Status of HIWPP Project

Unified representation of Turbulence and Clouds

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Status of HIWPP Project

Why am I presenting this?

Prior to 2013 any funding to improve GFS/CFS physics came primarily from NOAA/CPO
In 2013 CPO funded our proposal
"A CPT for improving Turbulence and Cloud processes in NCEP Global Models"
- We requested for two postdocs but one was supported

Due to budget cuts in 2013, funding was postponed to 2014

In the mean time, in early 2014, Robert Pincus of ESRL received funding from HIWPP to improve GFS physics.

Since Robert was a member of our CPT and since we were underfunded from CPO, Robert put the HIWPP money into this project

Alex Belochitsky was hired in July 2014 as UCAR visiting scientist to work on this project of "Unified representation of Turbulence and Clouds"

Assumed PDF Method

One approach to unified representation of SGS turbulence and clouds is the assumed PDF method.

This method assumes the existence joint PDF of vertical velocity, $\boldsymbol{w}$, total water (vapor + cloud condensate) mixing ratio, $\boldsymbol{q_t}$, and a temperature variable, $\boldsymbol{\theta}_l$:

$$P = P(w, q_{t,} \boldsymbol{\theta}_l)$$

This makes it possible to couple subgrid interactions of vertical motions and buoyancy (Randall et al.1992).

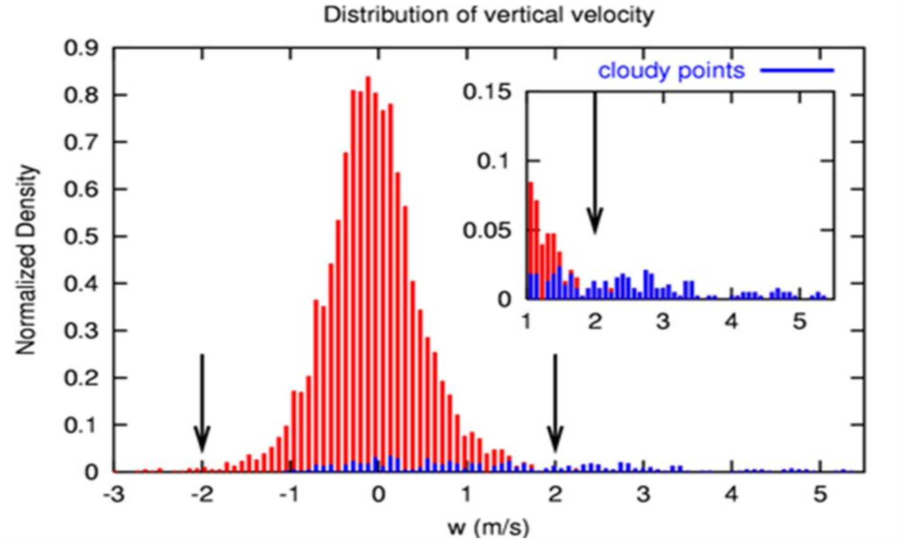
Assumed PDF Method

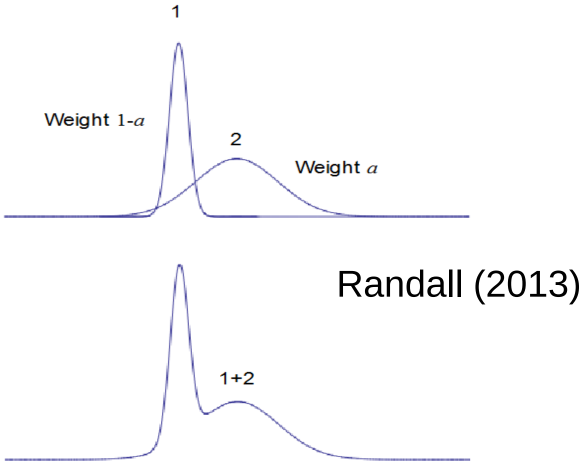
- Larson et al (2002), Bogenschutz et al (2010) show that in both precipitating and non-precipitating trade-wind cumulus, continental cumulus, stratocumulus and stratocumulus-to-cumulus transition regimes PDFs of $\boldsymbol{w}$, $\boldsymbol{\theta_l}$, and $\boldsymbol{q}$ are either single- or bi-modal.

