The relative importance of the boundary layer and the stratosphere in the dissipation of trapped lee waves

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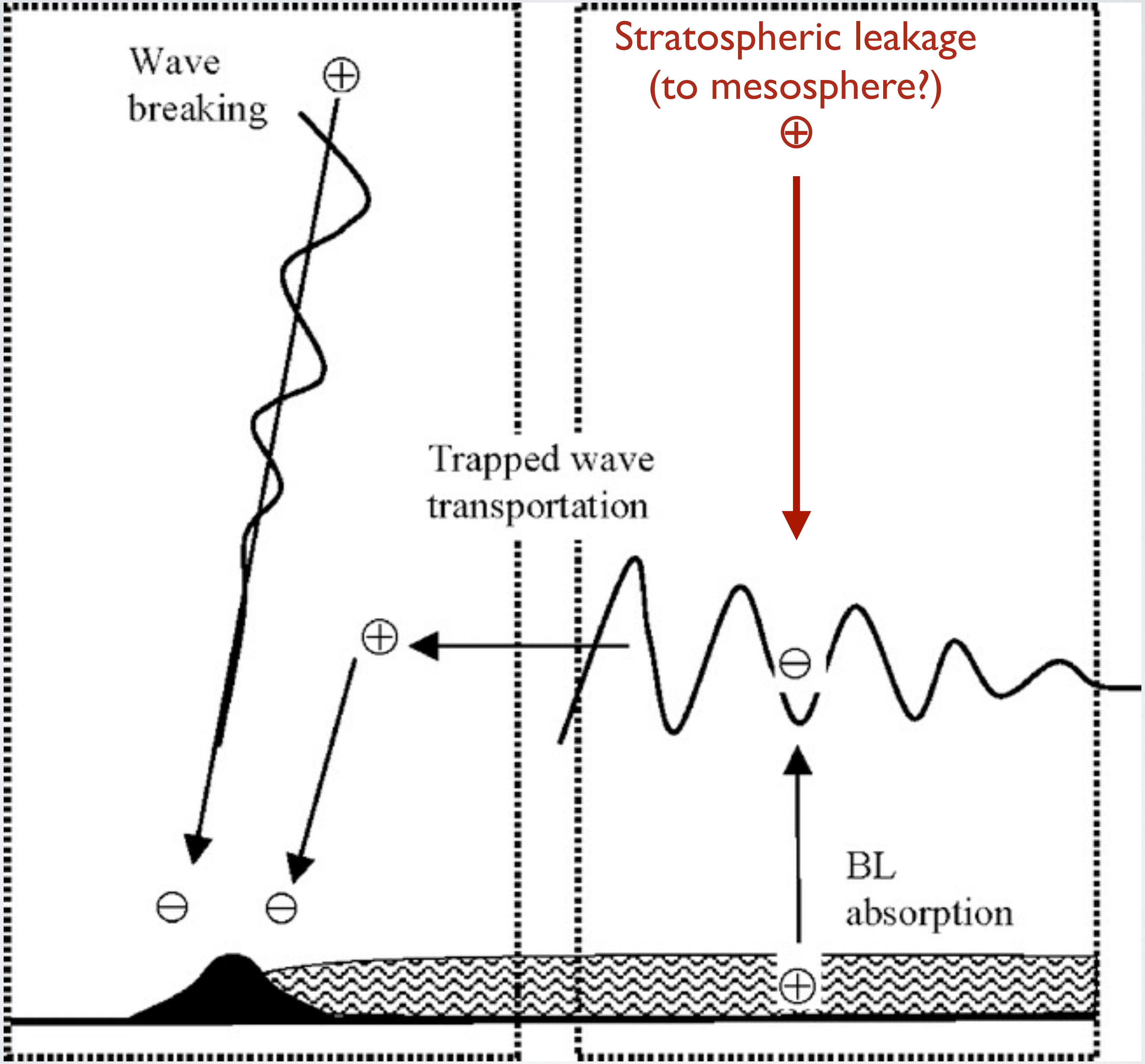
Impact on momentum budget



Jiang et al., 2006

Real-World Reference Values

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- Observed lee-wave wavelengths (Ralph et al., 1997)
    - 8.3 to 28.6 km
    - Average over 24 events was 15.8 km

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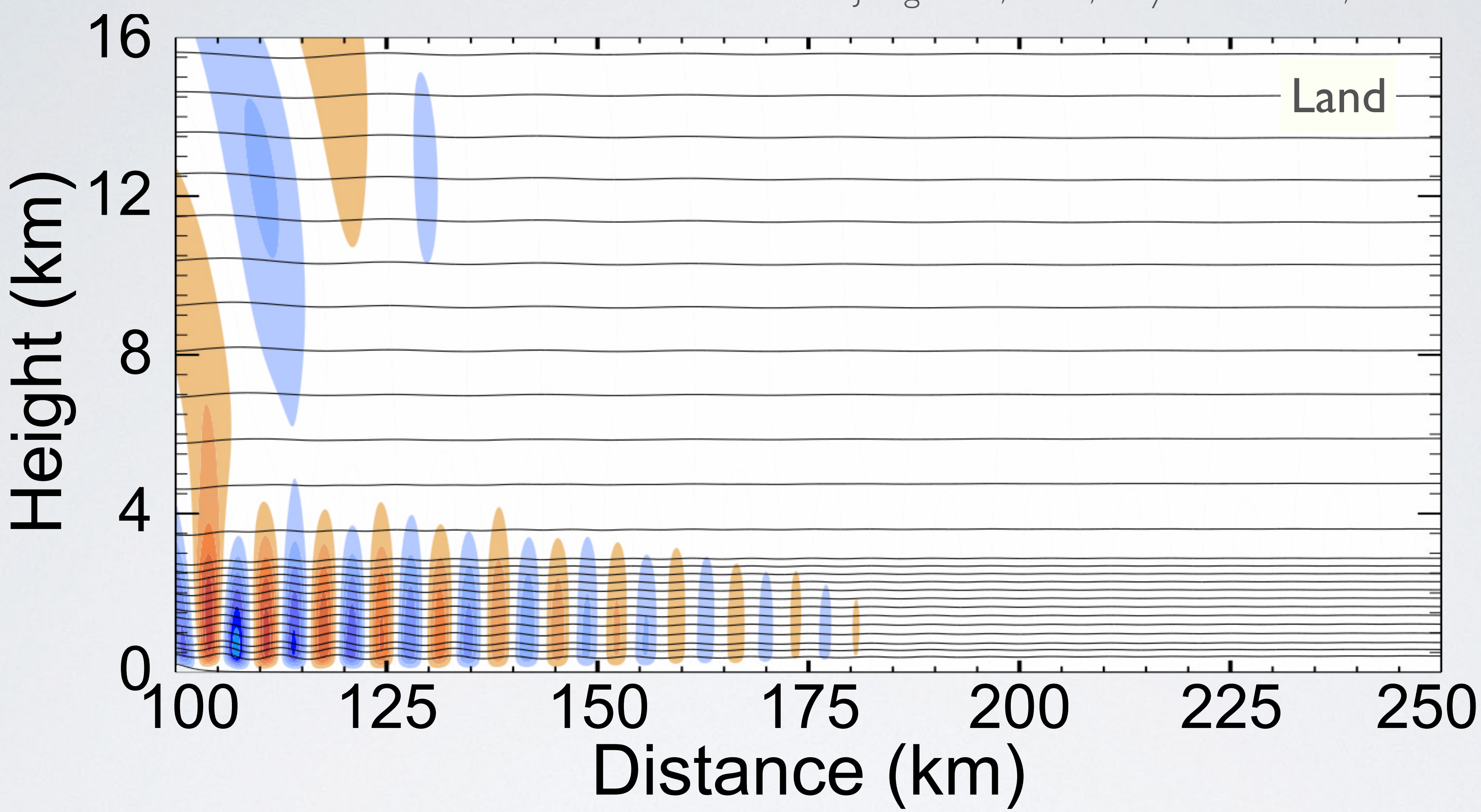
  - 8.3 to 28.6 km
  - Average over 24 events was 15.8 km
- Characteristic surface roughnesses
  - Ocean: z_0=0.0001 m
  - Land (open country): z_0=0.1 m

2 Layers, λ_i=7.5 km

Jiang et al., 2006, Doyle & Durran, 2002



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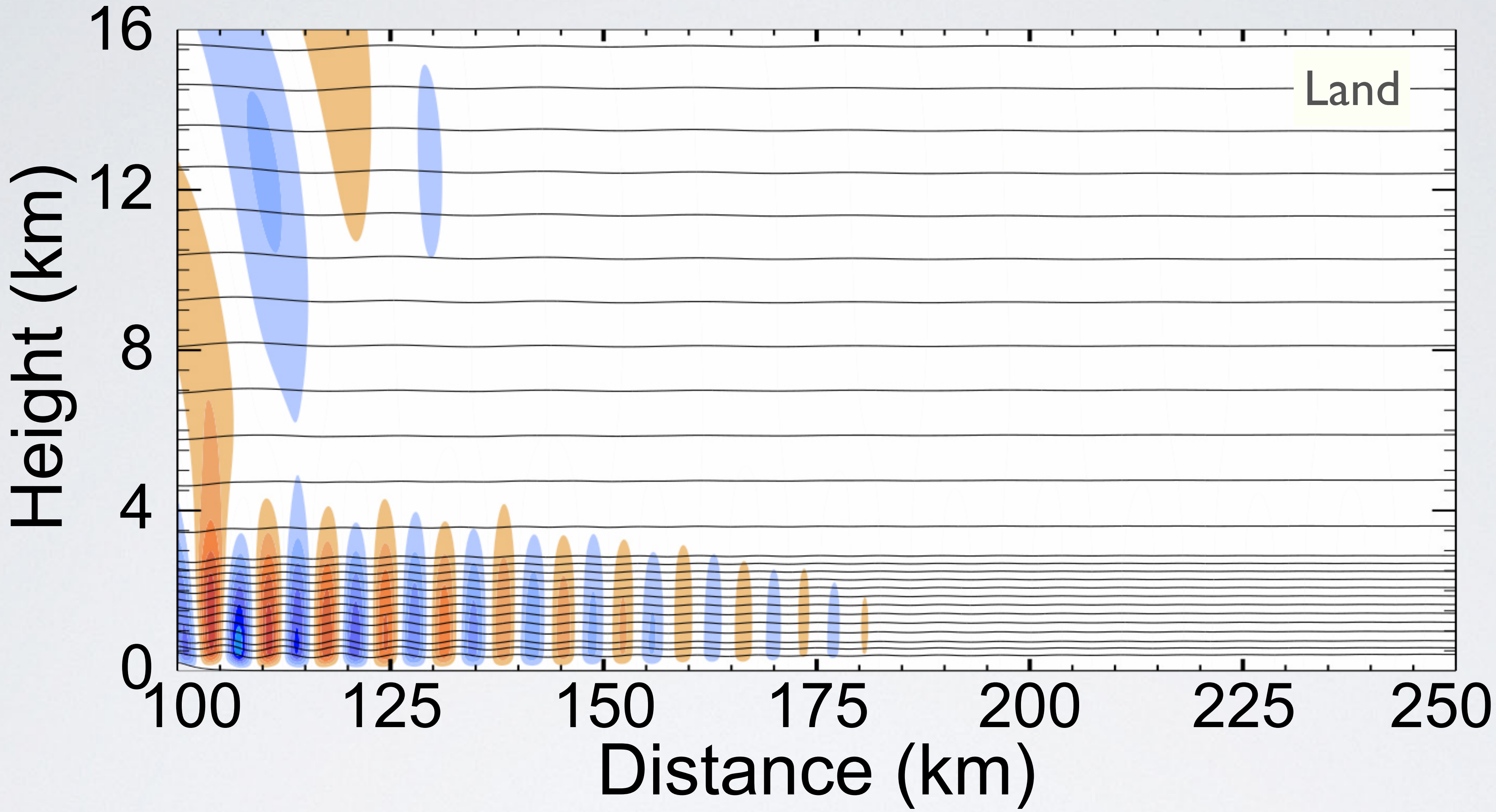

- Short-wavelength waves decay vertically before reaching typical tropopause heights.

