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Seamless Detection of Cutoff Low and Preexisting Trough

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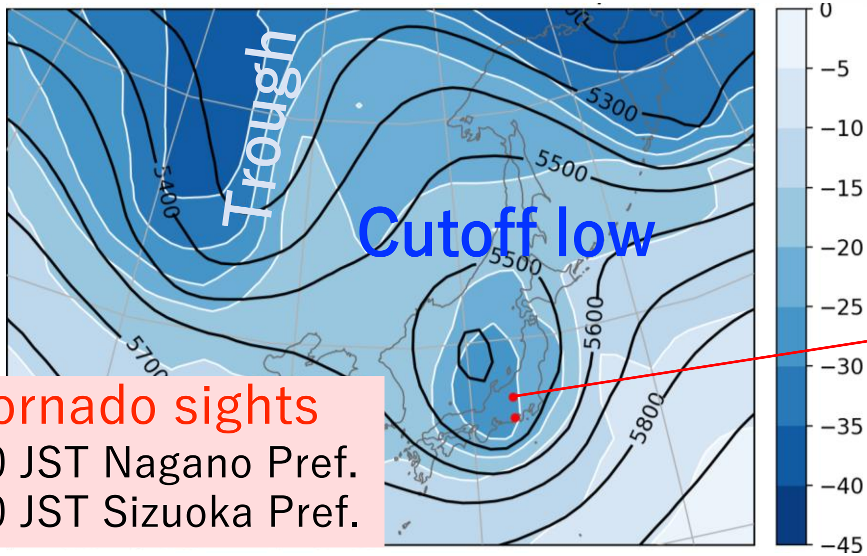
Cutoff low and Tornado event on 15 Apr 2015

(=upper tropospheric low)

500hPa height [m] & temp. [°C] 15 JST(=UTC+9h)



・Tornado sights
13:30 JST Nagano Pref.
14:00 JST Sizuoka Pref.

Shrine of Hanazura at Nagano Pref. (Asahi Pub. Co.)

- Cutoff lows last up to 4 days (Nieto et al. 2015).
- Cutoff lows often accompany meso-scale disturbances, e.g. tornadoes.
- But, the lifecycles of such cutoff lows have never studied.

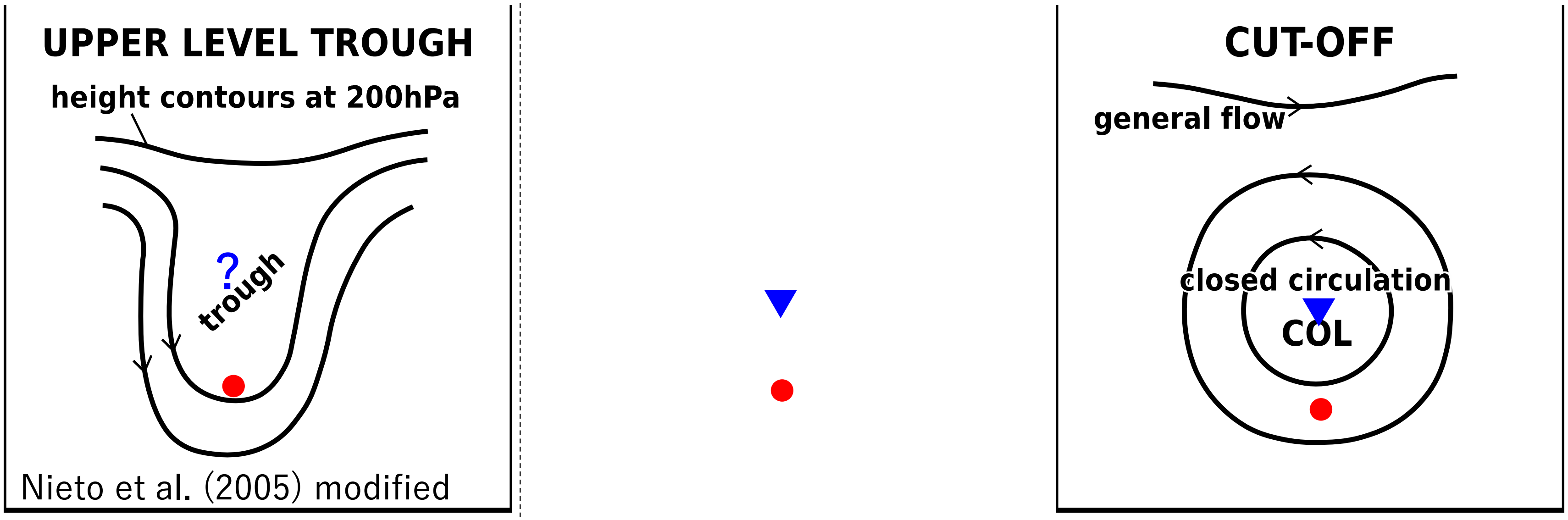
Problems

- “Intensity” of the cutoff lows has not been discussed enough.
- There is no such method that capture both cutoff lows and troughs.

Schematic life cycle and previous detectoin methods

Cutoff lows are developed from each "preexisting trough" (Palmén and Newton 1969)

preexisting trough: **preTR** cutoff low: **COL**



●vorticity max. ▼height min.

Height minimum based methods
preTR×, intensity×

- The most conventional methods (e.g. Nieto et al. 2005)

Vorticity maximum based methods
preTR○, intensity○

- detect COLs with longer duration including preTR (~8 days; Pinheiro et al. 2017)
- objective distinction for COL and preTR (Fuenzalida et al. 2005; Murray and Simmonds 1991)
- but, noisy detections because of derivative operations.

Performance goals for a new method to detect cutoff lows (COL) and preexisting troughs (preTR)

- It can seamlessly detect location of both.
- It can seamlessly evaluate intensity of both.
- It can objectively distinct both.
- It requires single variable (geopotential height).
- It requires no derivative operation.

Data: JRA-55 Reanalysis (Kobayashi et al. 2015; Harada et al., 2016)

200hPa geopotential height Z [m]

