The role of Asian summer monsoon anti-cyclone for transport efficiency into the tropical pipe

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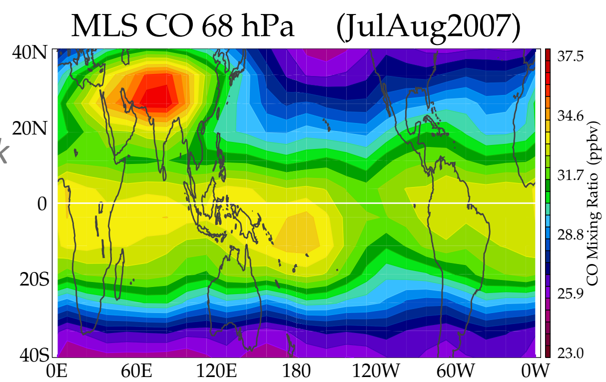
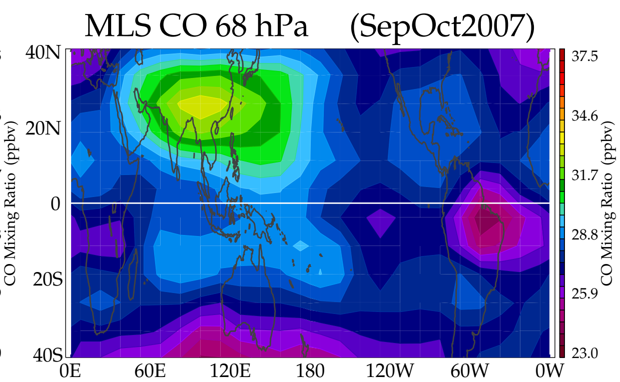
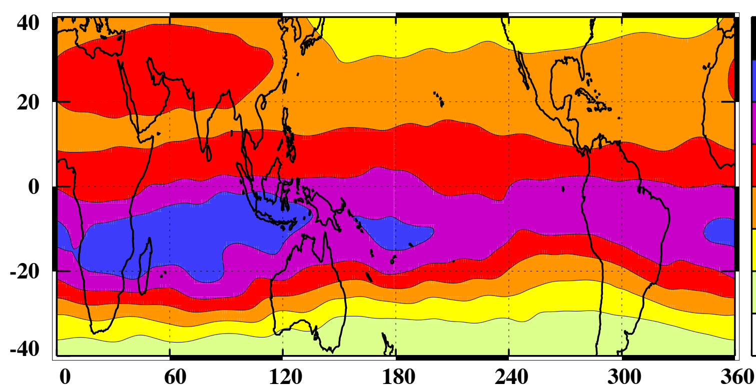
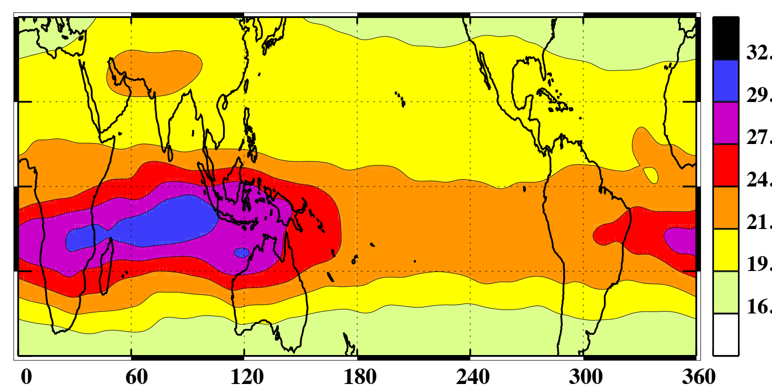
A Comparison of two models: Aura-MLS v WACCM
Carbon monoxide at 70 mb

Aura-MLS data
Courtesy of M. Park









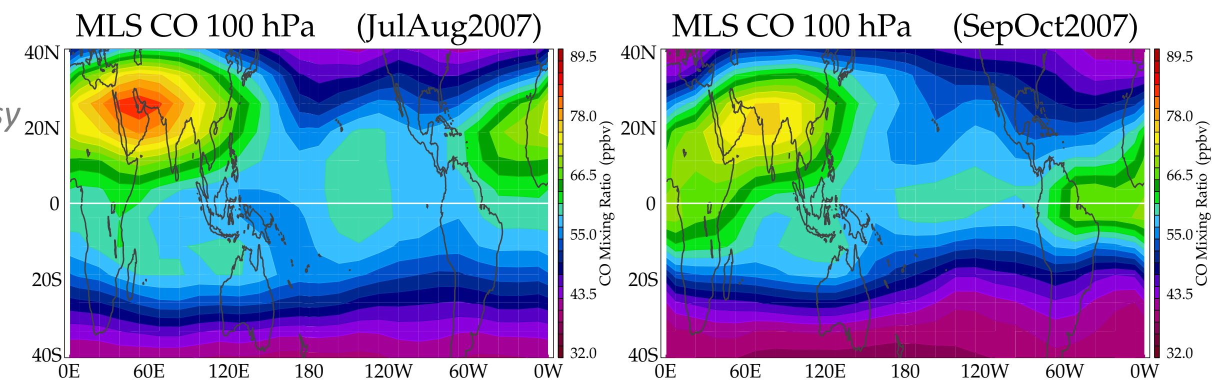
WACCM data courtesy of D. Kinnison

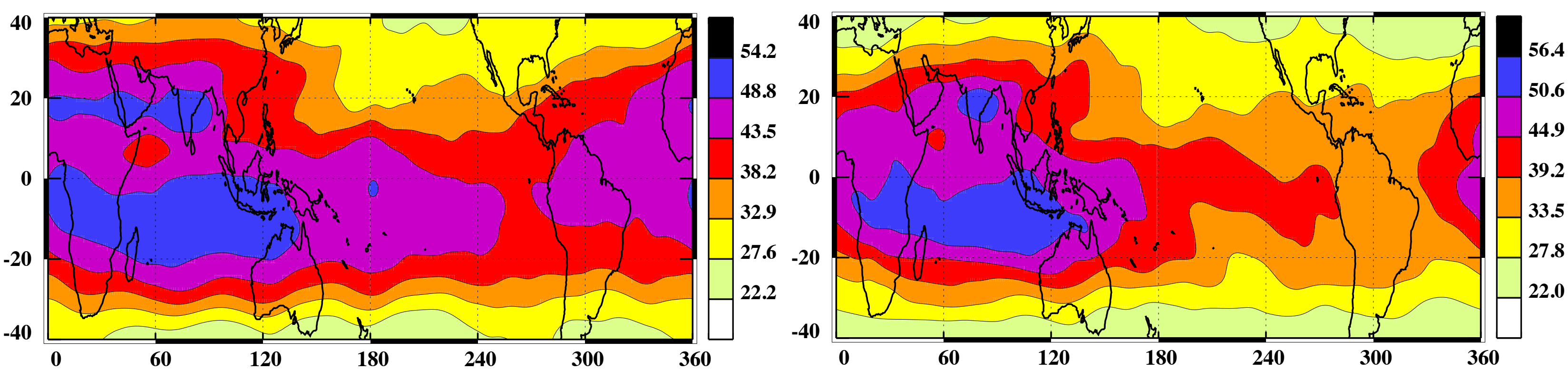
The anti-cyclone has a clear impact on CO concentrations

There are important similarities and discrepancies between the two simulations

A Comparison of two models: Aura-MLS v WACCM
Carbon monoxide at 100 mb

MLS data courtesy of M. Park





WACCM data courtesy of D. Kinnison

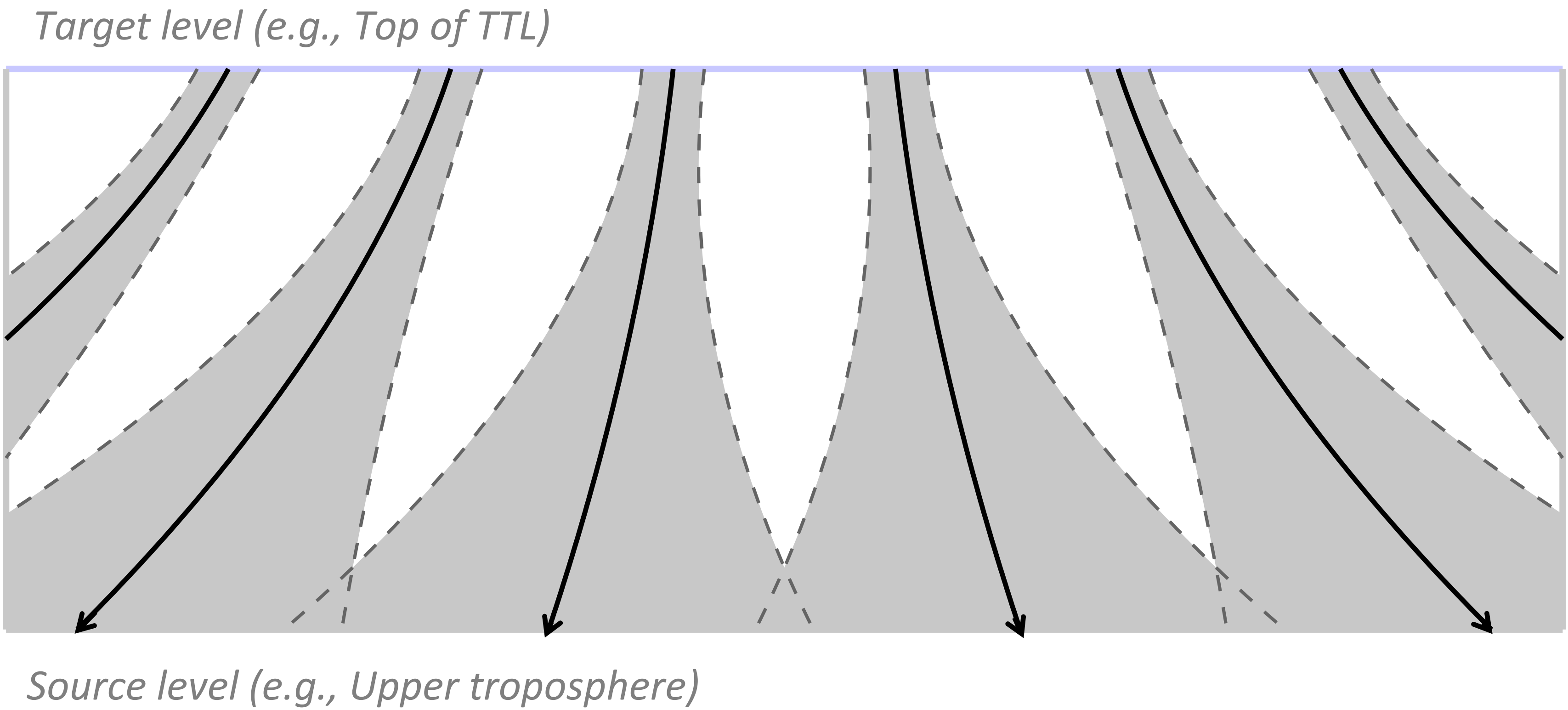
There are strong large-scale horizontal variations
with strong large-scale vertical variations
And strong large-scale seasonal variations

Motivation

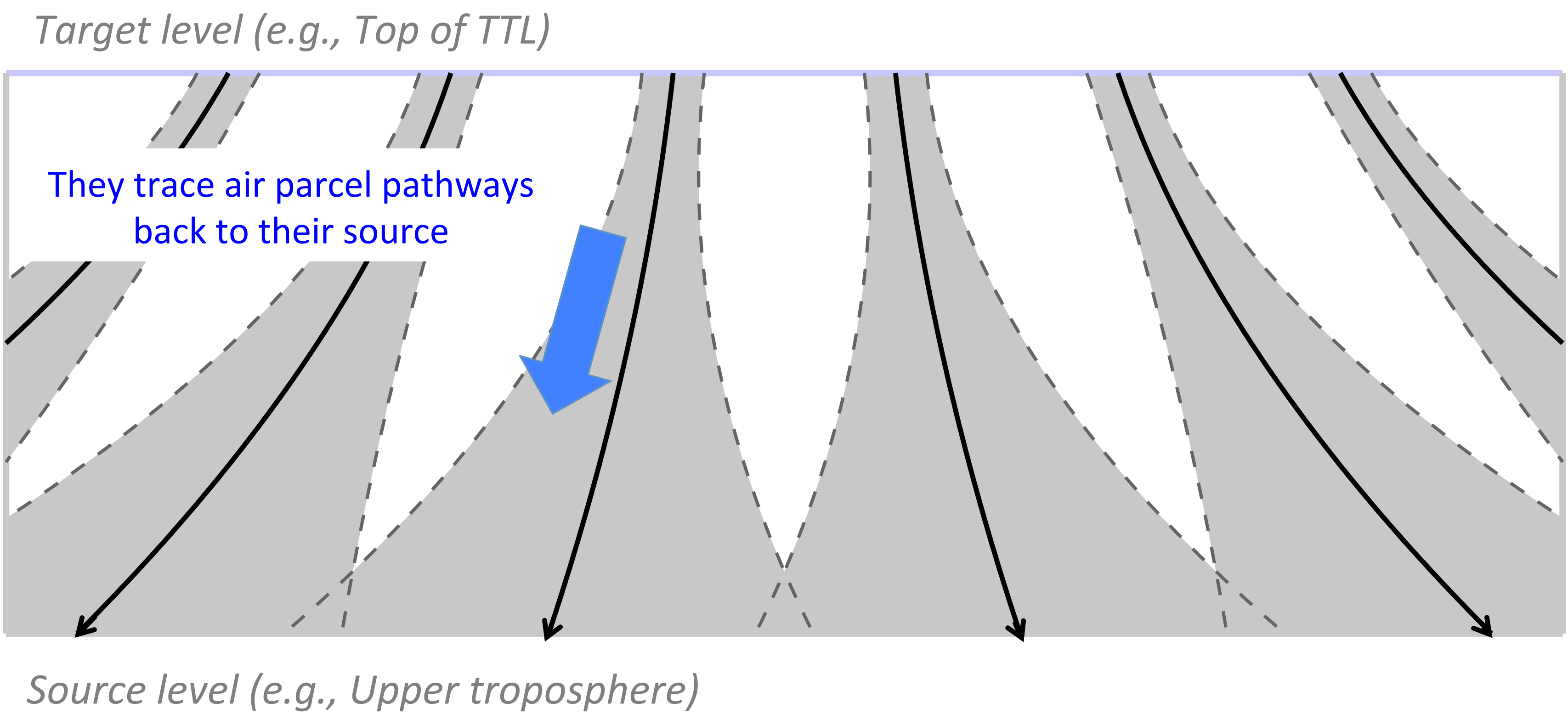
- Chemical constituent concentrations at the top of the TTL (70 mb) are important for impacts on stratospheric chemistry
- Global models with active chemistry have reliable representations of some aspects of these concentrations but not all
- Constituent concentrations in the TTL have large variations at large space-time scales
  - They represent a manageable analysis space

