JMA activities for reducing systematic errors

Numerical Prediction Division, Japan Meteorological Agency

Plans for major upgrades of the global NWP in recent few years

- FY2019
  - Introduction of a Hybryid-4dvar system
  - All-sky assimilation of microwave radiances
  - Refinement of drag processes and Land surface upgrades
- FY2020
  - Enhancement of vertical resolution (L100 -> L128)
  - Physics package upgrade
    - convection and boundary layer schemes
  - Update of background error covariance
- FY2021
  - Enhancement of horizontal resolution (20km -> 13km)
  - All-sky assimilation of Infrared radiances (FY2021-2022)

Topics

- Improving orographic drag
- Systematic errors against own analysis
- Precipitation verification
  - Implication from WMO LC-DNV

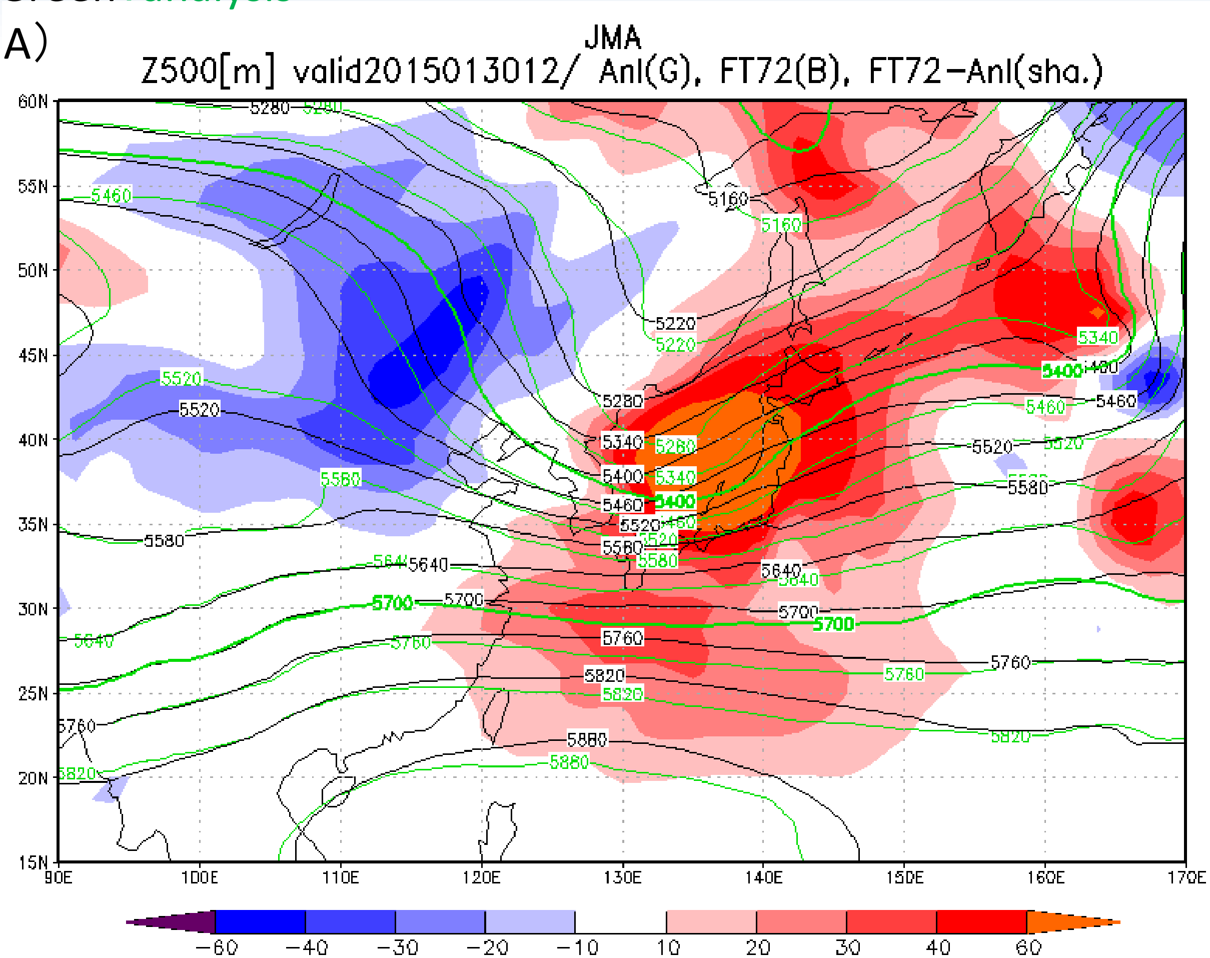
IMPROVING OROGRAPHIC DRAG

Chihiro Matsukawa, Hitoshi Yonehara, Kazutaka Yamada, Takafumi Kanehama, and Ryoji Nagasawa

Motivation: a long standing bias of GSM

Errors of 500hPa height（20150130VALID, T+72hr）

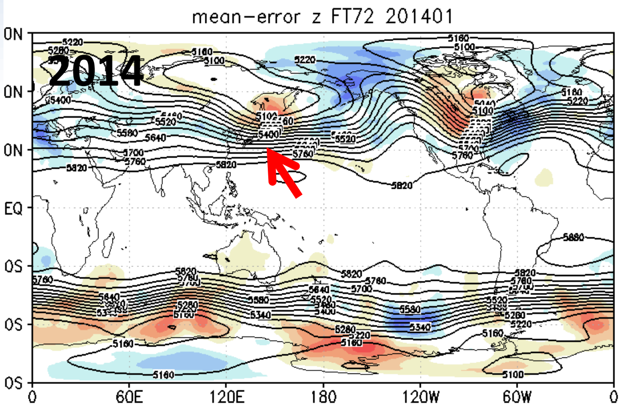
Black : forecast、Green : analysis
Color : error（ F - A）

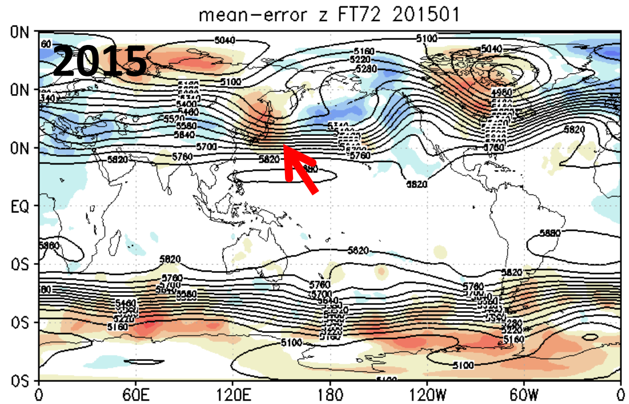


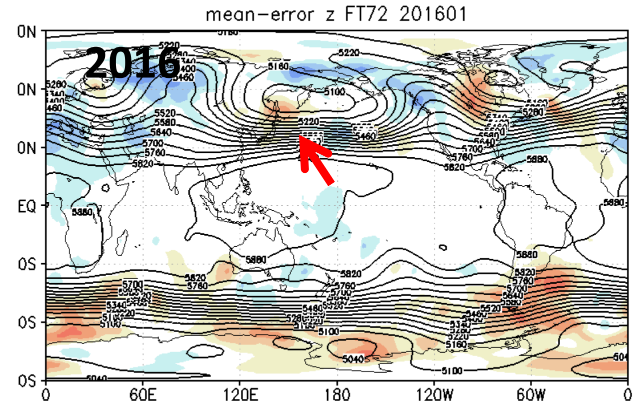
GSM predicts (a)shallower and (b) slower troughs than those in analysis

Robustness of the "shallow trough" bias

January mean errors of geopotential height at 500hPa(T+72hr)

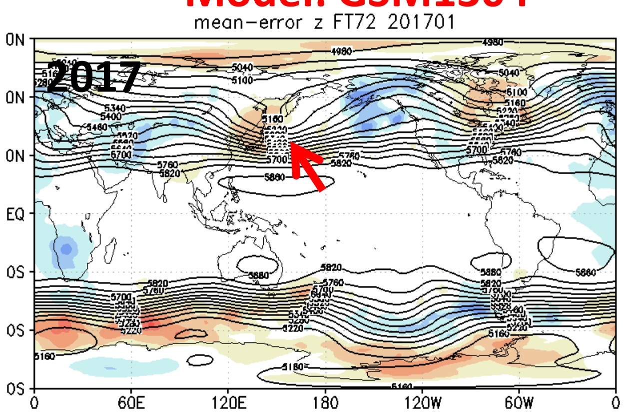


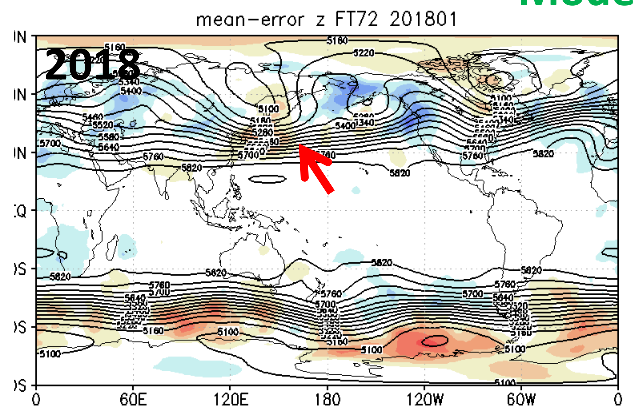


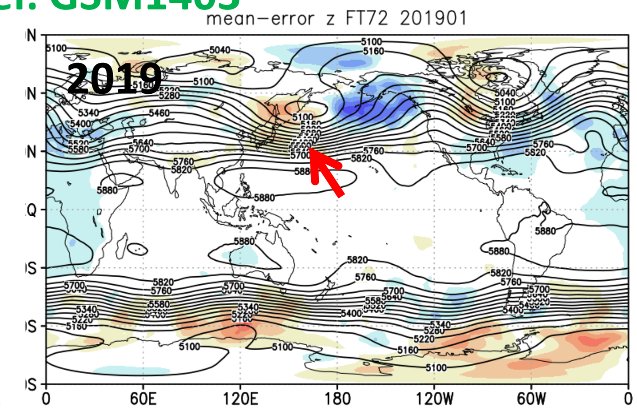


Model: GSM1304

Model: GSM1403

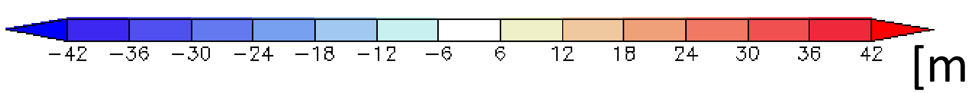






Model: GSM1603

Model: GSM1705



Reconsideration of orogprahic drag

- Recognized the importance of the orographic processes not only in JMA but also over the modelling community.
  - E.g. the WGNE-GASS drag projects, presentations in the WGNE systematic errors workshop, orography intercomparison (Elvidge et al. 2019)

