Nonstationarity in the surface layer time series over complex terrain

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CONTENT

I. INTRODUCTION

- Statistical theory of turbulence ➔ ensamble averaging of multiple realizations of the same turbulent process (e.g. Lenschow and Stankov 1986)

- Quite successful in laboratory conditions, but almost never in the atmosphere (e.g. Batchelor 1959; Tennekes and Lumley 1972; Wyngaard 2010)

- Ergodic assumption for the atmospheric data: average of a single realization represents an ensamble average

- Ergodicity ← **stationarity**

- Nonstationary atmospheric data ➔ time average is weak approximation of ensamble average ➔ enhanced scatter in turbulence statistics ➔ enhanced uncertainty in similarity functions (MOST)

- **OBJECTIVES**

  ➔ to investigate Monin-Obukhov similarity theory (MOST) in complex terrain using near-surface turbulence time series obtained during T-REX on NCAR ISFF towers by sonic anemometers

  ➔ to determine the nonstationarity of the means and (co-)variances of 30-min time intervals of these time series ➔ 11 moments:

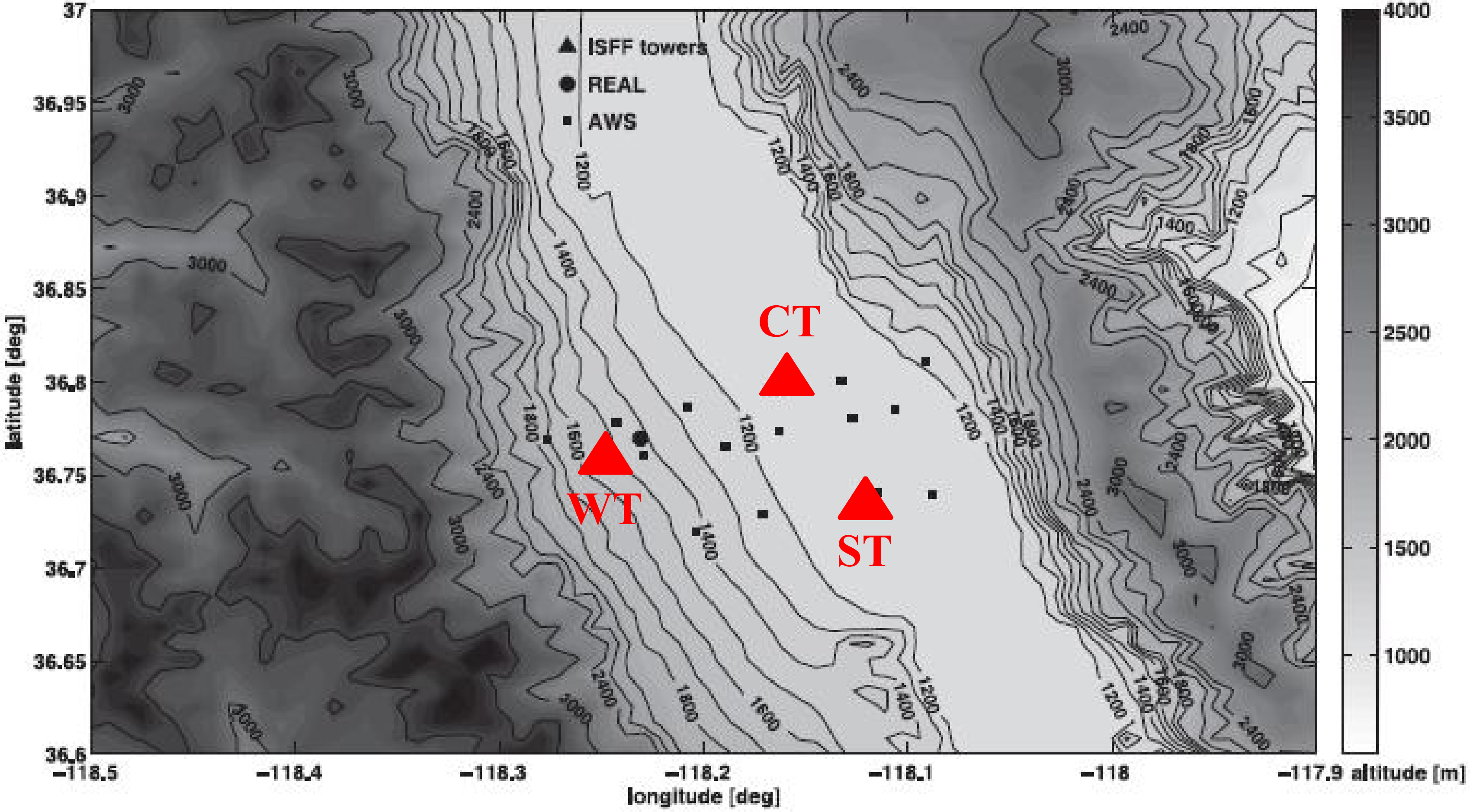
  - means: Q_U , Q_V , Q_W , Q_T
  - variances: Q_{uu} , Q_{vv} , Q_{ww} , Q_{tt}
  - covariances: Q_{uw} , Q_{vw} , Q_{wt}

  ➔ to use the stationary portion of data for investigation of MOST

- 30-min intervals ➔ based on the assumption that eddies with a time scale of 30 min contain most of the turbulence energy

II. DATA

- T-REX experiment ➔ Owens Valley, California ➔ March and April 2006
- Three NCAR-ISFF 30-m towers ➔ CSAT3 ultrasonic anemometers at heights of 5, 10, 15, 20, 25 and 30 m ➔ 60 Hz sampling frequency



- 61-day period (from 0000 UTC 1 March to 2359 UTC 30 April 2006) of *u*, *v*, *w* and *t* time series

- Gaps in observed 61-day time series due to:

  ➔ The occasional power loss at different towers

  ➔ the occasional malfunction of anemometers at different towers/levels

➔ not all 30-min intervals (2928 of them) are suitable for our analysis

z [m]	WT [%]	CT [%]	ST [%]
5	96.96	93.72	98.05
10	96.79	96.41	97.40
15	98.19	89.00	97.75
20	98.50	96.76	97.64
25	98.26	96.55	98.26
30	98.60	90.68	98.22