- These PDFs are well approximated by trivariate double Gaussians for $\boldsymbol{w}$, $\boldsymbol{\theta_l}$, and $\boldsymbol{q_t}$. The first Gaussian can be thought of as representing cloud-free environment, and the second the cloudy environment.

- With some simplifying assumptions, the moments required to find parameters of the PDFs are:

$$\overline{w},\ \overline{w'^2},\ \overline{w'^3},\ \overline{\theta_l},\ \overline{\theta_l'^2},\ \overline{q_t},\ \overline{q_t'^2},\ \overline{w'q_t'},\ \overline{w'\theta_l'},\ \overline{q_t'\theta_l'}$$





Randall (2013)

We use trivariate double Gaussians, for w, T, and q.

Steps in Assumed PDF Method

The assumed PDF method contains three main steps that must be carried out for each grid box and time step.

Prognose means (temperature, vertical velocity, and total water) and diagnose various higher order moments

Use these moments to select a particular PDF member from the assumed functional form

Use the selected PDF to compute many other higher order terms that have to be closed, e.g. buoyancy flux, cloud fraction, subgrid condensation

Details of Assumed PDF Method

$$\overline{\theta_l'^2}, \overline{q_t'^2}, \overline{w'^2}, \overline{w'\theta_l'}, \overline{w'q_t'}, \overline{q_t'\theta_l'}, \overline{w'^3}$$

Typically this method requires the addition of several prognostic equations (e.g. CLUBB, Golaz et al. 2002, Cheng and Xu 2006, 2008) to estimate the turbulence moments required to specify the PDF

We use a simpler approach - **Simplified Higher-Order Closure** (SHOC): Second-order moments are diagnosed using simple formulations based on Redelsperger and Sommeria (1986) and Bechtold et al. (1995)

Third-order moment is computed using diagnostic closure of Canuto et al. (2001)

All diagnostic expressions for the higher order moments are a function of SGS turbulent kinetic energy (TKE).

Model using SHOC thus needs prognostic SGS TKE.

Prognostic SGS TKE Equation

$$\frac{\partial \overline{e}}{\partial t} = -\overline{u_j}\frac{\partial \overline{e}}{\partial x_j} + \delta_{i3}\frac{g}{\theta_v}\left(\overline{u_i'\theta_v'}\right) - \overline{u_i'u_j'}\frac{\partial \overline{u_i}}{\partial x_j} - \frac{\partial \overline{u'e}}{\partial x_j} - \frac{1}{\rho}\frac{\partial \overline{u_i'p'}}{\partial x_i} - c_k\frac{\overline{e}^{3/2}}{L}.$$

- Buoyancy generation term uses buoyancy flux diagnosed from the sub-grid PDF.

- Shear generation term uses only velocity differences in the vertical.

- The dissipation term uses a new formulation for the general turbulence length scale, ***L***, that is specified separately for the boundary layers and the cloudy layers.

- Using turbulence length scale, ***L***, and SGS TKE, ***e***, SHOC determines turbulent mixing coefficient as ***K = -0.1L*sqrt(e)*** (Teixeira and Cheinet 2004)

- Remaining terms are parametrized as downgradient diffusion for TKE using the turbulent mixing coefficient ***K***.

SHOC: Simplified High Order Closure

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By integrating over the the portion of the PDF phase space where water vapor pressure is at or above the saturation value, we can determine

- the amount of condensed/deposited vapor in the grid box
- fractional volume of the phase space that is at or above saturation,
- and, therefore, fractional cloudiness in the given grid box

Details can be found in Bogenschutz, P. A., and S. K. Krueger (2013), *A simplified PDF parameterization of subgrid-scale clouds and turbulence for cloud-resolving models*, J. Adv. Model. Earth Syst., 5, 195–211, doi:10.1002/jame.20018

Implementation of SHOC in GFS and NEMS

SHOC has been installed in a version of GFS

SHOC also has been installed in NOAA Environmental Modeling System (NEMS)

SHOC derived Turbulent diffusion coefficients are used in the vertical diffusion in place of those produced by the operational boundary layer turbulence and shallow convection parameterizations (Han and Pan, 2011).

