Necessity of parameterizations for convective initiations and controlling convection in high resolution cloud permitting models

-from experience of JMA’s operational regional models-

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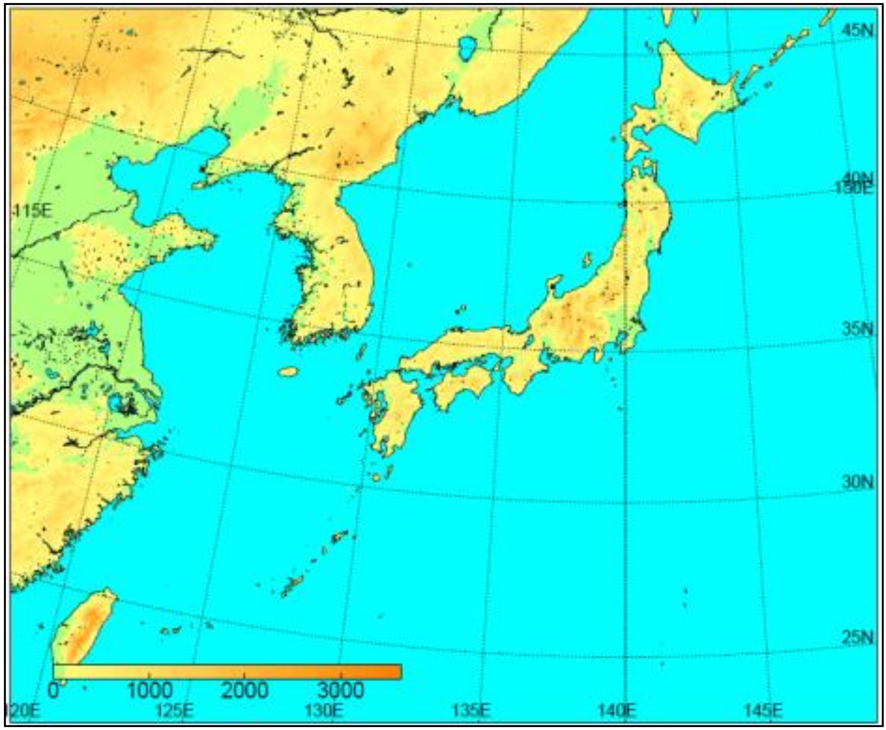
JMA's 2-km operational model
- Local NWP system -

- The **Local NWP system** provides 9-hour period forecasts every hour.
- In the system design, frequent updates of forecasts (24 times a day) assimilating the latest observation are highly emphasized.

- The Local NWP system consists of two subsystems
  - **Data assimilation system**: The **Local Analysis (LA)** employs an analysis system based on the three dimensional variational data assimilation (3D-Var) at a 5-km resolution.
  - **NWP model**: The **Local Forecast Model (LFM)** has a 2-km horizontal grid spacing and 58 vertical layers.
    - In Jan. 2015, the model was replaced with a newly developed one. Until then, no cumulus parameterization was employed.

Forecast:1581x1301 (2km grids)
Analysis:633x521 (5km grids)

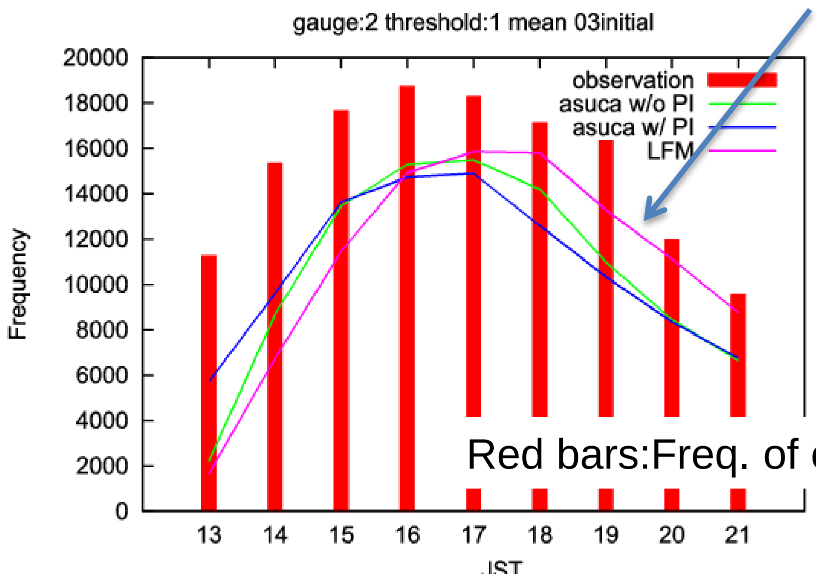


Statistics showed the delay of convective initiation

- JMA's 2-km operational high resolution model can predict heavy rain events more realistically than coarser one.
- However, time series of frequency of observed and predicted precipitation by the used-be operational model without any cumulus related parameterizations showed delay of convective initiation (See pink line and red bar).
  - Cases in which unstably stratified layer brought intensified precipitation are collected.

