On the detection of icing conditions at altitude in conjunction with mesoscale convective complexes using balloon sondes

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Motivation:

On 8 July 2021. An ozonesonde was released at 11:44 UTC (6:44 CDT) at Texas A&M University-Corpus Christi (27.72°N, 97.33°W). The flight occurred during light rain as a tropical system brought heavy precipitation to the Corpus Christi area. Instead of rising continuously to burst, the balloon altitude oscillated between 3 - 5 km. Four cases of similar oscillating balloon flights (Figure 1 and 2) are collected to understand this type of events.

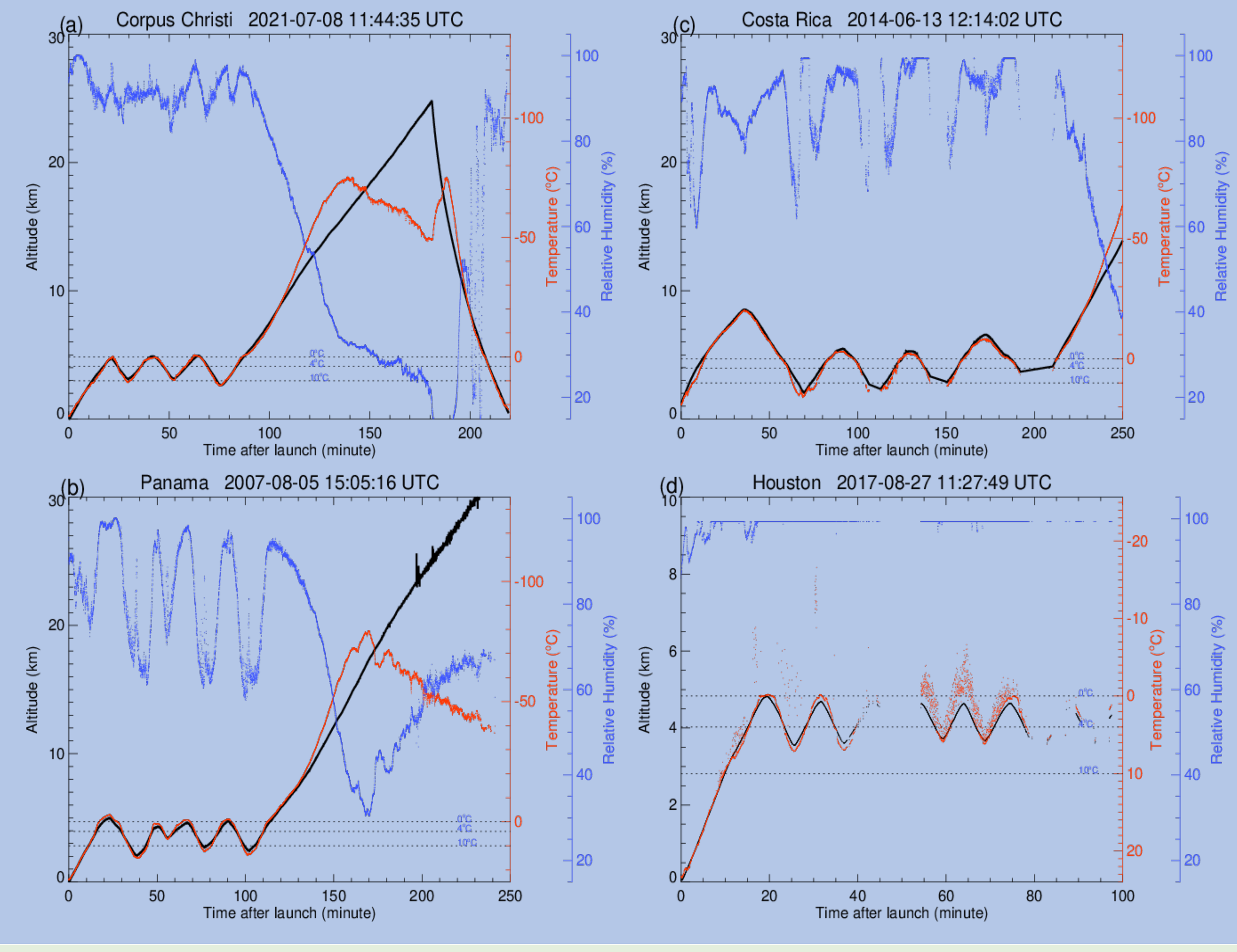


Figure 1. Time evolution of temperature (red), altitude (black), and relative humidity (blue) during four unusual weather balloon launches over (a) Corpus Christi (ozonesonde + radiosonde, payload 1.5 kg, 800 g balloon), (b) Panama (ozonesond + radiosonde, 1.5 kg, 1200 g balloon), (c) Costa Rica (Ozonesonde + radiosonde + CFH, payload 3.5 kg, 1200 g balloon), and (d) Houston (radiosonde only, 0.4 kg payload, 350 g balloon).