SHOC generated cloudiness is used in both microphysics and radiation, thus unifying the cloudiness formulation

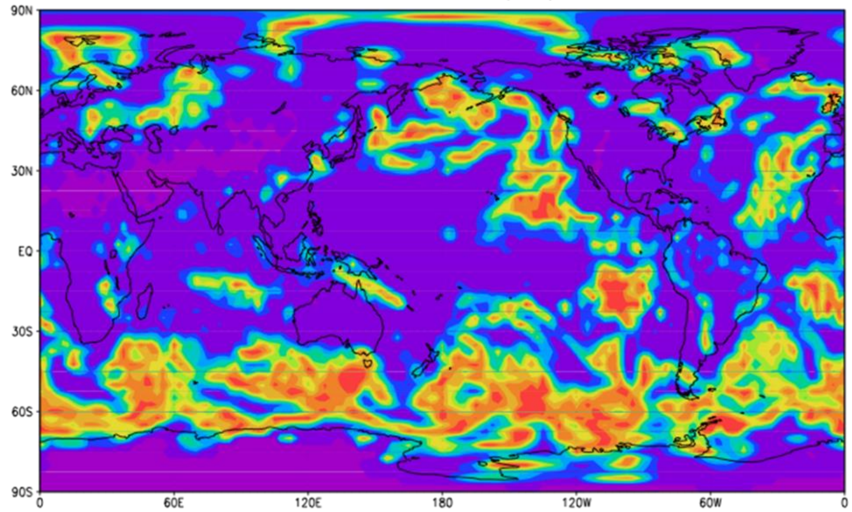
However, there are still outstanding issues - one is the interaction of SHOC with detrained cloud condensate from convection, particularly in the tropics

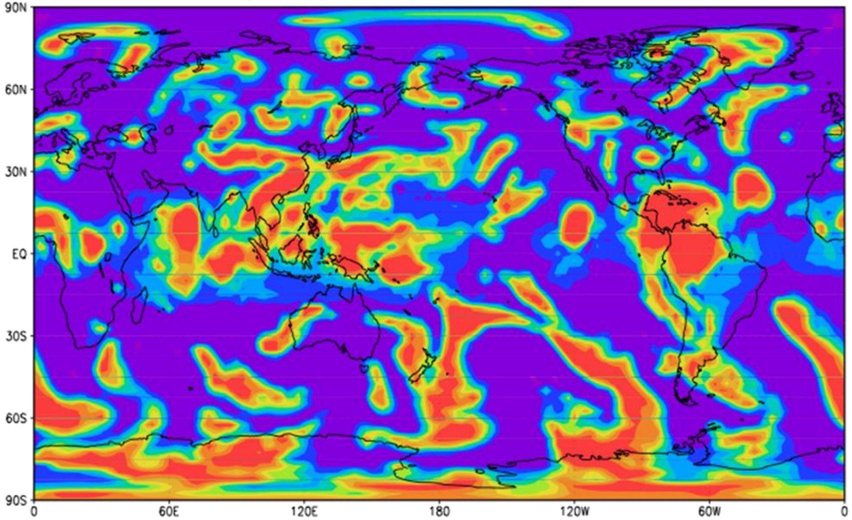
– work is ongoing to address this issue.

