Warm air intrusions in Arizona’s Meteor Crater – evidence for hydraulic jumps?

Bianca Adler

C. David Whiteman, Manuela Lehner, Sebastian W. Hoch
Outline

1. Meteor Crater topography and instrumentation

2. Data analysis

3. Conceptual model

4. Summary and conclusions
What is so special about Meteor Crater?

- Near-circular basin
- Surrounded by a uniform plain sloping upwards to the SW with 2% slope
- Uniform rim height - no major saddles or passes

© John S. Shelton
Nocturnal temperature and wind fields

- Near-isothermal "residual" layer
- Stable surface layer
- Near-isothermal layer
- Mesoscale drainage flow
- Crater floor inversion
- Weak wind
Temperature and wind during *warm air intrusions*

- West side of crater atmosphere 4-5°C warmer than center and east side
- Strong wind with same wind direction as for mesoscale drainage flow
- Cold air near slope and crater floor inversion persist (max. intrusion depth 140 m)
Temperature and wind during *warm air intrusions*

- 5 of 6 IOP nights, 23% of all soundings with warm air intrusion on west side
- A signature of warm air intrusions is found in WU surface pressure and wind

→ Characteristics of warm air intrusions for whole month

(Total number: 138; mean duration: 13 minutes)
Main characteristics of *warm air intrusions*

- Occur **episodically** on >50% of all nights
- Penetrate crater in the **immediate lee** of the upwind rim
- **Penetration depth** up to 140 m; never penetrate the crater floor inversion
- Warm air **originates from the residual layer** over the plain
- **Wind speed and direction** in the warm air is the same as for the mesoscale drainage flow on the plain
- **High wind speeds and turbulence** occur beneath the warm air
Conditions at upwind rim during *warm air intrusions*

- RIM tower is at the west rim high point (12 m above mean rim height)
- Sometimes the RIM tower is in the cold air inflow layer; sometimes not
- Warm air intrusions start when temperature decreases and wind speed increases

→ Warm air intrusions start when the depth of the cold air layer flowing over the rim and the wind speed at the rim increase!
Warm air intrusions occur when ...

On quiet synoptically undisturbed nights

→ Stable surface layer and mesoscale drainage flow form on the plain outside the crater

→ Near-continuous cold air inflow over the upwind rim of the crater

Pulsations in the mesoscale drainage flow or in the volume of cold air sliding down the plain

→ Increase of cold air inflow layer depth and increase of wind speed at the crater rim

→ Warm air intrusion
Why does the warm air intrude the colder stable crater atmosphere?

• Warm air intrusions occur in a stratified flow over topography
• Similarity to downslope windstorms; although crater scale is much smaller
• Various theories exist like wave-breaking, hydraulic jumps, ...

→ Hypothesis based on a hydraulic jump inside the crater basin
Conceptual model
Summary and conclusions

• We found evidence for sporadic hydraulic jumps inside Meteor Crater basin during METCRAK 2006

• Hydraulic jumps result when the flow at the crater rim turns supercritical and penetrates the crater in the immediate lee of the upwind rim

• Hydraulic jumps are controlled by the stability and wind conditions in the approaching flow and by stability inside the crater basin

• Unique combination of the topography inside and outside the crater allow formation of a hydraulic jump
  – Relative depth of stable surface layer, drainage flow and rim height
  – Depth of crater basin

• Further observations and/or numerical studies are planned to verify the hydraulic jump hypothesis
Thank you!

Questions?
Suggestions?

This work was supported by a KHYS scholarship and a DAAD scholarship.
Conditions on the plain surrounding Meteor Crater

- **Strong stable surface layer** (depth around rim level)
- **SW mesoscale drainage flow** (deeper than rim level)
Origin of the air in “warm air intrusion”

Potential temperature in the warm air intrusion and in the residual layer above the plain are about the same

→ Warm air originated from the residual layer above the plain and was transported downwards
Continuous near-surface measurements

Δp oscillations

Temperature datalogger
Tethersonde
Tower

WU
EU
FLR

TKF (m² s⁻²) Wind speed (m s⁻¹)
Continuous near-surface measurements

\[ \Delta p \] oscillations

![Graphs showing pressure changes](image)
Downslope windstorms
Definition: Very strong surface winds that develop when air flows over a high mountain ridge with a steep lee slope (Durran 1990).

→ Hydraulic jump
What is a hydraulic jump?

- Stratified fluid with free surface flows over an obstacle (compare with water flowing over rocks in a river)
- Flow is subcritical upstream of the ridge, i.e. fluid thins and accelerates approaching the ridge
- A transition to supercritical flow occurs at the ridge top, i.e. fluid further thins and accelerates during descent
- The flow eventually returns to ambient conditions downstream of the ridge through a hydraulic jump
- There are limitations to applying this theory to an unbounded continuously stratified atmosphere