NGGPS Physics Overview

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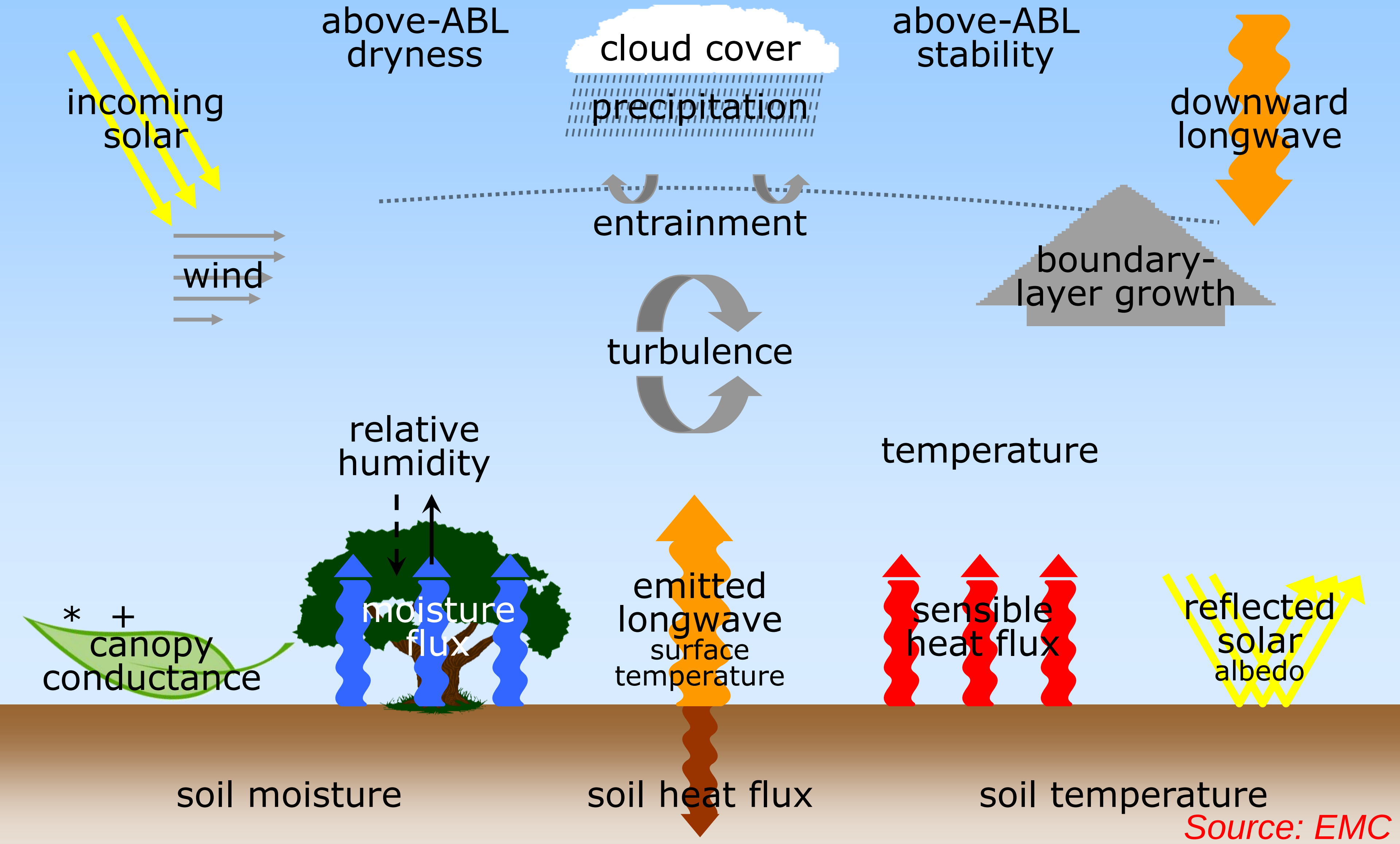
Complex Interactions (Land-Atmosphere)

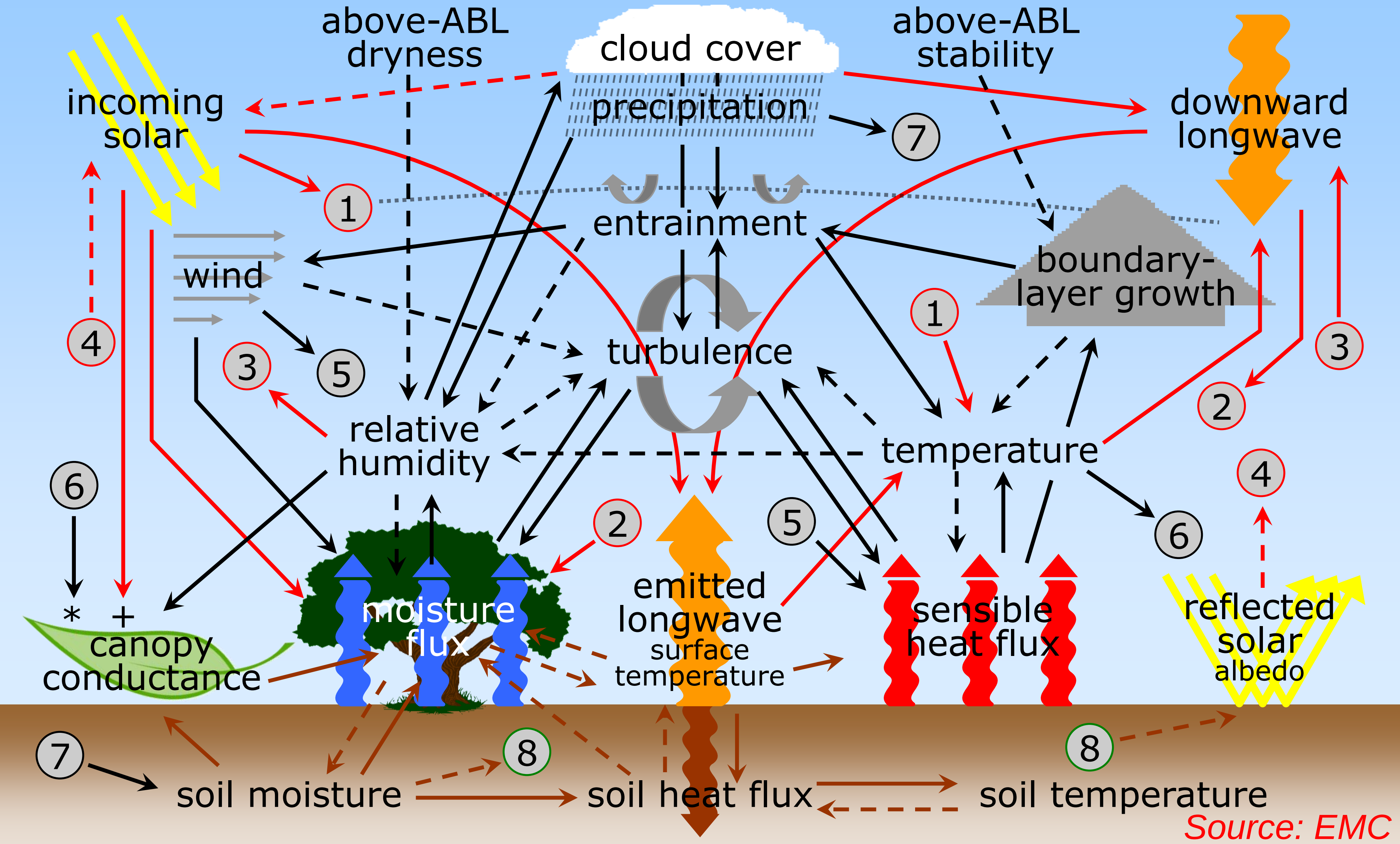


radiation **surface layer & ABL** **land-surface processes** **feedbacks:**

+positive feedback for C3 & C4 plants, negative feedback for CAM plants **positive**

