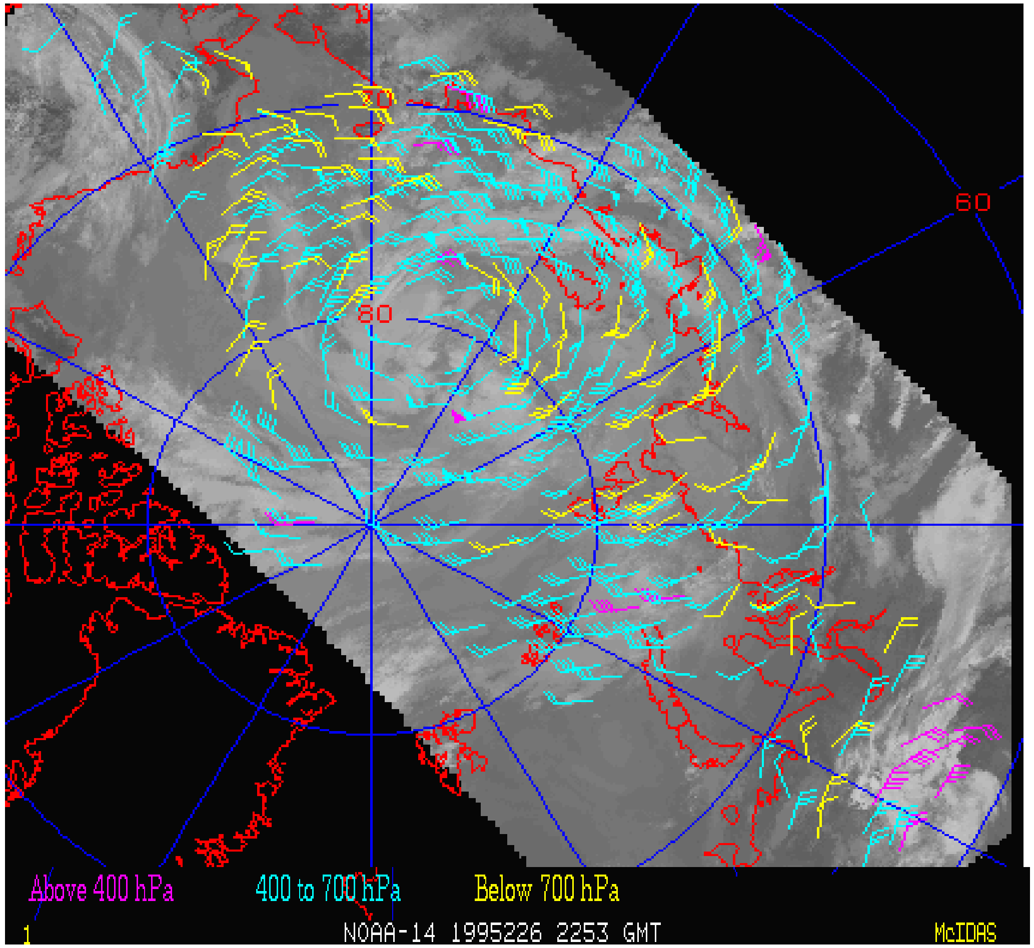
Assessing the Quality of Historical AVHRR Polar Wind Height Assignments



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Special Thanks to William Straka and Xuanji Wang

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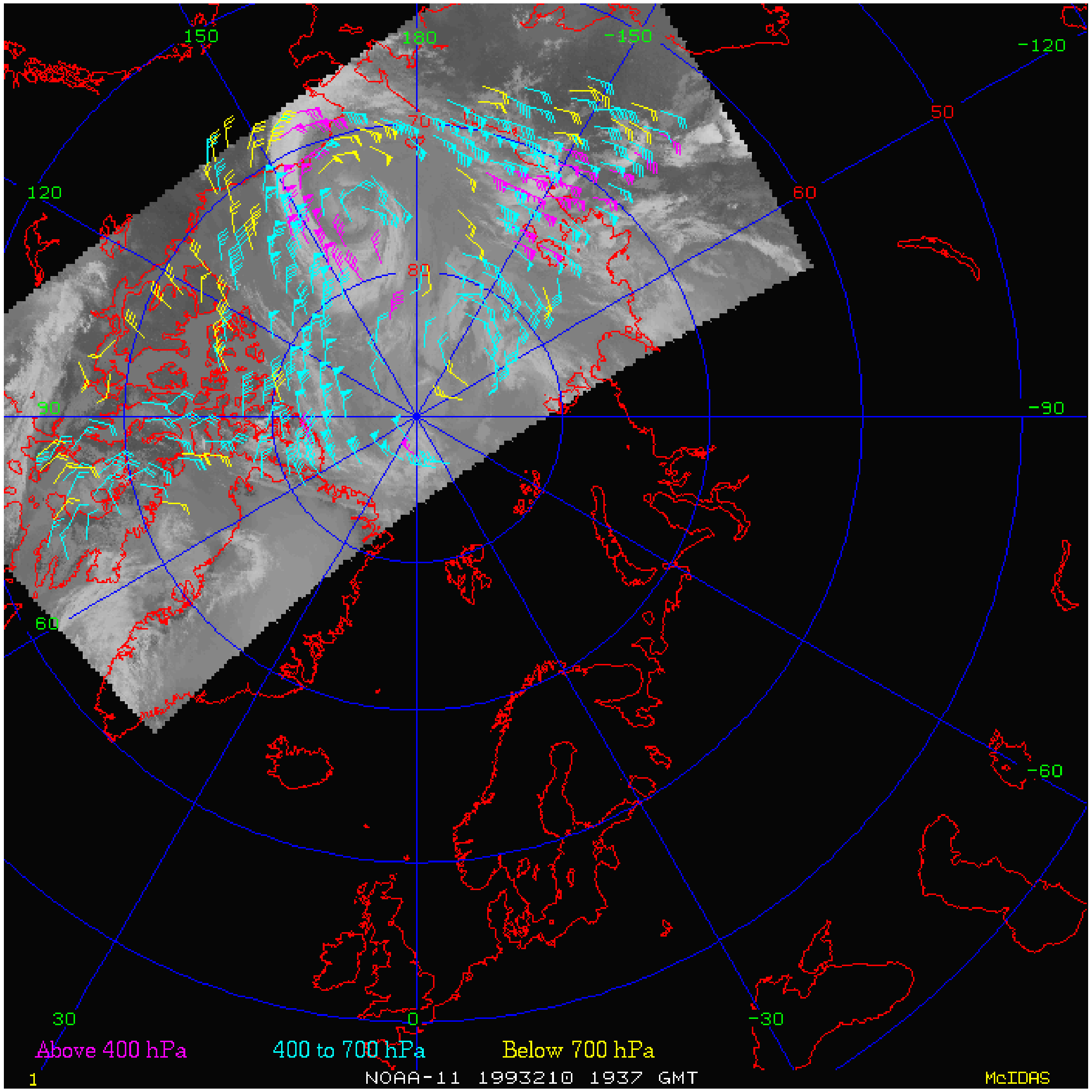
*NOAA/NESDIS at CIMSS

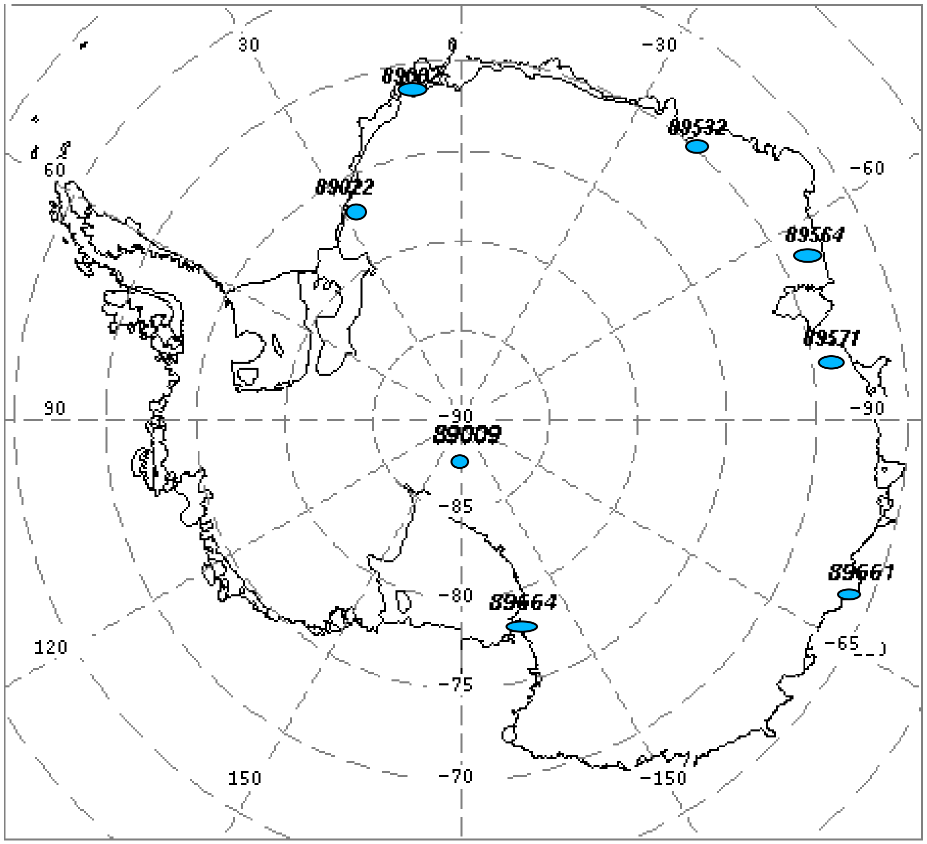
Historical AVHRR Polar Winds

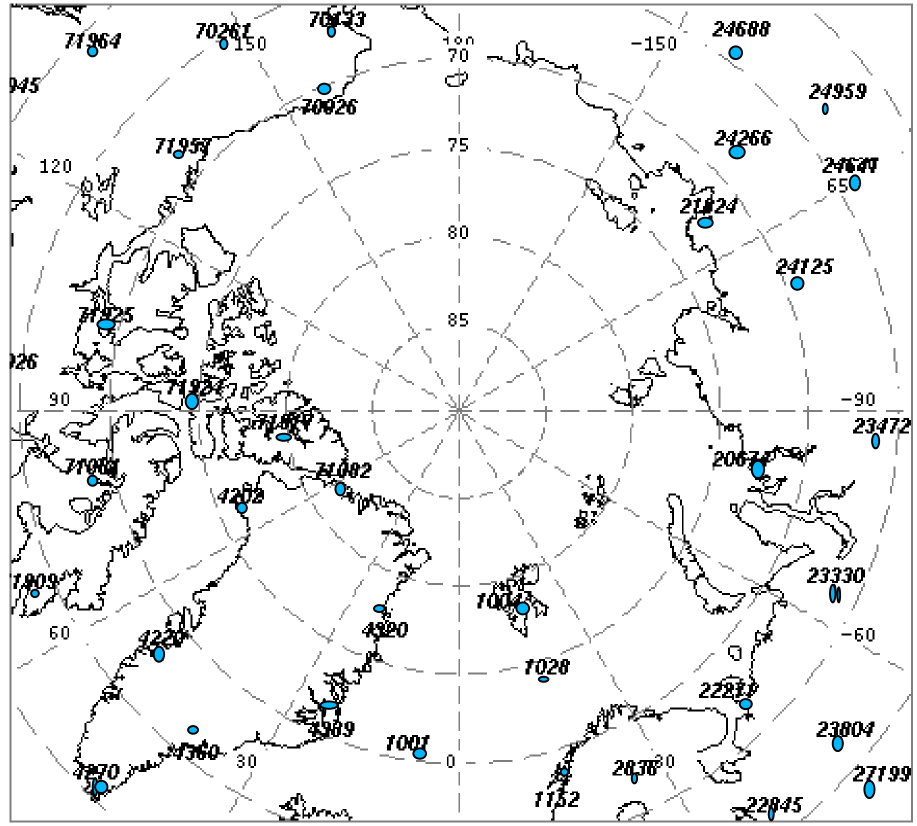


- January 1, 1982 to August 31, 2002.
- One satellite at any given time, NOAA-7, -9, -11, -14, -16.
- Global Area Coverage (GAC) data gridded at 4 km.
- Cloud-track winds using IR channel only (no water vapor channel).
- **Infrared Window Channel (WIN) is primary method in determining AMV heights for AVHRR.**
- ERA-40 used as background. ERA-40 is ECMWF's 1957-2002 reanalysis product.
- Available in BUFR Format

