National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

Icelandic Met Office

Observations of a breaking mountain wave

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Mountain waves

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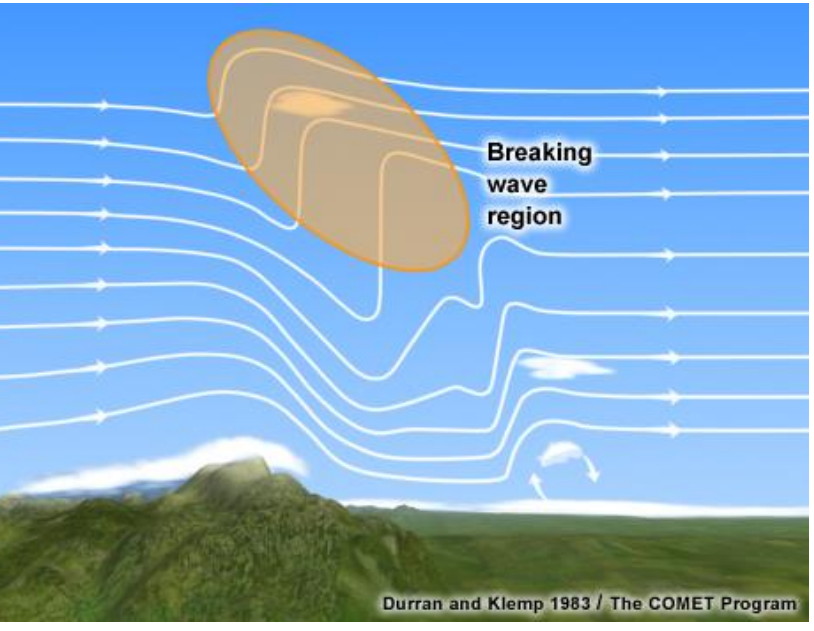
- Mountain waves can develop in stable atmosphere when airflow impinges upon a mountain
- Creation depends on the upstream stability, windspeed, mountain height, dimensions and surface friction
- Inversions close to mountain top enhance wave activity




Stefan Johannes


Páll Önundarson

Low level inversions enhance wave activity

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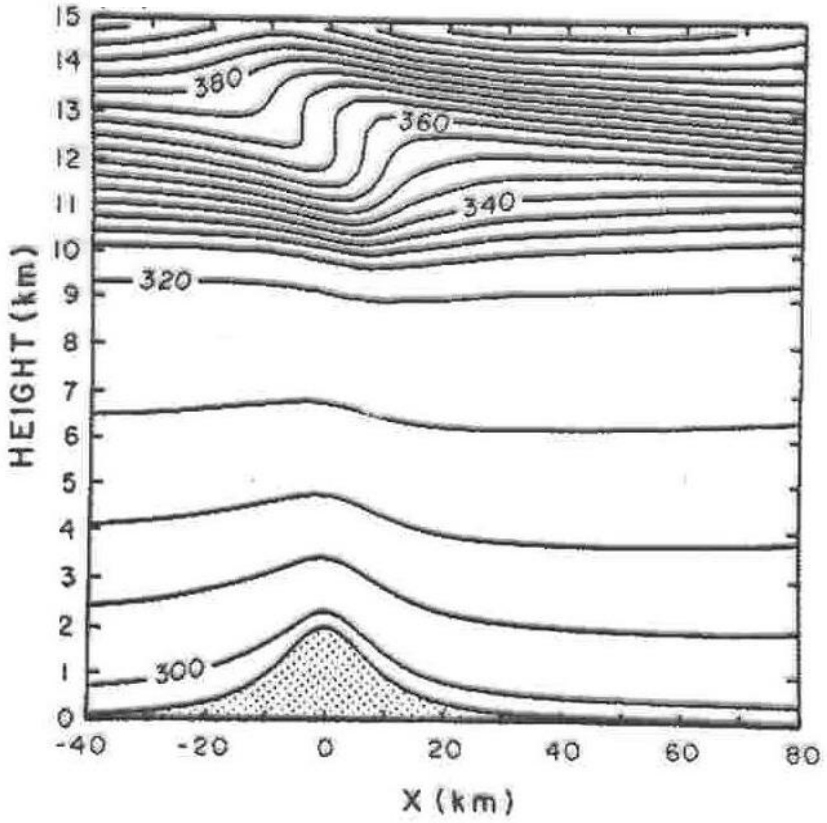
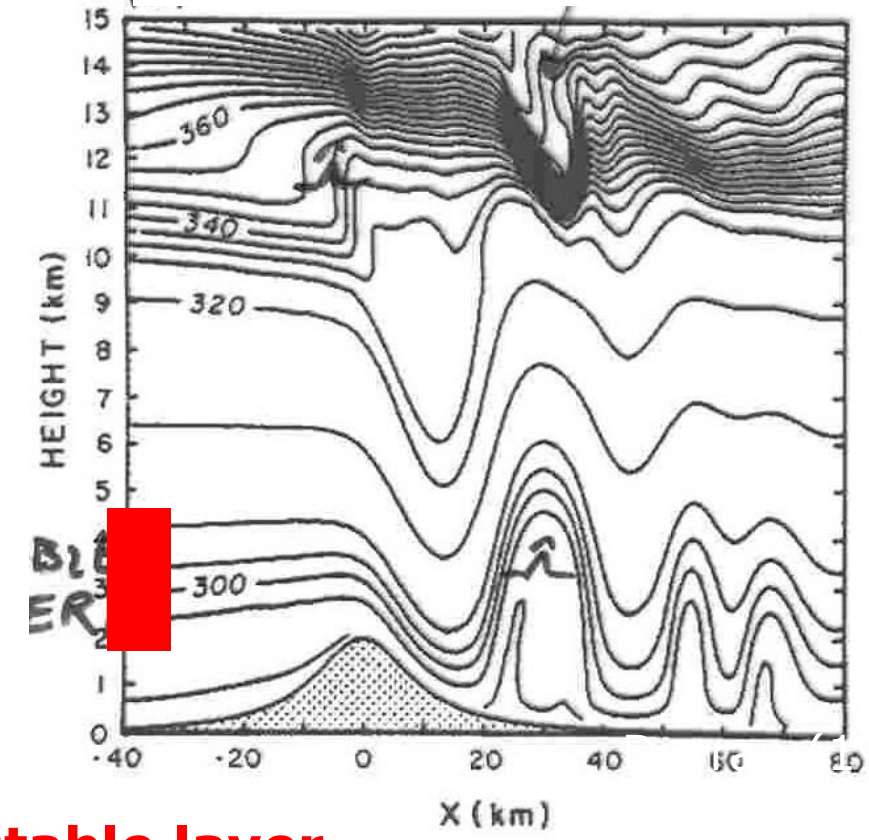
Little wave activity in the troposphere



