Trip Report: McMurdo Station, Antarctica
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1. Introduction

I arrived at the United States Antarctic Program's (USAP) McMurdo Station on a C-17 via Christchurch, New Zealand on 30 November 2006. My research work was done at the McMurdo weather office ("MacWeather"), which supports all airborne operations in and out of all McMurdo area runways, undertakes station surface and upper air observations, and provides support for field operations throughout the continent. Further details regarding MacWeather can be found in trip reports by A. Monaghan (2001) and R. Fogt (2003), http://polarmet.mps.ohio-state.edu/PolarMet/events.html. The Antarctic Mesoscale Prediction System (AMPS, Powers et al. 2003) is an experimental, real-time mesoscale forecast system utilizing MM5 (Grell et al. 1995) in support of USAP operations in Antarctica. The field visit was in support of AMPS, in order to both assess the performance of AMPS during the current field season and to obtain ideas for improvement from the forecasters. AMPS is in the process of transitioning from MM5 to the Weather Research and Forecasting model (WRF, Skamarock et al. 2005), so feedback was also requested from the forecasters regarding the performance of the AMPS WRF product under development. Unfortunately, due to continual bandwidth issues at

McMurdo, the WRF forecast is not downloaded like the MM5 forecast is, so WRF has received little attention from the forecasters. A project to evaluate the performance of AMPS parameters involved in the production of Terminal Aerodrome Forecasts (TAF) for McMurdo area runways was proposed prior to the trip, and data was collected in support of this project. Finally, being my first visit to McMurdo and to Antarctica, the trip provided beneficial exposure to the challenges faced in forecasting for McMurdo and the Antarctic continent in general.

During my stay, weather conditions were generally fair and the region was under the influence of weak flow. Except for delaying my arrival by several hours, the weather at McMurdo had literally no influence on operations during my three-week stay. The favorable weather was appreciated by operations personnel and by the general population of the base, however it resulted in continual frustration for the forecasters. As stated by forecasters and in trip reports by R. Fogt (2005 and 2006), AMPS often lacks skill during weak flow. Therefore, the trip provided an opportunity to further analyze AMPS performance during difficult weak-flow conditions. Following a discussion of forecaster feedback regarding AMPS, several case studies are presented that illustrate the difficulties for AMPS during weak flow. Further discussion of the TAF verification project follows, prior to a summary.

2. General Feedback on AMPS

a. Model Performance

Forecasters note that during the current field season, AMPS has performed with high skill in representing synoptic scale systems, which are typically analyzed on the 20-km resolution Ross-Beardmore grid. As a quick verification, forecasters typically compare the 300-hPa relative vorticity plot, along with the 850-hPa geopotential height plot if necessary, to the infrared (IR) imagery in a similar geographic orientation as the Ross-Beardmore grid. Co-location of features indicates rough agreement between the model and reality, and on the synoptic-scale AMPS verified well during the span of my visit. A common issue with the Ross-Beardmore grid forecast is that AMPS continually pushes weather events back in time each forecast. According to the forecasters and also noted during my visit, after 3-4 forecast cycles, if the weather event still exists within 48 hours forecast time, the model tends to be correct. This postponement of weather systems is not seen as a major problem, as the model still provides ample warning time for legitimate weather systems. Forecasts beyond 72 hours are regarded as unreliable and are rarely analyzed.

AMPS continues to have difficulty representing mesoscale and microscale features impacting McMurdo, which are generally associated with a broad-scale region of high pressure over the Ross Ice Shelf and weak flow. During these events, AMPS typically overforecasts low-level moisture (represented by relative humidity at 925 hPa and/or 1 km), especially after 24 hours forecast time on the 6.7 km Western Ross Sea and

2.2 Ross Island grids. Some of the excess moisture results from the model initialization, as AMPS would often begin with a pocket of high low-level relative humidity north of Ross Island, and local circulations would advect the moisture around Ross Island and intensify it as it crossed the sea ice boundary over McMurdo Sound. If this pocket of moisture does not exist in reality, the forecast ends up being erroneous. On the larger spatial scale, there is question as to the validity of the model representation of upper level conditions over the plateau, west of McMurdo. During weak flow there is often a persistent upper-level low-pressure system over the plateau that results in off-continent flow at upper levels over McMurdo. One of the forecasters, Al Hay, noted that AMPS has had problems representing this flow regime. Off-continent flow tends to result in dry mid- and upper levels, but the associated cyclonic vorticity advection and regions of upper level divergence cause enough instability to prevent the formation of a capping inversion necessary for low clouds and fog. AMPS, whether not correctly capturing the orientation of an upper level low pressure system or not accurately representing upper level divergence, tends to maintain low-level stability that leads to forecasts of erroneously low cloud ceilings. If the region was instead influenced by an upper-level high-pressure system over the interior, AMPS did better in representing the resulting fair conditions associated with subsidence. However, small errors in the location or orientation of the upper-level anti-cyclone when a low-level cyclone was skirting the area to the east lead to tenuous conditions, as small-scale effects have the potential to impact operations.

b. Suggestions for improvements

The following are questions and ideas for improvement taken during my visit:

- On the meteograms, does the wind chill product use the new formula?
- A product showing at what vertical level(s) clouds are forming
    - Based on the relative humidity needed to form clouds at a particular level
    - Could be a compliment or an add-on to the cloud ceiling or pseudo-satellite products
- There are no meteograms for McMurdo area sites for the 6.7 or 2.2 km grids in AMPS WRF
- A product showing divergence and/or vertical motion at 300 hPa
    - Would provide for more efficient analysis than interpreting the effects of certain patterns of relative vorticity and upper level flow
    - An option for displaying streamlines at 300 hPa is also desired, to better identify confluence/difluence aloft.

3. Specific Events

a. December 13th Erebus Winds Event

The 0000 UTC 12 December AMPS forecast predicts low clouds at McMurdo beginning around 0000 UTC 13 December. The forecast indicates a mesoscale high pressure region forming northeast of Ross Island after 1500 UTC 12 December, which forms as a result of weak off-continent flow south of Minna Bluff and the deflection of that flow around the east side of Ross Island, along with easterly flow on the southern boundary of a mesoscale cyclone located near Cape Washington. The resulting northerly flow down McMurdo Sound brings low-level moisture into McMurdo (Fig. 1). The 1200 UTC 12 December AMPS forecast has a similar synoptic-scale structure as the previous forecast, but features less low-level moisture pushing into McMurdo from the north, as the low-level anticyclone does not become organized and bring substantial low-level moisture into McMurdo until about 1200 UTC 13 December.

IR imagery indicates a region of disorganized anticyclonic flow north of Ross Island late on the 12th, and scattered low cloud being advected down McMurdo Sound. The anticyclonic rotation of clouds is not evident early on the 13th, however cloud is still being advected southward into the McMurdo area. Imagery from 0852 UTC 13 December (Fig. 2) shows scattered cloud throughout the region, with a gap in cloud cover over McMurdo. A bank of low clouds frequently pushes southward along the western coast of Ross Island, but never reaches McMurdo. Williams Field observations indicate a ceiling at 2500 ft from 1640 UTC 12 December until 1040 UTC 13 December. However, during the same time period cloud ceiling observations at McMurdo never fall below 12,000 ft. AMPS does not resolve the distinction in ceilings between McMurdo and Williams Field; if anything it indicates lower ceilings at McMurdo, as it is less sheltered from flow down McMurdo Sound.

Overall, the 0000 UTC 12 December AMPS forecast overestimates the amount of low-level moisture for this event. The 2500 ft ceilings at Williams Field have little impact on operations, and the 1000 ft ceilings that AMPS predict during several hours of the model run never materialize. The 1200 UTC 12 December AMPS forecast fares better, as it predicts higher ceilings that are more in line with observations, at least for Williams Field. The difference in ceiling height between McMurdo and Williams Field is due to “Erebus Winds.” This wind regime appears to be similar to glacier winds, as weak flow in the lower troposphere near Mt. Erebus leads to radiational cooling when air remains in contact with the snow-covered terrain. The 0000 UTC 13 December McMurdo sounding (Fig. 3) indicates an inversion present near 1500 ft, and weak flow between the surface and 500 hPa, indicating radiational cooling and a subsidence inversion. Easterly winds above 10 kts and a temperature decrease at the surface accompany these events, and these effects are more prominent at McMurdo compared with Williams Field for this event. The 2.2-km AMPS meteograms for McMurdo from both forecasts do not show the weak flow in the lower troposphere or the low-level inversion, both of which are on the sounding. AMPS does not resolve the Erebus Winds for this case, and further study is needed to both identify the physical processes involved in production of this wind regime, along with determining the rate of success AMPS has in forecasting such events.

b. December 15th AMPS low cloud forecast bust

The AMPS 2.2-km and 6.7-km resolution forecasts initialized at 1200 UTC 14 December indicate low-level moisture being advected southward towards McMurdo between 1800 UTC 15 May and 0000 UTC 16 May. The corresponding AMPS cloud ceiling forecasts indicate ceilings as low as 1000 ft during the previously indicated time period. The 20-km resolution Ross-Beardmore region AMPS forecast shows low-level moisture along the southern edge of a synoptic-scale cyclone located northwest of Cape Adare advected southward along the Transantarctic Mountains into the McMurdo area. Observations at Williams Field and McMurdo both indicate lowering ceilings after 0300 UTC 15 December, corresponding with the building of stratus clouds from the north on IR and visible satellite imagery. Taking the AMPS forecast and observations into account, the 0300 UTC 15 December TAF calls for ceilings as low as 1000 ft from about 1600 UTC until about 0000 UTC 16 December.

Beginning around 0700 UTC, satellite imagery shows clearing over McMurdo Sound, as a decaying mesoscale cyclone over the central Ross Ice Shelf and all other stray clouds push eastward. The 0800 UTC observation at Williams Field and 0900 UTC observation at McMurdo both indicate only "few" clouds and no ceilings. The 0900 UTC TAF removes any mention of lower cloud ceilings that were present in the 0300 UTC TAF, as imagery continues to show dry conditions to the north of McMurdo, past Terra Nova Bay. Dry conditions in the McMurdo area, with only few clouds, remain through 0600 UTC 16 December.

Several factors could have lead to the incorrect forecast of low-level clouds in AMPS late December 15th. Comparison of the 925-hPa relative humidity field (Fig. 4) with IR imagery (Fig. 5) shows that AMPS overestimates low-level moisture over the southern Ross Sea on the 20-km grid at 1200 UTC 15 December. AMPS also overestimates low-level moisture on the 6.7 and 2.2-km grids as moisture is advected southward into the McMurdo area. The IR imagery shows the cloud signature associated with the synoptic-scale cyclone to be tighter than the low-level moisture pattern in

AMPS. AMPS shows off-continent flow associated with an upper-level ridge, which is correct, as both the 1200 UTC 15 December McMurdo sounding and MODIS winds show off-continent flow aloft. The 300-hPa relative vorticity distribution verifies well with the imagery, indicating that AMPS likely gives a reasonable position for this upper level ridge. A different orientation or variations in intensity of the ridge are possible discrepancies between AMPS and reality. However, either factor would be difficult to determine since the upper level ridge lacks a clear signature on the imagery. Regardless, subsidence associated with the off-continent flow in AMPS does not sufficiently dry the lower troposphere. The AMPS virtual soundings for McMurdo contain inversions up to about 5° C in strength beneath 1000 ft during daytime hours between 1800 UTC 15 December and 0000 UTC 16 December (the 1800 UTC sounding is shown in Fig. 6a). The actual McMurdo sounding from 1200 UTC 15 December (Fig. 6b) indicates an inversion of about 2° C at about 2000 ft at night. Therefore, even if the low-level moisture was present, it would be unlikely to result in cloud ceilings under 1000 ft that would be debilitating to flight operations.

c. December 19th Snow Event

The 0000 UTC 18 December AMPS 6.7-km grid forecast indicates the formation of a mesoscale cyclone near Terra Nova Bay around 1500 UTC 18 December. Katabatic outflow often plays a role in the formation of mesoscale cyclones near Terra Nova Bay, but there is no evidence of outflow for this case in imagery or in the model. The mesoscale cyclone appears to form in association with a low-level ridge that extends from the Ross Sea southward across the entire Ross Ice Shelf, which induces anticyclonic flow to the east of the mesoscale cyclone, and from cyclonic vorticity advection in the upper troposphere, as the Terra Nova Bay region is located just downstream of a trough axis at 500 hPa. The weak circulation is shown at 1800 UTC 18 December in Fig. 7a. The 6.7-km 0000 UTC 18 December AMPS forecast through 1200 UTC 19 December has the mesoscale cyclone roughly maintaining its current position near the Drygalski Ice Tongue, up against the Transantarctic Mountains. Low-level moisture is advected southward along the eastern edge of the mesoscale cyclone into the northern coast of Ross Island, where it splits around the island and reaches the McMurdo area after 0600 UTC 19 December in the form of low clouds.

