Model Process Group Report

General Question - 1

- What is hindering progress on improving atmospheric predictability?
  - Lack of sufficient (observational, lab experiment data, simulation) data to help improve parameterization of individual processes (e.g., many microphysics conversion terms) and to reduce their uncertainty;
  - Lack of knowledge of the variability and parameterization uncertainties of many physical processes, in particular microphysics processes, subgrid-scale turbulence processes (including PBL), land/ocean surface interactions, and cloud/aerosol radiation/microphysics interactions;
  - Lack of multi-scale data assimilation systems that can effectively and simultaneously assimilate observations sampling the atmosphere from the convective (e.g., radar) through synoptic (e.g., rawindsone) scales, and in all weather conditions (e.g., cloudy radiance), and at full spatial and temporal resolutions (e.g., every radar scan, and native satellite pixel resolutions) so that predictions are sufficiently constrained by observations through DA cycles and problems are more linear and error more Gaussian;
  - Lack of sufficient computing resources that would allow fast and automated running of a large number of data assimilation and forecast experiments with sufficient cases, and sufficient online storage for storing experiment inputs and analyzing output, and for statistical evaluations and data mining;
  - Lack of well trained young scientists in fundamental physical processes, data assimilation, and availability of software development support. Insufficient collaborations among physical, (applied) mathematical, atmospheric, and computational scientists. Within atmospheric, among instrumental/remoting sensing and physics/dynamical/modeling scientists.

General Questions - 2

- What are the key sources of uncertainty, and how can they be reduced or minimized?
  - This is largely unknown. MP schemes have dozens of processes and ~100 parameters, and to understand their uncertainties require observations that are not easily available
  - To test sensitivity to ~100 uncertain parameters requires $O(2^{100}) \sim 10^{30}$ experiments (even only 2 values of each are tested) over many cases; understanding of sensitivity can help narrow down the parameter list to perturb and to reduce uncertainty estimate (via obs, experiments
  - MP and PBL/SGS turbulence are likely two of the most sensitive and uncertain processes affecting 0-3 day forecasts at 1-3 km grid spacing.
  - LES/direct simulations can provide certain truth (though often limited to idealized situations) to help parameterization design but microphysics has no converged truth to count on.

- What additional tools, models, observations and resources are needed to address these challenges?
  - It is strongly desirable for parameterization developers to document/estimate level and range of uncertainty of parameters involved, and to carry-out/facilitate parameter sensitivity studies, and inform stochastic parameterization scheme design
  - Multi-physics ensemble predictions over seasons and continental scale grids (e.g., CAPS CAM ensembles for HWT) can be utilized to provide large samples to examine parameter/process variabilities within/across schemes for a wide range of cases
  - Large ensembles of O(100) members with simultaneous parameter perturbations can be run and used to determine forecast sensitivities using linear and nonlinear statistics methods (e.g., correlation, machine learning)
  - Lagrangian particle-based modeling, cloud particle-level simulations as well as cloud chamber studies should be pursued/funded, as do aircraft observations.
  - Databases of LES simulations for different stability and shear conditions should be created and utilized to help design/improve PBL and GSG turbulence parameterization, while boundary profiles at ~1 h intervals collected to evaluate the schemes.
  - Need better diagnostic tools/methods to determine main sources of model errors (e.g., identify processes that cause fastest deviation away from analyses/observations)
  - Development of accurate/model physics consistent observation operators/measurement simulator (e.g., dual-pol radar simulator) and use them to help identify model deficiencies
  - Output/intercompare process terms in physics schemes.

Specific Questions for Modeling/Predictability/Data Assimilation Groups:

- What uncertainties are limiting the production of better quantitative forecasts (e.g., of precipitation but also other forecast variables)? What are the natural limits of the predictability of various phenomena?
  - For 0-2 h forecasts, uncertainties/errors in convective-storm-scale IC
  - Model errors are limiting the quality of DA of remotely sensed data that rely heavily on model constraint (or its statistical representation)
  - For 2 – 12 h forecasts, uncertainties/errors in storm environment, as well as storm initial condition and model errors are limiting factors
  - For 12h – 3 day forecasts, surface forcing (LSM, etc), LBC, larger-scale IC and model errors are limiting forecasting skills.
  - Natural limits of (intrinsic) predictability still unknown for most convective-scale phenomena and need systematic studies (via e.g., small perturbation experiments).

