Coherent Structures in the Stable Boundary Layer:

climatology and conceptual models of micro-fronts and solitary-trains

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ECMWF/GABLS Workshop, Reading, 7-10 November, 2011

Talk overview:

Introduction:

sporadic turbulence and the missing physics

[radiation]

bursts

fine structure in the SBL

focus on “events”: bores, µfronts, solitary trains

Ice Shelf SBL studies: the Halley Site

Data

µBarograph array → velocity and pressure gradients

C_T^2 profiler → vertical structure

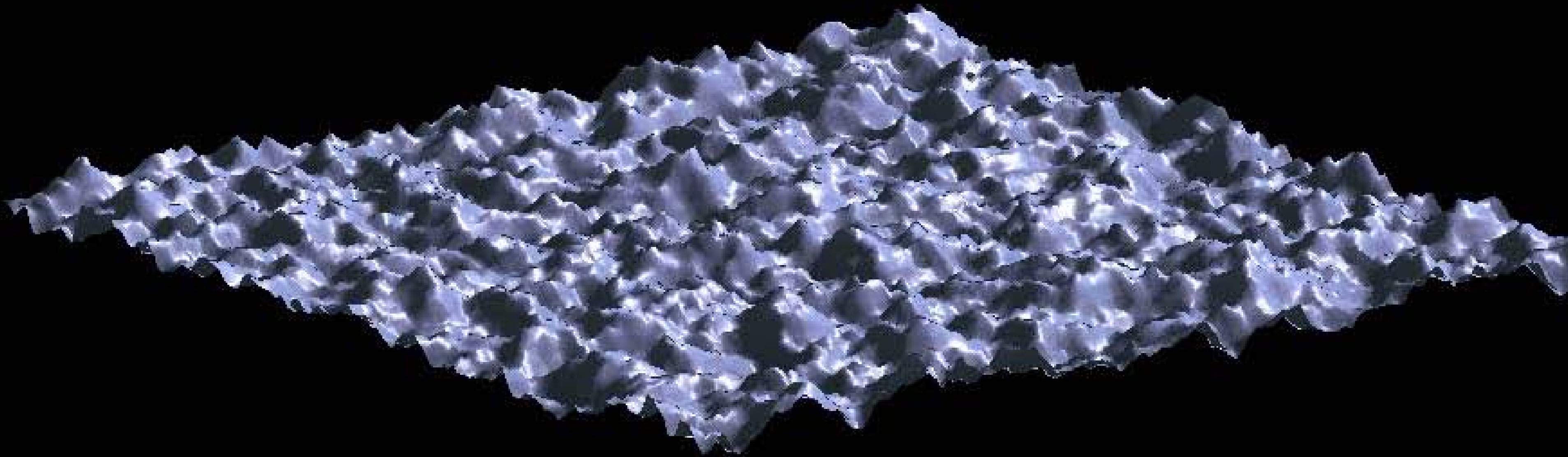
sonic anemometer → internal structure

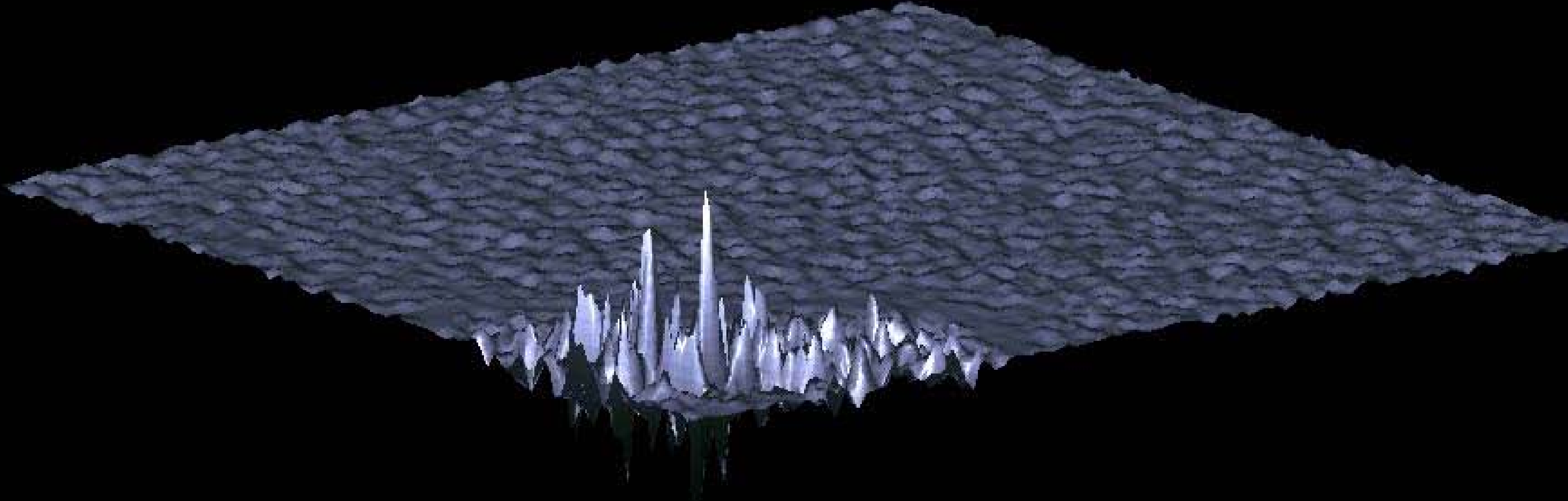
Results

Climatology of velocity: inherent flow characteristics

Internal structure and conceptual models

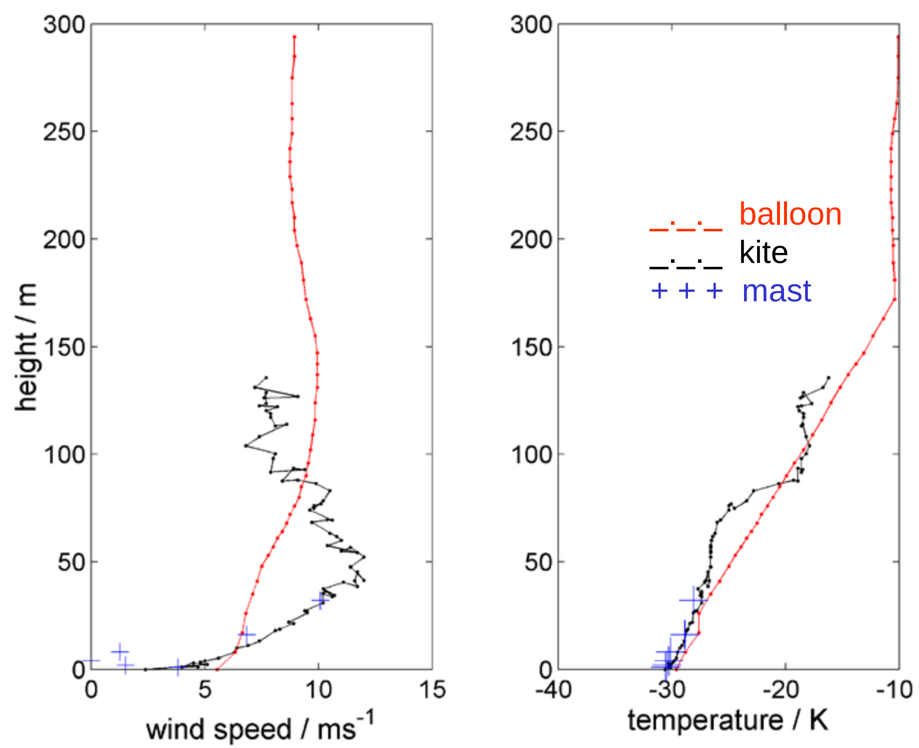
Possible evolution: a related family of structures.





Introduction: sporadic turbulence and the missing physics: ***radiation***

Radiation in the upper boundary layer and above: $T(z)$ tends to an isothermal regime ... possibly; data from commercial radiosondes exhibit inherent (and unknown) averaging.



