UTLS and STE: A Review with a Tropospheric Perspective

(and maybe a little TOLNet bias)

Andrew O. Langford
NOAA/ESRL/CSD
TOLNet/NDAAC 2018 meeting
Huntsville, AL
7-11 May 2018

Stratosphere-troposphere transport (STT)

“To be as consistent as possible with previous nomenclature while removing ambiguities, we propose that STE should refer to exchange in both directions in the most general sense, whereas **stratosphere-to-troposphere transport (STT)** and troposphere-to-stratosphere transport (TST) should be used to refer specifically to one-way transport.”

Andreas Stohl   STACCATO 2003

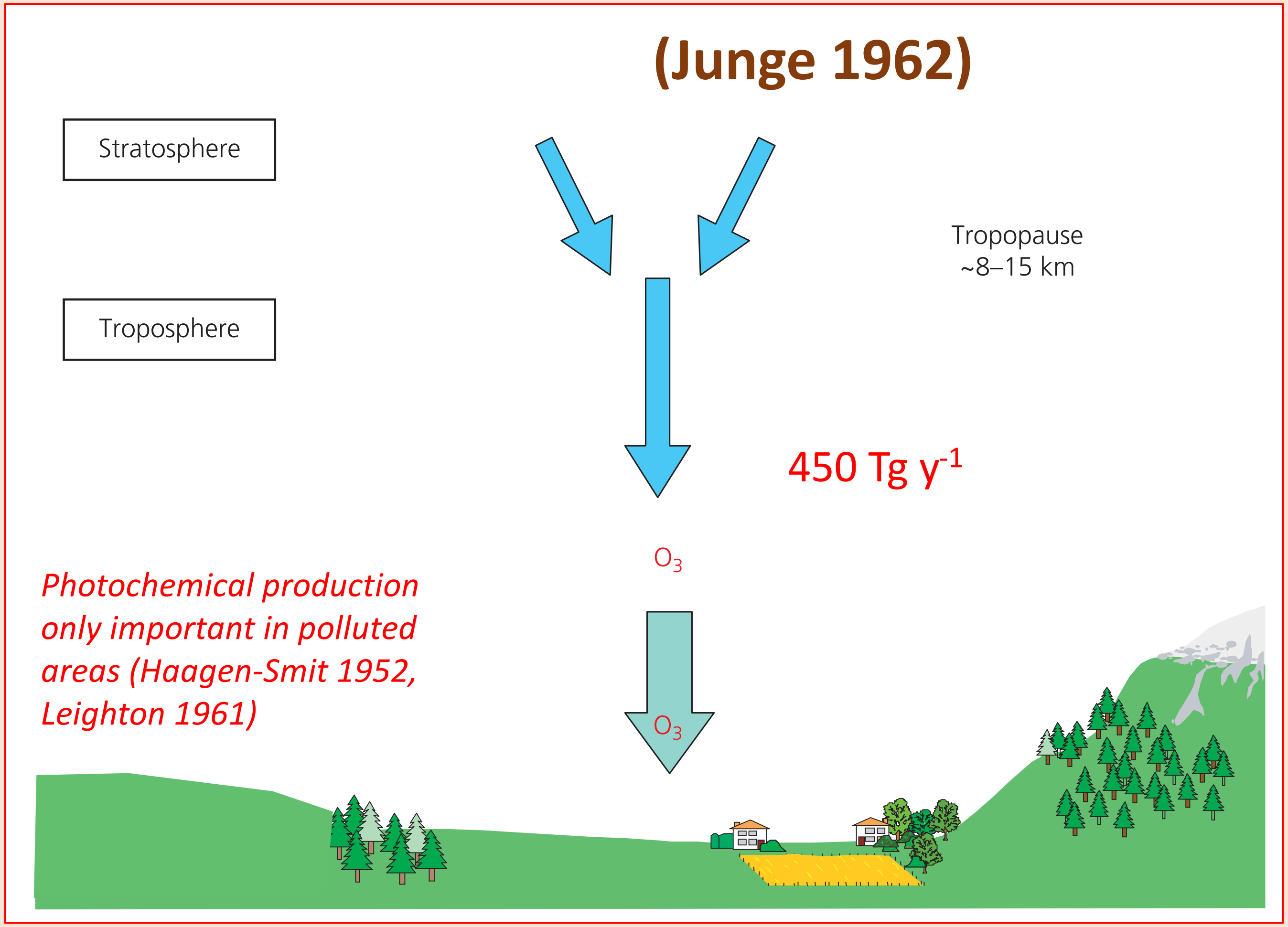
Outline

- How much does STT contribute to free tropospheric O_3?
- What physical processes are responsible?
- How have ozone lidars advanced out knowledge?
- Does STT significantly impact surface air quality?

How much does STT contribute to free tropospheric O_3?

The Classical view…

Before 1970: Nearly all free tropospheric ozone thought to originate in the lower stratosphere


(Junge 1962)

450 Tg y^{-1}

Photochemical production only important in polluted areas (Haagen-Smit 1952, Leighton 1961)

Stratospheric influx balanced by surface deposition

Examples of high surface ozone attributed to stratospheric intrusions during the 1970s

