ESA Climate Change Initiative Phase-II

Sea Surface Temperature (SST)

www.esa-sst-cci.org

Optimal Estimation of Sea Surface Temperature from AMSR2

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Overview

- Part of SST CCI Phase 2.
- Assess the suitability for incorporating microwave data into the SST CCI retrieval scheme (GBCS).
- Demonstrate ability to carry out retrievals from AMSR2 data in a research (non-production) mode.
- Information Content
- Simulated Retrievals
- Retrievals from L1R AMSR2 orbit files.

Optimal Estimation - Equations

Best estimate of the state variables in the vector **x,** given an initial estimate $\mathbf{x}_a$ with corresponding (modelled) observations $\mathbf{y}_a$ and new (real) observations **y**.

$$\hat{\boldsymbol{x}} = \boldsymbol{x}_a + \boldsymbol{S}_a\boldsymbol{K}^T\left[\mathbf{K}\mathbf{S}_a\mathbf{K}^T + \mathbf{S}_\varepsilon\right]^{-1}(\mathbf{y} - \mathbf{y}_\mathbf{a})$$

$$\boldsymbol{x} = \begin{pmatrix} SST \\ \ln(TCWV) \\ u_{10} \\ v_{10} \\ \ln(TCLW) \end{pmatrix} \qquad \mathbf{y} = \begin{pmatrix} BT_1 \\ BT_2 \\ BT_3 \\ \vdots \\ BT_{14} \end{pmatrix}$$

Optimal Estimation - Equations

Best estimate of the state variables in the vector **x,** given an initial estimate $\mathbf{x}_a$ with corresponding (modelled) observations $\mathbf{y}_a$ and new (real) observations **y**.

$$\hat{\boldsymbol{x}} = \boldsymbol{x}_a + \boldsymbol{S}_a\boldsymbol{K}^T\left[\mathbf{K}\mathbf{S}_a\mathbf{K}^T + \mathbf{S}_\varepsilon\right]^{-1}(\mathbf{y} - \mathbf{y}_\mathbf{a})$$

$$\mathbf{K} = \begin{pmatrix} \frac{\partial BT_1}{\partial SST} & \frac{\partial BT_1}{\partial \ln(TCWV)} & \frac{\partial BT_1}{\partial u} & \frac{\partial BT_1}{\partial v} & \frac{\partial BT_1}{\partial \ln(TCLW)} \\ \frac{\partial BT_2}{\partial SST} & \frac{\partial BT_2}{\partial \ln(TCWV)} & \frac{\partial BT_2}{\partial u} & \frac{\partial BT_2}{\partial v} & \frac{\partial BT_2}{\partial \ln(TCLW)} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \frac{\partial BT_{14}}{\partial SST} & \frac{\partial BT_{14}}{\partial \ln(TCWV)} & \frac{\partial BT_{14}}{\partial u} & \frac{\partial BT_{14}}{\partial v} & \frac{\partial BT_{14}}{\partial \ln(TCLW)} \end{pmatrix}$$

Optimal Estimation - Equations

Best estimate of the state variables in the vector **x,** given an initial estimate $\mathbf{x}_a$ with corresponding (modelled) observations $\mathbf{y}_a$ and new (real) observations **y**.

$$\hat{\boldsymbol{x}} = \boldsymbol{x}_a + \boldsymbol{S}_a \boldsymbol{K}^T \left[\mathbf{K}\mathbf{S}_a\mathbf{K}^T + \mathbf{S}_\varepsilon\right]^{-1} (\mathbf{y} - \mathbf{y}_\mathbf{a})$$

$$\mathbf{S}_a = \begin{pmatrix} \sigma_{SST}{}^2 & \sigma_{lnTCWV,SST}{}^2 & \sigma_{u,SST}{}^2 & \sigma_{v,SST}{}^2 & \sigma_{lnTCLW,SST}{}^2 \\ \sigma_{SST,lnTCWV}{}^2 & \sigma_{lnTCWV}{}^2 & \sigma_{u,lnTCWV}{}^2 & \sigma_{v,lnTCWV}{}^2 & \sigma_{lnTCLW,lnTCWV}{}^2 \\ \sigma_{SST,u}{}^2 & \sigma_{lnTCWV,u}{}^2 & \sigma_{u}{}^2 & \sigma_{v,u}{}^2 & \sigma_{lnTCLW,u}{}^2 \\ \sigma_{SST,v}{}^2 & \sigma_{lnTCWV,v}{}^2 & \sigma_{u,v}{}^2 & \sigma_{v}{}^2 & \sigma_{lnTCLW,v}{}^2 \\ \sigma_{SST,lnTCLW}{}^2 & \sigma_{lnTCWV,lnTCLW}{}^2 & \sigma_{u,lnTCLW}{}^2 & \sigma_{v,lnTCLW}{}^2 & \sigma_{lnTCLW}{}^2 \end{pmatrix}$$

Information Content - Equations

Degrees of Freedom for signal:

$$d_s = tr\,([\mathbf{K}^T \mathbf{S}_\varepsilon{}^{-1}\mathbf{K} + \mathbf{S}_a{}^{-1}]\mathbf{K}^\mathrm{T} \mathbf{S}_\varepsilon{}^{-1}\mathbf{K})$$

Expected retrieval (uncertainty) covariance matrix:

$$\boldsymbol{S} = [\mathbf{K}^T \mathbf{S}_\varepsilon{}^{-1}\mathbf{K} + \mathbf{S}_a{}^{-1}]$$

Information Content - Equations

Using diagonal covariance matrixes with:

$S_{a,ii}$=[(3.31K)^2, (0.1)^2, (0.92 m/s)^2, (0.92 m/s)^2 ,(0.1)^2]

$S_{\varepsilon,ii}$=[(0.34)^2, (0.34)^2 ,(0.43)^2,(0.43)^2, (0.7)^2, (0.7)^2, (0.7)^2, (0.7)^2, (0.6)^2, (0.6)^2, (0.7)^2, (0.7)^2, (1.2)^2, (1.2)^2]

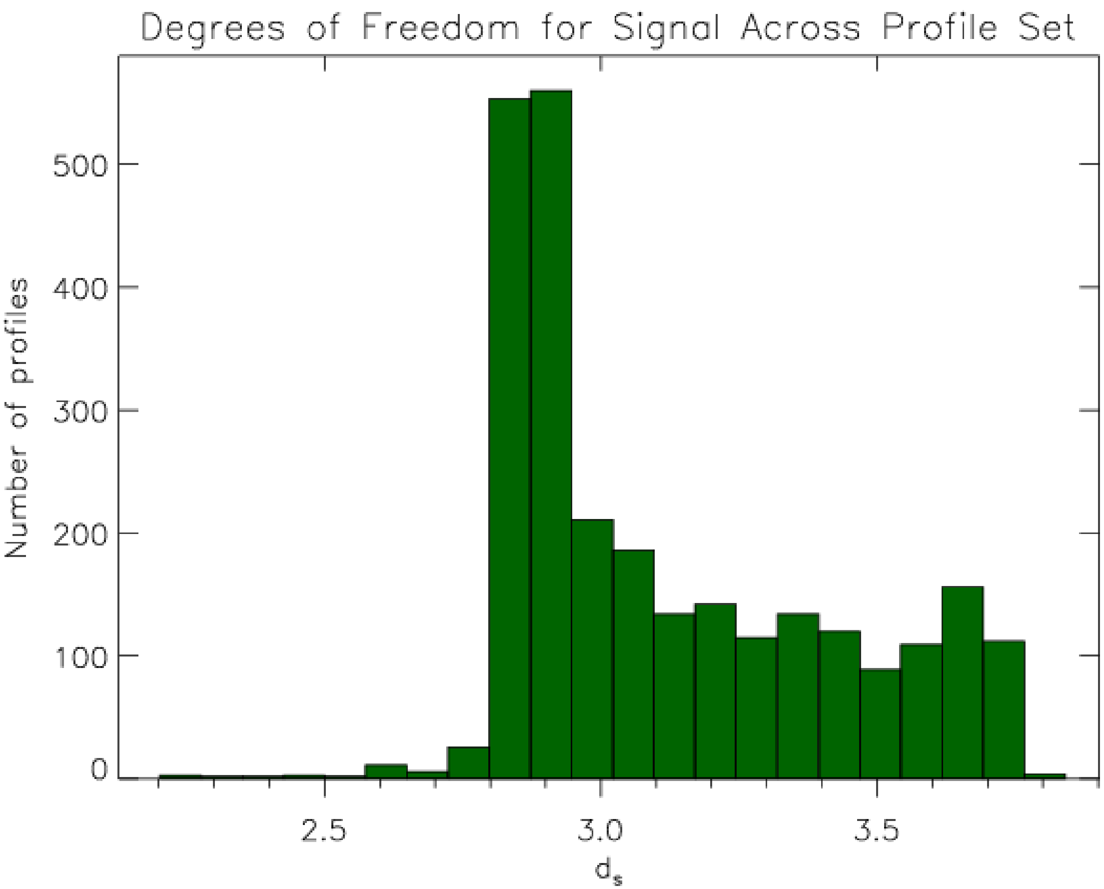
$S_{a,ii}$ taken from Prigent et al., 2013, JGR:O, **118**, 3074

TCLW added here and 10% error in TCWV,TCLW = 0.1 in ln(TCWV),ln(TCLW)

Use ~2700 profiles from NWP SAF q-sampled profile set and constant salinity of 35 PSU.

