NOAA RESEARCH • ESRL • PHYSICAL SCIENCES DIVISION

Stable Boundary Layers

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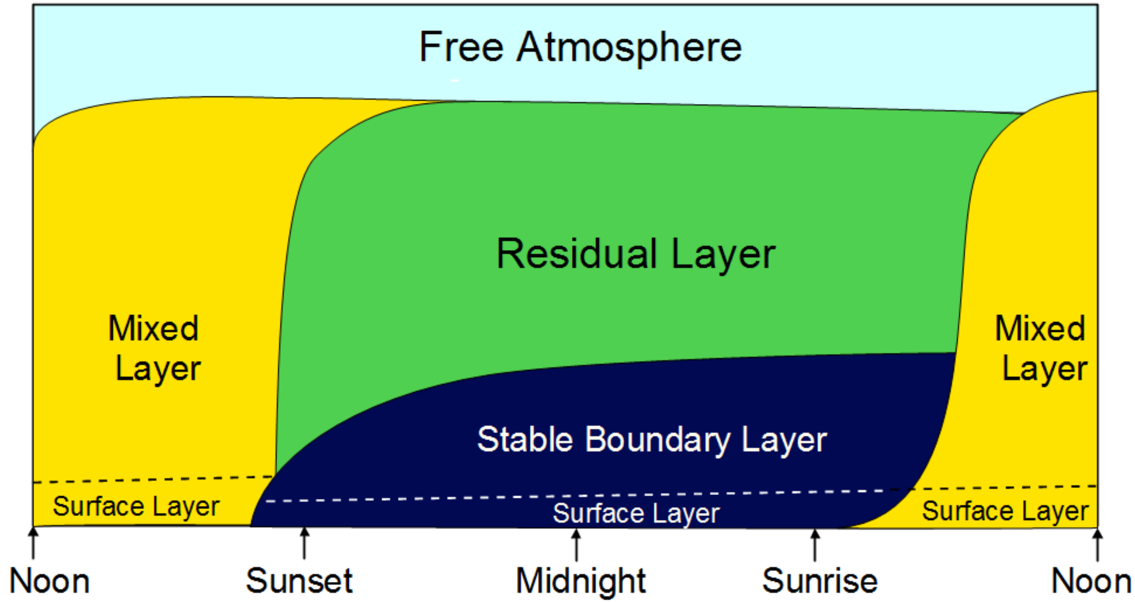
Atmospheric Boundary Layer Structure

- Atmospheric boundary layers are usually classified into three types: **neutral**, **convective** and **stable**, based on atmospheric stability (buoyancy effects) and production of turbulence by wind shear.
- Turbulence in the **stable boundary layer (SBL)** is generated by shear and destroyed by negative buoyancy and viscosity. The strength of turbulence in the SBL is much weaker and it is much shallower in comparison to the neutral and convective boundary layers.



A typical daily cycle of the atmospheric boundary layer in fair weather (after Stull, 1988).

Why do we care about the SBL?

