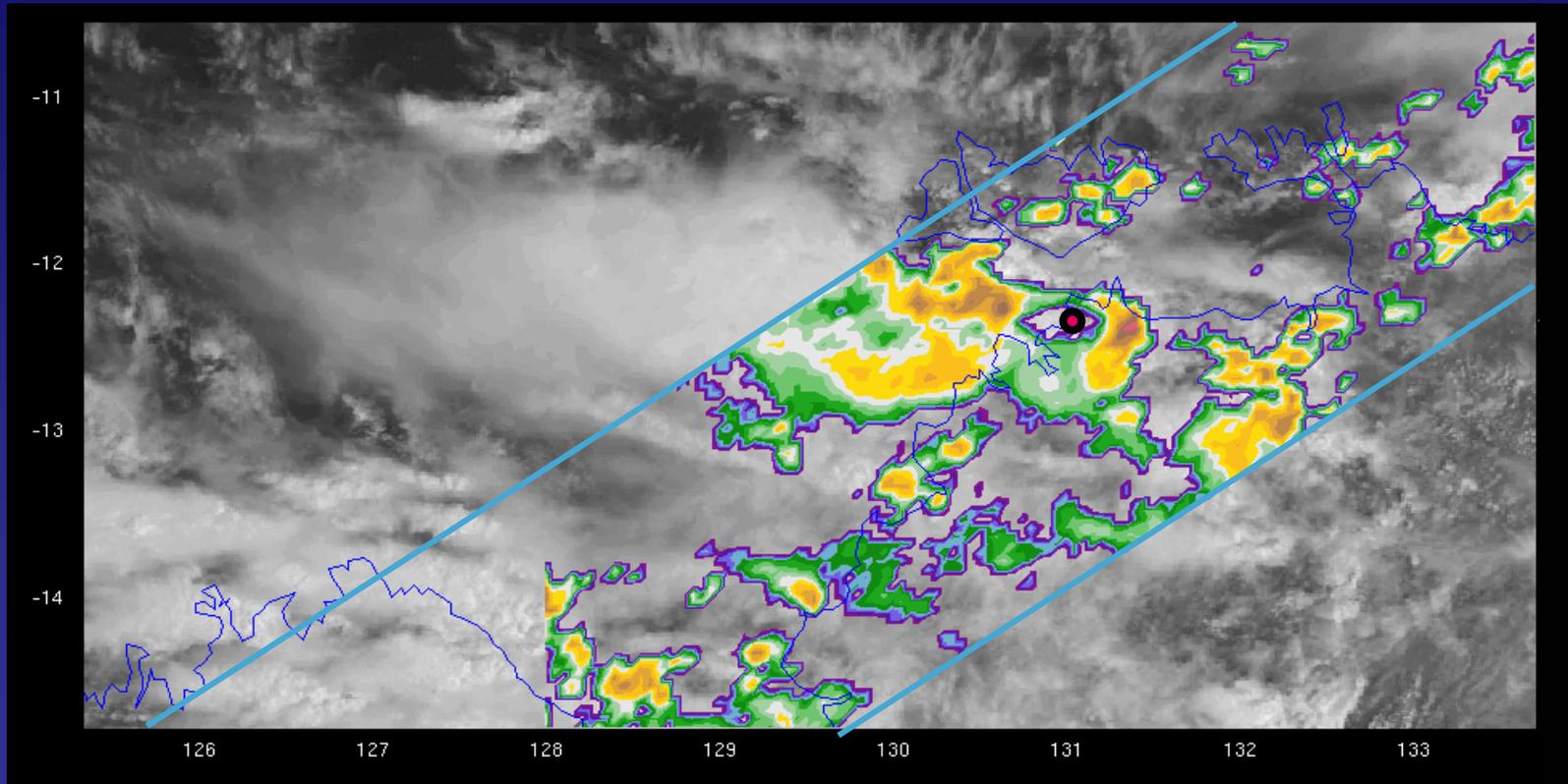


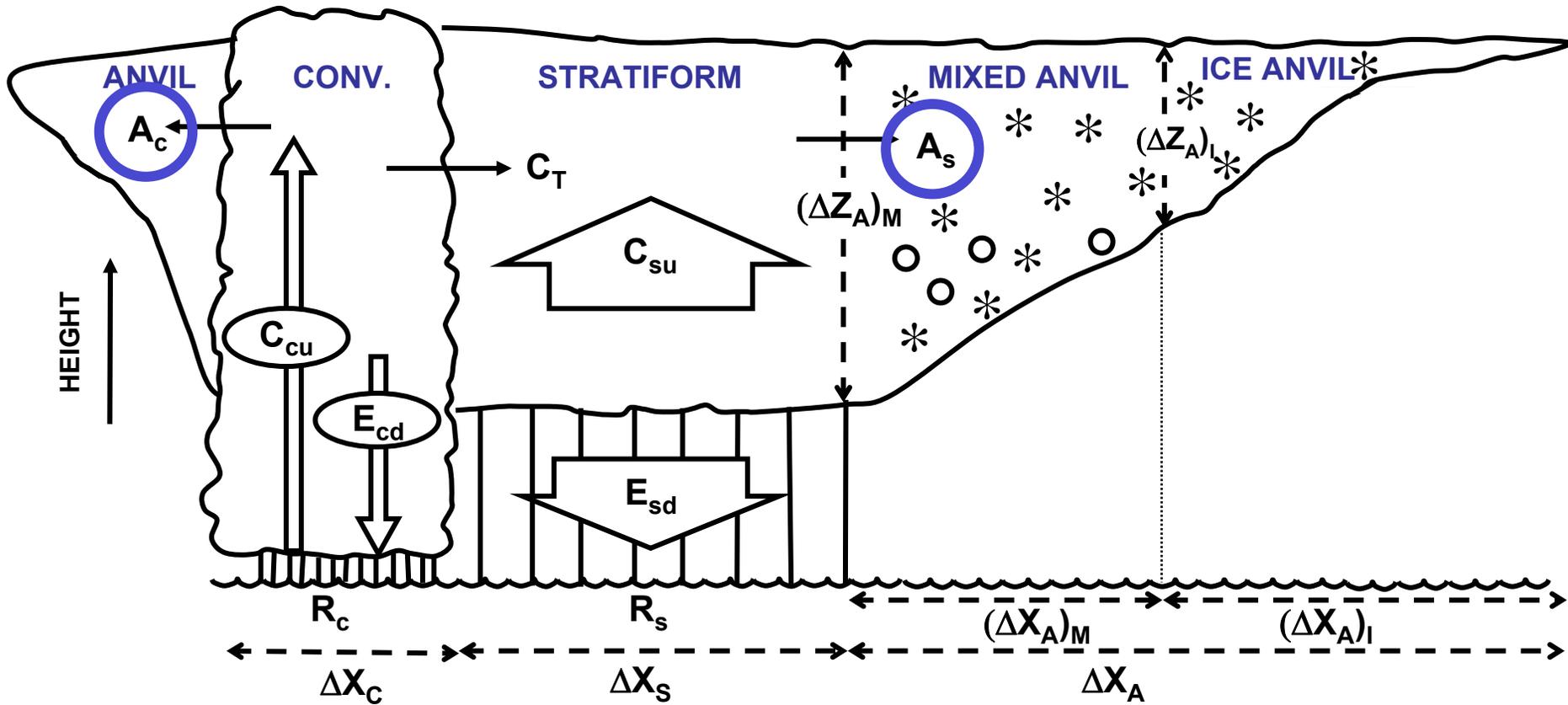
Anvil Generation in Relation to Cloud System Water Budget: TWP-ICE Case of 19-20 January 2006



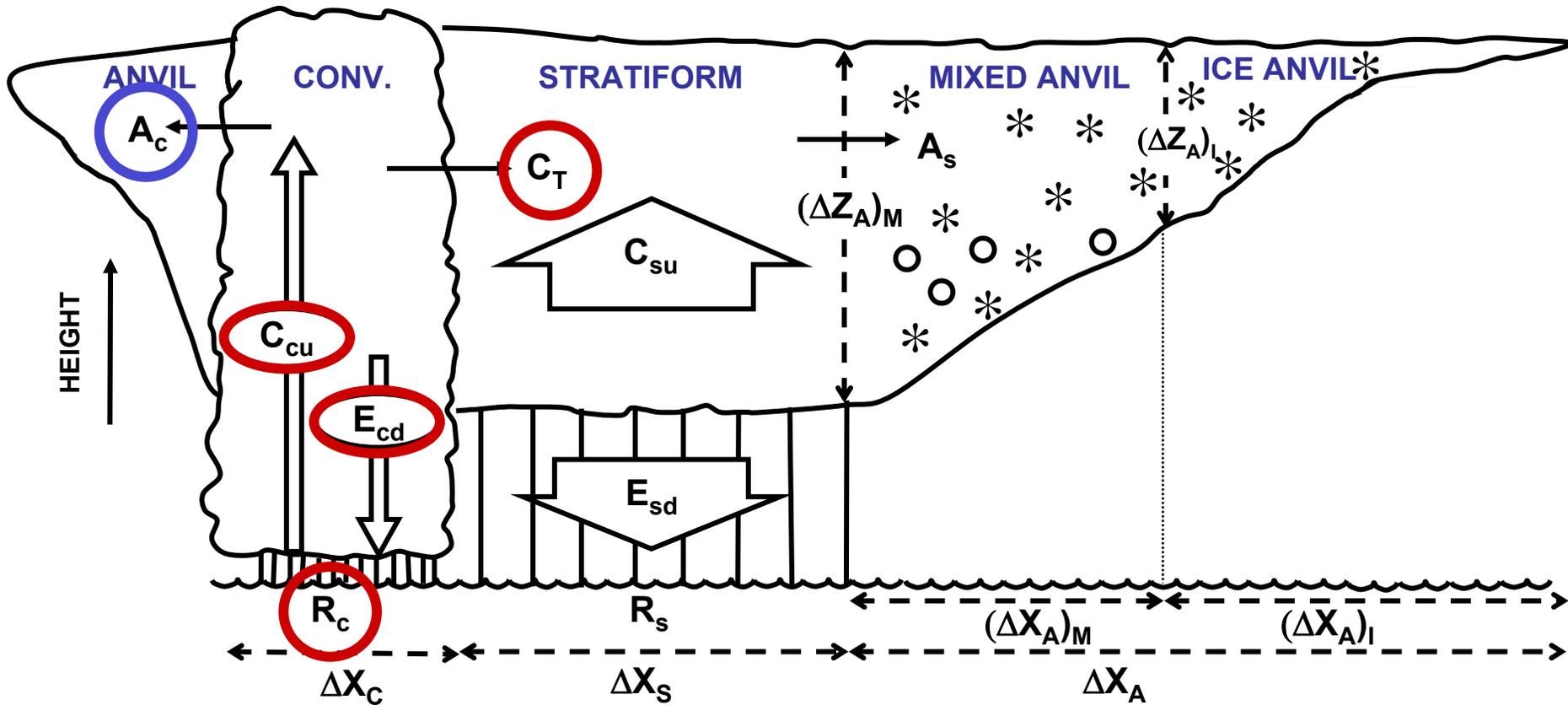
Jasmine Cetrone and Robert Houze
University of Washington

