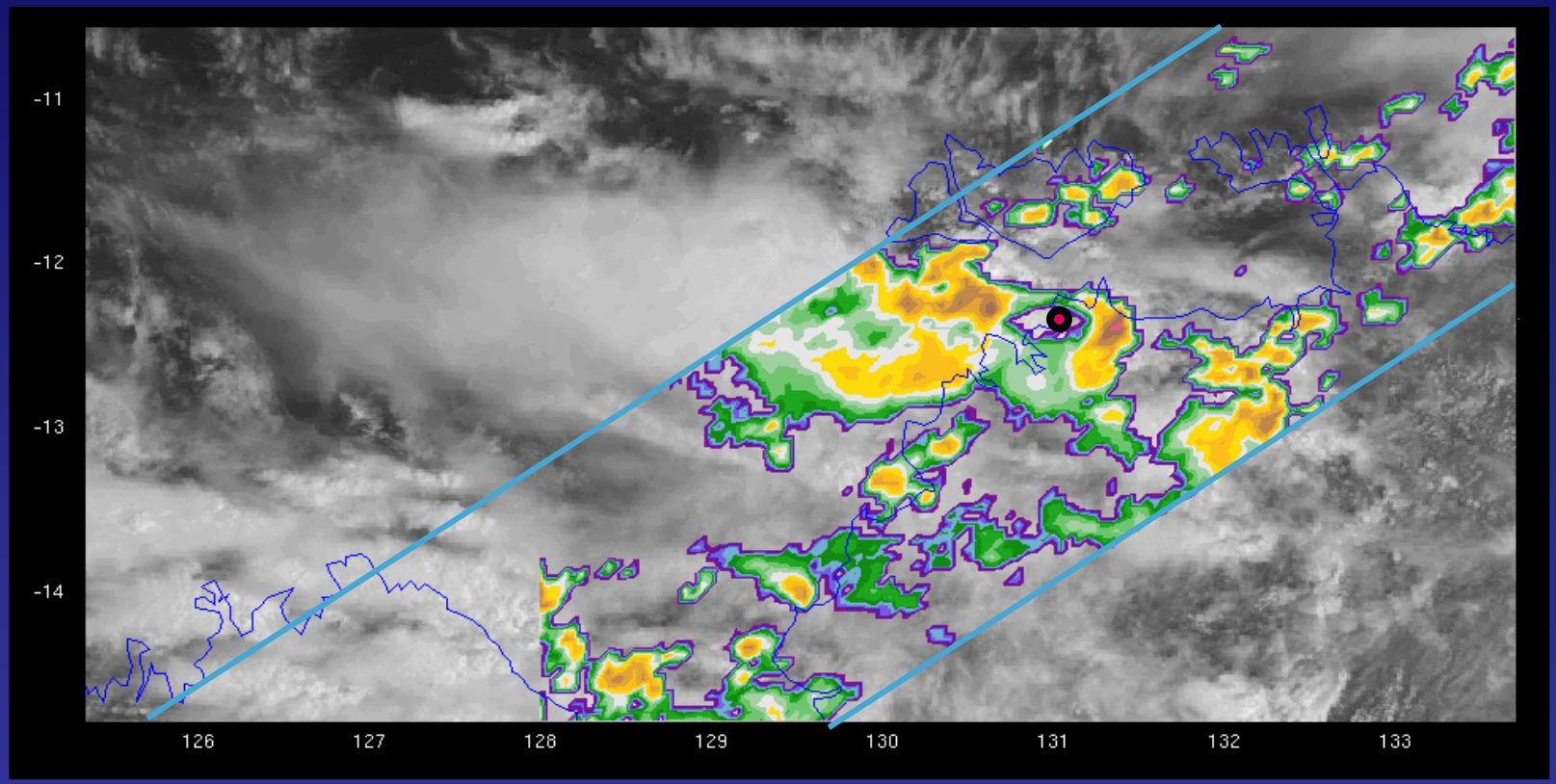
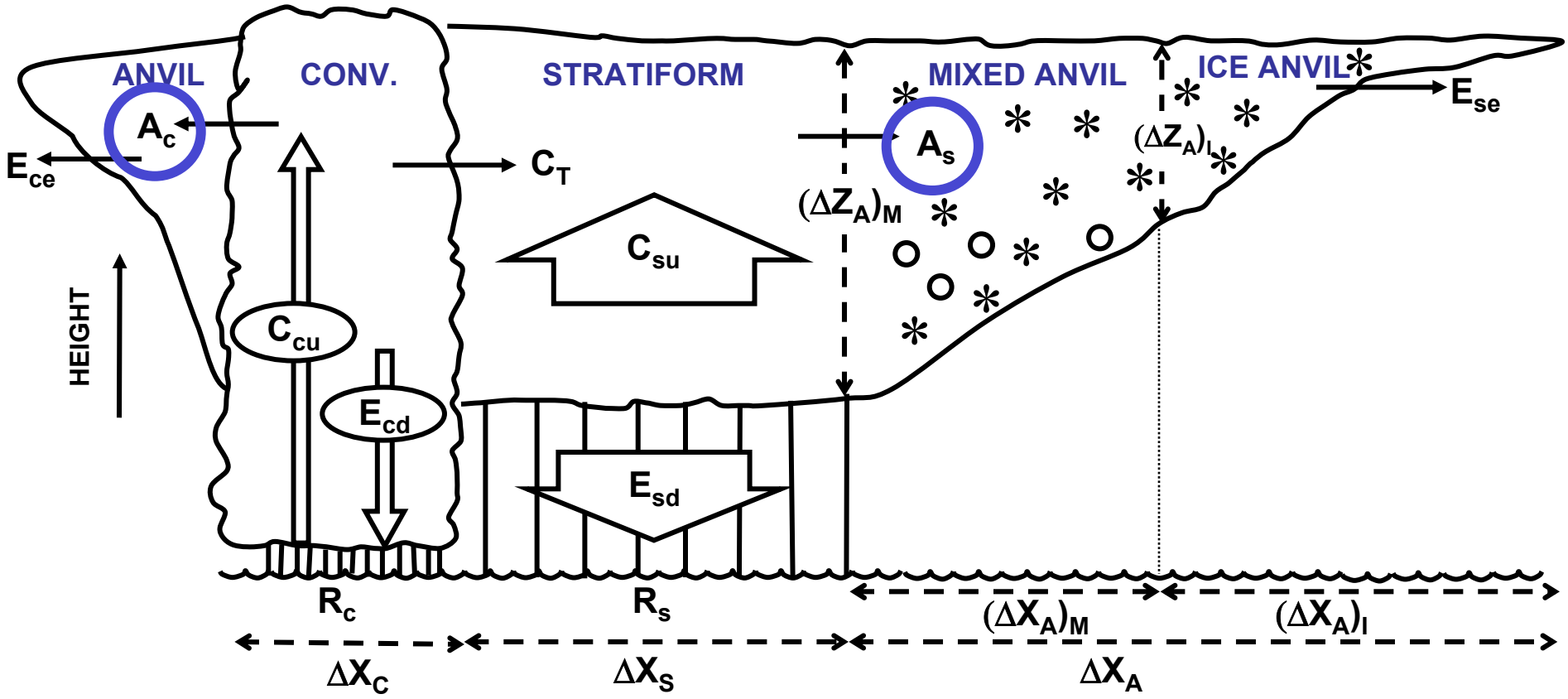
Anvil Generation in Relation to Cloud System Water Budget: TWP-ICE Case of 19-20 January 2006



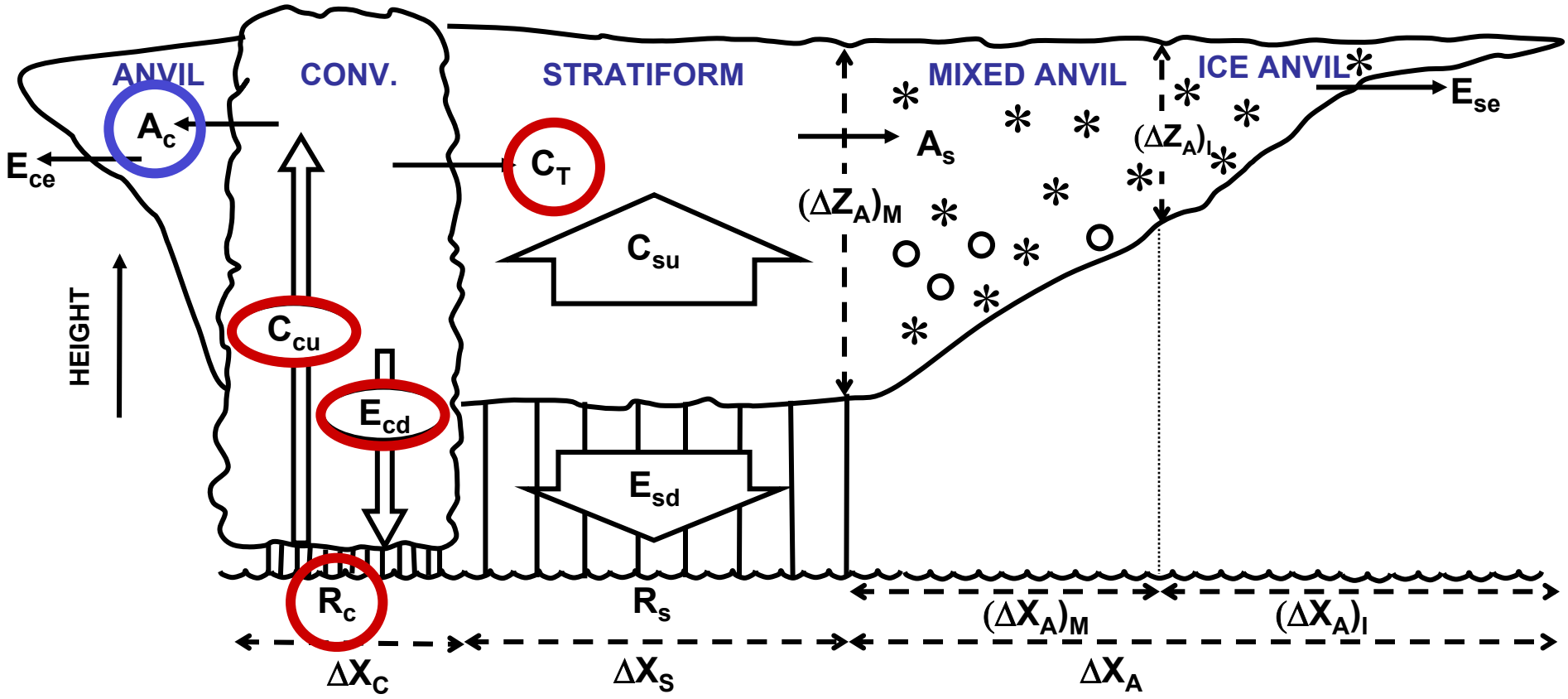
Jasmine Cetrone and Robert Houze
University of Washington

Presented 14 November 2006 at the TWP-ICE Workshop

Water Budget of an MCS



Water Budget Equations



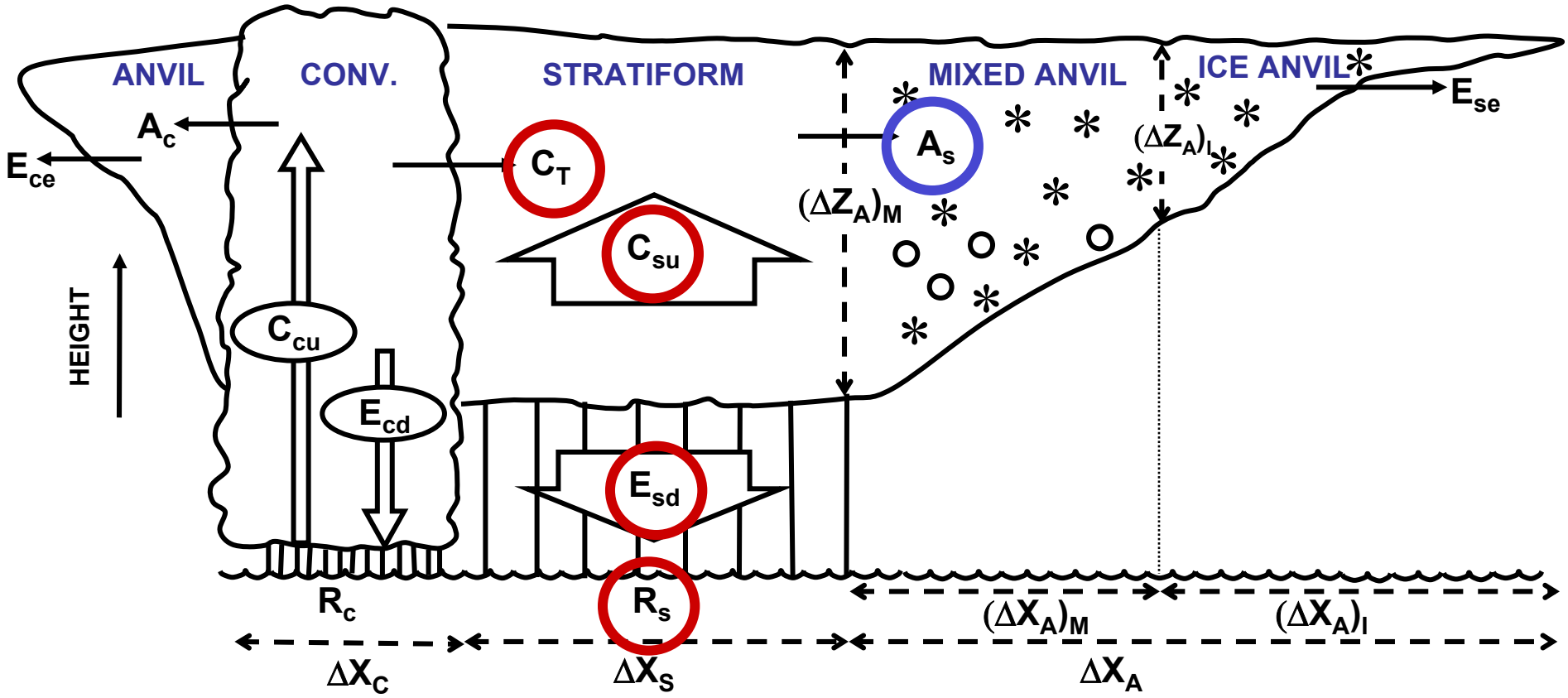
Convective region water budget equation

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

$$R_c = \varepsilon_c C_{cu}$$
$$E_{cd} = \alpha C_{cu}$$
$$A_c = \beta C_{cu}$$
$$C_T = \eta C_{cu}$$

