第4回超高精度メソスケール気象予測研究会：2014.3.7

下層水蒸気の蓄積過程における水平解像度依存性 ー2012年5月6日つくば竜巻のケースー

Dependency of horizontal resolution on accumulation processes of low-level water vapor - Case study of Tsukuba tornado -

加藤輝之（気象庁 気象研究所）

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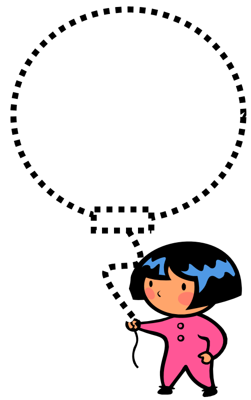
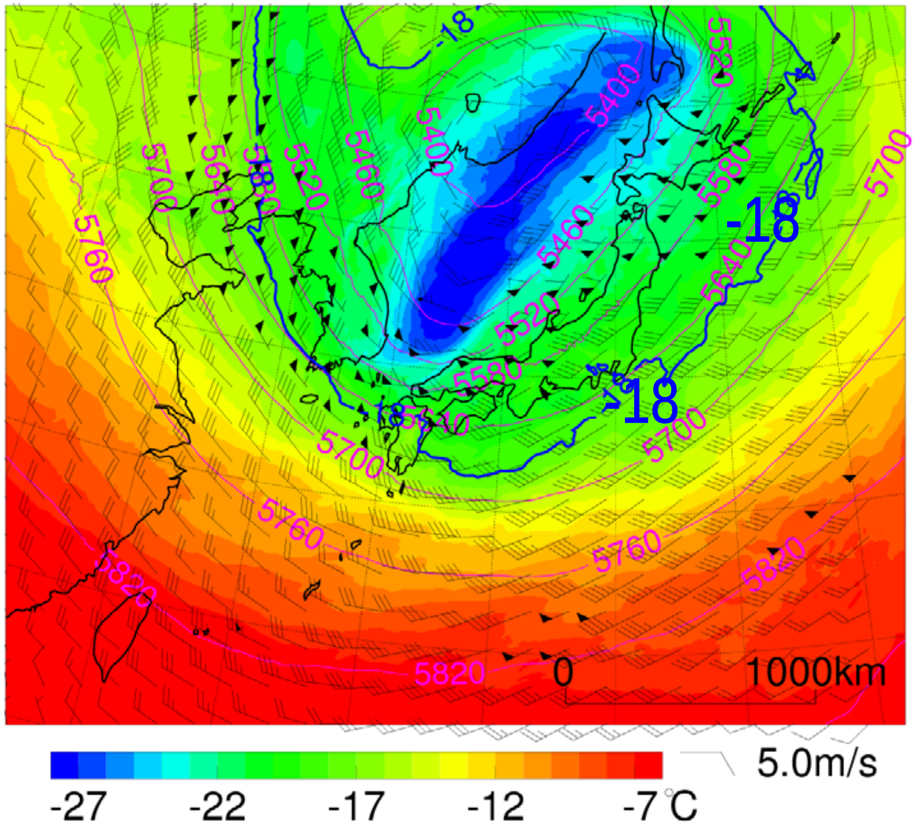


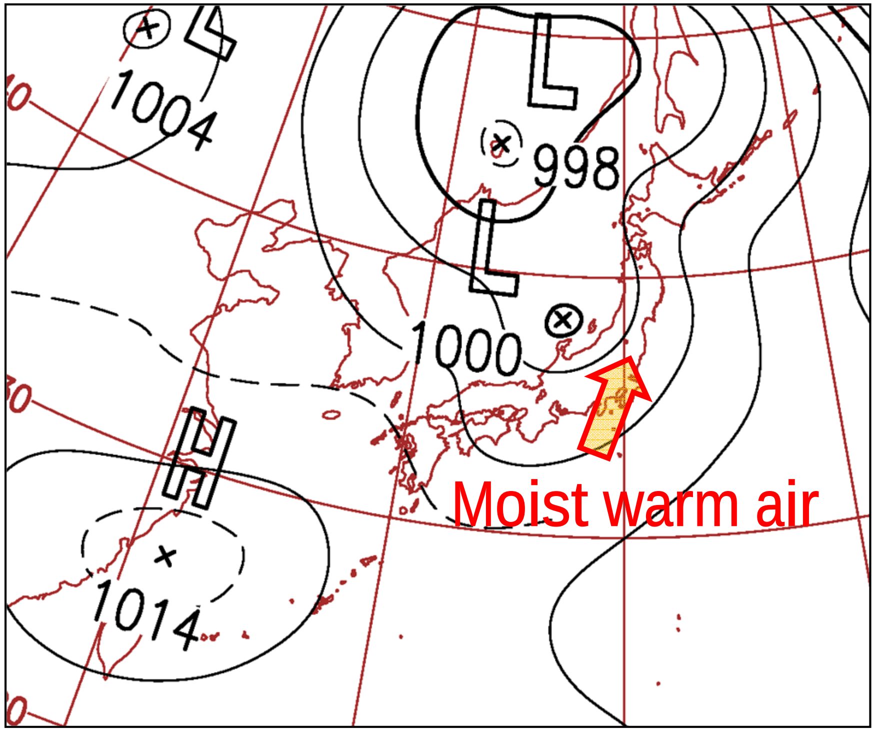
Synoptic situation on 6 May 2012 (Tornado day)

500 hPa temperature: 0900 JST



A cold air-mass with less than -18 degrees in Celsius at 500hPa covered almost the whole area of Japan.

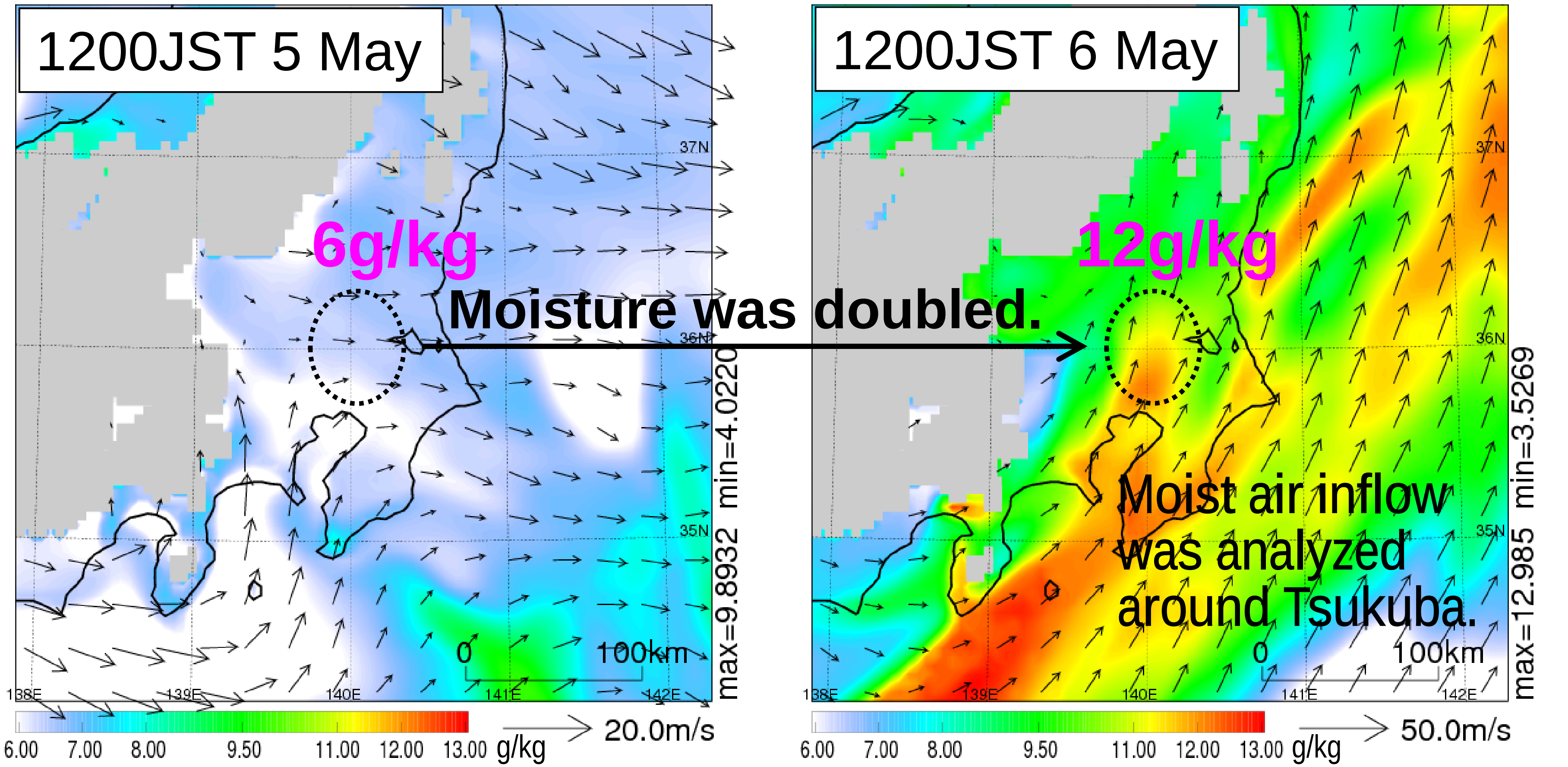
Surface weather map : 0900 JST



Warm moist air flow towards a low-pressure system in the Sea of Japan prevailed in eastern Japan.

Specific humidity at 500 m above sea level

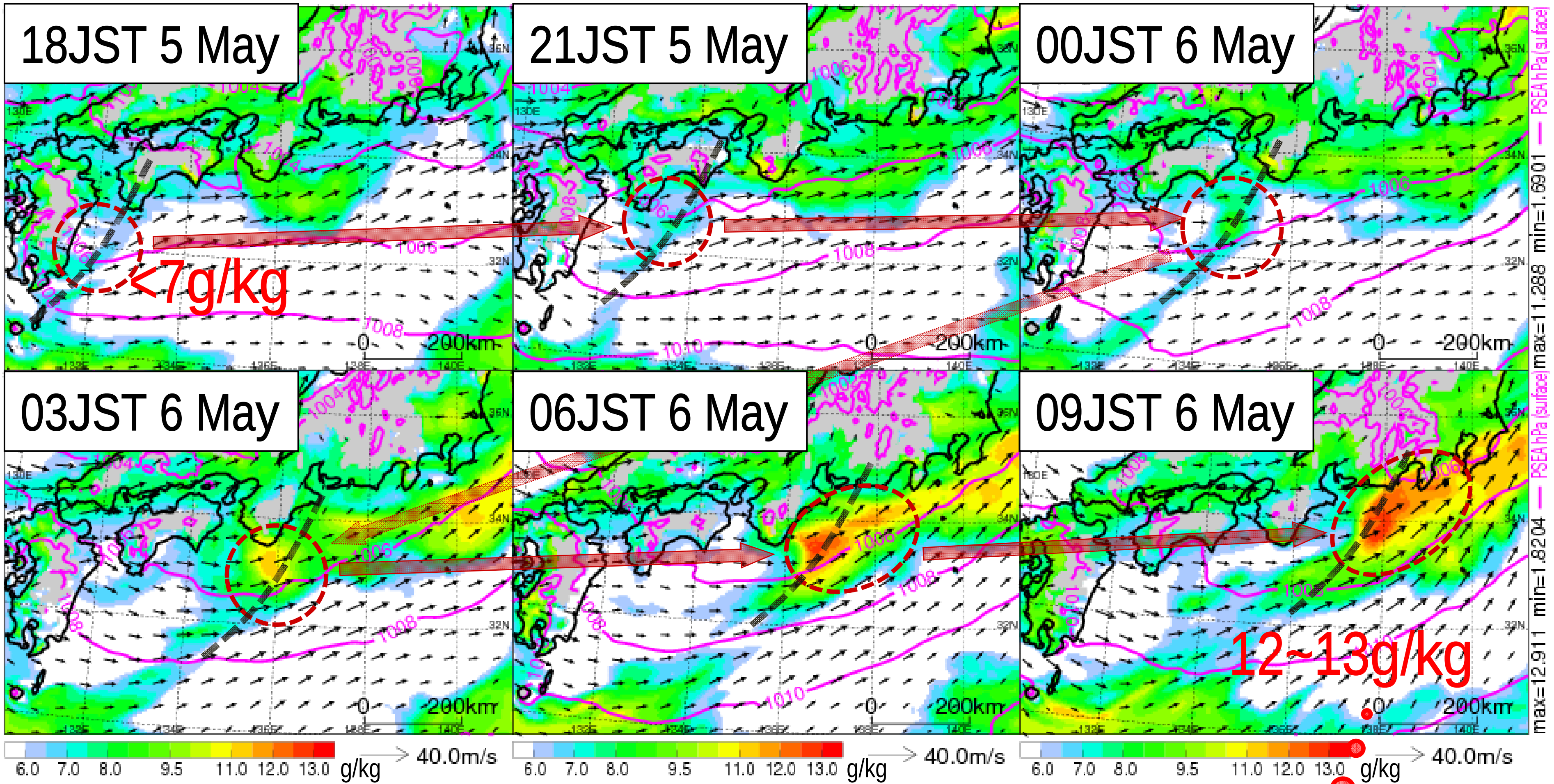
depicted from JMA-MA



1200JST 6 May	Huge water vapor at low levels made favorable conditions for initiation and development of deep convection.

Time change of 500m-height specific humidity

depicted from JMA-MA



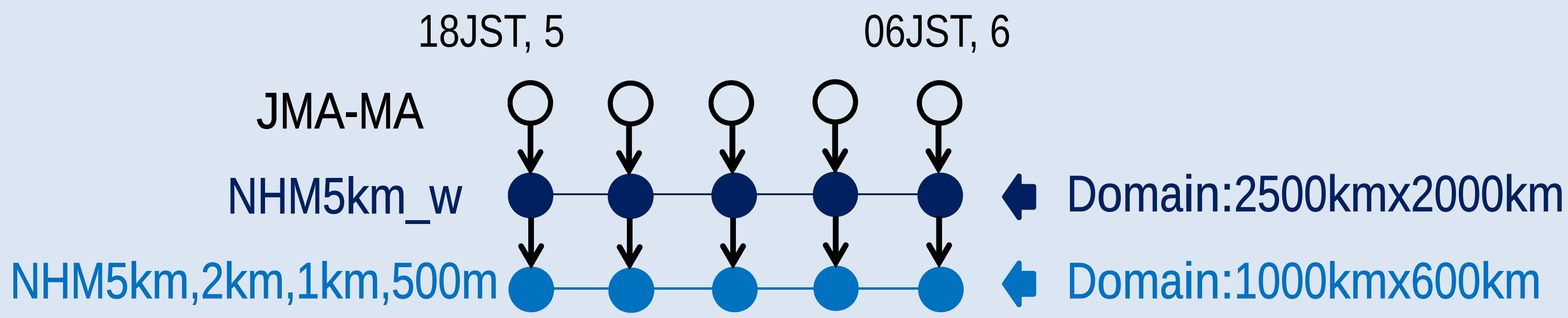
Moist air was produced associated with low-level trough travelling eastward over the ocean south of the Japanese Islands, and it flowed into Kanto Area.

