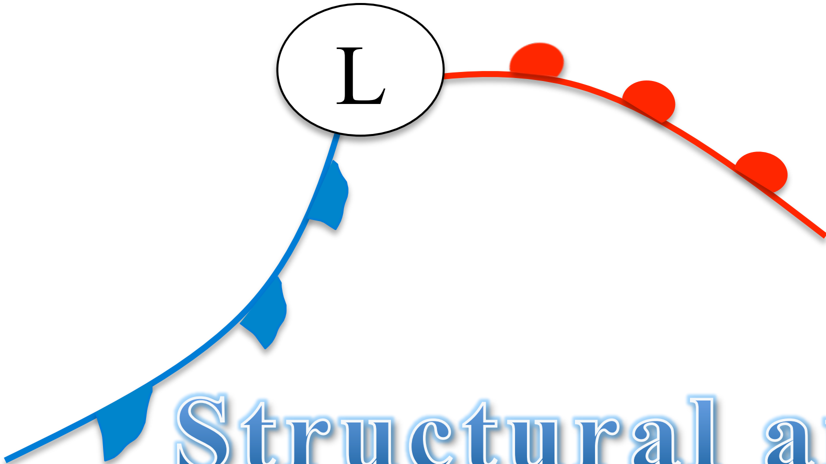
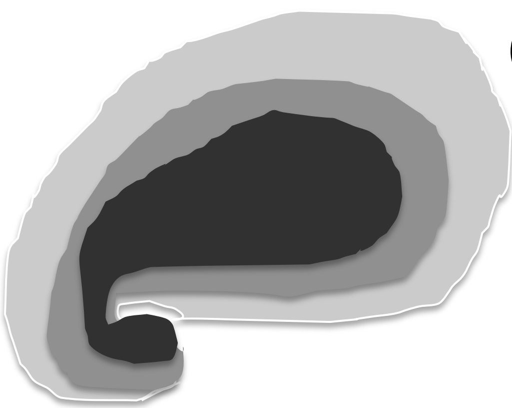


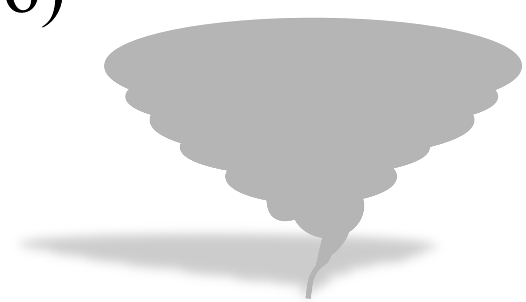
28th Conference on Severe Local Storms
11 Nov. 2016

Structural and Environmental Characteristics of Tornado-Spawning Extratropical Cyclones around Japan

Eigo Tochimoto and Hiroshi Niino

(AORI, The Univ. of Tokyo)



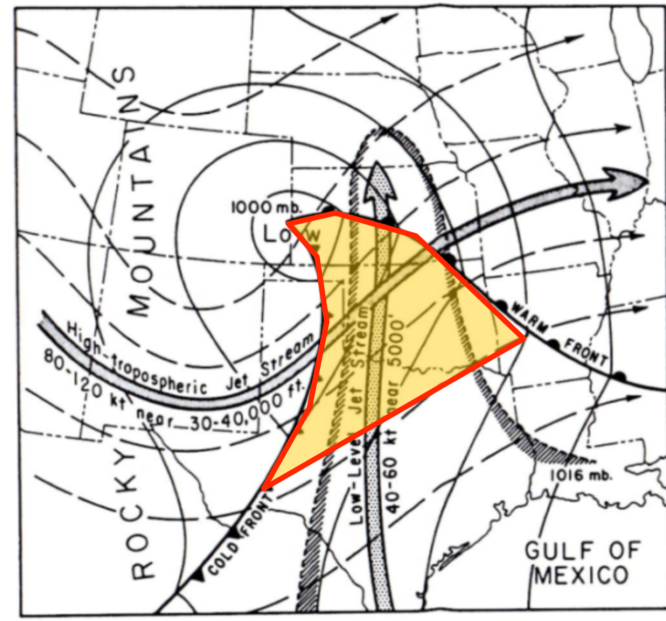


Introduction

In the warm sector of extratropical cyclones (ECs), there are strong upper-level westerly winds and low-level southerly winds.

Vertical shear is strong
Warm and moist air is advected in low-levels

The warm sector is favorable to tornadogenesis



Newton (1967)

Not all ECs cause tornadoes.
There are ECs that cause tornadoes (tornadic ECs: TECs) and that do not (non-tornadic ECs: NTECs).
What are differences between TECs and NTECs ?

Introduction

- In Japan, 46 % of tornadogenesis are associated with ECs.
- There is few studies for environments of tornadogenesis associated with ECs
  - Seko et al. (2009)
    - Saroma (Hokkaido) tornado in November 2009
    - Confined to case studies

- The structures and environment of TECs are not fully understood.

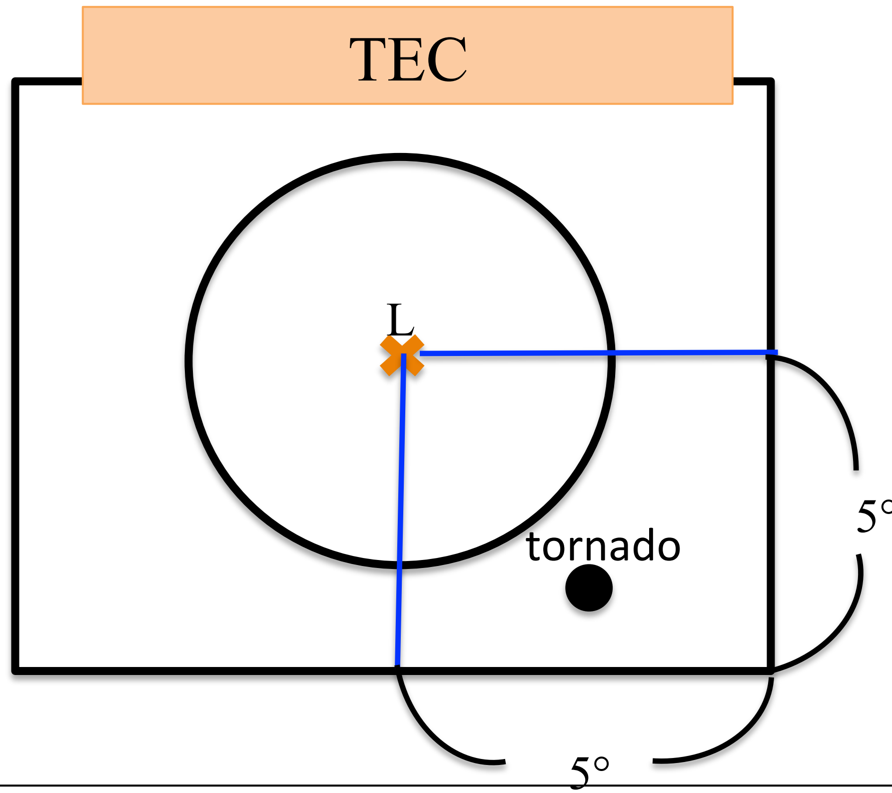
The purposes of this study

- What are the characteristics of tornado-spawning ECs?
  - Comparison between TECs and NTECs
  - Focusing on environmental parameters (CAPE, SREH, and EHI) and horizontal and vertical structures of ECs
  - Comparison between TECs around Japan and the US

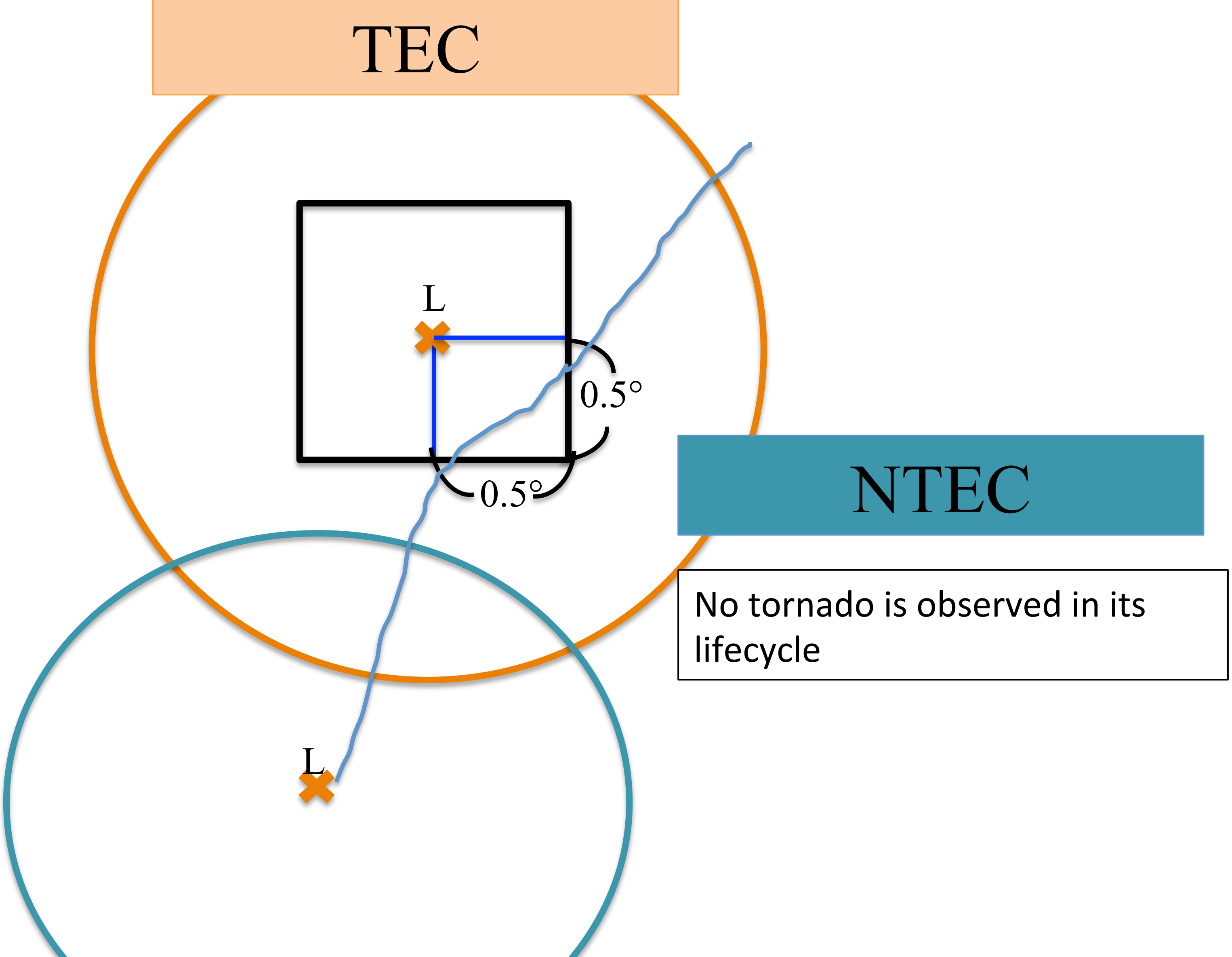
- ◆Data and Period
  - ◆Period：1961～2011（JRA-55 used）
  - ◆Tornado data：1961～1993 used at Niino et al. (1997), 1994-2011:　JMA

Methodology

1. ECs between 1961 and 2011 are automatically detected (Hodges 1994, 1995, 1999)

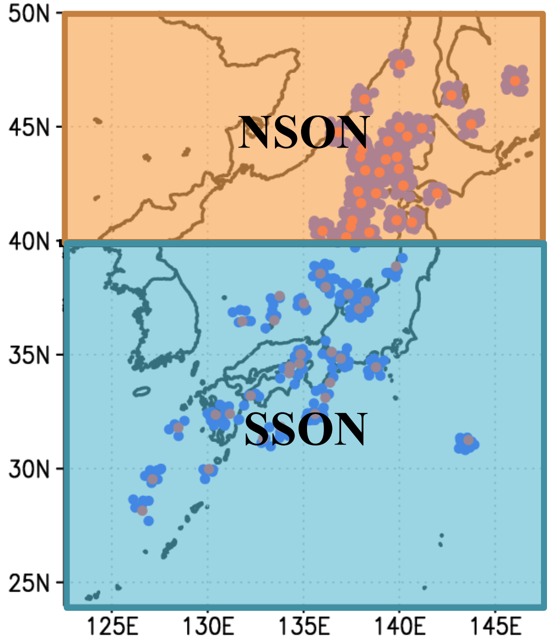


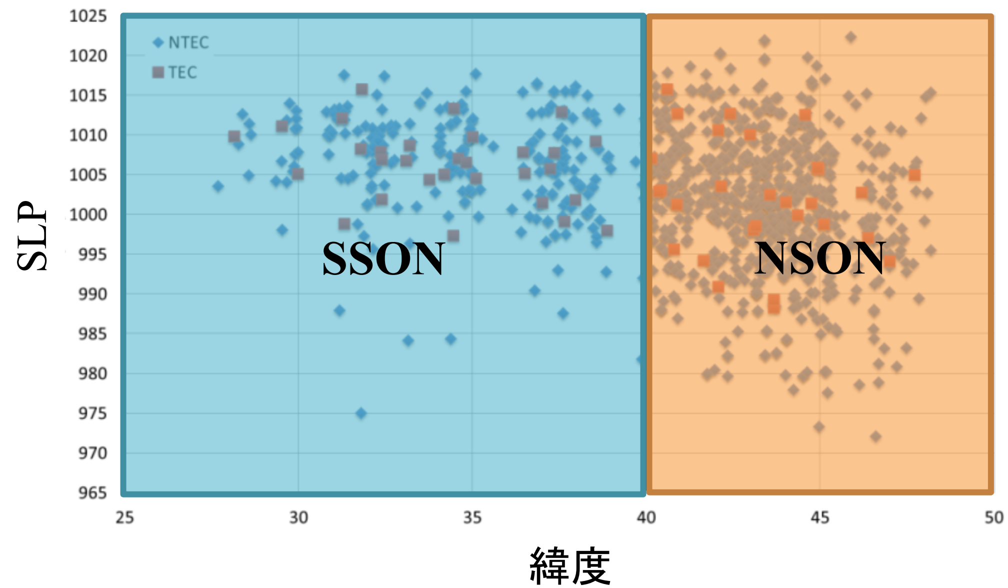
2. Tornadic ECs (TECs) in MAM, SON, and DJF are defined as ECs that are accompanied by a tornado within 3 hours of the 6 hourly analysis time of JRA-55



3. Non-tornadic ECs（NTECs） are defined as ECs that passed the region within 0.5° × 0.5° from the center of TECs in each season, and no tornado was observed within 5° × 5° from the center of the ECs.