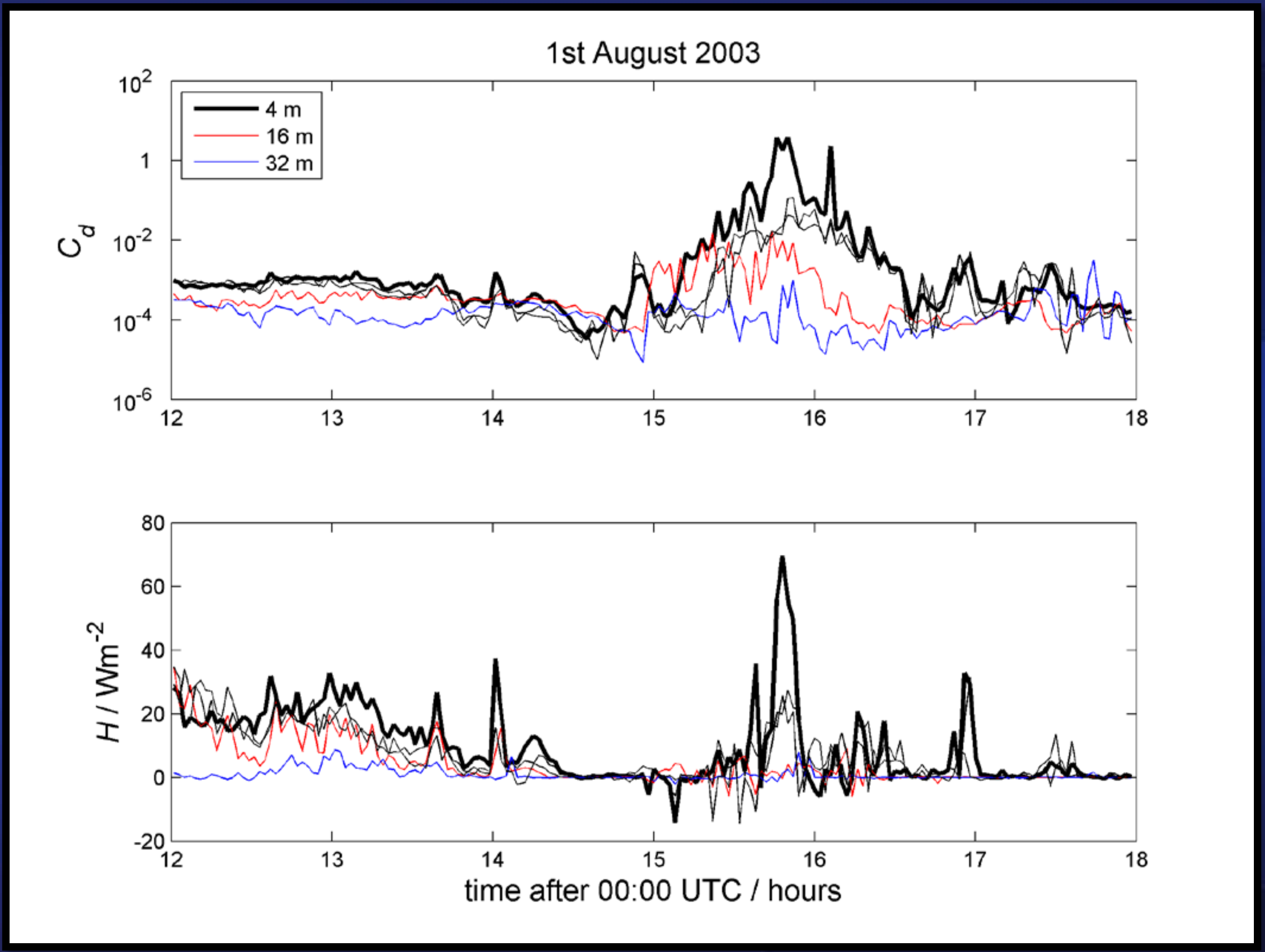
Upper level:
N= 0.02 rad s^{-1}
Period = 5 minutes

Lower level:
N= 0.07 rad s^{-1}
Period = 1.5 minutes

Comparison of radiosonde, kite and mast platform instruments: structure is smoothed out in the radiosonde, but likelihood that the upper levels tend to isothermal regime. Parameterisation on upper level *N* will therefore be invariant.

*Introduction: sporadic turbulence and the missing physics: **bursts***

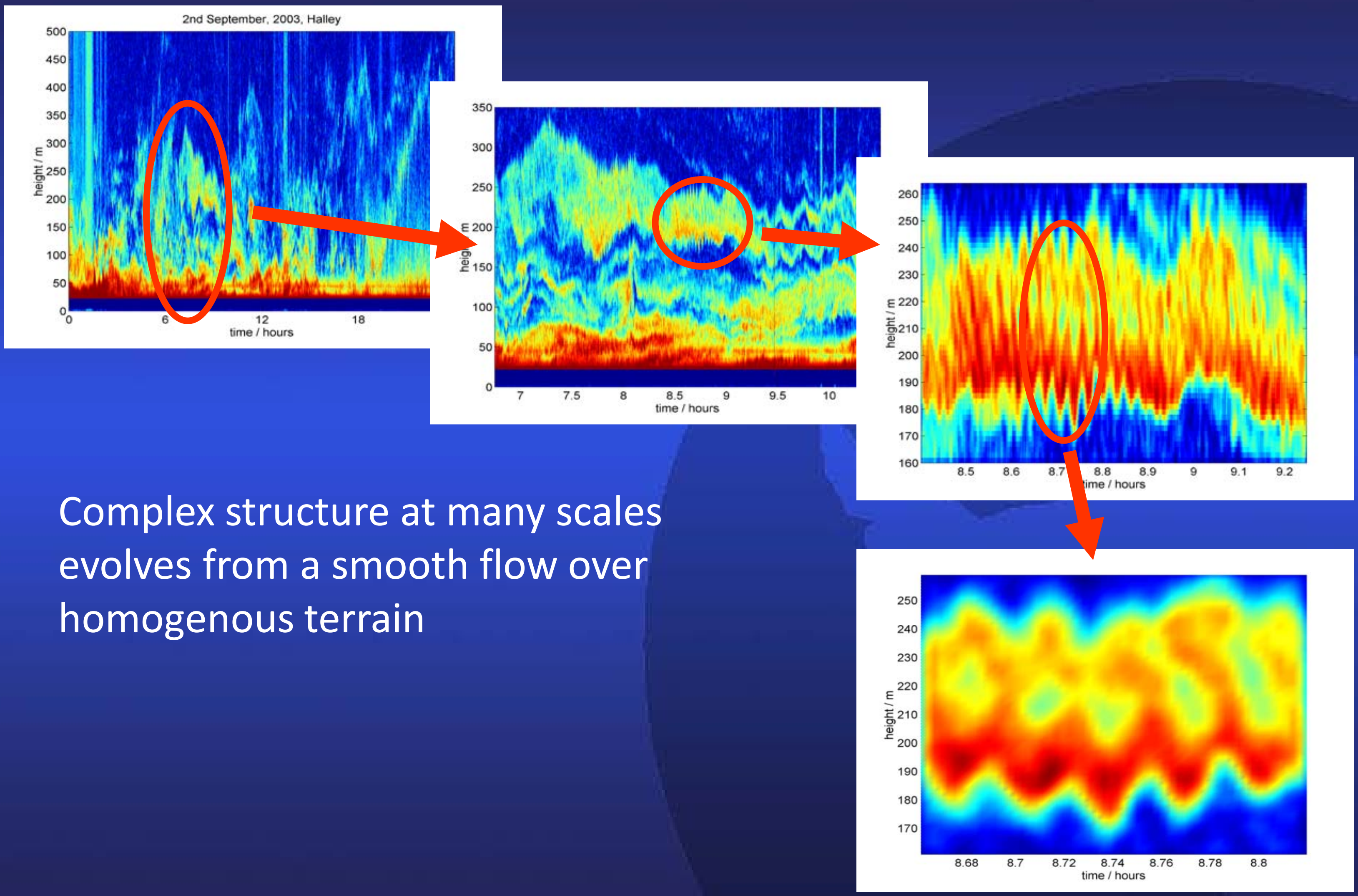
Evidence for significant vertical fluxes occurring as bursts, but understanding of their generation mechanism or climatology remains limited.



