Water vapor forecasting for Chilean sites

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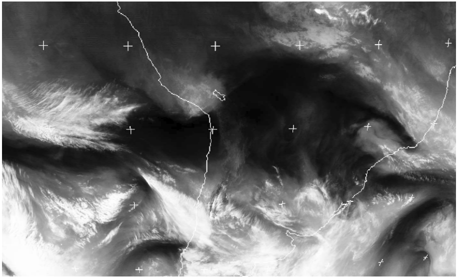
Outline

- PWV forecasts from GOES satellite data
- PWV forecasts from a high-resolution numerical model
- PWV forecasts using data assimilation
- Long-term PWV forecasts

PWV forecasts from GOES data (high-altitude sites)

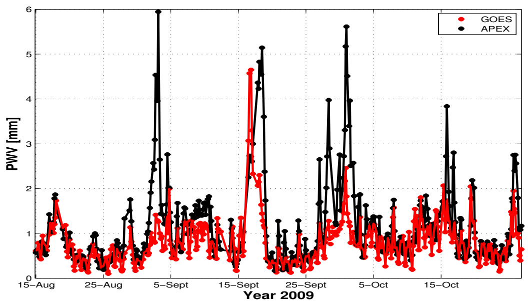
GOES-12 channels

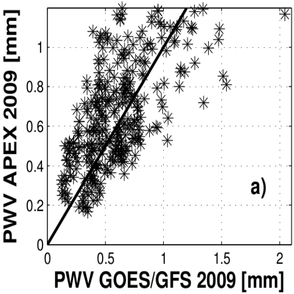
Channel	Central wavelength	Resolution
1 Visible	0.65 (μm)	1 km
2 Infrared	3.9 (μm)	4 km
3 Infrared	6.5 (μm)	4 km
4 Infrared	10.7 (μm)	4 km
6 Infrared	13.3 (μm)	8 km



- Cloud-clearance algorithm was implemented
- $UTH = \frac{\exp(a+b\cdot Tb)\cdot\cos(\theta)}{P_o}$ (Soden and Bretherton, 1993)
- $PWV = \frac{1}{g}\int_{p1}^{p2} UTH \cdot q_{vs} dp$
- qv_s from global analysis/forecasts

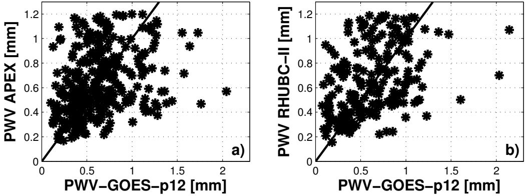
PWV forecasts from GOES data (high-altitude sites)





- Estimated PWV from GOES/GFS reproduces well the APEX radiometer.
- PWV errors larger for high PWV and lower for low PWV

PWV forecasts from GOES data (high-altitude sites)



	APEX		RHUBC-II	
RMSE [mm]	12 h	24 h	12 h	24 h
[0–1.2 mm]	0.35	0.38	0.35	0.38
[0–0.4 mm]	0.25	0.27	0.24	0.29
[0.4–0.8 mm]	0.35	0.36	0.36	0.37
[0.8–1.2 mm]	0.41	0.45	0.41	0.43

	APEX		RHUBC-II	
RE [%]	12 h	24 h	12 h	24 h
[0–1.2 mm]	34.5	34.2	39.2	40.3
[0–0.4 mm]	54.0	46.5	42.8	58.4
[0.4–0.8 mm]	33.0	33.3	47.4	42.7
[0.8–1.2 mm]	32.2	34.2	30.4	29.2

- Persistence method used:
  - $PWV(t+24h) = PWV(t)$
- PWV forecasts at 12h better than 24h forecasts