Satellite infrared images

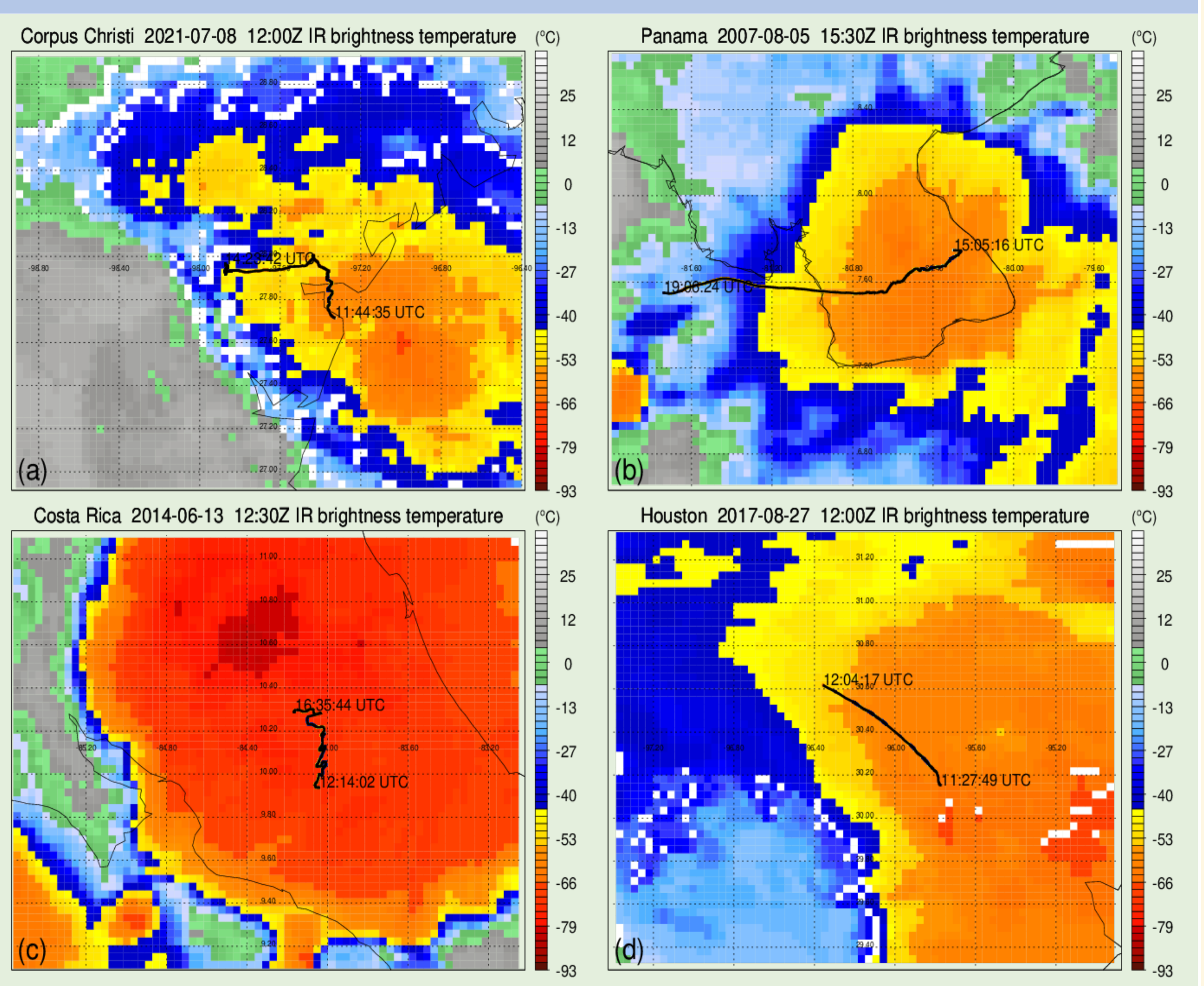


Figure 2. The infrared brightness temperature field in the middle of the balloon flights. The balloon flight trajectories are superimposed on the infrared brightness temperature field for a time in the middle of the balloon flights. The black line traces the balloon paths. The thin black lines show the coast lines and country borders. a) a tropical type Mesoscale Convective System (MCS) over Corpus Christi; b) a dissipating MCS over south Panama, balloon was launched from Las Tablas; c) A mature MCS over central Costa Rica. Balloon was released near San José; d) Stratiform precipitation region from Hurricane Harvey. Balloon was released from northwest of Houston.