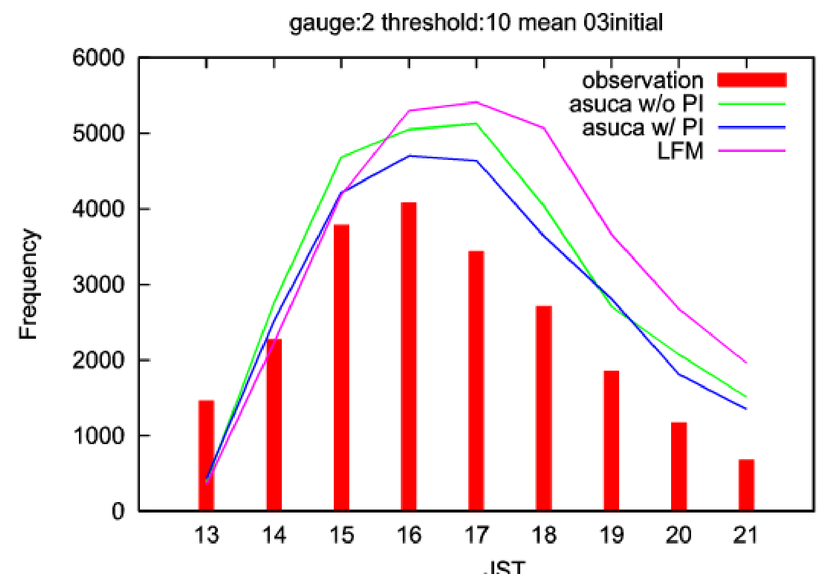
Pink line: Freq. of Prediction

over 1mm/h



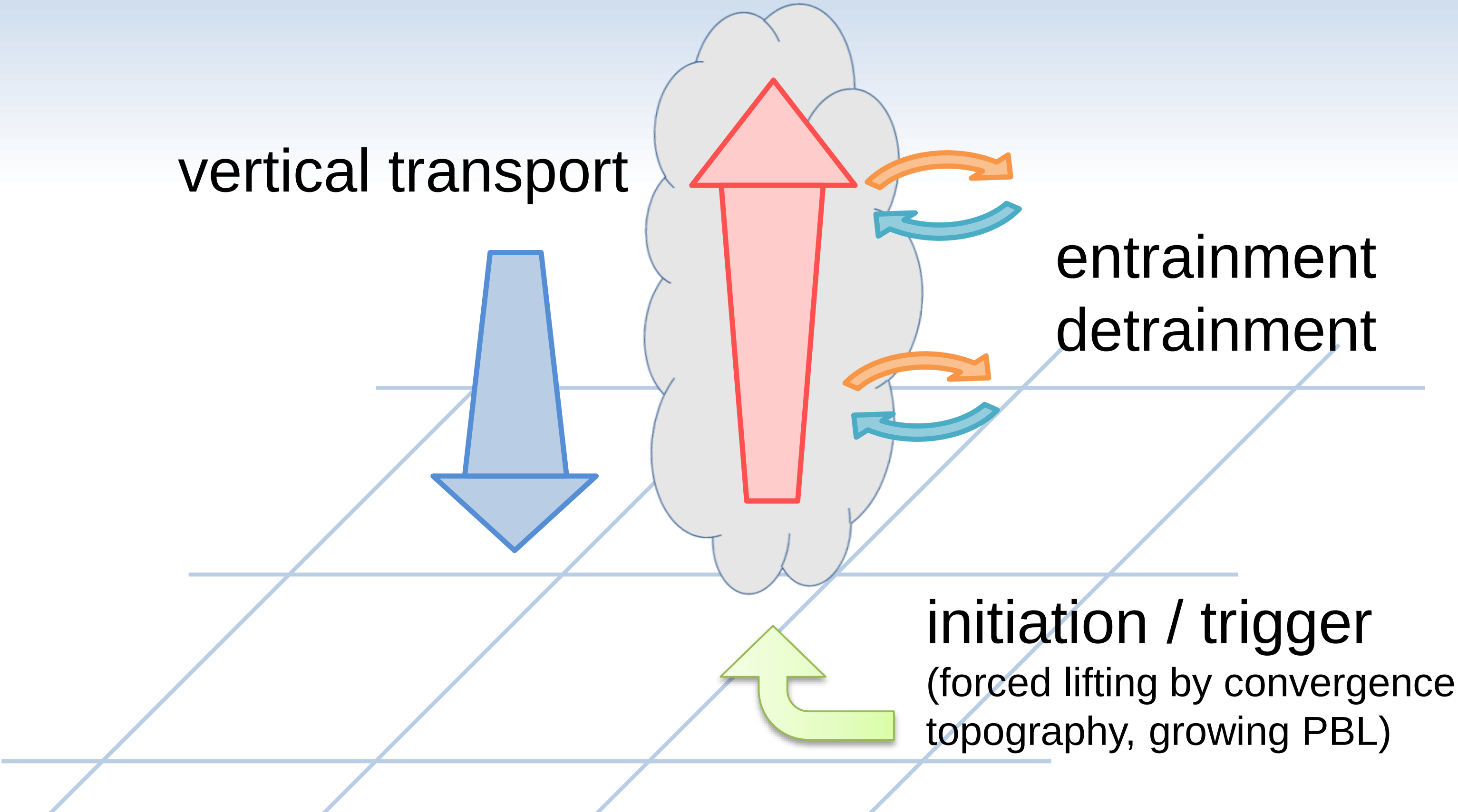
Red bars:Freq. of obs.

over 10mm/h



Peaks of frequency of the 2-km model forecasts are delayed in comparison with that of observations.

Processes in convection



Vertical transport (updraft and downdraft): Major feedback
Entrainment/Detrainment: contributing to controlling convection

- Driven by small-scale turbulence near “cumulus walls”

If cumulus parameterization is not employed, these phenomena must be resolved using grid-mean values.

Grey Zone in convection

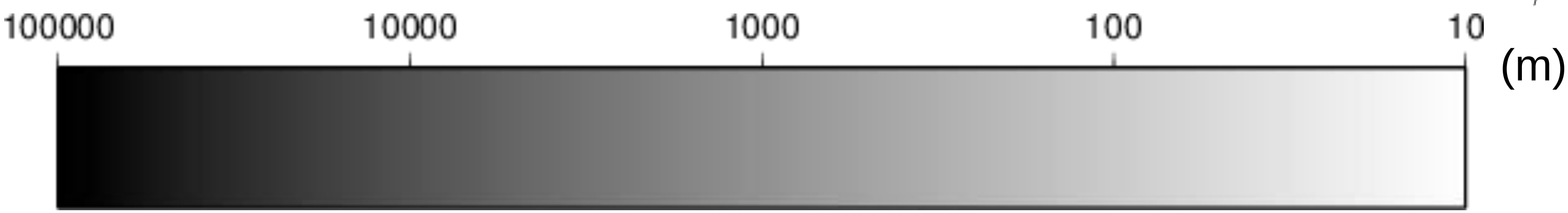
Not represented by grid-mean vertical velocities at all

Mixed resolved and unresolved part of vertical transport

Grid-mean vertical velocities can represent all vertical transport

$$\overline{w\phi} \simeq f'_{w\phi}, \quad \overline{w} \sim 0$$

$$\overline{w\phi} \simeq \overline{w}\,\overline{\phi}, \quad f'_{w\phi} \sim 0$$



