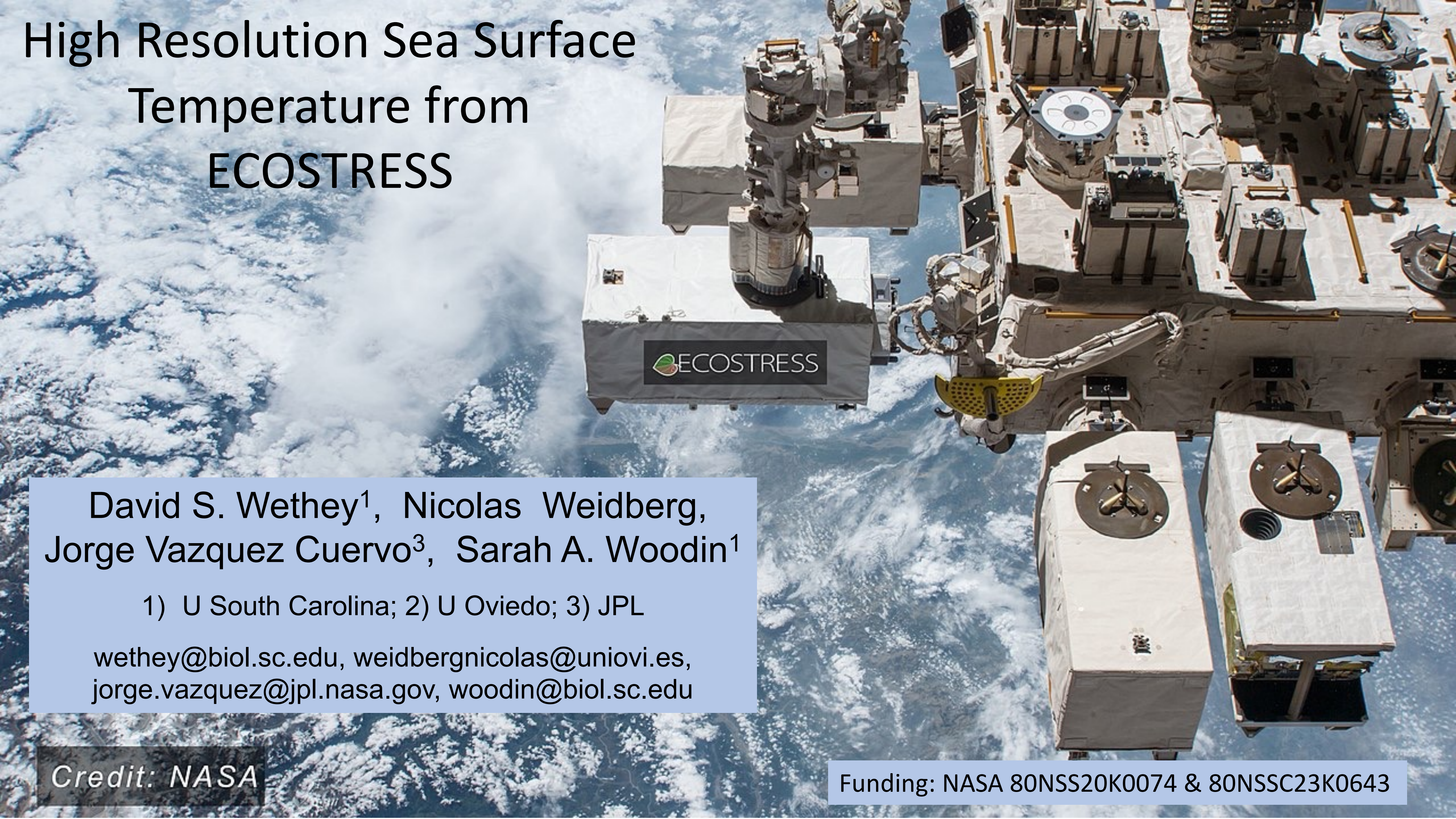
High Resolution Sea Surface Temperature from ECOSTRESS



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ECOSTRESS
A Precursor to TRISHNA, SBG and LSTM

- 70-m scale thermal radiometer on the International Space Station
- Inclined orbit: 51N – 51S coverage region
- Revisit time 5-days to subdaily depending on latitude
- >360,000 scenes since August 2018
- Swath width 384 km
- Scenes 5632 × 5400
- 3 active thermal bands (8.78, 10.49, 12.09 µm)
- NEdT 0.13, 0.10, 0.29 K
- Focal plane 256×4 downscaled to 128×1 per band
- 2 Blackbodies (295 K, 325 K) imaged on every mirror swath

ECOSTRESS Ocean Validation 2018-2022

Advantages over land-based Cal/Val

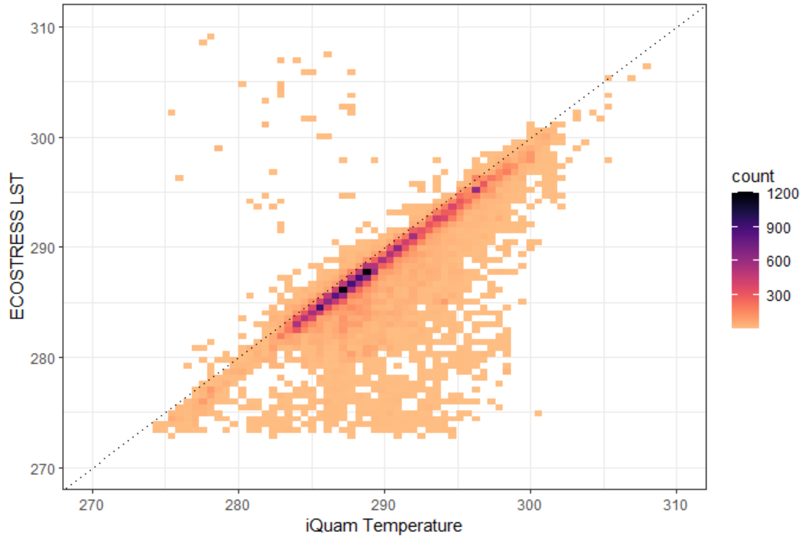
- Many more observations per month available from NOAA iQuam
- Emissivity more tightly constrained over ocean than over land
- Validation of Collection-1 using >200,000 triple matchups among
  - 1: ECOSTRESS LST (Temperature-Emissivity-Separation Algorithm)
  - 2: Best quality NOAA iQuam in-situ observations
  - 3: Best quality geostationary observations (MSG-SEVIRI, GOES-ABI, Himawari-AHI)
  - RTTOV radiance transfer models of brightness temperatures and emissivities
    - ERA-5 temperature and water vapor profiles plus surface winds, humidity, air temperature