8 November 2006, ARM Cloud Processes Working Group, Annapolis, MD

Water Budget of an MCS



Water Budget Equations



Convective region water budget equation

$$C_{cu} = R_c + E_{cd} + A_c + C_T$$

$$R_c = \varepsilon_c C_{cu}$$

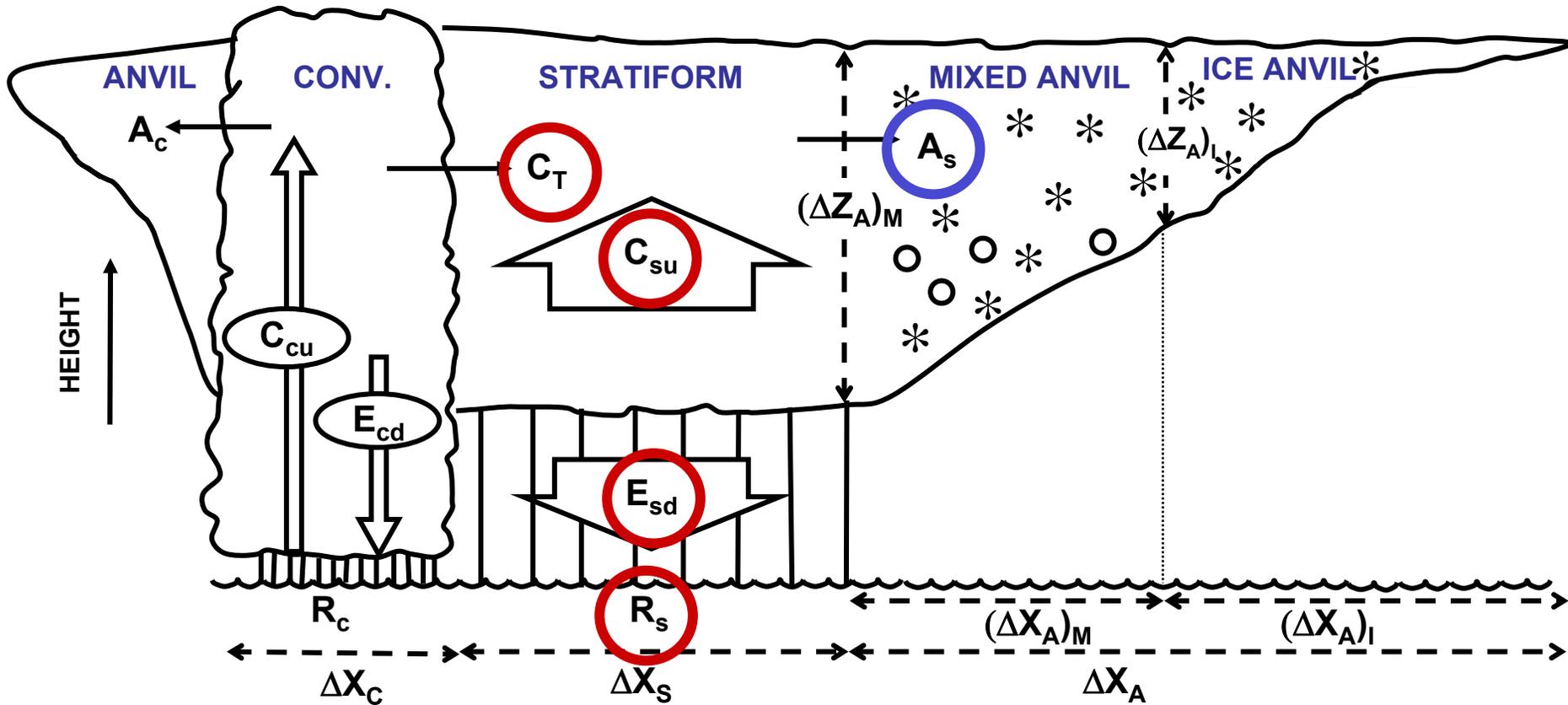
$$E_{cd} = \alpha C_{cu}$$

$$A_c = \beta C_{cu}$$

$$C_T = \eta C_{cu}$$

$$\varepsilon_c + \alpha + \beta + \eta = 1$$

Water Budget Equations



Stratiform water budget equation

$$C_{su} + C_T = R_s + E_{sd} + A_s$$

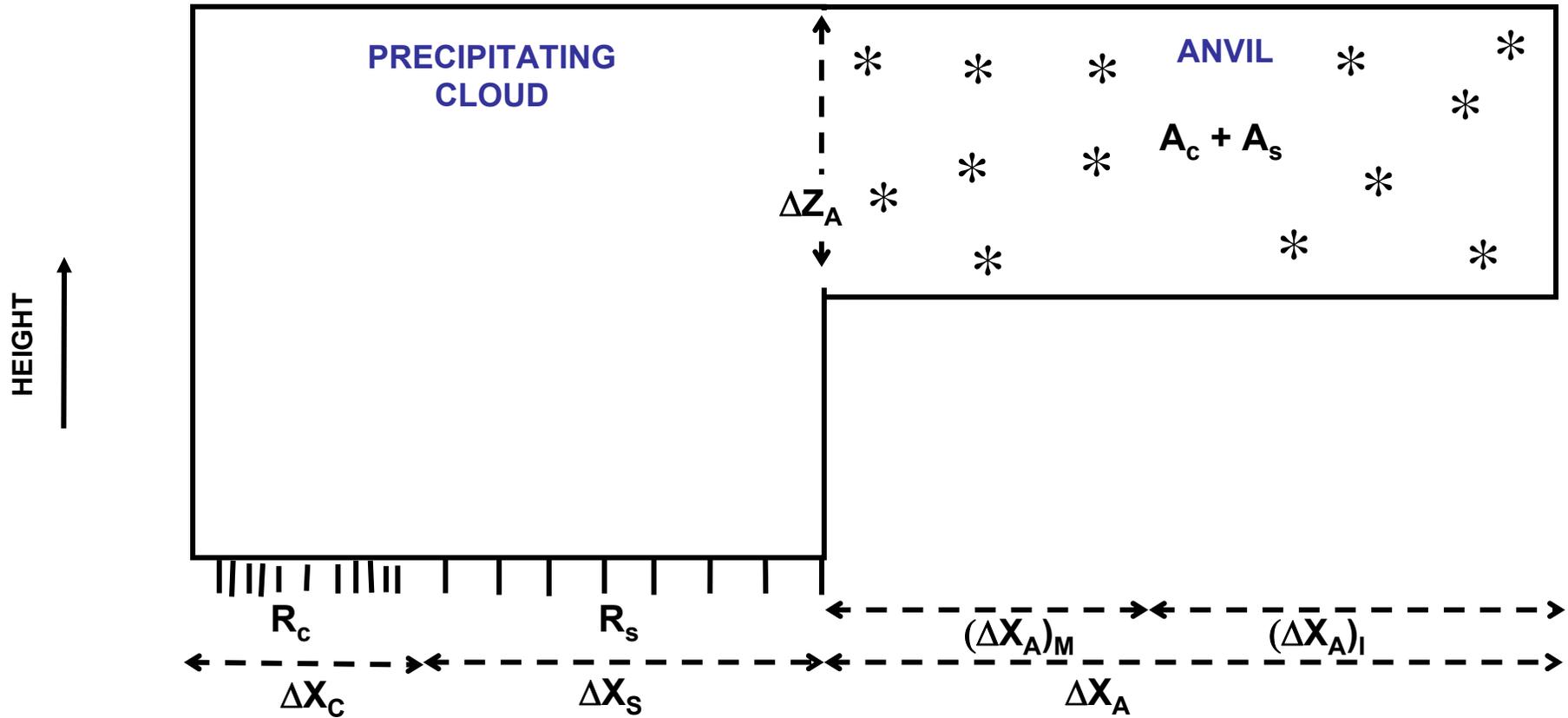
$$R_s = \varepsilon_s (C_{su} + C_T)$$

$$E_{sd} = a (C_{su} + C_T) \quad \varepsilon_s + a + b = 1$$

$$A_s = b (C_{su} + C_T)$$

Rain not simply related to condensation

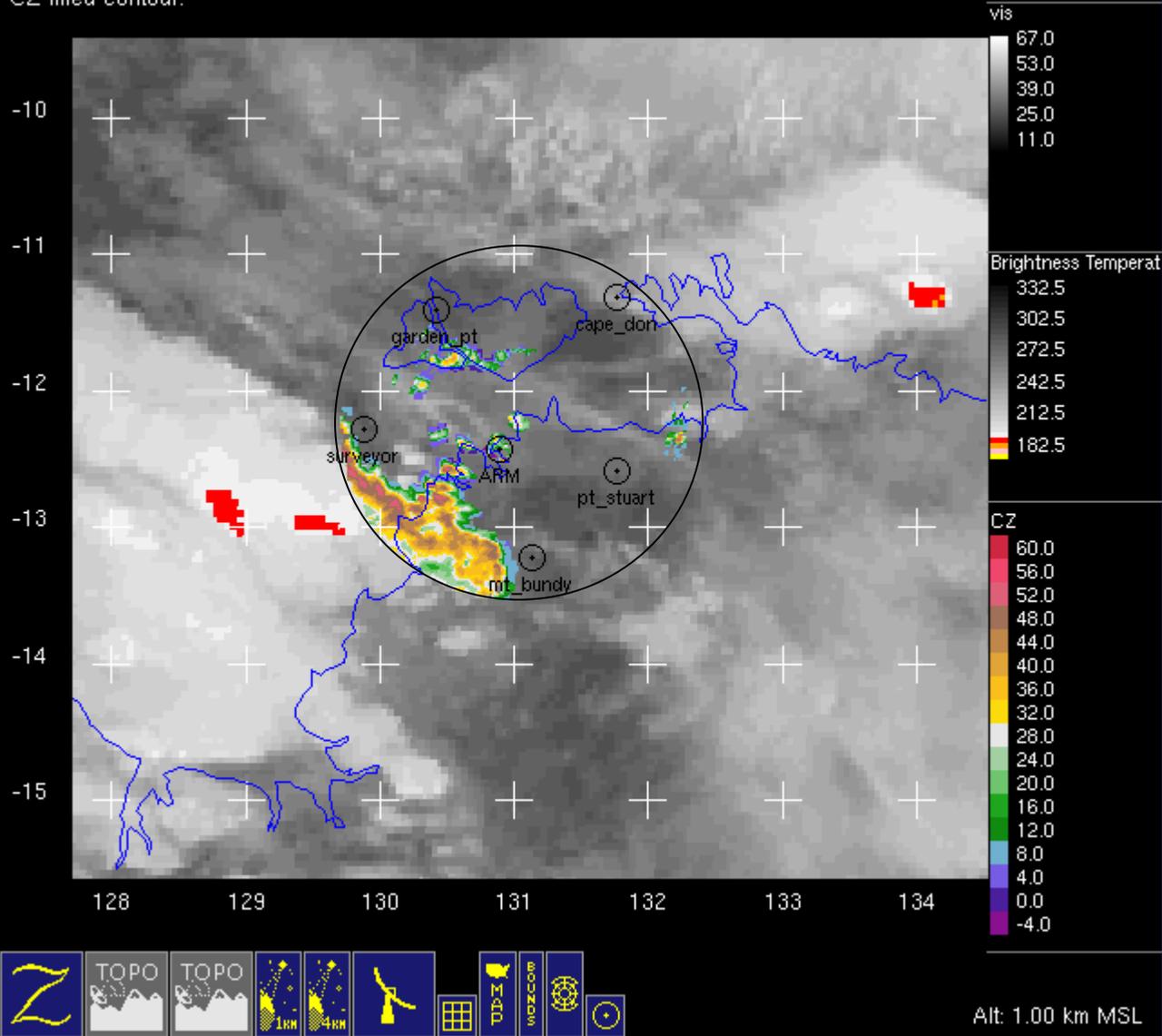
Simplified Water Budget Model



$$A_c + A_s = R_c \left(\frac{1}{\varepsilon_c} (1 - \alpha \eta) - 1 \right) + R_s \left(\frac{1}{\varepsilon_s} (1 - a) - 1 \right)$$

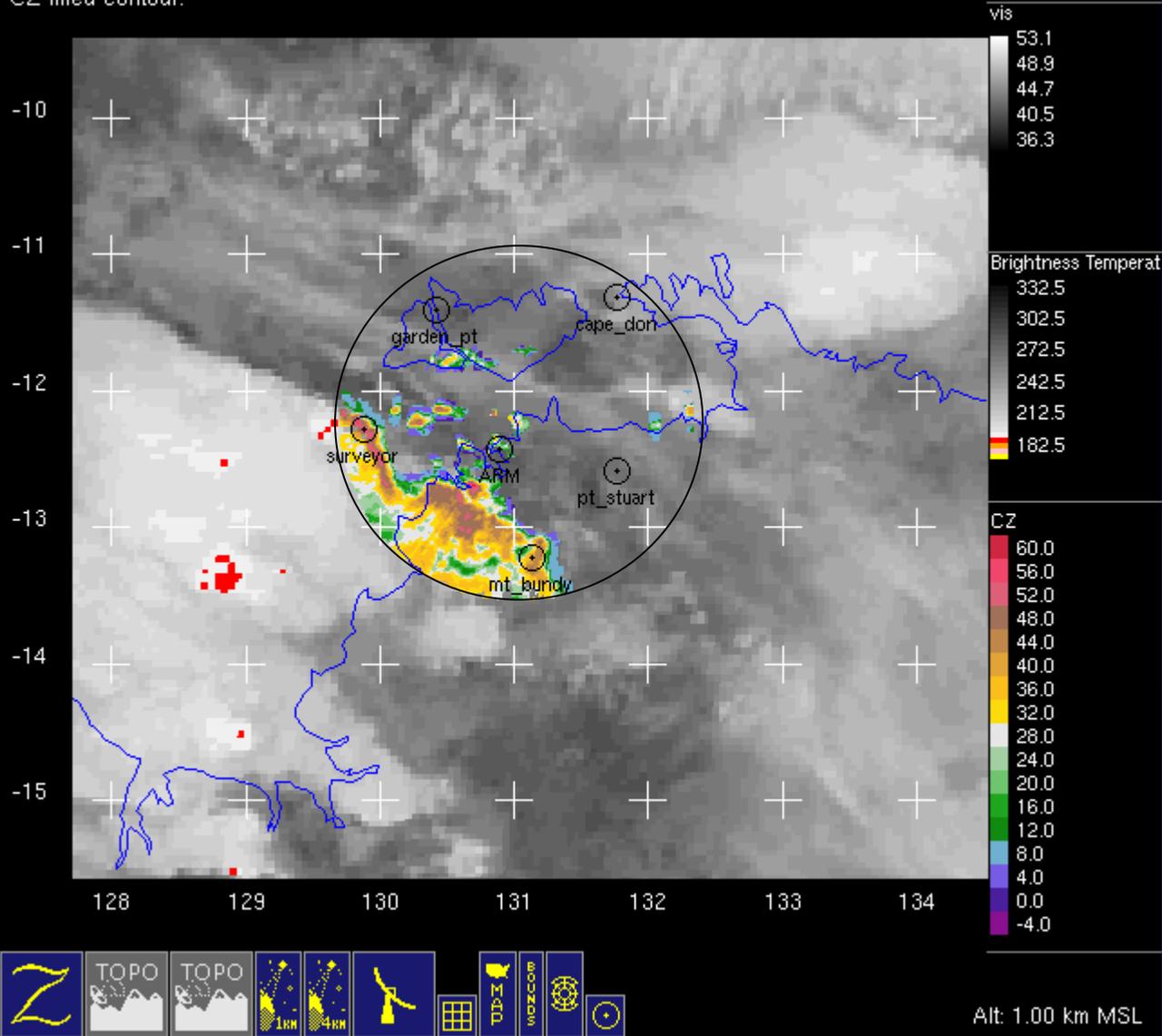
19-20 January MCS

19-jan-2006,20:03:00 mtsat_vis_1km vis plot. mtsat_ir_4km Brightness Temperature plot. GunnPt_polar_qc CZ filled contour.



