Geophysical Fluid Dynamics Group

Physics of the Ocean-Atmosphere Coupling in Extreme Winds

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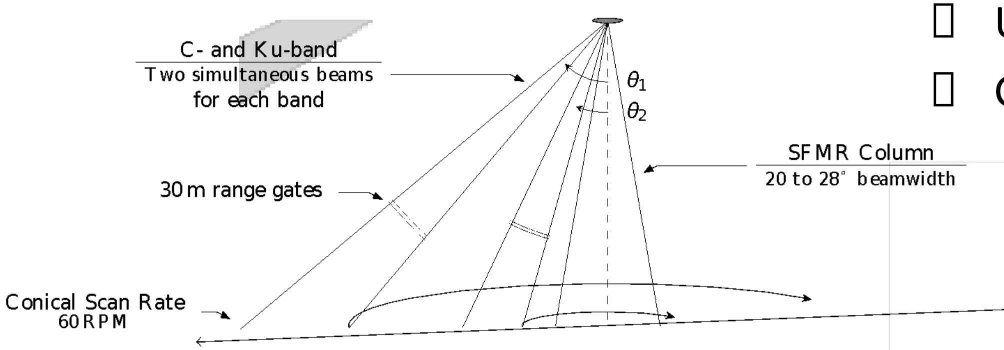
Collaborators: NOAA/NESDIS (Joe Sapp/Zorana Jelenak/Paul Chang)

Objectives:

(1) Characterize coherent turbulent structures (CTS) in the PBL

(2) Role of CTS in ocean-atmosphere coupling; satellite footprint

IWRAP Data and Cases



Retrieval Products

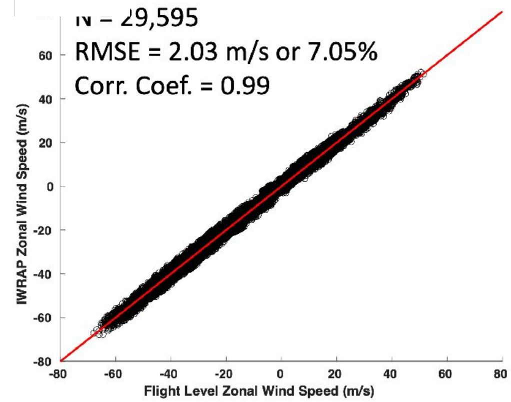
- U,V,W/reflectivity/derivatives on 3D grid
- Grid spacing, along-track/across-track/vertical
  - 125 m/125 m/30 m

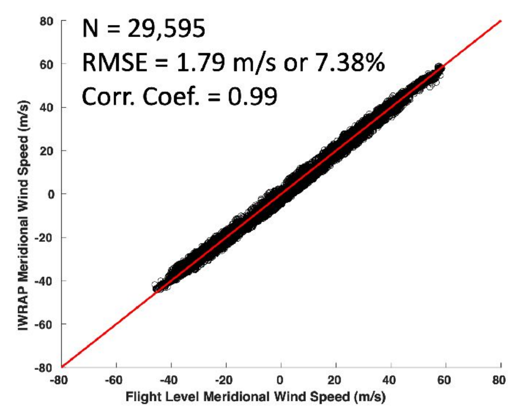
Guimond et al. (2014), JTECH; Guimond et al. (2018), JAS

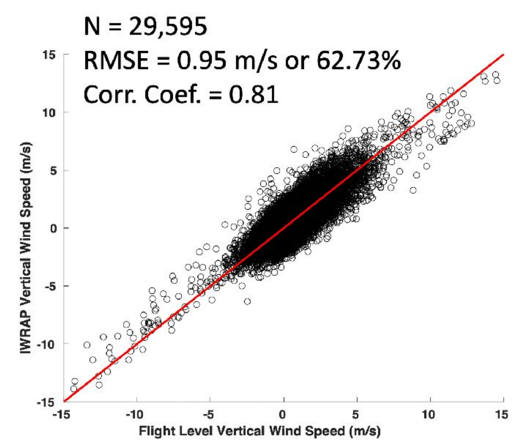
Storm Cases for Focused Analysis:

- Hurricane Laura (2020), RI case
  - 8/25 (Cat-1, I); 8/26 (Cat-3, I)
- Hurricane Teddy (2020)
  - 9/17 (Cat-4, S); 9/18 (Cat-3, W)
- Hurricane Delta (2020)
  - 10/06 (Cat-4, S)
  - 10/08 (Cat-2, I); 10/09 (Cat-3, W)

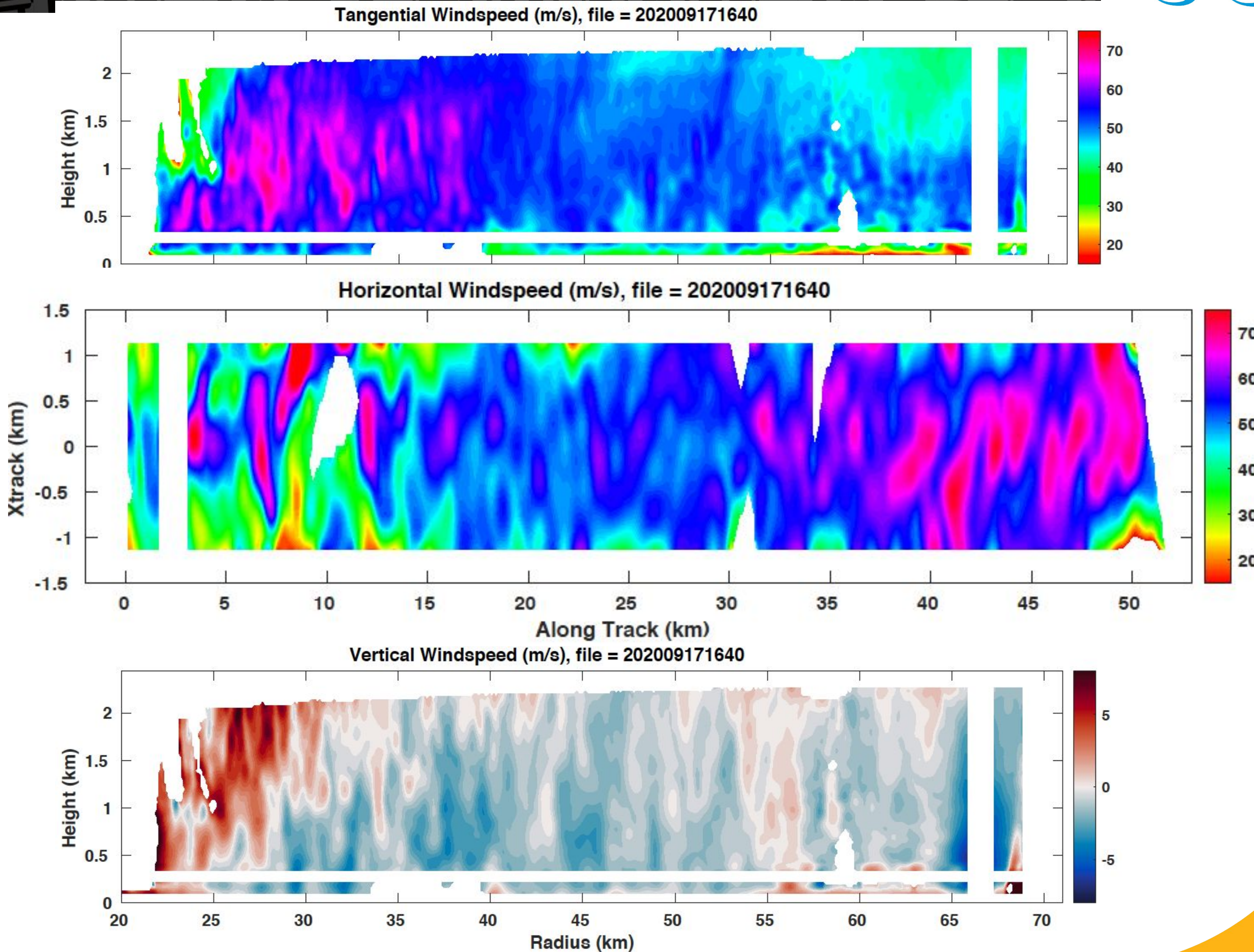
Cal/Val 2020







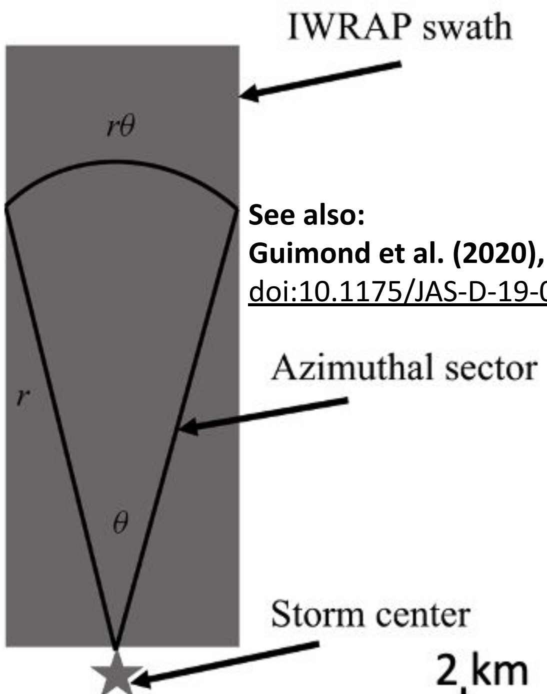
IWRAP Examples - Teddy



Energy Transfer in the Hurricane Boundary Layer

Mathematical Methodology

Sroka, S. and S.R. Guimond, 2021. Organized kinetic energy backscatter in the hurricane boundary layer from radar measurements. *Journal of Fluid Mechanics, 924*, A21. doi:10.1017/jfm.2021.632



See also:
Guimond et al. (2020), JAS
doi:10.1175/JAS-D-19-0284.1

$$\tilde{u}_i(r,z) = \int u_i(r^*,z)G(r-r^*)\,\mathrm{d}r^* \qquad \bar{\phi}(r,z) = \frac{1}{r\theta}\int_0^{r\theta}\phi(r,\theta^*,z)r\,\mathrm{d}\theta^*.$$

$$u_i'(r,z) = u_i(r,z) - \tilde{u}_i(r,z).$$

