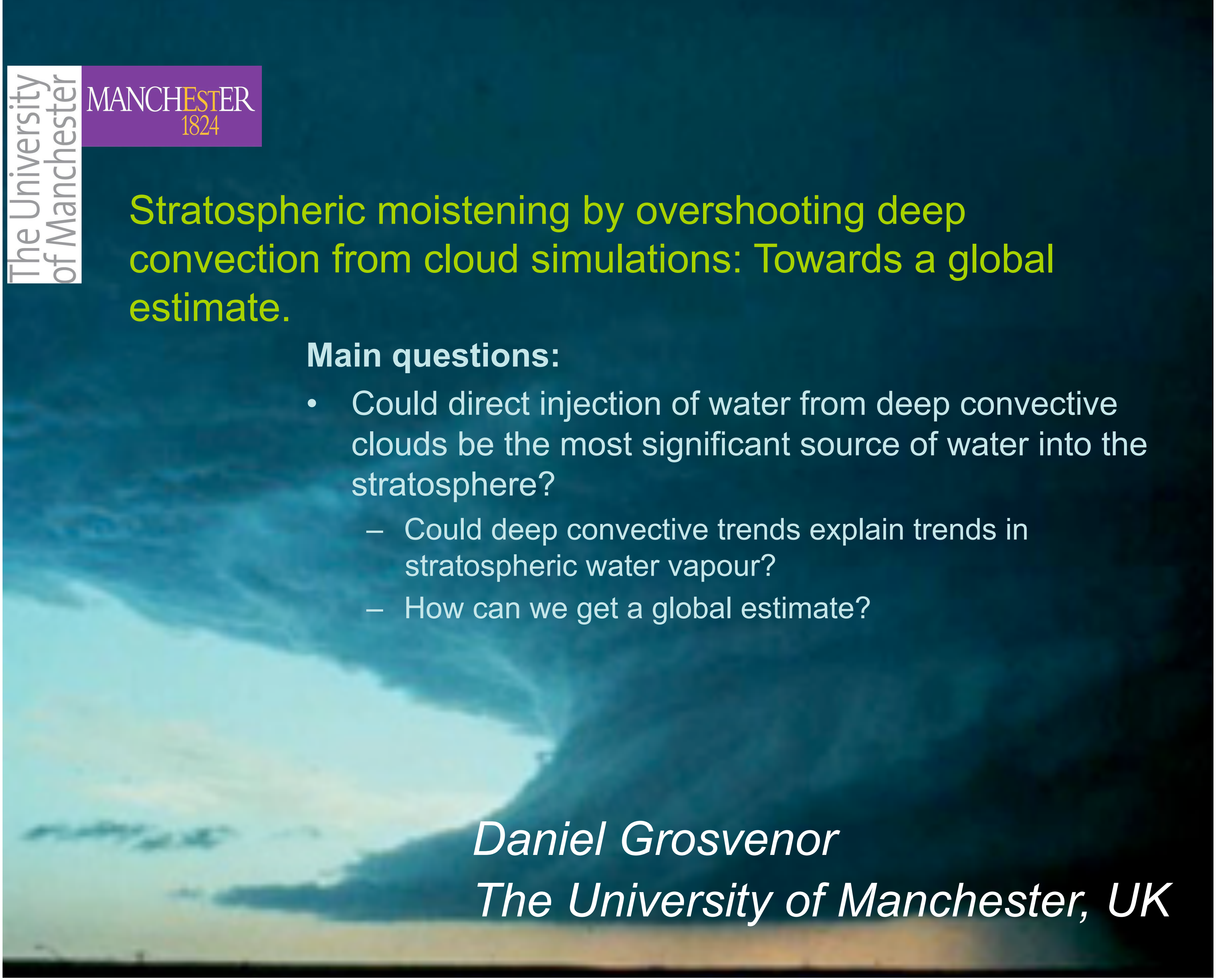


Stratospheric moistening by overshooting deep convection from cloud simulations: Towards a global estimate.

Main questions:

- Could direct injection of water from deep convective clouds be the most significant source of water into the stratosphere?
  - Could deep convective trends explain trends in stratospheric water vapour?
  - How can we get a global estimate?

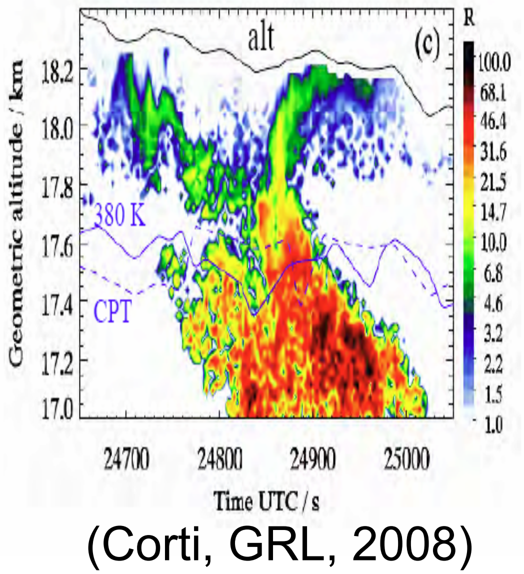
Daniel Grosvenor

The University of Manchester, UK

What is overshooting deep convection and what evidence is there for them affecting stratospheric water?

- What is overshooting convection?
  - Kinetic energy sends most vigorous clouds past the tropopause temperature inversion despite negative buoyancy encountered
  - Reaches colder temperatures than the environment due to saturated adiabatic expansion – possibility of dehydration of the stratosphere *but only if the ice can separate from the dry air before it mixes with stratospheric air*
  - Otherwise the ice is likely to be mixed with the stratospheric air and evaporate – moistening

LIDAR backscatter

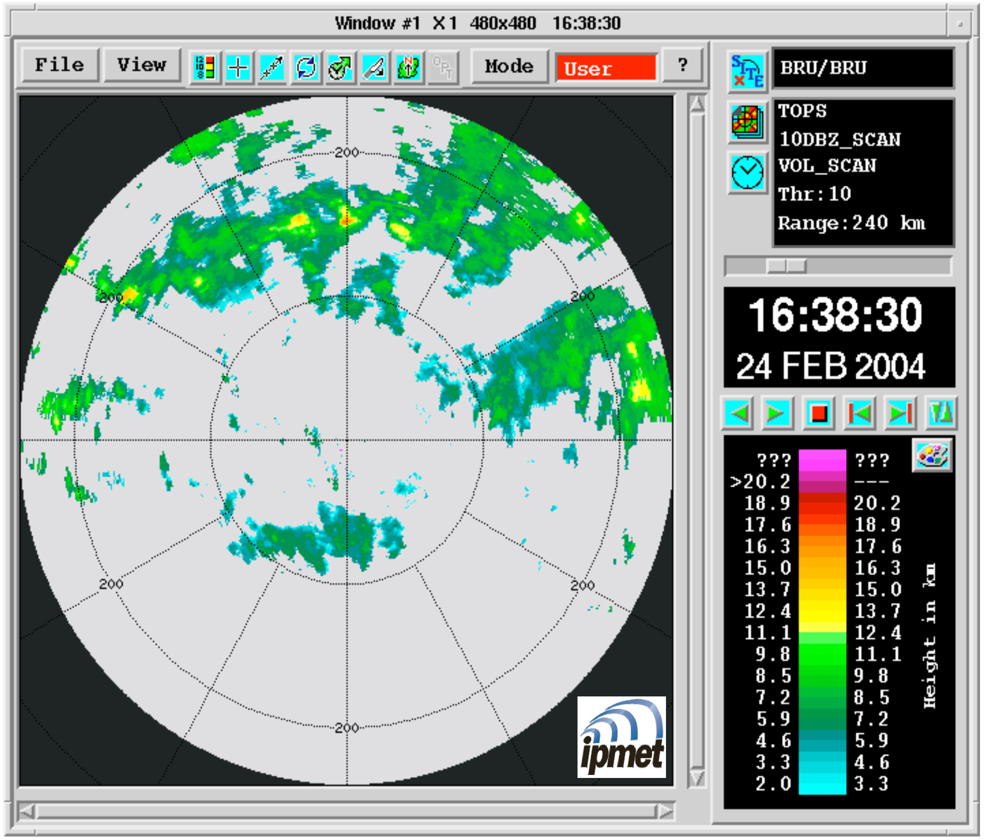


(Corti, GRL, 2008)

- Recent evidence that tropical overshoots occur and that they moisten the stratosphere:
  - Aircraft measurements of ice particles >0.8 km above the tropopause from LIDAR, FSSP and FISH/FLASH instruments over Tiwis near Darwin, Australia (Corti et al., GRL, 2008)
  - An estimated ~100 tonnes of water permanently transferred to stratosphere in this case (T. Peter, ACTIVE workshop, Manchester, 2008)
  - Particles observed in stratosphere near very deep convection in Bauru, Brazil (Nielsen et al., ACP, 2007)
  - AMMA balloon measurements (Africa)

CRM modelling of overshoot – semi-idealized simulation

- 24th Feb, 2004 case study from HIBISCUS project
- Bauru, Brazil (centre of radar image) : 22.36 S, 49.03 W.
- 240km radius radar image
- Large multi-cellular system moving from north passes over Bauru.
- 10 dbZ echo tops of up to ~17-18km (tropopause at 15.8 km)


Window #1 X1 480x480 16:38:30

BRU/BRU
TOPS
10DBZ_SCAN
VOL_SCAN
Thr:10
Range:240 km

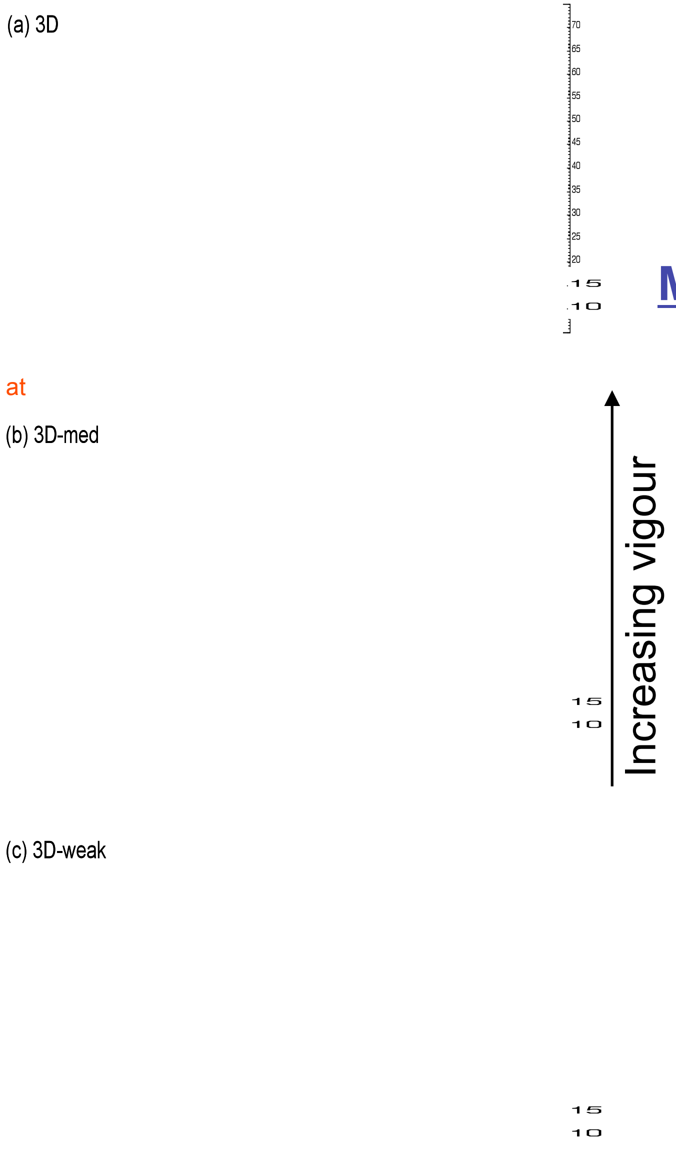
16:38:30
24 FEB 2004

- Large Eddy Model (LEM), UK Met Office (Brown, A.R., et al, QJRMS, 2002)
- Bulk 2 moment microphysics
- 75 m to 125 m vertical resolution
- 2 km horizontal resolution
- Convection initiated artificially using warm moist bubble

The University of Manchester

MANCHESTER 1824

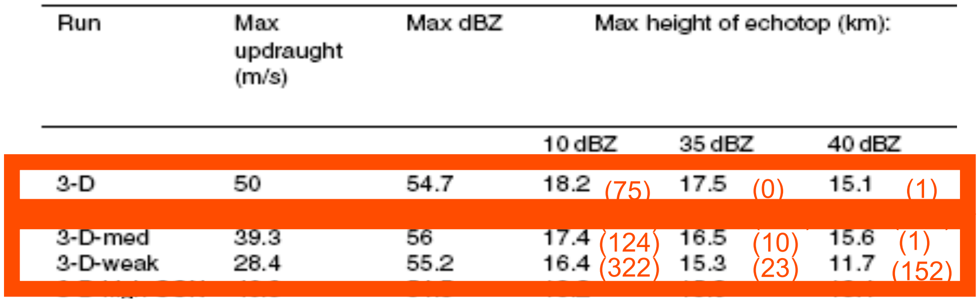
Different strengths of clouds and radar statistics (21st Jan – 11th March)



Tropopause at ~15.8 km

- *Storm dimensions approximately as in reality*
- *However, reflectivity too high at storm top in strongest case*
- *Due to excess graupel at storm top*

Model & radar stats:

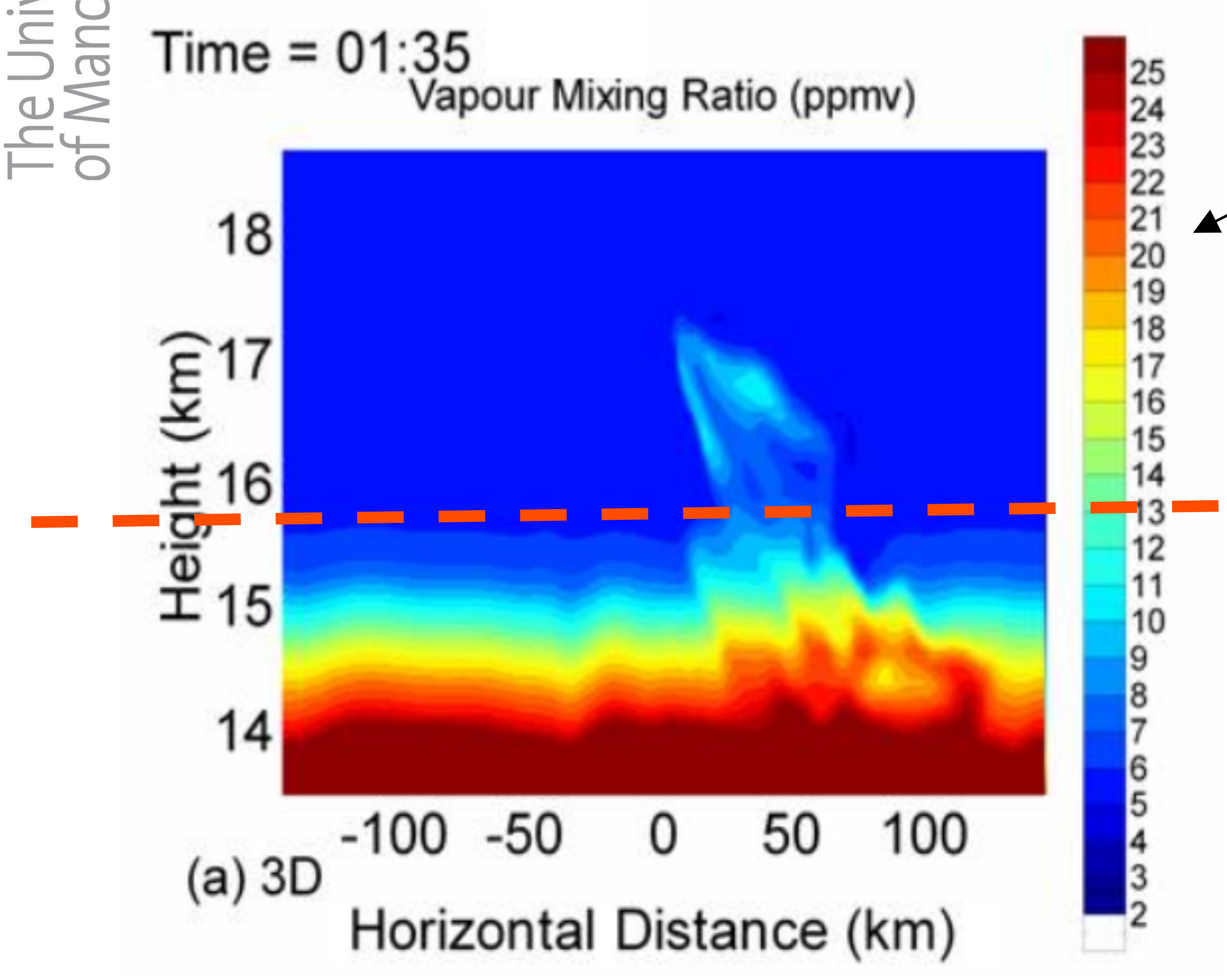


Run	Max updraught (m/s)	Max dBZ	Max height of echotop (km):		
			10 dBZ	35 dBZ	40 dBZ
3-D	50	54.7	18.2 (75)	17.5 (0)	15.1 (1)
3-D-med	39.3	56	17.4 (124)	16.5 (10)	15.6 (1)
3-D-weak	28.4	55.2	16.4 (322)	15.3 (23)	11.7 (152)

- *Numbers in red in brackets are number of real clouds with same max echo top heights*
- *Radar stats for 51 days over 240 km circular radius radar region*
- *Few real clouds with 35 and 40 dBZ echotops as high as in the more vigorous simulations*
- *Higher reflectivity contours in weaker cases don't reach as high – more consistent with observations*
- *But 10 dBZ (likely indicative of cloud top) consistent with many real clouds for all simulations*

See Grosvenor et al., ACP, 2007 for more details

Effect on stratospheric water vapour



Strong “3D” case

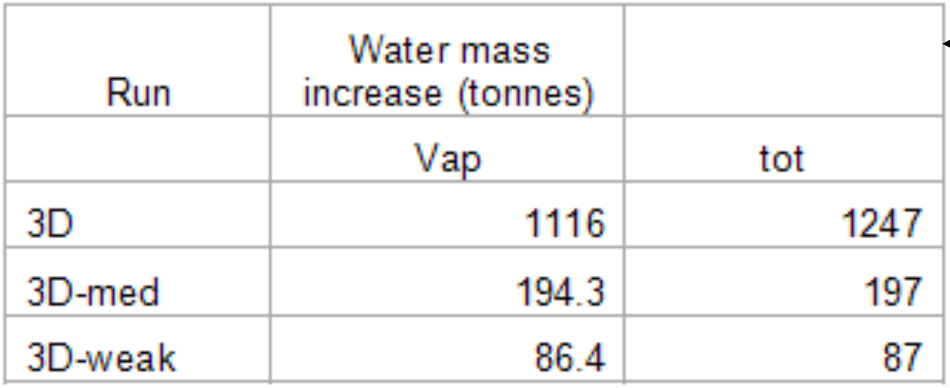
stratosphere

tropopause

troposphere

- No permanent dehydration in any cases
- Less moistening to lower heights with weaker cases

Water increase in stratosphere & global estimate



Run	Water mass increase (tonnes)	
	Vap	tot
3D	1116	1247
3D-med	194.3	197
3D-weak	86.4	87

- Water mass increase in stratosphere due to the simulated clouds
- 18.2, 17.4 & 16.4 km 10 dBZ echo tops
- A small difference in overshoot distance has a large effect on water transported
- Cf. ~100 tonnes observed near Darwin

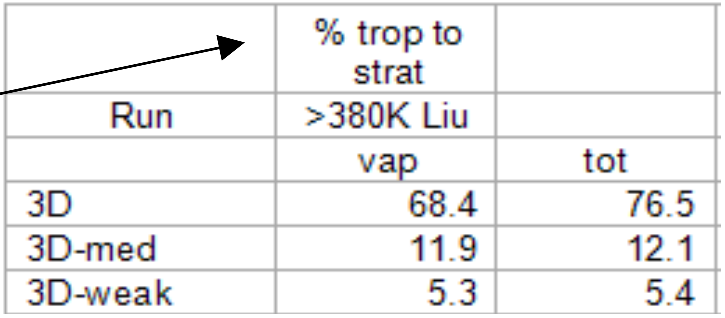
Extrapolation to global scale:

- Need an estimate of frequency of overshoots
- Done here based on counting of overshoots by the TRMM satellite (Liu and Zipser, JGR, 2005) – number of times the 20 dBZ echo is seen above mean 380 K level
- BUT… only has views "snapshots" of tropics so for frequency estimate:-
  - Require estimate of lifetime of 20 dBZ signal above the tropopause – frequency inversely proportional to this number
  - Used values from model here – ranges from 10.5 to 16.7 mins
  - NCEP 380 K height used

$$f_{overshoot} \propto \frac{1}{T_{20dBZ}}$$

$$\% = \frac{f_{overshoot} M_{water}}{\left(\frac{dM}{dt}\right)_{BD}} \text{ x100}$$

- Converted to % of the Brewer Dobson flux of vapour (usual candidate for main source of stratospheric water vapour)
- Suggests that overshoots could a major contributor to stratospheric water if most overshoots behave like in the strongest case

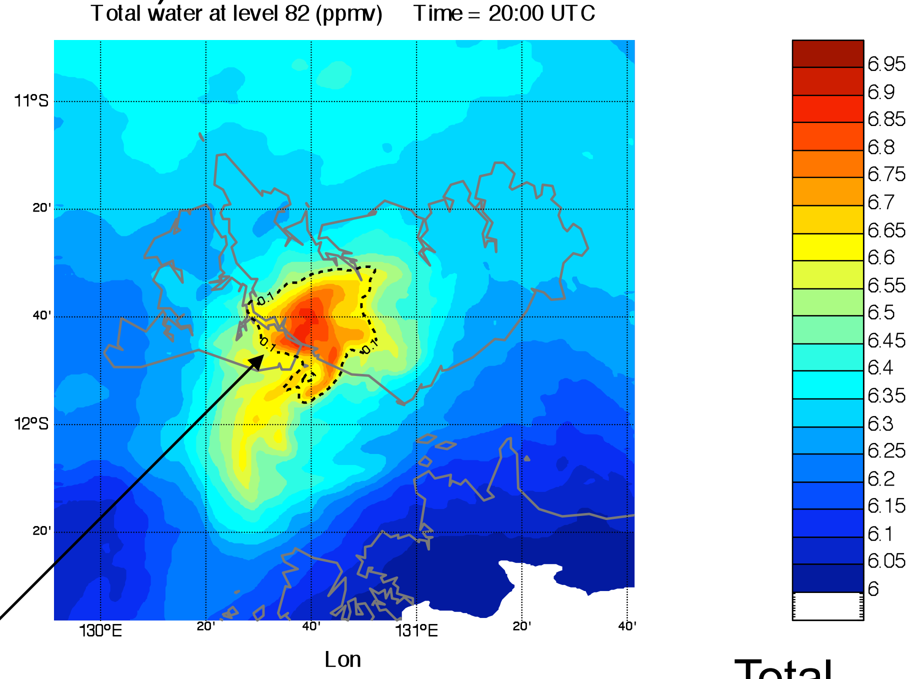


Run	% trop to strat >380K Liu	
	vap	tot
3D	68.4	76.5
3D-med	11.9	12.1
3D-weak	5.3	5.4

WRF 27-30th Nov, 2005 case study

- Early results from recent WRF simulation
- 3 nests of 9, 3 and 1 km resolution
- Aim to compare to the observed overshoot over Tiwi Islands on 30th Nov
- But overshoots all occur a day early…
- Comparison with radar data of real clouds to come

Cross sections of a stratospheric model level – corresponds to mean potential temperature of ~387 K (cold point at ~369 K)



200 km

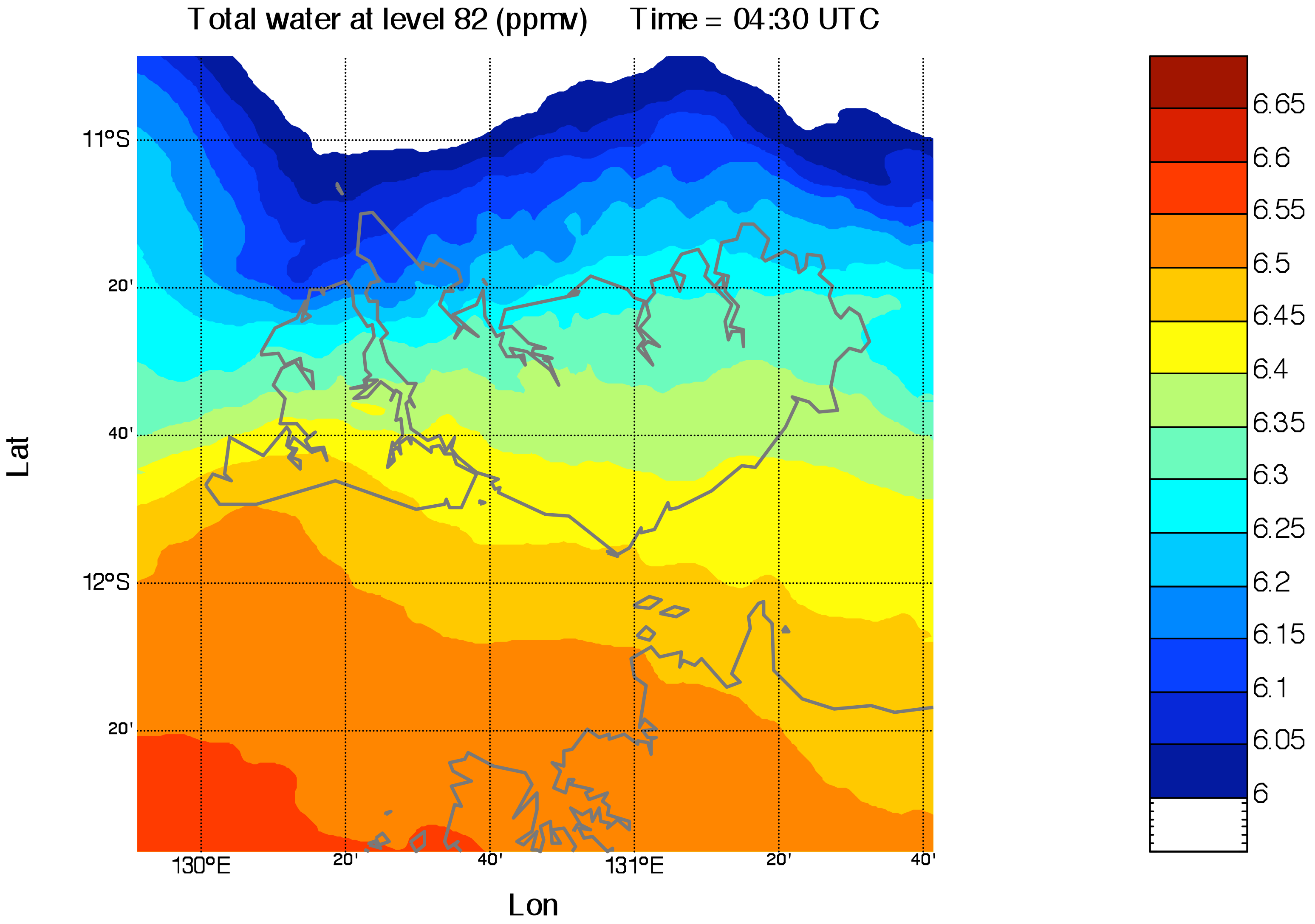
200 km

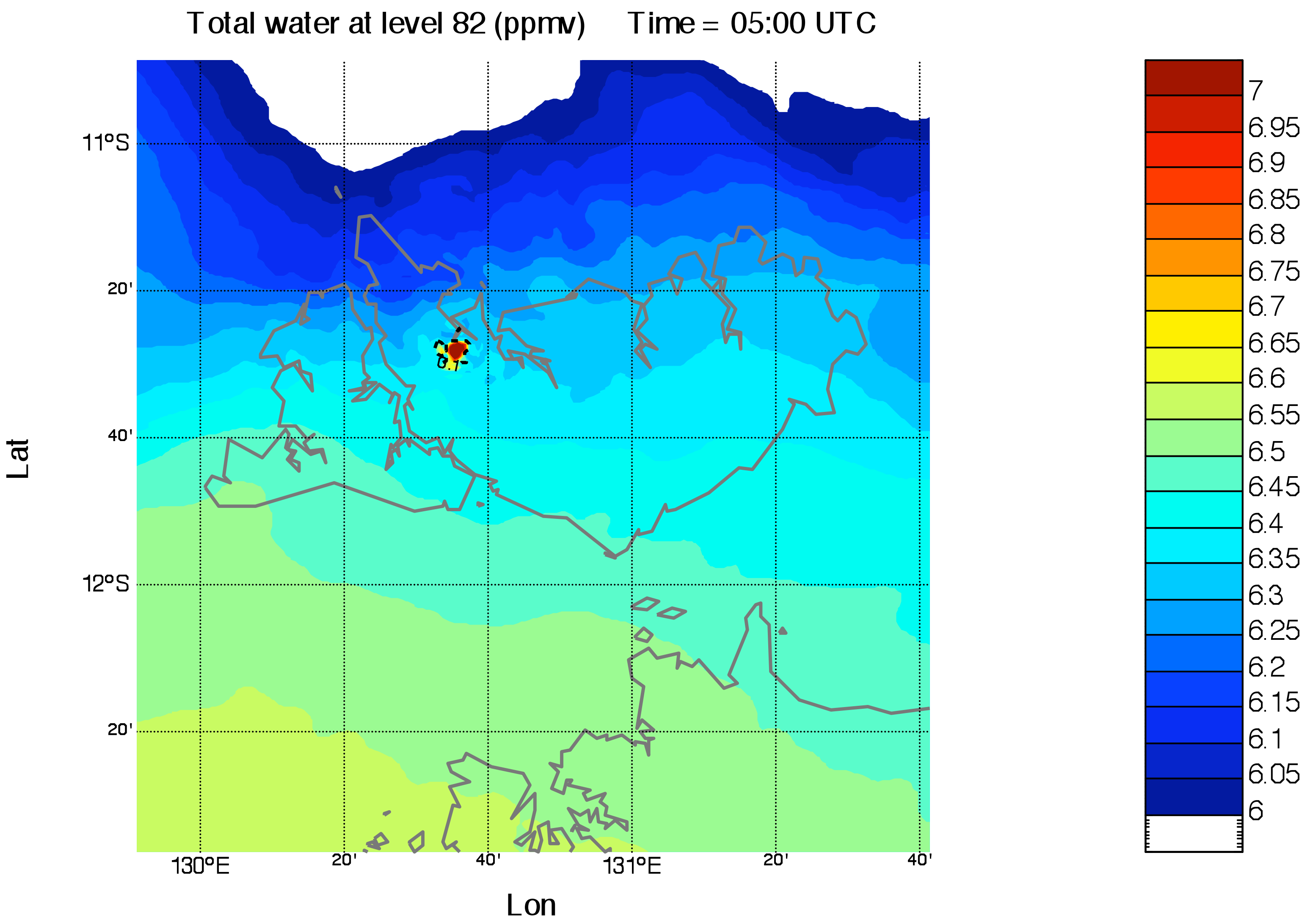
0.1 ppmv ice contour

Inner nest (1 km res)

Vertical resolution ~250 m at this level

Total water (ppmv) - scale limited to 7 ppmv


Total water at level 82 (ppmv)   Time = 04:30 UTC
11°S
20'
40'
12°S
20'
Lat
130°E
20'
40'
131°E
20'
40'
Lon
6.65
6.6
6.55
6.5
6.45
6.4
6.35
6.3
6.25
6.2
6.15
6.1
6.05
6

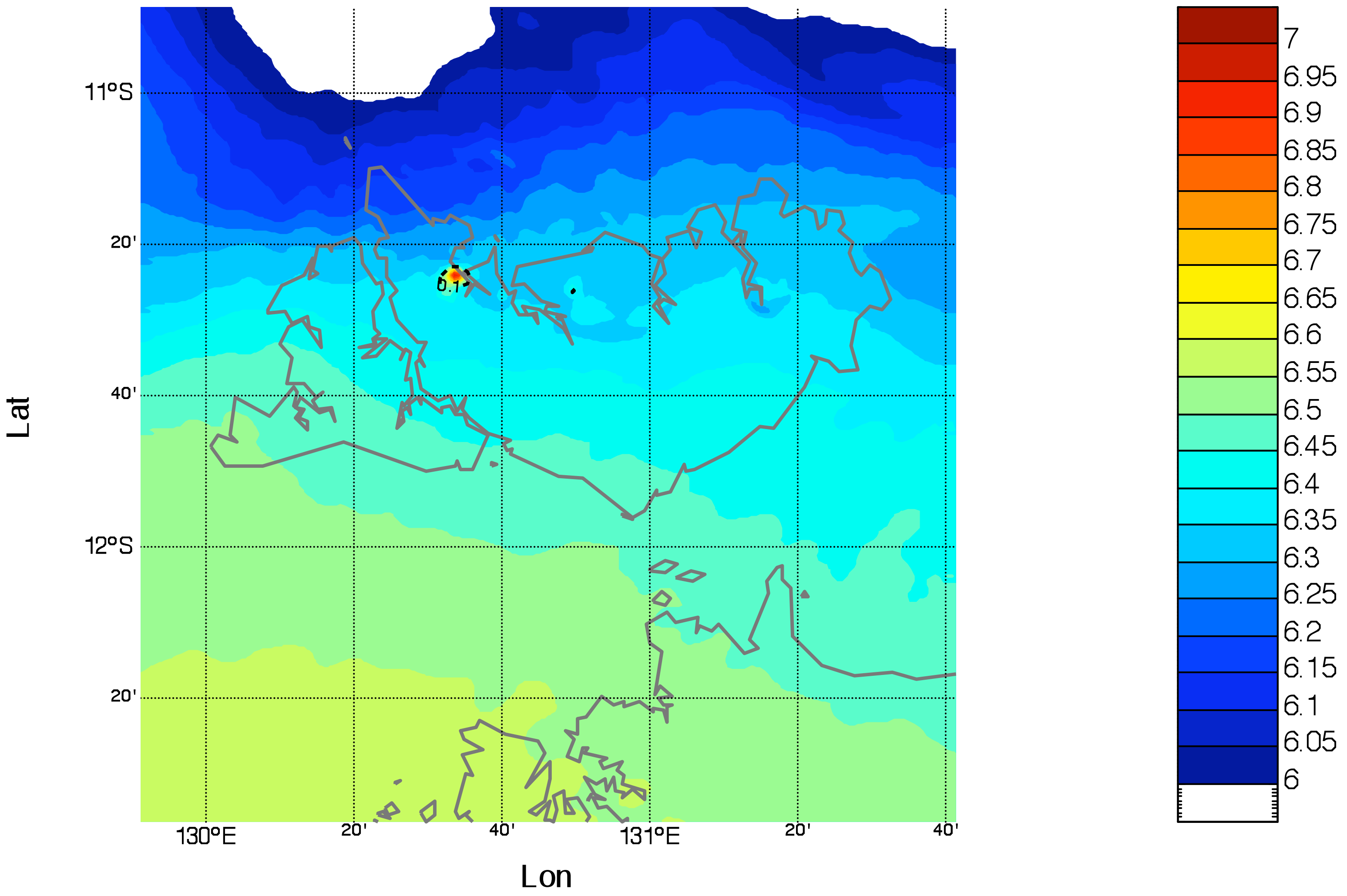


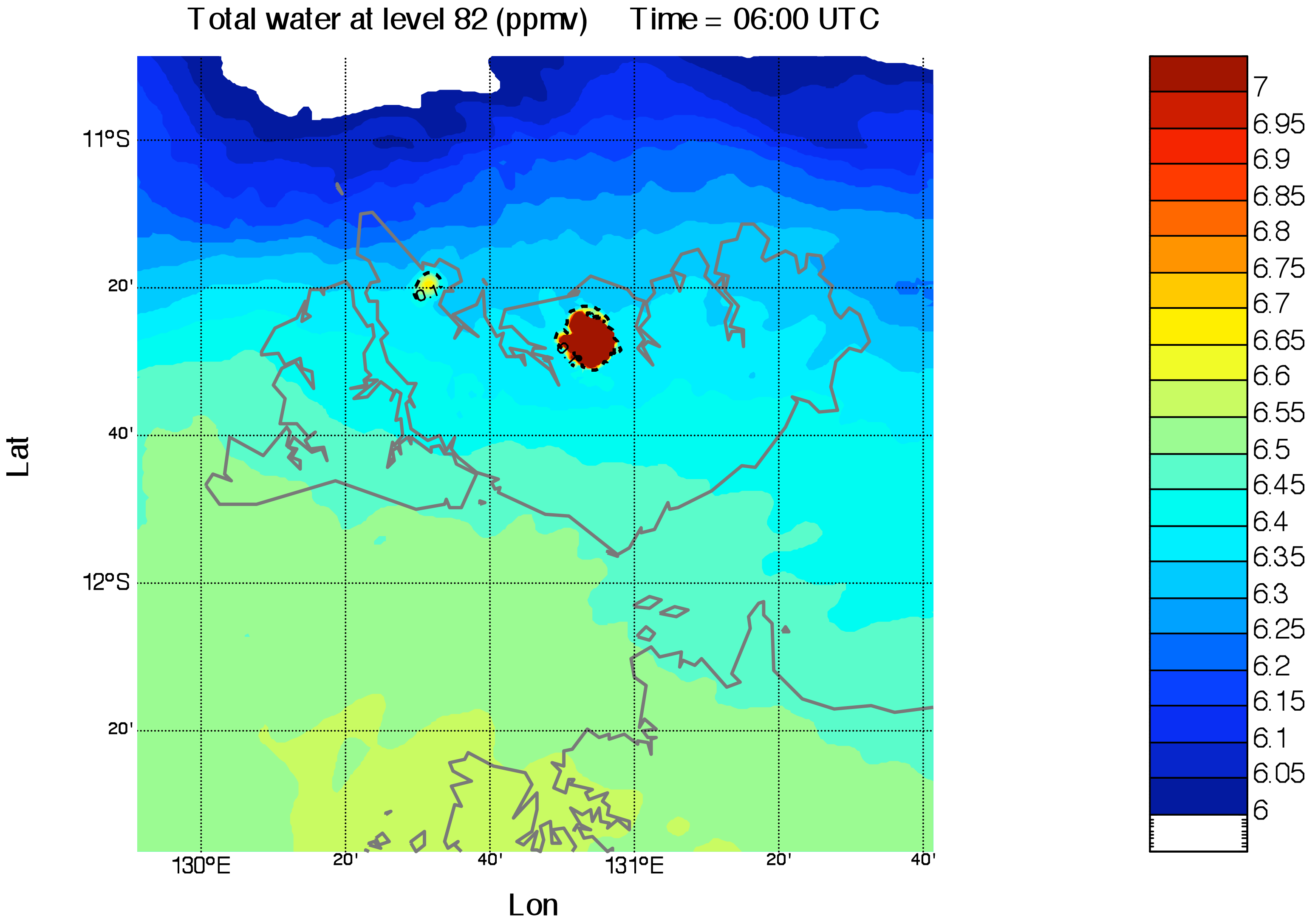
Total water at level 82 (ppmv)   Time = 05:00 UTC