Momentum conservation

$$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} - w\frac{\partial u}{\partial z} - \frac{1}{\rho}\frac{\partial p}{\partial x} + 2\Omega v \sin(\phi) + F_x$$

$$\frac{\partial v}{\partial t} = -u\frac{\partial v}{\partial x} - v\frac{\partial v}{\partial y} - w\frac{\partial v}{\partial z} - \frac{1}{\rho}\frac{\partial p}{\partial y} - 2\Omega u \sin(\phi) + F_y$$

$$\frac{\partial w}{\partial t} = -u\frac{\partial w}{\partial x} - v\frac{\partial w}{\partial y} - w\frac{\partial w}{\partial z} - \frac{1}{\rho}\frac{\partial p}{\partial z} - g + 2\Omega u \cos(\phi) + F_z$$

Mass conservation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0$$

Energy conservation

$$\frac{\partial \theta}{\partial t} = -u\frac{\partial \theta}{\partial x} - v\frac{\partial \theta}{\partial y} - w\frac{\partial \theta}{\partial z} + S_\theta$$

Water phase conservations

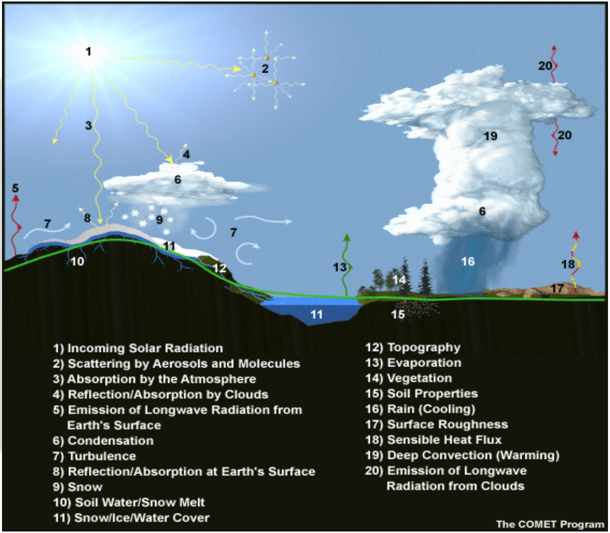
$$\frac{\partial q_n}{\partial t} = -u\frac{\partial q_n}{\partial x} - v\frac{\partial q_n}{\partial y} - w\frac{\partial q_n}{\partial z} + S_{q_n}$$

State equation

$$p = \rho R_d T_v$$

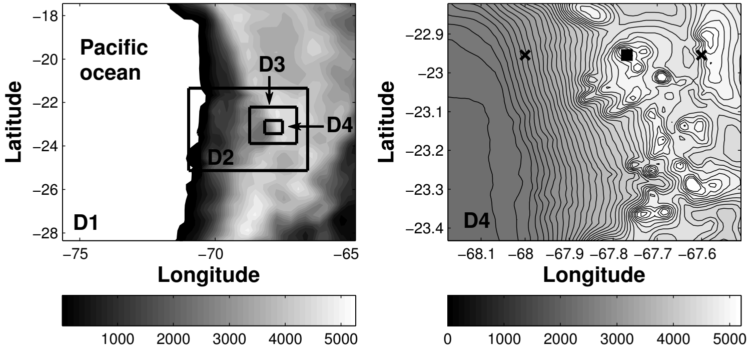
Why to parametrize?

- Some processes can not be explicitly solved
- Processes we do not know very well
- Effects on forecast variables crucial for their proper prediction.

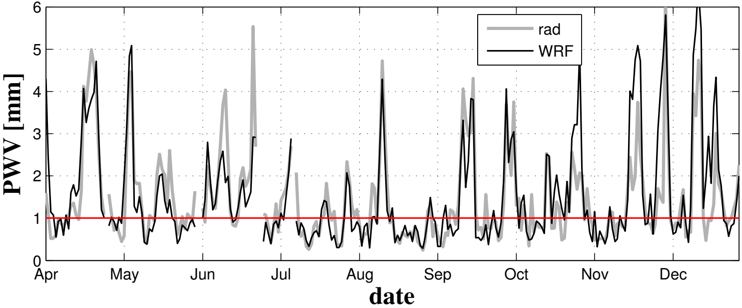


Model configuration

- 4 domains: 27 km, 9 km, 3 km and 1 km
- 54 sigma vertical levels
- Choose longwave, shortwave radiation, cumulus, microphysics, PBL, land-surface model schemes.

