The efficiency of transport into the stratosphere via the Asian and North American summer monsoon circulations

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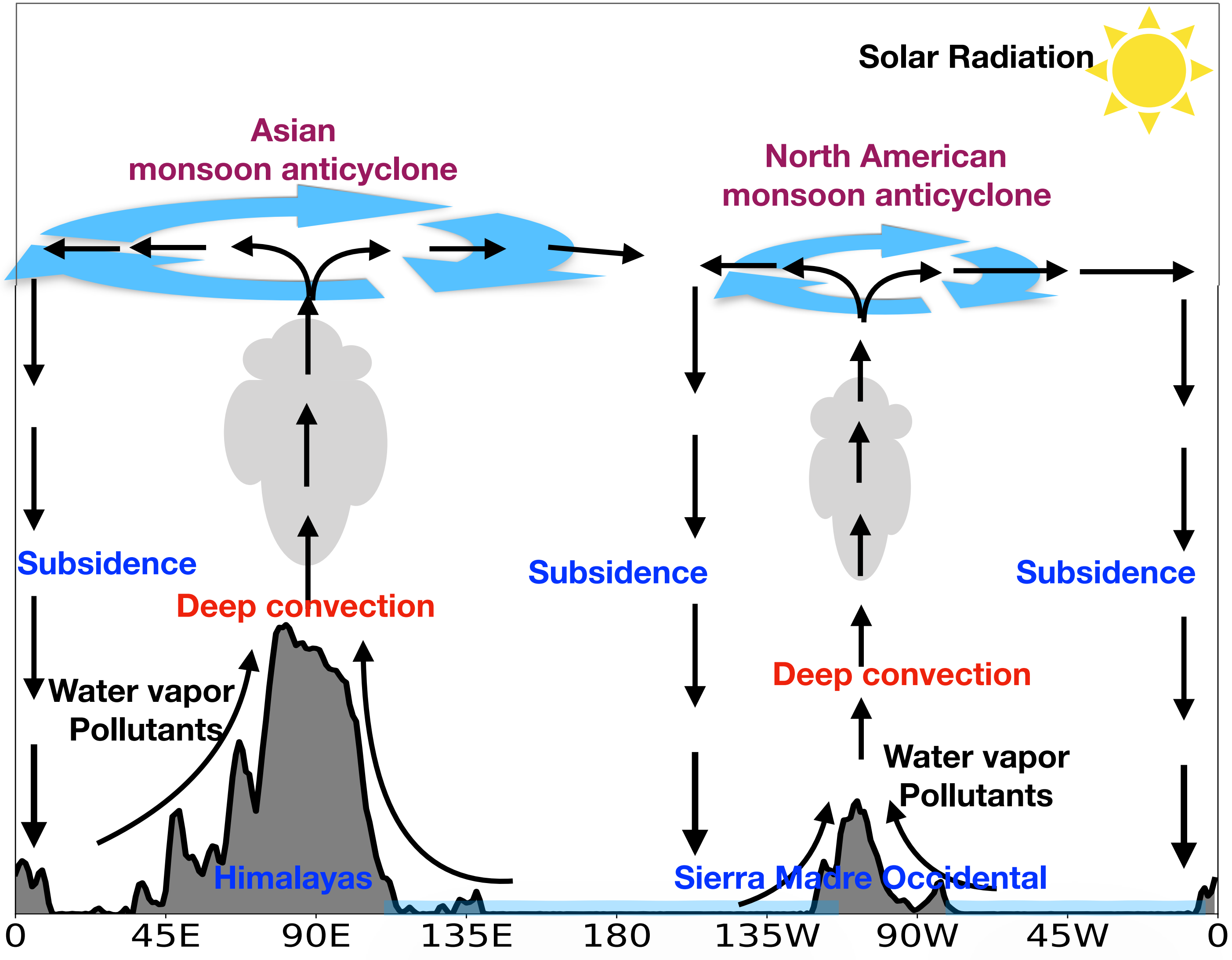
Introduction: Asian and North American summer Monsoon



- Monsoons are primarily driven by the strong continent-ocean thermal contrasts during summer
- The high elevation difference between the mountain and the ocean adds the temperature contrasts
- The onset of monsoons occur typically in late May to early June and last until September
- Uplift the water vapor and pollutants to the UTLS locally and globally

e.g. Bannister, Chen, Fu, Garny, Pan, Ploeger, Randel, Santee, Vernier, Vogel, Wright, Yu

Motivation

- *How does transport from the ASM and NASM affect stratospheric composition?*
- *How large are contributions from the ASM and NASM regions to the stratosphere relative to contributions from the inner tropics?*
- *From which levels within the ASM and NASM regions do the most effective transport pathways to the stratosphere originate?*

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↓

- The relative influences of the ASM and NASM on stratospheric composition
- The transport pathways from monsoon regions to the stratosphere
- Quantitative contributions and efficiencies of transport from different altitudes in these two monsoon regions to the stratosphere.

Data and methods

CLaMS Model
2010-2013

ERA-Interim (CLaMS-EI)
MERRA-2 (CLaMS-M2)

Source Region

ASM	(30ºE - 120ºE, 15ºN-45ºN)
NASM	(160ºW-60ºW, 15ºN-40ºN)
Tropics	(15ºS - 15ºN)

$$M_i = \begin{cases} 1 & \text{inside the source region, July-August} \\ 0 & \text{elsewhere} \end{cases}$$

Destination Region

- Lower stratosphere in the Southern Hemisphere (LS-SH: 50ºS - 70ºS)
- Lower stratosphere in the Northern Hemisphere (LS-NH: 50ºN-70ºN)
- Tropical pipe (TrP: 15ºS - 15ºN)

