Bias in Arctic Ocean SST Retrieval from Metop-A AVHRR

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Introduction

- Perception that SST retrieval biases are poor in Arctic
- Retrieval informed by simulations helps reduce biases from atypical atmospheric profiles
- But biases may arise in simulations from
  - forward model errors
  - biases in NWP used for simulations
  - sensor calibration
- Moreover, the error covariance of simulations is not well known

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Aims

- Assess significance of biases vs drifters
  - OSTIA
  - operational 3-channel SST retrieval coefficients
    - ditto plus simulated SST bias correction
  - naïve implementation of optimal estimation
    - with and without SAF BT bias adjustment
- Consider two candidate "bias tolerant" approaches to retrieval
  - can we design the retrieval such that the BT bias adjustment is unnecessary

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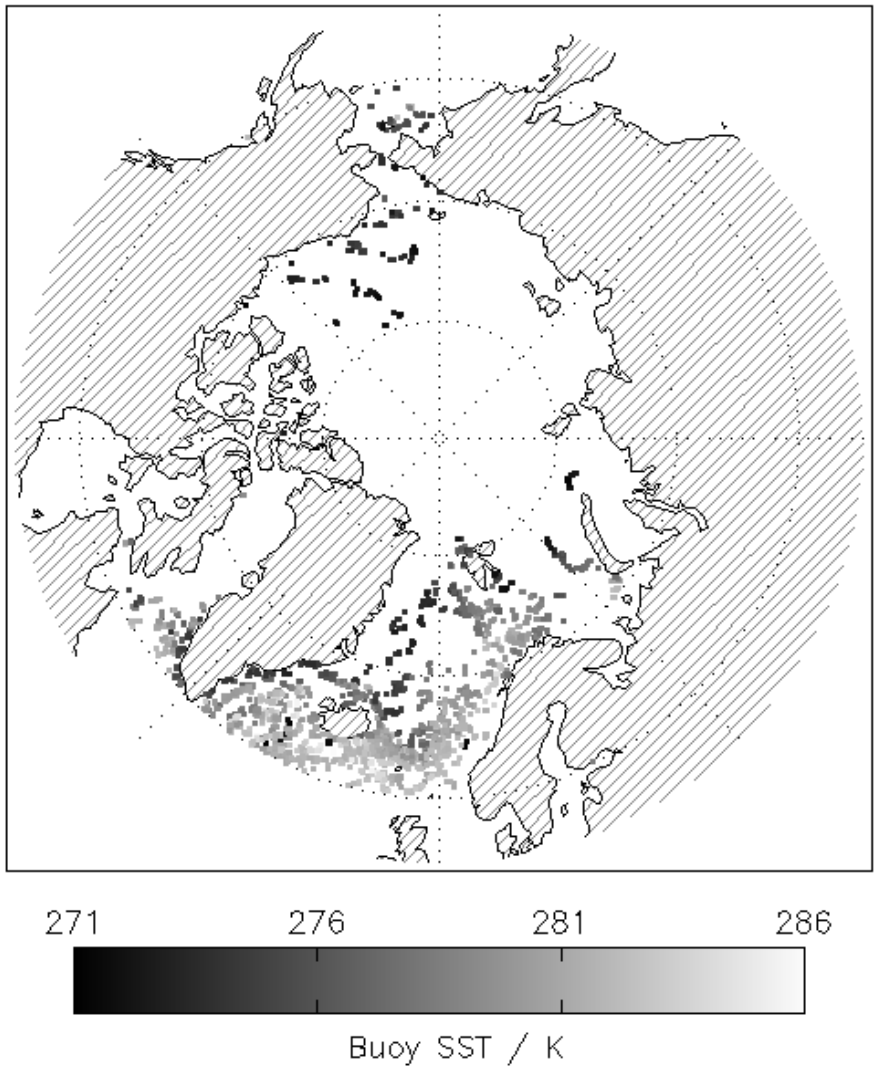
Data

- Match-up dataset from SAF
- Metop-A AVHRR
- 1 year of data, filtered against buoy blacklist
- Solar zenith angles > 90 deg (twilight and night)
- 3.7, 11 and 12 um BT, dBT/dx, dBT/dw
- CLs, angles, OSTIA, lat etc
- 4383 matches only



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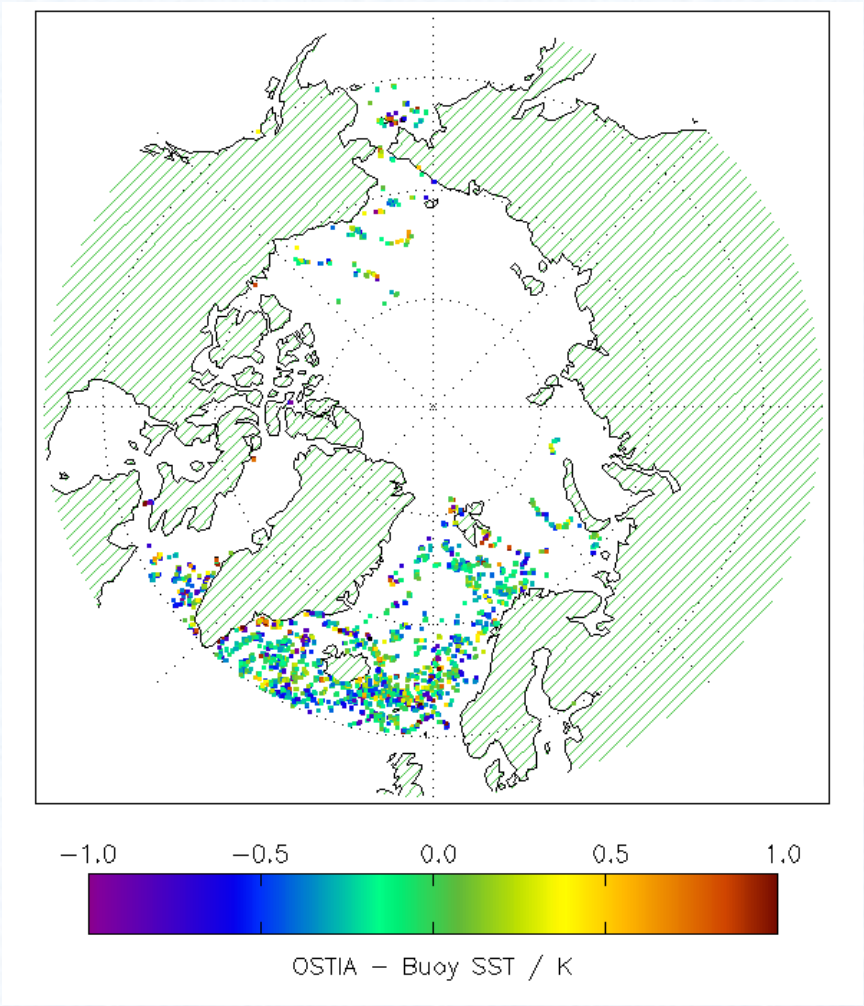
OSTIA vs Drifters



Note: not an independent comparison

Mean: -0.14 +/- SD 0.51 K

Median: -0.14 +/- RSD 0.34 K

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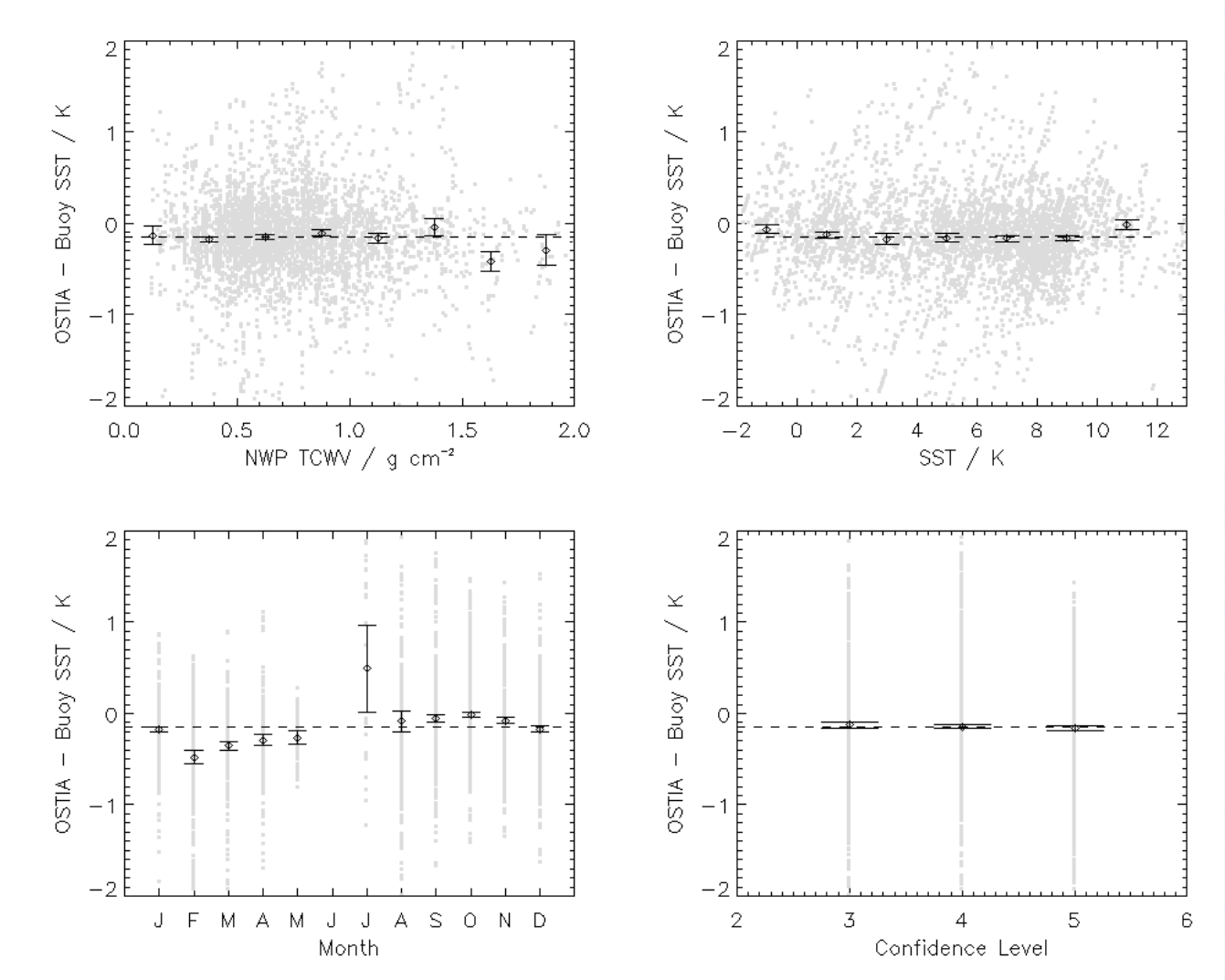
OSTIA vs Drifter



Diamond:
mean difference in bin

Bar:
95% confidence interval on the mean difference

Dashed line:
Overall mean difference

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Interpretation of the confidence interval

- How the CI was calculated
  - mean +/- t-factor * (standard deviation/sqrt(n-1))
  - for large n, t-factor → 1.96 (i.e., ~"two sigma")
  - for n = 3, t-factor ~ 4
- Assumption is independent errors
- But buoy contribution to difference is probably correlated for each buoy ID, so CIs are still underestimated
- Can't confidently say bias exists if bar overlaps