A backward (Lagrangian) approach to transport

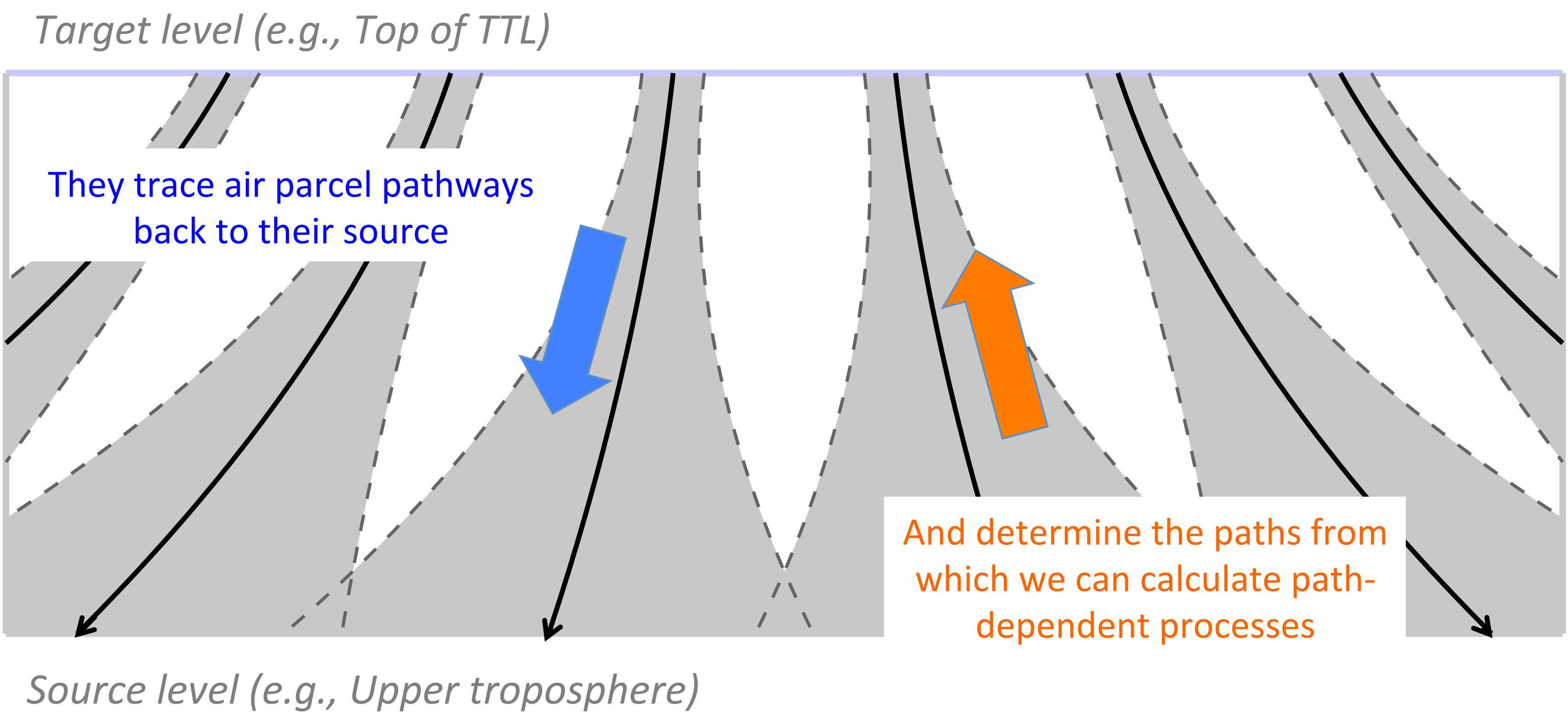
Backward trajectories are potentially a valuable diagnostic tool for understanding constituent concentrations



Backward trajectories are potentially a valuable diagnostic tool for understanding constituent concentrations



Backward trajectories are potentially a valuable diagnostic tool for understanding constituent concentrations near the tropical tropopause



A backward view of chemical composition

$$X(\mathbf{x},t) = \sum_{all\ ensemble\ members} \frac{1}{N}\left\{X(\mathbf{x_0},t_0) + \int_{parcel\ path} \mathrm{d}s\, \frac{\delta X(s)}{\delta s}\right\}$$

The **constituent concentration** ***X*** at a target location **(*x*,*t*)**

depends on the average of the **source concentrations**

plus the the average of the **constituent changes**

over the **parcel paths** from source to target

A backward view of chemical composition:

Complications

- Source concentrations are needed
  - Data is scarce
  - What represents a meaningful source location is ambiguous
- Processes that change concentrations along the path are needed
  - Chemical models need additional constituents and reaction rates
  - Turbulent mixing requires knowledge of unresolved wind fields
  - Phase changes require temperature data and microphysical models
- The paths must be known
  - Requires reliable wind/heating rate data
  - Requires trajectory dispersion models and/or ensemble strategies
- The above components are coupled

The parcel trajectories form the foundation for understanding constituent concentrations

So, what can we learn about parcel pathways, the dynamics that influence them, and how reliable our calculations of these pathways are?

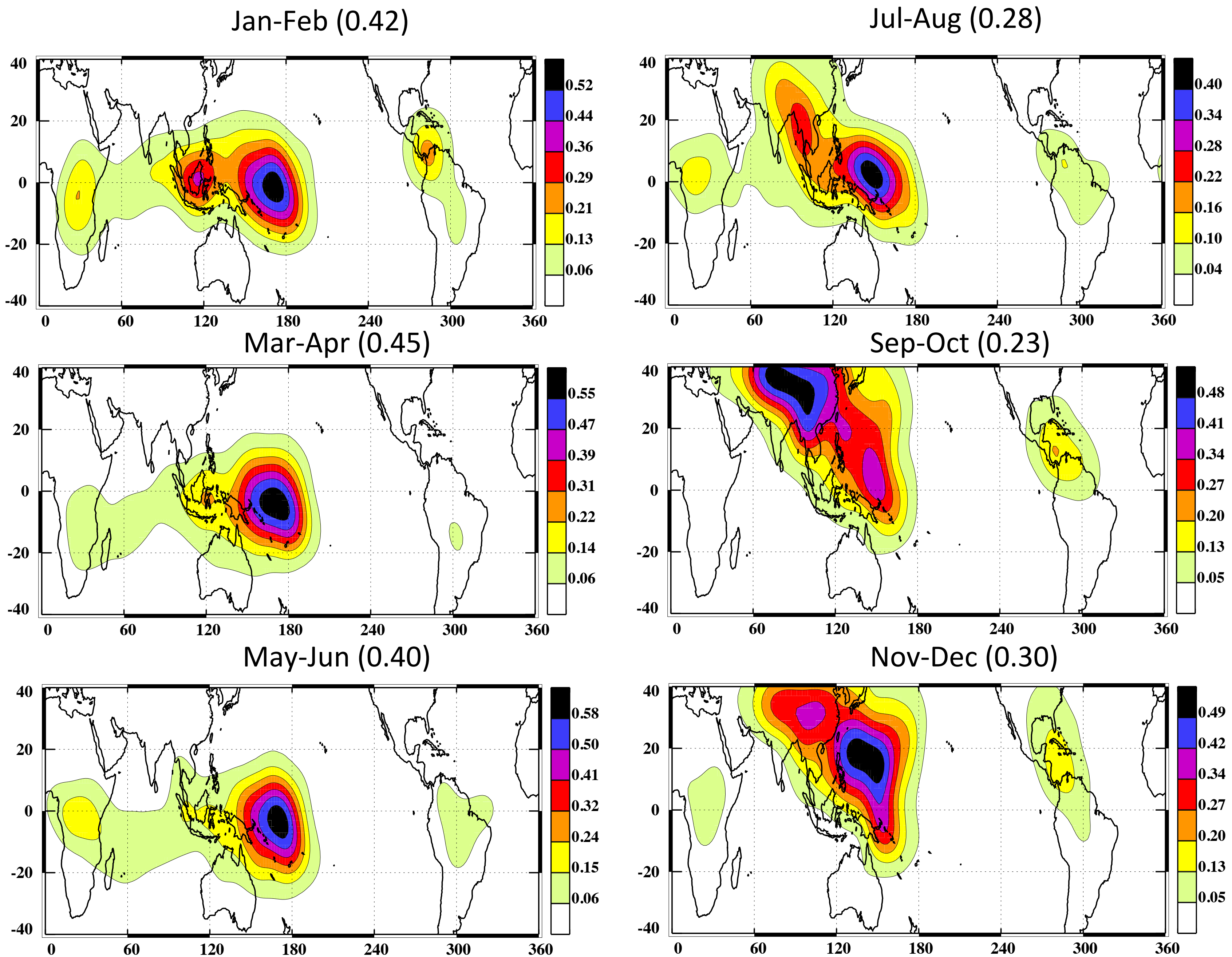
Parcel density distributions

120 d backward trajectory calculations
Initialized every 42 h at 70 mb

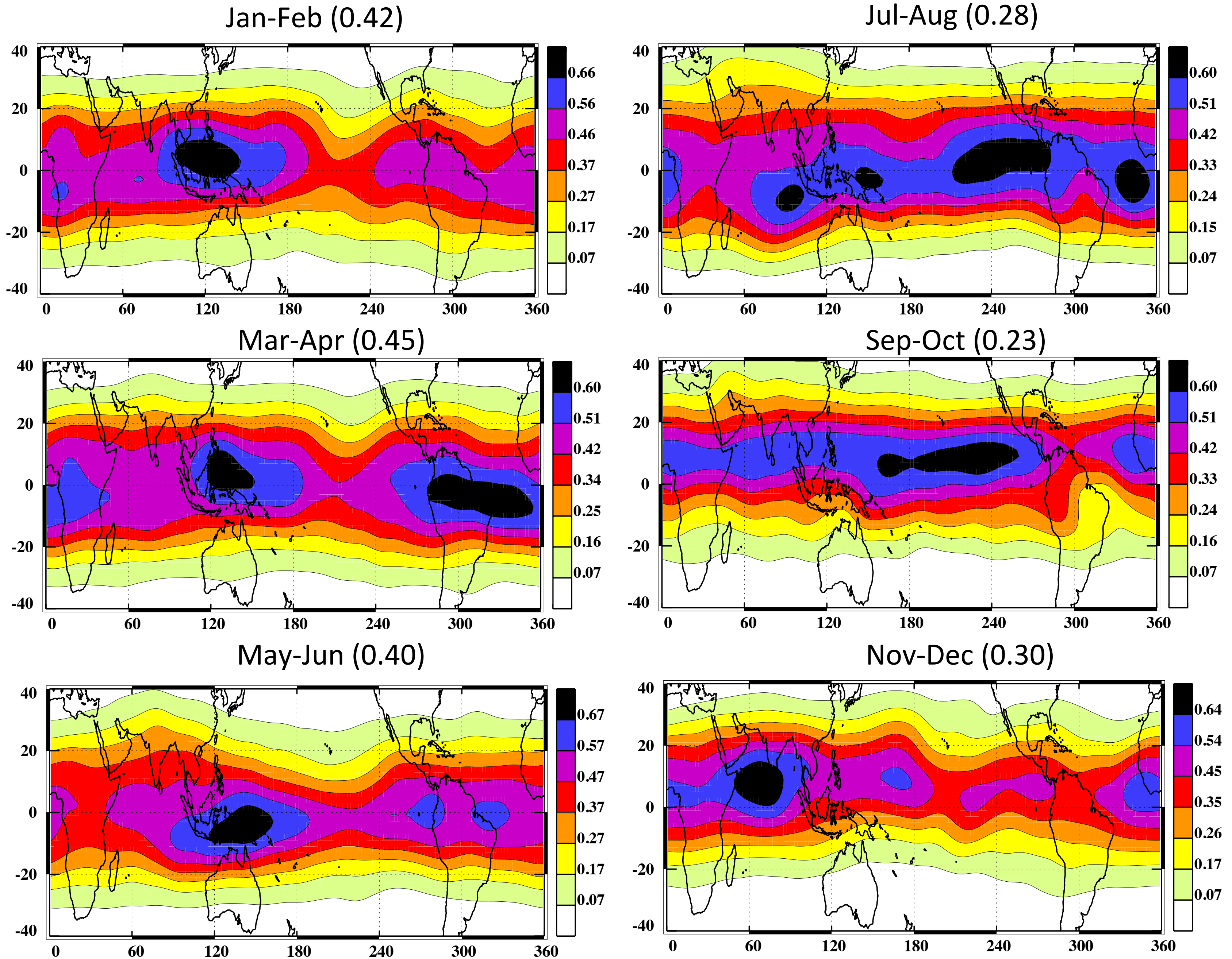
Kinematic calculations
(formulated in pressure coordinates)
Using ERA-interim winds

