A Sensor Network for Mixing at the Ocean's Bottom Boundary

Kurt Polzin[1], Matthew Alford[2], Cynthia Bluteau[3], Annalisa Bracco[4], Kathleen Donohue[5], Eleanor Frajka-Williams[6], Mark Inall[7], Joe Kuehl[8], Jim Ledwell[1], Sonya Legg[9], David Marshall[10], Trevor McDougall[11], Marie-Jose Messias[12], Ruth Musgrave[13], Alberto Naveira Garabato[6], Jonathan Nash[14], Keith Nicholls[15], Maxim Nikurashin[16], Al Plueddemann[1], Steve Rintoul[17], Hesam Sehelipour[18], Vitelii Sheremet[5], John Taylor[19], Fred Thwaites[1], John Trowbridge[1], Martin Visbeck[20], A.J. Williams III[1], Zhankun Wang[21]

[1]Woods Hole Oceanographic Institution; [2]Scripps Institute of Oceanography; [3]Institut des Sciences de la Mer, UQAR; [4]Georgia Institute of Technology; [5]University of Rhode Island; [6]National Oceanography Centre Southampton; [7]Scottish Association for Marine Science; [8]University of Delaware; [9]Princeton University; [10]University of Oxford; [11]University of New South Wales; [12]University of Exeter; [13]Dalhousie University; [14]Oregon State University; [15]British Antarctic Survey; [16]University of Tasmania; [17]Commonwealth Scientific and Industrial Research Organization; [18]University of Toronto; [19]University of Cambridge; [20]GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel; [21]National Oceanic Atmospheric Administration

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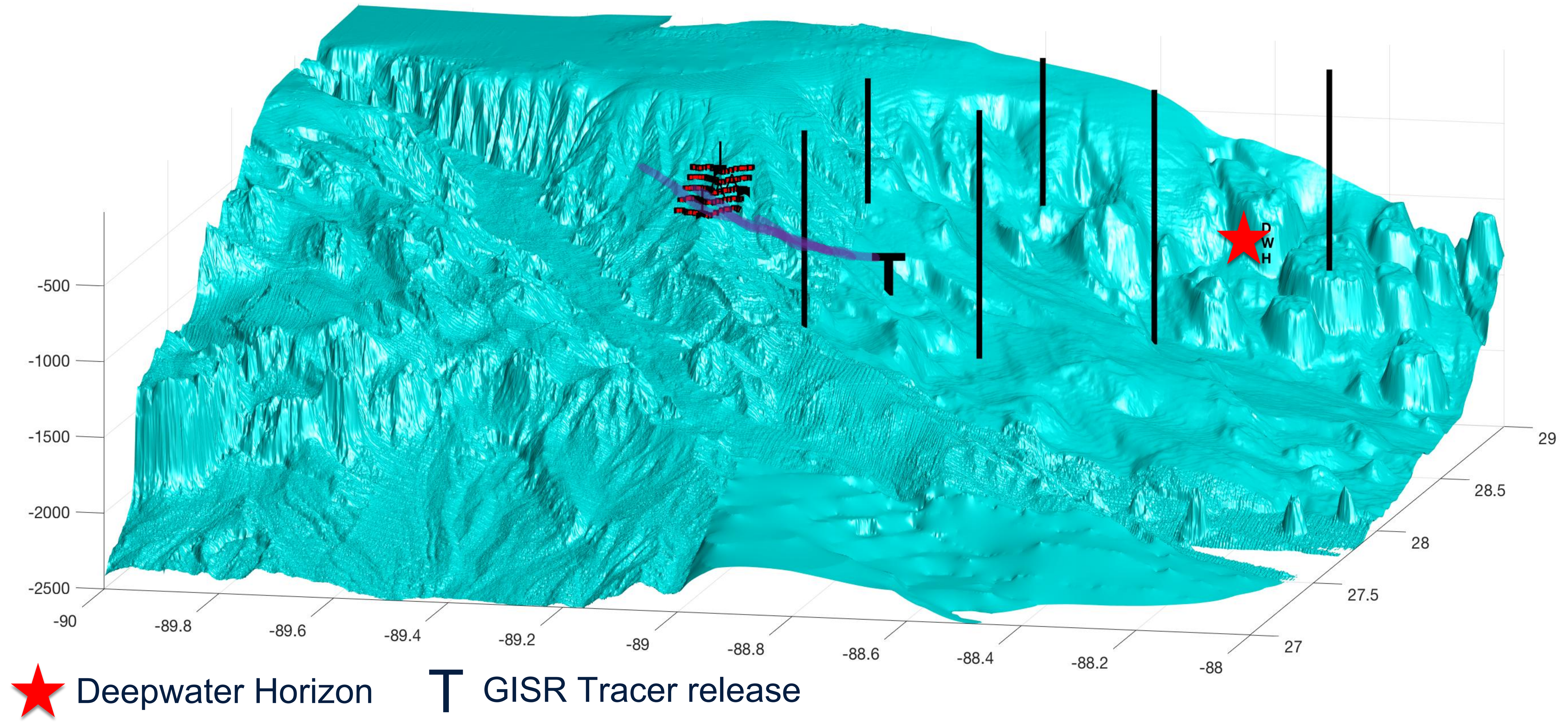
Abstract

Mixing at the ocean's bottom boundary plays a crucial role in global ocean upwelling, thus underpinning long-term climate trends, and controlling the dispersion of tracers. The interplay between boundary conditions, stratification, rotation and coupling with internal wave band variability determines the overall structure of the planetary boundary layer. Yet key pieces are not understood because the multiple independent forcing parameters combine nonlinearly. A realistic approach to this problem is beyond current numeric capability and theory will have limited success unless strongly guided by expanded observations.