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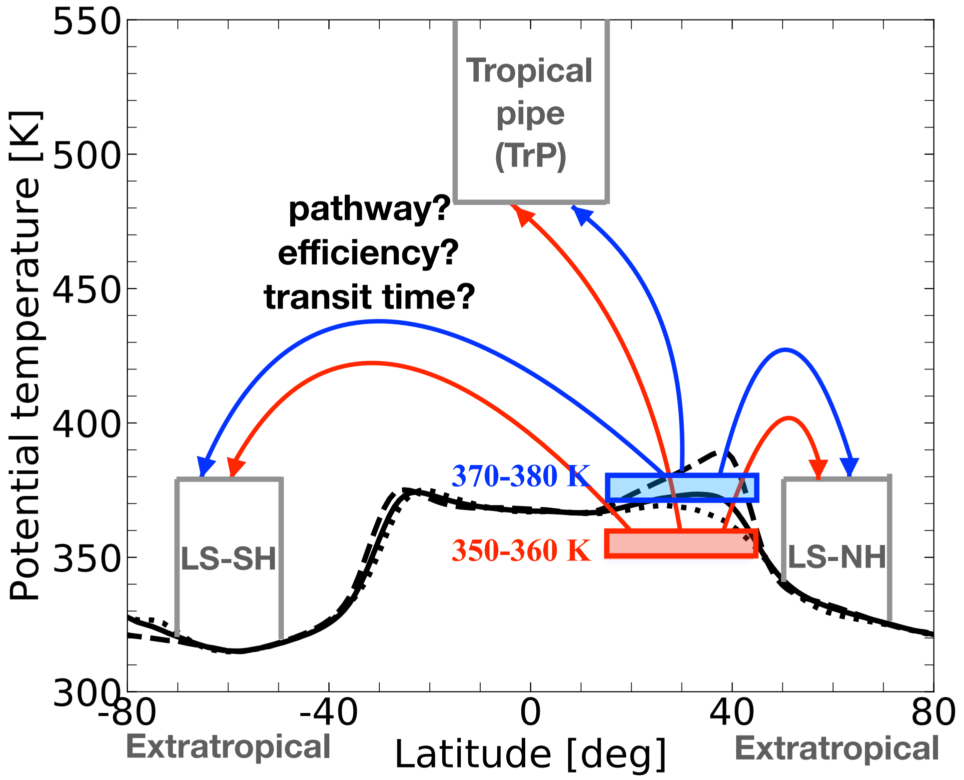
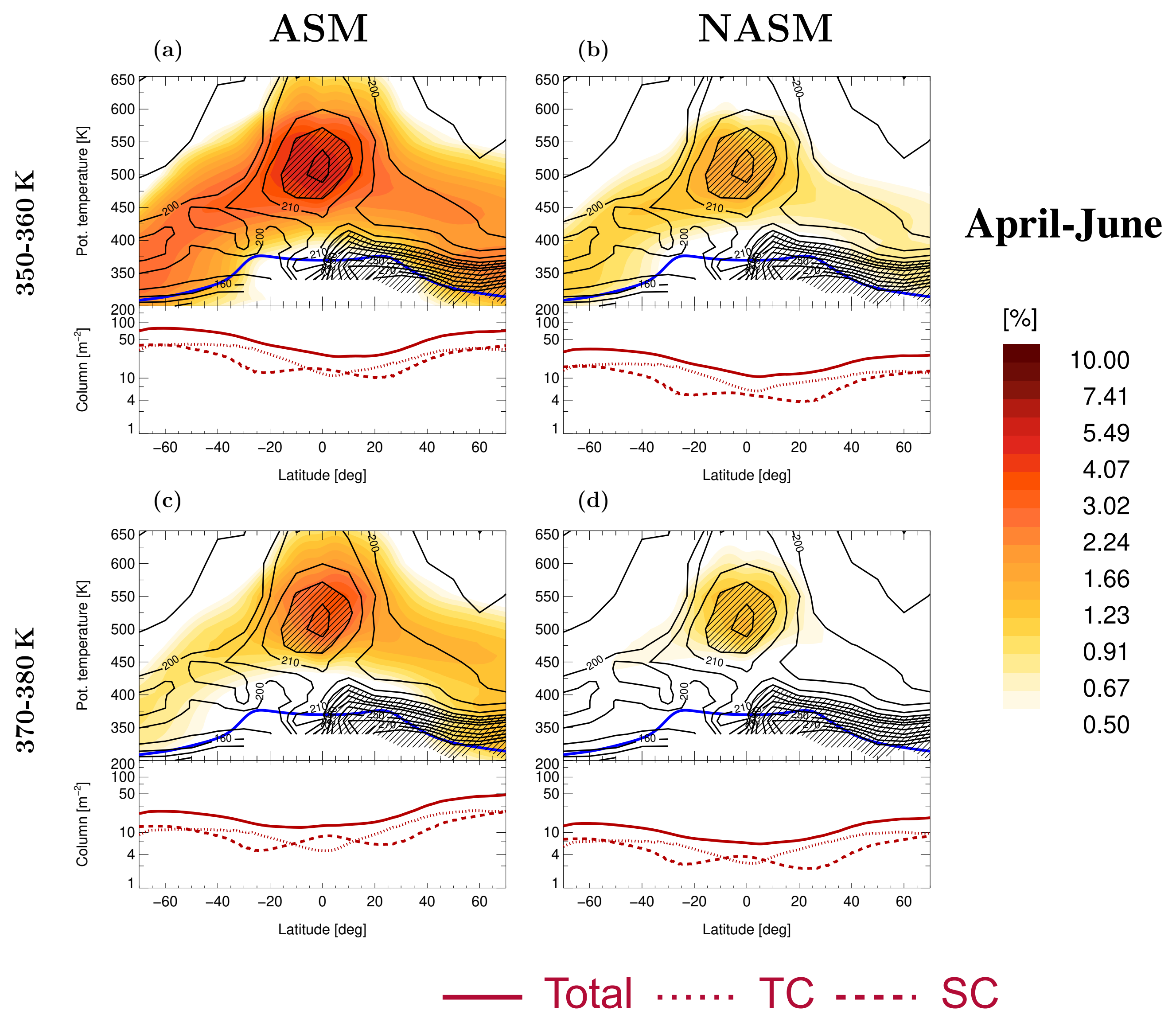
340-350K, 350-360K, 360-370K, 370-380K



ClaMS H_2O, young air mass fraction

MLS CO, MLS H_2O, and ACE-FTS HCN

Zonal-mean perspective on transport: CLaMS-EI



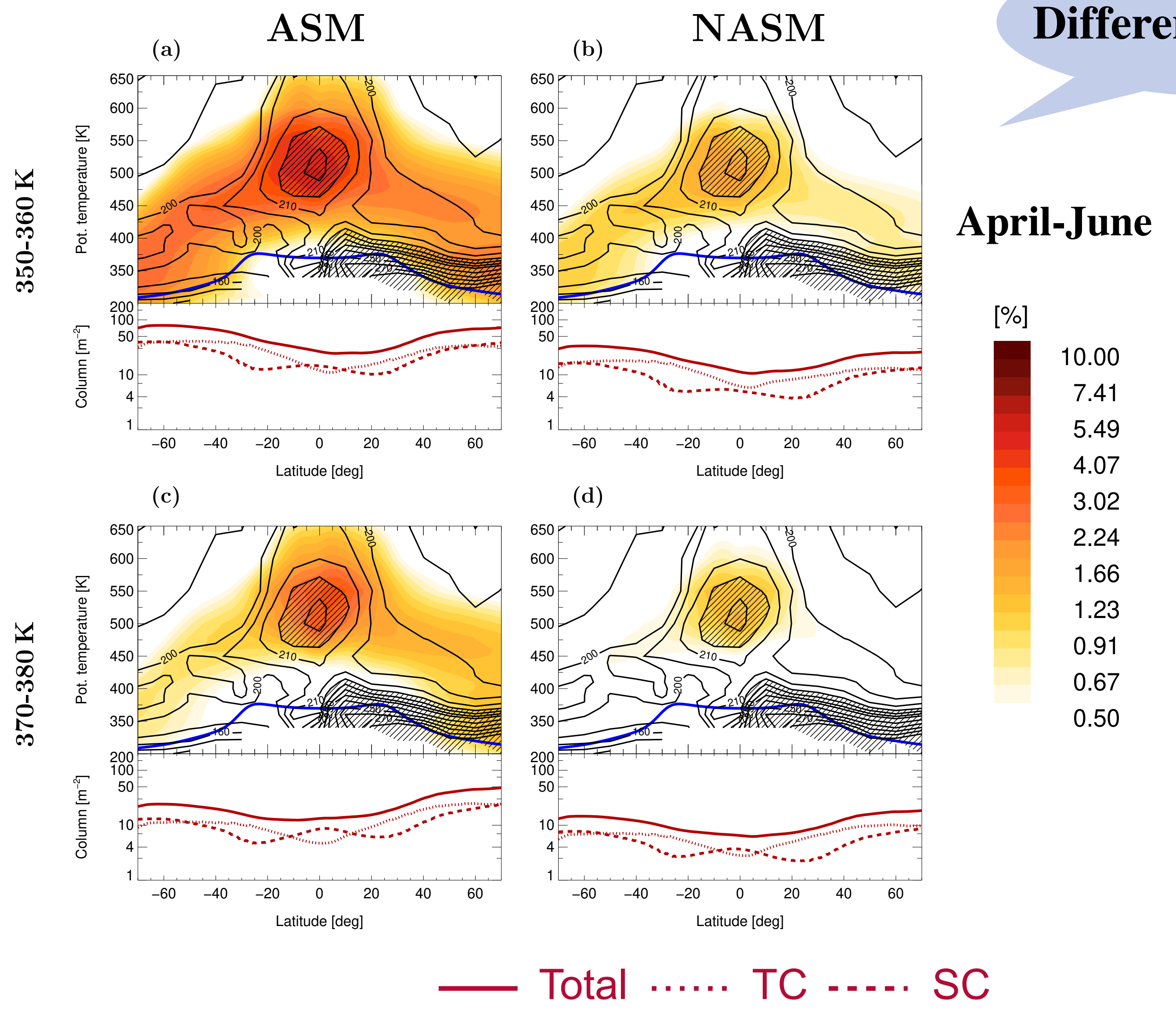
- ASM ==> larger contribution
  NASM ==> smaller contribution