****negative feedback above optimal temperature*** **negative**

Complex Interactions (Land-Atmosphere)



radiation | surface layer & ABL | land-surface processes | feedbacks:

+positive feedback for C3 & C4 plants, negative feedback for CAM plants | positive

****negative feedback above optimal temperature*** | negative

NGGPS Physics Overview

- Objective
  - *Systematically* develop a next generation physics suite for NGGPS for weather to climate for deterministic, ensemble, and coupled applications
  - Physics suite should be scale and aerosol aware, and contain options for varying degrees of sophistication and physical realism
  - Emphasis on the interactions between components within the suite
- Strategy
  - Coordinated development efforts centered on EMC and GMTB, with close collaborations with NGGPS developers and key physics developers in the community
  - Common Community Physics Package (CCPP) with carefully vetted physics suites for global modeling at various resolutions/time scales
  - Semi-prognostic single column model capability for the suite
  - Comprehensive physics diagnostics and datasets
  - Comprehensive testing in 1D and 3D versions of NGGPS model, as well as thorough testing in a DA cycling mode

NGGPS Physics Team Plan Broad Focus Areas

- Scale aware convective and boundary layer formulations.
  - Address grey zone issues with convection and boundary layer clouds and shallow convection
- Microphysics sophistication
  - Options for increasing sophistication (single, double moment)
- Improved interactions between physical processes
  - Radiation, clouds, microphysics and aerosol interactions
- Physically-based framework for stochastics in key physics
  - Ensemble and deterministic applications will benefit
- Advanced code structures.
  - Increasing level of complexity that can be added or omitted depending on application.
  - Implementation of NUOPC physics driver (Interoperable Physics Drive) including single column physics system consistent with the available physics suites

NGGPS Physics Team Plan Priorities

- Unified convection parameterization that provides a scale-aware capability.
- Advance the sophistication of the microphysics parameterization, which should include a double moment capability; option for coupling w/ aerosols.
- Boundary layer parameterization improvements that are coupled with turbulence, clouds, shallow convection, and radiation. Approaches include the Simplified Higher-Order Closure (SHOC) and moist version of the Eddy Diffusivity-Mass Flux (EDMF) approach.
- Advance the parameterization of the land surface to address systematic biases and errors in weather to climate forecasts; improve the representation of diurnal cycle.
- Improved parameterizations to represent stationary and non-stationary orographic and non-orographic gravity wave drag to improve representation of momentum fluxes, momentum budget and phenomena such as the QBO.
- Advance the radiation parameterization and in particularly the interaction with clouds and microphysics, and aerosols.

EMC plan for atmospheric physics in NGGPS

- Major objective of NGGPS is to develop world's best weather prediction model.
  - EMC's goal includes developing world's best extended range and seasonal climate prediction models.
  - Development of a Unified Global Coupled System will enable a seamless unified earth system model that includes ocean, land, sea ice, ocean waves, atmosphere, aerosols...
  - Formulation of model physics be applicable to all resolutions, including the so called "grey zone"

Radiative Transfer Physics

- Accurate treatment of radiative transfer in the atmosphere
  - The current radiation treatment in NEMS is a modified version of McICA/RRTMG
  - Major inaccuracy is associated with the uncertainty in prediction of clouds and aerosols
  - Focus on improving the cloud and aerosol treatment by providing sub-grid scale variability from the treatment of moisture and turbulence processes and spectral dependency of the surface albedo.

Surface fluxes at the earth-atmosphere interface (Land)

- Accurate representation of fluxes of heat, momentum and tracers (including water, aerosols etc.) over land
  - Improve the prediction of land surface fluxes through continued improvement of Noah land model and possibly using Noah-MP version
  - A more sophisticated treatment of land surface model through the use of Land Information System (LIS) developed at NASA will be adopted for high performance terrestrial hydrology modeling and data assimilation.

Surface fluxes at the earth-atmosphere interface (Water & Ice)

- Accurate representation of fluxes of heat, momentum and tracers (including water, aerosols etc.) over ocean and sea ice
  - Improve the fluxes over ocean and sea ice with atmospheric model coupled to ocean, sea ice and wave models
  - Implement fresh water lakes (flake model) to accurately represent surface fluxes over large number of lakes that are not handled by the ocean model.

Planetary Boundary Layer Physics

- Advanced treatment of Boundary Layer Physics
  - TKE based scale aware moist EDMF PBL scheme
  - PDF based scale-aware turbulence and cloudiness scheme based on Simplified Higher Order Closure (SHOC) approach which unifies boundary layer turbulence, shallow convection and cloudiness schemes
  - any additional schemes developed and implemented in NEMS through R2O/NGGPS supported projects (with support from GMTB)

Physics of penetrative convection

- Advanced treatment of Deep Convection
  - Scale awareness becomes extremely important when it comes to the treatment of deep convection.
  - Modified scale aware and aerosol aware GFS bulk massflux deep and shallow convection scheme (based on Simplified Arakawa-Schubert scheme)
  - Chikira and Sugiyama spectral convective scheme (a collaboration with CSU) with prognostic closure and Arakawa-Wu Scale-Aware extension
  - other advanced schemes developed through NGGPS R2O funding (e.g. Grell-Freitas scheme)

Cloud Microphysics

- Advanced treatment of cloud microphysics
  - currently implementing a version of Morrison double moment microphysics along with aerosol activation package.
  - other advanced schemes developed and implemented through NGGPS R2O funding

Gravity Waves and Drag

- Stationary orographic gravity waves and non-stationary non-orographic gravity waves play major role in upper atmosphere
  - Momentum deposition in the stratosphere is important for accurate prediction of the Quasi-Biennial Oscillation in the stratosphere
  - Implement unified gravity wave physics into NGGPS (collaboration with SWPC and CIRES) that includes turbulent heating and eddy mixing due to wave dissipation and breaking

Ozone Photo-Chemistry & Stratospheric Water Vapor

- The operational GFS currently parameterizes ozone production and destruction based on monthly mean coefficients provided by NRL through CHEM2D chemistry model.
  - upgrade this parameterization through latest coefficients and adding two more terms that depend on the temperature and column ozone climatology
  - implement stratospheric water vapor forcing to represent slow production of H2O through methane oxidation and photolysis of H2O in the upper mesosphere due to solar Lyman alpha absorption.

NGGPS/CTB Physics Developments

Project Area	Collaborations	Description
Physics Driver	EMC	Develop and deliver a GFS physics suite and an associated interoperable physics driver that can be used with all NGGPS candidate dynamic cores during Phase 2 testing.
Convection and Boundary Layer	EMC; ESRL/GSD & PSD University of Washington; University of Utah; GFDL	Develop and test new schemes for convection and boundary layer to improve scale-aware capability and scores dependent on these parameterizations.
Cloud Microphysics	EMC; ESRL/PSD; NCAR University of Maryland University of Albany	Develop and test new schemes for cloud microphysics and improve interactions with other parameterizations such as radiation.
Radiation	EMC University of Colorado ESRL/GSD & PSD	Support development and use of operational radiation codes to meet requirements of other parameterizations (e.g., aerosol specification), and improve accuracy of radiation schemes (e.g., improved spectroscopic basis) for improved GFS performance
Gravity Waves and Drag	EMC; SWPC; NRL	Improve GFS accuracy with improved parameterizations of large-scale surface drag, non-orographic drag and gravity waves
Earth System Surface Fluxes and State	EMC; NCAR	Improve surface state and fluxes into the atmospheric model for land, ocean, sea ice and glacial ice.

