Waveguidability of a midlatitude jet and the limitation of ray tracing

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WAVES TO WEATHER

The paper: Wirth, 2020, W*ea. and Clim. Dyn*., **1**, 111-125

Motivation:

waveguidability and midlatitude Rossby wave amplitude

Quasi-resonance theory

Quasiresonant amplification of planetary waves and recent Northern Hemisphere weather extremes

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Contributed by Hans Joachim Schellnhuber, January 16, 2013 (sent for review June 15, 2012)

PNAS 2013

The key idea:

a good zonal waveguide is conducive to large Rossby wave amplitude

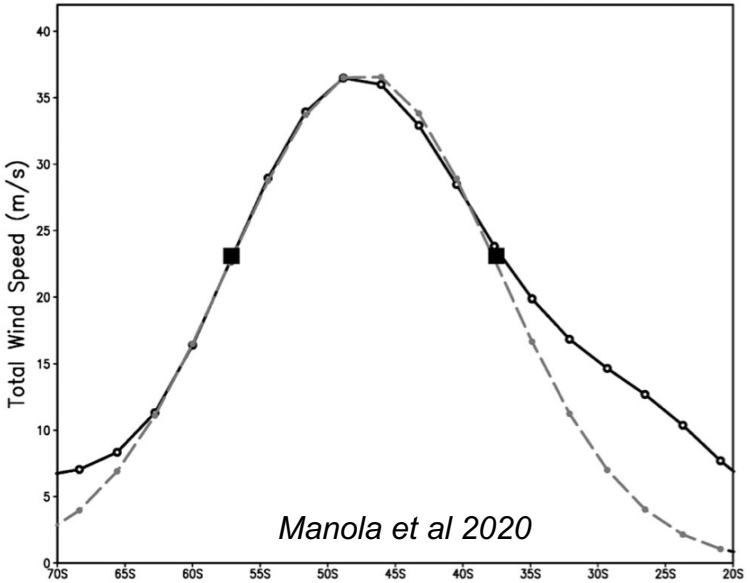
…and subsequent publications:

- Coumou et al. 2014, PNAS
- Petoukhov et al. 2016, PNAS
- Stadtherr et al. 2016, Sci. Adv.
- Kornhuber et al. 2016, Clim. Dyn.
- Mann et al. 2017, Sci. Reports

Waveguidability of idealized jets

Manola et al. 2013

Waveguidability = propensity of a background state to lead to Rossby wave ducting in the zonal direction



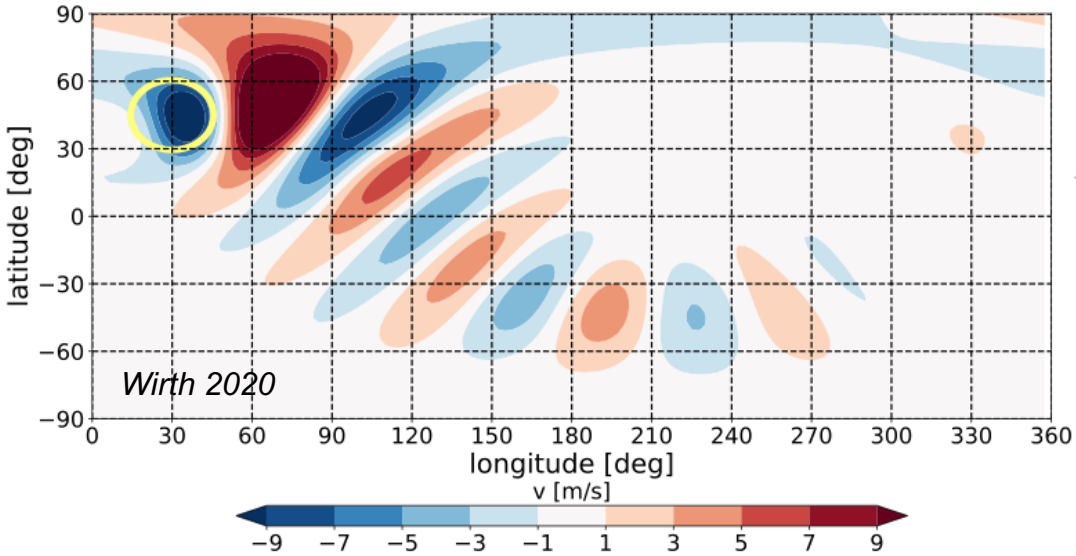
- idealized Gaussian jets
- numerical simulations
- **Result**: good waveguidability for **strong and narrow jets**

Waveguidability ←→ background flow

background flow: no jet = no waveguide

→ Rossby wave activity refracted away from the NH midlatitudes

→ **no** chance of quasi-resonance



Idealized model setup in the barotropic model:

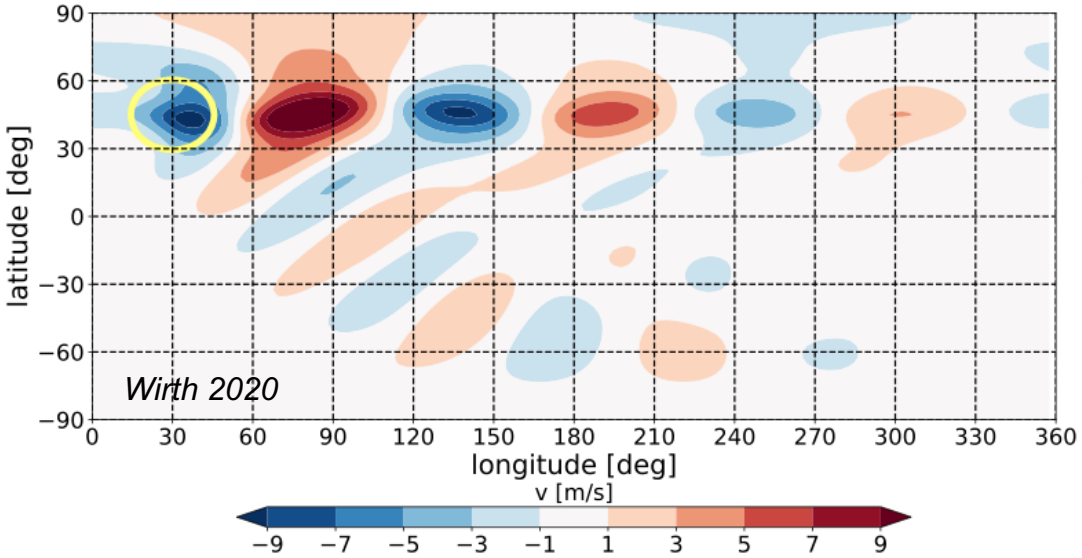
- local **forcing** (yellow circle)
- **background flow**: solid body rotation
- Rossby are refracted **towards the subtropics**