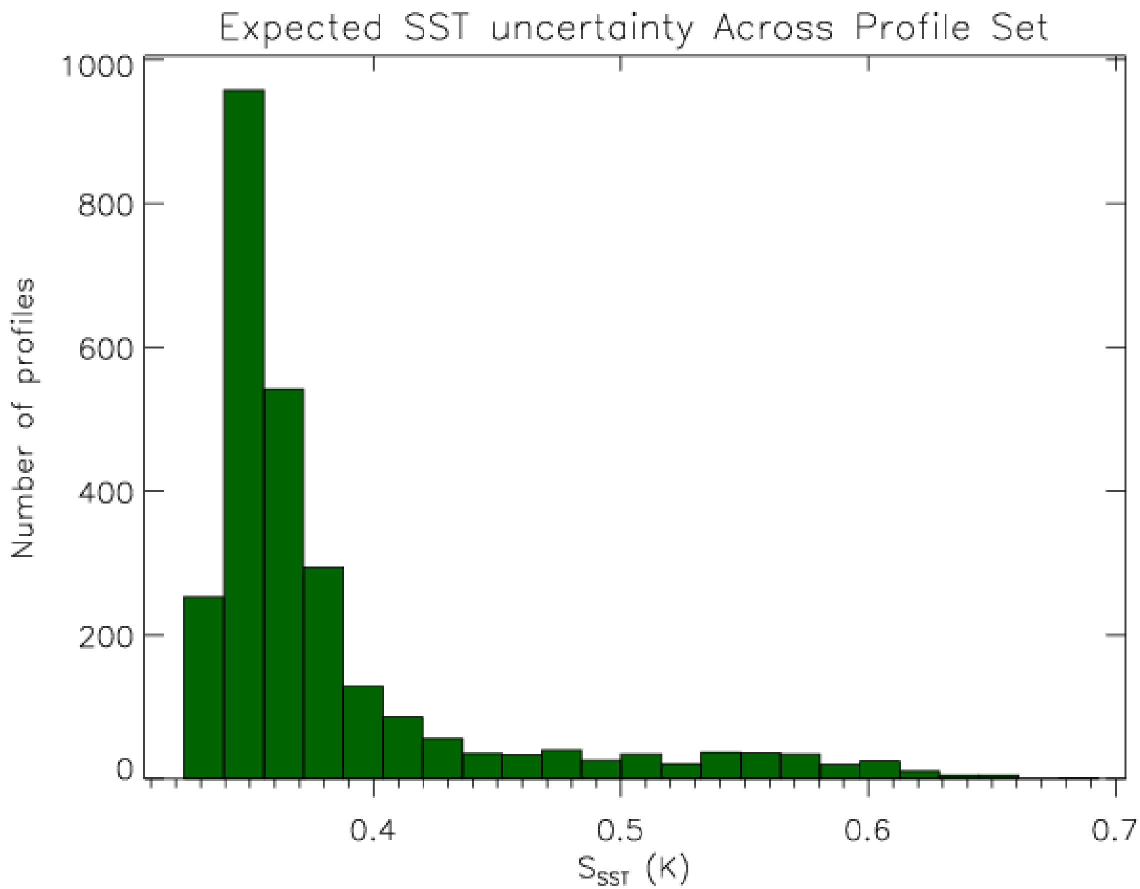
Rain free!

IC – dof distribution across profiles



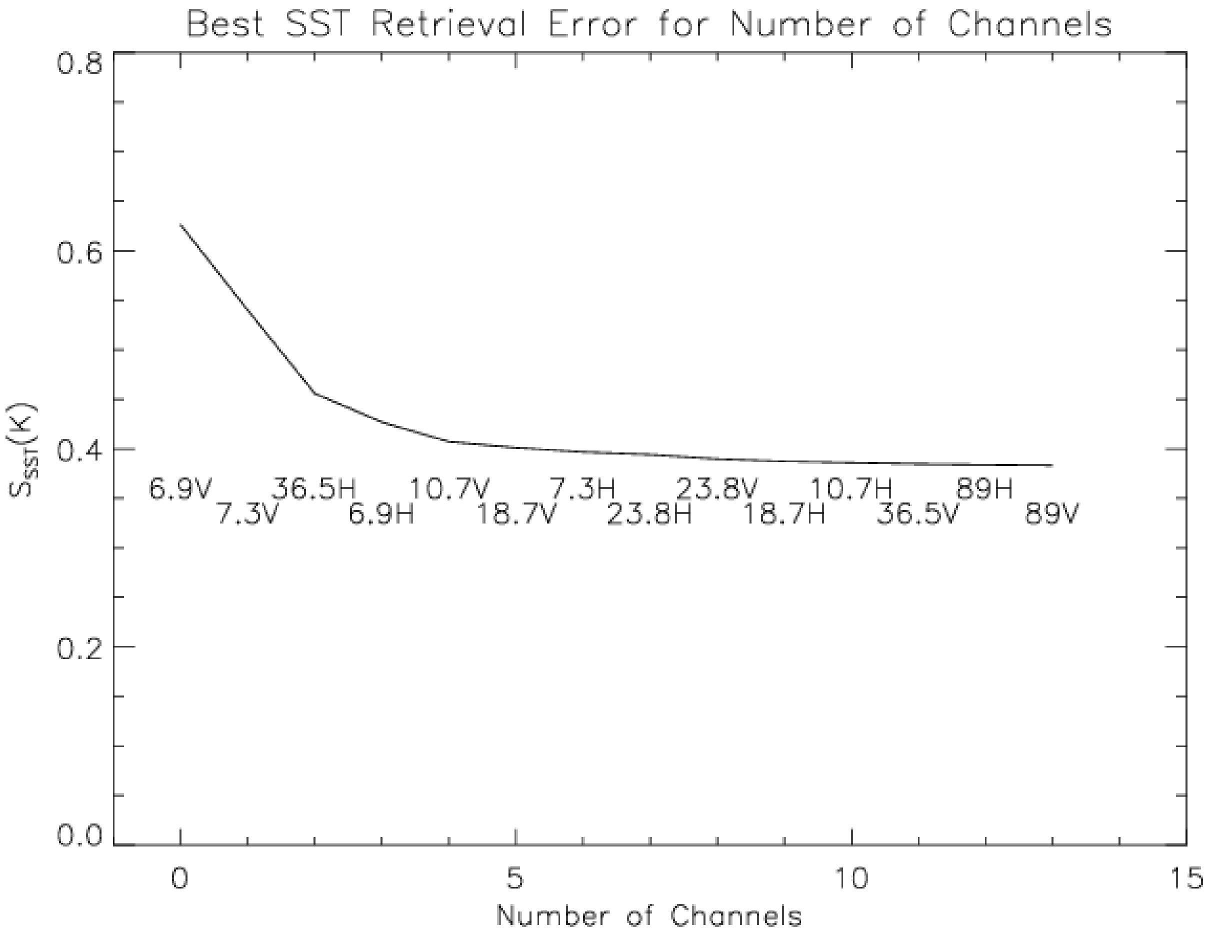
- Using all 14 channels there are ~3.1 degrees of freedom for signal on average with the 5 variable retrieval. SST, TCWV with some u, v, CLW.

IC – S_{sst} across profiles



- Using all 14 channels expected SST uncertainty also peaked but with a long tail.

IC – S_{sst} for best channel combination



- Ordered by decreasing S_{sst}. 6.9V and 7.3V good for SST and 36.5H removes ambiguity with TCWV.

