Evidence of Atmospheric Canopy Wave Breaking

Alejandro Espinoza-Ruiz[1], Shane D. Mayor[1], William D. Smyth[2]
[1] Department of Earth and Environmental Sciences, California State University Chico
[2] College of Earth, Ocean and Environmental Sciences, Oregon State University, Corvallis, Oregon

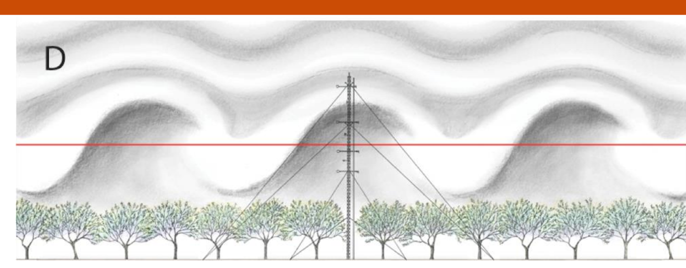
Introduction

What is this peculiar cloud formation?

Kelvin-Helmholtz (KH) Billows

- Are observable in clouds, although they are rare
- Phenomenon occurs at all altitudes; they do not require clouds to be present
- KH billows are caused by the flow on top being faster than the flow below it
- Occur in statically stable fluids
- Observable in other places apart from atmosphere such as oceans and estuaries
- KH Billows are important as they result in vertical mixing, or sometimes referred as turbulence

Canopy Waves



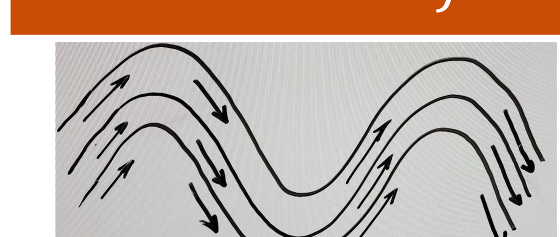
- Canopy Waves are a type of KH Instability
- Occur at night when the atmosphere is stable
- Tree branches and leaves slows down the wind in the canopy
- Difficult to detect through traditional meteorological methods due to the waves not being fully turbulent or laminar
- May grow and "break"
- The breaking of these waves occur in turbulence which results in the transport of heat, momentum, and trace gases in and out of forest canopies.

REAL

Raman-shifted Eye-safe Aerosol Lidar (REAL)

- Horizontal scanning atmospheric lidar
- Able to map out the particulate matter over an area (Approx. 10 sq. km)
- Colors correspond to the intensity in particulate matter (bright = more)
- Used in CHATS in 2007
- 1 image every 15 seconds and a total of 300,000 images captured in CHATS experiment
- 53 canopy wave episodes were recorded which had 1600 images in total

Why is it important?



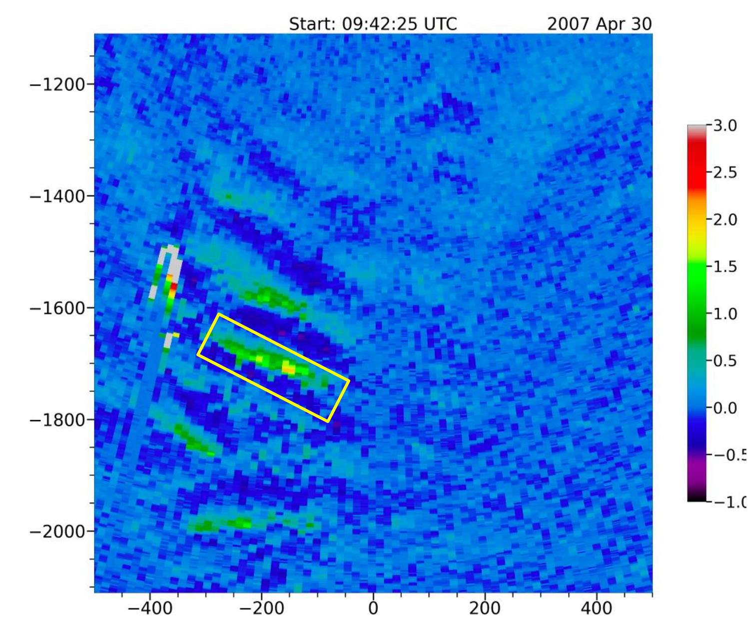
Pure fluid wave (non-turbulent)