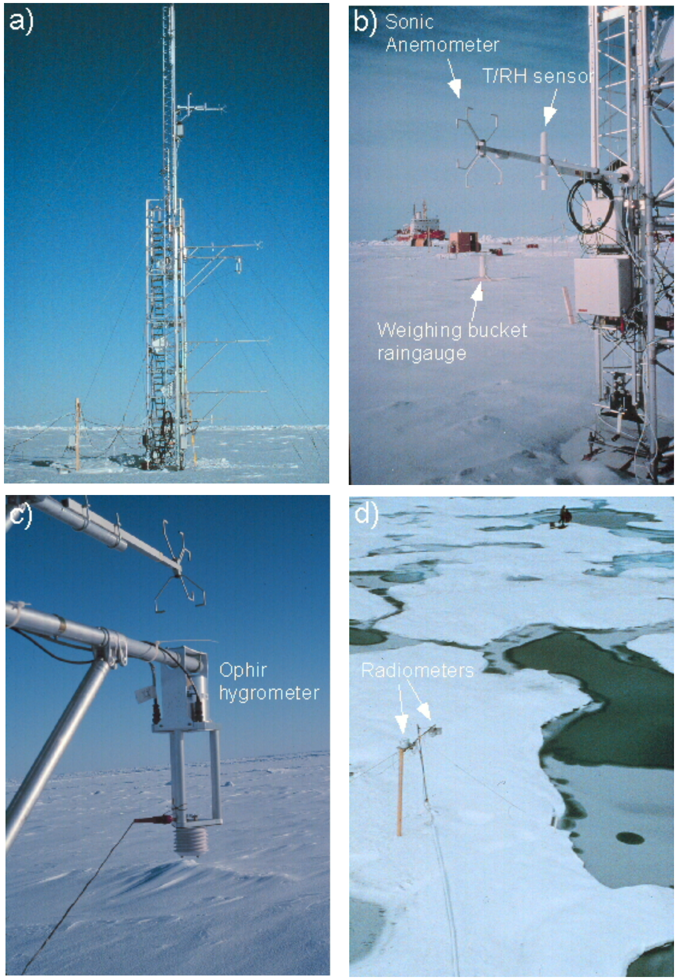
- The SBL remains the least understood element of the atmospheric boundary layer.
- Principal characteristic of SBL – suppresses vertical mixing

- Allows buildup of high concentrations of contaminants; dispersion models perform poorly;
- Nocturnal weak-wind clear-sky: frost damage, fog formation;
- Unrealistic 'runaway' surface cooling in numerical models;
- Polar atmospheric boundary layers are stable for long periods;
- Other civilian and military applications, e.g., safe aviation, visibility (fog and aerosol) predictions for the battlefield, circulation in complex terrain, katabatic winds etc.)

