Revisiting water vapour seasonal cycle observed in tropical lower stratosphere (TLS): Role of BDC, convective activity and ozone

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TLS water vapour seasonal cycle consists of a hydrating and dehydrating phase

HYDRATION OF TLS

Observed during NH summer monsoon

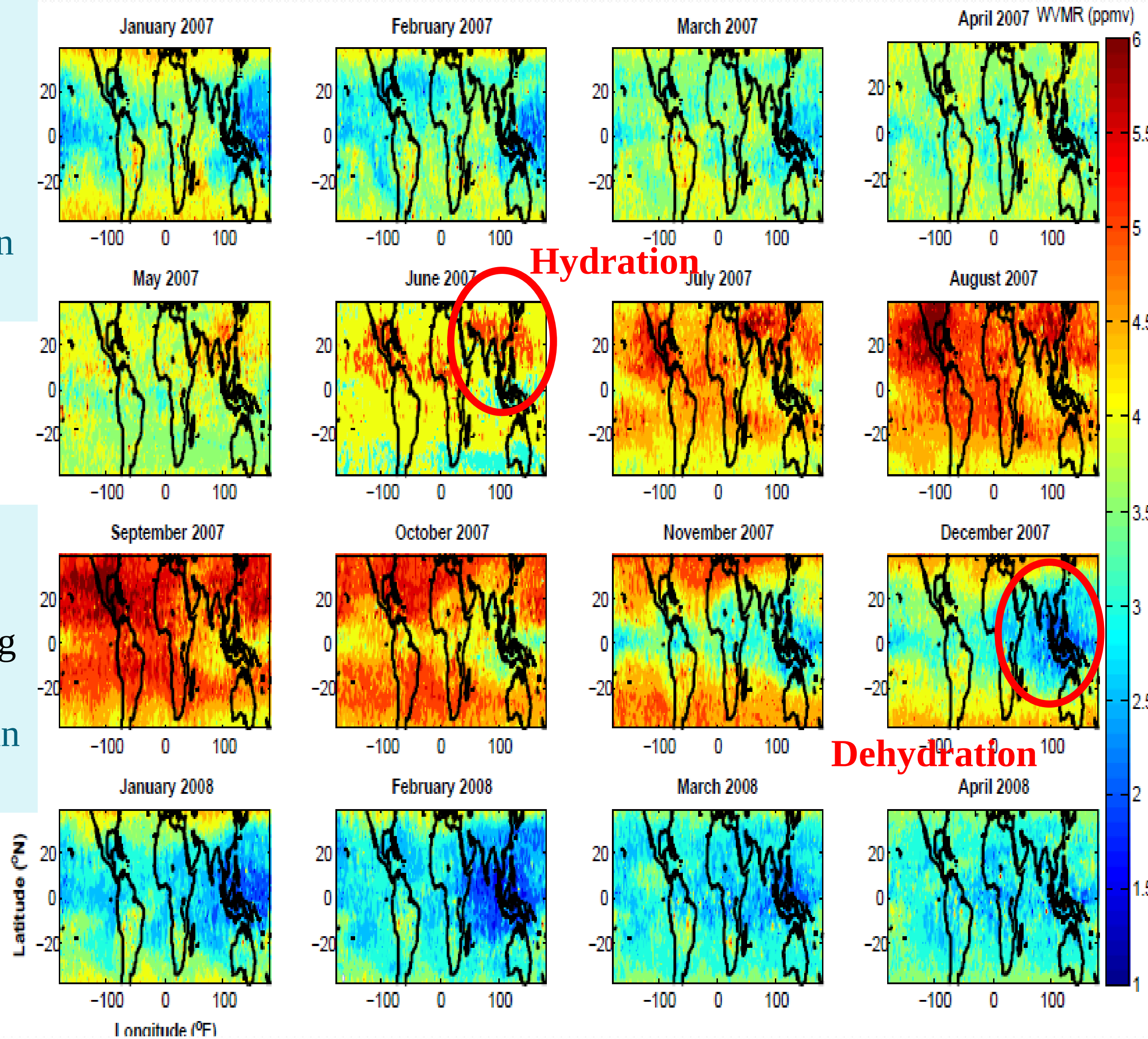
Location: Asian (AMR), American and African monsoon region

DEHYDRATION OF TLS

Observed during NH winter-spring

Location: Indonesian Australian western Pacific region (IAWPR)

Monthly mean WVMR at 100 hPa level obtained from Aura MLS



Hydration of TLS

OLR- proxy for convective activity

Low OLR + Deep penetrating convective clouds

Deepest convection over Asian monsoon region (AMR) during NH Summer -monsoon period

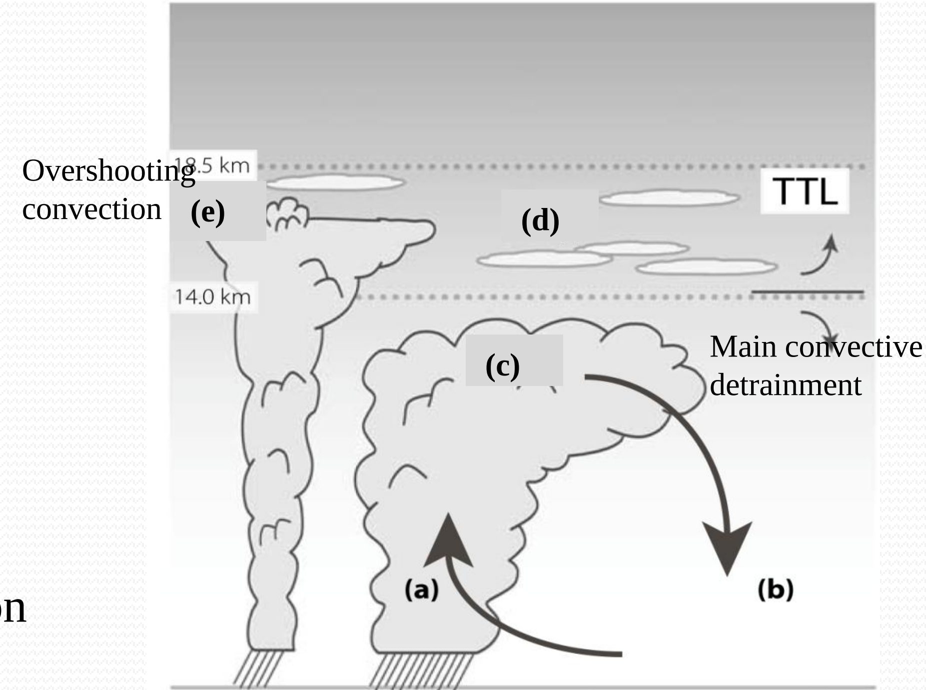
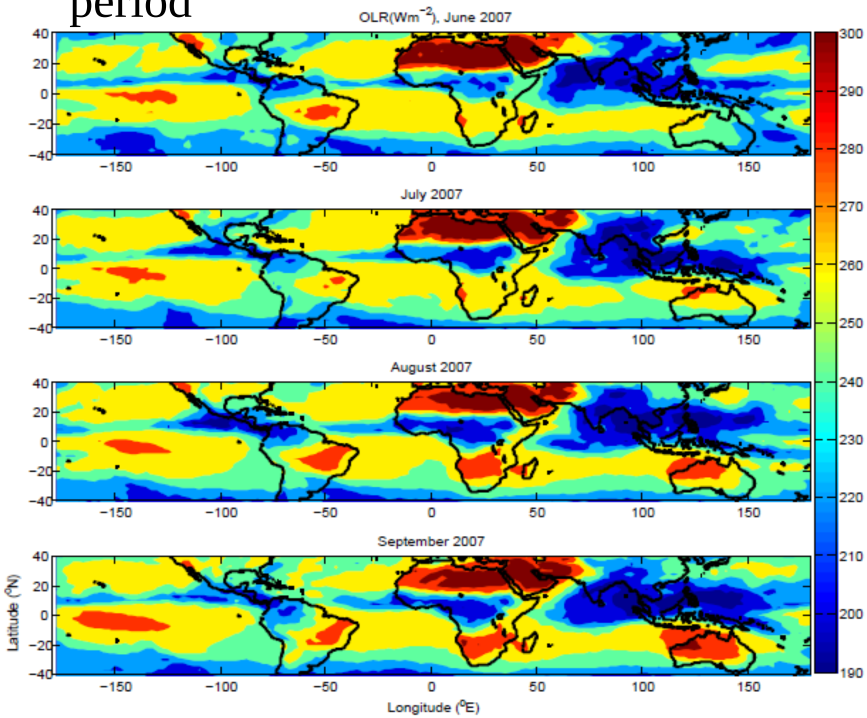
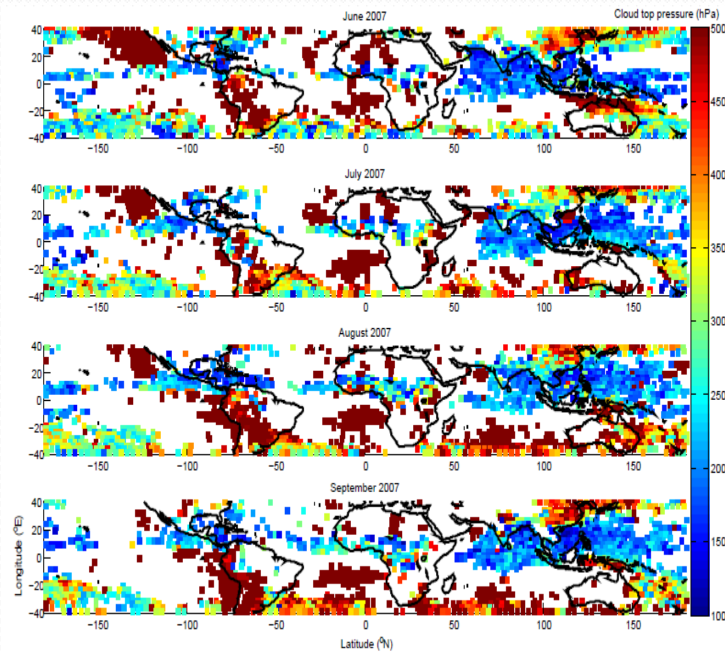


