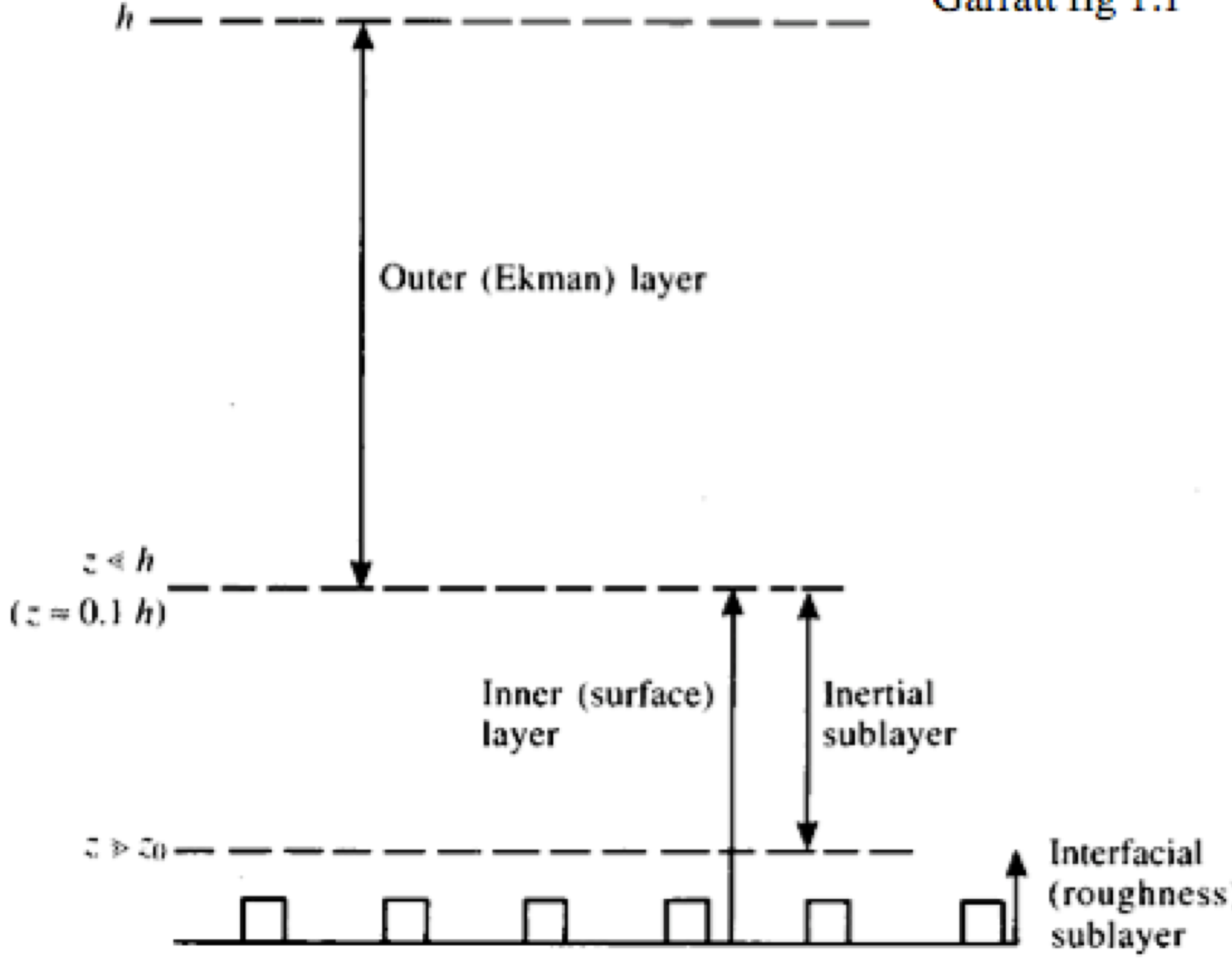
The Atmospheric Boundary Layer (ABL or PBL)

- The layer of fluid directly above the Earth's surface in which significant fluxes of momentum, heat and/or moisture are carried by turbulent motions whose horizontal and vertical scales are on the order of the boundary layer depth, and whose circulation timescale is a few hours or less (Garratt, p. 1). A similar definition works for the ocean.
- The complexity of this definition is due to several complications compared to classical aerodynamics:
  - i) Surface heat exchange can lead to thermal convection
  - ii) Moisture and effects on convection
  - iii) Earth's rotation
  - iv) Complex surface characteristics and topography.

