

第51回メソ気象研究会・台風研究連絡会・第6回観測システム・予測可能性研究連絡会

第12回気象庁数値モデル研究会

2019/5/14 気象庁講堂

台風進路予測に残された課題



京都大学防災研究所/JAMSTEC APL

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本研究はJSPS科研費JP26282111の助成を受けたものです。

科 研 費
KAKENHI

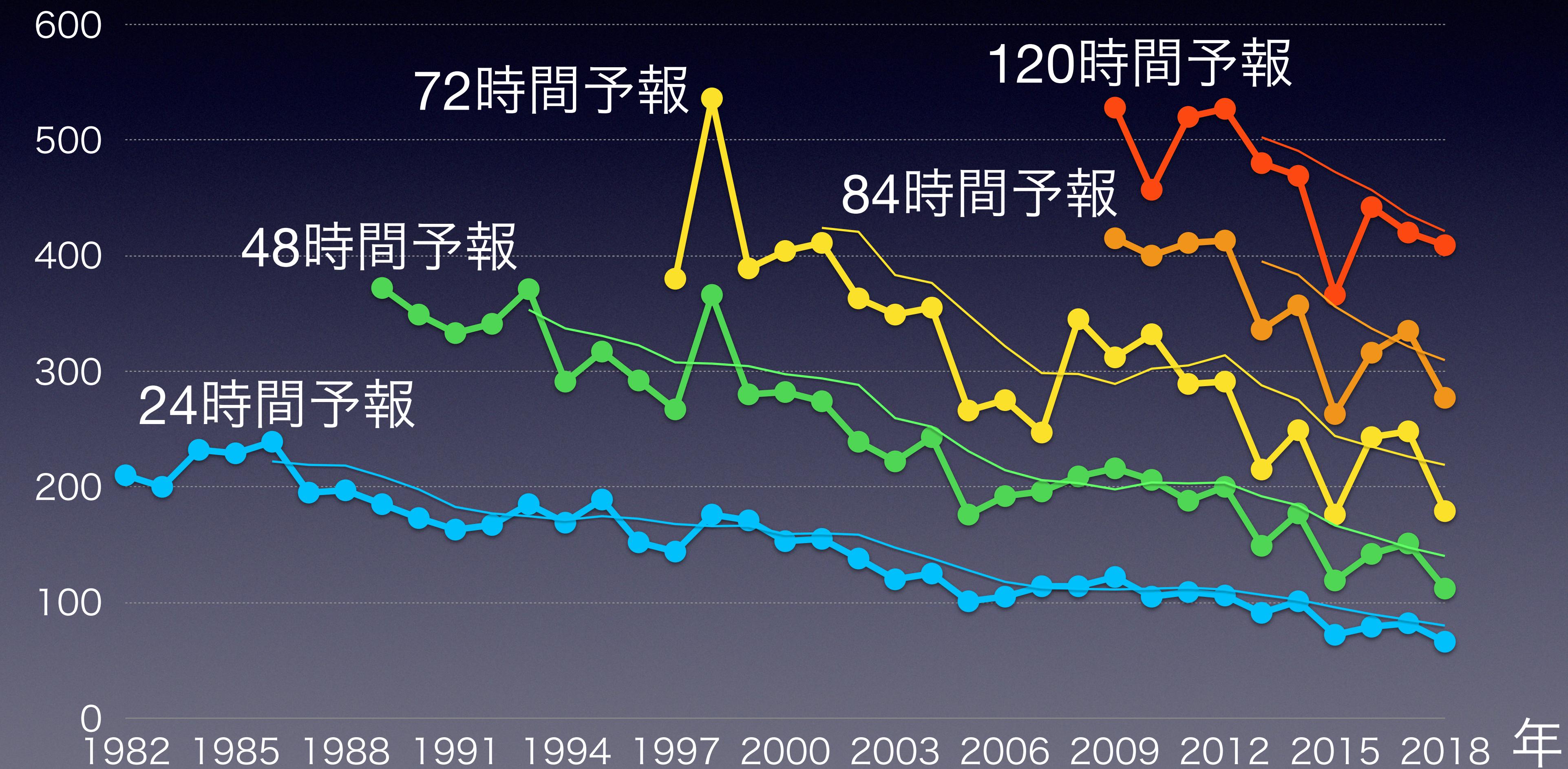
概要

- ・ 近年の台風予測誤差の改善
- ・ 涡としての台風
- ・ 初期値かモデルか
- ・ 波浪・海洋の重要性

台風進路予測誤差

予報誤差 km

気象庁



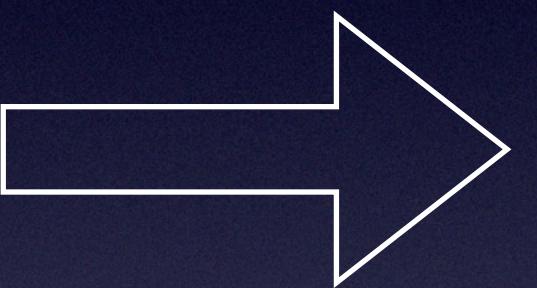
2030年の科学技術を見据えた 気象業務のあり方（提言）

2030 年には、数値予報技術の大幅な高度化により、
台風の3日先の進路予測誤差を 100km 程度
(現在の1日先の予測における誤差程度)にまで改善

台風進路予測の重要性

進路予測精度の向上

進路のメカニズムの理解の進展



メソスケール構造

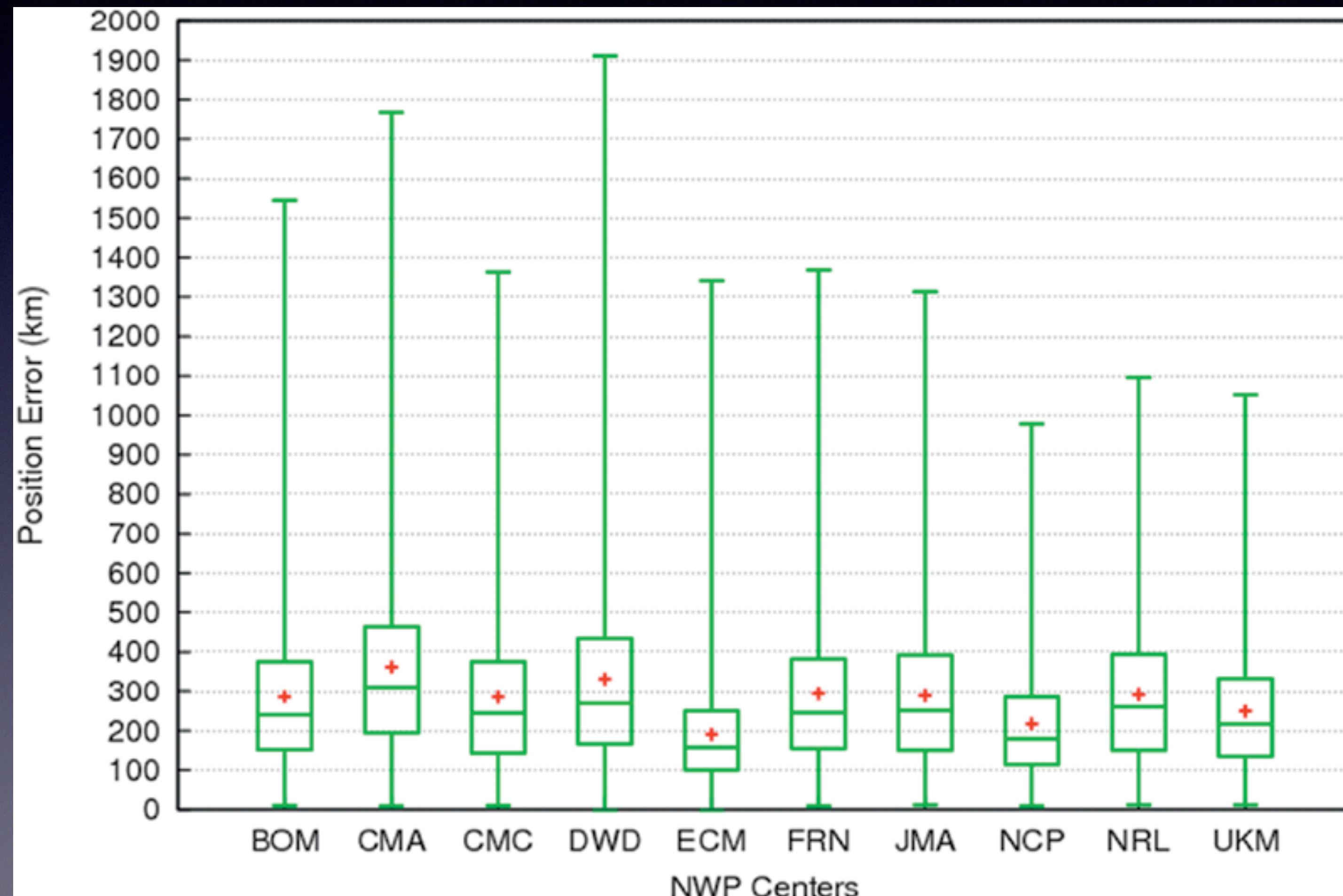
発生メカニズム

発生・強度予報

進路予測誤差が
大きい事例

防災上の重要性

3日進路予報誤差のばらつき



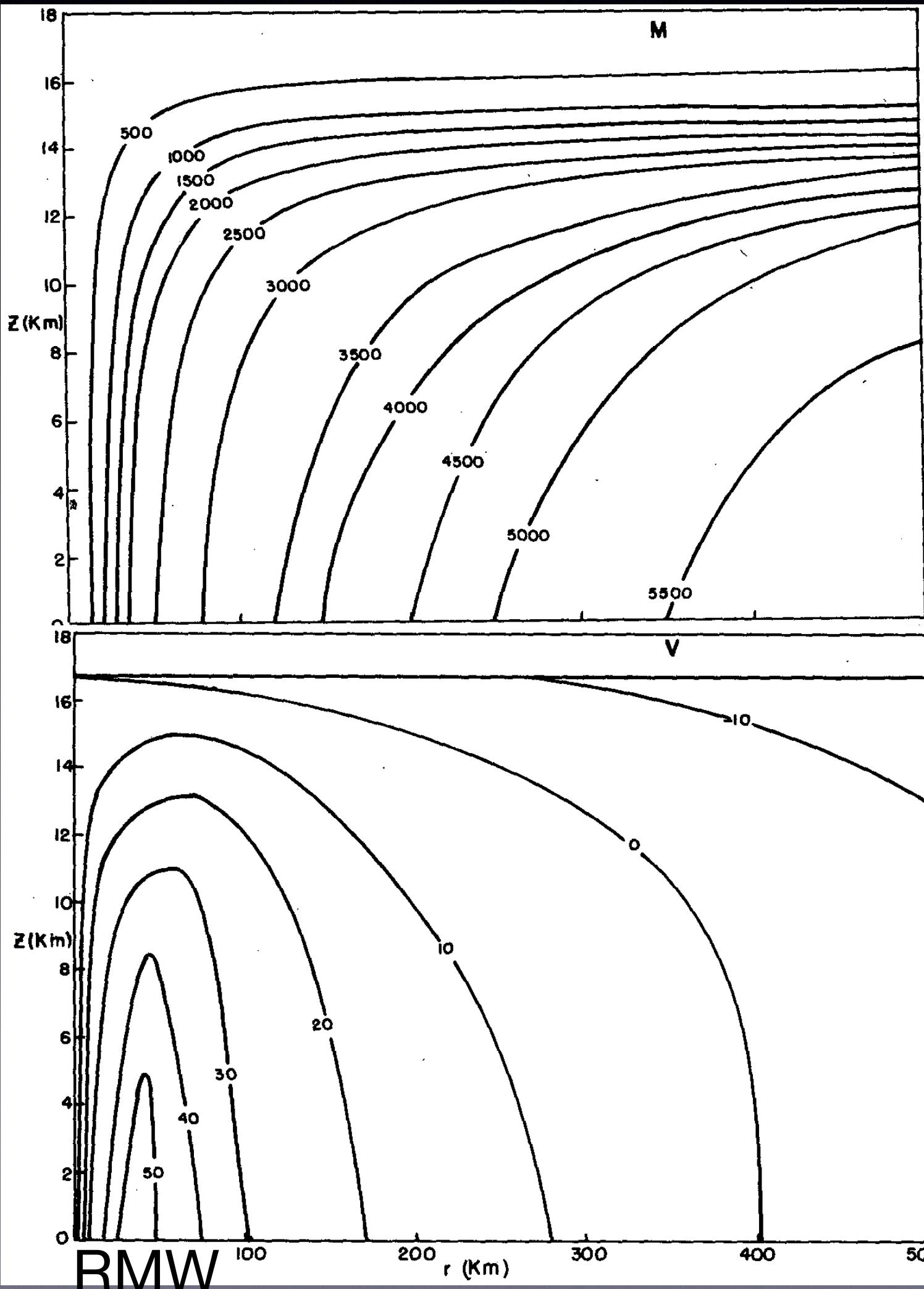
Yamaguchi et al. 2017

Axisymmetric steady state model

$$M \equiv rV + \frac{1}{2}fr^2$$

V

tangential wind



Above PBL

Hydrostatic

$$\frac{\partial p}{\partial z} = -\rho g$$

Gradient wind

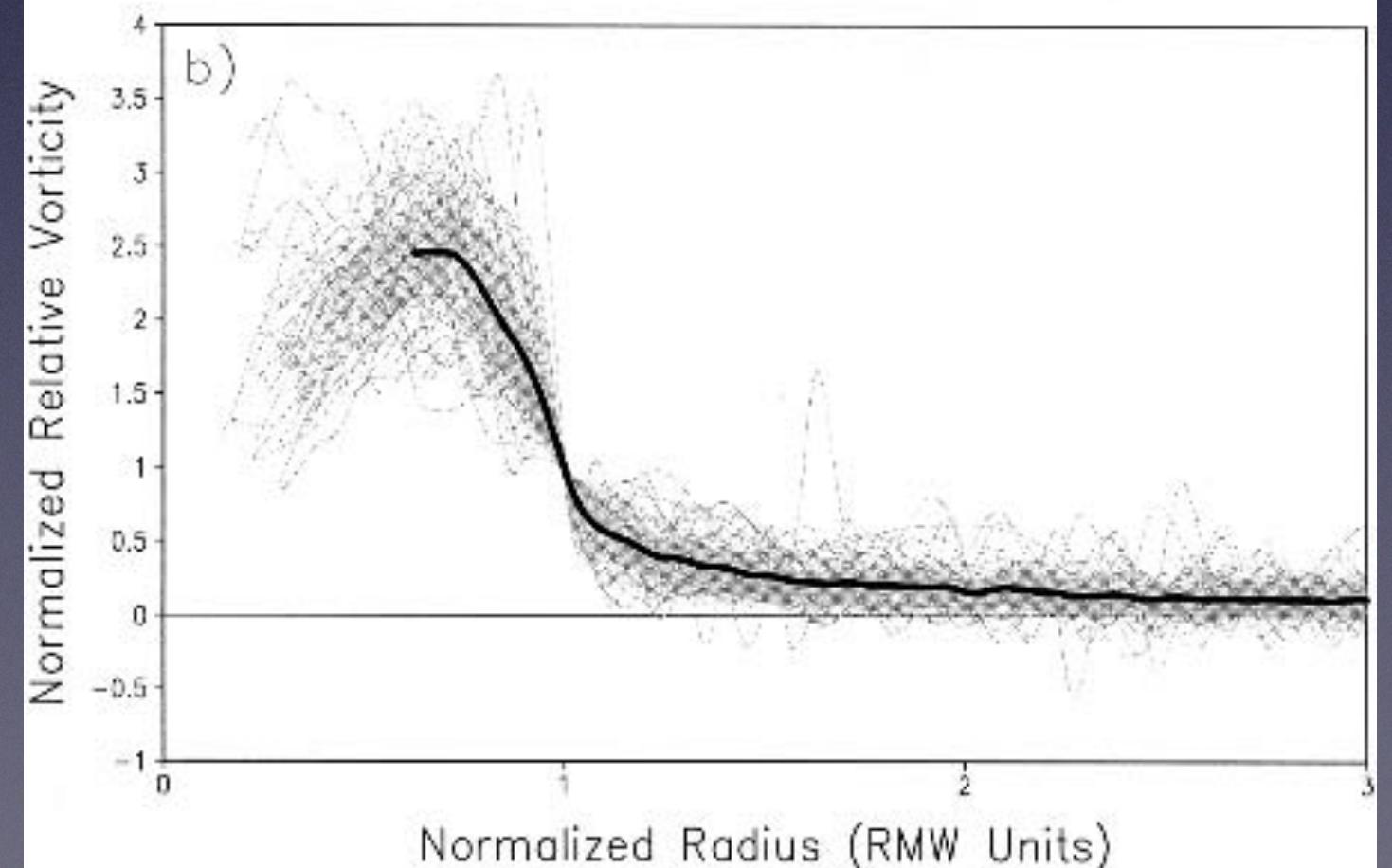
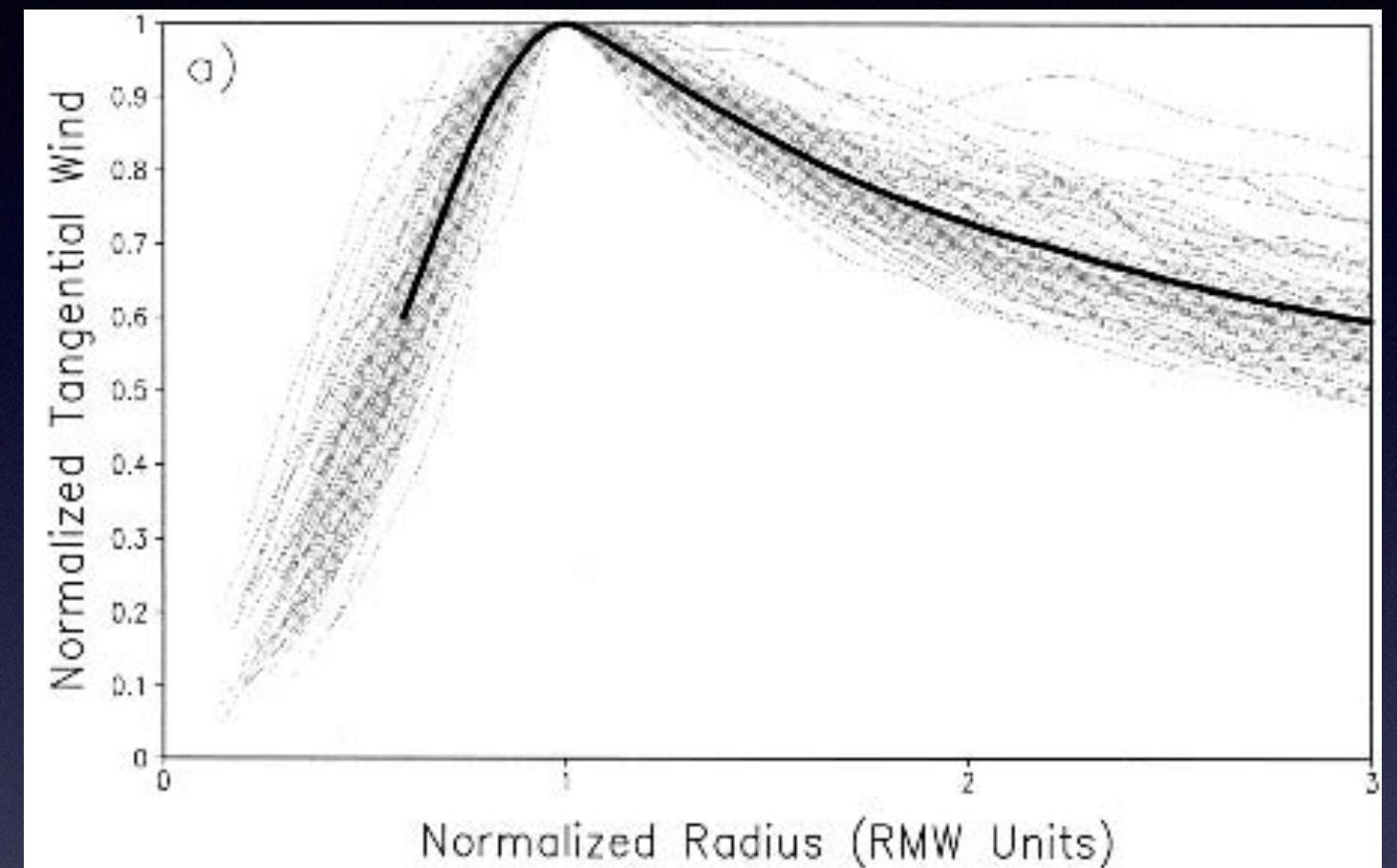
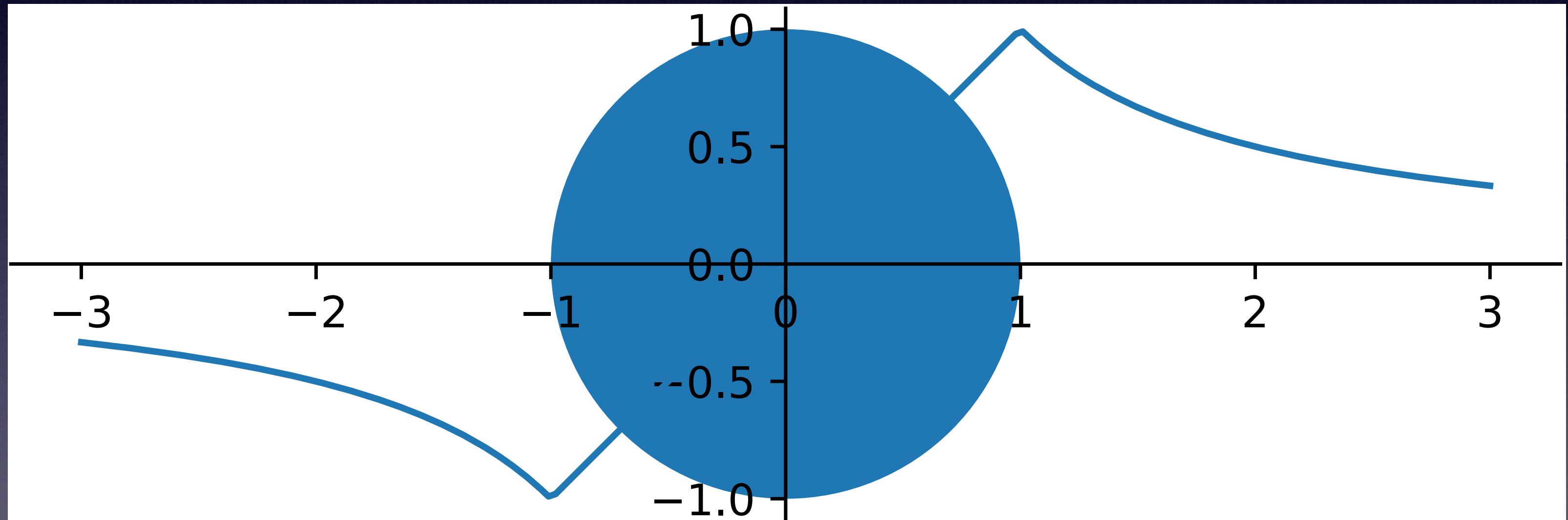
$$\frac{1}{\rho} \frac{\partial p}{\partial r} = \frac{V^2}{r} + fV$$

