Does Pollution Impact Stratospheric Water Vapor?

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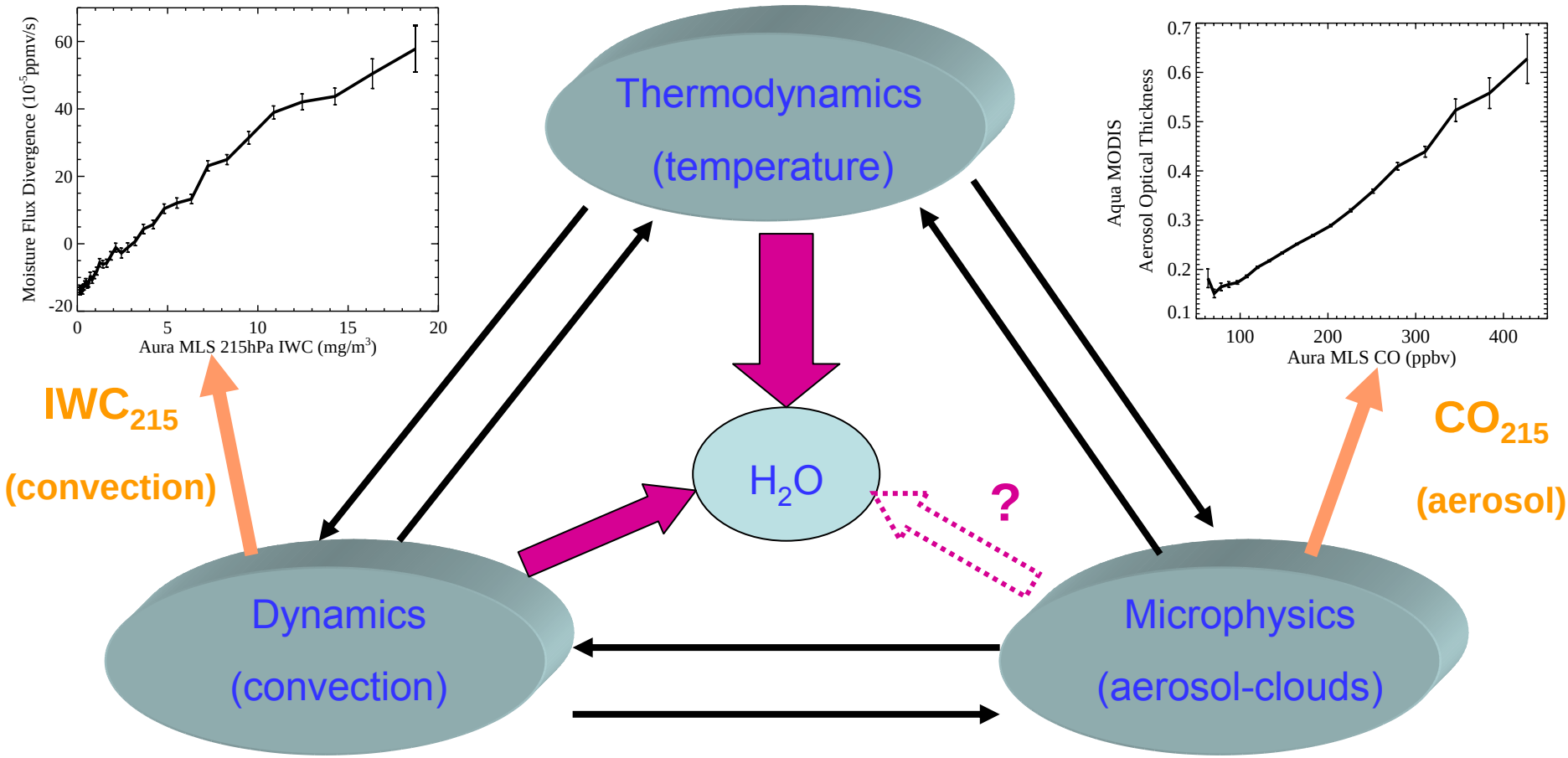
Motivation

- It was postulated that microphysical impact of aerosol pollution on cirrus clouds may play a role in the entry of tropospheric water vapor into the stratosphere and thus the stratospheric water vapor trends (e.g. Sherwood 2002; Liu et al. 2007).
- Observational substantiation of the postulation/model results is yet available.