In the 1200 UTC 18 December forecast, AMPS has the mesoscale cyclone developing farther to the east than in the previous forecast (Fig. 7b), and has it more mobile through the rest of the forecast, but remaining north of Ross Island and west of 175° E until it gets sheared away by the end of the forecast period (0000 UTC 20 December). The eastward shift of the mesoscale cyclone between forecasts may be from a different orientation of the low-level ridge, as the anticyclonic flow in lower levels has shifted southward in the new forecast. With the more eastward location of the mesoscale cyclone, low-level moisture approaches McMurdo more from the east, around the eastern edge of Ross Island.

IR imagery indicates that a mesoscale cyclone does indeed form north of Ross Island near 170° E around 1200 UTC 18 December, which is in reasonable agreement with the 1200 UTC 18 December AMPS forecast. However, the actual mesoscale cyclone propagates southeast towards Ross Island, and is shown at 1800 UTC 18

December in Fig. 8. A cloud ceiling of 7000 ft forms at 1800 UTC 18 December at Williams Field, dropping to 1000 ft by 2100 UTC. Visibility is reduced to 500 ft at one point, and snow, blowing snow, and drifting snow are all present through 0400 UTC 19 December. Ceilings remain below 2500 ft through 1400 UTC 19 December, as the northern edge of the cyclone wraps into McMurdo after 0600 UTC 19 December, bringing in low clouds after the main snow event had ended. A C-17 training mission from Christchurch to South Pole, with refueling at McMurdo, was cancelled due to technical reasons. However, Pegasus Runway had similar conditions to Williams Field throughout the time period, and weather would have likely grounded that flight.

The AMPS 1200 UTC 18 December forecast has the overall structure of the mesoscale cyclone (size, cloud ceiling distribution) correct. However, AMPS has the cyclone remaining north of Ross Island before pulling away to the east and then south before getting sheared apart, instead of having it immediately propagate southwest towards Ross Island. The 0000 UTC 19 December forecast still has the mesoscale cyclone positioned to the north of Ross Island, despite the fact that the cyclone had been propagating southeast and was already impacting McMurdo. Initially, it was thought that the cause of the differences between the model and reality was that an upper level ridge approaching from the northwest was moving faster than the model indicated, pushing the mesocyclone south. However, the AMPS forecasts of 300 hPa relative vorticity between 1200 UTC 18 December and 0000 UTC 19 December show consistent positions of the ridge, which also verify well with the position of the ridge in the imagery. This comparison is shown for the 1800 UTC analysis time in Figs. 9a and b. Another possible cause for model error is a different orientation of the upper level trough. In AMPS, the western Ross Sea region is just downstream of the trough axis, so that any discrepancy in orientation of the trough axis could lead to a different storm track in lower levels.

4. TAF – AMPS comparison project

In order to evaluate the performance of AMPS in the production of Terminal Aerodrome Forecasts (TAF), the AMPS parameters that are used in the production of TAFs are compared with observations. The TAFs themselves are also present in the comparison for reference. The comparison is done every six hours (0000, 0600, 1200, and 1800 UTC) from 0600 UTC 4 December to 1800 UTC 20 December 2006 at Williams Field. There are 256 total forecast comparisons, as there are four forecasts for each observation time (except for the first three and last three observations). During the field visit, four of the local Saturday night TAFs (0300 and 0900 UTC 9 December and 0300 and 0900 UTC 16 December) were produced remotely in Charleston, SC, and comparisons are not done for these forecasts, leaving 240 total comparisons between TAFs and observations. The other McMurdo runways (Pegasus runway and Ice runway) only have observations when they are in operation, so only Williams Field can be used in the comparison. TAFs are produced for Williams Field and other runways in operation every six hours at 0300, 0900, 1500, and 2100 UTC. The forecasts are valid for 24 hours, and can be amended at any time. The observations are compared with the forecasted conditions for that time in the TAF and from the AMPS forecast that would be used by the forecaster in production of the TAF. "BECMG" (becoming) lines, which take into account anticipated changes during the forecast period, are included. Ceilings within

"TEMPO" (temporary) lines are also used in the comparison. The AMPS 2.2-km Ross Island grid is used. Data on cloud ceiling, wind speed, altimeter setting, and precipitation were collected. Ceiling and wind speed are straight-forward comparisons. In the TAF, the minimum altimeter setting is listed, and will not directly correspond with the altimeter reading from observations or that forecast by AMPS. Also in the TAF, quantity of precipitation is not present as in observations and AMPS. Instead, there are light, moderate, and heavy amounts of precipitation as options. AMPS has three hour accumulated precipitation, rather than an indication of instantaneous precipitation. Finally, the bases of individual cloud layers are not available in AMPS. Rather, the percentage relative humidity at 1000, 2000, and 3000 m is available, and only layers with relative humidity greater than 70% are recorded.

In the following subsections, comparisons of ceiling, wind speed, wind direction, altimeter, and precipitation will be analyzed. Comparisons of cloud cover are not done here, as a reliable comparison cannot be done with the available AMPS data. A more sophisticated scheme would be needed to facilitate a comparison.

a. Ceiling

Model cloud ceiling is determined by computing the visibility in the vertical, based on the mixing ratios of model-forecasted hydrometeors. Following Stoelinga and Warner (1999), horizontal visibility is determined by

$$\frac{I(x_{obs})}{I_0} = \exp\left[-\int_0^{x_{obs}} \beta(x)dx\right] \quad (1)$$

where I_0 is the illuminance of the object, $I(x_{obs})$ is the illuminance that reaches an observer at distance x, and β is an extinction coefficient. Mass concentrations of cloud water, cloud ice, rain, and snow are determined by the model, and related to β through observed and derived relationships. Hydrometeors are assumed to be all liquid if temperature $T > 0$, and all frozen if $T < 0$ Discernment of the object is taken to be lost when the LHS of (1) falls below 0.02. In the vertical, the ceiling height is often greater than the distance between model levels, so that β is integrated with height to get ceiling z_{clg}

$$-\ln(0.02) = \int_0^{z_{c\lg}} \beta(z)dz \tag{2}$$

Table 1 shows a comparison of TAF and AMPS forecasts for cloud ceiling with observations. When there is a ceiling present in observations, there are far less forecasts of "no ceiling" conditions in TAFs compared to AMPS. The disparity between TAFs and AMPS is surprising, considering that the impression gathered during the study period was that AMPS was overestimating low-level moisture. For the total study period, AMPS only has 36 out of 256 forecasts with ceilings, compared to 135 out of 240 for TAFs and 124 out of 256 for observations. The excessive low-level moisture located over McMurdo Sound for many AMPS forecasts is either not progressing far enough southward to Williams Field, or cloud ceilings are not being generated correctly. For events when there is no ceiling in observations, AMPS actually fares better than TAFs. However, the greater number of ceilings in TAFs is likely due to the necessity of alerting pilots and other forecasters to the chance of inclement weather that may be represented in the model, yet is uncertain due to being late in the forecast period or contradicted by imagery and/or observations. Still, only 25% of observed no-ceiling conditions are forecasted as ceiling events, and with the difficult runway conditions of the region, the policy is to be proactive and cautious. The rate of success for TAFs and AMPS, calculated as the total number of forecasts where a ceiling or non-ceiling event is correctly forecasted, is 82% and 63%, respectively. When TAFs or AMPS have a ceiling forecasted, and observations also indicate a ceiling, both forecasts featured biases towards lower ceilings. The average magnitudes of the biases were large and similar to each other (around 5600 ft).

Table 2 shows contingency tables for TAFs and AMPS as in Table 1, but for the forecast periods 12-36 hours, every 6 hours. Figure 10 shows the rate of success in identifying ceiling or non-ceiling events by forecast hour, in order to assess the change in forecast skill with time. From Table 2 and Fig. 10 it can be shown that TAFs outperform AMPS in forecast skill throughout the time period, especially in forecasting ceiling events, as mentioned previously. TAF forecast skill drops off after 18 hours. The cyclical pattern of AMPS forecast skill in Fig. 10 is peculiar. It appears to result from the greater amount of observations with ceilings in 18 and 30-hour forecasts compared to the other forecast times. A longer study period would be required in order to better gauge the change in forecast skill with time in AMPS.

Overall, TAFs have 44 out of 240 forecasts with ceilings at or under 3000 ft, whereas AMPS only has 9 out of 256. There are 36 forecasts done for TAFs and AMPS for observed ceilings at or under 3000 ft. For those forecasts, TAFs have 15 of them at 3000 ft ceilings or below, whereas AMPS only has 4. These forecasts can be separated into four events in order to better understand the context of the forecasts, starting with events with lowest ceilings. Sixteen of the first twenty forecasts involve all of the forecasts for the December 19th snow event, when ceilings ranged between 1200 ft and 2300 ft. For this case, TAFs do not forecast the proper low ceilings until 6-12 hours before the respective observation time. However, this is reasonable and provides ample warning for the adjustment of flight operations, if needed. The duration of the event was underestimated, as the forecasts do not predict lower ceilings past 1800 UTC 19 December until the 1500 UTC 19 December forecast. The AMPS ceiling forecasts fared much worse, as they do not forecast any ceilings below 10,000 ft until the 0000 UTC 19 December forecast predicts 1000 ft ceilings by 1800 UTC 19 December. A 2000 ft ceiling event at 1800 UTC 13 December has the TAF predict ceilings of 2000 ft or 2500 ft for three of the four forecasts, while AMPS does not have a ceiling for any of them. The event between 1800 UTC 12 December and 0600 UTC 13 December with 2500 ft ceilings features mixed results for TAFs, as the 2100 UTC 11 December and 0300 UTC 12 December TAFs correctly have ceilings under 2500 ft, while the 0900 UTC 12 December and 1500 UTC 12 December TAFs do not. The 0000 UTC 12 December AMPS forecast for 0000 UTC 13 December has ceilings at 3000 ft, but otherwise AMPS misses the event. Finally, the dissipating 0600 UTC 15 December event with 3000 ft ceilings has TAFs correct for two of the four forecasts, whereas AMPS has no ceilings.

b. Wind speed

Table 3 shows the mean values and standard deviations for observed, TAF, and AMPS wind speeds, along with biases and root mean square error (RMSE) values for TAFs and AMPS. Surface wind speed in TAFs correspond with surface observations, whereas AMPS surface wind speed values are taken from the lowest half-sigma level (about 14 m AGL). The average wind speed from the TAFs is over 1 kt higher than both AMPS and observations. Again, this may result from the cautionary strategy used in the production of TAFs. The standard deviation is lower for TAFs than for AMPS and for observations, likely because of the longer time span of TAFs compared to AMPS and observations, along with the degree of persistence in forecasts, especially during fair weather. The standard deviation of AMPS wind speeds is over 1 kt higher than observations, indicating that the forecasts may fluctuate too much. Biases are slightly larger for TAFs than AMPS, with both being positive. The RMSE values are indicative of random errors for both TAFs and AMPS, which is expected for wind speed forecasts, especially under weak flow, as was the case for most of the study period.