- HCN (ACE-FTS)
  A strong origin from ASM
  A weak one from NASM

- 350-360K ==> more in the stratosphere
  more in the SH
  370-380K ==> less in the stratosphere
  more in the NH

Zonal-mean perspective on transport: CLaMS-EI

Different pathways?



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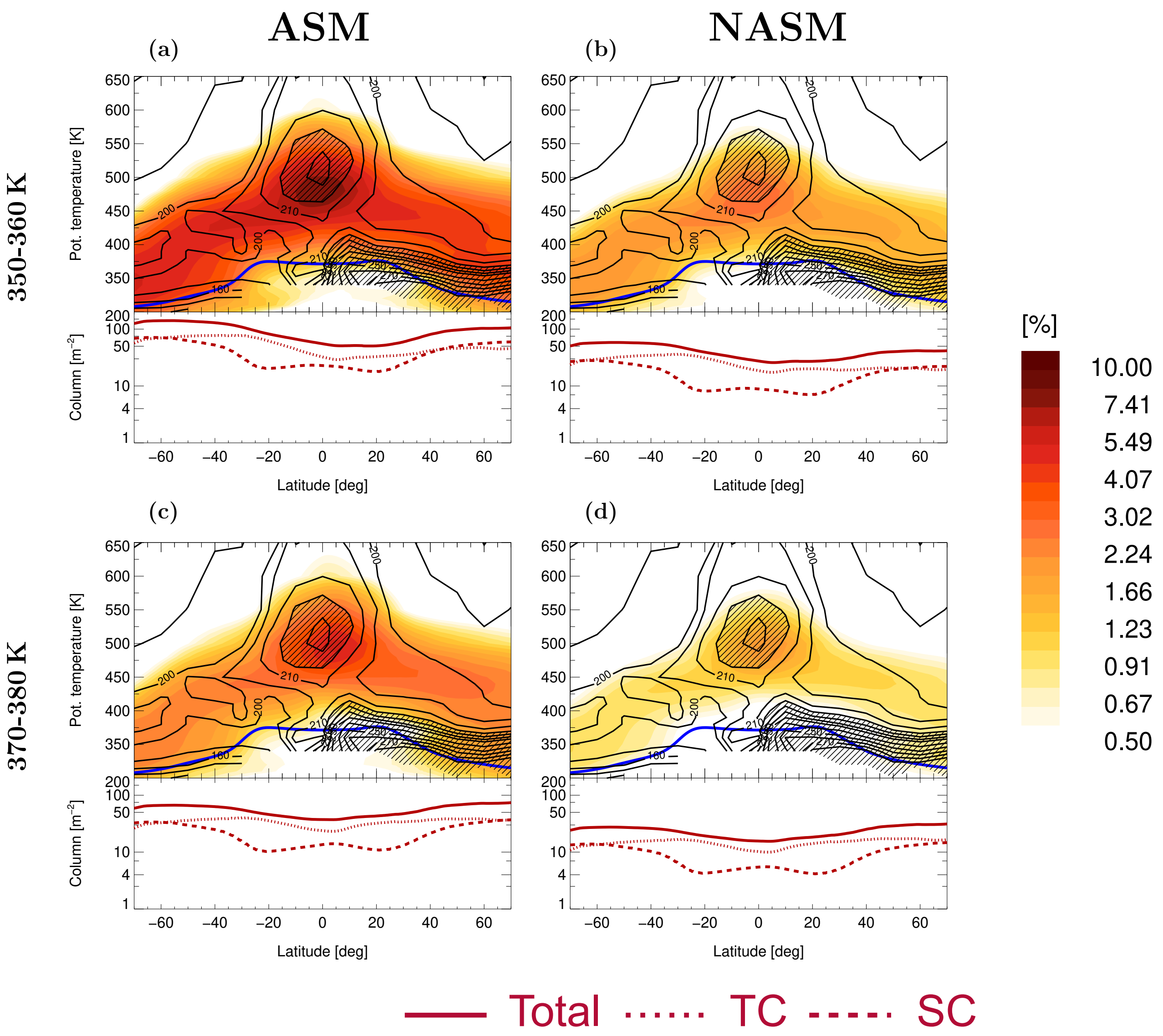
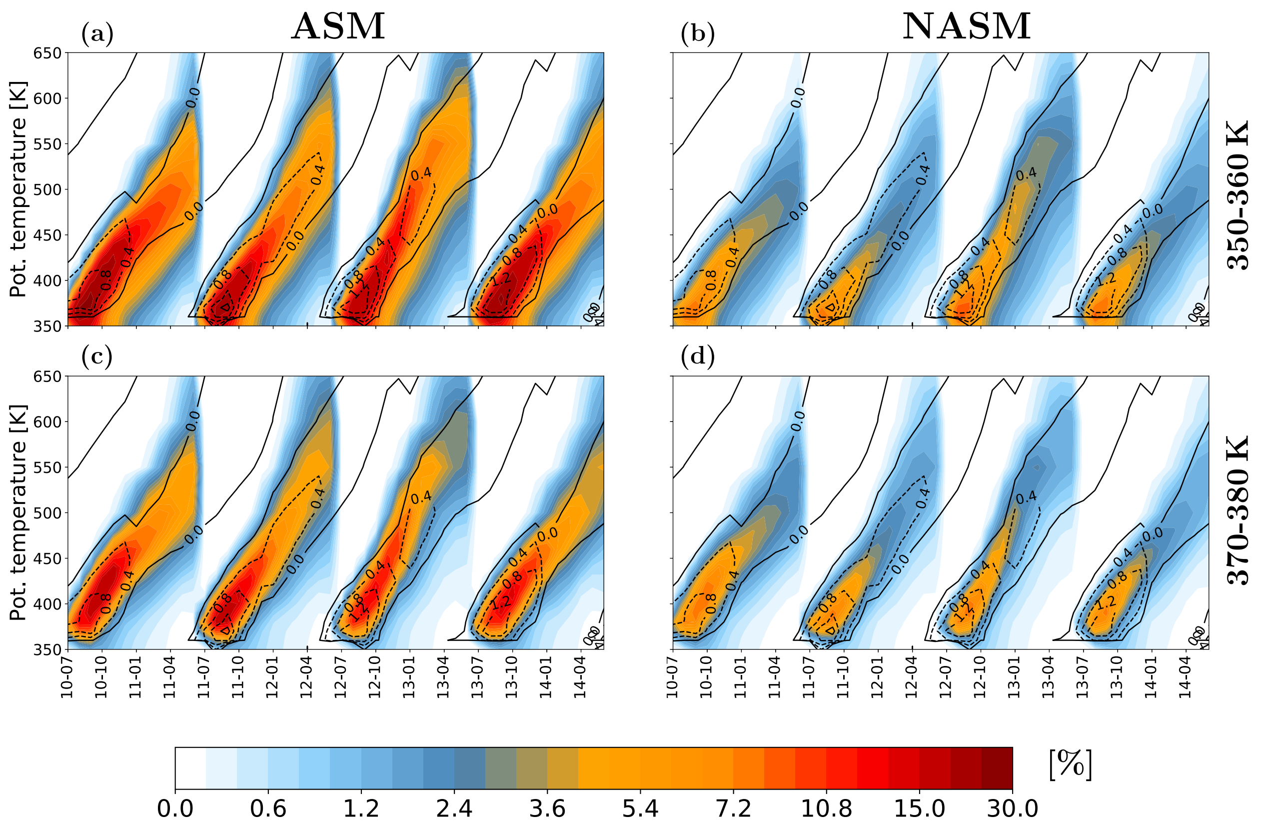
Zonal-mean perspective on transport: CLaMS-M2