Physics: Two-Stream Strategy

Physical Process	Operational Physics (Evolved)	Advanced Physics
Radiation	RRTMG	RRTMG (scale and aerosol aware, w/sub-grid scale clouds)
Penetrative convection and Shallow convection	SAS RAS	Scale-aware Chikira-Sugiyama & Arakawa-Wu Grell-Freitas (GF)
Turbulent transport (PBL)	Hybrid EDMF	CS+SHOC (unified convection & turbulence)
Cloud microphysics	Zhao-Carr WSM-6	WSM-6, Ferrier-Aligo; One Double Moment (DM) scheme (Morrison, Thompson Barahona or other)
Gravity wave drag	Orographic GWD Stationary convective GWD	Unified representation of GWD
Ozone physics	NRL simplified scheme	NRL simplified scheme
Land surface model (LSM)	Noah	Noah
SST	Reynolds/RTG SST	NSST

Physics Evaluation Strategy

- Stress tests
- Computational efficiency
- Wide range of model resolutions (scale-aware)
- Process oriented diagnostics
- Selected test cases
- Large-scale tests covering different seasons
- Fully cycled tests
- Decision gates: what qualifies a parameterization to be considered for R2O?

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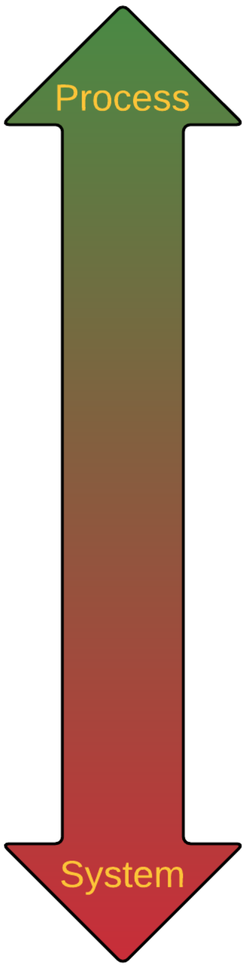
Hierarchical Protocol for Physics Testing and Evaluation



1. Individual Parameterizations
2. Single Column Model
3. Limited-Area Domains
4. Global (Cold-Started w/o DA)
5. Global (Cycled w/ DA)

For each tier, the testing protocol is to:

1. Define relevant test cases.
2. Provide initialization and/or forcing for each case.
3. Create benchmarks using operational codes.
4. Compare candidate model runs with benchmarks and observations.

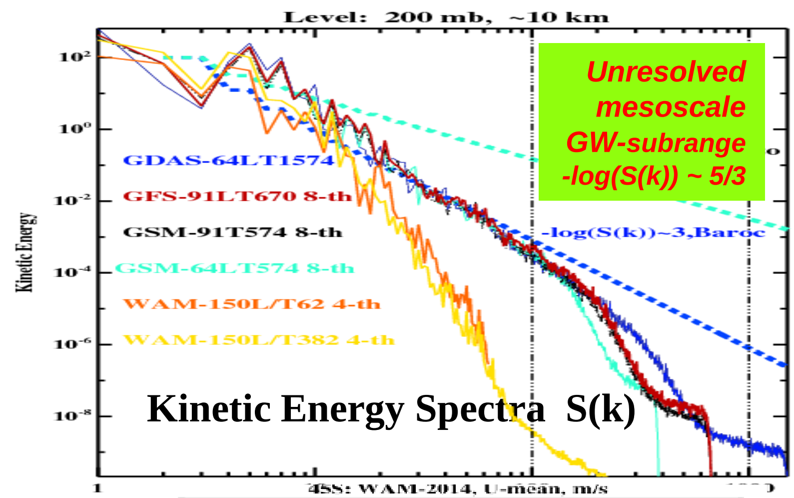
NGGPS Physics Development in Progress

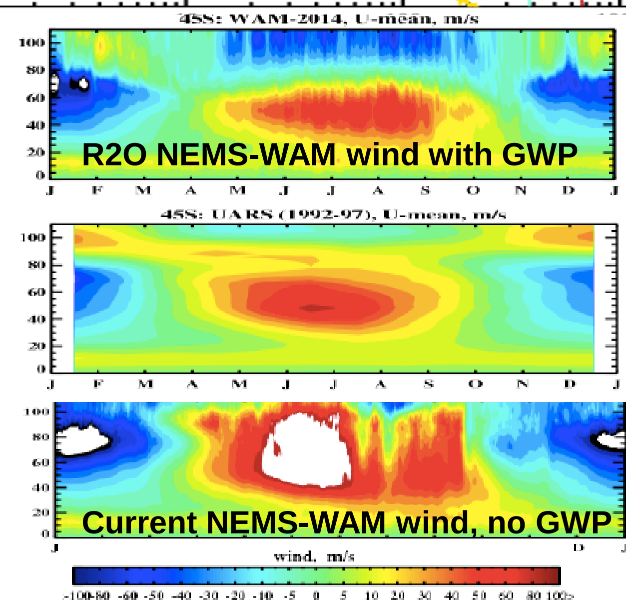
- *Integrating Unified Gravity Wave Physics into the Next Generation Global Prediction System*
  - Timothy Fuller-Rowell, (2015 FFO)
- *Further Testing and Evaluation of a Scale-Aware Stochastic Convection Parameterization in NOAA's Next Generation Global Prediction System*
  - Georg Grell, (2015 AO)
- *Evaluation and Adaptation of Advanced Microphysics Schemes in NOAA's Next Generation Global Prediction System Using the NOAA-HMT Observations*
  - Jian-Wen Bao (2015 AO)
- *Accelerated Implementation of Scale-aware Physics into NEMS*
  - Shrinivas Moorthi, EMC (2015 AO)
- *Moist EDMF for shallow PBL convection*
  - Chris Bretherton, Univ. of Washington (CPO)
- *SHOC for PBL turbulence and shallow convection*
  - Steve Krueger (CPO)
- *Improving CFS through representation of soil-hydrology-vegetation interactions*
  - Fei Chen, NCAR (CPO)

Integrating Unified Gravity Wave Physics into the Next Generation Global Prediction System

Timothy Fuller-Rowell and Valery Yudin, CU-CIRES

- **As R2O NGGPS effort,** this project implemented the non-stationary Gravity Wave (GW) schemes in NOAA weather and climate predictions system, GFS and NEMS to extend them above ~50 km and improve vertical atmosphere coupling.
- **Expected outcome:** improvement of forecast skills from the surface to the thermosphere for time windows from ~2 weeks to ~1mth by adding physics of GWs for unresolved momentum, heat and energy depositions.
- **Deliverables:** GFS-91L, WAM-150L with GW physics





- **Connection to NGGPS:** Development and implementation of **Unified Sub-Grid scale GW physics in the vertically extended global atmosphere models of NGGPS** that resolve upper stratosphere and mesosphere for the terrestrial weather and climate predictions **(NEMS-GFS/GSM 90 level, ~80 km lid)** and space weather predictions **(NEMS-WAM, 150L, ~500 km top lid**).

Integrating Unified Gravity Wave Physics into the Next Generation Global Prediction System

Timothy Fuller-Rowell and Valery Yudin, CU-CIRES

- ***Summary of the 1-year results***

GW physics in NEMS-WAM improved zonal mean flows, planetary waves and tides.