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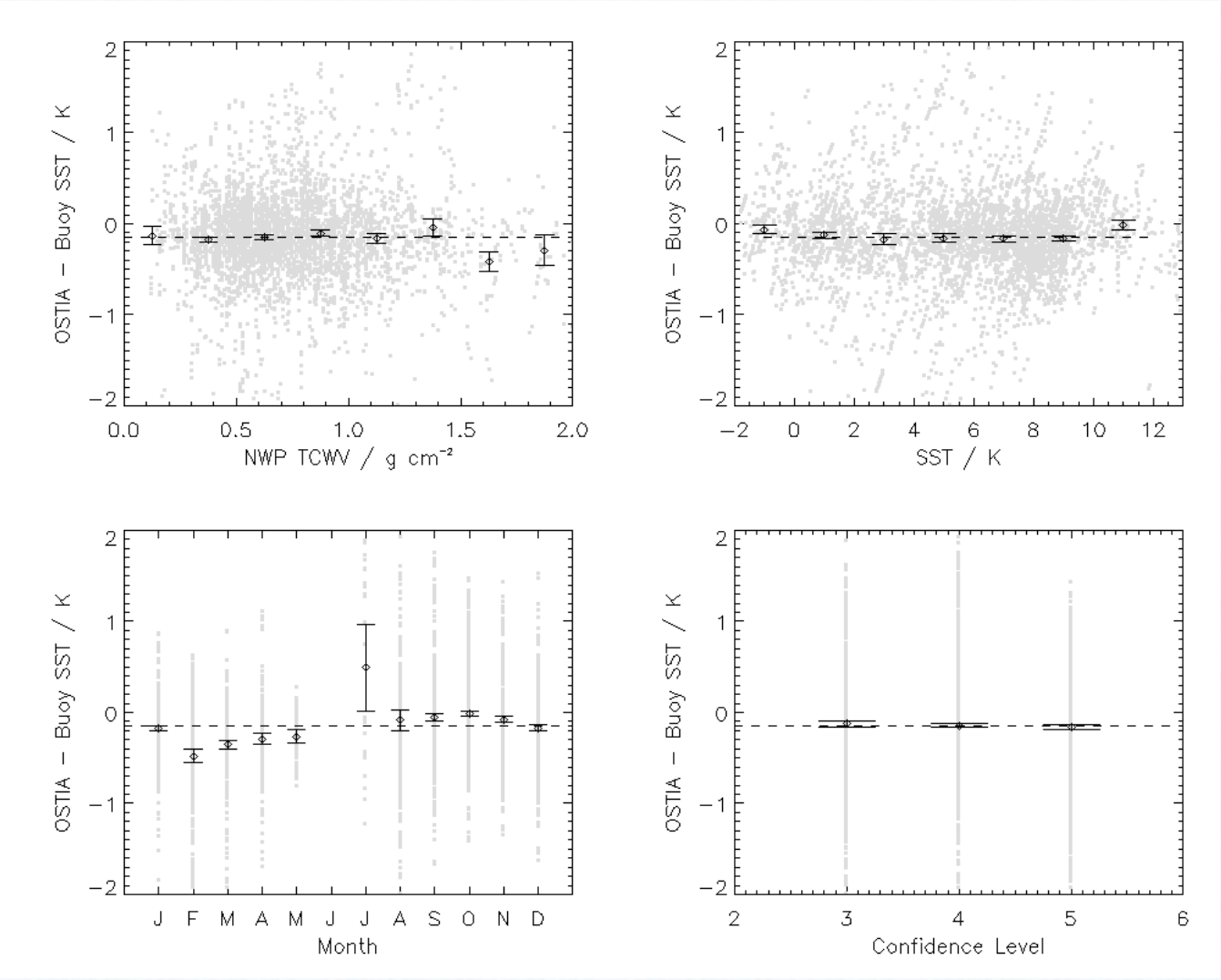
OSTIA vs Drifter



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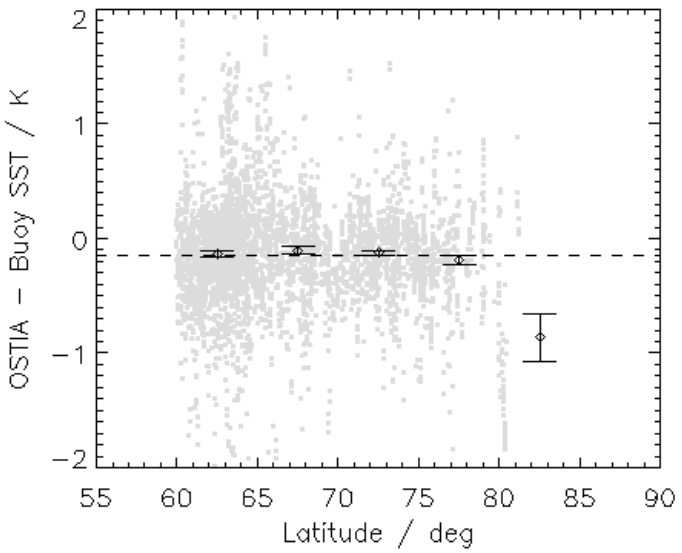

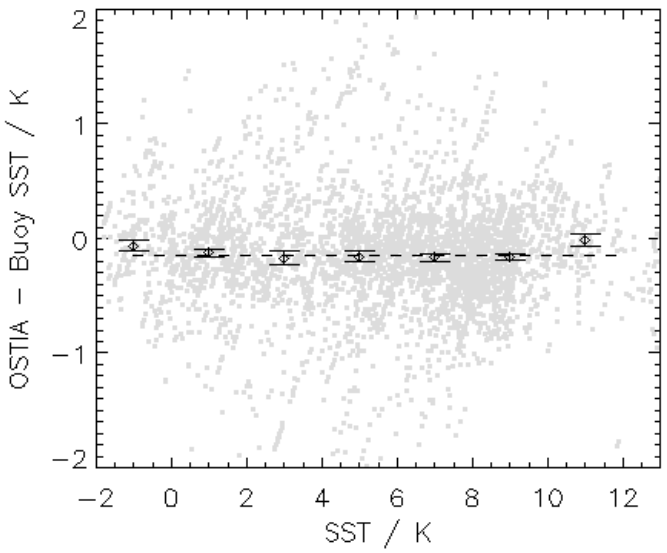

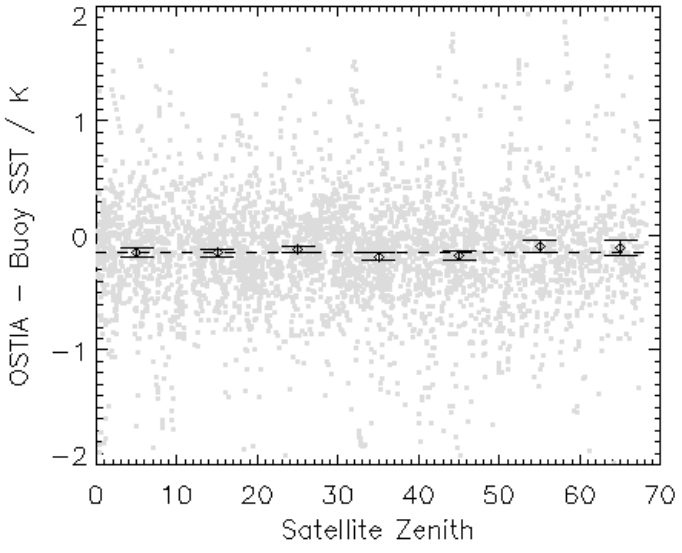

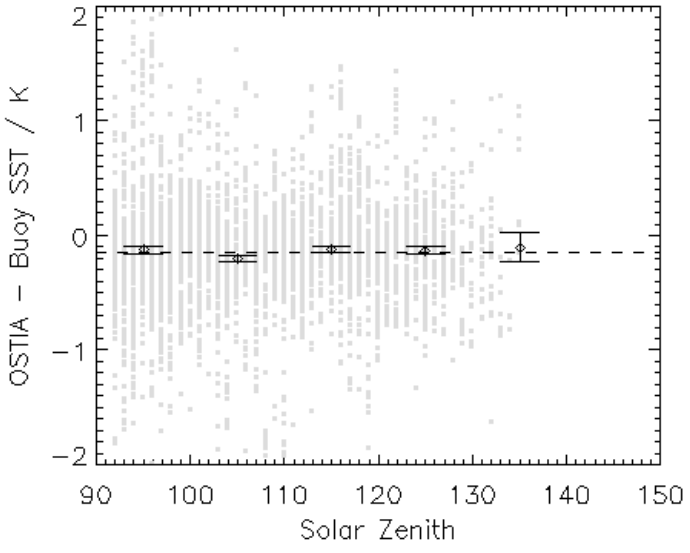

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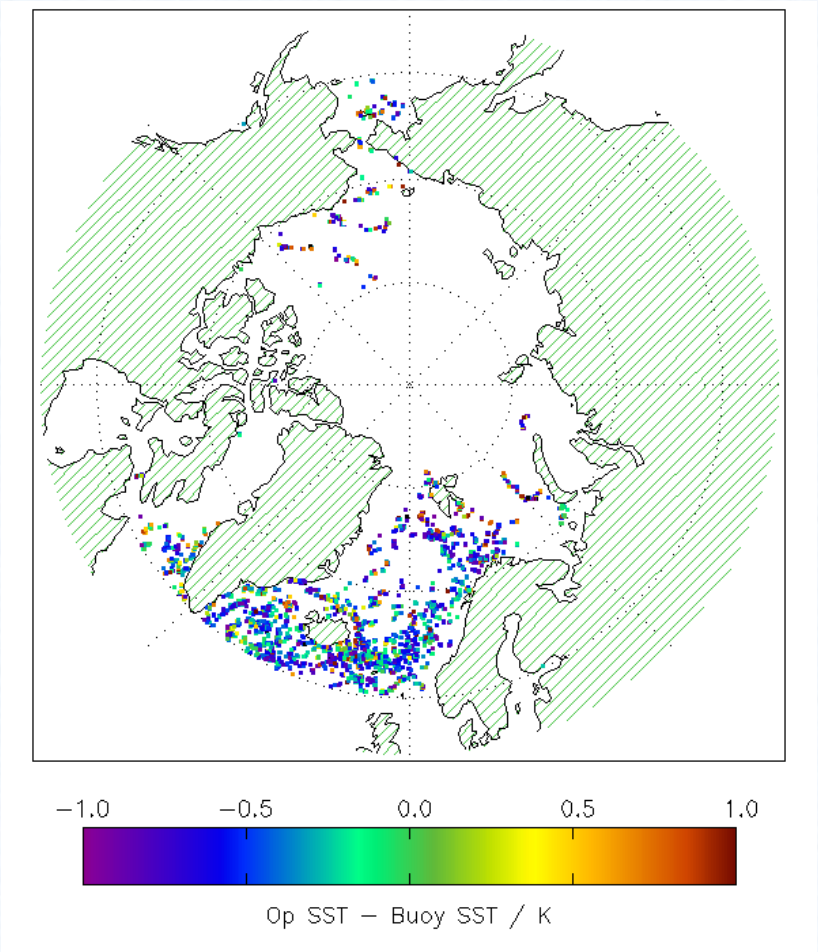
Operational Triple Coefficients



Mean: -0.55 +/- SD 0.60 K (4383)
Median: -0.53 +/- RSD 0.42 K

CL = 5
Mean: -0.52 +/- SD 0.48 K (1629)
Median: -0.52 +/- RSD 0.39 K
CL = 4
Mean: -0.53 +/- SD 0.59 K (1710)
Median: -0.50 +/- RSD 0.39 K
CL = 3
Mean: -0.61 +/- SD 0.76 K (1044)
Median: -0.61 +/- RSD 0.52 K

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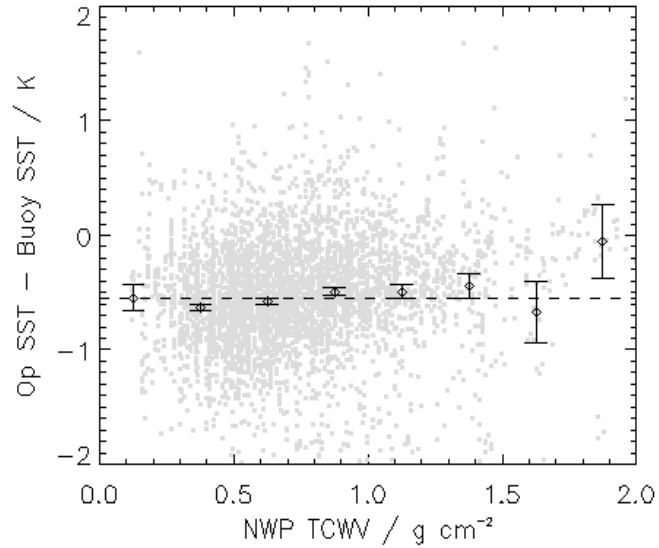