In order to understand the change in forecast skill with time, wind speed biases and RMSE values for TAFs and AMPS are shown in Fig. 11. TAFs show consistently small positive wind speed biases, while AMPS feature variable biases that are largest at 24 hours, and that are near zero at 30 and 36 hours. The RMSE values again indicate random errors, and consistently of larger magnitude for AMPS than for TAFs. For a better look at forecast dependence on wind speed, Table 4 shows statistics for wind speed at or below 10 kts (low) and above 10 kts (high). Of interest in these tables is the overestimation of wind speed for the low regime and the underestimation of wind speed in the high regime for both TAF and AMPS. Also, for the high regime, the errors become more systematic for both TAF and AMPS than for the low regime, which is expected, due to the chaotic nature of weak flow.

c. Wind Direction

Table 5 shows statistics for wind direction for TAF and AMPS. Wind direction differences crossing 360° / 0° have been accounted for. TAFs have a northerly wind direction bias, whereas AMPS has a southerly direction bias off of the general easterly observed wind direction. The standard deviation is too low for TAFs, and likely results from the degree of persistence in TAFs. The RMSE values for TAFs and AMPS reflects a shift in several wind direction categories from observations (for example, an easterly observed wind would get shifted to northeasterly in TAFs, and almost to south-southeasterly in AMPS). However, wind direction is a variable field, so the fact that TAFs and AMPS are generally getting the correct compass direction (N, S, E, W) is adequate.

Figure 12 shows the wind direction bias and RMSE values based on forecast hour. TAF bias and RMSE values are consistently smaller than AMPS values. Both bias and RMSE values for AMPS decrease in magnitude with time after 18 hours, with wind direction errors becoming more random by 36 hours.

d. Altimeter

The altimeter setting is used to calibrate the altimeter in aircraft, displaying pressure read from a barometer aboard the aircraft as altitude. TAFs use QNH, which refers to an altimeter setting that reads altitude above mean sea level (differing from QFE, which reads altitude above a specific aerodrome). Table 6 shows the mean values and standard deviations for observed, TAF, and AMPS altimeter setting, along with biases and RMSE values for TAFs and AMPS. The lower average TAF altimeter is a result of the fact that minimum altimeter setting is used. The larger standard deviation is likely caused by different methods for determining a minimum altimeter by different forecasters. AMPS has a slightly higher average altimeter setting than observations, but a very agreeable standard deviation. The larger RMSE in TAFs compared to AMPS is again likely related to differences in estimation of altimeter setting between forecasts, resulting in random errors. Fig. 13 shows the altimeter bias and RMSE values for TAFs and AMPS based on forecast hour. With time, TAF errors become more random, while AMPS forecast skill actually improves between 24 hours and 36 hours.

e. Precipitation

For the twenty forecasts during observed snow conditions (all “-SN”), TAFs have either “vicinity snow” (VCSN) or “light snow” (–SN) for fourteen of the forecasts. Of the 220 remaining forecasts, TAFs only gives false predictions of snow for 32 of them. This again shows that TAFs are being constructed with caution in mind, yet remain objective and useful by not constantly predicting weather when none occurs. There were 4 fog forecasts during the period, all “shallow fog” (MIFG), and TAFs correctly identify 2 of the 4 with “vicinity fog” (VCFG). Of the remaining 236 forecasts, there are only 4 false fog forecasts. Comparison of AMPS forecasts is not as straightforward, as there is no “instantaneous” precipitation field in AMPS. Instead, there is an accumulated precipitation field, being of 3-hour duration for the text forecasts. Using the accumulated precipitation from the past three hours as a rough comparison to observations, AMPS identifies 5 of the 20 precipitation events, while only having 20 false snow forecasts in the remaining 236 forecasts.

5. Summary

The 2006-2007 field visit was another beneficial endeavor for Ohio State and the AMPS project. Even though feedback could not be obtained for AMPS WRF, the visit provided beneficial interaction with forecasters that will result in improvements for the AMPS program. The weak flow and overall fair conditions during the visit did not allow for the analysis of model performance during weather that has effect on flight operations. The lack of any coherent weather patterns was frustrating for myself and especially the forecasters. However, the weak conditions provided an opportunity to analyze AMPS performance during what is already known as difficult circumstances for the model. There are no direct solutions to the model’s problems during weak flow, however clues were obtained as to some causes of the problems. It appears that slight inaccuracies in position or orientation of synoptic-scale weather systems in the upper levels over the interior plateau can cause varying storm tracks and vertical stability that have the potential to greatly influence weather in the McMurdo area. More specifically, during weak flow conditions, the common synoptic setup for the region is an upper level low pressure system over the interior, west of McMurdo, and weak high pressure over the Ross Ice Shelf and southern Ross Sea. Changes in location or orientation of these weather systems allows for enhanced upper level divergence, causes the fringe of a synoptic-scale cyclone to impact McMurdo, or allows for mesoscale cyclones to propagate to McMurdo, among other scenarios. To this end, more observations over the continental interior and Ross Sea may improve model representation of weak flow more than further increases in model resolution. Continued improvements of data assimilation in AMPS, especially over the continental interior, should aid forecast skill as well.

The TAF-AMPS comparison project, which compares forecasts for selected variables in TAFs and AMPS to observations at Williams Field, provides insight into the behavior of the AMPS cloud ceiling product. The general consensus during the field visit was that AMPS was overestimating moisture, especially at low-levels, in the McMurdo area. However, during the study period it is found that AMPS has forecasts with cloud ceilings about a quarter of the time that TAFs and observations have ceilings, with a similar ratio compared to TAFs when ceilings are 3000 ft or lower. Further study would be needed to better understand issues associated with AMPS cloud ceiling, and a more sophisticated and detailed study would be needed to provide a more robust validation of the selected forecast fields. Additionally, modifications to the calculation of cloud ceiling, whether through use of different relationships between mass concentrations of each type of hydrometeor and extinction coefficient, and/or assumptions of the state of hydrometeors (liquid or frozen), may improve cloud ceiling forecasts. Additional experiments would be needed to determine the impact of such changes to model calculations.

Regardless, this study shows that McMurdo forecasters bring additional and necessary skill into aviation forecasts. The additional forecast skill is most apparent with the cloud ceiling forecasts, as forecast accuracy increases by almost 20% when forecasters are involved.

Finally, the visit proved beneficial for my own professional development, allowing me to gain valuable exposure to the challenges facing weather forecasting and flight operations in McMurdo and Antarctica in general. Also, others in the Polar Meteorology Group and myself have worked extensively on a case study of the May 2004 windstorm that caused severe damage to McMurdo (Steinhoff et al. 2007), a storm that is still talked about by forecasters and others at McMurdo. Getting to see first-hand the locations and patterns of damage, along with a better perspective of the local geography, will benefit this project, even as it approaches its completion.

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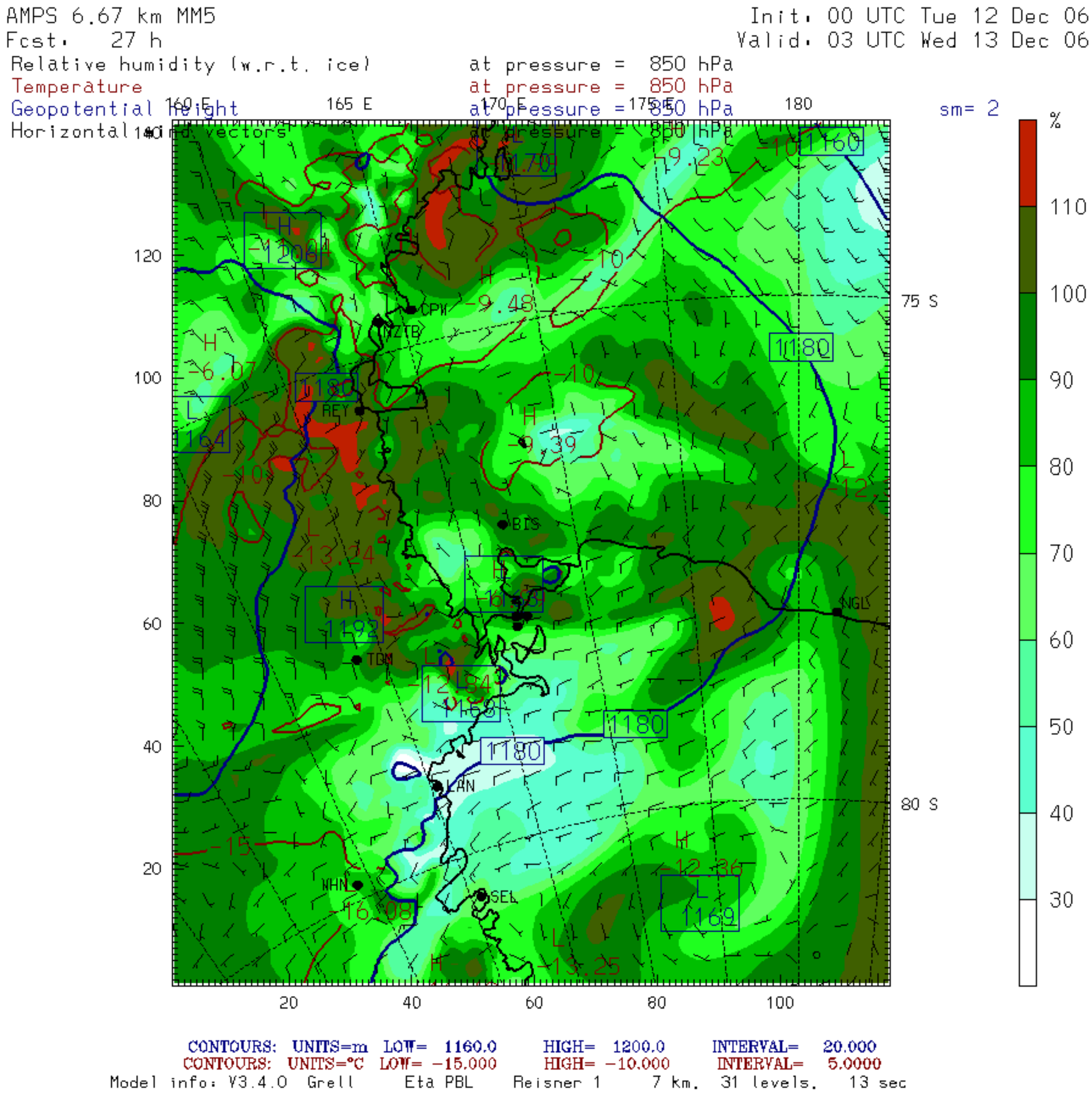


Figure 1. 6.7-km AMPS 850 hPa relative humidity with respect to ice (shaded), temperature (red contours), geopotential height (blue contours), and wind barbs at 0300 UTC 13 December 2006 from 0000 UTC 12 December 2006 forecast.

