The potential of radio occultation data for climate wind field monitoring: an overview of latest results

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Motivation

Problem with the observational basis for global wind field monitoring:

- Most wind data show either:
  - High vertical resolution or
  - Global coverage

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Are radio occultation data suitable for wind field monitoring?

- **Global coverage**, typically with highest profile numbers at mid-latitudes
- Dense **multi-satellite** coverage of equatorial to mid-latitudes with COSMIC-2 mission
  - We test this multi-satellite coverage, focusing our studies on the years 2007-2020
- Provision of **high-vertical resolution** atmospheric profiling
- Essentially **independent of cloud influences**; near-global troposphere coverage
- Best accuracy in **upper troposphere and lower stratosphere**

Estimation of wind fields

Local approximations of the dynamical equations

- Geostrophic balance:
  - Pressure gradient force and Coriolis force
- Gradient wind balance:
  - Includes also centrifugal force
- Equatorial balance:
  - Solution when Coriolis force approaches zero towards the equator
- Friction not relevant in the free atmosphere (above the boundary layer)

Brief outlook

- Including advection into the dynamic solution

Evaluation

Based on …

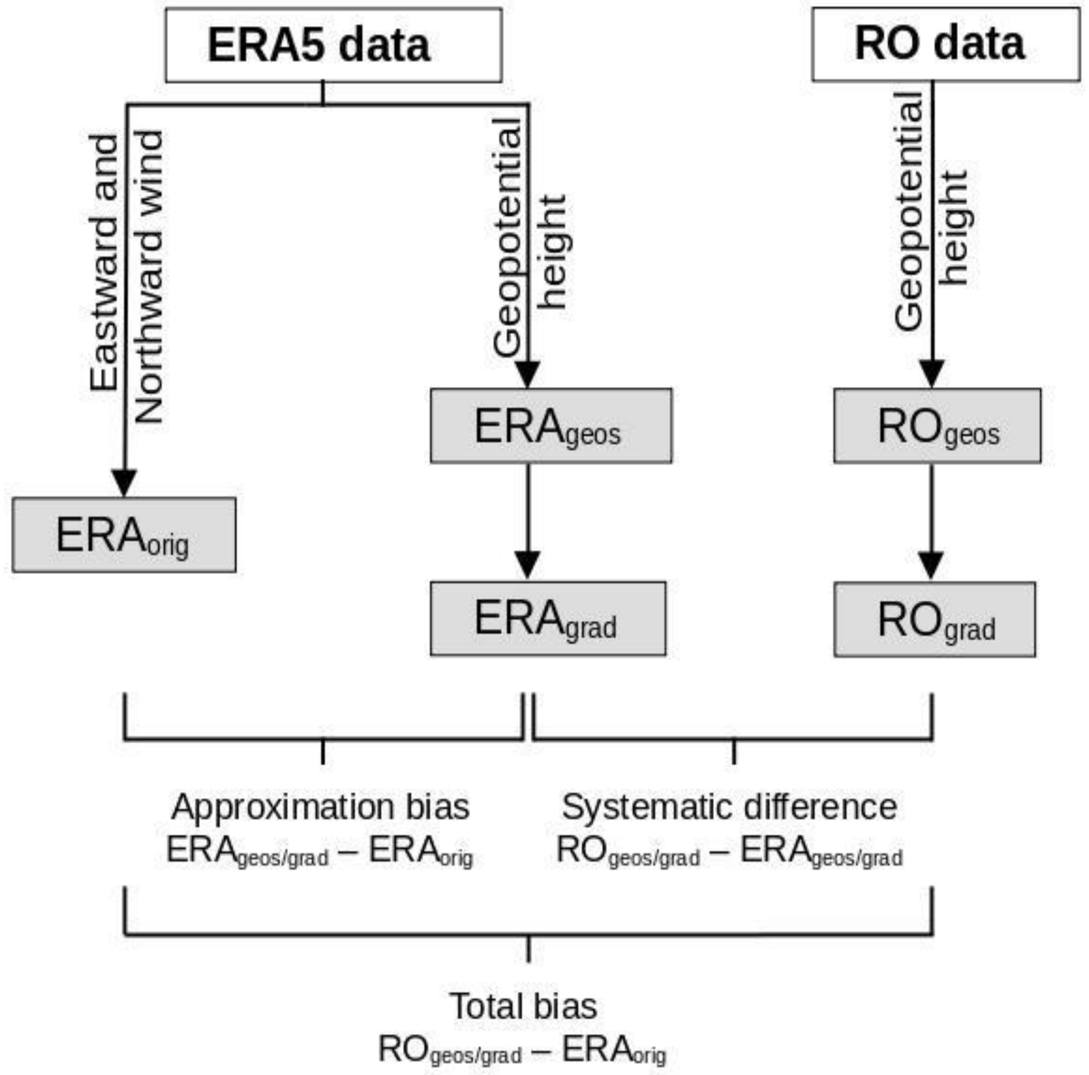
- ERA5 reanalysis data over 2007 - 2020
- Multi-satellite RO data from 2007 - 2020