Very amplified waves



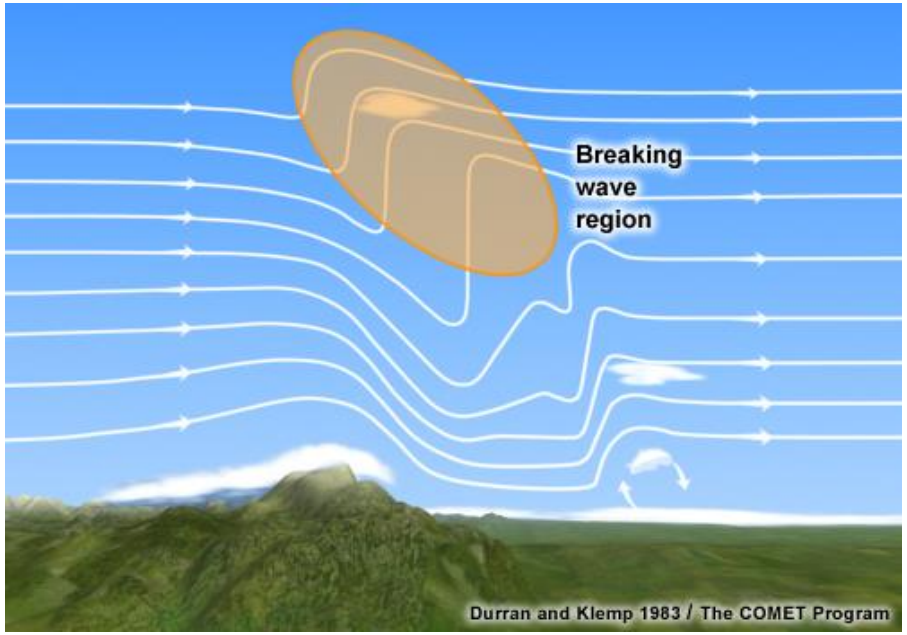
A stable layer

Isentropes (K) in two numerical simulations without and with a low level inversion

Downslope windstorms - over lee slopes of mountains

Three conceptual models proposed

- There is an analogue between the flow of water over an obstacle creating a hydraulic jump, and the flow over a ridge in downslope windstorms (Long, 1954)
- Vertically propagating mountain waves
  - Reflection and resonance of vertically propagating waves (Klemp and Lilly, 1975)
  - Creation of a self-induced critical layer through wave breaking which then reflects vertically propagating waves