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

Water Budget Equations



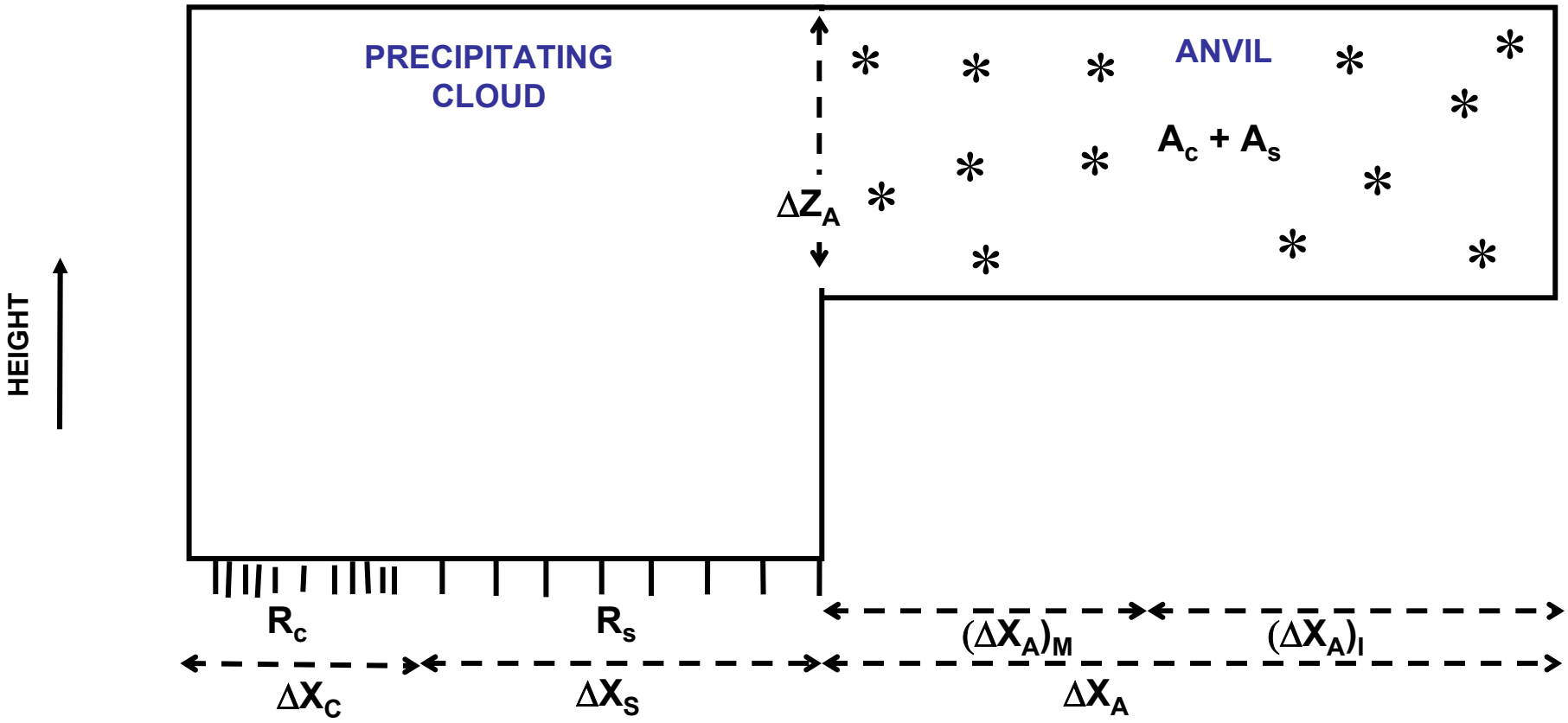
Stratiform water budget equation

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

Rain not simply related to condensation

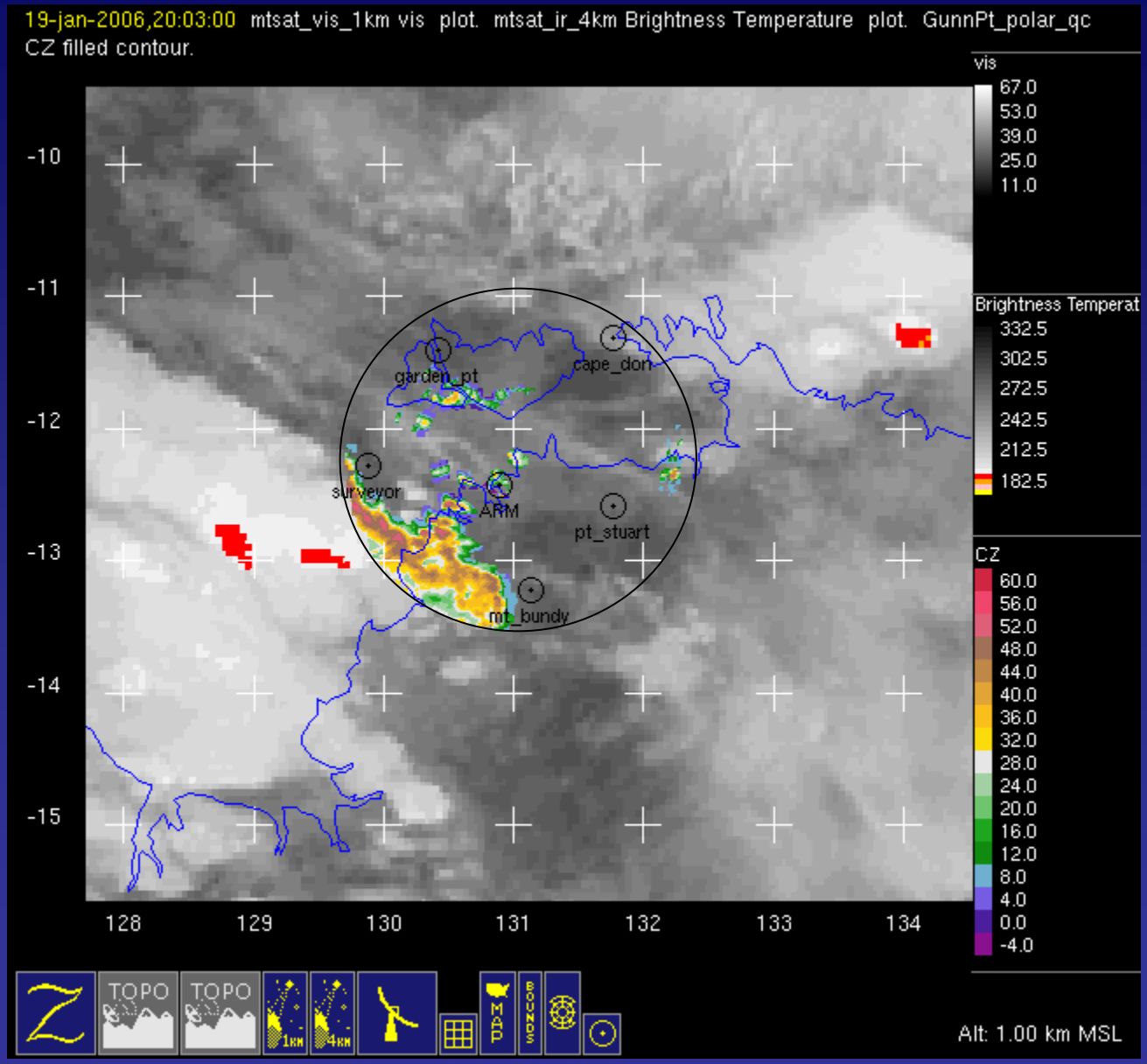
$$R_s = \varepsilon_s(C_{su}+C_T)$$
$$E_{sd} = a(C_{su}+C_T) \quad \varepsilon_s+a+b=1$$
$$A_s = b(C_{su}+C_T)$$

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



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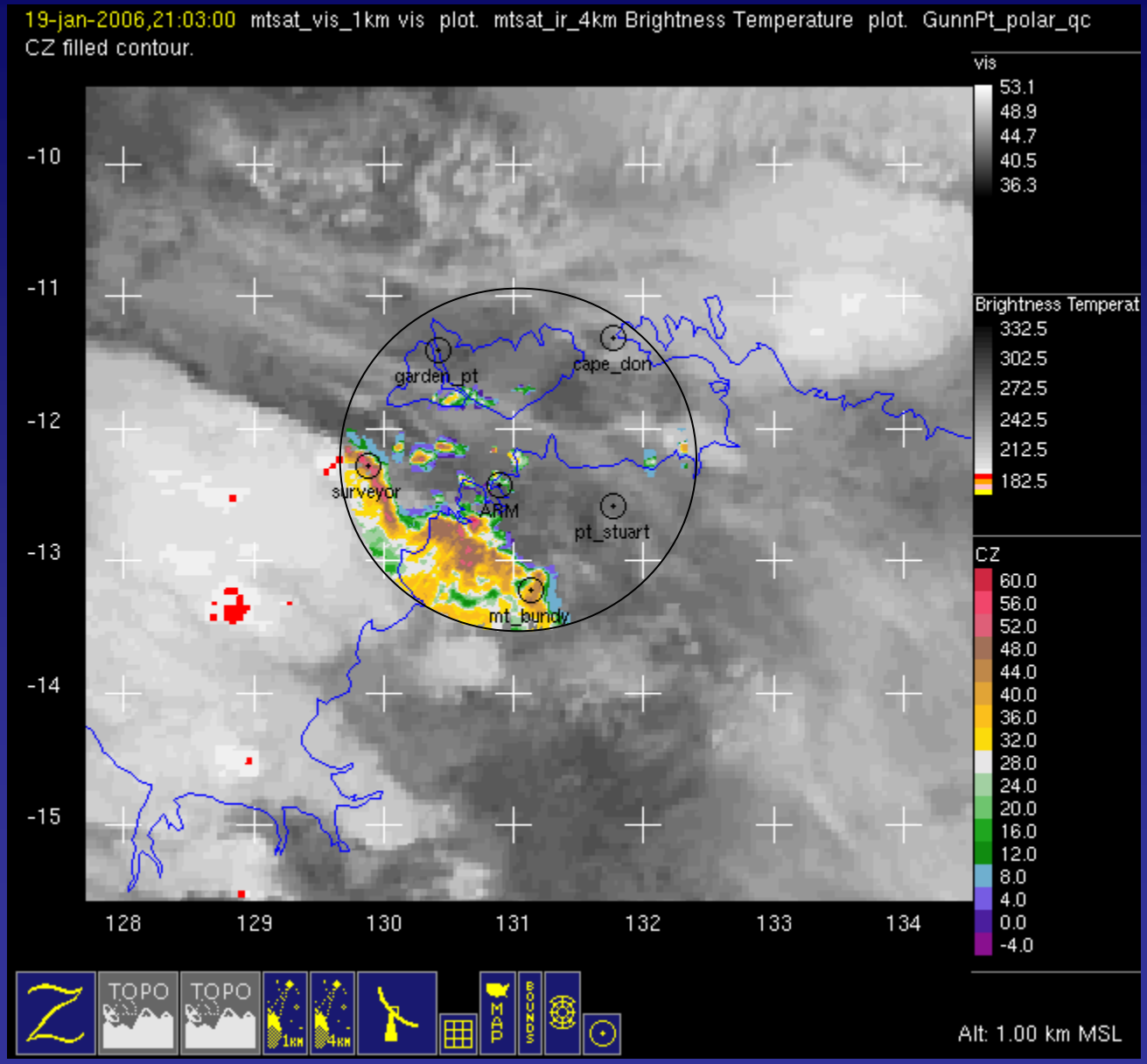

