New Interpretations of Targeting Techniques for Tropical Cyclones

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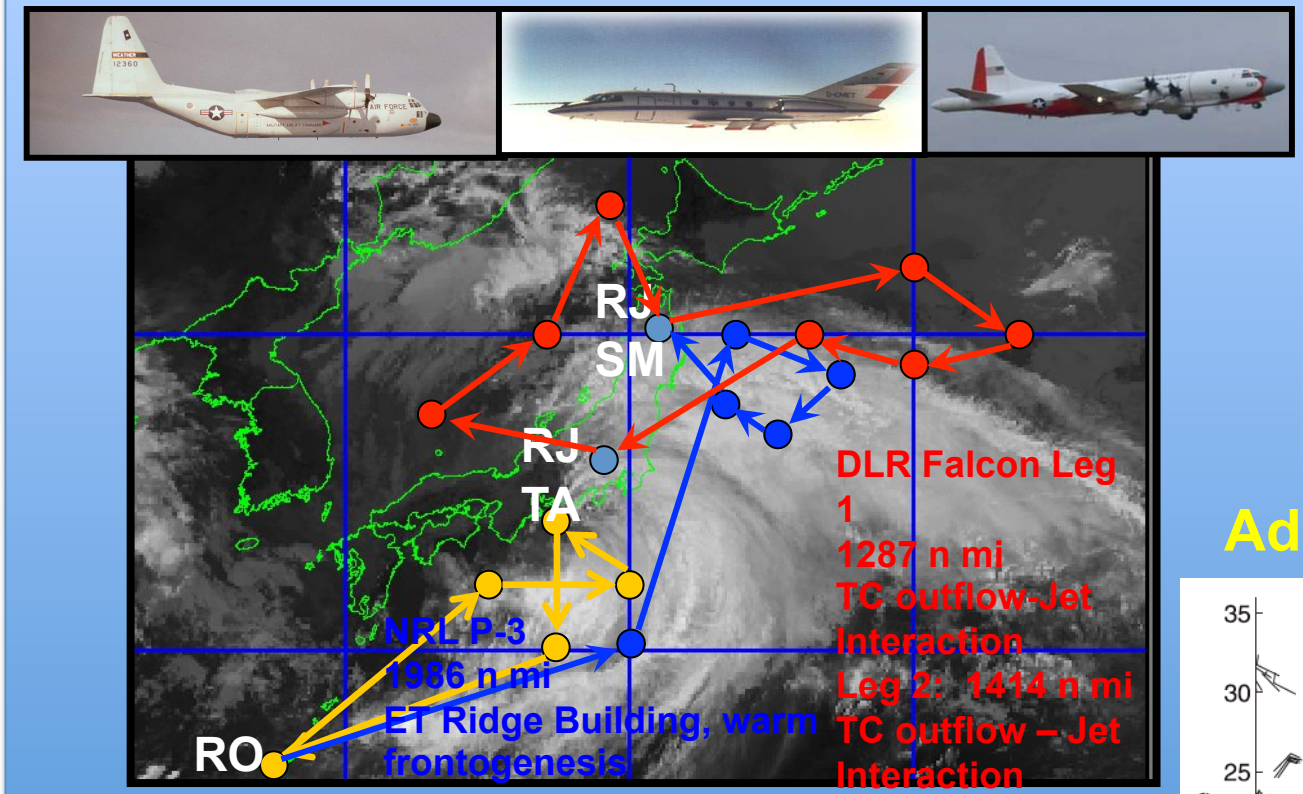
The Targeted Observing Problem

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

Potential Aircraft Sampling Strategy during Extratropical Transition

Adaptive Satellite Obs.

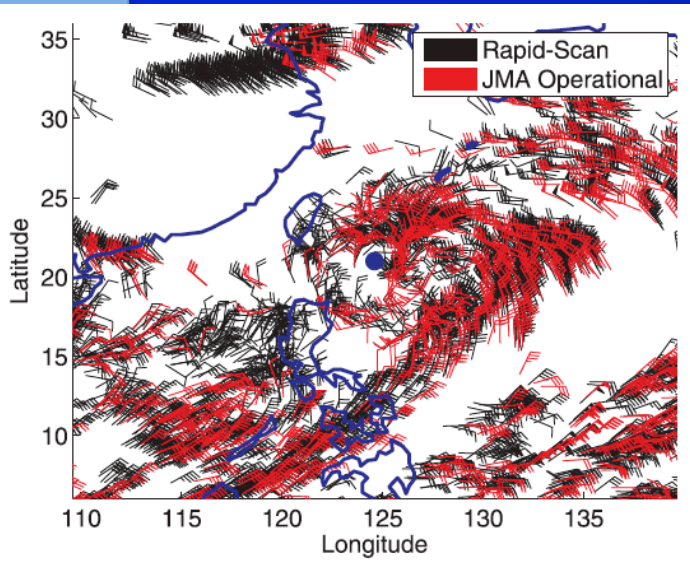


FIG. 1. Upper-level (100–350 hPa) operational (red) and rapid-scan (black) AMVs near Typhoon Sinlaku (blue dot = center) valid for 0000 UTC 11 Sep 2008.

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.

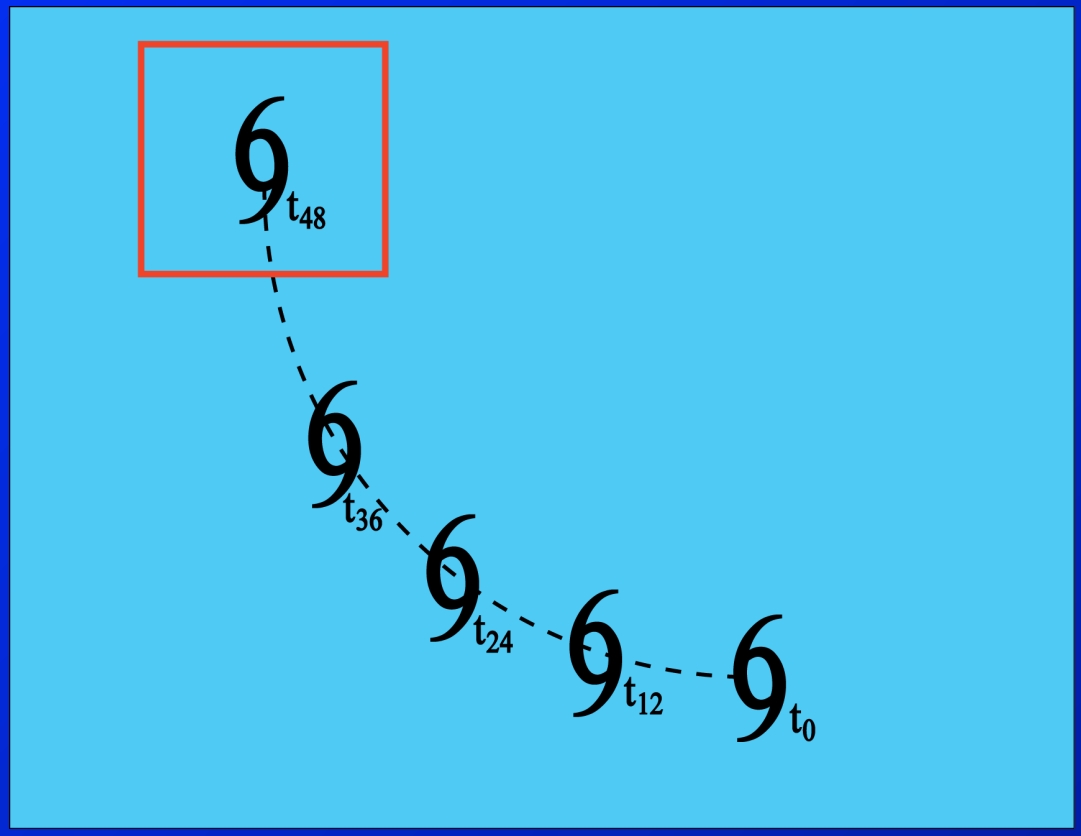
The Targeted Observing Problem

- 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**?

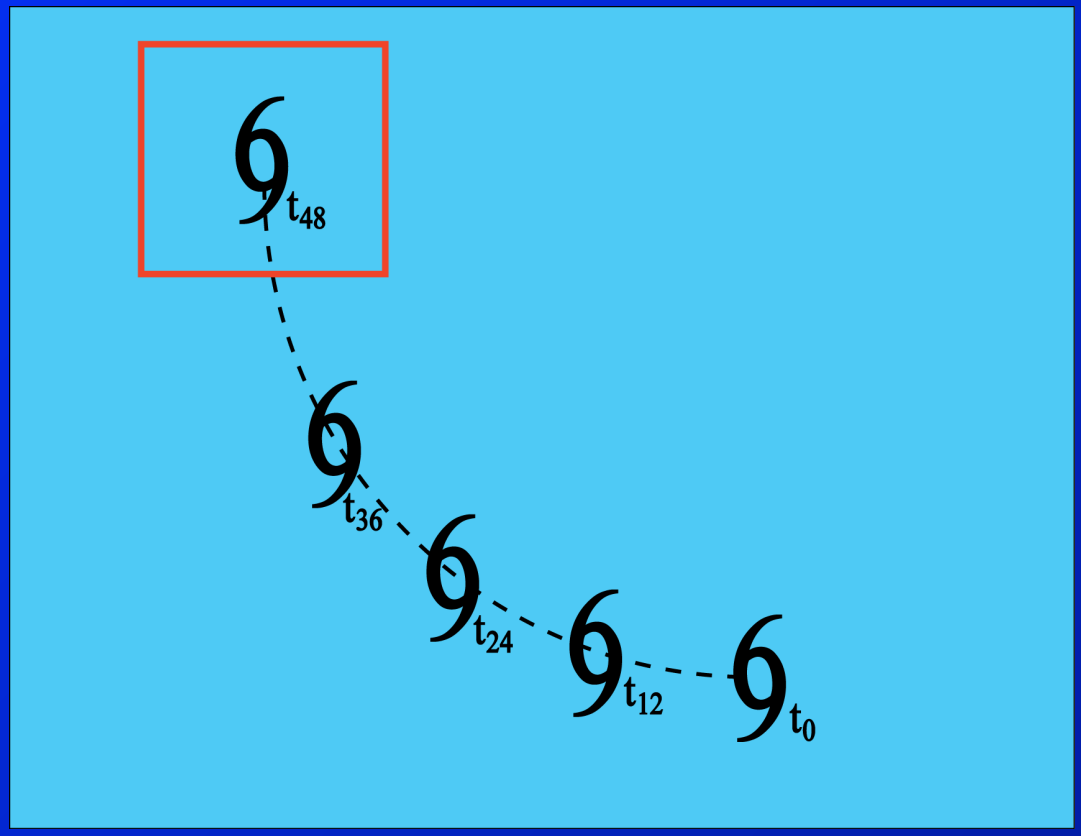
Errors that project onto SVs will create the most perturbation energy around the TC at the final time, **presumably having the largest impact on steering/ intensity at that time**.

