# Troposphere, stratosphere and what lies between: a selective overview

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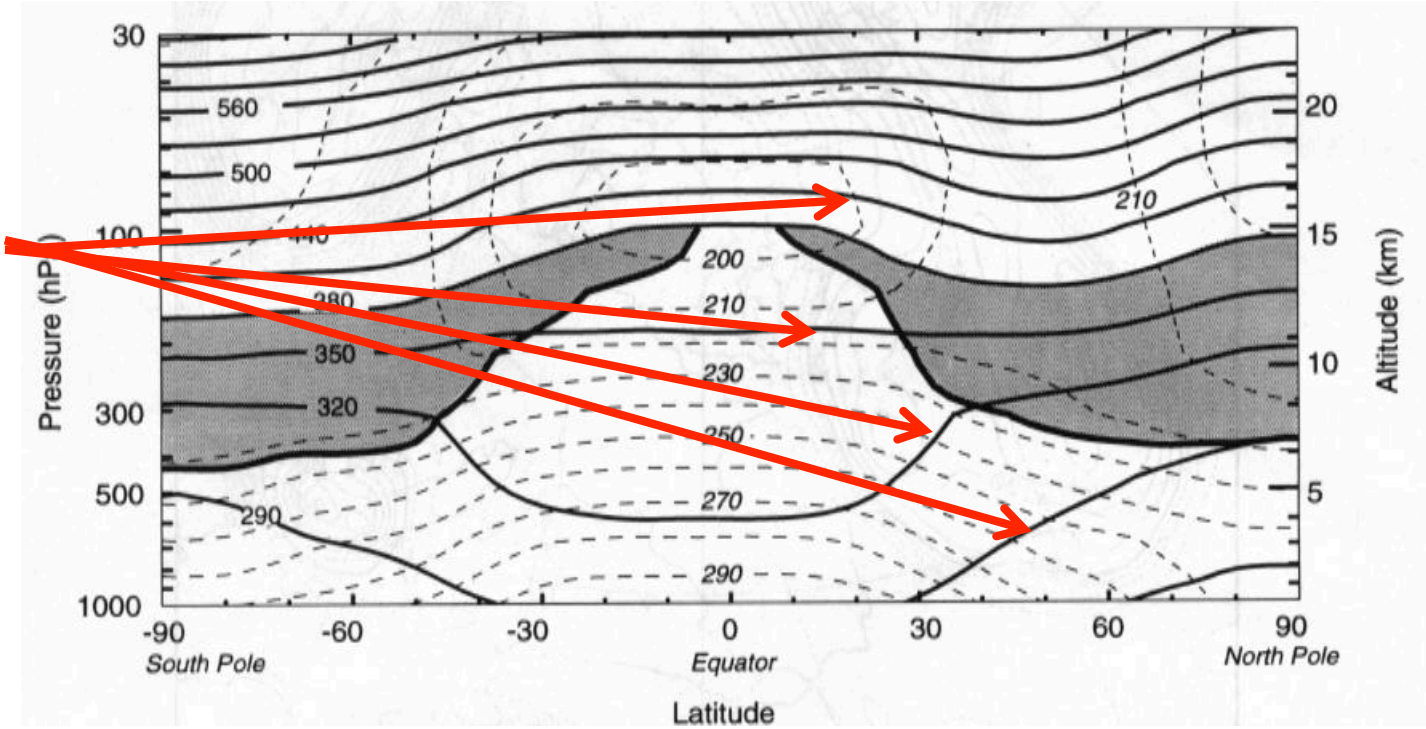
Height/latitude structure of temperature field

Holton et al (1995)

θ surfaces

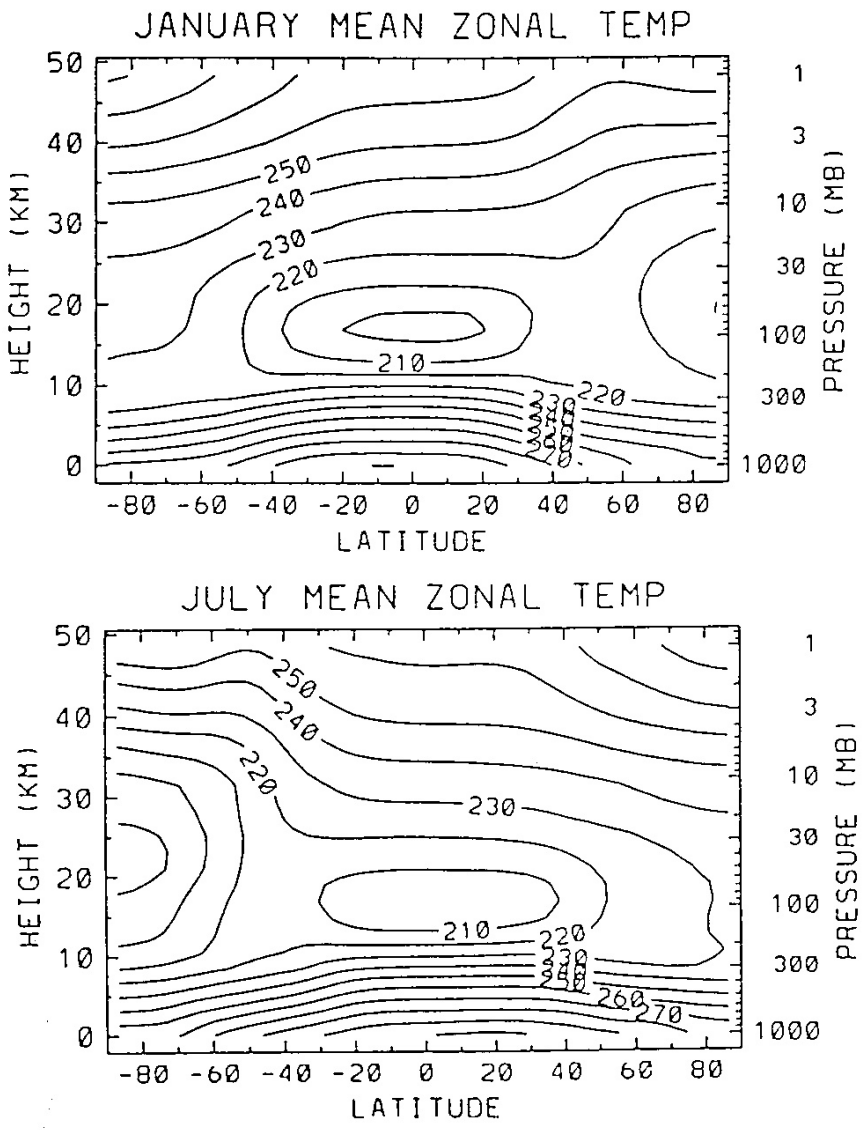



Strongly sloping θ (isentropic) surfaces in extratropical troposphere.

In θ coordinates vertical motion requires diabatic heating or cooling – *slow* transport *across* θ surfaces, *rapid* transport *along* θ surfaces.

# Height/latitude structure of temperature field

## Randel (1992)



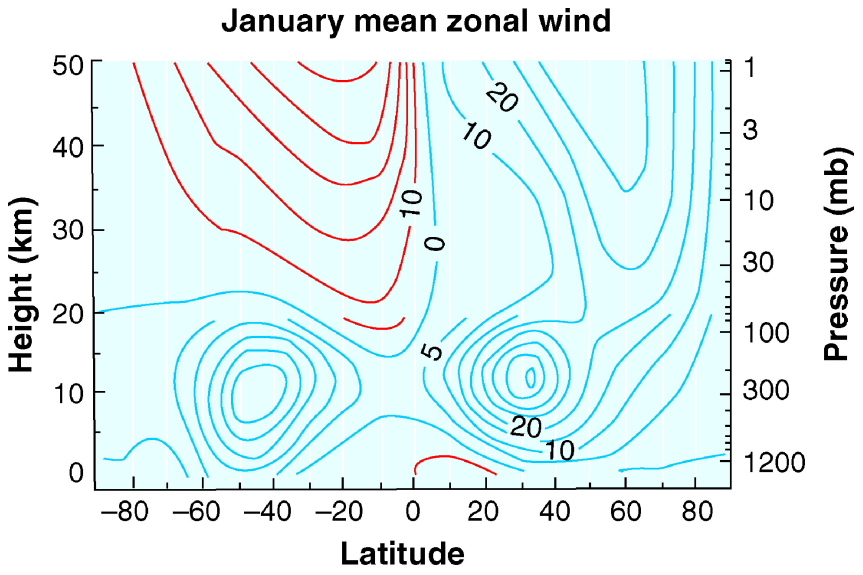

- Troposphere – maximum temperature at low latitudes
- Stratosphere – maximum temperature at summer poles
- Tropopause – coldest in tropics
- Colder temperatures in stratosphere in SH winter than in NH winter