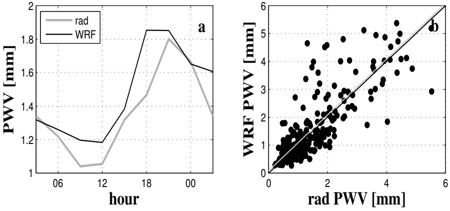


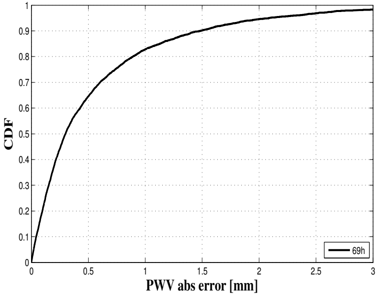
PWV forecasts with the WRF model



- PWV from WRF and APEX (April-December 2007).
- Good performance of WRF representing the seasonal and intraseasonal PWV evolution at Chajnantor.

PWV forecasts with the WRF model

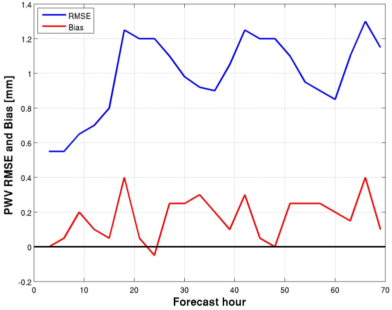


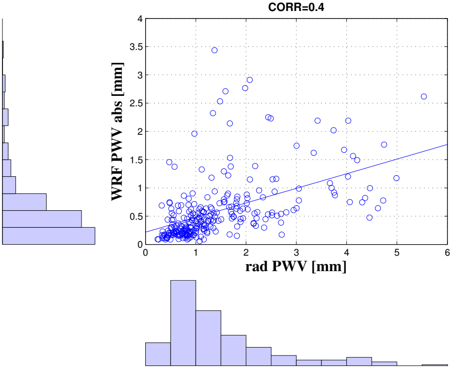


- WRF represents reasonably well the PWV diurnal evolution
- PWV is overestimated
- Errors smaller during nighttime and larger during daytime.

- 10% data with errors $>$ 1.5 mm
- 65% data with errors $<$ 0.5 mm
- 45% data with errors $<$ 0.25 mm

PWV forecasts with the WRF model

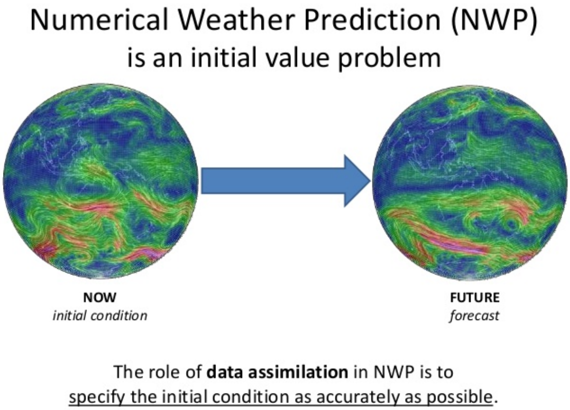




- PWV bias < 0.4 mm in 0-69h
- RMSE increases from 0 to 69h
- RMSE < 0.75mm in 0-12h

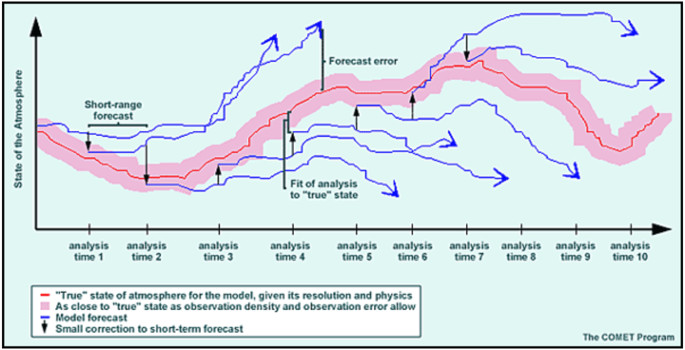
- PWV bias increases when PWV increases
- PWV bias mostly < 1mm when PWV < 1 mm.

