Hydraulic Jump Dynamics in an Above-Anvil Cirrus Plume in a 50-m Resolution Simulated Supercell

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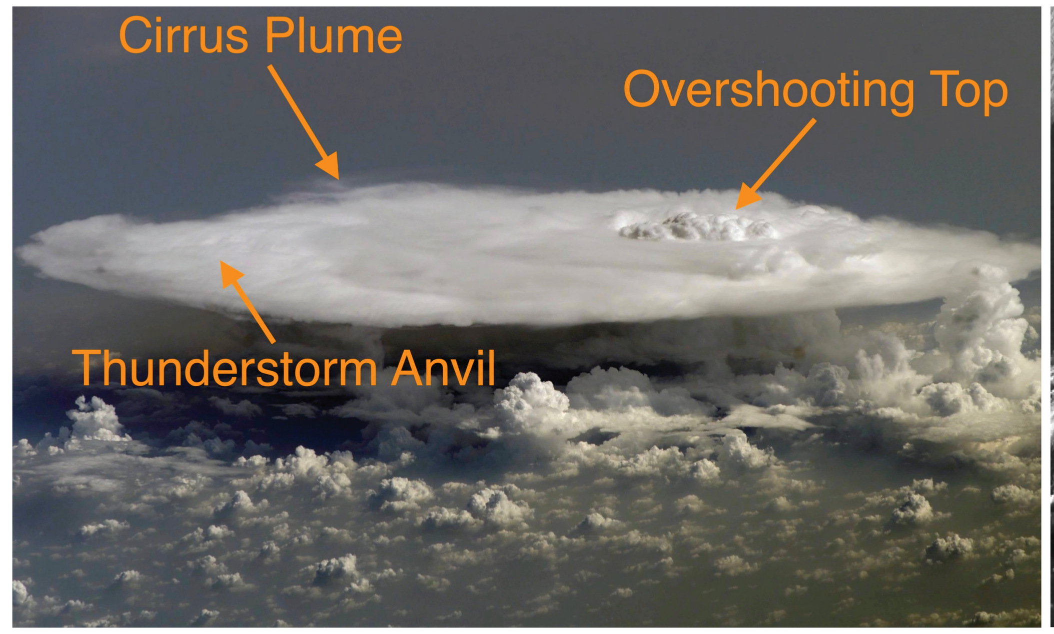
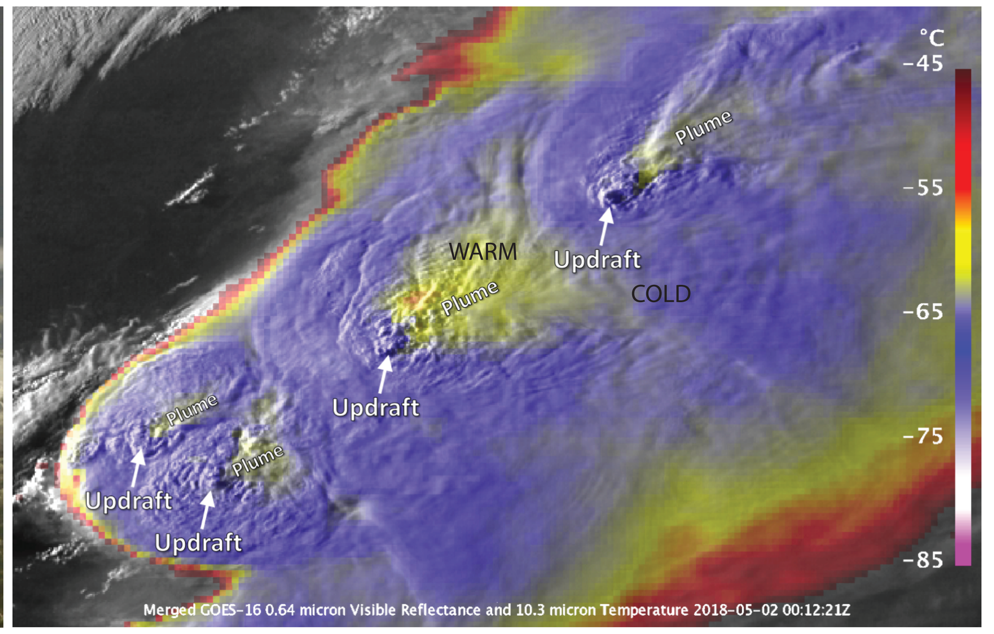
Above-Anvil Cirrus Plumes