ftp://stratus.ssec.wisc.edu/pub/avhrr_winds

Motivation for Polar Wind Data: Sparsity of Raobs



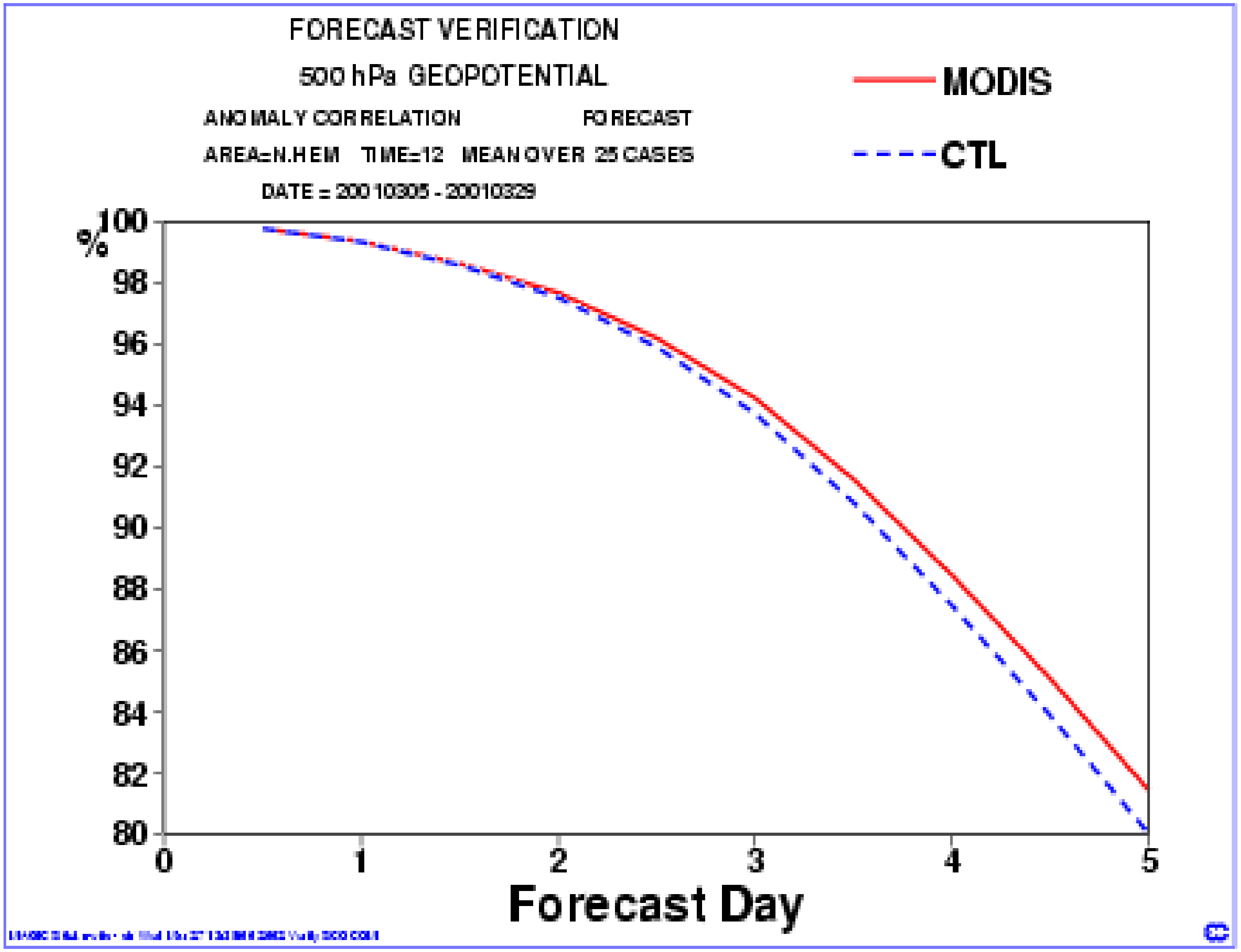


Regularly reporting radiosonde stations in the Arctic and Antarctic.

Motivation for Polar Wind Data: Positive Impact

Model impact studies have shown that the MODIS polar winds have a positive impact on weather forecasts not just in the polar regions, but globally.

The MODIS winds are now used operationally by 10 NWP centers in 6 countries.



Anomaly correlations as a function of forecast range for the 500 hPa geopotential over the Northern Hemisphere extratropics (north of 20 degrees latitude). The study period is 5-29 March 2001. Forecast scores are the correlation between the forecast geopotential height anomalies, with and without the MODIS winds, and their own analyses.

Motivation for Historical Wind Data: Reanalysis Wind Errors

Francis (2002) examined differences between NCEP/NCAR and ECMWF Reanalysis winds and rawinsonde ("raob") winds that were **not** assimilated into the reanalysis, from the LeadEx (1992) and CEAREX (1988) field experiments.

It was found that both reanalyses exhibit large biases in zonal and meridional wind components, being too westerly and too northerly. Winds are too strong by 25-65%.

Statistical comparison of historical AVHRR and ERA-40 winds to CEAREX and LEADEX .

	ERA	AVHRR
SPD RMSE	6.69 m s^{-1}	6.55 m s^{-1}
SPD BIAS	**+ 1.64 m s^{-1}**	**+ 0.41 m s^{-1}**
SPD DIFF	4.47 m s^{-1}	4.34 m s^{-1}
DIR RMSE	52.79 deg	55.21 deg
DIR BIAS	- 1.66 deg	- 5.70 deg

AVHHR vs RAOB Winds

Arctic: comparisons are made to winds from IGRA - Integrated Radiosonde Archive

Below 700 hPa	700 – 400 hPa	Above 400 hPa
Speed RMSE: 4.98 m/s	Speed RMSE: 5.18 m/s	Speed RMSE: 7.57 m/s
Direction RMSE: 65.17°	Direction RMSE: 52.55 °	Direction RMSE: 42.40 °
Speed Bias: +0.1 m/s	Speed Bias: -0.29 m/s	Speed Bias: +0.77 m/s
Direction Bias: -0.49°	Direction Bias: -0.71°	Direction Bias: +1.48 °
Correlation Coeff: .62	Correlation Coeff: .8	Correlation Coeff: .81
NRMS: 0.68	NRMS: 0.45	NRMS: 0.37
MeanAVHRRSpd: 7.42 m/s	MeanAVHRRSpd: 11.17 m/s	MeanAVHRRSpd: 21.04 m/s

- Speed RMSE increases with height, while direction RMSE decreases with height.
- AVHRR more counter-clockwise in direction at low and middle levels, while more clockwise at upper levels.
- AVHRR slightly faster at low-levels, slower at middle levels and faster at upper levels.
- Correlation Coefficients (NRMS) increase (decreases) with height, indicating that the overall quality of AVHRR winds improve with height.

Overview of WIN Method

- Calculate the bilinear brightness temperature(T_b) gradient in a 11 X 11 pixel target box.

- A potential AMV target is identified if the T_b gradient is equal to or greater than the set threshold of 7° K.

- Take the coldest 25 % of the pixels in target box and average them to come up with a guess cloud top temperature.

- Take the guess cloud top temperature and compare it to the nearest background (ERA-40) temperature profile in a top to bottom of the atmosphere approach and interpolate the cloud height for the given target.

- Potential problems exist in cases in non-opaque cloud scenes
Warm surface/Cold target – Positive Height Bias (Pressure)
Cold surface/Warm target(Arctic winter) – Negative Height Bias
Also with target cloud features below the inversion and sub-pixel clouds.

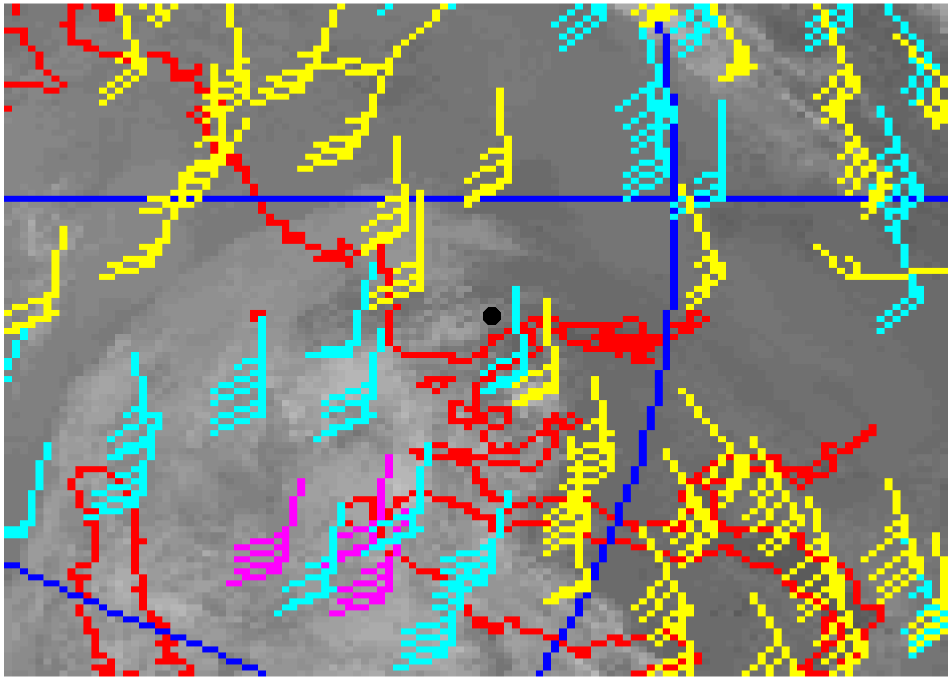
WIN Method Problem Case

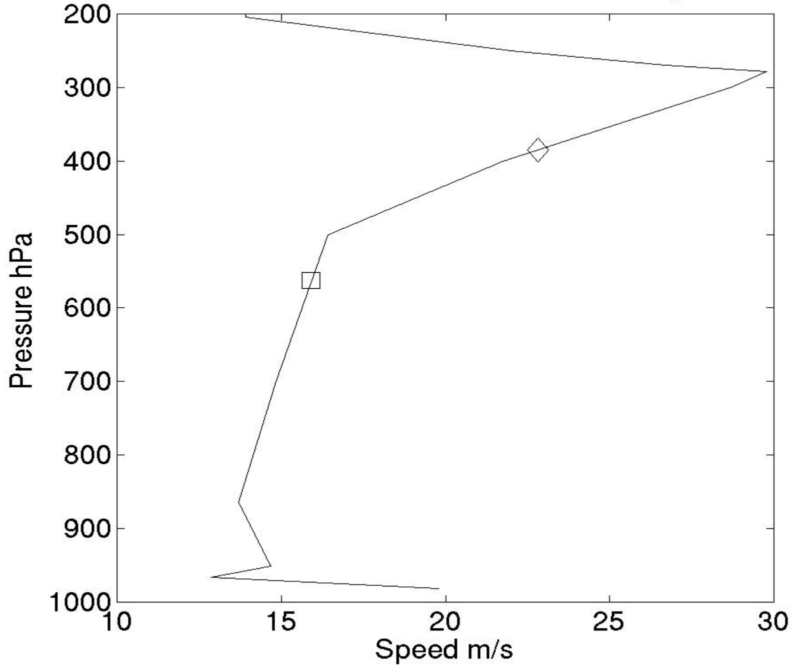
AVHRR AMV:
U_Wind Speed = 23 m/s
Direction = 263°
Target Temp = -18 °C

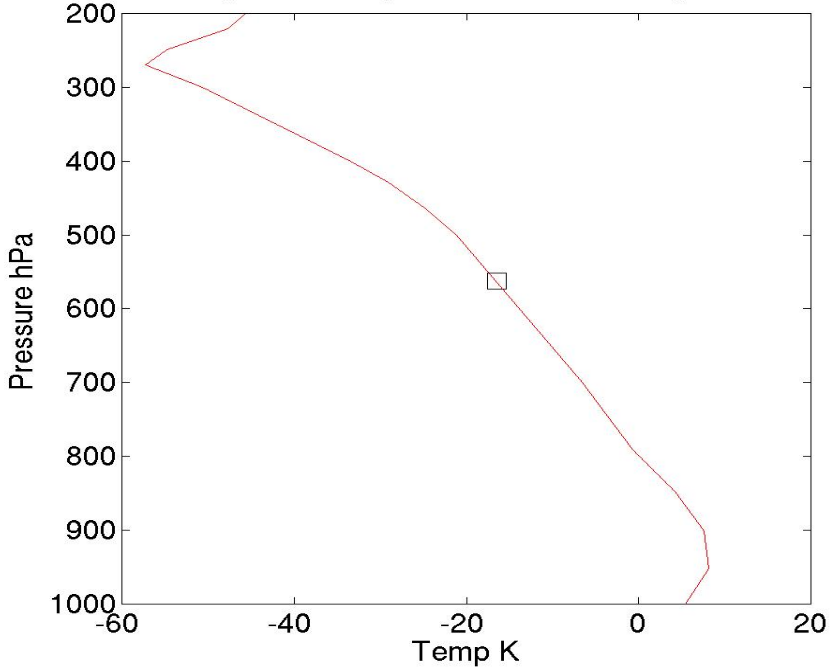
□ – 560 mb AMV height assign.

◇ - 390 mb Bestfit height assign.

Optical Depth = 2.17
Transmission = .114







Bestfit Height Method #1

$$\mathbf{C = (w_1 * abs\,(V_{diff})) + (w_2 * abs(P_{diff})) + (w_3 * abs(T_{diff}))}$$

(Straka et al. 2007)

C – Cost Function : The Pressure with the Minimum value is the bestfit height assignment.

W_n – weights: $\mathbf{w_1 = .55}$ $\mathbf{w_2 = .15}$ $\mathbf{w_3 = .30}$

V_{diff} – Vector difference: Not Normalized.

P_{diff} – Pressure difference: Normalized by 1000.

T_{diff} – Temperature diff: Normalized by 10.