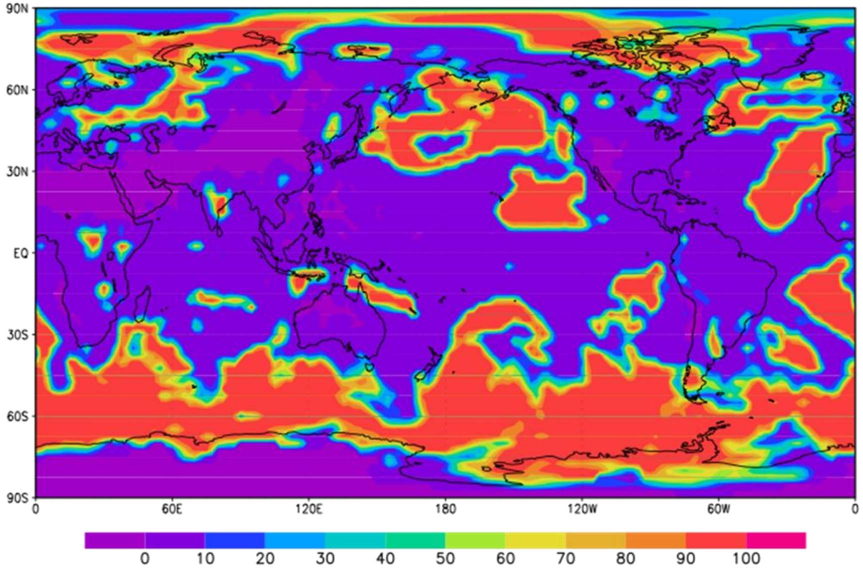
(in the interim, we have to substantially increase the autoconversion from ice to snow in microphysics)

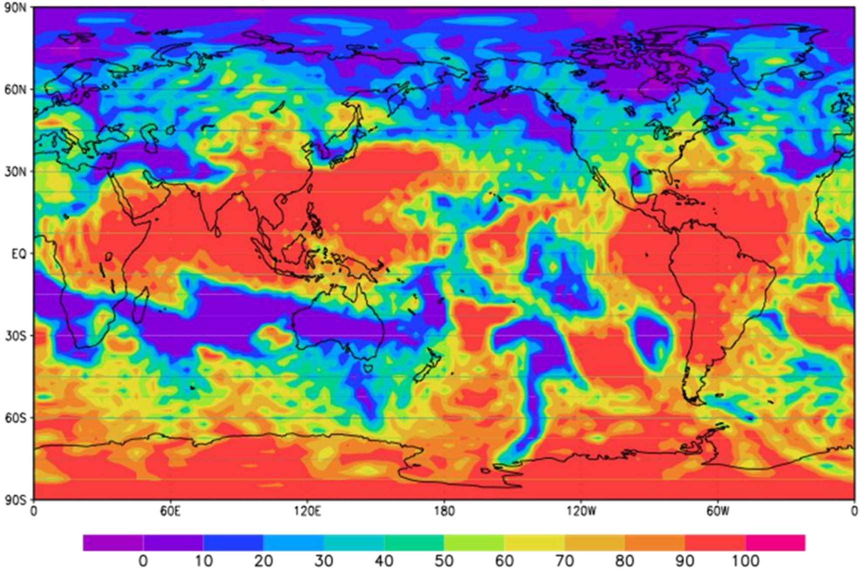
Also need to merge with other new physics components under development.