- An above-anvil cirrus plume (AACP) is a sheet of cirrus cloud sometimes found streaming downwind above an overshooting thunderstorm top. AACPs are typically warmer than the anvil cloud below.
- Bedka et al (2018) found that storms with AACPs generated 14 times the number of severe weather reports per storm compared to non-AACP storms, with 73% of significant severe weather reports produced by AACP storms, and that AACPs appeared, on average, 31 min in advance of severe weather, providing a possible aid for forecasters.
- Fujita (1982) referred to these lower stratospheric clouds as "jumping cirrus", hypothesizing that their relative warmth was due to their location inside stratosphere; Homeyer et al (2017) cite gravity wave breaking as main AACP formation mechanism.

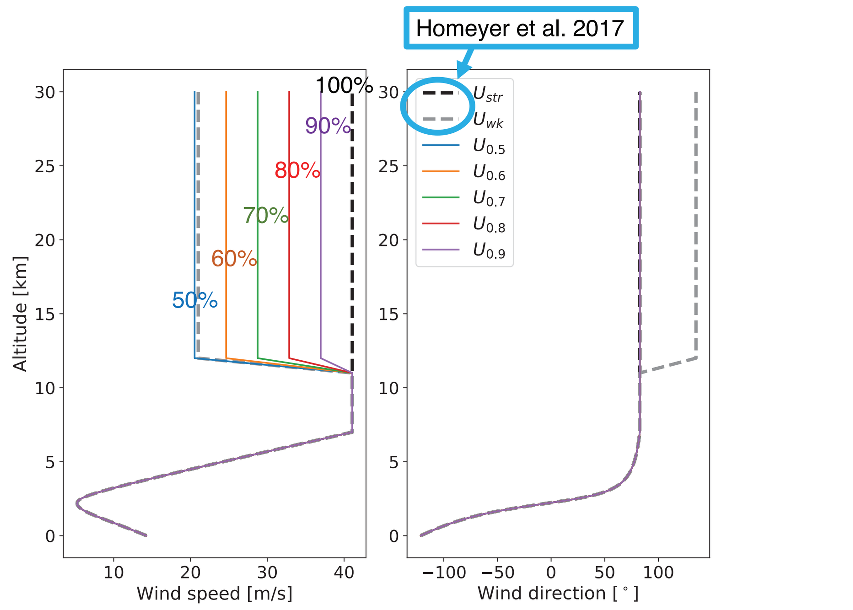




- **Using the CM1 model, we simulate an AACP-producing thunderstorm at very high resolution, and vary upper level environmental wind speed to explore AACP dynamics**