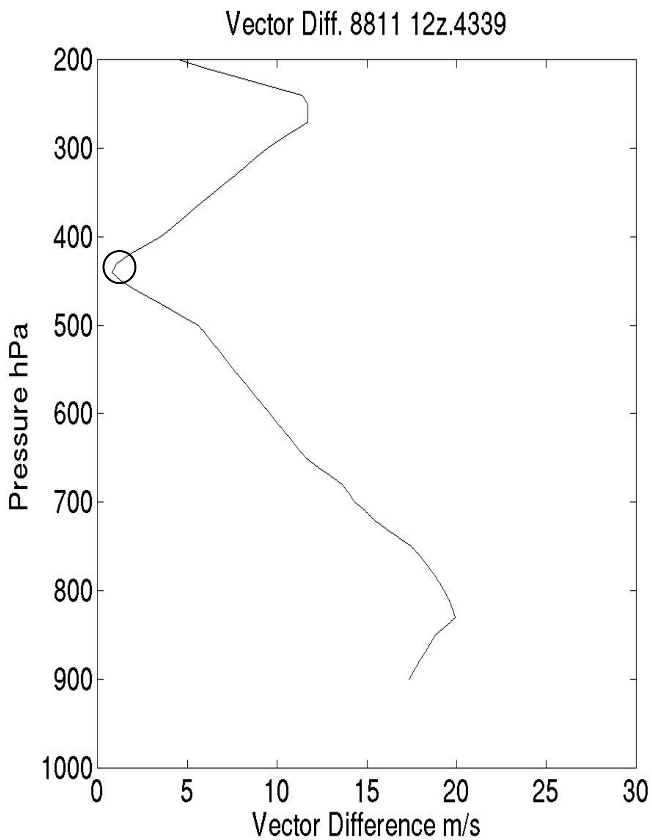
- AVHRR AMV heights are compared to Interpolated radiosonde profiles (@ 10 hPa height resolution) from the Integrated Radiosonde Archive (IGRA) to determine bestfit height assignments.

Bestfit Height Method #2

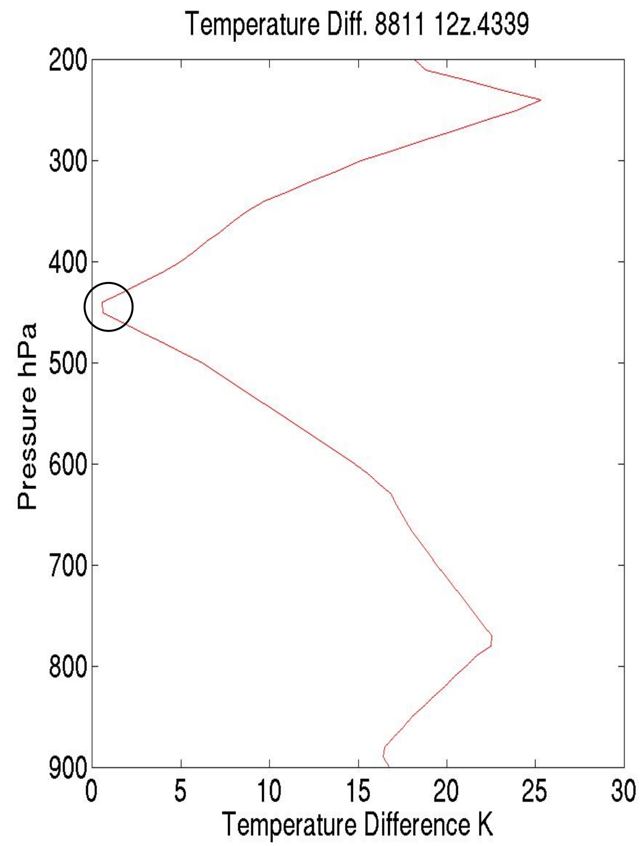
• Temperature difference between AMV and radiosonde observation is NOT taken into account.

• Vector Diff. Is the only variable used to determine bestfit height.

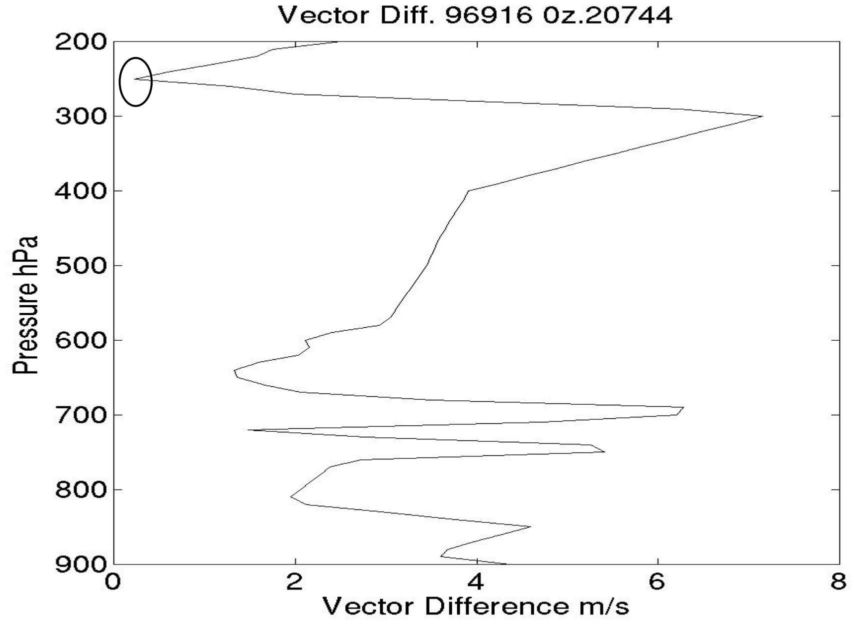
• Find the minimum Vector Difference between RAOB sounding and AMV.

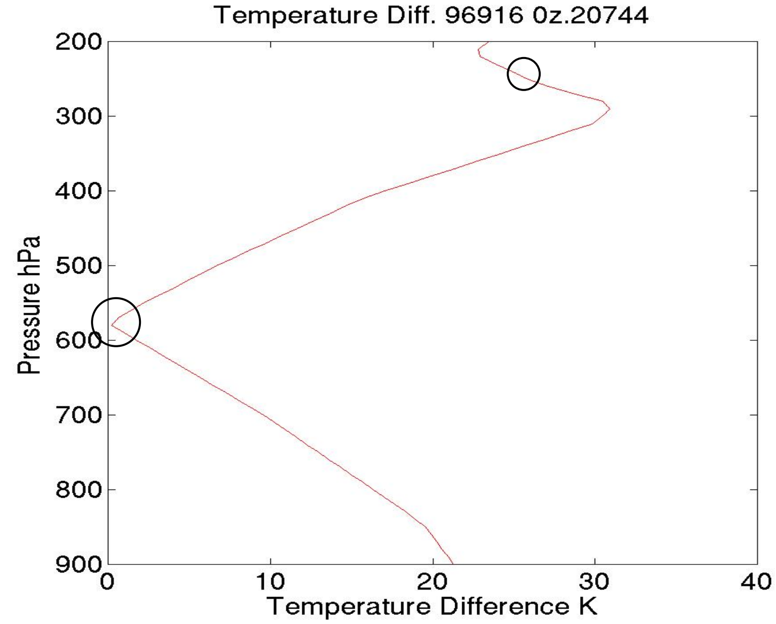


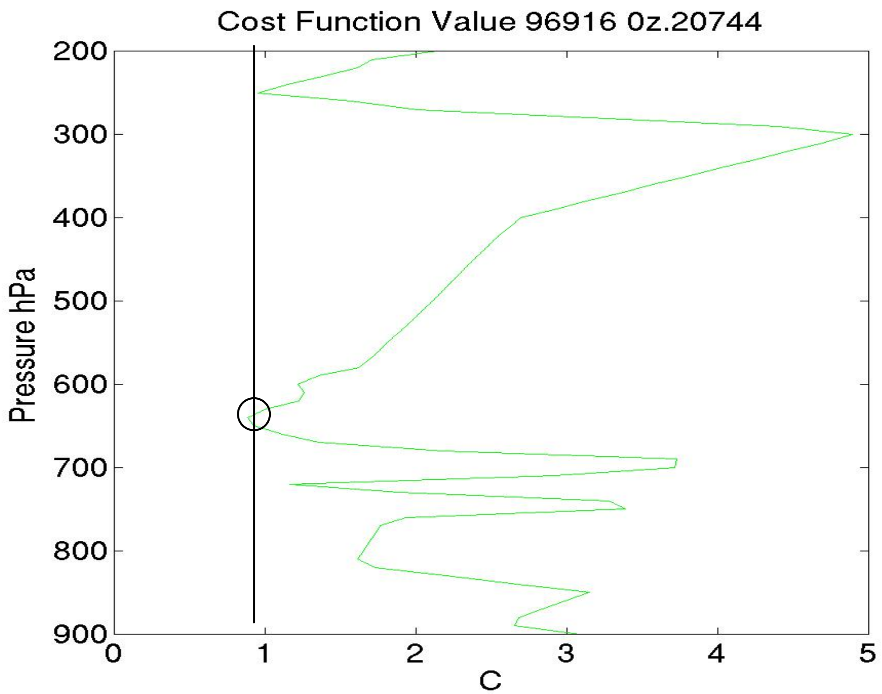
Heights
AVHRR: 462 hPa
Bestfit: 440 hPa



Problem with Method #2







AVHRR Height = 600 hPa

Method #2 Height = 250 hPa
Method #1 Height = 640 hPa

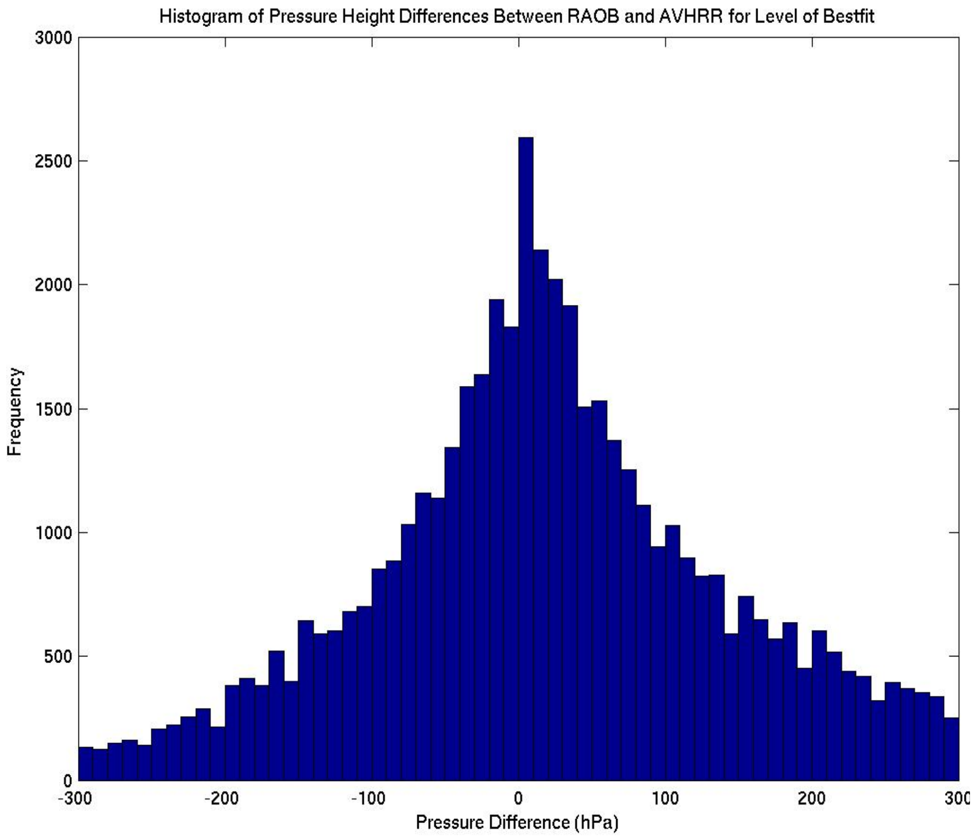
ΔTemp @ 250 hPa = 25º K
ΔTemp @ 640 hPa = 6.5º K

APP-x Optical Depth = 6.219
Transmission = .00199

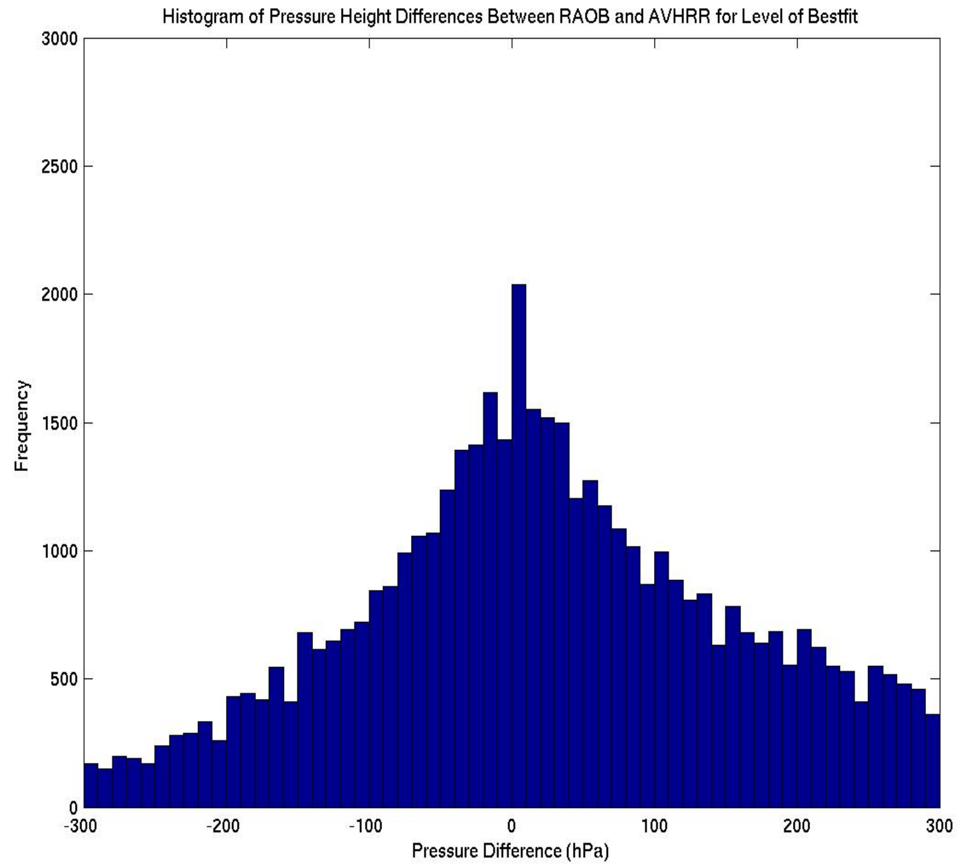
Therefore, ΔTemp needs to be included into bestfit determination.