Objective

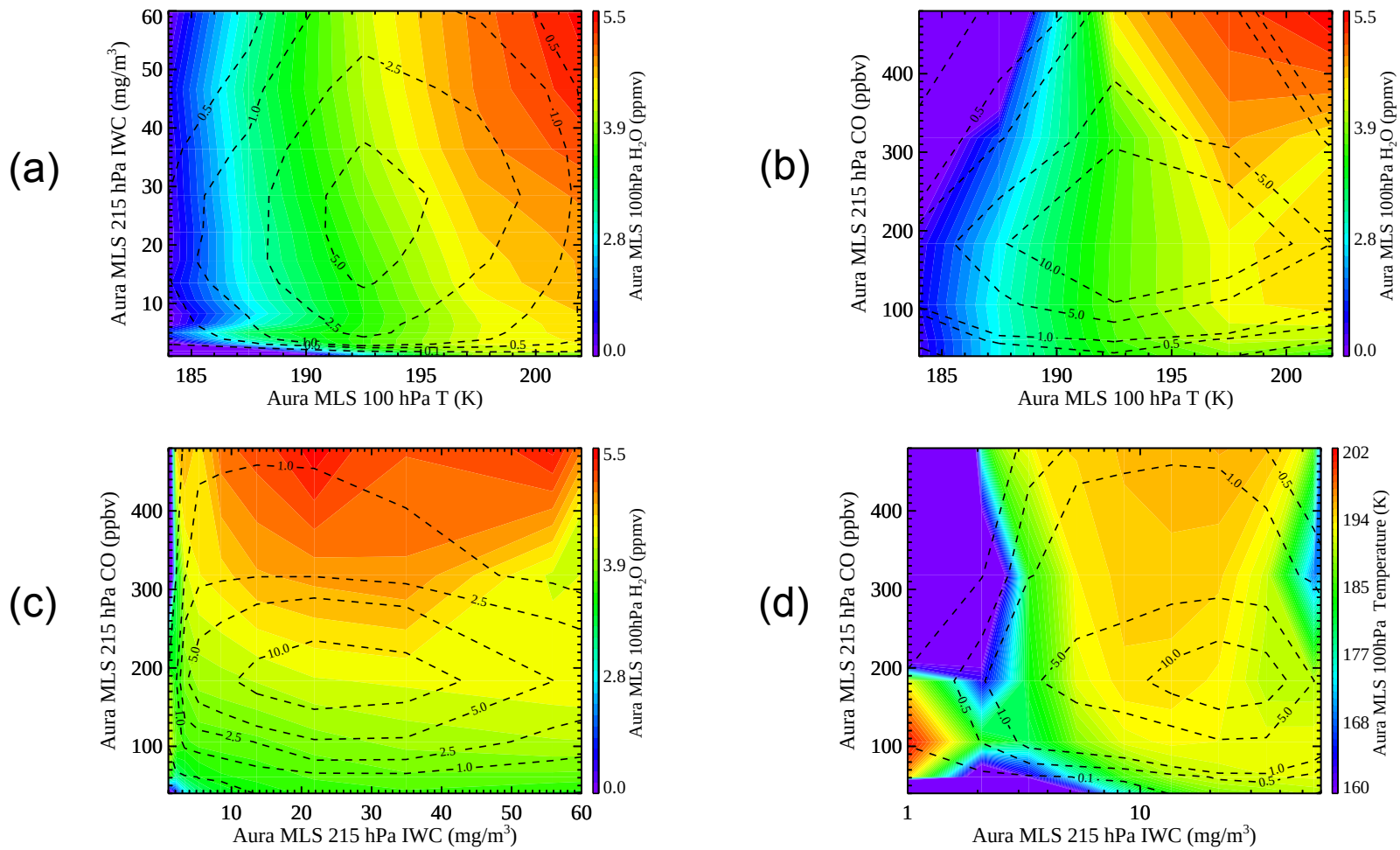
- Using collocated/coincident multi-satellite observations to explore the role of aerosol-cloud interactions on tropical tropopause layer (TTL) water vapor and its transport into the stratosphere.
- Data used:
  Aura MLS water vapor, temperature, relative humidity, ice water content, carbon monoxide
  Aqua MODIS cloud fraction, cloud effective radius, aerosol optical thickness
  Aqua AIRS water vapor, temperature and cloud fraction

