

# Mesoscale AMSU-A Radiance Assimilation with COAMPS®/NAVDAS

William F. Campbell, William T. Thompson, and Keith D. Sashegyi Naval Research Laboratory, Monterey, CA

## Issues for Mesoscale Assimilation

- Model top, level density, and radiance weighting functions
- Quality control and data density
- Bias correction

## COAMPS® Upper Boundary

- Standard COAMPS has 30 levels and a model top at 35 km
- The upper B. C. is a sponge layer spanning the upper 5 levels, covering the 20 km between 15 km and the model top at 35 km
- Channels with weighting functions that have significant sensitivity above 15 km may not perform well
- In addition to the standard configuration, experiments are also performed with 30 levels and 3 sponge layers (17 km and up), and with a 45 level version with 3 sponge layers (21 km and up)

## Experimental Design

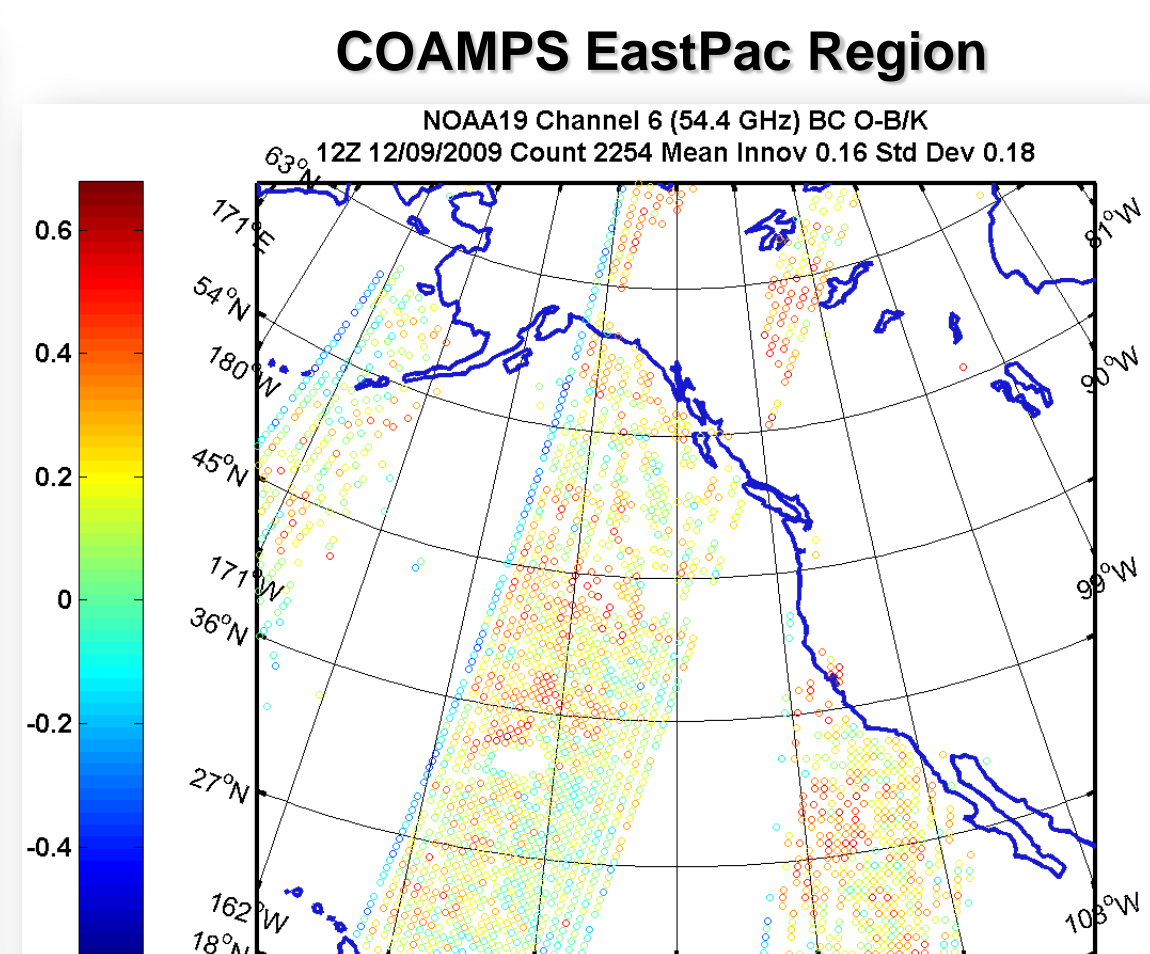
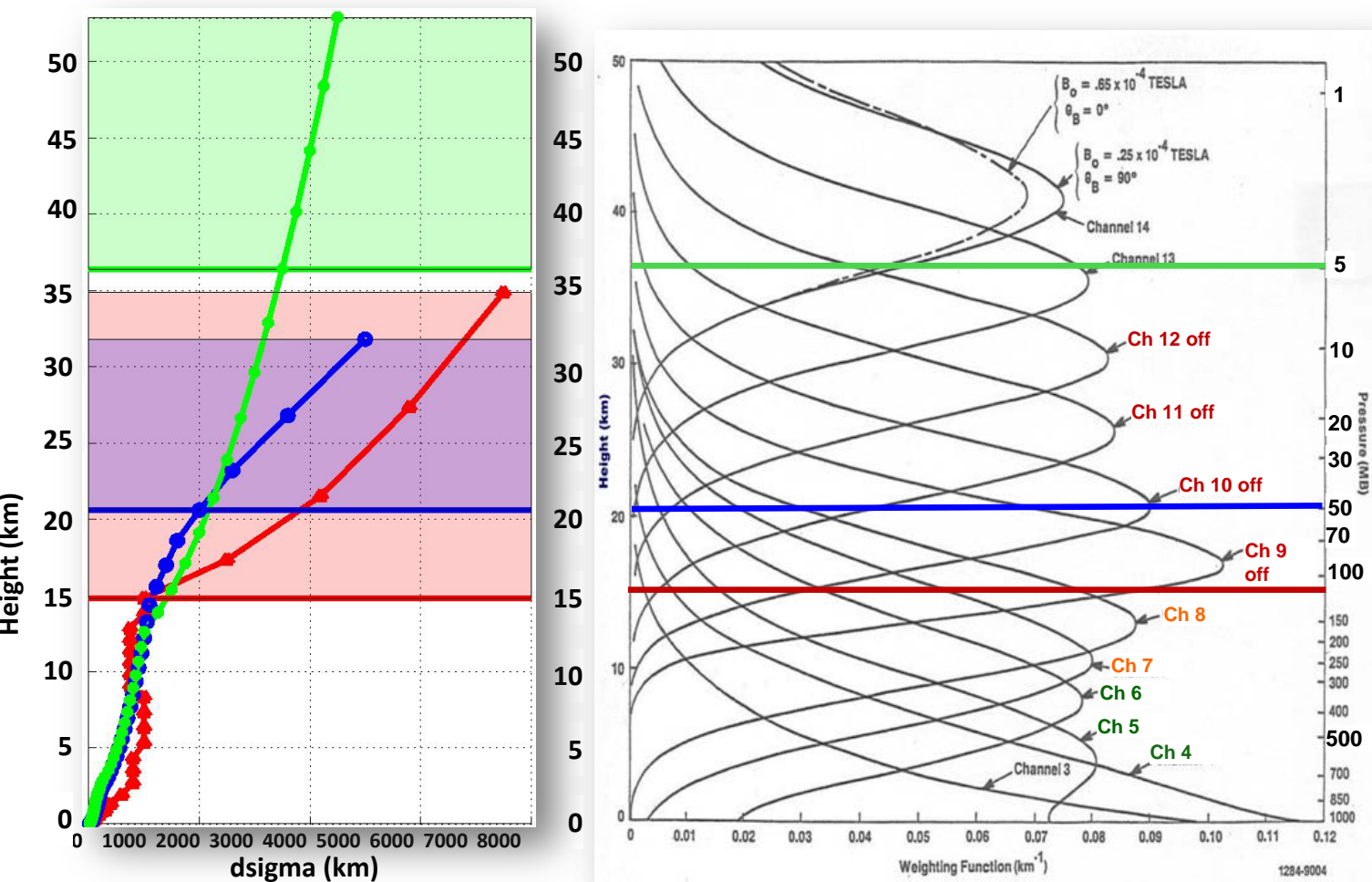
- COAMPS is a nonhydrostatic, fully compressible nested grid model (staggered Arakawa C-grid, leapfrog time differencing) with a sigma-z vertical coordinate
- COAMPS was run **doubly nested over the EastPac region**, with the **inner nest** covering most of the domain with **27 km resolution**
- EastPac was chosen because weather systems propagate from the (conventionally) poorly observed Pacific to the well-observed West Coasts of the US and Canada, where we can validate forecasts