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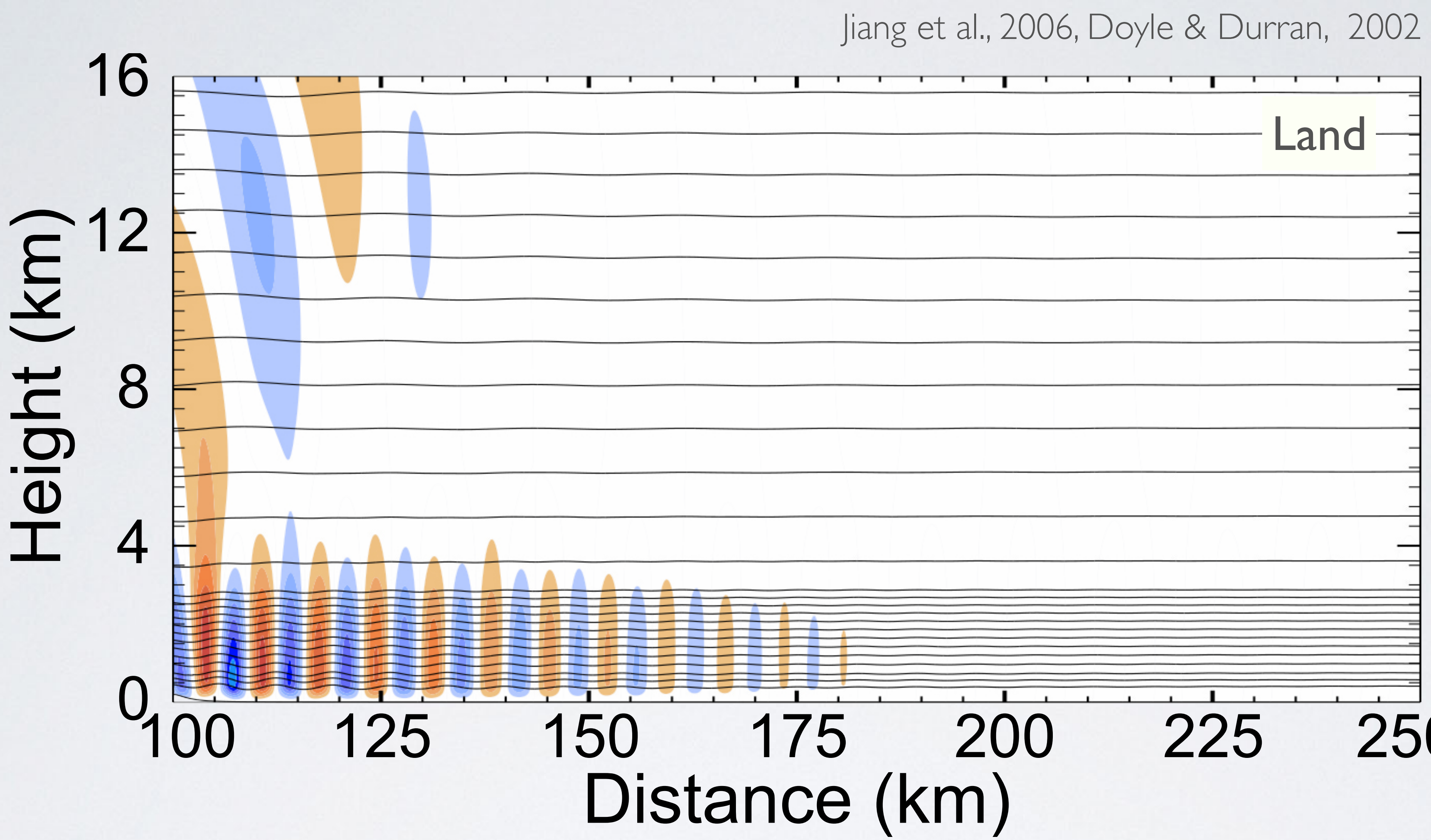


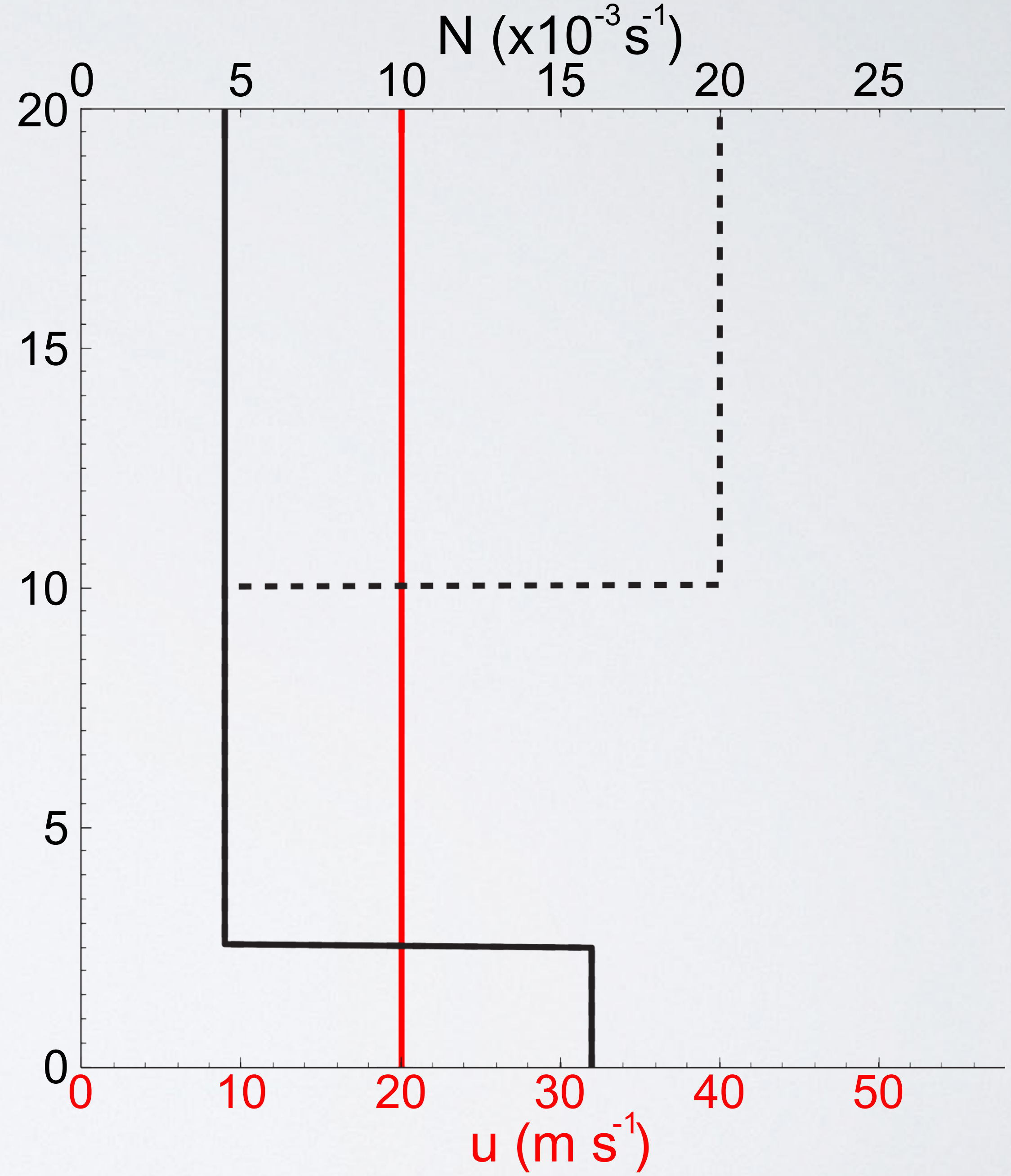
- Short-wavelength waves decay vertically before reaching typical tropopause heights.
- Stratospheric leakage is totally dominated by BL friction.

2-layers, λ_i=20.5 km

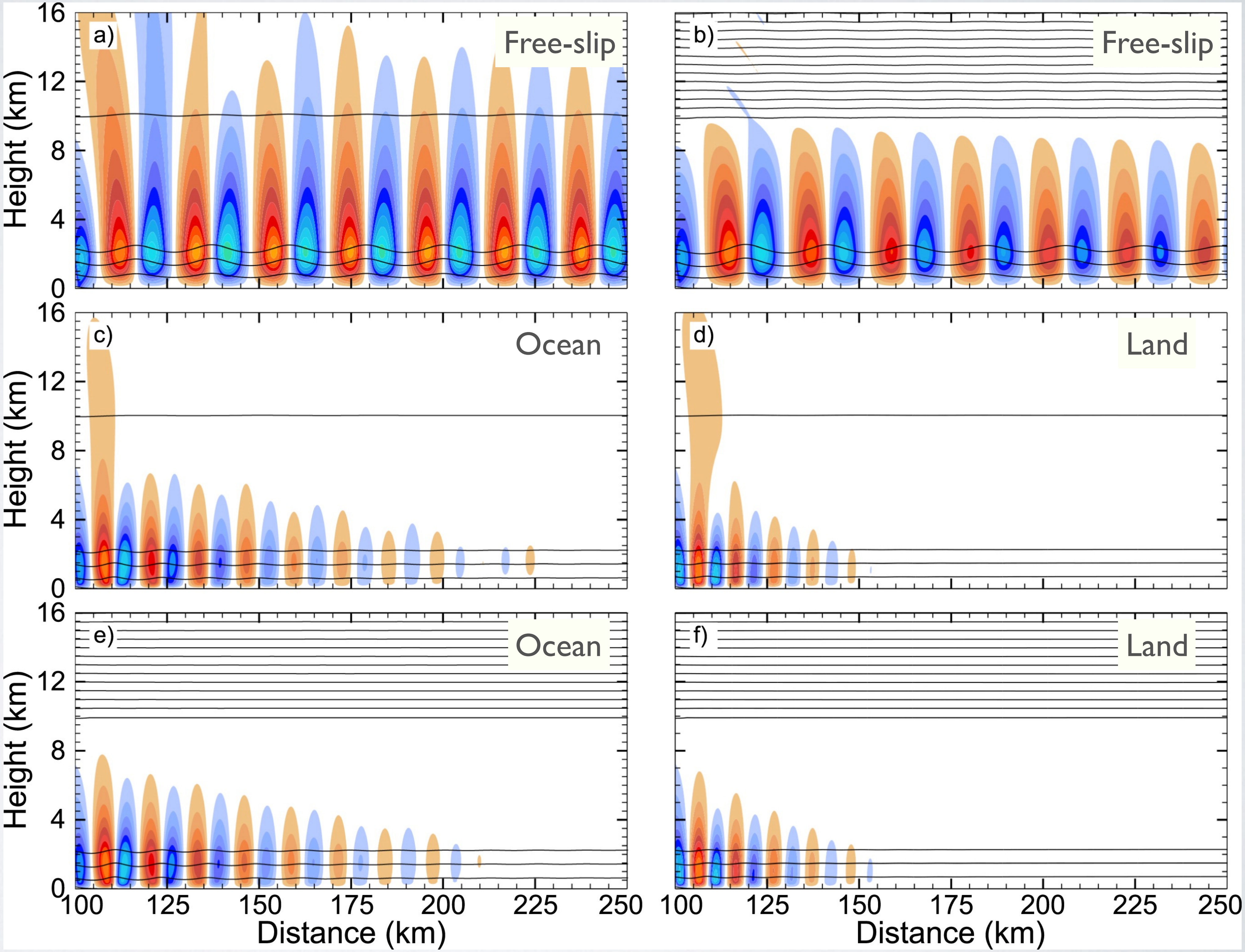
- For constant upper-layer Scorer parameter, e-folding decay scale is

$$\left[\left(\frac{2\pi}{\lambda}\right)^2 - l_u^2\right]^{-1/2}$$

- Decay scale decreases as λ decreases



2 or 3 uniform layers: λ_i=20.5 km



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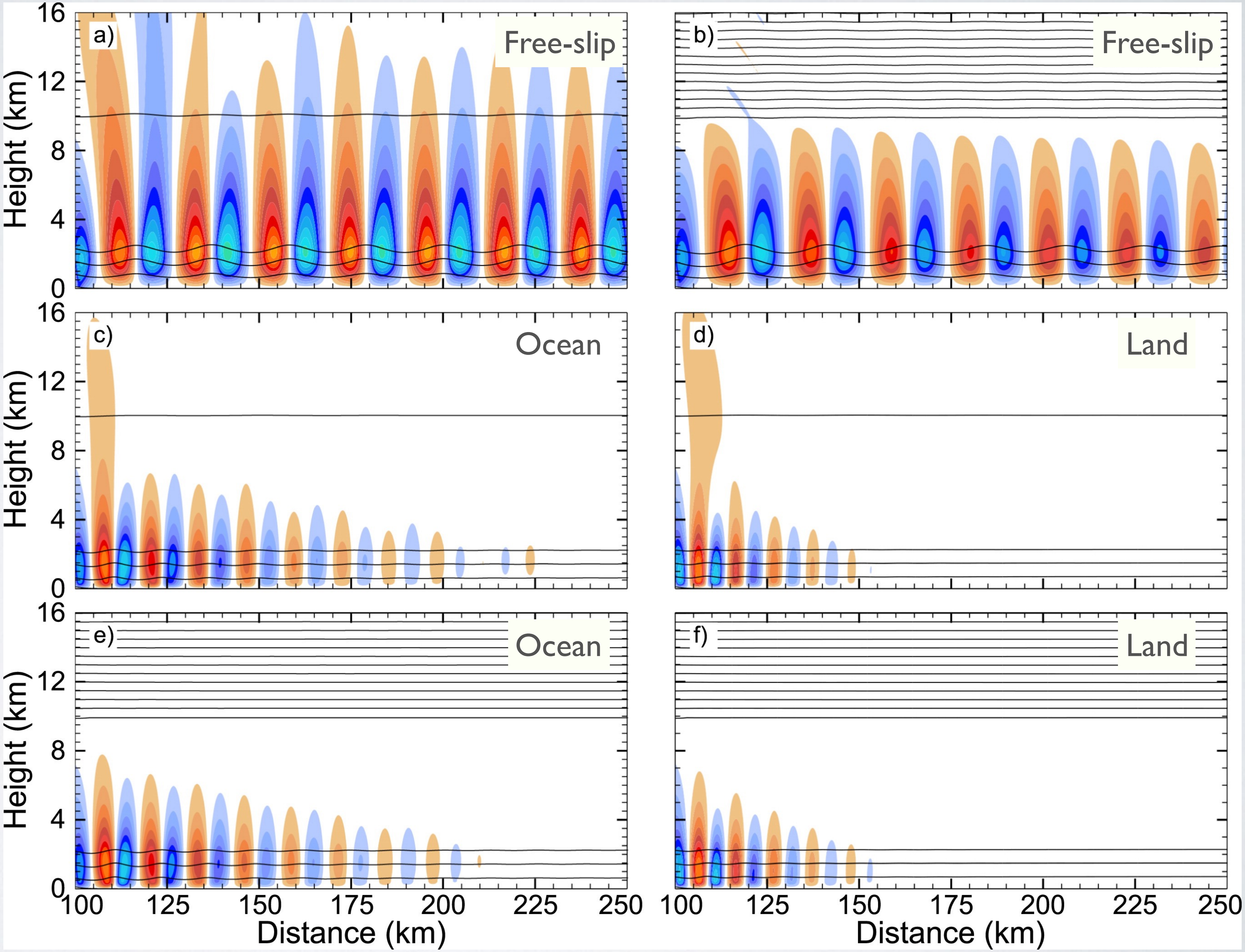
Surface friction reduces λ