Step 1: Evaluation of the approximation bias

- Geostrophic wind, gradient wind, equatorial-balanced wind

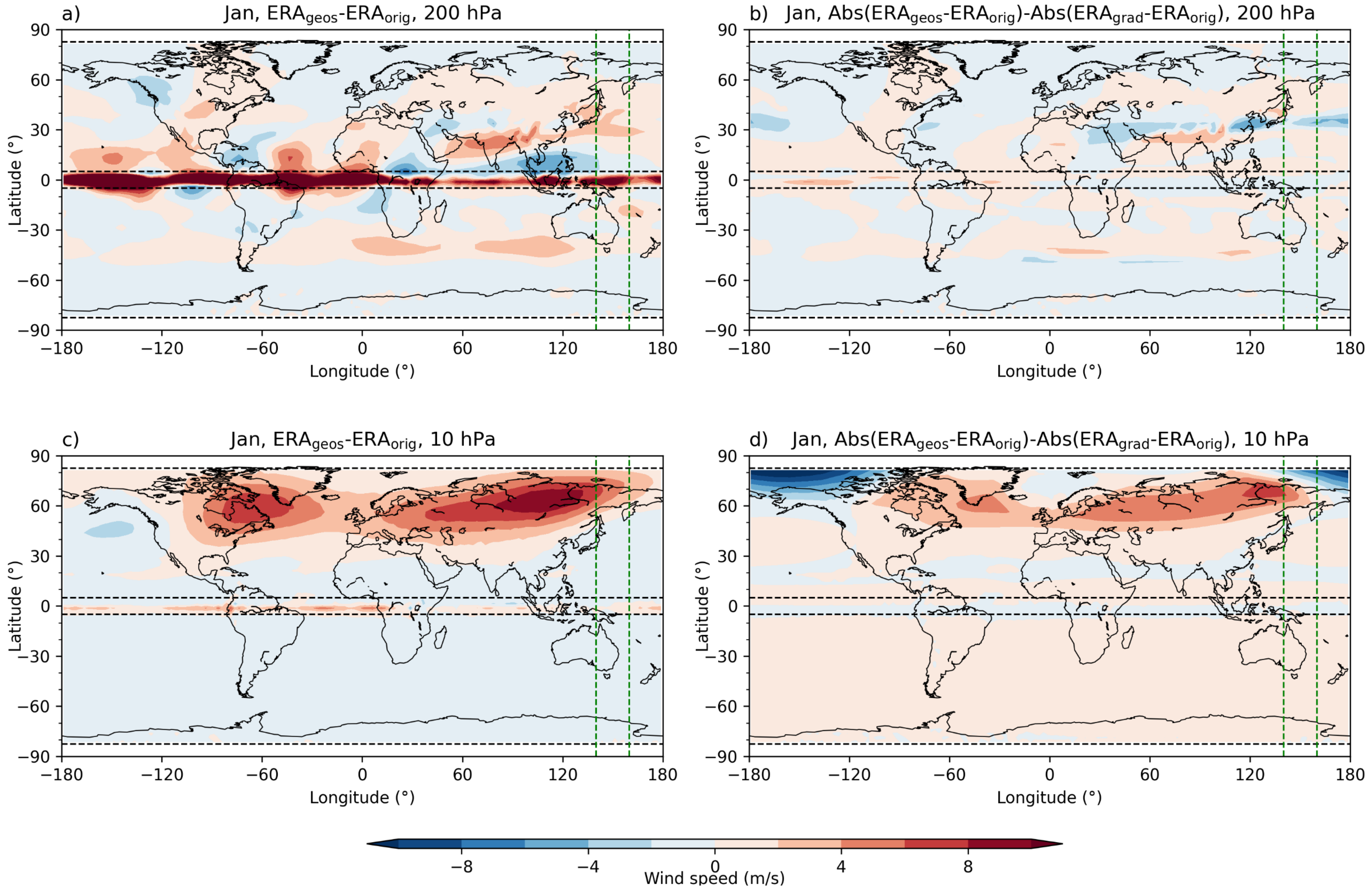
Step 2: Evaluation of the systematic difference

- Agreement between wind speed datasets
- Potential and added value of RO



Step 1: The approximation bias

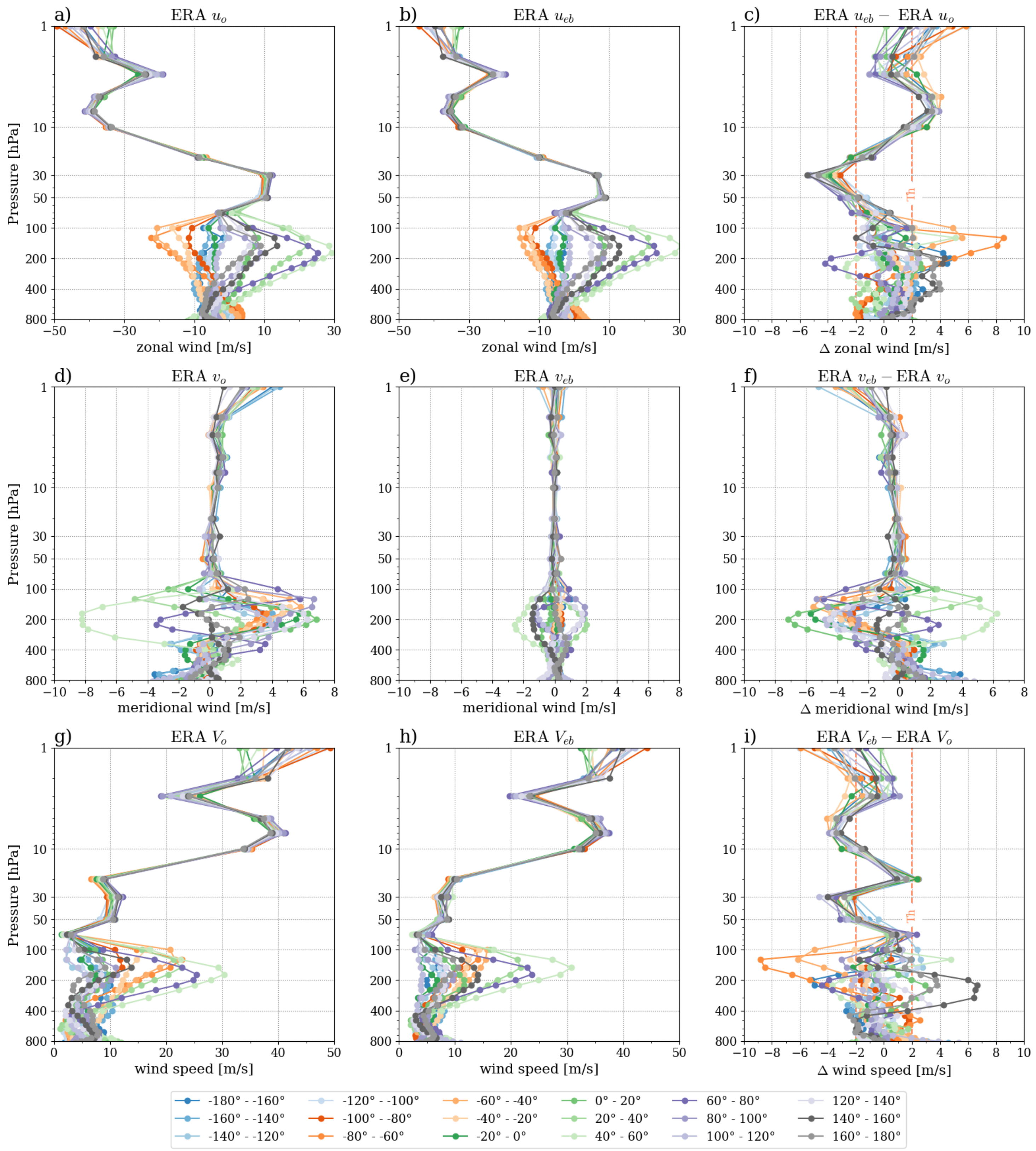
Horizontal latitude-vs-longitude cross section



Geostrophic vs gradient approximation

- Long-term wind speed difference
- Example: January (two altitude layers)
- Note the polar region