- Eléa Paul et al poster Wednesday described an in-situ matchup database for use with TRISHNA and ECOSTRESS in the European coastal zone, including aquaculture sites.

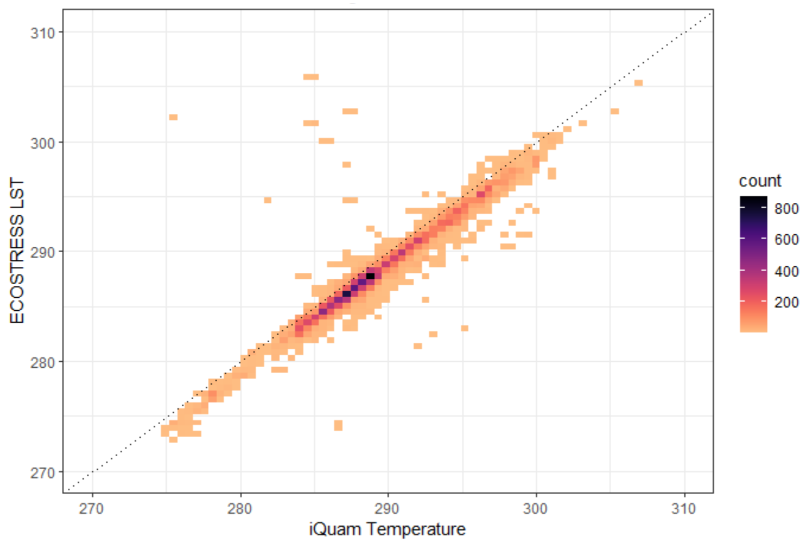
ECOSTRESS Collection 1 LST has ~1 K Cold Bias vs In-Situ SST