Emanuel 1986

Rankin渦

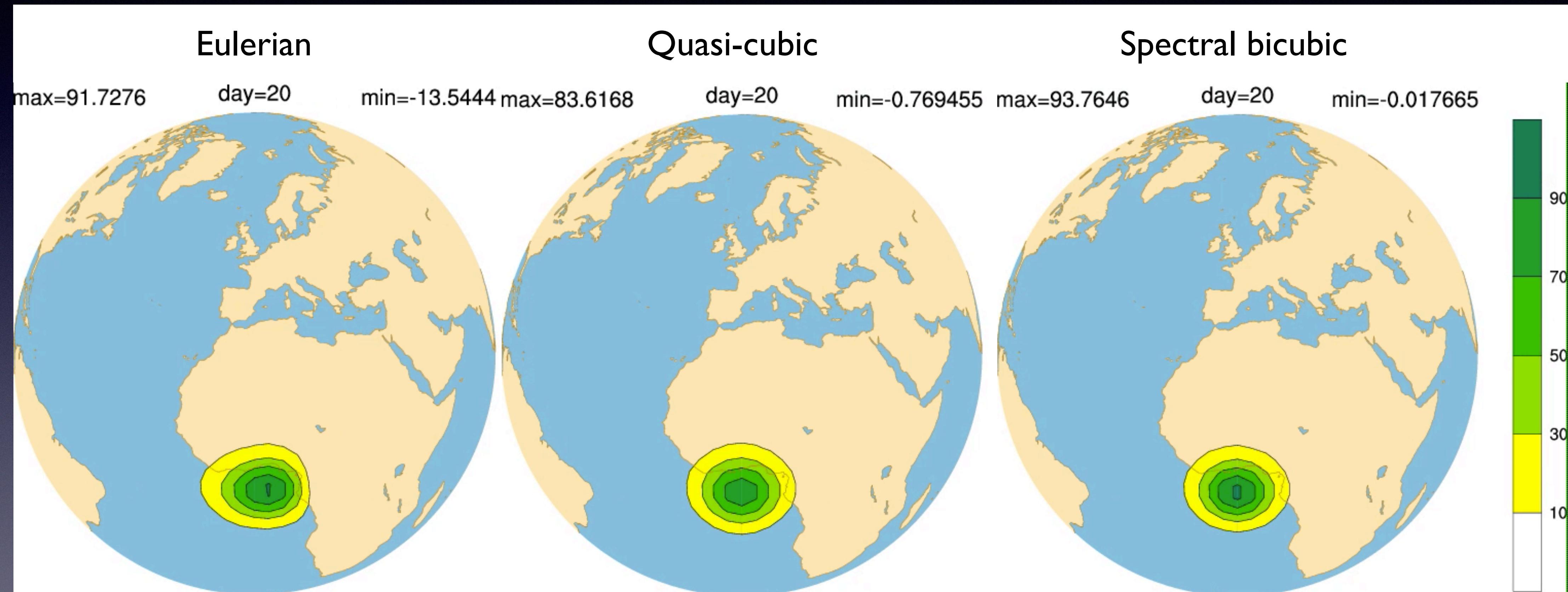
航空機観測

中心付近が剛体回転



Mallen and Montgomery 2005

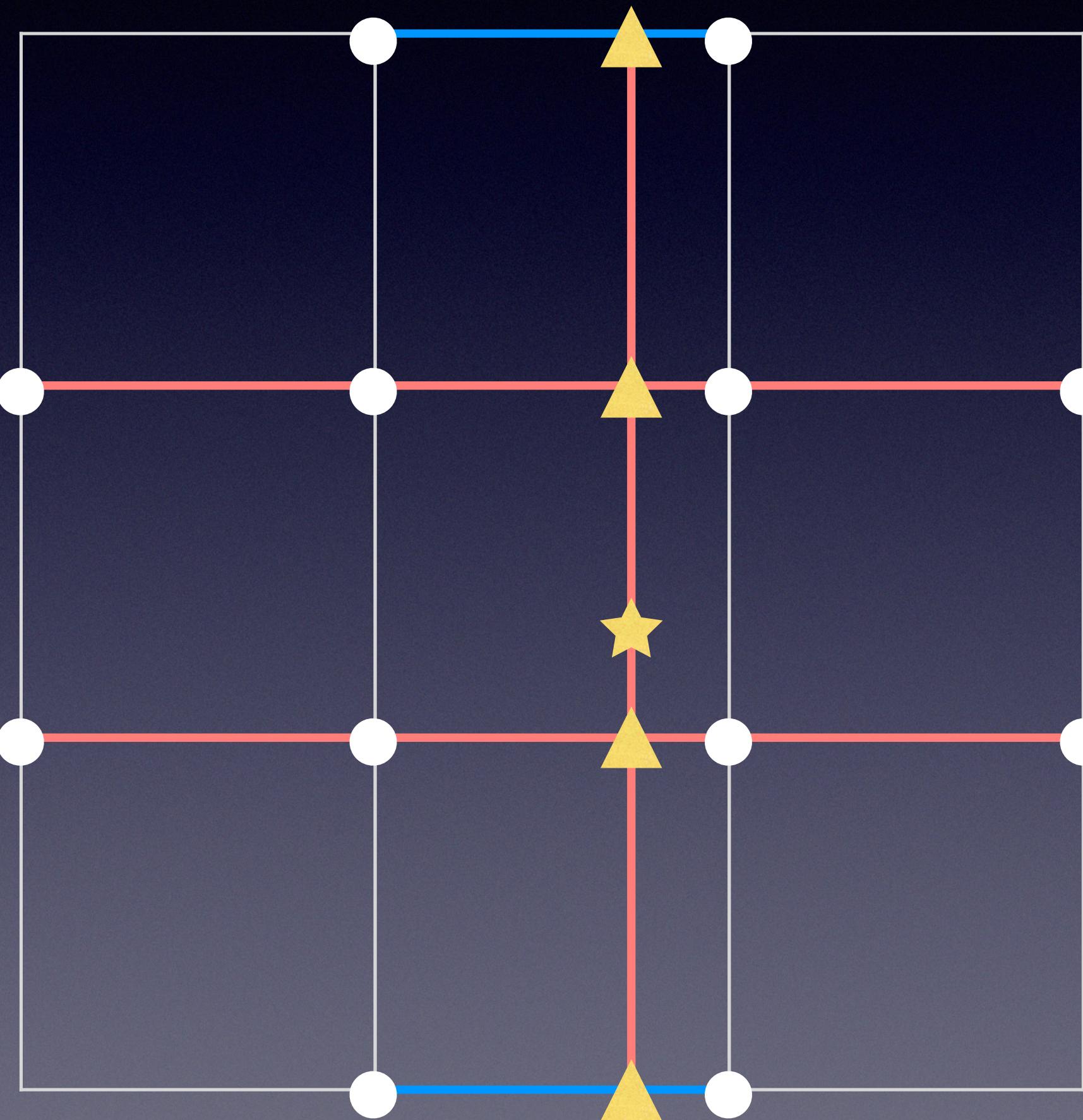
Advection of a Gaussian Hill



Dispersion

Dissipation

Quasi-cubic Interpolation

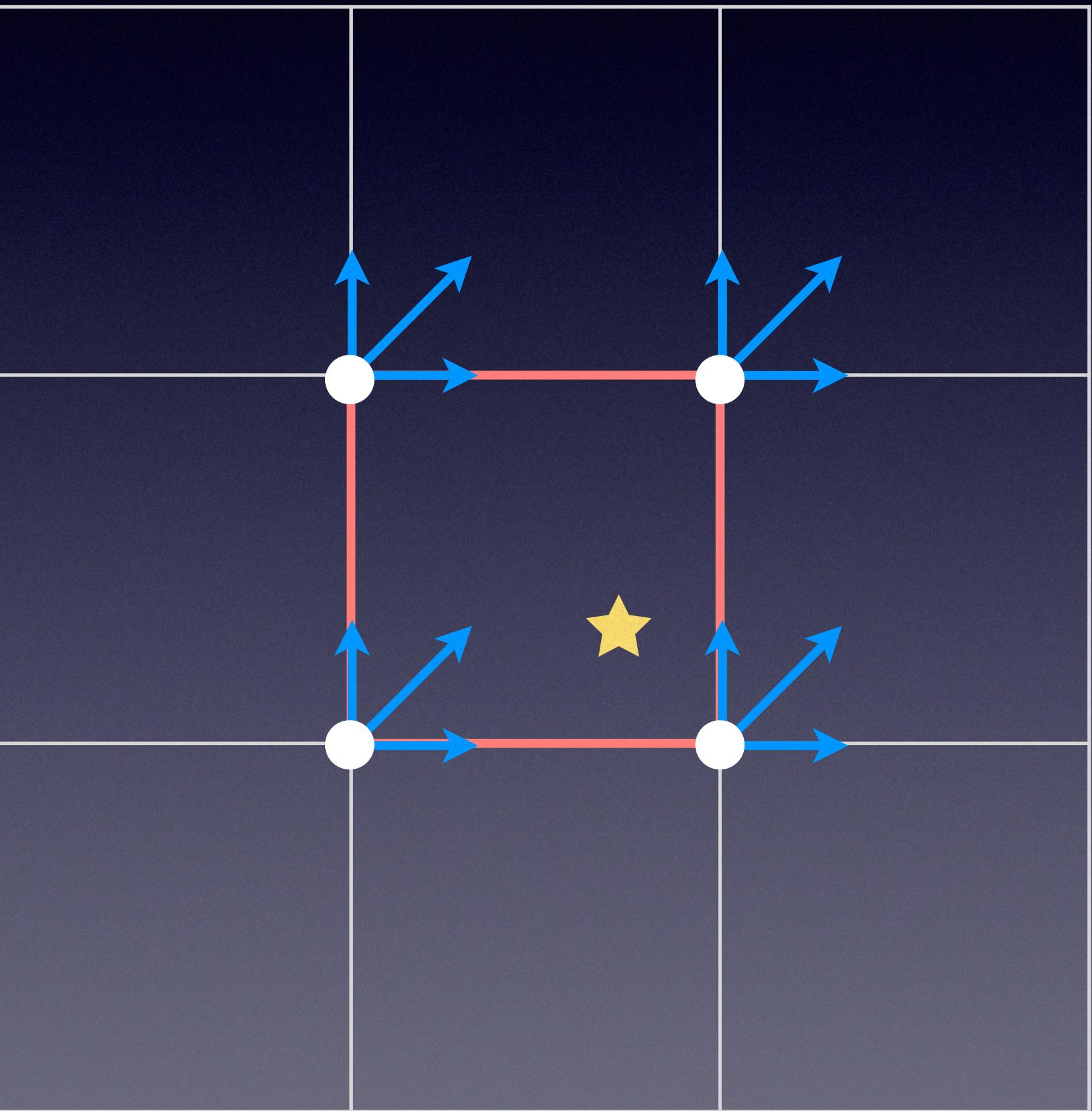


Ritchie et al. 1995

Bicubic Interpolation

Derivatives

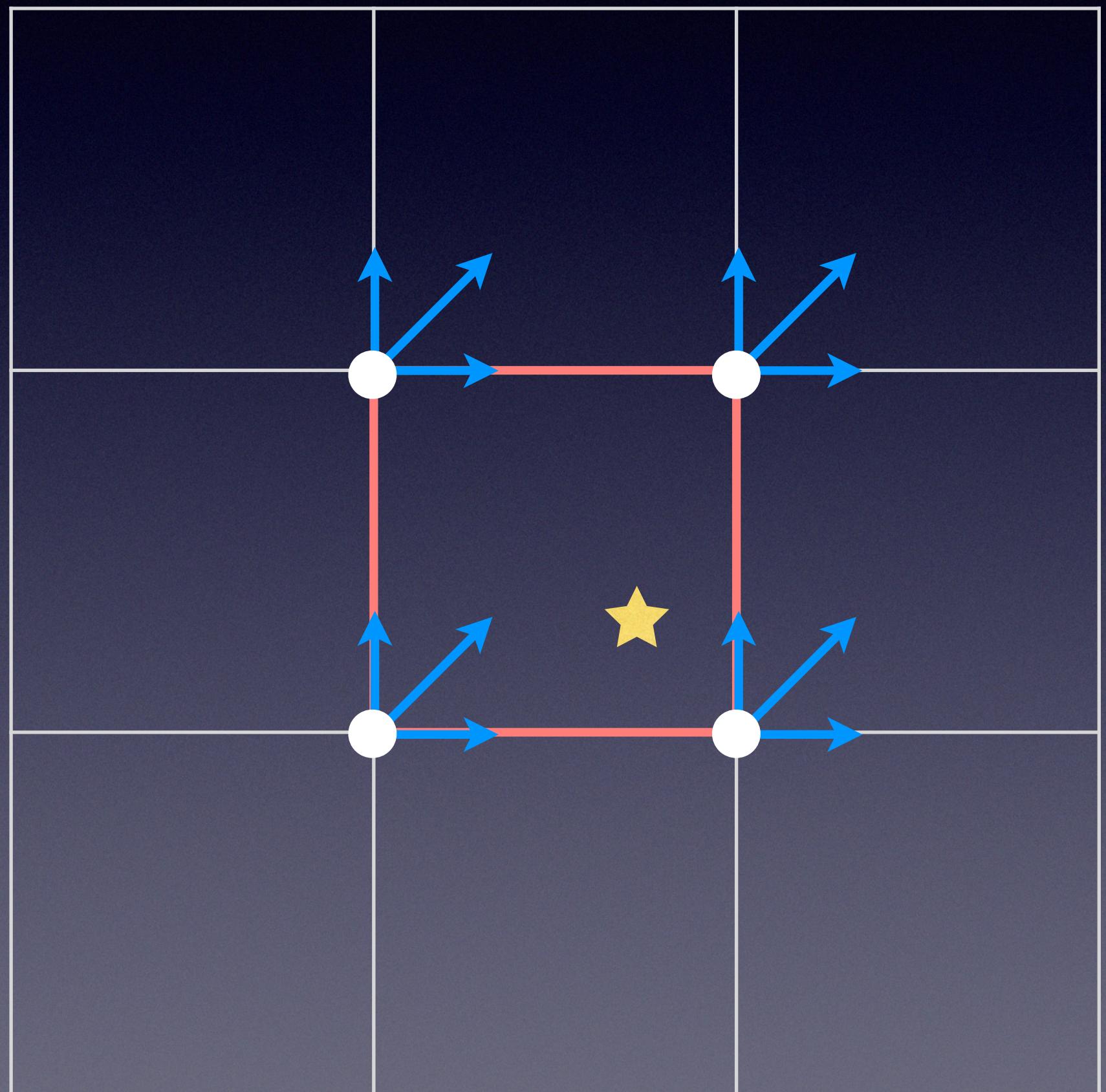
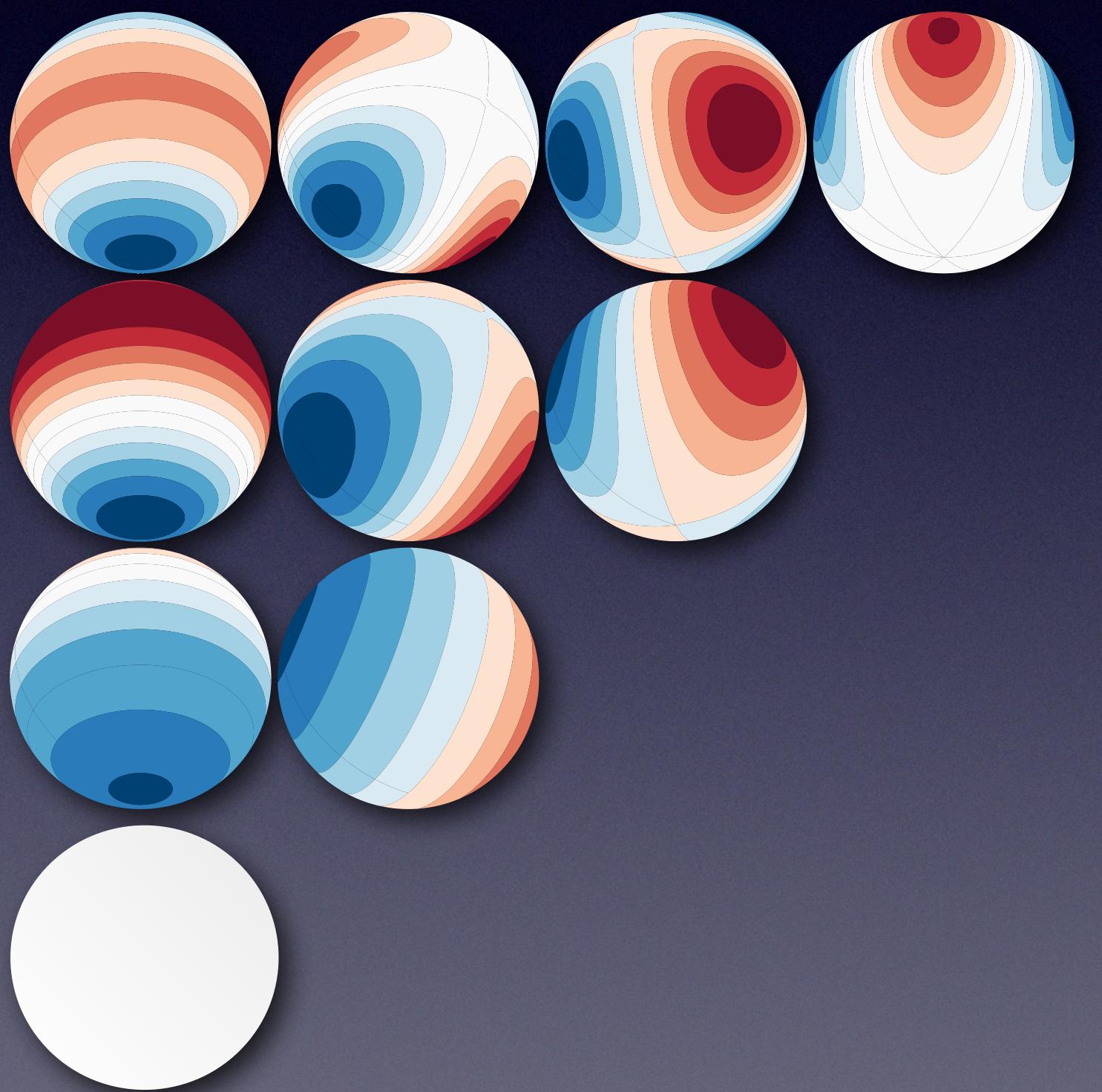
- Finite difference
- Prediction (CIP)
- Fourier/Legendre transform



Spectral bicubic interpolation

Derivatives from harmonics

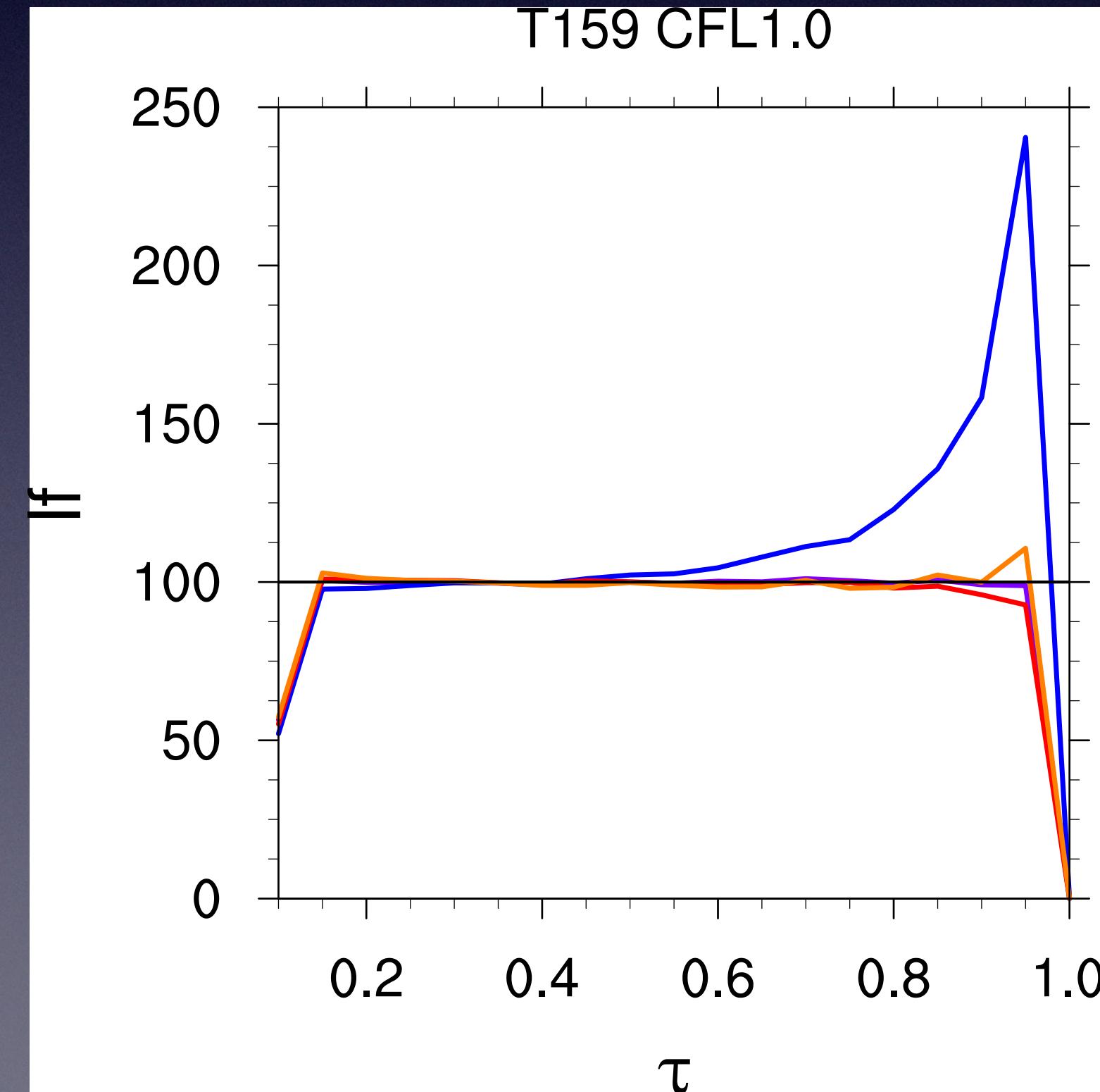
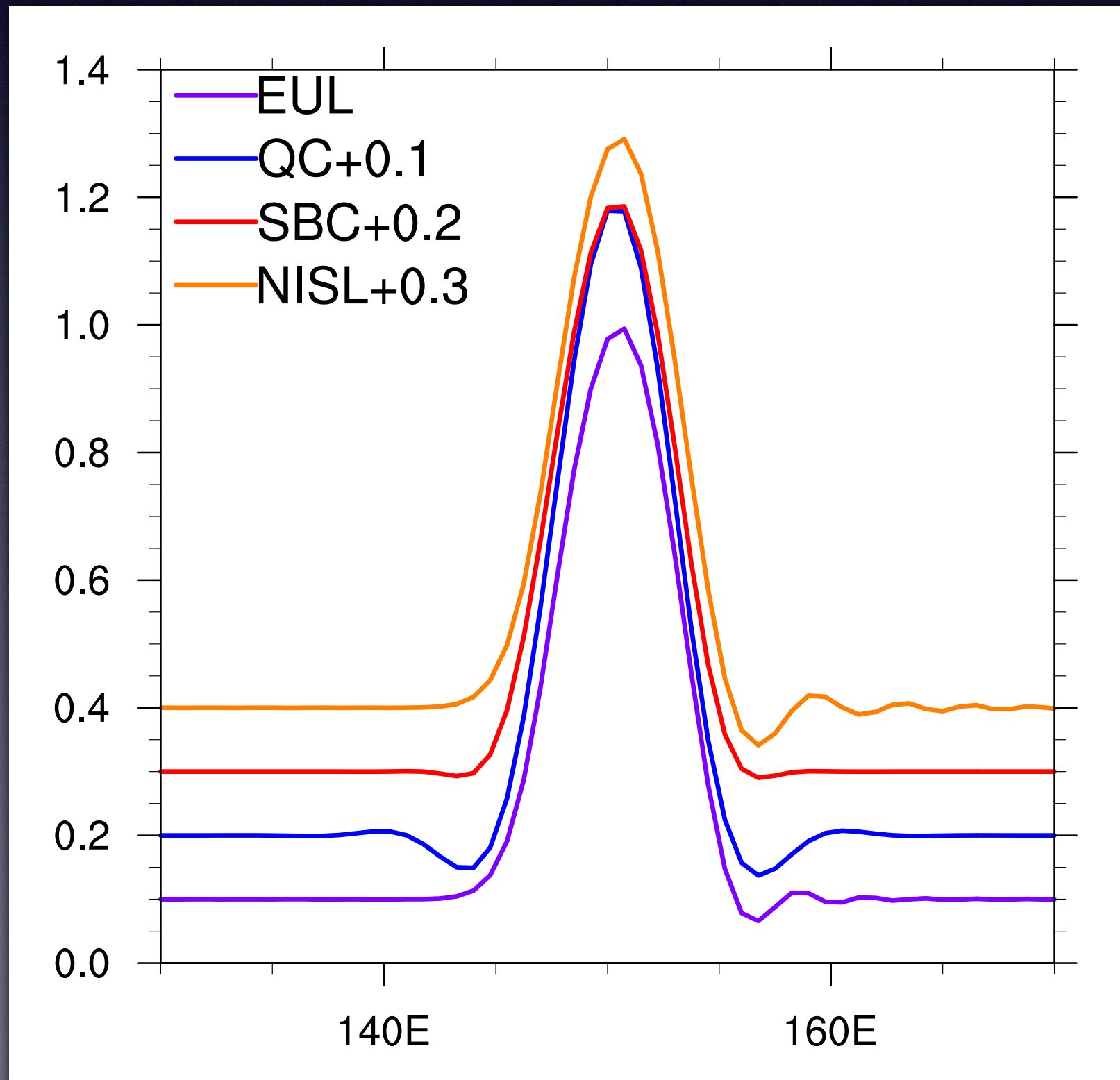
- Simple
- Accurate
- Compact



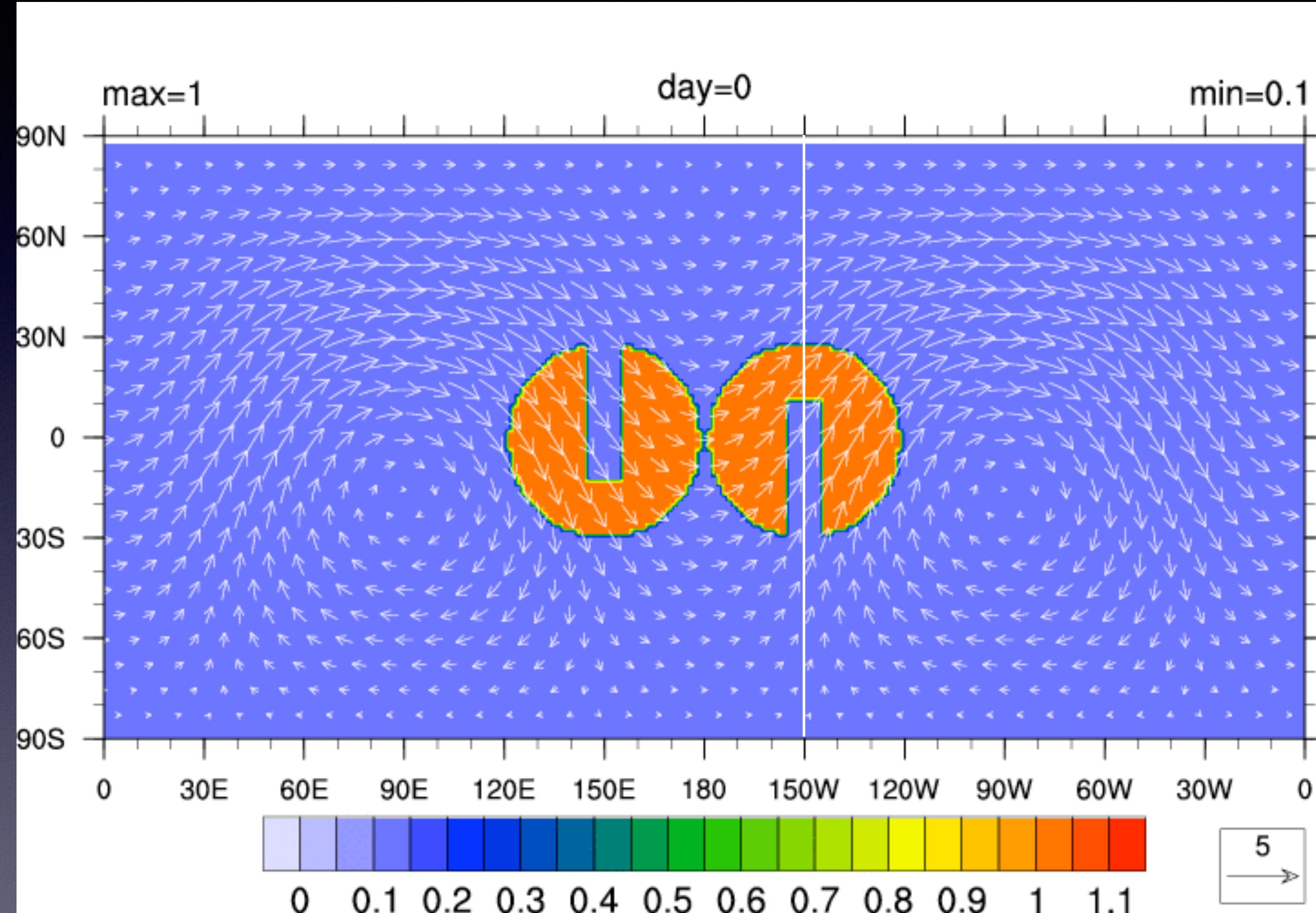
Enomoto 2008

Over/under-shootings

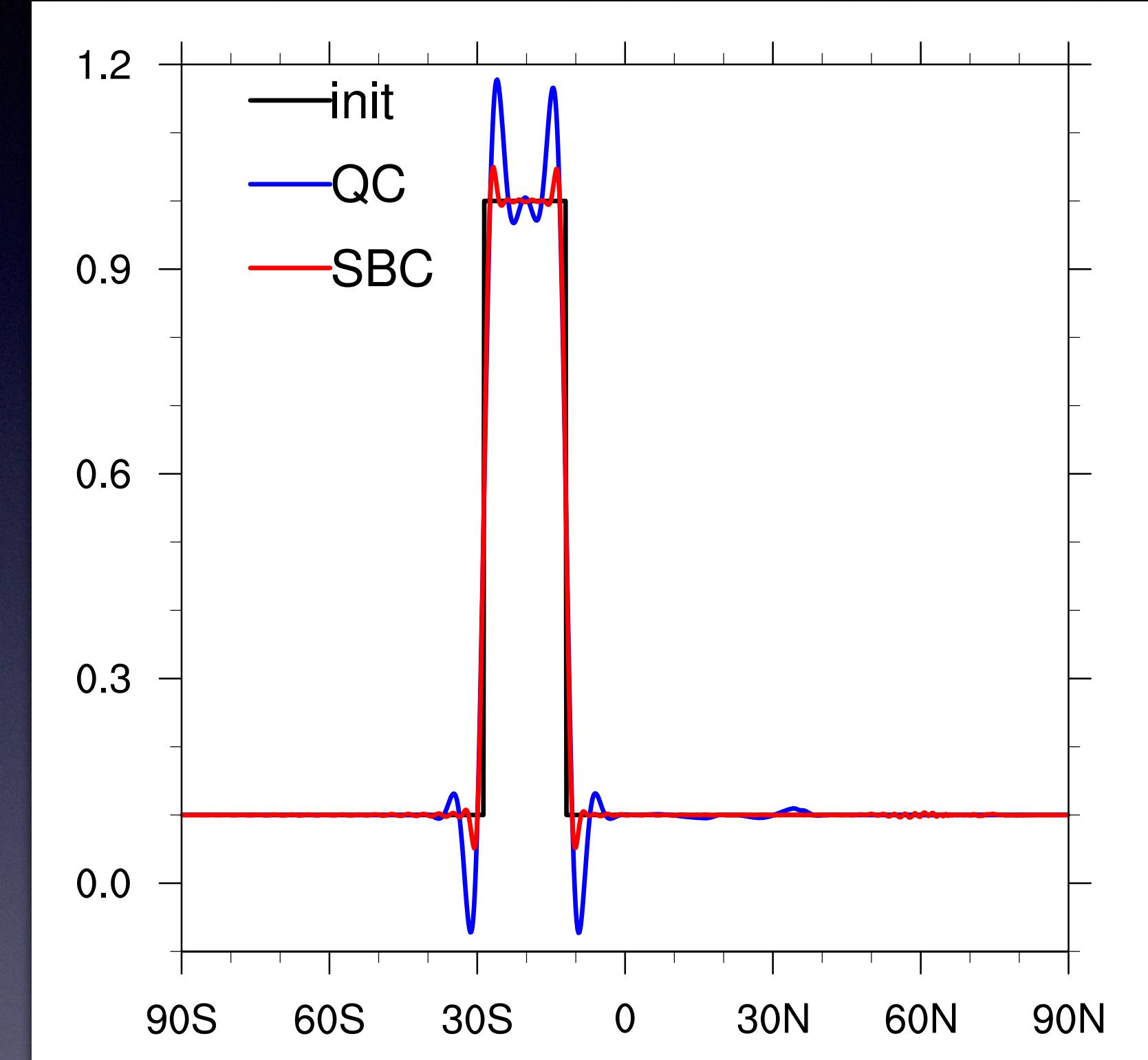
$$\ell_f(\tau) = 100 \times \frac{A(\tau, t = T/2)}{A(\tau, t = 0)}$$



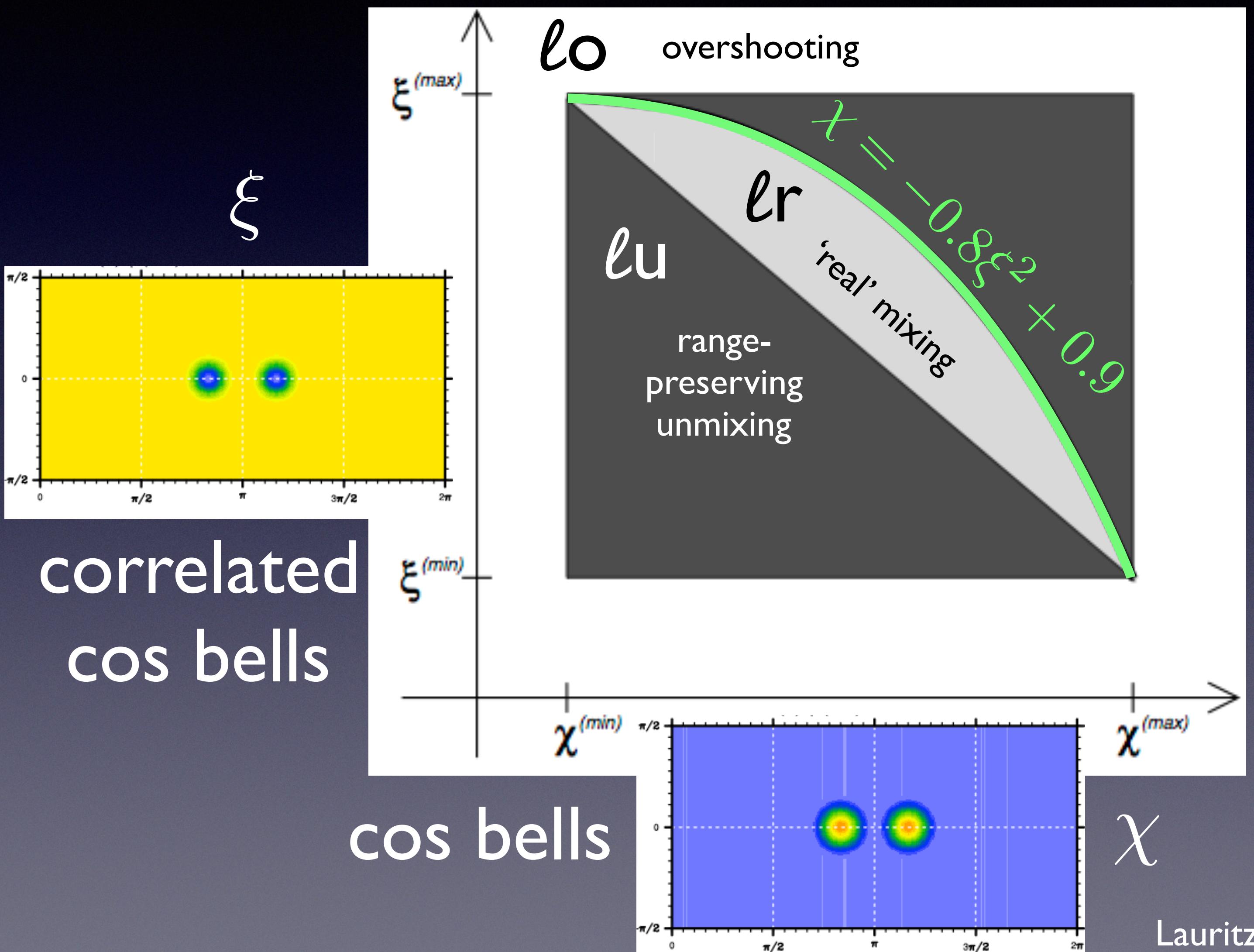
Spectral bicubic T119 CFL=5.2 filter+fix