- Everything that goes down comes back up
- This results in no **net** vertical transport

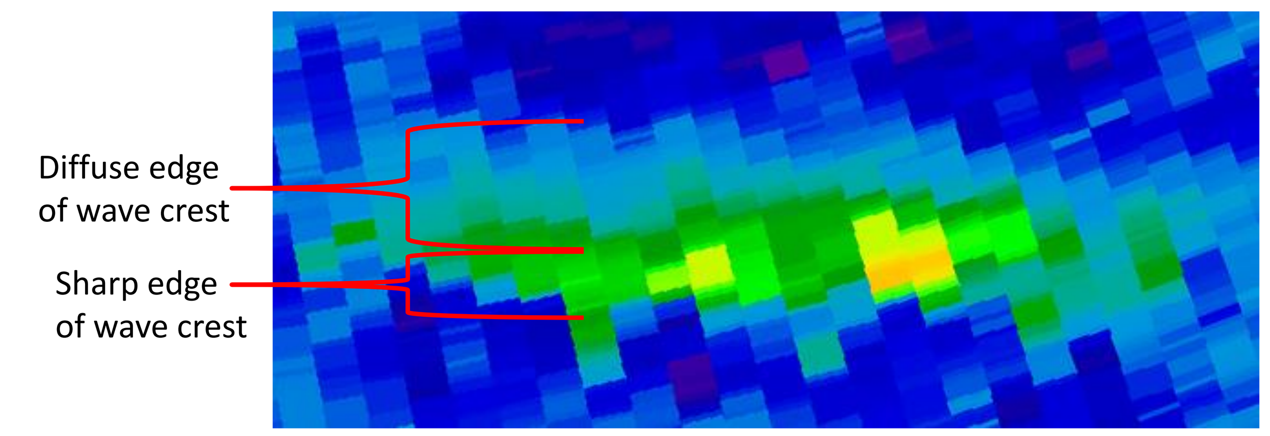
Billow (Breaking wave)

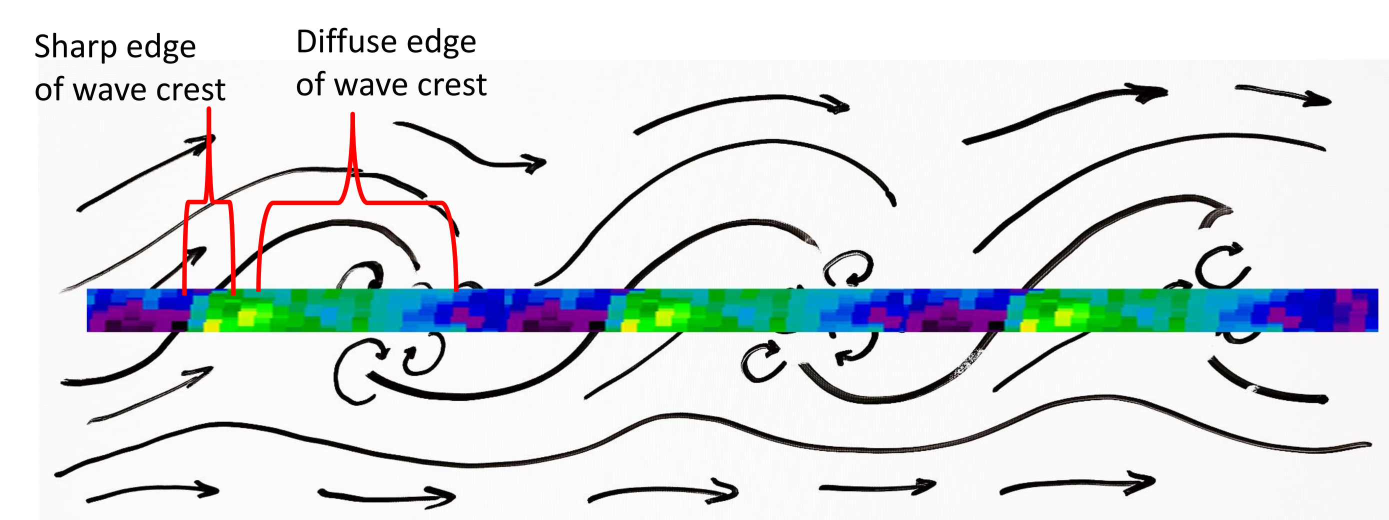
- Turbulence cause mixing and vertical transport
- Turbulence results in diffusion