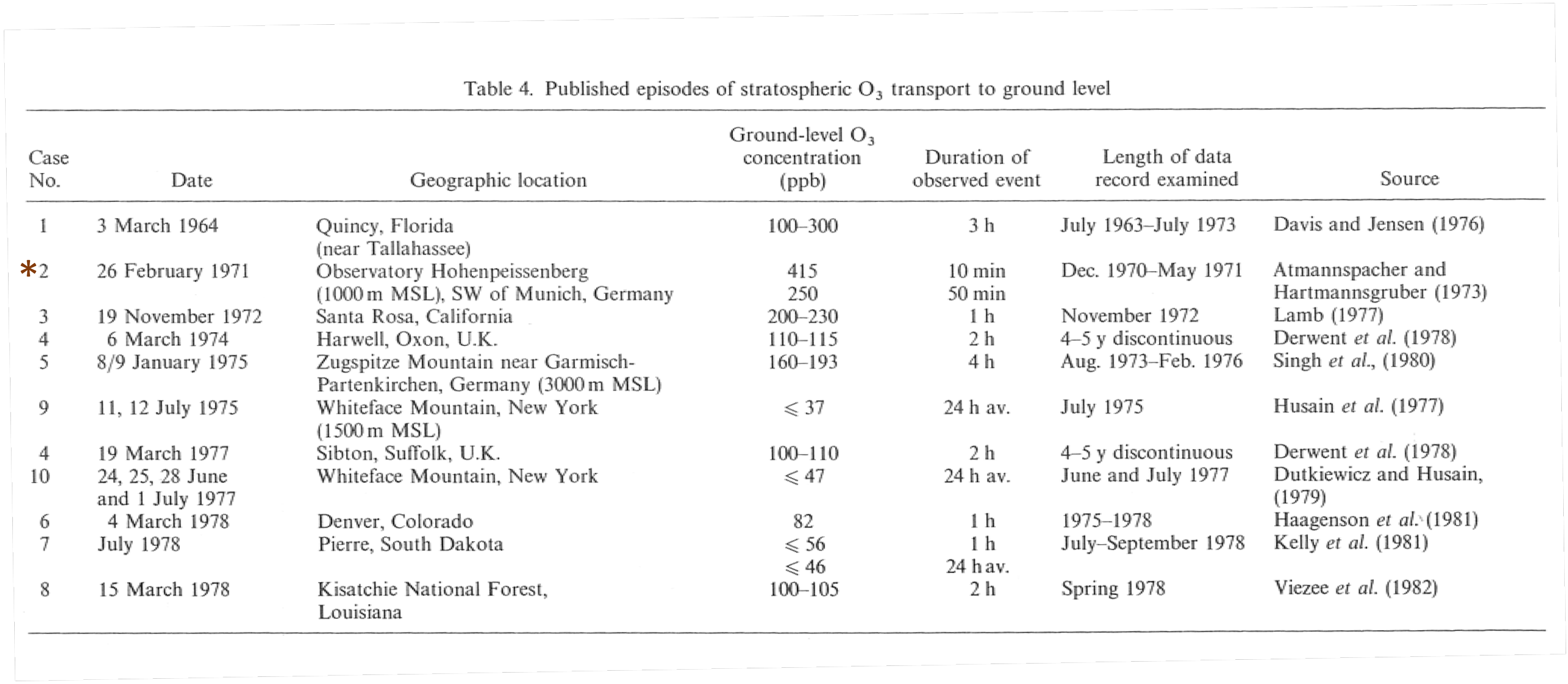


Table 4. Published episodes of stratospheric O_3 transport to ground level

Case No.	Date	Geographic location	Ground-level O_3 concentration (ppb)	Duration of observed event	Length of data record examined	Source
1	3 March 1964	Quincy, Florida (near Tallahassee)	100–300	3 h	July 1963–July 1973	Davis and Jensen (1976)
*2	26 February 1971	Observatory Hohenpeissenberg (1000 m MSL), SW of Munich, Germany	415 250	10 min 50 min	Dec. 1970–May 1971	Atmannspacher and Hartmannsgruber (1973)
3	19 November 1972	Santa Rosa, California	200–230	1 h	November 1972	Lamb (1977)
4	6 March 1974	Harwell, Oxon, U.K.	110–115	2 h	4–5 y discontinuous	Derwent *et al.* (1978)
5	8/9 January 1975	Zugspitze Mountain near Garmisch-Partenkirchen, Germany (3000 m MSL)	160–193	4 h	Aug. 1973–Feb. 1976	Singh *et al.*, (1980)
9	11, 12 July 1975	Whiteface Mountain, New York (1500 m MSL)	$\leqslant 37$	24 h av.	July 1975	Husain *et al.* (1977)
4	19 March 1977	Sibton, Suffolk, U.K.	100–110	2 h	4–5 y discontinuous	Derwent *et al.* (1978)
10	24, 25, 28 June and 1 July 1977	Whiteface Mountain, New York	$\leqslant 47$	24 h av.	June and July 1977	Dutkiewicz and Husain, (1979)
6	4 March 1978	Denver, Colorado	82	1 h	1975–1978	Haagenson *et al.* (1981)
7	July 1978	Pierre, South Dakota	$\leqslant 56$ $\leqslant 46$	1 h 24 h av.	July–September 1978	Kelly *et al.* (1981)
8	15 March 1978	Kisatchie National Forest, Louisiana	100–105	2 h	Spring 1978	Viezee *et al.* (1982)

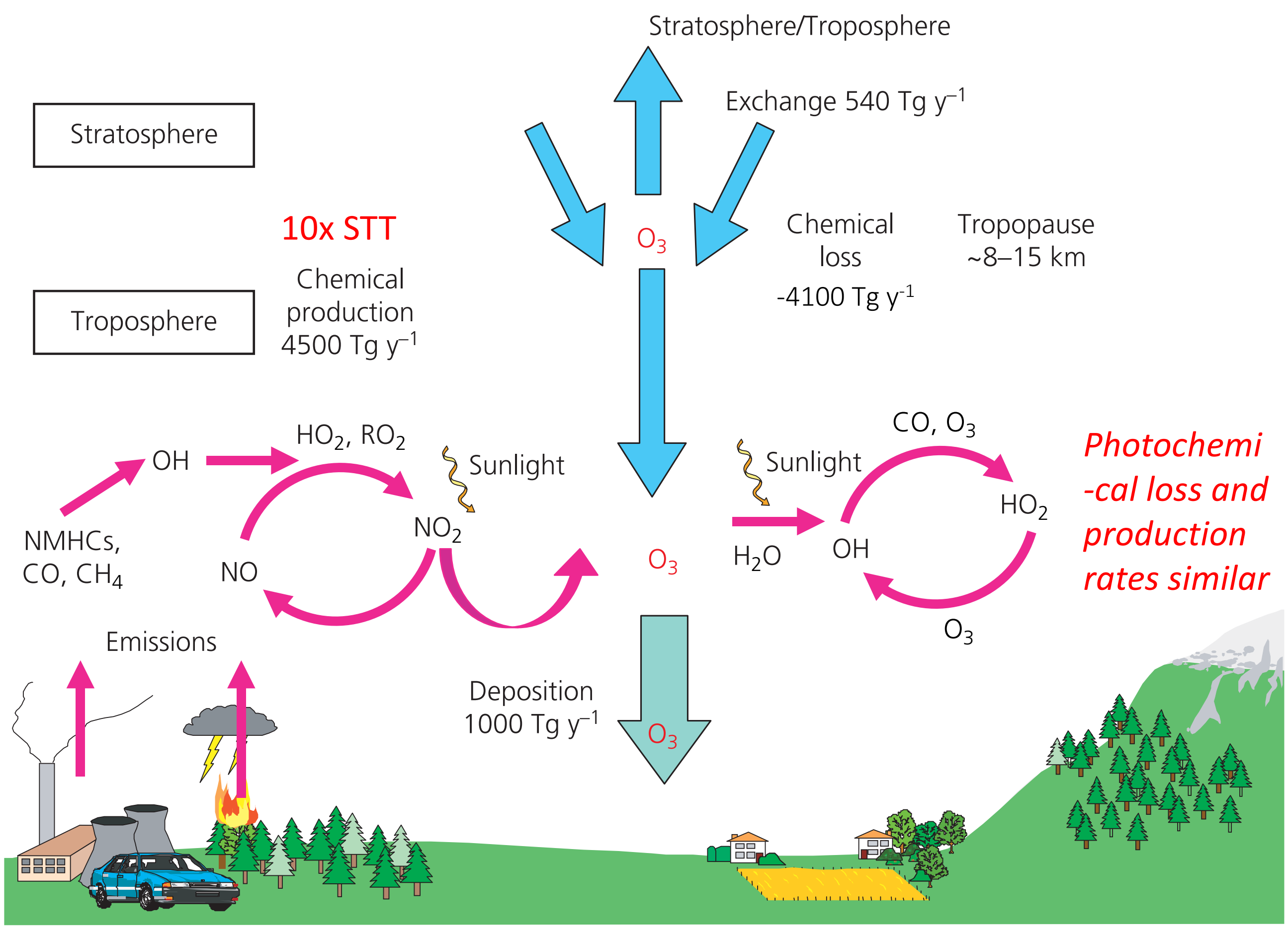
*Feb 1971 _Altmannspacher_ 415 ppbv O_3 (10 min)

From *Viezee and Johnson* 1983

The 1970s: The great transport vs photochemical control debate

1970	*Junge*	**Tropospheric O_3 controlled by transport**
1971	*Galbally*	Photochemical production in rural areas too.
1973	*Chameides and Walker*	Photochemical production globally important.
1974	*Crutzen*	
1974	*Fabian*	Observations don’t support your models.
1976	*Chatfield and Harrison*	…and here are more reasons why they don’t!
1977	Fishman and Crutzen	Here’s a new model supporting photochemistry.
1977	*Fabian and Pruchniewicz*	Here are *more* observations disproving it.
1977	*Chameides and Stedman*	Our model says that both are important.
1978	*Fishman and Crutzen*	And here’s an even better model...
1979	*Fishman, Solomon, and Crutzen*	…and some observations supporting it.
1980	*Liu et al.*	**Tropospheric O_3 controlled by photochemistry**

The Current View: Net contributions similar



The Royal Society, 2008 , Ground-level ozone in the 21st century,

IPCC Fourth Assessment Report Working Group, "The Physical Basis"

What physical processes contribute to STT?