Image Source: Fueglistaler et al., 2009



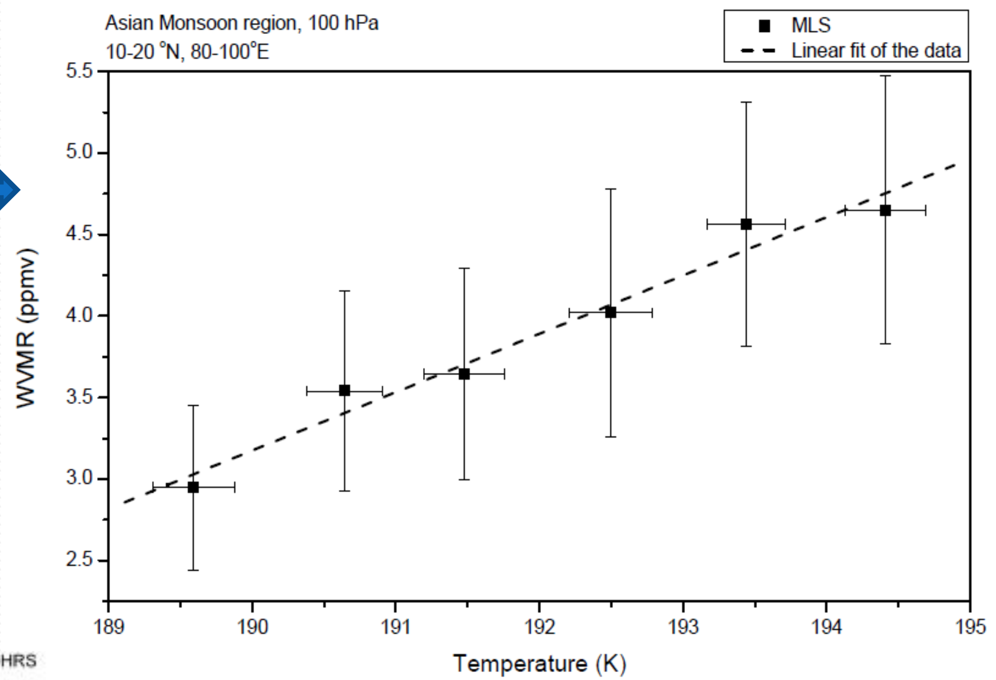
Interpolated OLR distribution from NOAA



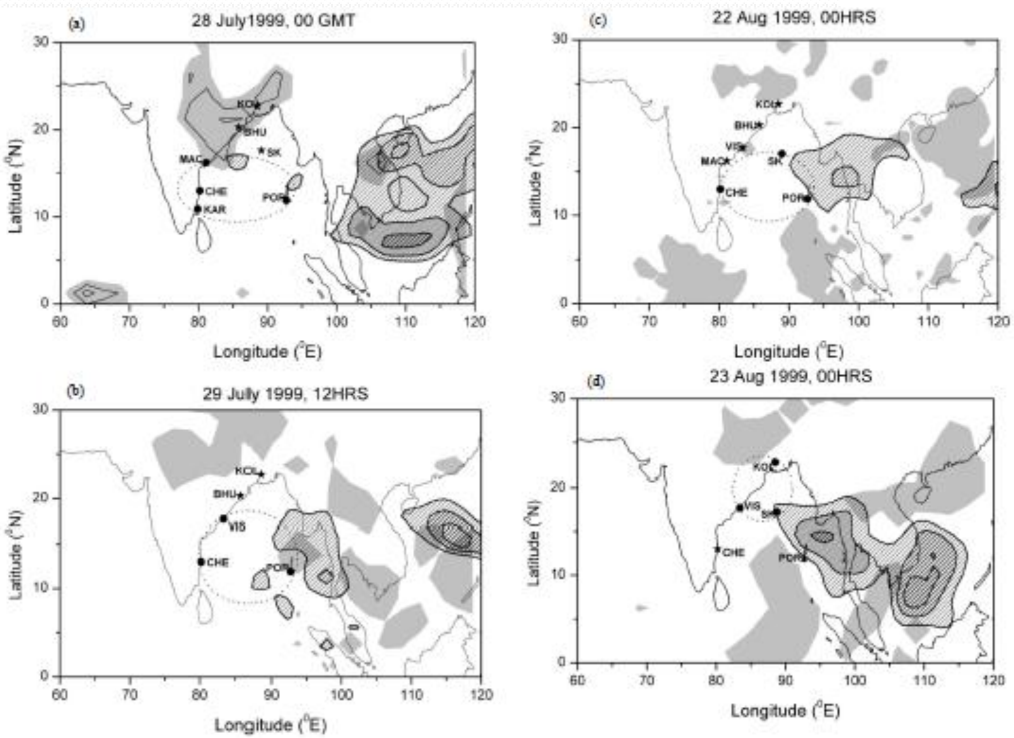
Convective cloud top pressure from ISCCP

Hydration of TLS

T_{100} and $WVMR_{100}$ are observed to be closely related over AMR (Jain et al., 2013).



Patches of extremely low temperatures near the tropopause level are also observed (Jain et al., 2006, 2010 and 2011).



It is not understood that how the hydration of TLS takes place despite the presence of patches of extremely low tropopause temperatures.