Current and new subgrid orographic stress τ parameterziations

GSM1705

Long-tail stability function	Mixing length as a function of subgrid orography (little impact)	Iwasaki et al (1989) • Short wave • Long wave

$$\tau_{\mathrm{LED}} + \tau_{\mathrm{FORM}} + \tau_{\mathrm{GWD}}$$

Under testing

Long-tailed stability function

TOFD (Beljaars et al. 2004) < 5km

BFD **GWD**
(Lott and Miller 1997 + Vosper 2015) 5km >

a joint implicit solver

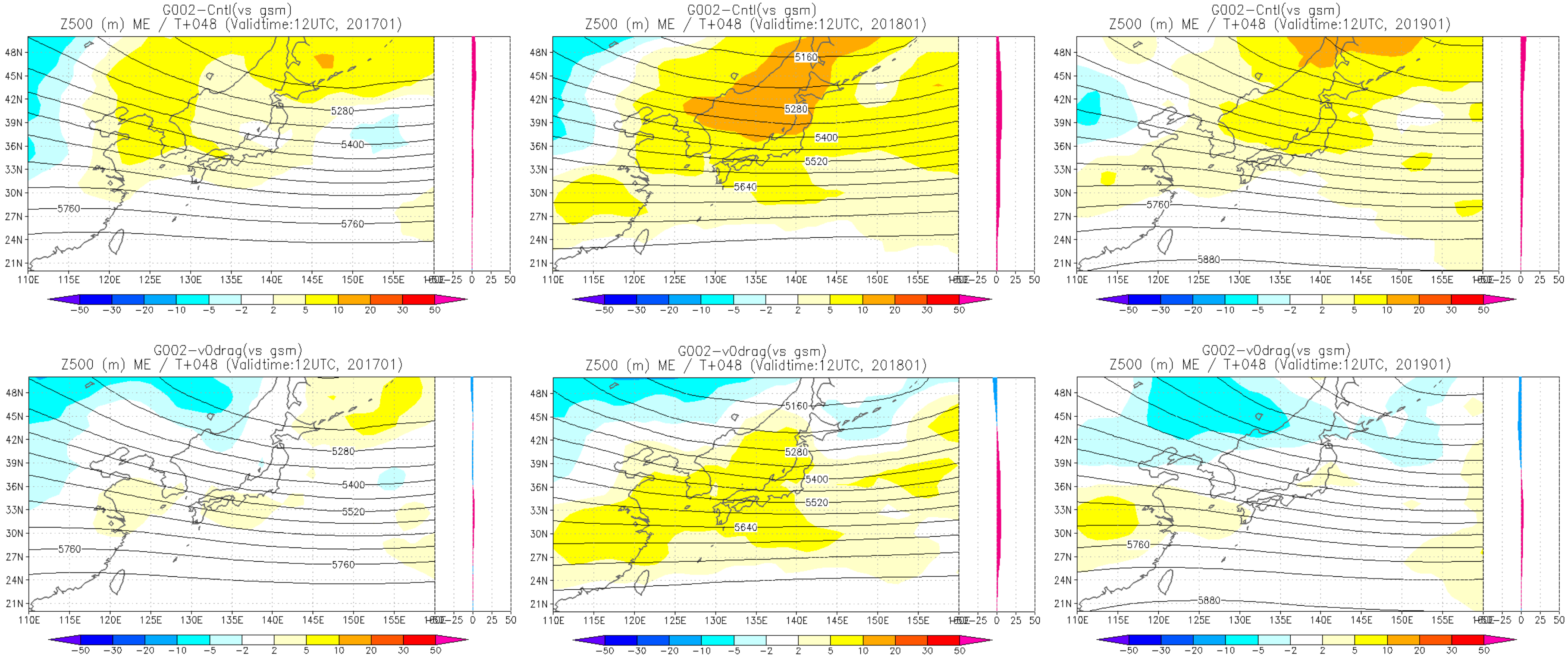
Impacts on the shallow trough bias: mean errors

T+48

Jan. 2017 | Jan. 2018 | Jan. 2019

CTRL

TEST

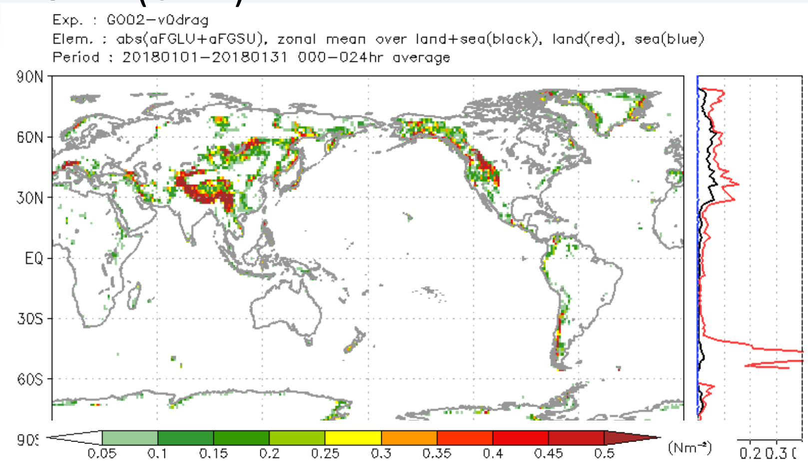


- Improving the drag process certainly reduces the shallow trough bias.

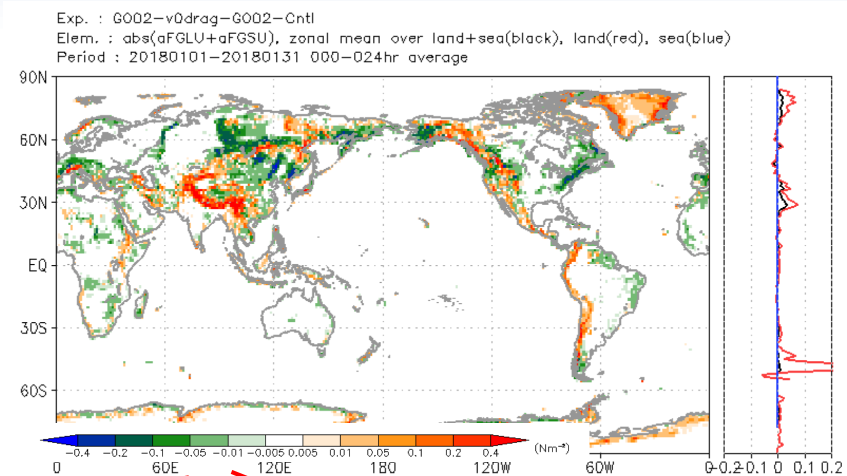
Surface stress by subgrid orographic orography

$$\mathrm{abs}\left(\frac{1}{\mathrm{tmax}}\sum_{t=1}^{\mathrm{tmax}}\tau_{x_{\mathrm{FT}=0-24,\,t}}\right)$$

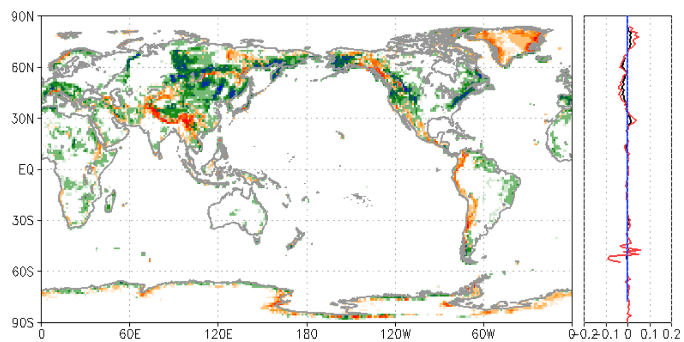
TOTAL (CTRL)



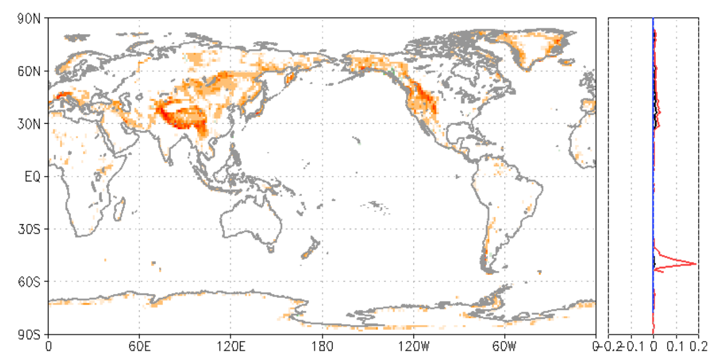
TOTAL(TEST-CTRL)



Contribution from low level drag (CTRL: SW)



Contribution from GWD (CTRL: SW)