Overall Comparison

Method # 1



Method # 2



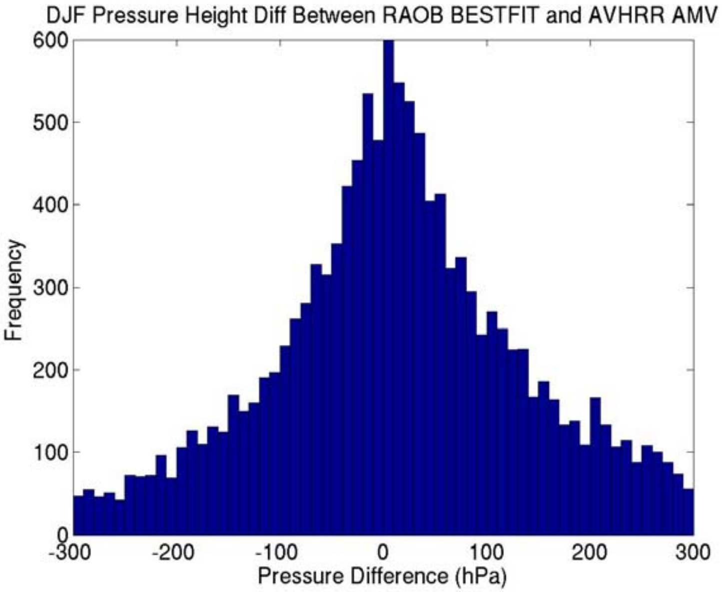
BIAS = + 33.0413
RMSE = 162.5145

BIAS = + 48.0856
RMSE = 192.1868

Pressure Diff = AVHRR_Pressure – Bestfit_Pressure

Collocation distance <= 100 km   time separation <= 1 hr

Seasonal Comparison Method #1

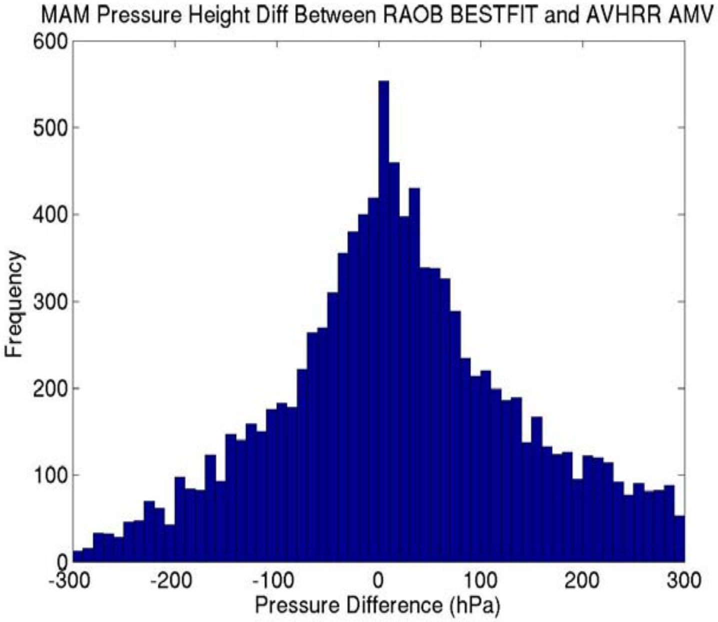


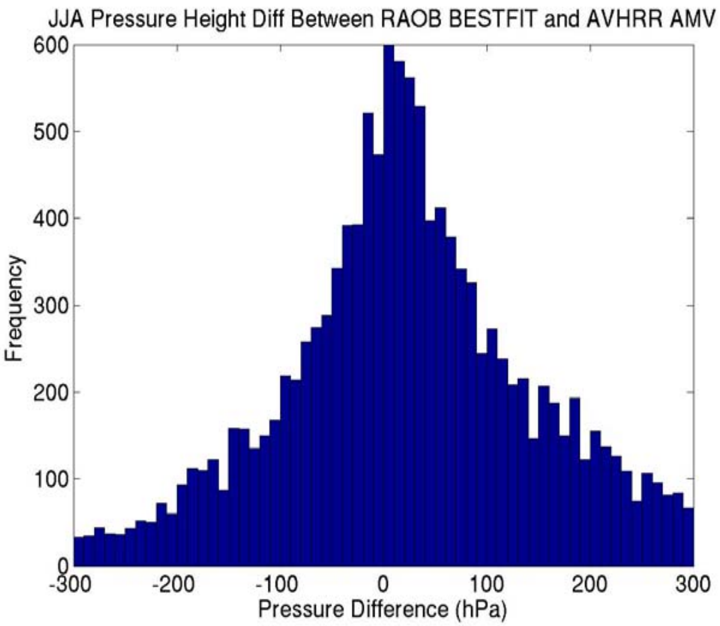
DJF

BIAS
+14.3861
RMSE
154.1727

MAM

BIAS
+41.6950
RMSE
167.5879



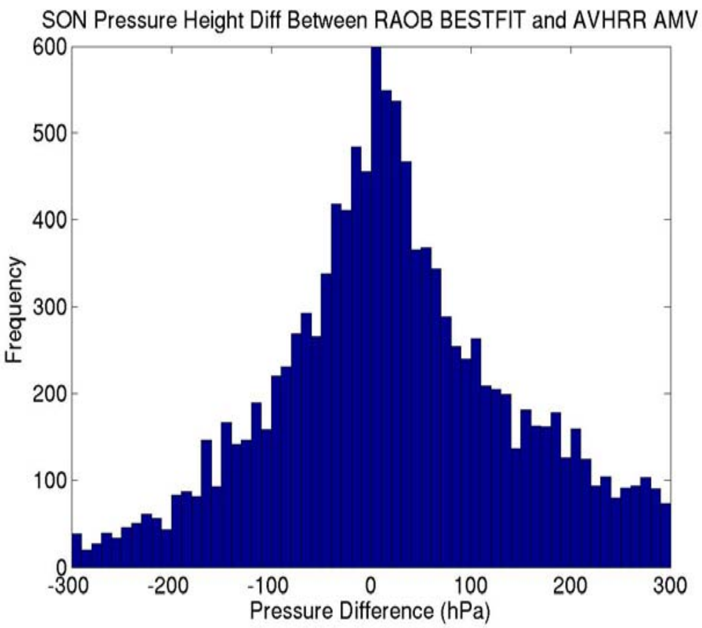


JJA

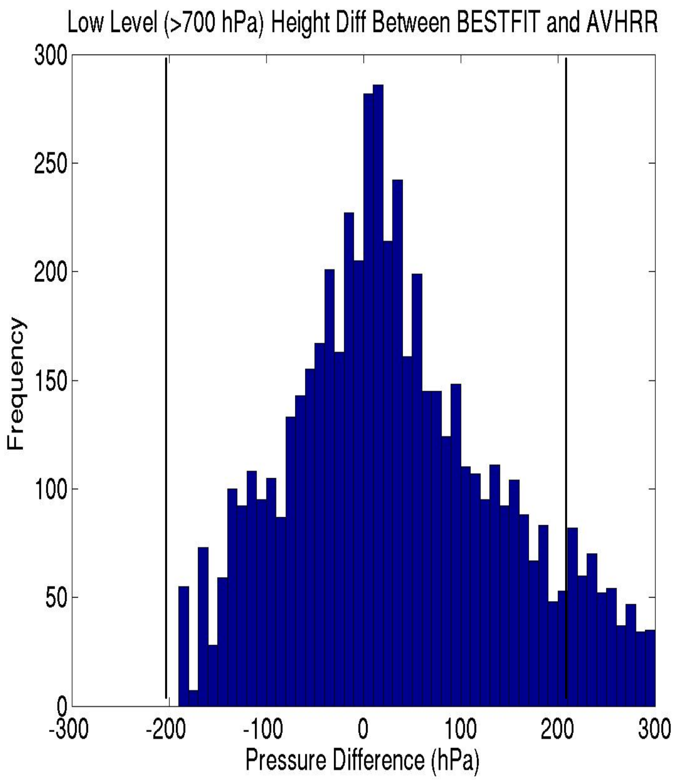
BIAS
+40.2636
RMSE
164.9142

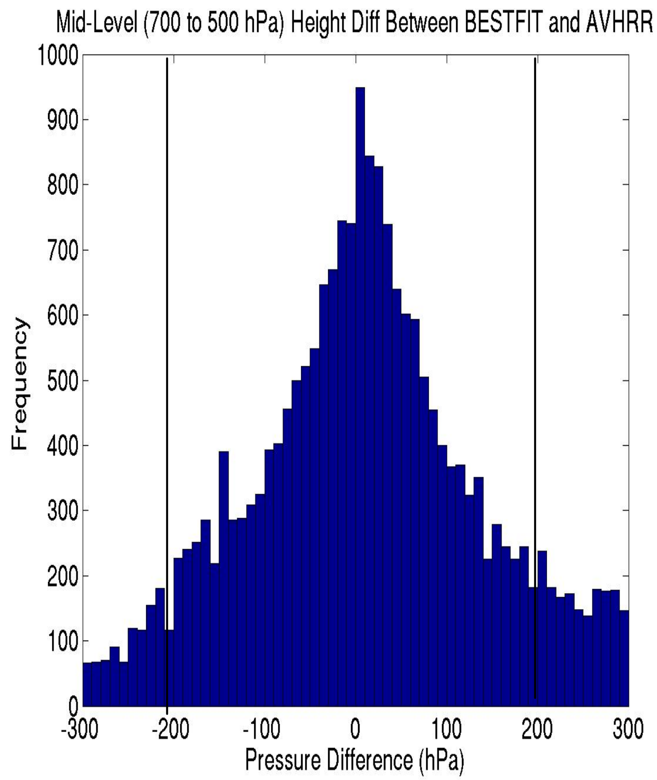
SON

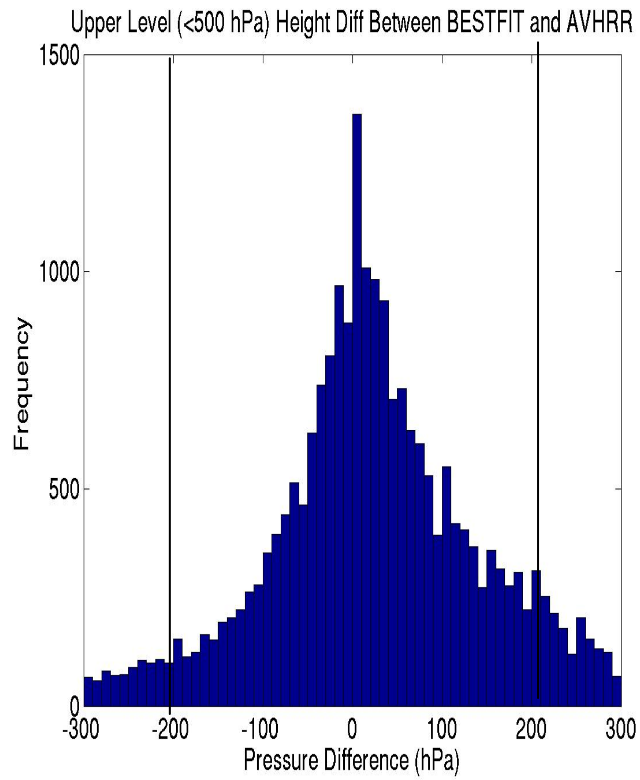
BIAS
+37.4850
RMSE
163.9697



Comparison by AVHRR Level







Low Levels (>700 hPa)

BIAS = + 12.50
RMSE = 207.77

Mid-Levels (700-500 hPa)

BIAS = + 0.98
RMSE = 171.29

Upper Levels (<500 hPa)