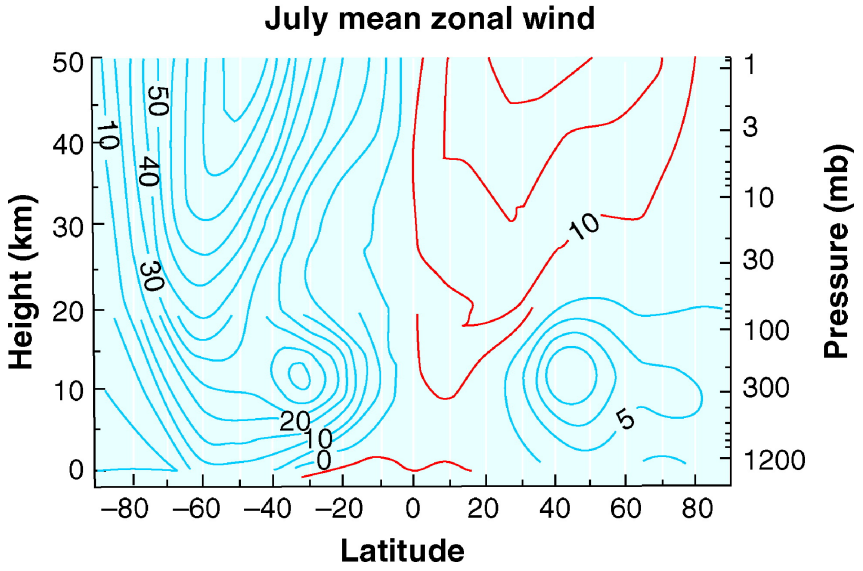
# Height/latitude structure of wind field

after Randel (1992)

- Troposphere – eastward jets in subtropics (and deeper extension to midlatitudes)
- Stratosphere – eastward jet in winter (stronger in SH winter than in NH winter), westward jet in summer

Interhemispheric differences in stratosphere are caused by interhemispheric differences at surface

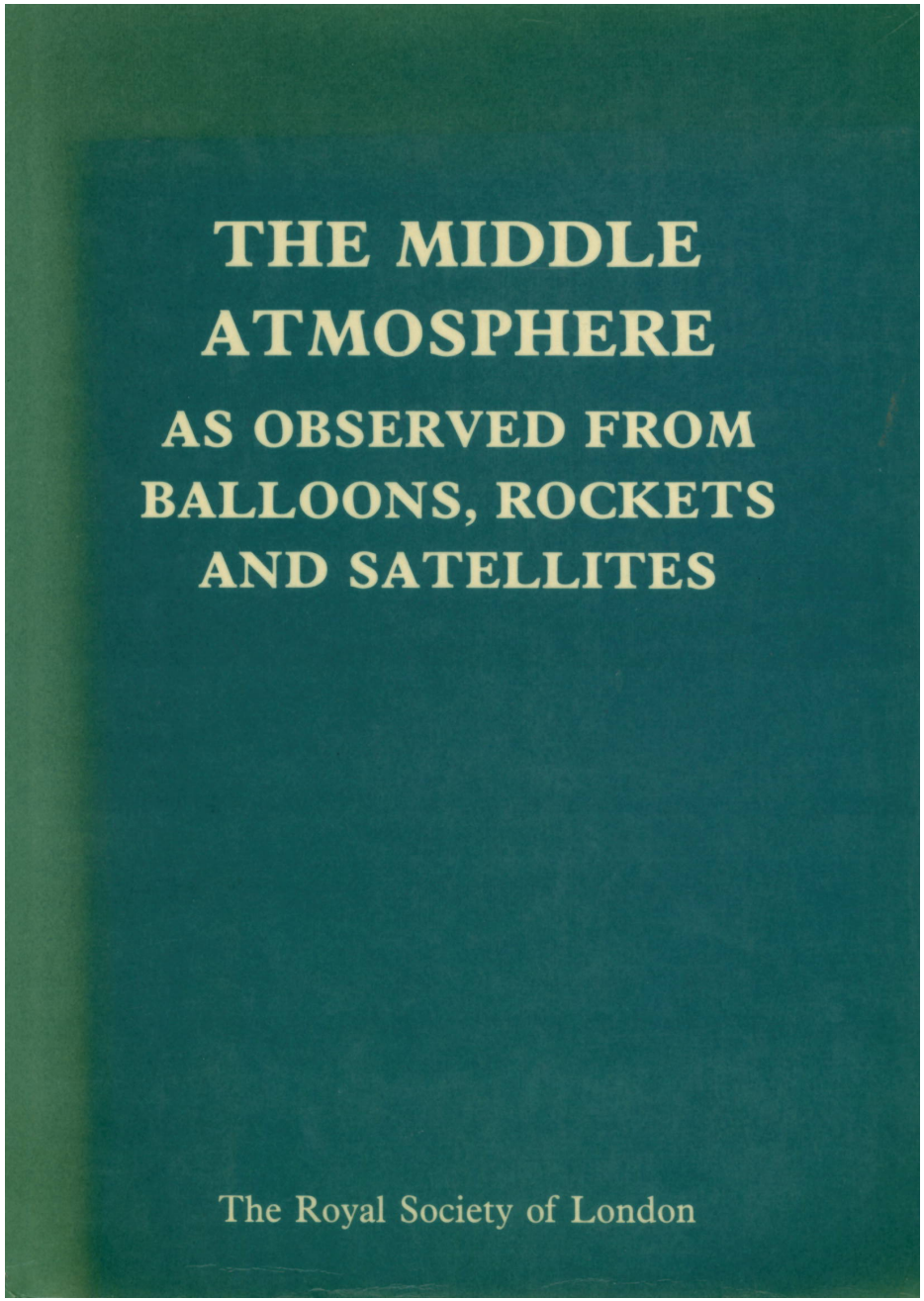


Royal Society Discussion Meeting
December 1978

Houghton Introduction

“Because of the possibilities presented by new observational methods and by the availability of satellites, a Middle Atmosphere Programme has been formulated … whose purpose is to encourage and coordinate research in the middle atmosphere in the early 1980s. That such a programme should be set up is also appropriate in the light of the concern which exists regarding the possibility that substantial changes in the ozone layer may occur because of the release into the atmosphere of chemicals (such as chlorofluoromethanes) arising as a result of man’s activities. We can, therefore, look forward to a considerable increase in research activity in the middle atmosphere during the next decade.”



Dynamical theory presented at the 1978 Discussion Meeting

Holton: Charney-Drazin criterion and modifications, wave mean-flow interaction described in terms of PV flux, wave transport of tracers, equatorial waves.

McIntyre: Lagrangian mean theory including GLM and possibility of a 'Modified Lagrangian Mean' based on PV-theta contours.

Wave activity conservation

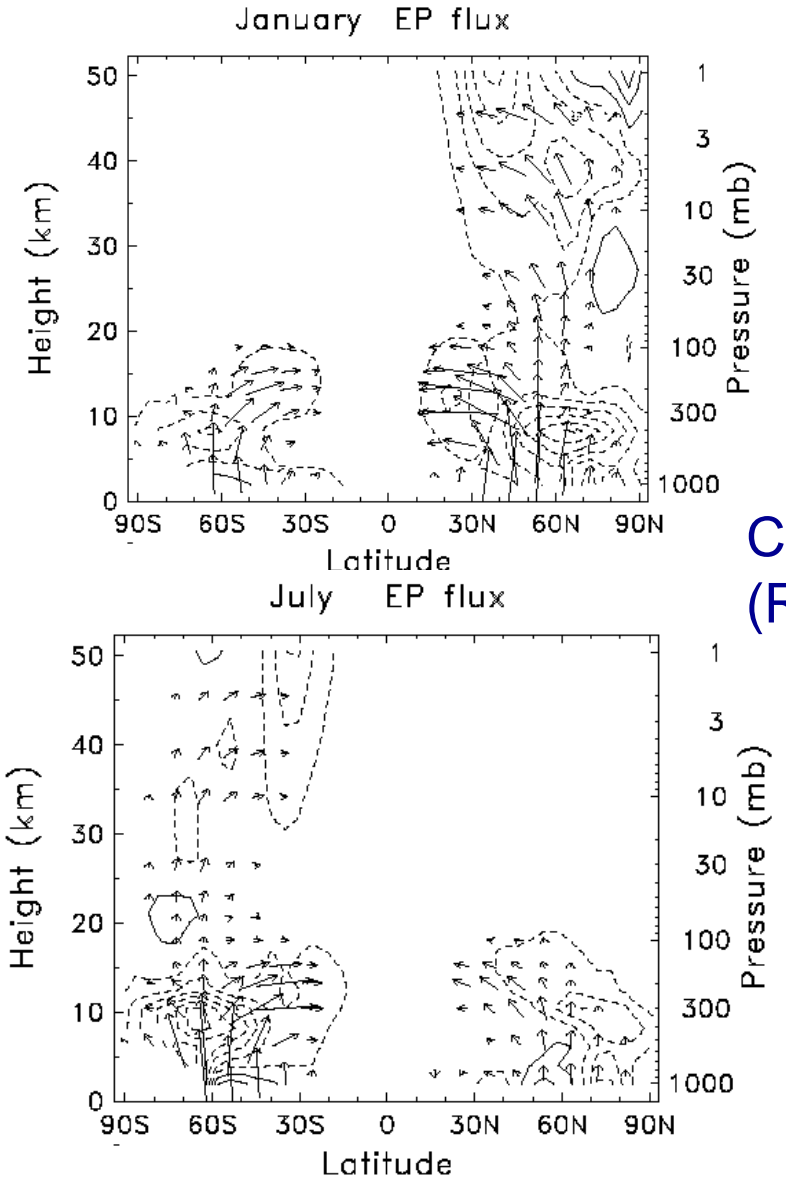
$$\frac{\partial \mathcal{A}}{\partial t} + \frac{\partial F^{(y)}}{\partial y} + \frac{\partial F^{(z)}}{\partial z} = \mathcal{D}_{\mathcal{A}}$$