Example of a burst of turbulence in stable, near calm conditions resulting in a >100-fold increase in drag coefficient and large pulse downward of sensible heat flux

Introduction: sporadic turbulence and the missing physics: ***fine structure***

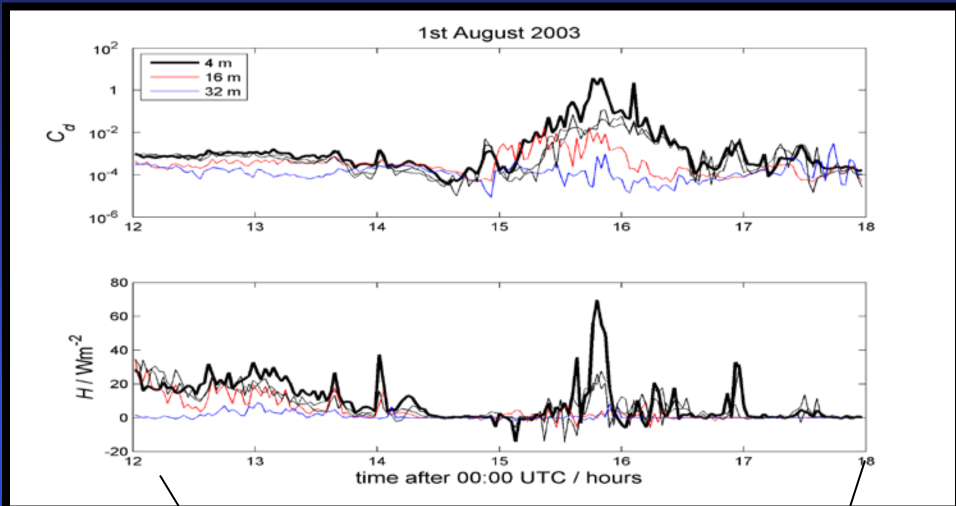
Evidence for significant vertical fluxes occurring as bursts, but understanding of their generation mechanism or climatology remains limited.



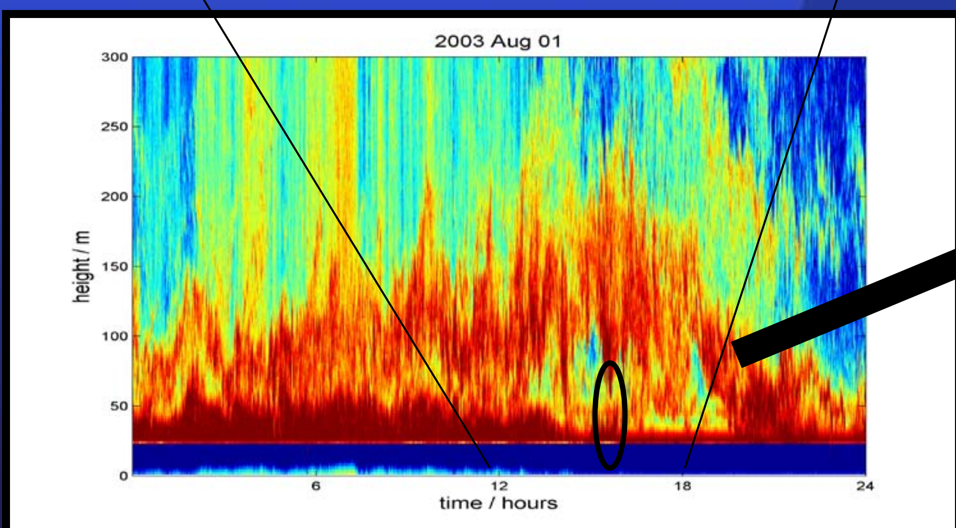
Complex structure at many scales evolves from a smooth flow over homogenous terrain

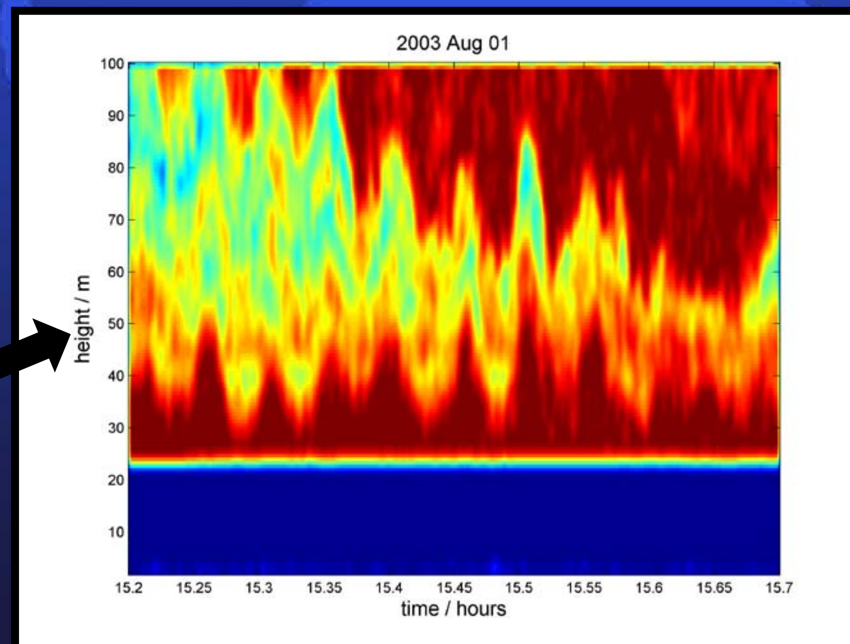
Introduction: sporadic turbulence and the missing physics: where to focus the search...

Indication that bursts are associated with coherent structures observed in other data such as the acoustic profiler...



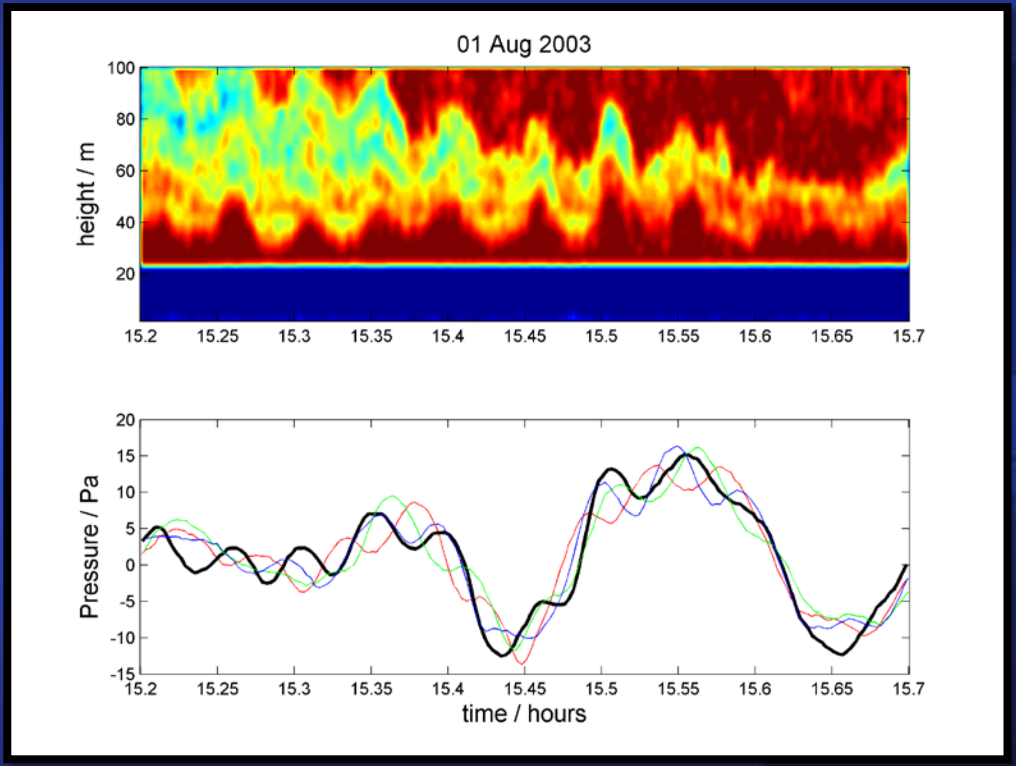
Turbulence and associated acoustic profile-time series data, $C_T^2(z,t)$: no associated large scale features are visible in C_T^2 but closer inspection indicates near-surface wave activity...





Introduction: where to focus the search...