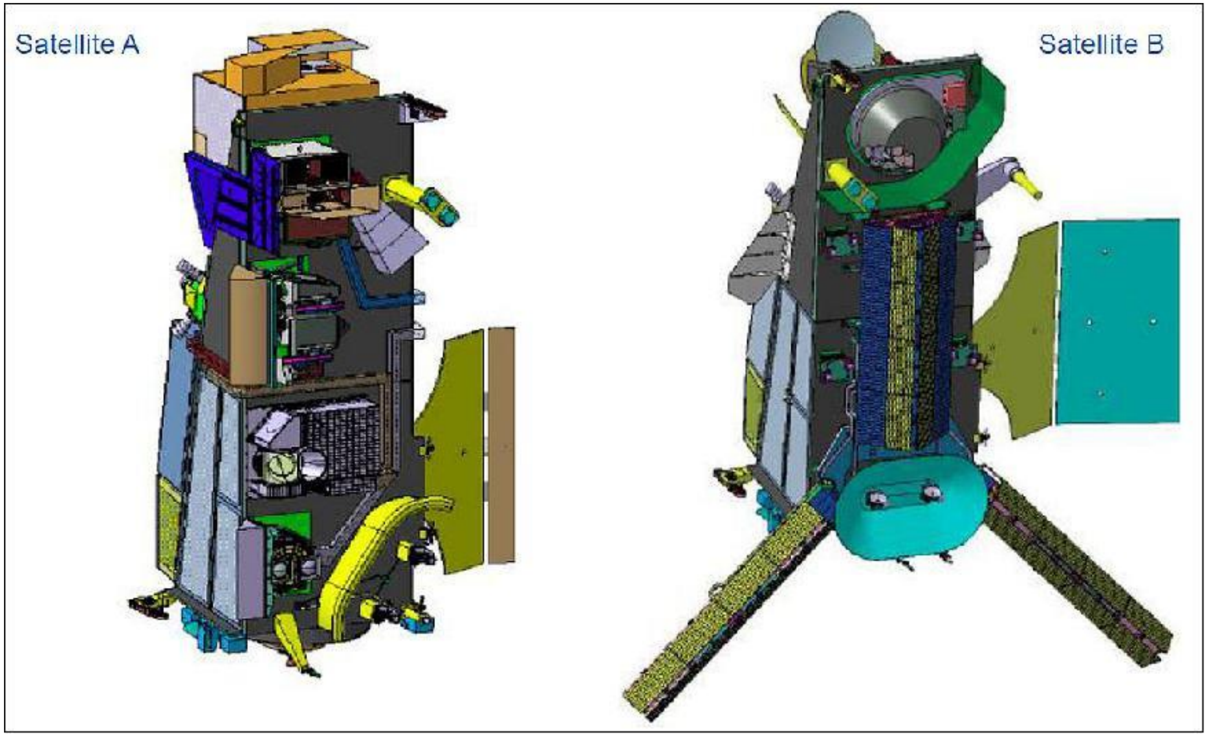
S – prediction table from IC

No. of Chans.	Added Chan.	S_{sst} (K)
1	6.9V	0.626
2	7.3V	0.540
3	36.5H	0.456
4	6.9H	0.427
5	10.65V	0.407
6	18.7H	0.401
7	7.3H	0.397
8	23.8H	0.394
9	23.8V	0.390
10	18.7H	0.387
11	10.65H	0.386
12	36.5V	0.385
13	89H	0.384
14	89V	0.383

- $S_{SST} = 0.38\mathrm{K}$
- $S_{\ln TCWV} = 0.011$
- $S_u = 0.64\mathrm{m/s}$
- $S_v = 0.71\mathrm{m/s}$
- $S_{\ln TCLW} = 0.078$

MWI – A Digression on Information Content

- Microwave Imager on MetOp-SG-B
- 26 channels – 8 dual polarization + 10 V only
- Launch ~2020/2021



MWI

Freq.(GHz)	18.7	23.8	31.4	50.3	52.61	53.24	53.75	89
Δv(MHz)	200	400	200	400	400	400	400	4000
NEΔT (K)	0.7	0.6	0.8	0.7	0.7	0.7	0.7	0.8

Freq.(GHz)	118.75	118.75	118.75	118.75	165.5	183.31
Δv(MHz)	2x500	2x400	2x400	2x400	2x1350	2x2000
NEΔT (K)	1.2	1.2	1.2	1.2	1.1	1.0

Freq.(GHz)	183.31	183.31	183.31	183.31
Δv(MHz)	200	400	200	400
NEΔT (K)	1.1	1.1	1.1	1.2

- d_s=2.02
- $S_{SST} = 2.10K$
- $S_{lnTCWV} = 0.016$
- $S_u = 0.89m/s$
- $S_v = 0.90m/s$
- $S_{lnTCLW} = 0.079$

Early access to RTTOV coefficients courtesy of James Hocking, Peter Rayer UKMO

MWI+

Freq.(GHz)	18.7	23.8	31.4	50.3	52.61	53.24	53.75	89
Δv(MHz)	200	400	200	400	400	400	400	4000
NEΔT (K)	0.7	0.6	0.8	0.7	0.7	0.7	0.7	0.8

Freq.(GHz)	118.75	118.75	118.75	118.75	165.5	183.31
Δv(MHz)	2x500	2x400	2x400	2x400	2x1350	2x2000
NEΔT (K)	1.2	1.2	1.2	1.2	1.1	1.0

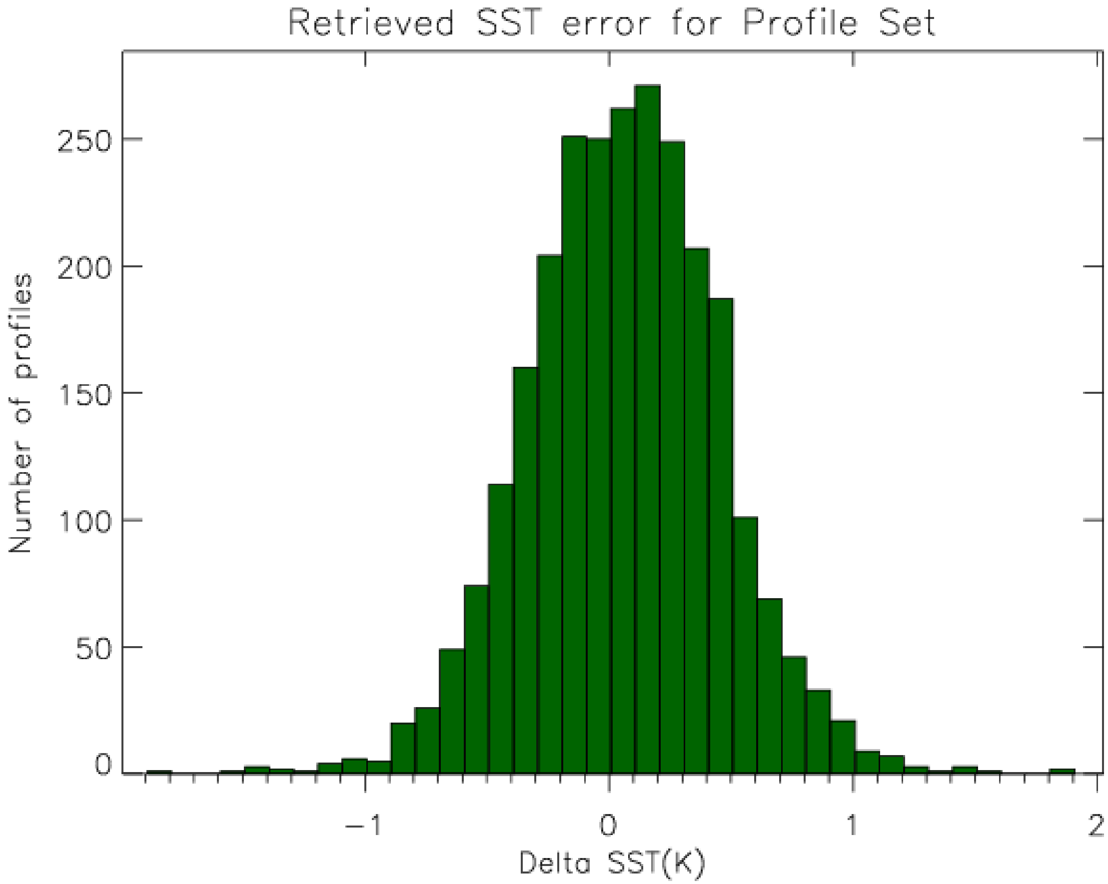
Freq.(G[illegible]	[illegible]3.31	183.31	183.31	183.31
Δv(MHz)	200	[illegible]	200	400
NEΔT (K)	1.1	1.1	1.1	[illegible]