Specific Questions for Modeling/Predictability/Data Assimilation Groups:

- What factors are limiting better representation of processes in models? What processes are still most certain? What information is needed to improve the representation of those processes?
  - Not enough data to judge/determine better representation of many processes – need more measurements and/or theoretical modeling (if possible) – e.g., CFD modeling of raindrop breakup

Specific Questions for Modeling/Predictability/Data Assimilation Groups:

- What is the best way of illustrating uncertainties in forecasts/models, and what are the best techniques to determine how uncertainties in initial conditions and processes propagate to model predicted fields? What is the role of ensembles of models in this process? Should all different forecast model products be treated equally?
  - By examining ensemble member differences
  - By examining time evolution of ensemble spread, ensemble pair difference and their spectra, and the pair difference fields themselves and employ physical knowledge
  - Ensembles are useful, though not necessarily multi-model
  - Depending on the goals and applications of forecasts – generally they should not be treated equally.

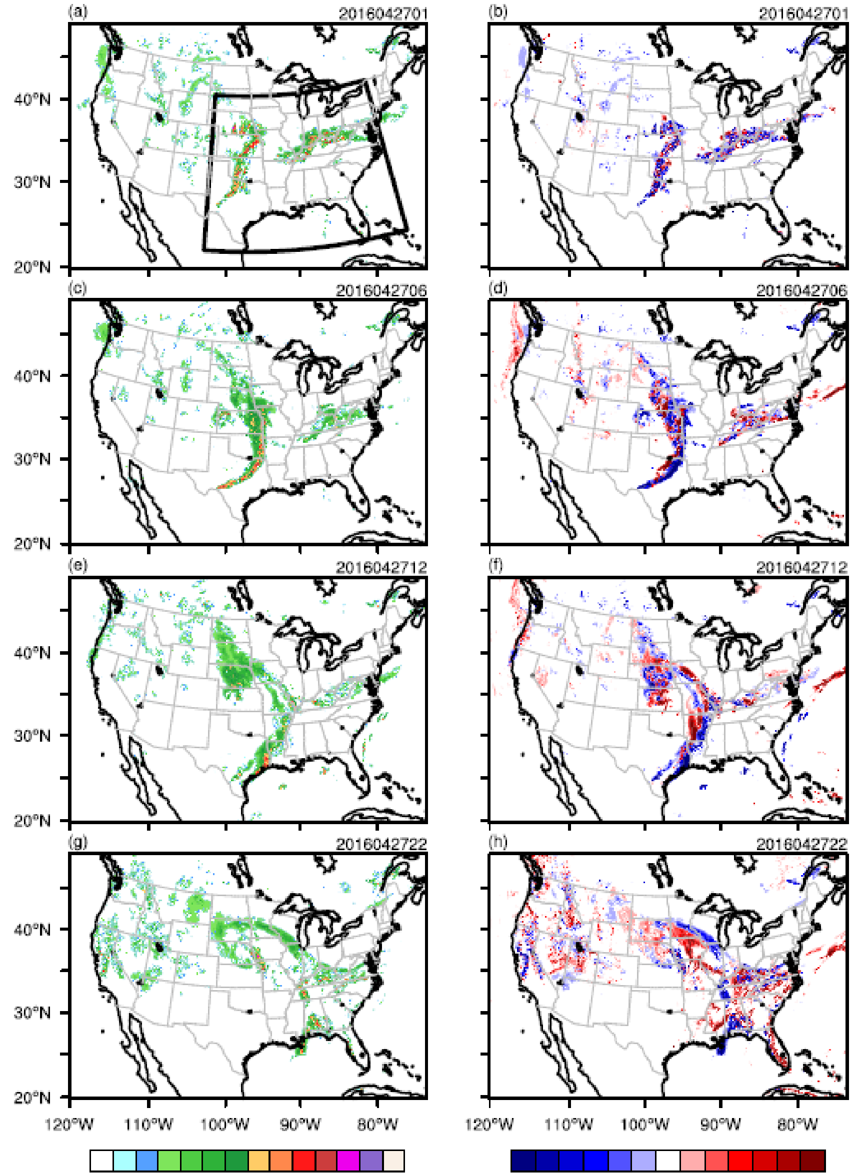
Specific Questions for Modeling/Predictability/Data Assimilation Groups:

- What are the most important products needed for assimilation into models to reduce forecast uncertainty? What are the major sources of uncertainty in those products? What steps need to be taken to refine those uncertainties?
  - Direct assimilation of observed quantities most desirable
  - Products that extract movement and/or structure information in the observations (e.g., MVs derived from temporal changes of texture, the presence of Zdr arc or column) that are otherwise difficult to assimilate directly
  - Sources of uncertainties depend on products
  - Develop advanced 4D DA methods that can utilize/extract all information contained in the data (field values, change rates, spatial gradients, etc)
  - Use more model constraint when producing the products

PBL and SGS Turbulence Parameterizations

- Modeling of deep moist convection at O(1km) grid spacing calls for better SGS/PBL turbulence closure schemes that can correctly model upgradient fluxes, entrainment/detrainment in deep convection, shallow cumulus clouds near PBL top, near surface fluxes in stable and unstable conditions;
- Newer scale-aware PBL schemes can introduce additional uncertainties that require further tuning and testing;
- Stable boundary layer parameterization is an even bigger challenge;
- Develop unified 3D, scale-aware PBL-SGS turbulence closure that include fluxes in all three directions

- Carefully designed stochastic perturbations may be necessary to facilitate ensemble forecasting.
- Single multi-process parameterization scheme preferred over multiple different schemes, and weight averages of different treatments of the same processes can be introduced with optional stochastic perturbations to the weights as well as process parameters or the terms to allow perturbations to both structures and parameter values.