Examine only trajectories that reach their source (100 mb or 200 mb) within 120 d

Parcel density for 200 mb sources at 200 mb for 2007



Parcel density for 200 mb sources at 70 mb for 2007

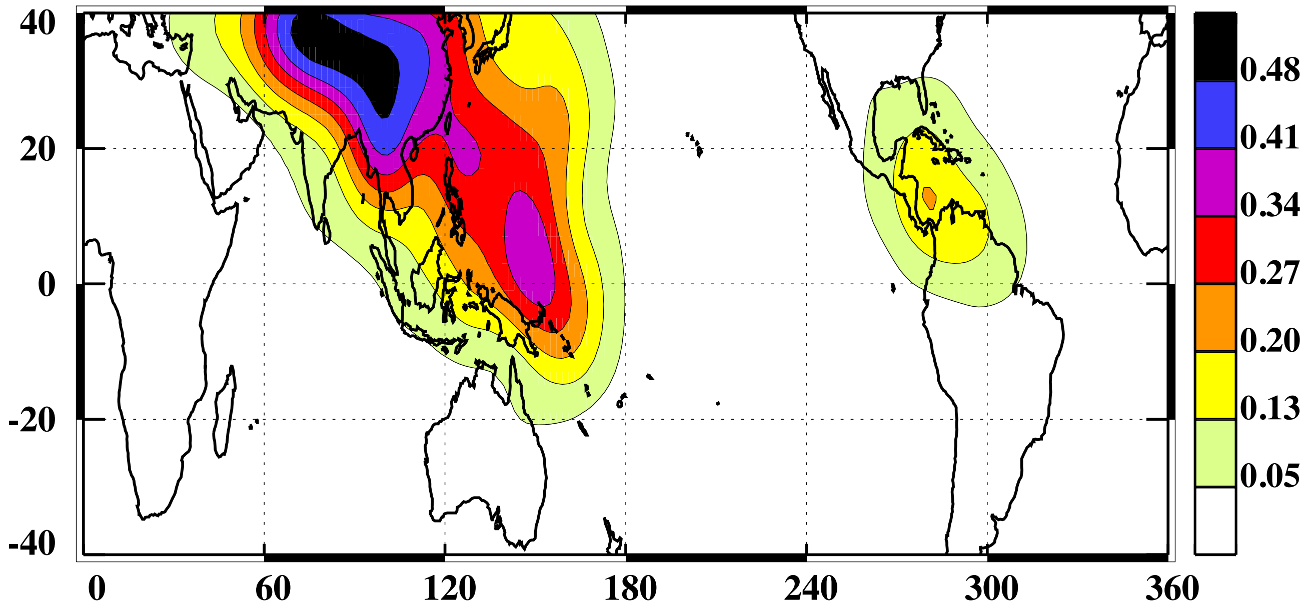


Transport ‘corridors’ 200 mb to 70 mb

Source fraction 0.23

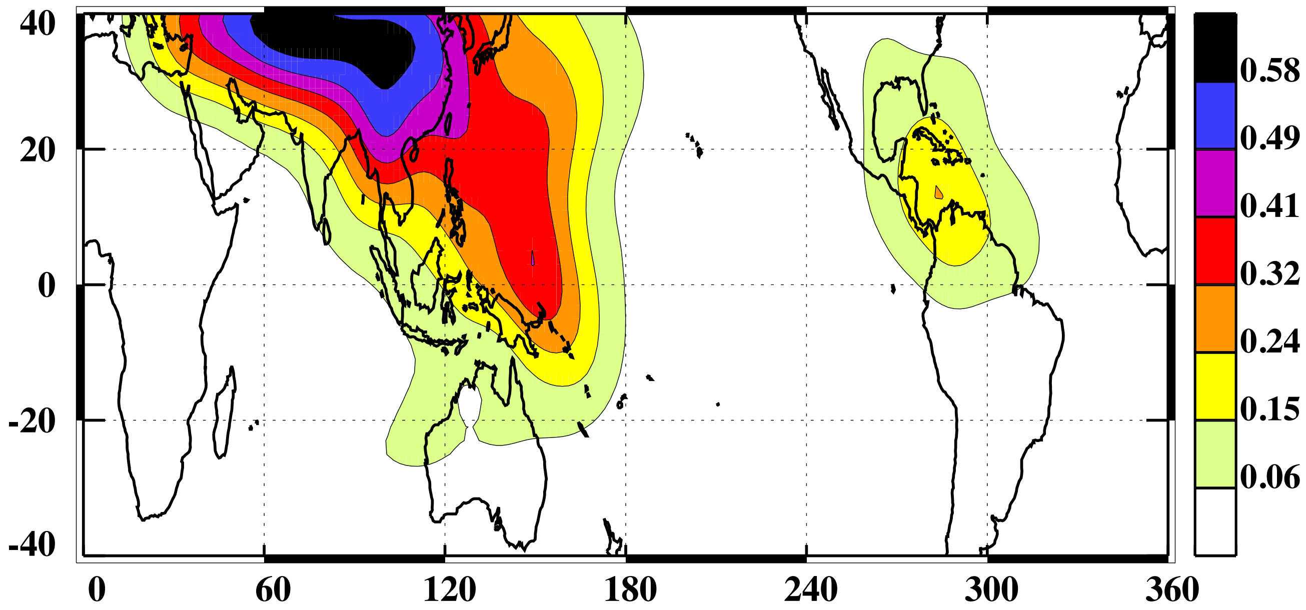
Sep-Oct 2007 Calculations

Parcel density at 200 mb



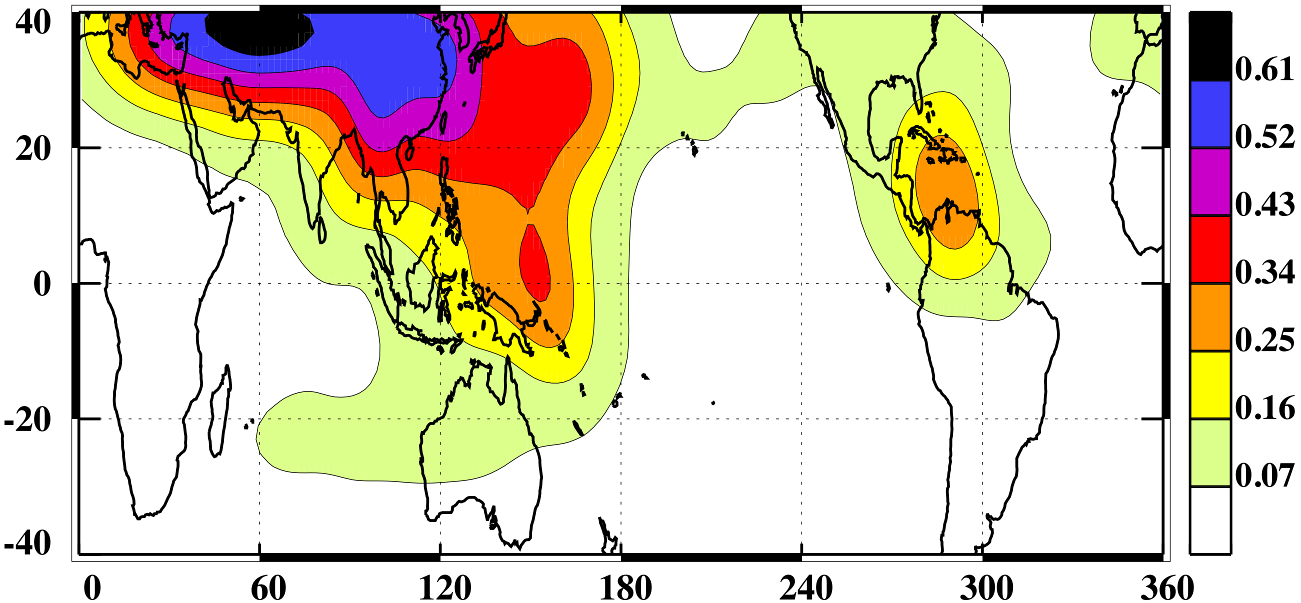
Spatial patterns influenced by distributions of convection