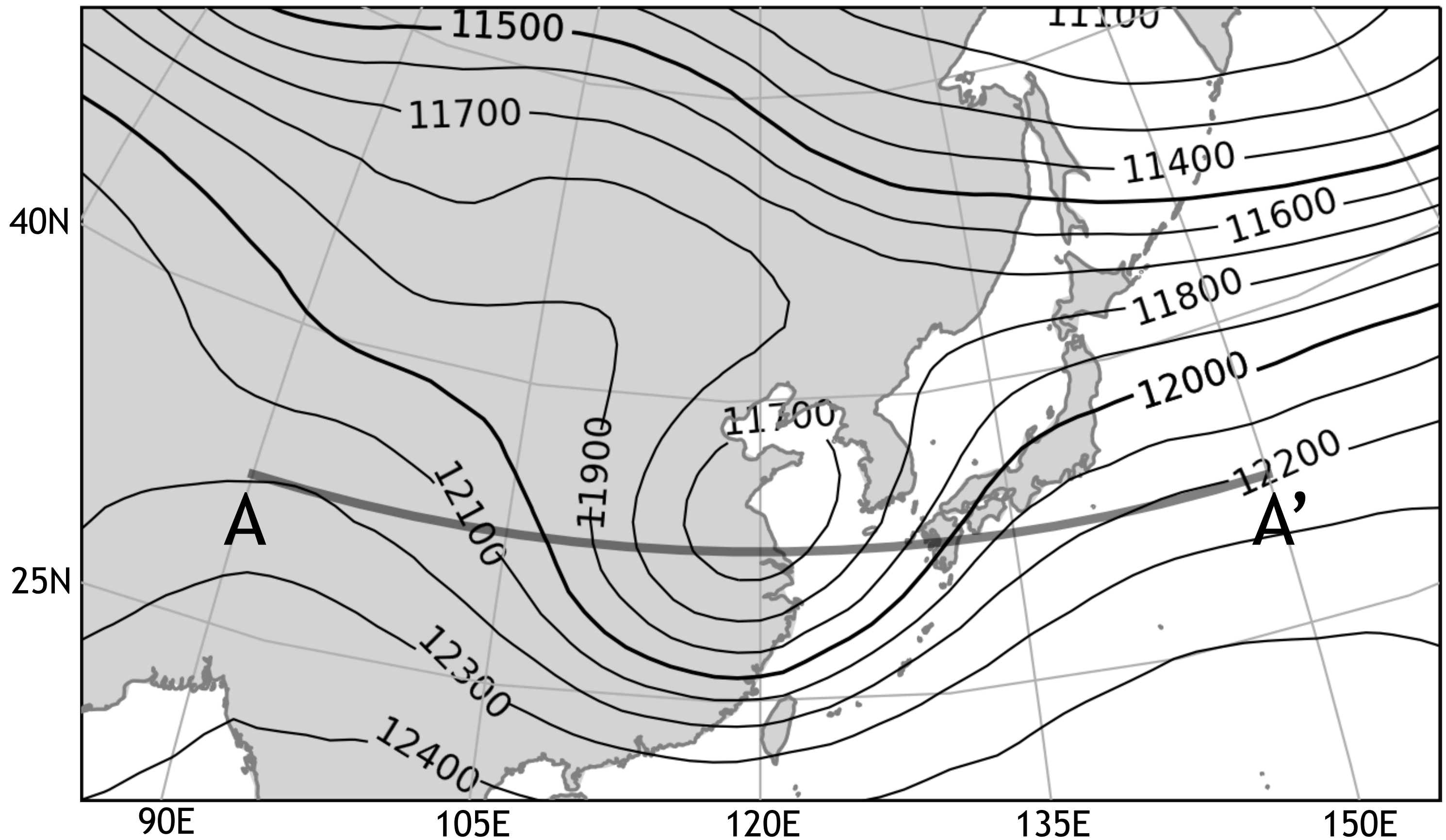
6-hourly, 1.25°x1.25° (~110kmx110km)

What is “intensity” of COL ?

“intensity” = height difference?
- △ anomaly from climatology or zonal mean
- △ difference of closed contour and its interior bottom

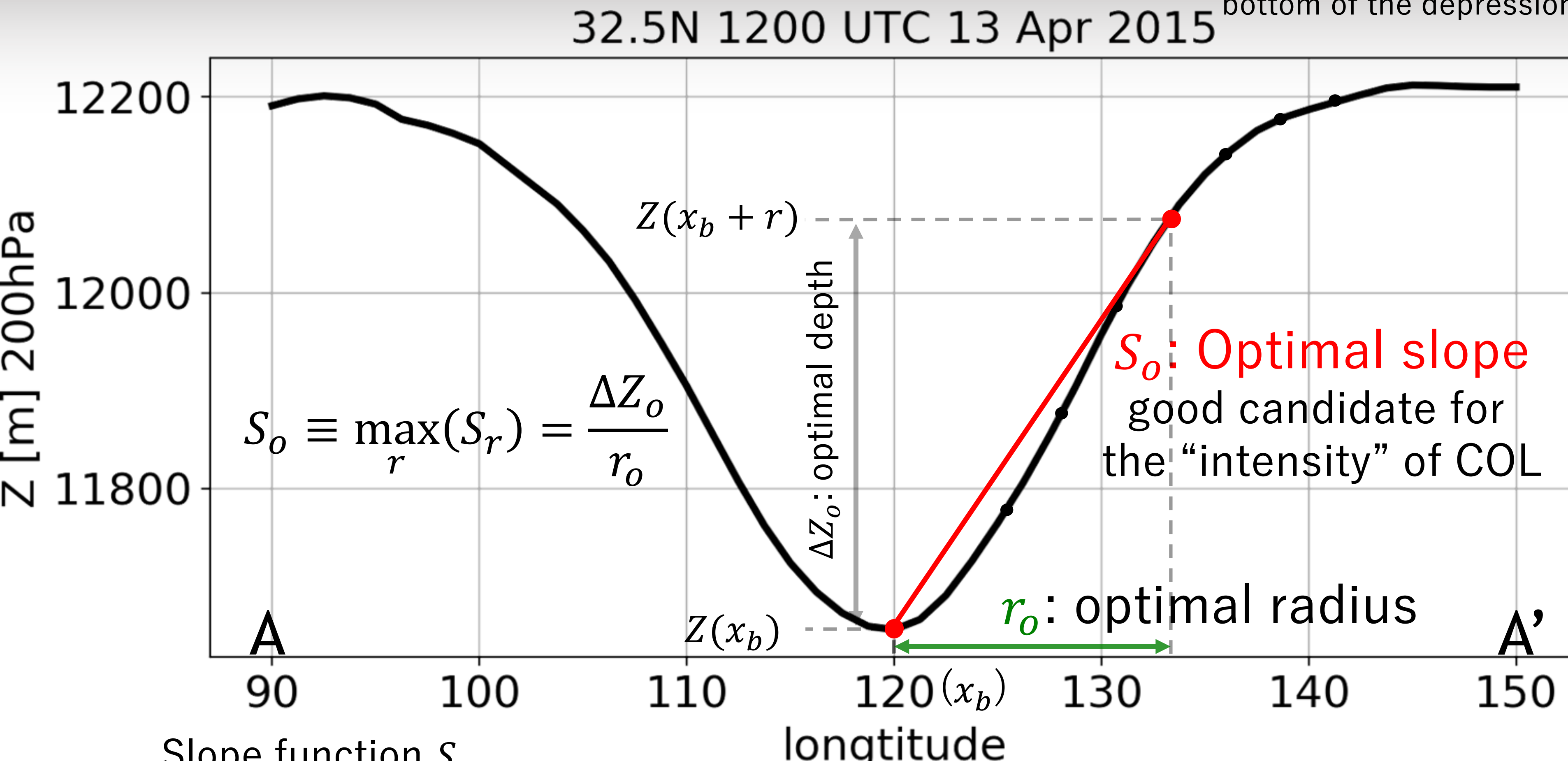
To minimize the subjectivity, we use a horizontal profile of height.

Z [m] 200hPa 1200 UTC 13 Apr 2015



Horizontal profile of the height depression

In the case x_b is known
(↑ x_b: bottom of the depression)



Slope function S_r

$$S_r = \frac{Z(x_b + r) - Z(x_b)}{r}$$

- local max. of S_r is not far from x_b
- local max. of S_r is proportional to the depth

