Global Distributions of Tropospheric and Stratospheric Gravity Wave Momentum Fluxes Resolved by the 9-km ECMWF Experiments

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Acknowledgments: ***Linus Magnusson, Inna Polichtchouk** from ECMWF*

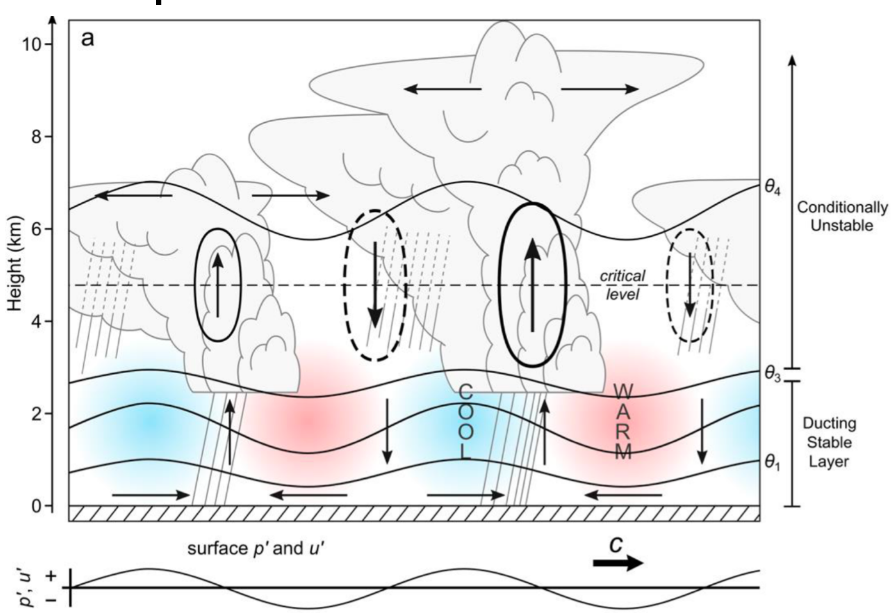
Why should we care?

Atmospheric Gravity Waves

Weather

Role in the Troposphere

Conceptual Model for Ducted Wave-CISK



Ruppert et al. (BAMS, 2022)

Mesoscale Gravity Waves & Midlatitude Weather

The Inspiring Determination and Dedication of Fuqing Zhang

BAMS, September 2022

Why should we care?

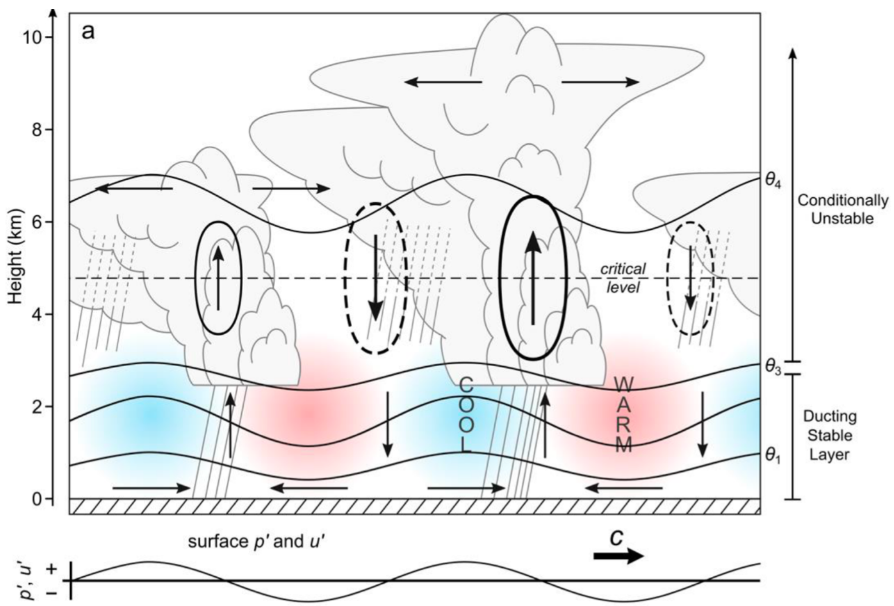
Atmospheric Gravity Waves

Weather → Role in the Troposphere

Climate → Impact on the Middle Atmosphere

Role in the Troposphere

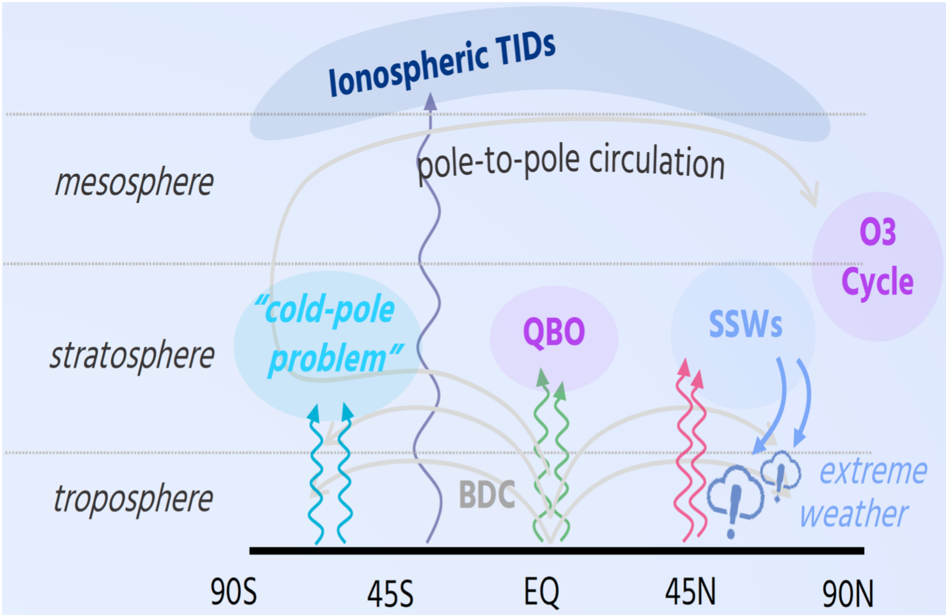
Conceptual Model for Ducted Wave-CISK



Ruppert et al. (BAMS, 2022)

