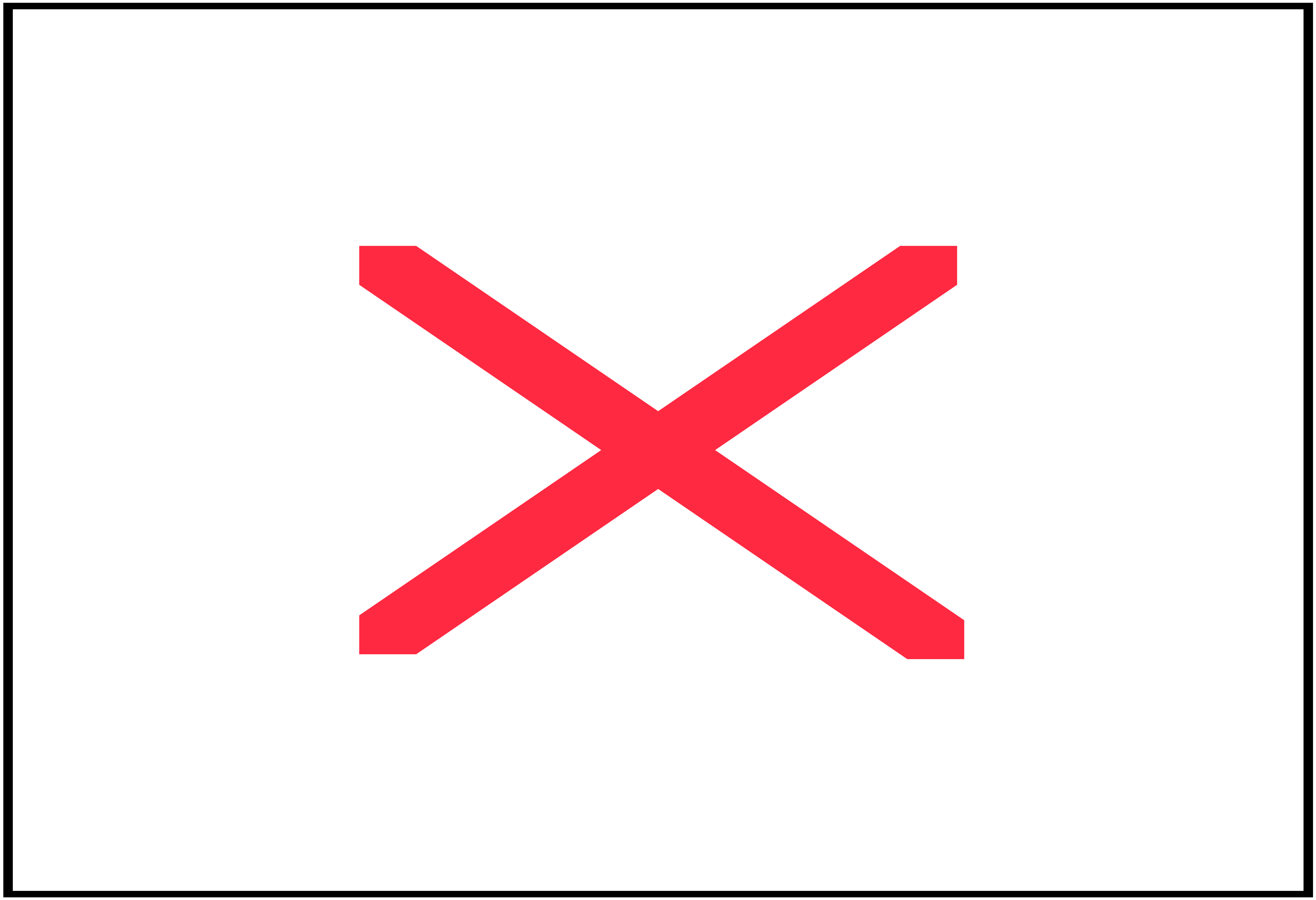
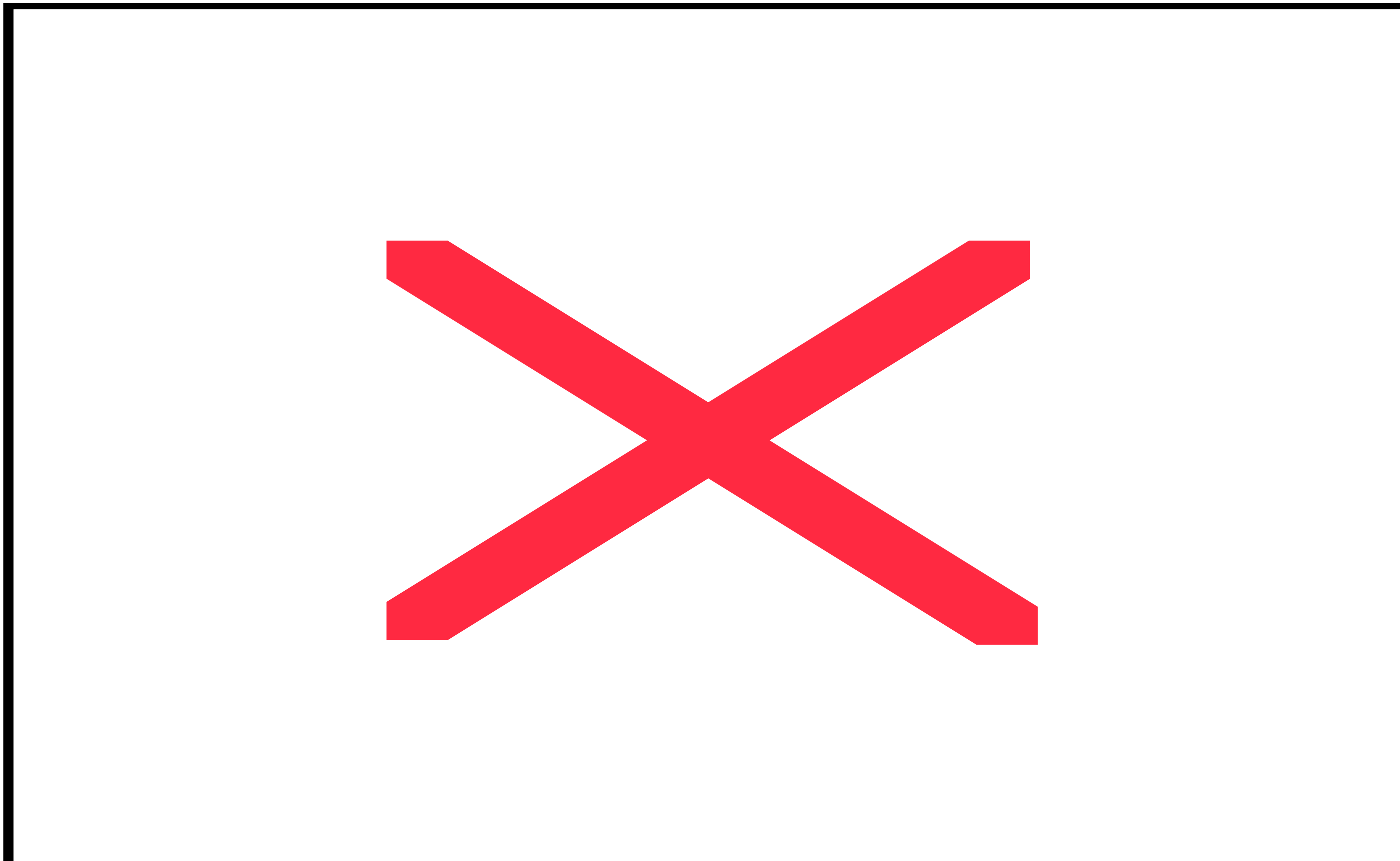
Operational Cumulus Parameterization Requirements at the NCEP Environmental Modeling Center 2003-2009

