Environnement Canada
Centre météorologique canadien

Environment Canada
Canadian Meteorological Centre

Processing of Aircrafts Observations at the Canadian Meteorological Centre

Version 2.6

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Revision history		
Version	**Date**	**Remarks**
1.0	2002/07/31	First version: March 2002 implementations details
1.1	2004/04/02	Addition of 10 Canadian aircraft
2.0	2005/01/01	Addition of new C-AMDAR observations 4DVar processing
2.1	2007/06/01	Update
2.2	2011/02/24	Addition of Humidity, I. Mati
2.3	2014/09/02	New vertical thinning and temperature bias correction
2.5	2018/09/15	Change Aircraft BURP format: from non-grouped to grouped
2.6	2021/05/10	New dynamic temperature bias correction by tail number (S. Macpherson), other updates (Y. Zaitseva)

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1. Introduction

The document is a simple summary of the processing of aircraft observations in the CMC assimilation system. Some technical aspects of the processing are discussed but without going in the details of the programs.

Recent history of aircraft observations usage:

In September 2000, the automated aircraft (AMDAR/MDCRS) wind observations were added to the old manual AIREP wind observations already assimilated, providing an important improvement to the quality of short term forecasts. Observation errors were modified and a thinning procedure was introduced to reduce the density of observation especially in areas such as the low levels near the airports.

In December 2001, the aircraft temperature observations were included in the analysis. The OI quality control was replaced by a combination of a background check prior to the analysis and the variational quality control during the minimisation.

In March 2002, the selection and thinning procedure was improved. The final thinning is now performed after the background quality check and can take into account the QC flags of the background check. The horizontal resolution of the thinning was increased from 1.5 to 1°. The number of vertical levels was increased. A blacklisting procedure was added to remove Aircrafts with "bad" observations. The blacklist is updated every month. Some additional aircraft observations were also added: European AMDAR in BUFR format and ADS observations.

In July 2002, some observations (about 10000 per 24 hours) from the Canadian AMDAR program are being processed for evaluation at CMC. The Canadian project is the first AMDAR program to include the smaller "regional" aircraft which provides observations from some remote regions of Canada and lower cruising altitudes than larger aircraft.

Starting in April 2004, the data from 10 CRJ aircraft, operated by Air Canada Jazz airline, are assimilated in the Canadian NWP system.

In December 2004, about 14 DHC-8 and 8 new CRJ aircrafts from Air Canada Jazz were added to the C-AMDAR observations assimilated at CMC. More should be added in the coming weeks.

Starting in January 2005, the C-AMDAR observations are transmitted on WMO GTS.

In March 2005, the 4DVar assimilation program became operational in CMC global system. The number of aircrafts observations assimilated in the 4DVar global analyses is more than double what it was in the 3DVar.

In October 2005, we stopped assimilating the DHC-8 Canadian AMDAR observations (stnid CNJDAxxx) because of relative large biases that are flight phase dependant. We assimilate the regional jet observations (stnid CNJCAxxx), from about 33 aircrafts.

As of June 2007, we are starting to assimilate the wind and temperature observations from the "Great Lakes Fleet Experiment", the Mesaba fleet equipped with TAMDAR.

As of spring 2011, we are starting to assimilate the humidity observations from the aircraft. Eventually new observation operators may be used for this purpose, but in this implementation it was decided to do a variable transformation; aircrafts humidity observations are transformed into a dew point depression (ES) variable. That necessitates smaller modification to the analysis program.

The necessary adjustments to the decoding program of aircraft reports have been made to include the humidity observations with their quality indicators; the value of ES computed from either the relative humidity or the mixing ratio, is added to each report and saved in the database for further processing. The maximum value of ES is set to 30 deg., for dry cases. The analysis output file also includes, as a diagnostic, the O-P value of lnQ, the variable used by the 3DVar code.

In fall 2014, a new vertical thinning according to the analysis levels, as well a temperature bias correction was implemented. The new thinning increases the number of assimilated observations by about 50%. The observation error statistics have also been revised.

In fall 2018 because of a limitation of BURP files, the all processing aircraft data was changed from non-grouped data (one record for one observation) to grouped data (one record with many observations).

Starting in April 2021, the data from 11 Boeing 737 aircraft, operated by Canadian North and First Air airlines, are assimilated in the Canadian NWP system.

In fall 2021, a new dynamic temperature bias correction by tail number was implemented.