SHOC in GFS at T62
Early 5 day forecast example

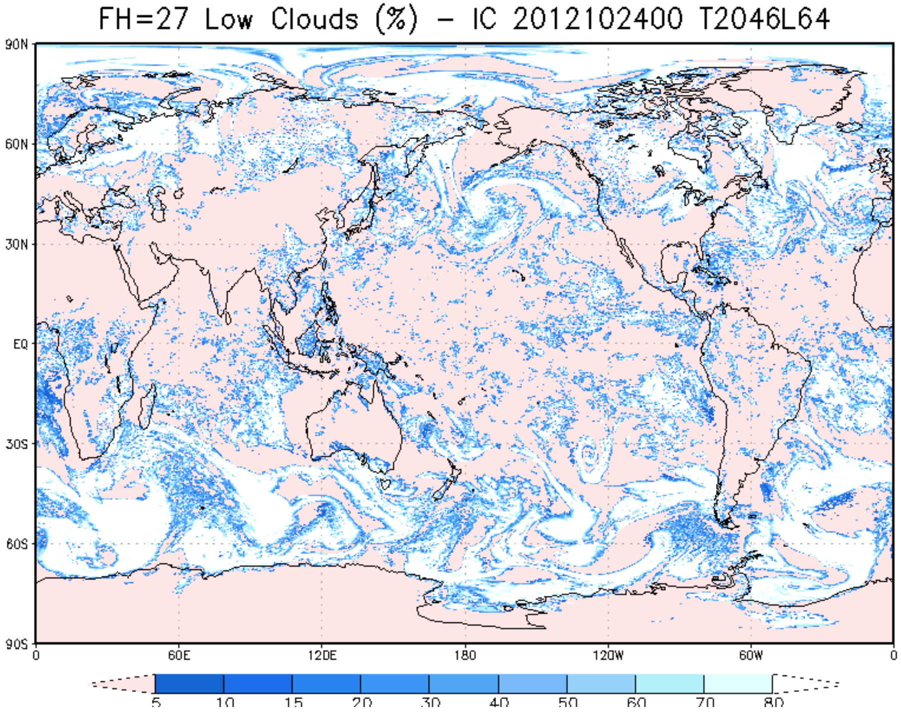

Low level cloud cover, %, Control


High level cloud cover, %, Control


Low level cloud cover, %, SHOC


High level cloud cover, %, SHOC

SHOC in NEMS/GSM at T2046 Gridded