Factors that Control TTL H_2O



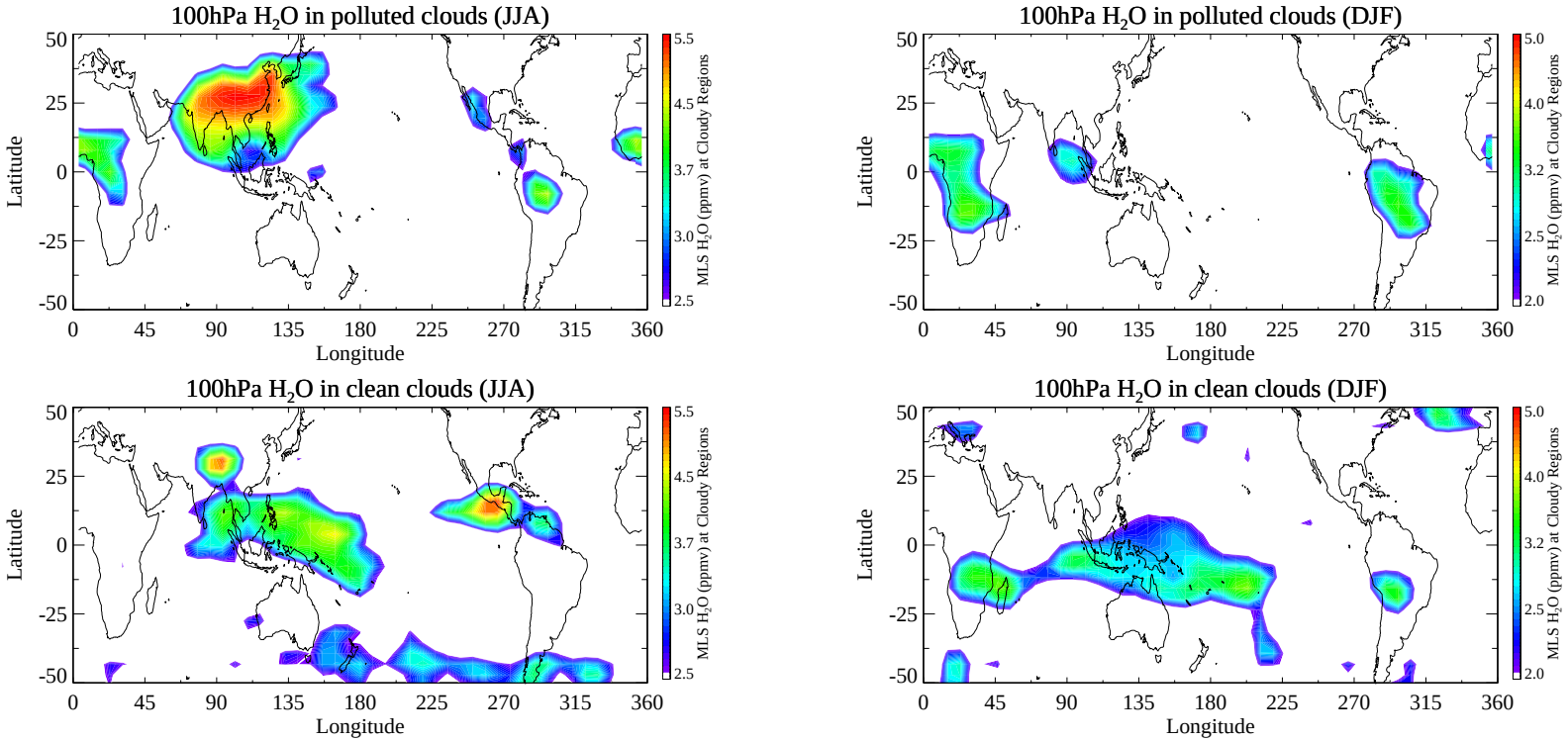
- IWC at 215 hPa (IWC_{215}) is approximately linear with the moisture flux divergence at 200 hPa → an index for convective strength
- CO at 215 hPa (CO_{215}) is approximately linear with AOT → an index for aerosol loading

Bi-Variate Composite (BVC) Analysis



- qv_{100} increases with the increase of T_{100}.
- When T_{100} < ~192 K, qv_{100} varies little with IWC_{215} or CO_{215}.
- When T_{100} > ~192 K, qv_{100} increases with IWC_{215} or CO_{215}.
- The increase of qv_{100} with IWC_{215} or CO_{215} is associated with the increase of T_{100}.