All transport should be parameterized

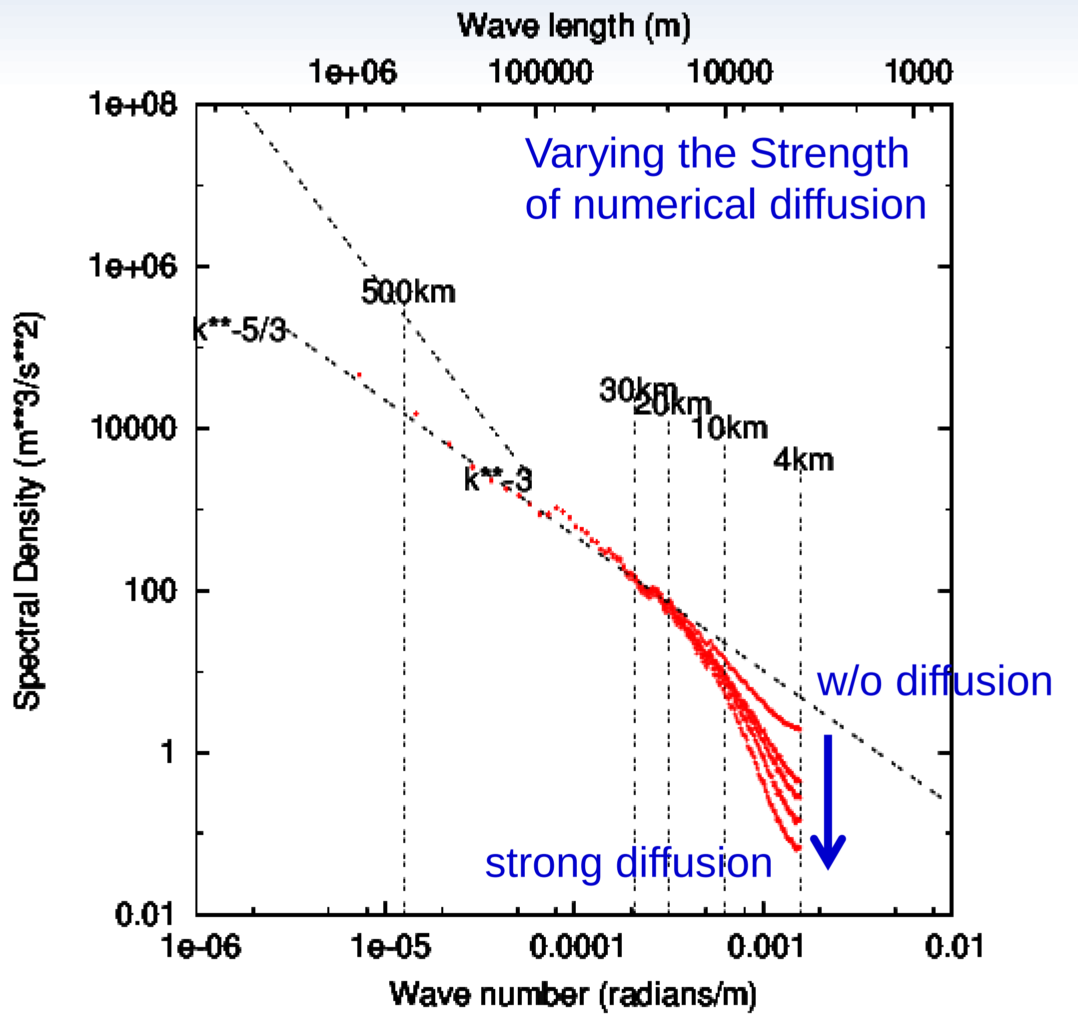
New Parameterization for partially unresolved transport considering resolved part is required

No parameterizations are necessary

Need to parameterize unresolved convective initiation and entrainment/detrainment

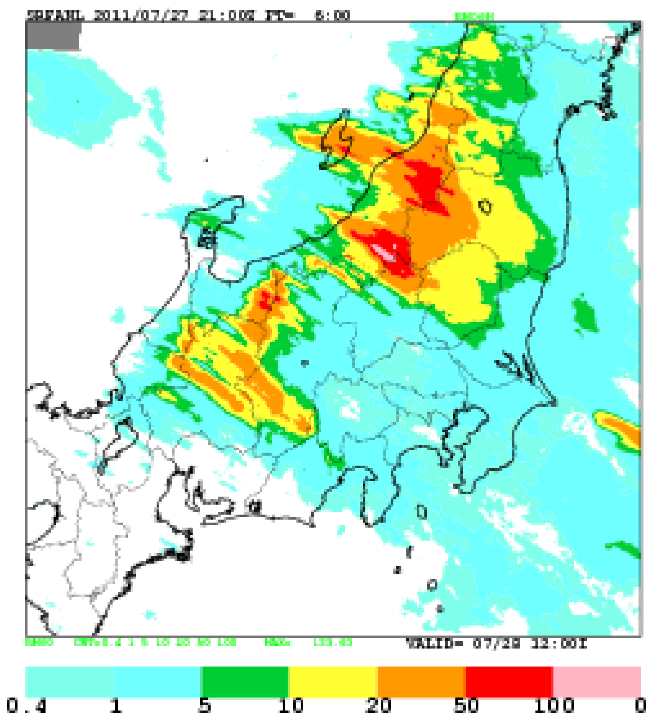
Convective Initiation and its sensitivity to small scale modes

- Unresolved small scale (high frequency) modes should be removed, usually by adding numerical diffusion.
- As just an experiment, the strength of numerical diffusion is changed to see sensitivity of convective initiation to small scale modes.

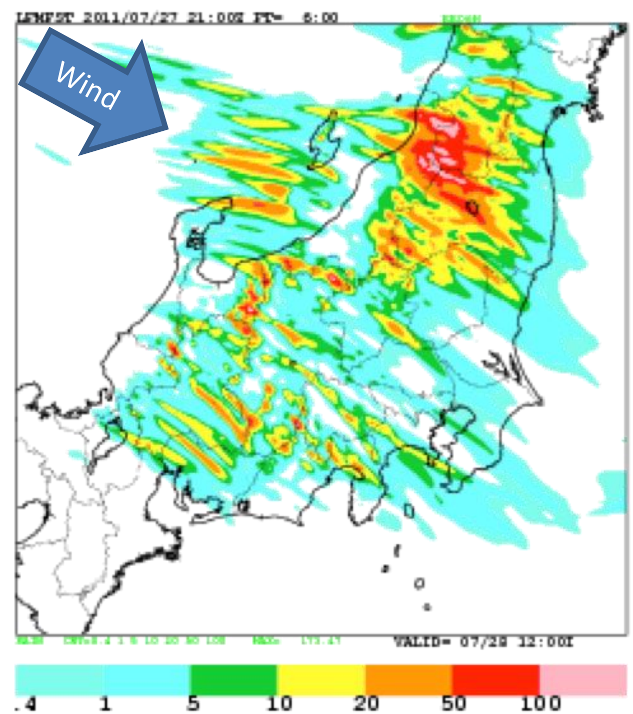


Sensitivity to numerical diffusion

small modes well suppressed with strong numerical diffusions



Obs.