The expanded, azimuthally averaged KE transport equation in cylindrical coordinates is

$$\frac{\partial \bar{\tilde{q}}^2}{\partial t} + \underbrace{\bar{\tilde{u}}\frac{\partial \bar{\tilde{q}}^2}{\partial r} + \bar{\tilde{w}}\frac{\partial \bar{\tilde{q}}^2}{\partial z}}_{\text{ADV}} = -2g\bar{\tilde{w}} \underbrace{-\frac{2}{\rho}\left(\bar{\tilde{u}}\frac{\partial \bar{\tilde{p}}}{\partial r} + \bar{\tilde{w}}\frac{\partial \bar{\tilde{p}}}{\partial z}\right)}_{\text{PGF}} -2\left[\frac{1}{r}\frac{\partial r\bar{\tilde{u}}\tau_{rr}}{\partial r} - \frac{\tau_{\theta\theta}\bar{\tilde{u}}}{r} + \frac{\partial \bar{\tilde{u}}\tau_{rz}}{\partial z} + \dots \frac{1}{r^2}\frac{\partial r^2\bar{\tilde{v}}\tau_{\theta r}}{\partial r} + \frac{\partial \bar{\tilde{v}}\tau_{\theta z}}{\partial z} + \frac{1}{r}\frac{\partial r\bar{\tilde{w}}\tau_{rz}}{\partial r} + \frac{\partial \bar{\tilde{w}}\tau_{zz}}{\partial z}\right] - 2\mathcal{P}, \quad (2.6)$$