Overshoot 1

MANCHESTER
1824

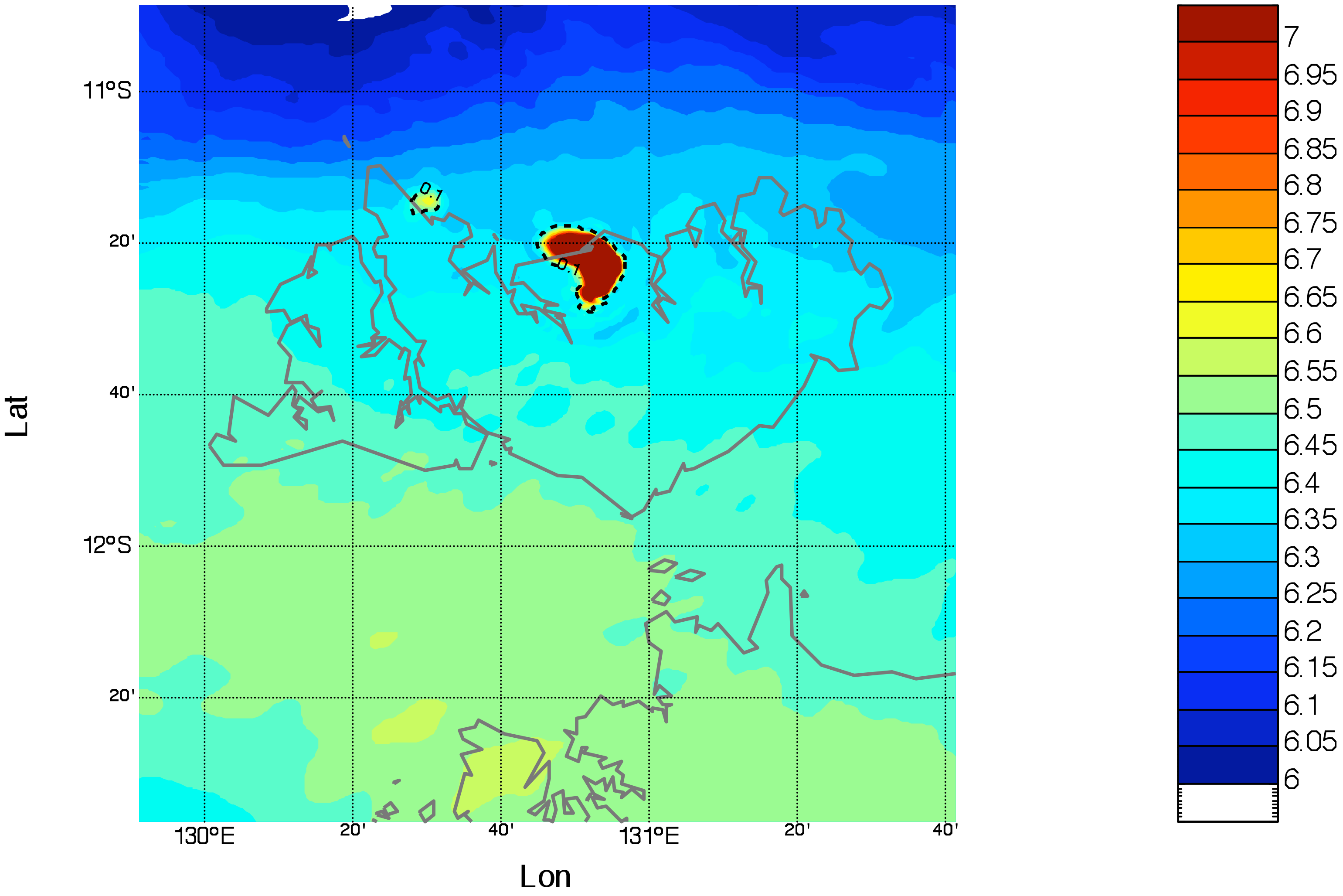
Total water at level 82 (ppmv)   Time = 05:30 UTC

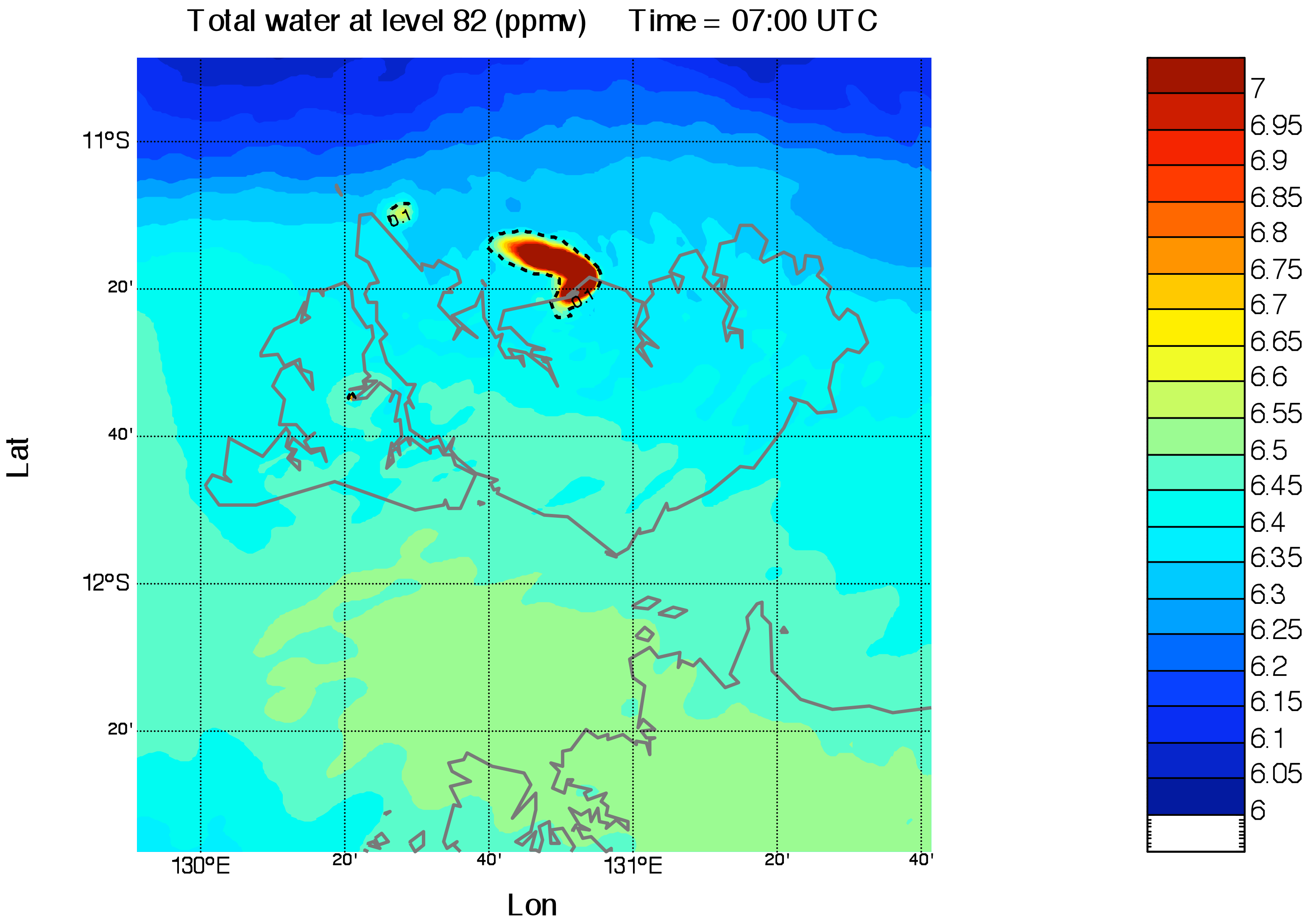



Total water at level 82 (ppmv)   Time = 06:00 UTC
11°S
20'
40'
12°S
20'
Lat
130°E
20'
40'
131°E
20'
40'
Lon
0.1
7
6.95
6.9
6.85
6.8
6.75
6.7
6.65
6.6
6.55
6.5
6.45
6.4
6.35
6.3
6.25
6.2
6.15
6.1
6.05
6

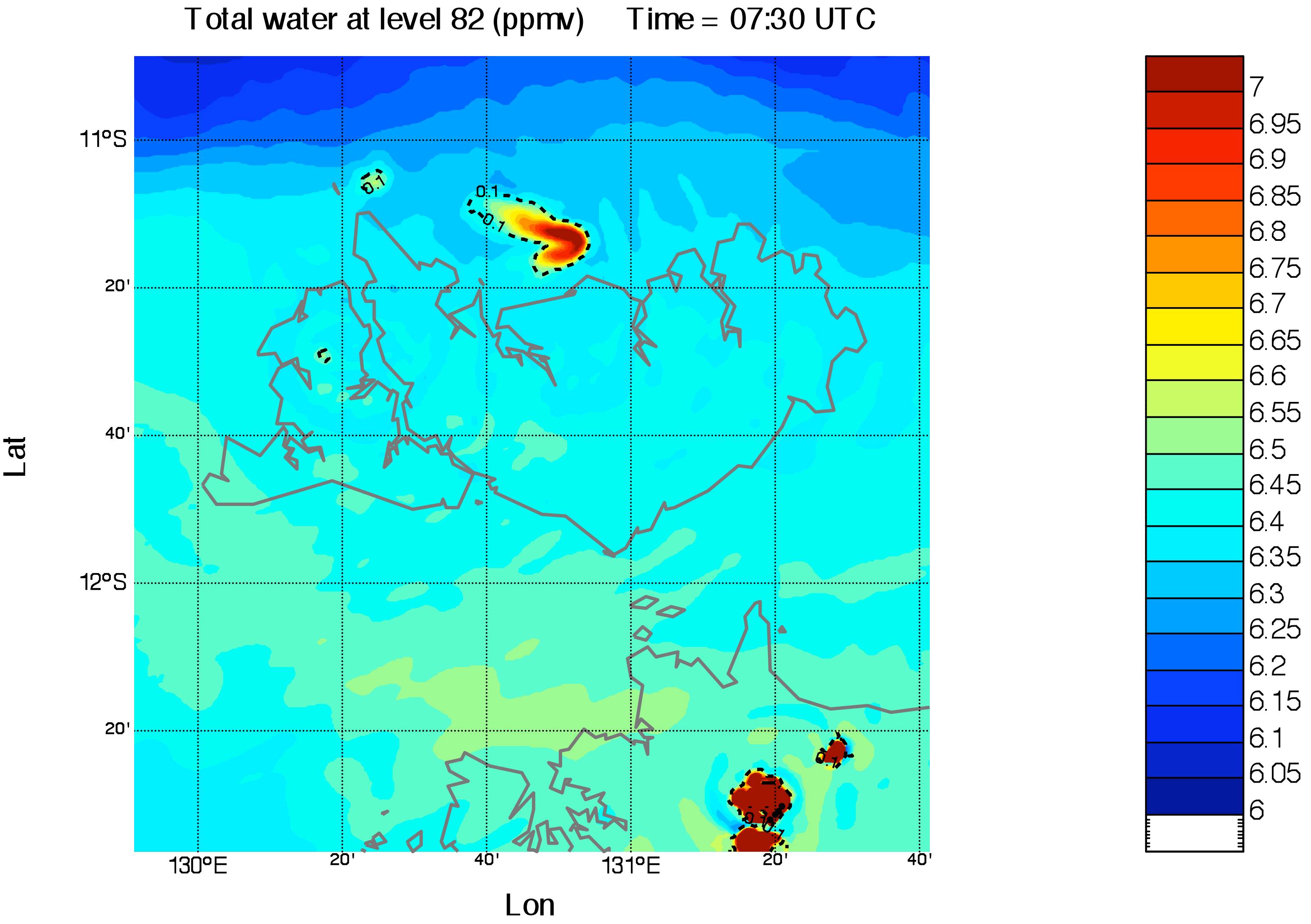
Overshoot 2

Total water at level 82 (ppmv)   Time = 06:30 UTC

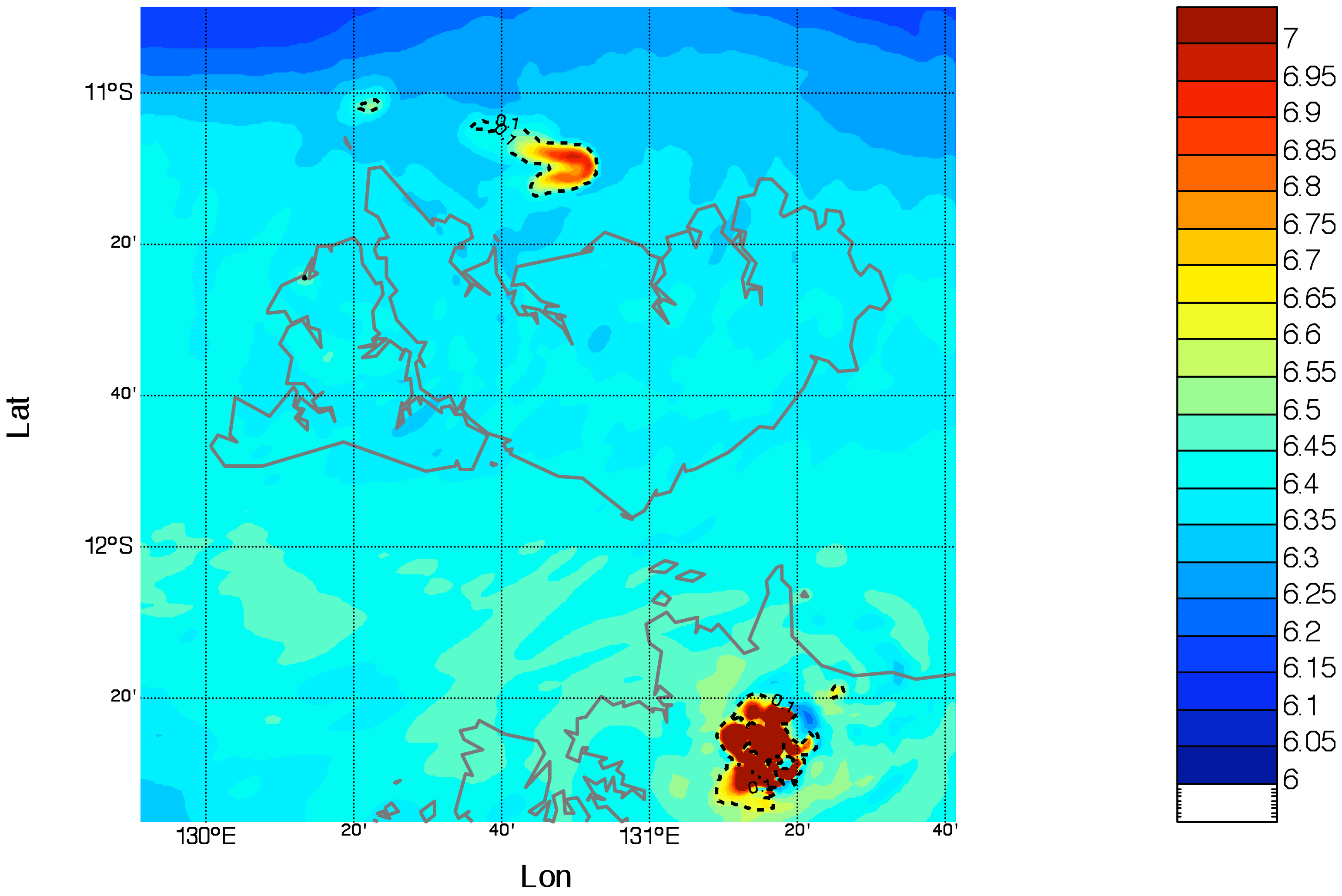




Overshoots 1 & 2 leave ~ 9 tonnes of vapour in the stratosphere and ~ 13 tonnes of total water

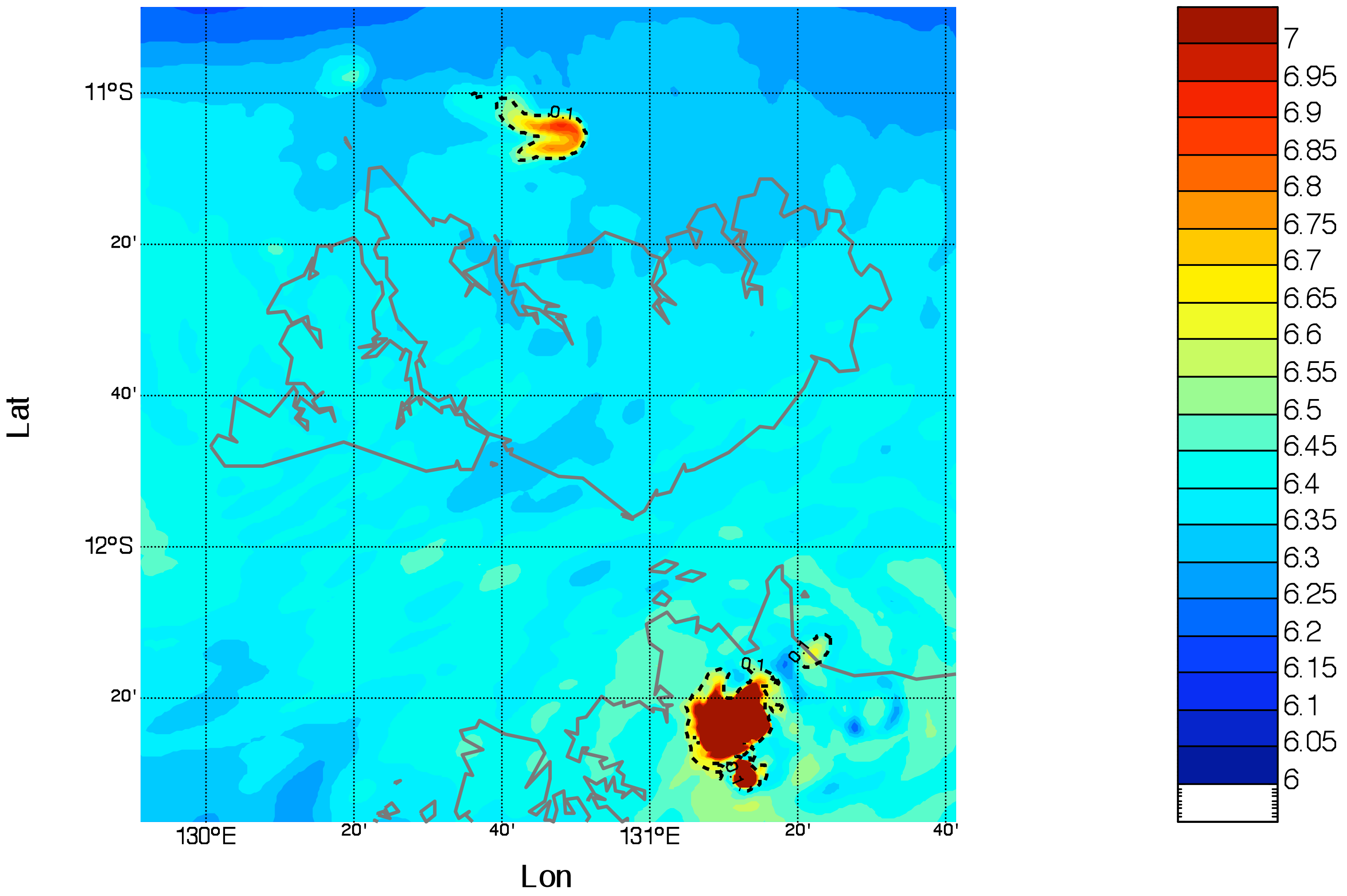

Total water at level 82 (ppmv)   Time = 07:30 UTC
Lat
Lon
11°S
20'
40'
12°S
20'
130°E
20'
40'
131°E
20'
40'
0.1
7
6.95
6.9
6.85
6.8
6.75
6.7
6.65
6.6
6.55
6.5
6.45
6.4
6.35
6.3
6.25
6.2
6.15
6.1
6.05
6

