Composition and transport in the Asian summer monsoon anticyclone (ASMA): A case study based on aircraft observations and model simulations

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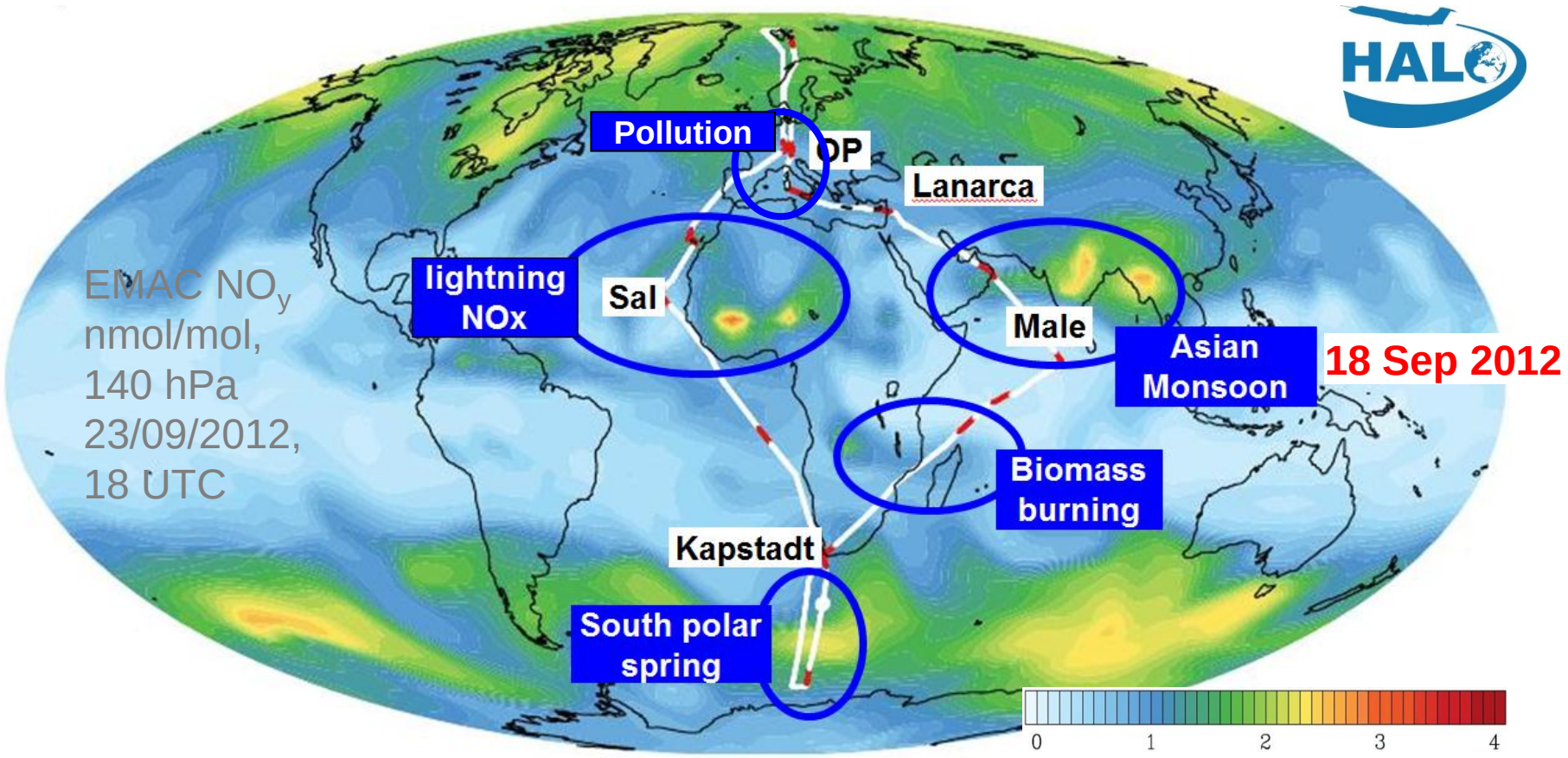
Outline

1. HALO ESMVal campaign
2. EMAC simulation & HYSPLIT trajectories
3. Measurements vs simulation
4. Back-trajectories
5. Tracer characteristics in the ASMA
6. Tracer-tracer relations
7. Entrainment at the eastern ASMA flank
8. Splitting and stirring

1. HALO ESMVal campaign



- 65 HALO flight hours from 10 – 24 September 2012
- in close collaboration with HALO TACTS mission
- targeting specific large scale features to gather data for ESM evaluation

2. EMAC simulation and HYSPLIT trajectories

EMAC (ECHAM/MESSy Atmospheric Chemistry model)

- CCMI Ref-C1SD setup, EMAC 2.5 (simulation REF-C1SD-base10a, project ESCiMo)

  Dynamics nudged towards ECMWF ERA-Interim re-analyses data

- T42L90MA resolution: ~150 km grid size, 90 vertical levels to 80 km

  Comparison to measurements based on highest possible resolution:
  time series along aircraft flight track, Δt =12 min (simulation time step)

HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory model)

- Back-trajectories starting @ flight track
- Driven kinematically by GDAS 1°x1°, 23 vertical levels (1000 … 20 hPa)

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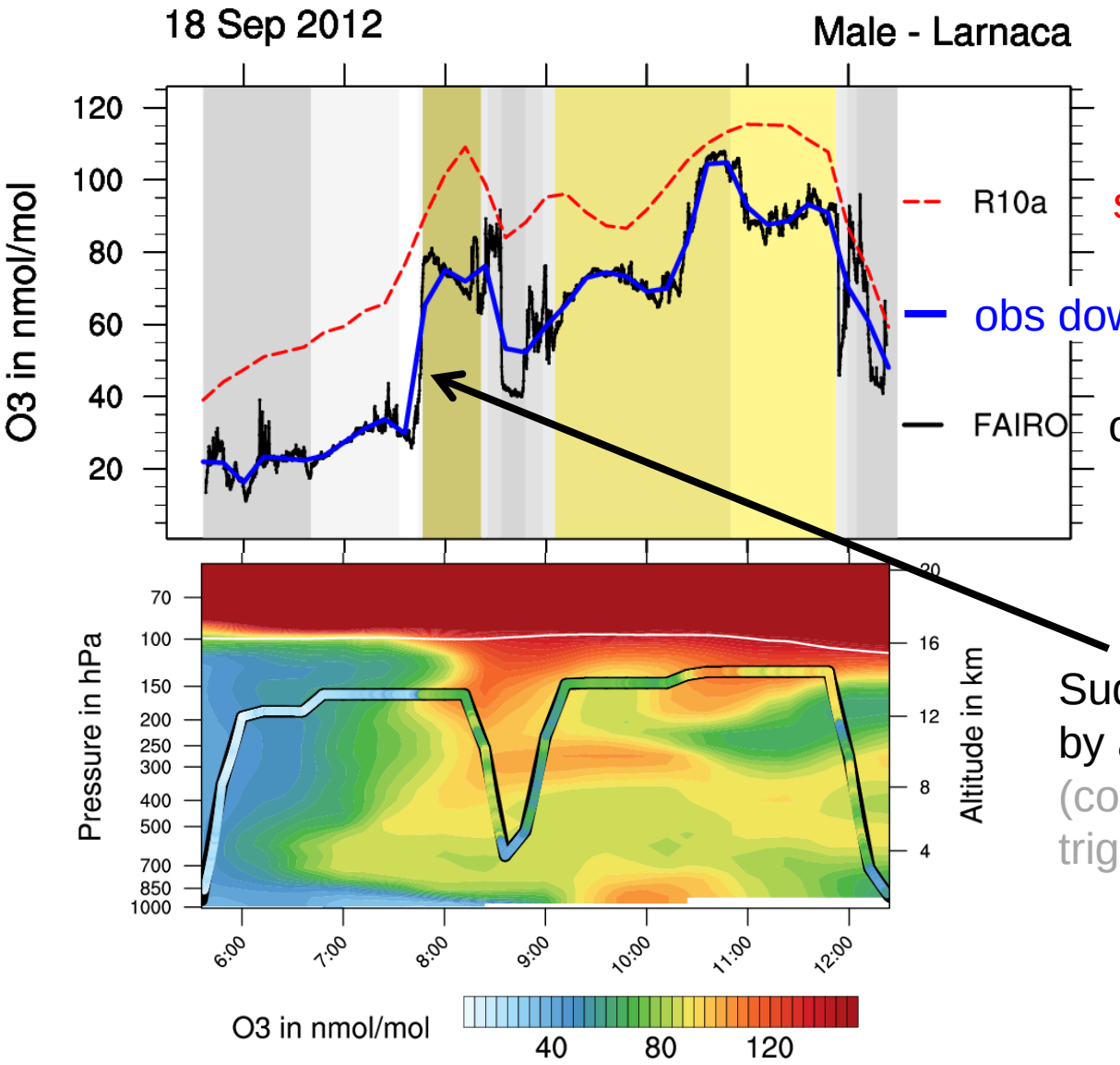
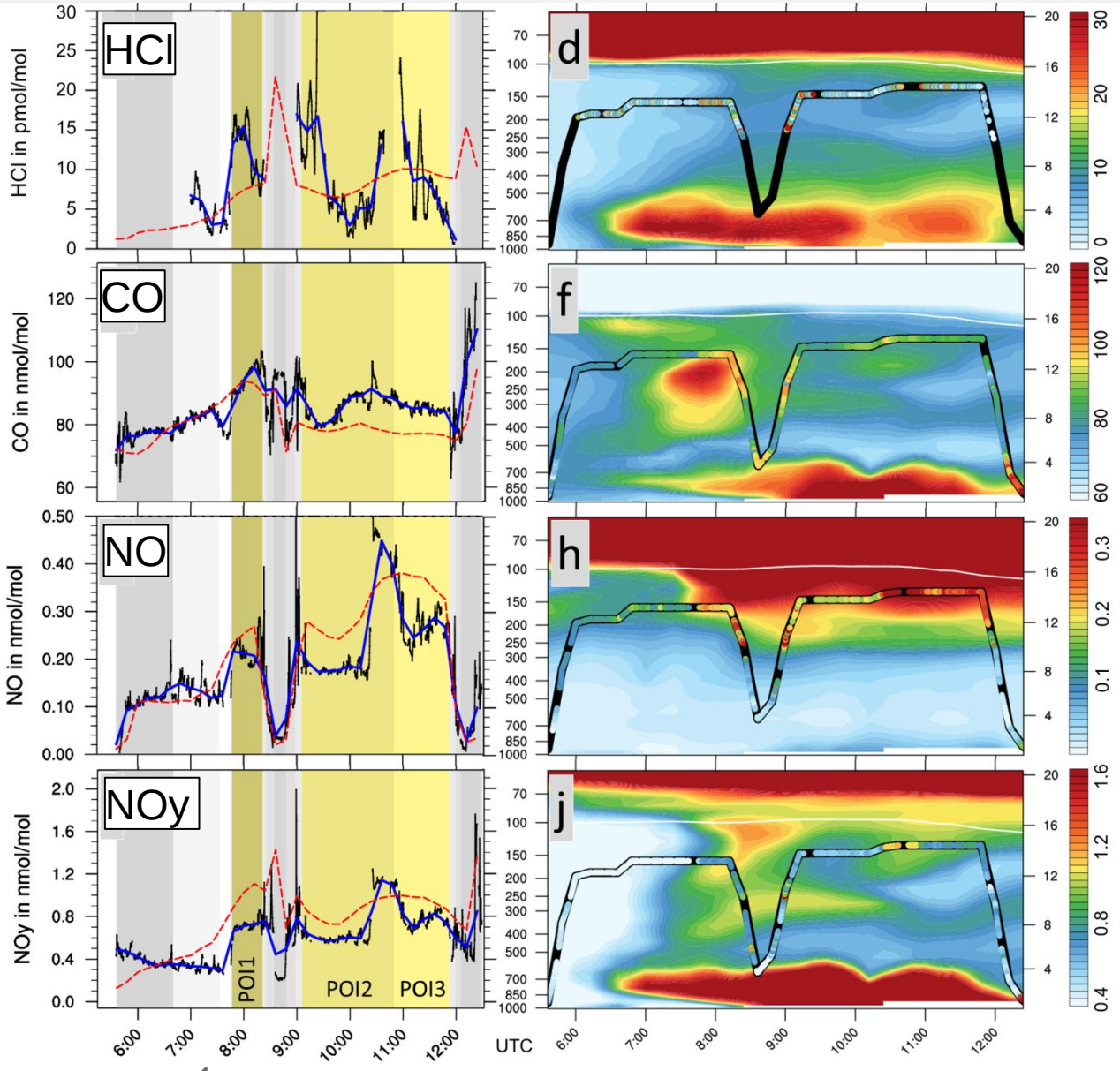
3. Measurements vs simulation > O3