Parcel density at 177 mb

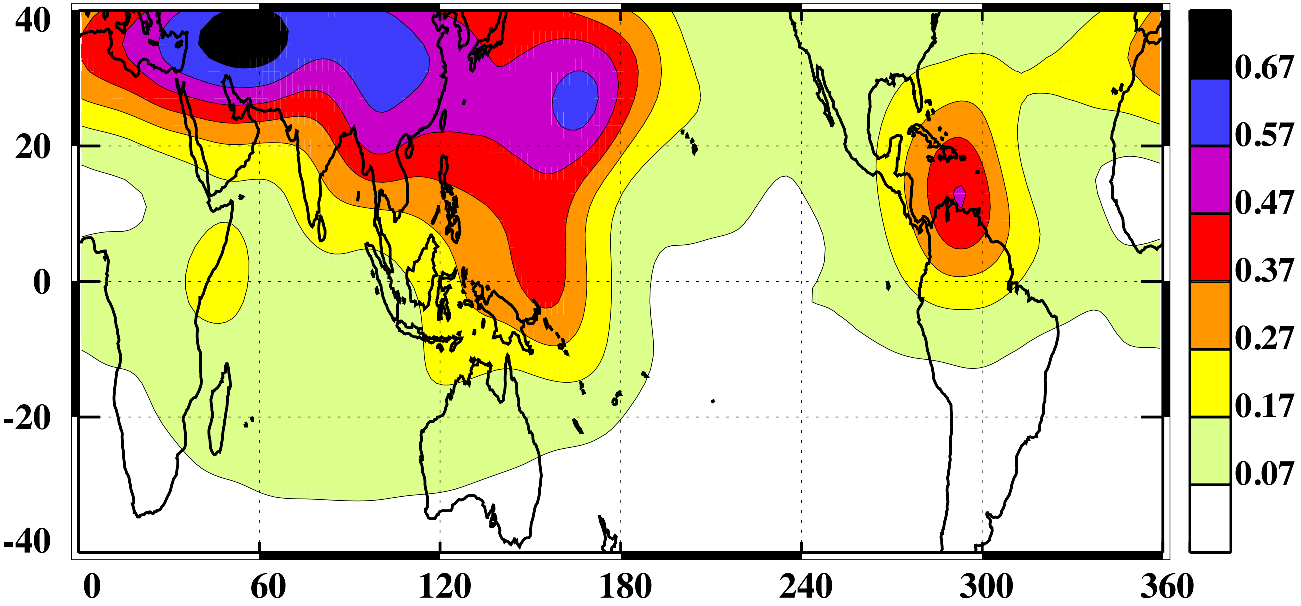


Density greatest on outskirts of the anticyclone

Parcel density at 158 mb

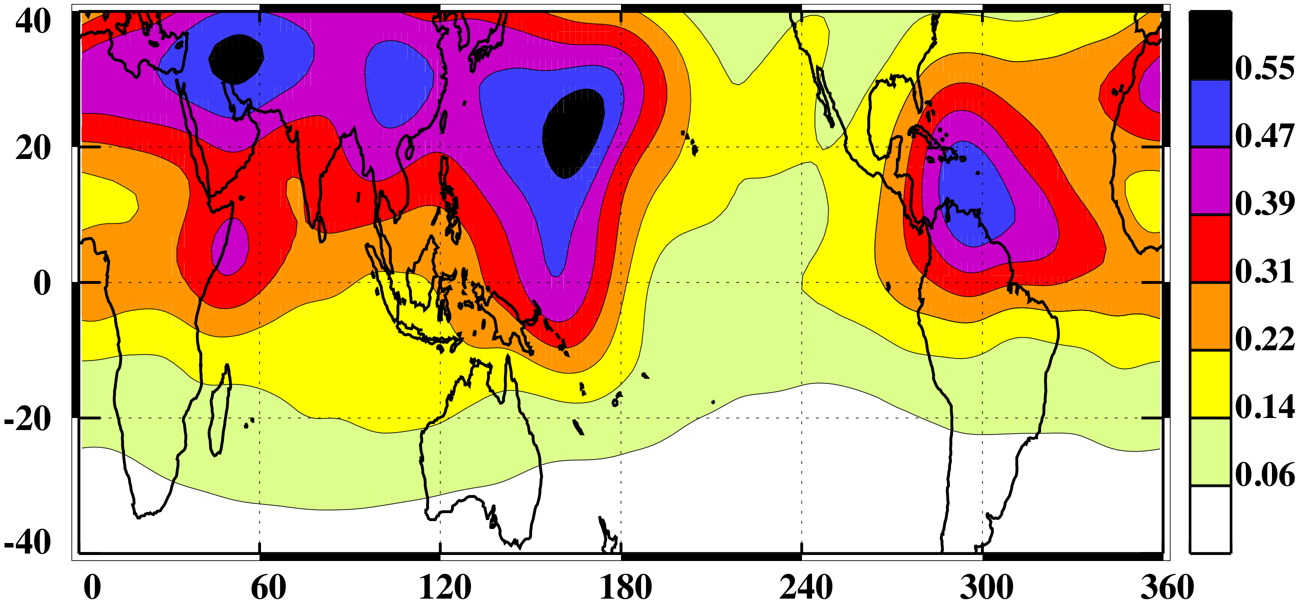


Parcel density at 140 mb



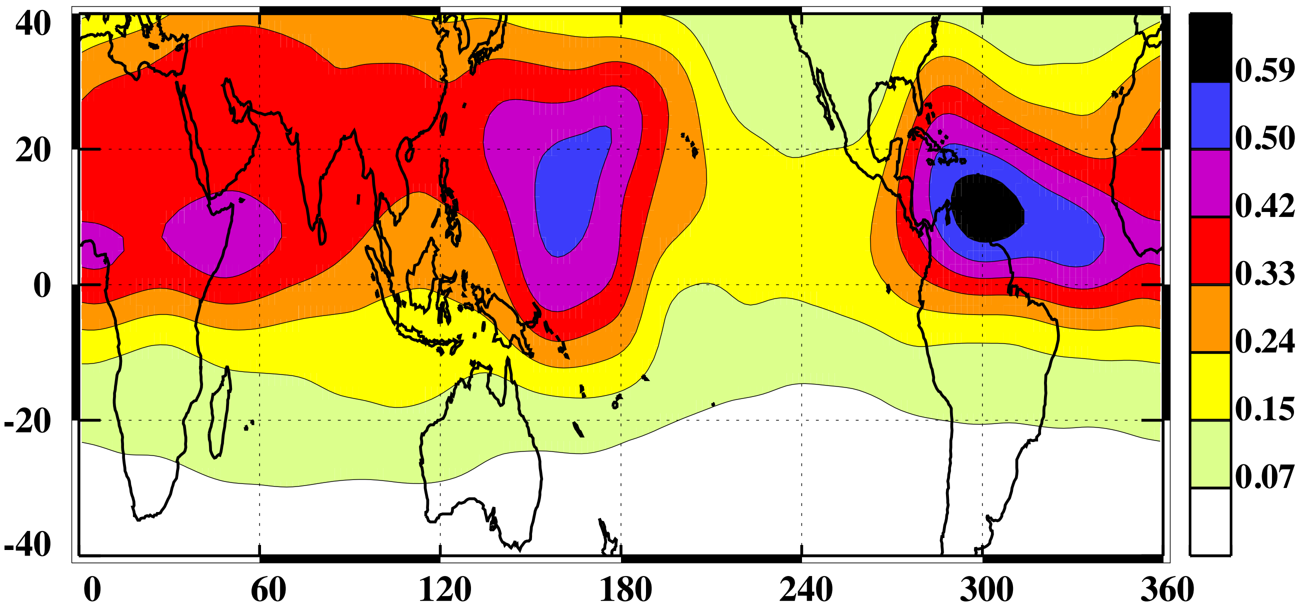
Emergence of a density maximum in the NW Pacific