Freq.(GHz)	6.925	7.30
Δv(MHz)	350	350
NEΔT (K)	0.30	0.43

- $d_s = 2.02$ (3.04)
- $S_{SST} = 2.10K$ (0.42)
- $S_{\ln TCWV} = 0.016$ (0.011)
- $S_u = 0.89$m/s (0.67)
- $S_v = 0.90$m/s (0.73)
- $S_{\ln TCLW} = 0.079$ (0.079)

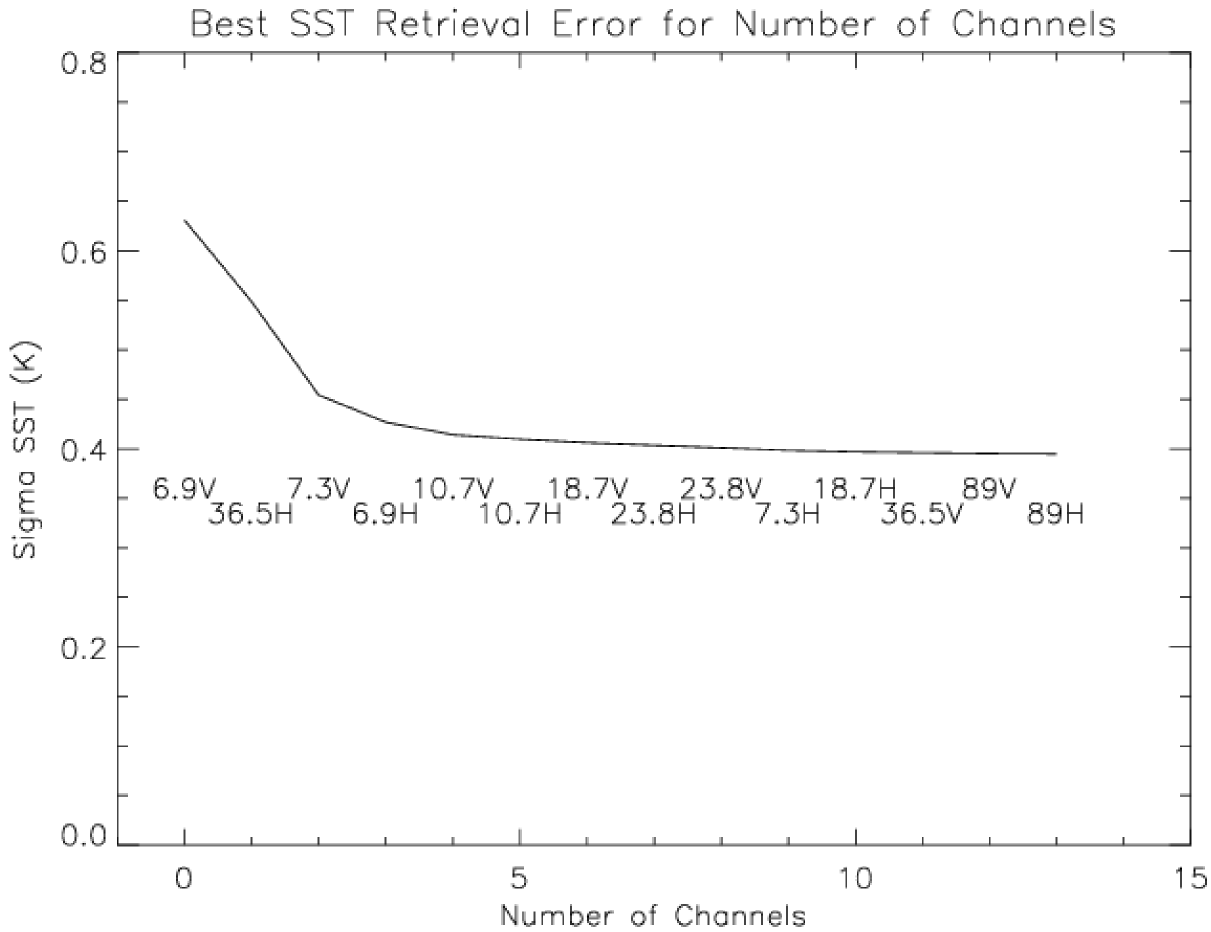
Retrieval Error across all profiles (all chan)

Back to AMSR2!



- Noise added with S_a and S_ε to the profiles and BTs to perform a simulated retrieval.

IC – S_{sst} for best channel combination



- Ordered by decreasing S_{sst}. 6.9V and 7.3V still good for SST and 36.5H removes ambiguity with TCWV.

Retrieval – σ_{sst} for given number of chans.

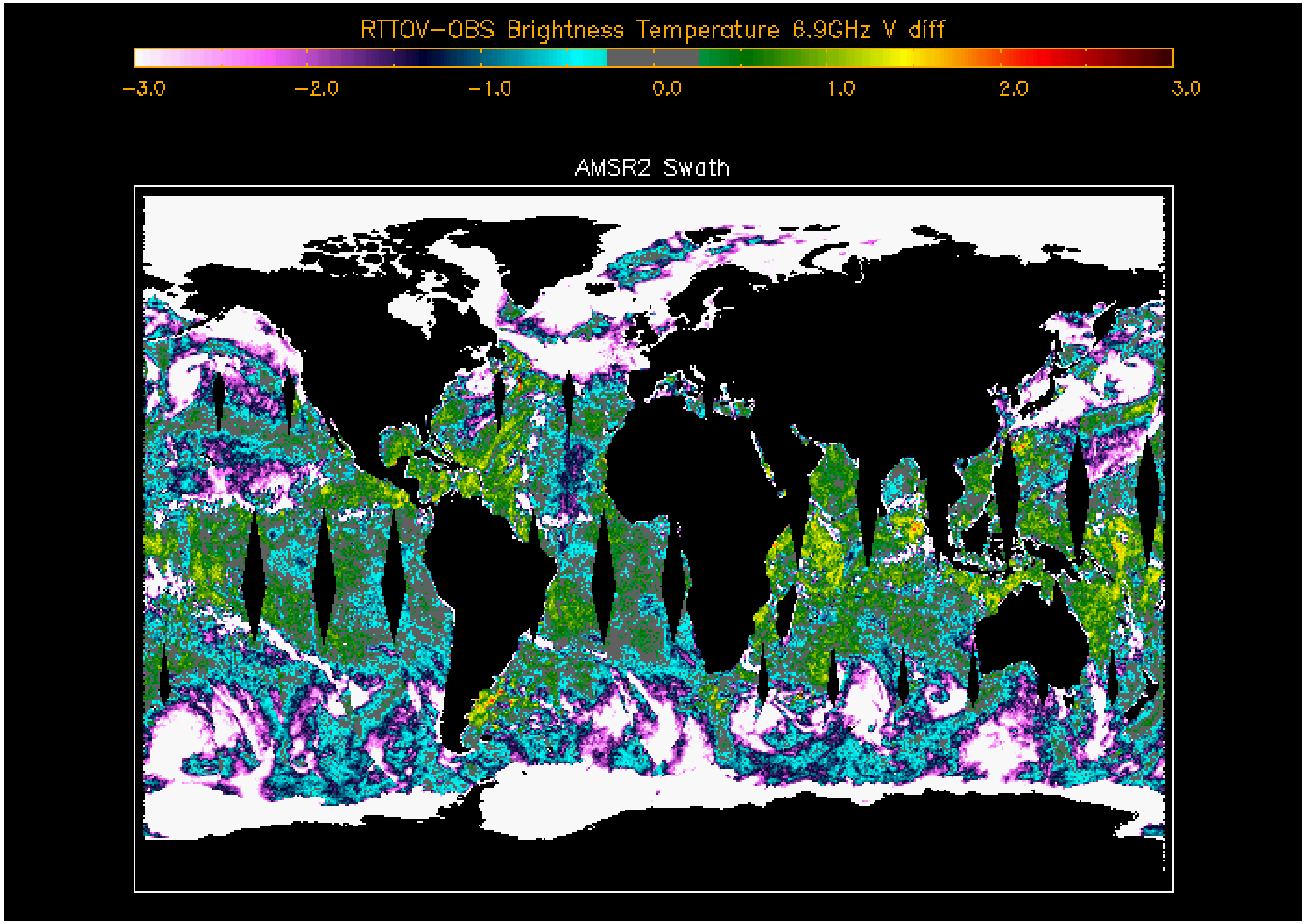
No. of Chans.	Added Chan.	σ_{sst} (K)
1	6.9V	0.631
2	36.5H	0.549
3	7.3V	0.454
4	6.9H	0.427
5	10.65V	0.414
6	10.65H	0.410
7	18.7V	0.406
8	23.8H	0.404
9	23.8V	0.401
10	7.3H	0.398
11	18.7H	0.397
12	36.5V	0.396
13	89V	0.395
14	89H	0.394

