Observation target regions for improving NWP tropical cyclone forecasts: Comparison of objective targeting techniques

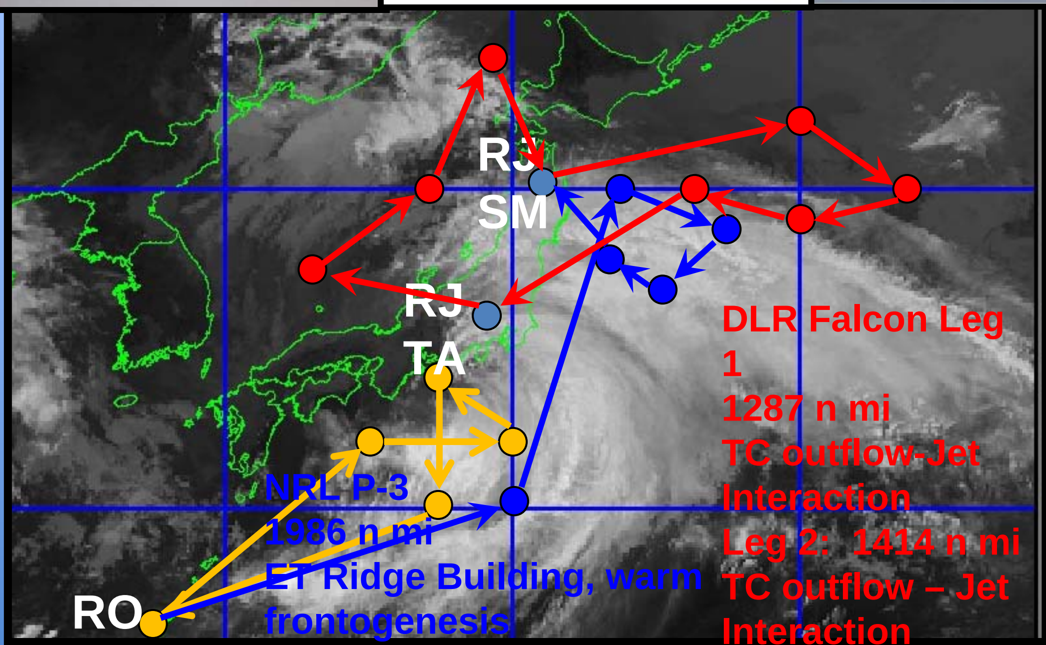
Brett Hoover – CIMSS (SSEC)
Chris Velden – CIMSS (SSEC)
Carolyn Reynolds – NRL
SharanMajumdar – RSMAS (Univ. Miami)

23 May 2012
5th WMO Workshop on the Impact of Various Observing Systems on NWP

The Targeted Observing Problem

- Tropical Cyclones represent a unique forecast challenge
  - High-impact weather events
  - Exist largely over the oceans == poor obs. coverage
  - How do we improve obs. coverage specifically to improve tropical cyclone NWP?

Dropsondes



WC-130
1787 n mi decaying TC Core
Satellite validation mission

Potential Aircraft Sampling Strategy during Extratropical Transition

Adaptive Satellite Obs.

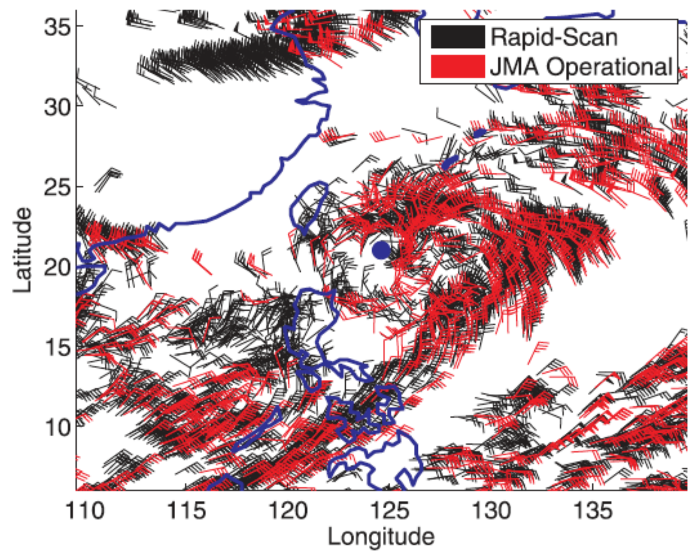


FIG. 1. Upper-level (100–350 hPa) operational (red) and rapid-scan (black) AMVs near Typhoon Sinlaku (blue dot = center) valid for 0000 UTC 11 Sep 2008.

Slide courtesy of "THORPEX-Pacific Asian Regional Campaign/Tropical Cyclone Structure-08 Experiments and Collaborative Efforts", http://met.nps.edu/~tparc/TCS-08.html

Berger, H., R. Langland, C. S. Velden, C. A. Reynolds, and P. M. Pauley, 2011: Impact of Enhanced Satellite-Derived Atmospheric Motion Vector Observations on Numerical Tropical Cyclone Track Forecasts in the Western North Pacific during TPARC/TCS-08. *Journal of Applied Meteorology and Climatology*, **50**, 2309-2318.

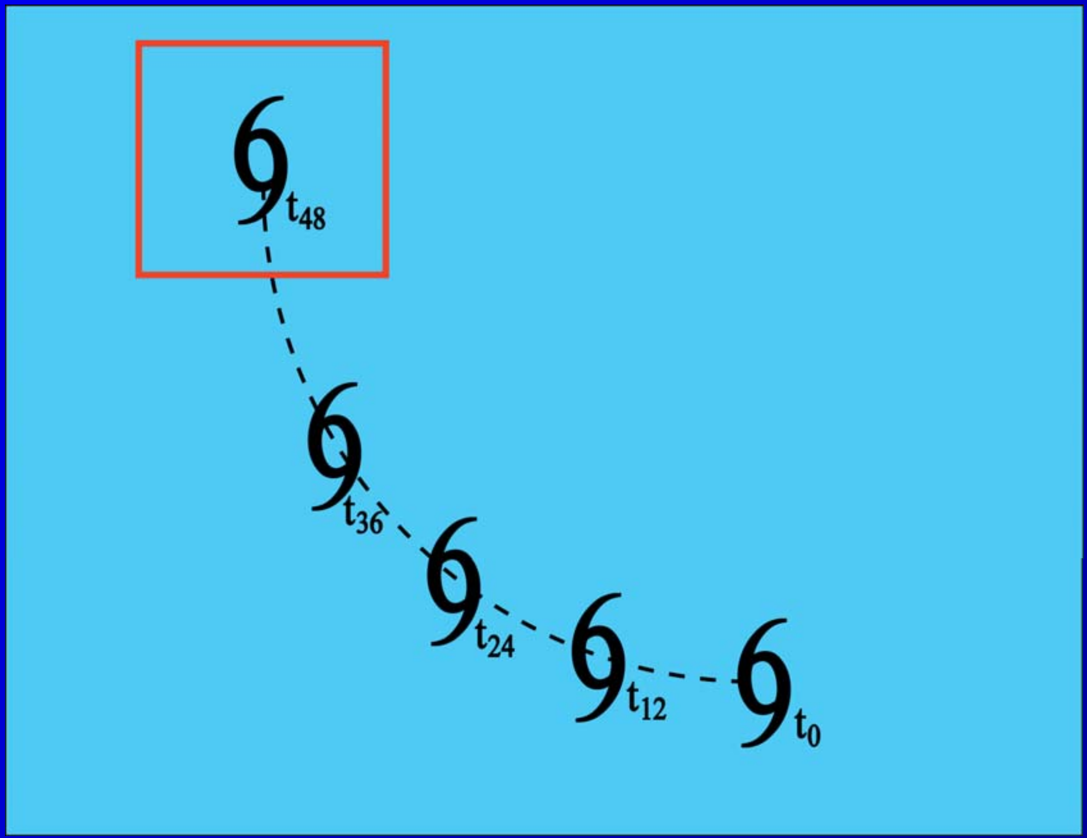
The Targeted Observing Problem

- How do we know our observations will have an impact on the TC forecast?
  - We require a way to **estimate the potential impact** additional observations will have on the TC forecast
  - Where is the TC forecast (steering, intensity) **most sensitive** to small changes (e.g. errors) in the initial conditions?

Singular Vector Guidance

What perturbation to the initial conditions will **grow the fastest** to fill a box surrounding the TC at 48 hours with **perturbation energy**?

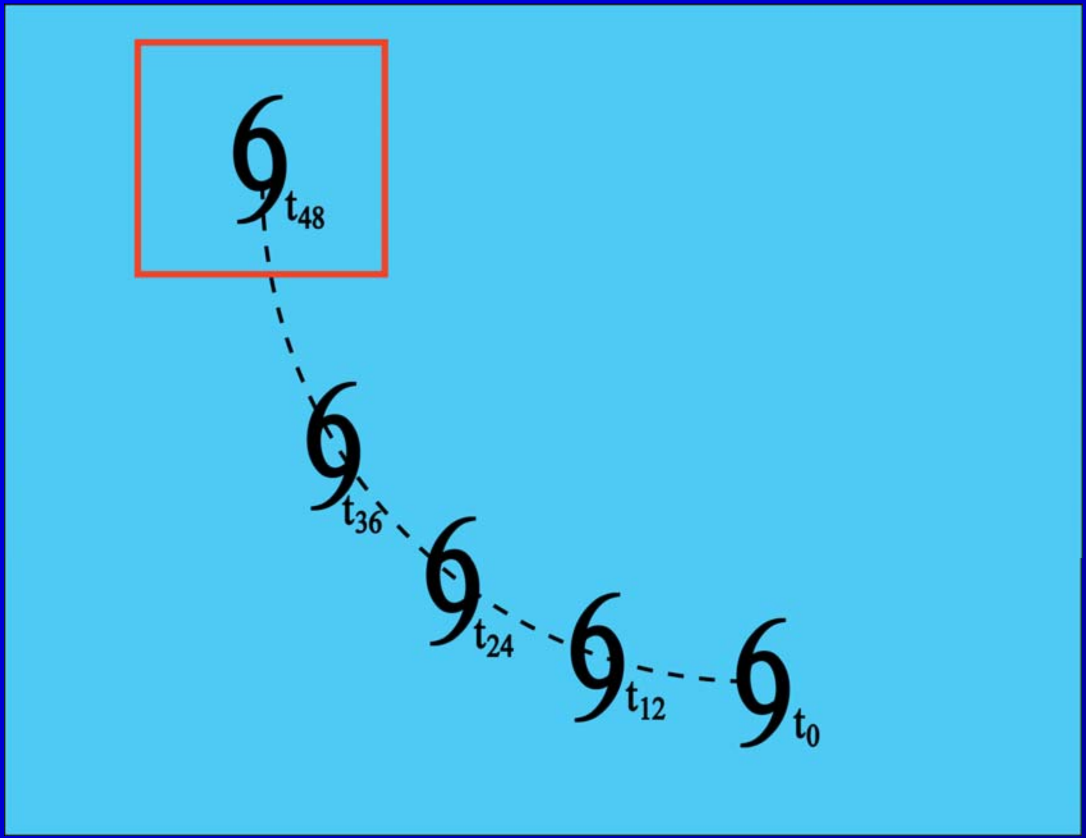
Errors that project onto SVs will create the most perturbation energy around the TC at the final time, **presumably having the largest impact on steering/intensity at that time**.