Vertical velocity, wind speed, and RH

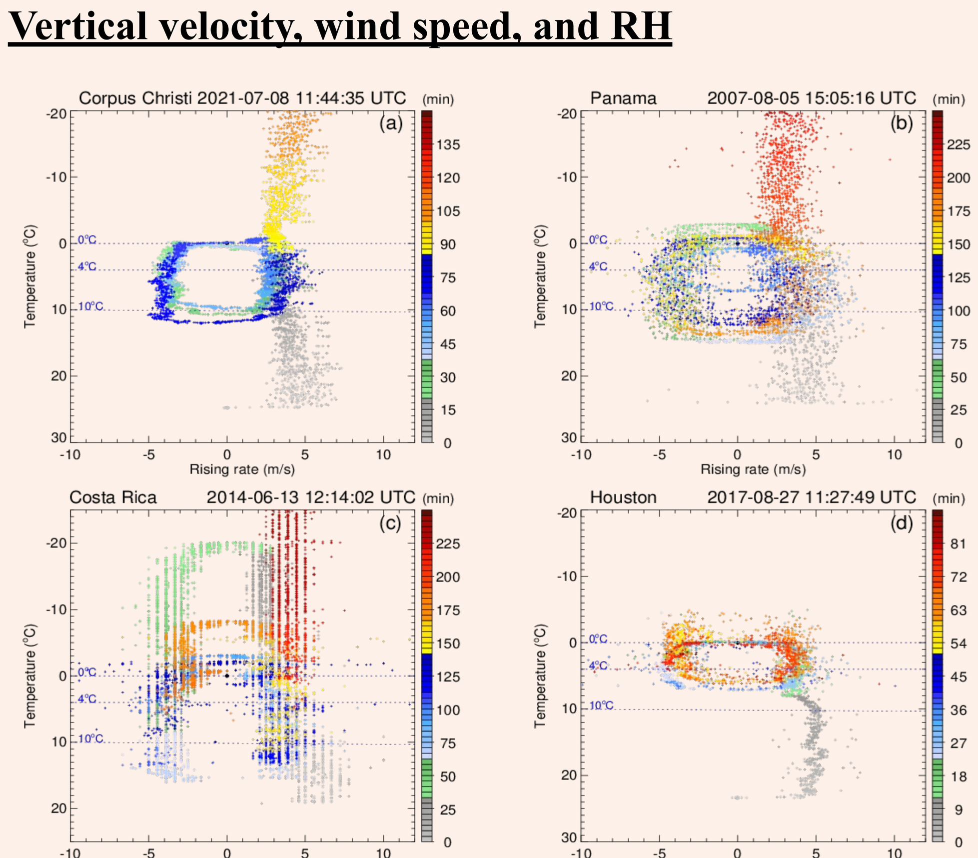


Figure 6. Scatter plots of the rising speed as a function of temperature during flights over Corpus Christi (a), Panama (b), Costa Rica (c), and Houston (d). The color of the symbol represents the time after the launch.