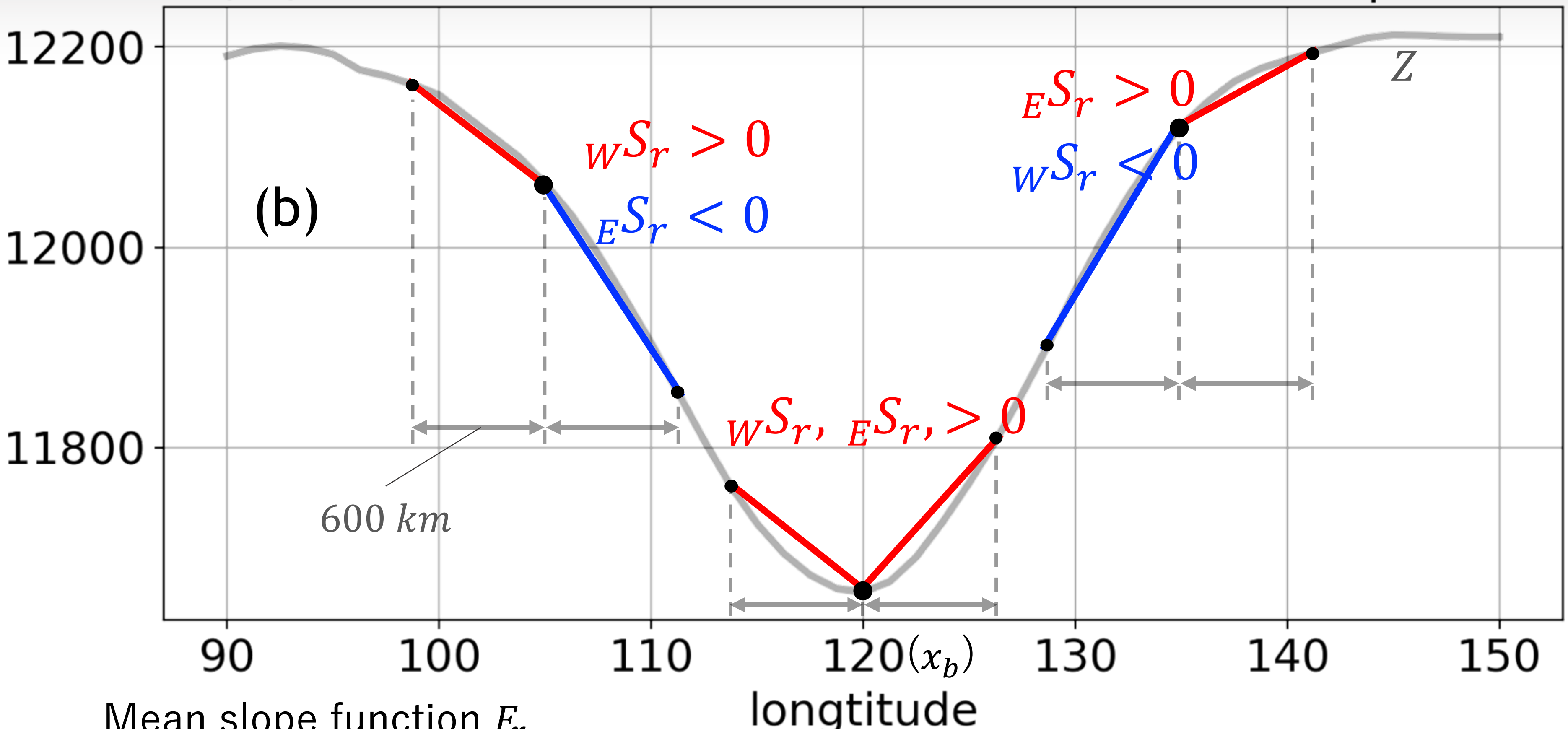
In the case x_b is NOT known: { functionalize S_r with x and r; expand S_r for east and west } ➡ It will peak at x_b if depression is symmetry.

Horizontal profile of height

Z (m) 32.5N 200hPa

In the case x_b is NOT known

1200 UTC 13 Apr 2015



Mean slope function F_r

$$F_r(x) = \frac{1}{2}\left[\underbrace{_ES_r(x)}_{\text{East}} + \underbrace{_WS_r(x)}_{\text{West}} \right]$$

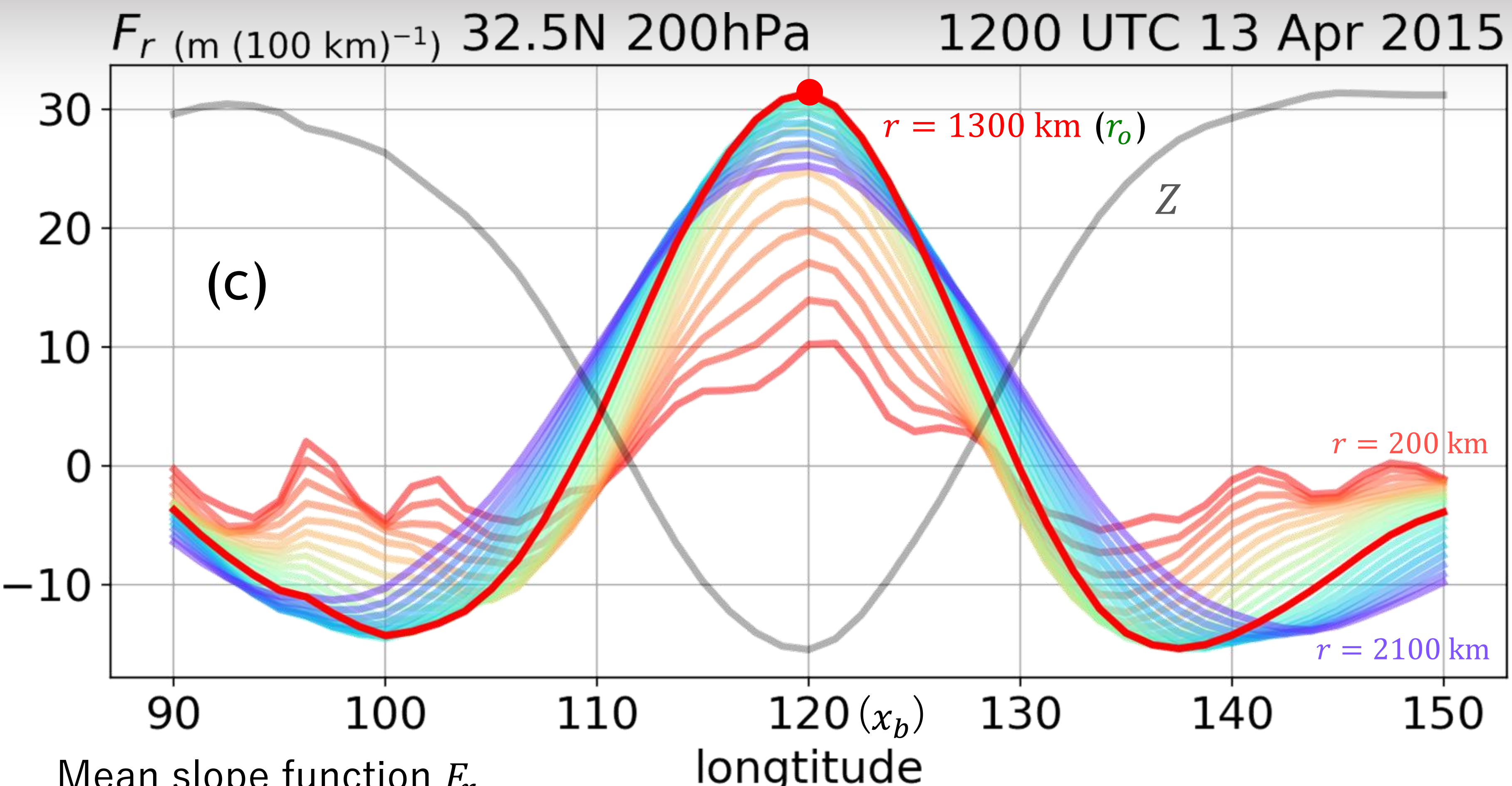
- F_r is maximized at x_b with any r

$$_ES_r = \frac{Z(x_b + r) - Z(x_b)}{r}$$

$$_WS_r = \frac{Z(x_b - r) - Z(x_b)}{r}$$

Horizontal profile of height

In the case x_b is NOT known



Mean slope function F_r

$$F_r(x) = \frac{1}{2}\left[{}_E S_r(x) + {}_W S_r(x) \right]$$

- F_r is maximized at x_b with any r
- F_r is further maximized at r =1300km(=r_o)

$${}_E S_r = \frac{Z(x_b + r) - Z(x_b)}{r}$$

$${}_W S_r = \frac{Z(x_b - r) - Z(x_b)}{r}$$

$$S_o = \max_r \left(\max_x (F_r(x)) \right)$$

Local max. of F_r(●) provides S_o, r_o, $\boldsymbol{x_b}$ for each depression.