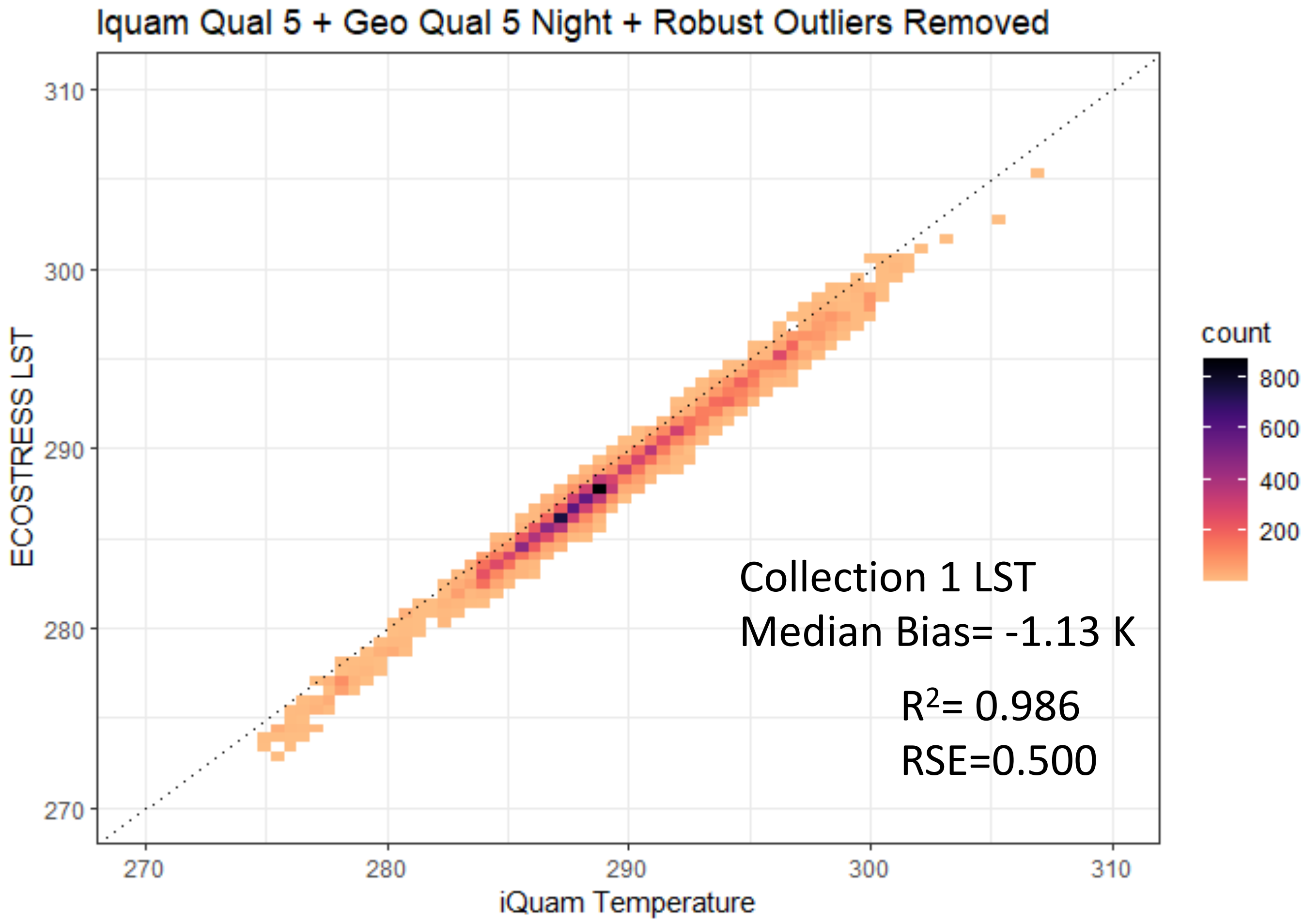
Collection 2 LST has slight Warm Bias

Iquam Qual 5 + ECO Cloud Mask



Iquam Qual 5 + NOAA Cloud Mask

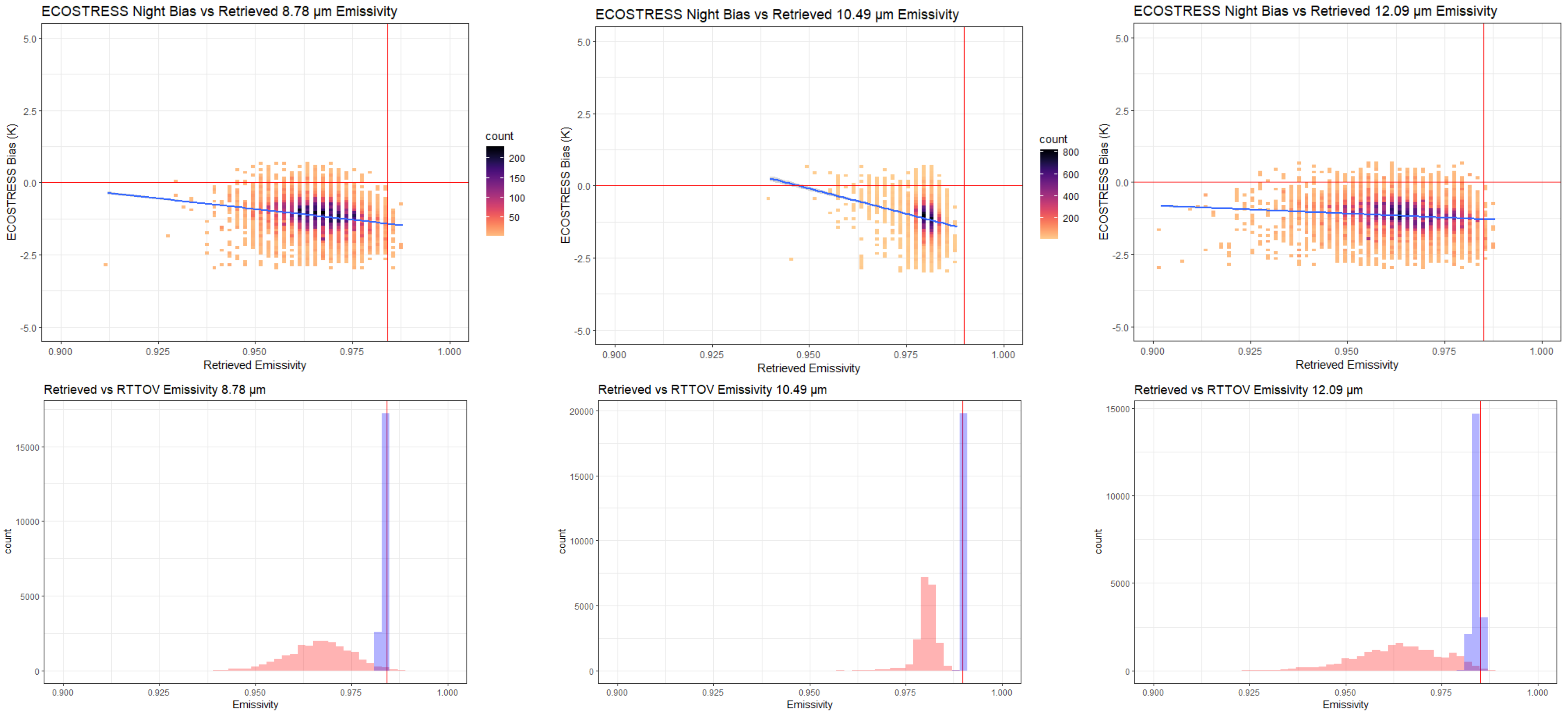




NOAA/ESA Geostationary Cloud Masks are Better than ECOSTRESS Collection 1 Cloud Mask

ECOSTRESS Collection 1 Ocean Emissivity Retrievals are Too Low

Vertical Red lines – ASTER Spectral Library Emissivity of Seawater
Blue lines – Linear regression of SST Bias vs Emissivity



Red Histograms: ECOSTRESS Emissivity   Blue Histograms: RTTOV Modelled Emissivity

Coastal Zone Caveats – Especially Important for Coastal Aquaculture Sites

Wideband Emissivity Changes Rapidly During Low Tide Drying of Surfaces

Apogee Radiometers (8-14 µm)