Waveguidability ←→ background flow

background flow: strong jet = good waveguide

→ Rossby wave ducted along NH midlatitudes

→ **potentially** a chance for quasi-resonance



Idealized model setup in the barotropic model:

- local **forcing** (yellow circle)
- **background flow**: strong jet
- Rossby are **ducted** in the **zonal direction**

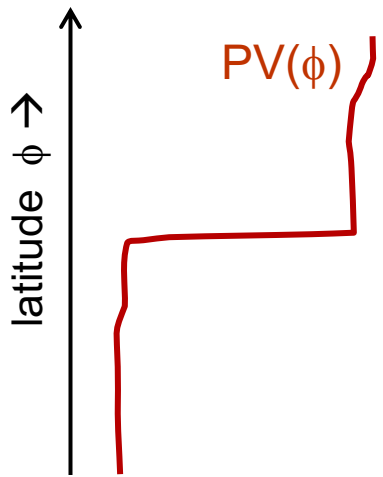
Theoretical concepts for a zonal waveguide

Wave guide theory

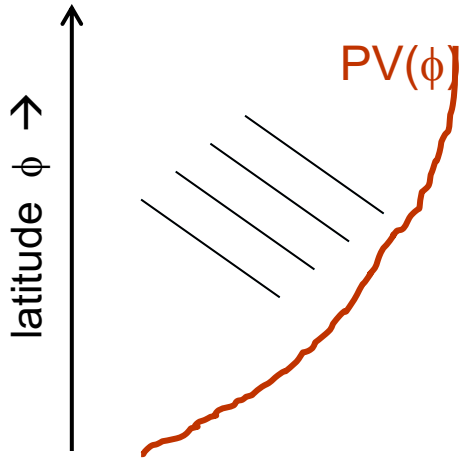
Why do strong narrow jets serve as zonal waveguides?

There are two rather different perspectives/frameworks:

Sharp gradient in PV(ϕ)

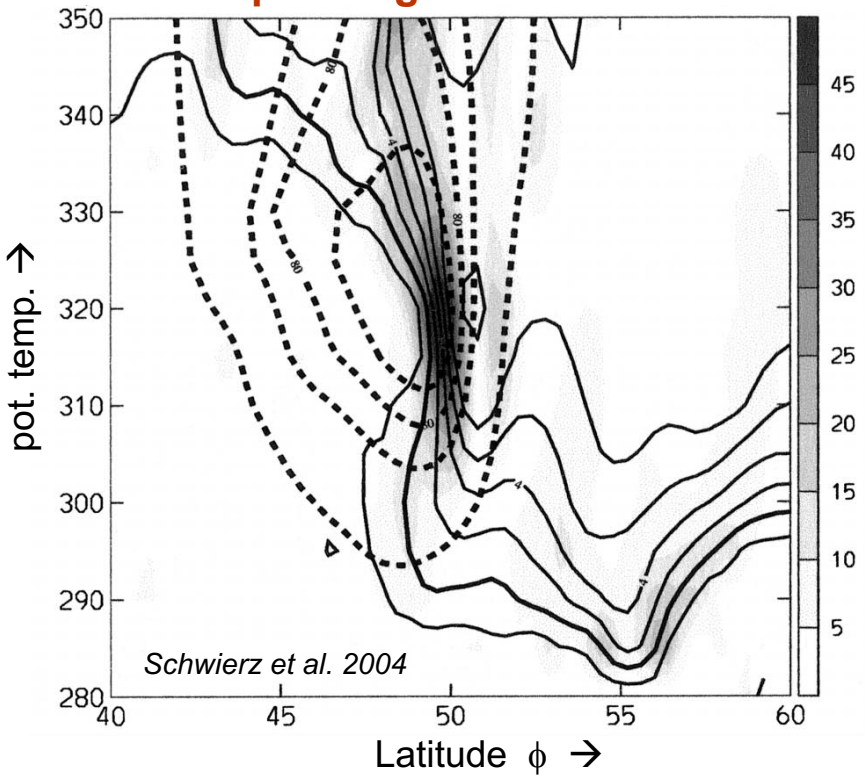


Ray tracing / WKB theory



Waveguide through sharp gradient in PV(ϕ)

Isentropic PV gradient



A sharp latitudinal gradient in PV serves as a zonal waveguide

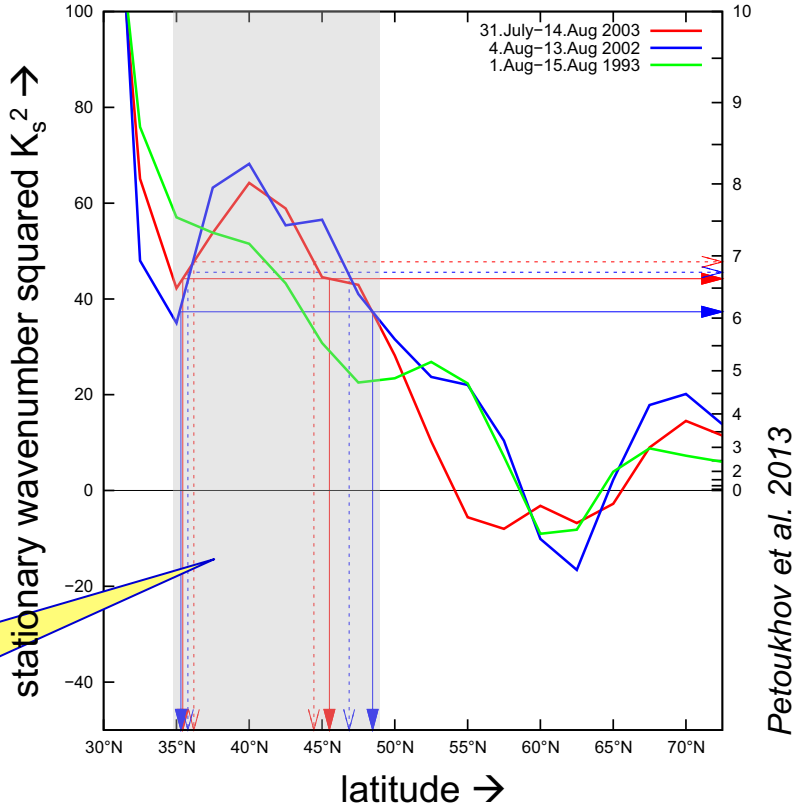
Schwierz et al. 2004
Martius et al. 2010
Platzmann 1949