2. Flowchart of processing

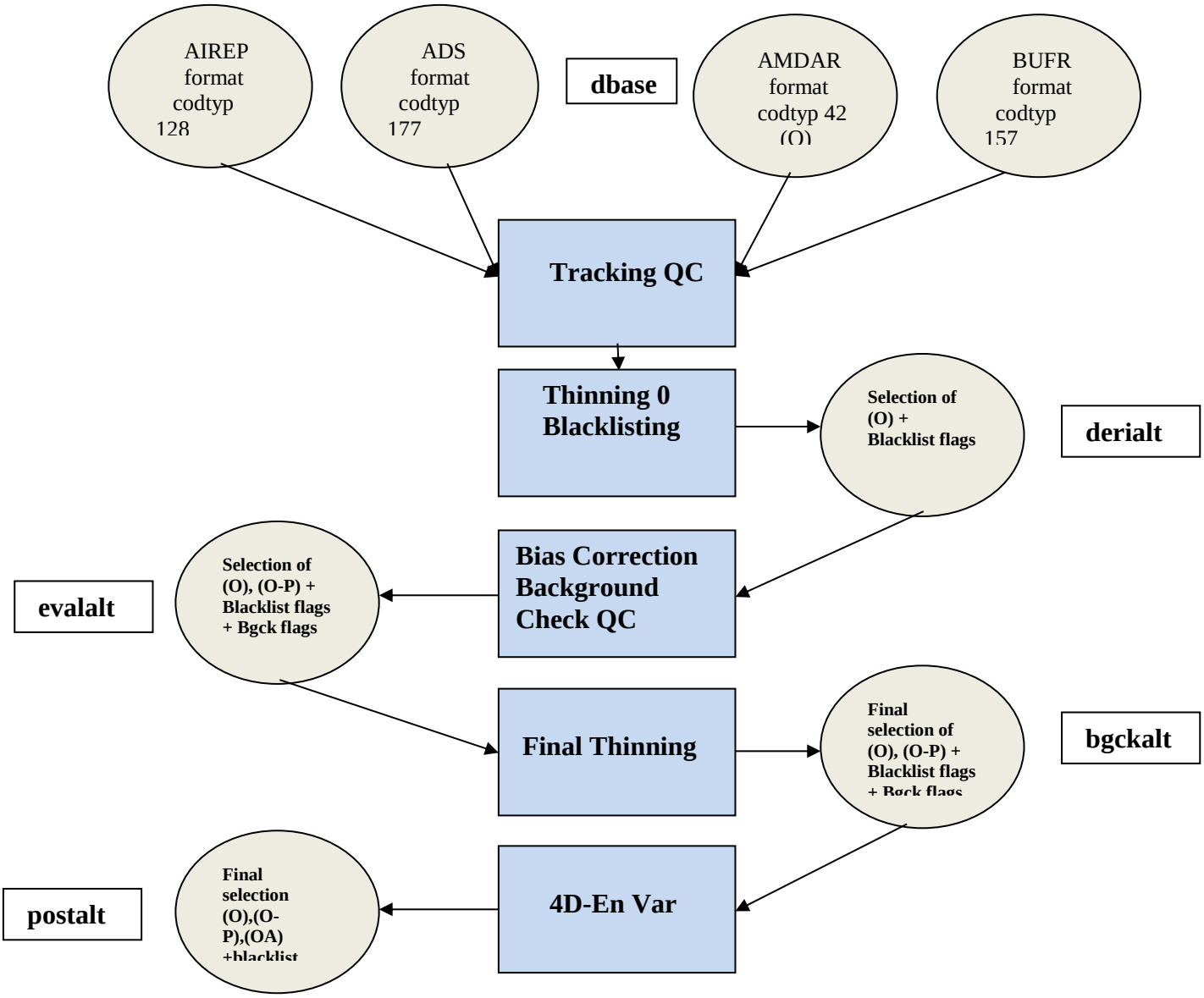

Figure 1: Aircraft observations processing; Operational branch, last file is in postalt directory.

