Using Stochastic Kinetic Backscatter Scheme (SKEBS) Ensembles to Better Understand Hurricane Predictability

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Hurricanes and Coupled Atmosphere-Ocean Systems

MIAMI

Error Sources in NWP

Initial condition error

Model error

Numerical formulation

Parameter uncertainty

Misrepresentation of physical processes

Physical parameterizations

SPPT
(Stochastically perturbed parameterization tendencies)

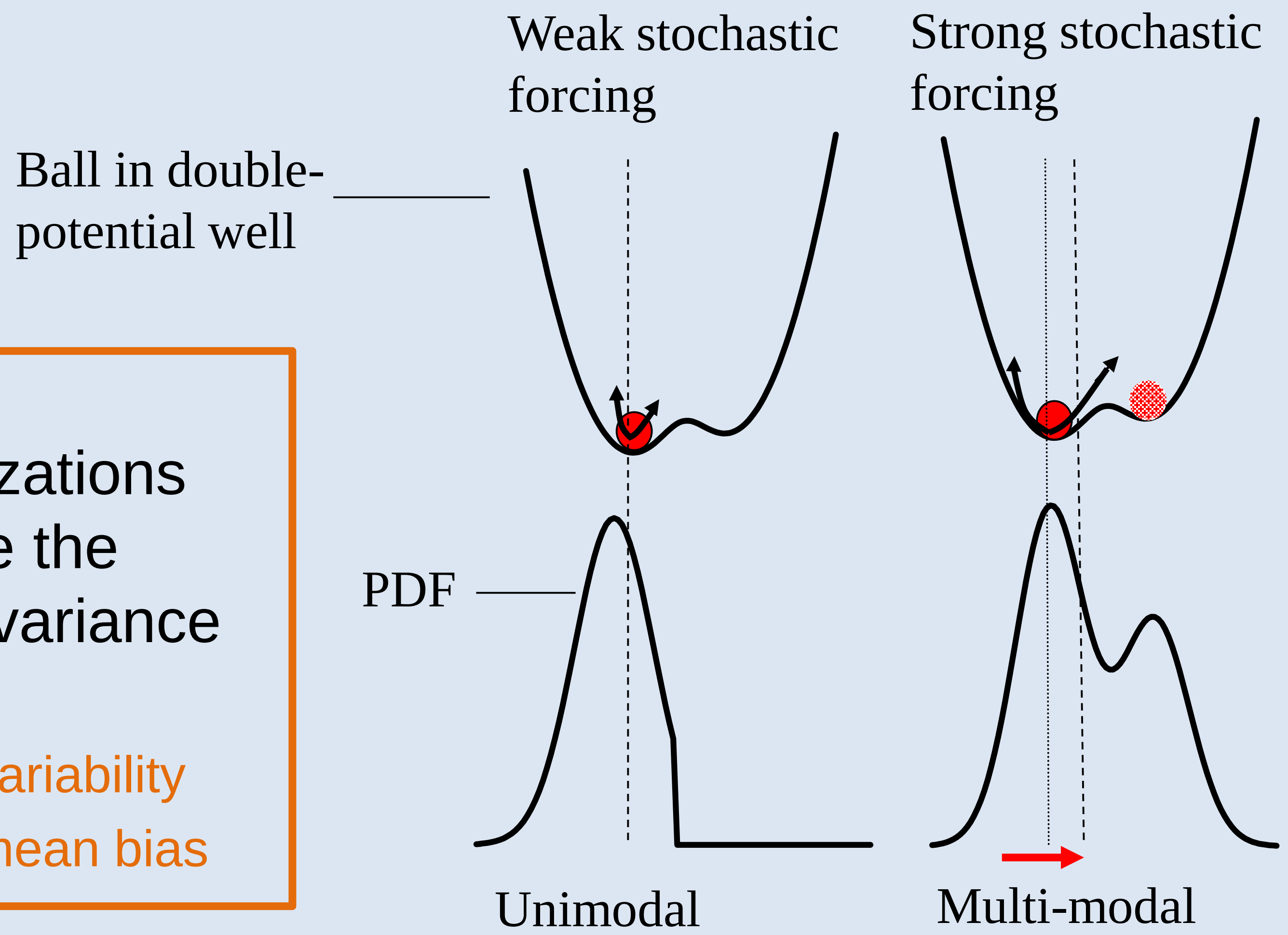
Subgridscale ⇄ resolved flow

SKEBS
(Stochastic kinetic energy backscatter scheme)

The Case for Stochastic Parameterizations

From J. Berner

- Stochastic parameterizations can change the mean and variance of a PDF
  - Impacts variability
  - Impacts mean bias