Waveguide in the ray tracing framework

Ray tracing and WKB theory:

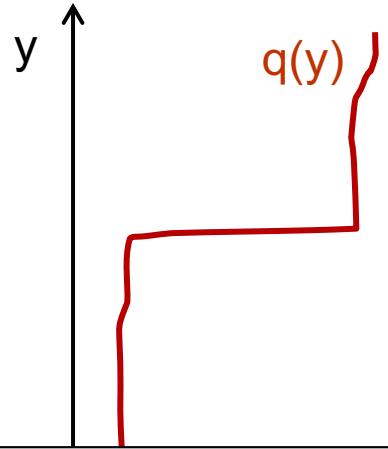
- **Key diagnostic**:
  the stationary wavenumber K_s
- **relative maximum** in $K_s(\phi)$ indicates a waveguide at that latitude

Example: waveguide between 35N and 48 N for s=7 (except in August 1993)



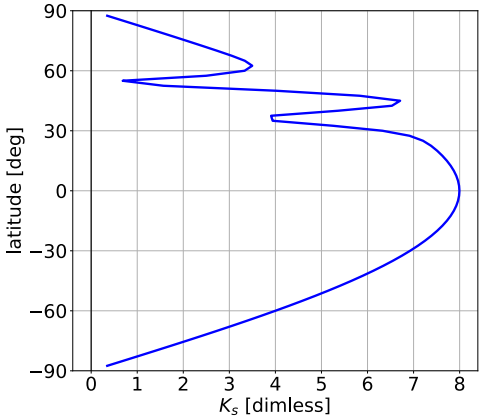
Symmary: two wave guide theories

Sharp gradient in PV(ϕ)



zonal ducting if PV(ϕ) has sharp gradient

Ray tracing / WKB theory



zonal ducting if $K_s(\phi)$ has a local maximum bounded by two turning latitudes

Diagnosing waveguidability in the barotropic model

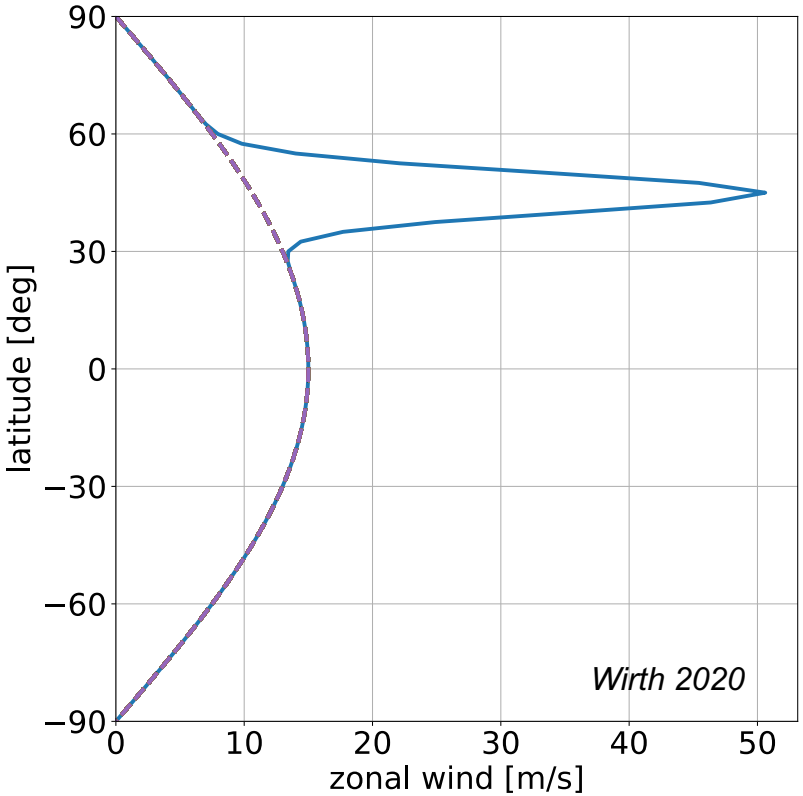
Barotropic model on sphere

$$\frac{Dq}{Dt} = -\lambda_r (q - q_0) + F$$

Forced-dissipative model configuration

- F = **local** orographic **forcing** (local RW source)
- **Relaxation** towards zonally symmetric background state $q_0(\lambda)$

Background state



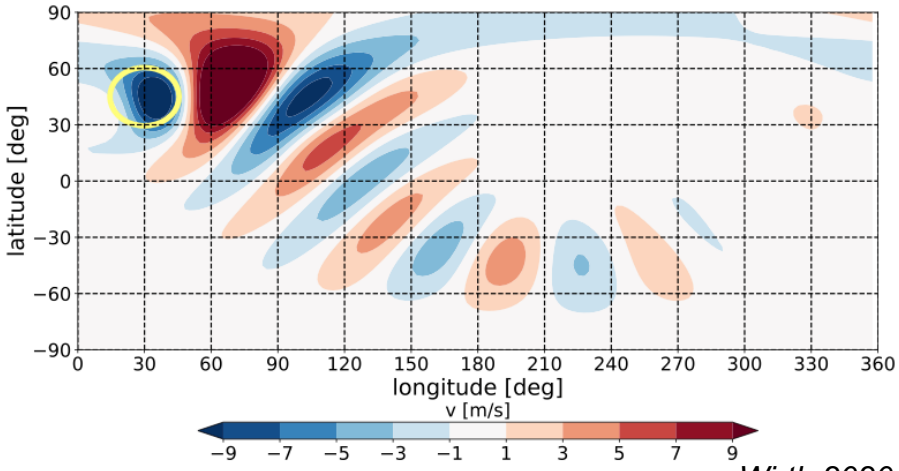
solid body rotation
plus a Gaussian jet
superimposed

Parameter sweep:
vary width σ_{jet} and strength U_{jet} of the jet

(cf. Manola et al. 2013)