Vertical displacement waves and pressure signature: not surprisingly these near-surface wave features are apparent on microbarograph time series. This gives a method to detect such wave activity automatically, and build a climatology of such events.



Co-located microbarograph time series (black) are correlated with the wave features apparent in the $C_T^2(z,t)$; correlation is due to hydrostatic effect of diffluence acting on a strong near surface stable gradient.

Possibility that such a dense surface layer may behave akin to a canal and be similar to John Scott Russell's "Wave of Translation"

Introduction: where to focus the search...summary

Rest of talk...

•Detect coherent events in the existing stable boundary layer data that appear similar to the near surface features.

•Estimate the climatology of such events.

Work in progress...

•Test Korteweg de Vries equation given event scales and mean properties of the flow

•Assess importance of solitary-like events to contributing to scatter in the flux-profile relationships in the stable boundary layer.

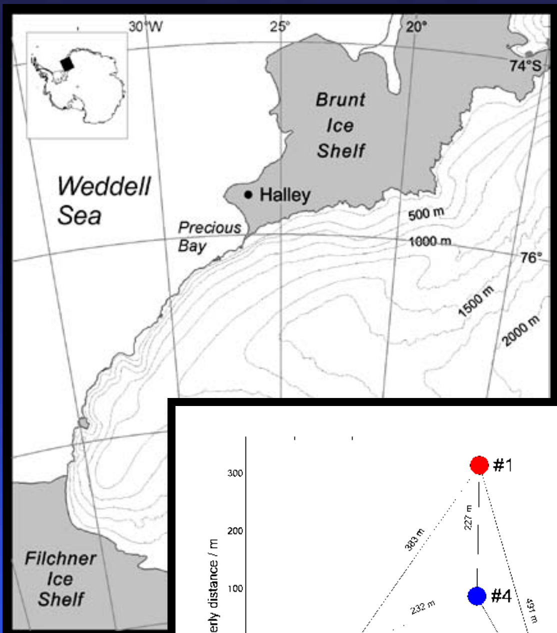
•Estimate if some *local* parameterisation of these events is possible.

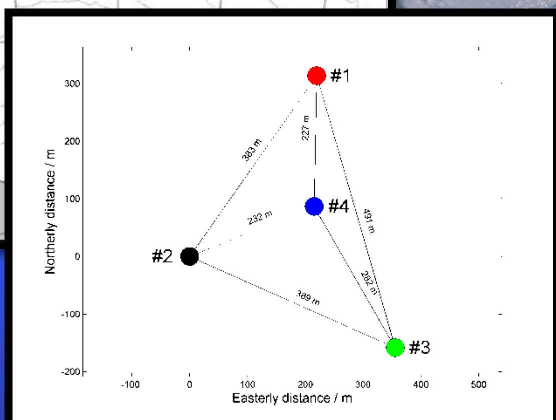
•Up-cascade of “2D turbulence” when vertical motion suppress horizontal aligned vorticity.

•Evolution of micro-fronts

Photo curtsey of Guenther Heinemann

Ice Shelf SBL studies: the Halley Site



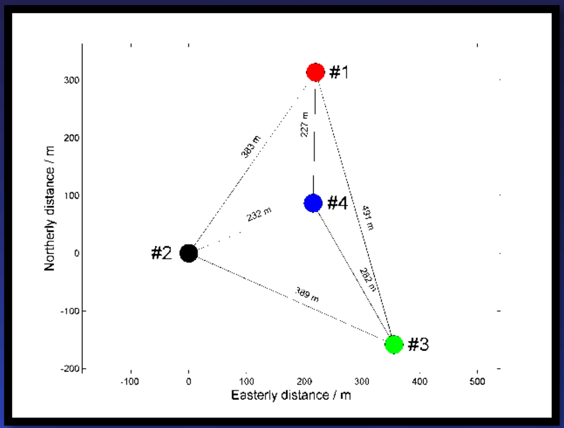


Data collected during March-November 2003 as part of stable flux-profile studies were searched for suitable events.

Relevant instrumentation within the Halley *Instrumented Clean Air Sector*:

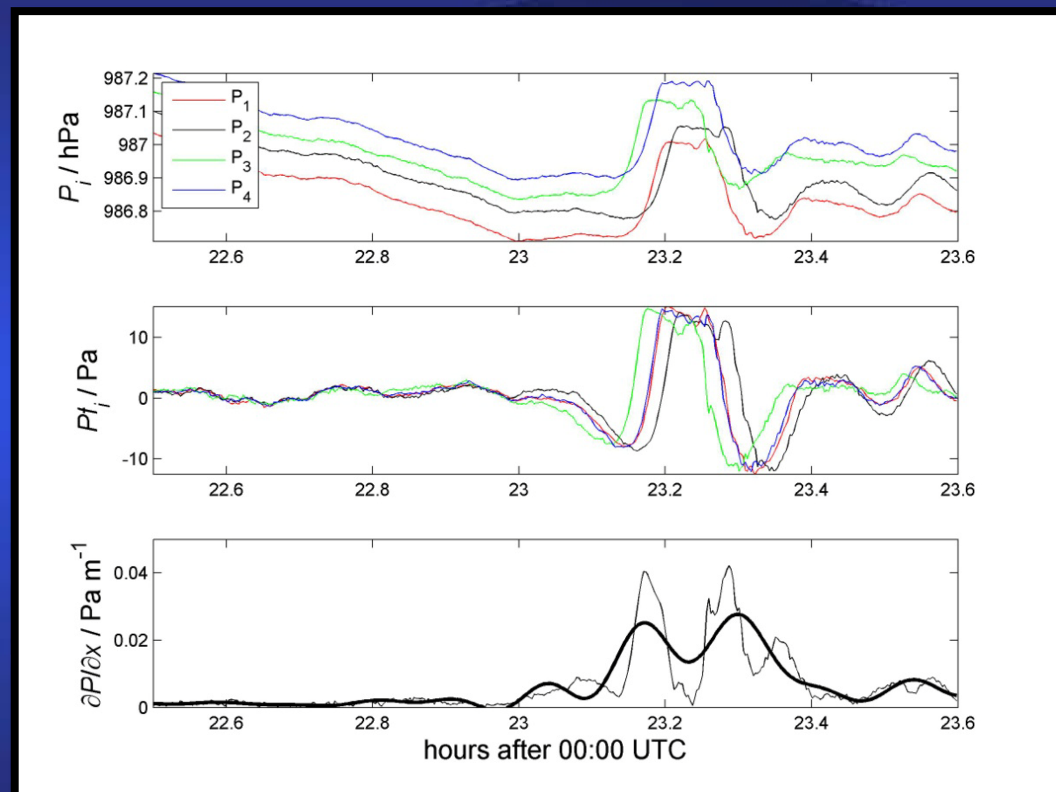
- Microbarograph array
- Profile-turbulence mast
- Acoustic radar
- 100 km-fetch ice shelf

Data: µBarograph array → velocity and pressure gradients



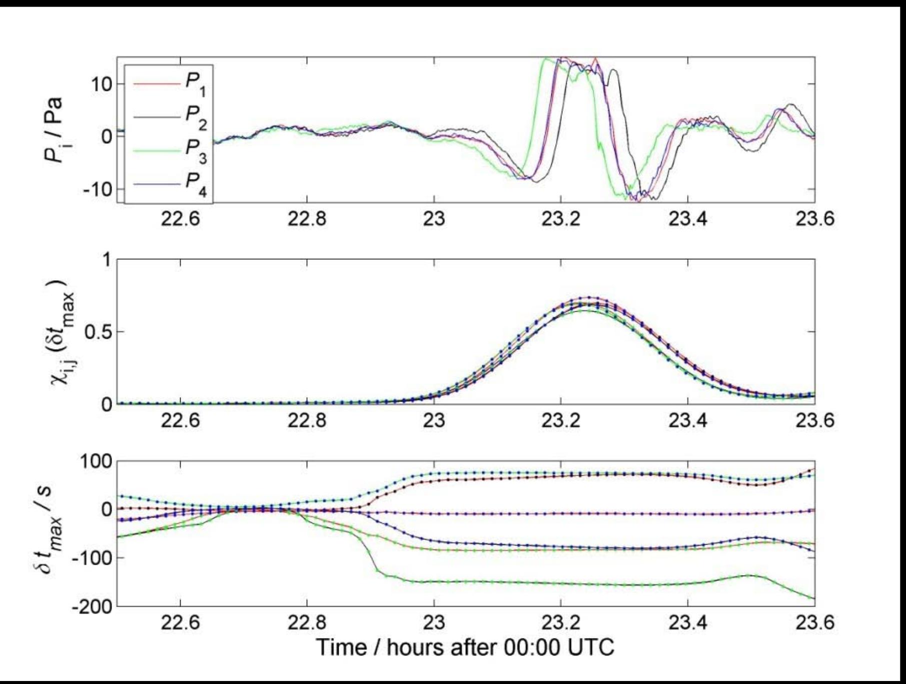
An array of four microbarographs with a sensitivity of 0.1Pa, buried ~1 m below the porous firn surface and sampled at 0.1Hz. Mean array distance *c*. 300 m.