Almost doubled

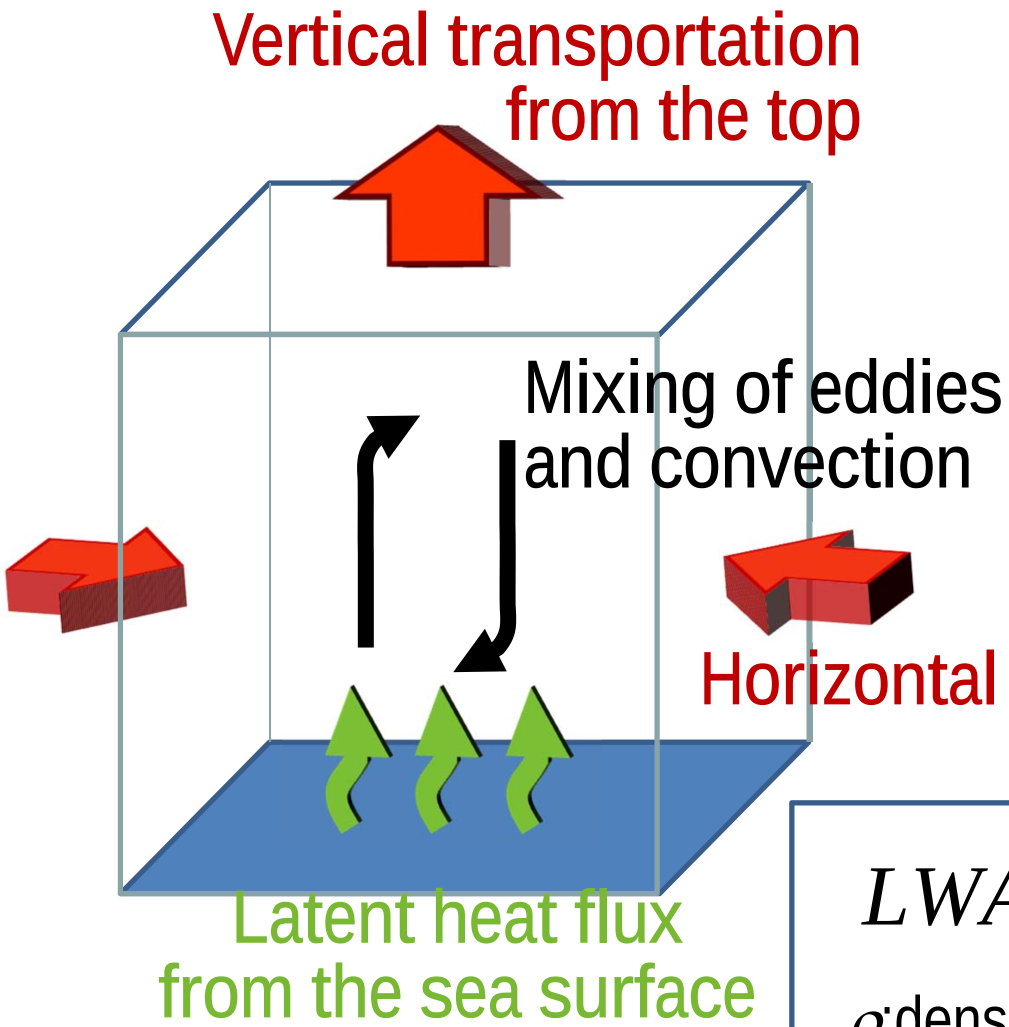
Numerical model and experimental design

Model: JMANHM (Saito et al. 2006)

Dynamics:	Fully compressible equations with a map factor
Cloud physics:	Bulk-type with six water species (qv, qc, qr, qi, qs, qg)
Convection:	Kain and Fritsch (1990) Only in 5km model
Turbulence:	MYNN (Nakanishi and Niino 2006), Deardroff (DD, 1980)
Surface flux:	Beljaars and Holtslag (1991)
Horizontal grid:	5km（MYNN), 2km（MYNN), 1km（MYNN,DD), 500m（DD)
Vertical layer:	50 layers（6 layers below 500m, model top:21.8km）
Initial/boundary:	JMA-MA adopting a 4DVAR assimilation system



Accumulation processes of low-level water vapor



Other processes:

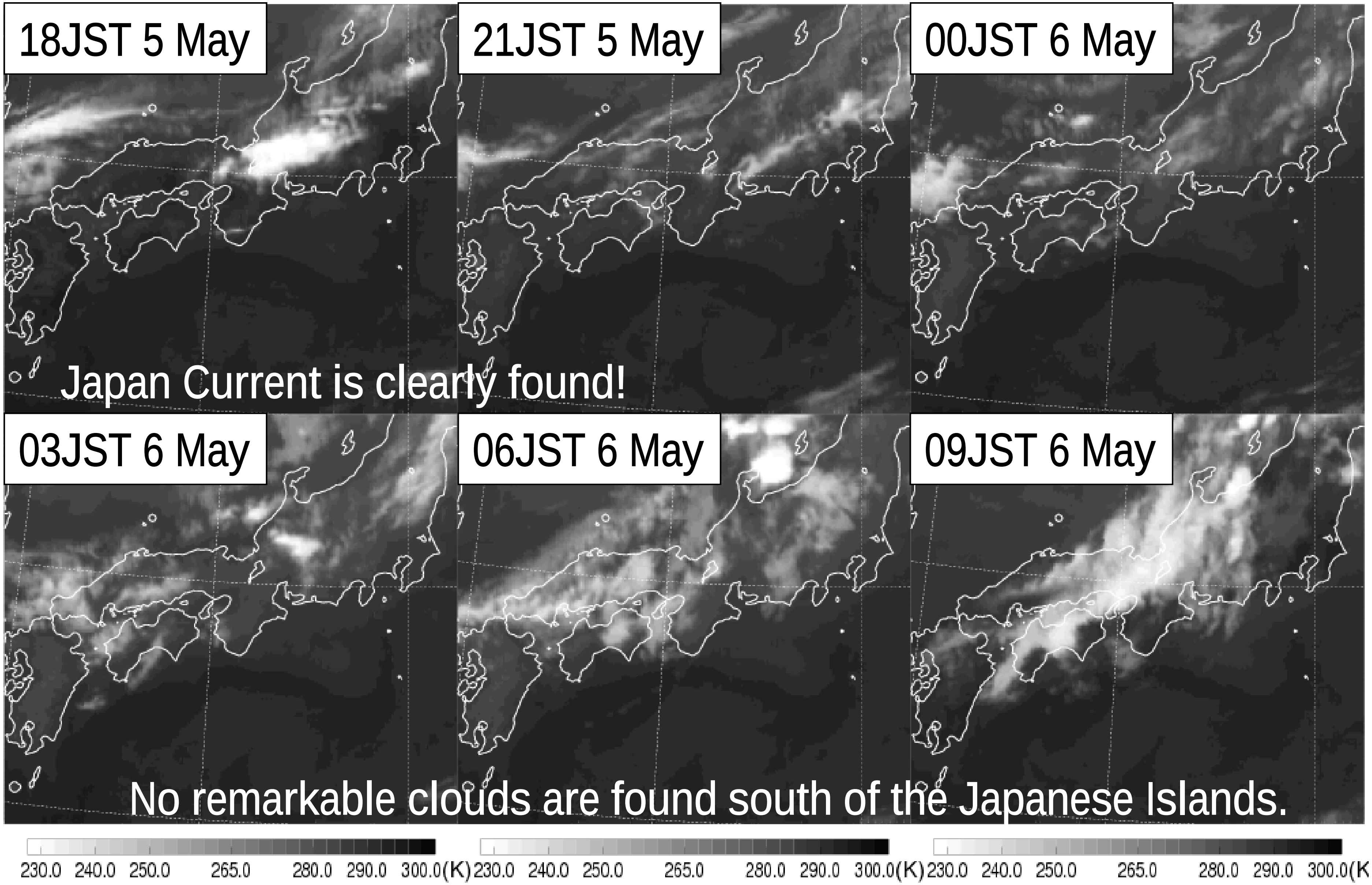
- Decrease due to condensation (product of clouds)
- Increase due to evaporation of raindrops

$$LWA = \int_0^{936m} \rho q_v dz$$

ρ:density, q_v: specific humidity

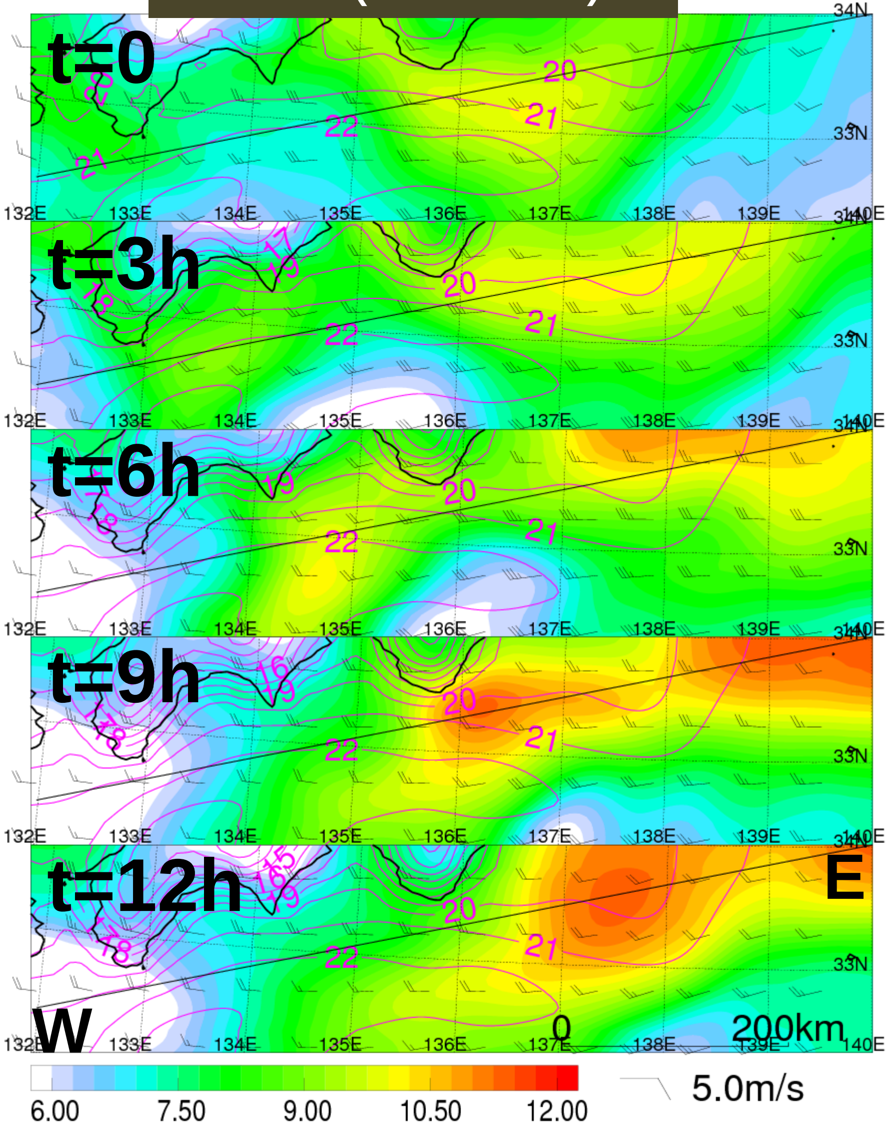
In this study, a budget analysis of *LWA* is made using NHM.

Brightness temperature (IR-image) of MT-SAT

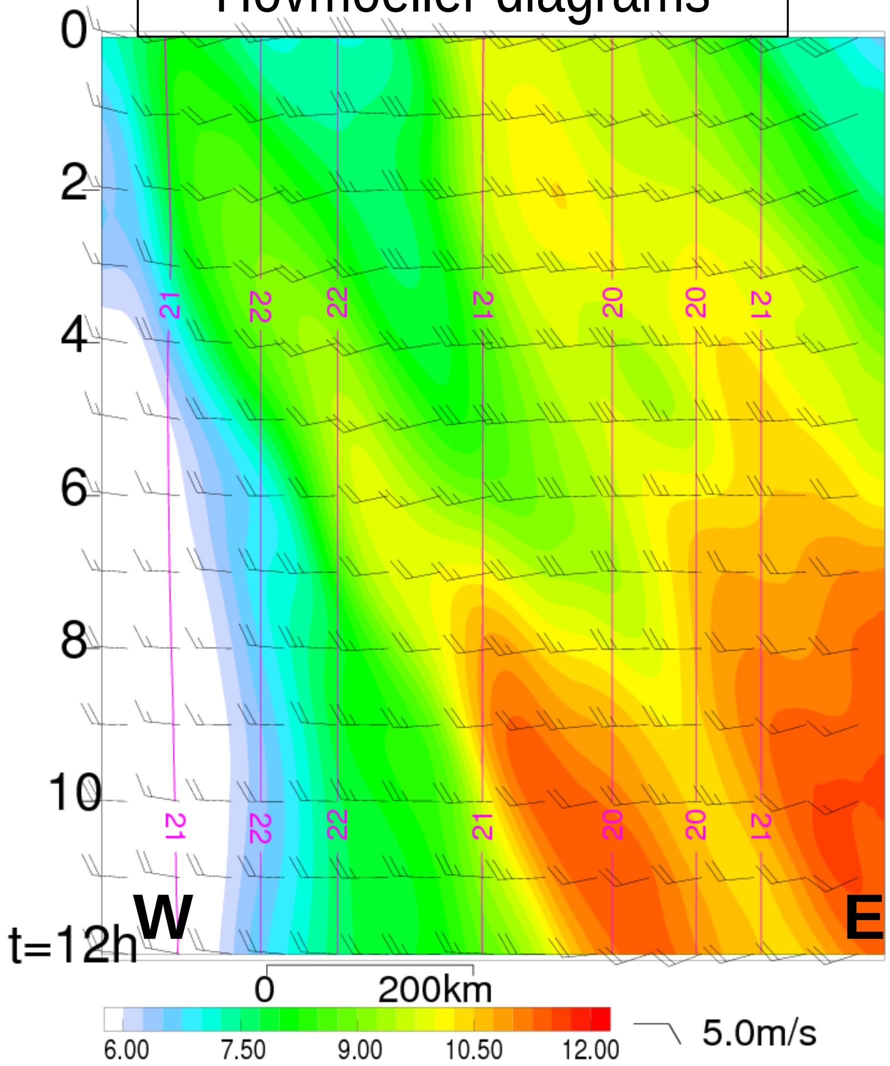


Time change of low-level water vapor amount (5km) -model

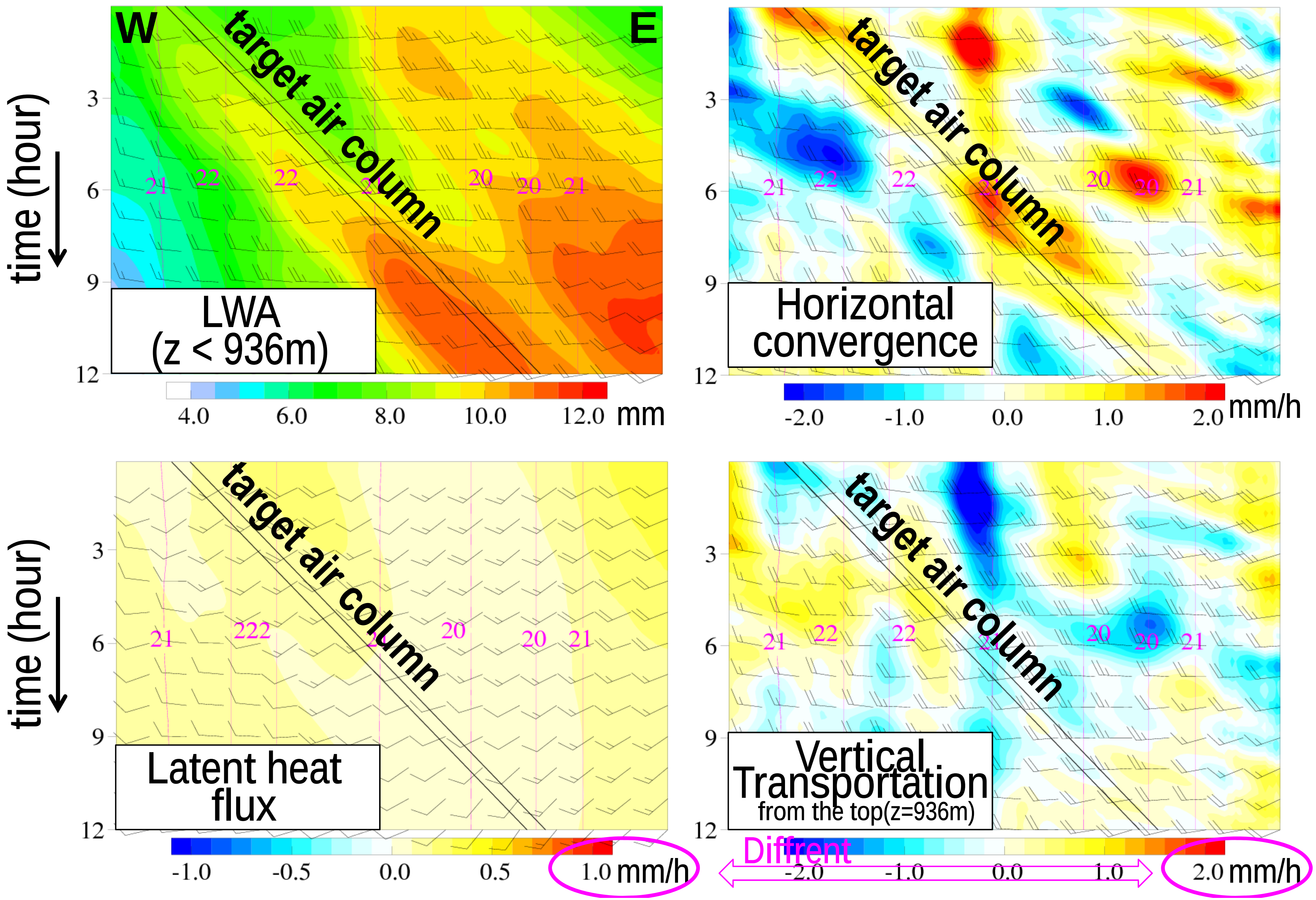
LWA (z < 936m)