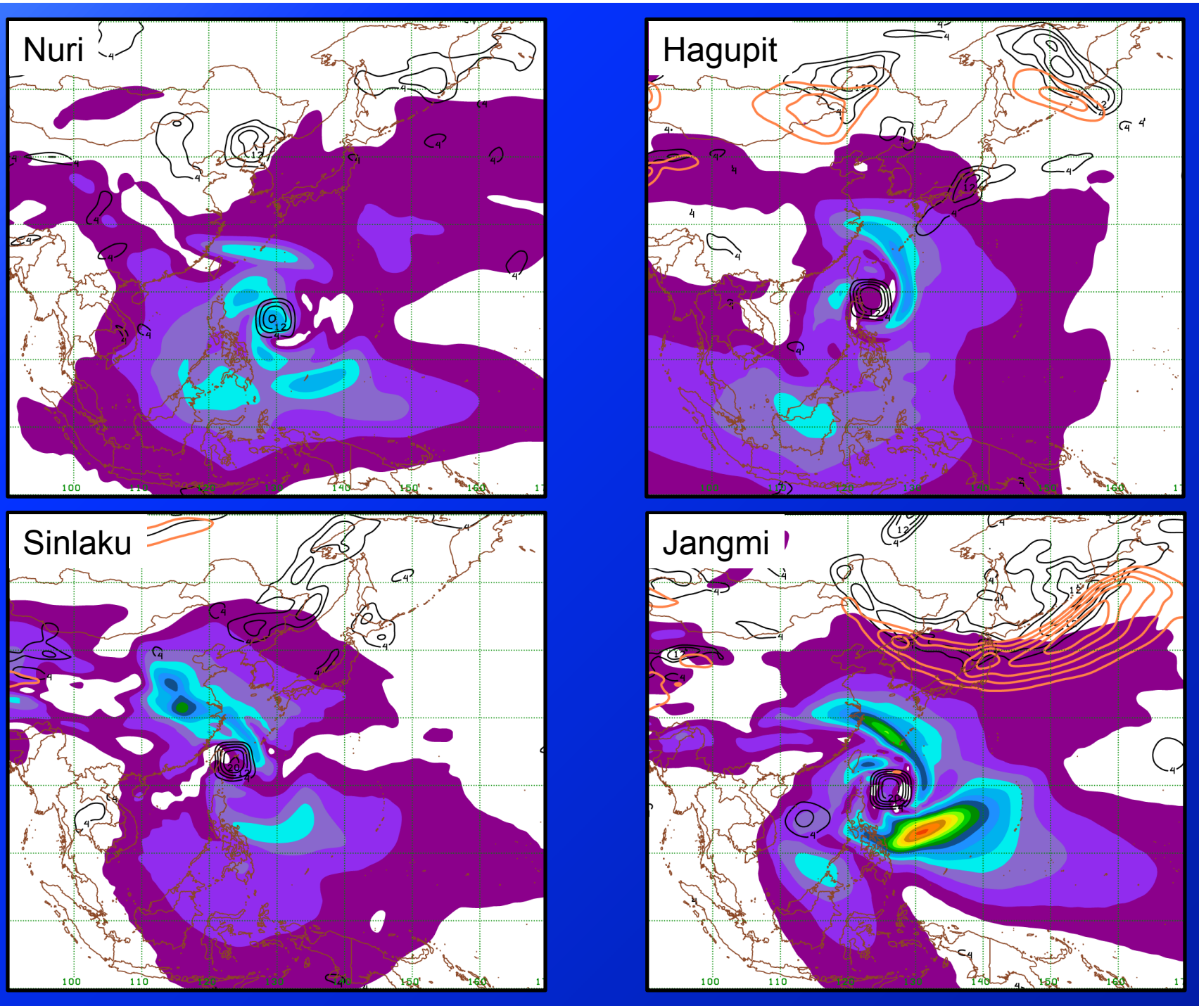


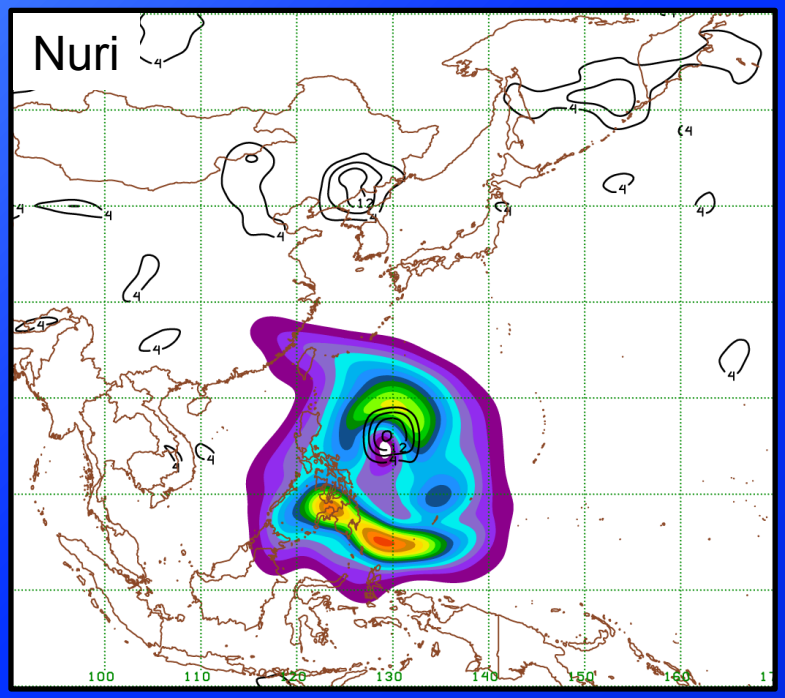
Adjoint-Derived Sensitivity Steering Vector (ADSSV) Guidance

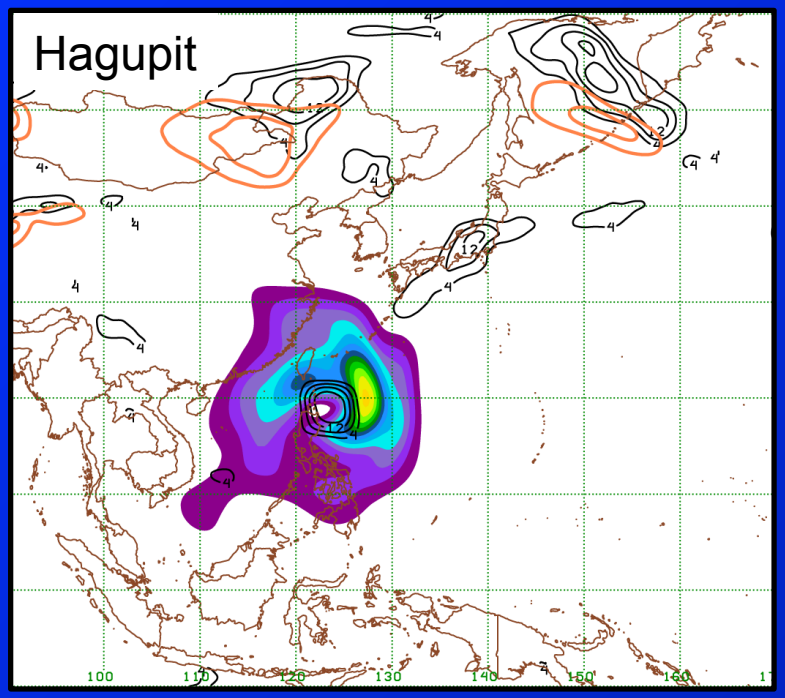
How much will any vorticity perturbation to the initial conditions **change the average flow** in a box surrounding the TC at 48 hours?

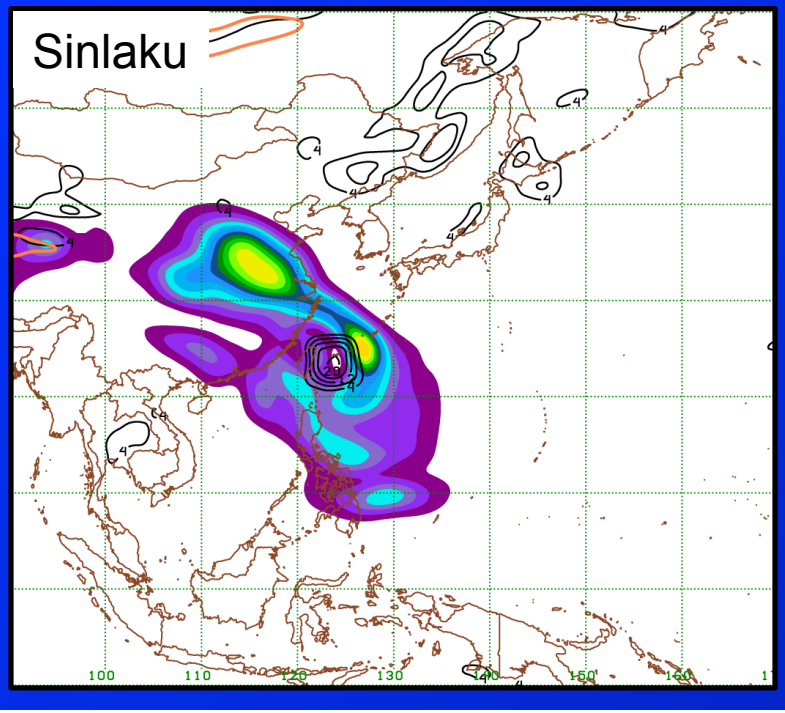
Errors that project onto ADSSVs will change the average flow around the TC at the final time, **presumably having the largest impact on steering at that time**.

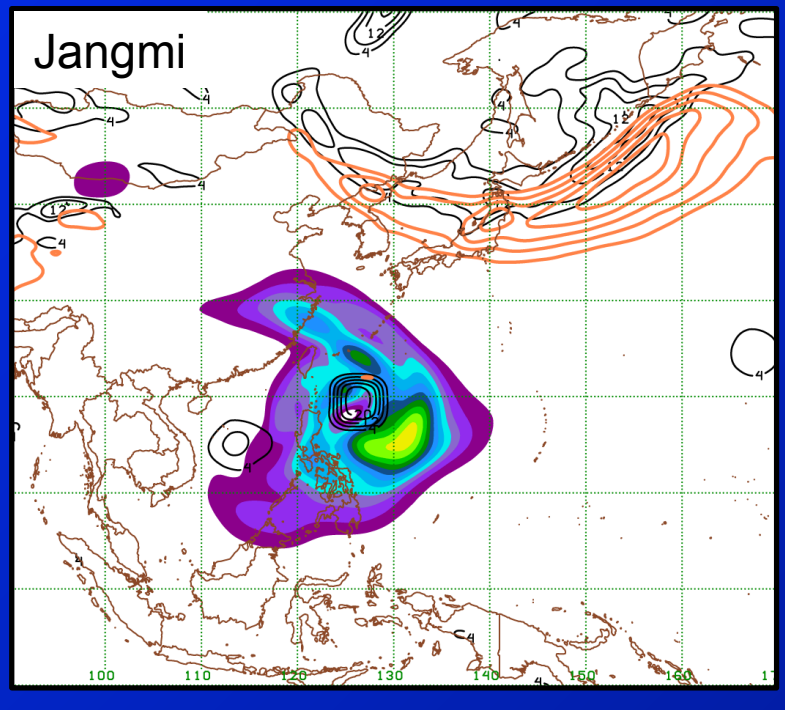


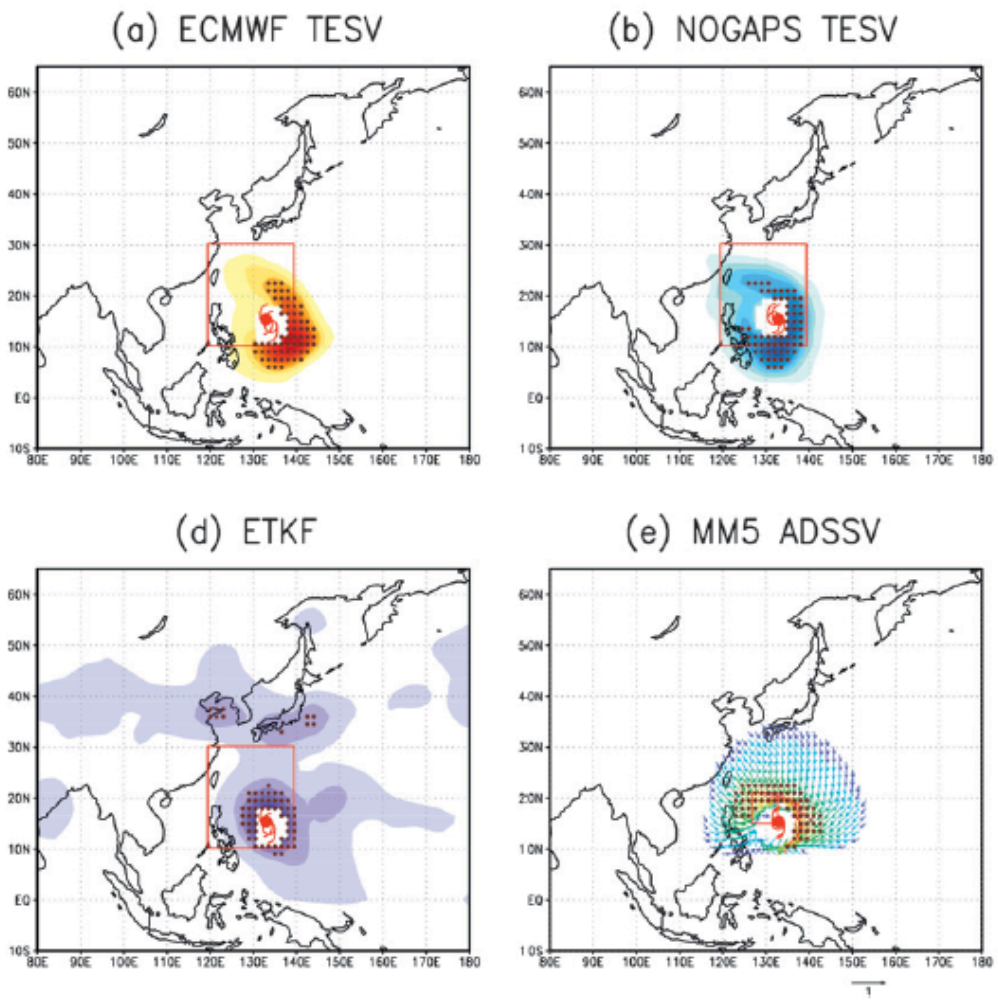

Nuri
Hagupit
Sinlaku
Jangmi


Nuri


Hagupit


Sinlaku


Jangmi



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.