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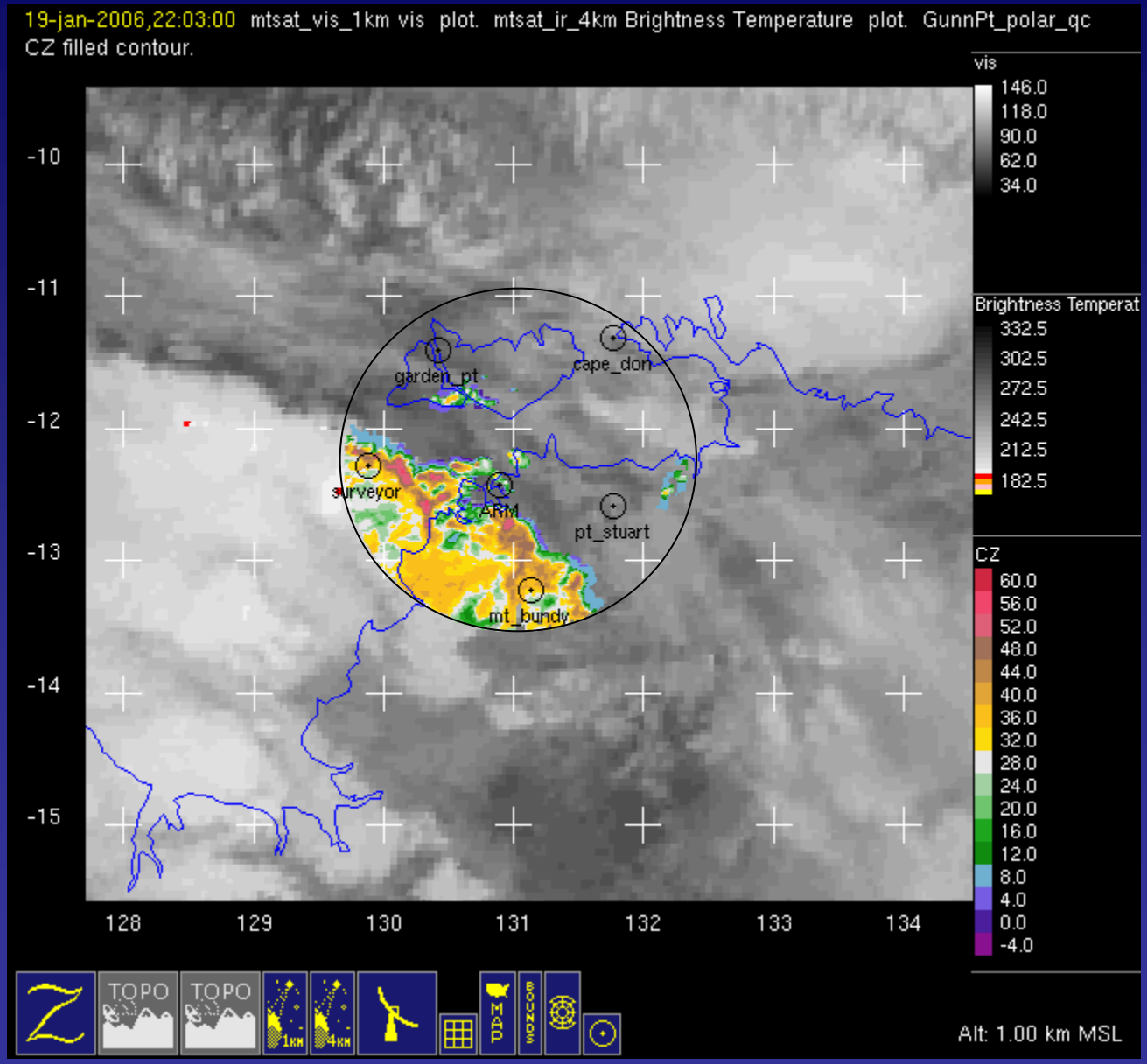

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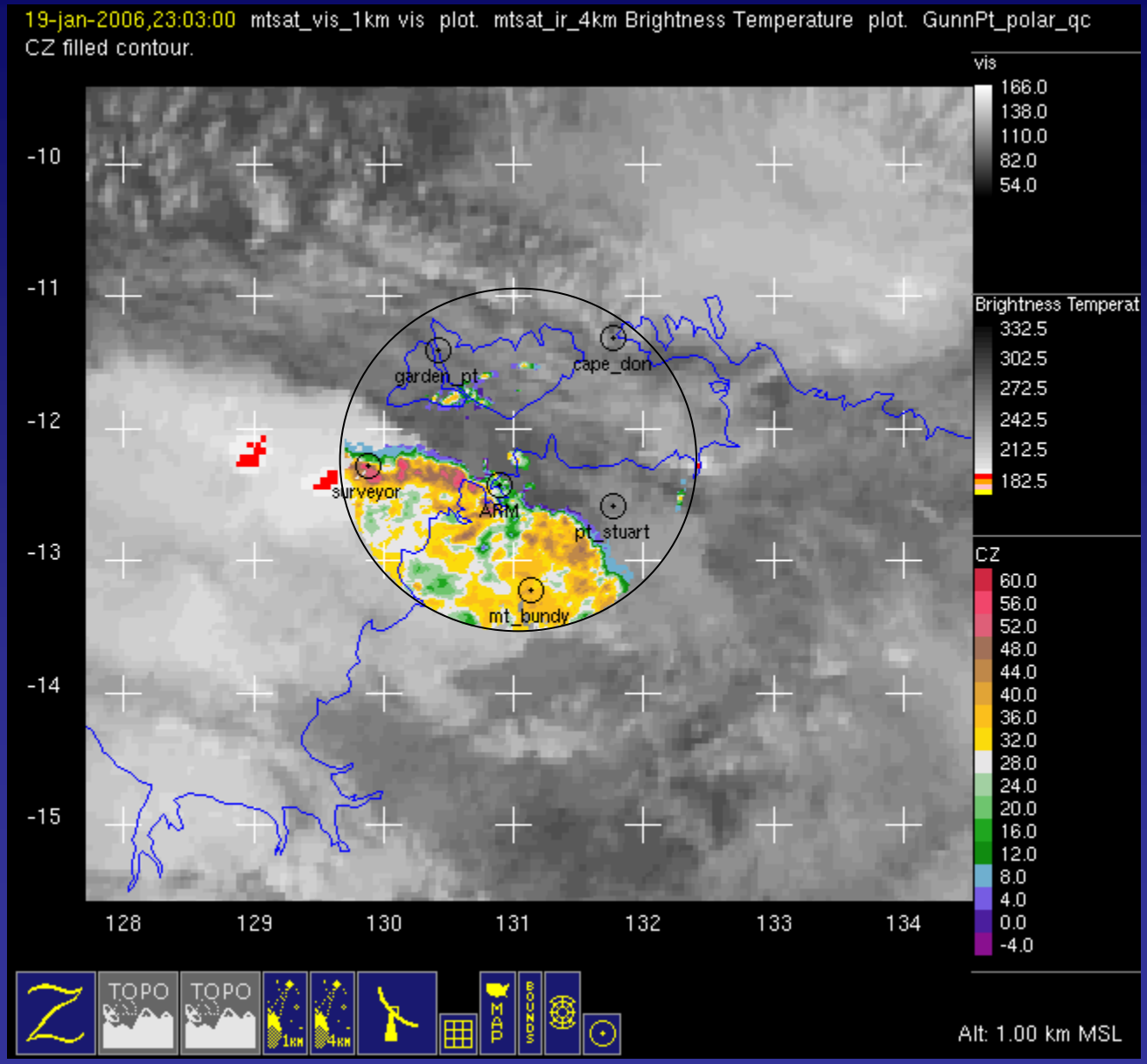

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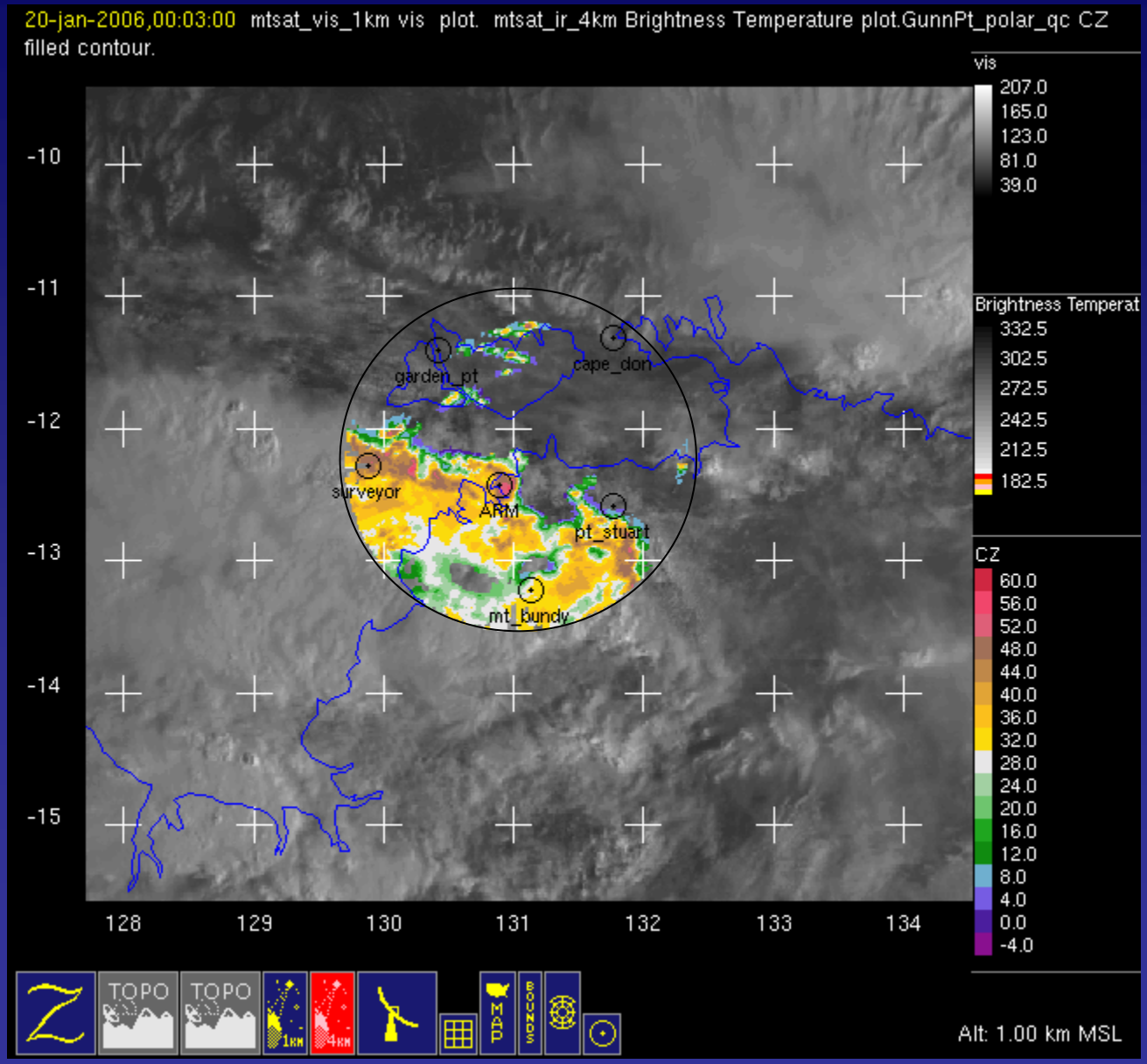