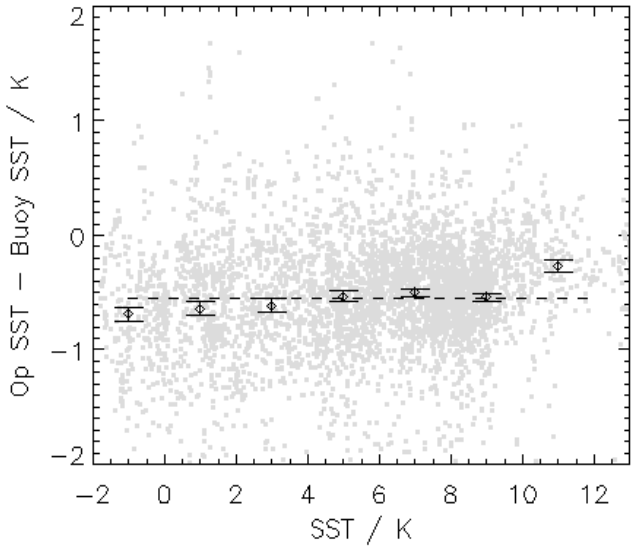

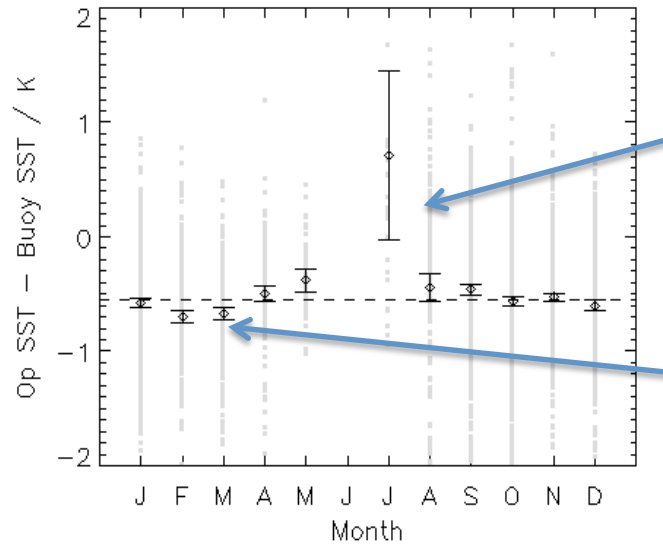

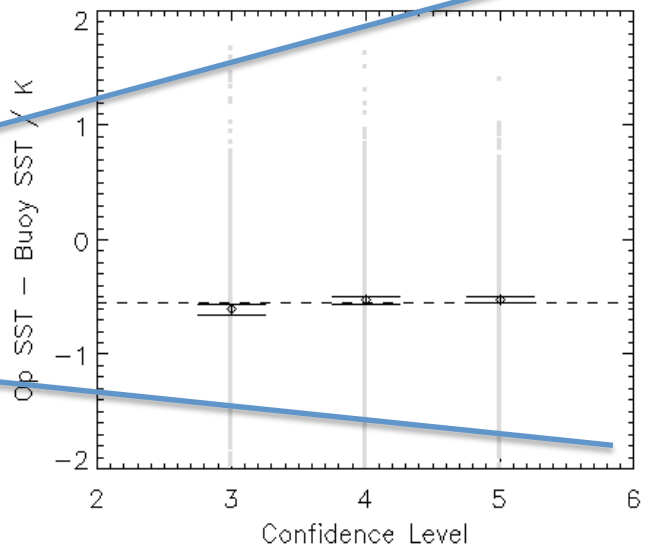

Speculation:

Influenced by real near-surface stratification between buoy and skin? Or a twilight effect?

Strong winter skin effect in satellite obs?

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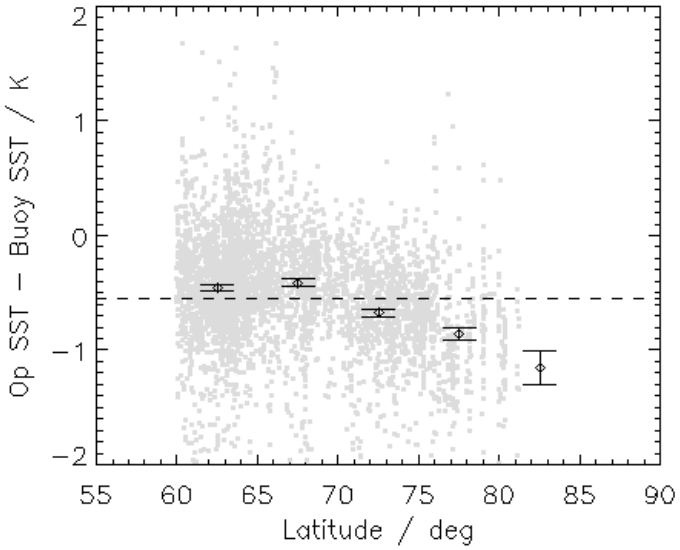

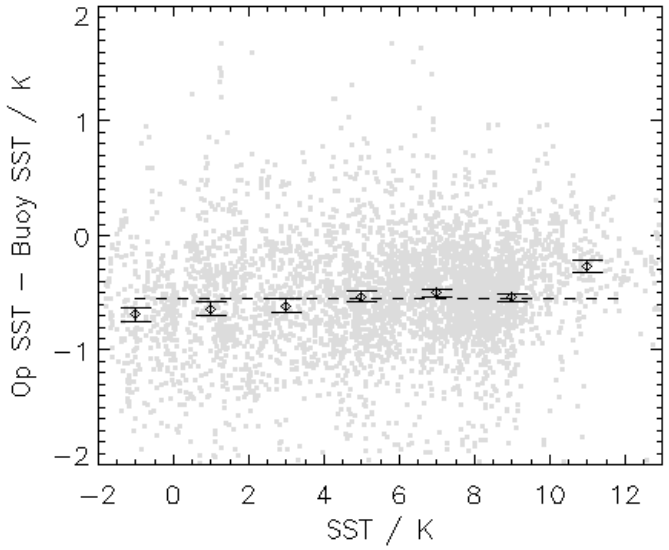

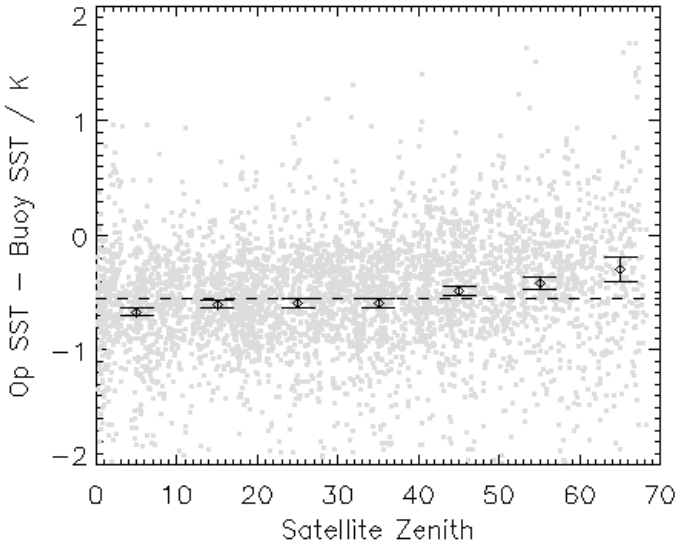

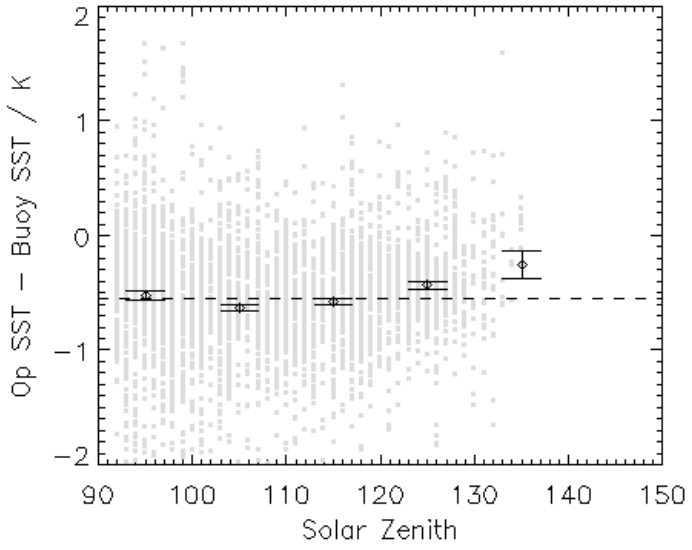

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Simulated Bias Correction

- Put the RTTOV-simulated BTs through the same retrieval coefficients
- Subtract the simulated retrieved bias (known given that we know the SST that went into the simulations)

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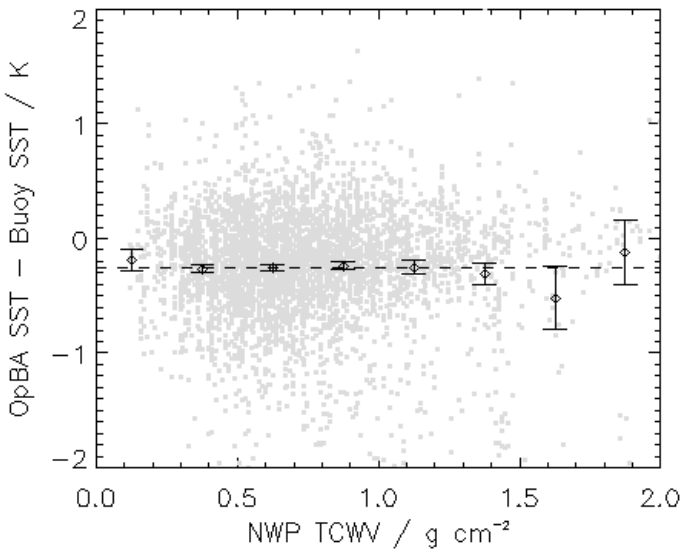

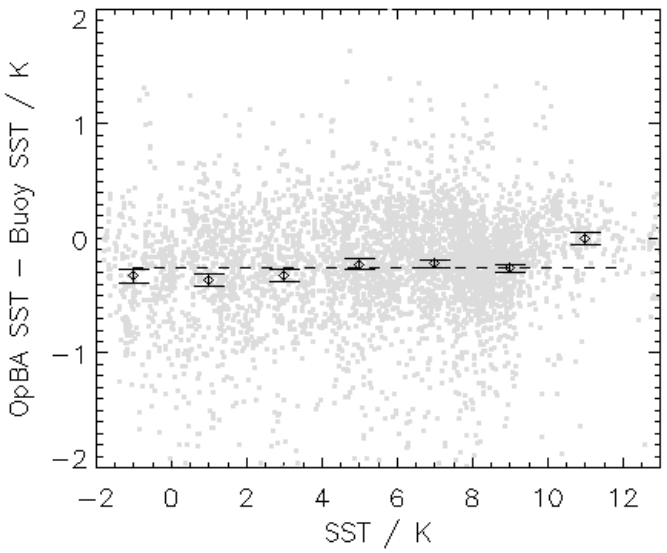

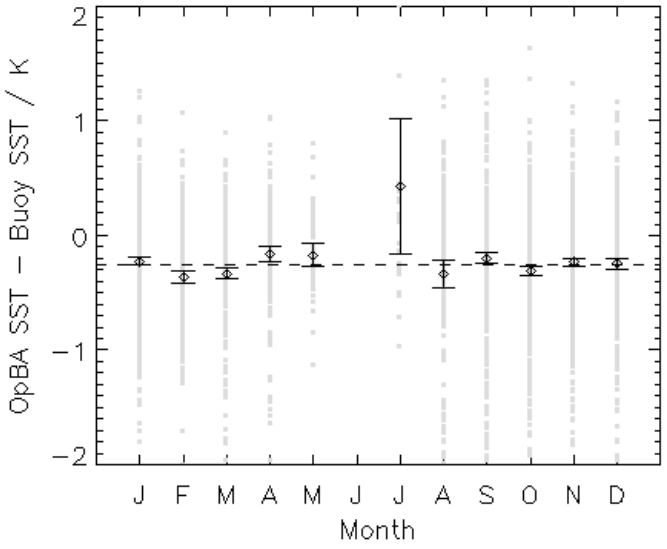

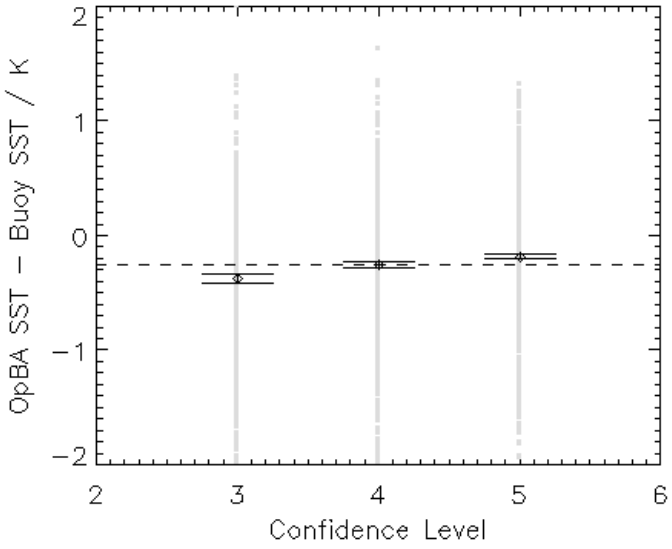

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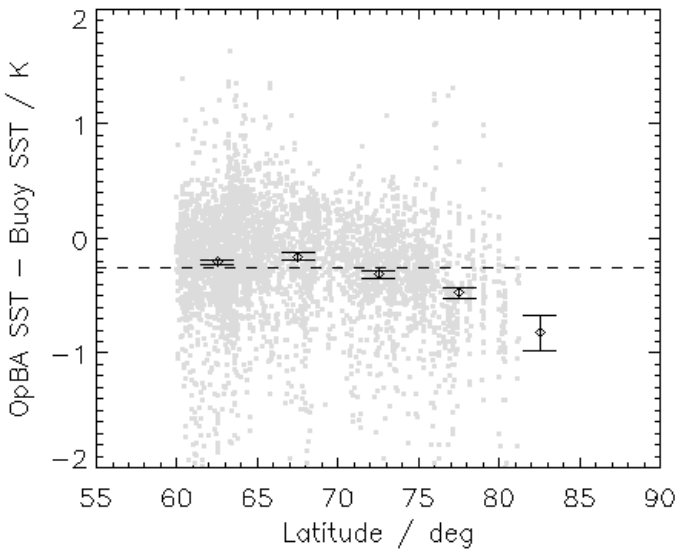