FAAM – Facility for Airborne Atmospheric Measurements

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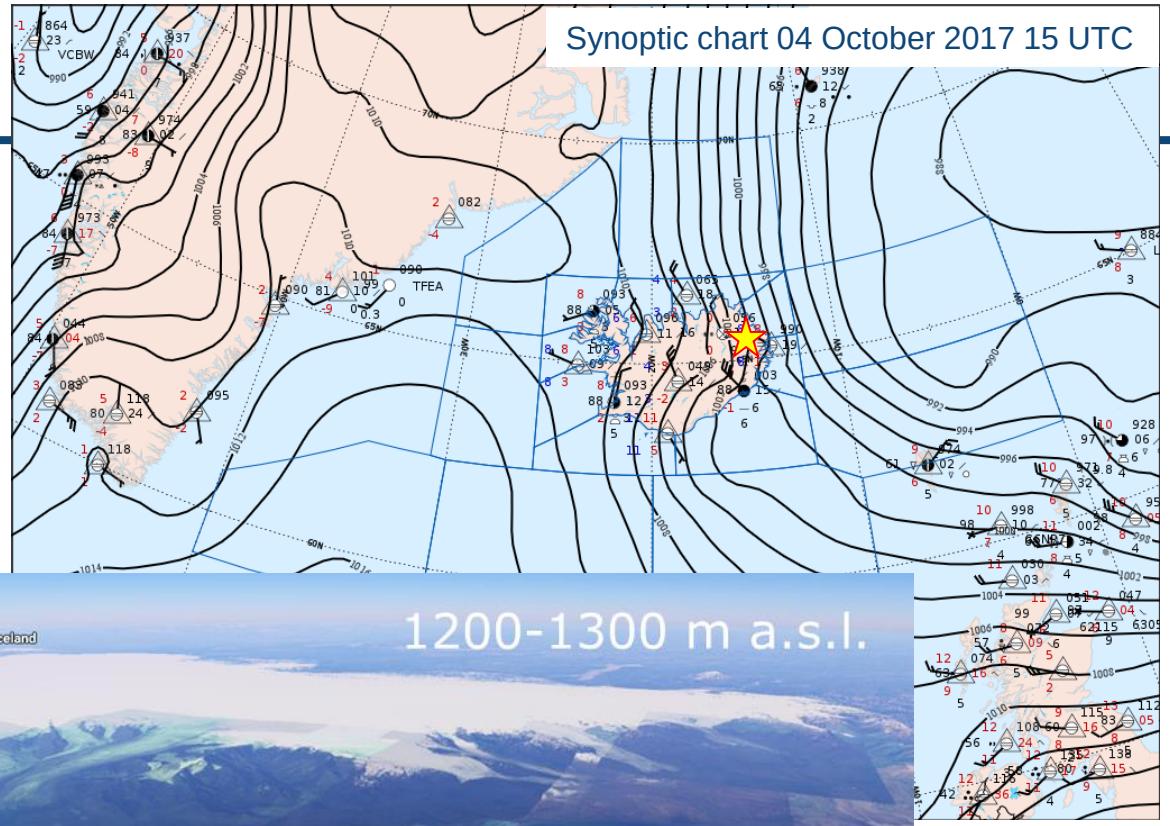
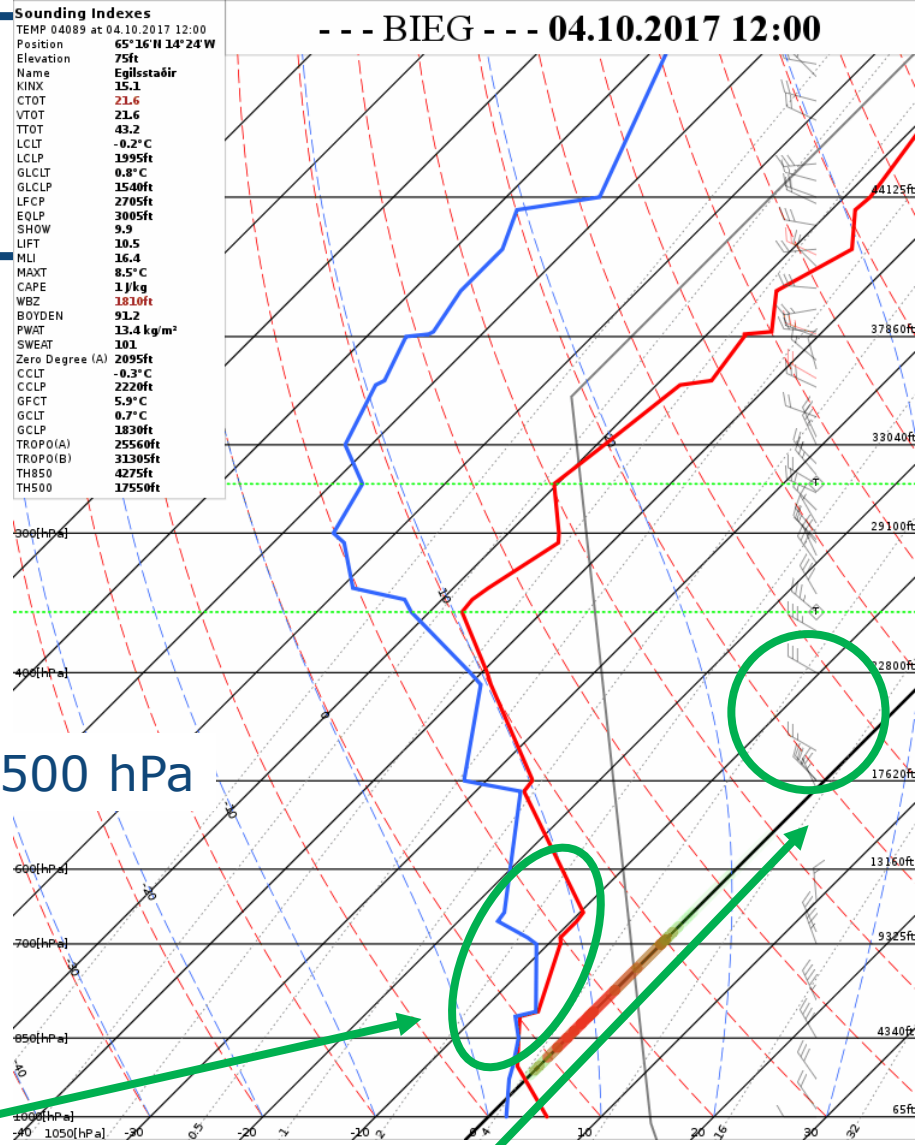
- In October 2017 we had the chance to measure a breaking wave with a research aircraft