Poleward transport by the Brewer-Dobson Circulation followed by:

• Tropopause folding	*Reed/Danielsen*	1958
• Jet stream turbulence	*Shapiro*	1978
• Erosion of cutoff lows	*Bamber et al.*	1984
• Thunderstorms	*Dickerson et al.*	1987
• Gravity wave breaking	*Lamarque/Langford*	1996
• Kelvin wave breaking/MJO	*Fuijiwara et al.*	1998

What physical processes contribute to STT?

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Most STT a result of tropopause folding

Early STT research motivated by concerns about radioactive fallout from stratospheric testing

Project Springfield (1964)

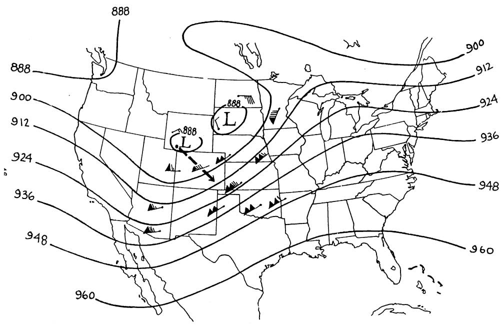
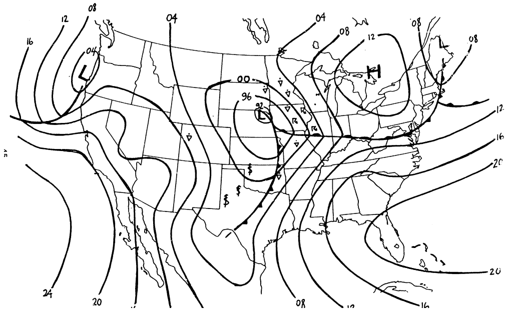
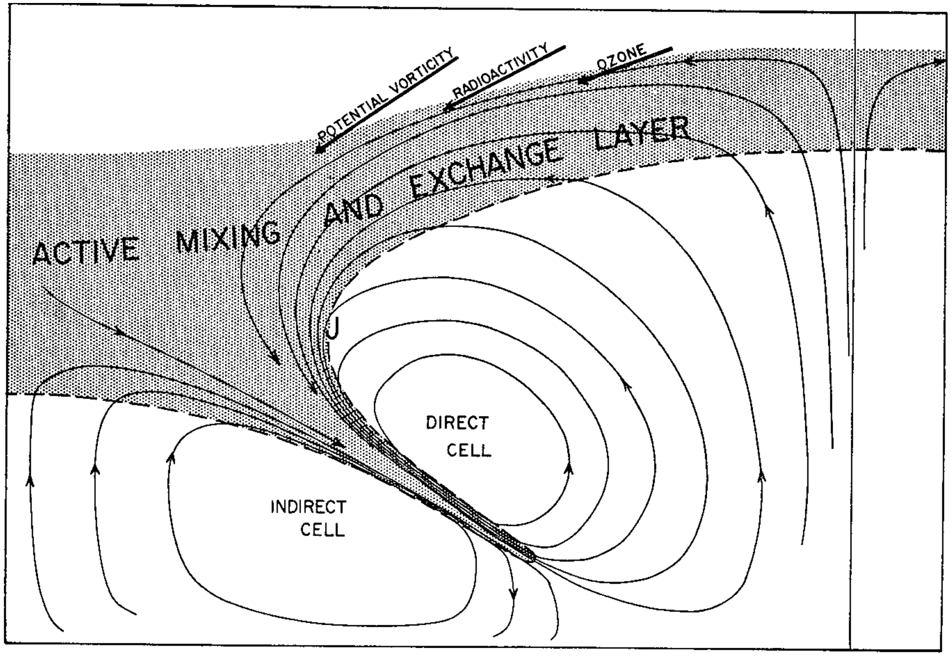


Figure 8b 300mb-April 19,0000z,1963.

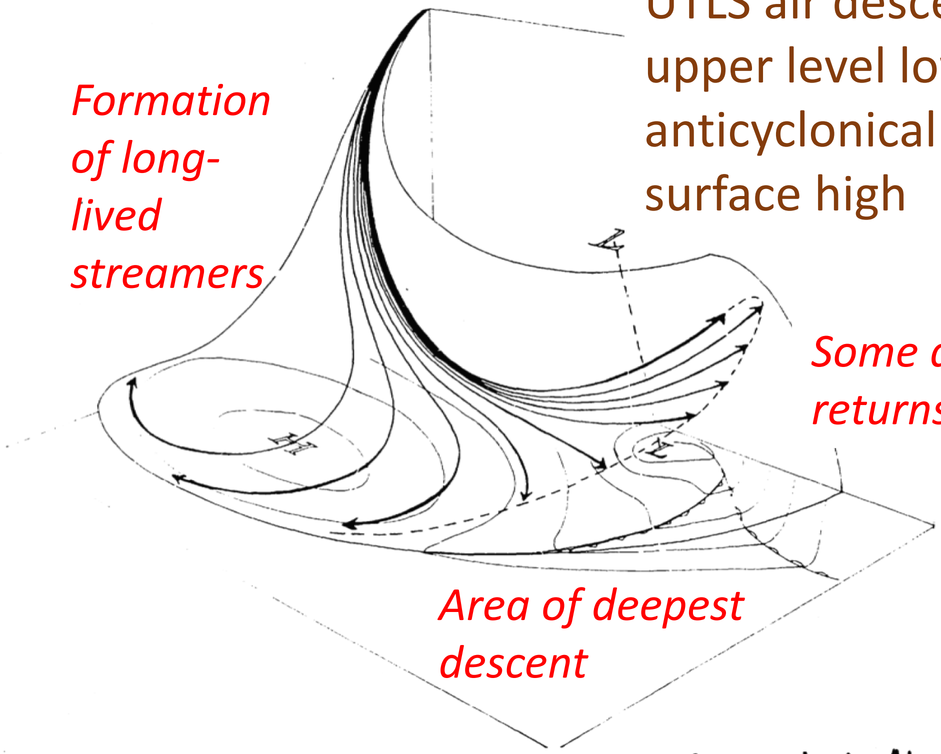




Localized acceleration of jet stream (i.e. jet streak) during cyclogenesis forces tongue of lower stratospheric air into the upper troposphere beneath the jet.