Categorization of ECs in SON



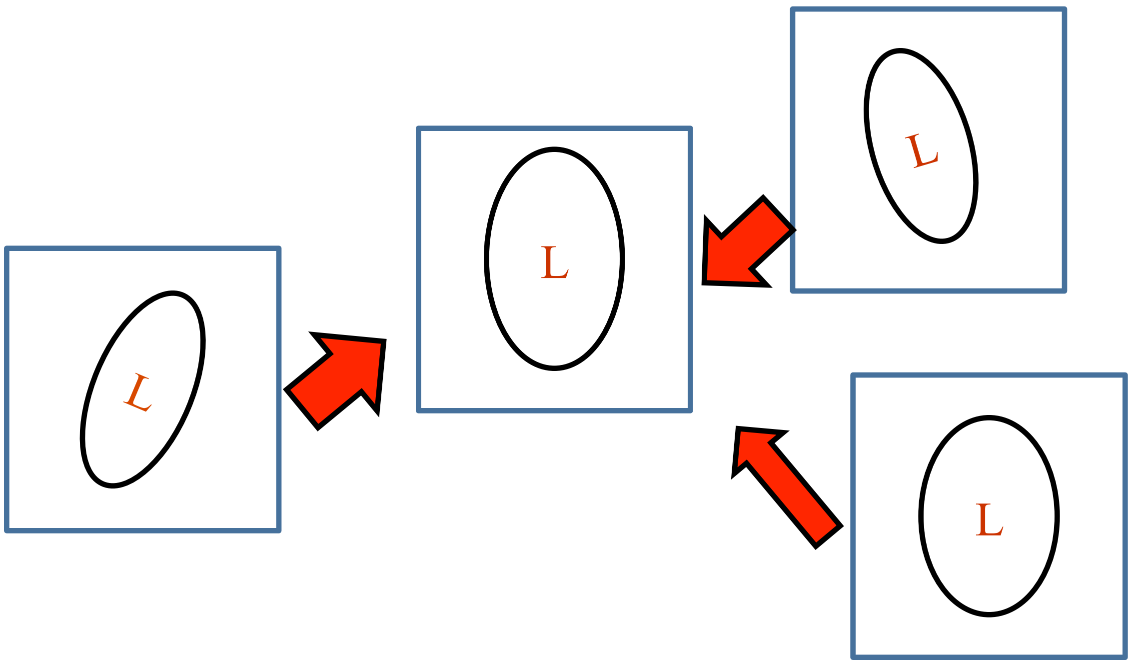


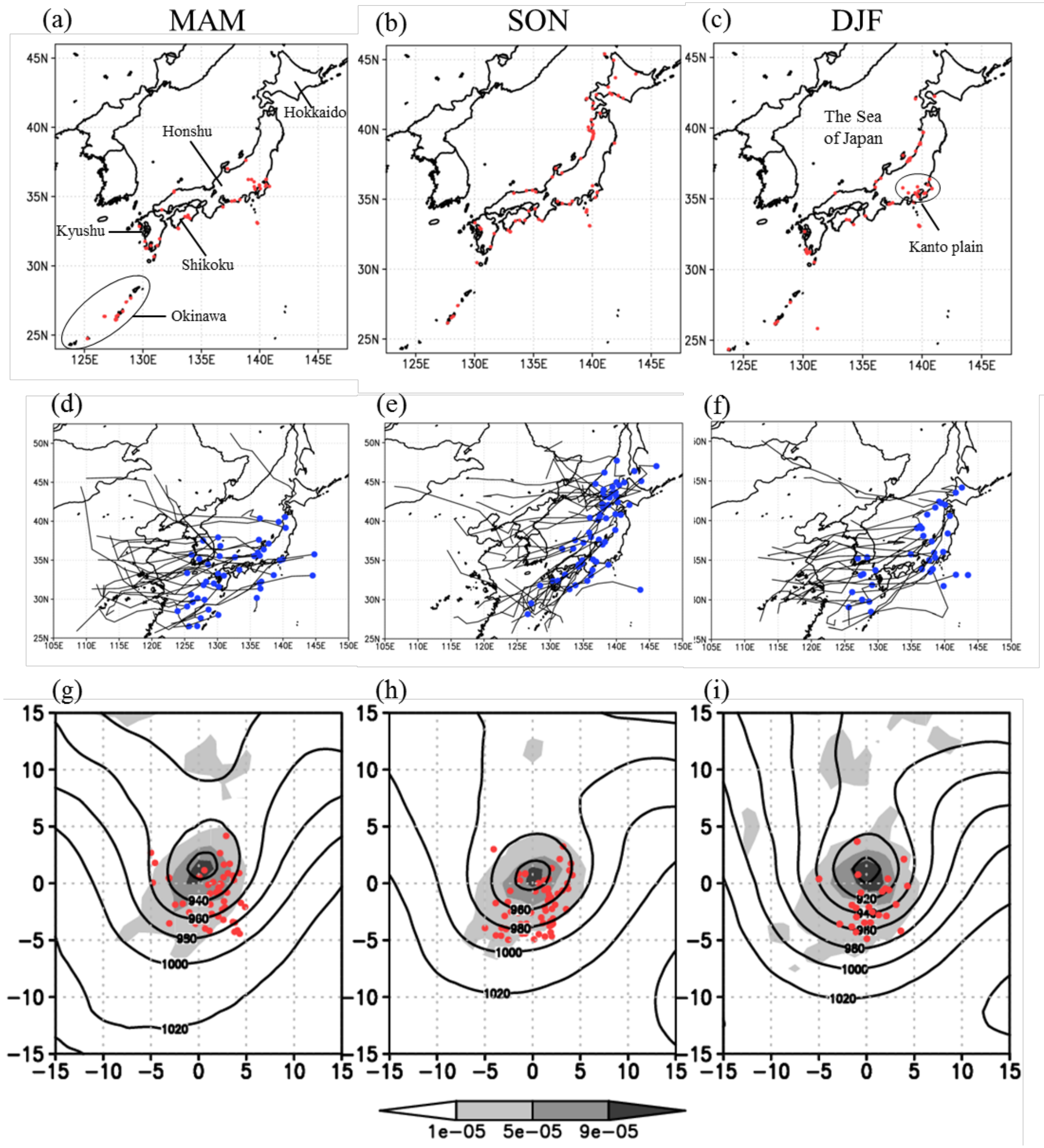
- Latitudinal bias
  - There is large latitudinal difference of the number of NTECs in the north and south of 40N.
  - ECs in SON are categorized in to those in the north of 40N (NSON) and those in the south of 40N (SSON).

The results for MAM, NSON and DJF will be presented.

Methodology

- Composite analysis
  - ✓ Physical variables are superposed with respect to the cyclone center.
  - ✓ Key-Time (KT) is defined as the nearest analysis time of JRA-55 from the occurrence of the tornado.
  - ✓ To clarify the differences between TECs and NTECs of similar intensity, ECs that have the central pressure between 985 and 1005 hPa are analyzed.





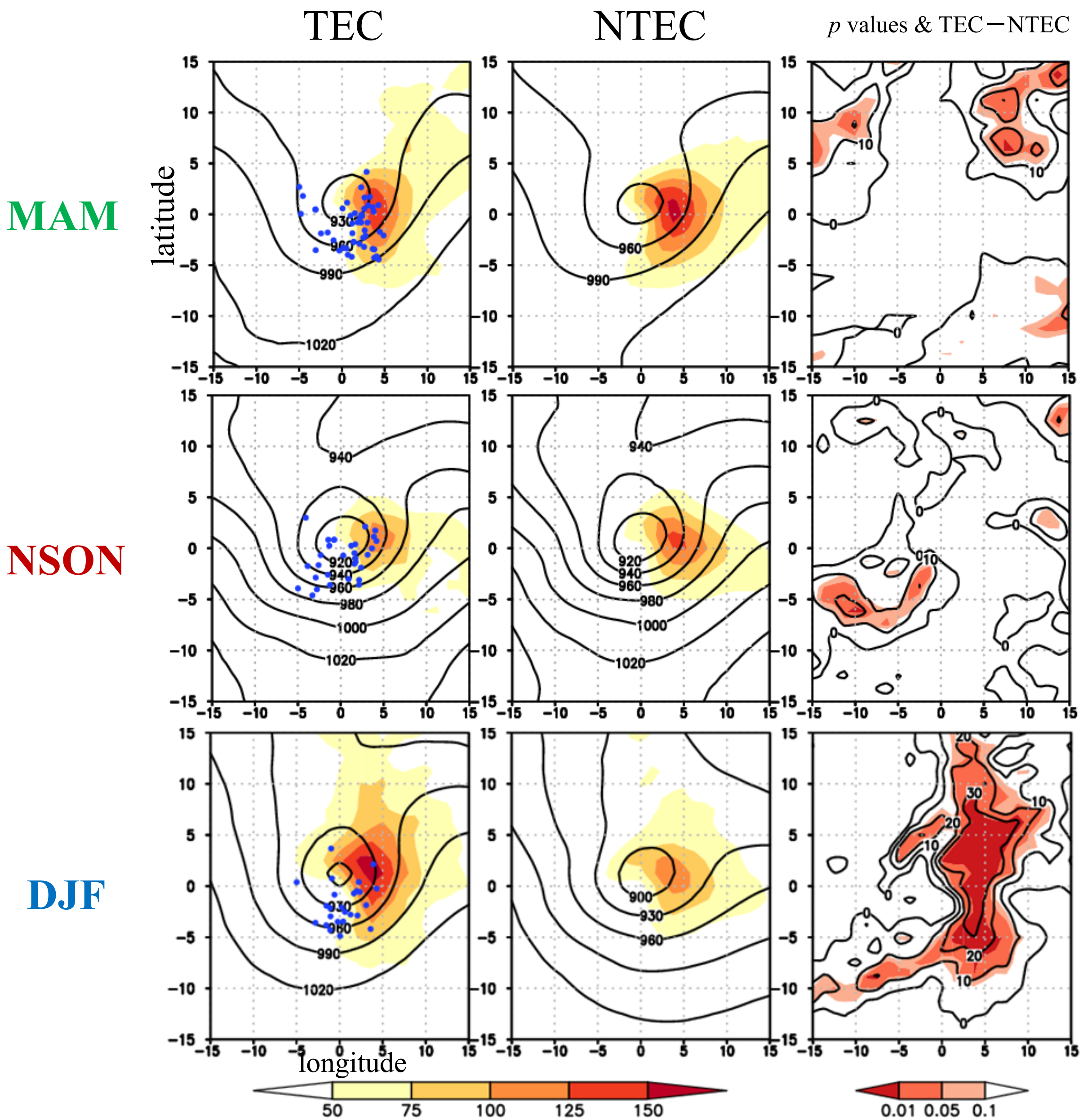
The distributions of tornadogenesis

Many tornadoes occur coastal regions and Kanto plain

The tracks of TECs

Vorticity (gray shading) and geopotential height at 900 hPa for the composite.

SREH & 900-hPa geopotential height



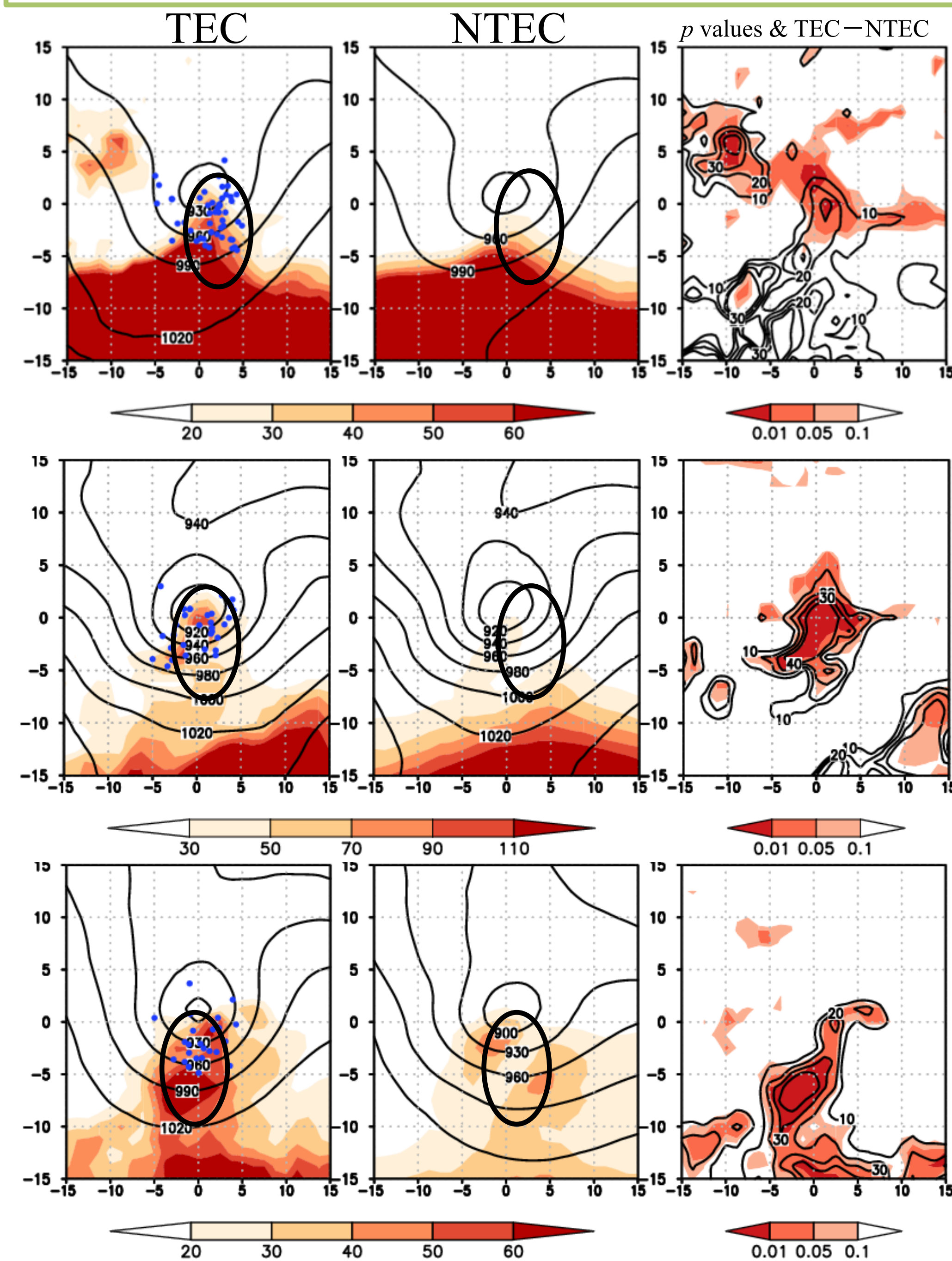
- ✓ There is little difference in SREH in MAM and NSON.
- ✓ SREH for TECs in DJF is significantly larger.
- ✓ About a half of tornadoes does not correspond to large SREH