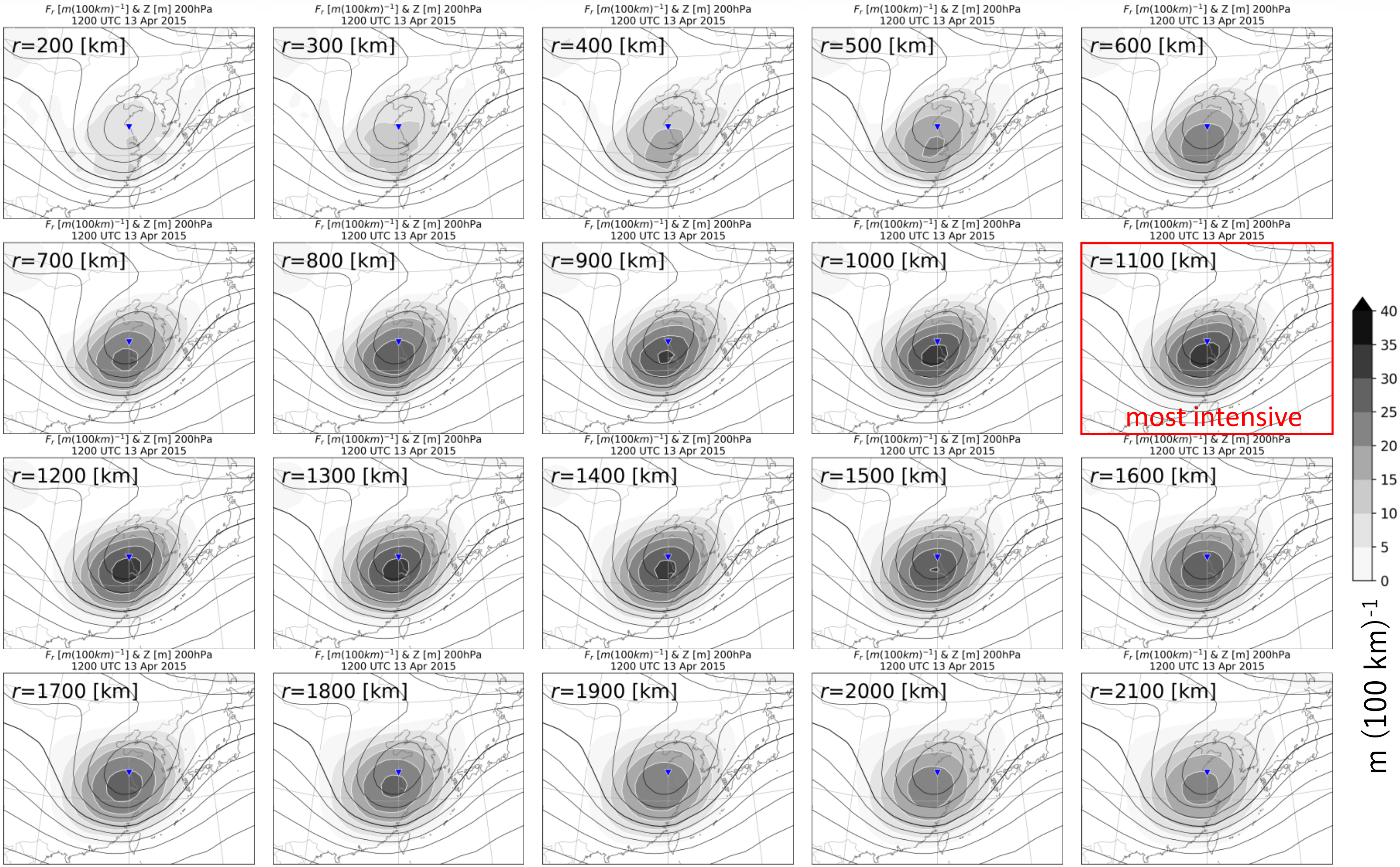
Algorithm to obtain S_o, r_o, $\boldsymbol{x}_b$ from Z of grided data

① Calculate 2D mean slope function $F_r(x, y)$ with r ranging 200–2100 km with 100 km int.

$$F_r(x,y) \equiv \frac{1}{4}\left({}_{E}S_r + {}_{W}S_r + {}_{N}S_r + {}_{S}S_r \right)$$

East West North South

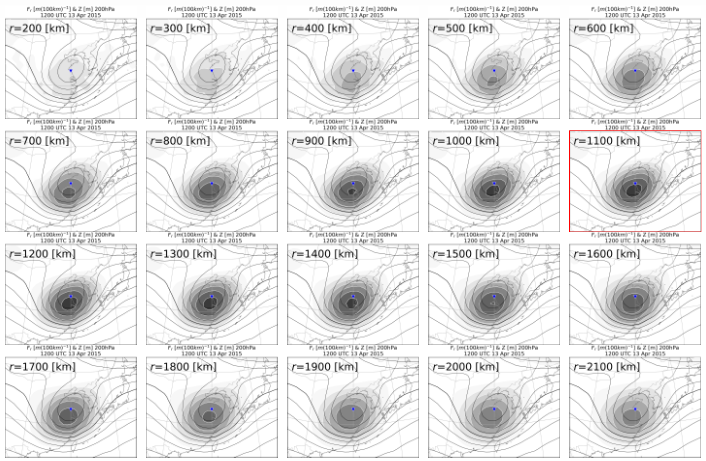
e.g. ${}_{S}S_r = \dfrac{Z(x, y-r) - Z(x,y)}{r}$



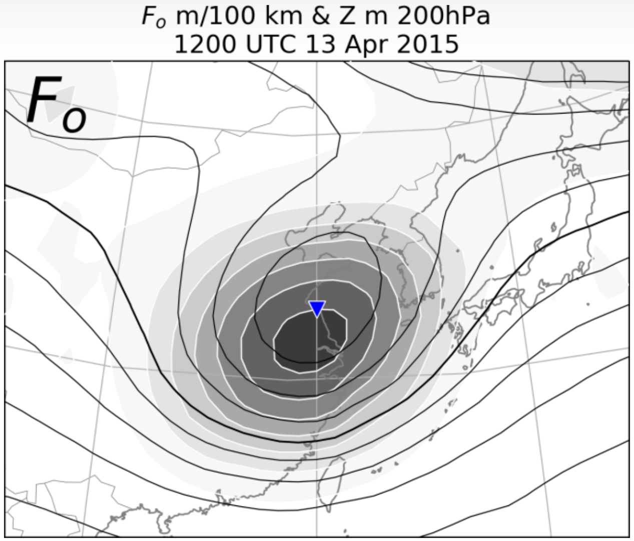
200hPa height Z (contours), F_r (shades), local Z min. (▼)

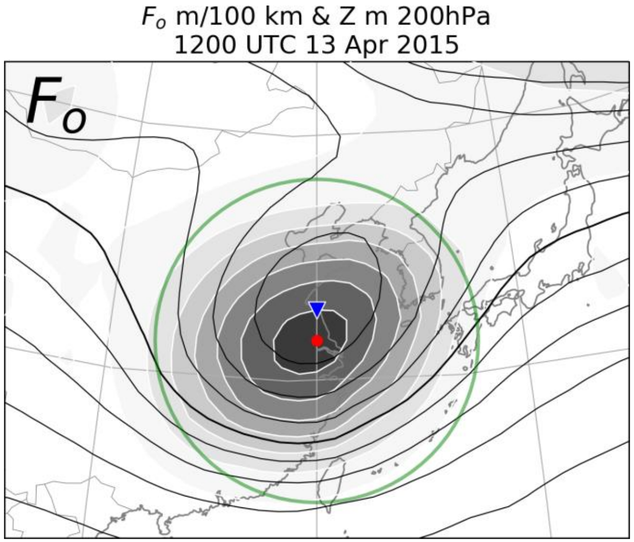
Algorithm to obtain S_o, r_o, $\boldsymbol{x}_b$ from Z of grided data