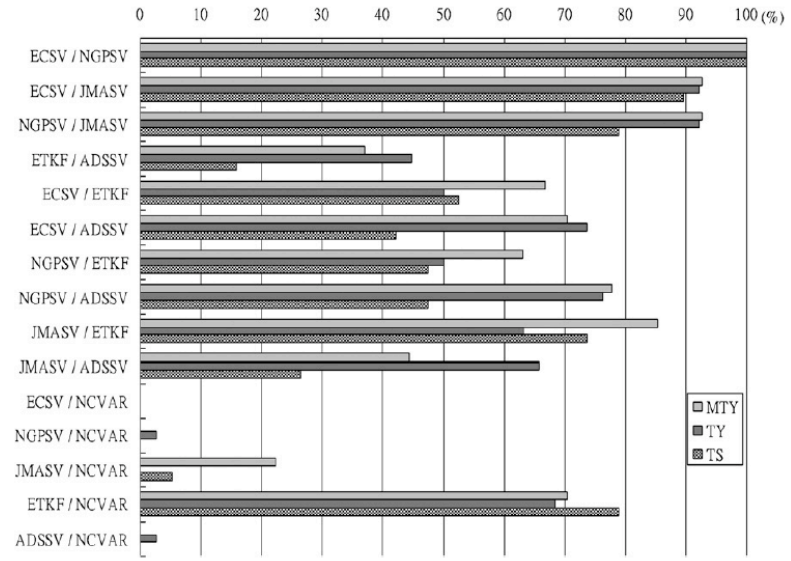
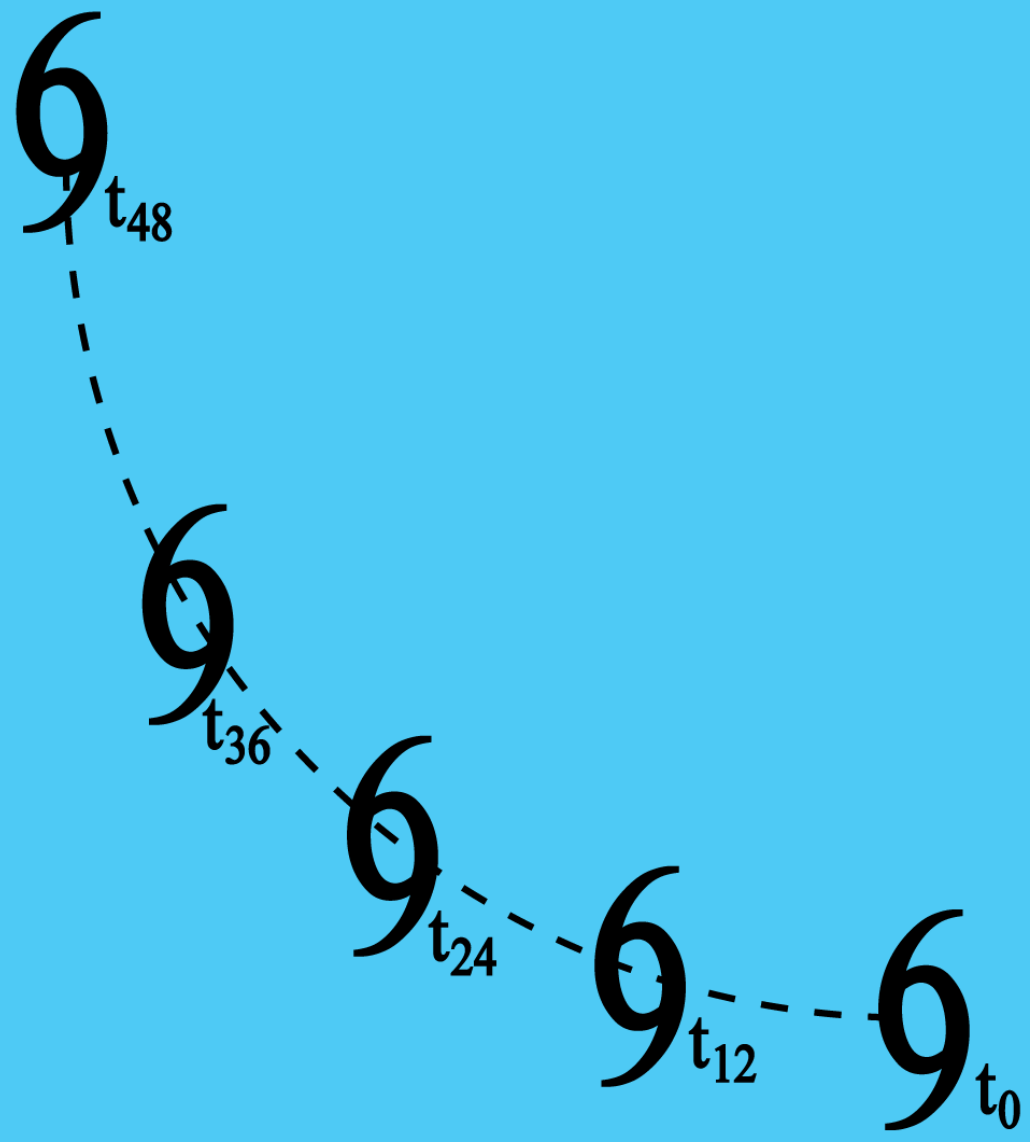
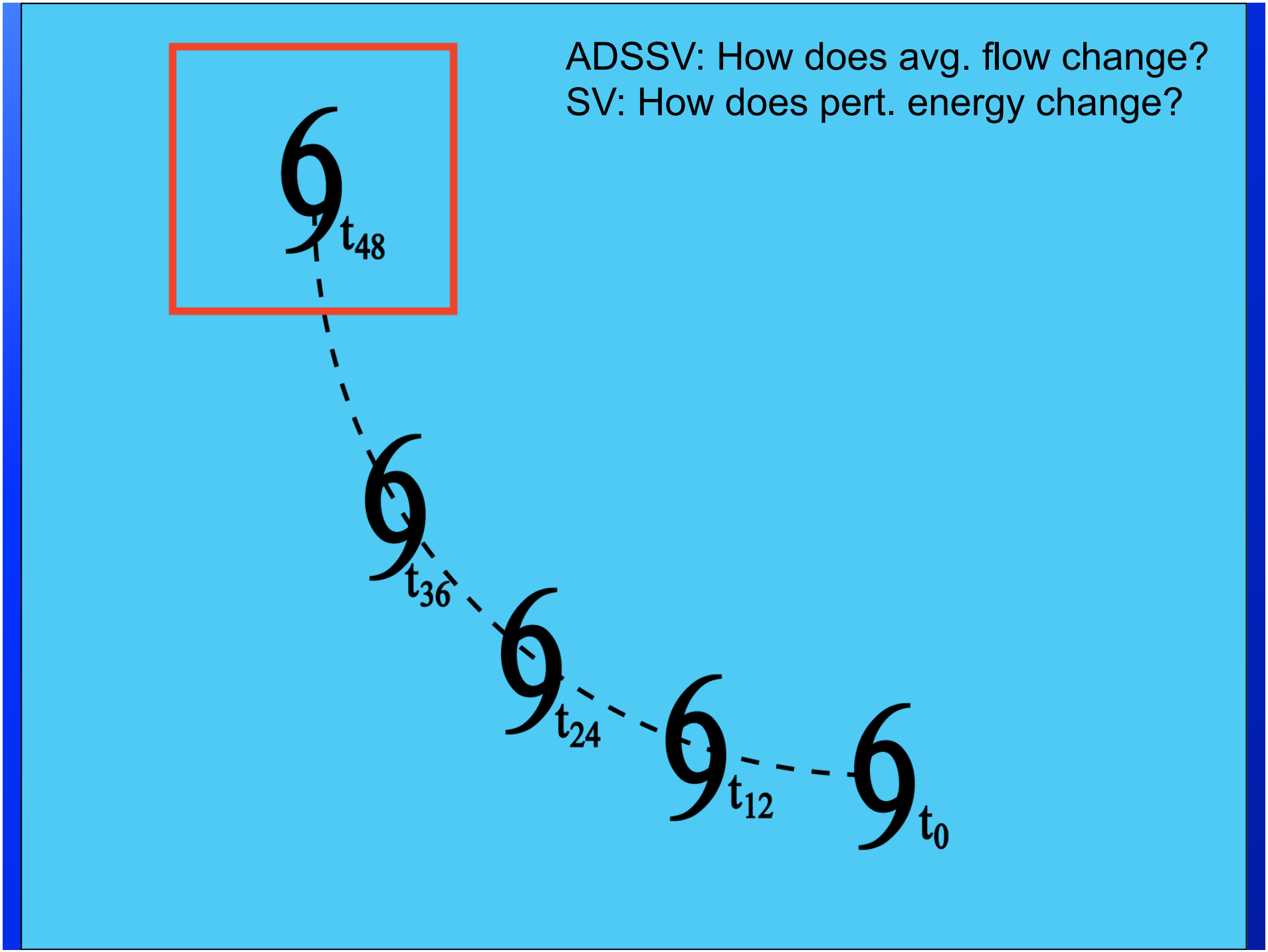


FIG. 8. Percentage of cases with the Spearman rank correlation coefficient (R_s) set to be larger than 0.2. Results are shown for typhoons of three different intensity categories: 27 major typhoons (MTY), 38 typhoons (TY), and 19 tropical cyclones (TC).

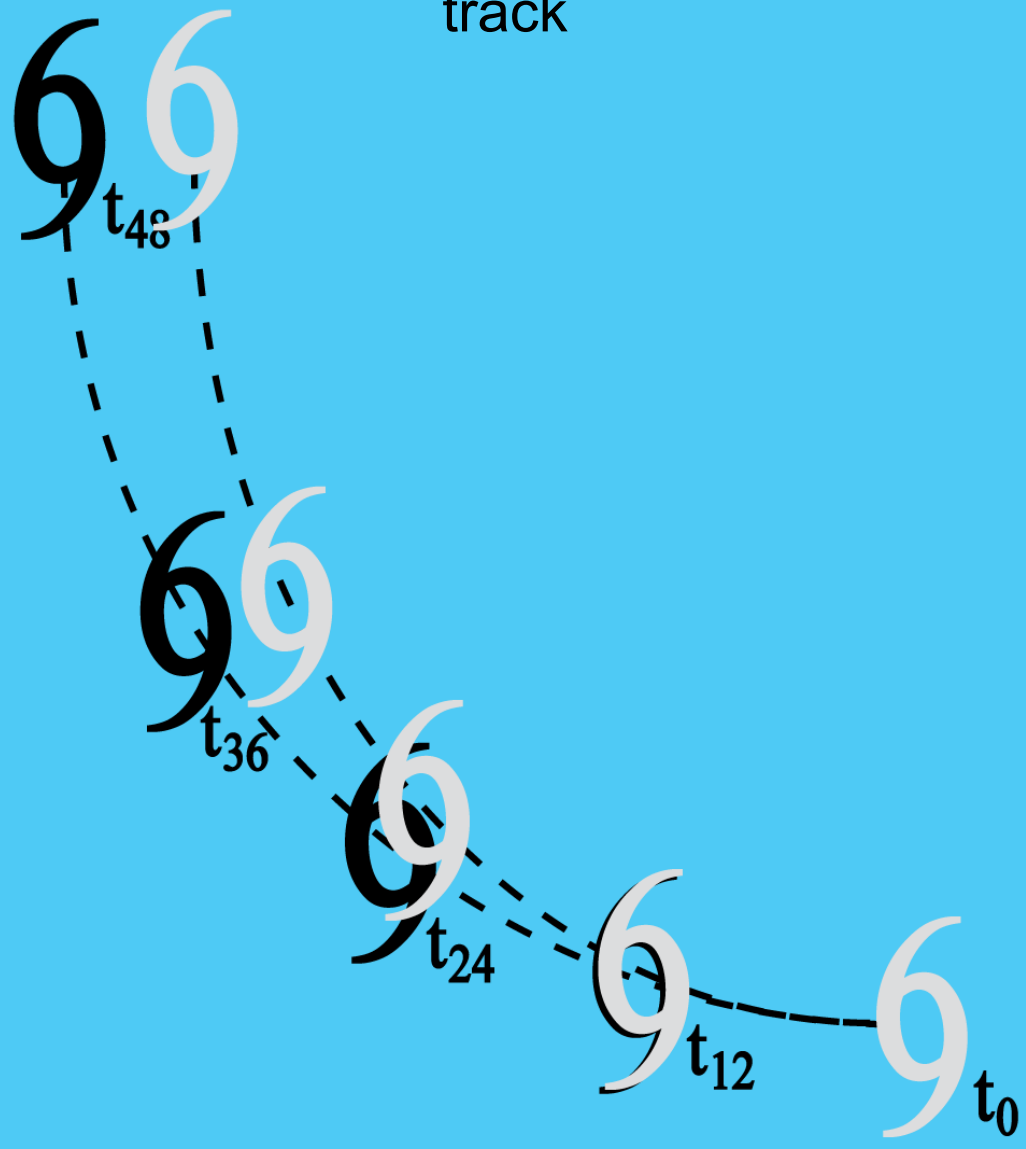
Wu, C.-C. and Coauthors, 2009: Intercomparison of Targeted Observation Guidance for Tropical Cyclones in the Northwestern Pacific. *Mon. Wea. Rev.*, **137**, 2471-2492.