density *y*-flux *z*-flux dissipation

Forcing on mean flow

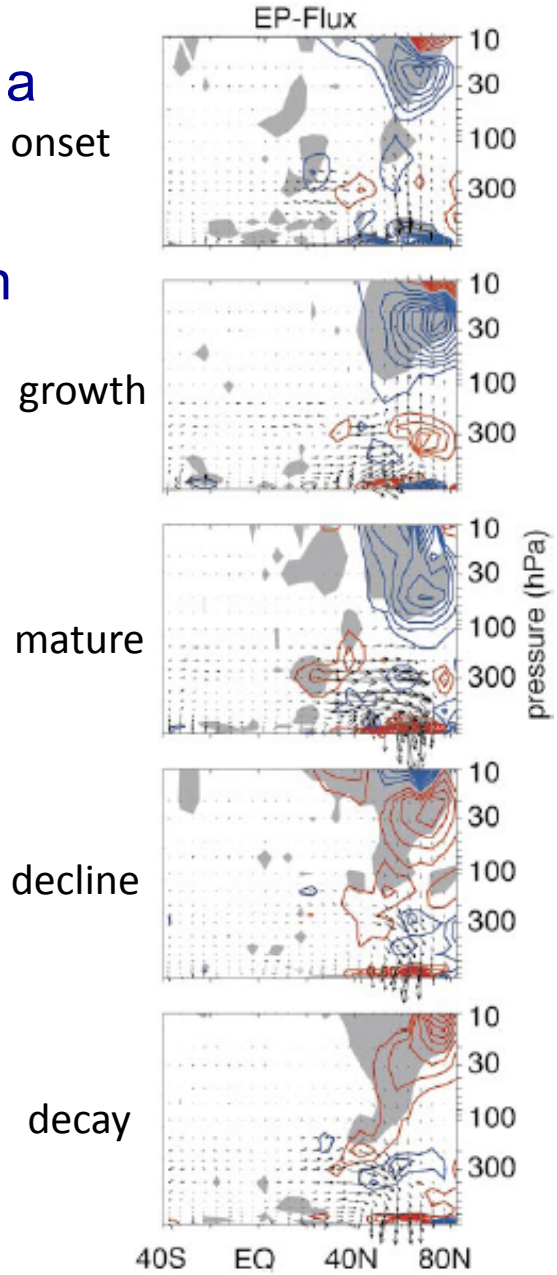
$$\nabla.\mathbf{F} = -\frac{\partial \mathcal{A}}{\partial t} + \mathcal{D}_{\mathcal{A}} = \overline{v'q'}$$

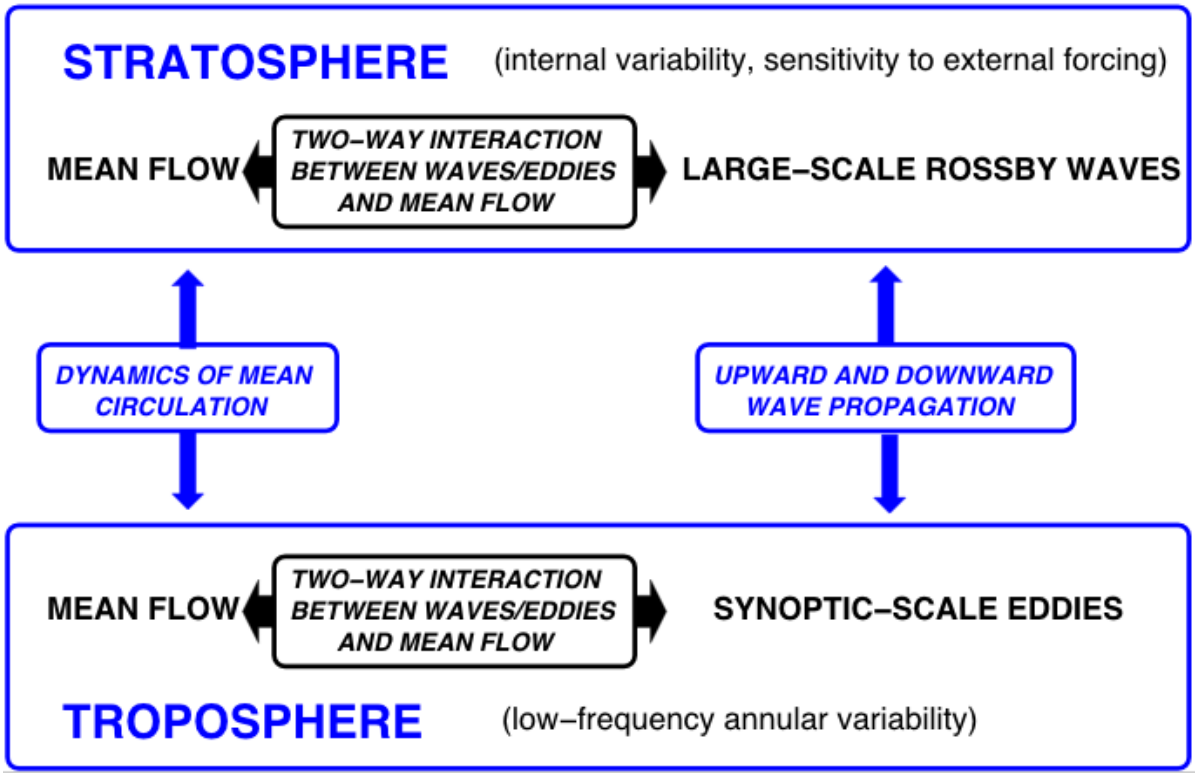
# Stratospheric EP fluxes

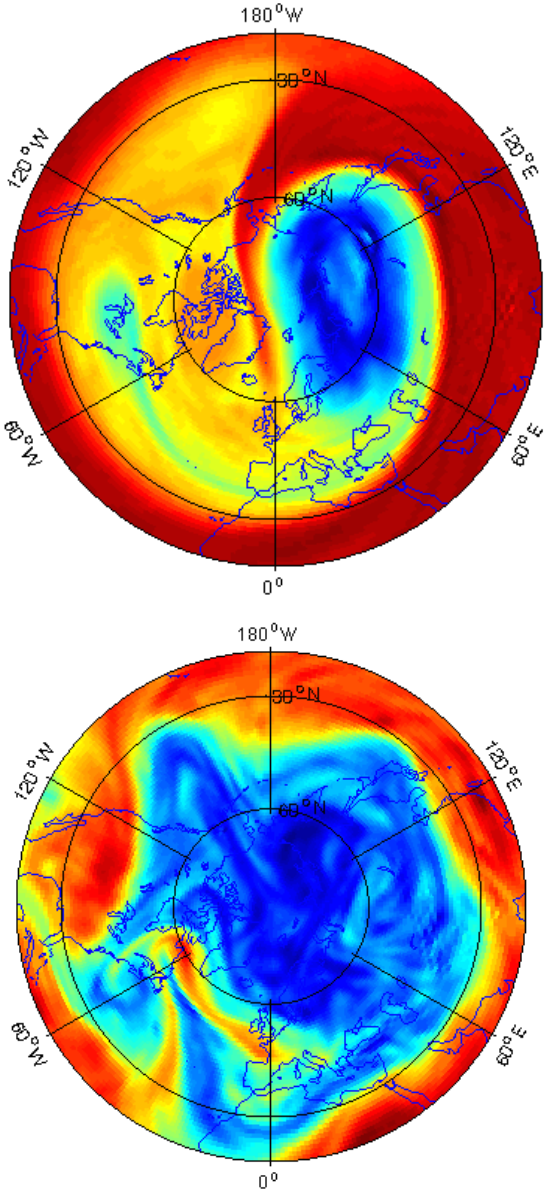



Climatology (Randel 1992)

Life-cycle of a sudden warming (Limpavusan et al 2004)




STRATOSPHERE
(internal variability, sensitivity to external forcing)
MEAN FLOW
TWO–WAY INTERACTION BETWEEN WAVES/EDDIES AND MEAN FLOW
LARGE–SCALE ROSSBY WAVES
DYNAMICS OF MEAN CIRCULATION
UPWARD AND DOWNWARD WAVE PROPAGATION
MEAN FLOW
TWO–WAY INTERACTION BETWEEN WAVES/EDDIES AND MEAN FLOW
SYNOPTIC–SCALE EDDIES
TROPOSPHERE
(low–frequency annular variability)