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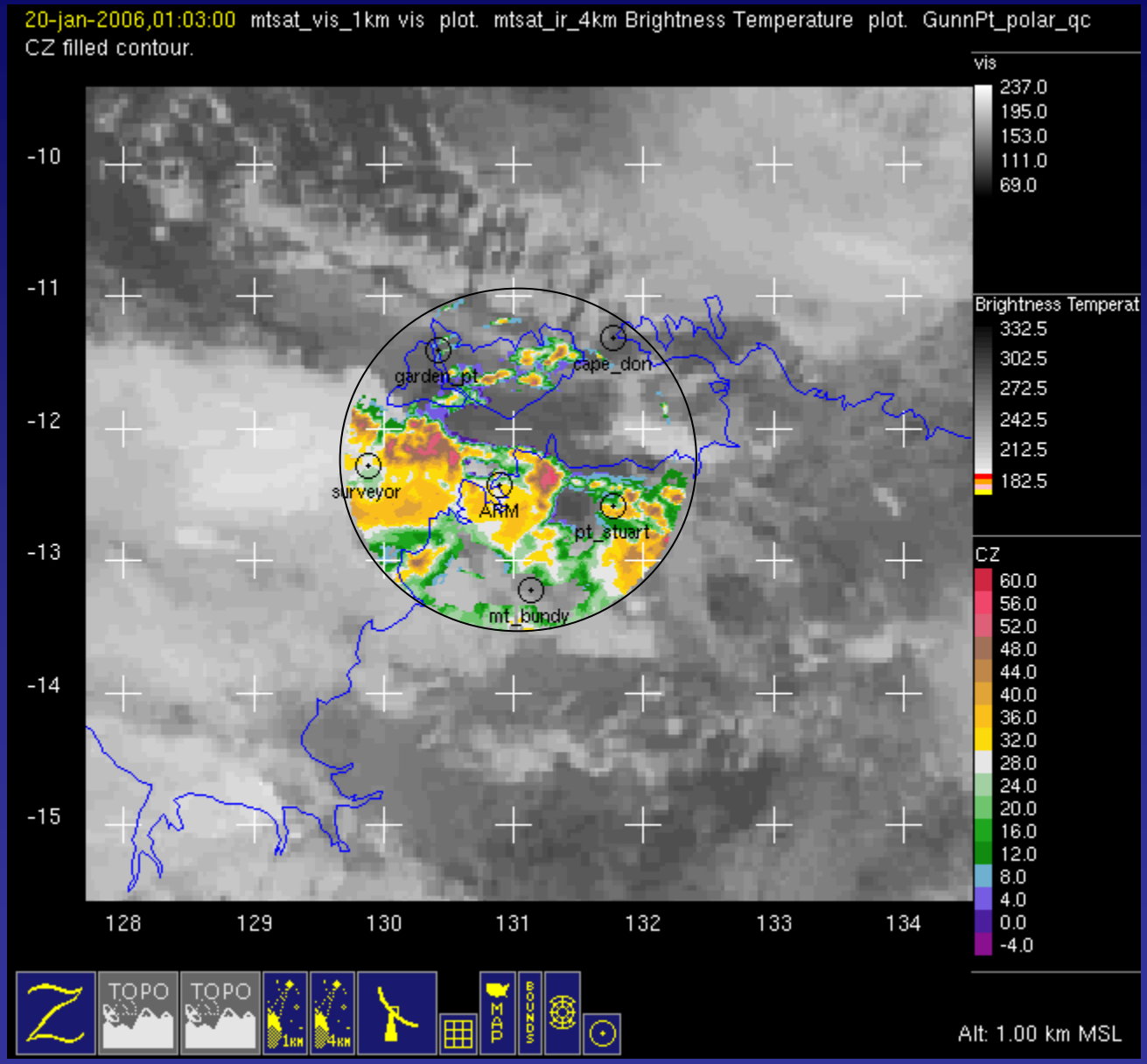

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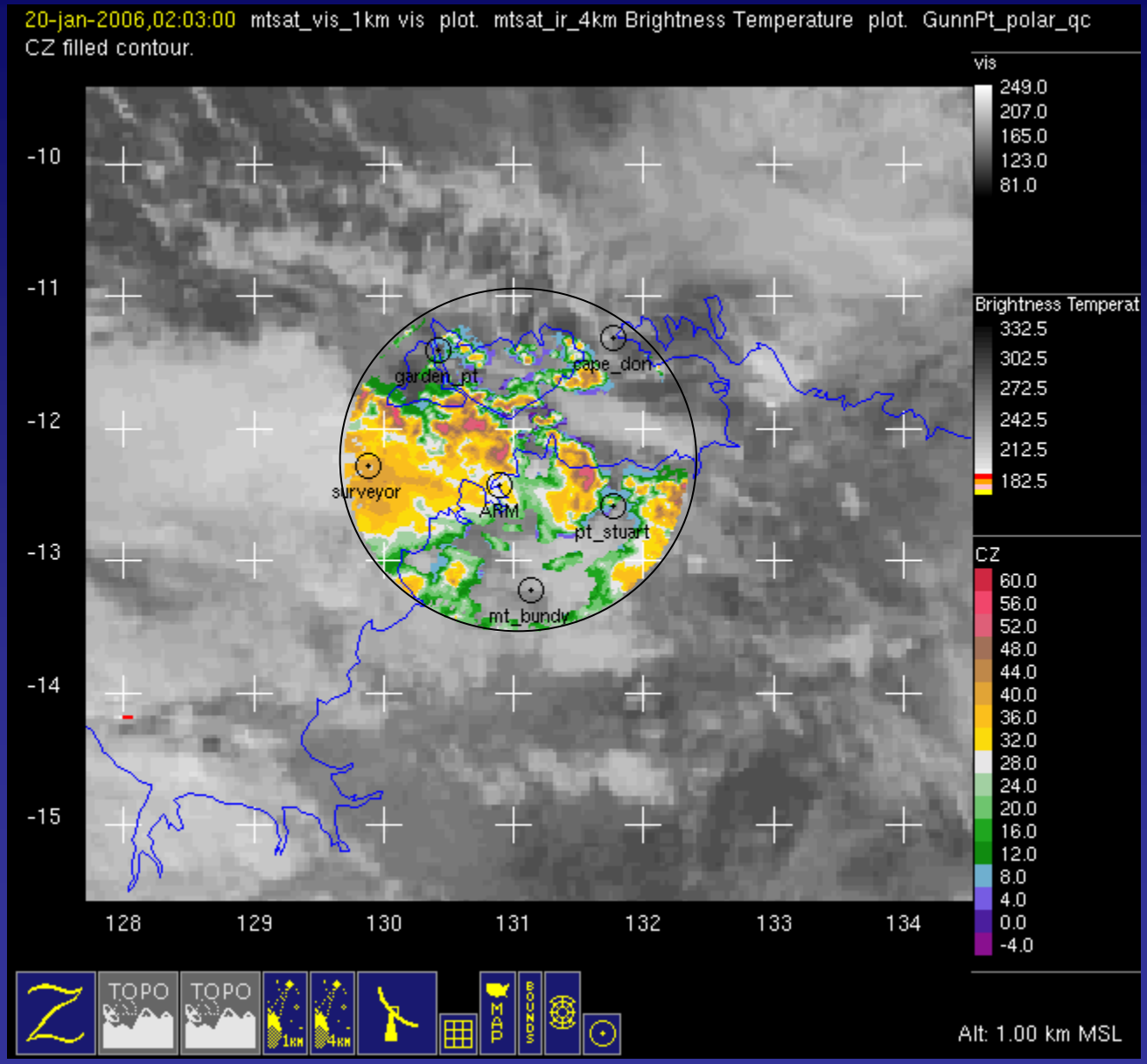

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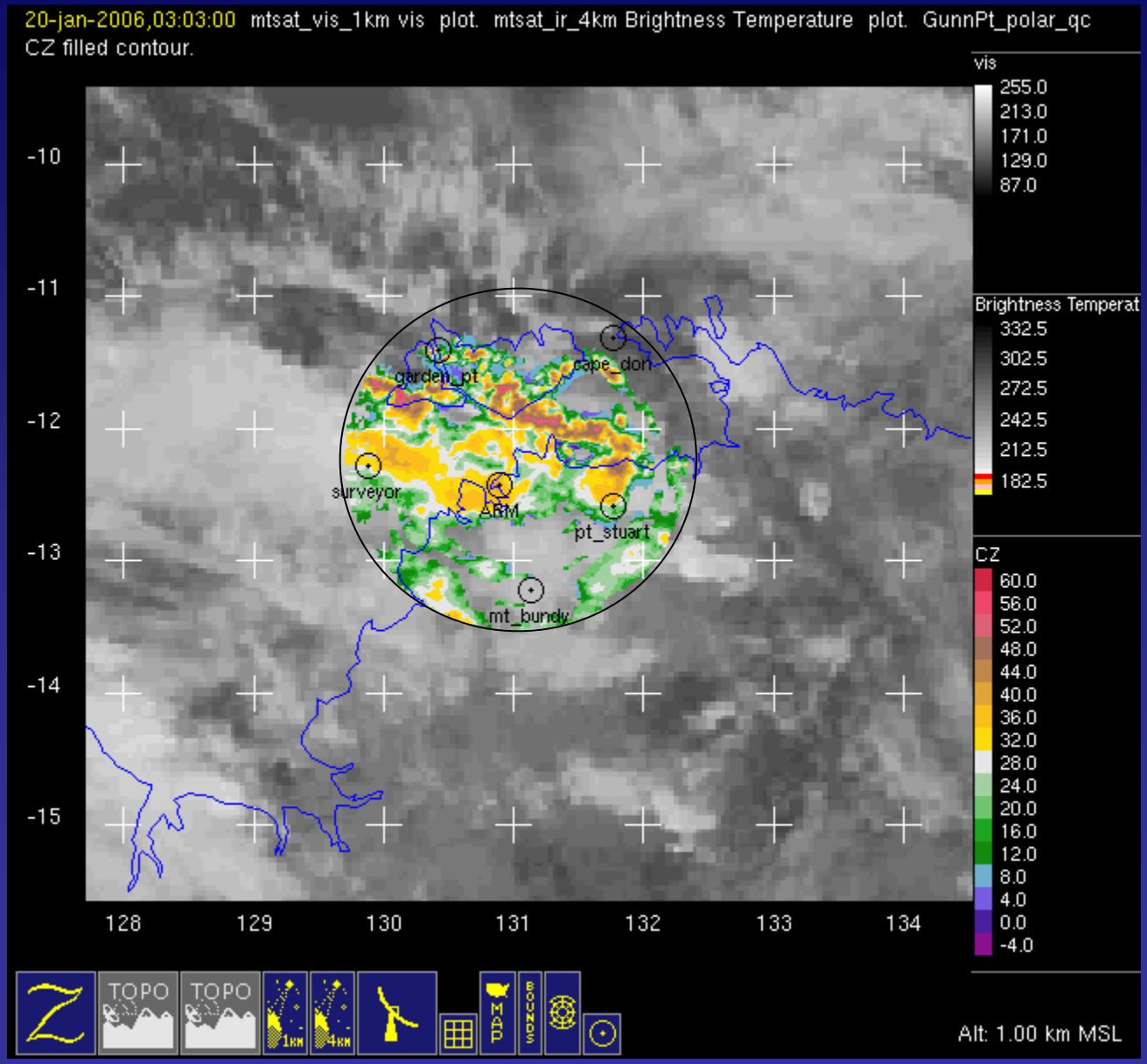

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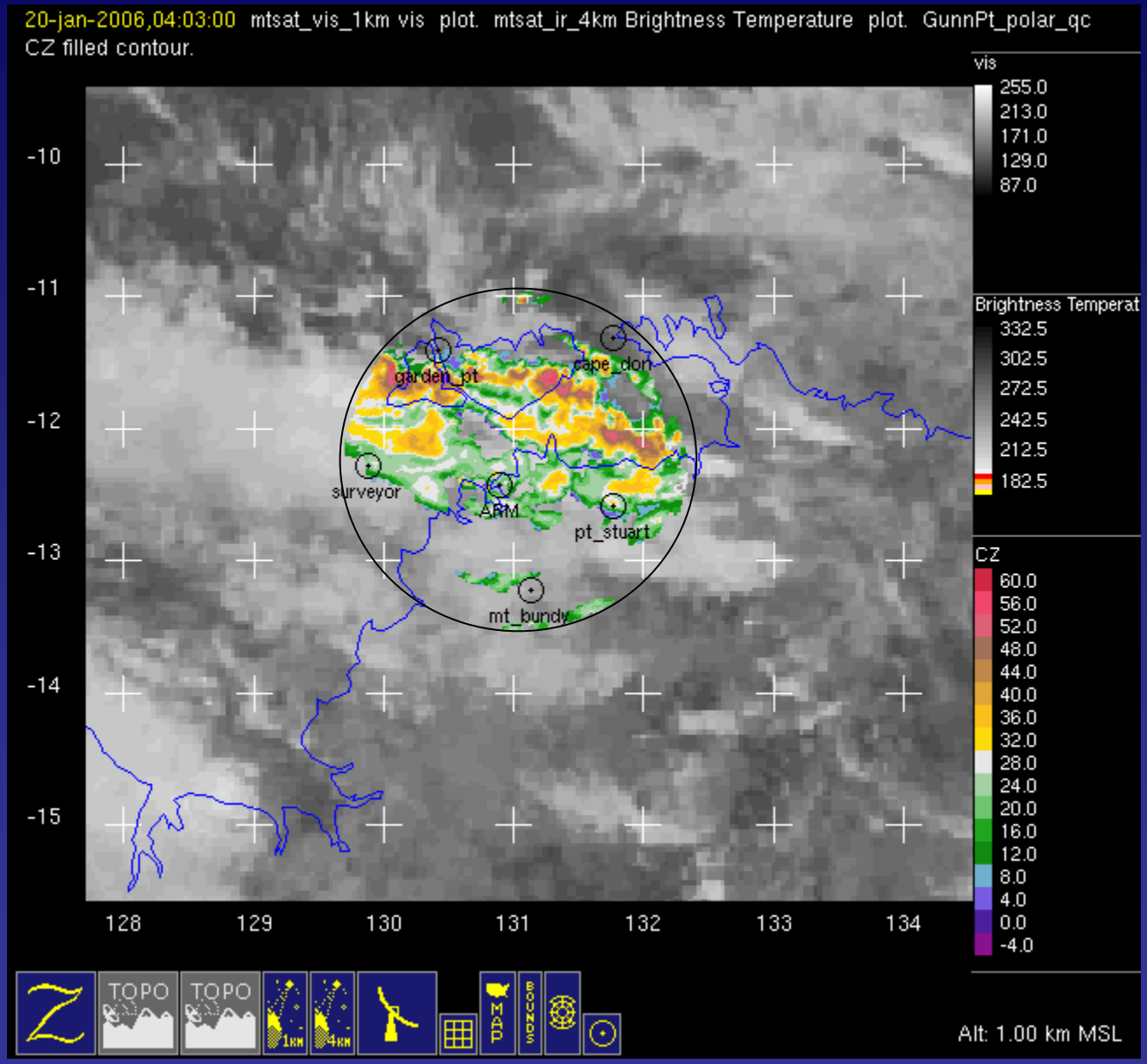