Dehydration of TLS

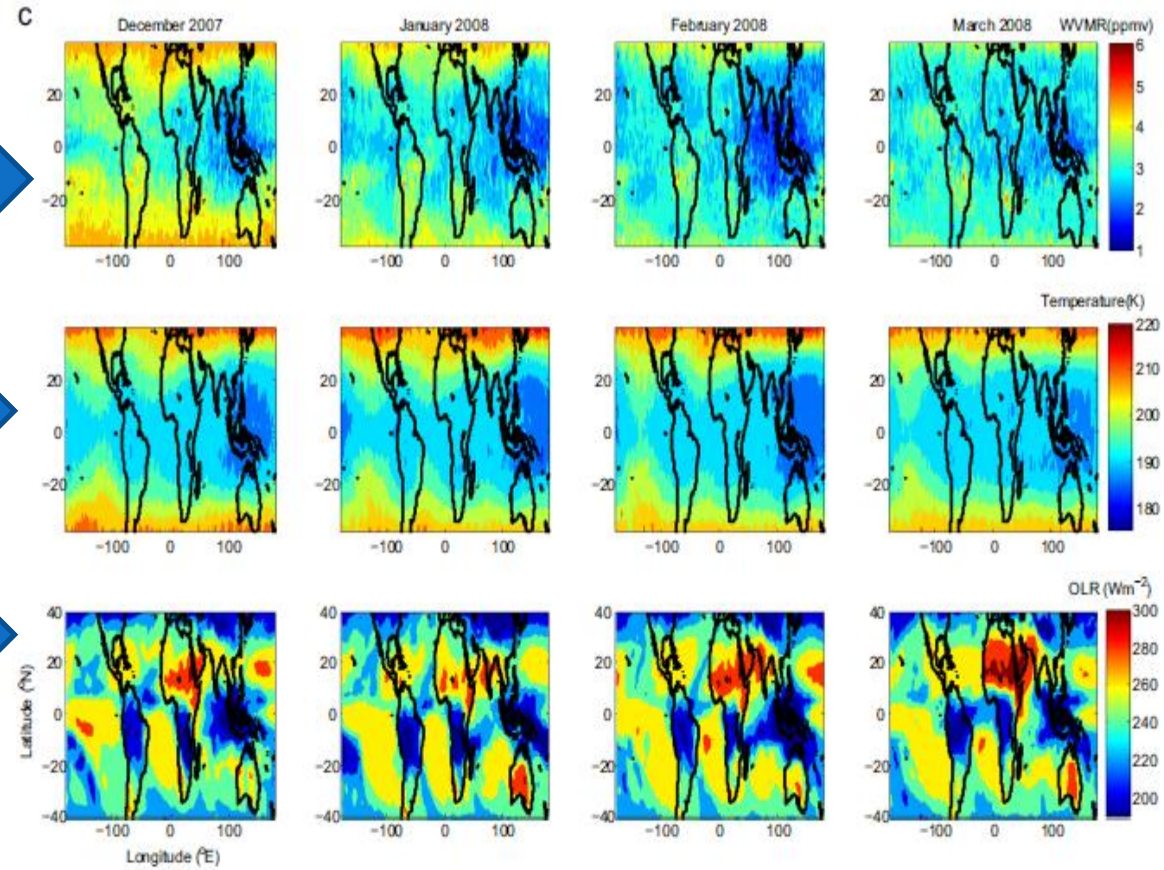
Low $WVMR_{100}$

Low T_{100}

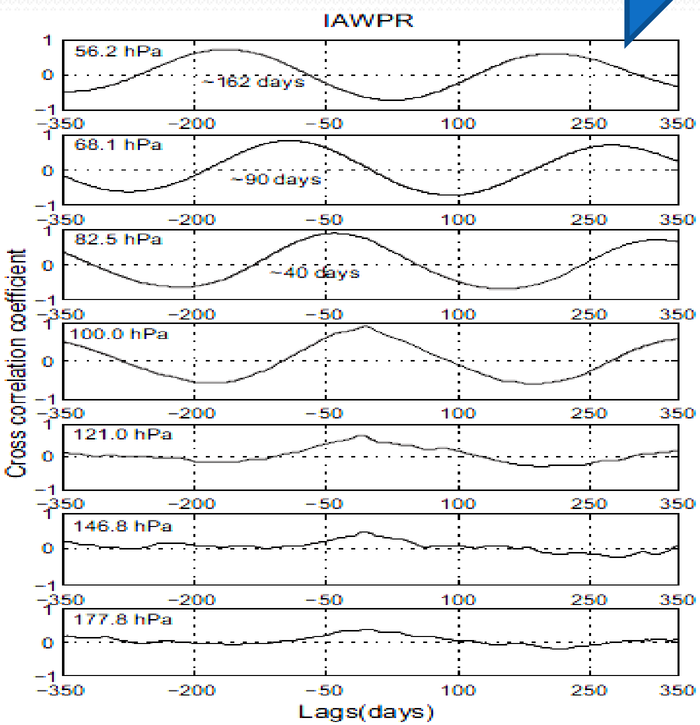
Low OLR

T_{100} as low as ~188 K are observed over IAWPR

Active convection over IAWPR



Spatial distribution of T_{100}, $WVMR_{100}$ and OLR over the tropical region



Plot of cross correlation coefficient between WVMR and temperature over IAWPR at different pressure level

$WVMR_{100}$ and T_{100} over IAWPR are observed to be closely related

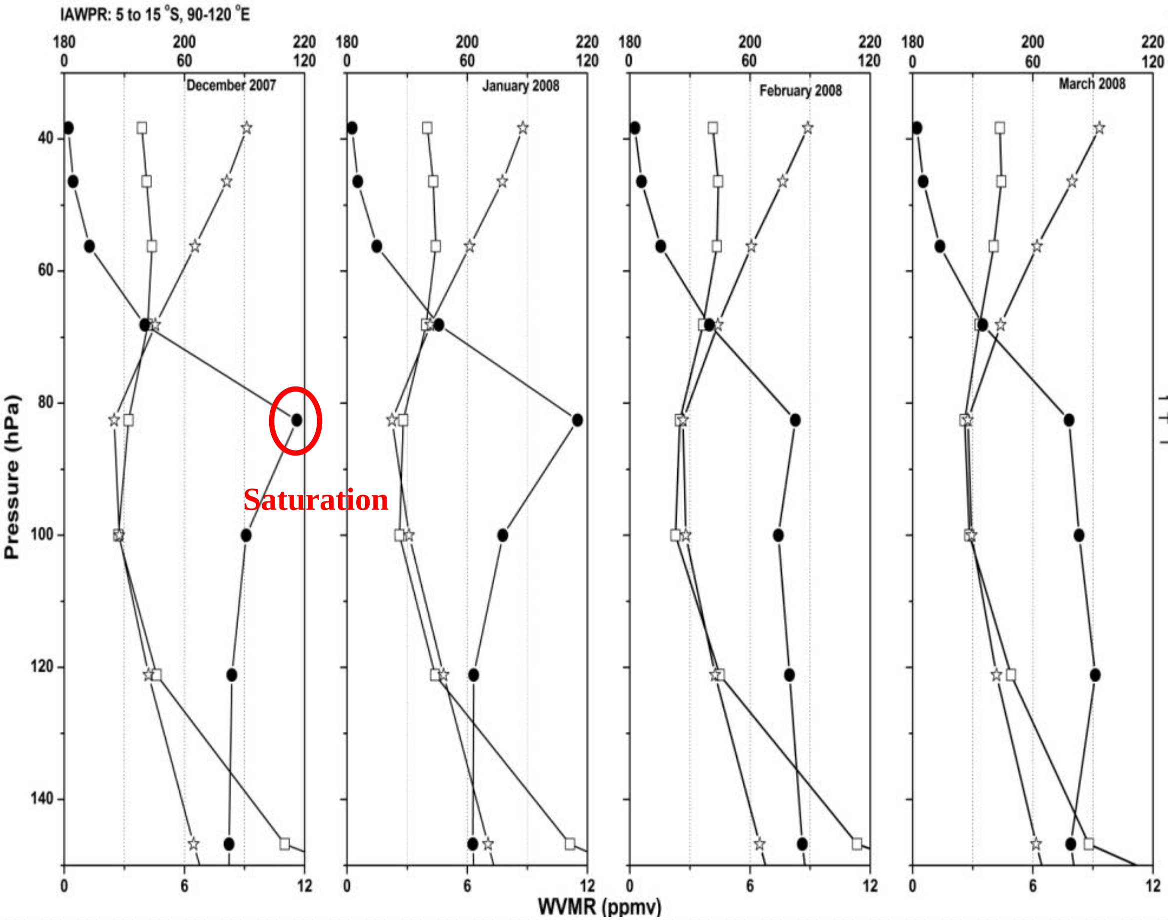
Image Source: Jain et al., 2014

Dehydration of TLS

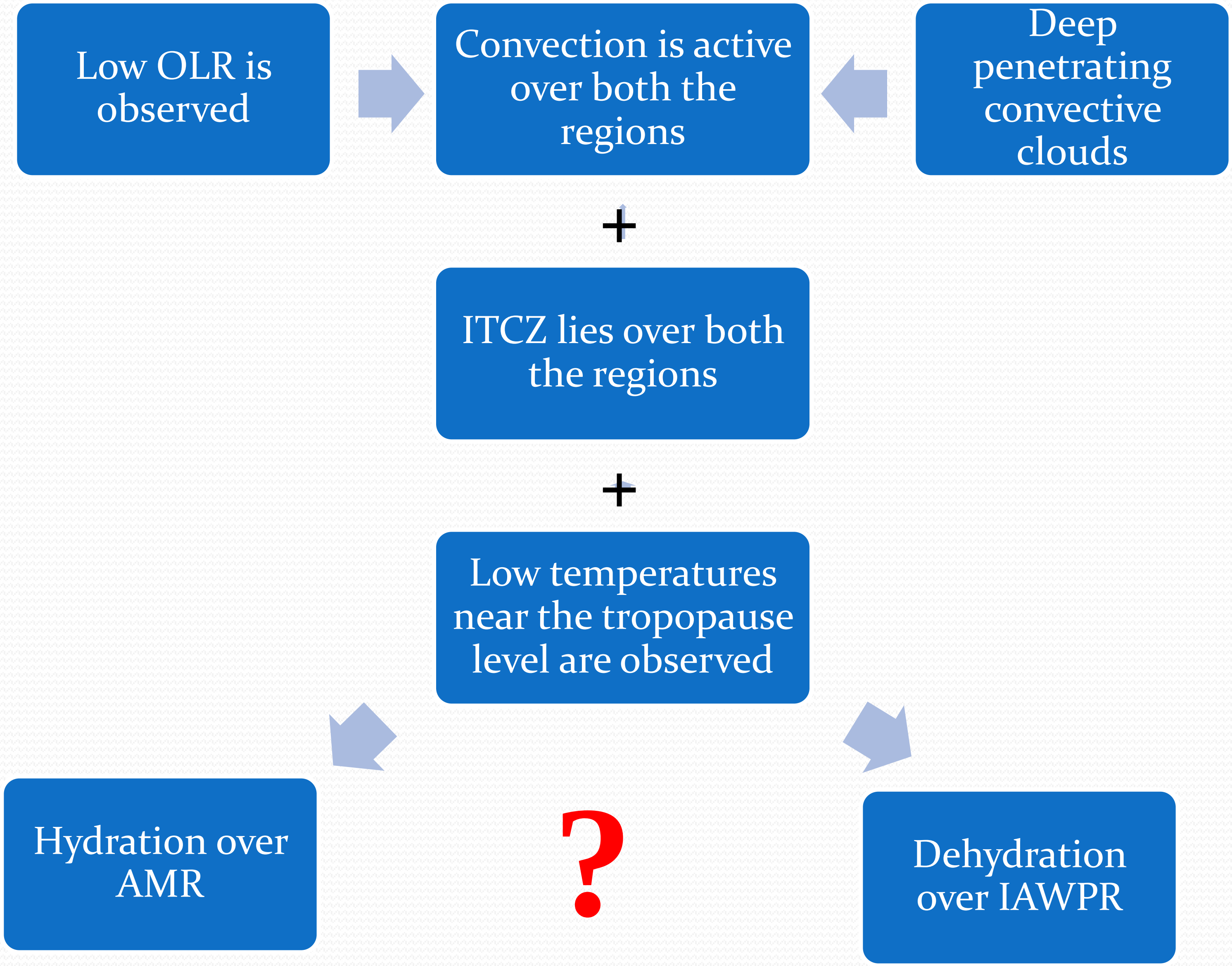
•Saturation is observed near the tropopause level.