The Case for Stochastic Parameterizations

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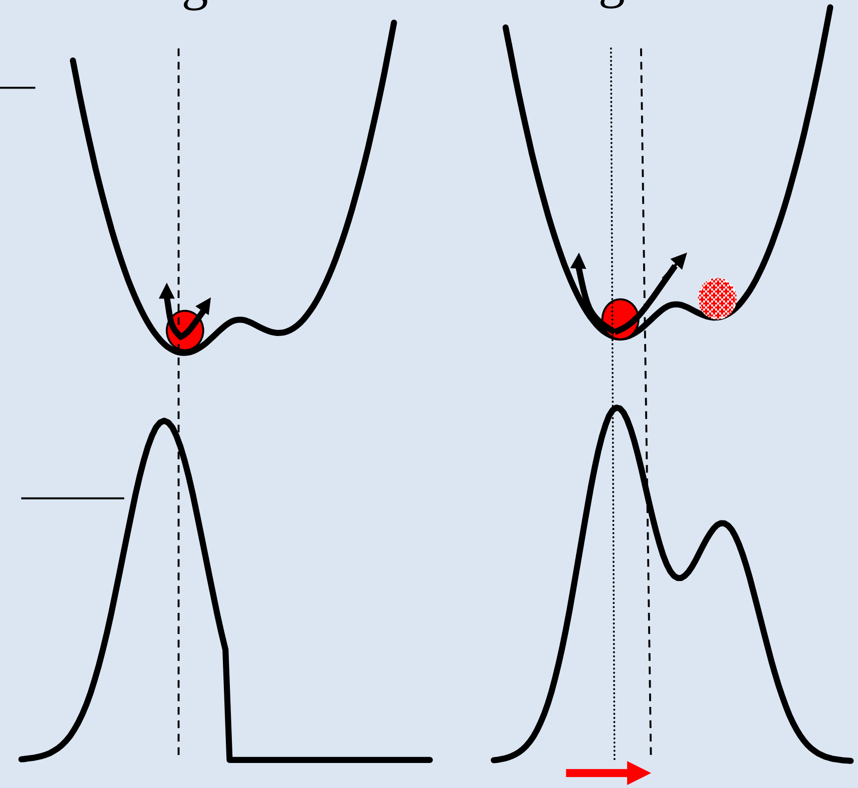