Imagine a 48-hr simulated TC track

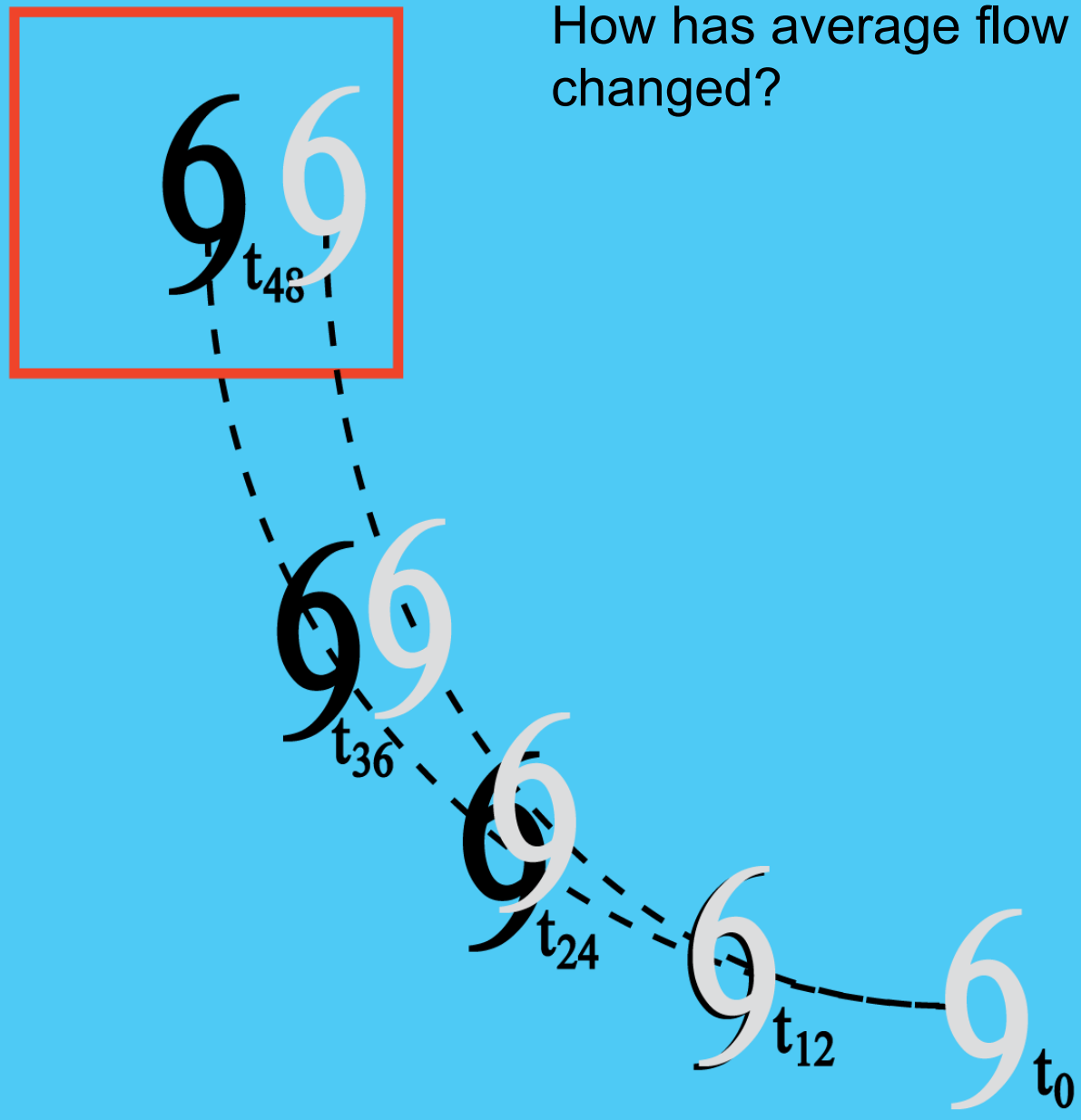


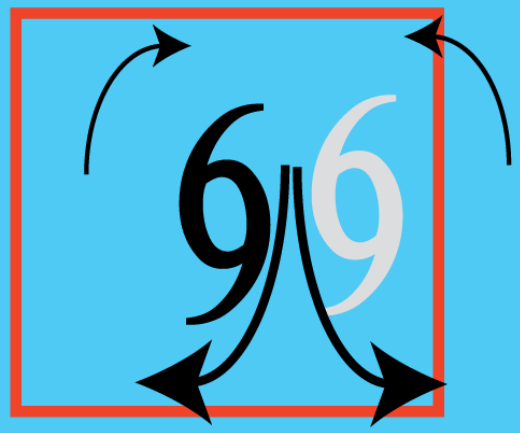

ADSSV: How does avg. flow change?
SV: How does pert. energy change?
t_{48}
t_{36}
t_{24}
t_{12}
t_0

Perturb initial conditions – New TC track

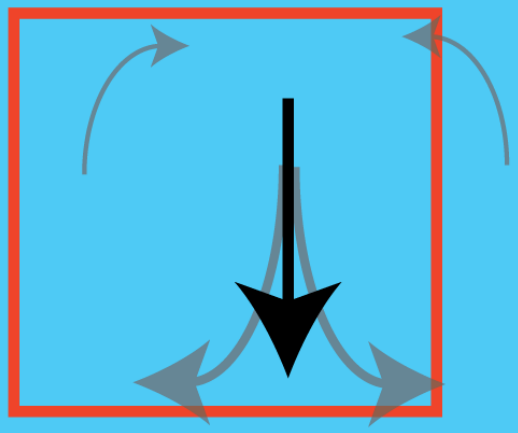


How has average flow in the box changed?





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



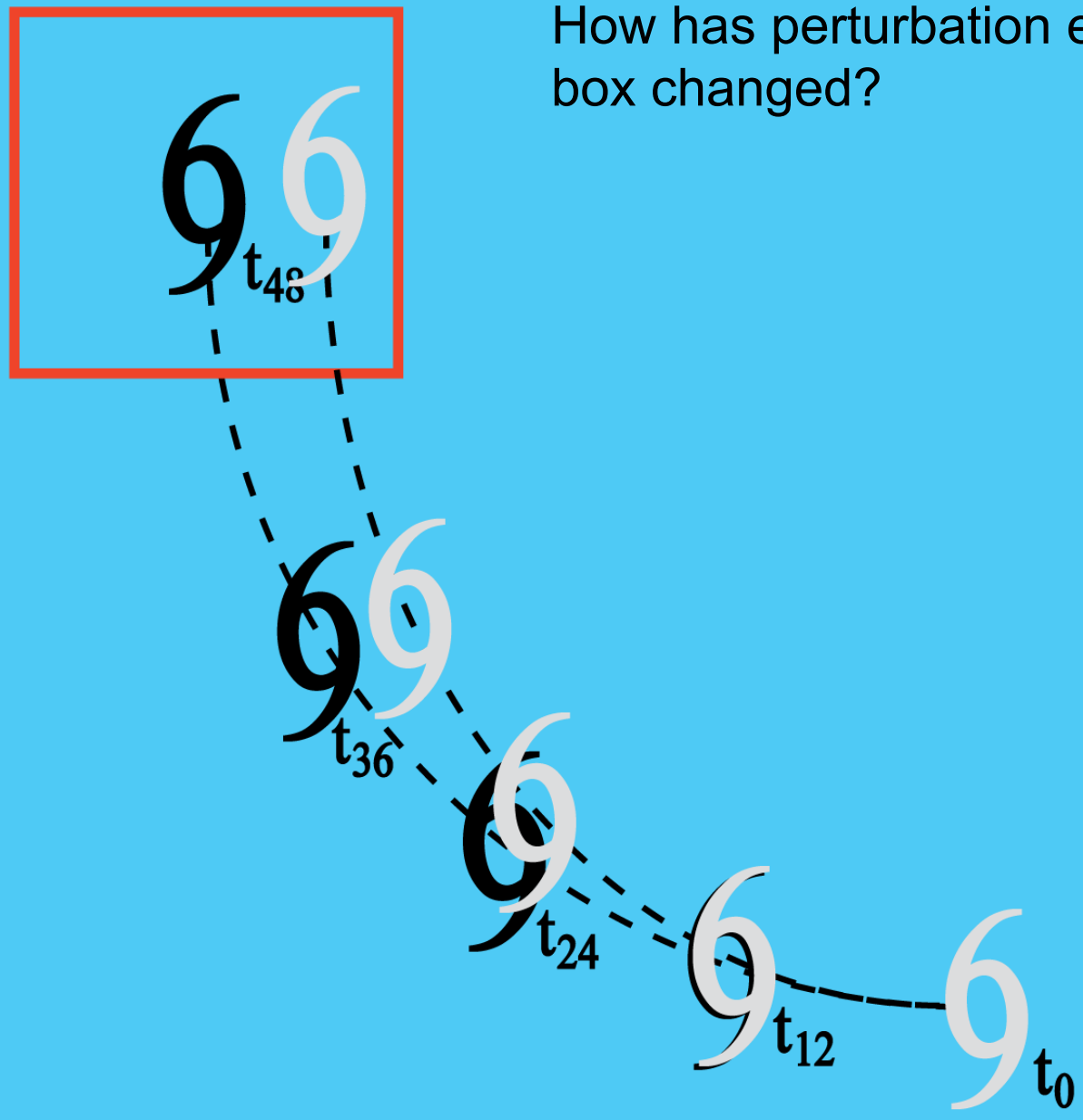
It is this flow which is **primarily responsible** for the change in the average flow in the box

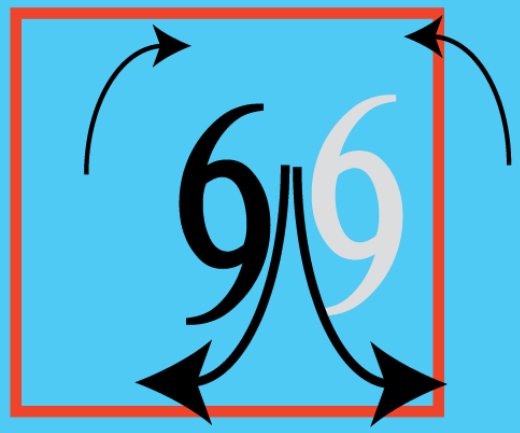
It is this flow which the ADSSV **(correctly) anticipated as a result** of perturbations to the initial state

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

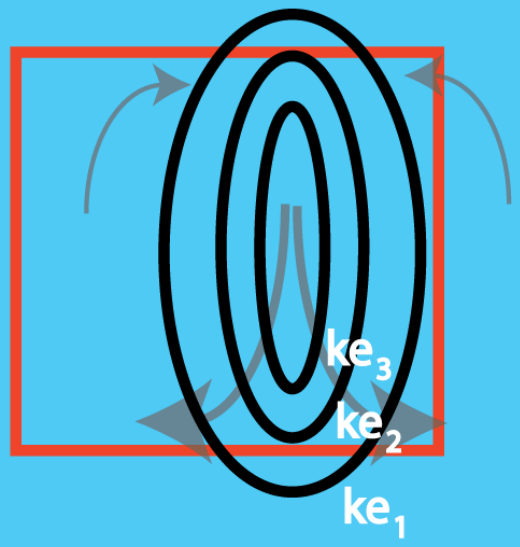
The ADSSV does not compute sensitivity of TC steering with respect to initial state perturbations, but rather sensitivity of some measure related to TC track changes. The interpretation of what ADSSV sensitivity actually measures is largely incorrect.