Sublayers of the atmospheric boundary layer

Garratt fig 1.1



Applications and Relevance of BLM

i) Climate simulation and NWP

ii) Air Pollution and Urban Meteorology

iii) Agricultural meteorology

iv) Aviation

v) Remote Sensing

vi) Air-Sea Interaction

History of Boundary-Layer Meteorology

1900 – 1910 Development of laminar boundary layer theory for aerodynamics, starting with a seminal paper of Prandtl (1904).

Ekman (1905,1906) develops his theory of laminar Ekman layer.

1910 – 1940 Taylor develops basic methods for examining and understanding turbulent mixing

Mixing length theory, eddy diffusivity - von Karman, Prandtl, Lettau

1940 – 1950 Kolmogorov (1941) similarity theory of turbulence

1950 – 1960 Buoyancy effects on surface layer (Monin and Obuhkov, 1954). Early field experiments (e. g. Great Plains Expt. of 1953) capable of accurate direct turbulent flux measurements

1960 – 1970 The Golden Age of BLM. Accurate observations of a variety of boundary layer types, including convective, stable and trade-cumulus. Verification/calibration of surface similarity theory.

1970 – 1980 Introduction of resolved 3D computer modelling of BL turbulence (large-eddy simulation or LES). Application of higher-order turbulence closure theory.

History continued...

1980 - 1990   Major field efforts in stratocumulus-topped boundary layers (FIRE, 1987) and land-surface, vegetation parameterization. Mesoscale modeling.

1990 - 2000   New Technologies

New surface remote sensing tools (lidar, cloud radar) and extensive space-based coverage of surface characteristics;

LES as a tool for improving parameterizations and bridging to observations.

Boundary layer - deep convection interactions (e. g. TOGA-COARE, 1992)

2000-2020   PBL processes in earth and human system models

Coupled ocean-atmosphere-ice-biosphere models create new requirements for BL parameterizations, e. g. better treatment of surface wind stress, vegetated surfaces, BL clouds and aerosols.

More accurate BL simulation needed for modelling air flow around buildings and urban areas, air pollution modeling near complex terrain.

