

# 中層大気の水蒸気と 熱帯対流圏界面

塩谷 雅人

(京大大学生存圏研究所)

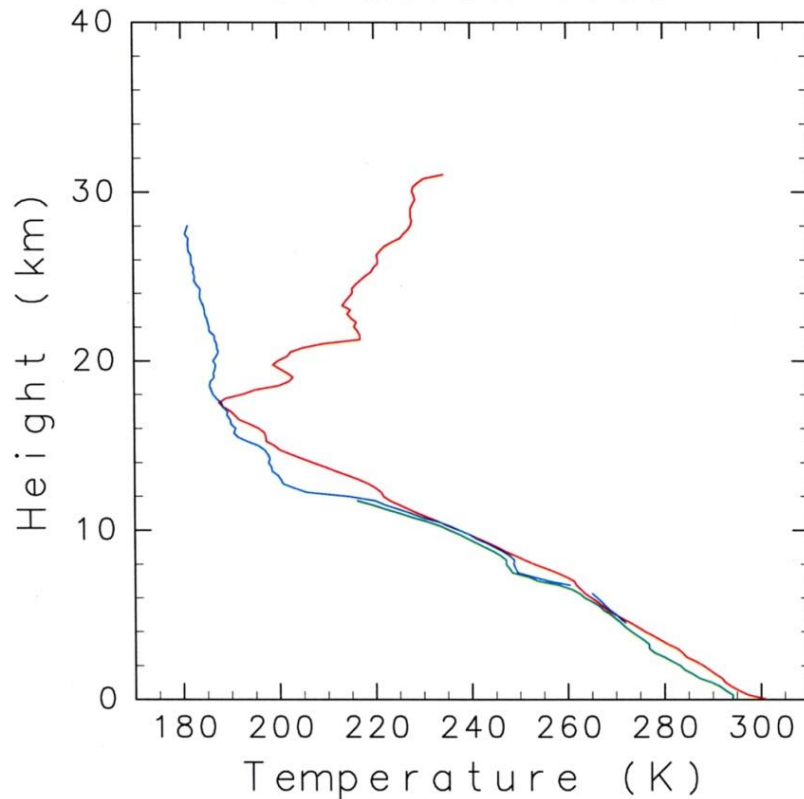
# 熱帶对流圈界面(層?)

- Holton, J. R., P. H. Haynes, M. E. McIntyre, A. R. Douglass, R. B. Rood, and L. Pfister (1995), Stratosphere-troposphere exchange, *Rev. Geophys.*, 33, 403–440.
- Fueglistaler, S., A. E. Dessler, T. J. Dunkerton, I. Folkins, Q. Fu, and P. W. Mote (2009), Tropical tropopause layer, *Rev. Geophys.*, 47, RG1004, doi:10.1029/2008RG000267.
- Randel, W. J., and E. J. Jensen (2013), Physical processes in the tropical tropopause layer and their role in a changing climate. *Nature Geoscience*, 6, 169-176, doi:10.1038/ngeo1733.

# 湿った対流圏と乾いた成層圏

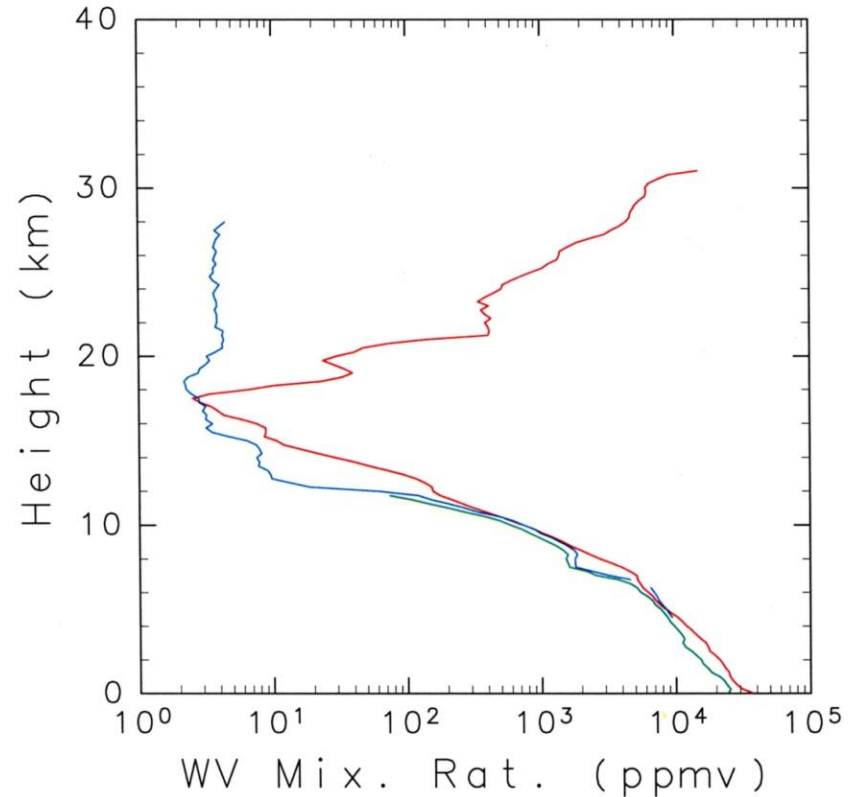
水蒸気ゾンデ観測による例

SOWER/San Cristobal  
01 March 1999



気温(赤)と露点(霜点)温度(青)

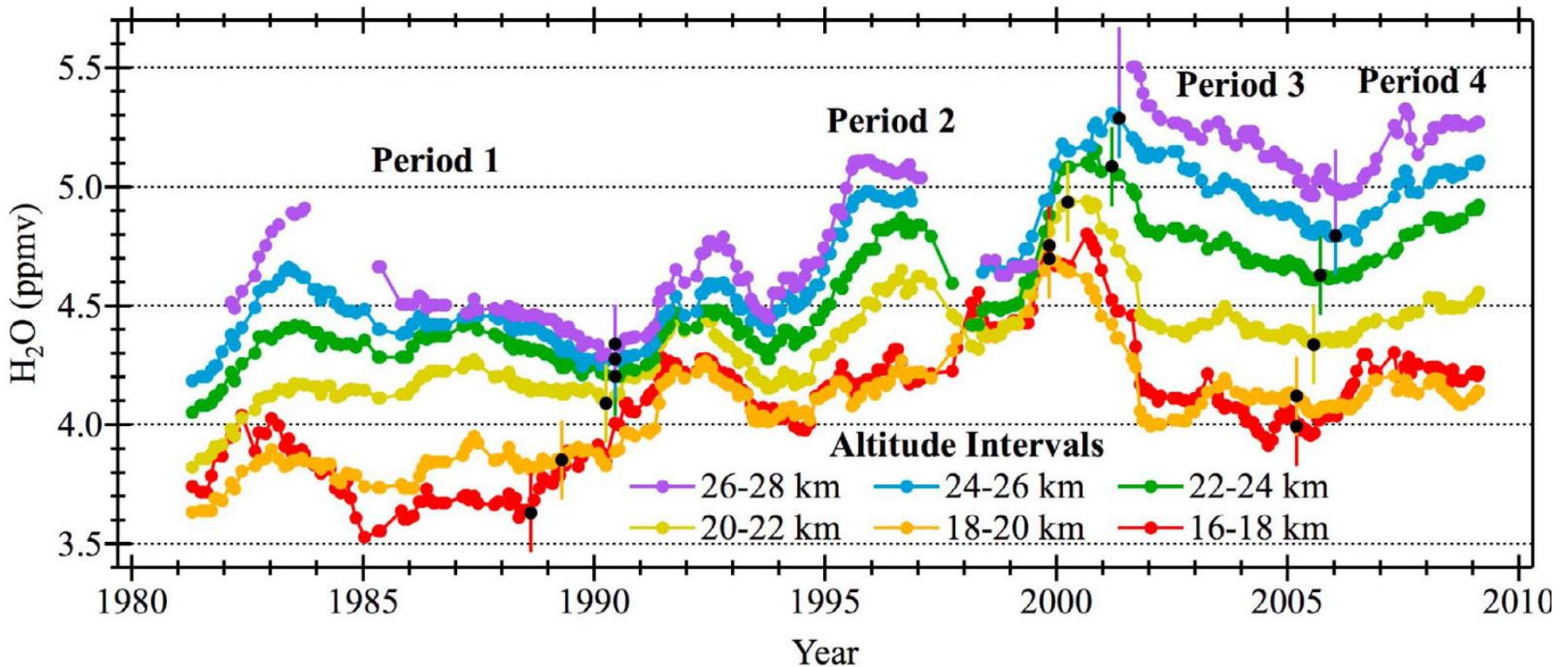
SOWER/San Cristobal  
01 March 1999



飽和水蒸気混合比(赤)と水蒸気混合比(青)

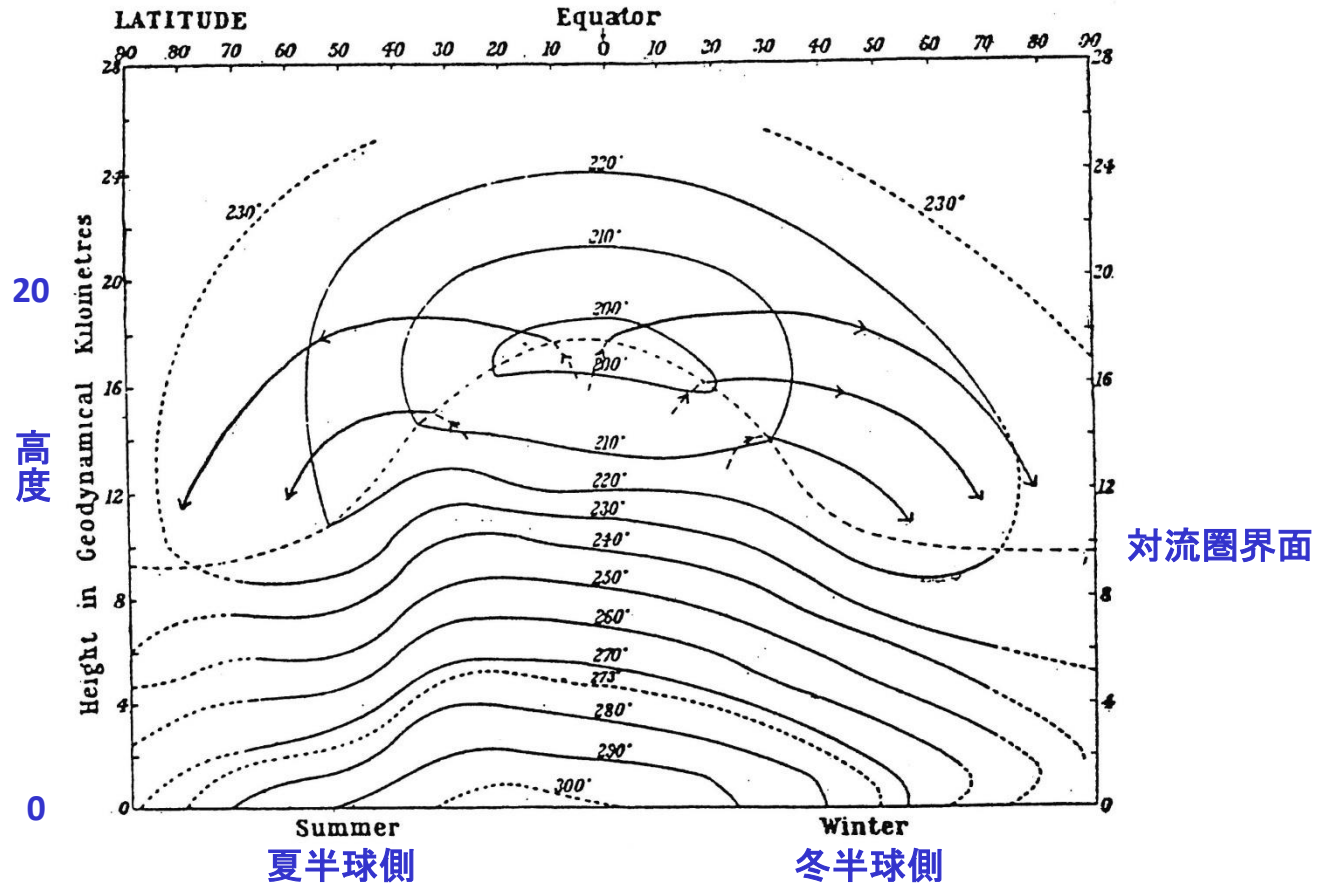
(話者ら unpublished figure)

# 成層圏水蒸気の増加トレンド



Boulderにおける水蒸気ゾンデ観測(Hurst et al., 2011)

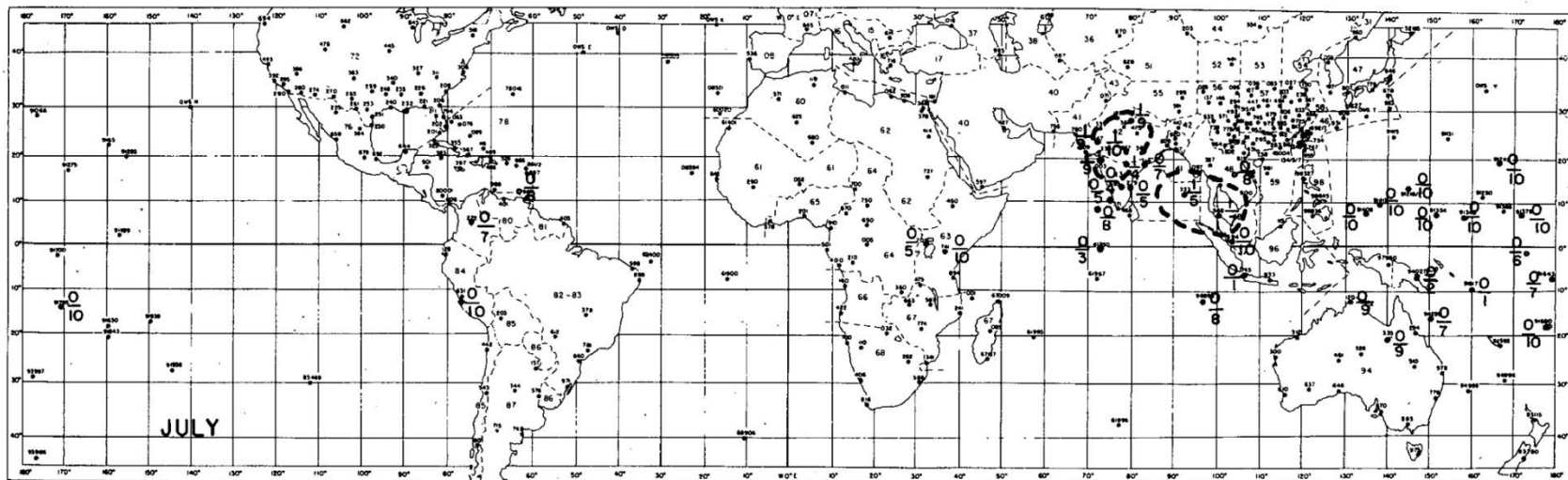
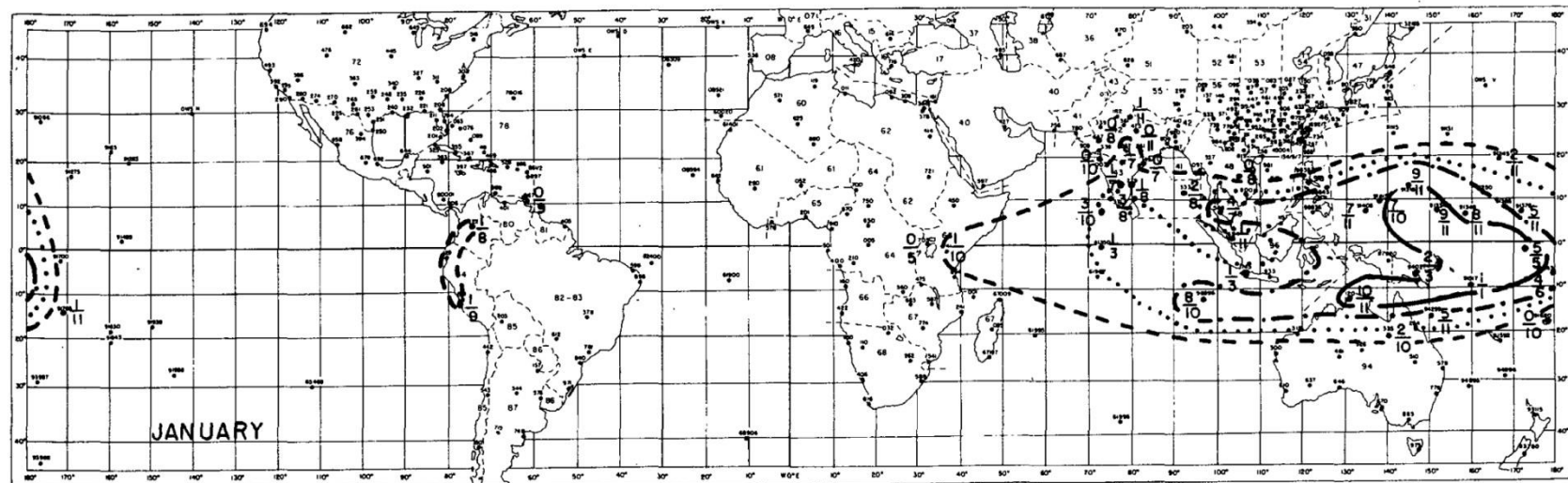
# Brewerの考えた子午面循環