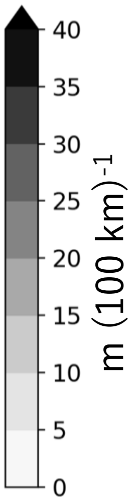
② Make an array of local max. of F_r with respect to r at all grids (F_o).



$$F_o(x, y) \equiv \max_r(F_r(x, y))$$







● : local F_o max. ○ : circle of r_o

③ Search spatial local max. of F_o and obtain params. below

(x_b, y_b): location of the bottom

S_o: optimal slope (=32.7 m (100 km)$^{-1}$)

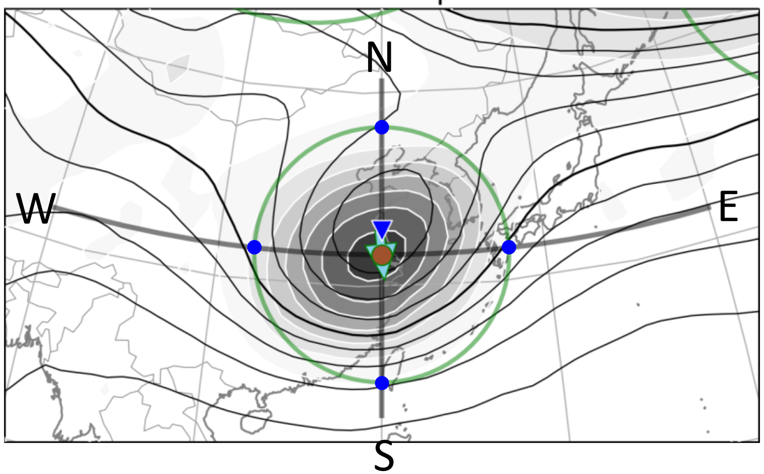
r_o: optimal radius (=1100km)

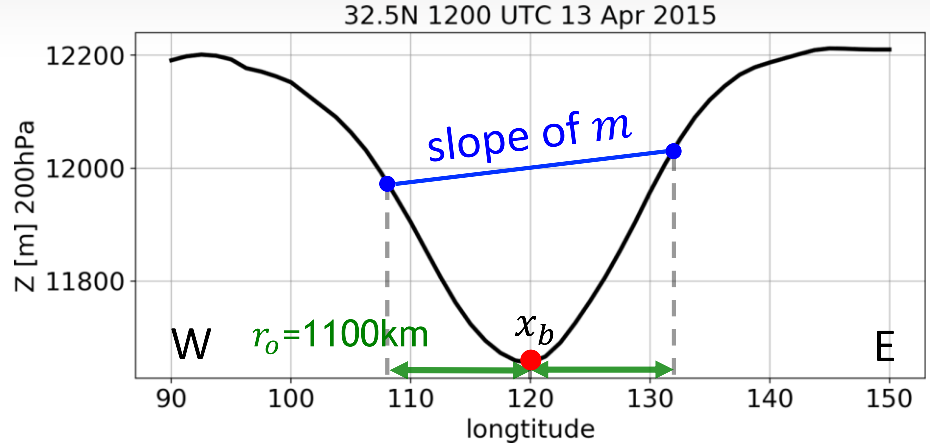
* Note that these params. are estimated values for an isotropic depression.

Definition of the local background slope S_b

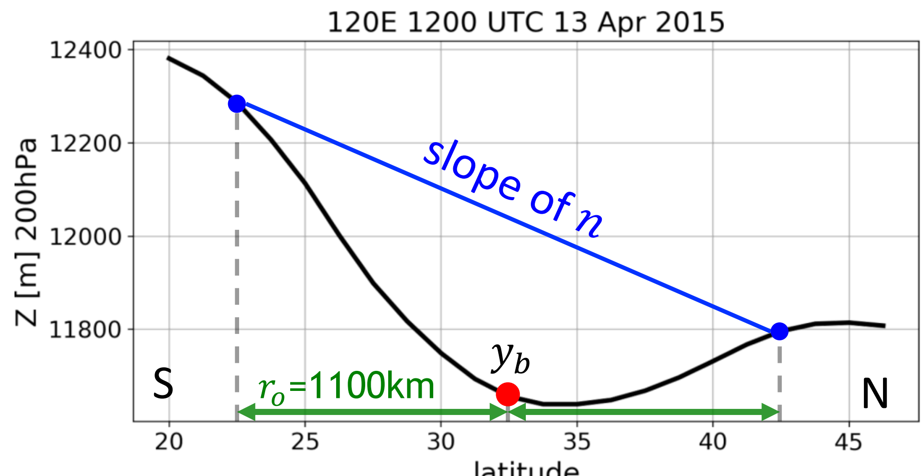
S_b (θ) is numerically defined as the magnitude (direction) of gradient of a surface paralleling to both m and n.

F_o m/100 km & Z m 200hPa
1200 UTC 13 Apr 2015





$m = 2.62$ m (100 km) -1



$n = -22.09$ m (100 km)$^{-1}$

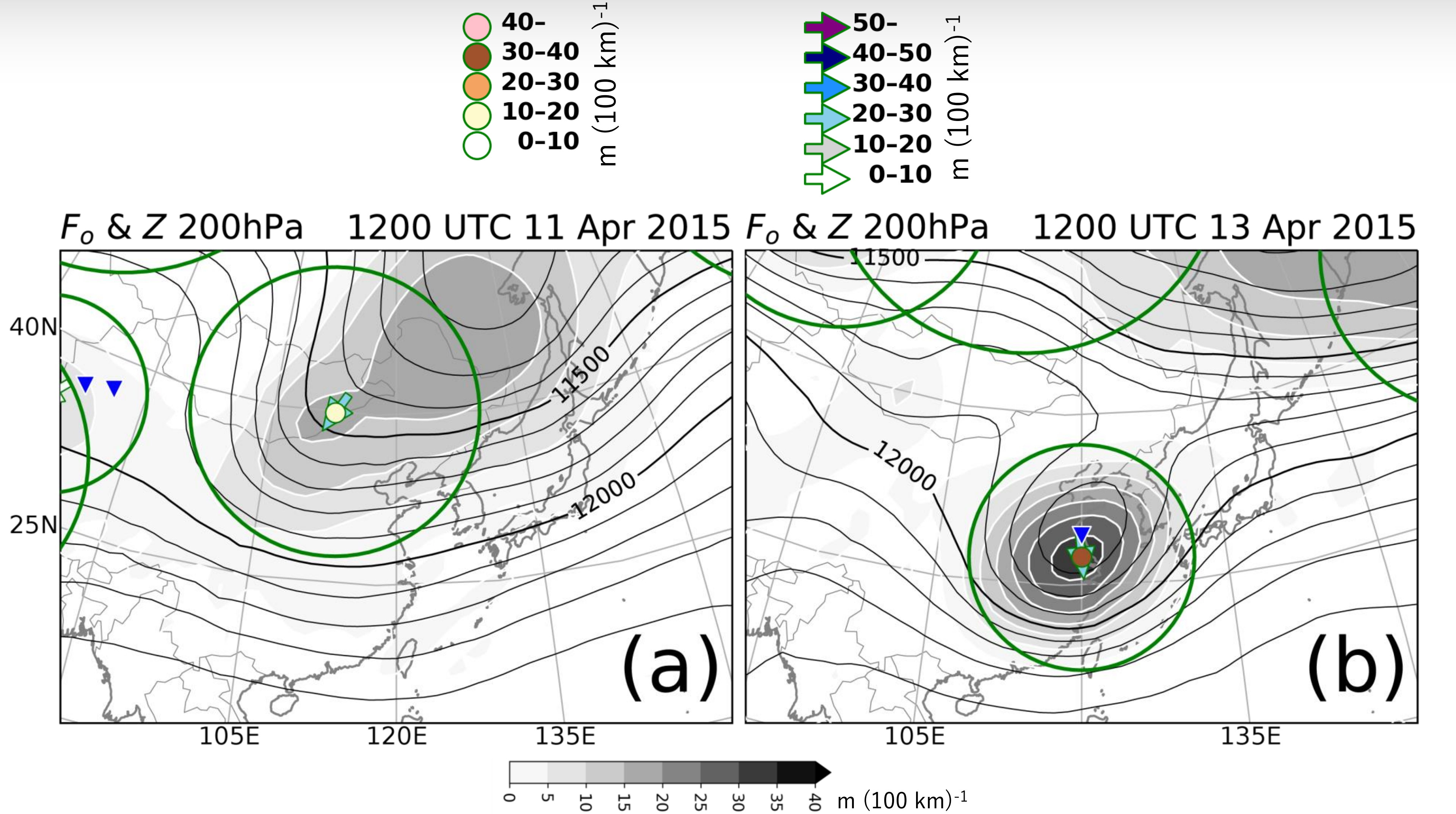
$$m = \frac{Z(x_b + r_o, y_b) - Z(x_b - r_o, y_b)}{2r_o}$$