III. DIAGNOSTIC OF THE NONSTATIONARITY

- 3 independent approaches ➔ 4 different methods:

(1) Statistical tests to determine trends

1a) Reverse arrangement test (RAT)

- if $162 \leq A \leq 272$ ➔ stat. moment is stationary

1b) Run test (RUT)

- if $10 \leq R \leq 21$ ➔ stat. moment is stationary

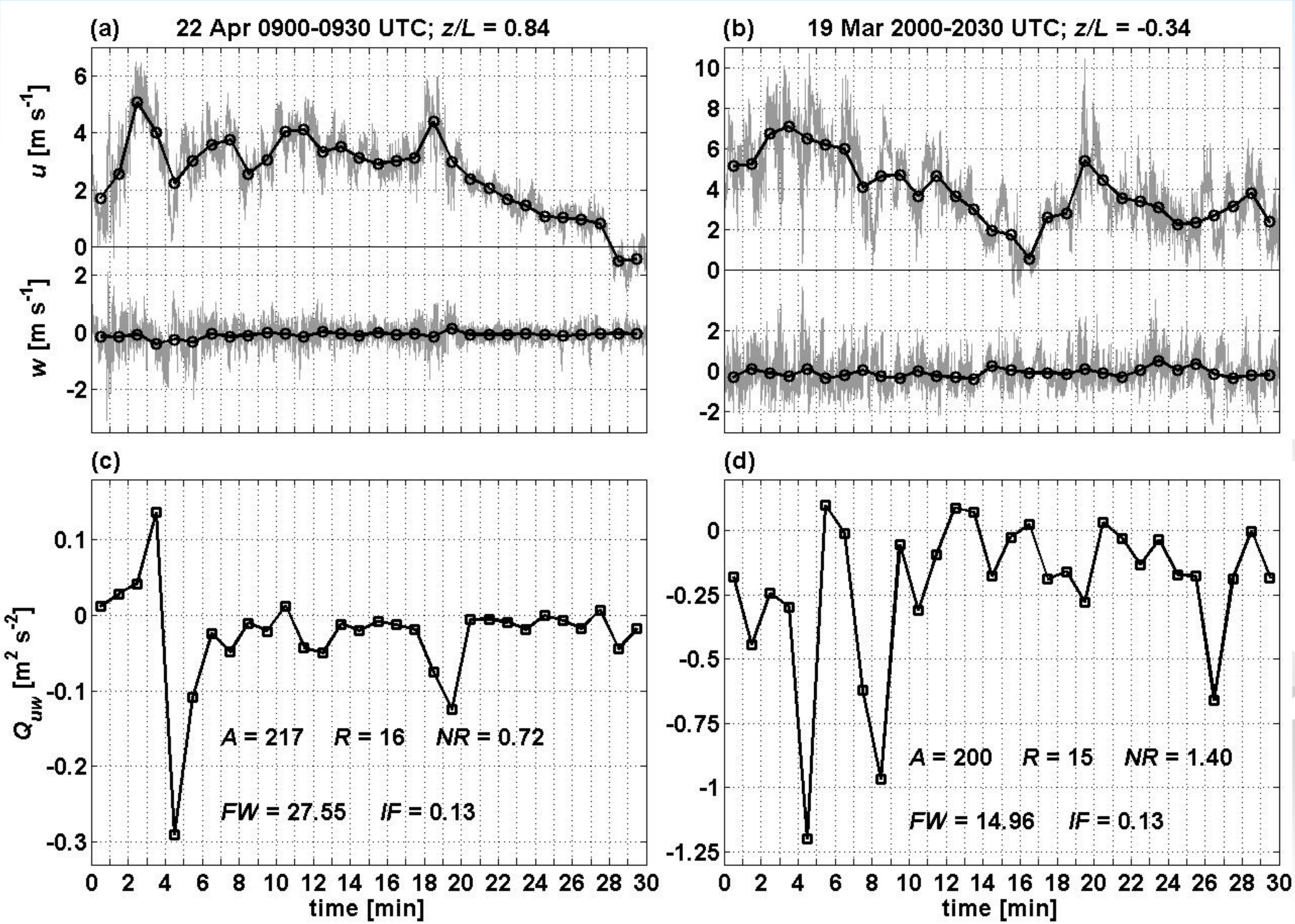
(2) Mahrt's (1998) method (M98)

- if $NR \leq 2$ ➔ stat. moment is stationary

(3) Foken and Whichura (1996) method (FW96)
➔ it works only for second order moments