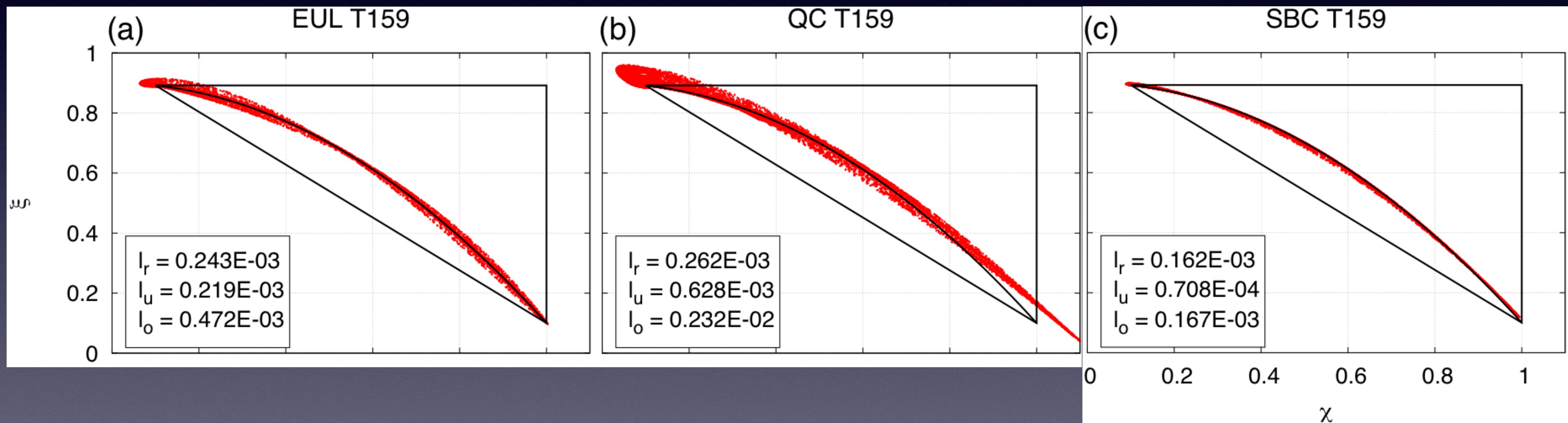
$$\Delta x = 1.5^\circ$$



Preservation of function relation



Mixing properties

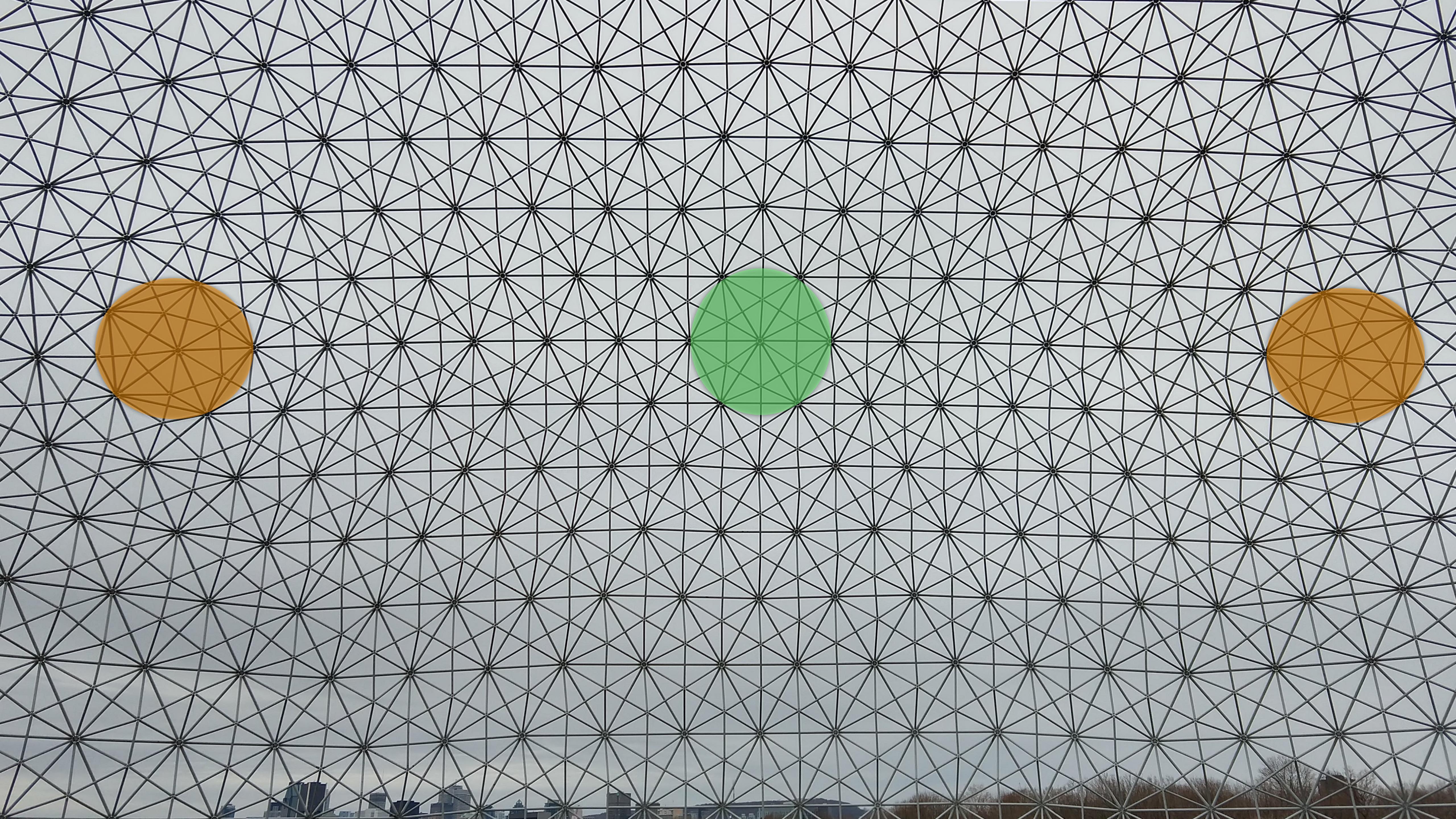


CFL=1.0 unlimited

台風は渦

- ・ 台風を順圧のRankin渦で近似し、発達・減衰を無視すれば、絶対渦度保存則に従う。
- ・ Rankin渦のようなシャープな構造を維持するには、精度の高い移流スキームが必要
- ・ 単調性や混合特性にも注意が必要。

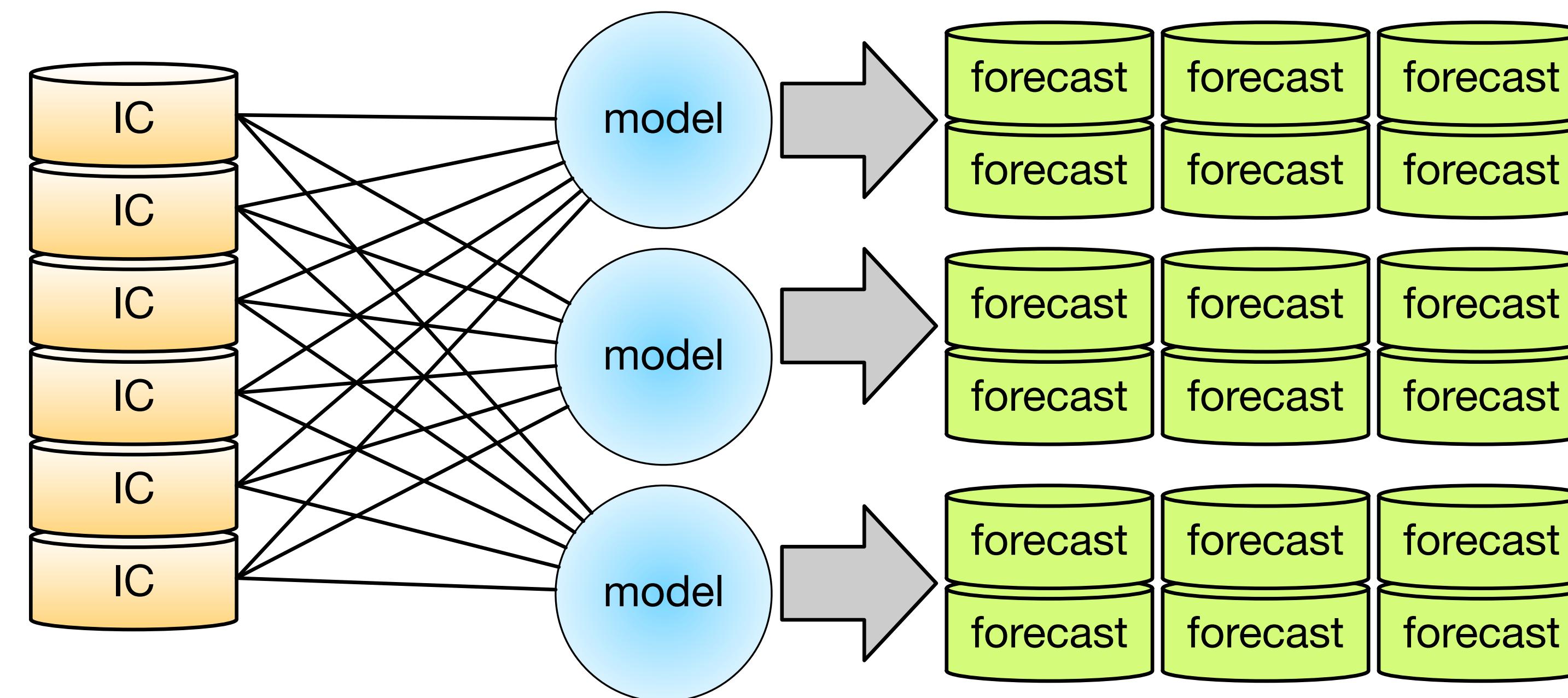




力学コアの動向

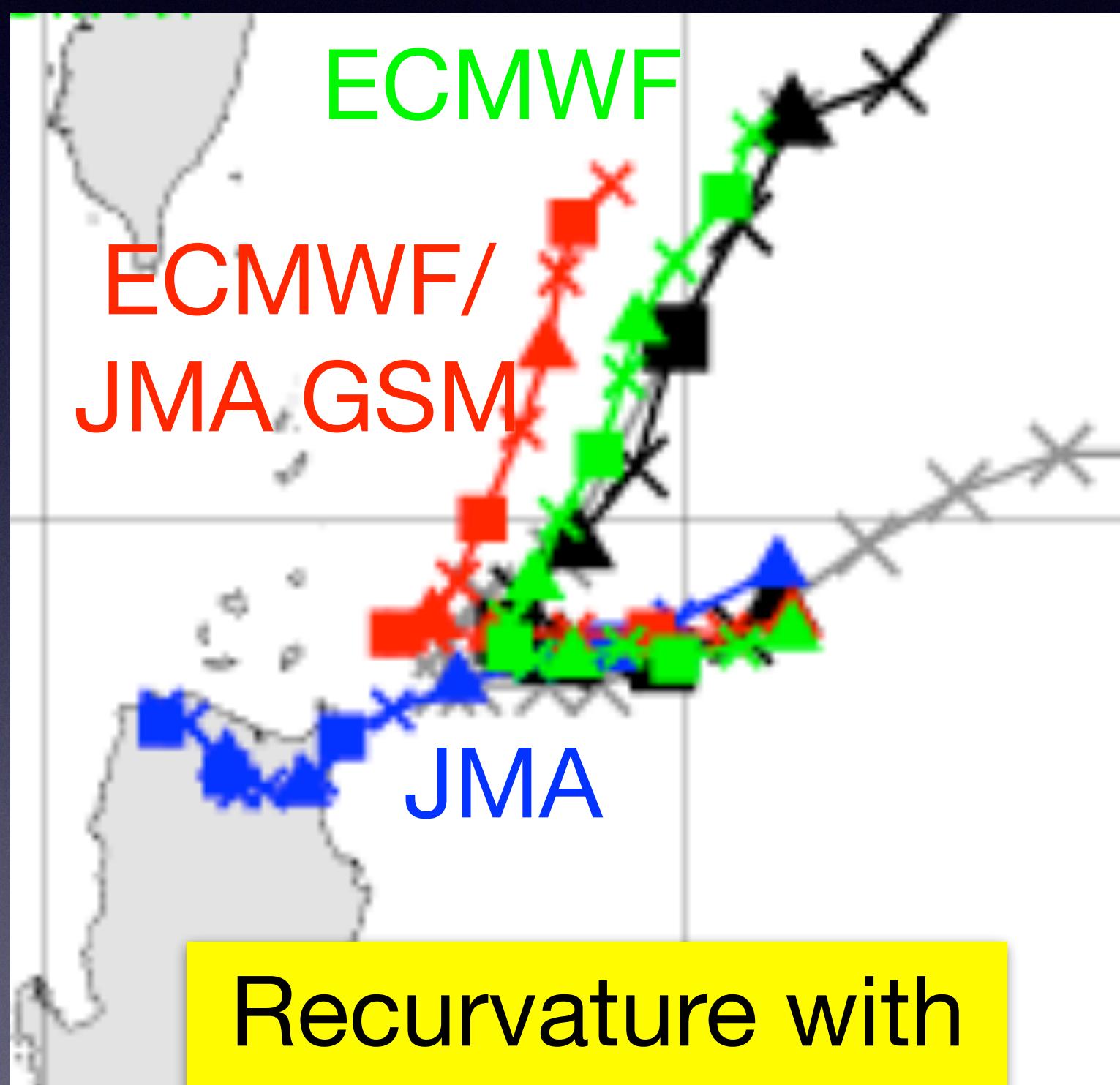
- Workshop on the Partial Differential Equations on the sphere 2019
28 Apr–3 May 2019, Montréal, Québec, Canada
- ECMWF, NCEPは有限要素法 (FV) へ
- スペクトル法はスケーリングが良く、通信のコストも悪くないとの報告や高速ルジヤンドル変換の発表も
- 時間積分法の工夫: 時間方向並列化, 指数積分など
- その他AMRやエネルギー保存性など。Cubed-sphereが復権している印象