$$n = \frac{Z(x_b, y_b + r_o) - Z(x_b, y_b - r_o)}{2r_o}$$

$$S_b = \sqrt{m^2 + n^2}, \quad \tan\theta = \frac{n}{m}$$

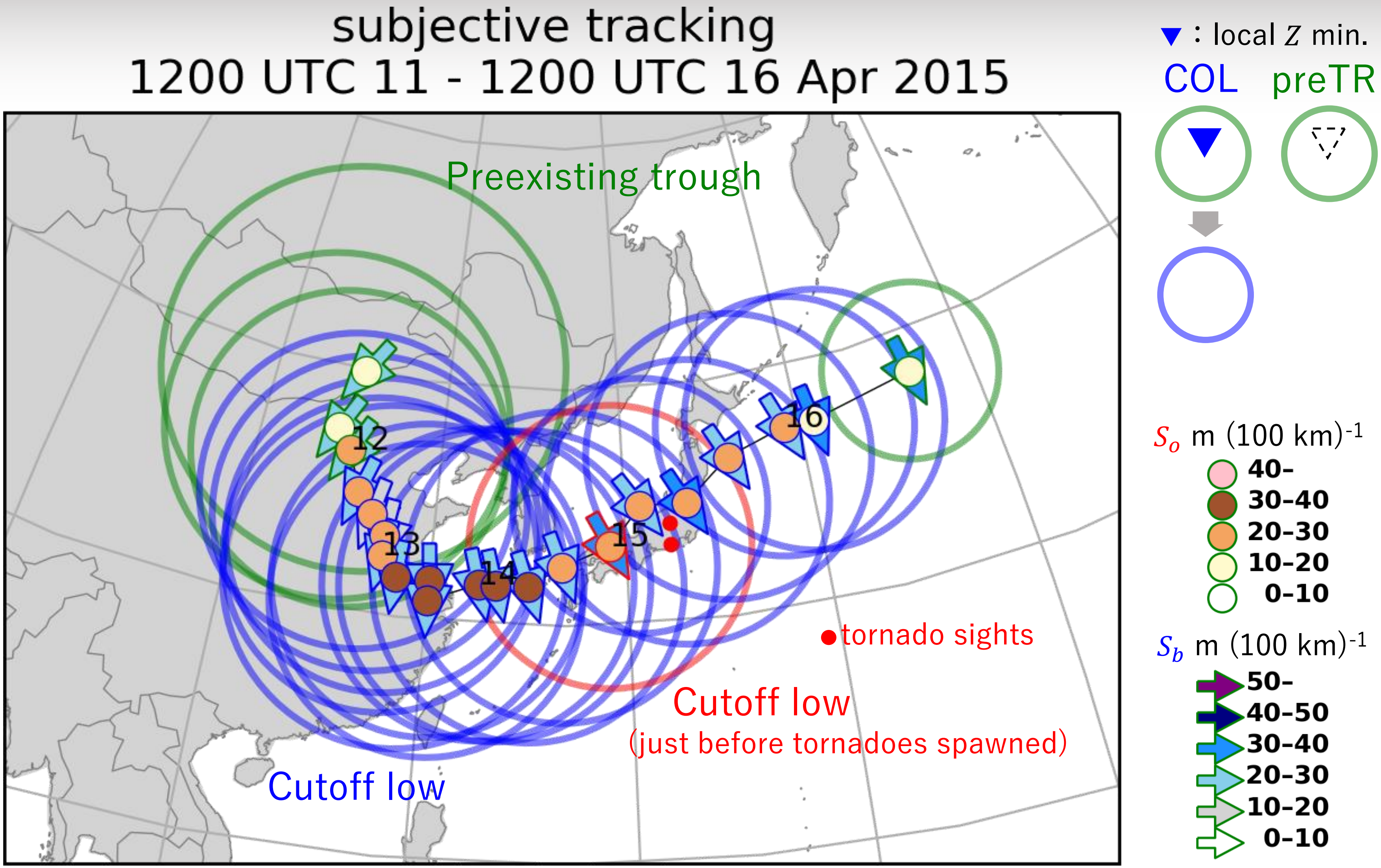
$S_b = 22.25$ m (100 km)$^{-1}$ $\quad \theta = -1.41$ rad ($-83.23°$ from the east)

Examples of S_o (colored dots), S_b (colored arrows), r_o (green circle)



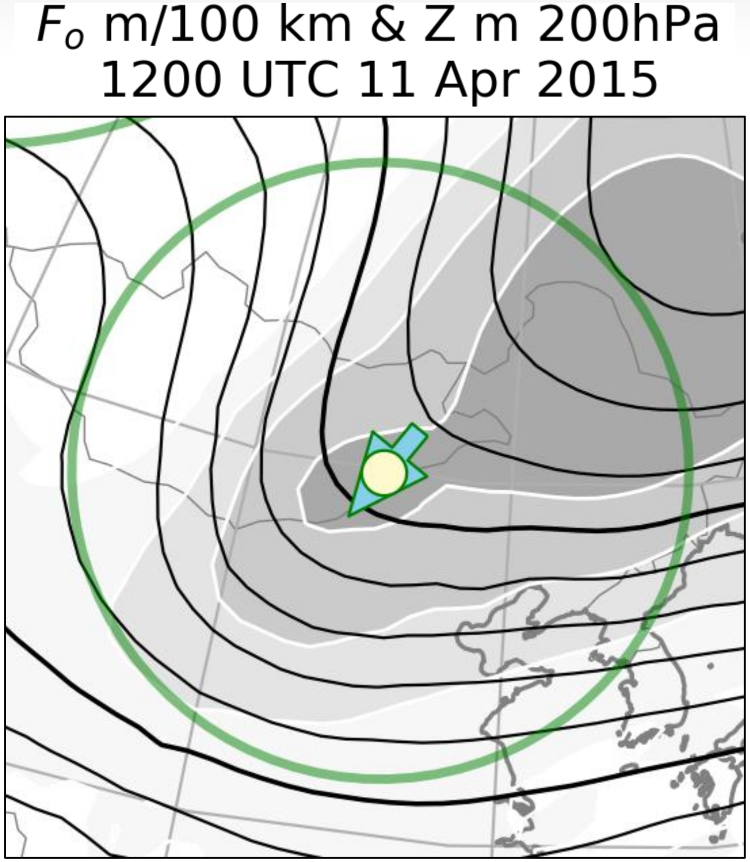
200hPa height Z (contours), F_o (shades), local Z min. (▼)