T_{Sky} and T_{Skin}

Thermocouples in top 1 mm of sediment

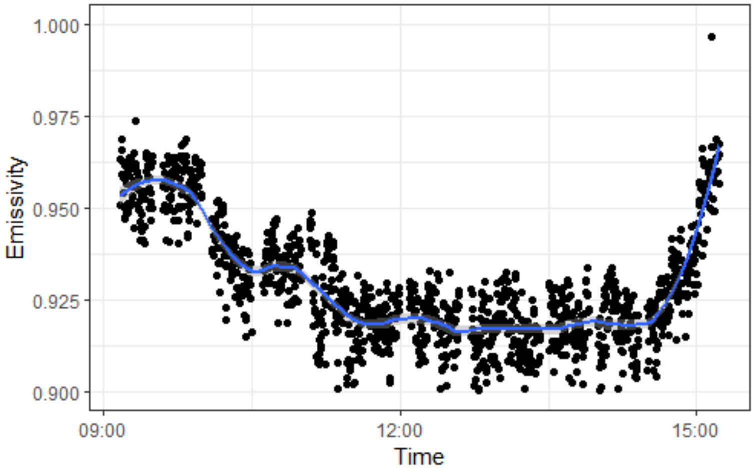
$T_{sediment}$

$$\varepsilon = \frac{(\sigma T_{Skin}^4 - \sigma T_{Sky}^4)}{(\sigma T_{Sediment}^4 - \sigma T_{Sky}^4)}$$

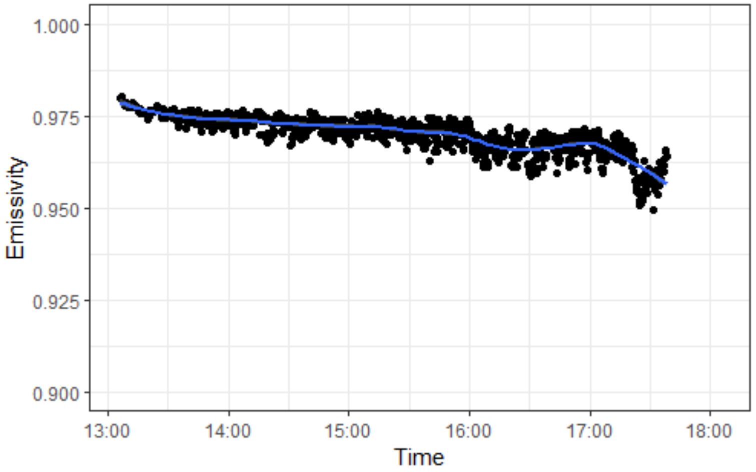
σ = Stefan Boltzmann constant

= 5.6704×10^{-8} W/m^{2}K^4

Sand



Sandy Mud



Sand emissivity decreases from 0.97 to 0.91 over 3 hours and rises back to 0.97 in the 30 min before immersion

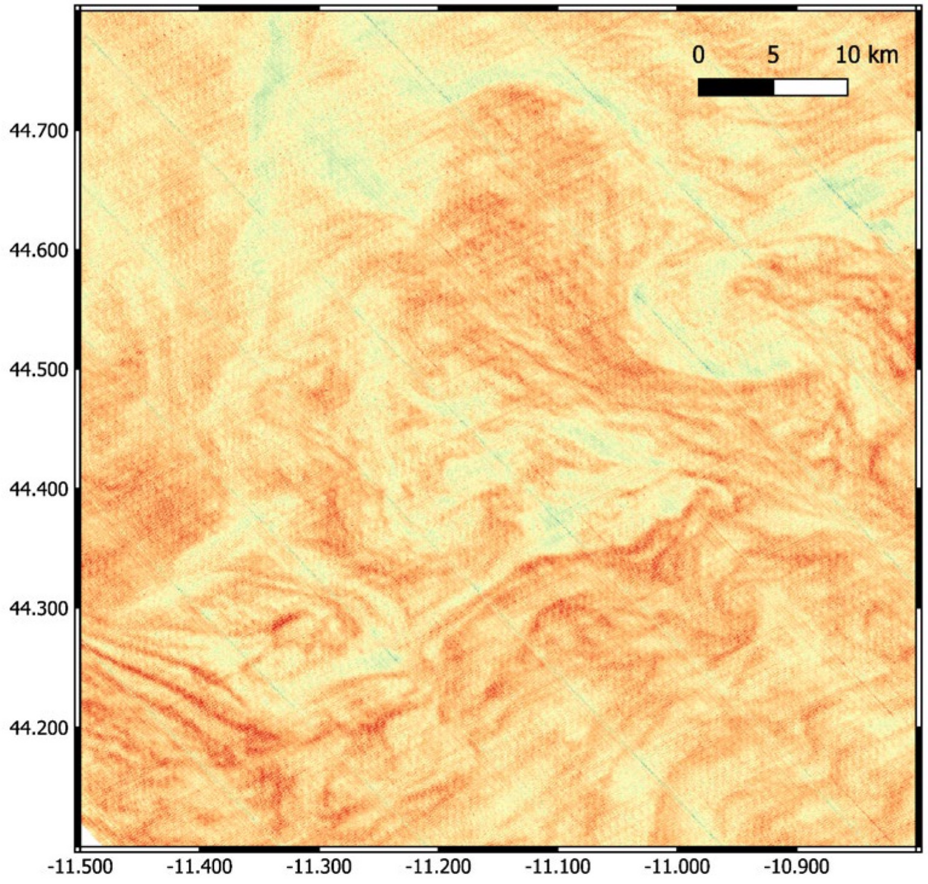
Sandy Mud emissivity remains close to that of water for most of low tide

Can improve intertidal temperature retrievals by taking into account the effect of surface drying rate on emissivity