(Brewer, Q. J. R. Met. Soc., 1949)

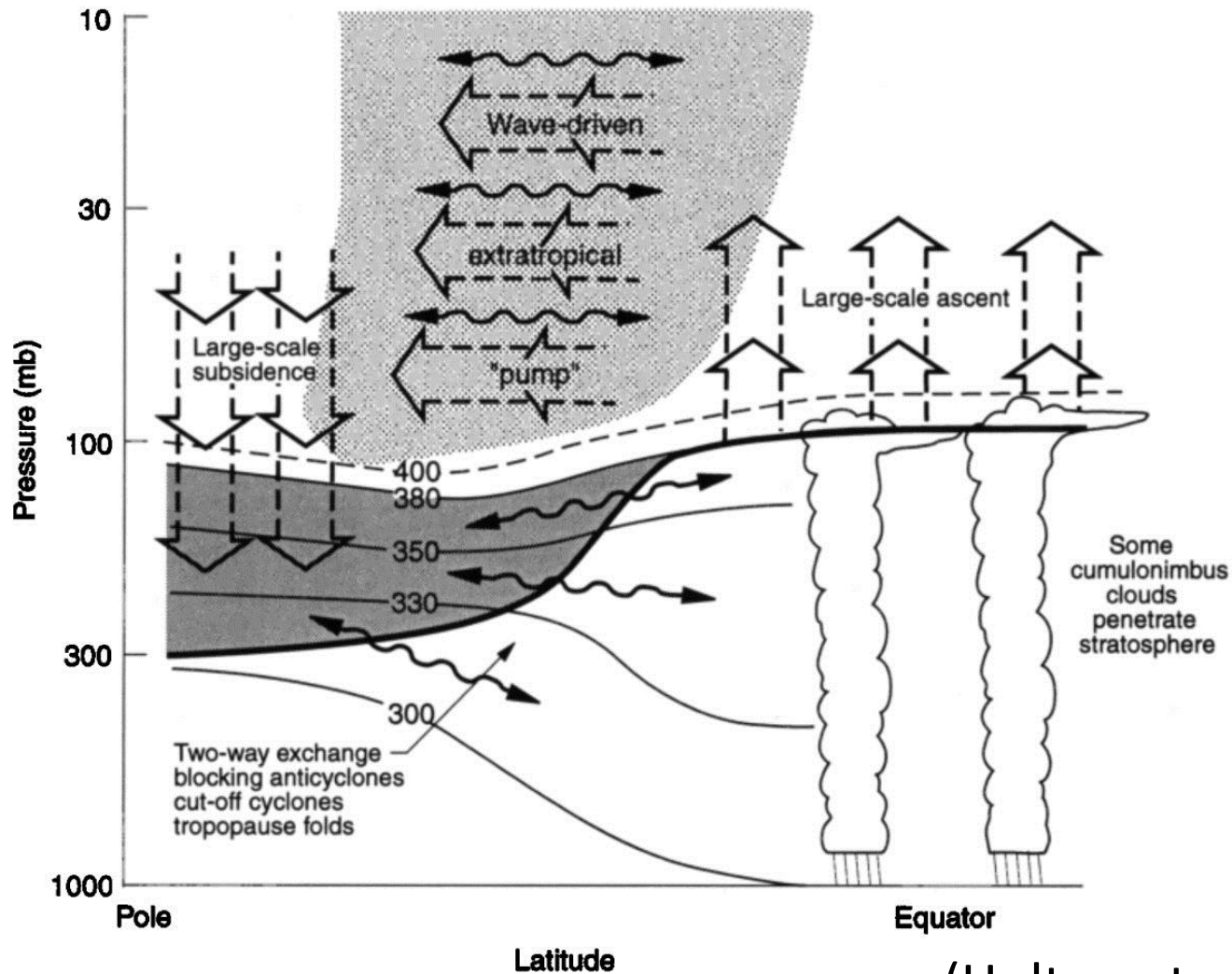
# 成層圏の泉 (A Stratospheric Fountain?)

(Newell & Gould-Stewart, 1981)



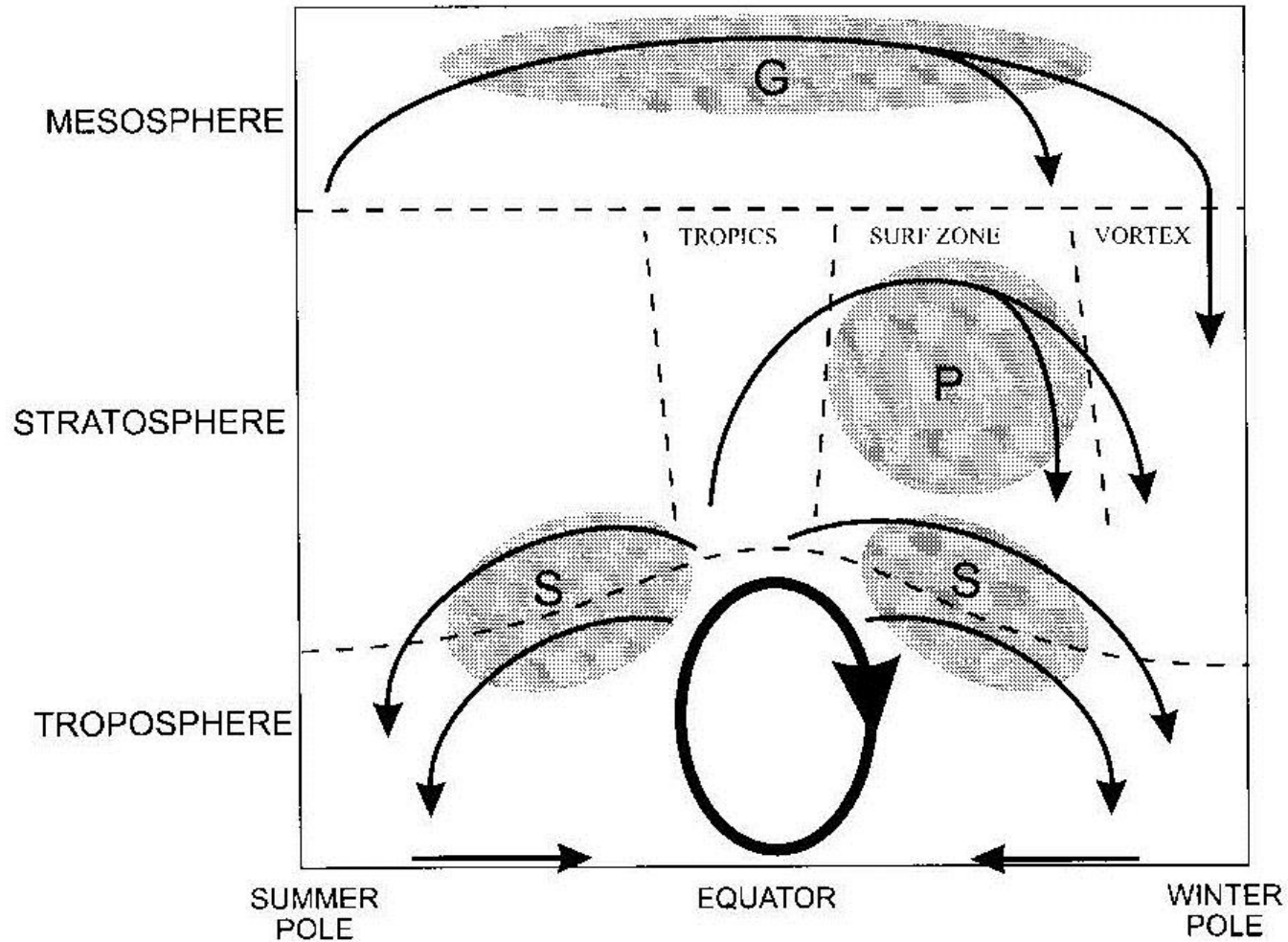
1970-1980期間の100hPa月平均気温が-82.4Cを下回った月の割合

# 成層圈-对流圈交換過程



(Holton et al., 1995)

# 中層大気の子午面循環

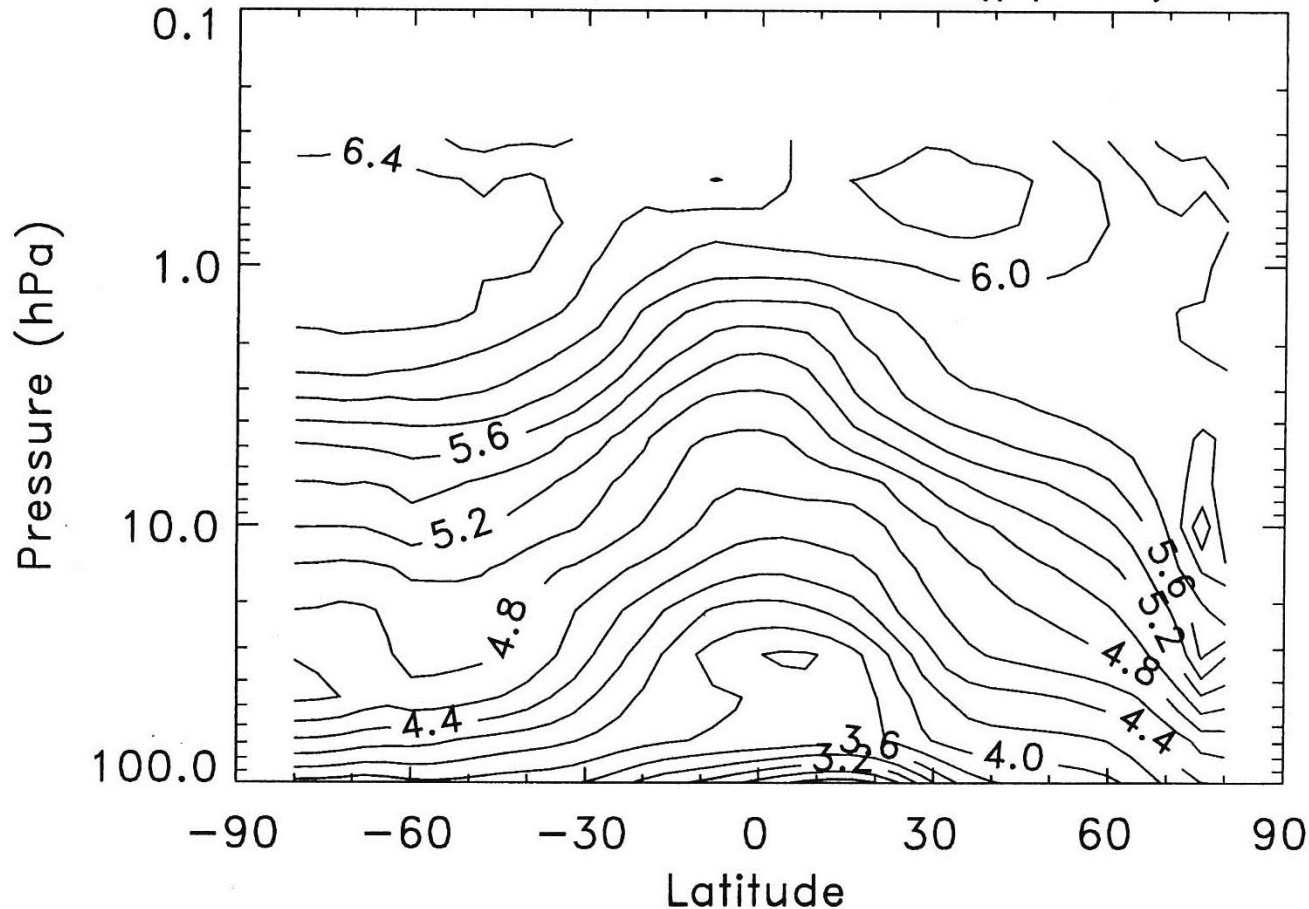


(Plumb, 2002)



# 水蒸気(H<sub>2</sub>O)の緯度-高度分布(1月)

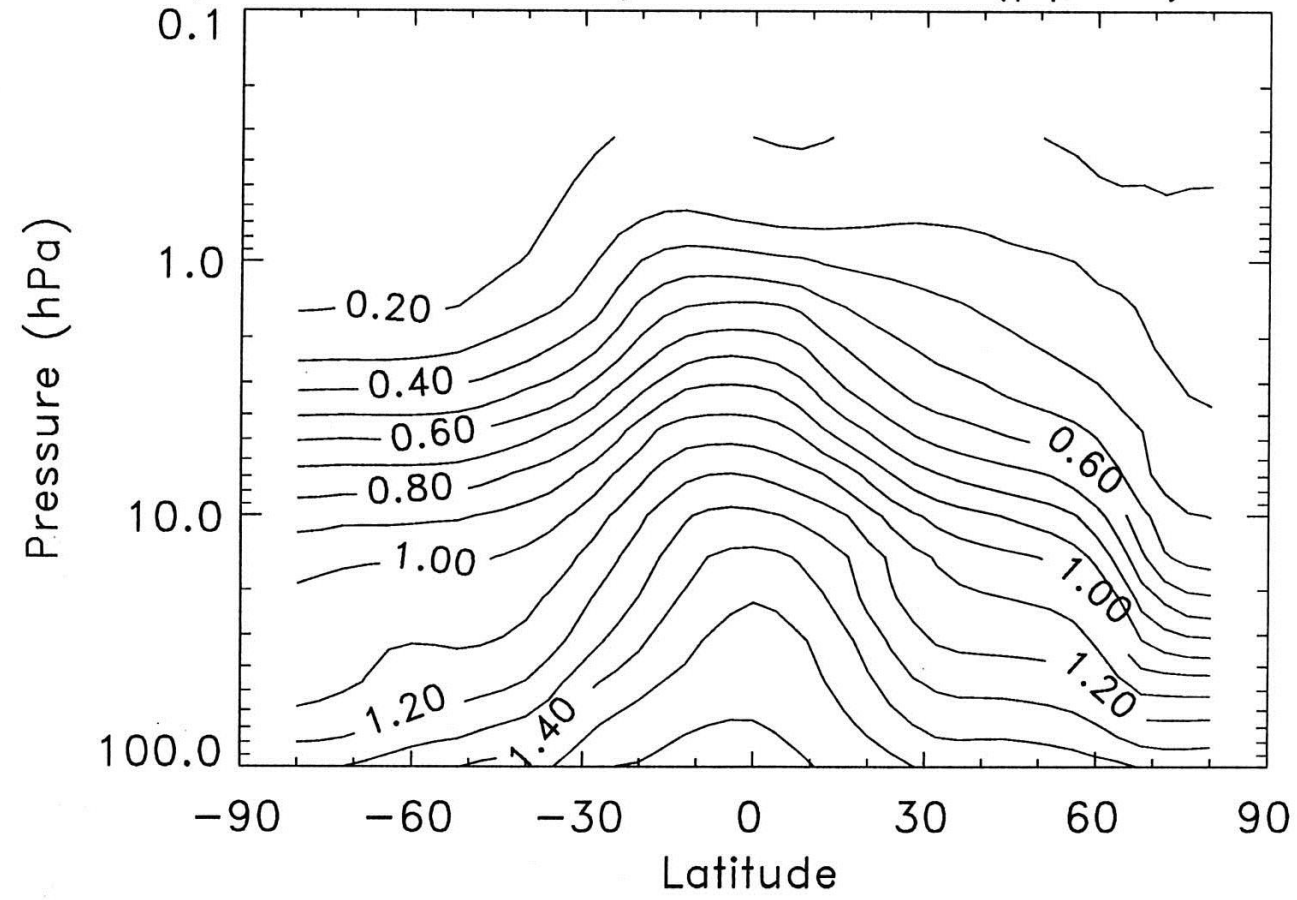
HALOE+MLS Monthly Mean H<sub>2</sub>O (ppmv) JANUARY