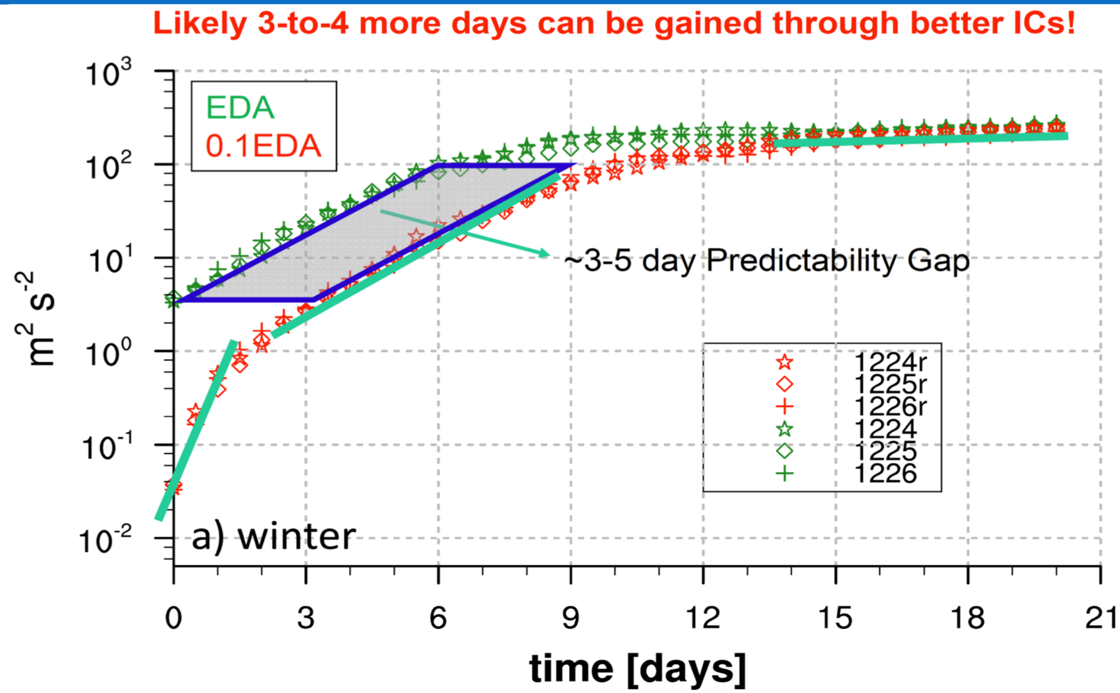
Impact on the Middle Atmosphere

Life Cycle of Propagating Atmospheric Gravity Waves



Adapted From the talk of Neil Hindley (2022)

A New Study After Zhang et al. (2019)



The Main Question in Zhang et al. (2019):

What is the Predictability Limit of Midlatitude Weather?

A New Main Question in This Study:

How About Their Resolved Gravity Wave Momentum Fluxes?

The High-Resolution GCM Outputs Employed in This Study:

9-km ECMWF experiments from Zhang et al. (2019)

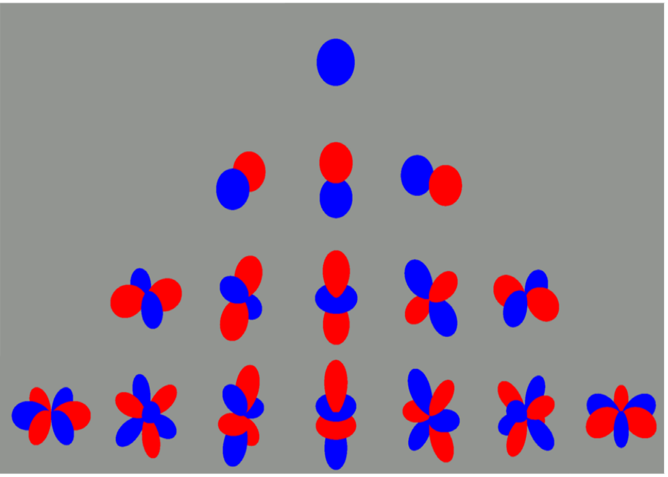
Flux Computation

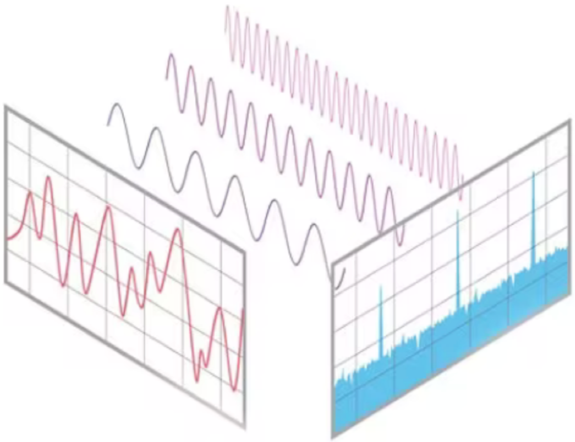
The 1st step: Retrieval of the large-scale background flows $u = \bar{u} + u'$