Tracers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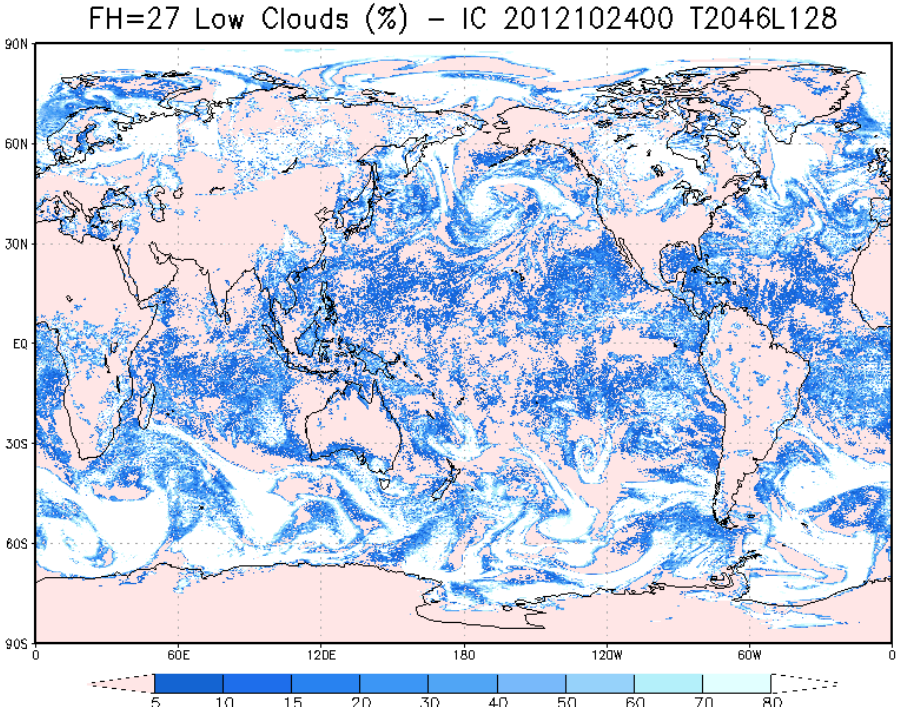
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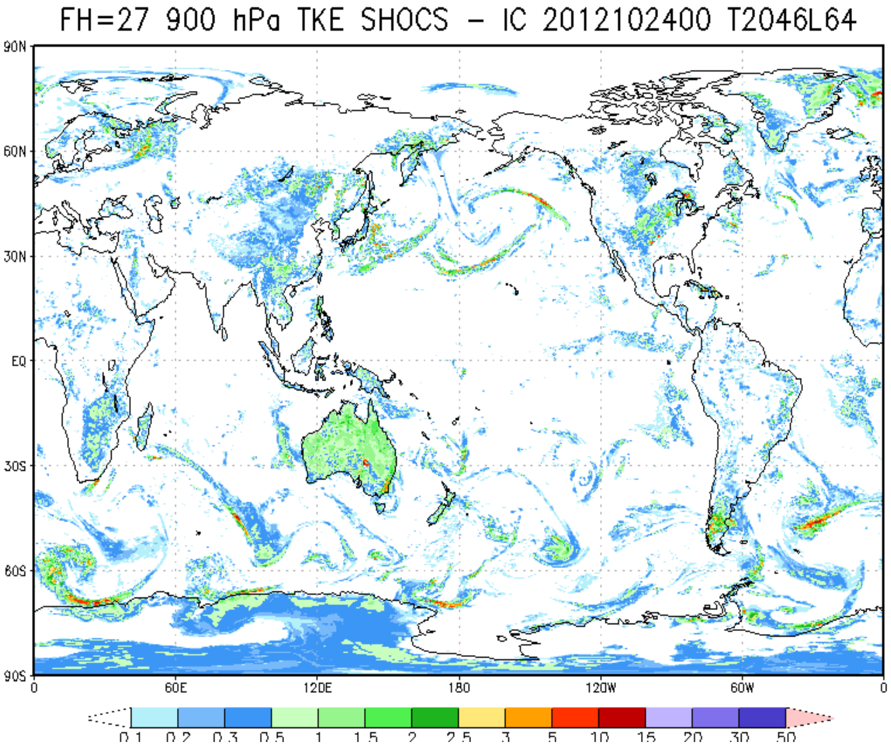
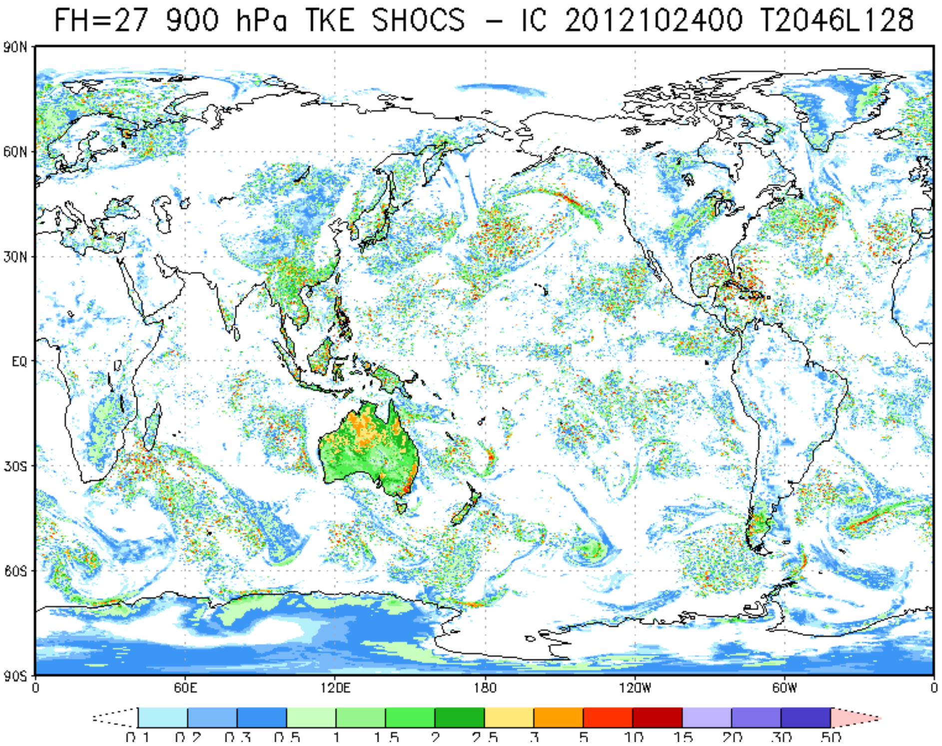
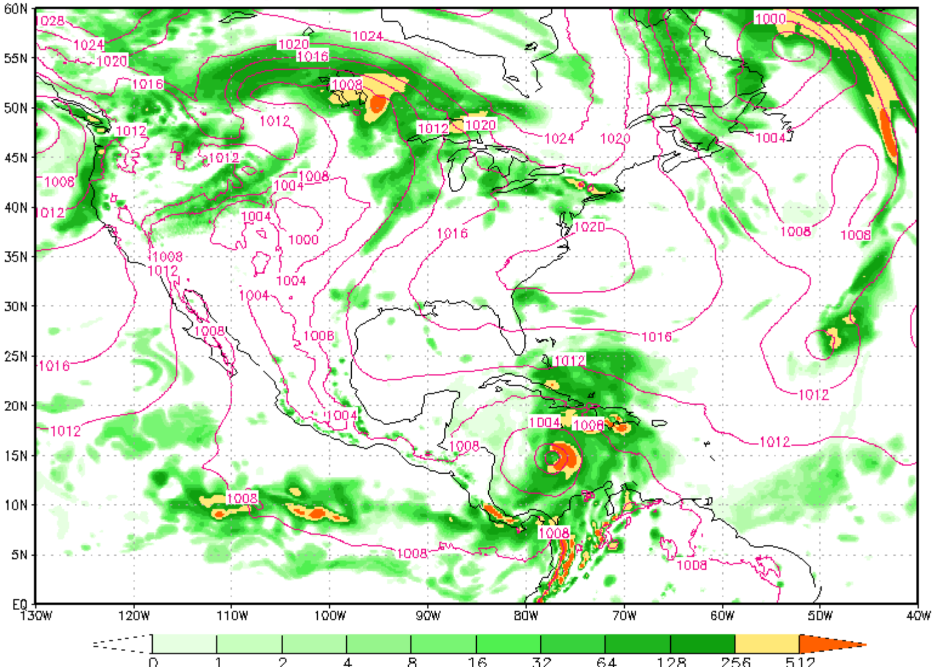
SHOC in NEMS/GSM at T2046 Gridded Tracers





