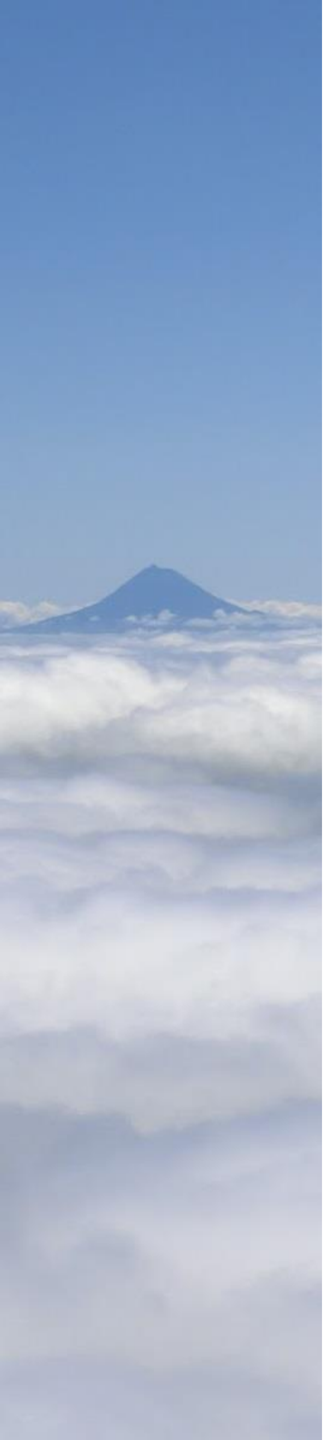


Turbulence properties in coupled and decoupled stratocumulus-topped marine boundary layer

Jakub L. Nowak

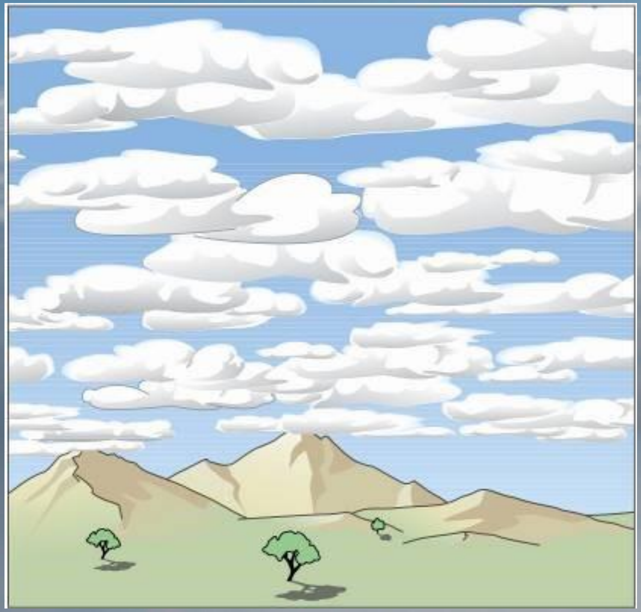
UNIVERSITY OF WARSAW | INSTITUTE OF GEOPHYSICS

10th December 2021

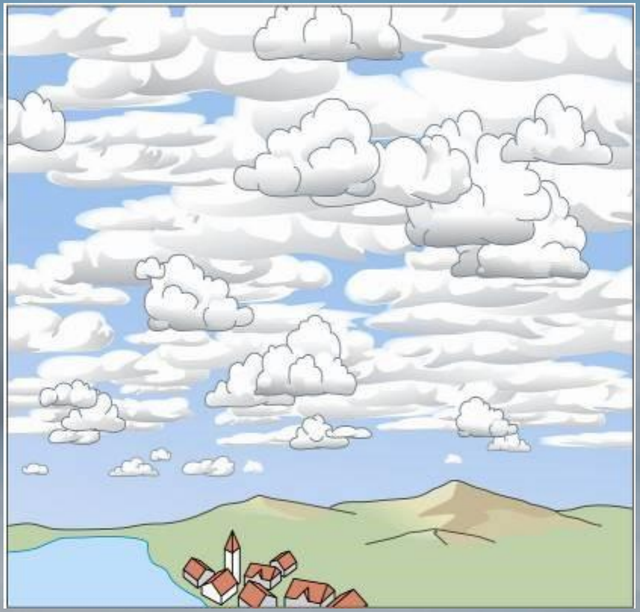
Stratocumulus clouds

stratus = cover, spreading

cumulus = heap, pile, accumulation



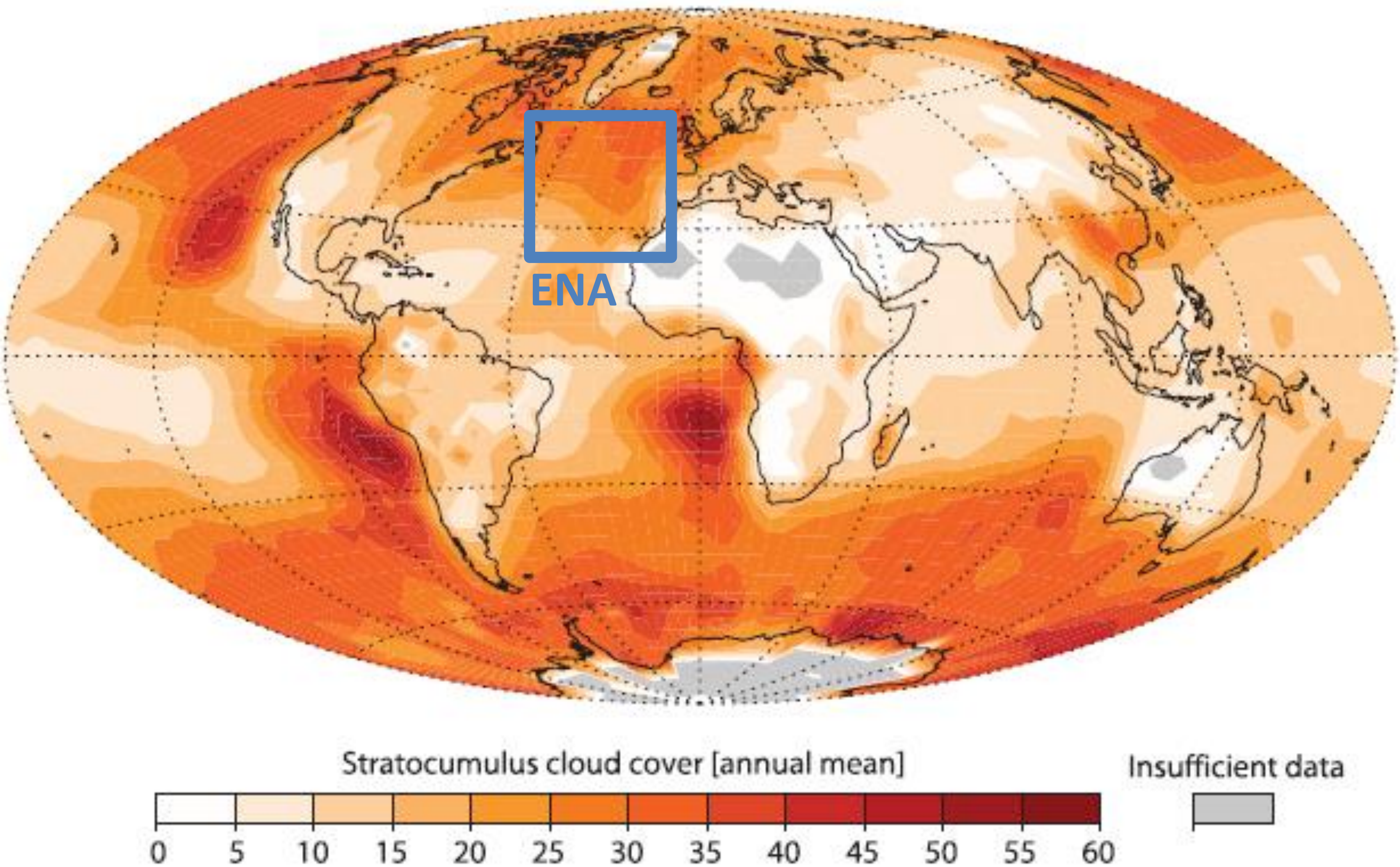
C_L5: stratocumulus non-cumulogenitus



C_L8: cumulus and stratocumulus

WMO International Cloud Atlas

Stratocumulus climatology



Wood 2012

Low cloud climate feedbacks

+0.42
[-0.10 0.94]
W m^{-2} K^{-1}

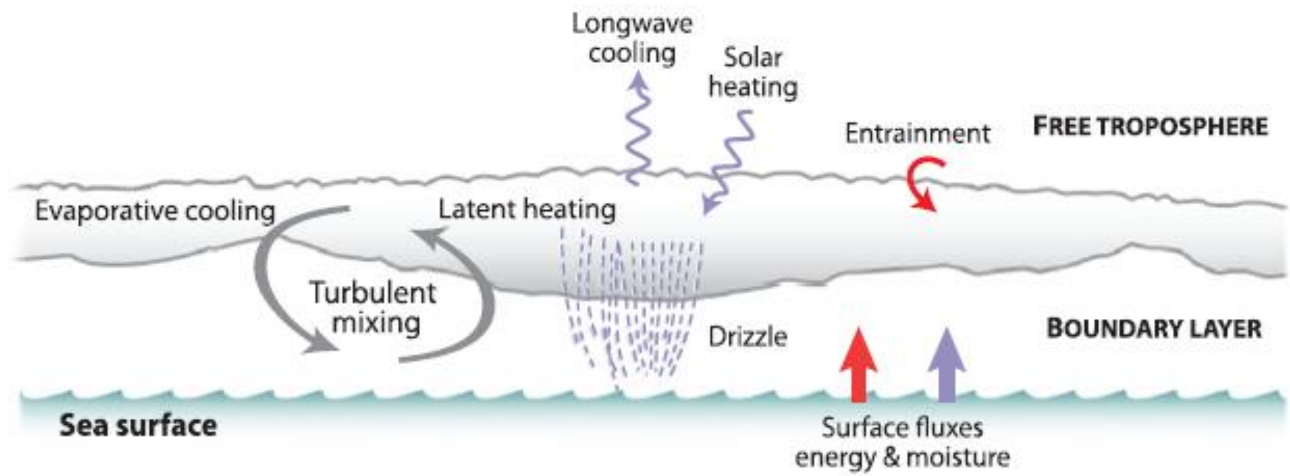
*While major advances in the understanding of cloud processes have increased the level of confidence and decreased the uncertainty range for the cloud feedback by about 50% compared to AR5, **clouds remain the largest contribution to overall uncertainty in climate feedbacks** (high confidence).*

[0.14 0.36]
W m^{-2} K^{-1}

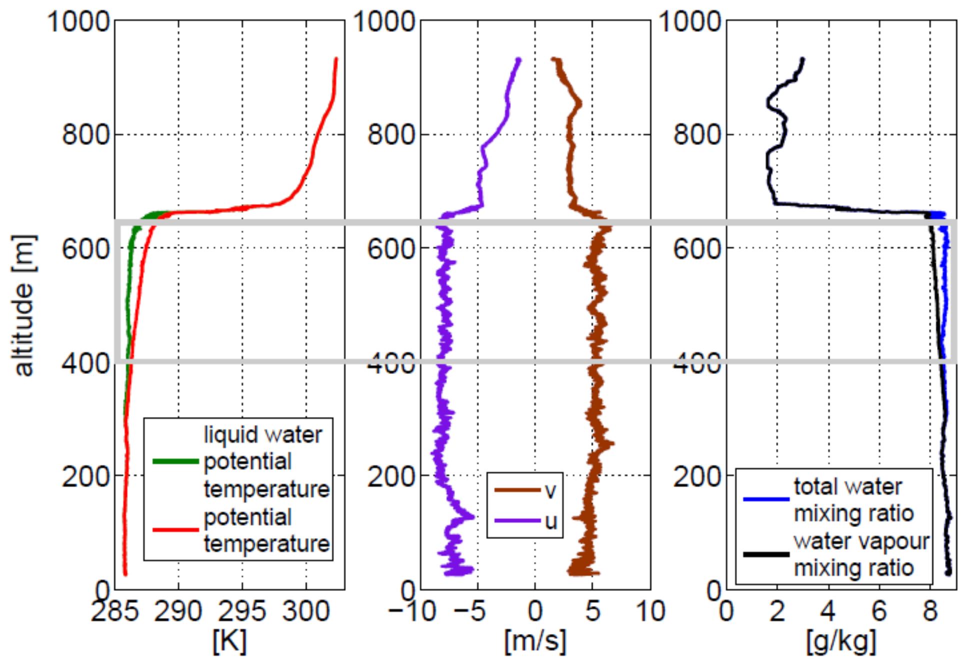
An assessment of the low-altitude cloud feedback over the subtropical ocean, which was previously the major source of uncertainty in the net cloud feedback, is improved (…) leading to strong evidence that this type of cloud amplifies global warming. (…) The feedback in the stratocumulus regime dominates over the feedback in the trade cumulus regime.