Sudden increase in ASMA
by about 50 nmol/mol
(contrasts satellite climatologies, triggered this study)

3. Measurements vs simulation > Other tracers



- @ instrument limit
- possibly spurious washing out or slightly misjudged gradient in sim

Surprisingly good for monthly BB

Lightning parameterized:
Can not expect exact match

Pattern ok

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3. Measurements vs simulation > Summary

Obs

O3, HCl, CO, NO, NOy enhanced in ASMA filament(s)

Sim

- Caution needed in regions with strong gradients / transport barriers
- Consider coarse resolution, approximations / parameterizations in the simulation (incl. initial and boundary conditions)

Surprisingly well reproduces observations of HALO ESMVal, at least large scale features

→ Ok to use for interpretation of the measurements

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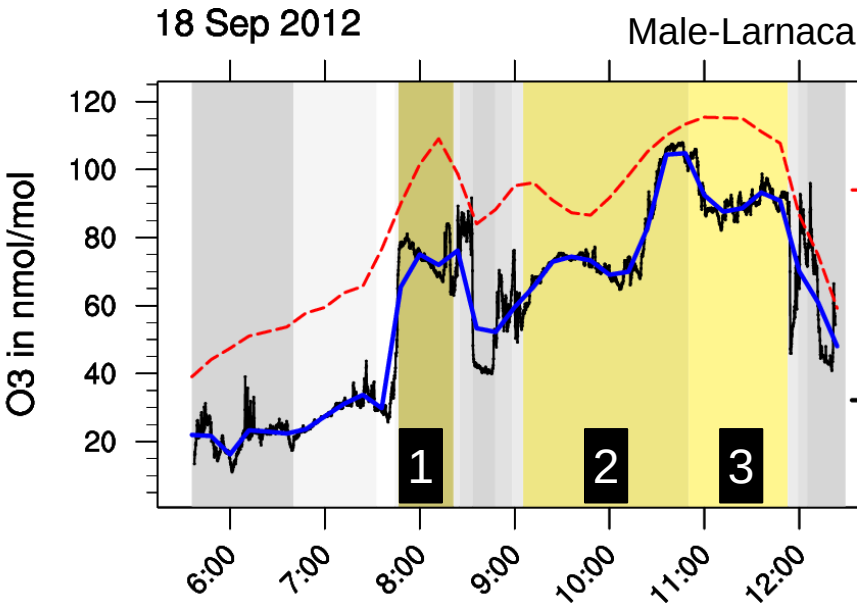
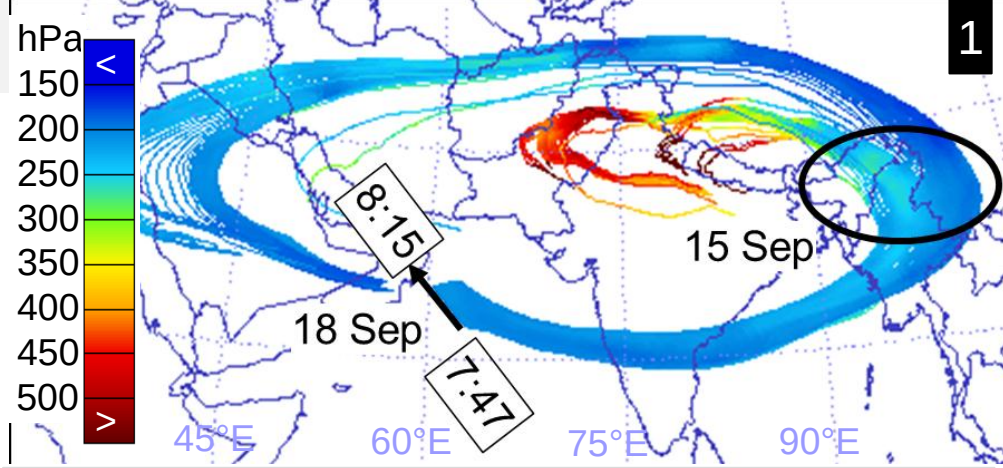
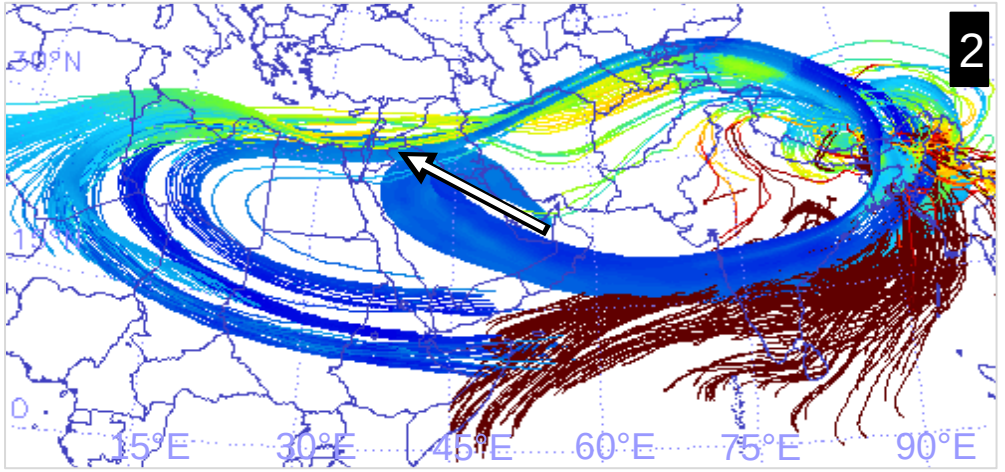
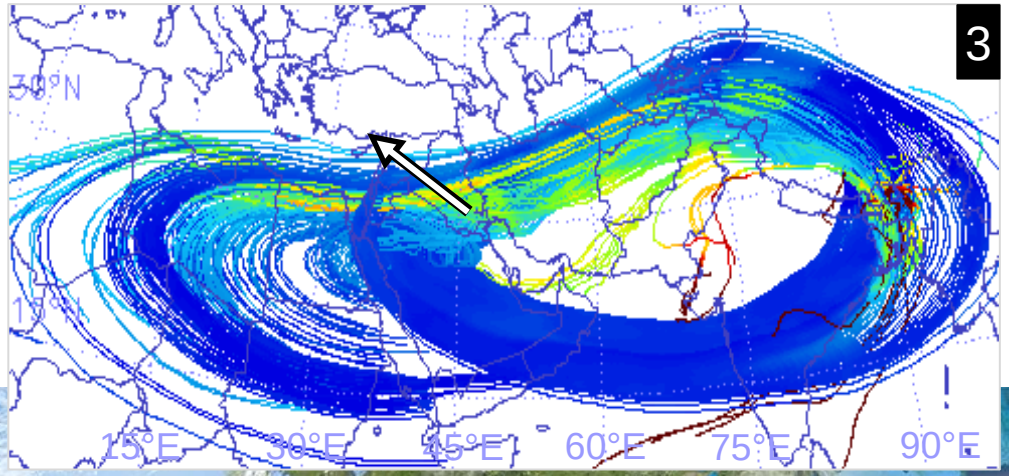
4. Back-trajectories









All 3 flight segments have seen a filament of similar genesis:

- At least one ASMA roundtrip in UT
- Entrainment by upwelling at eastern ASMA flank

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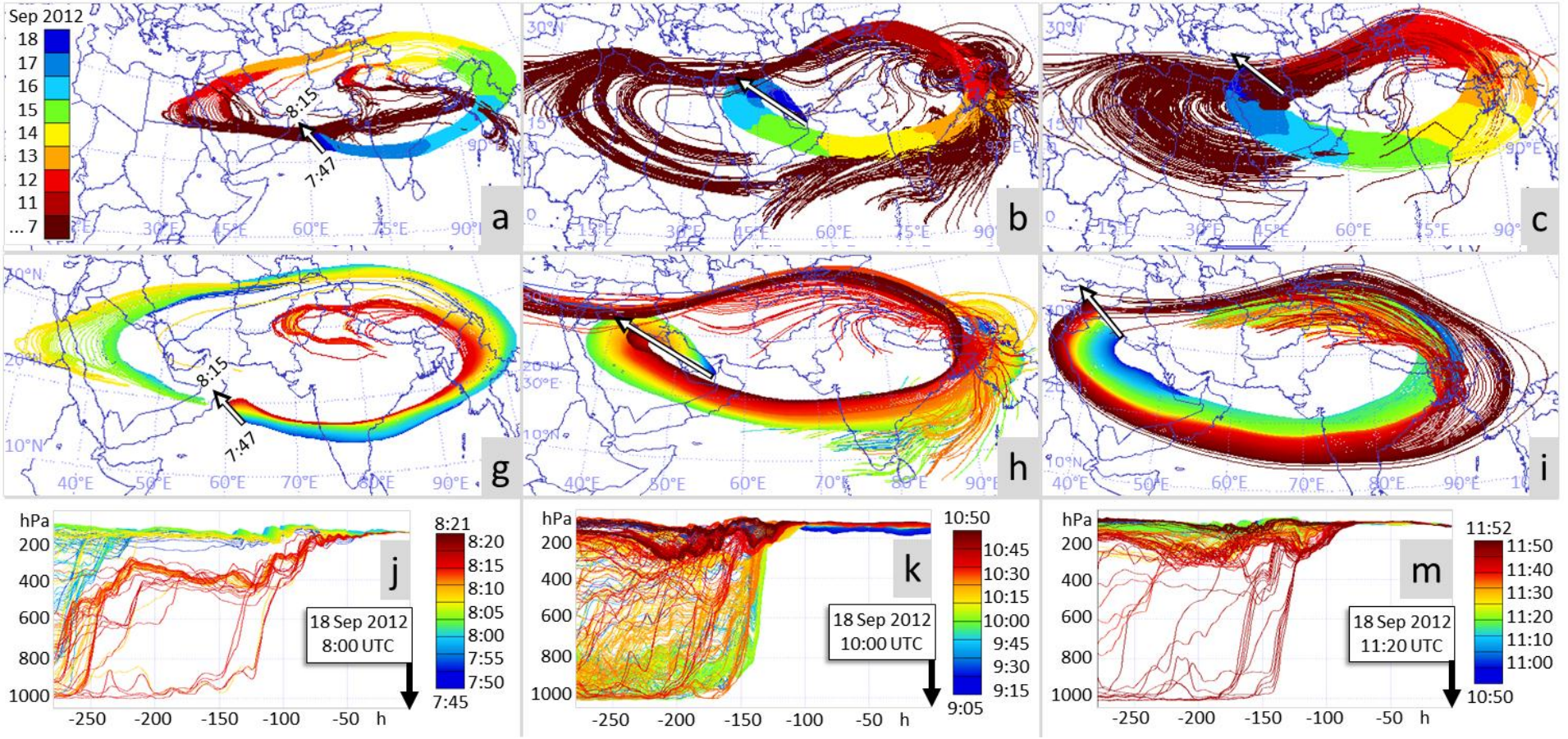
4. Back-trajectories