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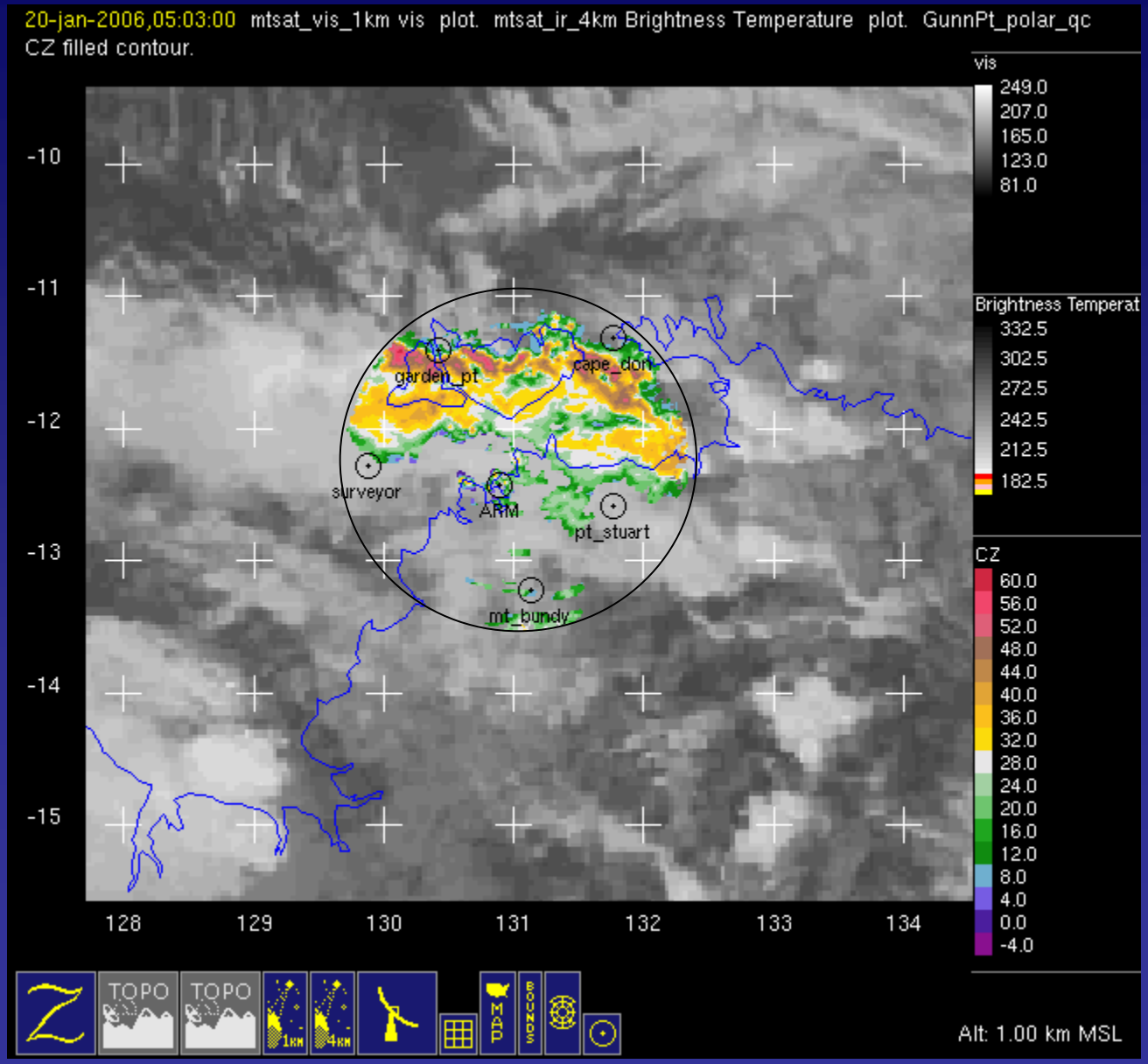

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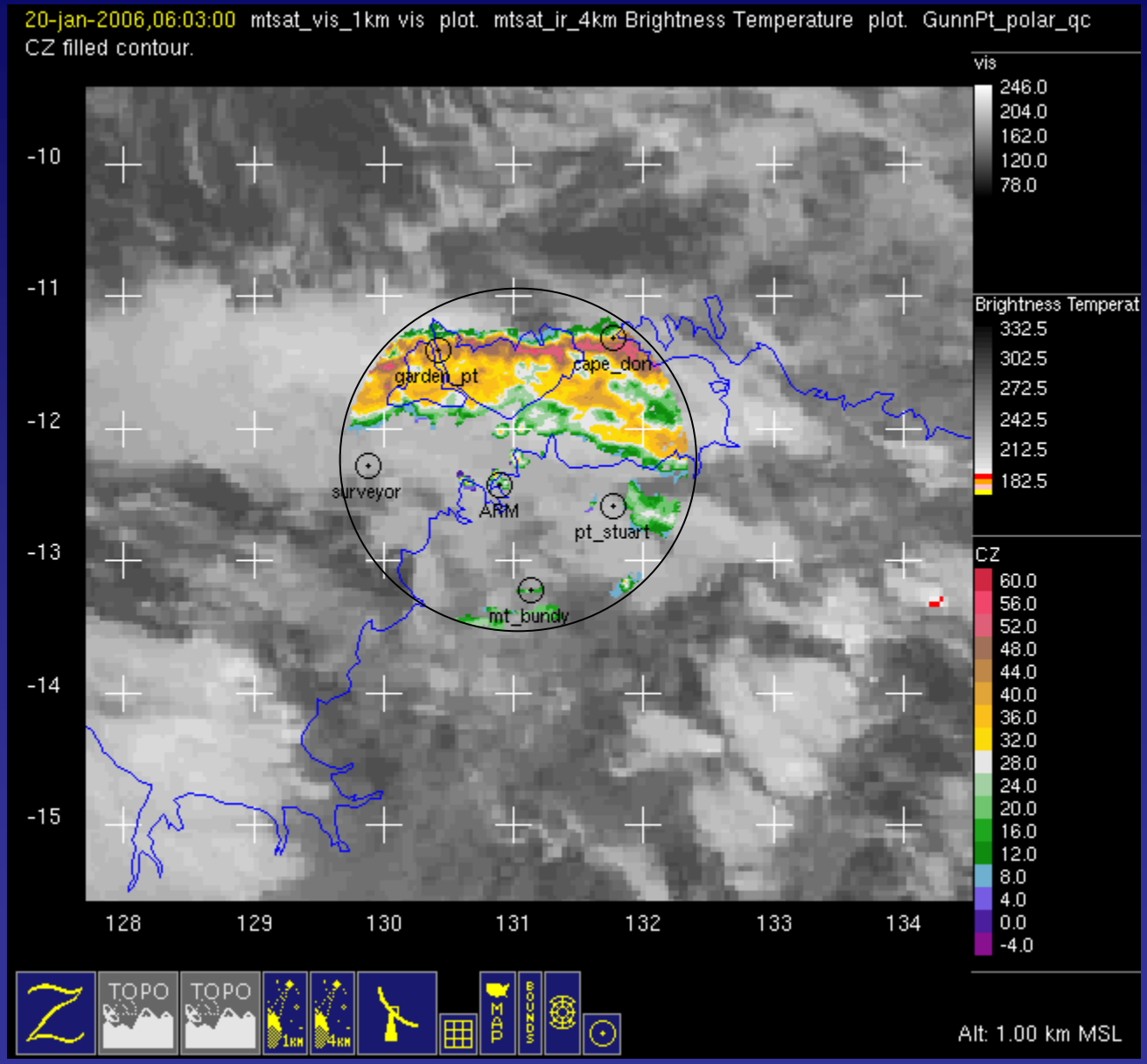

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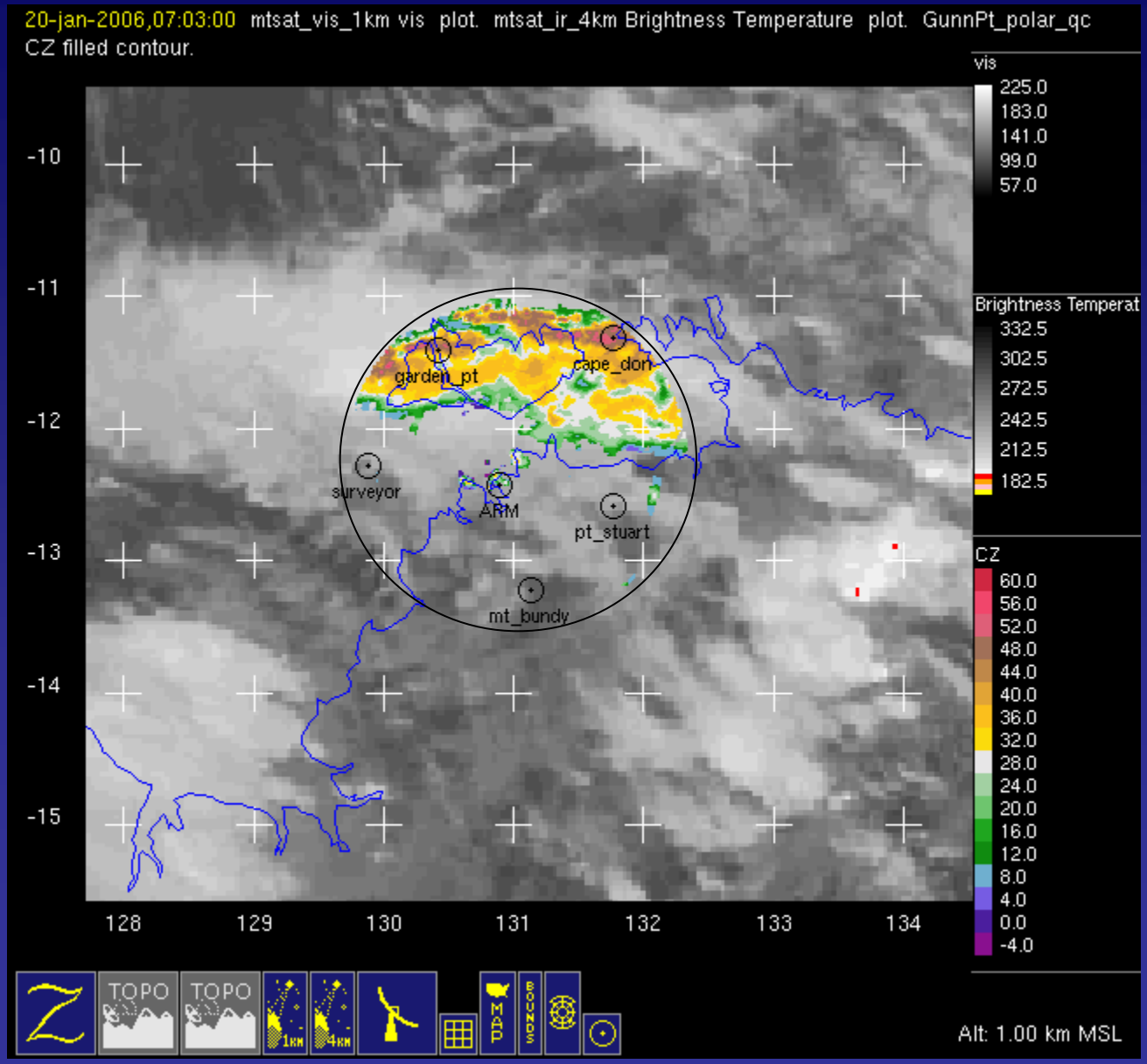