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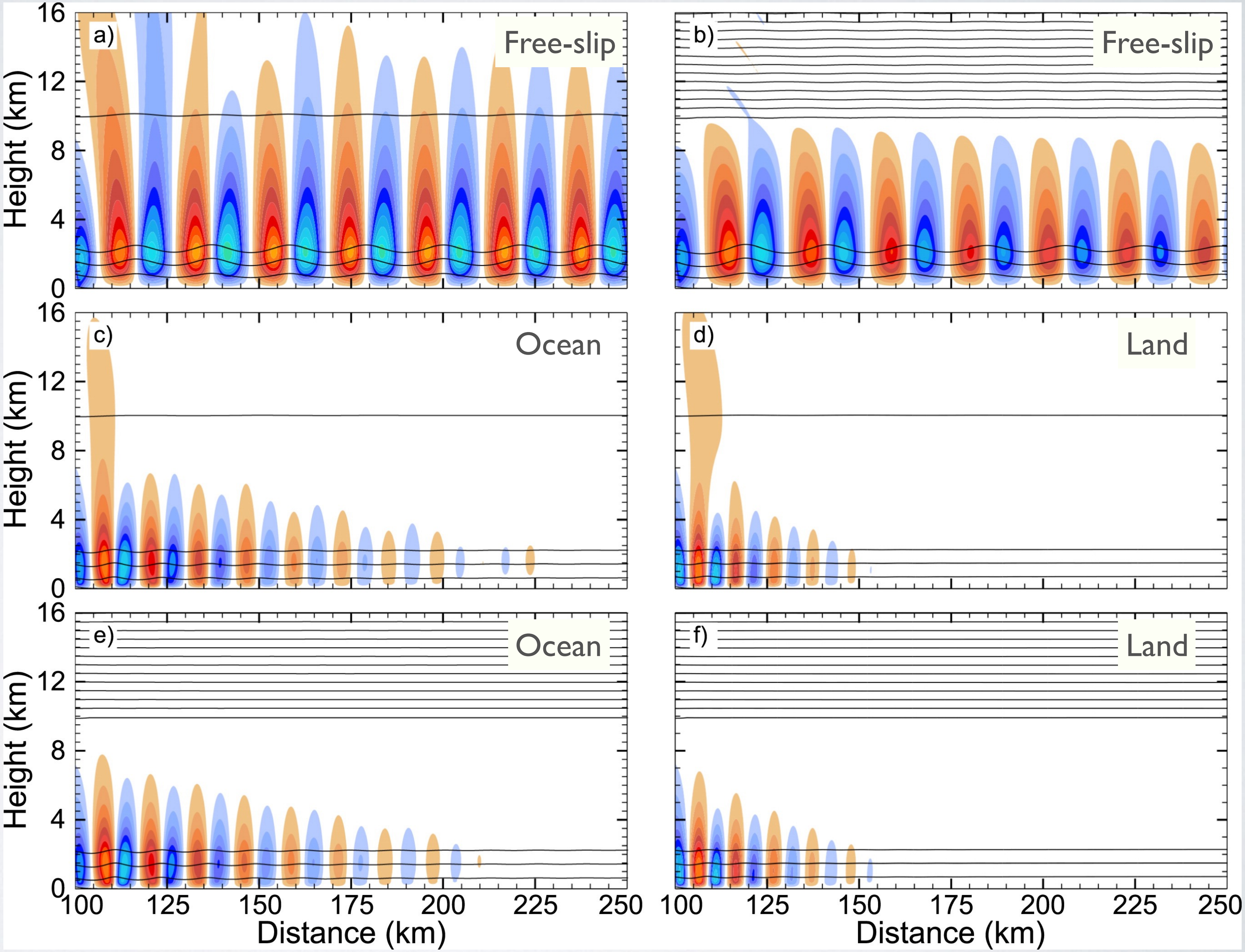
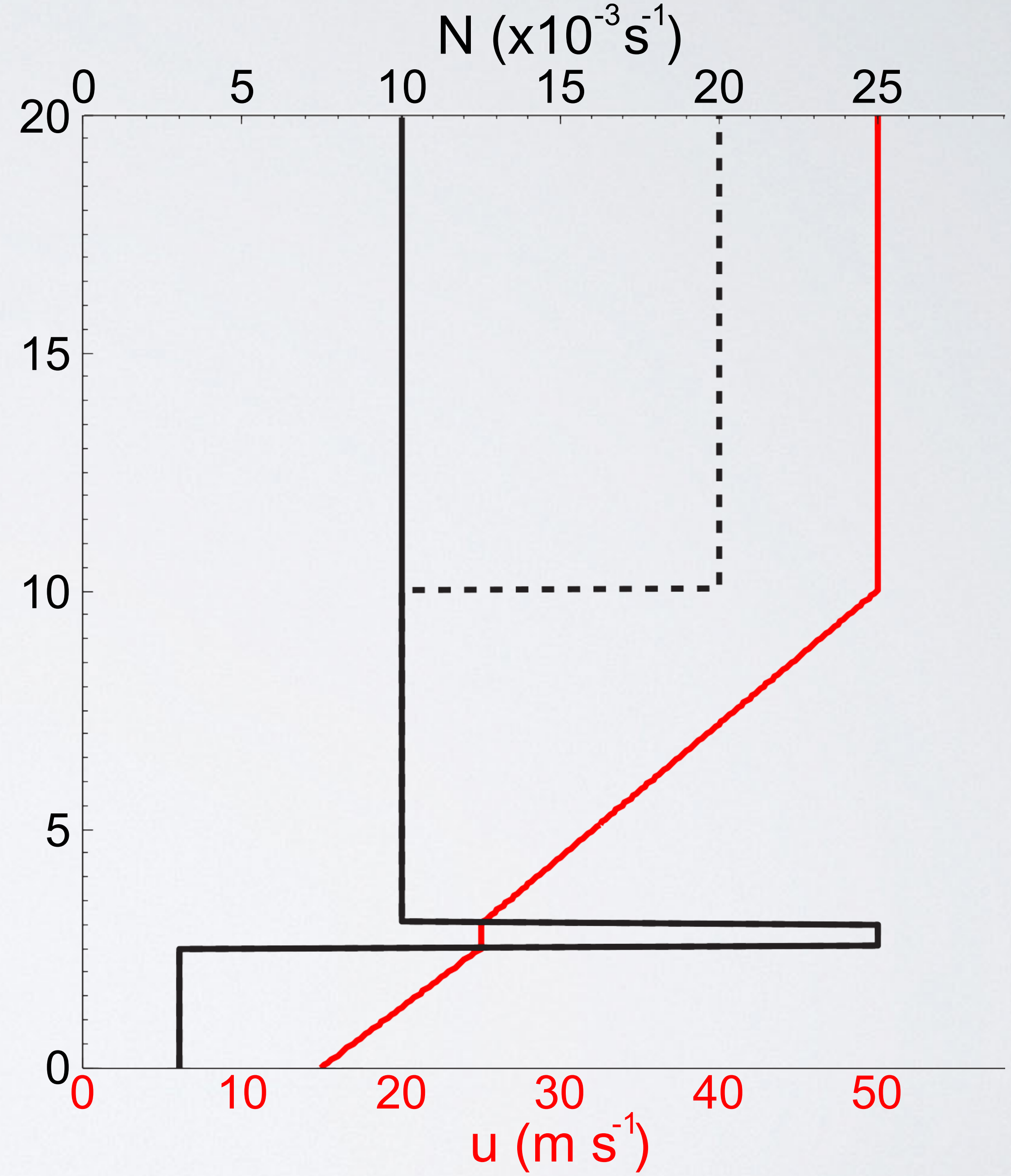
Frictional dissipation dominates



Elevated inversion & shear, λ_i=21.8 km

- Typical of many observed events



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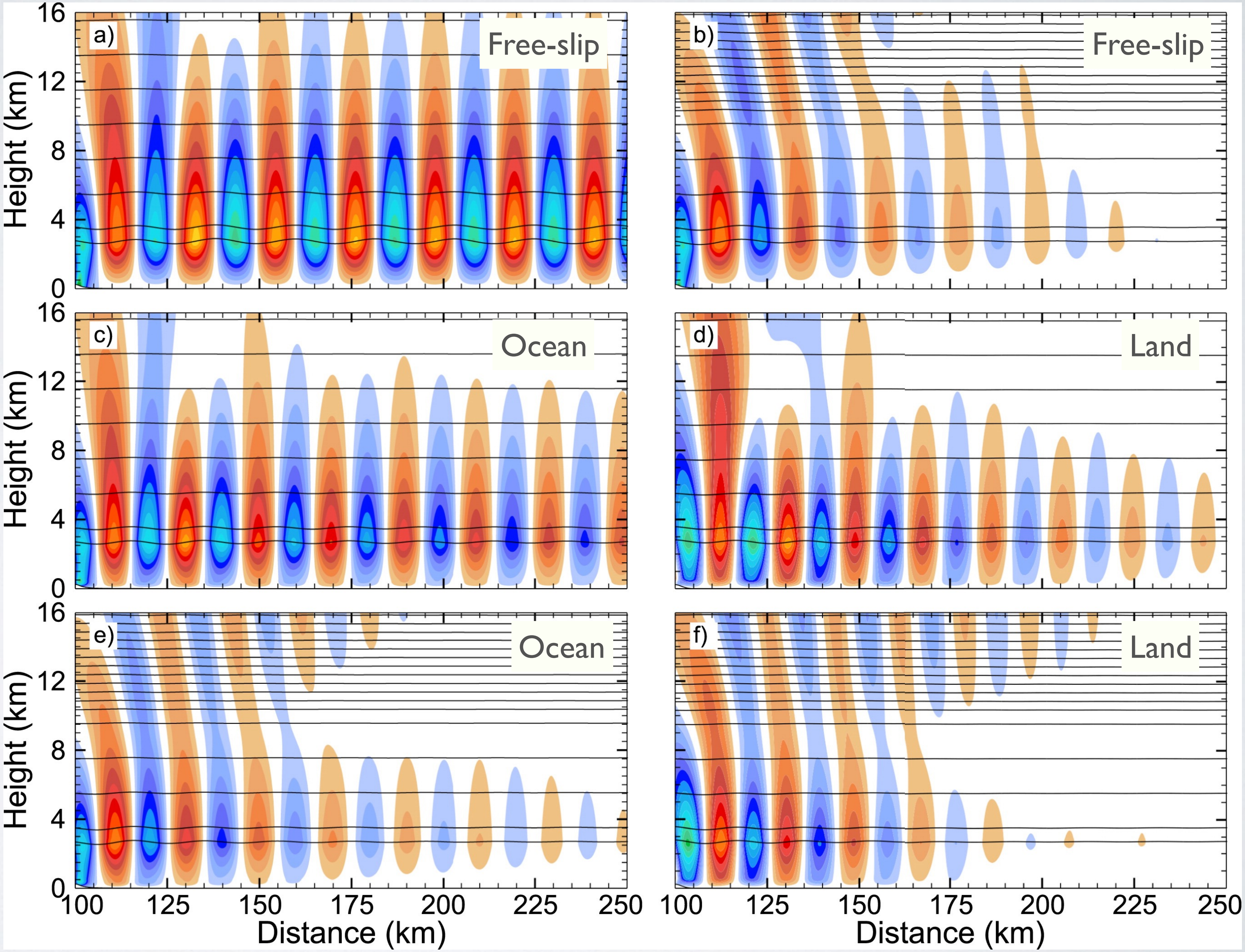
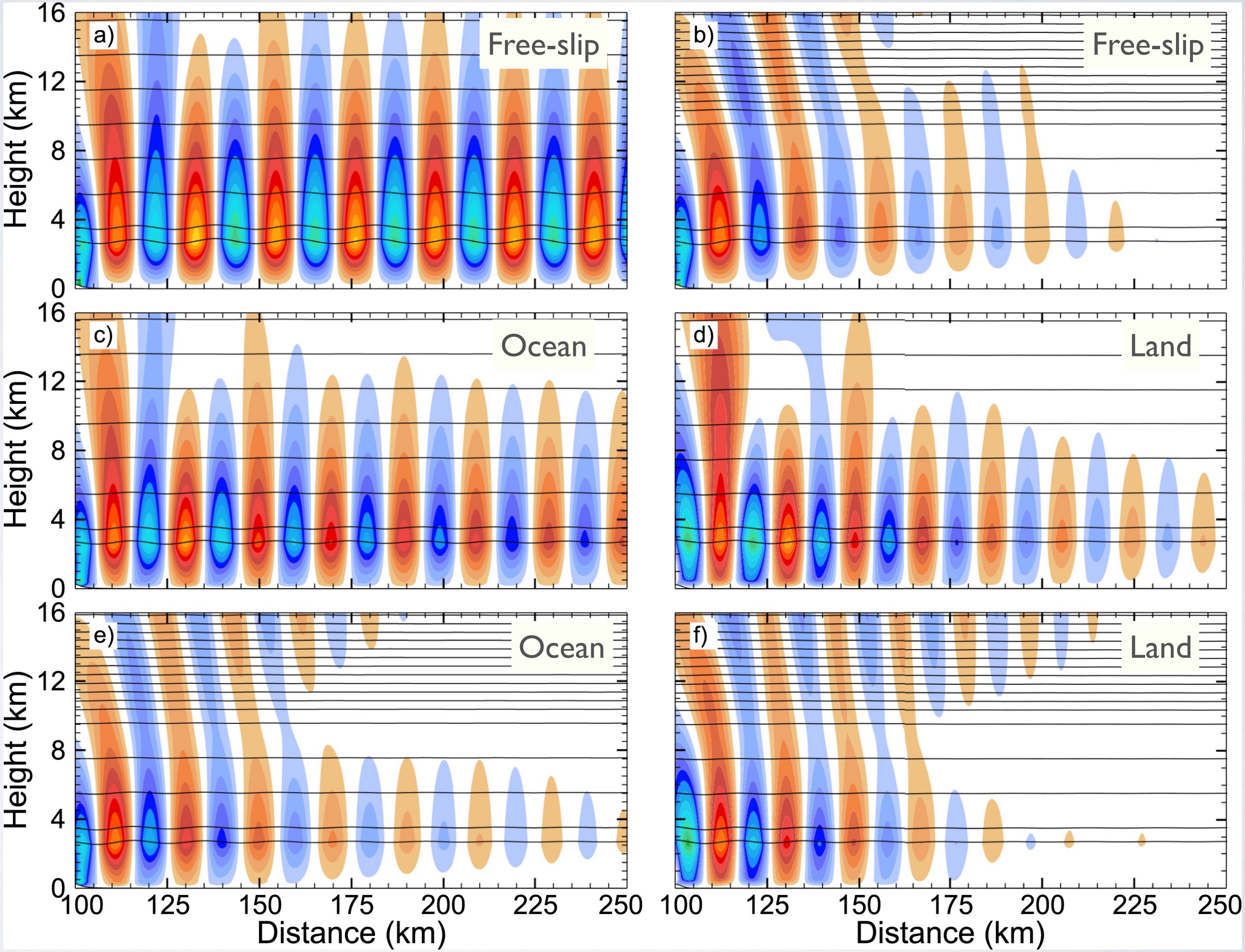