- Eastern ASMA flank passed 15 / 12 / 13 September 2012
- almost parallel streamlines in southern fringe @ ~const. altitude

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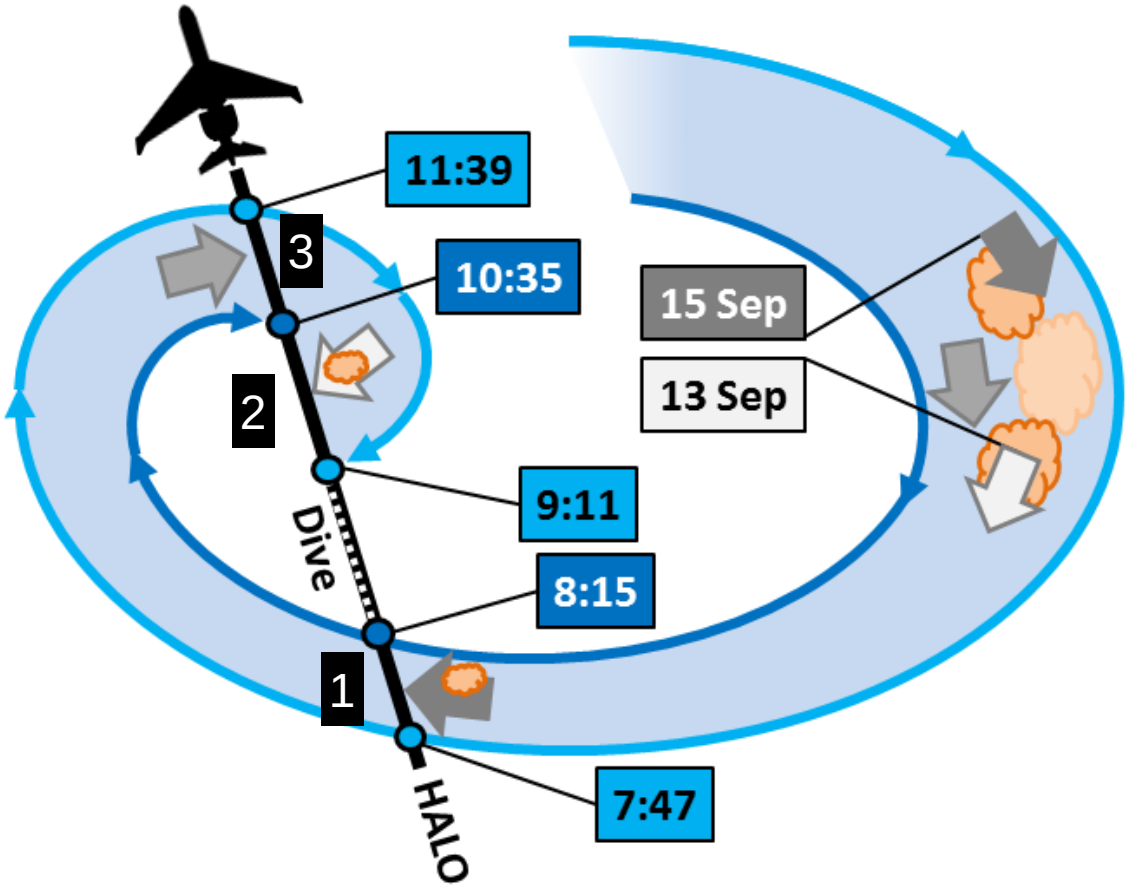
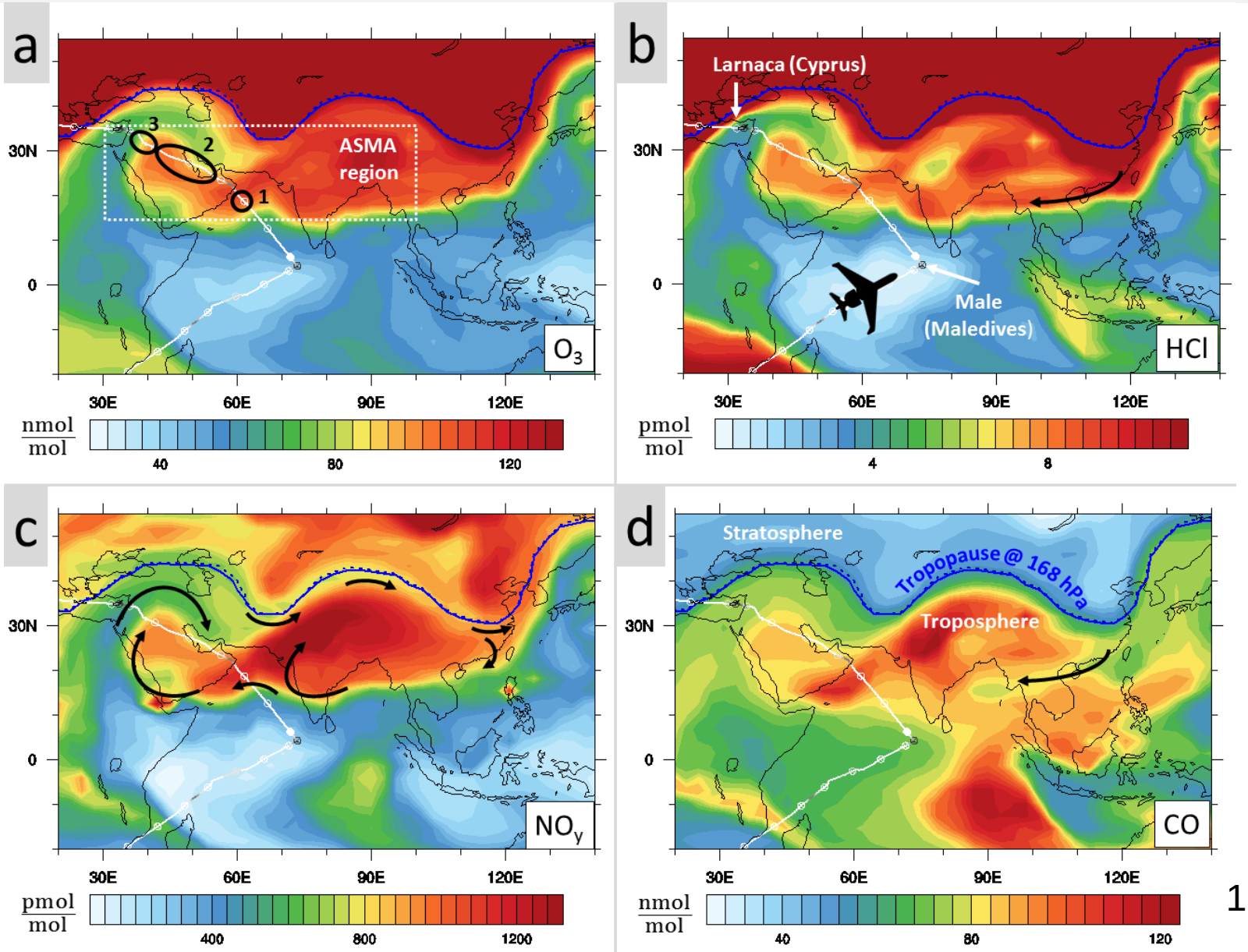
4. Back-trajectories > Summary



- Filament transected 1 outside-in, 2 outside in, 3 inside-out
- ASMA moved eastward during the considered period & became smaller

5. Tracer characteristics in the ASMA > Synoptic situation



168 hPa

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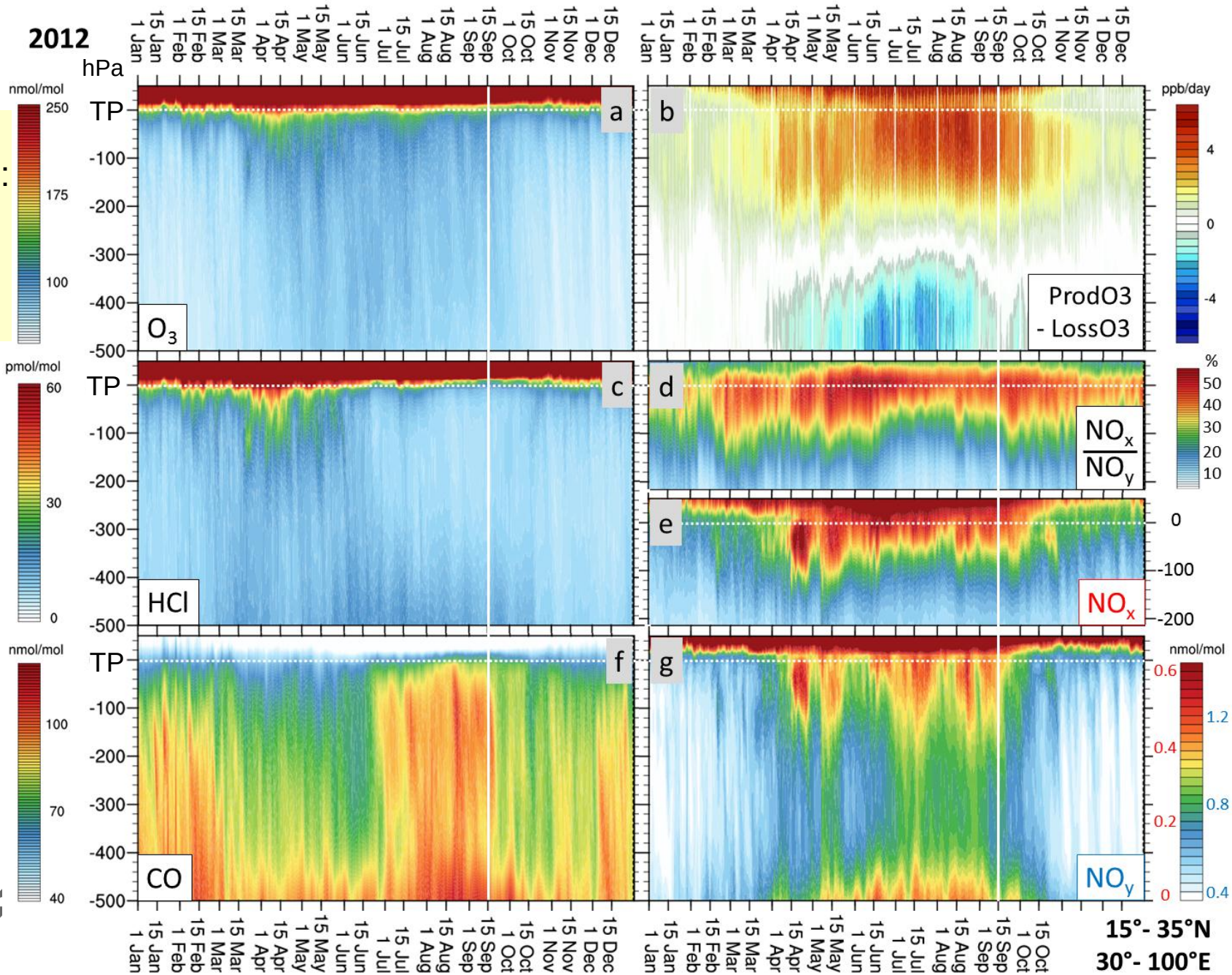
5. Tracer characteristics in the ASMA > Evolution 2012

TP
30°S-30°N:
WMO

else:
3.5 PVU



EMAC simulation

5. Tracer characteristics in the ASMA > Evolution 2012 (sim)

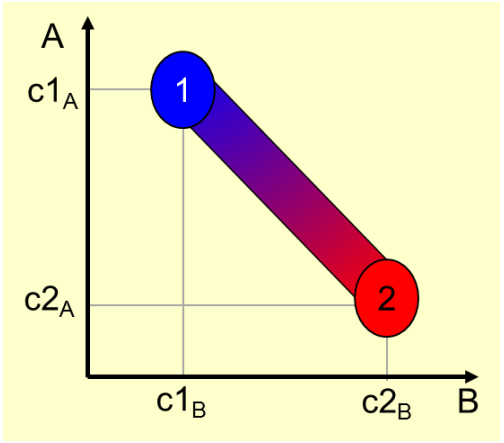
- no obvious O3 minimum in ASMA
- HCl stratospheric tracer in ASMA
- CO tropospheric tracer in ASMA; proxy for non-NOx O3 precursors
- E-shaped NOy profile in ASMA
- NOx has UT sources, probably lightning
- NOx/NOy max @ TP, rather constant throughout the year
- Net photochemical O3 production is >0 and has a local max in ASMA