The 2nd step: The smoothing of the quadratic quantities $\overline{u'w'}$

Statistical Approach:
Scale Separation Assumption between Background and Perturbation

Spherical Harmonic Filter | **FFT Filter** | **Spatial Running Average**





(a) Spectrally truncated retrieval of total wavenumbers <= 40

(b) Zonal retrieval of all zonal wavenumbers <= 72 at each available latitude

(c) The 5° × 5° latitude–longitude horizontal running average

Flux Computation

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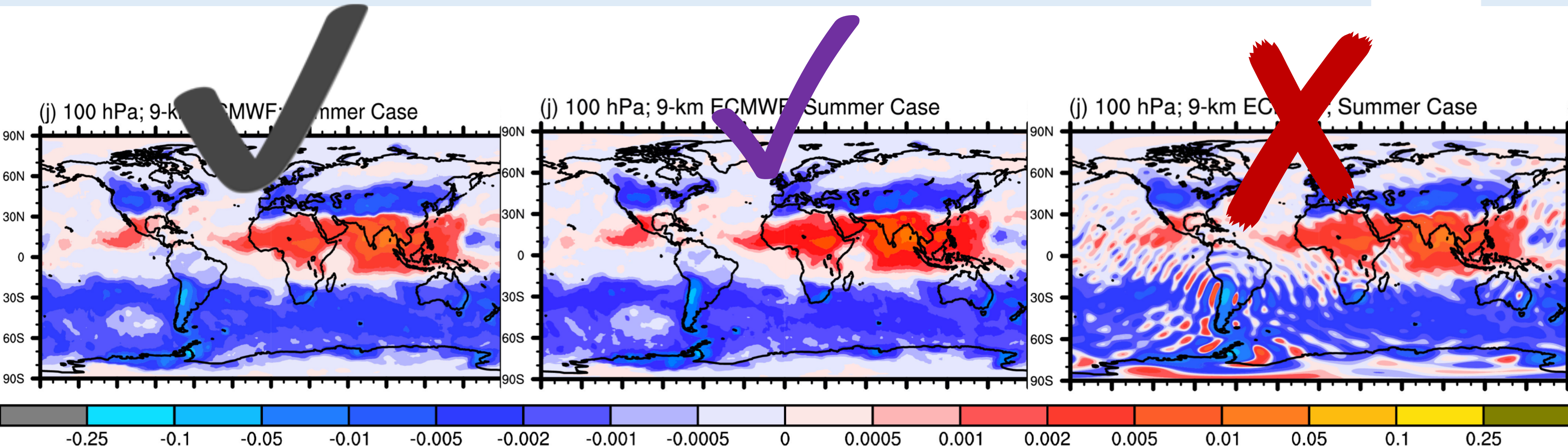

Method (a) in 1st overline; Method (c) in 2nd overline	**Method (c) in 1st overline; Method (c) in 2nd overline**	**Method (a) in 1st overline; Method (a) in 2nd overline**