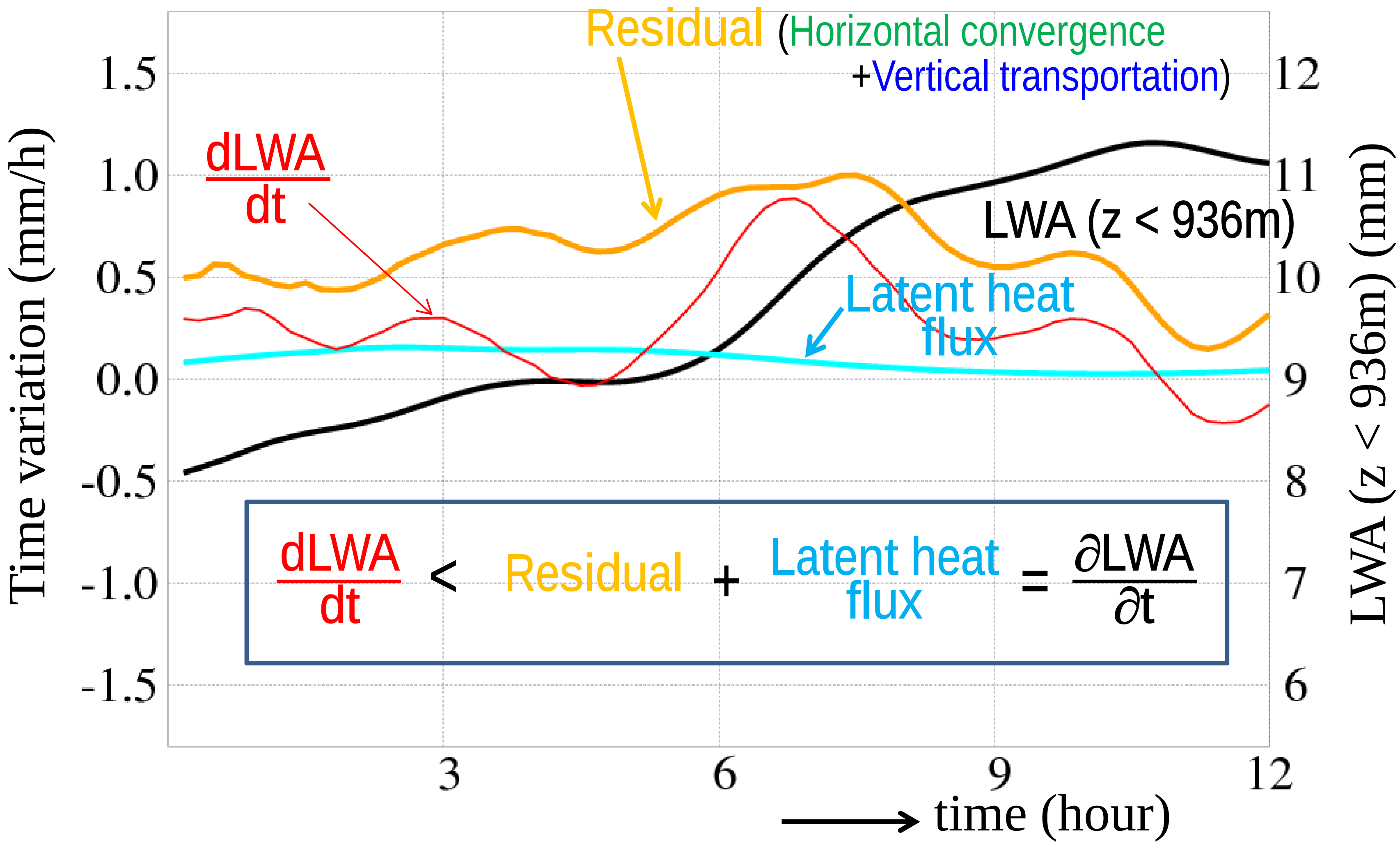
Hovmoeller diagrams



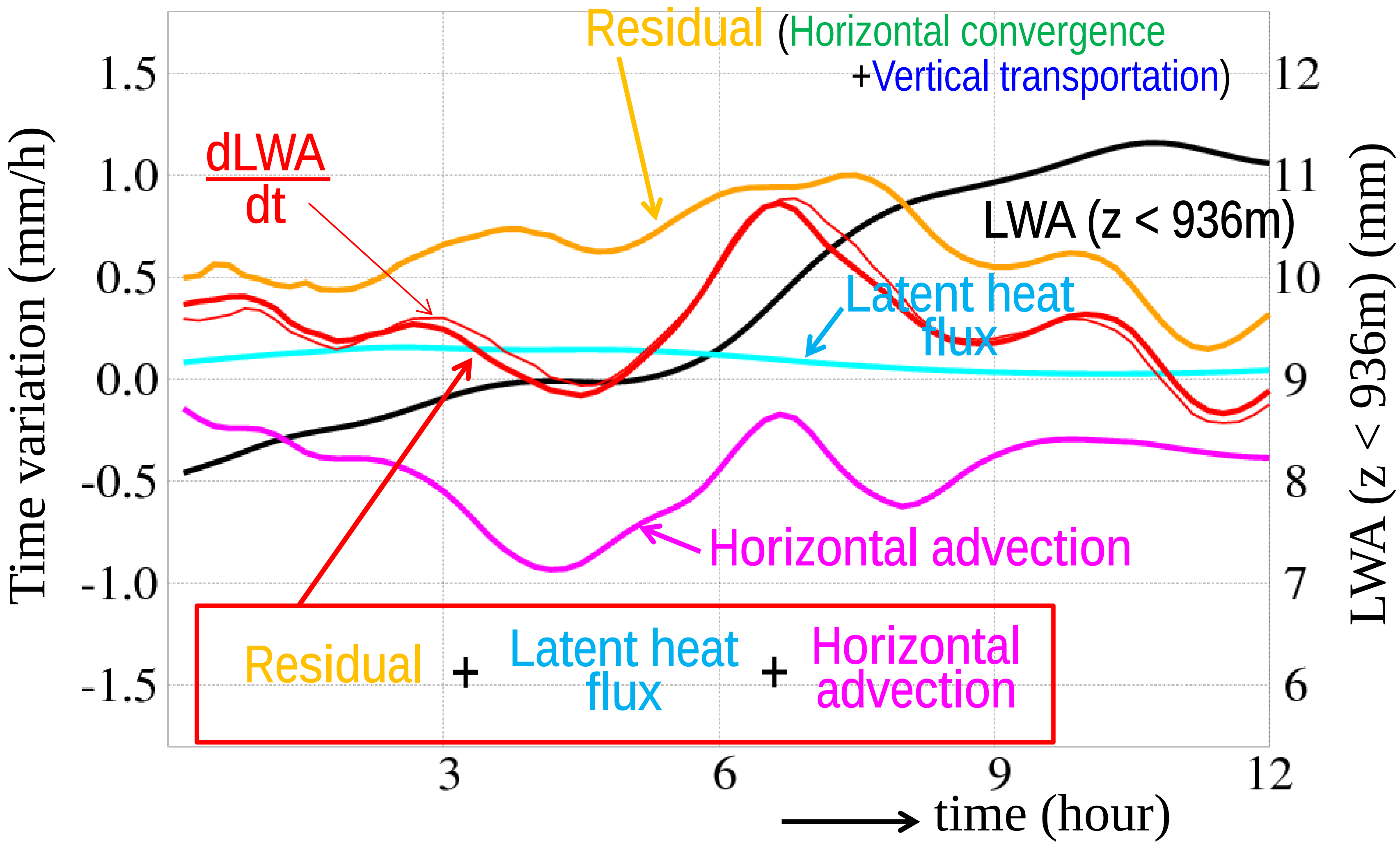
Time change of accumulation processes (5km-model)



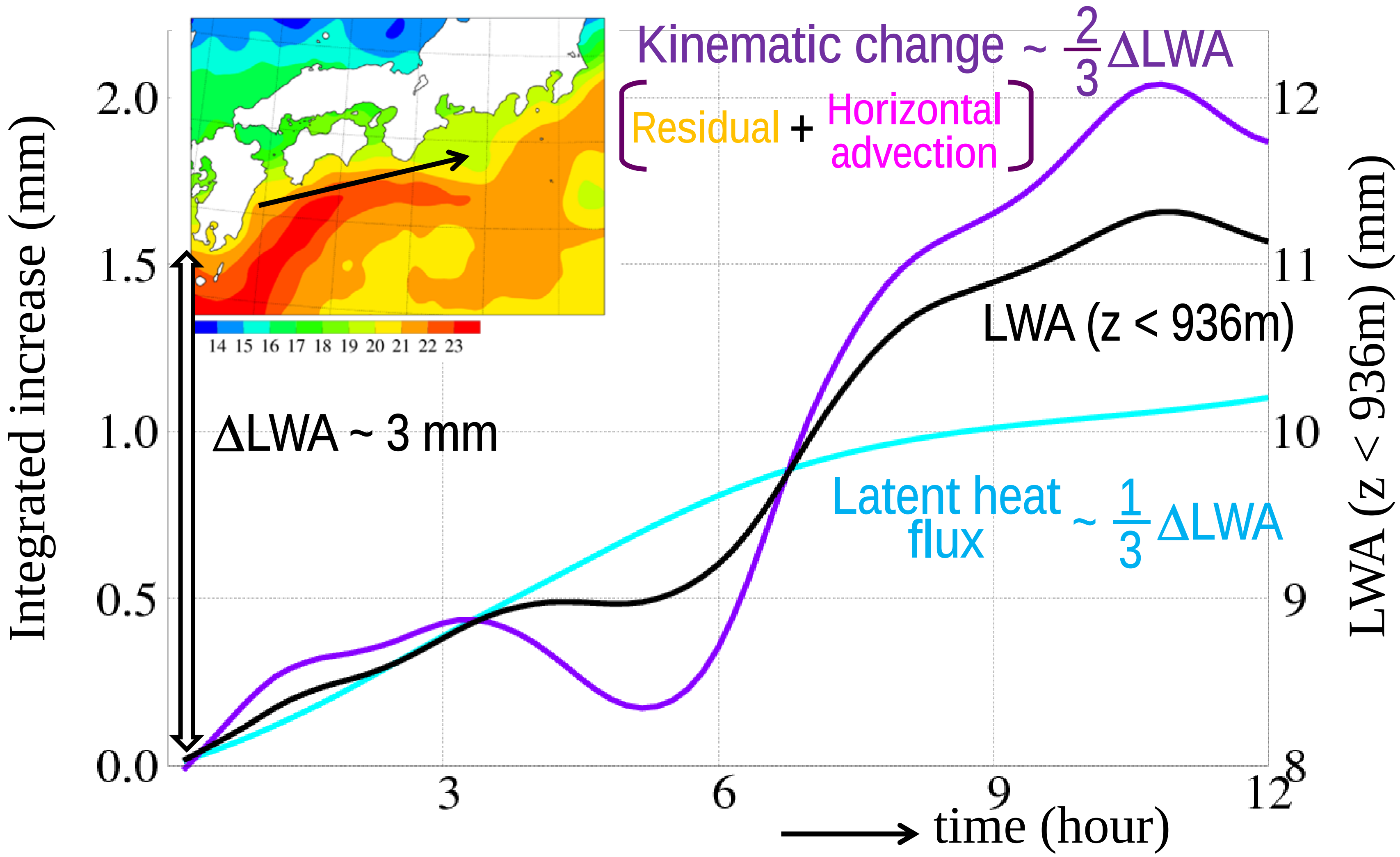
Time change of accumulation processes for target air column (5km-model)



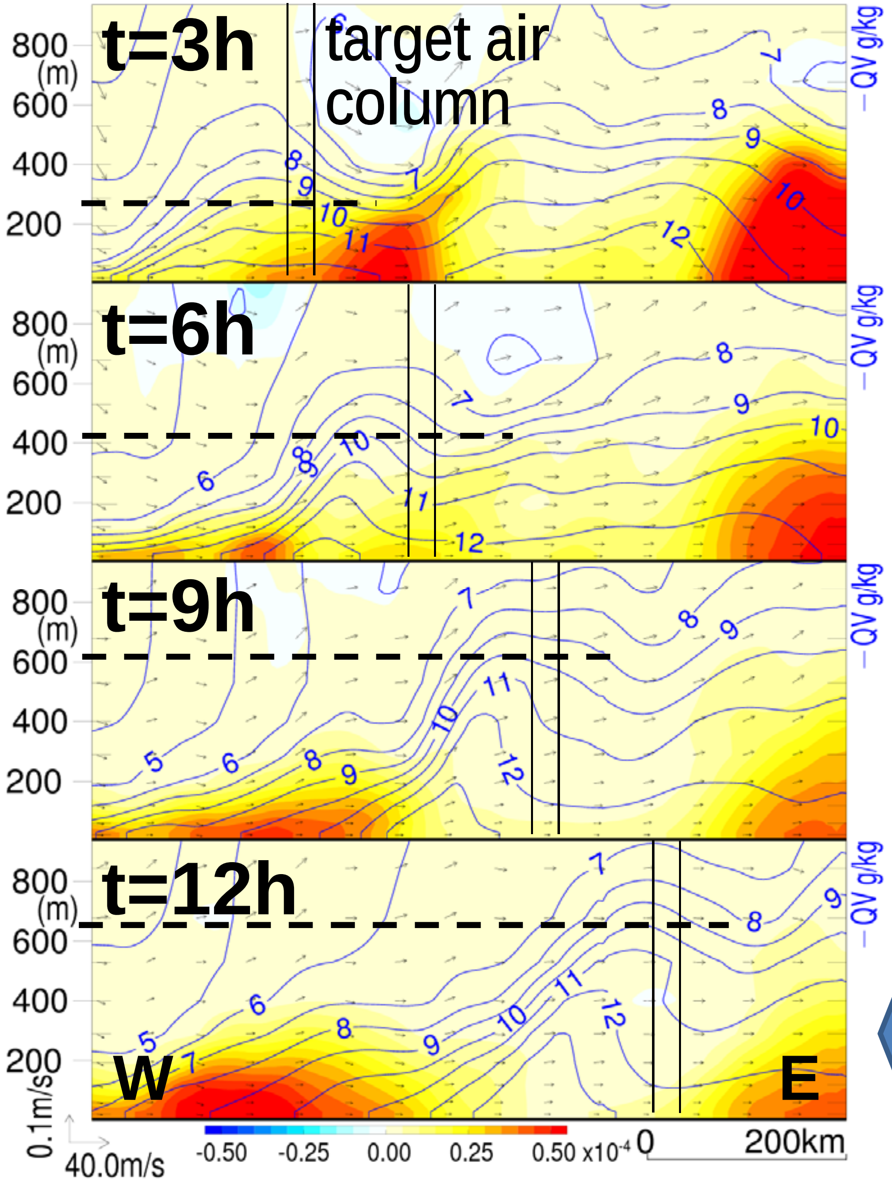
Time change of accumulation processes for target air column (5km-model)



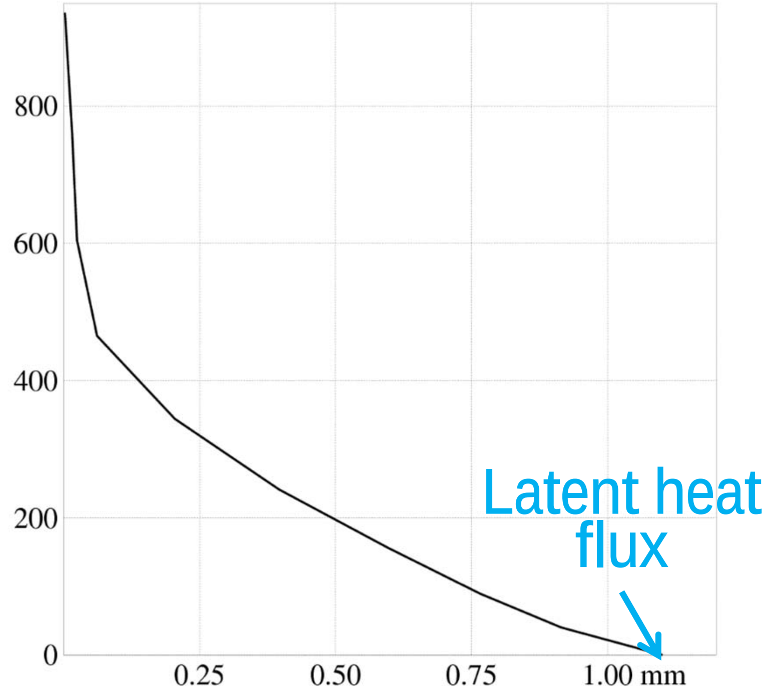
Comparison between integrated increase and LWA for target air column (5km-model)



Sub-grid vertical transportation of water vapor (5km-model)