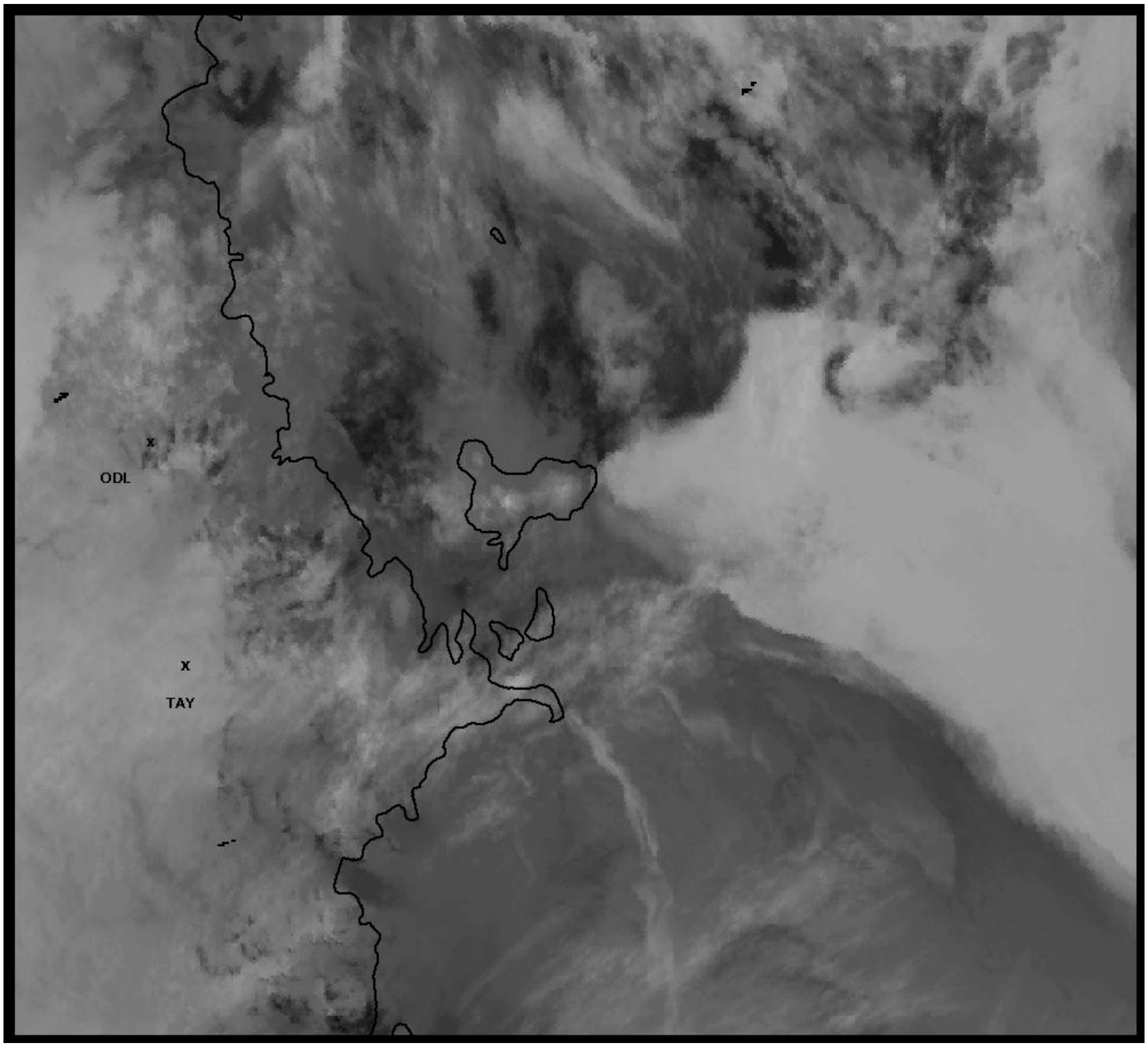


Figure 2. Infrared imagery taken 0852 UTC 13 December 2006.

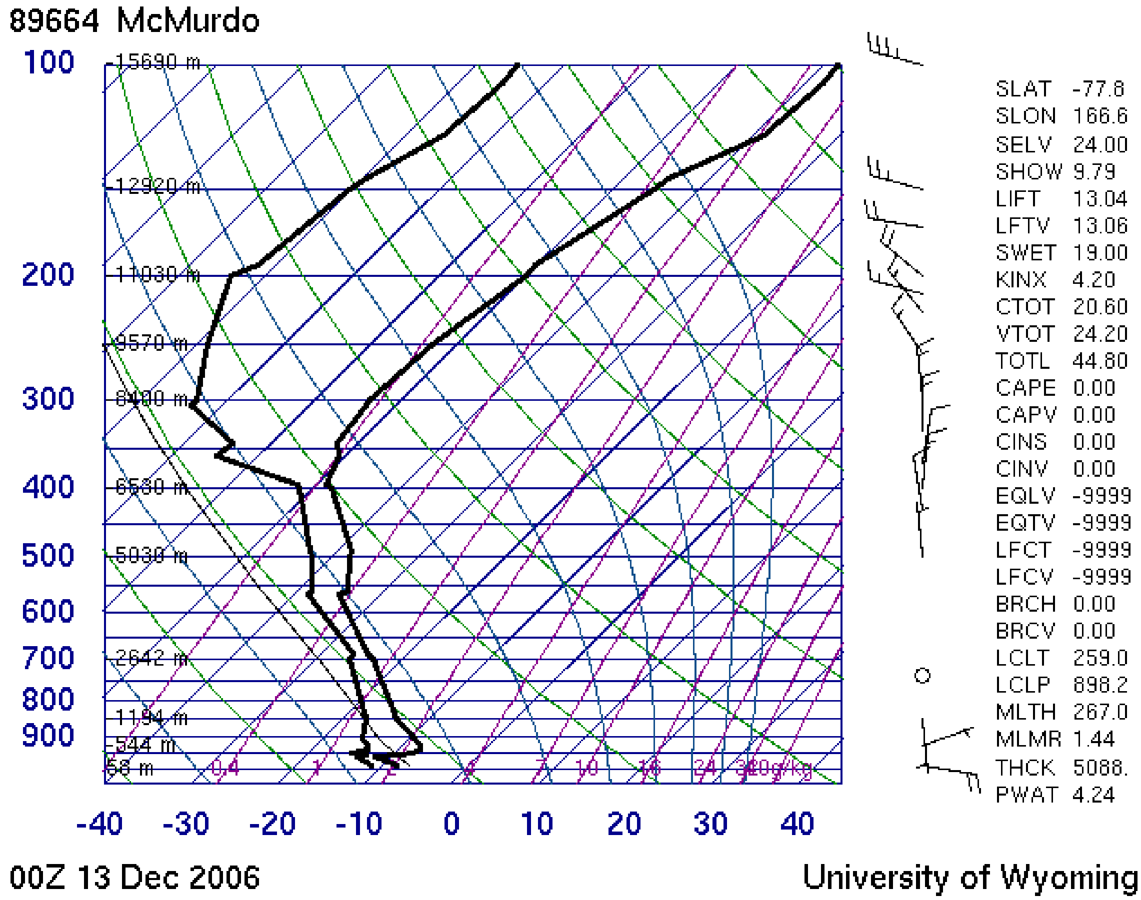


Figure 3. 0000 UTC 13 December 2006 McMurdo sounding.

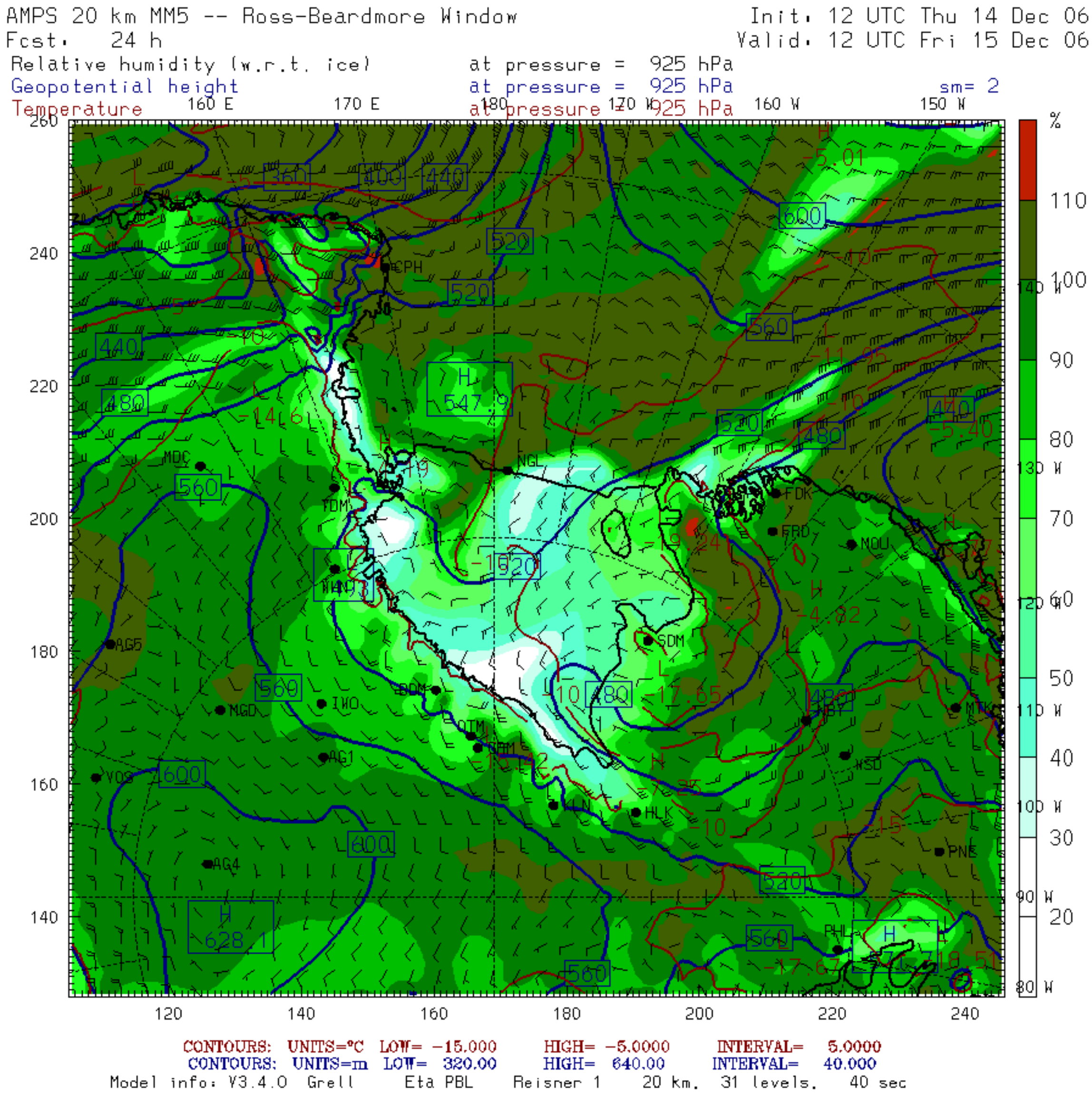


Figure 4. 20-km AMPS 925-hPa relative humidity (shaded), temperature (red contours), geopotential height (blue contours), and wind barbs at 1200 UTC 15 December 2006 from 1200 UTC 14 December 2006 forecast.