Successfully implemented in operational EPSs


ECMWF EPS

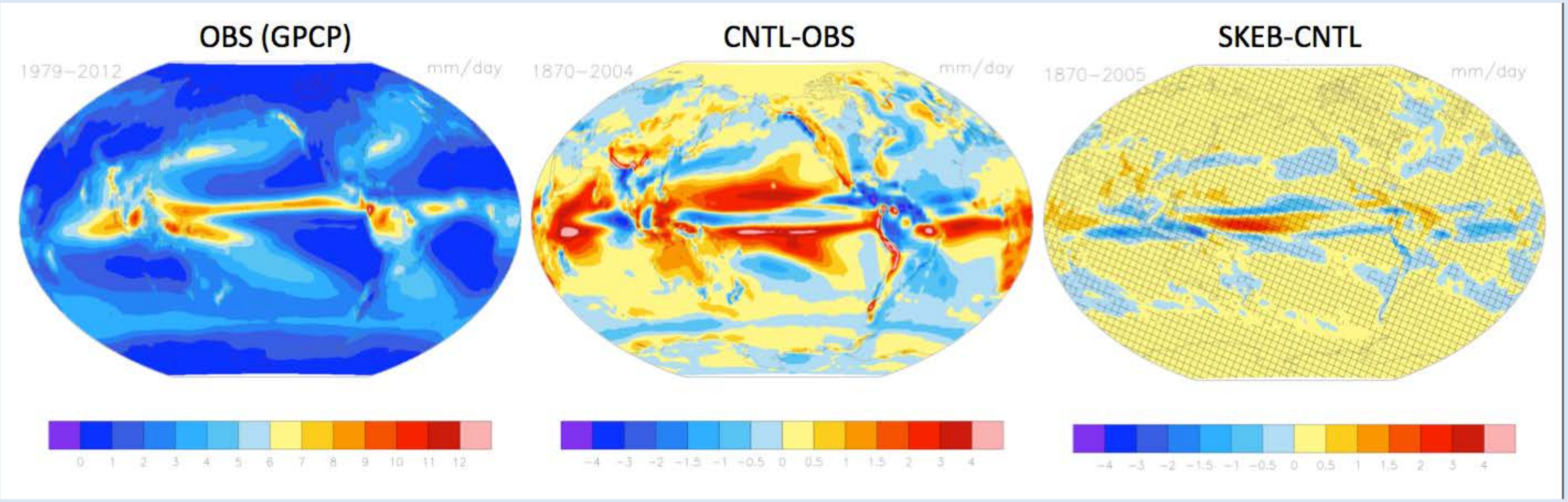

MOGREPS


CMC-GEPS


AWFA EPS

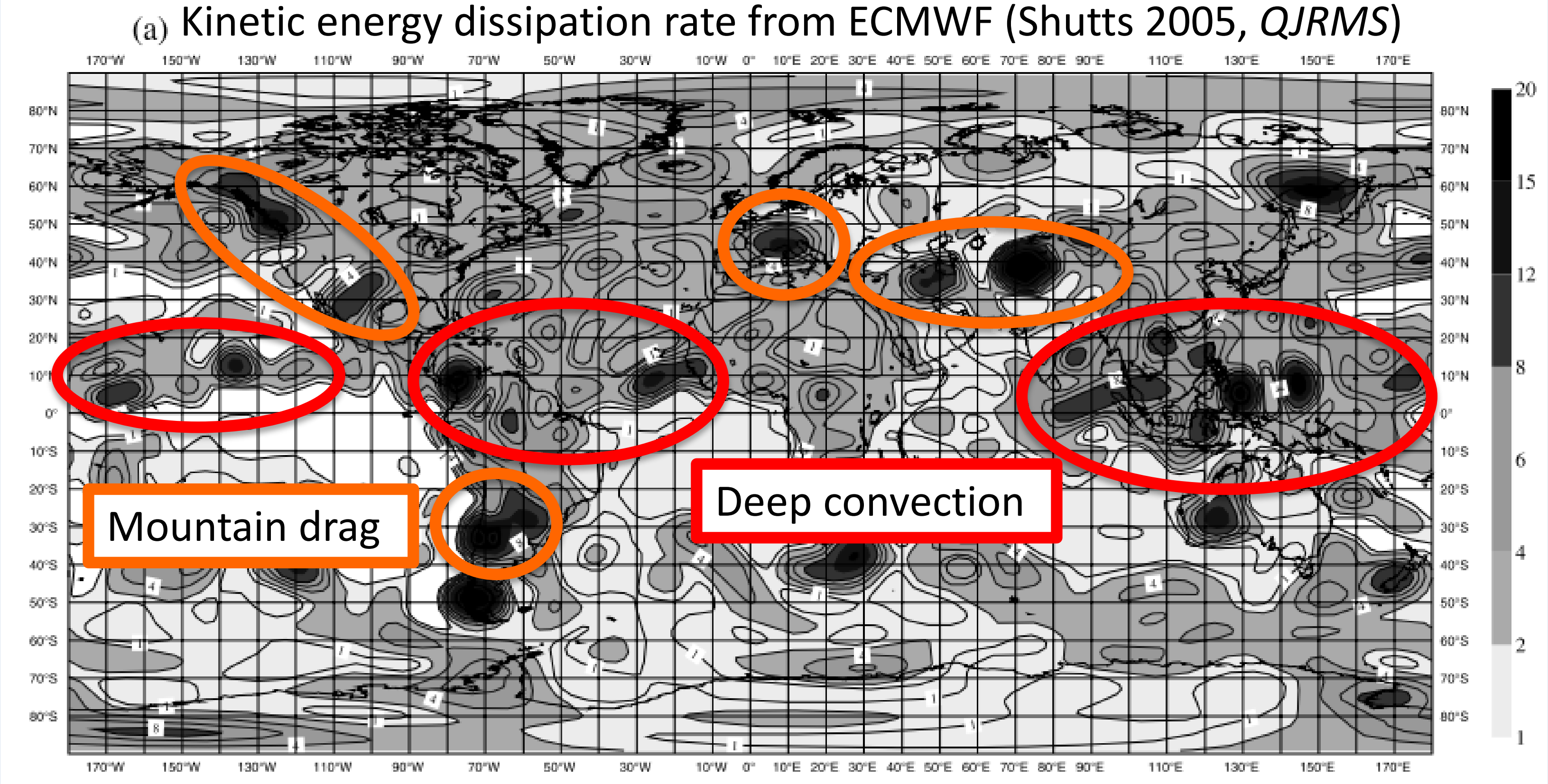
Example: Bias Reduction in a GCM Simulation

Simulation shows significant bias due to double ITCZ



✓ SKEBS reduces bias in precipitation

The Rationale behind SKEBS



A fraction of the subgrid-scale energy is scattered upscale and acts as forcing for the resolved flow.
(Mason and Thompson 1992, *J. Fl. Mech.;* Shutts 2005, *QJRMS*)

The Implementation of SKEBS

Implementation at ECMWF: Random streamfunction and temperature forcing for the resolved-scale flow, evolved by a first-order autoregressive process
(Shutts 2005, *QJRMS*; Berner et. al. 2008, *Philos. Trans. Roy. Soc. London*; Berner et al. 2009, *JAS*)

$$\frac{\partial X}{\partial t} = D_X + P_X + dD_{X,\,STOCH}$$

- $\frac{\partial X}{\partial t}$: Local tendency for variables U,V,T
- D_X: Dynamical tendencies => Resolved scales
- P_X: Physical tendencies => Unresolved scales
- $dD_{X,\,STOCH}$: Additive stochastic perturbation tendency

SKEBS in WRF

- Based on the ECMWF formulation, implemented by Judith Berner at NCAR (Berner et al. 2011, *MWR*)

  Some tweaks needed:
  - Global spectral model → Regional finite difference model
  - Dissipation rate assumed constant

- Perturbations simply considered as additive noise.

$$\Psi'(x,y,t) = r\,D\,\psi'(x,y,t)$$

backscatter ratio

dissipation rate

random streamfunction pattern

Amplitude:
10^{-4} m/s^2 10^{-9} K/s

SKEBS in WRF

- Control over SKEBS perturbations via *namelist.input*
- Very convenient for generating user-specific perturbations!