faam.ac.uk

- Owned by the UK National Environment Research Council
- Modified Bae 146-30
- Equipped with standard meteorological instruments as well as turbulence, aerosol and cloud particle instruments
- Flight attendant

Synoptic situation





- **Upstream northerly winds ~15 m/s**
- **Temperature inversion at ~800 hPa (close to mountain top)**
- **Reduction of wind speed + change in wind direction 500 hPa => potential for reflection of wave energy**

Synoptic & mesoscale situation

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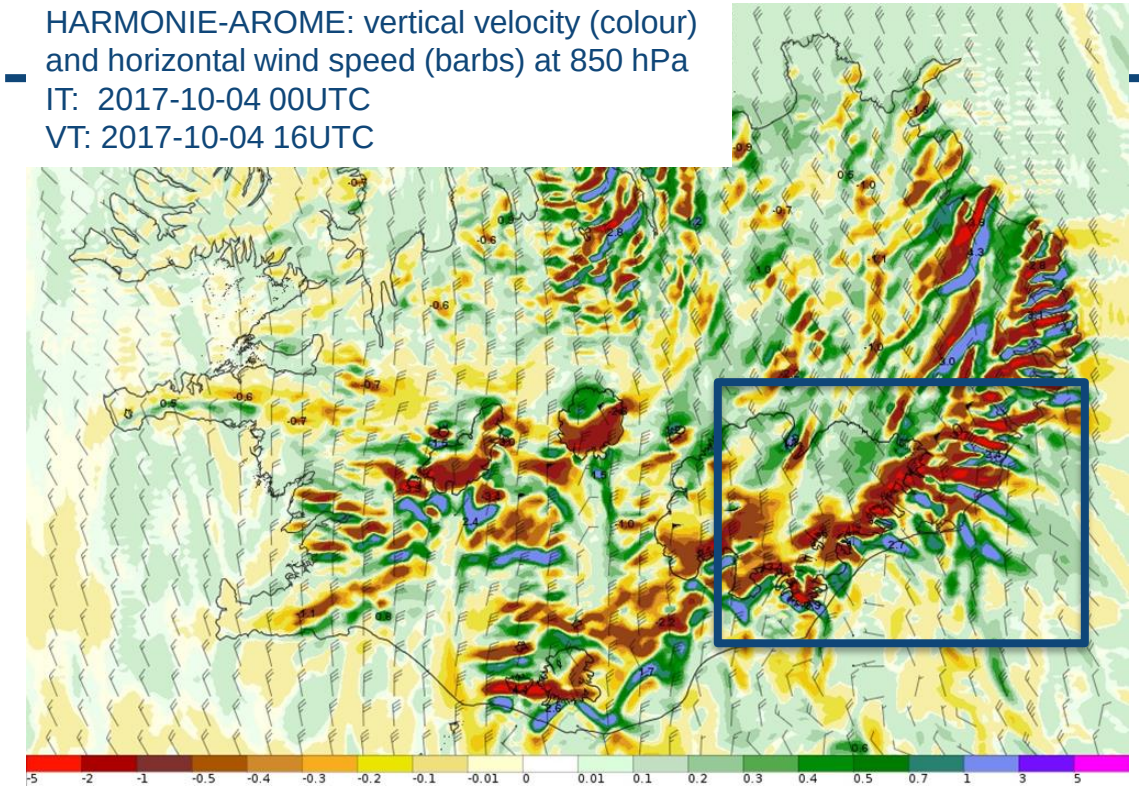
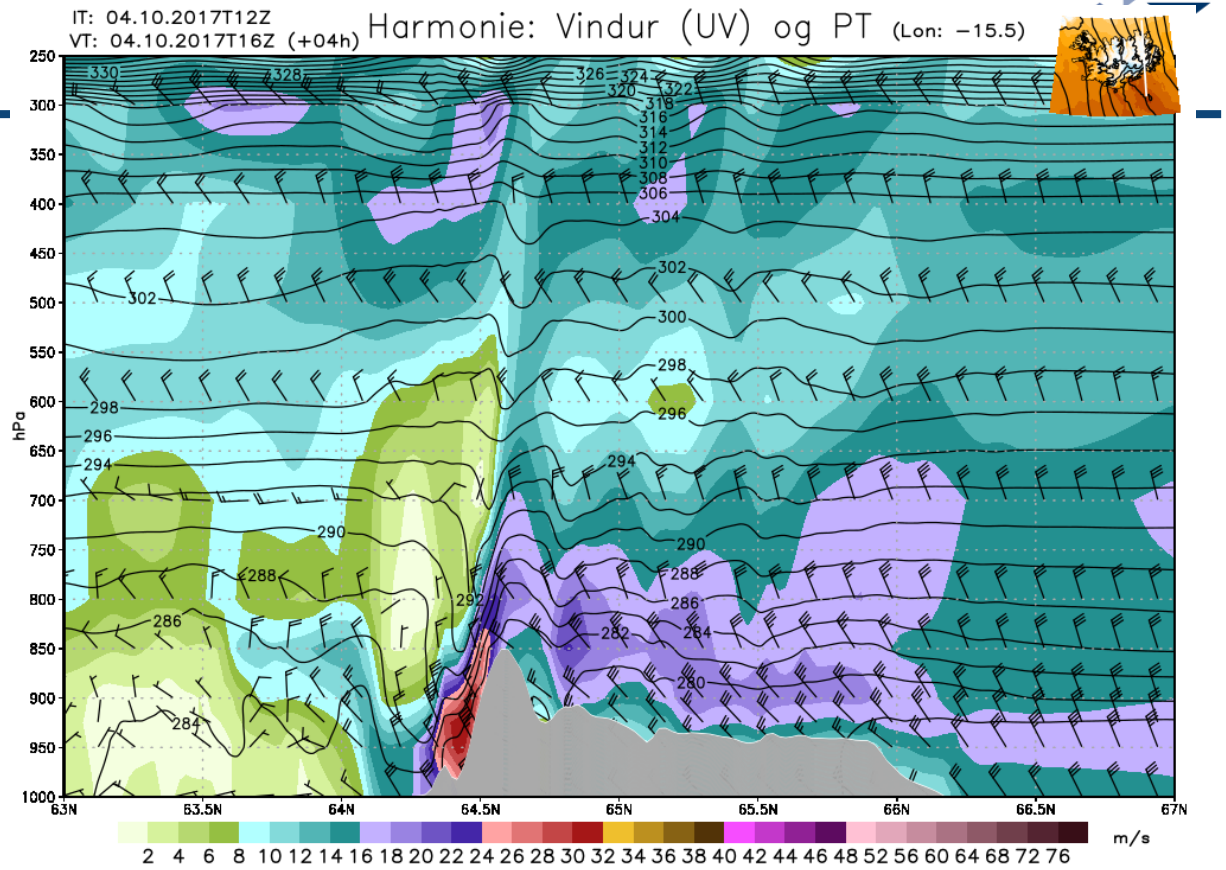
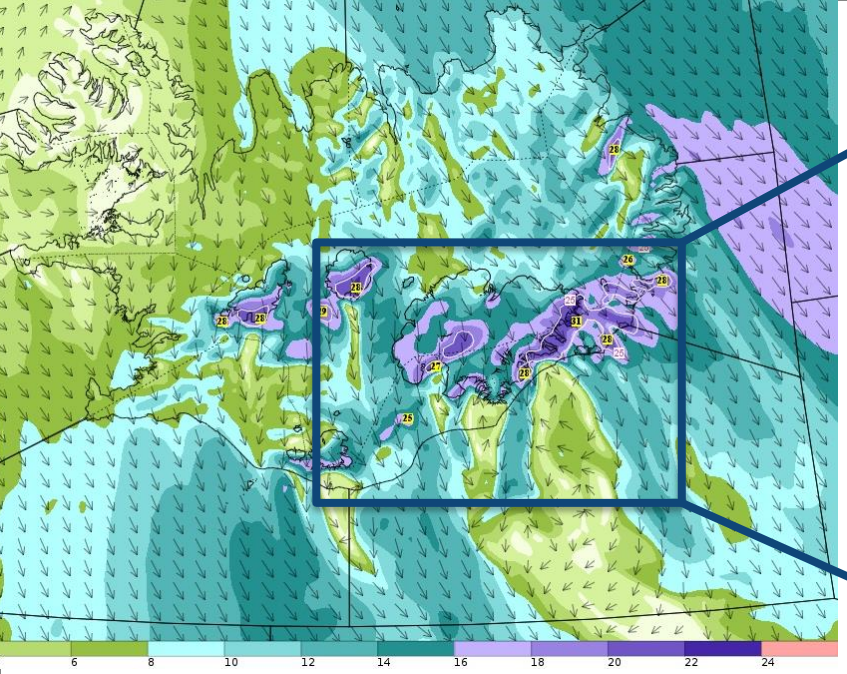
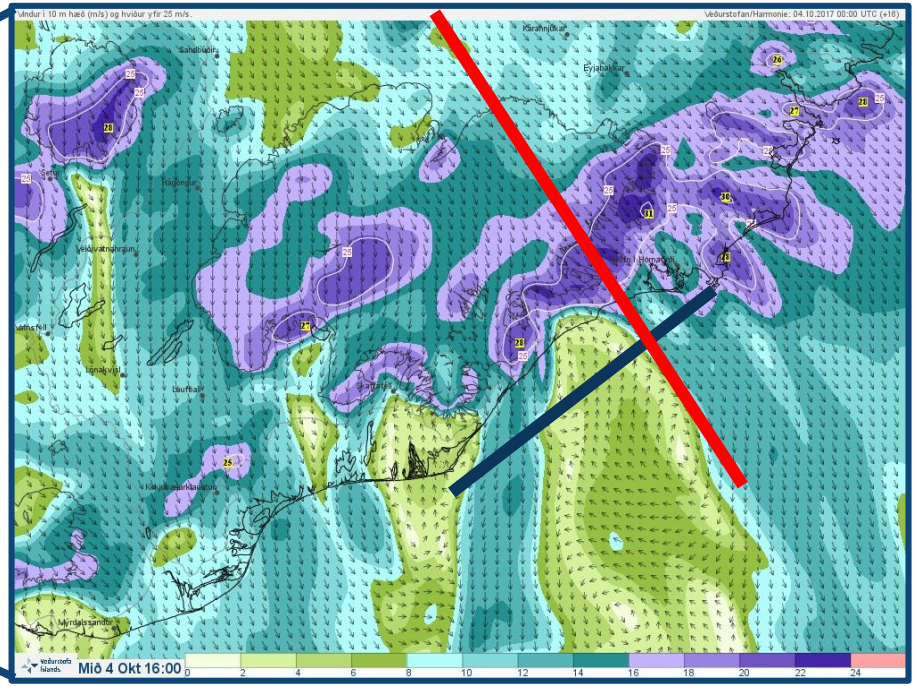
HARMONIE-AROME: vertical velocity (colour) and horizontal wind speed (barbs) at 850 hPa
IT: 2017-10-04 00UTC
VT: 2017-10-04 16UTC