$$\boxed{\mathcal{P} = -\tau_{ij}\bar{\tilde{S}}_{ij}.}$$

$$\tau_{ij} = \widetilde{u_i u_j} - \tilde{u}_i\tilde{u}_j \equiv L_{ij} + R_{ij} + C_{ij}$$
$$L_{ij} = \widetilde{\tilde{u}_i\tilde{u}_j} - \tilde{\tilde{u}}_i\tilde{\tilde{u}}_j$$
$$R_{ij} = \widetilde{u_i'u_j'} - \tilde{u}_i'\tilde{u}_j'$$
$$C_{ij} = \widetilde{\tilde{u}_i u_j'} + \widetilde{\tilde{u}_j u_i'} - \tilde{\tilde{u}}_i\tilde{u}_j' - \tilde{\tilde{u}}_j\tilde{u}_i'.$$

$$\bar{\tilde{S}} = \frac{1}{2}\begin{bmatrix} 2\dfrac{\partial\bar{\tilde{u}}}{\partial r} & \dfrac{\partial\bar{\tilde{v}}}{\partial r} - \dfrac{\bar{\tilde{v}}}{r} & \dfrac{\partial\bar{\tilde{u}}}{\partial z} + \dfrac{\partial\bar{\tilde{w}}}{\partial r} \\ \dfrac{\partial\bar{\tilde{v}}}{\partial r} - \dfrac{\bar{\tilde{v}}}{r} & \dfrac{\bar{\tilde{u}}}{r} & \dfrac{\partial\bar{\tilde{v}}}{\partial z} \\ \dfrac{\partial\bar{\tilde{w}}}{\partial r} + \dfrac{\partial\bar{\tilde{u}}}{\partial z} & \dfrac{\partial\bar{\tilde{v}}}{\partial z} & 2\dfrac{\partial\bar{\tilde{w}}}{\partial z} \end{bmatrix}$$

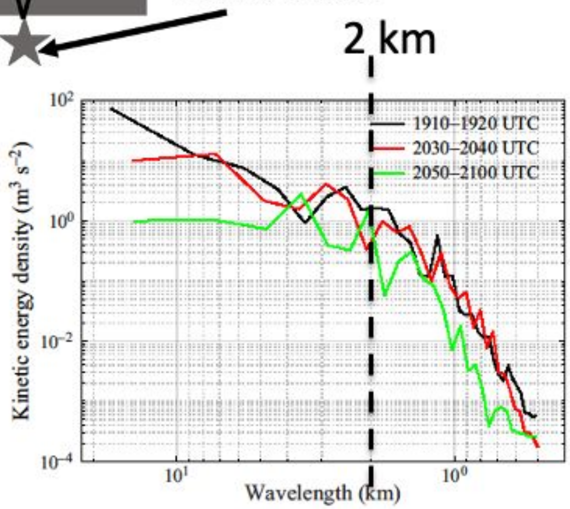
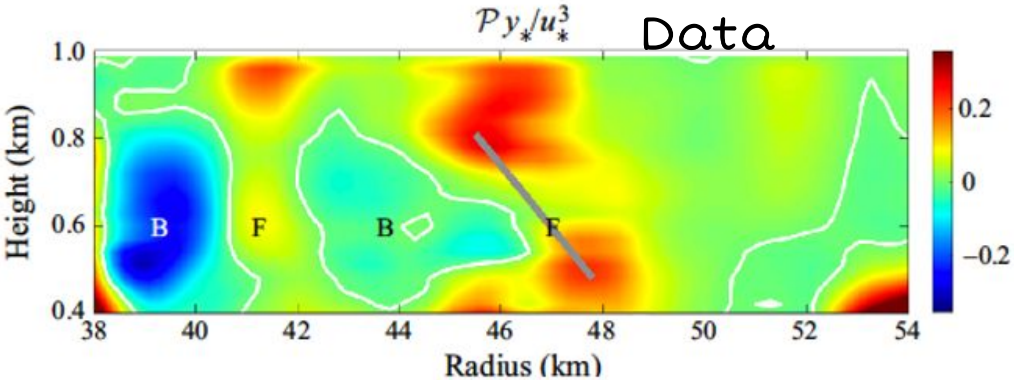
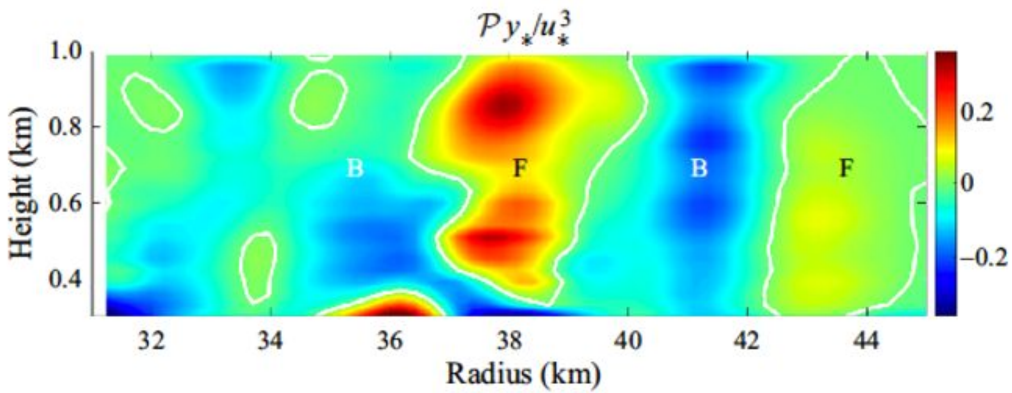