SKEBS: On

Vertical Variability

Amplitude

Timescale

Perturbation scale

Pert. Bdy: On

```
&stoch
stoch_force_opt                 = 1,       1,       1,
stoch_vertstruc_opt             = 1,       1,       1,
tot_backscat_psi                = 1.E-05,  1.E-05,  1.E-05,
tot_backscat_t                  = 1.E-06,  1.E-06,  1.E-06,
ztau_psi                        = 10800.0,
ztau_t                          = 10800.0,
rexponent_psi                   =-1.83,
rexponent_t                     =-1.83,
zsigma2_eps                     = 0.0833,
zsigma2_eta                     = 0.0833,
kminforc                        = 1,
kminforc                        = 1,
kminforct                       = 1,
lminforct                       = 1,
kmaxforc                        = 1000000,
lmaxforc                        = 1000000,
kmaxforct                       = 1000000,
lmaxforct                       = 1000000,
perturb_bdy                     = 1,
nens                            = 1,
```

High-res SKEBS Ensembles in TC Research

- TC predictability studies using SKEBS:

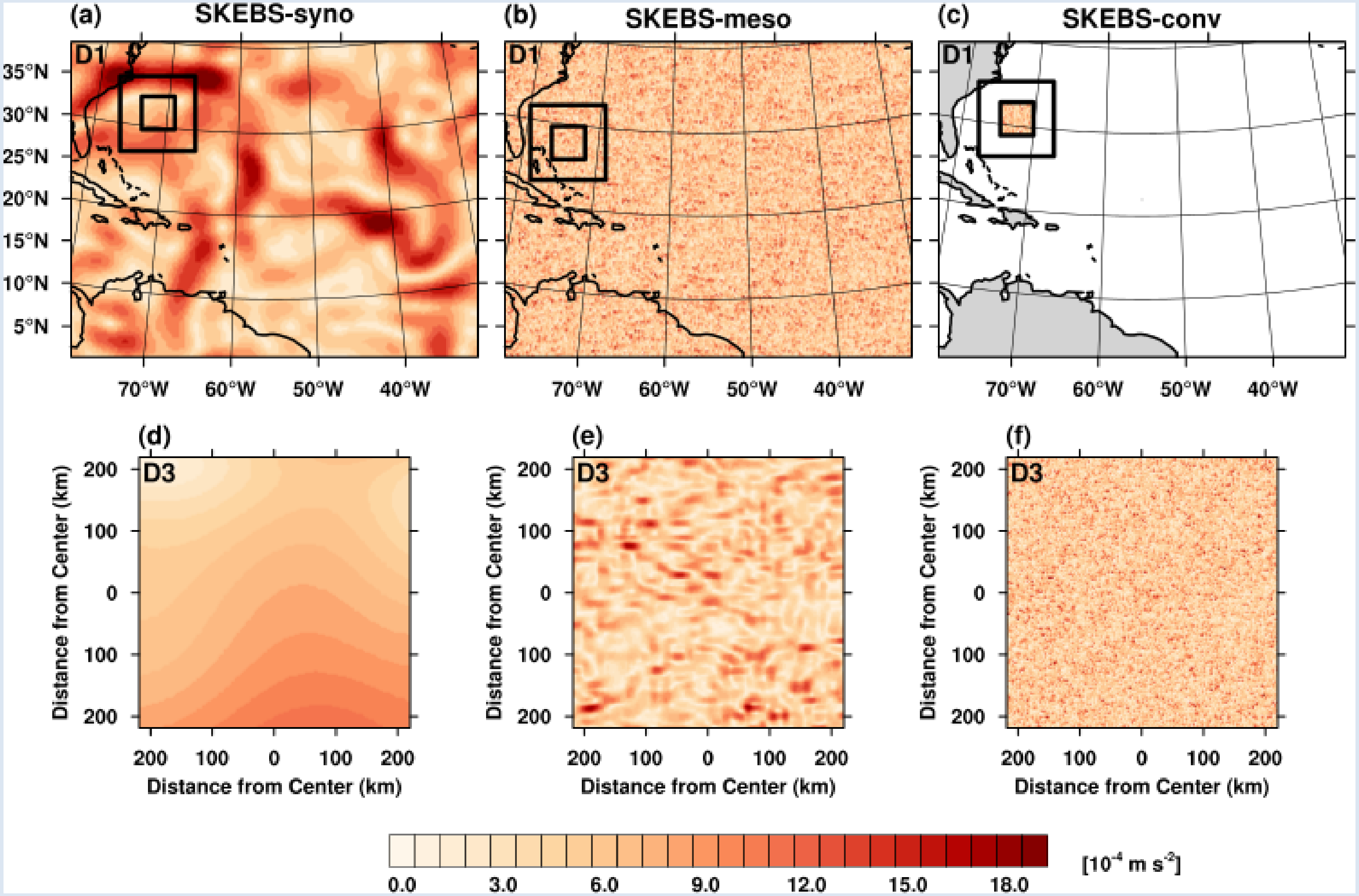
Judt et al. (2015, *QJRMS*):	Intrinsic predictability of TC intensity
Judt and Chen (2015, *GRL*):	Predictive skill of TC intensity
Judt and Chen (2015, *MWR*):	Predictability and dynamics of RI