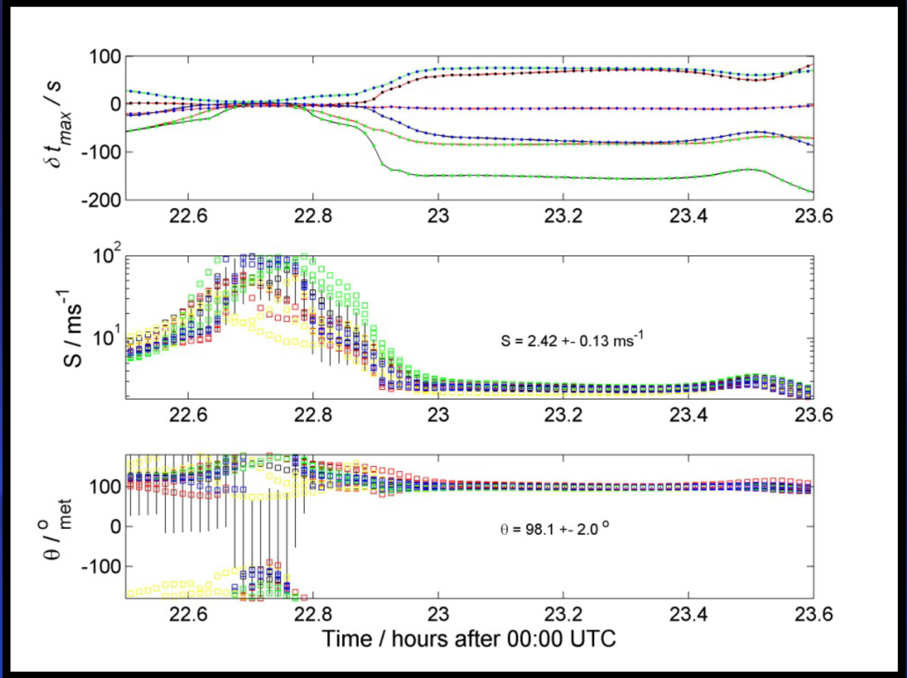
Wave-like events are not immediately apparent in the microbarograph pressure time series due to large-scale noise. High pass filtering can highlight large events, but detection is best using gradient estimates, where the mean difference between sensors is plotted as a proxy for δP/ δx.



An event starting at 23.2 hours arrives at the Green (South-Easterly) sensor, then simultaneously at Red and Blue, and finally at Black (westerly).

Data: μBarograph array → velocity and pressure gradients

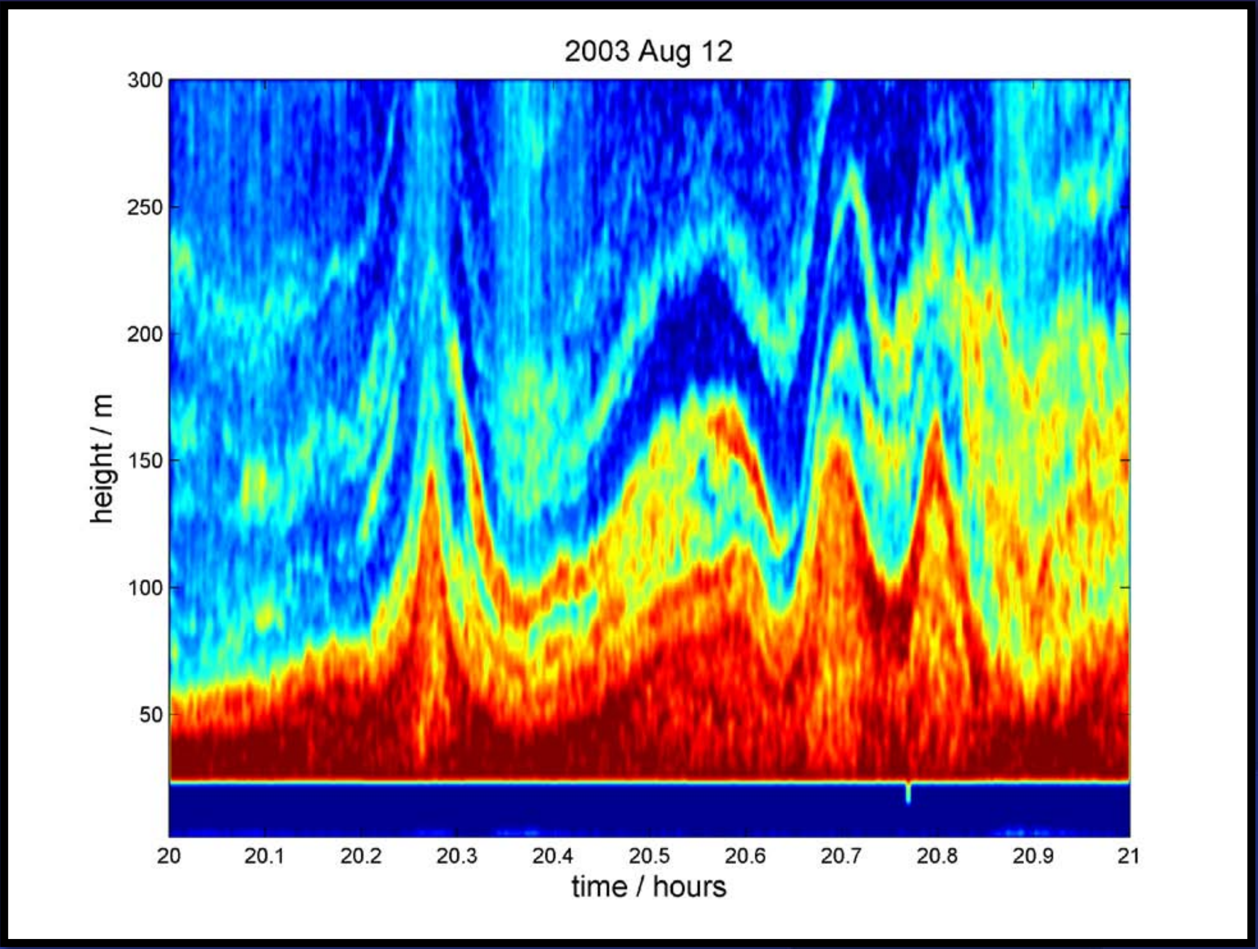




During the event the cross correlation, $\chi_{i,j}$, between the individual pressure time series becomes high. Six possible routes to speed and direction, [*S*,θ], for the event are then possible, and variance between estimates determine the error in [*S*,θ].

The technique will only work for large amplitude, single events, with high signal to noise against the back ground internal gravity wave signature. Superimposed waves cannot be resolved without resort to more sophisticated beam-steering techniques. This method, however, is transparent and checkable.