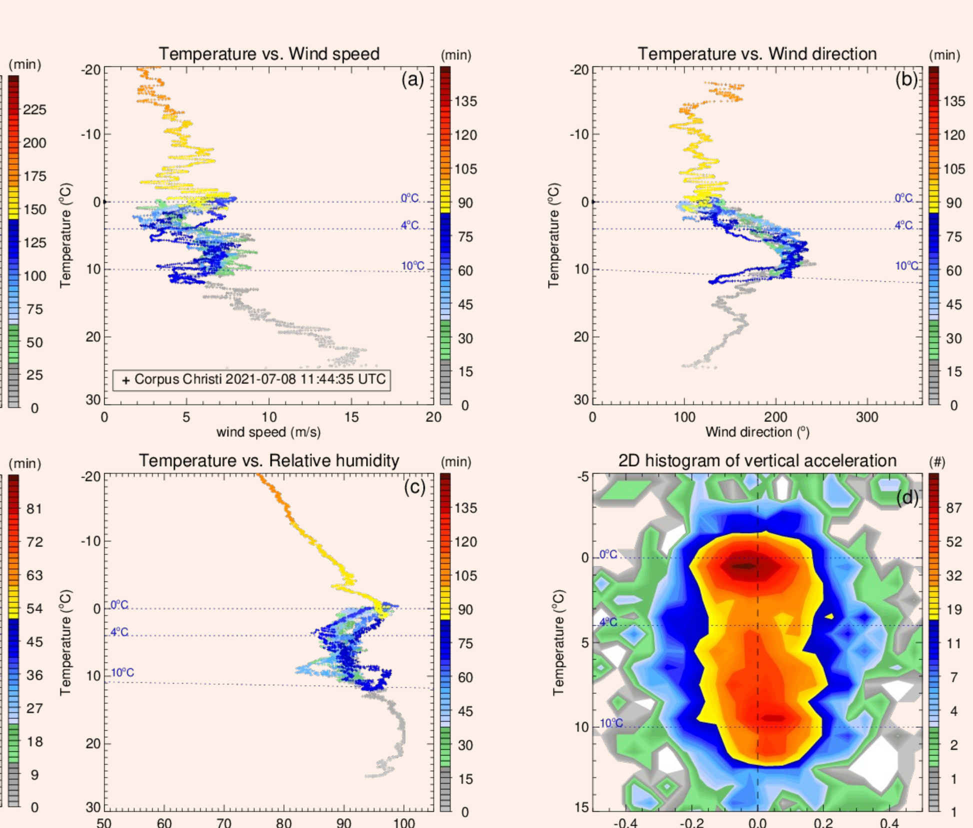


Figure 7. Scatter plots of the wind speed (a), wind direction (b), and relative humidity (c) as a function of temperature during flights over Corpus Christi. The colorbars in (a)-(c) represent the time after the launch. (d) A two-dimensional histogram of vertical acceleration.

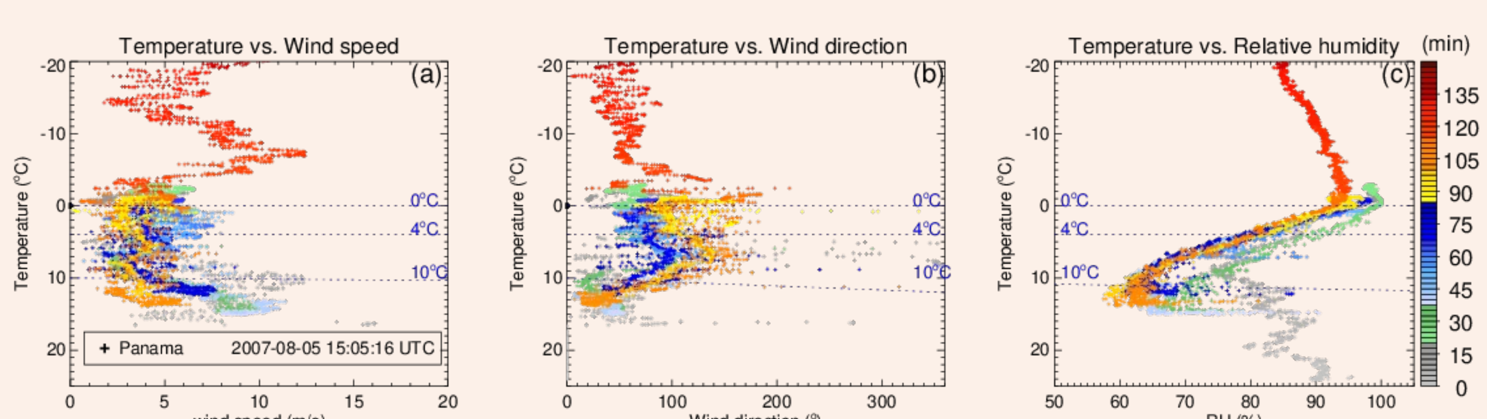
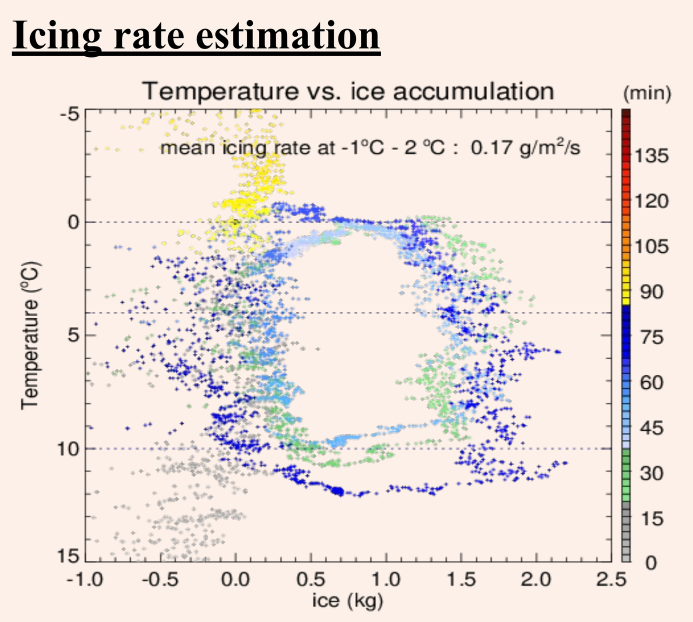


Figure 8. Scatter plots of the wind speed (a), wind direction (b), and relative humidity (c) as a function of temperature during flights over Panama. The colorbars in (a)-(c) represent the time after the launch.