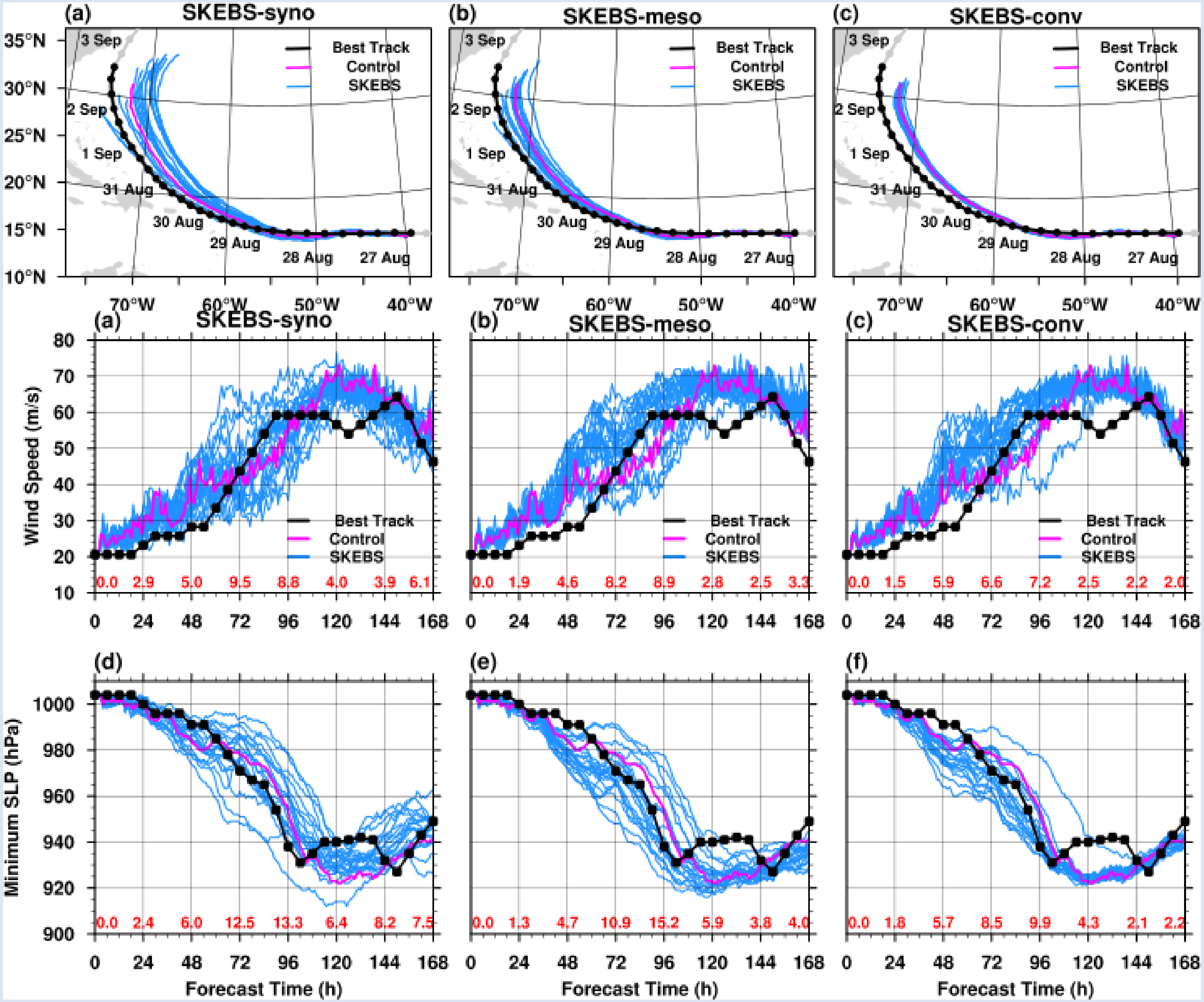
- Advantage of SKEBS:
  1. Control over perturbation scale, only constrained by $L_{x,y}$ and Δx
  2. Perturbed BC
  3. Perturbations added throughout integration

Important in regional models!

Perturbation scale in SKEBS Ensembles of Earl (2010)