Cross analysis–model experiments



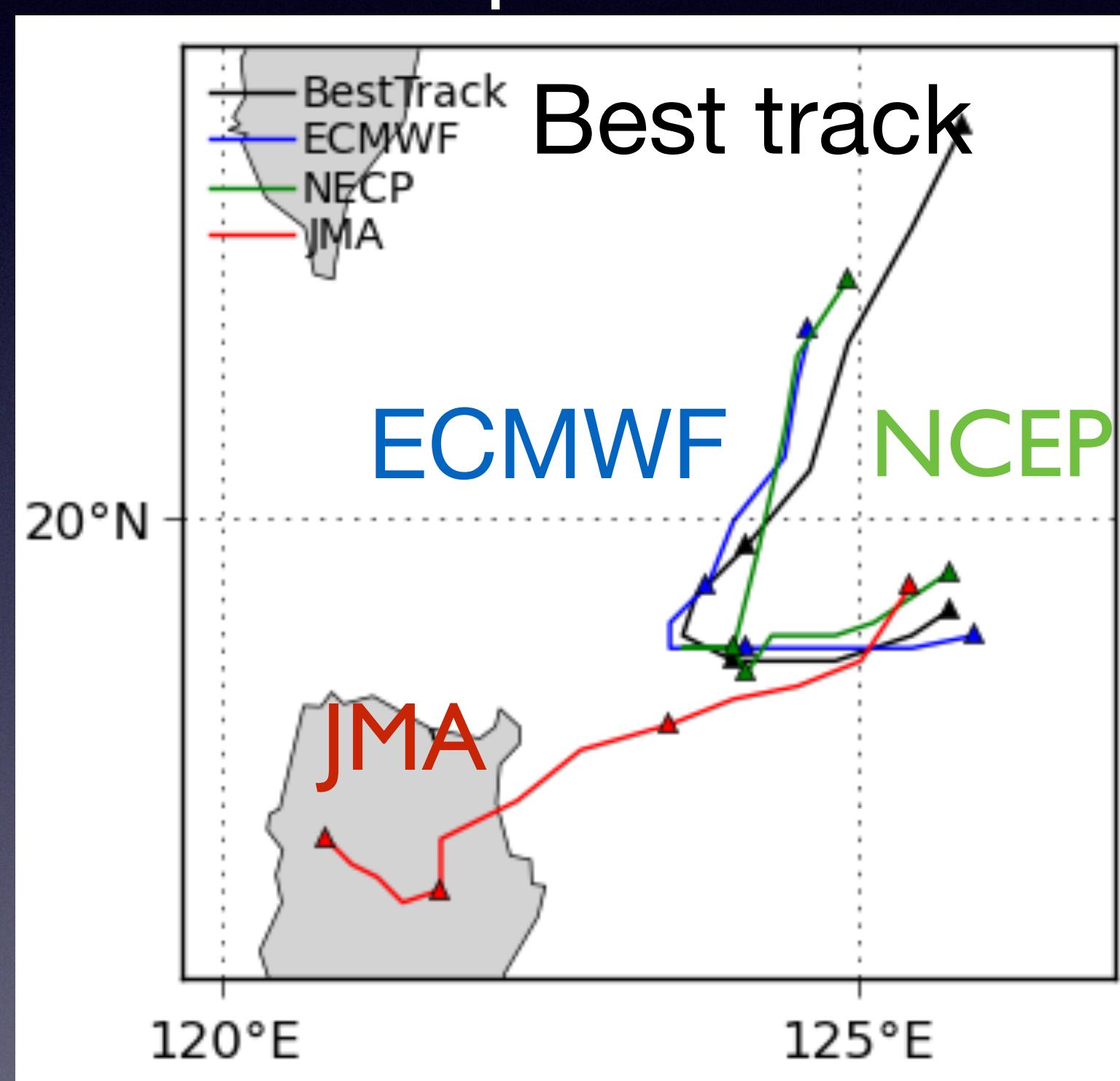
Lupit 2009

JMA GSM T319L60



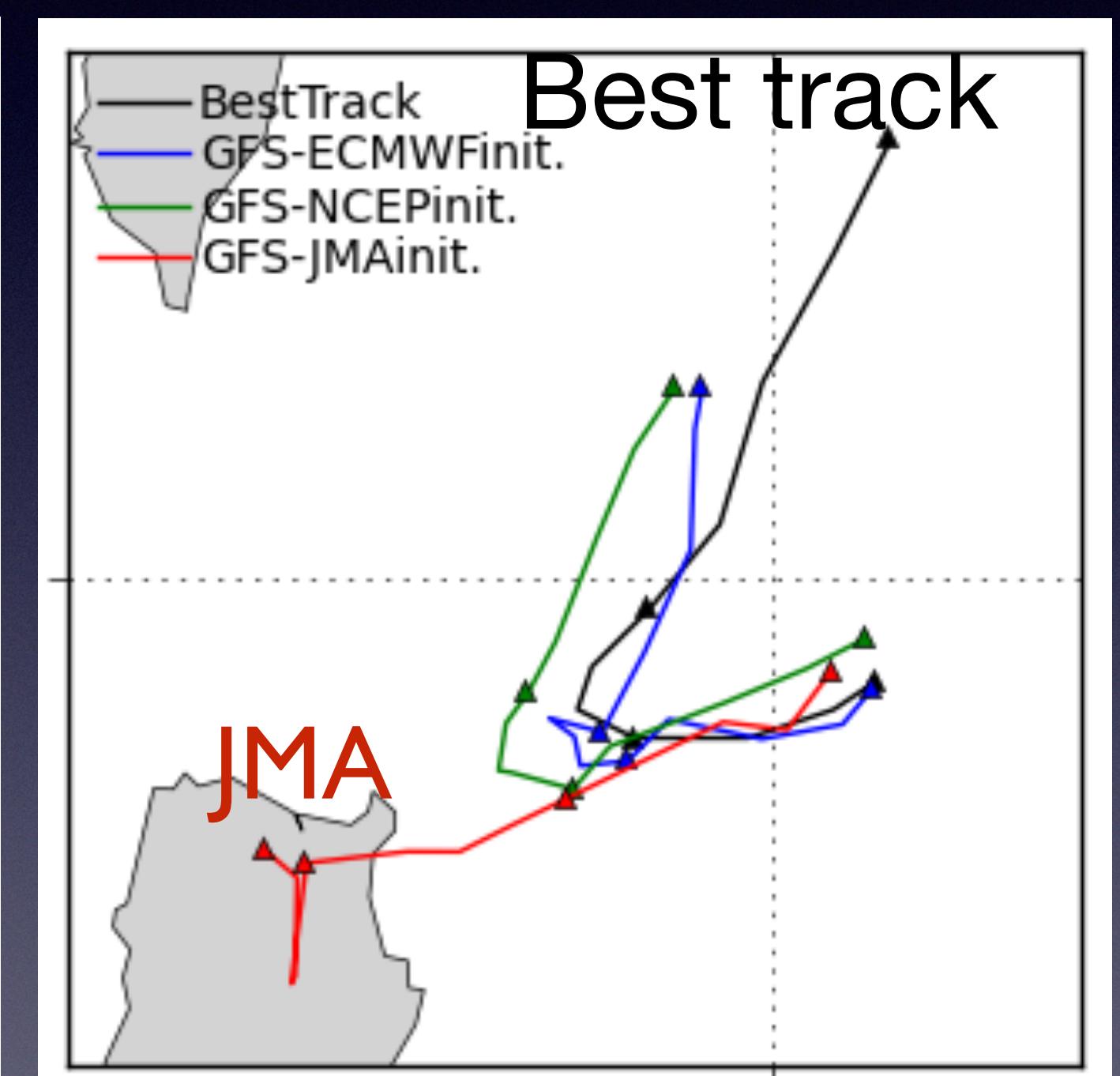
Yamaguchi et al. 2012

Operational



initial: 12 UTC 21 October

NCEP GSM T382L64

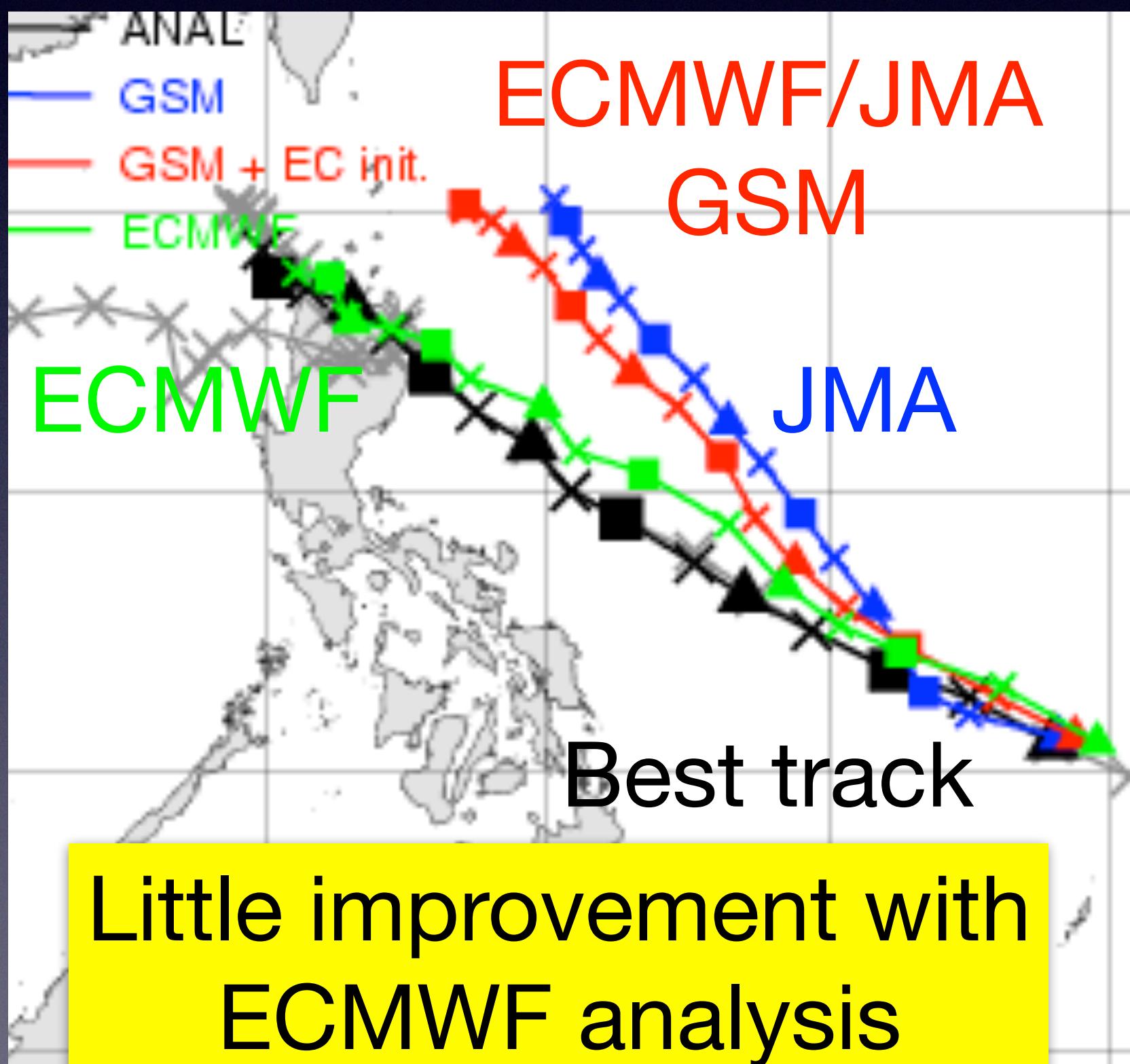


Sensitive to IC
insensitive to model

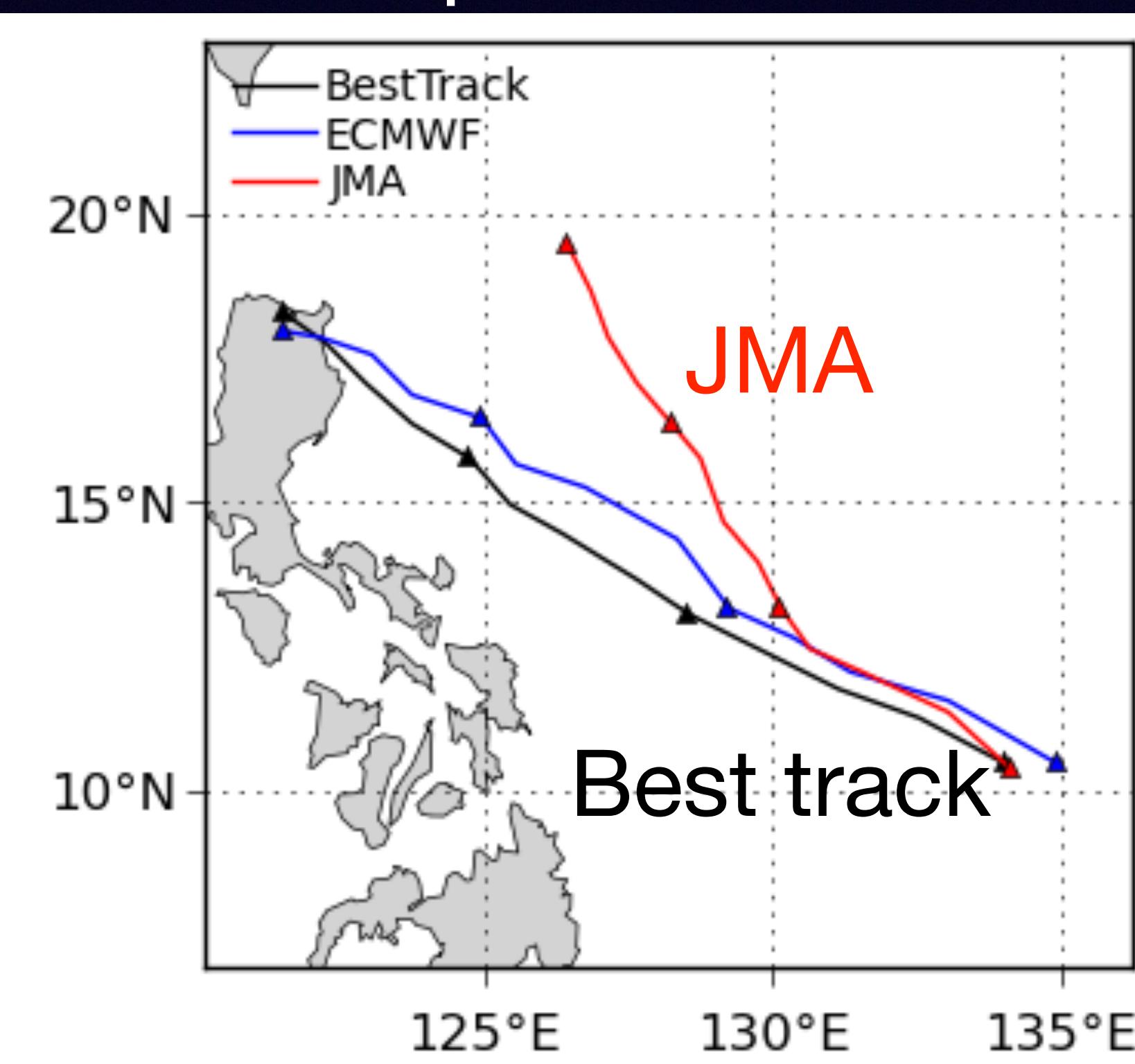
T. Miyachi

Parma 2009

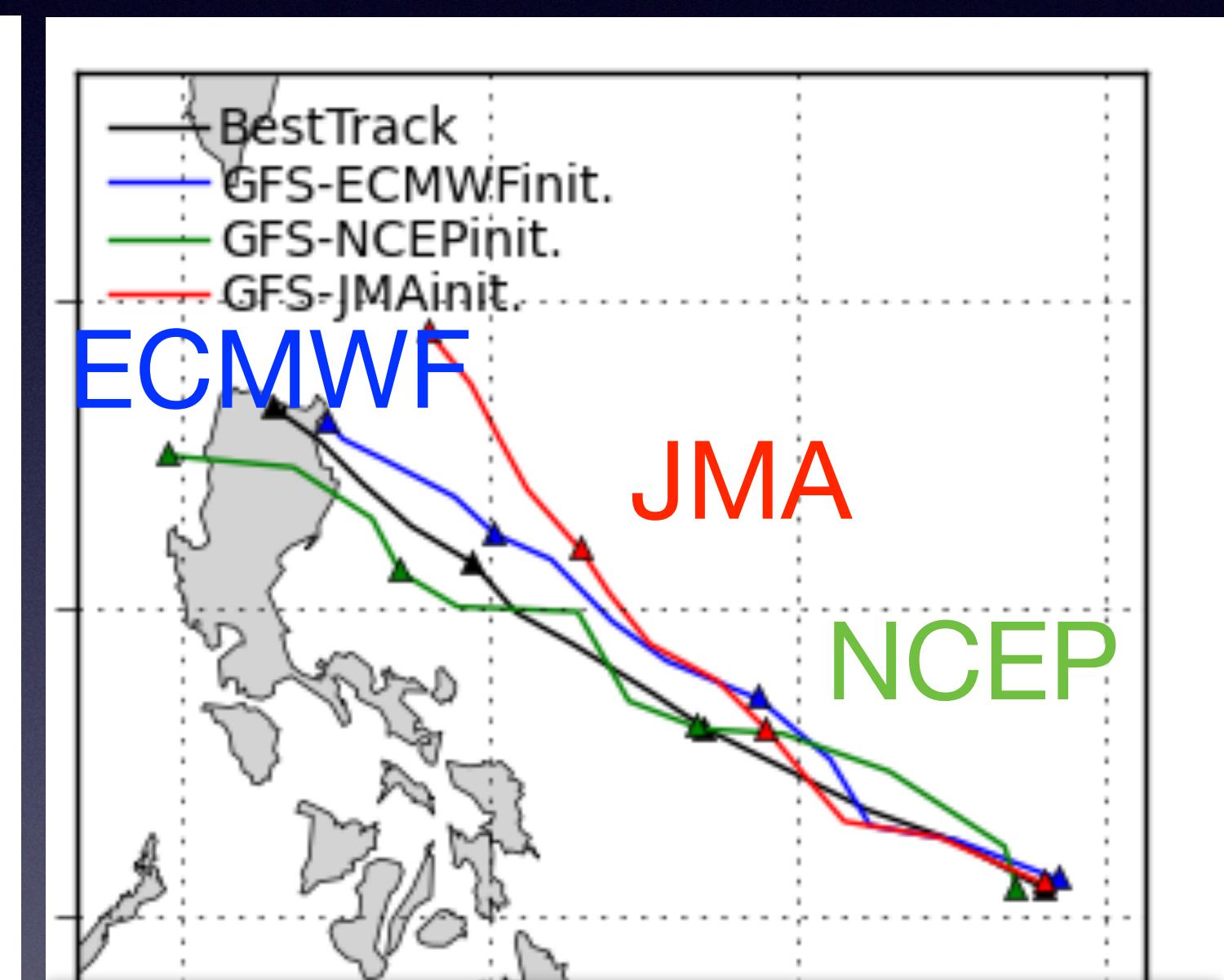
JMA GSM T319L60



Operational



NCEP GSM T382L64



72 h error reduced from
532 km to 296 km with
JMA analysis

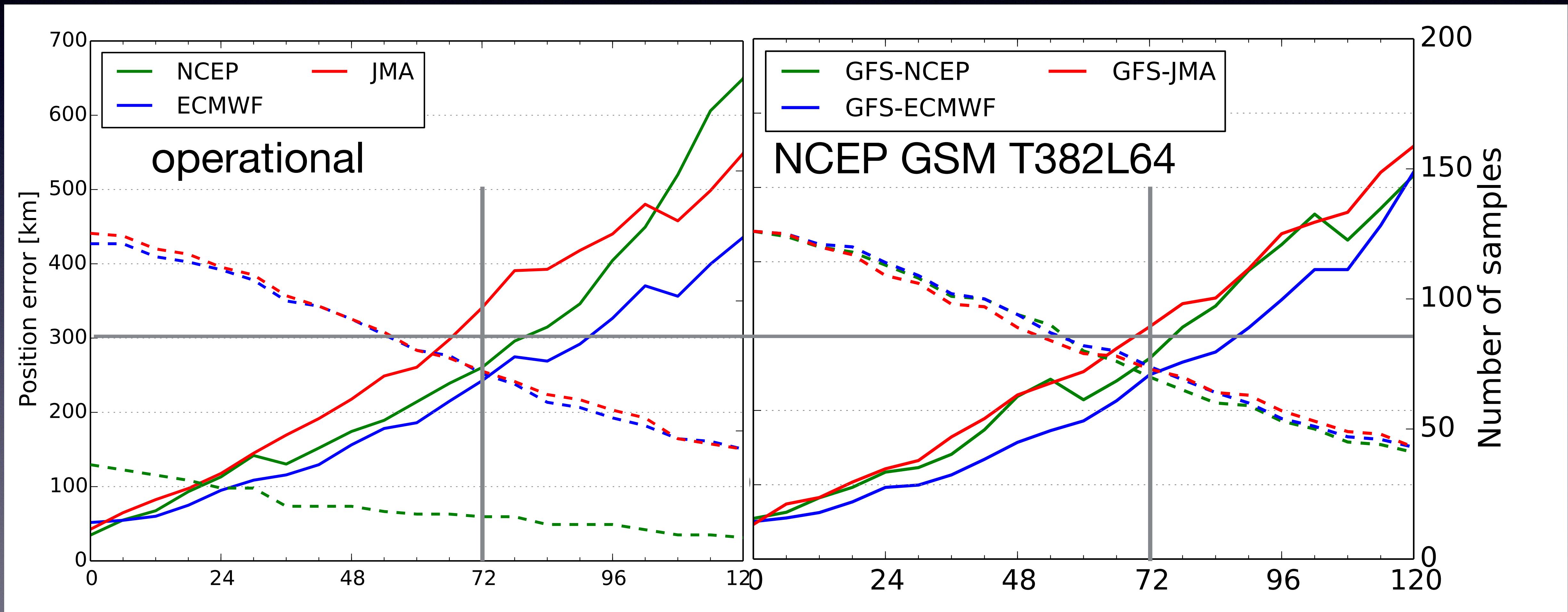
Yamaguchi et al. 2012

initial: 12 UTC 30 September

T. Miyachi

Positional error

NW Pacific 2009

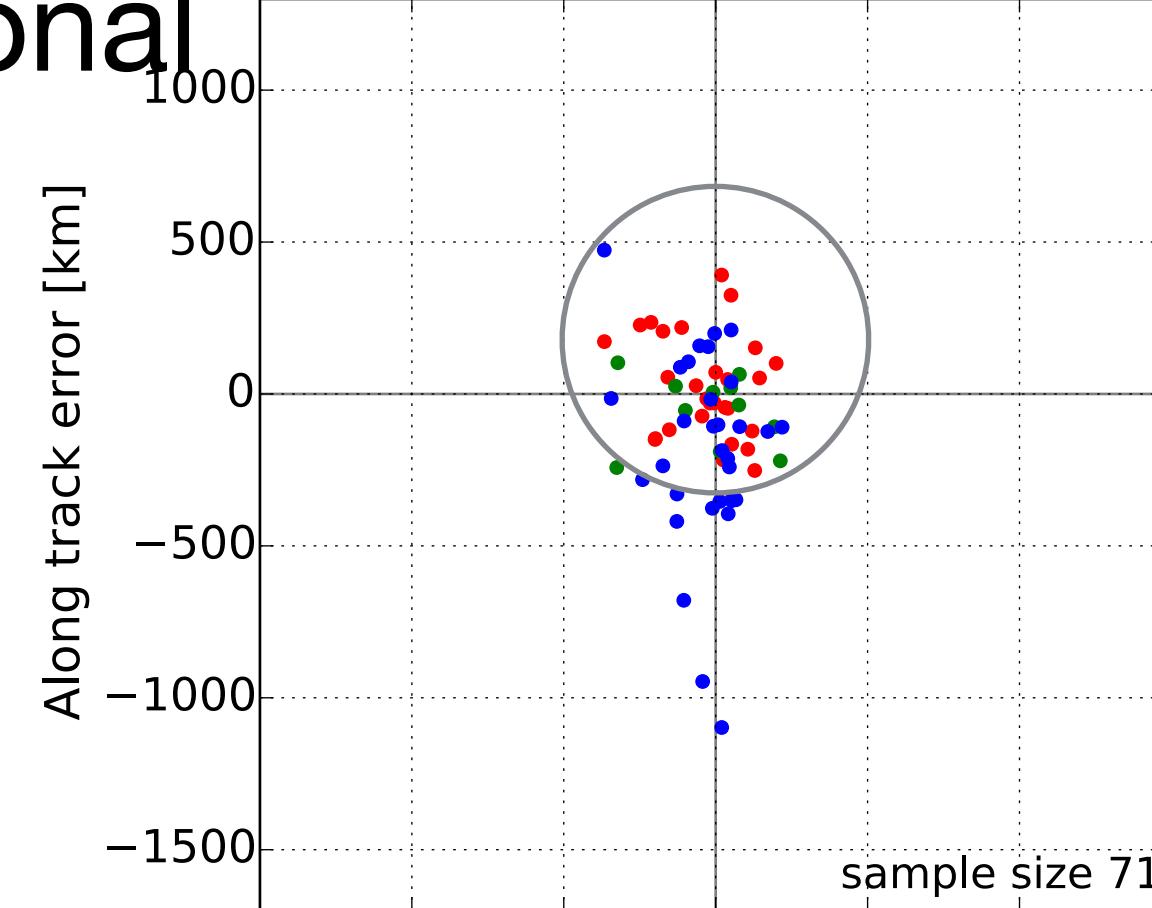


Along/Cross track error

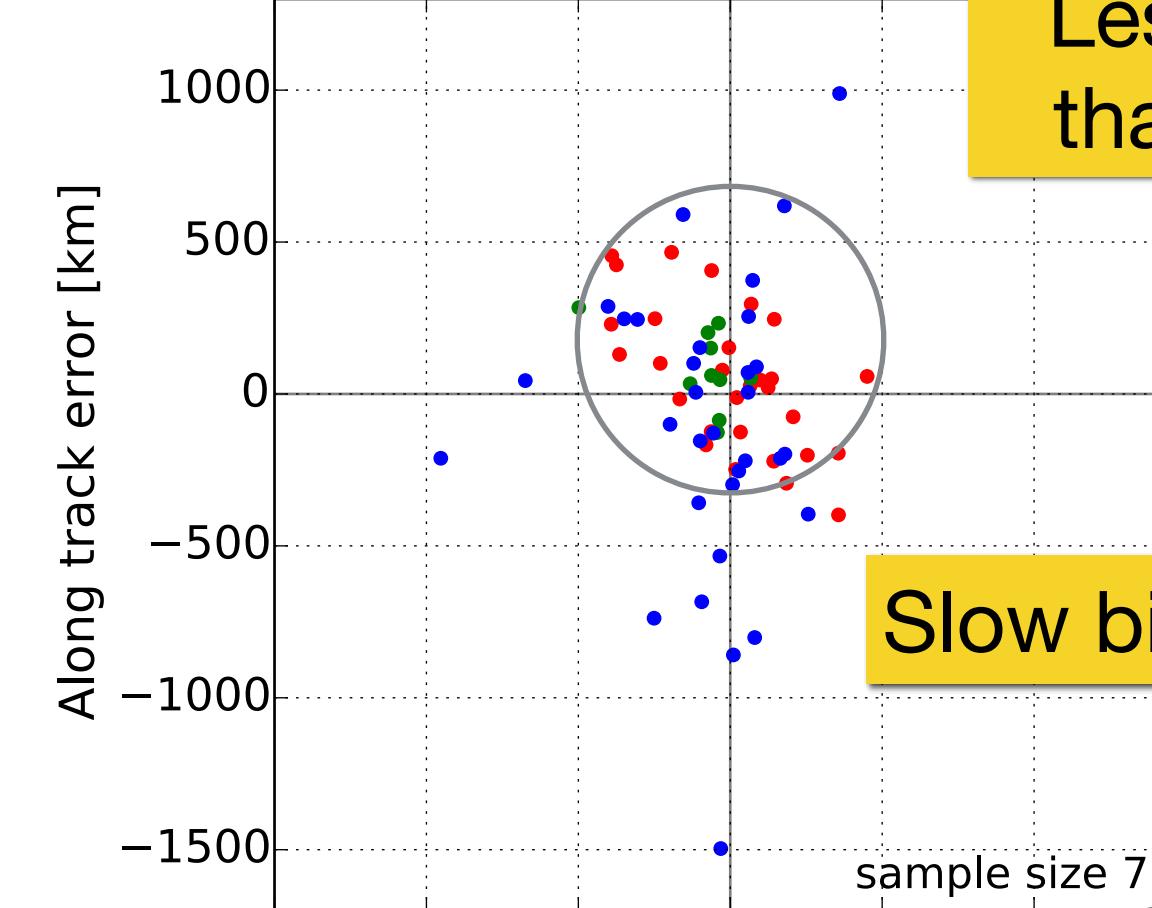
- before
- during