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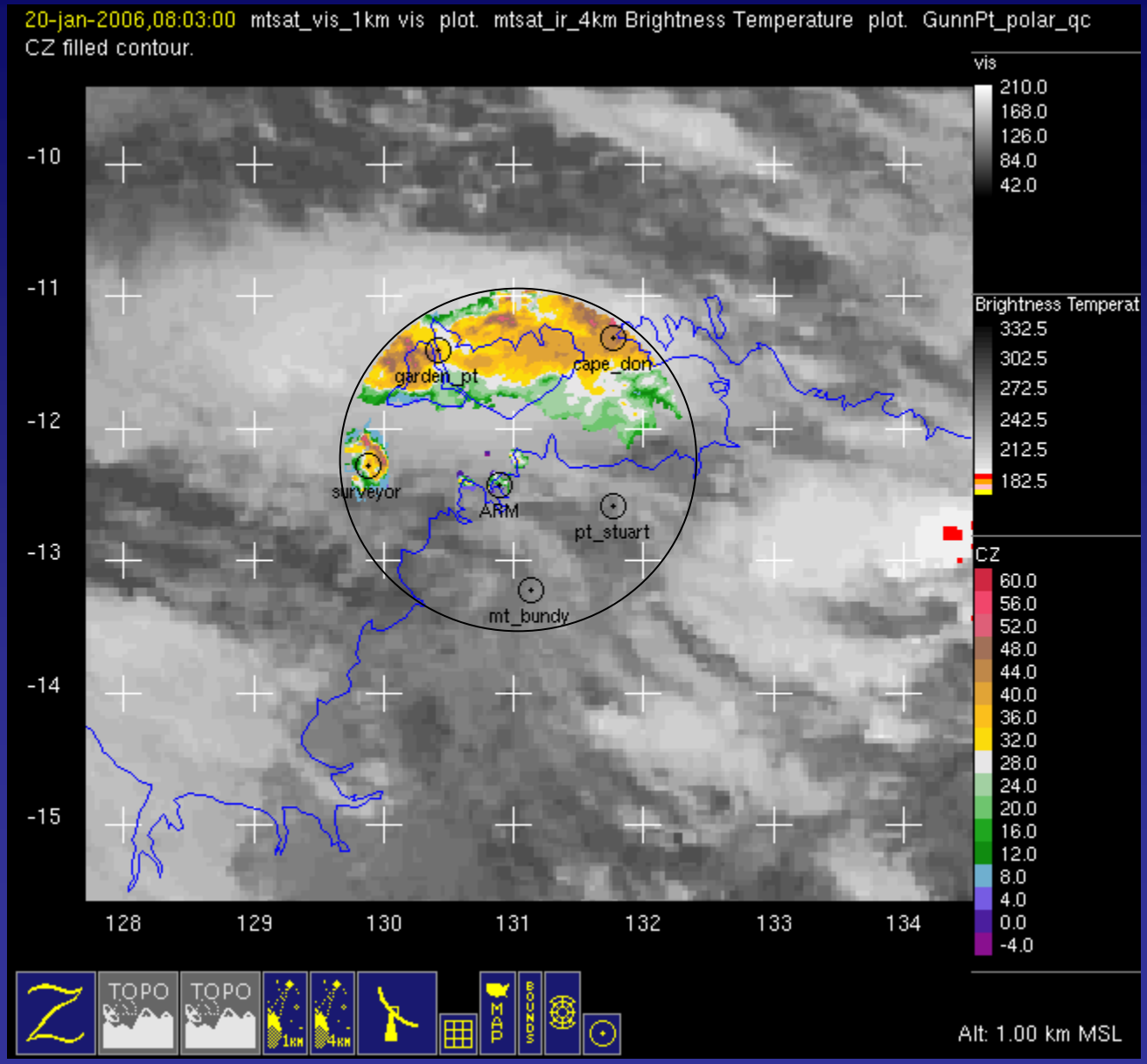

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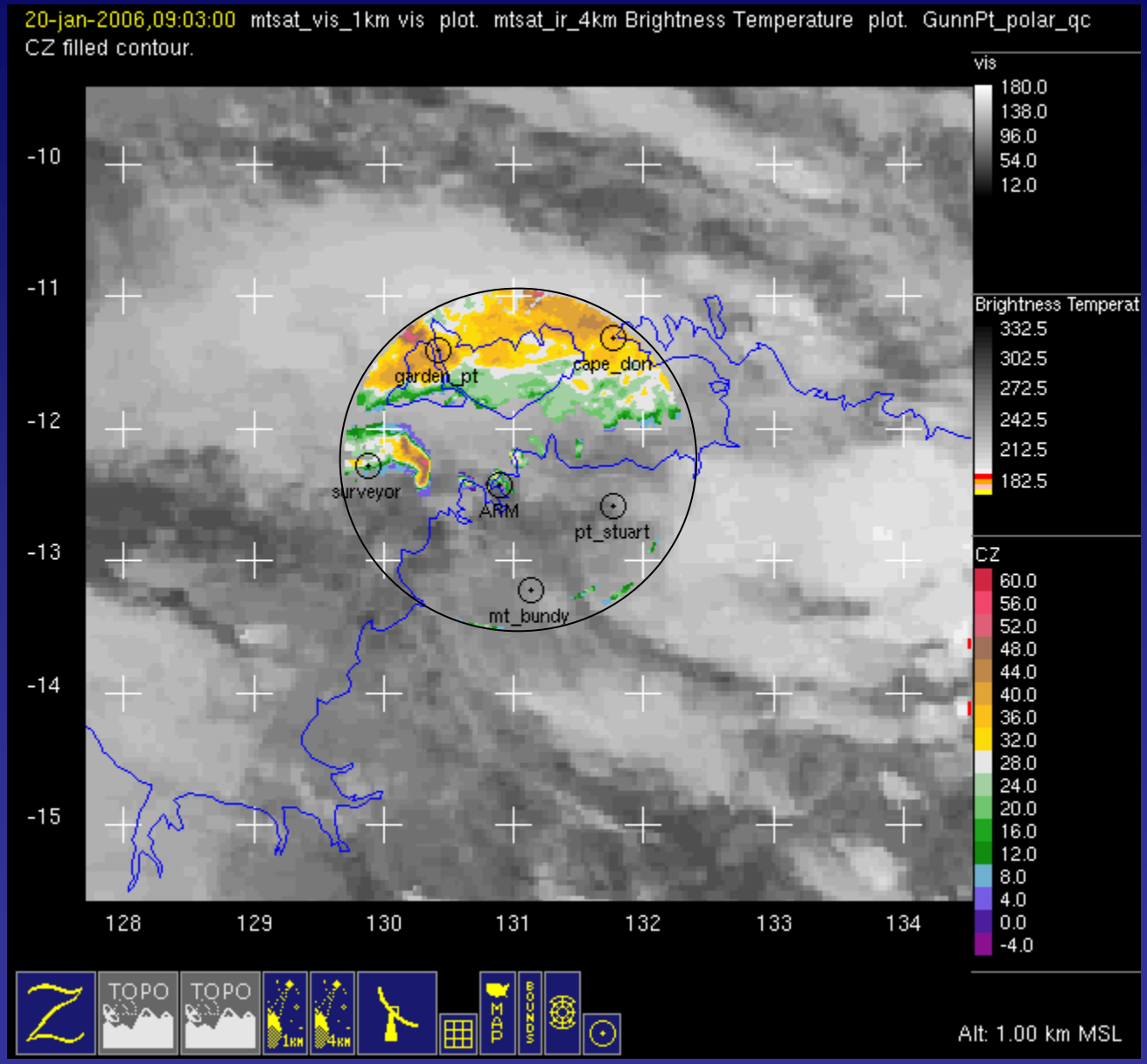

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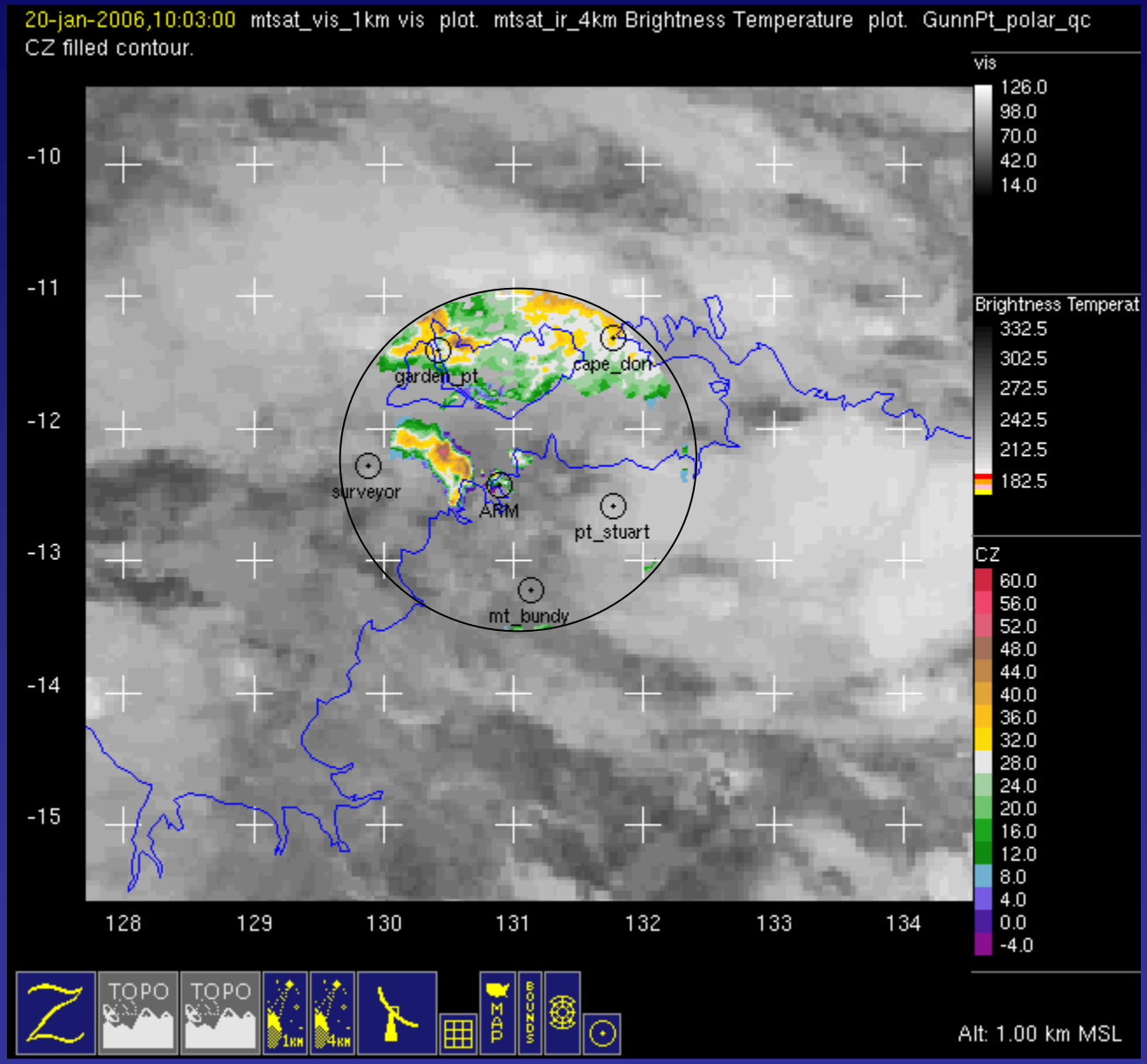

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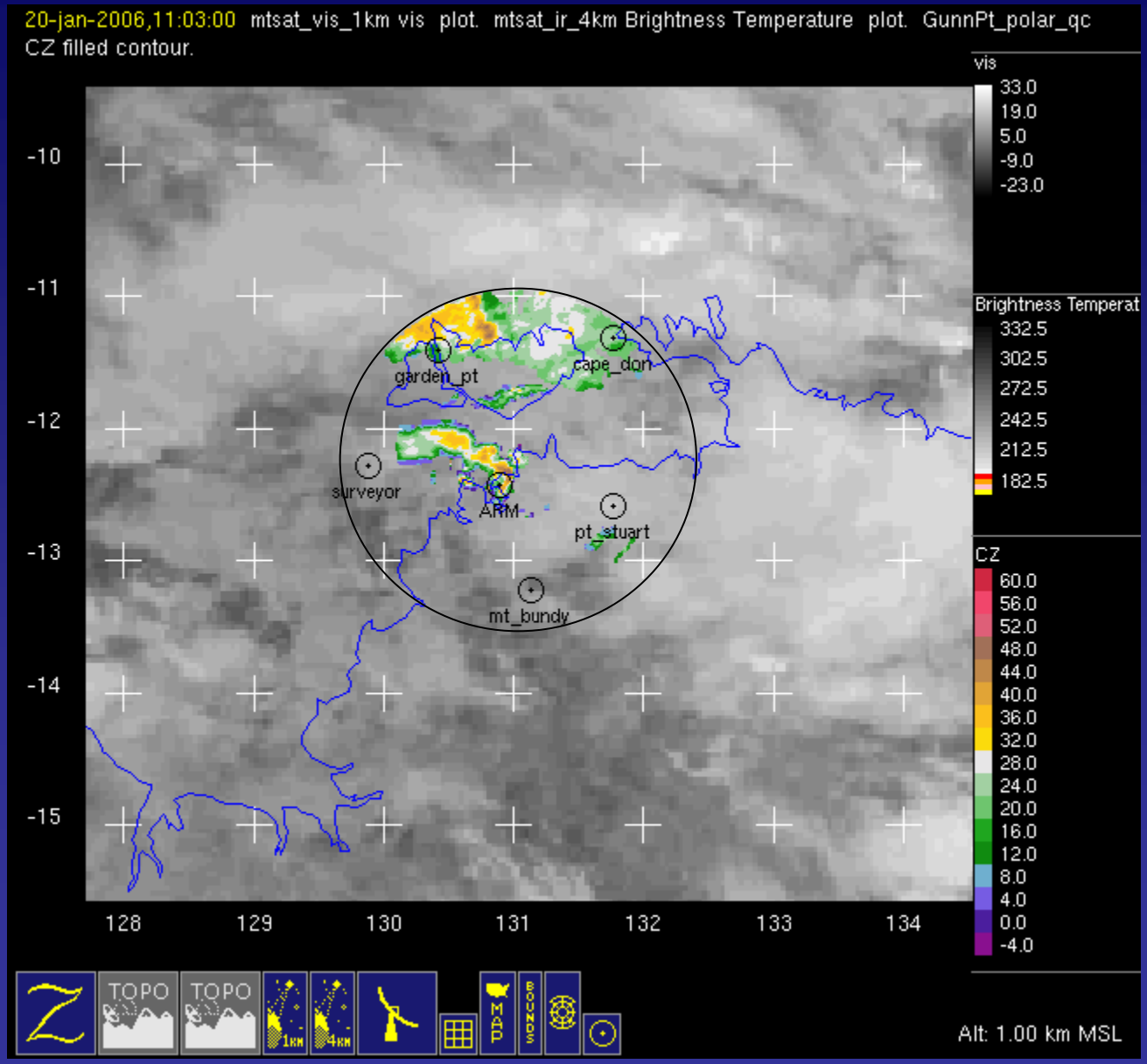