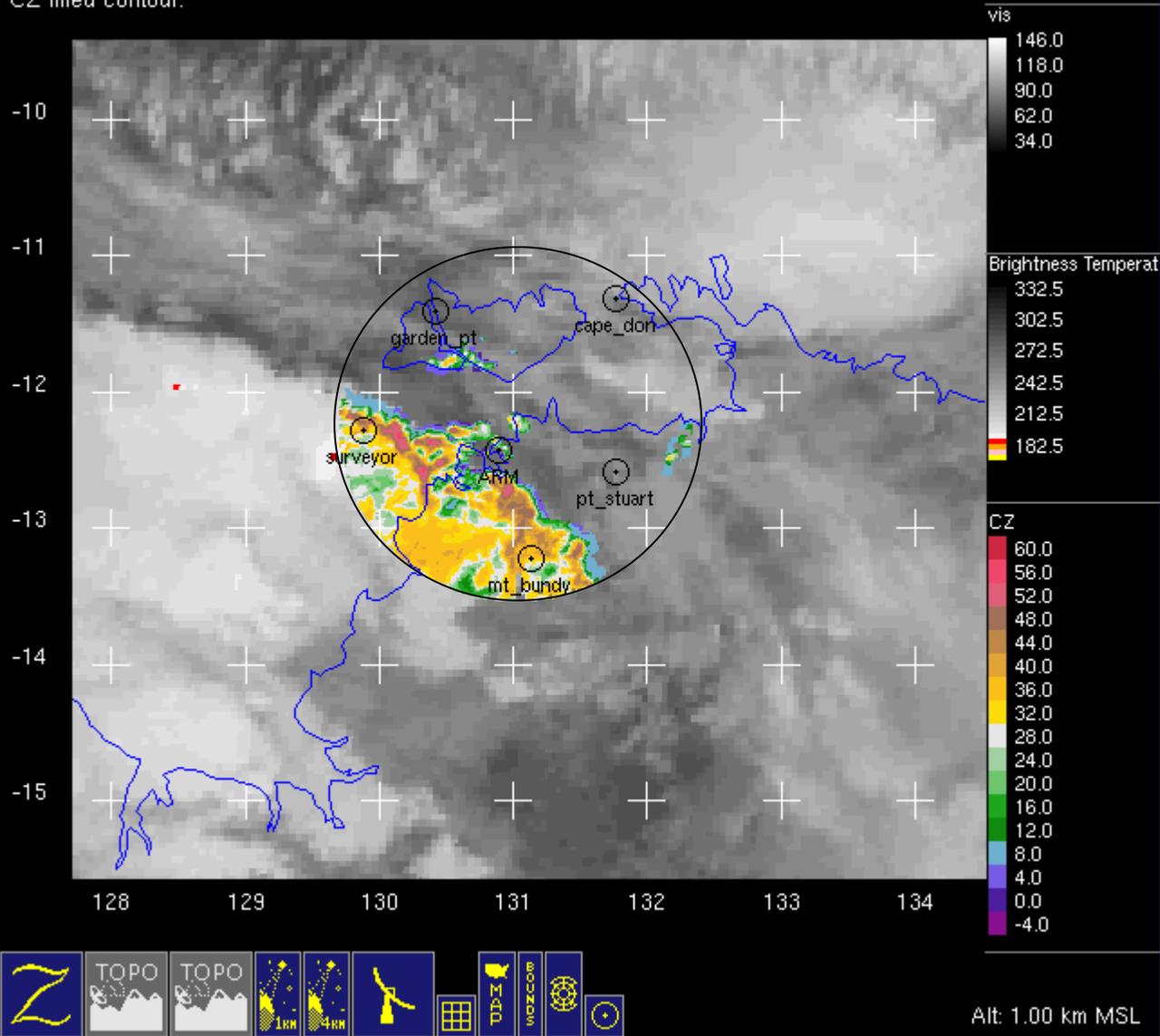
19-20 January MCS

19-jan-2006,21:03:00 mtsat_vis_1km vis plot. mtsat_ir_4km Brightness Temperature plot. GunnPt_polar_qc CZ filled contour.



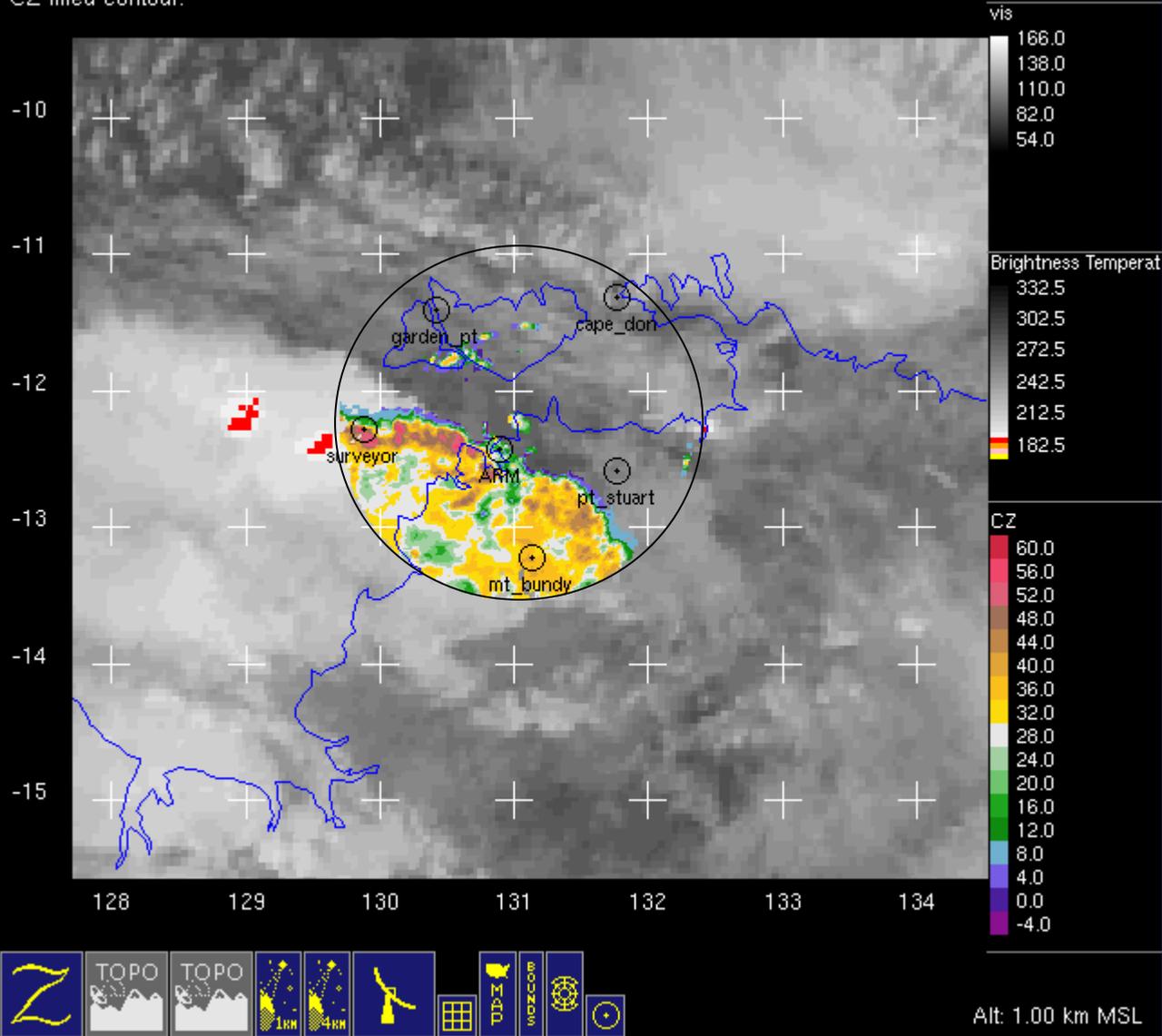
19-20 January MCS

19-jan-2006,22:03:00 mtsat_vis_1km vis plot. mtsat_ir_4km Brightness Temperature plot. GunnPt_polar_qc CZ filled contour.

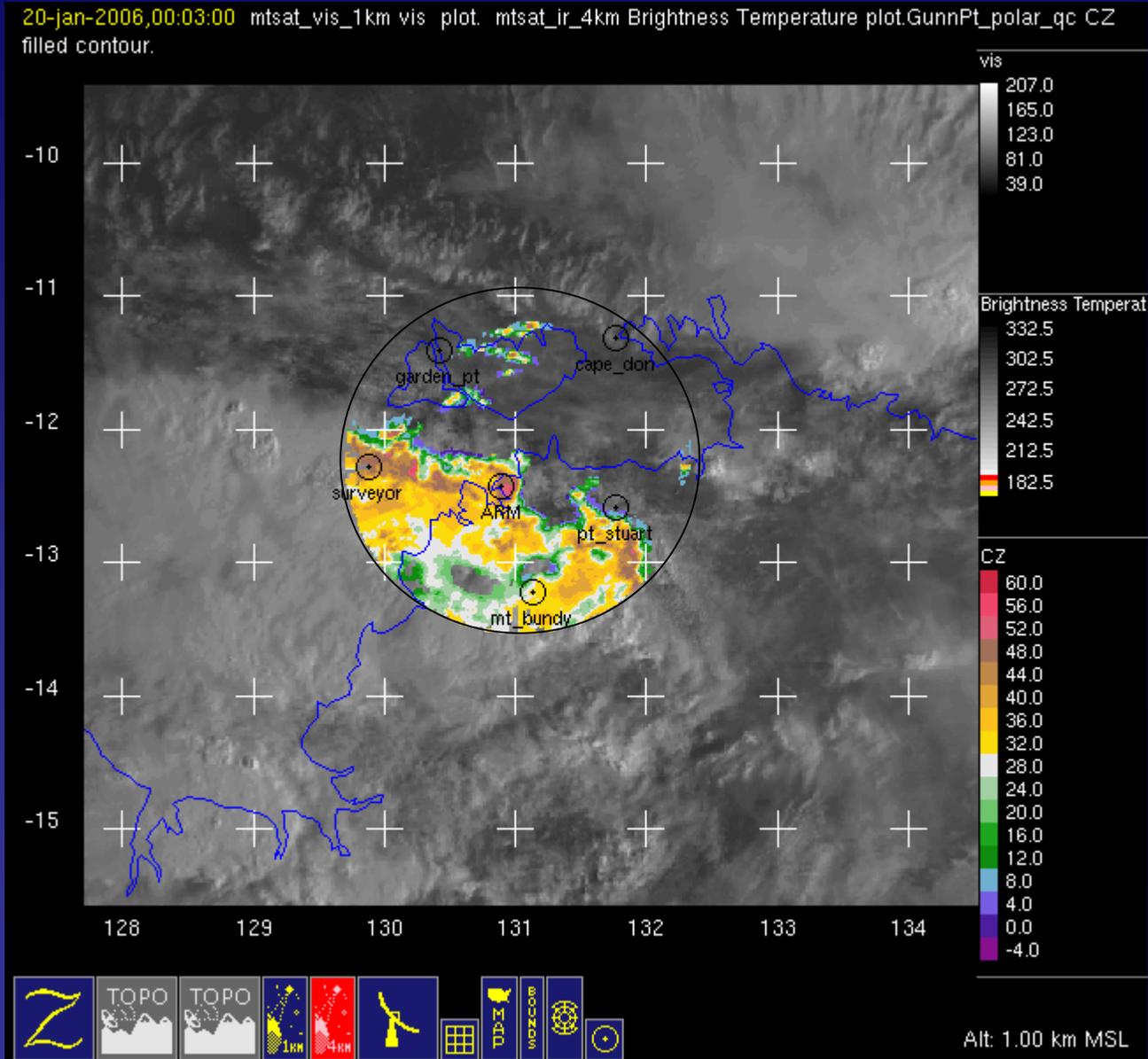


19-20 January MCS

19-jan-2006,23:03:00 mtsat_vis_1km vis plot. mtsat_ir_4km Brightness Temperature plot. GunnPt_polar_qc CZ filled contour.