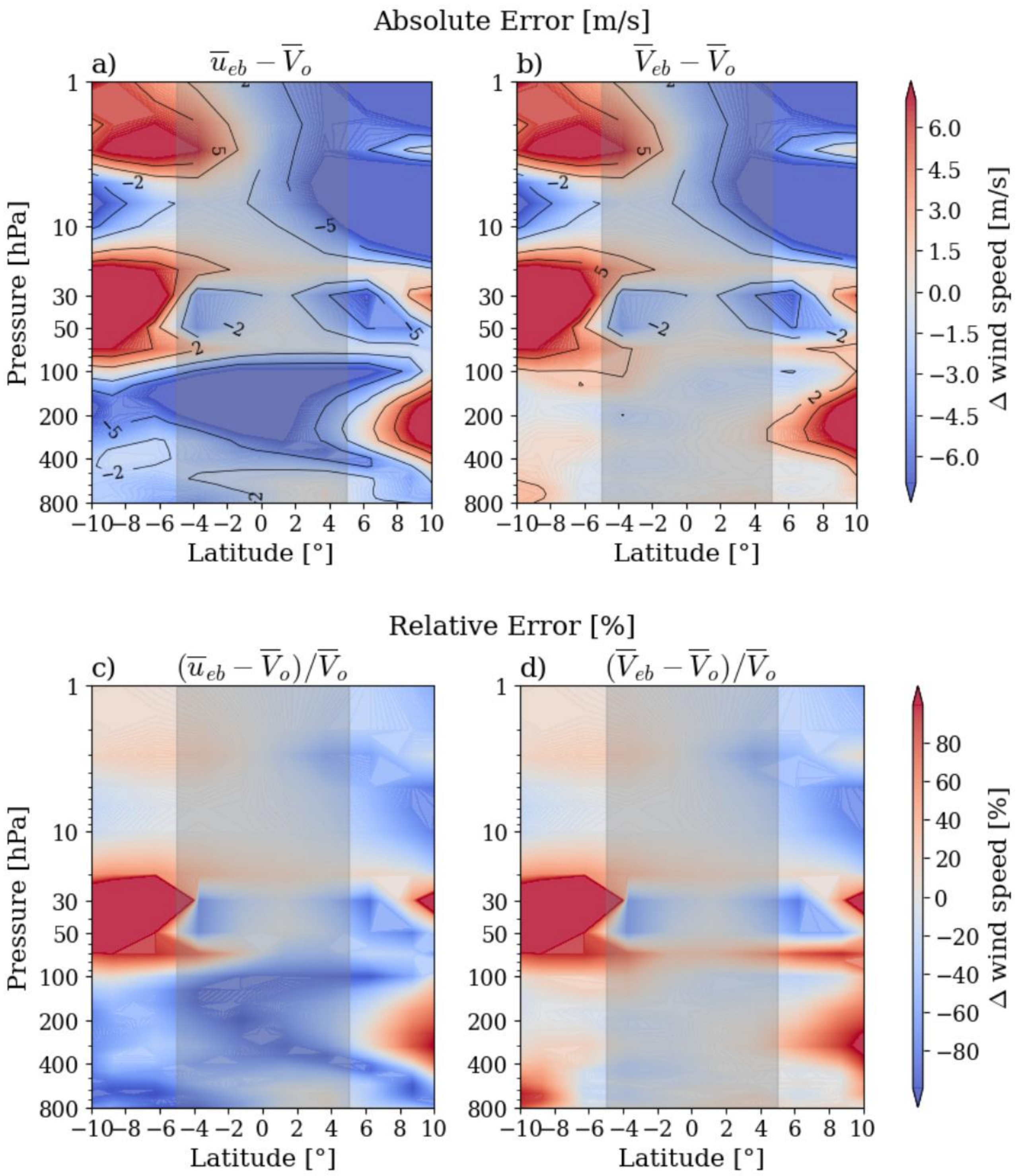
Analyzing winds across the equator



Equatorial balance equation

- Approximation bias
- 20° longitude sectors
- Comparison:
  - Zonal wind
  - Meridional wind
  - Wind speed

Analyzing winds across the equator

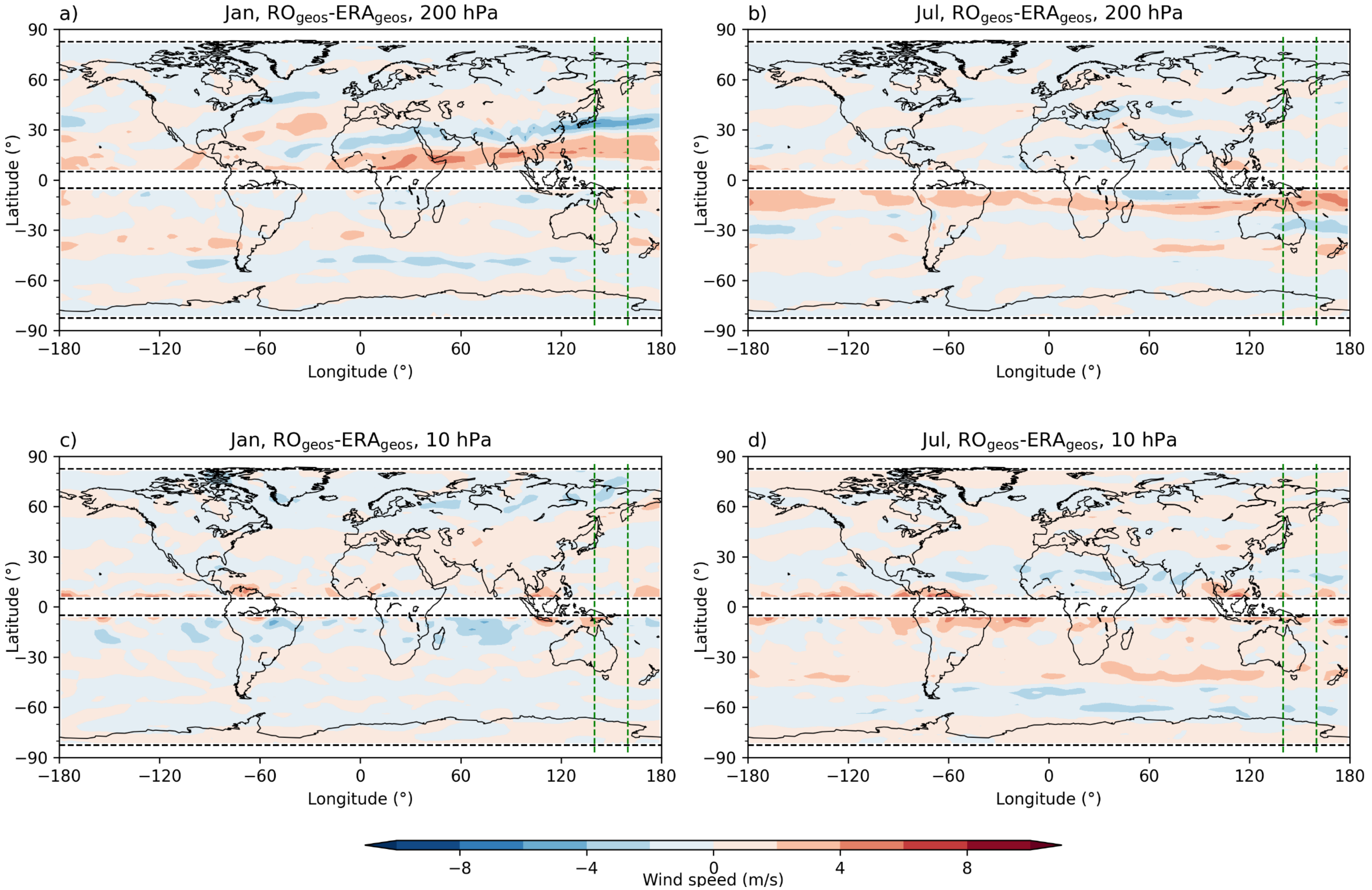


Vertical altitude-vs-latitude cross section

- Equatorial balance approximation
  - Zonal wind
  - Meridional wind
  - Wind speed
- Absolute and relative differences