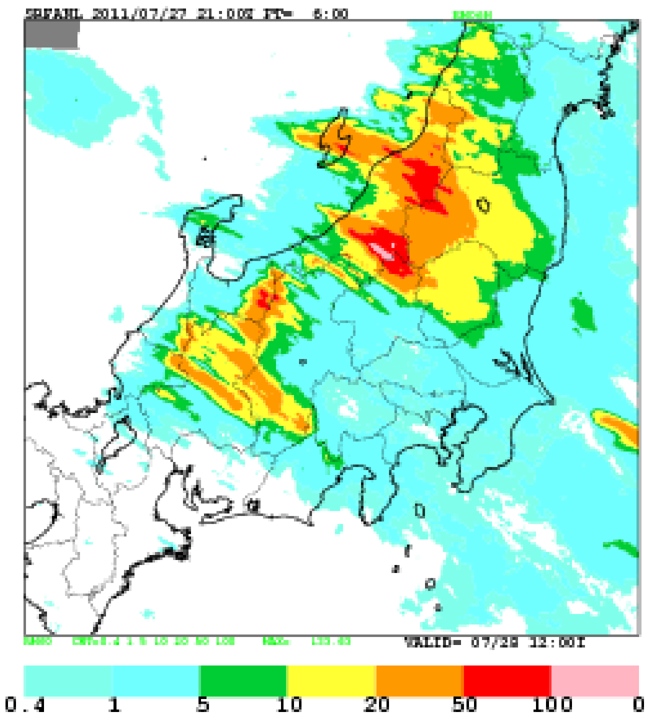


Model with
tau = 60 sec

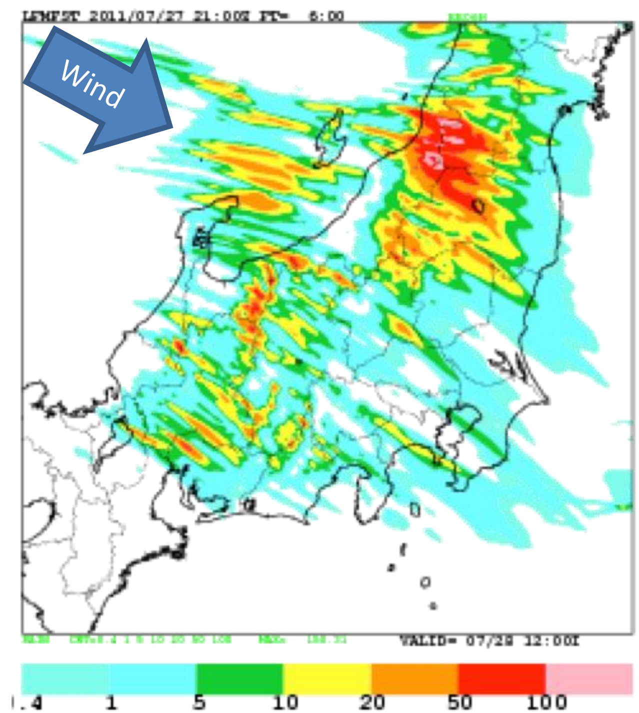
Sensitivity to numerical diffusion

little more small modes (less numerical diffusion)

6-hr accumulated precipitation amount



Obs.

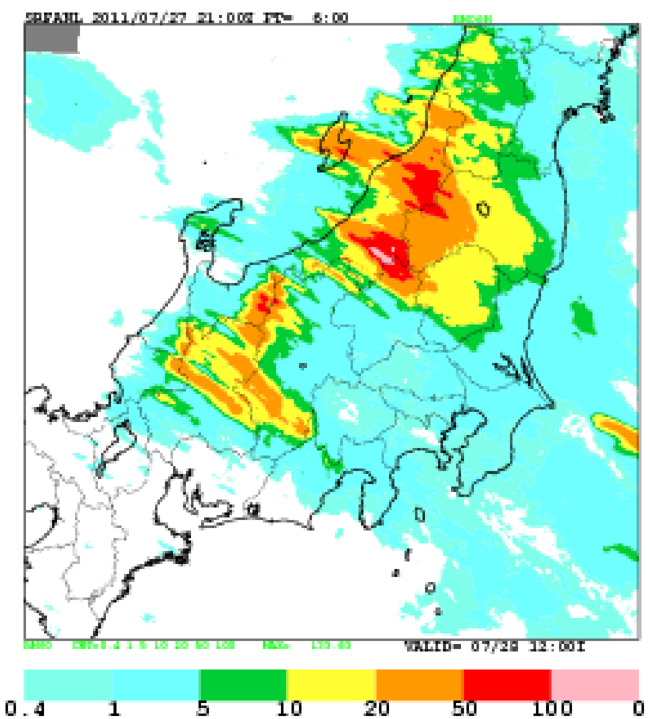


Model with
tau = 120 sec

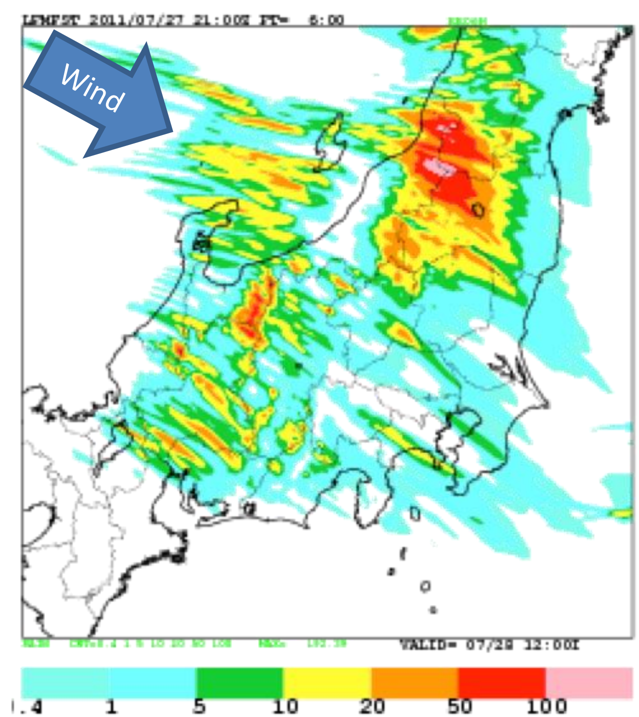
Sensitivity to numerical diffusion

more small modes

6-hr accumulated precipitation amount



Obs.

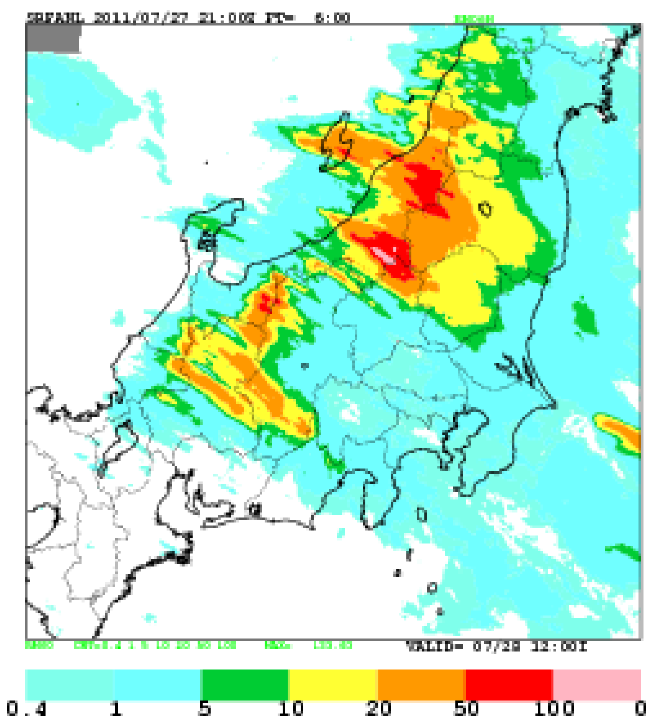


Model with
tau = 240 sec

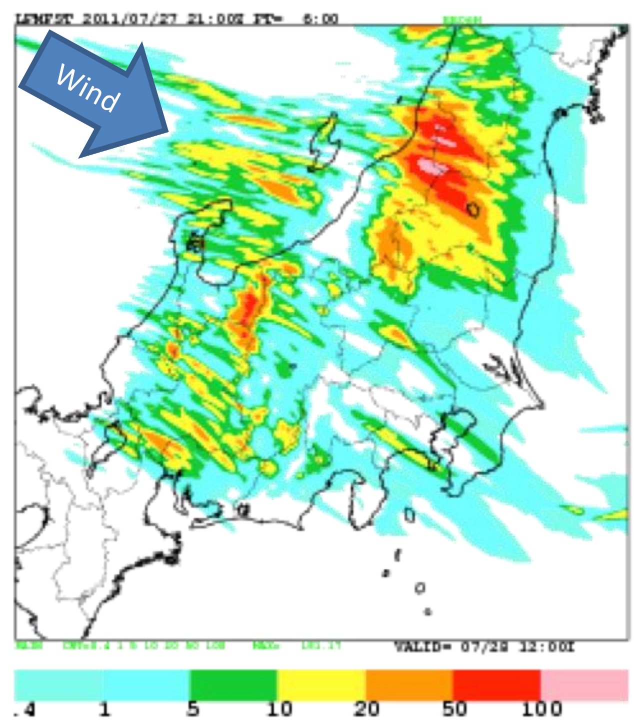
Sensitivity to numerical diffusion

more and mode small modes

6-hr accumulated precipitation amount



Obs.