CAPE & 900-hPa geopotential height

MAM

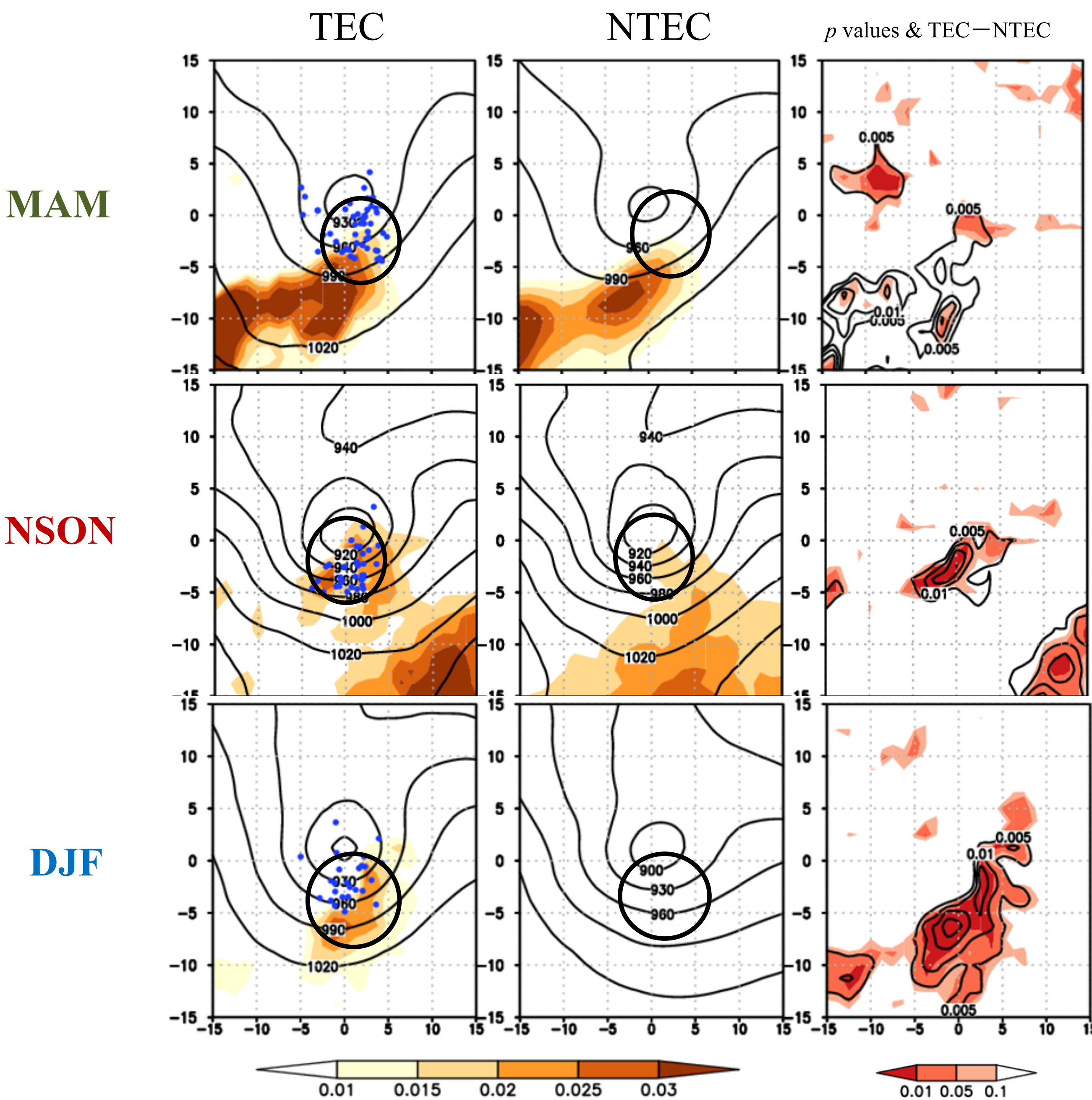
NSON

DJF



CAPE for TECs is significantly larger in **MAM**, **NSON**, and **DJF**
⇒tornadoes occur in more unstable region.

EHI & 900-hPa geopotential height



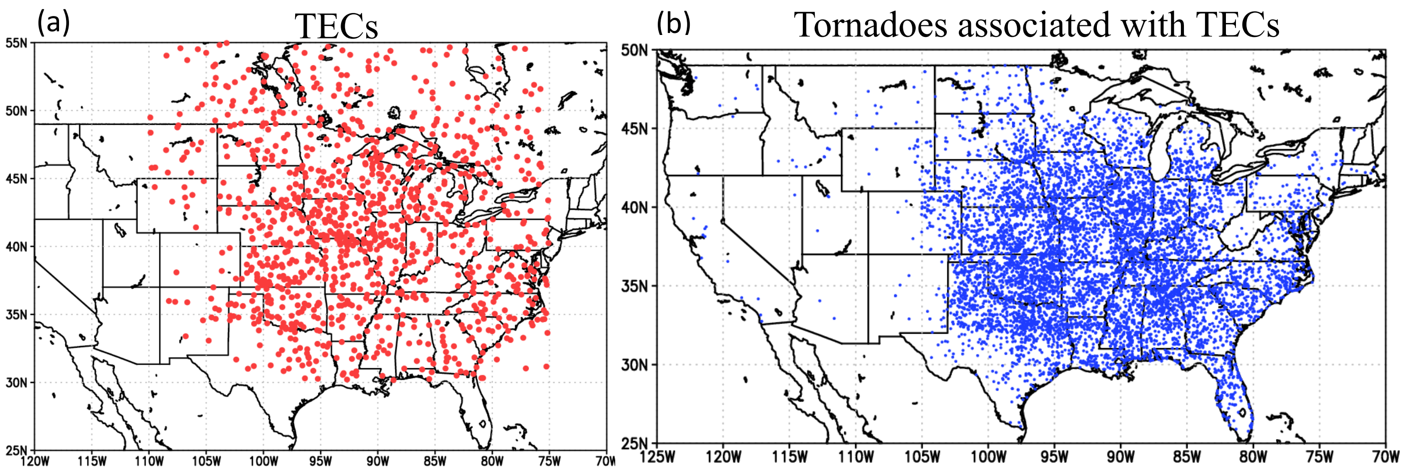
- ✓ There are significant differences in **NSON** and **DJF**
- ✓ Corresponds to the location of tornadoes

Summary of differences between TECs and NTECs

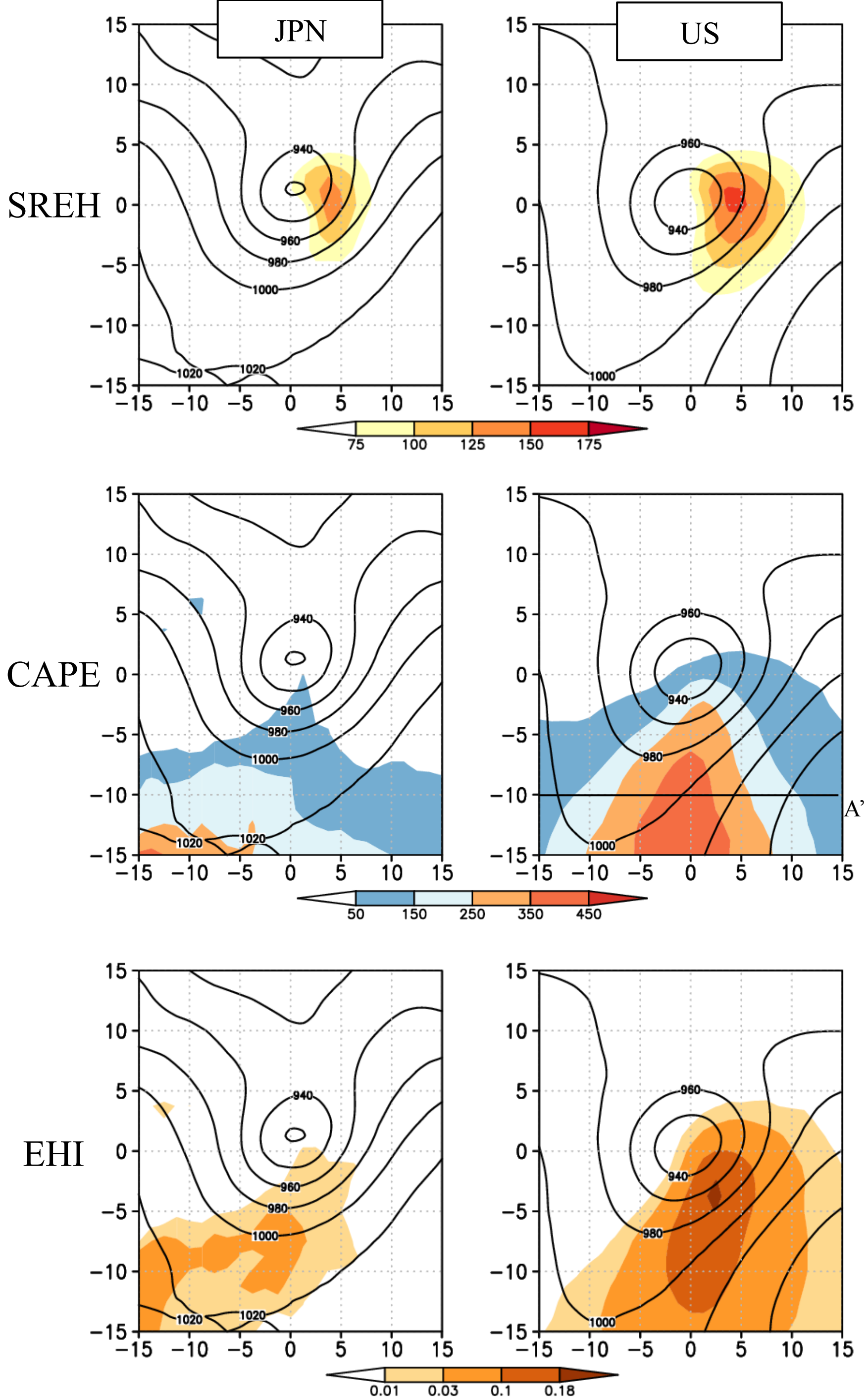
	SREH	CAPE	EHI	KI	KHI
MAM	×	○	×	×	×
SSON	×	△	△	×	△
NSON	×	○	○	×	×
DJF	△	○	○	○	○

For all seasons, CAPE may be useful to distinguish TECs from NTECs.

Comparison between Japan and the US（MAM）



Many tornadoes occur on land



SREH :

- ➢ Larger in the US
- ➢ Larger values extend over wider area.

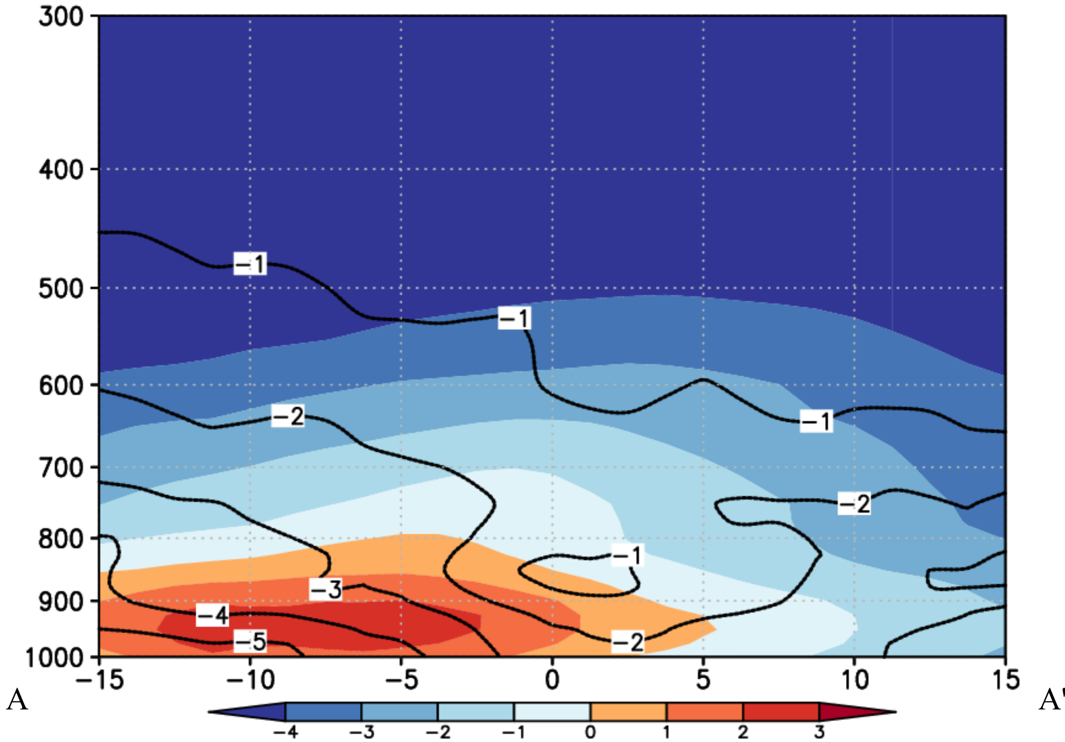
CAPE :