(話者ら unpublished figure)

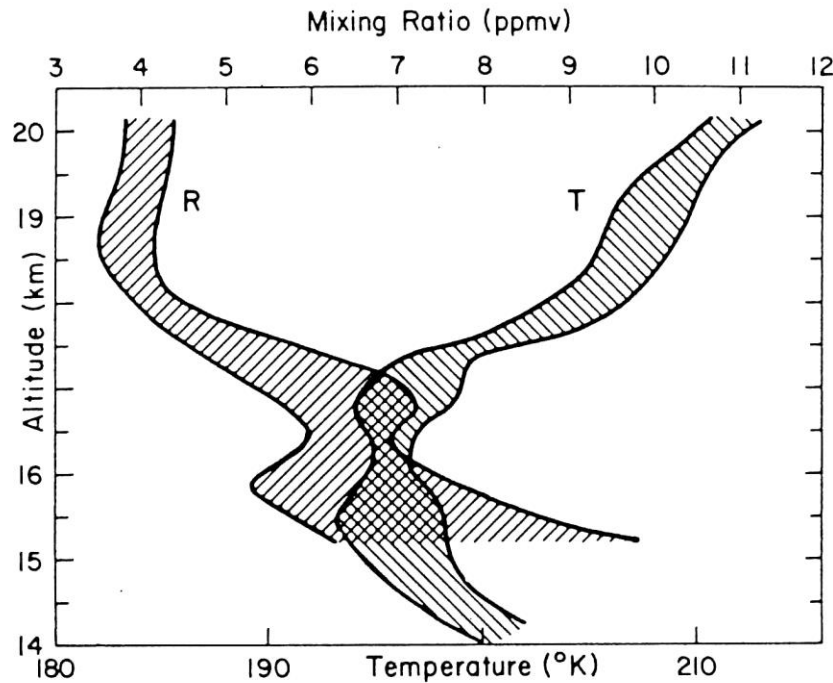
# メタン(CH<sub>4</sub>)の緯度-高度分布(1月)

HALOE/CLAES Monthly Mean CH<sub>4</sub> (ppmv) JANUARY



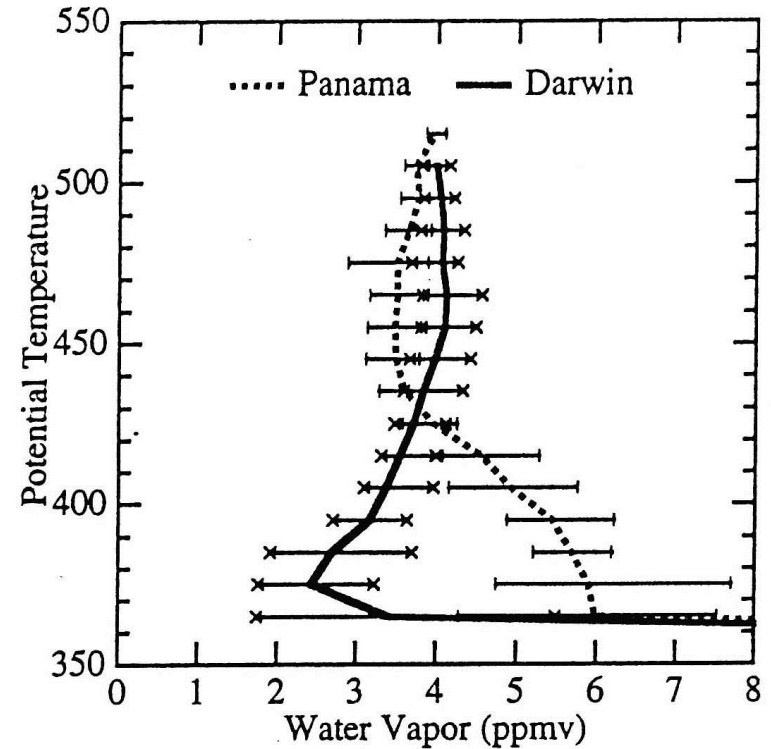
(話者ら unpublished figure)

# 熱帯域における水蒸気観測



1980年9月パナマでの観測

(Kley et al, GRL, 1982)



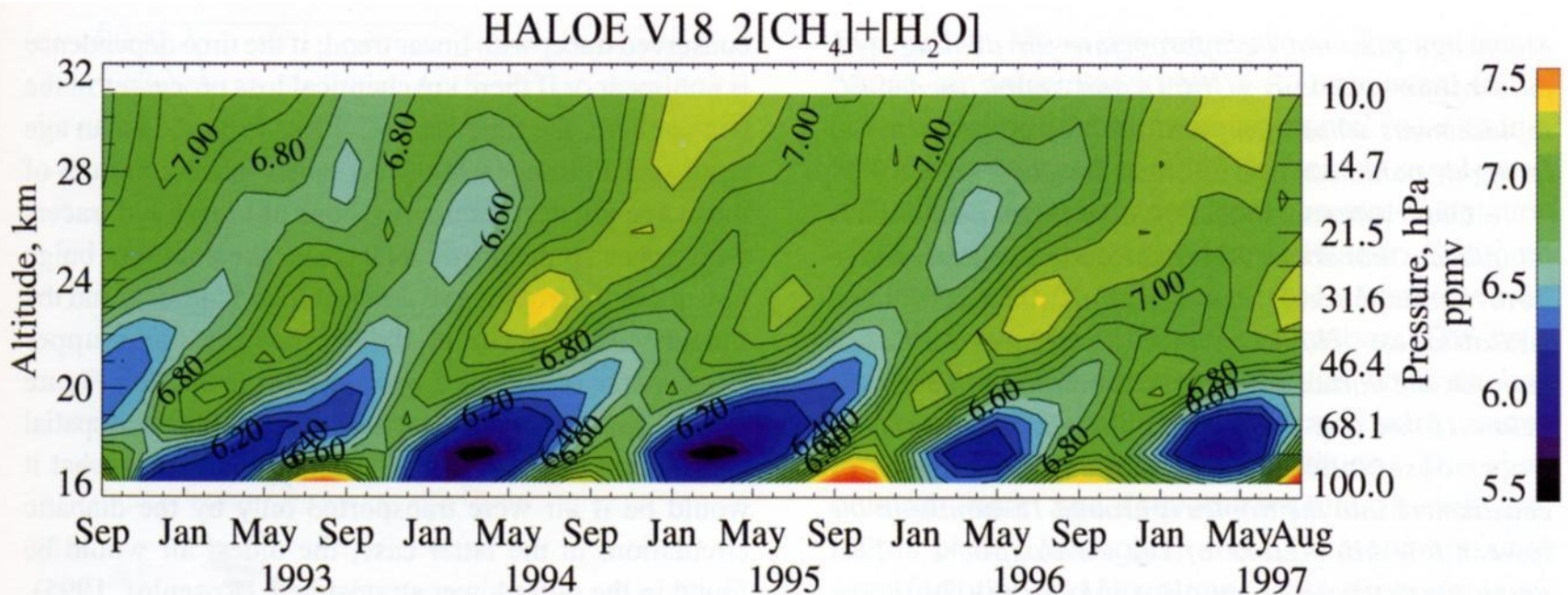
1987年北半球冬のダーウィンでの観測を加筆

(Kelly et al, JGR, 1993)

# 水蒸気のテープレコーダシグナル

An atmospheric tape recorder: The imprint of tropical tropopause temperatures on stratospheric water vapor

衛星から観測した赤道における水蒸気の時間-高度分布



(Mote et al., JGR, 1996の改訂版)

1年で10km, 1ヶ月で1km,  
1日30m, 1時間1mのオーダー

# 対流圏界面高度と気温の年変動

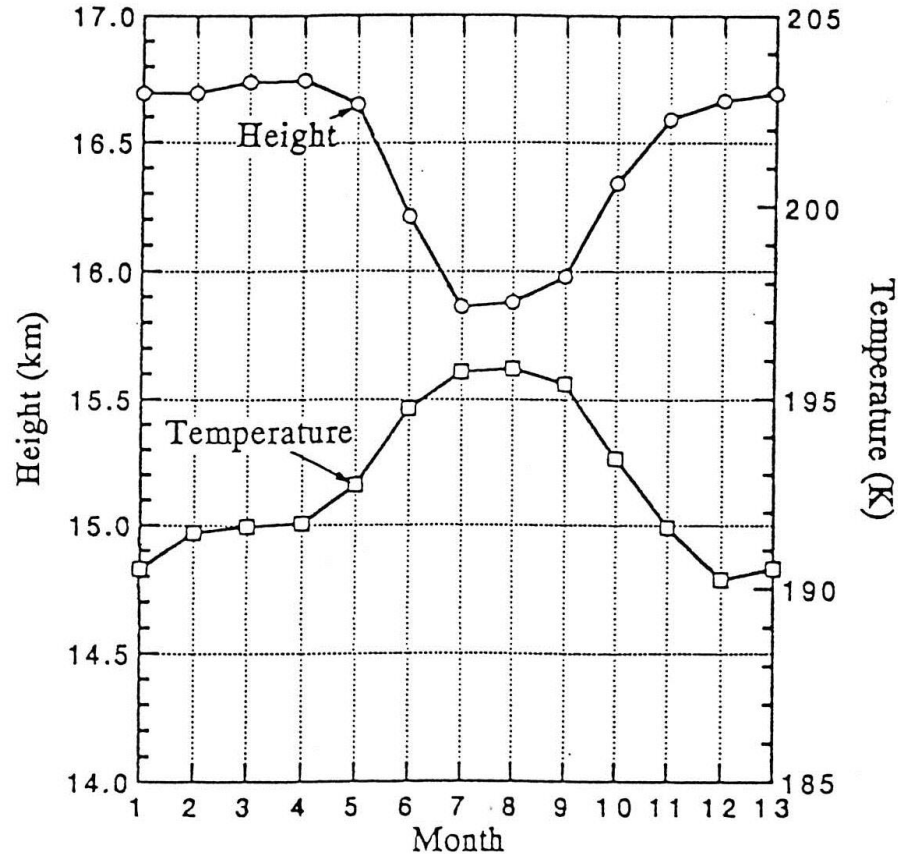


Figure 2. Annual variation of tropopause height and temperature, Koror, 1952-88 average.

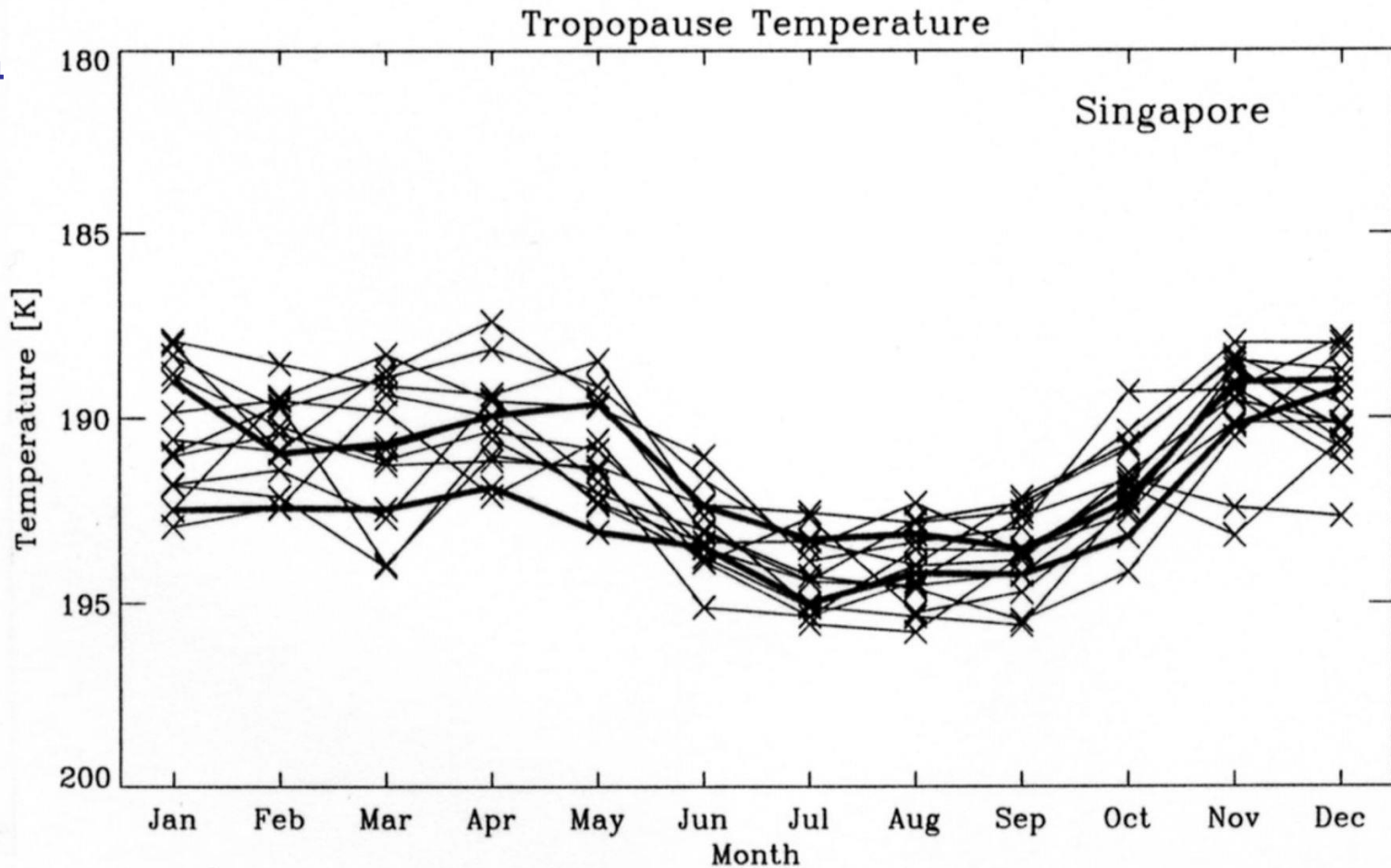
(Reid と Gage の一連の仕事の一部)

# 熱帯対流圏界面温度の年変動

低温

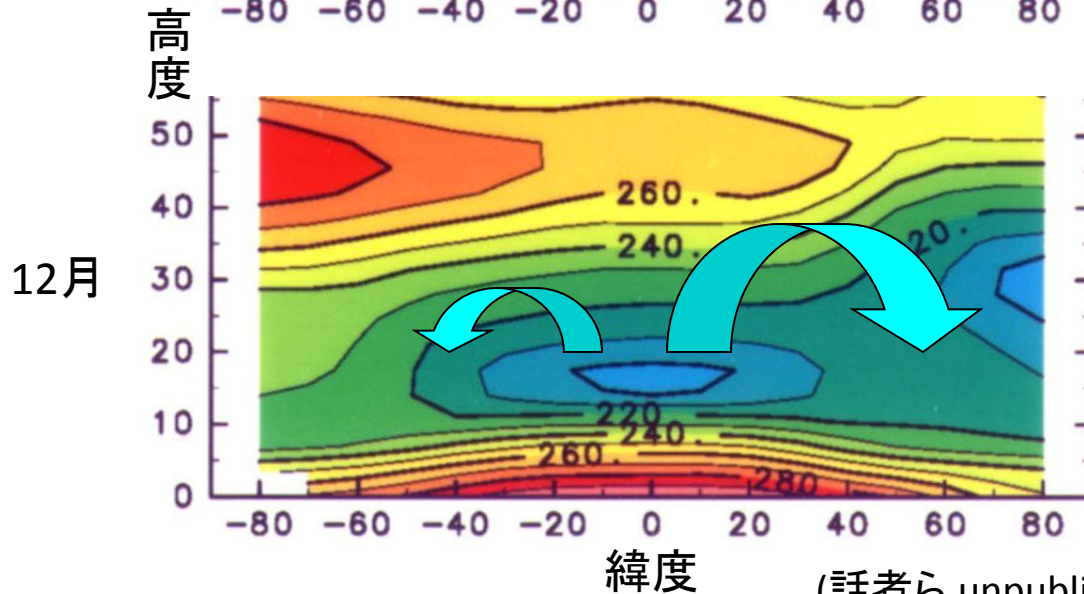
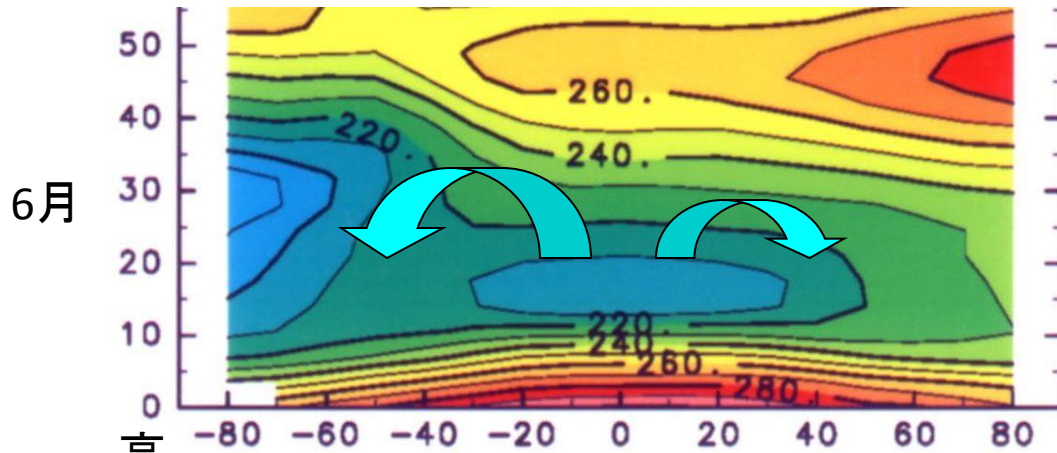
気温

高温



シンガポールにおける月平均対流圏界面温度 (長谷部, 私信)

# 熱帯対流圏界面の年変動メカニズム



- Holtonら(1995): 中緯度下部成層圏における波動の効果が赤道域から高緯度に向かう子午面流を誘起 ⇒ 熱帯域における上昇流, 高緯度における下降流.