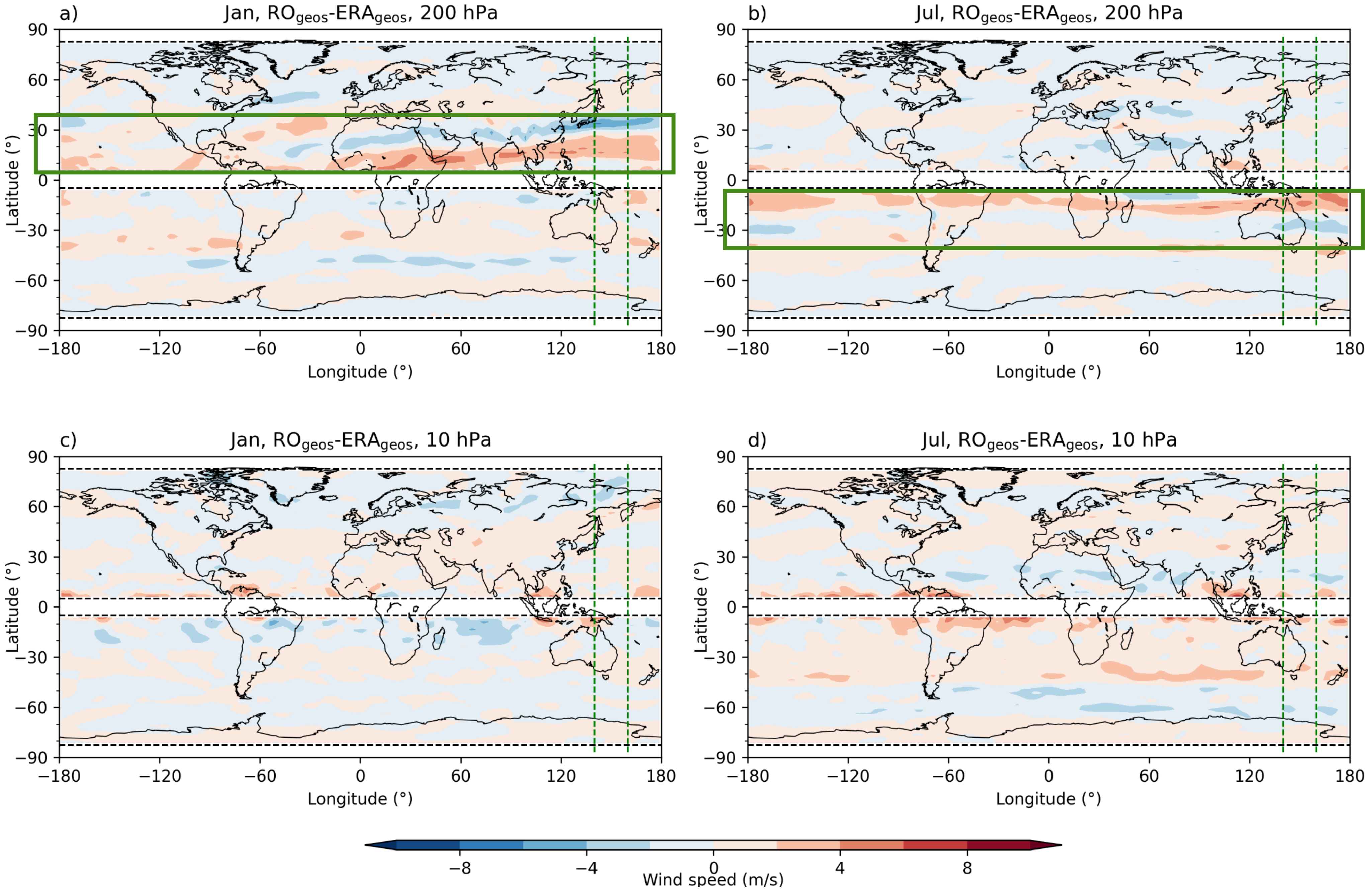
Step 2: The systematic difference

Horizontal latitude-vs-longitude cross section



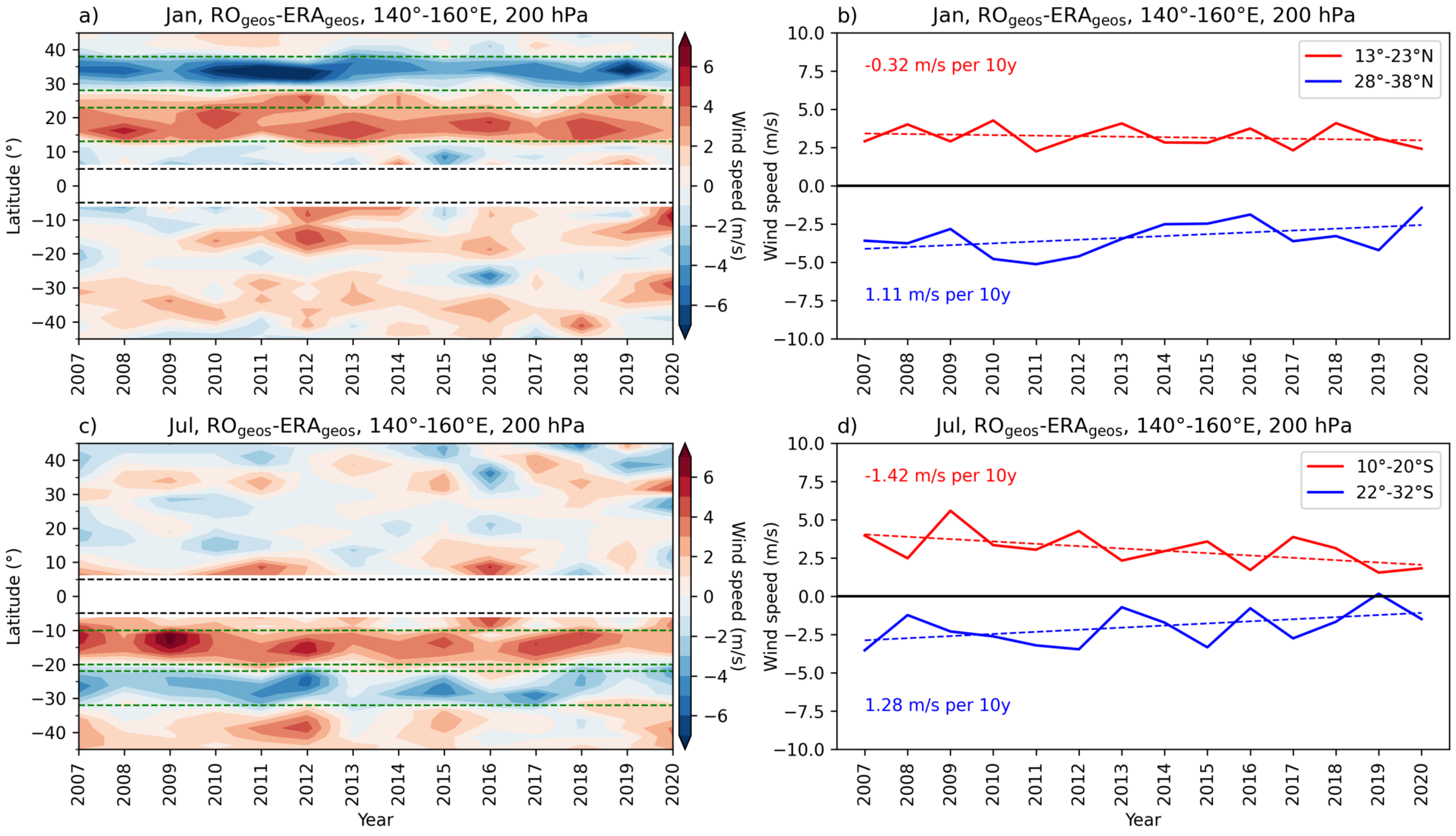
- Systematic difference between RO & ERA5
- Jan & Jul, 200 hPa and 10hPa