Total water at level 82 (ppmv)   Time = 08:00 UTC

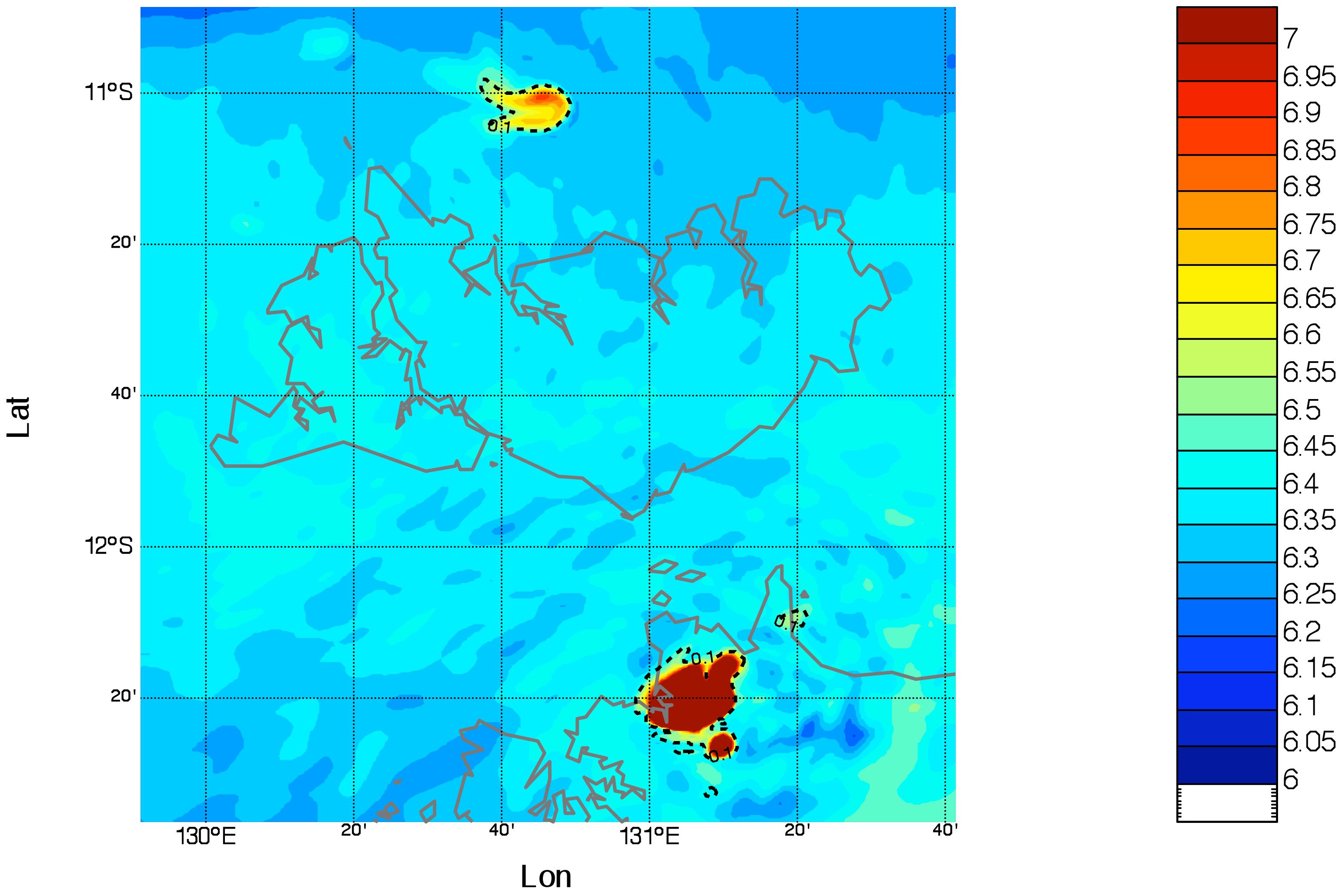


Overshoot 3

Total water at level 82 (ppmv)   Time = 08:30 UTC

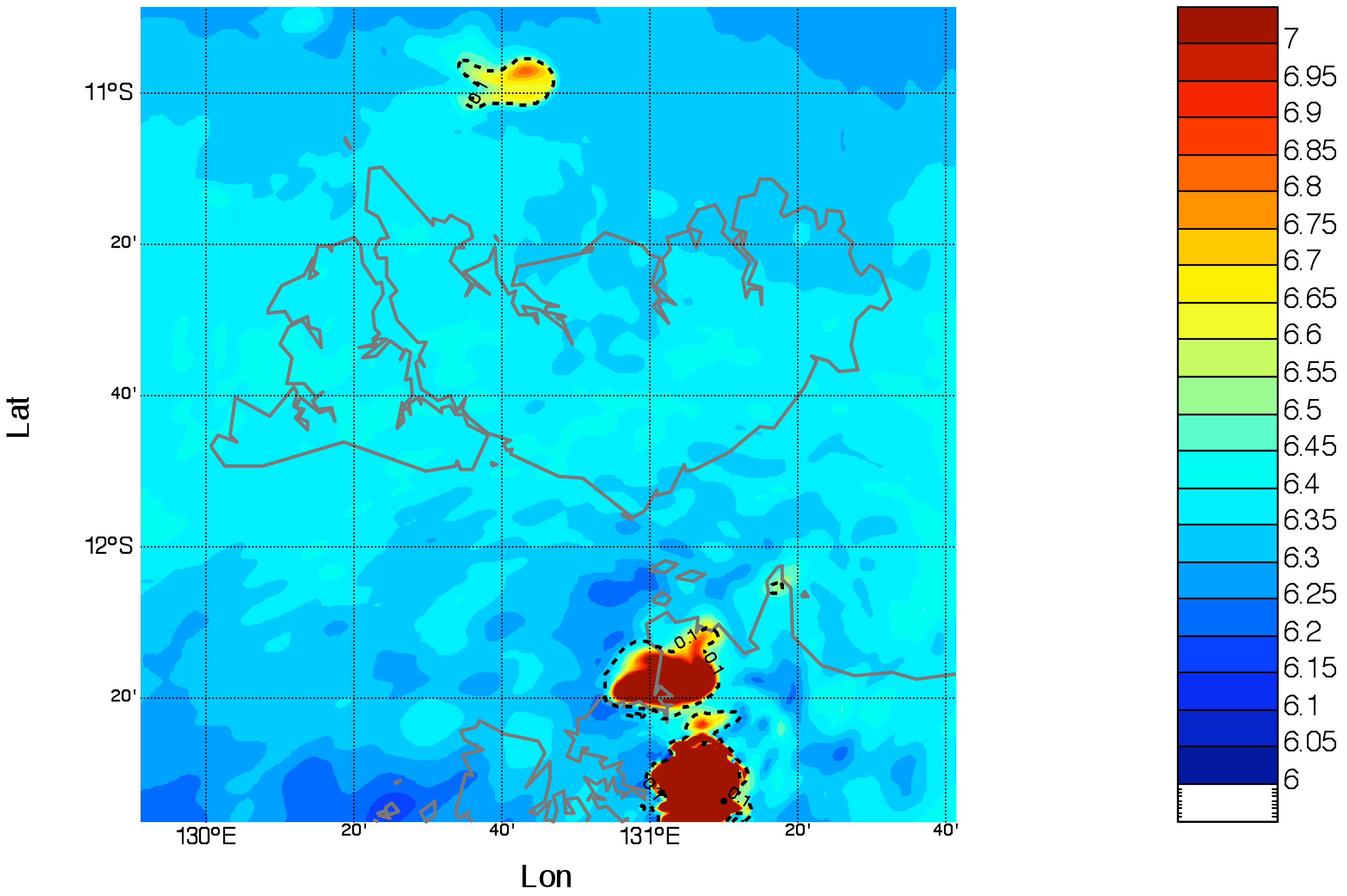


Total water at level 82 (ppmv)   Time = 09:00 UTC

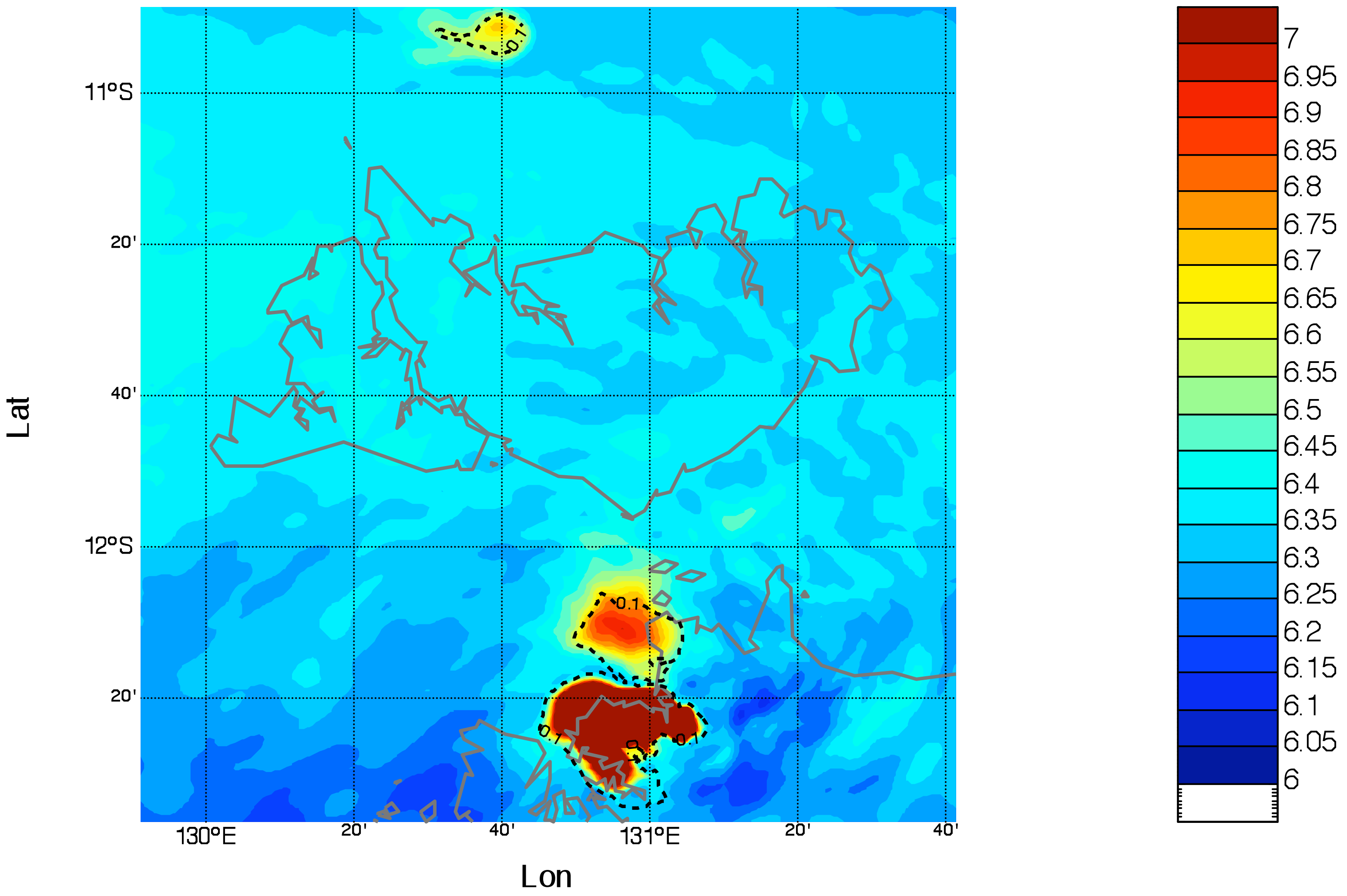


MANCHESTER
1824

Total water at level 82 (ppmv)   Time = 09:30 UTC

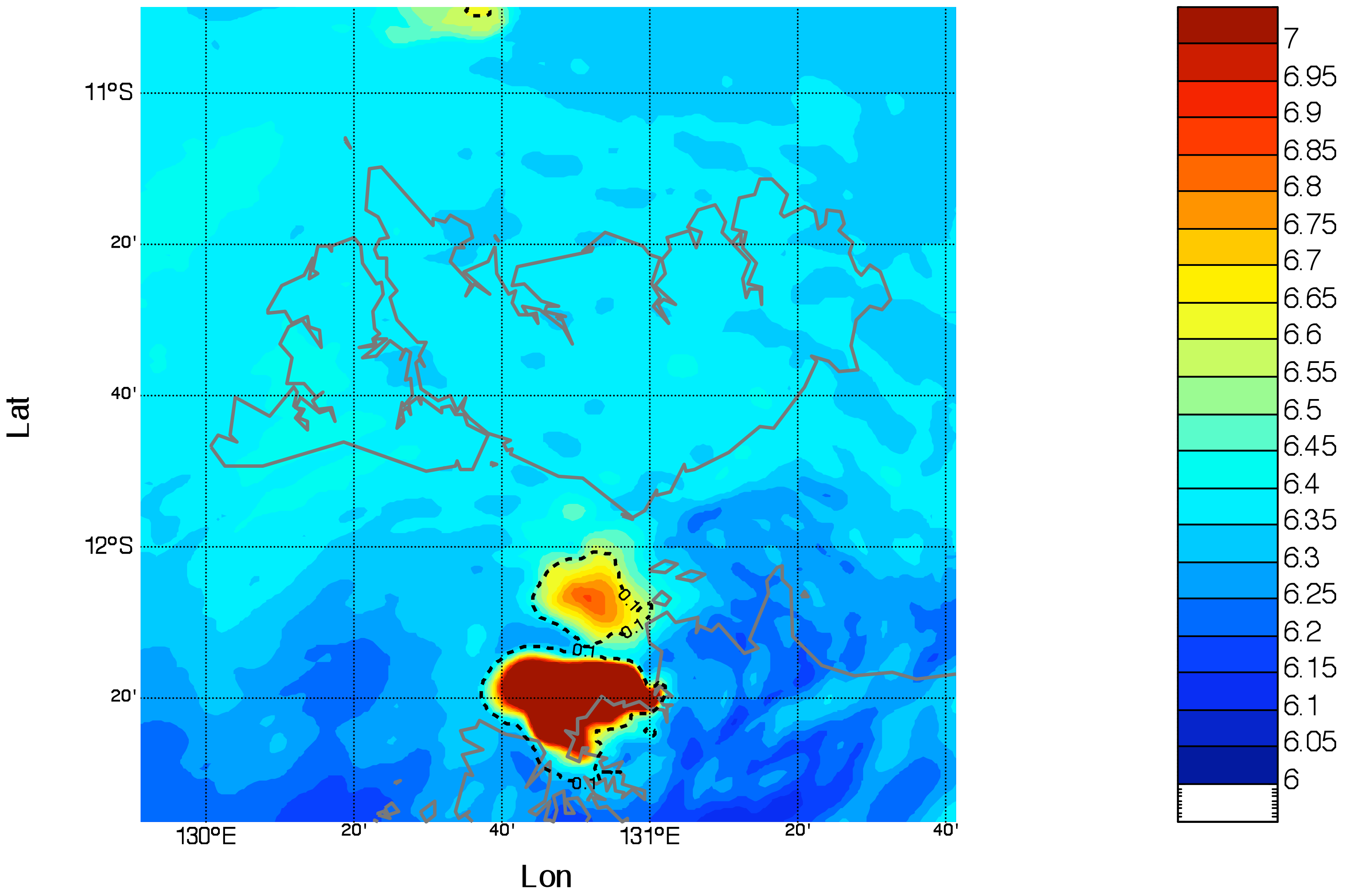


Overshoot 4

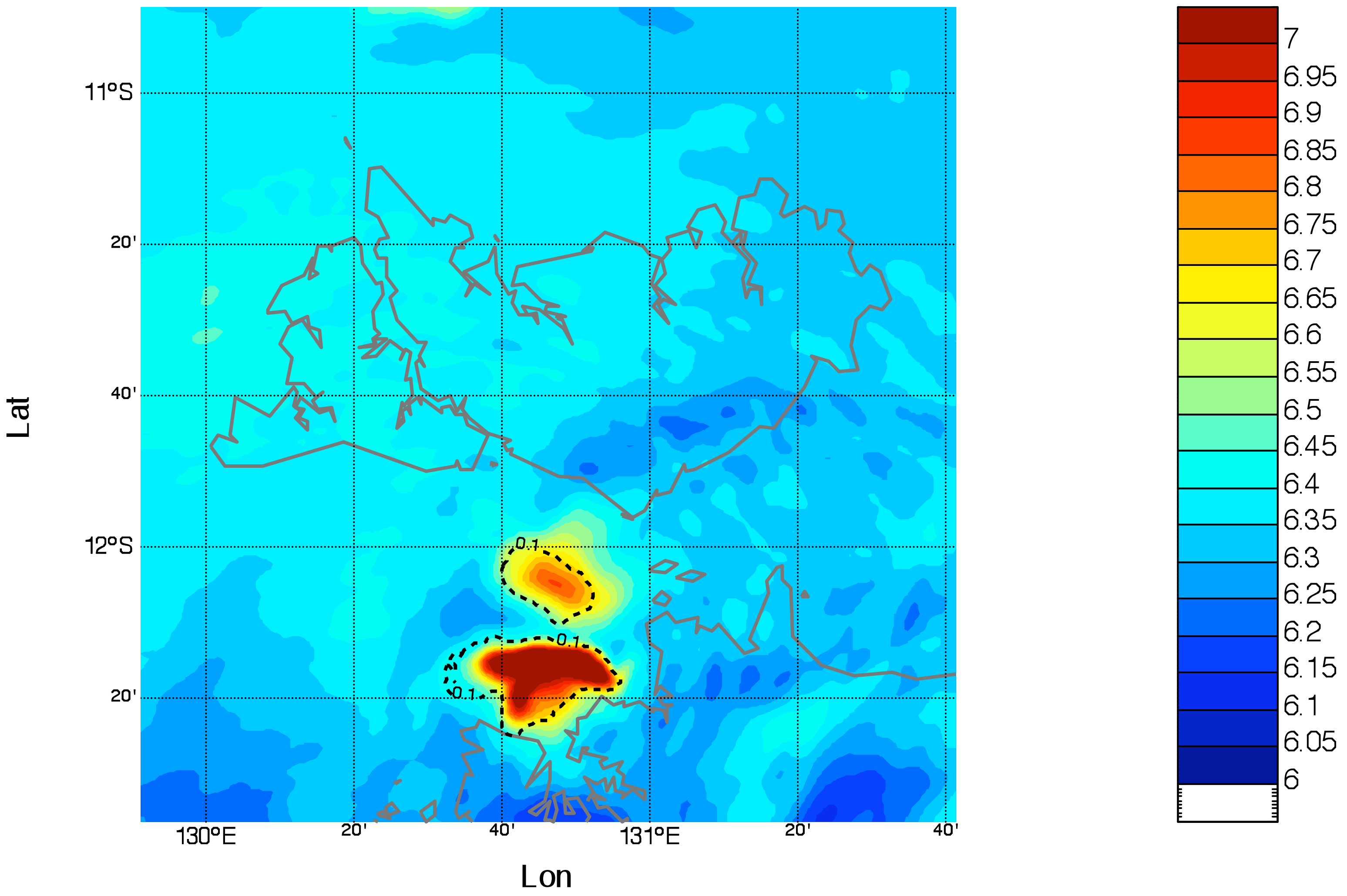


Total water at level 82 (ppmv) Time = 10:30 UTC

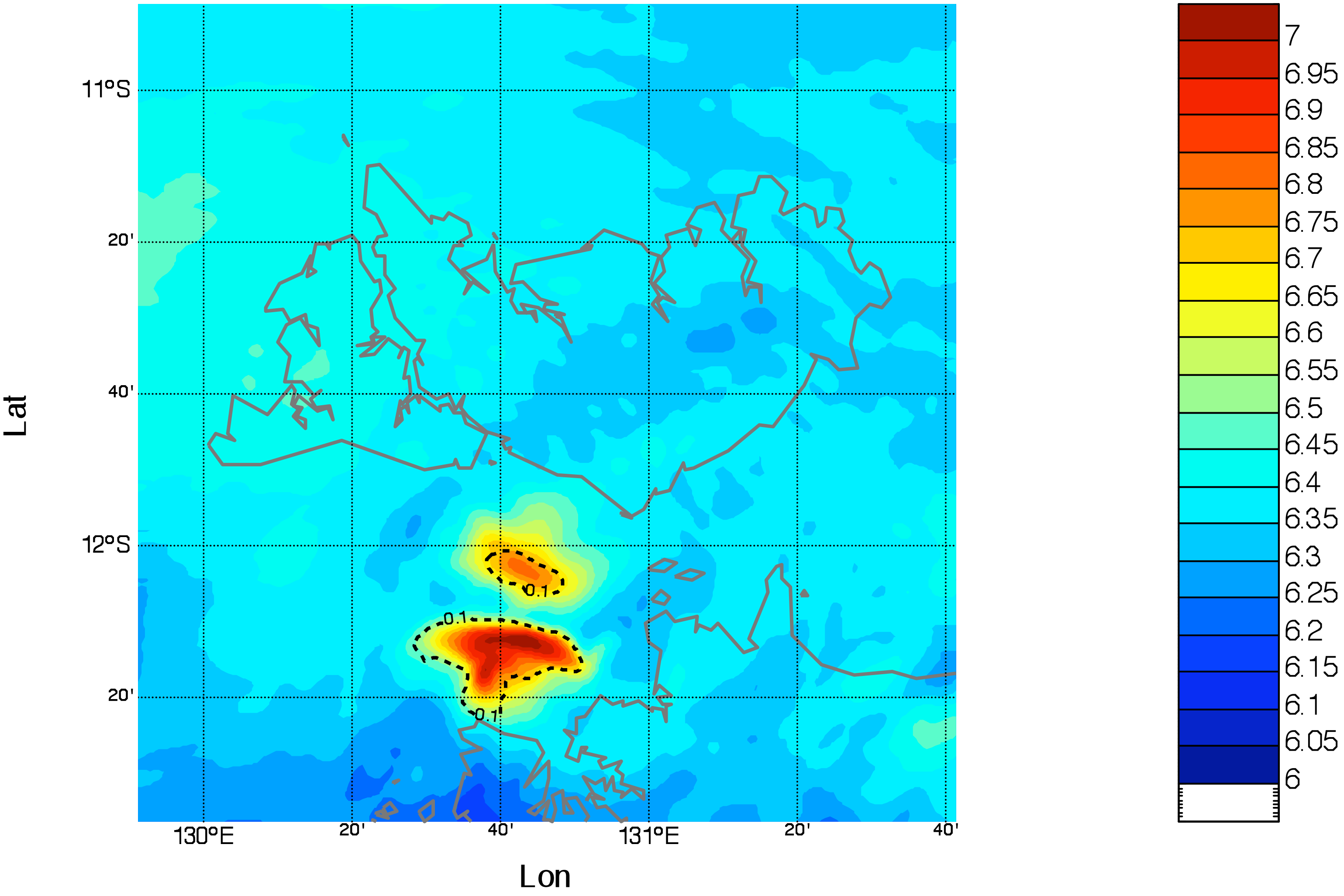
Total water at level 82 (ppmv)   Time = 11:00 UTC