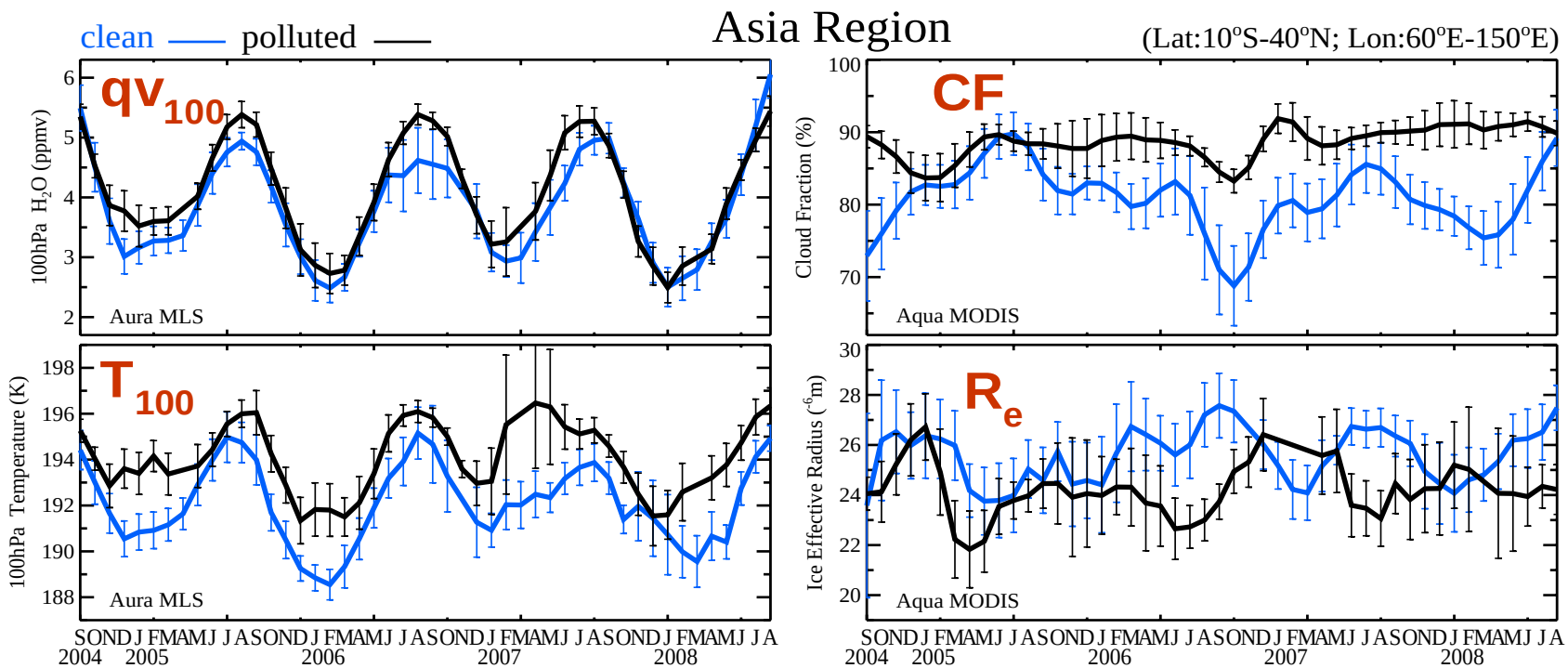
100 hPa H_2O in the Polluted and Clean Clouds



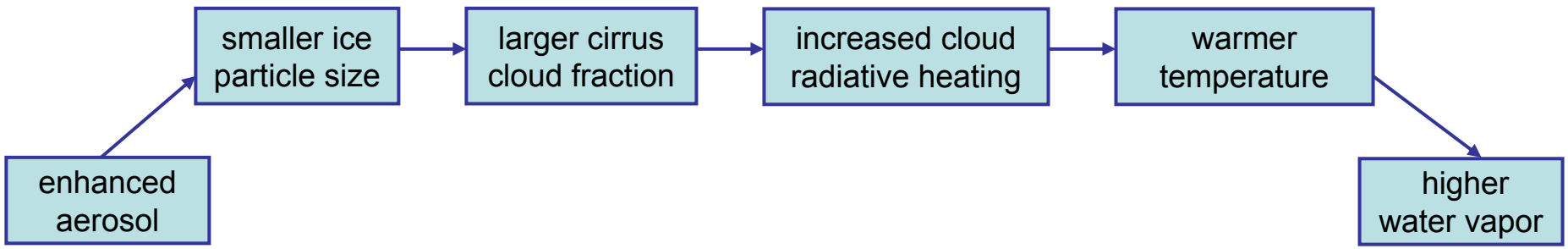
- The qv_{100} differences between the polluted and clean clouds are more pronounced in summer than in winter.

- In summer, three regions of polluted clouds are associated with higher qv_{100} than their clean cloud counterparts. South Asia continent shows the strongest enhancement of qv_{100} in the polluted clouds.