Time average flow

background:
solid body rotation



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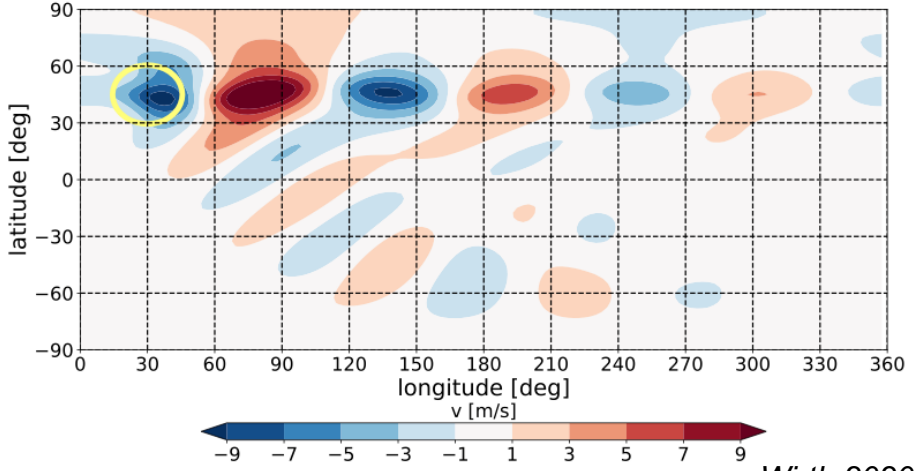
background:
strong narrow jet



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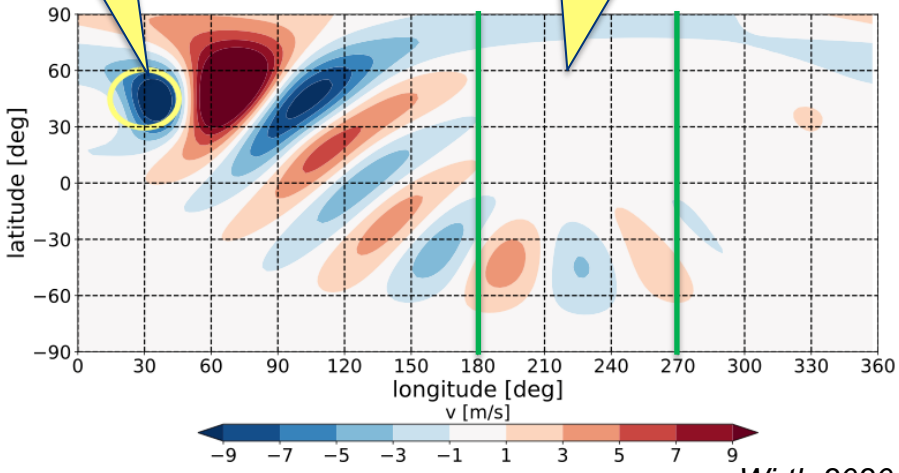
Diagnose waveguidability