Icing rate estimation



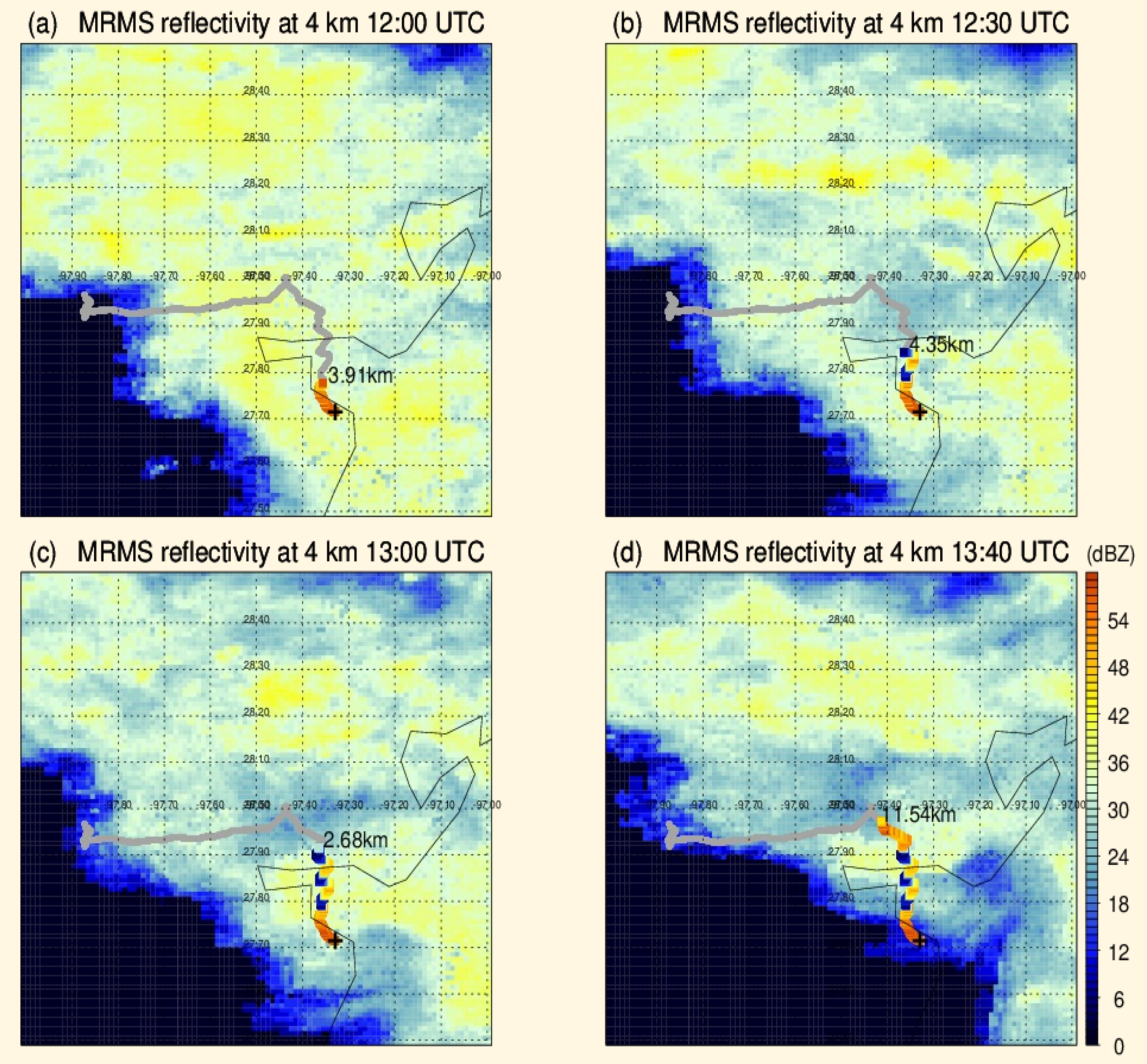
$$M_{ice}(t) = \frac{1}{a(t)+g}\Big(L + (M_{instrument} + M_{water})\, g - (M_{balloon} + M_{heluim} + M_{instrument} + M_{water})\, a(t) - \frac{1}{2} C_d\, |w(t)|\, w(t)\, A(t)\, \rho(t)\Big)$$

where $M_{ice}(t)$ is the mass of ice buildup; a(t) is the acceleration; L is the payoff weight while inflating the balloon; $M_{balloon}$, M_{helium}, $M_{instrument}$ are mass of balloon, helium and instrument; M_{water} is the mass of rainwater accumulated on the package; g is gravitation constant; w(t) is the vertical velocity of the sonde; ρ(t) is the air density; A(t) is the surface area of the whole balloon system. Cd is the air drag coefficient (here 0.13 is used for Corpus Christi case).