PWV forecasts with the WRF model (Data Assimilation)



- DA used to improve the IC of numerical weather simulations
- Better ICs will result in better forecasts

PWV forecasts with the WRF model (Data Assimilation)



- Short-range forecasts blended with observations create initial conditions
- The process can be repeated during a simulation
- Keep model forecasts close to true state

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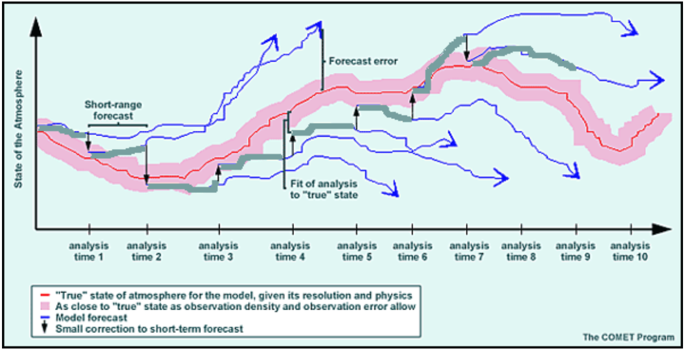

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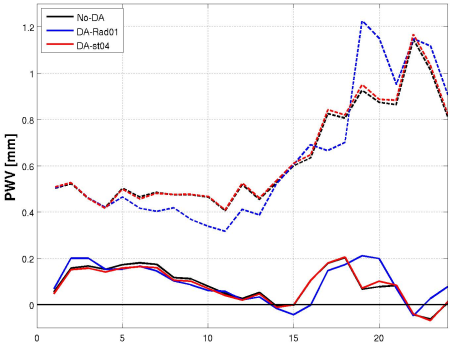
PWV forecasts with the WRF model (Data Assimilation)

WRF data assimilation

- No-DA: Sim. without DA
- DA-rad01: Assimilation of satellite radiance on domain 1
- DA-st04: Assimilation of AWS data on domain 4
- 1 month simulation

PWV RMSE and Bias [mm]



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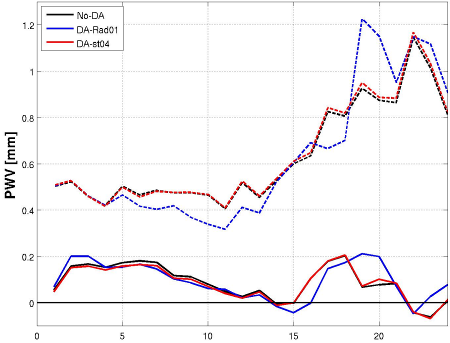
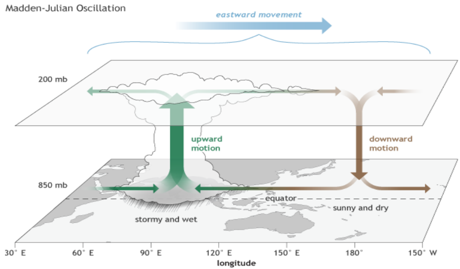


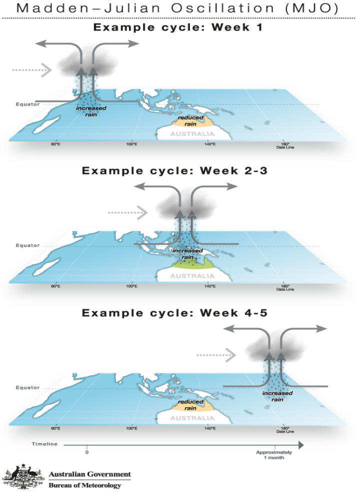
PWV forecasts improved in the first 12h of simulation.