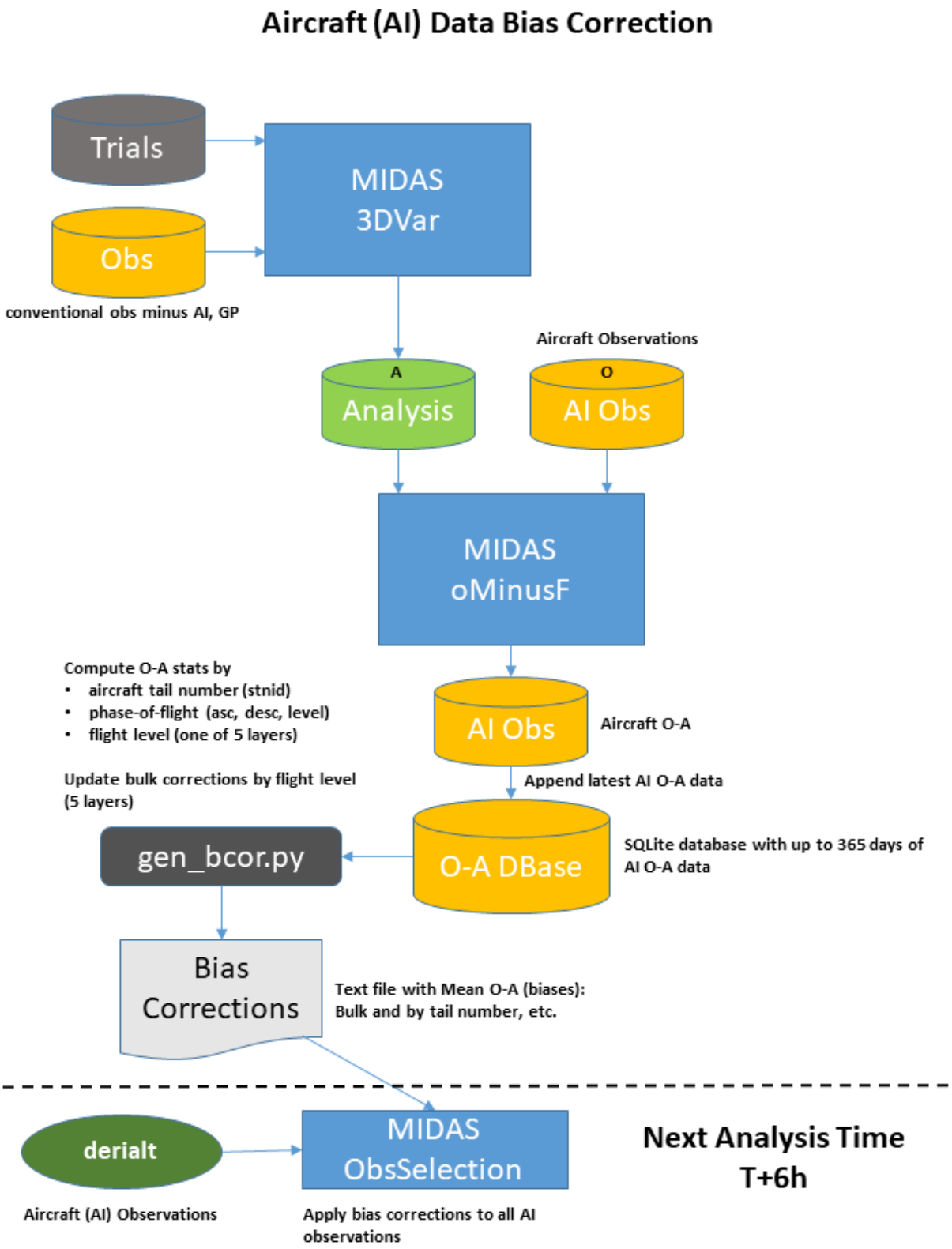

Figure 2: Dynamic bias correction system with corrections updated at each analysis time.

3. Observations details

Code type 128 Manual AIREP

~ 3000 per 24hrs

These meteorological observations are part of ICAO system requirements for aircraft navigation over the oceanic areas. These observations are in AIREP ICAO format for manual aircraft observations. These ASCII bulletins are received from the global telecommunication system. Gander and the Canadian arctic flight zone AIREP are gathered by NavCan.

Code type 177 ADS or Automatic AIREP

~ 25000 per 24hrs

This is the ICAO replacement for the old manual AIREP system over oceanic areas. In the coming years the number of AIREP should diminish and the number of automatic reports should increase. ADS meteorological observations format is specified by ICAO ADS Panel. Currently only the north Atlantic ADS meteorological observations are identified as ADS and received in modified AIREP format.