SHOC in NEMS/GSM at T2046 Gridded Tracers

FH=0 Rain(mm/dy)&SLP(hPa) SHOCS-IC 2012102400 T2046L64



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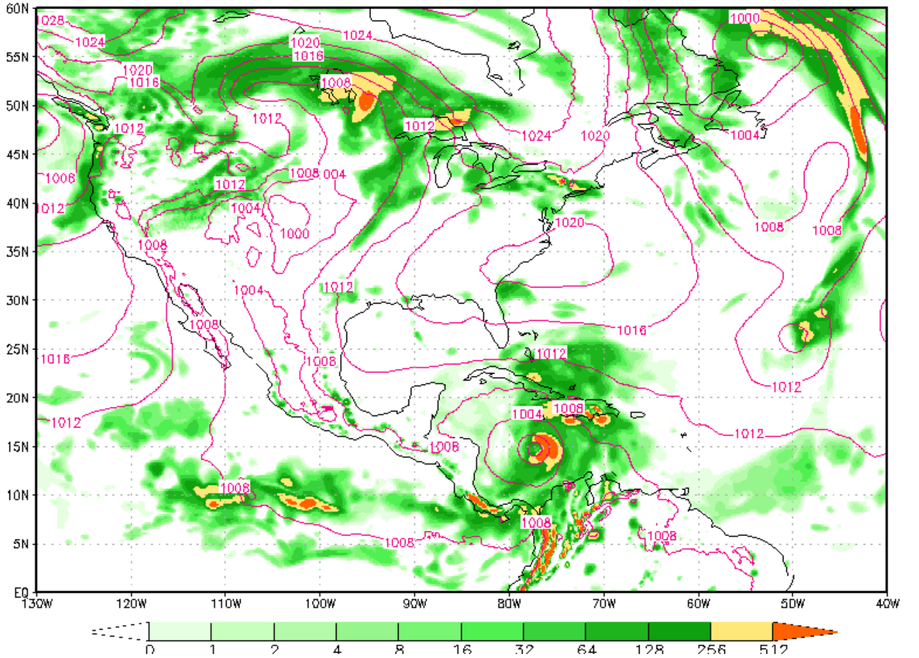
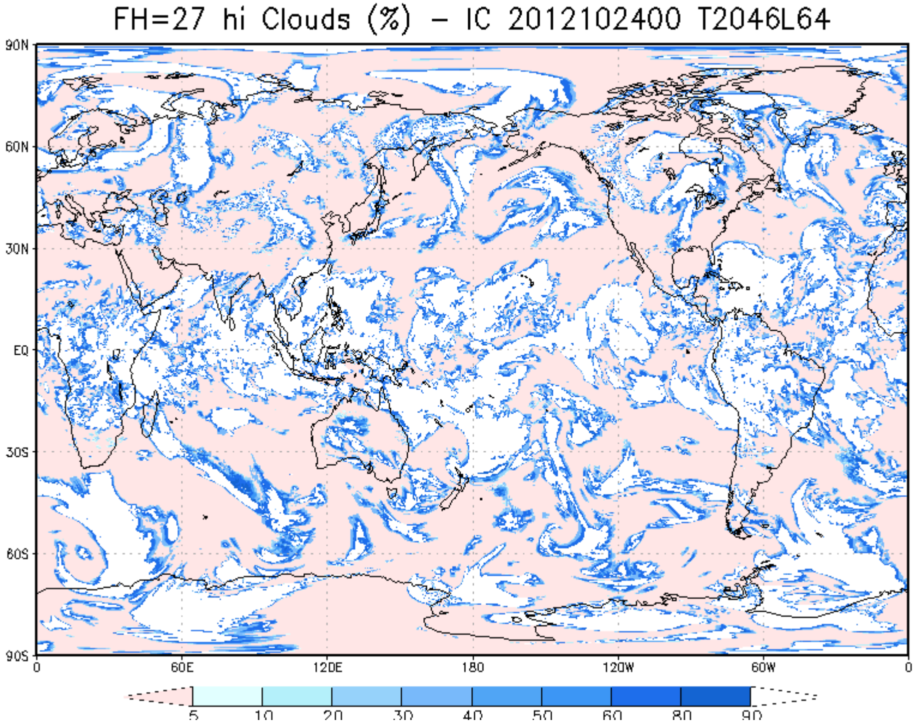