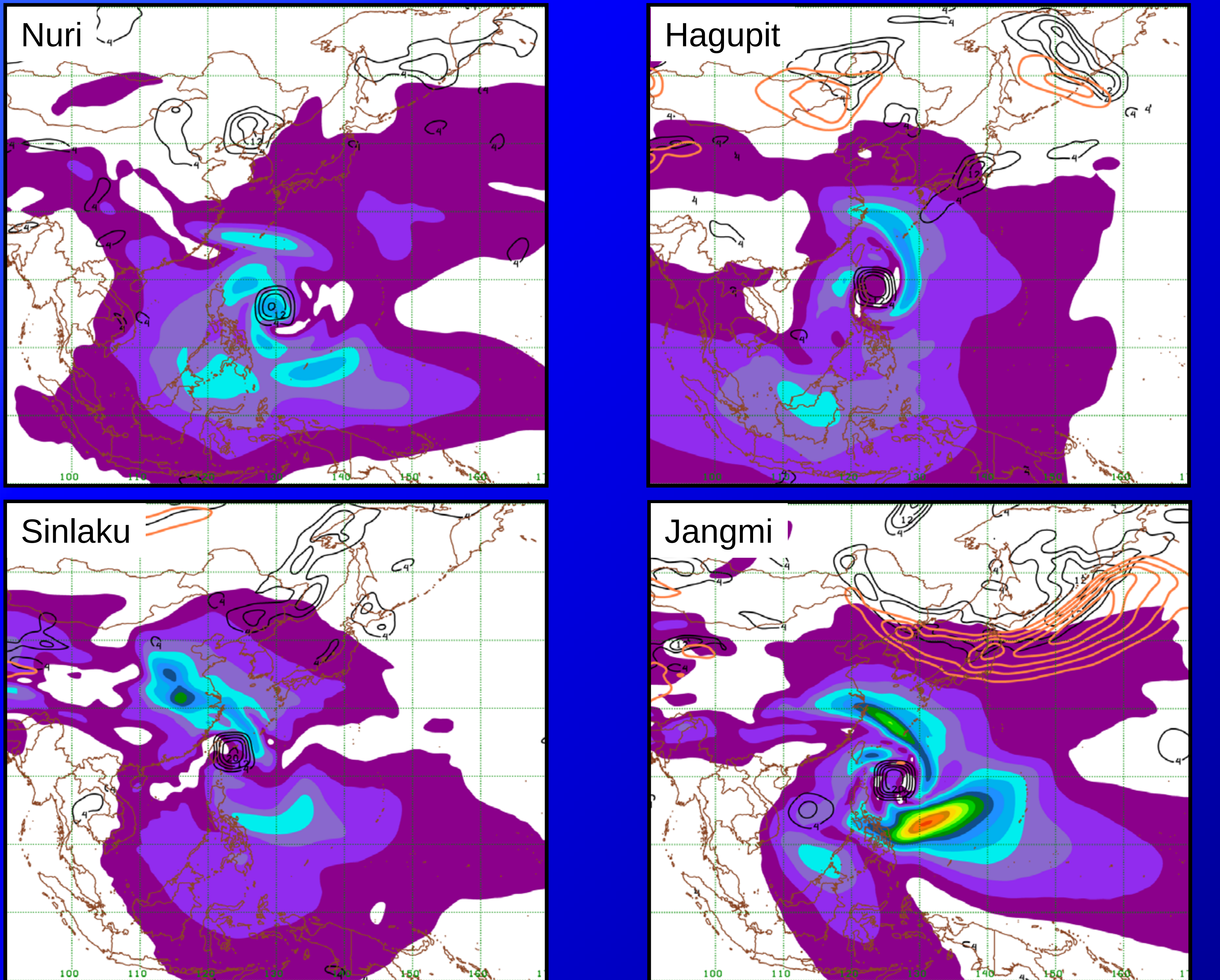


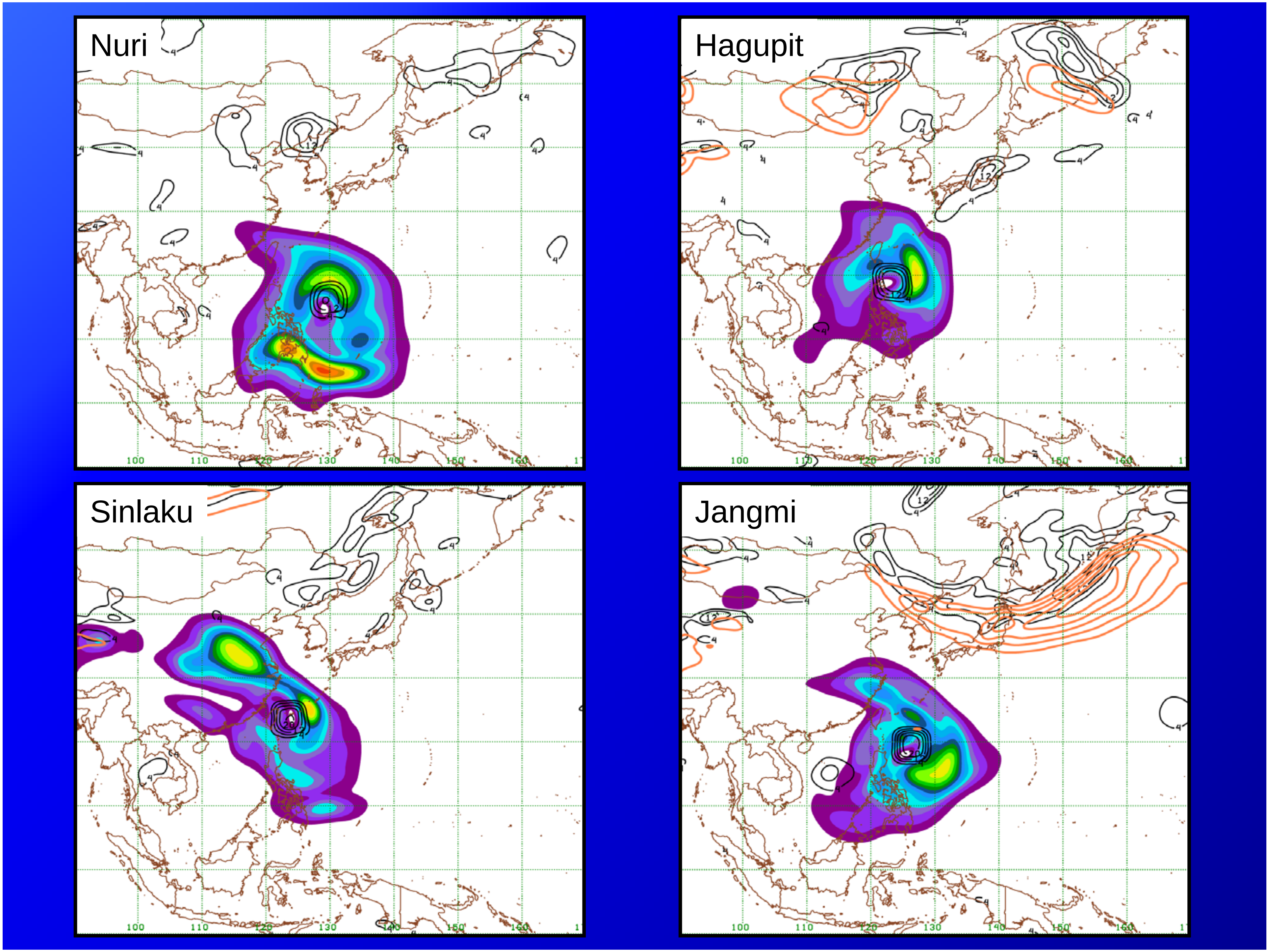
Adjoint-Derived Sensitivity Steering Vector (ADSSV) Guidance

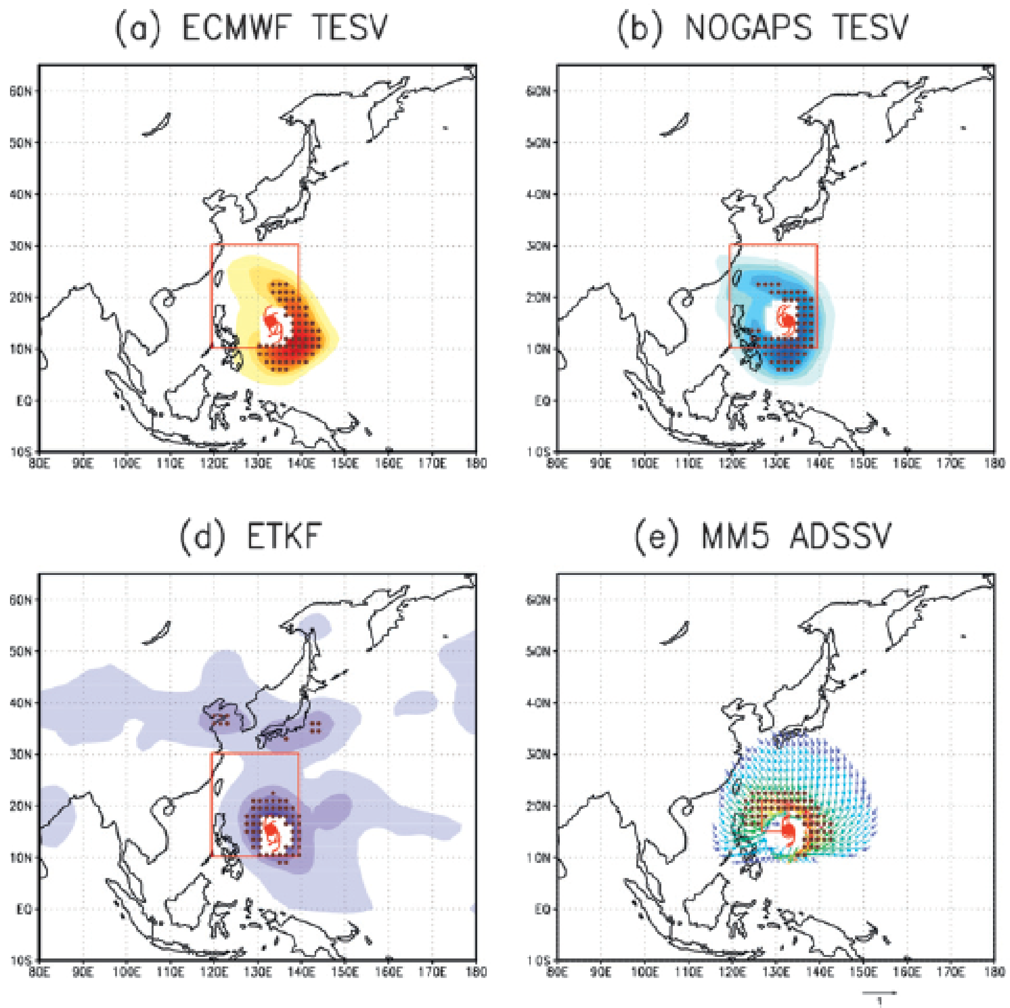
How much will any vorticity perturbation to the initial conditions **change the average flow** in a box surrounding the TC at 48 hours?

Errors that project onto ADSSVs will change the average flow around the TC at the final time, **presumably having the largest impact on steering at that time**.




Nuri
Hagupit
Sinlaku
Jangmi
100
110
120
130
140
150
160


Nuri
Hagupit
Sinlaku
Jangmi
100
110
120
130
140
150
160



The similarity between SV and ADSSV has been observed in previous studies.

Typically these intercomparison studies focus on **quantifying the amount of similarity/difference** rather than **physically interpreting** what these techniques are measuring.

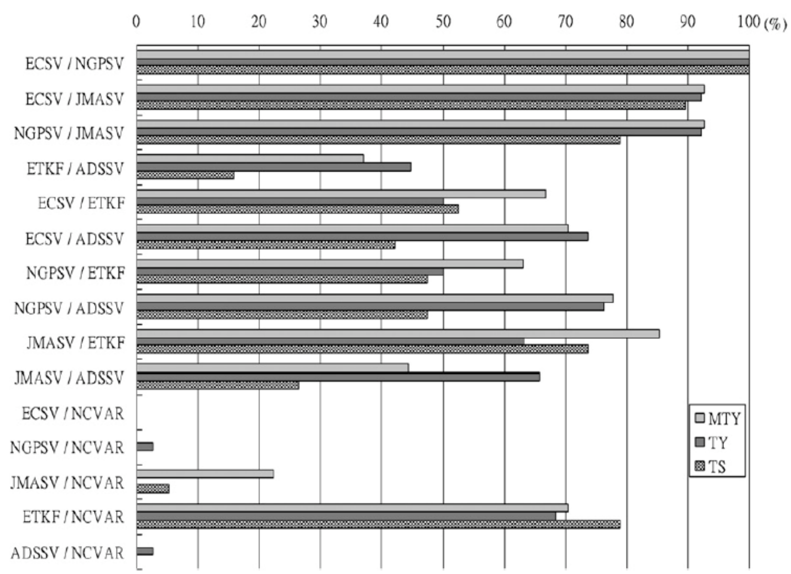
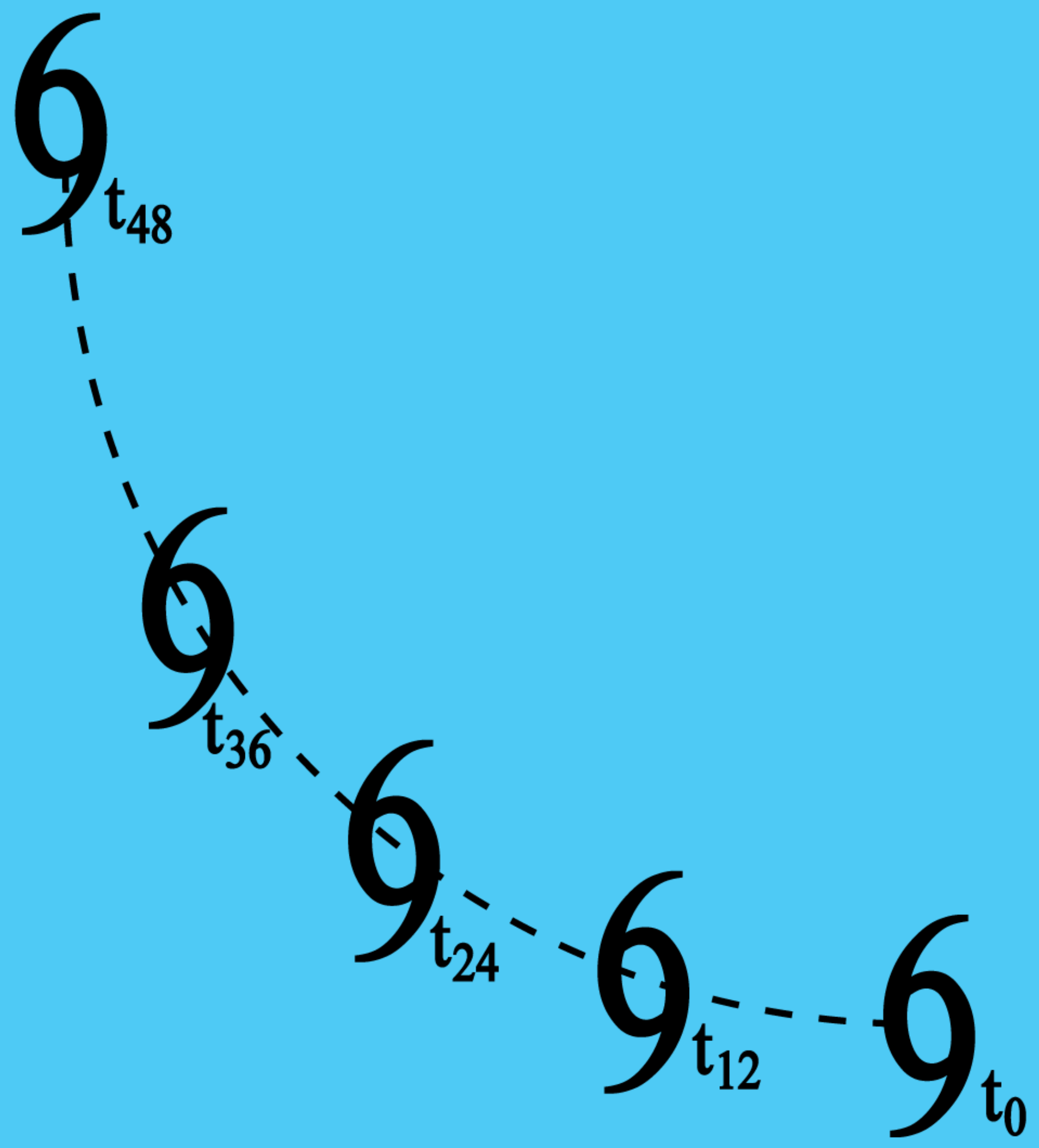


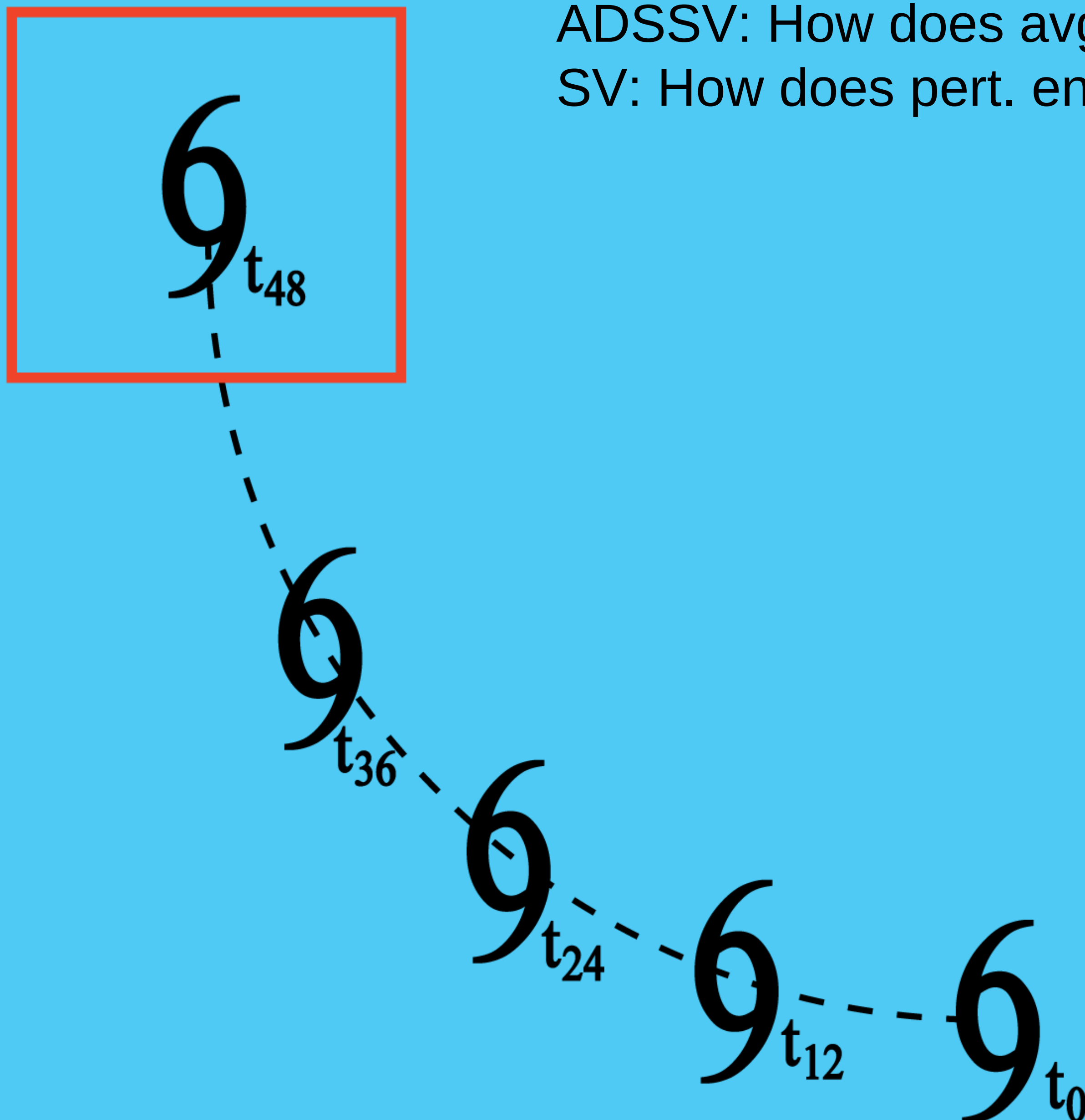
FIG. 8. Percentage of cases with the Spearman rank correlation coefficient (R_s) set to be larger than 0.2. Results are shown for typhoons of three different intensity categories: 27 major typhoons (MTY), 38 typhoons (TY), and 19 tropical cyclones (TC).

Wu, C.-C. and Coauthors, 2009: Intercomparisonof Targeted Observation Guidance for Tropical Cyclonesin the Northwestern Pacific. *Mon. Wea. Rev.*, **137**, 2471-2492.