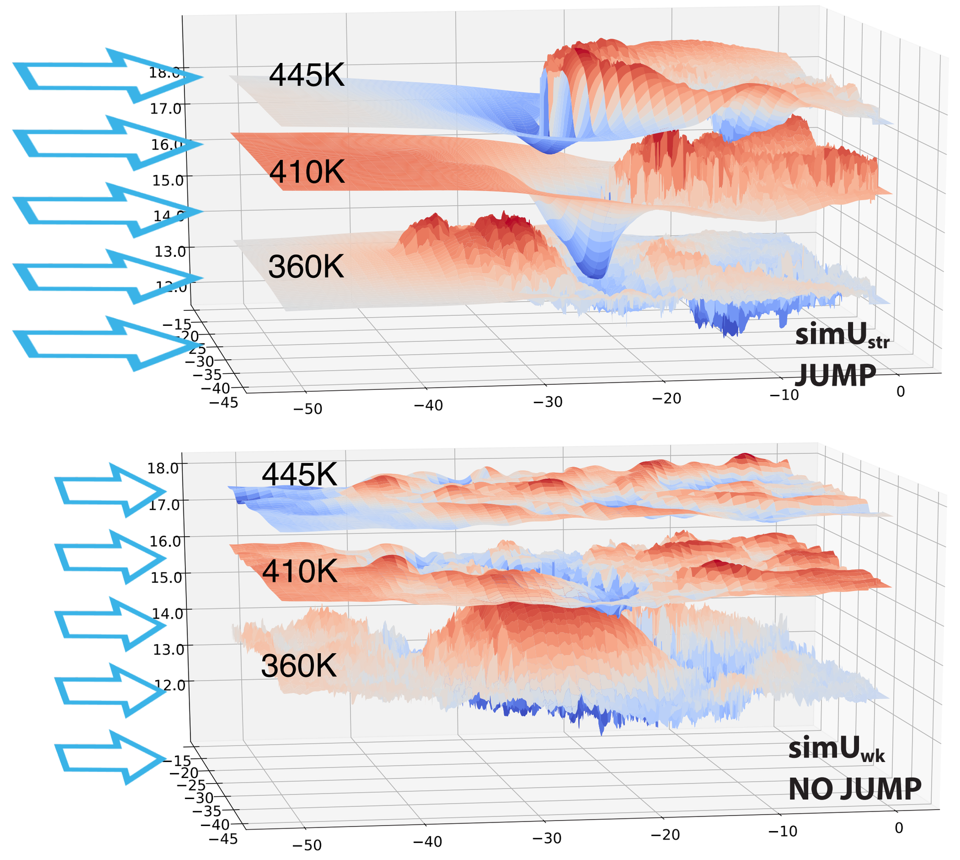
Methods

- George Bryan's CM1 model, release 16
- $\Delta x = \Delta y = \Delta z = 50\,\mathrm{m}$, 3.5 billion gridpoints
- Model domain: $122 \times 120 \times 30\,\mathrm{km}$
- Morrison microphysics, TKE closure
- simU_{str}: AACP-producing environment of Homeyer et al (2017)
- simU_{wk}: No-AACP environment of Homeyer et al (2017)
- sim$U_{0.5}$: Scale simU_{str} wind speed above 11 km by 50%
- Also four intermediate speed simulations



Jump vs. no jump simulations

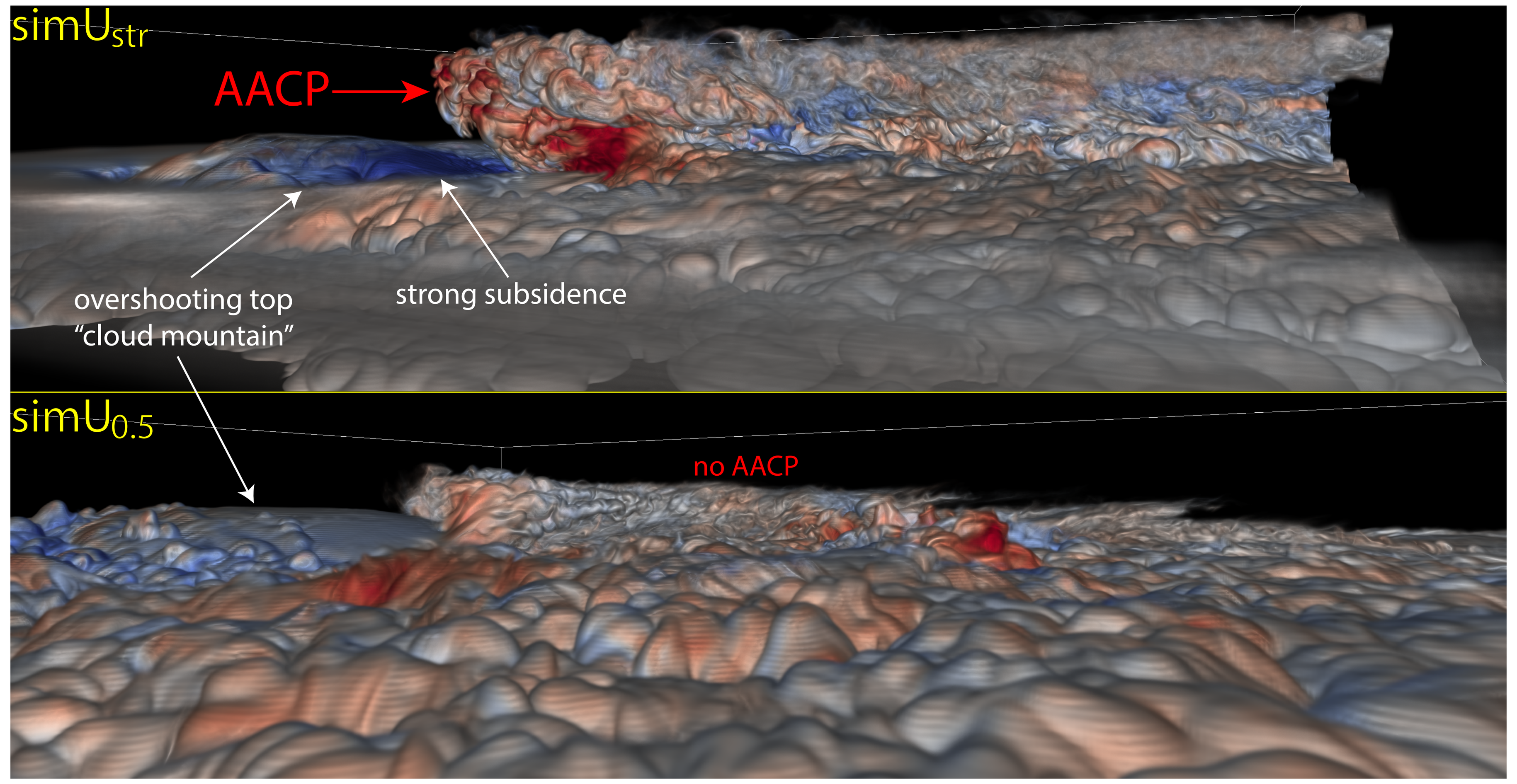
Jump results in AACP with relatively smooth inflow and little upstream gravity wave propagation