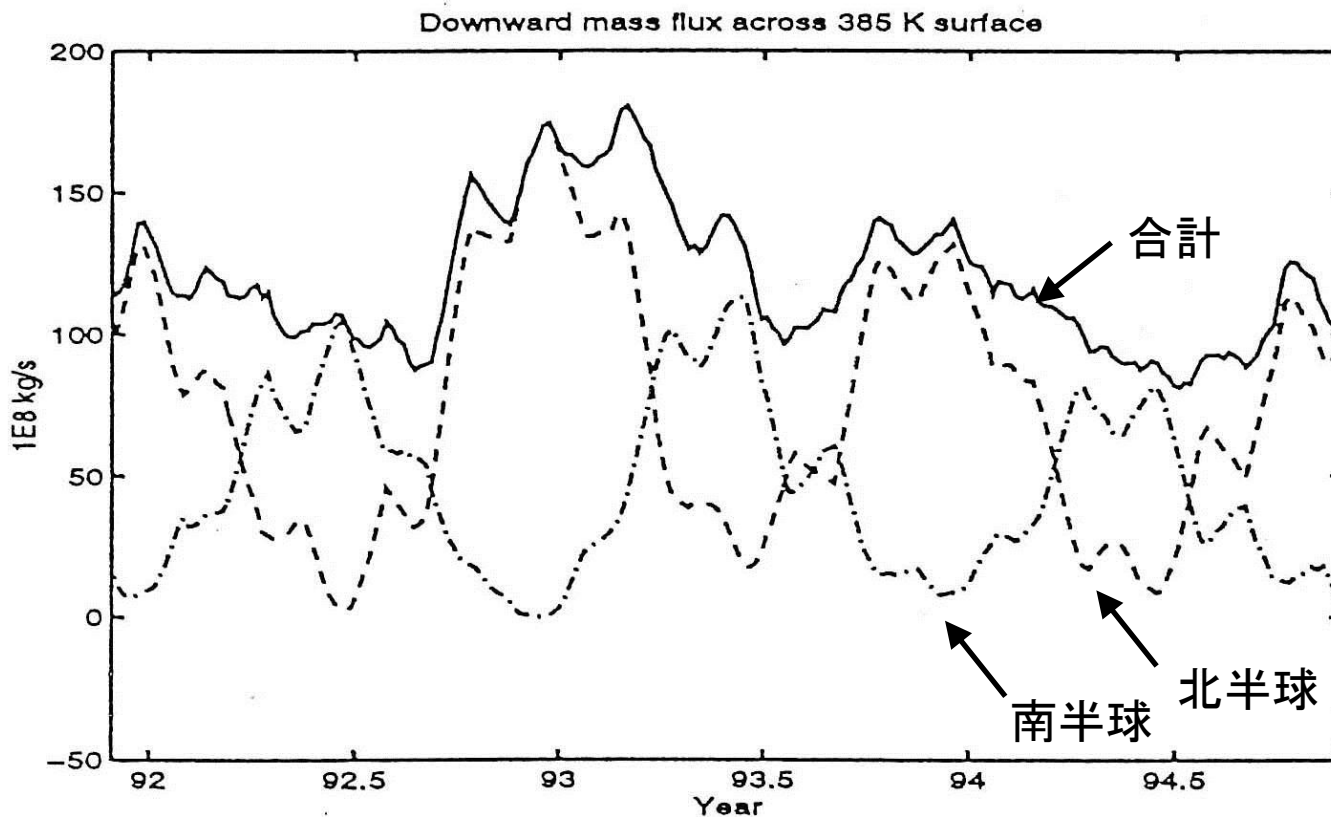
- この効果は波動の活動性が大きい冬半球側で大きい.

- さらに, 同じ冬でも, 南半球よりも北半球の方が大きい.

- 結果的に, 熱帯対流圏界面付近の上昇流は, 北半球の冬の時期に大きく, 夏の時期に小さくなる.

(話者ら unpublished figure)

# 空気塊流入量の季節変動

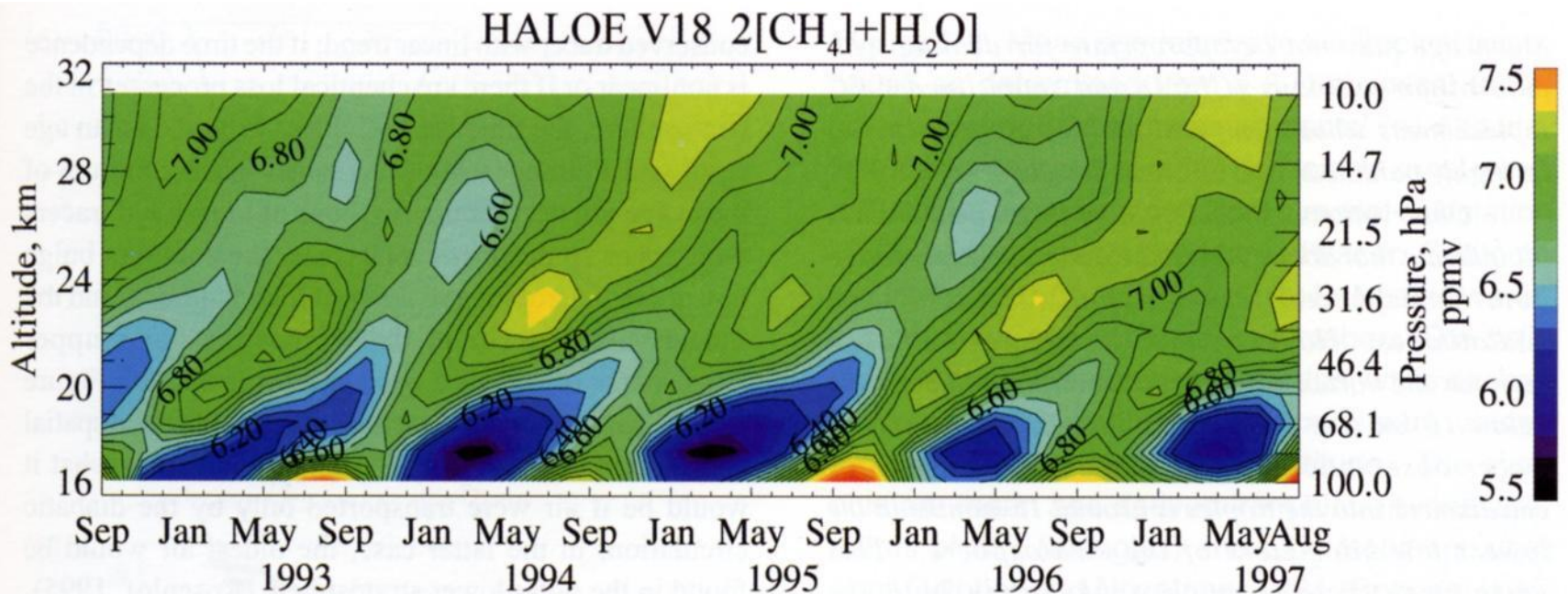


(Yang & Tung, JGR, 1996)



# 水蒸気のテープレコーダシグナル(再)

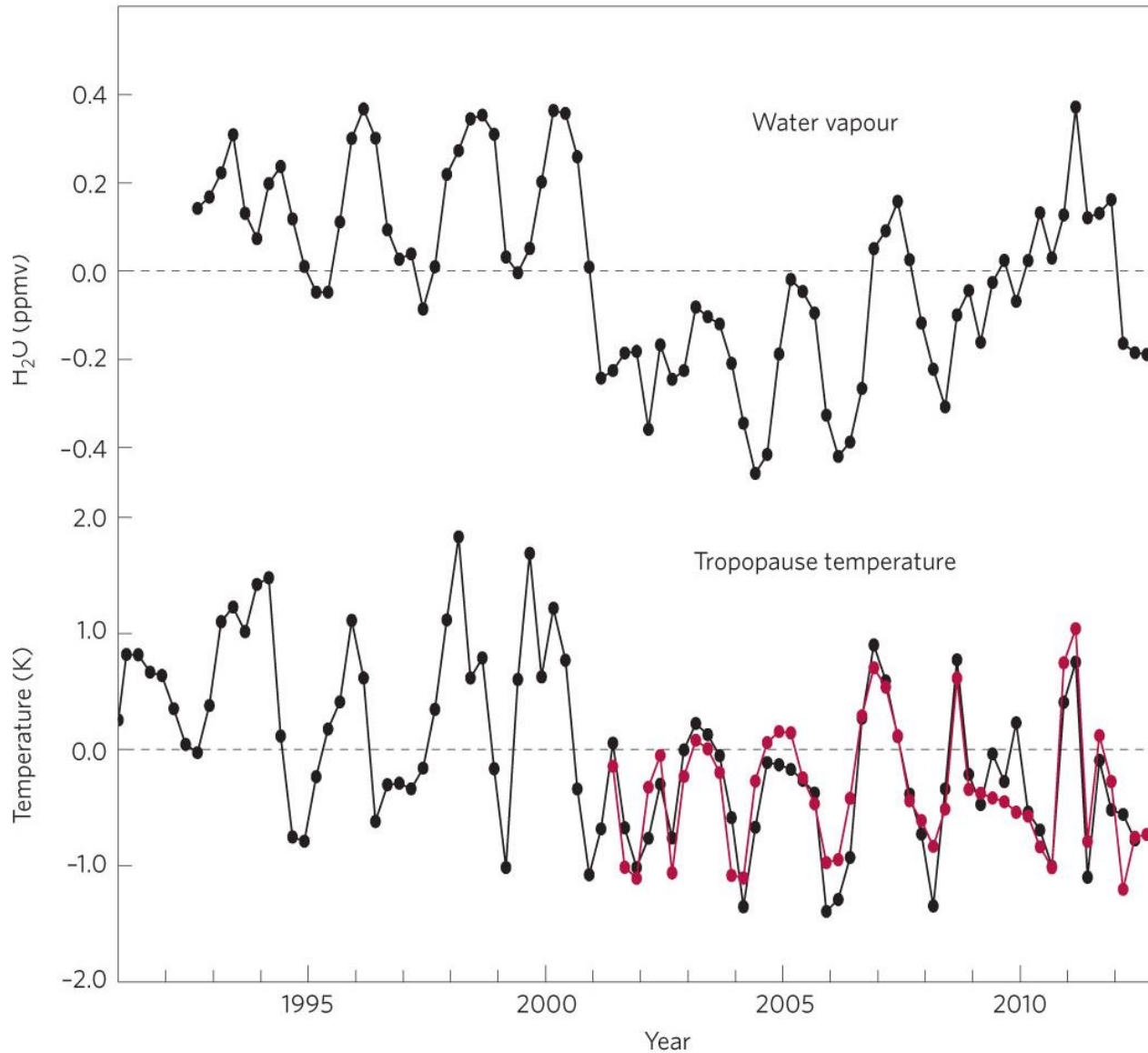
衛星から観測した赤道上的における水蒸気の時間－高度分布



(Mote et al., JGR, 1996の改訂版)

1年で10km, 1ヶ月で1km,  
1日30m, 1時間1mのオーダー

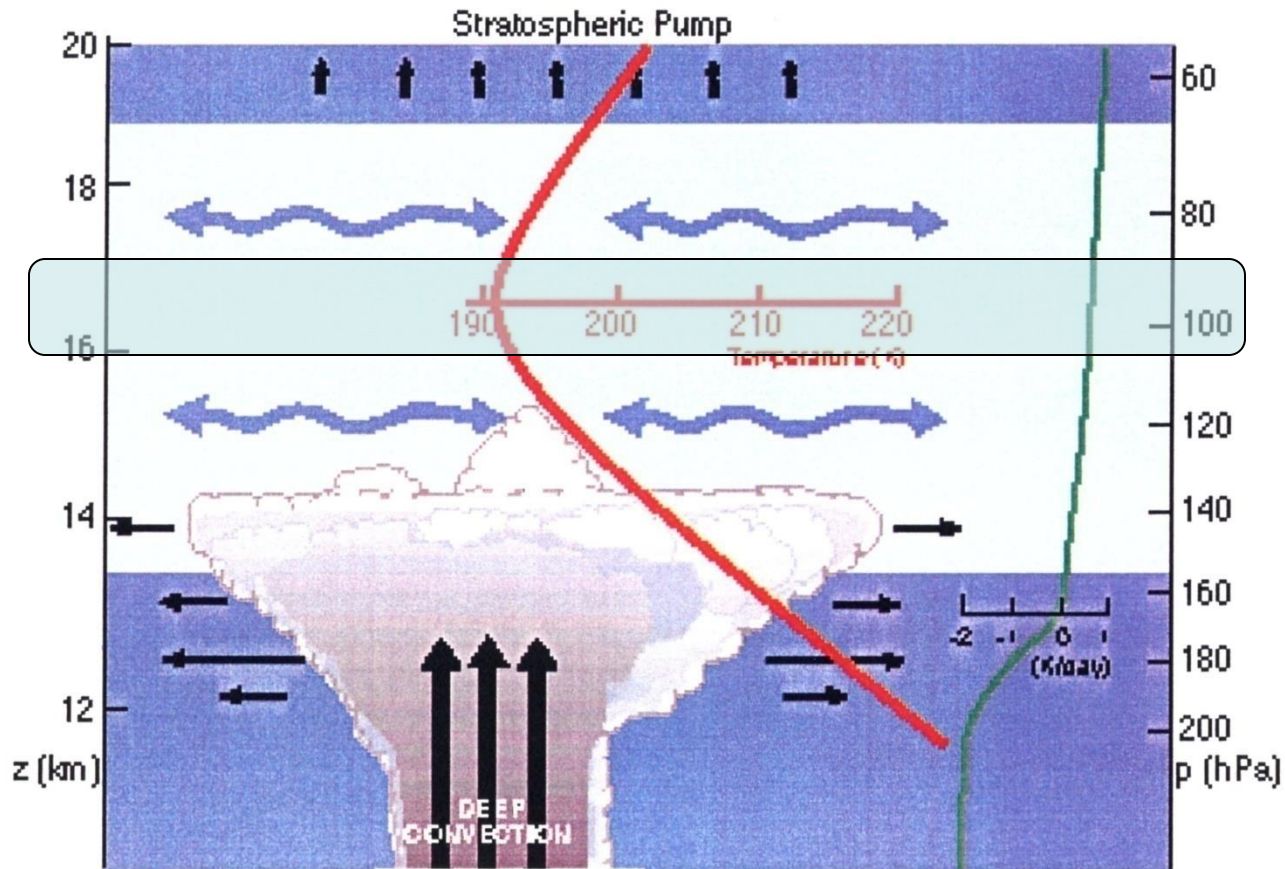
# 水蒸気の年々変動



Observed interannual changes in lower stratospheric water vapour from satellite measurements over the period 1992–2012 compared with interannual variations in tropical cold-point tropopause temperatures. Water vapour data are de-seasonalized near-global averages at 83 hPa from combined HALOE and MLS satellite measurements.