180°W
30°N
60°N
120°W
120°E
60°W
60°E
0°
180°W
30°N
60°N
120°W
120°E
60°W
60°E
0°

Royal Society Discussion Meeting
December 1986

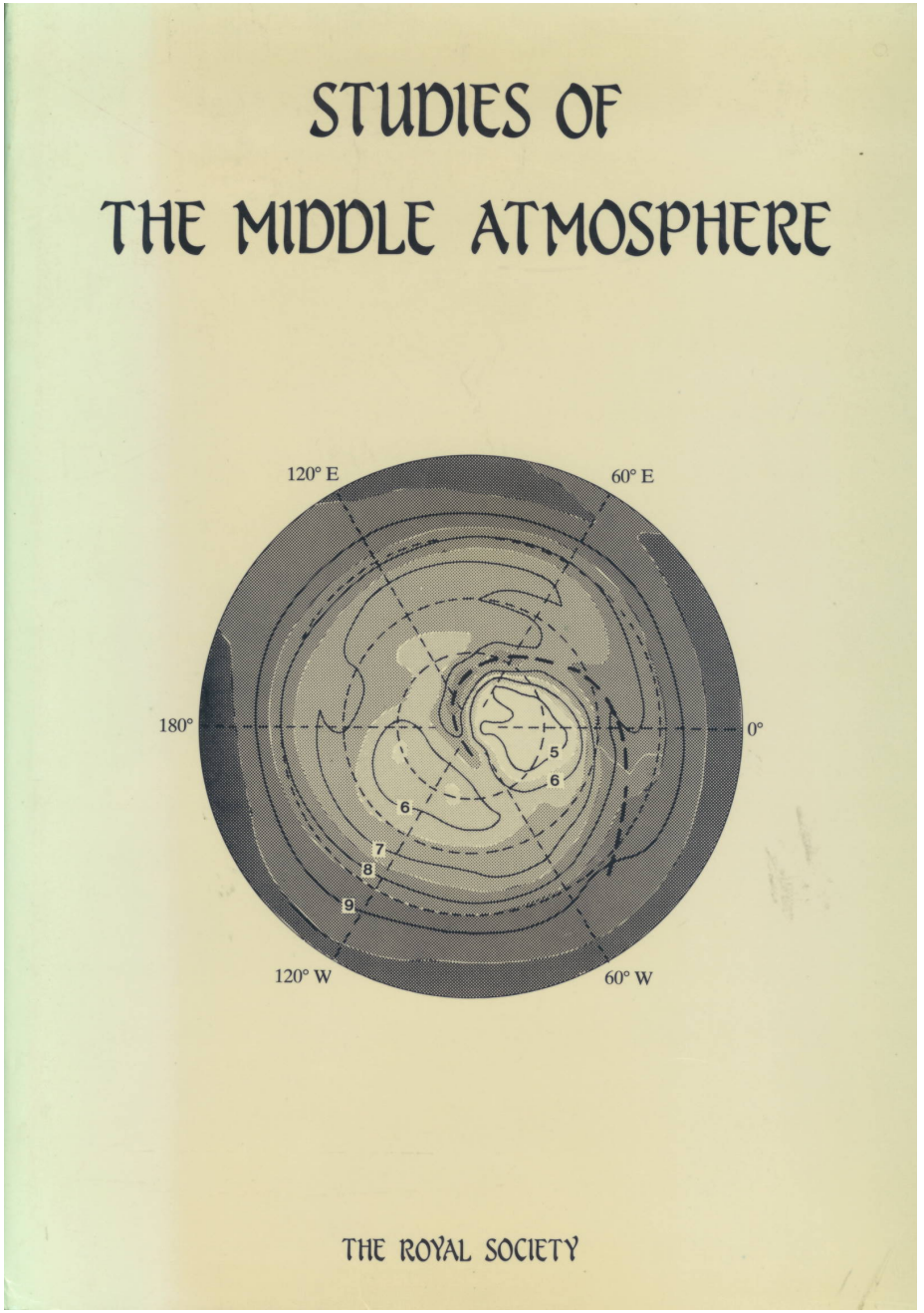
Barnett: satellites ‘routine observations of the whole stratosphere’, prospects for the future including UARS.

Russell, Pyle et al: satellite observations of composition and interpretation.

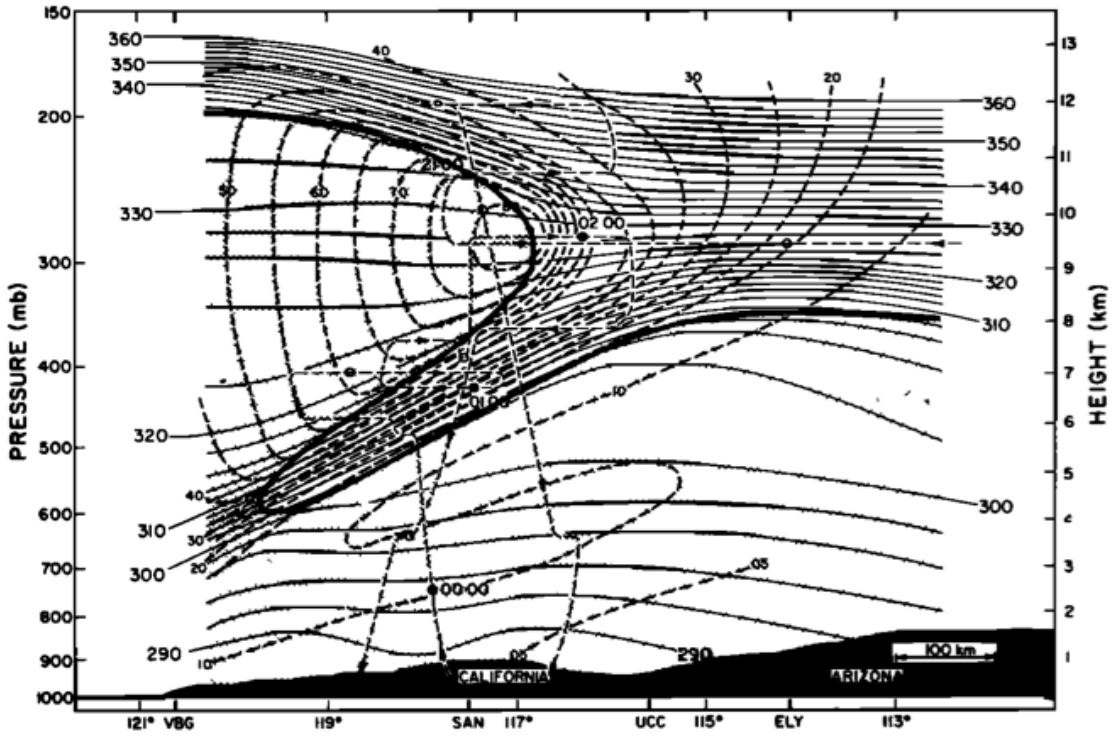
Fairlie and O’Neill: SSU data and numerical simulations of December 1984 warming including PV maps.

Solomon: mesospheric transport.

Farman: ‘Recent measurements of total ozone at British Antarctic Survey stations;



# Chemical and Dynamical contrasts between Troposphere and Stratosphere




Troposphere: low static stability, low PV, high water vapour, low ozone, …
Stratosphere: high static stability, high PV, low water vapour, high ozone, …

# The Brewer-Dobson Circulation

The dry air observed in the stratosphere above the UK must have entered the stratosphere in the tropics (Brewer 1949)

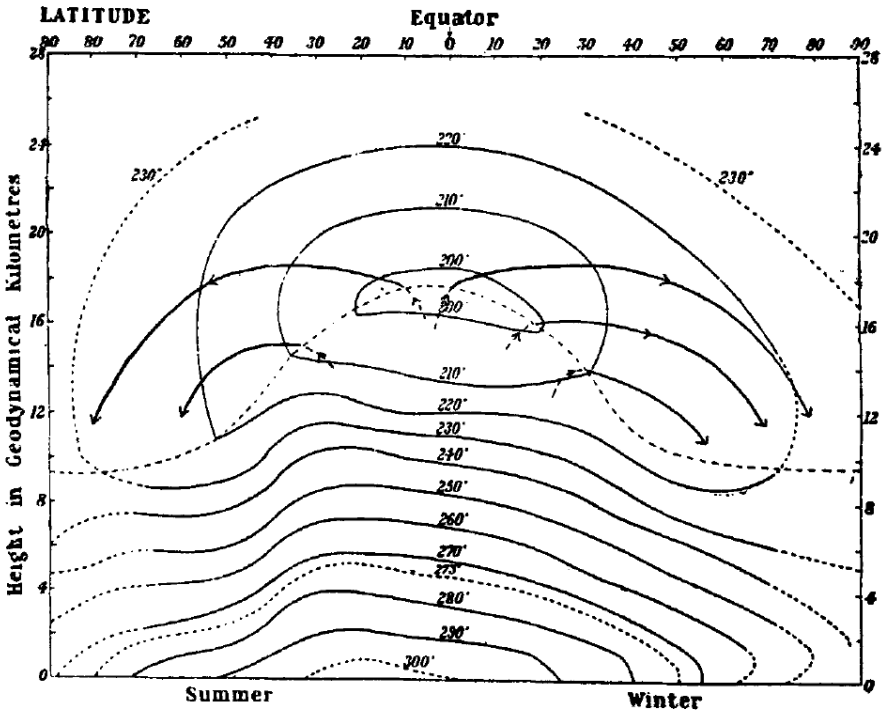
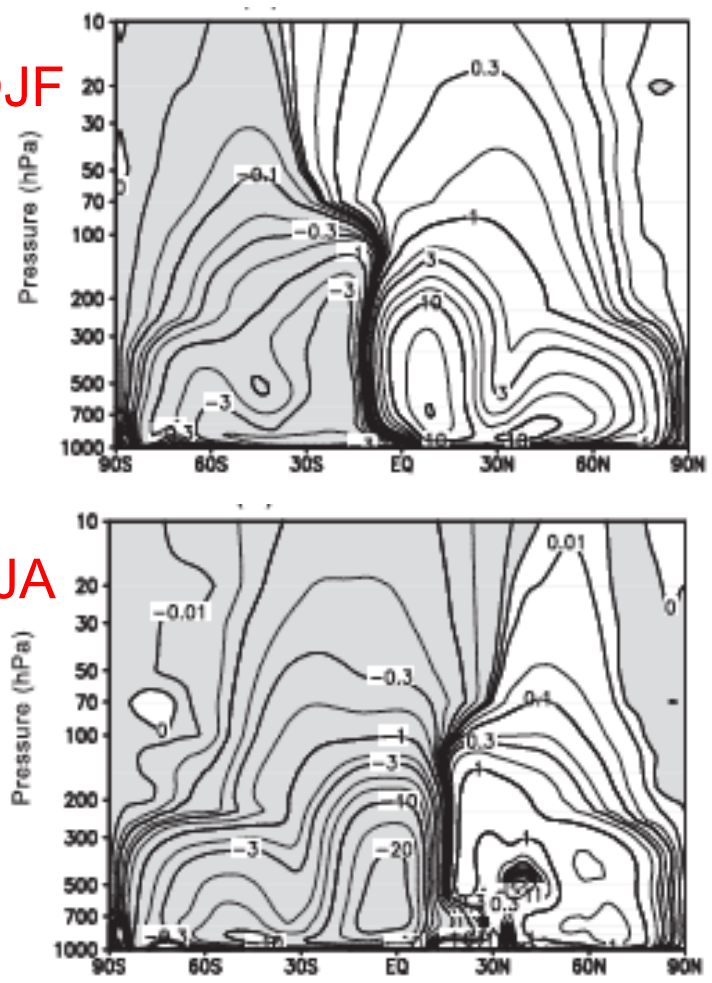