Stephen Lord, Hua-Lu Pan
S. Saha, S. Moorthi
NCEP/EMC

Overview

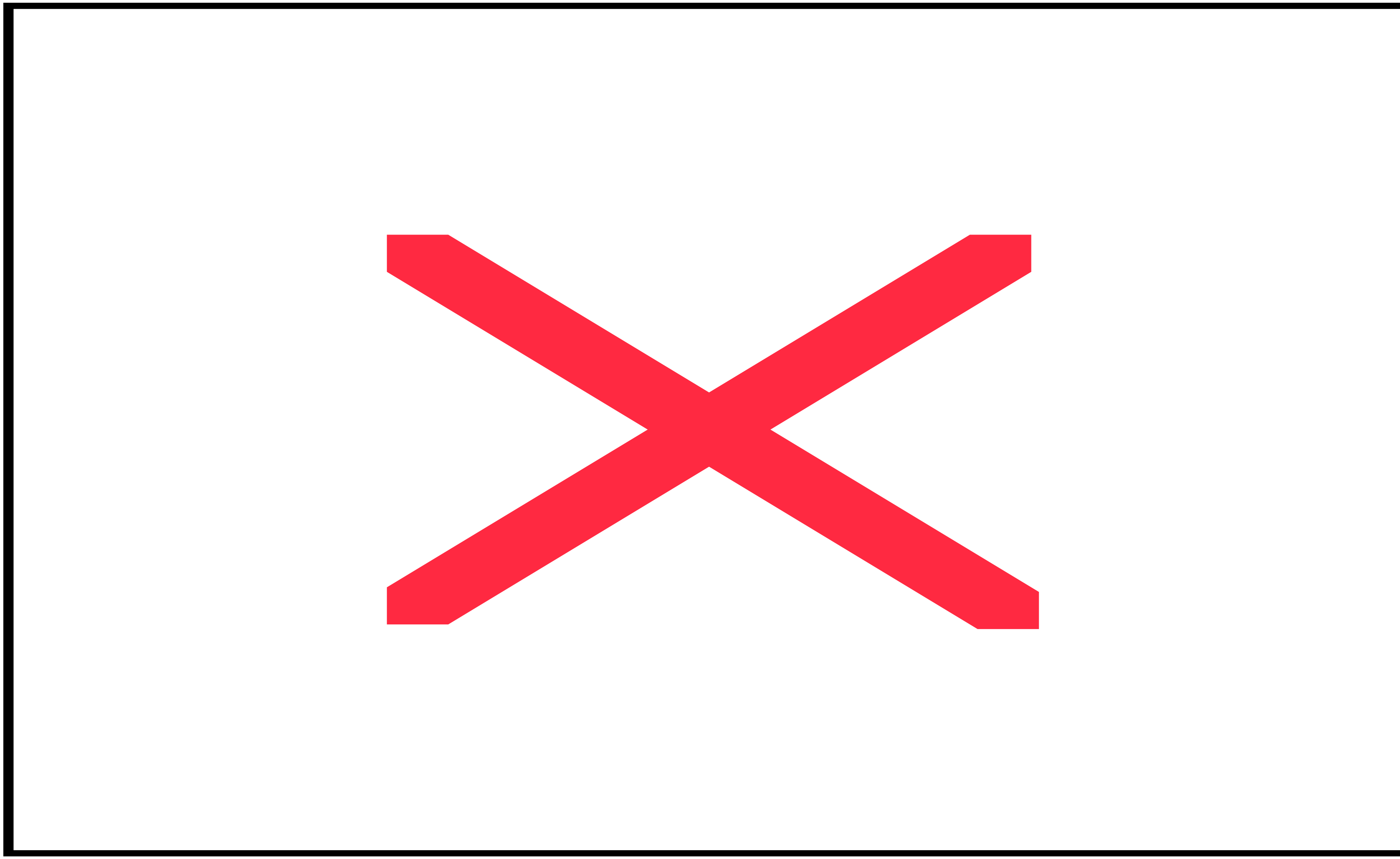
- NCEP Mission for Weather and S/I Climate
- NCEP computing environment and model plans
- History of NCEP cumulus parameterizations for global modeling
- Current Problems & Requirements for future physical parameterization development