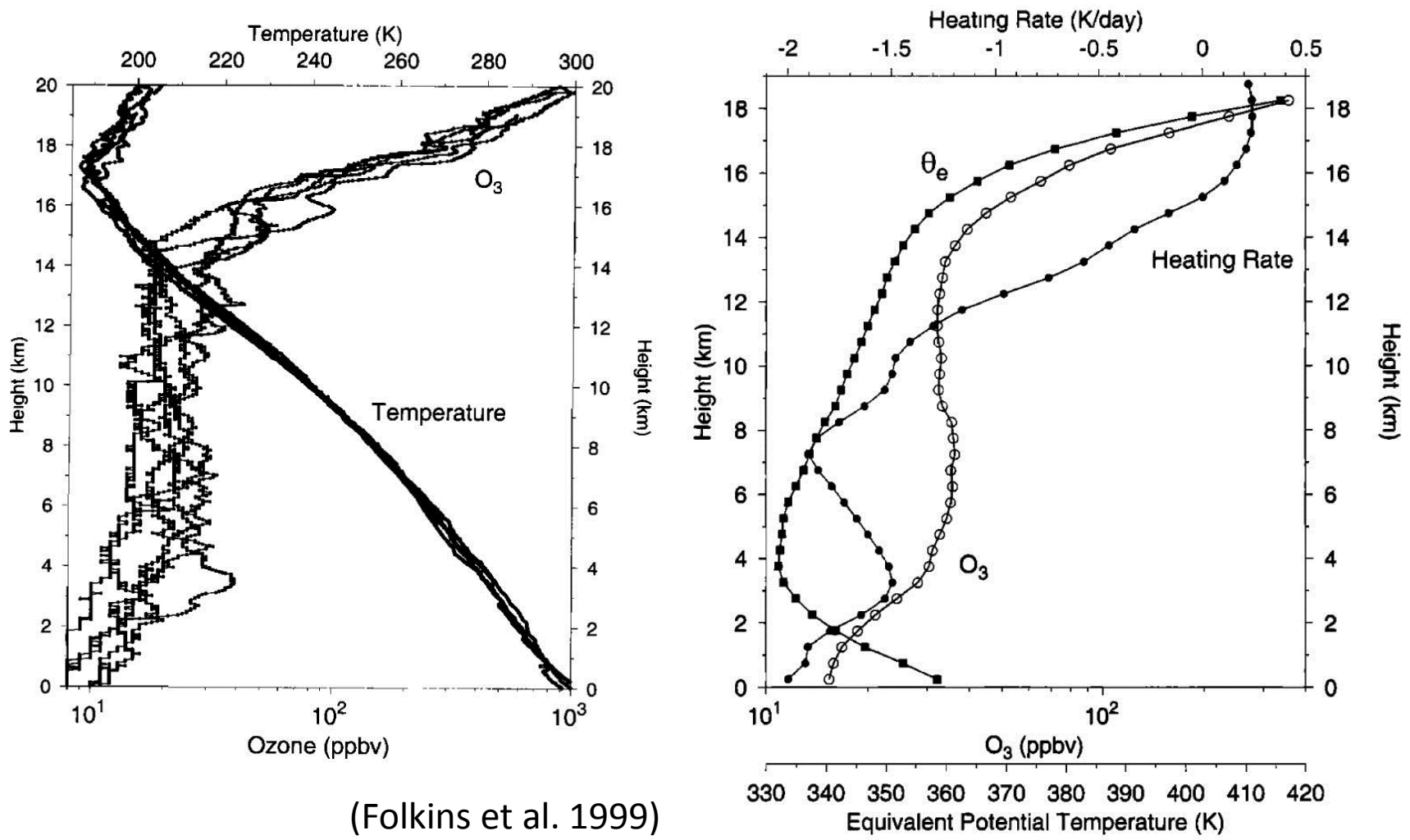
(Randel and Jensen, 2012)

# 熱帯対流圏界面領域 (Tropical Tropopause Layer: TTL)



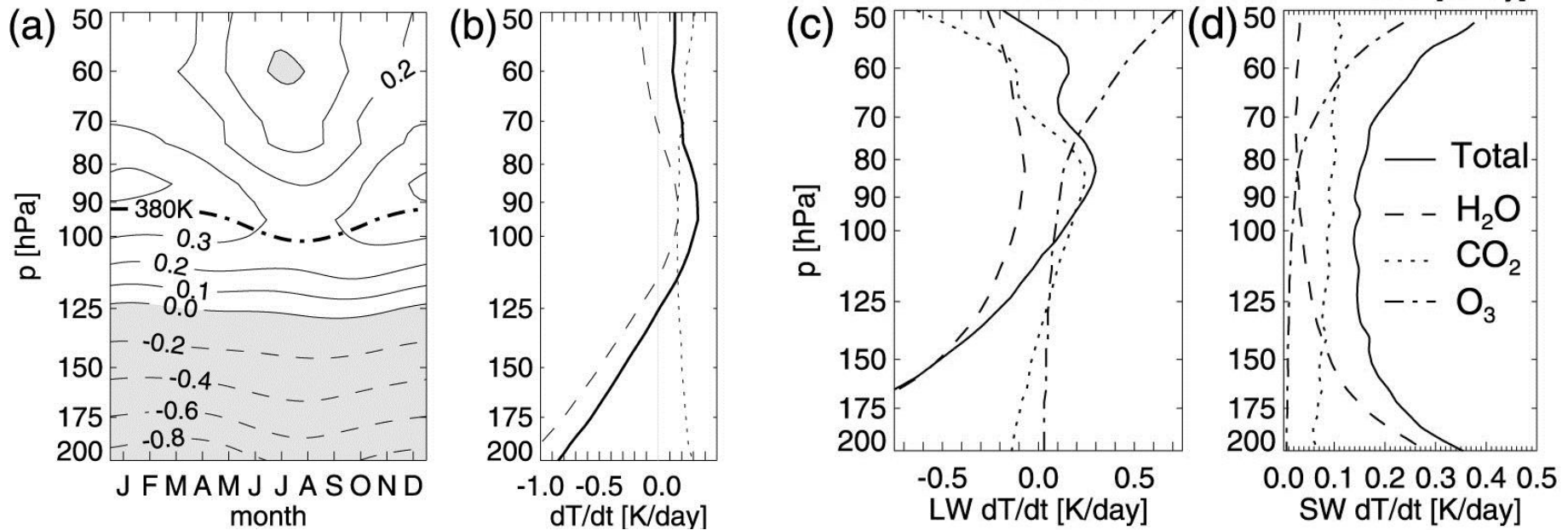
(Holton, ホームページより)

# 微量成分(O<sub>3</sub>)や熱バランスで見ると?



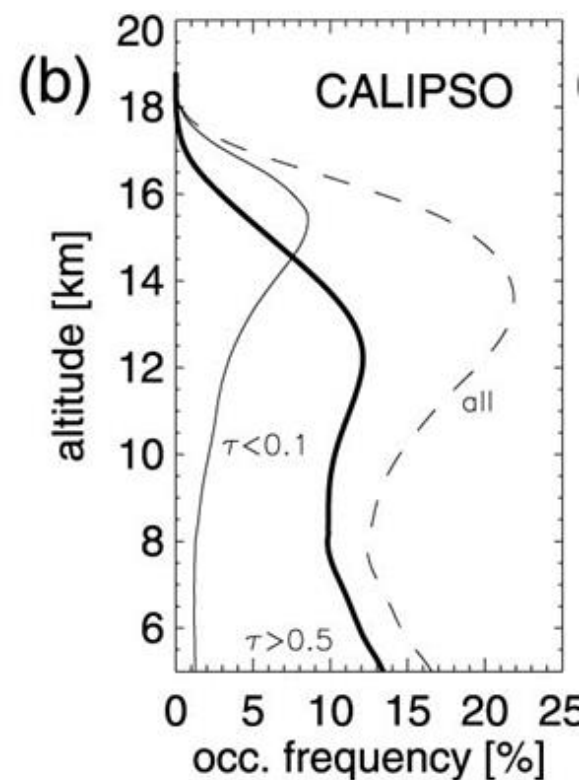
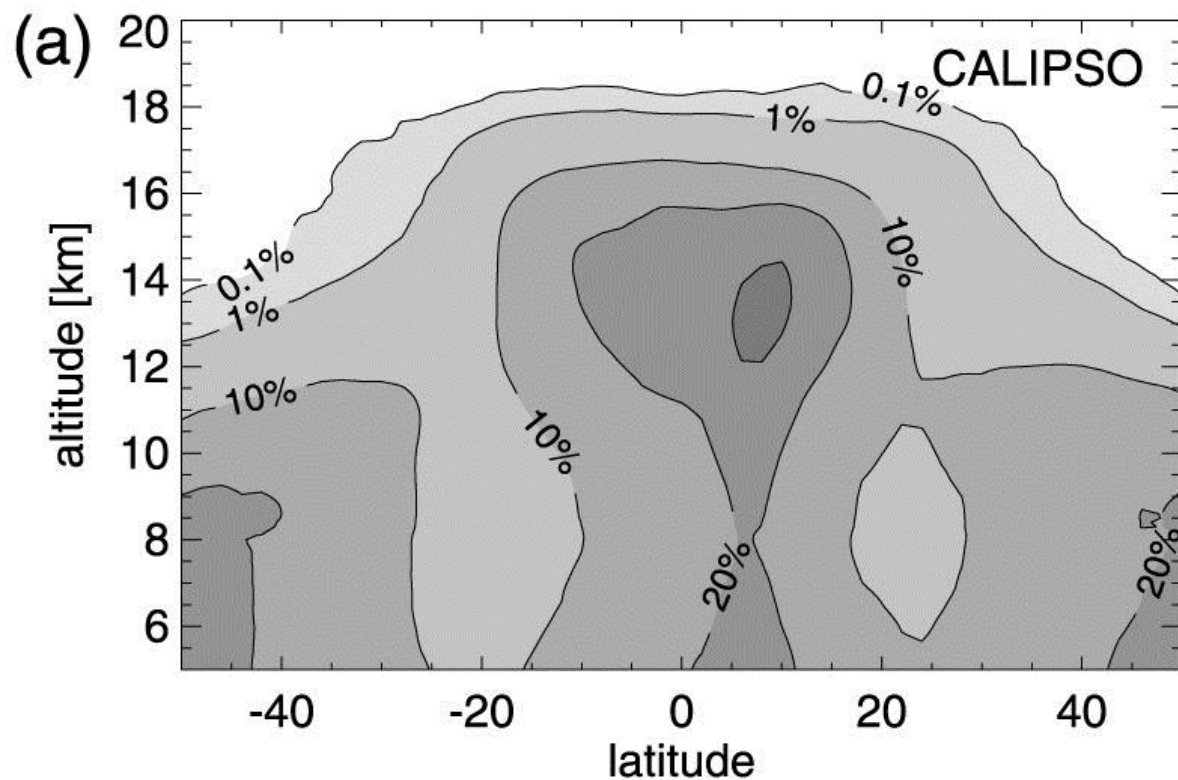
(Folkins et al. 1999)

# 放射加熱率(clear-sky condition)



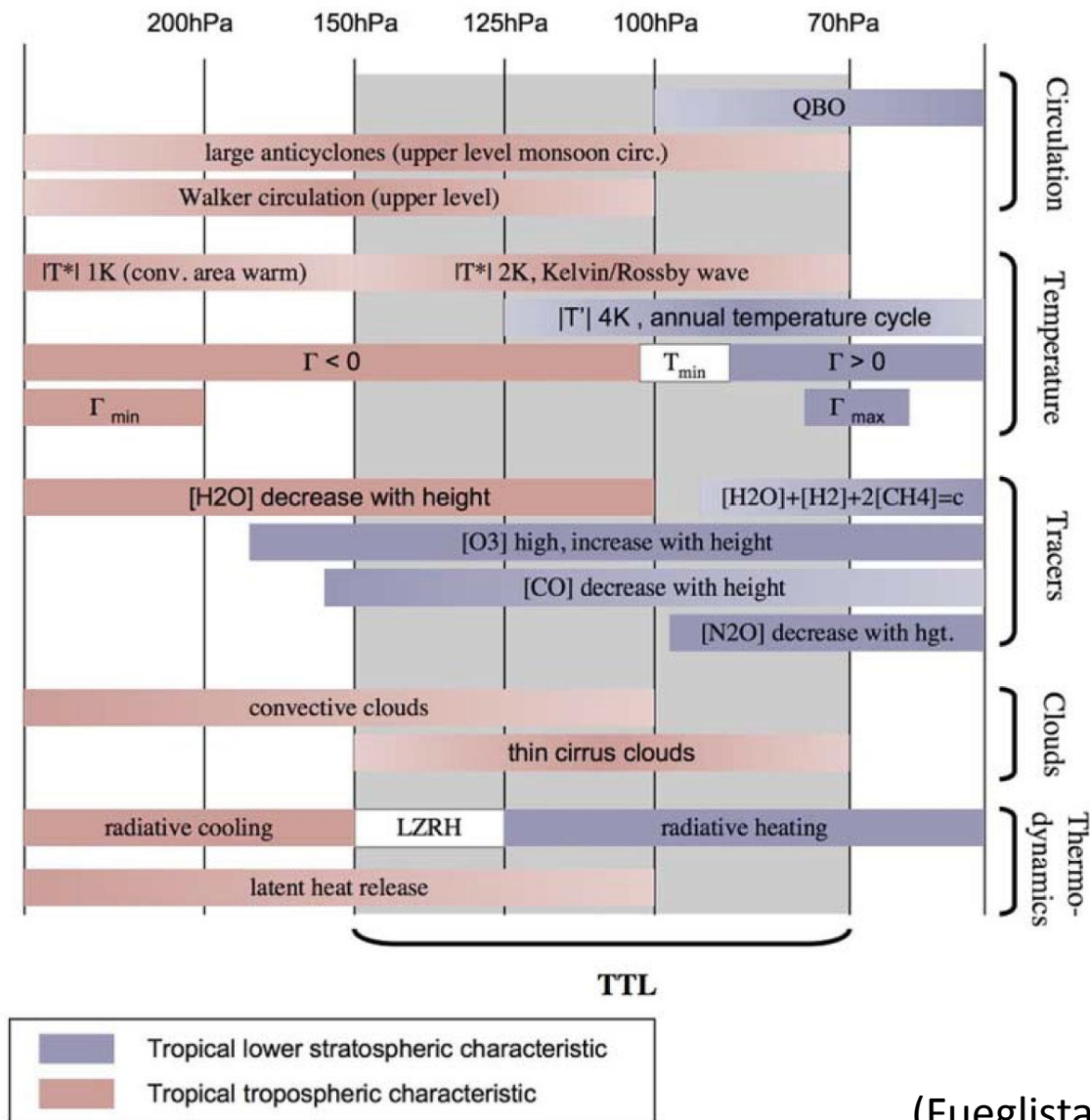
Clear-sky radiative heating rates. (a) Climatological mean annual cycle at tropical SHADOZ stations (calculated with an updated version of the Fu-Liou radiative transfer code). Dash-dotted line shows 380 K isentrope for reference. (b) Corresponding annual mean total (solid) and longwave (dashed) and shortwave (dotted) radiative heating rates. (c) Longwave and (d) shortwave radiative heating rates of typical tropical profile separated to contributions from ozone (dash-dotted), water vapor (dashed), and carbon dioxide (dotted). Data adapted from Gettelman et al. [2004a].