12 hour integrated amount for target air column

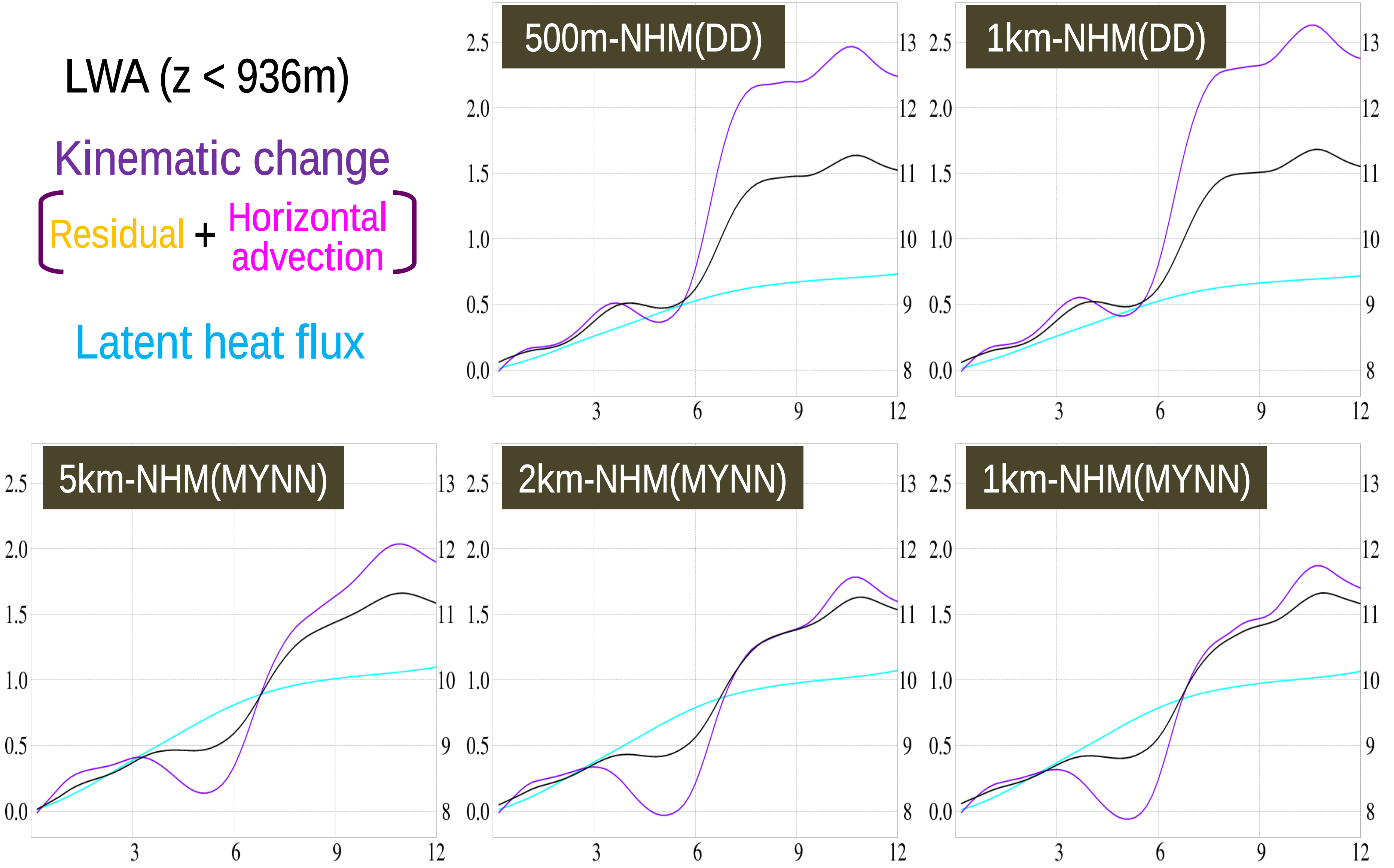


Sub-grid mixing dominates below a height of 500 m.

Depth of humid layer increases with time.

Comparison between integrated increase and LWA

Left axis: Integrated increase(mm/h) Right axis: LWA (z < 936m) (mm)



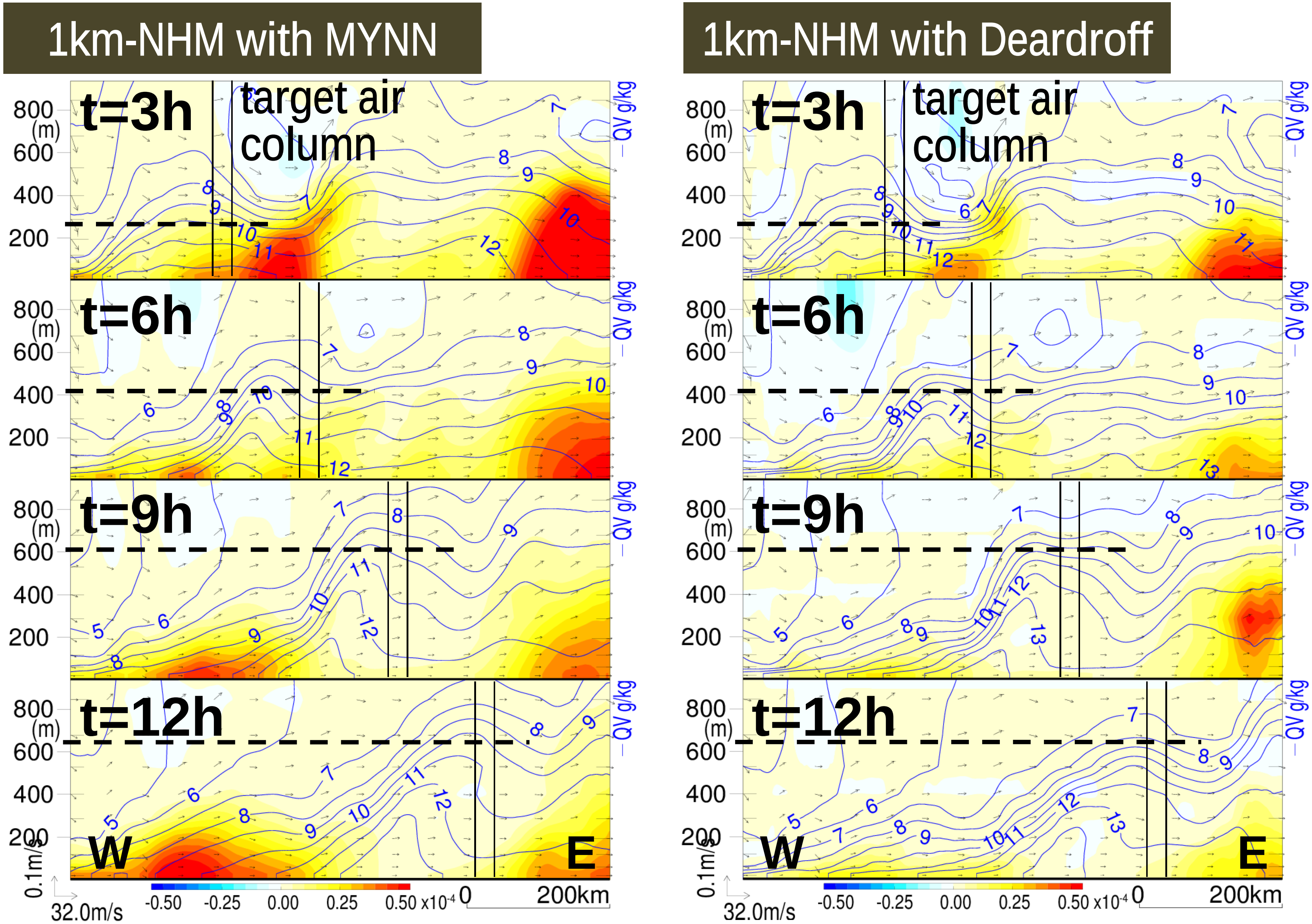
12 hour change of LWA for target air column

	500m-NHM(DD)		1km-NHM(DD)		1km-NHM	
Total (mm/12hours)	2.85	-	2.93	-	2.87	-
Kinematic change	2.11	74.3%	2.21	75.5%	1.80	62.9%
Horizontal convergence	8.79	(308.3%)	8.59	(293.2%)	9.26	(322.8%)
Vertical transportation (grid)	-0.46	(-16.1%)	-0.52	(-17.7%)	-1.58	(-55.2%)
Vertical transportation (sub-grid)	0.005	(0.18%)	0.006	(0.21%)	0.003	(0.10%)
Horizontal advection	-6.22	(-218.1%)	-5.86	(-200.2%)	-5.88	(-204.9%)
Latent heat flux	0.73	25.7%	0.72	24.5%	1.06	37.1%

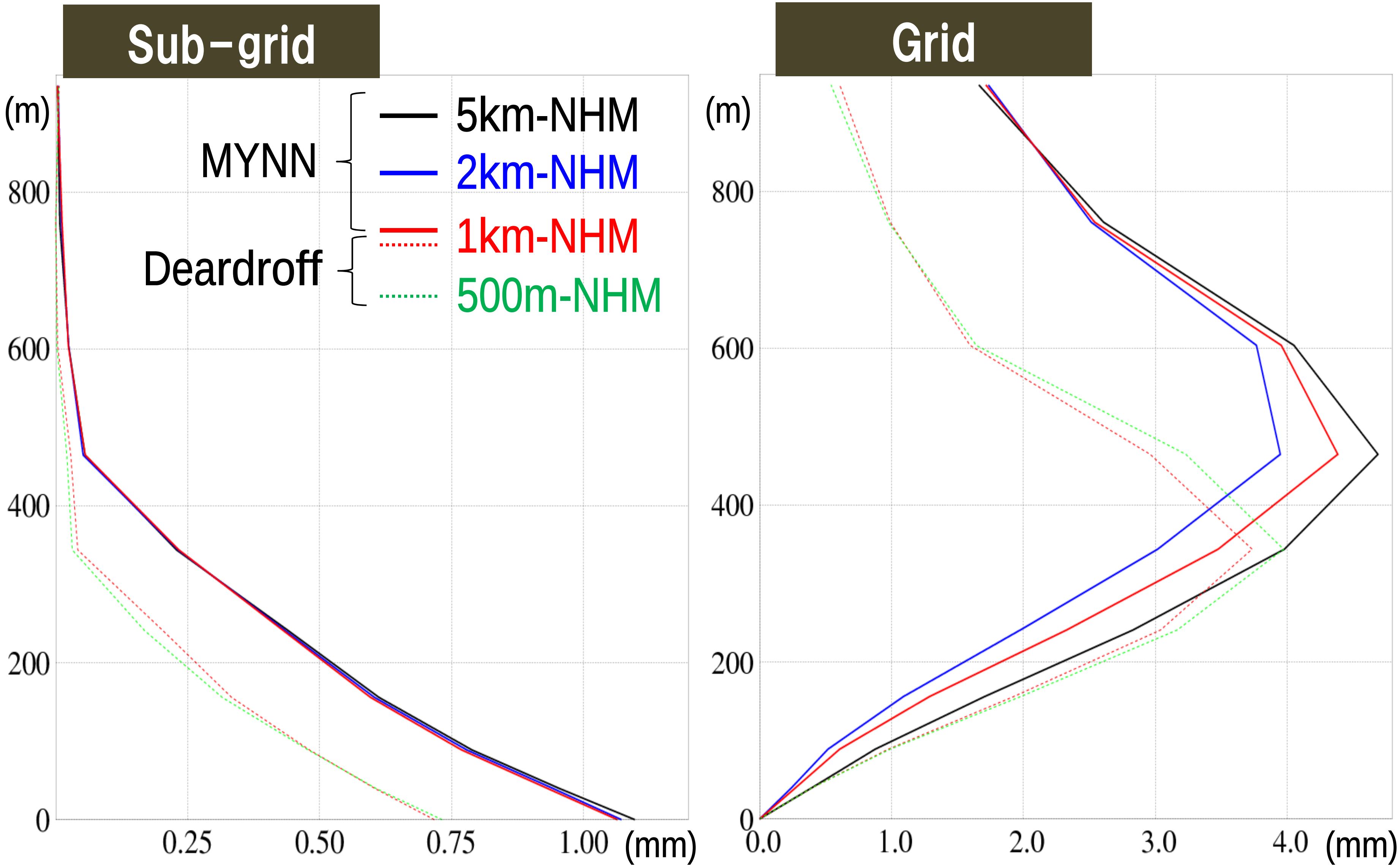
Difference between MYNN and Deardroff

⇨ is small for total change, but each term.

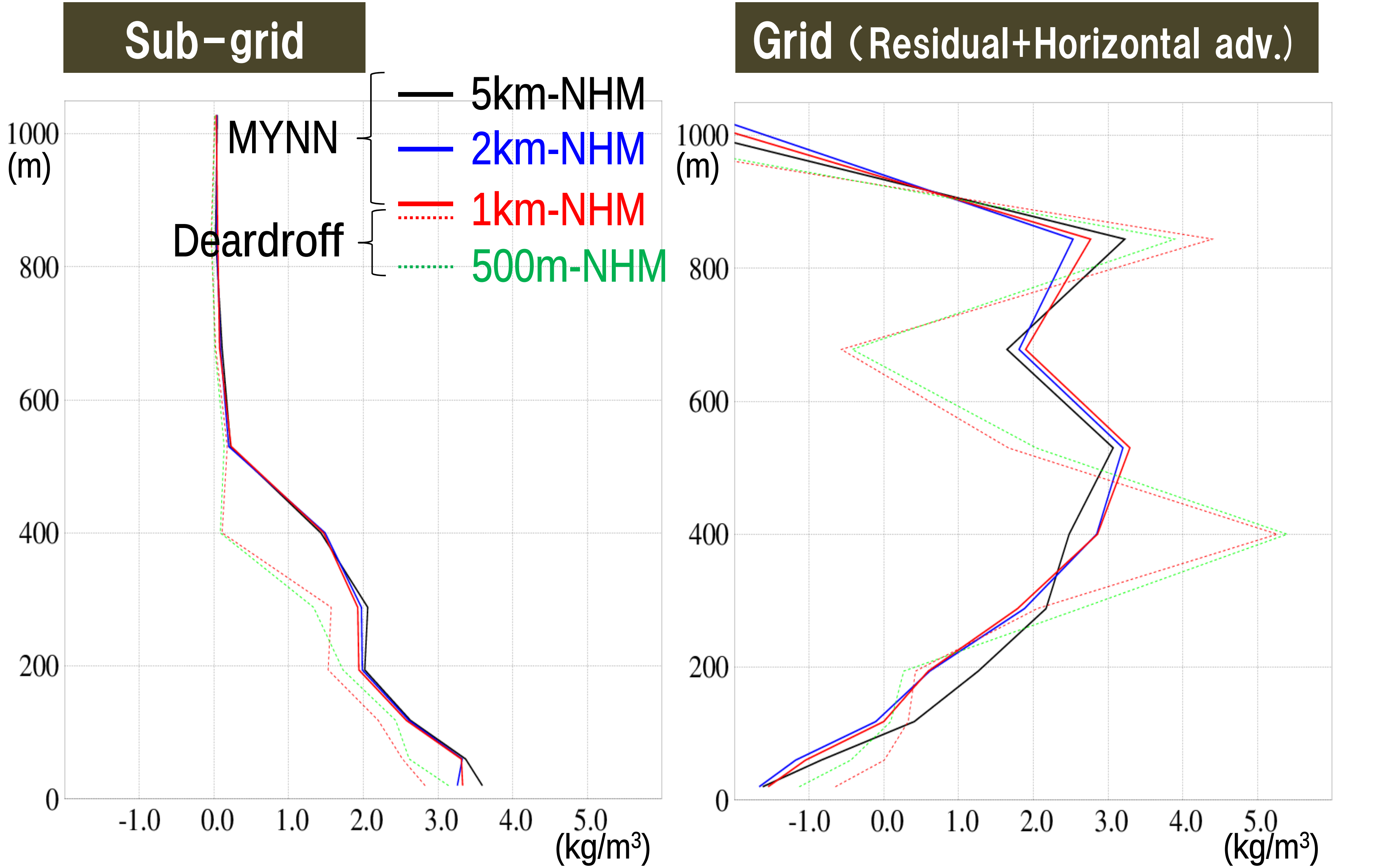
Sub-grid vertical transportation of water vapor