IPCC AR6 WG1, 2021

Stratocumulus-topped boundary layer



Wood 2012



Free Tropospheric Layer (FTL)

Entrainment Interface Layer (EIL)

Stratocumulus Layer (SCL)

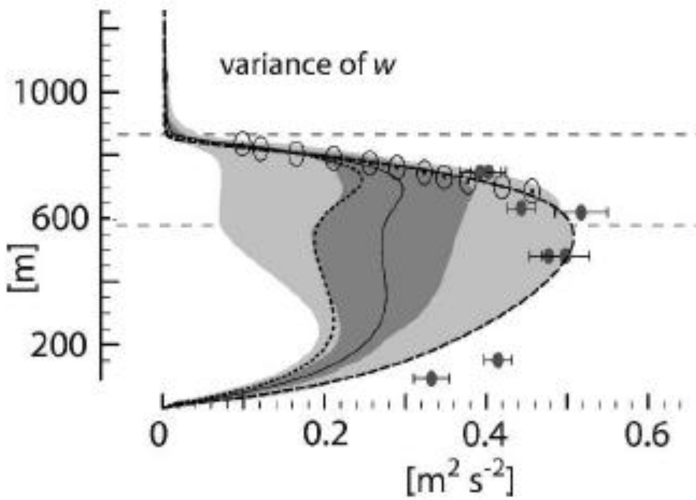
Subcloud Layer (SBL)

Malinowski et al. 2013

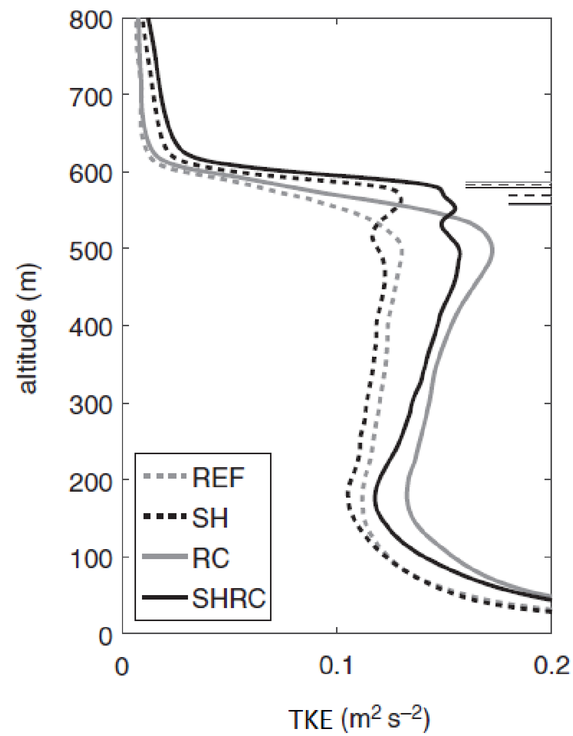
Turbulence in STBL

Reynolds decomposition $x(t) = \langle x(t) \rangle + x'(t)$

Turbulence Kinetic Energy $\mathrm{TKE} = \frac{1}{2}(\langle u'^2 \rangle + \langle v'^2 \rangle + \langle w'^2 \rangle)$



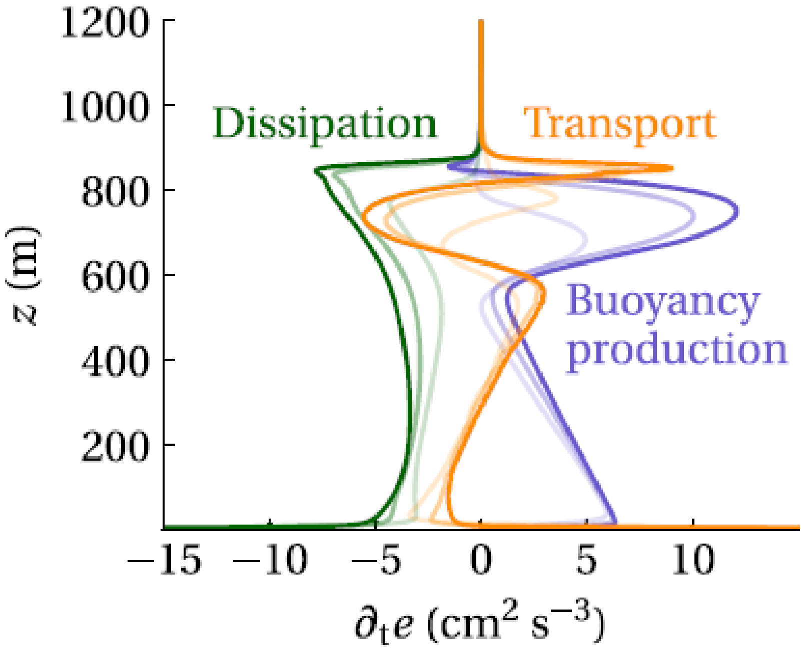
Stevens et al. 2005



Kopeć et al. 2016

TKE budget and turbulent fluxes

$$\frac{\partial}{\partial t}TKE = \underbrace{\frac{g}{\langle\theta_v\rangle}\langle w'\theta_v'\rangle}_{\text{buoyancy production/consumption}} \underbrace{-\langle u'w'\rangle\frac{\partial\langle u\rangle}{\partial z} - \langle v'w'\rangle\frac{\partial\langle v\rangle}{\partial z}}_{\text{shear production}} \underbrace{-\frac{\partial\langle w'\mathrm{TKE}\rangle}{\partial z}}_{\text{turbulent transport}} \underbrace{-\frac{1}{\langle\rho\rangle}\frac{\partial\langle w'P'\rangle}{\partial z}}_{\text{pressure correlation}} \underbrace{-\epsilon}_{\text{dissipation}}$$

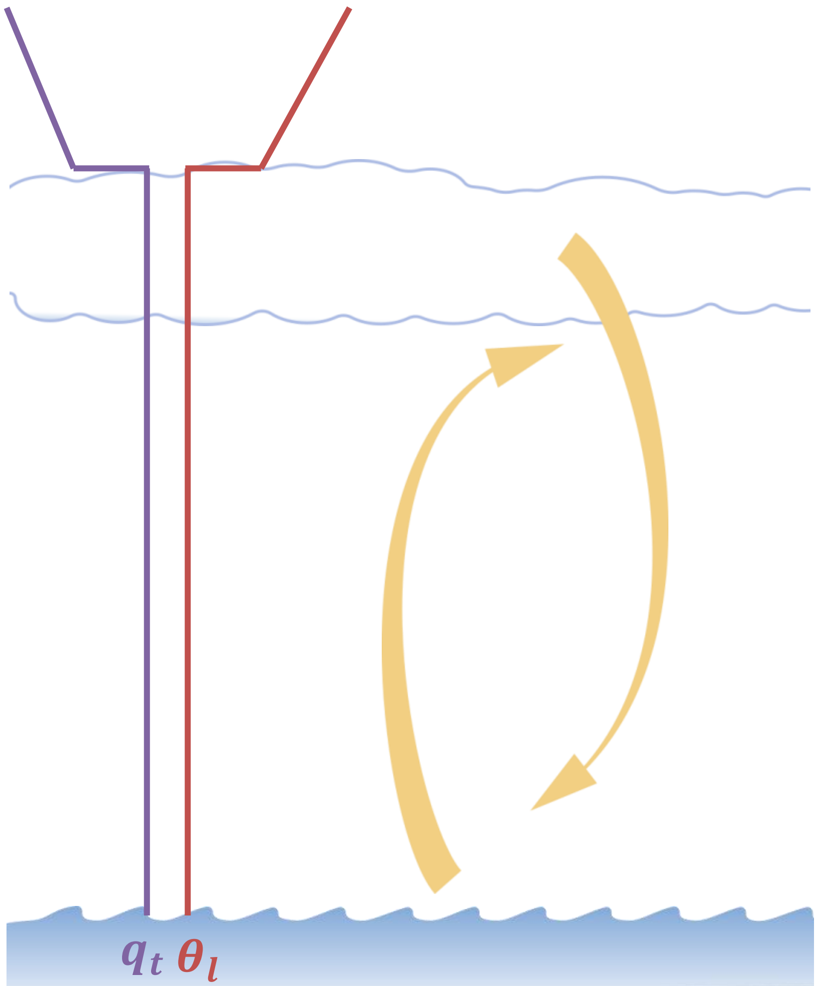


Mellado et al. 2016

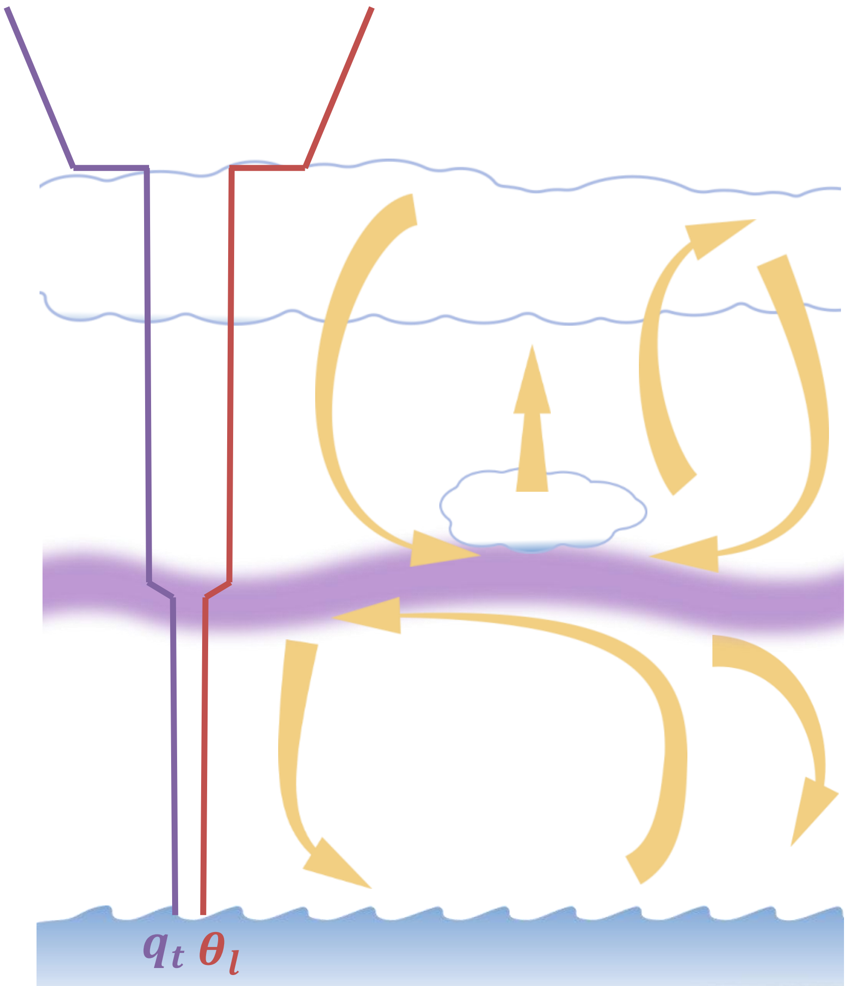
Sensible heat flux $Q_s = \rho c_p \langle w'\theta'\rangle$