# 背の高い雲の分布



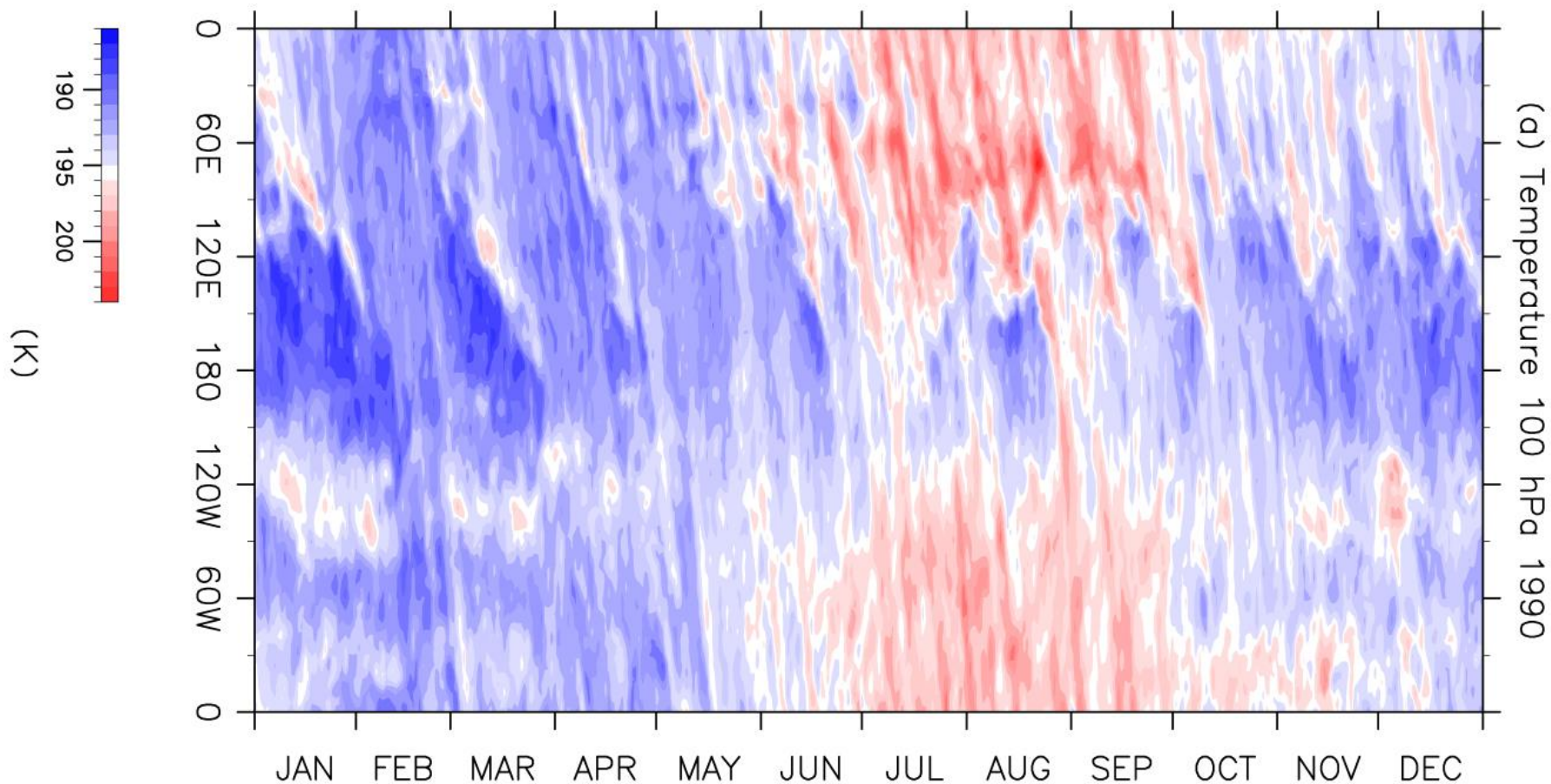
(Updated from Wang et al., 1996)

# Tropical Tropopause Layer のまとめ



(Fueglistaler et al., 2009)

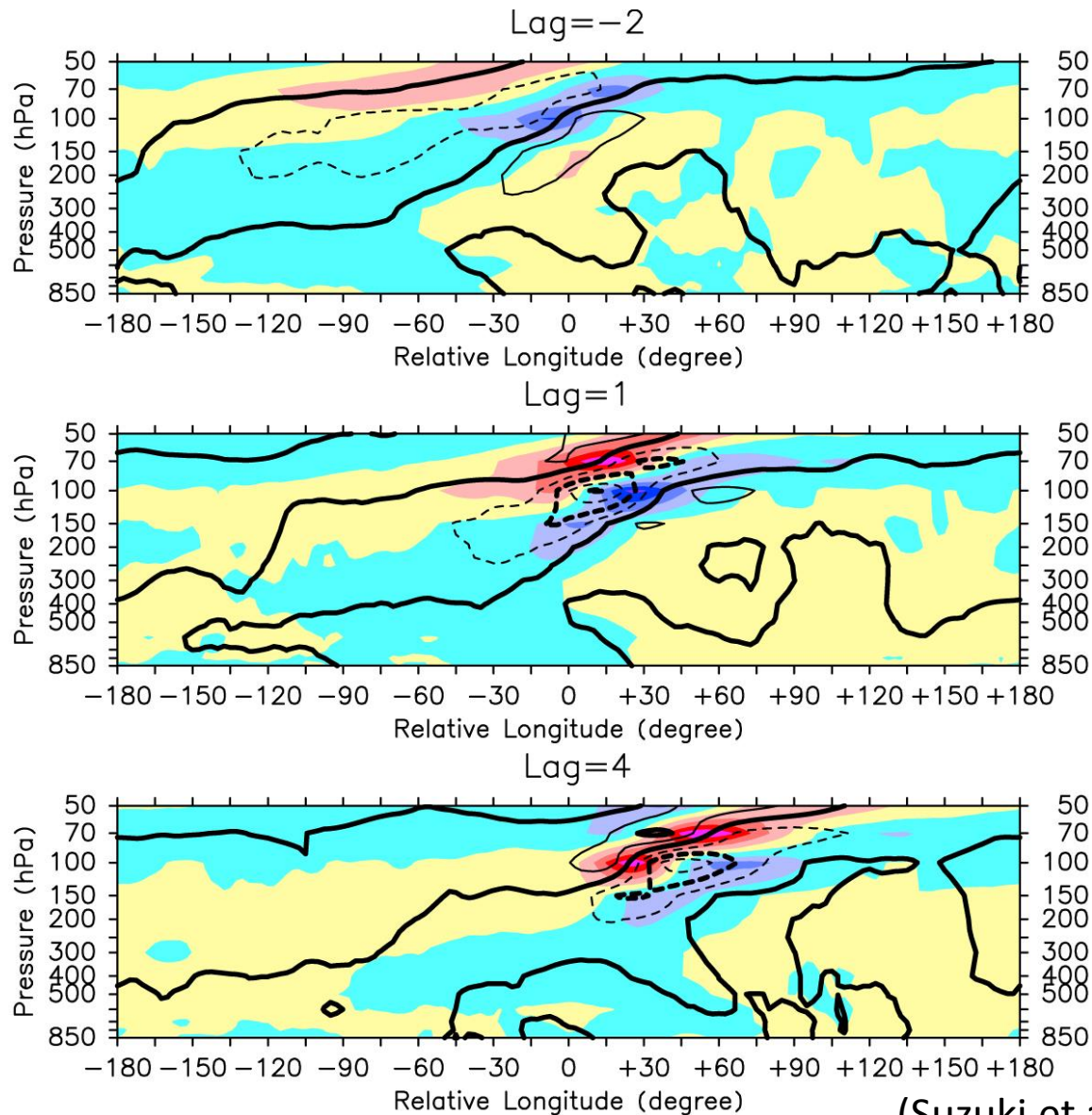
# 赤道域に特徴的な大気擾乱



(Suzuki and Shiotani, JGR, 2008)

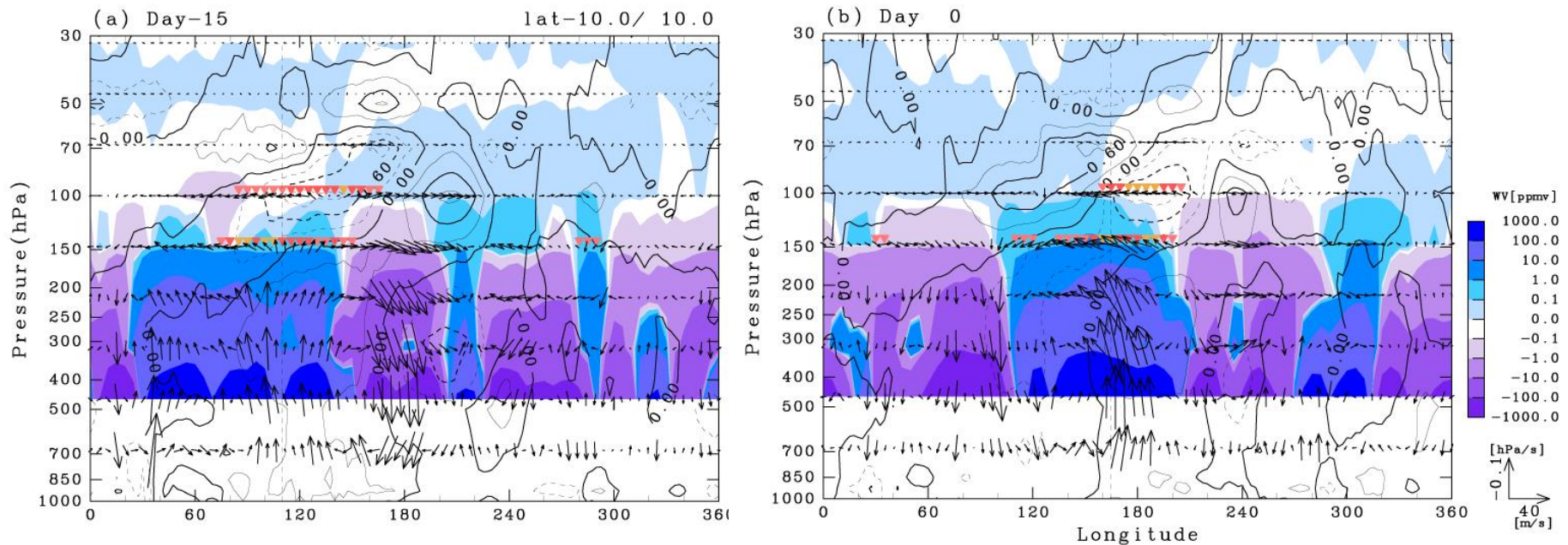


# ケルビン波にともなう温度擾乱



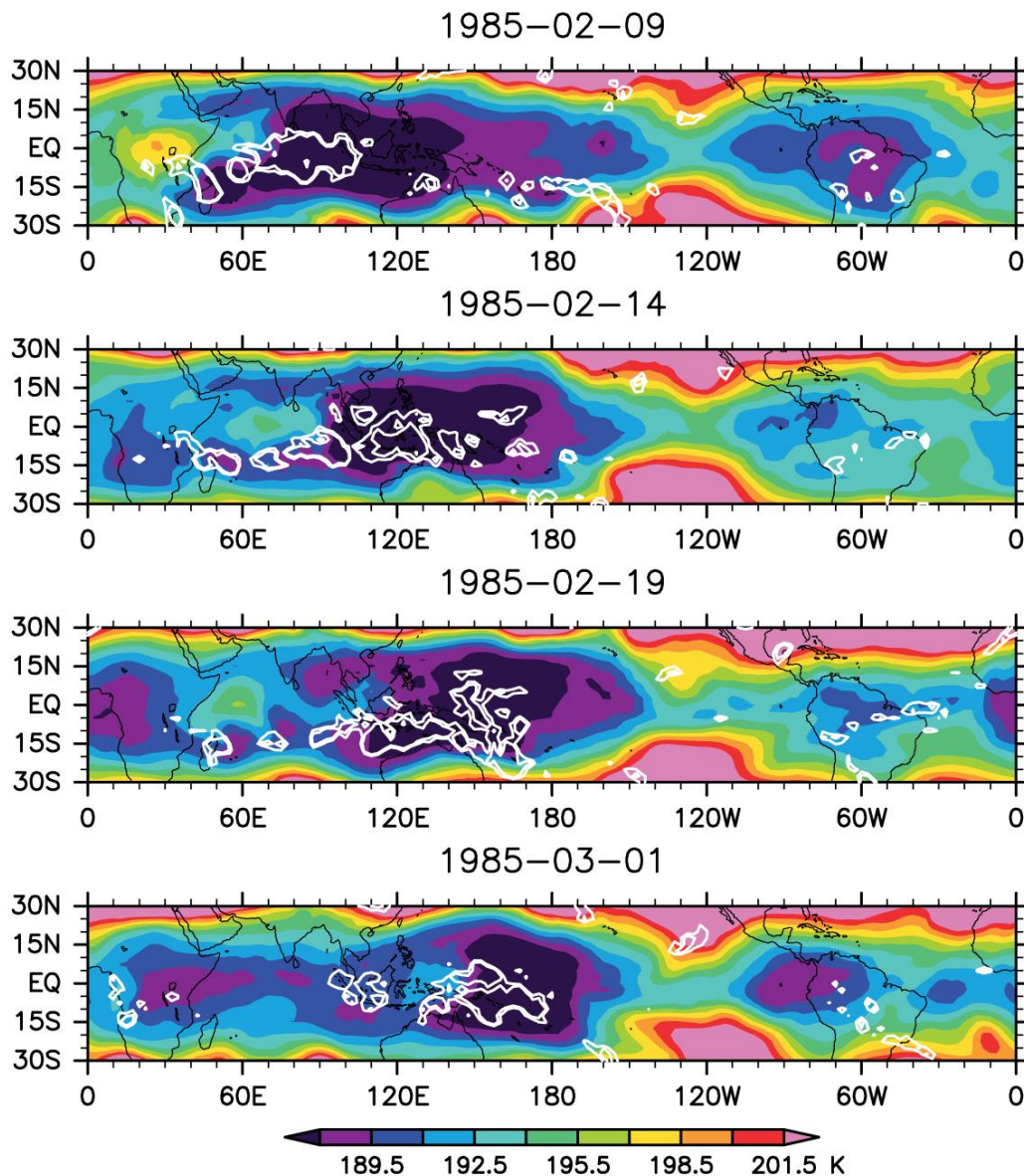
(Suzuki et al., JGR, 2008)

# 季節内振動(MJO)にともなう擾乱



(Eguchi and Shiotani, JGR, 2004)

# 緯度構造(馬蹄形)をもつ温度分布

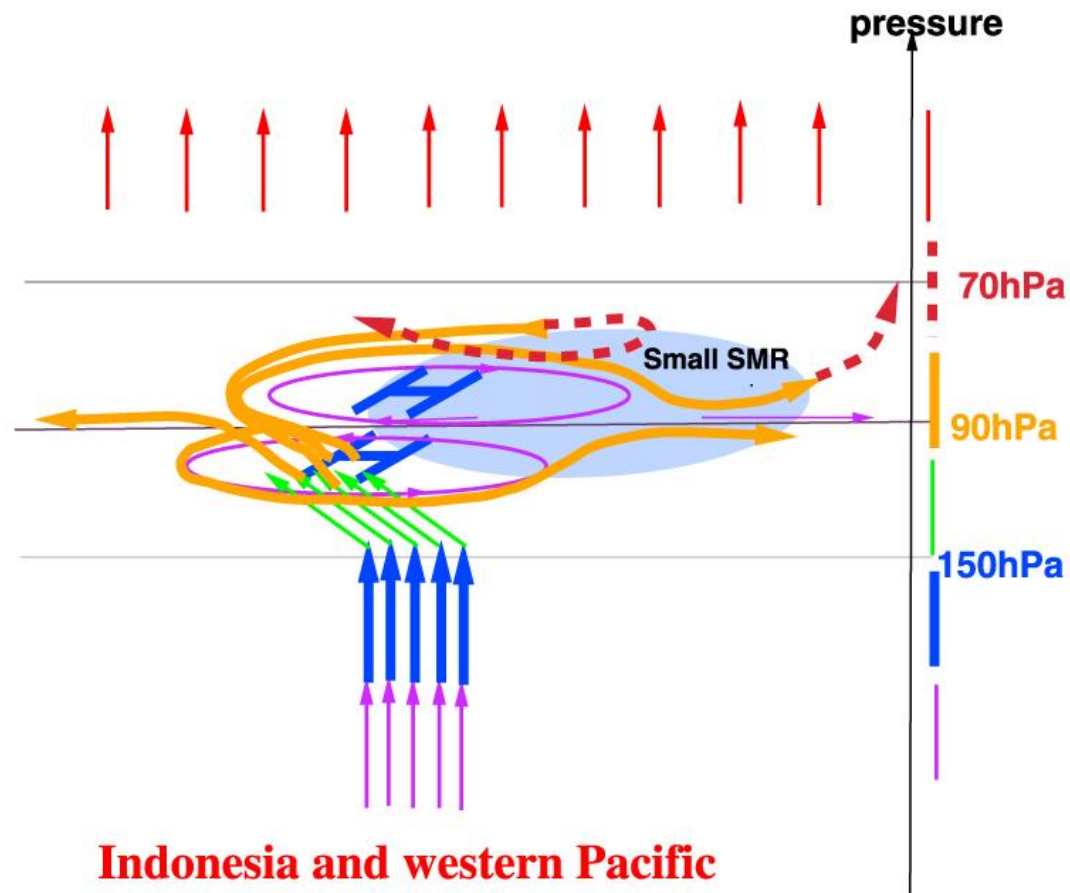


(Nishimoto and  
Shiotani, JGR, 2013)