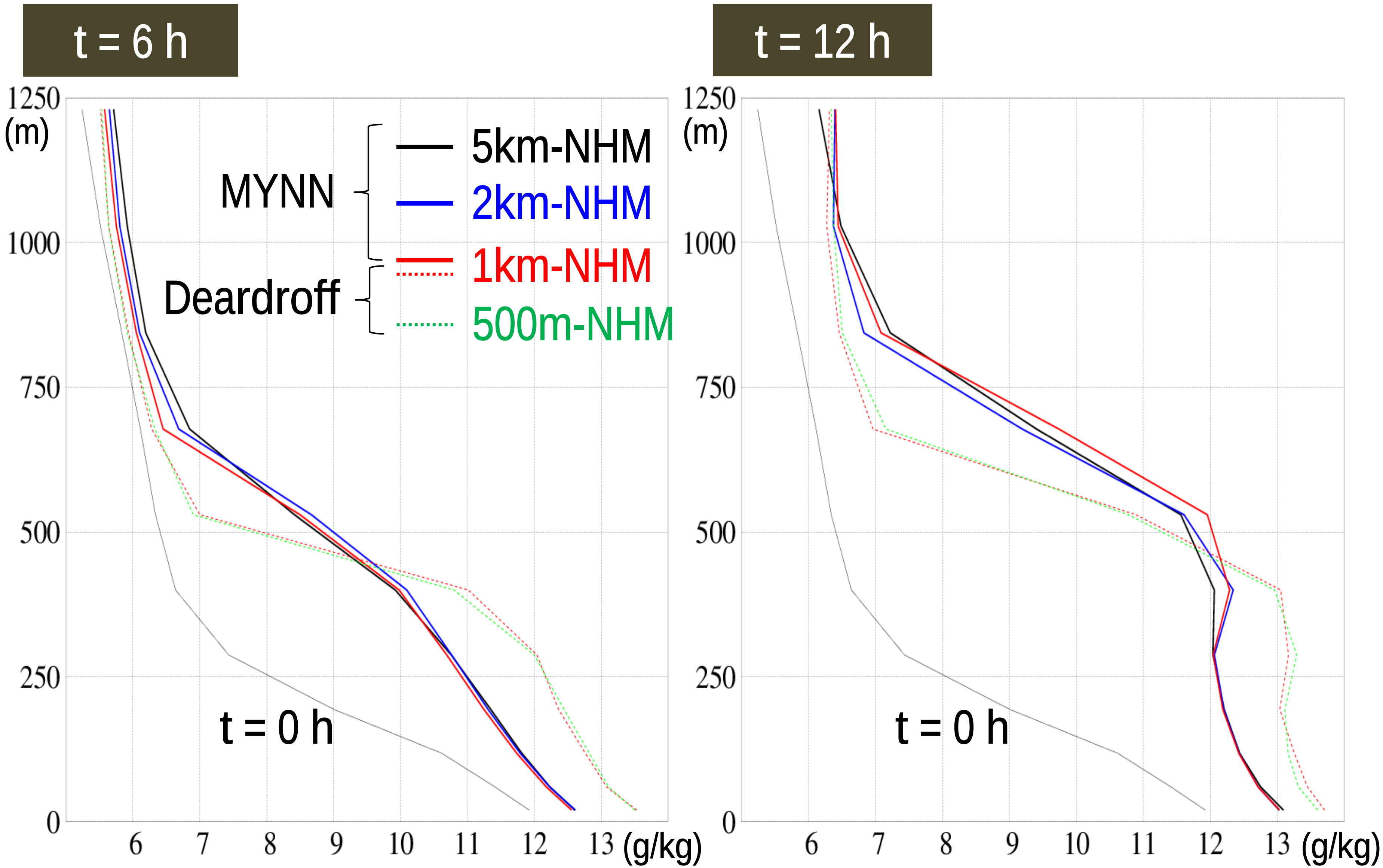
Vertical transportations of water vapor for target air column (12h accumulation amounts)



Vertical profiles of 12-hour accumulation amounts of water vapor for target air column



Vertical profiles of water vapor for target air column



Summary

✓Accumulation processes of low-level water vapor

Small dependency of horizontal res. & turbulence scheme on amounts

However, each process is difference by tub. scheme.

Accumulation process	MYNN	Deardroff
Kinematic change due to meso trough	~2/3	~3/4
Latent heat flux from the sea	~1/3	~1/4

✓ Sub-grid vertical transportation (water vapor buoyancy)

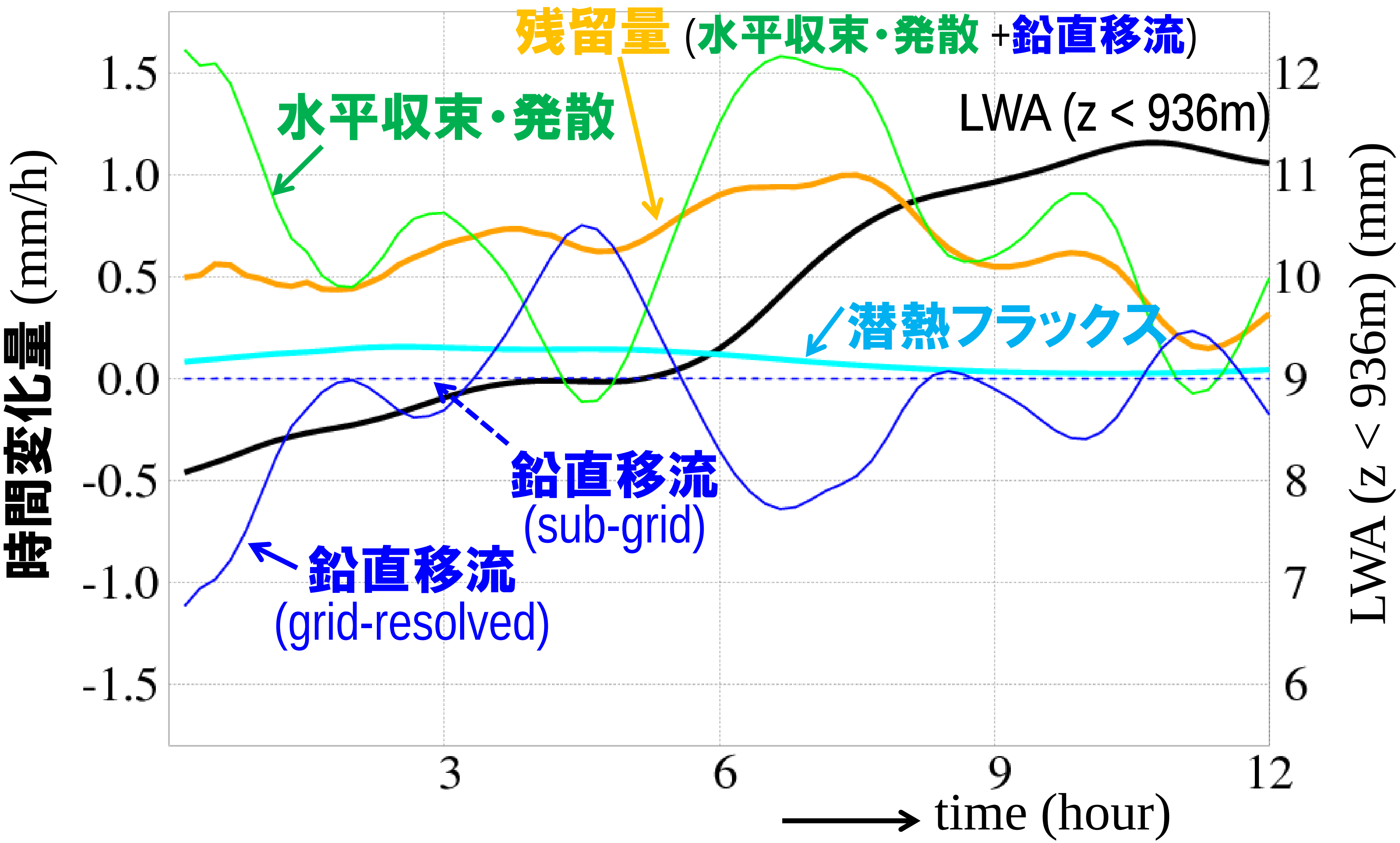
is limited below a height of 500m.

Small dependency of horizontal res., but large for tub. Scheme.

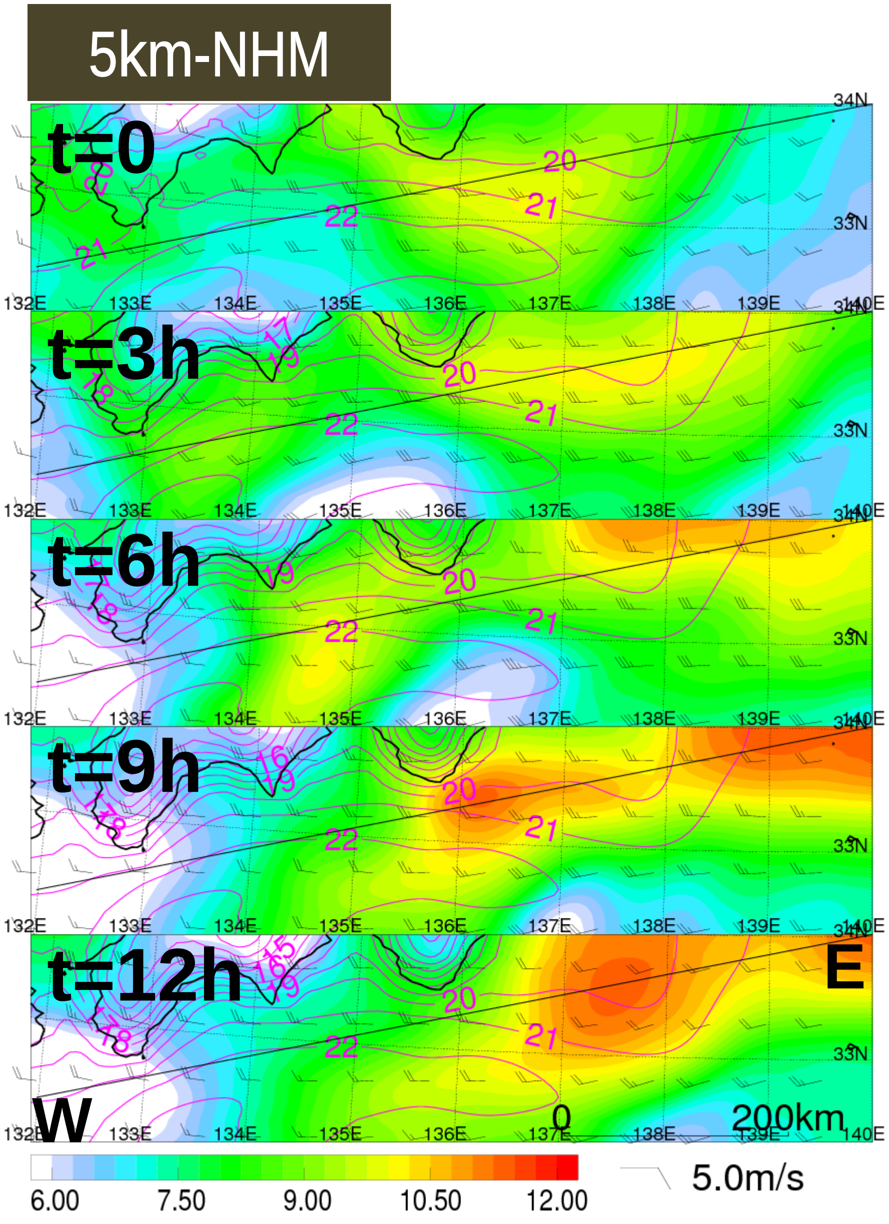
✓ Features of vertical profile of water vapor

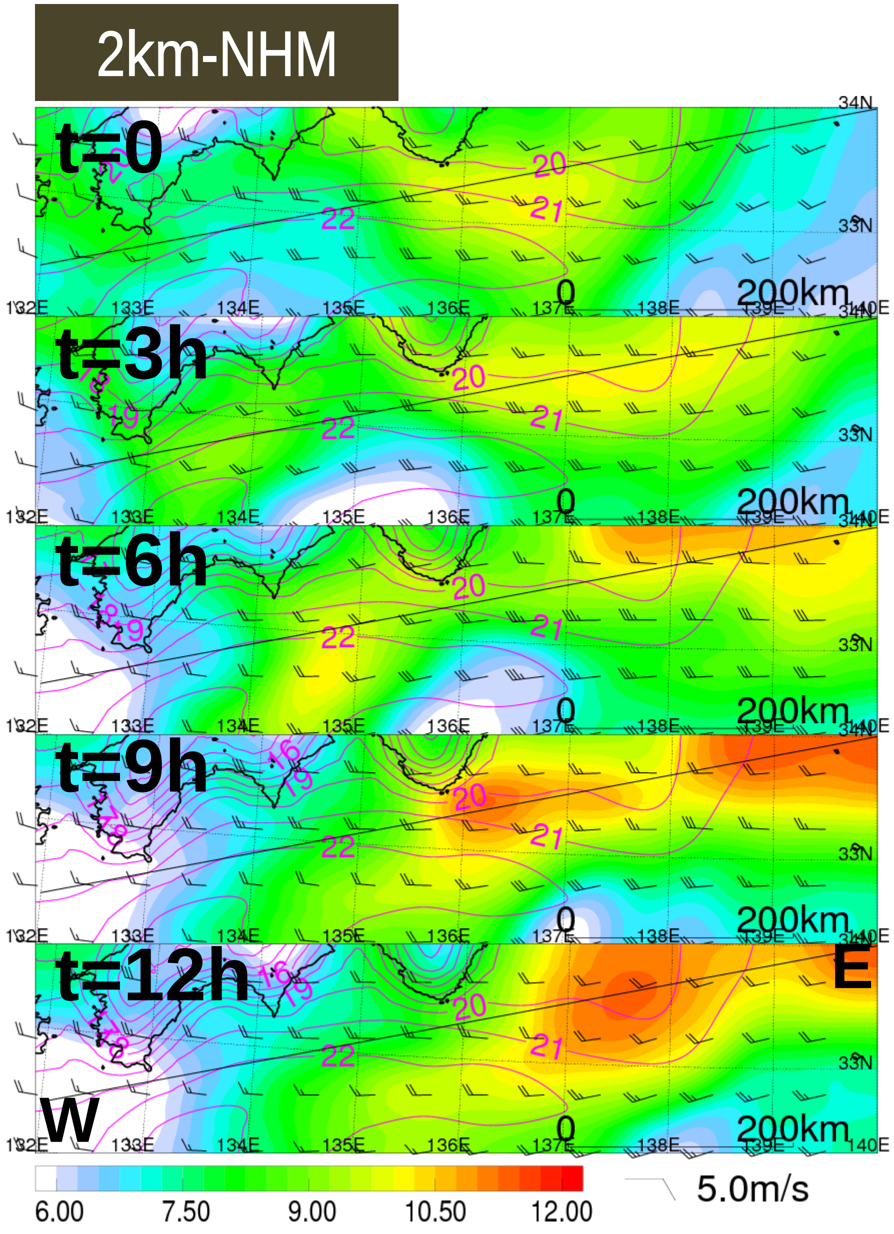
Deardroff accumulates water vapor in lower layers than MYNN