Evidence #1: Asymmetric Wave Crests



Asymmetry in clouds: similar structure as canopy waves in horizontal scanning lidar image





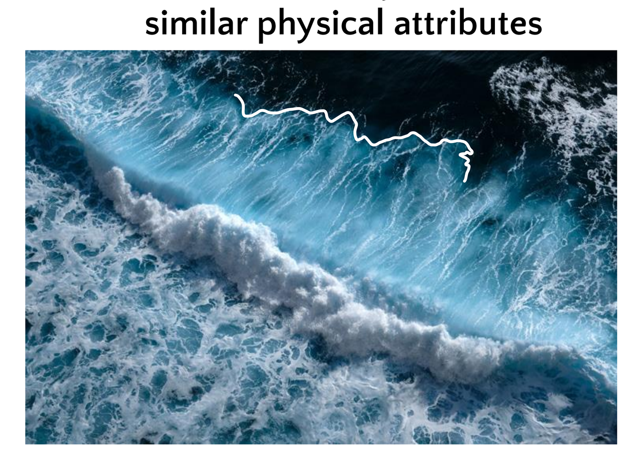
Vertical cross section of what the inside of a canopy wave would look like

Evidence #2: Secondary Instabilities

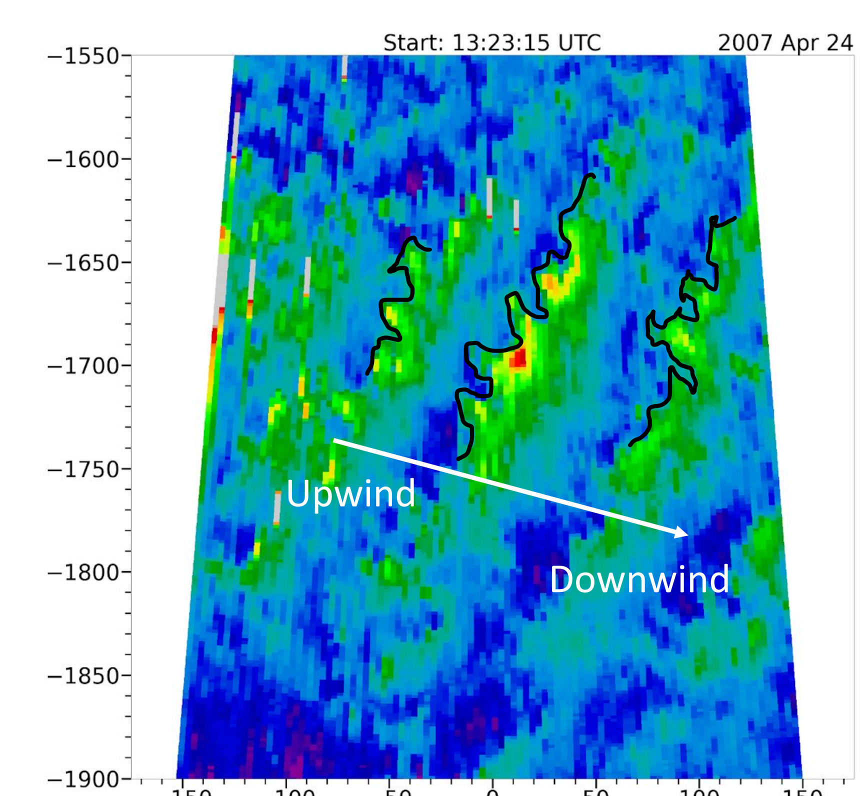
- Primary instability is the curling of the wave
- Secondary instability is the uneven collapsing of the wave crest
- Identifiable through their ragged edges in the lidar data
- Observable in the upwind side of the wave crest where the gradient is the sharpest