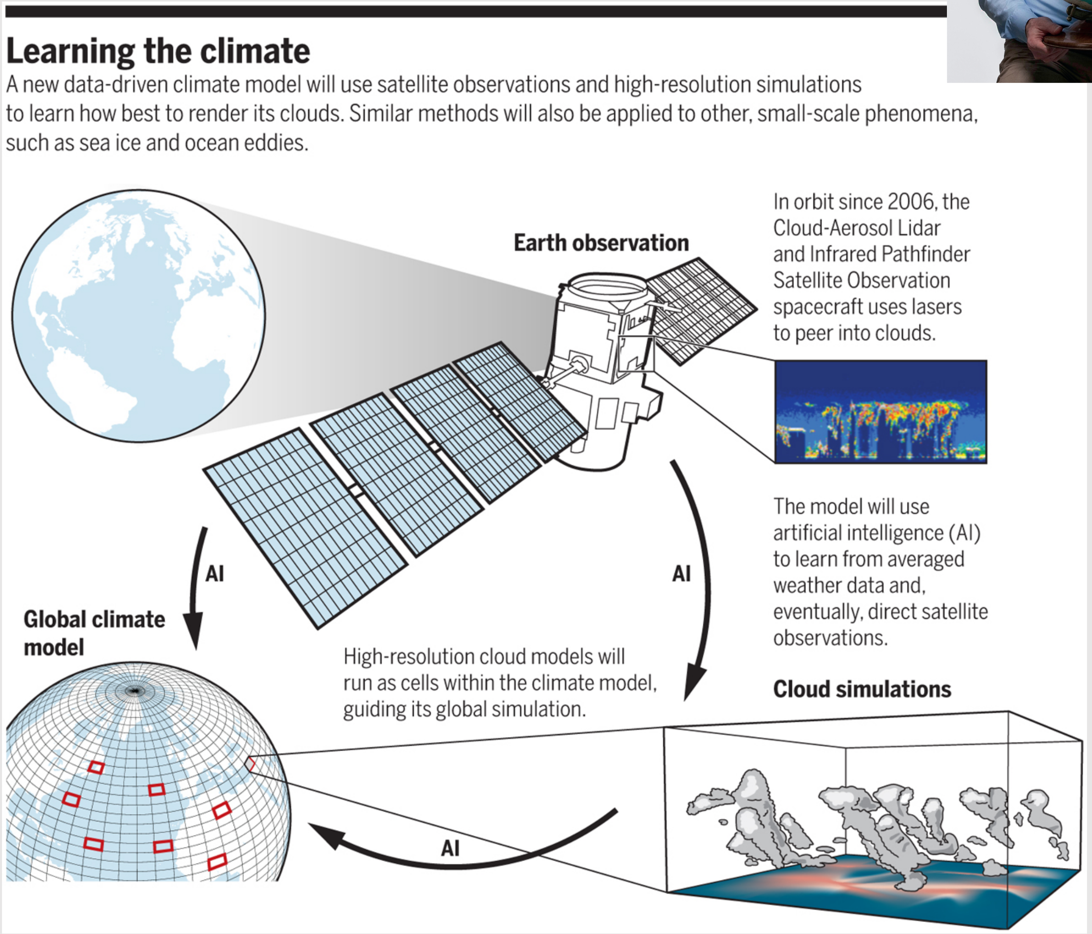
Ensemble data assimilation enables better use of near-surface and boundary-layer data over land surfaces

The Climate Machine

clima.caltech.edu

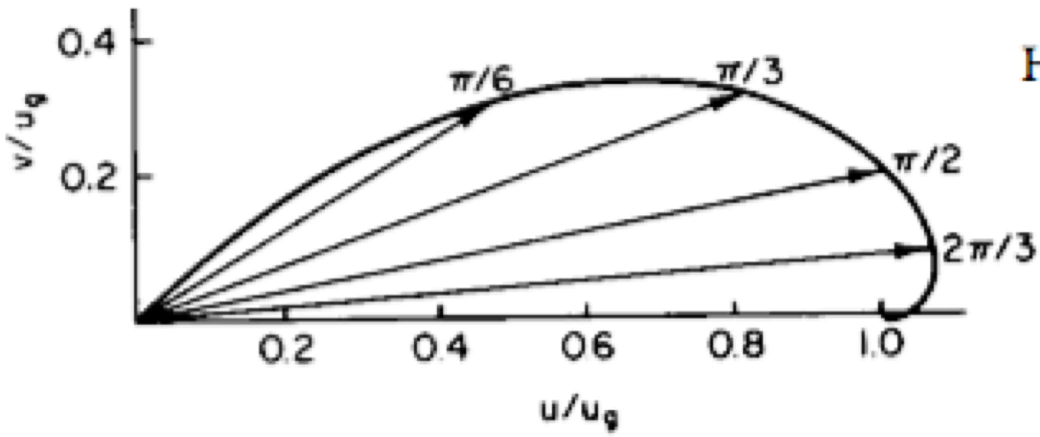
Tapio Schneider

Low stratocumulus clouds above the NW Pacific



Science (2018)

Laminar Ekman spiral



Holton, fig. 5.4

Fig. 5.4 Hodograph of the wind components in the Ekman spiral solution. The arrows show the velocity vectors for several levels in the Ekman layer, while the spiral curve traces out the velocity variation as a function of height. Points labeled on the spiral show the values of γz, which is a nondimensional measure of height.