We propose a community-level project gathering observationalists, turbulence modelers and general circulation model users and builders. The project core will be the development of a sensor network to estimate momentum and buoyancy fluxes within the planetary boundary layer, stress-driven drag at the bottom boundary and energy conversion rates associated with flow over topography.

The sensor network and associated high-resolution numerics will serve as a training ground for autonomous underwater vehicles (AUVS) in detecting pollutant sources from intentional dye releases. Having provided the AUV with onboard sensor metrics of the turbulent environment and an understanding of the boundary layer structure, the issue is to develop behavioral algorithms to optimize sampling for pollutant detection.



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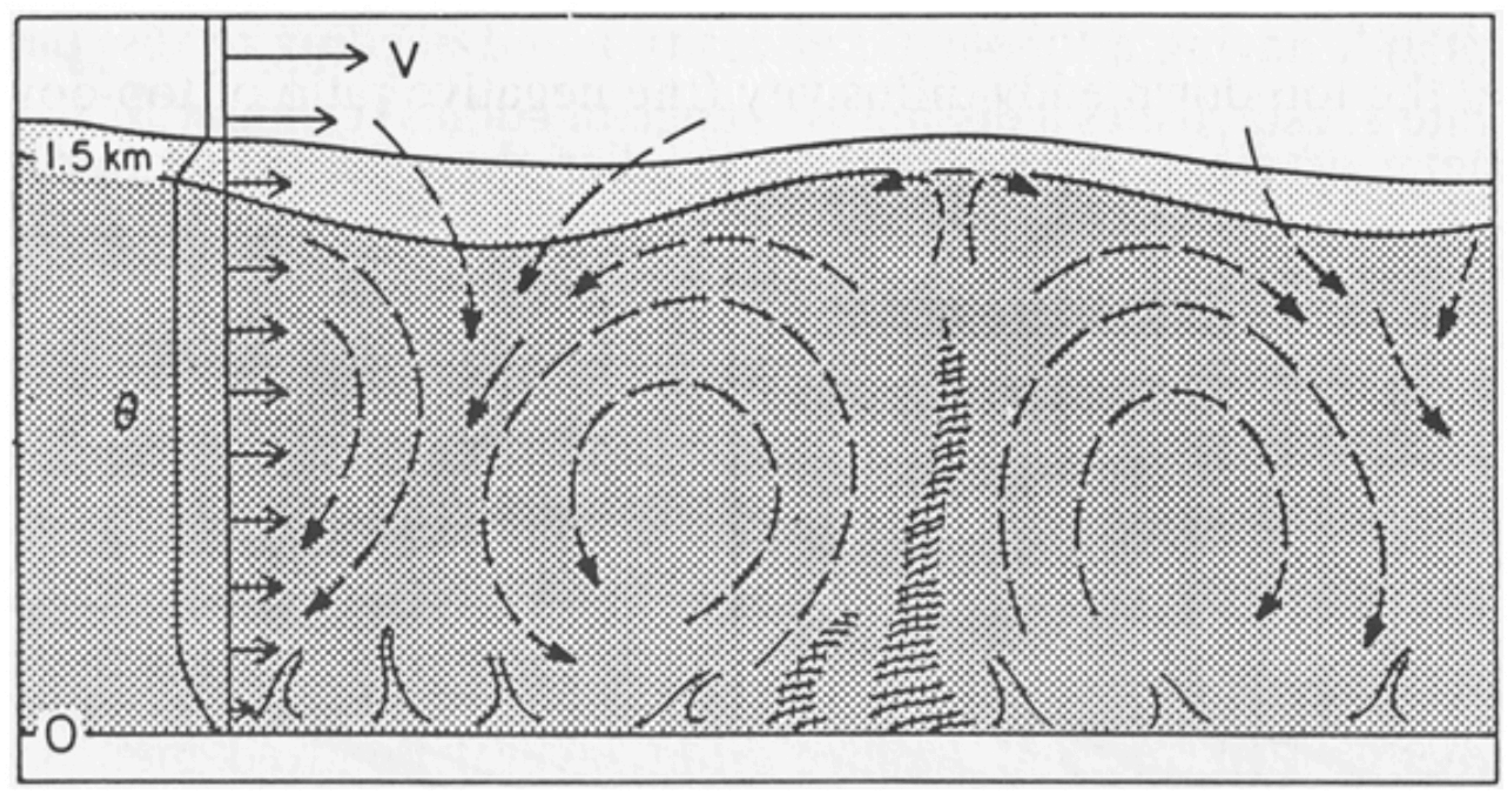
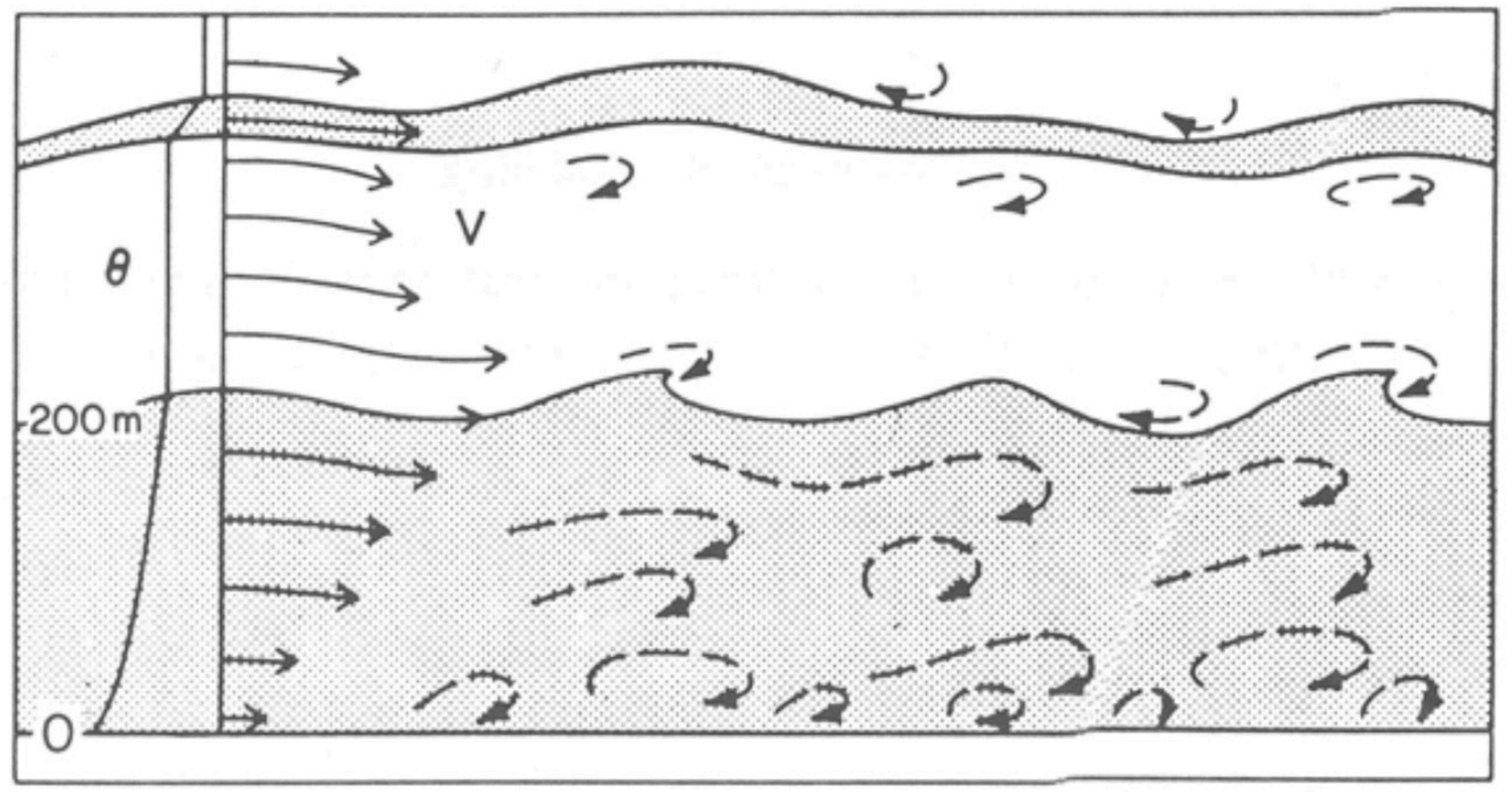
Vision: A straight-up boundary layer physics problem