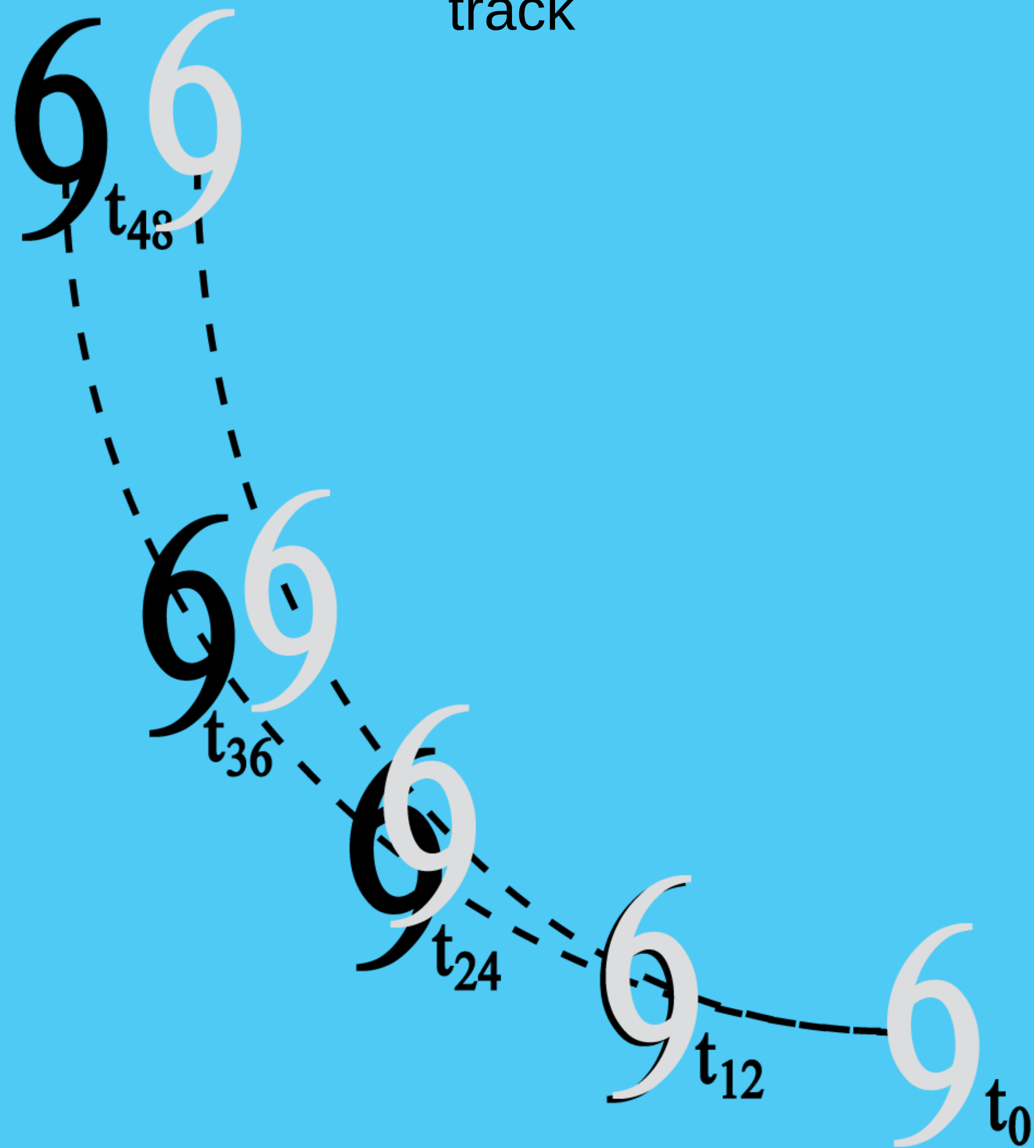
Imagine a 48-hr simulated TC track



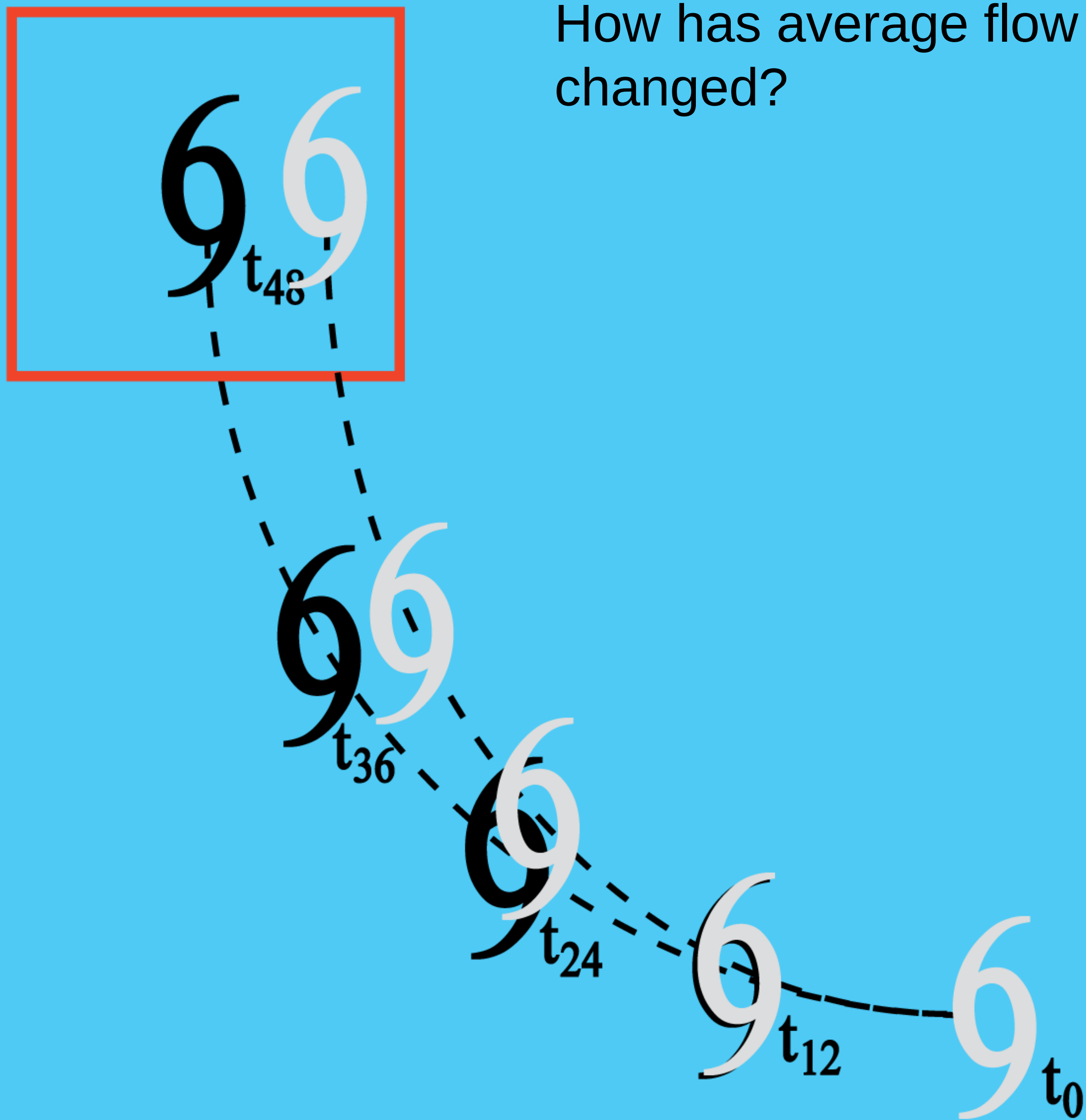
ADSSV: How does avg. flow change?
SV: How does pert. energy change?

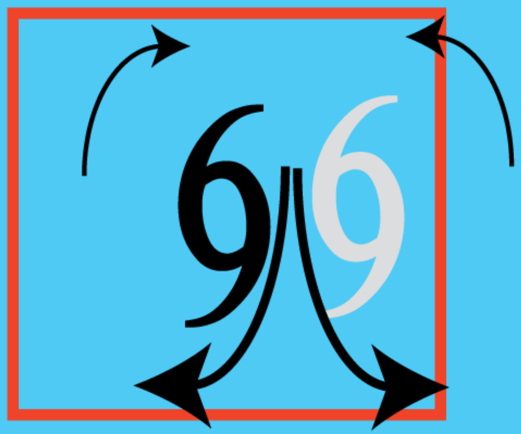


Perturb initial conditions – New TC track

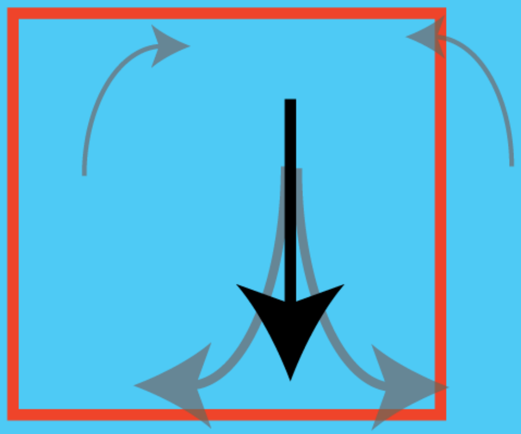


How has average flow in the box changed?





Displacement of TC creates a **dipole** with **strong flow to the south** within the box.



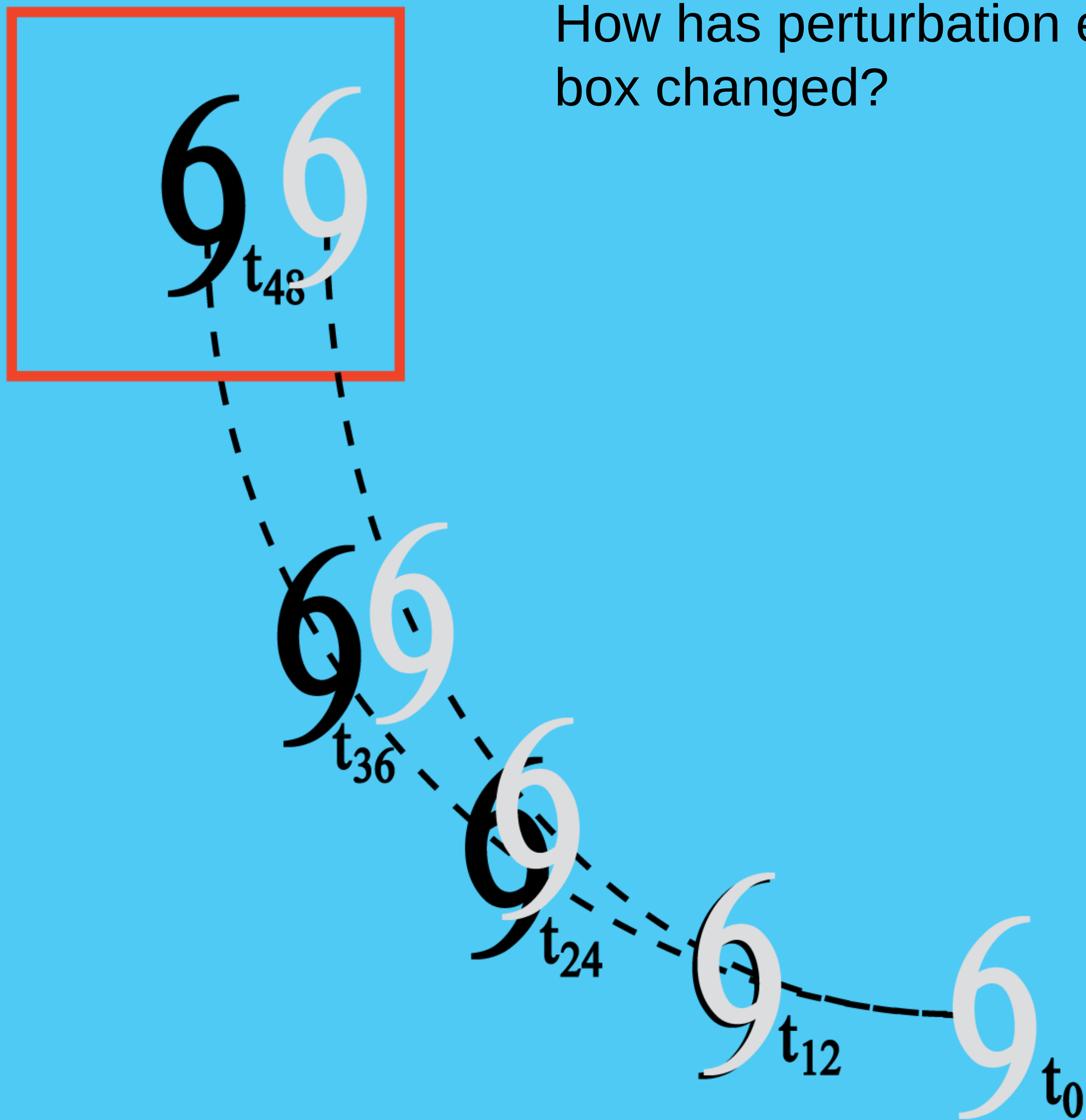
It is this flow which is **primarily responsible** for the change in the average flow in the box

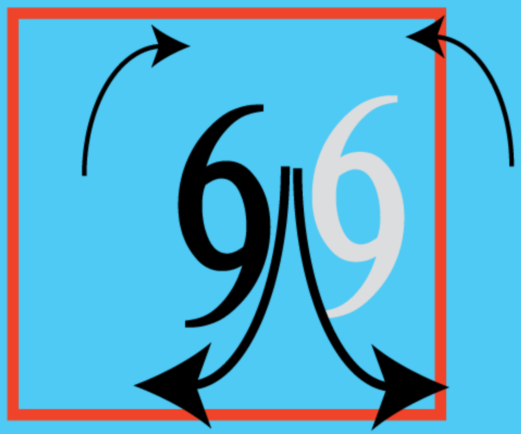
It is this flow which the ADSSV **(correctly) anticipated as a result** of perturbations to the initial state

This flow, however, is **not related to the steering of the TC** at the final time

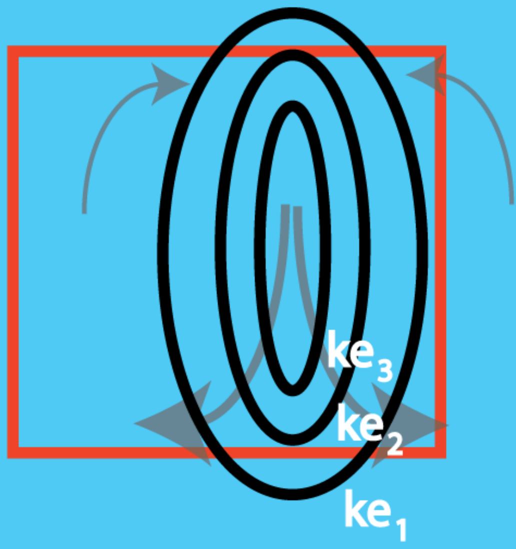
The ADSSV does not compute sensitivity of TC steering with respect to initial state perturbations, but rather sensitivity of some measure related to TC track changes. The interpretation of what ADSSV sensitivity actually measures is largely incorrect.

How has perturbation energy in the box changed?





Displacement of TC creates a **dipole** with **strong flow to the south** within the box.