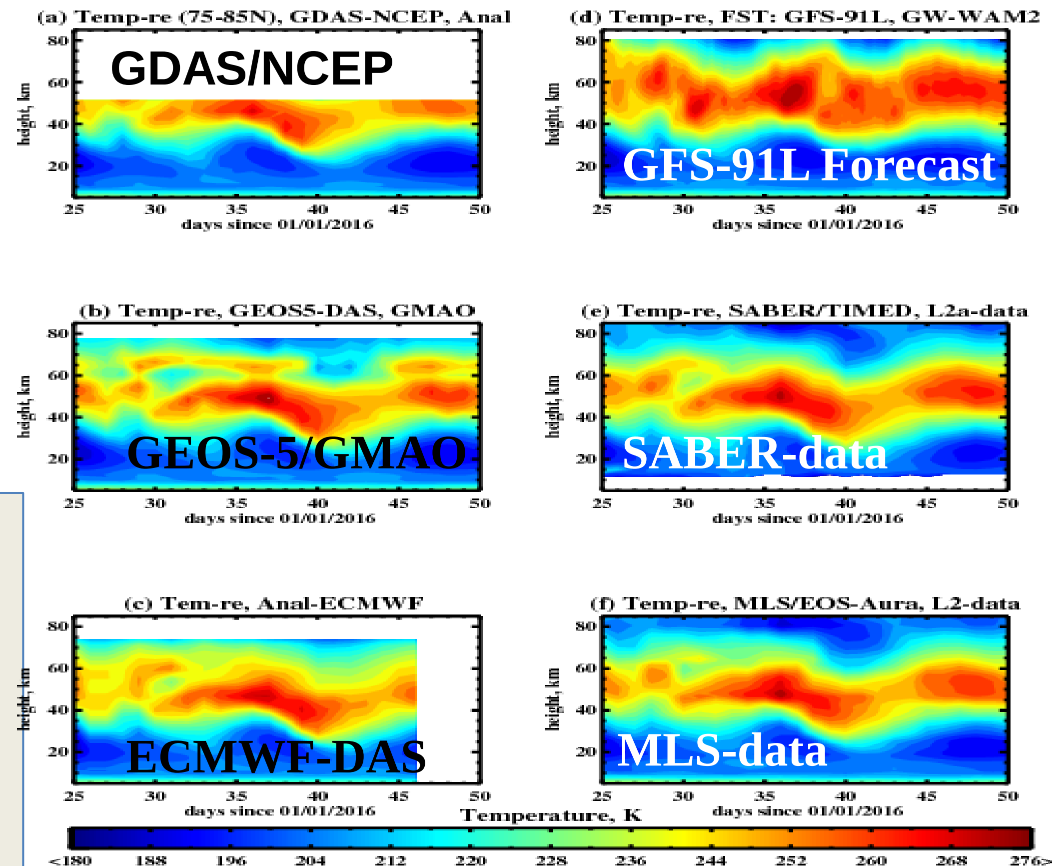
GW physics in GFS-91L brought a realism in the stratospheric dynamics during winters and winter-to-spring transitions comparing to the Rayleigh Friction simulations.

Transition to NOAA operations, climate tests, and future plans

a) ***Analysis-Forecast Cycling with GFS-91L*** (~80 km top) with "parallel" operational scripts;

b) ***NEMS-WAM multi-year climate runs*** for equatorial oscillations (QBO and SAO).

c) ***New related projects: Assimilation of middle atmosphere O_3, H_2O and T-re profiles*** (MLS & SABER) to properly initialize NGGPS forecasts.

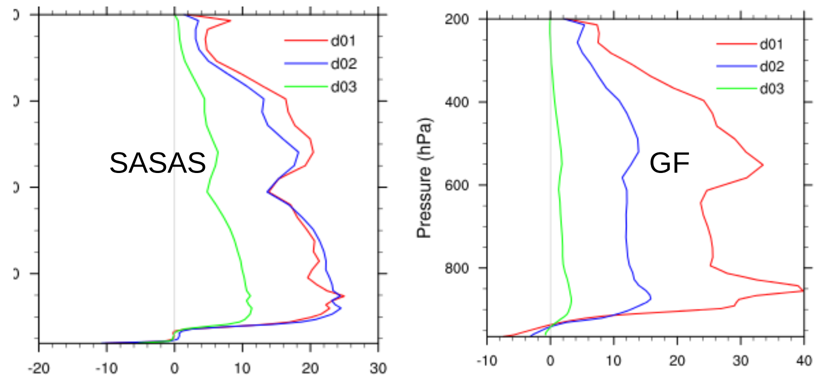


Jan-Feb 2016: GFS-91L 25-day polar temperature forecasts (d), SABER (e) & MLS (f) data (left); NWP analyses: GDAS (a), GEOS5 (b) & IFS (c).

Further Testing and Evaluation of a Scale-Aware Stochastic Convection Parameterization in NOAA's NGGPS

Georg A. Grell (ESRL/GSD), Jian-Wen Bao (ESRL/PSD) and Evelyn Grell (CIRES/ESRL)

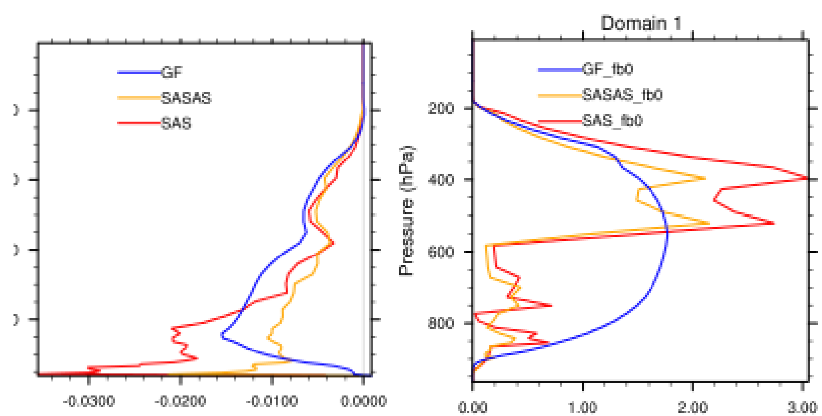
- The Grell-Freitas (GF) parameterization has been implemented into the latest HWRF version
- HWRF simulations are being evaluated in comparison with scale-aware SAS (SASAS) scheme
- 18/6/2km resolution experiments (d01,d02,d03)



Heating tendencies (deg/day) for HWRF runs (comparing scale aware SAS and GF) averaged with a 1 deg radius around the storm center

New improvements (also lead to improvements for global modeling)

- ECMWF momentum transport
- Diurnal cycle effect closure (also from ECMWF)
- Rain evaporation term (as is used in SAS)
- Probability Density Functions (PDFs) are used for normalized mass flux profiles – smooth profiles!
- Updated GF scheme also implemented into GFS