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Statistical Approach:
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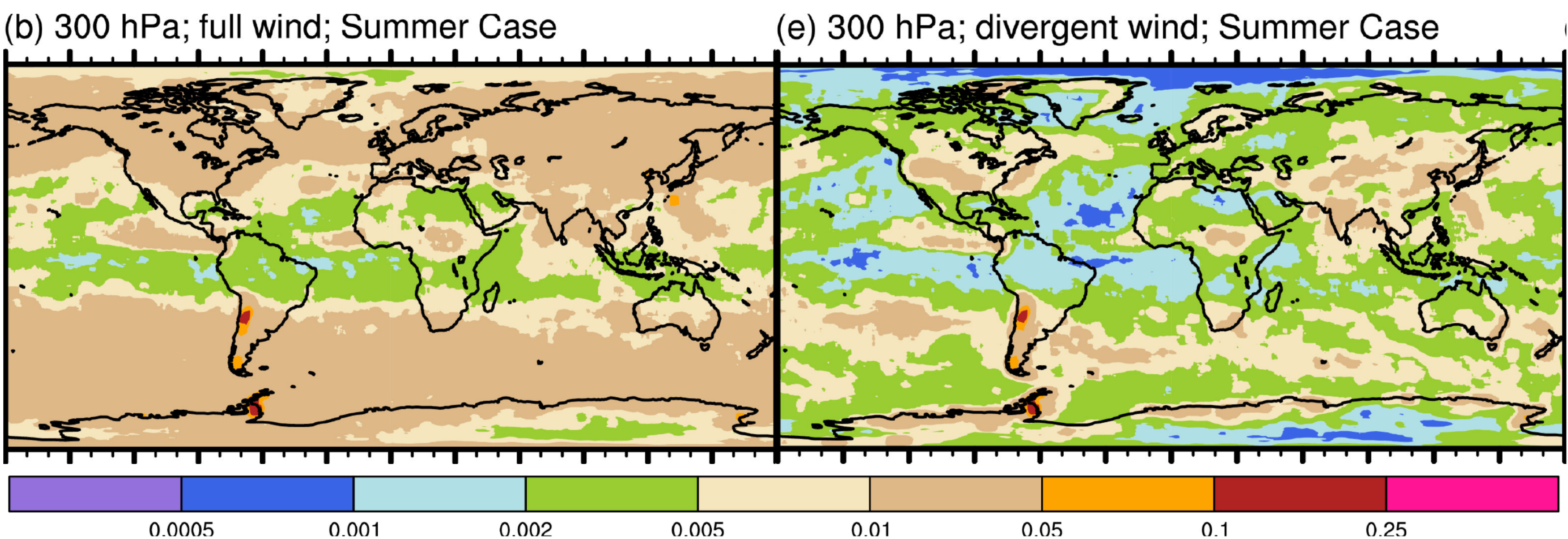
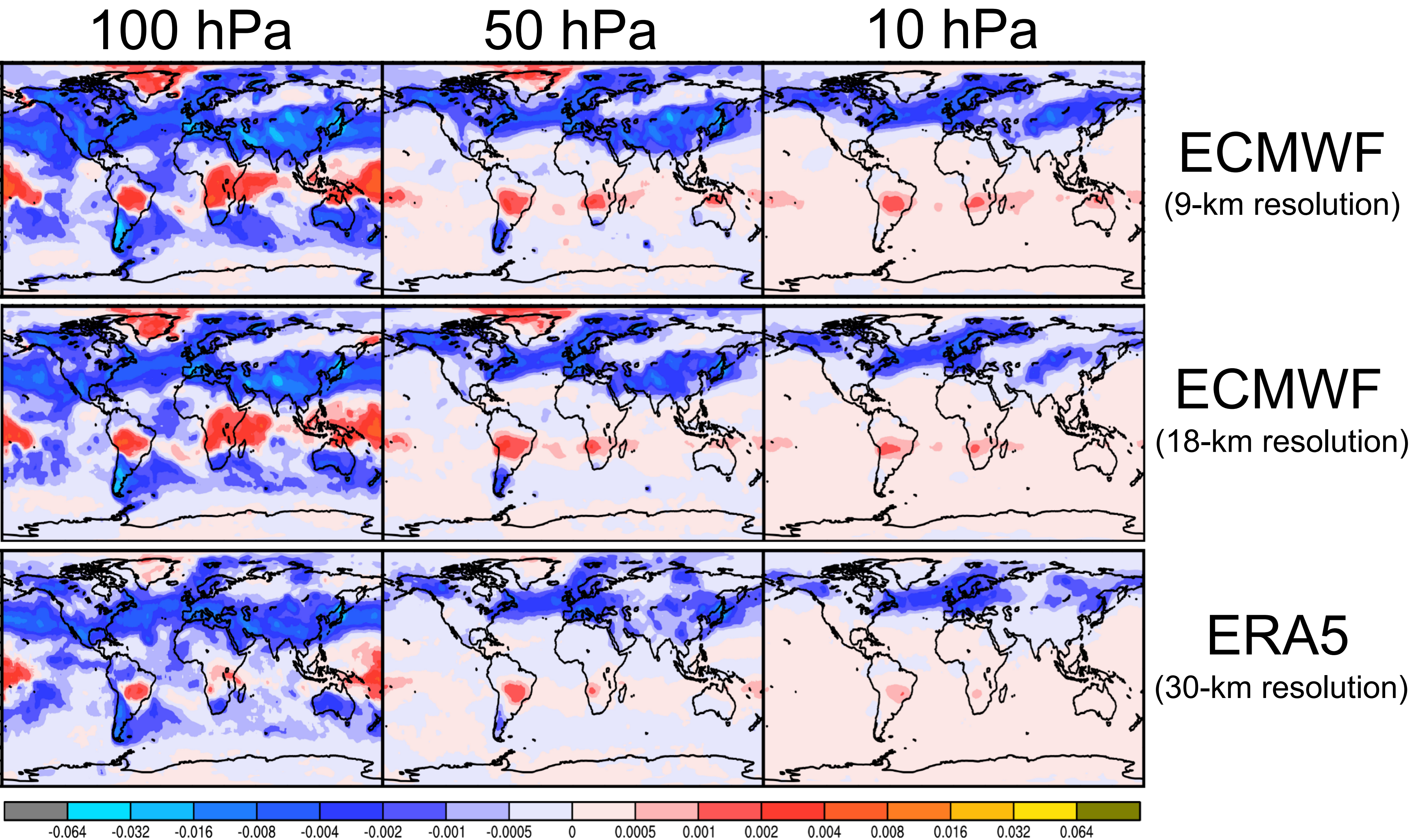
Dynamical Approach:
Link the Diagnostics with A Certain Balance Relation or Dynamical Constraint



