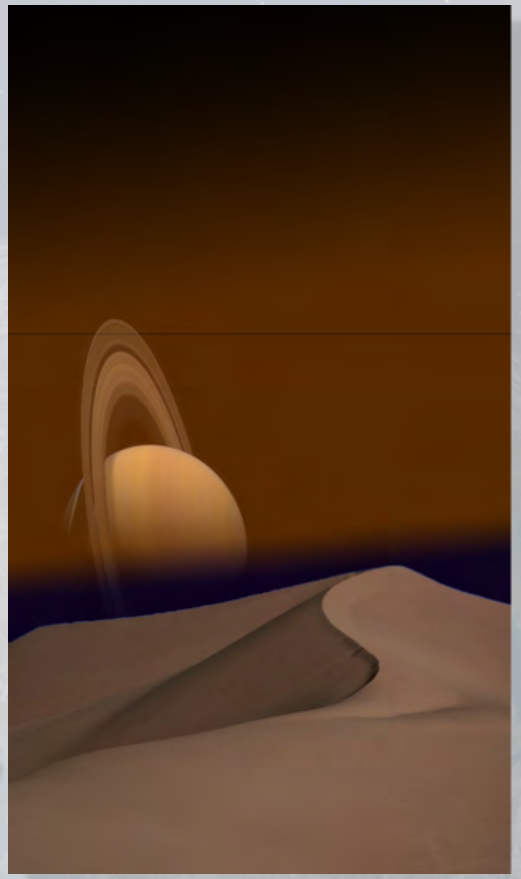
Origin of Dune Orientation on Titan

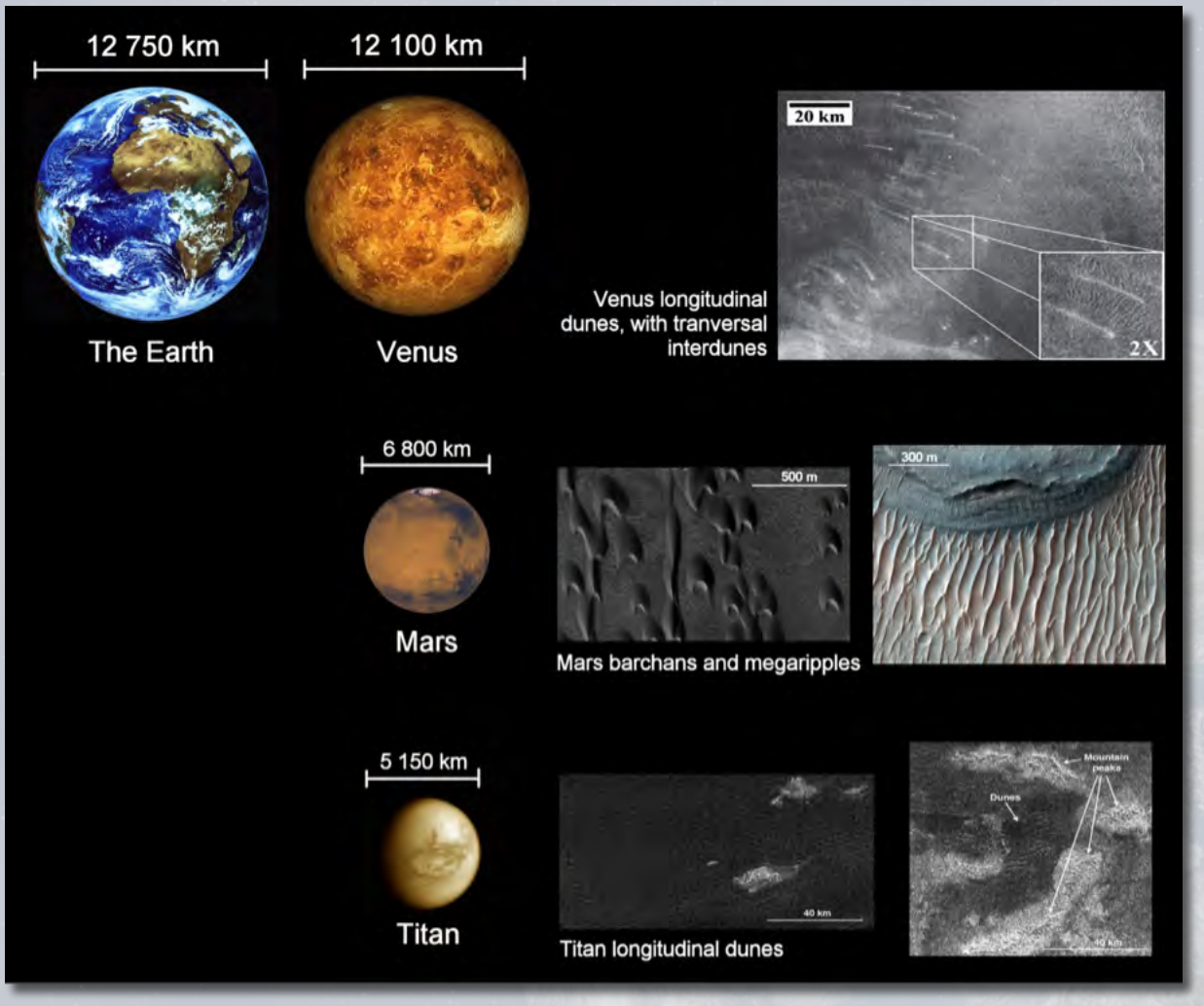
New Insights from experimental & field measurements