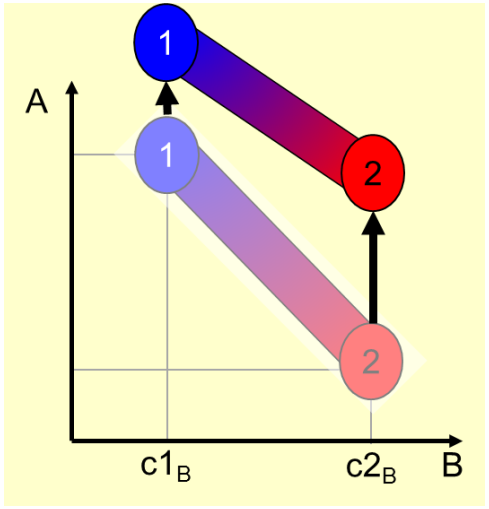
UT NOx meeting uplifted other precursors

6. Tracer-tracer relations > Mixing lines

Mixing of two reservoirs, 1 & 2, containing species A &B

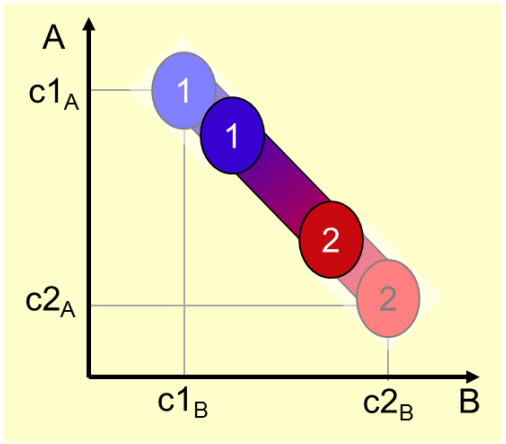
- c1 & c2 const.
  → slope const
- any component of c1 or c2 different (incl. via inmixing)
  → different slope

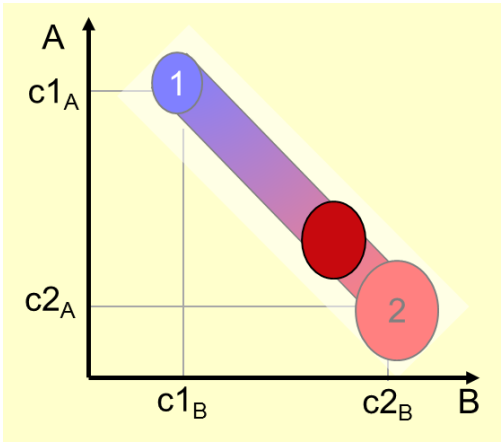




- different in-situ production changes slope

- mixing line exists as long as mixing continues
- shrinks, if reservoirs are not replenished





- non-equal contributions from reservoirs = non-symmetric shrinking of mixing line

- mixing complete = one point in tracer-tracer diagram

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6. Tracer-tracer relations > Mixing lines

Mixing of two reservoirs, 1 & 2 („end members“), containing species A &B

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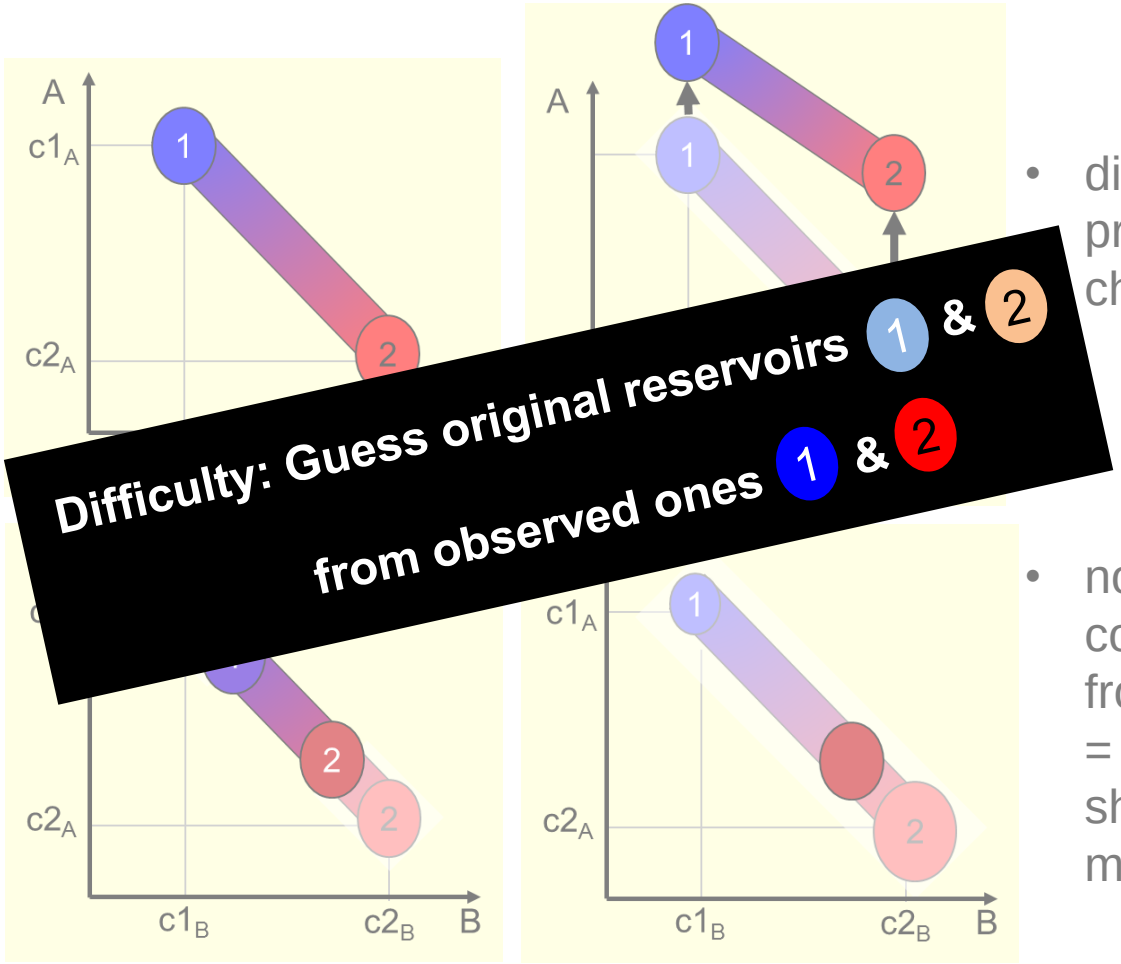
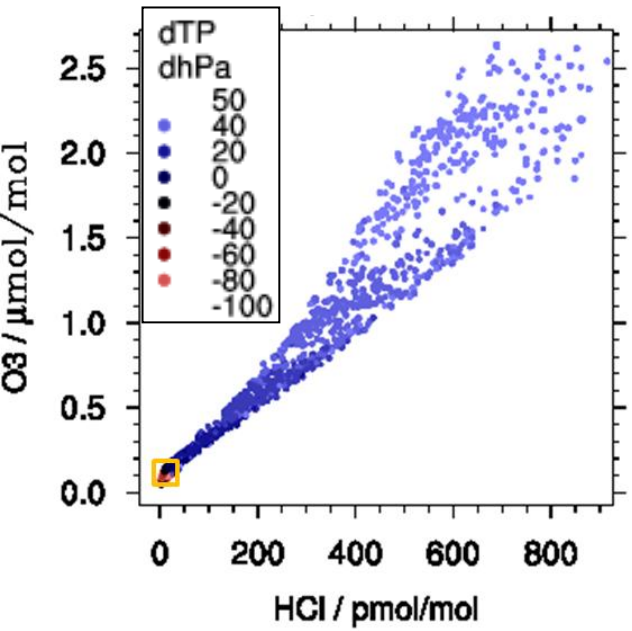


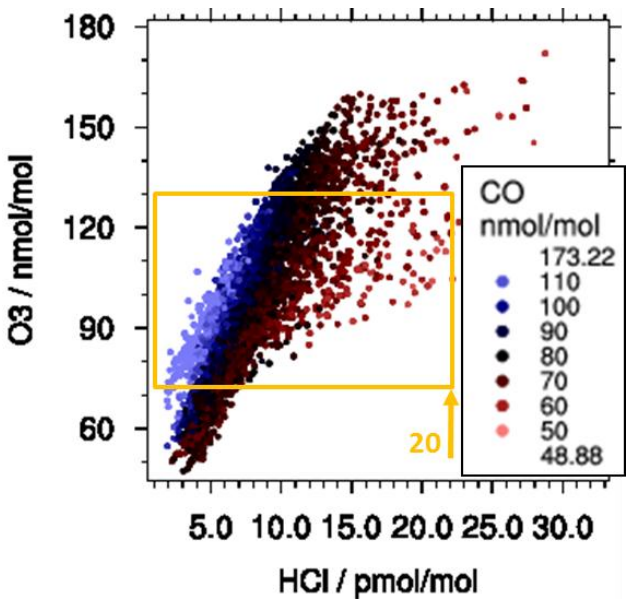
- different in-situ production changes slope
- non-equal contributions from reservoirs = non-symmetric shrinking of mixing line

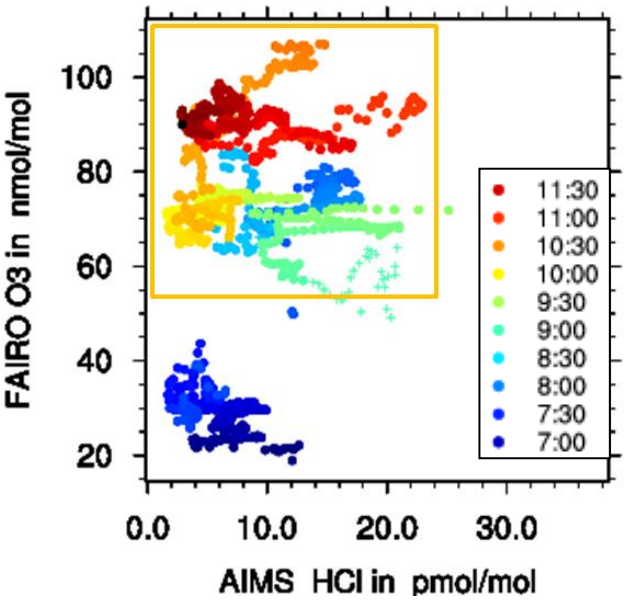
- mixing complete = one point in tracer-tracer diagram

6. Tracer-tracer relations > HCl vs O3

Simulation: TP +50 hPa -100 hPa | Simulation: 200-100 hPa | Observations







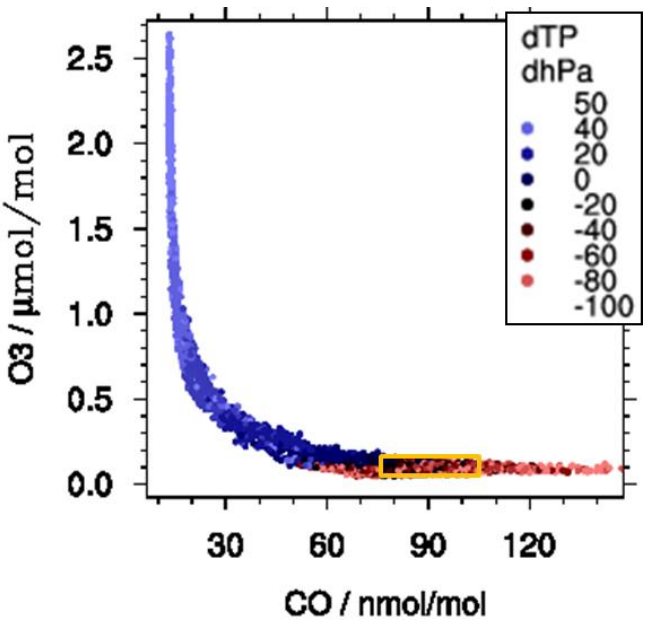
- Observations in tropospheric branch
- HCl ~ stratospheric
- CO ~ tropospheric influence