Elevated inversion & shear: λ_i=21.8 km

Surface friction only slightly reduces λ



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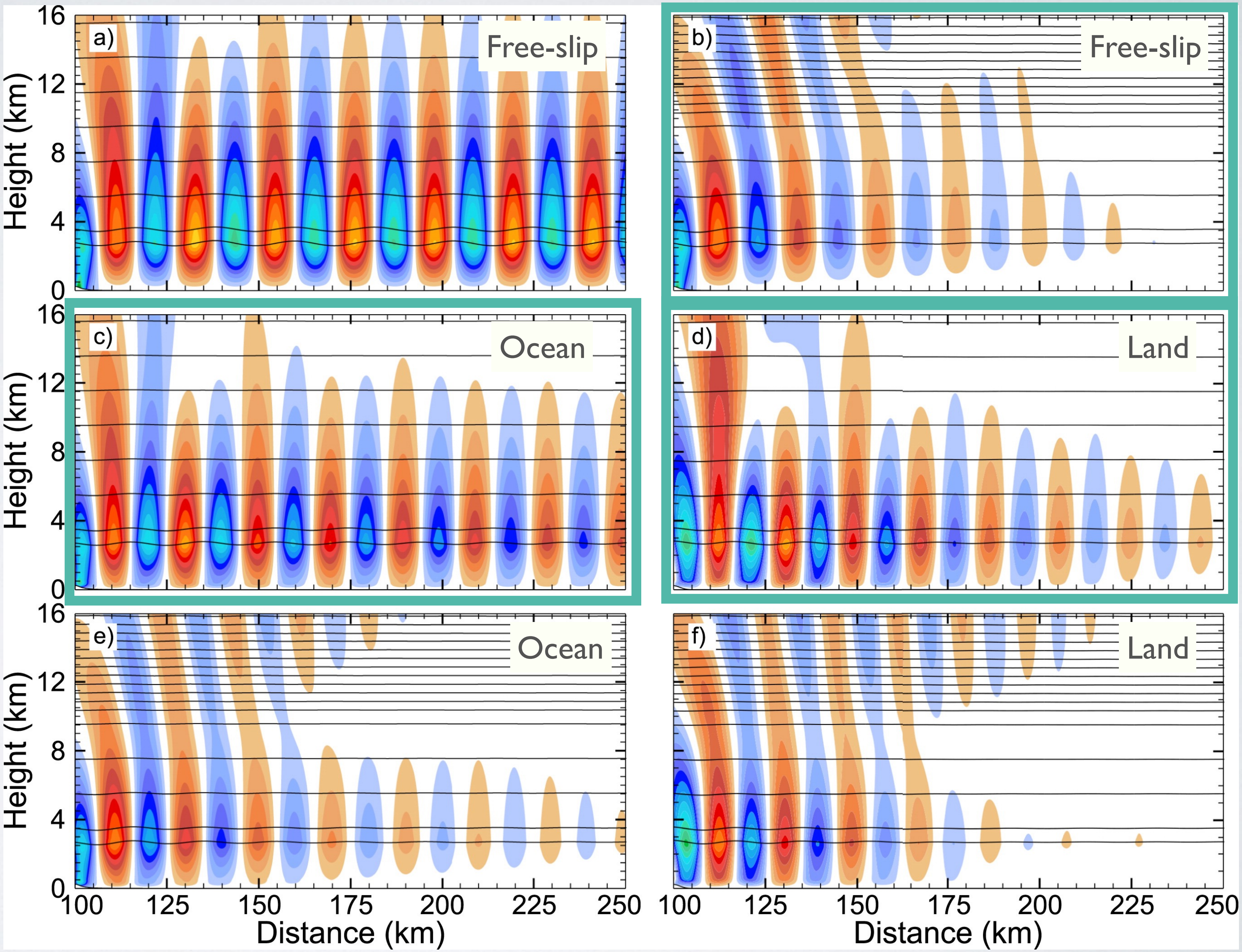

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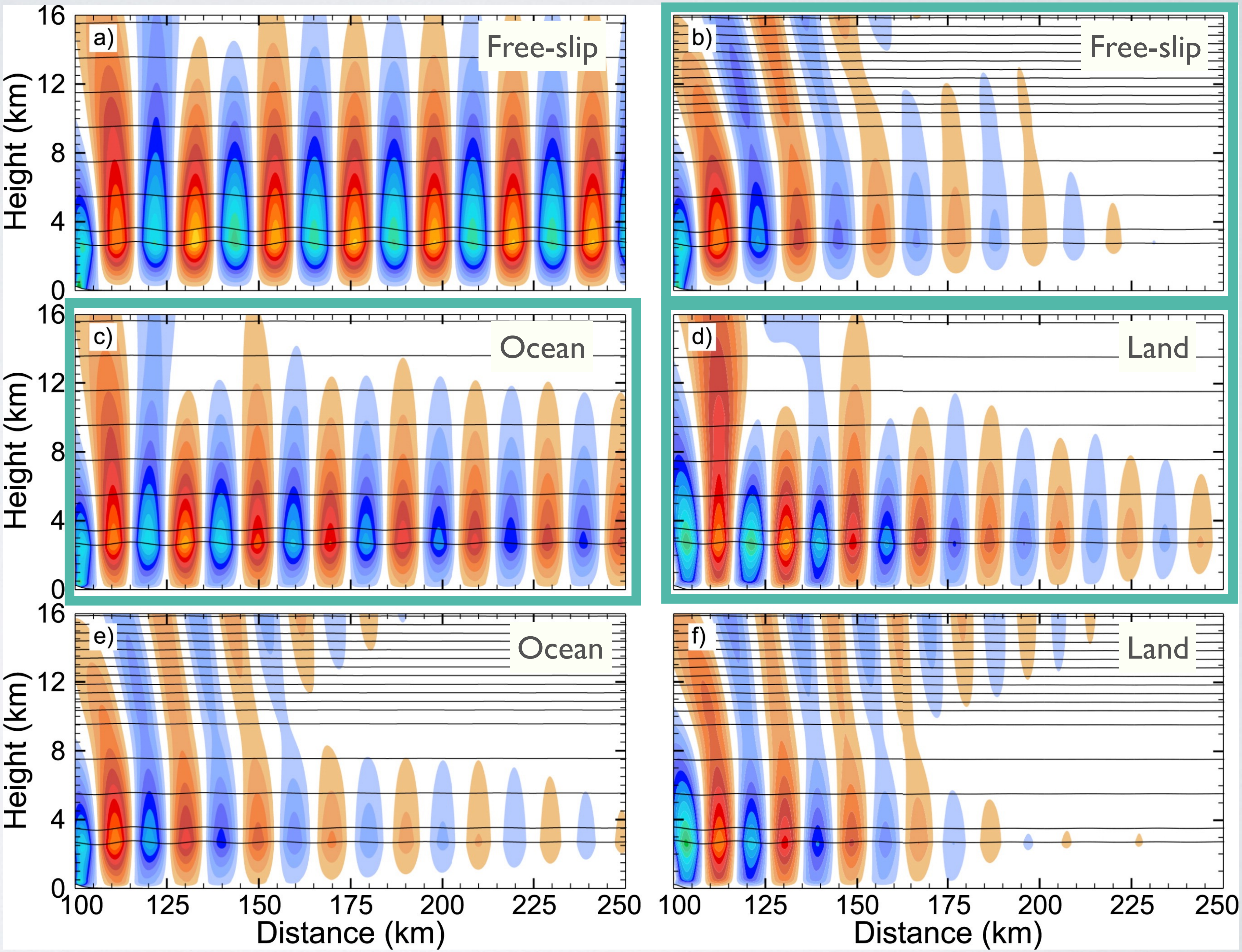

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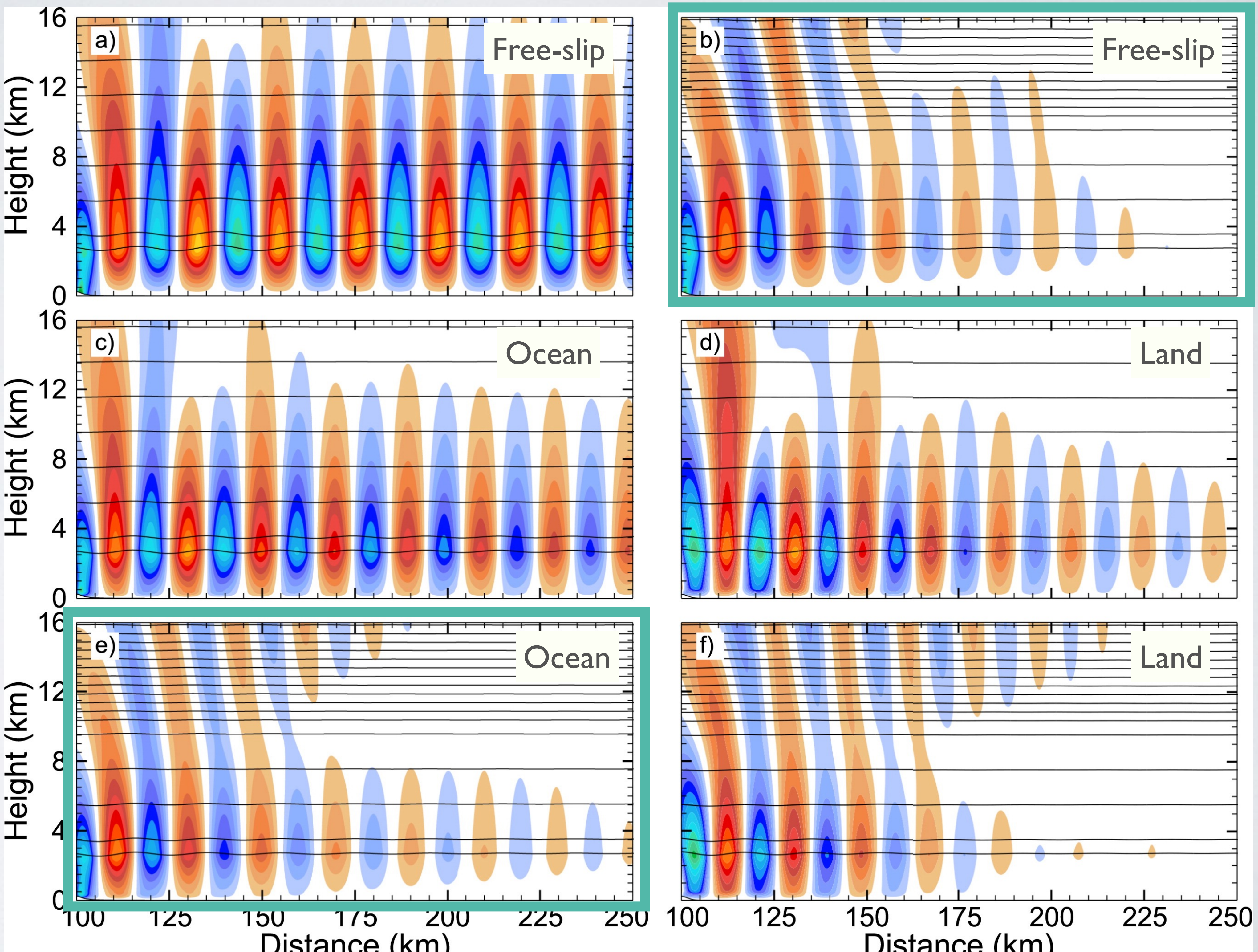

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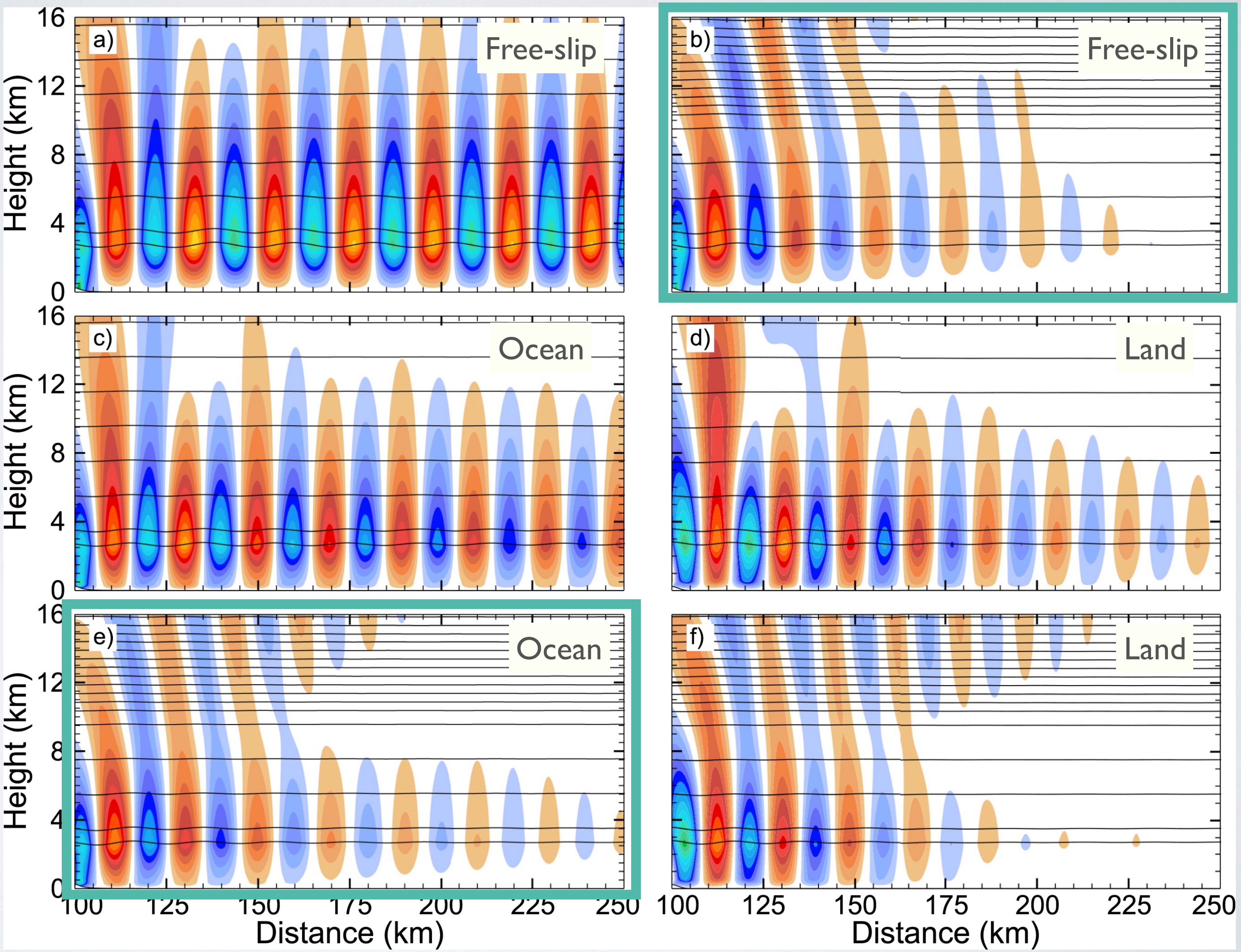
Ocean gives less leakage than free-slip