Accumulation of smoke near the upper boundary of the thin SBL

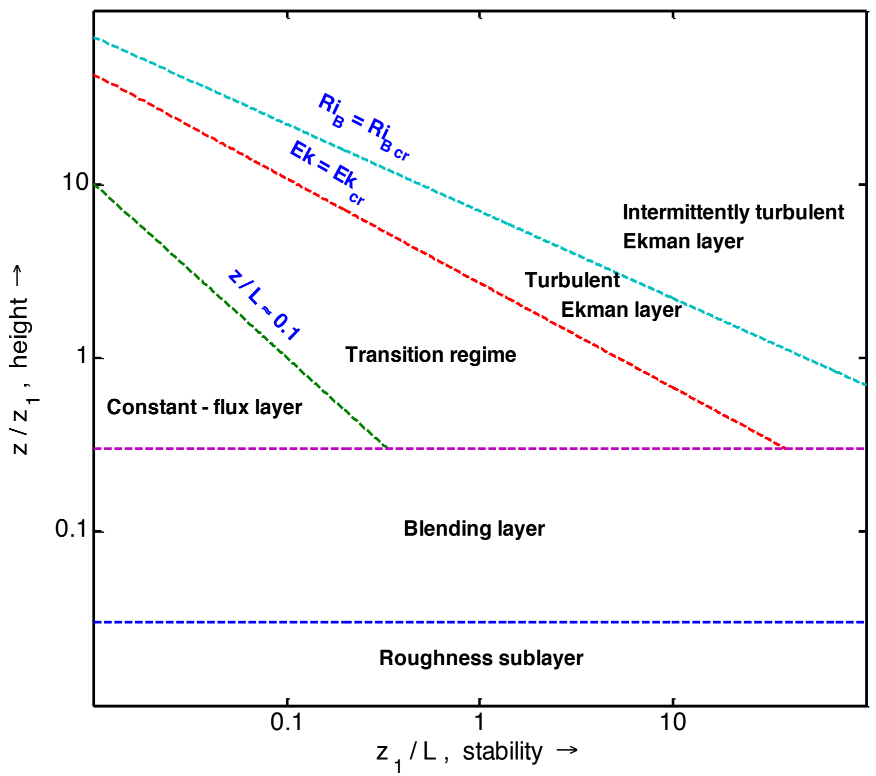
Recent PSD findings on the SBL

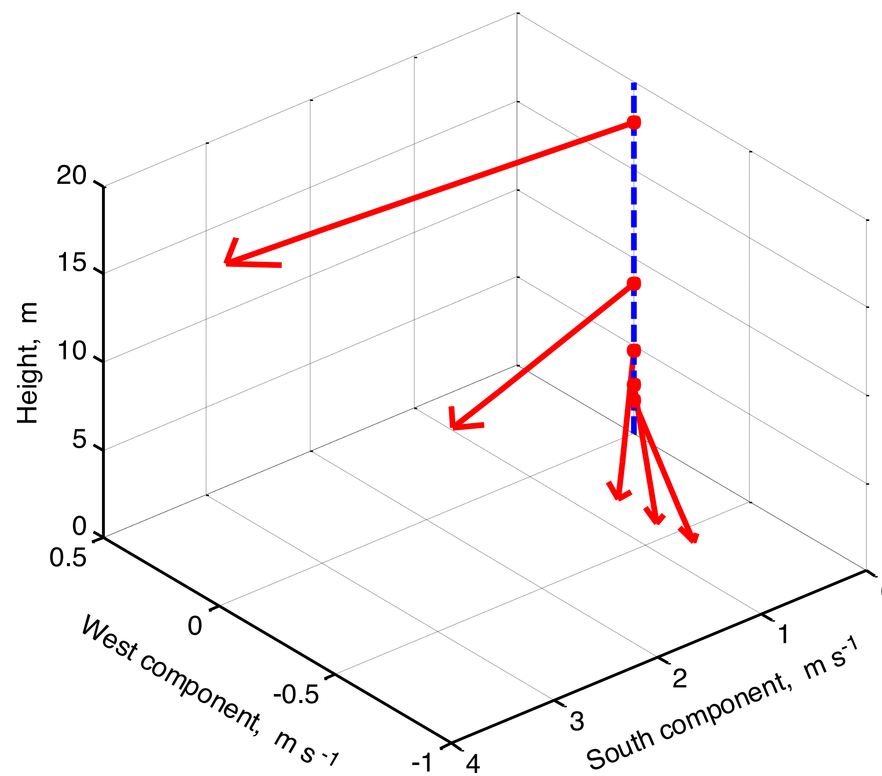
- The SHEBA flux algorithm (Andreas et al. 2010a, b);
- Outlier problem for gradient-based scaling in the SBL (Grachev et al. 2012);
- The critical Richardson number and limits of applicability of Monin-Obukhov similarity theory in the SBL (Grachev et al. 2013);
- Similarity theory based on the Dougherty-Ozmidov length scale (Grachev et al. 2014);
- The turbulence structure of katabatic flows below and above wind-speed maximum (Grachev et al. 2015);
- Turbulent mixing and similarity of scalars in the SBL (Grachev et al. 2015).



Surface Heat Budget of the Arctic Ocean Experiment (SHEBA)

Stable Boundary Layer Regimes





Stratification and Earth rotation control the SBL over a flat rough surface. Different SBL regimes:
*Monin-Obukhov stability parameter (*z/L*)
*Ekman number (Ek) influence of the Earth's rotation
*Bulk Richardson number (Ri_B) intensity of the turbulence.

3D view of the Ekman spiral for 14:00 UTC JD 507 (local time 6 a.m.), 22 May 1998. Note height scale.

Grachev et al. (2005), Boundary-Layer Meteorology.