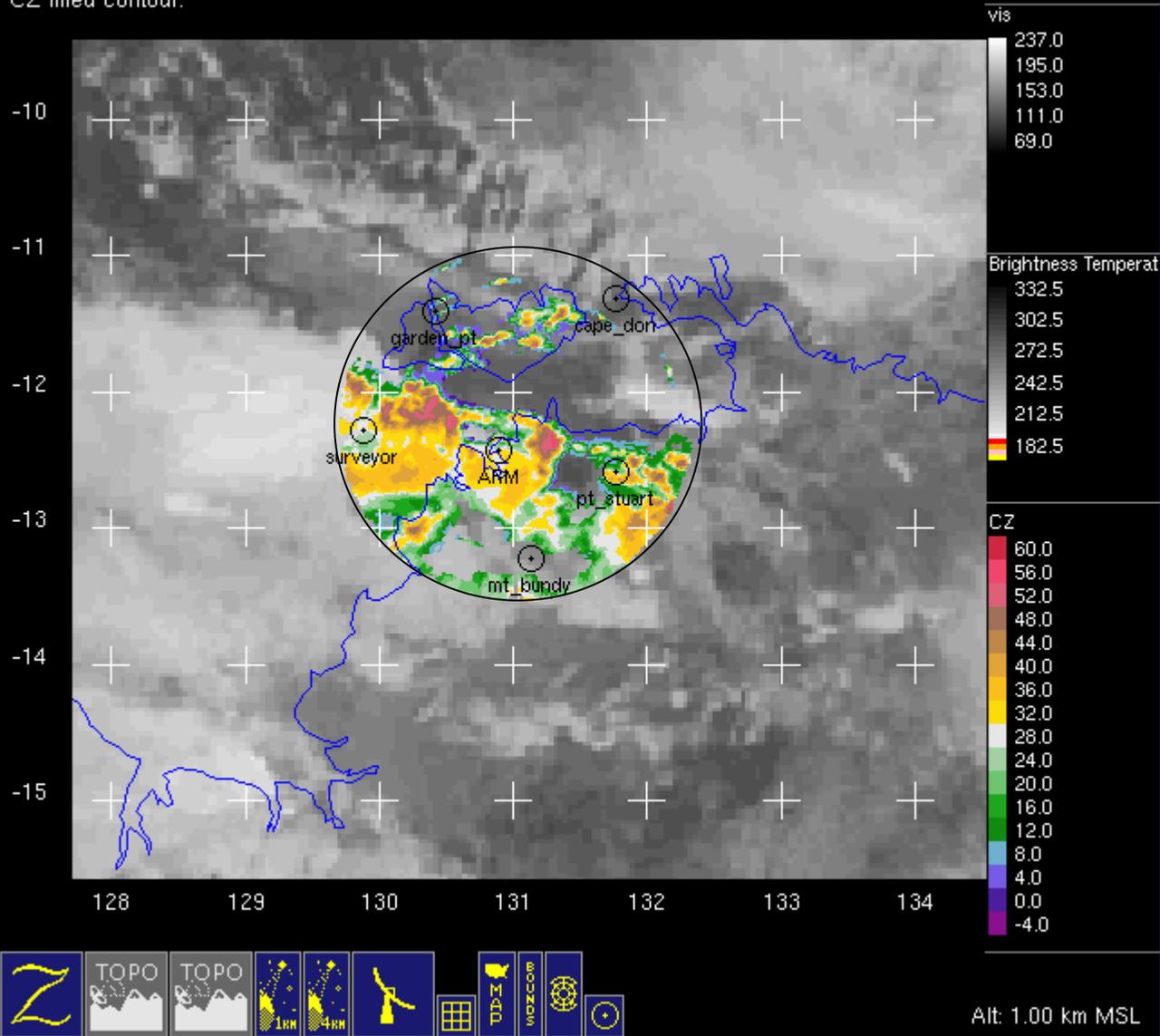


19-20 January MCS



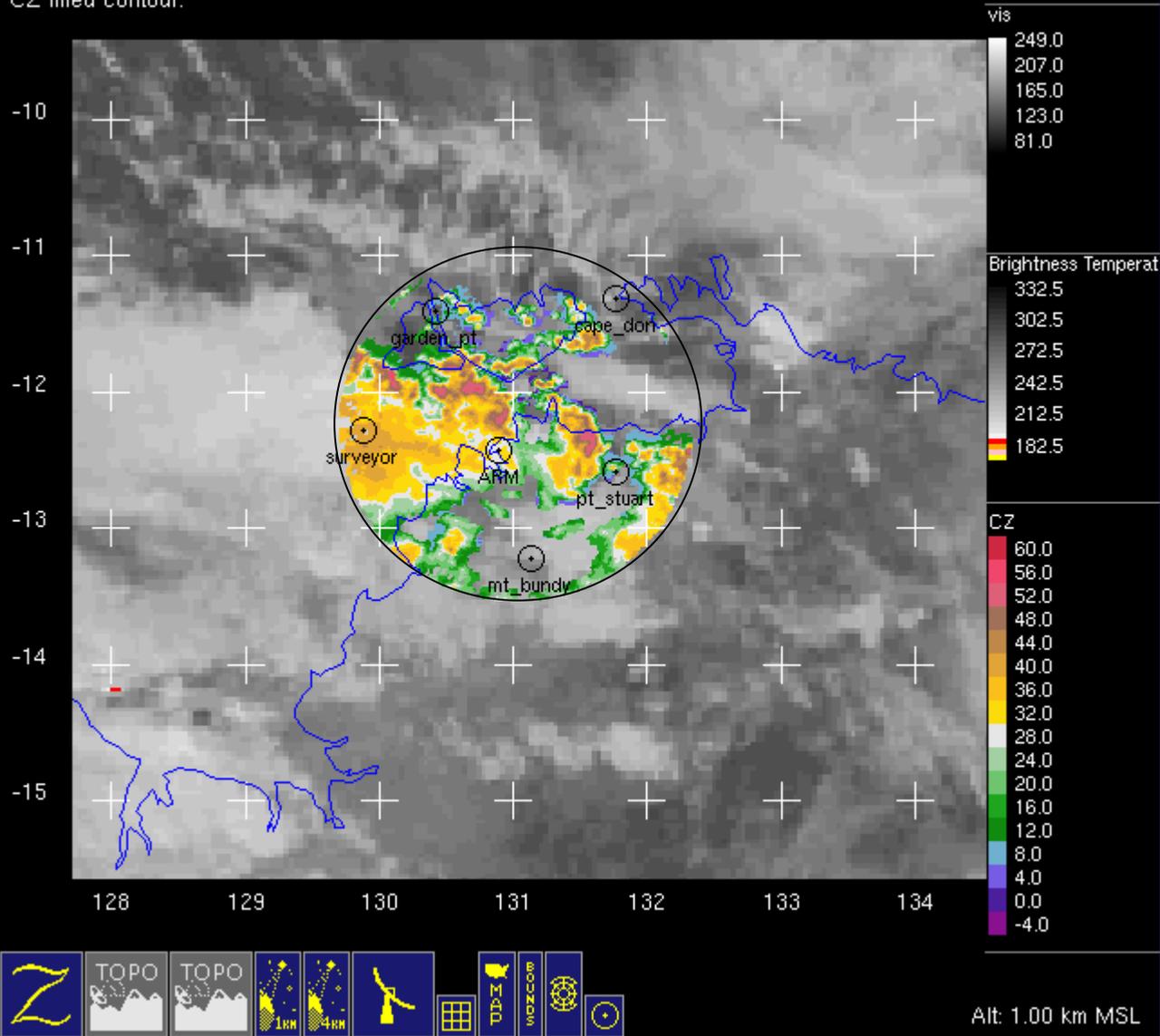
19-20 January MCS

20-jan-2006,01:03:00 mtsat_vis_1km vis plot. mtsat_ir_4km Brightness Temperature plot. GunnPt_polar_qc CZ filled contour.



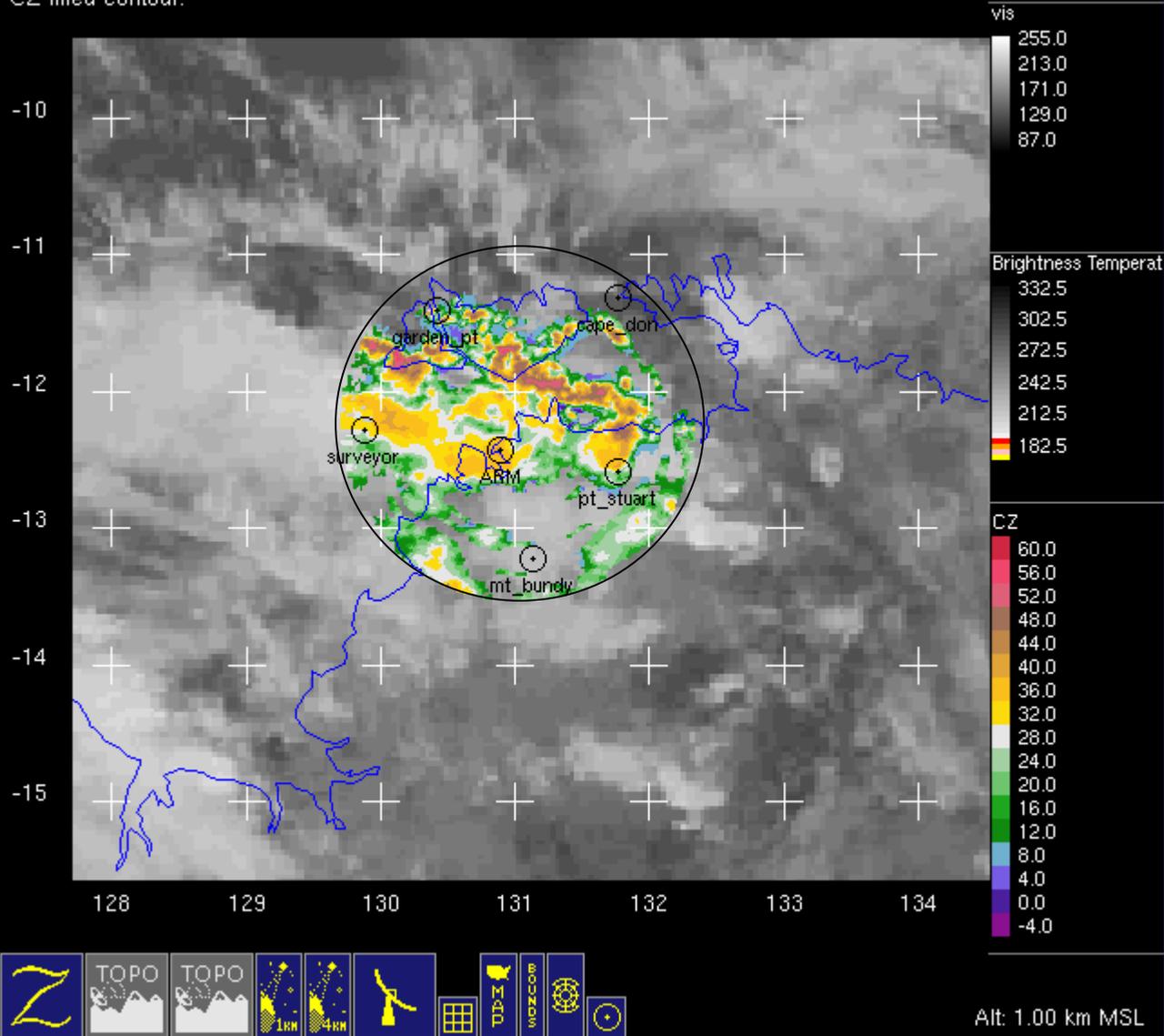
19-20 January MCS

20-jan-2006,02:03:00 mtsat_vis_1km vis plot. mtsat_ir_4km Brightness Temperature plot. GunnPt_polar_qc CZ filled contour.



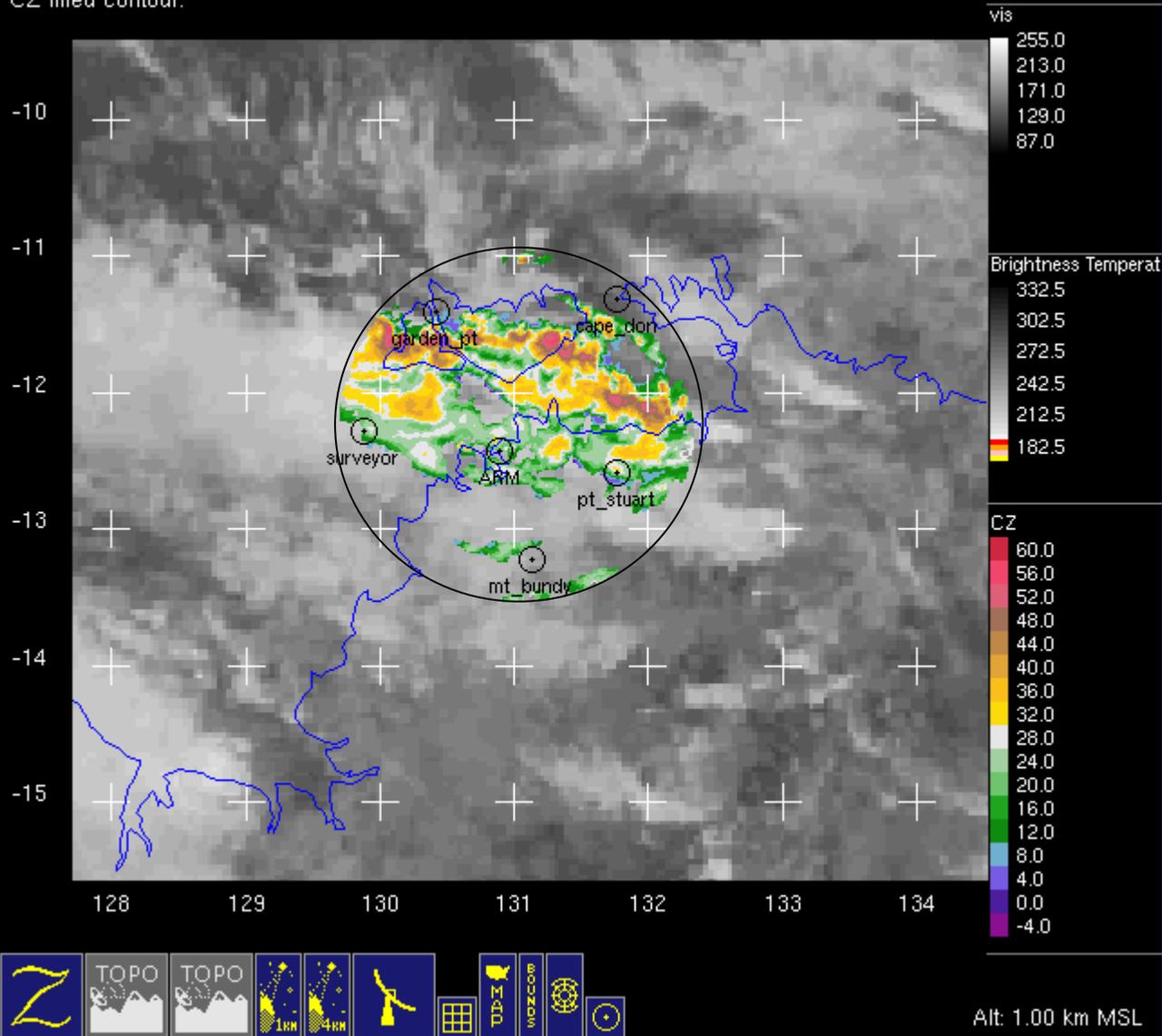
19-20 January MCS

20-jan-2006,03:03:00 mtsat_vis_1km vis plot. mtsat_ir_4km Brightness Temperature plot. GunnPt_polar_qc CZ filled contour.

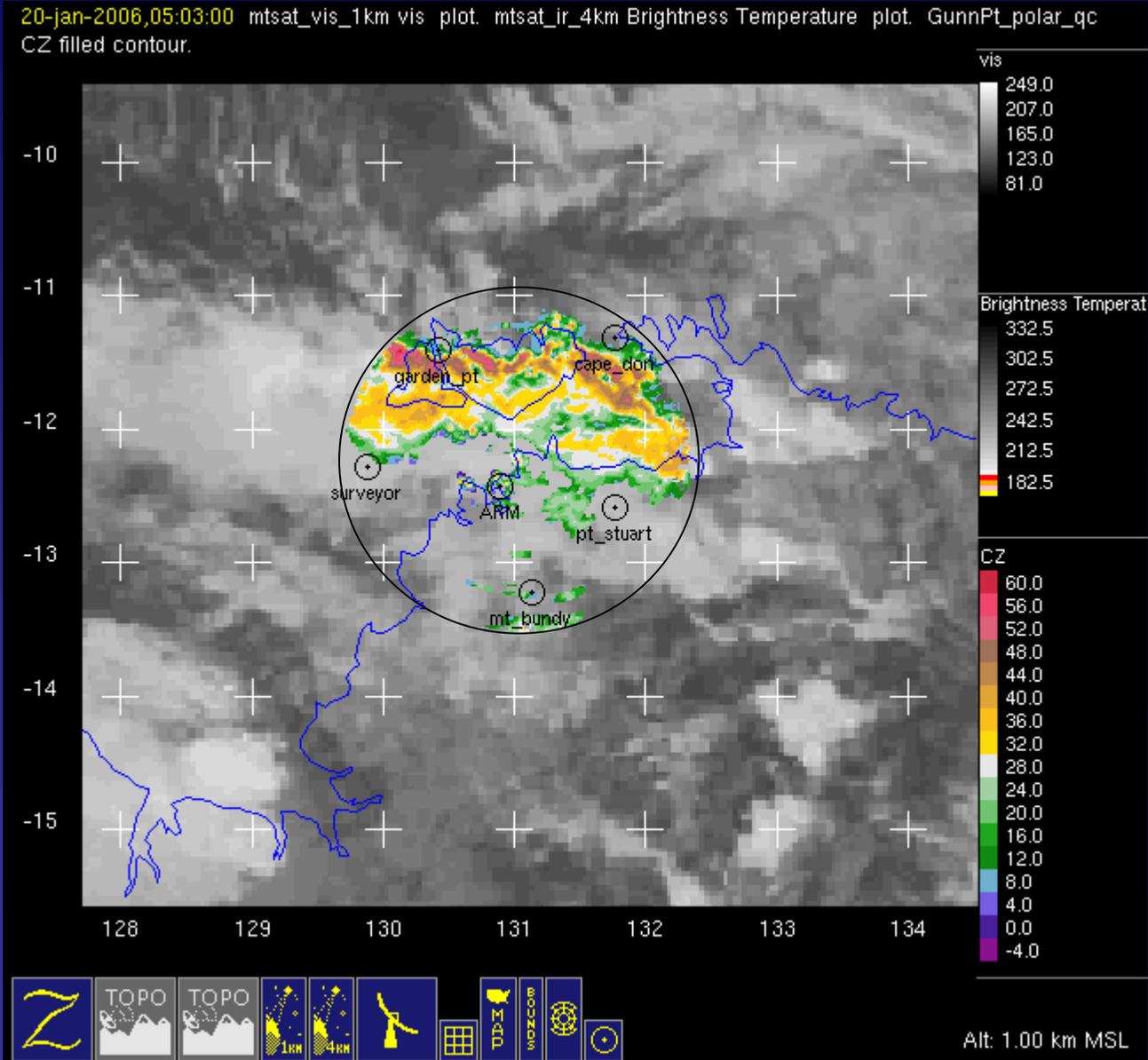


19-20 January MCS

20-jan-2006,04:03:00 mtsat_vis_1km vis plot. mtsat_ir_4km Brightness Temperature plot. GunnPt_polar_qc CZ filled contour.