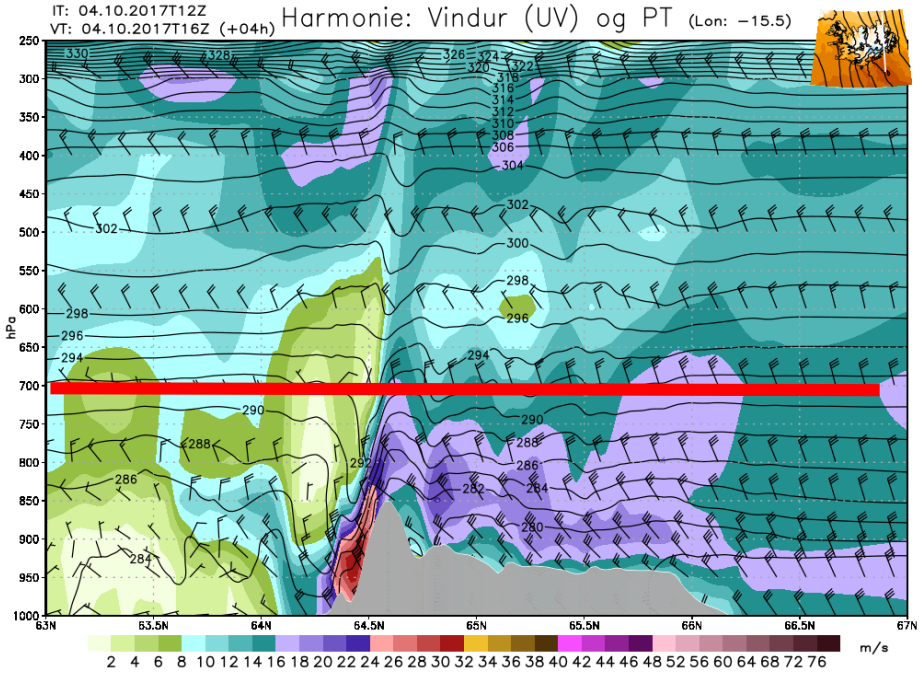




- **HARMONIE-AROME predicted strong downdrafts over the lee slopes of southern Vatnajökull**
- **Cross-section showed downslope windstorm in the lee with an area above with very low wind speed => self-induced critical layer? => indications of wave breaking**
- **Wind wake in the lee, with slow down and even reverse of wind direction**