The Atmosphere

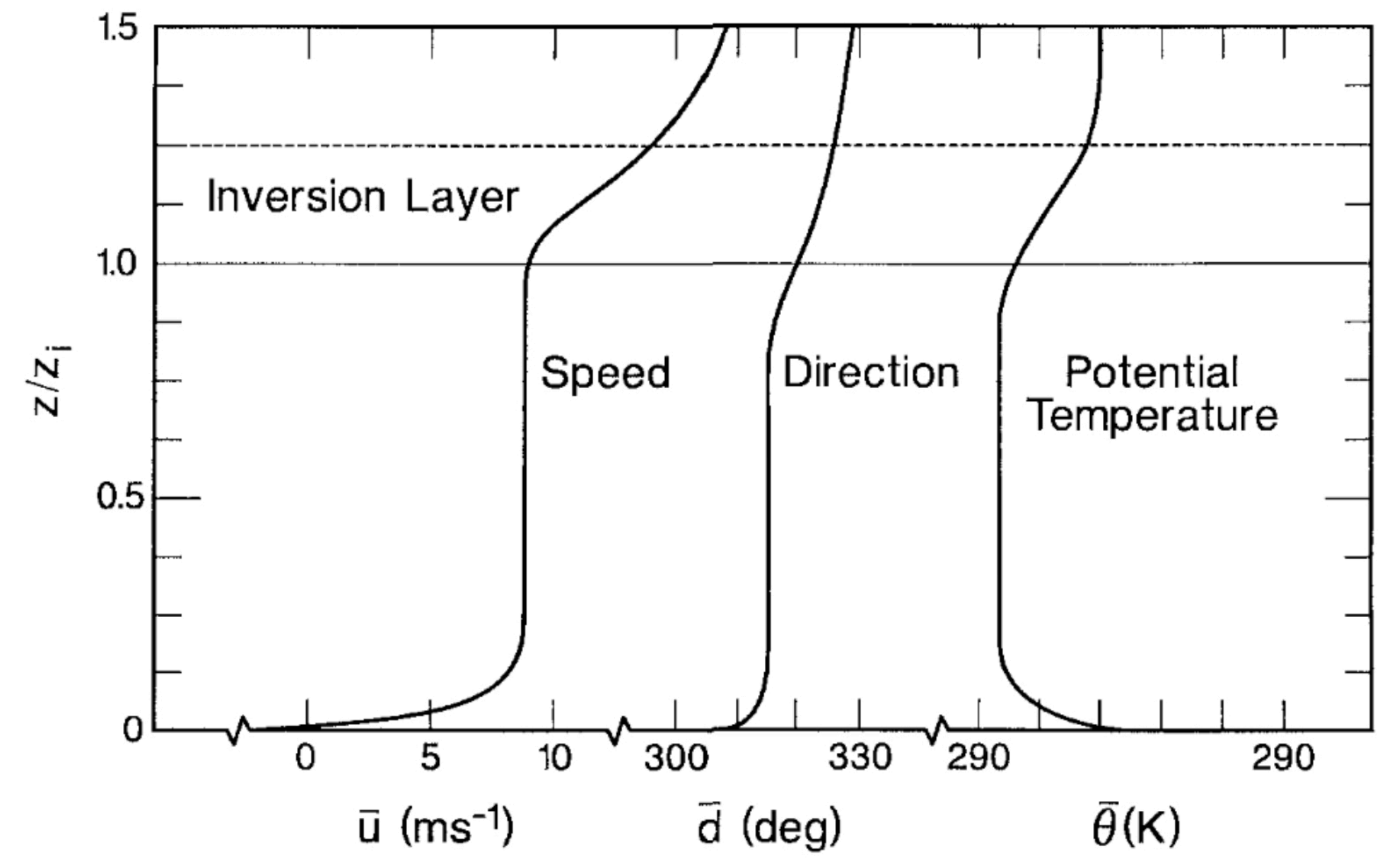


Wyngaard, 1990

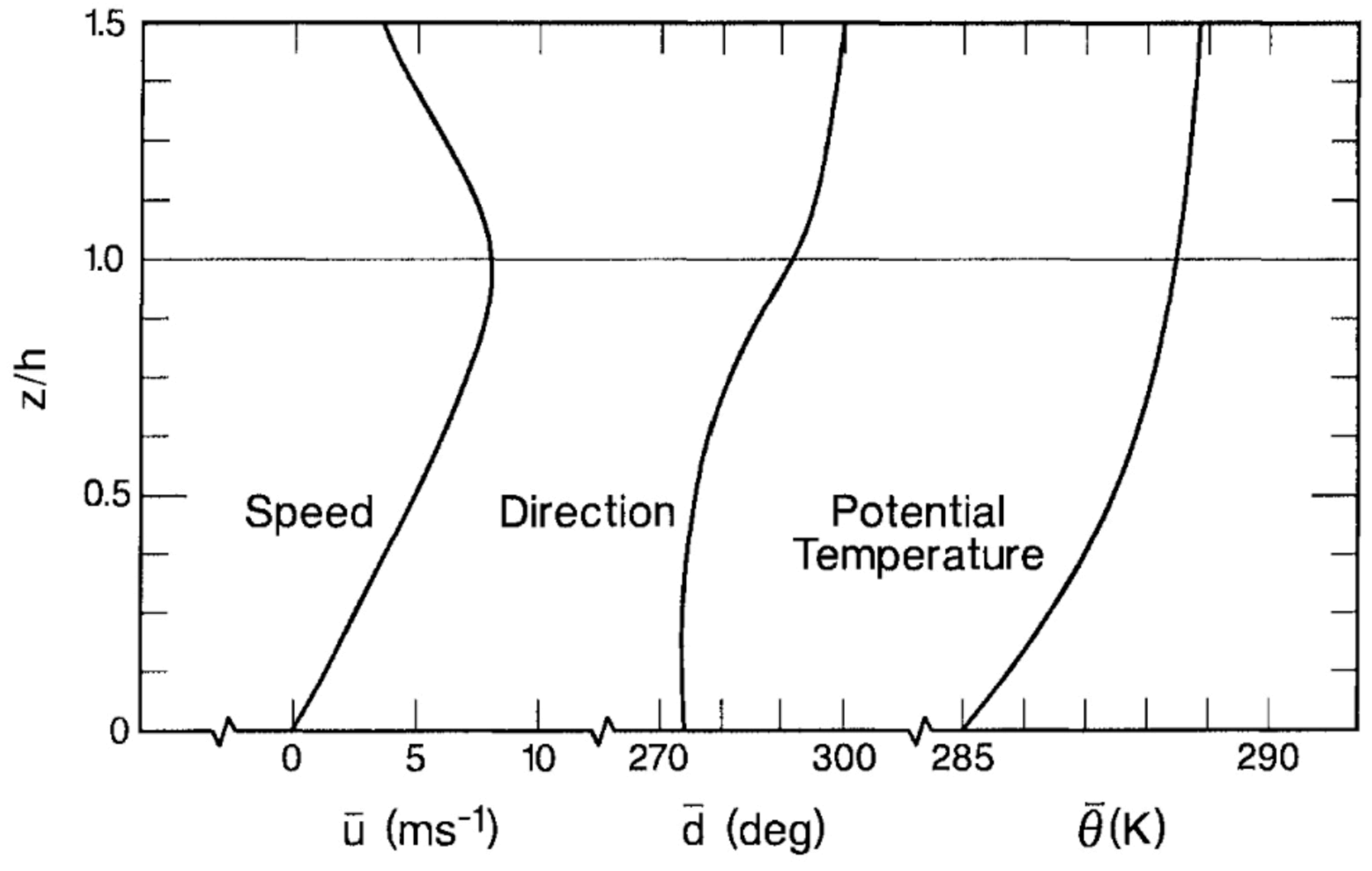


Wyngaard, 1990

The character of the atmospheric boundary layer is largely determined by 2 parameters: wind speed and solar insolation



Kaimal and Finnigan, 1994