- **Only using the statistical approach is not enough in the troposphere.**

Stratospheric Zonal Momentum Flux Based on ECMWF Forecasts and ERA5 reanalysis

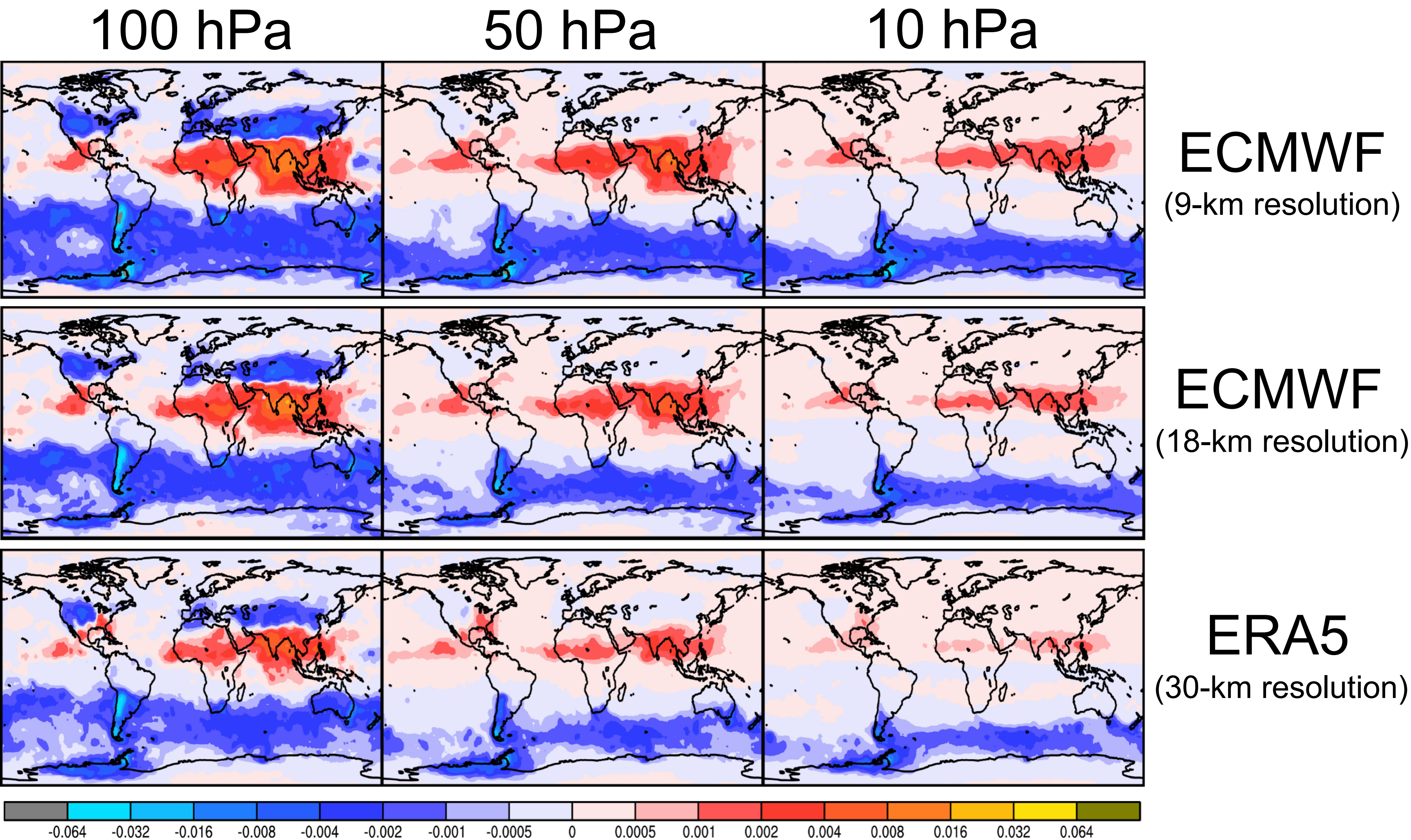
Winter Case (strong cold-surge event in northern Europe): 480-hr average between 12/25/2015 and 01/13/2016 with 12-hr interval



- **Dominance of negative fluxes over the middle latitudes of winter hemisphere with strong baroclinic instability**
- **Stronger signals of stratospheric zonal momentum fluxes in ECMWF forecast datasets with higher resolution**

Stratospheric Zonal Momentum Flux Based on ECMWF Forecasts and ERA5 reanalysis

Summer Case (historic rainfall-flooding event in China): 480-hr average between 06/25/2016 and 07/14/2016 with 12-hr interval



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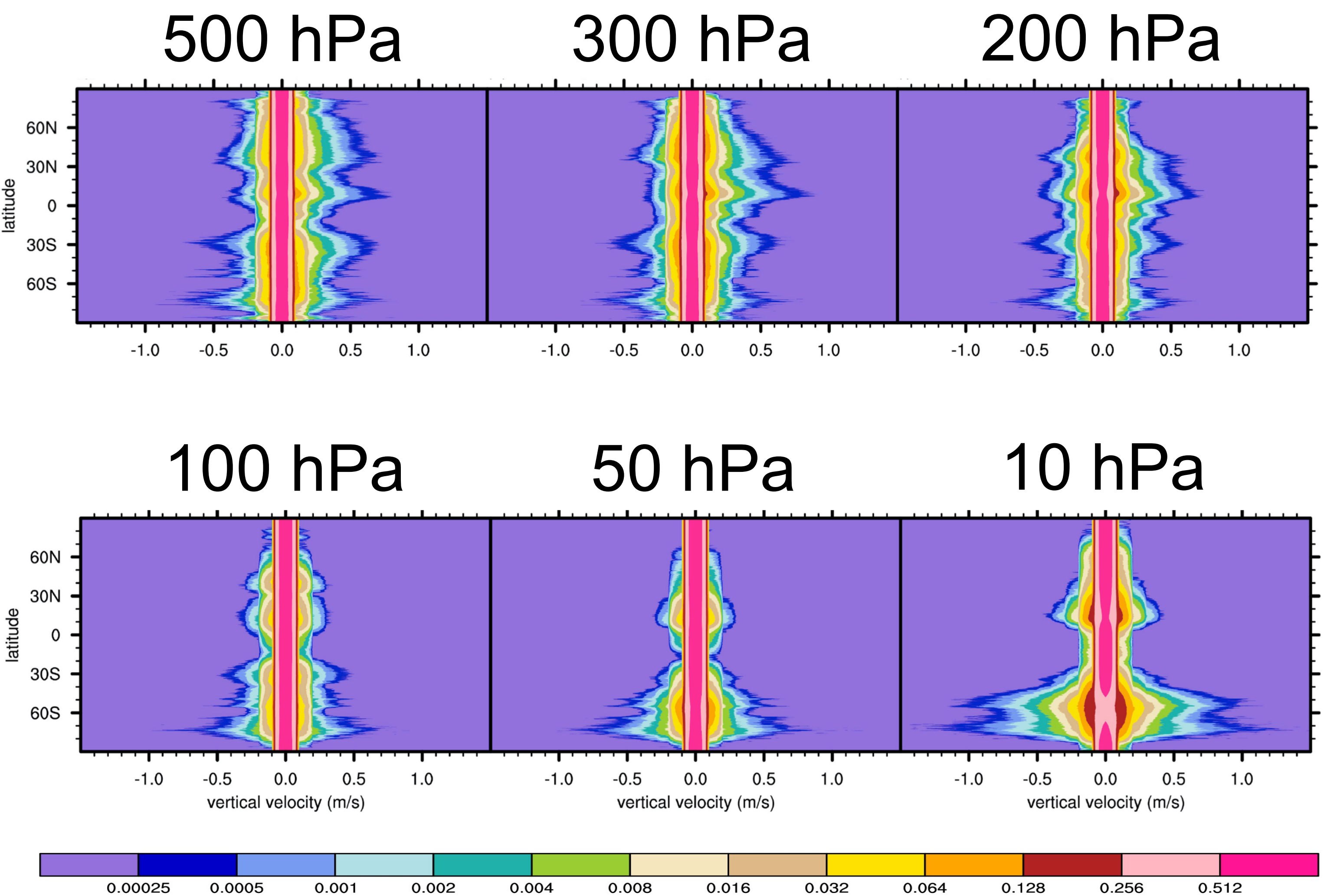
Probability Distribution of Vertical Motion in the Troposphere