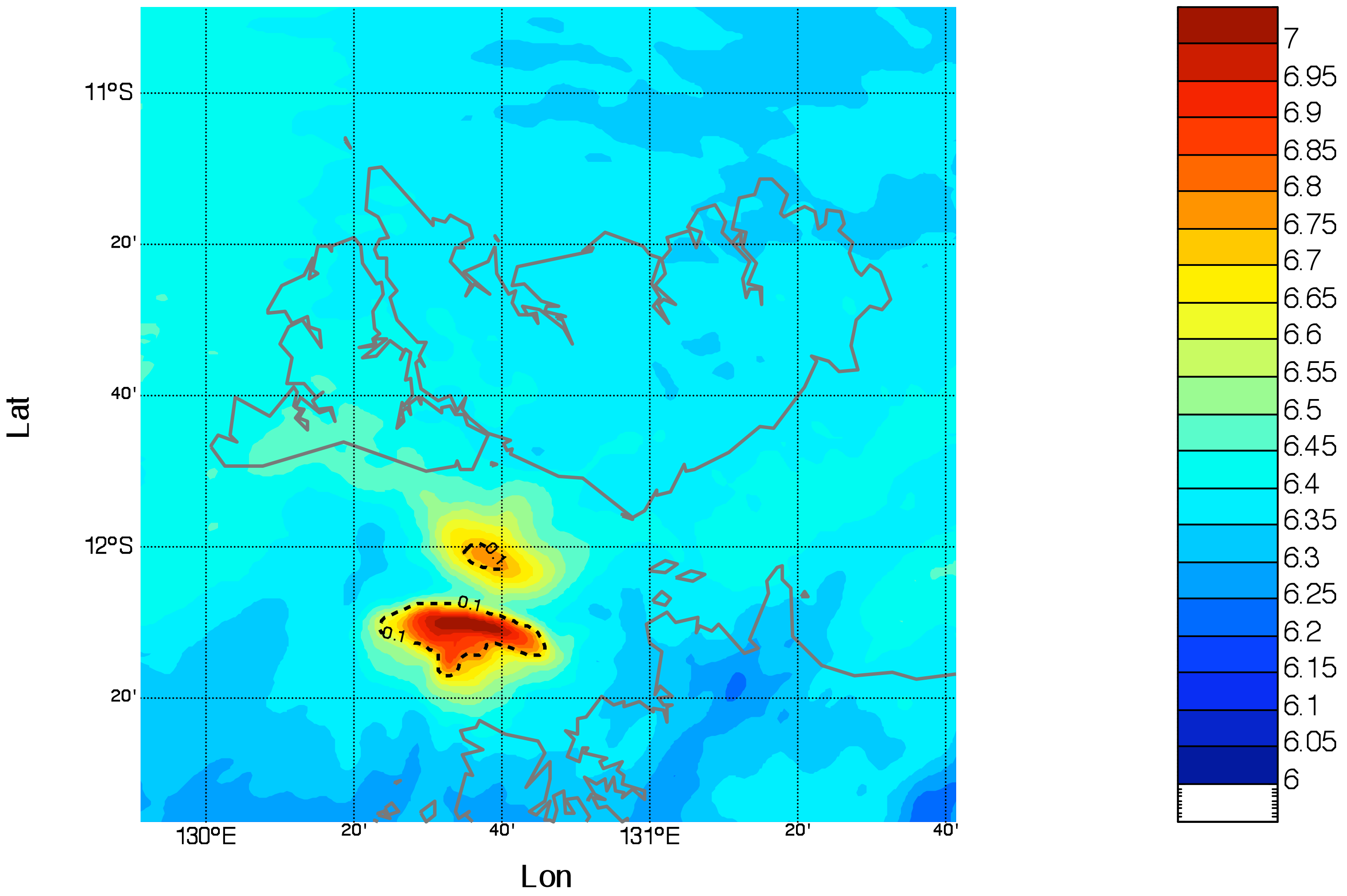


Total water at level 82 (ppmv)   Time = 11:30 UTC



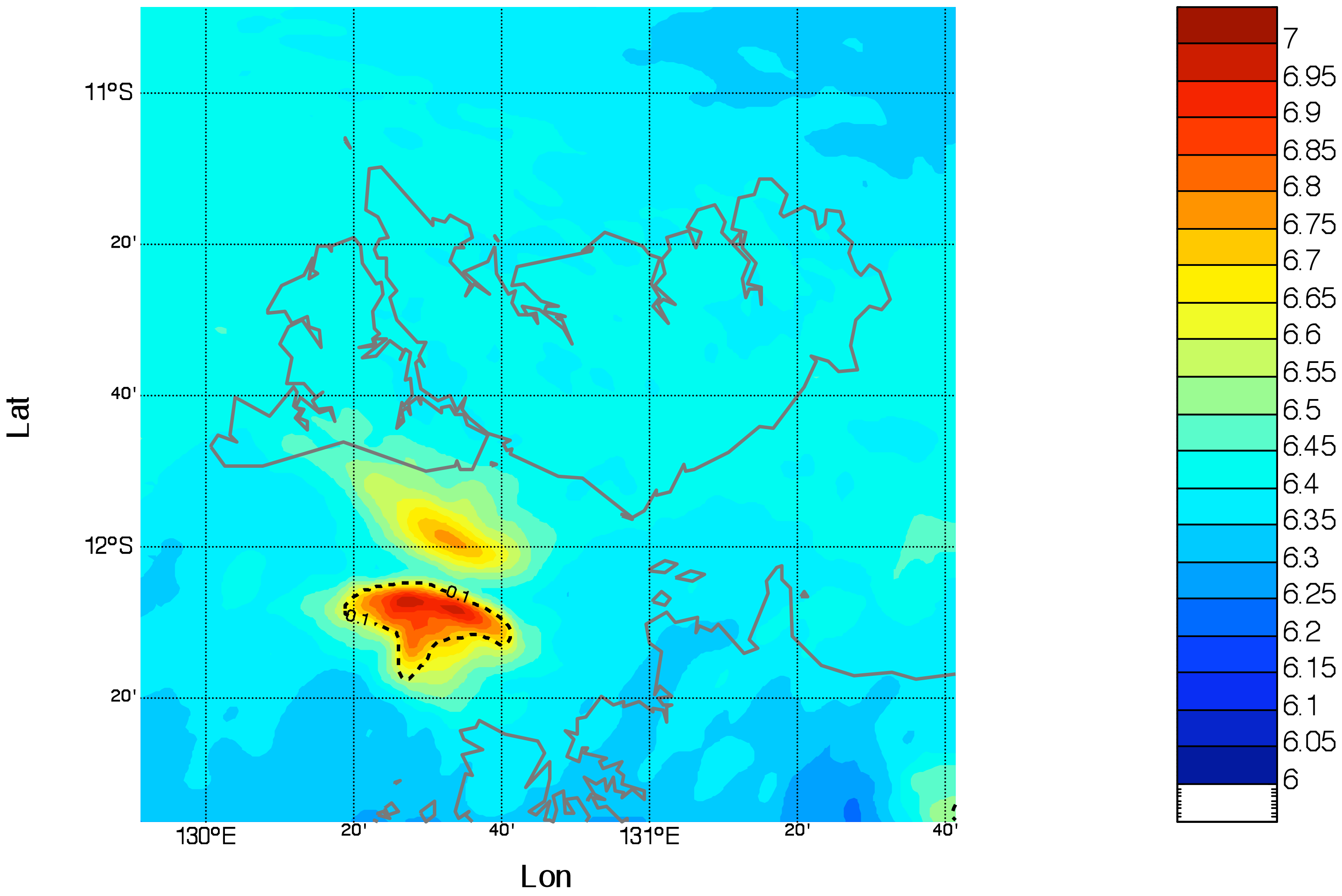
Total water at level 82 (ppmv)   Time = 12:00 UTC

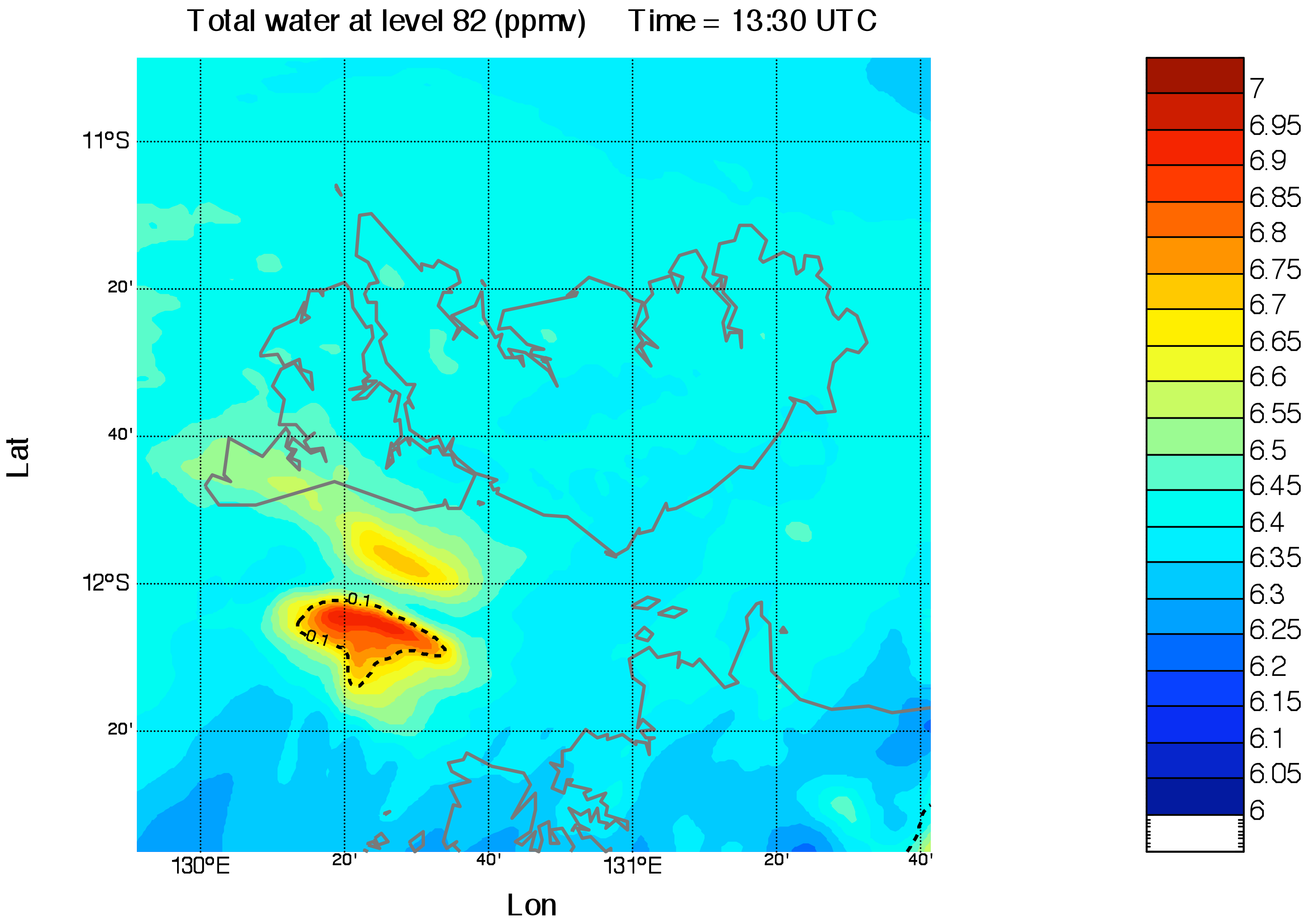




Total water at level 82 (ppmv)   Time = 12:30 UTC

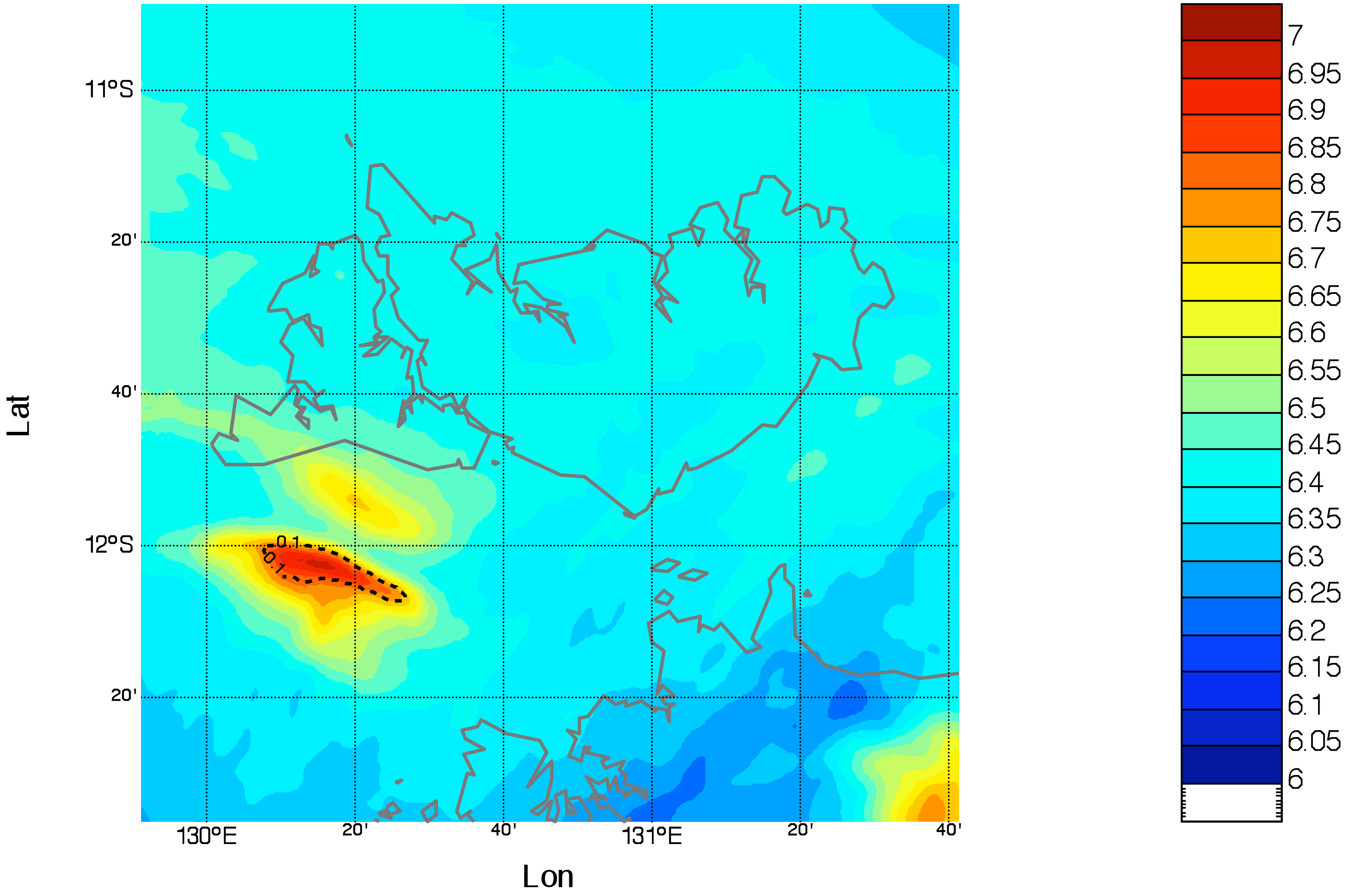
Total water at level 82 (ppmv)   Time = 13:00 UTC



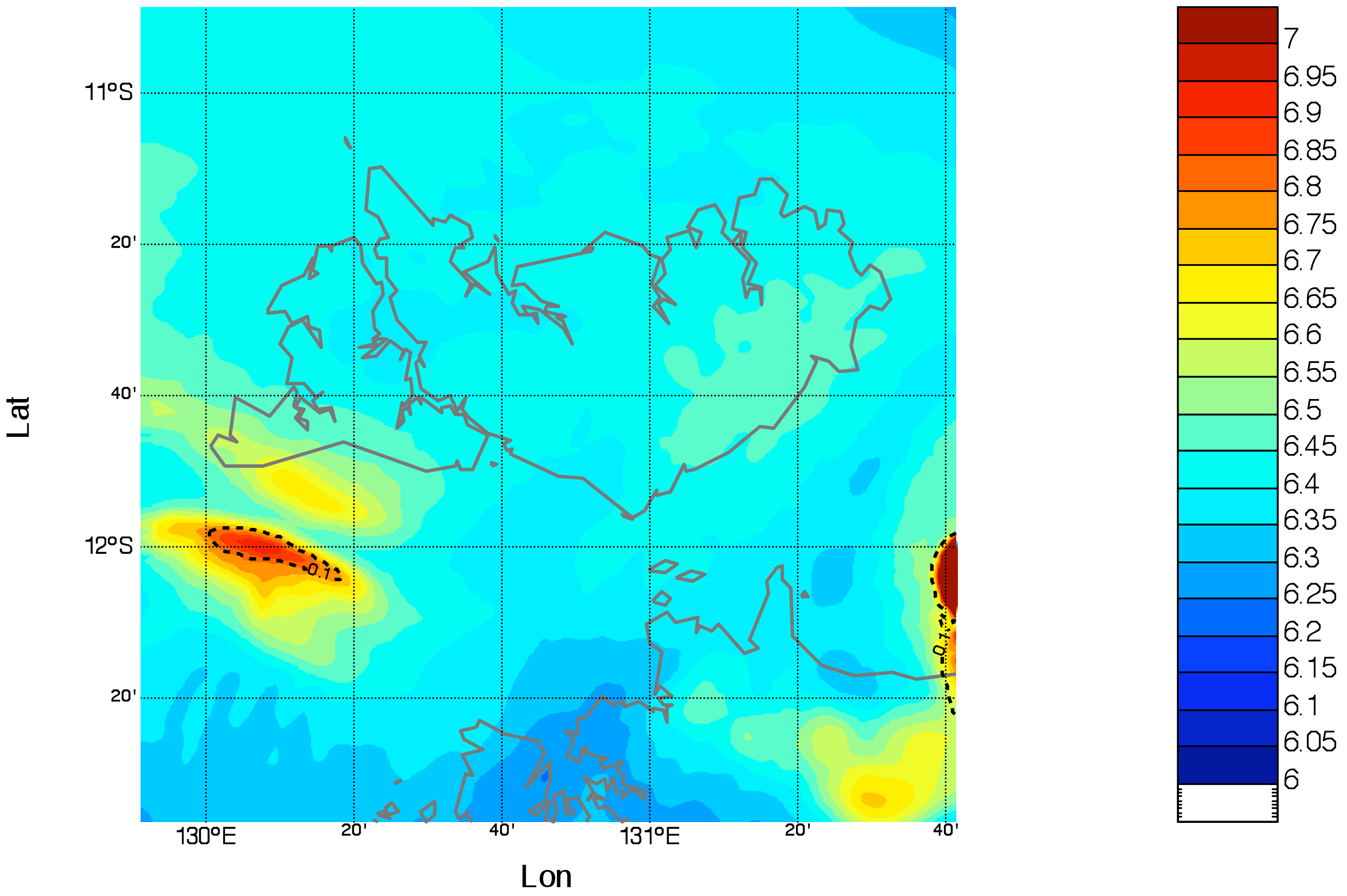


Overshoots 3 & 4 leave ~40 tonnes of vapour and ~ 50 tonnes of total water in the stratosphere