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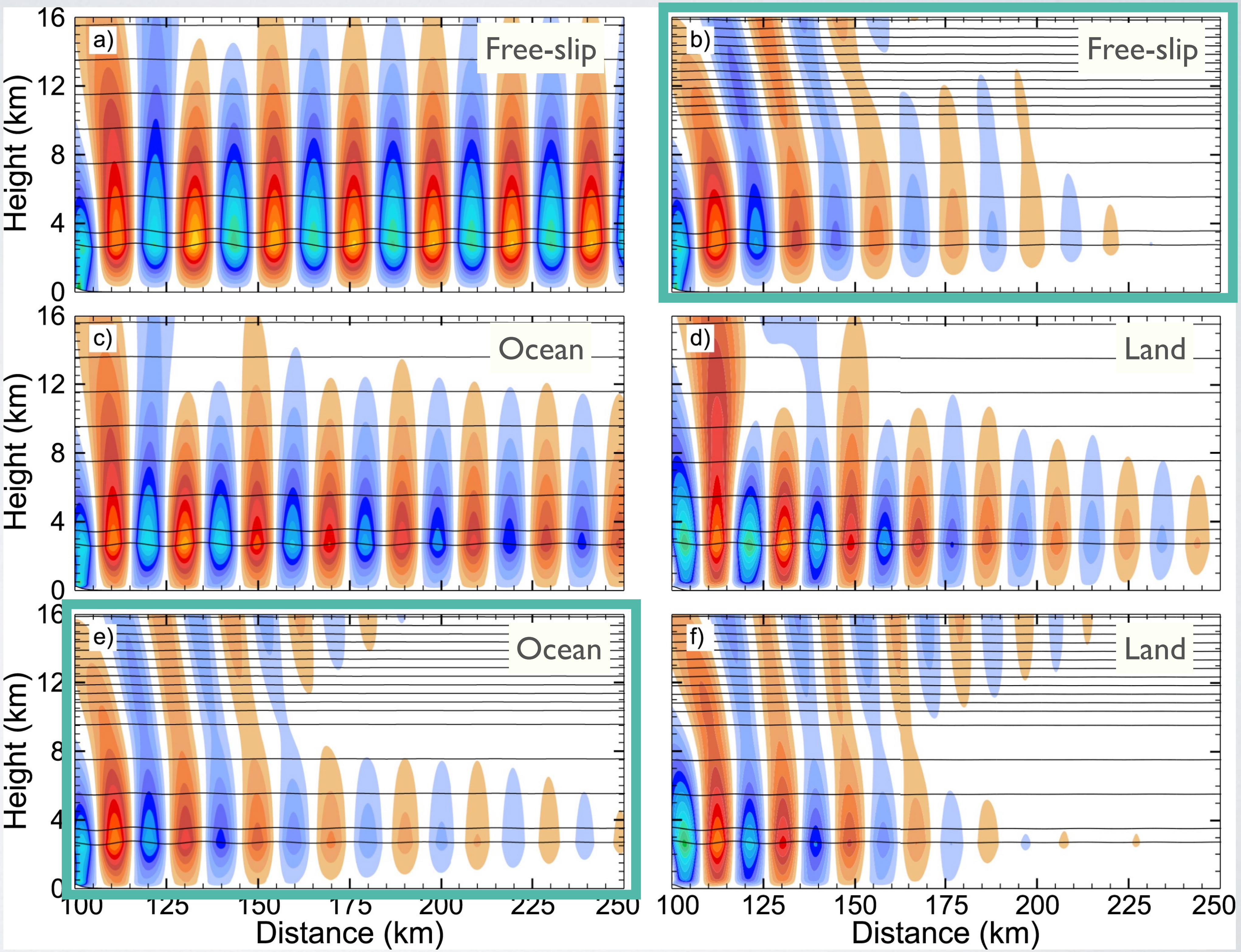
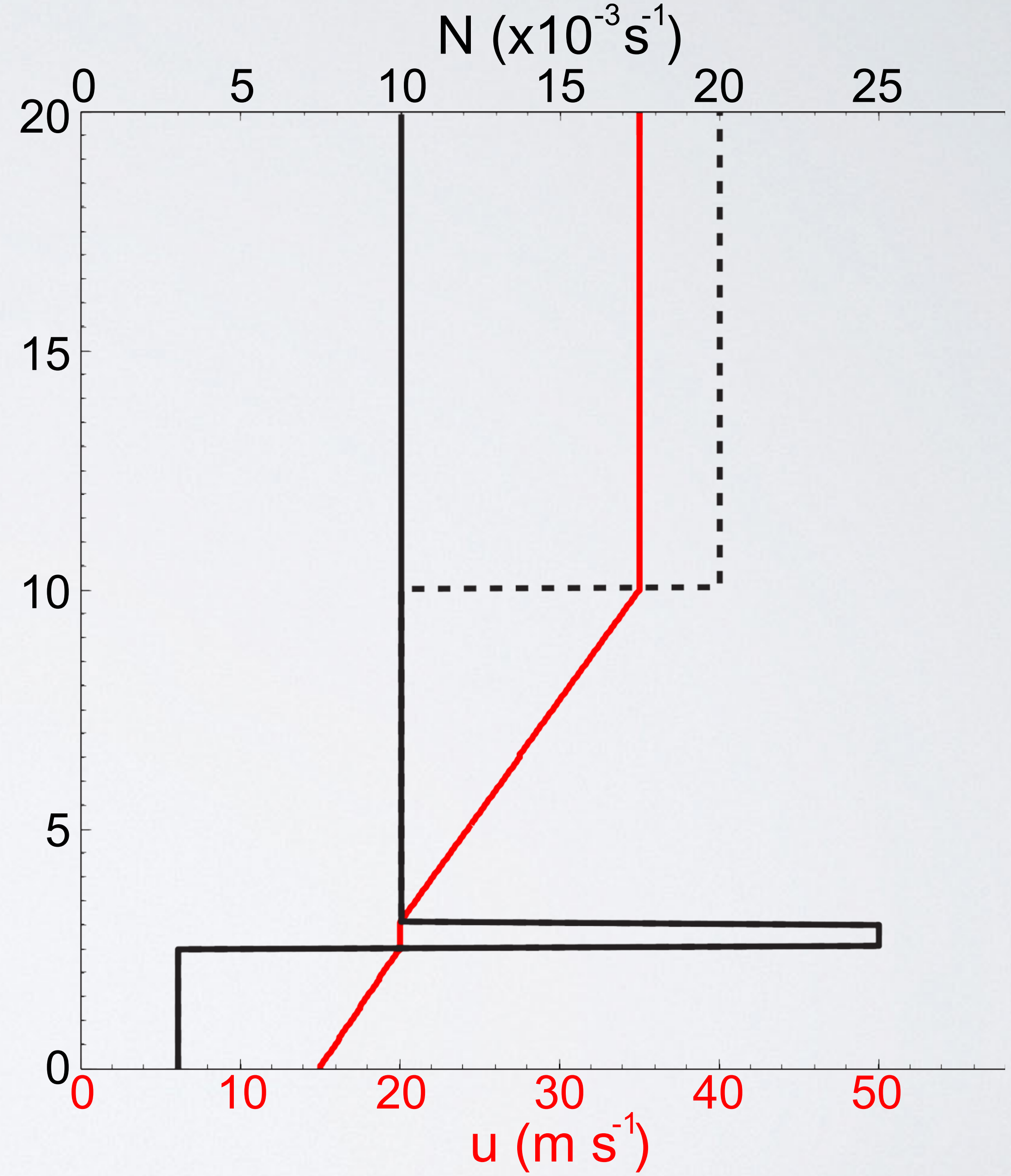
λ reduced to 19.8 km is better trapped.

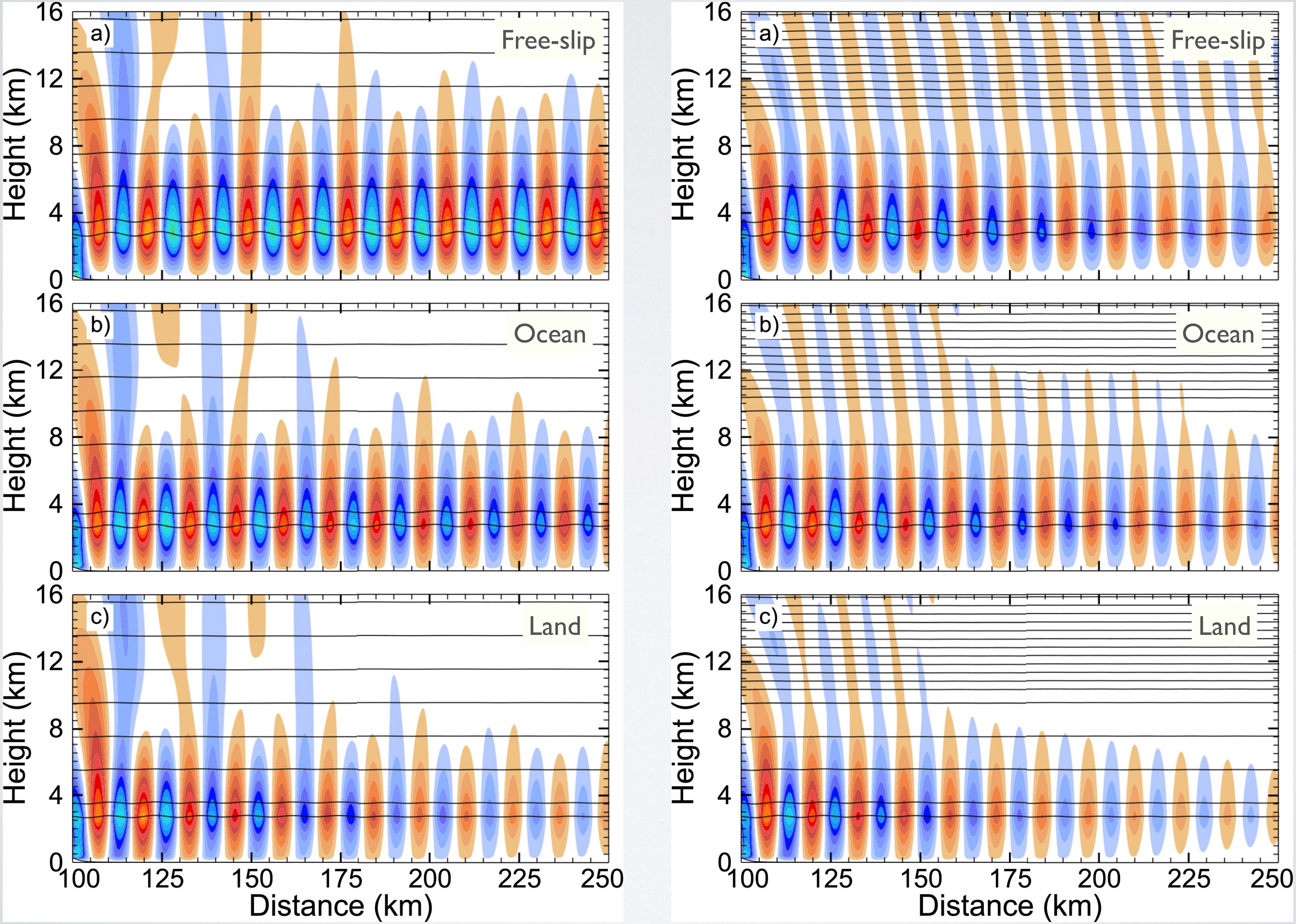


Elevated inversion & shear, λ_i=13.9 km

- Weaker winds aloft
- Shorter λ than observed average
- Consider tropopauses heights z_t of 9 and 10 km