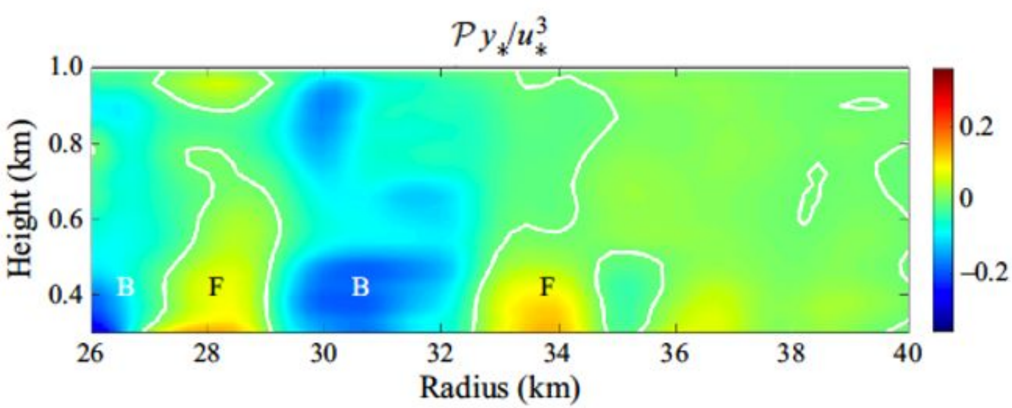
Figure 3. KE spectra for the three radial passes of IWRAP data analysed in this paper.