•Favorable conditions for 'Freeze drying' process provided the air in this region stays for a sufficiently long time.

Therefore, it remains to be resolved that how dehydration takes place over IAWPR in the presence of active convection.



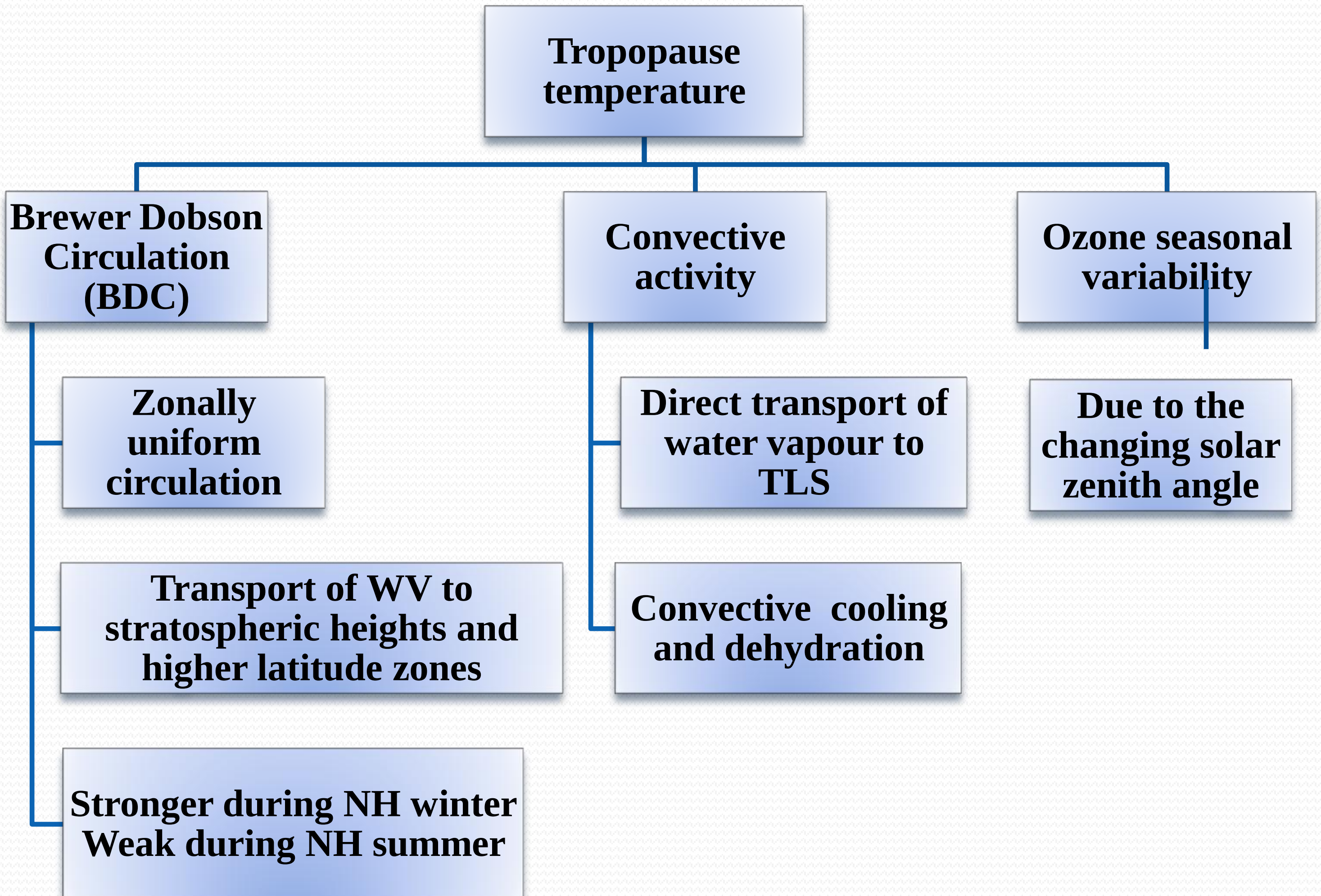
Height profiles of WVMR$_{100}$, T$_{100}$ and RHI over the IAWPR


Low OLR is observed
Convection is active over both the regions
Deep penetrating convective clouds
+
ITCZ lies over both the regions
+
Low temperatures near the tropopause level are observed
Hydration over AMR
?
Dehydration over IAWPR

Factors affecting water vapour seasonal cycle in TLS

TLS water vapour and tropopause temperatures are closely linked over both the regions

To understand the water vapour seasonal cycle, it is important to understand the processes which influence the tropical tropopause temperatures.



Quantification of the role of various processes is done by following methodology:

(a)BDC is a zonally uniform circulation and zonal mean temperatures are used to account the contribution of BDC to T_{100} seasonal cycle.

$$\Delta T_{100} = T_{100}\ (\text{LOCAL}) - T_{100}\ (\text{ZONAL})\ (\text{in K})$$

(b) Multiple linear regression analysis is carried out to explain the additional decrease or increase in tropopause temperatures over IAWPR due to convective activity and low ozone

$$\Delta T_{100} = a_0 + a_1 * (\Delta \text{OMR}_{100}) + a_2 * (\Delta \text{OLR})\ (\text{in K})$$