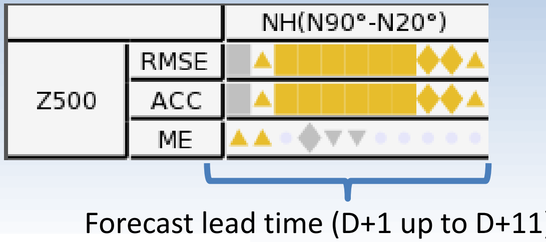
Reduced: Lowlevel drag (BFD and TOFD)

Increased: GWD

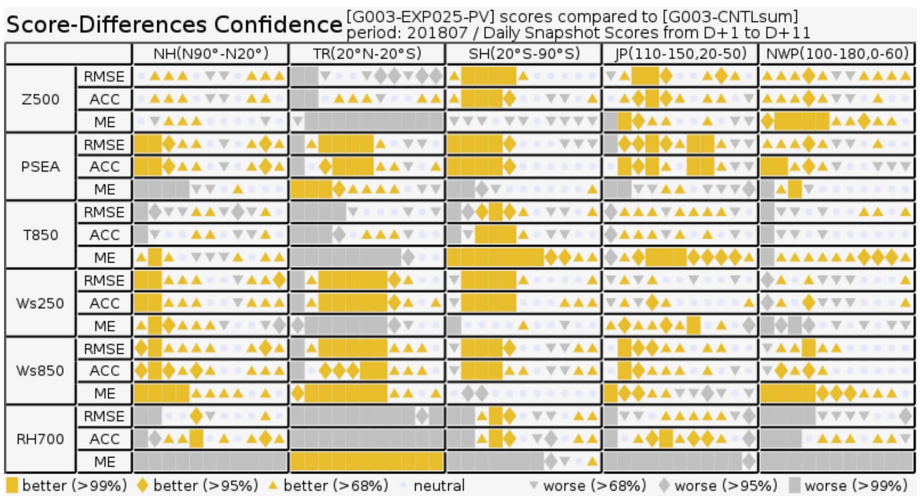
SYSTEMATIC ERRORS AGAINST ANALYSES

Scorecards

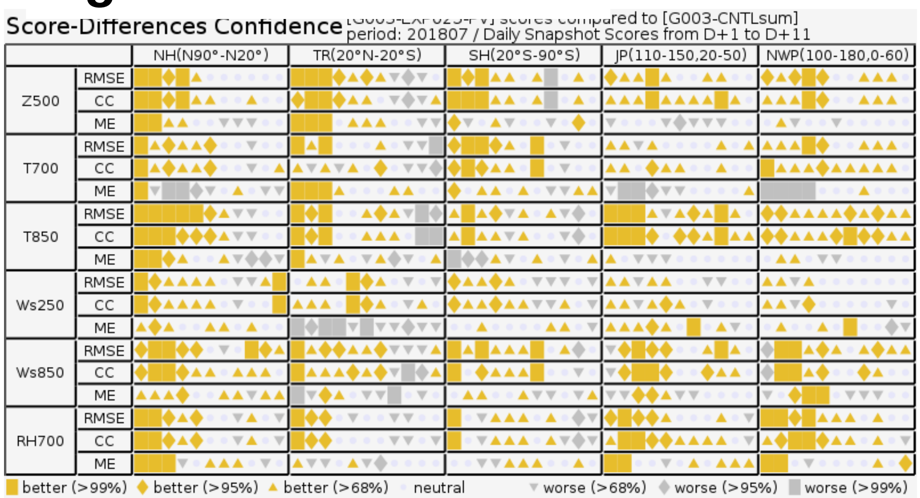
An example from a trial of "all-sky assimilation of microwave radiances + introduction of outer loops"



Against own analysis



Against radiosonde



better (>99%) better (>95%) better (>68%) neutral worse (>68%) worse (>95%) worse (>99%)

Scores against own analysis look "worse" although those against radiosonde look "better"

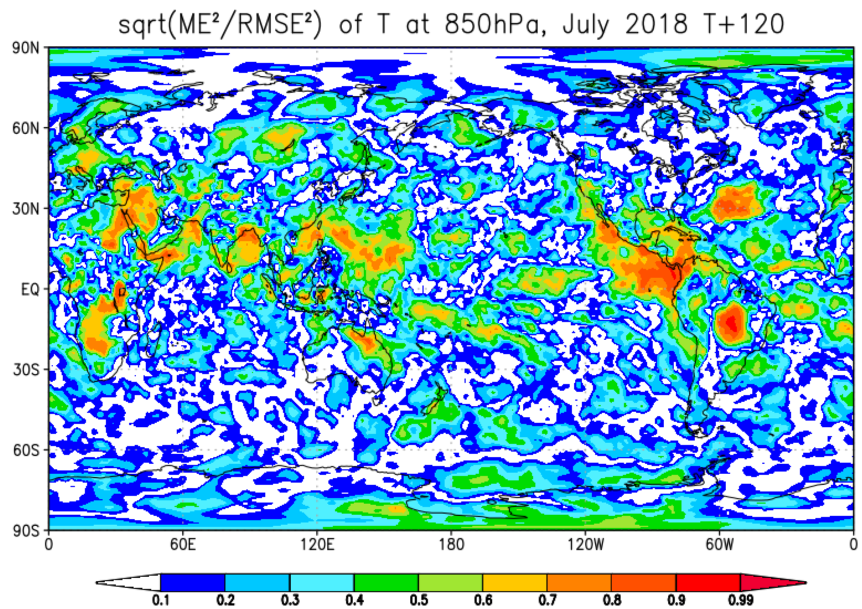
We encounter such kind of issues particularly at development of DA and obs. changes

(Experiments and verification are conducted by Hiroyuki Shimizu and Masahiro Kazumori)

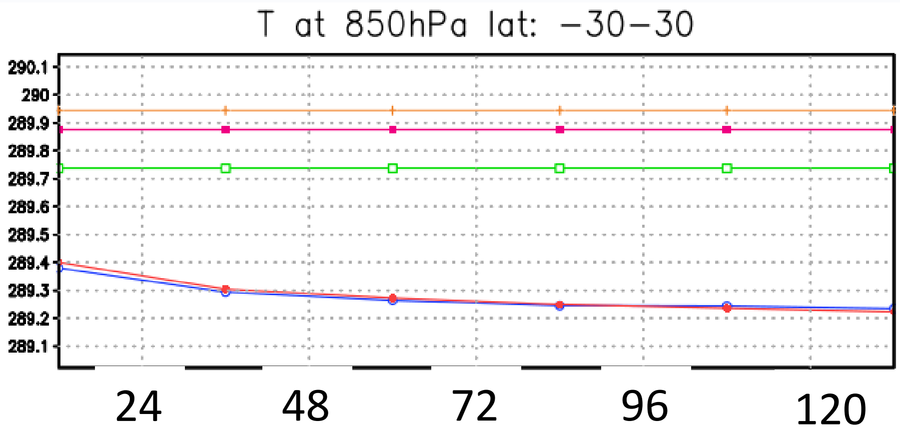
Possible reasons

- Correlation between forecast and analysis errors
  - If there is strong correlation between fcst and analysis errors (an extreme example: no observation), RMSE against own analysis tends to be small.
- Systematic differences in analyses
- Sparse radiosonde observation (e.g. tropics, southern hemisphere).
- Any other experience in your centre?
  - E.g. Geer et al (2018)

Ratio of |ME| to RMSE is relatively large over the tropics.

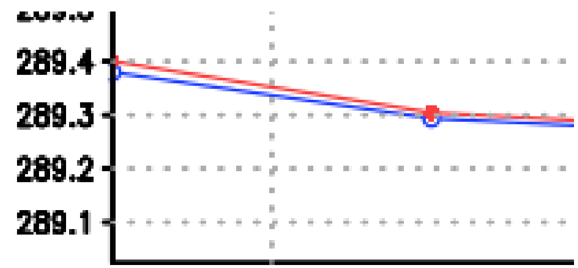


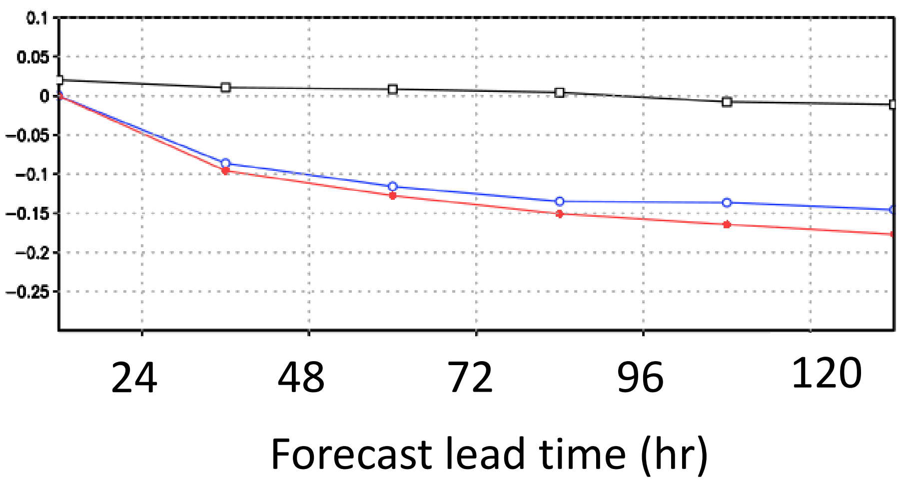
Systematic differences between analyses



NCEP an
Met Office an
ECMWF an

CTRL (Blue)
TEST (all-sky
+outer loop, Red)