Parcel density at 125 mb

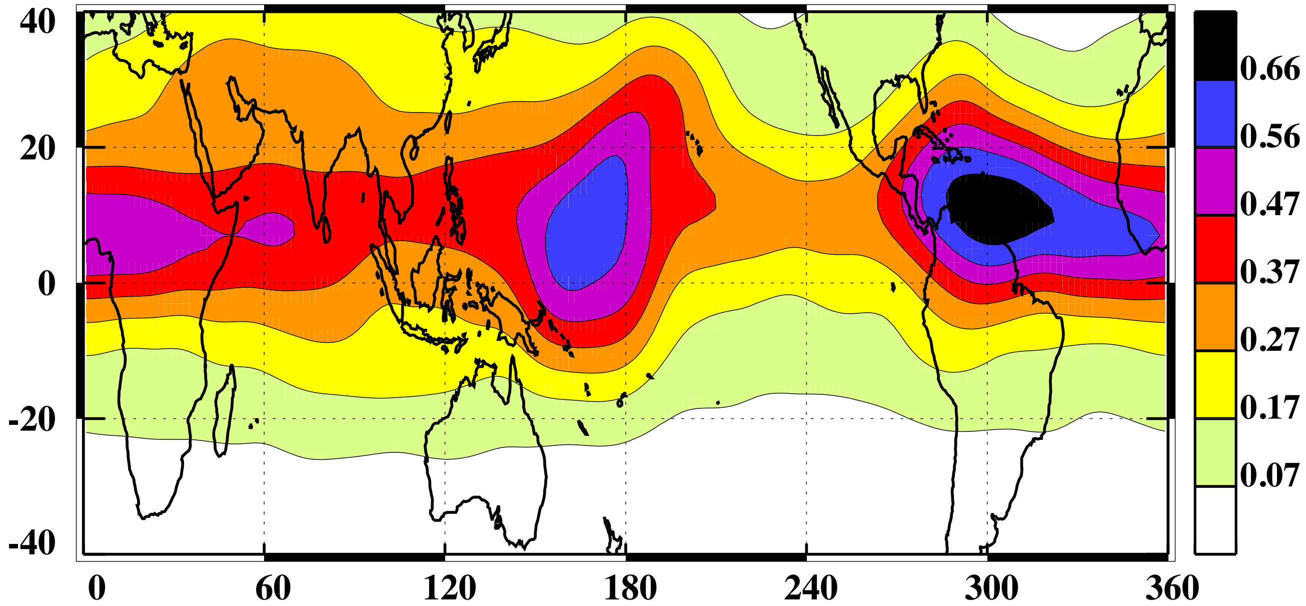


NW Pacific becomes an important region

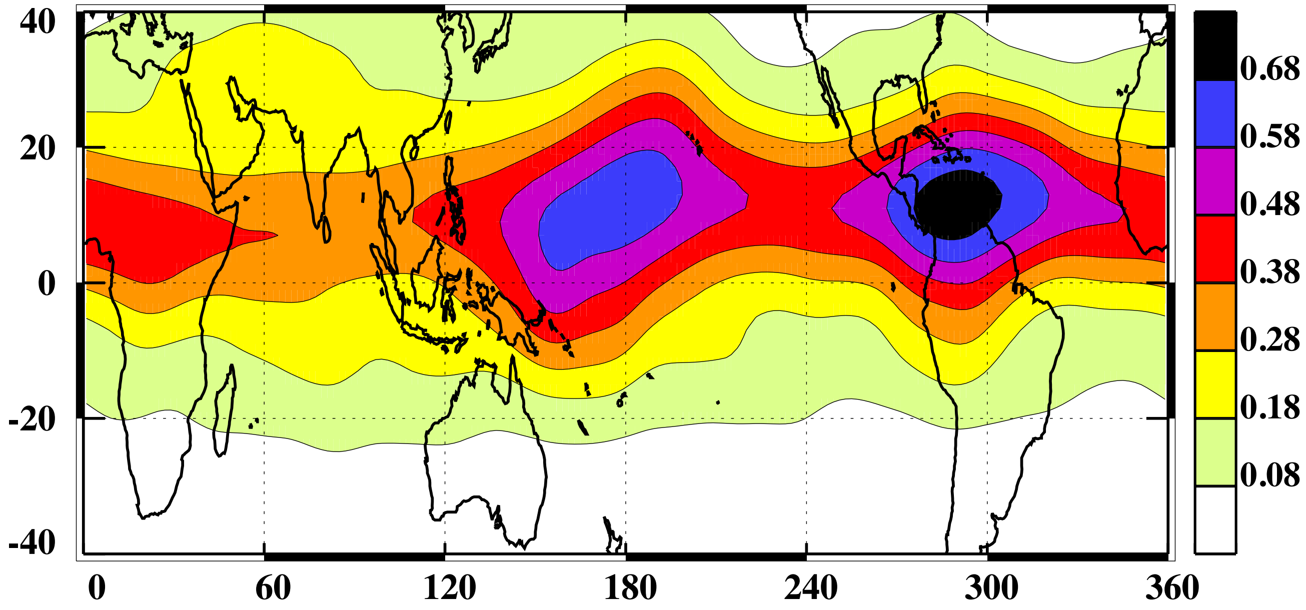
Parcel density at 110 mb



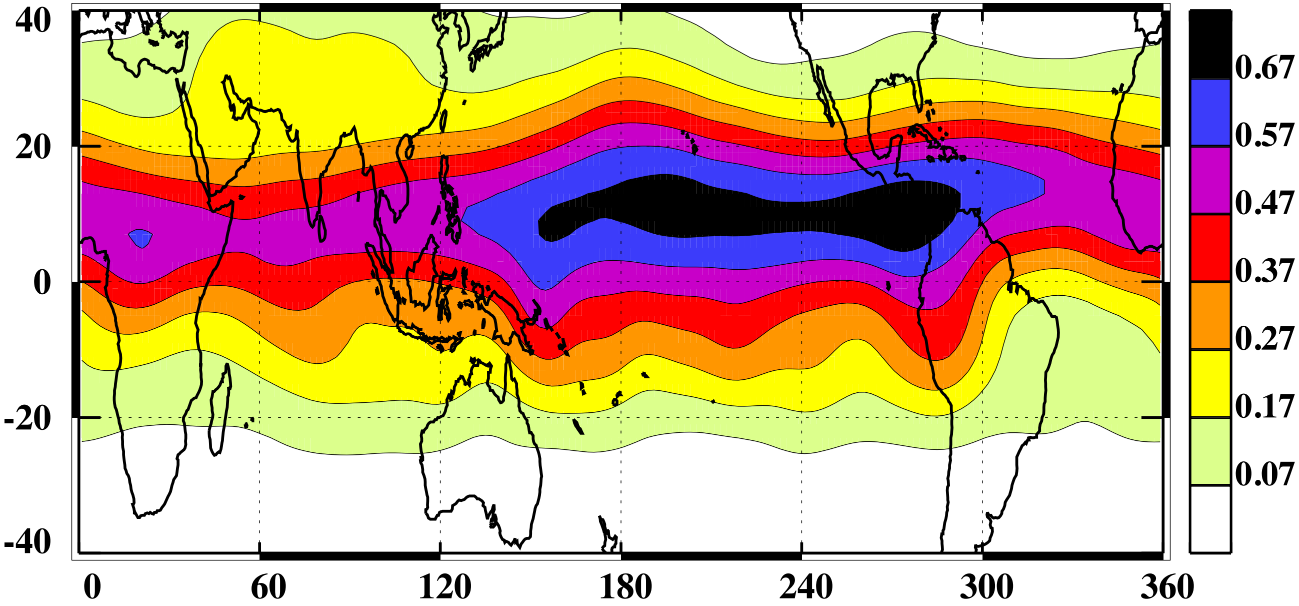
Parcel density at 100 mb



Parcel density at 88 mb

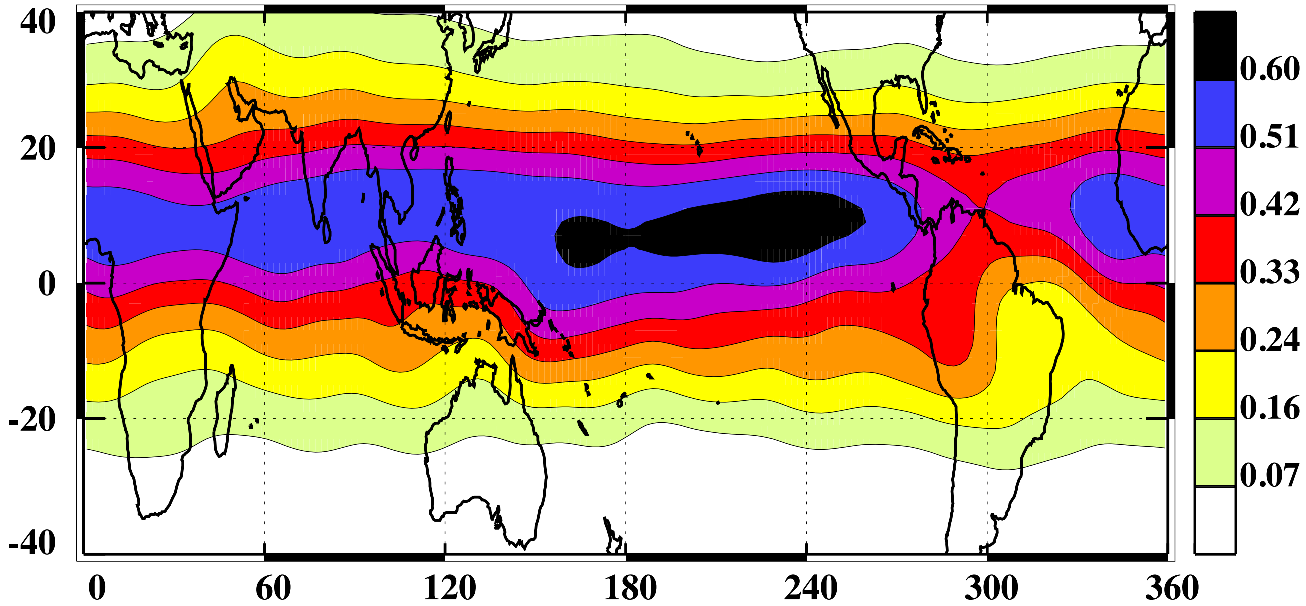


Parcel density at 78 mb



Distribution spreads to fill a tropical band

Parcel density at 70 mb

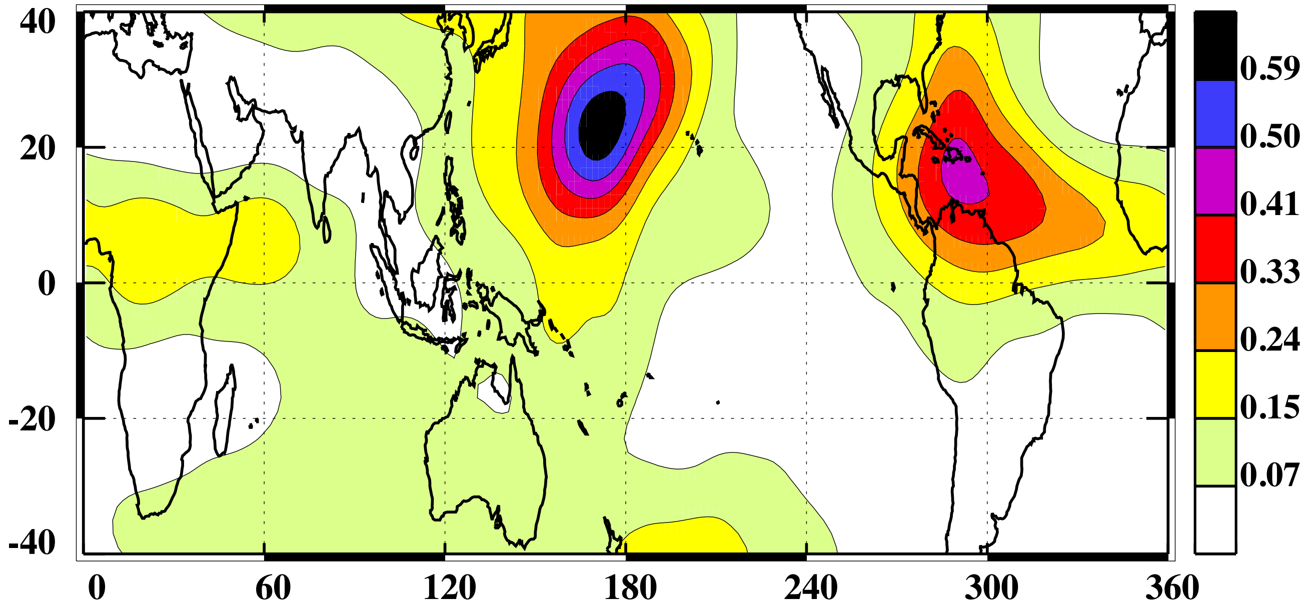


Transport corridors 100 mb to 70 mb

Source fraction 0.73

Sep-Oct 2007 Calculations

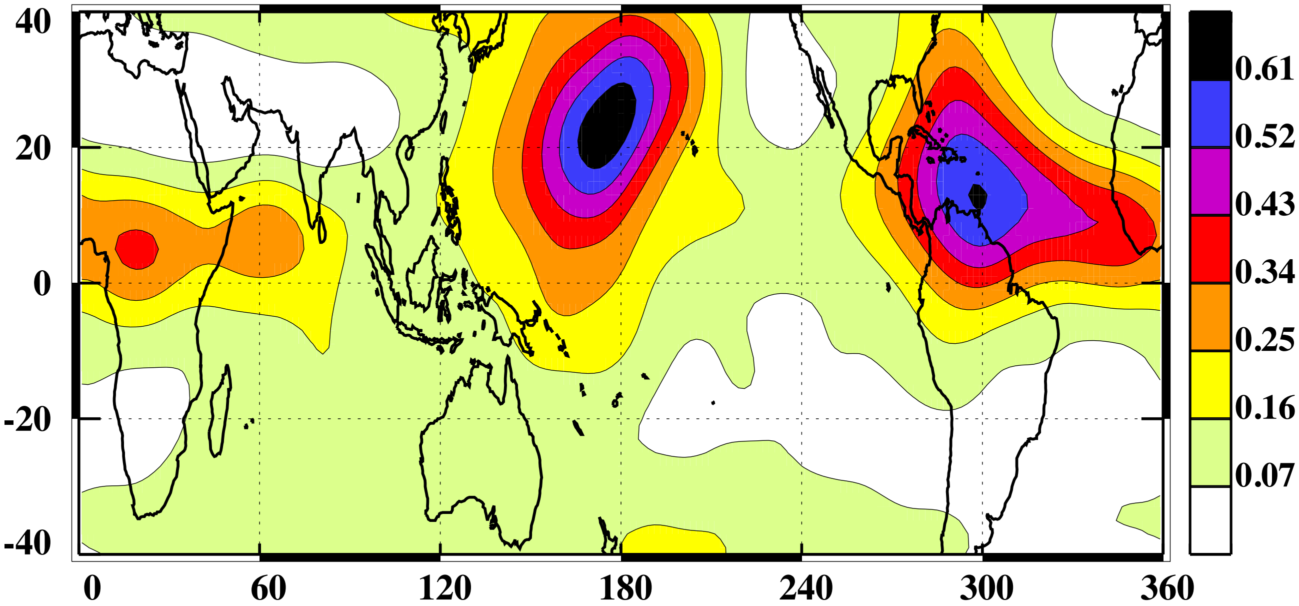
Parcel density at 100 mb



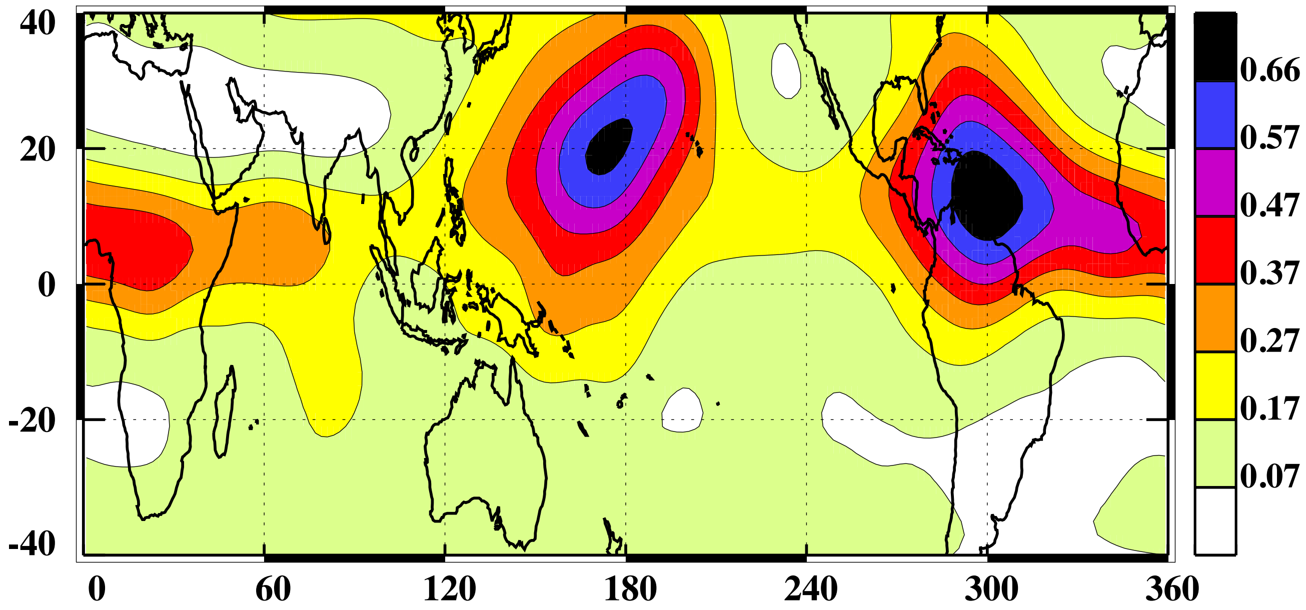
Strong source region in the NW Pacific

(also a feature of parcels that are transported from 200 mb to 70 mb within 120 d)