Latent heat flux $Q_l = \rho L_v \langle w' q_v'\rangle$

STBL decoupling



Coupled STBL



Decoupled STBL

Stratification in a decoupled STBL

Free Tropospheric Layer (FTL)

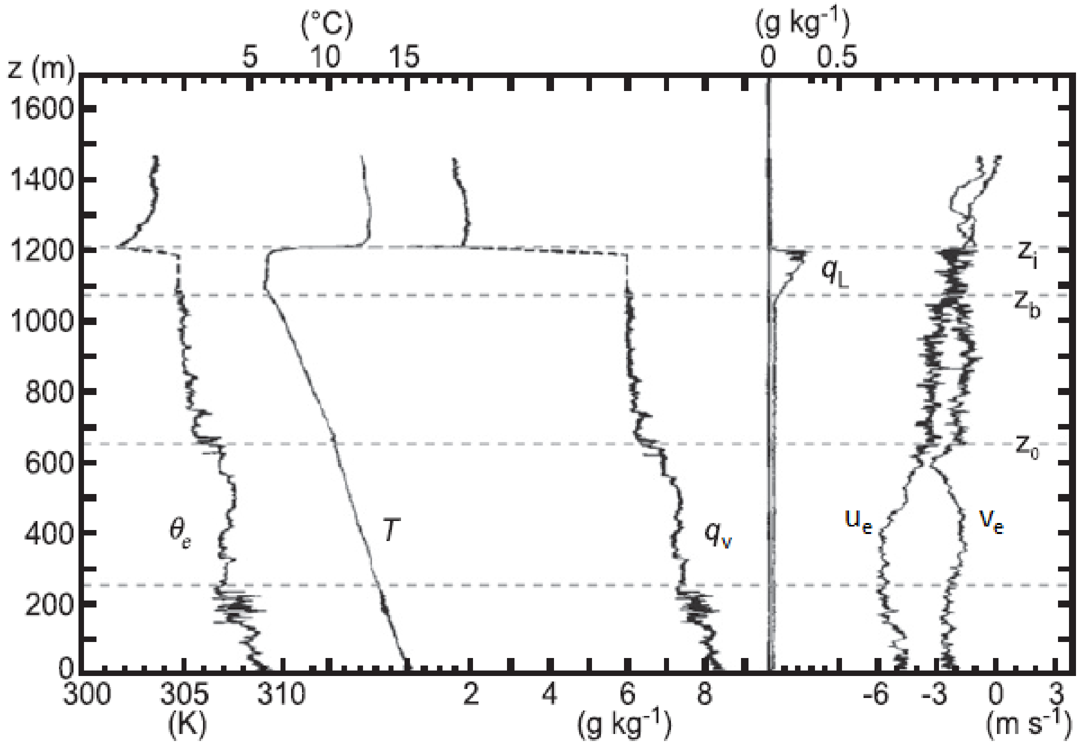
Entrainment Interface Layer (EIL)

Stratocumulus Layer (SCL)

Subcloud Layer (SBL)

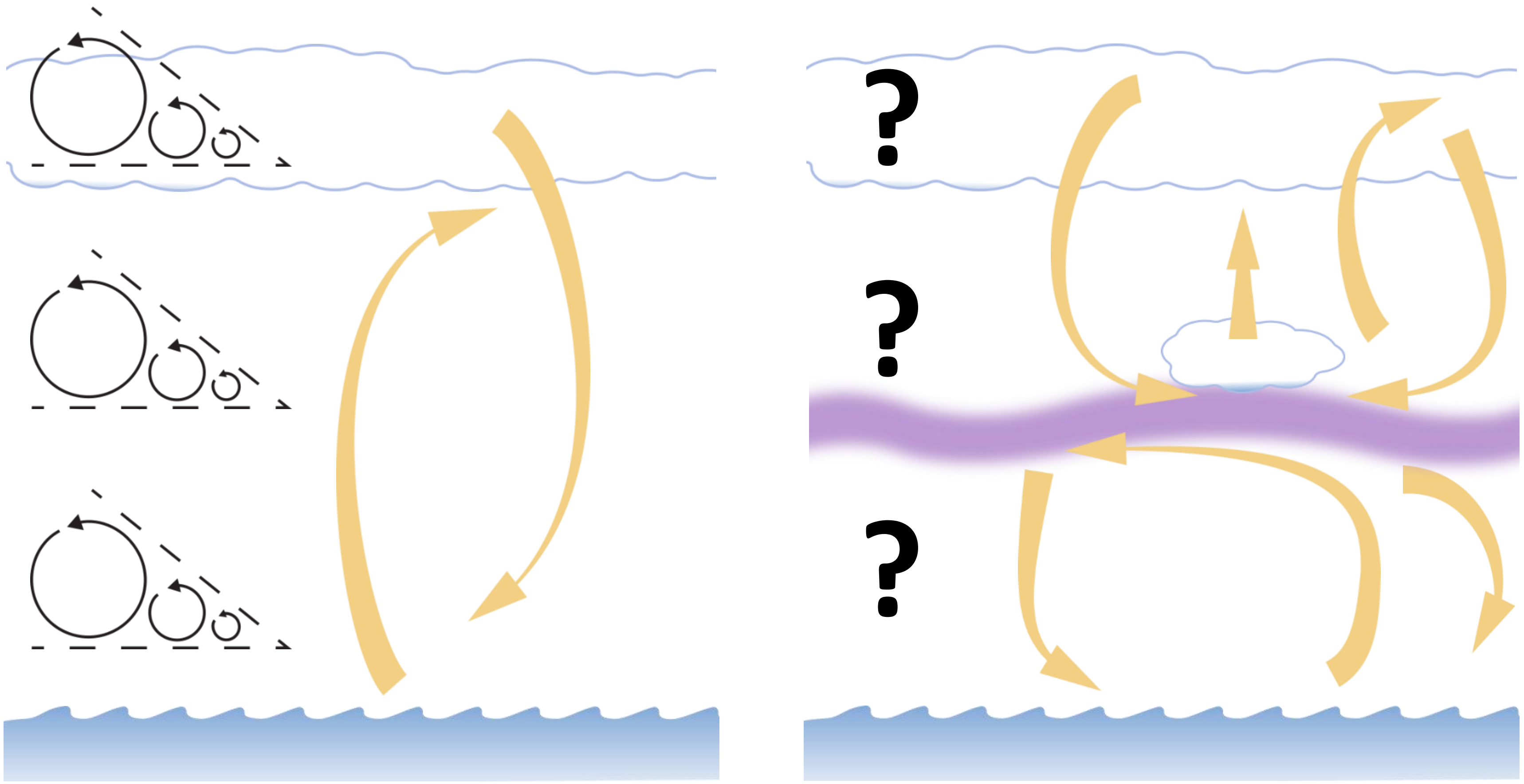
Transition Layer (TSL)

Surface Mixed Layer (SML)



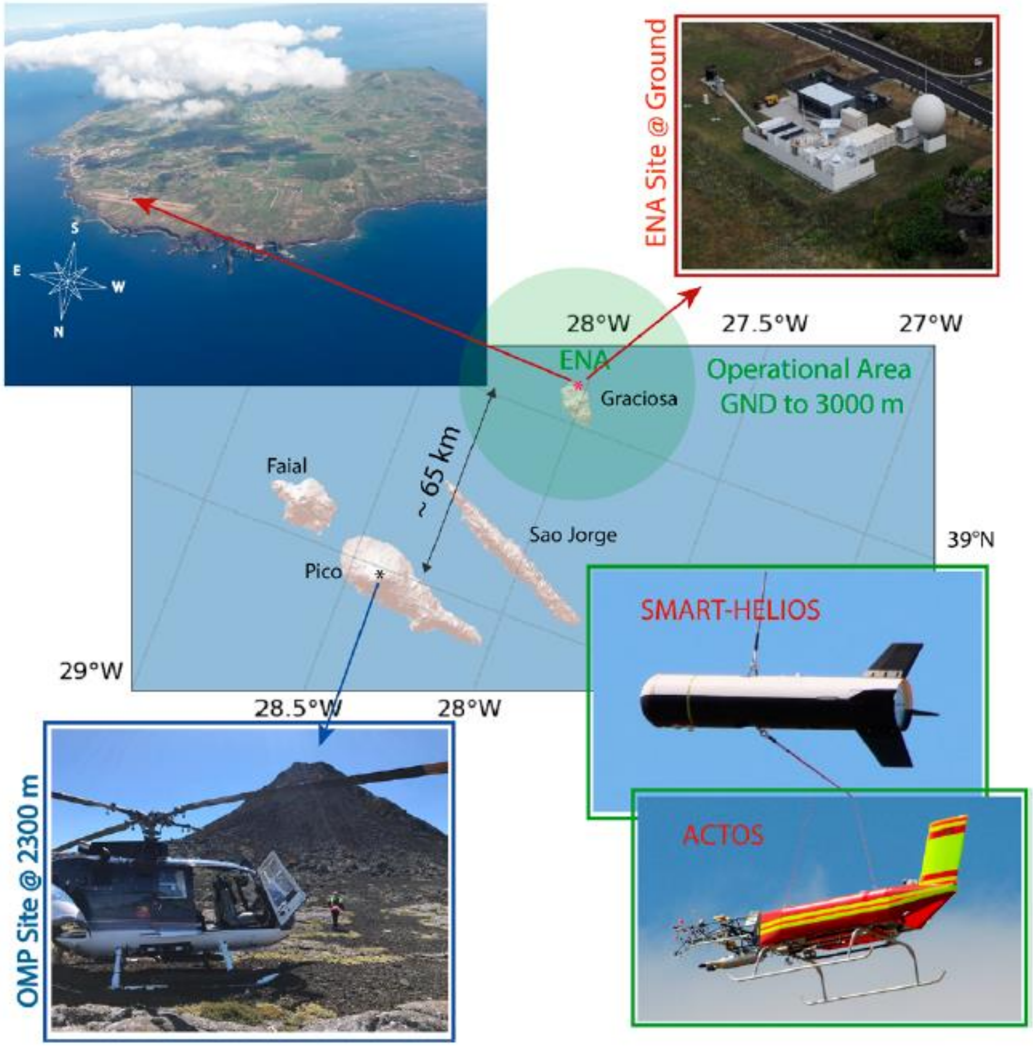
Nicholls and Leighton 1986

Research objectives



- What are the properties of small-scale turbulence in a decoupled STBL?
- How do they differ from the coupled case?
- Do they differ between the sublayers?