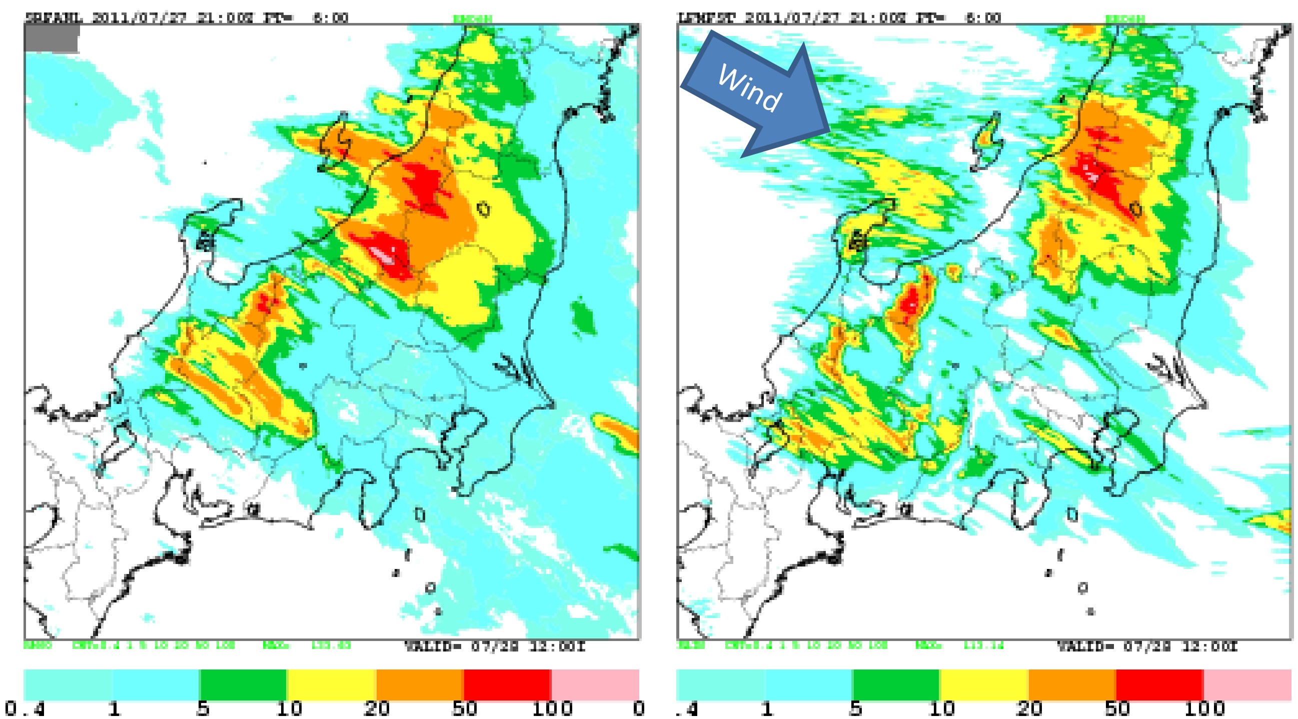


Model with
tau = 480 sec

Sensitivity to numerical diffusion

no numerical diffusion

As small modes are added more, convective cells are shifted to more upstream side, meaning that the small scale modes initiate convections.



Obs.

Model with
no num. diff.

Better than others?

