Typhoon Simulation Using the 3-Dimensional Atmosphere-Ocean Regional Coupled Model, CReSS-NHOES

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Third SoWMEX/TiMREX Science Workshop, Taipei, Taiwan, 3 to 5 November 2010
Motivation

- We have simulated Typhoon Morakot (T0908) using the CReSS to test the framework of the daily simulation for the SoWMEX2010.
Motivation

- **Maximum accumulated rainfall amount** during this simulation reaches **over 4300 mm** around the CMR over Taiwan Island.
Motivation

- Maximum accumulated rainfall amount during this simulation reaches over 4300 mm around the CMR over Taiwan Island.
- This rainfall amount should overestimate the observed one (about 3000 mm).

- What are causes of the overestimation of accumulate rainfall amount?
  * Cloud microphysics? (Suggestion from Dr. W.-K. Tao)
  * Air-sea interaction?

→ We focus on the air-sea interaction in this study.

- The CReSS uses the slab-ocean scheme that solve the equation of heat conduction under the sea surface, but the initial vertical profile of temperature gives constant same as the prescribed SST.
- This scheme is not realistic that SST is not decreasing by the warm water upwelling.
Dr. Aiki of JAMSTEC develop a three dimensional regional atmosphere-ocean coupled model in non-hydrostatic system, CReSS-NHOES.

The model is developed to use investigations for an effect of air-sea interaction under the typhoon condition.

An intense typhoon should changed the SST distribution, e.g., central pressure, wind speed, rainfall amount.

Upwelling (coastal upwelling) after typhoon passage should be caused by the oceanic mixed-layer cooling, and changes the SST distribution.
Models: CReSS and NHOES

• The Cloud Resolving Storm Simulator (CReSS)
  To simulate mesoscale atmospheric phenomena developed by Tsuboki and Sakakibara (2002)

• The NonHydrostatic Ocean model for ES (NHOES)
  To simulate oceanic phenomena developed by Aiki and Yamagata (2004), Aiki et al. (2006), Menesguen et al. (2009)
  • Three dimensional nonhydrostatic ocean model
  • Hybrid terrain-following and z-level system
  • Vertical mixed layer scheme near the surface is a simple diagnostic form based on $Ri$.
  • Wave model is not included in this framework.
3D-Ocean

CReSS

Momentum, Water fluxes

Heat flux

SST cooled by entrainment and Ekman upwelling

NHOES

1D-Ocean

CReSS

SST

Heat flux

SST is set by 1D-diffusion model
No entrainment and Ekman upwelling

Slab model
We hypothesized that accumulated rainfall amount reduce by using the CReSS-NHOES model compared with the 1-D ocean model.

1. 3-D ocean model should **activate upwelling** and **reduce** SST.
2. Cooler SST should **reduce** LHF from the sea surface.
3. Reduced water vapor amount should reduce central minimum pressure and also **reduce rainfall amount** around typhoons.
Typhoon Experiments
T0908 (Morakot)
T0908, Morakot experiments

**CReSS**
- Resolution: **Hor. 4 km**, Ver. 200 m (surface) to 400 m (stretched)
- Domain: 512 x 256 x 64 grids, DT: = 4 sec.
- Initial and lateral boundary condition: JMA/RANAL dataset
- Simulation starts at 00 Z on **August 5, 2009** and continues **120 hrs.**

1. **3-D ocean: NHOES**
   - Resolution: Hor. 4 km, Ver. 2 m for top 100 m (4000m depth)
   - Domain: 512 x 256 x 100 grids
   - Initial and lateral boundary condition: **JCOPE2 reanalysis**
     (3-D, lateral resolution of 1/12 degree)

2. **1-D ocean: JCOPE2 reanalysis SST**

3. **1-D ocean: MGDSST**
   - Resolution: Hor. 0.25 deg., Ver. 0.5 m for top 30 m (60 layers)
Integration period:
from 00Z on August 5 to 00Z on August 10 (120 hours)
T0908 landed on Taiwan Island at 18Z on August 7 (60 hours of integration time)
Surface precipitation (color)
Surface winds (arrows)
Sea-level pressure (contour)