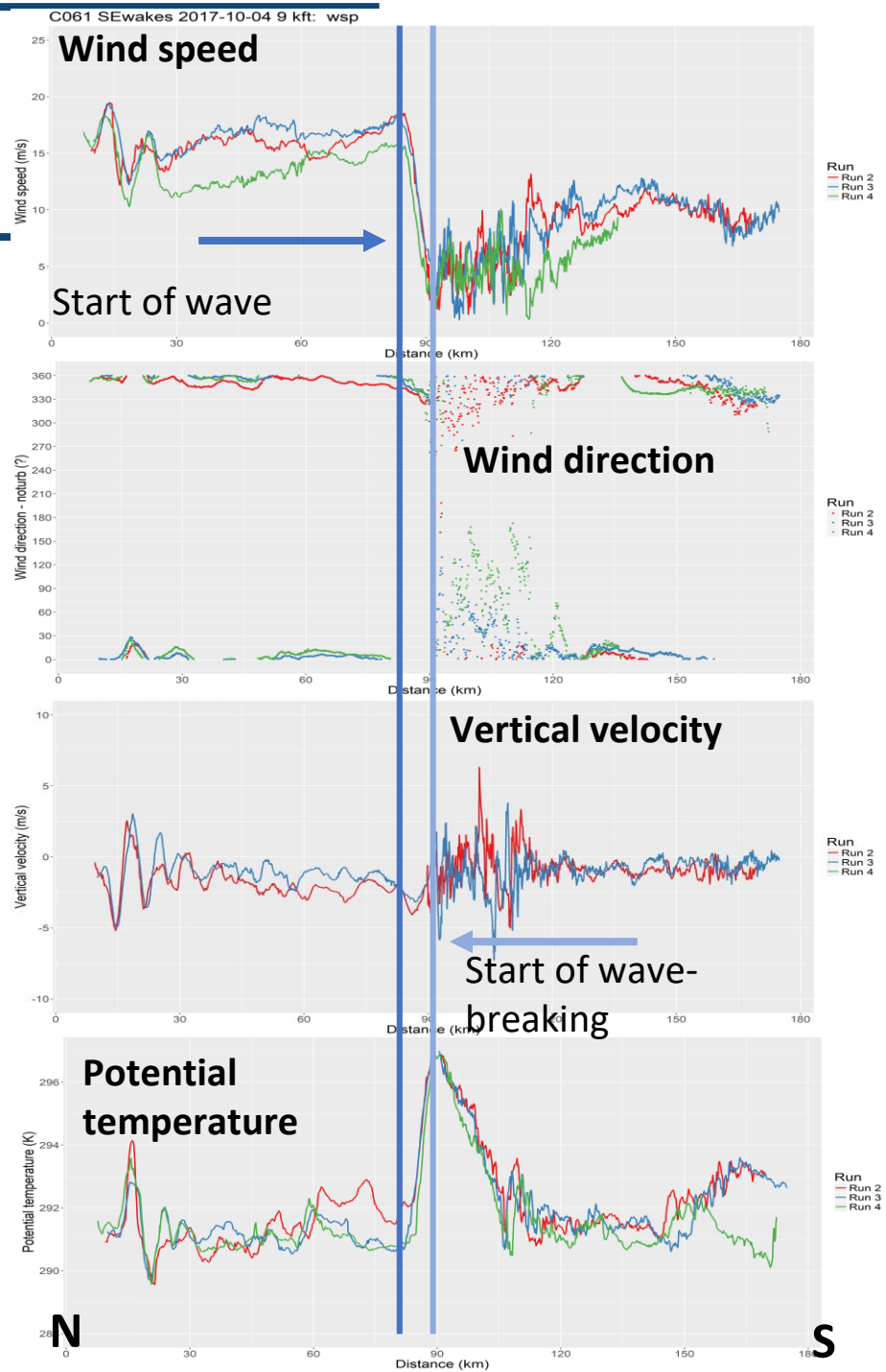
- Three runs at 9 kft parallel to the upwind wind direction
- Four runs in the lee at 0.8—4 kft

Aim:

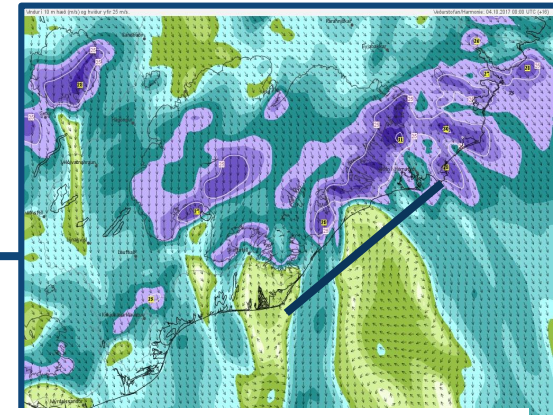
- Obtain measurements of wave breaking
- Capture the depth and characteristics of the wind wake
- Investigate how well the model performed

Aircraft observations at 9 kft (~700 hPa)