Compared to CLaMS-EI:

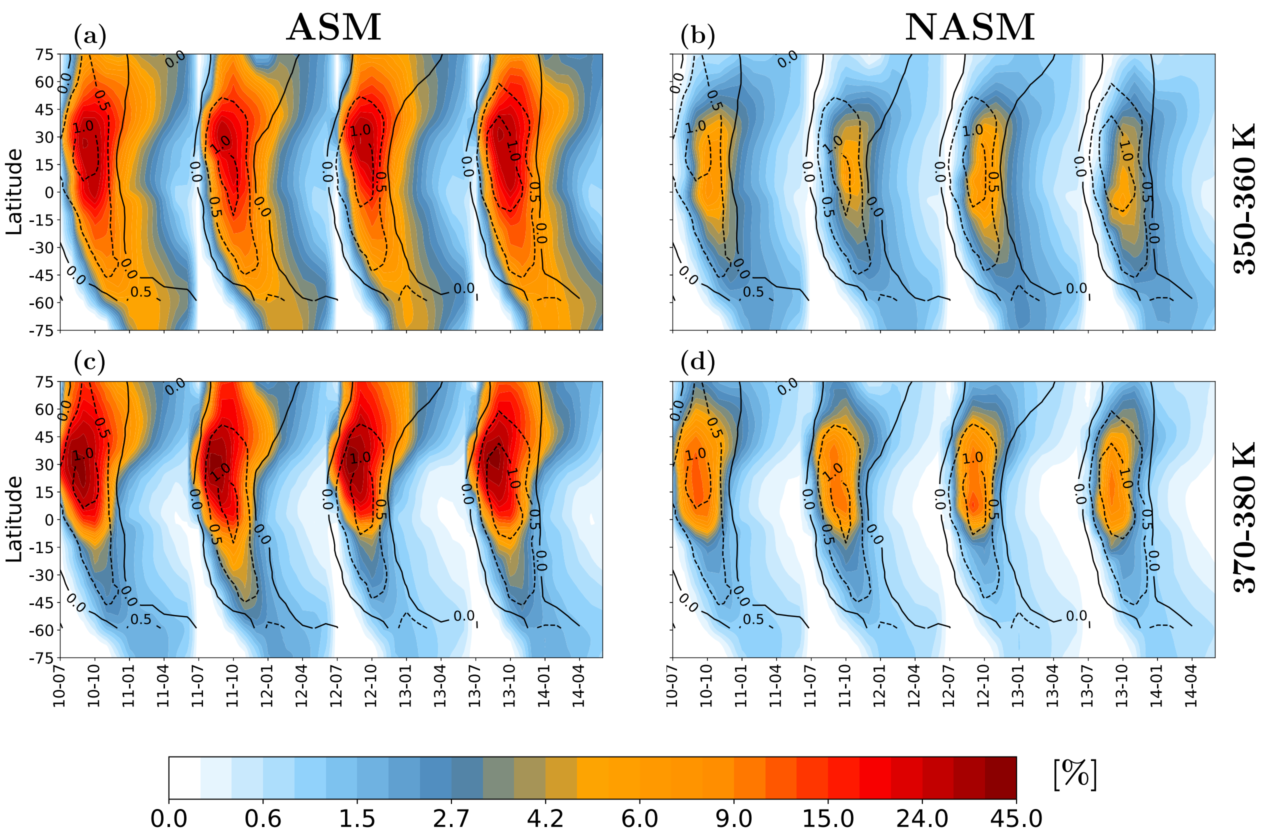
- More ASM and NASM air (profile and column)
- Monsoon air peak at lower than the HCN peak related to the slow tropical upwelling
- Smaller hemispheric asymmetry

Vertical transport into the tropics (15ºS-15ºN)



- Weak barrier between tropics and subtropics
- 350-360K ==> High monsoon air in tropics
  370-380K ==> Lower monsoon air in tropics
  large amount from 350-360K is transported through the tropics
- Good correlation between monsoon tracers and the 'wet' phase of MLS water vapor tape recorder signal

Horizontal transport into the lowermost stratosphere (400K)