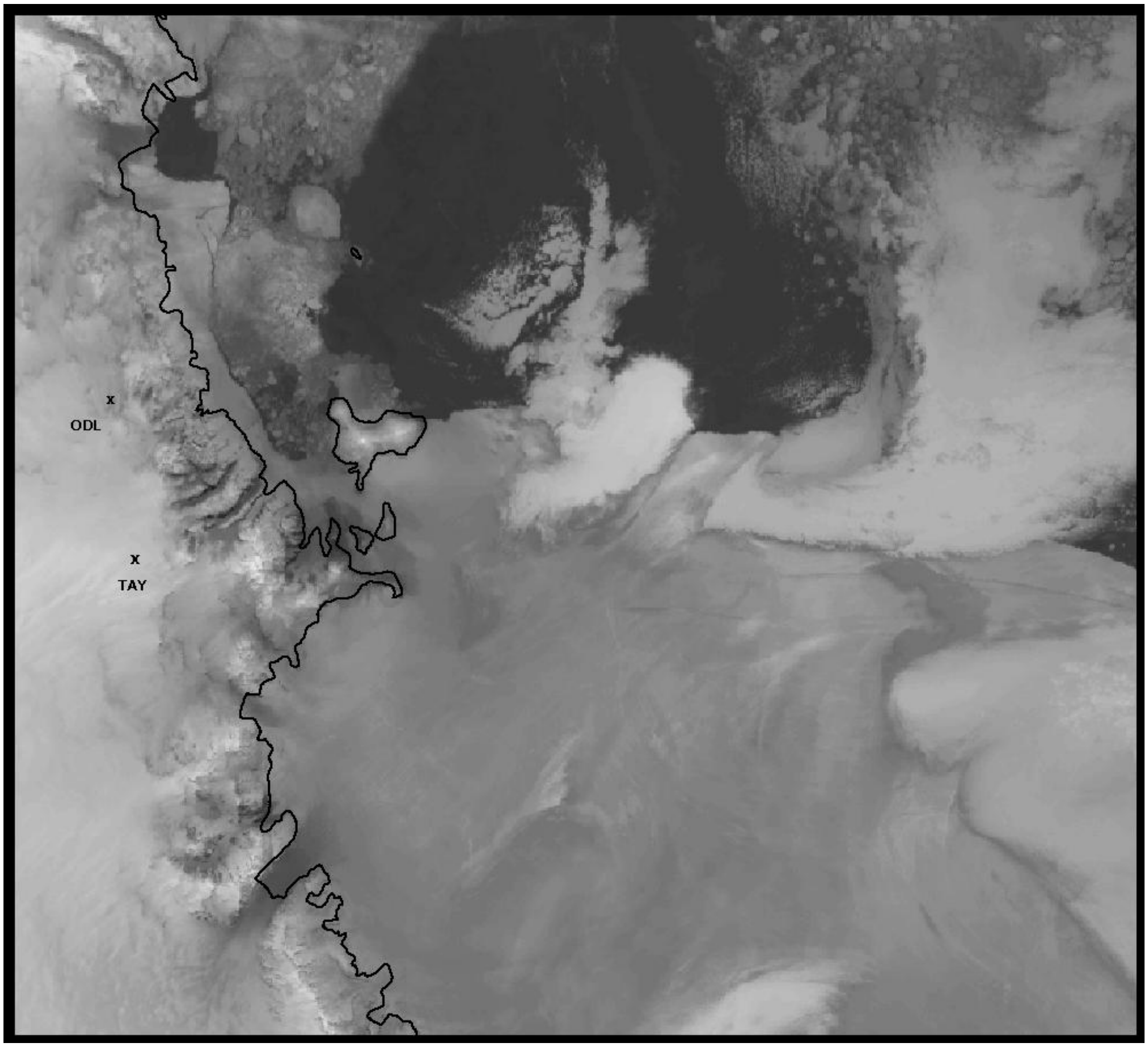


Figure 5. Infrared imagery from 1144 UTC 15 December 2006.

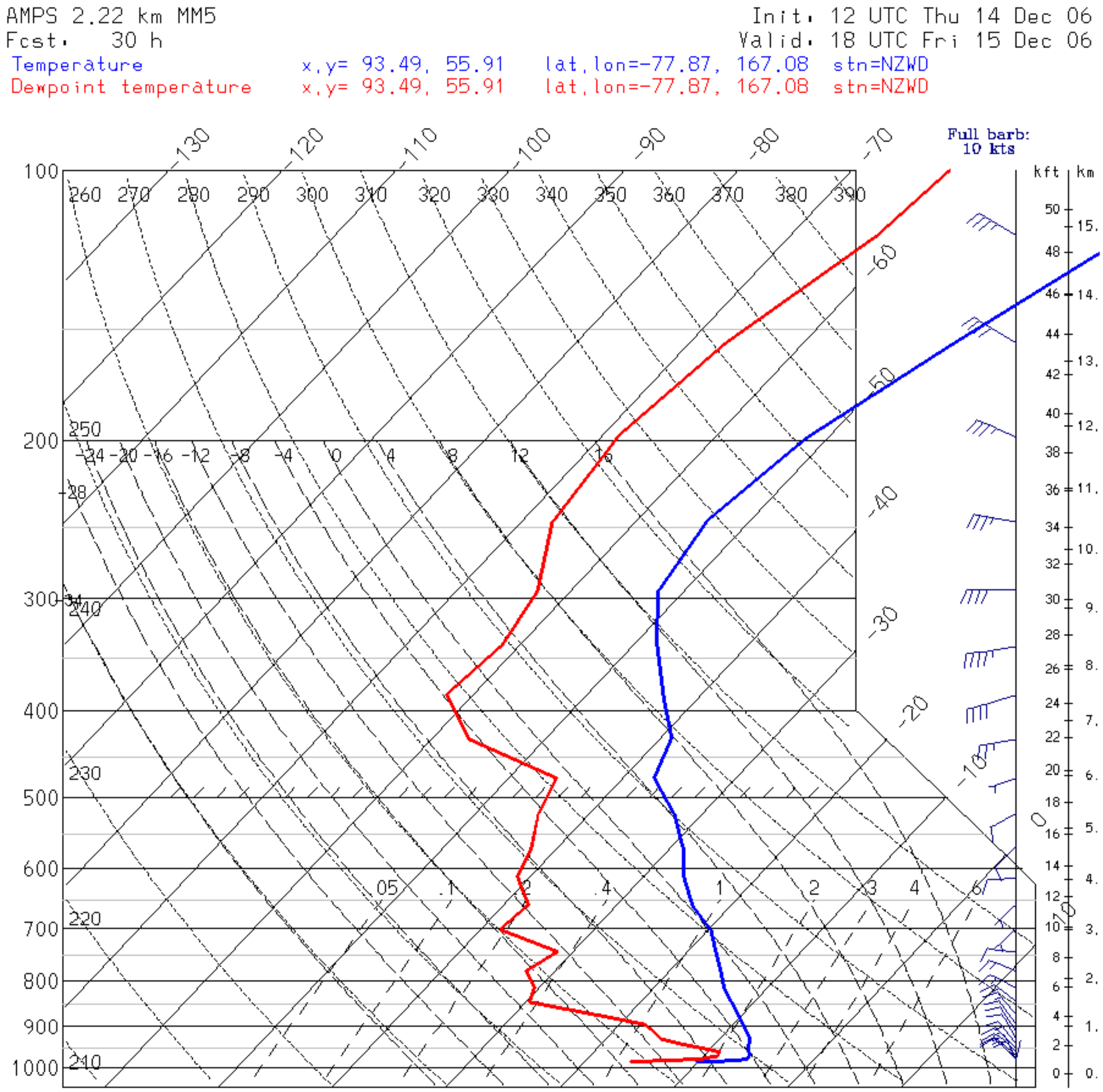
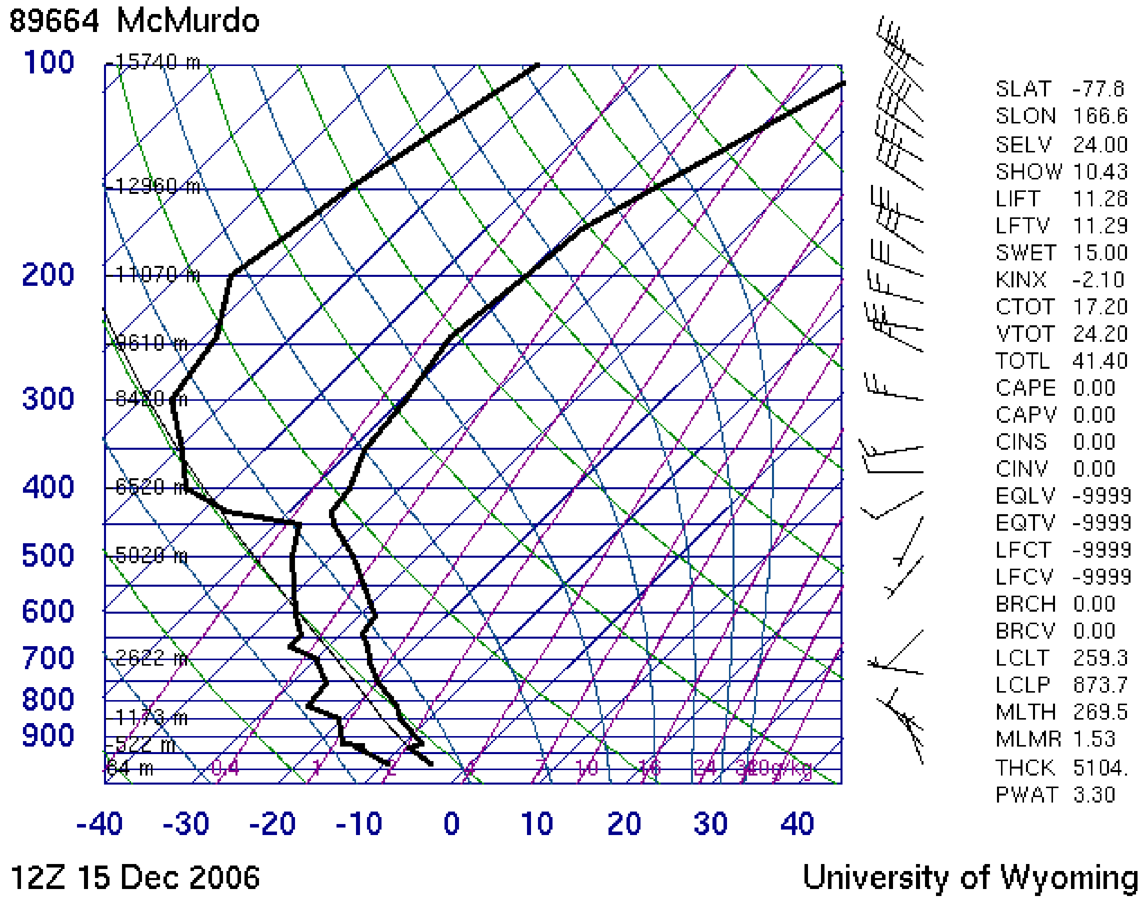


Figure 6. (a) AMPS virtual sounding for 1800 UTC 15 December 2006 for Williams Field from 1200 UTC 14 December forecast.



(b) 1200 UTC 15 December McMurdo sounding.