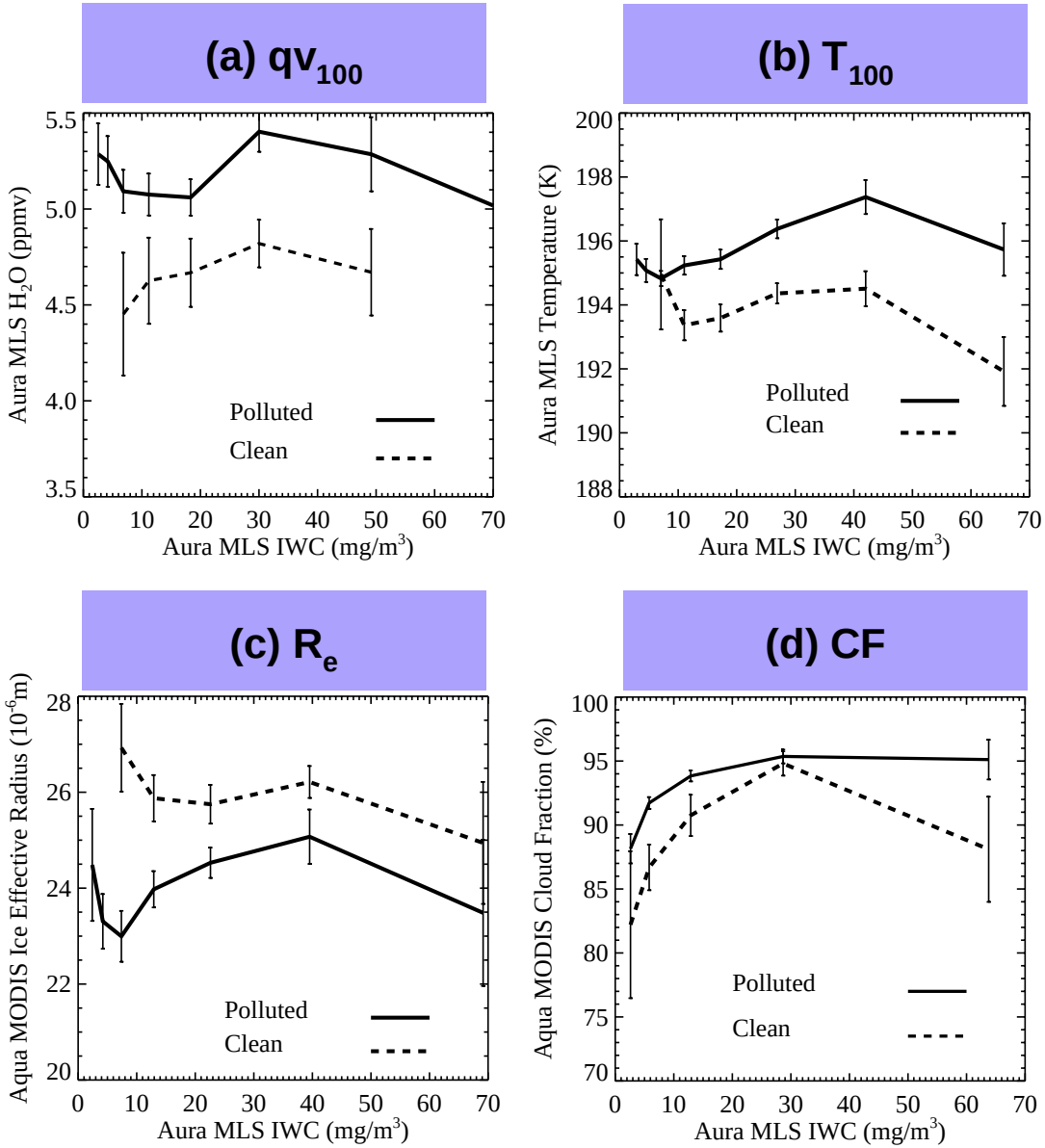
Observed Time Series over Asia



Working Hypothesis:



Focus Analysis of South Asia in Summer

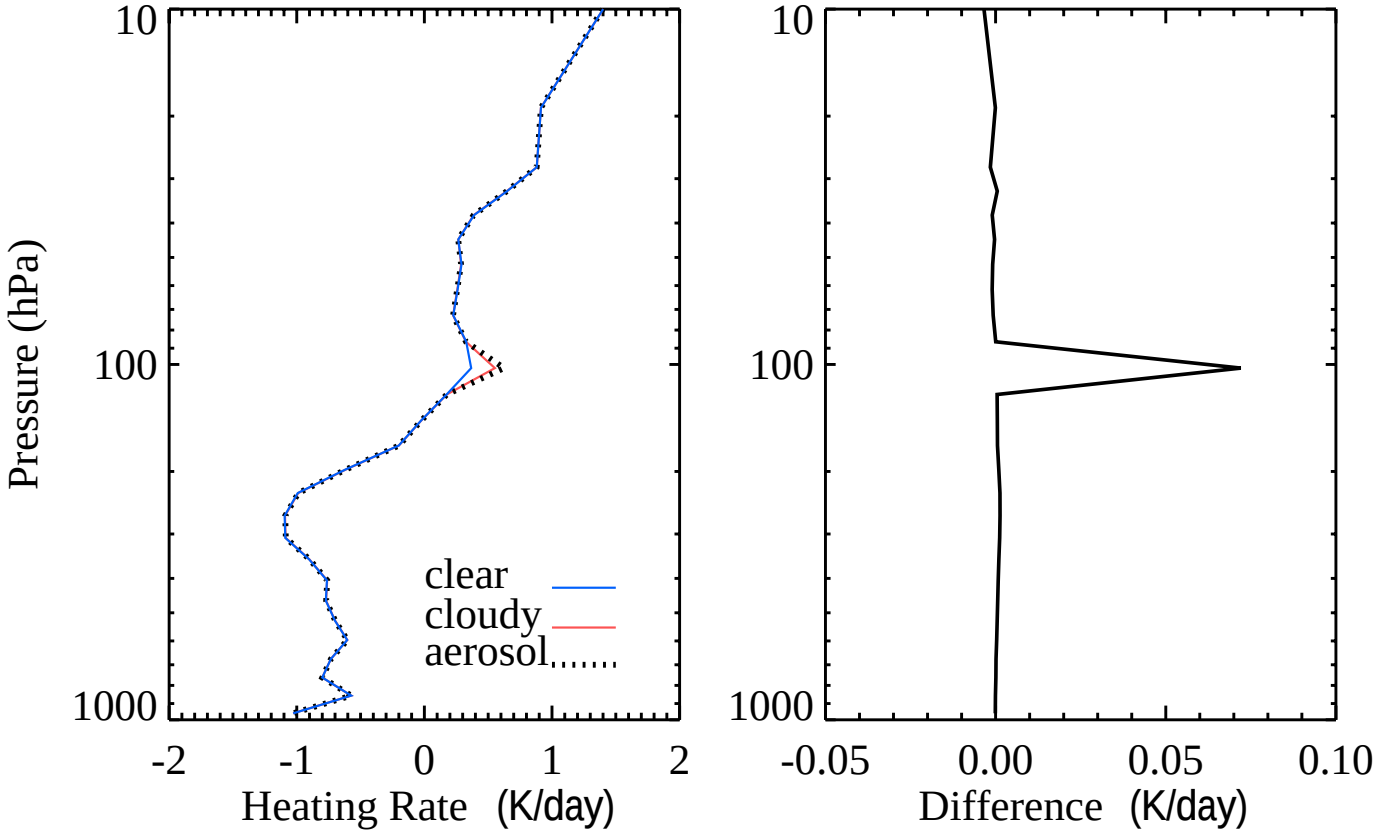


For the same amount of IWC (convection), compared to the clean clouds, the polluted clouds have:

- Higher water vapor at 100 hPa
- Warmer temperature at 100 hPa
- Smaller ice cloud effective radius
- Larger cloud fraction

enhanced aerosol
↓
smaller ice particle size
↓
larger cirrus cloud fraction
↓
increased cloud radiative heating
↓
warmer temperature
↓
higher water vapor