- after

operational

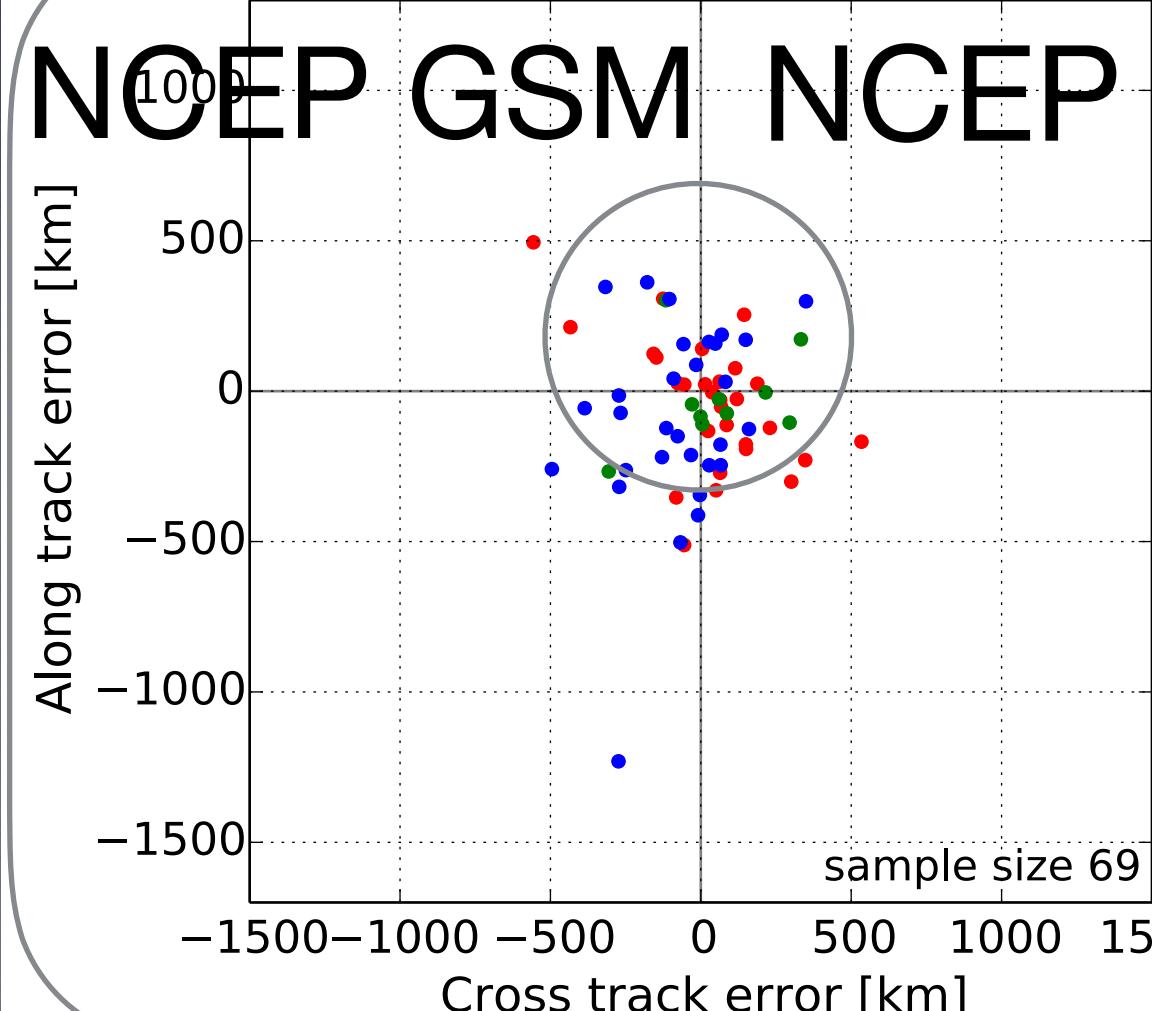
(a) ECMWF FH=72



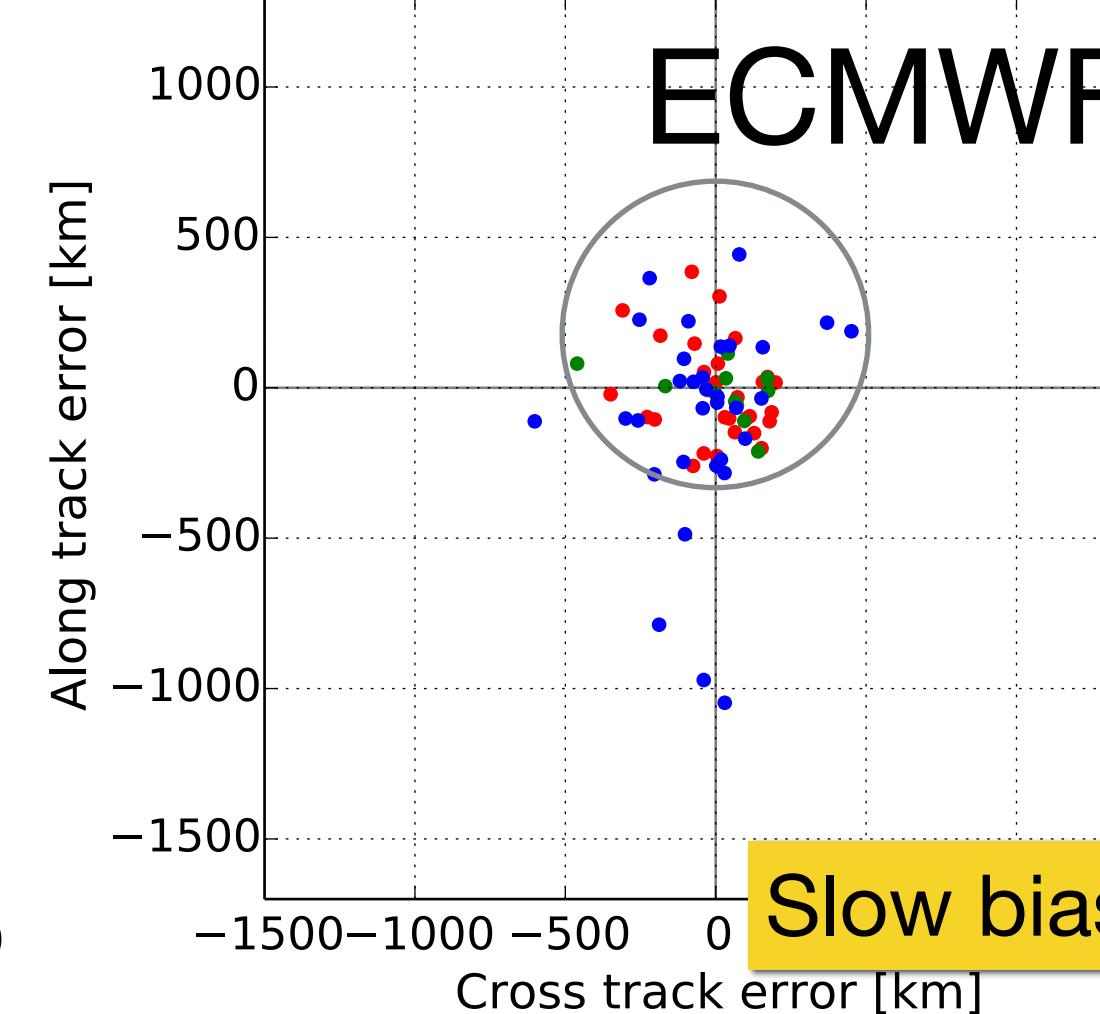
(c) JMA FH=72



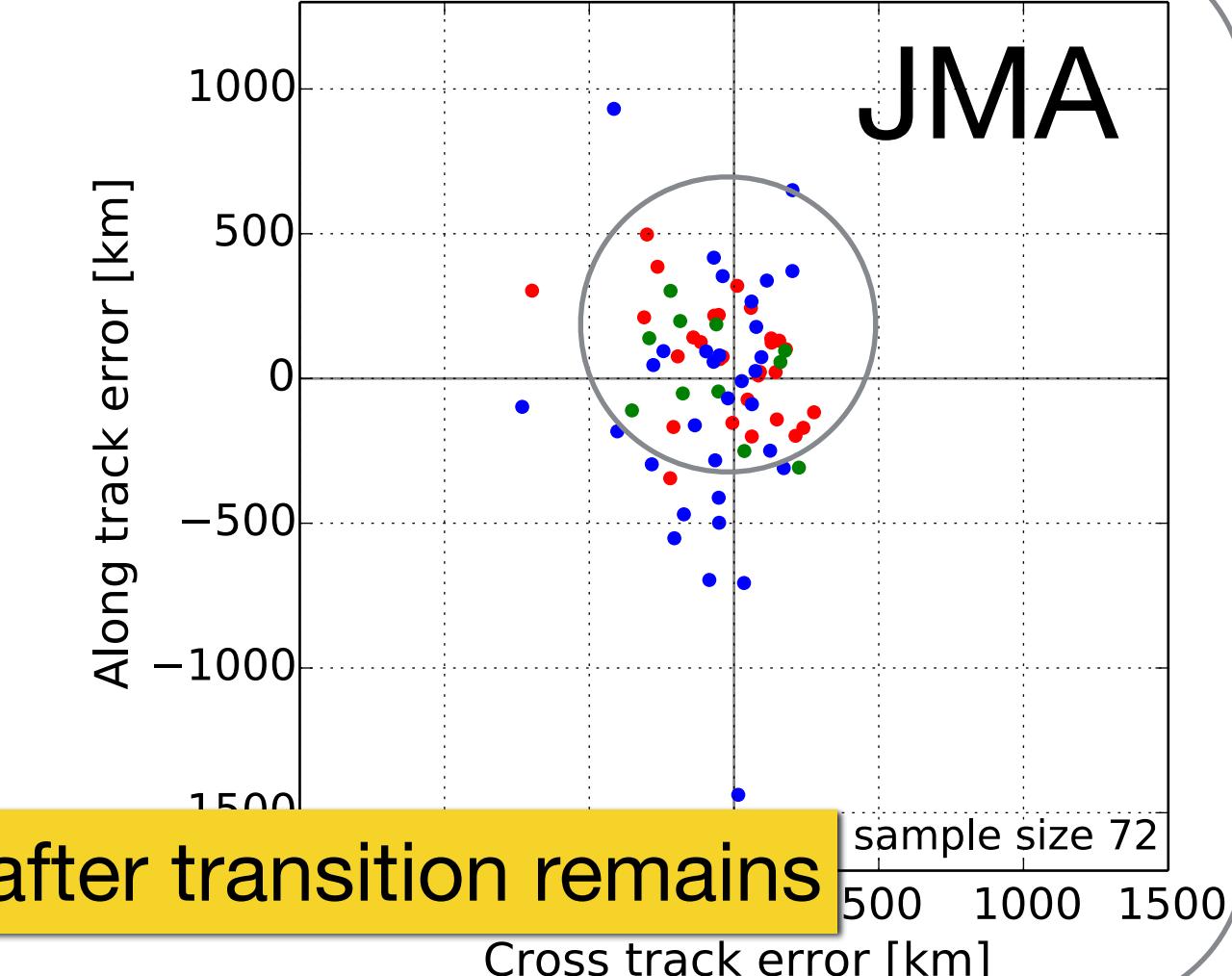
(b) T382 GFS-NCEP FH=72



(d) T382 GFS-ECMWF FH=72

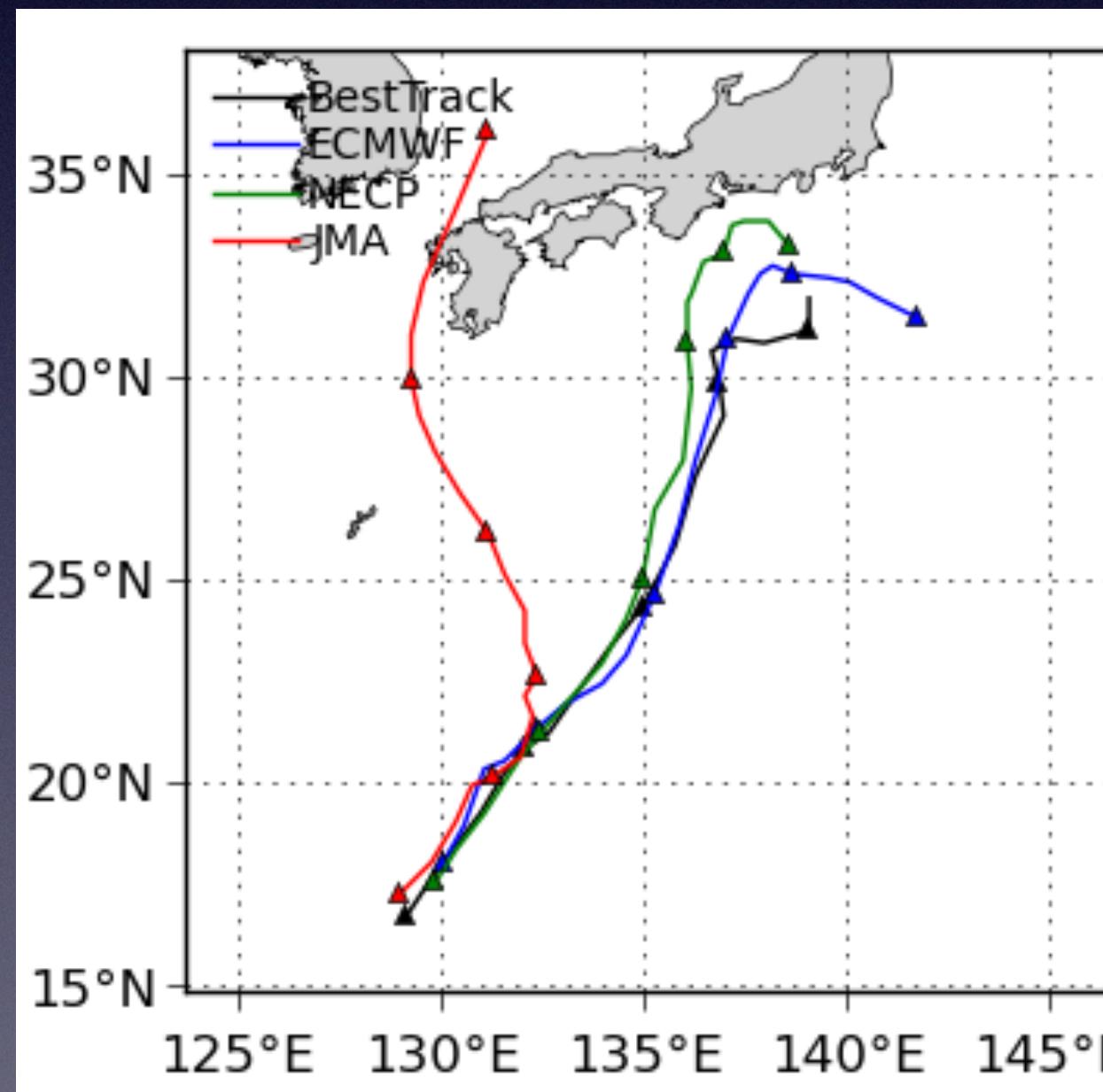


(f) T382 GFS-JMA FH=72

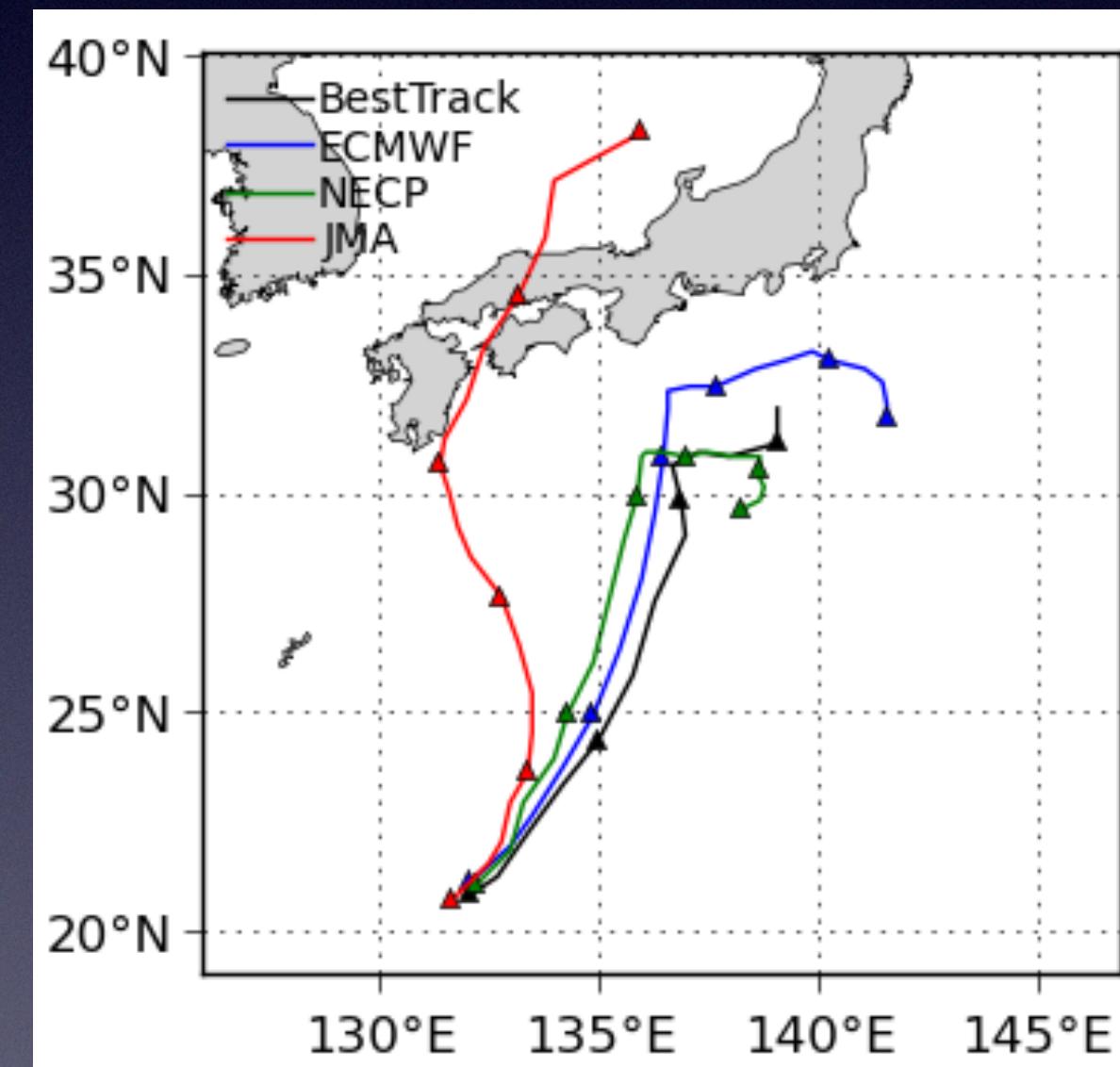


201303 Yagi

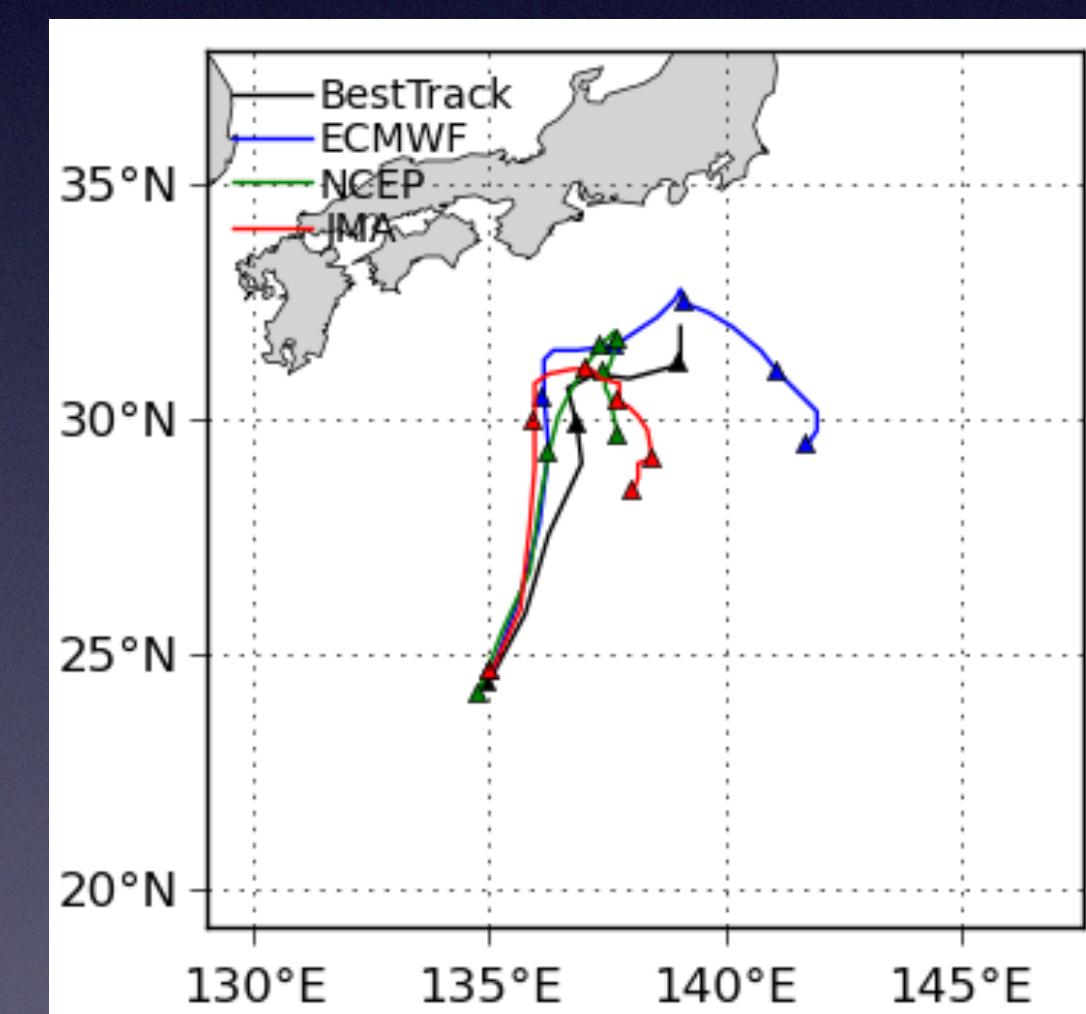
初期時刻 6/8 12 UTC



6/9 12 UTC

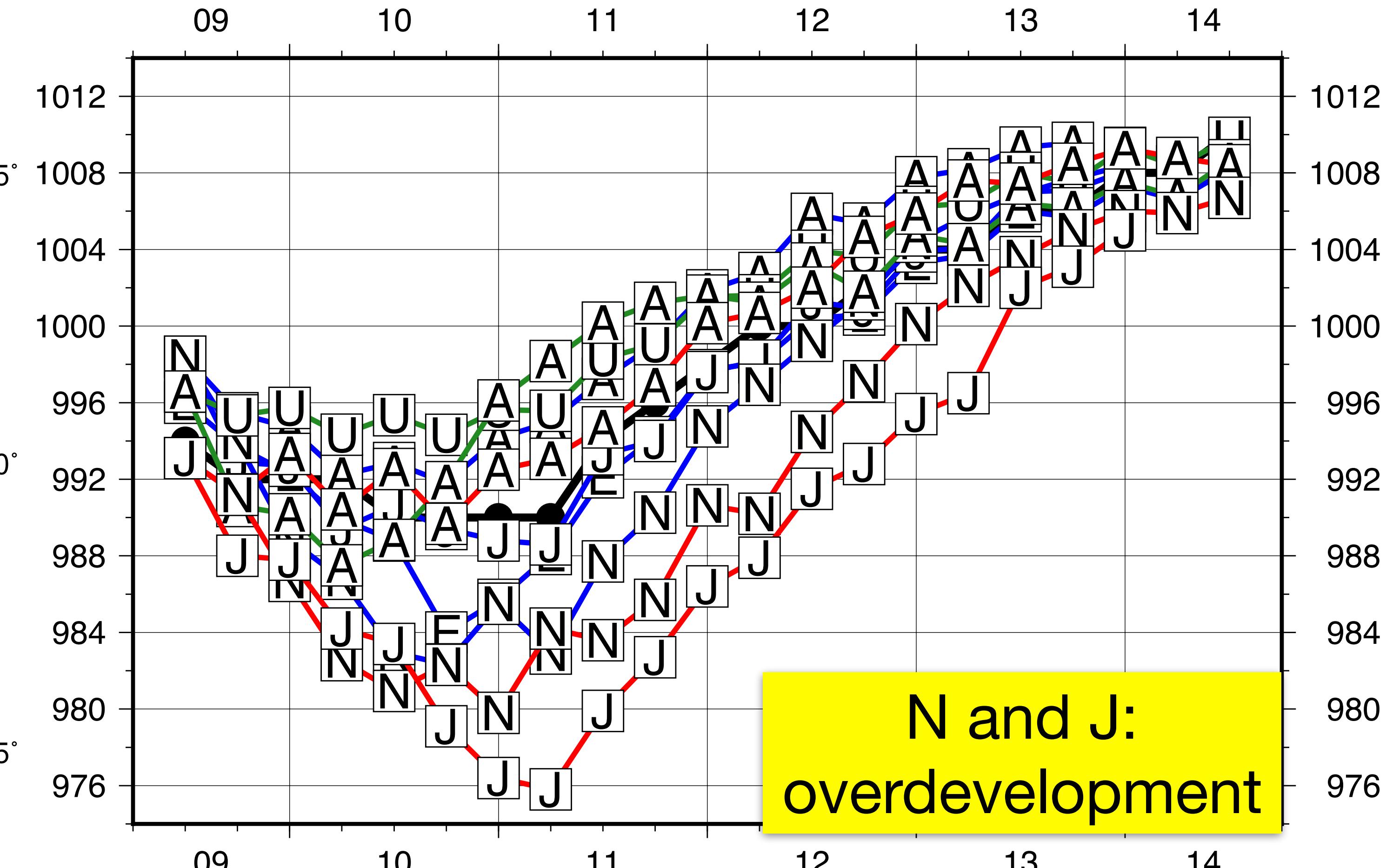
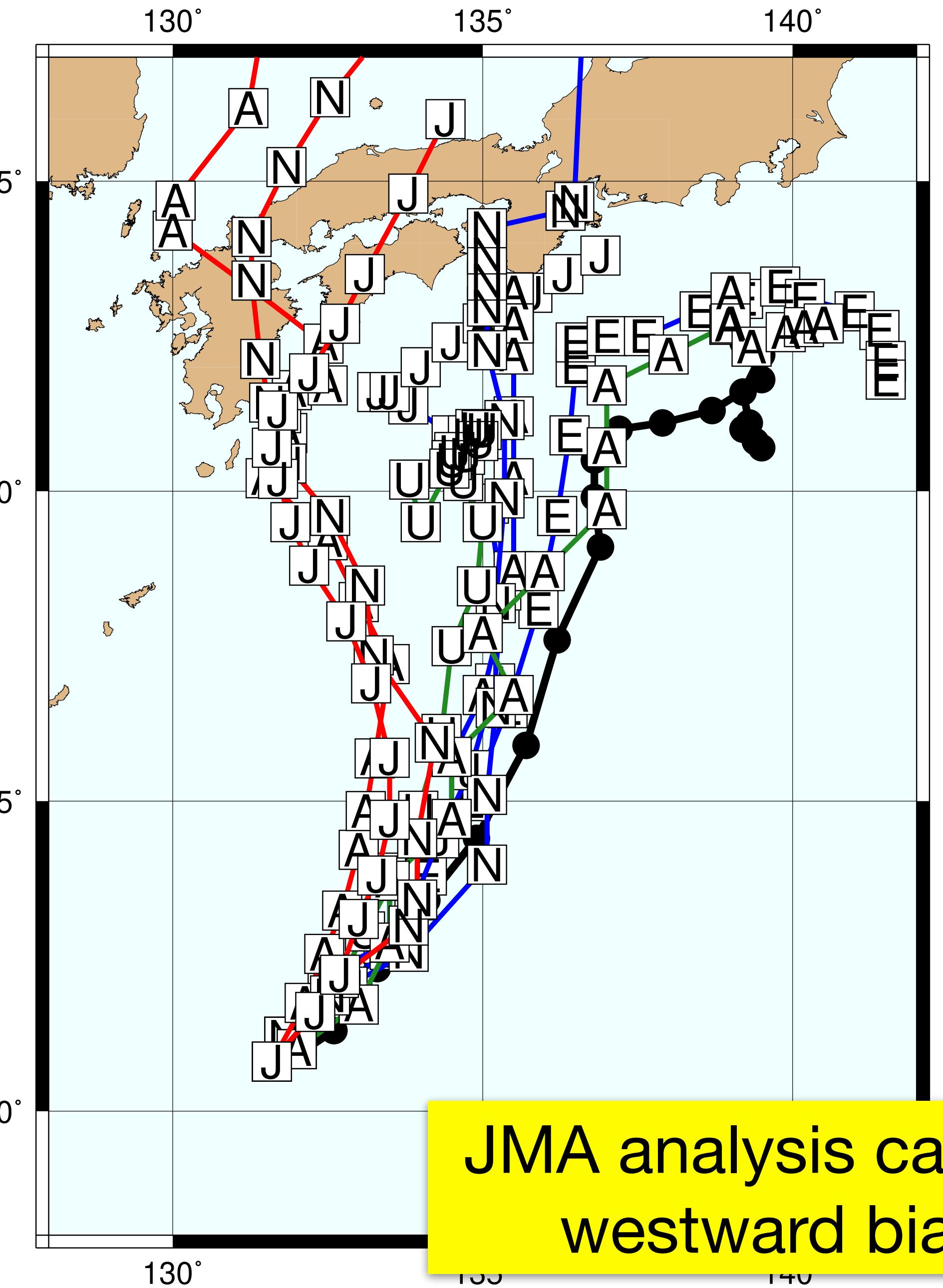


6/10 12 UTC



ECMWF TL1279L91 (~16km) NCEP T574L64 (~27km) JMA TL959L60 (~20km)

宮地哲郎

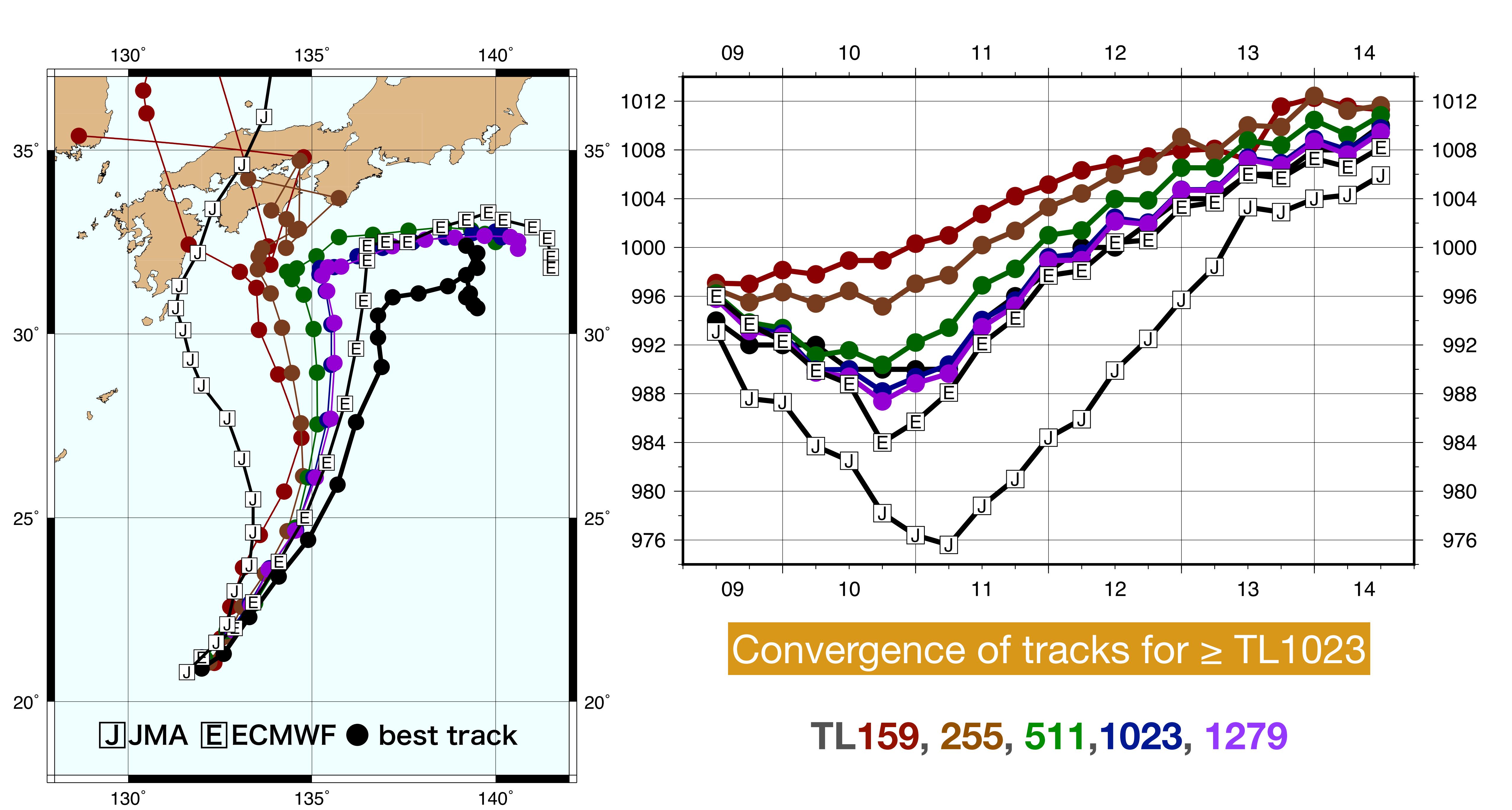


Analysis: **JMA**, **ECMWF**, **NCEP**
Models: A: AFES, E: ECMWF IFS, J: JMA GSM
 N: NICAM, U: NCEP GSM, Best track: •

Init: 12 UTC, 9 June 2013