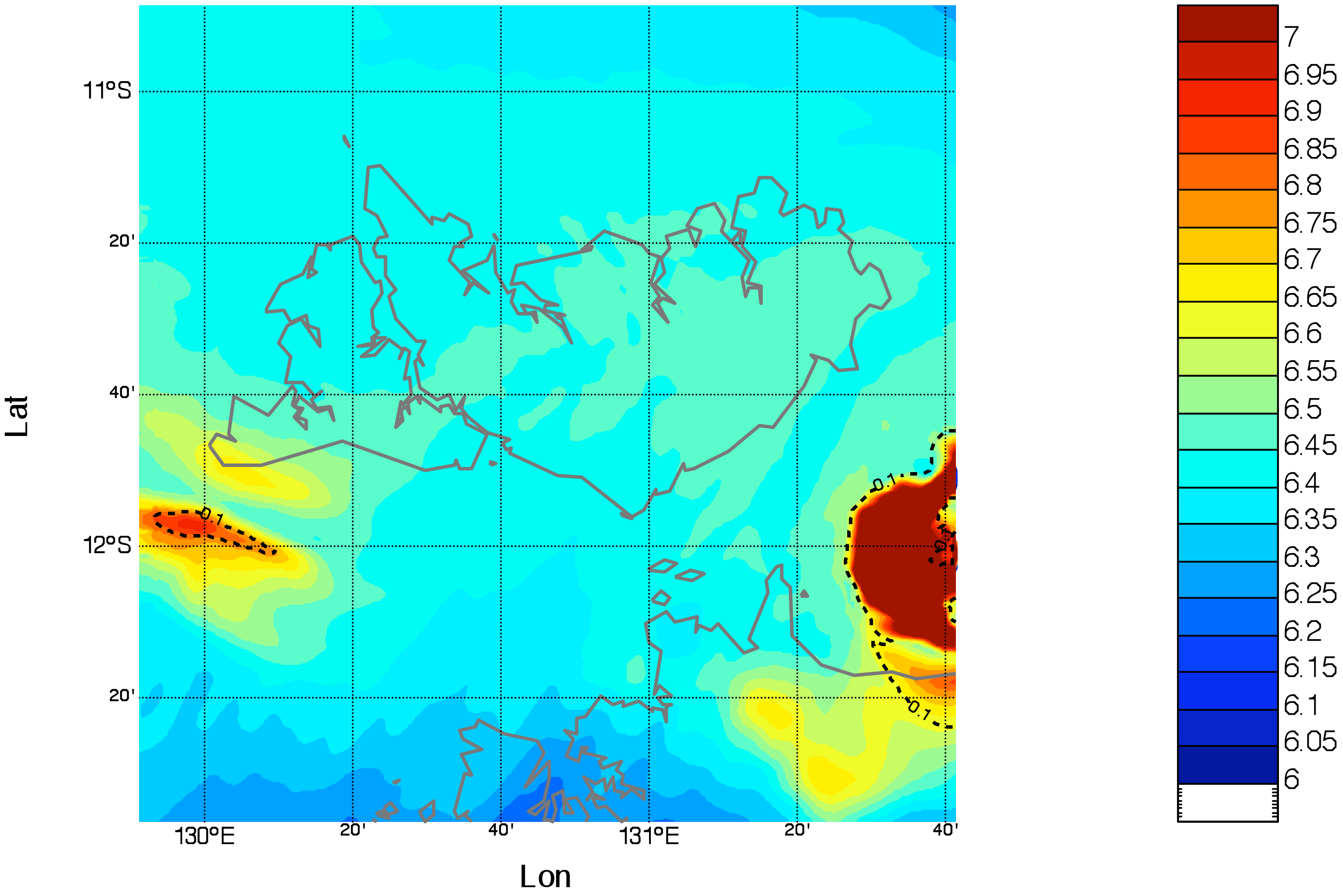
Total water at level 82 (ppmv)   Time = 14:00 UTC



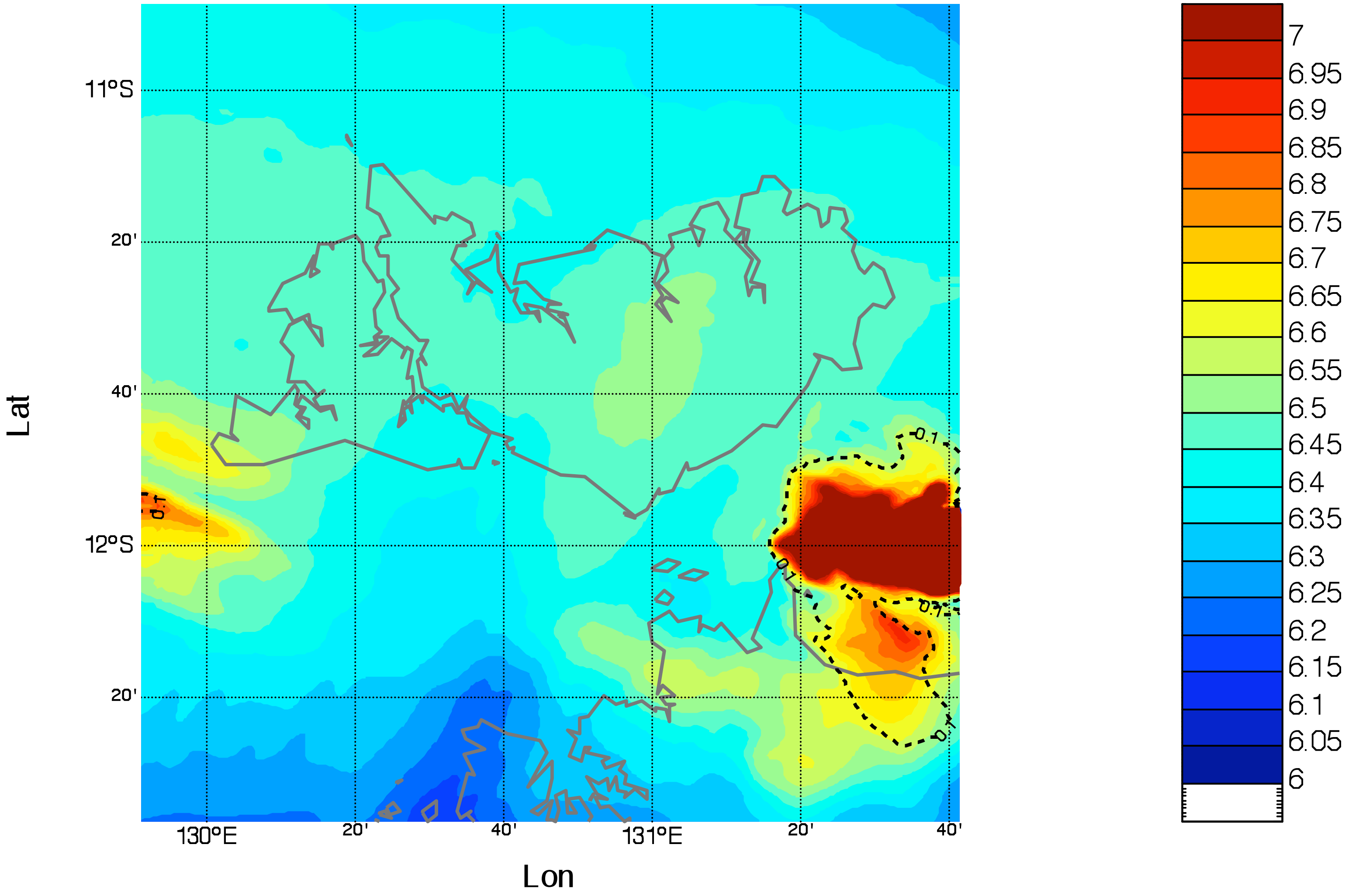
Total water at level 82 (ppmv)   Time = 14:30 UTC

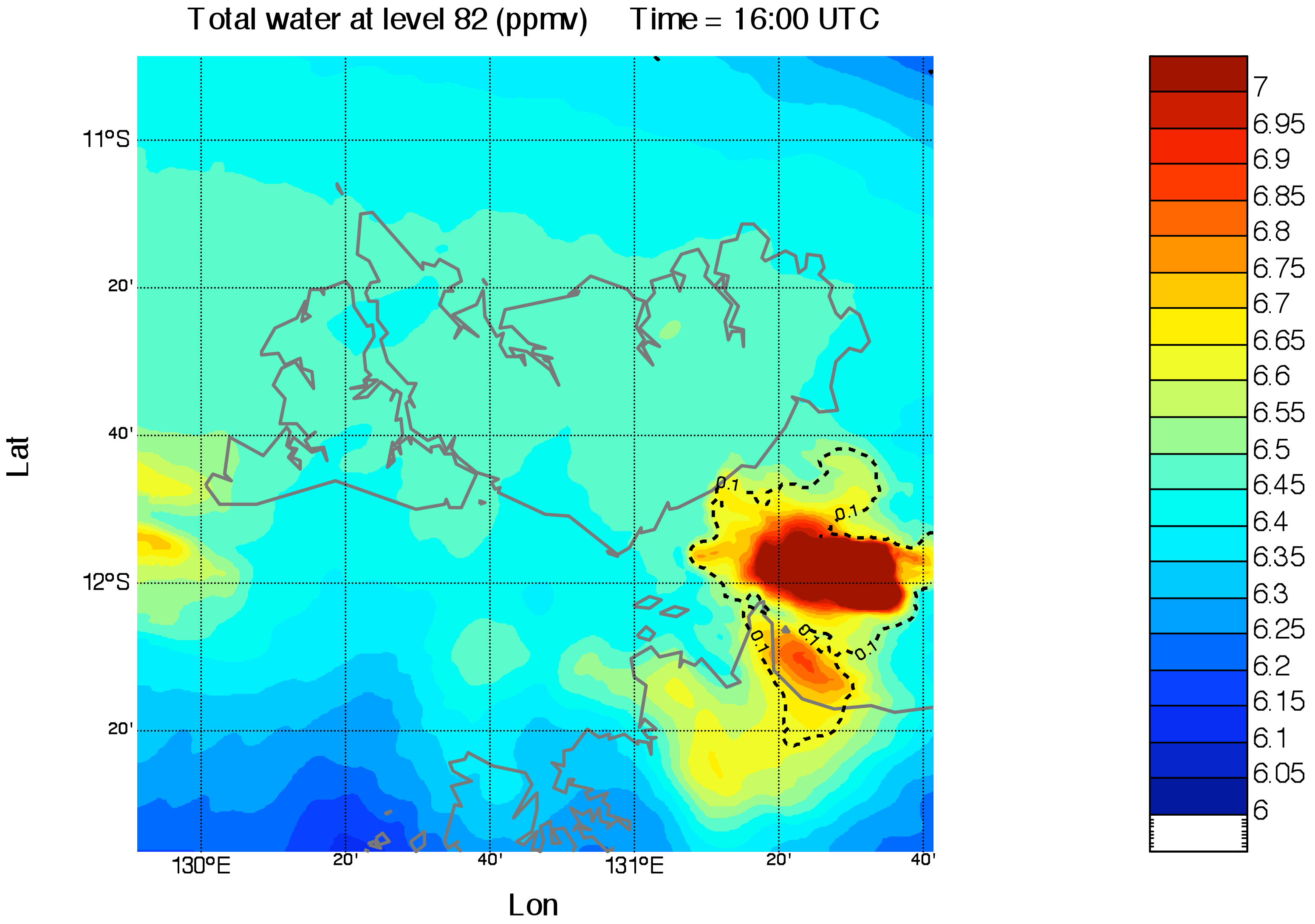


Total water at level 82 (ppmv)   Time = 15:00 UTC



Total water at level 82 (ppmv)   Time = 15:30 UTC

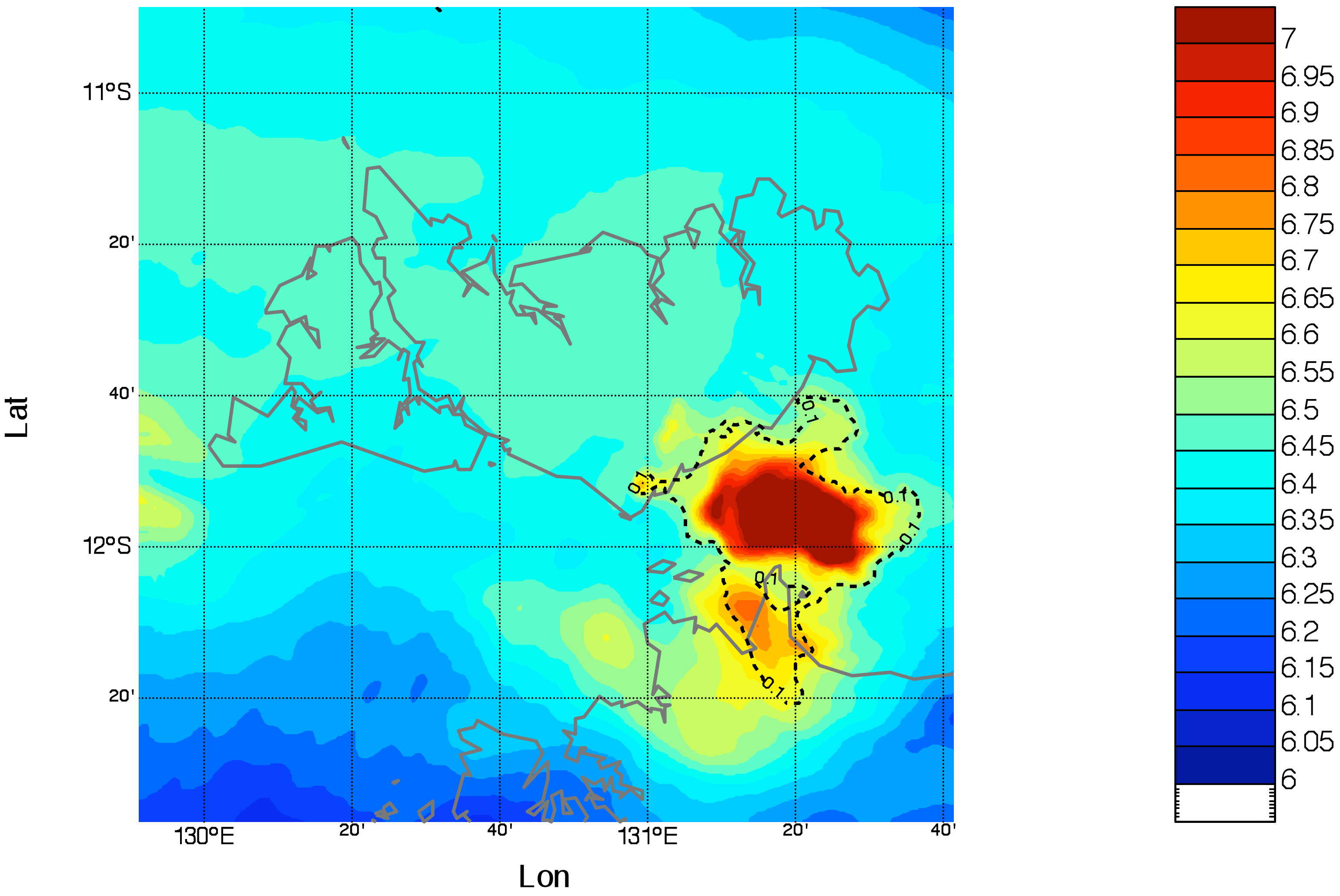




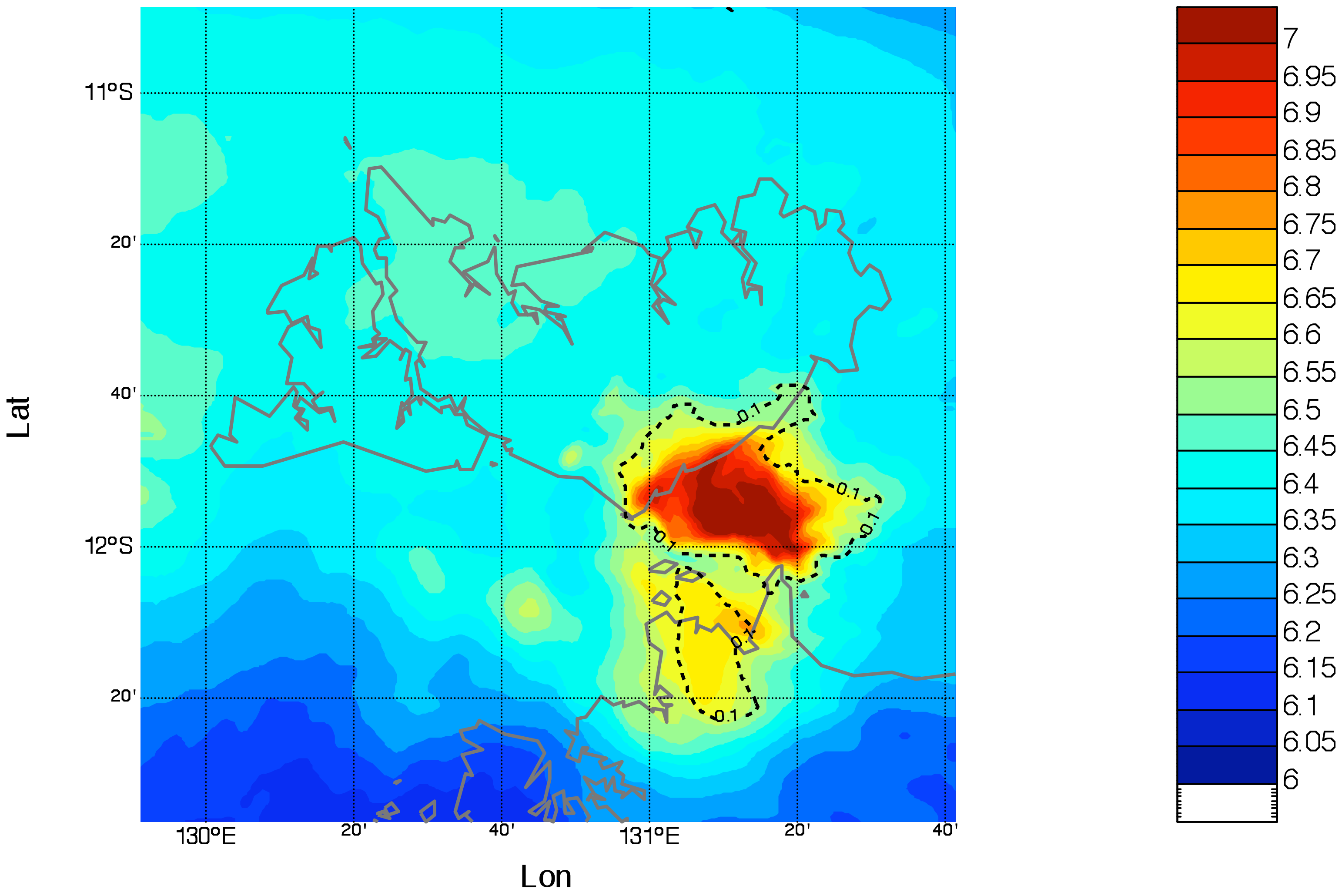
Overshoot 5 advects in from outer domain

MANCHESTER
1824

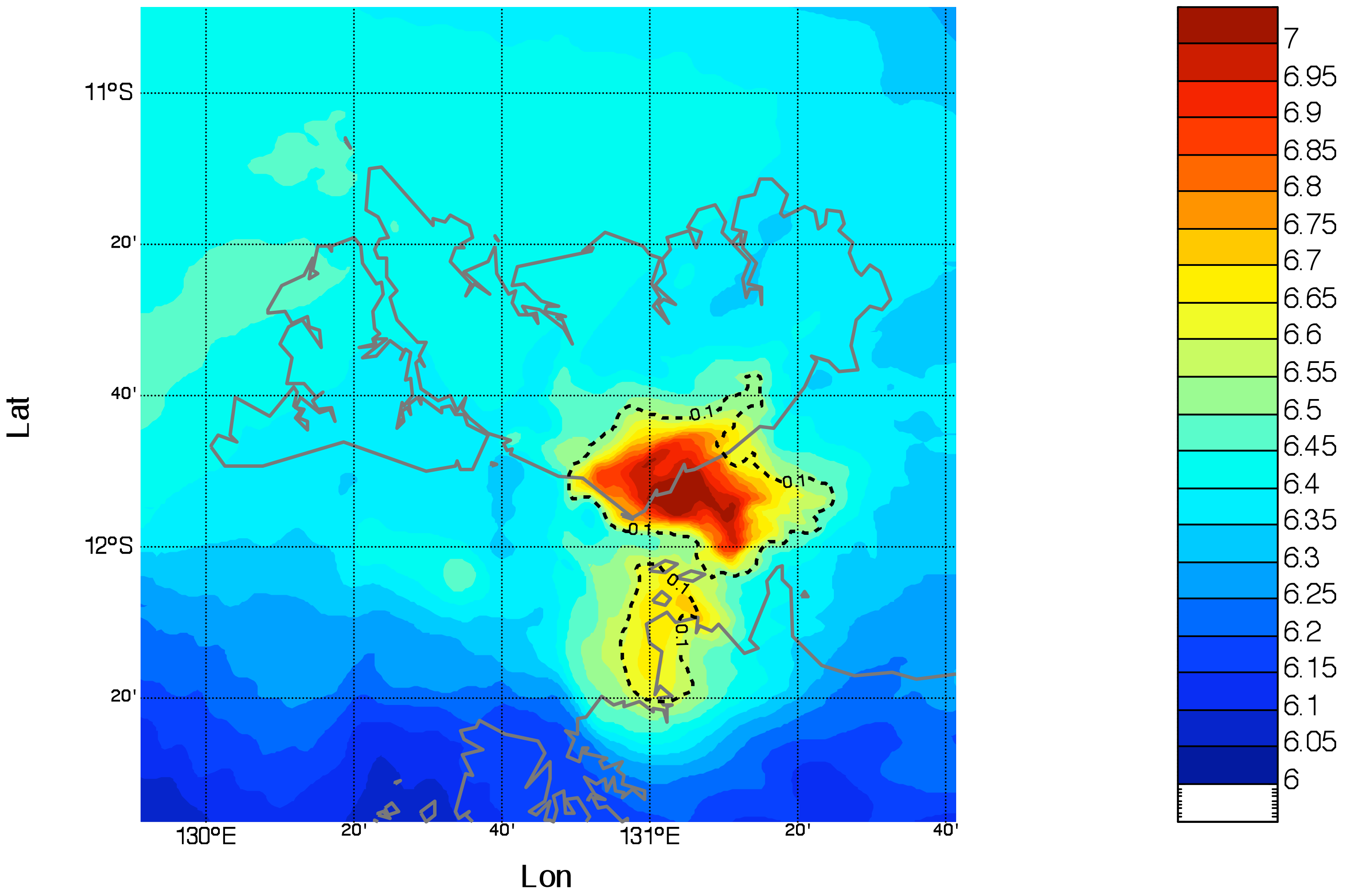
Total water at level 82 (ppmv)   Time = 16:30 UTC