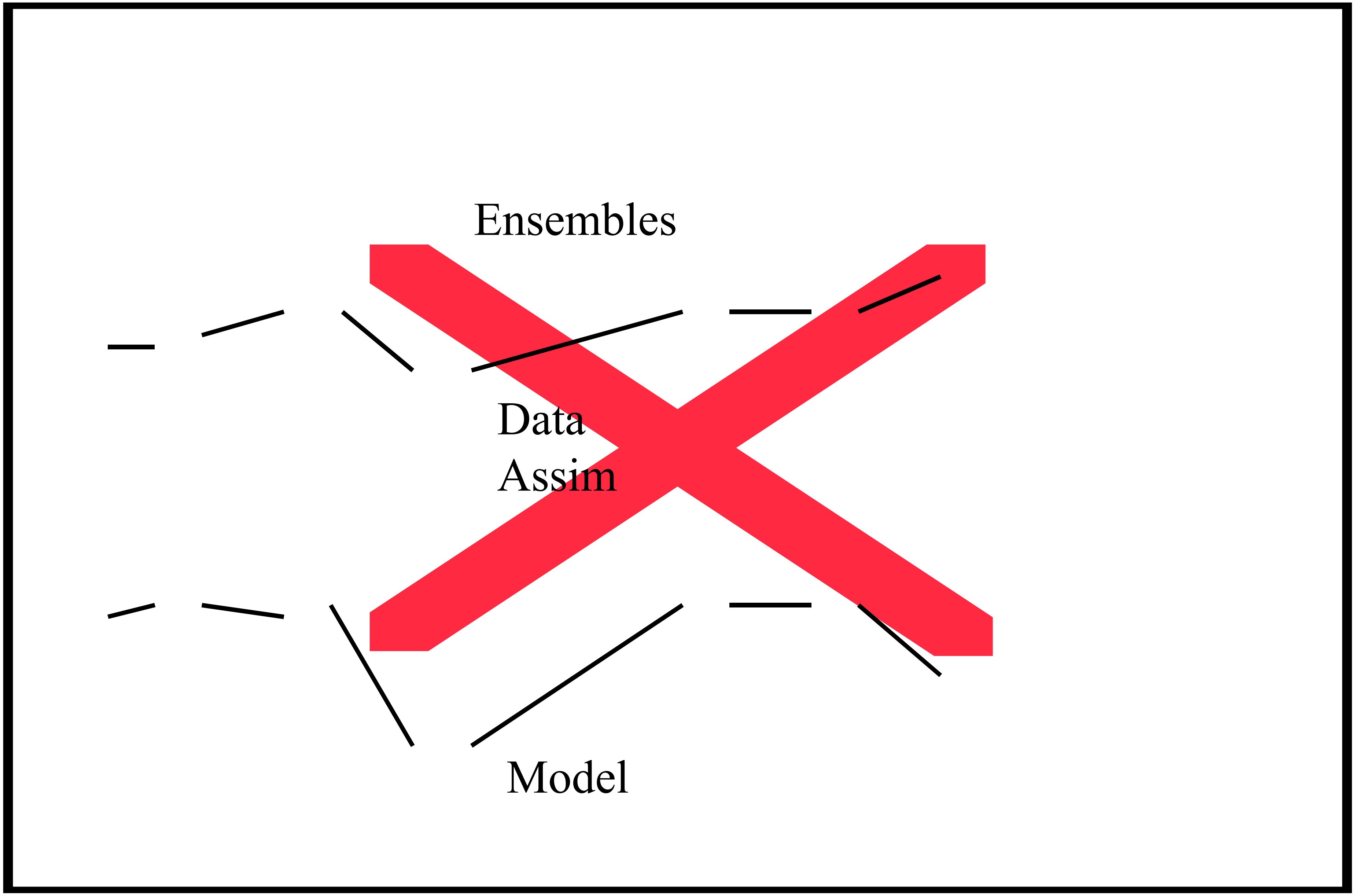


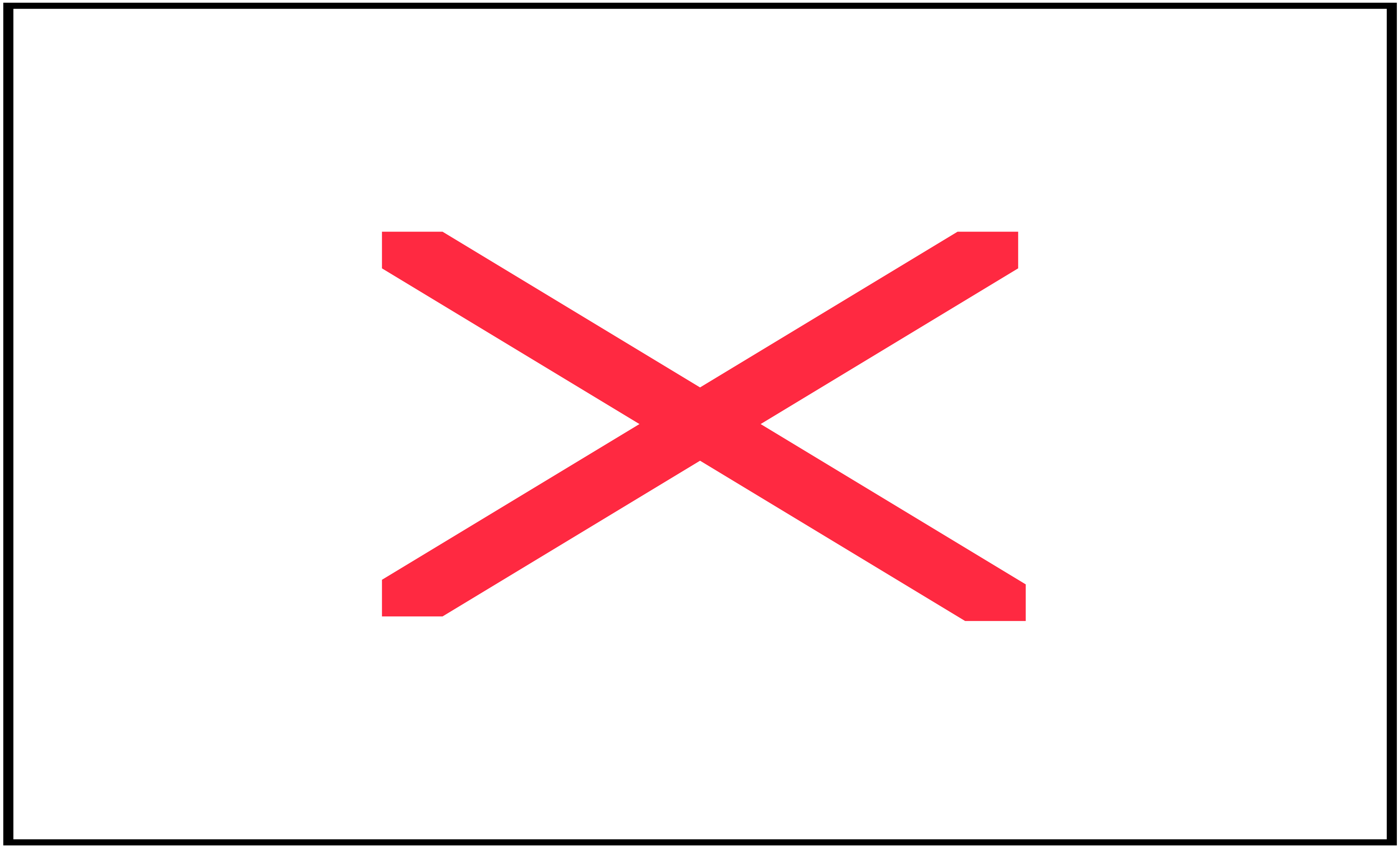


Computing Resource Consumption (wall time)

- T254/L64 (55 km) global spectral model
  - Dynamics (MPI comms) 75%
  - Physics 25%
    - Radiation 20%
    - Convection and PBL 5%




Ensembles
Data
Assim
Model



The Global Climate and Weather Modeling Branch

- Weather – medium-range forecasts 3-7 day range
- Climate – seasonal forecasts 3-6 month range
- Current emphasis – two weeks to two months to bridge the gap and to go for the seamless suite.
- Improvement of the weather model should be combined with the progress of the climate model

Model development philosophy

- Improve weather forecast model with emphasis on weather and climate
- Improve physical parameterizations for weather and climate
- Avoid specific parameter tuning for weather or for climate
- Calibration is essential for climate forecasts

Requirements on Convective Parameterization Weather and S/I Climate

- Convection scheme in the NCEP global modeling system must be able to
  - Provide accurate precipitation forecast for North America as well as for the rest of the world in the 6-72 hour time range,
  - Provide accurate forcing for the maintenance of the tropical large scale circulation.
- Time scale: 6 hours to 6 months.
- Spatial scale: mesoscale to global
- Resolution
  - 40-55 km/L64 (weather)
  - 100-200 km/L28/64 (climate)

Cumulus and PBL Parameterization Development at NCEP

- Grell scheme imported in 1992
  - Implemented in 1993 (Simplified AS, SASCNV)
  - Modified closure in 1996 and 1998
  - Added cumulus momentum mixing in 2001
  - Added random cloud top in 2001
- PBL implementation in 1995 … tropical storm genesis
- RAS (Moorthi and Suarez) installed 1999
  - Version 1 (original)
  - Version 2 (installed 2000)

SASCNV (I)

- Parcel method used to define cloud base and max top
- Simple trigger based on parcel and environment profiles – level of free convection concept
- Mass flux method to distribute heating and drying
- Saturated downdraft

SASCNV (II)

- Modified quasi-equilibrium closure
  - Major impact on mid-latitude springtime convection
- Momentum mixing with crude pressure gradient effect
  - Major impact on tropical cyclogenesis
- Random cloud top to emulate cloud ensemble
  - Vertical distribution of tropical moisture
- Convective precipitation re-evaporation
  - Tuned with data assimilation moisture cycle statistics

SASCNV (III)

- The impact of the SAS over the Kuo scheme:
  - Much smoother precipitation pattern over the tropics,
  - Improved precipitation prediction skill over US in summer,
  - Improved tropical storm track prediction.

Non-local PBL scheme

- The impact of the non-local pbl scheme (Troen and Mahrt) over the local scheme:
  – Improved precipitation prediction skill over US in summer
  – Improved mixing of temperature and moisture in the lowest 2 km
  – Much more active tropics.