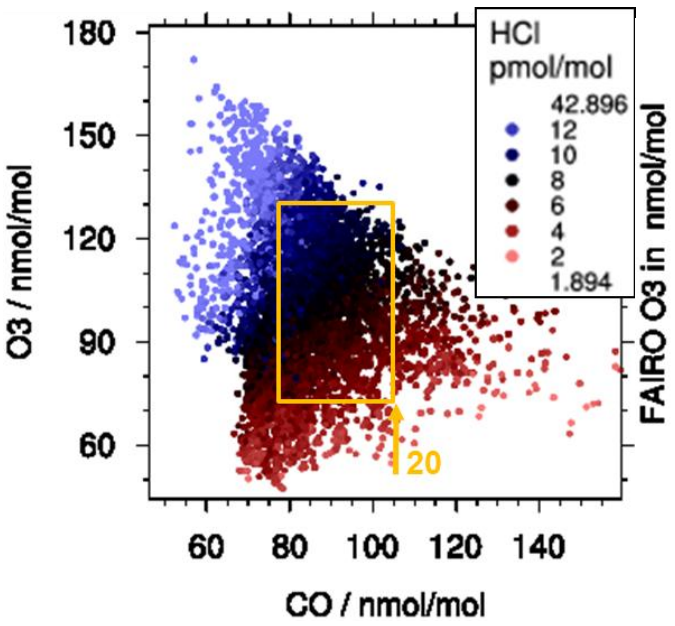
- HCl ~ O3 for a range of strat/trop gradients (incl. zero)
- const. O3 likely corresponds to strat/trop gradient
- const. HCl likely corresponds to gradient of net O3 production

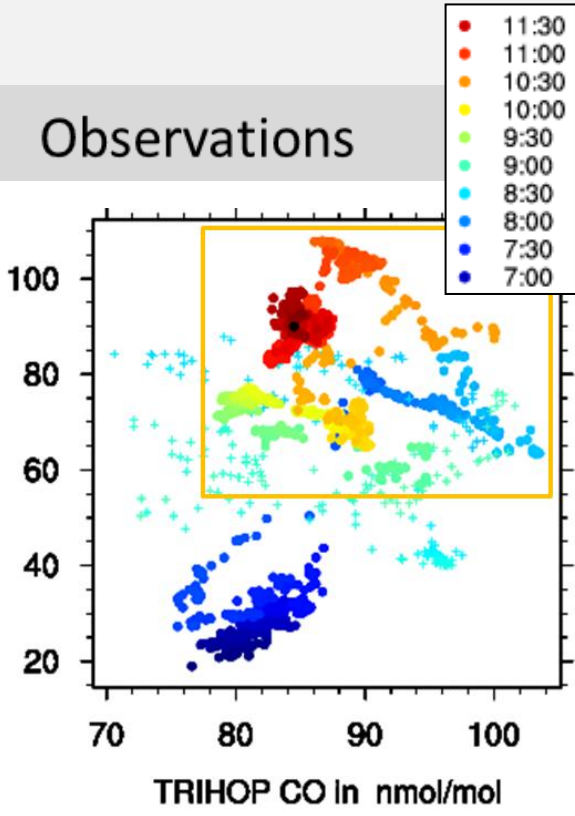
Obs show both scenarios + intermediates

6. Tracer-tracer relations > CO vs O3

Simulation: TP +50 hPa -100 hPa | Simulation: 200-100 hPa | Observations







- Observations in tropospheric branch
- Mixing lines O3 ~ CO likely originate from reservoirs of similar HCl, i.e. similar strat. influence → different ProdO3 - LossO3
- Mixing lines -O3 ~ CO likely to correspond to a gradient of strat./trop. influence
- negative slopes dominate
- Shifted by different ProdO3 - LossO3 ?

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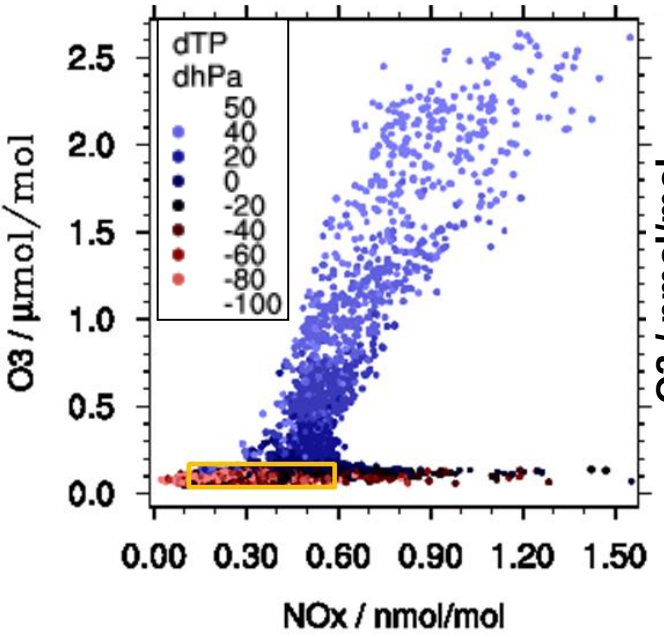
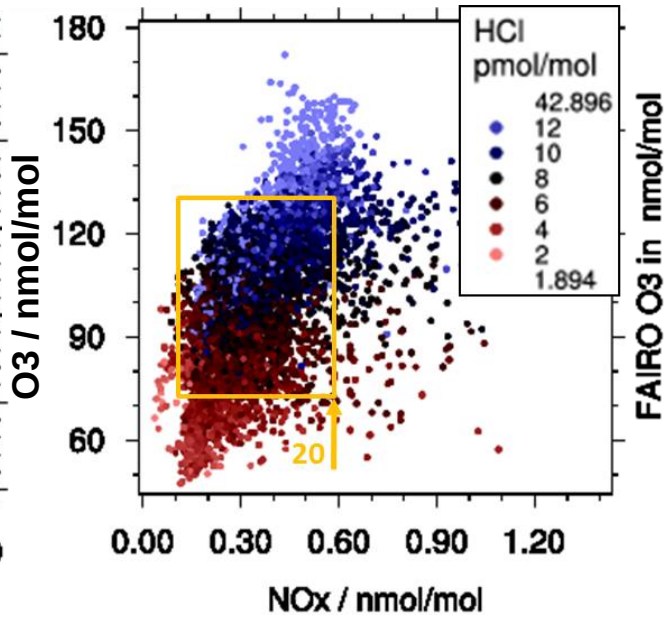
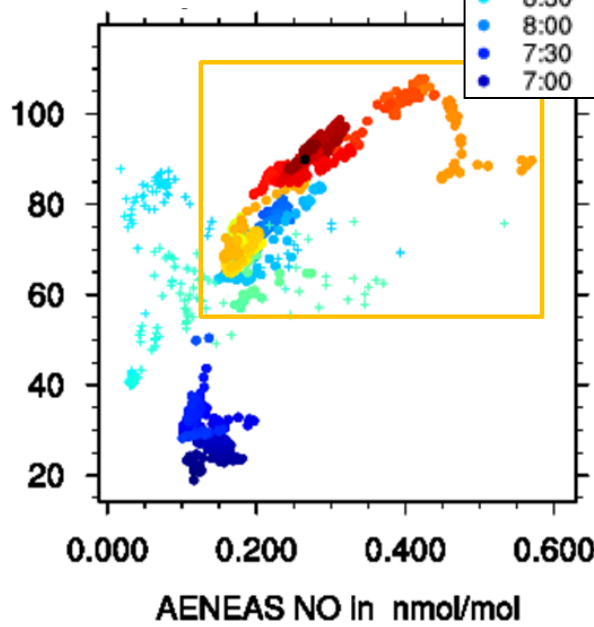
6. Tracer-tracer relations > $NO_{(x)}$ vs O3

Simulation: TP +50 hPa -100 hPa | Simulation: 200-100 hPa | Observations







- ambiguous @ intersection of tropospheric and stratosheric branch

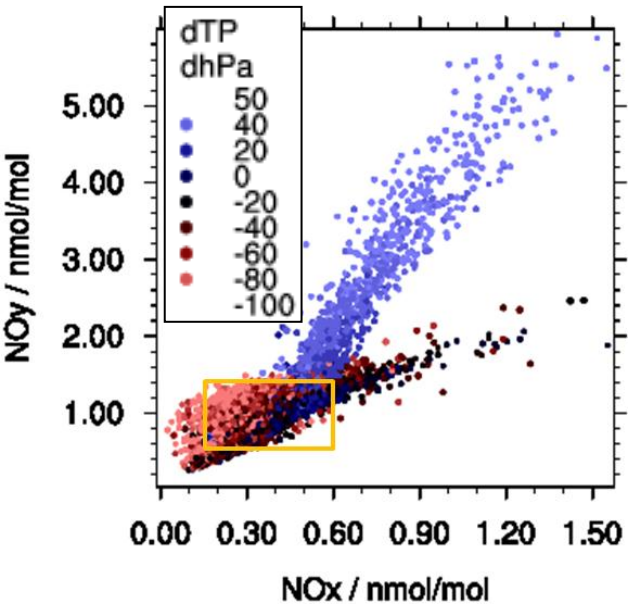
- Enhanced O3 may either coincide with

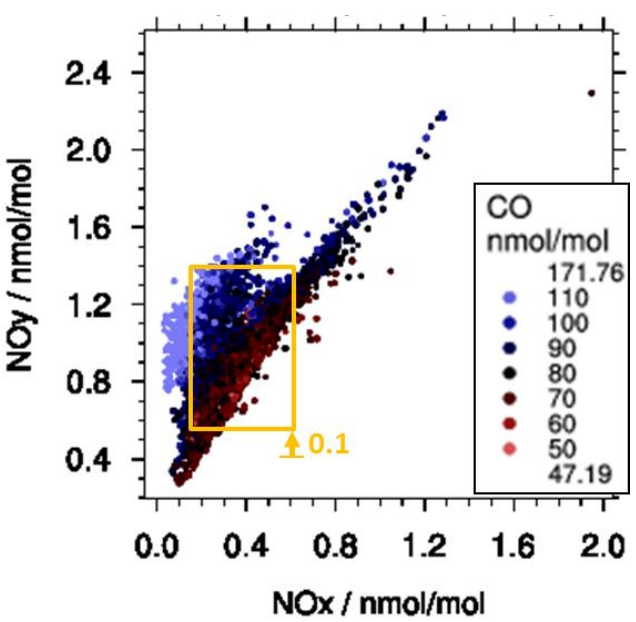
  enhanced (small) strat.
  or
  enhanced trop. contribution