Code type 42 AMDAR

~ 12000 per 24hrs

These are the AMDAR observations transmitted in the WMO FM-42 ASCII format. There are a few regional and/or national AMDAR programs, such as the New-Zeeland, Australian, Japan and South Africa programs transmit the observations in this format.

Code type 157 BUFR

~ 600000 per 24hrs

These are the observations transmitted in WMO FM-94 BUFR binary format. Most are from the MDCRS observations of the US airlines, but now also include European, Canadian and other airlines observations. They provide a very good coverage of the US, Europe, limited coverage of South-America, the North Atlantic and Pacific.

As a result of the Canadian AMDAR program, observations from Air Canada JAZZ, Canadian North, First Air and NavCanada aircraft are coded in BUFR format and transmitted on the WMO GTS.

Note: A rudimentary check is done at the decoding stage to flag or remove observations with format, climatological limits or consistency problems. Currently, observed wind, temperature and humidity are the three elements retained for assimilation. Observations files contain all reports available in 6-hour periods.

4. Processing details

Tracking QC

This program attempts to detect aircraft position error. The observations are regrouped by aircraft in chronological order and repetitions are eliminated. Then the speed and direction of displacement is computed from the latitudes, longitudes and time of observations. An observation is rejected if:

- horizontal speed > maximum (sound speed + 1/10)
- horizontal speed < minimum (1/10 sound speed)
- vertical speed > maximum (1700 m / min.)
- 2 or less observations from the aircraft, can't compute displacements

+

- for speed rejects: the observation and the following one are rejected
- for 3 or more rejects in the same flight: all observation for that flight are rejected
- for 2 rejects in the same flight: observations in between are also rejected

Input: cutoff file (acars/amdar/ads/airep)
Output: grouped and non-grouped files of each format + statistics per aircraft (stnid, nbobs-debut, nbpres<1200mb, nbrepet,nbobs-fin,nb-douteux,nb-liste noire+douteaux)

First Thinning and Blacklisting

An observation is removed if

- the pressure level of observation is out of range: <100 hPa or >1025hPa
- the observed wind speed = 0
- the observation was rejected by tracking QC
- the observation is from an aircraft with both wind and temperature on the blacklist

For the remaining observations, this program will add the blacklist flag (256 bit 8) to the elements (wind or temperature or humidity) on the blacklist and the flag 4 (bit 2) will be changed by flag 2048 (bi 11. element rejected by thinning). This program has two options:
Doblack=0: thinning + flags (output: derialt files)
Doblack=1: just flags (output: derieval files using for evalalt files)
The program thinning0 reads a complete file, double the memory and rewrites the new file using the special interface (prepared by H.Benhocine).

The blacklists are updated every month using observations statistics from the last 35 days.
Current conditions for an aircraft to be on the blacklist are the following:

- % reject from background check > 50% (wind and/or temperature, humidity)

When the number of available observations >= 20 and

- if % reject from background check > 5% (wind and/or temperature, humidity)
- if % reject from Tracking QC > 50% (wind, temperature and humidity)
- if vector rms > 8 m/s or abs(speed bias) > 2.0 m/s (wind)

- if temperature rms > 2.5° or abs(bias) > 1.6° (temperature)
- if humidity rms > 5.5° or abs(bias) > 2.0° (humidity)

A special vertical thinning for the dew point depression observations (ES) is made following the algorithm implemented for radiosonde data. Only observations in layers centred to the following pressure levels (hPa) are retained: 1000, 975, 950, 925, 900, 850, 800, 750, 700, 650, 600, 550, 500, 450, 400, 350, 300, 250, 150, 100, 70.

Bias Correction for Temperature

Aircraft temperature observations are warm biased on average. However, the actual bias depends on the specific aircraft (tail number), the phase-of-flight POF (ascending, descending or level) and the flight level FL. A new dynamic bias correction scheme was introduced for Innovation Cycle 3 in 2021. It replaced a simple static "bulk" scheme, where constant bias corrections depending only on flight level (layer) were applied to all temperature observations. This scheme assumed a constant warm bias for all aircraft that increases with height (flight layer) and the fixed bias corrections were applied early on in the derivate stage of data processing. With the new scheme, the application of the corrections is moved to the assimilation cycle suite just before the background check using a new MIDAS bias correction subroutine. A flowchart of the new bias correction system is shown in Figure 2 of Section 2.

In the new scheme, the biases, as a function of tail number, POF and FL (layer), are taken as the Mean O-A obtained from O-A data accumulated in a master SQLite database containing up to one year of data. Five layers shown in the following table are used to define the dependency of bias on FL.