Database

Sea surface temperature (SST)- Era Interim reanalysis

Outgoing longwave radiation (OLR)- NCEP/NOAA

WVMR and Temperature- Aura MLS

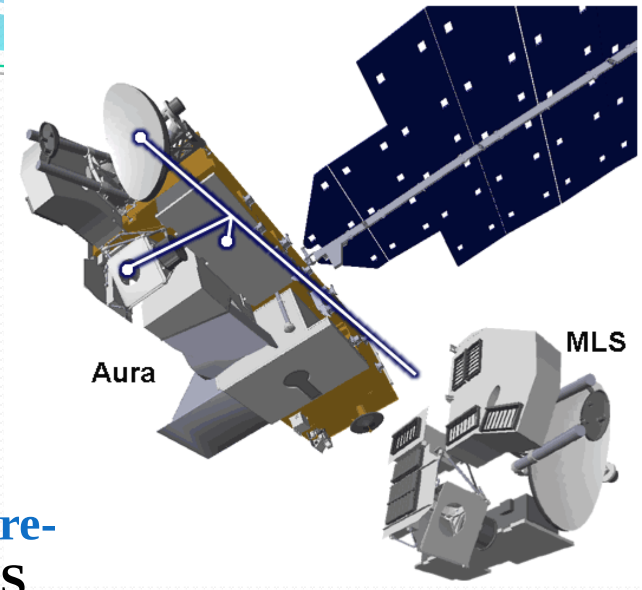


Image source: mls.jpl.nasa.gov

Ozone mixing ratio- Aura TES

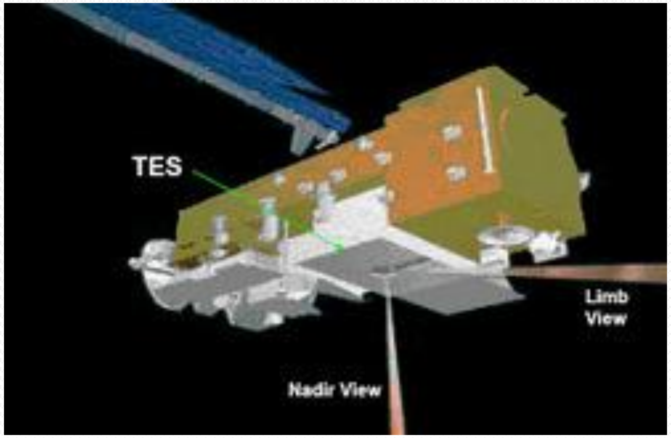
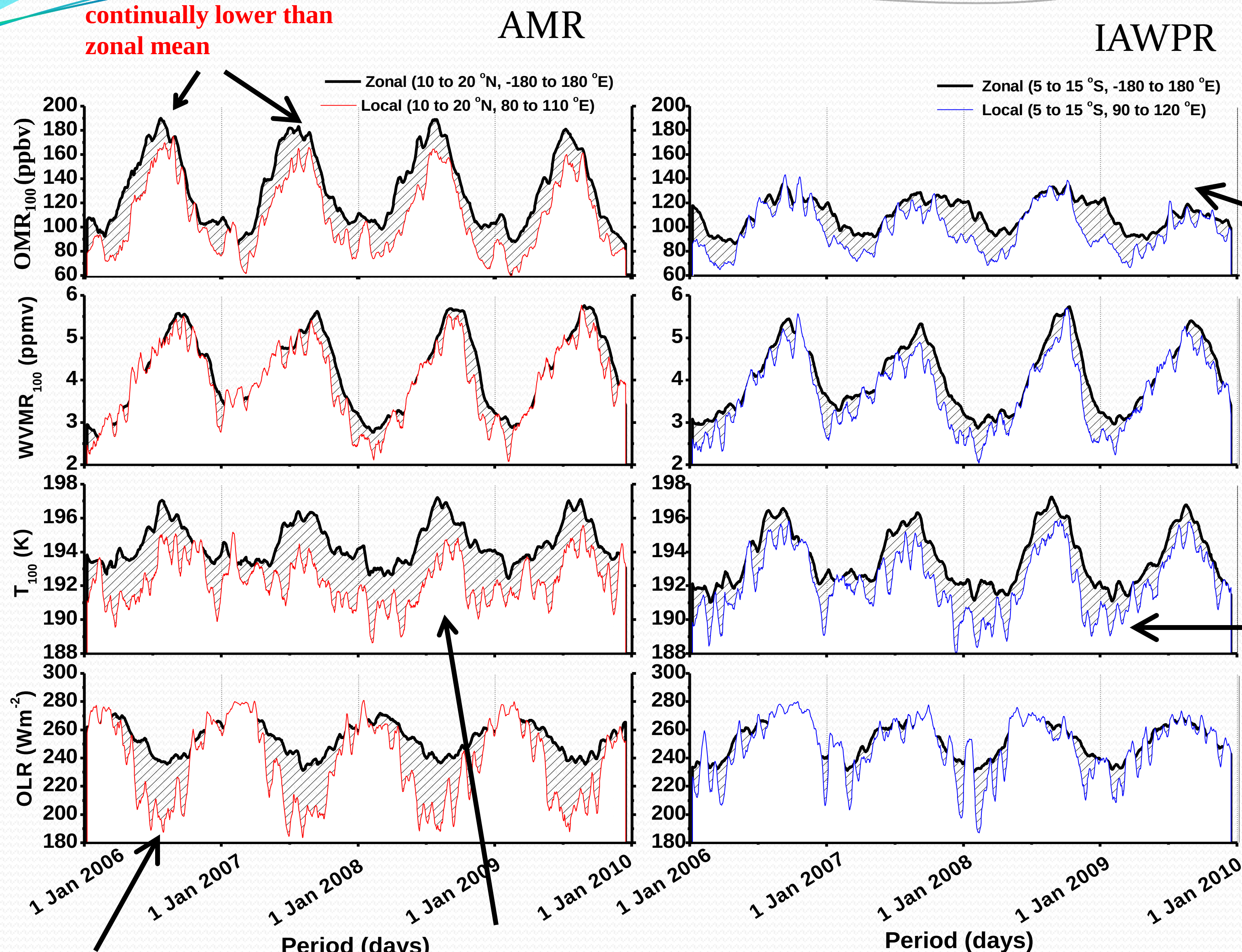


Image source: mynasadata.larc.nasa.gov

Convective cloud data- ISCCP D1

Time series of OLR, OMR_{100}, T_{100} and $WVMR_{100}$ over AMR and IAWPR

Higher peak values, continually lower than zonal mean



Comparatively smaller seasonal variation over IAWPR

Lower temperatures during local convective period

Intense convection over AMR

Higher temperatures during local convective period

Temperatures are continually lower than the zonal mean values over both regions

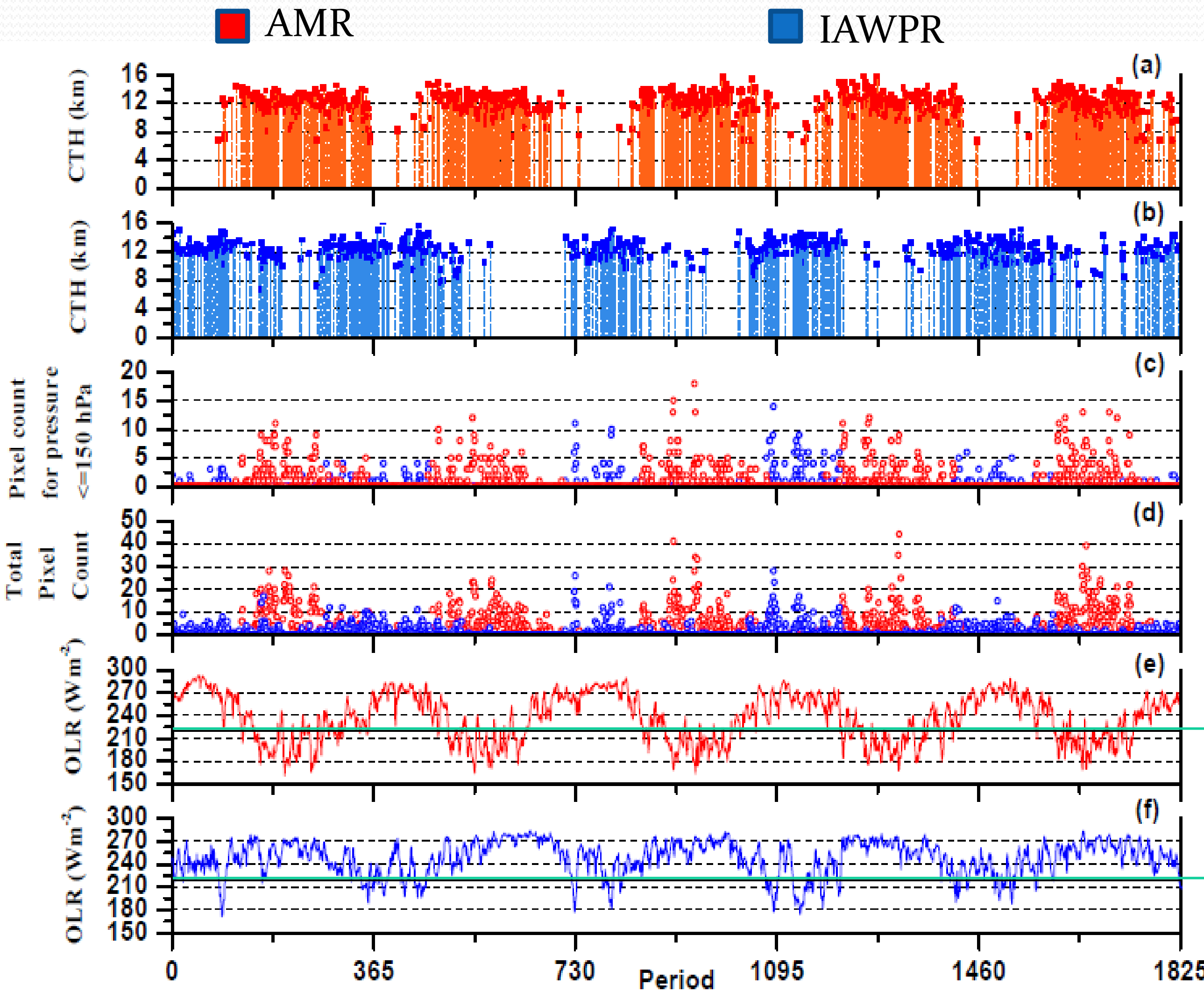
Relatively intense convection over AMR

1. AMR: OLR is consistently low during whole NH summer .
   IAWPR: Only few low OLR events are observed over during NH winter.

2. Total convective cloud pixel count is greater over AMR, suggesting more number of convective events over AMR.

3. Convective cloud pixel count with pressure ≤ 150 hPa is also high over AMR indicating that deep penetrating convection is significantly more over AMR.

4. Deep convective clouds with top height ≥ 14 km are observed more often over AMR.



Therefore, the above observations indicate a relatively intense convective activity over AMR.