solid body rotation

local wave source

waviness in downstream sector

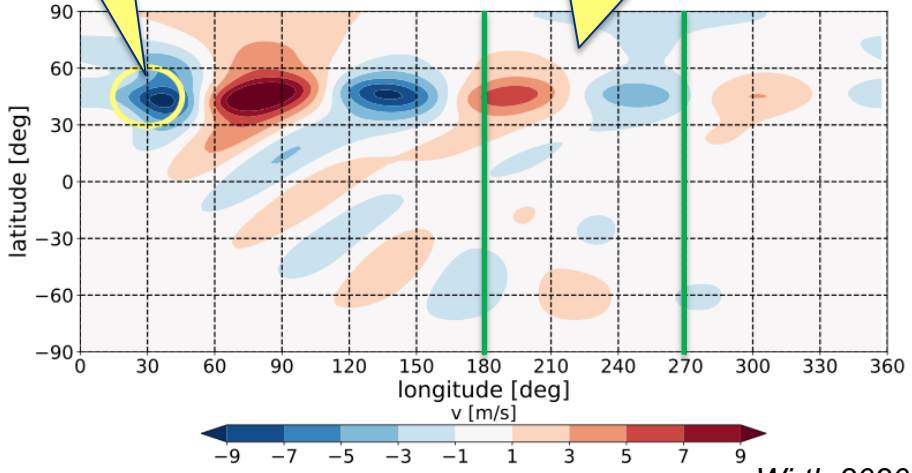


Wirth 2020

strong narrow jet

local wave source

waviness in downstream sector



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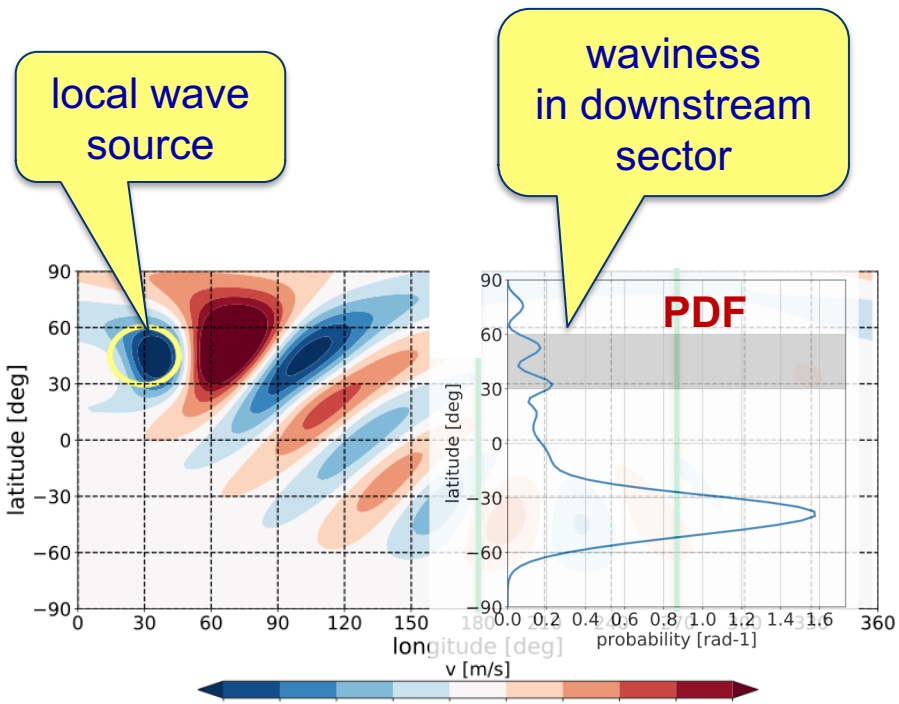
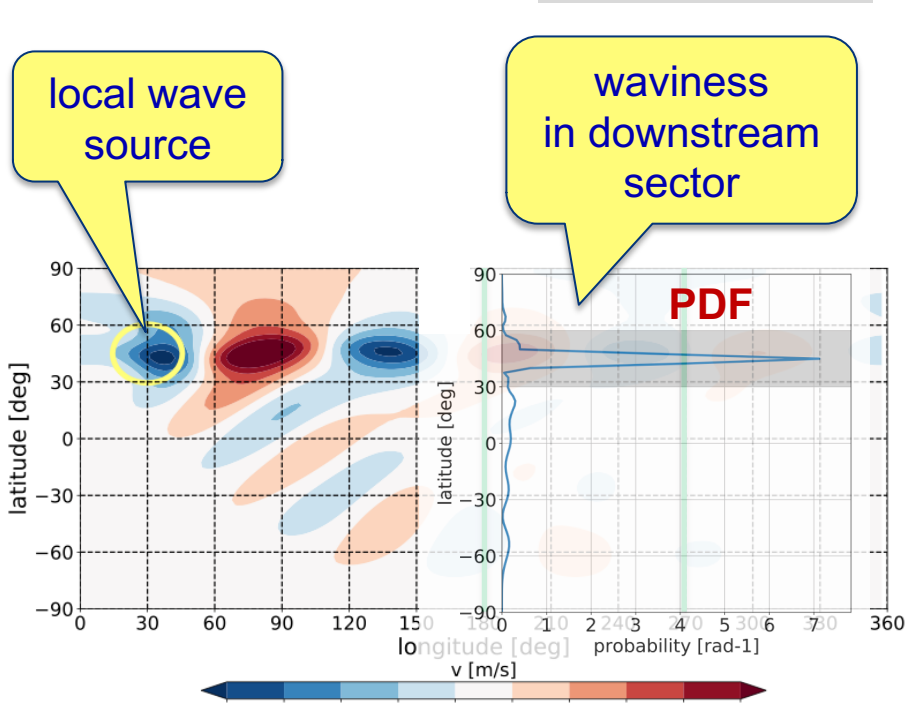
Diagnose waveguidability