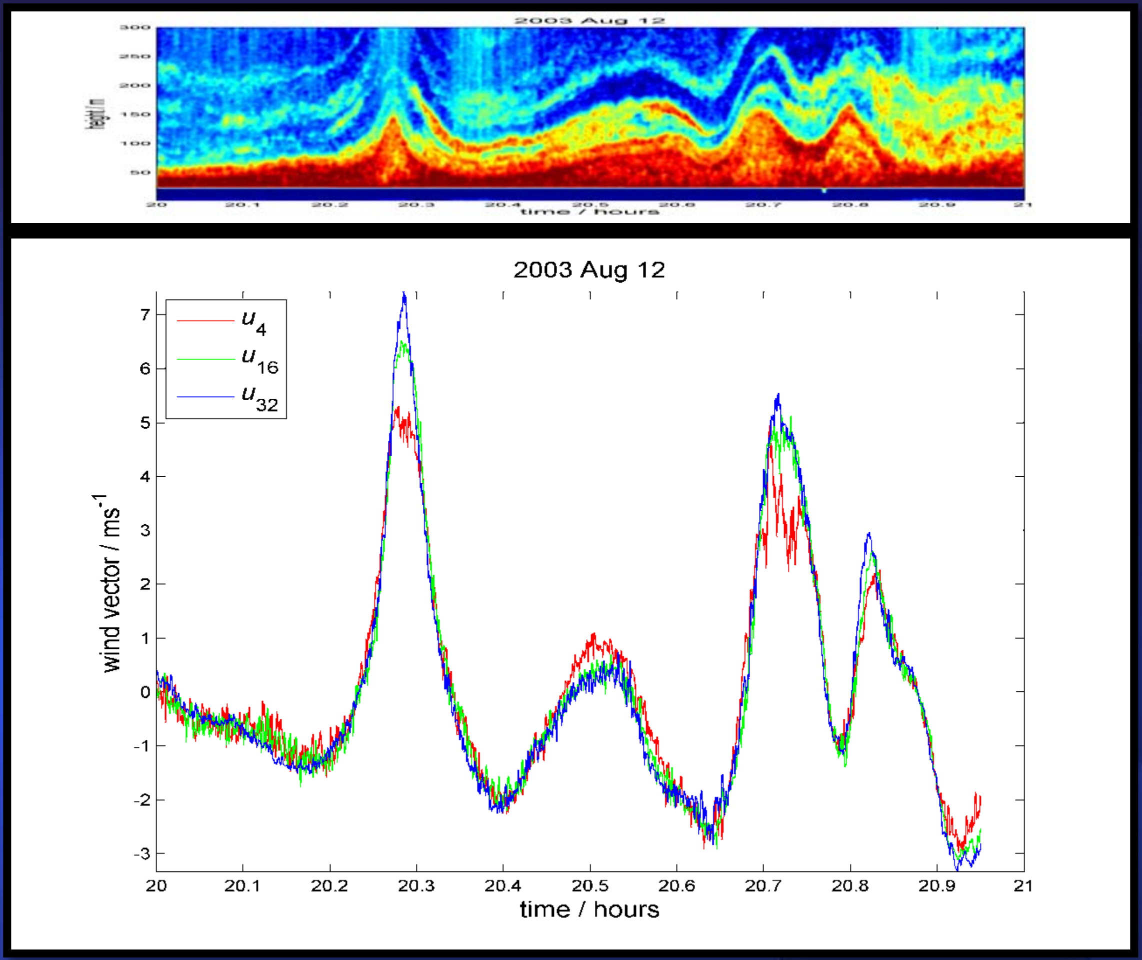
Data: C_T^2 profiler → vertical structure



Waves are frequently visible within sodar echogrammes, and can indicate the vertical structure of the wave. The greatest diffluence is observed within the lower strong echo region: above this, there is less change in depth between layers.

Acoustic backscatter reveals volumes of turbulence within the stratified troposphere. Short duration wave events perturb the atmosphere on time scales too short for the stratified TKE to adjust. Backscatter then acts as a tracer.

Data: sonic anemometer → internal structure

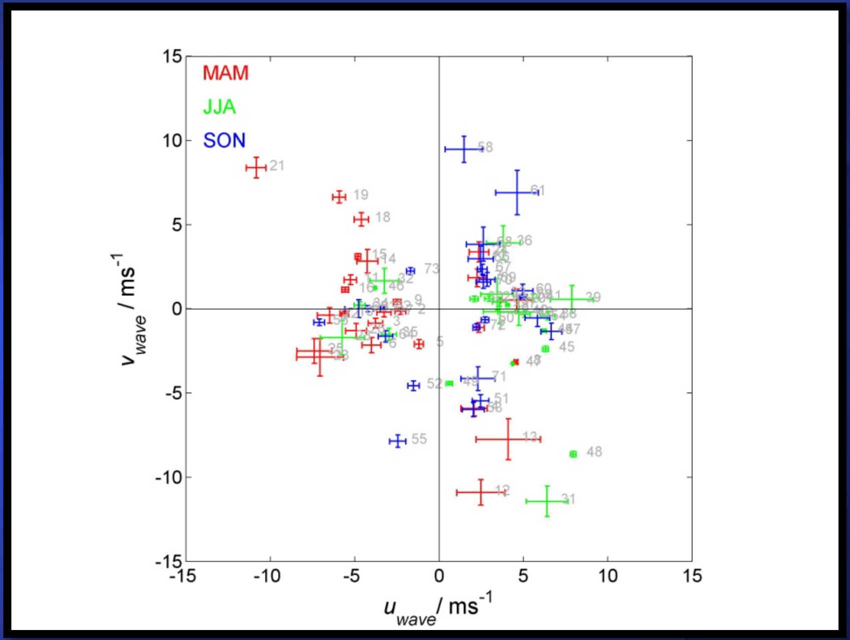


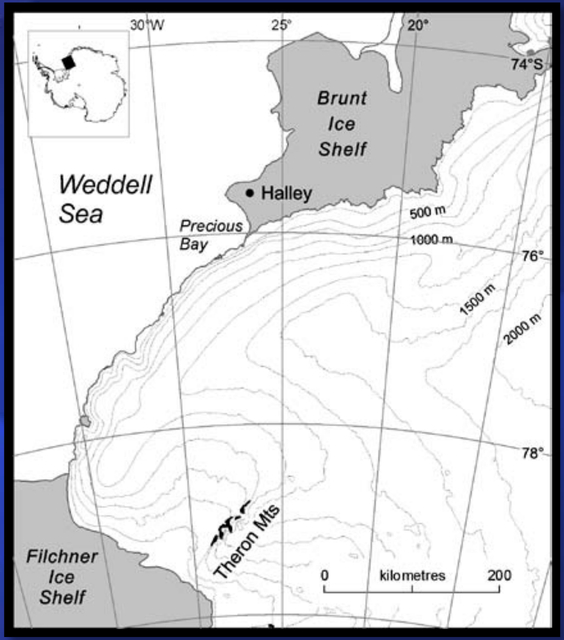
The larger waves under study are most often > 32 m deep, and the mast instruments are carried within the wave core. Some events have a re-circulating rotation in the core, and transport air mass over large distances. Others are purely diffluent effects with no transport. Both have enhanced surface shear.

Wind vectors show fine-scale perturbation of the mean wind field. Frequently the inner-most section of the time series shows a plateau, associated with the inner core of a rotor.

Results: Explicit velocities, (relative to surface) .

73 events detected from March to November 2003, which allow explicit event velocity (i.e. relative to surface) to be determined. These data indicate where wave originated but speed is contaminated by air mass movement.

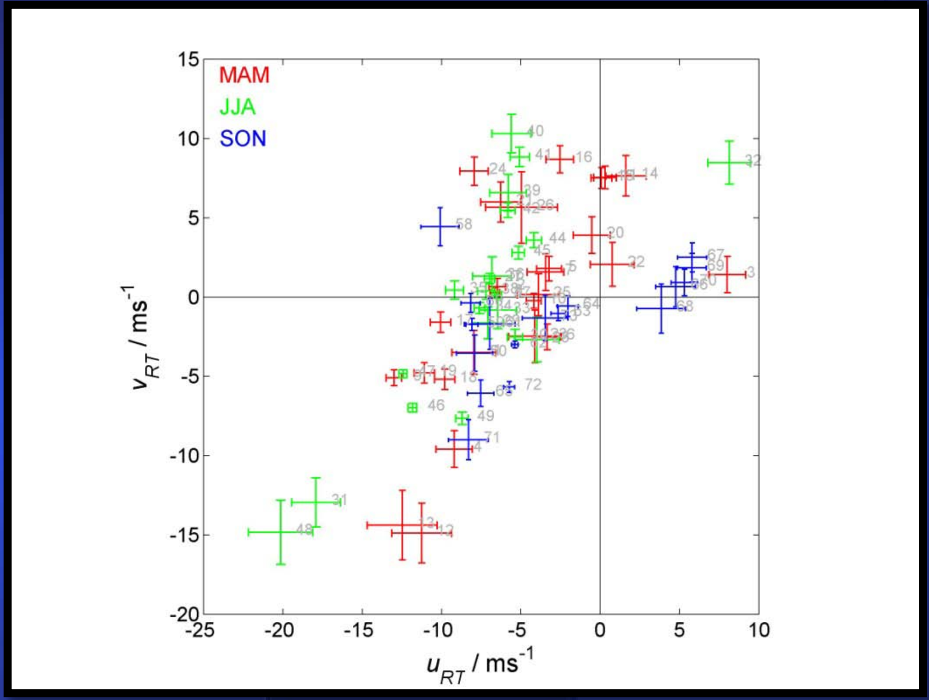




Most surprising is the apparent *lack* of dominant wave direction: initial hypothesis was that these events were remnants of the hydraulic jump associated with continental katabatic flow terminating on the ice shelf.