Parcel density at 96 mb

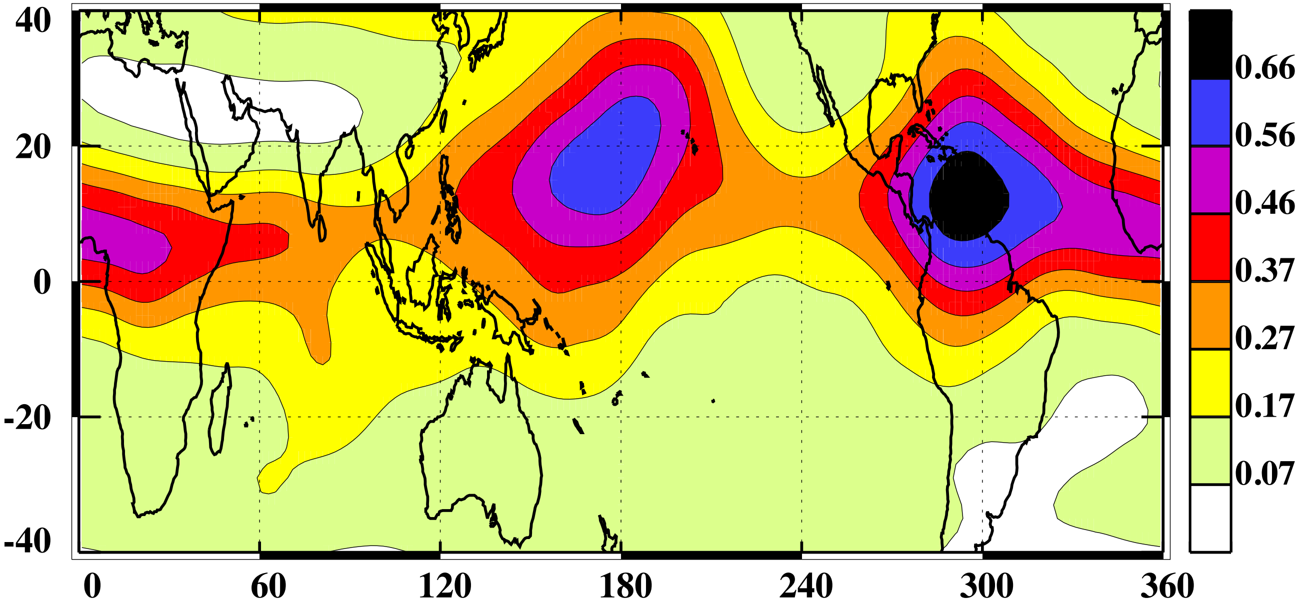


Parcel density at 92 mb

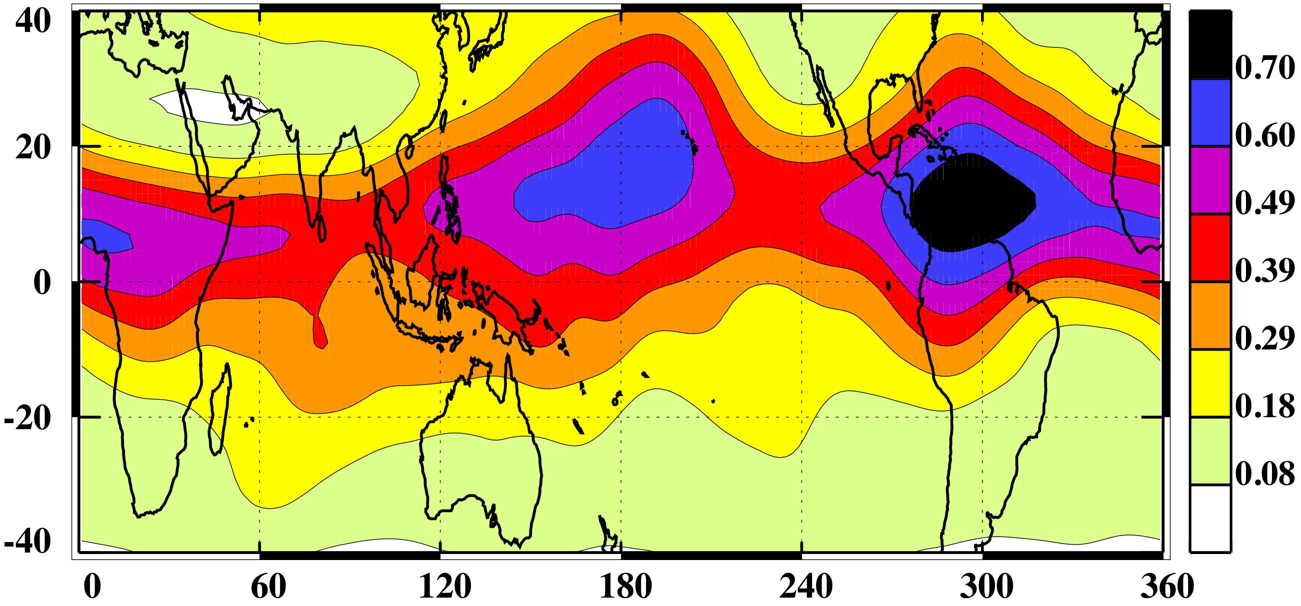


Source regions maintain their locations

Parcel density at 88 mb

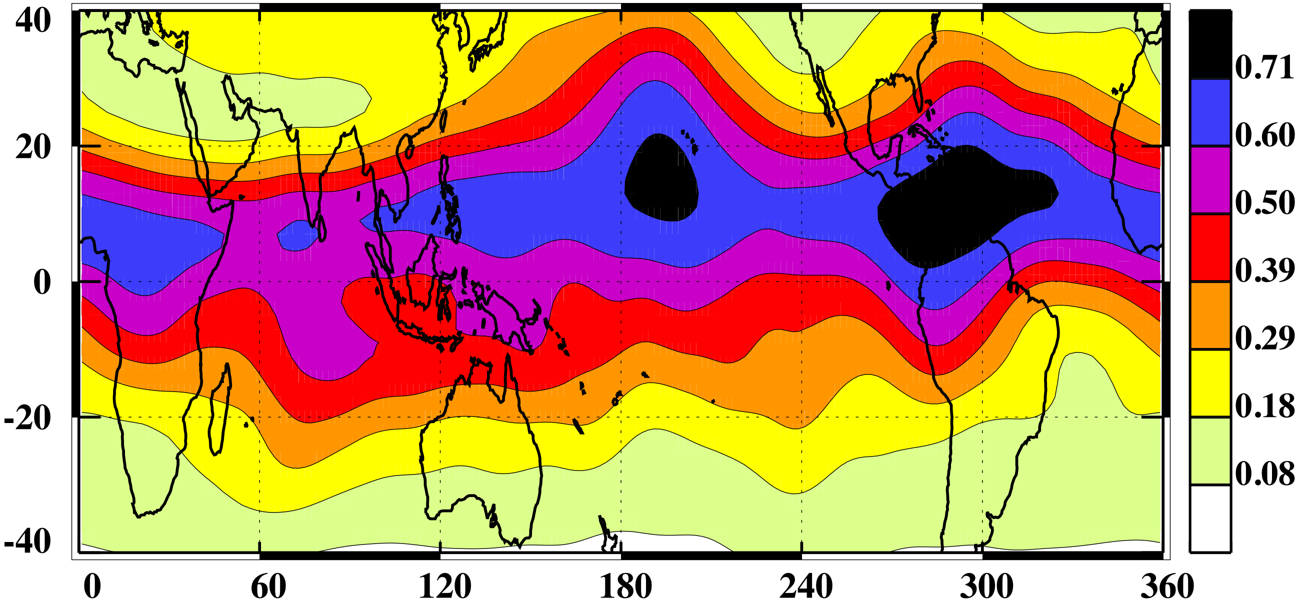


Parcel density at 85 mb

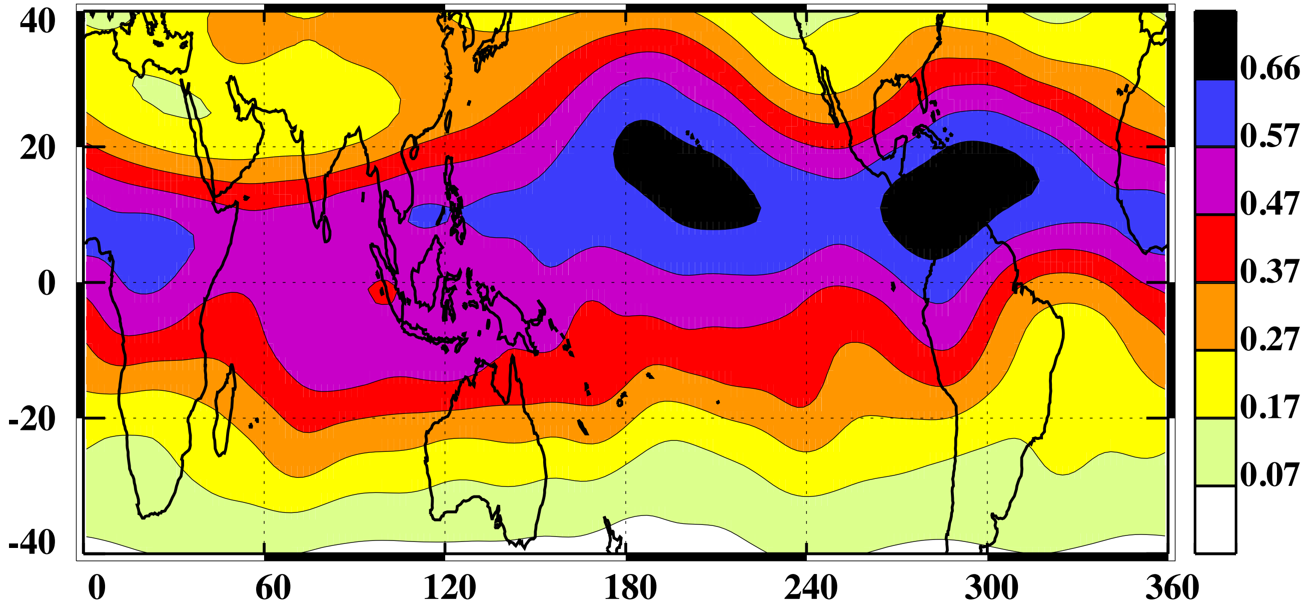


While density spreads

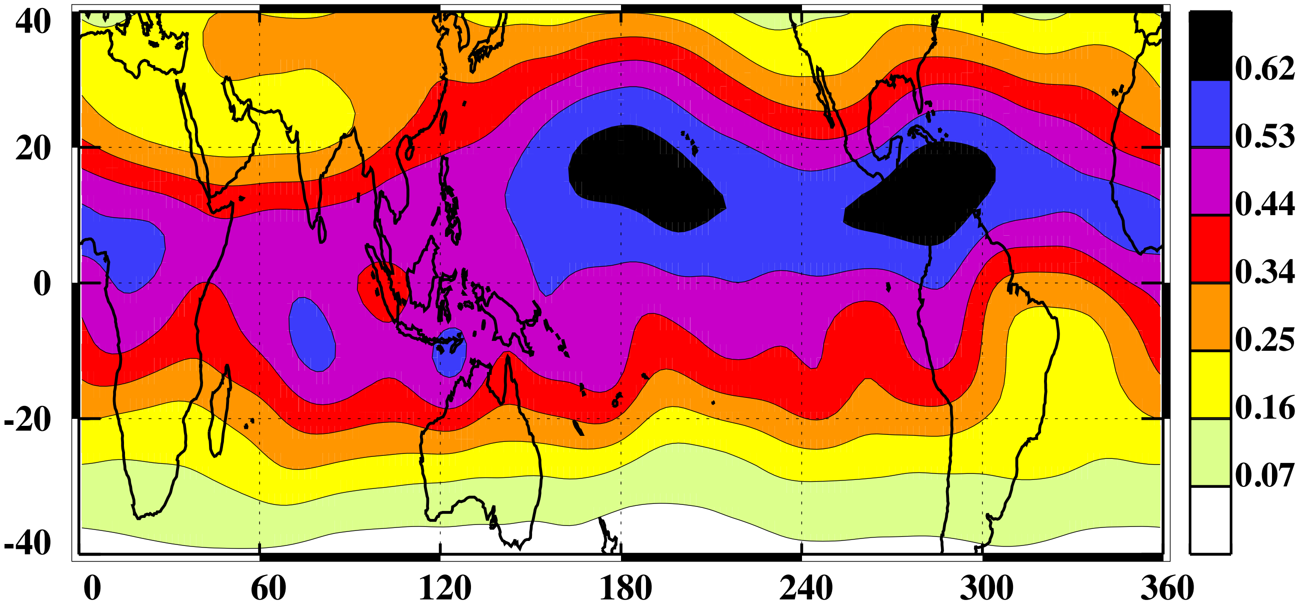
Parcel density at 82 mb



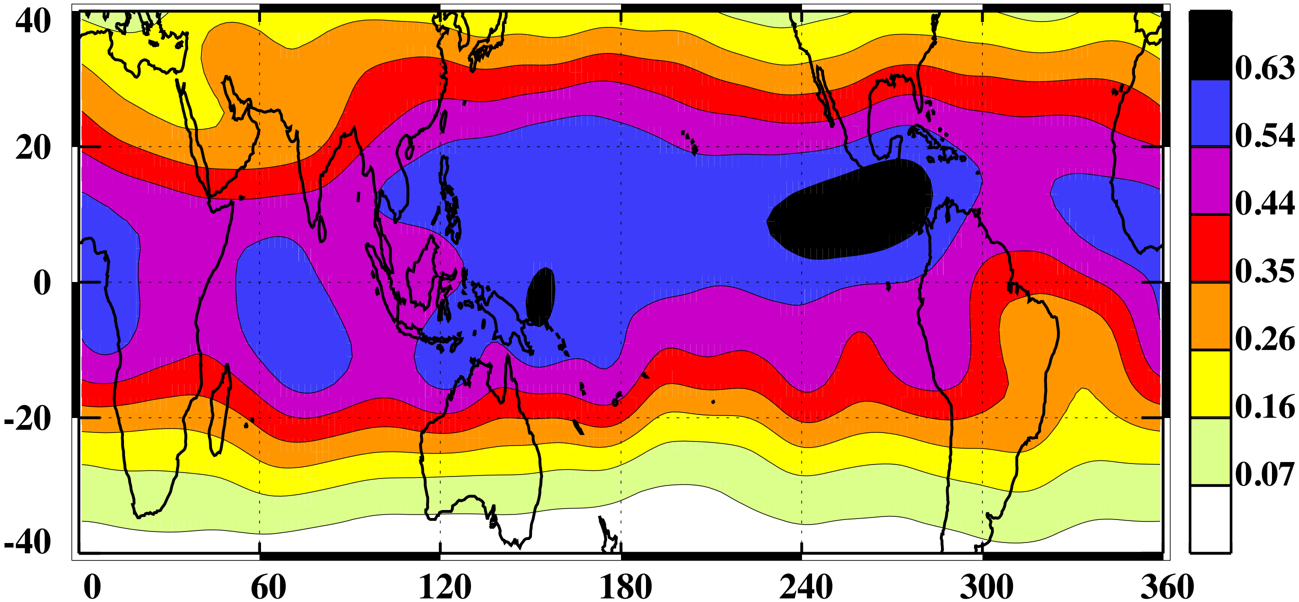
Parcel density at 78 mb



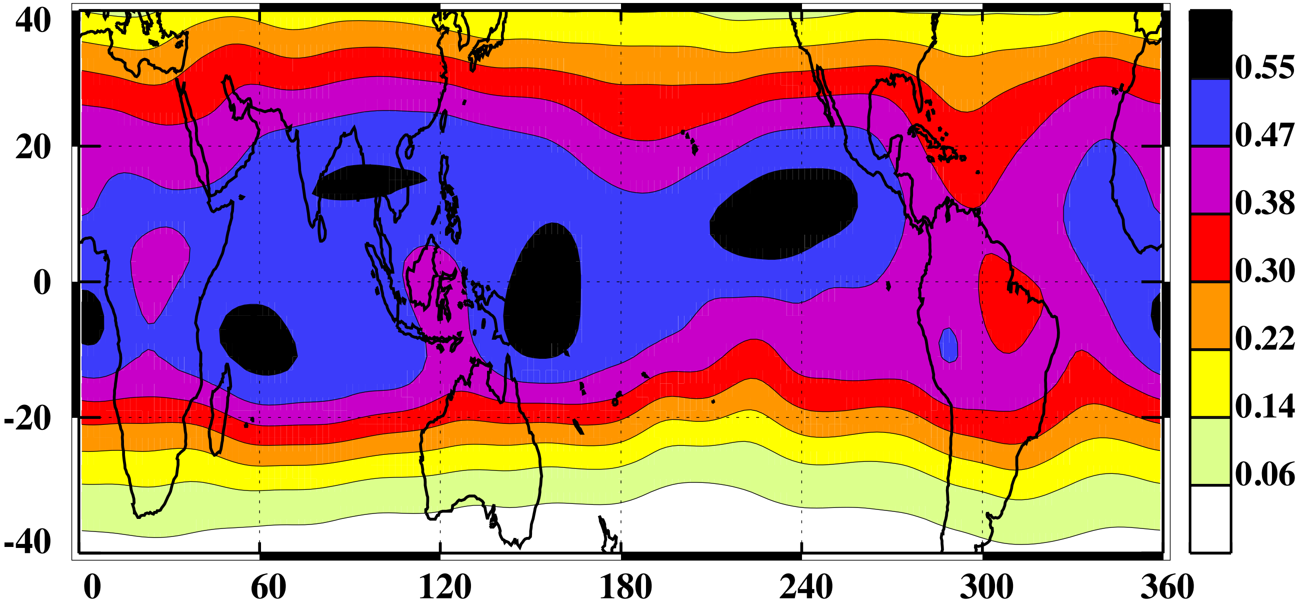
Parcel density at 75 mb



Parcel density at 72 mb



Parcel density at 70 mb



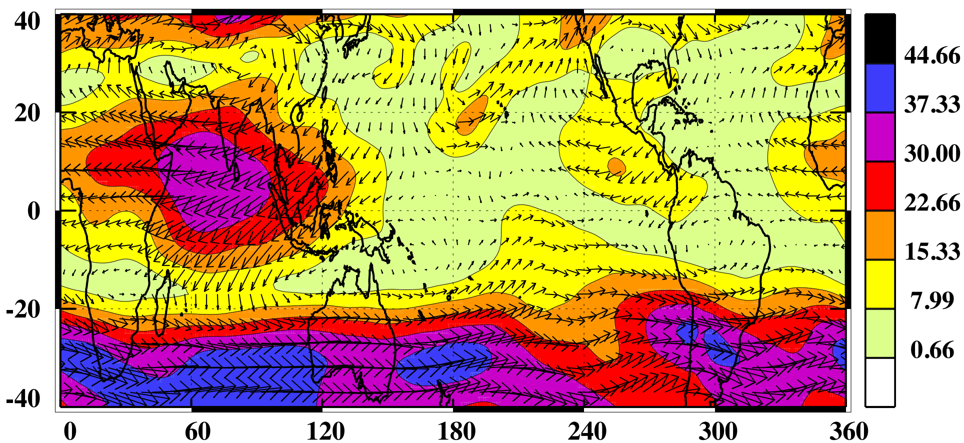
To fill the tropics

Dynamical Influences on parcel density

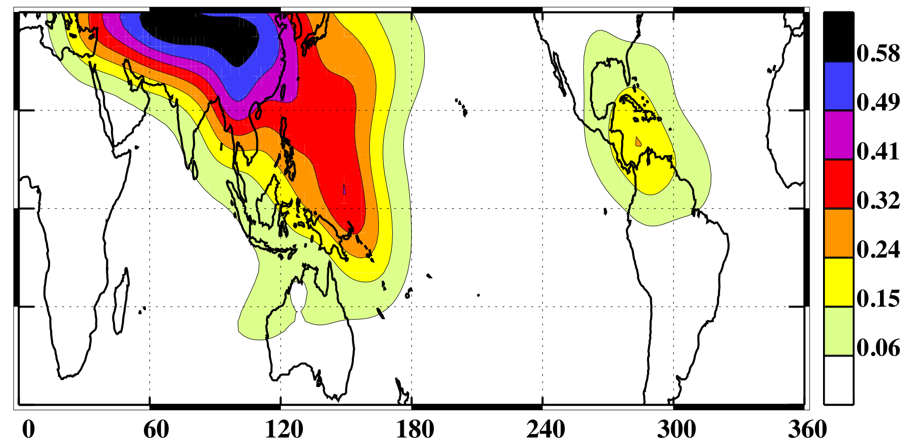
- Parcel density is not (necessarily) an advected quantity
  - Behaves more like a wave
- Parcel density for 200 mb sources is enhanced in regions of strong vertical motion
  - Those parcels are likely to get to 200 mb
  - But, are there other factors that affect path density?
    - Divergence: paths are 'compressed' (in a backward sense)
    - Do low winds and/or closed streamlines allow parcels to remain in a specific horizontal region

