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Vertical Turbulent Mixing of Momentum and Heat in the Summer Time Stable Arctic Lower Troposphere

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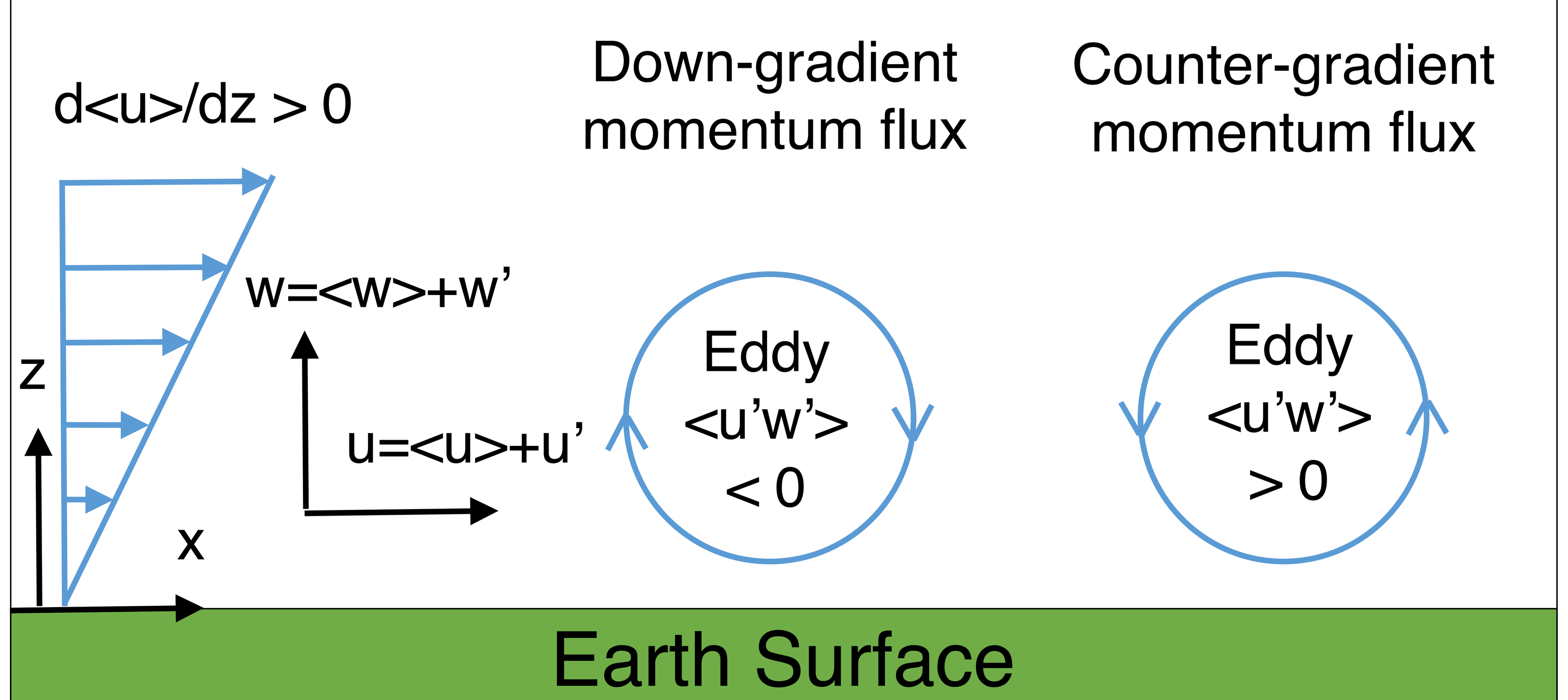
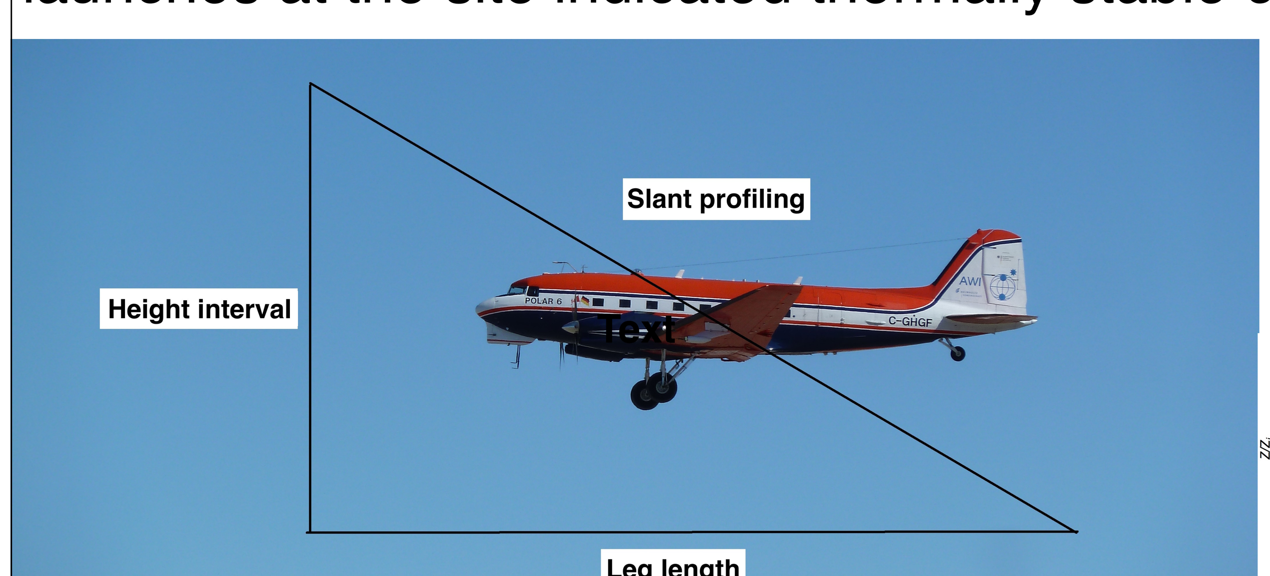
Introduction