Summer Case **(historic rainfall-flooding event in China): 480-hr average between 06/25/2016 and 07/14/2016 with 12-hr interval**



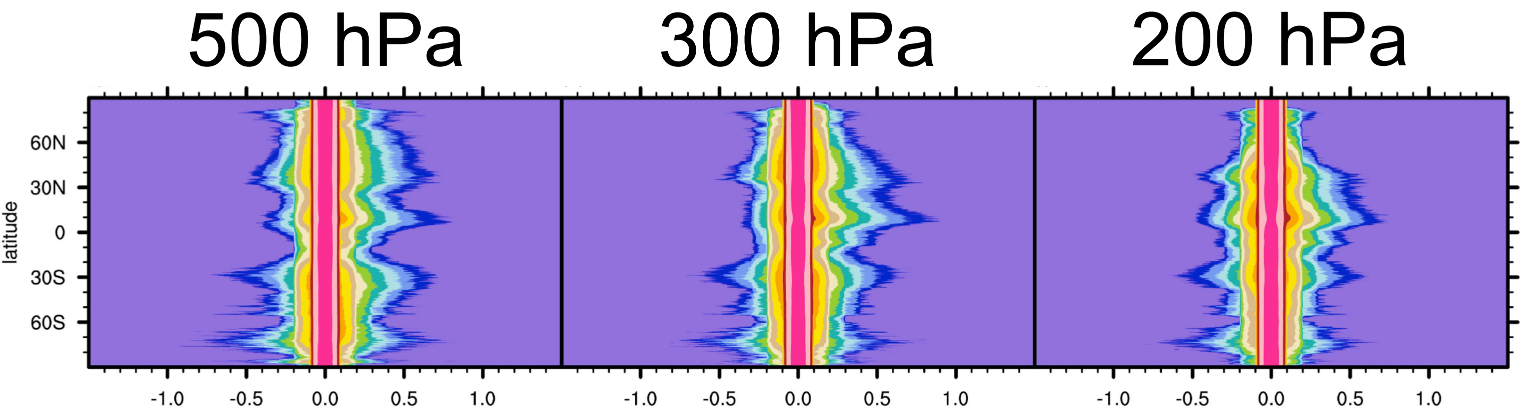
Troposphere (No Filtering)

Stratosphere (No Filtering)

❑**No Filtering: Noticeable asymmetric behavior around zero velocity in the troposphere.**

Probability Distribution of Vertical Motion in the Troposphere

Summer Case (historic rainfall-flooding event in China): 480-hr average between 06/25/2016 and 07/14/2016 with 12-hr interval



Troposphere (No Filtering)

The C1 Approach: Filtering w' with **12-hour precipitation accumulation > 0.01m**