PBL-stratosphere comparison, z_t=10 km



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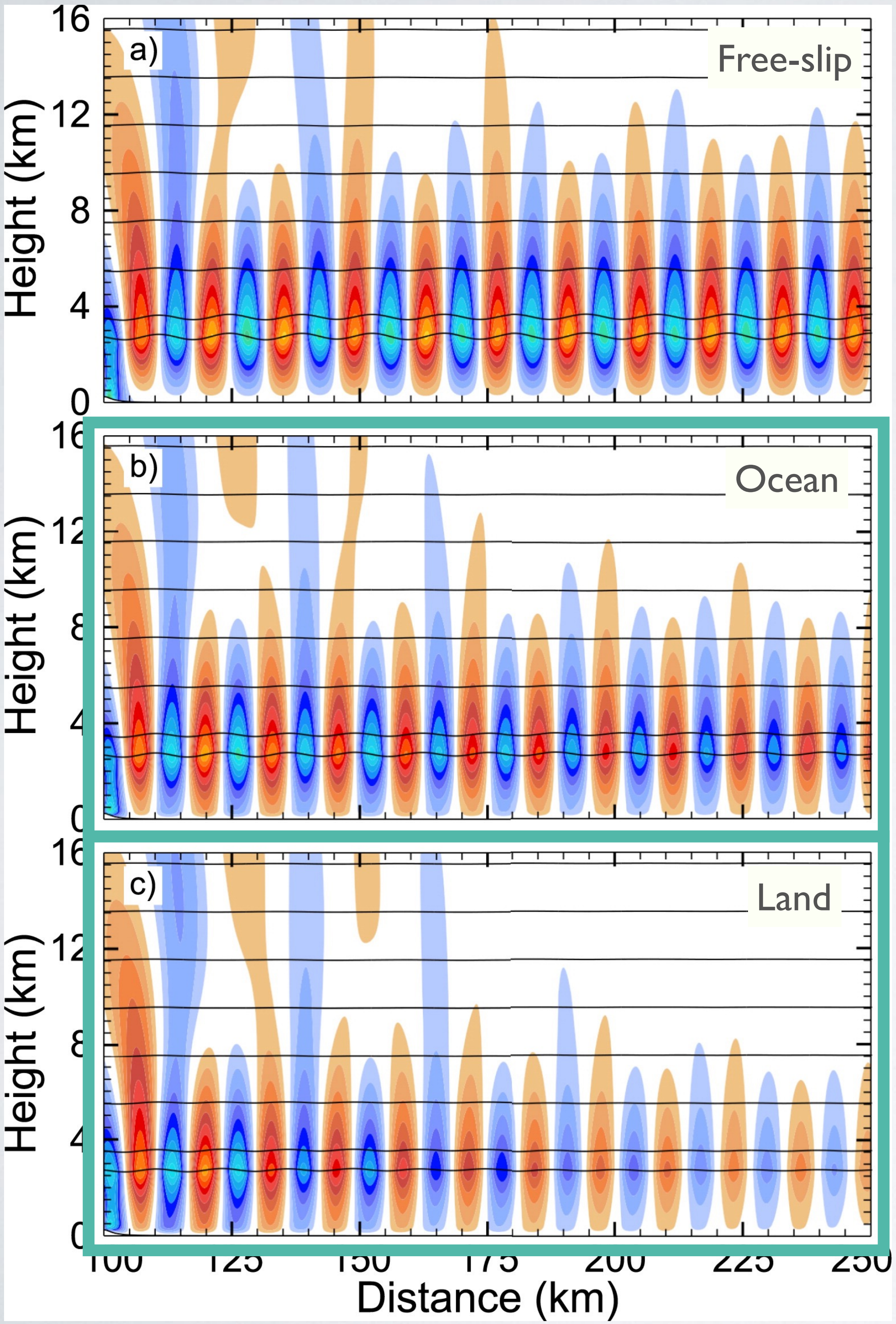
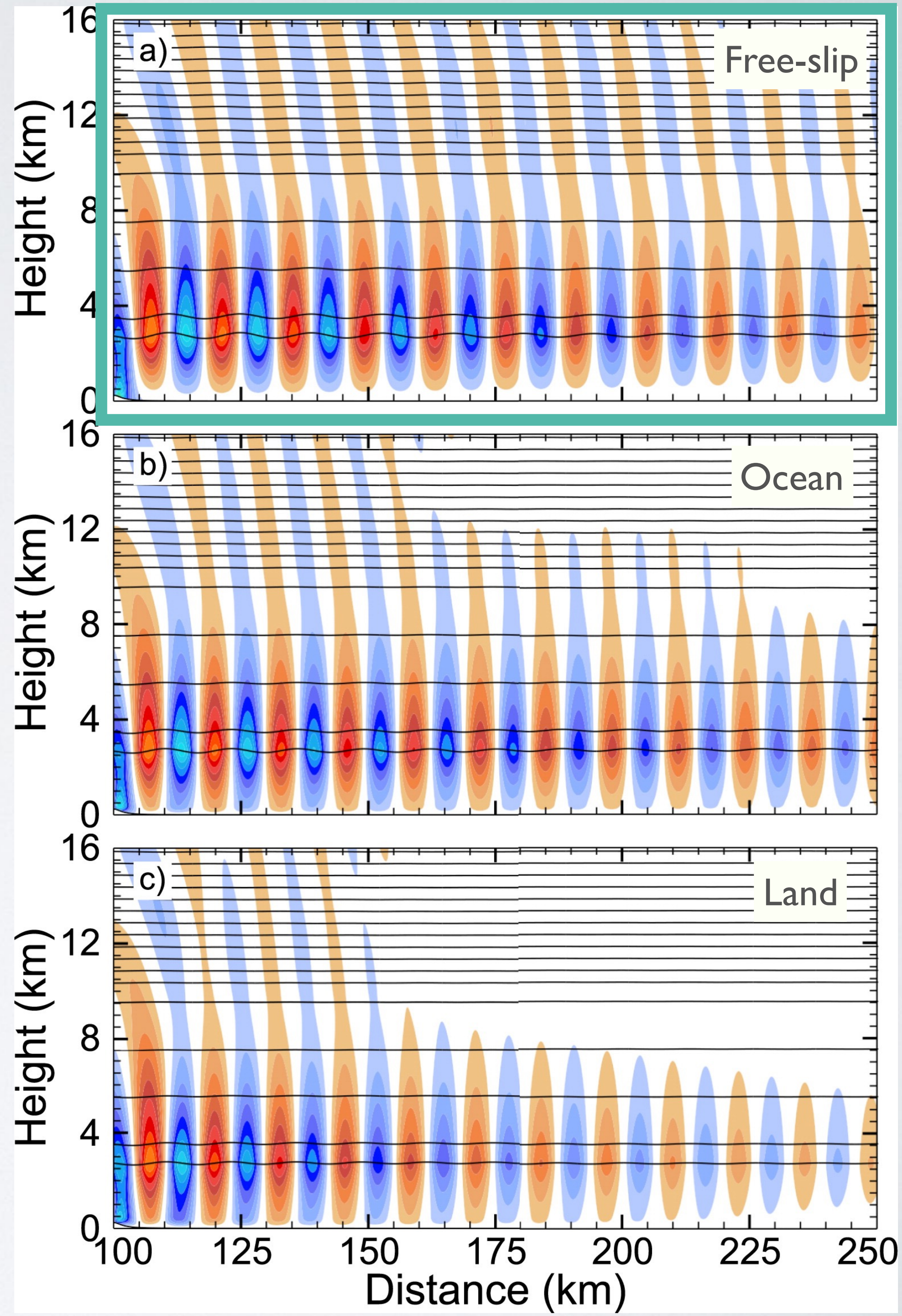
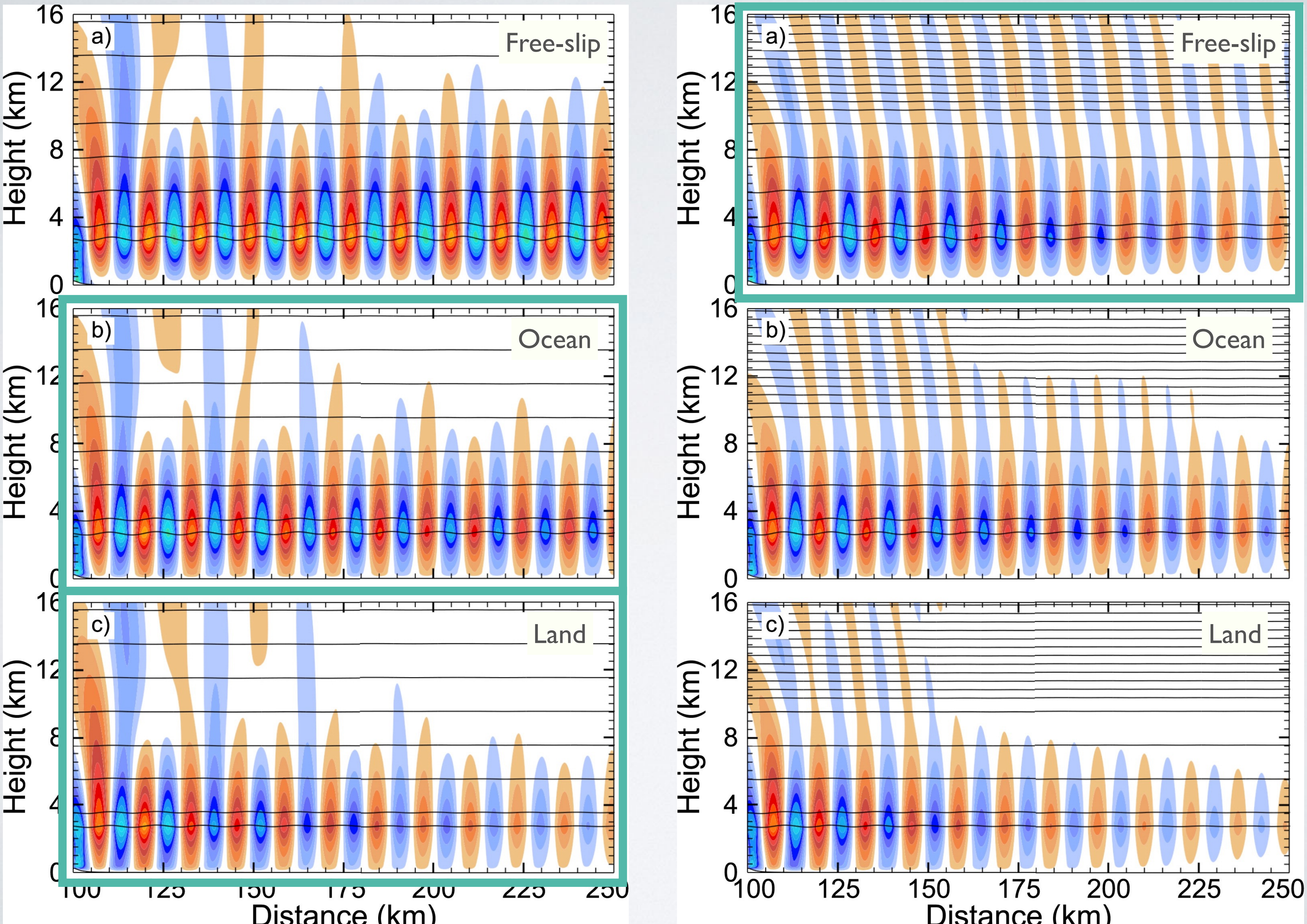