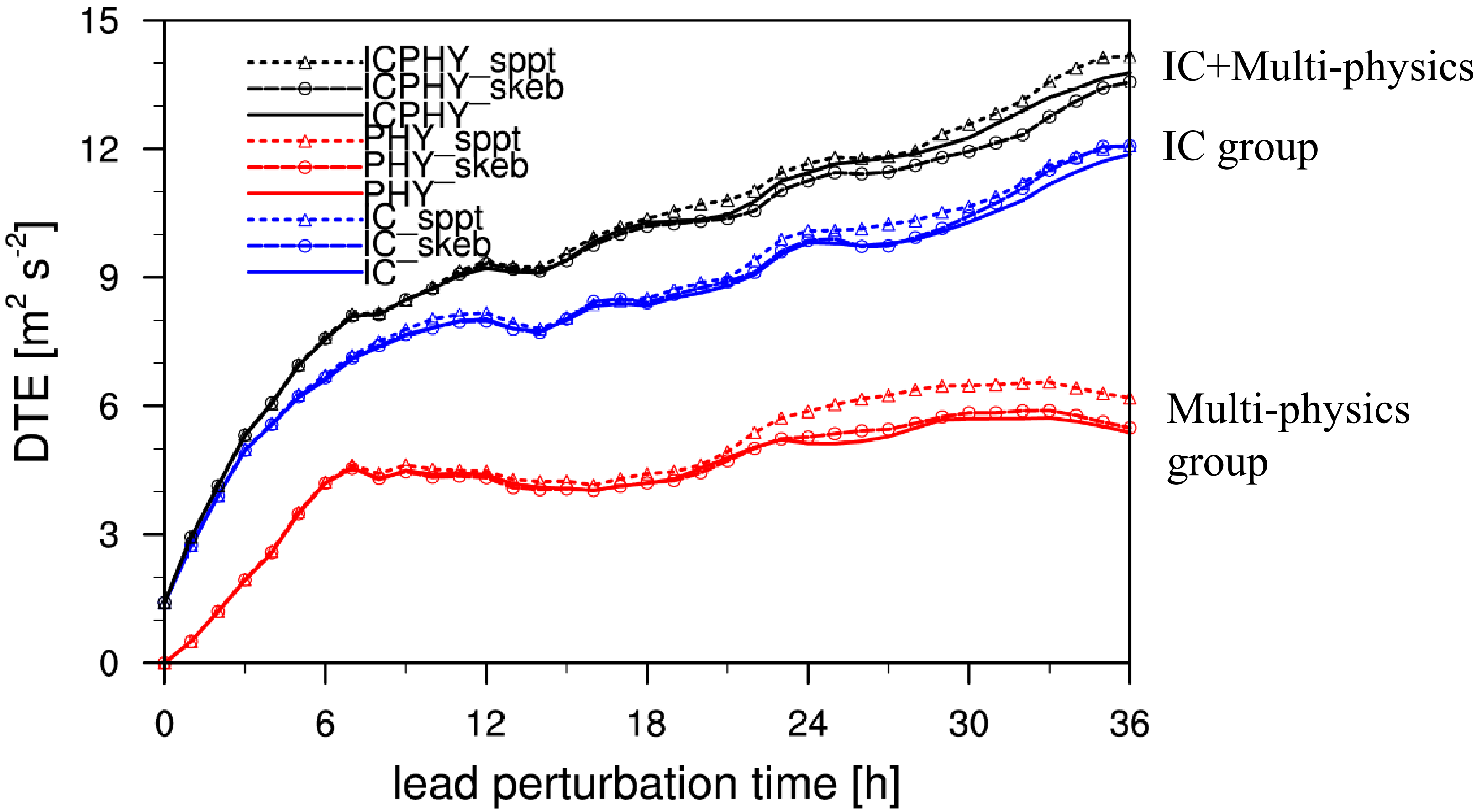


From Ming

Zhang et al (2008)

Hourly precipitation at selected times. Left panels are control forecasts and right panels are the difference between control forecast and observation.