Example of primary instability

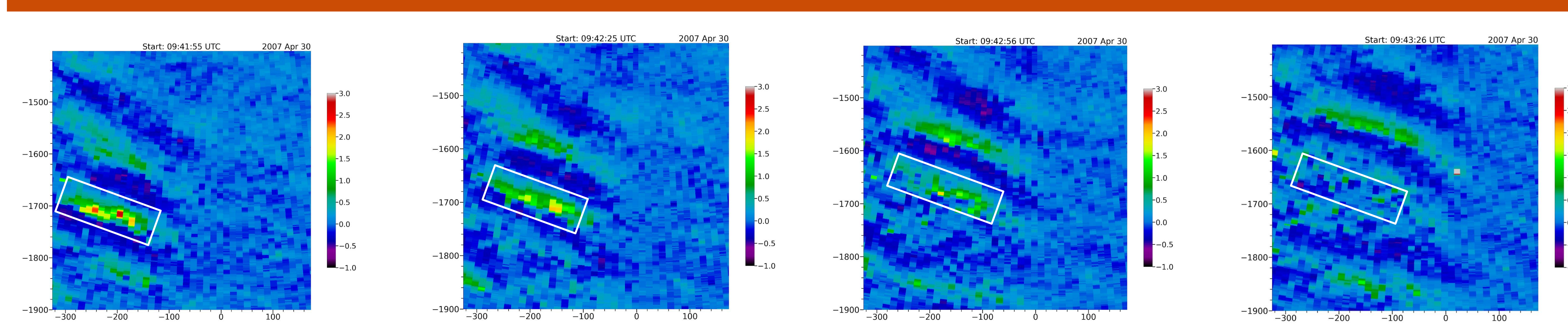
NOTE: Ocean waves are not KHI but they do share similar physical attributes



Secondary instabilities are outlined in the image



Evidence #3: Evolution of specific wave crest from asymmetry to turbulent

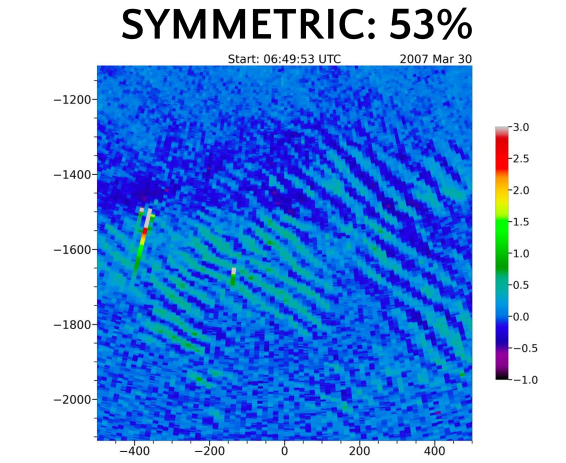


Above (from left to right): Evolution of a wave crest going from asymmetric to turbulent over a period of roughly 1 minute and 30 seconds.
Image 1 (left most): Wave crest exhibits asymmetric structure through appearance of diffuse downstream and sharp upstream edges.
Image 2: After 30 seconds have elapsed, the wave crest begins to show jagged upstream edges which are attributed to secondary instabilities.
Image 3: Another 30 seconds have passed, and the wave crest continues to lose coherent structure.
Image 4 (right most): After another 30 seconds, the wave crest has disintegrated into turbulence.