- $\sigma_{SST} = 0.39$K
- $\sigma_{lnTCWV} = 0.014$
- $\sigma_u = 0.71$m/s
- $\sigma_v = 0.77$m/s
- $\sigma_{lnTCLW} = 0.083$

For comparison:

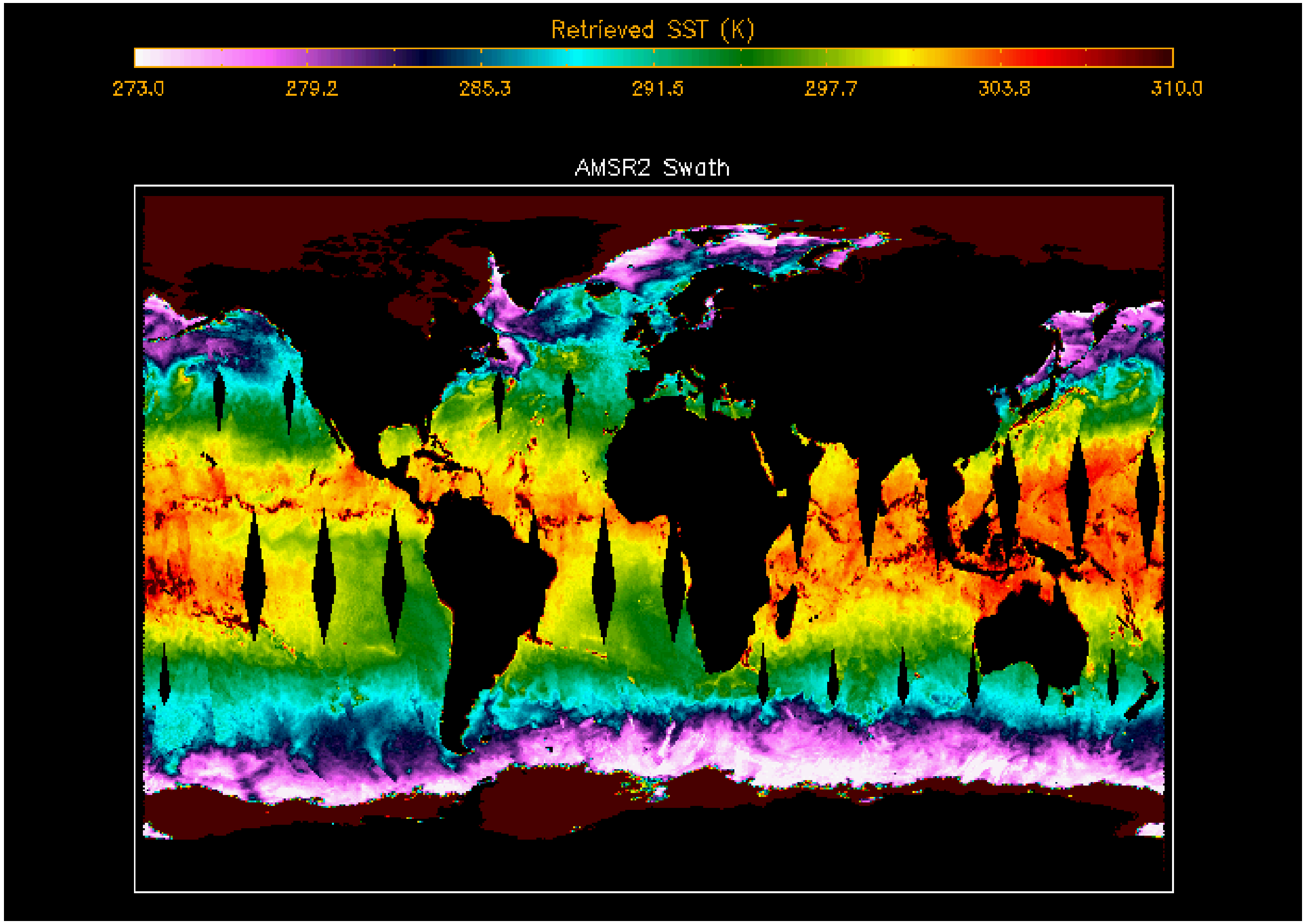
- $S_{SST} = 0.38$K
- $S_{lnTCWV} = 0.011$
- $S_u = 0.64$m/s
- $S_v = 0.71$m/s
- $S_{lnTCLW} = 0.078$

AMSR2 RTTOV-Observed BT - 15/12/2012



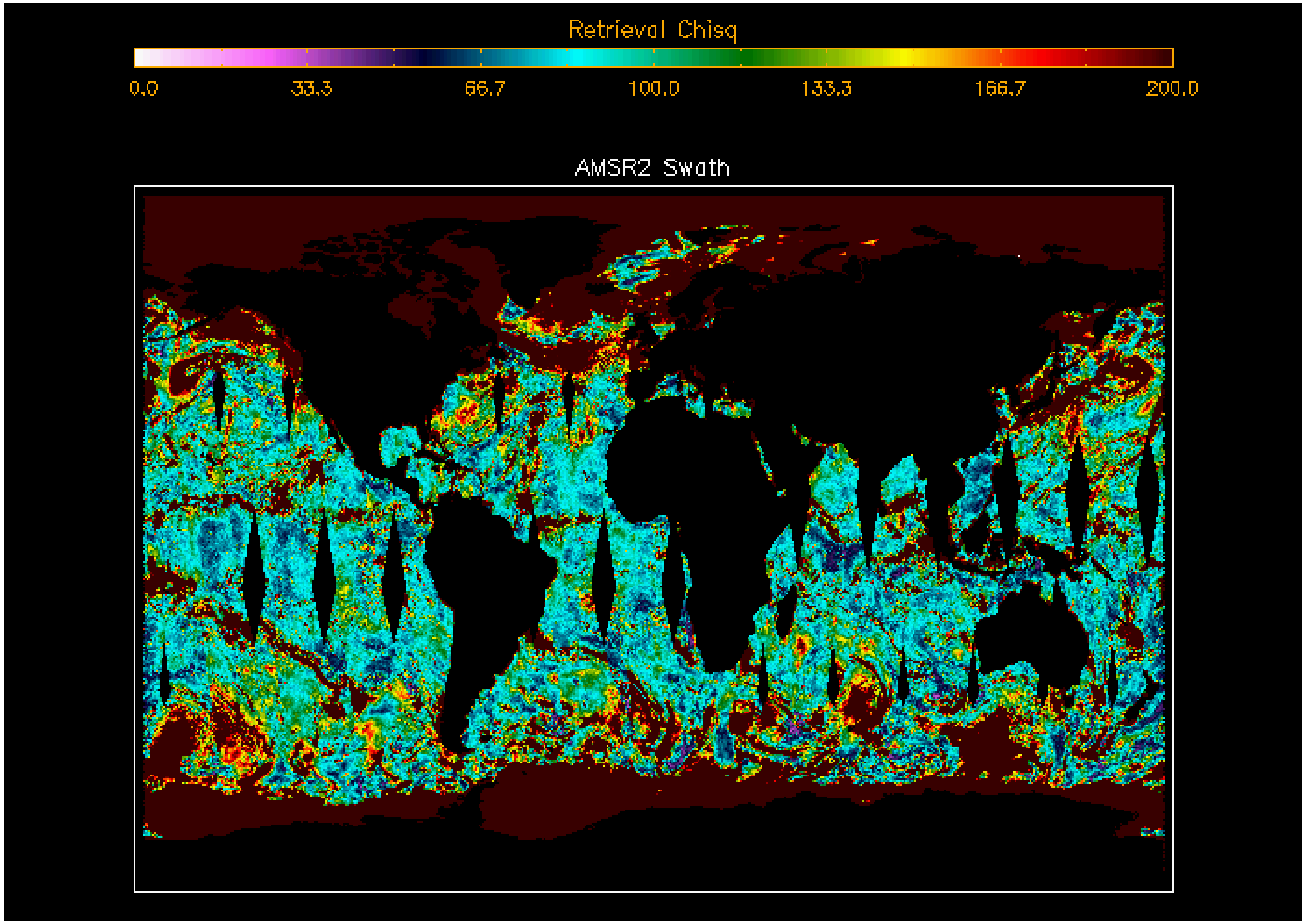
- Can ingest AMSR2 L1R orbit files into GBCS and run RTTOV using appropriate ECMWF profiles.