Archetypal shear flows

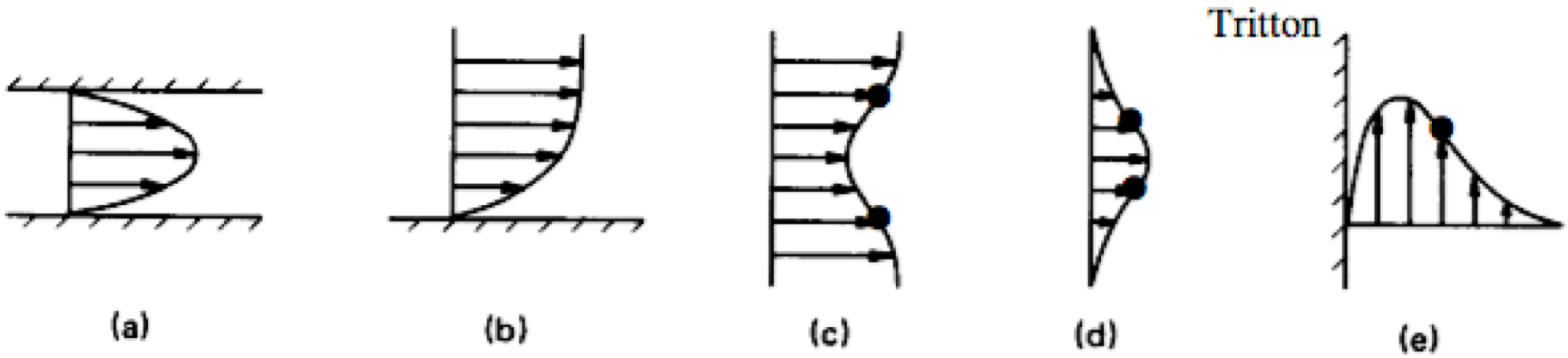


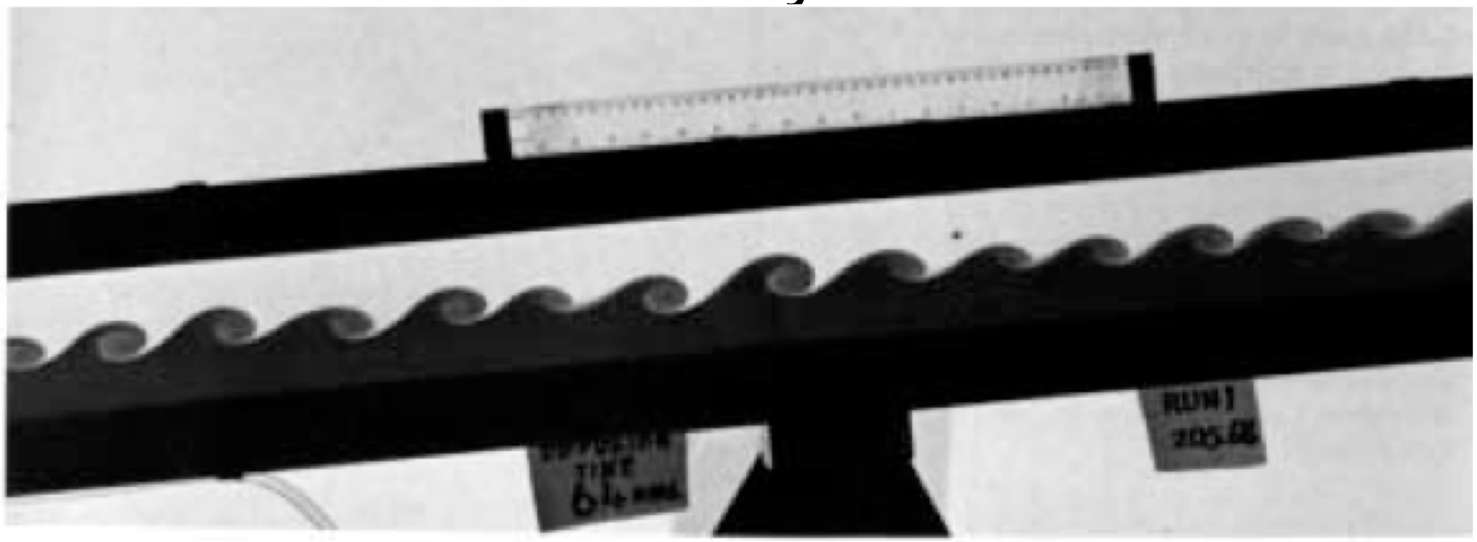
Figure 17.13 To illustrate that the velocity profiles of (a) pipe flow, (b) a boundary layer, (c) a wake, (d) a jet, and (e) a free convection boundary layer are all shear flows.