Based on high altitude sampling by WB-50 and RB-57 aircraft

Schematic view of tropopause fold (Danielsen 1964)



UTLS air descends on flank of upper level low and wraps anticyclonically around trailing surface high

Formation of long-lived streamers

Some air returns to LS

Area of deepest descent

Figure 6 Trajectories of Extruded Stratospheric Air

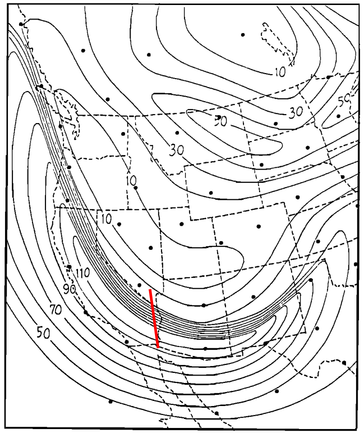
Project Springfield Report (1964)

First lidar measurements of ozone within a tropopause fold (Browell et al. 1987)

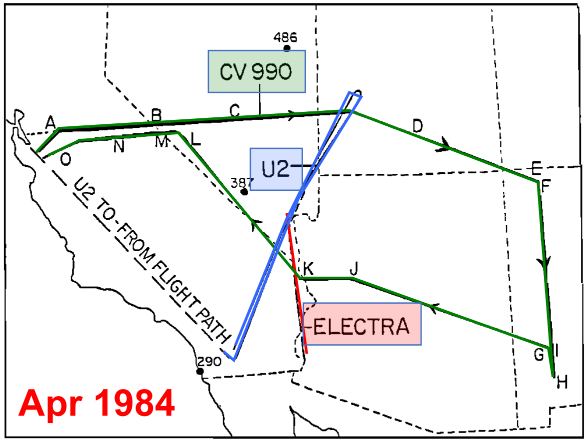
Tropopause Fold Structure Determined From Airborne Lidar and in Situ Measurements

E. V. BROWELL,[1] E. F. DANIELSEN,[2] S. ISMAIL,[3] G. L. GREGORY,[1]
AND S. M. BECK[1]

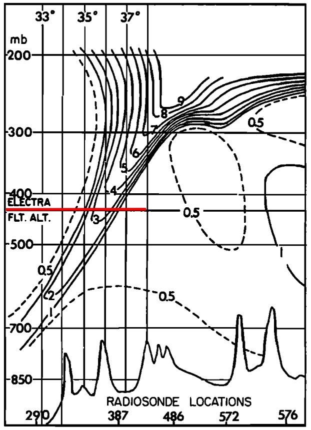
500 hPa winds

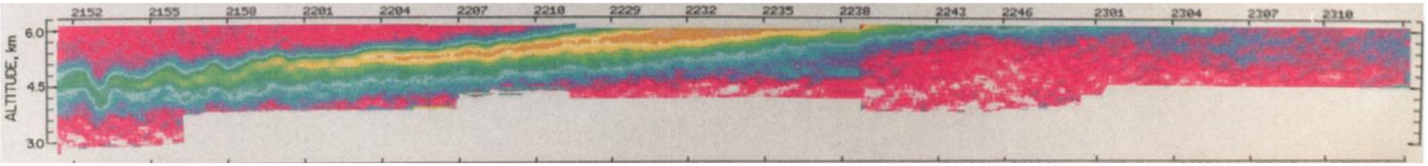


Flight paths



Potential Vorticity

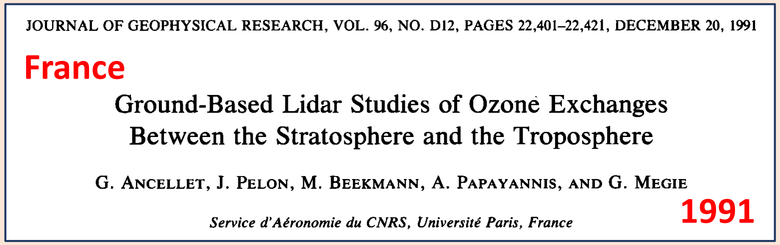




JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 92, NO. D2, PAGES 2112–2120, FEBRUARY 20, 1987

NASA Airborne lidar measurements of stratospheric intrusion over Las Vegas

25 years of ground-based lidar TF measurements



JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 96, NO. D12, PAGES 22,401–22,421, DECEMBER 20, 1991

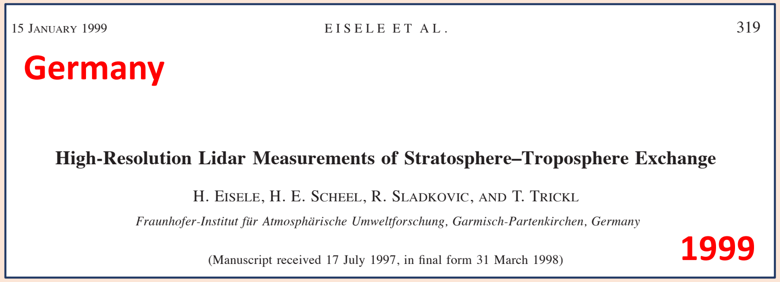
France

Ground-Based Lidar Studies of Ozone Exchanges Between the Stratosphere and the Troposphere

G. Ancellet, J. Pelon, M. Beekmann, A. Papayannis, and G. Megie

Service d'Aéronomie du CNRS, Université Paris, France

1991



15 January 1999 EISELE ET AL. 319

Germany

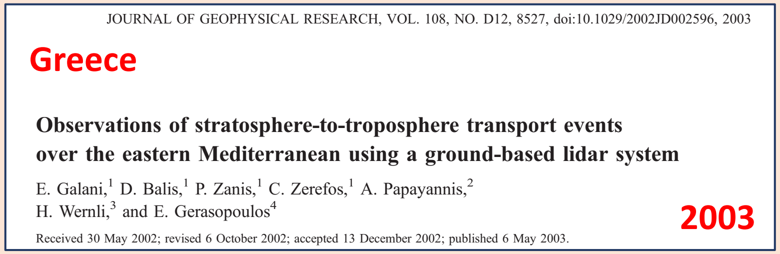
High-Resolution Lidar Measurements of Stratosphere–Troposphere Exchange

H. Eisele, H. E. Scheel, R. Sladkovic, and T. Trickl

Fraunhofer-Institut für Atmosphärische Umweltforschung, Garmisch-Partenkirchen, Germany

(Manuscript received 17 July 1997, in final form 31 March 1998)

1999



JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 108, NO. D12, 8527, doi:10.1029/2002JD002596, 2003

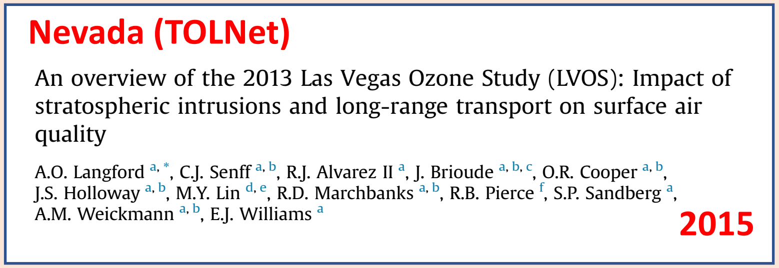
Greece

Observations of stratosphere-to-troposphere transport events over the eastern Mediterranean using a ground-based lidar system

E. Galani,[1] D. Balis,[1] P. Zanis,[1] C. Zerefos,[1] A. Papayannis,[2]
H. Wernli,[3] and E. Gerasopoulos[4]

2003

Received 30 May 2002; revised 6 October 2002; accepted 13 December 2002; published 6 May 2003.