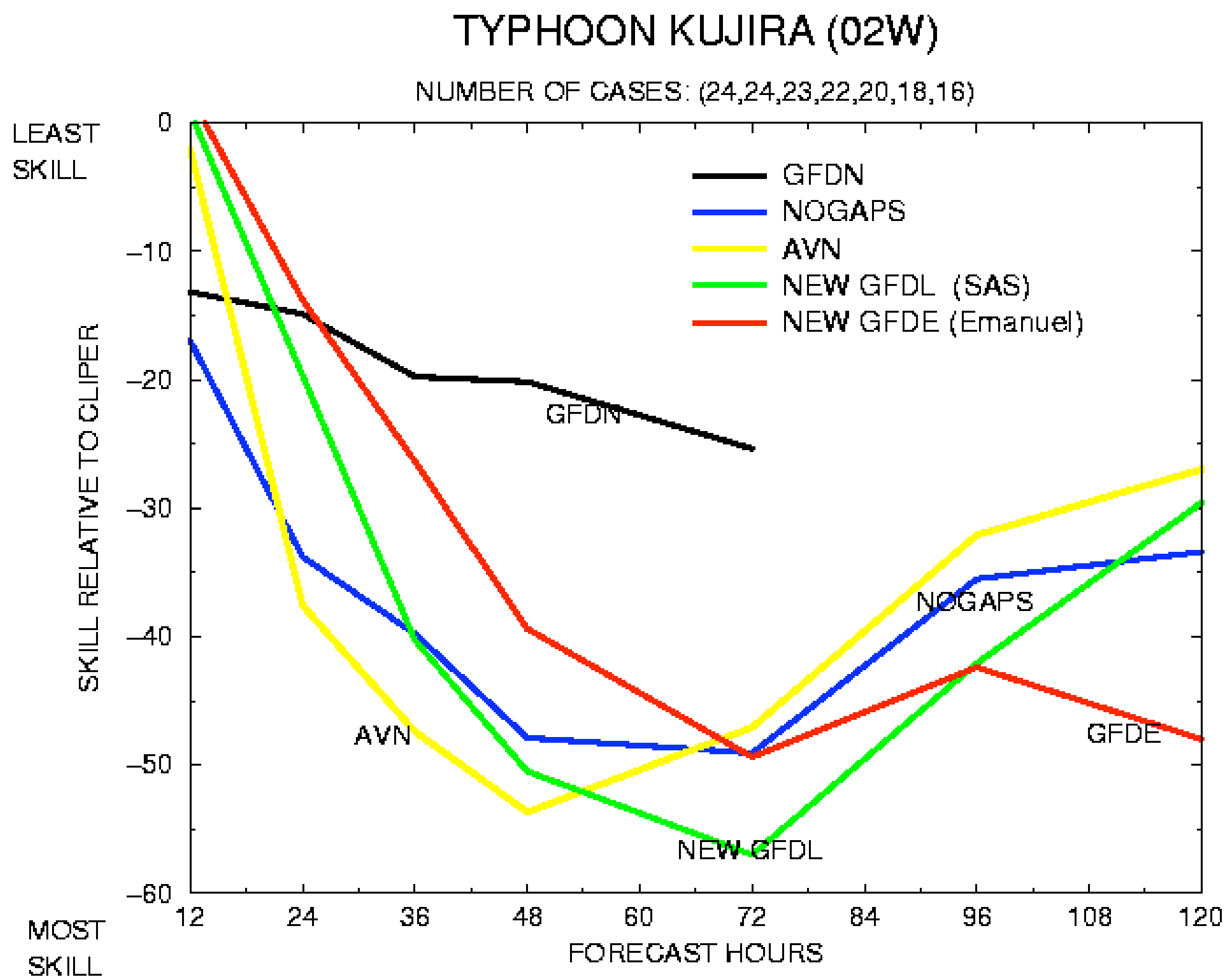
Relaxed Arakawa-Schubert Scheme (RAS)

- Moorthi & Suarez (1992)
  - Linear normalized mass flux
  - Condensate loading ignored
  - Unsaturated downdraft allowed
  - Multiple cloud types, one at a time, each time step
  - Fractional adjustment by each cloud type (tunable parameter)

Relaxed Arakawa-Schubert Scheme – Version 2 (RAS2)

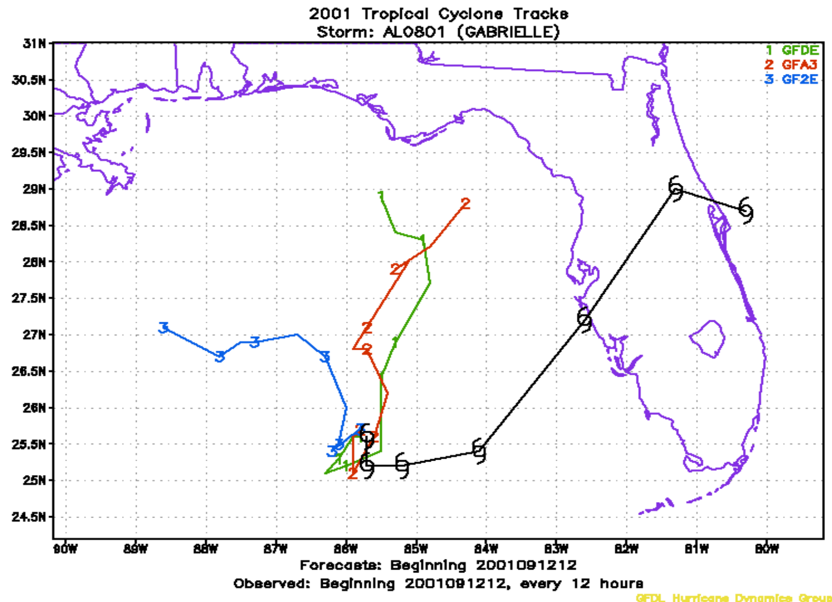
- Condensed water budget added
  - Condensate loading
  - Virtual temperature effect
- Evaporatively driven downdraft (Cheng & Arakawa, 1997 a,b)
  - Prescribed downdraft vertical tilt
  - Unsaturated downdraft allowed
  - Evaporation of falling rain included
  - Downdraft penetrates & mixes in PBL
- Conserving momentum transport
- Tracer transport added

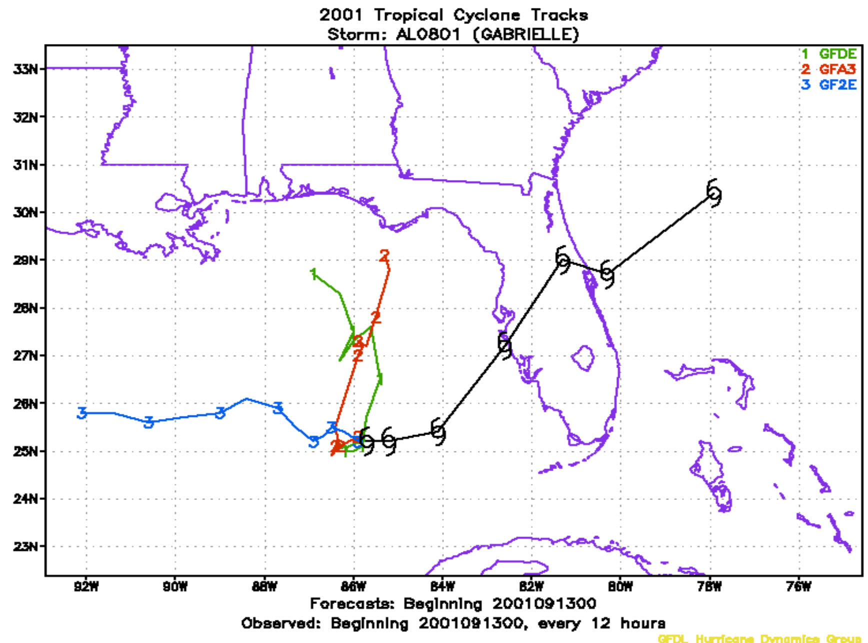
Impact of Cumulus Parameterization on Hurricane Track Forecasts April 2003 Cases