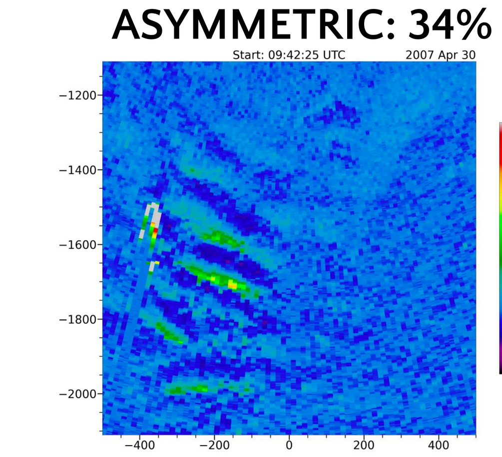
Results and Methodology

- 1600 images were visually inspected
- Categorized if the wave crests in the lidar image were symmetric, asymmetric, or inconclusive

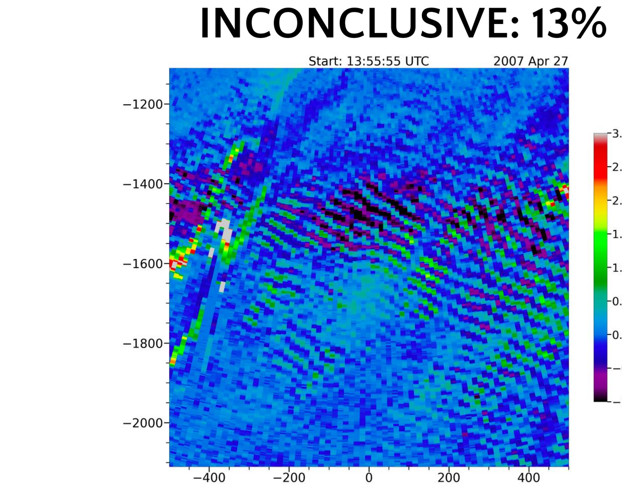
SYMMETRIC: 53%



ASYMMETRIC: 34%



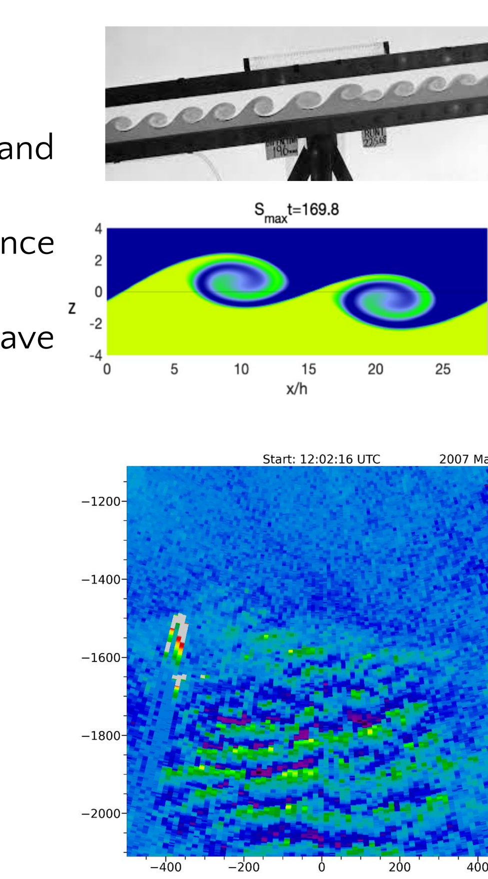
INCONCLUSIVE: 13%



(From left to right):

Conclusion and Summary

- KH billows are observable in the clouds
- Canopy waves are a type of KHI
- KHI have been recreated in lab tanks and through numerical simulation
- Important because the induced turbulence results in vertical mixing
- REAL can be used to identify canopy wave episodes



NEW:

- Horizontal lidar data can be used to distinguish if a canopy wave is symmetric (non-breaking) or asymmetric (breaking)
- 34% of the 1600 images showed signs of breaking
- 53% showed no signs of breaking

Questions for the future:

- Why do most asymmetric waves stay asymmetric
- Why do few of them disintegrate into turbulence
- Why do symmetric waves stay symmetric

References

Mayor, S. D., 2017: Observations of microscale internal gravity waves in very stable atmospheric boundary layers over an orchard canopy. *Agric. For. Meteorol.* **244-245**, 136-150.

Mayor, S. D., W. D. Smyth, Q. Lian, and A. Mashayek, 2019: Primary and secondary instabilities of turbulent, nocturnal canopy flows. Poster A13N-3148 at Fall meeting of the American Geophysical Union, 9 December, San Francisco, CA.