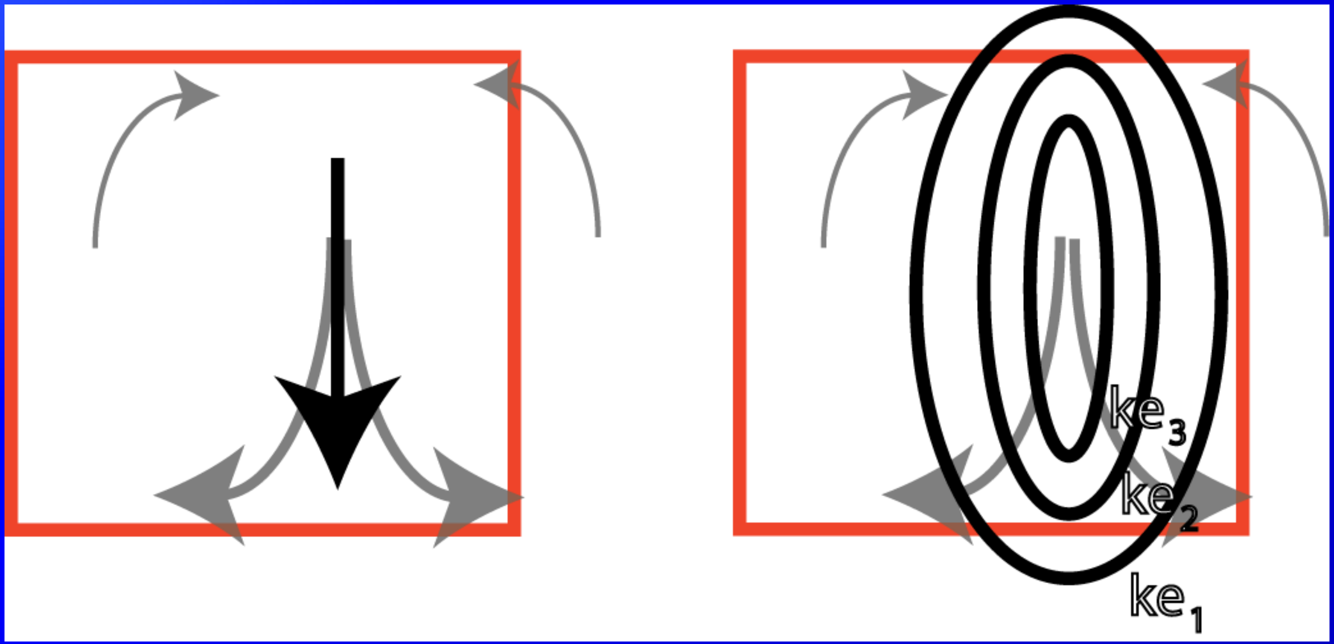


It is this flow which is **primarily responsible** for the change in the perturbation kinetic energy in the box

It is this flow which the SV **(correctly) anticipated as a result** of perturbations to the initial state

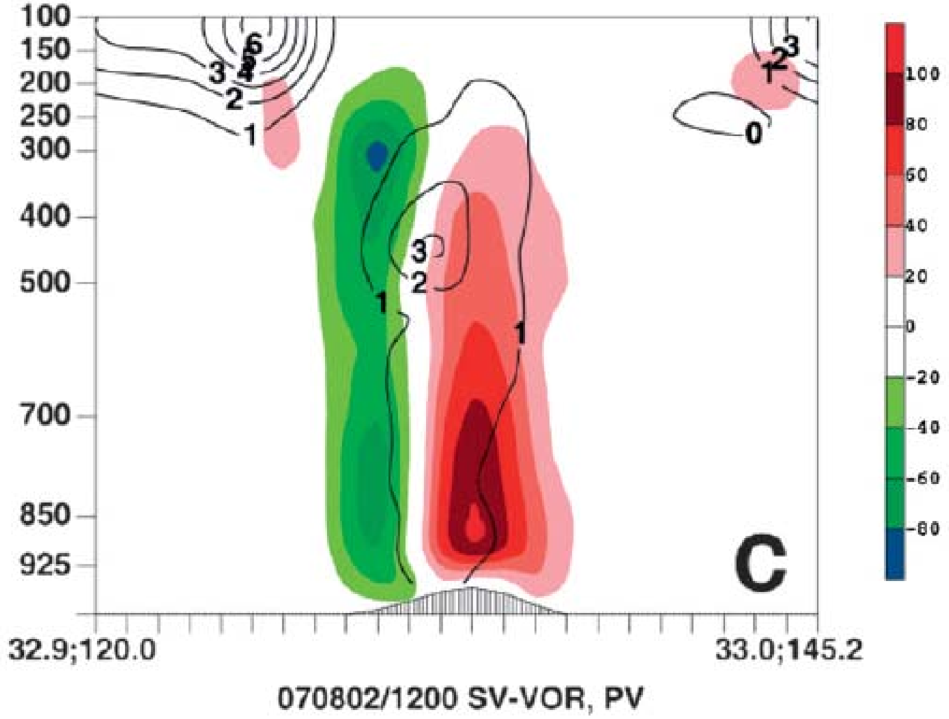
This flow, however, is **not related to the steering of the TC** at the final time

The SV does not compute sensitivity of TC steering with respect to initial state perturbations, but rather sensitivity of some measure related to TC track changes.



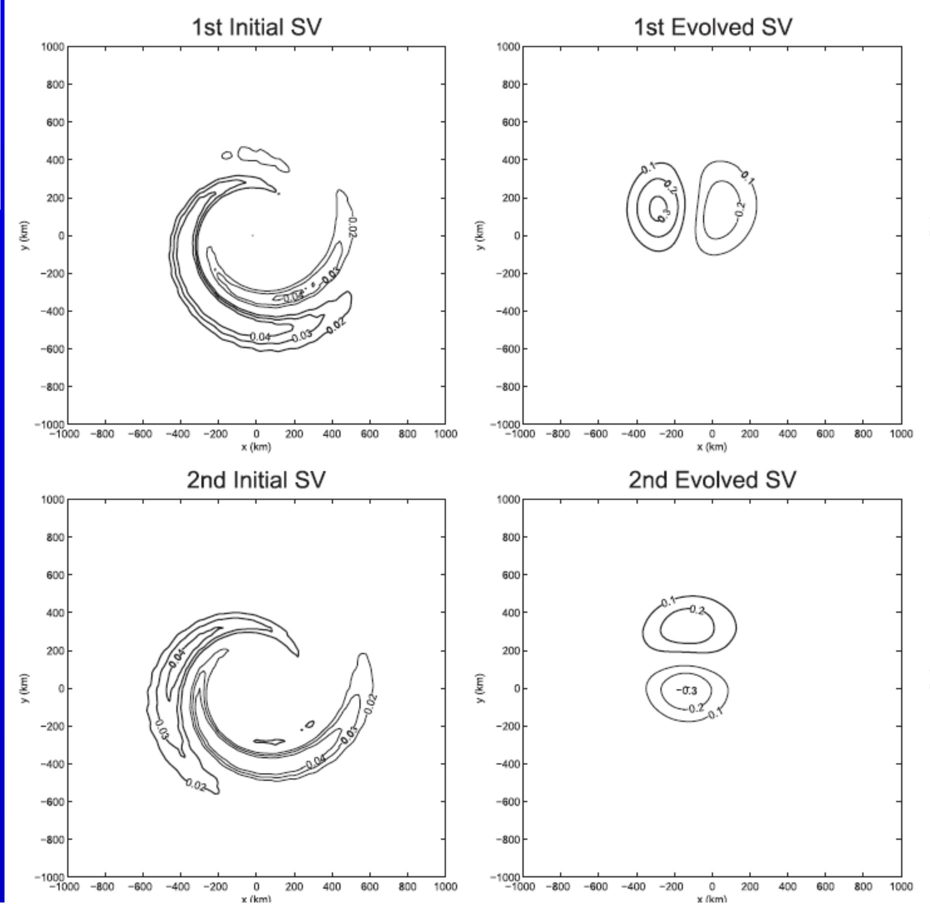
It is this effect, the **displacement of the TC vortex** at the final time, which has the dominant impact on the metrics used by **both** ADSSV and SV techniques, and it has **nothing** to do with steering at the final time

This explains the **strong correlation** between ADSSV and SV fields for TC simulations



Kim, H. M., and B. J. Jung, 2009: Singular Vector Structure and Evolution of a Recurving Tropical Cyclone. *Mon. Wea. Rev.*, **137**, 505-524.

Vorticity of evolved SVs is often a **translation-induced dipole**.

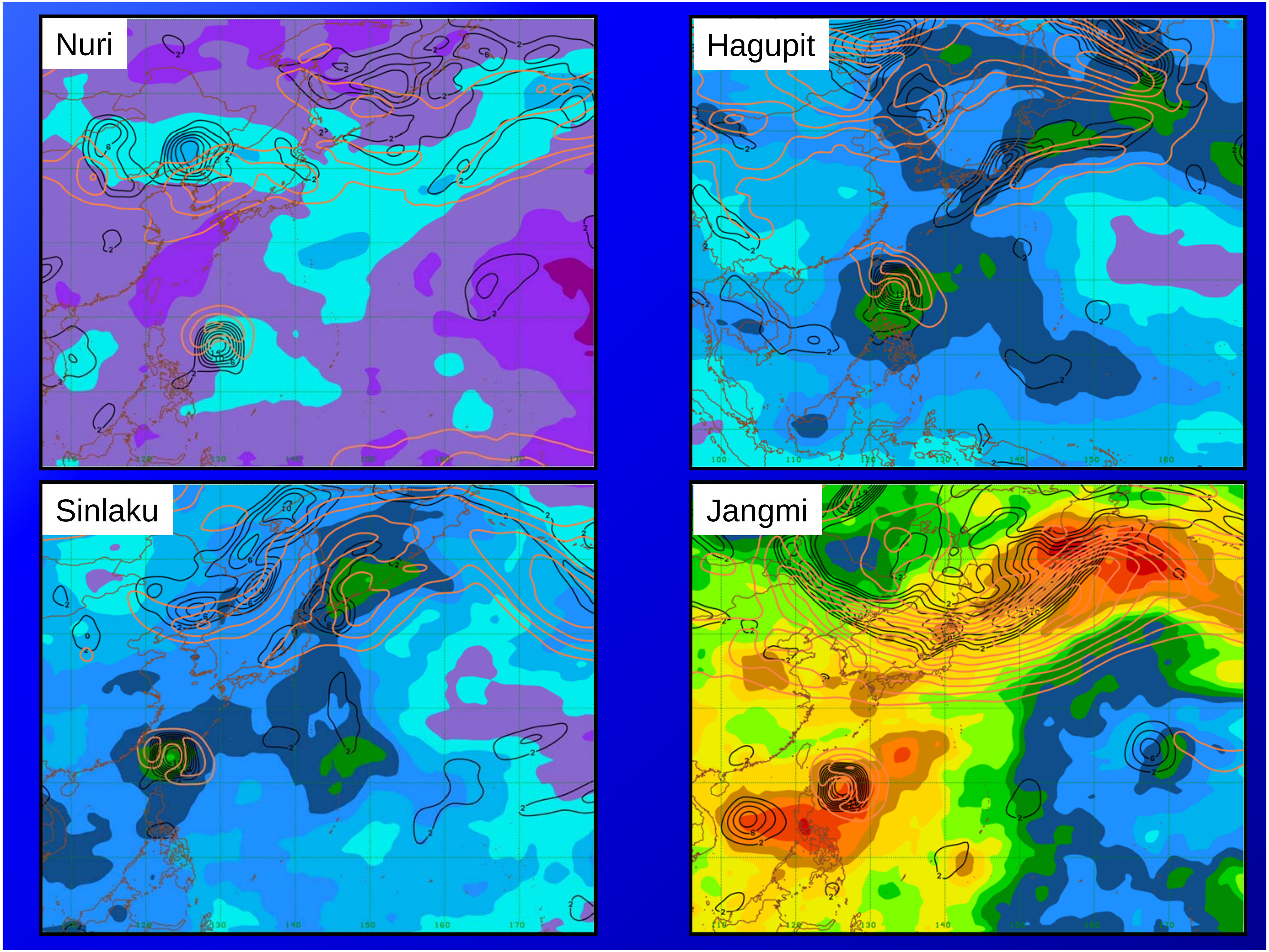


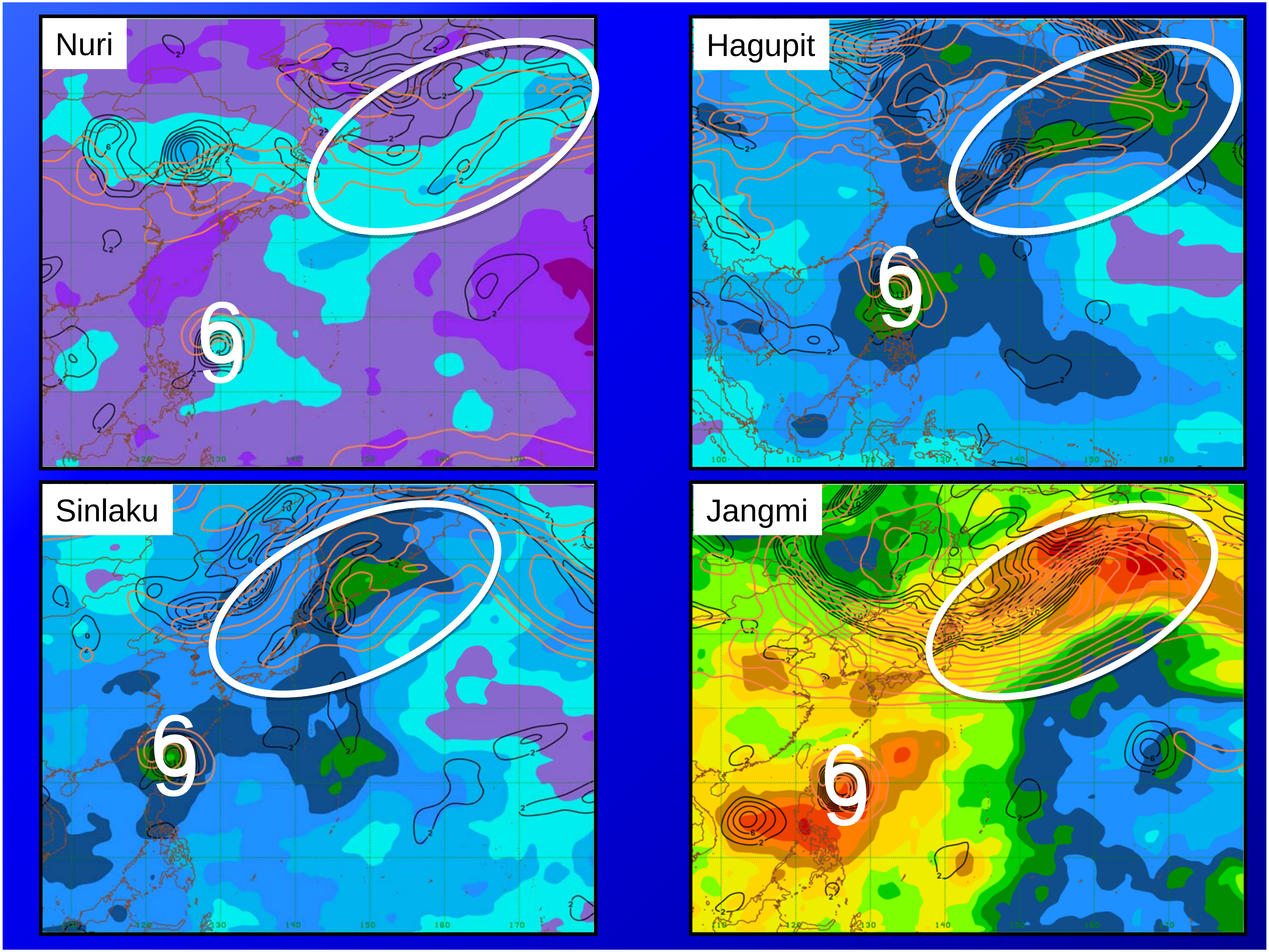
In an idealized case, perturbing the **leading SV** translates the vortex in **one direction**, and perturbing the **next SV** translates it in a **perpendicular direction**.