Kaimal and Finnigan, 1994

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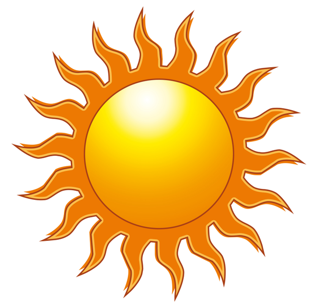
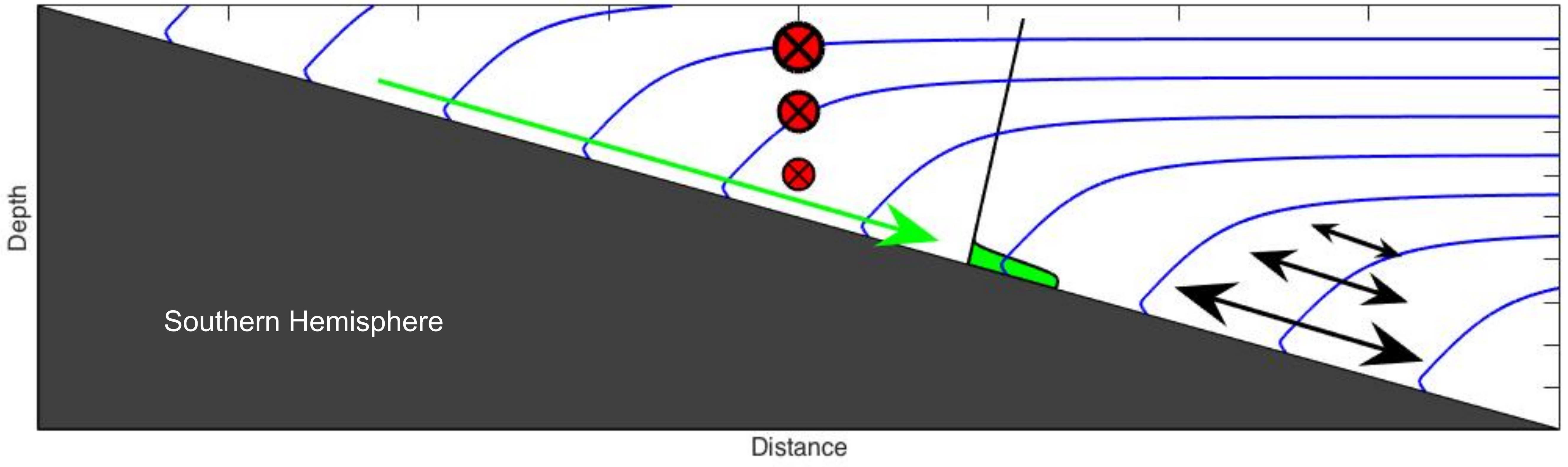
The Vision

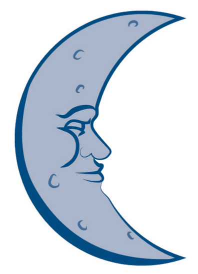
In the ocean, the sun doesn't shine and the bottom is insulating.