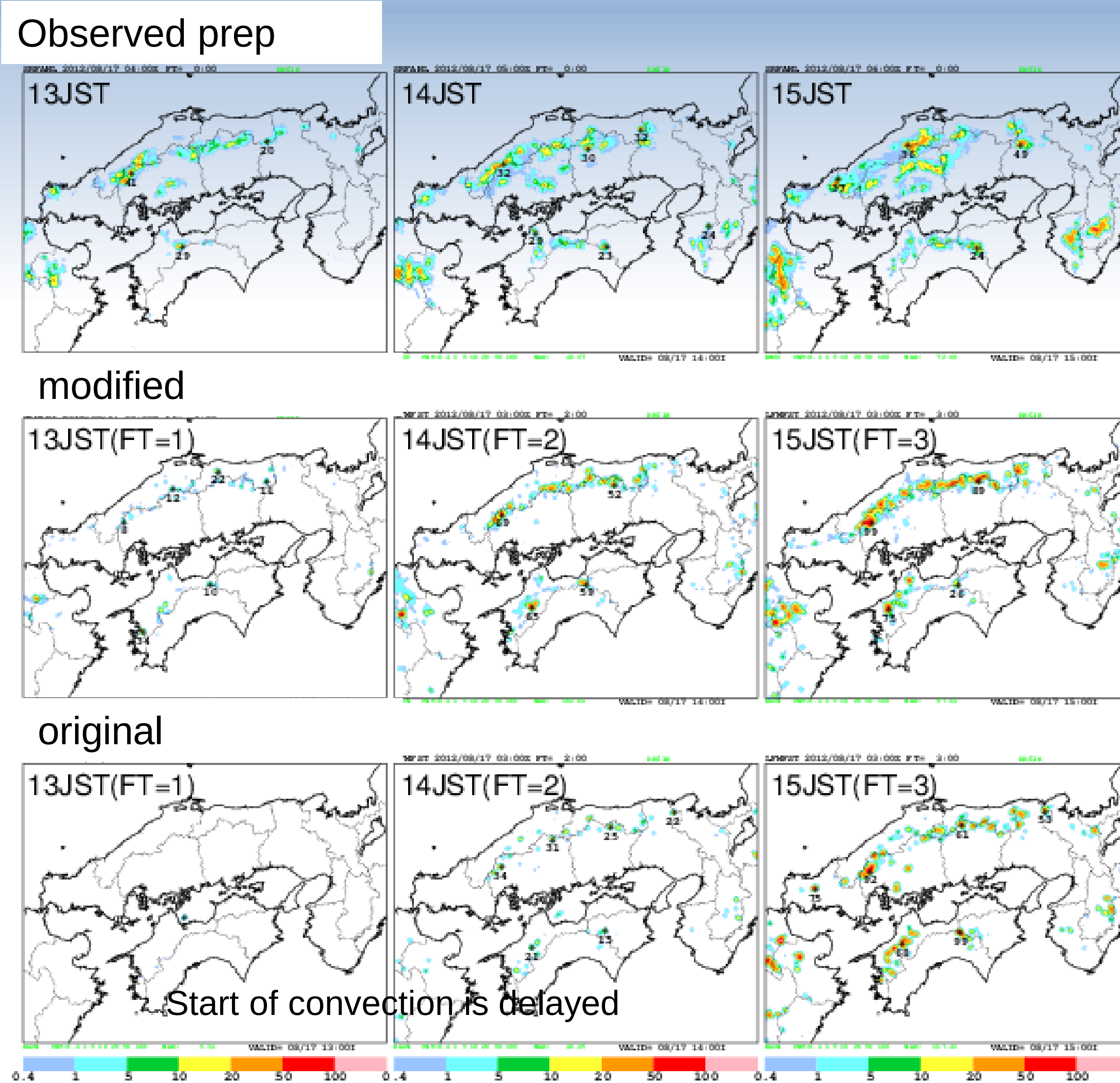
Convective Initiation

- Convective initiation is highly related to unresolved small-scale modes.
  - Physically, the small-scale modes can correspond to phenomena leading to convective initiation such as convergence, topography effects, and growing boundary layer, which are often smaller than resolvable scale.
- These unresolved phenomena associated with convective initiation should be parameterized because dynamics cannot resolve them.
  - Note that the parameterization depends on dynamical scheme.

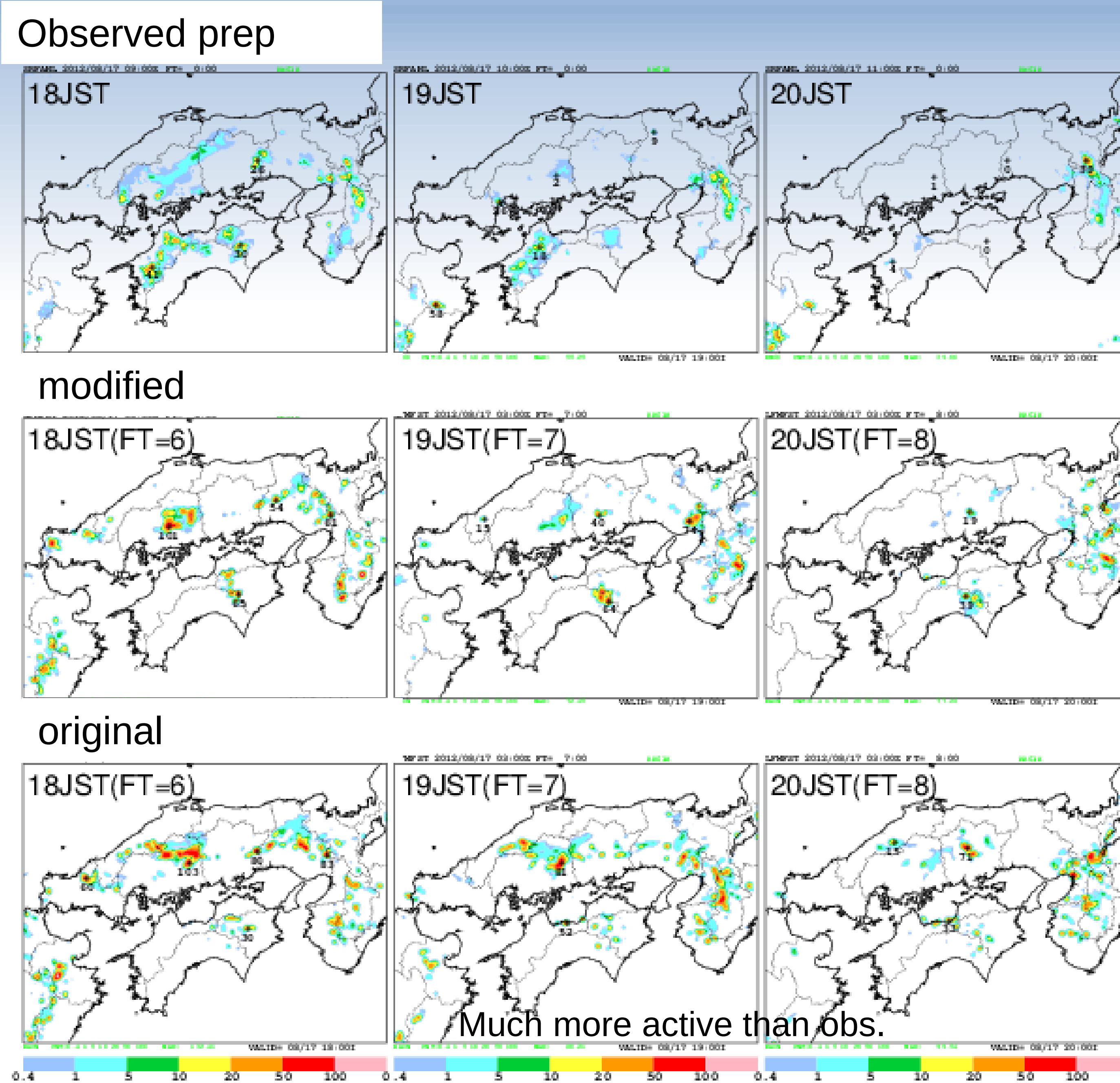
To overcome the delay of convective initiation

- Introduced a weakly activated cumulus parameterization.
  - the convection scheme used in the 5-km operational model, but with a longer timescale in the CAPE closure.
- Effects of the parameterization and processes
  - At the initiation stage, if the dynamics does not produce updraft due to convection even with unstably stratified layer realized, the parameterization is activated and modifies layer stratification by weakly transporting heat and moisture vertically and releasing latent heat through phase transition of water, resulting in producing local low pressure area.
  - Once such local low pressure area is generated, the dynamics of the model calculates convergence into the low pressure area and promotes development of convection.
  - Because it acts very weakly, the parameterization just helps dynamics foster convective system.