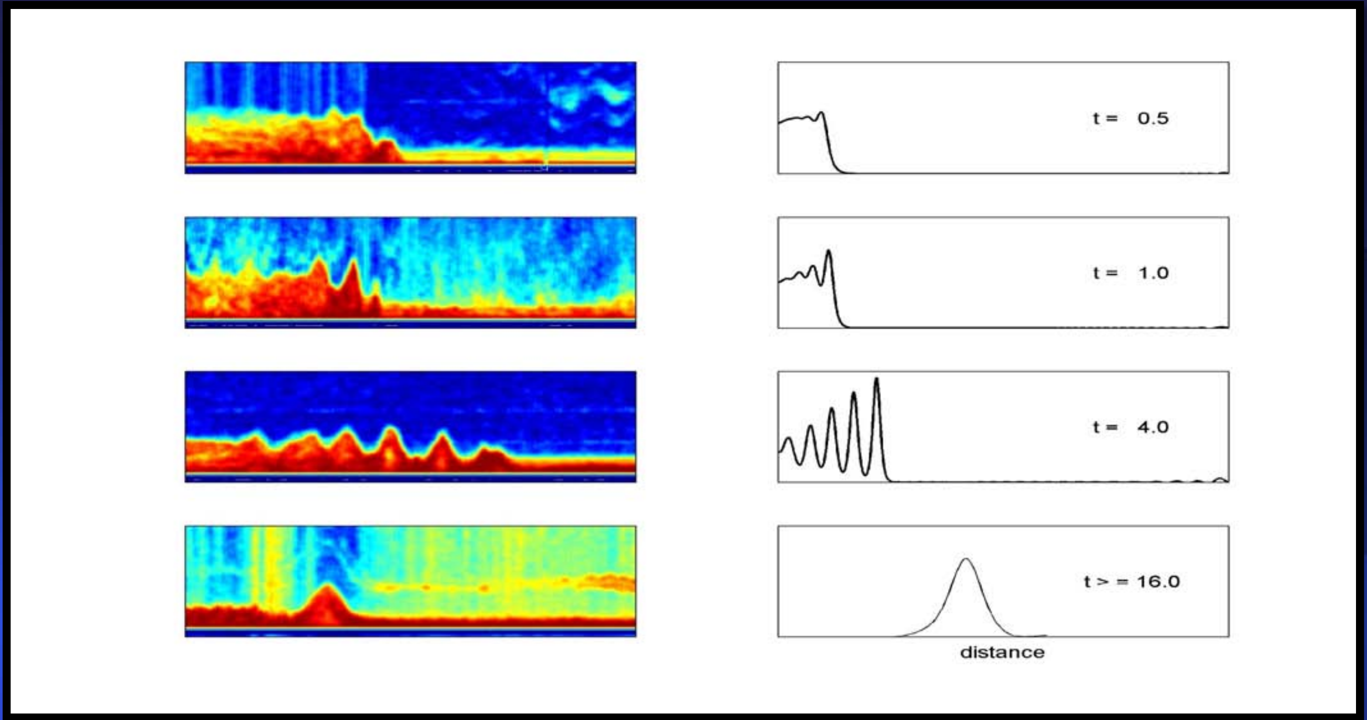
Results: Implicit velocites (relative to air mass)

These data are the implicit velocities , where the coordinate frame is rotated and translated to give the wave direction towards +ve *x* and wave velocity = 0; axes are then air velocity [u_{RT}, v_{RT}] relative to this coordinate frame.



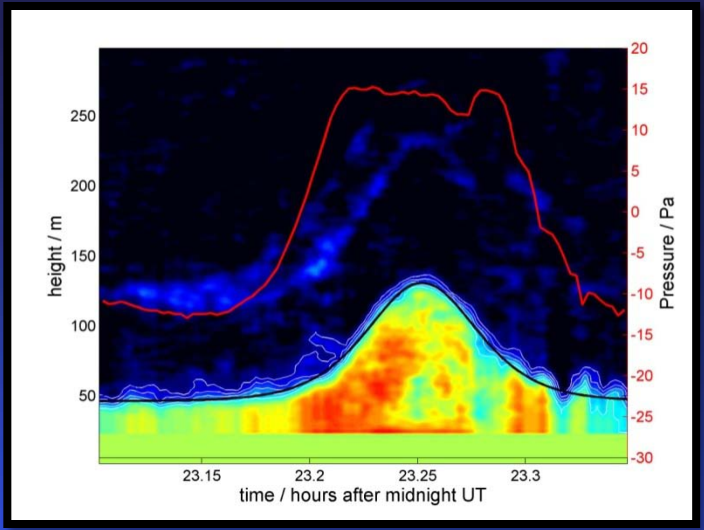
The dominance of negative u_{RT} implies that the waves tend to travel *into* the wind. This preference therefore indicates a flow-surface interaction (otherwise the waves would travel irrespective of the velocity vector of the surface relative to the air).

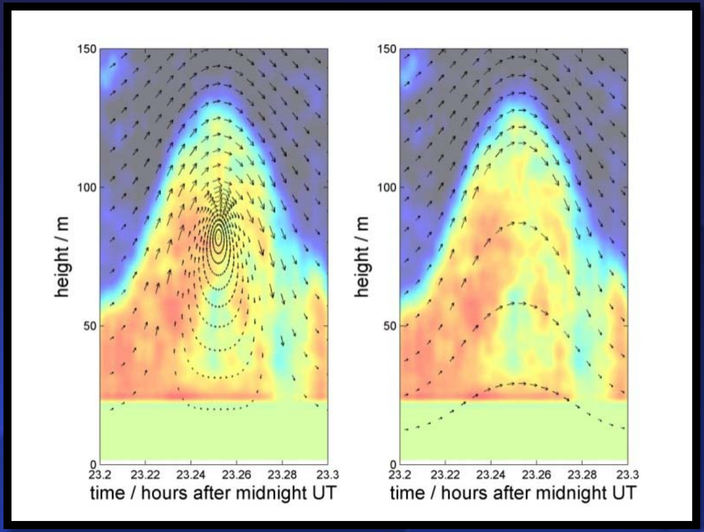
Results: suggestion of a *related family* of structures



The left-hand panels show four *unrelated* images: the time axis is reversed, intending to show the events travelling from left to right. The upper most panel appears similar to a bore or micro-front whilst the lowest is similar to a solitary wave; two intermediate images are also shown. The right hand panels are the evolution of the KdV equation initialised with a decaying *tanh* step. Similarites are not conclusive but suggest that the events could all be observations of frontal decay at various stages.

Results: Internal structure





The upper edge of significant $C_T^2(z,t)$ is frequently well described by the solution to a shallow layer soliton, $\mathrm{sech}^2(t)$, also known as the Korteweg-de Vries wave. Flowlines in the outer domain (from layered sodar echogrammes) can be approximated by the far field potential flow around a cyclinder. The inner domain remains uncertain, due to error in air velocity: both rotating and pure diffluent solutions match the data. However, as observed in the data, both have near stationary points relative to the *wave*, and thus generate enhanced shear relative to the *surface*.