Turbulence Suppression in the SBL

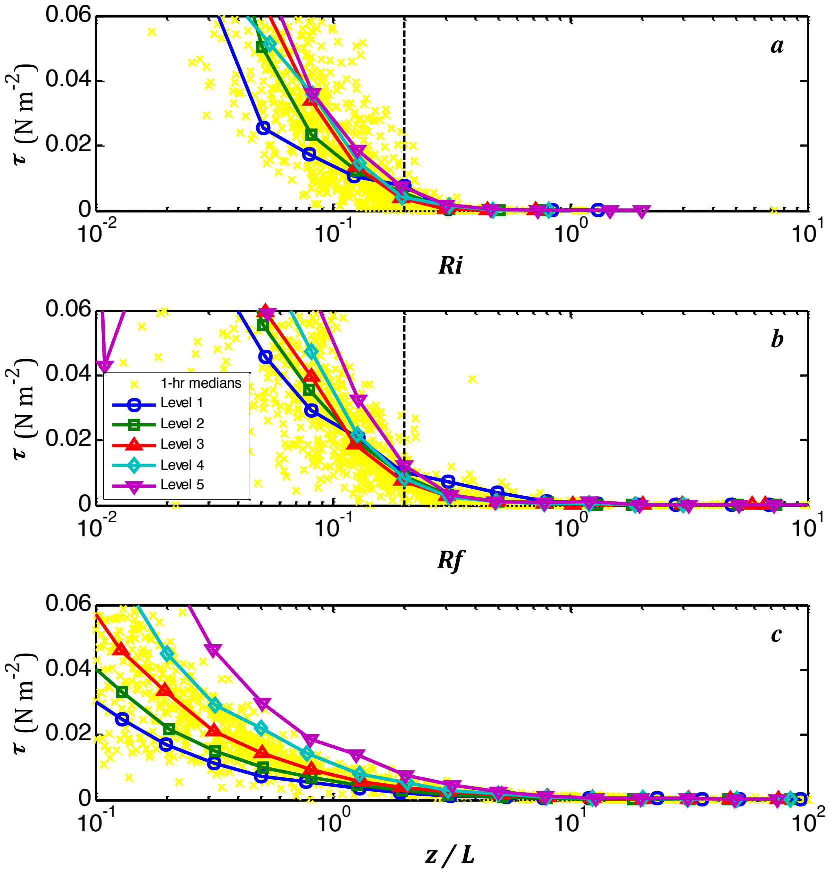
Turbulent stress and the critical Richardson number

Behavior of the downward momentum flux for five levels of the main SHEBA tower plotted versus

(a) Local gradient Richardson number,*Ri*,
(b) Flux Richardson number, *Rf*
(c) Monin-Obukhov stability parameter, *z/L*.

The median fluxes for the five levels are shown as the background x-symbols. The vertical dashed lines correspond to *Ri* and *Rf* = 0.2.

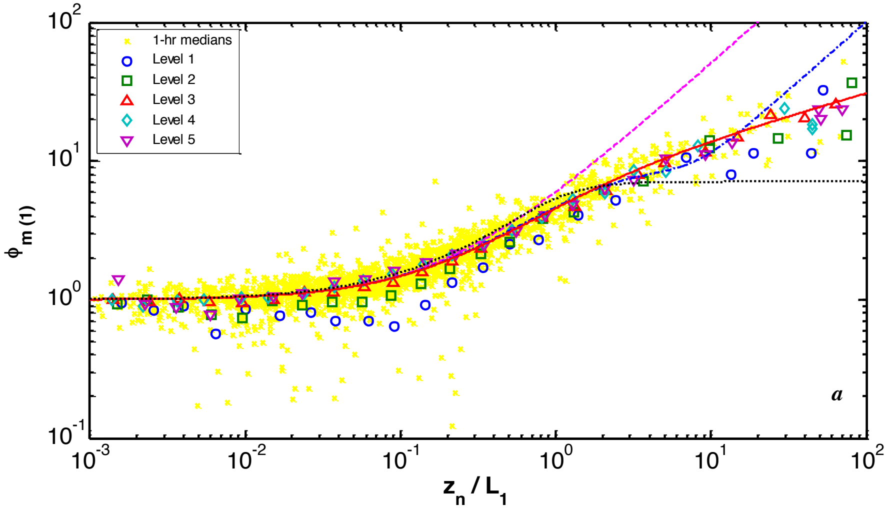
Increasing stability suppresses the momentum flux from atmosphere to surface