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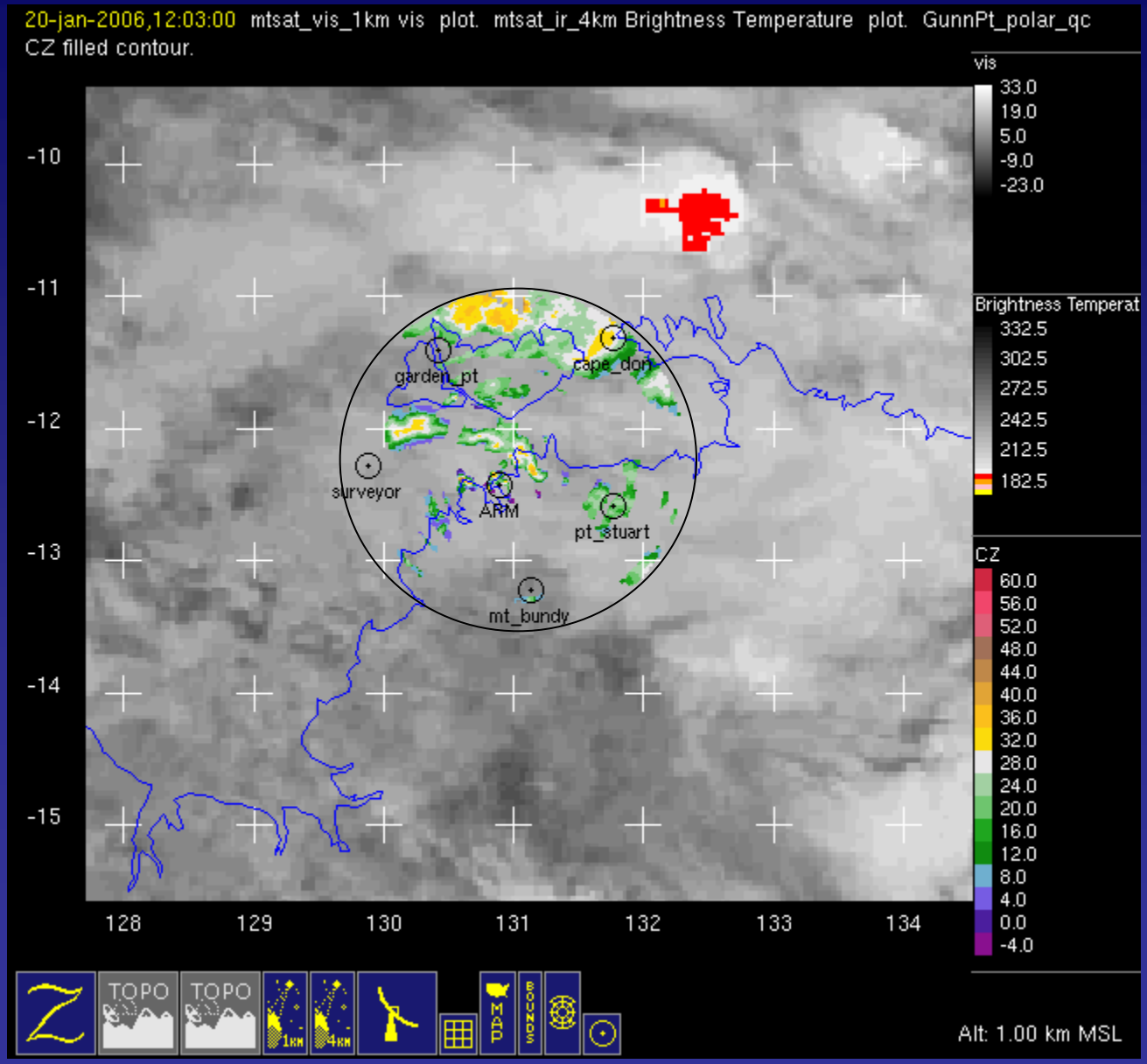

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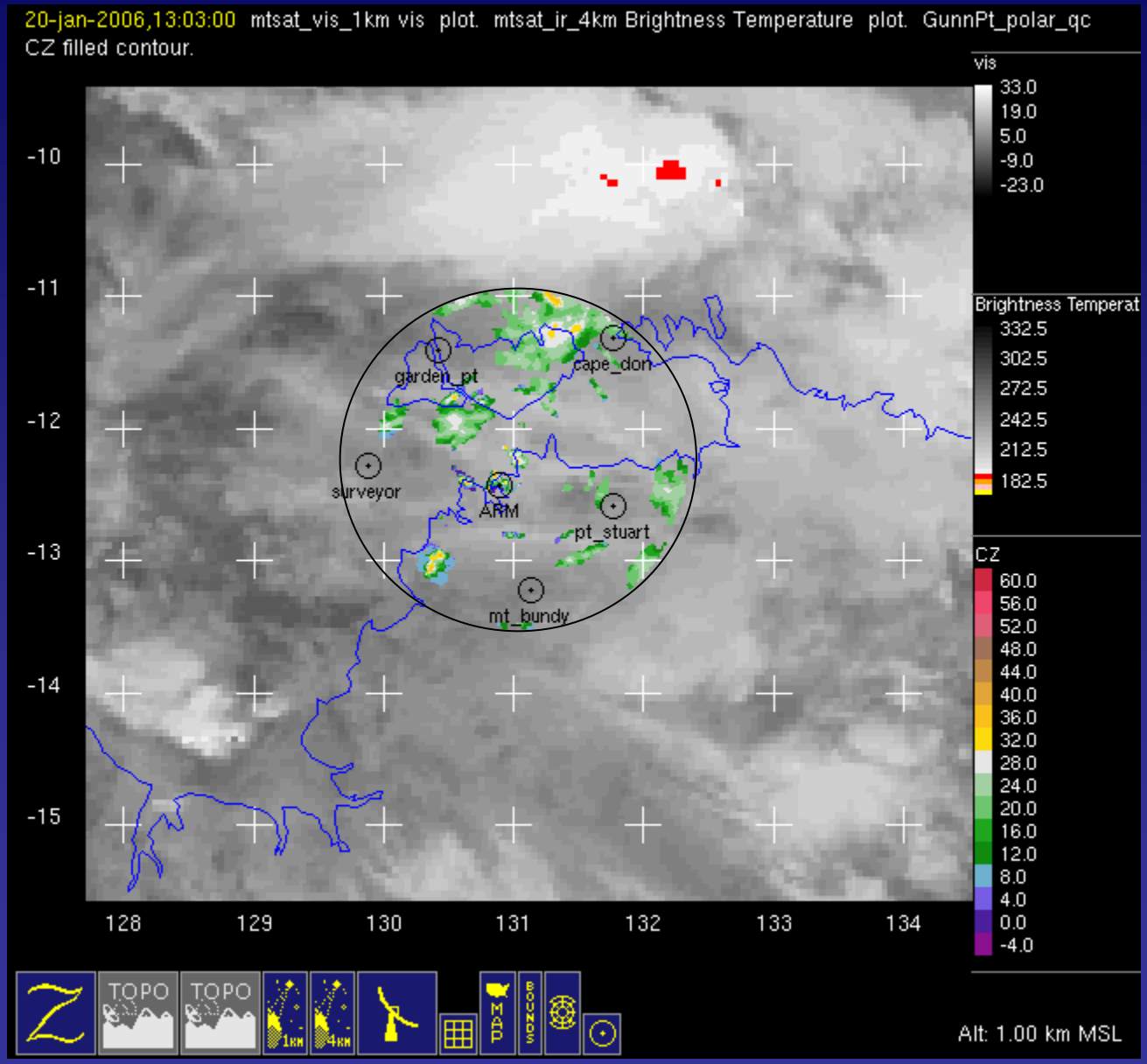

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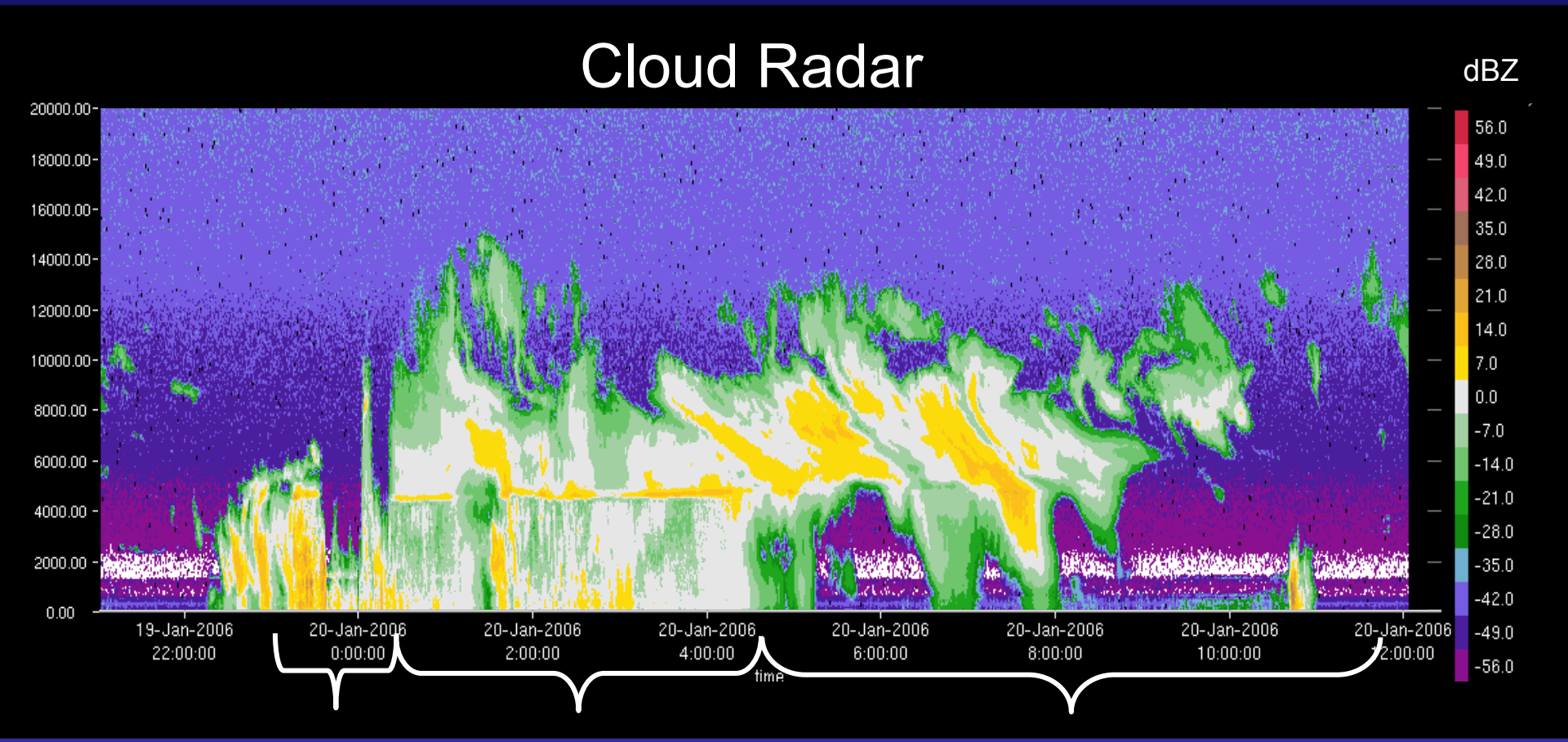