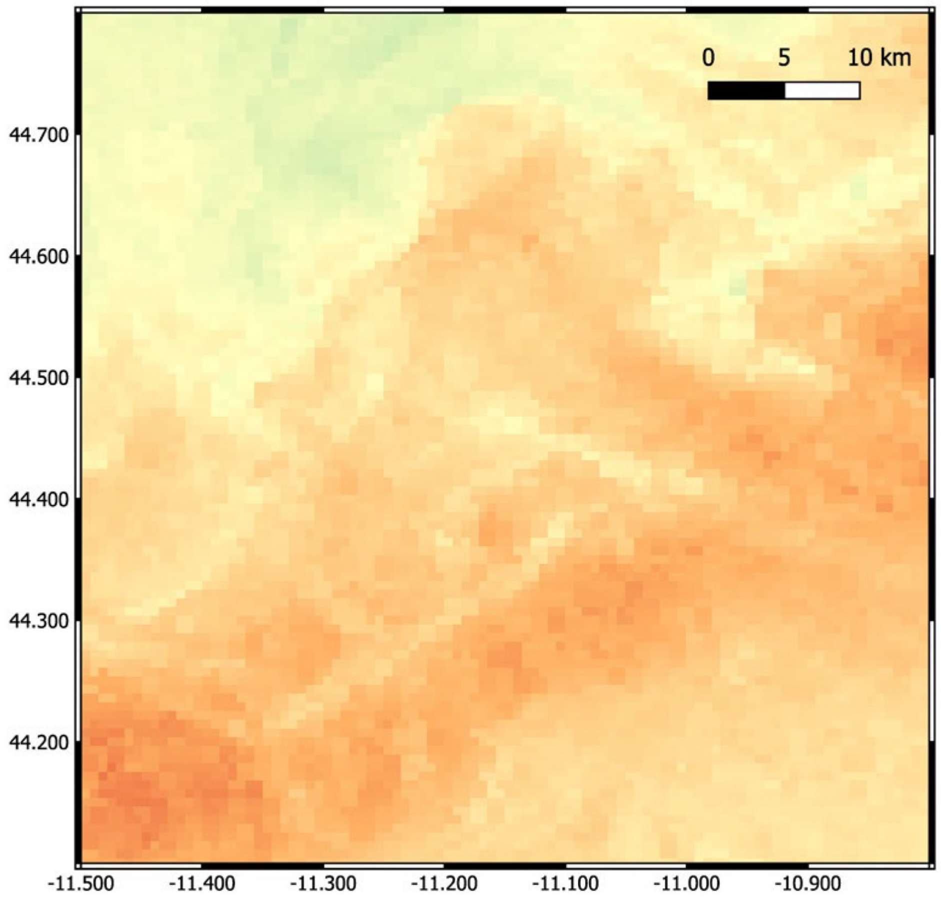
ECOSTRESS is a Game Changer for Oceanography