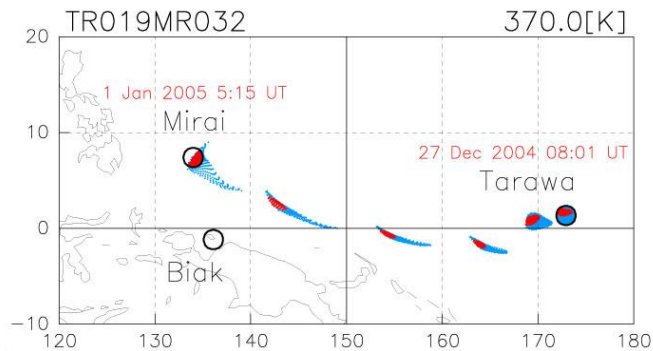
# Stratospheric drain over Indonesia

(Hatsushika and Yamazaki, 2003)

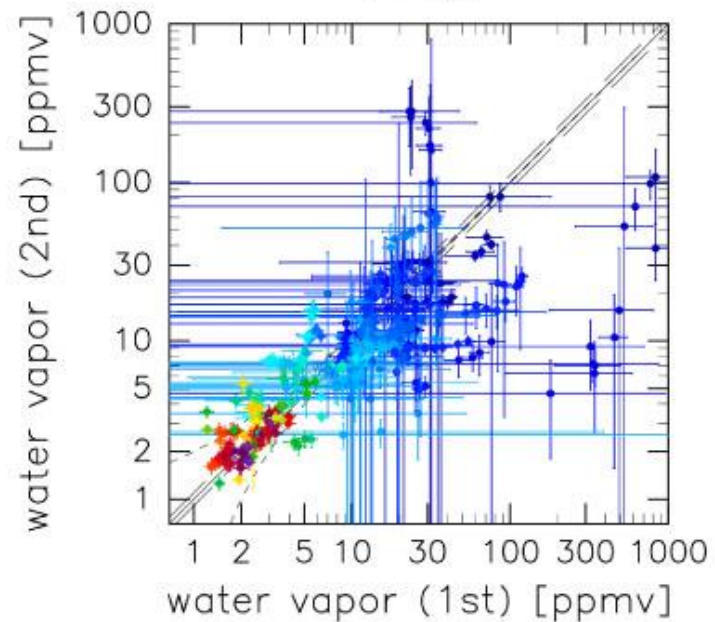
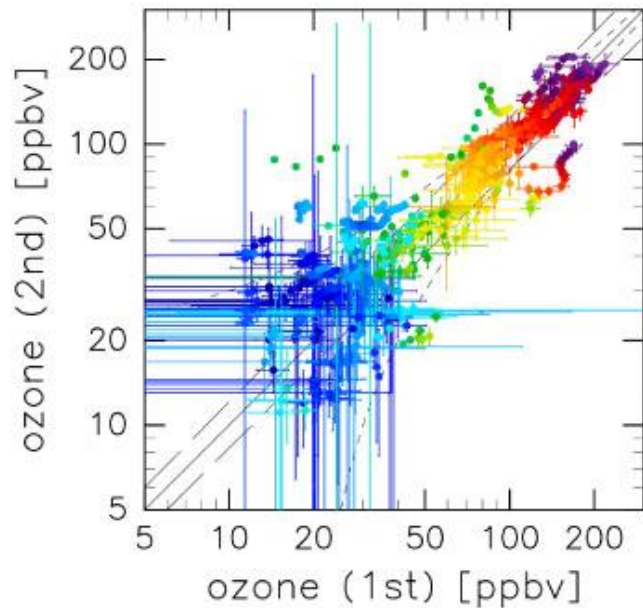
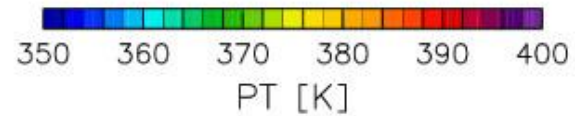
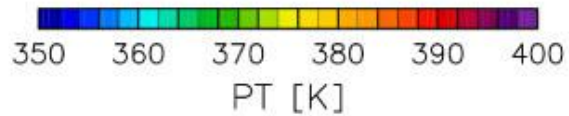
## Path of the tropospheric air into the stratosphere



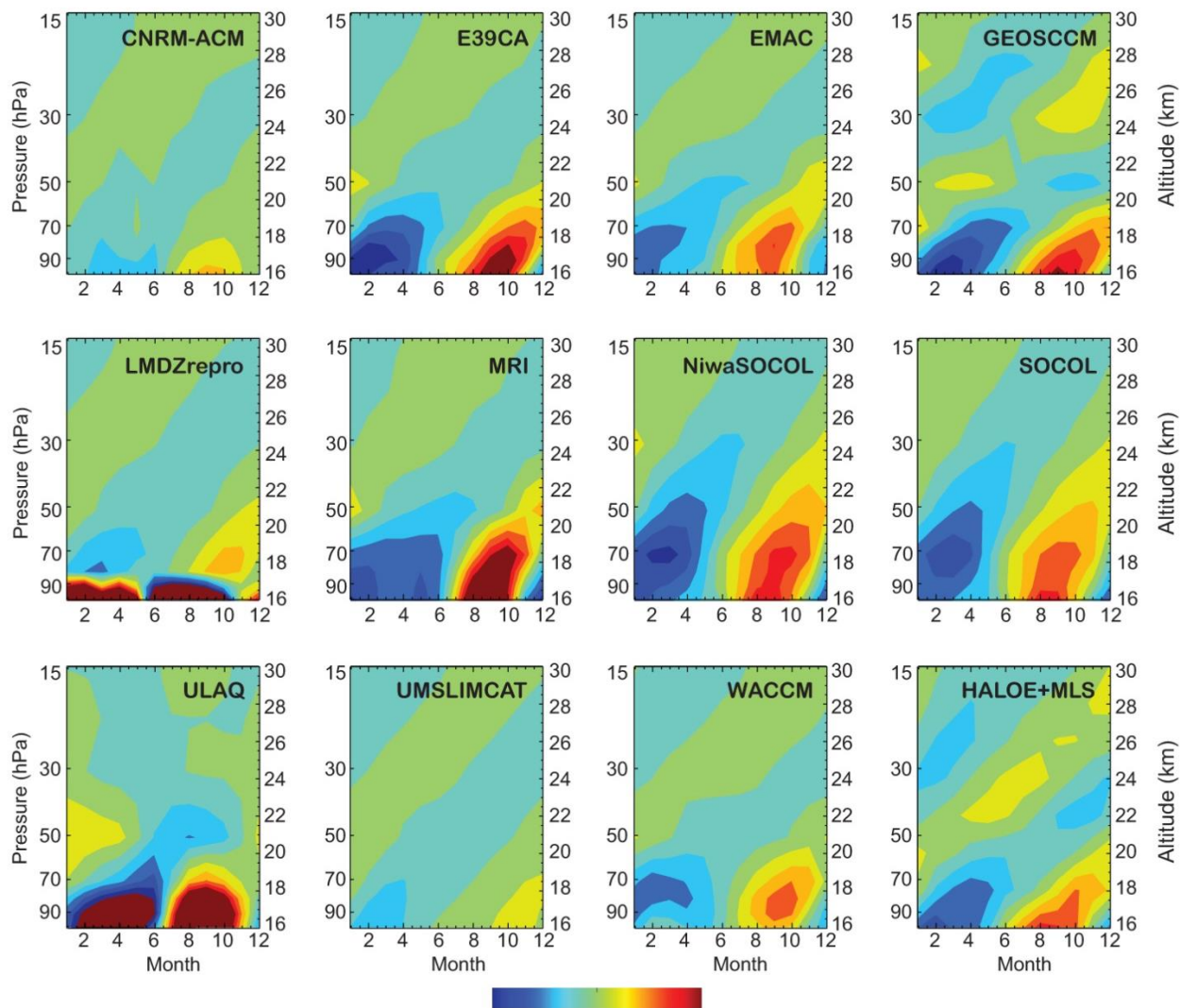
# 水蒸気のマッチ観測



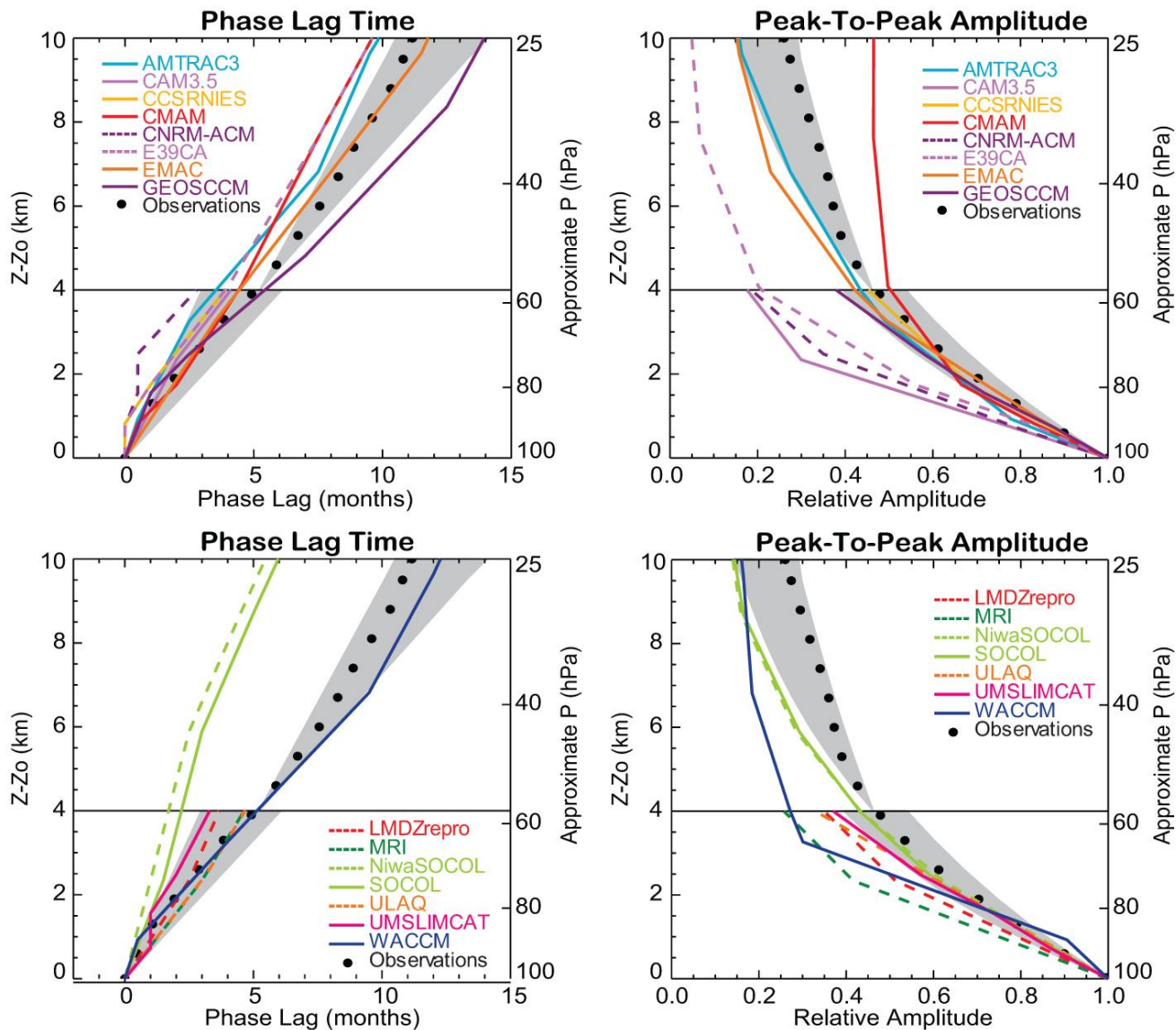
(Inai et al., ACP, 2013)



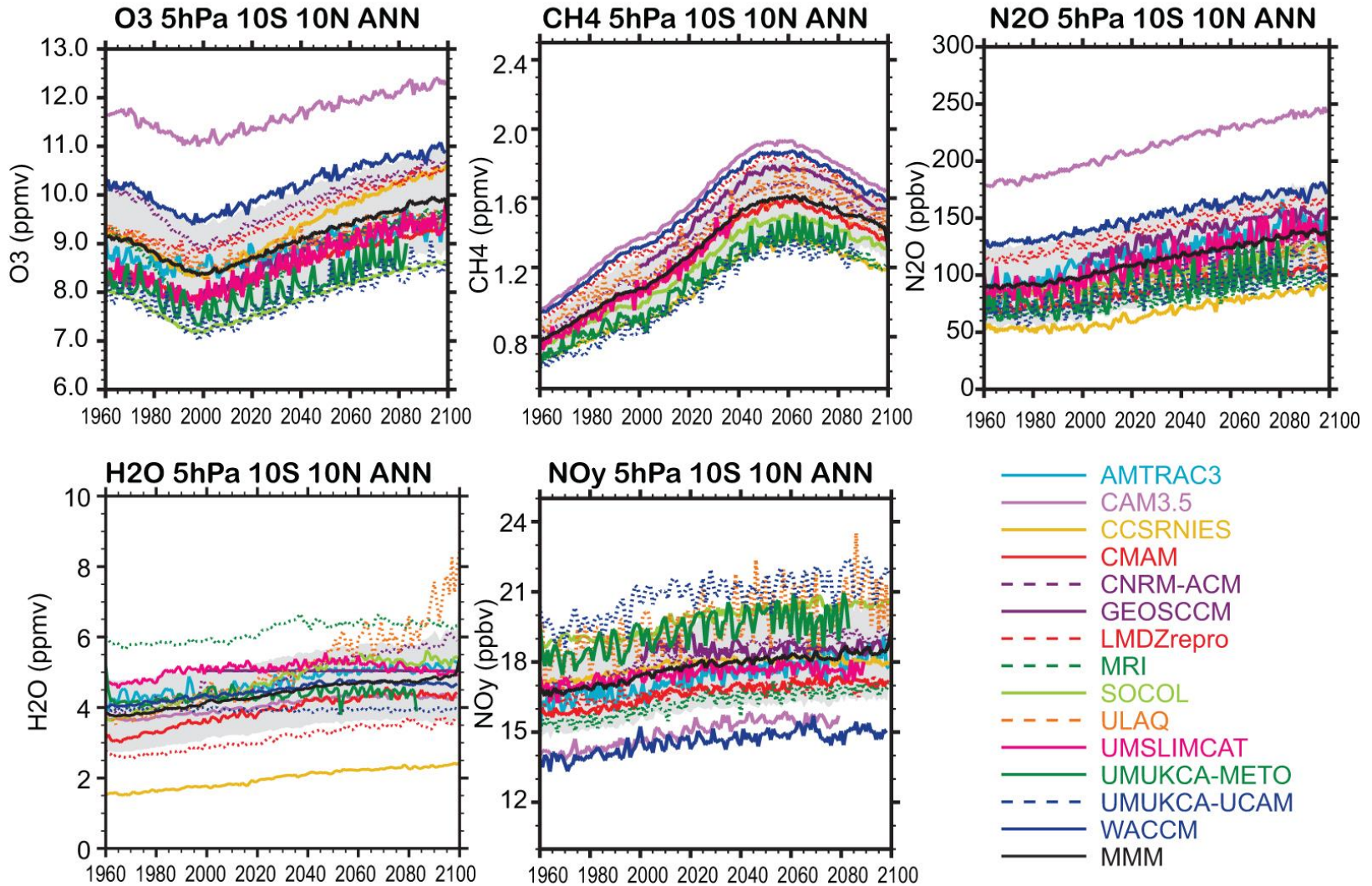
# CCMVal (Chemistry-Climate Model Validation Activity) によるテープレコーダシグナルの再現