ACORES: campaign overview



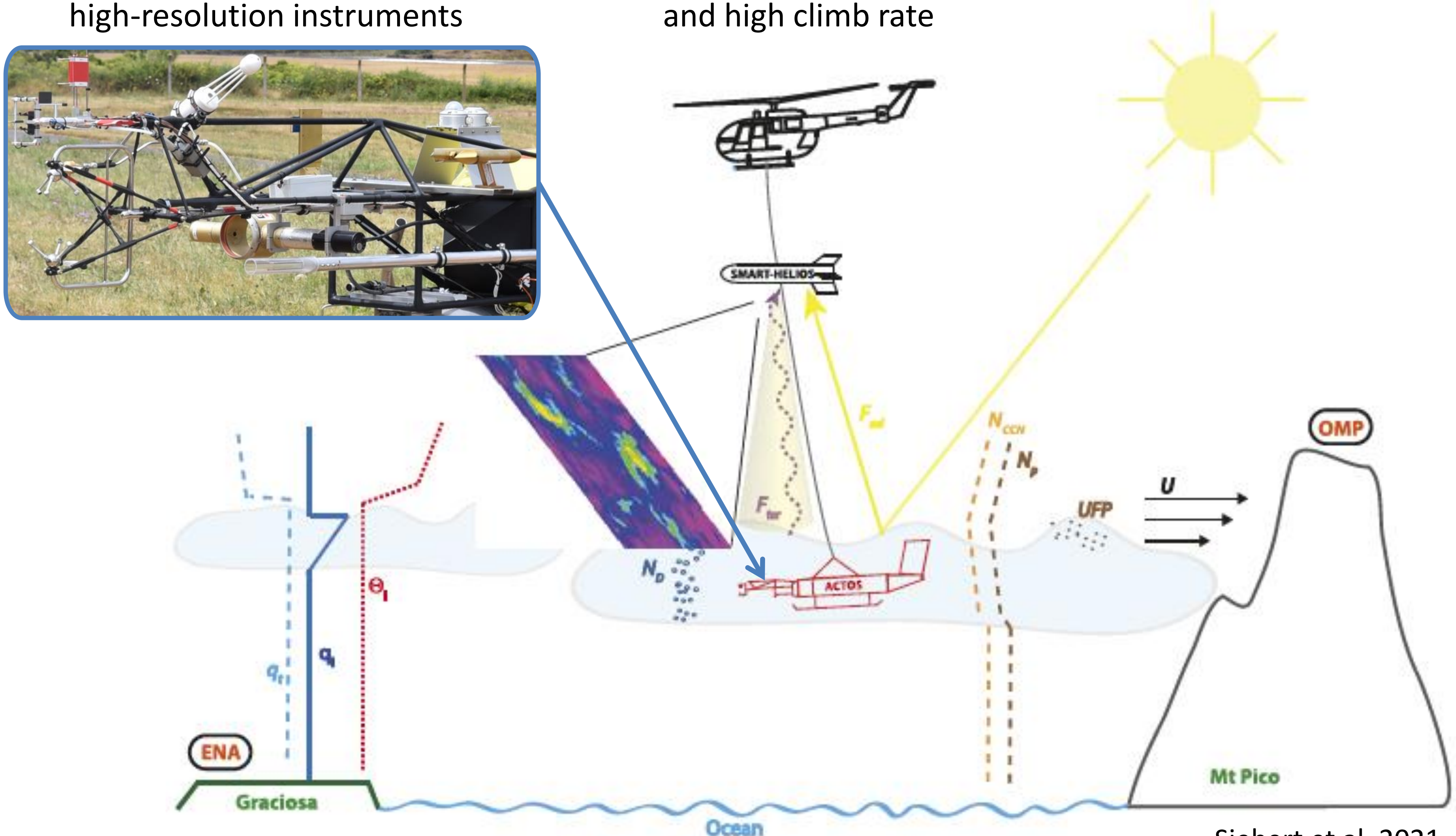
Siebert et al. 2021

Azores stratoCumulus measurements Of Radiation, turbulEnce and aeroSols

ACORES: observation strategy

Close collocation (~30 cm) of high-resolution instruments

Moderate TAS (~20 m/s) and high climb rate



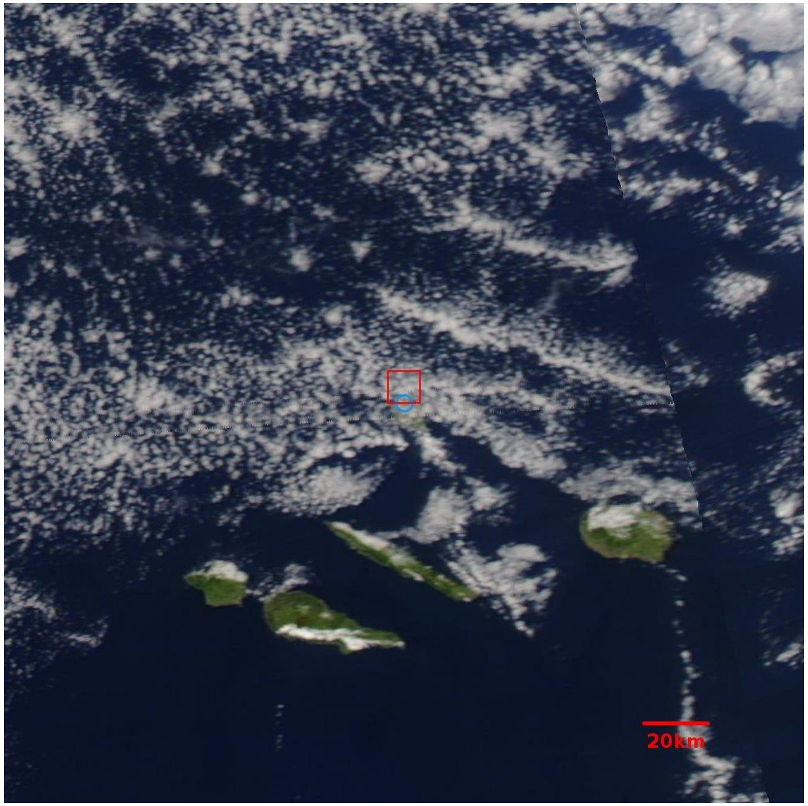
Siebert et al. 2021

ACORES: selected instrumentation on ACTOS

Variable		Instrument	Samp.	References
U, dd	horizontal wind speed and direction	ultrasonic anemometer-thermometer Solent HS, Gill Instruments + inertial navigation + GPS	100 Hz	Siebert and Teichmann 2000
u, w	longitudinal and vertical wind components			Nowak et al. 2021
T_v	virtual temperature			Siebert and Muschinski 2001
T	temperature	UltraFast Thermometer, University of Warsaw	1-4 kHz	Haman et al. 1997 Nowak et al. 2018
q_v	specific humidity	open-path LI-7500, LI-COR Environmental	20 Hz	Lampert et al. 2018
q_l	liquid water mass fraction	Particle Volume Meter, Gerber Scientific	1 kHz	Gerber et al. 1994 Wendisch et al. 2002