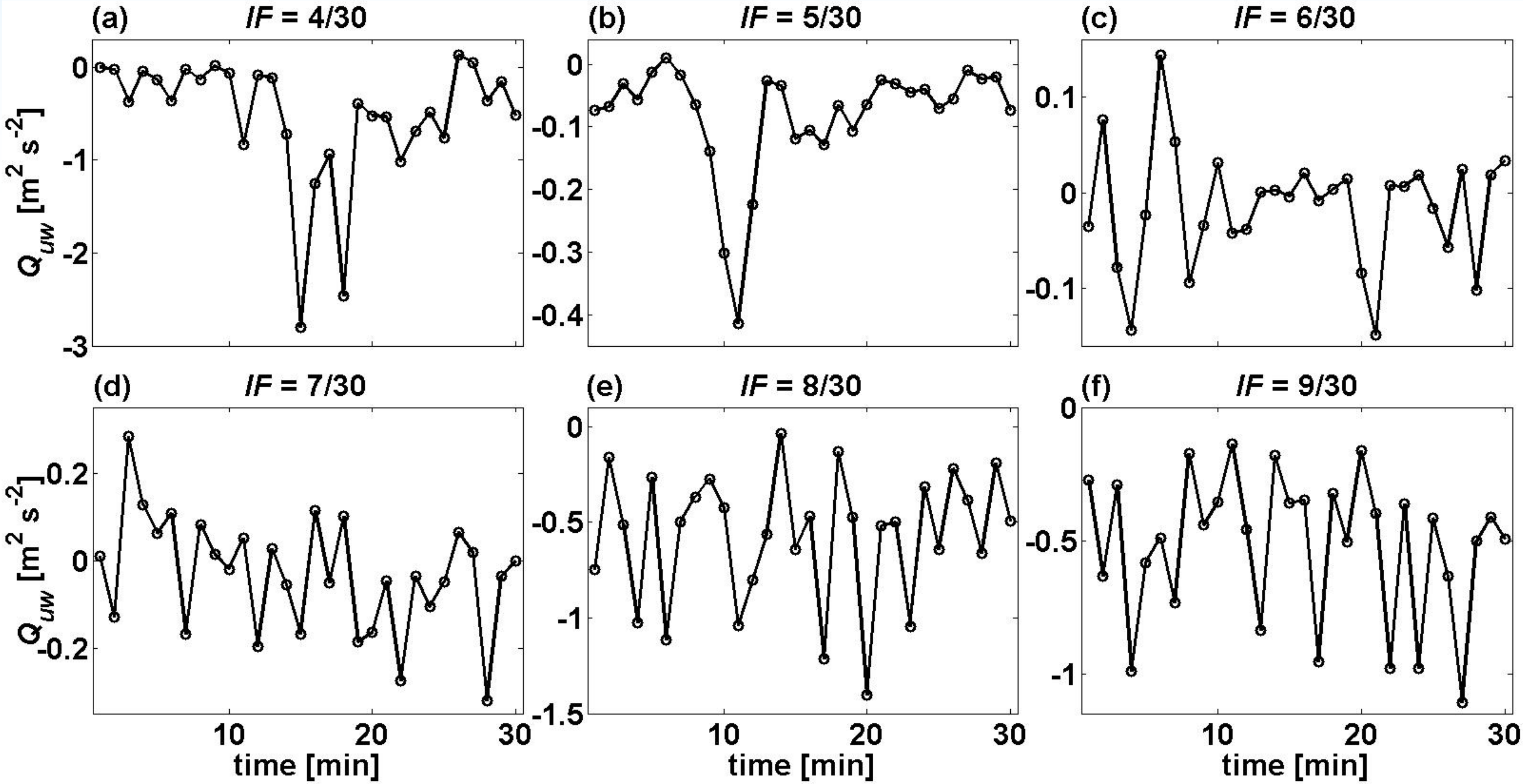
- if $FW < 30$ % ➔ stat. moment is stationary

❖ Examples: stationary by RAT, RUT, M98 and FW96 methods but still nonstationary ➔ INTERMITTENCY