AMSR2 SST – 15/12/2012

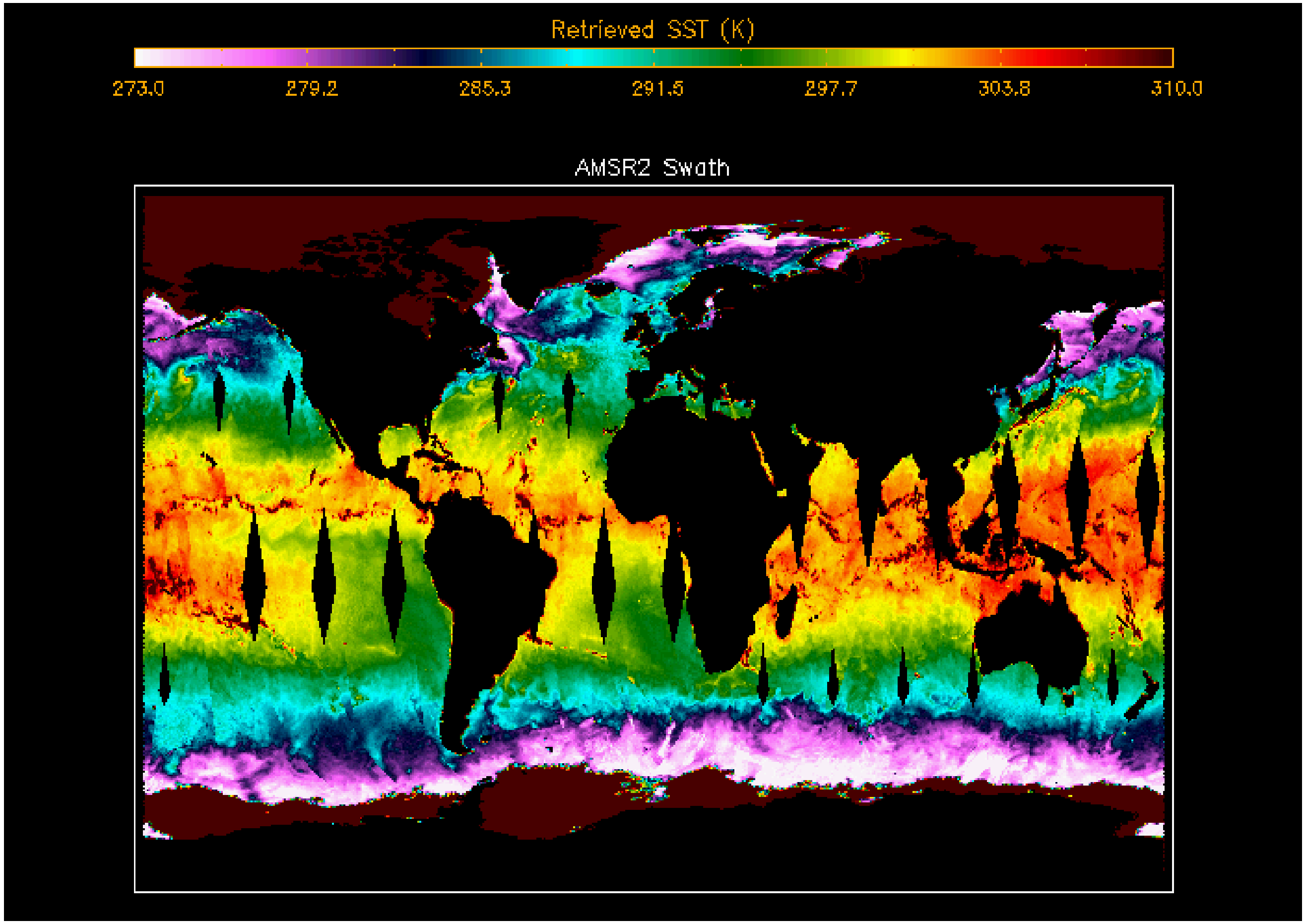


- SST from a 5-variable state vector retrieval (SST, ln(TCWV), u, v,ln(TCLW)) using all 14 channels.