- ➢ Notably larger in the US

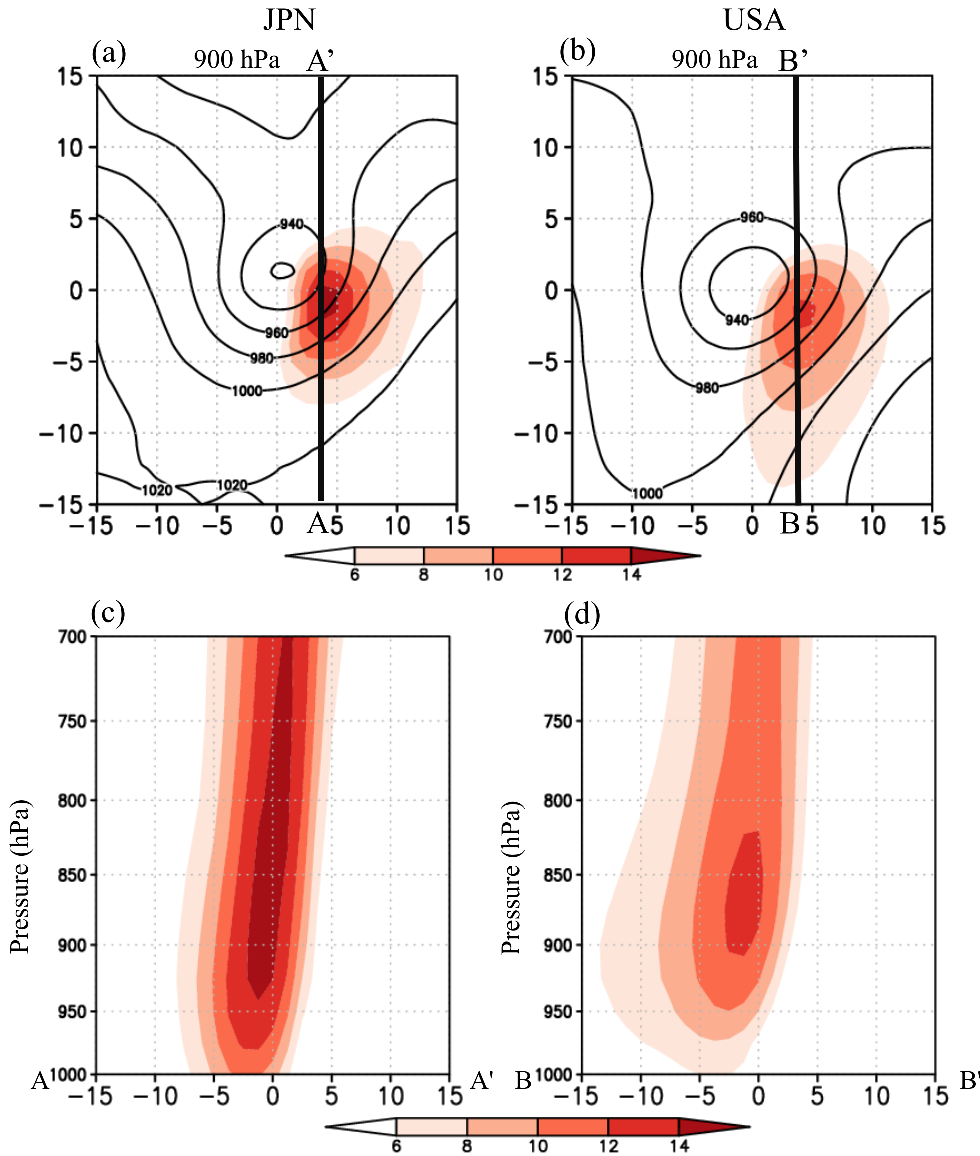
EHI :

- ➢ Larger in the US.

Vertical distributions of differences in temperature (color) and specific humidity (contour lines) between the US and Japan



Lower layer: warmer
Upper layer: colder
⇒larger CAPE
A large number of tornadoes occurs on land in the US ⇒ radiative heating is important for higher temperature



Japan :

- ✓ Smaller scale of EC
- ✓ Stronger low-level southerly

Japan :

- ✓ Stronger wind near the surface
- ⇒ weaker vertical wind shear
- ⇒ smaller SREH

Conclusions 1

	SREH	CAPE	EHI	KI	KHI
MAM	×	○	×	×	×
SSON	×	△	△	×	△
NSON	×	○	○	×	×
DJF	△	○	○	○	○

- There is no notable difference in SREH between **TEC** and **NTEC.**
- CAPE shows significant differences between TECs and NTECs in **MAM**, **NSON** and **DJF**
- EHI also shows the differences in **NSON** and **DJF**.

Conclusions 2

- Differences between Japan and the US

	Japan	US
SREH	small	large
CAPE	small	large
EHI	small	large
Upper-layer temperature	high	low
Lower-layer temperature	low	high
Wind near the surface	strong	weak

Environments in the US are favorable for tornadogenesis

Environmental parameters

Convective available potential energy (CAPE)

$$\mathrm{CAPE} = g\int_{LFC}^{LNB} \frac{\theta(z) - \bar{\theta}(z)}{\bar{\theta}(z)} dz$$

Storm relative environmental helicity (SREH)

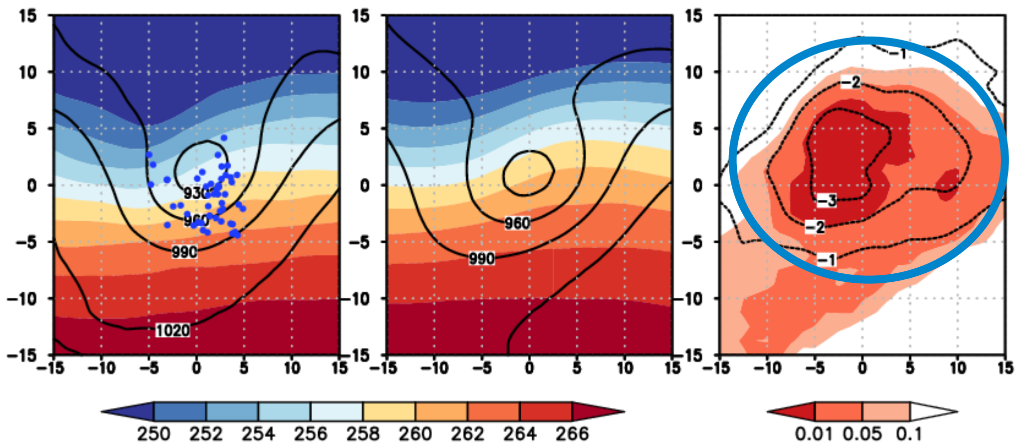
$$\mathrm{SREH} = \int_0^h \boldsymbol{k} \times \frac{\partial \boldsymbol{V}}{\partial z} \cdot (\boldsymbol{V} - \boldsymbol{c}) dz$$