FIG. 5. A supply of dry air is maintained by a slow mean circulation from the equatorial tropopause.

BDC in ERA-Interim (Iwasaki et al 2009)

DJF

JJA



# The Angular Momentum Puzzle

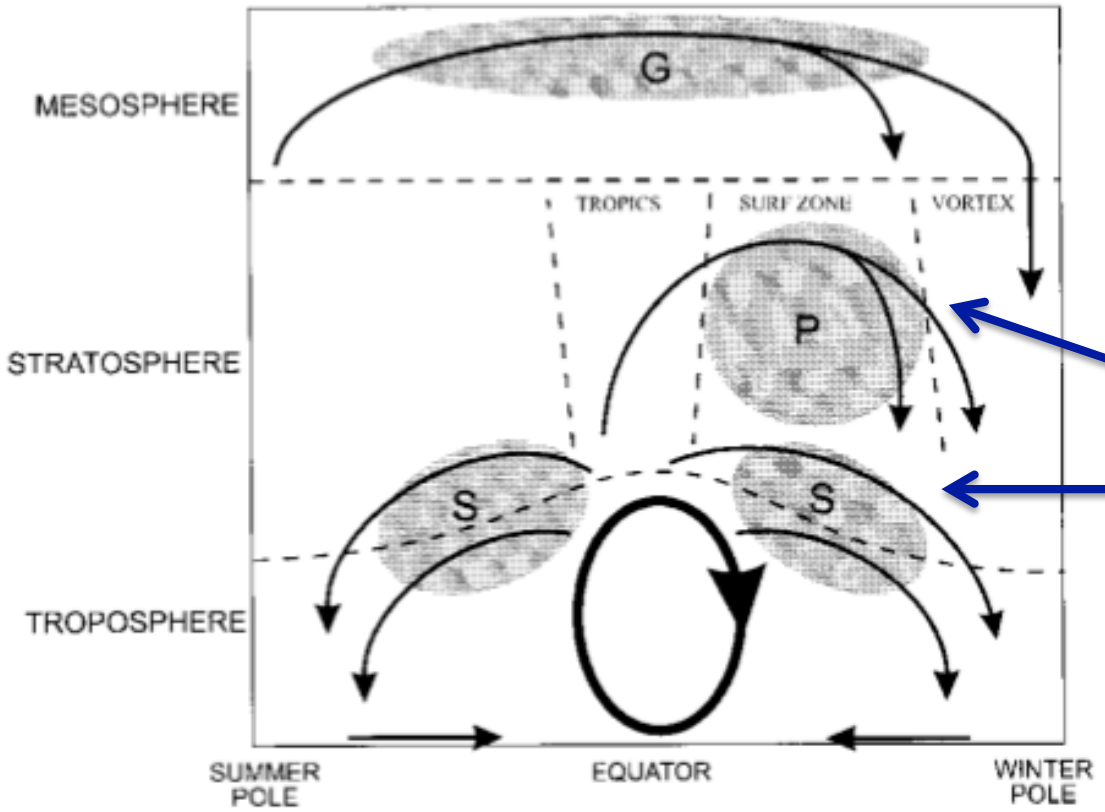
Brewer (1949) 'The dynamic consequences of the circulation have not been discussed. There are considerable difficulties in this respect.'

Air moving poleward should increase its eastward speed around latitude circles to conserve angular momentum. This is not observed.

Missing westward force?

$$\nabla . \mathbf{F} < 0 \, !!$$

# Dynamical balance for the BDC?




Upper branches of stratospheric BDC

Lower

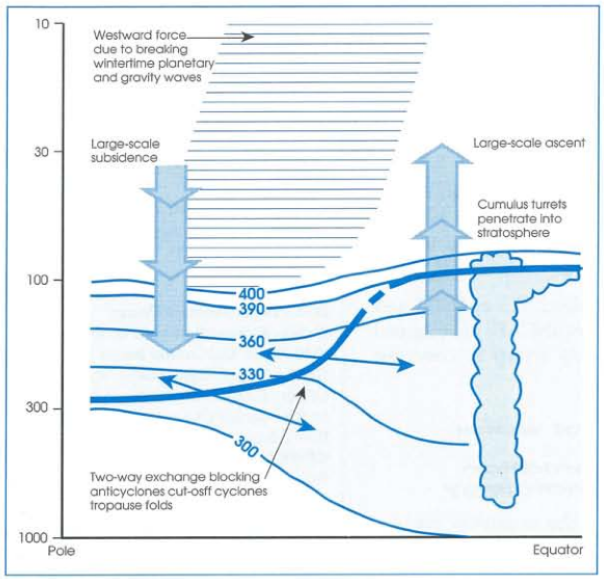
Plumb (2002)

# Stratosphere-troposphere exchange and the tropopause region

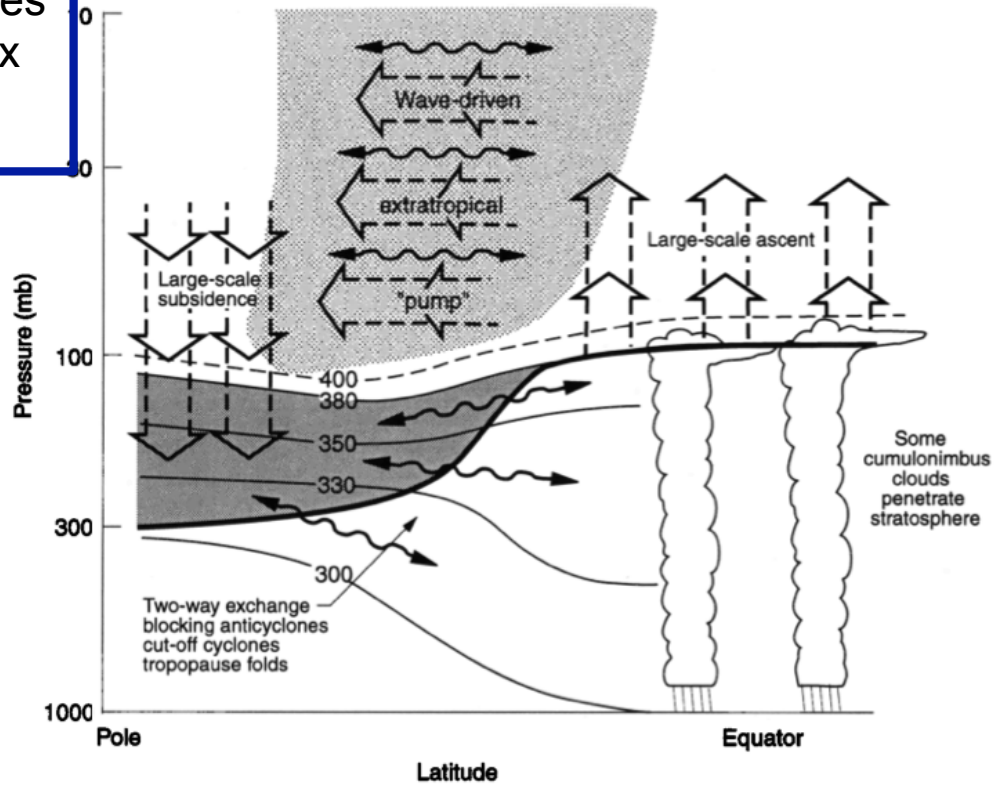
Building on Hoskins (1991)
*(Stratospheric) Overworld*
*Lowermost Stratosphere*