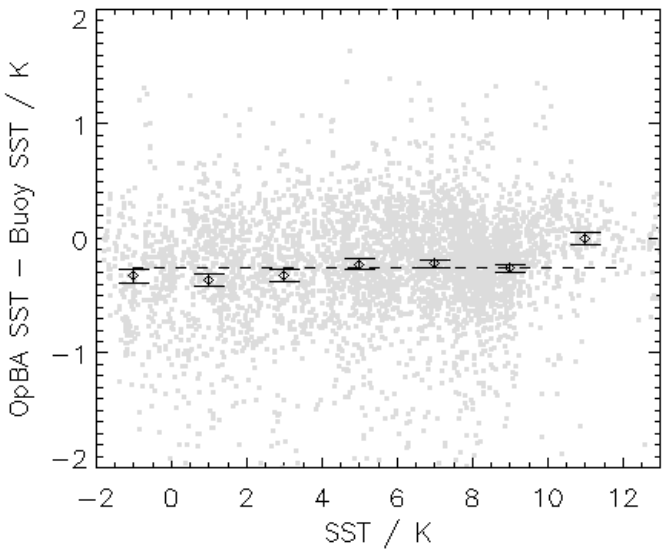

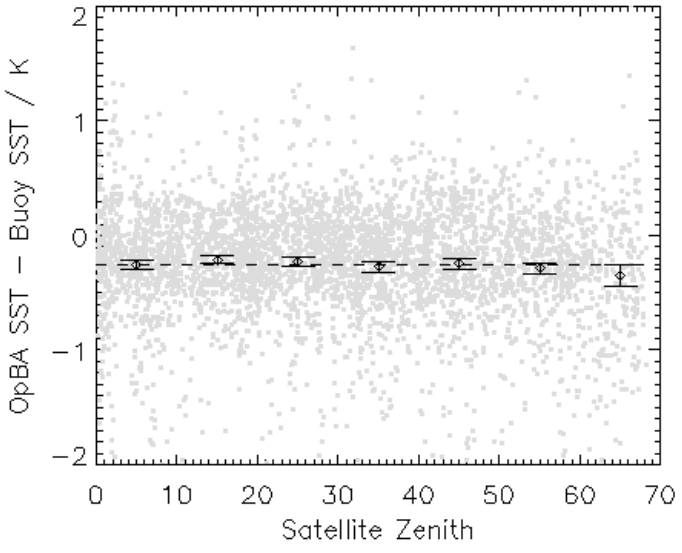

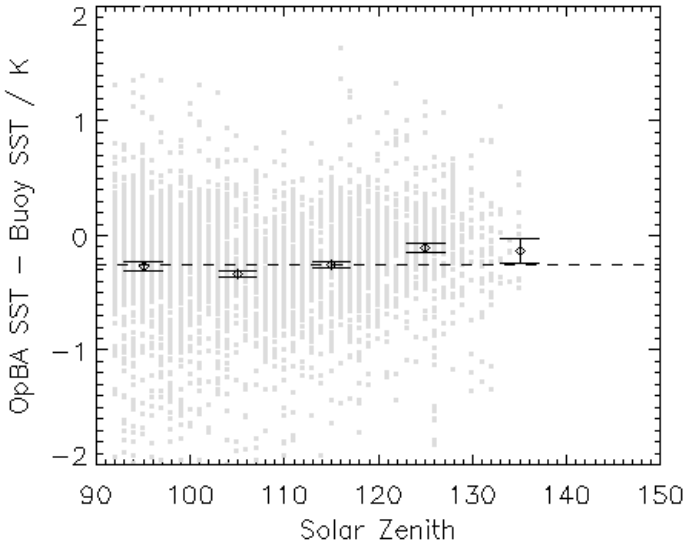

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Op with Sim Bias Correction

- Mean: -0.26 +/- SD 0.57 K (4383)
- Median: -0.21 +/- RSD 0.39 K

- Question: are these coefficients intended to deliver skin or subskin SST? (Is the T_corr coefficient tuned to buoys or buoys – 0.17 K?)
- If subskin, there is an overall bias still
- If skin, bias is <0.1 K

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Optimal Estimation (MAP)

- OE assumes
  - zero bias in simulation relative to observation
  - we have good estimates of the prior error covariance (Sa)
  - we have good estimates of the sensor noise and forward model error covariance (Se)
- All are not true, and the first in particular prompts BT bias adjustment efforts

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Naïve OE implementation

- Assume zero S-O bias, don't use SAF BT bias adjustments
- exb = 1.0 K
- ewb = as recent SEVIRI paper
- ey = 0.1 K (same noise all channels)
- eF = 0.15 K (RTTOV error independent between channels)
- Skin SST retrieval, then add 0.17 K to cf. drifters

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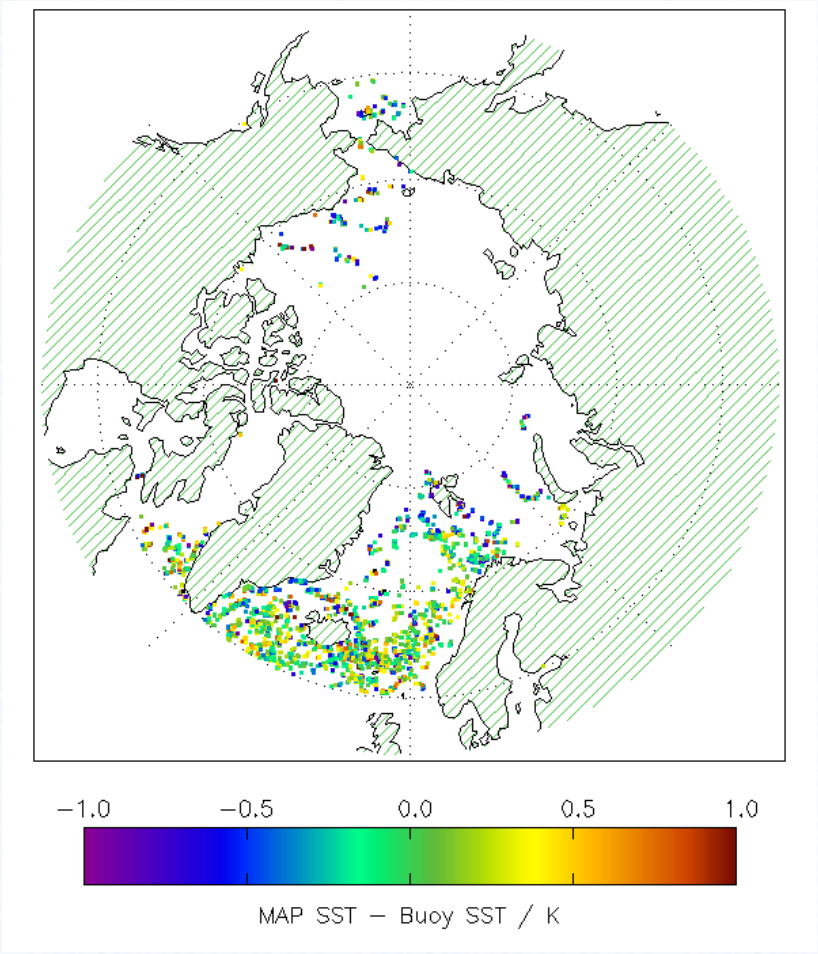
OE (MAP no BC) vs drifters



MAP, no SAF bias correction

CL = 5

Mean: -0.01 +/- SD 0.48 K (1629)

Median: 0.04 +/- RSD 0.38 K

CL = 4

Mean: -0.06 +/- SD 0.59 K (1710)

Median: 0.01 +/- RSD 0.37 K

CL = 3

Mean: -0.19 +/- SD 0.68 K (1044)

Median: -0.15 +/- RSD 0.49 K

ALL

Mean: -0.07 +/- SD 0.58 K (4383)

Median: -0.01 +/- RSD 0.40 K

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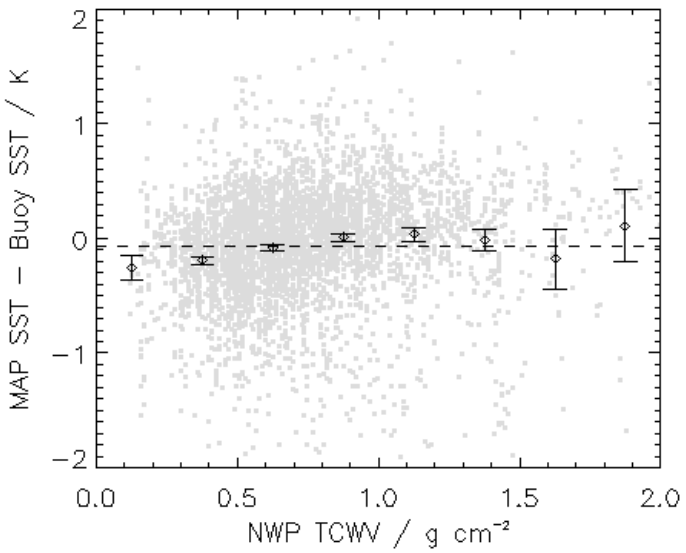