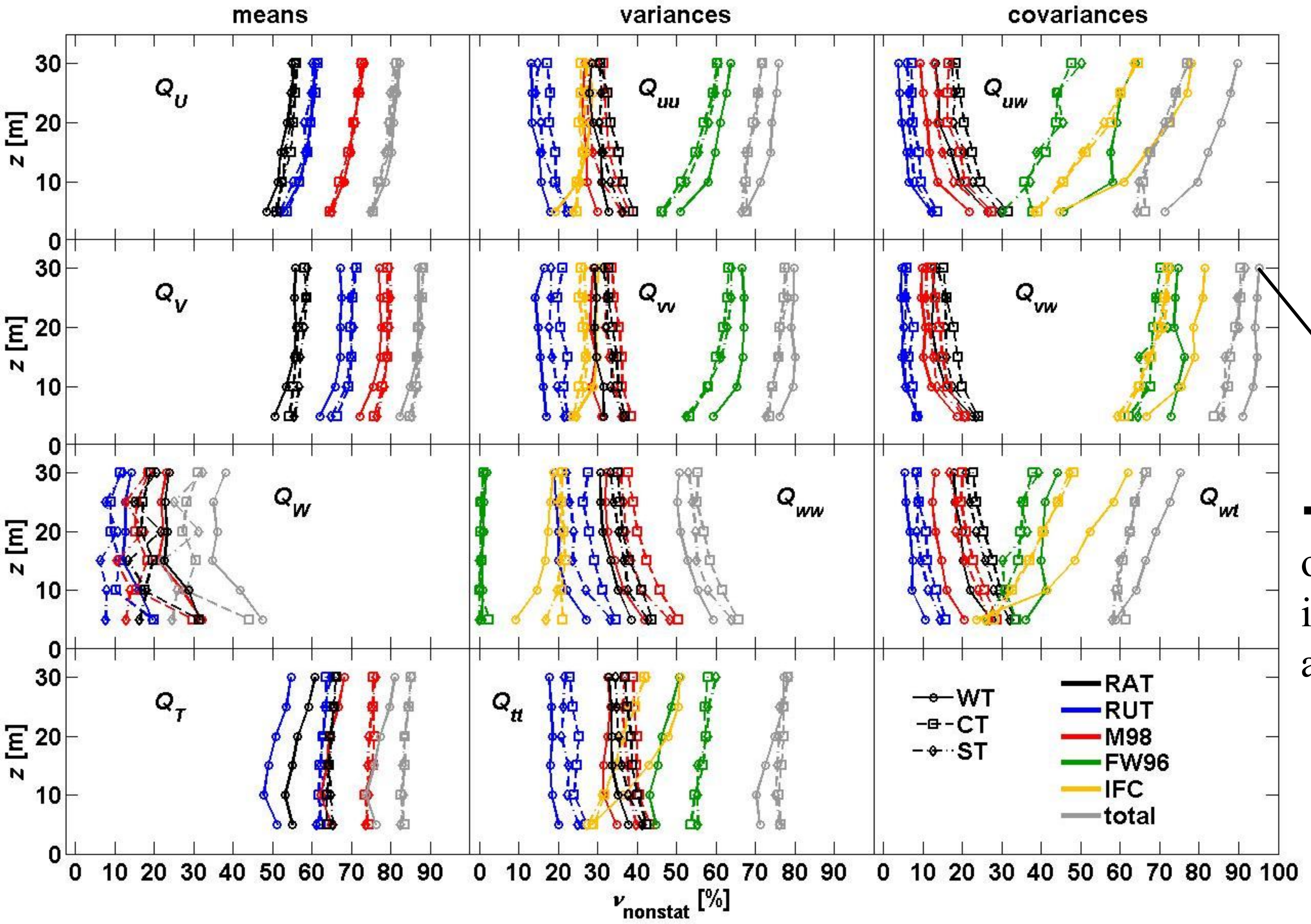


❖ Additional criterion for stationarity of second orderr moments ➔

- if *IF* > 6/30 ➔ stat. moment is stationary



IV. COMPARISON OF DIFFERENT APPROACHES

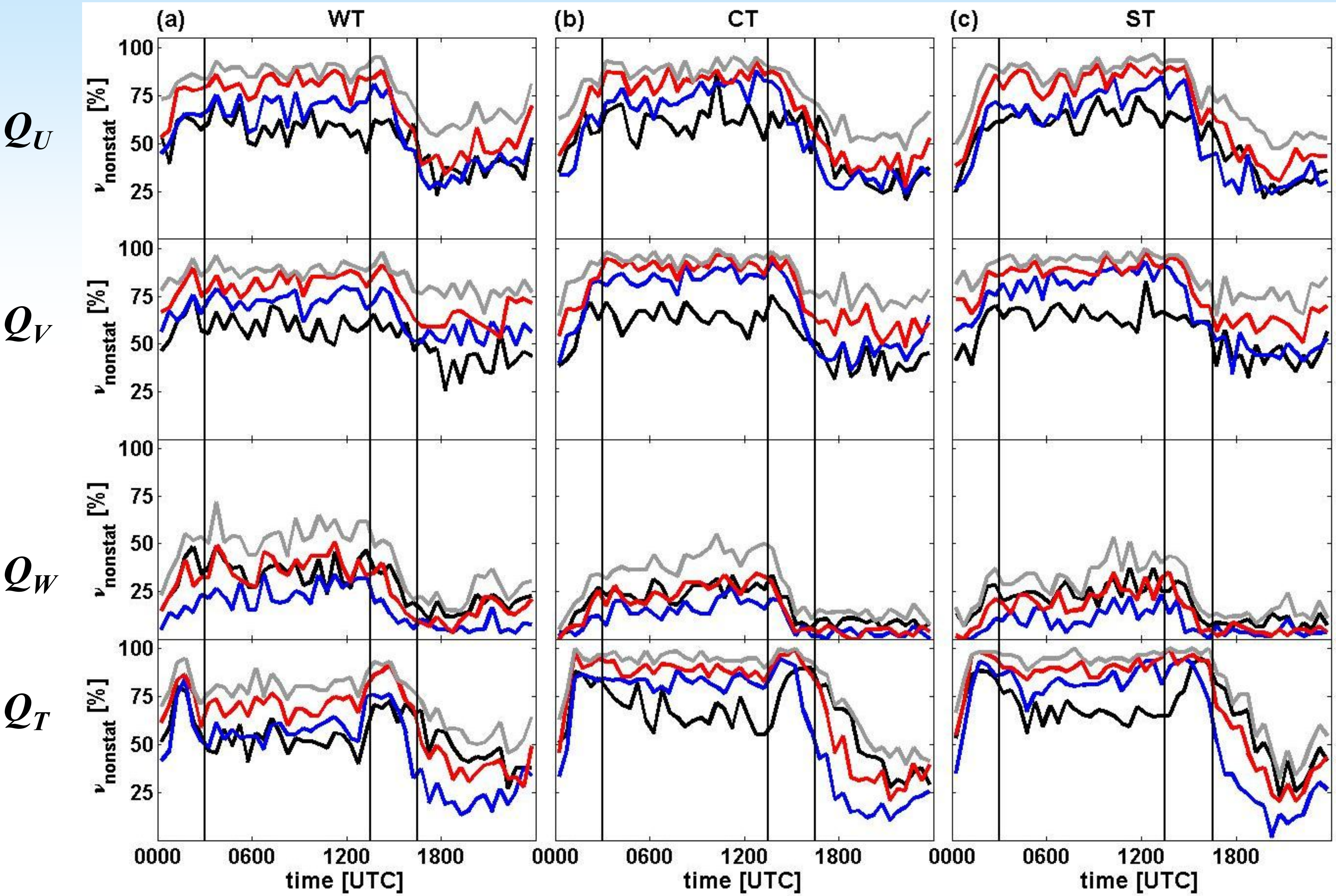


95.08 %

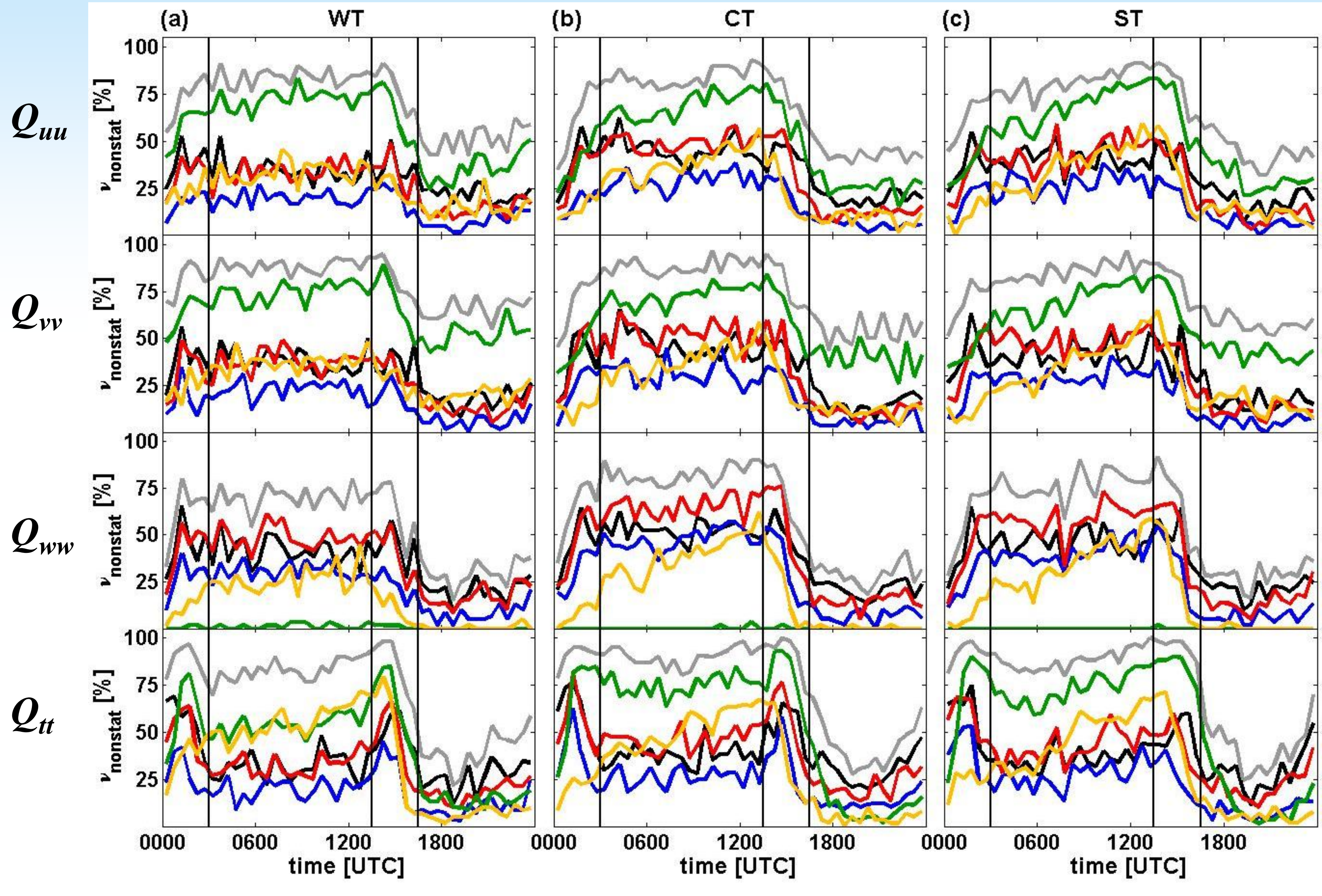
➔ 142 out of 2887 intervals are stat.

V. SUMMARY

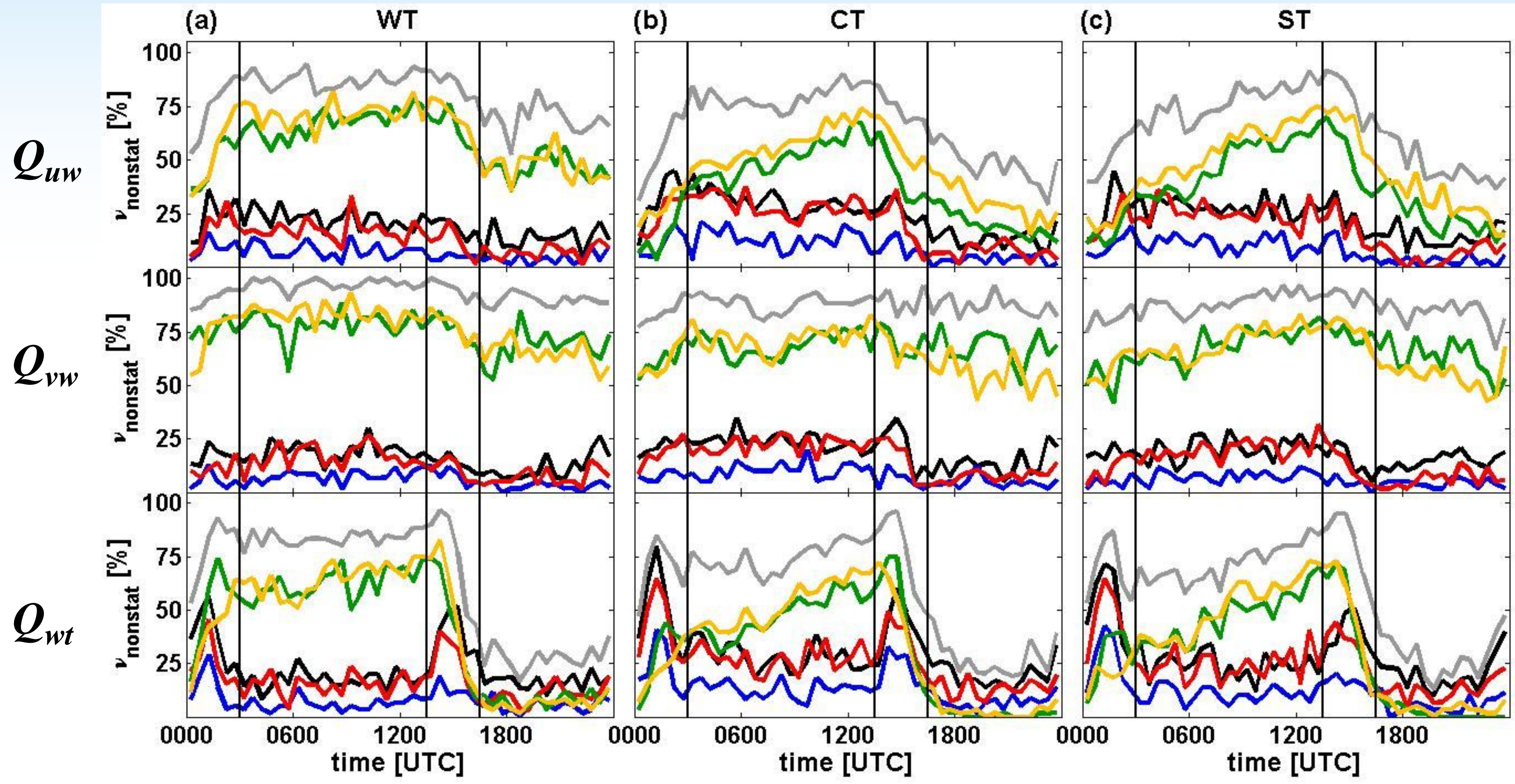
- Degrees of nonstationarity vary considerably with the used approach ➔ extremely ambiguous results
- Not clear which method(s) would be most suitable for detecting nonstationarity in T-REX near-surface time series of statistical moments
- Simultaneous implementation of criterions imposed by RAT, RUT and M98 methods to means and criterions imposed by RAT, RUT, M98, FW96 and IFC methods to (co-)variances ➔ extremely rigorous approach
- For the statistical moments that are declared as stationary by this approach, we have no further doubts in their stationarity