Intraseasonal PWV variability (MJO)



Madden-Julian Oscillation (MJO)

- Largest element of intraseasonal variability in tropical atmosphere
- Eastward moving pulse of clouds and precipitation
- Moves near the Equator with a period of 30-60 days



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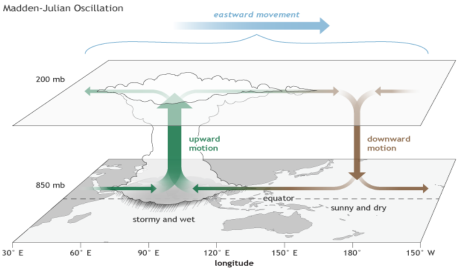

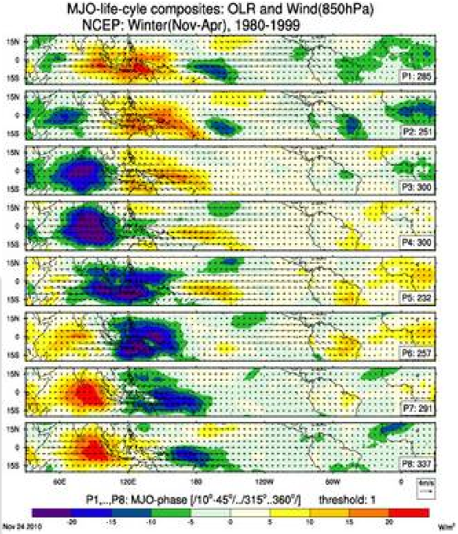

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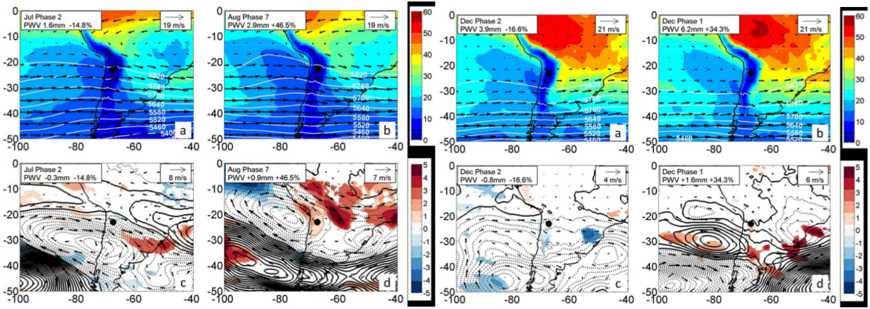

- Month with largest (magnitude) PWV anomaly associated with MJO phase
- Summer vs winter

Intraseasonal PWV variability (MJO)

- MJO phases 6-8 were most associated with largest positive PWV anomalies
- MJO phases 1-3 were associated with largest negative PWV anomalies

Month	High PWV phase	Low PWV phase
January	**Phase 7**	*Phase 1*
February	**Phase 7**	**Phase 1**
March	**Phase 2**	*Phase 3*
April	**Phase 2**	**Phase 8**
May	**Phase 6**	*Phase 1*
June	**Phase 7**	*Phase 1*
July	*Phase 8*	*Phase 2*
August	**Phase 7**	*Phase 2*
September	*Phase 6*	*Phase 1*
October	*Phase 5*	**Phase 3**
November	*Phase 7*	**Phase 5**
December	*Phase 1*	**Phase 2**

Summary

- Numerical weather models are a very useful tool to forecast PWV in northern Chile
- The WRF model has shown good skill to forecast the seasonal and diurnal PWV evolution at Chajnantor region.
- Models can be used to provide 3-5 days PWV forecasts operationally
- Seasonal PWV with the WRF model will be performed and validated in the near future.