- Control run** is standard COAMPS with satellite and geostationary winds plus all conventional data, plus the NESDIS ATOVS retrievals
- The lateral boundary conditions are provided by NOGAPS running with our 4DVAR global data assimilation system NAVDAS-AR
- Experiments were all run from 12/9/2009 through 12/31/2009 with 3DVar cycling data assimilation (NAVDAS) and fixed bias coefficients (that varied between runs)
- We ran a number of experiments with **radiance on the 30 standard COAMPS levels**, which **all performed poorly** (e.g. the sp3\_ch47\_nbc\_as experiment)
- We ran an experiment [atovs\_i45\_sp3] using **ATOVS retrievals with 45 levels and 3 sponge layers**, which **compared favorably with standard COAMPS**
- Three AMSU-A radiance assimilation experiments also compared favorably**: all had 45 levels and 3 sponge layers, two had global bias coefficients, and one had a 50-50 blend of global and regional bias coefficients
- The blended bias coefficient experiment used 1 ob/channel/55km x 55km box/satellite, resulting in the assimilation of approximately 3 times the data of the other two experiments, which used 1 ob/channel/55km box
- AMSU-A radiances from METOP-A and NOAA 15, 16, 18, 19 were assimilated; channels 4 and 5 over oceans only, higher-pressure channels over terrain with surface pressure greater than 850 hPa