Nevada (TOLNet)

An overview of the 2013 Las Vegas Ozone Study (LVOS): Impact of stratospheric intrusions and long-range transport on surface air quality

A.O. Langford [a,*], C.J. Senff [a,b], R.J. Alvarez II [a], J. Brioude [a,b,c], O.R. Cooper [a,b],
J.S. Holloway [a,b], M.Y. Lin [d,e], R.D. Marchbanks [a,b], R.B. Pierce [f], S.P. Sandberg [a],
A.M. Weickmann [a,b], E.J. Williams [a]

2015

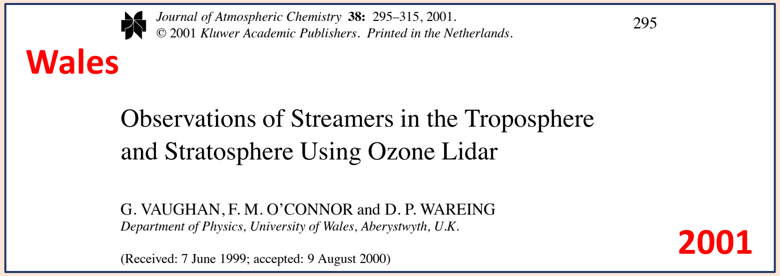
GEOPHYSICAL RESEARCH LETTERS, VOL. 23, NO. 18, PAGES 2501-2504, SEPTEMBER 1, 1996

Colorado

Ozone measurements in a tropopause fold associated with a cut-off low system

A. O. Langford, C. D. Masters[1], M. H. Proffitt[1], E.-Y. Hsie[1], and A. F. Tuck
NOAA Aeronomy Laboratory, Boulder, Colorado 80303

1996



Journal of Atmospheric Chemistry **38:** 295–315, 2001.
© 2001 *Kluwer Academic Publishers. Printed in the Netherlands.* 295

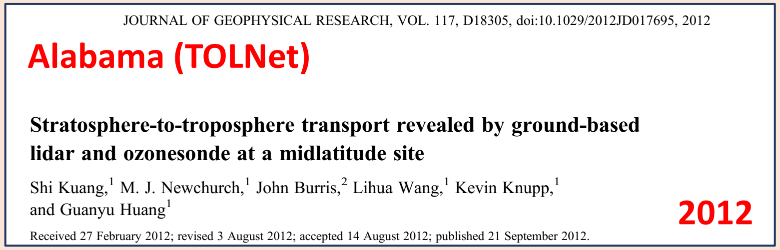
Wales

Observations of Streamers in the Troposphere and Stratosphere Using Ozone Lidar

G. VAUGHAN, F. M. O'CONNOR and D. P. WAREING
Department of Physics, University of Wales, Aberystwyth, U.K.

(Received: 7 June 1999; accepted: 9 August 2000)

2001



JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 117, D18305, doi:10.1029/2012JD017695, 2012

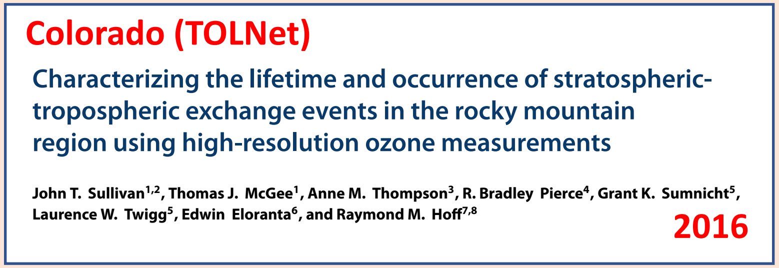
Alabama (TOLNet)

Stratosphere-to-troposphere transport revealed by ground-based lidar and ozonesonde at a midlatitude site

Shi Kuang,[1] M. J. Newchurch,[1] John Burris,[2] Lihua Wang,[1] Kevin Knupp,[1]
and Guanyu Huang[1]

2012

Received 27 February 2012; revised 3 August 2012; accepted 14 August 2012; published 21 September 2012.



Colorado (TOLNet)

Characterizing the lifetime and occurrence of stratospheric-tropospheric exchange events in the rocky mountain region using high-resolution ozone measurements

John T. Sullivan[1,2], Thomas J. McGee[1], Anne M. Thompson[3], R. Bradley Pierce[4], Grant K. Sumnicht[5], Laurence W. Twigg[5], Edwin Eloranta[6], and Raymond M. Hoff[7,8]

2016

Tropopause folds 101

- Primarily develop during cyclogenesis (spin up or re-intensification of midlatitude cyclones).
- Occur year round, but most common fall-to-spring.
- Greatest impact on tropospheric O_3 in springtime (more O_3 in the lower stratosphere).
- ENSO creates interannual variability by shifting jet stream north or south.
- Most are dissipated in the free troposphere and add to regional and hemispheric background.
- Deep intrusions (i.e. <3 km) may affect surface concentrations.

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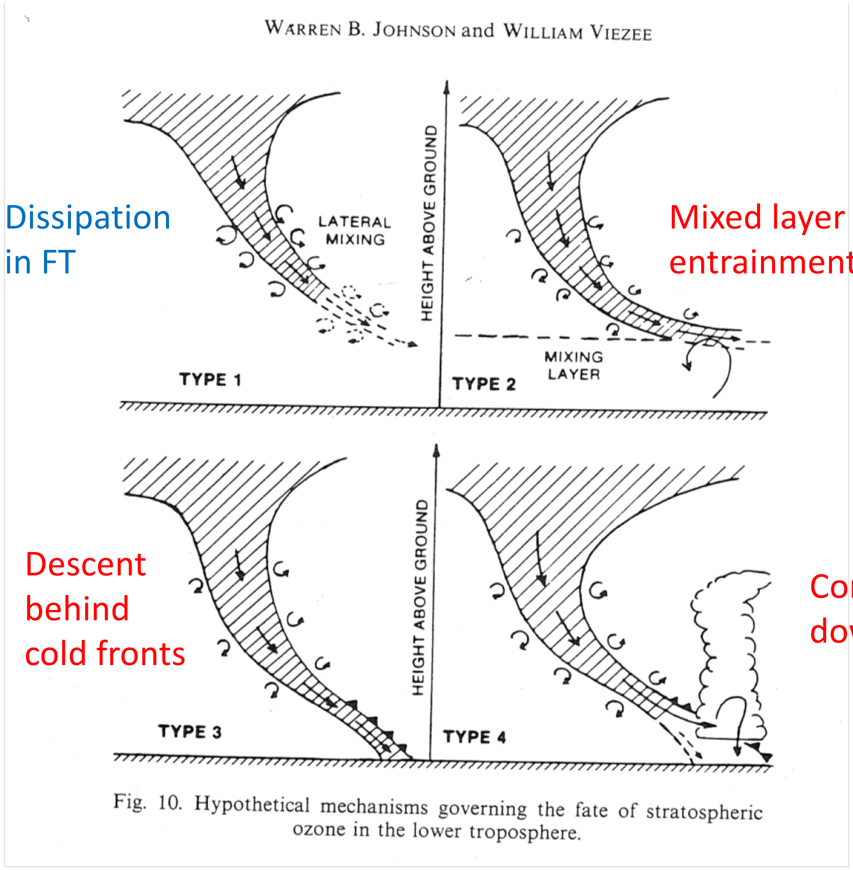
How does UTLS air get to the surface?

“Deep” intrusions can directly affect the surface


WARREN B. JOHNSON and WILLIAM VIEZEE

Dissipation in FT

Mixed layer entrainment

Descent behind cold fronts

Convective downdrafts

Fig. 10. Hypothetical mechanisms governing the fate of stratospheric ozone in the lower troposphere.

Johnson and Viezee *Atmos. Environ.* 1980

How much does STT impact surface O$_3$ in U.S.?