60 hours starting from the simulation (at 18Z on August 7)

The pattern of rainfall distribution of the 3-D NHOES model is quite same to that of the 1-D slab ocean model.
Upwelling after the passage of typhoon
Time variation of hourly rainfall amount averaged all over Taiwan Island

- Hourly rainfall amount using the 3-D ocean model is decreasing a little compared with that 1-D ocean model from 50 to 80 hours.
Time variation of accumulated rainfall amount averaged all over Taiwan Island

• Difference among these 3 experiments is significant in accumulated rainfall.
• Accumulated rainfall amount using the 3-D ocean model is decreasing compared with that 1-D ocean model.
Time variation of accumulated rainfall amount averaged over the western CMR

Accumulated rainfall amount averaged in this area using the 3-D ocean model is decreasing about 100 mm compared with that 1-D ocean model.
Time variation of accumulated rainfall amount averaged over the foothill of western CMR

- Also, accumulated rainfall amount averaged in this area using the 3-D ocean model is decreasing about 50 mm compared with that 1-D ocean model.
Typhoon Experiments
T0505 (Haitang)
Integration period:
from 00Z on September 14 to 00Z on September 20 (144 hours)
Time variation of hourly rainfall amount averaged all over Taiwan Island

- Hourly rainfall amount using the 3-D ocean model is quite same compared with that 1-D ocean model.
Time variation of accumulated rainfall amount averaged all over Taiwan Island

- Difference among these 3 experiments is quite small.
Accumulated rainfall amount averaged in this area using the 3-D ocean model is quite same compared with that 1-D ocean model.
Summary

• The developed 3-D non-hydrostatic regional atmosphere-ocean coupled model, CReSS-NHOES, successfully simulates typhoons, T0505 and T0908.
  * Tracks were close to the JMA best-tracks.

• Accumulated rainfall was reduced about 5% using the 3-D ocean experiments in T0908 case.
  * That was quite same in T0505 case.
  * We have to explore the reason not to reduce rainfall amount in T0505 case. Shall we mistake our hypothesis?
  * We have to compare with the observation data (surface raingauge).
Future Plans of the CReSS-NHOES

- Comparison/Check the case on **PALAU 2010**
  * We have carried out daily simulation using the non-coupled CReSS.
- Application for **CINDY/DYNAMO 2011** over the Indian Ocean for daily simulation (forecasting).
- Application for snow clouds over/in the Sea of Japan using high resolution of 1-km or higher.
- Application for the variation over/in the Yellow Sea after extra-tropical cyclones’ passing.
Thank you for your kind attention!!
Backup slides
CReSS-NHOES

• Both single models are well developed models:
  – Non-hydrostatic system
  – Three dimensional model
  – Apply regional domain in latitude-longitude coordinate
  – Utilize MPI communication method in parallelization
  – Available hybrid parallel decomposition methods
    • MPI for inter-nodes and OpenMP/microtask for intra-nodes
  – Conduct calculations mainly on the Earth Simulator (ES) and show good performance
  – Achieve mesoscale simulations at high resolution
T0908, Morakot

Calculation: August 05 - 10
T0908, Time variation of average moving speed of the TC center, (5hr moving average)

1-D Ocean (CReSS, JMA/MGDSST) - Red
1-D Ocean (CReSS, JCOPE2 reanalysis SST) - Green
3-D Ocean (CReSS-NHOES, JCOPE2 reanalysis) - Blue

Speed (m/s)

Time of integration (hour)

40km/hr, less
10km/hr

Landing TW
Leaving TW
Landing C
Accumulated rainfall amount at Alishan point (120.8E, 23.5N) was 2935 mm from August 6 to 10 (from Japanese newspaper).