solid body rotation

strong narrow jet





PDF = latitudinal distribution of „waviness“ in the downstream sector

Diagnose waveguidability

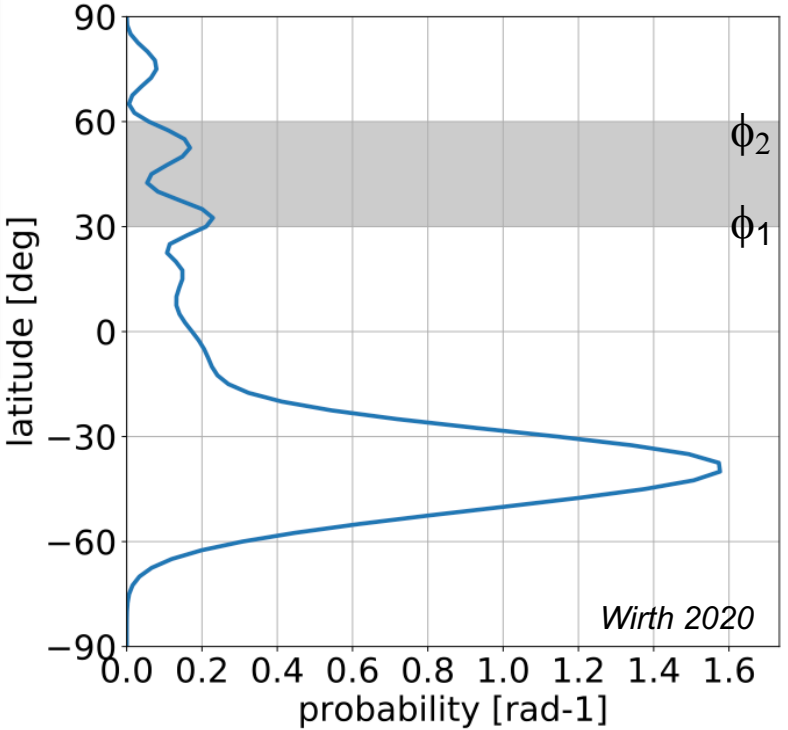
Diagnose waveguidability

as the fraction of waviness

within the latitude range of the jet

$$\mathcal{W} = \int_{\phi_1}^{\phi_2} P(\phi')\, d\phi'$$

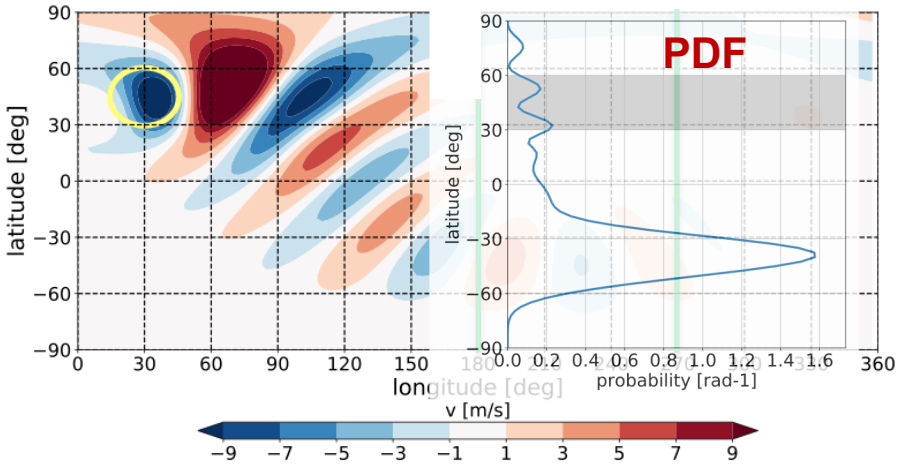
PDF of downstream waviness



Diagnose waveguidability

solid body rotation

W = 7.5%

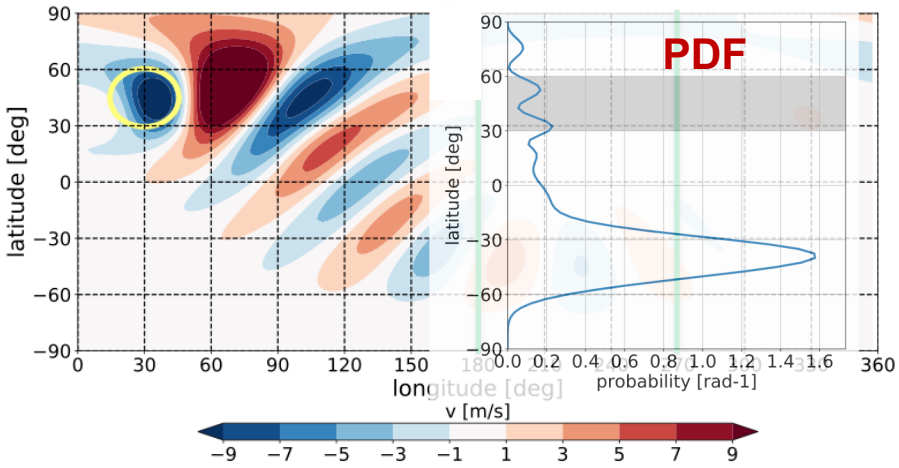


Diagnose waveguidability

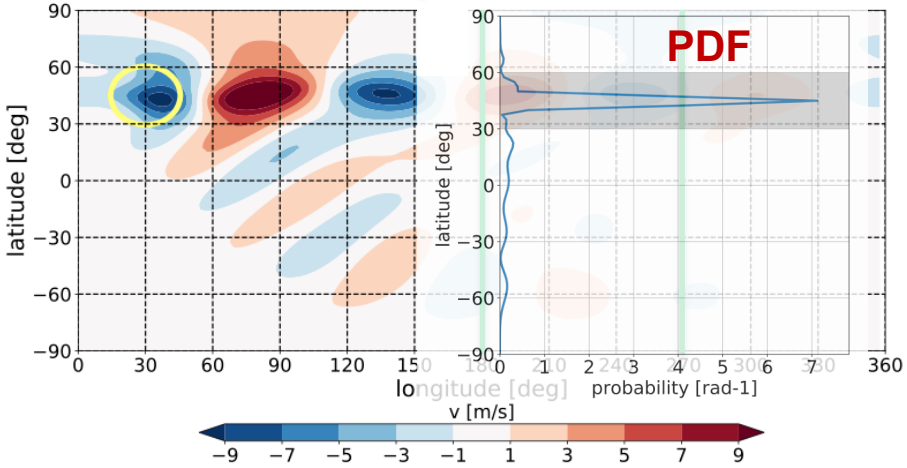
solid body rotation

strong narrow jet

W = 7.5%

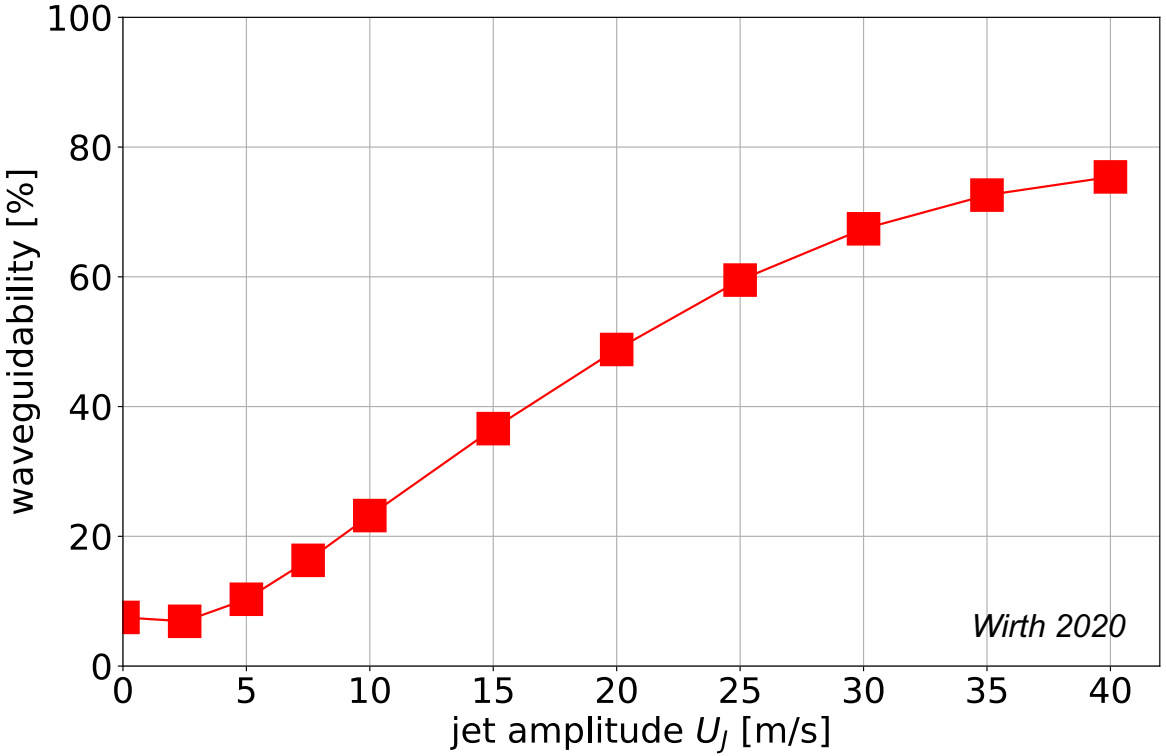


W = 75%



Now systematically vary
the jet strength and jet width
and diagnose waveguidability
from the numerical solution