(a)
WT
(b)
CT
(c)
ST
Q_U
Q_V
Q_W
Q_T
$\nu_{nonstat}$ [%]
100
75
50
25
0000
0600
1200
1800
time [UTC]

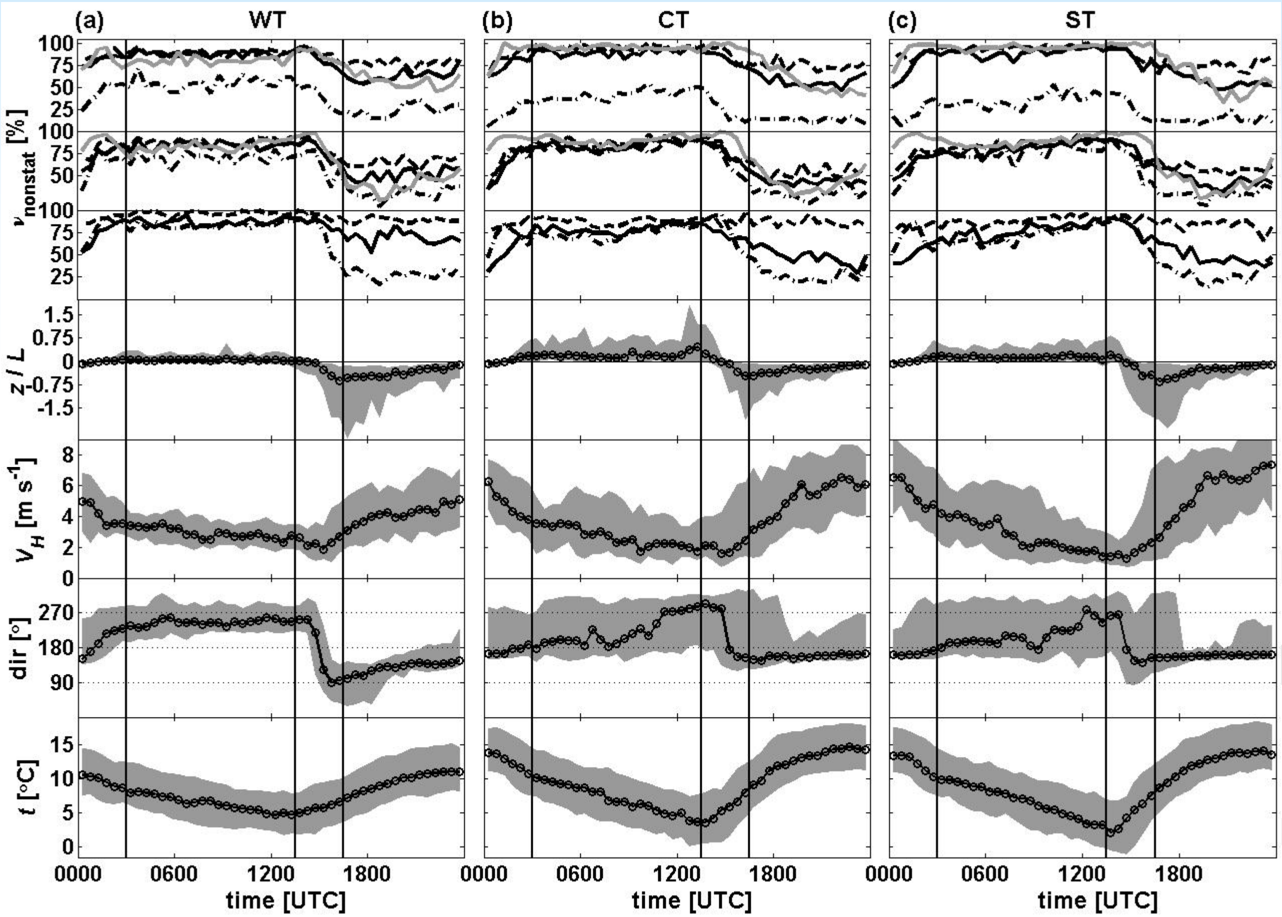


(a)
WT
(b)
CT
(c)
ST
Q_{uu}
Q_{vv}
Q_{ww}
Q_{tt}
$\nu_{nonstat}$ [%]
100
75
50
25
0000
0600
1200
1800
time [UTC]