A. Lucas, S. Rodriguez, C. Narteau, B. Charnay,
A. Garcia, S. Courrech du Pont, A.G. Hayes



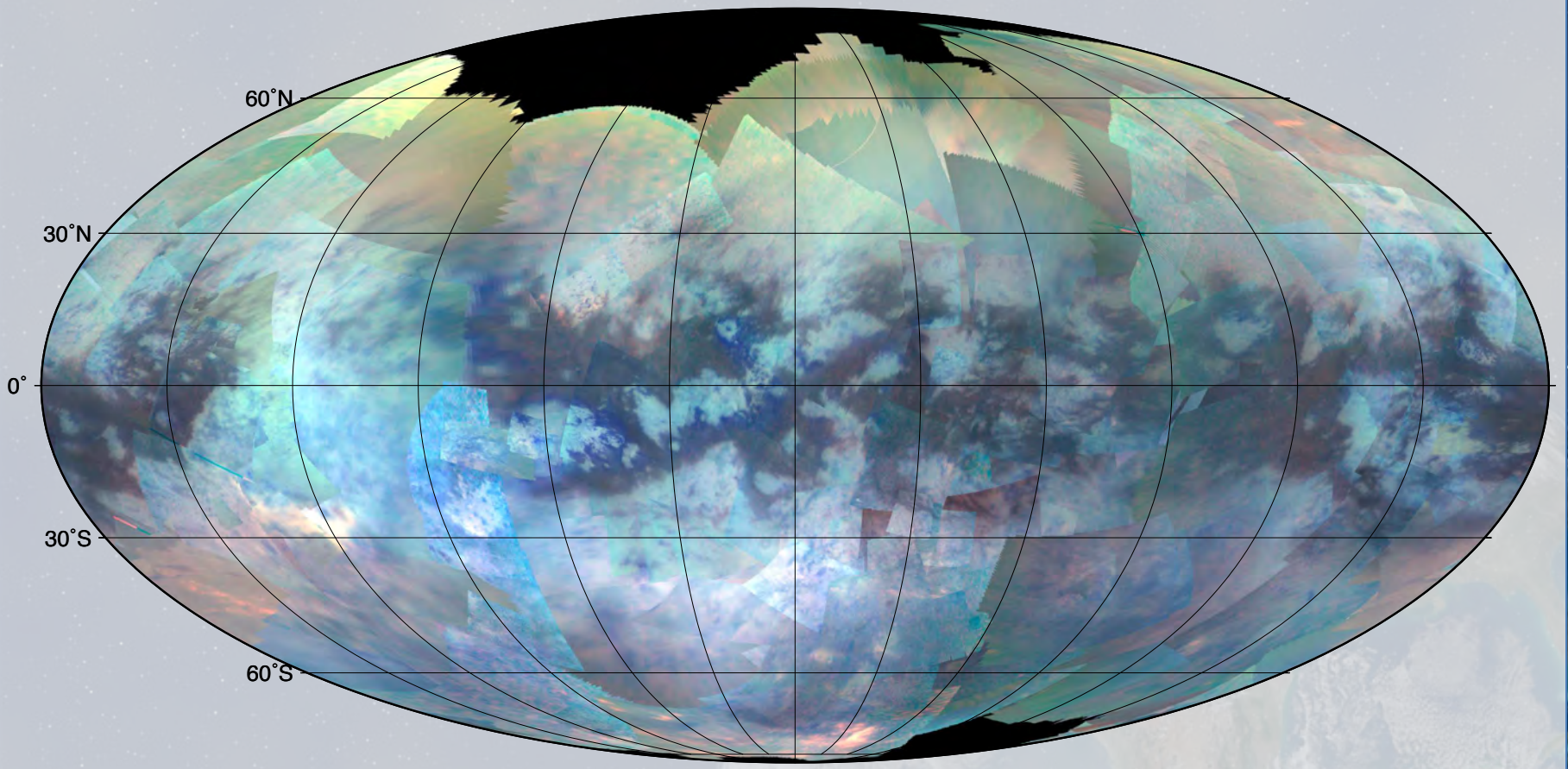
Sand Seas, a common landscape in the Solar System