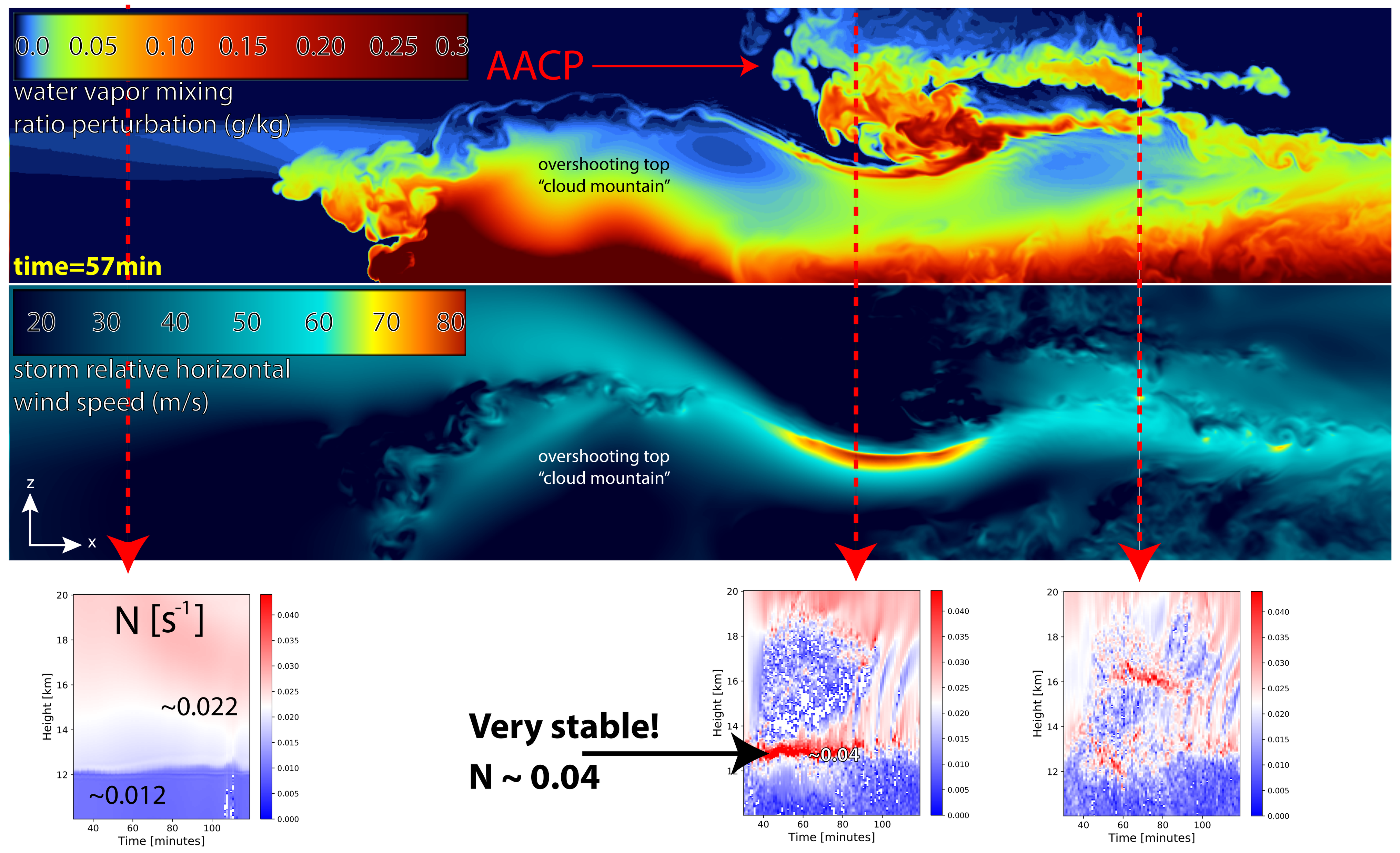
No jump results in no AACP with gravity waves and turbulent mixing everywhere - gravity waves are able to propagate upstream due to weaker upper winds