Examples of S_o (colored dots), S_b (colored arrows), r_o (green circle)

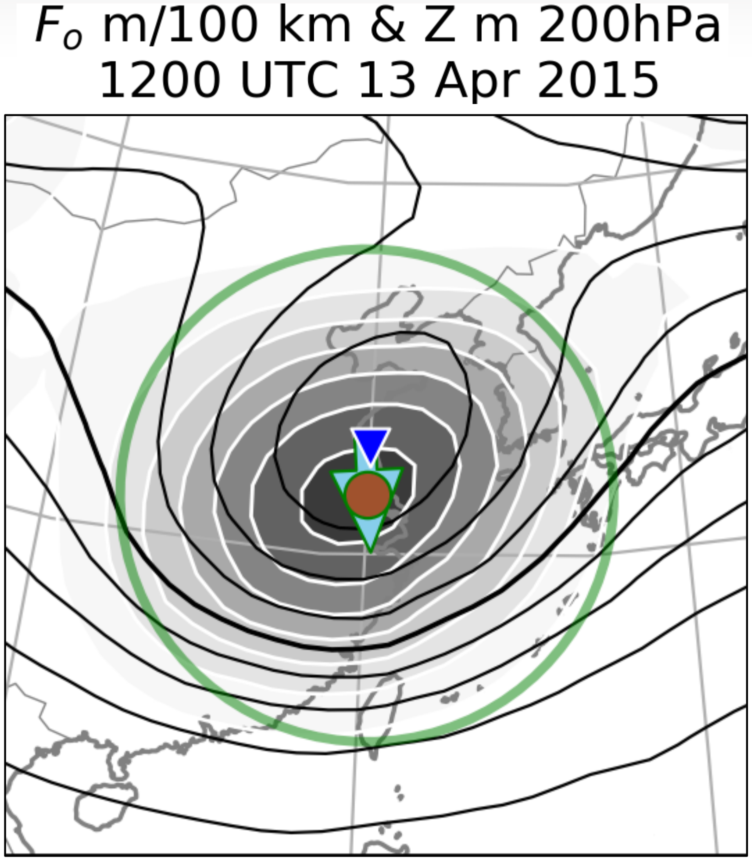


- Successfully represent the lifecycle from preTR to COL with S_o and achieve 18-hour (3-timestep) earlier detections.

Remained problems



What S_o, r_o, S_b mean for preTR?



Why height min. and F_o max. are displaced？

=> verify with "ideal height fields"

Ideal height fields Z^* and F_r, F_o fields (-1.0–1.0; 201x201 grids)

(pure vortex) ↓

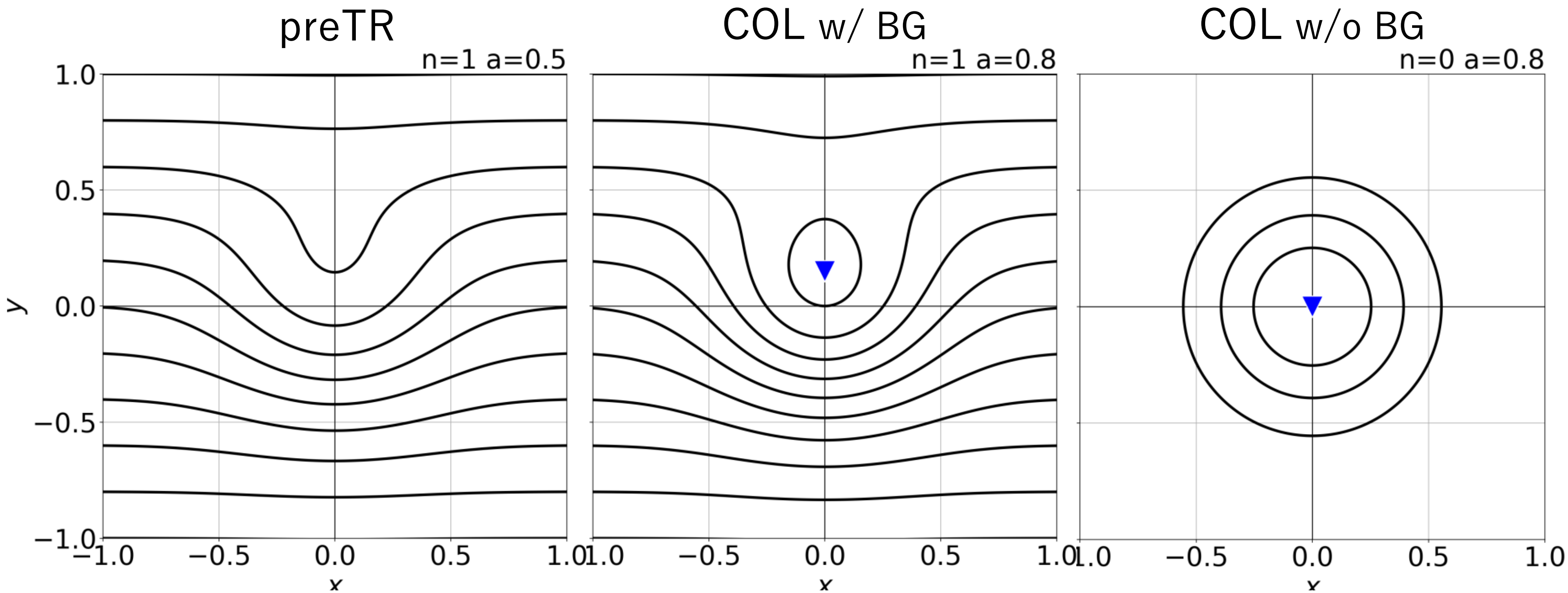
$$Z^* = G + L$$

↑ (BG flow)

$$G = -a \exp\left(-\frac{x^2 + y^2}{b}\right)$$

$$L = mx + ny$$

Here, $b = 2/9, m = 0$



Z^* (contours), Z^* min. (▼), F_o (shades), F_o max. (●), r_o (○)

- F_o is independent of BG and evaluating the amplitude of the pure vortices (a).
- i.e. preTRs can be detected as weak vortices behind BG (“seamless detection”).

Ideal height fields Z^* and F_r, F_o fields (-1.0–1.0; 201x201 grids)