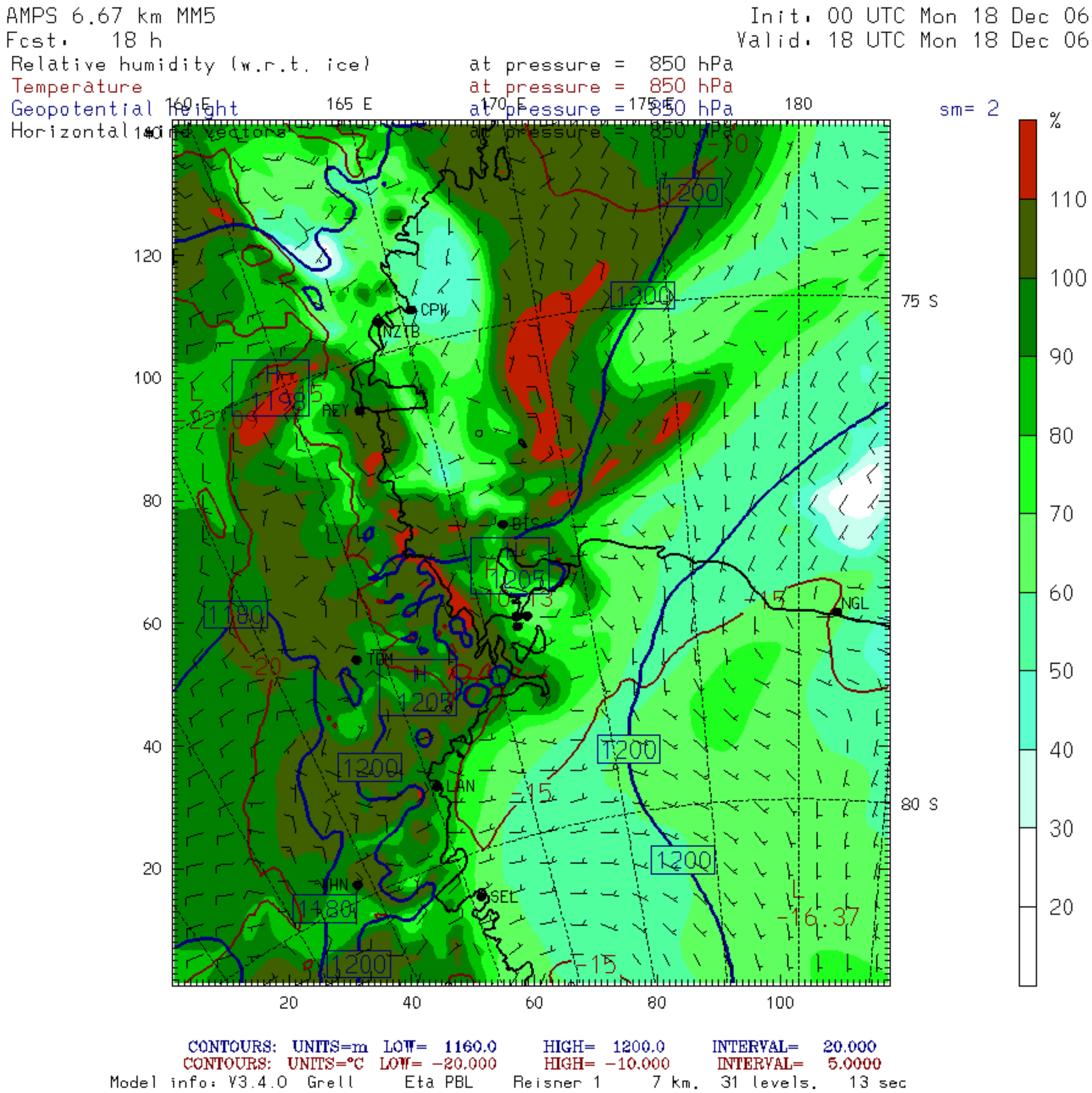
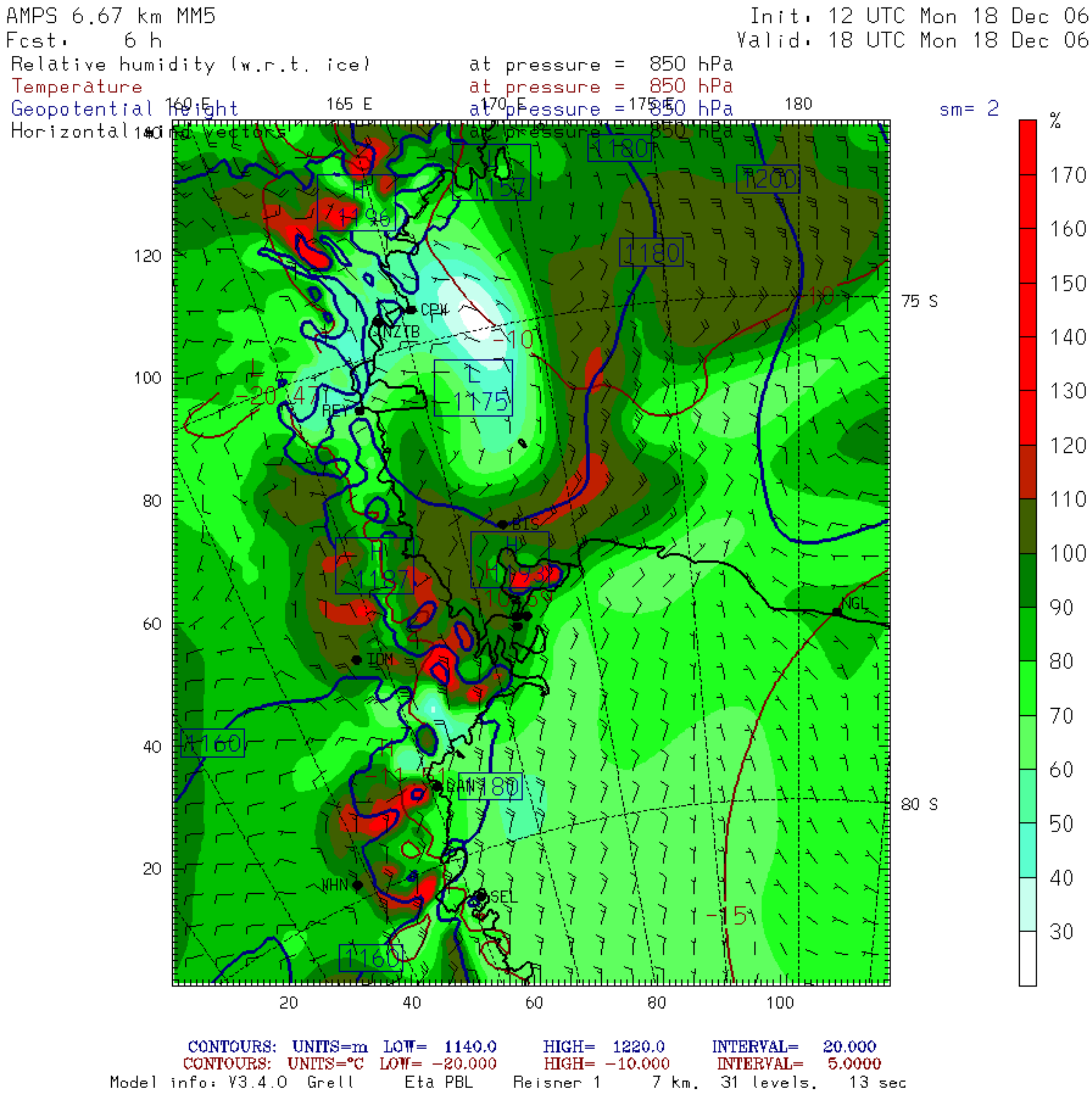


Figure 7. (a) 6.7-km AMPS 850-hPa relative humidity with respect to ice (shaded), temperature (red contours), geopotential height (blue contours), and wind barbs at 1800 UTC 18 December 2006 from 0000 UTC 18 December 2006 forecast.



(b) Same as (a) except from 1200 UTC 18 December 2006 forecast.

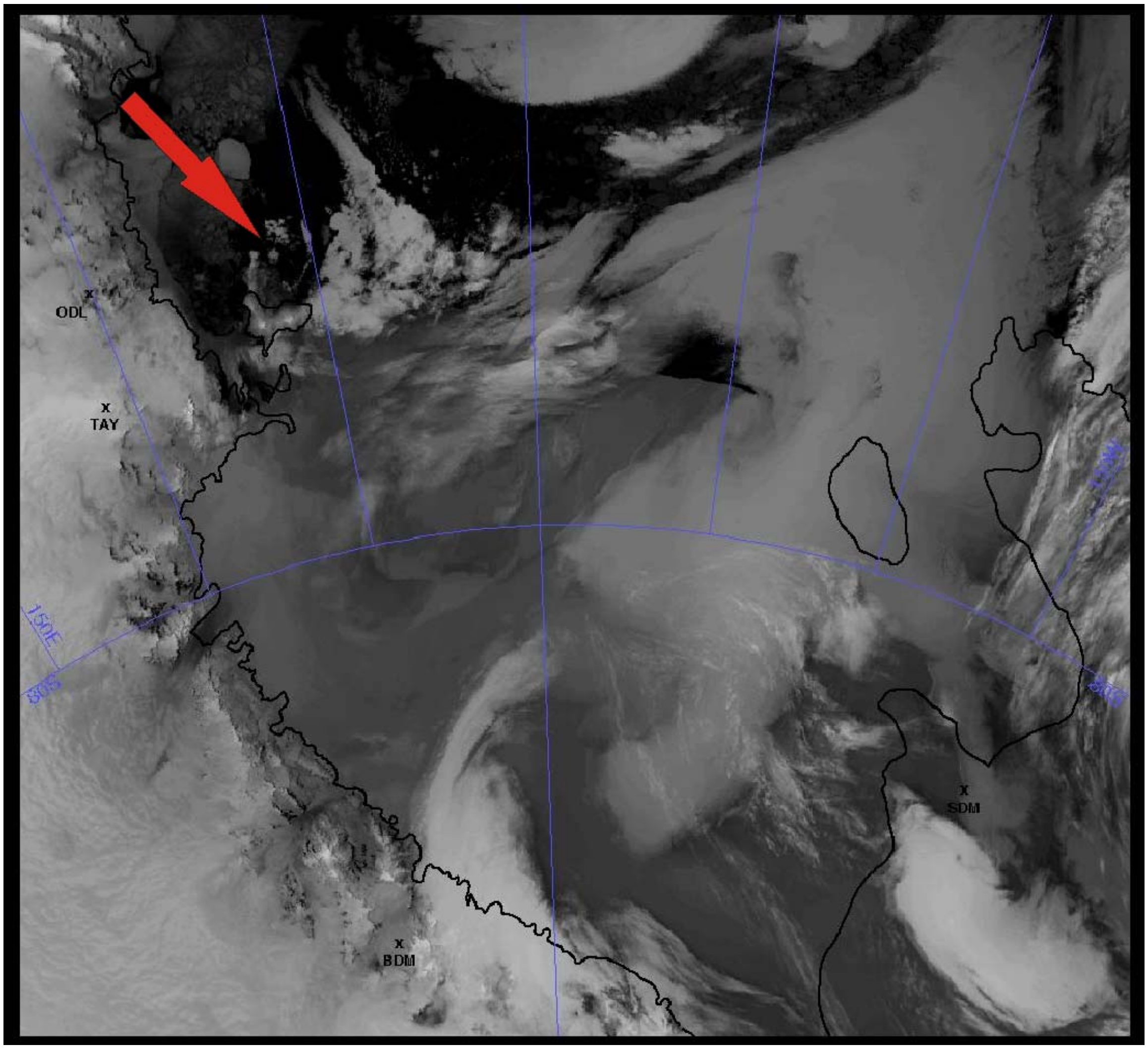


Figure 8. NOAA-17 infrared image from 1812 UTC 18 December 2006. Red arrow indicates location of mesoscale cyclone described in text.