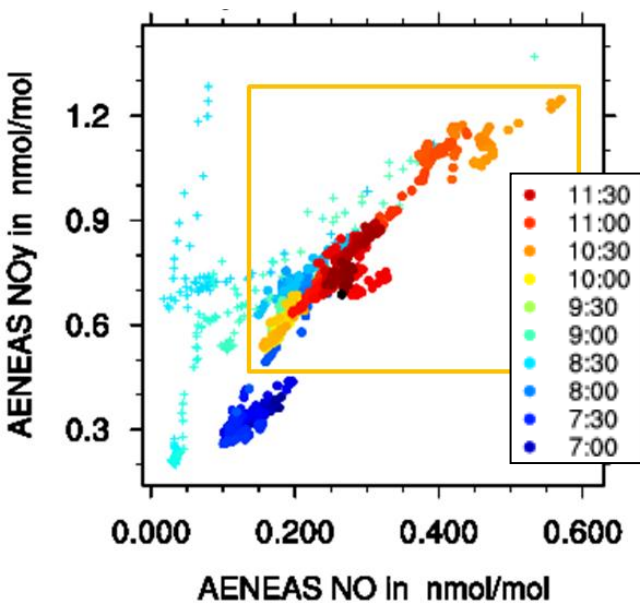
} Observations mostly O3 ~ NO

6. Tracer-tracer relations > $NO_{(x)}$ vs NOy

Simulation: TP +50 hPa -100 hPa | Simulation: 200-100 hPa | Observations



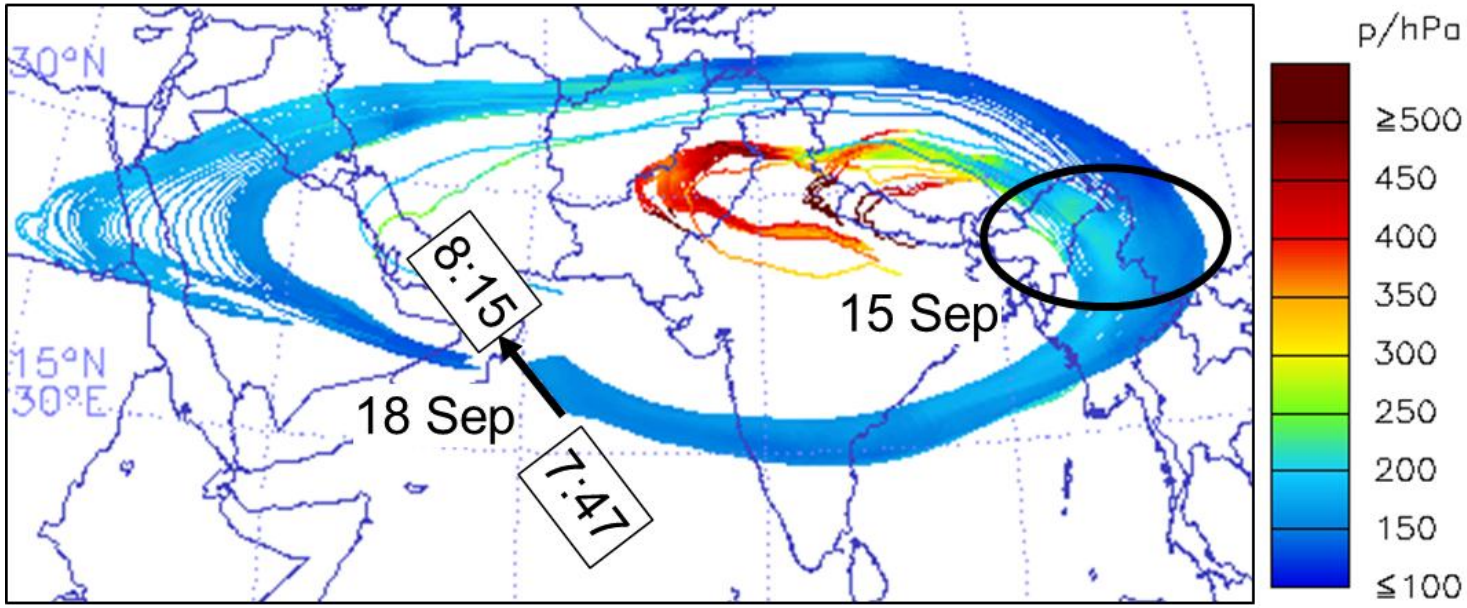




- TP branch is lower than stratospheric branch or UT region
  → consistent with local NOy minimum at TP

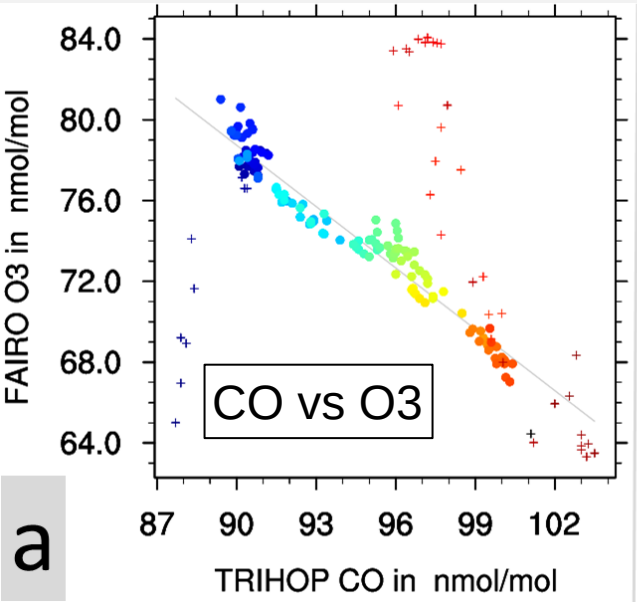
- NOy ~ NOx favoured for a range of gradients of tropospheric influence

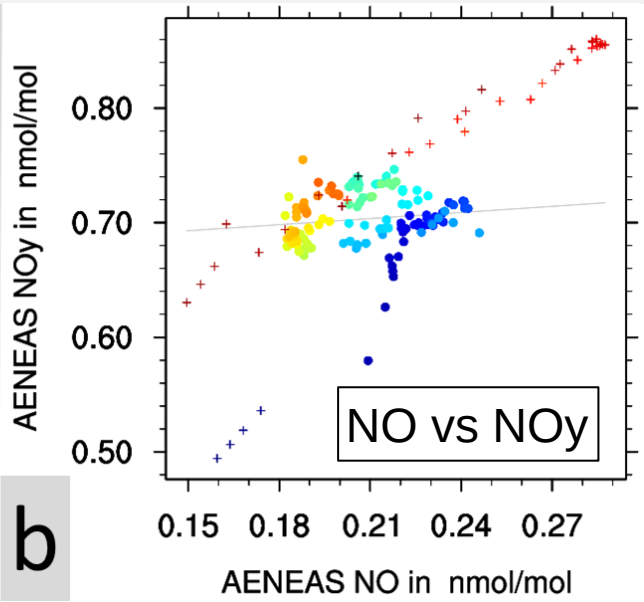
7. Entrainment @ eastern ASMA flank > Zoom in

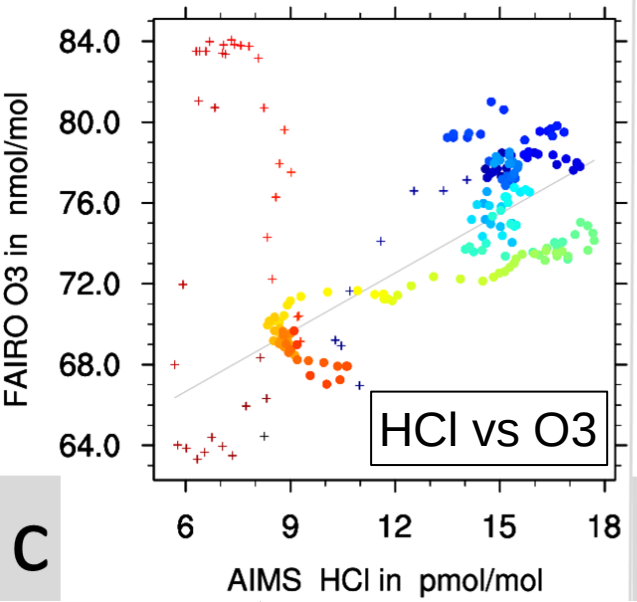


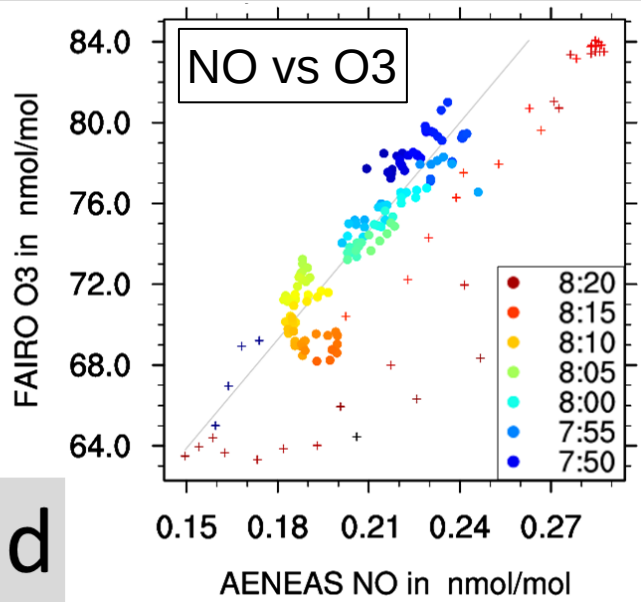
Fringe filament measured outside-in

7. Entrainment @ eastern ASMA flank > Zoom in









Mixing line between
CO↓↑O3 (out)
&
CO↑↓O3 (in)

Negative slope:
~ strat./trop. gradient

a

Suite of parallel lines
NOx ~ NOy
Corresponding to different CO

b

O3 ~ HCl: some strat./trop. Gradient

c

O3 ~ NO: ?