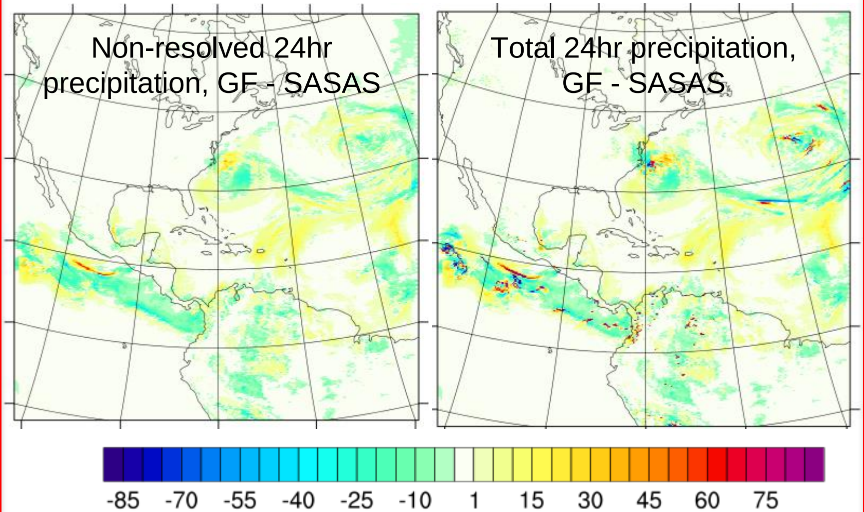


Drying and clw/ice tendencies (g/kg/day) for runs with GF, SAS, and SASAS schemes, averaged with a 1 degree radius around the storm center

Further Testing and Evaluation of a Scale-Aware Stochastic Convection Parameterization in NOAA's NGGPS

Georg A. Grell (ESRL/GSD), Jian-Wen Bao (ESRL/PSD) and Evelyn Grell (CIRES/ESRL)

- Large drying rates in lowest levels from SAS and SASAS schemes
- GF has much smoother cloud water/ice tendencies
- In general scale-awareness appears to work well. Non-resolved tendencies may still be somewhat large for HWRF with SASAS on 6km and 2km horizontal resolution
- Microphysics tendencies are very sensitive to convective tendencies for cloud water



Precipitation differences (mm) from HWRF runs with GF and SASAS, for precipitation from convective parameterization (non-resolved) and explicit microphysics. Precip appears a little lighter in ITCZ when using GF.

Transition to operations is optional, depending on seasonal evaluation of track and intensity forecasts

Further improvements may be possible if:

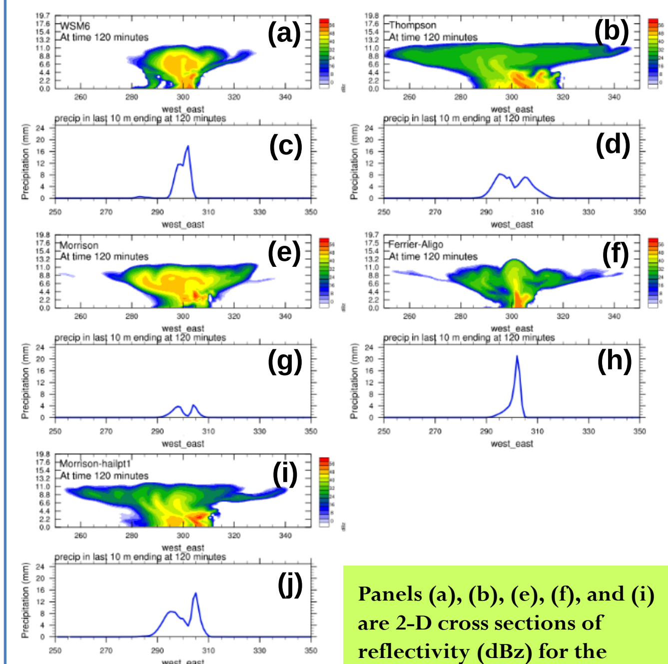
- GF is ideally suited to couple with stochastic approach
- For global modeling the implementation of memory and organization (how long was non-resolved convection active) may be promising – could also be used for HWRF
- NGGPS (global modeling) will offer more options for evaluation

Evaluation of Advanced Microphysics Schemes

Jian-Wen Bao and Robert Cifelli, NOAA/ESRL/PSD

- Compare advanced bulk microphysics schemes (including current operational schemes) with each other and observations
- Develop budget analysis procedure to compare parameterized microphysical processes (Bao *et at*., 2016, MWR)
- Establish a hierarchy of evaluation platforms, from 1-D kinematic column model to 2-/3-D idealized and real case studies

2-D idealized Squall line: Reflectivity and Precipitation at 2 hours



Panels (a), (b), (e), (f), and (i) are 2-D cross sections of reflectivity (dBz) for the WSM6, Thompson, Morrison, Ferrier-Aligo, and Morrison-hailopt1 (with hail-like graupel) runs respectively at 2 hours into the simulations. Panels (c), (d), (g), (h) and (j) are the accumulated precipitation (mm) along the cross section for the last 10 minutes ending at 2 hours into the simulations for the WSM6, Thompson, Morrison, Ferrier-Aligo, and Morrison-hailopt1 runs respectively.

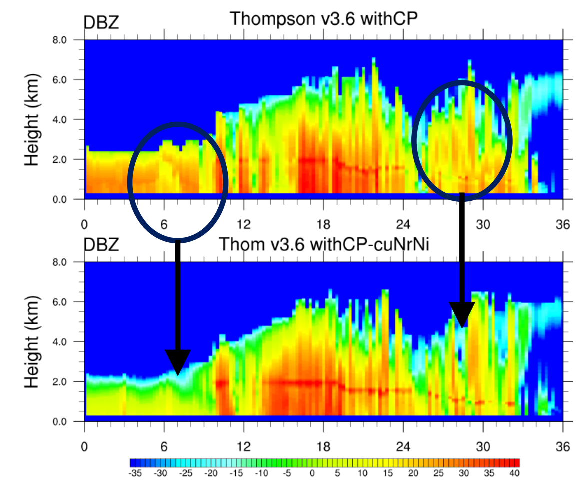
- Monthly teleconferences have been held between PSD and EMC to discuss results and findings.
- The Ferrier-Aligo scheme, which is currently being used in NCEP's operational models, has been imported into the evaluation platforms based on the WRF model as part of the project.

Evaluation of Advanced Microphysics Schemes (cont'd)

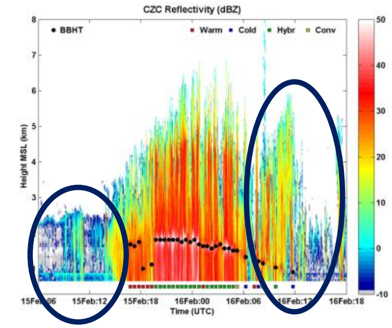
Jian-Wen Bao and Robert Cifelli, NOAA/ESRL/PSD

- Deliverables
  - Detailed analysis of microphysics budgetary evaluation of various advanced MP schemes (Michelson et al., 2016, in preparation)
  - An effective solution to alleviating physically inconsistent interaction between subgrid and grid-resolved cloud parameterizations at the resolution of the NGGPS (Grell et al., 2016, in preparation)
  - Results and findings from the evaluation of the current operational MP scheme and other advanced schemes to help current operational update and the selection of a computationally efficient and physically sufficient scheme for the NGGPS

Double-moment MP schemes should properly account for detrained precipitating hydrometeors associated with subgrid clouds in the grid-resolved number concentration calculation.