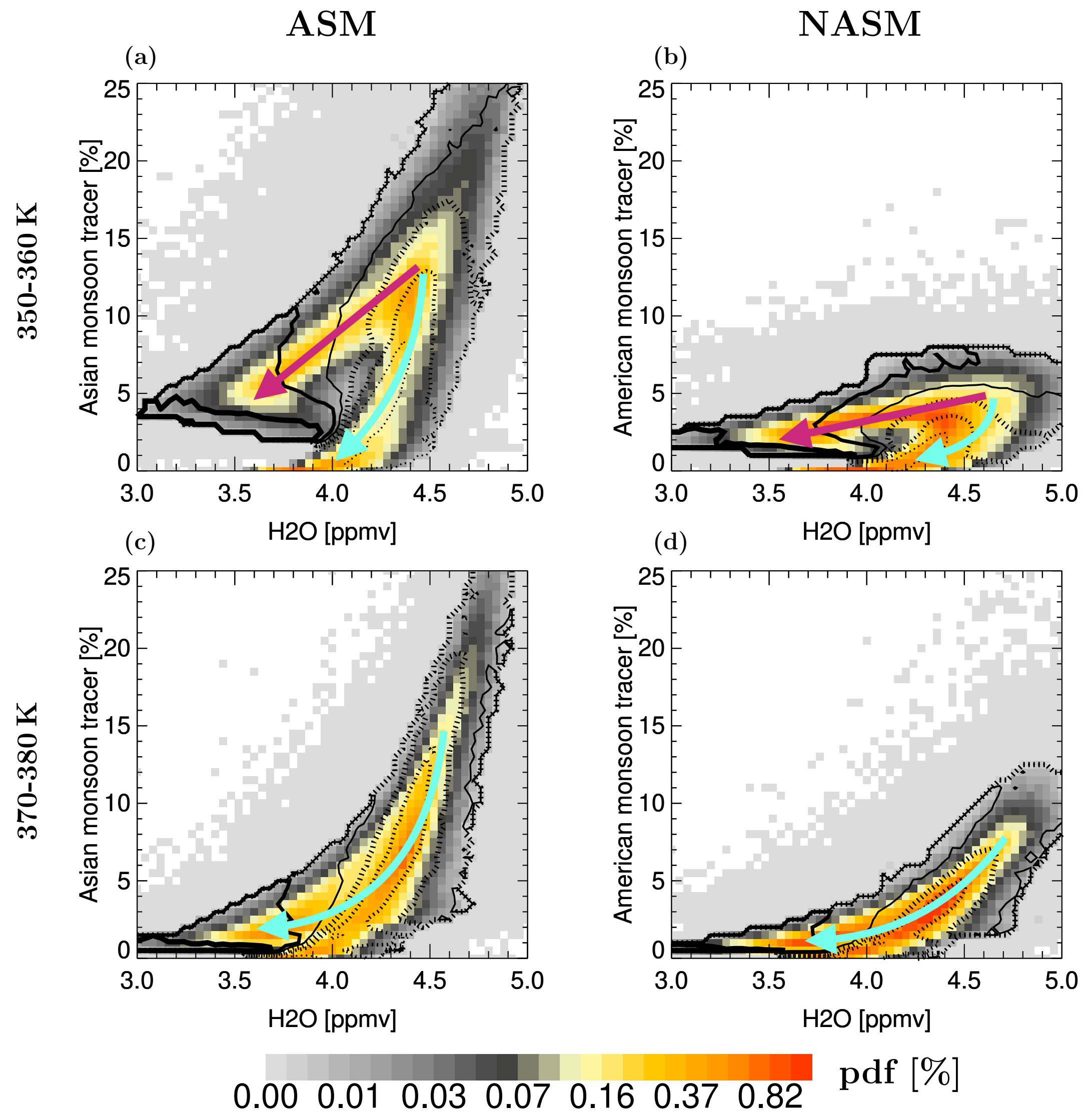


- ASM and NASM: similar horizontal transport features, but the ASM contributes much more

- 350-360K ==> less confined in latitude
more to the SH
370-380K ==> more confined in latitude
less to the SH

- Good correlation with the 'wet' phase of MLS water vapor

Correlation between monsoon tracers and water vapor in the Tropical Pipe

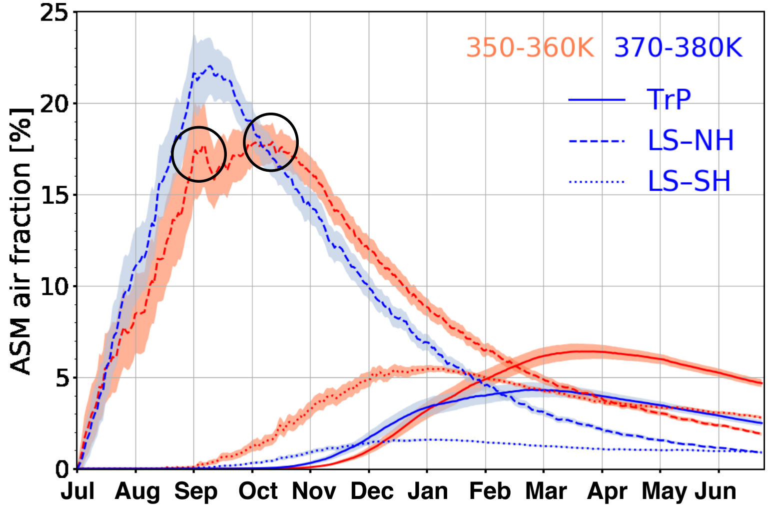


15°S-15°N   420-500K

- Positive correlation between monsoon tracers and water vapor
- Two pathways from 350-360K over monsoon regions to tropics
  Tropical pathway (magenta): drier
  Monsoon pathway (cyan): moister
- More young air mass fraction in the tropical pathway: faster
  Less young air mass fraction in the monsoon pathway: slower

24%, 33%, and 42% (from thin to thick dotted isolines)
51%, 60%, and 69% (from thin to thick solid isolines)

Time evolution of the monsoon tracer



- Peak 1: at the beginning of September
  (the rapid isentropic poleward transport)
- Peak 2: one month later
  (the additional vertical transport)
- 350-360K: more 370-380K: less
  (LS-NH, LS-SH, TrP)

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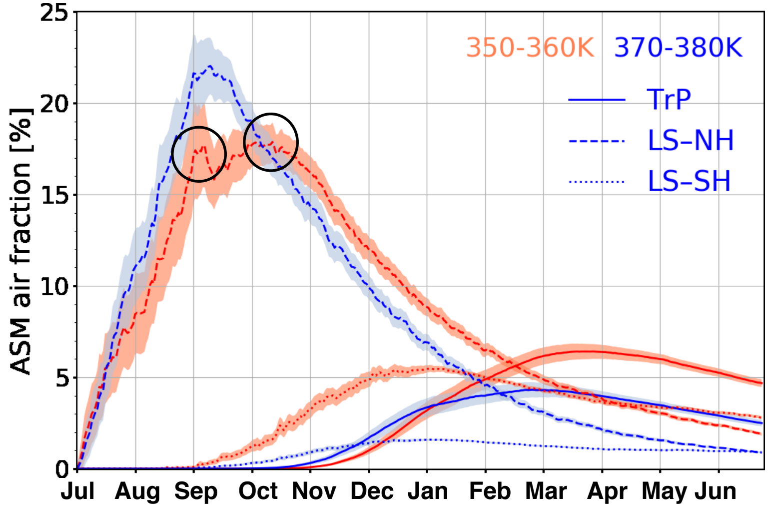

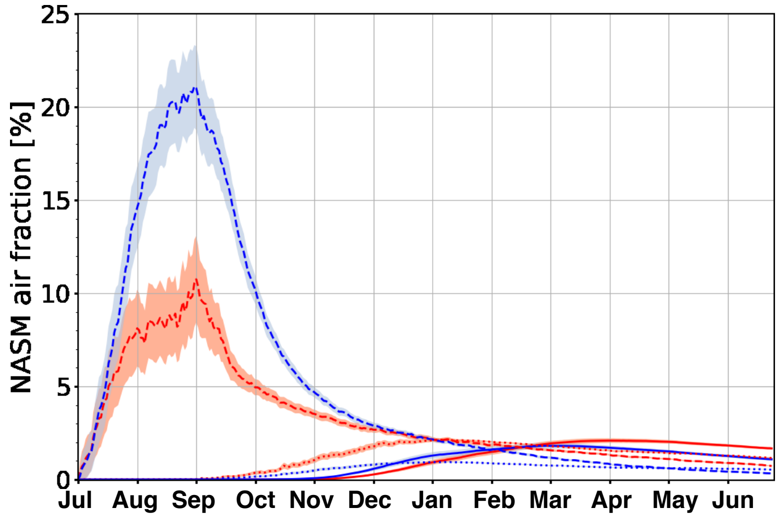

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- two weeks earlier than ASM
  (weaker dynamical confinement)
- smaller contribution

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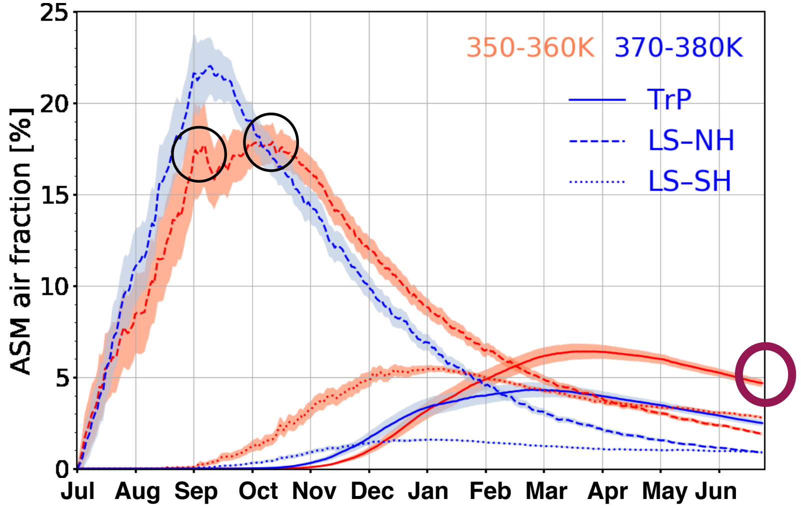