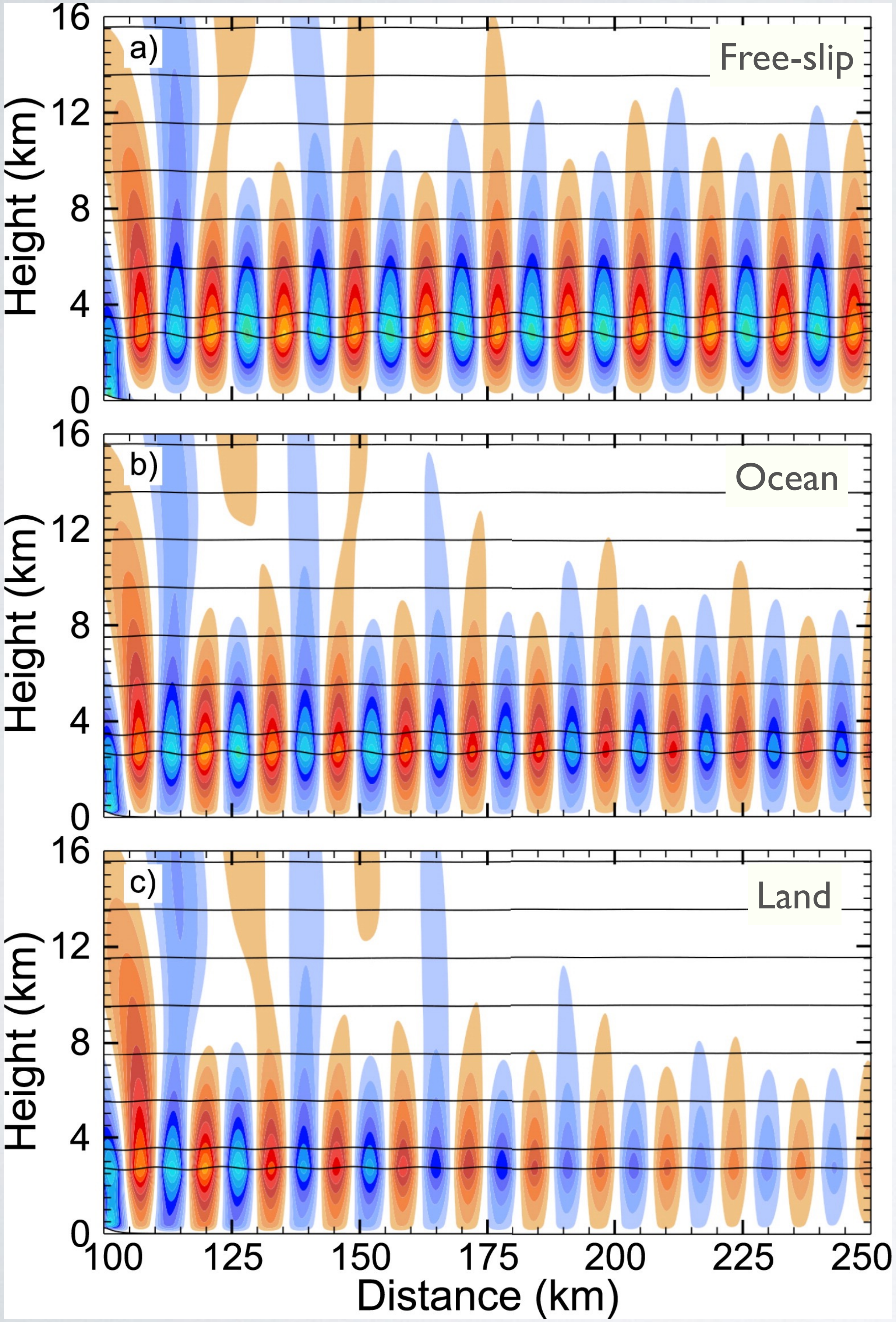


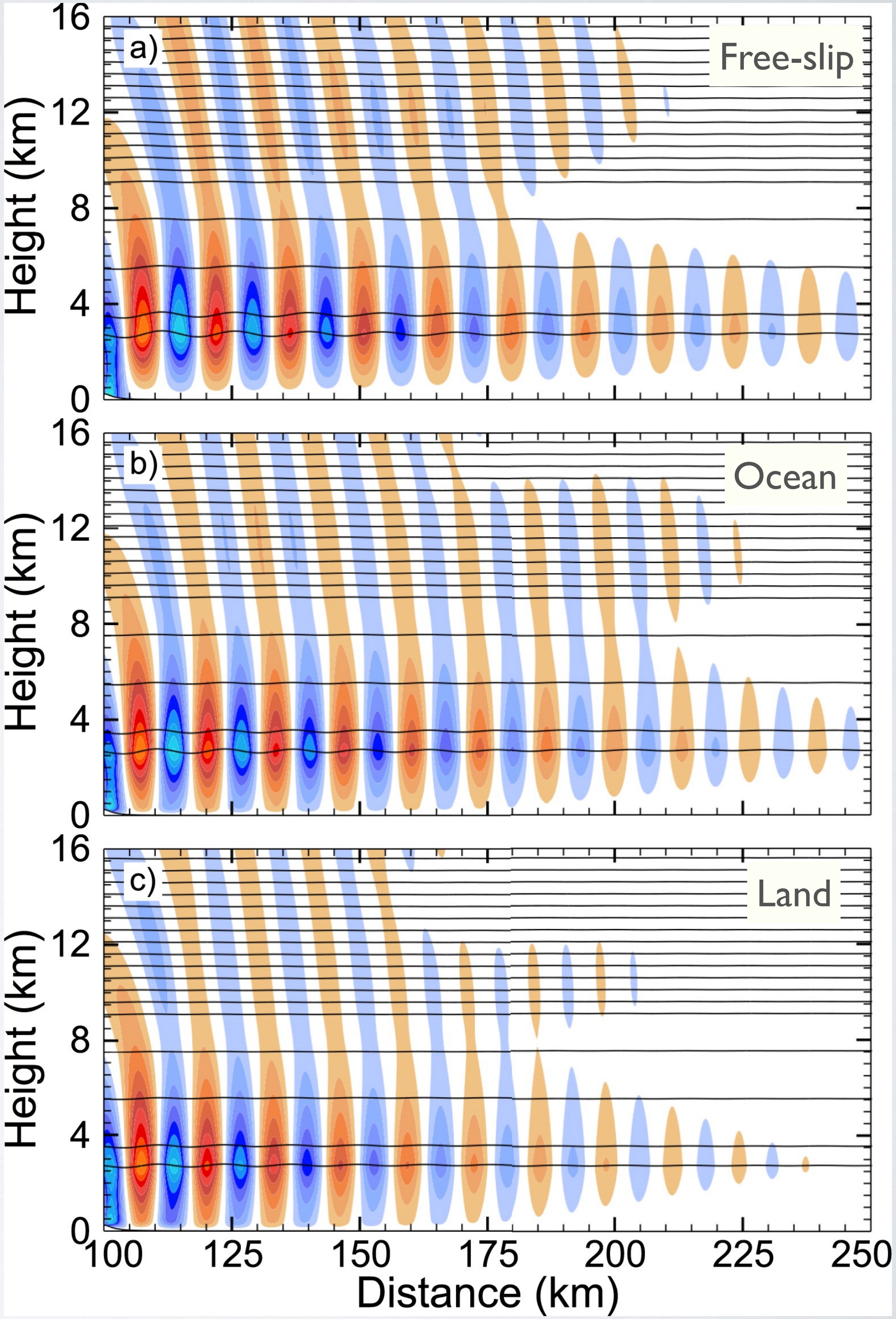
PBL-stratosphere comparison, z_t=10 km

Leakage ~ friction



PBL-stratosphere comparison, z_t=9 km





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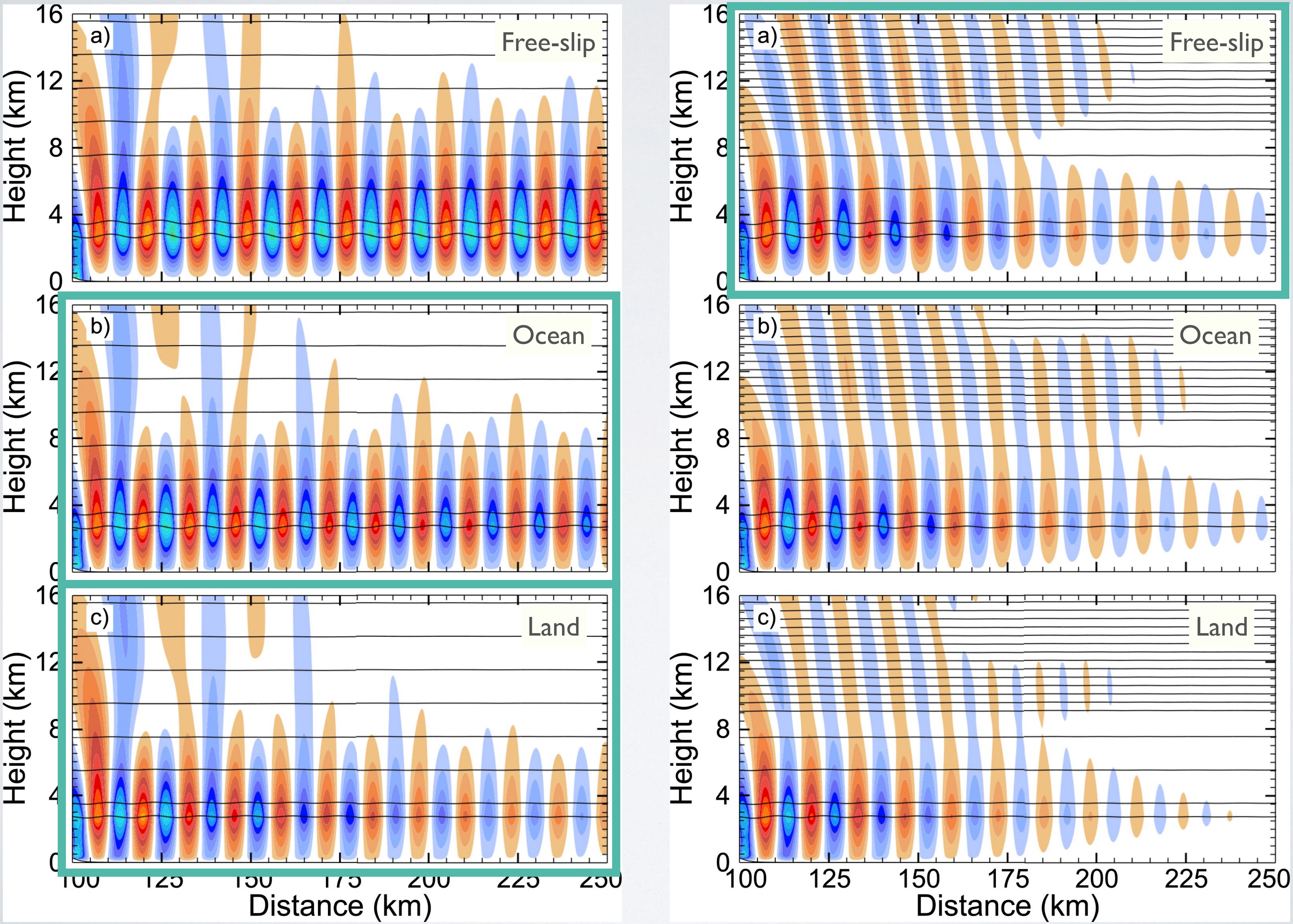
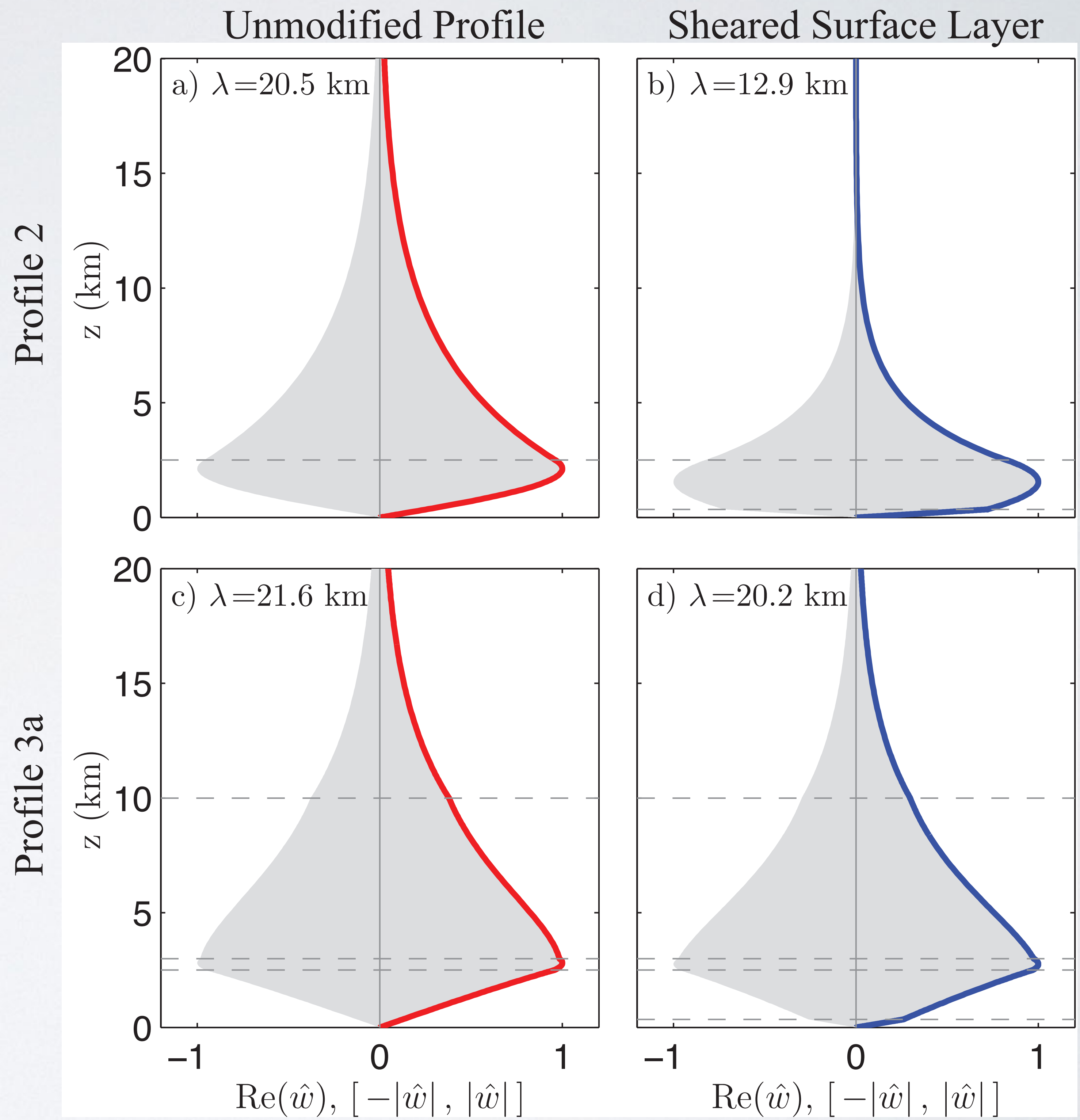
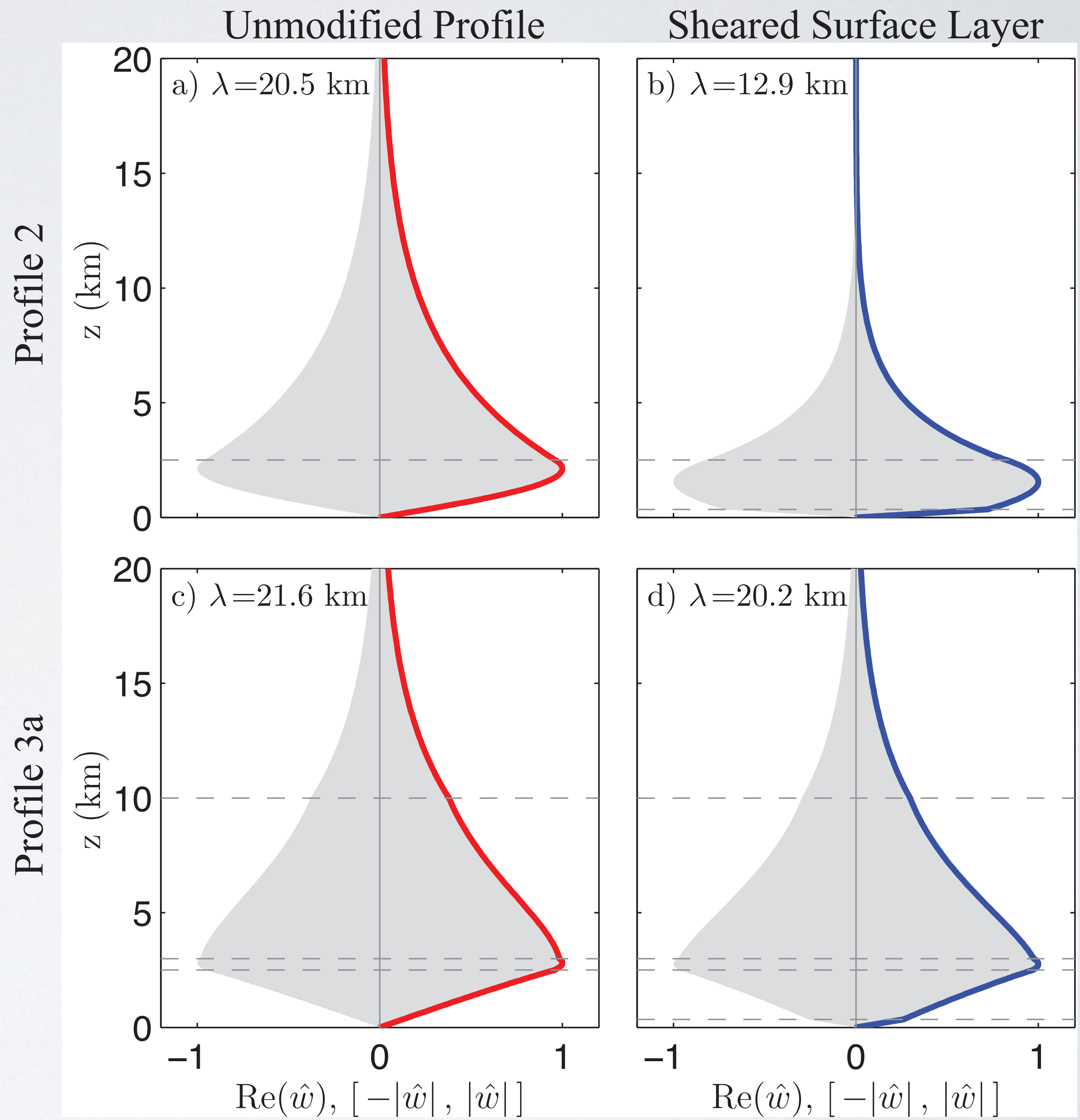


Surface friction reduces λ by changing the mean low-level wind



Surface friction reduces λ by changing the mean low-level wind

- Inviscid problem with friction induced low-level shear layer predicts modified λ.