## Verification and Scorecard

- Experiments were **scored against a set of reference radiosondes** (which were assimilated)
- Statistics were evaluated at the **surface** as well as at **850, 500, and 250 hPa** at all radiosonde locations in EastPac
- Bias is defined as the mean difference over all radiosondes of the measured value and the 48-hr forecast value; standard deviation is defined similarly, and vector RMS wind error in the standard way
- The above statistics are computed every 12 hours, forming time series of predicted and measured values, which are then subjected to a one-tailed paired-comparison t-test that was **corrected for serial correlation**
- Two scorecards are shown**: the first requires a **5% improvement** with 95% confidence to score +1 and a **5% degradation** with 95% confidence to score -1, while the second requires **only statistically significant improvement** with 95% confidence to score +1, and vv.
- Some statistics e.g. 10m Wind VecRMS, 850hPa mean temperature, etc. are given greater weight in the scorecard
- We use the first scorecard to determine if the improvement is real, but the second scorecard is useful in guiding experimentation
- A score of -2 or better on the first scorecard is the minimum requirement for FMOC to make a major model/data assimilation upgrade
- The plots in the results section each have two panels; a time series of the statistic for the control and experiment and their absolute difference, and a box-and-whiskers summary plot with shaded confidence intervals
- The boxes cover the middle 50% of the data (q1 to q3), with the median indicated by a red line, and whiskers drawn to at most 1.5 times (q3-q1) interquartile distance, corresponding to +/- 2.7σ for normally distributed data
- If the shaded confidence interval of the B[a] - |C[a]| does not include zero, then the null hypothesis (no improvement) can be rejected

### COAMPS 30, 45, and 60 Level Configurations

### AMSU-A Weighting Functions



## Quality Control and Data Density

Bias correction and quality control (QC) are intimately related. The QC procedures used in COAMPS®/NAVDAS are similar to those we use for our global model, and are summarized below. Note that these procedures are serially applied to one observation at a time, so that the entire distribution of the innovations of the day is not known at the time of the innovation check. The innovation check is therefore not relative to the mean bias-corrected innovation of the day, but relative to zero.

- Data are ingested from multiple satellites (for NOGAPS, they are downsampled by a factor of 4 or 5 by skipping beam positions, but this is not done in our experiments) for a 6-hour data assimilation window.
- Data are (further) downsampled to a user-controlled density of about one radiance observation per channel per 55 km by 55 km area. The data density is four times what we typically use in our global data assimilation system.
- QC flags bad beam position, bad zenith angle, high terrain (higher than 850 hPa), and bad surface skin temperature.
- Scan correction is applied -- a single offset at each beam position that is obtained from the training run for the bias coefficients, which is simply a 15-day average at each beam position minus the 15-day average of the two center beam positions.
- The CRTM computes background brightness temperatures at all of the unflagged observation locations.
- Land and sea-ice QC is applied using the model fields. Selected channels are rejected based on the fields of view, which can consist of land, ocean, sea ice, or land-snow.
- The model-based bias predictors (850-300 and 200-50 hPa thicknesses) are computed at each unflagged observation location, and are multiplied by the so-called air mass coefficients, which were calculated from the previous 15 days of innovations, and then summed with the scan-corrected brightness temperatures to form the bias-corrected brightness temperatures. In most of our experiments, fixed bias corrections from NOGAPS/NAVDAS-AR were applied instead.
- Gross temperature and gross innovation checks, emissivity, cloud liquid water content, and scattering checks are performed, followed by the innovation check (a.k.a. a rogue or outlier check).
- The innovation check flags any innovations whose absolute value exceeds three times the stated observation error in each channel. The default observation errors for channels 4-8 are satellite dependent, but approximately: 0.75, 0.42, 0.30, 0.35, and 0.40 K. In our experiments, we fixed those values at 0.5 K in every channel we assimilated.
- The background brightness temperatures are subtracted from the bias-corrected observed brightness temperatures to form the final innovation that is ingested by the NRL Atmospheric Variational Data Assimilation System (NAVDAS), along with the rest of the innovation vector formed by other observation types.
- We currently treat all observations as if they occur at the center of the data assimilation window, and only use background fields valid at that time, rather than interpolating forecast fields valid at multiple times (as we do in our global data assimilation system).