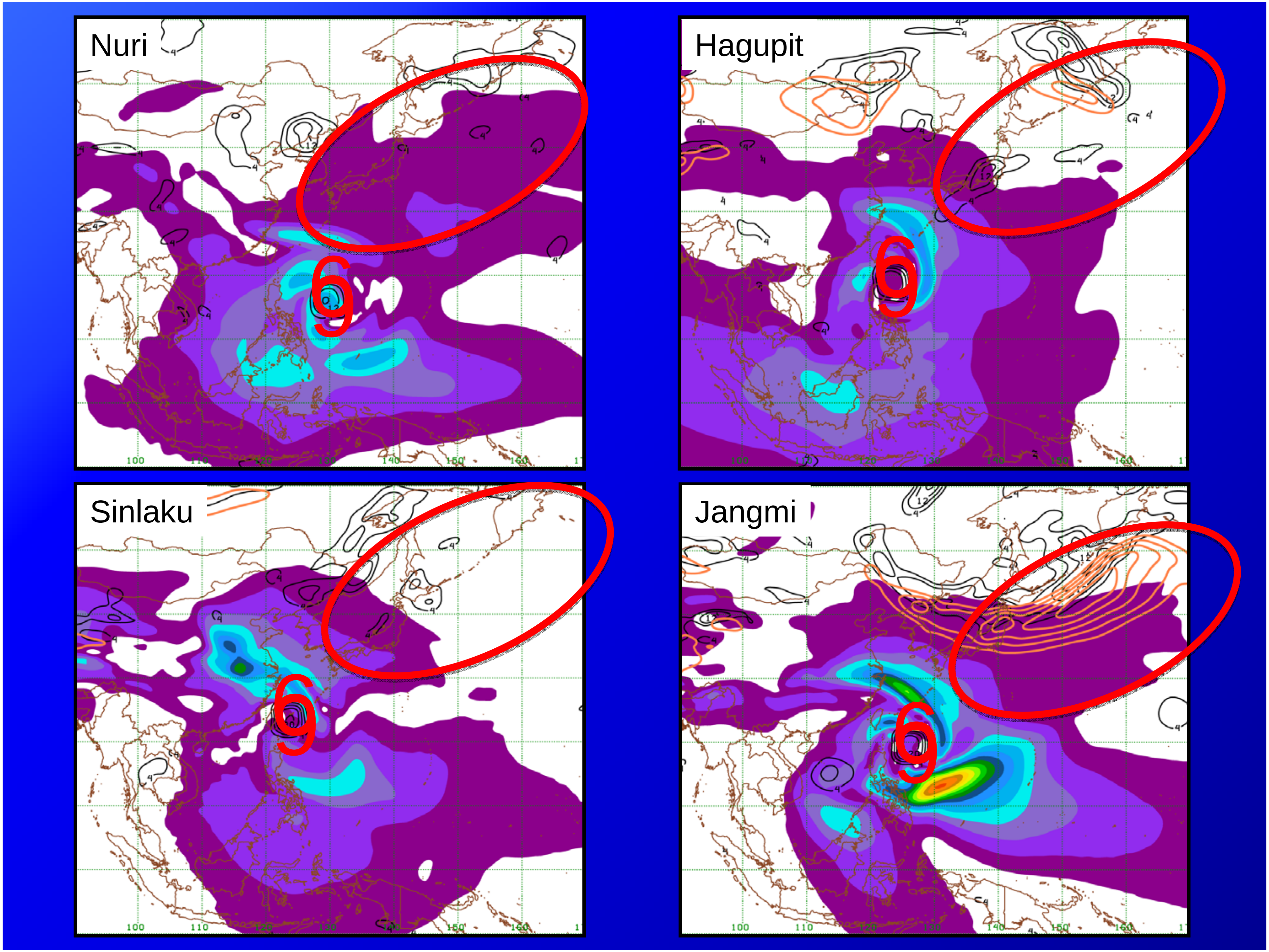
Yamaguchi et al. 2011: Singular Vectors for Tropical Cyclone–Like Vortices in a Nondivergent Barotropic Framework. *J. Atmos. Sci.*, **68**, 2273-2291

A Different Strategy: ETKF

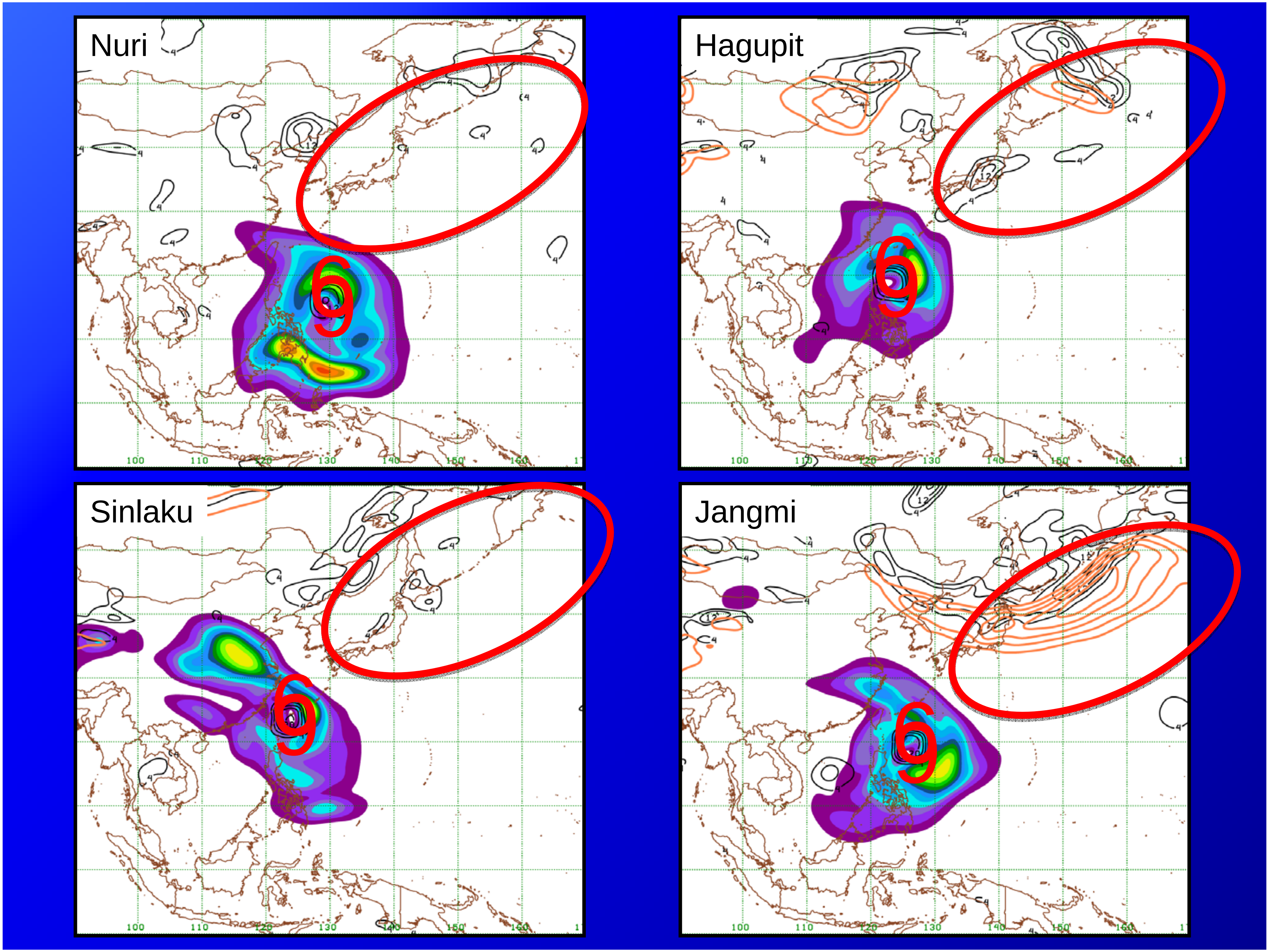
- **SV/ADSSV** guidance = strictly based on **dynamics of perturbation growth**
- **ETKF** guidance = estimate of the impact of a potential, new observation using **ensemble-derived estimates** of both the **dynamics AND the (ETKF) assimilation** of new data


Nuri
Hagupit
Sinlaku
Jangmi


Nuri
Hagupit
Sinlaku
Jangmi



Nuri
Hagupit
Sinlaku
Jangmi

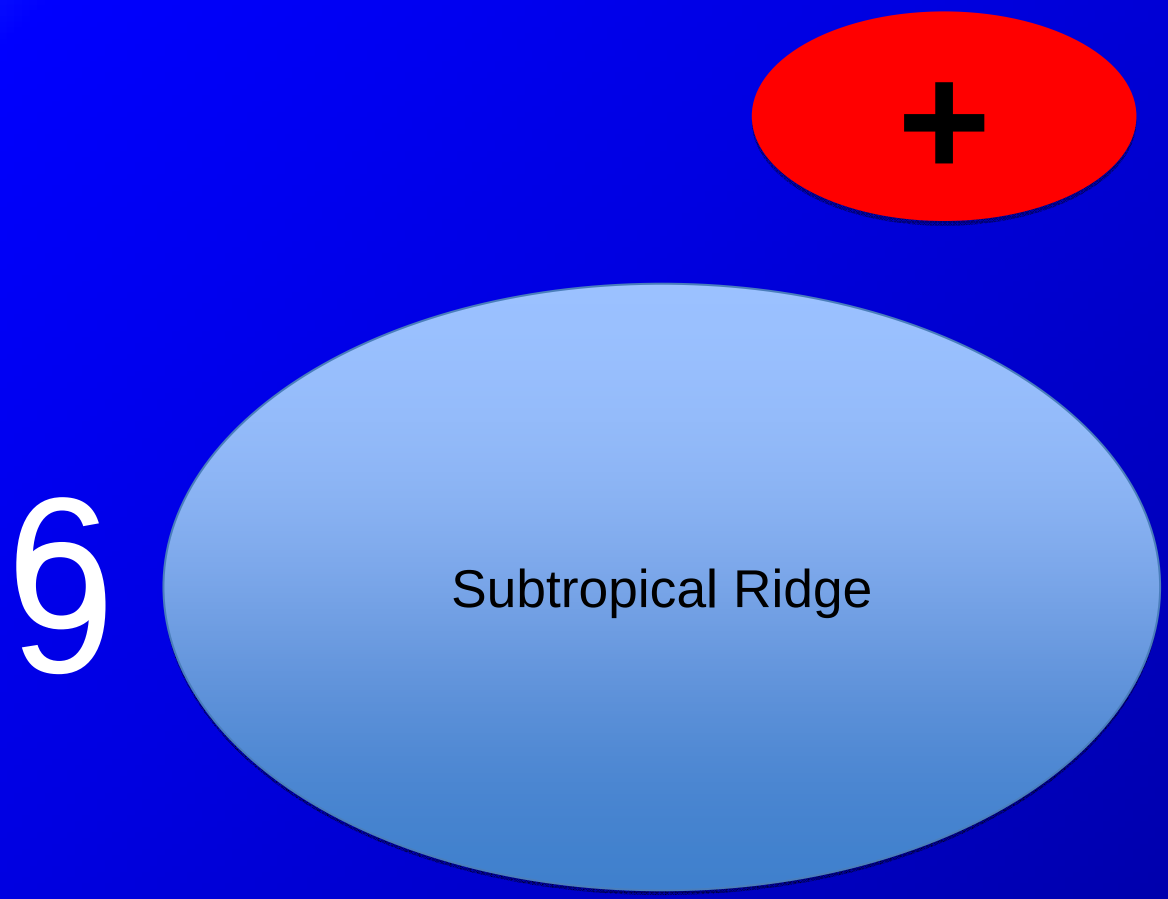

Nuri
Hagupit
Sinlaku
Jangmi
100
110
120
130
140
150
160

Downstream Sensitivity

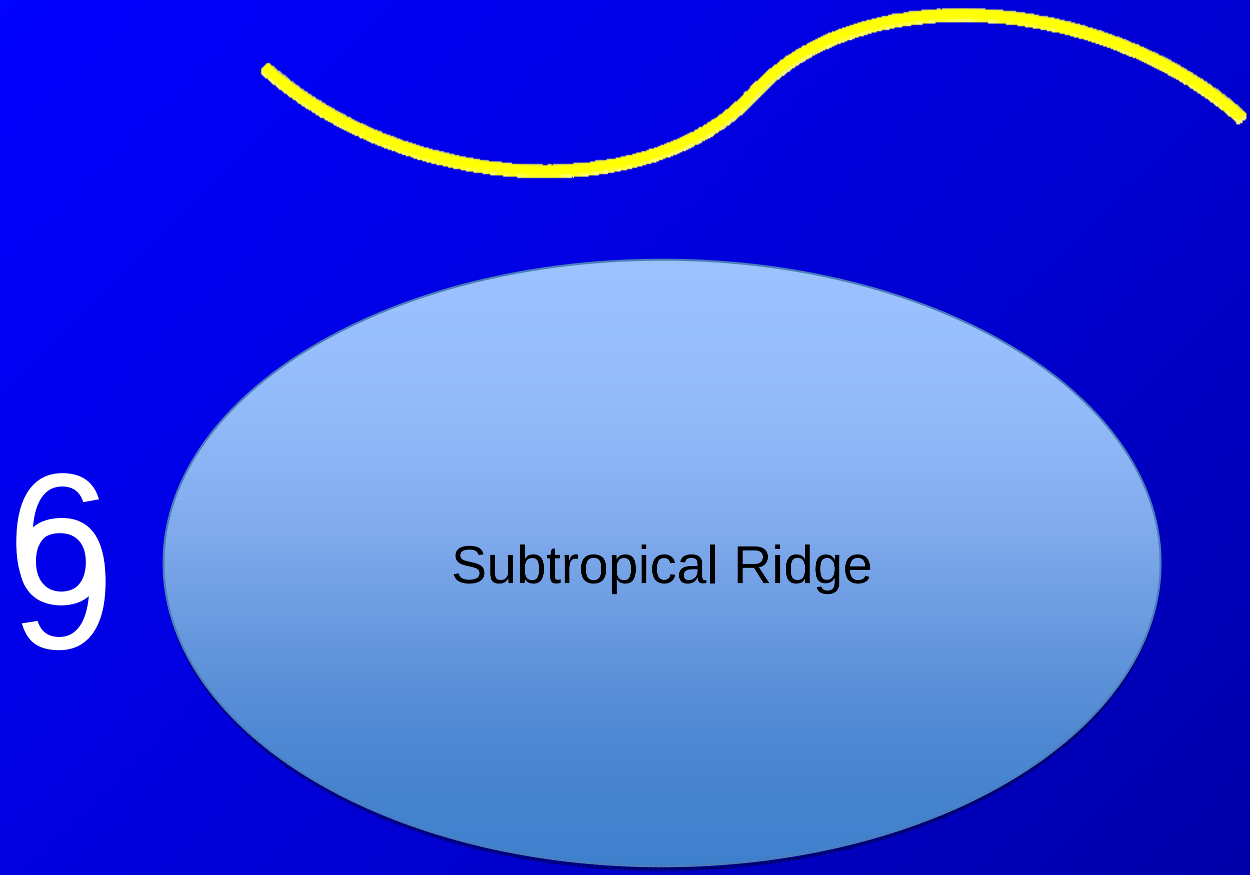
- Practically **ubiquitous** in ETKF
- Observed **sometimes** in ADSSV
- Practically **non-existent** in SV

- Let’s look at a conceptual model of how a **downstream perturbation** can affect the TC through **modifying the subtropical ridge**:

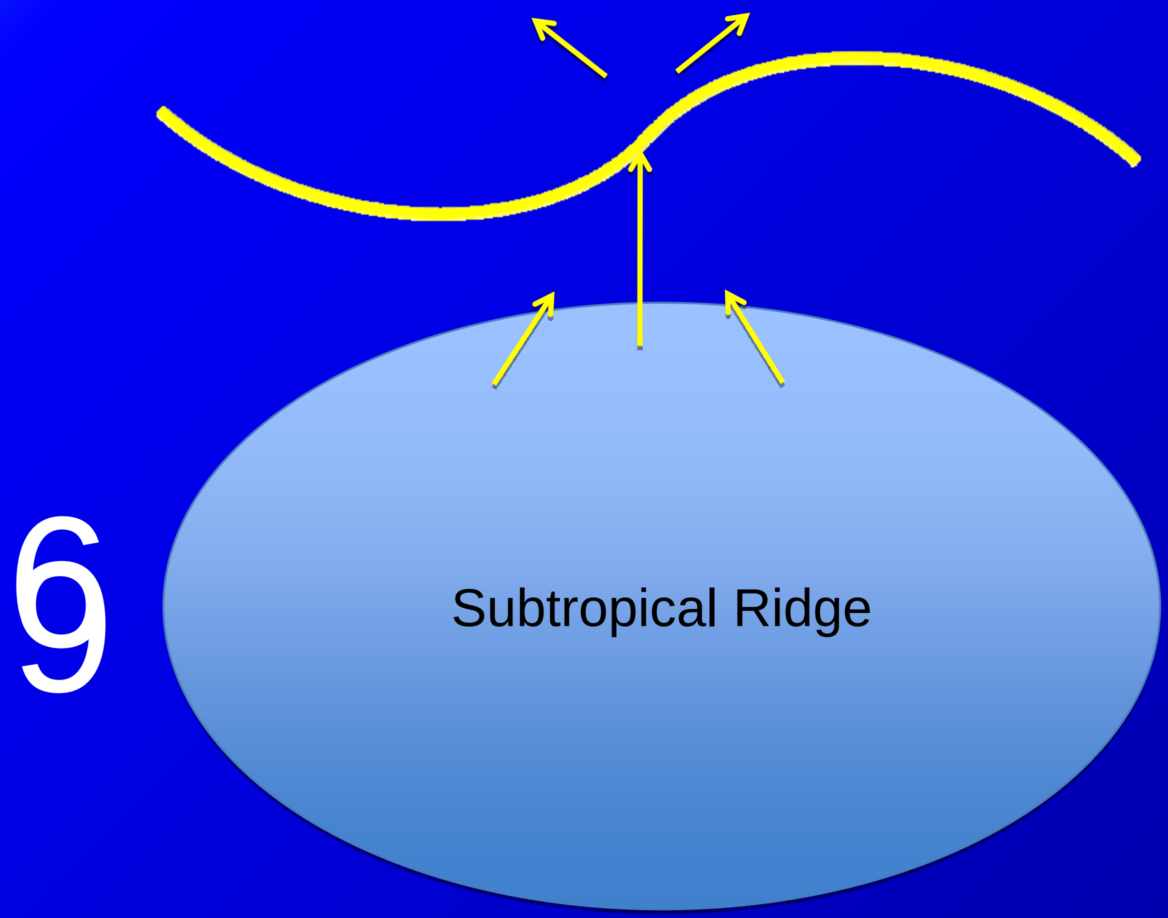
Positive vorticity introduced downstream