Temporal evolution of ensemble mean DTE at 500hPa from different ensembles

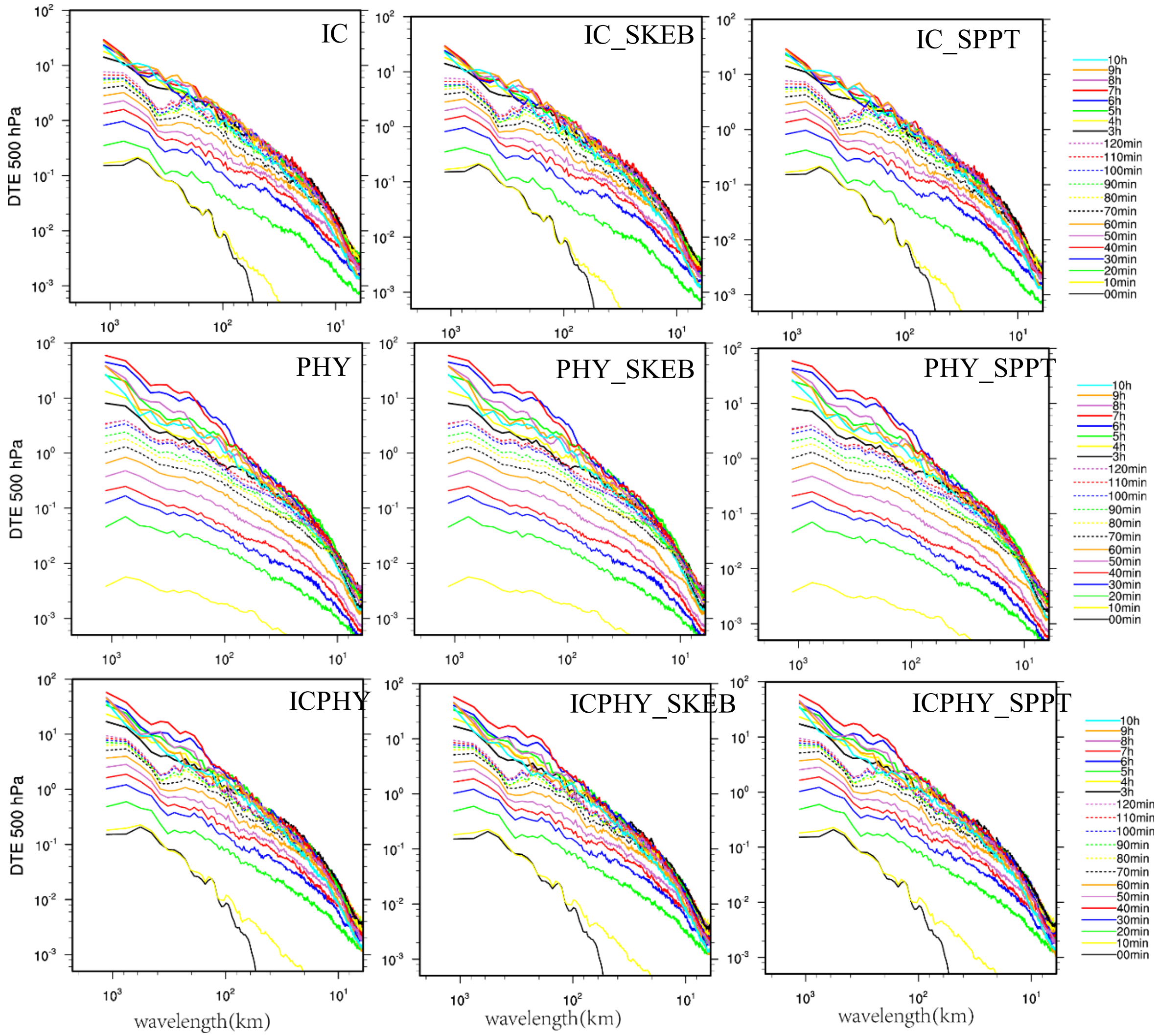


Spectra of ensemble mean DTE at 500 hPa

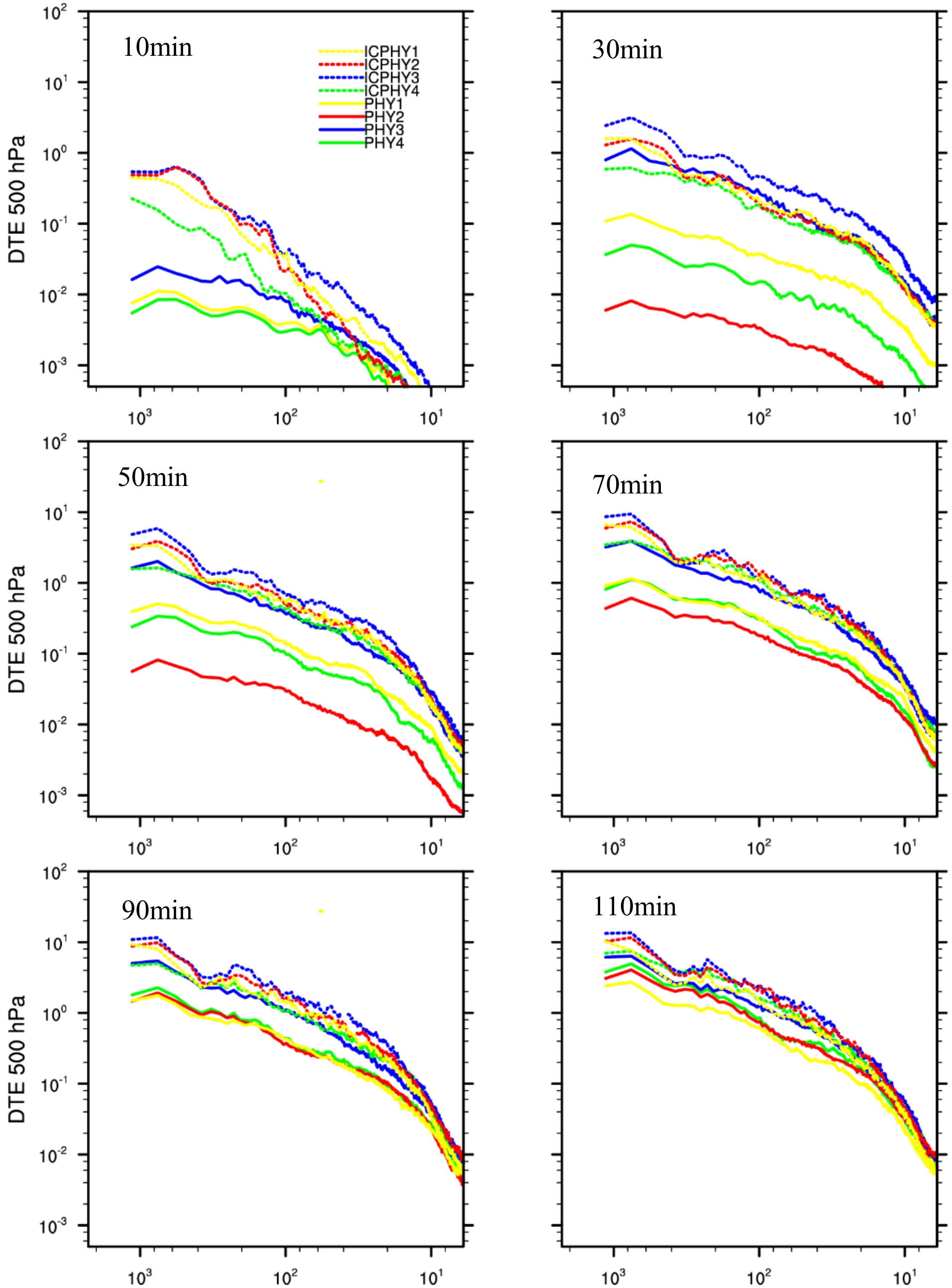
IC

MPHY

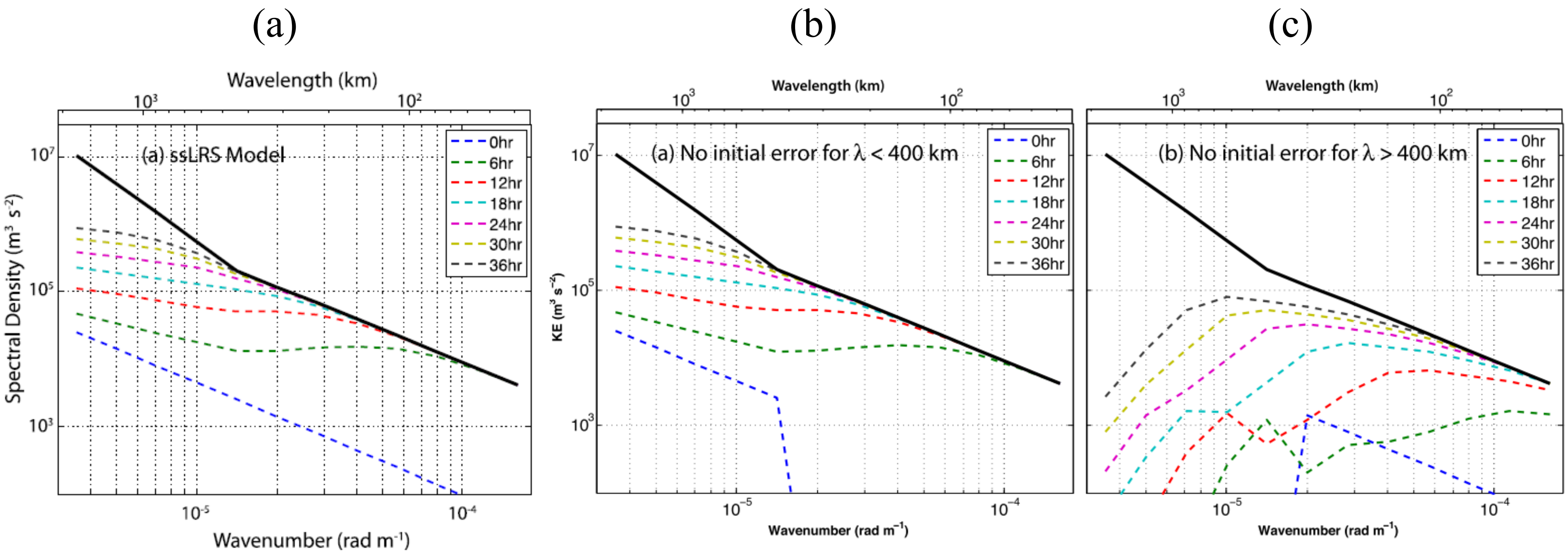
IC+MPHY



Spectra of DTE of individual PHY member at 500 hPa with selected time



Abbreviations	microphysics schemes	PBL schemes
phy0 (control)	Thompson	MYJ
phy4	Milbrandt-Yau	MYNN 2.5 level
Phy5	Morrison	MYJ
Phy6	P3	YSU
Phy7	Morrison	MYNN