## Radiance Bias Correction

It is well known that radiance measurements from satellite instruments such as the Advanced Microwave Sounding Unit A (AMSU-A) temperature sounders are biased with respect to radiances simulated from NWP model fields and a radiative transfer model such as the Community Radiative Transfer Model (CRTM) or the Radiative Transfer for TOVS (RTTOV). The bias stems from a variety of sources including instrument noise, scan bias, inaccuracies in the radiative transfer, lack of measurement representativeness, and systematic errors in the NWP model fields. The bias varies by instrument, channel, and scan position, as well as spatially and temporally. Ideally one would like to correct for instrument, scan, and RT errors while leaving model errors and the underlying signal untouched.

Radiance bias correction in global models is typically performed by subtracting a bias estimate formed by linear regression of prior innovation data against a small number of predictors. At most operational centers, these predictors include a tropospheric and a stratospheric thickness estimate from the NWP model fields (Harris & Kelly, 2001), e.g. at NRL, we use 850-300 hPa and 200-50 hPa thicknesses as our sole bias predictors (apart from scan bias prediction, which can be treated separately).

The problem of radiance bias correction for mesoscale models is more difficult than it is for global models for several reasons:

- Regional models typically have a lower model top, and nonhydrostatic models often have filtering or damping in several layers near the top, making it difficult to effectively utilize high-peaking satellite channels.
- For non-global domains, it takes significantly longer to build up the statistics needed for accurate bias correction. A further difficulty is that if it takes longer than ~1 month, real seasonal changes may be "corrected" as bias.
- Lateral boundary conditions may introduce spatially-dependent biases that are inaccurately predicted, especially in moisture.

The first problem is serious, but easily addressed. To successfully assimilate AMSU-A radiances from channels 4-8, we had to raise the model top and reduce the size of the sponge layer. No radiance assimilation experiments with the standard model top were successful relative to the control run. The second two problems can be addressed by either using bias coefficients from a global data assimilation system (in our case NAVDAS-AR) that uses the same predictors and the same radiative transfer model. This solution works surprisingly well. We also performed experiments with blended bias coefficients, combining those derived from the COAMPS run with the global coefficients. Preliminary results are not promising, but we do not yet have a clean comparison.

