# Isentropic mixing in the NH summer UTLS

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# **Outline**

- Effective diffusivity: strong mixing in boreal summer LS
- What are the effects on the tracers?
- Which waves lead to the mixing?

# **Artificial tracer** advected by non-divergent isentropic wind from ERA-Interim + small diffusion κ for unresolved scales

$$\frac{\partial c}{\partial t} + \mathbf{u} \cdot \nabla c = \nabla \cdot (\kappa \nabla c)$$



Following Haynes and Shuckburgh JGR (2000a,b)

### **Effective diffusivity (Nakamura JAS 1996)**



**Tracer gradient in tracer space** 

Constant diffusivity parameter (depends on the resolution)

#### **Effective diffusivity: strong mixing in summer lower stratosphere**



Abalos et al. (2016) accepted, QJRMS

#### Change of seasonality with height: summer maximum in the UTLS



Abalos et al. (2016) accepted, QJRMS

#### Tracer evolution at 390 K: rapid spread of tracer across the NH



#### Latitudinal evolution of the tracer at 390 K



#### Latitudinal evolution of the tracer at 390 K



#### **Global zonal mean tracer evolution in boreal summer**



#### **Tracer spread consistent with O3 observations**



#### Isentropic stirring is linked to the tracer eddy flux

Tracer continuity equation on isentropes



Tracer eddy flux [V'X']

Use tracer eddy flux to evaluate wave driving of mixing

### Tracer eddy flux [V'X'] JJA climatology



 $[V'X'] > 0 \rightarrow poleward tracer$ eddy transport

#### Use tracer eddy flux to evaluate wave driving of mixing



 $[V'X'] > 0 \rightarrow poleward tracer$ eddy transport Mixing structure obtained from [V'X'] similar to Keff

# Effective diffusivity **Keff**

## Eddy diffusivity Kyy=-[V'X']/Xy



#### Wave decomposition of [V'X'] boreal summer Stationary/planetary tropics, transient extratropics

Planetary vs. synoptic

Stationary vs. transient





#### Phase-speed spectra [V'X'] at 380 K (only transient waves) dominated by synoptic-scale



#### Phase-speed spectra [V'CO'] from WACCM similar (opposite sign in SH due to CO gradient, ASM?)



#### **Spatial structure of V'X'** eddy flux JJA at 380 K



**Stationary** 

**Transient** 



## Main points

- Keff: Strong isentropic stirring in boreal summer lower stratosphere
- Artificial tracer shows rapid isentropic spread, consistent with tracer observations (O3, H2O)
- Eddy diffusivity (Kyy) based on [V'X'] captures the overall mixing structure in Keff
- **Stationary** tracer eddy flux [V'X'] dominated by **Asian Monsoon Anticyclone** (equatorward of 30N)
- Transient tracer eddies (mainly wn>3) dominate extratropical mixing (poleward of 30N)