2001	*Lefohn et al.*	Frequent occurrences of 50–60 ppbv at remote northern U.S. sites in spring are of stratospheric origin, implying that current O$_3$ standard (0.08 ppmv) may be unattainable.
2002/3	*Fiore et al.*	GEOS-Chem model shows stratospheric contribution to surface O$_3$ is <2 ppbv in summer and always ≤20 ppbv.
2009	*Langford et al.*	Exceedances of the 85 ppbv NAAQS directly caused by descent of UTLS air to the surface in Denver (May 1999).
2012	Lin et al.	GFDL-AM3 model shows 22±12 ppbv *mean* stratospheric contributions in Western U.S. during spring
2014	**Zhang et al.**	**Updated** GEOS-Chem model shows 8-10 ppbv in Western U.S. during spring
2015	*Langford et al.*	Stratospheric intrusions cause 3 exceedances of the 75 ppbv NAAQS in Las Vegas during LVOS (May - June 2013).

Potential impact of STT on Air Quality has increased

…as the primary O_3 NAAQS has decreased

In 1971, the U.S. Environmental Protection Agency (EPA) promulgated **National Ambient Air Quality Standards (NAAQS)** to protect the public health and welfare from adverse effects of photochemical oxidants.

1971	0.08 ppmv (85 ppbv)	1-h
1979	0.12 ppmv (125 ppbv)	1-h
1997	0.08 ppmv (85 ppbv)	8-h
2008	0.075 ppmv (75 ppbv)	8-h
2015	0.070 ppmv (70 ppbv)	8-h

Compliance based on the 3-y average
of the 4th highest MDA8* (Design Value)

*Exceptional Events Rule can be invoked to exclude high values caused by stratospheric intrusions, wildfires, or other factors outside of local control

Other ways stratospheric intrusions can affect surface ozone

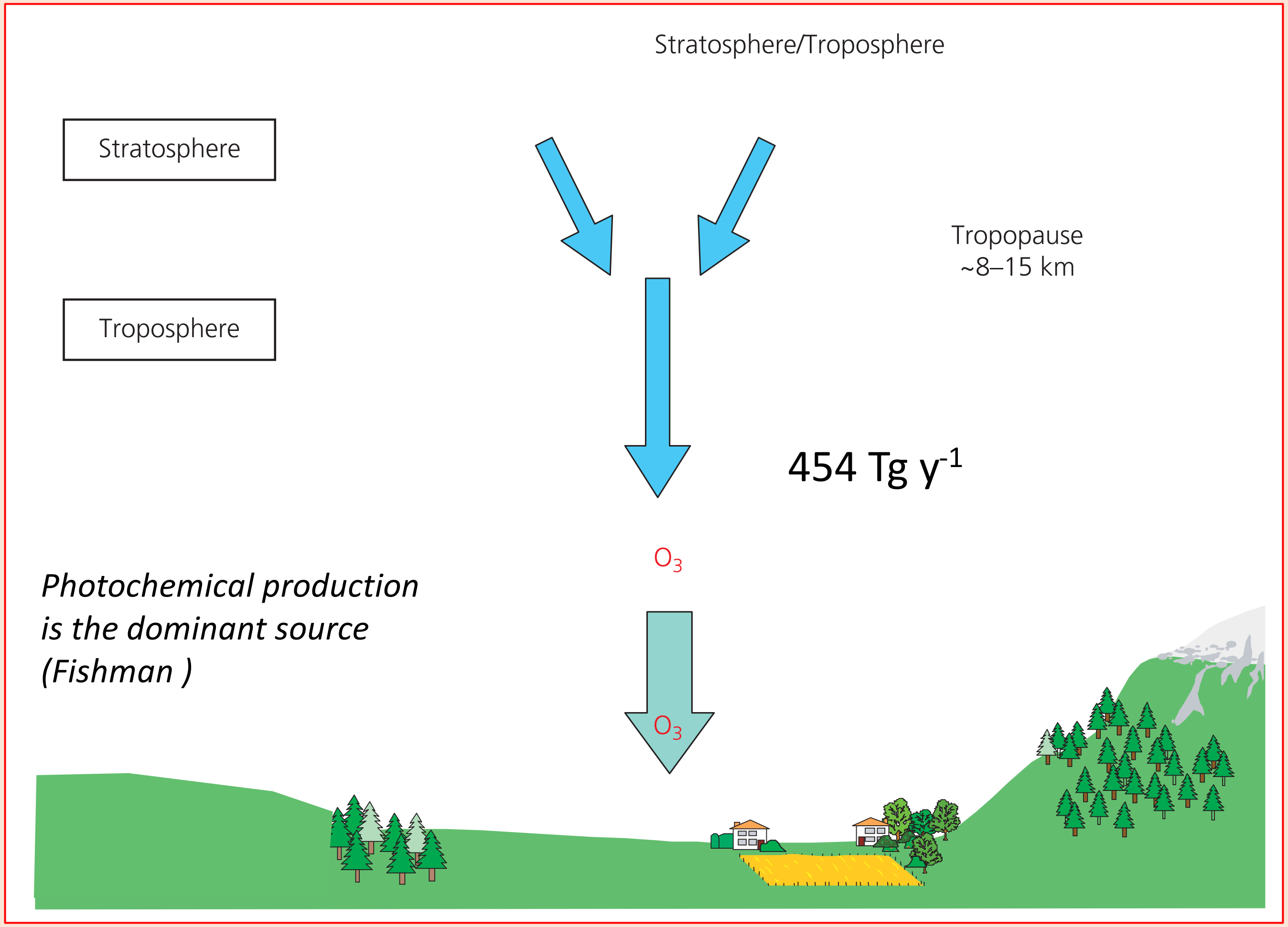
- **Transport O_3-rich air directly from the UTLS to the surface (Colorado).**
- Transport O_3-rich air from the UTLS to the lower free troposphere followed by boundary layer entrainment (Las Vegas).
- Transport O_3-rich pollution plumes mingled with the dry airstream (Las Vegas).
- Allow locally-produced O_3 to accumulate by capping the mixed layer (Las Vegas, Houston).
- Create strong, dry winds that foster the spread of wildfires and associated O_3 production (Los Angeles, Las Vegas).
- Transport O_3-rich air directly from the UTLS to the surface in polluted areas (Los Angeles, San Joaquin Valley).
- Redistribute locally-formed O_3 by reinforcing or cancelling local circulation patterns (Sacramento Valley).


STOP

Extras

Extras

Stratospheric influx balanced by surface deposition (Junge 1962)