h=1km

CAPEの違いについて（**MAM**）

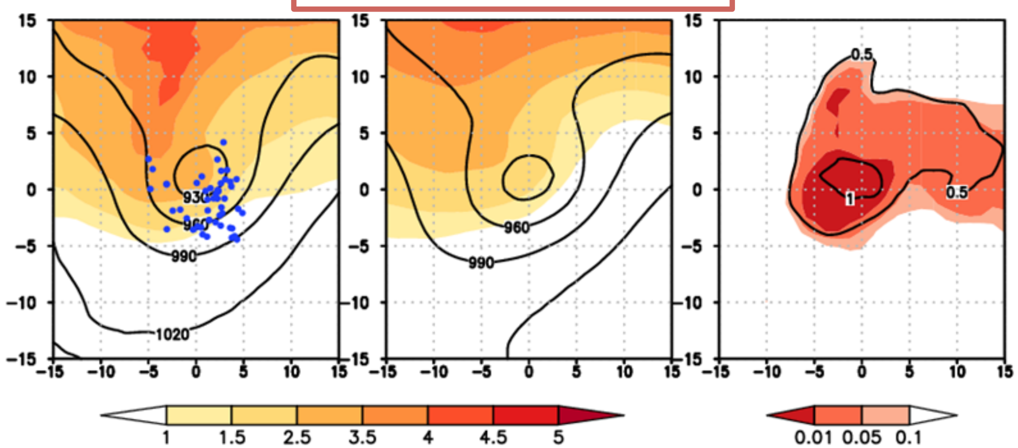
温度 at 500 hPa

TEC　　NTEC　　TEC−NTEC



TEC：中層はより低温
⇒より大きなCAPE

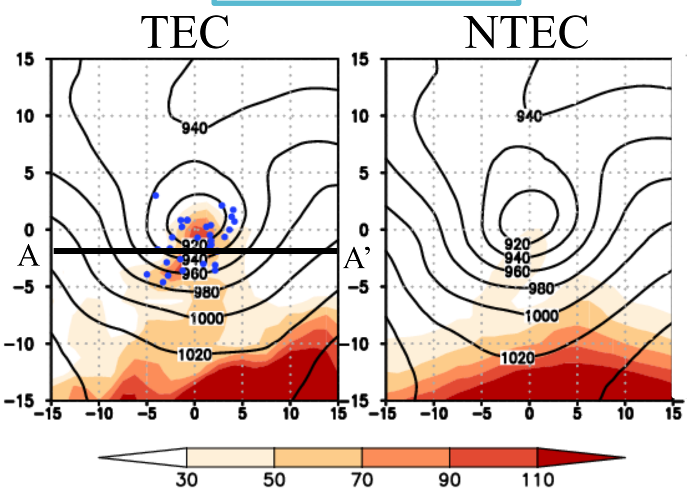
250-hPa 渦位



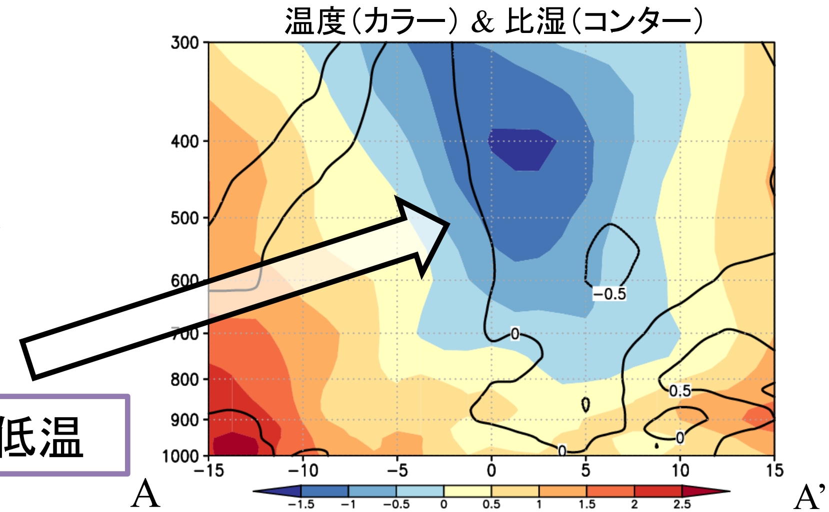
TEC：より強い上層擾乱が接近
⇒上空の低温に寄与
⇒より大きなCAPE

CAPEの違いについて（**NSON**）

CAPE

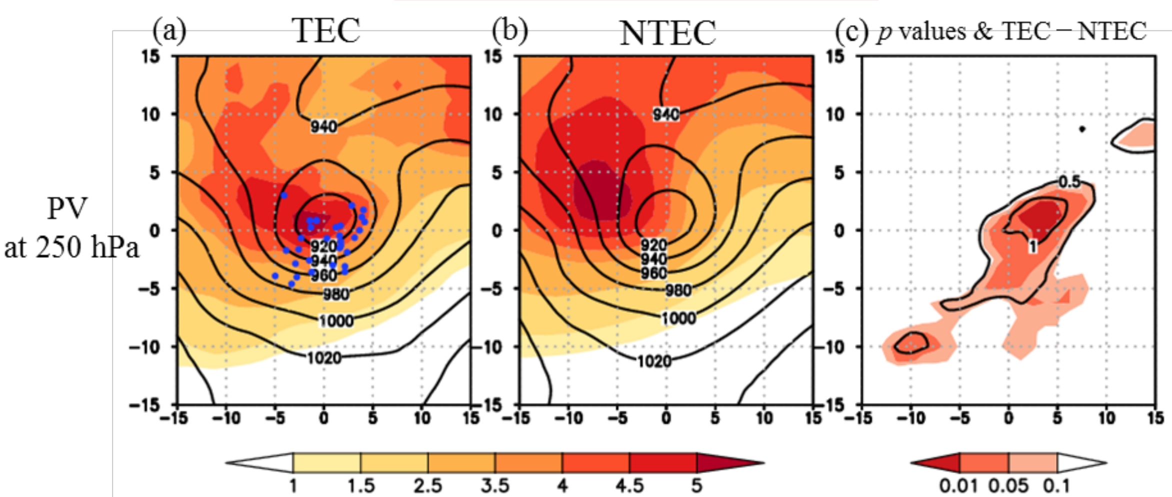


TEC－NTECの鉛直断面



上空で低温

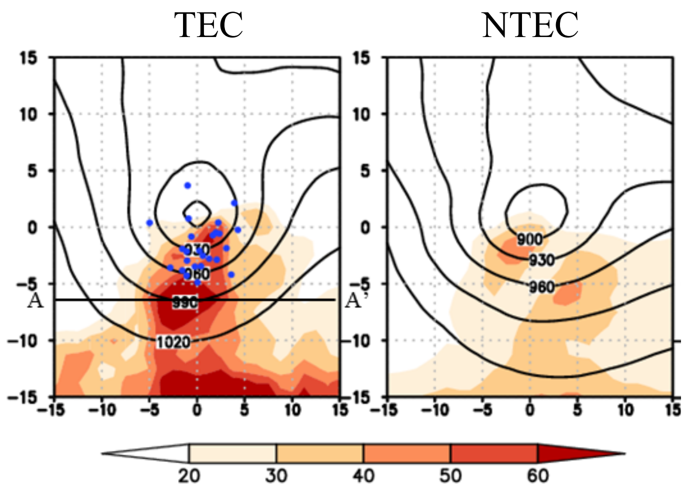
250-hPa 渦位



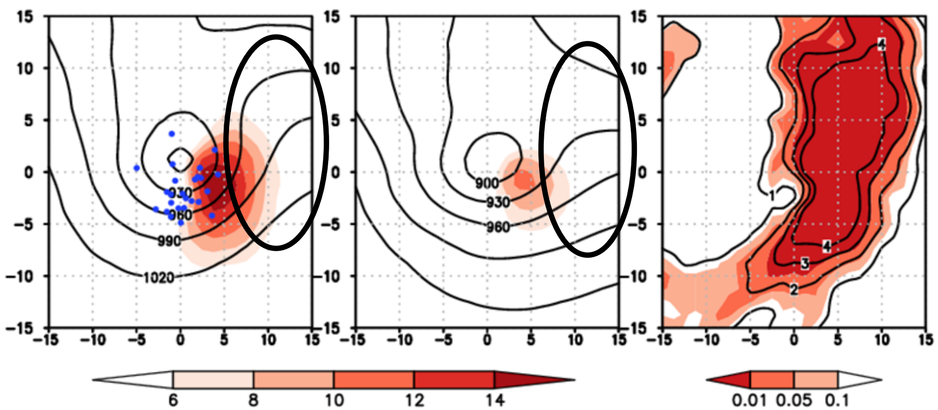
TEC: より上層擾乱が接近
⇒上空が低温化
⇒CAPE大

CAPEの違いについて（DJF）

CAPE

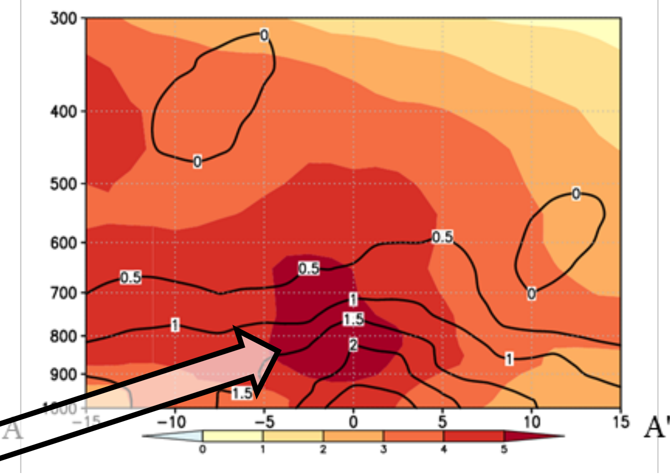


南風 at 900 hPa



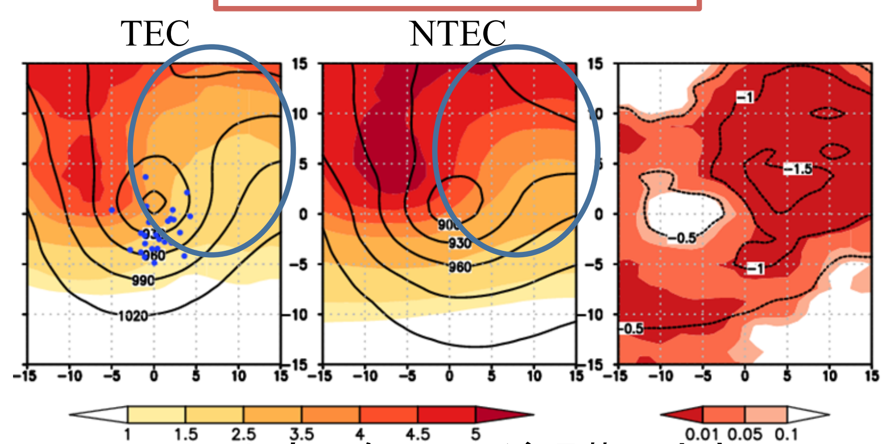
TEC:東側の高気圧が卓越
⇒より強い南風
⇒暖湿な空気の流入
⇒CAPE大

TEC−NTECの鉛直断面



TEC:下層が暖湿

250-hPa 渦位

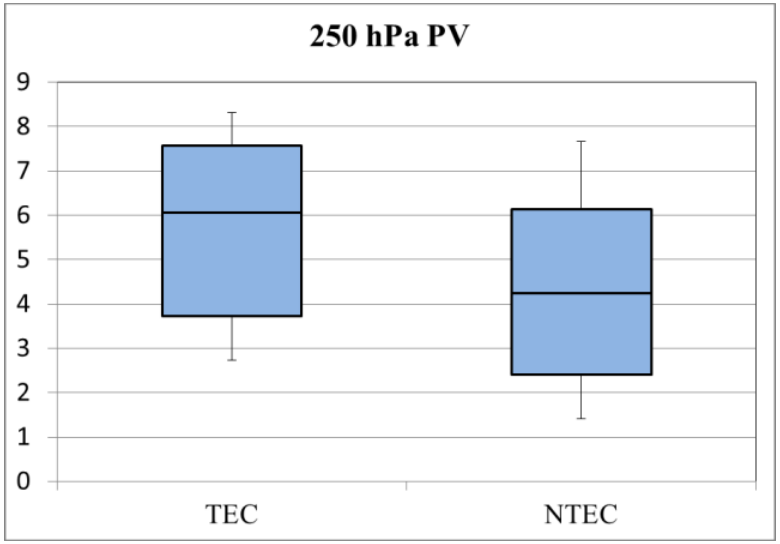


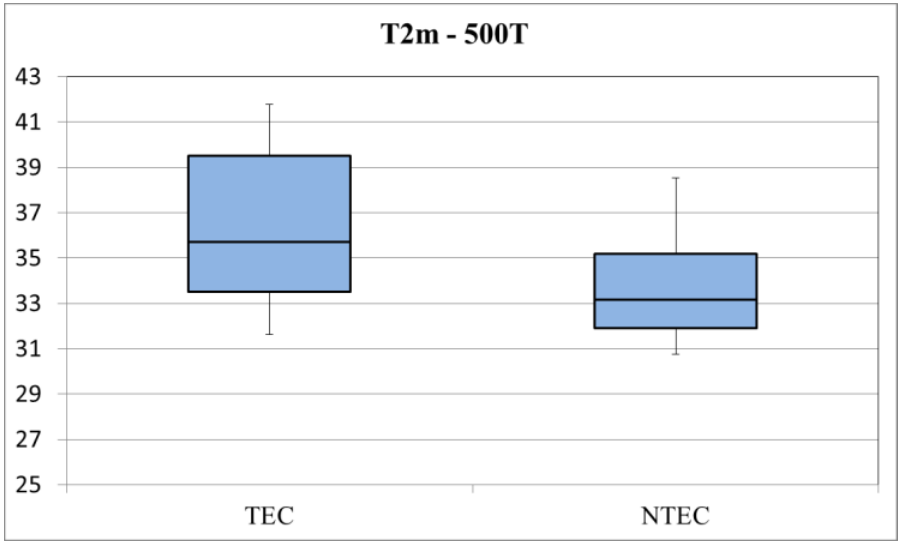
TEC:上空で負のPVが顕著に大きい
⇒深い構造を持った高気圧

環境パラメータ

- ストームに相対的なヘリシティ（SREH）
- CAPE
- Energy Helicity Index (EHI)
- ~~K Index (KI)~~
- ~~K-Helicity Index (KHI, 桜井-川村 2008)~~

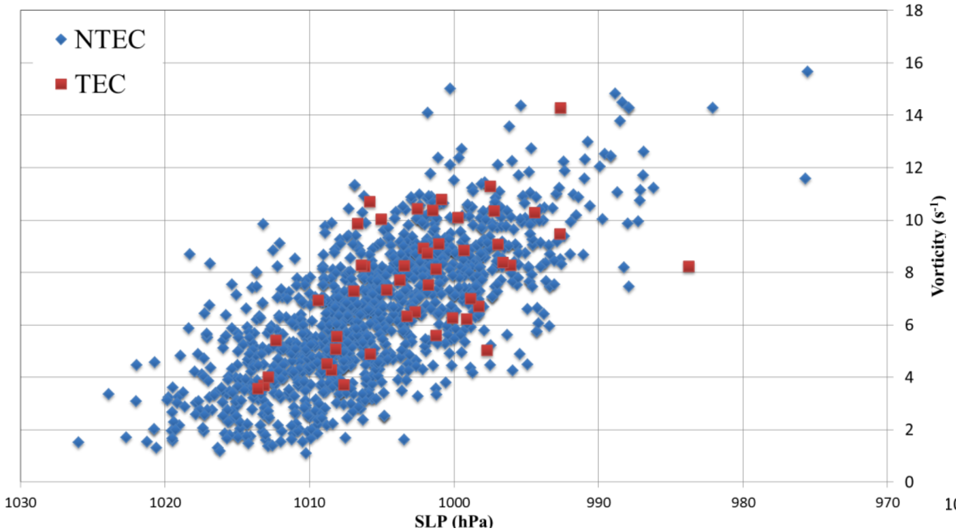
MAM


250 hPa PV
9
8
7
6
5
4
3
2
1
0
TEC
NTEC

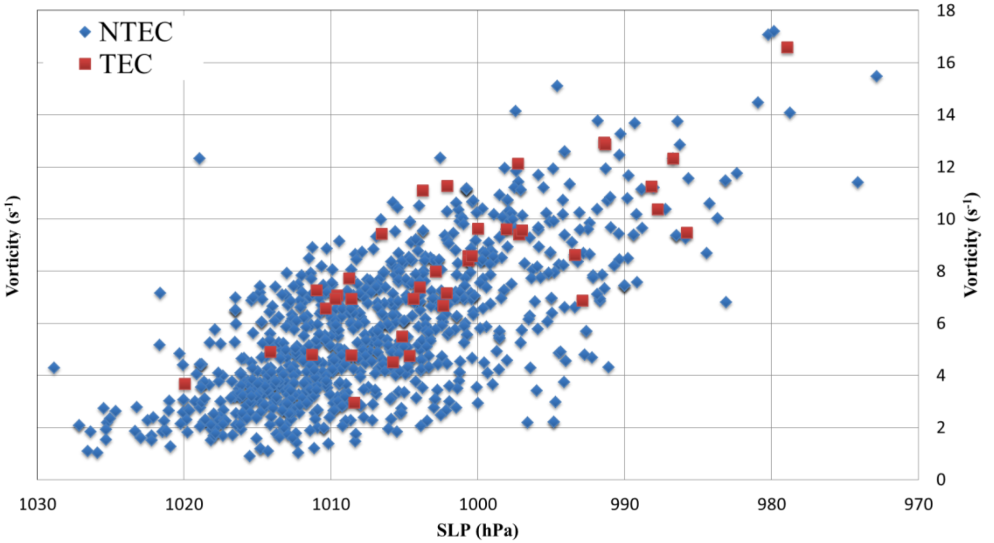

T2m - 500T
43
41
39
37
35
33
31
29
27
25
TEC
NTEC

Exclusion of weak NTECs

MAM

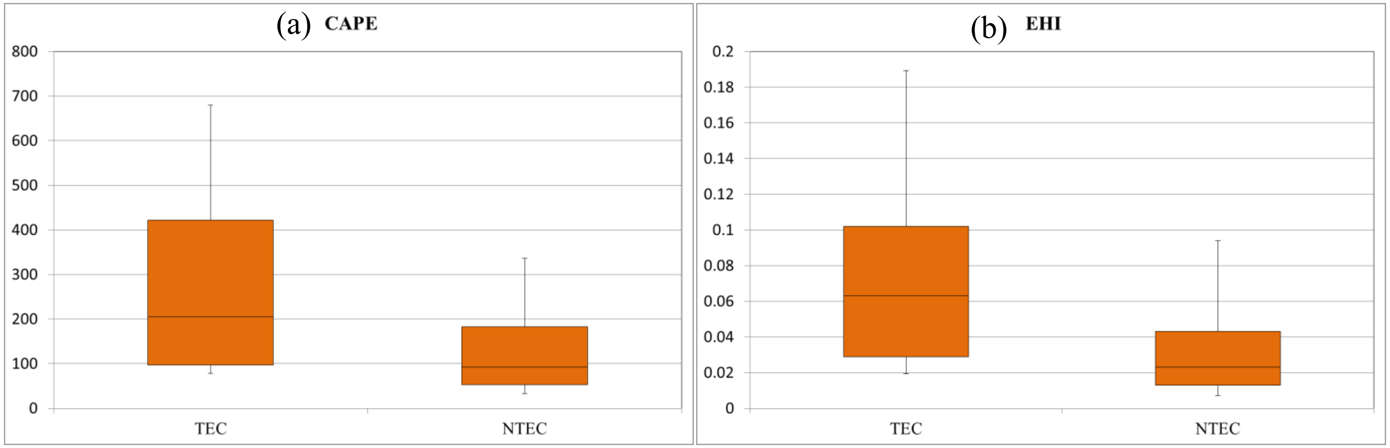


DJF



- 渦度・SLPともにTECよりもNTECの方が強い傾向（統計的に有意）
  - ✓ 渦度が3.5×10^{-5}よりも小さいものは除く。
  - ✓ 中心気圧が1010 hPaよりも小さいものは除く。
- 985 hPaよりも強い低気圧はほとんど竜巻を伴っていない。
  - ✓ 985 hPaよりも低いものは除く

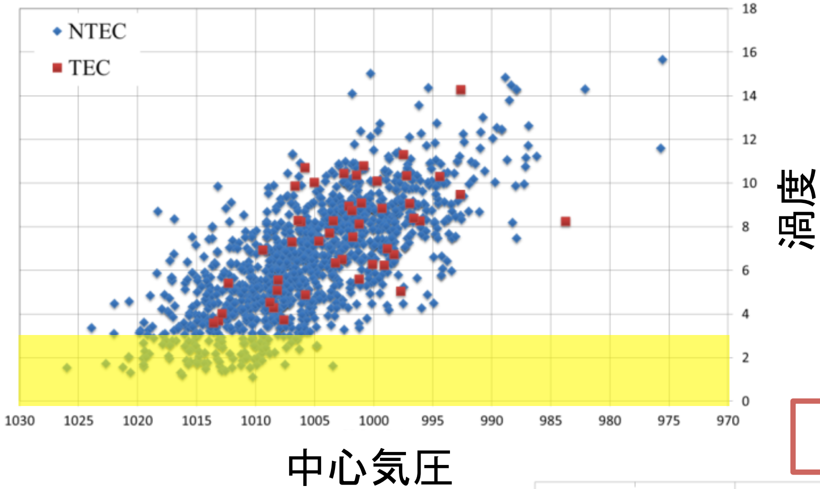
NSON



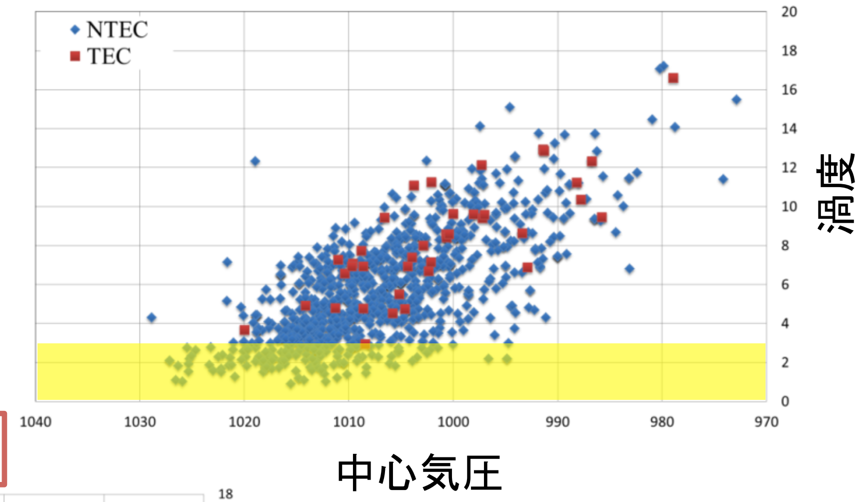
(a) CAPE
800
700
600
500
400
300
200
100
0
TEC
NTEC
(b) EHI
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
TEC
NTEC