Flat bottoms are boring, but sloping topography presents a dynamic analogy.

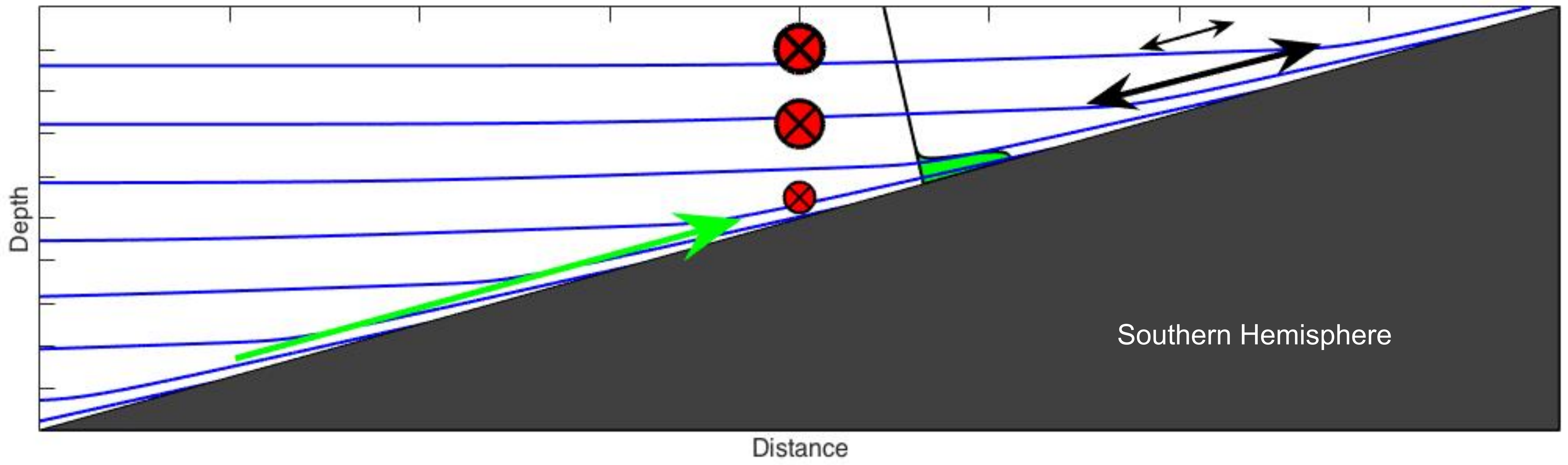




When flow over a sloping boundary is in the direction of Kelvin wave propagation, the bottom stress results in a downslope transport and convection (overturning).



When flow over a sloping boundary opposes the direction of Kelvin wave propagation, the bottom stress results in an upslope transport and increased density contrasts that suppresses turbulence.



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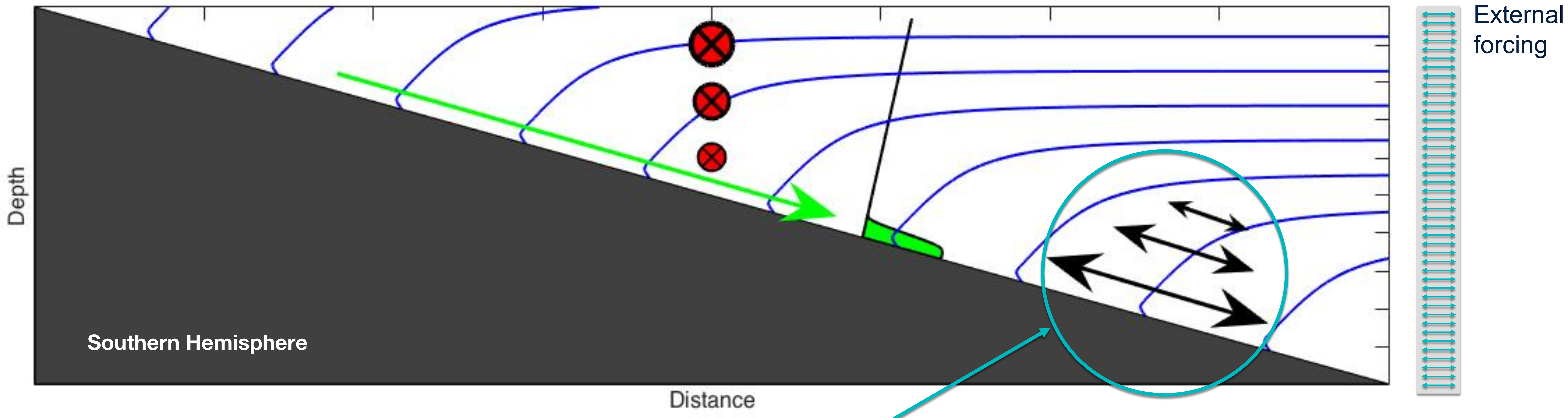
The atmosphere presents two major parameters: wind speed and solar insolation.

The ocean presents five!