# テープレコーダシグナルの振幅と位相

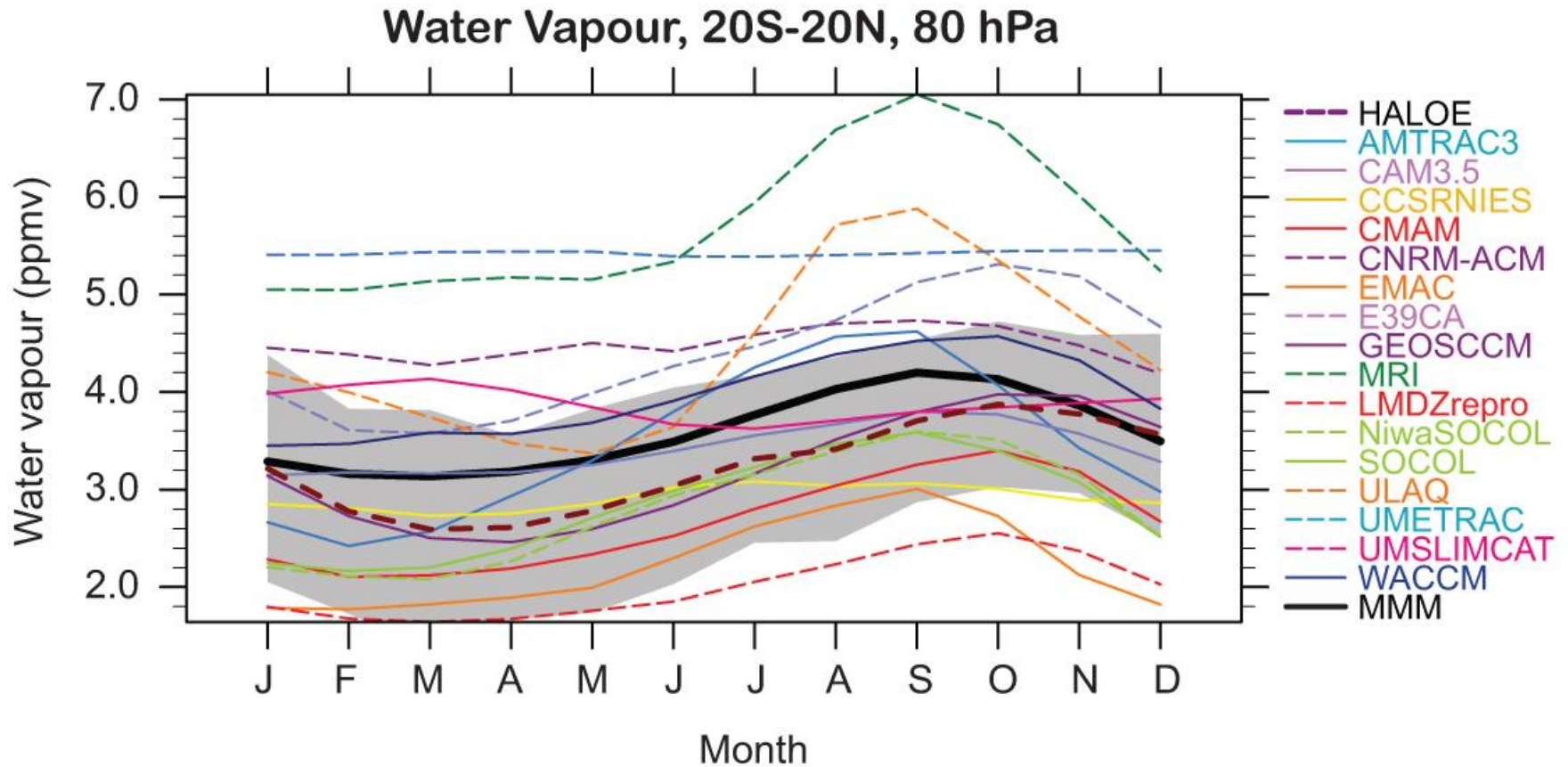


# 微量成分の将来予測

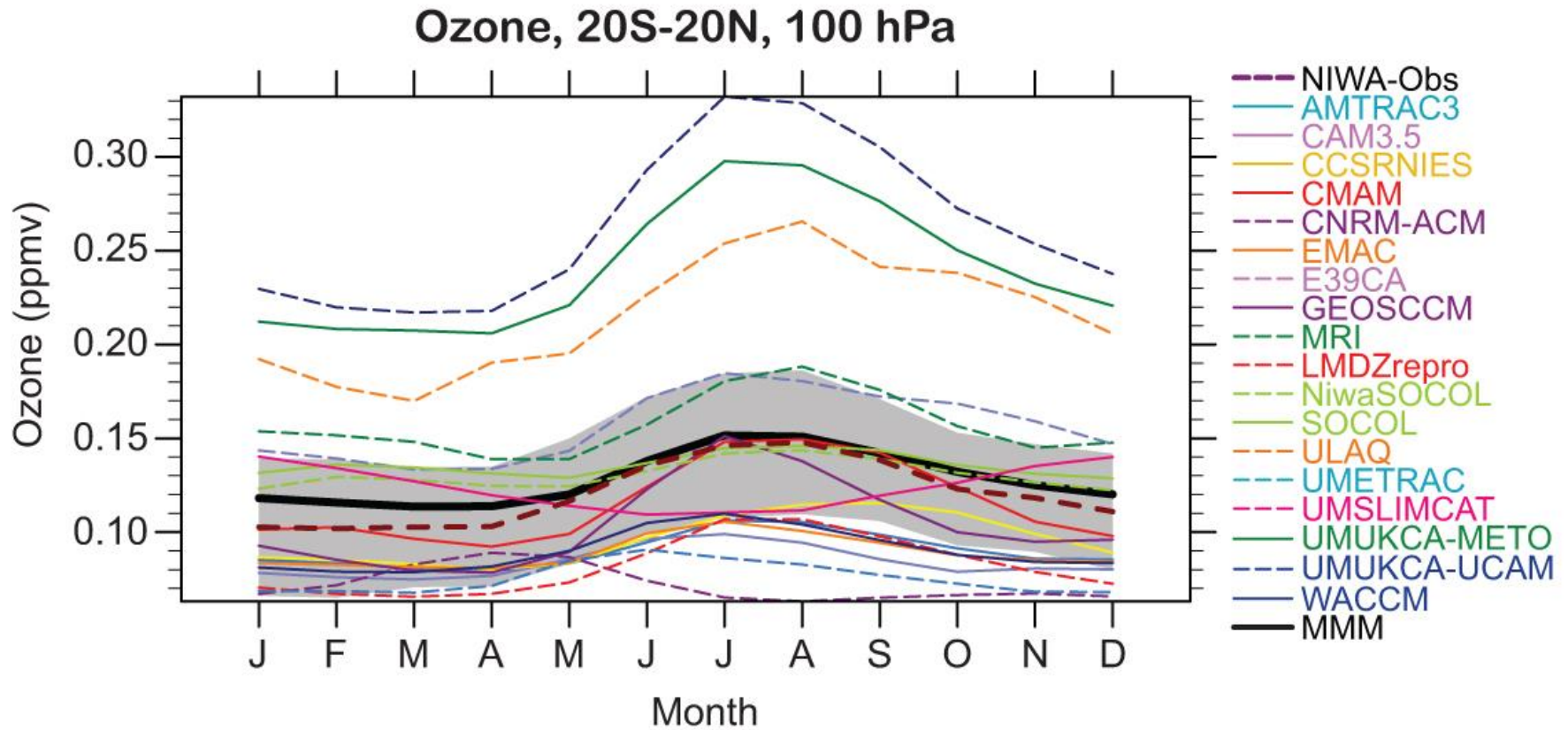




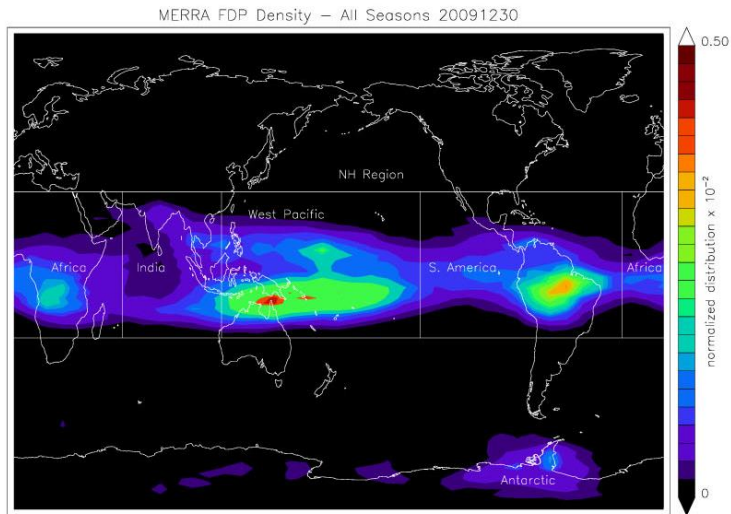
# TTL領域の水蒸気



# TTL領域のオゾン

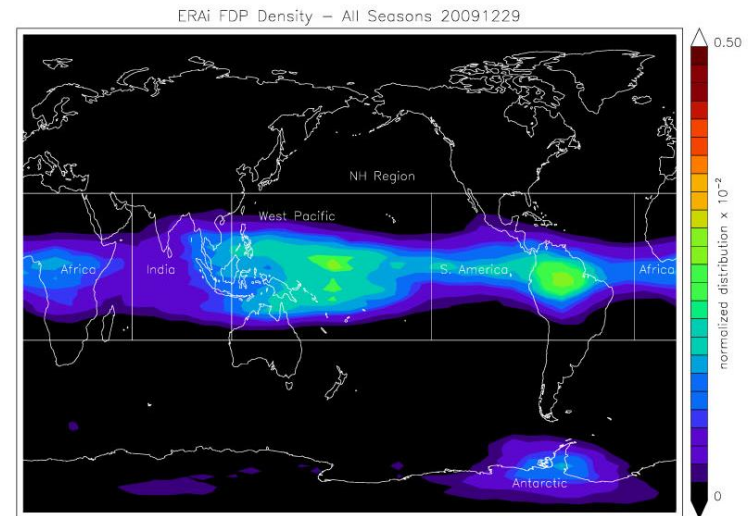
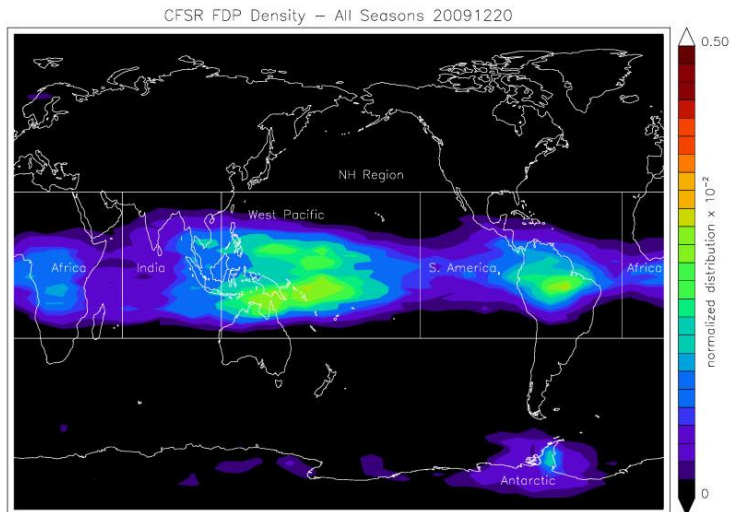


# Trajectory model による研究

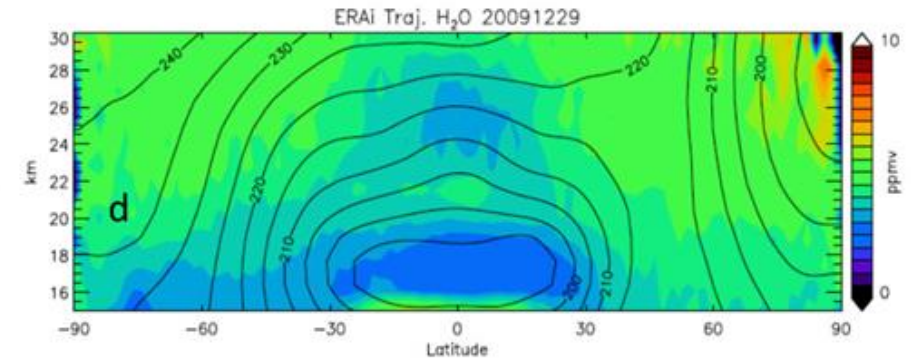
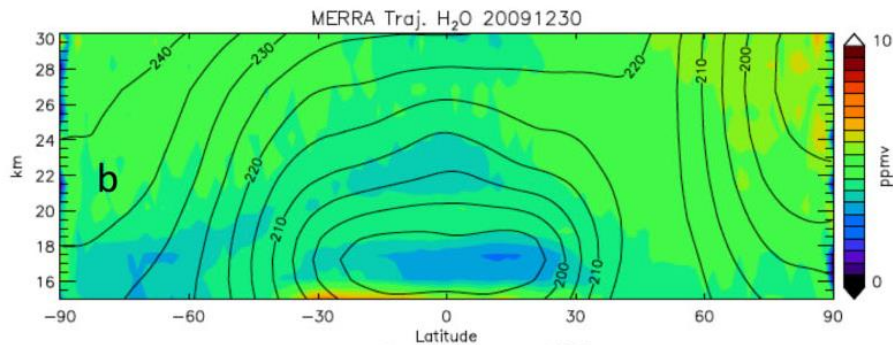
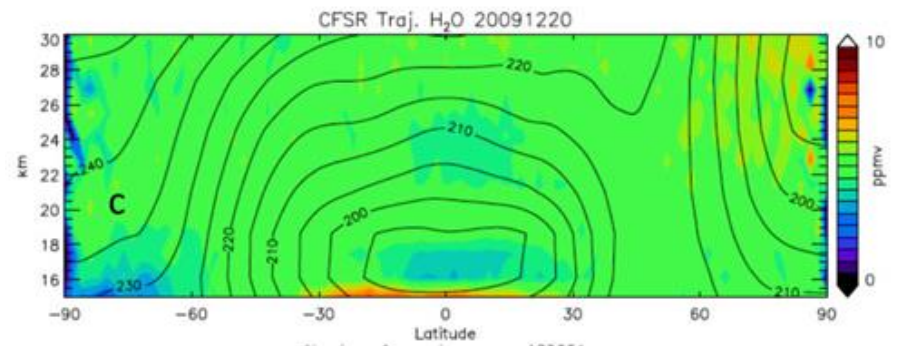
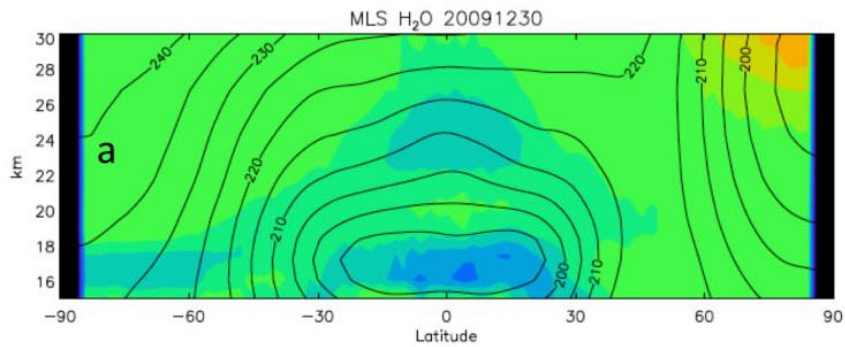


3つの再解析データ, NASA's MERRA, NCEP's CFSR, ECMWF's ERAi に対して domain-filling, forward trajectory calculation model (Schoeberl and Dessler, 2011) を用い水蒸気の振る舞いを解析 (Schoeberl et al., ACP, 2012).

図は, 最後に脱水を受けた場所の頻度を描いたもの



# 再解析データに基づき 計算された水蒸気分布



(Schoeberl et al., ACP, 2012)

# 中間圏の水蒸気

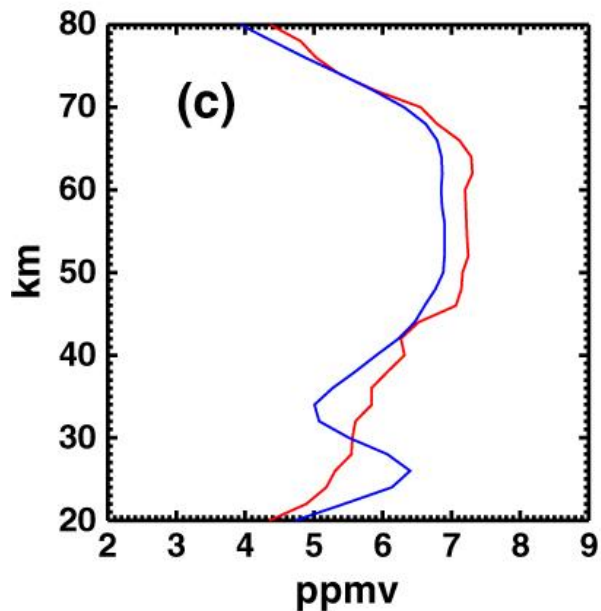


Table Mountain, California (34.4N, 242.3E) とMauna Loa, Hawaii (19.5N, 204.4E)における観測.

(Nedoluha et al., JGR, 2012)