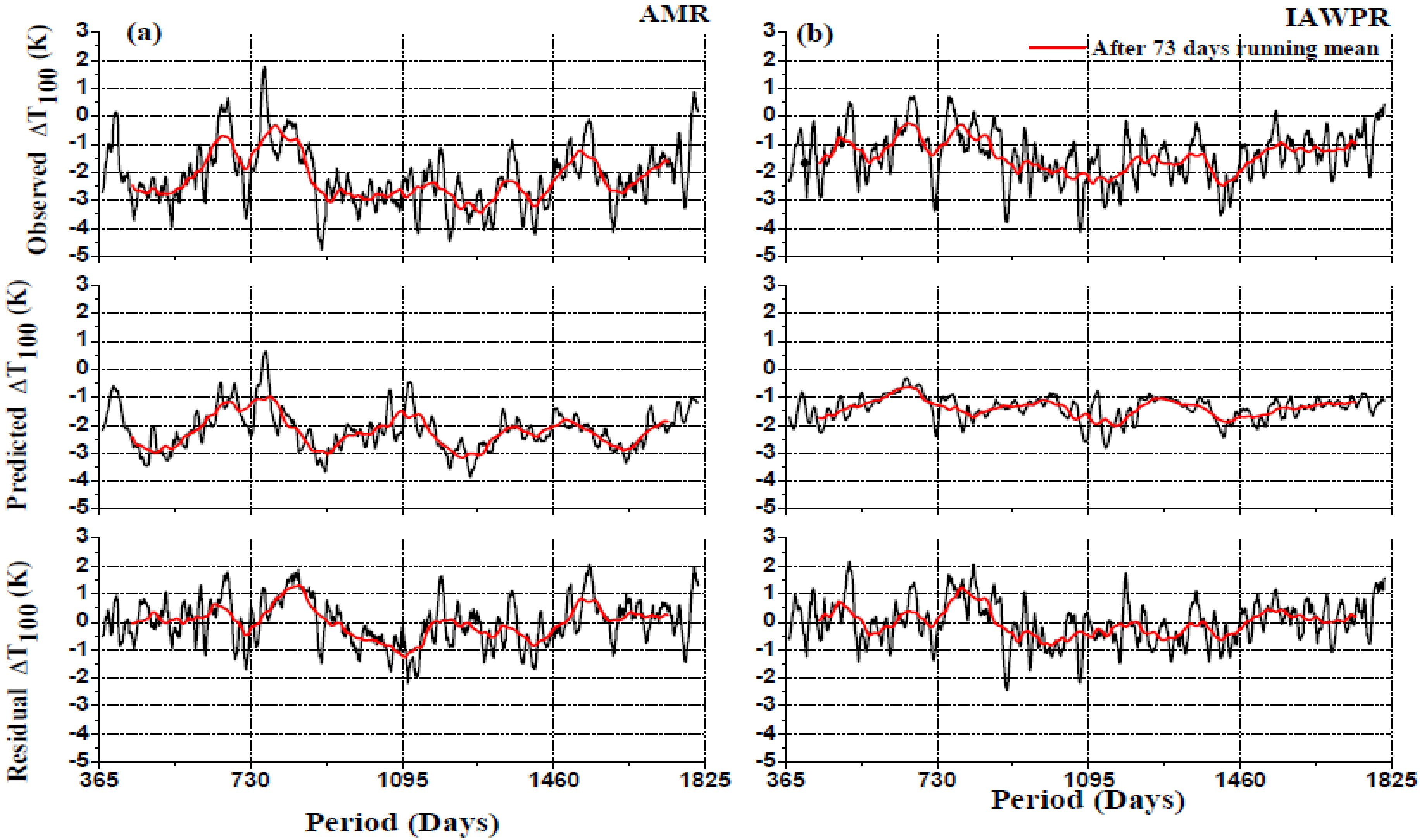
Values of coefficients obtained from regression analysis

	Regression statistics over the Asian region	Regression statistics over the western Pacific region
No. of observations	1437	1437
Intercept (a_0)	-0.643 ± 0.051	-1.179 ± 0.032
ΔOLR (a_1)	0.019 ± 0.001	0.028 ± 0.001
ΔOMR_{100} (a_2)	0.052 ± 0.002	0.011 ± 0.002

Quantitative contribution of various processes in giving rise to seasonal cycle in T_{100} over AMR and IAWPR

S. No.	Process	Mean Change in T_{100} over Asian region (K)	Mean change in T_{100} over the western Pacific (K)
1.	BDC	2.38 ± 1.19	3.47 ± 1.68
2.	a_0 (Mean ΔT_{100} throughout the year)	-0.64 ± 0.05	-1.18 ± 0.03
3.	Contribution of ΔOLR to seasonal change in T_{100}	0.74 ± 0.04	0.26 ± 0.01
4.	Contribution of ΔOMR to seasonal change in T_{100}	0.11 ± 0.09	0.22 ± 0.06
	Sub total	2.5-5.2	3.4-7.0
5.	Contribution of wave activity (sub seasonal)	1-2	1-2
	Grand total	3.5-7.2	4.4- 9.0

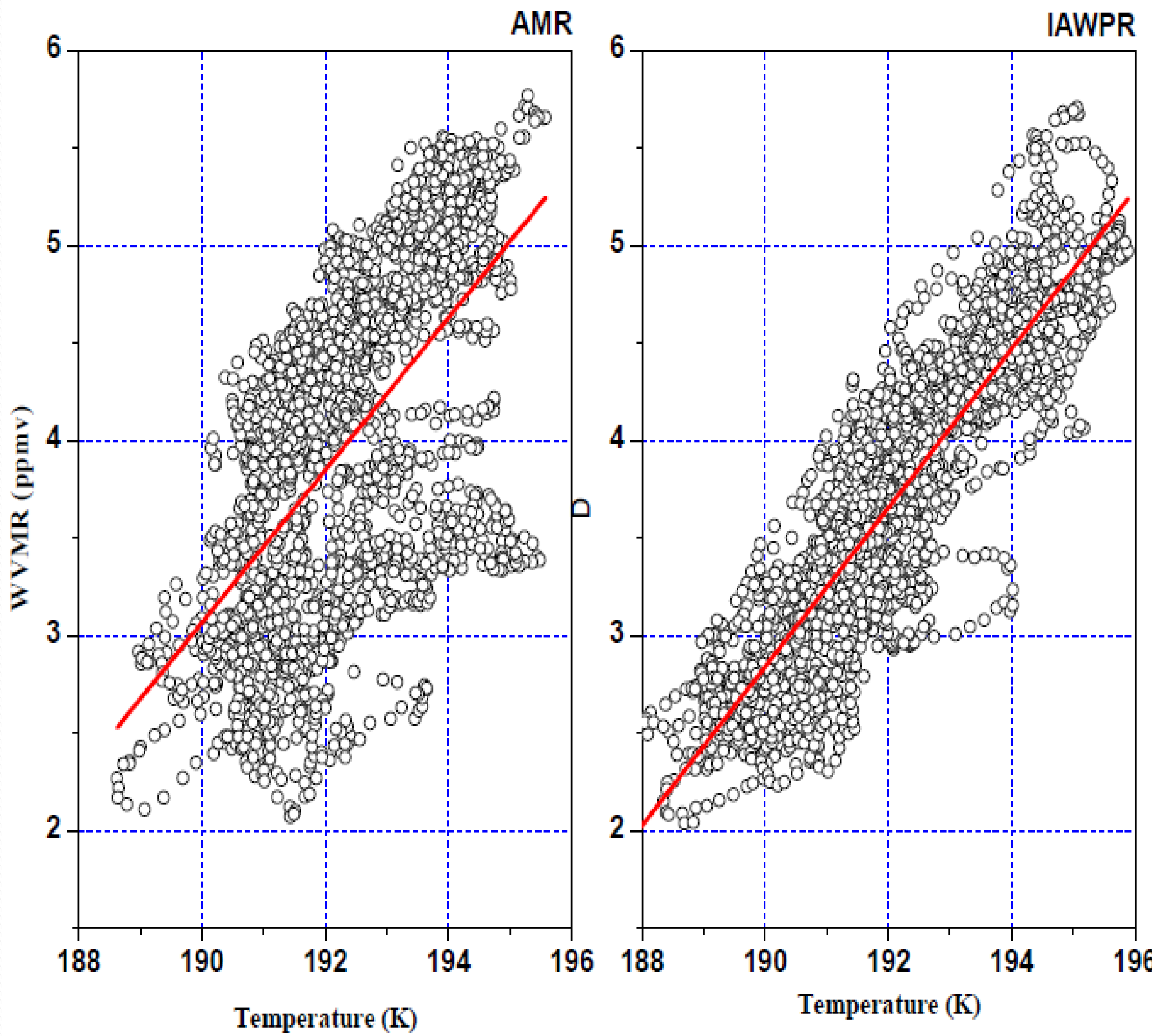
Observed, predicted and residual time series for T_{100}