TEST-CTRL

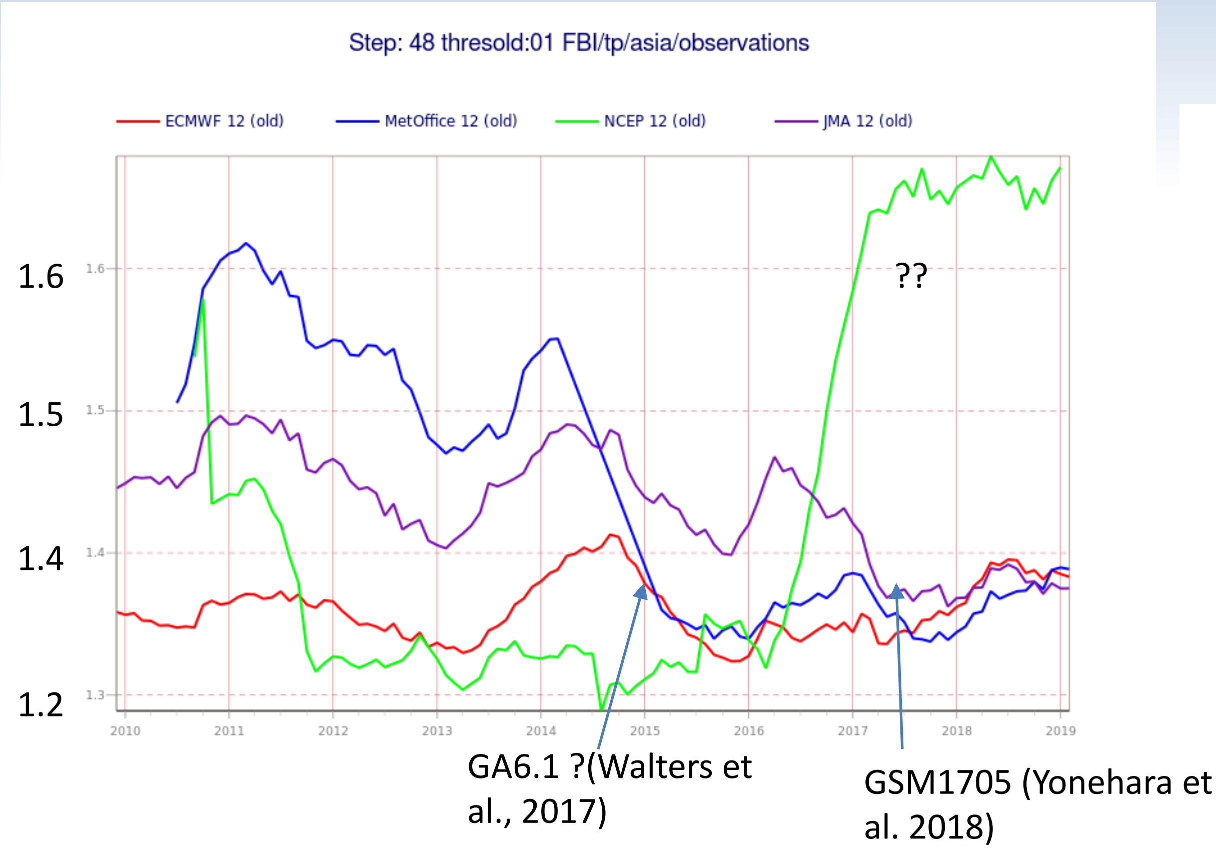
CTRL-CTRL(T+0)
TEST-TEST(T+0)

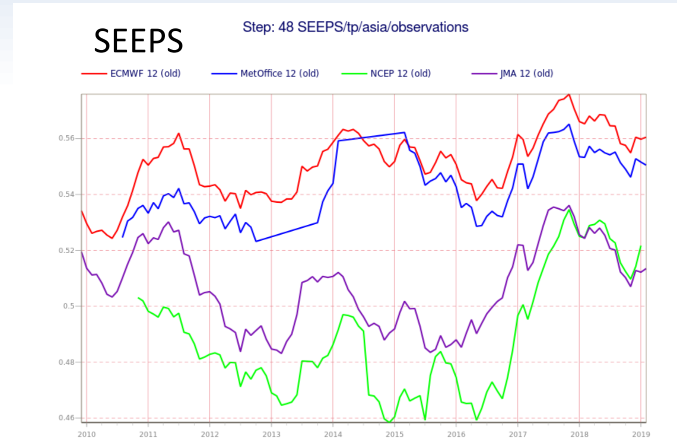
- Large spread between analyses
- TEST analyses higher temperature and is closer to those of other centres.
- However, mean error of TEST against own analysis is larger since the model (both for TEST and CTRL) drifts to lower temperature state.

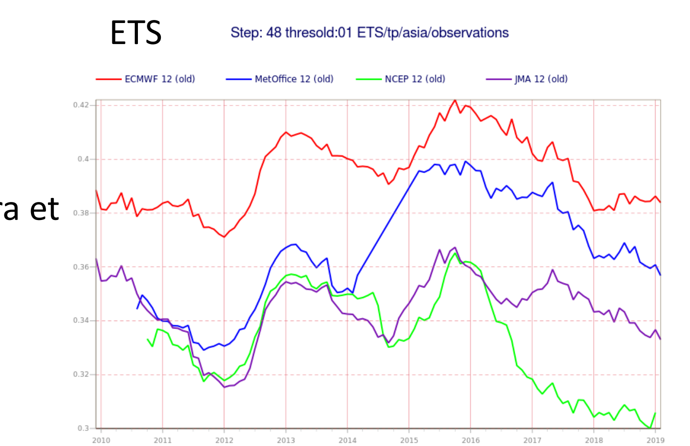
PRECIPITATION VERIFICATION: IMPLICATIONS FROM WMO LC-DNV SCORE PLOTS

12-months running-mean Frequent Bias score (threshold : 1mm/24hr, T+48) over Asian region

Plot by the WMO LC-DNV website https://apps.ecmwf.int/wmolcdnv/scores/surface.time_series/tp

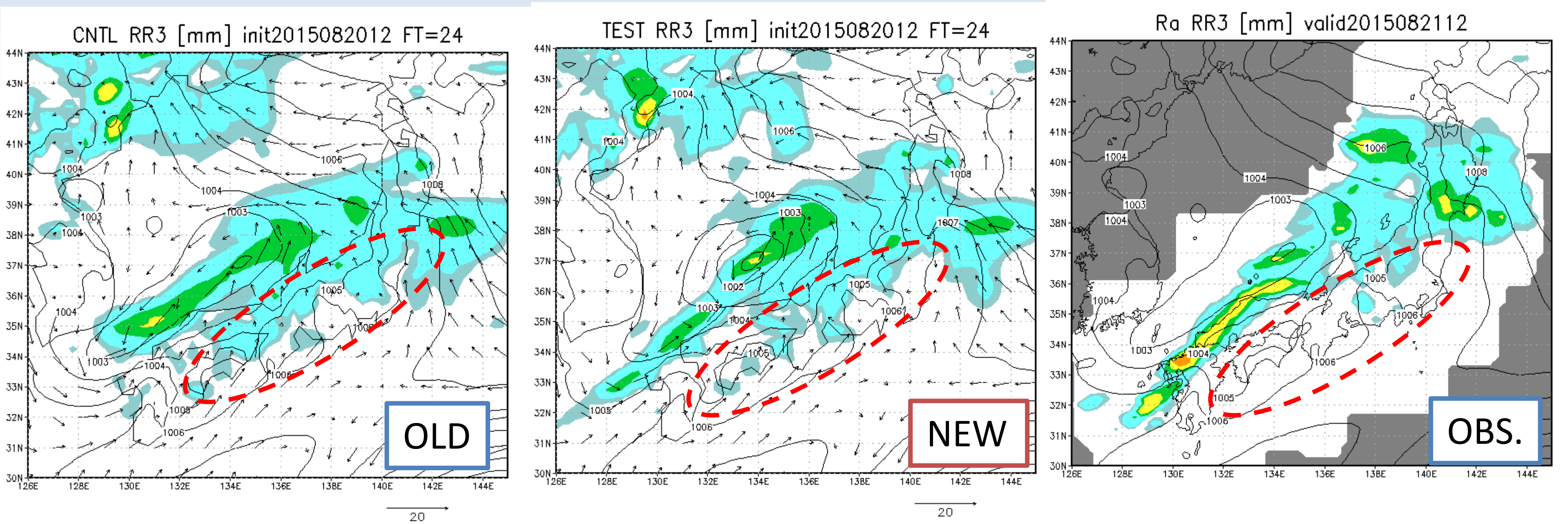






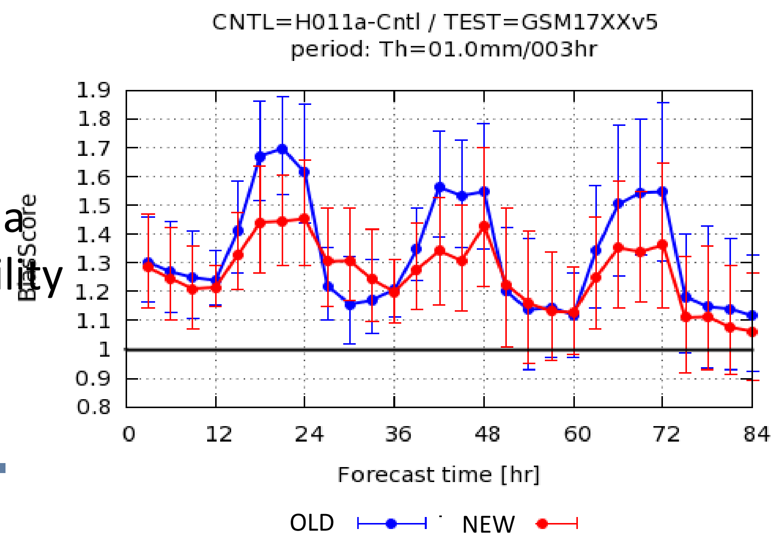
- Bias Score appears to be more sensitive to model physics upgrades than those in other scores
- The WMO LC-DNV website can play roles, which WGNE QPF verif. used to play, of monitoring QPF performance.