Resolves 1 km scale internal waves in upwelling zone off NW Iberia

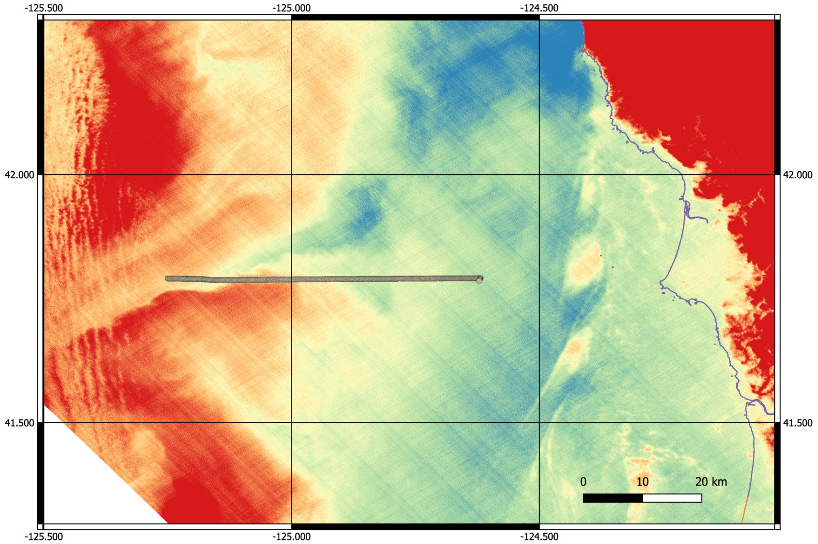
ECOSTRESS LST

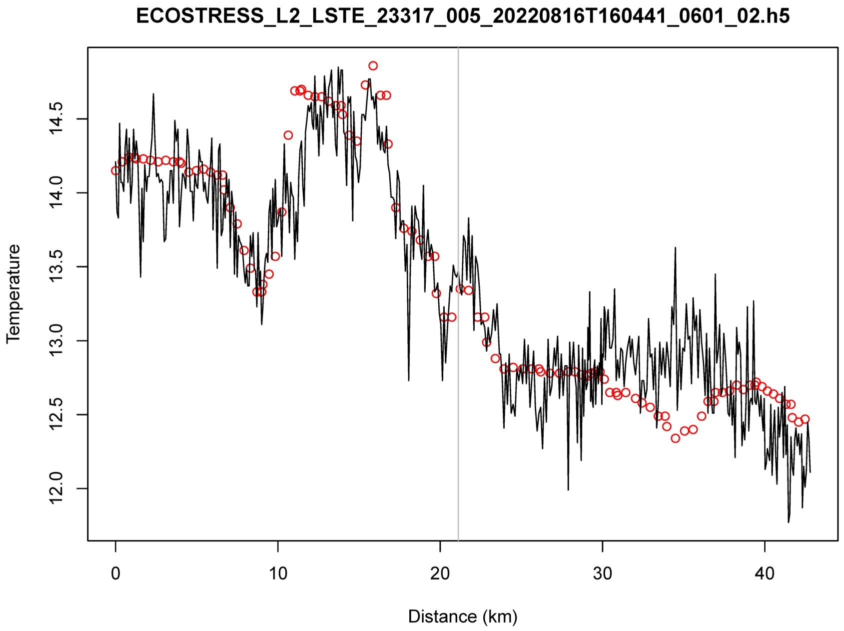


VIIRS N20 SST



ECOSTRESS Resolves 2D SST Gradients at the Spatial Scale of Saildrones

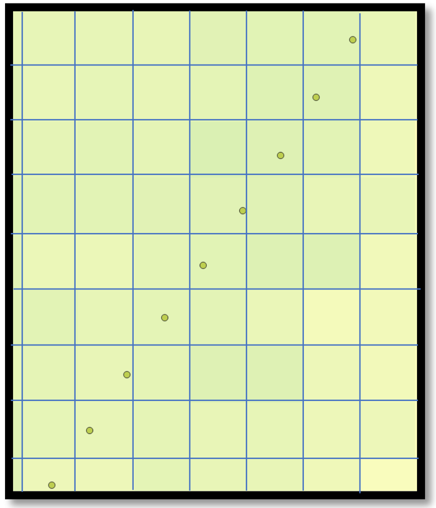


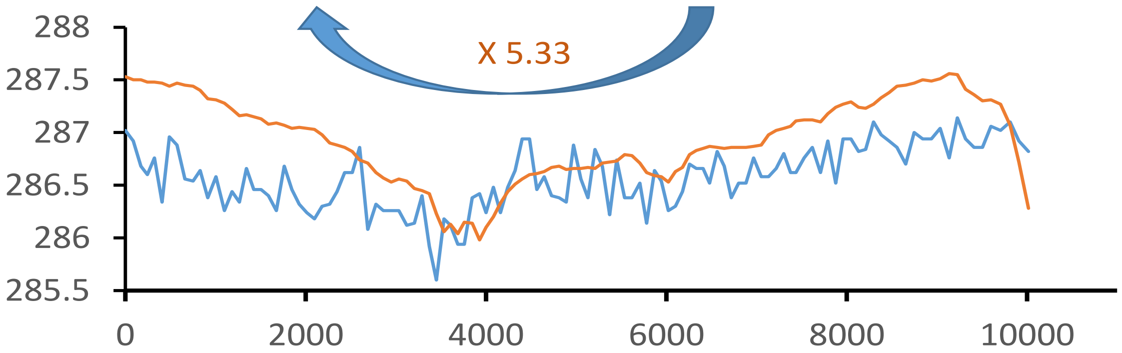


Upwelling front boundaries off northern California.

ECOSTRESS – black line
Saildrone – red circles

Trajectory covers 4 h before and after ECOSTRESS scene.