Horizontal latitude-vs-longitude cross section



- Systematic difference between RO & ERA5
- Note the difference at 200 hPa in the jet stream region

Temporal stability



- Systematic difference
- Check in jet stream core regions
- WMO wind speed stability requirement: 0.5 m/s per decade

- Threshold exceeded in the jet stream core region

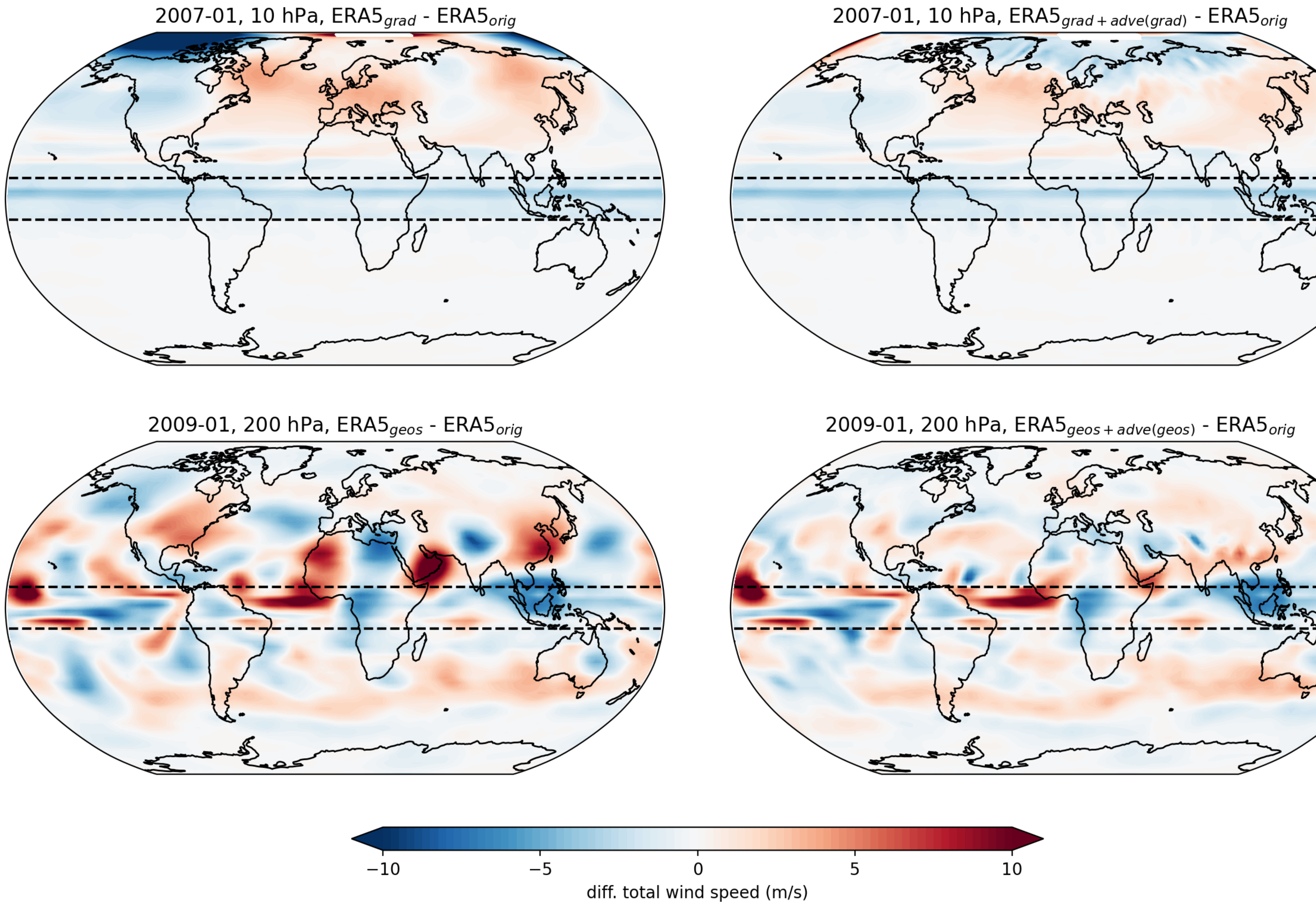
Intermediate summary

- **Geostrophic** approximation works better in the **troposphere**
- **Gradient** wind works better in the **stratosphere**
- Systematic difference small, except in the **jet stream** region
- Equatorial balance approximation:
  - Possible to compute zonal & meridional components
  - Zonal wind dominates in the stratosphere, meridional wind essentially zero
  - However, focus on wind speed: including both components improves the wind speed estimate