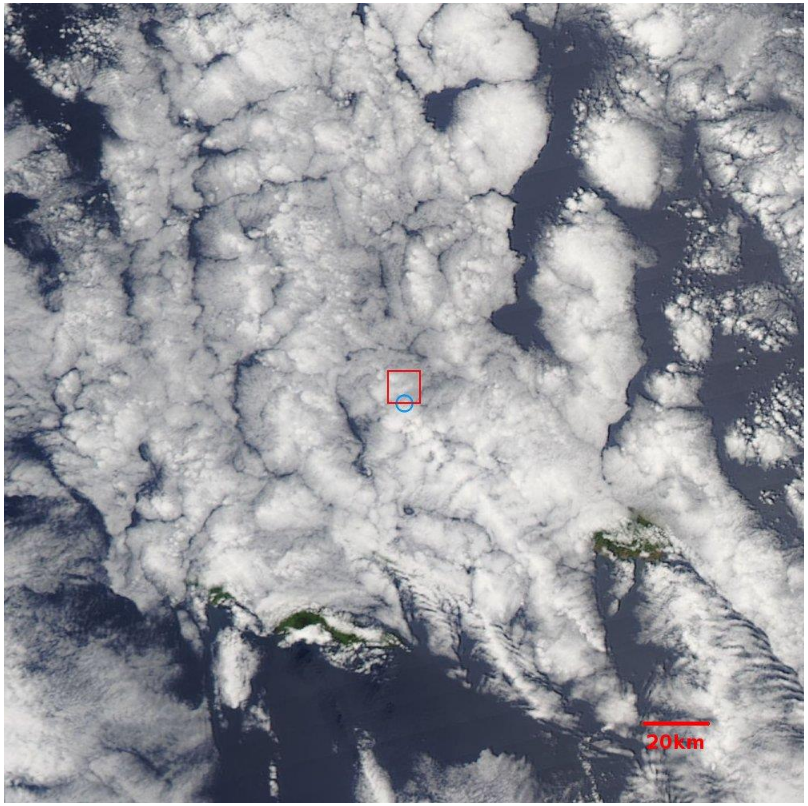
Data selection

Flight #5, 8 July 2017



15:45 UTC

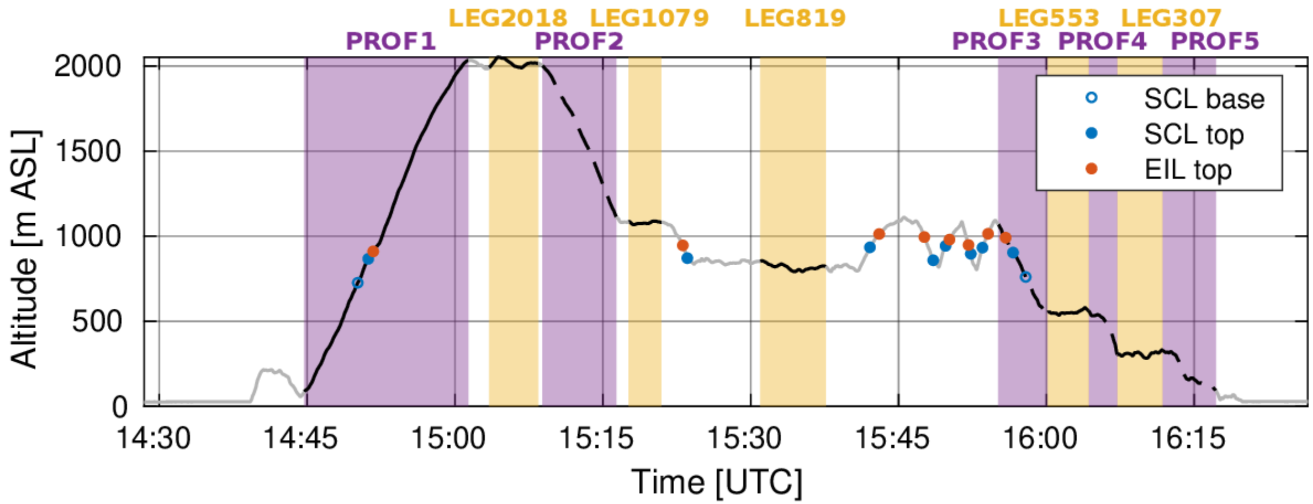
Flight #14, 18 July 2017



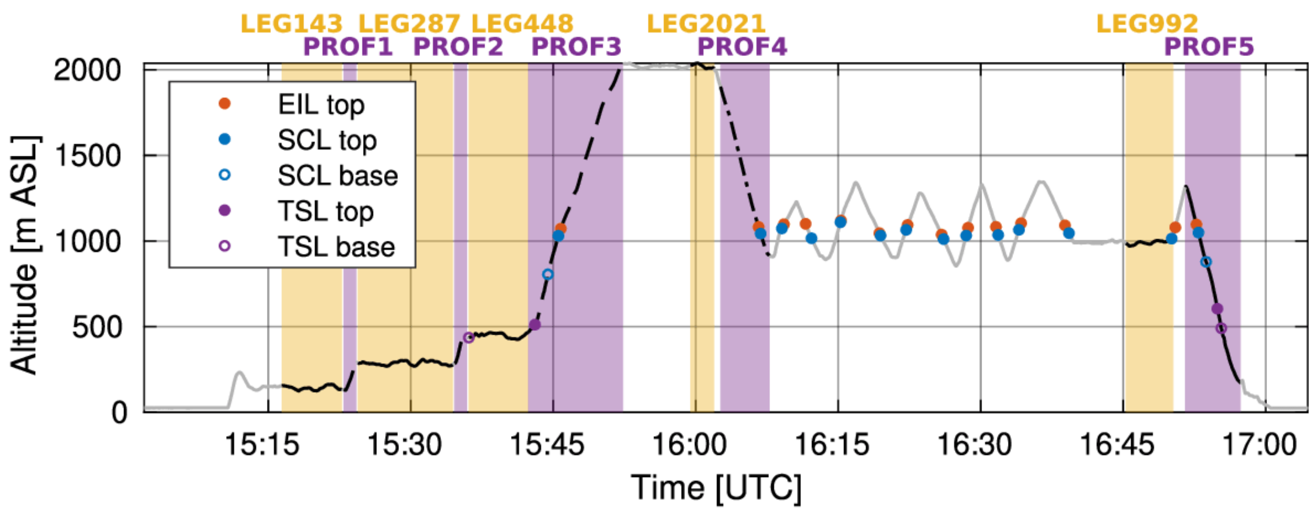
14:43 UTC

True color image, MODIS Aqua, NASA Worldview Snapshots

Flight segmentation

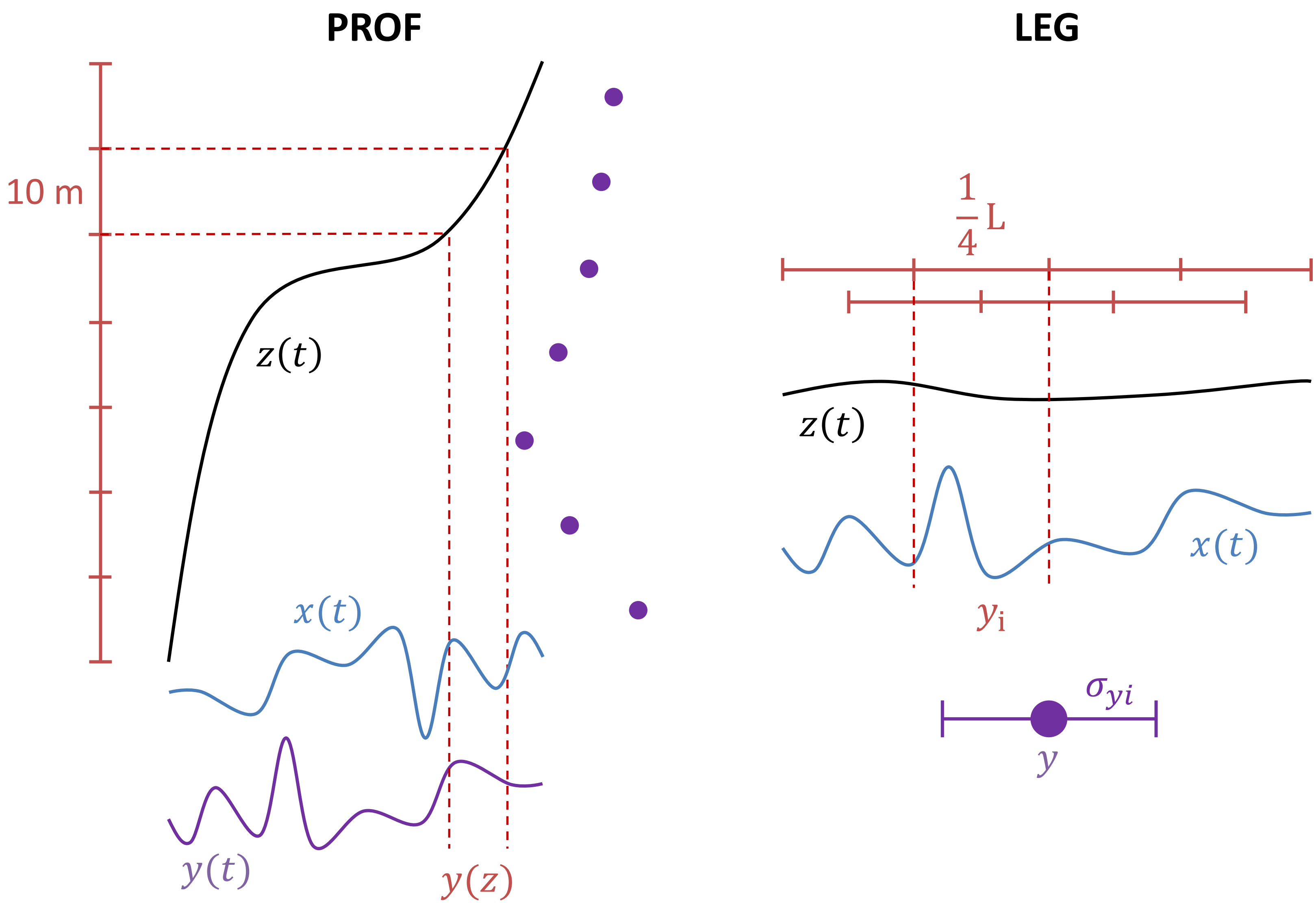


Flight #5
8 July 2017

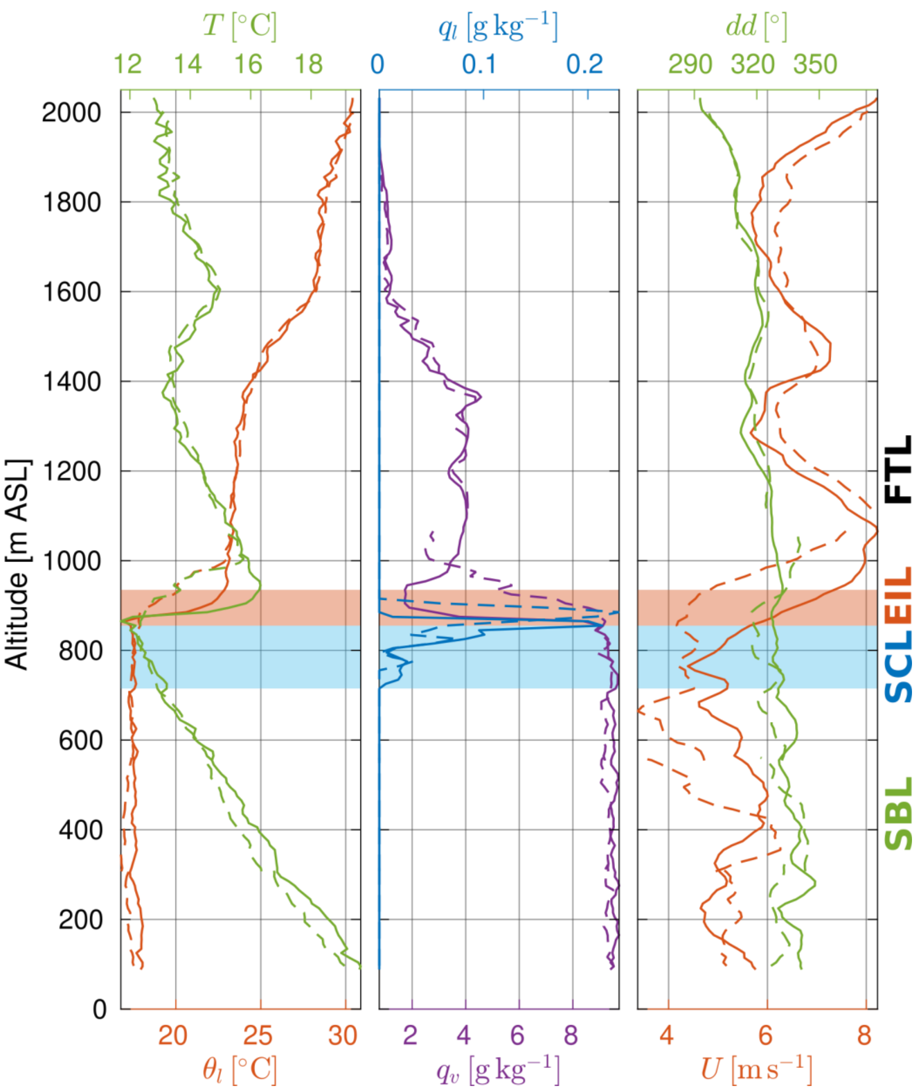


Flight #14
18 July 2017

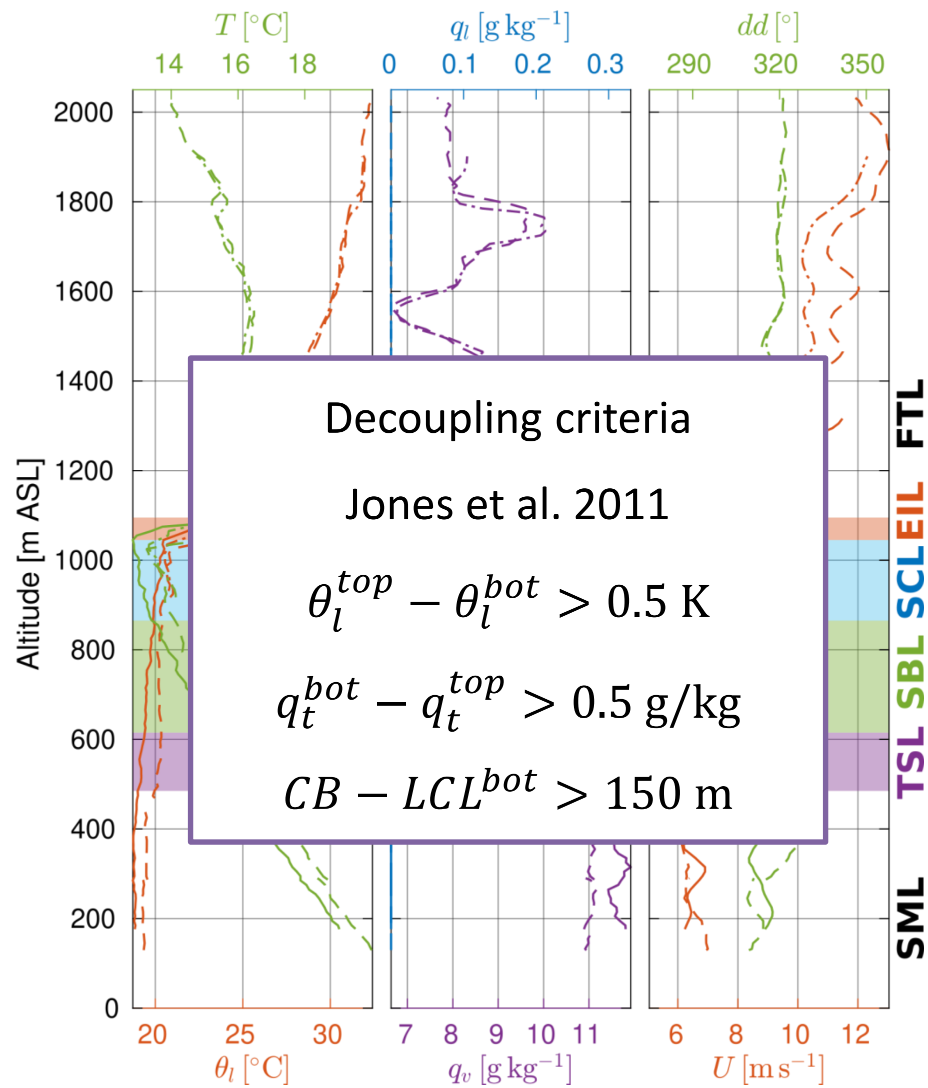
Derivation of parameters



Stratification



Coupled STBL



Decoupling criteria

Jones et al. 2011

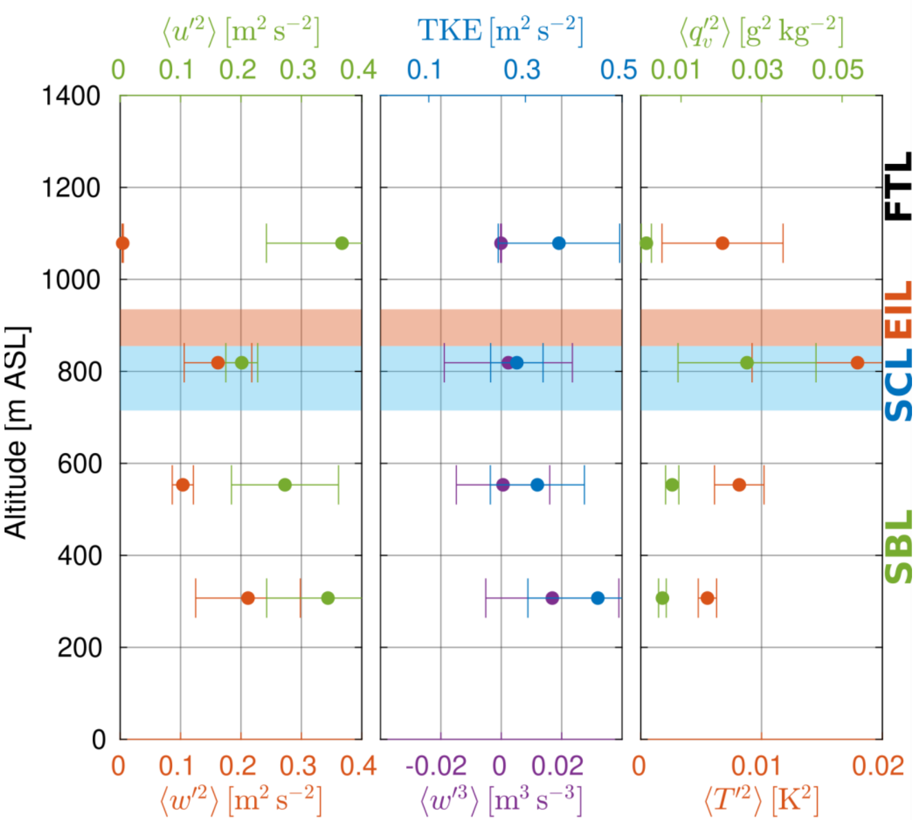
$$\theta_l^{top} - \theta_l^{bot} > 0.5\ \mathrm{K}$$