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- Large change in low-level vertical wavelength in 2-layer case where
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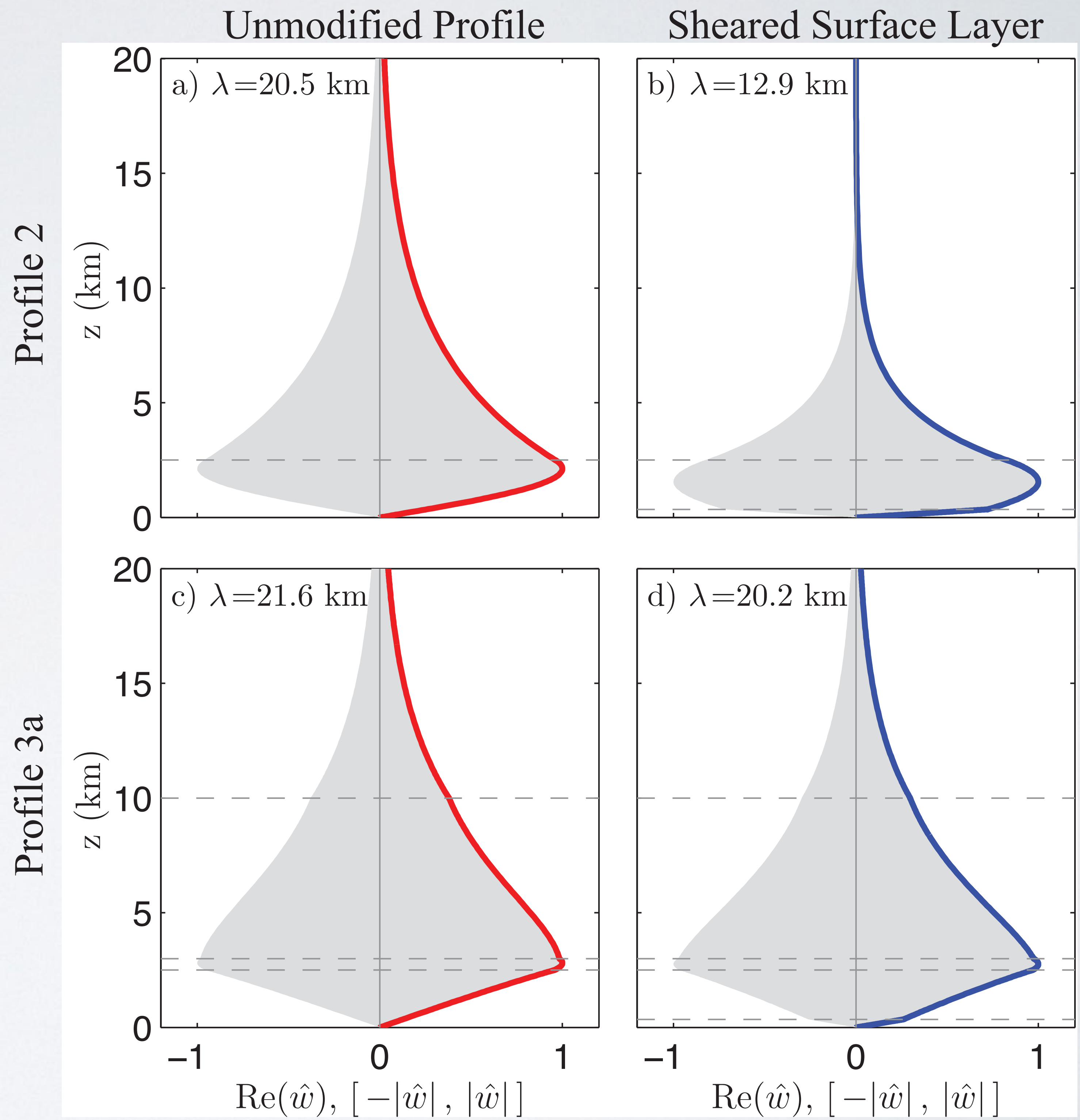
  - stability is high
  - large reduction in λ_i



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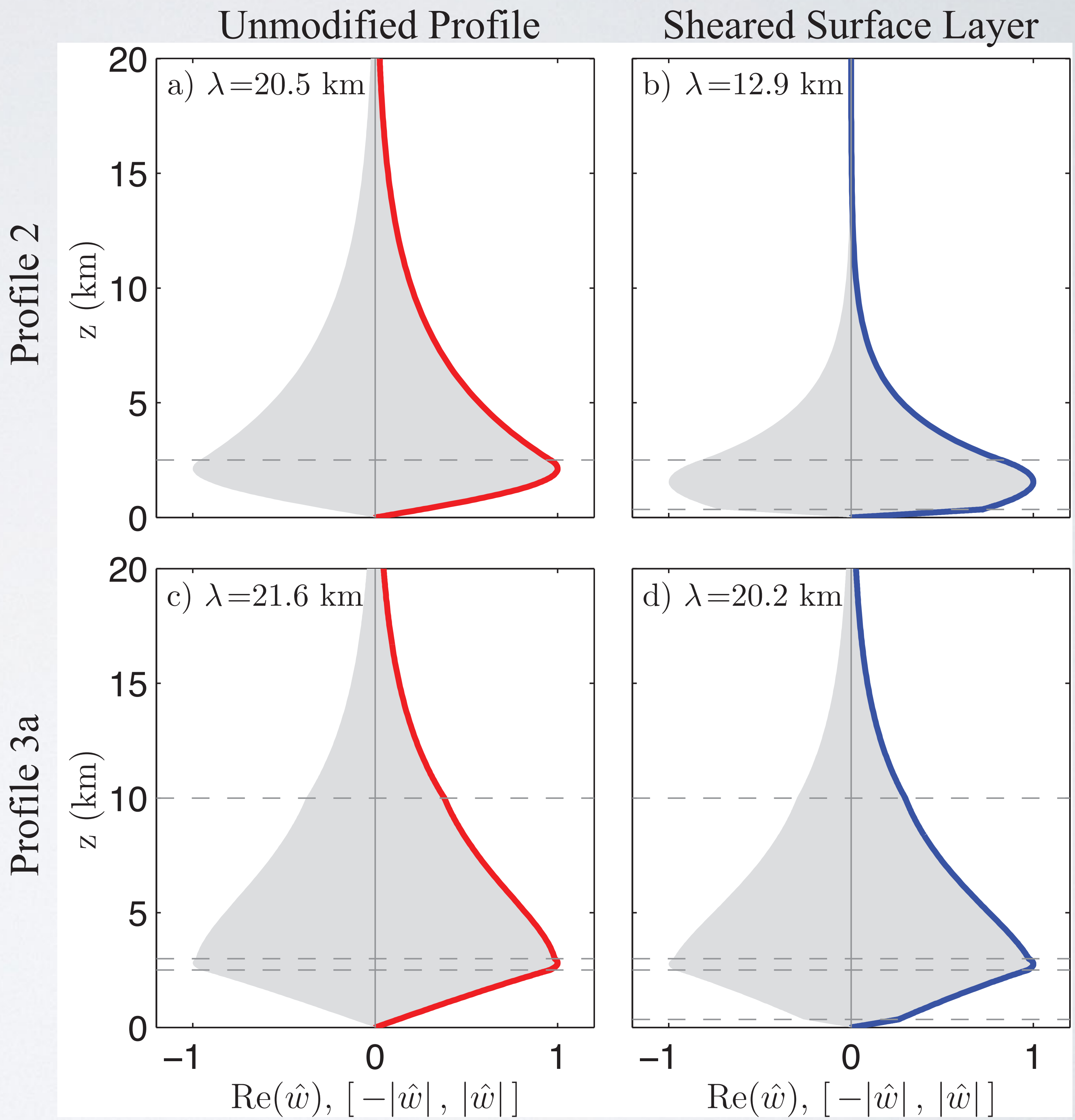
- Inviscid problem with friction induced low-level shear layer predicts modified λ.
- Large change in low-level vertical wavelength in 2-layer case where
  - speeds are low
  - stability is high
  - large reduction in λ_i
- Little change low-level vertical wavelength with elevated inversion
  - little reduction in λ_i



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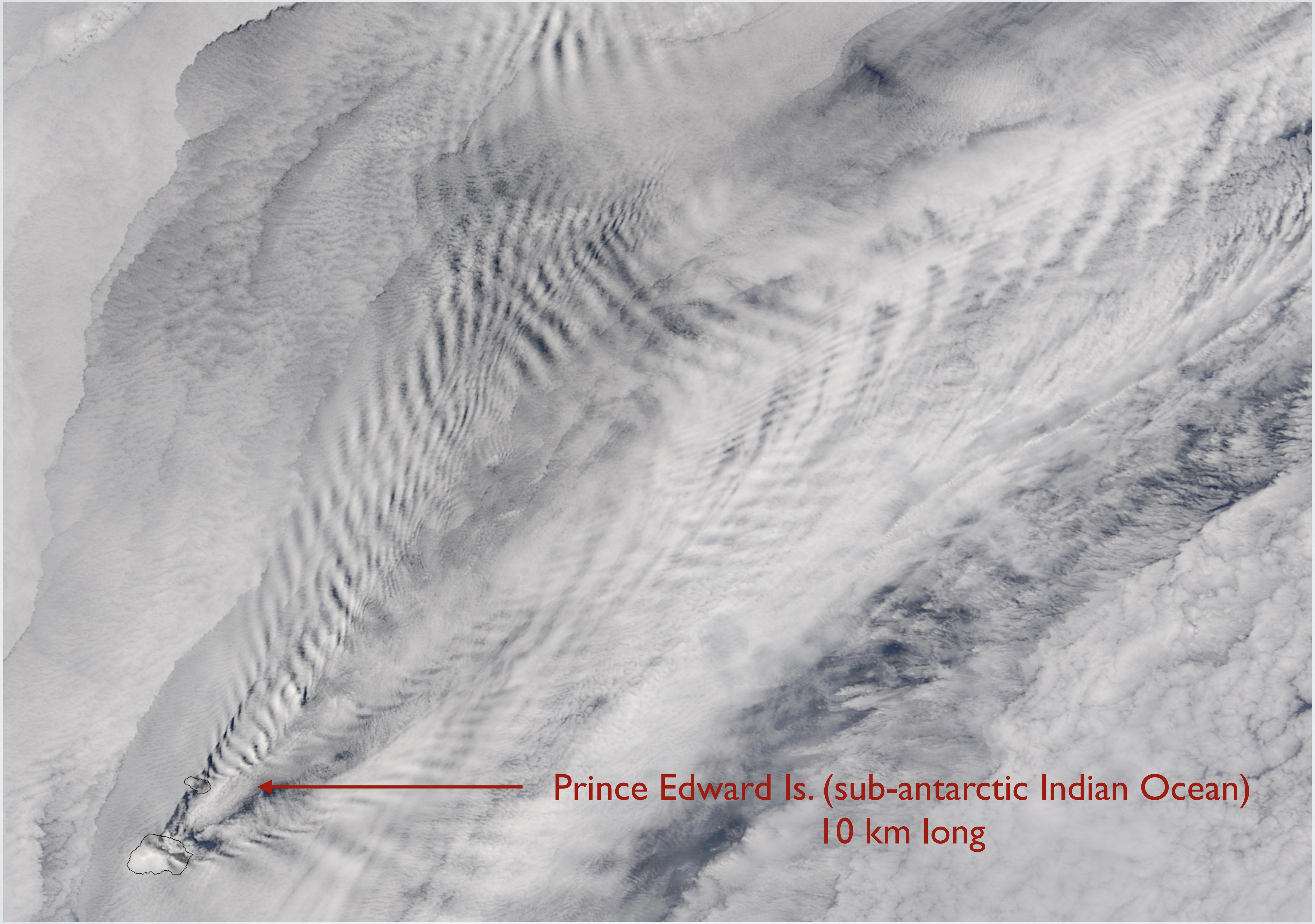
- Boundary layer friction is most important
  - For short wavelengths (λ approaching 8 km from above)
  - In idealized problems with high low-level static stability where the BL friction greatly reduces λ
- Stratospheric leakage is most important
  - For long wavelengths (λ approaching 28 km from below)
  - In cases with elevated inversions, where BL friction shows little tendency to reduce λ.

Low BL friction key factor in length of oceanic lee-wave trains?



Further Reading

Durran, D.R., M.O.G. Hills, and P.N. Blossey, 2015: The dissipation of trapped lee waves. Part I: Leakage of inviscid waves into the stratosphere. *J. Atmos. Sci.,* **72,** 1569-1584.

Hills, M.O.G., D.R. Durran and P.N. Blossey, 2016: The dissipation of trapped lee waves. Part II: The relative importance of the boundary layer and the stratosphere. *J. Atmos. Sci,* **73,** 943-955.