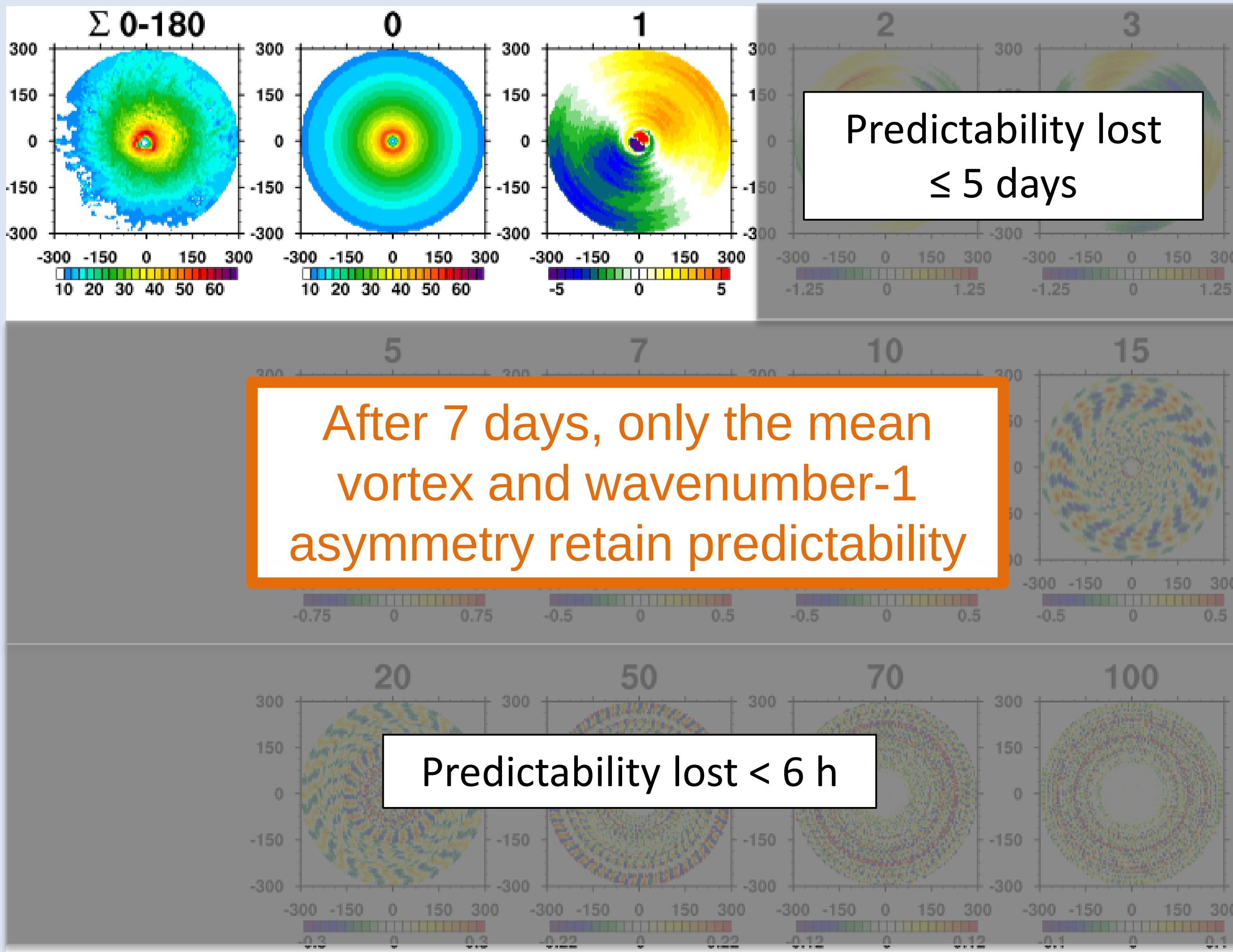
500-4200 km | 24-500 km | 2.7-12 km



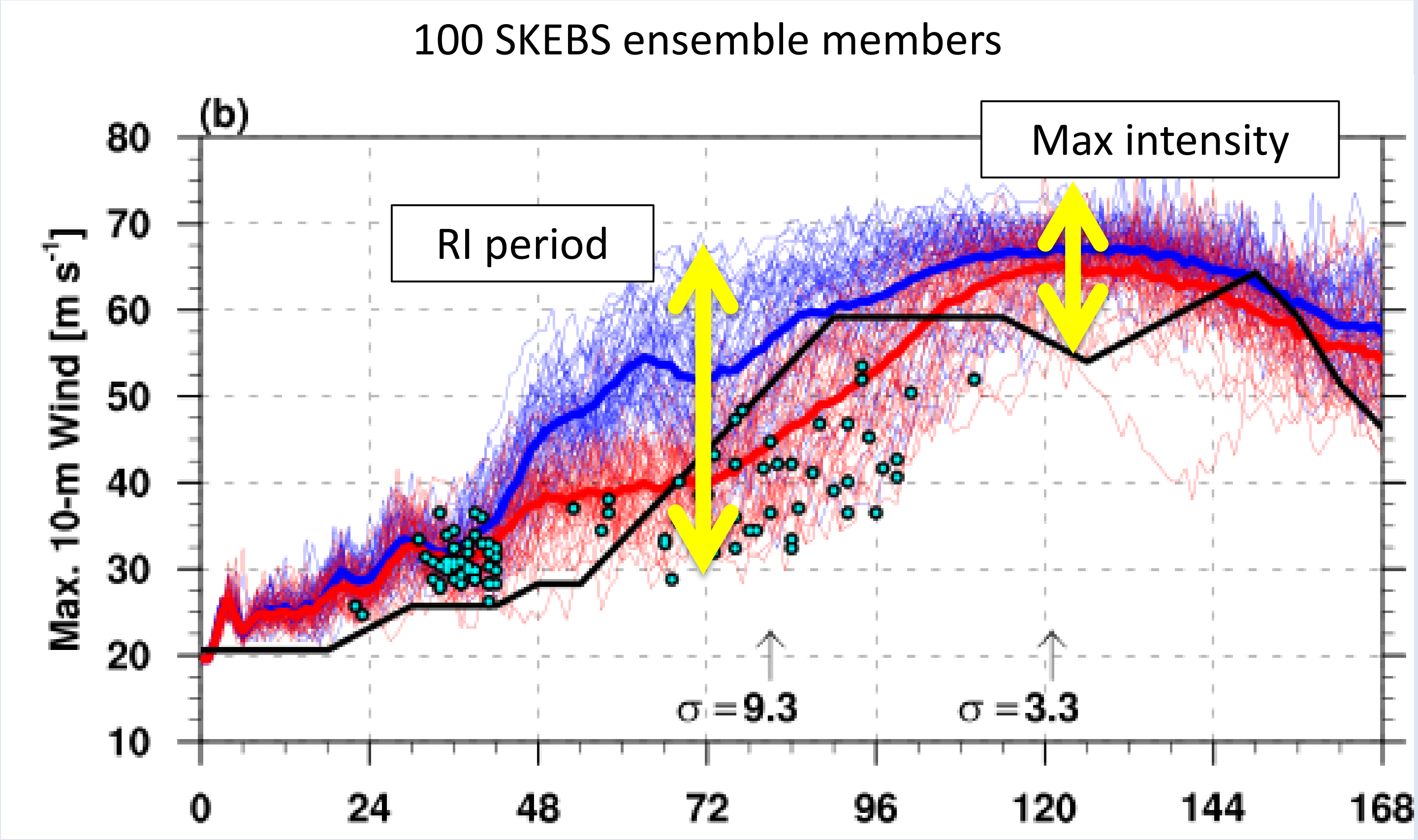

(a) SKEBS-syno
(b) SKEBS-meso
(c) SKEBS-conv
Best Track
Control
SKEBS
3 Sep
2 Sep
1 Sep
31 Aug
30 Aug
29 Aug
28 Aug
27 Aug
35°N
30°N
25°N
20°N
15°N
10°N
70°W
60°W
50°W
40°W
Wind Speed (m/s)
0.0 2.9 5.0 9.5 8.8 4.0 3.9 6.1
0.0 1.9 4.6 8.2 8.9 2.8 2.5 3.3
0.0 1.5 5.9 6.6 7.2 2.5 2.2 2.0
(d)
(e)
(f)
Minimum SLP (hPa)
0.0 2.4 6.0 12.5 13.3 6.4 8.2 7.5
0.0 1.3 4.7 10.9 15.2 5.9 3.8 4.0
0.0 1.8 5.7 8.5 9.9 4.3 2.1 2.2
Forecast Time (h)

Predictability of Scales of Motion

(based on Lorenz 1969, *JAS*)