Outlook: Including advection

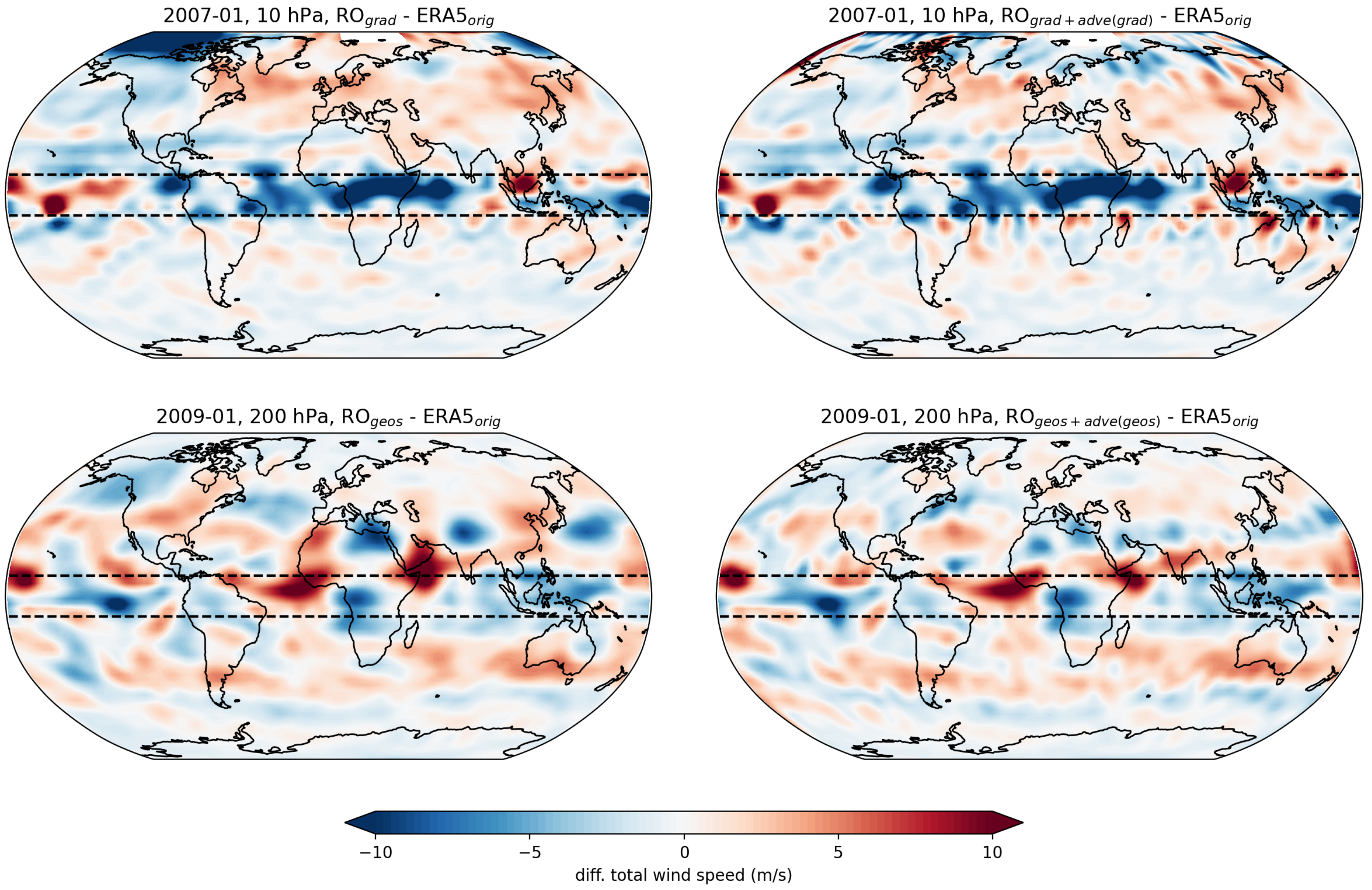
(preliminary work of I. Nimac & J. Unegg et al.)

Improved estimates ERA5 – vertical level maps



- Systematic wind differences ERA5estimates vs. ERA5orig
- Jan 2007, 10 hPa and Jan 2009, 200 hPa

Improved estimates RO data – vertical level maps



- Systematic wind differences ROestimates vs. ERA5orig
- Jan 2007, 10 hPa and Jan 2009, 200 hPa