Forecast examples at the initiation stage



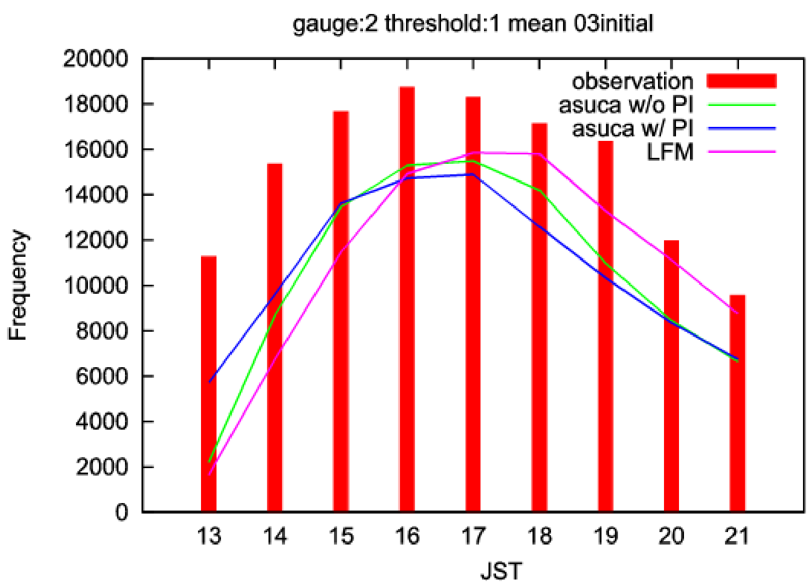
Forecast examples at the ending stage



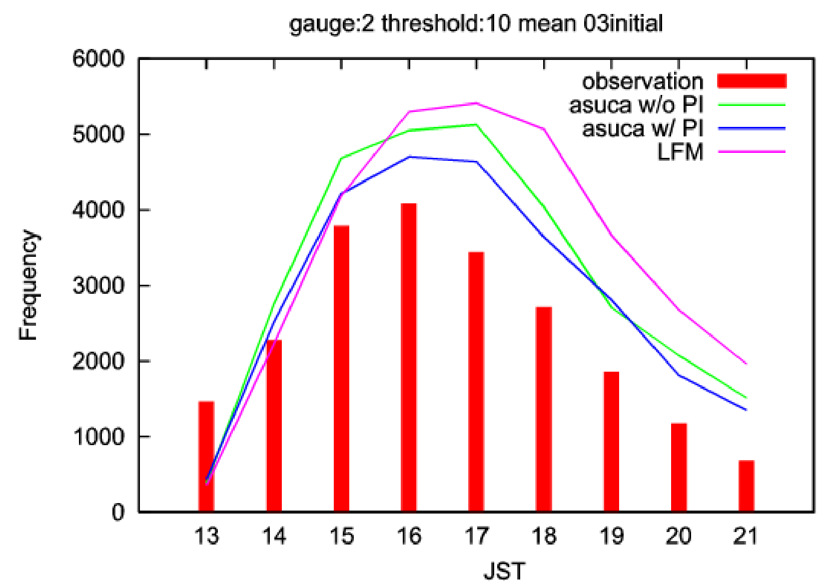
Time series of precipitation frequency

- Red bars: observation
- Pink lines : the previous operational model
- Green lines: the new operational mode but w/o the parameterization for initiation
- Blue Lines: the modified model with the parameterization for initiation

over 1mm/h

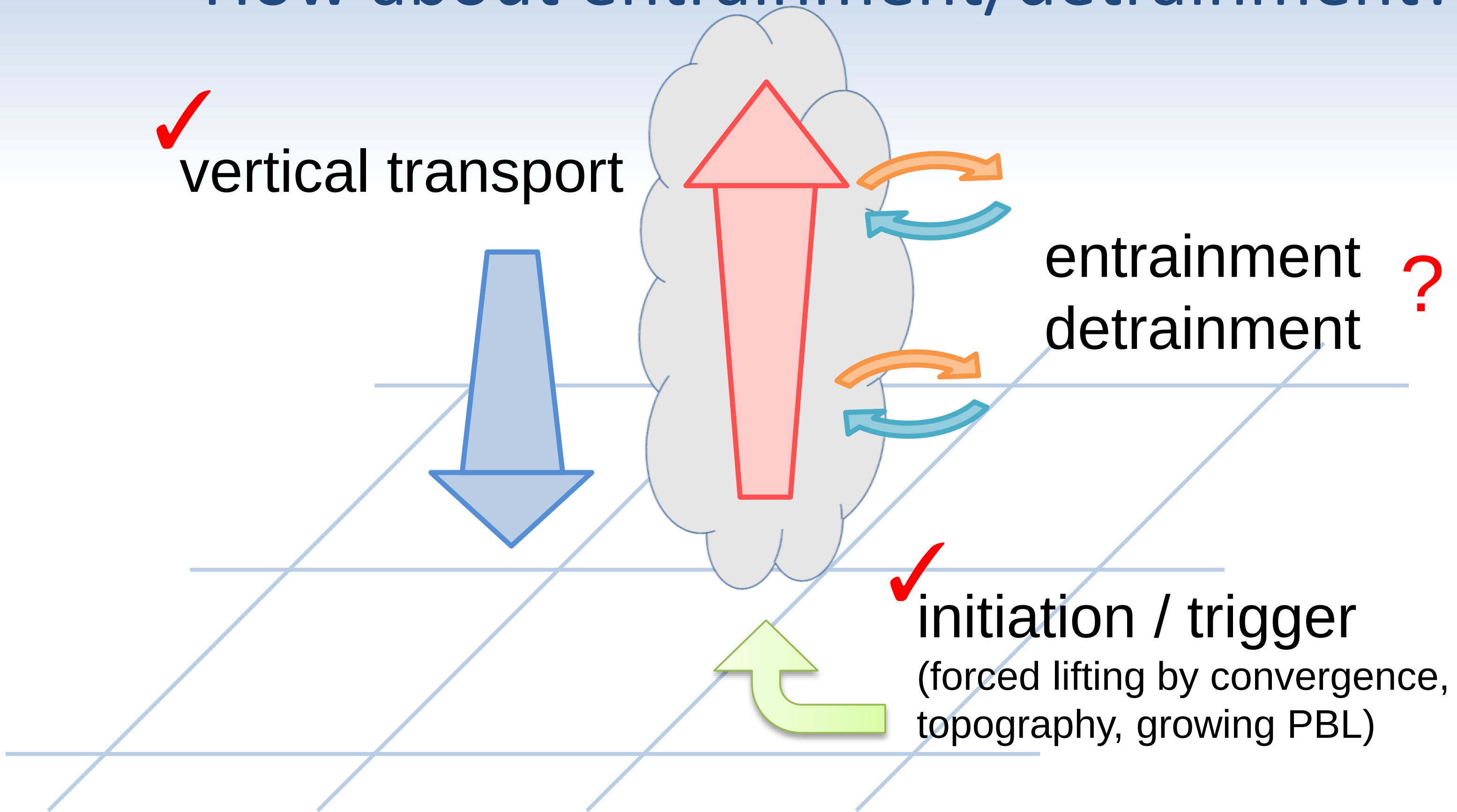


over 10mm/h



By employing the parameterization, peaks of frequency almost coincide with observed ones, though frequency of prep >= 1mm/h is still too low and that of prep >=10mm/h is still too high

Processes in convection
How about entrainment/detrainment?