How has perturbation energy in the box changed?





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

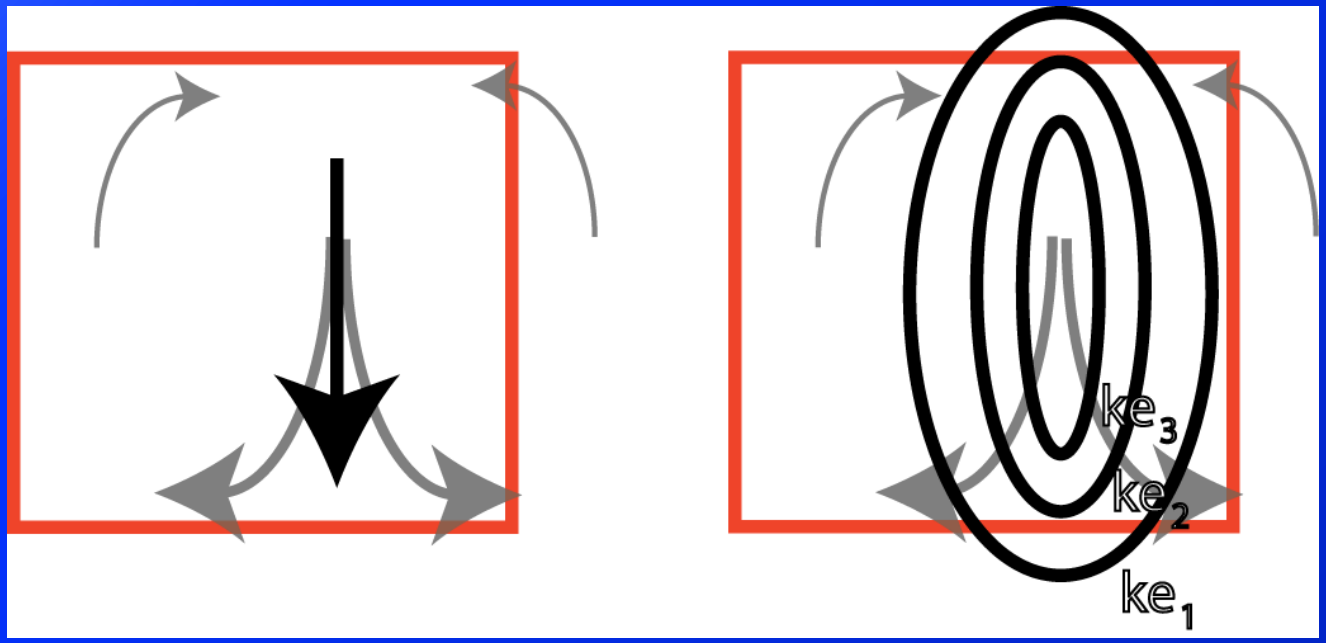


It is this flow which is **primarily responsible** for the change in the perturbation kinetic energy in the box

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

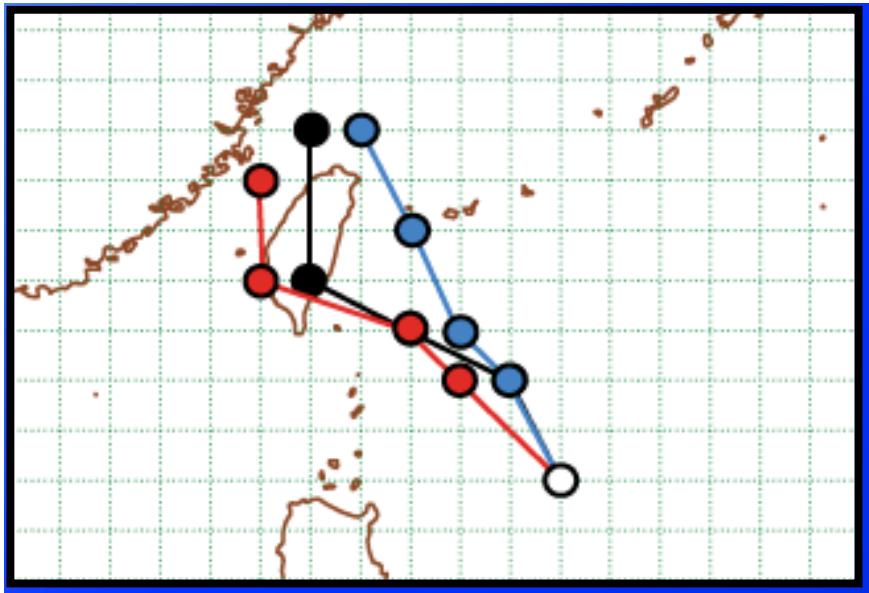
The SV does not compute sensitivity of TC steering with respect to initial state perturbations, but rather sensitivity of some measure related to TC track changes.

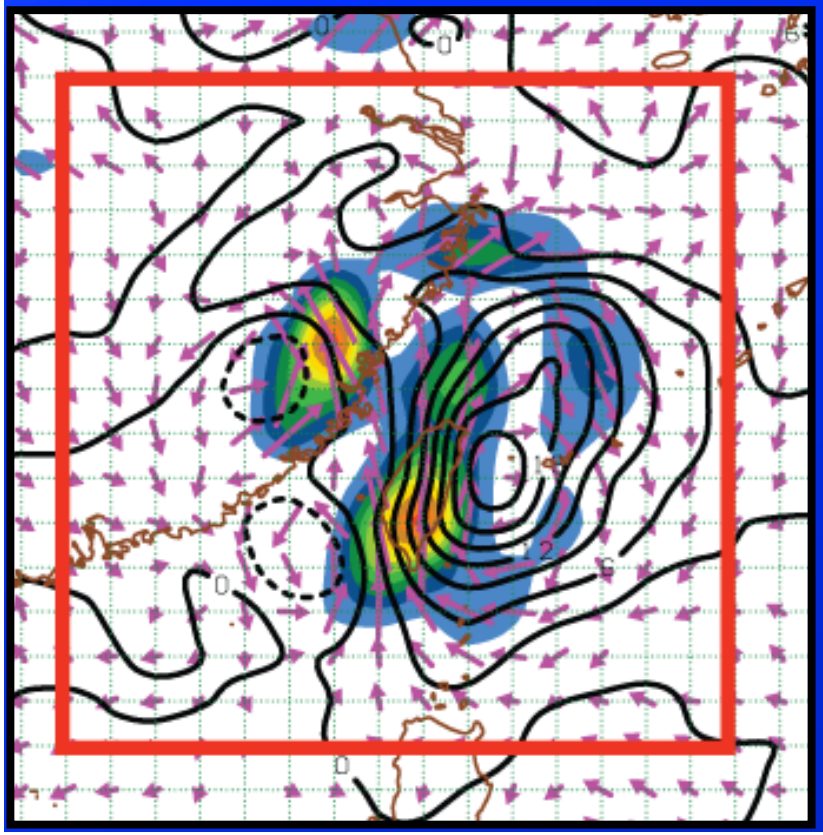


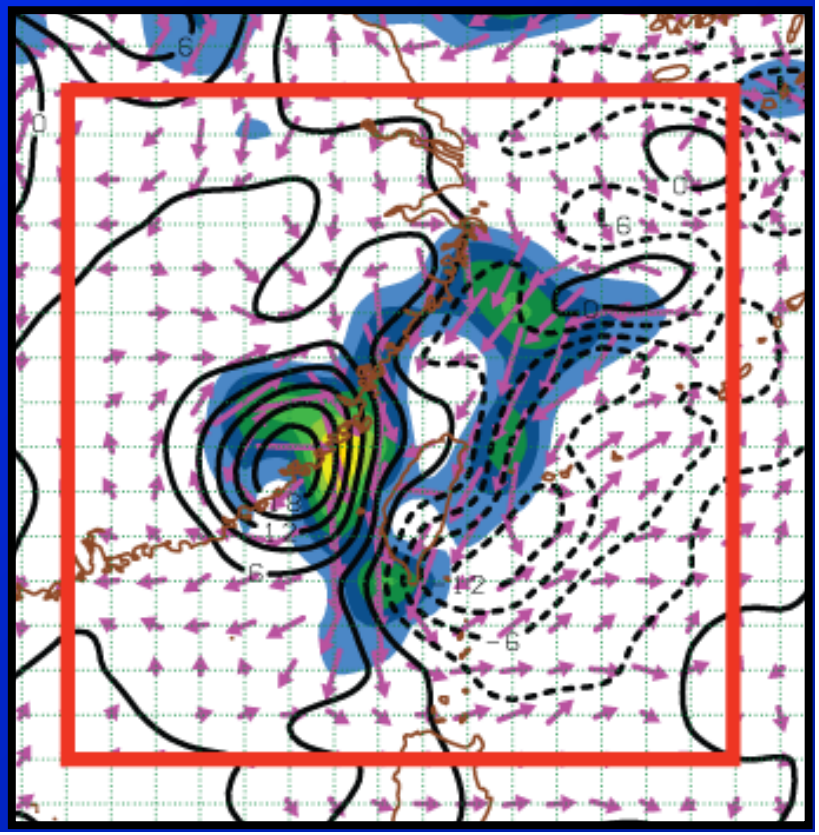
It is this effect, the **displacement of the TC vortex** at the final time, which has the dominant impact on the metrics used by **both** ADSSV and SV techniques, and it has **nothing** to do with steering at the final time

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

Jangmi (2008) Perturbation Experiment:

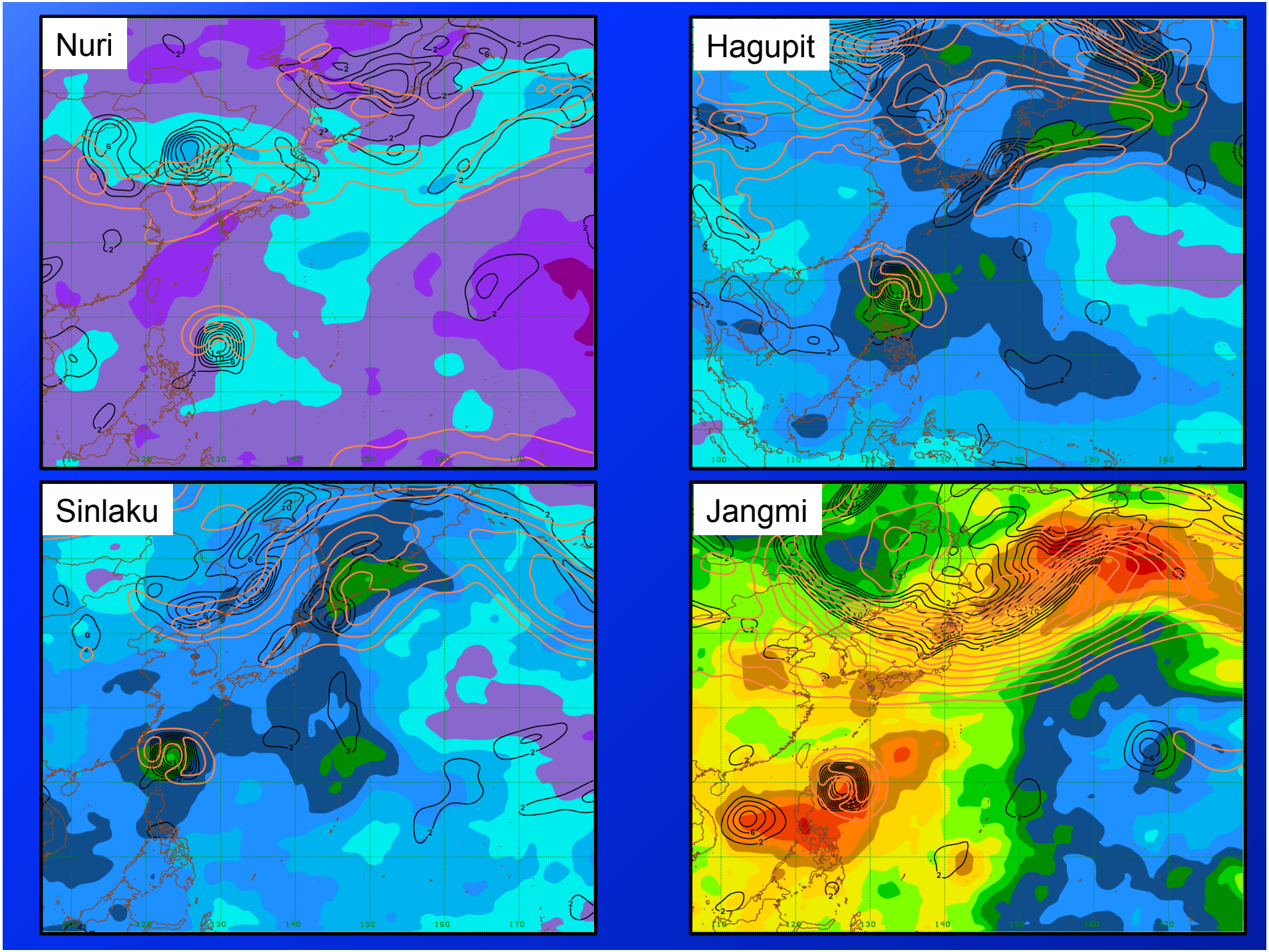






A Different Strategy: ETKF

- **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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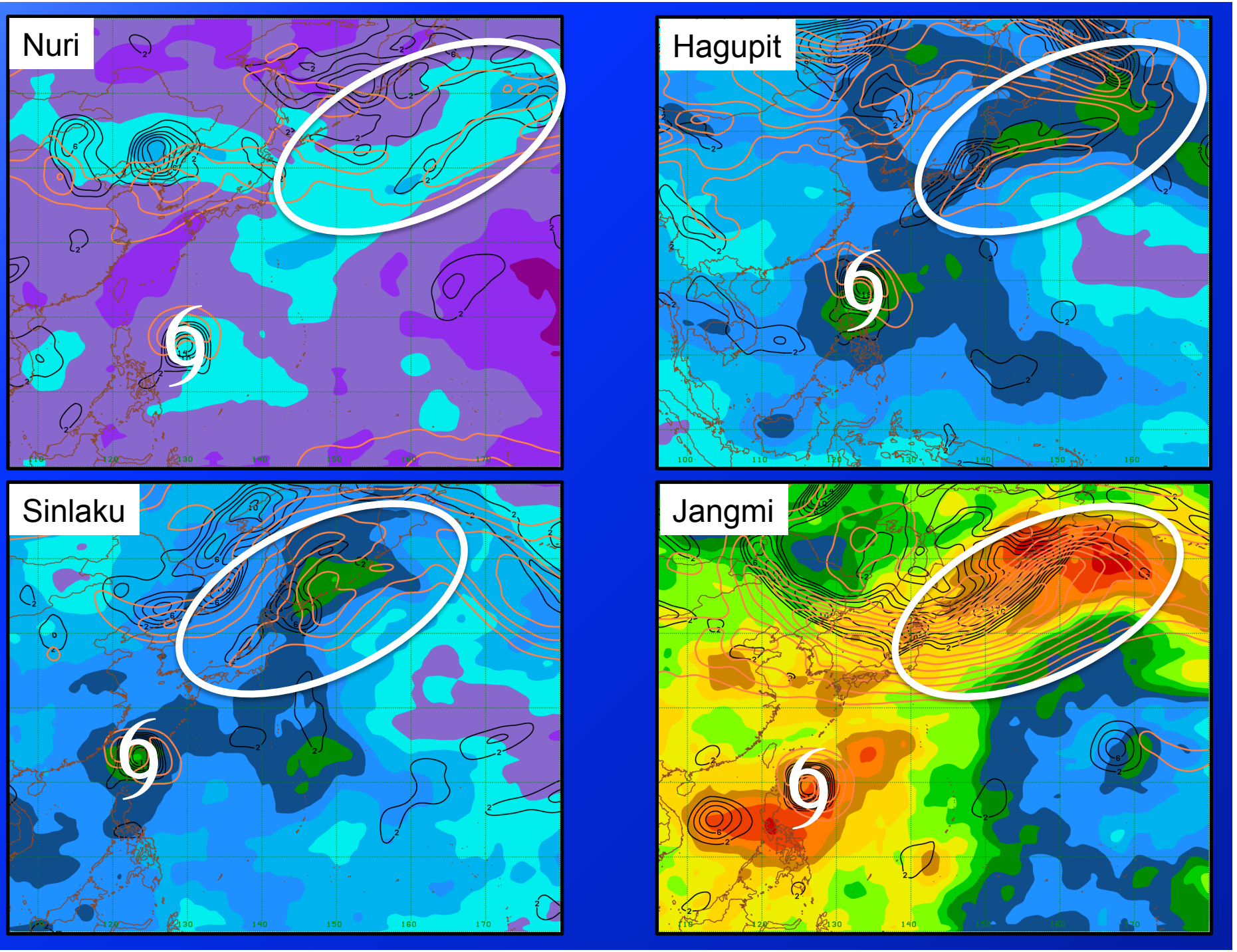
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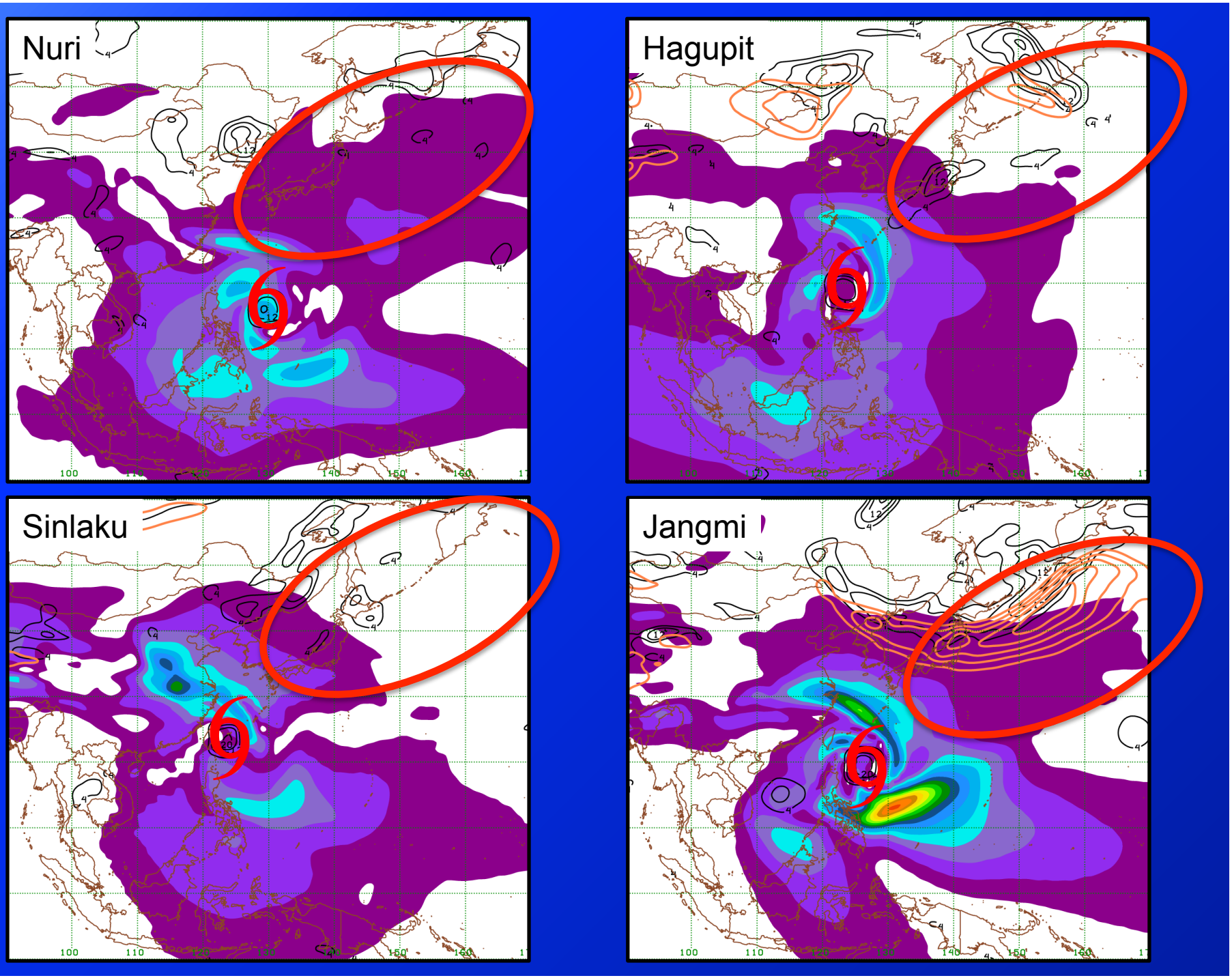
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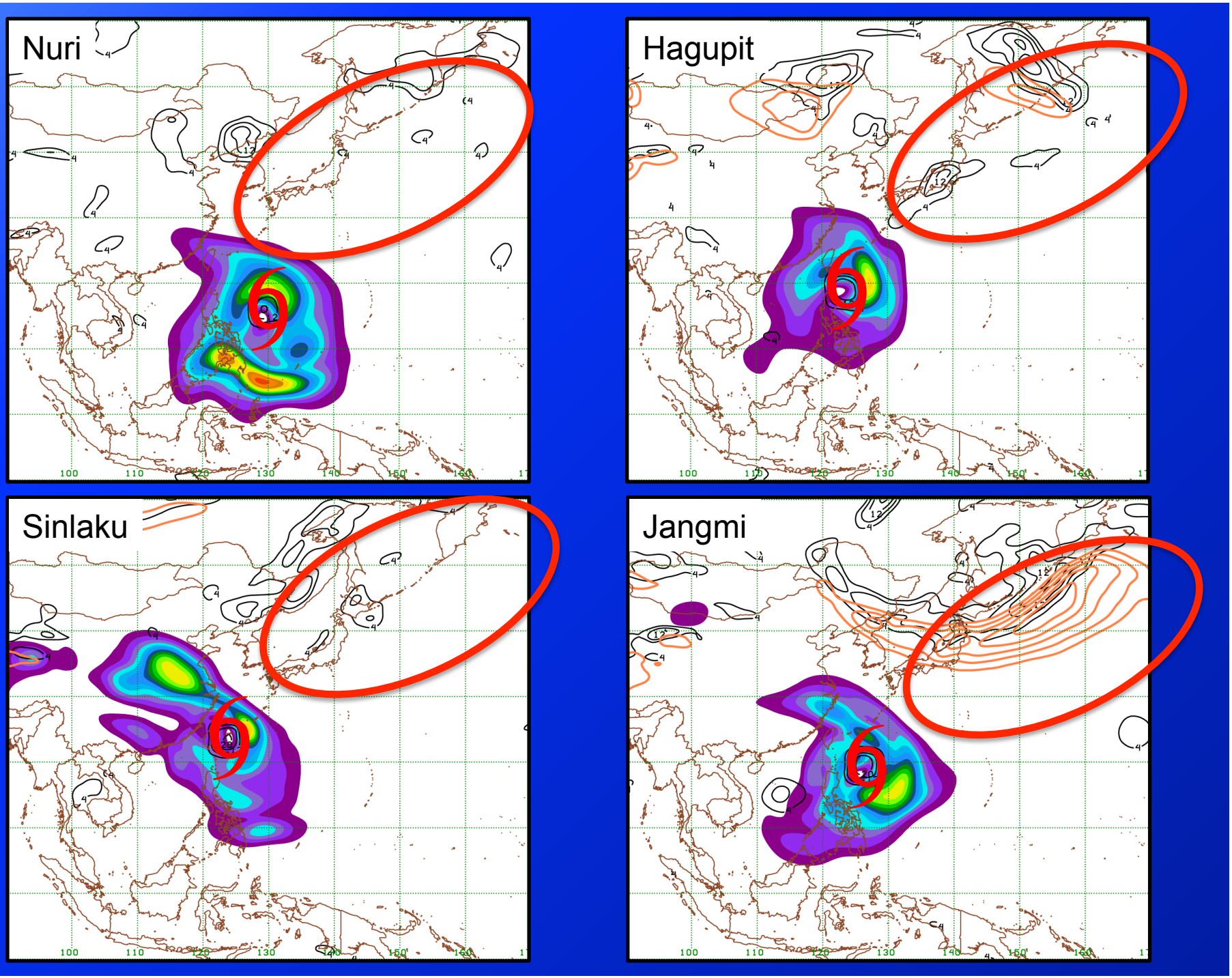
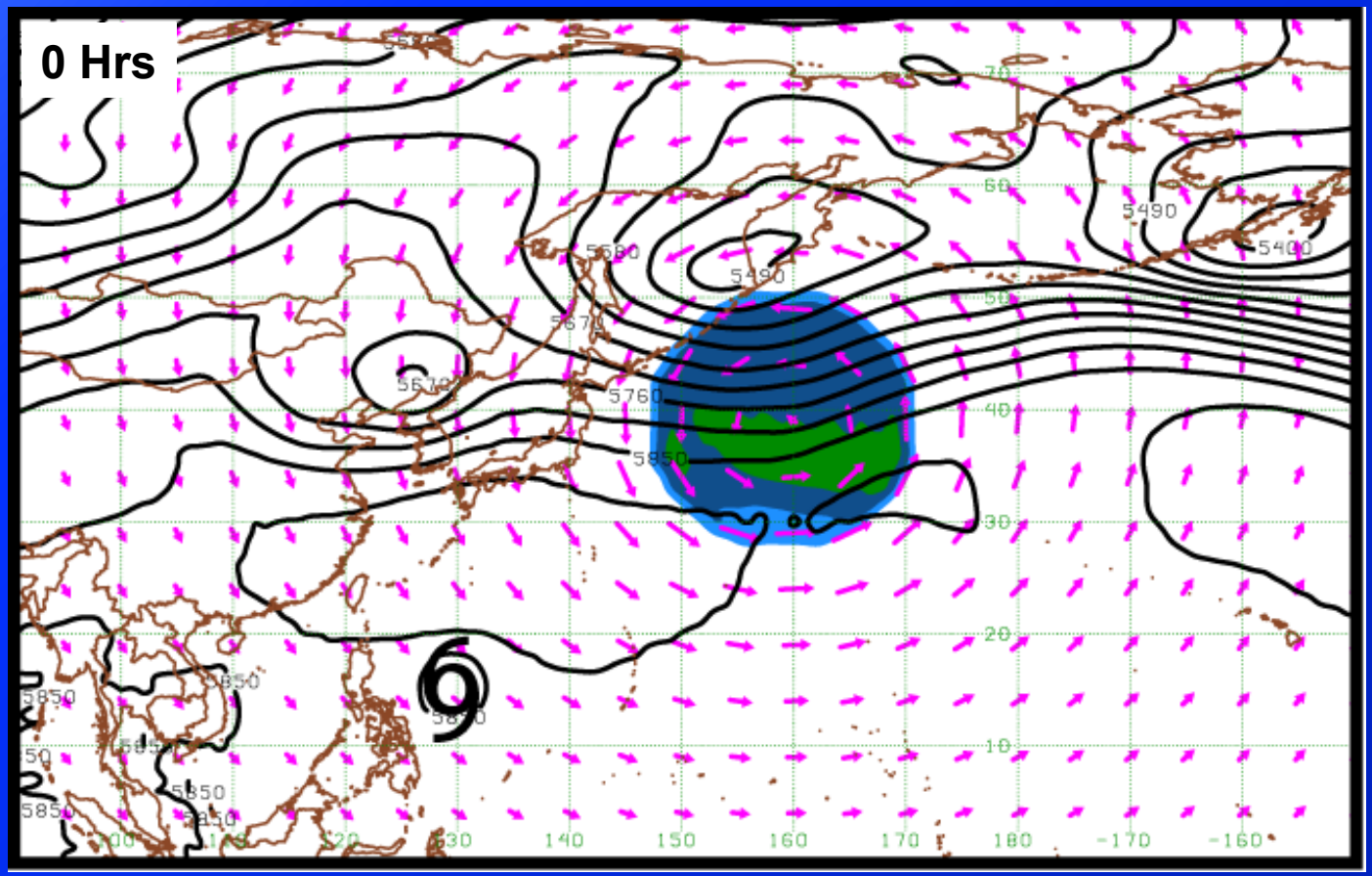