Improvement in GSM1705



- GSM1705 improved
  - precipitation evaporation and snow melting processes both in the cloud and convection schemes.
    -> Representing evaporation and snow melt in a thin layer with maintaining computational stability
  - precipitation coalescence process in the cloud scheme

These reduced bias score (>1) for light precipitiation.



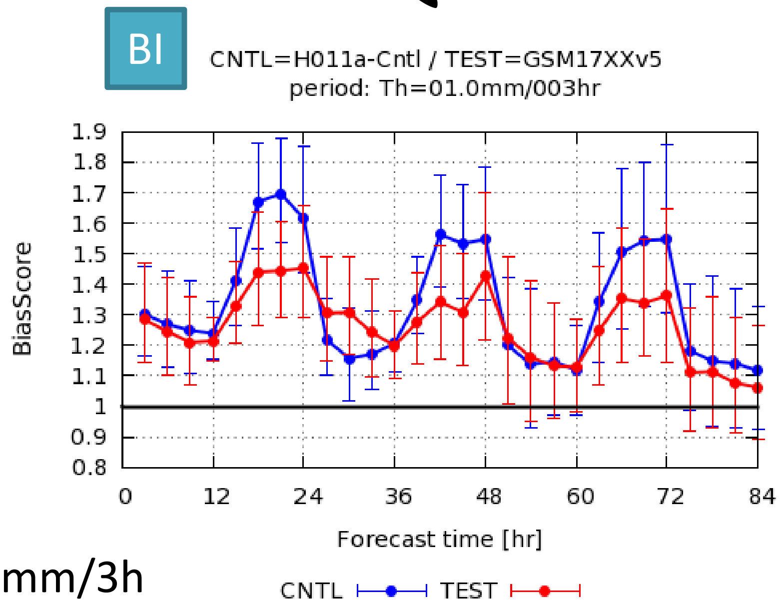
Summary

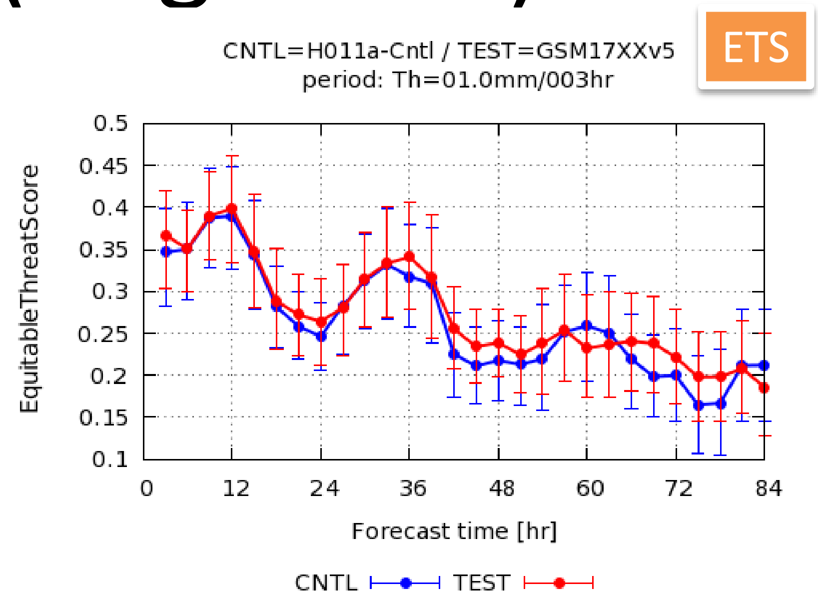
- Orographic drag processes have large impacts on the performance of synoptic-scale circulation over the East Asia
  - More understanding of orographic drag impacts on circulation over the East Asia is required.
- Precipitation scores, particularly Bias Score, are sensitive to physics upgrades. WMO LC-LNV plots could suggest that (This is what WGNE QPF verif. used to do).
- Careful interpretation is necessary when we discuss systematic errors against analyses.

BACKUP SLIDES

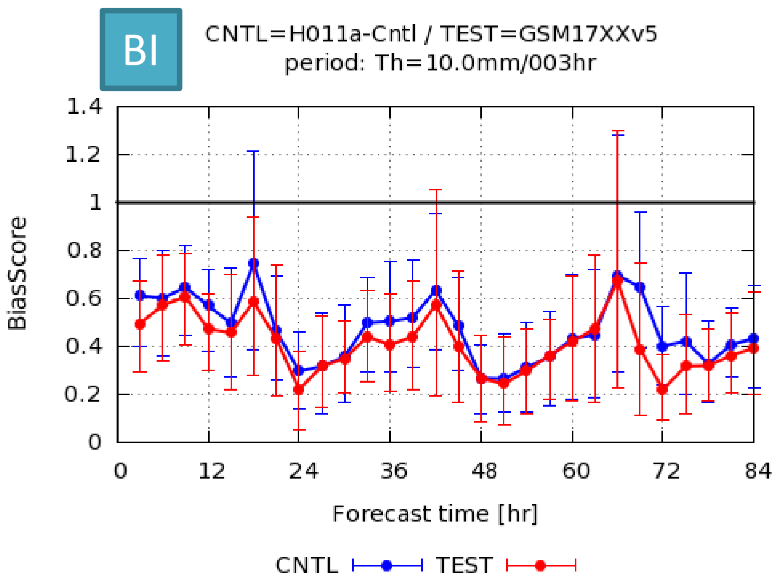
QPF scores(Aug. 2015)

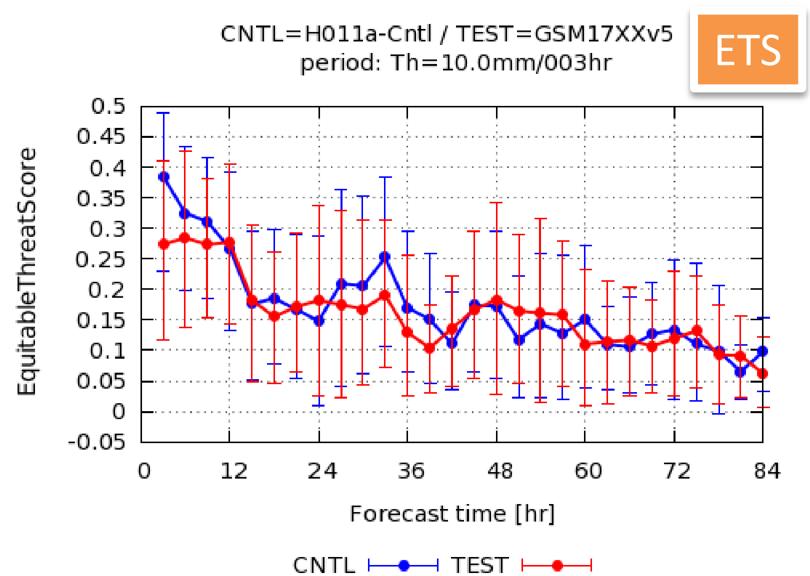
1mm/3h





10mm/3h





Solving drag and PBL jointly

- Blocked Flow Drag (BFD, Lot and Miller 1997, Vosper 2015)

$$\left(\frac{\partial u}{\partial t}\right)_{BFD} = -C_d E(r)\frac{\sigma}{\mu}\left(\frac{z_{blk}-z}{z+\mu}\right)^{\frac{1}{2}}\left(B\cos^2\Psi + C\sin^2\Psi\right)\frac{|u|u}{2} = \underline{\beta_b u}$$

a nonlinear damping term

- Turbulent Orograpic Flow Drag (TOFD, Beljaars et al. 2004)

$$\left(\frac{\partial u}{\partial t}\right)_{TOFD} = -\alpha\beta C_{md}C_{corr}|u|u\left(2.109e^{-\left(\frac{z}{1500}\right)^{1.5}}\right)a_2 z^{-1.2} = \underline{\beta_t u}$$

a nonlinear damping term

- Tendency U wind due to sum of GWD, BFD, TOFD and PBL

$$\left(\frac{\partial u}{\partial t}\right)_{GWD+BFD+TOFD+PBL} = \left(\frac{\partial u}{\partial t}\right)_{GWD} + \left(\frac{\partial u}{\partial t}\right)_{BFD} + \left(\frac{\partial u}{\partial t}\right)_{TOFD} + \left(\frac{\partial u}{\partial t}\right)_{PBL}$$

$$= \underline{\left(\frac{\partial u}{\partial t}\right)_{GWD}} + \underline{\beta_b u + \beta_t u + \frac{\partial}{\partial z}\left(K_m\frac{\partial u}{\partial z}\right)}$$

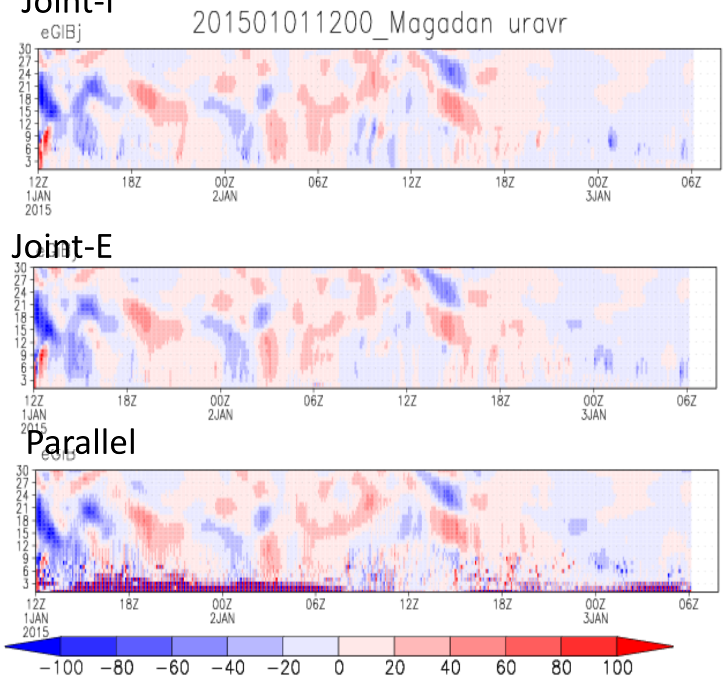
Treated as a forcing term

solved using a implicit solver
(coefficients are calculated explicitly)

Impacts of the joint solver

Exp. name	Configuration
Parallel	PBL, GWD and BFD are calculated in parallel
Joint-E	PBL, GWD and BFD are jointly calculated.
Joint-I	Same as Joint-E but BFD is treated implicitly.