d

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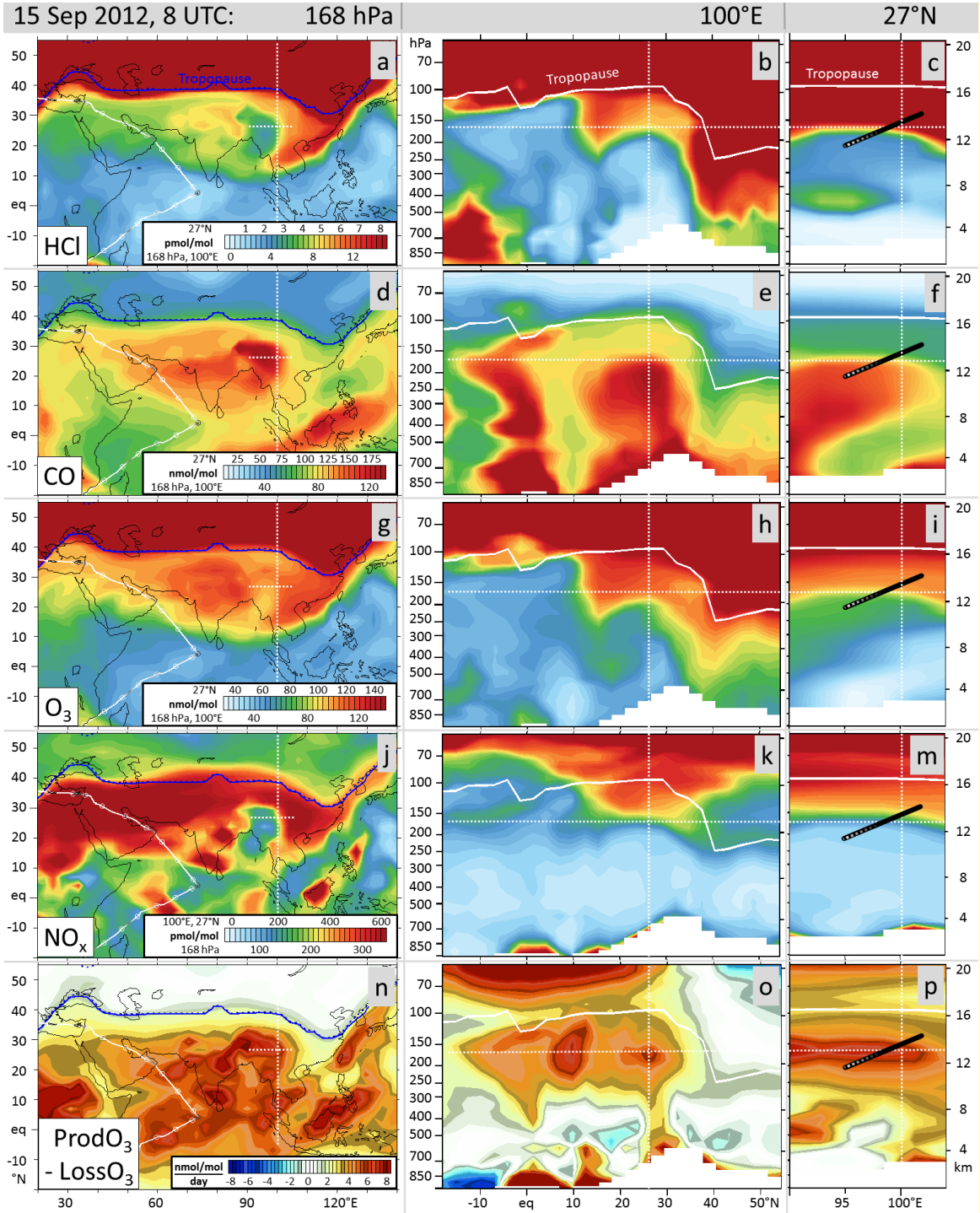
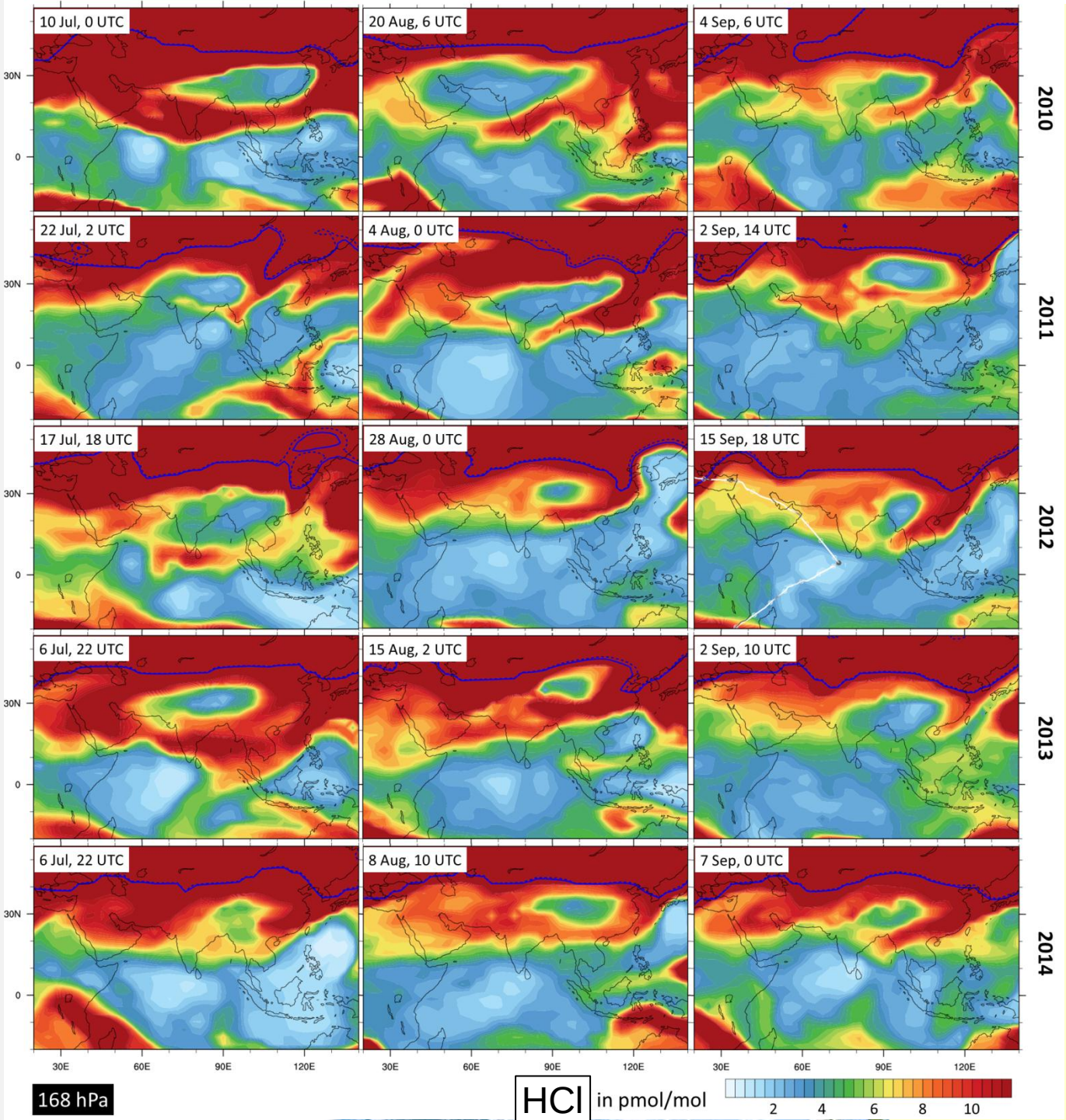
7. Entrainment @ eastern ASMA flank > Zoom in



Situation as seen by simulation:

- Measurements originate in gradient between UT air and uwelling
- veering away from TP
- Net ProdO3 max at interface (CO↑ + NO↑): O3 gradient in mixing line not due to ΔProdO3
- Net Prod O3 rather ~CO than ~NO
- Entrainment from TP region at tropopause trough (may not have contributed to actual measurements)

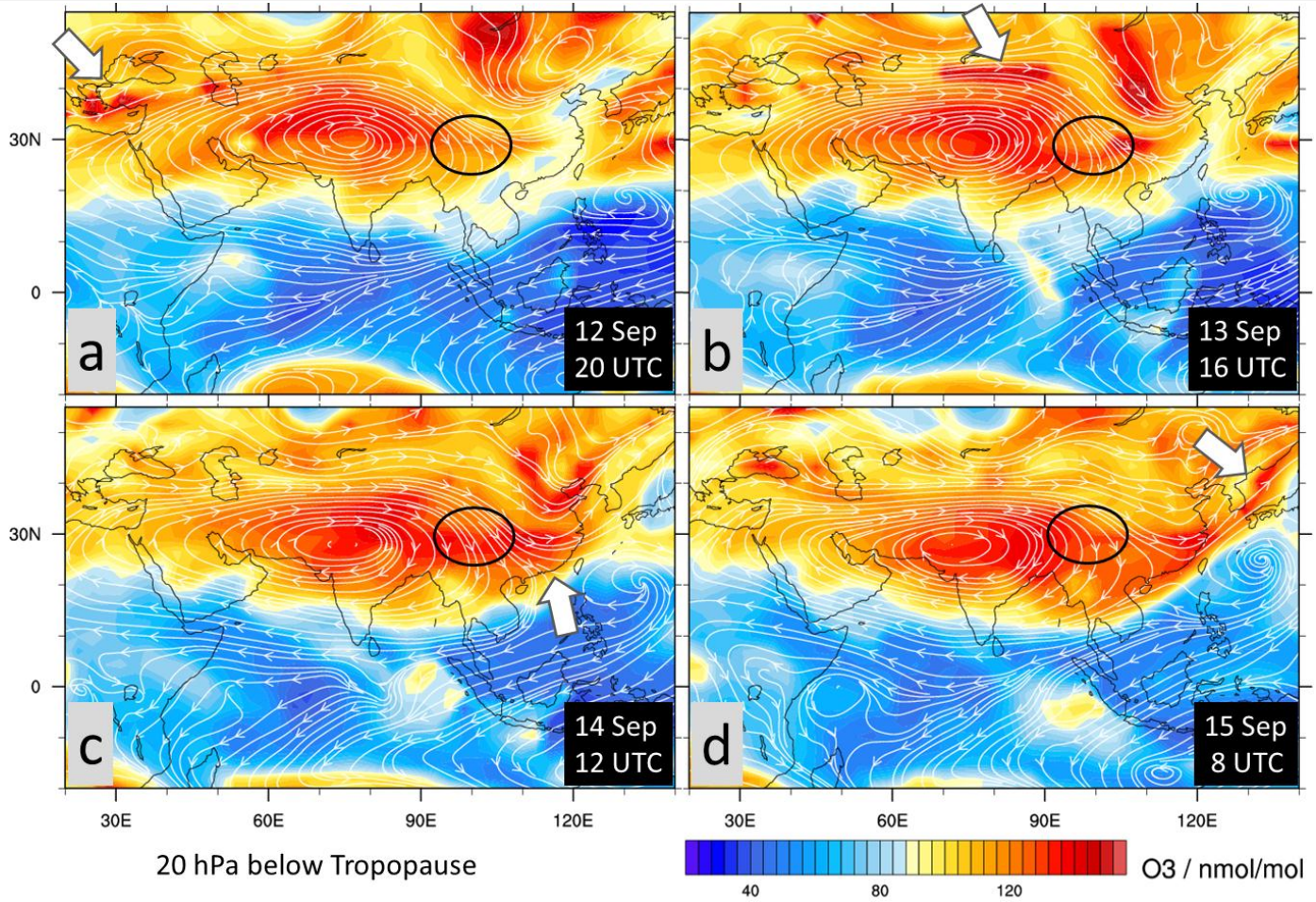
7. Entrainment @ eastern ASMA flank > Zoom out



Simulation:

- Entrainment of stratospheric tracer (incl. TP region) at eastern ASMA flank not a rare event
- mostly associated with TP trough

7. Entrainment @ eastern ASMA flank > STE



- STE hotspot over Eastern Mediterranean may contribute some stratospheric signatures to ASMA
- Event shown here was too early for HALO ESMVal
- Note: there is always entrainment of enhanced O3 at eastern flank