$$q_t^{bot} - q_t^{top} > 0.5\ \mathrm{g/kg}$$

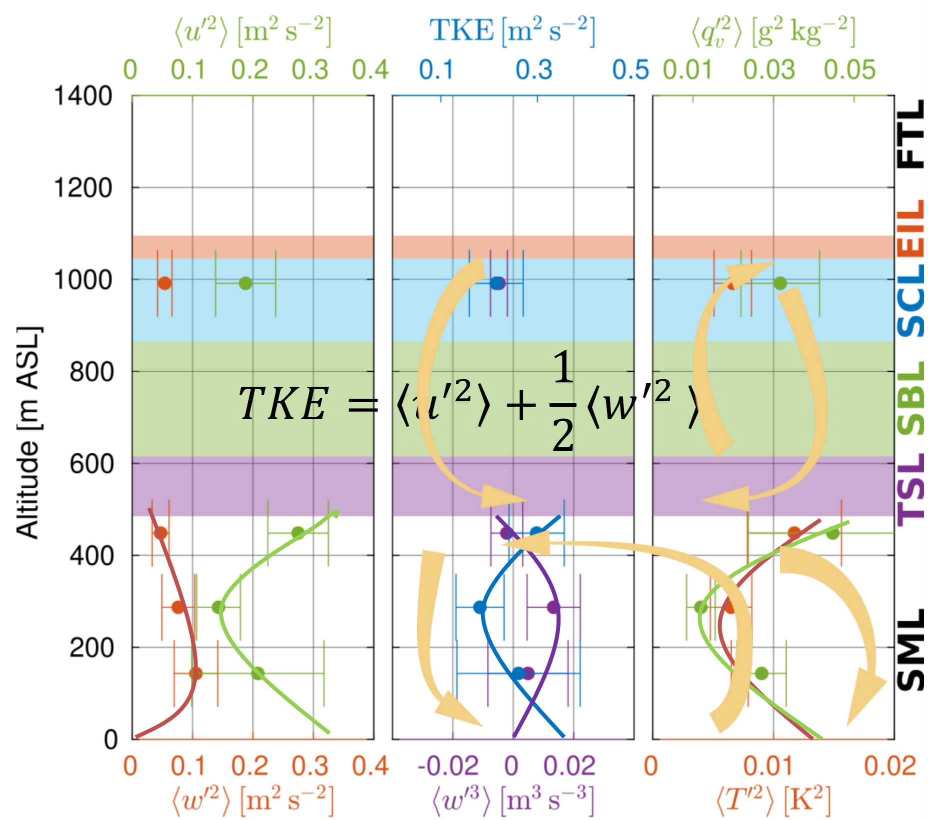
$$CB - LCL^{bot} > 150\ \mathrm{m}$$

Decoupled STBL

TKE and variances

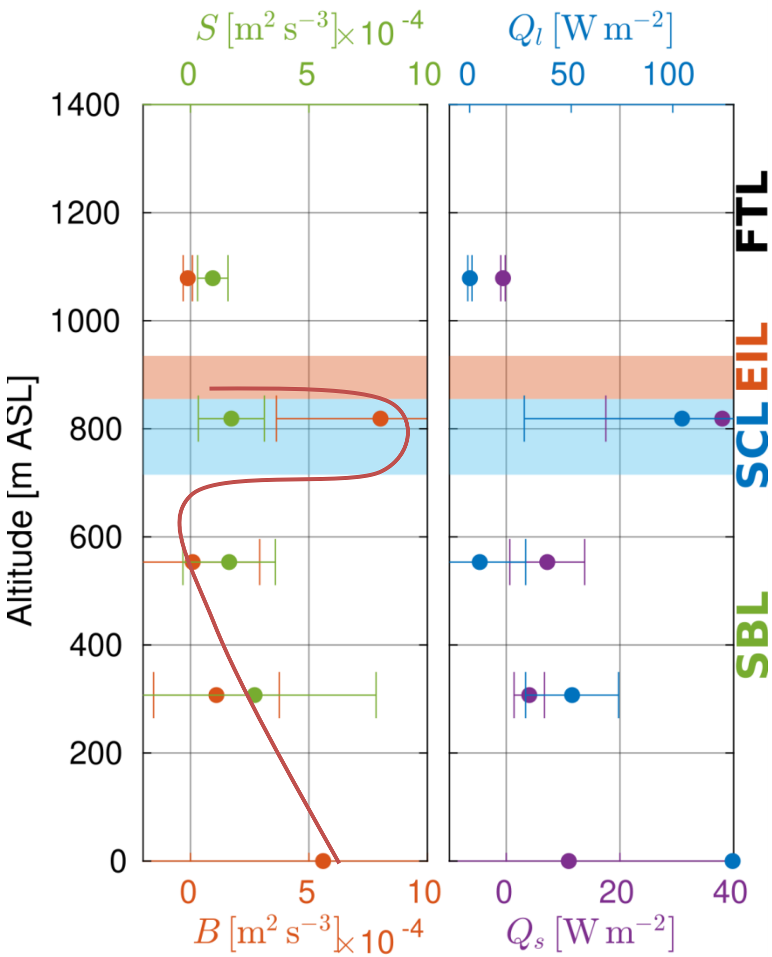


Coupled STBL



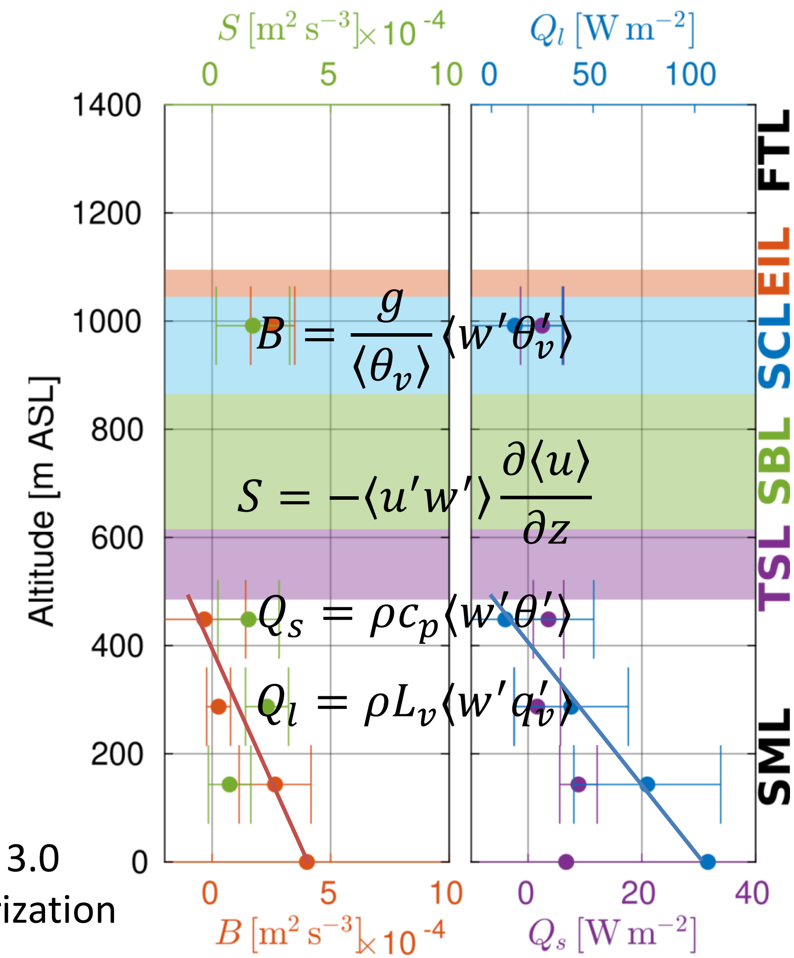
Decoupled STBL

TKE production and turbulent fluxes



Coupled STBL

COARE 3.0 parameterization



$$B = \frac{g}{\langle \theta_v \rangle} \langle w' \theta_v' \rangle$$

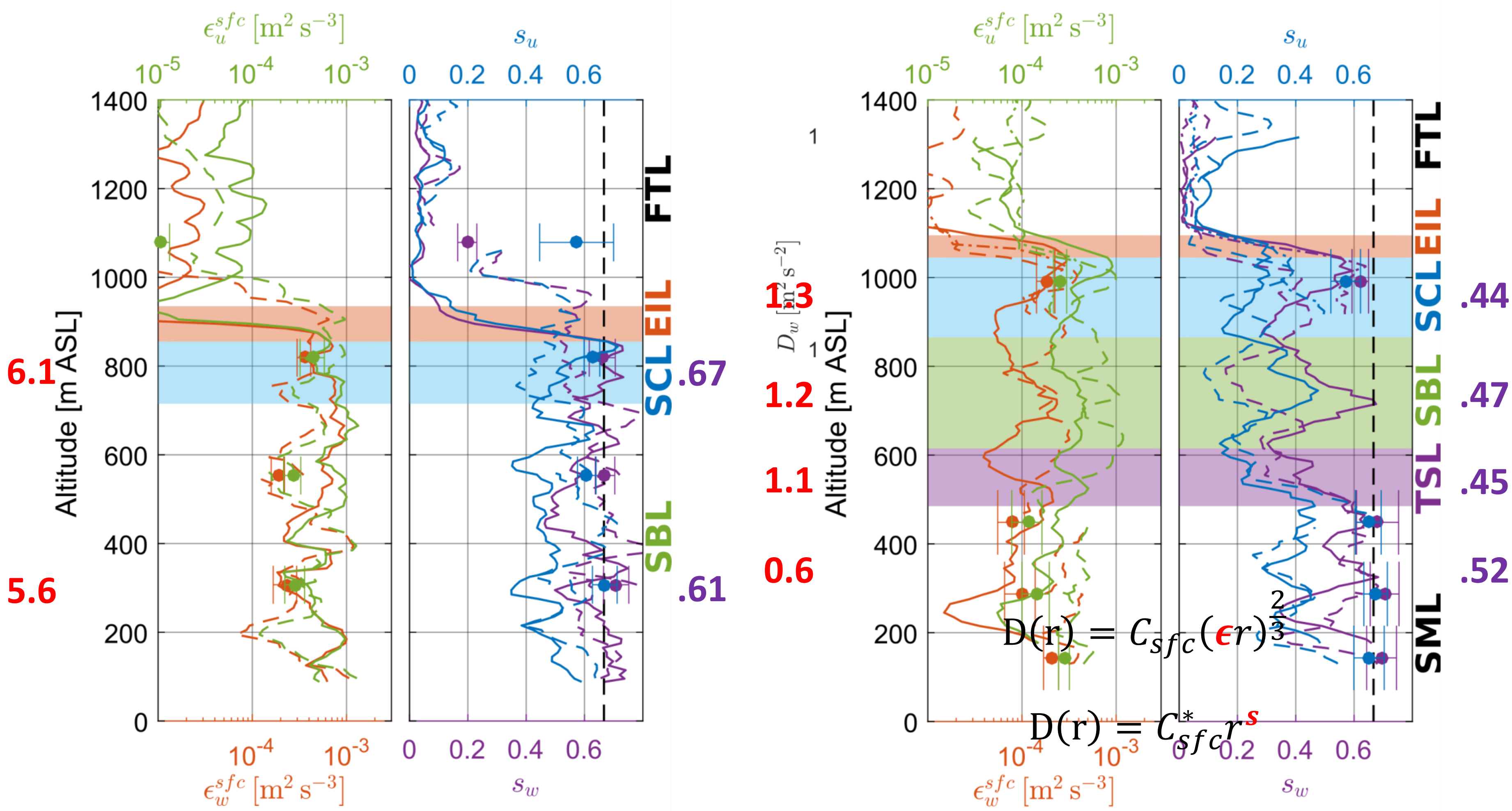
$$S = -\langle u' w' \rangle \frac{\partial \langle u \rangle}{\partial z}$$