対象領域のLWAに対する収支の時間変化

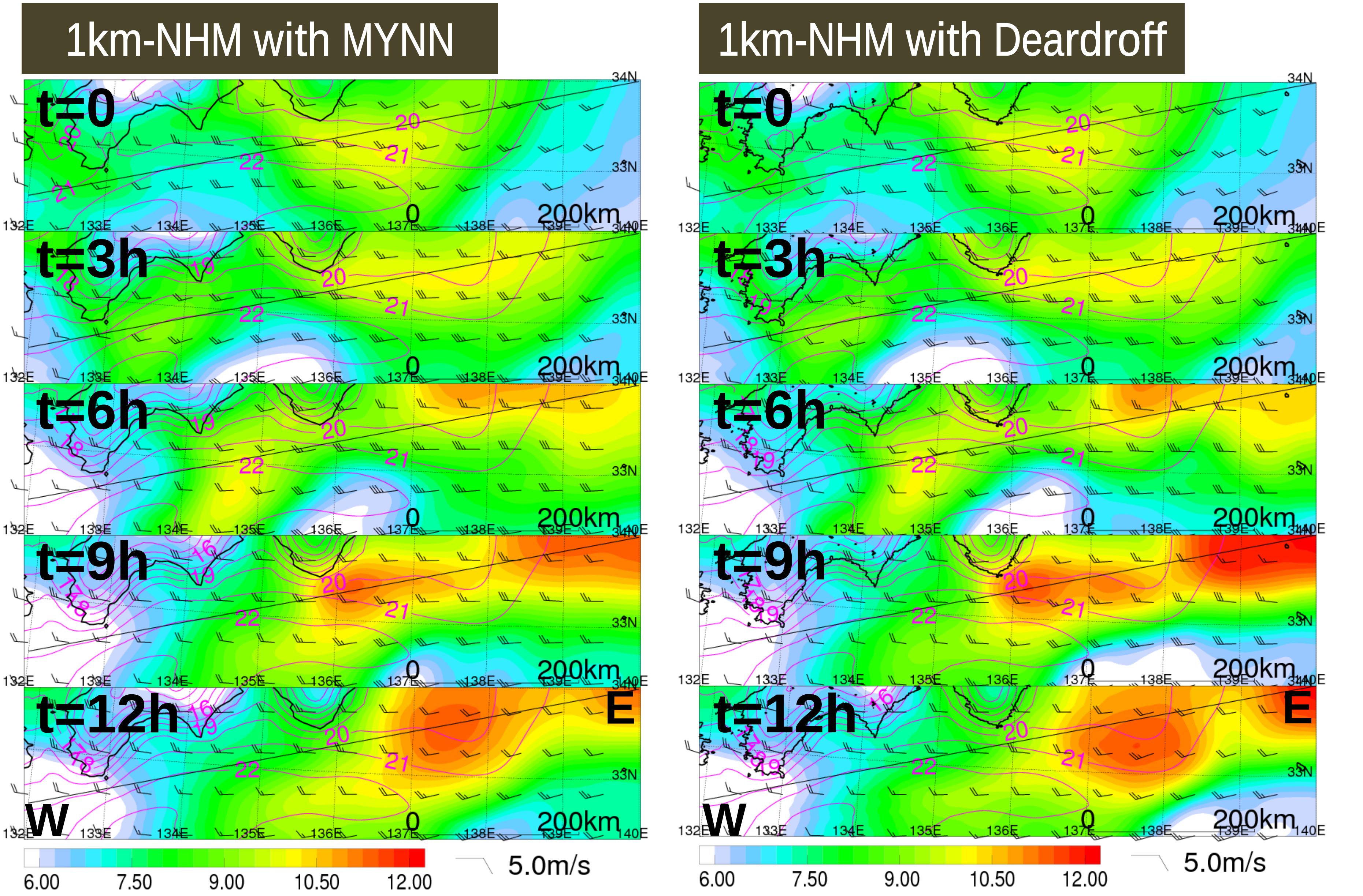


下層水蒸気量の時間変化(5日18時～6日6時)

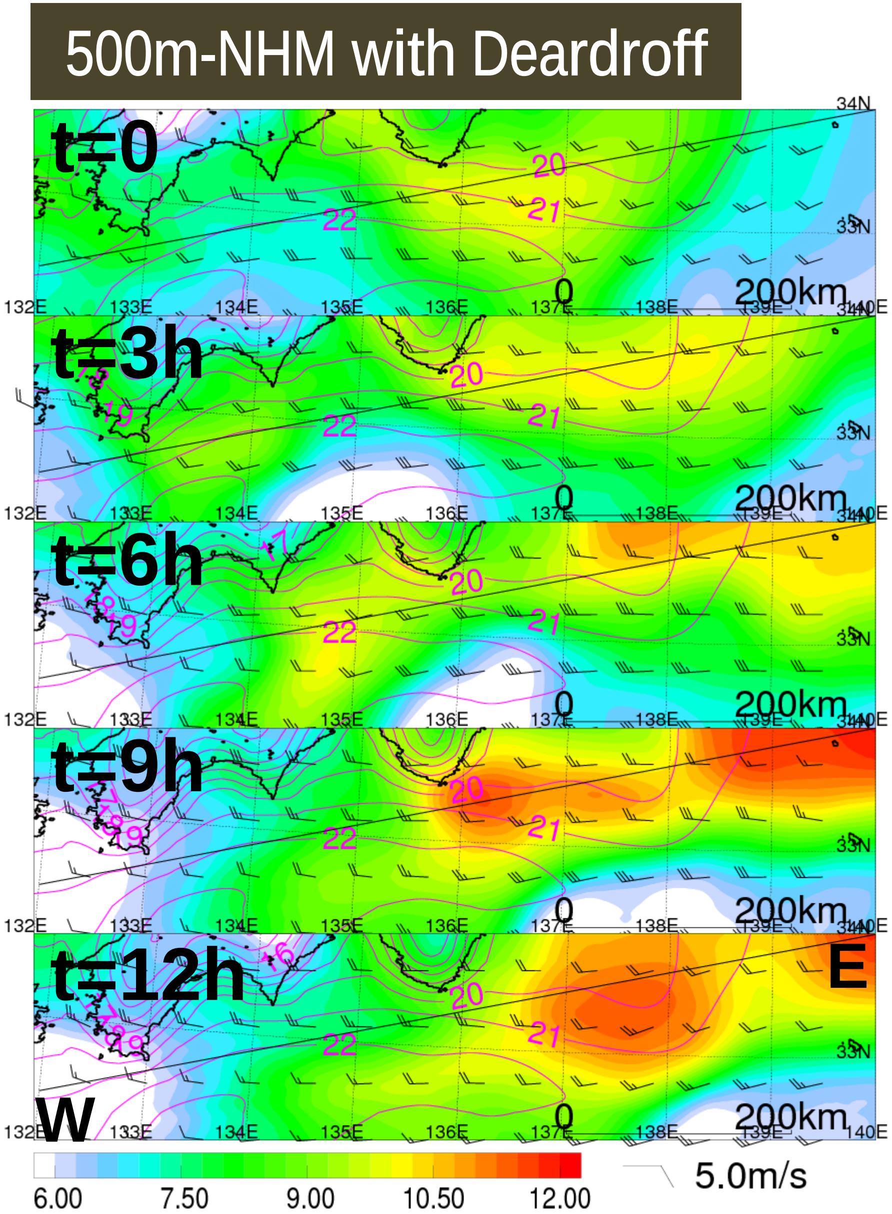


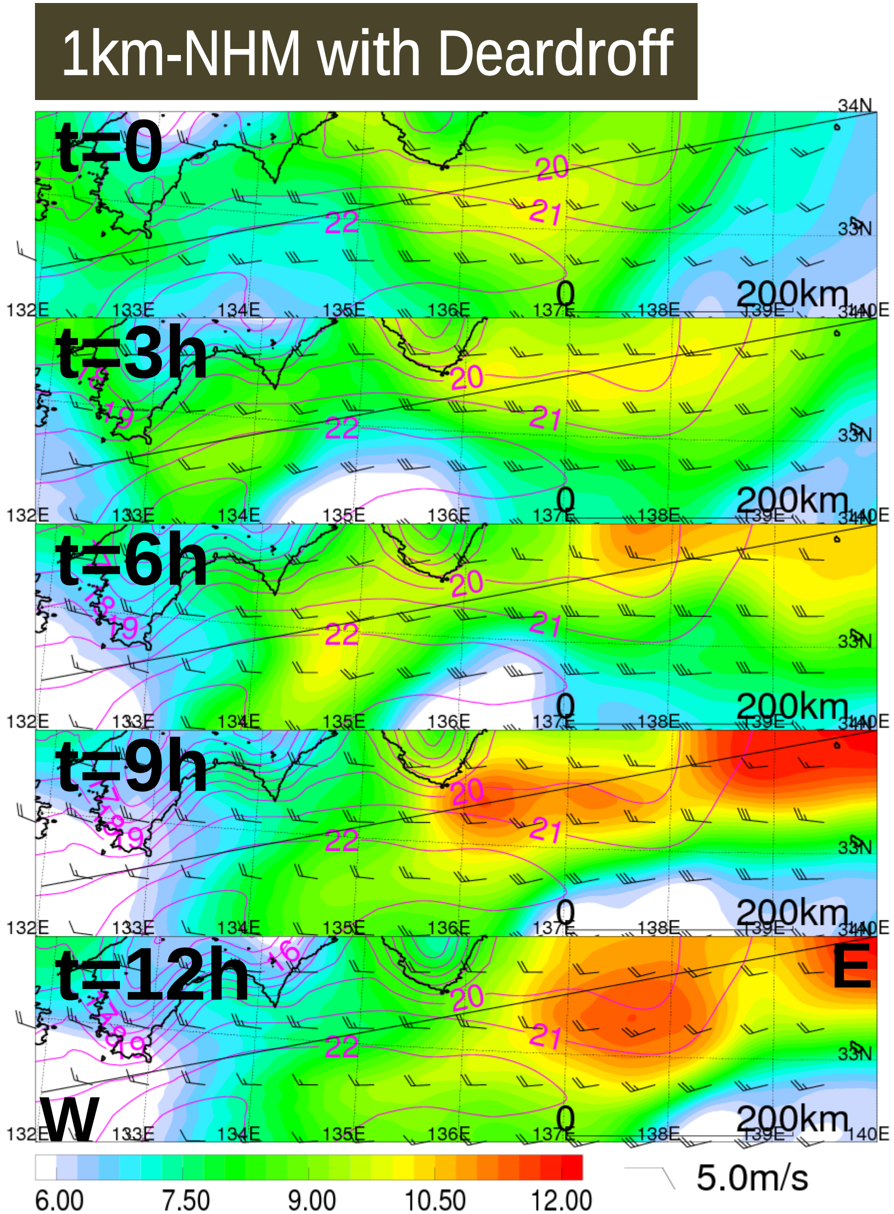


下層水蒸気量の時間変化（5日18時～6日6時）



下層水蒸気量の時間変化（5日18時～6日6時）





対象領域のLWAに対する収支の時間変化

左縦軸：時間変化量 (mm/h)　**右縦軸：**LWA (z < 936m) (mm)

LWA (z < 936m)

残留量

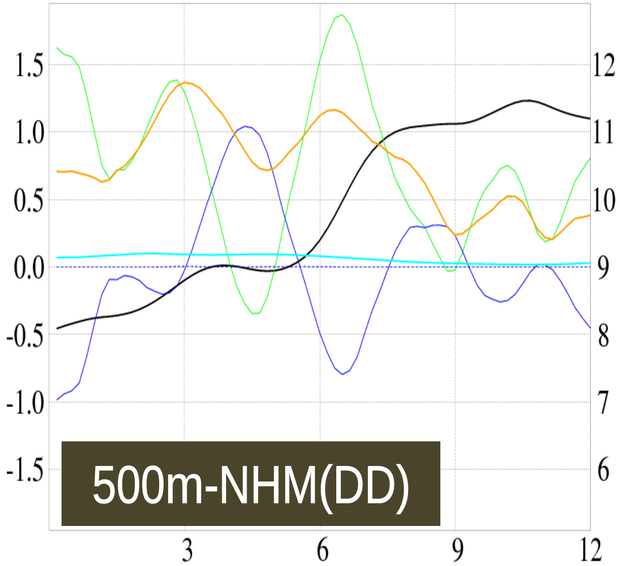
(**水平収束・発散** +**鉛直移流**)

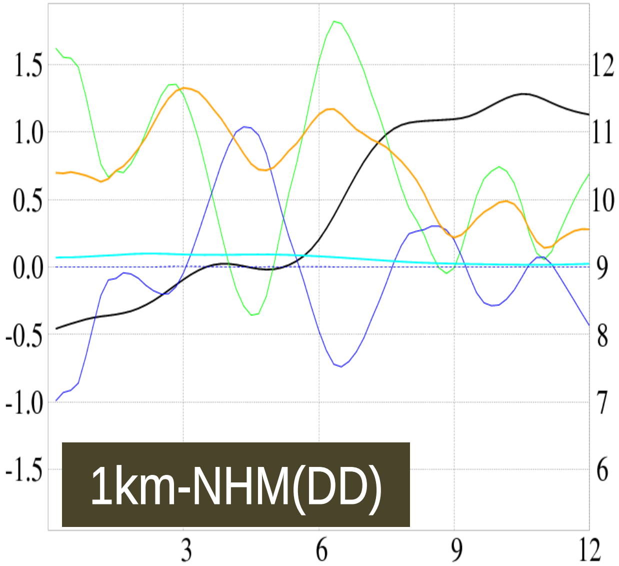
鉛直移流

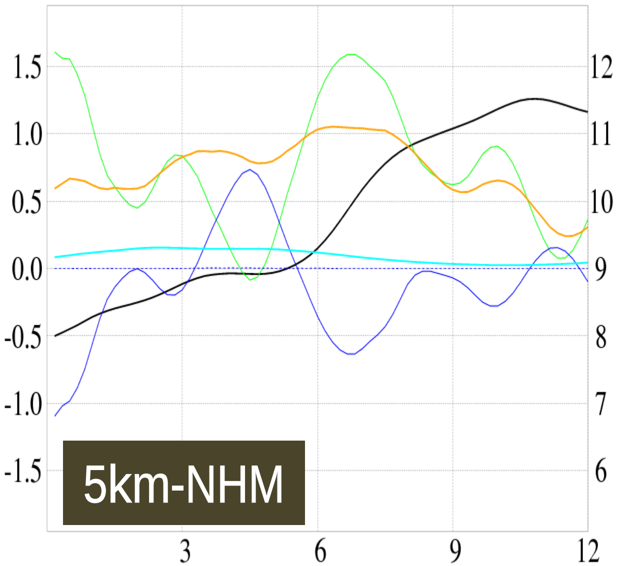
sub-grid ----

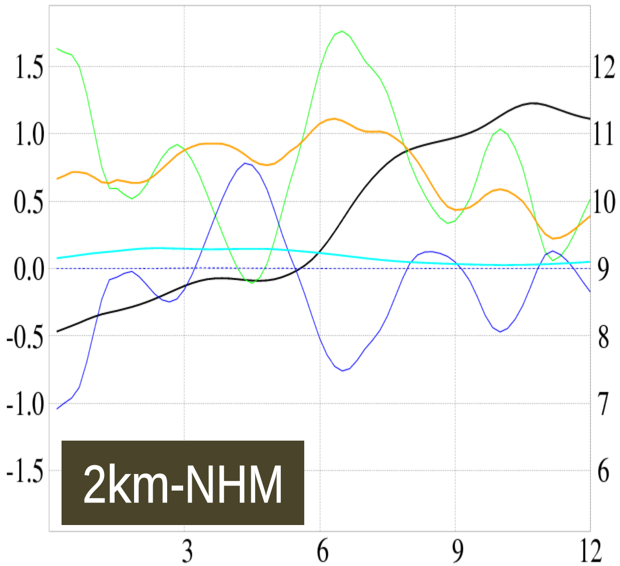
grid-resolved ——

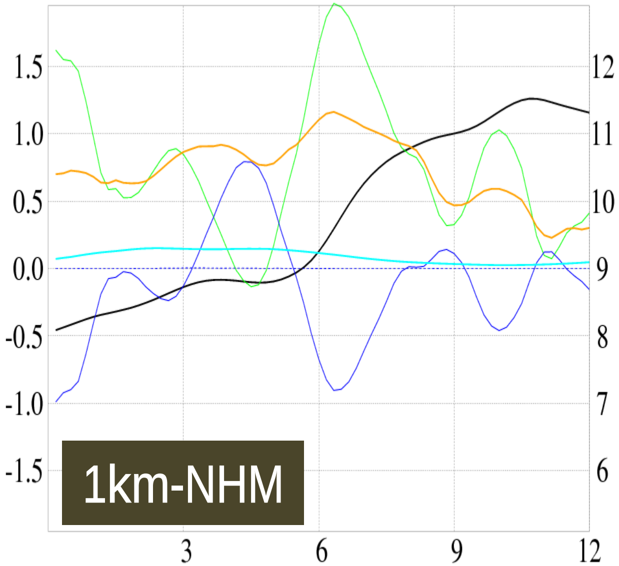
潜熱フラックス











time (hour)

対象領域のLWAに対する収支の時間変化

左縦軸：時間変化量 (mm/h)　右縦軸：LWA (z < 936m) (mm)

LWA (z < 936m)

残留量

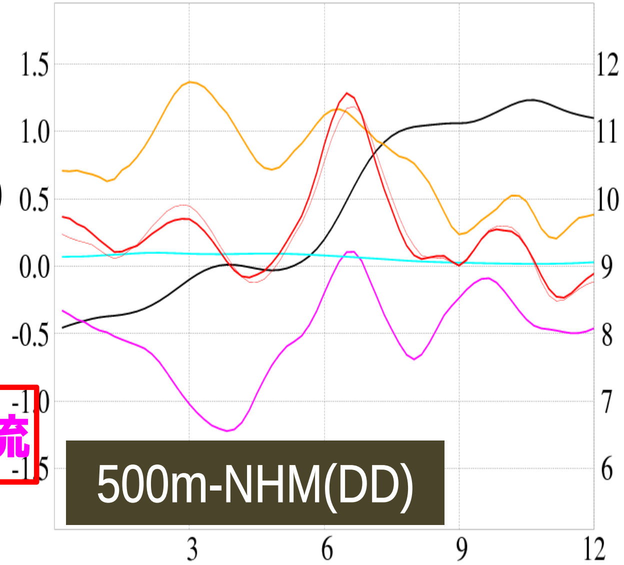
(水平収束・発散 +鉛直移流)