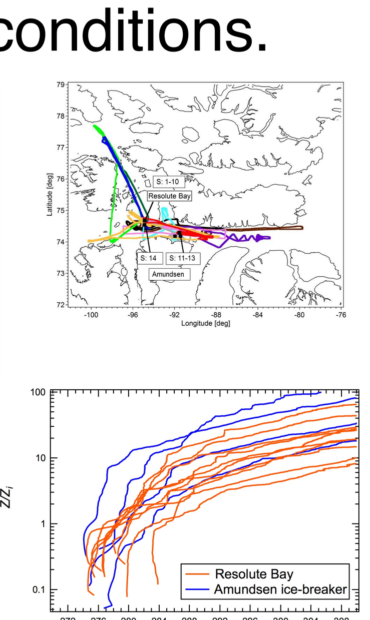
Vertical turbulent mixing of momentum and heat in the atmosphere are parameterized using the *gradient diffusion hypothesis*. Under *thermally stable* conditions, there has been a lack of observations to probe turbulent eddies and so to parameterize vertical *turbulent fluxes* of *momentum* and *heat,* i.e. <u'w'> and <θ'w'>, properly. It is unclear if these fluxes are *down-gradient* or *counter-gradient*.



Methodology

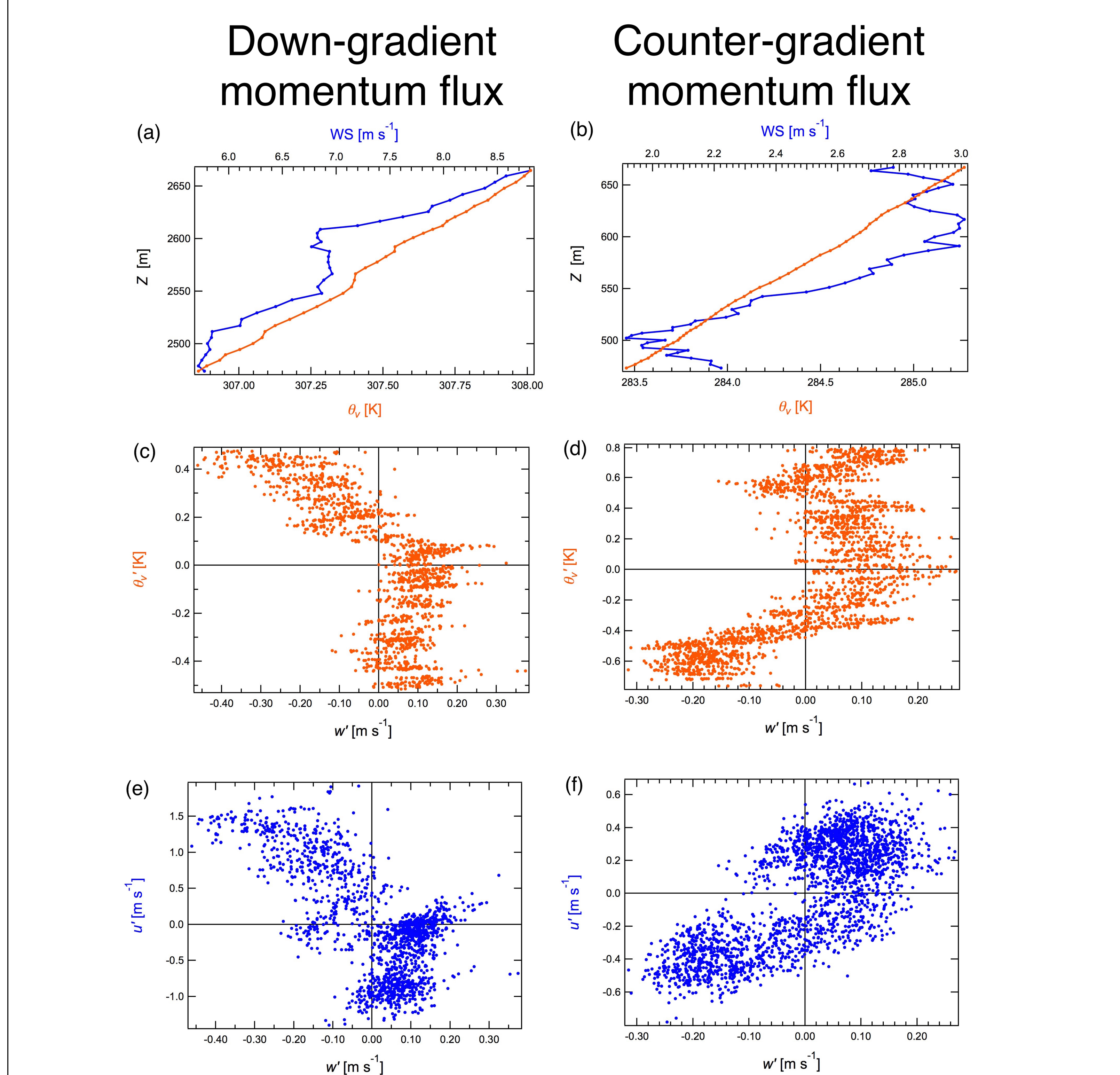
During the Summer 2014 campaign near Resolute Bay, Polar 6 measured meteorological parameters using the AIMMS-20 instrument at 40 Hz. 920 *slant profiles* of the aircraft were analyzed each