Energy Transfer Breakdown

Hurricane Rita (2005) Data



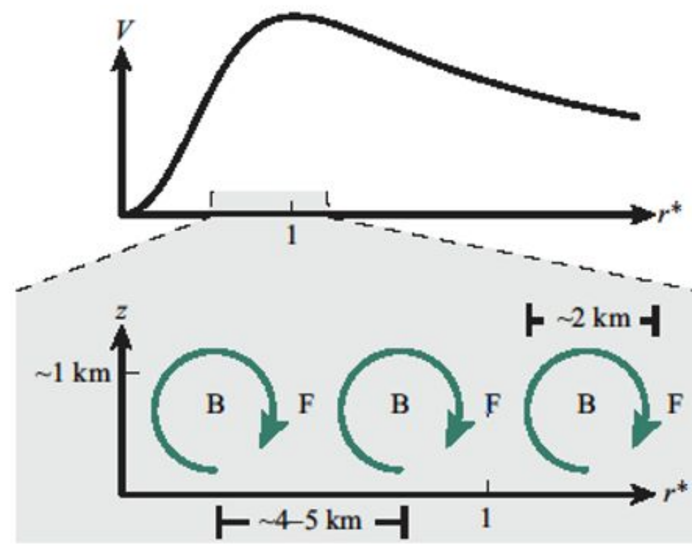




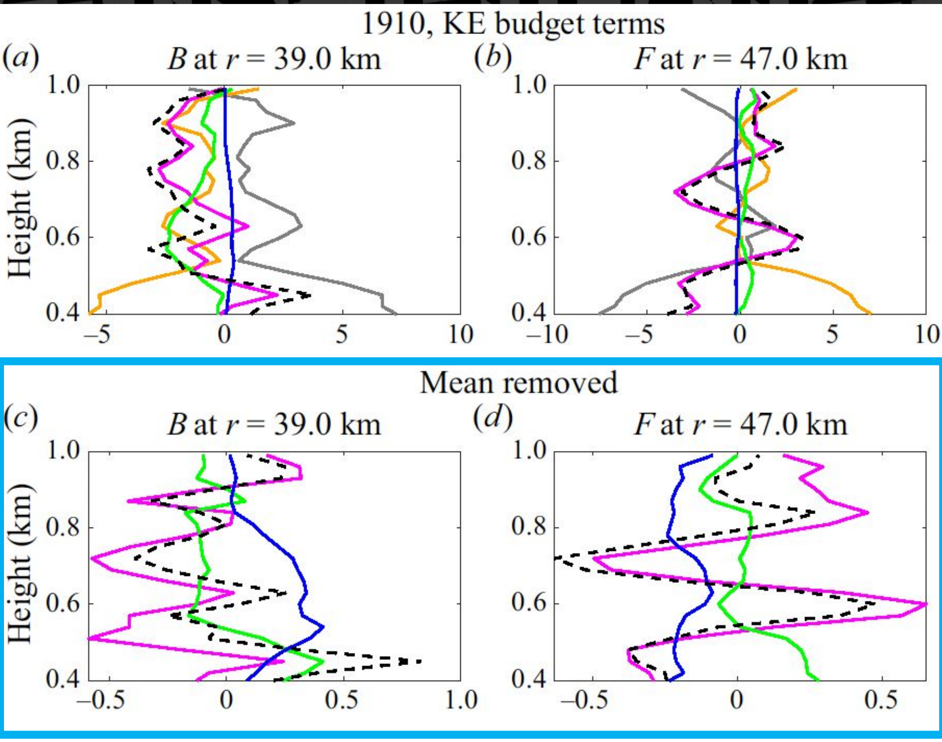
$$\boxed{\mathcal{P} = -\tau_{ij}\widetilde{S}_{ij}.}$$

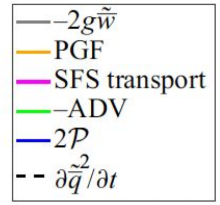
Stress Tensor (τ) Correlations to $\mathcal{P}$

- Radial-vertical (τ_{13}) 79%
- Azimuthal-vertical (τ_{23}) 49%
- Sign of $\mathcal{P}$ → Sign of τ →Sign of ∂w/∂r (vertical velocity)