Dynamical influences near 200 mb (200 mb sources)

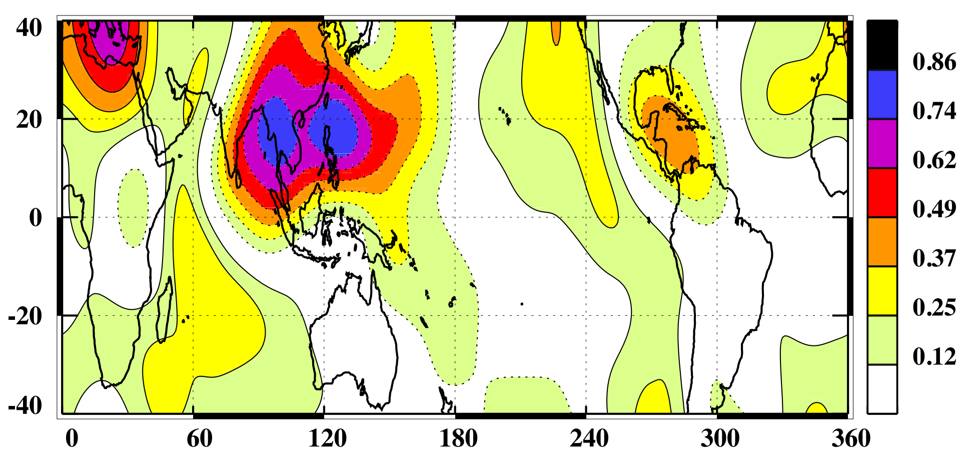
150 mb Horizontal winds (Jul-Aug)



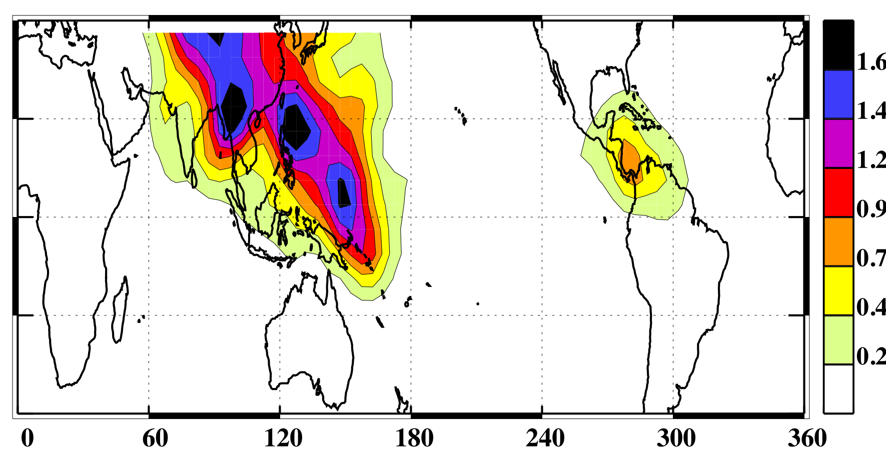
Parcel density at 170 mb



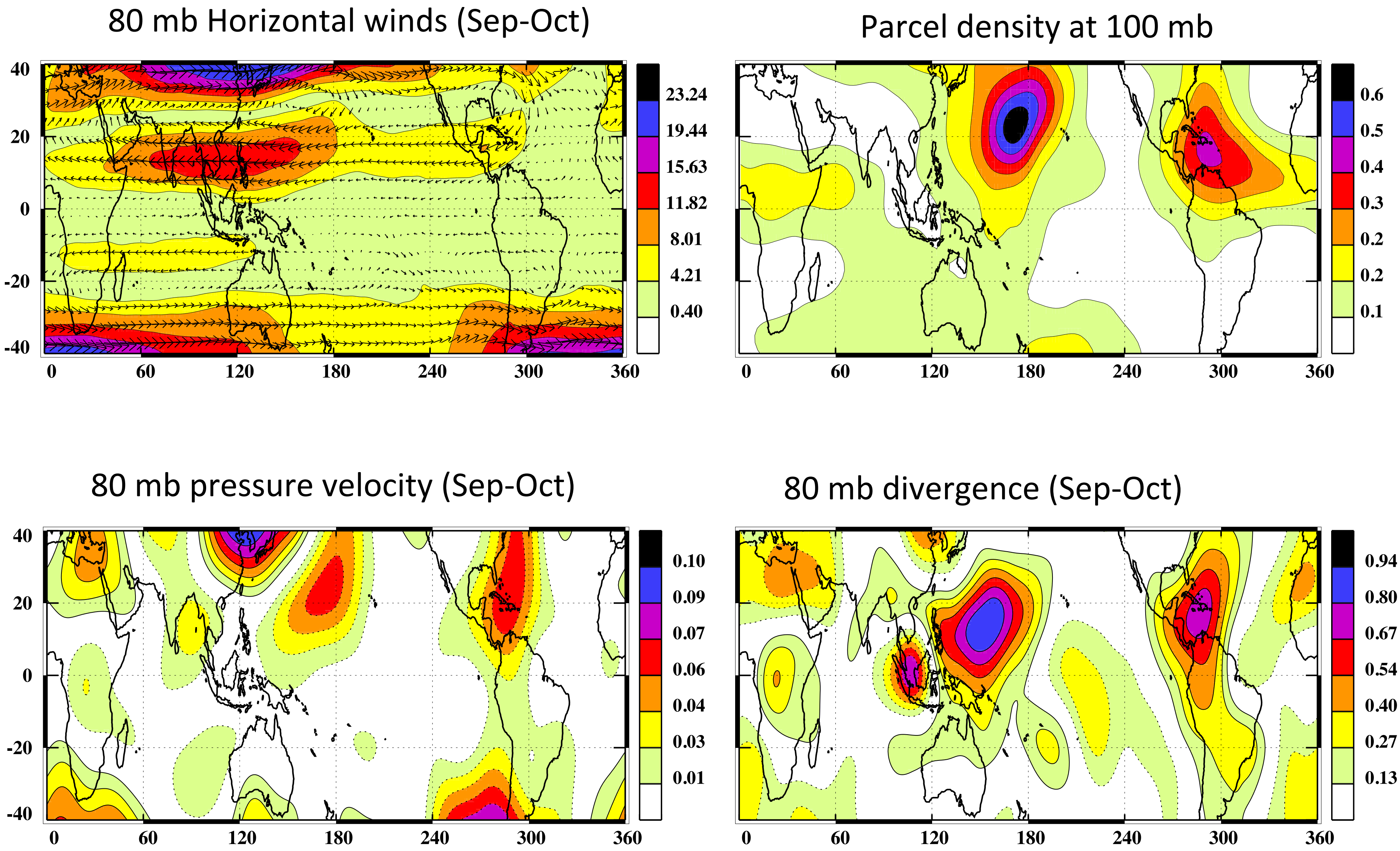
150 mb pressure velocity (Jul-Aug)



Parcel density at 200 mb



Dynamical influences near 100 mb (100 mb sources)

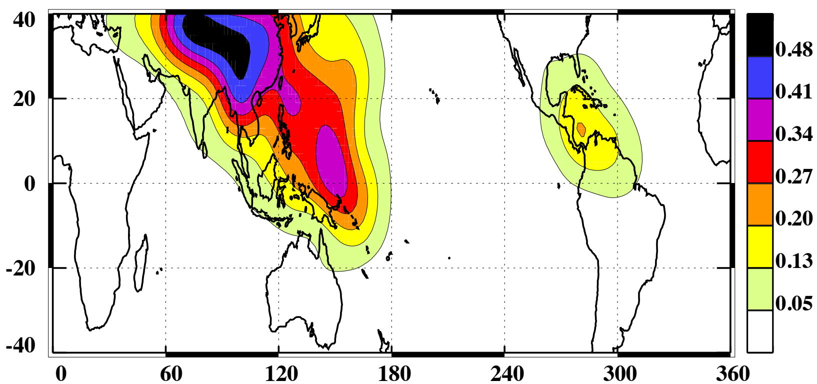


Caveats and robust features

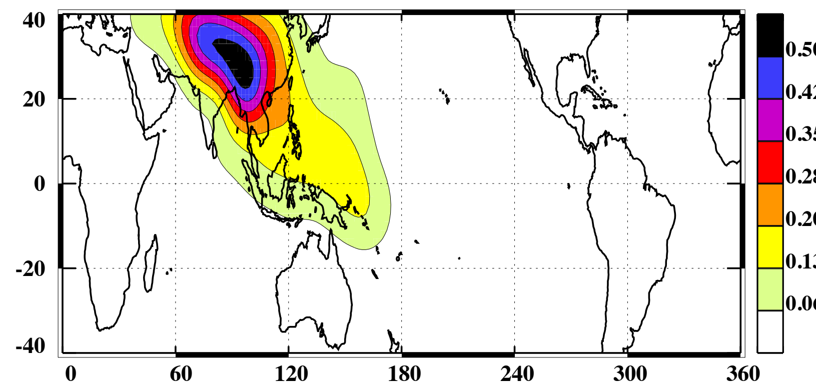
Parcel density Inter-Calculation Comparisons
ERA-interim kinematic
ERA-interim diabatic
CFSR kinematic
CFSR diabatic

Parcel density for 200 mb sources at 200 mb: Sep-Oct

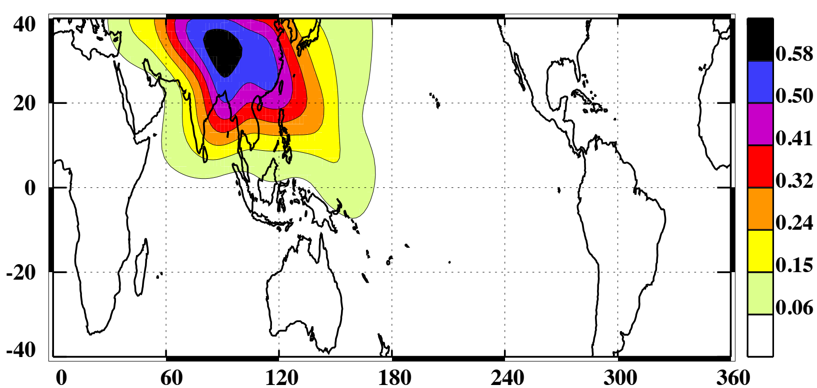
ERA-interim kinematic (0.23)



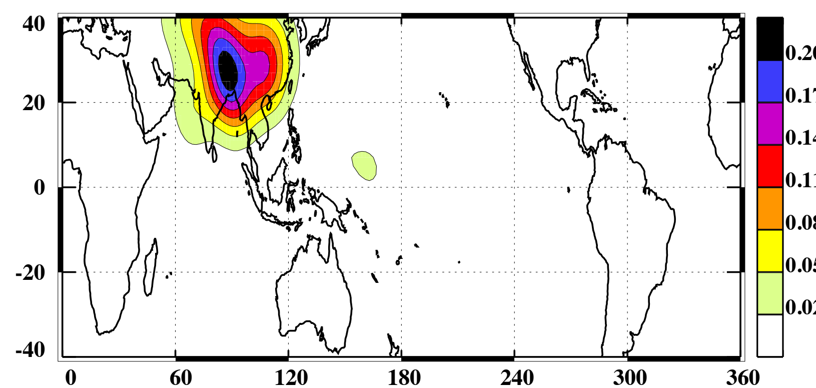
ERA-interim diabatic (0.26)



CFSR kinematic (0.40)