BIAS = +14.98
RMSE = 136.62

AVHRR Based Height Seasonal Level Comparison

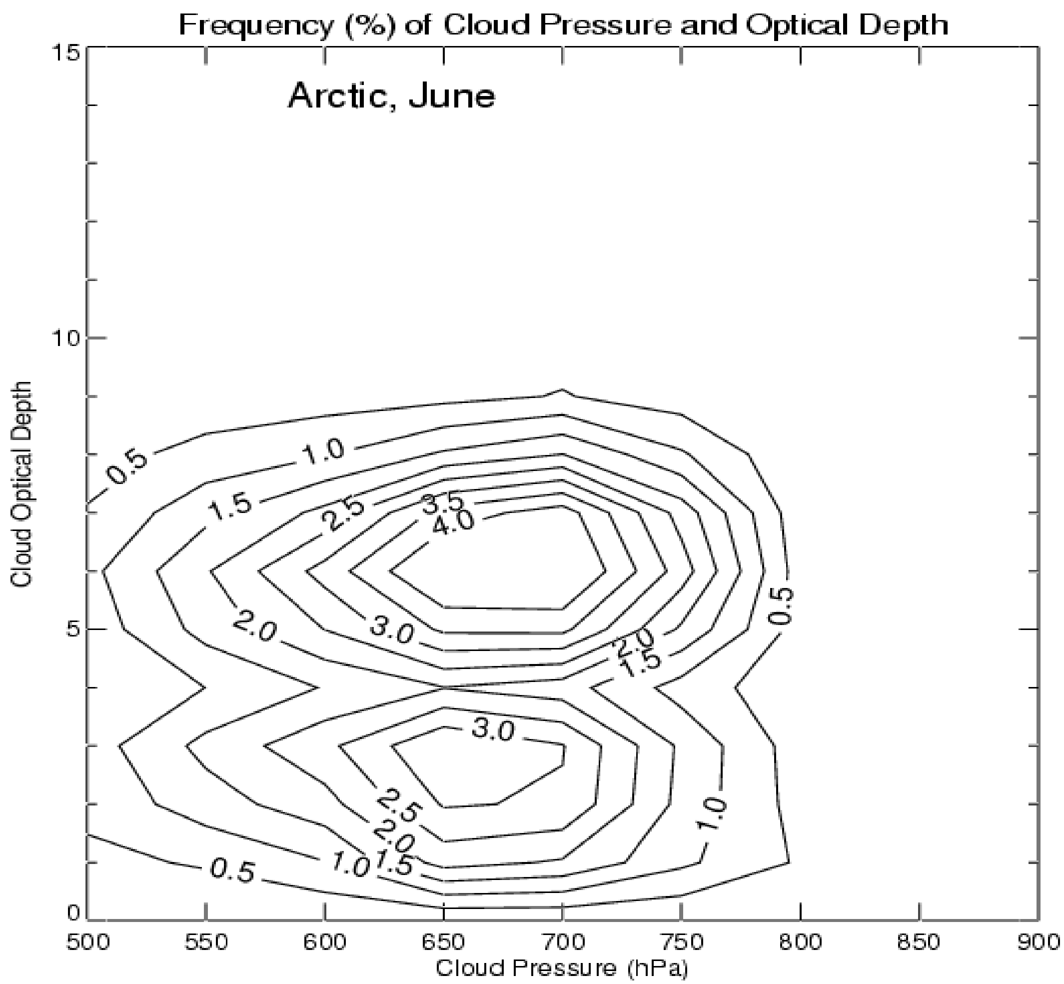
Low (>700 hPa)	BIAS	RMSE
DJF	**+ 2.07**	**169.99**
MAM	+ 8.72	209.09
JJA	+ 16.18	**226.16**
SON	+ 16.37	199.14
Middle (500-700 hPa)		
DJF	**- 1.84**	**166.69**
MAM	+ 1.85	**175.22**
JJA	**+ 3.88**	170.79
SON	+ 0.21	172.15
High (< 500 hPa)		
DJF	**+ 12.24**	**141.78**
MAM	+ 14.60	134.16
JJA	**+ 17.41**	**131.18**
SON	+ 16.15	137.48

Optical Depth

IR Window (WIN Method)

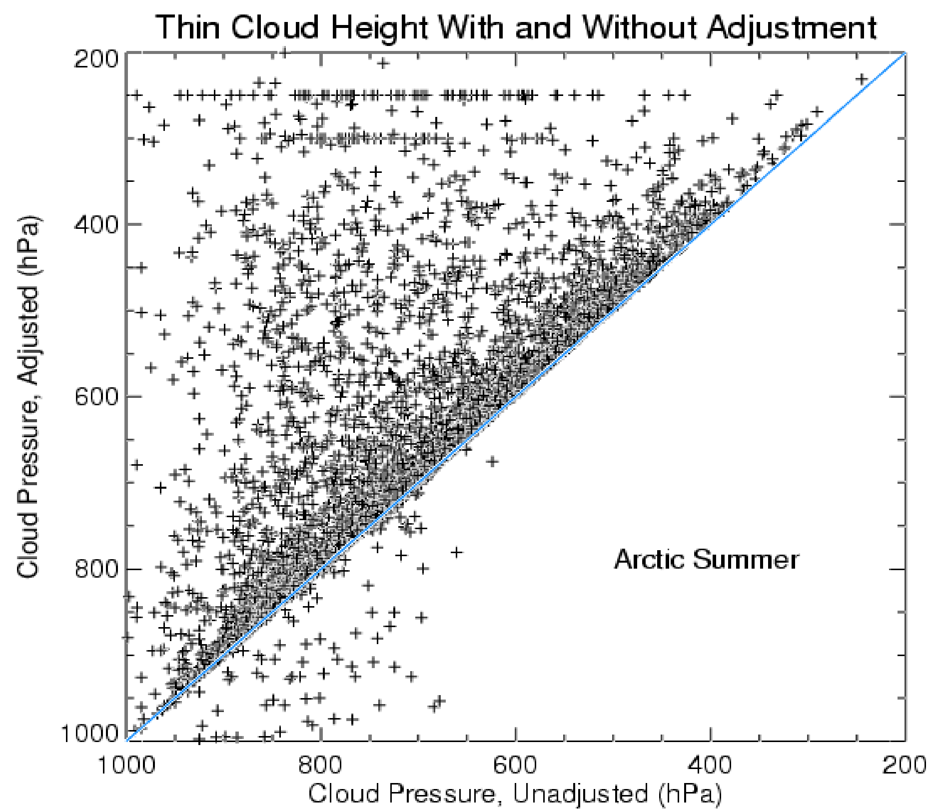
Currently, this approach assumes the cloud is opaque so that the IR brightness temperature is also the cloud temperature. Find the temperature in the profile to get the height.

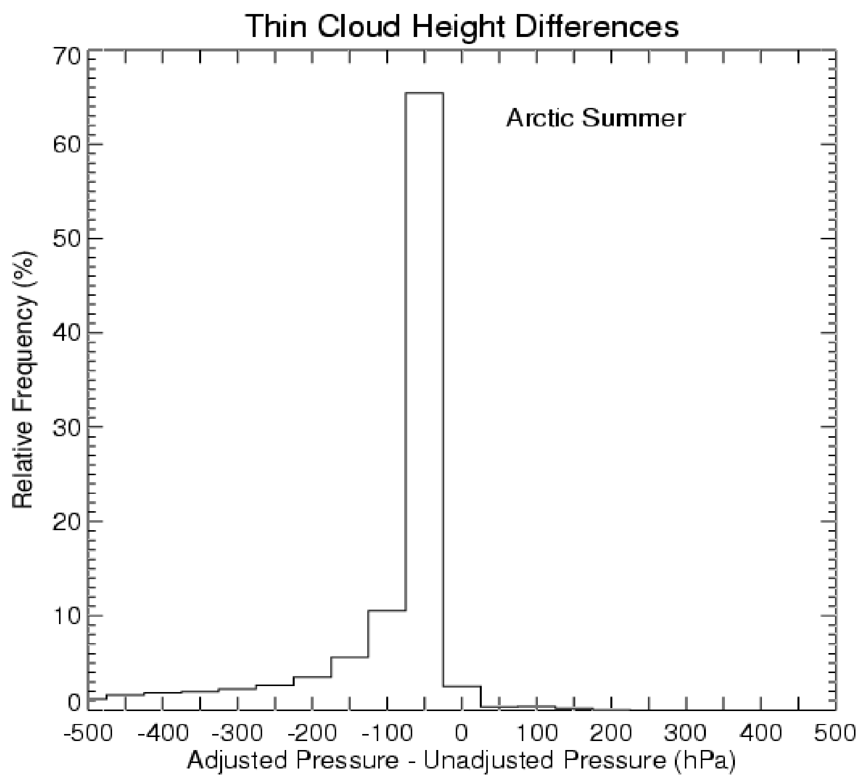
An adjustment for surface emission should be used with thin clouds, which means optical depth must be calculated.



Optical Depth

Converting the cloud temperature to a cloud pressure (lookup in the profile), the adjustment in summer will generally increase the cloud altitude. In winter the direction of change may be mixed due to inversions.





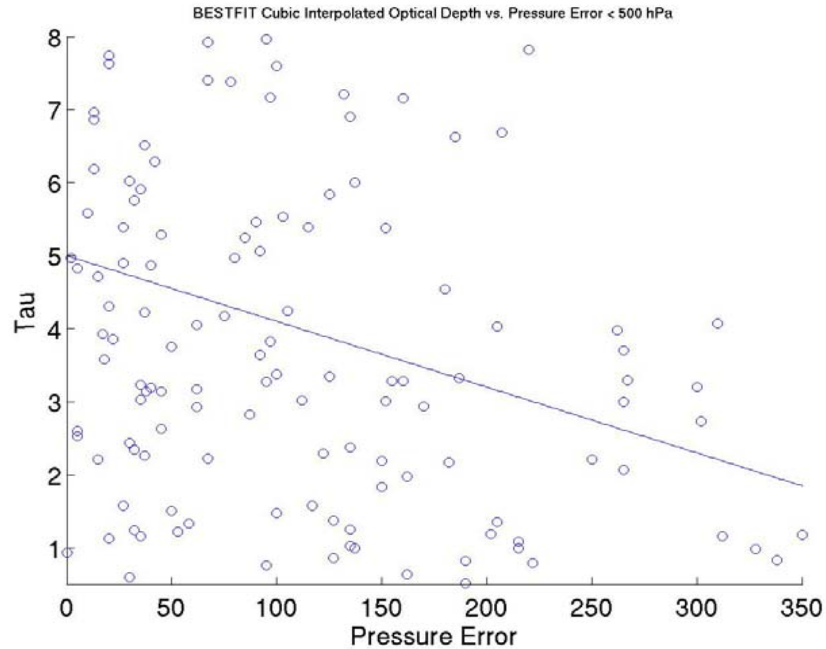
The point-by-point retrievals, with and without the adjustment for optical depth, are shown above for one summer image. Only clouds with visible optical depths less than 5 are shown.

The relative frequency of the pressure differences is shown at left.

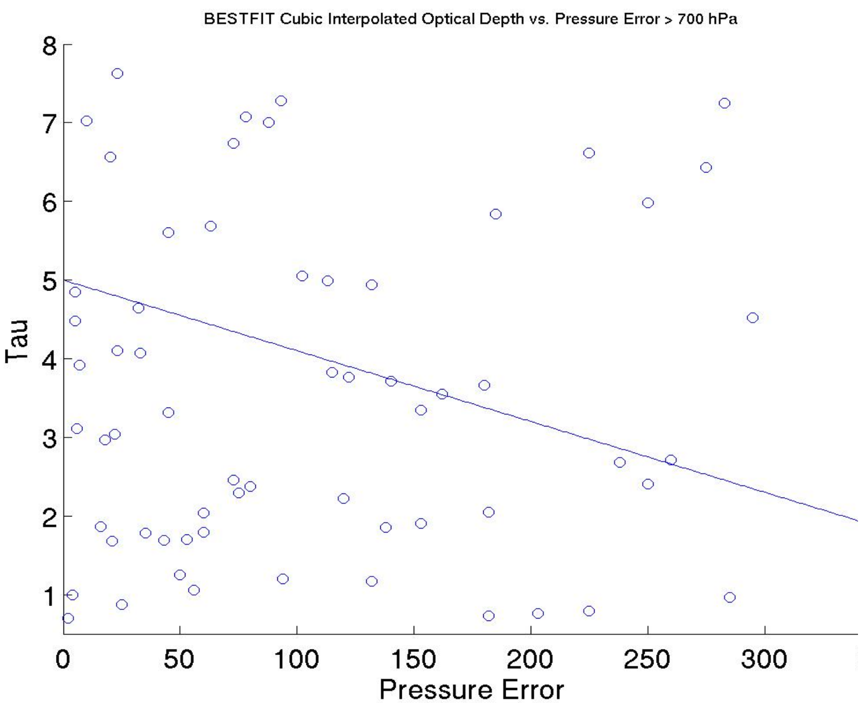
Optical Depth vs. Pressure Error

NO Indirect relationship between Optical Depth (APP-x) and Pressure Error (AVHRR AMV) was found. However, for upper level bestfits (upper-right plot), there are noticeably more pressure errors < 200 hPa for Optical Depths > 4.5