Total water at level 82 (ppmv)   Time = 17:00 UTC

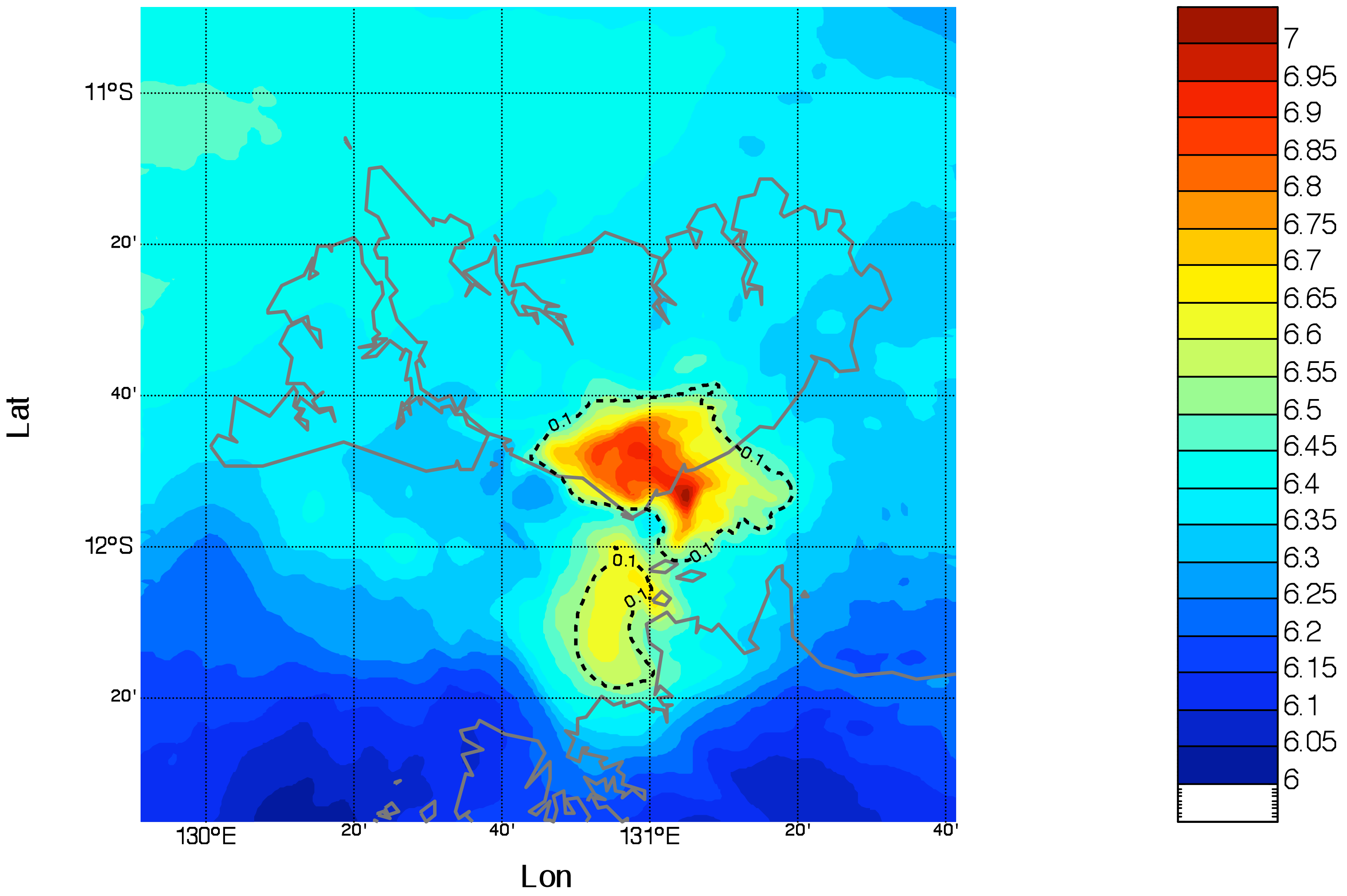


Total water at level 82 (ppmv)   Time = 17:30 UTC

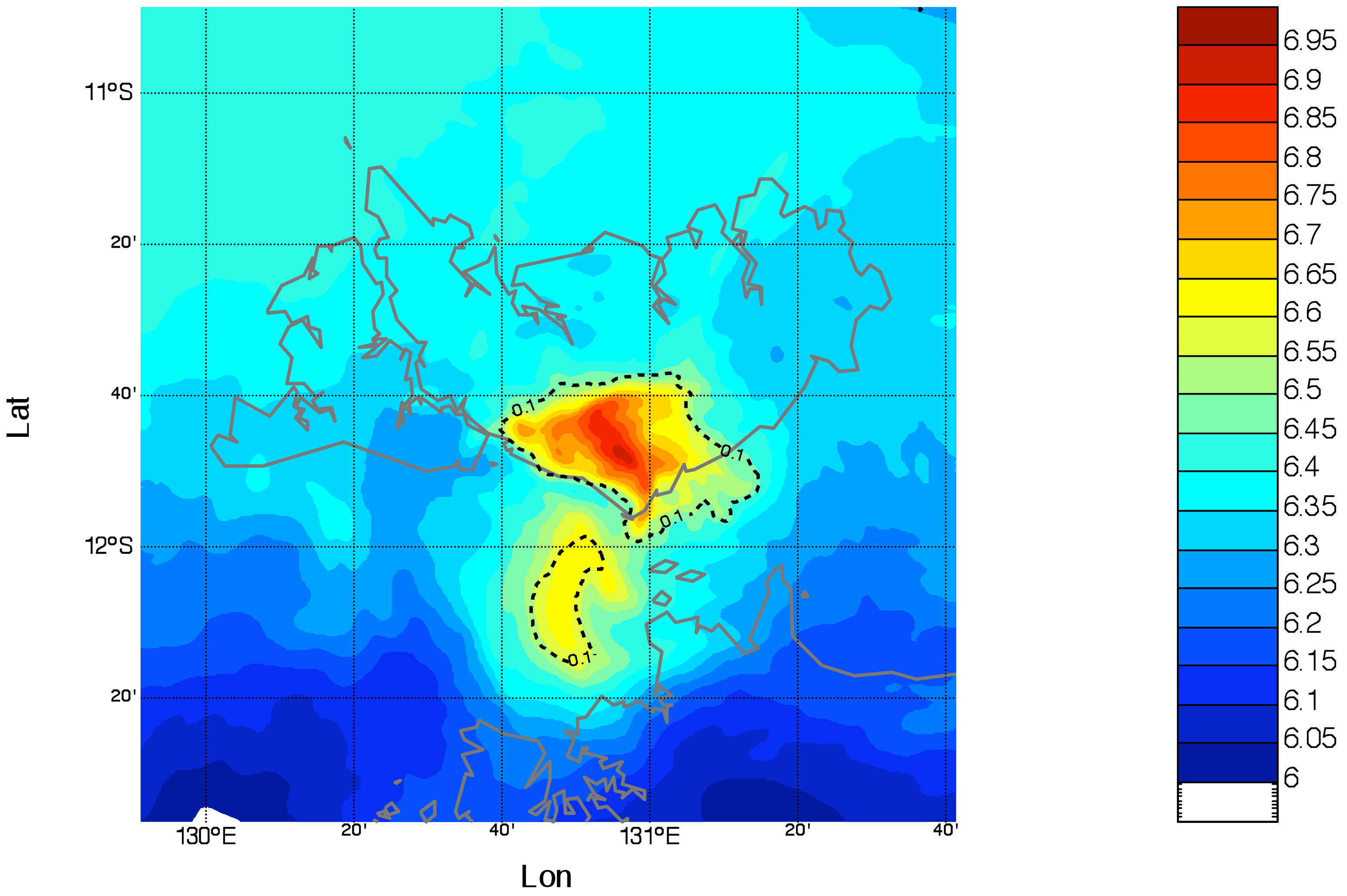


MANCHESTER
1824

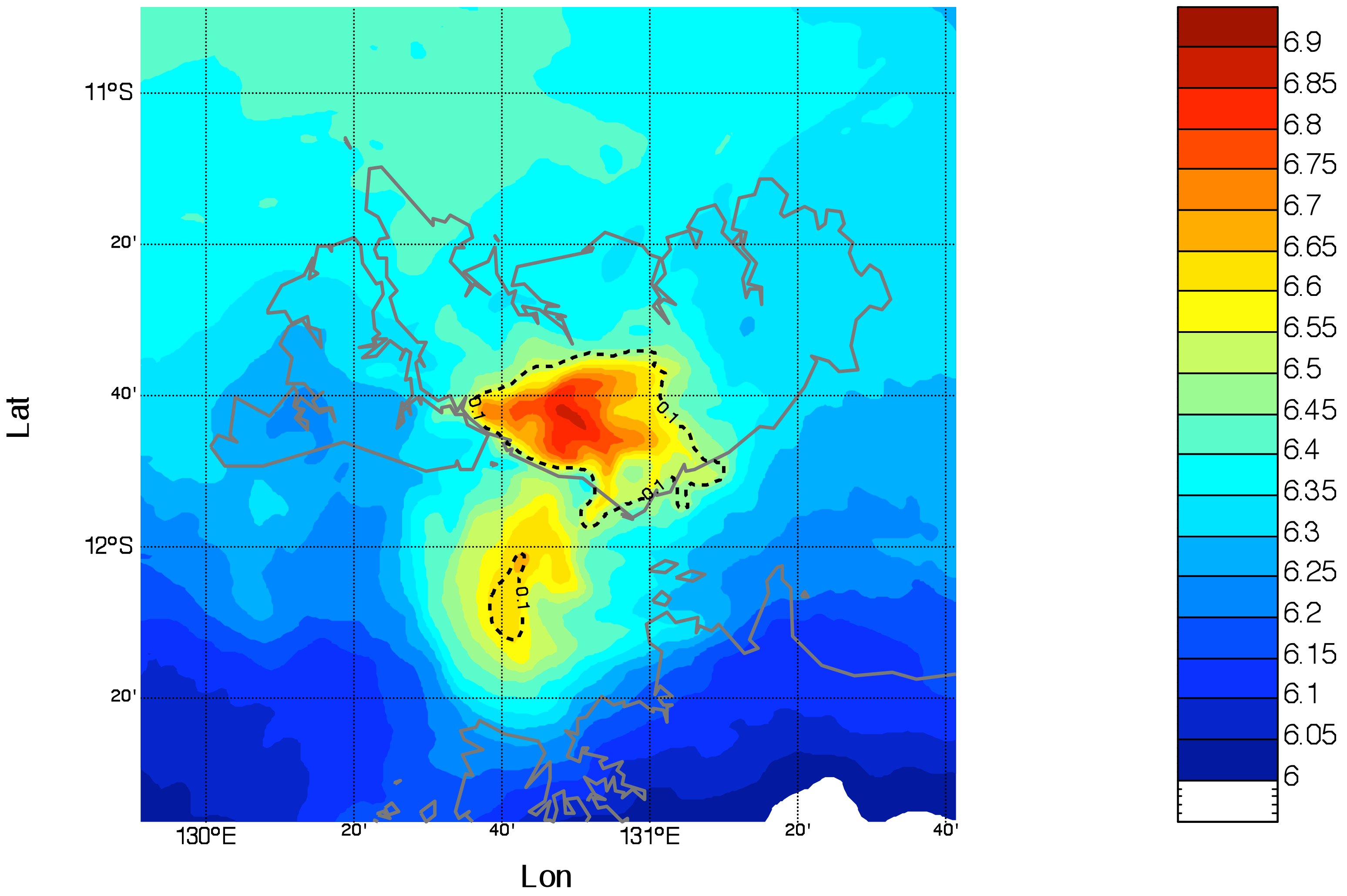
Total water at level 82 (ppmv)   Time = 18:00 UTC



Total water at level 82 (ppmv)   Time = 18:30 UTC

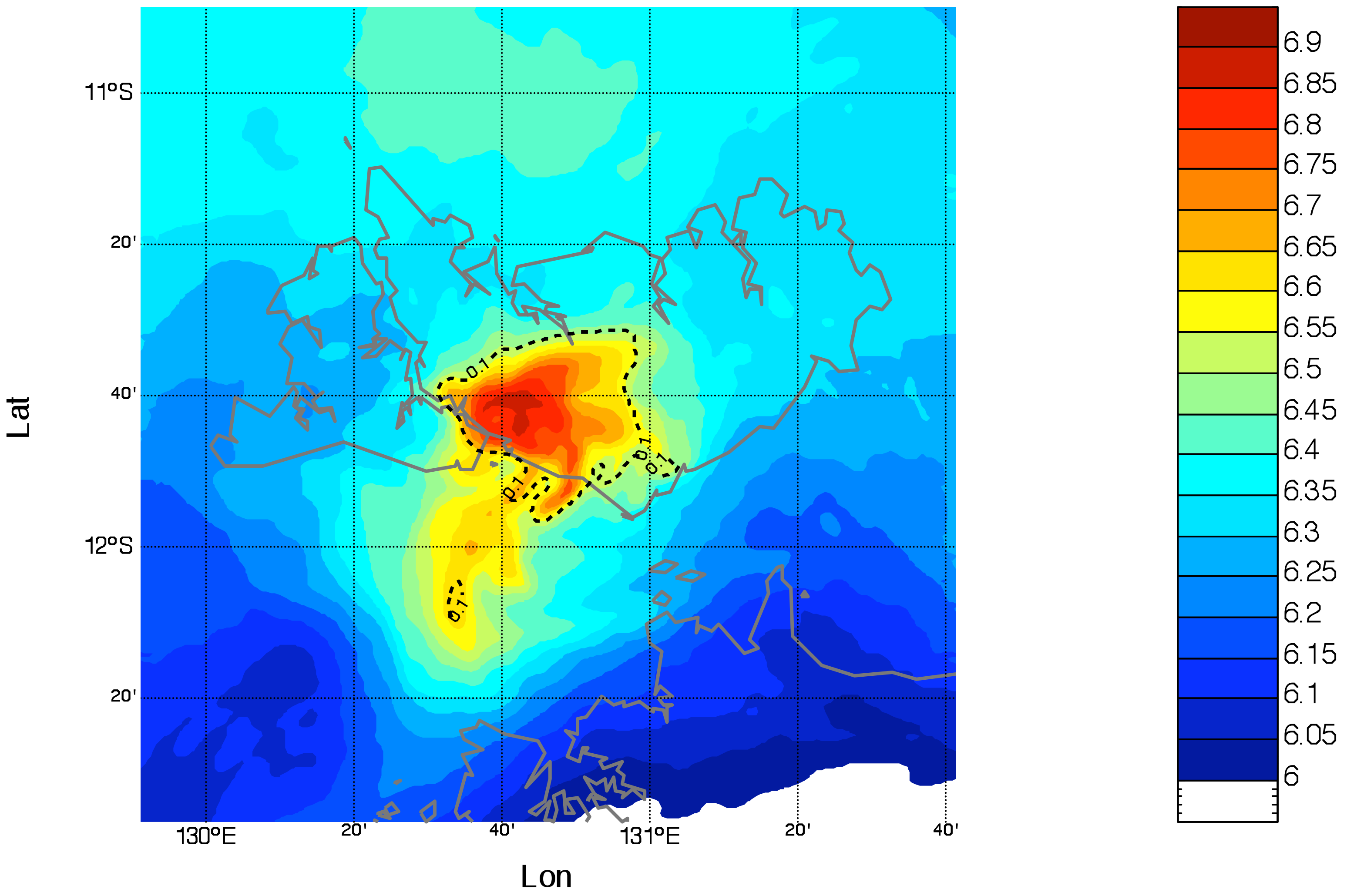


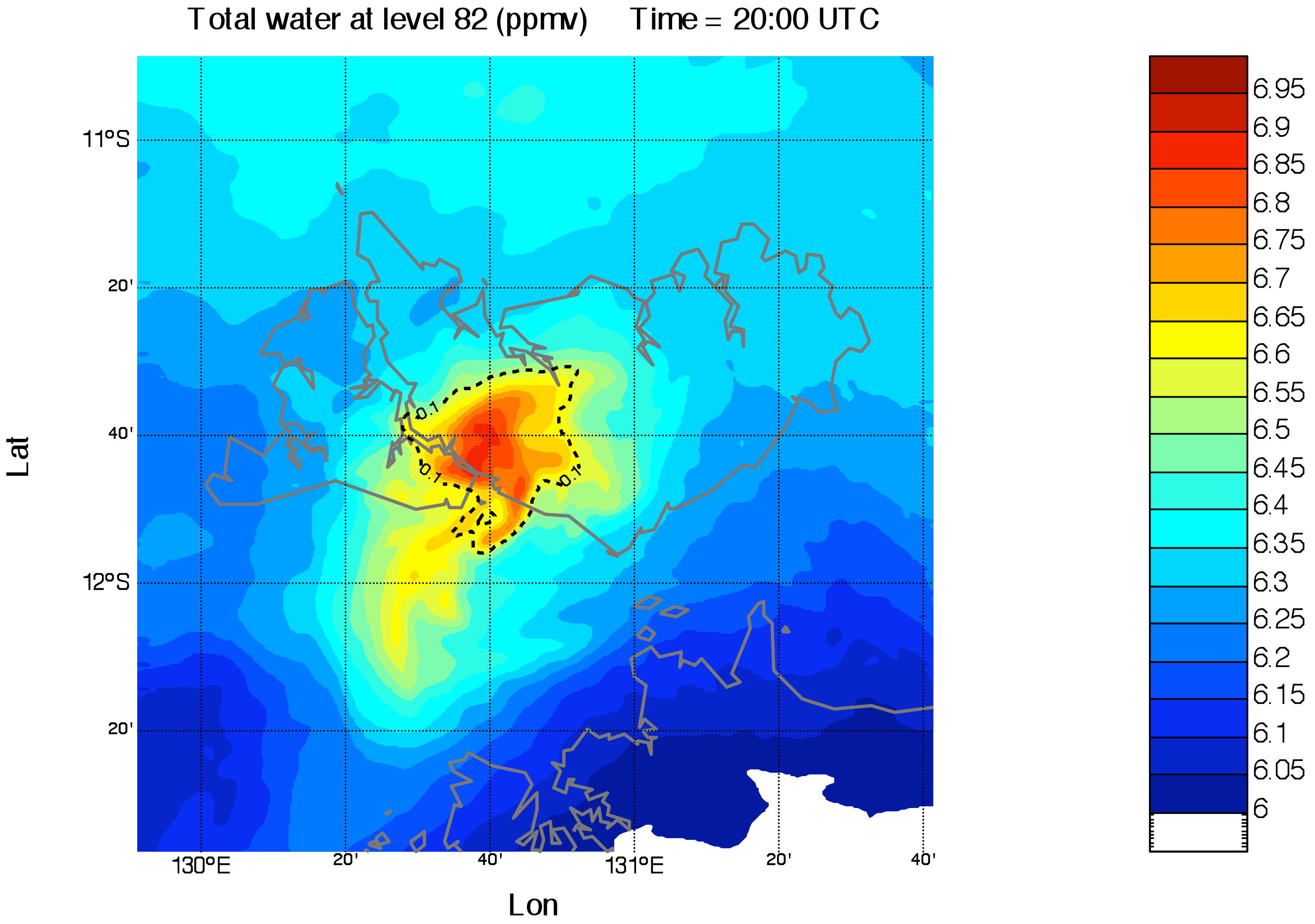
Total water at level 82 (ppmv)   Time = 19:00 UTC