## Scorecards 1 and 2

### SCORECARD 1

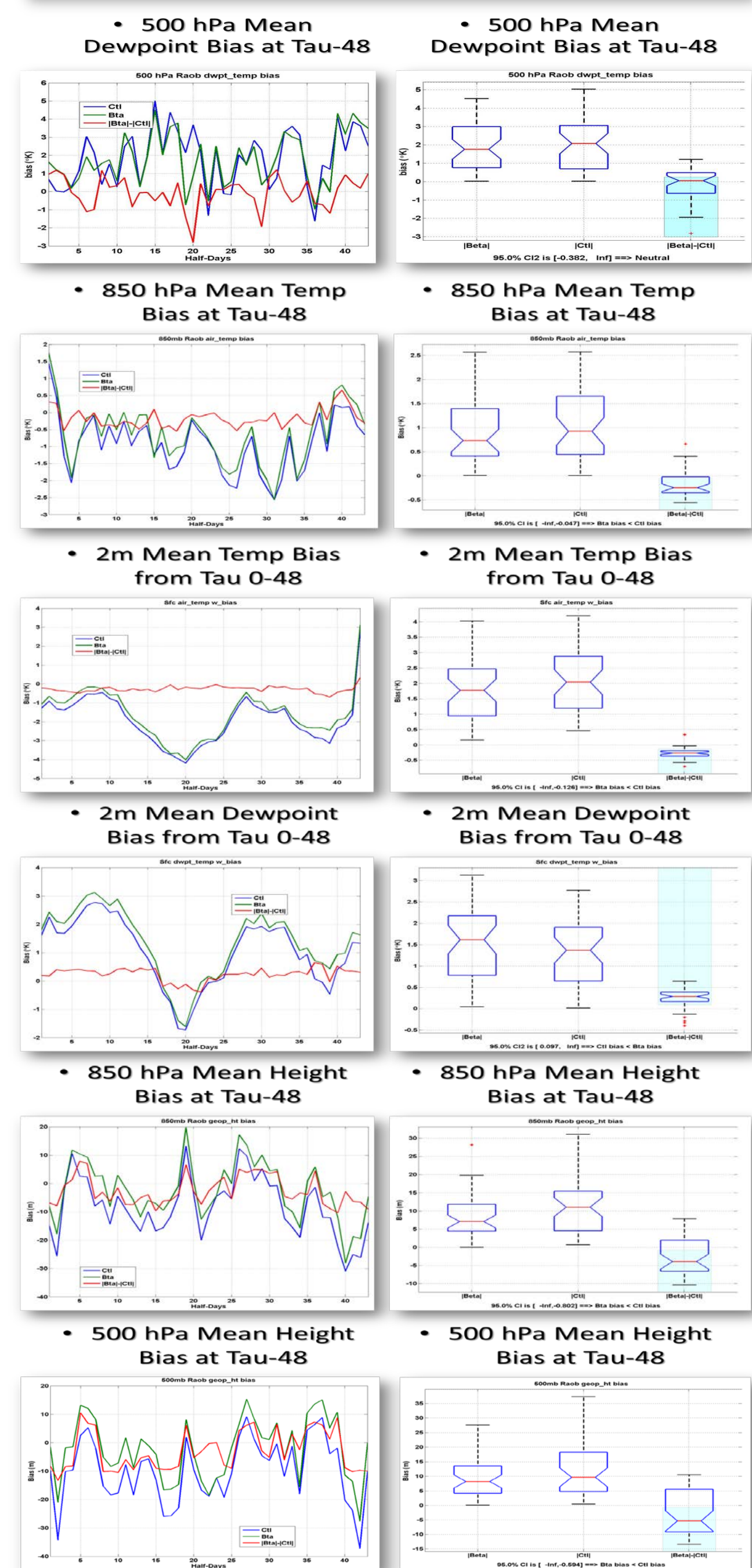
Exp vs. Ctl (5% diff at 95% conf)	Weight	atovs_i45_sp3	i45_sp3_ch48_nbc_rs	i45_sp3_ch47_nbc_as	i45_sp3_ch48_alldata_rs	sp3_ch47_nbc_as	sp3_ch48_bbc_rs	sp3_ch48_cbc_rs
Raob 250mb Wind VecRMS 48hr	2							
Raob 250mb Height Std 48hr	1							
Raob 250mb Height Mean 48hr	1							
Raob 250mb Temp Std 48hr	1							
Raob 250mb Temp Mean 48hr	1							
Raob 500mb Height Std 48hr	1	1						
Raob 500mb Height Mean 48hr	1							
Raob 500mb Temp Std 48hr	1							
Raob 500mb Temp Mean 48hr	1							
Raob 500mb Dewpoint Std 48hr	1							
Raob 500mb Dewpoint Mean 48hr	1		1	1				1
Raob 850mb Wind VecRMS 48hr	2							
Raob 850mb Height Std 48hr	1							
Raob 850mb Height Mean 48hr	1	1						1
Raob 850mb Temp Std 48hr	1							
Raob 850mb Temp Mean 48hr	2	1	1	1				1
Raob 850mb Dewpoint Std 48hr	1							
Raob 850mb Dewpoint Mean 48hr	2							
Sfc 10m Wind VecRMS 0-48hr	4							
Sfc 2m Temp Std 0-48hr	2							
Sfc 2m Temp Mean 0-48hr	2	1	1	1	1		1	1
Sfc 2m Dewpoint Std 0-48hr	2							
Sfc 2m Dewpoint Mean 0-48hr	2	-1	-1	-1	-1		-1	-1
Final Score		4	3	3	0	0	5	0