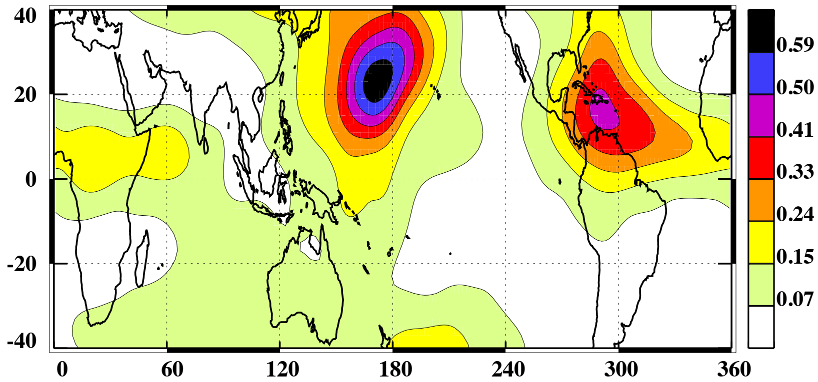


CFSR diabatic (0.05)

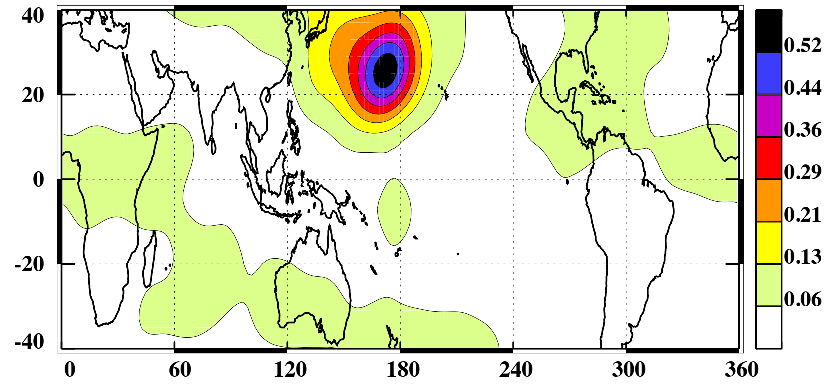


Parcel density for 100 mb sources at 100 mb: Sep-Oct

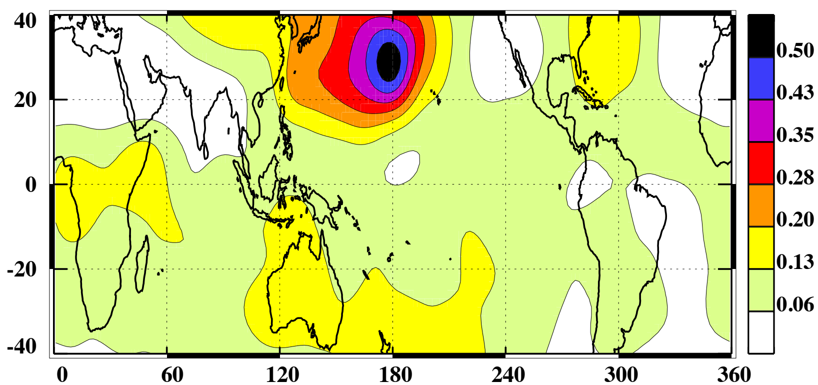
ERA-interim kinematic (0.73)



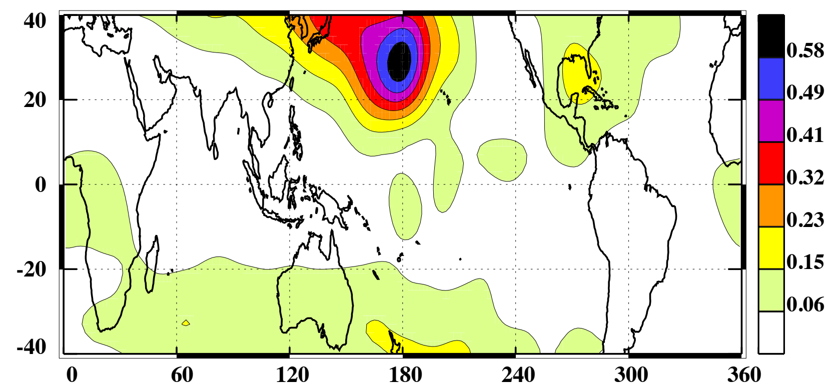
ERA-interim diabatic (0.83)



CFSR kinematic (0.79)

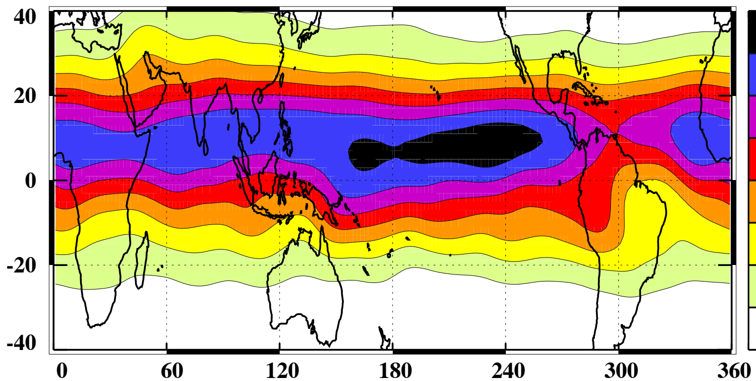


CFSR diabatic (0.77)

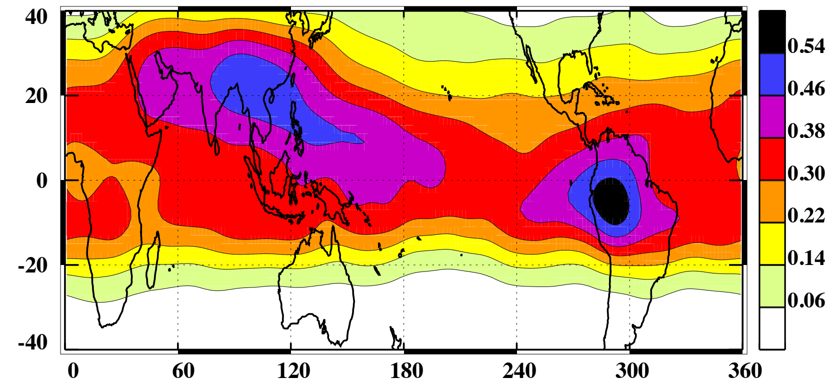


Parcel density for 200 mb sources at 70 mb: Sep-Oct

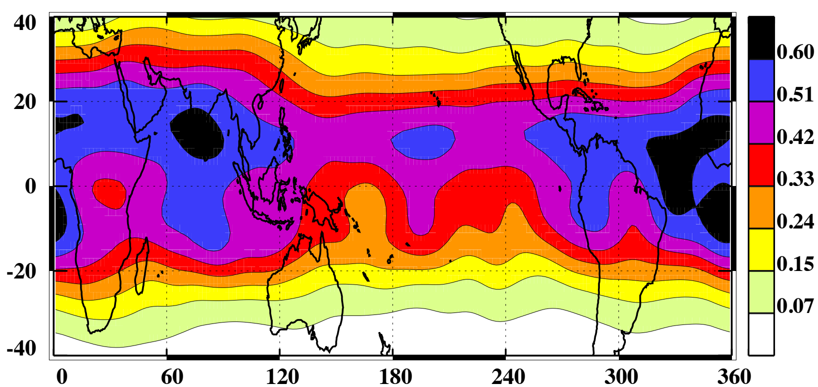
ERA-interim kinematic (0.23)



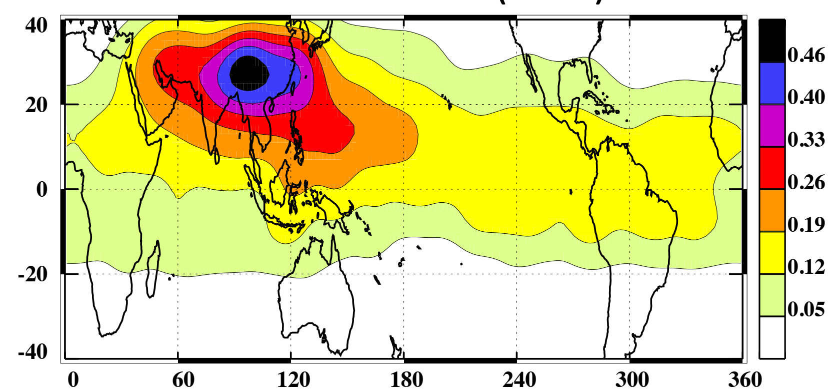
ERA-interim diabatic (0.26)



CFSR kinematic (0.40)

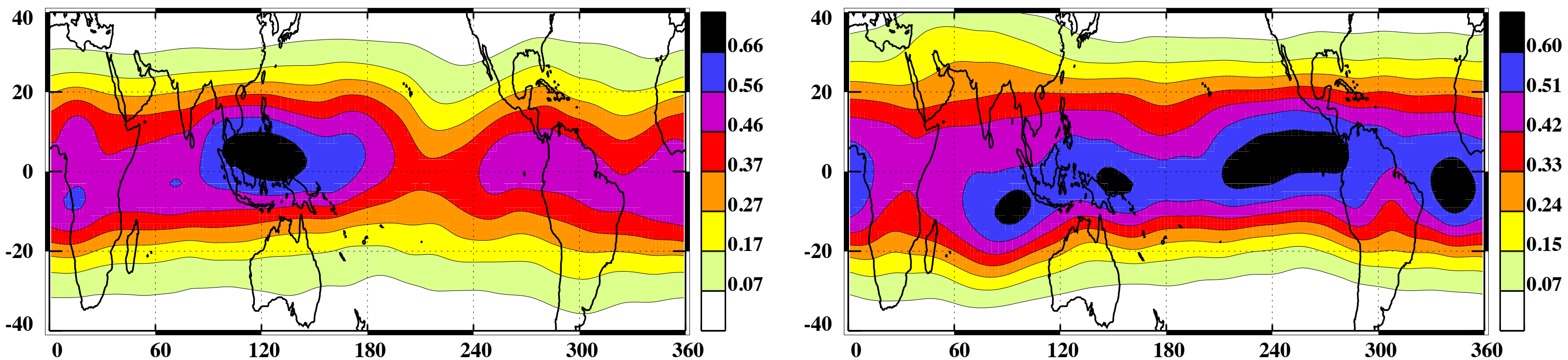


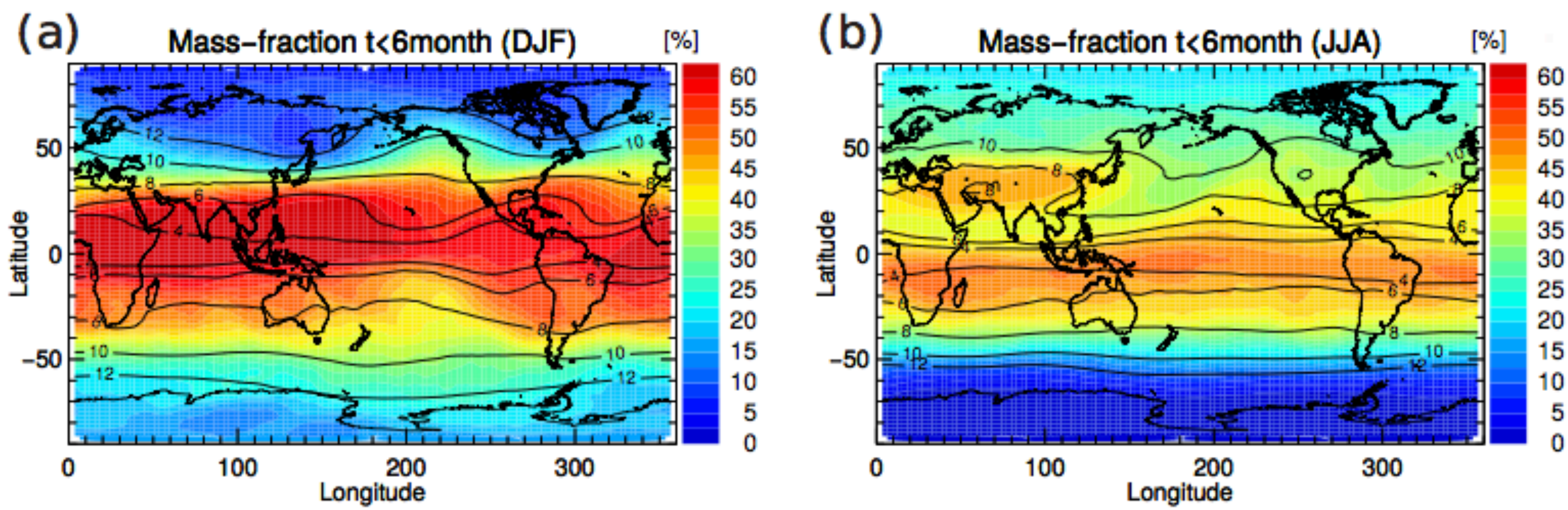
CFSR diabatic (0.05)



Parcel density for 200 mb sources at 70 mb (425-450 K) for 2007 compared with Age-of-air calculations (at 400 K) in Ploeger and Birner (ACPD 2016)

Jan-Feb | Jul-Aug





Conclusions

- Transport in the upper troposphere in the Asian monsoon regions represents a substantial challenge for transport calculations despite (because of) being a dominant dynamical feature
  - Other studies have shown that the anti-cyclone has a strong influence on horizontal transport into the extra-tropical stratosphere
  - But it has a debatable impact on transport efficiency into the tropical pipe
- The Lagrangian parcel location probability density function is (could be) a valuable diagnostic quantity
- ‘Source distributions’ are robust features of Lagrangian calculations
- A region of strong horizontal divergence and upward motion in the north Pacific is (appears to be) a robust feature that apparently promotes efficient transport into the tropical pipe