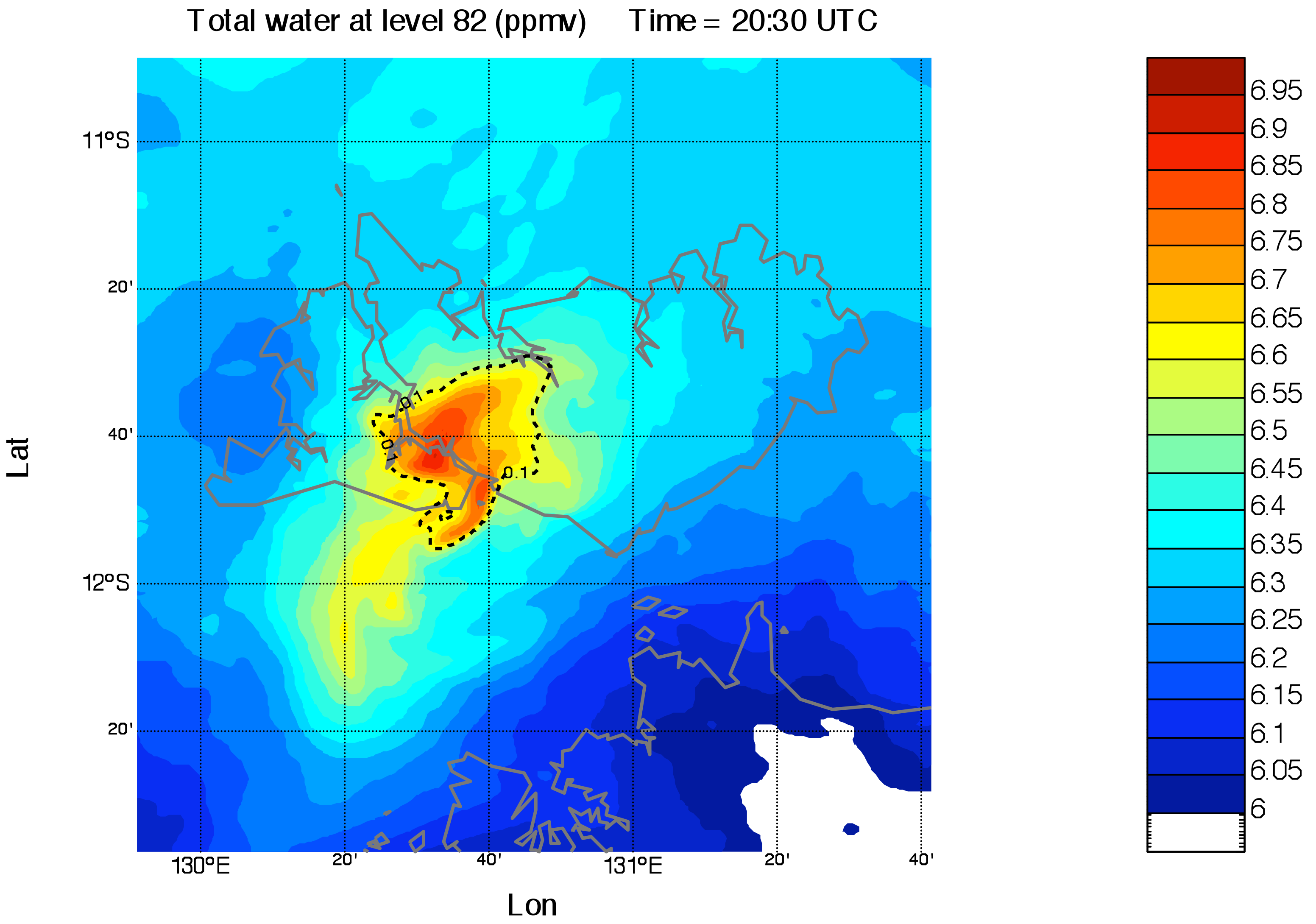


MANCHESTER
1824

Total water at level 82 (ppmv)   Time = 19:30 UTC



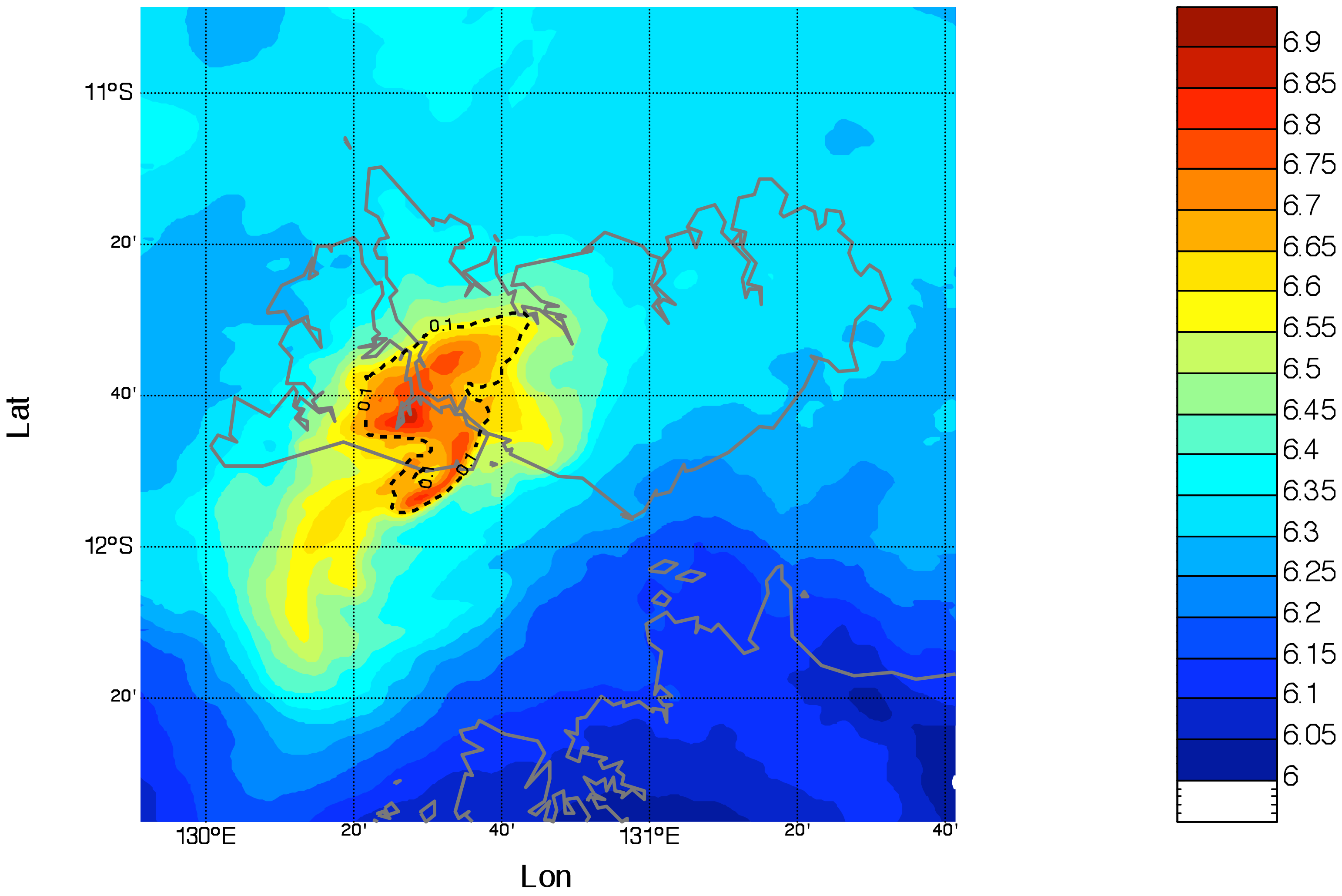

Total water at level 82 (ppmv)
Time = 20:00 UTC
11°S
20'
40'
12°S
20'
Lat
130°E
20'
40'
131°E
20'
40'
Lon
0.1
0.1
0.1
6.95
6.9
6.85
6.8
6.75
6.7
6.65
6.6
6.55
6.5
6.45
6.4
6.35
6.3
6.25
6.2
6.15
6.1
6.05
6



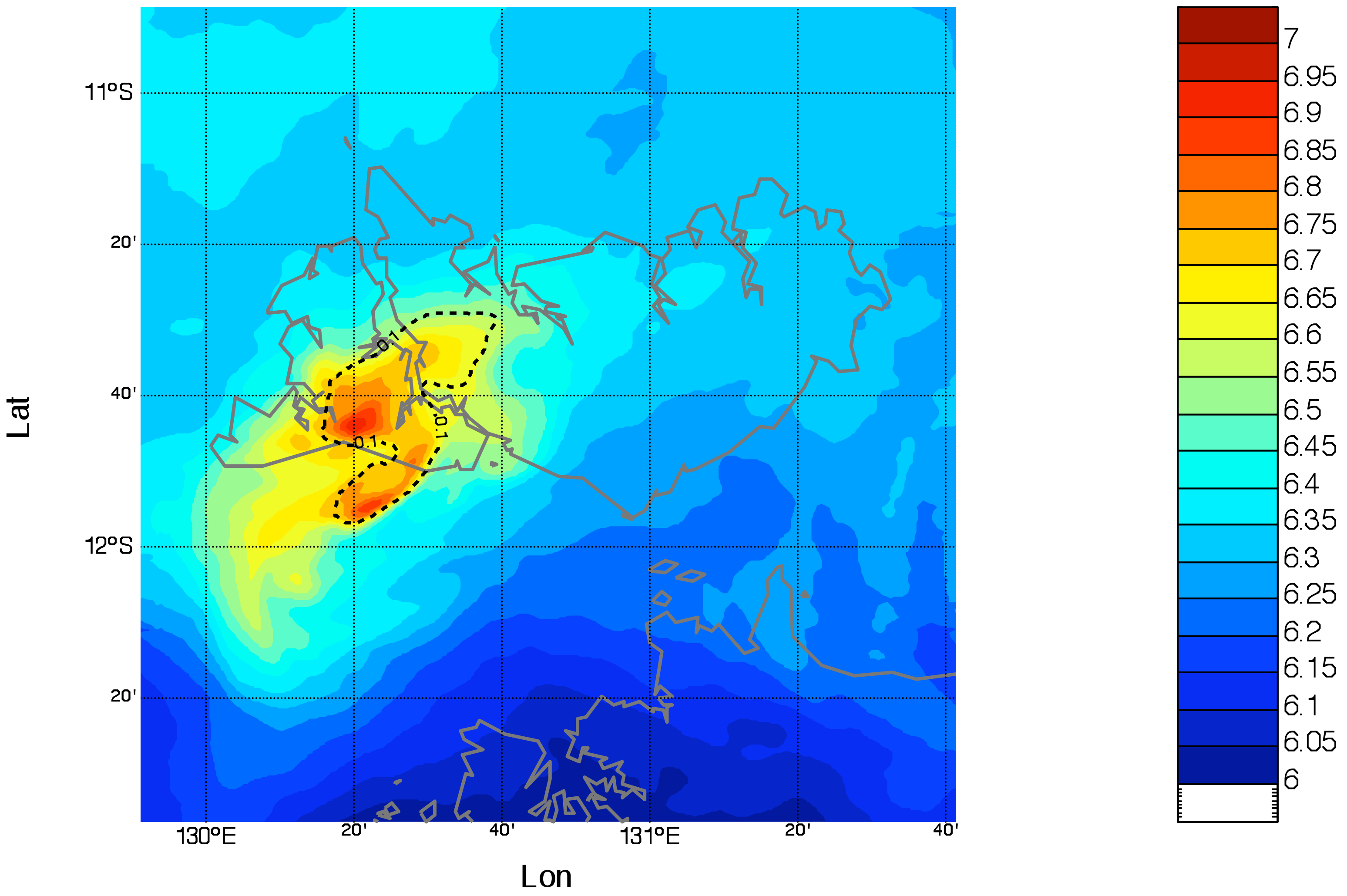
Total water at level 82 (ppmv) Time = 20:30 UTC

Overshoot 5 leaves ~65 tonnes of vapour and 88 tonnes of total water in the stratosphere

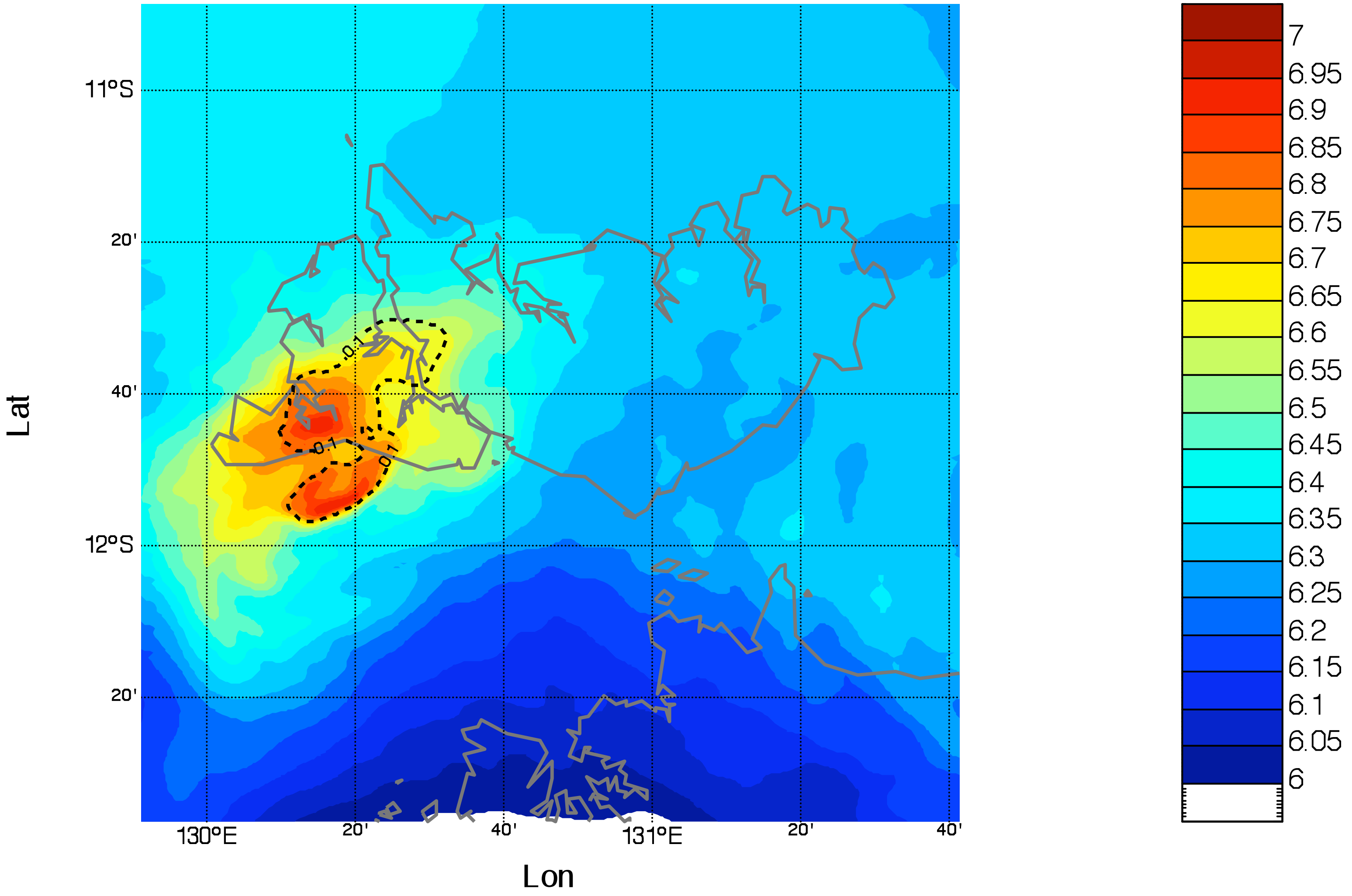
Total water at level 82 (ppmv)   Time = 21:00 UTC



Total water at level 82 (ppmv)   Time = 21:30 UTC



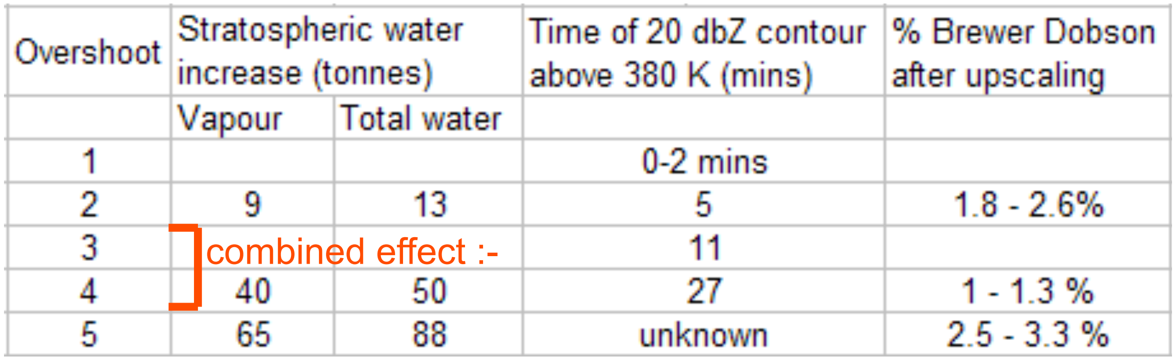
Total water at level 82 (ppmv)   Time = 22:00 UTC



The University of Manchester

MANCHESTER 1824

Overall stratospheric water input and global estimate



Overshoot	Stratospheric water increase (tonnes)		Time of 20 dbZ contour above 380 K (mins)	% Brewer Dobson after upscaling
	Vapour	Total water		
1			0-2 mins	
2	9	13	5	1.8 - 2.6%
3	combined effect :-		11	
4	40	50	27	1 - 1.3 %
5	65	88	unknown	2.5 - 3.3 %

$$f_{overshoot} \propto \frac{1}{T_{20dBZ}}$$

$$\% = \frac{f_{overshoot} M_{water}}{\left(\frac{dM}{dt}\right)_{BD}} \times 100$$

- Total water mass injected by last event comparable to weakest simulation of the first model (87t) and to estimate from Geophysica aircraft observations (100t)
- But % of Brewer Dobson flux is lower since are using a longer lifetime for the 20 dBZ signal above the tropopause (27 mins but likely to be higher)
- WRF results suggest a low contribution to stratospheric water by these types of overshoot
- ***BUT…***
    - Overshoots are a day early
    - WRF sims need validating with radar and aircraft comparisons, which could also lead to a change in the T_{20} figure
    - Simulation of large mesoscale convective systems also needed – water input could be much larger
    - What happens if use Cold Point Tropopause instead of 380K?
    - Ice size distribution in model needs to be examined and compared to reality – plus sensitivity tests (e.g. CCN)
    - Better calculation of the water input is possible with improved model outputs
    - Model resolution issues
    - Estimation of $T_{20\ dbZ}$ from radar data
    - NCEP tropopause vs. local tropopause height?
    - Other ways to estimate overshoot frequency – radar, CloudSat? Is 20 dBZ too large so that some overshoots are missed?

Conclusions

- Direct stratospheric moistening predicted in 3D simulations in two different CRM models for different cases.
- Weakest run of semi-idealised model agrees roughly with biggest WRF storm on approx mass of water injected ~ 87 tonnes. Similar to that estimated from one observation.
- Global mass input into stratosphere by overshoots estimated from satellite frequencies – WRF sims and observations suggest a low percentage of the Brewer Dobson flux of water can be supplied by the type of convection simulated (1 - 3%).
- Suggests little contribution possible to stratospheric vapour trends
- Many uncertainties in these percentages though – both in model water masses predicted and the global upscaling
- In reality larger mesoscale storms may be more prevalent, which are likely to input more water – no consideration of storm area in estimate of frequency.
- Possible effect of aerosols on deep convective moistening through effect on droplet numbers at cloud base and therefore ice numbers transported to the TTL.