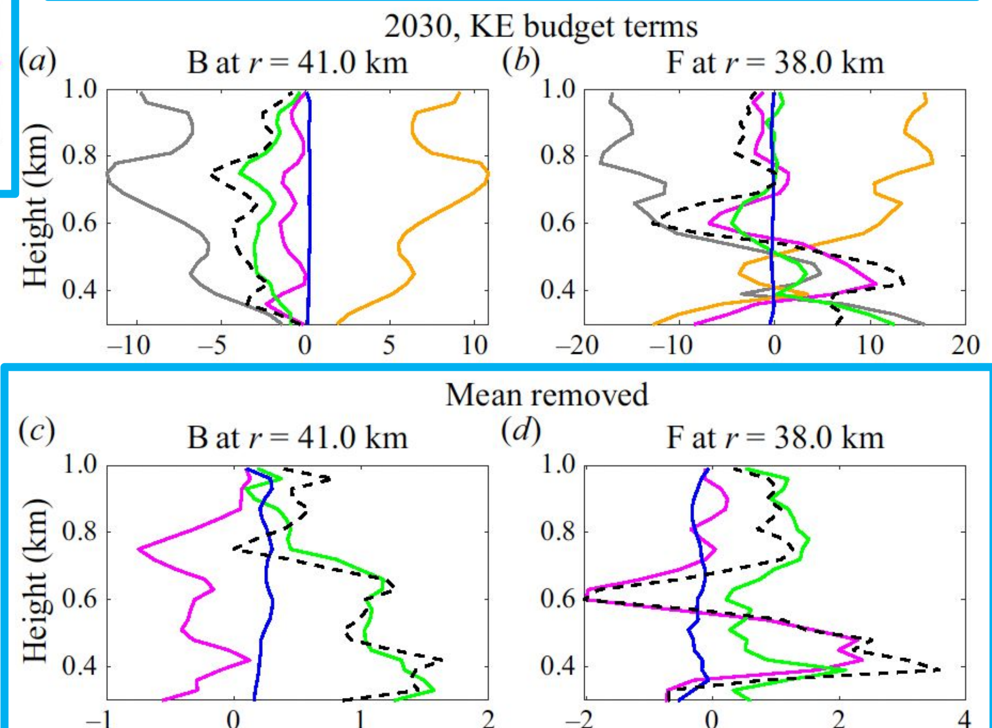
TKE Budgets in HBL





The expanded, azimuthally averaged KE transport equation in cylindrical coordinates is

$$\frac{\partial \tilde{\bar{q}}^2}{\partial t}+\underbrace{\tilde{\bar{u}}\frac{\partial \tilde{\bar{q}}^2}{\partial r}+\tilde{\bar{w}}\frac{\partial \tilde{\bar{q}}^2}{\partial z}}_{\text{ADV}}=-2g\tilde{\bar{w}}\underbrace{-\frac{2}{\rho}\left(\tilde{\bar{u}}\frac{\partial \tilde{\bar{p}}}{\partial r}+\tilde{\bar{w}}\frac{\partial \tilde{\bar{p}}}{\partial z}\right)}_{\text{PGF}}-2\left[\frac{1}{r}\frac{\partial r\tilde{\bar{u}}\tau_{rr}}{\partial r}-\frac{\tau_{\theta\theta}\tilde{\bar{u}}}{r}+\frac{\partial \tilde{\bar{u}}\tau_{rz}}{\partial z}\right.$$
$$\left.+\ldots\frac{1}{r^2}\frac{\partial r^2\tilde{\bar{v}}\tau_{\theta r}}{\partial r}+\frac{\partial \tilde{\bar{v}}\tau_{\theta z}}{\partial z}+\frac{1}{r}\frac{\partial r\tilde{\bar{w}}\tau_{rz}}{\partial r}+\frac{\partial \tilde{\bar{w}}\tau_{zz}}{\partial z}\right]-2\mathcal{P}, \quad (2.6)$$



- **Energy transfer term ("2P") contributes on average ~ 30% to "eddy scale" time tendency**
- **Backscatter affects larger-scale waves, which can feed energy to mean flow**
- **HBL has large non-conservative effects**

Key Findings for OVWST

- **How does kinetic energy (wind) change in the PBL?**
  - Turbulence models (Smag, TKE; downscale only)
    - Sroka and Guimond (2021), J. Fluid Mech., 924, A21.
    - HBL contains organized KE backscatter
    - Driven by coherent structures ~ 2 km wavelength
    - Secondary circulations, esp. vertical fluxes
  - Small-scale waves □ Larger-scale waves □ Mean flow
- **OVWST applications**
  - role of CTS in ocean-atmosphere coupling
    - Currents and ocean mixing
    - Surface fluxes, convection, storm intensity change
  - Relevant for satellite footprints and OVW data