Sensitivity to model resolution

- OpenIFS Cy40r1v2, TL159, 255, 511, 1279L60, T1279L91
- Initial condition: ECMWF operational analysis
- Initial time: 12UTC, 9 June 2013
- Time step: 3600 s (TL159L60), 2700 s (TL255L60),
1200 s (TL511L60), 600 s (TL1279L60, 91)
- Kyoto University Supercomputer System A (Xeon Phi Knights Landing)



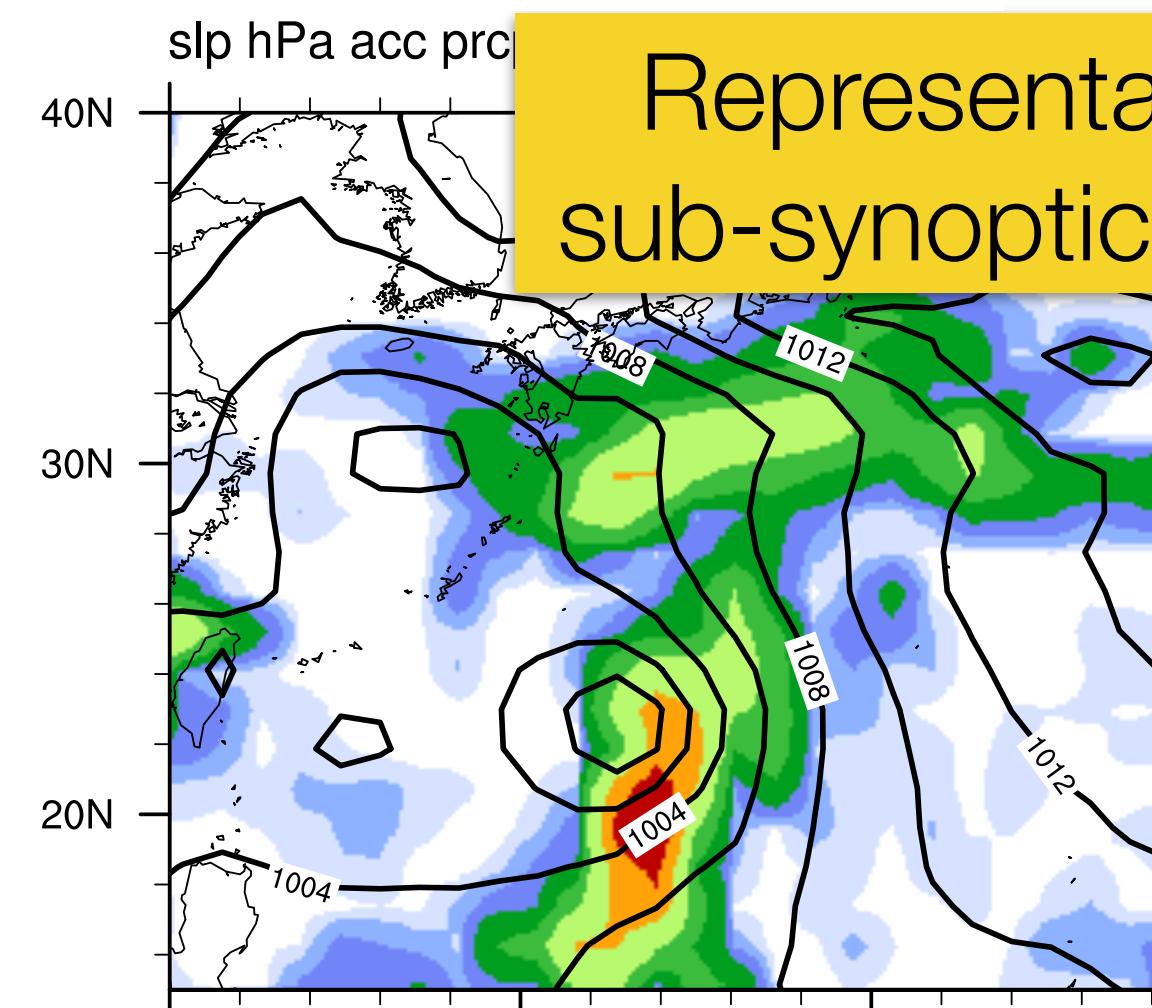
6 h-accumulated
precipitation mm

sea-level
pressure hPa

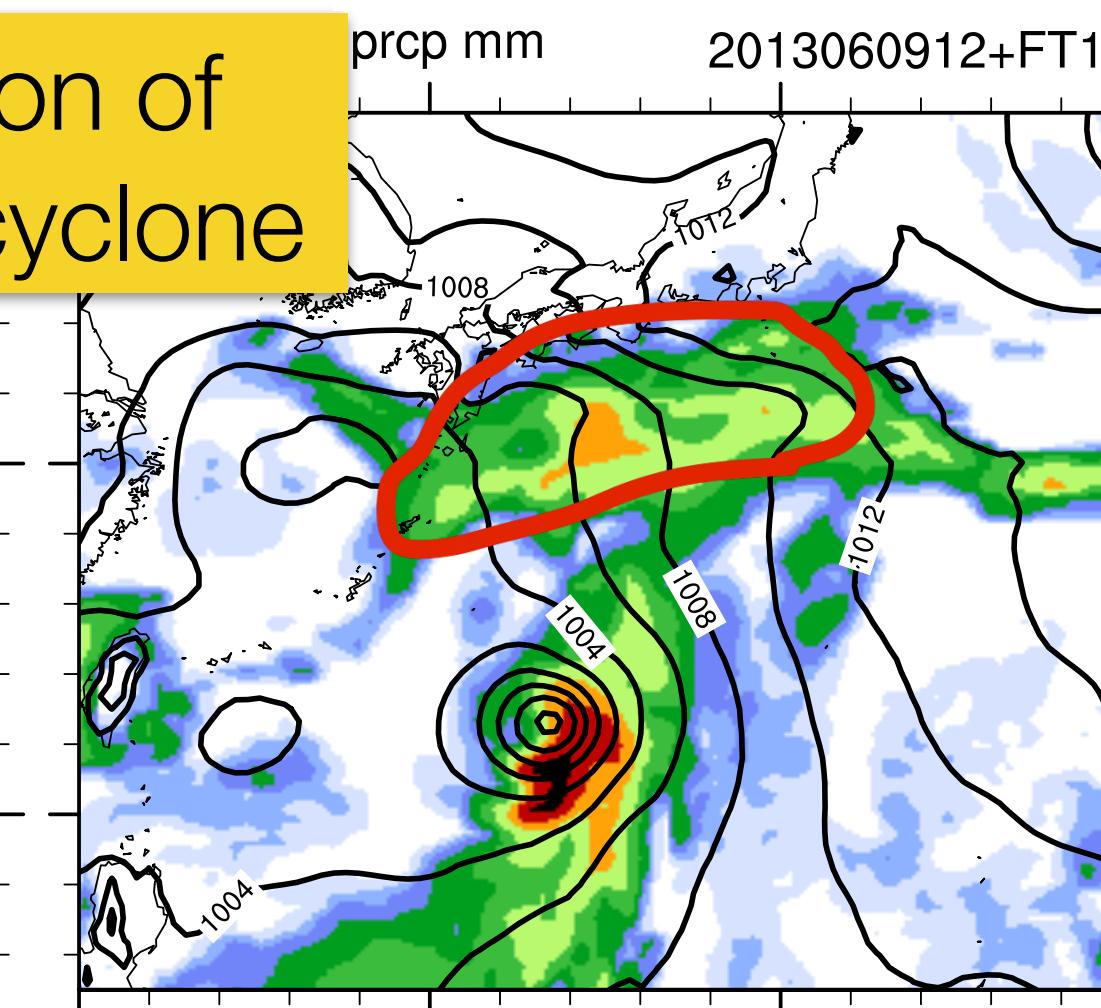
Init: 12 UTC, 9
June 2013

FT12

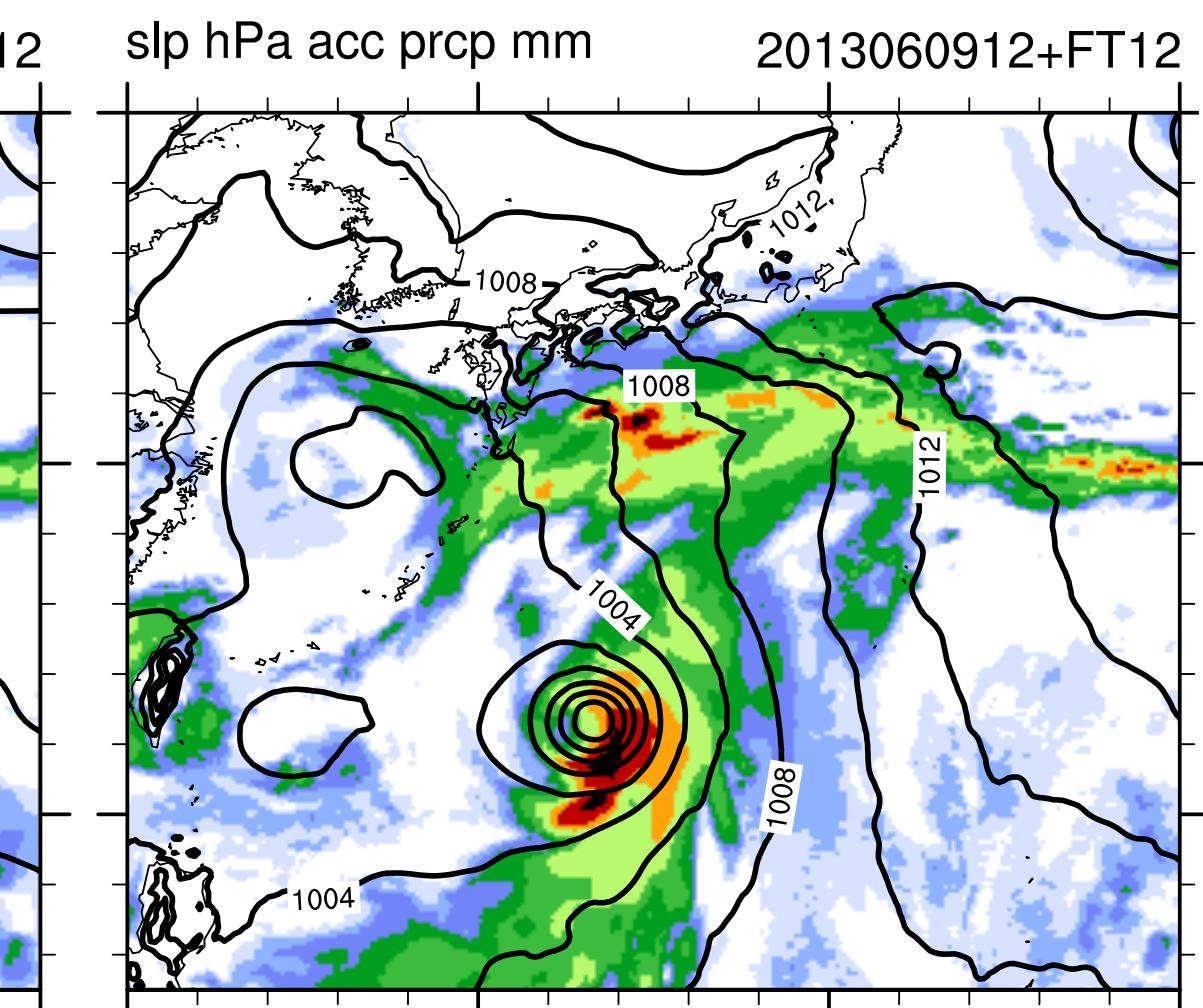
TL159L60



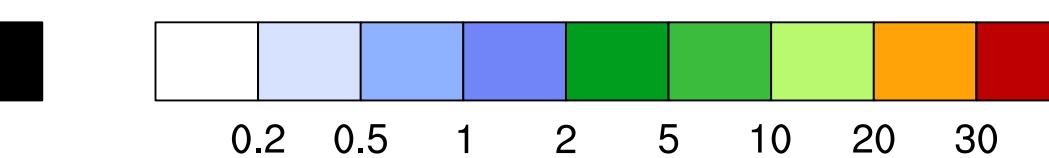
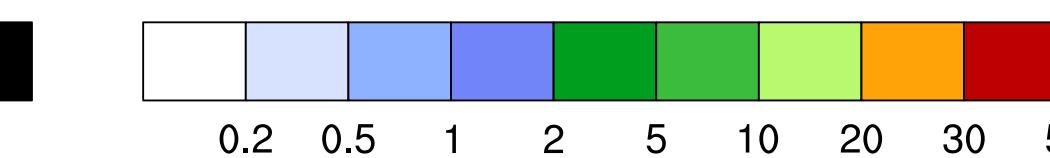
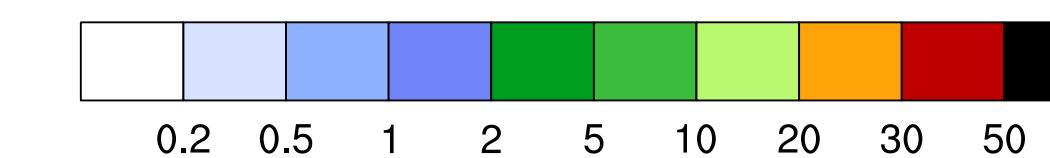
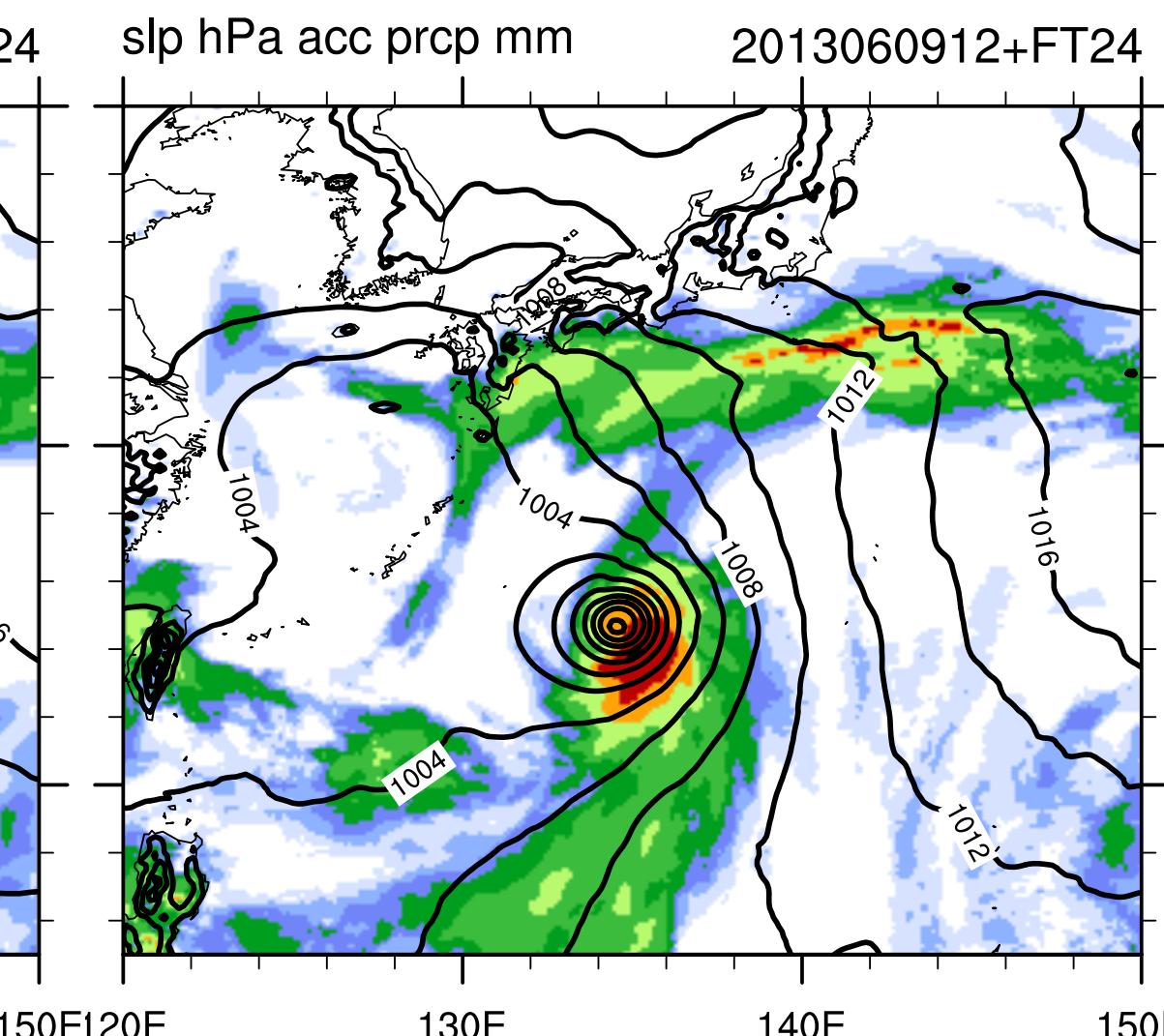
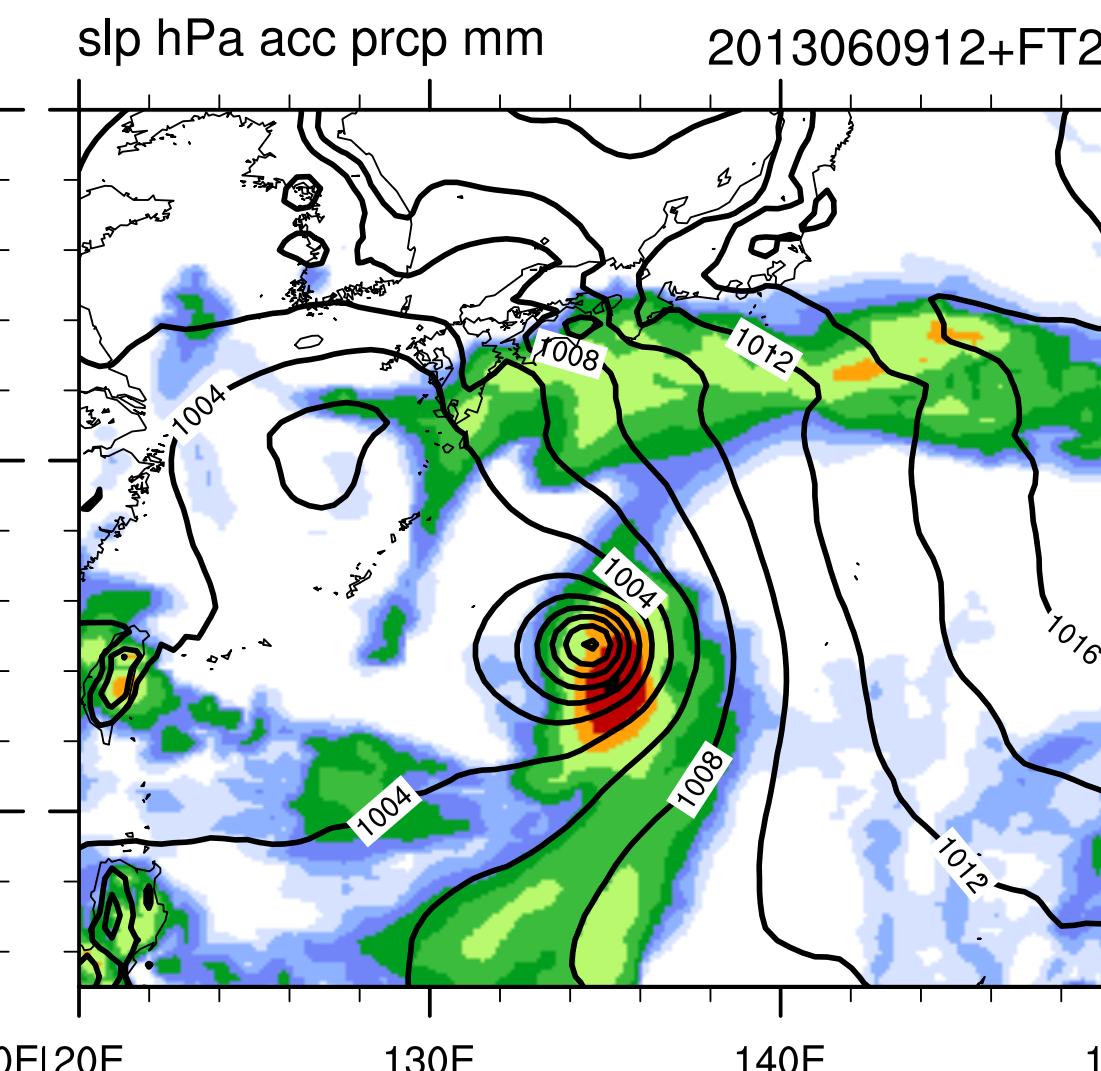
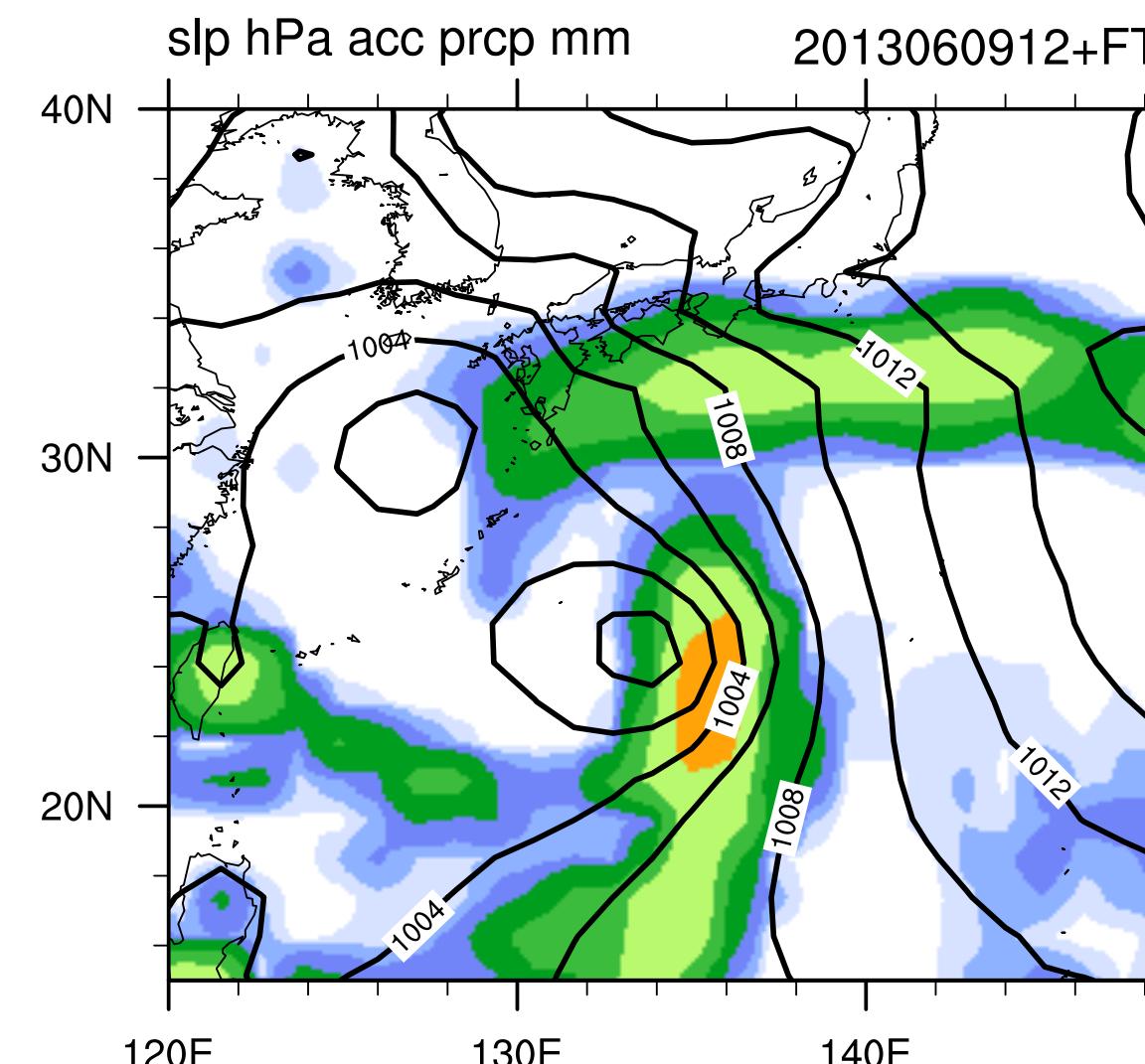
TL511L60