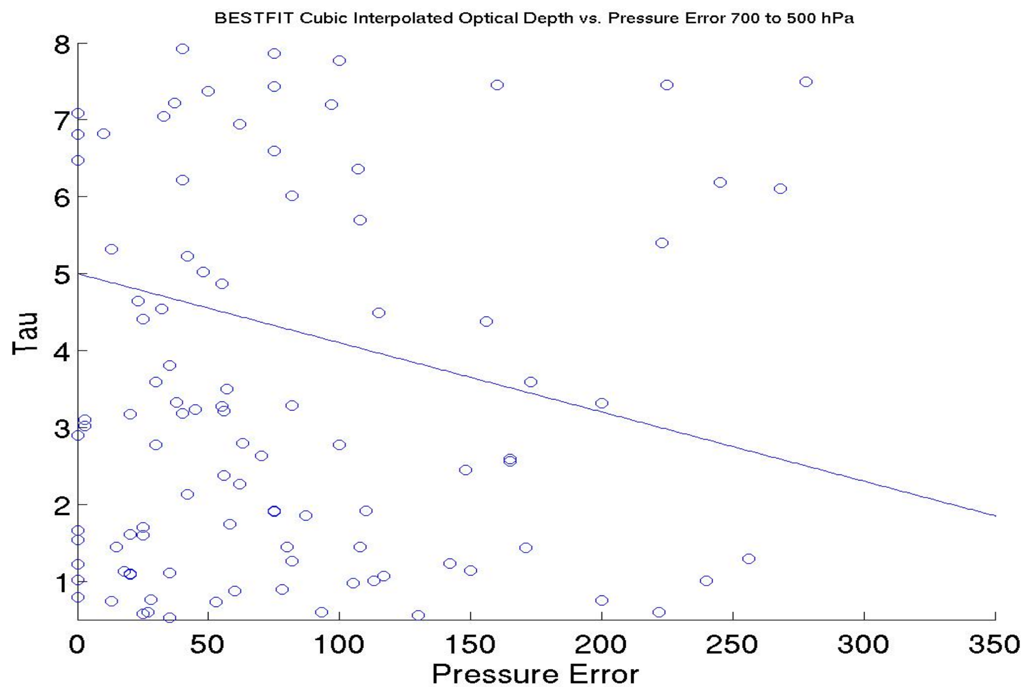
Bestfit < 500 hPa



Bestfit > 700 hPa



Bestfit 700 to 500 hPa



Summary and Conclusions

- **AVHRR GAC data were used to create a 20+ year polar wind product for the period 1982-2002.**

- **The two major reanalysis products have significant errors in winds over the Arctic where there are no radiosonde data. AVHRR has an overall smaller speed bias than ERA-40 when compared to radiosondes not assimilated into reanalysis.**

- **AVHRR ONLY has clear window 11 µm channel for use in height determination, with NO Water Vapor or CO_2 channels. Therefore, the WIN Method is the primary method in determining the AMV heights.**

- **The quality of AVHRR AMV heights is determined through comparison to radiosonde wind profiles using a besfit height assignment technique that uses a Cost Function that weighs Vector (55%), Pressure (15%) and Temperature (30%) Differences.**

- **The AVHRR winds are on average assigned too low in altitude. The smallest bias and RMSE occur during winter (DJF). For all other seasons the bias and RMSE are similar.**

- **When AVHRR heights are partitioned by level, the smallest bias is @ middle levels (700 to 500 hPa) and smallest RMSE is found to be @ upper levels (<500 hPa), with the largest RMSE @ low-levels (>700 hPa).**

Summary and Conclusions

- **For middle and upper levels the + bias was slightly higher during JJA compared to other seasons. The bias becomes – only for DJF @ middle levels. At upper levels the RMSE was smallest for JJA and highest for DJF. At low levels the RMSE is noticeably largest for JJA and smallest for DJF.**

- **From simulations, cloud tracers with small optical depths are expected to result in large height assignment errors. NO indirect relationship between APP-x optical depth and AVHRR AMV pressure error was found.**

- **Problems: 1) Determining optical depths at cloud edges 2) Non height assignment errors - tracking and targeting. How to partition out the Non height assignment errors ? If able to do so a relationship between Optical Depth and Pressure Height Error could be found.**

Optical Depth vs. Pressure Error

- Compare AVHRR AMV to APP-x Optical Depths for the months April through September.

- Convert the AVHRR AMV UTC to APP-x LST (Local Solar Time) by using the longitude of the AMV: ***1) LST(min) = UTC(min) + (1440/360)*LON***

- Calculate the LST of the nearest APP-x point, using the Solar Zenith angle from APP:

2) ***Soldec=ArcSin(sin(Obliquity of Ecliptic) + sin(Ecliptic of Longitude))***

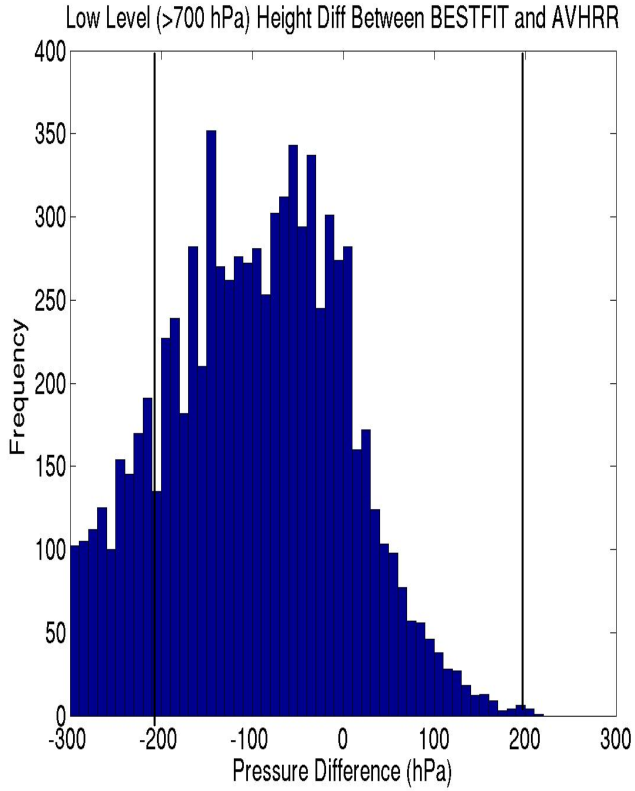
SolHr=ArcCos(Cos(SolZenith) –(Sin(Soldec)*Sin(Lat))/(Cos(Soldec)*Cos(Lat))

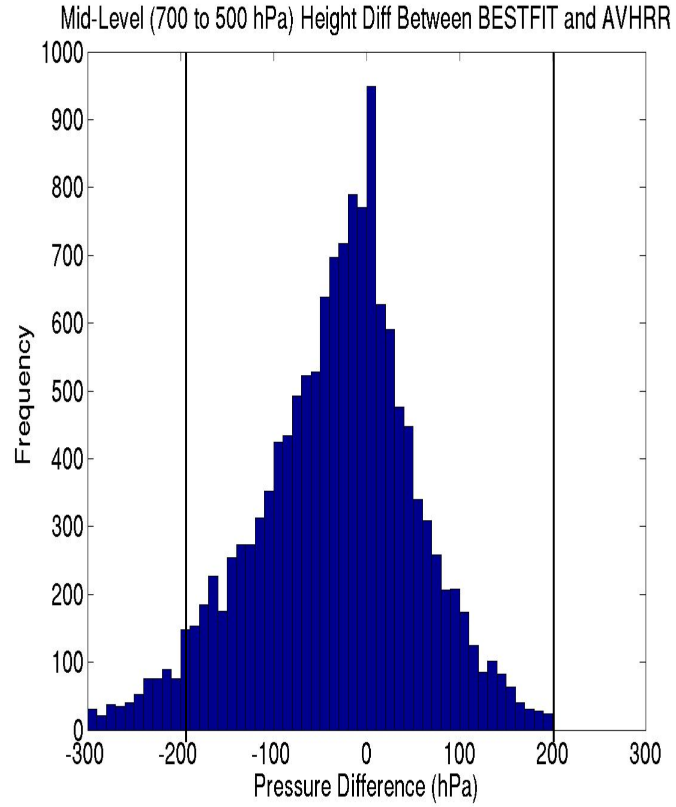
LST(min)=(720+(SolHr/.25))

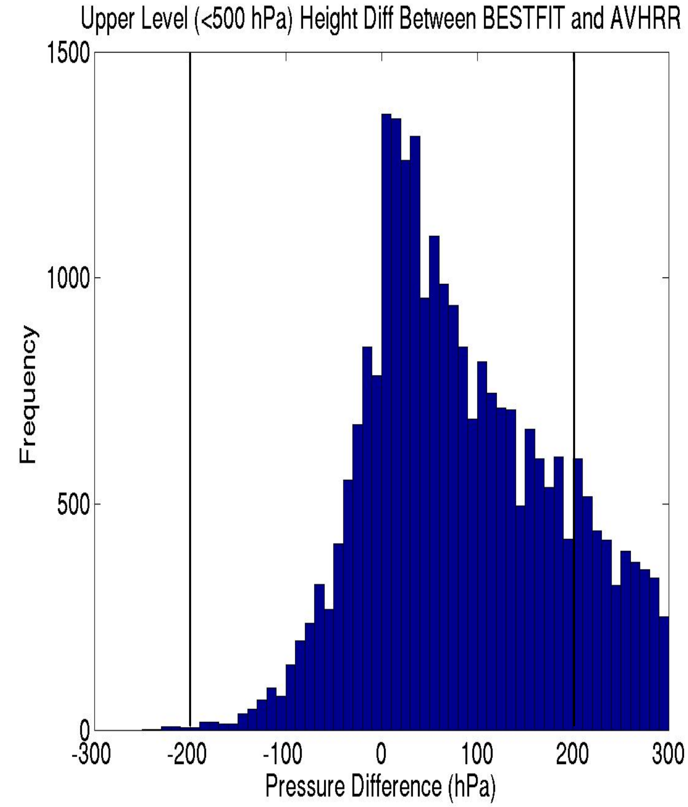
- If the ΔLST between 1) AMV LST and 2) APP-x point LST is less than 50 minutes (RMS difference between 1) and 2) was found to be 20 minutes) and AMV is 25 km of the calculated location of drifted RAOB , a comparison between Tau and ΔP is made.

- The Optical Depth at the location of the AMV is determined by cubic interpolation within a 3 X 3 box of APP-x Optical Depth points surrounding the AMV.

Comparison by Bestfit Level







<u>Low Levels (>700 hPa)</u>

BIAS = - 66.78
RMSE = 180.65

<u>Mid-Levels (700-500 hPa)</u>

BIAS = - 25.44
RMSE = 95.94

<u>Upper Levels (<500 hPa)</u>

BIAS = + 52.99
RMSE = 181.06

The change in sign occurs roughly @ 450 mb

AVHRR vs ERA-40 Winds

Arctic:

Below 700 hPa	700 – 400 hPa	Above 400 hPa
speed rms: 2.94 m/s	speed rms: 2.93 m/s	speed rms: 3.45 m/s
direction rms: 17.66°	direction rms: 14.16°	direction rms: 11.54°
mean speed diff: -0.32 m/s	mean speed diff: 0.11 m/s	mean speed diff: 0.34 m/s
mean direction diff: -0.47°	mean direction diff: 0.13°	mean direction diff: 0.51°
mean AVHRR: 12.35 m/s	mean AVHRR: 16.02 m/s	mean AVHRR: 25.36 m/s
mean ERA40: 12.67 m/s	mean ERA40: 15.91 m/s	mean ERA40: 25.02 m/s

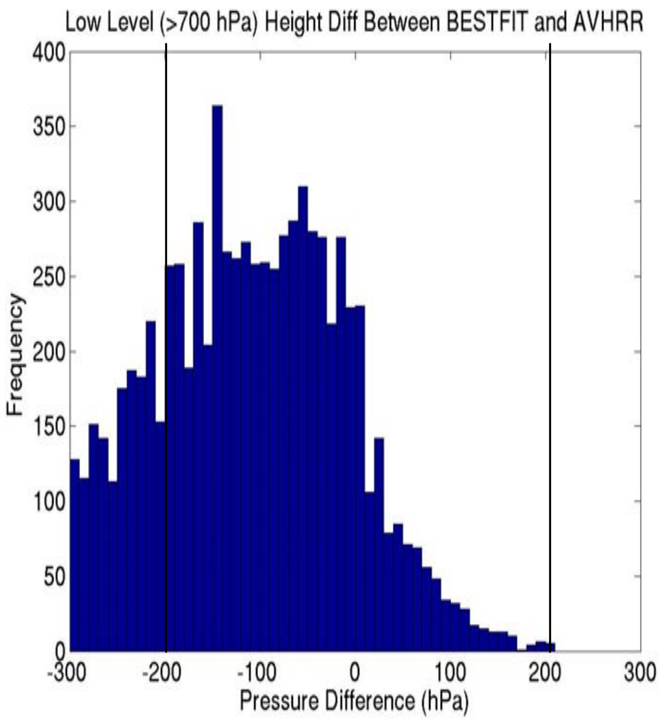
- AVHRR slower on average at low-levels and faster at middle and upper levels.