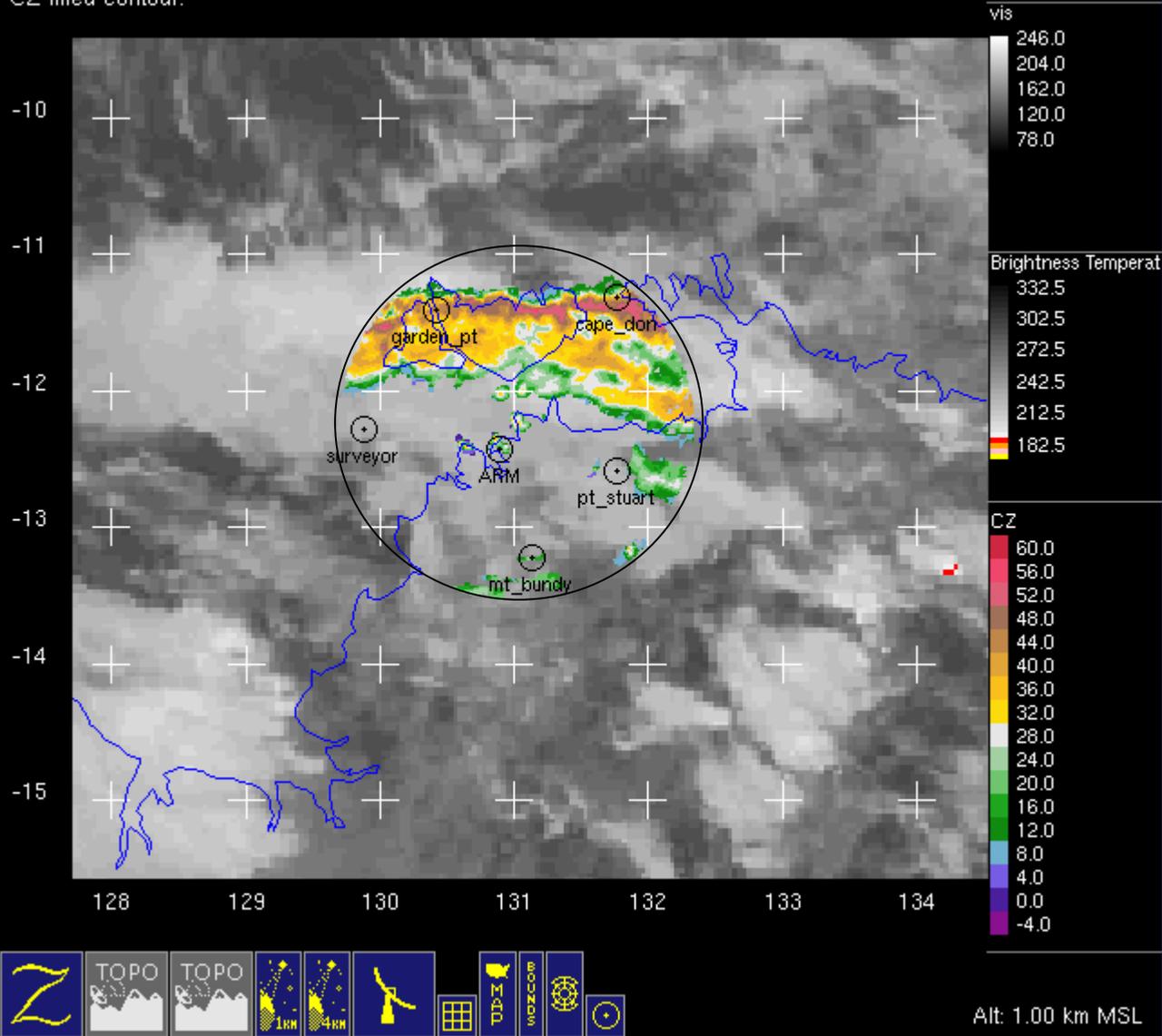


19-20 January MCS



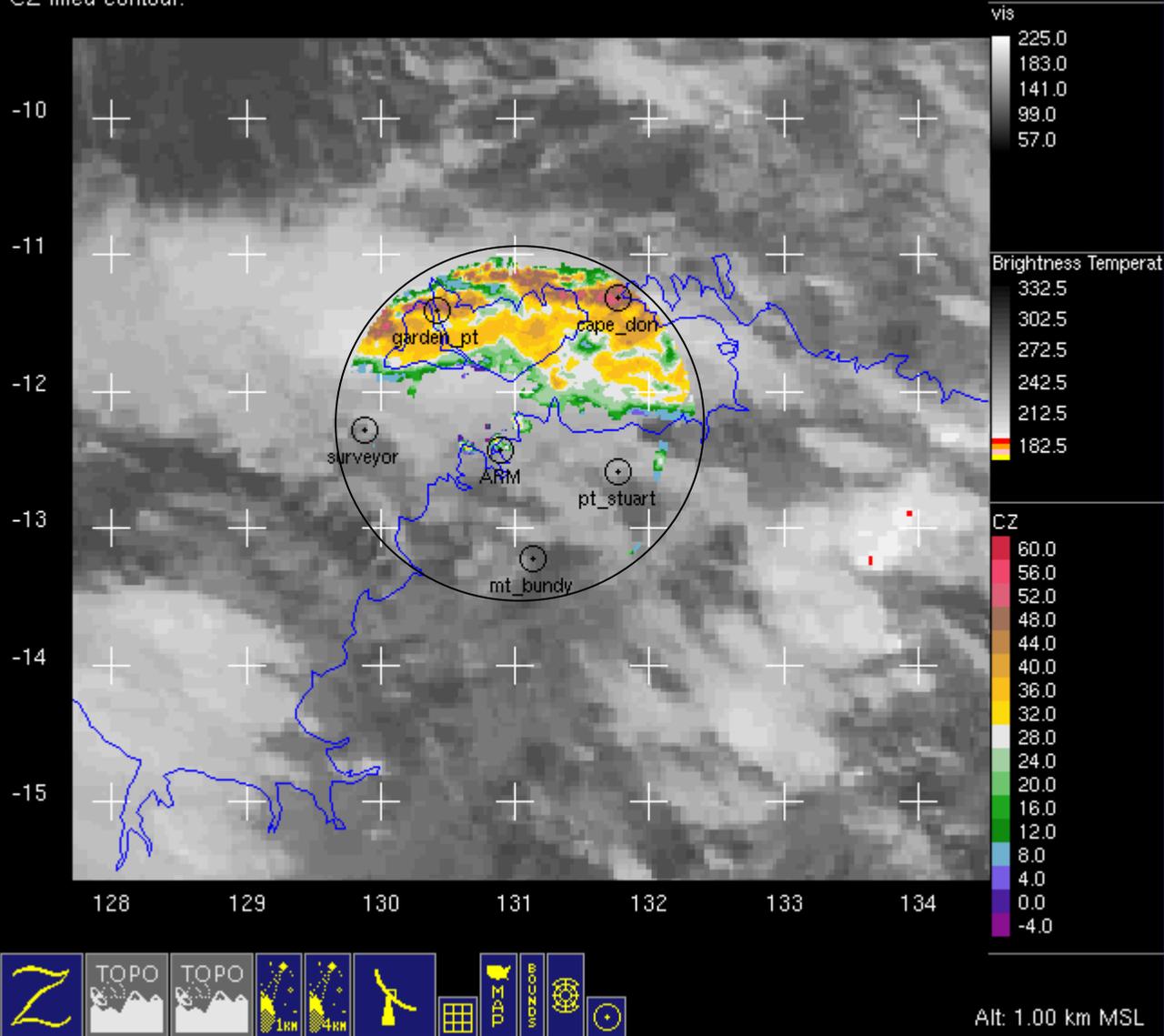
19-20 January MCS

20-jan-2006,06:03:00 mtsat_vis_1km vis plot. mtsat_ir_4km Brightness Temperature plot. GunnPt_polar_qc CZ filled contour.



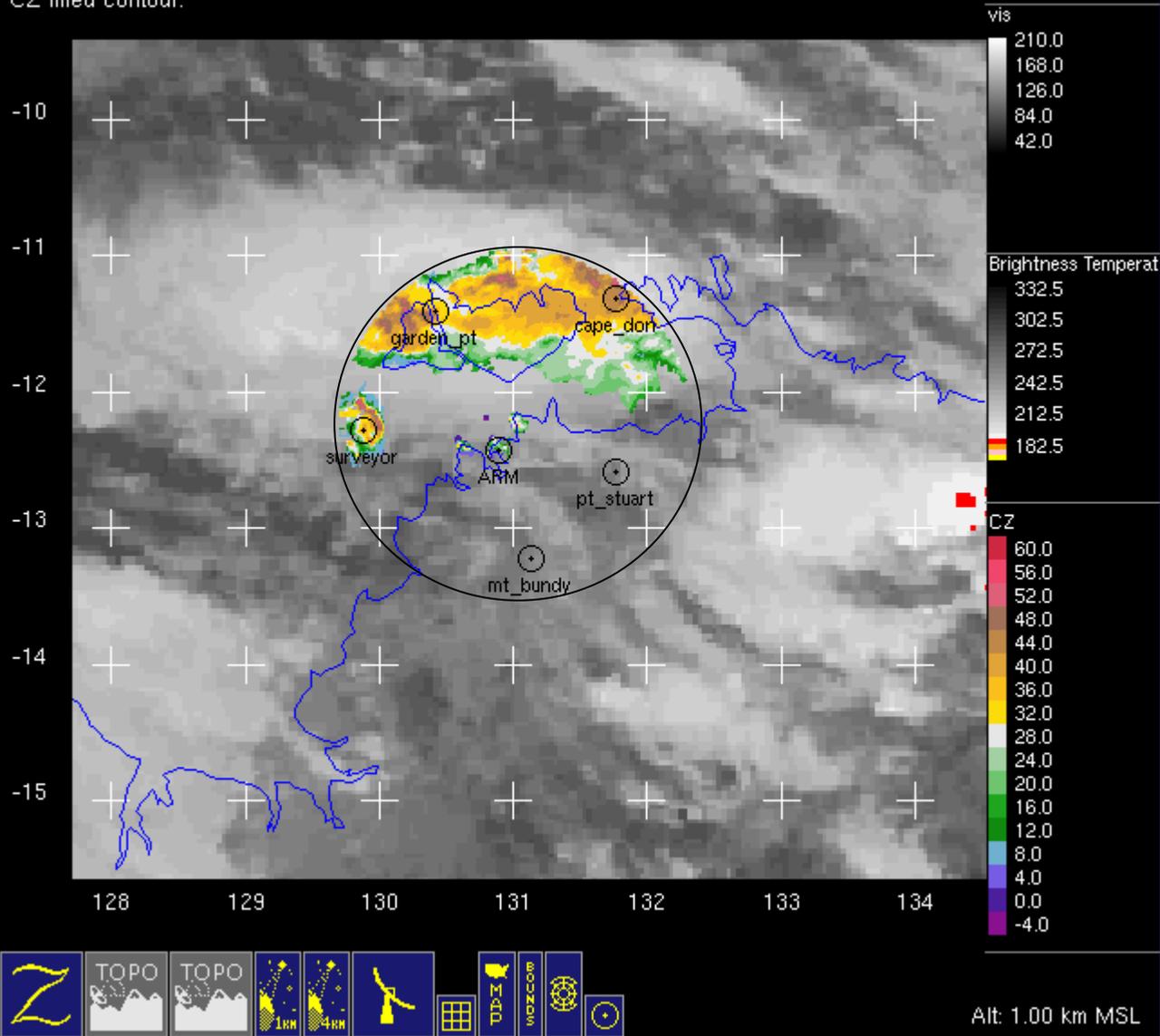
19-20 January MCS

20-jan-2006,07:03:00 mtsat_vis_1km vis plot. mtsat_ir_4km Brightness Temperature plot. GunnPt_polar_qc CZ filled contour.