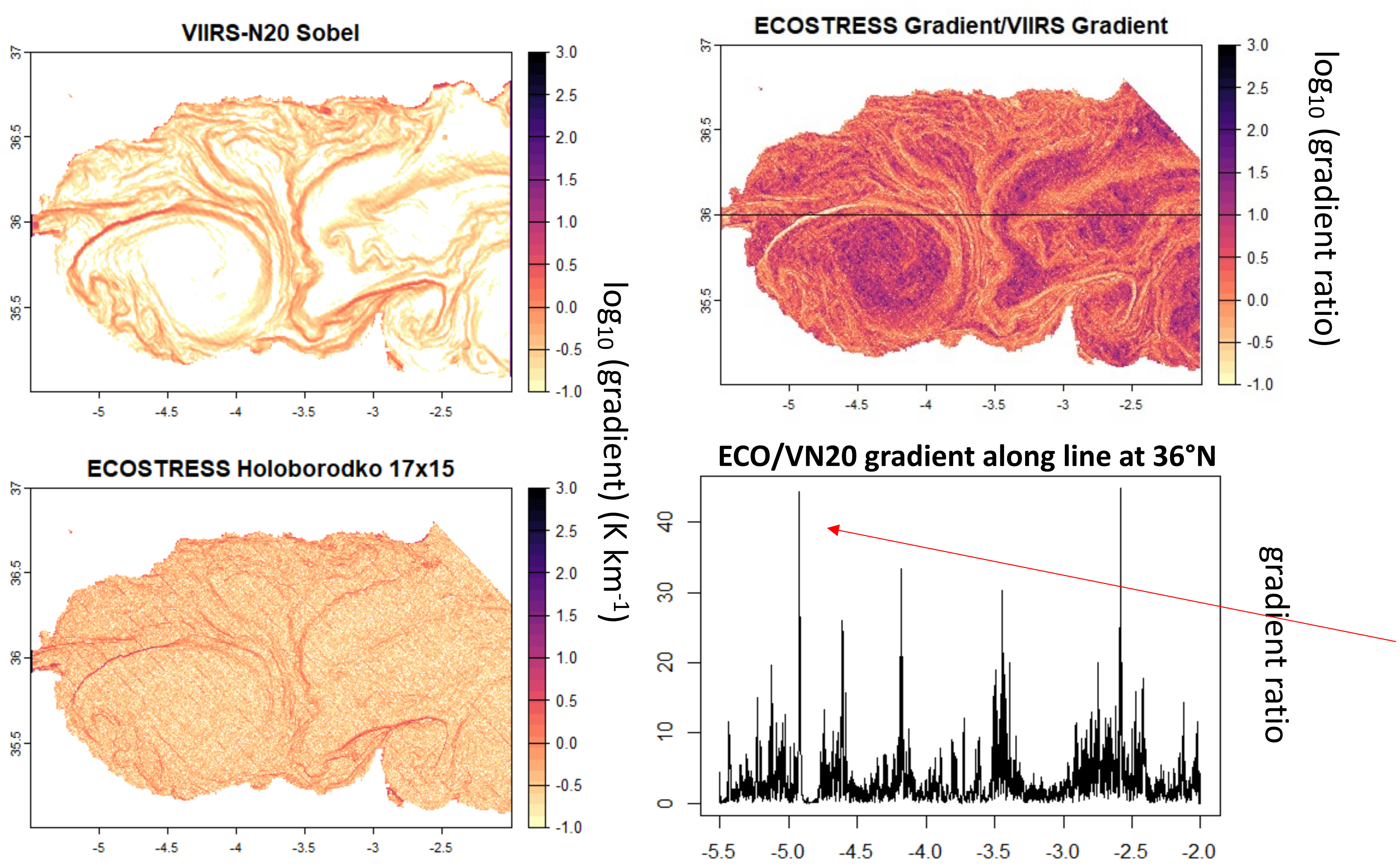


ECOSTRESS pixel-pixel noise is ~5× greater than Saildrone CTD sampling at 1-pixel intervals.

von Neumann successive difference noise estimator

ECOSTRESS is a Game Changer for Oceanography

ECOSTRESS Resolves Magnitude and Position of SST Gradients Better than VIIRS-N20 and other GHRSST L2 Products

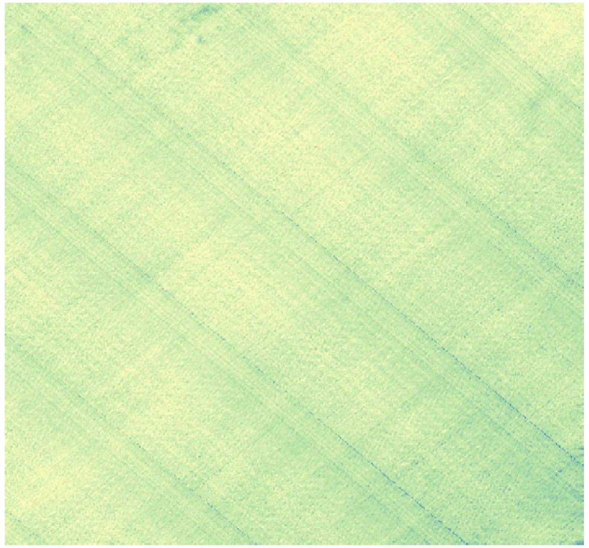


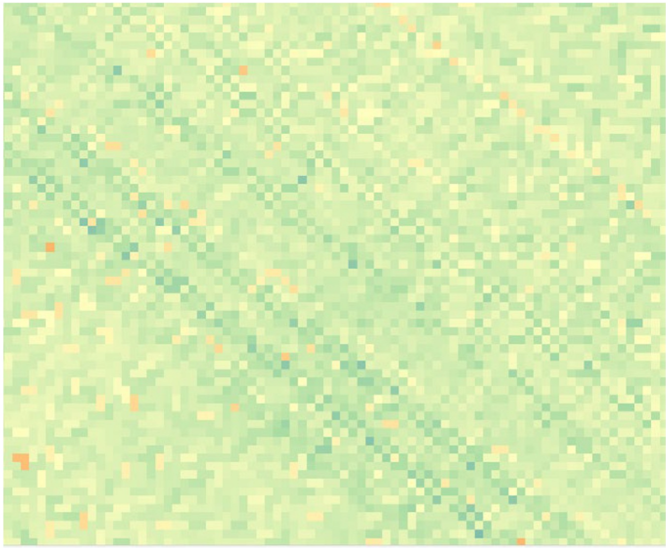
ECOSTRESS noise level is high enough that Sobel 3×3 gradient operators don’t work.

Holoborodko smooth low-noise gradient kernels are necessary for resolving SST gradients in ECOSTRESS scenes.

ECOSTRESS SST gradients are **up to 40 ×** steeper than measured with other instruments.

ECOSTRESS Ocean Retrieval Problems
Striping and Checkerboard Artifacts and Gaussian Noise



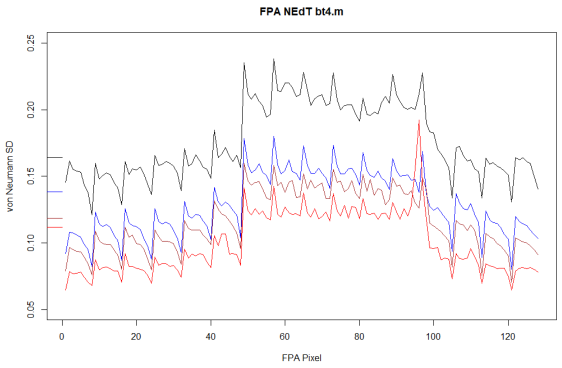


- Systematic noise makes detection of ocean fronts and gradients more difficult in ECOSTRESS than in operational SST sensors like VIIRS, MODIS, AVHRR.
- Simple 3x3 Sobel gradient operators work well for operational SST products, but gradient detection in ECOSTRESS requires large (11x11 and larger) low noise gradient operators like those developed by Pavel Holoborodko (see Ciani et al. Remote Sensing 2023, 15(4), 1163).
- If the striping and checkerboard problems can be solved, ECOSTRESS will be the best instrument available for quantifying ocean temperature fronts and gradients.
- Poster yesterday by Gianluigi Liberti et al on noise reduction by spatial averaging of the split window term in SST retrievals (also new paper in Remote Sensing 2023, 15(9), 2453.