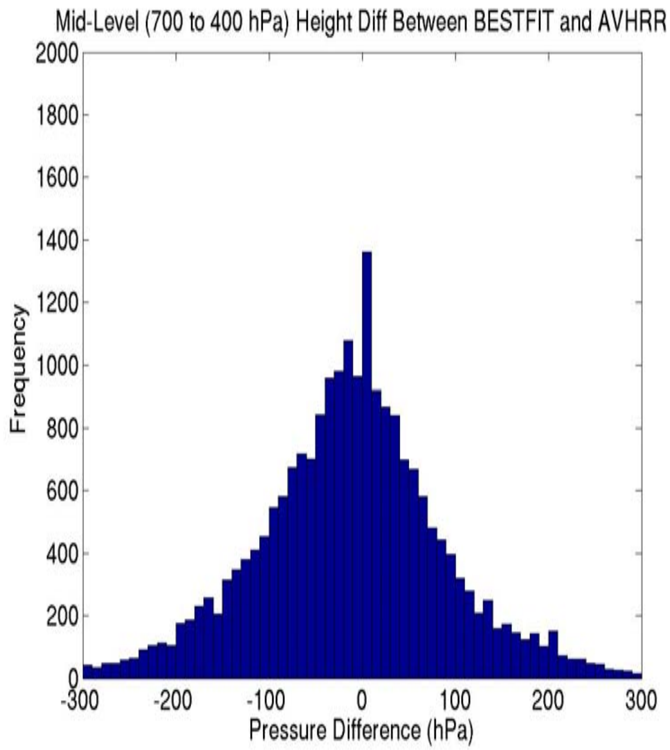
- AVHRR more counter-clockwise in direction at low-levels and clockwise at middle and upper levels.

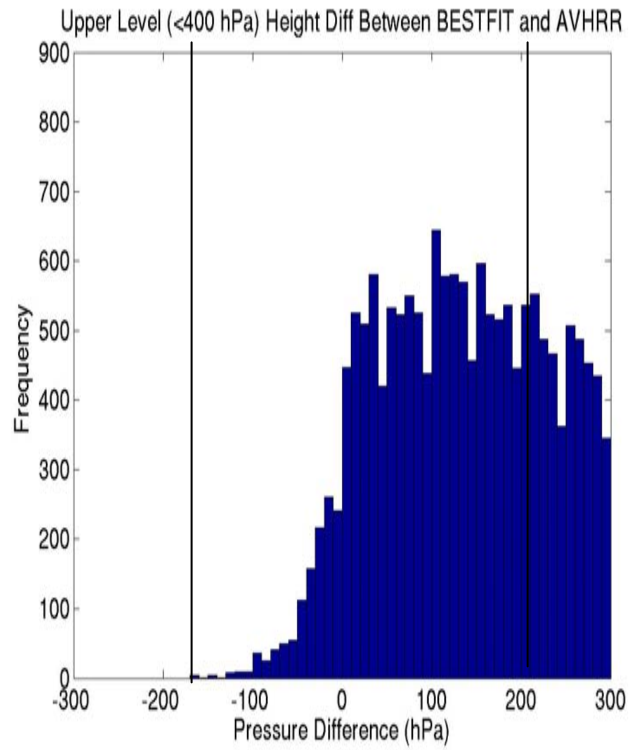
- Speed rms difference between AVHRR and ERA-40 increase with height.

- Direction rms differences decreases with height.

Comparison by Bestfit Level Method # 2







<u>Low Levels (>700 hPa)</u>

BIAS = - 150.71
200hPaRangeBias = - 72.97
RMSE = 202.47

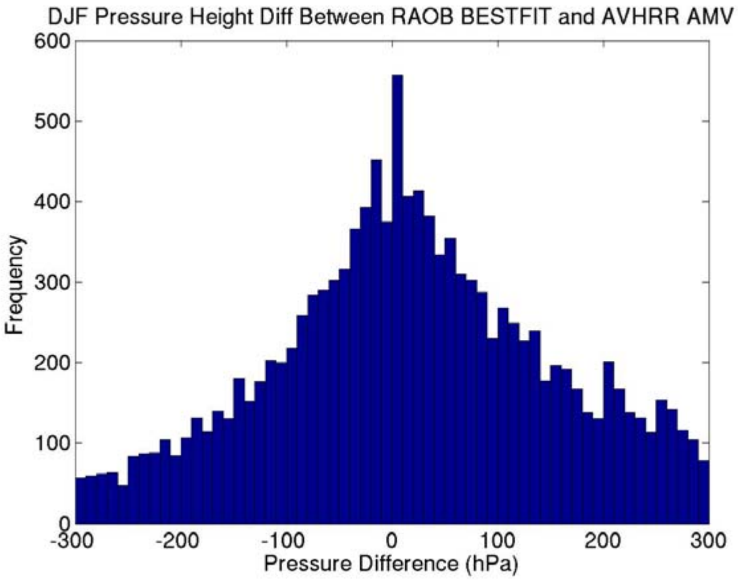
<u>Mid-Levels (700-400 hPa)</u>

BIAS = - 16.18
RMSE = 102.79

<u>Upper Levels (<400 hPa)</u>

BIAS = + 197.71
200hPaRangeBias = + 85.39
RMSE = 247.86

Seasonal Comparison Method #2

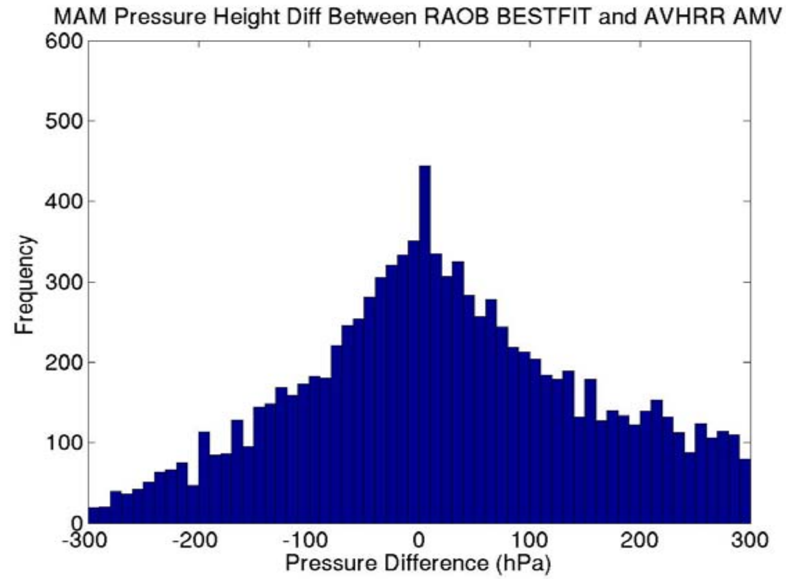


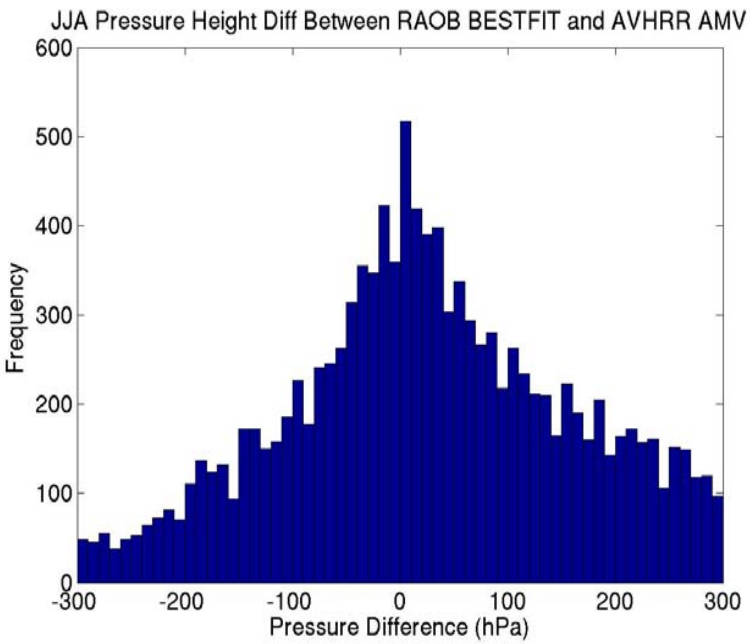
DJF

BIAS
+22.9125
RMSE
176.5995

MAM

BIAS
+59.8007
RMSE
197.5193



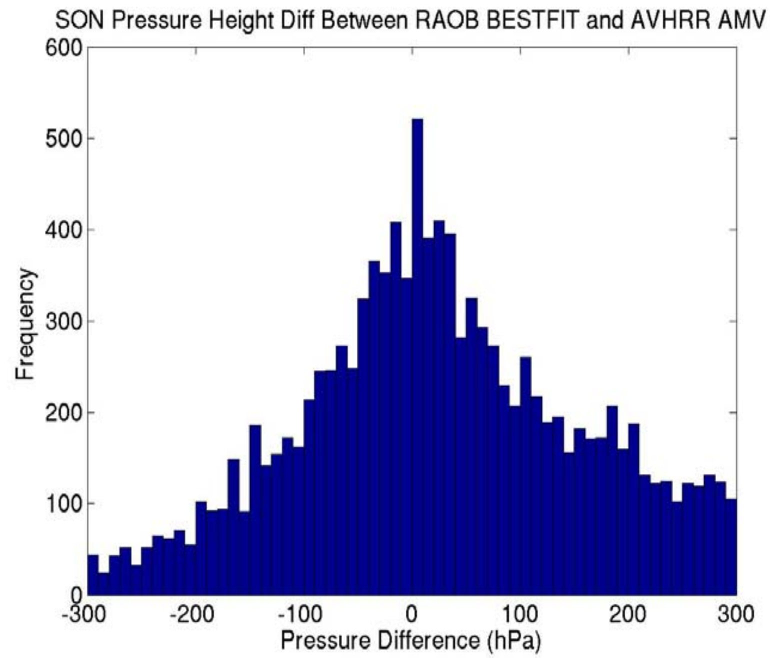


JJA

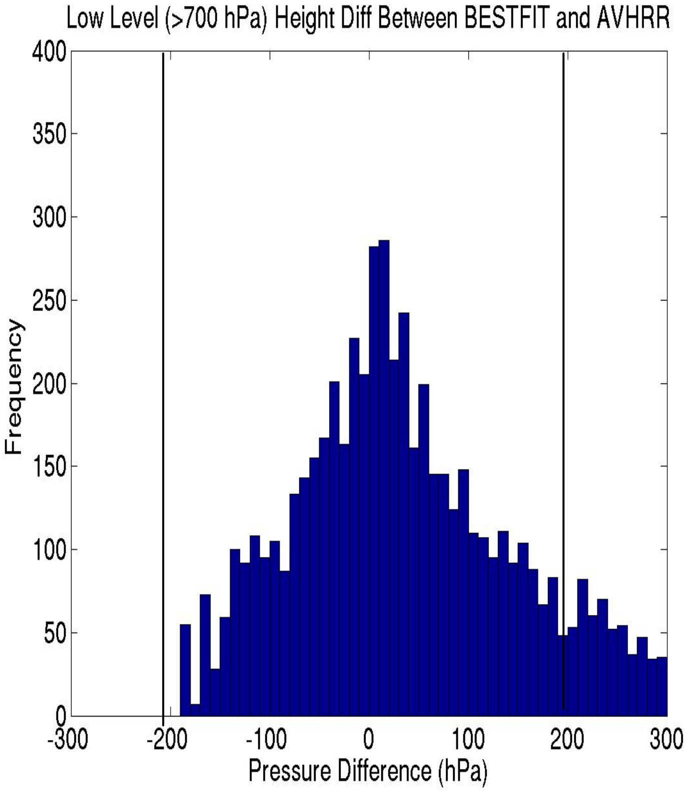
BIAS
+57.8056
RMSE
201.6313

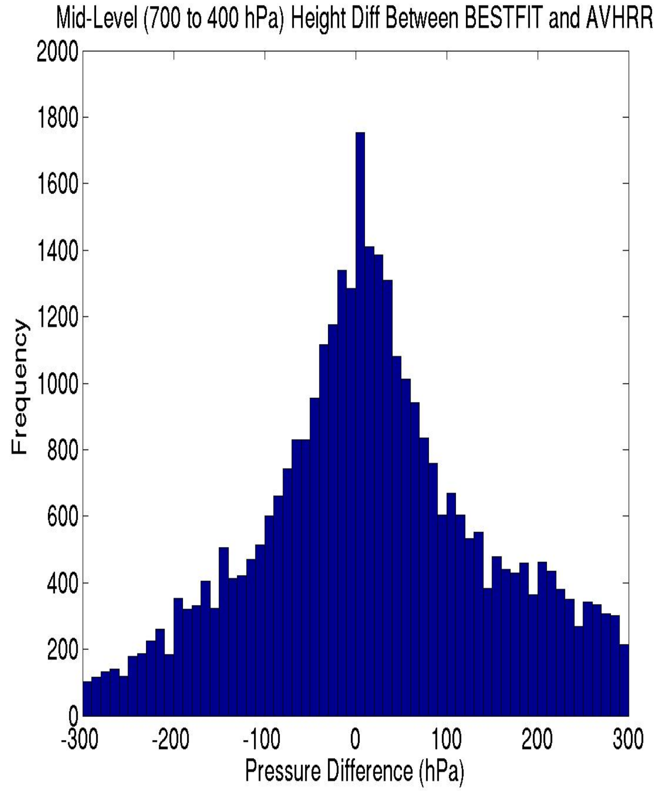
MAM

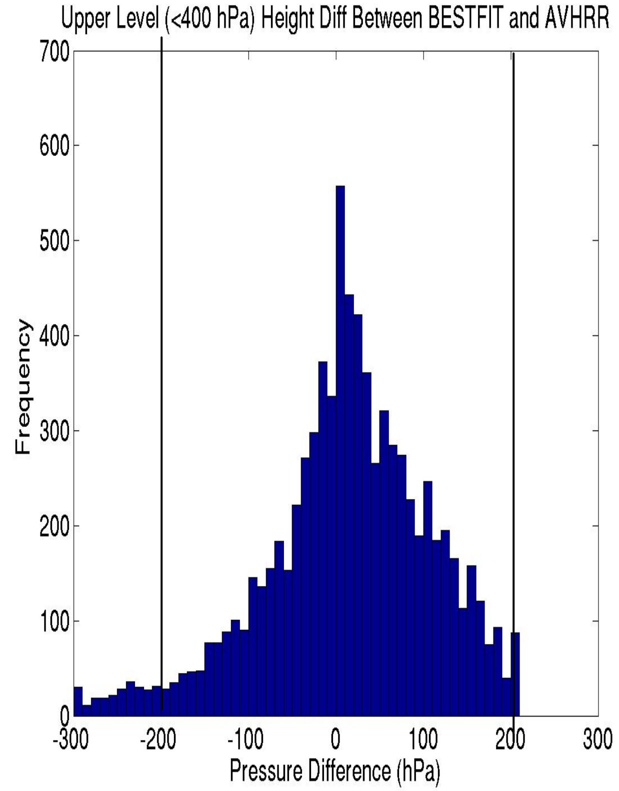
BIAS
+54.0756
RMSE
193.0507



Comparison by AVHRR Level Method # 1







Low Levels (>700 hPa)