Back-of-Envelope Calculations
aerosol-clouds-radiation-water vapor interactions



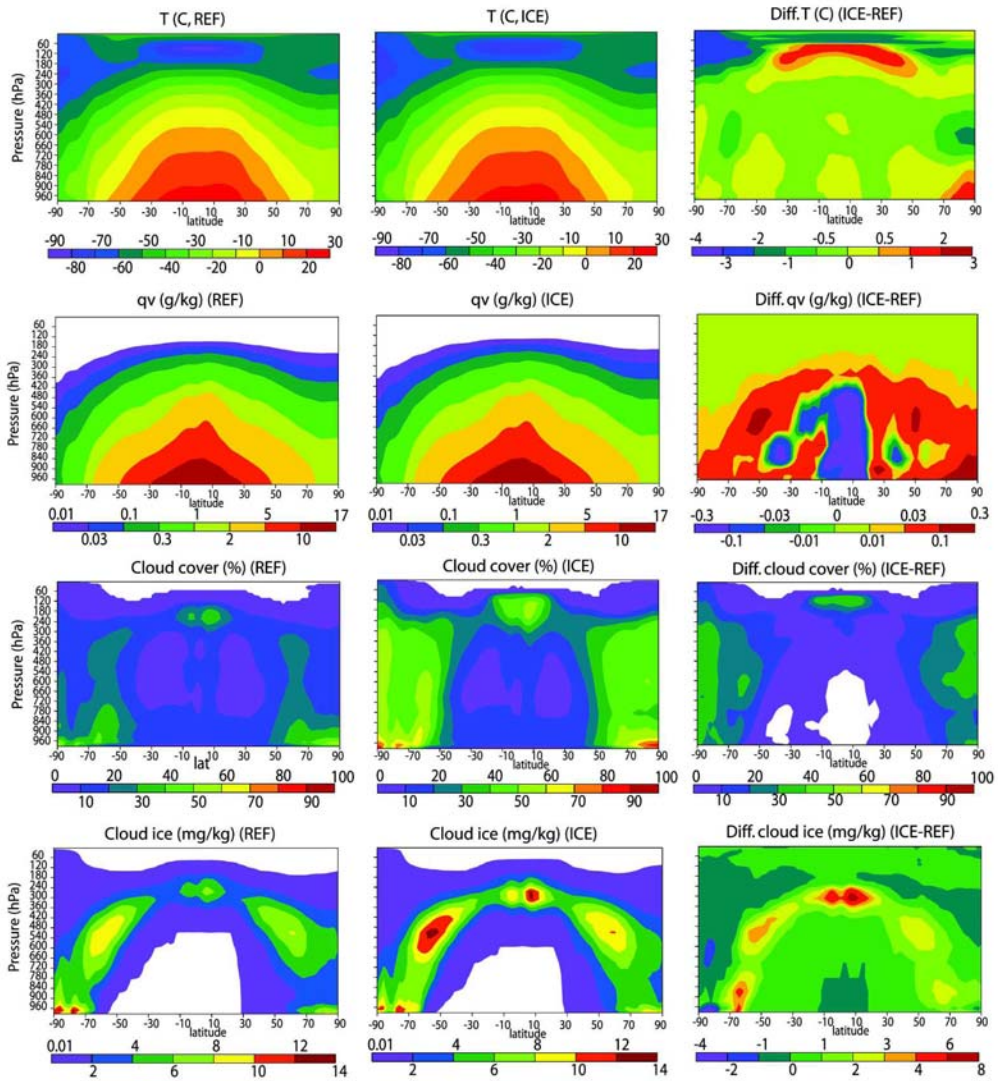
IWC_{100}: 0.1 mg/m^3

R_e: 25 μm → 22.5 μm

CF: 40% → 50%

⇒ ΔHR: 0.07 K/day ⇒ ΔT: ~2 K ⇒ Δqv_{100}: ~1 ppmv

Aerosol-Cloud-Climate Model Results



T

q_v

CF

IWC

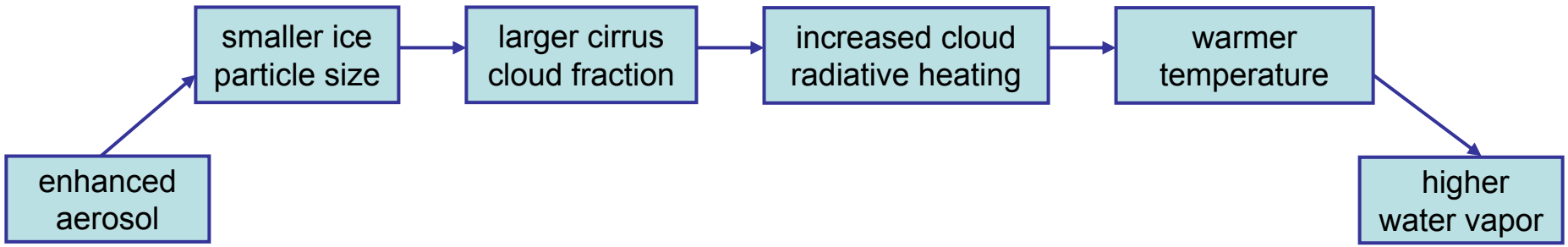
FIG. 7. Annual zonal mean latitude vs pressure cross sections of temperature (K), specific humidity (g kg^{-1}), cloud cover (%), and cloud ice mass mixing ratio (mg kg^{-3}) for simulations REF and ICE, and the difference, ICE – REF.

From Liu, et al. 2007, J. Clim

Conclusions

- Using Aura MLS observed CO at 215 hPa as an index for aerosol pollution loading to classify clouds as “polluted” or “clean”, we find that the polluted clouds are generally associated with higher water vapor (specific humidity) at 100 hPa than the clean clouds, notably in South Asia during summer.