Uncertainty and mechanisms of RI

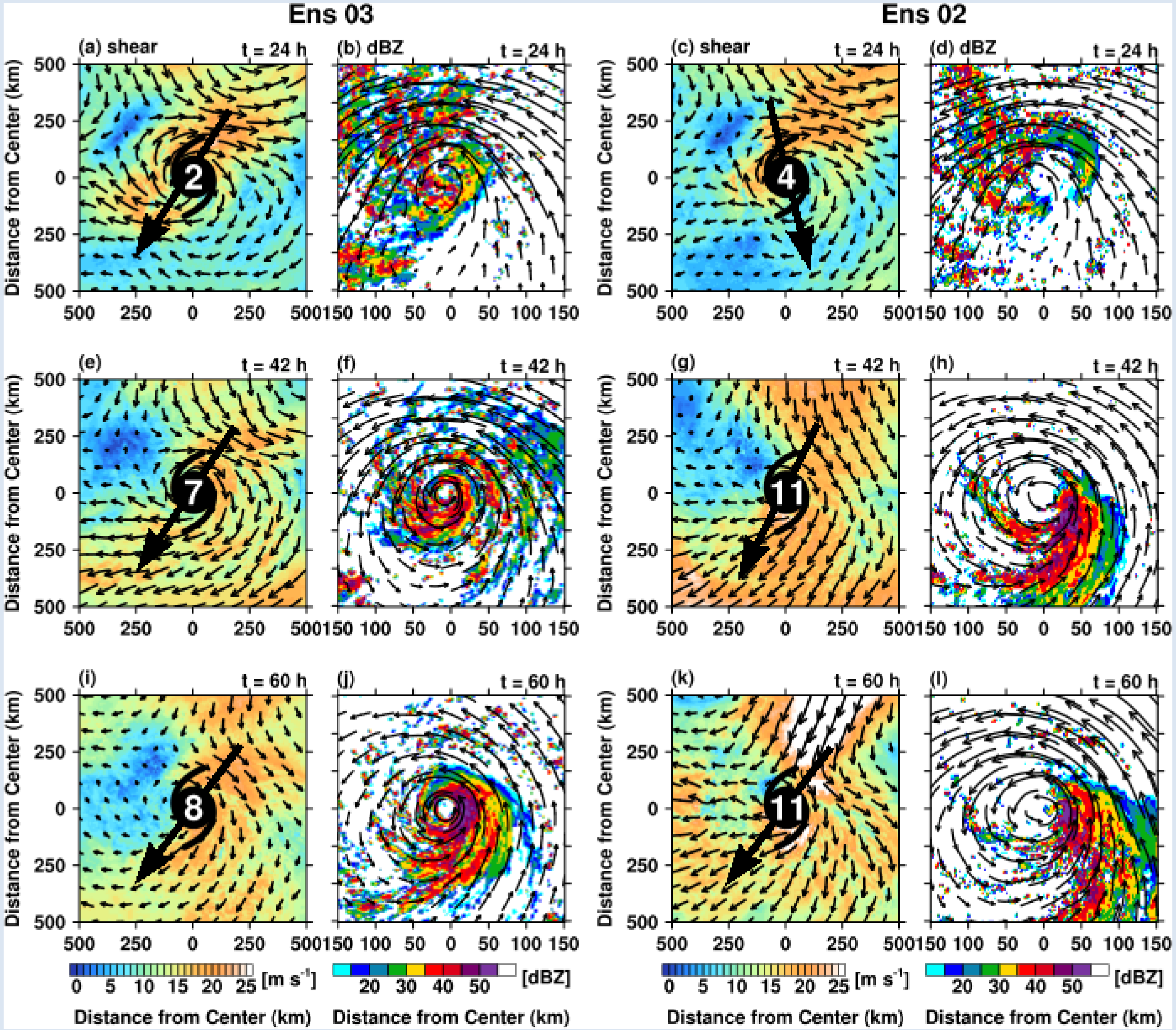


High uncertainty: RI timing

Low uncertainty: Maximum intensity

Large-scale perturbations: differences in shear

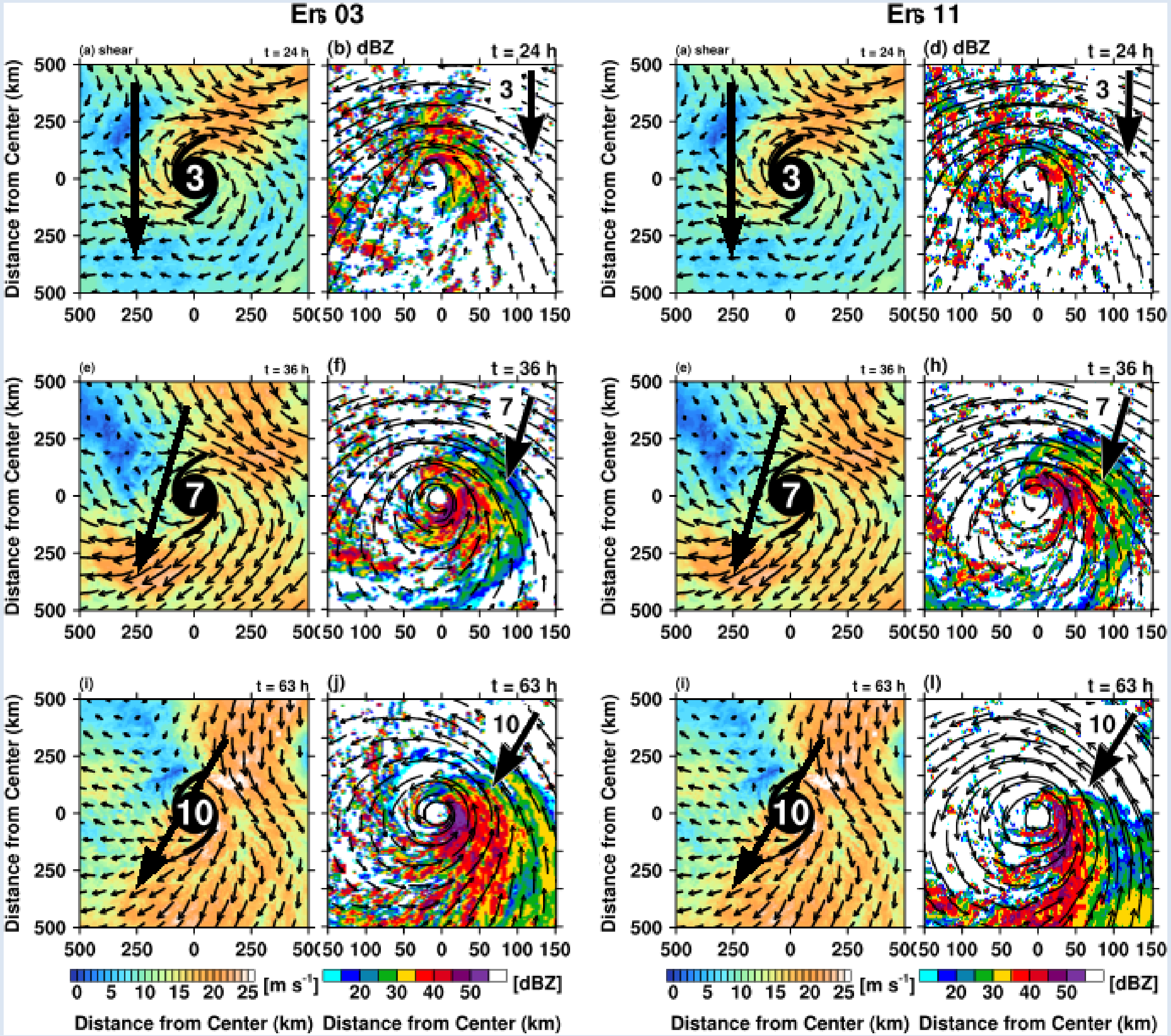
Moderate shear: RI



Strong shear: No RI

Conv.-scale perturbations: differences in inner-core structure

Moderate shear, high IS: RI



Moderate shear, low IS: No RI

- SKEBS is useful
  - Improves ensemble spread / bias
  - Run time not an issue
  - Easy to control, users can specify perturbations

- Predictability of TC intensity
  - Need to focus on getting WN 0-1 right
  - RI yes/no predictable, RI timing highly uncertain
  - Mechanisms leading to RI uncertainty:

shear ⇄ mean vortex ⇄ convection