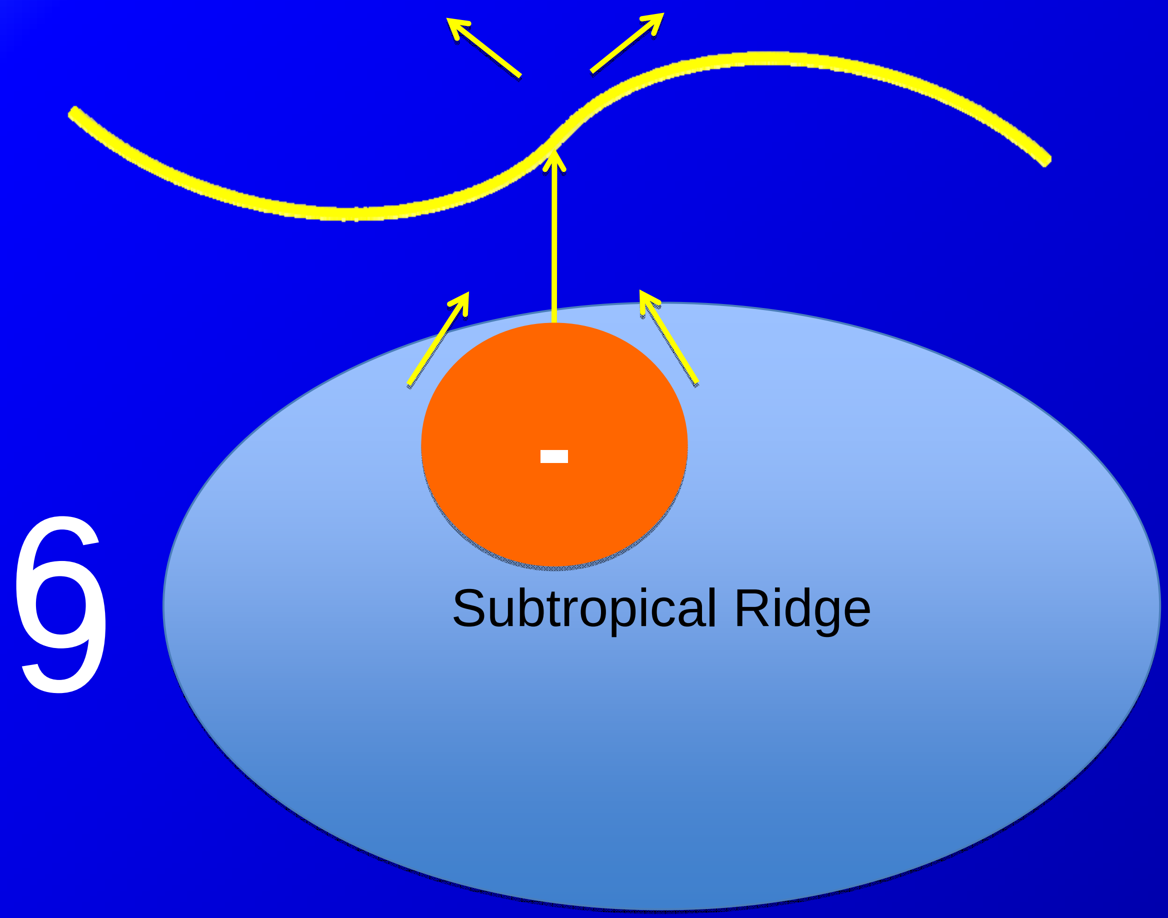
Positive vorticity introduced downstream
Rossby wave propagates upstream



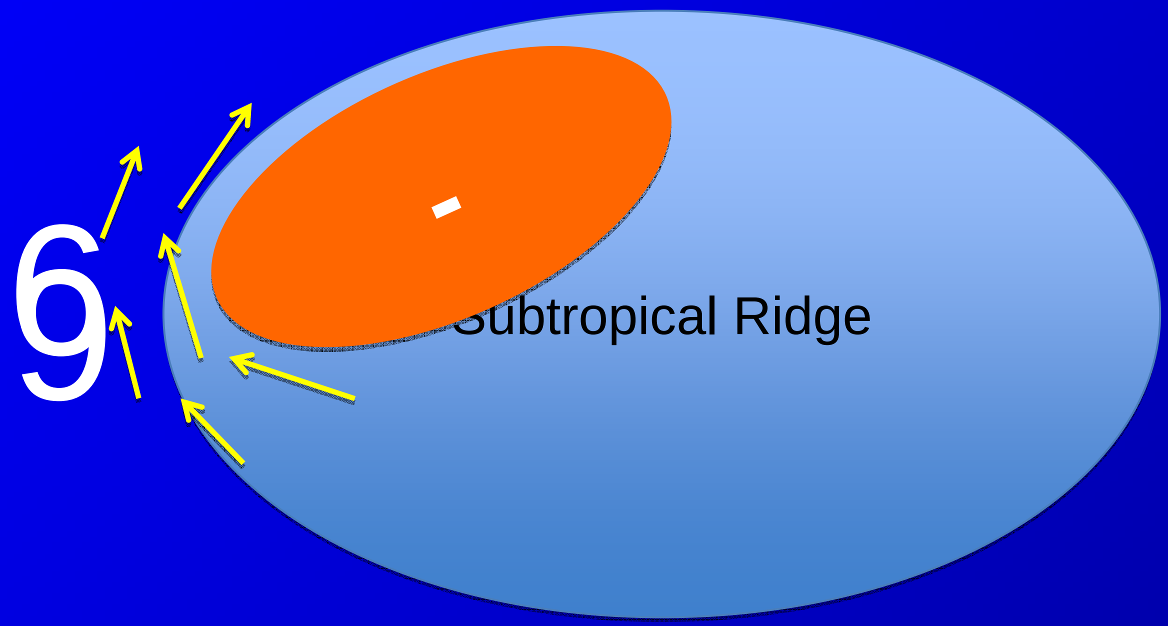
Positive vorticity introduced downstream
Rossby wave propagates upstream
Poleward perturbation flow through subtr. ridge



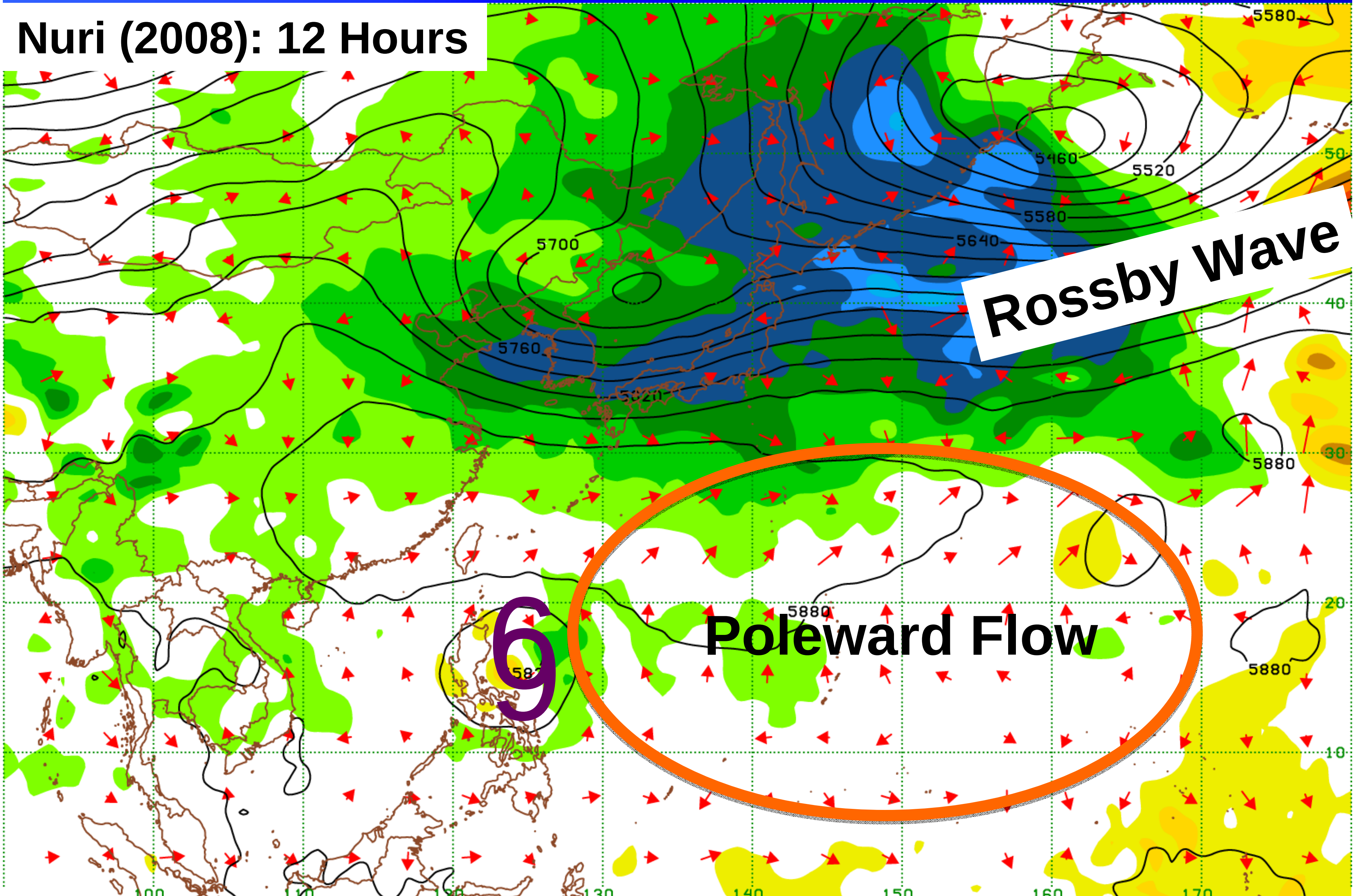
Positive vorticity introduced downstream
Rossby wave propagates upstream
Poleward perturbation flow through subtr. Ridge
Conservation of absolute vorticity increases anticyclonic vorticity in ridge



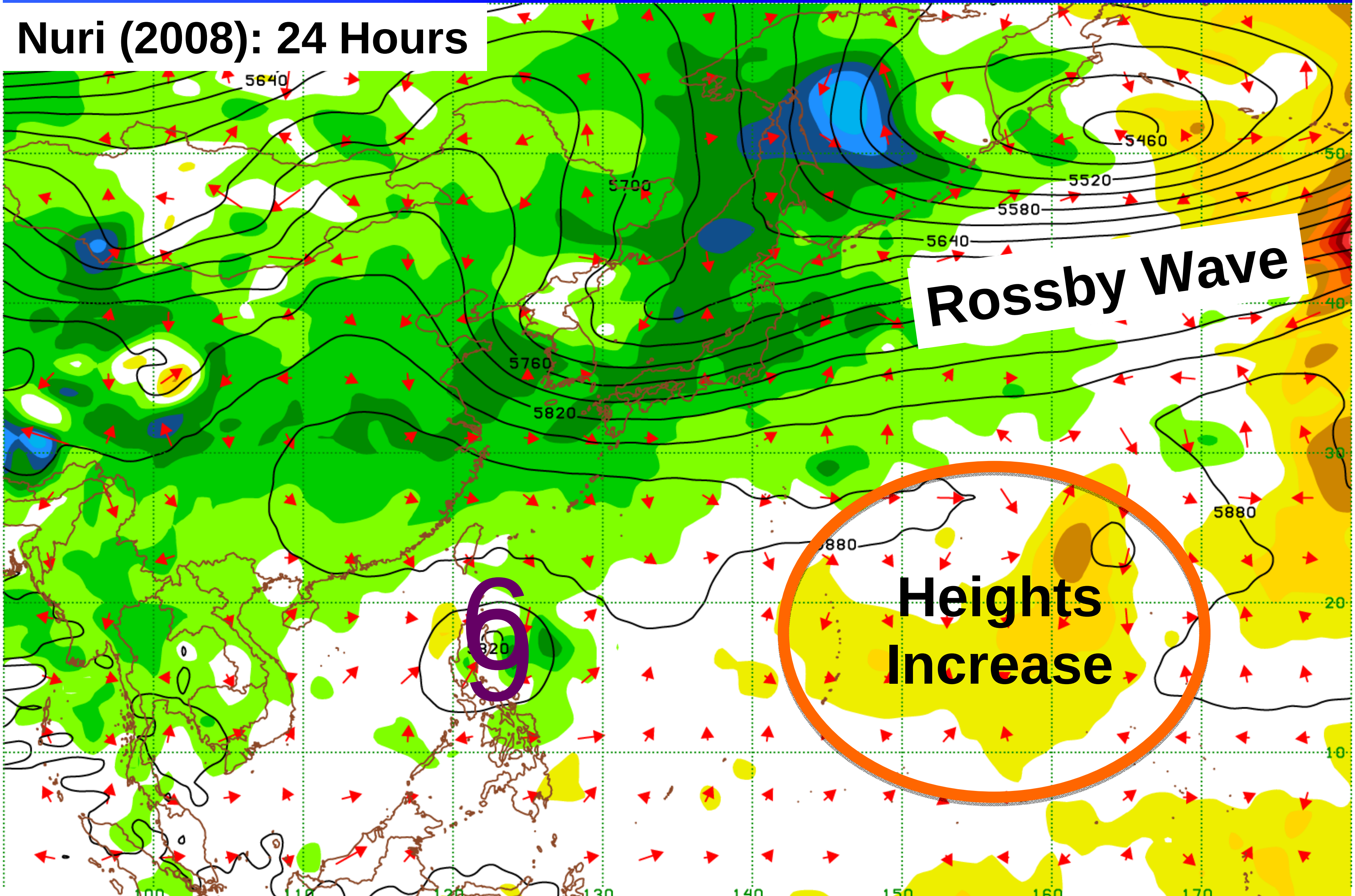
Positive vorticity introduced downstream
Rossby wave propagates upstream
Poleward perturbation flow through subtr. Ridge
Conservation of absolute vorticity increases anticyclonic vorticity in ridge
Enhanced anticyclonic flow in ridge steers TC to NE