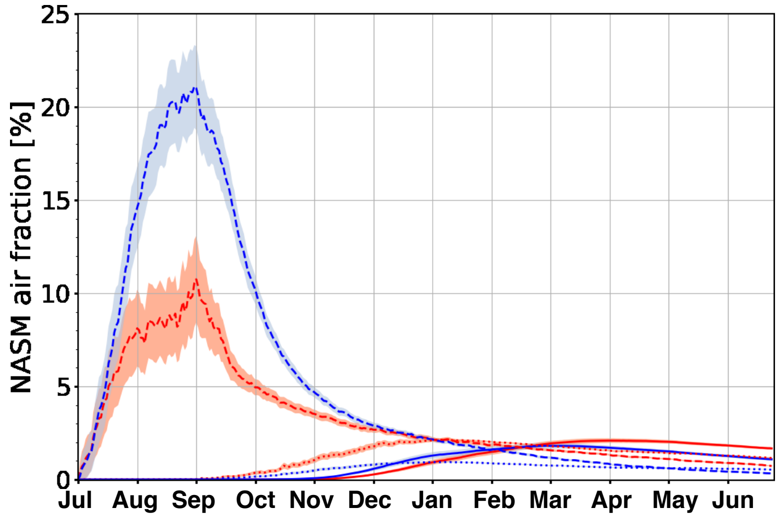

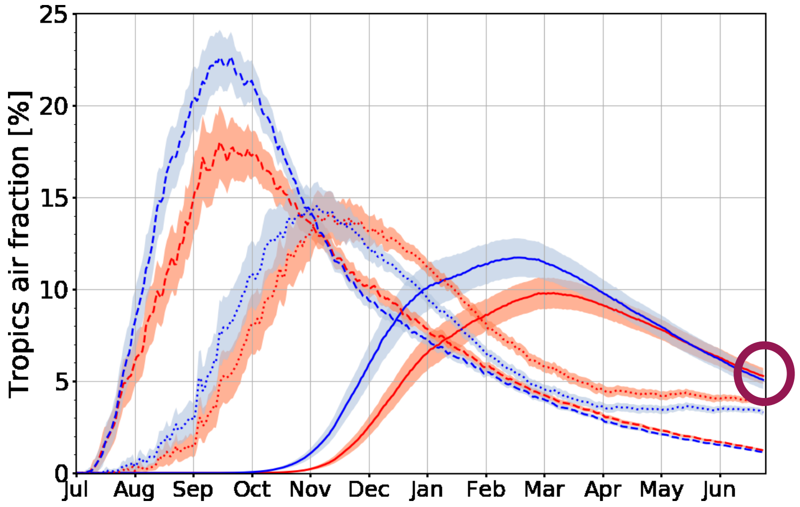

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LS-NH:ASM ≅ Tropics
LS-SH: ASM < Tropics
TrP: ASM ≅ Tropics

ASM, Tropics > 2×NASM
(LS-SH and TrP)

Transport efficiency

source air fraction × air mass of destination / air mass of source domain

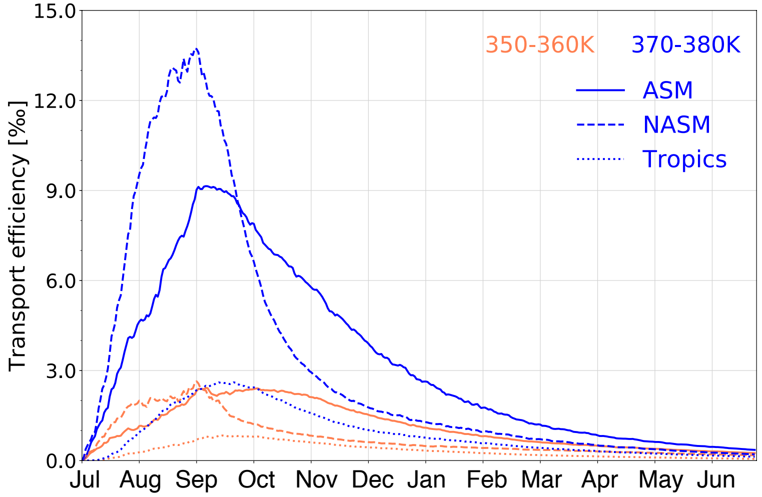
Mean air mass of initial source domain [kg]

ECMWF	340-350K	350-360K	360-370K	370-380K
ASM	2.276×10^{10}	1.877×10^{10}	1.179×10^{10}	6.118×10^{9}
NASM	1.916×10^{10}	1.042×10^{10}	5.649×10^{9}	3.930×10^{9}
Tropics	8.524×10^{10}	5.484×10^{10}	3.406×10^{10}	2.207×10^{10}
MERRA-2	340-350K	350-360K	360-370K	370-380K
ASM	2.284×10^{10}	1.890×10^{10}	1.124×10^{10}	6.334×10^{9}
NASM	2.006×10^{10}	9.868×10^{9}	5.927×10^{9}	3.993×10^{9}
Tropics	8.795×10^{10}	5.420×10^{10}	3.398×10^{10}	2.254×10^{10}

Transport efficiency

source air fraction × air mass of destination / air mass of source domain

LS-NH



Beginning: NASM > ASM

End: ASM > NASM

ASM, NASM > Tropics

Transport efficiency

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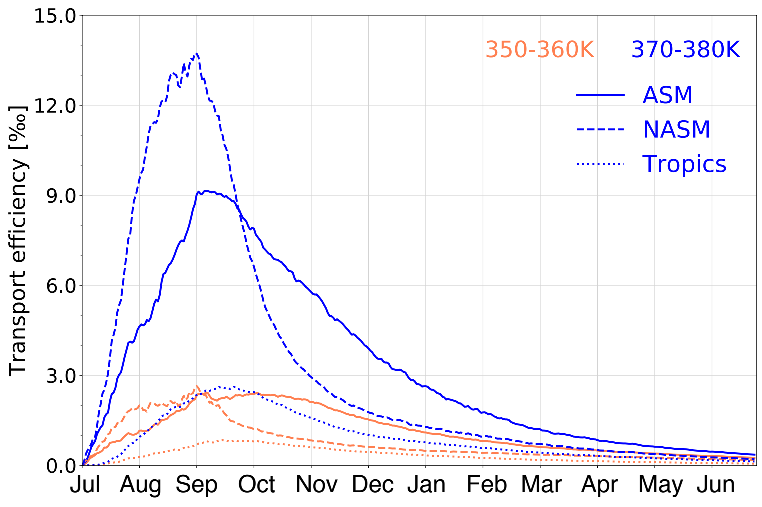
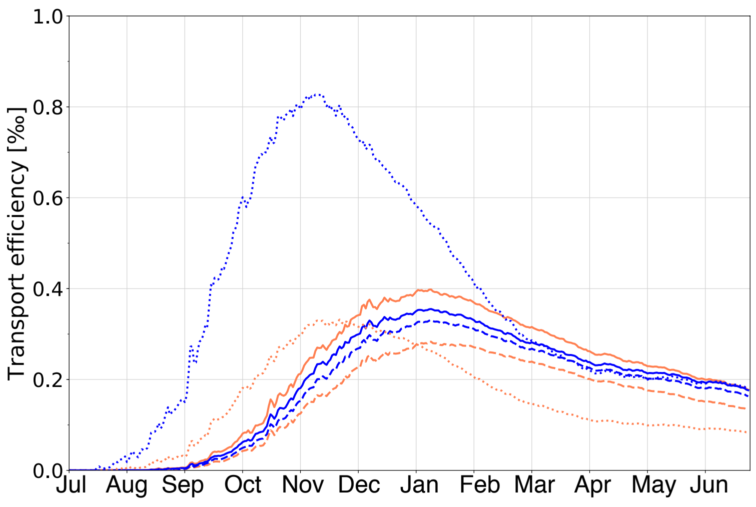
LS-NH