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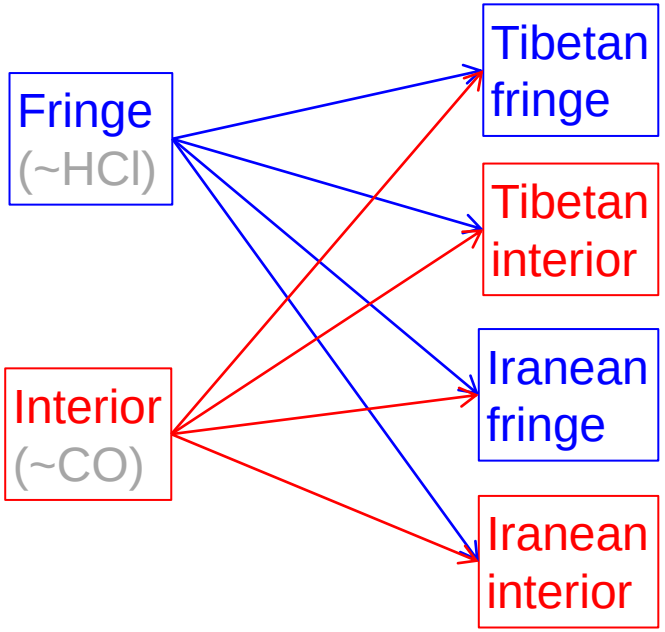
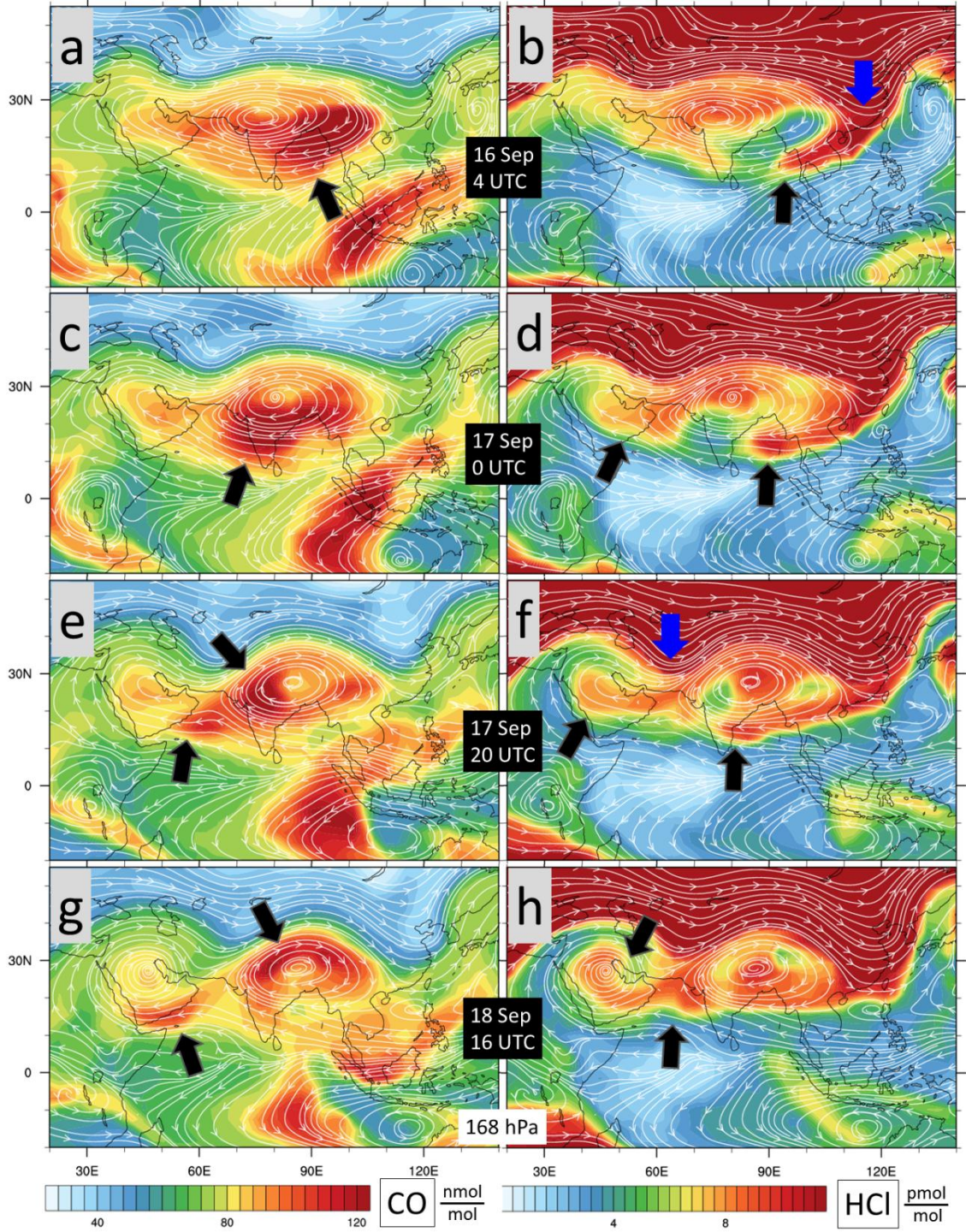
8. Splitting and stirring
> Event @ HALO ESMVal

- ASMA splits in response to a 2nd TP trough, moving in from the West
- Redistribution across former transport barriers:





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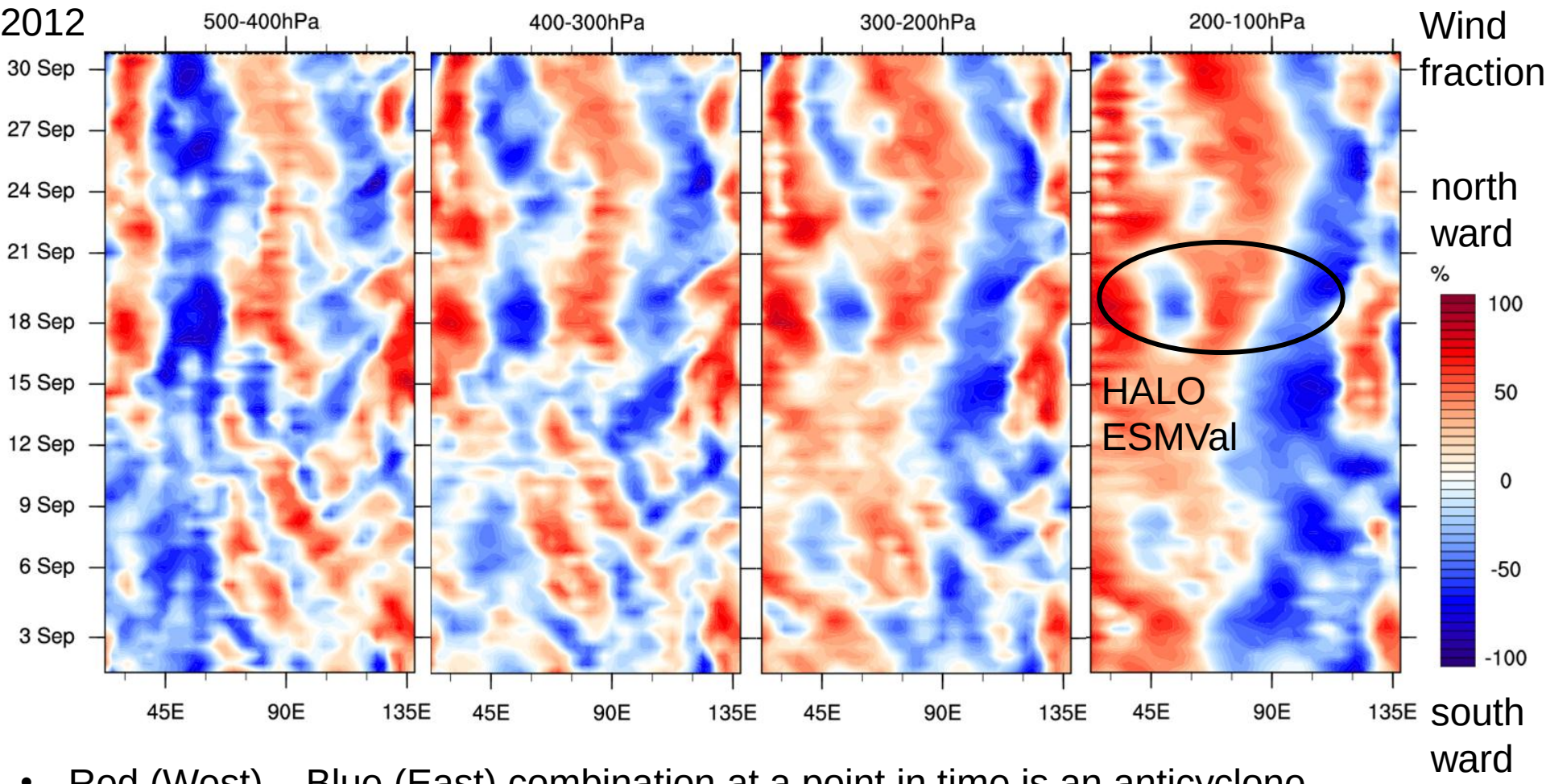
8. Splitting and stirring > @ Different altitudes



- Red (West) – Blue (East) combination at a point in time is an anticyclone
- Tibetan anticyclone dominates UT
- Iranean anticyclone becomes more important in middle troposphere

10–40°N

8. Splitting and stirring
> 5 seasons

c

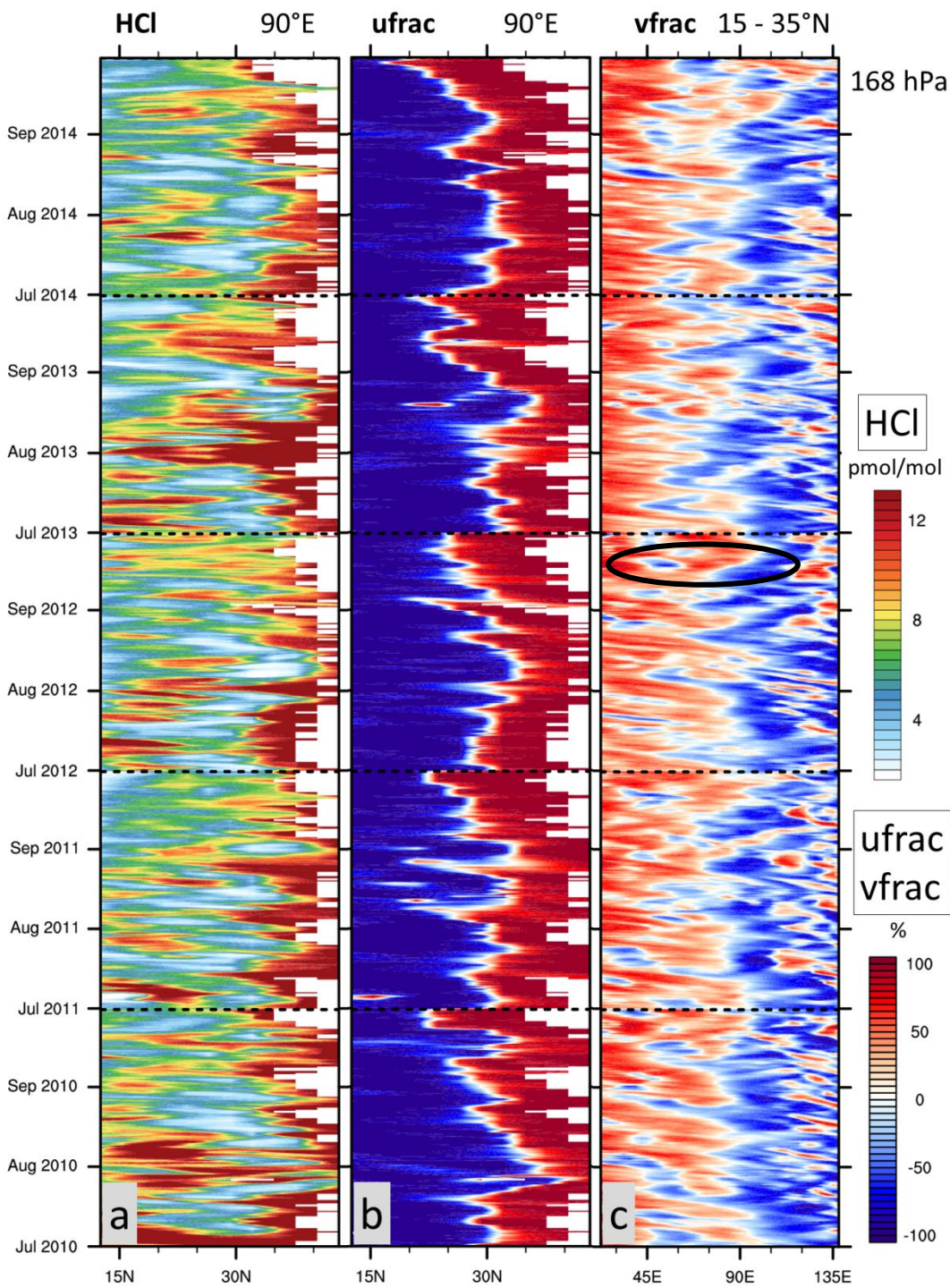
- ASMA splitting events occur quite frequently
- Tibetan part dominates UT

b

- Ridgeline latitude varies

a

- Southern fringe often associated with increased HCl, i.e. TP entrainment



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Summary

- HALO ESMVal transected ASMA filament 3 times in September 2012: increased O3, CO, HCl, NOy
- mixture of lower tropospheric upwellings and UT ASMA air
- ASMA UT trace gas signatures show entrainment of stratospheric components, probably from the TP region at eastern ASMA flank
- In-situ net O3 production increased in ASMA, where UT NOx meets lower tropospheric precursors: Certainly contributes to increased O3
- ASMA splitting / Eddy shedding overcomes transport barriers of the intact anticyclone and stirs effectively
- Entrainment at eastern ASMA flank & Eddy shedding sensu lato are common