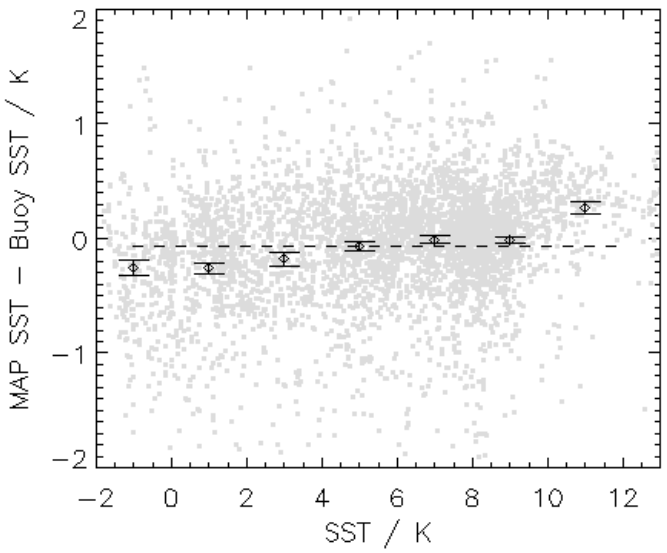

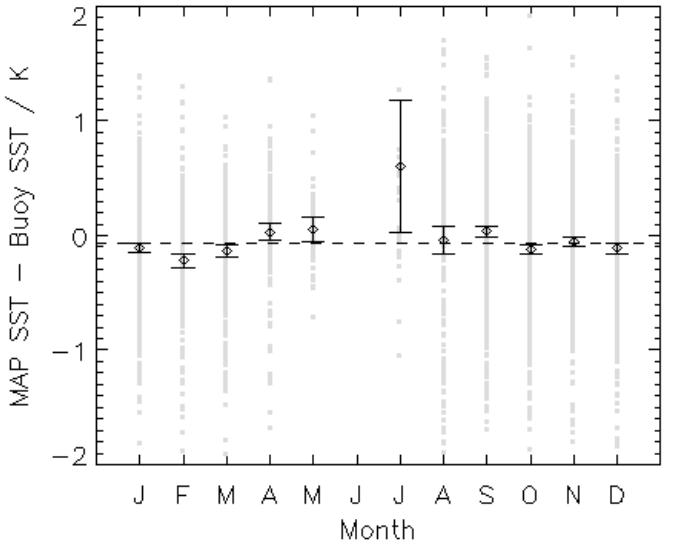

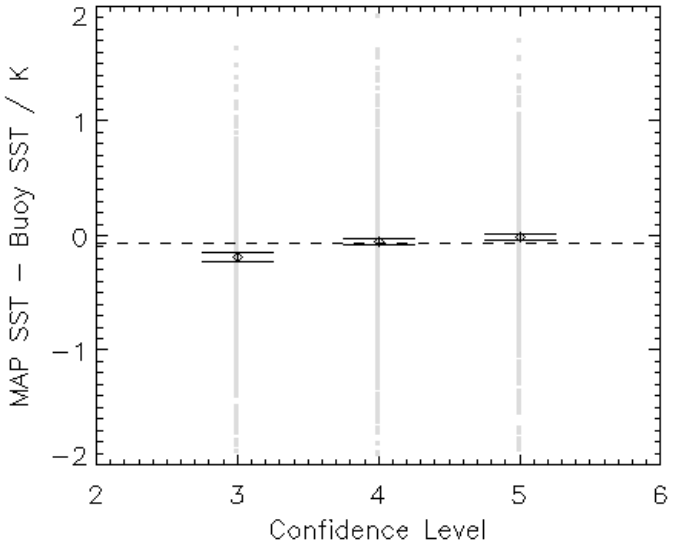

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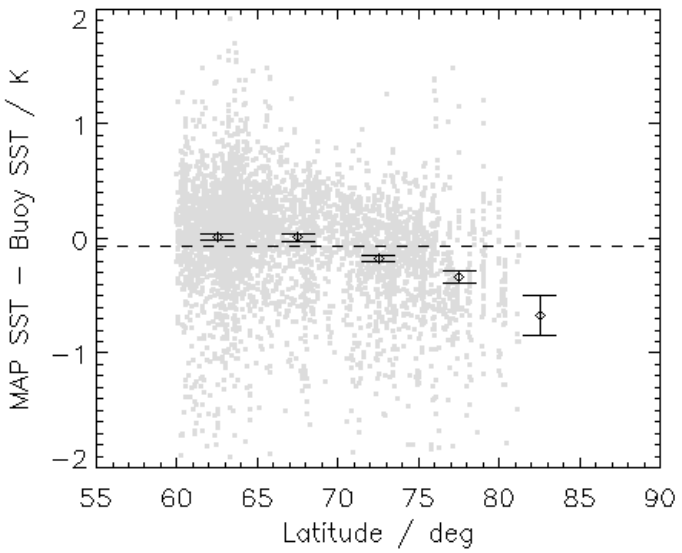

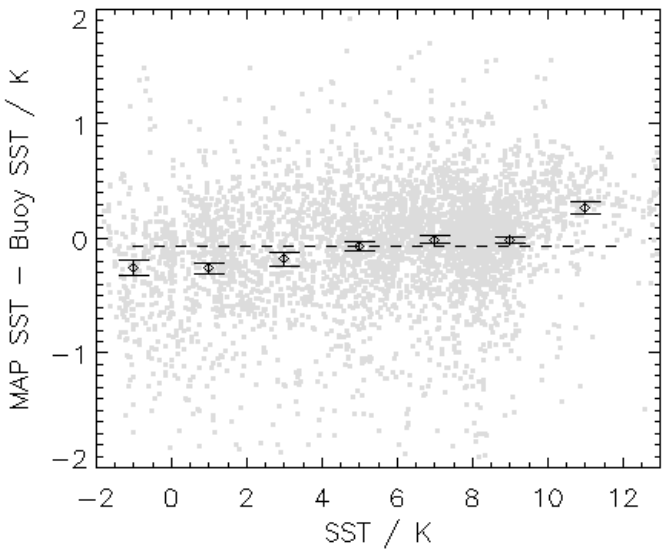

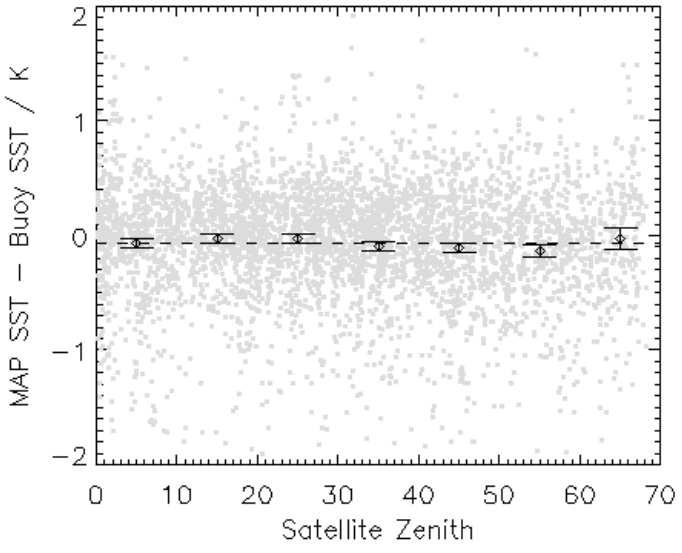

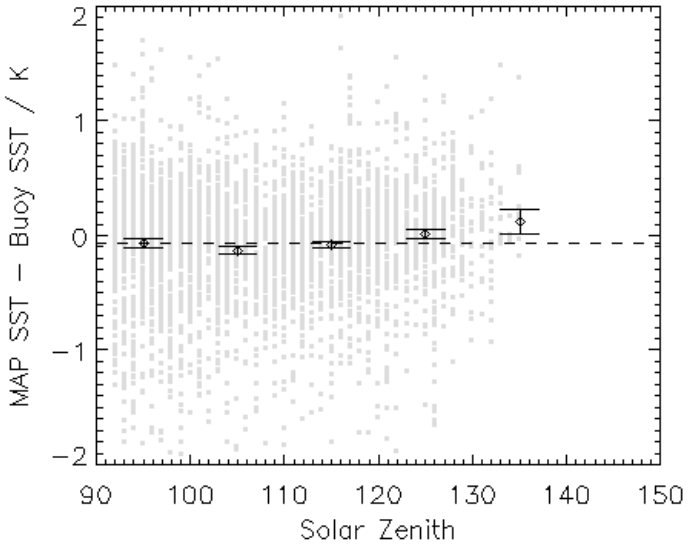

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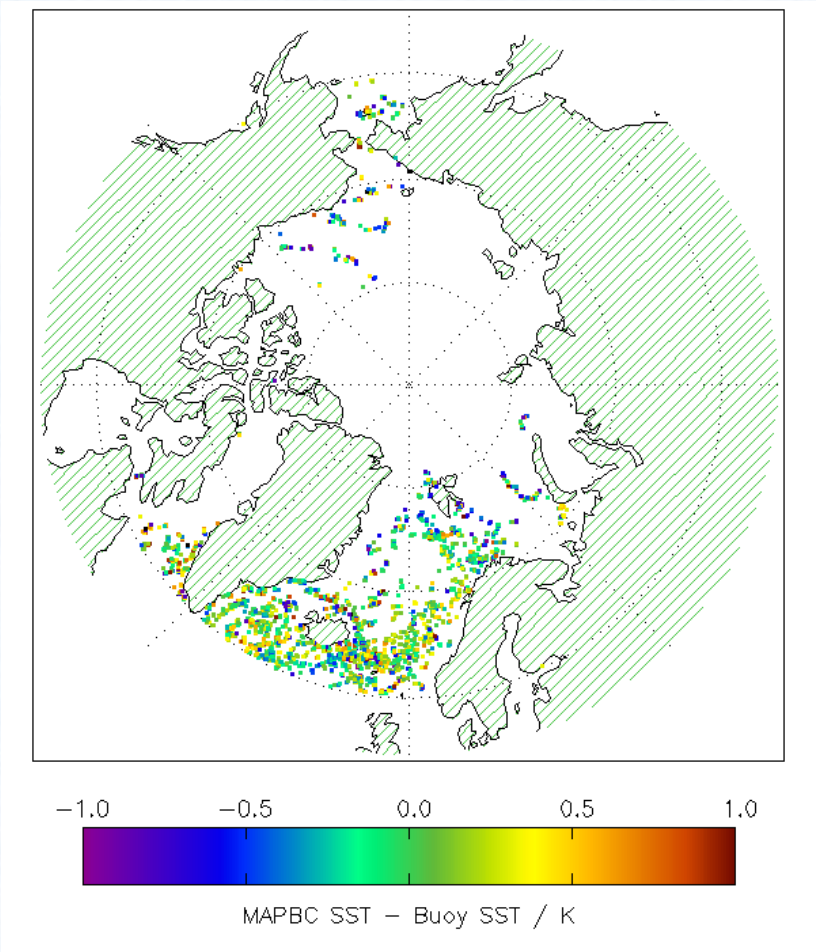
Does using the BT adj help OE MAP?



MAP, SAF bias correction
CL = 5
Mean: -0.01 +/- SD 0.48 K (1628)
Median: 0.04 +/- RSD 0.36 K
CL = 4
Mean: -0.03 +/- SD 0.59 K (1708)
Median: 0.03 +/- RSD 0.37 K
CL = 3
Mean: -0.11 +/- SD 0.69 K (1042)
Median: -0.07 +/- RSD 0.49 K
ALL
Mean: -0.04 +/- SD 0.58 K (4378)
Median: 0.02 +/- RSD 0.39 K

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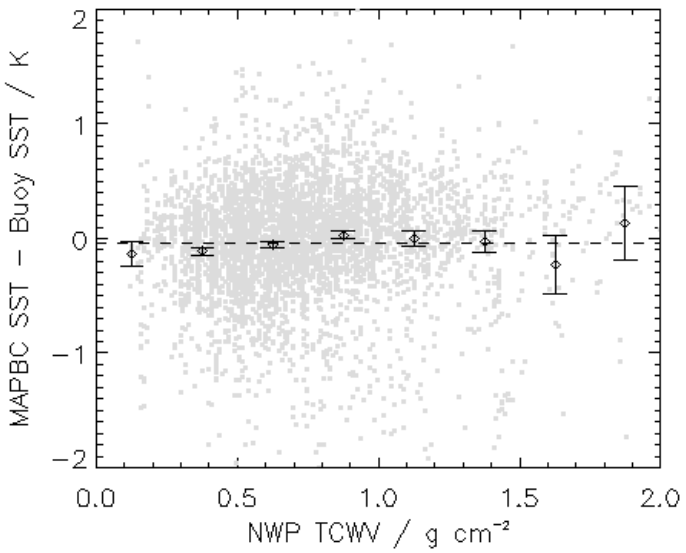