Strong vs. weak upper winds

Here we compare water vapor mixing ratio (q_v') shaded by vertical wind speed (blue: downdraft; red: updraft) between simU_{str} and sim$U_{0.5}$. View is looking towards the northwest at $t = 4280\,\mathrm{s}$.

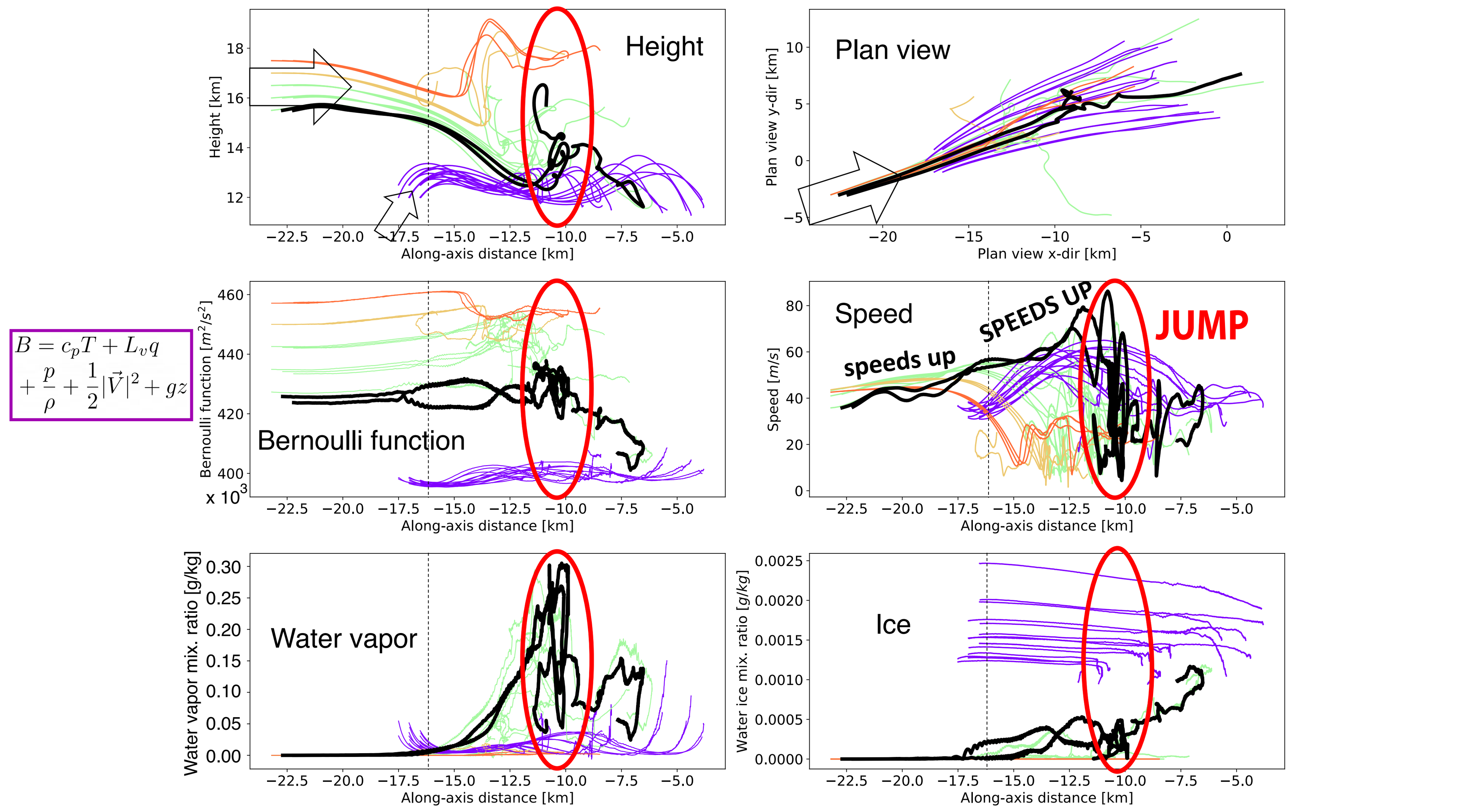


Hydraulic jump in simU_{str}

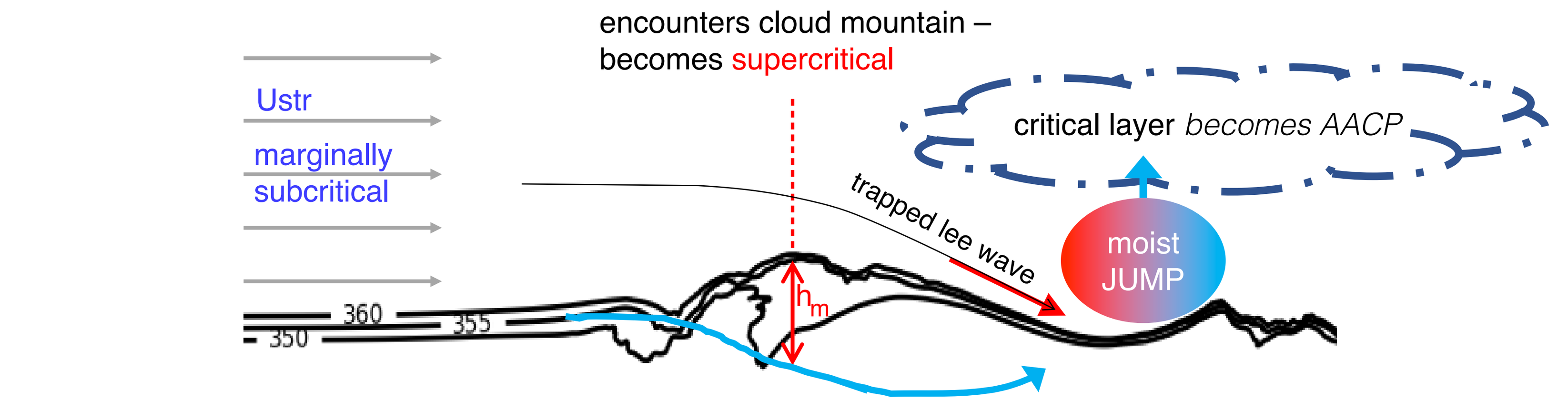


Hydraulic jumps in the atmosphere are typically associated with topography, when subcritical flow becomes supercritical; Supercritical flow becomes unstable, gravity waves break

Jumping trajectories



Conceptual model and preliminary conclusions



- We get qualitatively the same AACP as Homeyer et al (2017) at 20x the resolution
- Subsidence is almost certainly the cause of the Close-In Warm Area leeside of the overshooting top
- The "topographical Froude number" U/Nh_m is less than 1, but this doesn't preclude a jump
- The Above-Anvil Cirrus Plume appears to be dynamically very simple - linear theory works
- Breaking gravity waves on the lee side of the cloud mountain create a stagnant **critical layer**
- The critical layer reflects the upward propagating wave energy downward, creating a **trapped lee wave**
- The flow becomes supercritical on the leeside and is arrested by a hydraulic jump which then moistens the critical layer; this is the (usually warm) AACP above sinking, adiabatically warming strat/trop air
- **Conclusion: A moist, permeable evolving "cloud mountain" (thunderstorm overshooting top) induces a downslope windstorm and hydraulic jump**

References/Acknowledgments

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Homeyer et al, 2017: On the Development of Above-Anvil Cirrus Plumes in Extratropical Convection. J. Atmos. Sci., 74, 1617–1633.

Bedka, et. al 2018: The Above-Anvil Cirrus Plume: An Important Severe Weather Indicator in Visible and Infrared Satellite Imagery. Weather Forecast., 33, 1159–1181.

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