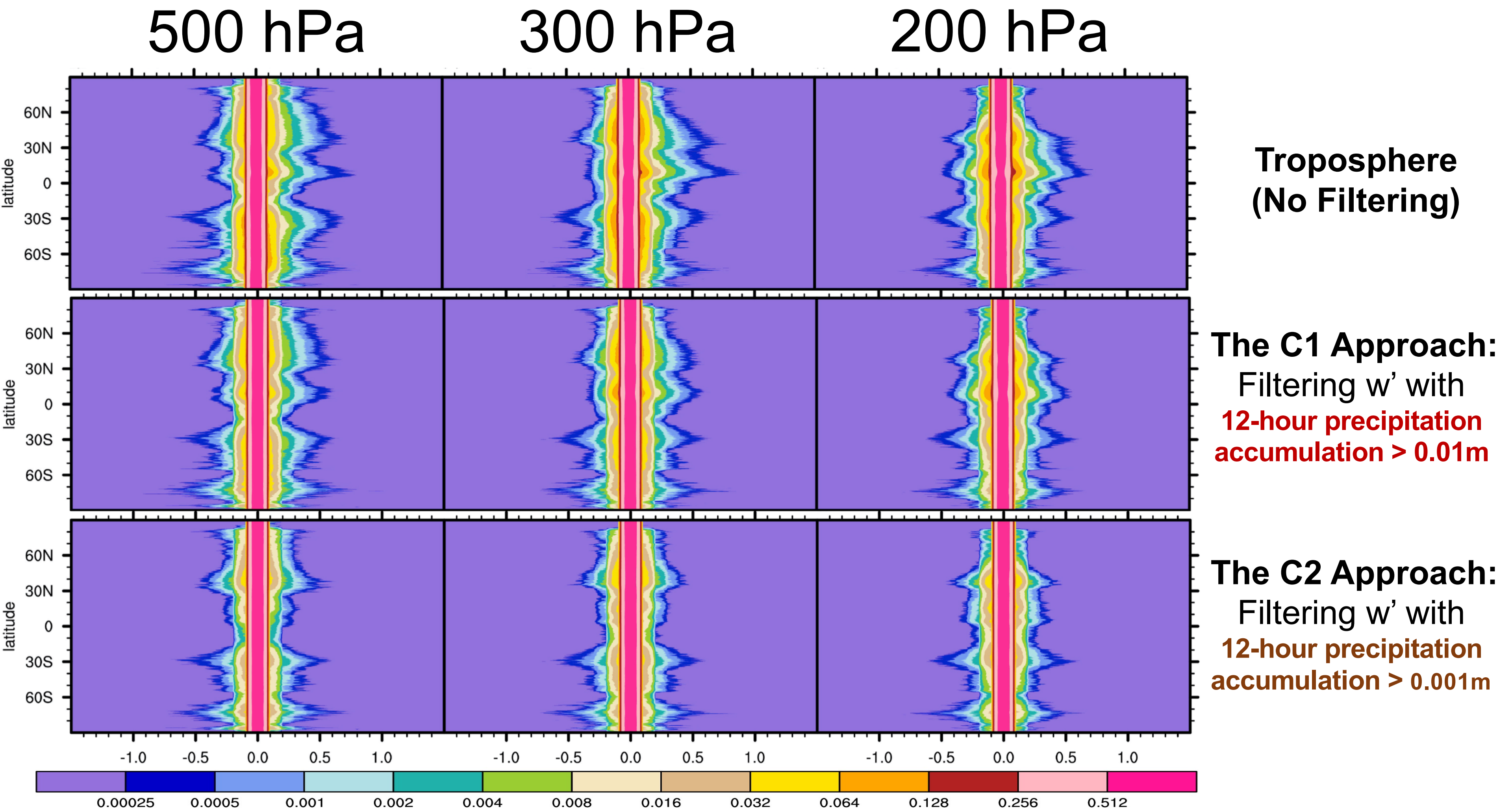
A filtering method is proposed, using precipitation accumulation.

The C2 Approach: Filtering w' with **12-hour precipitation accumulation > 0.001m**

- ❑ **No Filtering: Noticeable asymmetric behavior around zero velocity in the troposphere.**

Probability Distribution of Vertical Motion in the Troposphere

Summer Case (historic rainfall-flooding event in China): 480-hr average between 06/25/2016 and 07/14/2016 with 12-hr interval



- **No Filtering: Noticeable asymmetric behavior around zero velocity in the troposphere.**
- **Filtering Experiments: This asymmetric behavior should be due to convective forcing, rather than freely propagating gravity waves (see also Alexander et al. 2006).**

Flux Computation

Directional Momentum Flux

$$MF_x \equiv \rho_0 \overline{u'w'}$$

Zonal Momentum Flux

$$MF_y \equiv \rho_0 \overline{v'w'}$$

Meridional Momentum Flux

Absolute Momentum Flux

ORI Approach

$$\mathrm{M} = \sqrt{{\rho_0}^2 \left[\left(\overline{u'w'}\right)^2 + \left(\overline{v'w'}\right)^2 \right]}$$

WTQ Approach

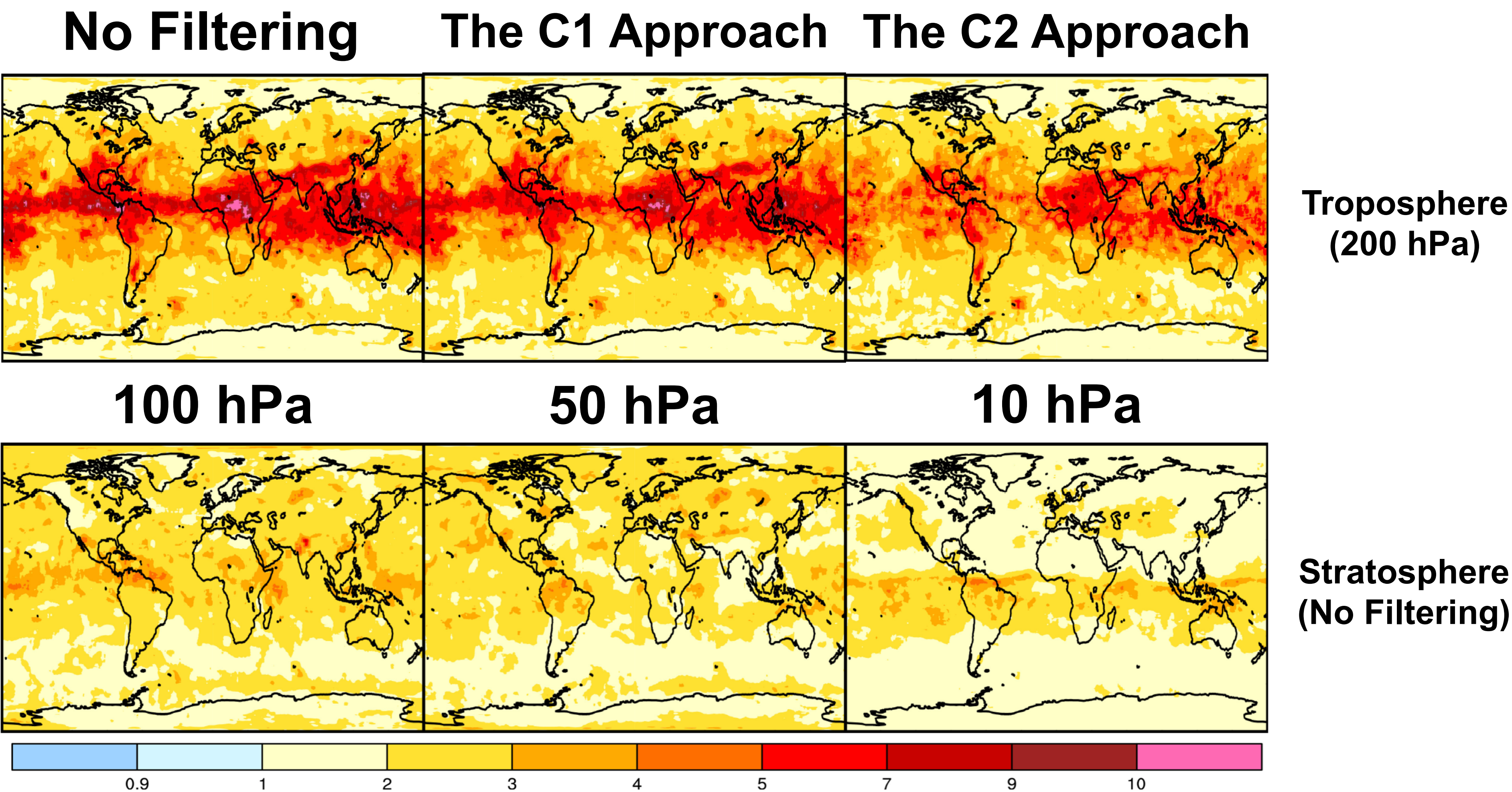
$$\mathrm{M} = \sqrt{{\rho_0}^2 \overline{w'w'} \left(\overline{u'u'} + \overline{v'v'}\right) \left[1 + \frac{f^2}{\Omega^2}\right]^{-1}}$$