BIAS = + 96.50
200hPaRangeBias = + 12.50
RMSE = 207.77

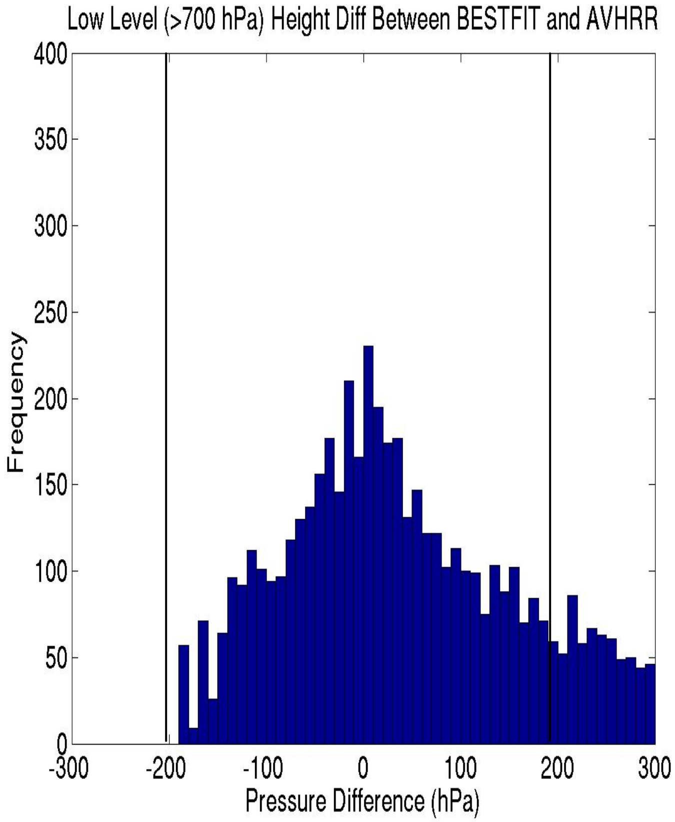
Mid-Levels (700-400 hPa)

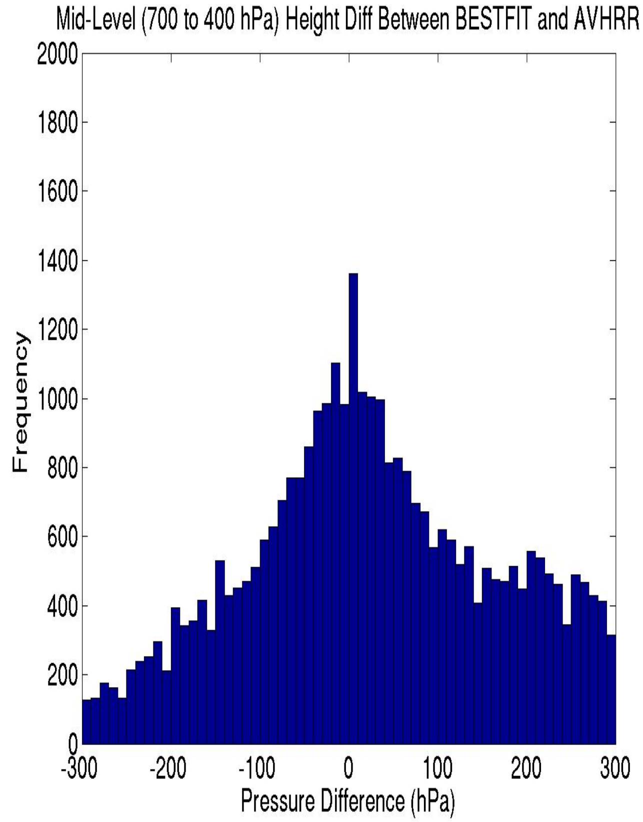
BIAS = + 29.84
RMSE = 161.31

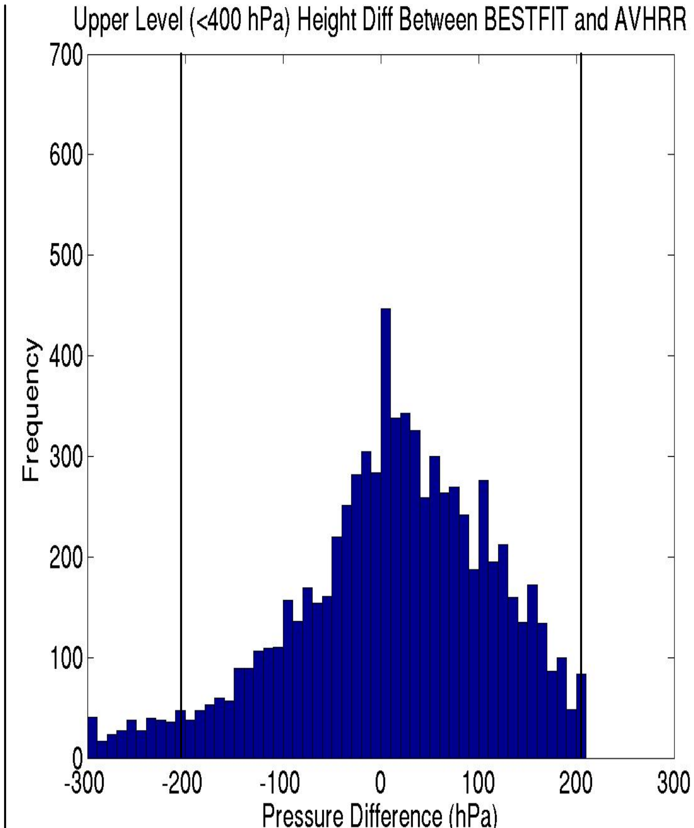
Upper Levels (<400 hPa)

BIAS = -2.69
200hPaRangeBias = + 20.51
RMSE = 122.08

Comparison by AVHRR Level Method # 2







<u>Low Levels (>700 hPa)</u>

BIAS = + 140.35
200hPaRangeBias = + 9.71
RMSE = 258.63

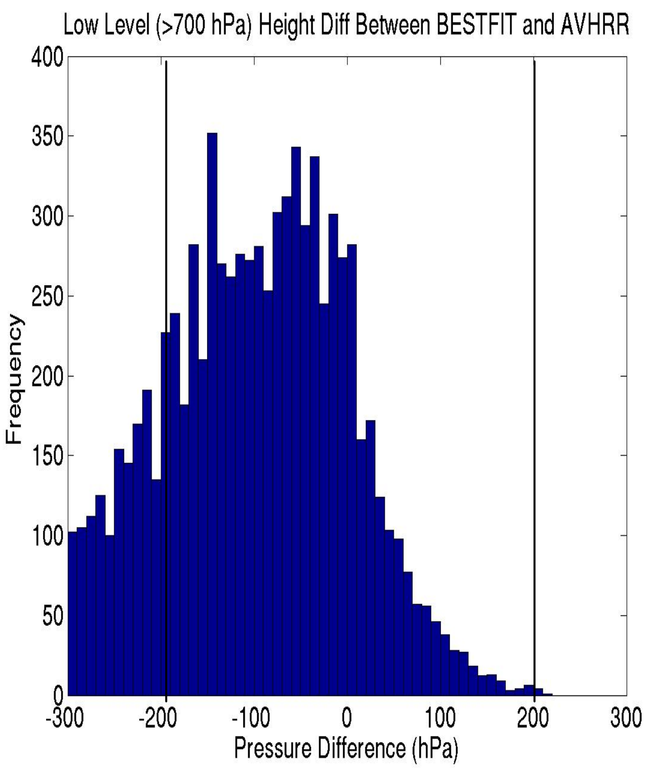
<u>Mid-Levels (700-400 hPa)</u>

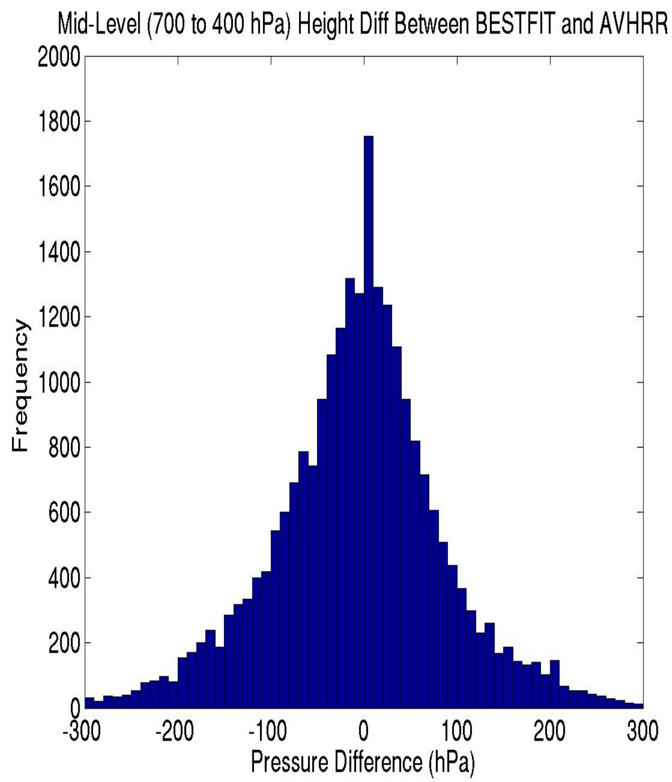
BIAS = + 46.05
RMSE = 188.01

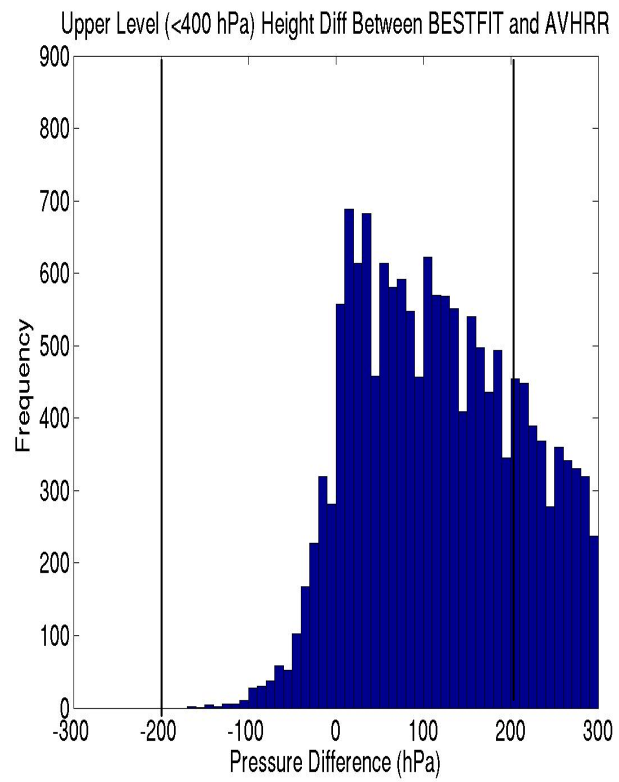
<u>Upper Levels (<400 hPa)</u>

BIAS = - 15.05
200hPaRangeBias = + 20.42
RMSE = 142.93

Comparison by Bestfit Level Method # 1







<u>Low Levels (>700 hPa)</u>

BIAS = - 127.35
200hPaRangeBias = - 66.58
RMSE = 180.65

<u>Mid-Levels (700-400 hPa)</u>

BIAS = - 8.61
RMSE = 92.19

<u>Upper Levels (<400 hPa)</u>

BIAS = + 164.47
200hPaRangeBias = + 78.88
RMSE = 215.56

Bestfit Based Height Seasonal Level Comparison

Low (>700 hPa)	BIAS	RMSE
DJF	**- 82.36**	**225.91**
MAM	- 69.96	**163.00**
JJA	**- 59.03**	165.86
SON	- 62.65	168.90
Middle (400-700 hPa)		
DJF	**- 34.05**	103.56
MAM	**- 2.97**	**95.31**
JJA	- 5.88	**115.59**
SON	- 5.85	103.31
High (< 400 hPa)		
DJF	+ 47.64	**154.58**
MAM	**+ 54.25**	**205.58**
JJA	**+ 46.99**	185.23
SON	+ 50.61	189.85