Emphasis on net fluxes – STE flux of species with source in stratospheric overworld = flux across 380K

Early 1990s

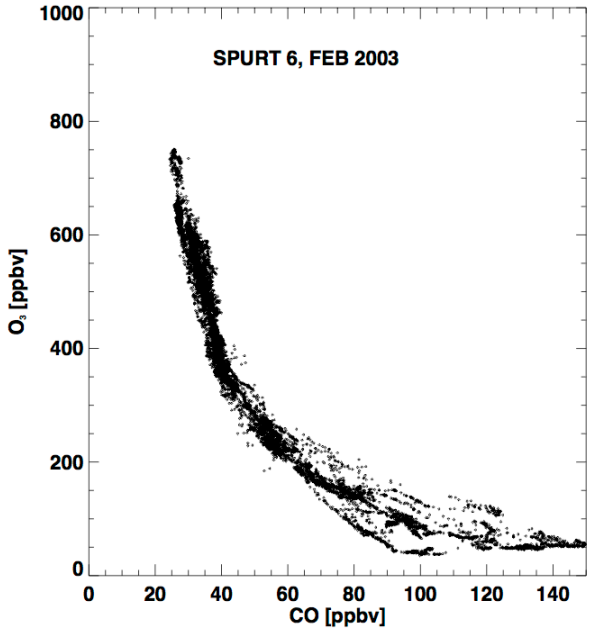



SPARC newsletter 1993

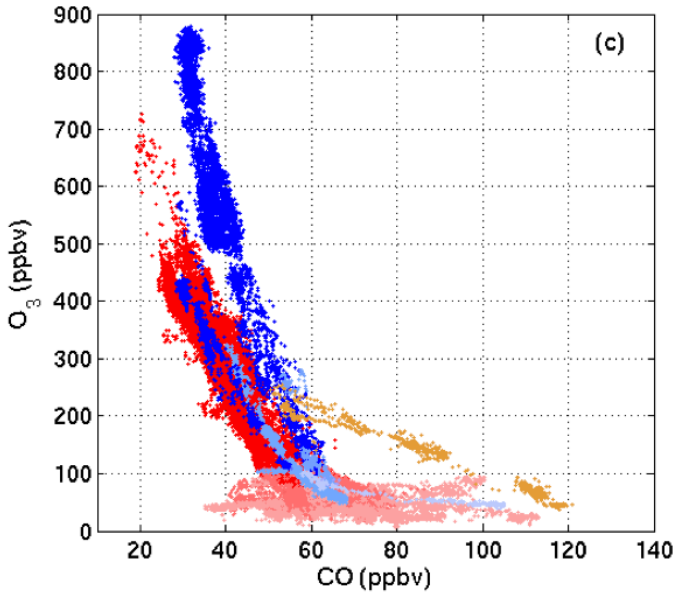



Holton et al (1995)

# Mixing between tropospheric and stratospheric air

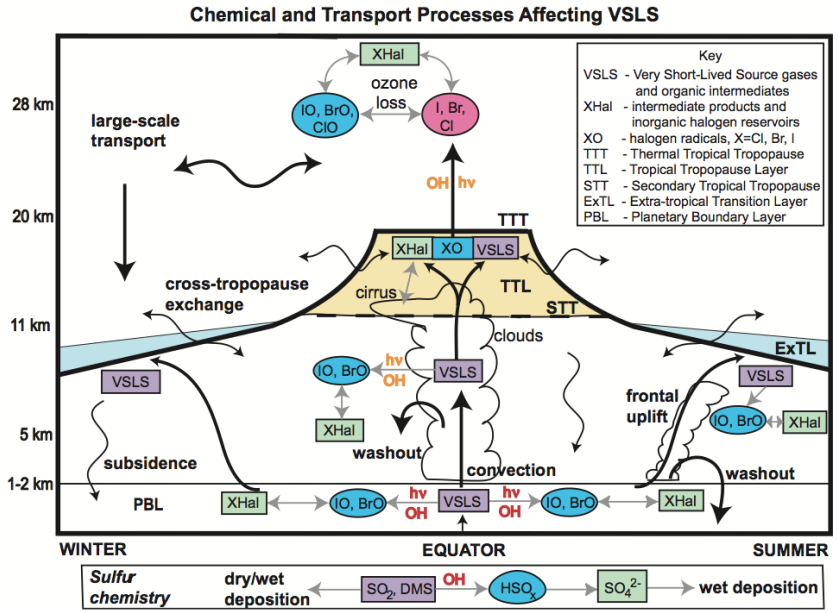



Hoor et al (2004)

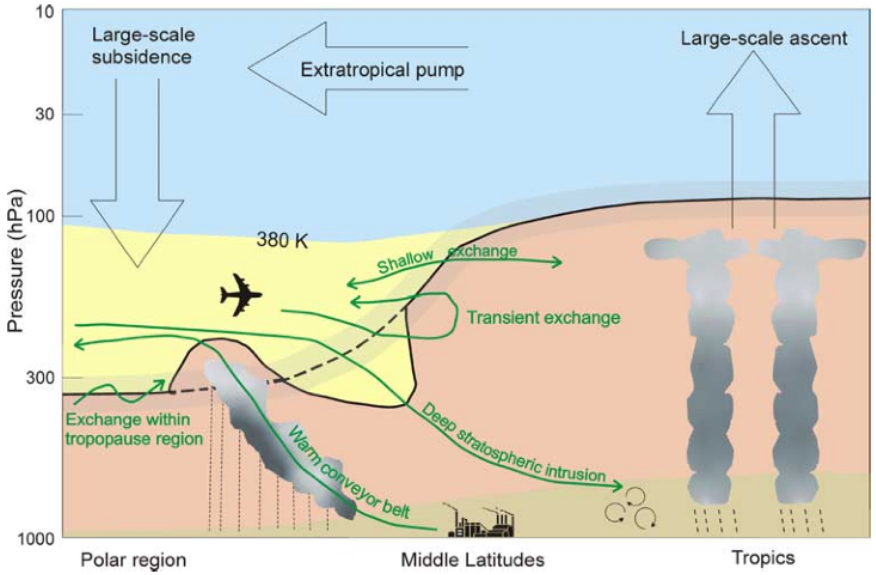



James and Legras (2009)

# Early 2000s




Law, Cox, H (WMO 2003)



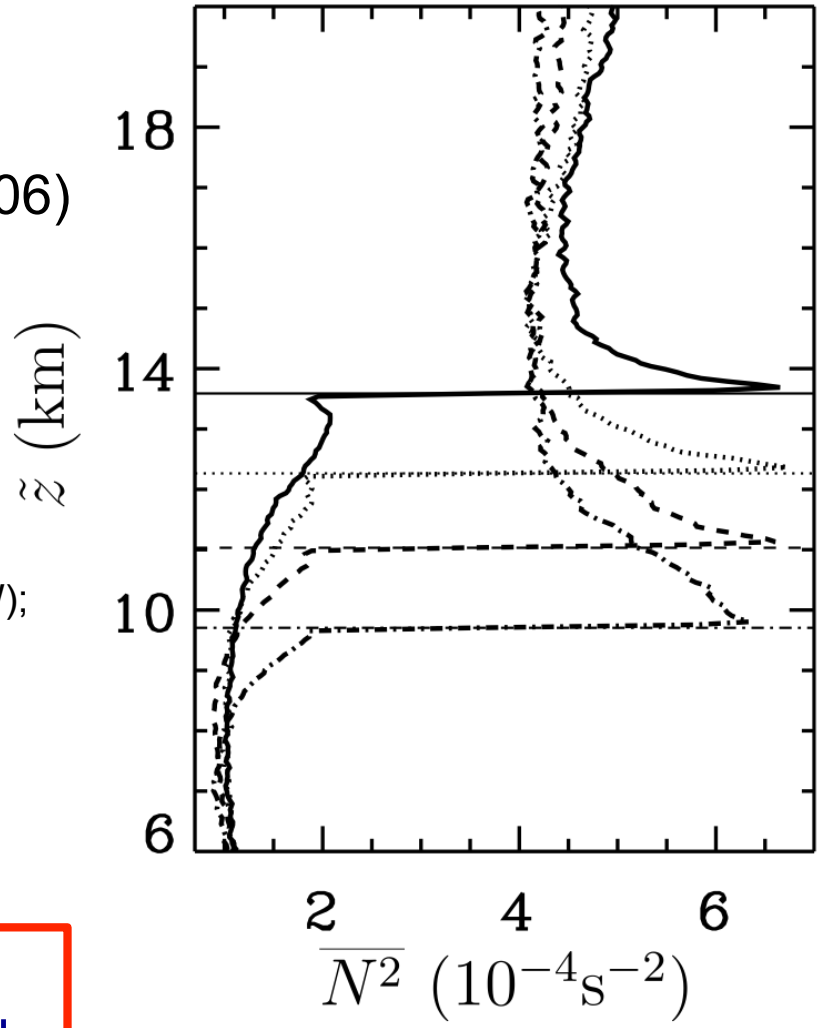

Stohl et al (2003)

Extratropics: ExTL ('mixing layer', 'very lowermost stratosphere'), 'deep exchange' vs 'shallow exchange', role of WCBs

Tropics: Most convection does not reach the tropopause, TTL as layer with intermediate characteristics.