Figure 9. The estimated amount of ice accumulation on the balloon package during the ozonesonde flight at Corpus Christi using above equation. The icing rate at 0-2°C is estimated at 0.17 g m^{-2} s^{-1}.

Radar observations

Figure 3. Snapshots of MRMS interpolated radar reflectivity at 4 km during the balloon flight at Corpus Christi. The balloon flight trajectories are shown as gray lines. The color of the line represents the rising rate (negative in blue, positive in orange) of the balloon before the time of the radar image. The altitude of the balloon at the radar image time is labeled. The location of the launch site is marked with a black cross.



- The balloon was flying in a horizontally uniform region with ~35 dBZ during the up and down cycles (Figure 3).
- The balloon escaped after flying out of 35 dBZ zone for both Corpus Christi and Panama cases (Figure 4).
- There is no strong downdraft around (Figure 5b). The only plausible explanation to the downward motion of balloon is due to the ice accumulation.
- The melting band is clearly shown by high vertical resolution radar reflectivity and doppler velocity from MRR. The icing on balloon is right above the melting band.
- Though during the icing, the sensors in radiosonde could fail, the GPS location and altitude should be reliable because they relies on time differences, so does the wind speed and direction. For Corpus Christi case, the temperature measurements are reasonable during the oscillation because they maintain a consistent lapse rate near the freezing levels. However, RH measurements could be problematic, and no validation can be provided.