Bias Correction FL Layers (hPa)
300-100
400-300
500-400
700-500
1100-700

The analysis (A) in O-A is a special 3D-Var analysis obtained from assimilation of "unbiased" conventional observations only, excluding all aircraft (AI) and GB-GPS (GP) data. The aircraft O-A database is appended with O-A data at each analysis time and older data removed. Bulk corrections (Mean O-A) by FL are also computed. These bulk corrections, similar to the static corrections applied in the previous system but dynamically updated, are applied when the aircraft tail number is not known, which is the case for AIREP/ADS reports, or when the data sample size for a particular aircraft is insufficient to compute a reliable Mean O-A. The Standard Error of the Mean (SEM), a function of the number of observations and the Standard Deviation of O-A, is used to determine if the Mean O-A (bias correction) is reliable enough. If the SEM is larger than a prescribed maximum value, the bias correction is assumed to be unreliable and will be set to "missing" in the aircraft bias correction text file. The SEM is also used to limit the growth of the O-A database. All O-A data for a particular aircraft in excess of the minimum needed to obtain a

sufficiently low SEM are trimmed from the database at each analysis time. All data older than one year are also removed at the same time.

Background Check

The objective of the background check is to identify observations with gross errors. It is a comparison between the observed elements and the same elements from the analysis first guess interpolated at the observation location. The variance of the background departure can be estimated as the sum of observation and background error variances. In the background quality check, the background departure is considered suspect when it exceeds its expected variance by more than predefined multiples.

Final Thinning

- removes observations with wind, temperature and humidity, either rejected by QC or on the blacklist

For the remaining observations, a horizontal thinning is performed to a resolution of about 1°x1° on analysis layers, which are approximately defined by the momentum levels of the GEM model. This thinning is done for each time step of the background fields (currently 15 minutes apart), over the 6-hour assimilation period.

The priority is given to the observation
- with 3 elements to assimilate
- automatic report over manual AIREP
- minimum time difference with the analysis

Modification in bgckalt and evalalt files

- change btyp for block of data (1056 replaced by 1120) and for block of flags (7200 replaced by 7264)
- add two more elements in data and flag blocks (11003 UU and 11004 VV)
- add a bgckalt resume recording (for both bgckalt and evalalt files)
- add a new O-P block (bfam=14 and btyp=1130) with O-P values for each element, the number of elements is the same as in block of data

Variational QC

This is the last stage of the quality control; it is done at the same time than the variational analysis. Each observation is given a prior probability of gross error (PGE) base on the characteristics and past statistics of that type of observation. At each iteration of the variational analysis, a posterior PGE is given to the observation based on the departure with the preliminary analysis for that

iteration. The observation cost function is modified by a factor based on the PGE. An observation with a high PGE is given a weight of near zero in the analysis. Observations with a PGE > 0.75 are flagged as rejected in the observation file.

Modification in postalt files

- btyp is the same for all blocks (data, flags and 3D, O-P) comparing to bgckalt files
- add a postalt resume recording
- add a new O-A block (bfam=12 and btyp=1130) with O-A values for each element, the number of elements is the same as in block of data
- add a new block (bfam=10 and btyp=1134) with observation error values for each element

Calculation of humidity observations

CMC receives the moisture observations from aircraft in form of mixing ratio (BUFR element is 013002 and unit "kg/kg"). This value has been transformed into a dew point depression (ES = T - Td) variable using the thermodynamic function developed by RPN:

SHUAES(hu,tx,px,lnps,modp,swtt,swph)

where hu - specific humidity (kg/kg); tx - temperature (deg K); px – pressure (pa), modp – mode of pressure calculation set to 5, lnps is logarithm of surface pressure (not used); swph – logic key for phase selection set to ".false." (for water phase only); swtt – logic key set to ".true.".

The specific humidity (q) is calculated using a mixing ratio value (r): q = r / r+1.

The dew point Td is calculated using the Alduchov and Eskridge equation for water:

$Td = (b*\ln(e_s/e_o) – a*273.16) / (\ln[e_s/e_o] – a)$,

where: a and b constants for water phase (a = 17,625 and b=30.11); e_s – saturation vapor pressure; e_o = 610.94.

WIKI documentation:
https://wiki.cmc.ec.gc.ca/wiki/Nouveau_traitement_des_rapports_d'avion