SHOC in NEMS/GSM at T2046 Gridded Tracers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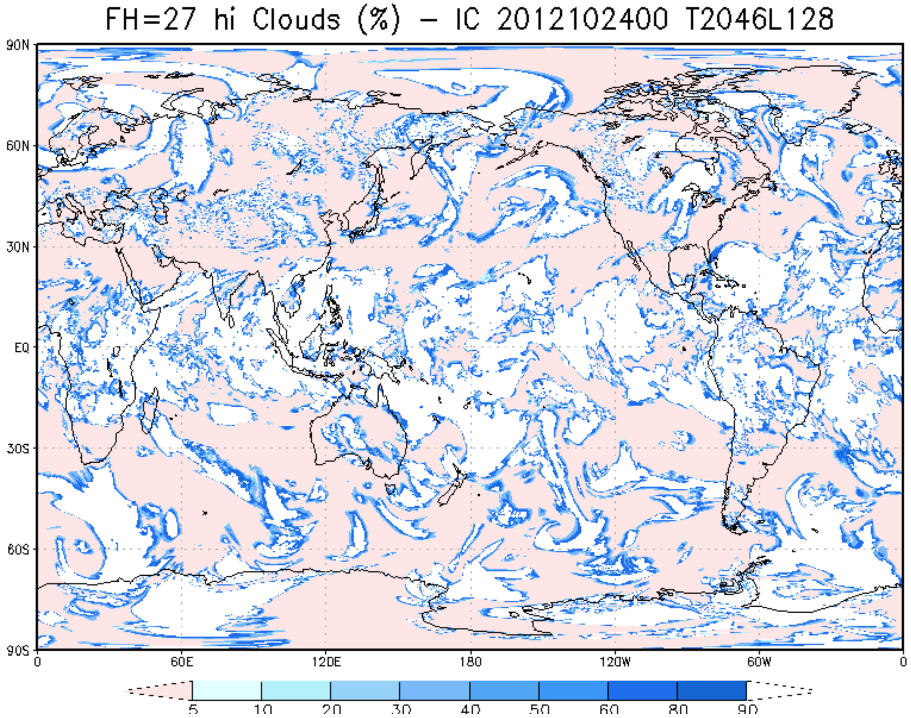
FH=27 hi Clouds (%) – IC 2012102400 T2046L128

Conclusion and Next Steps

SHOC has been successfully implemented in GFS and NEMS/GSM

SHOC seems to produce reasonable results from T62 to T2046 resolution

Further tuning and remedy for outstanding issues related to interaction with other physics need to be addressed

Once that is done, needs to be evaluated in parallel mode for potential operational deployment for

- weather
- climate