Results: Evidence for micro-fronts: trace gas (ozone) and wind profiles

Case study 1: apparent ideal stable boundary layer profile: colour indicates both temperature *and* ozone

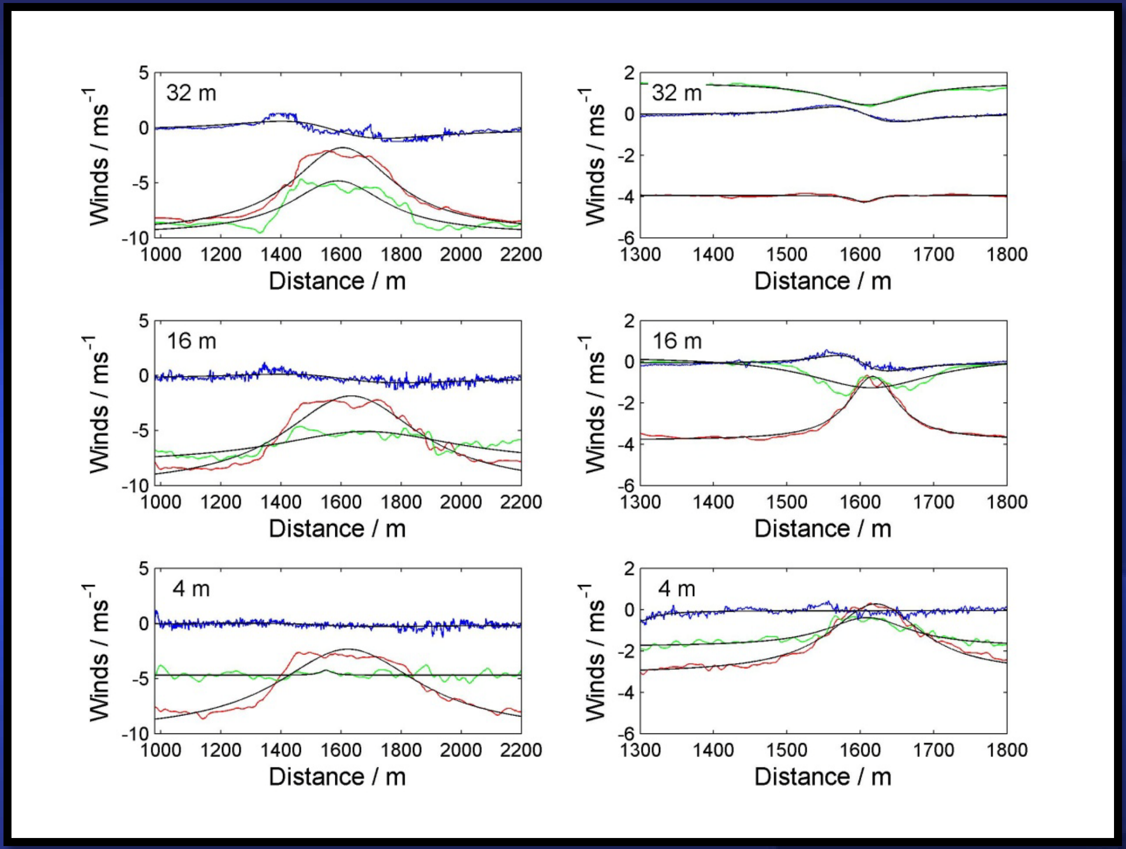
... Correlation between potential temperature and ozone is suspicious!

Results: Evidence for micro-fronts: trace gas (ozone) and wind profiles

Case Study 2: a counter-flow boundary layer

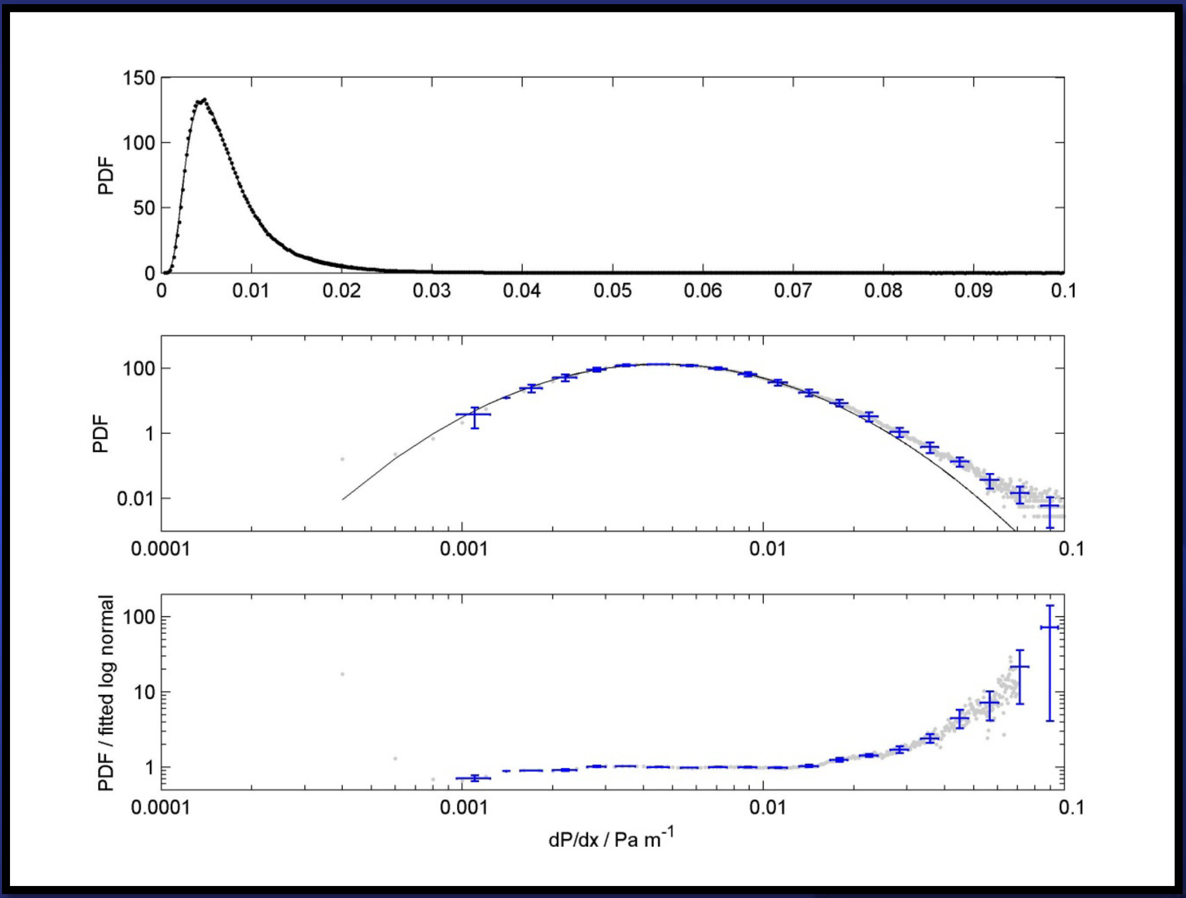
Case study 2: strong correlation between ozone and winds, but winds show counter geostrophic flow.

Work in progress: Fitting sech^2(x) functions to [u,v] and sech^2(x)tanh(x) to [w] gives a metric for amplitude and length scale at 3 near-surface levels.



Additional data (B.V. frequency, density, u_{RT}, $P(x)$) will test Korteweg deVries model for shallow wave solitary-like waves.

Work in progress: Answering the "so what?". Are the observed events a freak curiosity, or the tip of an iceberg. Climatology of pressure gradient observed across the microbarograph array.



Upper panel: pdf of d*P*/d*x*

Mid panel: pdf against log(d*P*/d*x*). Largest gradients do not fit the normal distribution.

Lower panel: log-normal fit subtracted from the data to highlight deviation. *Observed* events are in the right-hand two bins...

Summary

•A stable boundary layer bursts has been identified, associated with solitary-like events (or a solitary train).
•Such events are a ubiquitous feature of the Brunt Ice Shelf environment (and similar events have been observed at Dome A).
•There is no apparent directional preference for these events; they are orographic in origin.
•The structures observed on acoustic radar suggest a possibility that the events evolve from bores or “micro-fronts”; this begs the question, however: where do the micro-fronts originate.
•Climatology of the pressure gradient across a microbarograph array implies that the observed waves are merely the largest and most obvious events of a continuum normally masked by non-surface wave features.

Questions?