Joint-I



Joint-E

Parallel

More strongly coupled

Worse

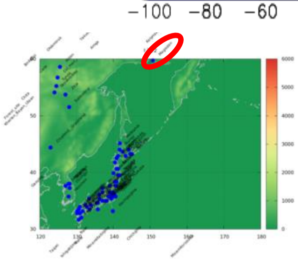
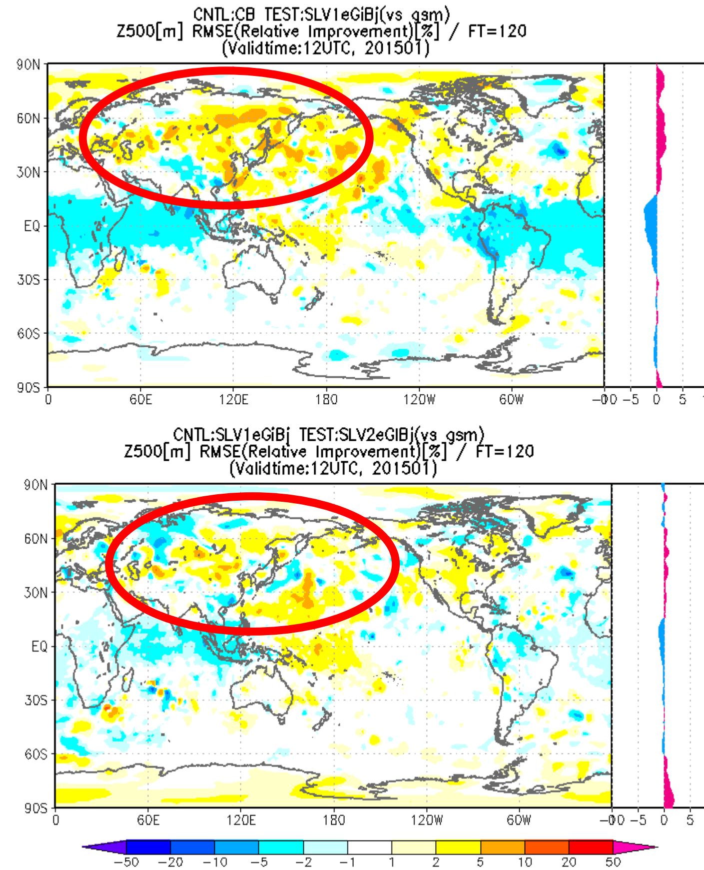


Figure. 1 Time-height cross sections of du/dt (m/s/day) over Magadan circled on the map

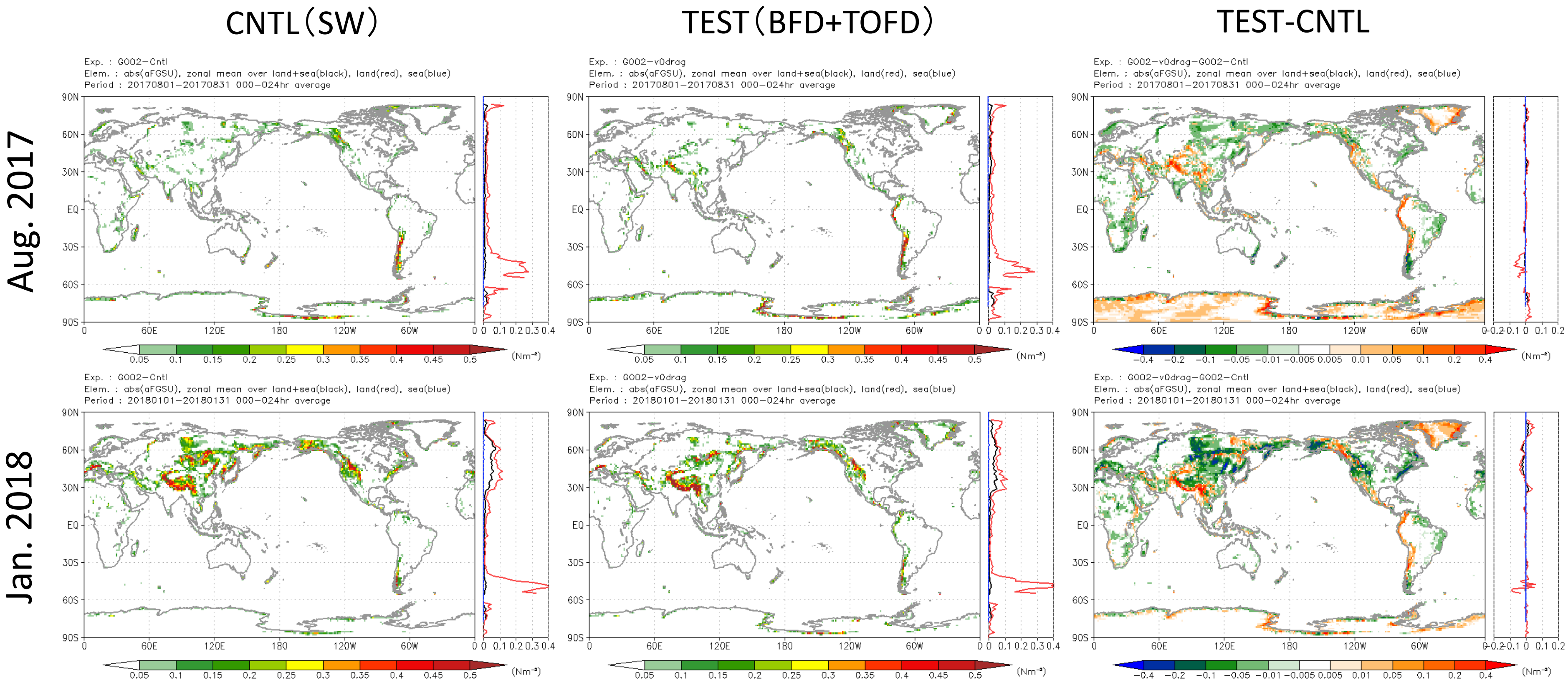


Worse

Better

Figure. 2 Normalized RMSE of 500hPa height
(a) Joint-E against Parallel, (b) Joint –I against Joint-E

Changes in surface stress（SW / BFD+TOFD）



- Increase the surface stress in TEST
- Decrease stress over the East Asia

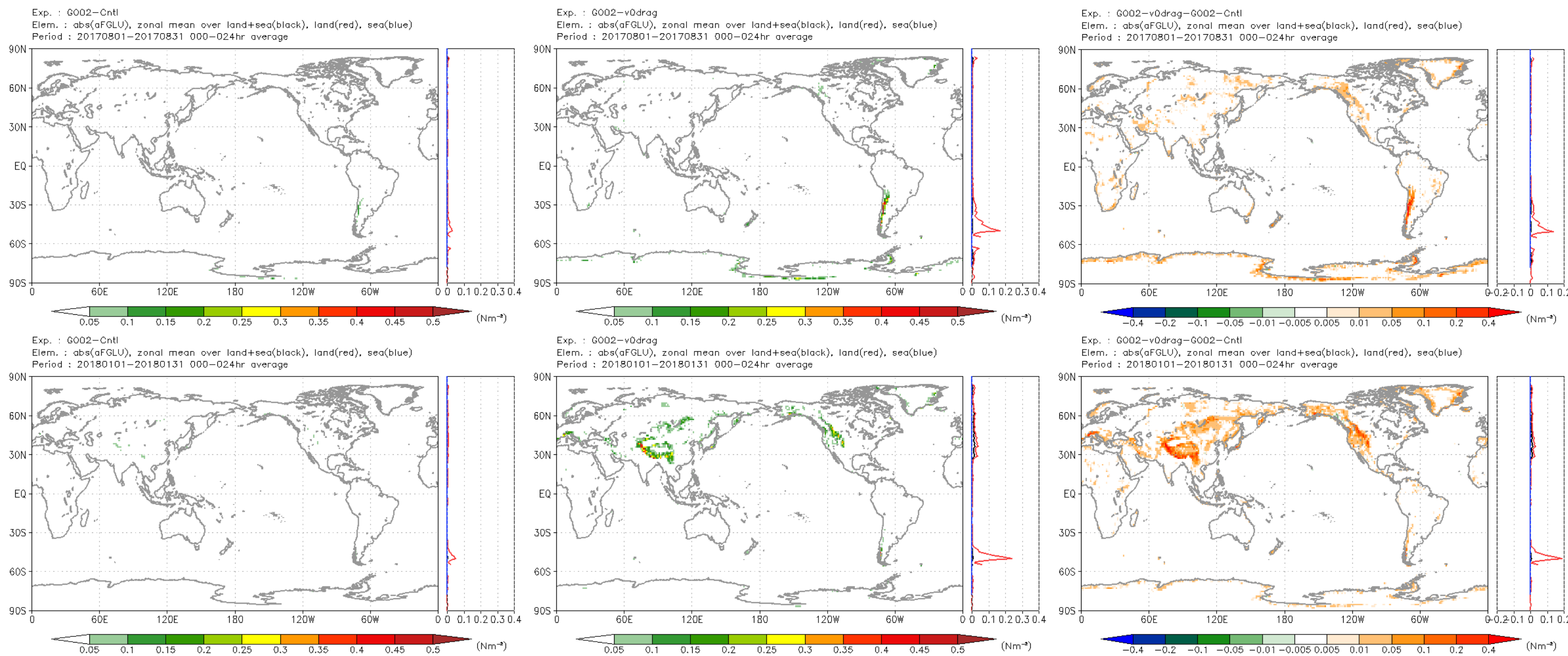
$$\mathrm{abs}\left(\frac{1}{\mathrm{tmax}}\sum_{t=1}^{\mathrm{tmax}} \tau_{x_{\mathrm{FT}=0-24,\,t}}\right)$$