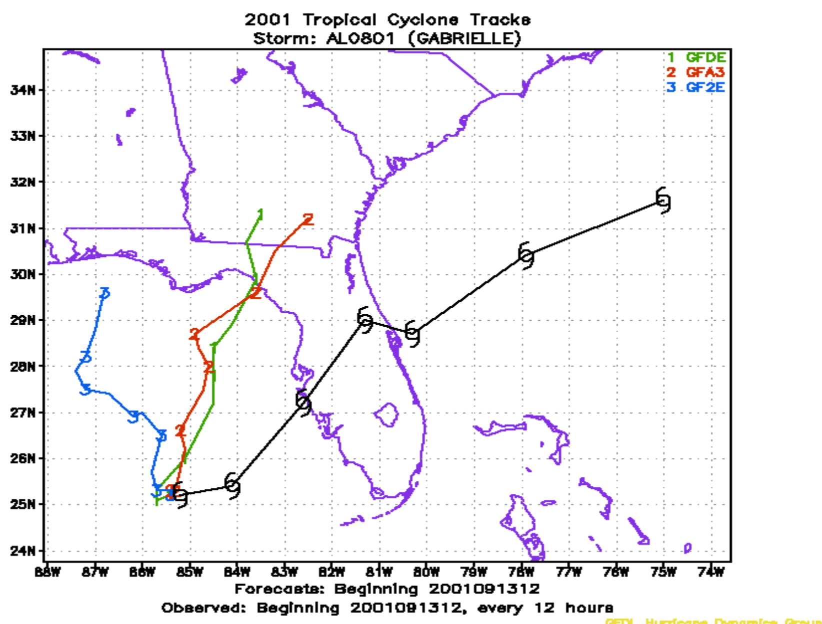


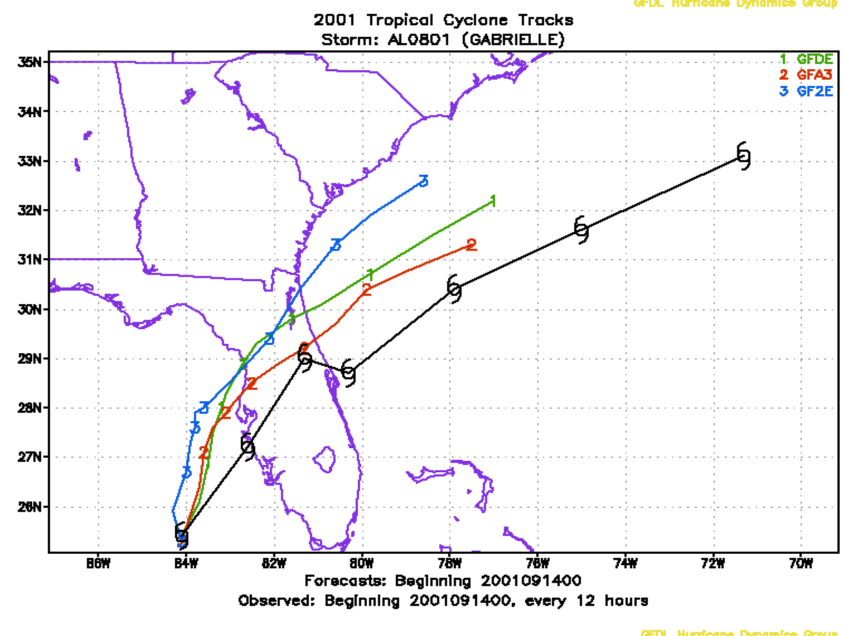
Sensitivity to PBL Parameterization

Emanuel + MY2.5 (blue); Emanuel + NCEP PBL (green); NCEP SAS + NCEP PBL (red)









Further Examples of Sensitivity to Model Cumulus and PBL Physics:
Global Moisture Cycle

- Model physics is primary determinant of tropical climate
- In data assimilation, the model exerts a strong influence on the analysis because of sparseness of data.
- Moisture analysis is especially dependent on the first guess.
- When observations such as the SSM/I precipitable water is used in the analysis, the model physics must create a compatible climatology or the model simply spins up or down to get to its climatology.
- Over a 6 month data assimilation, moisture incompatibilities in the data assimilation resulted in drying up the soil in South America and the Amazon rain stopped.

Further Examples of Sensitivity to Model Cumulus and PBL Physics:

False Alarm Tropical Storms

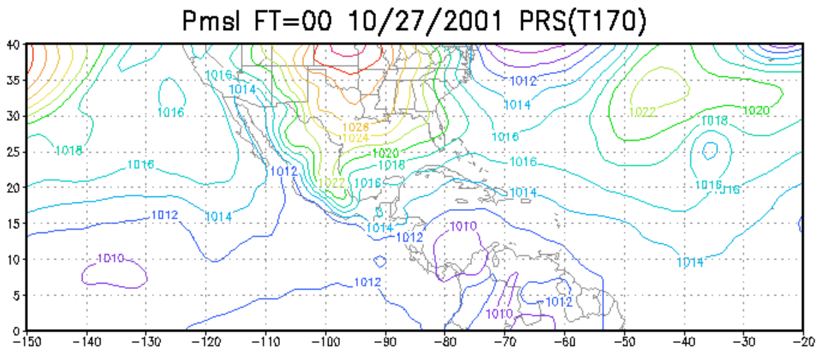
- In 1995, NCEP implemented a non-local PBL scheme in the model. Tropics became more active.
  - False alarm storms. There were more storms in the model first guess than in reality.
  - First guess storms interferes with the synthetic observations based on the observed storm.
  - Global precipitation is now above the satellite estimates.
  - Over North America during the northern spring and fall, the AVN/MRF started predicting grid-scale storms where MCCs tended to form.
- In 1999, NCEP tested relocating the model generated storm and turning off the synthetic observations for tropical storms

Further Examples of Sensitivity to Model Cumulus and PBL Physics:

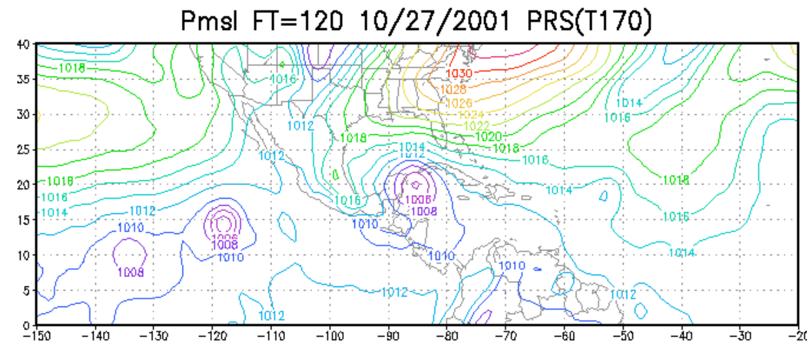
False Alarm Tropical Storms (cont)

- 2001: cumulus momentum mixing added
- Parameterized the pressure change effect with additional entrainment.
- Added random cloud top algorithm similar to RAS.
  - detrained cloud water from the convection to the new prognostic cloud water scheme
  - More realistic tropical moisture distribution
- Most of the false alarm tropical storms removed while preserving the real storms

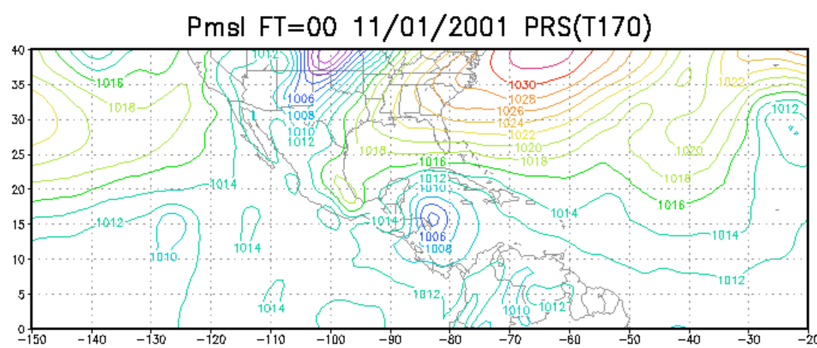
Analysis



5 day forecast



Verifying Analysis



Michelle and Octave, 2001

Further Examples of Sensitivity to Model Cumulus and PBL Physics:

Spurious Mid-Latitude Grid-Scale Storms

- Over North America during the northern spring and fall, the global model began predicting grid-scale storms where MCCs tended to form
- Recent work has concentrated on delaying grid-scale saturation in conditionally unstable atmosphere.
- Closure is modified to allow for adjustment toward neutral (zero CAPE) condition when the atmosphere is in disturbed condition.
- Time scale of the adjustment was also modified in disturbed conditions.