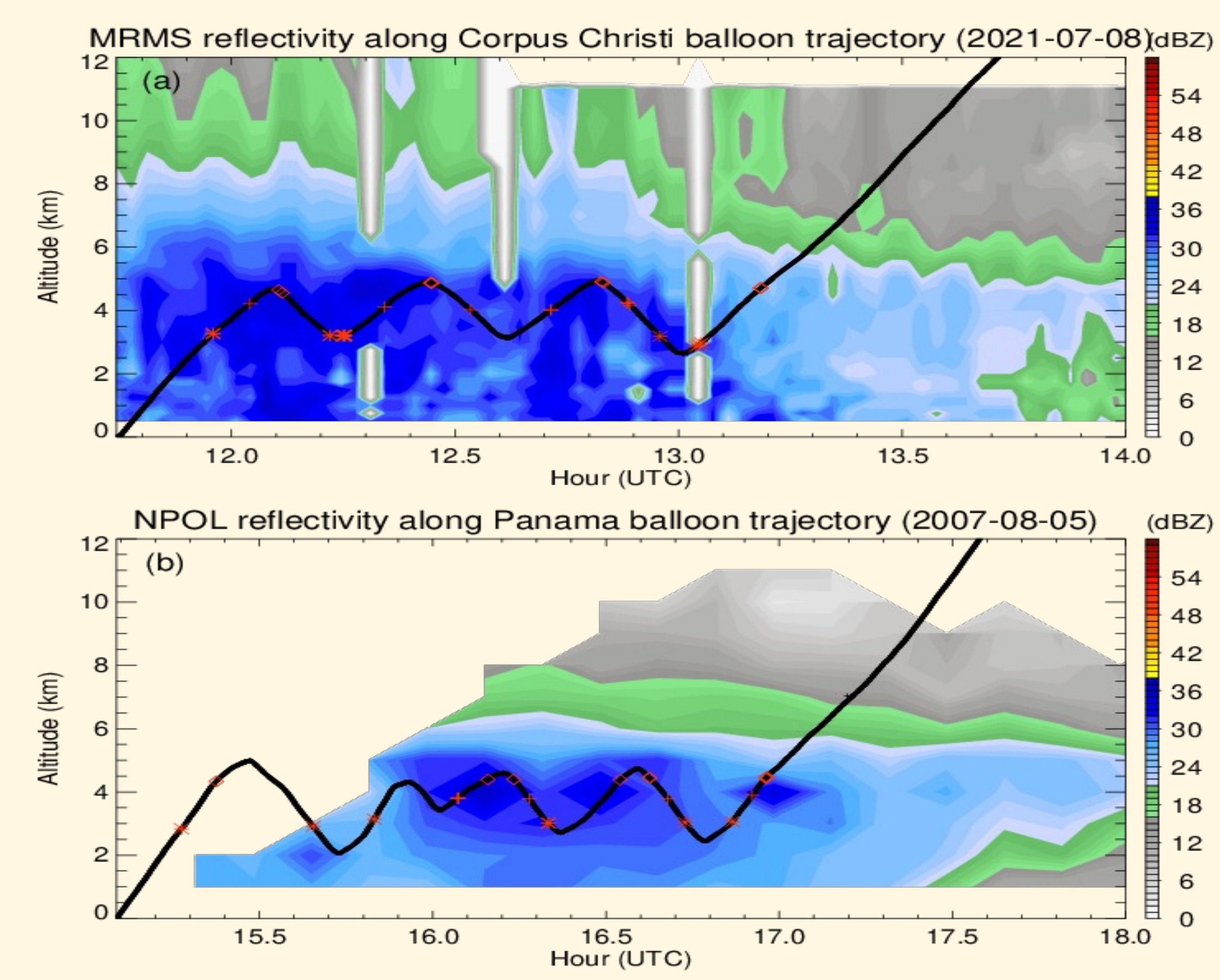


Figure 4. The field of vertical radar reflectivity profiles at the time and location of balloon trajectory derived from MRMS (a) and NPOL (b) 3D reflectivity products. The black line shows the altitude of the balloon. The altitudes at 0°C, 4°C, and 10°C are marked with diamonds, crosses and asterisks along the trajectory.

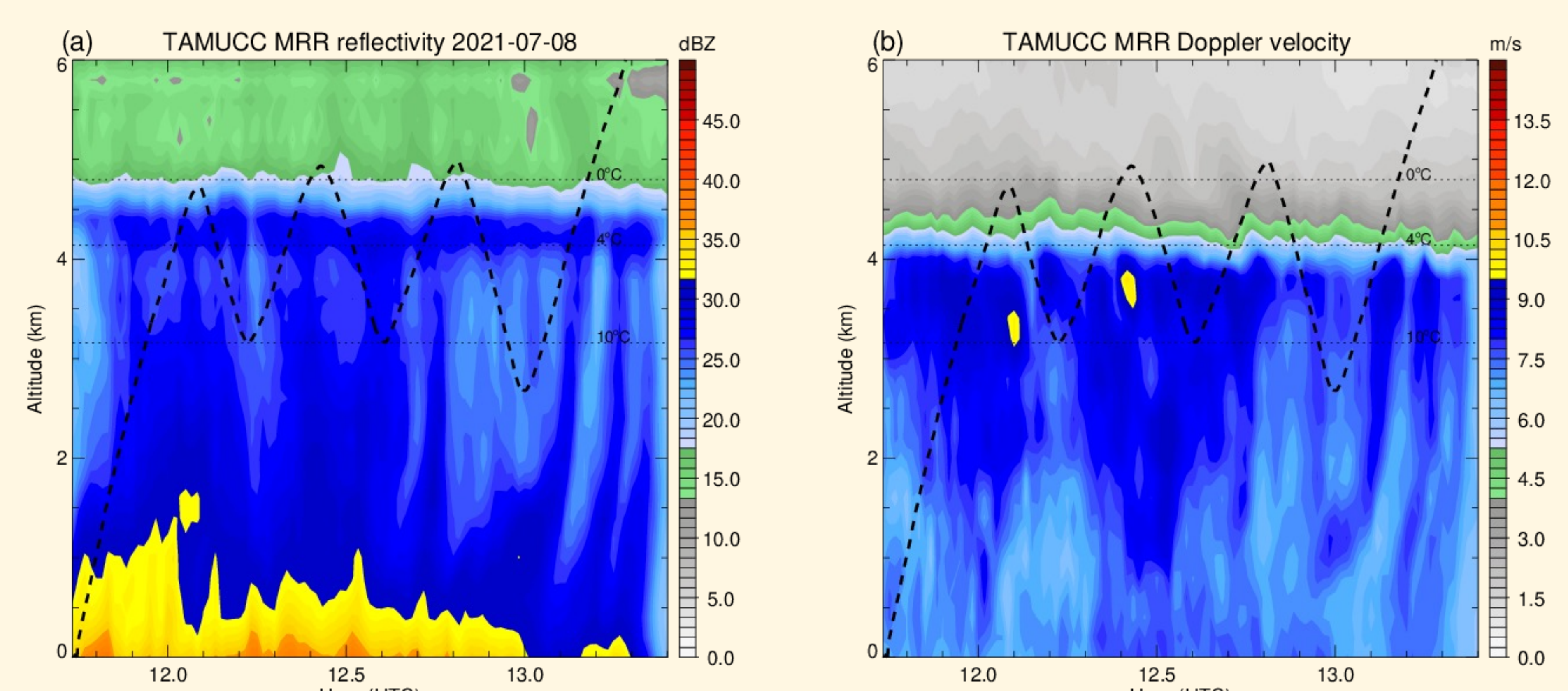
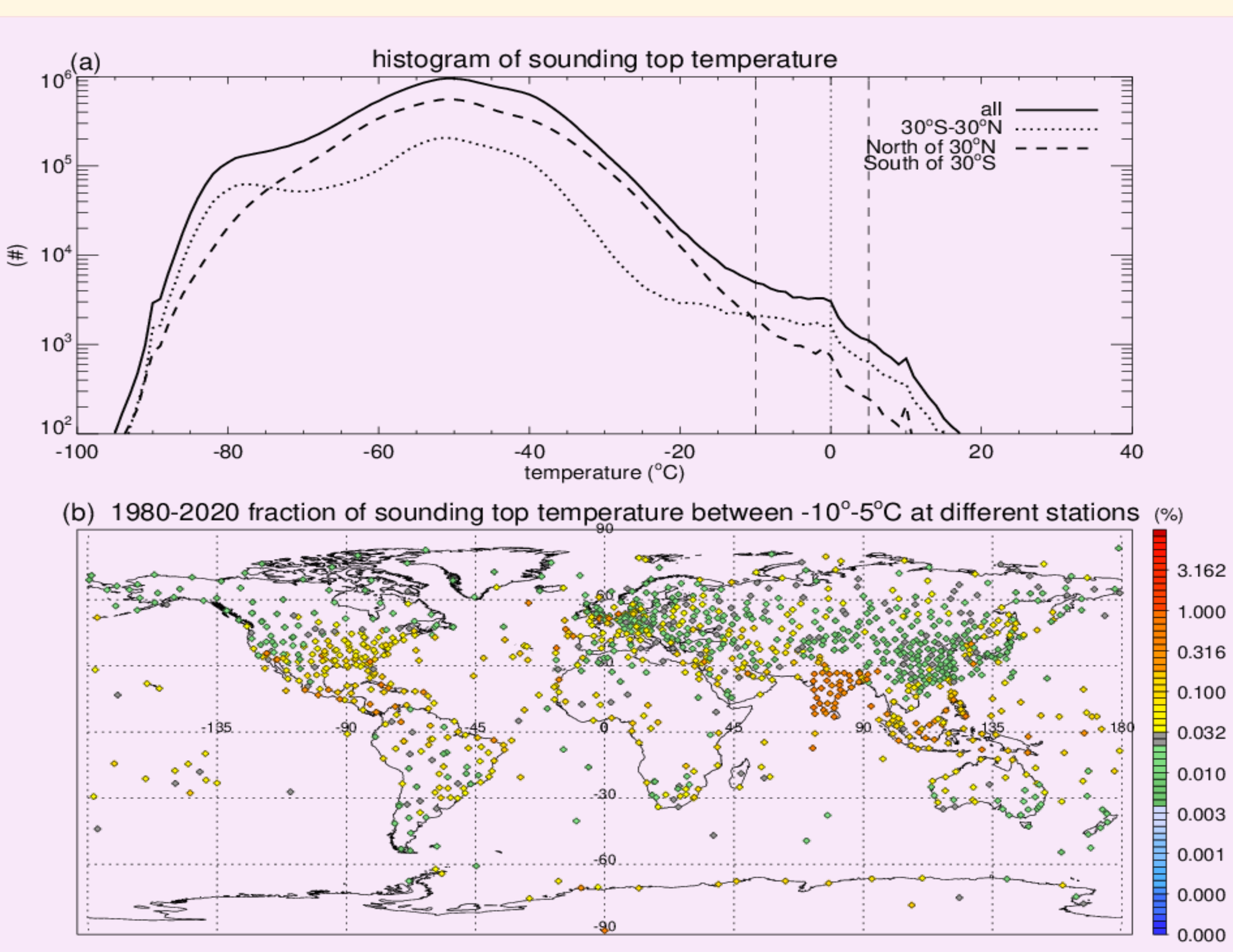