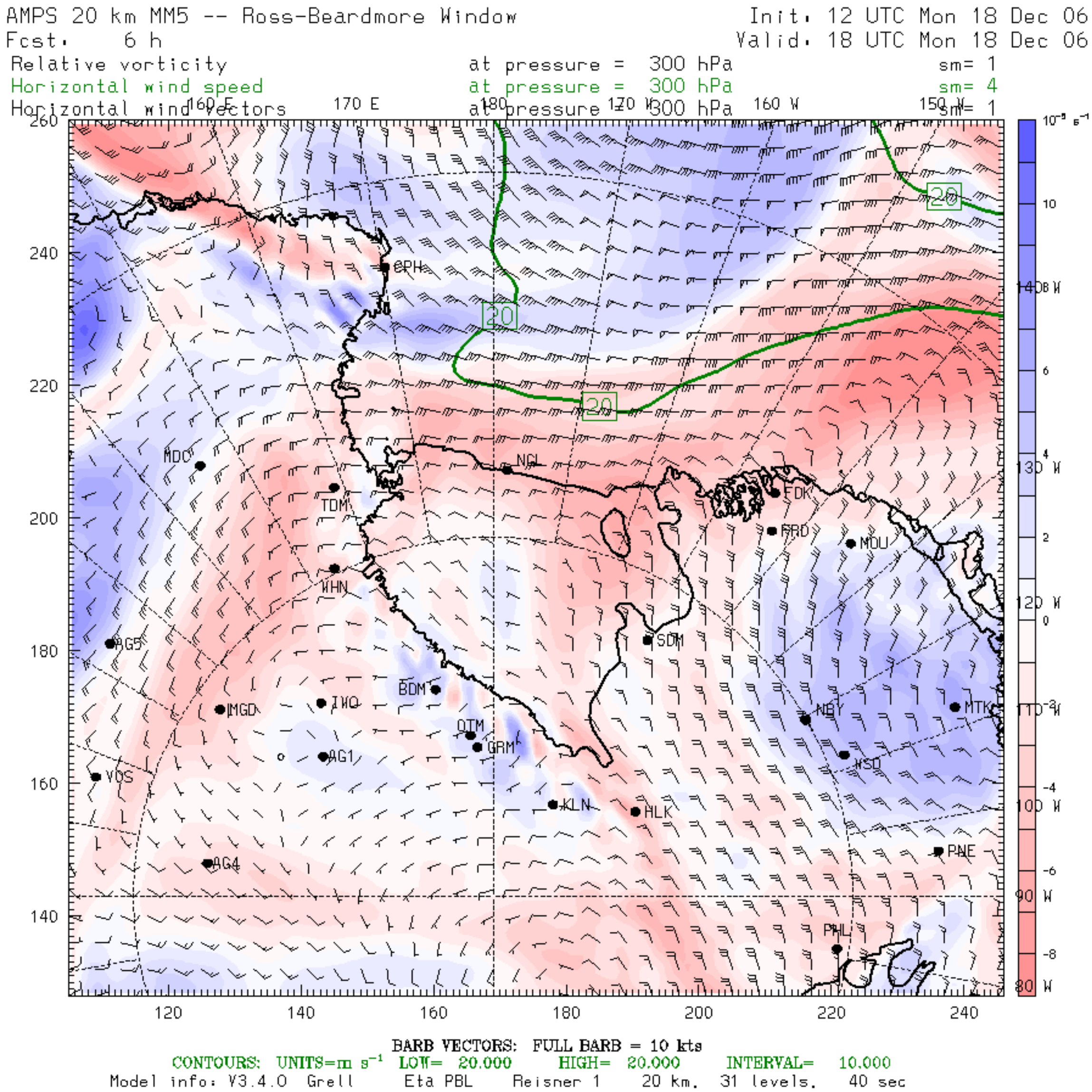
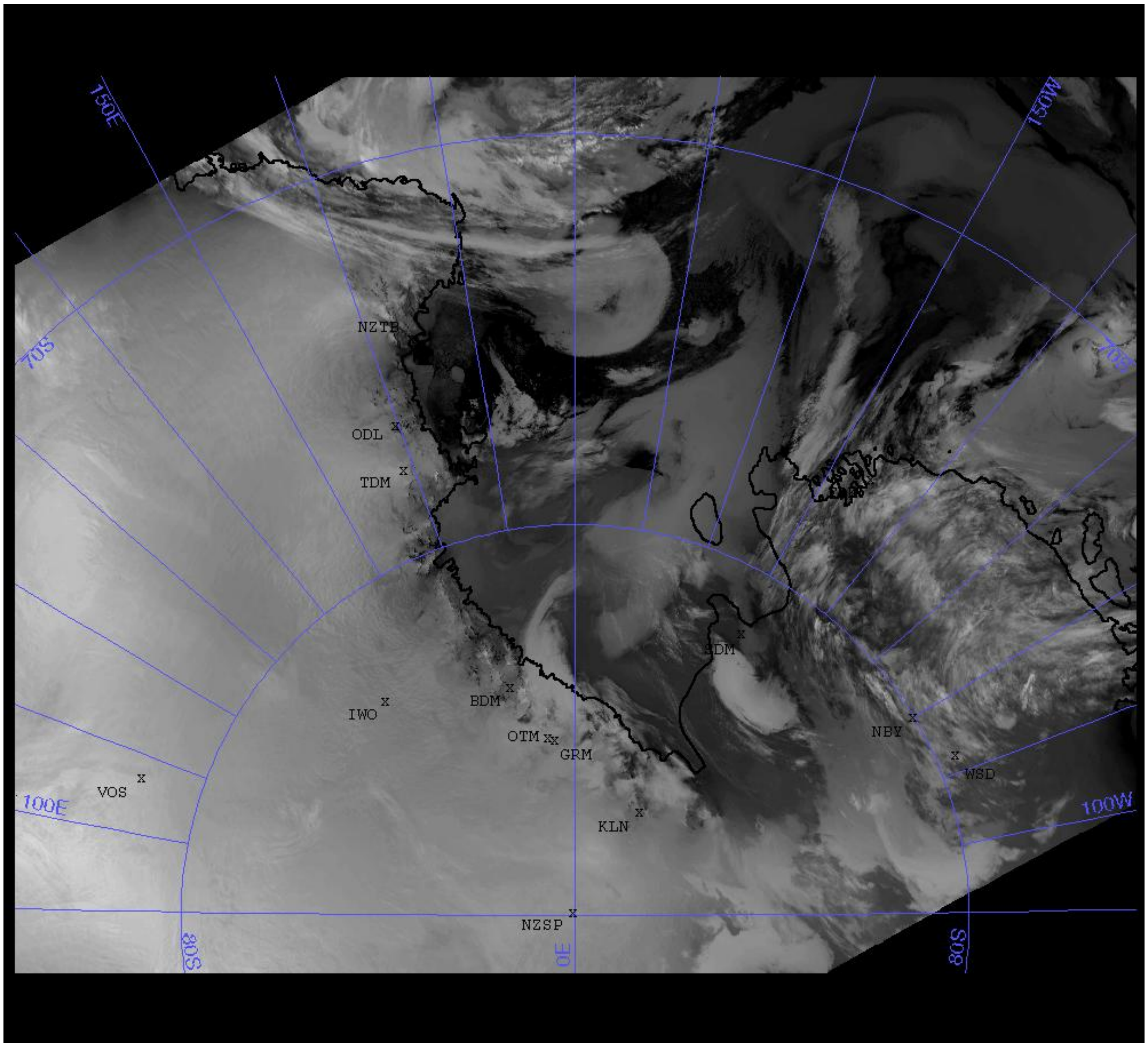


Figure 9. (a) 20-km AMPS 300 hPa relative vorticity (shaded), horizontal wind speed (green contours), and wind barbs at 1800 UTC 18 December 2006 from 1200 UTC 18 December forecast.



(b) NOAA-17 infrared image from 1812 UTC 18 December 2006.

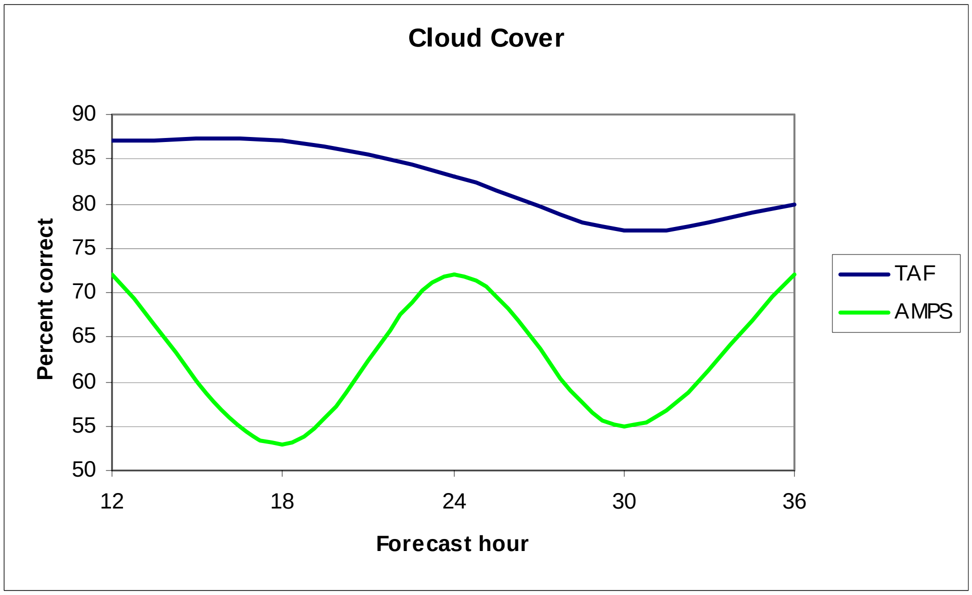
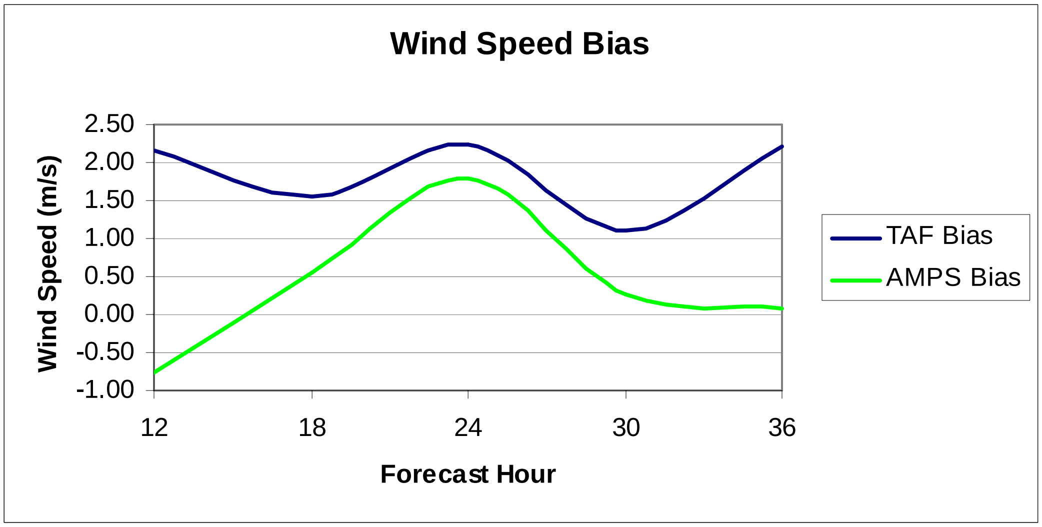


Figure 10. Percentage of correct cloud ceiling forecasts (ceiling or no-ceiling) for TAFs and AMPS for 12-36 hour forecasts.