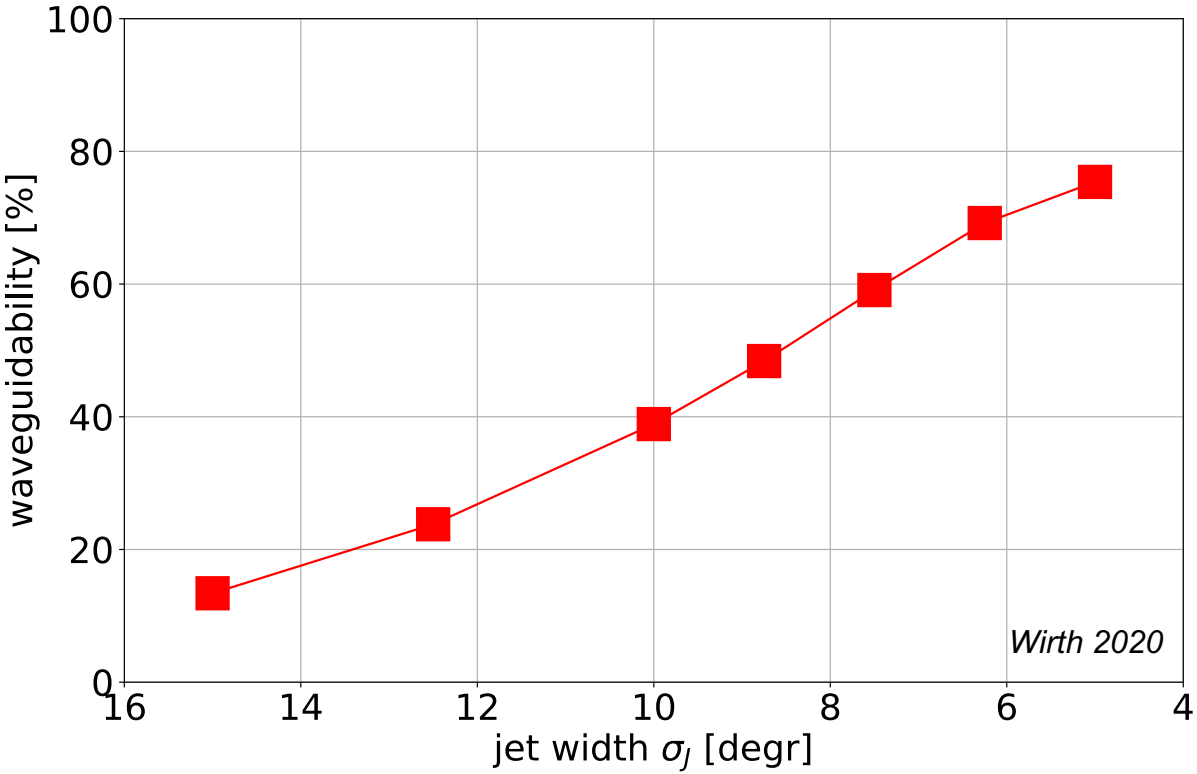
Vary jet strength



very gradual increase with increasing jet strength

consistent with Manola et al. 2013

Vary jet width

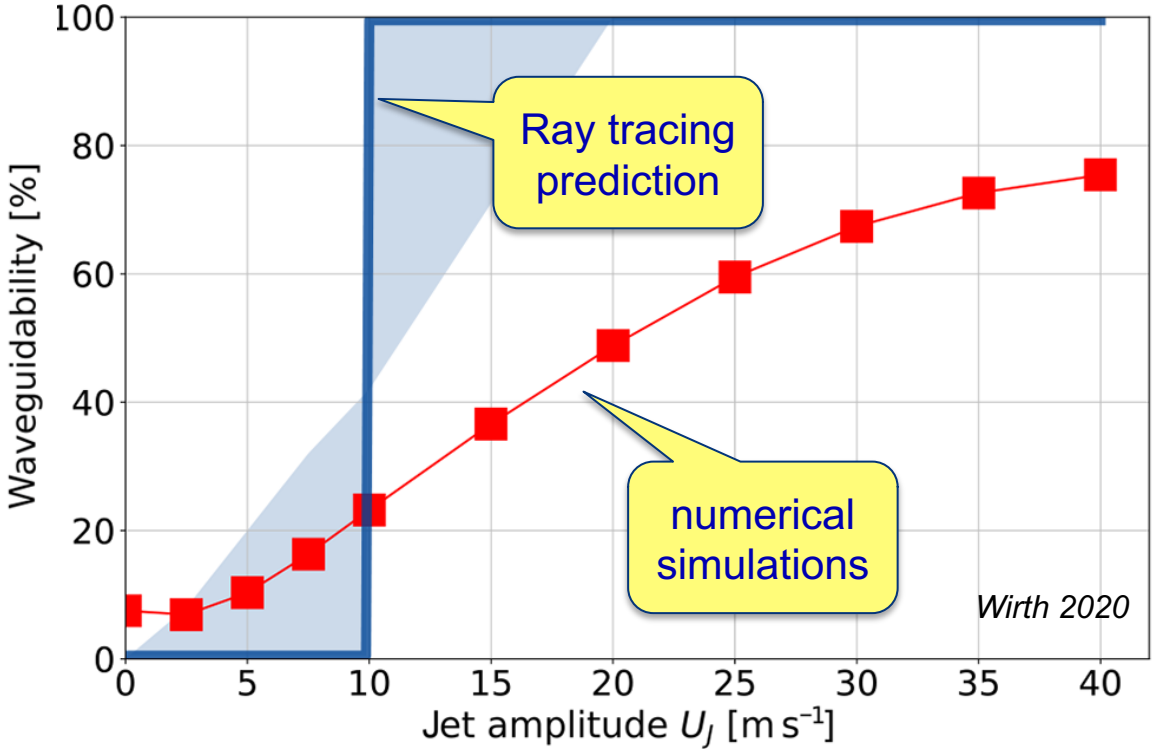


very gradual increase with decreasing jet width

consistent with Manola et al. 2013

Comparison with the theoretical concepts

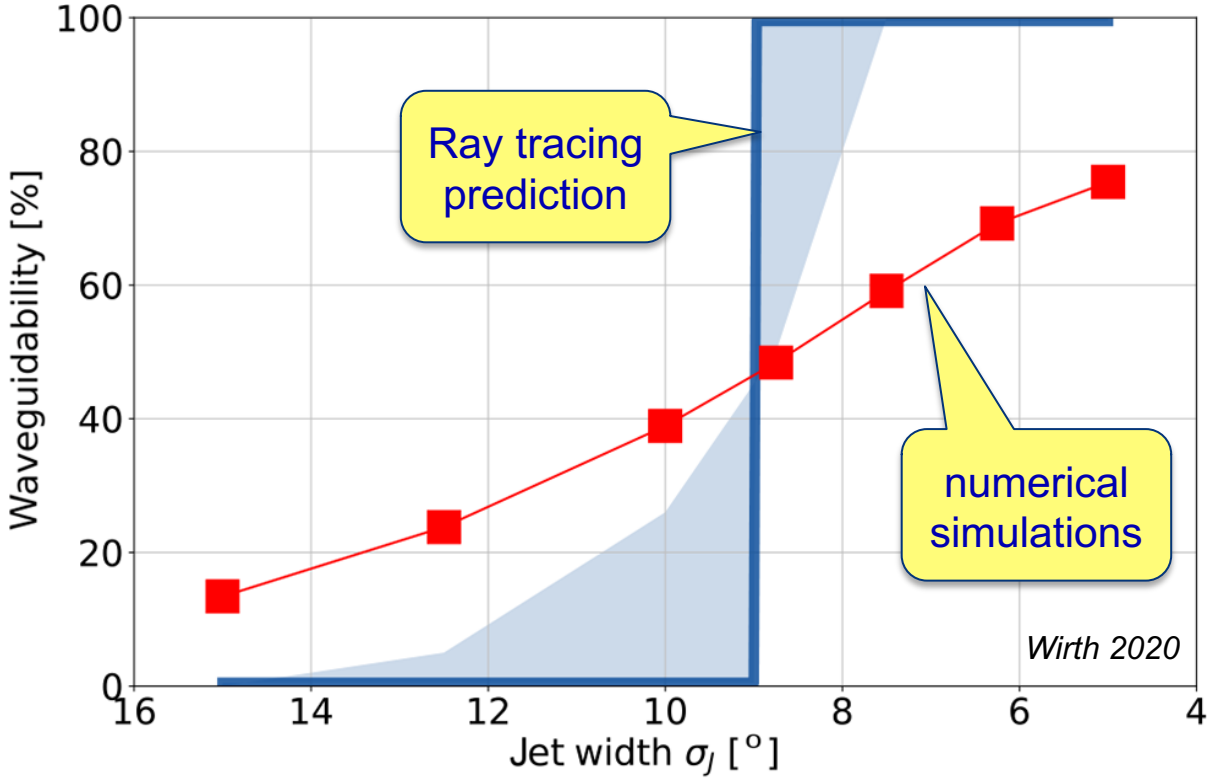
Vary jet amplitude



blue shading: uncertainty because zonal wavenumber is not given a priori

Ray tracing prediction not very successful

Vary jet width

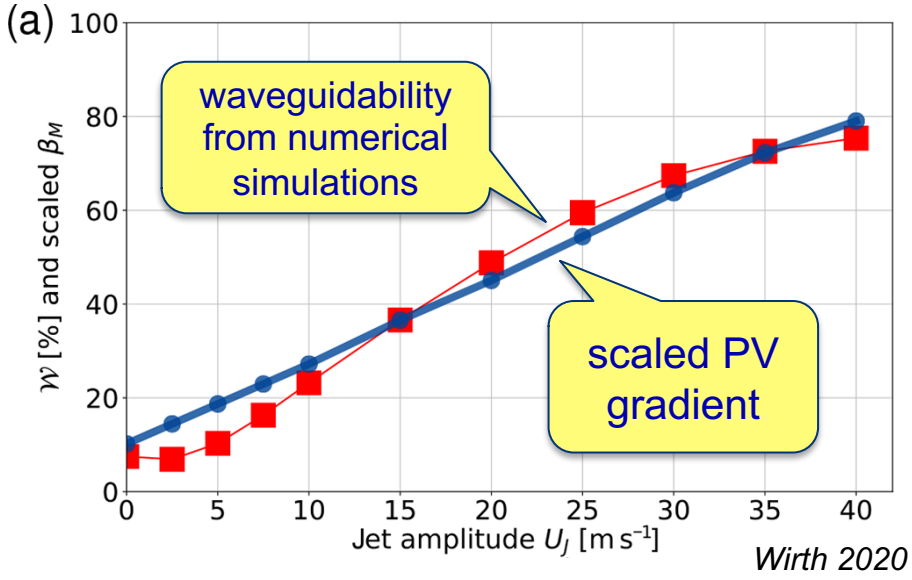


blue shading: uncertainty because zonal wavenumber is not given a priori

Ray tracing prediction not very successful

PV gradient does a better job

Waveguidability in the numerical simulations is rather well correlated with the meridional PV gradient:



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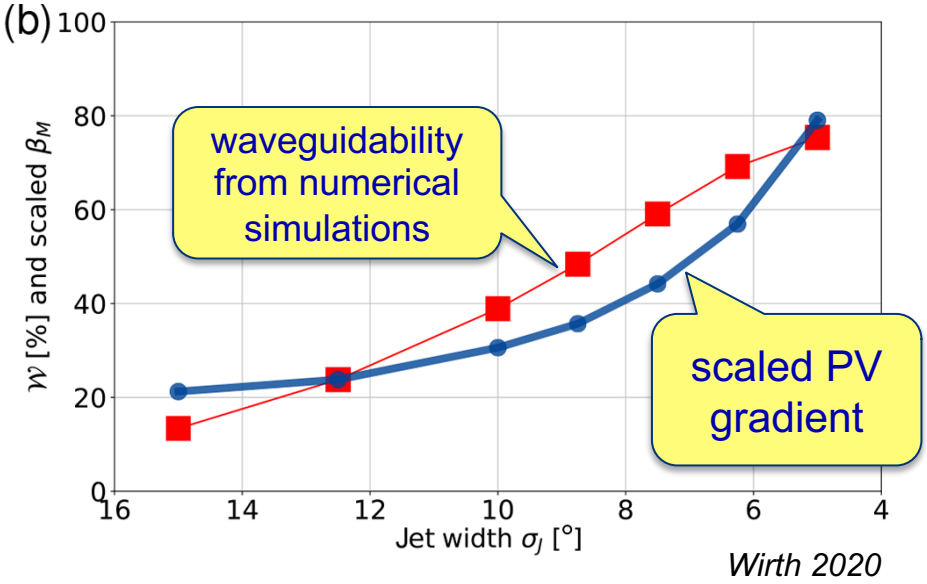

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Summary

Summary

- Good **waveguidability** important for large-amplitude waviness
- **Previous authors** used concepts from ray tracing (based on WKB)
- **Problem**: WKB assumptions not satisfied in practice
- **This work**: investigate waveguidability in barotropic framework

- **barotropic model** on sphere, forced-dissipative set-up
- **diagnose waveguidability** by following path of Rossby waves
- **parameter sweep** w.r.t. jet strength and jet width
- waveguidability **varies very smoothly** with U_{Jet} and σ_{Jet}
- qualitatively **inconsistent** with prediction from ray tracing theory
- much better **correlation with q_{0y}**

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For the full paper see:

Weather Clim. Dynam., 1, 111–125, 2020
https://doi.org/10.5194/wcd-1-111-2020

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Thank you