$$Z^* = G + L$$

(pure vortex) → G; (BG flow) → L

$$G = -a \exp\left(-\frac{x^2 + y^2}{b}\right)$$

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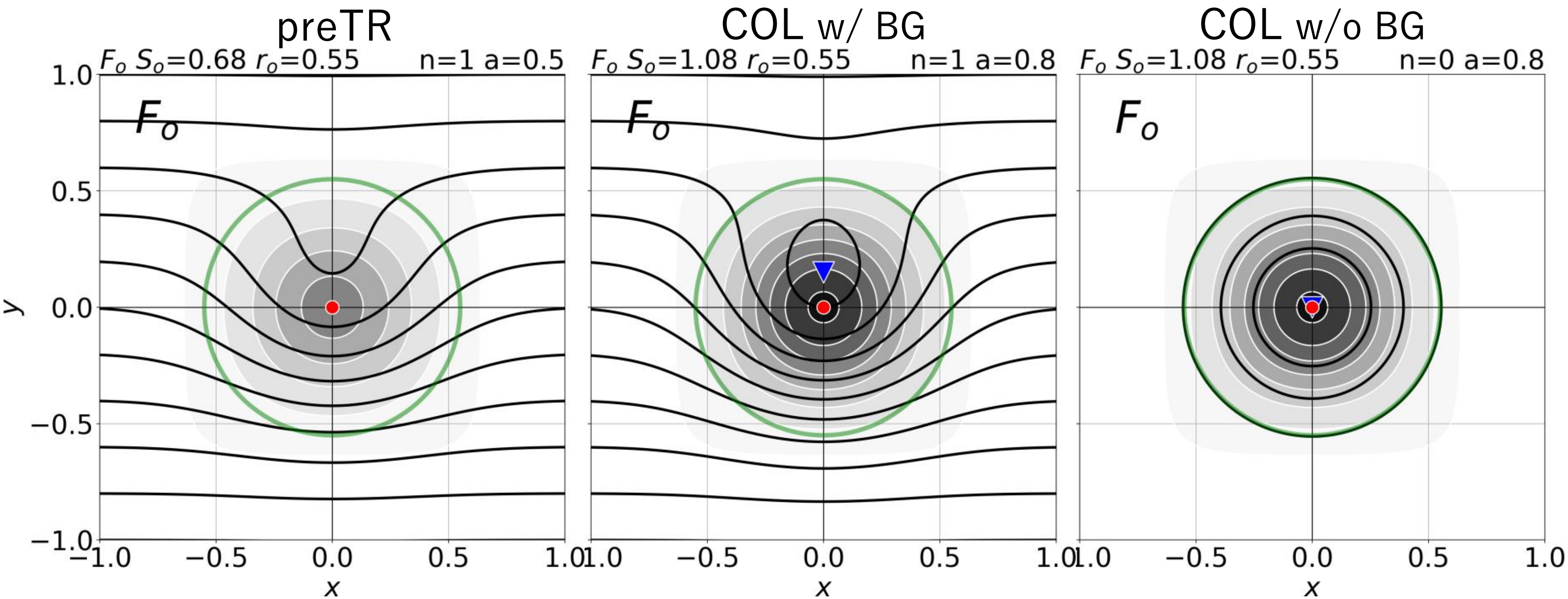

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- F_o is independent of BG and evaluating the amplitude of the pure vortices (a).
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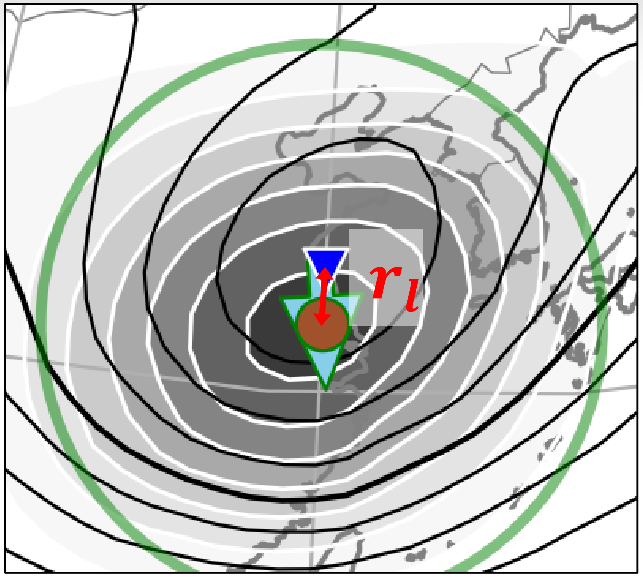
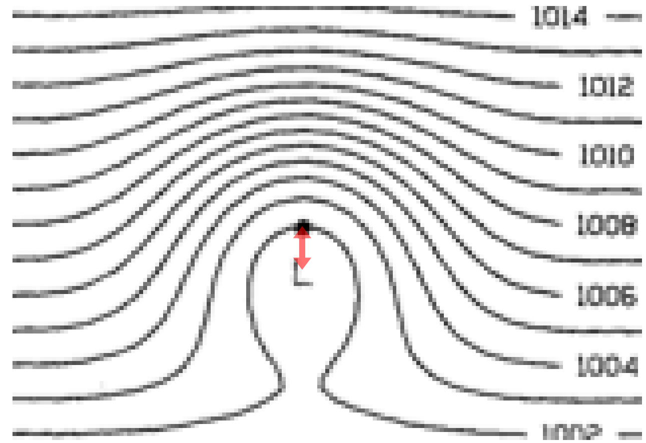
The displacement of F_o max. and Z min. (r_l) and a ratio of BG slope (S_b) and optimal slope (S_o)



SLP min. (L) tend to be displaced from vorticity centers (●) for mobile cyclones (Poleward displacement; Sinclair 1994)



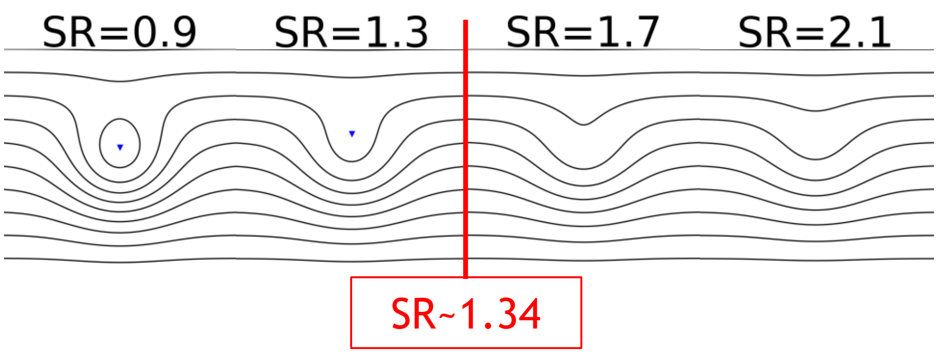
$$Z^{*\prime} = G' + L' = 0 \;\Rightarrow\; \frac{2\mathrm{B}}{1-e^{-\mathrm{B}}}\frac{r_l}{r_o}\exp\left[-\mathrm{B}\left(\frac{r_l}{r_o}\right)^2\right] = \frac{S_b}{S_o} \equiv \mathrm{SR}$$

(slope ratio)

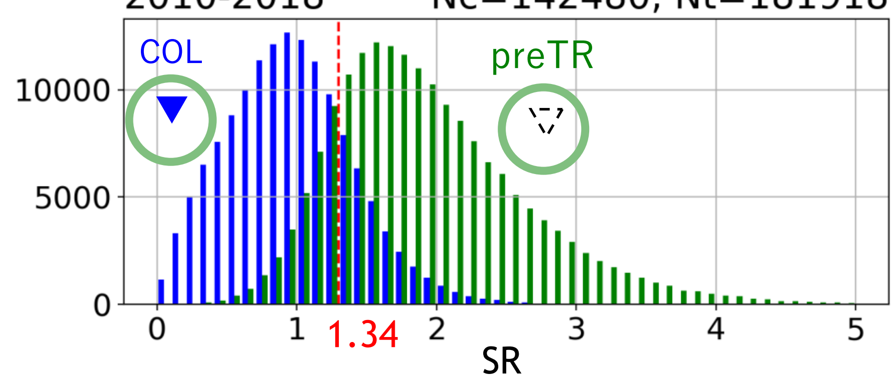
$\mathrm{B} \in \mathbb{C}$ (~1.26)

r_l depends on SR

Z^* for various SR



Histograms of COL and preTR from 9yr JRA-55



SR=1.34 may be useful for an instant distinction between COL and preTR.

Summary

We introduced the new method to detect cutoff lows (COL) and preexisting troughs (preTR) based on the optimal slope (S_o).

- ✓ It can seamlessly detect location of both.
- ✓ It can seamlessly evaluate intensity of both.
- ✓ It can objectively distinct both.
- ✓ It requires single variable (geopotential height).
- ✓ It requires no derivative operation.

and...

- It can provide local BG slope (S_b) for each depression. *novel point
- The slope ratio (SR= S_b/S_o) would be useful to distinguish them.

Future works

- clairfy climatological features of COLs accompanying tornadoes
- understand the physics of such COLs
- contribute to reduce risks of the next strongest tornadoes...