1-2 **Current speed**
Topographic slope
Current direction

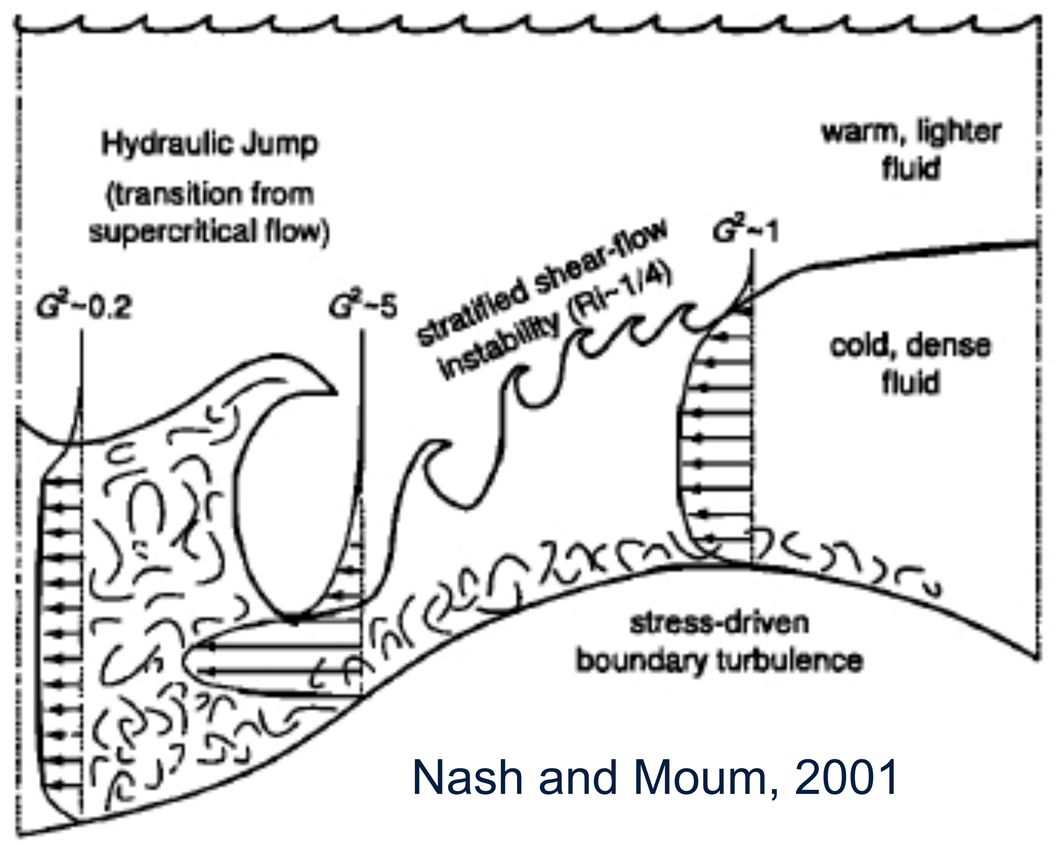
The allegory of wind speed and solar insolation

3 **There is now an internal waveband resonance at ~ f**

i) **The buoyancy flux is carried by the cross-slope motions, indirectly related to the "downwind" turbulence stress**
ii) **The across-slope wave momentum flux exceeds the along-slope turbulent stress**
iii) **There is forcing about that resonance - it's called a tide, or ambient internal wavefield**

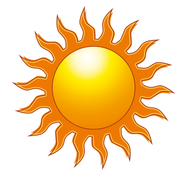
4 **The bandwidth of the internal wave guide (N/f) is important for behavior**

5 **And there are bumps**



Nash and Moum, 2001

In the atmosphere, you can use dimensional analysis and similarity scaling with the two basic parameters.

That's how you get  **and**  **pictures.**

The hypothesis: Despite the fact that there are 5 ocean parameters, one can obtain a similar characterization.

It's going to take lots of measurements and a community level project. Theory needs to be strongly guided by observation.