That in this area using the 3-D ocean model is decreasing about 180 mm compared with that 1-D ocean model.
T0908, Time variation of accumulated rainfall on Taiwan Island (121.0E-121.3E, 23.0N-23.5N)

Graph showing accumulated rainfall over time for different ocean models:
- 1-D Ocean (CRESS, JMA/MGDSST)
- 1-D Ocean (CRESS, JCOPE2 SST)
- 3-D Ocean (CRESS-NHOES, JCOPE2)

Color scale indicating rainfall amounts: 250, 500, 750, 1000, 1500, 2000 mm.
T0505, Haitang

Calculation: September 14 - 20

September 11
T0505, Haitang experiments

CReSS

- $DX=DY=4\text{km}$, $DZ = 200\text{m}$ (surface) to $400\text{m}$ (stretched)
- $380 \times 250 \times 60$ grid, $DT=4\text{sec}$
- Initial and lateral boundary condition: JMA/RANAL dataset

1. 3-D ocean: NHOES

- $DX=DY=4\text{km}$, $DZ = 2\text{m}$ for top $100\text{ m}$ ($4000\text{m}$ depth)
- $380 \times 250 \times 100$ grid
- Initial and lateral boundary condition: JCOPE2 reanalysis (3-D)

2. 1-D ocean: 30m depth (60 layers)

- Initial SST dataset is MGDSST (0.25degree)
- Initial SST dataset is JCOPE2 reanalysis (1/12 degree ~ 10km)

3. Fixed-SST (NO time variation) with MGDSST
T0505, Time variation of center minimum pressure, JMA RANAL, CReSS model results

1-D ocean (MGDSST)
Fixed SST (MGDSST)
JMA RANAL

~7hPa suppressed
T0505 landed on Taiwan Island at 02Z July 18 (98 hours of integration time)
Costal upwelling

Upwelling after typhoon’s passing

1-D ocean 98 hours
1-D ocean 144 hours
3-D ocean 98 hours
3-D ocean 144 hours
1-D ocean 98 hours

1-D ocean 144 hours

3-D ocean 98 hours

3-D ocean 144 hours
Topography of Taiwan, 120.5E–121.0E, 23.5N–24.0N

TO505, Time variation of accumulated rainfall on Taiwan Island (120.5-121.0E, 23.5-24.0N)

- 1-D Ocean (CReSS, JMA/MGDSST)
- 1-D Ocean (CReSS, JCOPE2 SST)
- 3-D ocean (CReSS-NHOES, JCOPE2)

~30mm reduced
T0505, Time variation of accumulated rainfall on Taiwan Island (121-121.5E, 23.5-24N)

1-D Ocean(CReSS, JMA/MGDSSST)
1-D Ocean(CReSS, JCOPE2 SST)
3-D ocean(CReSS-NHOES, JCOPE2)

~60mm reduced
Backup slides-2
T0914, Choi-Wan

Calculation: September 16 - 26

September 17 03Z
T0914, Choi-Wan experiments

• CReSS
  – DX=DY=4km, DZ = 200m(surface) to 400m (stretched)
  – 380 x 480 x 60 grid
  – Initial and lateral boundary condition: JMA/RANAL dataset

• 3-D ocean: NHOES
  – DX=DY=4km, DZ = 2 m for top 100 m
  – 380 x 480 x 100 grid
  – Initial and lateral boundary condition: JCOPE2 reanalysis

• 1-D ocean:
  – 30m depth (60 layers of dz=0.5m) with JCOPE2 SST

• Integration period: 00Z 9/16 -- 00Z 9/26 (10days)
T0914, Time variation, center minimum pressure, CReSS(MGDSST), CReSS(JCOPE2), CReSS-NHOES

- 1-D ocean (MGDSST) [red]
- 1-D ocean (JCOPE2) [green]
- 3-D ocean [blue]

- ~7hPa suppressed

- 00Z 09/17
- 72 hours
- 00Z 09/19
T0914: SLP and SST distribution

1-D ocean

Day=19, hr=00, Surface Temperature (Deg - C)
T0914 dx=4km, stretch dz=200-450m,

After 72 hours

3-D ocean

Day=19, hr=00, Surface Temperature (Deg - C)
T0914 dx=4km, stretch dz=200-450m,
T0914: SLP and SST distribution