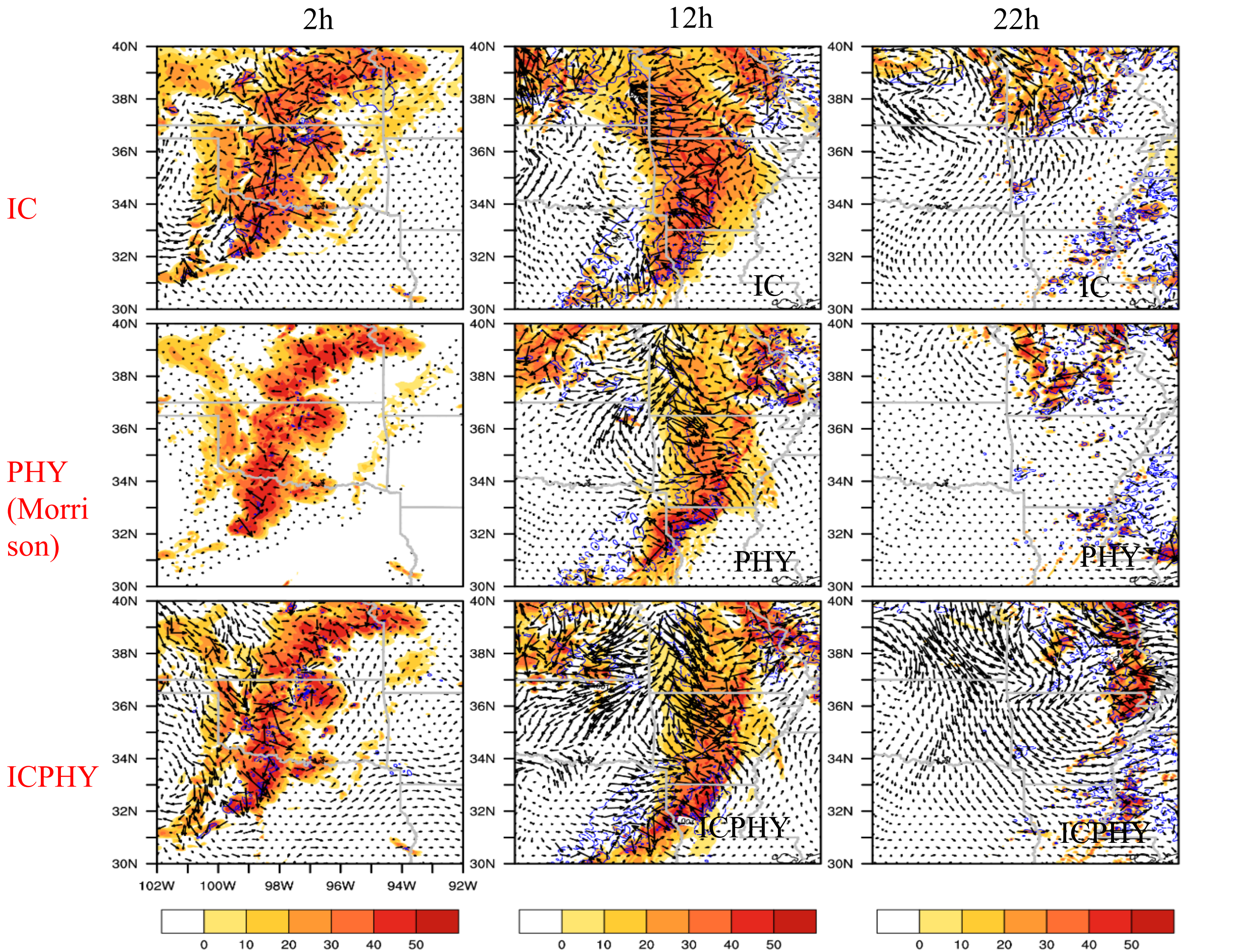


KE0 spectral density Zk/k as a function of wavenumber k for the dimensional ssLRS model every 6 h (line colors given in the legend). Black curve shows the saturation spectrum Xk/k. Initial error is present in all scales (a), is removed at wavelengths (b) less than 400 m and (c) greater than 400 km.

Durran and Gingrich (JAS 2014)

Growth of errors of different sources and across scales

- Inclusion of IC errors is clearly essential in CAM ensemble;
- Multiple MP and PBL physics produce much larger errors than either SKEB or SPPT
- MP and PBL schemes have different effects across scales;
- Errors of less than 100 km scale do grow quickly to saturation within ~12 hours – perhaps it is not that spread grow to slower, but the systematic model error is too large! Perhaps that's why HREF made up of different forecasting systems beats formally designed CAM ensemble (in terms of giving larger spread – because systematic errors of different forecasting systems can be different)
- scale errors would be important for very short range forecasting, they do not seam to matter much beyond a couple of hours as larger scale errors quickly propagate to the smallest scales or smallest scale errors growth very quickly;
- Perhaps its time to pay more attention to the observation of storm environment? Would love to have clear-air radar wind observations!



Composite reflectivity (shaded), and horizontal wind vector difference of an IC member, a PHY (Morrison) member, and a member with both IC and PHY (Morrison) perturbations from control (Thompson).