Finding anvil amounts from water budget equations

- 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

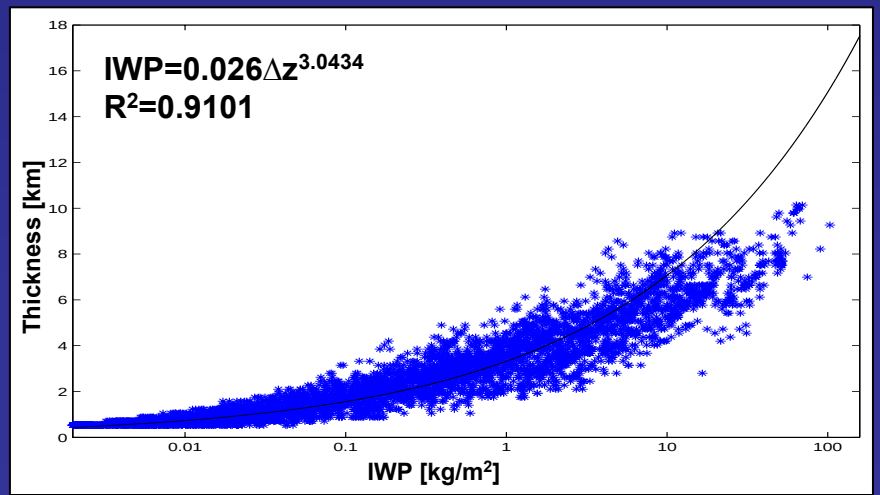
R_c=2.8586 x 10^{12} kg, R_s=6.7226 x 10^{11} kg

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

Realistic Values, acc. to Houze and Cheng 1981

Finding anvil amounts from MMCR and CPol

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

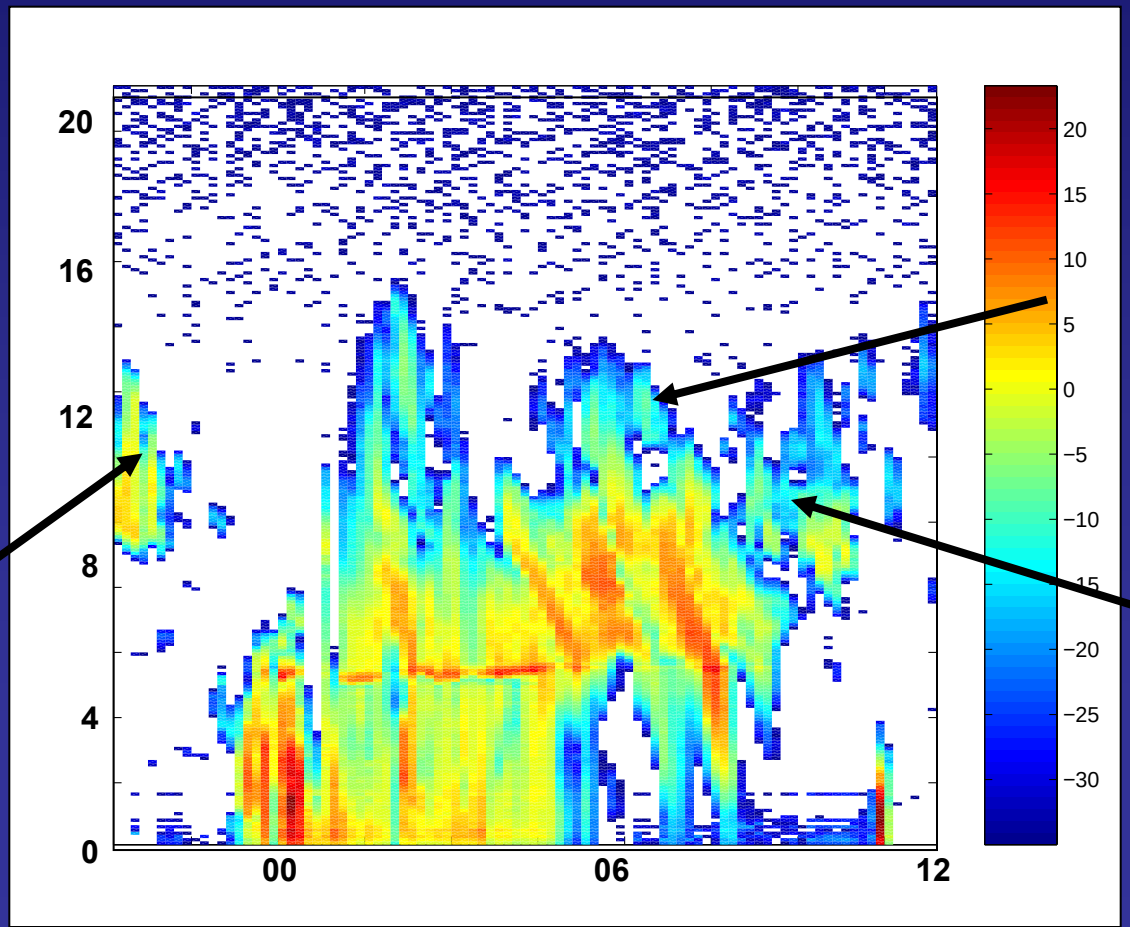


→ $A_c + A_s = 4.2730 \times 10^{10}$ kg

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

Why such a difference??

1. The CPol will miss some anvil because of it's lower sensitivity



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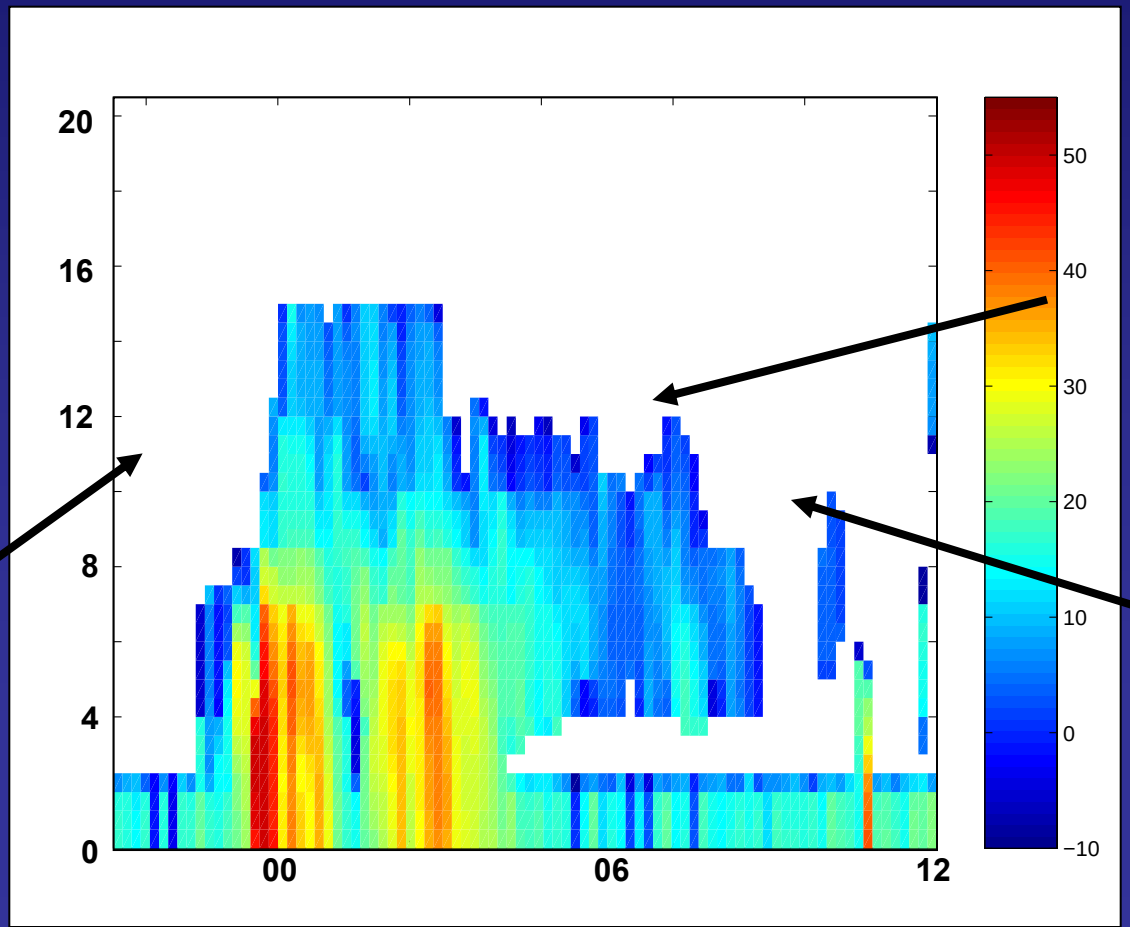
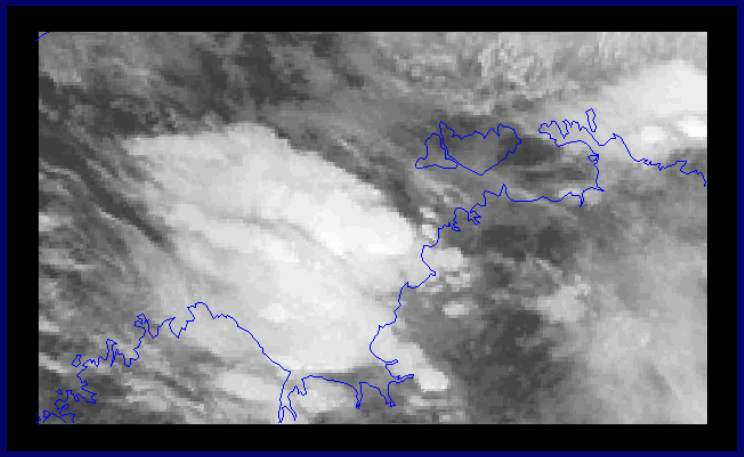
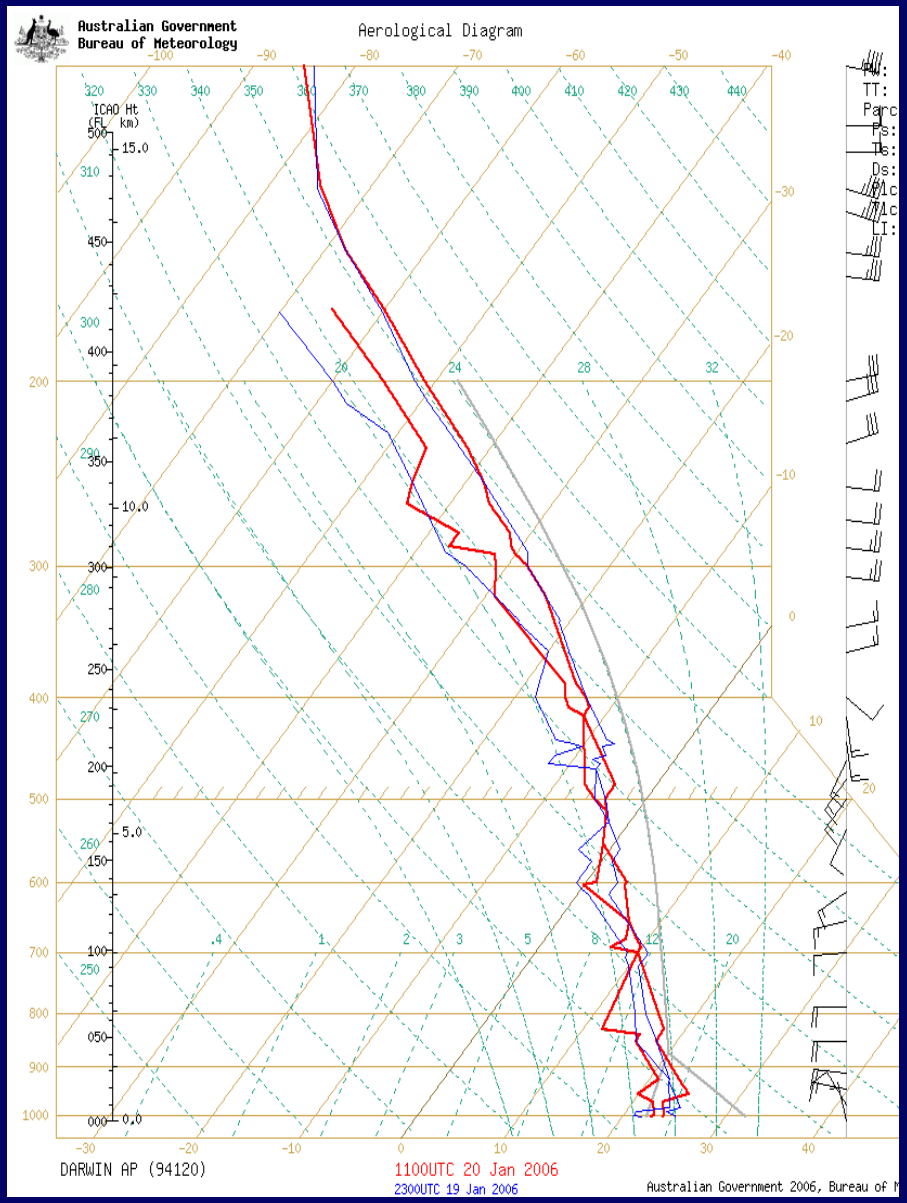


Why such a difference??

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)





Why such a difference??

3. Problems with MMCR sensitivity

Future Improvements

- Use **dual-Doppler** velocities, cloud radar, and sounding data to compute other values (C_T, C_{cu}, E_{cd}, C_{su}, E_{sd}) 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

Thanks