1-D ocean

Day=20, hr=00, Surface Temperature (Deg-C)
T0914 dx=4km, stretch dz=200-450m,

After 96 hours

3-D ocean

Day=20, hr=00, Surface Temperature (Deg-C)
T0914 dx=4km, stretch dz=200-450m,
T0914, Time variation of average moving speed of TC, (6hr moving average)

1-D Ocean (CReSS, JMA/MGDSST)
1-D Ocean (CReSS, JCOPE2 reanalysis SST)
3-D ocean (CReSS-NHOES, JCOPE2 reanalysis)

Speed (m/s)

Time of integration (hour)

00Z 09/19 72 hours
00Z 09/20 96 hours

KEO
KEO and JKEO are part of the global network of OceanSITES time series reference sites:  [http://www.oceansites.org](http://www.oceansites.org)

**Purpose of OceanSITES reference stations**

- To provide data for assessing model, data, and satellite products
- To detect rapid changes and episodic events, as well as long-term changes in the climate system
- To provide a test-bed for studying processes within the climate system

**OceanSITES data are...**

- Long, ongoing time series, following best practices and quality control
- Common netcdf format that includes all necessary meta data
- Freely available through OceanSITES DACS and GDACS
17 Sept 18Z  60m/s, gusts to 72m/s, 11 m wave ht

Passed KEO - 19 Sept 17Z

Time variation of SST at KEO(32N,145E), 1-D Ocean(JCOPE2), 3-D Ocean

Sea Surface Temperature (degC)

Time of integration (hour)
More Investigation for Choi-wan...

- We are planning to use KEO data to check difference between observation and simulation...
  - BUT, KEO dataset is NOT available in the target period, NOT completed after passing T0914... because of T0914 itself (caused some trouble on the KEO buoy)
  - People of KEO group in NOAA/PMEL are working on quality check now.
  - We are waiting for uploading data...
After 72 hours

**Z=0** (SST)

**Z=-1m**

**Z=-50m**

**Z=-100m**

Temperature Anomalies from t=0
After 72 hours

Temperature Anomalies from $t=0$

$Z=0$ (SST)

$Z=-1m$

$Z=-50m$

$Z=-100m$
T0914
After 80 hours
Pressure minimum

Z=0
(SST)

Temperature Anomalies from t=0

Z=-1m

Z=-50m

Z=-100m
Cloud Resolving Storm Simulator (CReSS)

- Tsuboki and Sakakibara (2002)
- DX = 4km, 380 * 250 * 60 grid
- Initial and lateral B. C.:
  - RANAL from NPD/JMA

NonHydrostatic Ocean model for ES (NHOES)

- Aiki and Yamagata (2004)
- Aiki et al. (2006)
- Menesguen et al. (2009)

- DX = 1km, DZ = 2 m for top 100 m
- 1500 * 1000 * 100 grid
- Initial and lateral B. C.:
  - JCOPE2 reanalysis
時間経過（時間）

07/16 00Z 07/15

1-D海洋（MGDSST）
固定SST（MGDSST）
JMA RANAL

約7hPa抑制
1D-ocean, 3D-ocean (CReSS-NHOES) with JCOPE2

1-D ocean (JCOPE2 reanalysis SST)  
\(\text{\textbackslash CReSS-NHOES, JCOPE2 reanalysis}\)
TO914, Time variation, center minimum pressure, JMA/GPV, JMA/BestTrack, CReSS(JMA/MGDSST), CReSS(JCOPE2), CReSS(JCOPE2 reanalysis SST), NH0ES-CReSS 2way.
Difference in SST dataset

JCOPE2 Reanalysis    JMA/MGDSST

Day=21, hr=00, Surface Temperature (Deg-C)
T0914 dx=4km, stretch dz=200-450m,
T0914: Difference in SST distribution

1-D ocean

Day=21, hr=00, Surface Temperature (Deg C)
T0914 dx=4km, stretch dz=200-450m,

3-D ocean

Day=21, hr=00, Surface Temperature (Deg C)
T0914 dx=4km, stretch dz=200-450m,