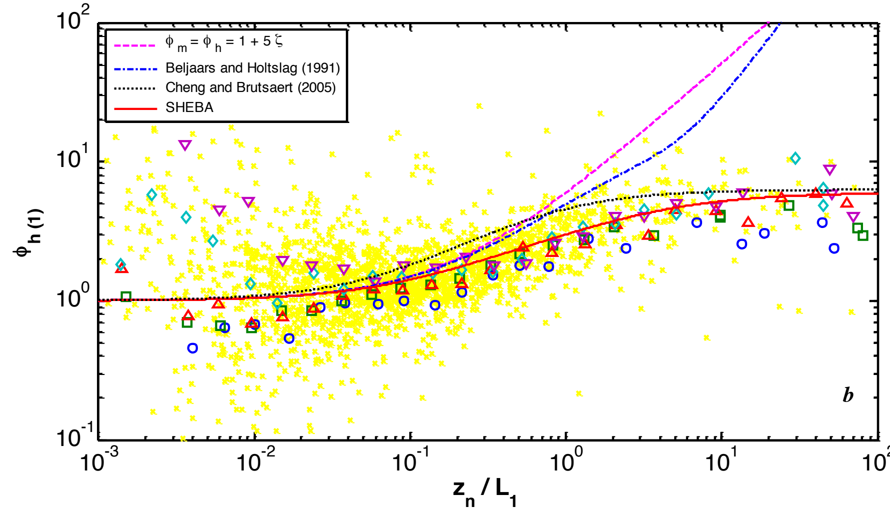


Grachev et al. (2013), *Boundary-Layer Meteorology*.

Non-Dimensional Vertical Gradients

The SHEBA parameterizations



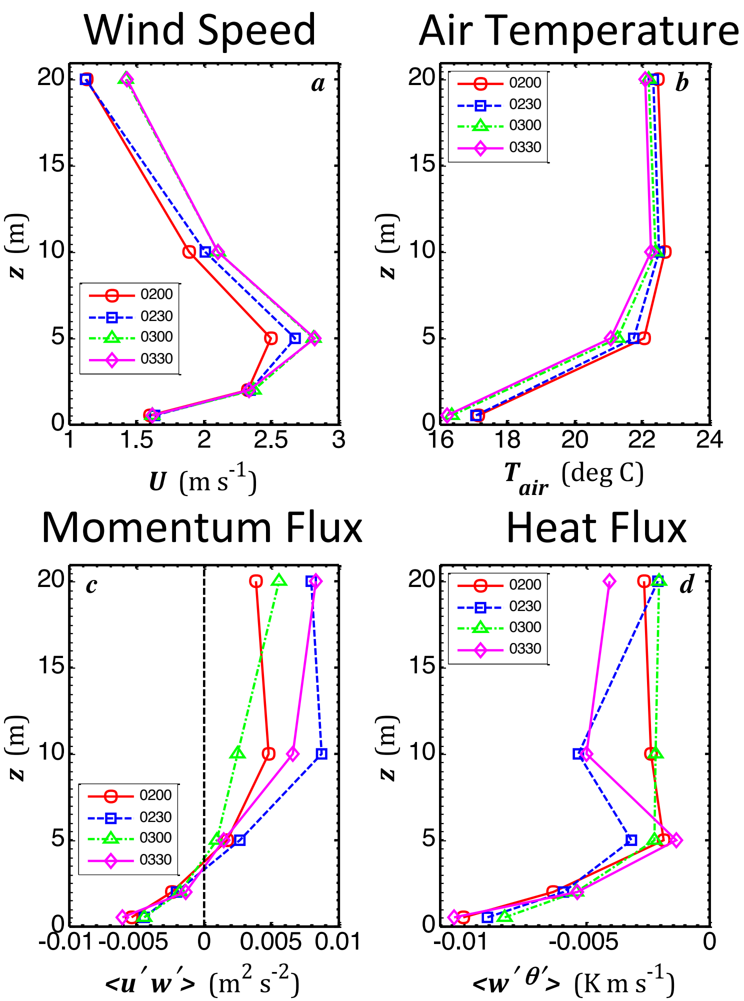


The Phi functions relate the *local gradients* of wind speed and temperature to the turbulent *fluxes* of momentum and heat.