Von Karman vortex street

94. Kármán vortex street behind a circular cylinder at R=140. Water is flowing at 1.4 cm/s past a cylinder of diameter 1 cm. Integrated streaklines are shown by electrolytic precipitation of a white colloidal smoke, illuminated by a sheet of light. The vortex sheet is seen to grow in width downstream for some diameters. *Photograph by Sadatoshi Taneda*

van Dyke, p. 56

Kelvin-Helmholz instability in the lab and in nature

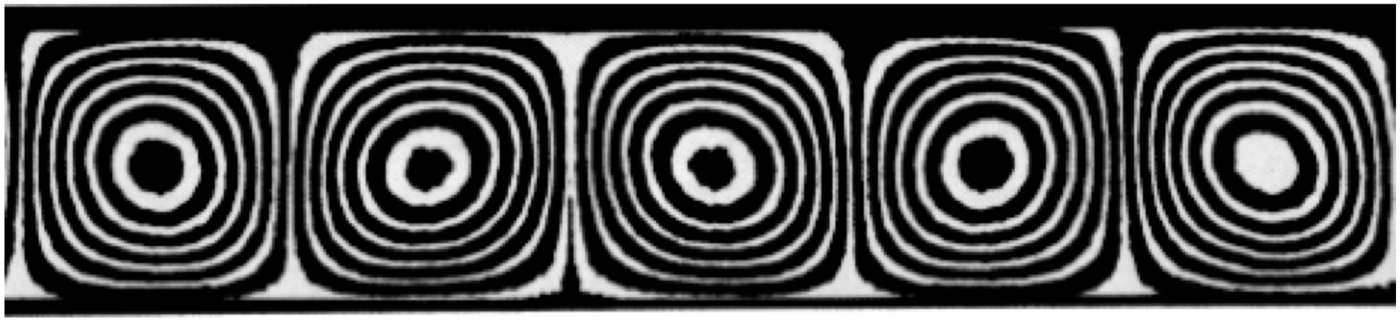


145. Kelvin-Helmholtz instability of stratified shear flow. A long rectangular tube, initially horizontal, is filled with water above colored brine. The fluids are allowed to diffuse for about an hour, and the tube then quickly tilted six degrees, setting the fluids into motion. The brine accelerates uniformly down the slope, while the water above similarly accelerates up the slope. Sinusoidal instability of the interface occurs after a few seconds, and has here grown nonlinearly into regular spiral rolls. *Thorpe 1971*

van Dyke, p. 85

Figure 2
Turbulent eddies forming in a wind shear zone produce these clouds.