TIL in radiosonde data

Birner et al (2002), Birner (2006)




Miramar NAS, California (33 N, 117 W);
Reno, Nevada (40 N, 120 W);
Quillayute, Washington (48 N, 125 W);
Yakutat, Alaska (60 N, 140 W)

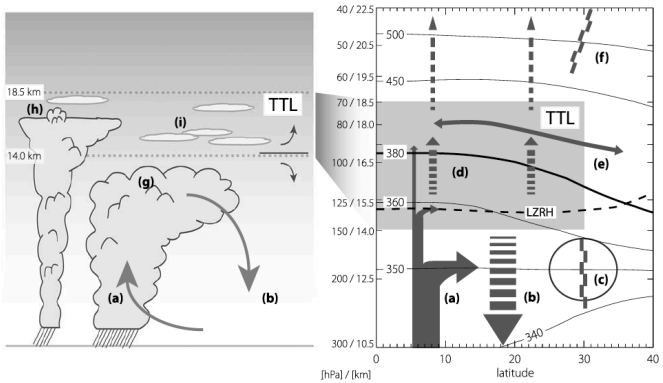
TIL now accepted as important feature of the extratropical (and perhaps tropical) UTLS

# Late 2000s

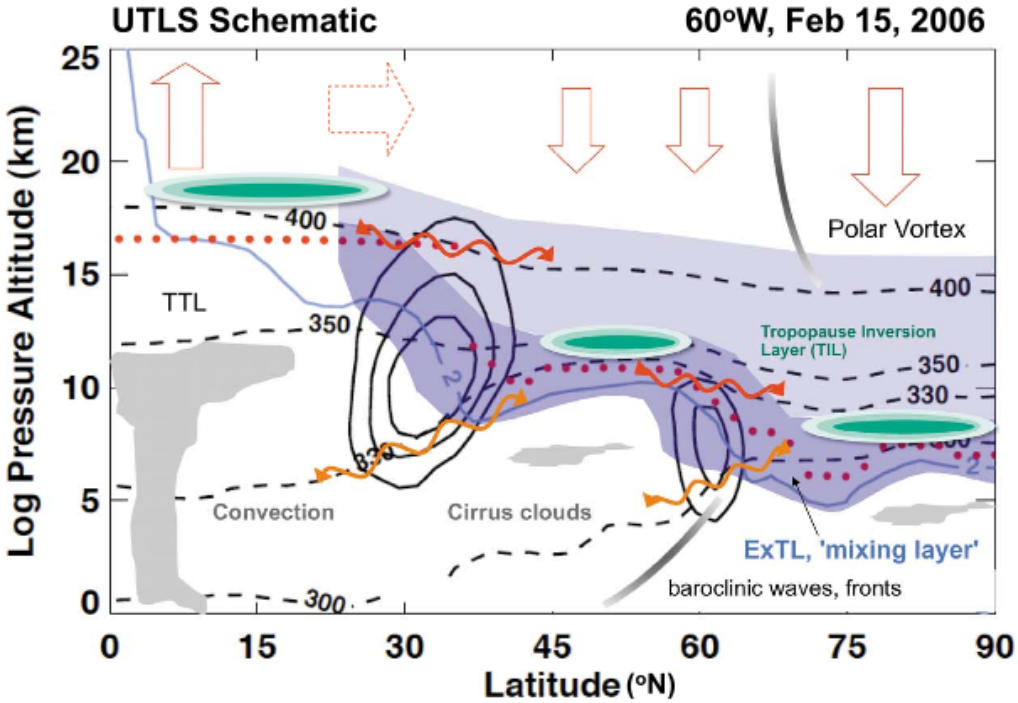
Extratropics: Tropopause Inversion Layer (TIL), exchange above and below jets

Tropics: TIL, shallow branch of BDC

Fueglistaler et al (2009)




Gettelman et al (2011)



# Transport/Trajectory calculations using meteorological analysis datasets

Available re-analysis datasets (Fujiwara et al 2012, SPARC Newsletter)

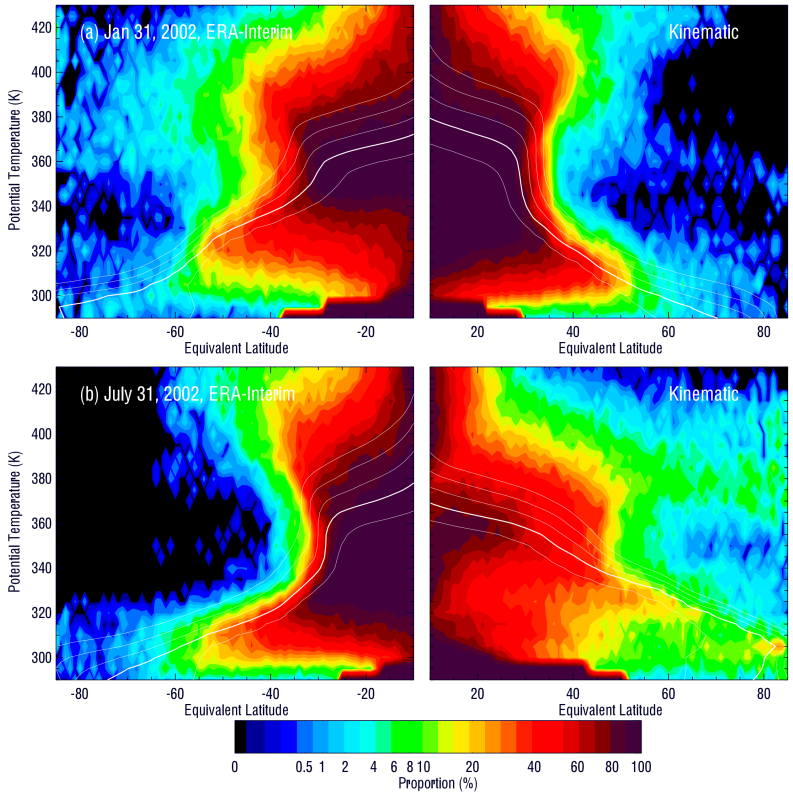
| Product | Centre | Period | Resolution and Lid Height of the Forecast Model |
|---|---|---|---|
| NCEP-1 | NCEP and NCAR | 1948-present | T62, L28, 3 hPa |
| NCEP-2 | NCEP and DOE AMIP-II | 1979-present | T62, L28, 3 hPa |
| ERA-40 | ECMWF | 1958-2001 | TL159 and N80 reduced Gausiian, L60, 0.1 hPa |
| ERA-Interim | ECMWF | 1979-present | TL255 and N128 reduced Gausiian, L60, 0.1 hPa |
| JRA-25/JCDAS | JMA and CRIEPI | 1979-present | T106, L40, 0.4 hPa |
| MERRA | NASA | 1979-present | (2/3)x(1/2) deg., L72, 0.01 hPa |
| NCEP-CFSR | NCEP | 1979-present | T382 (T574 for post 2010), L64, 0.266 hPa |
| NOAA-CIRES 20th Century Reanalysis (20CR)* | NOAA/ESRL PSD | 1871-2008 | T62, L28, 2.511 hPa |

- FLEXPART (Stohl and collaborators)
- OFFLINE3 (Methven, Liu)

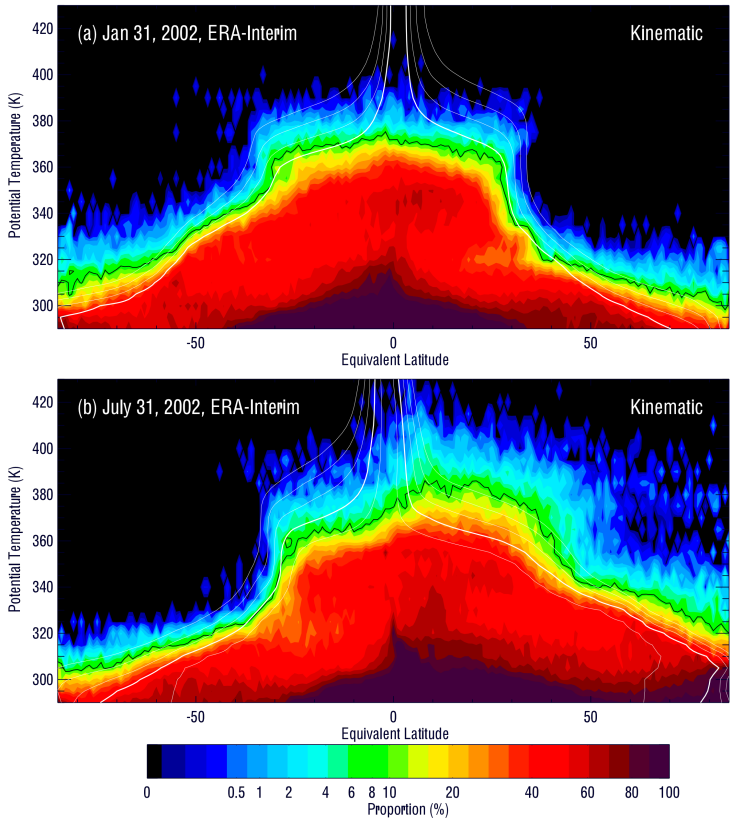
'kinematic' or 'diabatic'