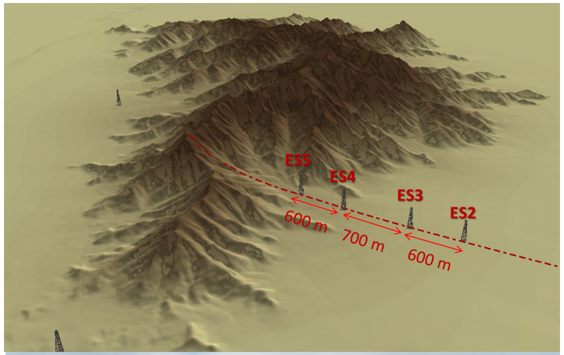
These parameterizations are widely used in numerical models:
*The COARE bulk flux algorithms
*SHEBA bulk flux algorithm by Andreas et al. (2010a, b)
*Radar and EM propagation ducting models (Ding Ju-li et al. 2011)
*Evaporation from the Arctic Ocean (Boisvert et al. 2015).

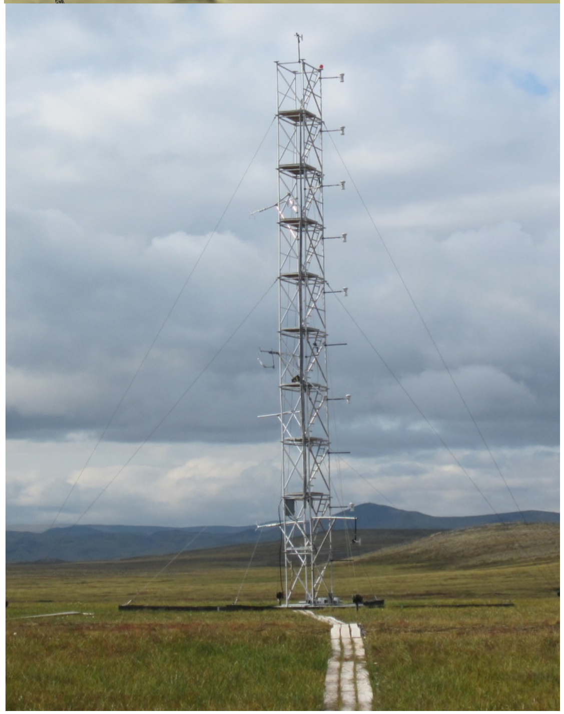
Grachev et al. (2007), Boundary-Layer Meteorology.
Grachev et al. (2013), Boundary-Layer Meteorology.

Katabatic winds: Nocturnal Flow From Steep Terrain



Plots of vertical profiles of the (*a*) wind speed, (*b*) air temperature, (*c*) momentum flux, (*d*) heat flux observed at the ES3 flux tower (on the right) on the East slope of Granite Mountain, US Army Dugway Proving Grounds in Utah, on 28 September 2012.





Summary and Conclusions

- SBL direct data are used principally to develop parameterizations, improve the observing system, and 'verify' model results;
- Research feeds fundamental physics of the SBL (turbulence structure, critical Richardson number, turbulent Prandtl number etc.);
- Products include flux-profile parameterizations, flux algorithms, and flux-profile databases;
- Applications include better measurements in the SBL, better flux formulations for NWP and climate models, and flux-profile datasets for calibration and validation of regional and large-scale models;
- Our research will also improve the formulation of turbulent and mesoscale transport in dispersion models for cases of weak winds and weak turbulence.