Best-approximation classes ERA5 – vertical level maps

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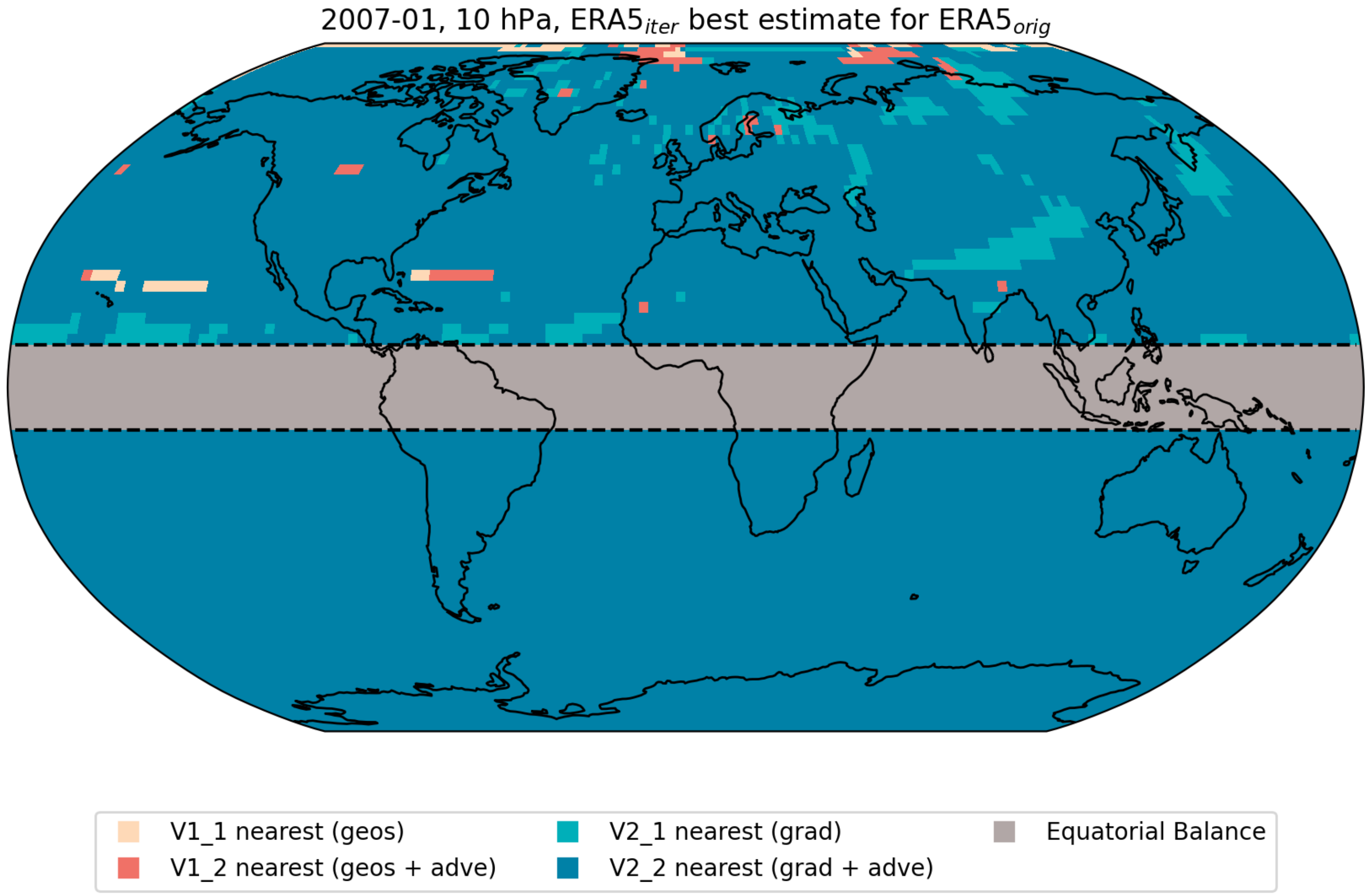
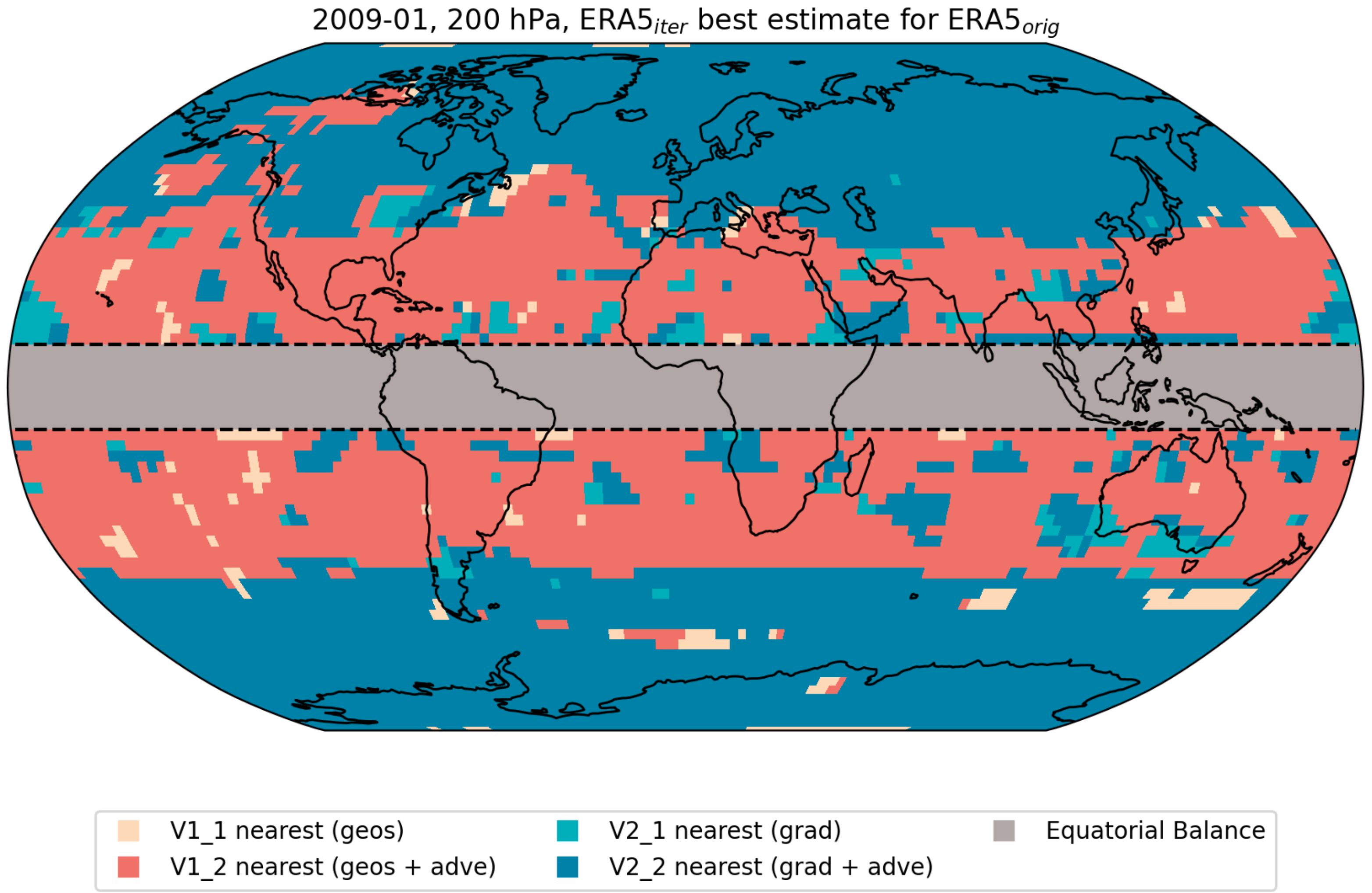
stratosphere (10hPa level)

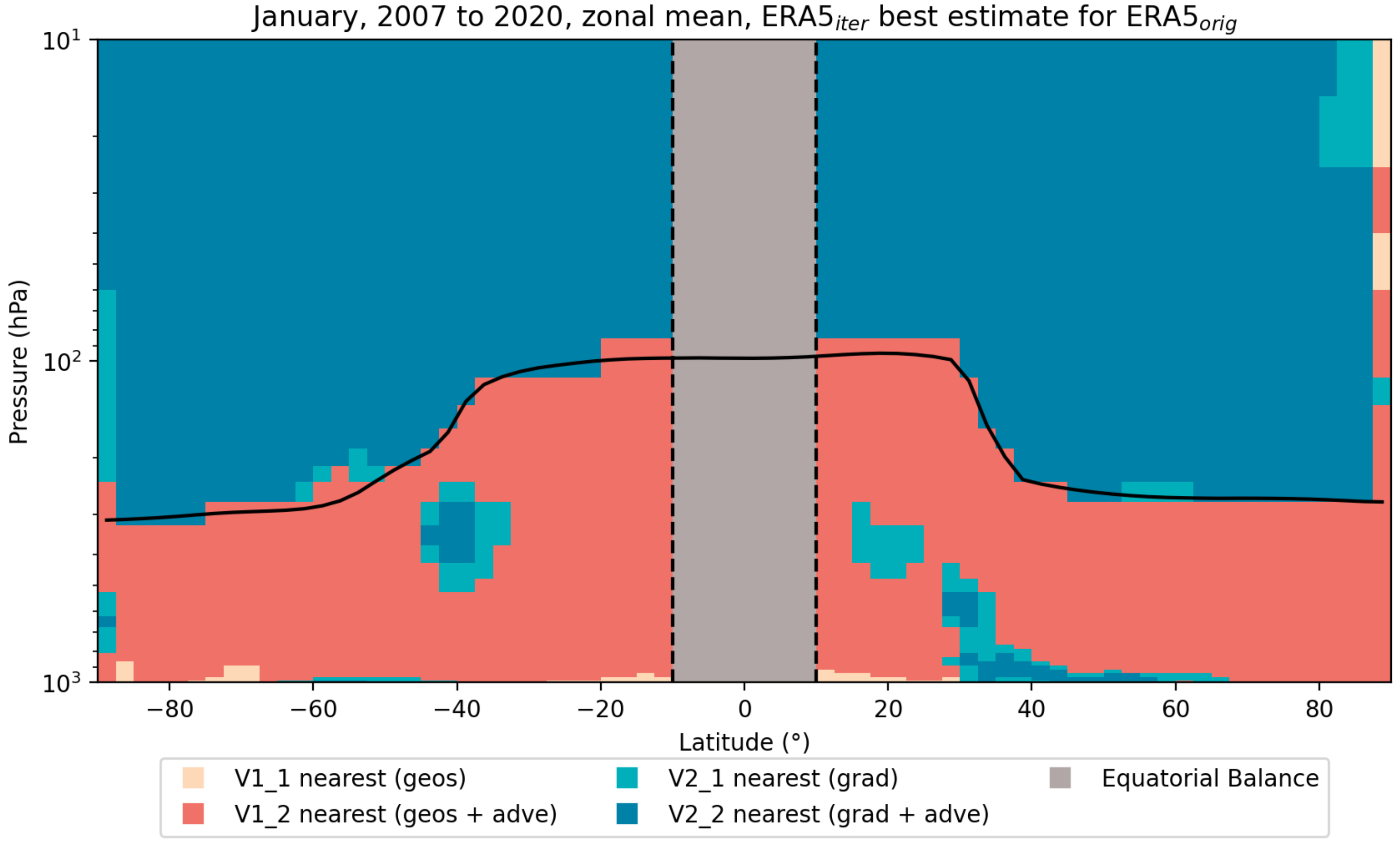


troposphere & stratosphere (200hPa level)