Origins of ECOSTRESS Noise and Striping: NEdT and Focal Plane Array Calibration

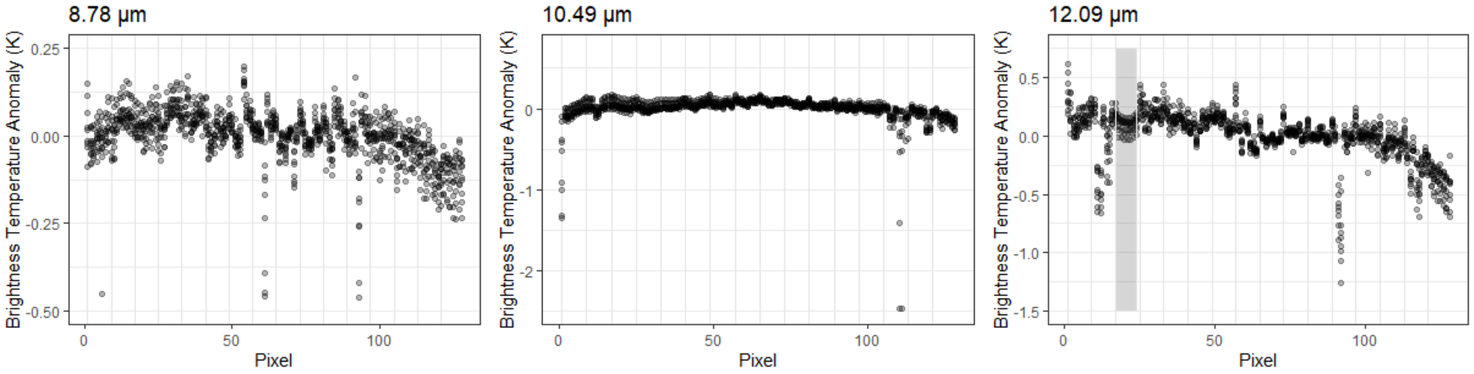
Noise level variation within Focal Plane Array (FPA)

Cross track noise measured with median absolute deviation of successive ocean pixel BT differences (von Neumann SD).
Middle of focal plane array noisier than ends.
8-pixel periodicity in the noise level.
Cold scenes have higher noise levels.



Black – Sakhalin Island BT 271.4
Blue – English Channel BT 279.7
Brn – Australia BT 291.0
Red – Arabian Gulf BT 301.8

Variation in pixel sensitivity within Focal Plane Array
Is not completely compensated by calibration algorithm
Brightness Temperature anomalies relative to mean focal plane BT of ocean pixels.
Pixels 100-128 have negative anomalies in all bands.
This is the origin of the checkerboard pattern because pixels 1-30 overlap pixels 86-128 in scenes.
Max anomaly 8.78µm -0.25K, 10.49µm -0.25K, 12.09µm -0.75K



Each dot is mean pixel anomaly within Focal Plane Array in a scene.
9 scenes of English Channel Feb 2019 – Sept 2021.
Grey area pixels at 12.09 µm are non responsive and radiance data are interpolated in JPL processing.

New NASA Project: Collaboration with Jorge Vazquez – JPL PODAAC
Develop a L2 split window Sea Surface Temperature Product From ECOSTRESS

- ECOSTRESS produces the highest resolution skin temperature currently available, but L2 products do not include SST and are not in a format used by the oceanographic community.
- ECOSTRESS has the potential to be a game changer for the oceanographic community because of the need for ultra high resolution for understanding
  - Air-sea coupling, Fronts and gradients, Coastal dynamics, Biodiversity
- New Project:
  - Develop processing pipeline for L2 SST and validate with in situ & satellite data
  - Address image checkerboarding and striping which limits ECOSTRESS utility
  - Archive validated product at PODAAC in standard Group for High Resolution SST (GHRSST) format
- Emmanuelle Autret at IFREMER is leading a similar effort in preparation for TRISHNA

ECOSTRESS Split Window SST Tests

Algorithm	R^2	RSE
NAVO	0.996	0.456
NRL	0.996	0.487
MCSST	0.995	0.487
NLSST	0.996	0.456
VIIRS-SST	0.996	0.465

Weidberg et al. 2021. Remote Sensing 2021,13, 5021

See the next talk by Laura Orgambide for additional algorithm comparisons.

Lessons from ECOSTRESS

- SST is an Essential Climate Variable – uncertainty < 0.2 K is the goal for Climate Data Records in order to detect climate change in the ocean (75% of the earth's surface)
- NEdT of ECOSTRESS, and proposed missions is higher than for most SST missions – may cause problems for GHRSST-compatible SST retrievals and measurement of temperature gradients.

	8.5 µm	11 µm	12 µm	**SST Products**
ECOSTRESS	0.13	0.10	0.29	
TRISHNA	0.18	0.15	0.15	IFREMER
SBG	0.20	0.20	0.20	
LSTM		0.15	0.15	
VIIRS	0.055	0.023-0.027	0.029-0.031	NOAA/NASA
SLSTR		0.011-0.016	0.015-0.021	ESA
MODIS	0.03	0.03	0.04	NASA

- Ocean Cal/Val provides validation of TES emissivity retrievals more easily than land measurements.
- For SST applications, black body temperatures should span the SST range 273K to 305K
    - ECOSTRESS cold black body (295 K) is warmer than most SST
- Nonlinearities in HgCdTe focal plane arrays could be compensated by occasional warm-up cool-down cycles of the hot blackbody like VIIRS calibration cycles or with preflight data like AVHRR & ASTER
- Geolocation is difficult in the coastal zone: the land water boundary on sandflats can change by kilometers within hours as tides rise and fall. Ground control points need to be on steep rocky shores, not sandflats.

Shameless advertising

- Jorge Vazquez and I are looking for a postdoc for our project to develop a GHRSST compatible SST product from ECOSTRESS
- Starting date – later this year or early next year
- Postdoc will spend the first months at U South Carolina and then move to JPL-PODAAC for the majority of the project
- Duration 1.5-2 years

- Contacts
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