LS-SH



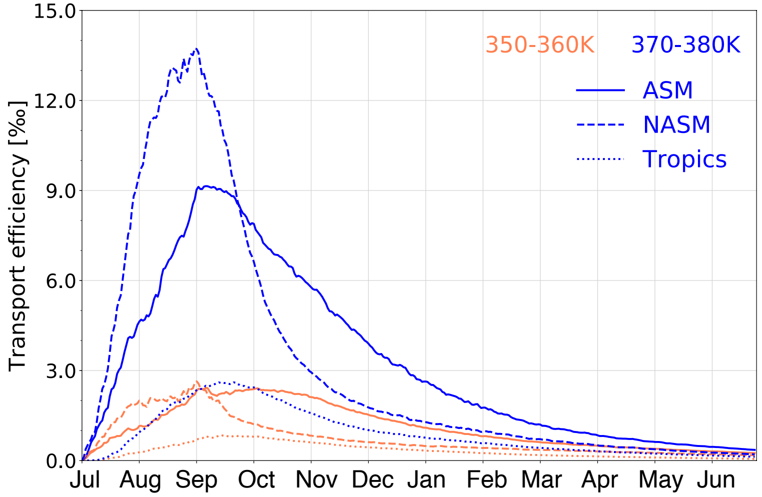
Beginning: NASM > ASM
End: ASM > NASM
ASM, NASM > Tropics

Beginning: Tropics > ASM, NASM
End: Tropics < ASM, NASM
Especially ASM (350-360K)

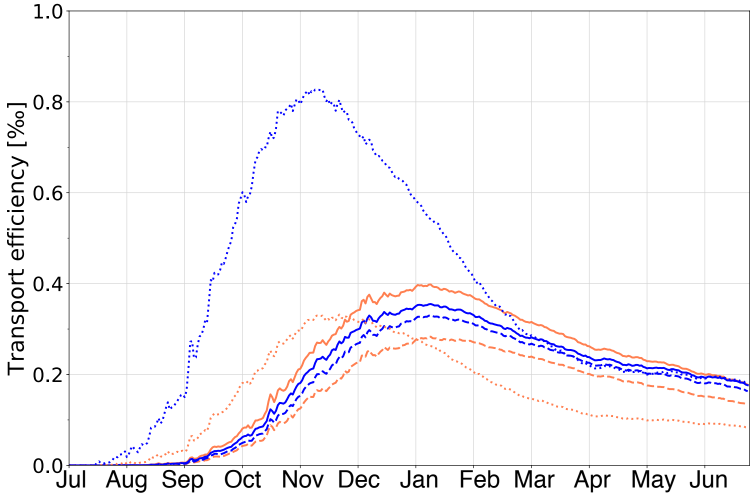
Transport efficiency

source air fraction × air mass of destination / air mass of source domain

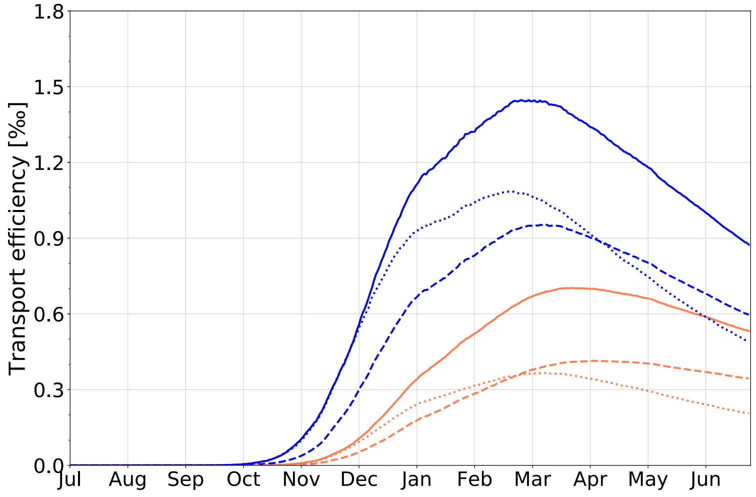
LS-NH



LS-SH



TrP

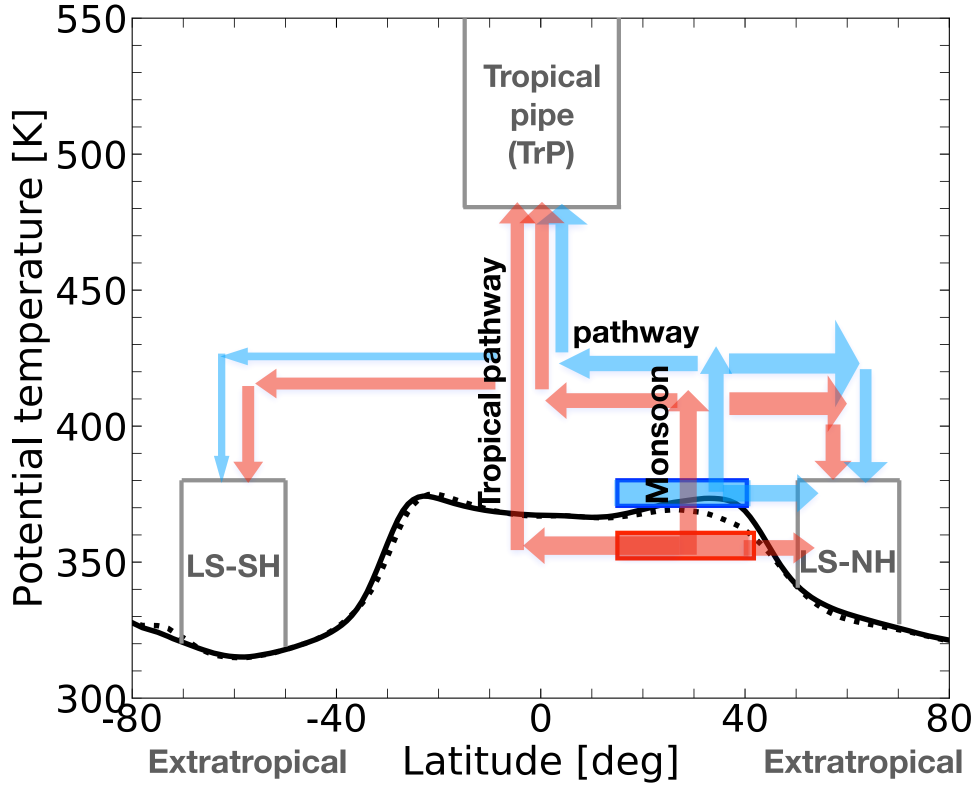


Beginning: NASM > ASM
End: ASM > NASM
ASM, NASM > Tropics

Beginning: Tropics > ASM, NASM
End: Tropics < ASM, NASM
Especially ASM (350-360K)