χ^2 map – 15/12/2012

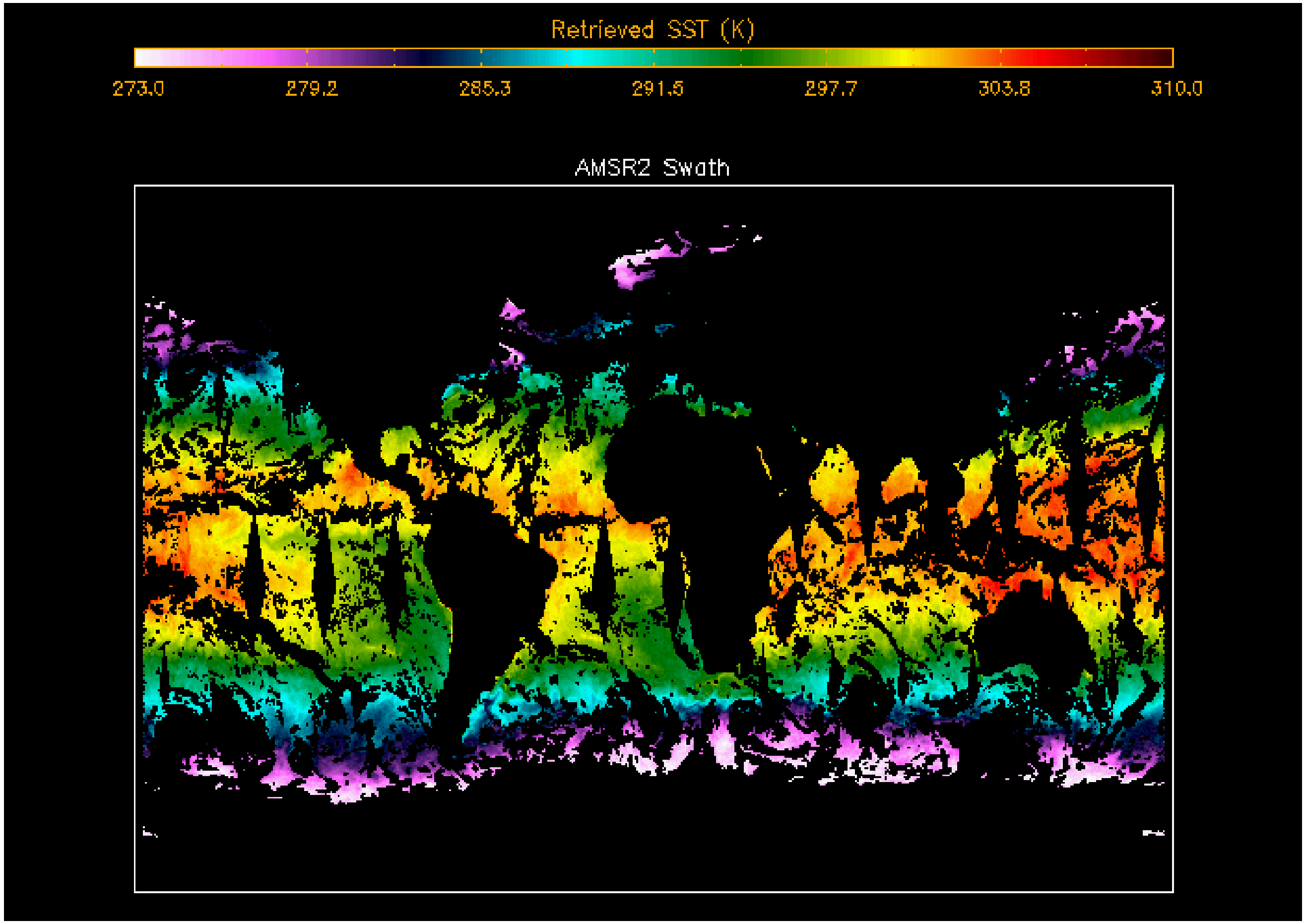


SST 5 Var – 15/12/2012



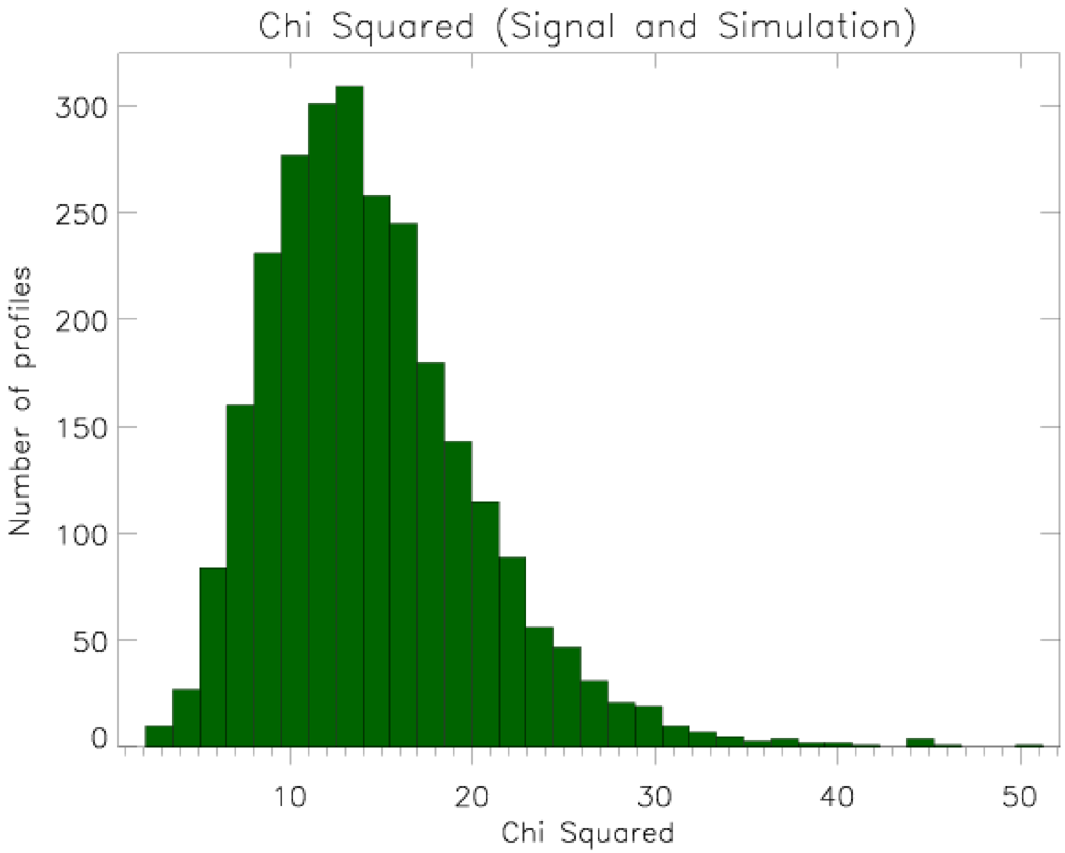
- Unfiltered for rain, RFI, ice, strong wind etc.

SST with χ^2 >150 masked– 15/12/2012



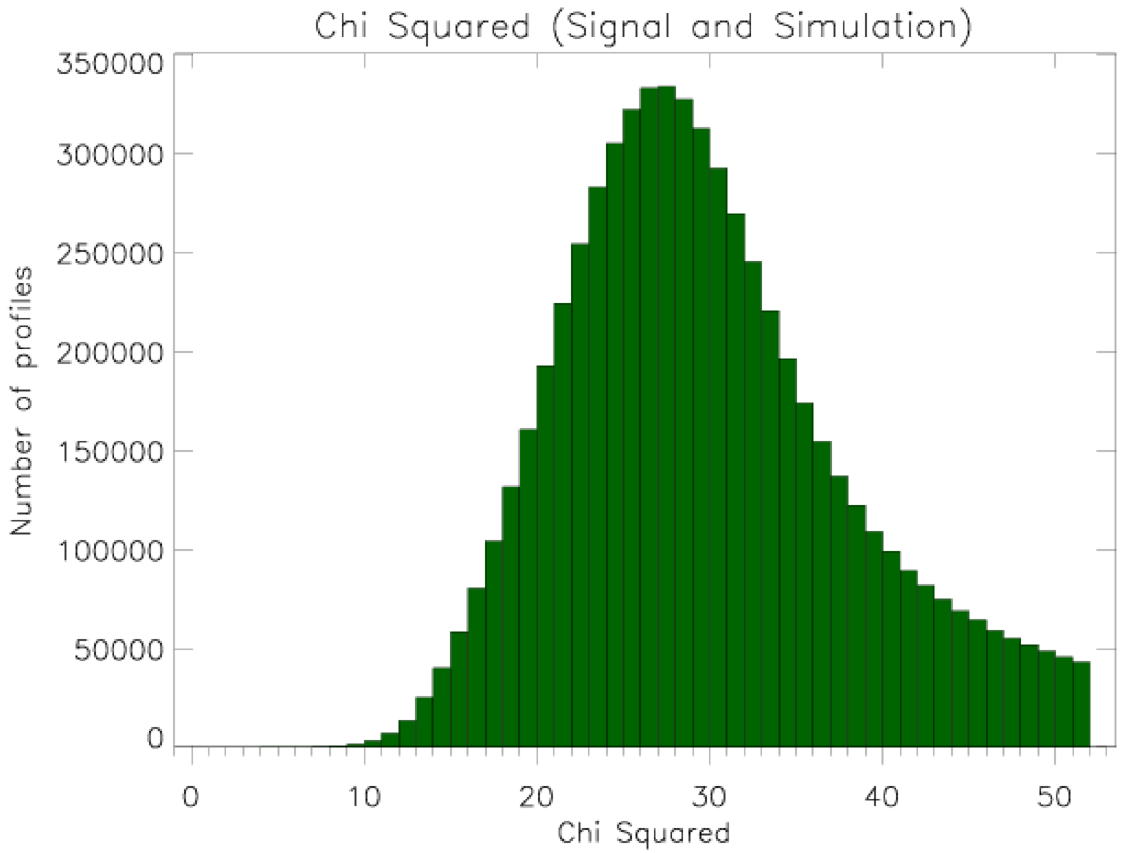
- χ^2>150 masked for regions of rain, RFI, ice, stong wind etc.

χ^2 Distribution for Simulated Retrieval



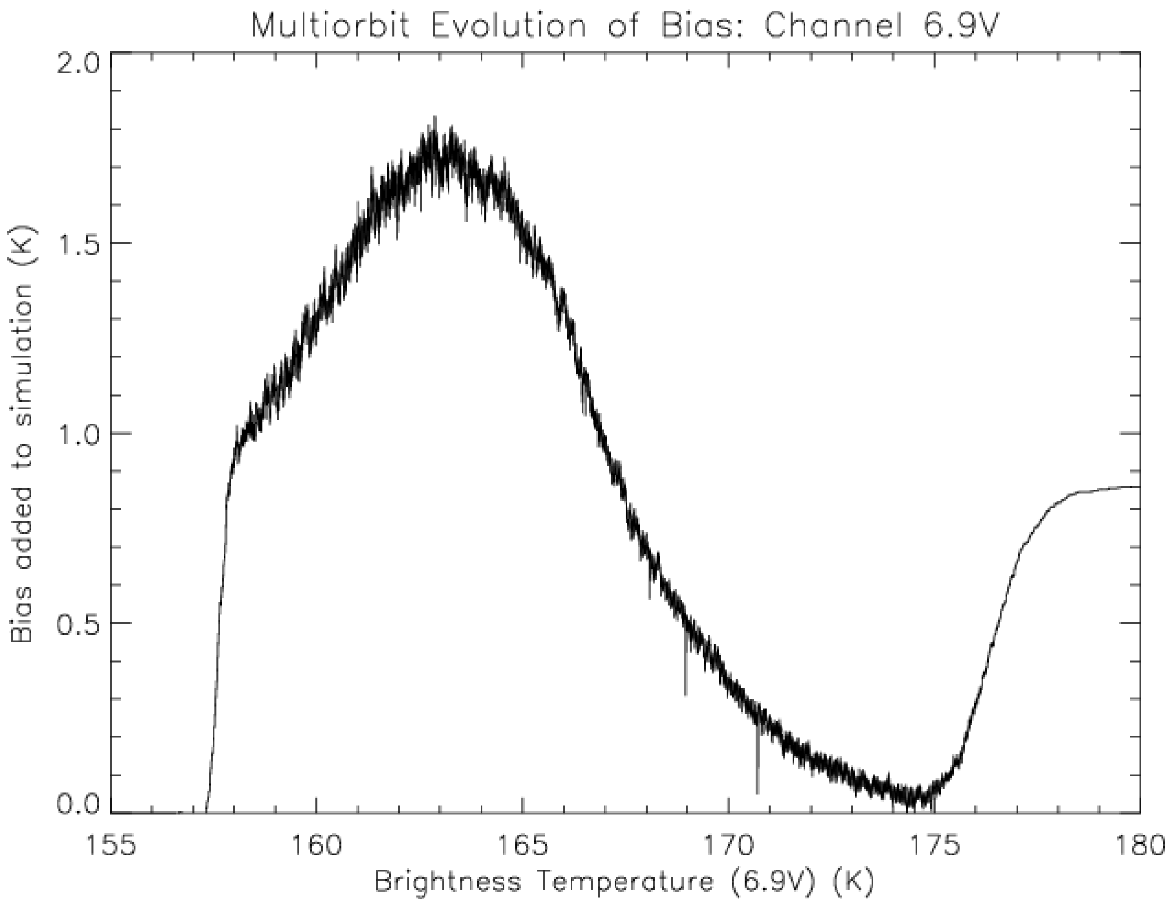
Reassuringly peak at ~14 as one would expect.