IWRAP Examples - Teddy

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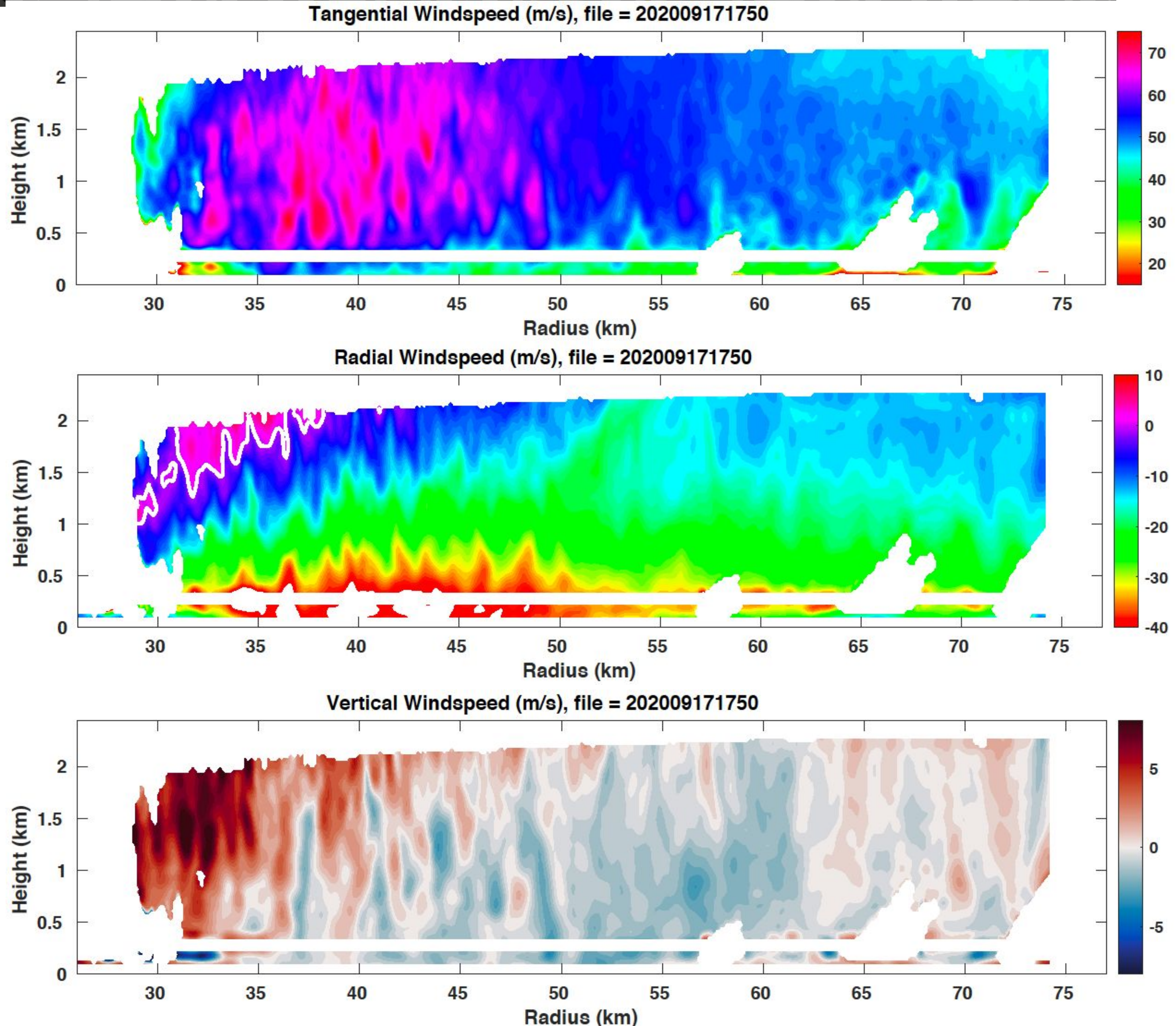

IWRAP Examples - Laura