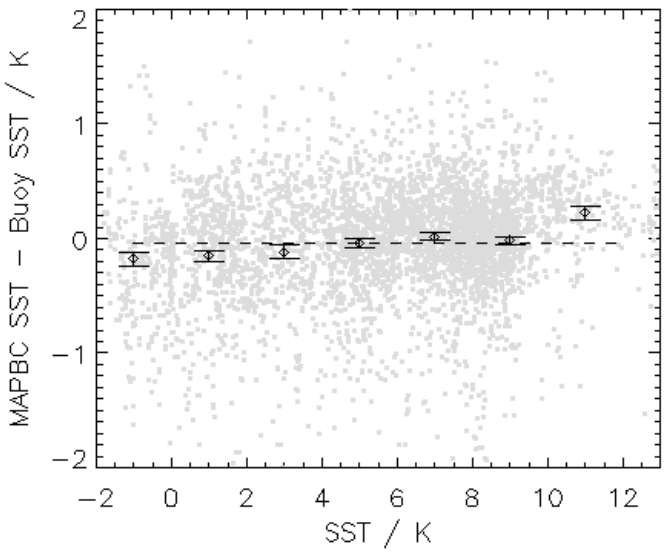

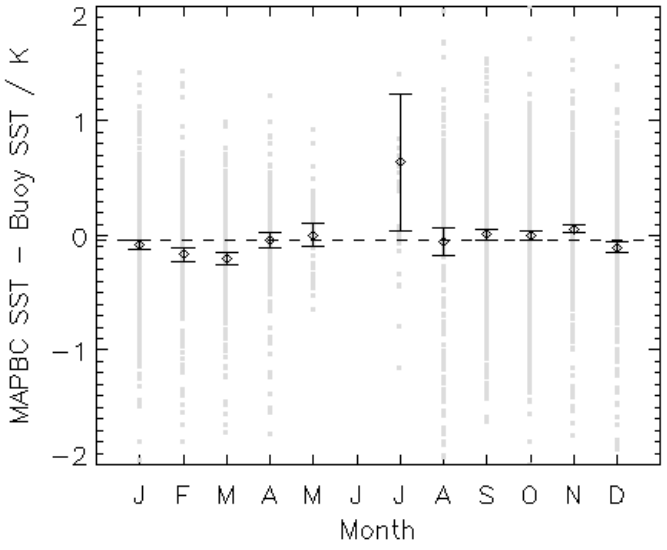

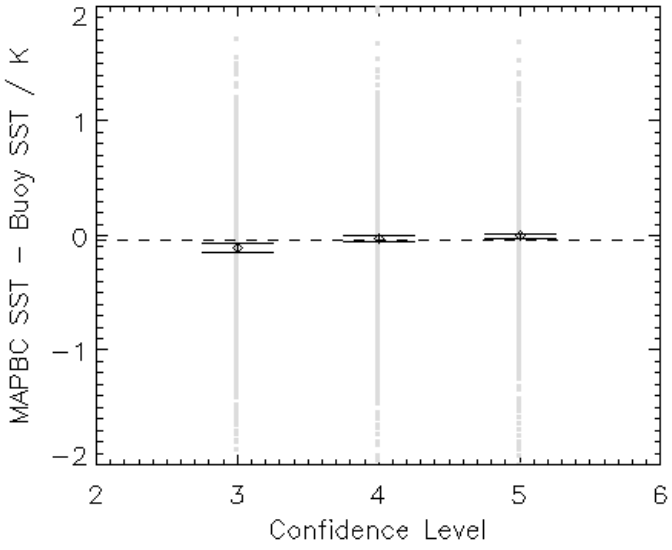

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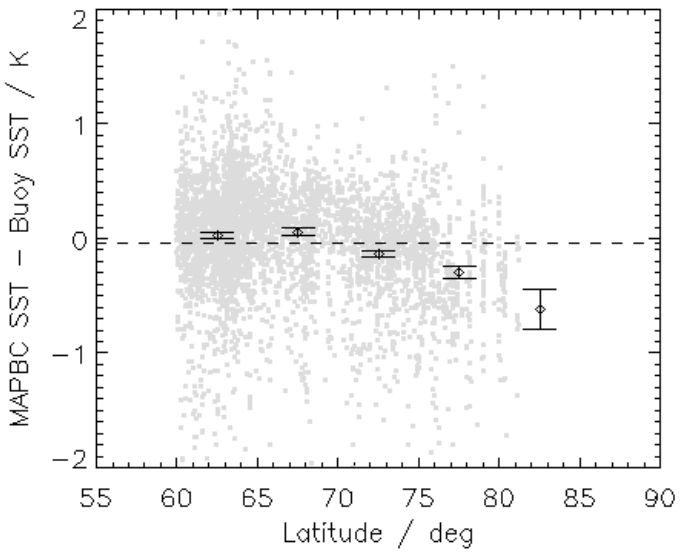

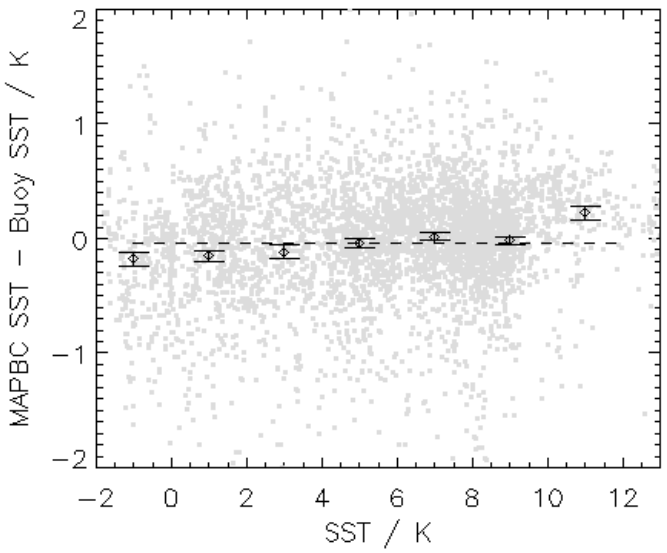

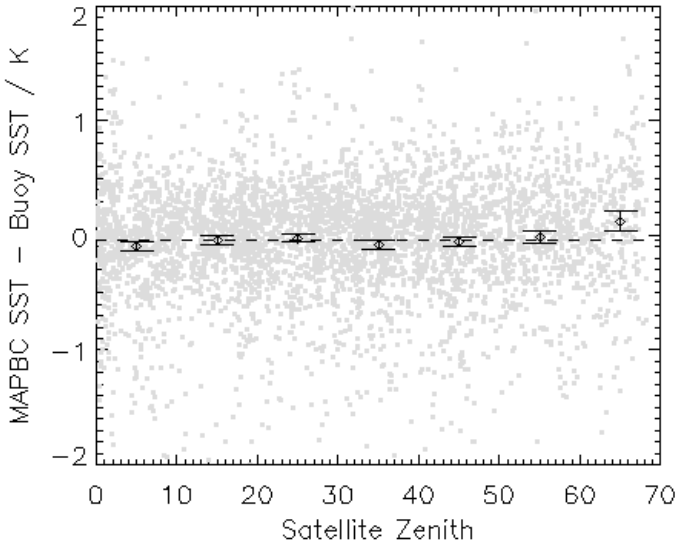

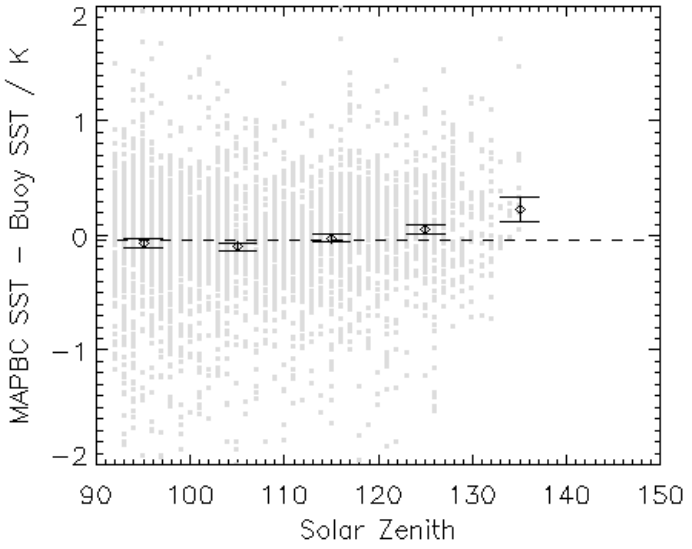

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Mid-point conclusions

- OSTIA small negative diffs overall (-0.14 K)
- Differences vary round year
- Op retrieval improved by using simulated bias correction, but negative diffs overall (-0.26 K)
- Varying differences round the year similar to OSTIA
  - Reflecting influence of Metop SSTs on OSTIA?
  - Moderated by use of simulated bias correction
  - Could near-surface stratification / strong winter skin effect between playing a role annual cycle of difference?
- OE relatively unbiased relative to drifters (-0.01 K)
- Varying differences round year damped in OE cf. OSTIA
- OE improved by SAF BT adjustment mainly for CL = 3
- All SSTs negatively biased cf. drifters at highest latitudes

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Ideas for bias-tolerant retrieval

- Modified Total Least Squares
  - Reported by Prabhat Koner at GHRSST to need no BT bias correction for GOES-12 retrieval using 3.7, 11 and 13 um
  - At same time OE without BC did badly
- Bias-aware Optimal Estimation
  - Empirical mean BT bias adjustment
  - Empirical forward model error covariance matrix, which reflects any correlated BT bias components

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Description of MTLS

- Like all similar methods, takes form of

$$x - x_b = \mathbf{G}(\mathbf{y} - \mathbf{f})$$

- In MTLS the gain **G** is

$$(\mathbf{K}^T\mathbf{K} + \lambda\mathbf{I})^{-1}\mathbf{K}^T$$

- The "clever" bit:
  - the regularisation parameter λ is variable
  - based on assessment of how much regularisation a particular inverse needs

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Deciding on λ

- The **K** matrix contains d**y**/dx and d**y**/dw terms
- If **y** – **f** is close to a linear combination of columns of **K** then **y** - **f** is plausibly explained by perturbations to x and w
  - Therefore, the simulation is "good" and the observation error is "small" and the inverse needs minimal regularisation ➔ small λ
- Otherwise, simulations and observations poorly match
  - the inverse should be strongly regularised ➔ large λ
- The actual recipe of Prabhat is
  - Find eigenvalues of [**K** **y**-**f**], call these **w**
  - $\lambda = 2.\ln(\max(\mathbf{w})/\min(\mathbf{w})).\min(\mathbf{w})^2$
  - This form is apparently a choice based on experiment

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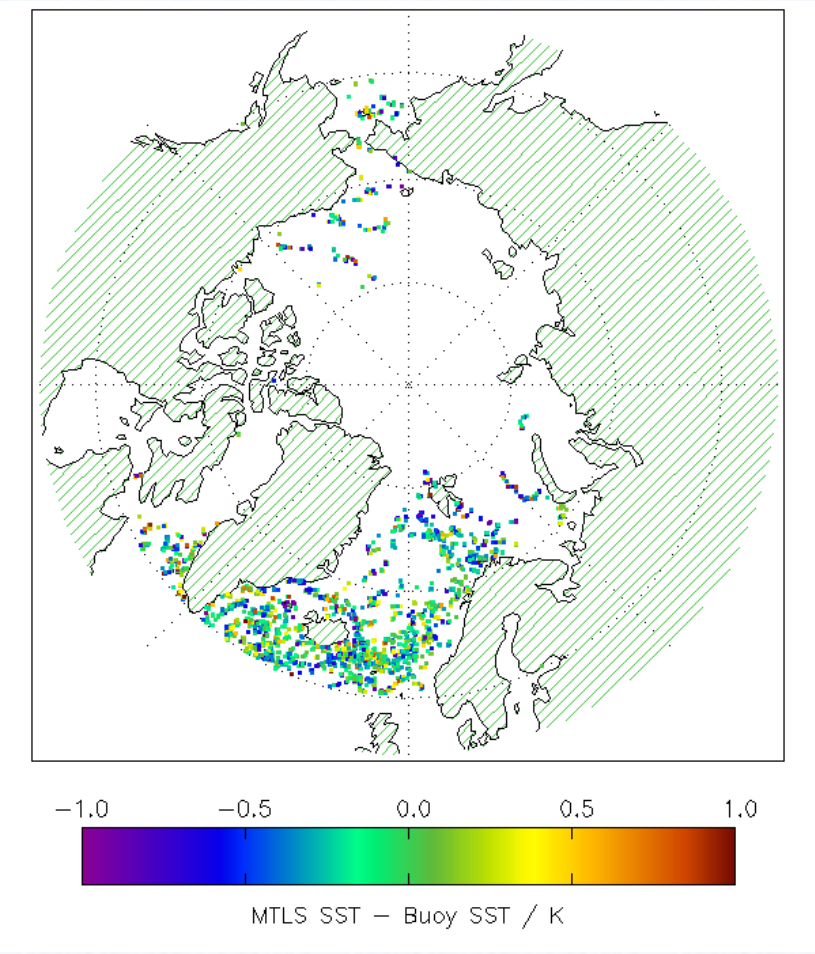
MTLS vs drifters



MLTLS, no BT bias correction
CL = 5
Mean: 0.02 +/- SD 0.45 K (1629)
Median: 0.03 +/- RSD 0.37 K
CL = 4
Mean: -0.04 +/- SD 0.57 K (1710)
Median: 0.01 +/- RSD 0.36 K
CL = 3
Mean: -0.15 +/- SD 0.72 K (1044)
Median: -0.11 +/- RSD 0.51 K
ALL
Mean: -0.04 +/- SD 0.58 K (4383)
Median: -0.00 +/- RSD 0.39 K