Figure 5. (a) Radar reflectivity during the balloon going up and down from vertical pointing Ka band Micro Rain Radar (MRR) at the balloon launching site (Texas A&M Corpus Christi campus). (b) Doppler velocity from MRR. The altitude of the balloon is overplotted with a dashed line. The mean altitudes at 0°C, 4°C, and 10°C are indicated with the dotted lines. Note that the balloon drifted within 20 km from the launch site during the period.

Similar cases around the globe

Figure 10. a) The histogram of the coldest temperature from profiles measured by radiosondes from 1980 to 2020 around the globe. b) Fraction of the radiosonde profiles stopped at temperature between -10°C and 5°C at each station with at least 10,000 sounding records.



- Current NWS operation stops collecting radiosonde observations once the sonde start to descend after the launch, mainly to keep observation quality..
- The fraction of radiosondes data stopped at lower altitudes could be from many factors, including balloon quality, weather, manmade errors.
- Globally, 0.18% of soundings stopped between -10°C and 5°C. A large proportion of these events could be related to the icing.

Conclusions:

- This oscillation is due to the accumulation and melting of ice on the balloon, causing the pattern to repeat multiple times.
- We recommend that soundings that show descent at altitudes lower than typically expected continue to be tracked, particularly up-down oscillating soundings can provide valuable information of icing conditions that might lead to aviation safety concerns.

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