χ^2 Distribution for L1R Orbit Retrieval



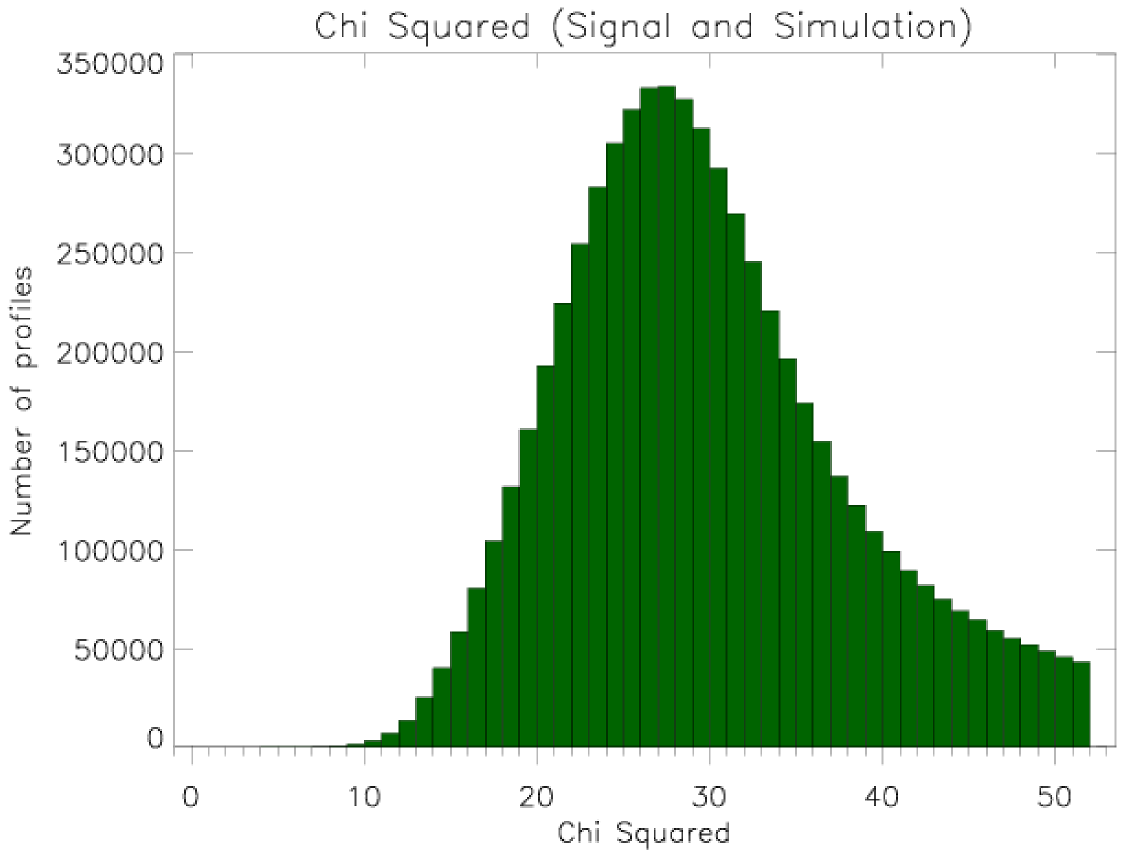
- χ^2 much larger and shifted from zero which suggests uncorrected biases.

Retrieved Bias as a Function of BT(6.9V)



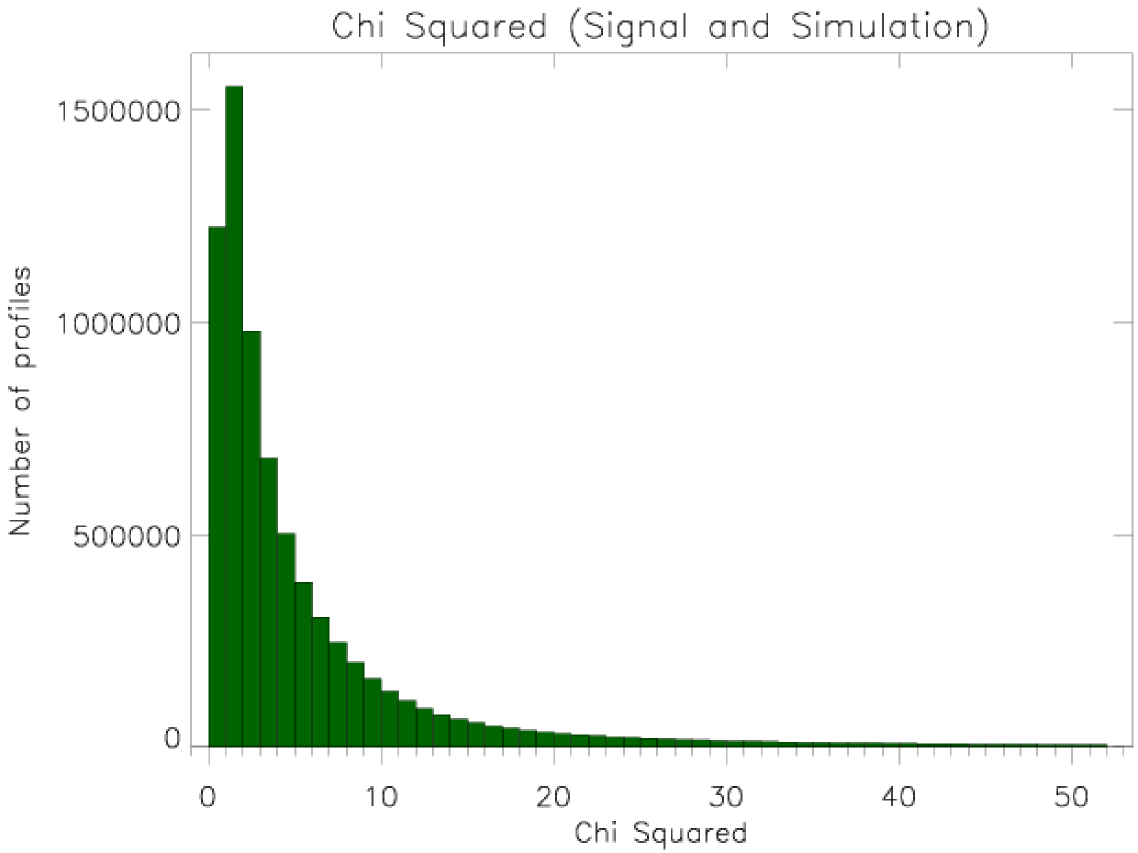
For a given retrieval, bias is a separate constant value for each channel. Allowed to evolve slowly with BT.

χ^2 Distribution for L1R Orbit Retrieval



- χ^2 much larger and shifted from zero which suggests uncorrected biases.

χ^2 Distribution for L1R Bias Aware Retrieval



- χ^2 collapses down to being very (too?) small. Perhaps reflecting overly pessimistic S_a.

Summary

- Information content, simulated retrievals and L1R data retrievals run.

- Simulated BTs generated using GBCS processor running RTTOV using FASTEM-6.

- Demonstration retrievals run using IDL.

- χ^2 cut-off seems able to identify precipitation locations, potentially other sources of “bad” retrievals eg. RFI.

- “Bias aware” optimal estimation has been incorporated into retrieval scheme (see poster by Chris Merchant).