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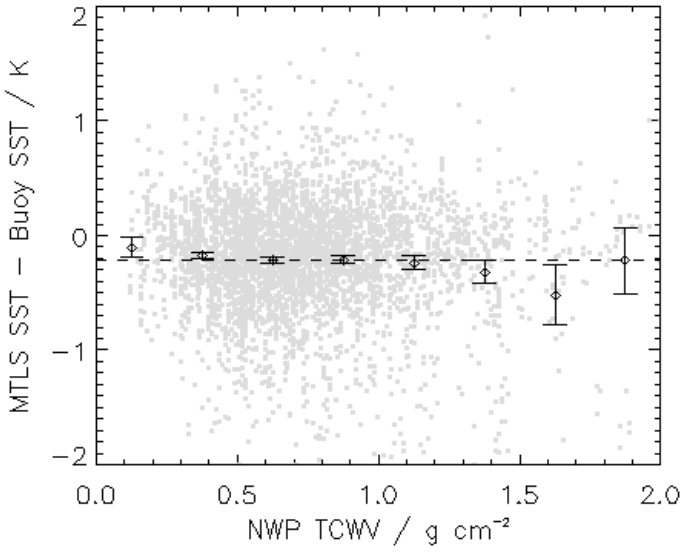
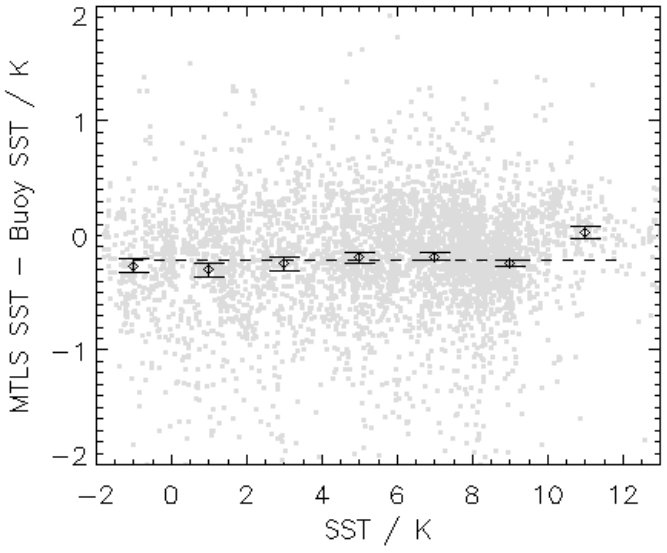
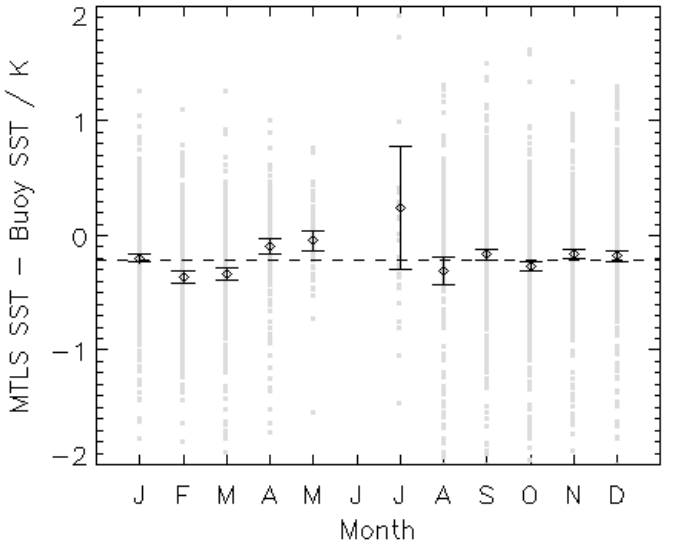
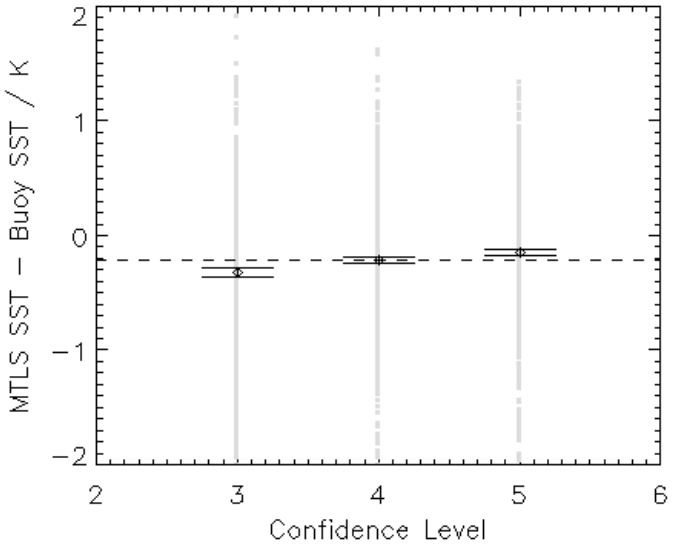
NB Figures done **without** adding 0.17 K to account for skin









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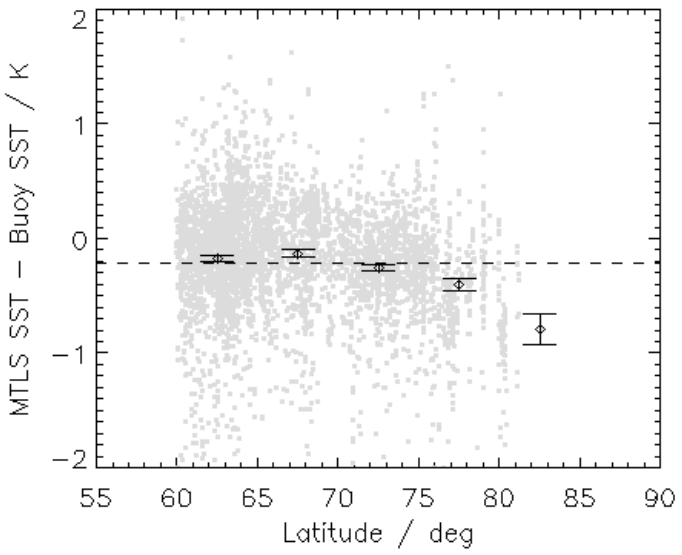
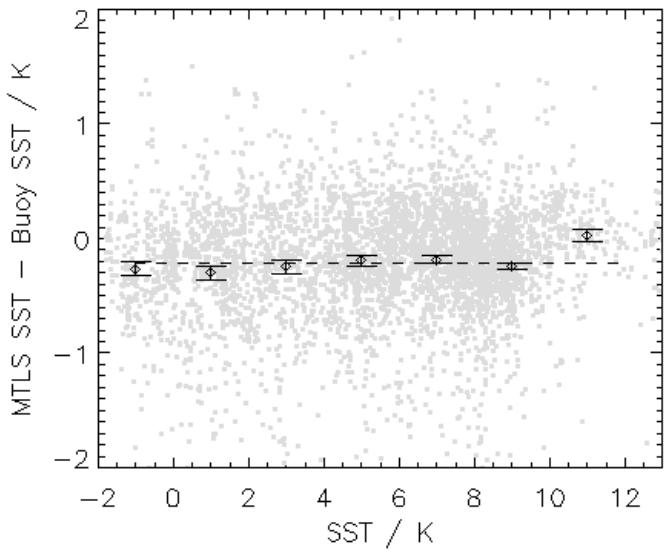
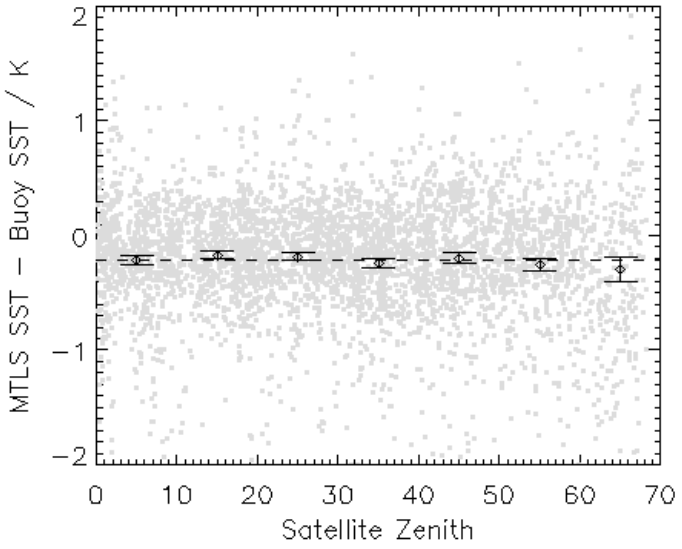
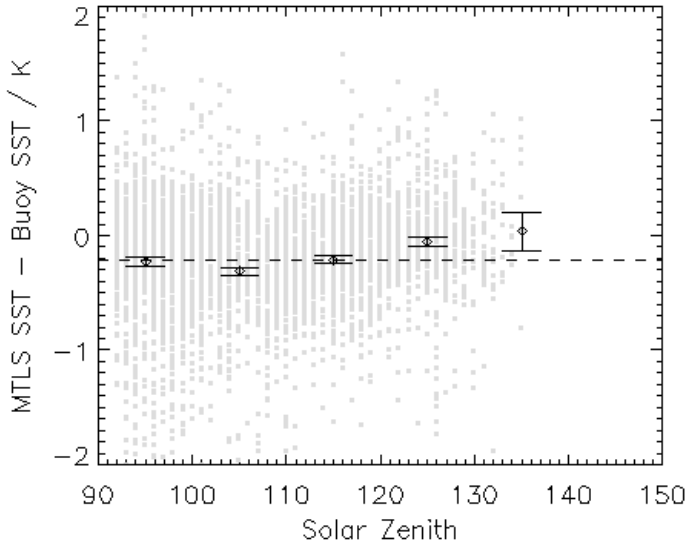
NB Figures done **without** adding 0.17 K to account for skin









The OE MAP gain matrix

- In normal OE the gain matrix can be written

$$\mathbf{S}_a\mathbf{K}^T(\mathbf{K}\mathbf{S}_a\mathbf{K}^T+\mathbf{S}_e)$$

$\mathbf{S}_e$ represents noise plus forward model, both of which have been modelled simply as diagonals

$\mathbf{S}_a$ includes the prior SST error variance (which we think we know well) and the TCWV (which we don't know well)

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“Bias-aware” OE formulation

- First calculate mean $\mathbf{\Delta f = y - f}$
  - accounting for skin effect when using OSTIA x_a
  - stratified by CL, since varies systematically
- Then, find covariance($\mathbf{y - f - \Delta f}$)
- This should equal the mean of ($\mathbf{KS_aK^T + S_e}$) but it doesn’t because the error covariances are not well known
- Get a new estimate of $\mathbf{S_e}$ as

$$\mathbf{S_e}^{BA} = \text{covariance}(\mathbf{y - f - \Delta f}) - \text{mean}(\mathbf{KS_aK^T})$$

- This then estimates the correlated forward model or BT errors across the domain (plus real sensor noise)
- Retrieval is: $x - x_a = \mathbf{S_aK^T(KS_aK^T + S_e}^{BA}\mathbf{)(y - f - \Delta f})$