ASM > NASM, Tropics
Beginning: Tropics > NASM
End: NASM > Tropics
ASM (370-380K)

Summary:



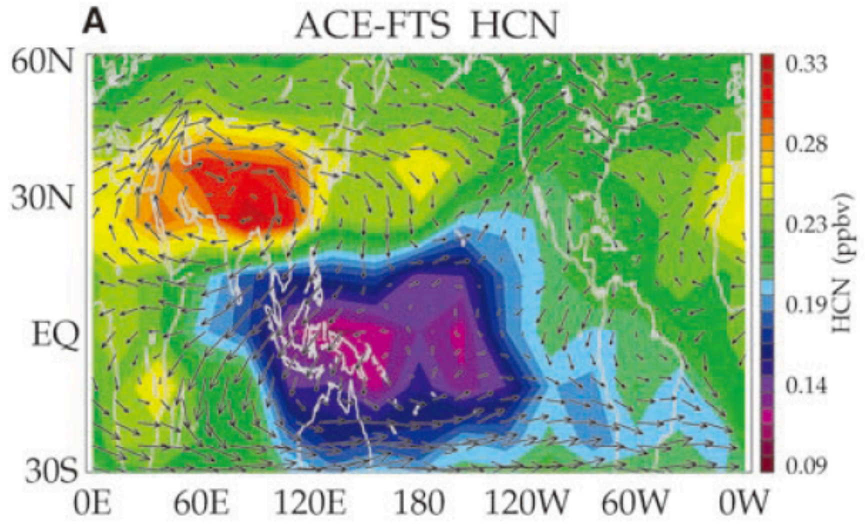
- **350-360K:**
  more in the SH
  larger contribution
  lower efficiency
  longer transit time

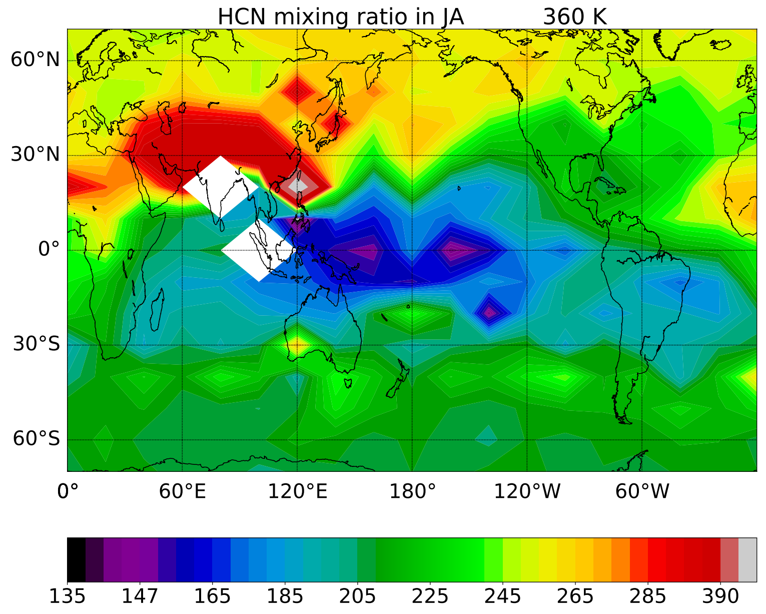
- **370-380K**
  more in the NH
  smaller contribution
  high efficiency
  shorter transit time

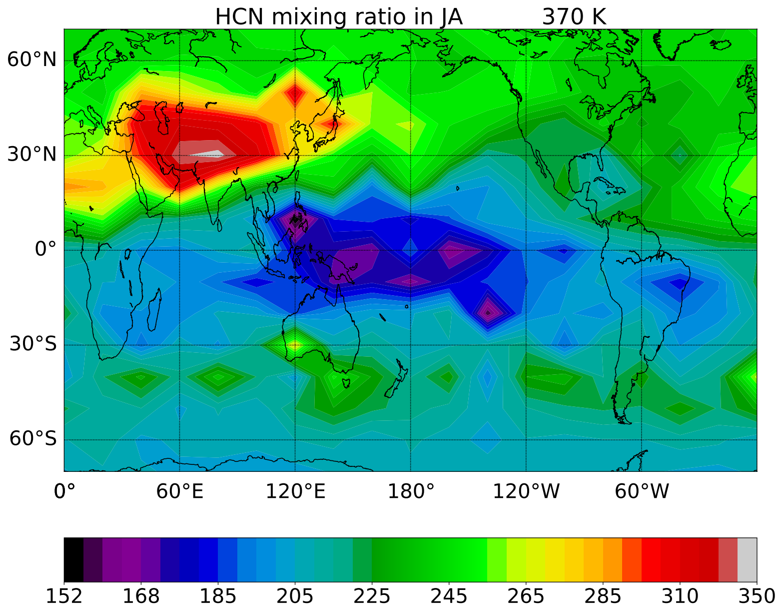
- **Strong positive correlation with water vapor**

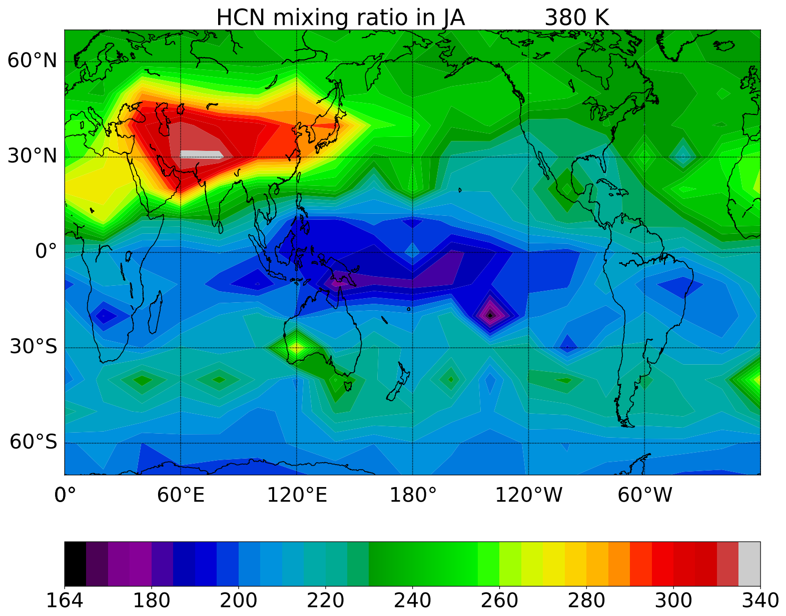
- **Two pathways:**
  Monsoon pathway (slower, moister)
  Tropical pathway (faster, drier)

- **CLaMS-M2 relative to CLaMS-EI**
  larger contributions / higher efficiency / longer transit time


A
ACE-FTS HCN
60N
30N
EQ
30S
0E
60E
120E
180
120W
60W
0W
0.33
0.28
0.23
0.19
0.14
0.09
HCN (ppbv)


HCN mixing ratio in JA 360 K
60°N
30°N
0°
30°S
60°S
0°
60°E
120°E
180°
120°W
60°W
135 147 165 185 205 225 245 265 285 390


HCN mixing ratio in JA 370 K
60°N
30°N
0°
30°S
60°S
0°
60°E
120°E
180°
120°W
60°W
152 168 185 205 225 245 265 285 310 350


HCN mixing ratio in JA 380 K
60°N
30°N
0°
30°S
60°S
0°
60°E
120°E
180°
120°W
60°W
164 180 200 220 240 260 280 300 340