Initial time: 2018.09.17.00UTC
FCST: +120hr
Initial time: 2018. 09. 17. 00UTC
FCST: +126hr

KIM 3.2

KMA UM
Initial time : 2018. 09. 17. 00UTC
FCST : +132hr

KIM 3.2

KMA UM
Initial time: 2018. 09. 17. 00UTC
FCST: +138hr

KIM 3.2

KMA UM
Initial time: 2018. 09. 17. 00UTC
FCST: +144hr

KIM 3.2

KMA UM
Initial time: 2018. 09. 17. 00UTC
FCST: +150hr
Initial time: 2018.09.17.00UTC
FCST: +156hr

KIM 3.2

KMA UM
Initial time: 2018.09.17.00UTC
FCST: +162hr

KIM 3.2

KMA UM

KIM 3.2 ne240 L91

UM GDAPS N1280 L70

Solid line: Sea Level Pressure (hPa)
Shaded: 6 hr Accumulated precipitation (mm)
Initial time: 2018. 09. 17. 00UTC
FCST: +168hr
Initial time: 2018.09.17.00UTC
FCST: +174hr

KIM 3.2

KMA UM
Initial time: 2018. 09. 17. 00UTC
FCST: +180hr
Initial time : 2018. 09. 17. 00UTC
FCST : +186hr

KIM 3.2

KMA UM
Initial time: 2018.09.17.00UTC
FCST: +192hr
Initial time : 2018. 09. 17. 00UTC
FCST : +198hr
Initial time : 2018. 09. 17. 00UTC
FCST : +204hr
Initial time : 2018.09.17.00UTC
FCST : +210hr
Initial time: 2018.09.17.00UTC
FCST: +216hr
Initial time : 2018.09.17.00UTC
FCST : +222hr

KIM 3.2

KMA UM
Initial time : 2018.09.17.00UTC

FCST : +228hr

KIM 3.2

KMA UM
Initial time: 2018. 09. 17. 00UTC
FCST: +234hr
Initial time: 2018.09.17.00UTC
FCST: +240hr

KIM 3.2

KMA UM
From the updates in KIM since July 2015, revisions in DA, physics and dynamic cores have proven the reduction of errors in NWP skill.

Two model system differ in all aspects of the components but the synoptic features are quite similar up to day 7 (deterministic).

Recognizing the fact that error in sub-seasonal and seasonal is the accumulation of error in NWP, it would be interesting to apply the stochastic effects with time.
Why stochastic physics?

- Model error might arise from a misrepresentation of physical processes on unresolved subgrid-scales.

- Lorenz (1975): *the ultimate climate models will be stochastic, i.e., random numbers will appear somewhere in the time derivatives.*

**Stochastically perturbed physical tendency**

\[ X_p = (1 + r_X)X_c \]

- In medium-range and seasonal prediction,
  1) broad ensemble spread
  2) reduced outlier

*From Buizza et al. (1999) and Palmer et al. (2009)*
Why stochastic dynamics?

- Approximation in governing equation
- Computational representation of governing equations, (i.e. spatial and temporal truncation)
- Heterogeneous momentum forcing at a given grid
- Physics: “unknowns” dynamics: “Uncertain”

Stochastically perturbed dynamical tendency

Koo and Hong (APJAS, 2014)
**Perturbed model tendencies**

\[
\frac{\partial \chi}{\partial t} = [N + L] + P
\]

- **Linear tendency (spectral)**
- **Nonlinear tendency**
- **Dynamical tendency**
- **Physical tendency**
- **Total tendency**

\[N_j' = \langle r_j \rangle \chi N(\chi^n)\]

\[D_j' = \langle r_j \rangle \chi \left[\frac{\chi_j^+ - \chi_j^{n-1}}{2\Delta t}\right]\]

\[P_j' = \langle r_j \rangle \chi \left[\frac{\chi_j^{n+1} - \chi_j^+}{2\Delta t}\right]\]

\[T_j' = \langle r_j \rangle \chi \left[\frac{\chi_j^{n+1} - \chi_j^{n-1}}{2\Delta t}\right]\]

*Forcing strength is controlled by random interval (I=0.1, 0.2, 0.5, 1.0, and 2.0)*

\[ex) \ I = 1.0 : \ r_j \in [0.50, 1.50]\]

\[I(\eta, t) = \begin{cases} 
I_{\text{max}} e^{-\frac{(t-t_r)}{\alpha}} \text{, if } t \leq t_r \\
I_{\text{max}} e^{-\frac{t}{\alpha}} \text{, if otherwise}
\end{cases}\]
Forecast skill in 500 hPa geopotential height (August 2010)

RMSE

Anomaly correlation

DYN

PHY

DPT

positive
Standing eddy of 500 hPa geopotential height: JJA 1996

Contour: standing eddy
Shading: 95% confidence level

DPT > DYN > CTL > PHY
Transient eddy momentum flux ($u'v'$) for JJA 1996

GFS analysis

CTL-GFS

DYN-CTL

PHY-CTL

DPT-CTL
Seasonal Simulation (2017 JJA)

* To see stochastic effect in ocean-atmos coupling
• 01 May 2017 : MJJA (4-mon integration)
  * JJA for analysis
• 5 ensemble members

<table>
<thead>
<tr>
<th>EXP</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNTL</td>
<td>KIM3.2 (about 100 km resolution)</td>
</tr>
<tr>
<td>STOC</td>
<td>CNTL + Stochastically parameter perturbing (ch, cm only over ocean)</td>
</tr>
</tbody>
</table>
Stochastic perturbation to ocean surface

1) perturbed parameter : $C_m, C_h$ over oceans
2) Length scale : 100 km
3) time decorrelation : 6 hour
4) standard deviation : 0.5

Stochastically perturbed forcing
Ollinaho et al. 2017

\[
\begin{align*}
  u^* &= \sqrt{C_m (1 + r)} \left| \frac{\mathbf{u}}{U} \right| \\
  SH &= \rho C_p C_h (1 + r) \Delta \theta \left| \frac{\mathbf{u}}{U} \right| \\
  LH &= \rho C_h (1 + r) \Delta q \left| \frac{\mathbf{u}}{U} \right|
\end{align*}
\]
Precipitation Variance

[cntl] JJA Rain Variance

[stoc] JJA Rain Variance

[stoc-cntl] JJA Rain Variance Diff
Negative EP divergence in jet region

- weakening of westerly flow
- Polar shift of planetary waves:

* vector: EP flux vector
* shading: EP divergence
Temperature bias was also improved by the improvement of wind fields...

Stochastic perturbation is needed....

The issue is how to apply...
Thank you
KIM-HYCOM Coupling

- rotated cubed-sphere grid centered Korean Peninsula in the cube panel

Global HYCOM (GLBb1.50)

- tripole grid
- Insert bi-polar patch in north pole

Pre-run (24hr)

net sw flux, net rad flux, wind stress (avg), precipitation, water vapor mixing ratio, wind speed

fcst +00h     +06h     +12h

Every 6 hr

Skip receiving sst at intial

MCT-based Coupler

* Remap
* Variable exchanges

KIM

HYCOM

KIAPS
(1) Need to use ocean reanalysis as an temperature initial con. (currently climatology used), but hard to interpolate (hycom uses hybrid coordinate)

(2) Need to check another bug for decreasing SST and small diurnal cycle.

(3) HYCOM GLBb version does not expect serious results. (just for test) Considering to replace with NEMO.