- A possible mechanism for the increased water vapor in the polluted clouds is through aerosol-cloud-radiation-water vapor interaction, i.e.,



- Further analysis using improved cirrus clouds and aerosol observations (such as CALIPSO data) will help to corroborate the microphysical effect of aerosol cloud interaction on 100 hPa water vapor and thus influencing transport of water vapor into the stratosphere.

Acknowledgements

- We thank funding support from the NASA ACMAP, IDS and AST programs, and Aura MLS project.

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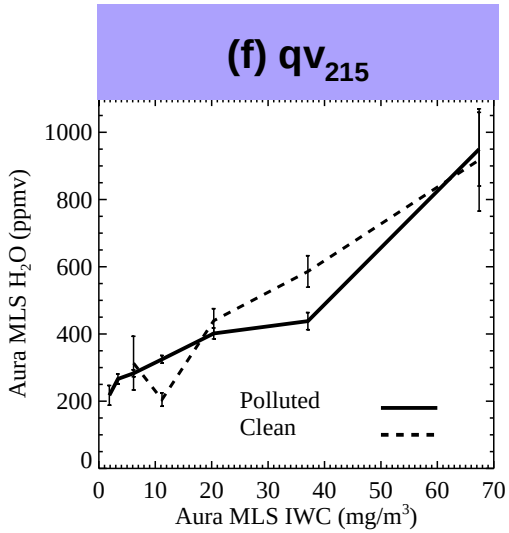
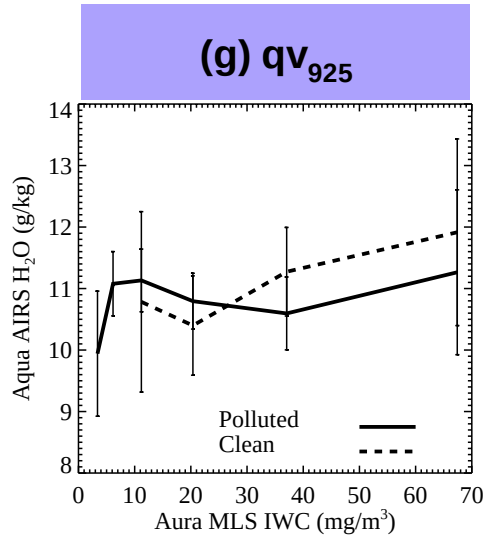
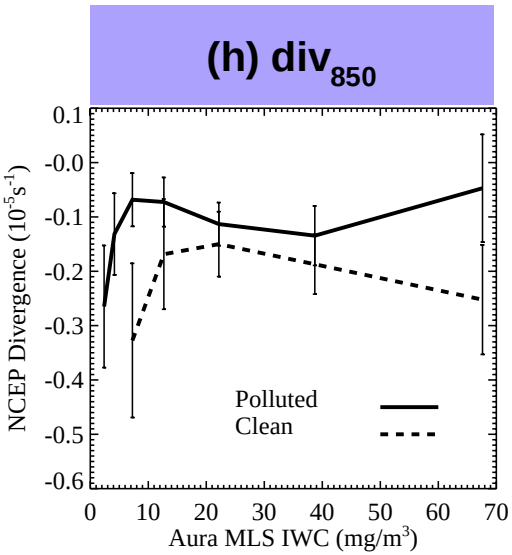
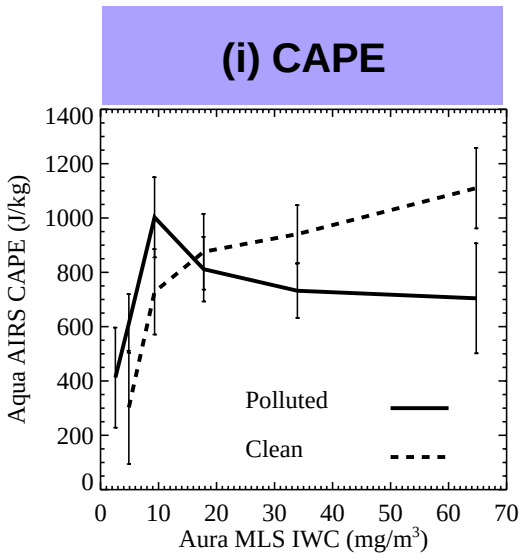
Other Meteorological Differences









Comparing to the clean clouds, polluted clouds have:

- Lower water vapor at 215 hPa
- Similar water vapor at 925 hPa
- Weaker lower-level convergence
- Similar convective available potential energy (CAPE)

Cannot explain the higher qv_{100}.