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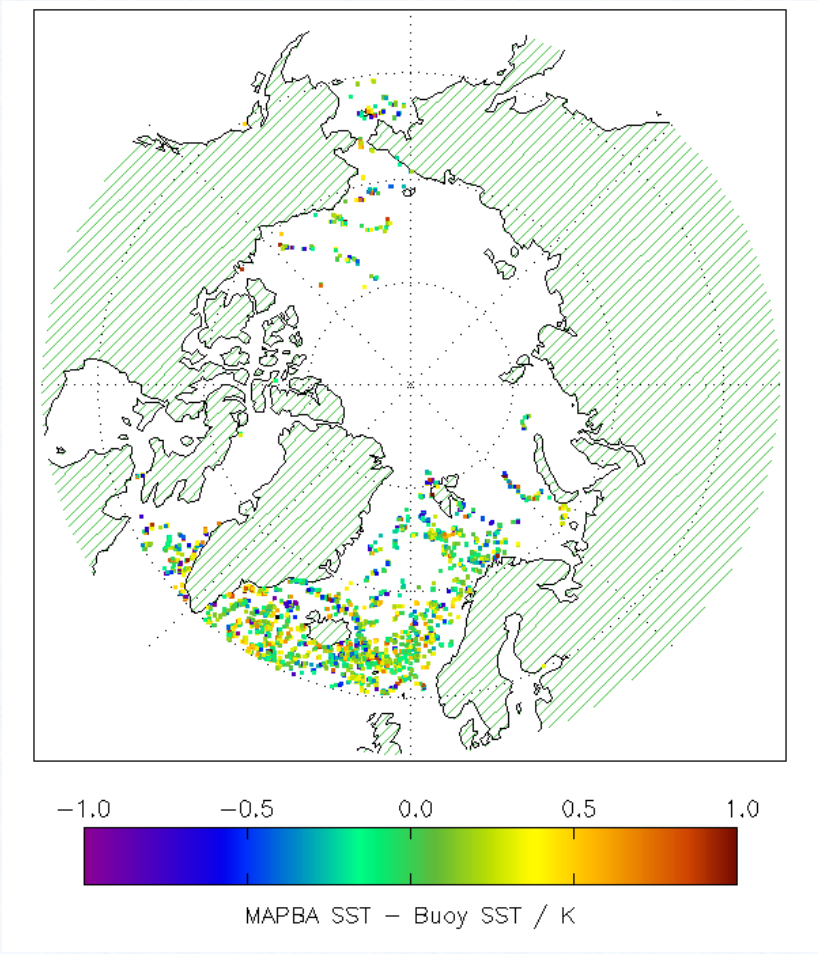
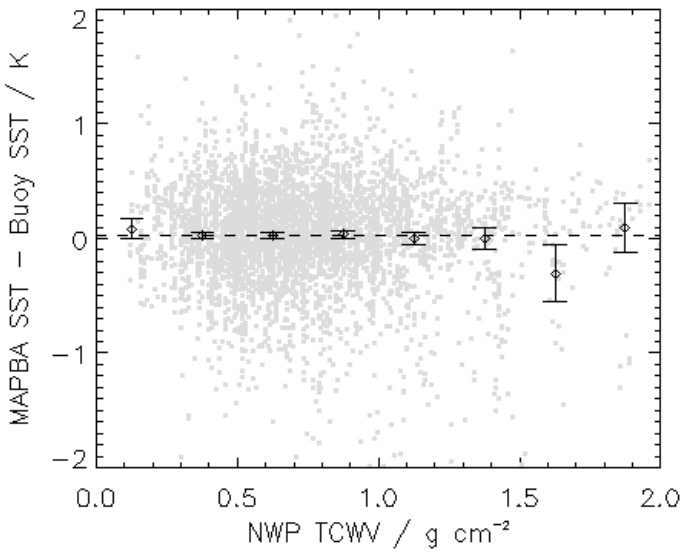
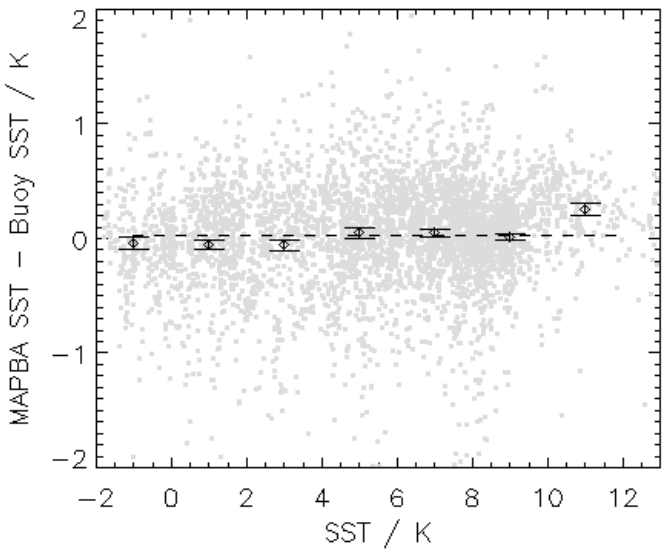
OE-BA vs. drifters

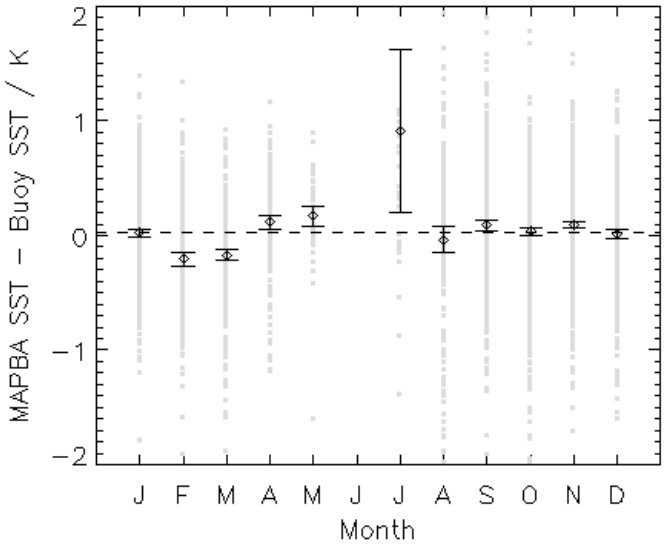


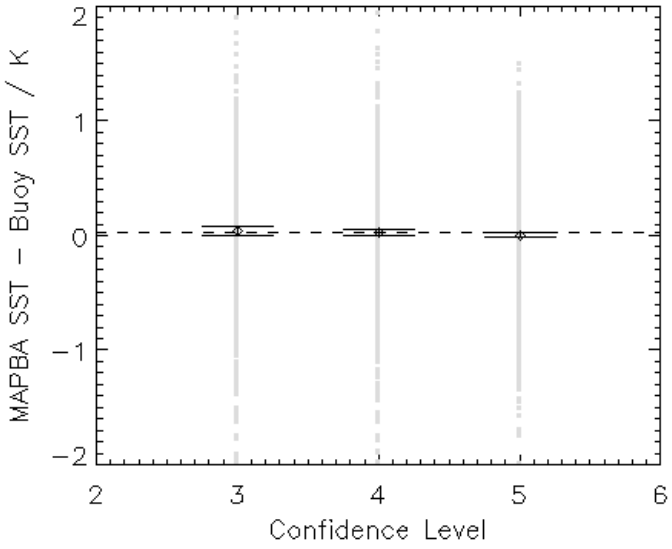
ALL
Mean: 0.02 +/- SD 0.53 K (4383)
Median: 0.05 +/- RSD 0.37 K

Reduction in SD!









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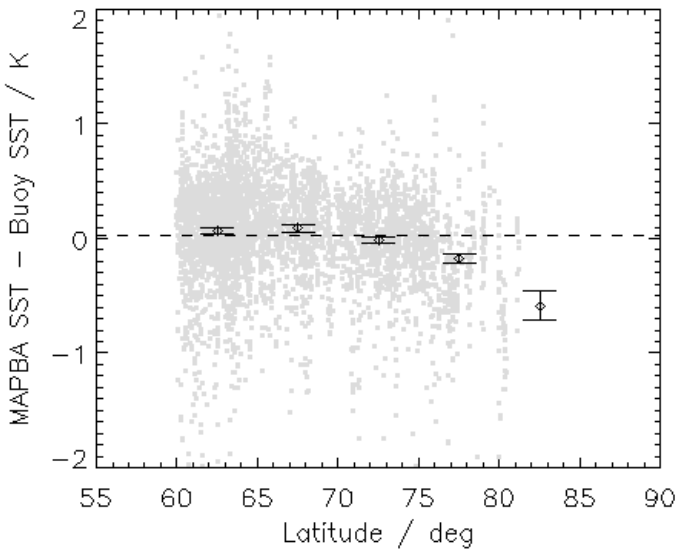

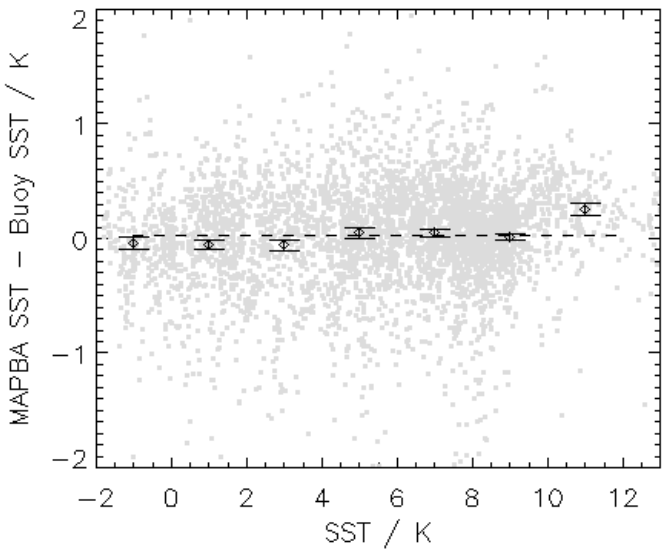

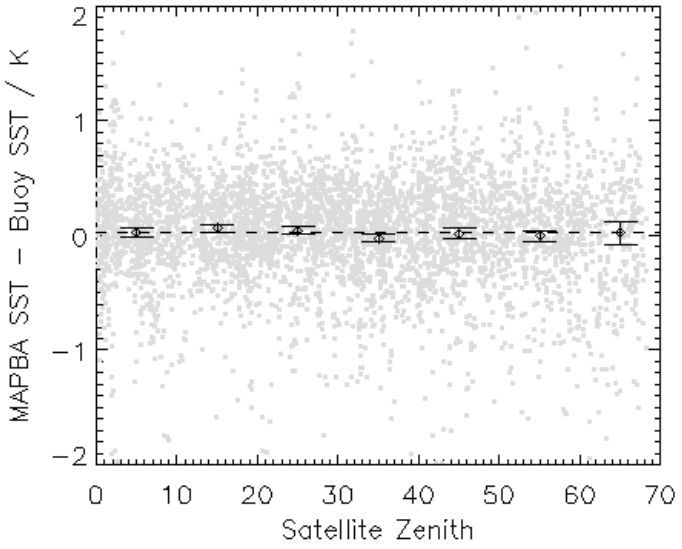

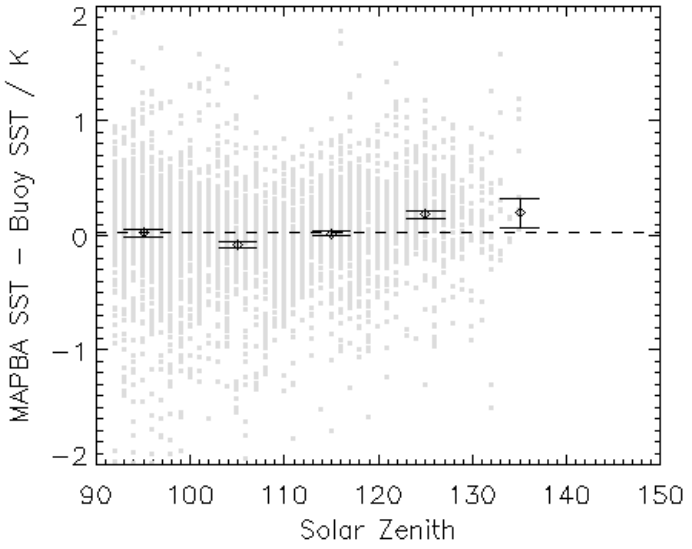

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Conclusions on new methods

- MTLS performance similar to OE naive
  - |mean diff| < 0.1 K
  - similar dispersion statistics
  - some functional biases improve, others degrade
- OE BA performance similar to OE BC
  - note CL biases flattened out
    - result of stratifying **Δf** by this variable
    - suggests strategy for attacking bias dependencies
  - seasonal variations not as good as OE BC
  - solar ZA and SST dependencies improved cf. OE BC

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Final remarks

- Bias-tolerant alternatives to BT adjustment scheme worth exploring further
  - But note: MTLS won't work for split window
  - Not sure if OE BA will work for split window
- All physics-based approaches seem to give different-but-similar-quality results
  - Coeffs + Sim Bias Corr (biased), OE BC, MTLS, OE BA
- Don't see in this data set any twilight problems using three channels
- Recommend adding calculated Fairall skin effect to MDs – skin effect variability may matter
  - Consider using skin estimate in forward model, retrieving skin explicitly (and adding skin estimate back to get subskin SST if required)

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