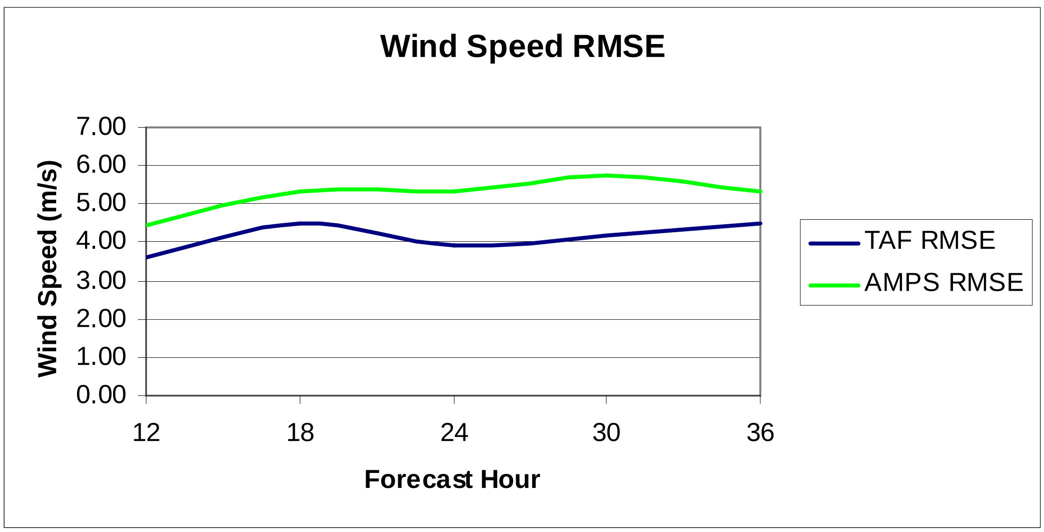
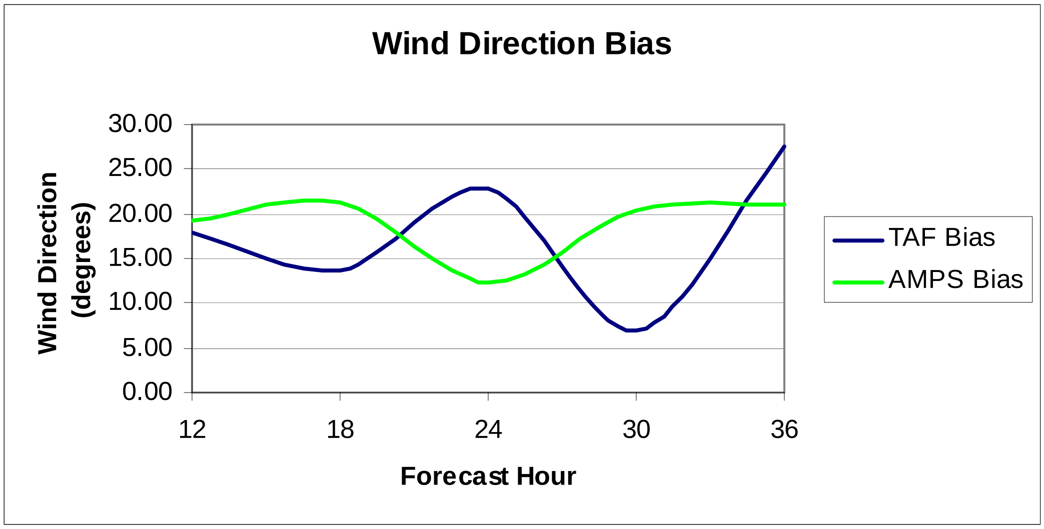


Figure 11. Wind speed bias and RMSE (m s^{-1}) for TAFs and AMPS for 12-36 forecast hours.



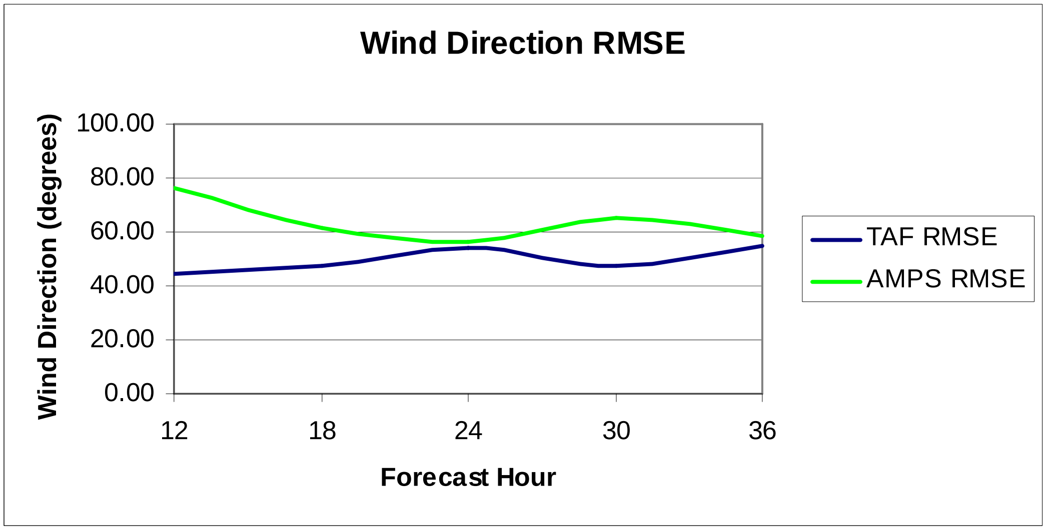
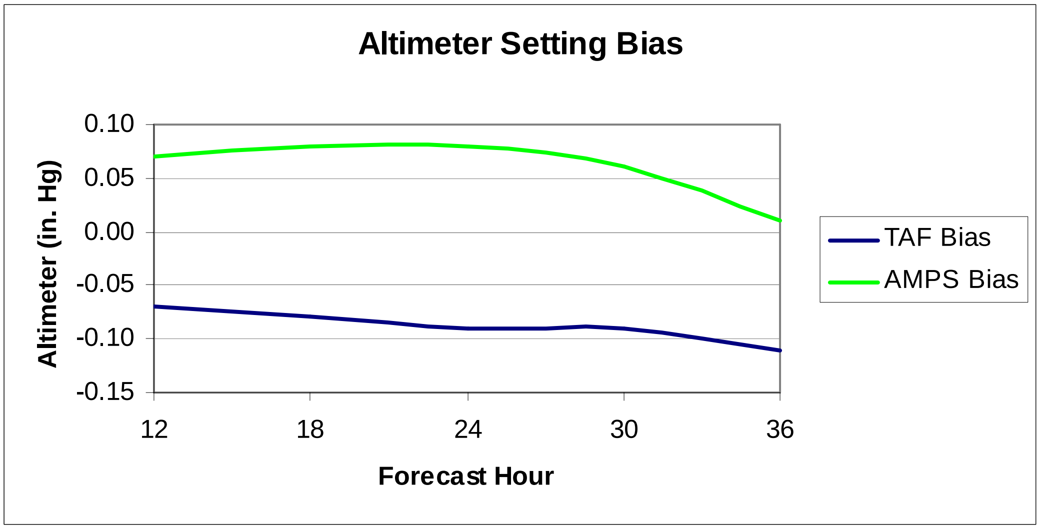


Figure 12. Wind direction bias and RMSE (degrees) for TAFs and AMPS for 12-36 forecast hours.



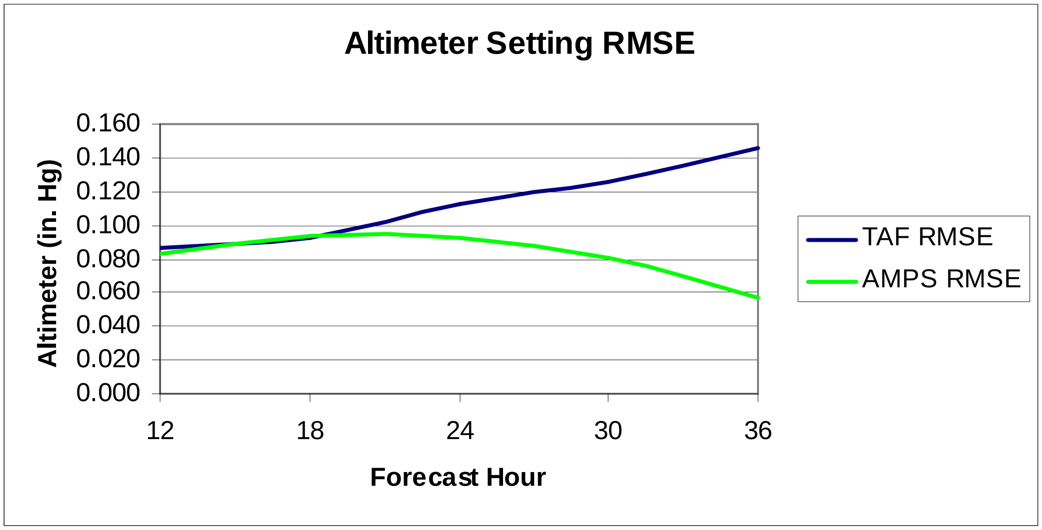


Figure 13. Altimeter setting bias and RMSE (inches mercury) for TAFs and AMPS for 12-36 forecast hours.

TABLE 1. Contingency tables for cloud ceiling comparison between TAF and AMPS when TAF/AMPS has ceiling and observations do not, TAF/AMPS does not have ceiling and observations do, both have ceiling, and neither have ceiling. Green boxes indicate correct forecasts, red indicate incorrect forecasts.

		TAF		
		C	NC	Total
OBS	C	103	12	115
	NC	32	93	125
		Percent Correct:		82

		AMPS		
		C	NC	Total
OBS	C	33	91	124
	NC	3	129	132
		Percent Correct:		63

TABLE 2. As in Table 1, but for specific forecast hours 12-36 hours, every 6 hours.

12hr		TAF		
		C	NC	Total
OBS	C	12	0	12
	NC	4	14	18
		Percent Correct:		87

12hr		AMPS		
		C	NC	Total
OBS	C	5	8	13
	NC	1	18	19
		Percent Correct:		72

18hr		TAF		
		C	NC	Total
OBS	C	29	5	34
	NC	3	23	26
		Percent Correct:		87

18hr		AMPS		
		C	NC	Total
OBS	C	6	30	36
	NC	0	28	28
		Percent Correct:		53

24hr		TAF		
		C	NC	Total
OBS	C	24	0	24
	NC	10	26	36
		Percent Correct:		83

24hr		AMPS		
		C	NC	Total
OBS	C	10	16	26
	NC	2	36	38
		Percent Correct:		72

30hr		TAF		
		C	NC	Total
OBS	C	25	7	32
	NC	6	18	24
		Percent Correct:		77

30hr		AMPS		
		C	NC	Total
OBS	C	8	27	35
	NC	0	25	25
		Percent Correct:		55

36hr		TAF		
		C	NC	Total
OBS	C	12	0	12
	NC	6	12	18
		Percent Correct:		80

36hr		AMPS		
		C	NC	Total
OBS	C	4	9	13
	NC	0	19	19
		Percent Correct:		72

TABLE 3. Mean values and standard deviation of wind speed (kts) for observations, TAF, and AMPS.

Wind Speed	Mean (kts)	Standard Deviation (kts)	Bias (kts)	RMSE (kts)
Observations	7.2	3.6	-	-
TAF	8.9	1.7	1.85	4.20
AMPS	7.8	4.8	0.65	5.34

TABLE 4. Mean values and standard deviation of wind speed (kts) for observations, TAF, and AMPS when wind speed is less than or equal to 10 kts and when wind speed is greater than 10 kts.

Wind Speed <= 10 kts	Mean (kts)	Standard Deviation (kts)	Bias (kts)	RMSE (kts)
Observations	6.2	2.8	-	-
TAF	8.8	1.3	2.8	4.1
AMPS	7.7	4.7	1.5	5.0

Wind Speed > 10 kts	Mean (kts)	Standard Deviation (kts)	Bias (kts)	RMSE (kts)
Observations	12.8	2.0	-	-
TAF	9.8	3.0	-3.1	4.6
AMPS	8.7	5.1	-4.2	6.8

TABLE 5. Mean values and standard deviation of wind direction (degrees) for observations, TAF, and AMPS.

Wind Direction	Mean (deg.)	Standard Deviation (deg.)	Bias (deg.)	RMSE (deg.)
Observations	91.2	87.2	-	-
TAF	73.4	33.6	17.4	49.8
AMPS	106.3	79.5	18.5	62.5

TABLE 6. Mean values and standard deviation of altimeter setting (inches) for observations, TAF, and AMPS.

Altimeter Setting	Mean (inches)	Standard Deviation (inches)	Bias (inches)	RMSE (inches)
Observations	29.18	0.08	-	-
TAF	29.07	0.20	-0.09	0.11
AMPS	29.24	0.09	0.06	0.09