弱いNTECを除く①

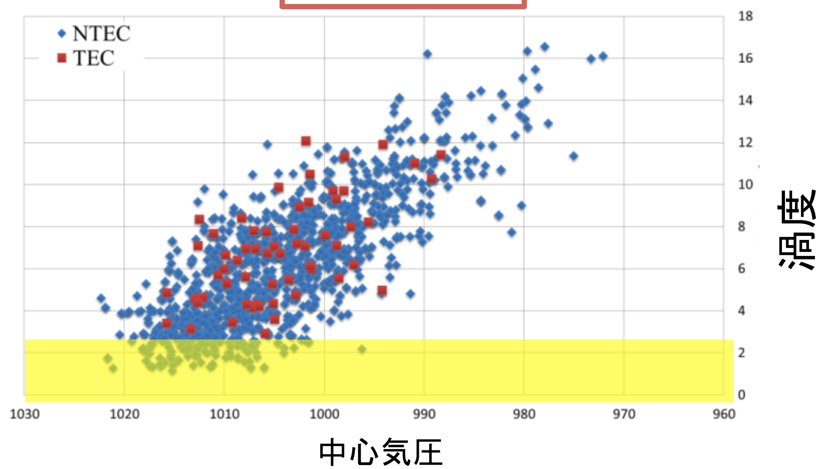
MAM



DJF



SON

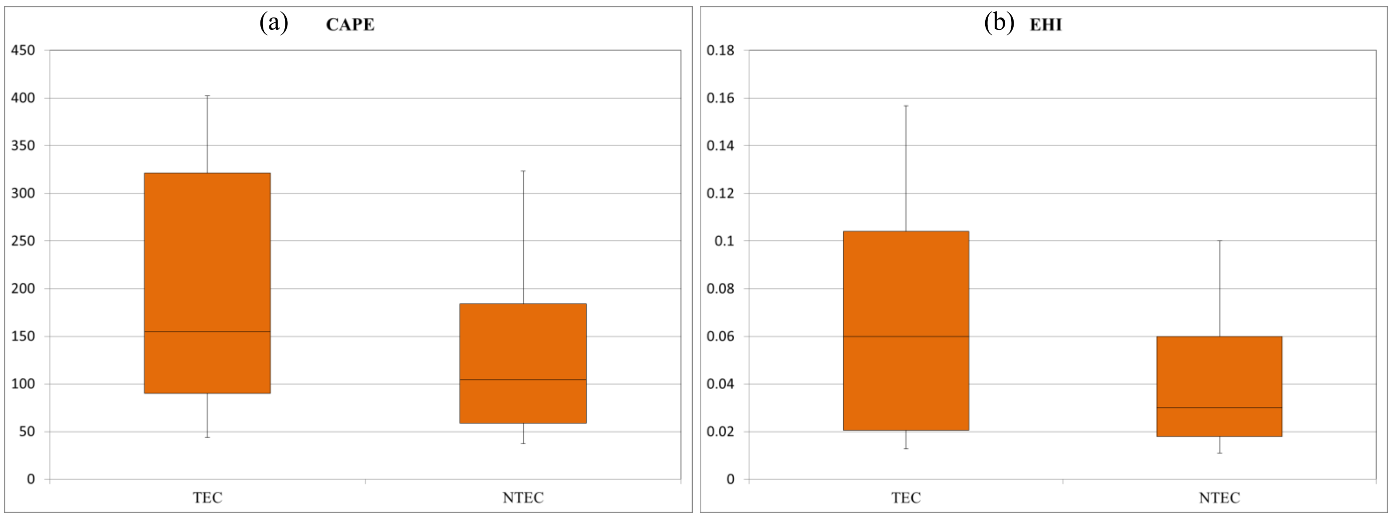


✓ 3×10^{-5}(**SON**) or 3.5×10^{-5}（**MAM**, **DJF**）よりも小さい渦度の低気圧は竜巻を起こさない

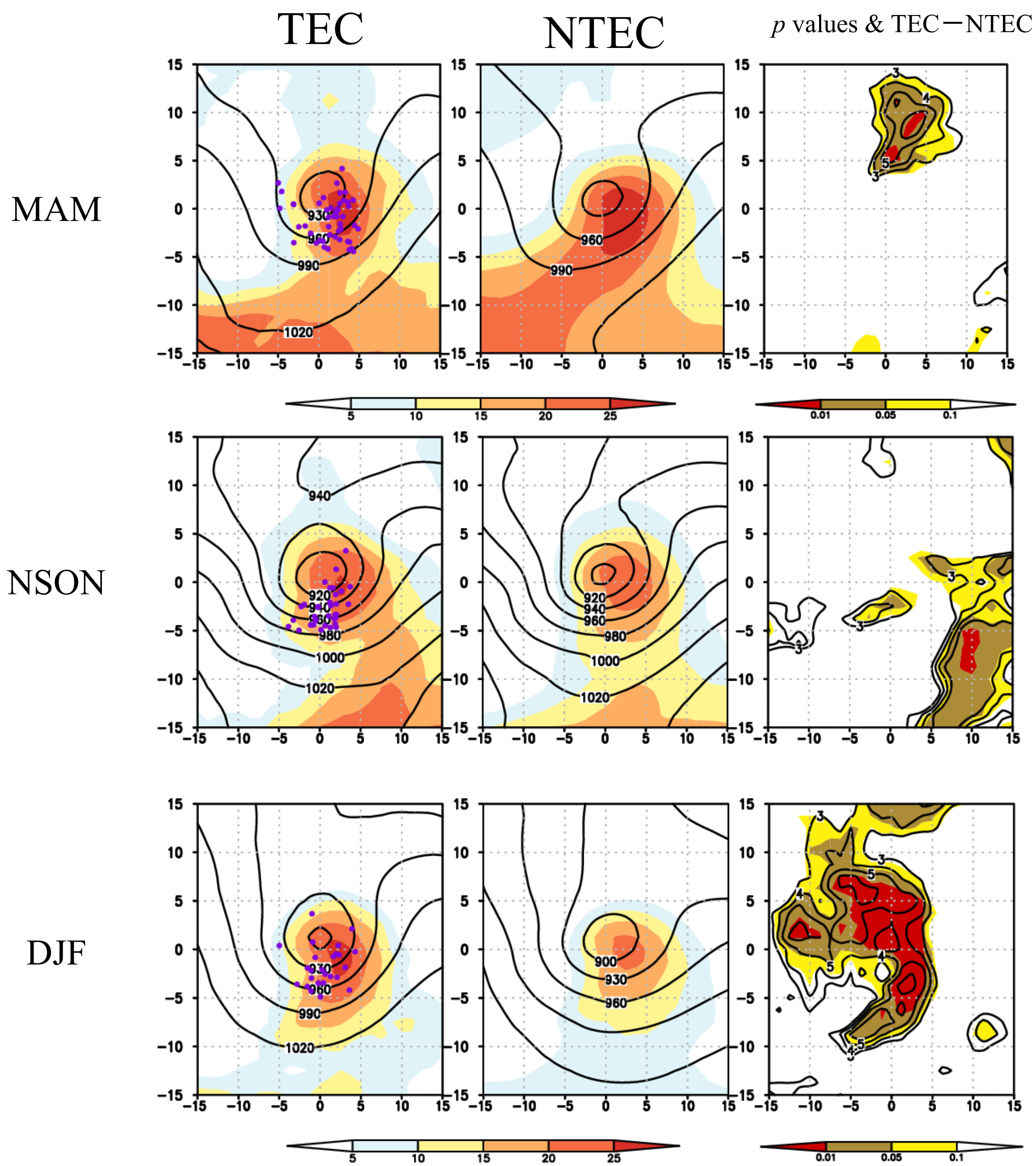
⇒これらのNTECを除く

✓ 春と冬はTECの方が中心気圧が低い（統計的に有意）。

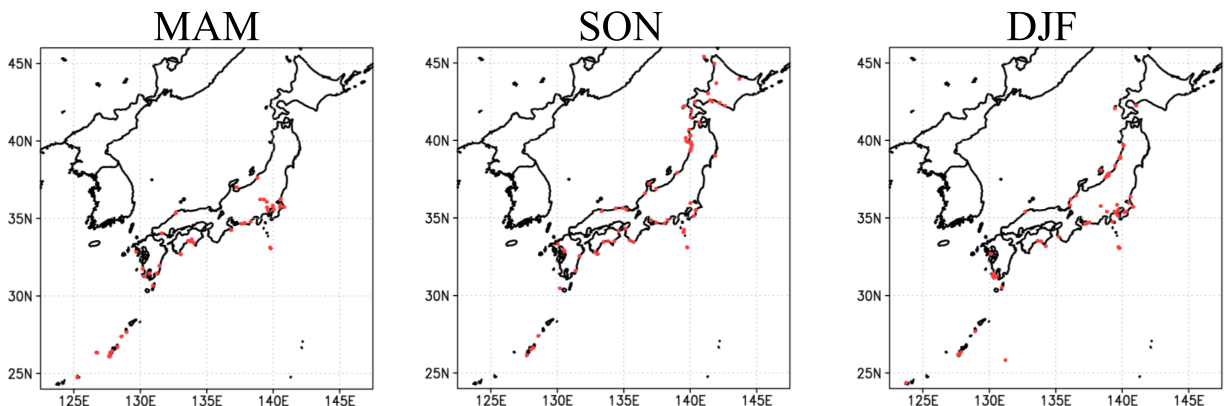
DJF


(a) CAPE
450
400
350
300
250
200
150
100
50
0
TEC
NTEC
(b) EHI
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
TEC
NTEC

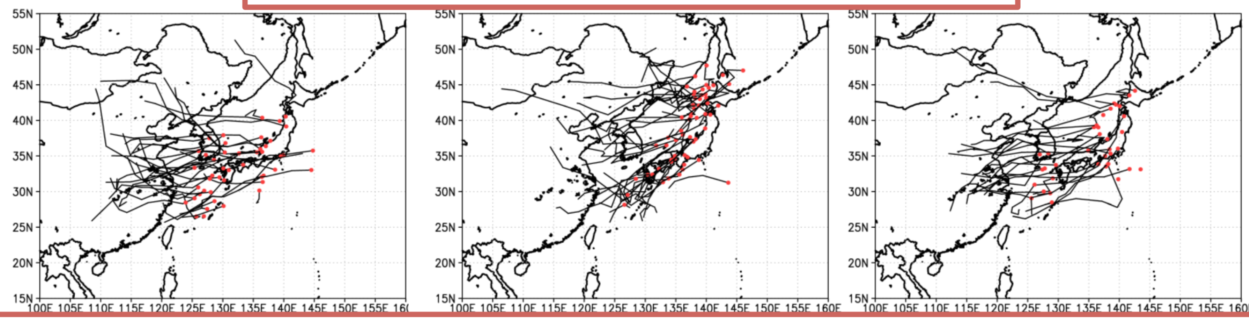
KIの分布



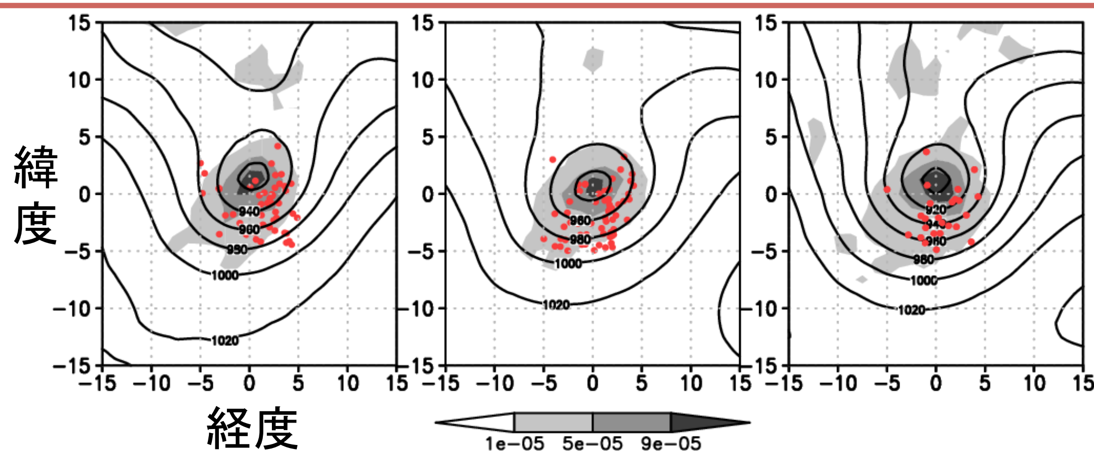
温帯低気圧に伴う竜巻の発生位置



低気圧経路

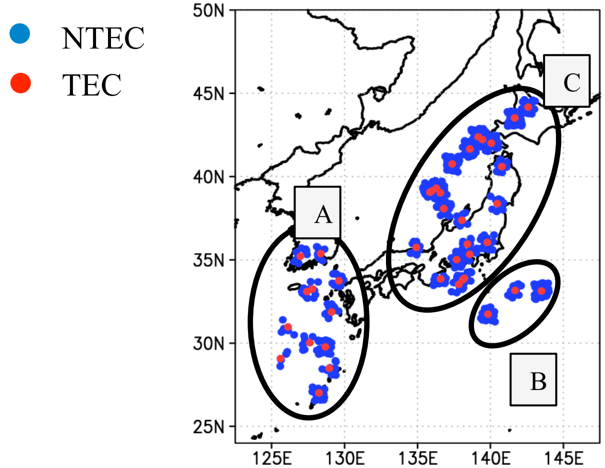


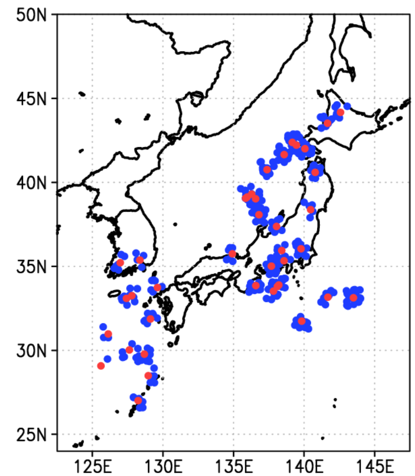
低気圧中心を合わせたコンポジット場（グレー：渦度、コンター：900-hPa高度）