Simulation of Tropical Climate with the NCEP Global Model

H.-L. Pan, W. Wang, S. Saha,
S. Moorthi, Y. Hou, M. Iredell,
and J. Sela
GCWMB/EMC/NCEP

Procedures

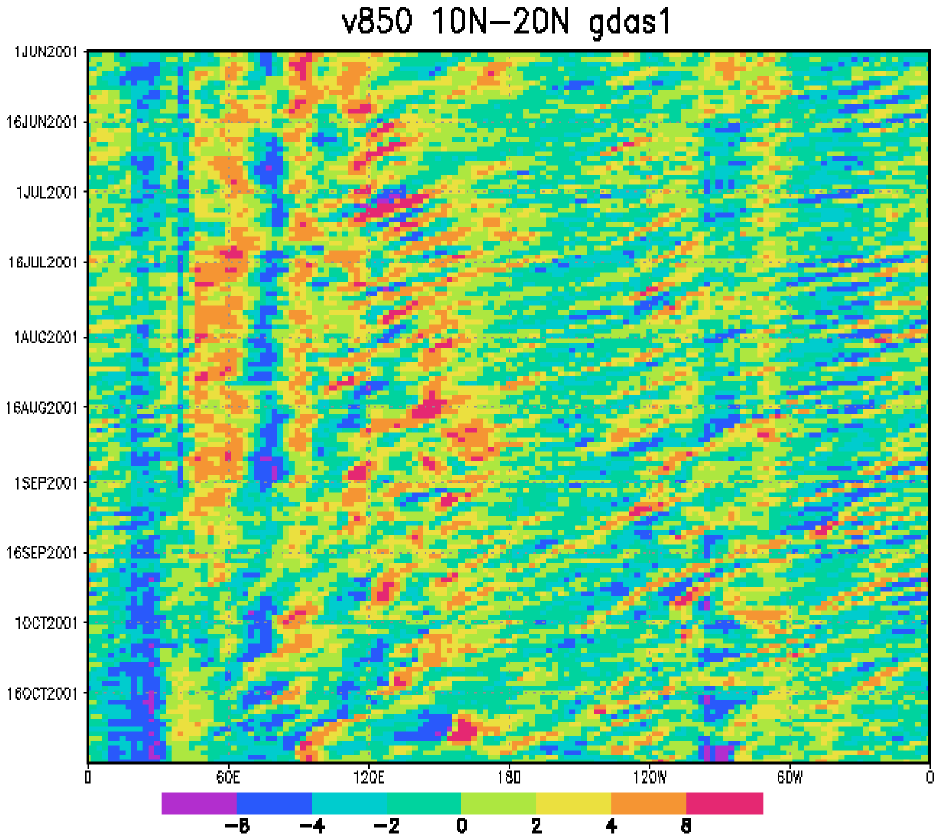
- NCEP global forecast model
- AMIP mode
  - Climatological SST
  - 6 year run (last 5 years retained)
    - Model climatology subtracted to produce anomalies
  - 13 month run (last 12 months retained)
    - Observed climatology from Climate Data Assimilation System (CDAS) subtracted to produce anomaly
    - Most stringent test (model bias remains)

Sensitivity experiments

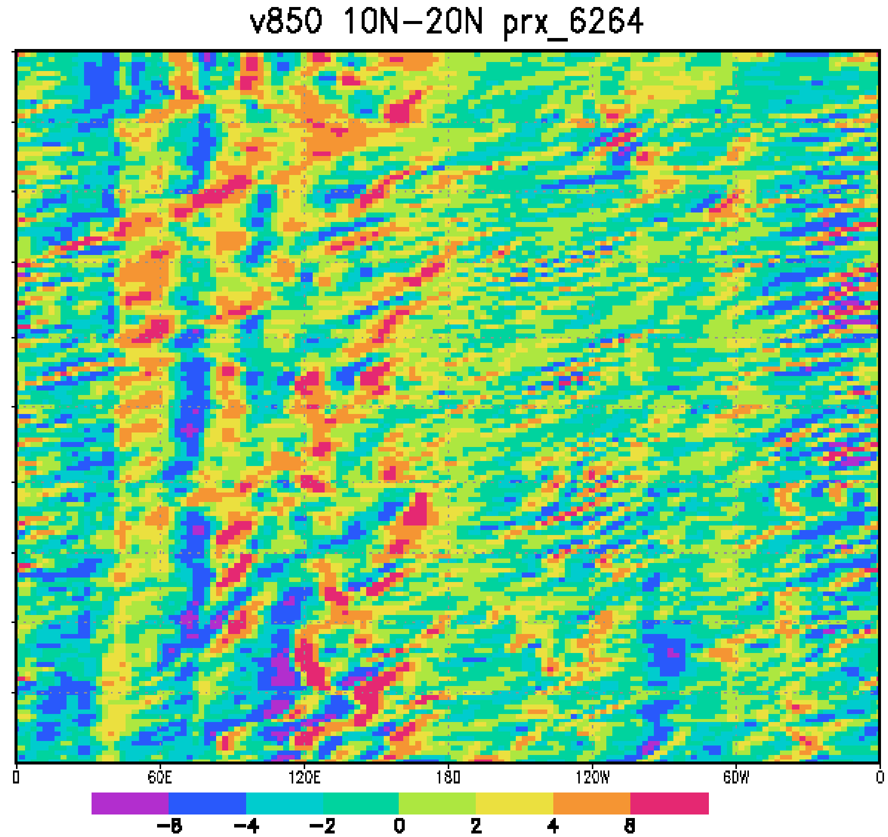
- Various model configurations
  - 28 (2.0), 42 (2.0), 64 (0.2) levels (mb top)
  - T62 (200 km), T126 (100 km), T170 (75 km) horizontal resolution
- Current SFM (ca. 1996 physics)
- Different convections (SAS and RAS)

Easterly waves

Observations (CDAS)