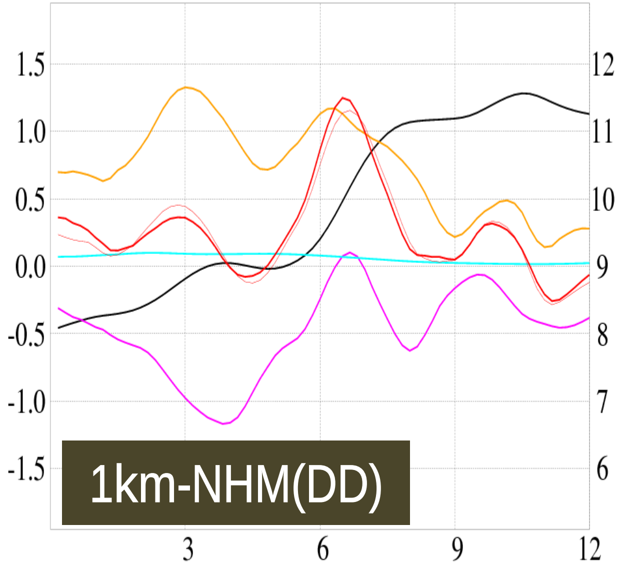
潜熱フラックス

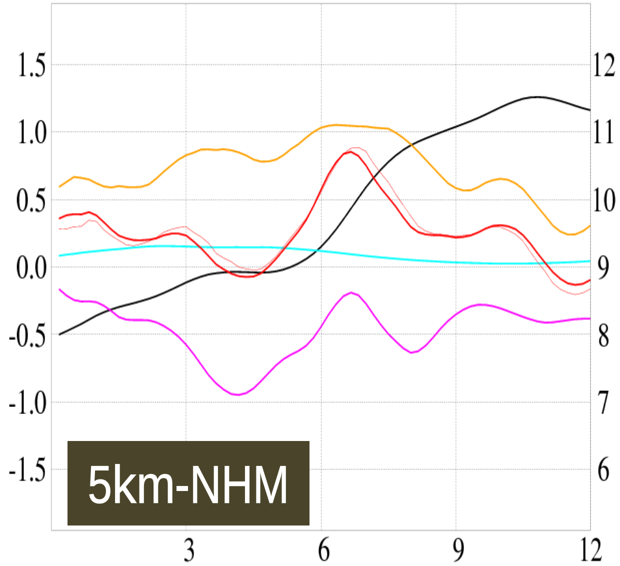
水平移流

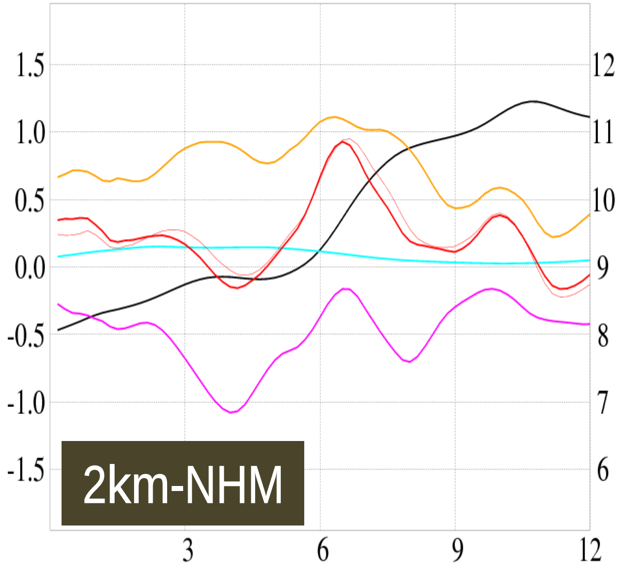
残留量+潜熱フラックス+水平移流

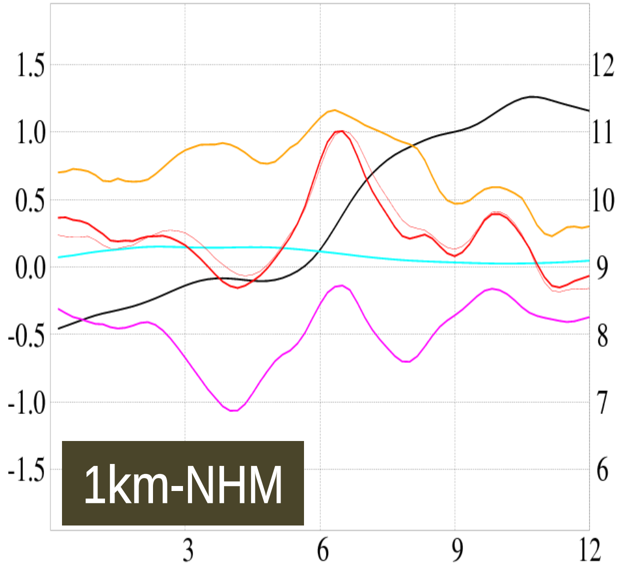
dLWA/dt: 赤細線











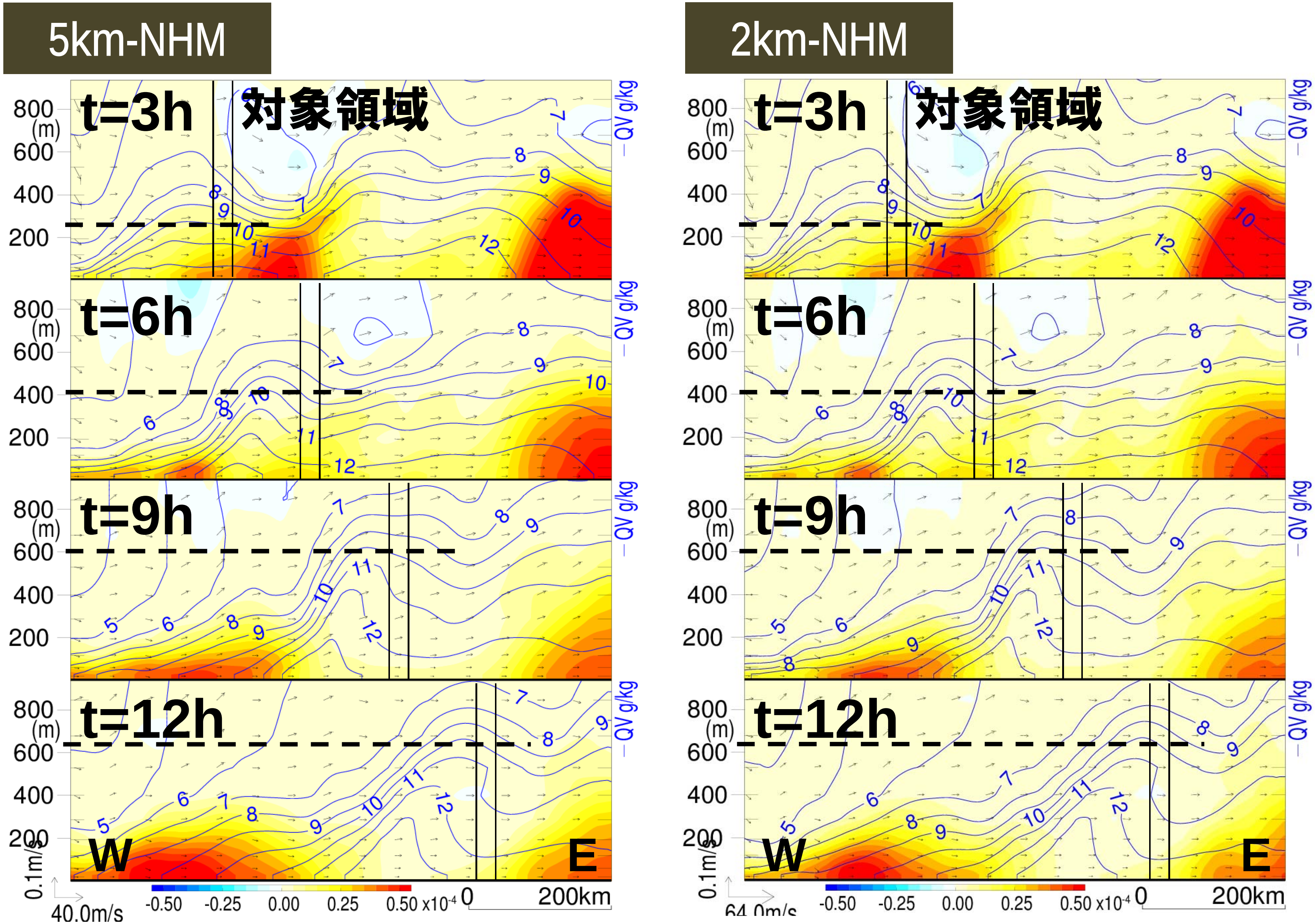
対象領域のLWAの12時間の変化量

	5km-NHM		2km-NHM		1km-NHM	
合計 (mm/12hours)	3.06	-	2.78	-	2.87	-
運動学的変化	1.97	64.2%	1.71	61.4%	1.80	62.9%
水平収束	9.10	(296.9%)	9.15	(329.1%)	9.26	(322.8%)
鉛直移流 (grid)	-1.50	(-48.8%)	-1.60	(-57.4%)	-1.58	(-55.2%)
鉛直移流 (sub-grid)	0.003	(0.11%)	0.004	(0.15%)	0.003	(0.10%)
水平移流	-5.64	(-184.0%)	-5.85	(-210.4%)	-5.88	(-204.9%)
潜熱フラックス	1.10	35.8%	1.07	38.5%	1.06	37.1%

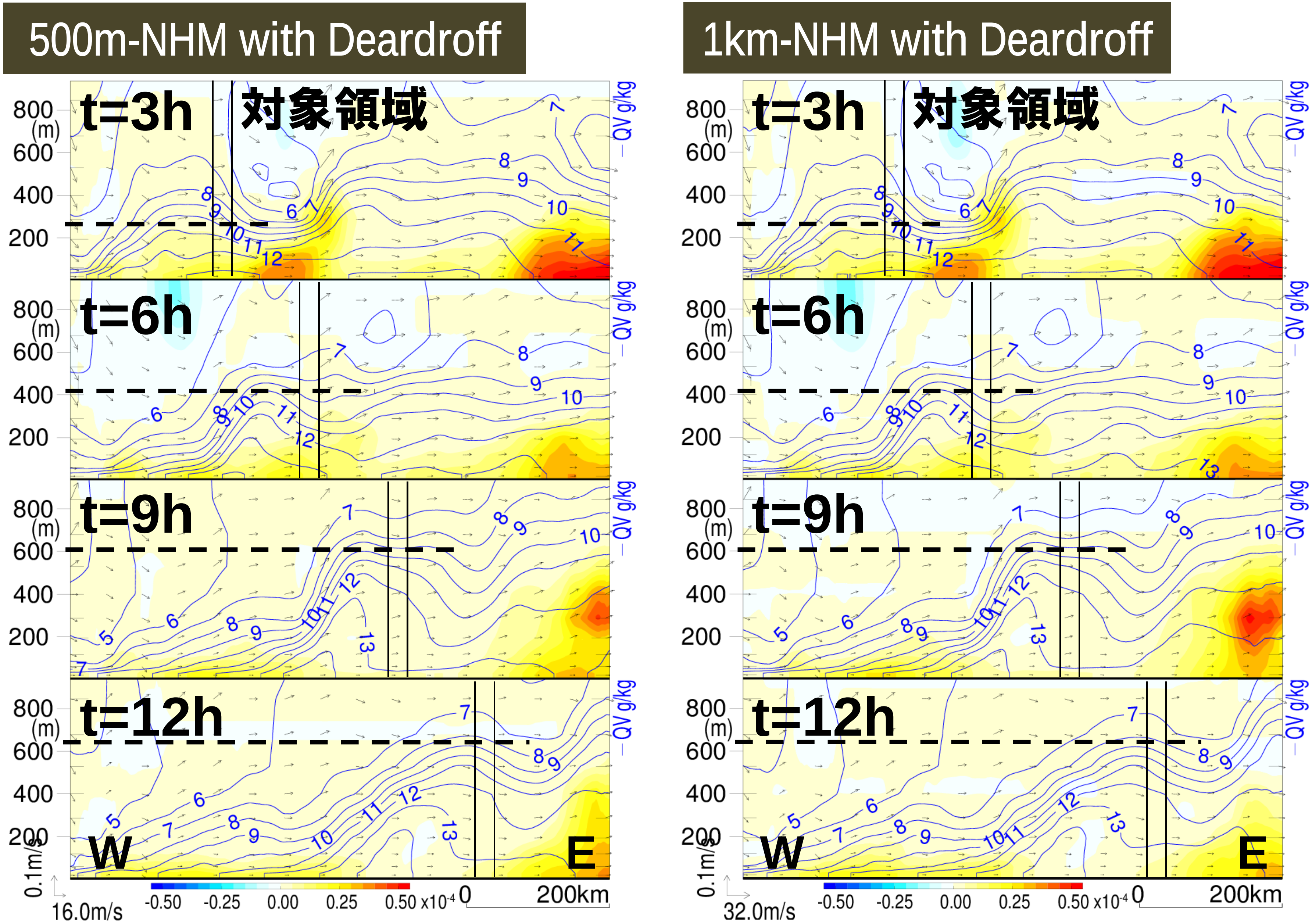
水平分解能による違い（境界層スキームが同じ場合：MYNN）

➡ **ほとんど差がない（水平移流を除く）**

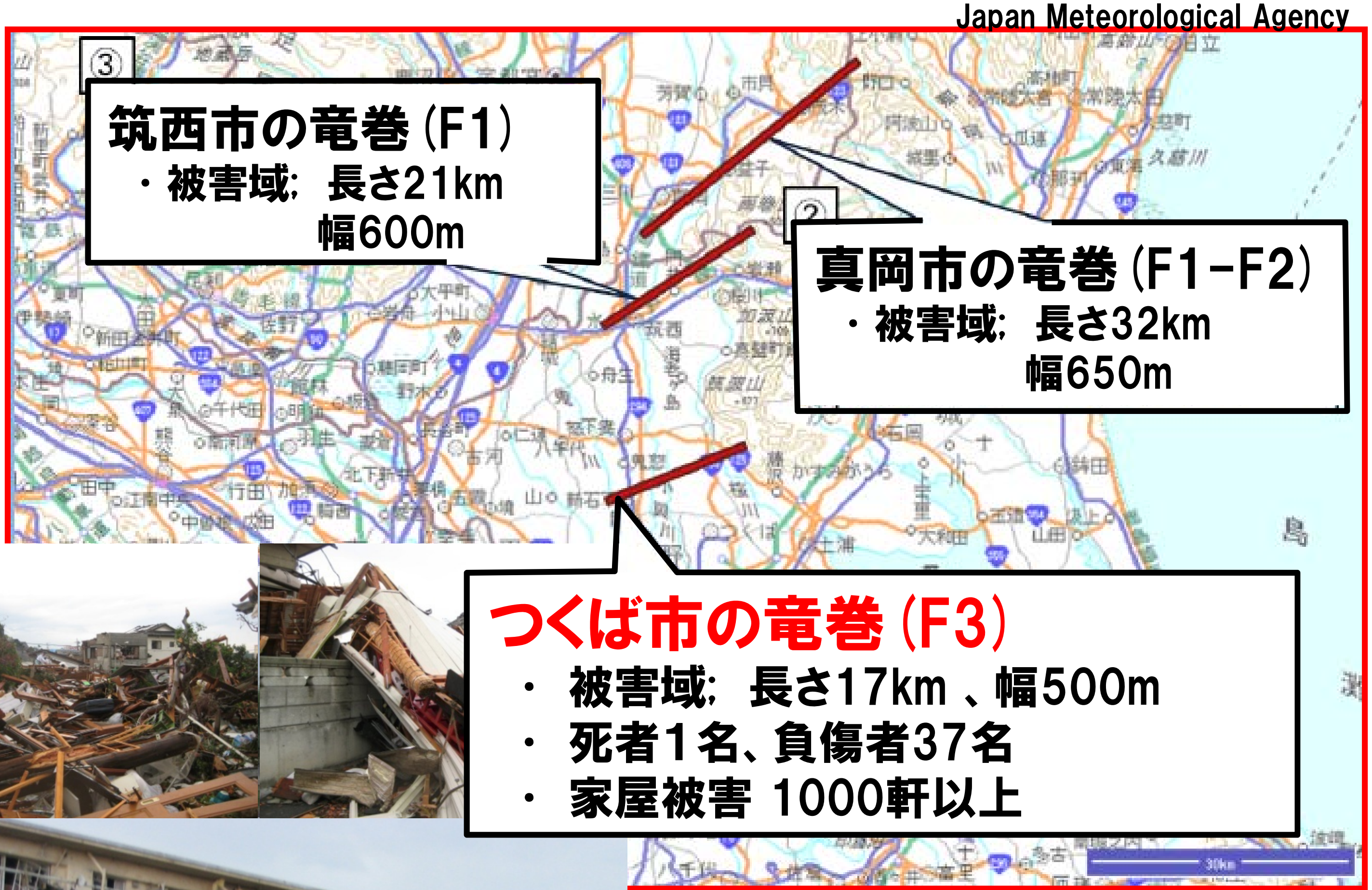
サブグリッドによる水蒸気の鉛直輸送

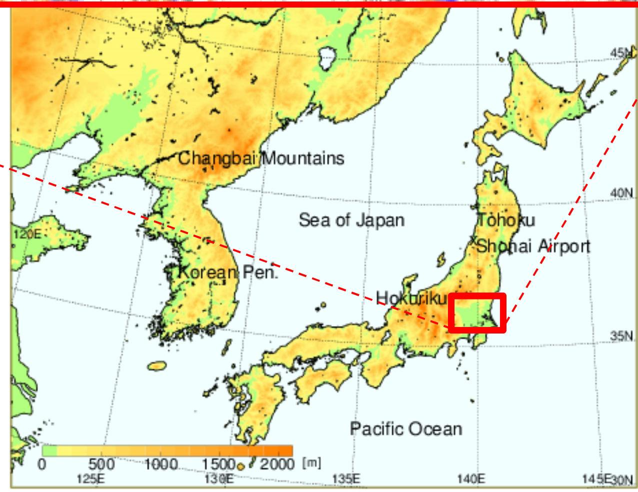


サブグリッドによる水蒸気の鉛直輸送



つくば竜巻の概要 2012.5.6





つくばでの地上観測と上空の大気状態（前日との比較）

上空の大気状態は気象庁メソ解析から判断

		6日12時	5 日12時
気温	500 hPa (~ 5600 m)	-18 °C	-17 °C
	地上	25.6 °C	25.9 °C
気温差(地上 – 500 hPa)		43.6 °C	42.9 °C
500 m高度の水蒸気量		12 g/kg	6 g/kg
CAPE (対流有効位置エネルギー)		2300 J/kg	-
SREH (ストームに相対的なヘリシティー)		250 m²/s²	50 m²/s²