NOAA-HMT Observed radar reflectivity (dBZ) from 06 UTC 15 February to 18 UTC 16 February at Cazadero (CZC)



Future:

- Gather more microphysical property observations and use them to further evaluate the advanced MP schemes
- Work with EMC colleagues to carry out further evaluation of the advanced MP schemes in the NGGPS

Accelerated Implementation of Scale-aware Physics into NEMS

PI :Shrinivas Moorthi, GCWMB/EMC/NCEP
CO-I Steven Krueger, University of Utah
CO-I Yu-Tai Hou, GCWMB/EMC/NCEP
Collaborator – Donifan Barahona, NASA/GSFC

- **Employee supported by this project – Anning Cheng**

- **Objective(s): To accelerate the implementation of scale aware physics in S. Krueger CPT and S. Lu CPT funded by NOAA/CPO via NCEP/CTB**

- **Deliverable(s): Implement Morrison double moment microphysics (from GMAO's GEOS model) and Chikra-Sugiyama (CS) convection with Arakawa-Wu (AW) extension into NEMS**

Connection to NGGPS :

- **Advanced scale-aware atmospheric physics that are applicable for both high resolution weather and low resolution climate models.**

- **They are being implemented in NEMS, thus readily available to NGGPS.**

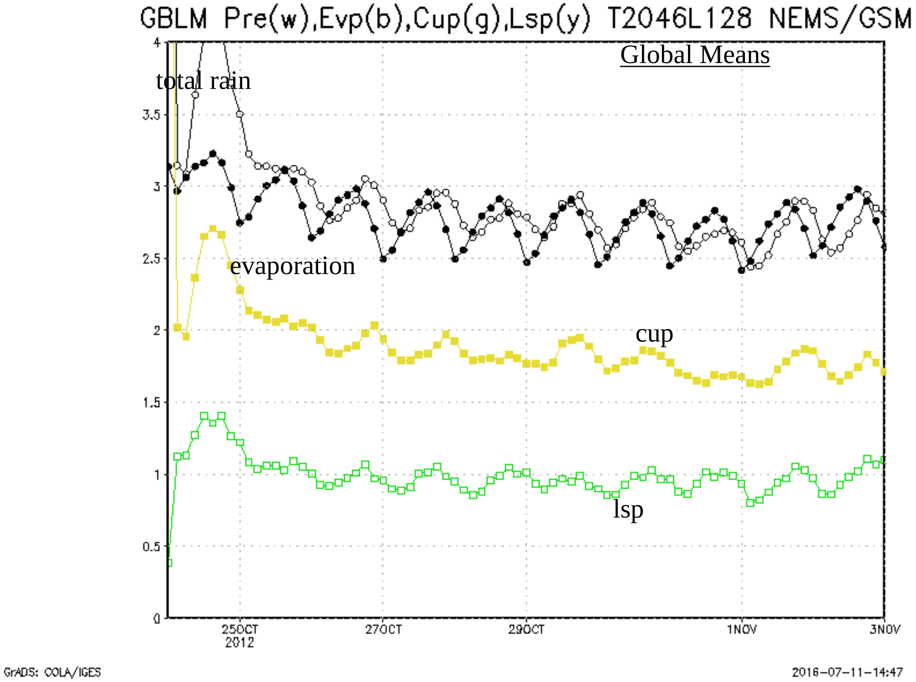
Accelerated Implementation of Scale-aware Physics into NEMS

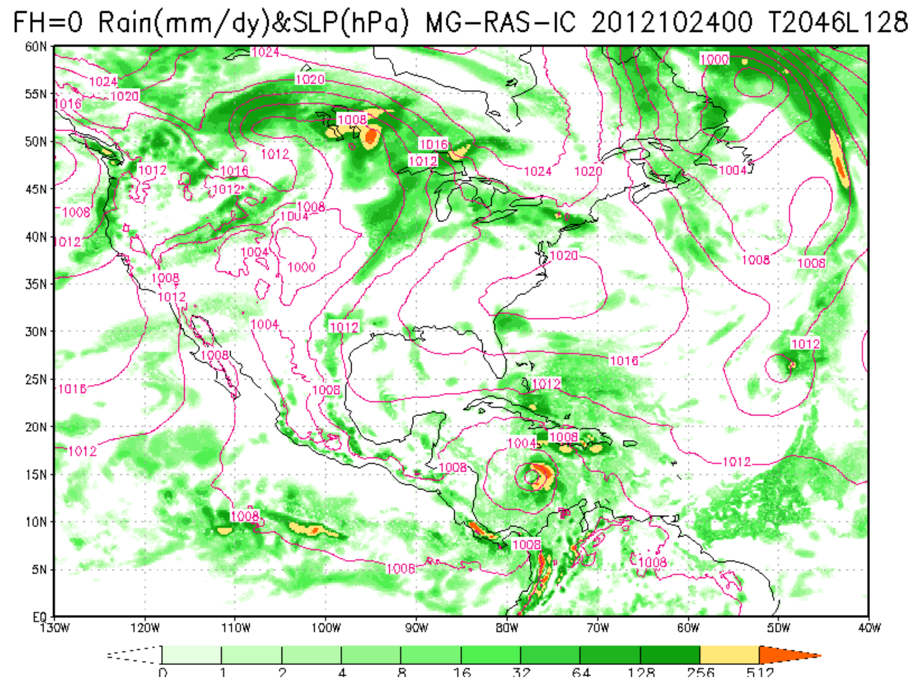
Current Status :

- The Chikira-Sugiyama convection parameterization with prognostic closure is implemented in NEMS and tested with GSM from resolutions of T62 to T2046 and L64/128 (the Arakawa-Wu scale-aware extension is still pending)
- Morrison double moment microphysics from GSFC has been installed in NEMS and tested at T62, T574 and T2046 at both L64 and L128 (still needs tuning/optimization)
- Current installation is coupled to the RAS convection parameterization and GMAO Macrophysics and optionally includes GMAO Aerosol Activation package
- Additional work needed to couple to Chikira-Sugiyama convection and SHOC (Krueger CPT) and to unify cloudiness and it's interaction with radiation and McICA
- Current implementation has cloud water/ice and their number concentrations as prognostic variables
- Need to extend the scheme to optionally include snow/rain as prognostic variables
  – needed for high resolution weather – not so important for low resolution climate

Accelerated Implementation of Scale-aware Physics into NEMS

Preliminary Results : Results from a ten day forecast from Oct 24, 2012 – T2046 L128 with 2m MG and RAS





Path toward transition to operations:

Need to : optimize and tune the package
couple with other physics packages
perform cycled experiments with data assimilation and show forecast improvements for both weather and climate

CPT to Improve Cloud and Boundary Layer Processes in GFS/CFS

Lead PI: Chris Bretherton (U. Washington); Institutional Pis: Jongil Han (EMC), Ming Zhao (GFDL), J. Teixeira (JPL)

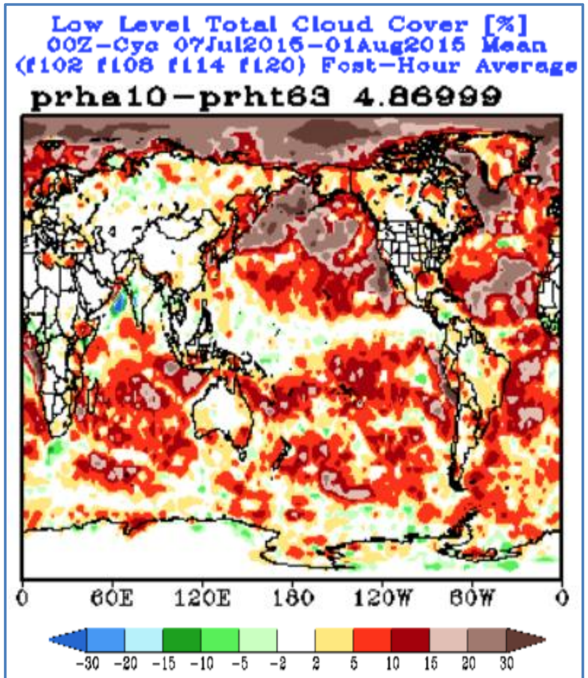
Goals: Improve fidelity of cloud and boundary-layer processes in GFS/CFS and reduce cloud-related radiative flux biases

GFS/CFS Deliverables: Eddy-Diffusion Mass-Flux (EDMF) parameterization of moist boundary layer turbulence and shallow cumulus (right).