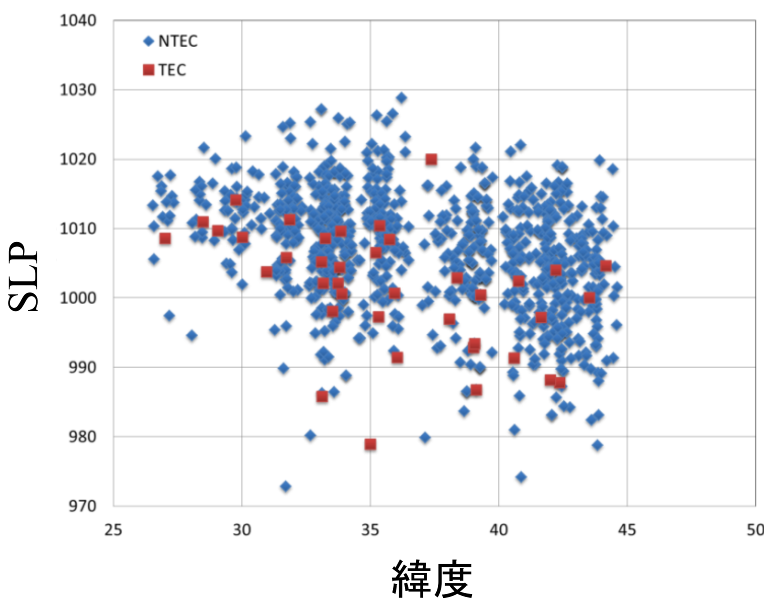


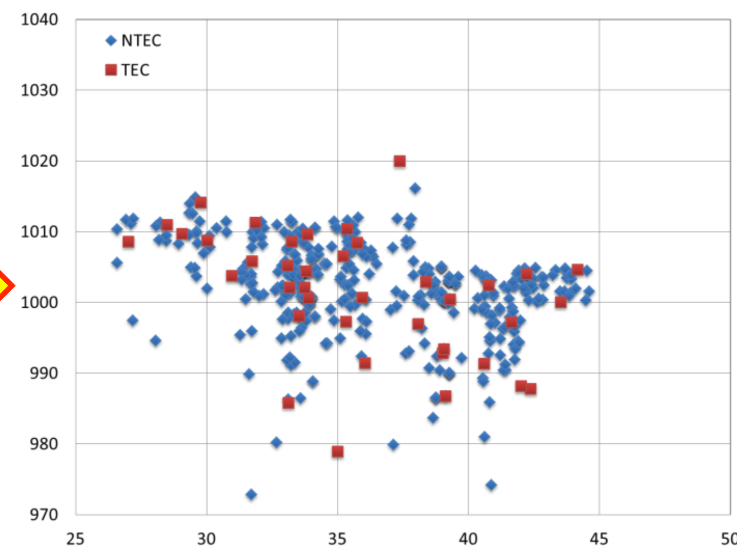
- ✓ 竜巻の発生位置や低気圧の経路は季節により異なる特徴を持つ
- ✓ 竜巻を起こす低気圧の構造も季節により異なる