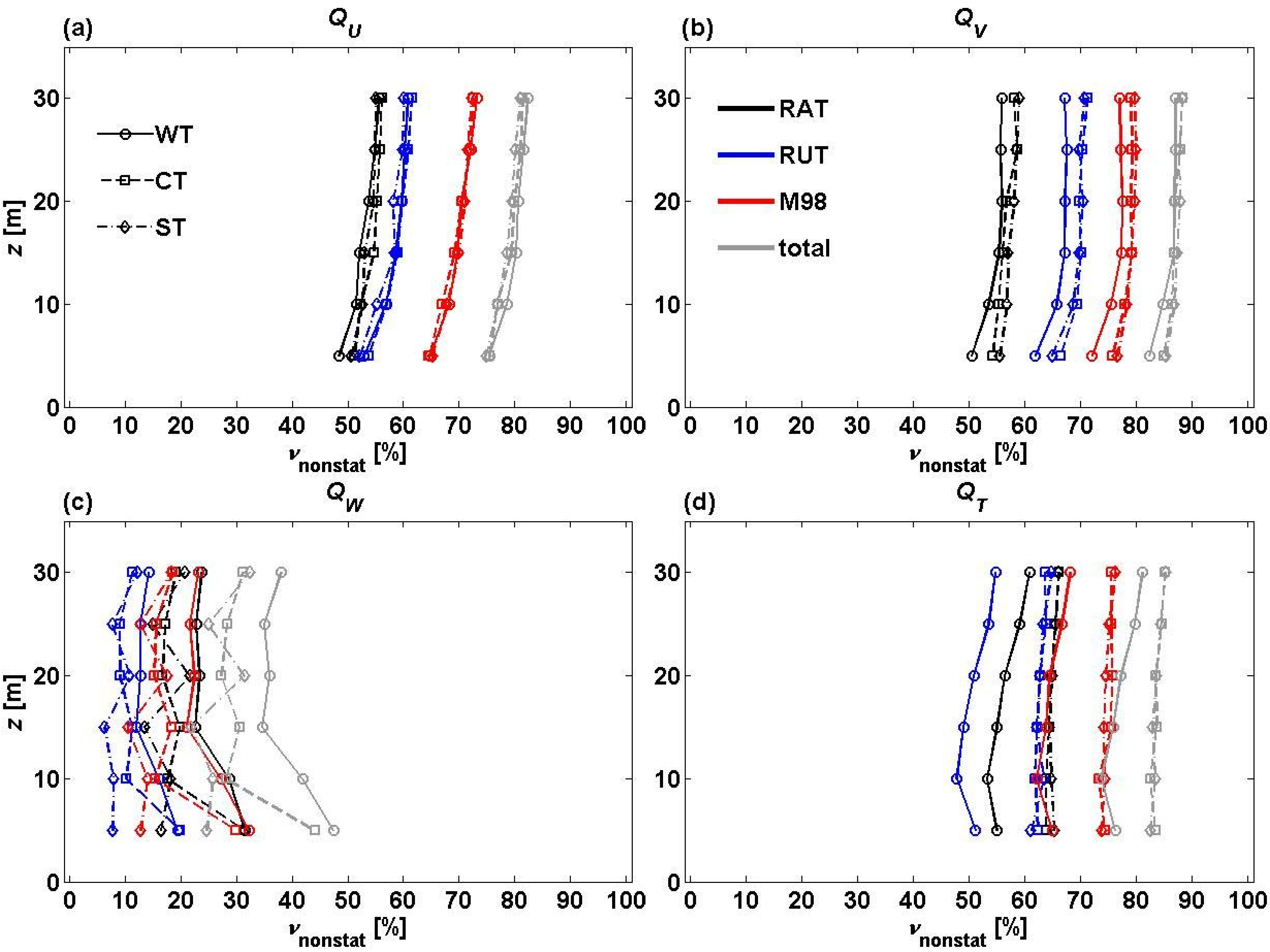


Q_uw
Q_vw
Q_wt
(a)
WT
(b)
CT
(c)
ST
ν_nonstat [%]
100
75
50
25
0000
0600
1200
1800
time [UTC]

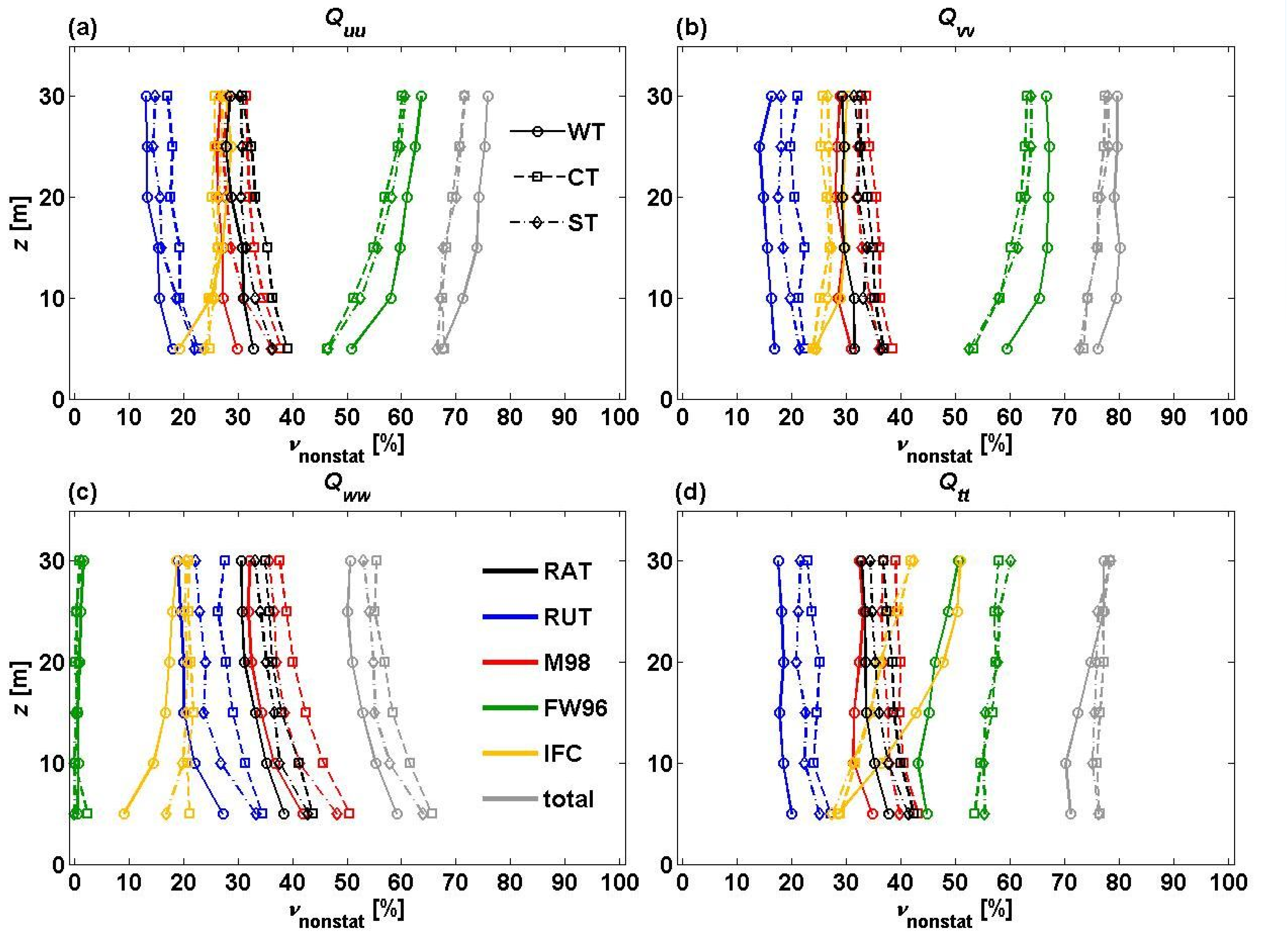
VI. CHARACTERISTICS OF THE NONSTATIONARITY