covering a height interval (altitude change) of 200 m and an average leg length (horizontal distance) of 5304 m. These measurement allowed full parameterization of momentum and heat fluxes using the gradient diffusion hypothesis. Radiosonde launches at the site indicated thermally stable conditions.



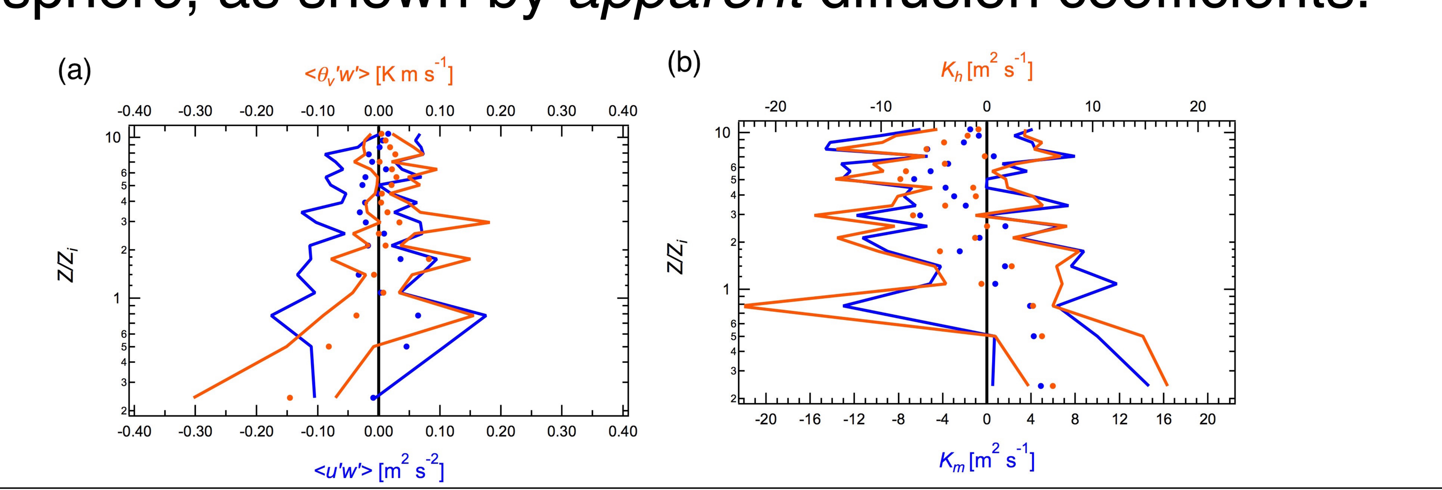


Results: Flux Observations

Both down- and counter-gradient turbulent fluxes of momentum and heat were observed. This was contrary to previous limited observations that did not predict counter-gradient turbulent fluxes under thermally stable conditions. Counter-gradient transport was specifically probed at *large scales*, i.e. *small wave numbers*.