Modified Thompson cloud microphysics scheme

Modernized daily cloud diagnostics

NGGPS connection: This CPT aims to modernize GFS physical parameterizations to reduce substantial underprediction of cloud and its radiative effects that are particularly important for seasonal forecast applications, while not degrading weather forecast skill.



New EDMF scheme desirably increases GFS marine low cloud cover

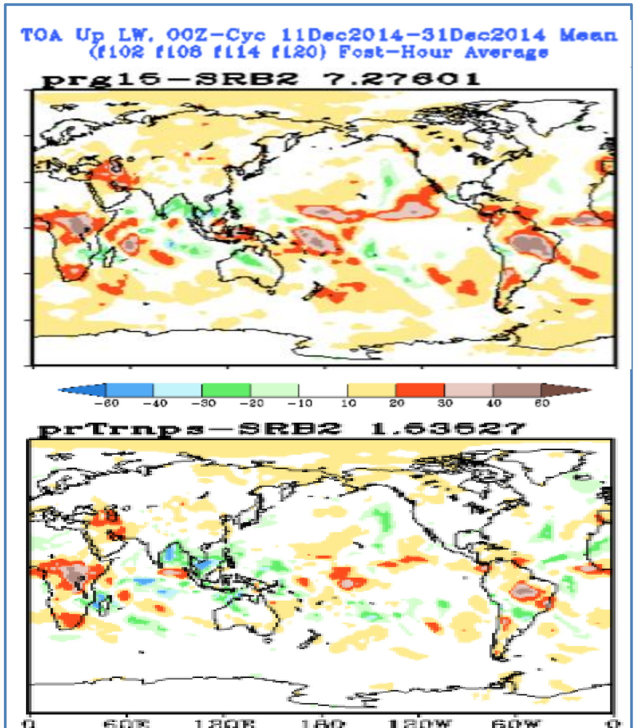
CPT to Improve Cloud and Boundary Layer Processes in GFS/CFS

Lead PI: Chris Bretherton (U. Washington); Institutional Pis: Jongil Han (EMC), Ming Zhao (GFDL), J. Teixeira (JPL)

Progress so far:

Han (EMC), advised by the CPT, implemented a new TKE-based moist EDMF scheme in GFS that increases cloud cover and maintains mid-latitude and CONUS forecast skill but slightly degrades tropical winds.

Sun (EMC), advised by the CPT, developed a modified Thompson GSM6 microphysics scheme in GFS that increases cloud and removes most global TOA radiation biases



Modified Thompson microphysics (bottom) reduce operational GFS OLR biases (top); also true for shortwave.

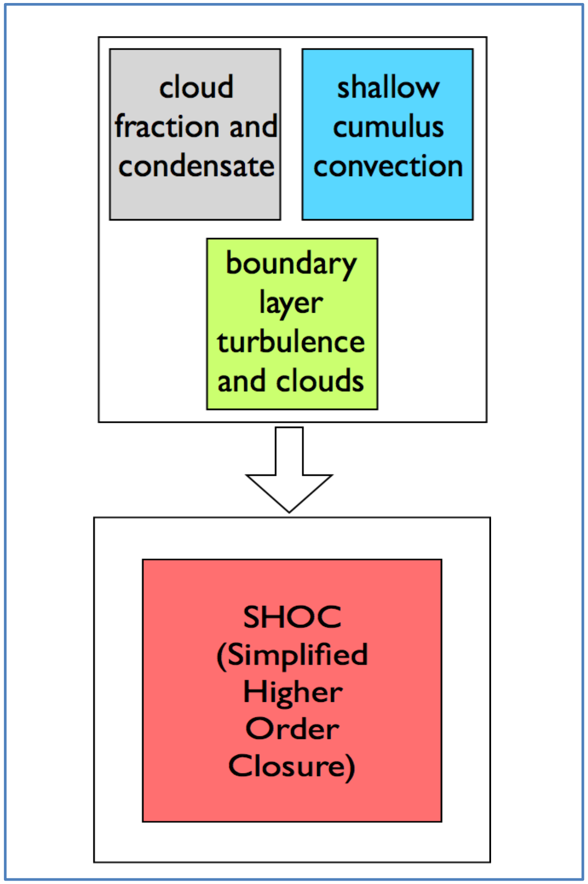
Potential transition to operations:

Both of the above schemes are being further tuned and developed for possible implementation in a 2018 release of GFS and will be tested in seasonal forecast mode for possible implementation in CFSv3.

A CPT for Improving Turbulence and Cloud Processes in the NCEP Global Models

Steven Krueger - U. Utah, Shrinivas Moorthi - EMC/NCEP, Robert Pincus – U. Colorado, David Randall – CSU, Peter Bogenschutz - NCAR

- Objective(s): Install an integrated, self-consistent description of turbulence, clouds, deep convection, and the interactions between clouds and radiative and microphysical processes.
- Deliverable(s): Implement a PDF-based SGS turbulence and cloudiness scheme, a "Unified" cumulus parameterization that scales continuously between simulating individual clouds and conventional parameterization of deep convection, and an improved representation of the interactions between clouds, radiation, and microphysics.



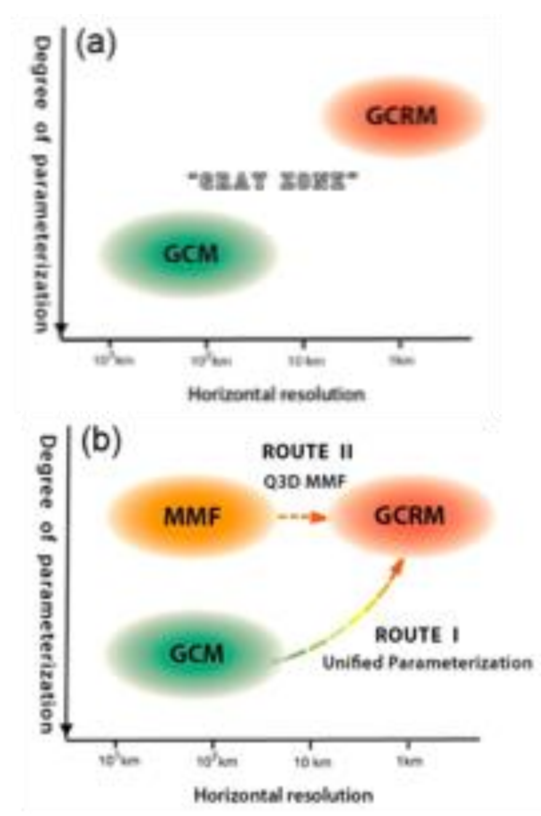
- The connection to NGGPS is obvious.

A CPT for Improving Turbulence and Cloud Processes in the NCEP Global Models

Steven Krueger - U. Utah, Shrinivas Moorthi - EMC/NCEP, Robert Pincus – U. Colorado, David Randall – CSU,
Peter Bogenschutz - NCAR

- We have installed and tested our PDF-based SGS turbulence and clouds scheme called SHOC (Simplified Higher-Order Closure) into the NEMS as well as the operational versions of the GFS, and are improving SHOC's coupling to parameterized deep convection.
- The (conventional) Chikira-Sugiyama (CS) cumulus parameterization has been installed into the GFS in flux divergence source/sink form and tested.
- A closure for updraft fraction of multiple cloud types has been developed and tested diagnostically.