Changes in surface stress（LW / GWD）

CNTL（LW） TEST（GWD） TEST-CNTL

Aug. 2017

Jan. 2018



- Weaker stress in CNTL
- Increase the surface stress in TEST

$$\mathrm{abs}\left(\frac{1}{\mathrm{tmax}}\sum_{t=1}^{\mathrm{tmax}} \tau_{x_{\mathrm{FT}=0-24,\,t}}\right)$$

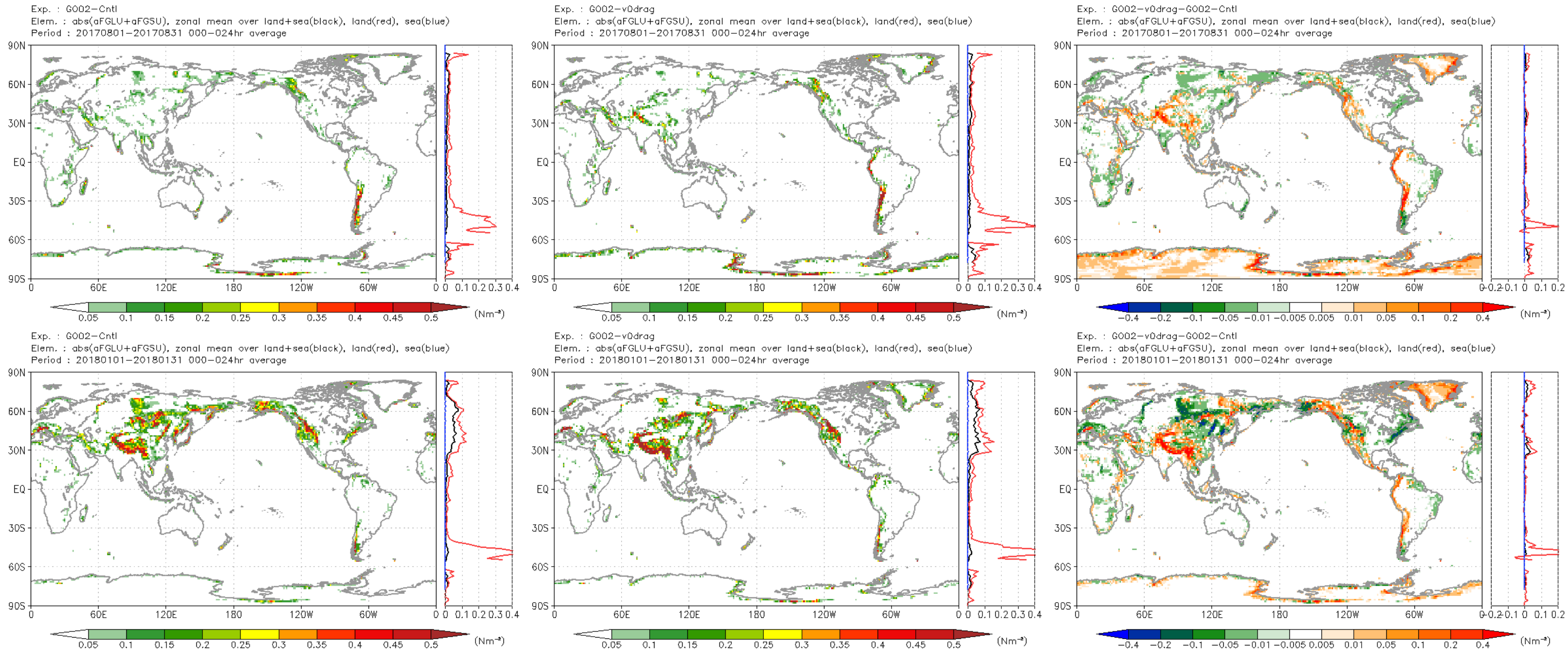
Changes in surface stress（TOTAL）

x成分

CNTL（SW+LW）　TEST（BFD+TOFD+GWD）　TEST-CNTL

Aug. 2017

Jan. 2018



描画している要素：

$$\mathrm{abs}\left(\frac{1}{\mathrm{tmax}}\sum_{t=1}^{\mathrm{tmax}}\tau_{x_{\mathrm{FT}=0-24,\,t}}\right)$$

Surface stress by orography

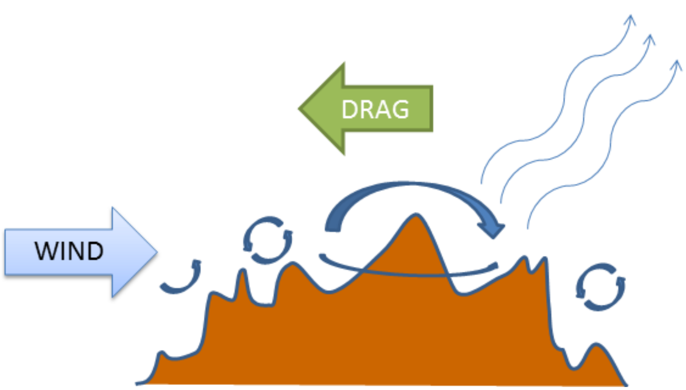
$$\boldsymbol{\tau} = (\tau_x, \tau_y)$$ total surface stress

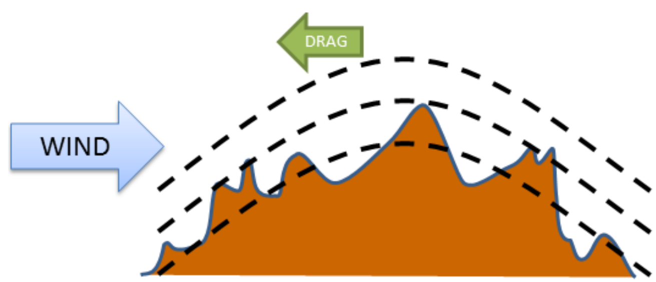
$$= \boldsymbol{\tau}_{res} + \boldsymbol{\tau}_{unres}$$:scale separation
Resolved + Subgrid

$$= p_s \nabla h + \boldsymbol{\tau}_{unres}$$

$$= p_s \nabla h + \boldsymbol{\tau}_{pbl} + \boldsymbol{\tau}_{sgo}$$:demarcation
PBL + Subgrid-orography

$$= p_s \nabla h + \boldsymbol{\tau}_{LED} + \boldsymbol{\tau}_{Form} + \boldsymbol{\tau}_{GWD}$$:processes
Local-eddy + Form-drag
+ Gravity-wave-drag





Surface stress by subgrid orographic orography

$$\mathrm{abs}\left(\frac{1}{\mathrm{tmax}}\sum_{t=1}^{\mathrm{tmax}} \tau_{x\,\mathrm{FT}=0-24,\,t}\right)$$