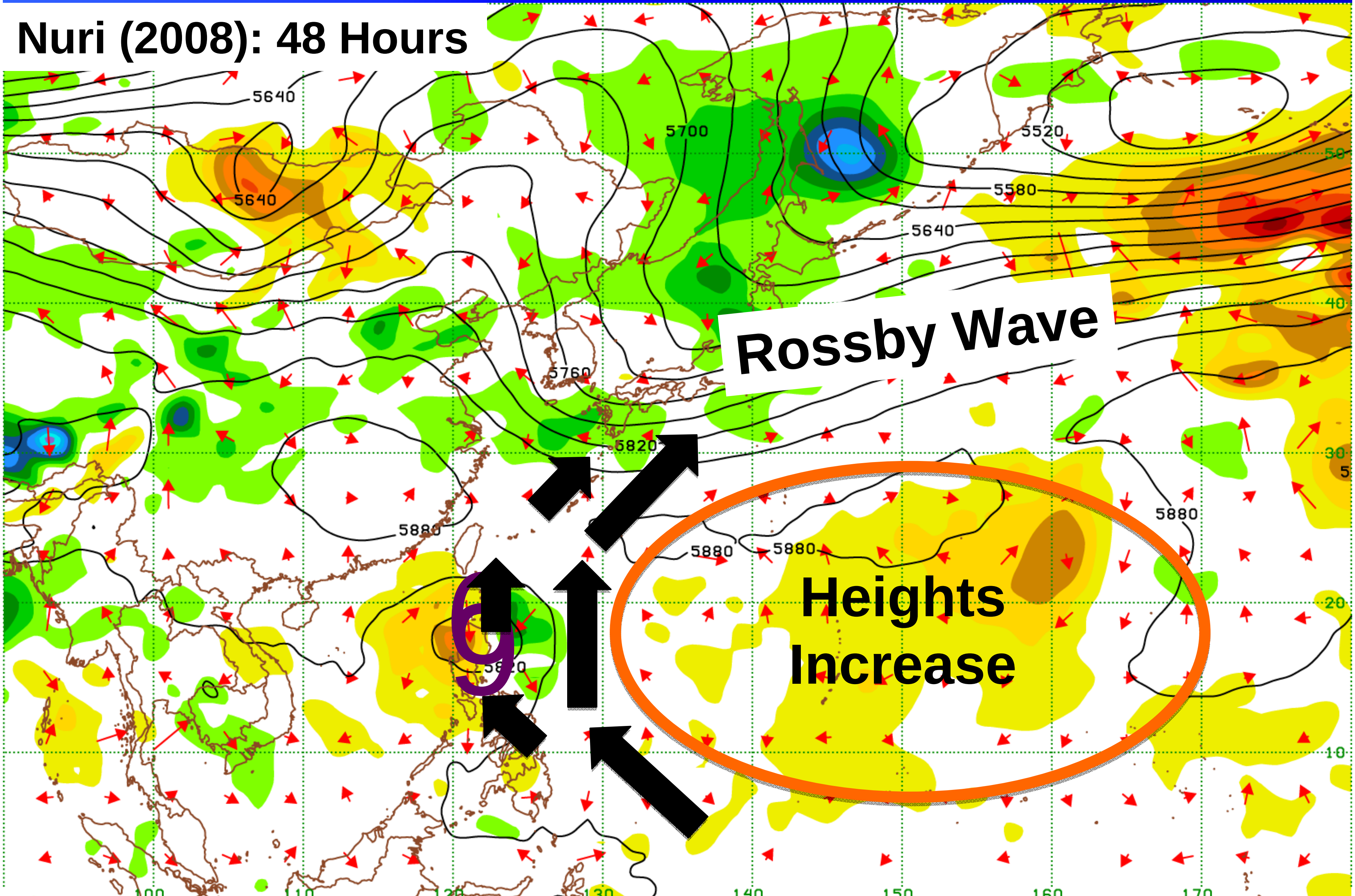
Nuri (2008): 12 Hours



Nuri (2008): 24 Hours



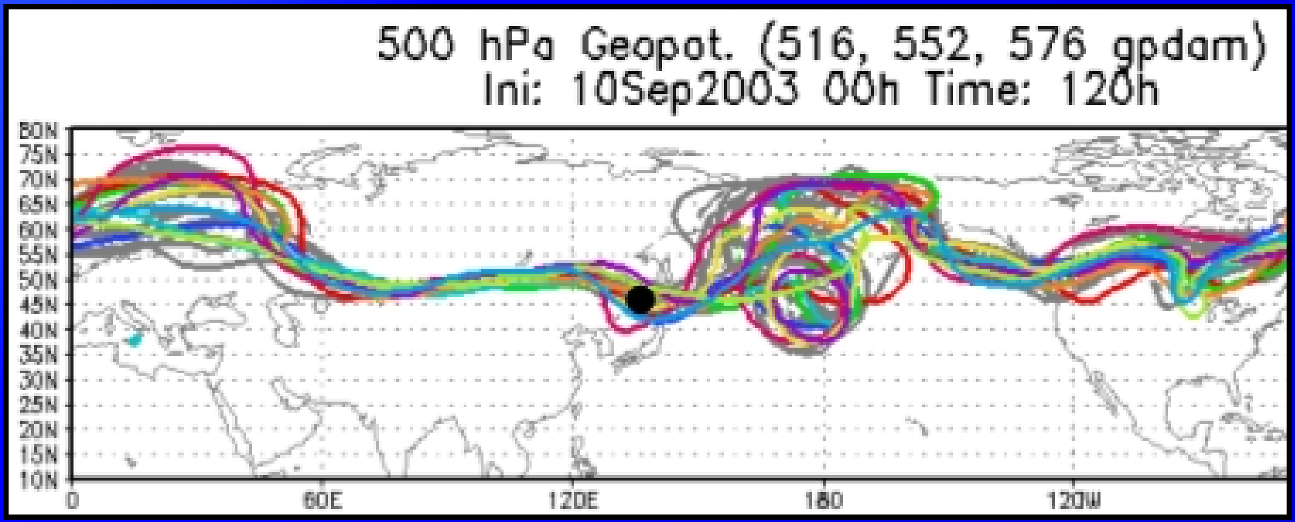
Nuri (2008): 48 Hours

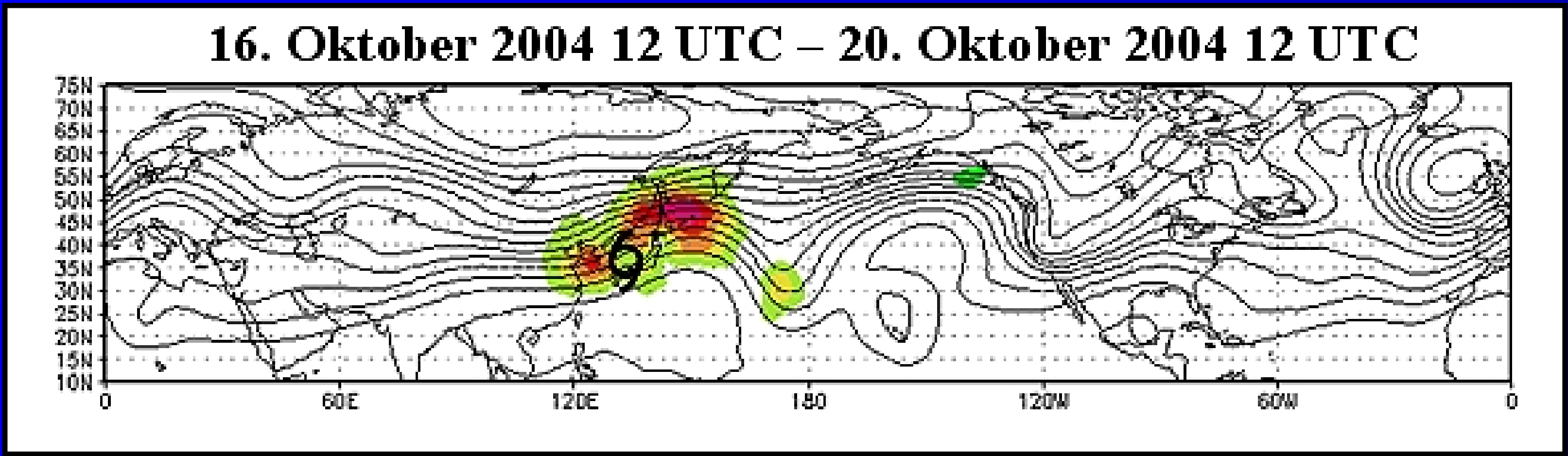


Downstream Sensitivity

- A physical mechanism exists to explain it (hence why it sometimes appears in ADSSV)
- Requires a large initial perturbation and creates a small perturbation to TC (hence why it is non-existent in SV)
- Why is it ubiquitous in ETKF guidance?

- ETKF = Dynamics + DA
  - Downstream sensitivity would be ubiquitous if uncertainty downstream of TC is usually high



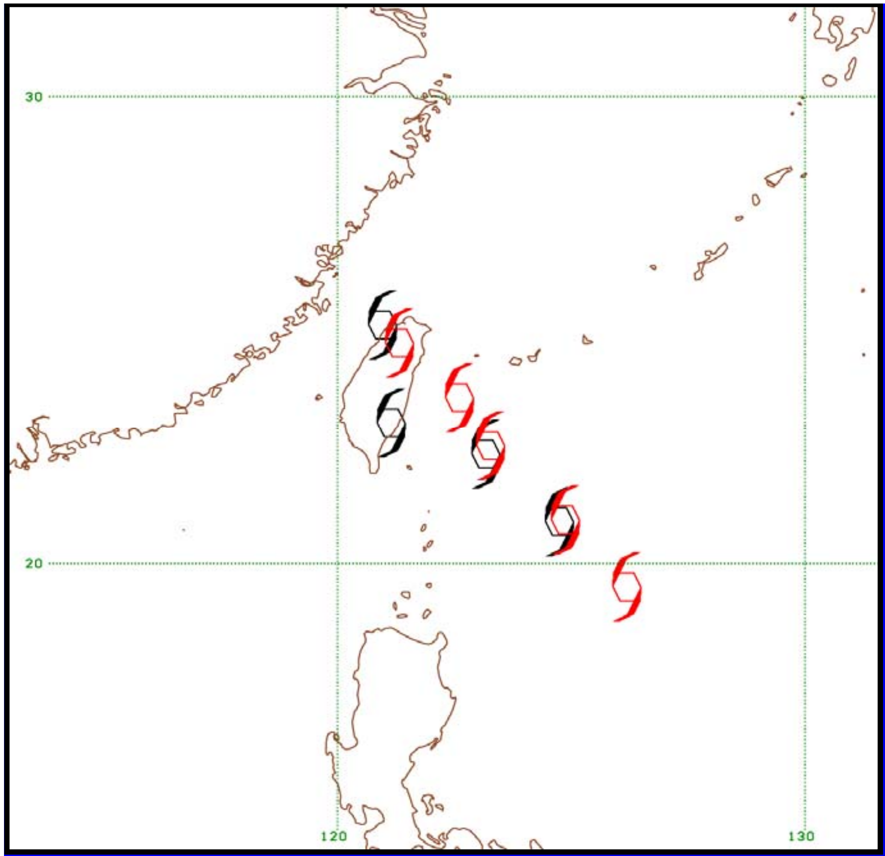


Figures courtesy of D. Anwender, Karlsruhe Institute of Technology: “Extratropical Transition of tropical cyclones: representation in Ensemble Forecasts” - http://www.imk-tro.kit.edu/english/683_2736.php

Final Thoughts

- SV may not target based on final-time steering, but that doesn't mean they are useless – TC track divergence is important!
- ADSSV fails to estimate steering changes, but it can be modified*
- Downstream sensitivity in ETKF may in part be due to TC's ability to generate significant downstream uncertainty

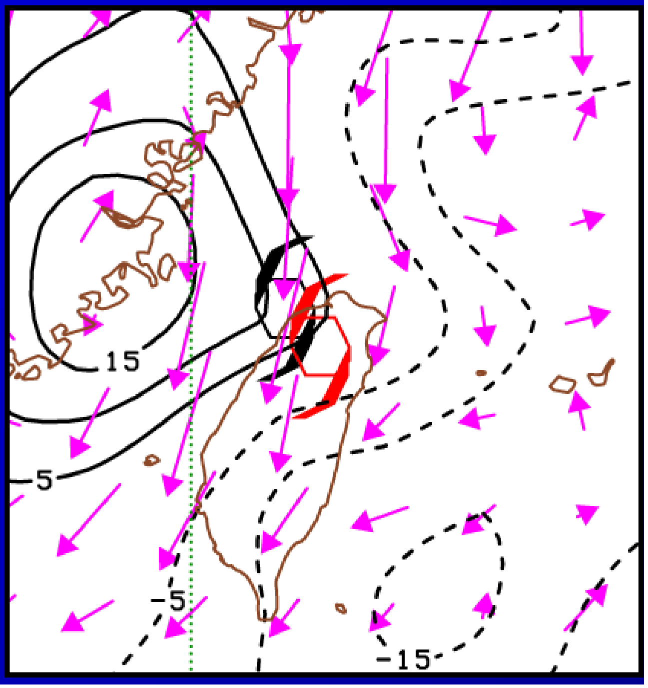
*See Hoover, B. T. and M. C. Morgan, 2010: Validation of a tropical cyclone steering response function with a barotropic adjoint model. *J. Atmos. Sci.*, **67**, 1806-1816.

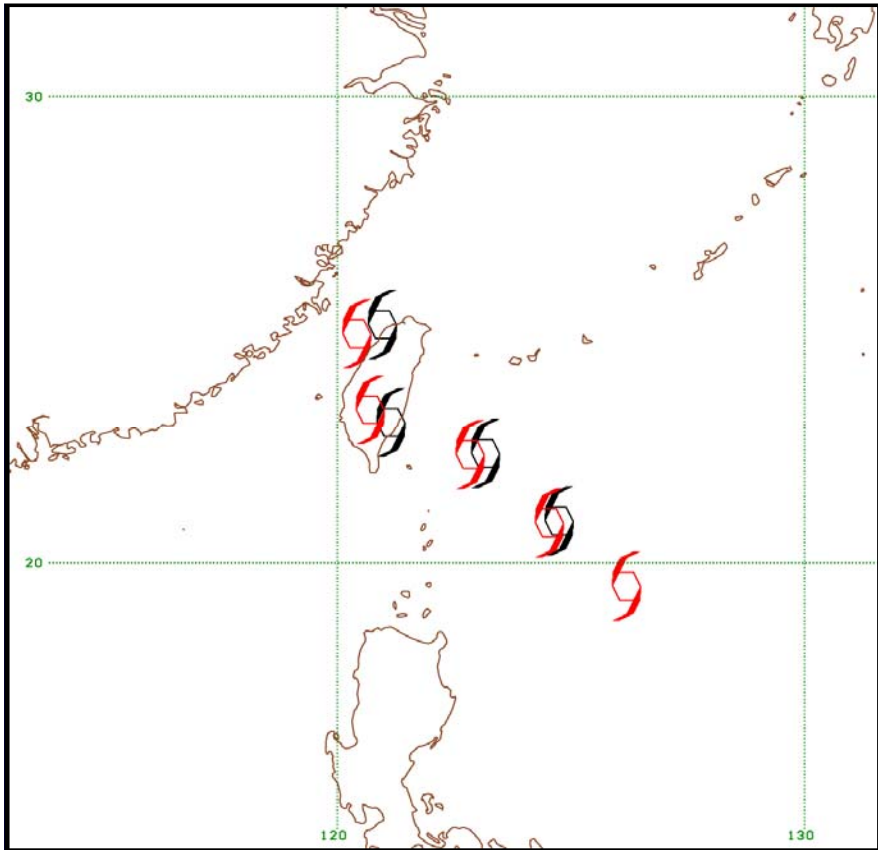


Jangmi (2008) Perturbation Experiment:

48-hr simulation (black) perturbed to excite a **southward steering change** at final time