### SCORECARD 2

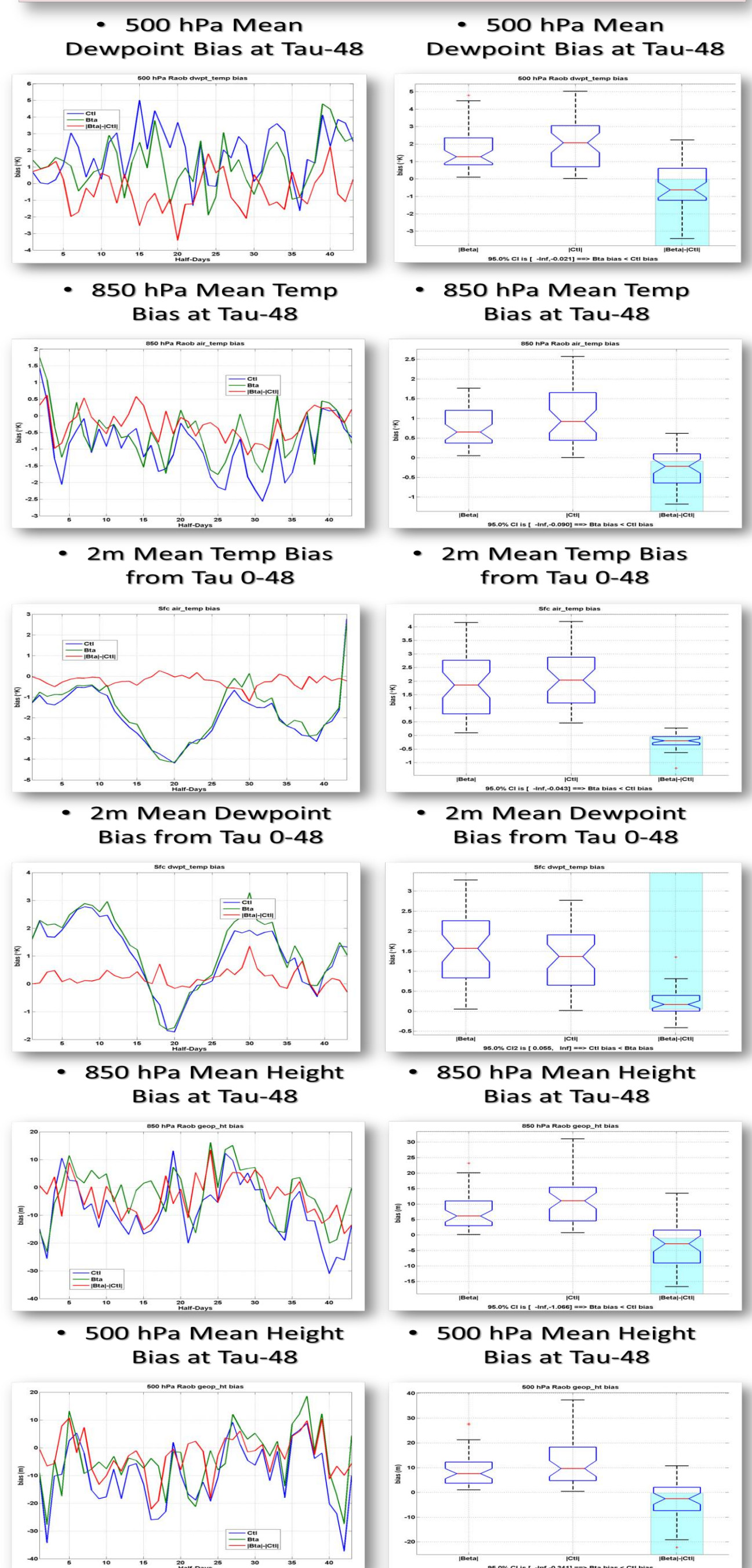
Exp vs. Ctl (sig diff at 95% conf)	Weight	atovs_i45_sp3	i45_sp3_ch48_nbc_rs	i45_sp3_ch47_nbc_as	i45_sp3_ch48_alldata_rs	sp3_ch47_nbc_as	sp3_ch48_bbc_rs	sp3_ch48_cbc_rs
Raob 250mb Wind VecRMS 48hr	2							
Raob 250mb Height Std 48hr	1							
Raob 250mb Height Mean 48hr	1		-1					
Raob 250mb Temp Std 48hr	1	1	1	1	1			
Raob 250mb Temp Mean 48hr	1							
Raob 500mb Height Std 48hr	1							
Raob 500mb Height Mean 48hr	1	1		1		-1		1
Raob 500mb Temp Std 48hr	1							
Raob 500mb Temp Mean 48hr	1	-1			-1			-1
Raob 500mb Dewpoint Std 48hr	1							
Raob 500mb Dewpoint Mean 48hr	1		1	1				1
Raob 850mb Wind VecRMS 48hr	2						-1	-1
Raob 850mb Height Std 48hr	1						-1	-1
Raob 850mb Height Mean 48hr	1	1						1
Raob 850mb Temp Std 48hr	2							
Raob 850mb Temp Mean 48hr	2	1	1	1				1
Raob 850mb Dewpoint Std 48hr	2							
Raob 850mb Dewpoint Mean 48hr	2						-1	-1
Sfc 10m Wind VecRMS 0-48hr	4	-1				-1	-1	-1
Sfc 2m Temp Std 0-48hr	2		1		1			
Sfc 2m Temp Mean 0-48hr	2	-1	1	1	1		1	1
Sfc 2m Dewpoint Std 0-48hr	2							
Sfc 2m Dewpoint Mean 0-48hr	2	-1	-1	-1	-1		-1	-1
Final Score		-2	7	5	0	-12	-5	-4