Thermal convection in the lab and in nature



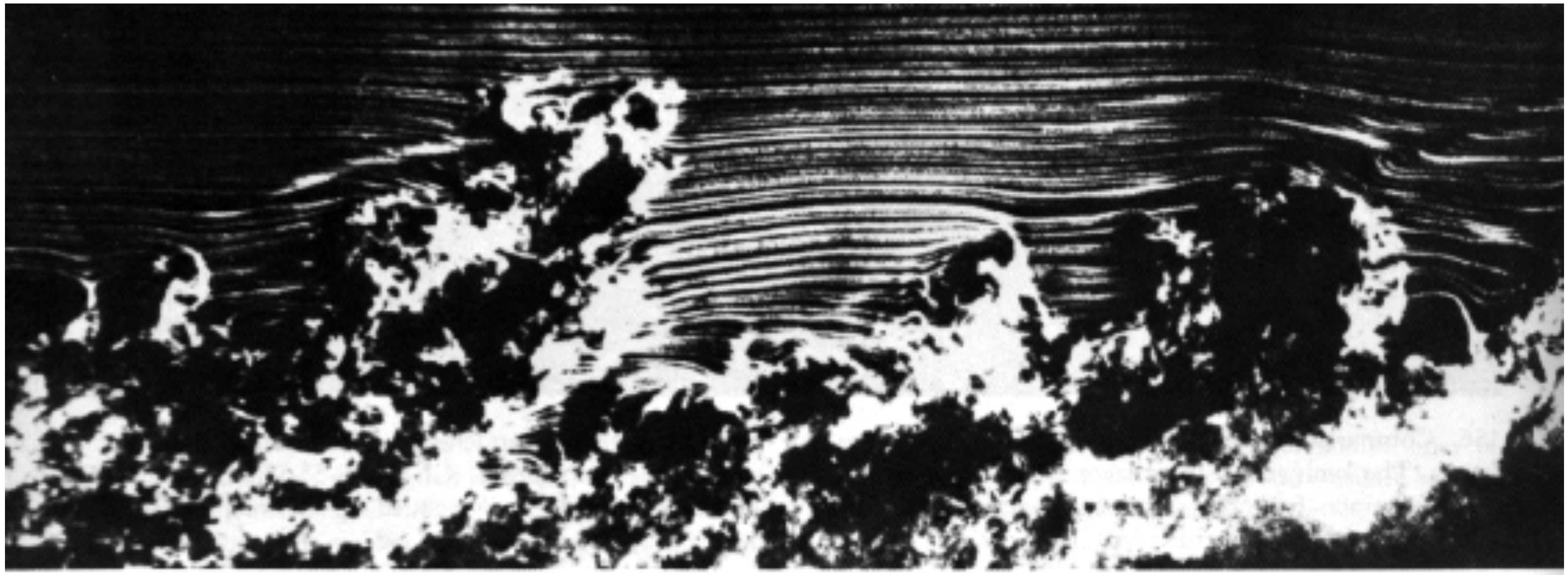
Slightly unstable convection in silicone oil van Dyke p. 82

Fig. 7.2. Convective clouds in an unstable layer, aligned in 'streets' along the direction of shear. (Compare with fig. 4.14 pl. 8, which shows clouds formed by a shear instability and aligned across the flow. The form of 'billow' clouds can vary widely according to the relative importance of shear and convection.) (Photograph: R. S. Scorer.) Turner

Instability and transition to turbulence in a jet

102. Instability of an axisymmetric jet. A laminar stream of air flows from a circular tube at Reynolds number 10,000 and is made visible by a smoke wire. The edge of the jet develops axisymmetric oscillations, rolls up into vortex rings, and then abruptly becomes turbulent. *Photograph by Robert Drubka and Hassan Nagib*

The boundary layer for other fluid dynamicists



157. Side view of a turbulent boundary layer. Here a turbulent boundary layer develops naturally on a flat plate 3.3 m long suspended in a wind tunnel. Streaklines from a smoke wire near the sharp leading edge are illuminated by a vertical slice of light. The Reynolds number is 3500 based on the momentum thickness. The intermittent nature of the outer part of the layer is evident. *Photograph by Thomas Corke, Y. Guezennec, and Hassan Nagib.*