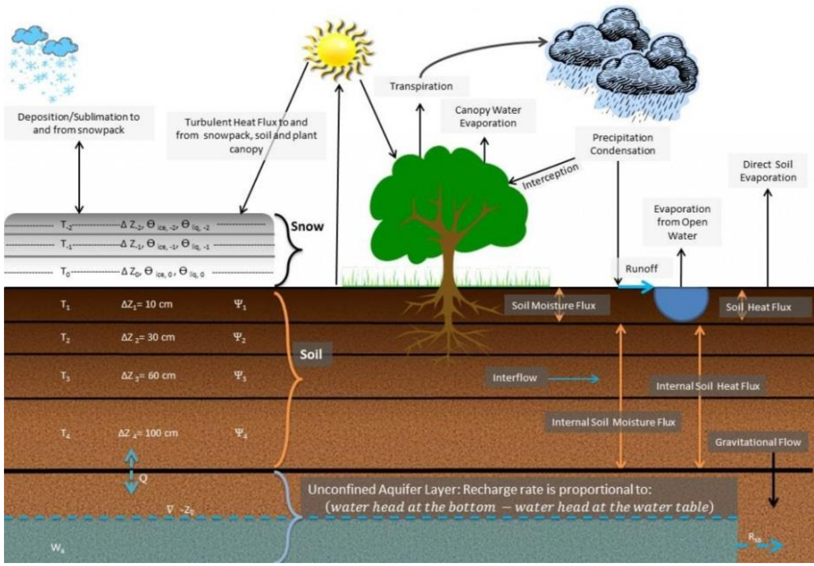
- All three aspects of our project have the potential for transition to operations/future implementation.



Improving Land Model in NCEP CFS

PI: Fei Chen, Research Applications Laboratory, National Center For Atmospheric Research.
Collaborators: Michael Ek (NCEP), Michael Barlage (NCAR), Zong-Liang Yang (UT-Austin)

- Incorporate Noah-MP into CFSv2 to enhance the representation of the soil – hydrology-vegetation interactions.
- Deliverable(s): Coupled CFSv2 with the latest version of the community Noah-MP land surface models.



The Noah with multiparameterization options (Noah-MP) community land model

Connection to NGGPS

- Support unification of the land models in NWS numerical weather prediction suite
- Accelerate forecast performance improvement through transition of the community Noah-MP LSM community codes to NCEP operations

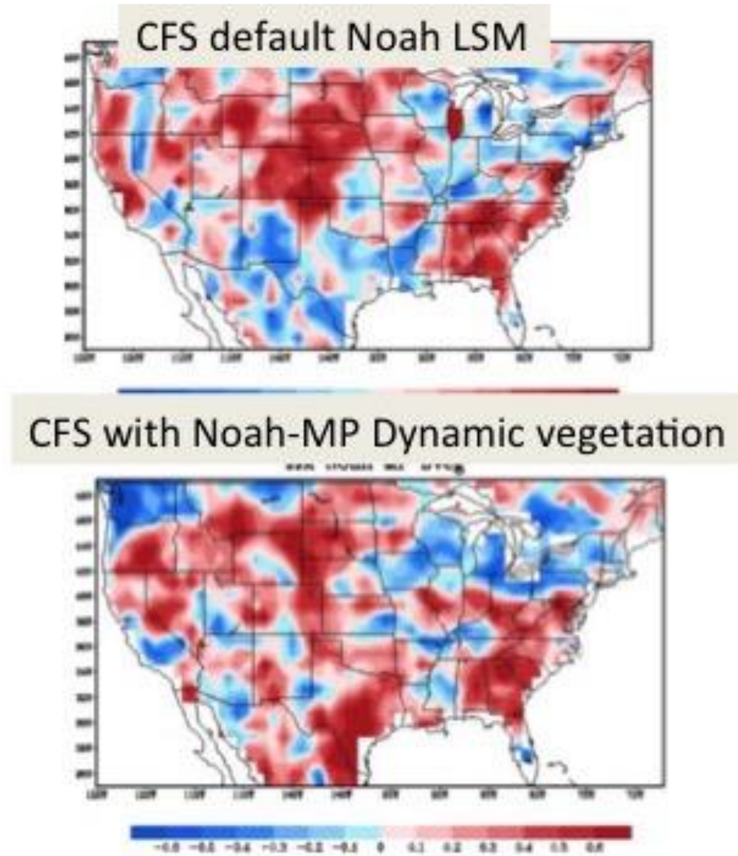
Improving Land Model in NCEP CFS cont.

PI: Fei Chen, Research Applications Laboratory, National Center For Atmospheric Research.
Collaborators: Michael Ek (NCEP), Michael Barlage (NCAR), Zong-Liang Yang (UT-Austin)

- Preliminary results show promising improvements in CFS precipitation and temperature skills using Noah-MP with dynamic vegetation physics.

Potential transition to operations/future implementation

- R2O implementation planned for FY17.



Anomaly Correlation (AC) skill of averaged JJA precipitation
Averaged over 11 years with four ensemble members

Physics PI workshop

- **Committee**
  - Louisa Nance, Jimy Dudhia, Vijay Tallapragada, Jim Doyle
- **Focus/Goal**
  - Discuss current atmospheric physics relevant for NGGPS Physics Team Plan and identify gaps in the plan and community.
  - Discuss challenges for distributed physics development and protocols/procedures for working within this framework
- **Date, Venue**
  - 7-9 Nov at NCWCP
- **Invitees**
  - Scientists developing parameterizations, NGGPS Physics PIs, and EMC developers

NGGPS Physics Team Telecon

- In order to better coordinate and improve communication among the physics team and developers, we have established a bi-weekly telecon to:
  - Updates from individuals and teams on progress
  - New results from physics community at large
  - Coordinate among individual PIs and groups; NGGPS
  - Discuss near-term and long-term plans for physics
  - Share NGGPS and EMC updates and plan
  - Share EMC specific needs and requirements

NGGPS Physics Team Summary

- **Major Accomplishments in FY16:**
  - Development, testing, evaluation of scale aware physics:
    - Grell-Freitas CPS (testing in HWRF)
    - Advanced microphysics (Ferrier-Aligo, WSM6, Thompson, Morrison comparisons)
    - Morrison double moment & Chikra-Sugiyama convection (incorporated into NEMS)
    - Improved cloud and boundary layer processes (EDMF, modified Thompson) – 2018?
    - SHOC boundary layer scheme testing
    - Advancement of NOAH-MP and testing in CFSv2
    - New gravity wave physics in GFS and NEMS-WAM; higher top for GFS
- **Priority Focus for FY17**
  - Scale aware convective and boundary layer formulations.
  - Microphysics sophistication
  - Improved interactions between physical processes (radiation, land, aerosols, clouds etc.)
  - Advanced code structures.
- **Key Issue**
  - Diagnostics, full testing, and R2O transition process
    - Most promising advancements need to be fully tested (1D to 3D, 3D with DA cycling, full diagnostics), properly integrated with the other components and advancements
- **Gaps and Opportunities**
  - Better integration with Aerosols, Stochastic (model error), coupled model physics
  - Organize, focus and then leverage the U.S. weather community physics development

NGGPS Physics Team Plan
Team Structure

1. Convection and Boundary Layer
2. Cloud Microphysics
3. Radiation
4. Gravity Wave and Large-scale Orographic (and non-Orographic) Drag
5. Earth System Surface Fluxes and State