TC is **displaced to the east**, creating dipole with strong northerly flow

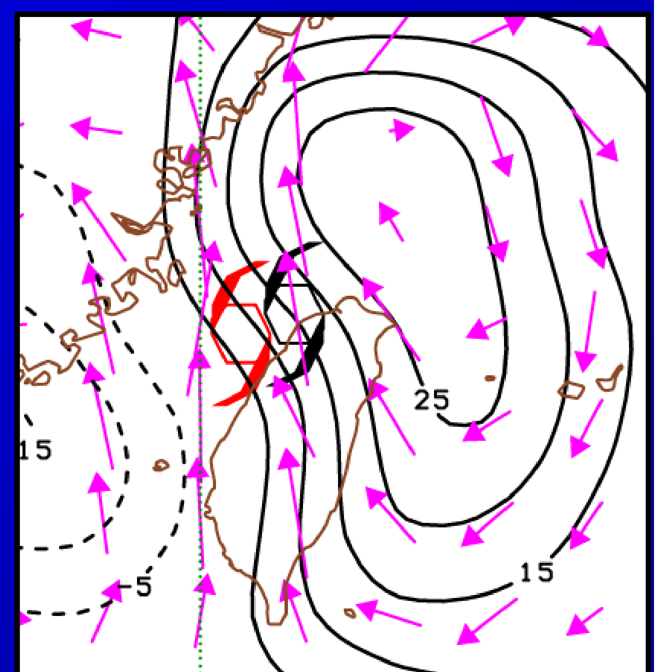


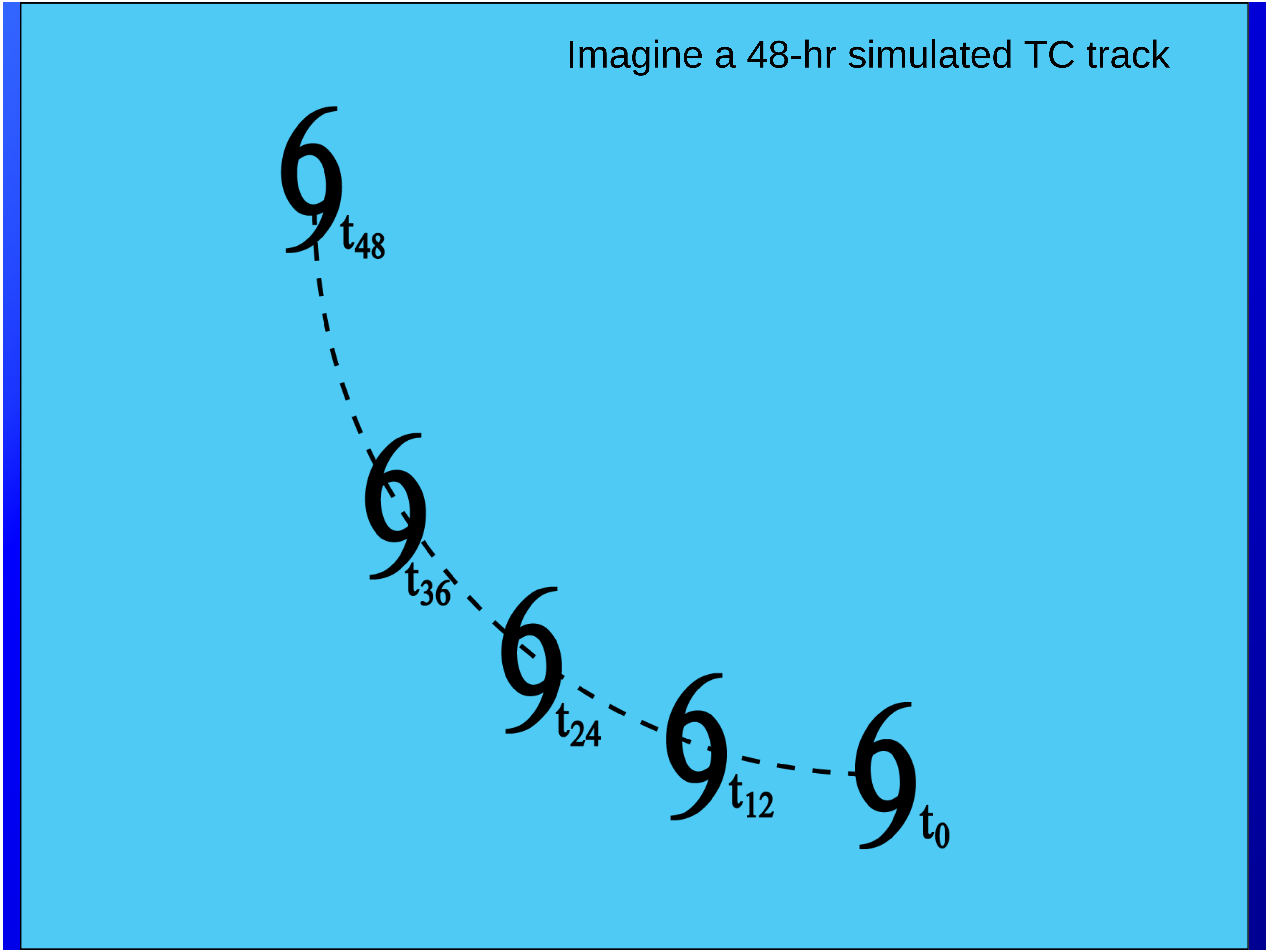


Jangmi (2008) Perturbation Experiment:

48-hr simulation (black) perturbed to excite a **northward steering change** at final time

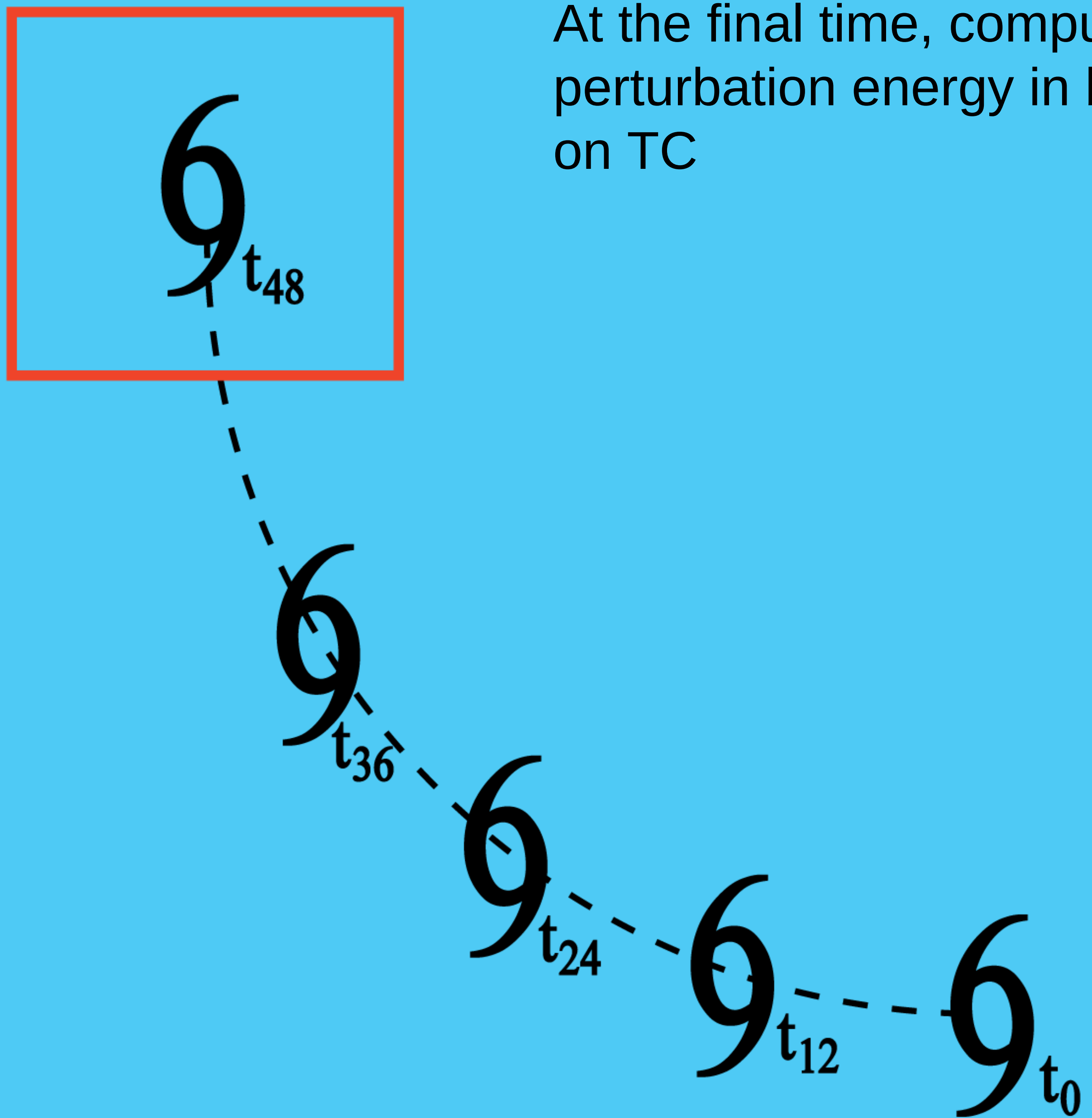
TC is **displaced to the west**, creating dipole with strong southerly flow



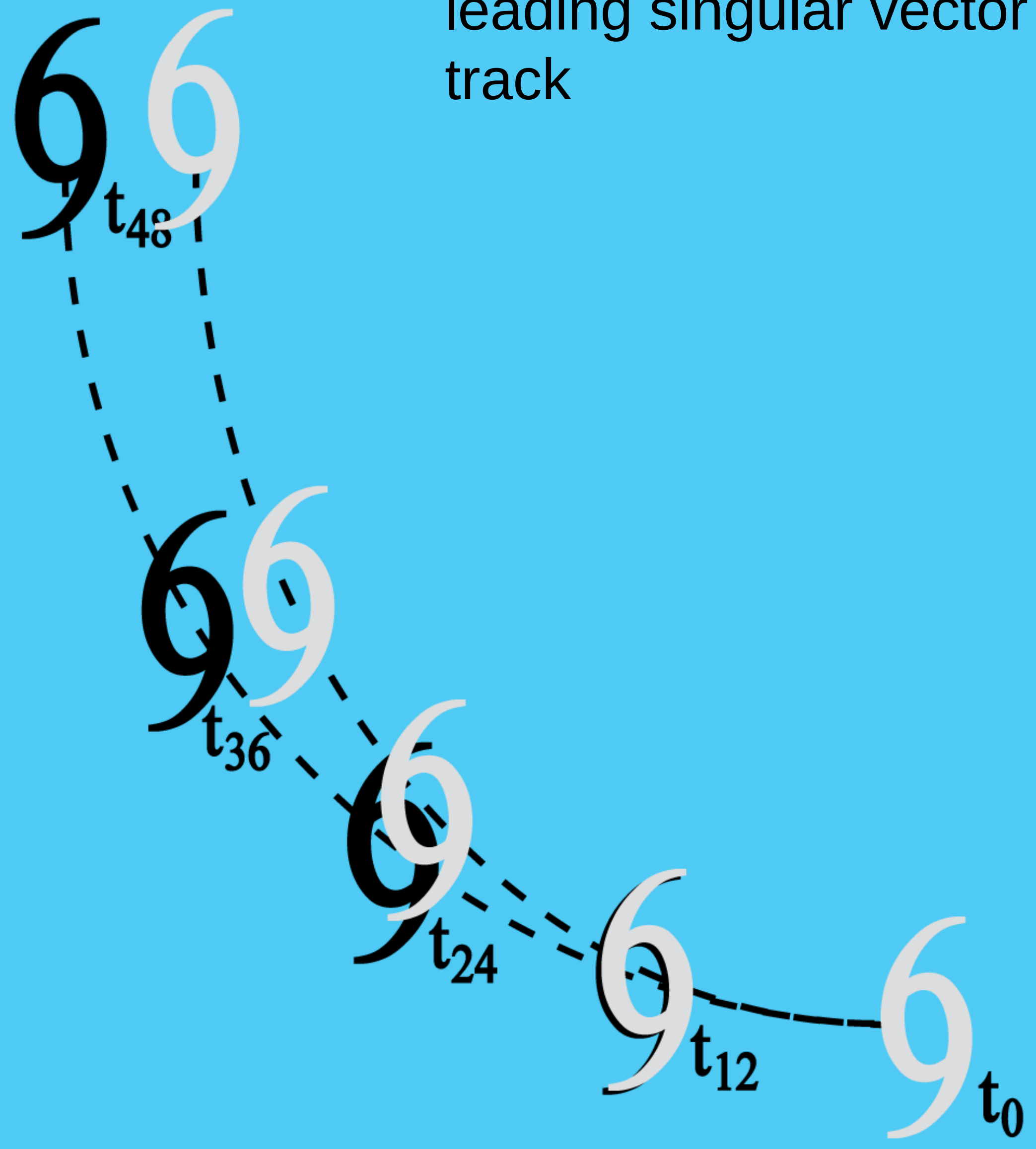


Imagine a 48-hr simulated TC track
t48
t36
t24
t12
t0

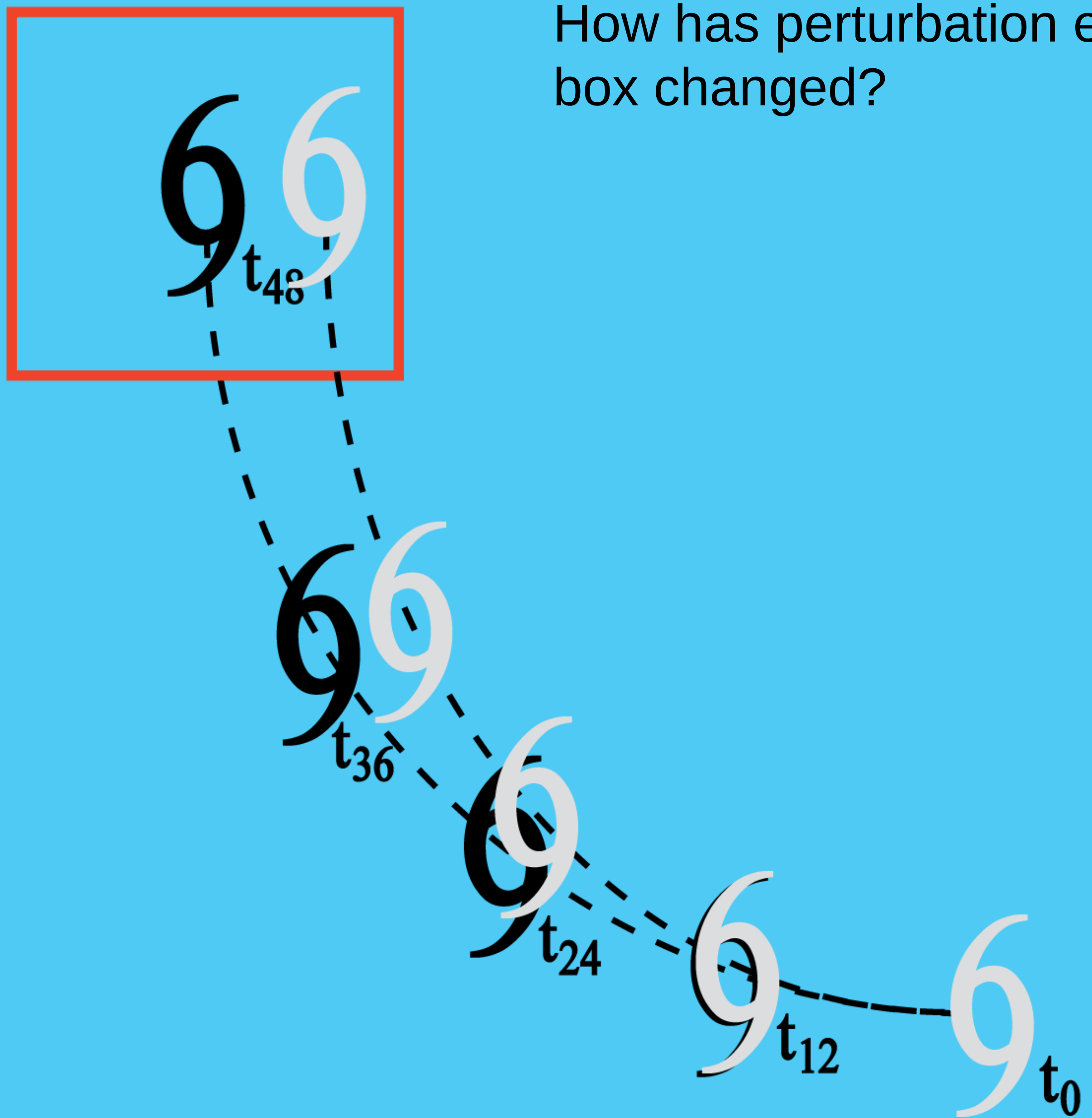
At the final time, compute SV for perturbation energy in box centered on TC

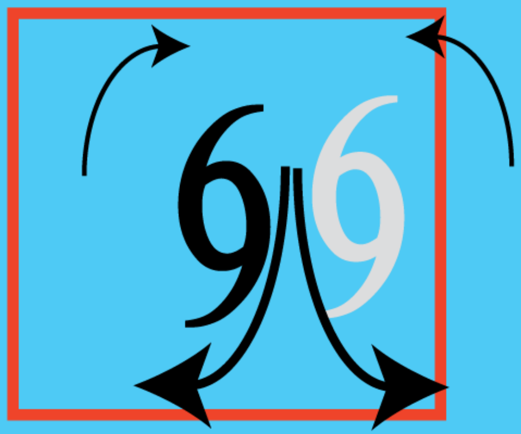


Perturb initial conditions to excite leading singular vector – new TC track



How has perturbation energy in the box changed?





Displacement of TC creates a **dipole** with **strong flow to the south** within the box.