$$Q_s = \rho c_p \langle w' \theta' \rangle$$

$$Q_l = \rho L_v \langle w' q_v' \rangle$$

Decoupled STBL

TKE dissipation rate



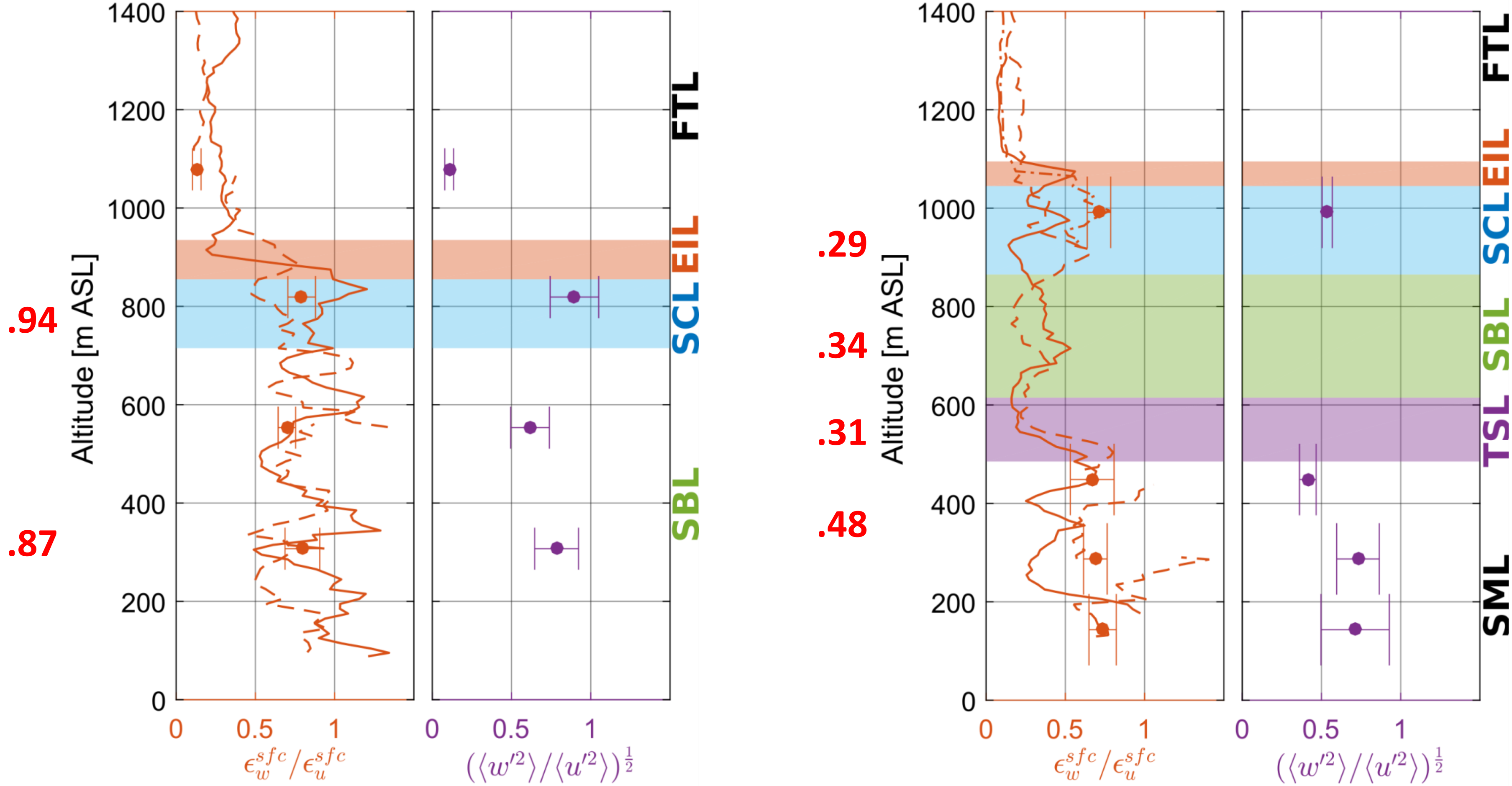
$$D(r) = C_{sfc}(\epsilon r)^{\frac{2}{3}}$$

$$D(r) = C^{*}_{sfc} r^{s}$$

Coupled STBL

Decoupled STBL

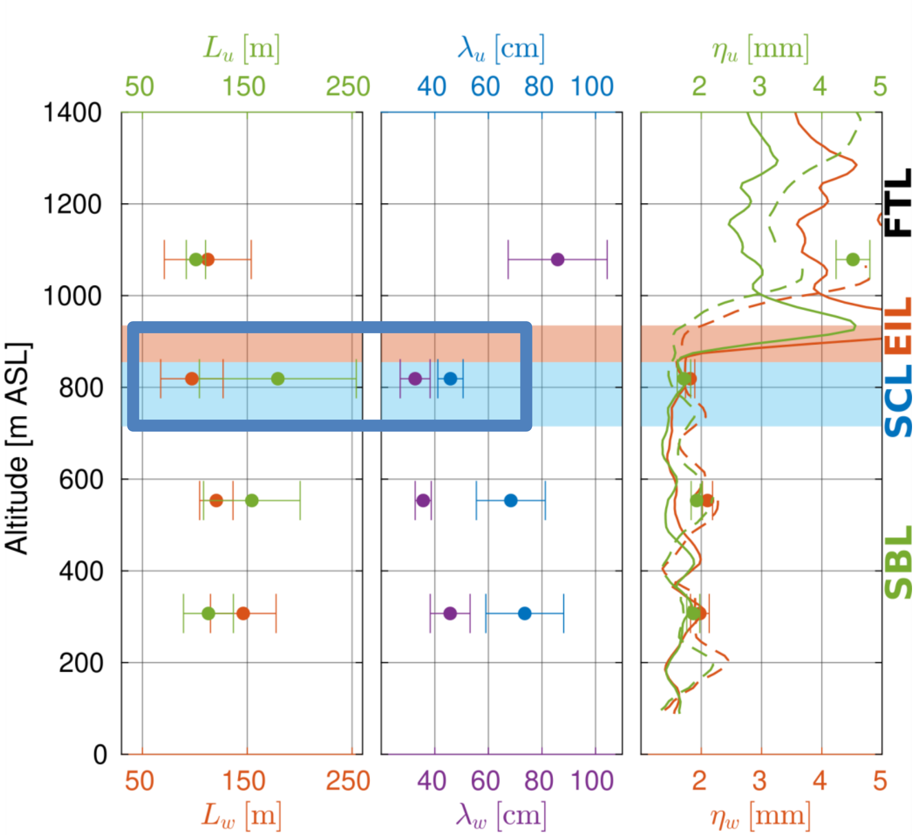
Anisotropy



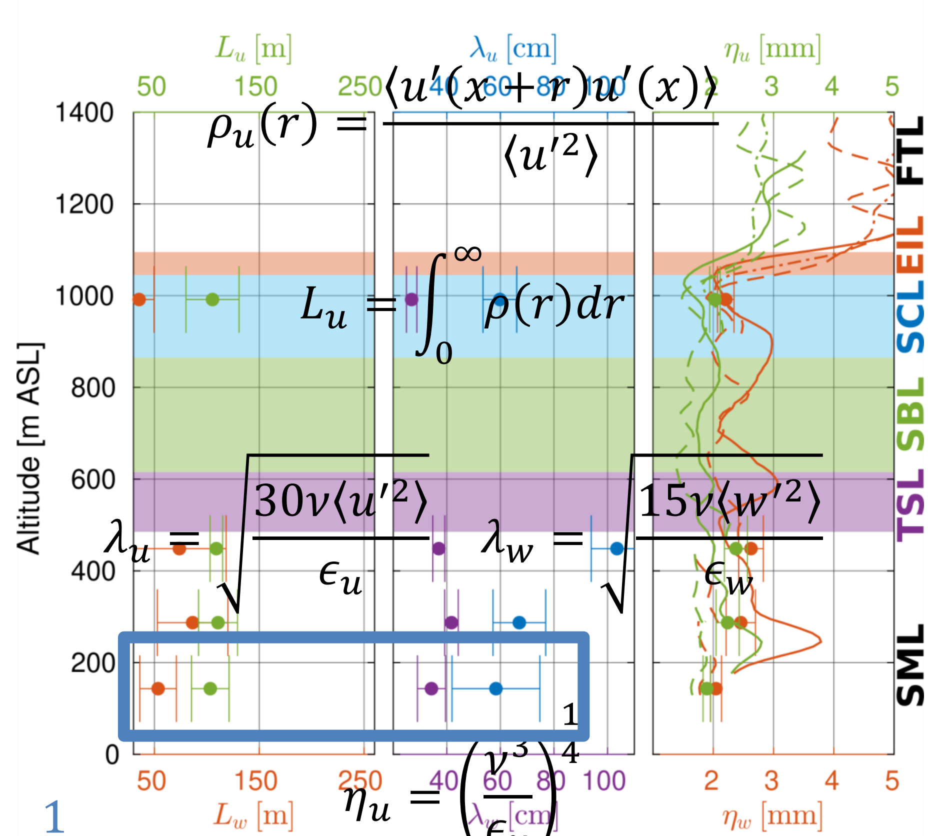
Coupled STBL

Decoupled STBL

Length scales



Coupled STBL



Decoupled STBL

$$\rho_u(r) = \frac{\langle u'(x+r)u'(x)\rangle}{\langle u'^2\rangle}$$

$$L_u = \int_0^\infty \rho(r)dr$$

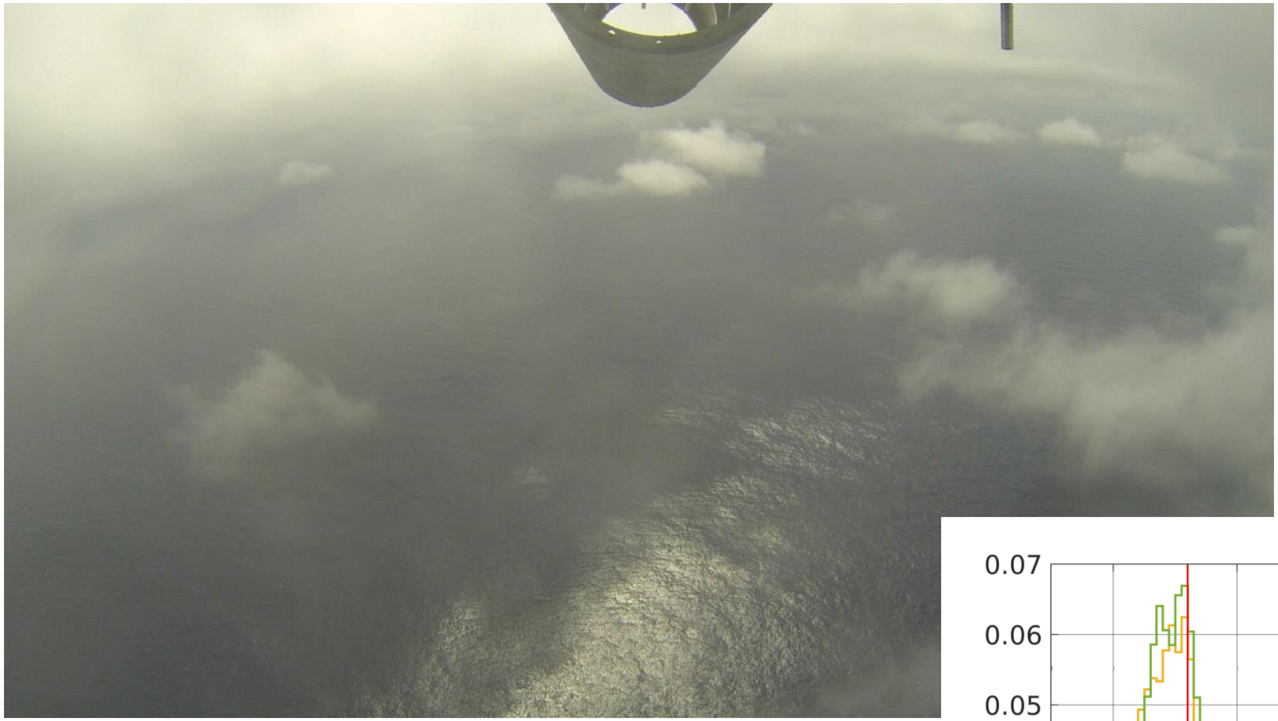
$$\lambda_u = \sqrt{\frac{30\nu\langle u'^2\rangle}{\epsilon_u}} \qquad \lambda_w = \sqrt{\frac{15\nu\langle w'^2\rangle}{\epsilon_w}}$$