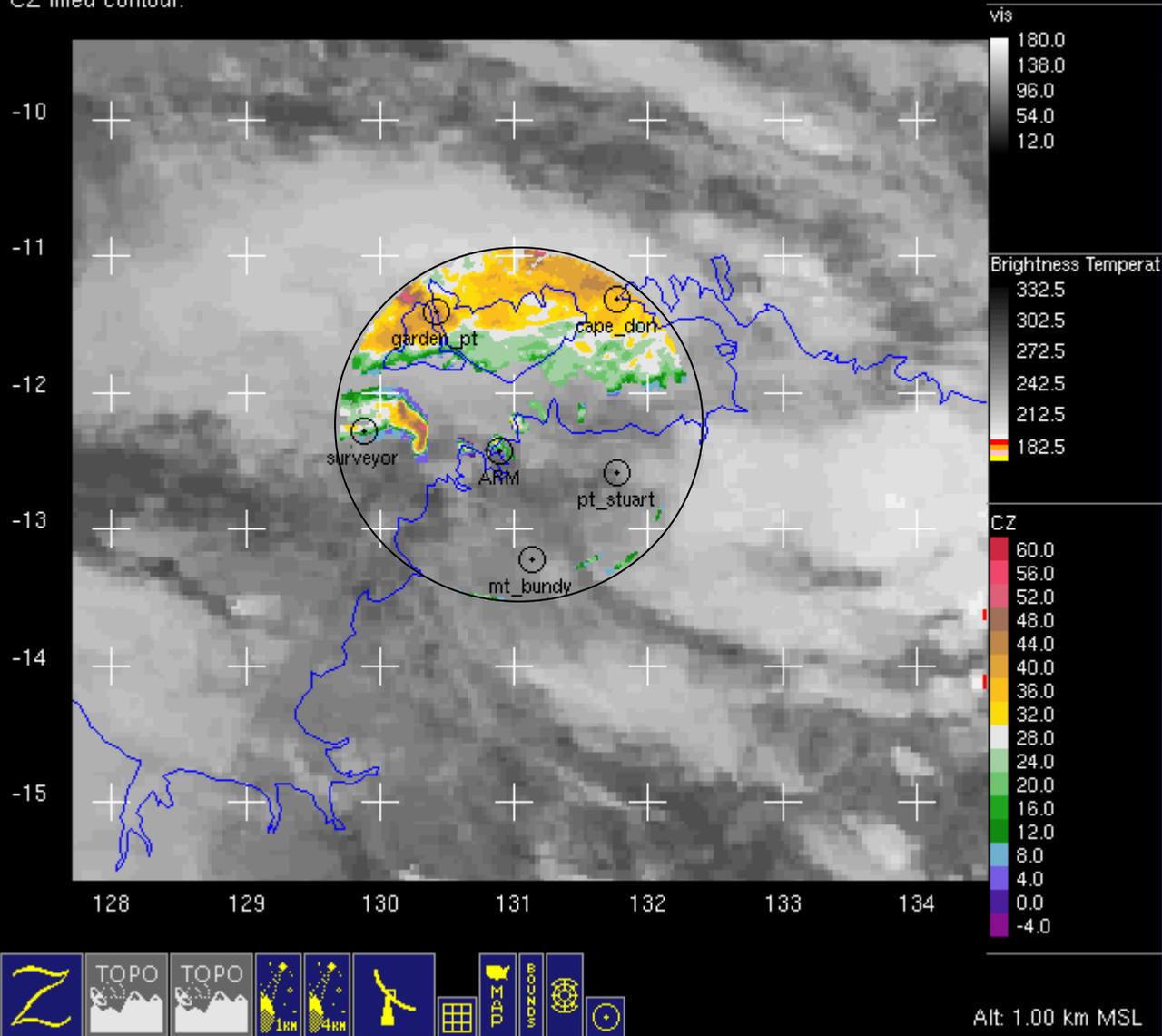
19-20 January MCS

20-jan-2006,08:03:00 mtsat_vis_1km vis plot. mtsat_ir_4km Brightness Temperature plot. GunnPt_polar_qc CZ filled contour.



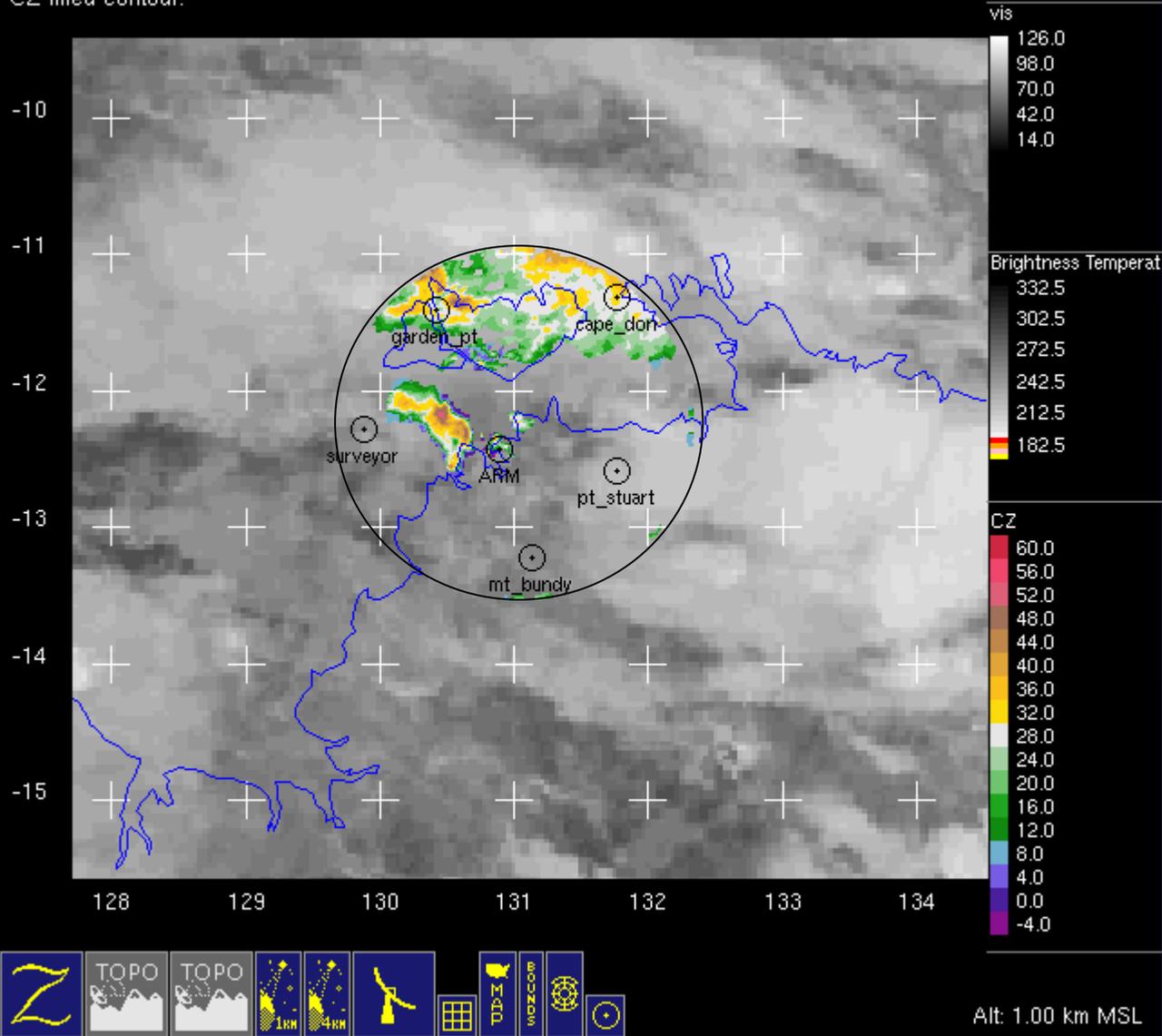
19-20 January MCS

20-jan-2006,09:03:00 mtsat_vis_1km vis plot. mtsat_ir_4km Brightness Temperature plot. GunnPt_polar_qc CZ filled contour.



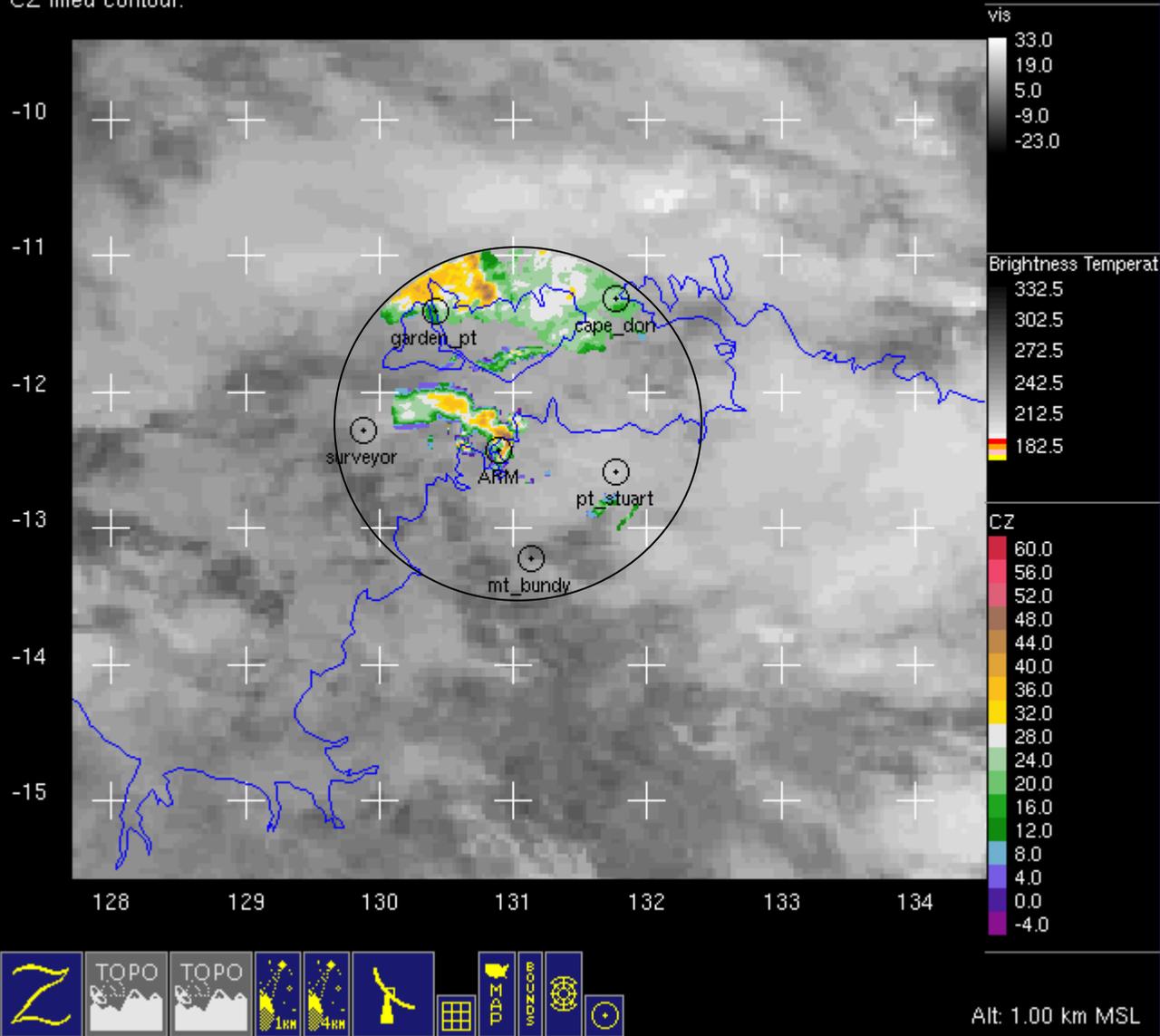
19-20 January MCS

20-jan-2006,10:03:00 mtsat_vis_1km vis plot. mtsat_ir_4km Brightness Temperature plot. GunnPt_polar_qc CZ filled contour.



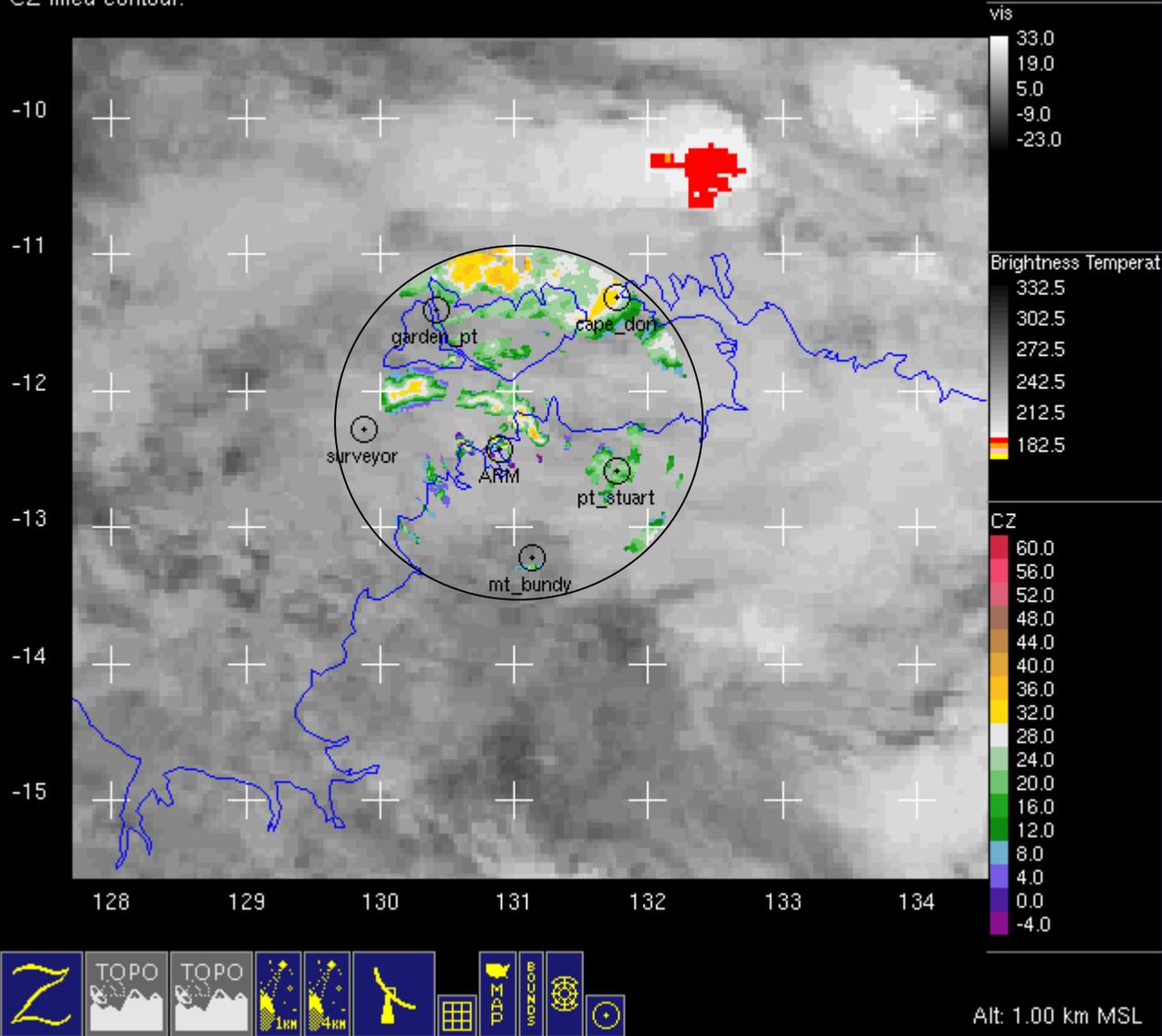
19-20 January MCS

20-jan-2006,11:03:00 mtsat_vis_1km vis plot. mtsat_ir_4km Brightness Temperature plot. GunnPt_polar_qc CZ filled contour.