Nuri
Hagupit
Sinlaku
Jangmi

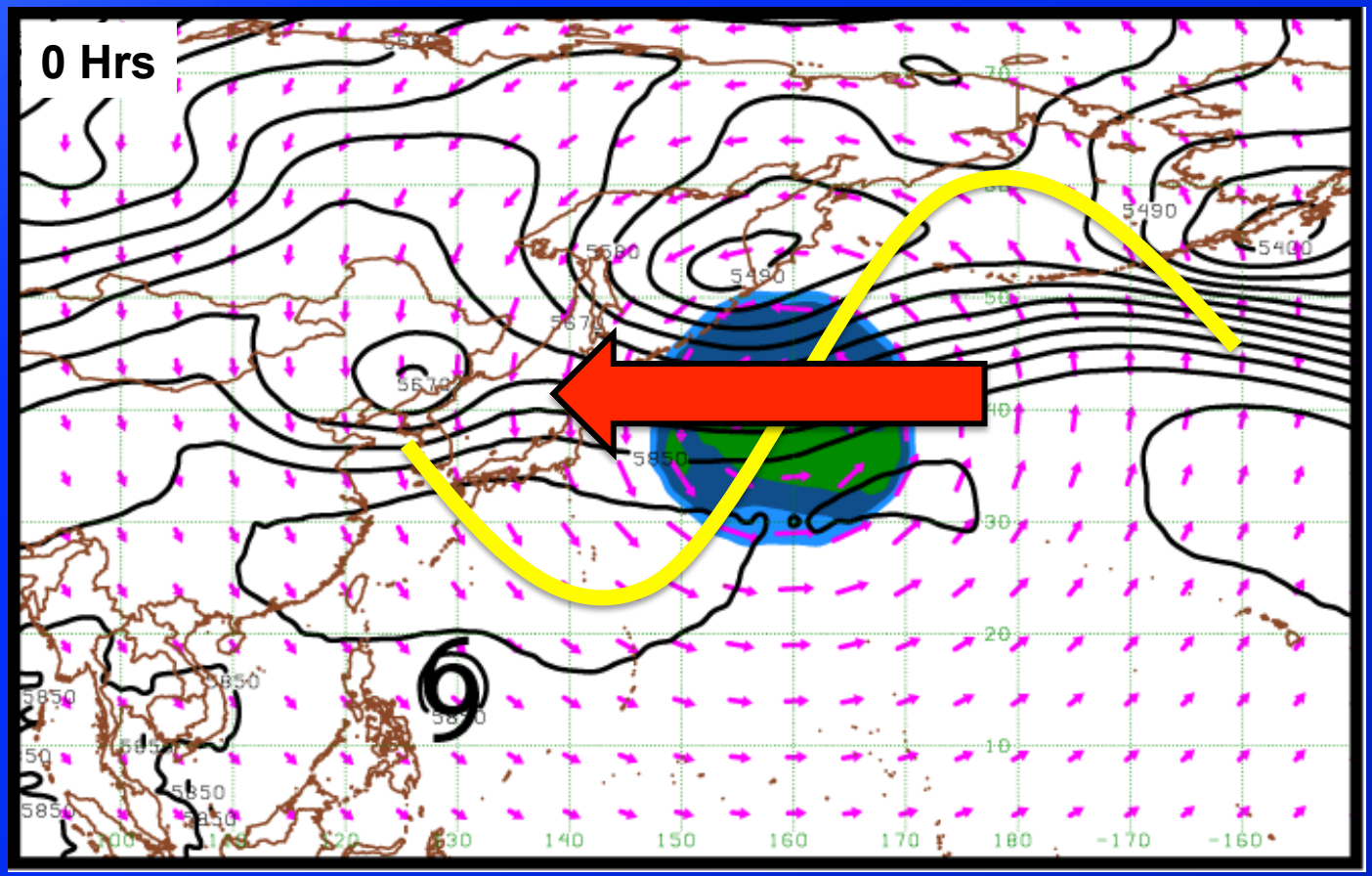
Downstream Sensitivity

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

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

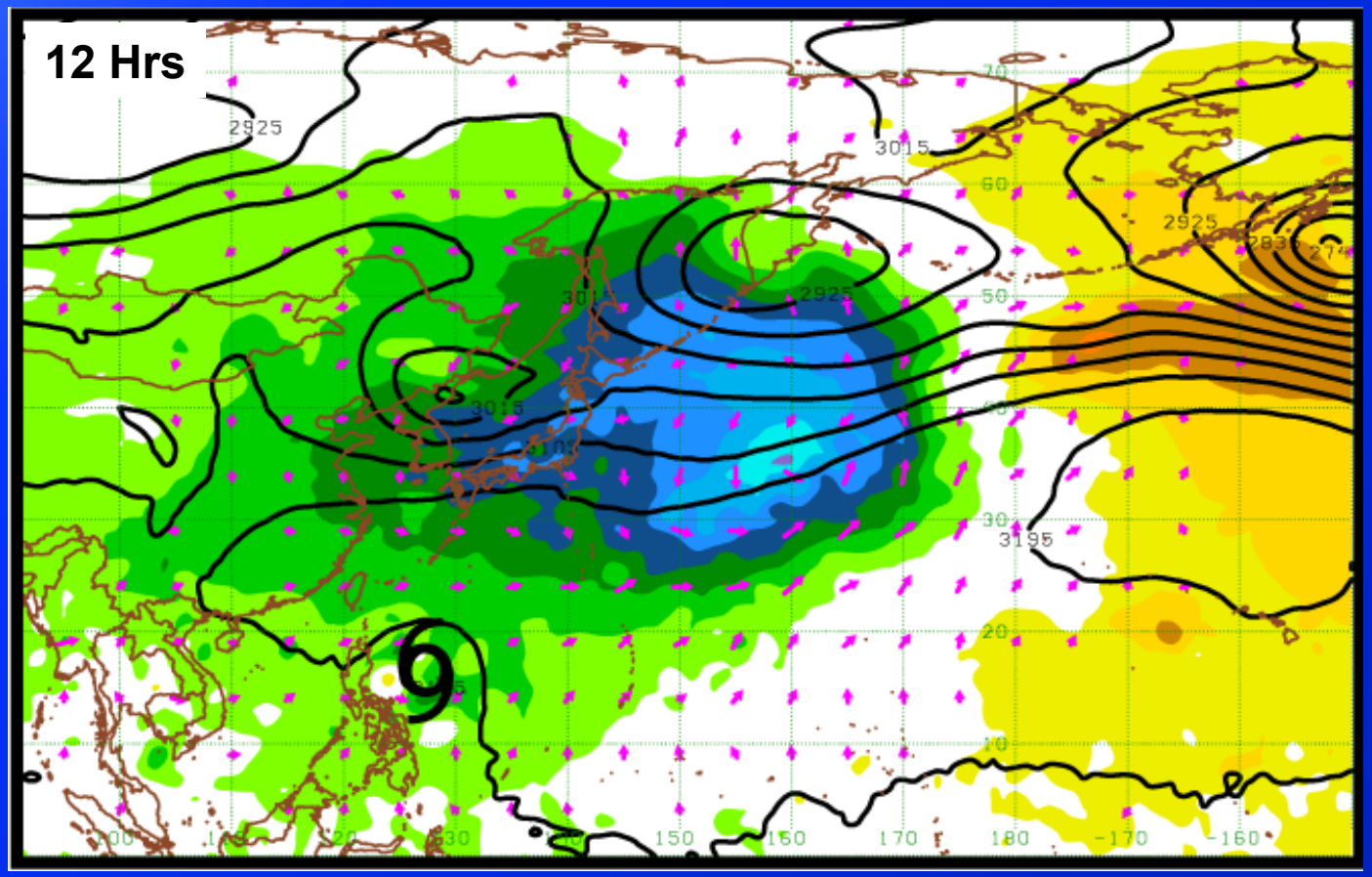


A small vorticity perturbation is inserted upstream of Nuri in a region defined by ADSSV as an downstream target.