CTRL

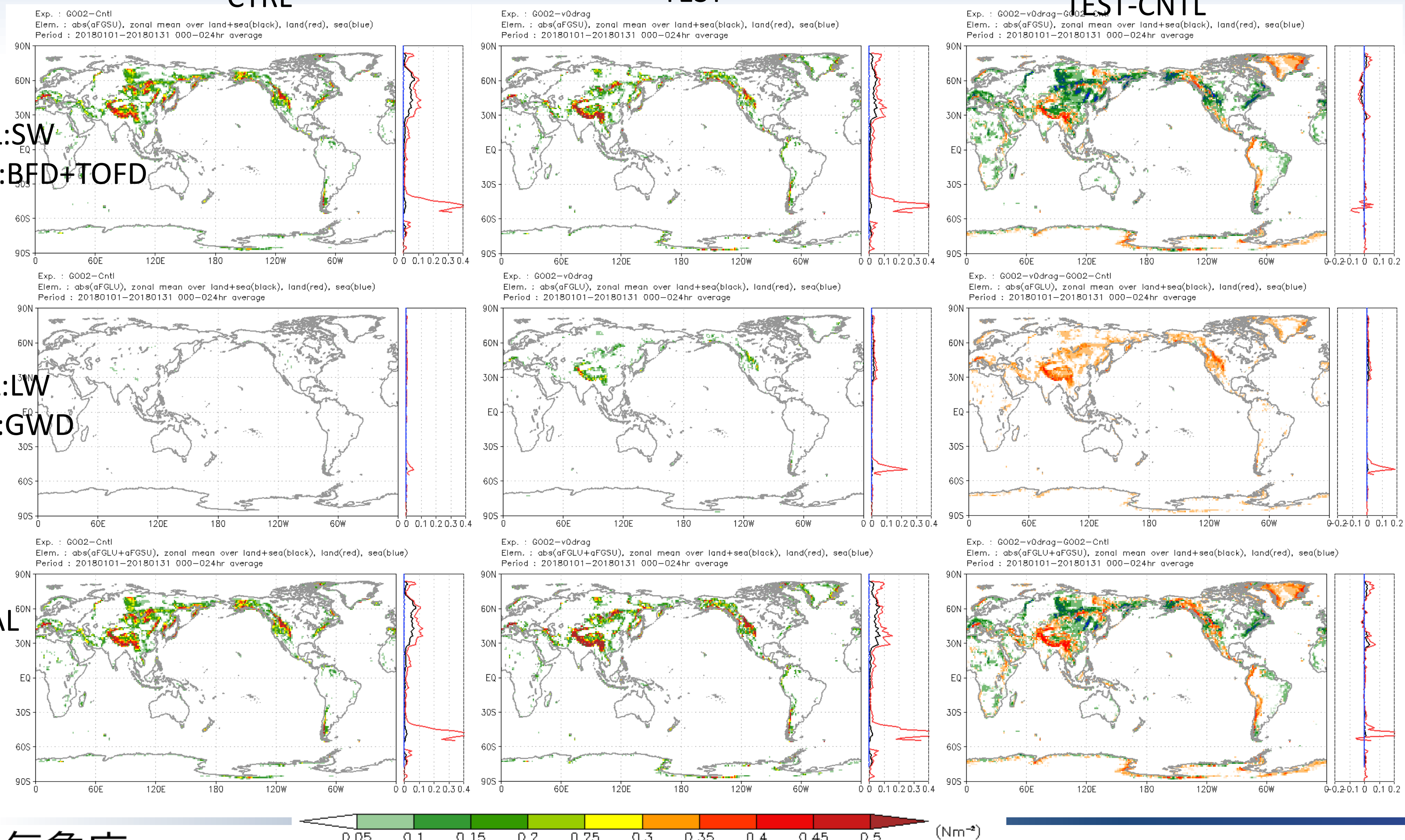
TEST

TEST-CNTL

CTRL:SW
TEST:BFD+TOFD

CTRL:LW
TEST:GWD

TOTAL



New HPC (launched in June 2018)

	Previous	New
Model	Hitachi SR16000/M1 (Vendor: Hitachi)	Cray XC50 (Vendor: Hitachi)
Theoretical Peak Performance	847 TFlops*	18,166 TFlops
Capacity of Main Memory	108 TByte	528TByte
Capacity of Magnetic Disk	348 TByte	10,608TByte

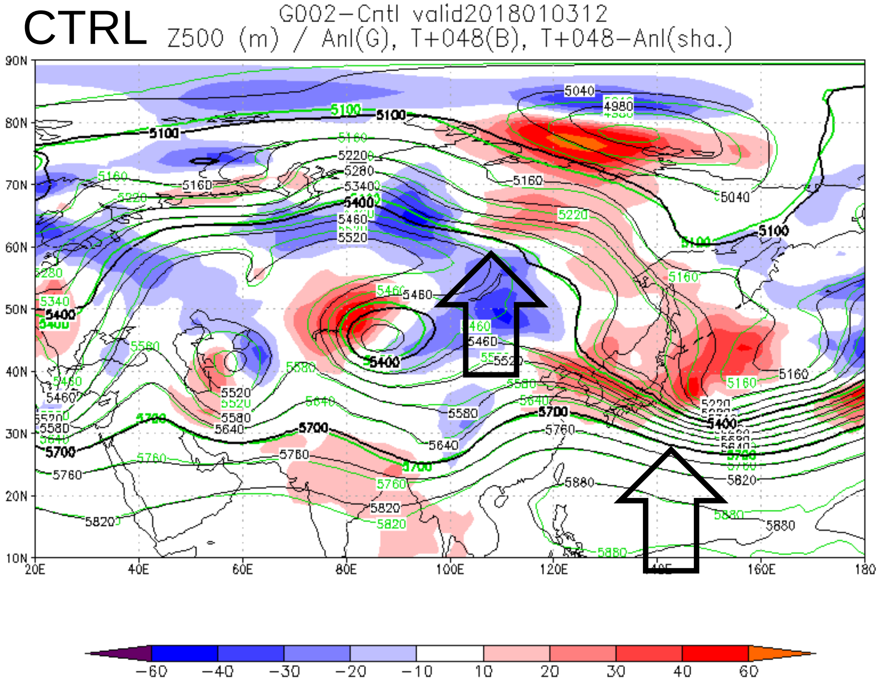
JMA news release:
http://www.jma.go.jp/jma/en/News/JMA_Super_Computer_upgrade2018.html
Ranked 32nd and 33rd on top 500 June 2019 https://www.top500.org/list/2019/06/?page=1

Impacts on the shallow trough bias: a case

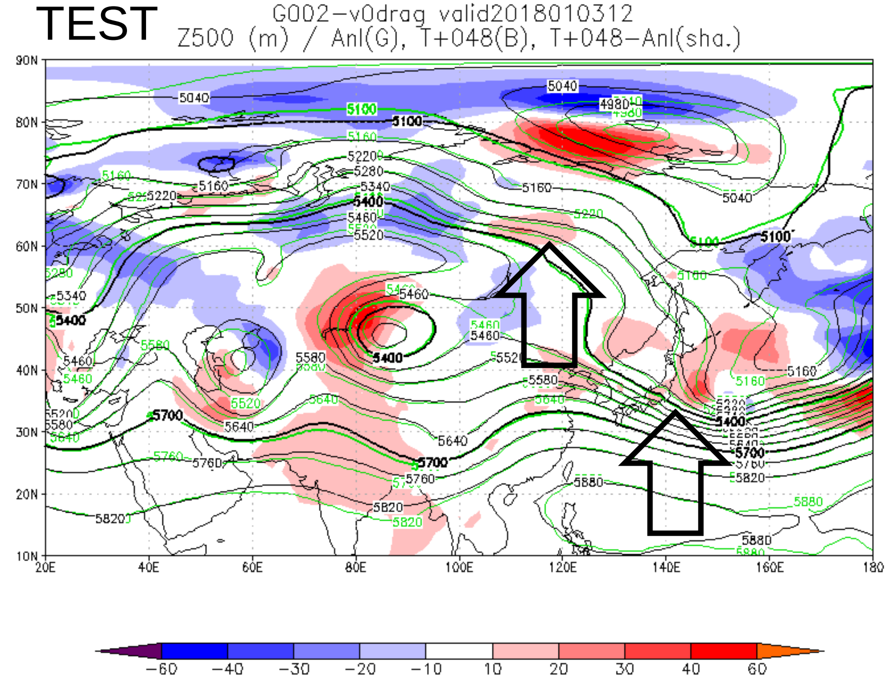
Valid：12UTC 30 Jan. 2018

Black(Green) contours: forecast at T+48(analysis)
Colors:error

CTRL



TEST



Drag parameterization: history

Progress of modelling

- 1980s: parameterization scheme of momentum transport by gravity waves considering vertical propagation
  - Palmer et al. (1986), McFarlane (1987) etc
- 1990s-2000s: Progress in research of low level drag parameterization
  - Shift from Palmer type to "GWD + low level drag" type (e.g. Lott and Miller (1997))
  - Using effective roughness (Milton and Wilson 1996) to implicitly considering τ_{form}
- 2000s : considering τ_{form} by TOFD

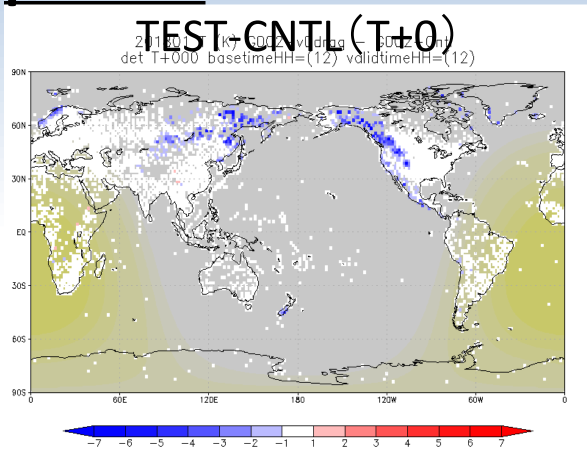
At JMA

- 1989: Introduction of a Gravity Wave Drag (GWD) scheme by Iwasaki et al. (1989)
  - Parameterizing momentum transport by GWD short (for the lower troposphere) and long waves (Palmer type)
  - The formulation of the short wave scheme is quite similar to low level drag schemes.
- 1990s and 2000s: few upgrades in the drag process
- Now: Studying impacts of drag on synoptic flow over the Far East Asia.

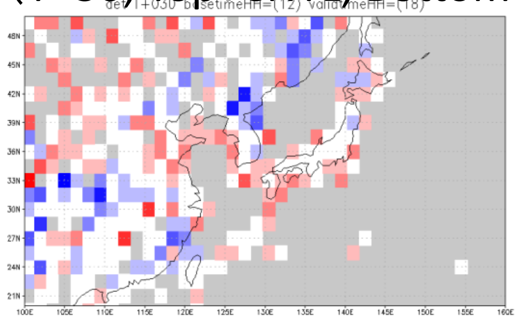
  Following progresses of the drag research in the recent years

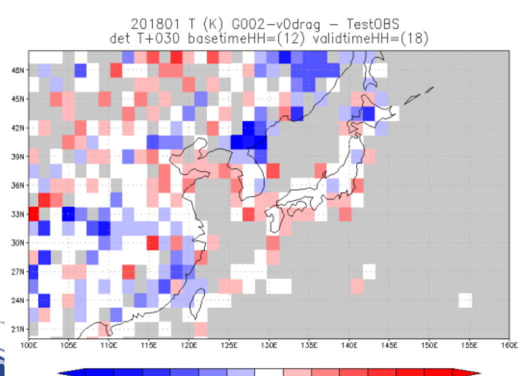
Drag improvement revealed compensating errors in the surface process

TEST-CNTL (T+0)



ME of Tsfc against SYNOPE
（T+30; Top：CNTL, Bottom：TEST1）





- Introduction BFD+TOFD make Tsfc lower in night time, that enhances the systematic error.
  1. Deceleration of winds in the block layer
  2. Weakening of vertical shear
  3. Stratification becomes more stable, hence, mixing is weakened in PBL
  4. Tsfc becomes lower in night time

Introduction of improvement in the land surface model together with the drag improvement as a “package” is planned to fix the error compensation.