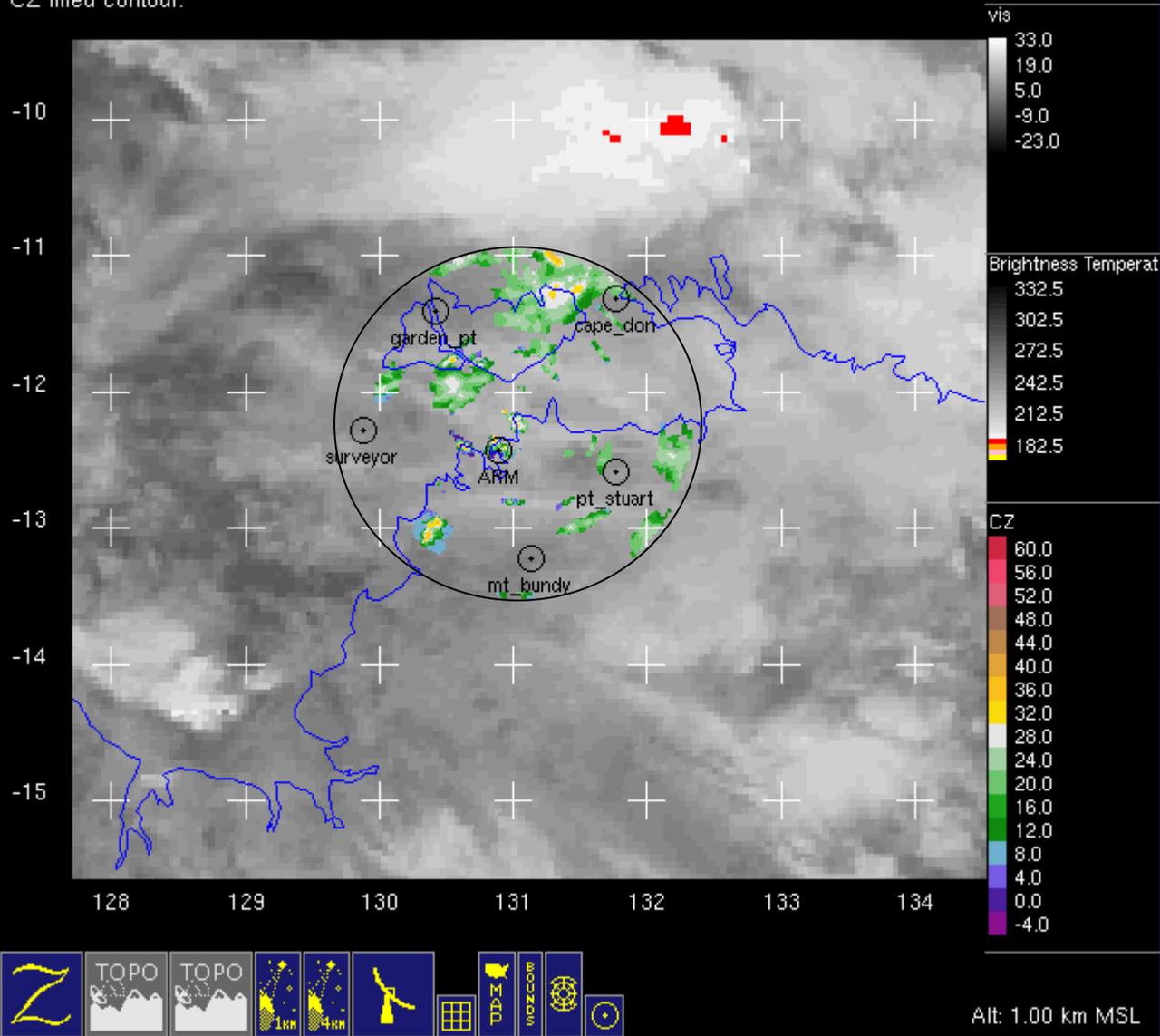
19-20 January MCS

20-jan-2006,12:03:00 mtsat_vis_1km vis plot. mtsat_ir_4km Brightness Temperature plot. GunnPt_polar_qc CZ filled contour.



19-20 January MCS

20-jan-2006,13:03:00 mtsat_vis_1km vis plot. mtsat_ir_4km Brightness Temperature plot. GunnPt_polar_qc CZ filled contour.



Finding anvil amounts from water budget equations

- Assume portion of cloud system passing over radar was representative of whole system (not true)
- Compute total convective and stratiform rain amounts from C-Pol radar (in radar domain)
- Use a range of assumed values of the water budget parameters $\varepsilon_c, \alpha, \eta, \varepsilon_s, a$ (from Houze and Cheng 1981)
- Compute $A_c + A_s$

Results using water budget

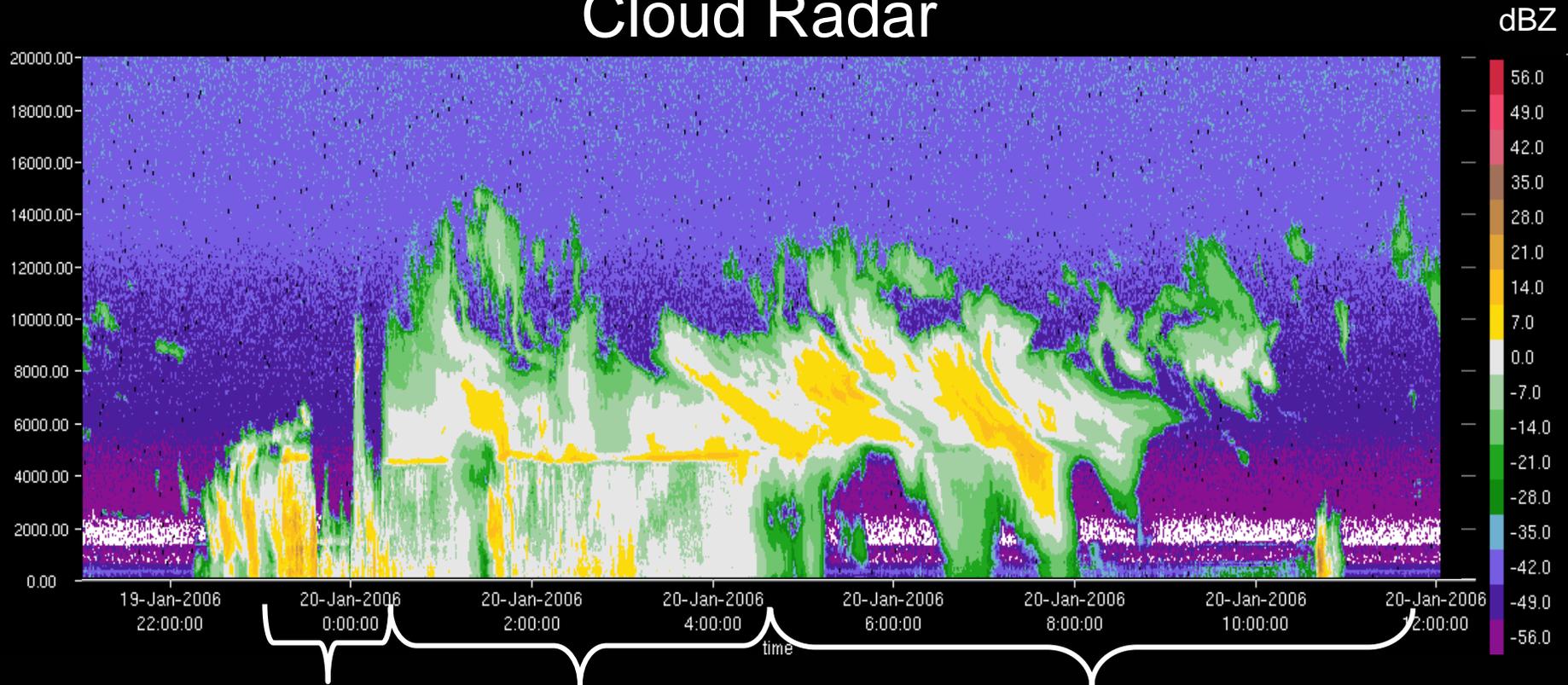
$$R_c = 2.8586 \times 10^{12} \text{ kg}, R_s = 6.7226 \times 10^{11} \text{ kg}$$

α	a	ε_c	$A_c + A_s$
0.13	0.35	0.38	$1.0538 \times 10^{12} \text{ kg}$
0.13	0.20	0.49	$6.9538 \times 10^{11} \text{ kg}$
0.13	0.15	0.50	$6.6096 \times 10^{11} \text{ kg}$
0.13	0.08	0.54	$5.6997 \times 10^{11} \text{ kg}$
0.13	0	0.50	$6.2993 \times 10^{11} \text{ kg}$
0.13	0	0.61	$4.4759 \times 10^{11} \text{ kg}$

→ Realistic Values, acc. to Houze and Cheng 1981

19-20 January MCS

Cloud Radar



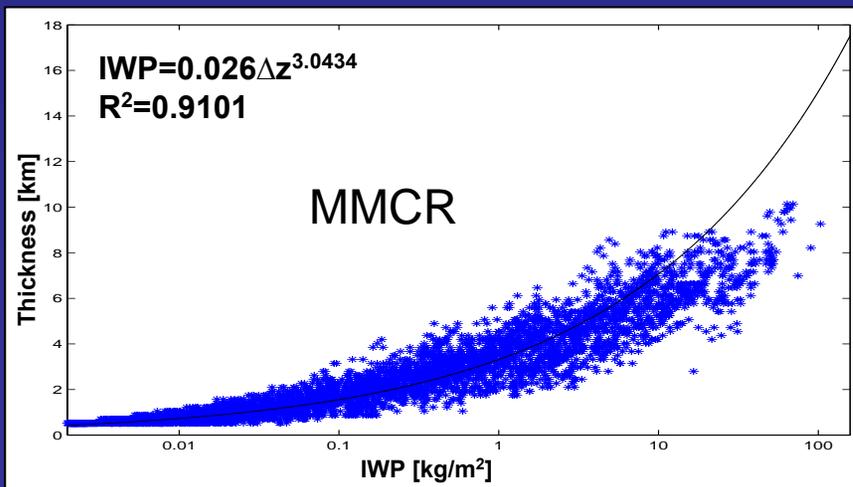
Convective

Stratiform

Anvil

Finding anvil amounts from MMCR and C-Pol

- Find a relationship between cloud thickness and IWP (MMCR)
- Compute the average area and thickness of anvil clouds in radar range using C-Pol
- Calculate the amount of anvil water/ice ($A_c + A_s$) that is in range of C-Pol

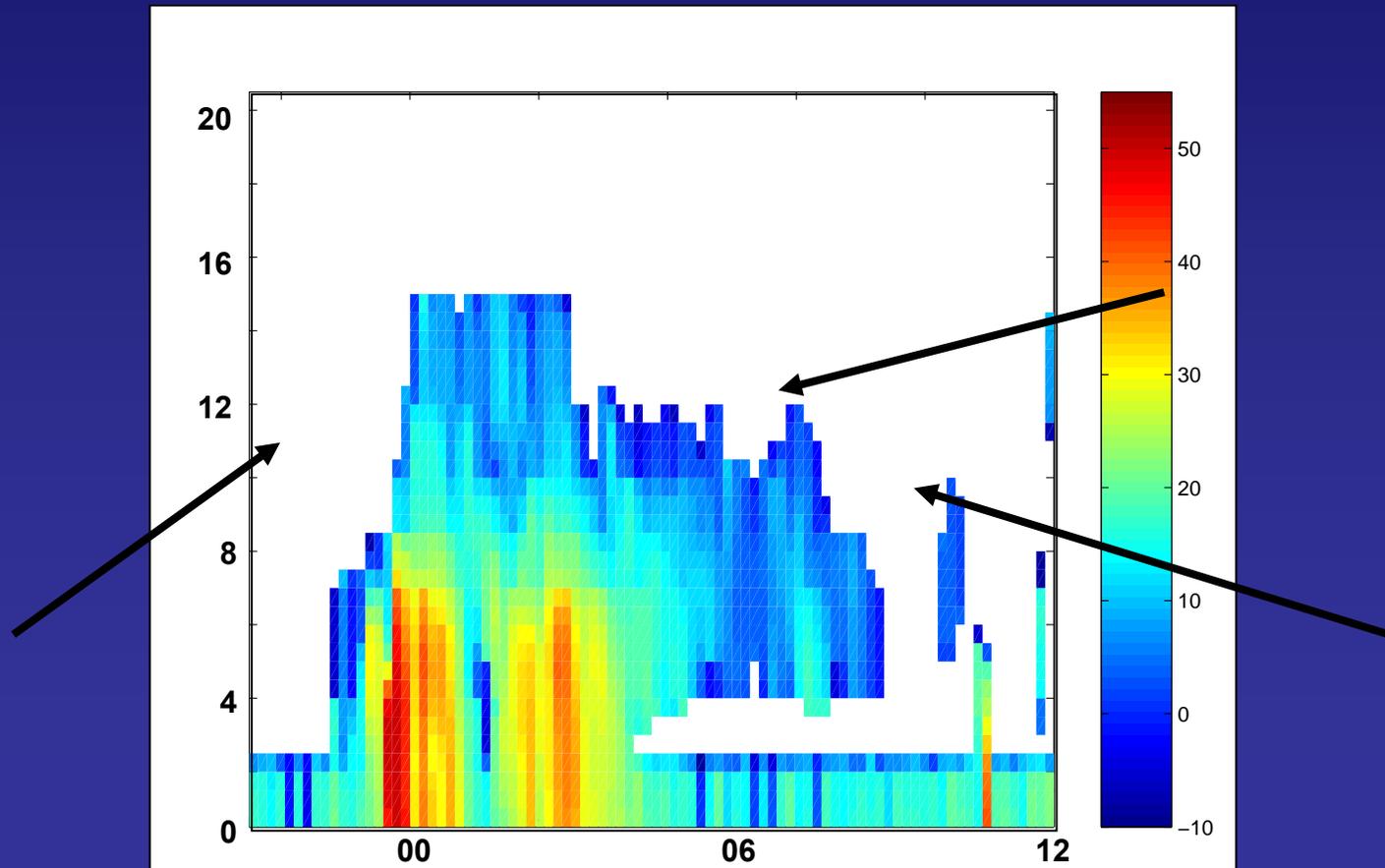


$$\rightarrow A_c + A_s = 4.2730 \times 10^{10} \text{ kg}$$

We're only getting about 10% of the anvil calculated by the water budget equations