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Network solutions

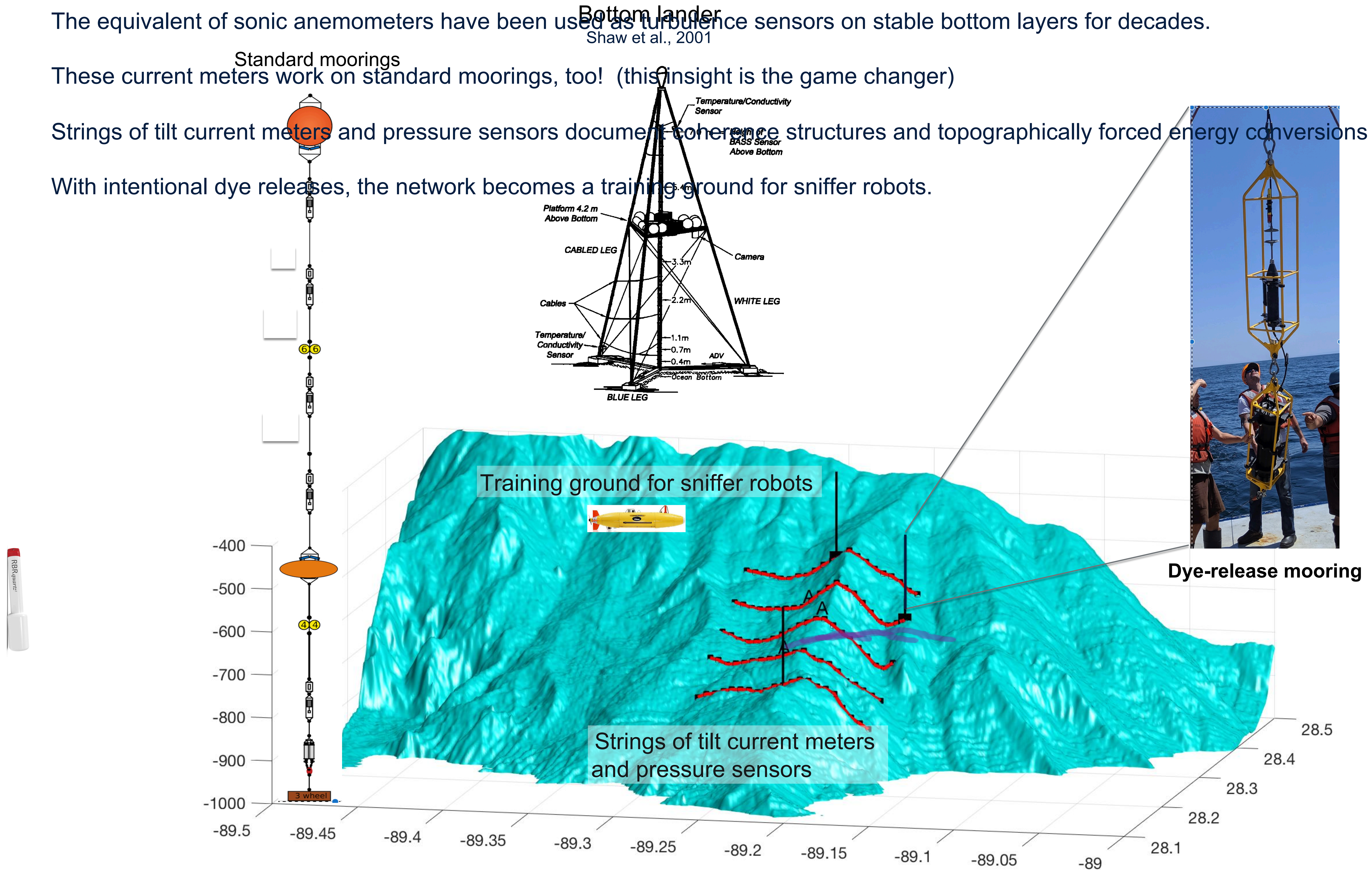
The ocean sensor network: Connecting existing technology to foster **emergent, game-changing techniques**

The equivalent of sonic anemometers have been used as turbulence sensors on stable bottom layers for decades.

These current meters work on standard moorings, too! (this insight is the game changer)

Strings of tilt current meters and pressure sensors document coherence structures and topographically forced energy conversions

With intentional dye releases, the network becomes a training ground for sniffer robots.



Add lobster trap or milk crate

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References to lhs
1: Ferrari et al., 2016. Turning ocean mixing upside down. J. Phys. Oceanogr.
2: Dotto et al., 2019. Wind-driven processes controlling oceanic heat delivery to the Amundsen Sea, Antarctica. J. Phys. Oceanogr.
3: Marshall et al. 2017. Eddy saturation and frictional control of the Antarctic Circumpolar Current. Geophys. Res. Letters.
4: Gillibrand et al., 2013. A box model of the seasonal exchange and mixing in regions of restricted exchange: application to two contrasting Scottish inlets. Env. Modeling and Software.

Connections and collaborators

This is technology we have NOW, repackaged, embedded within an international, community-level project across multiple disciplines.

Connecting people and disciplines . . .

Physical Oceanography
- Boundary layer dynamics
- Ocean General Circulation Modeling
- Climate dynamics
- Geophysical fluid dynamics

Computer Science
- Machine learning: find patterns in 5-dimensional parameter space
- Artificial intelligence: Write/test behavior algorithms for pollution detection with knowledge of the turbulent field
- Improvements in climate models
- High-performance computing

. . . And more

Crossing temporal scales
- The structure of Boundary Mixing determines global ocean upwelling[1], underpins long term climate trends and directly relates to carbon sequestration.
- Boundary Mixing figures into the cross-shelf break transport of heat, relating to heat balances in glacial environments[2] and thus figuring into sea level rise.
- Boundary Mixing is a key player in the overall energetics of the Antarctic Circumpolar Current and thereby is crucially linked to the response to wind stress variations[3].

Addressing societal issues
- Boundary mixing disperses pollutants and controls the downstream evolution of contaminant concentration.
- Boundary mixing enters into control volume estimates that determine the carrying capacity for aquaculture in Regions of Restricted Exchange environments[4].

Underlying these connections is a multi-parameter boundary-layer physics problem that is poorly understood.