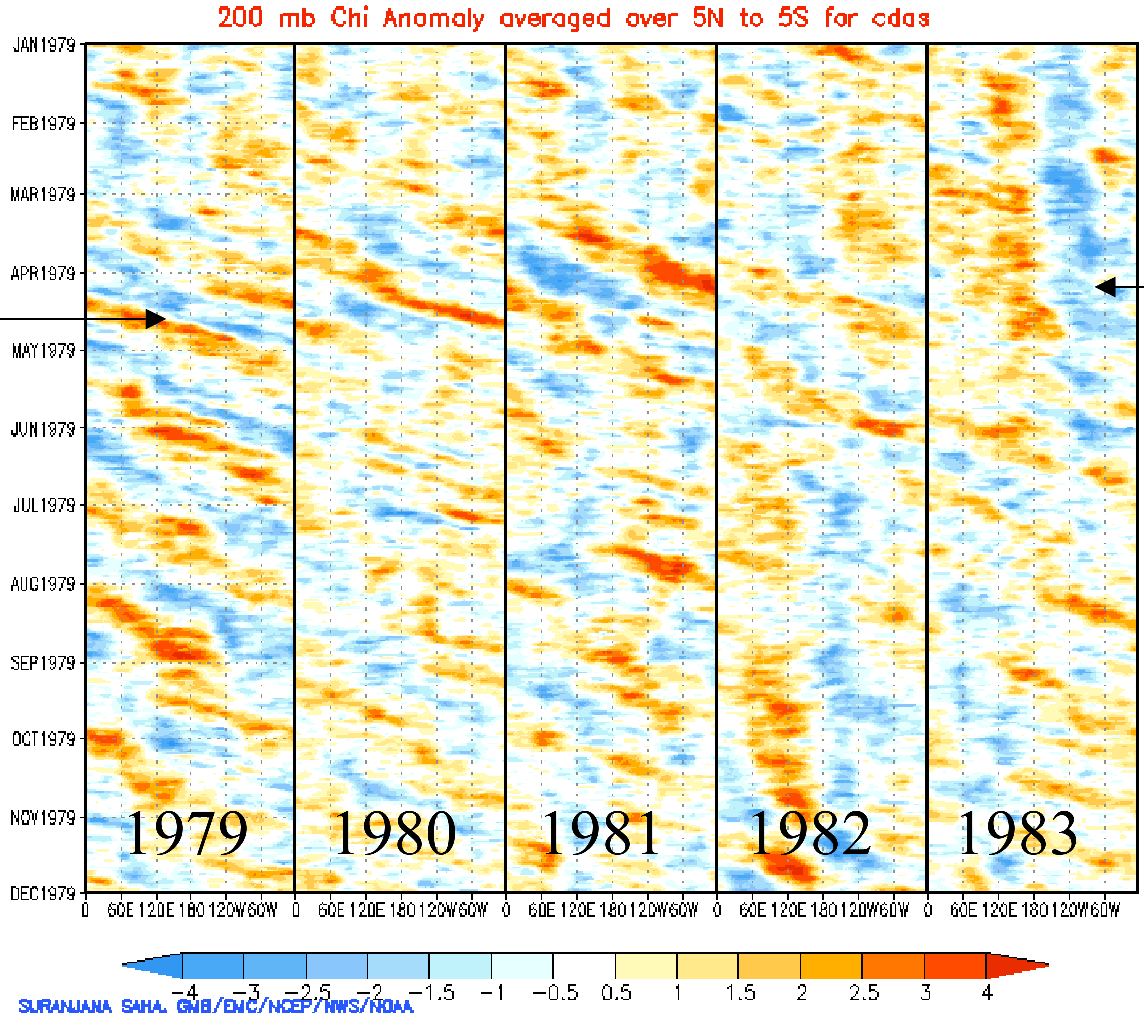
AMIP run (T62/L64)



CDAS Chi anomalies 1979-1983

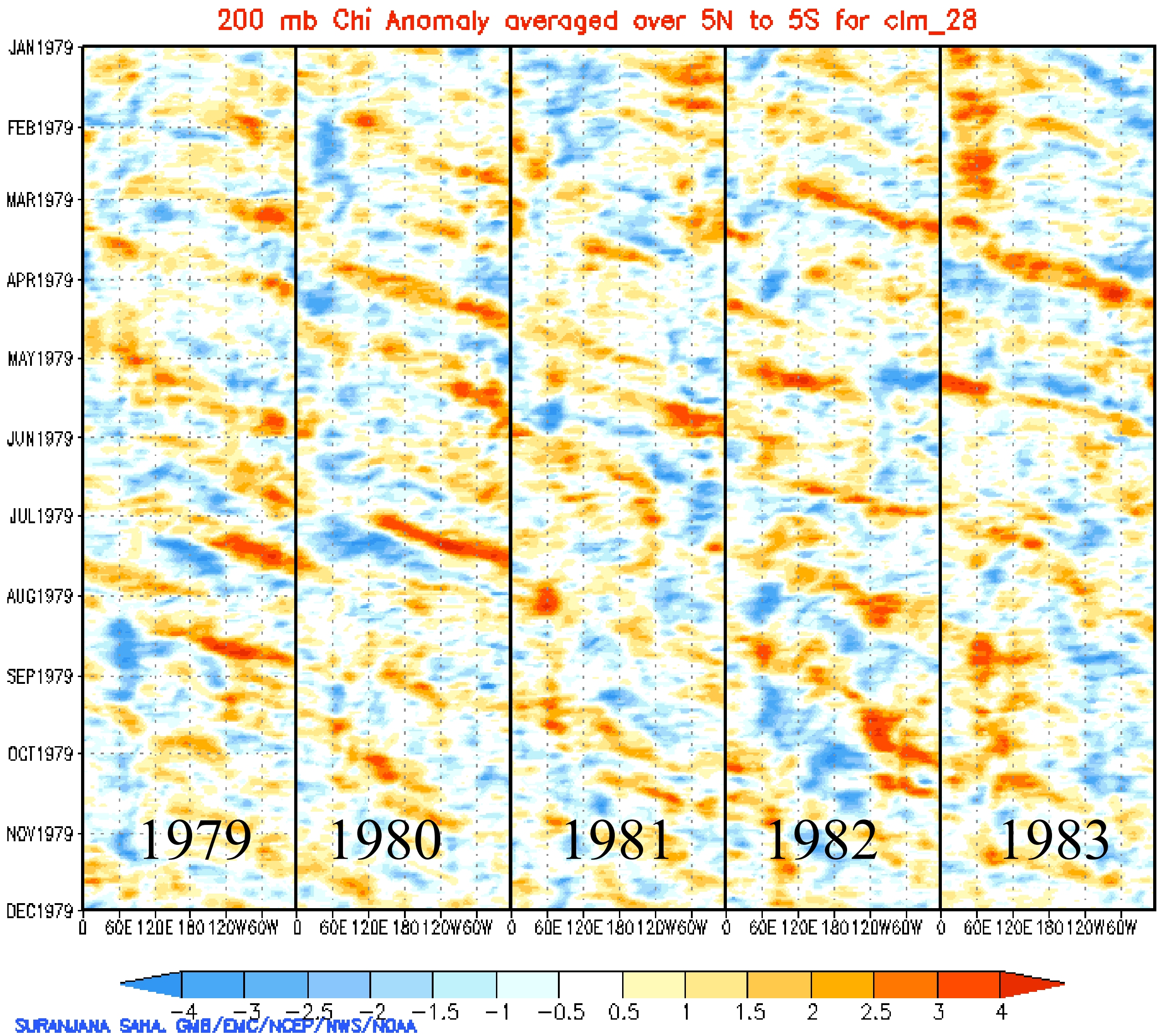
(Observed from Analysis)