TL1279L60



FT24



CONTOUR FROM 994 TO 1030 BY 2

CONTOUR FROM 992 TO 1030 BY 2

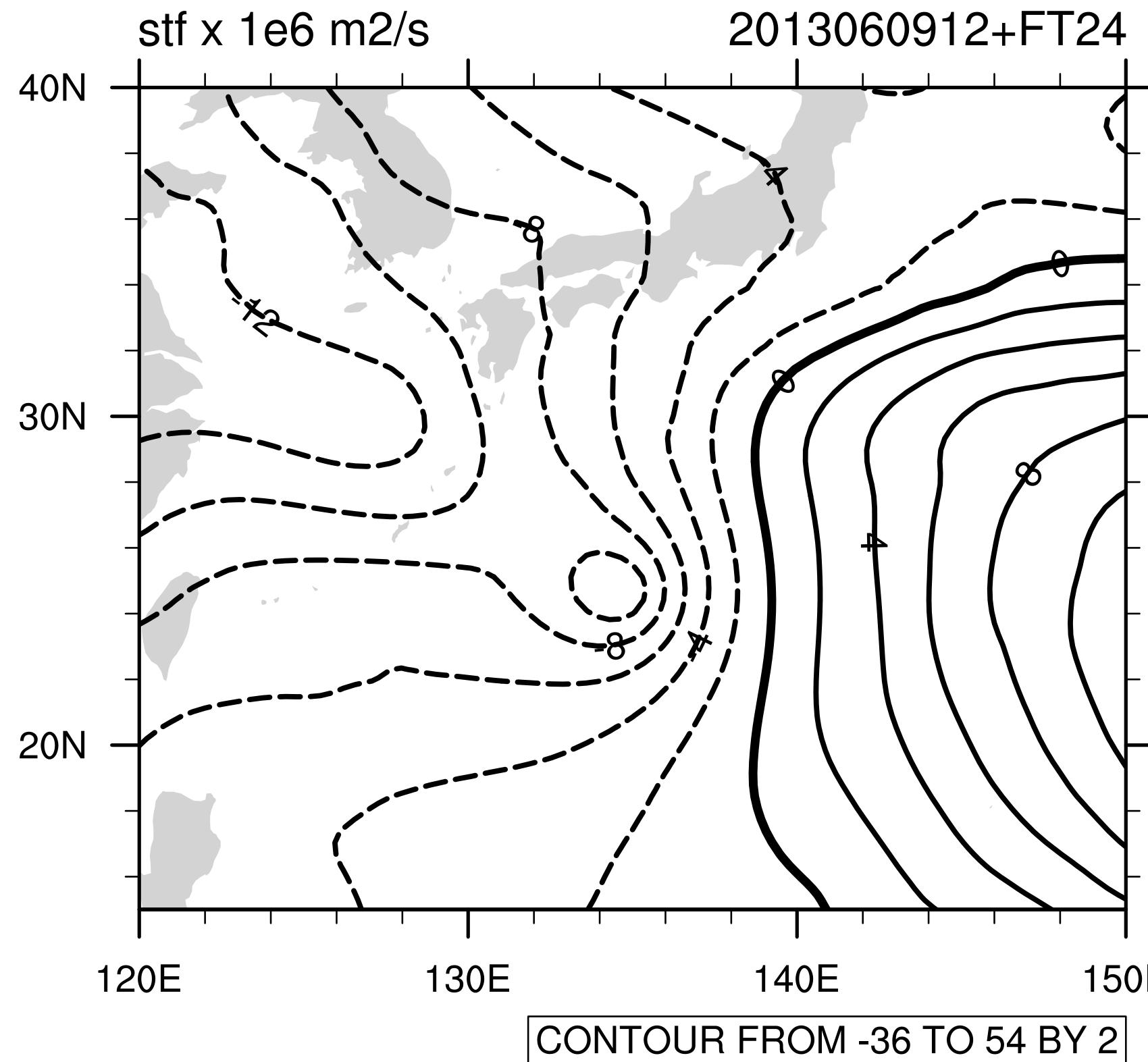
CONTOUR FROM 990 TO 1030 BY 2

700 hPa stream function

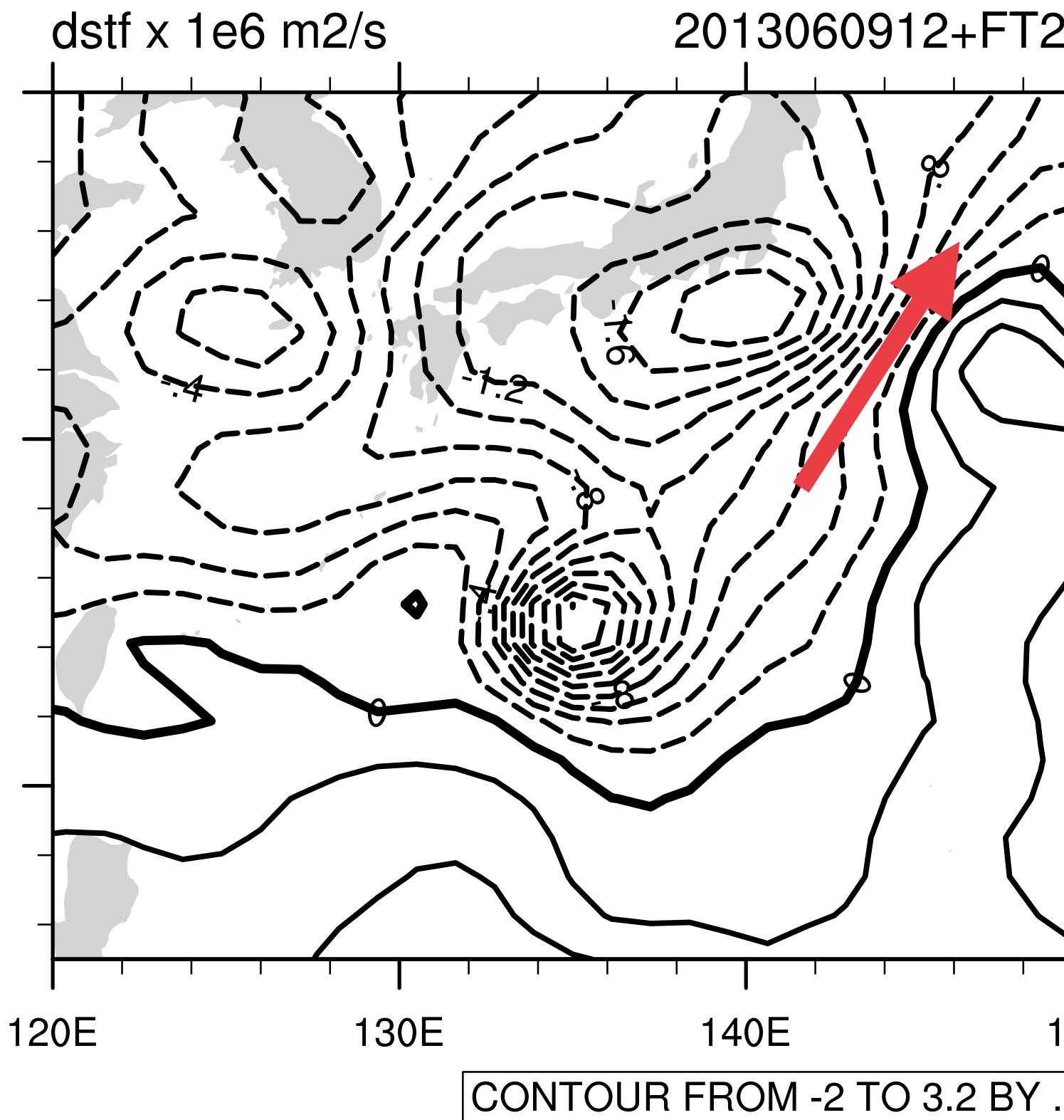
Init: 12 UTC, 9
June 2013

FT24

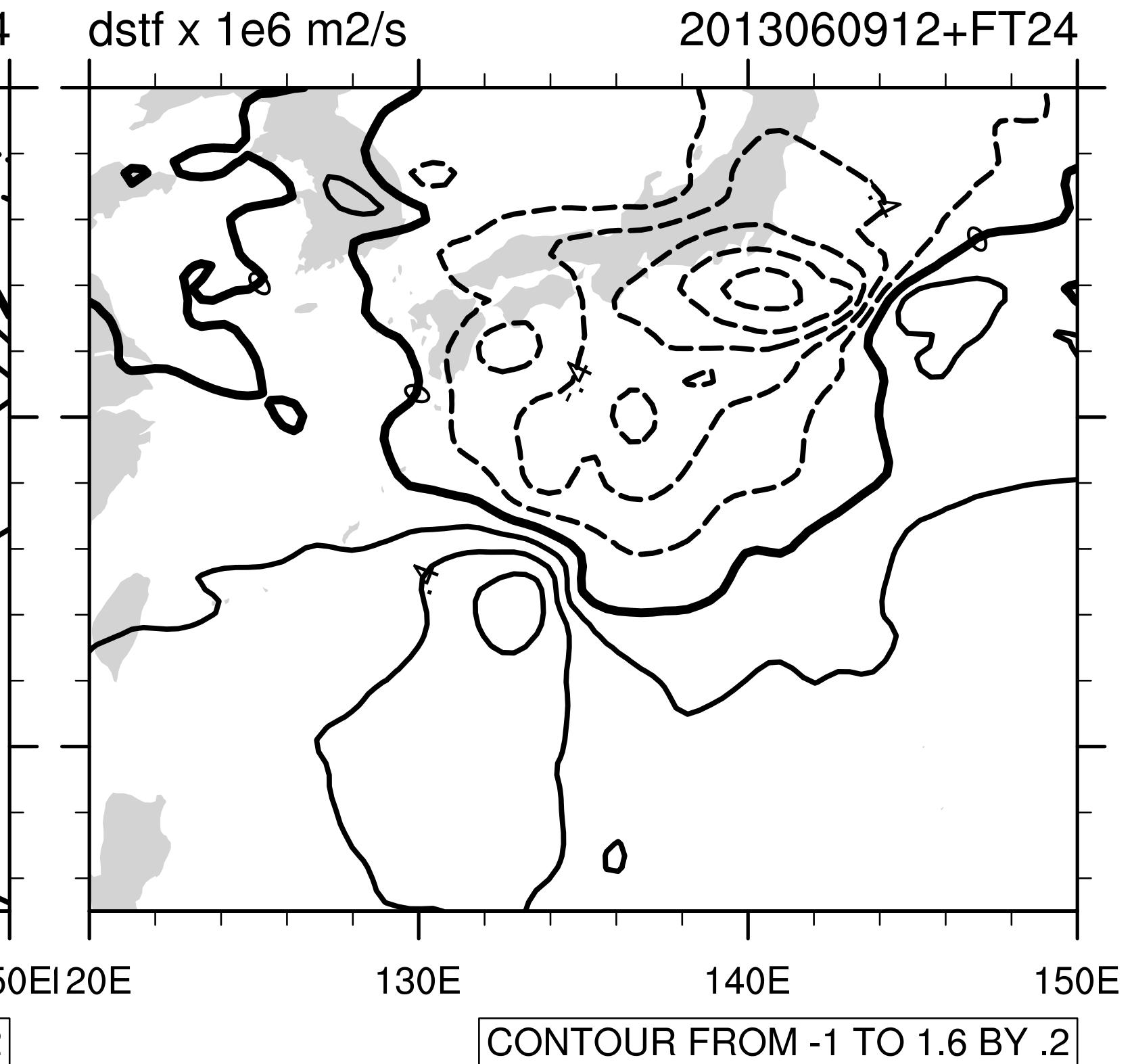
TL1279L91



TL1279L91-TL159L60



TL1279L91-TL511L60



300 hPa Z gpm
wind speed m/s

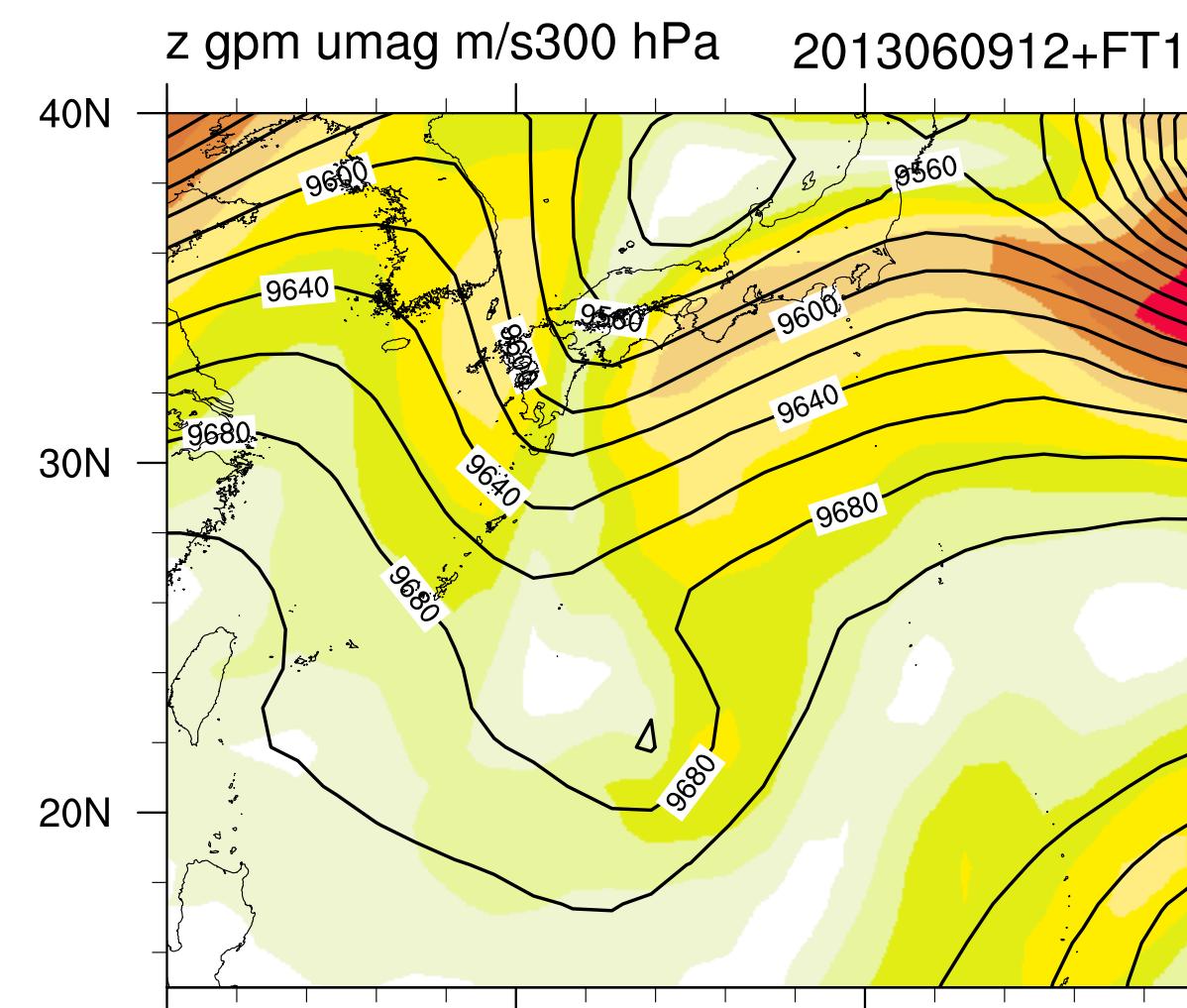
TL159L60

**Init: 12 UTC, 9
June 2013**

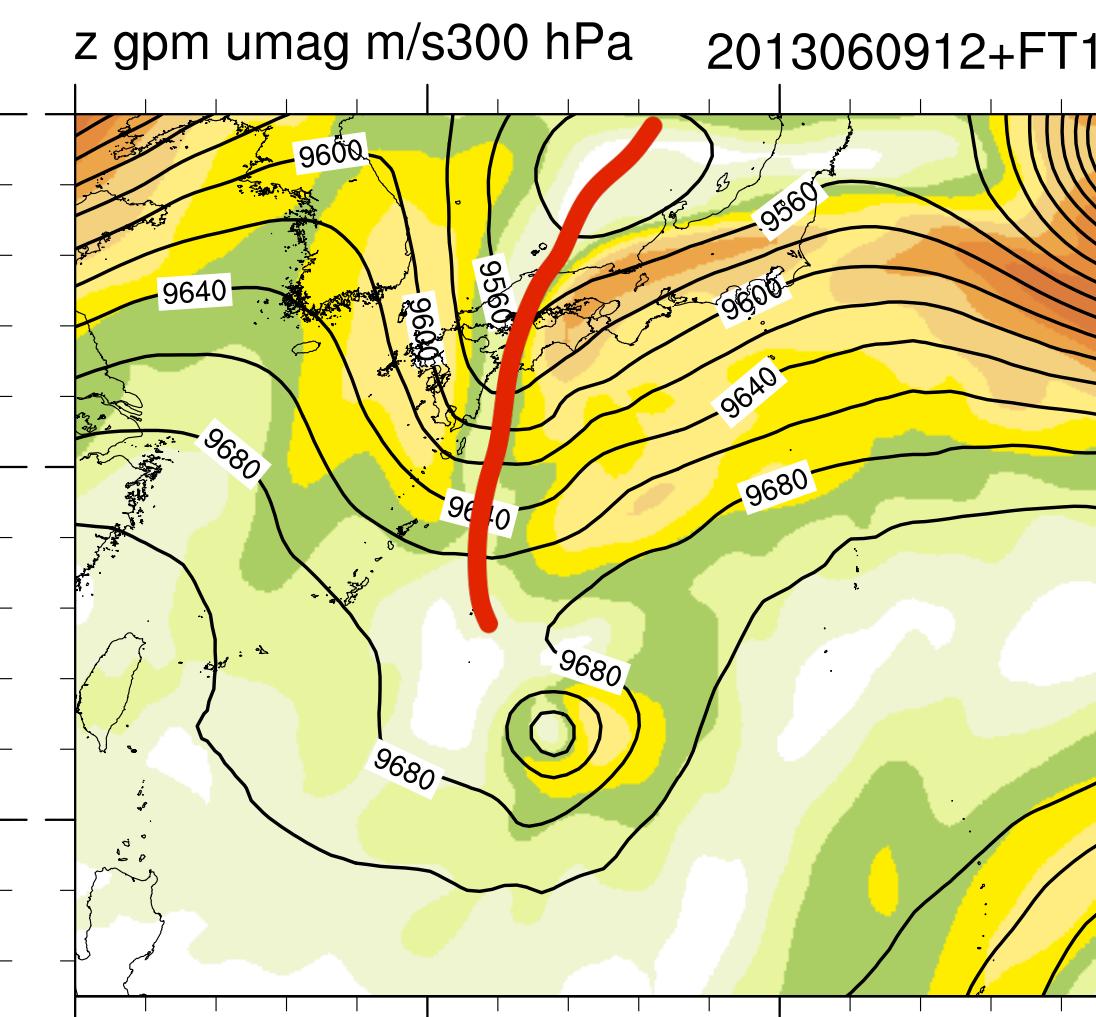
TL511L60

TL1279L60

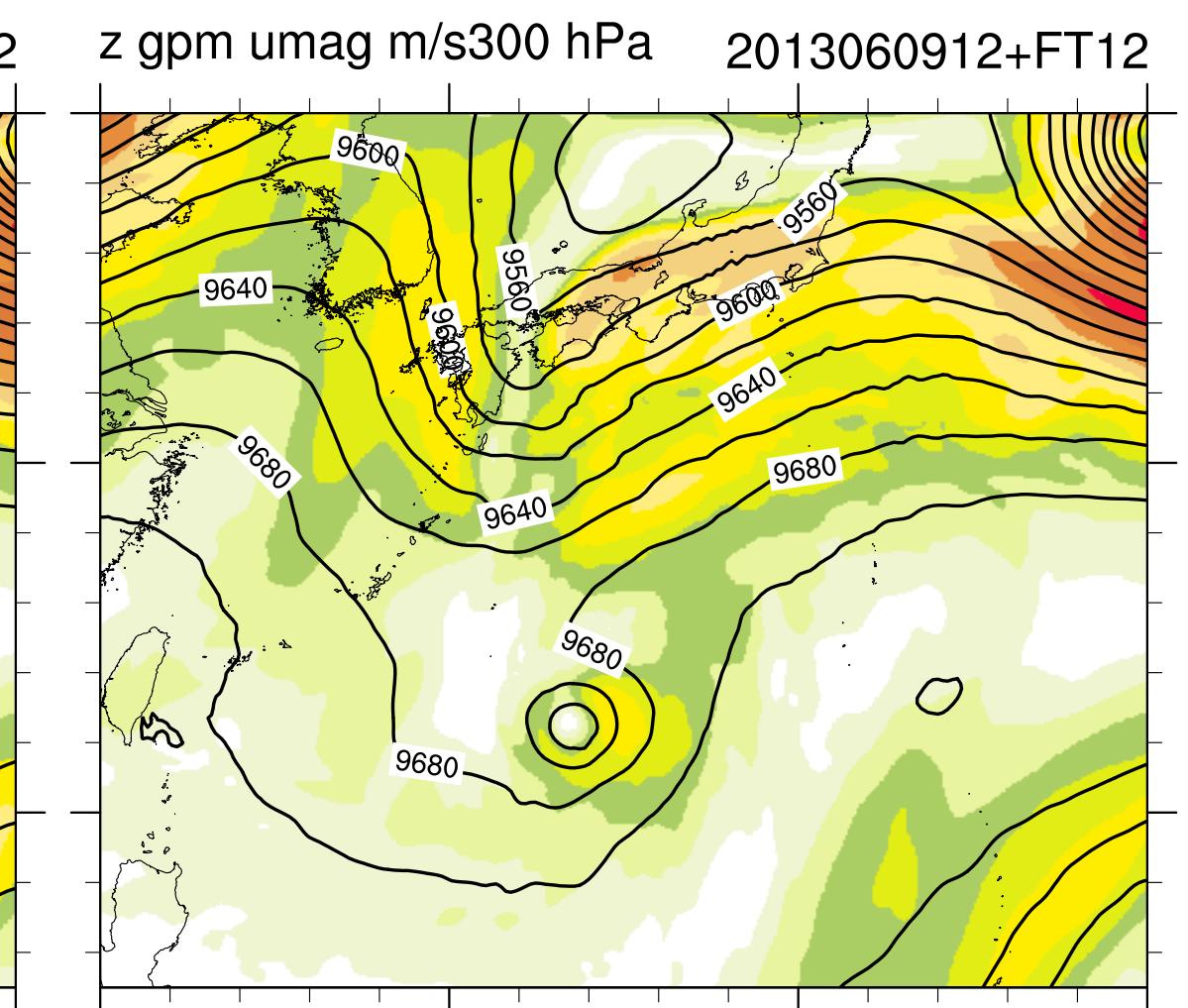
FT12



40r1v2 TL159L60

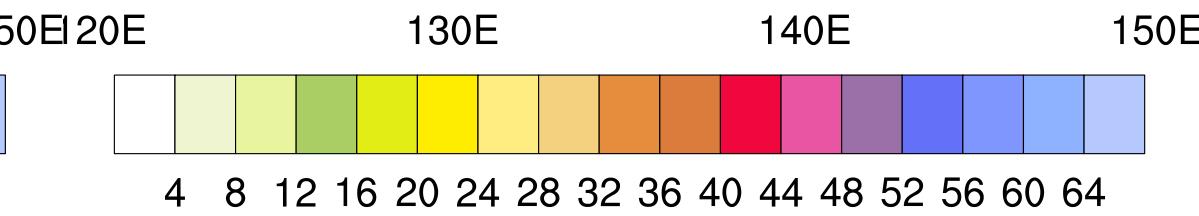
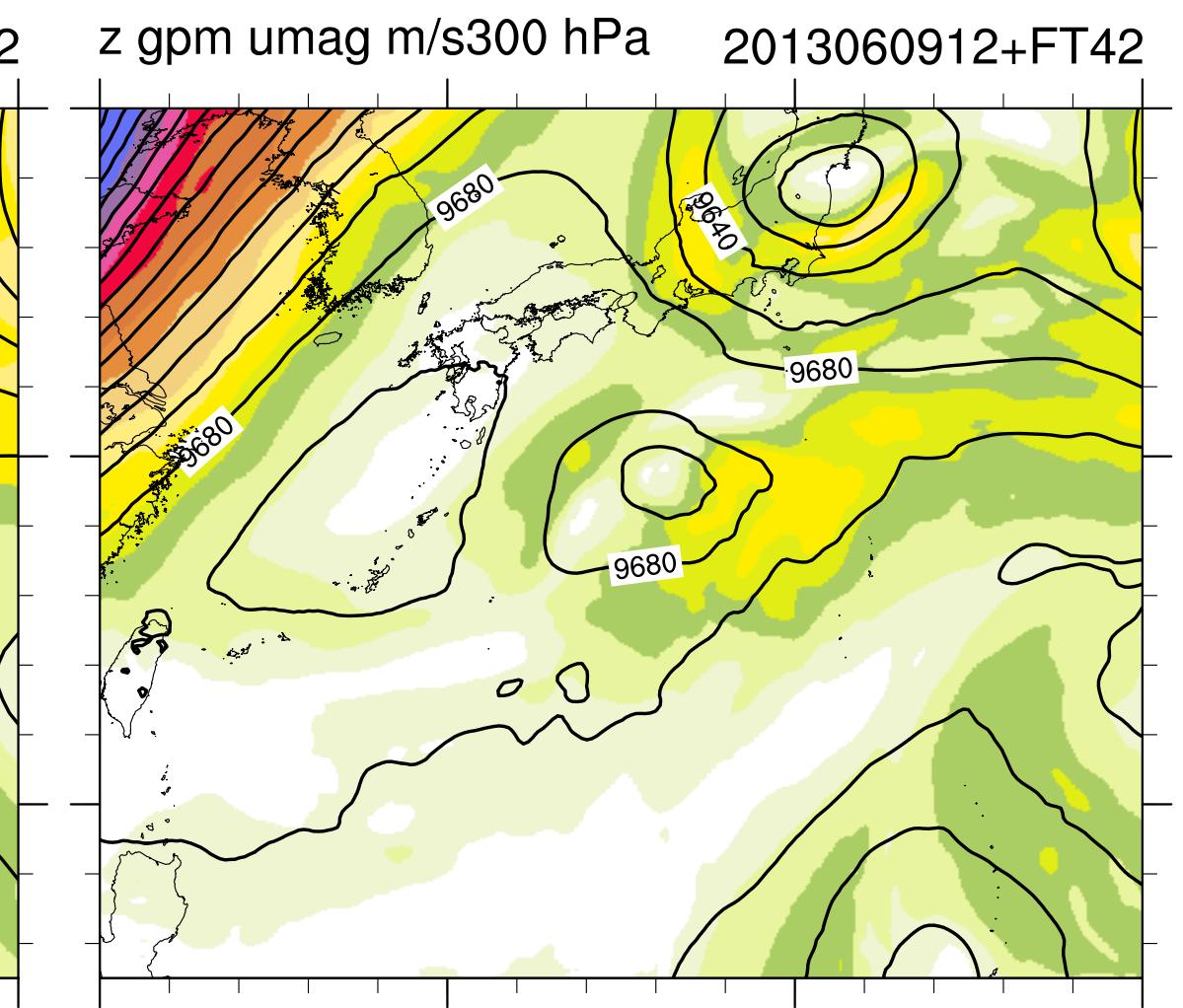
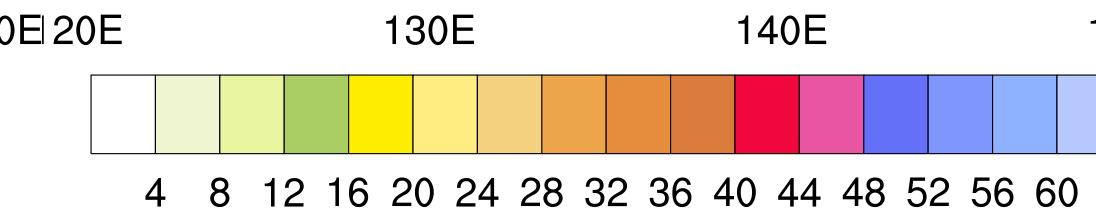
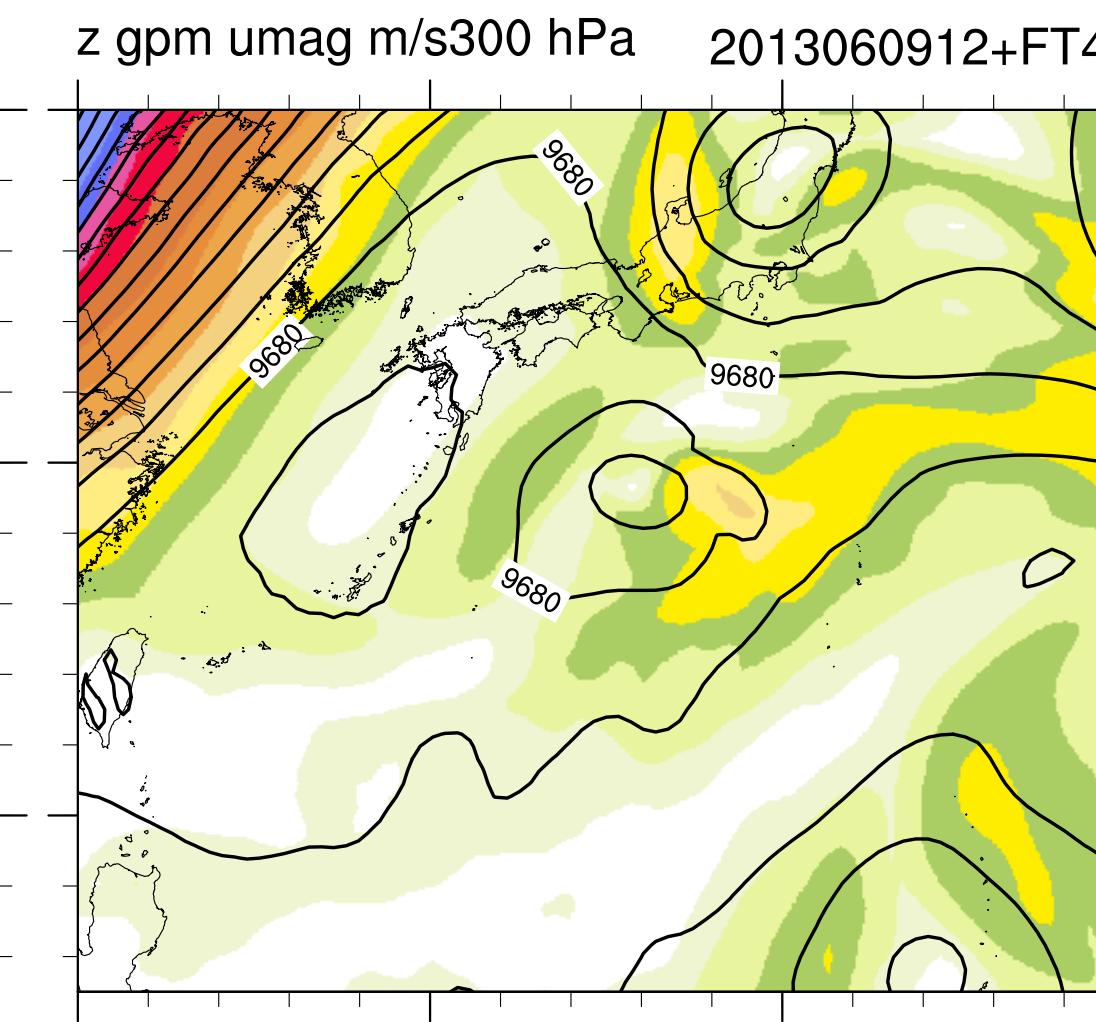
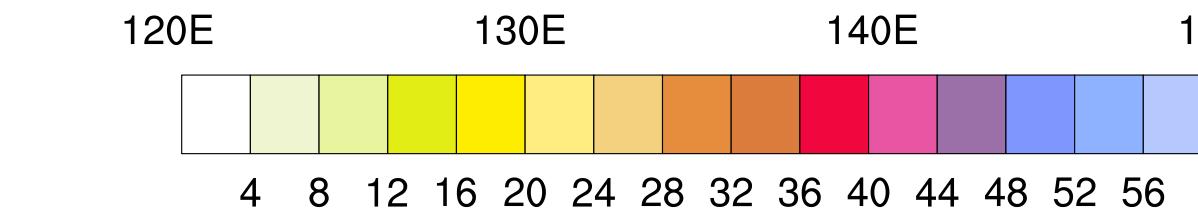
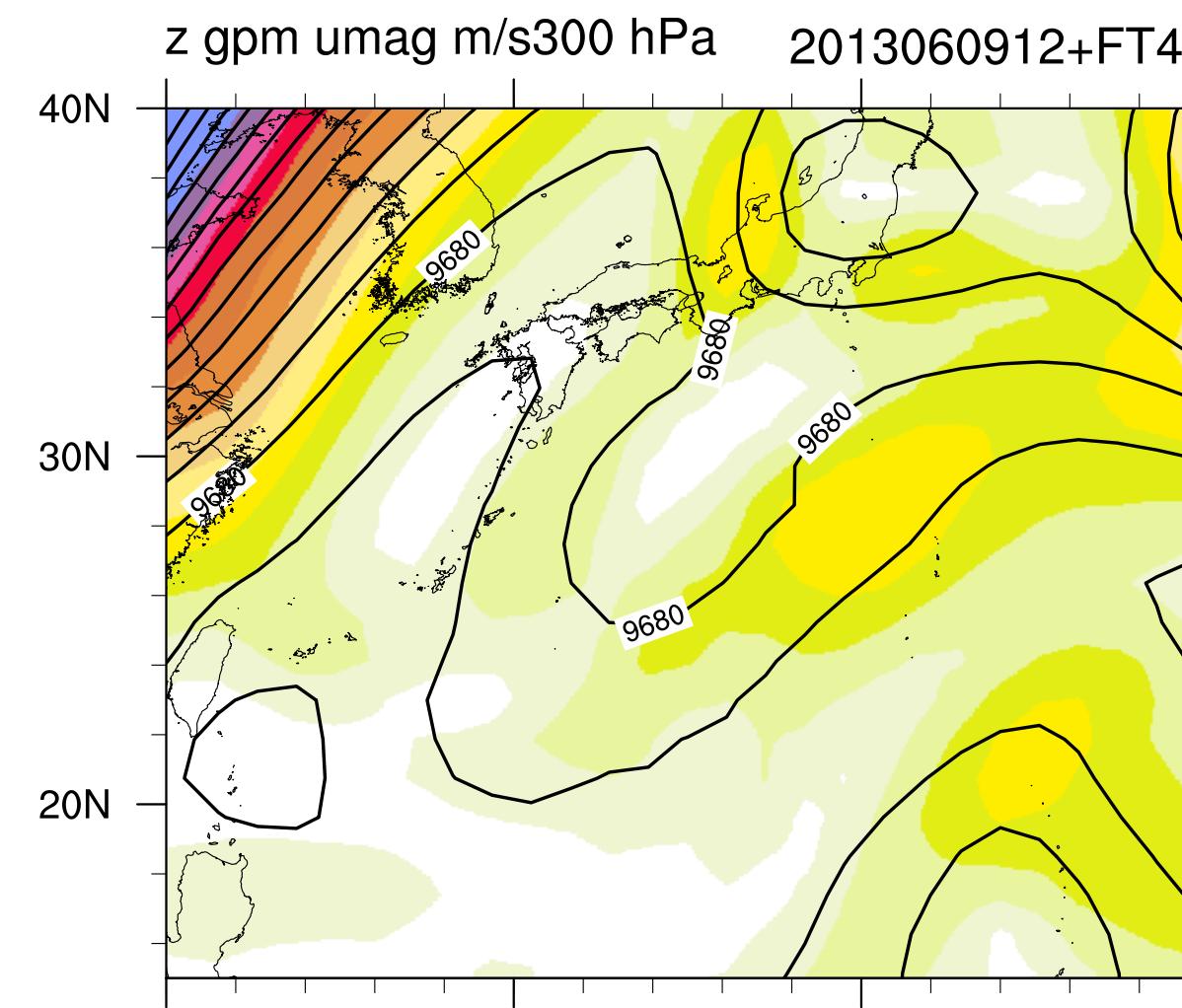