Down-gradient fluxes were dominant in the boundary layer, but counter-gradient fluxes were dominant in the free troposphere, as shown by *apparent* diffusion coefficients.



Results: Flux Parameterizations

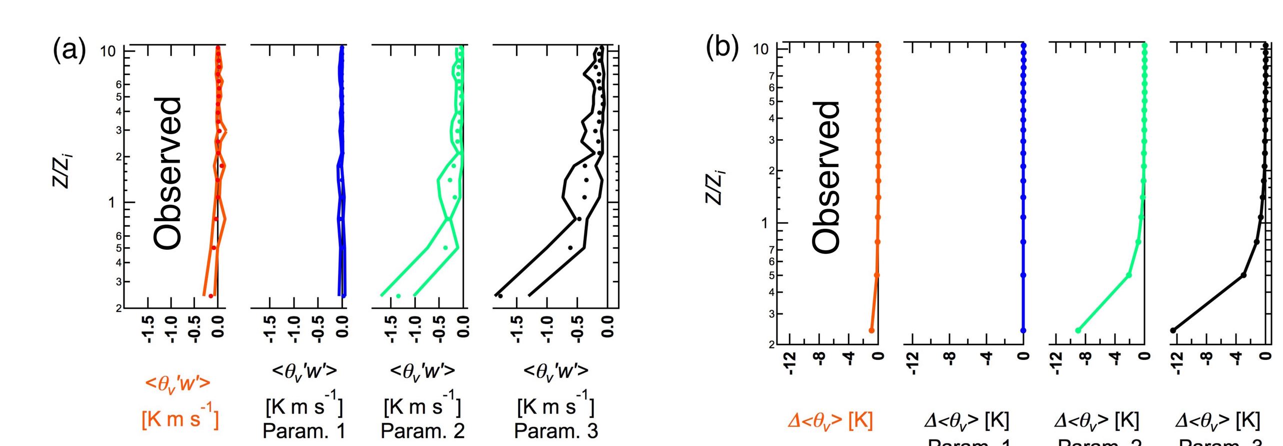
Three parameterization for heat flux were developed and fitted by the observations. Parameterization 1 accounted for down- and counter-gradient fluxes, and anisotropic turbulence. Parameterization 2 accounted for down- and counter-gradient fluxes, but assumed isotropic turbulence. Parameterization 3 only accounted for down-gradient fluxes and assumed isotropic turbulence (the case for typical atmospheric models).

Parameterization 1
$$\overline{\theta_v' w'} = -\underbrace{\frac{3 l_h \overline{w'^2}}{q}}_{K_h}\left(\frac{\partial\overline{\theta_v}}{\partial z} - \underbrace{\frac{Cg}{\overline{w'^2}}\frac{\overline{\theta_v'^2}}{\overline{\theta_v}}}_{\Gamma_h}\right),$$

Parameterization 2
$$\overline{\theta_v' w'} = -\underbrace{l_h q}_{K_h}\left(\frac{\partial\overline{\theta_v}}{\partial z} - \underbrace{\frac{3Cg}{q^2}\frac{\overline{\theta_v'^2}}{\overline{\theta_v}}}_{\Gamma_h}\right),$$

Parameterization 3
$$\overline{\theta_v' w'} = -\underbrace{l_h q}_{K_h}\frac{\partial\overline{\theta_v}}{\partial z}.$$

Based on the observations, the errors in heat flux and mean temperature due to using these parameterizations can be significant if *counter-gradient fluxes* and *anisotropic turbulence* in the atmosphere are not accounted for.



The turbulent Prandtl number was also fitted, allowing for the parameterization of the turbulent momentum flux.

Conclusions

Under *thermally stable* conditions, the performance of atmospheric models can be improved by accounting for *counter-gradient fluxes* and *anisotropic turbulence* in the atmosphere.

Full analysis of this research project can be found in article: Aliabadi, A. A., Staebler, R. M., Liu, M., & Herber, A. (2016), Characterization and Parametrization of Reynolds Stress and Turbulent Heat Flux in the Stably-Stratified Lower Arctic Troposphere Using Aircraft Measurements, *Boundary-Layer Meteorology*, 161(1), 99-126, doi: 10.1007/s10546-016-0164-7. The authors acknowledge the following individuals for their contributions: M. Wasey, A. Elford, M. Gehrman, C. Konrad, J. Burkart, J. de Grandpre, S. Belair, P. Makar, J. Abbatt, R. Leaitch, and J. Garratt.
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