$$\text{where } \frac{f^2}{\Omega^2} = \left(\frac{fg}{N^2}\right)^2 \left(\frac{\overline{(T'/T_0)^2}}{\overline{w'w'}}\right)$$

Based on polarization relation, ORI and WTQ should be identical in theory.

Ratio Map Between WTQ and ORI

Summer Case (historic rainfall-flooding event in China): 480-hr average between 06/25/2016 and 07/14/2016 with 12-hr interval



- ❑The proposed filtering method helps in reducing the ratio between WTQ and ORI.
- ❑The ratio is reduced remarkably in the stratosphere.
- ❑However, WTQ > ORI still holds true!

Flux Computation

ORI can result in gross underestimation.

Geller et al. (2013, JC).

ORI Approach

$$M = \sqrt{{\rho_0}^2\left[\left(\overline{u'w'}\right)^2 + \left(\overline{v'w'}\right)^2\right]}$$

WTQ Approach

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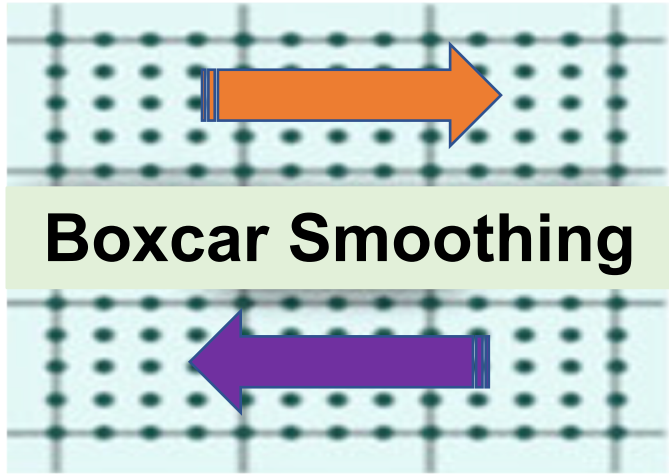
Flux Computation

Spatial Running Average



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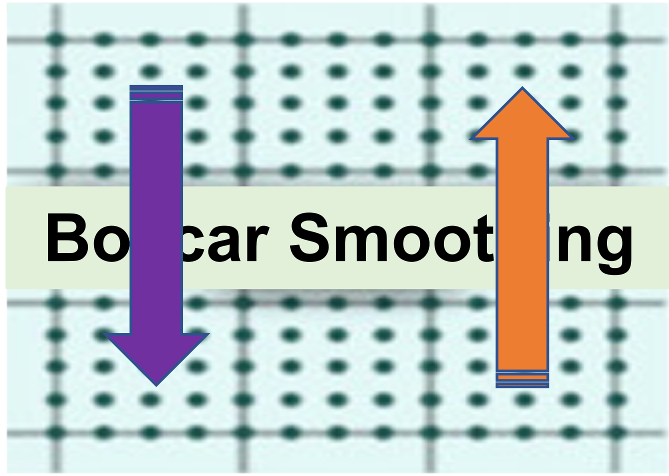

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**Based on polarization relation,
ORI and WTQ should be identical in theory.**

Conclusion

Wei et al. (2022, JAS)
Volume 79: Issue 10; https://doi.org/10.1175/JAS-D-21-0173.1

1. Stratospheric Flux Comparison

- ***9-km ECMWF IFS*** *versus* ***18-km ECMWF IFS*** *versus* ***30-km ERA5 reanalysis***
- ***Stronger fluxes with higher resolution***

2. Tropospheric Flux Computation

- ***Statistical Approach*** + ***Dynamical Approach***
- ***A proposed filtering approach using the information of precipitation***

3. Absolute Momentum Flux Computation

- ***Reduction of the tropospheric ratio between WTQ and ORI by the filtering***
- ***WTQ*** > ***ORI in both troposphere and stratosphere***