MJO prominent in non-ENSO periods



MJO stationary during ENSO events

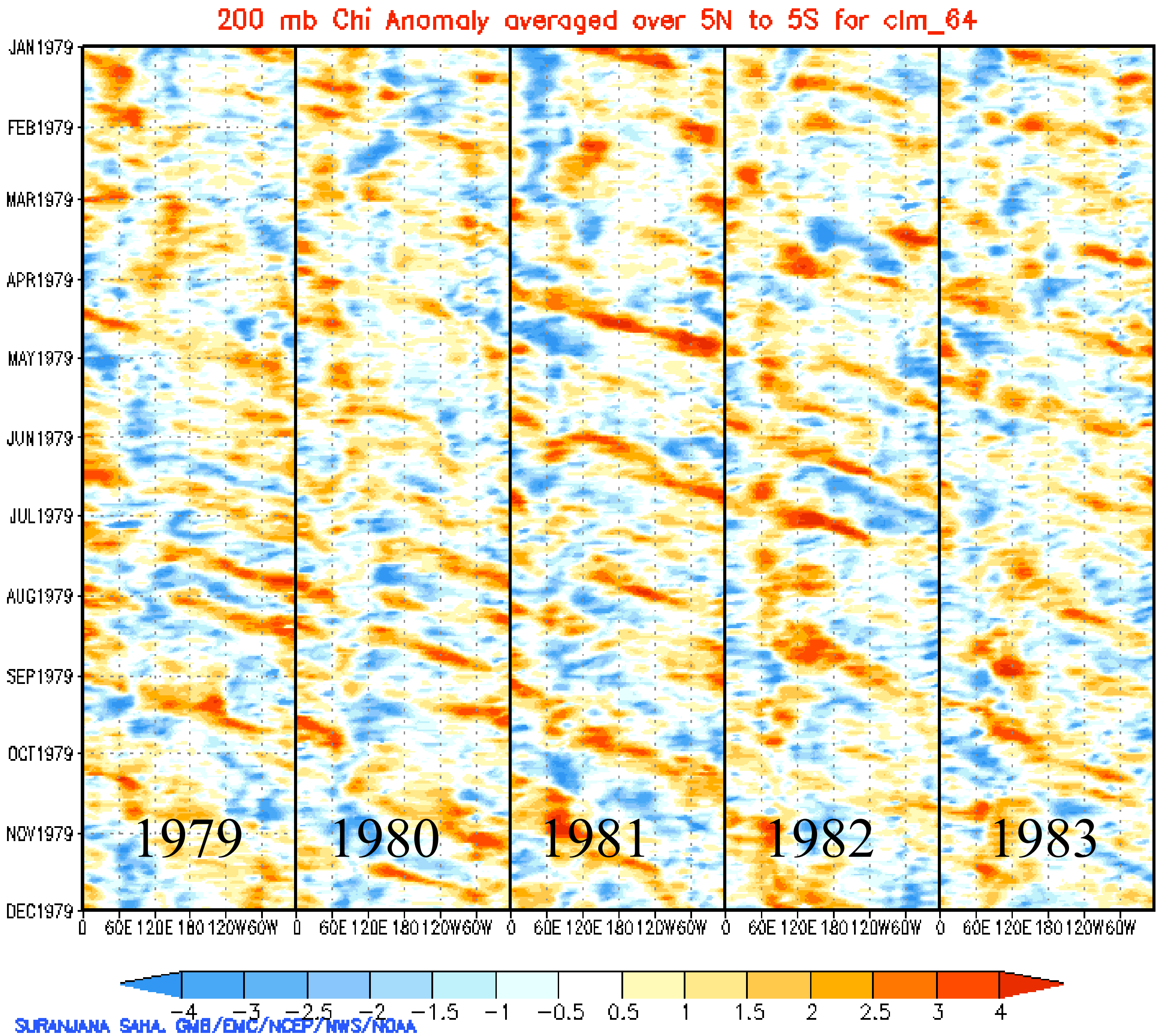
28 Layer model Chi anomaly with Climatological SST



No ENSO events so MJO prominent

Model climatology removed

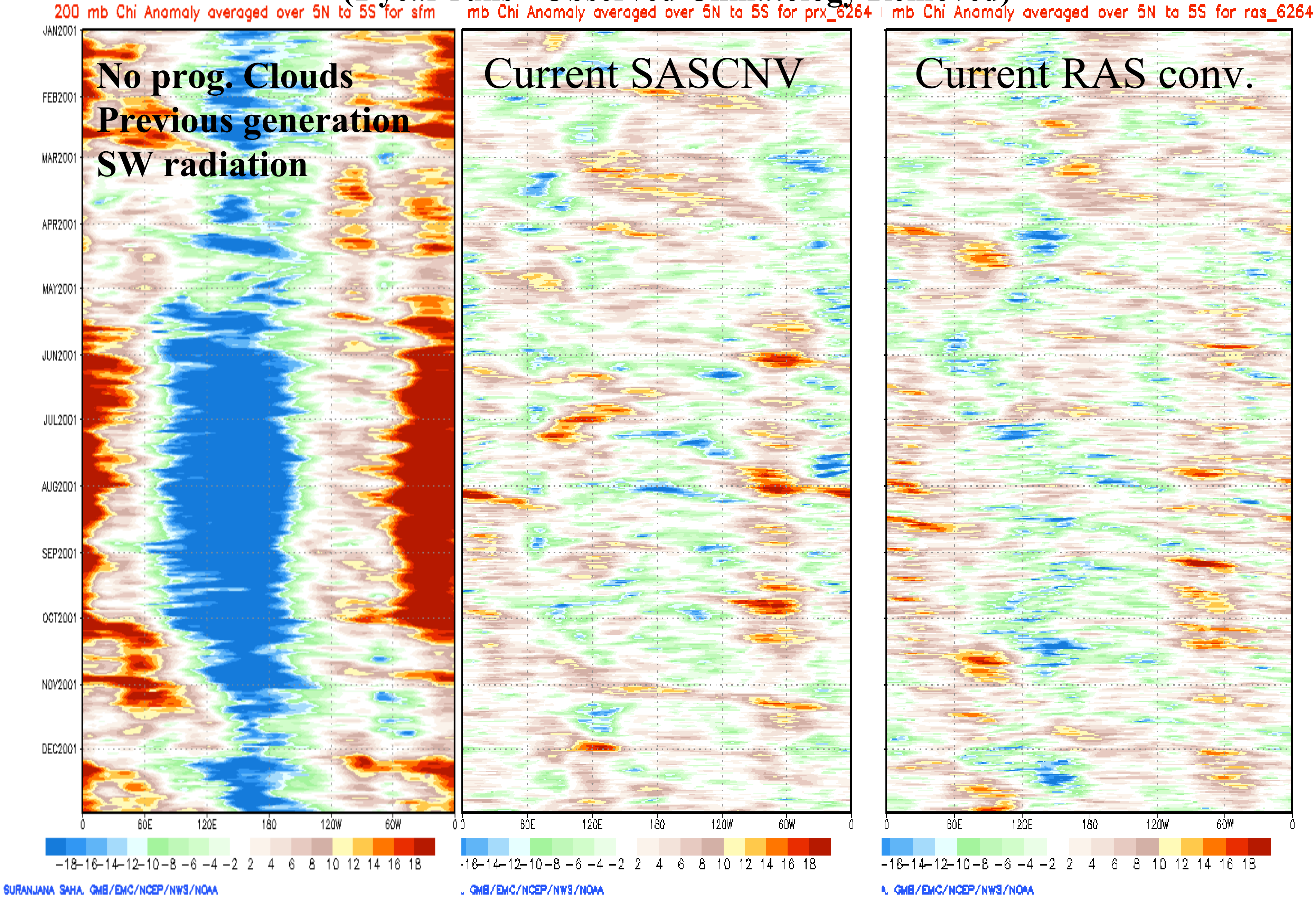
64 layer model Chi anomaly with climatological SST



More realistic MJO propagation with 64 levels

Impact of Different Parameterizations

(1 year runs - Observed Climatology Removed)



Conclusions

- The NCEP MRF model generates realistic easterly synoptic disturbances in its climate state
- The model generates MJO-like disturbances with realistic amplitudes
- The propagation speed of the ‘MJO’ is very sensitive to model configurations

Summary

- The last decade has seen remarkable progress in operational development of convection & PBL parameterizations:
  - More realistic tropical analysis (general circulation)
    - Major decrease in tropical cyclone track forecast errors
    - Reduced false alarms (convective momentum transport)
    - Increased use of satellite data (AMSU-A, AMSU-B)
    - Prognostic water and interactive radiation
  - tropical storm genesis beginning to be skillful
  - tropical storm intensity and intensity change are potentially skillful

Summary (cont)

- Future challenges
  - finding ways to deal with midlatitude MCCs, grid saturation with unstable forcing
  - improve MJO predictions
  - seasonal response of the model to SST anomalies including ENSO.

Summary (cont)

- Application of good physical insights is needed to improve parameterizations
  - multiple spatial and temporal scales from several km to 100's of km, hours to months
  - NWP modeling and data assimilation provides much information on numerical forecast system climate
  - Unified approach to subgrid and grid scale effects across spatial and temporal scales
  - Superparameterization studies can be valuable
    - Provide data and ideas for advanced parameterizations
    - Tuning and incremental improvements of current generation parameterizations

Summary (cont)

- At NCEP, soundly tested and validated physical parameterizations will be necessary for the foreseeable future