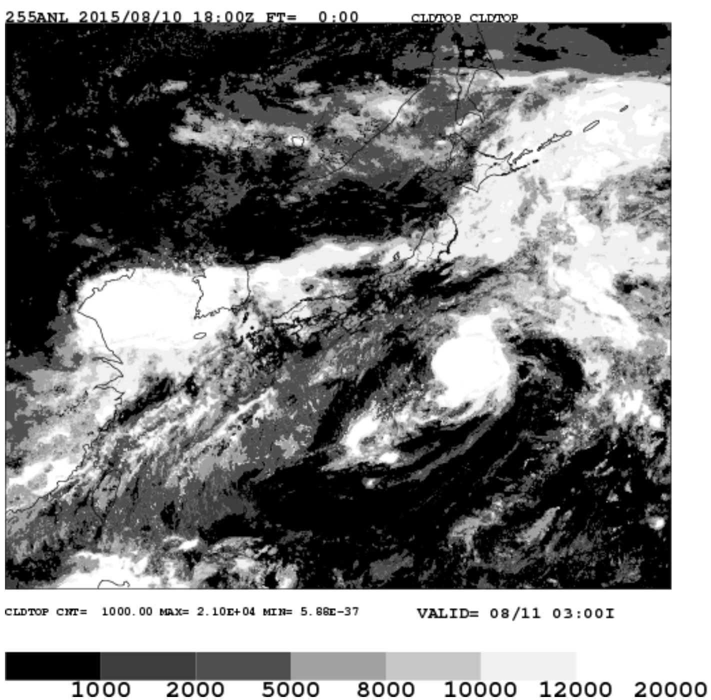


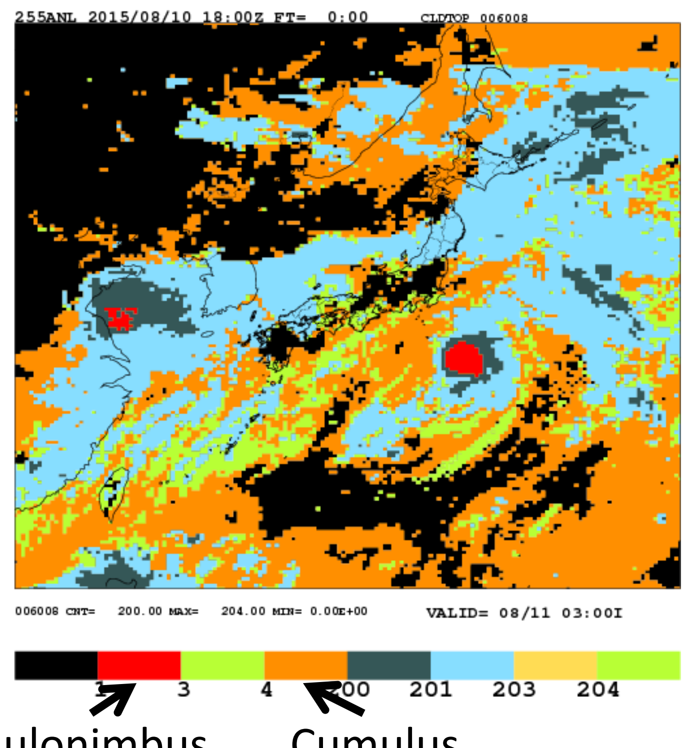
If effects of entrainment are insufficient, convection would be excessively active.

→Compare cloud top height of predicted cumulus with satellite observations.

Himawari-8 Cloud Top Height Product

- developed by Meteorological Satellite Center in JMA.
  - Estimate of cloud top height(CTH) using Advanced Himawari Imager, radiative transfer model and cloud type product(CT).

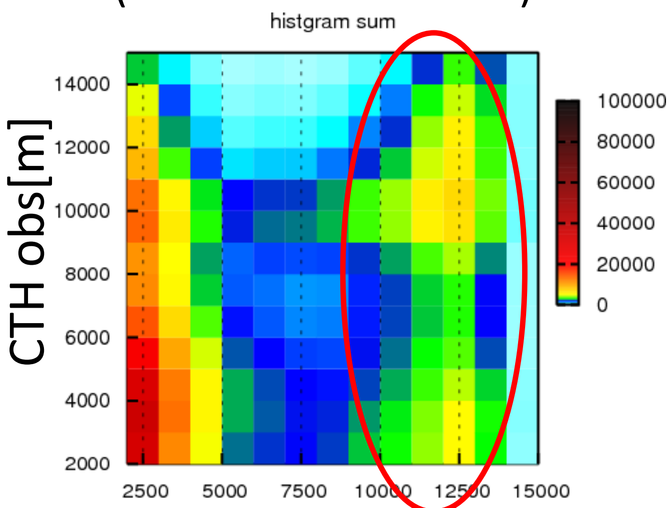




Comparison of cloud top height of cumulus in 2km model with satellite

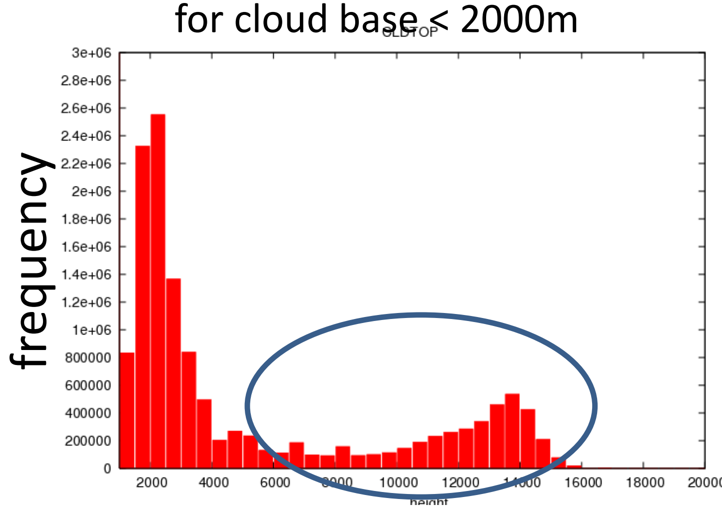
- Not a few cumulus clouds reach tropopause even if observed cloud height does not.

2-D histogram
model vs. satellite obs.
(statistics for 3weeks)



CTH of model[m]
2km resolution model

Frequency distribution of cloud top height in the model:
for cloud base < 2000m



CTH of model [m]

High frequency below 4000m is due to vertical velocity along orography.

Height of cloud top in the model is identified as the height where vertical velocity decreases below 1m/s.

Convection in the 2km resolution model

- Too high cumulus clouds are often predicted.
  - Entrainment/ detrainment might be too weak.
  - Since entrainment/detrainment is driven by small scale turbulence, the 2km resolution model cannot fully resolve entrainment/detrainment by its grid mean value.

Entrainment/detrainment should be still parameterized even if vertical transport is well resolved.

How to do it?

- How about employing horizontal diffusion (based on Smagorinsky etc.)?
  - We tried it, but it did not work well as entrainment / detrainment.
- How is it physically and mathematically formalized?
  - It might depend on horizontal derivative of vertical velocity and/or humidity between grids because they are mainly activated around cumulus walls.
- Alternatively, instead of directly parameterizing mass flux brought by entrainment/detrainment, resulting effects (suppressing vertical velocity, vertical flux, …) could be parameterized.
- Now we are trying ……

Summary

- JMA's 2-km operational high resolution model can predict heavy rain events more realistically, but it suffers from delay of convective initiation and too long convective activities, which are serious problems for forecasters issuing warning for severe weather.
- Unresolved small phenomena is often relevant to convective initiation. The small phenomena related to convective initiation should be parameterized even in 2-km resolution models.
- It has been confirmed that an attempt to parameterize convective initiation improves the delay of convection.
- Parameterizing effects of entrainment/detrainment is necessary, but still challenging.
  - Too high cumulus clouds in the current 2-km model might come from lack of entrainment / detrainment.
  - We need to understand physics of entrainment and detrainment using observation, LES, etc.