454 Tg y^{-1}

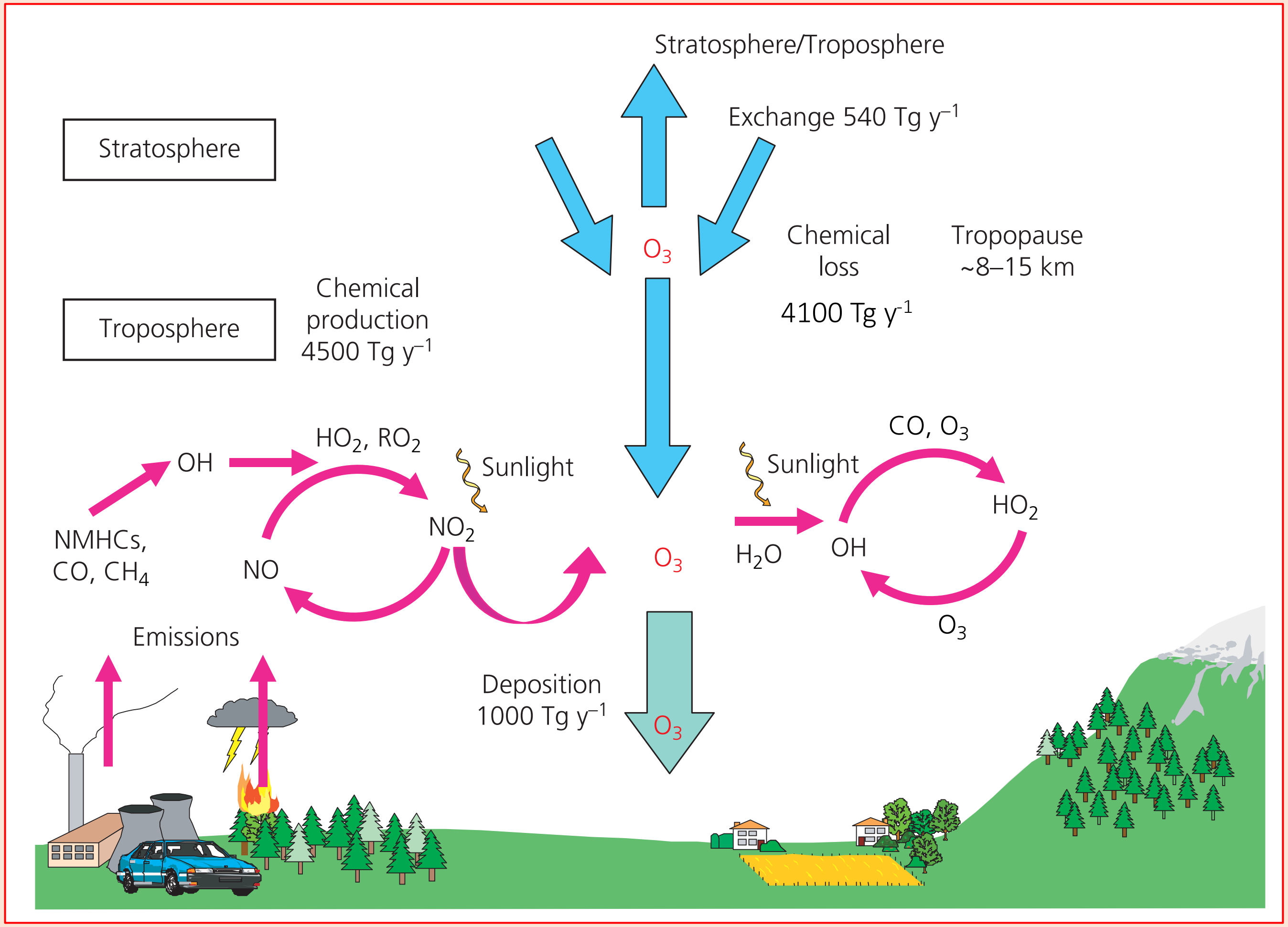
Photochemical production is the dominant source (Fishman)

The classical view

Some History…

1992	*Follows and Austin*	O_3 originating in the stratosphere composes less than 5% of zonally averaged O_3 near the surface.
2001	*Lefohn et al.*	frequent occurrences of 50–60 ppbv at remote northern U.S. sites in spring are of stratospheric origin, implying that current O_3 standard (0.08 ppmv) may be unattainable.
2002	*Fiore et al.*	GEOS-Chem model estimates stratospheric contribution to surface O_3 is <2 ppbv in summer.
2003	*Fiore et al.*	GEOS-Chem model estimates stratospheric contribution to surface O_3 is usually <10 ppbv and always <20 ppbv.

Net photochemical production and stratospheric influx similar (2008)



The Royal Society, 2008 , Ground-level ozone in the 21st century,

IPCC Fourth Assessment Report Working Group, “The Physical Basis”

In the beginning…

Schönbein 1840

Ozone (from *ozein*, Greek for "to smell")

In the beginning…

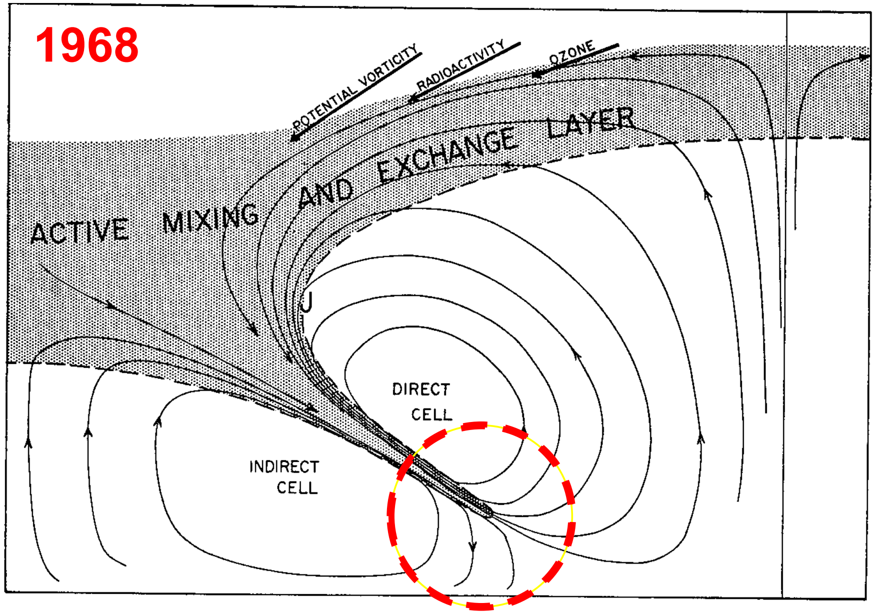
Schönbein 1840

It has commonly been assumed that almost all of the ozone in the troposphere is of stratospheric origin, that no significant production or destruction of ozone can take place within the troposphere, and that ozone is destroyed mainly by contact with the material of the earth's surface. (Crutzen 1974)

Stratosphere-to-Troposphere Transport (STT) by tropopause folding

Stratospheric-Tropospheric Exchange Based on Radioactivity, Ozone and Potential Vorticity[1]