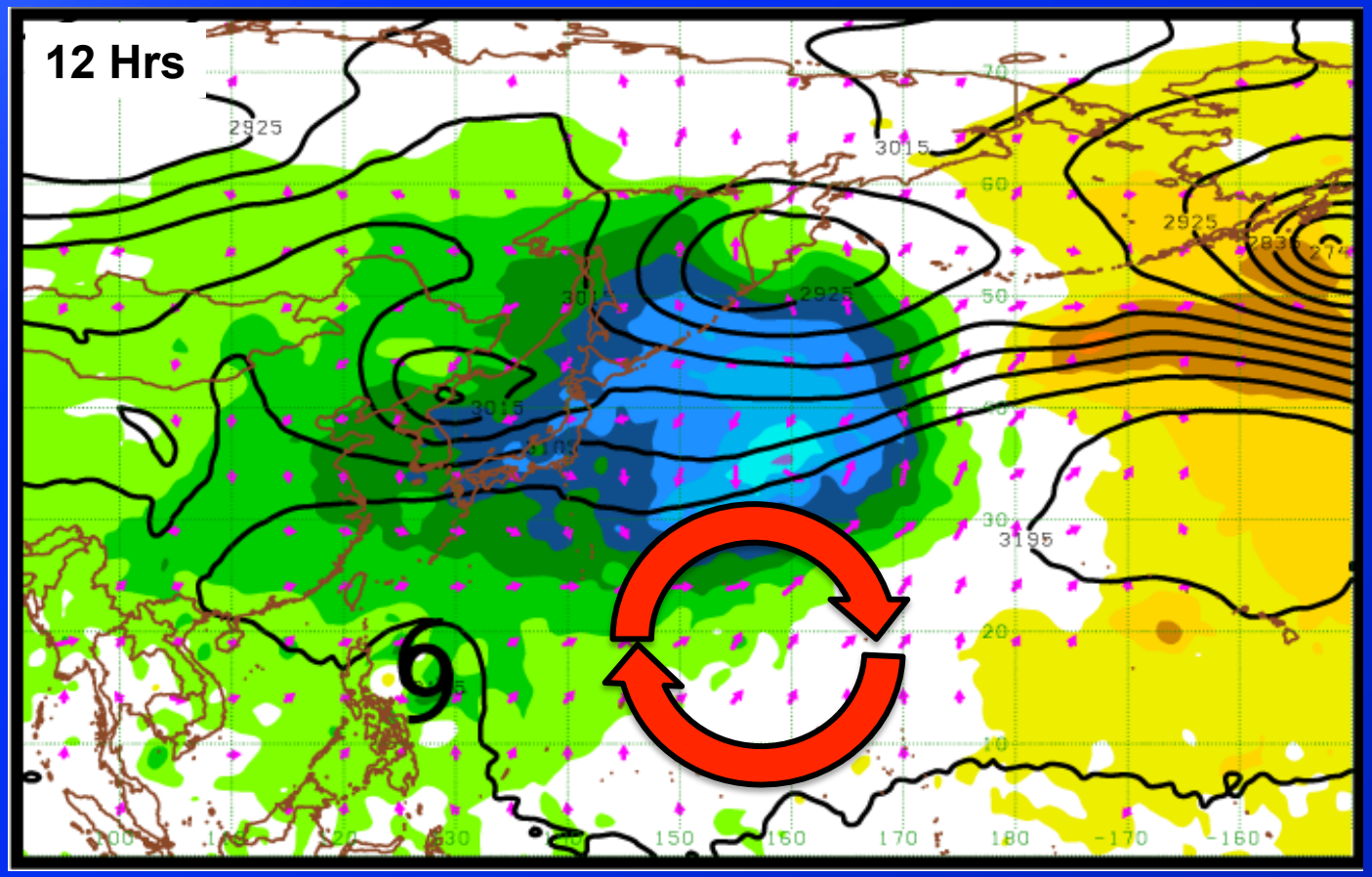


A small vorticity perturbation is inserted upstream of Nuri in a region defined by ADSSV as an downstream target.

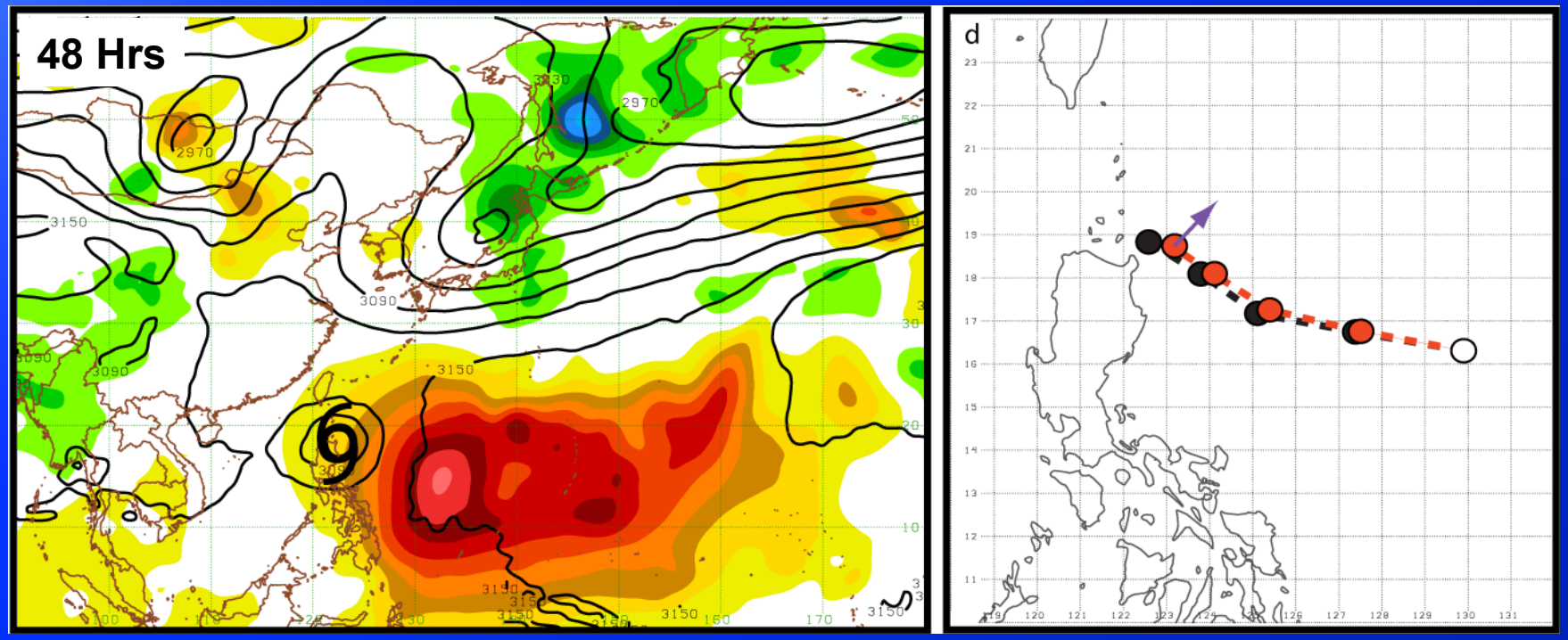
This perturbation creates a **westward-propagating wave** that travels **upstream** along the midlatitude PV waveguide.



Flow around this wave forces **northward flow** in the (sub-) tropics.



Flow around this wave forces **northward flow** in the (sub-) tropics. Increased **anticyclonic flow** results from **conservation of absolute vorticity**.

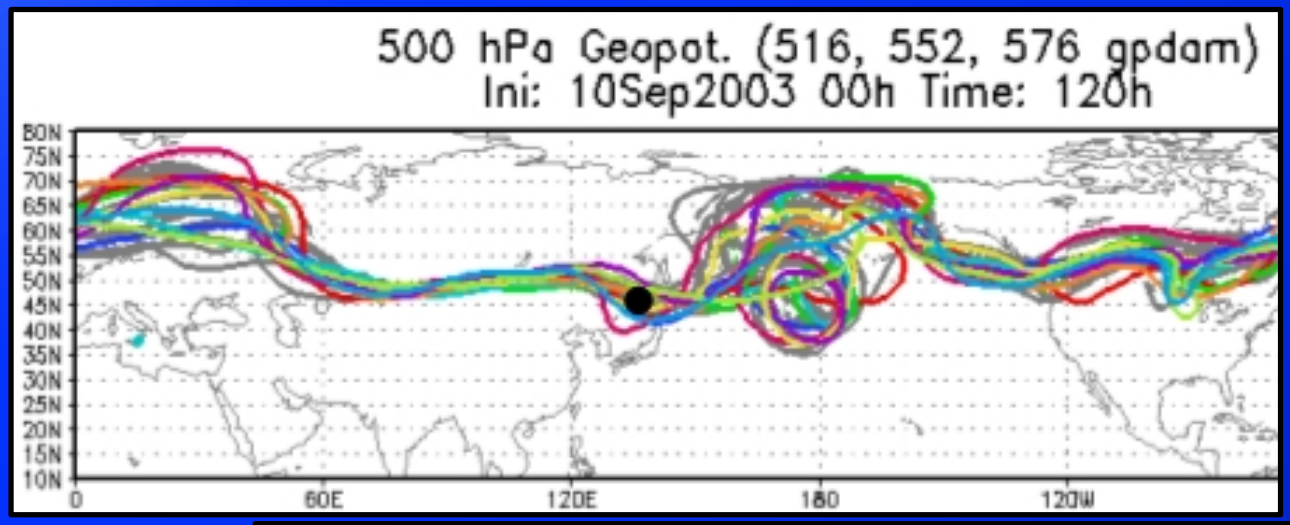


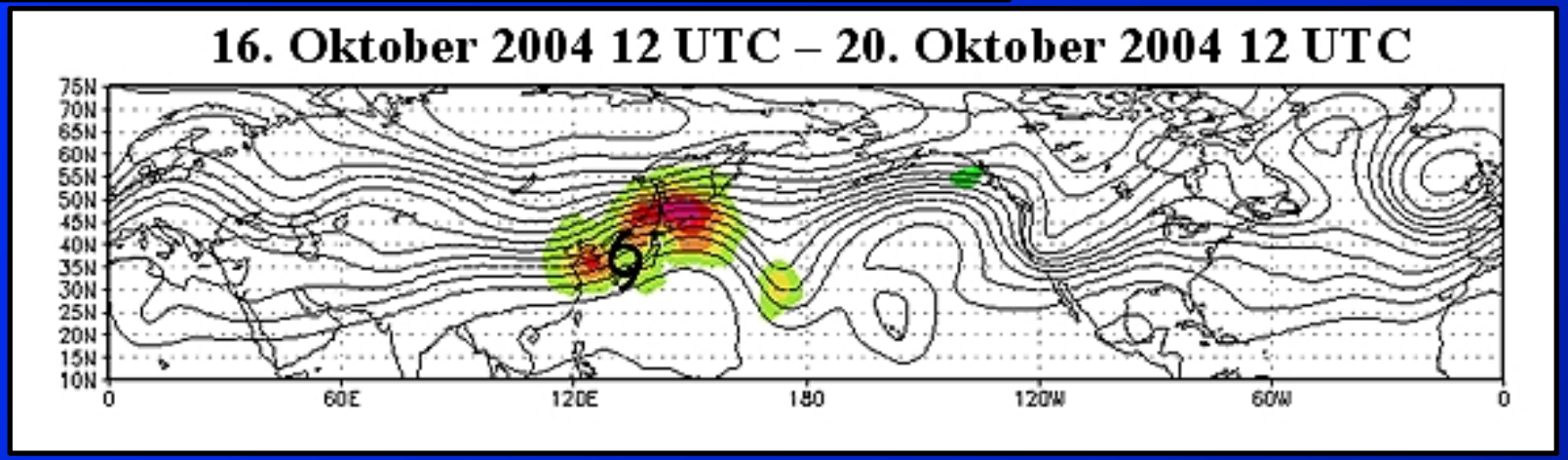
At 48 hours, the **perturbation flow** of **Nuri's environment** shows **enhanced anticyclonic flow** (streamfunction maximum) to the southeast of Nuri. This is **consistent** with a change in **Nuri's motion** to the northwest at this time.

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.