40r1v2 TL511L60



40r1v2 TL1279L60

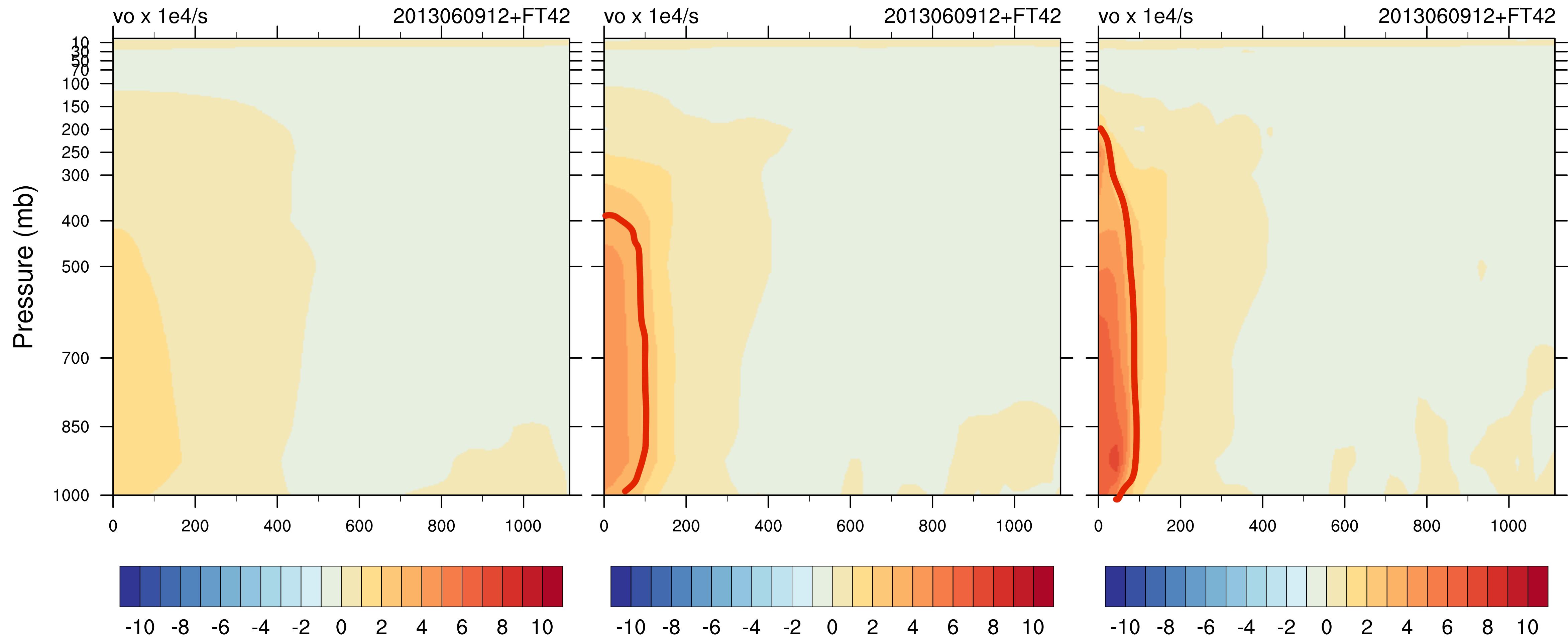
FT42



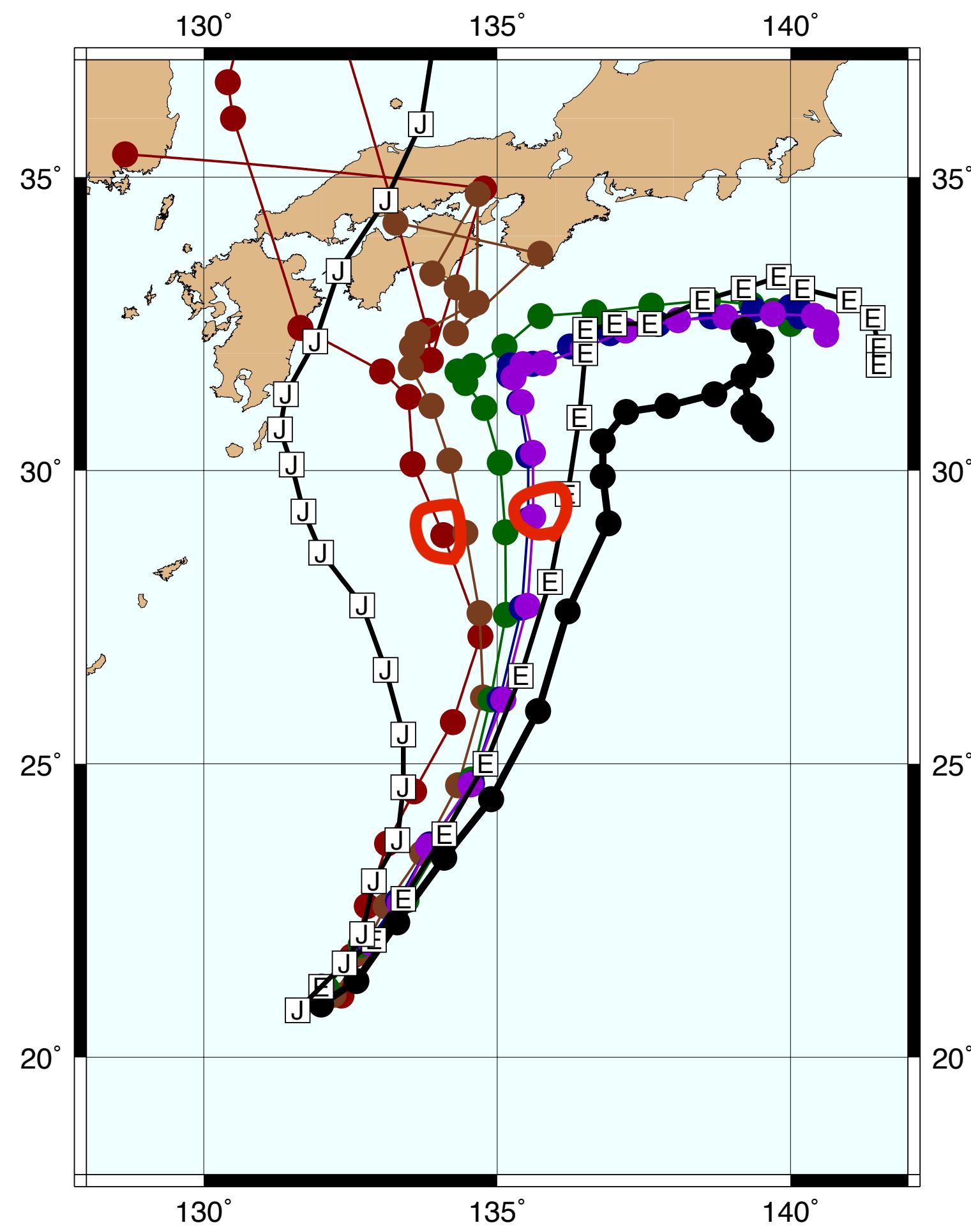
Axisymmetric vorticity

FT42

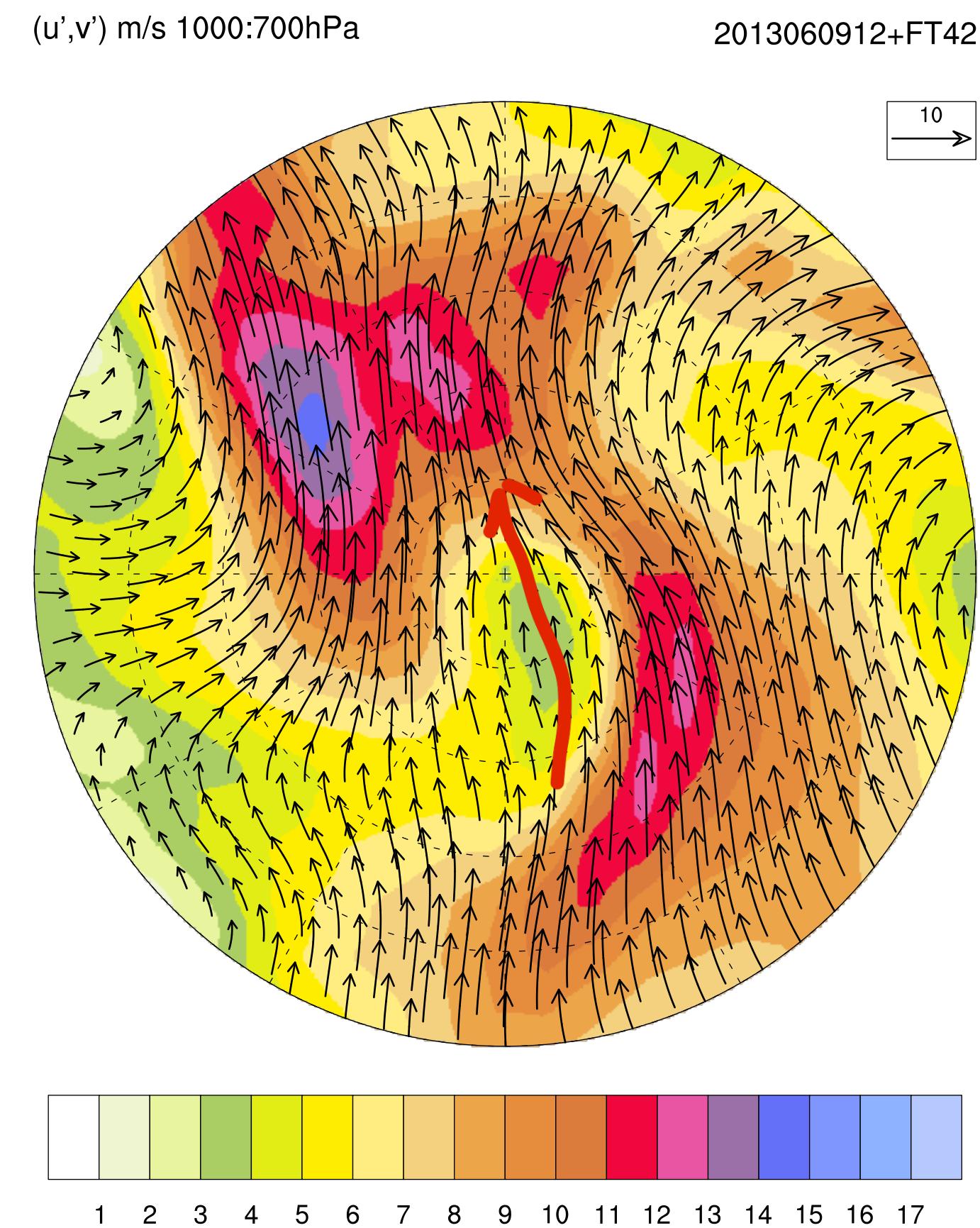
TL159L60



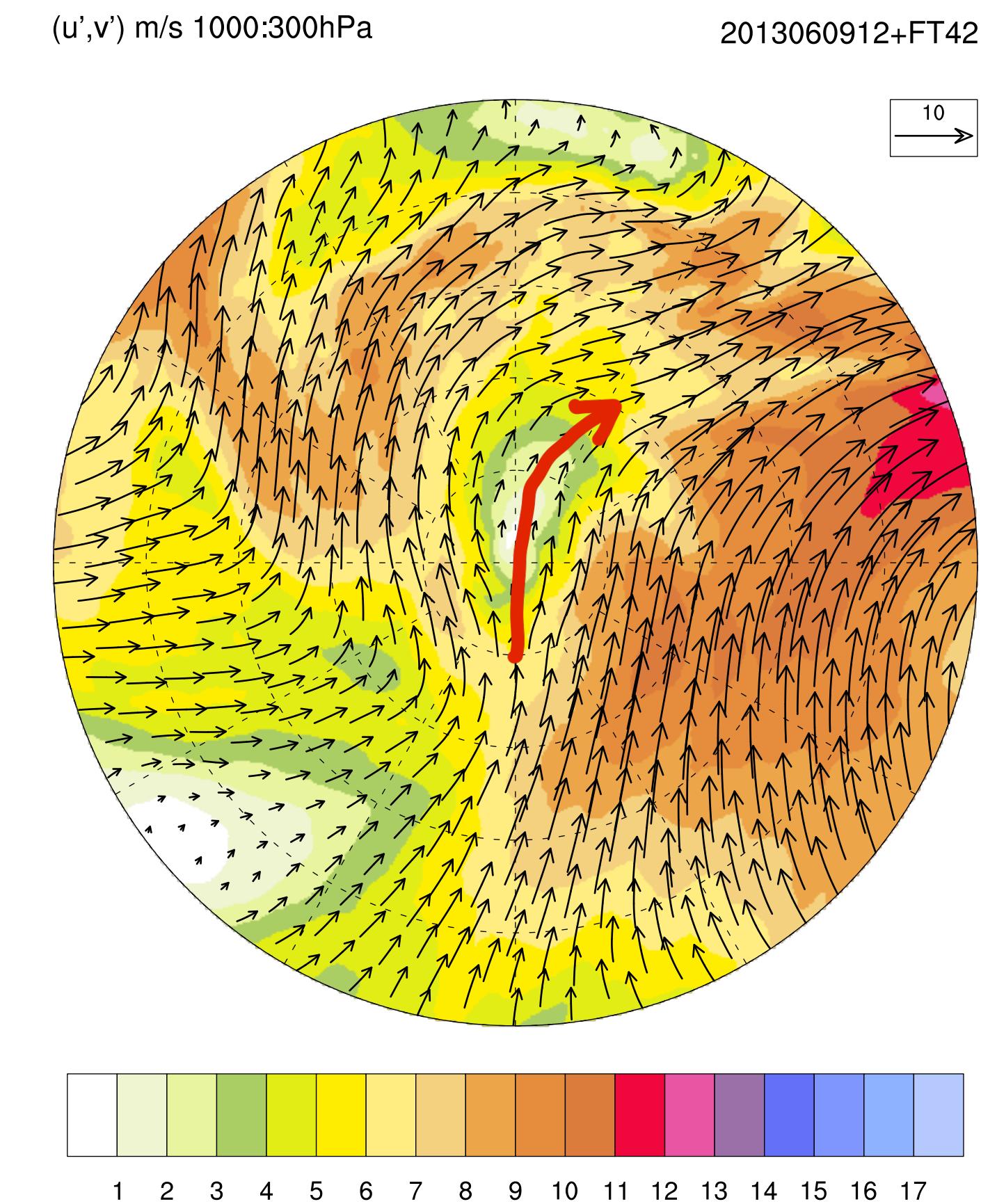
Axis non-symmetric winds



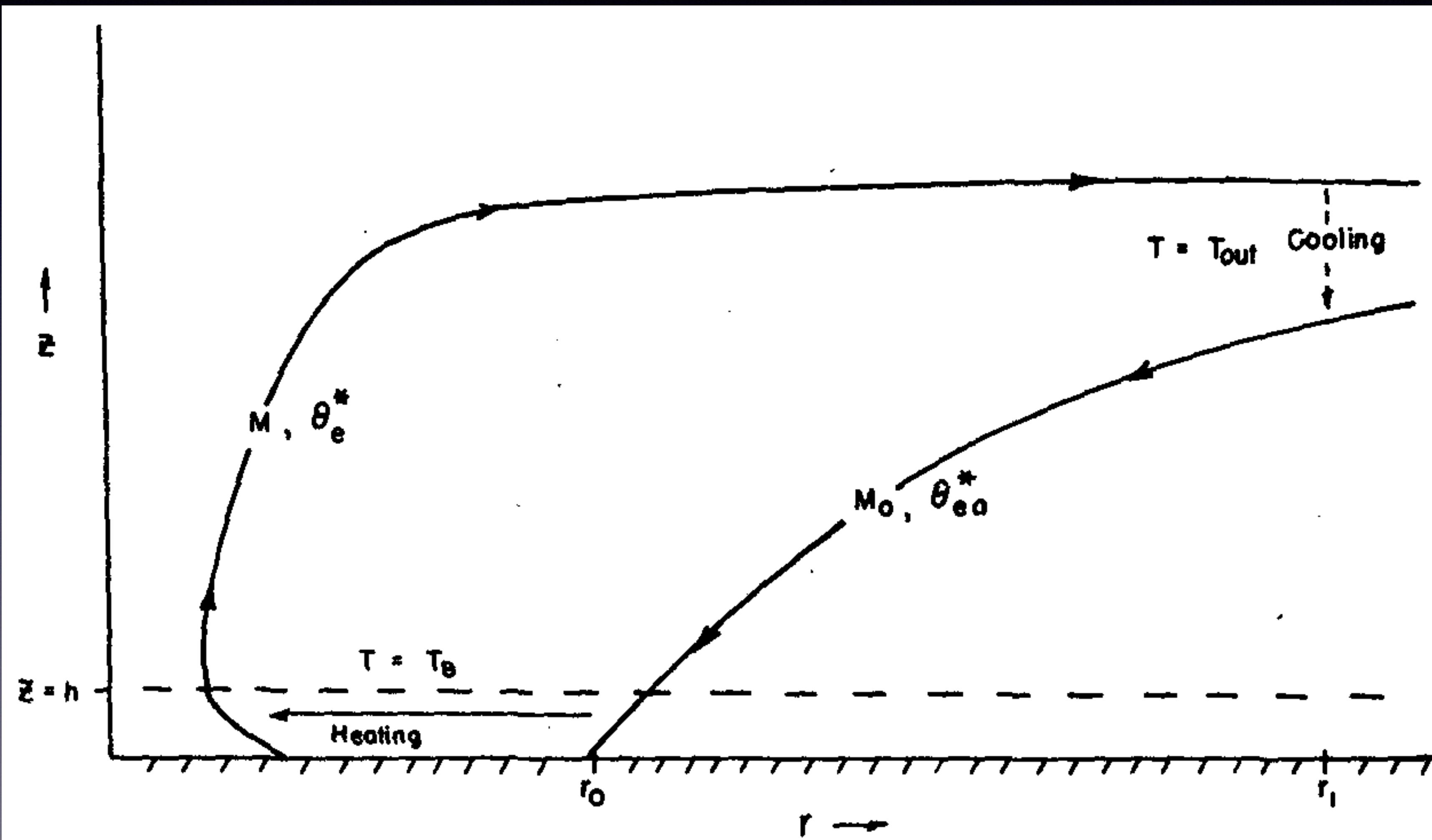
**TL159L60
1000:700hPa**



**TL1279L60 FT42
1000:300hPa**



Tropical cyclone as a Carnot heat engine

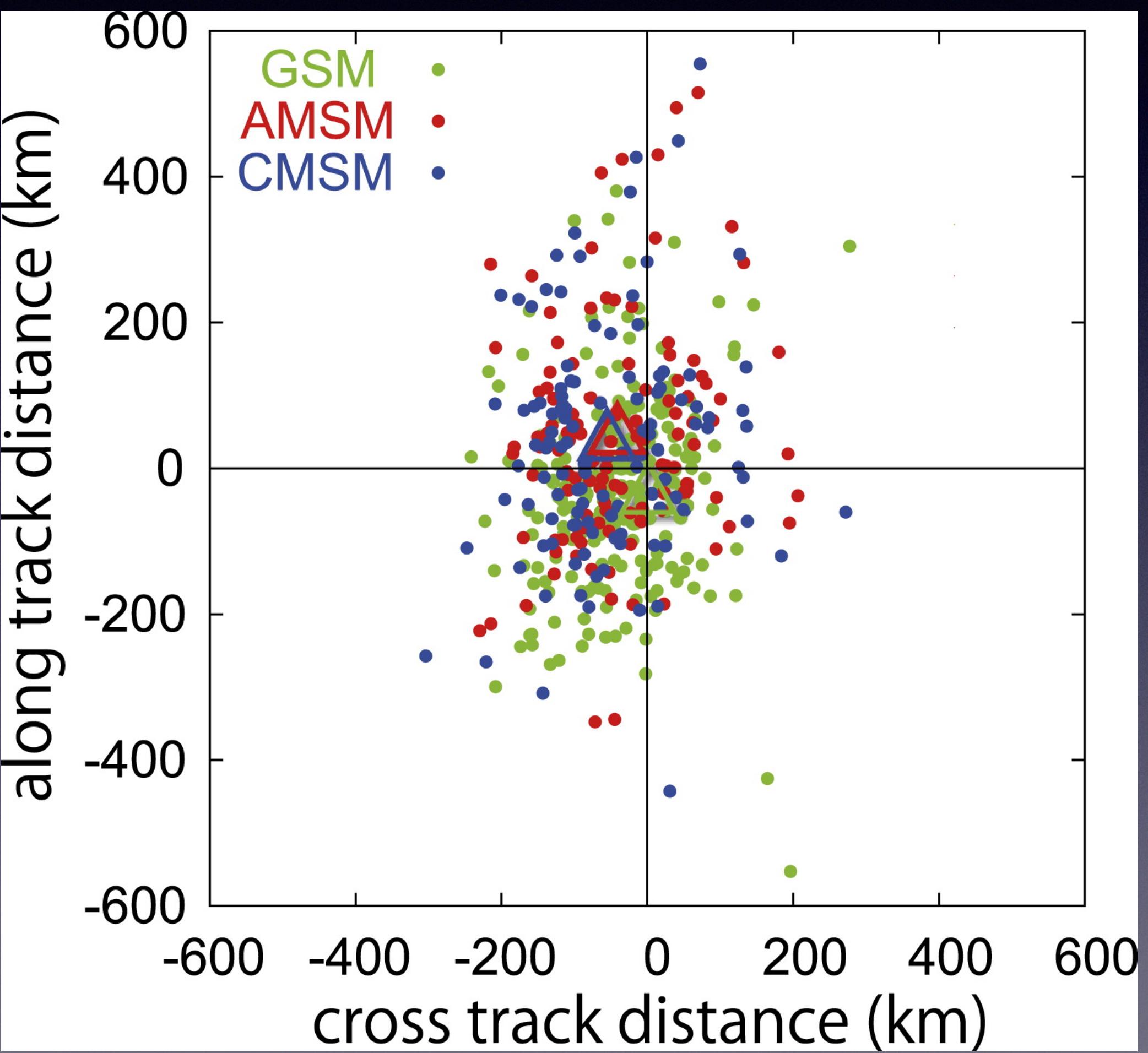


ocean

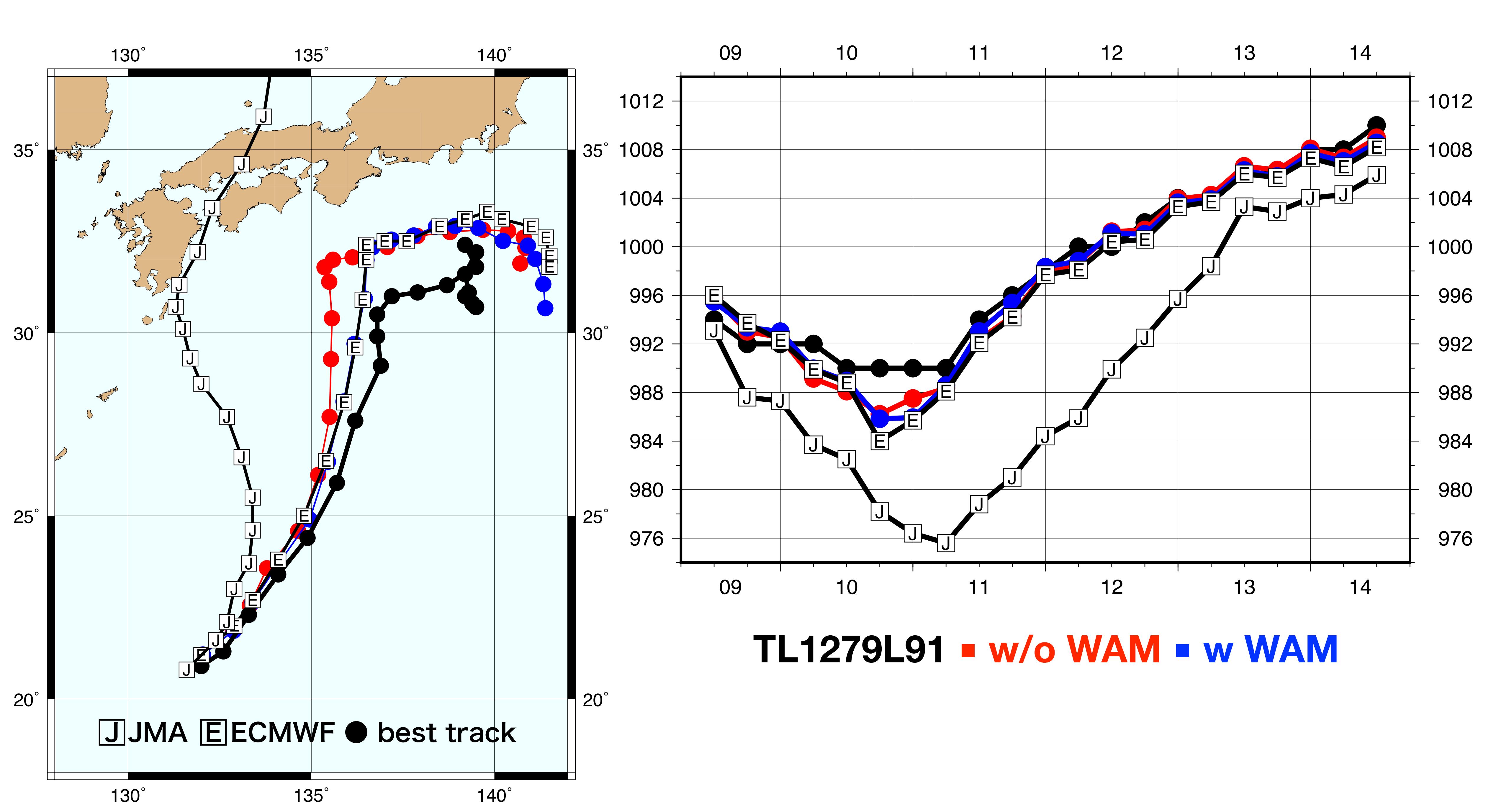
radiation

Emanuel 1986

大気海洋結合の効果



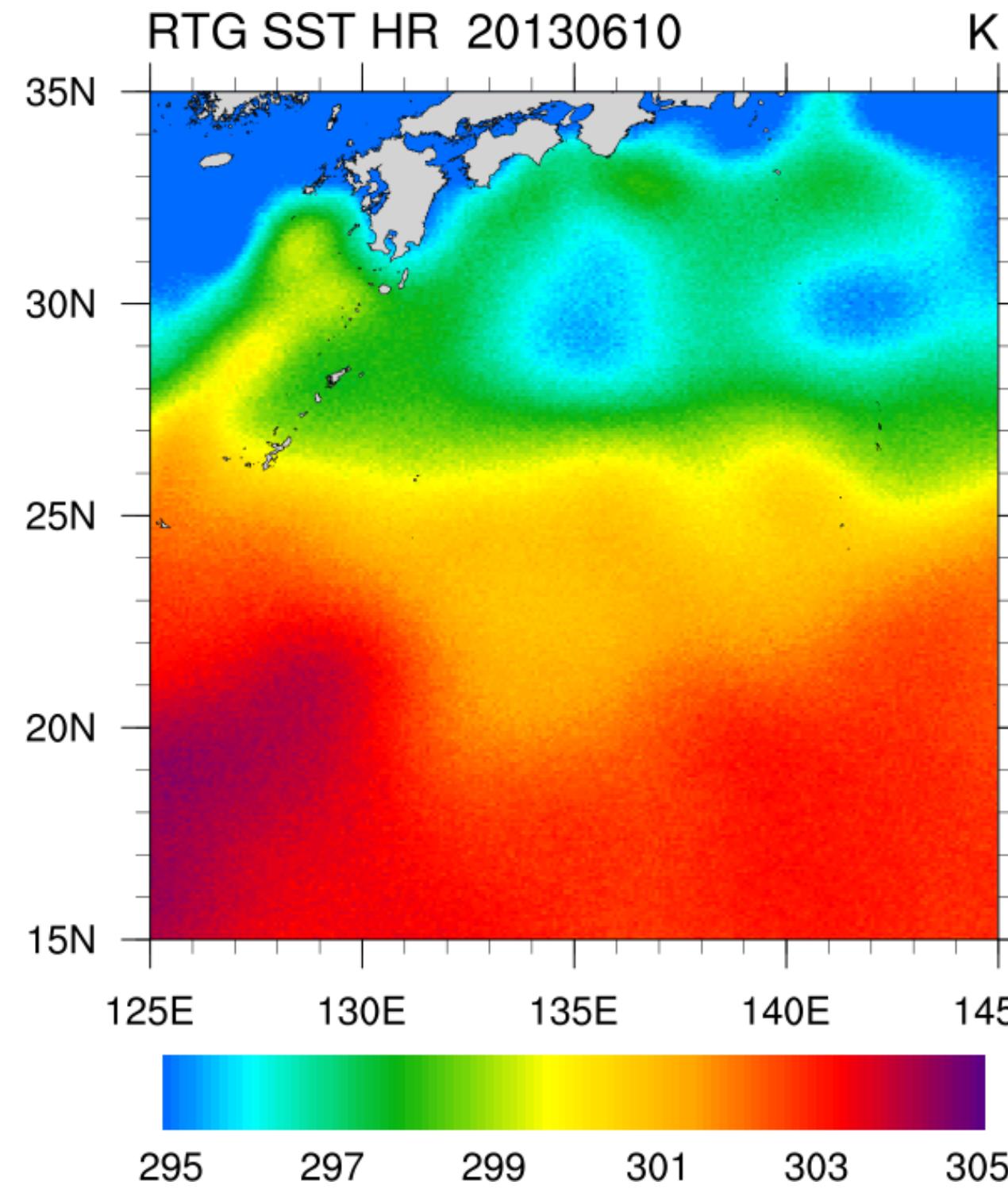
Ito et al. 2015



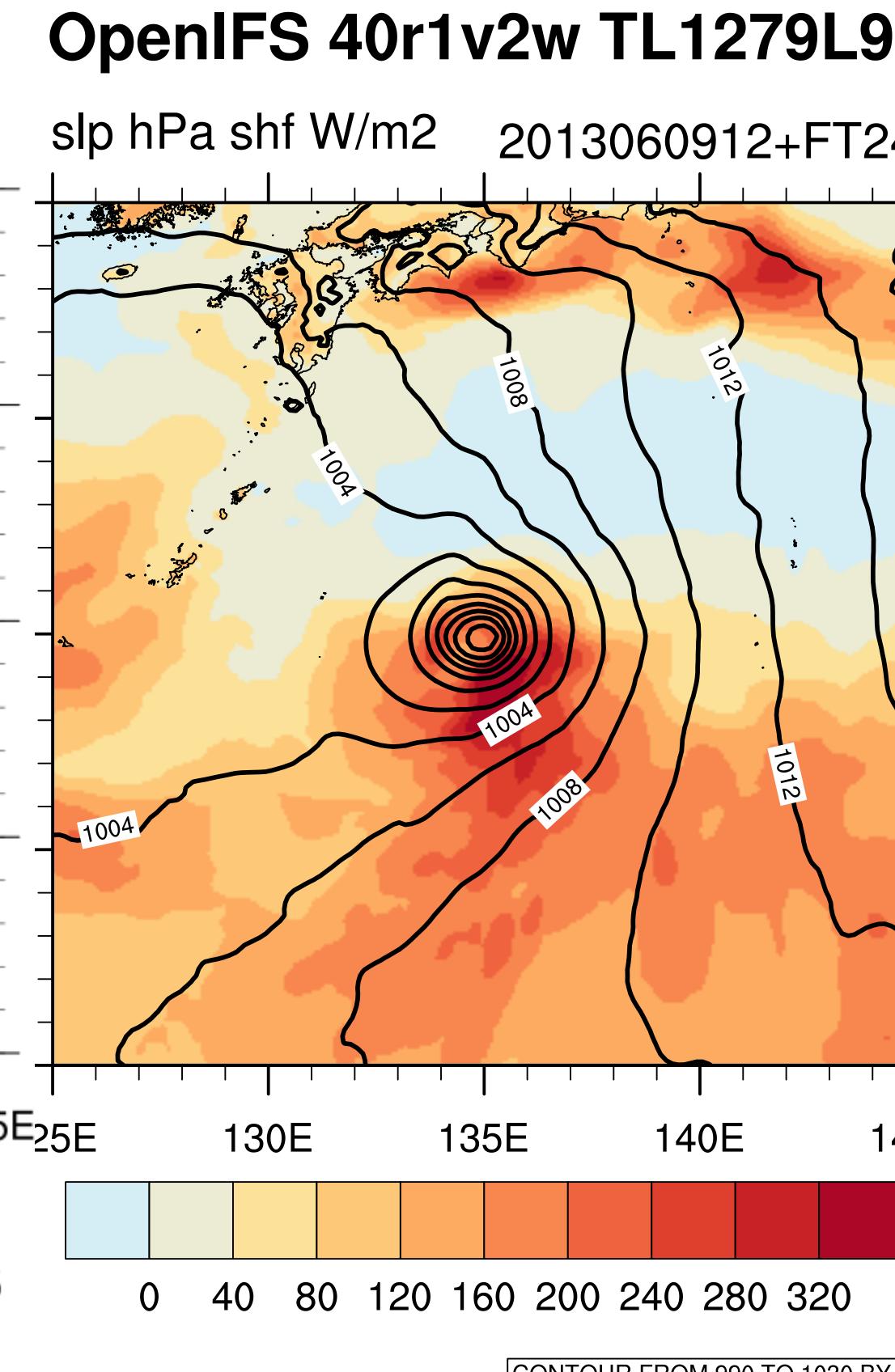
Sea-surface flux

FT24

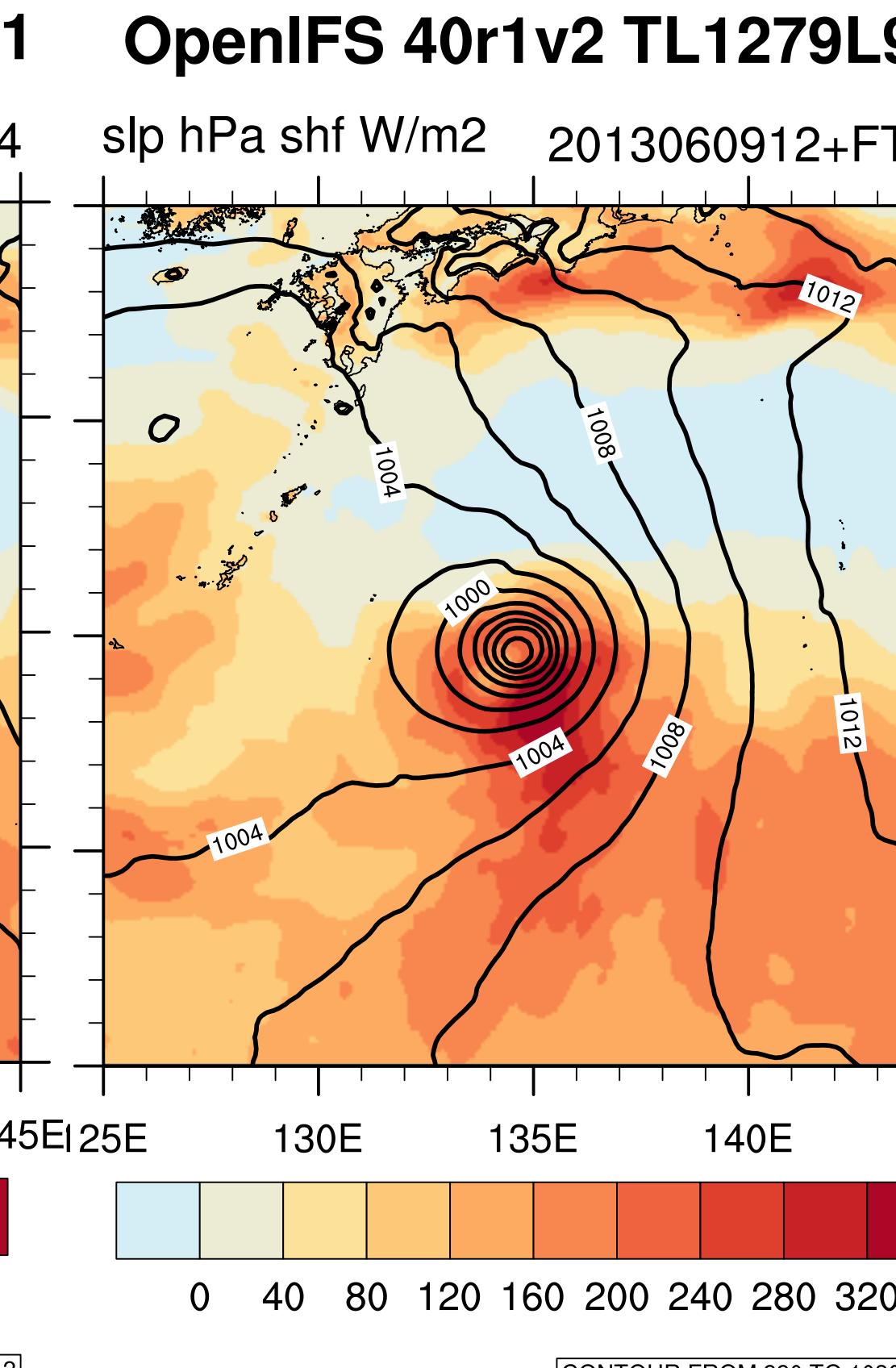
RTG SST HR



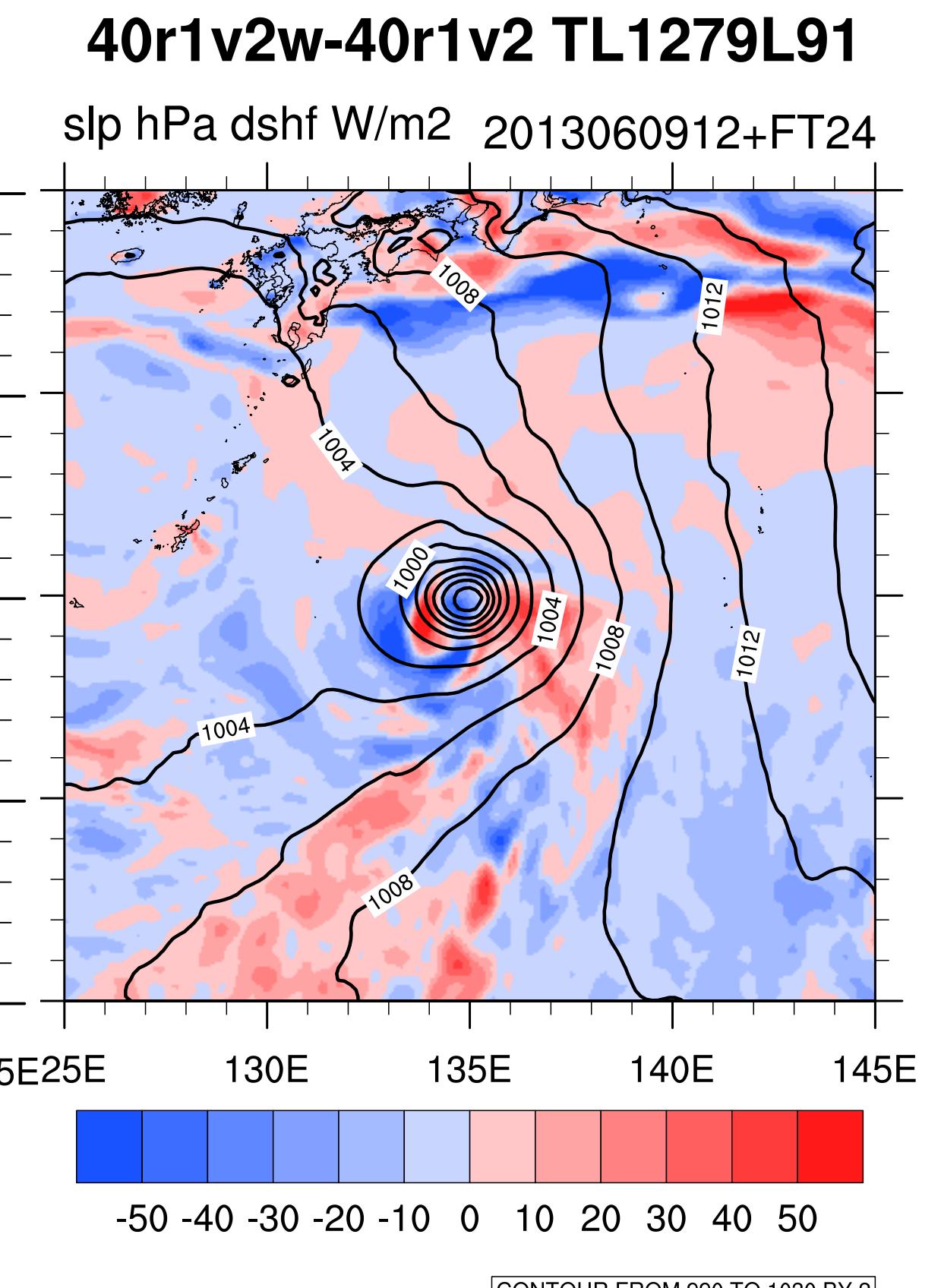
w WAM



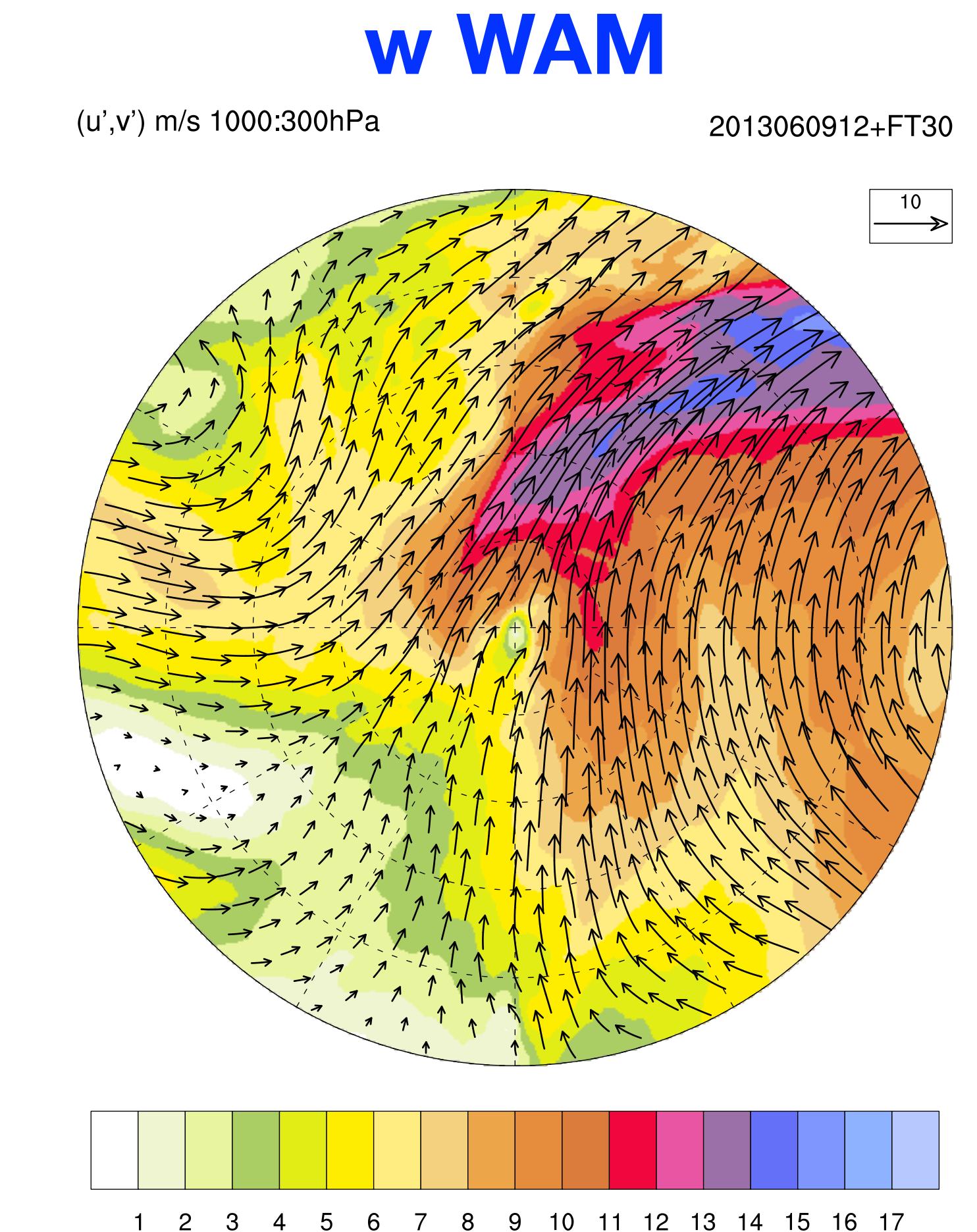
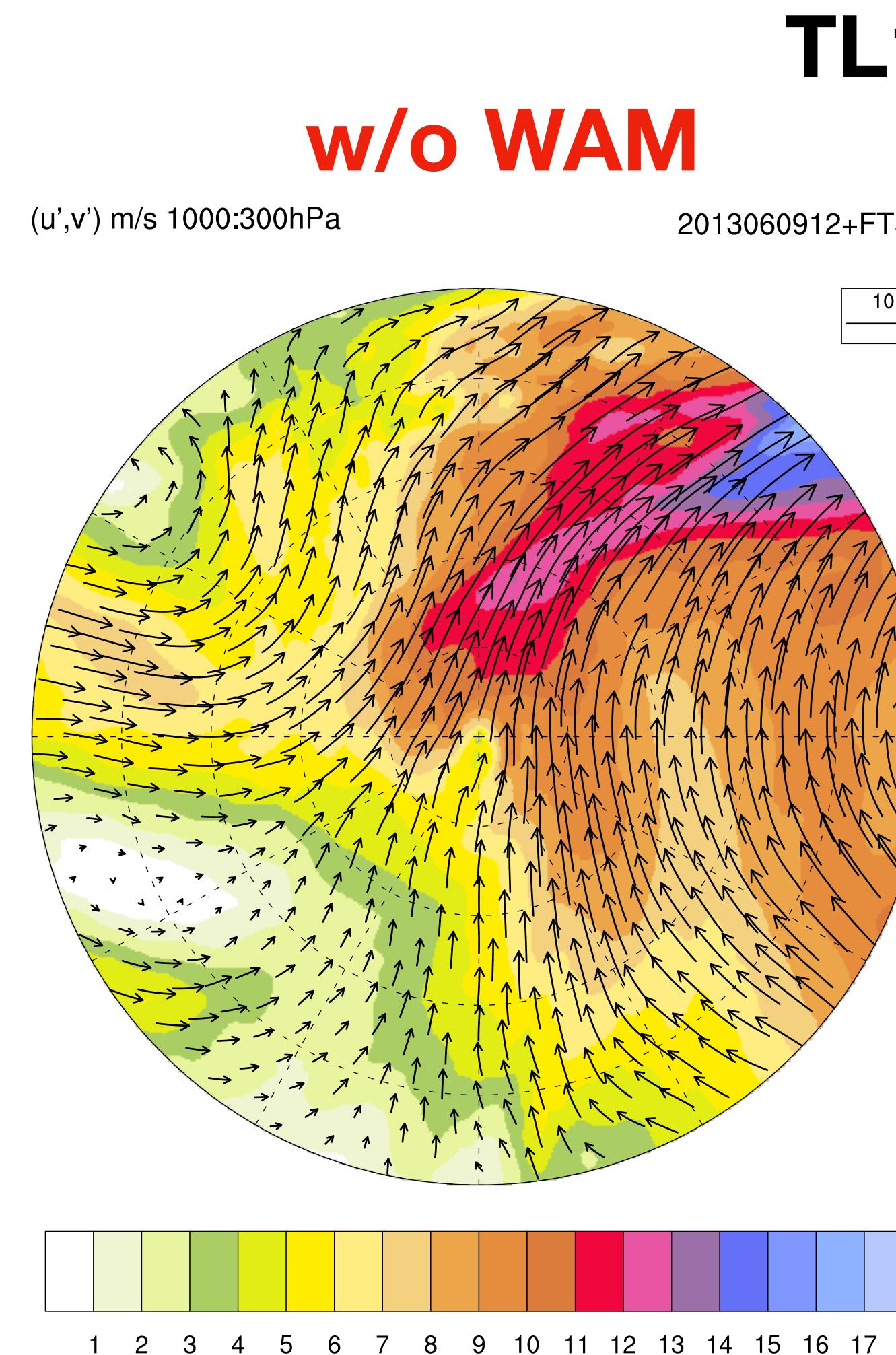
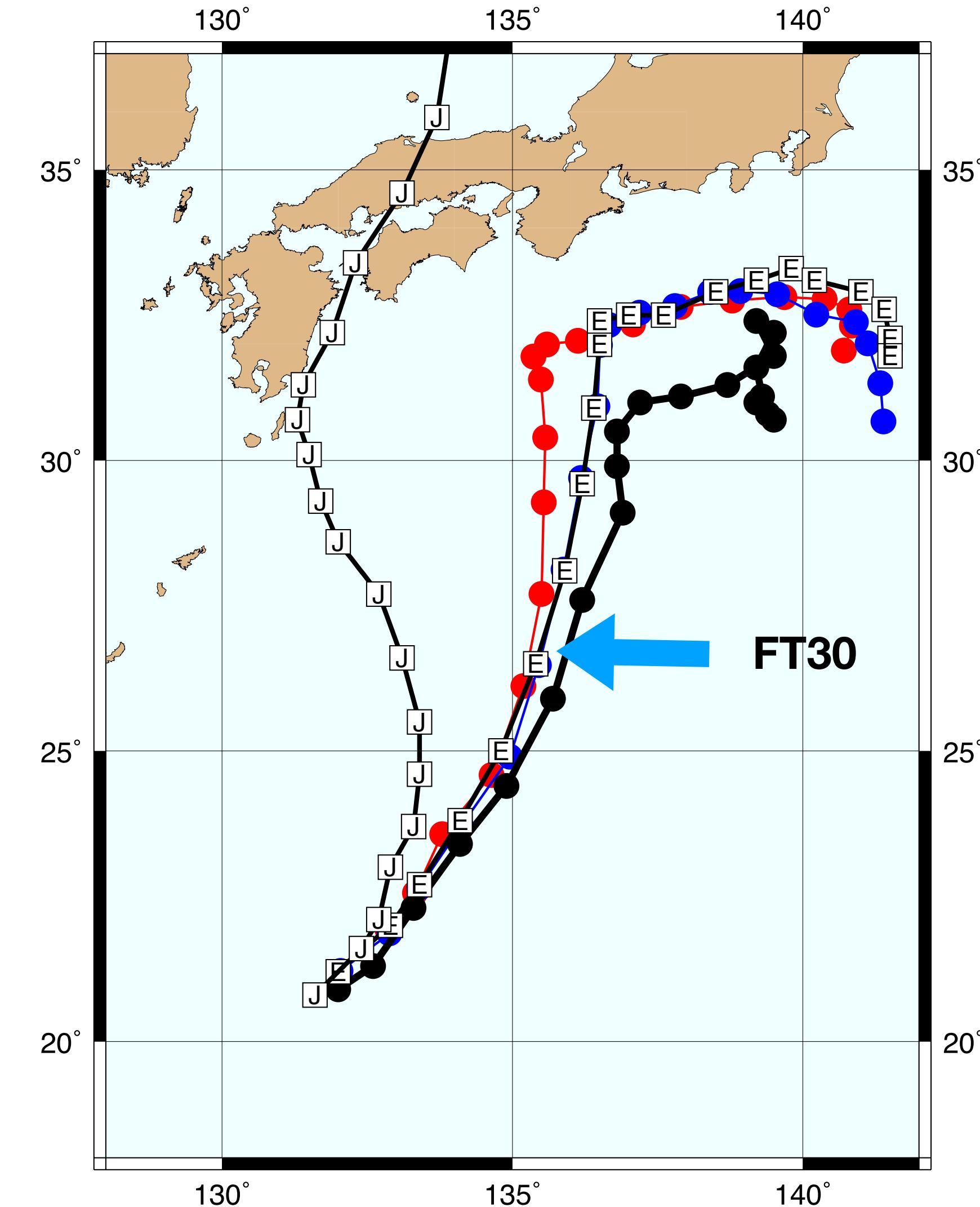
w/o WAM



difference



Axis non-symmetric winds



The physical processes that were previously considered to
be “minor” have become “substantial”

–Kosuke Ito and Chun-Chieh Wu

9th IWTC topic 2.1 report

まとめ

- ・ 台風は1000 kmスケールの風というよりは、高々100 km程度の渦
- ・ 高解像度、高精度で高度な力学コアが必要
- ・ 指向流となる環境場を正しく再現した上で、
鉛直構造を再現することが必要→非断熱過程
- ・ 台風の力学には、放射（→雲）や波浪や海洋との結合が本質的
- ・ 非軸対称構造や境界層、メソスケール構造