Edwin F. Danielsen



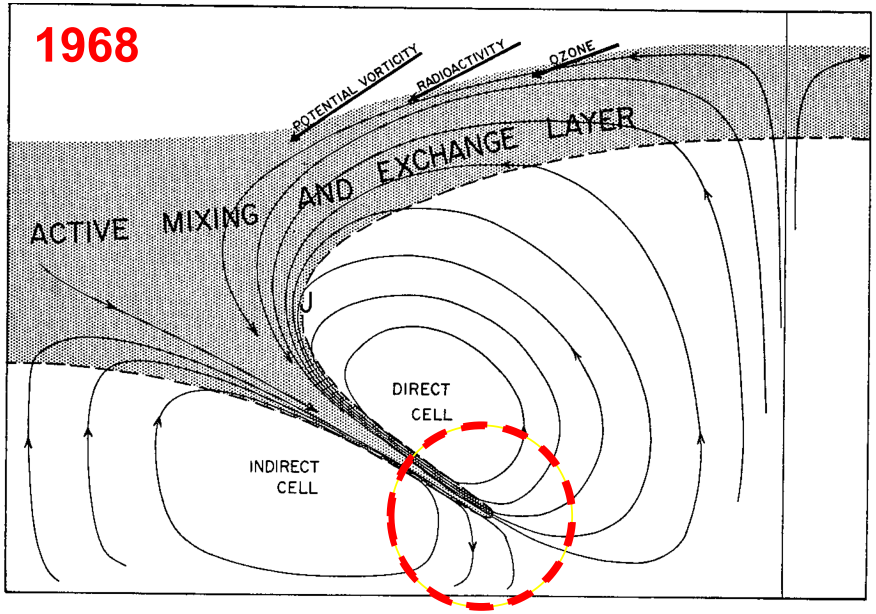
1968

Tongue of dry, ozone-rich UTLS air with high static stability

Stratosphere-to-Troposphere Transport (STT) by tropopause folding

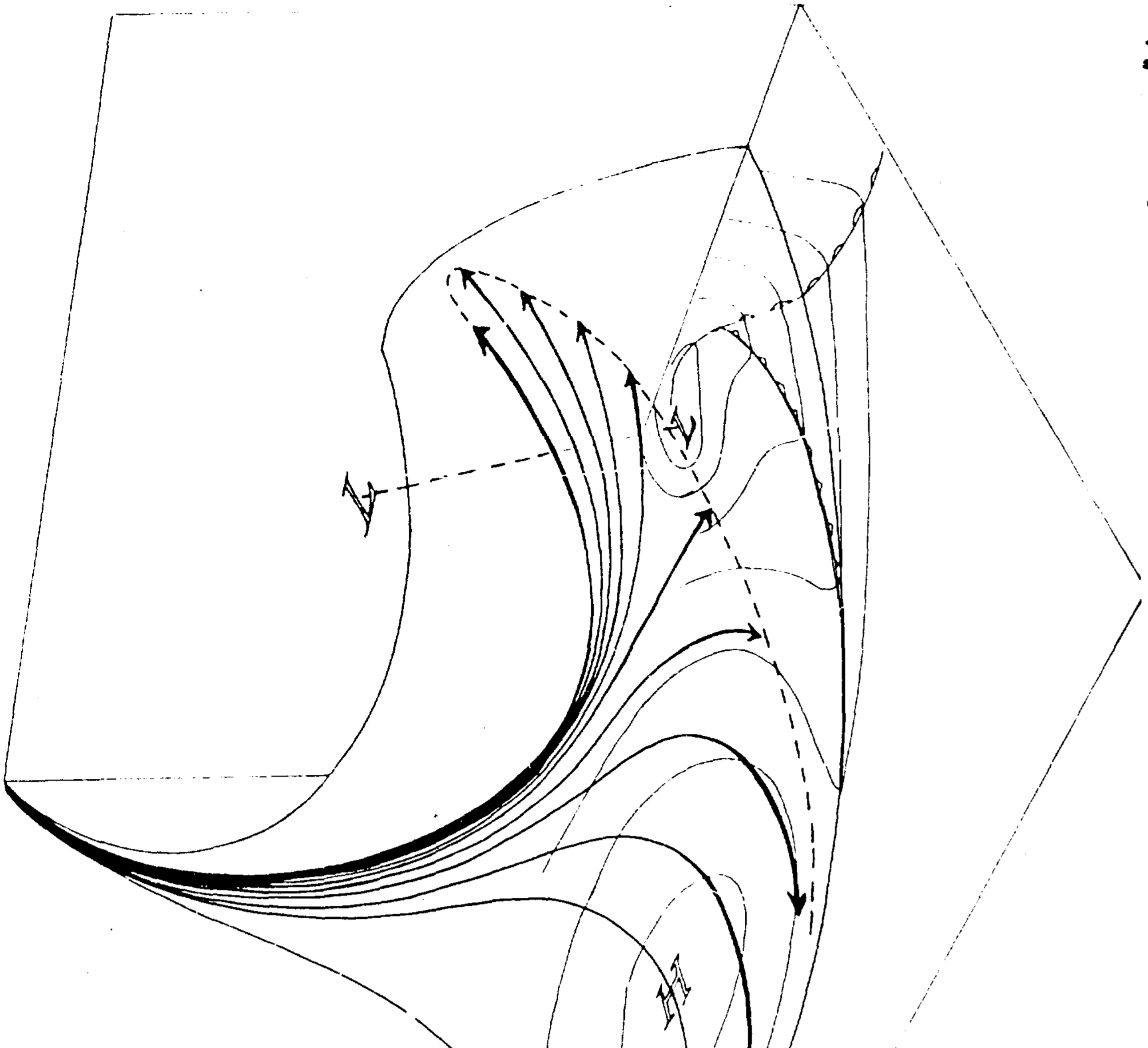
Stratospheric-Tropospheric Exchange Based on Radioactivity, Ozone and Potential Vorticity[1]

EDWIN F. DANIELSEN



Tongue of dry, ozone-rich UTLS air with high static stability

en 1964)



6 Trajectories of Extruded Stratospheric Air

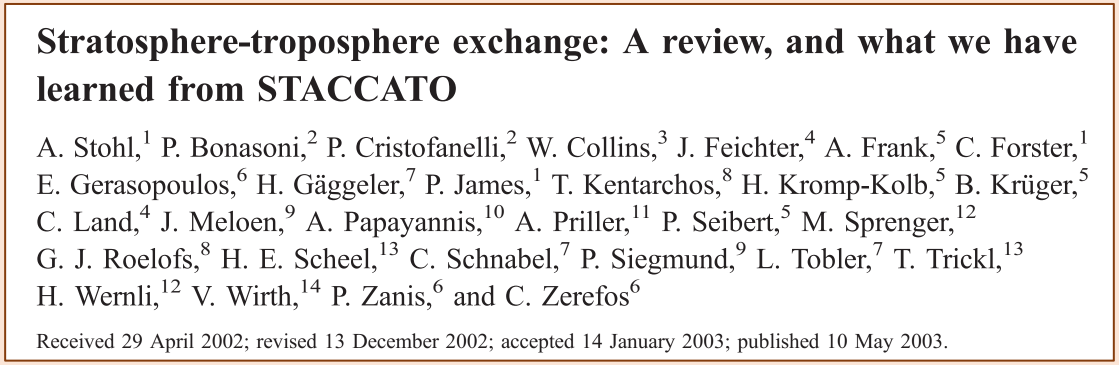
e fallout

s on flank
v and wraps
round
gh

s

Stratosphere-troposphere transport (STT)

"To be as consistent as possible with previous nomenclature while removing ambiguities, we propose that STE should refer to exchange in both directions in the most general sense, whereas **stratosphere-to-troposphere transport (STT)** and troposphere-to-stratosphere transport (TST) should be used to refer specifically to one-way transport."



Stratosphere-troposphere exchange: A review, and what we have learned from STACCATO

A. Stohl,[1] P. Bonasoni,[2] P. Cristofanelli,[2] W. Collins,[3] J. Feichter,[4] A. Frank,[5] C. Forster,[1] E. Gerasopoulos,[6] H. Gäggeler,[7] P. James,[1] T. Kentarchos,[8] H. Kromp-Kolb,[5] B. Krüger,[5] C. Land,[4] J. Meloen,[9] A. Papayannis,[10] A. Priller,[11] P. Seibert,[5] M. Sprenger,[12] G. J. Roelofs,[8] H. E. Scheel,[13] C. Schnabel,[7] P. Siegmund,[9] L. Tobler,[7] T. Trickl,[13] H. Wernli,[12] V. Wirth,[14] P. Zanis,[6] and C. Zerefos[6]

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Examples of high ozone attributed to UTLS air reaching the surface

1973	*Altmannspacher and Hartmanngruber*	415 ppbv O_3 (10 min)	Hohenpeissenberg (1 km asl)
1977	*Lamb*	200-230 ppbv (1-h)	Santa Rosa, CA (0 km asl)
1981	*Haagenson et al.*	>200 ppbv of O_3	Denver, CO (1.6 km asl)