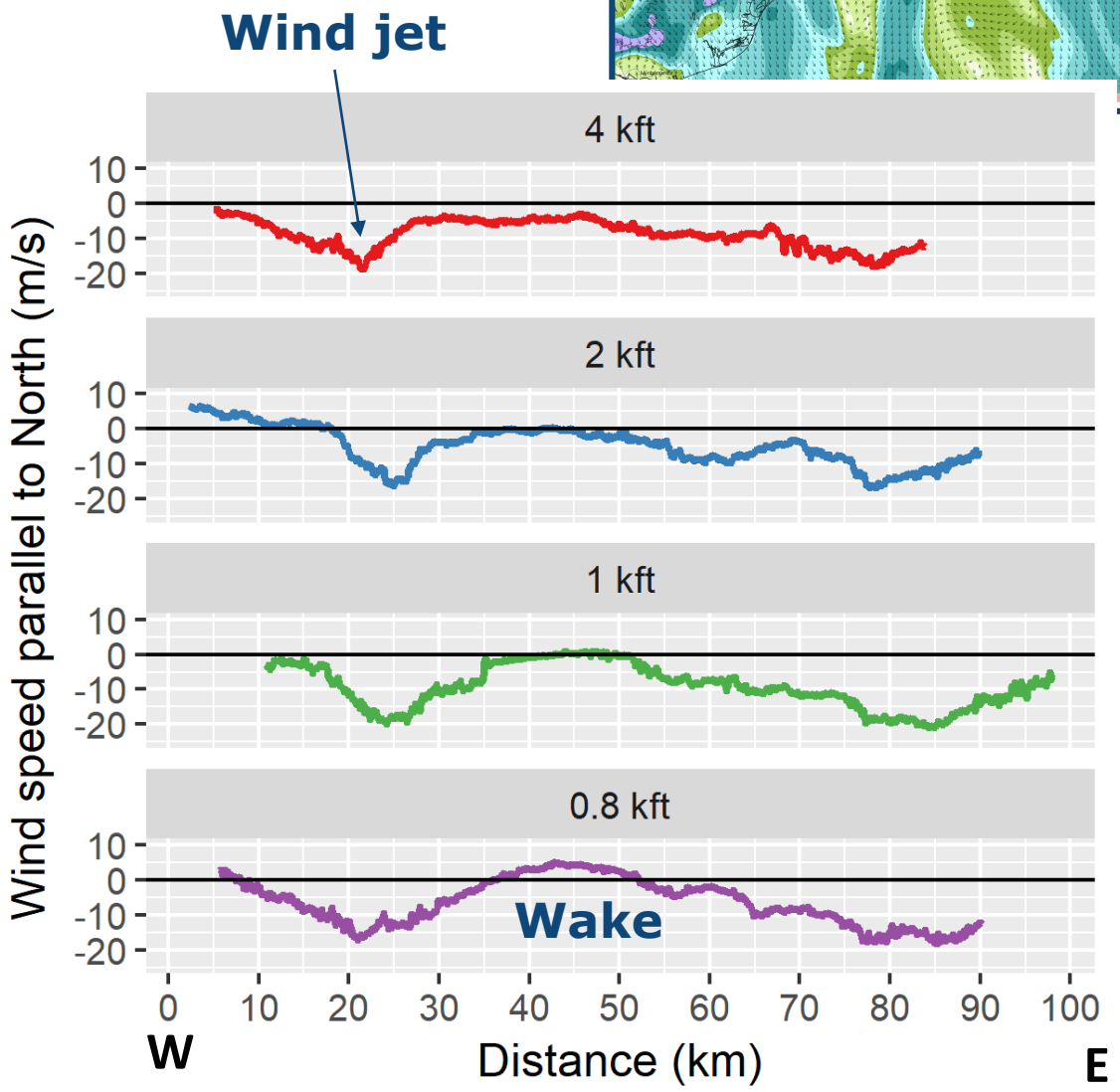
- **One wave**
  - Pot. temp increased by 6K over 5 km
  - Wind speed decreased to 3-5 m/s
- **Wave breaking**
  - Pot. temp slowly decreased to upstream values
  - Wind speed 3-5 m/s
  - Wind direction erratic
  - Vertical velocity turbulent -5 to 5 m/s
- **In lee of the glacier**
  - Wind speed lower than upstream
  - Wind direction similar to upstream
  - Vertical velocity neglible



In lee of the glacer: Northerly wind component at 0.8—4 kft in the lee of the glacier (in wind wake)



- **Negative values: northerly wind**
- **Positive values: southerly wind**
- **800 feet:**
  - Clear reversal of wind direction in wake
  - Wake flanked by increase in the wind speed at eastern side
  - Wind jet extending into the wake at the western side of measurement runs
  - Furthest west low wind speed again
- **1—4 kft:**
  - Wake features clear
  - No reversal of wind direction
  - Dampening of features with altitude



Summary and future plans

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- **In October 2018 there was an opportunity to measure a breaking wave over the lee slope of S-Vatnajökull glacier**
- **The measurements where as expected from the theory**
  - Increase in potential temperature in wave
  - Turbulent wave breaking region
- **The operational HARMONIE-AROME run simulated the wave breaking and the wind wake well**
  - Wind wake had low wind speed and reverse flow
  - A wind jet in the eastern part of the wake observed & simulated
- **Next steps: Rerun the case and retrieve data from aloft**

Thank you

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