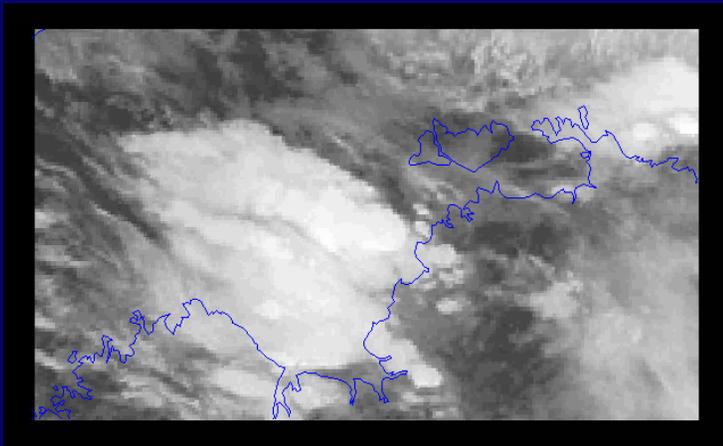
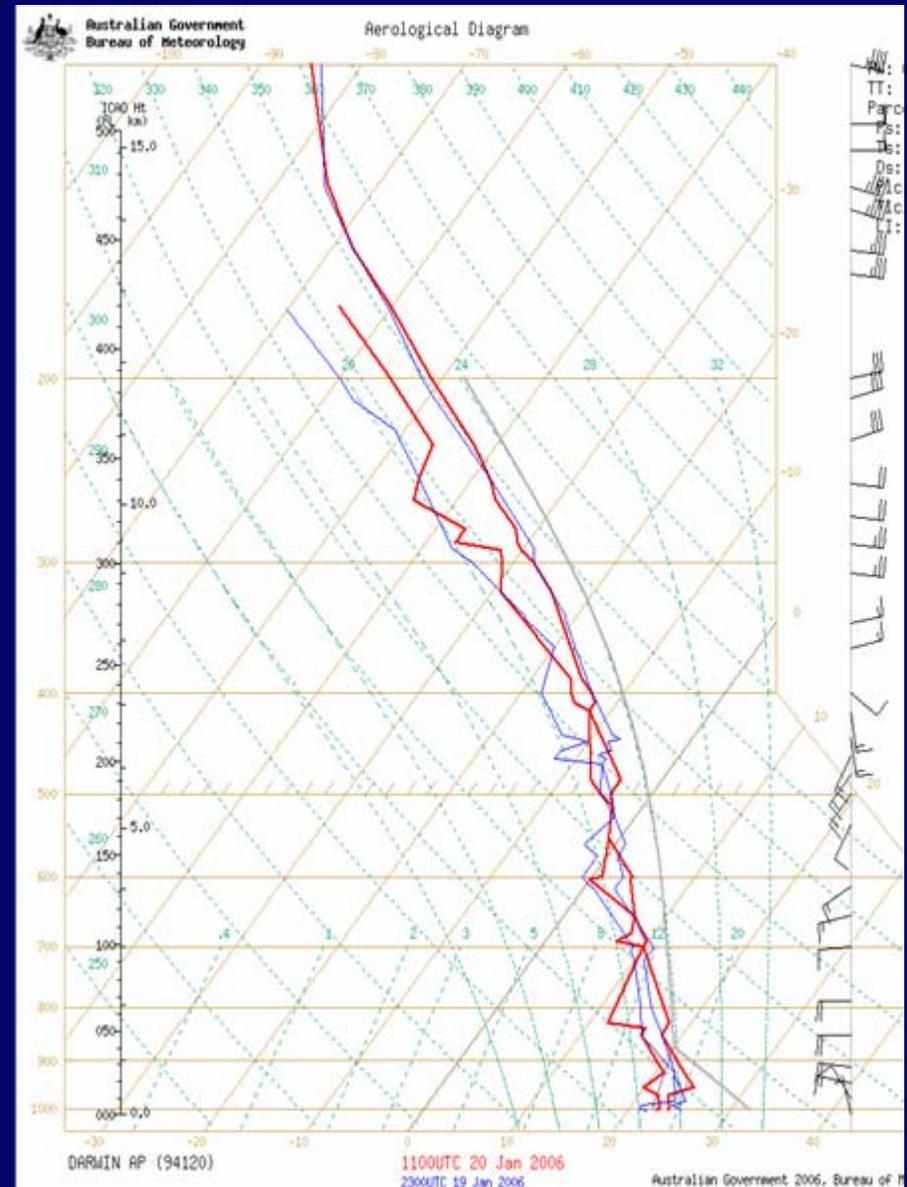
Why such a difference??

1. The CPol will miss some anvil because of its lower sensitivity



Why such a difference??

2. Above about 8-km, the winds were easterly, shearing much of the anvil to the west instead of it trailing behind the system (i.e. out of CPol's range)



Future Improvements

- Use **dual-Doppler** velocities, cloud radar, and sounding data to compute other values (CT , Ccu , Ecd , Csu , Esd) to calculate the water budget parameters
- Use **satellite data** to extend water budget to the whole system, rather than just radar area
- Use **model simulations** to help close the water budget
- Connect water budget to the **TRMM** PR overpass
- Find **other cases** → JASMINE, KWAJEX

JASMINE

India

Bay of Bengal

JASMINE
Ship Radar
Data

TRMM
Precipitation
Radar Swath

PR Reflectivity



maxdz



23 May 1999 0650 LST

80

85

90

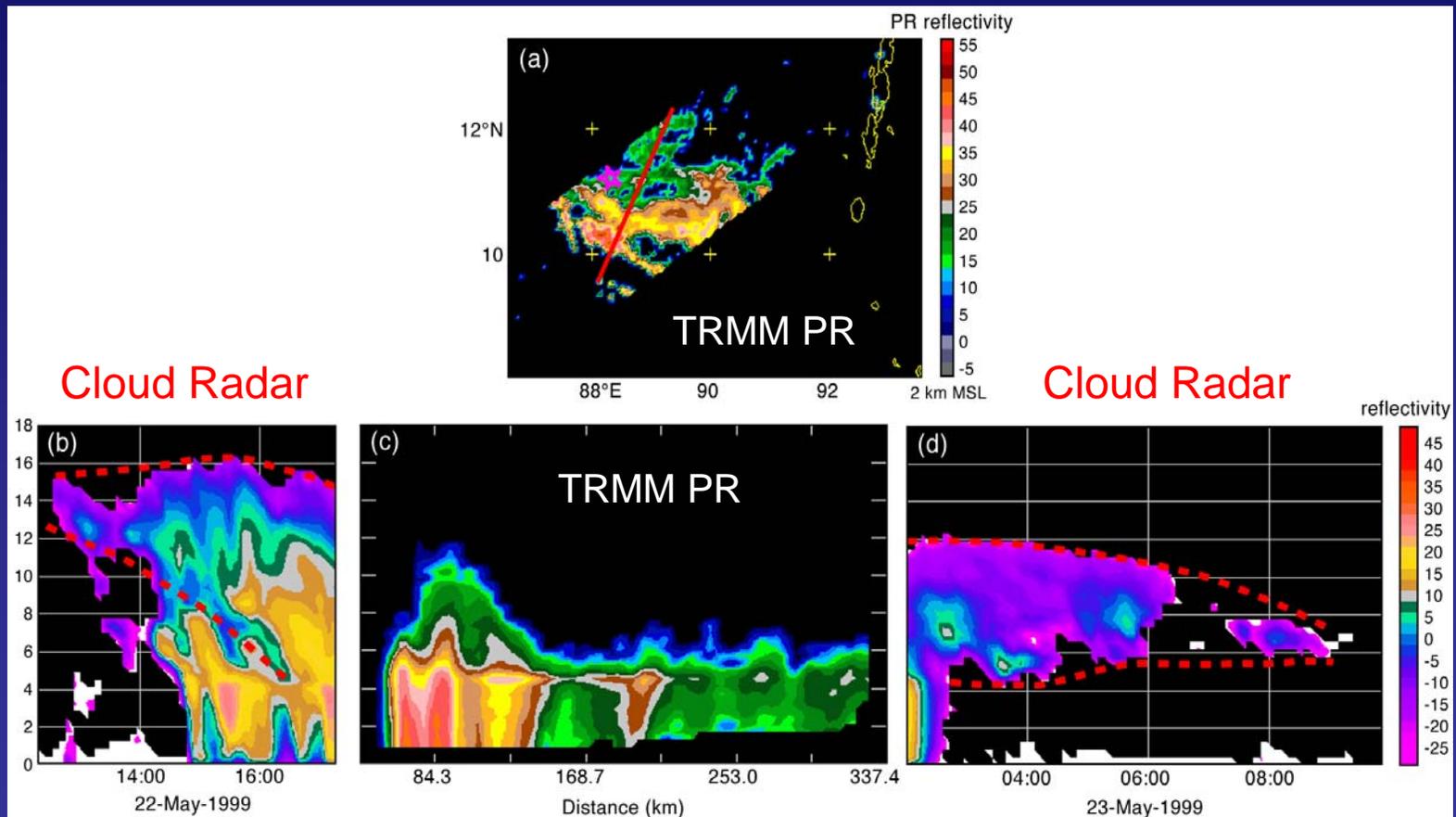
95

brown+pcode



Alt: 3.50 km MSL

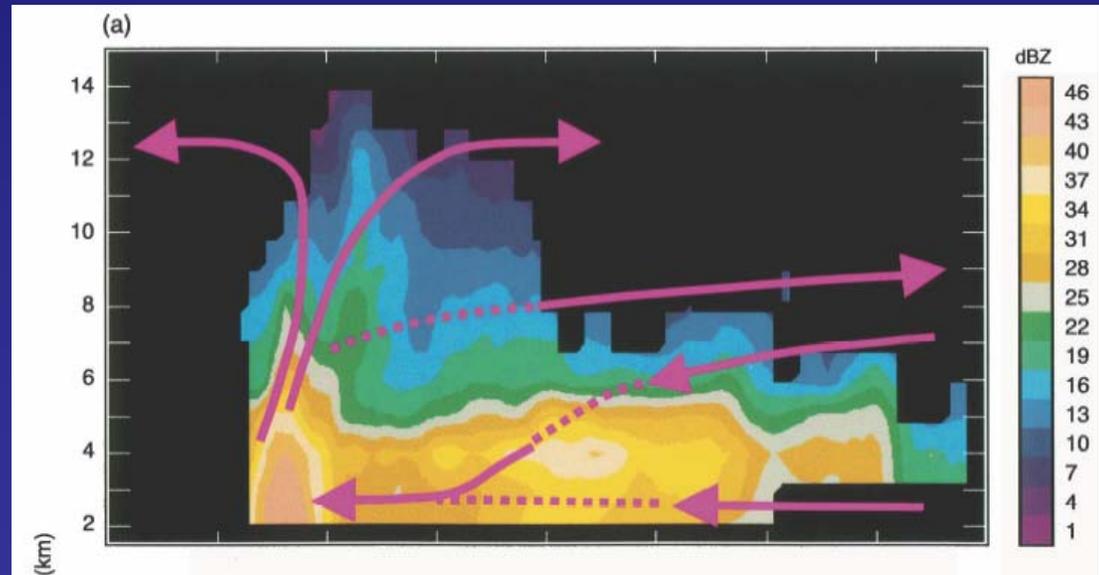
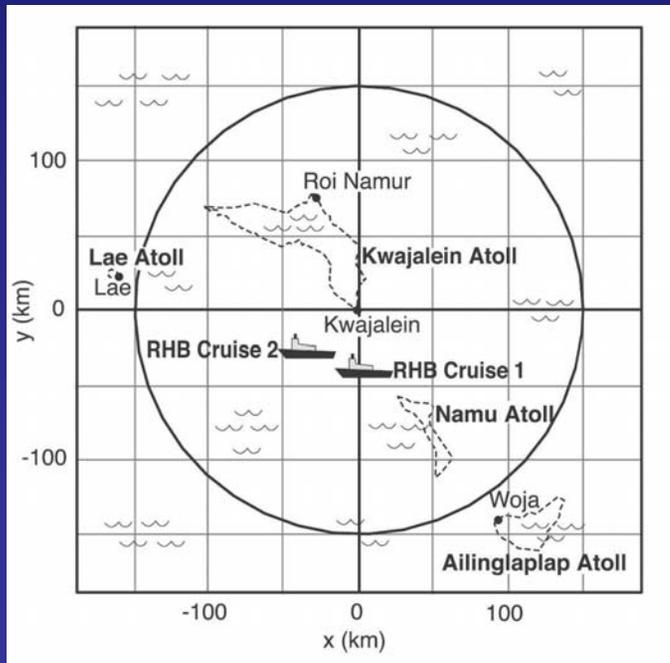
Cloud radar on ship shows anvil



Also: Scanning radar and ship soundings

KWAJEX

- TRMM
- Scanning C- and S-band Doppler radars
 - Vertically Pointing S-band radar
- Sounding Net



Thanks!

KWAJEX