## Results

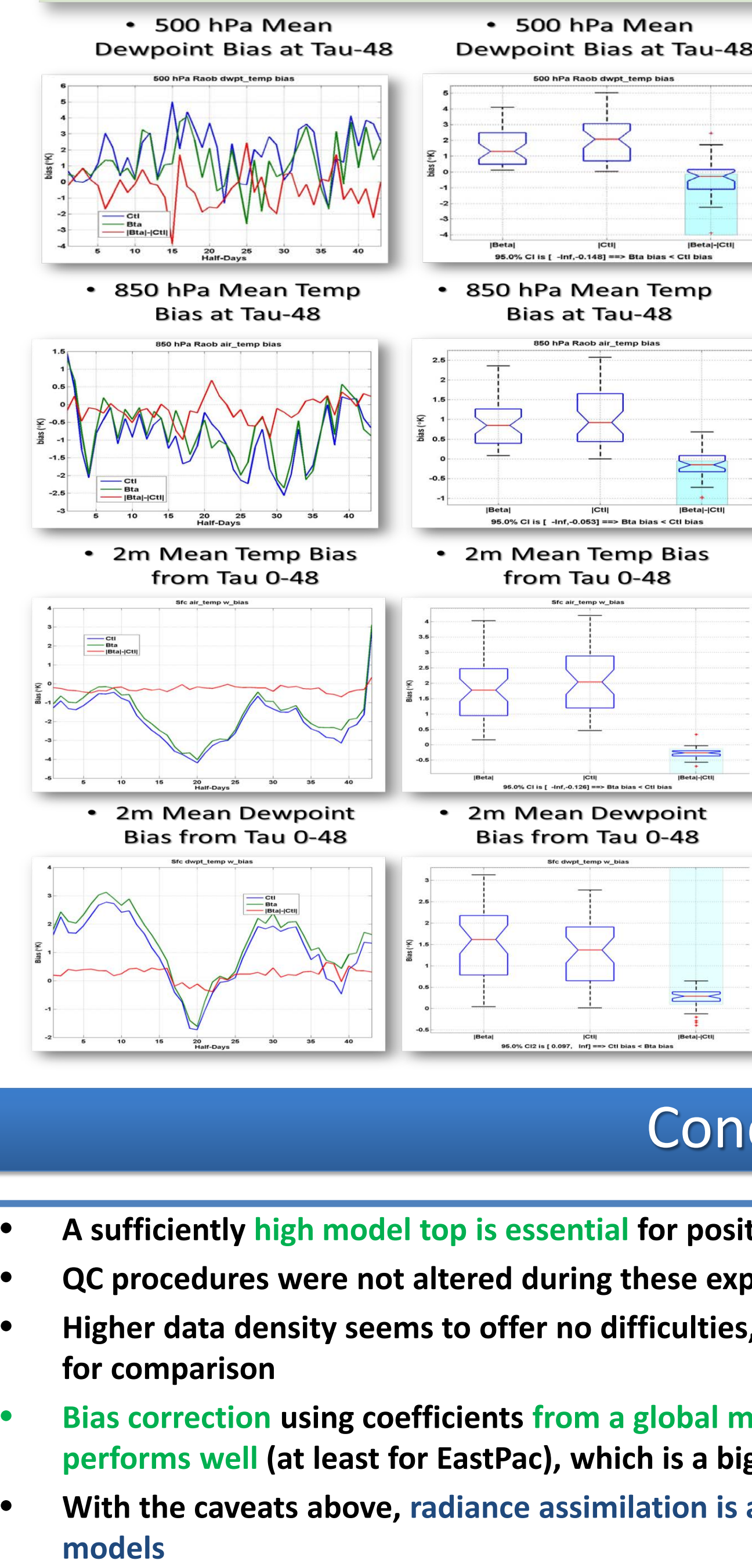
### ATOVS v. ATOVS\_I45\_sp3



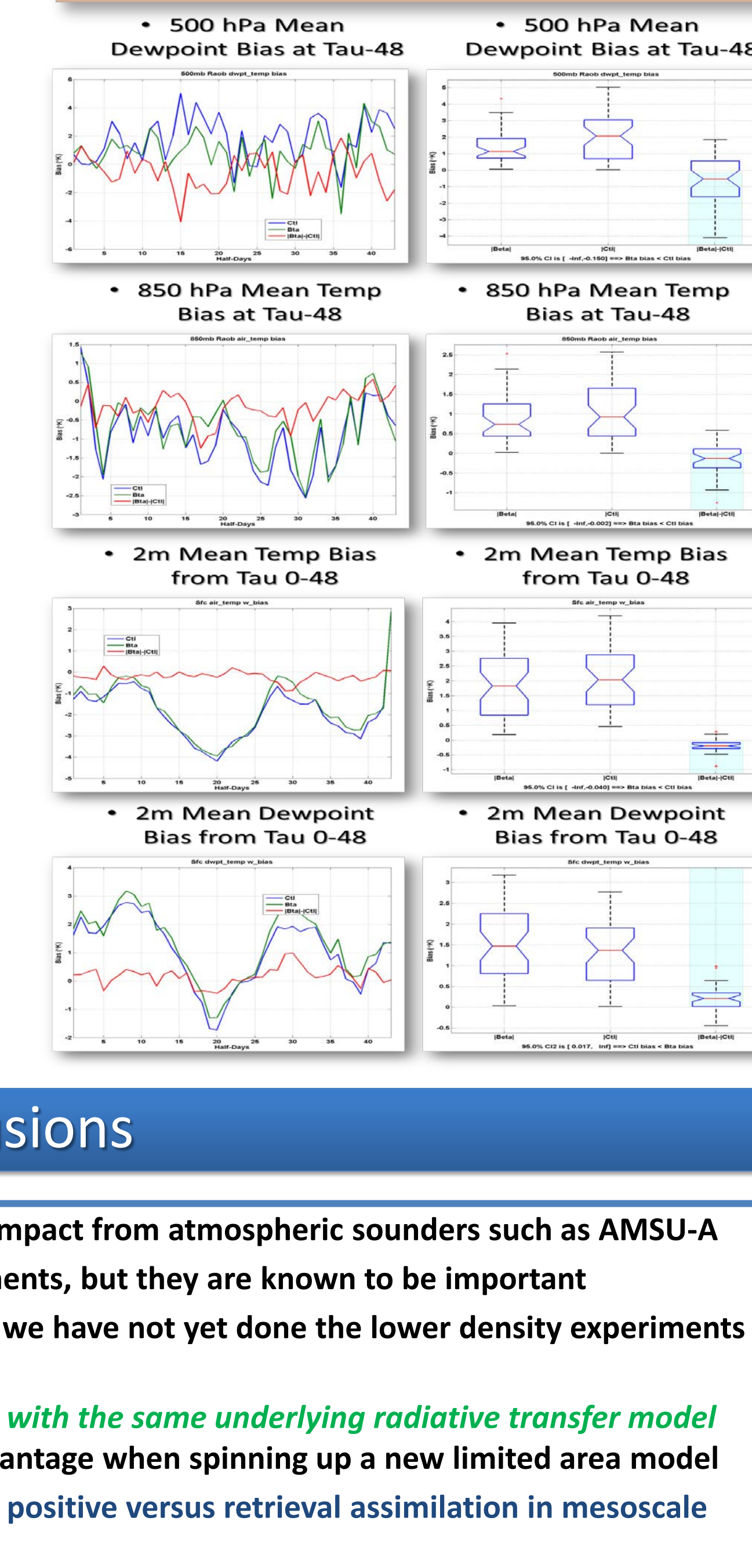
### ATOVS v. AMSUA\_I45\_sp3\_ch48\_bbc\_rs



### ATOVS v. AMSUA\_I45\_sp3\_ch48\_rs



### ATOVS v. AMSUA\_I45\_sp3\_ch47\_as



## Conclusions

- A sufficiently **high model top** is essential for positive impact from atmospheric sounders such as AMSU-A
- QC procedures were not altered during these experiments, but they are known to be important
- Higher data density seems to offer no difficulties, but we have not yet done the lower density experiments for comparison
- Bias correction using coefficients from a global model with the same underlying radiative transfer model performs well** (at least for EastPac), which is a big advantage when spinning up a new limited area model
- With the caveats above, radiance assimilation is a net positive versus retrieval assimilation in mesoscale models