Wave activity in T_{100} with amplitude 1-2 K is visible over AMR and IAWPR

Scatter plot of T_{100} and $WVMR_{100}$ over AMR and IAWPR

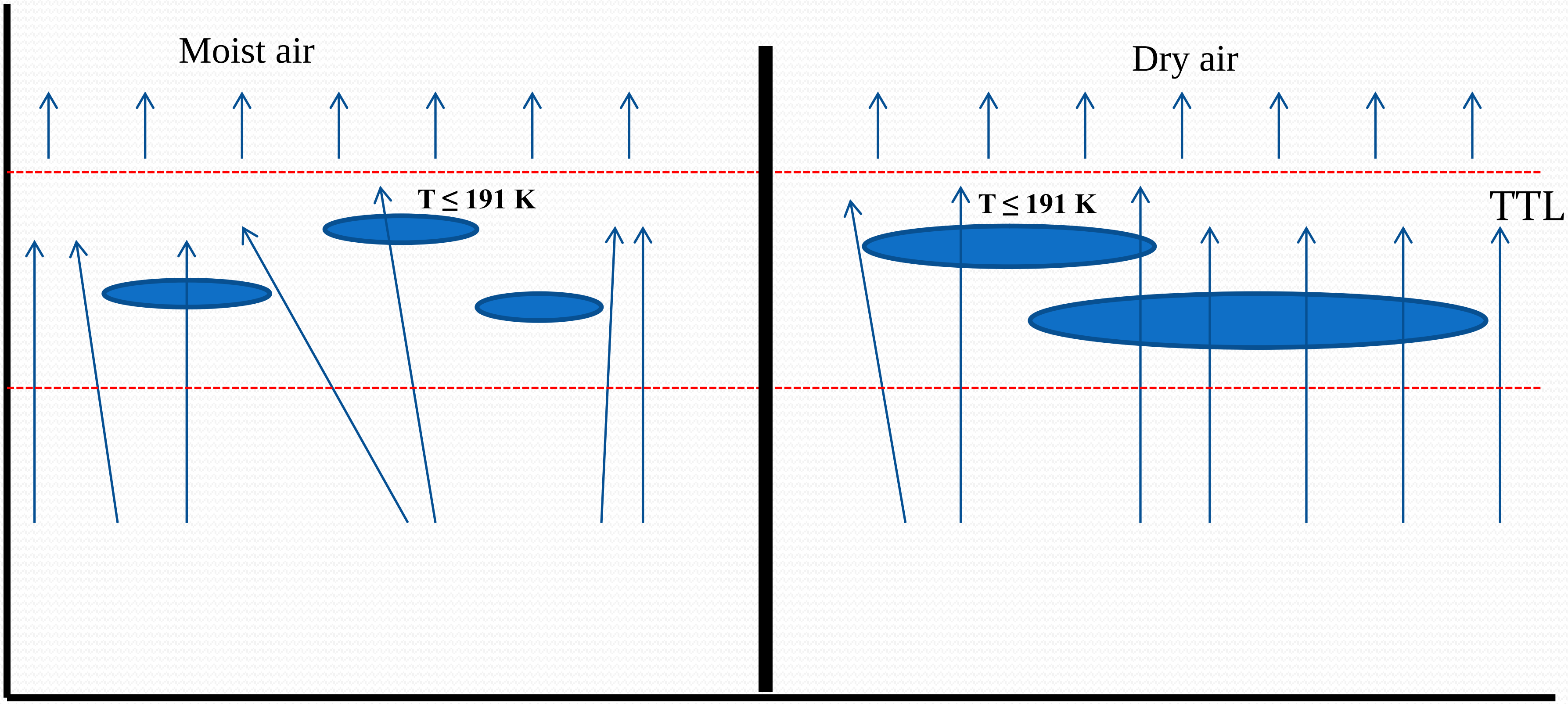
AMR	IAWPR
r = 0.6	r = 0.9
More scatter (Due to anomalous increase in temperature during NH winters)	Less scatter



$WVMR_{100}$ responds poorly to the abrupt changes in T_{100} over AMR.

It is evident from this analysis that $WVMR_{100}$ follows T_{100} more closely over IAWPR as compared to AMR.

Conceptual picture of likely air transport over Asian monsoon and western Pacific region



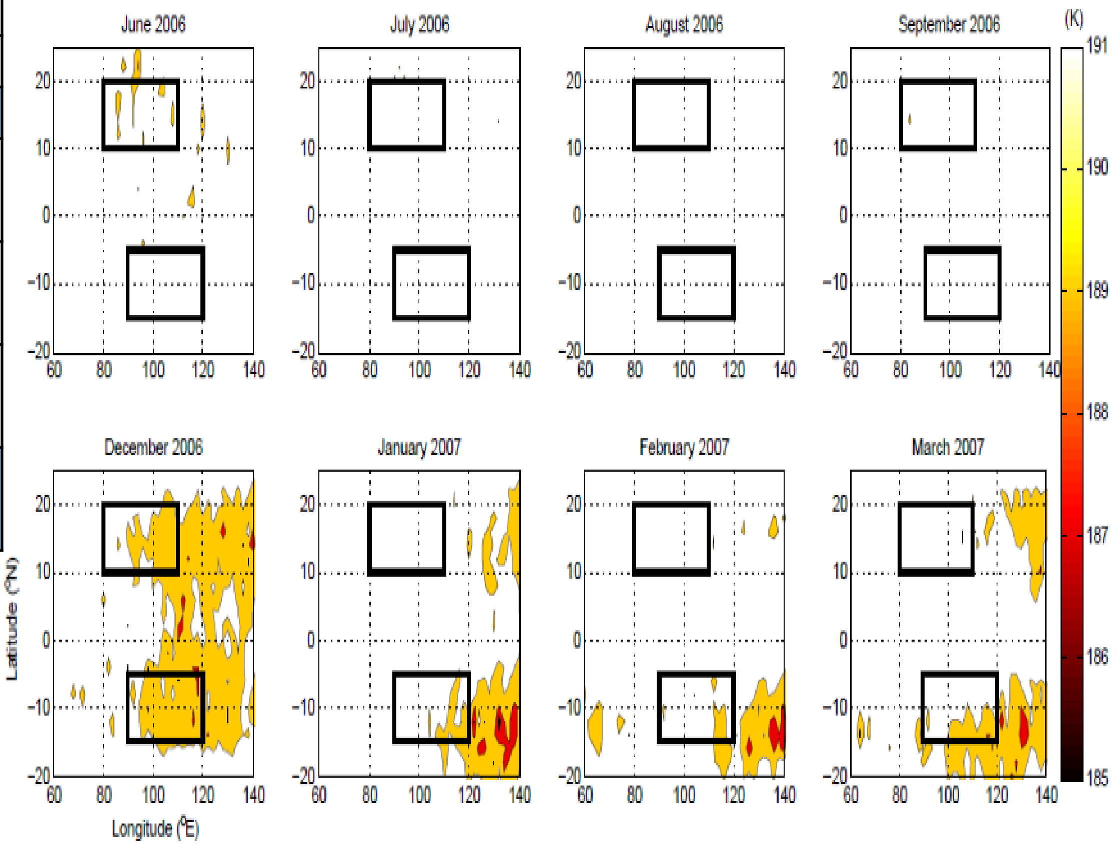
Asian Monsoon region
NH summer-monsoon
(Local convective period)

Western Pacific region
NH winter-spring
SH summer-monsoon
(Local convective period)