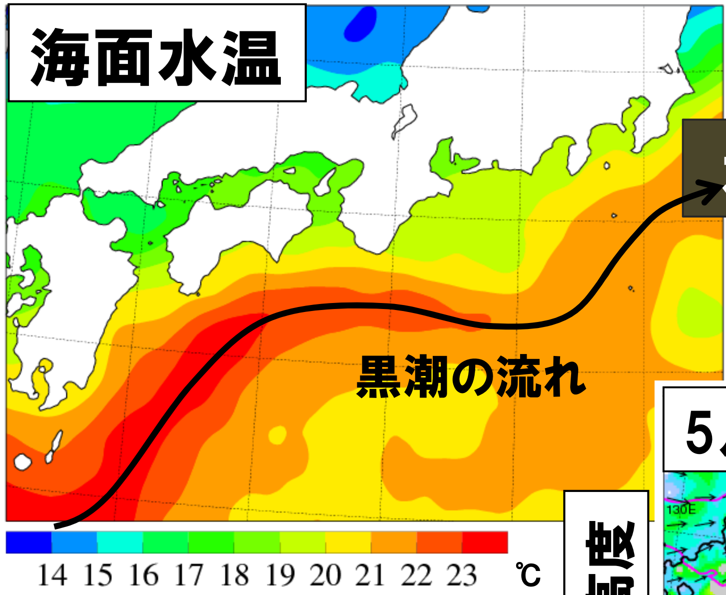
環境場の鉛直シアから見積もられるストームに
貫入する水平渦度の程度を示す

$$SREH = \int_{0m}^{h} \left(\vec{V} - \vec{C}\right) \cdot \vec{\omega} \, dz$$

維持	上下の大きな**気温**差（40度以上）の変化は小さい
変化	下層の**水蒸気量**が倍増

キーポイント

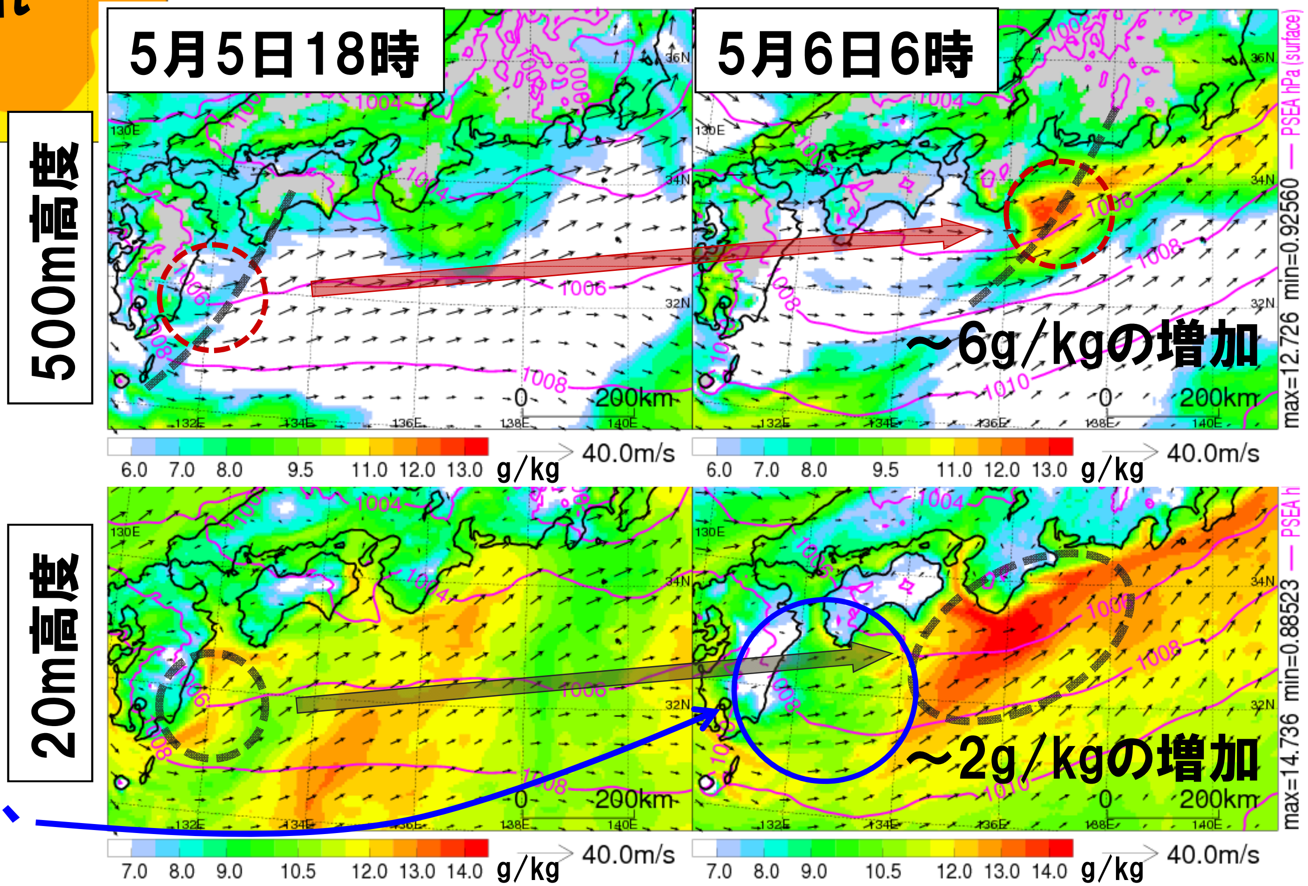
下層水蒸気量の増加と黒潮との位置関係



気象庁メソ解析から作成

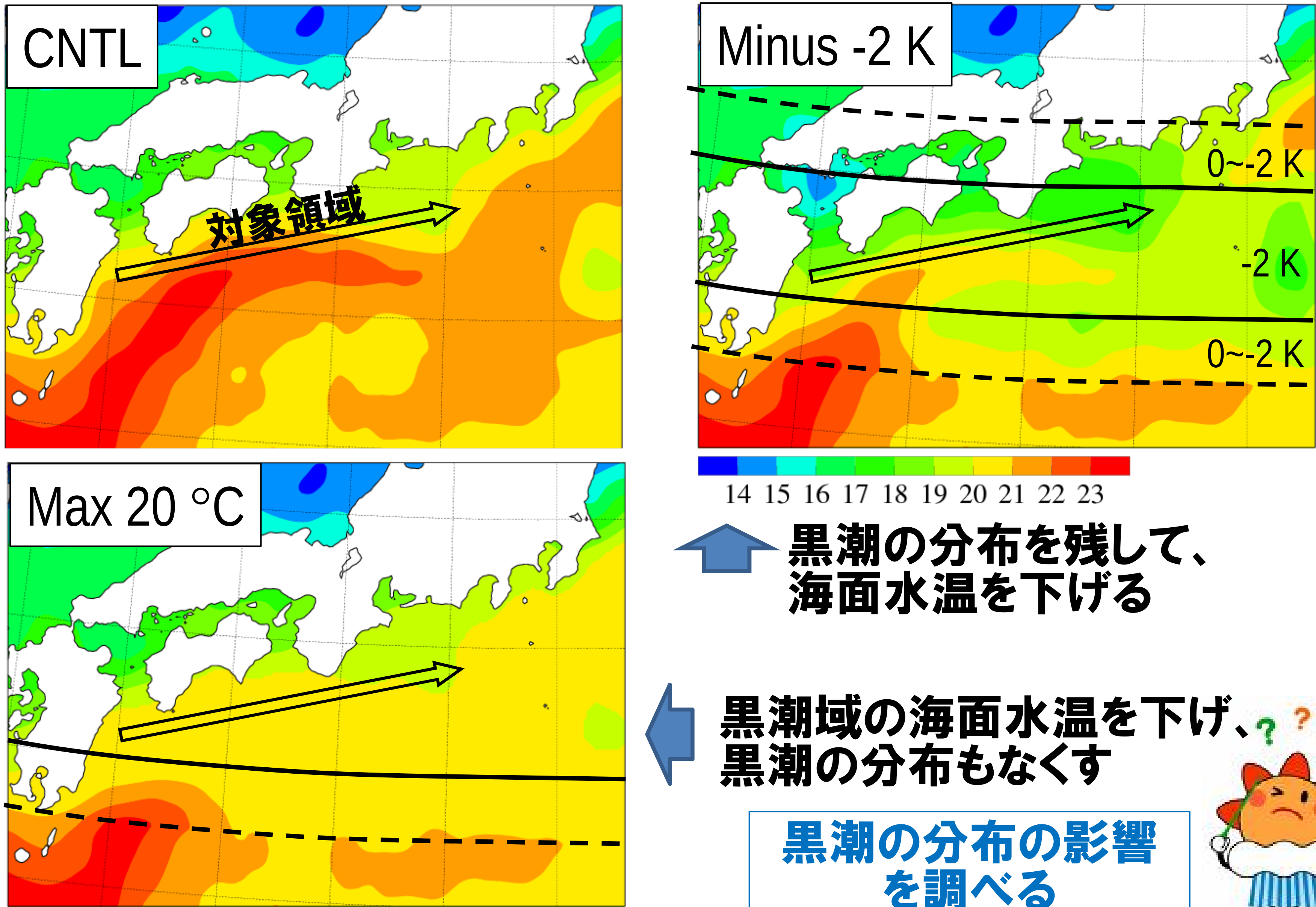
水蒸気の増加期間・領域が黒潮域に一致

⇨ 数値実験により黒潮の影響を調査



なお、
増加領域の西側は
低比湿空気の流入で、
水蒸気量が減少

感度実験における海面水温の設定



黒潮の分布を残して、
海面水温を下げる

黒潮域の海面水温を下げ、
黒潮の分布もなくす

黒潮の分布の影響
を調べる

対象領域のLWAの12時間の変化量

	CNTL		Max 20 °C		Minus 2 K	
合計 (mm/12hours)	3.02	-	2.17	-	2.04	-
運動学的変化	1.92	63.5%	1.33	61.5%	1.54	75.1%
水平収束	8.92	(295.3%)	5.39	(248.1%)	6.21	(303.5%)
鉛直移流 (grid)	-1.48	(-49.1%)	-0.54	(-24.7%)	-0.45	(-21.7%)
鉛直移流 (sub-grid)	0.002	(0.08%)	0.004	(0.2%)	0.004	(0.2%)
水平移流	-5.52	(-182.7%)	-3.52	(-162.1%)	-4.24	(-206.9%)
潜熱フラックス	1.10	36.5%	0.84	38.5%	0.51	24.9%

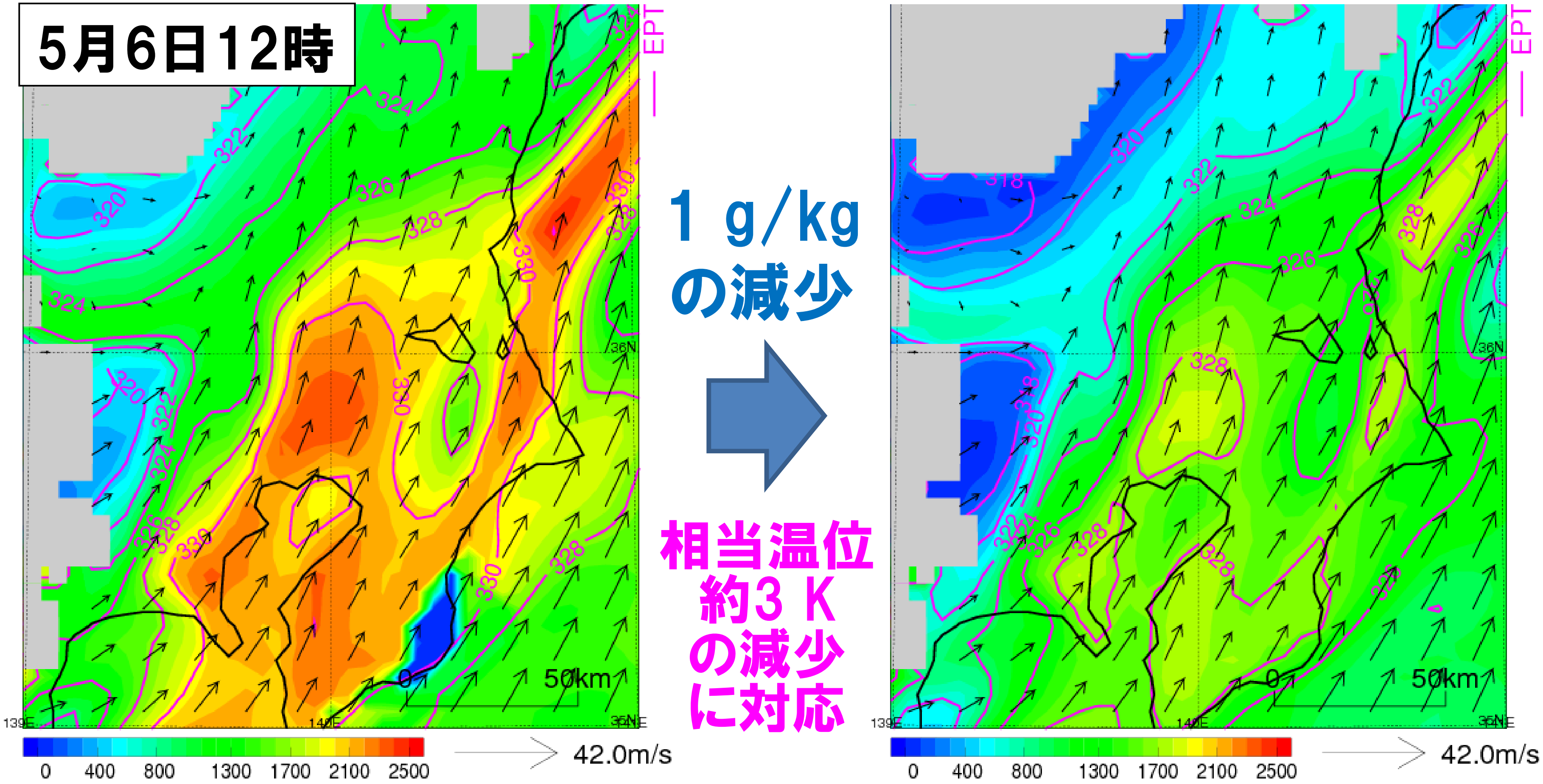
運動学的変化の寄与がMinus 2Kで増加, Max 20 °Cでは減少.

➡ 黒潮の分布が運動学的変化を強めている

水蒸気量が1g/kg減った場合の影響

500m高度の気塊を
持ち上げた場合のCAPE

気象庁メソ解析から算出



CAPE: 2300 J/kg ⇨ 1700 J/kg（25%の減少）

標準実験－Max20℃実験（5月6日3時の予想値での差）