弱いNTECを除く②（**DJF**）

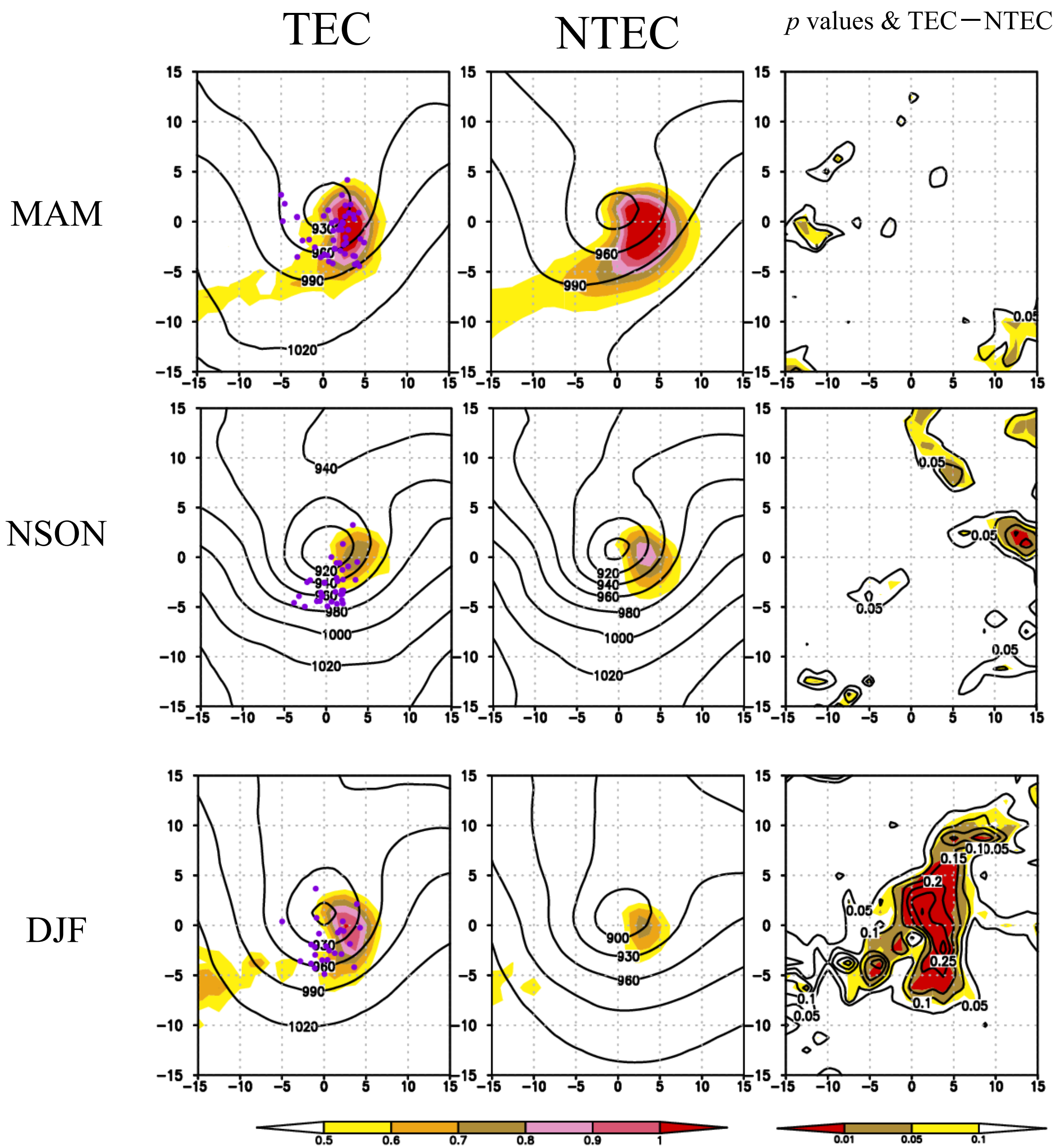


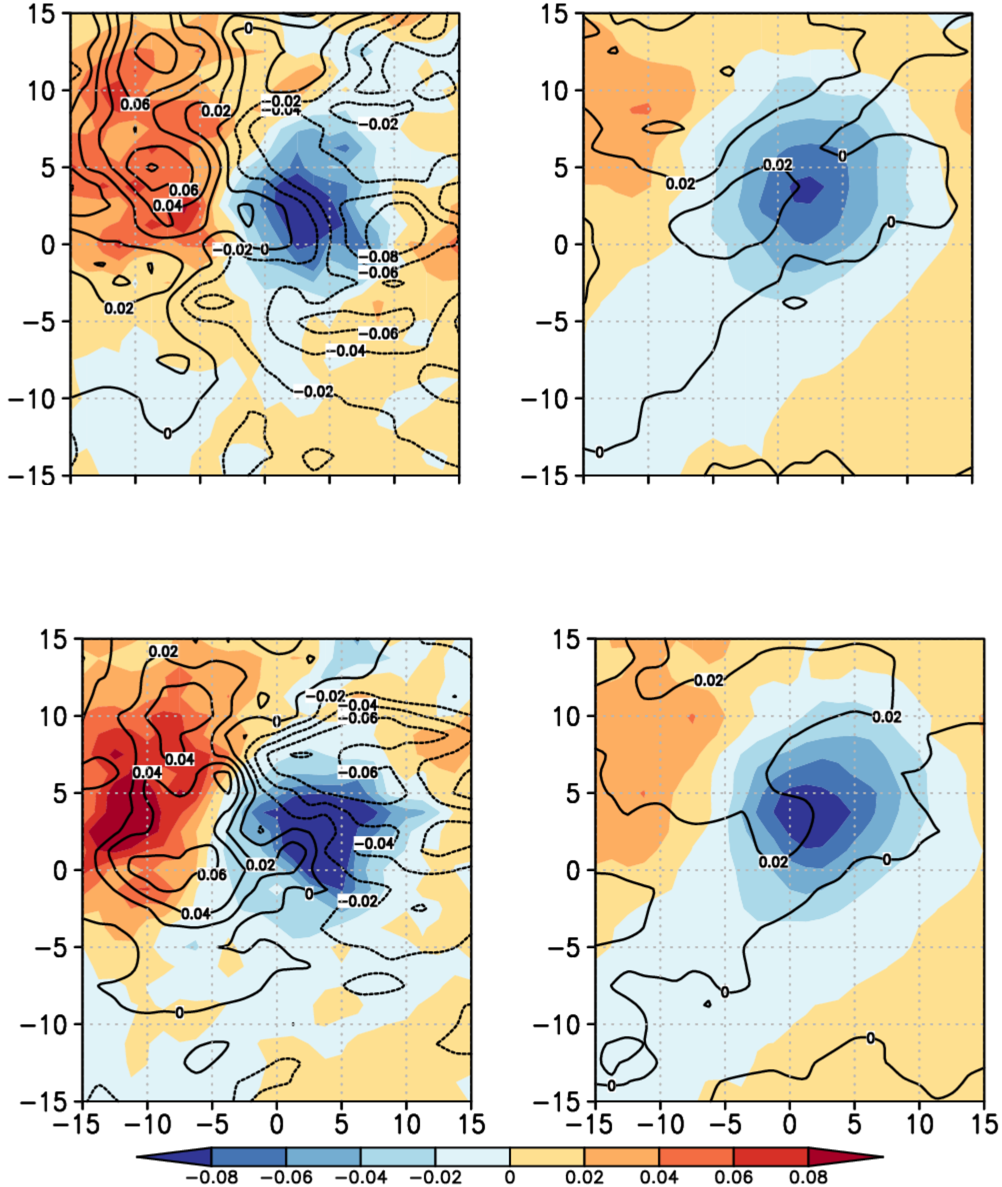




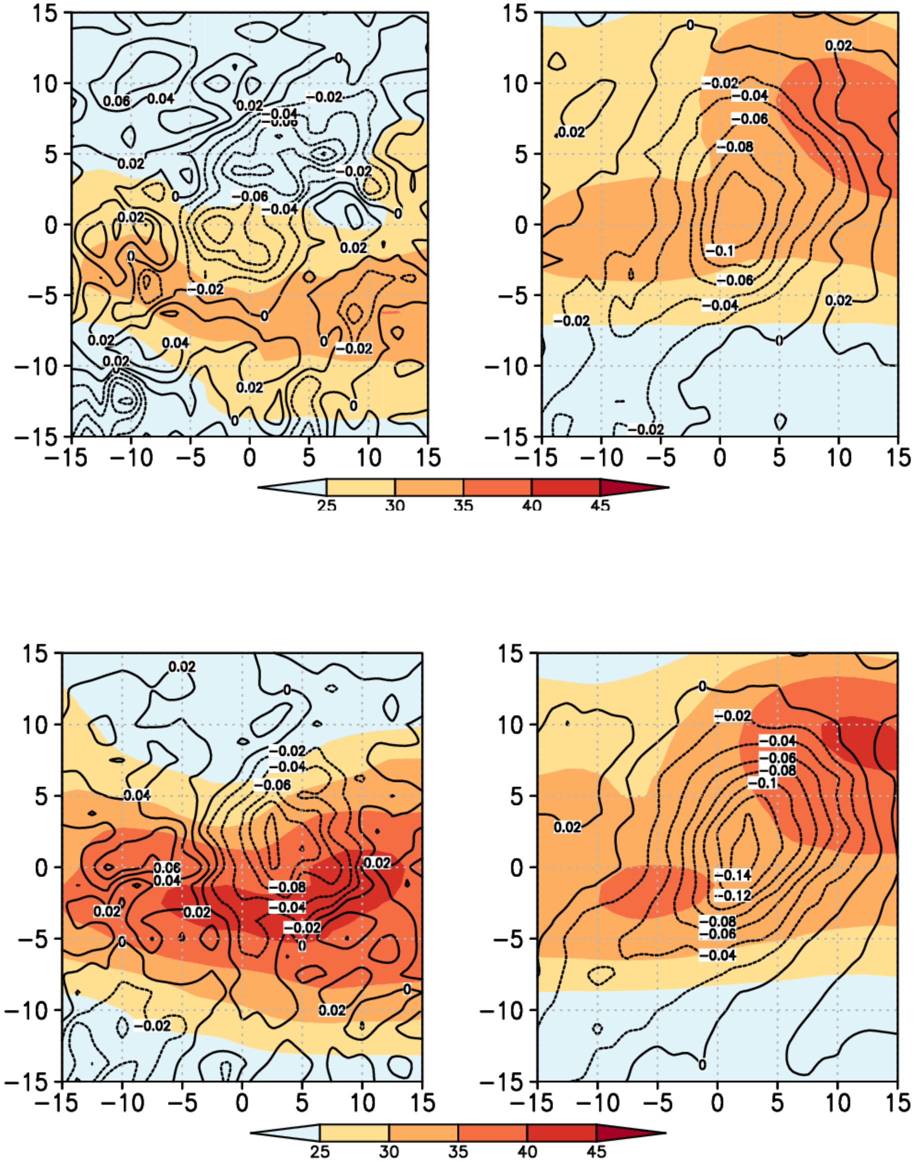


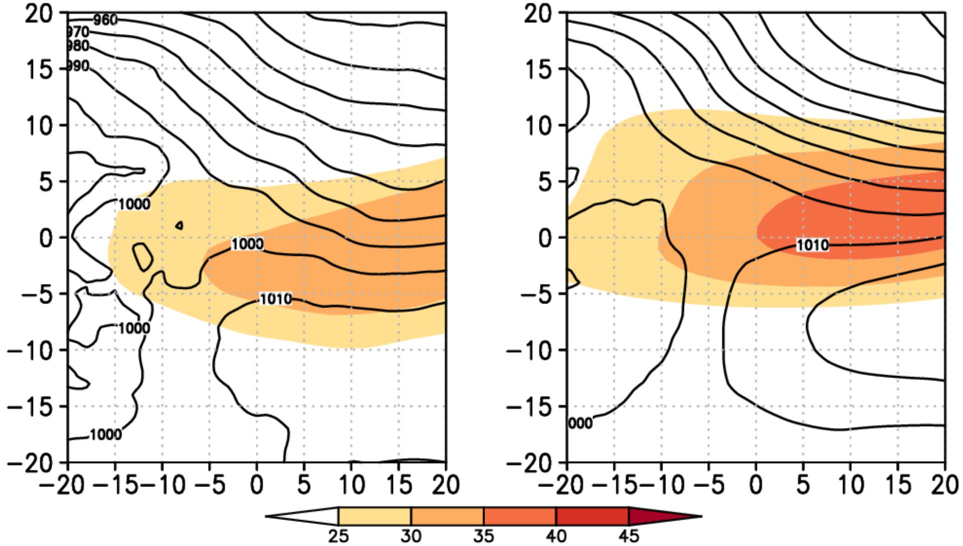
KHIの分布

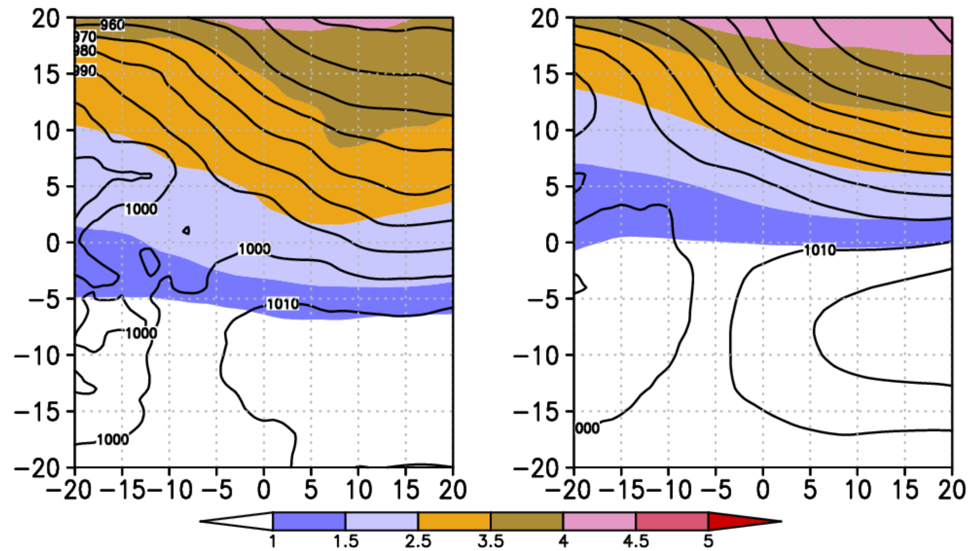


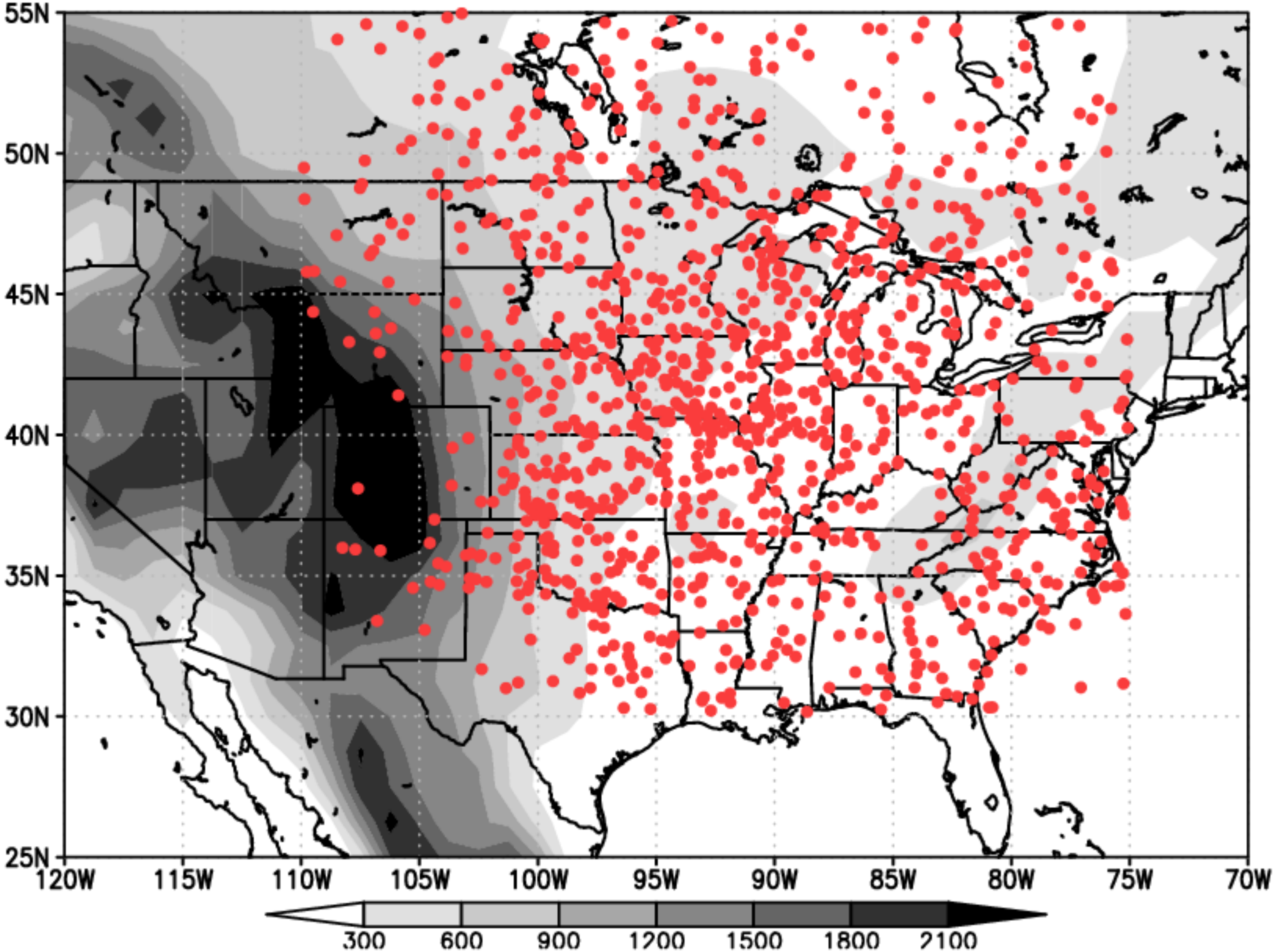


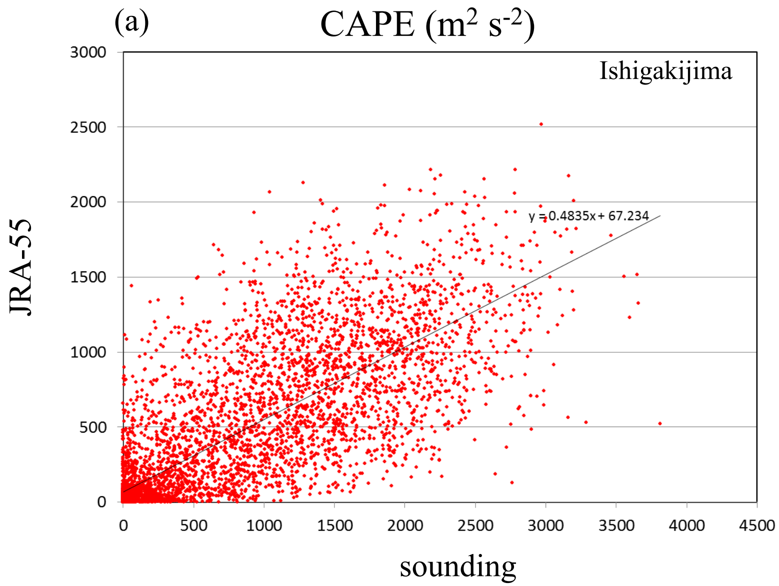
15
10
5
0
−5
−10
−15
−15 −10 −5 0 5 10 15
−0.08 −0.06 −0.04 −0.02 0 0.02 0.04 0.06 0.08

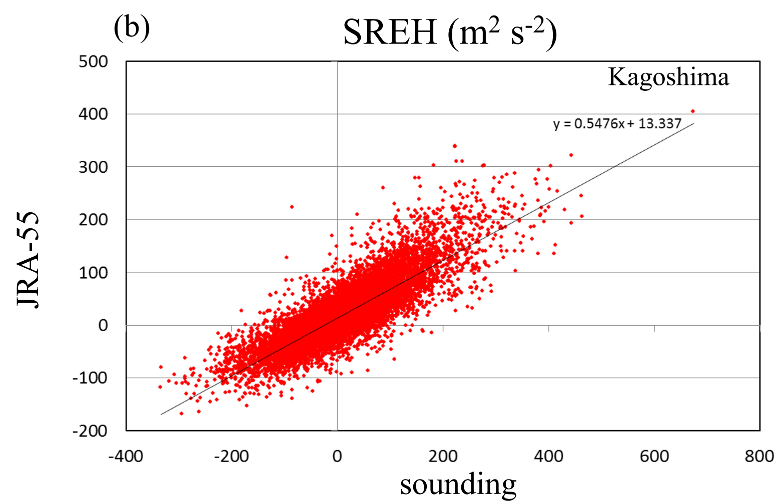

25
30
35
40
45


960
970
980
990
1000
1010
000
25 30 35 40 45

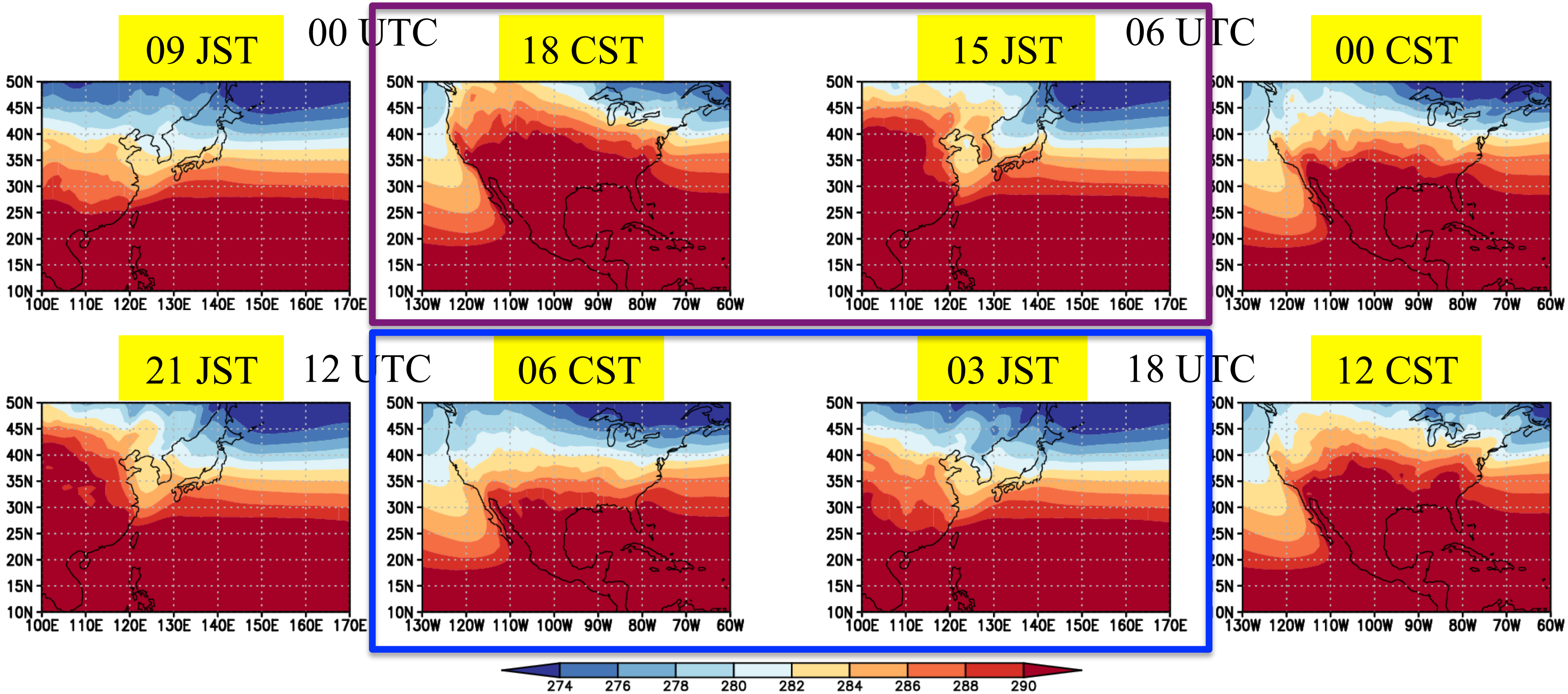

960
970
980
990
1000
1010
000
1 1.5 2.5 3.5 4 4.5 5


55N
50N
45N
40N
35N
30N
25N
120W
115W
110W
105W
100W
95W
90W
85W
80W
75W
70W
300
600
900
1200
1500
1800
2100


(a)
CAPE (m2 s-2)
Ishigakijima
y = 0.4835x + 67.234
JRA-55
sounding
0
500
1000
1500
2000
2500
3000
3500
4000
4500


(b)
SREH (m2 s-2)
Kagoshima
y = 0.5476x + 13.337
JRA-55
sounding
-200
-100
0
100
200
300
400
500
-400
600
800

975 hPaにおける1962年-2011年までの各時刻の4月の平均温度



日中の大陸でより温まっている。