# Transport in the troposphere/UTLS visualised using trajectory ensembles

Berthet, Esler, H (2007), Liu (2010)



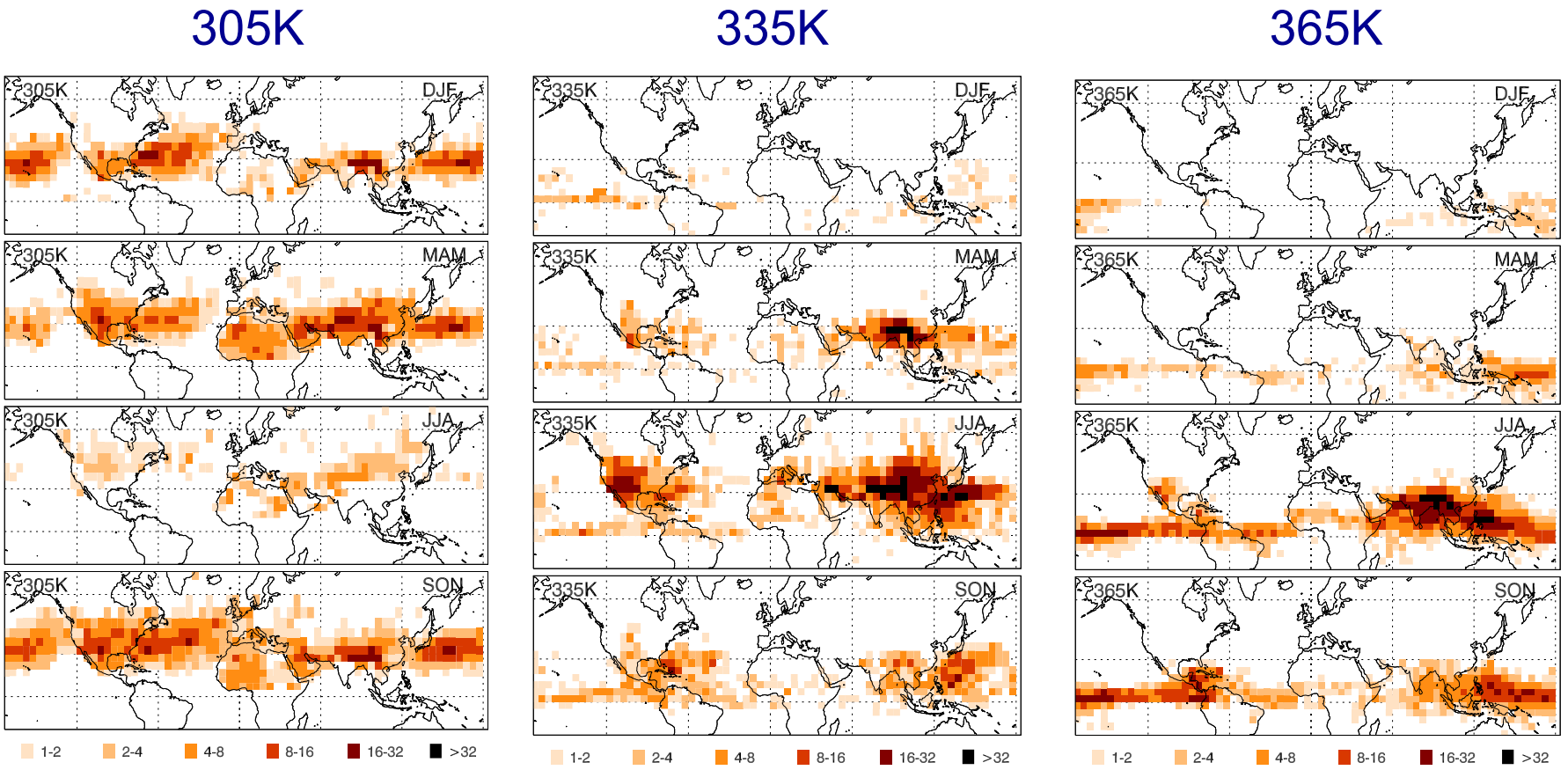

Proportion coming from [10S,10N] in 30 days as function of θ and PV equivalent latitude




Proportion coming from below 1km in 30 days as function of θ and PV equivalent latitude

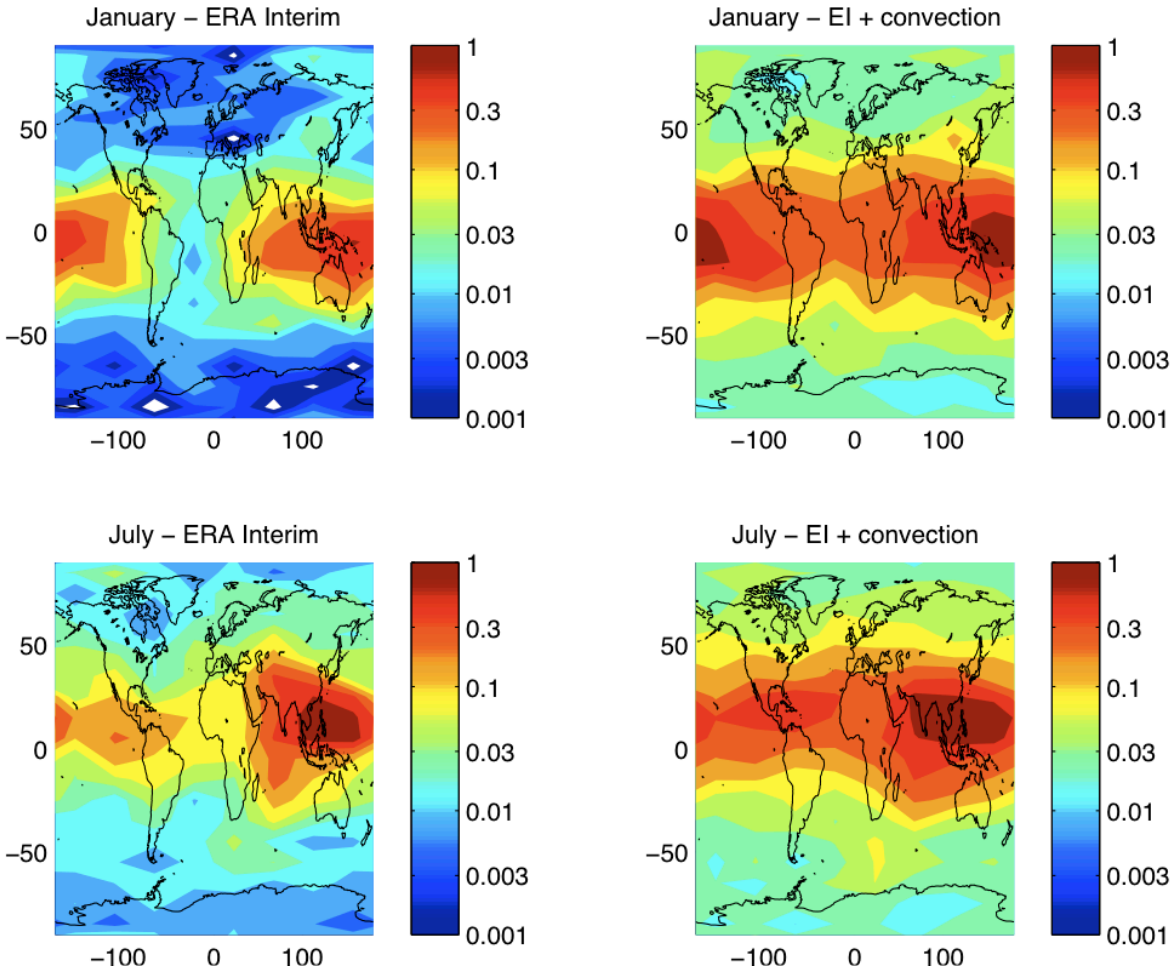
# Surface origin for air that reaches stratosphere within 30 days

Berthet et al (2007)



Pisso et al 2010

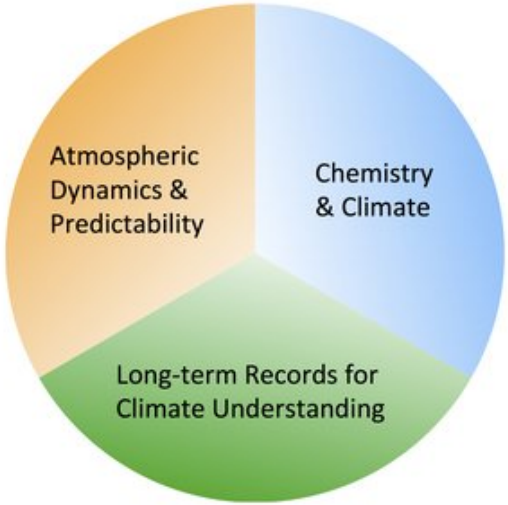
# ODP for ‘nPB’




Dependence on convective parametrization?

# UTLS/Stratosphere Science Questions?

… On regional scales, unlike the global mean, it is the dynamics as much as the thermodynamics that determines climate. …




… Three-way coupling between chemical, dynamical, and radiative processes could have important effects on climate, including modulation of climate sensitivity. …