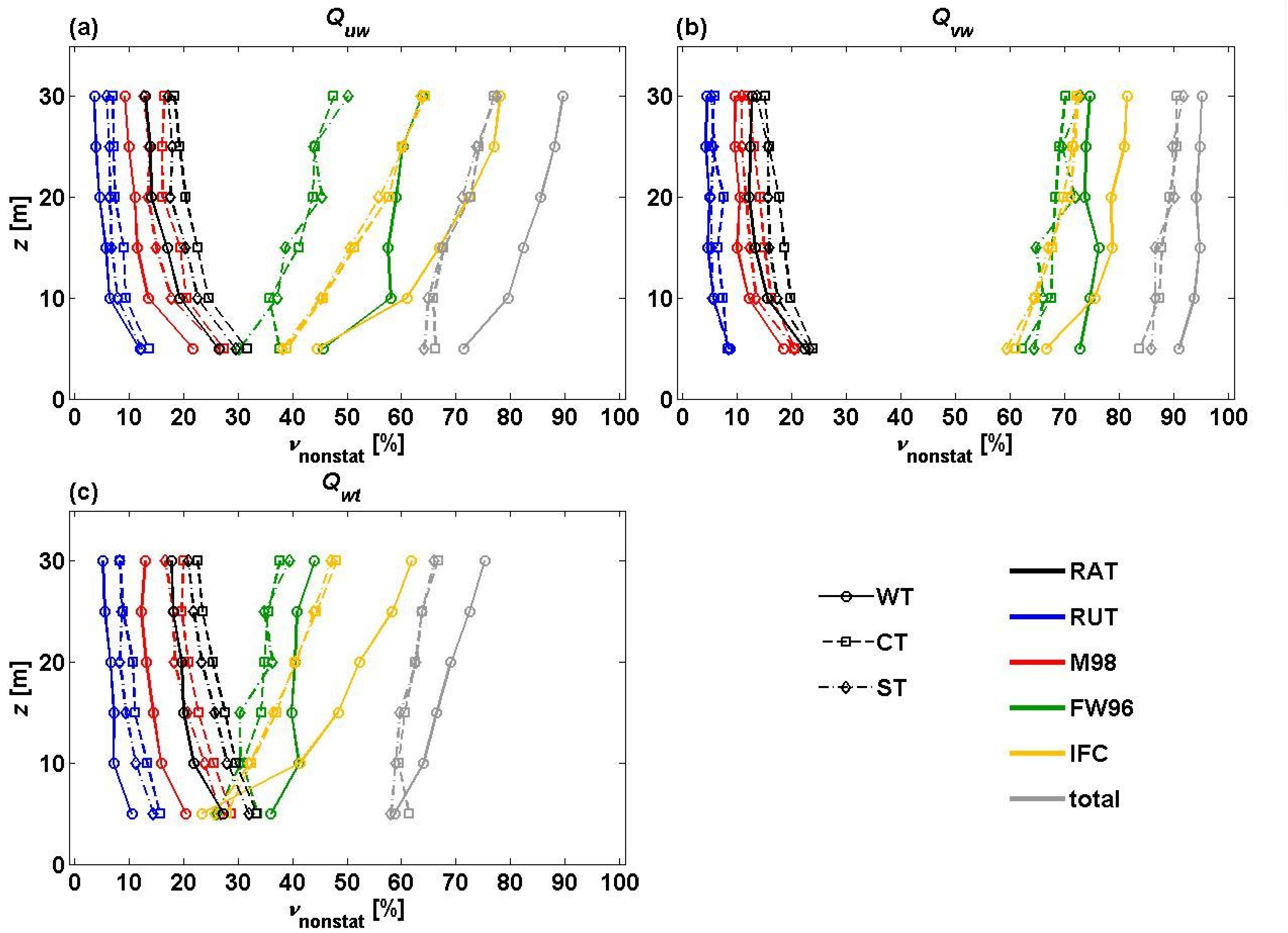
- Daily cycle of nonstationarity fractions of means, variances and covariances
- Composited daily cycle of *z*/*L* ➔ evening transition ➔ nighttime period ➔ morning transition ➔ daytime period



(a)
Q_U
(b)
Q_V
(c)
Q_W
(d)
Q_T
WT
CT
ST
RAT
RUT
M98
total
z [m]
$\nu_{nonstat}$ [%]



(a)
Q_uu
(b)
Q_vv
(c)
Q_ww
(d)
Q_tt
z [m]
ν_nonstat [%]
WT
CT
ST
RAT
RUT
M98
FW96
IFC
total



(a)
Q_{uw}
(b)
Q_{vw}
(c)
Q_{wt}
z [m]
$\nu_{nonstat}$ [%]
WT
CT
ST
RAT
RUT
M98
FW96
IFC
total