Percentage area covered by $T_{100} \leq 191$ K over AMR and IAWPR

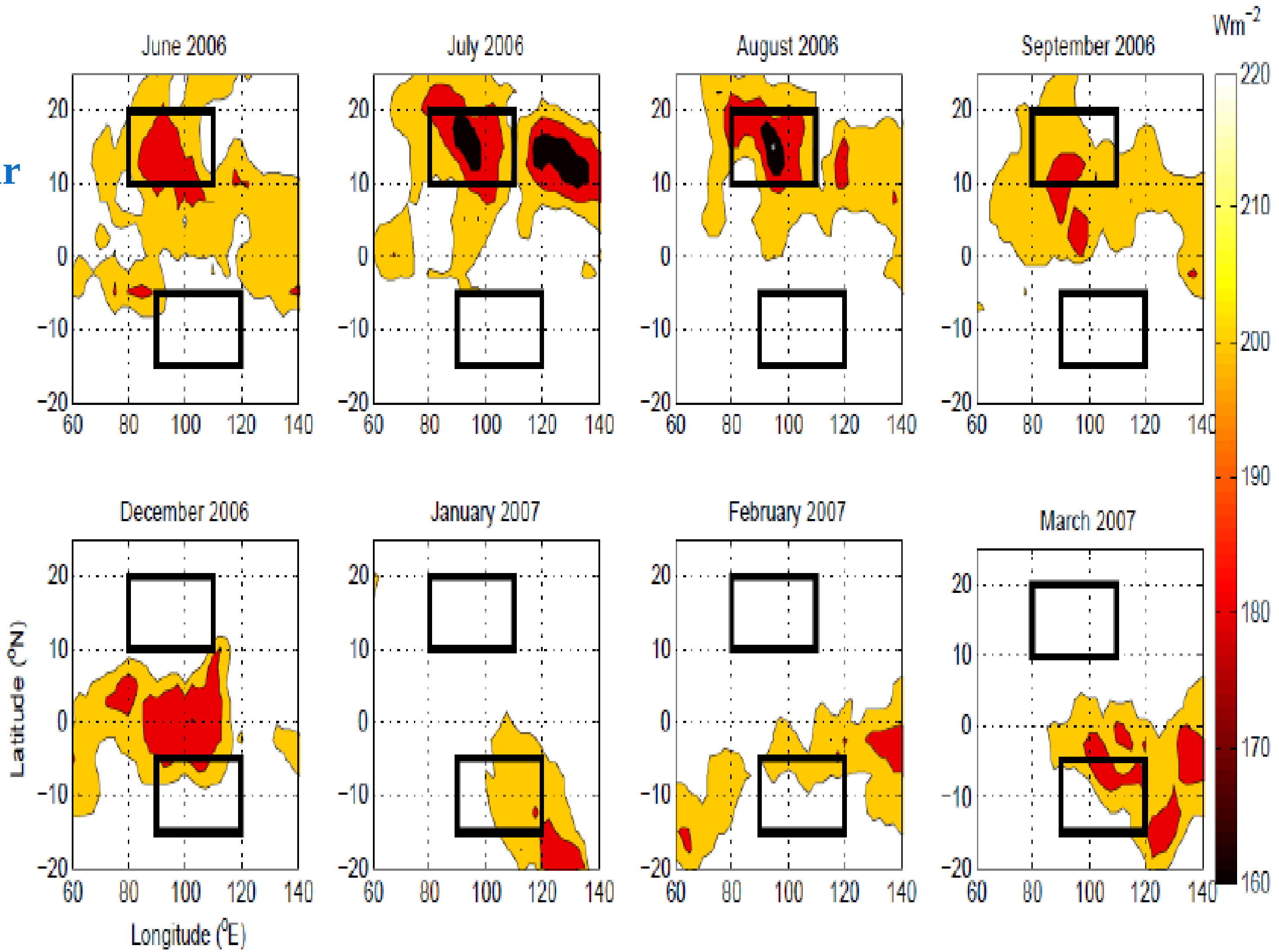
Year	Area coverage (%)	
	Asian	Western Pacific
June-September 2006	5.45	0.3
June -September 2007	12.3	1.9
June-September 2008	6.8	0.0
Mean	8.2 ± 3.6	0.7 ± 1.0
December 2006 to March 2007	11.2	28.2
December 2007 to March 2008	54.2	86.3
December 2008 to March 2009	19.0	64.4
Mean	28.0 ± 22.9	59.6 ± 29.3

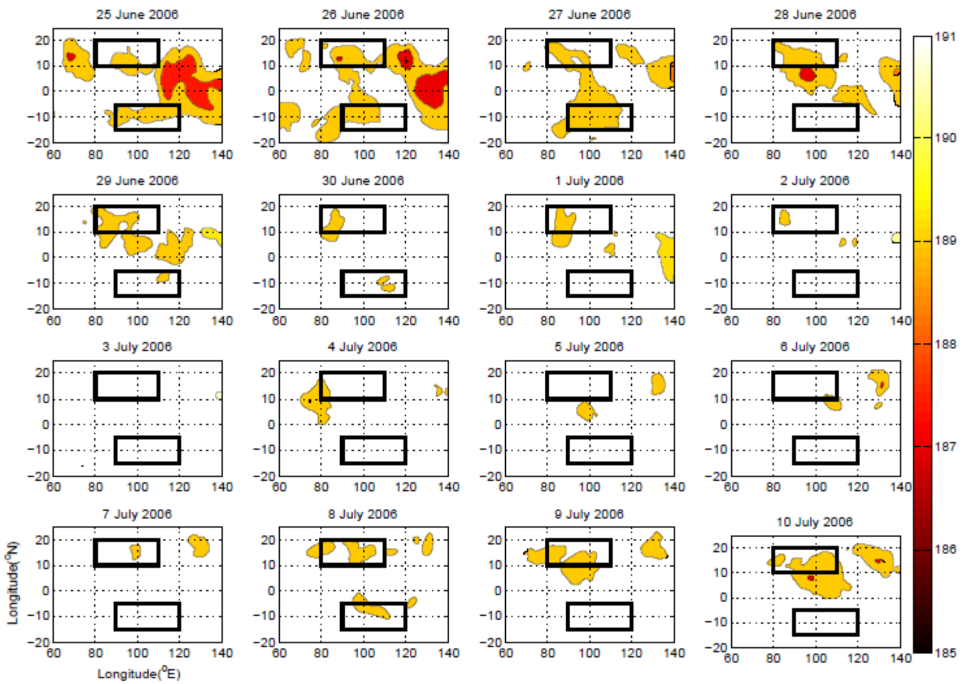
Spatial distribution of T_{100} (K) over the tropical region



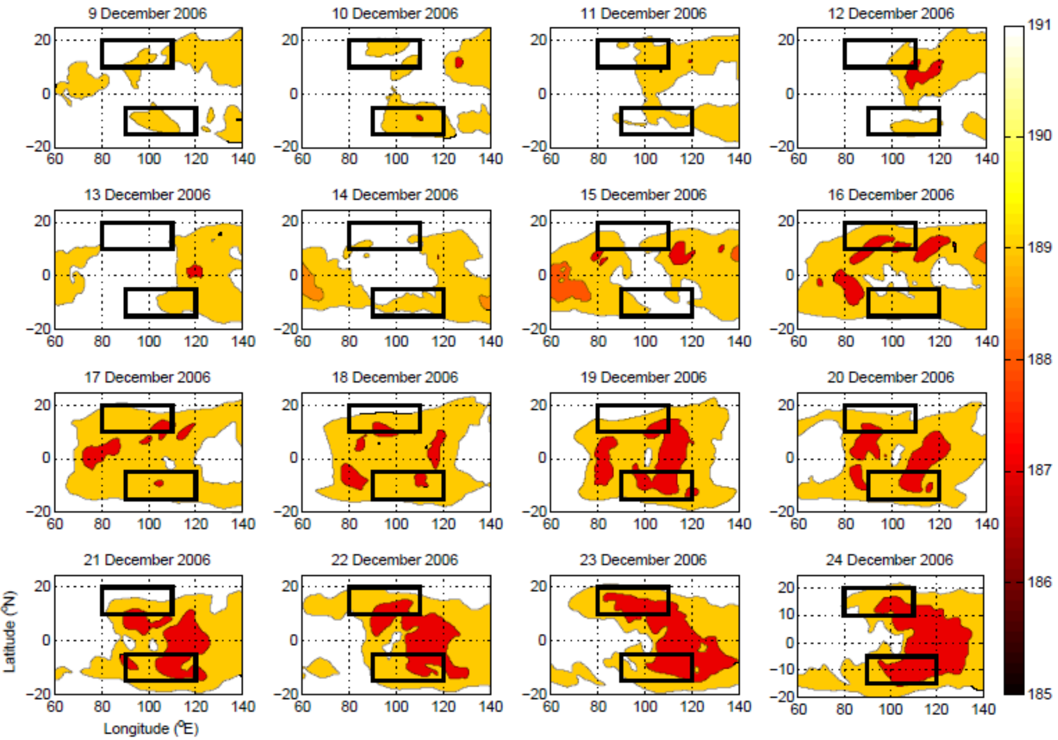
Spatial distribution of OLR (Wm^{-2}) over the tropical region

Low OLR occur over the same general area as low T_{100}





Spatial distribution of daily T_{100} (K) obtained from the Era Interim data over the tropical region for 25 June 2006 to 10 July 2006



Spatial distribution of daily T_{100} (K) obtained for 9 December 2006 to 24 December 2006

CONCLUSIONS

Hydration over AMR

BDC contributes maximum to the T_{100} seasonal cycle but the contribution of convection is also significant.

More number of deep penetrating convection clouds is observed over this region as compared to IAWPR.

Areas over which extreme low T_{100} occur are patchy and tropopause temperatures > 191K occur over a relatively much larger area. This indicates that freeze-drying process is perhaps occurring over a relatively smaller area and therefore it may not be so effective.

CONCLUSIONS

Dehydration over IAWPR

Deep penetrating convection is relatively less frequent.

The tropical upwelling driven BDC is relatively enhanced during the NH winter spring season, resulting in extremely low T_{100} over a large geographical area of the Southern tropics covering IAWPR.

Low OMR_{100} during the NH winter also seem to contribute to the low values of T_{100} over this region.

Occurrence of extreme low T_{100} ($\leq$ 191 K) over a relatively larger area of the tropics, coupled with a relatively lesser number of deep penetrating convection events, indicates that 'Freeze and dry process' perhaps occur over a relatively larger area resulting in dehydration of TLS.

Thank you