$$\eta_u = \left(\frac{\nu^3}{\epsilon_u}\right)^{\frac{1}{4}}$$

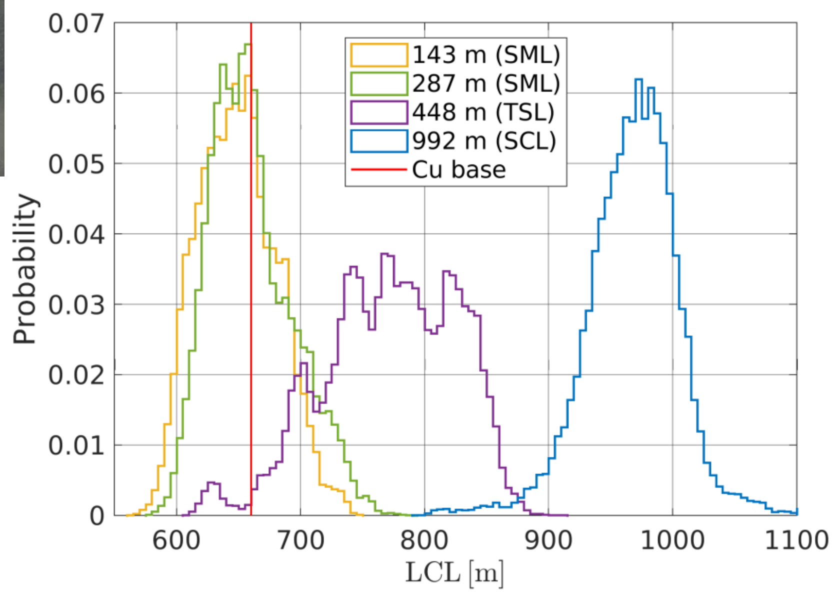
$$L_w \approx \frac{1}{2}L_u$$

$$\lambda_w \approx \frac{1}{\sqrt{2}}\lambda_u$$

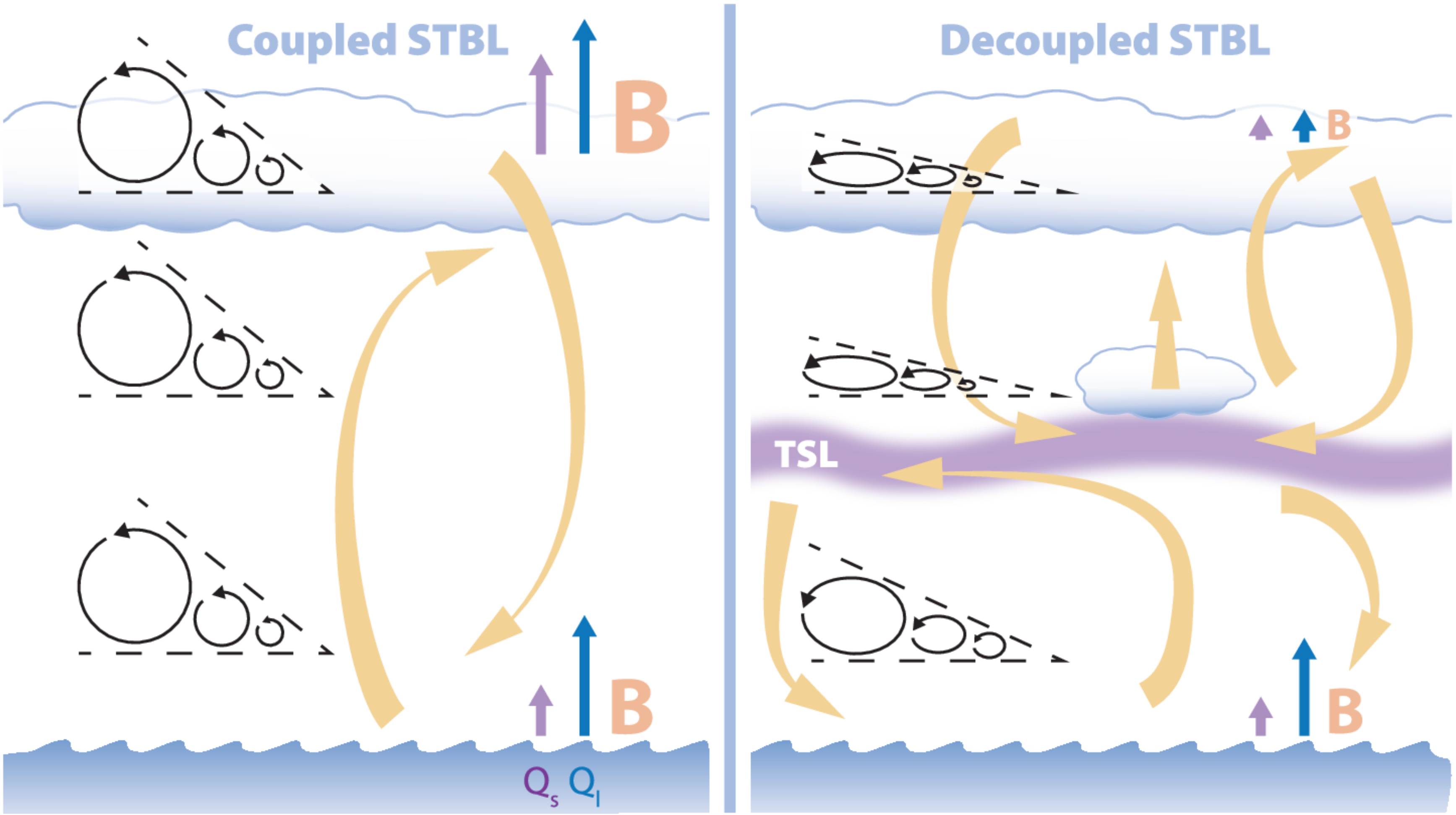
Transition layer and cumulus convection



GoPro on ACTOS



Summary



Drawing by K. Nurowska

More details …

Jakub L. Nowak

Turbulence properties
in coupled and decoupled
stratocumulus-topped
marine boundary layers

A doctoral dissertation
under the supervision of
Prof. Szymon P. Malinowski

UNIVERSITY
OF WARSAW

Institute of Geophysics
Faculty of Physics
University of Warsaw

Warsaw 2021

Atmos. Chem. Phys., 21, 10965–10991, 2021
https://doi.org/10.5194/acp-21-10965-2021
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Coupled and decoupled stratocumulus-topped boundary layers: turbulence properties

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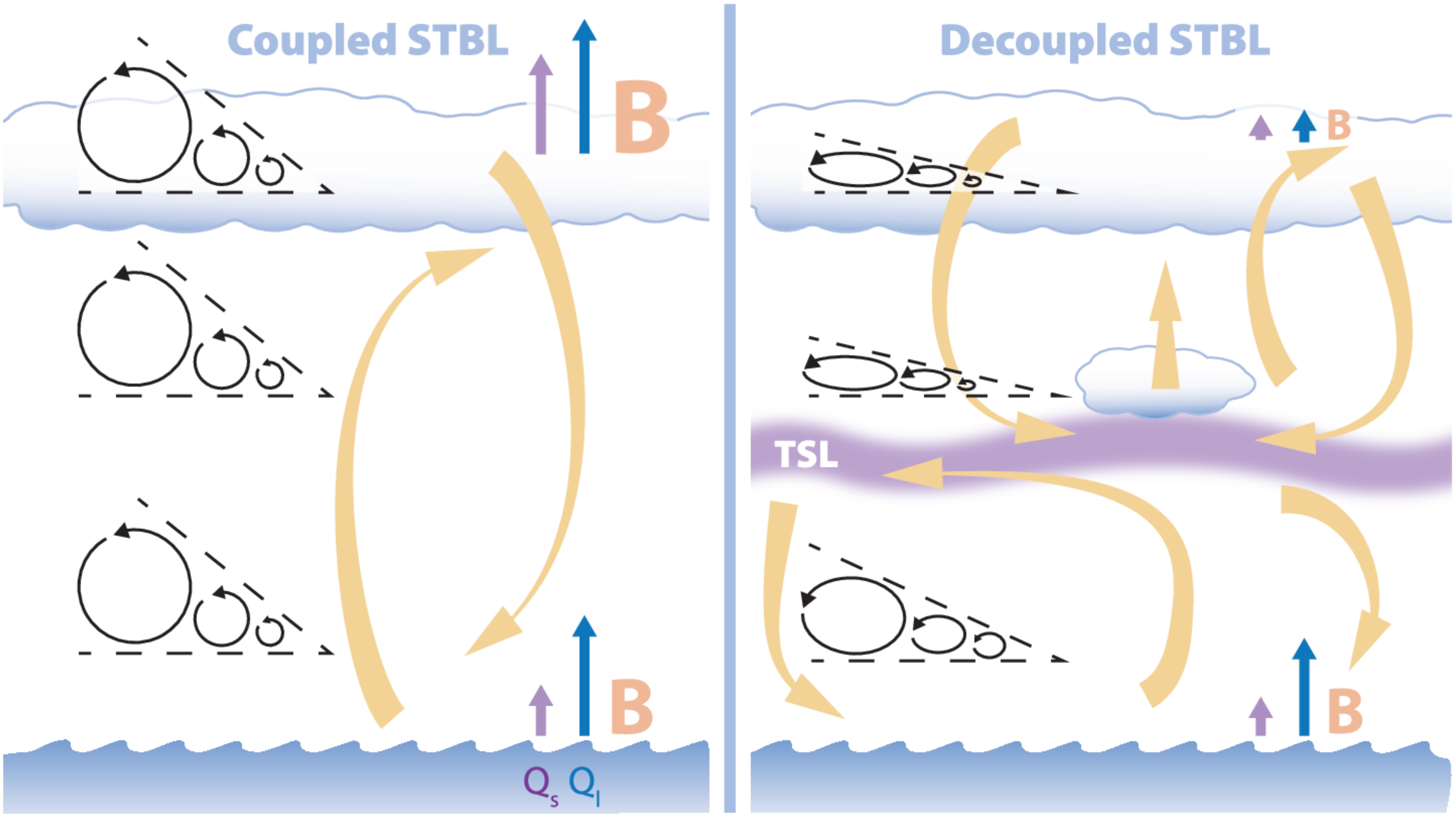
Acknowledgements

- ACORES team: scientists, technicians, pilots
- ACORES funding: DFG (DE), DOE (US), NCN (PL)
- Personal funding for a 1y stay in Leipzig: DAAD

Summary



Drawing by K. Nurowska