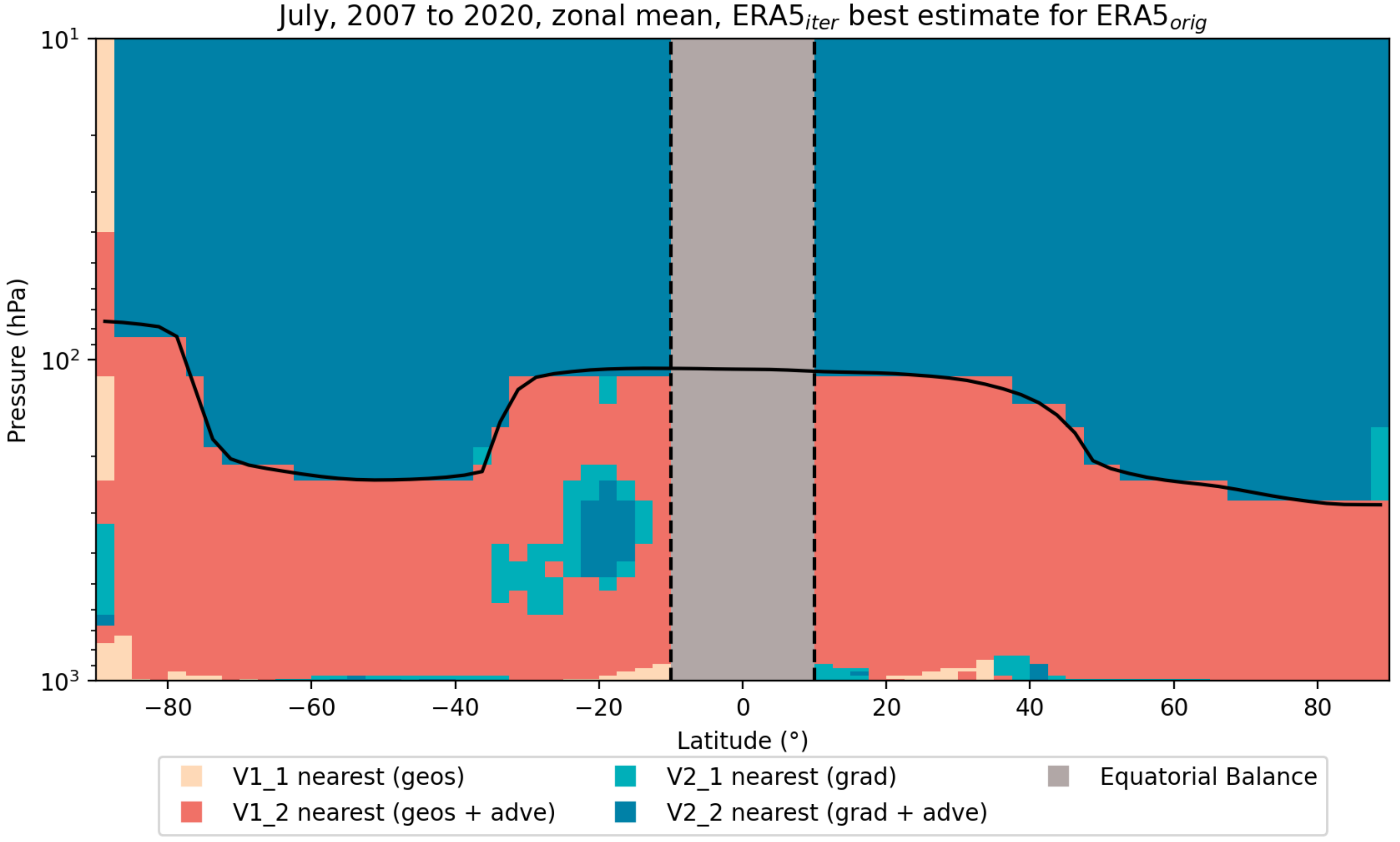


Best-approximation classes ERA5 – lat-vs-alt. sections

January conditions (zonal mean 2007-2020)



July conditions (zonal mean 2007-2020)



Summary

Geostrophic, gradient, equatorial-balance wind approximations:

- Wind speed differences generally **within ±2 m/s WMO requirement**
- Larger **wind speed differences**
  - partially in the winter hemisphere
  - over polar regions in the stratosphere
- **Gradient** wind (influence of centrifugal force) takes over with improved quality in the **stratosphere**
- **Systematic difference small**, **except** in the regions of the **jet stream**
- **Equatorial-balance approximation:**
  - Zonal wind dominates in the stratosphere
  - Wind speed benefits from both components, especially in the troposphere

Conclusion and outlook

Conclusion

- Possible to derive monthly 2.5° x 2.5° RO wind fields for climate monitoring
- Expected added value due to high vertical resolution, global coverage, long-term stability
  - Reanalysis shows observing system changes in their time series; uncertainties are less clear

Outlook

- Derivation of complete three-dimensional wind fields based on RO reprocessing
- Dynamic application of the joint best-estimate approximations
- Including **advection in the wind-field estimate**
- **... more** StratoClim **work in progress** & **research proposal** in preparation

StratoClim-Literature

https://wegcenter.uni-graz.at/de/forschen/forschungsgruppe-arsclisys/projekte/stratoclim/
https://homepage.uni-graz.at/de/julia.danzer/

Danzer, J., Pieler, M., & Kirchengast, G. (2024). Closing the gap in the tropics: the added value of radio-occultation data for wind field monitoring across the equator. Atmospheric Measurement Techniques, Vol. 17, Issue 16, 4979-4995, https://doi.org/10.5194/amt-17-4979-2024.

Nimac, I., Danzer, J., & Kirchengast, G. (2024). The added value and potential of long-term radio occultation data for climatological wind field monitoring. Atmospheric Measurement Techniques Discussions, https://doi.org/10.5194/amt-2024-59, preprint, April 2024.

Nimac, I., Danzer, J., & Kirchengast, G. (2023). Validation of the geostrophic approximation using ERA5 and the potential of long-term radio occultation data for supporting wind field monitoring. Atmospheric Measurement Techniques Discussions, 2023, 1-24, https://doi.org/10.5194/amt-2023-100.

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Thank you for your attention!

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We work for tomorrow

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