We need sediment and atmosphere

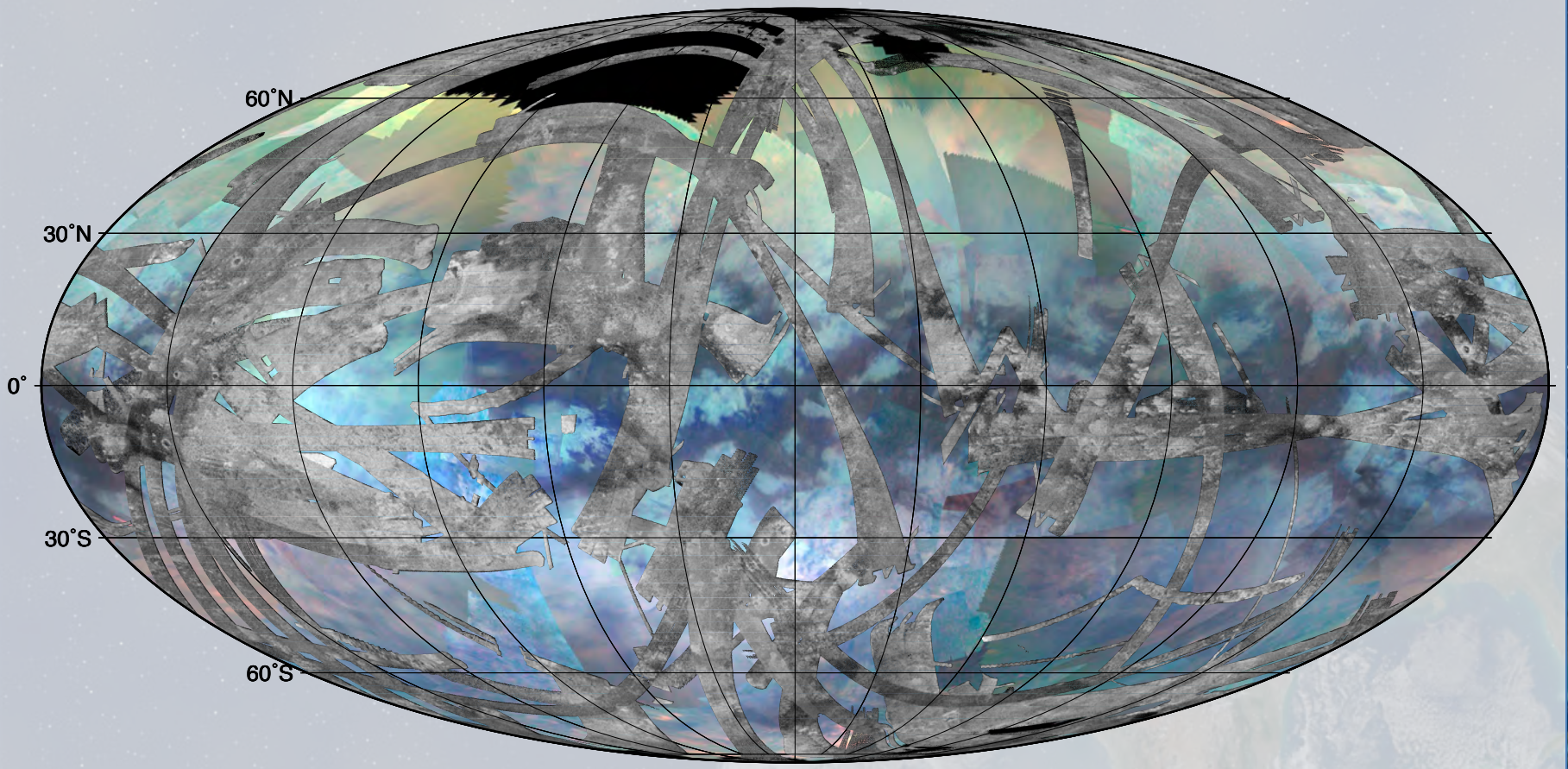


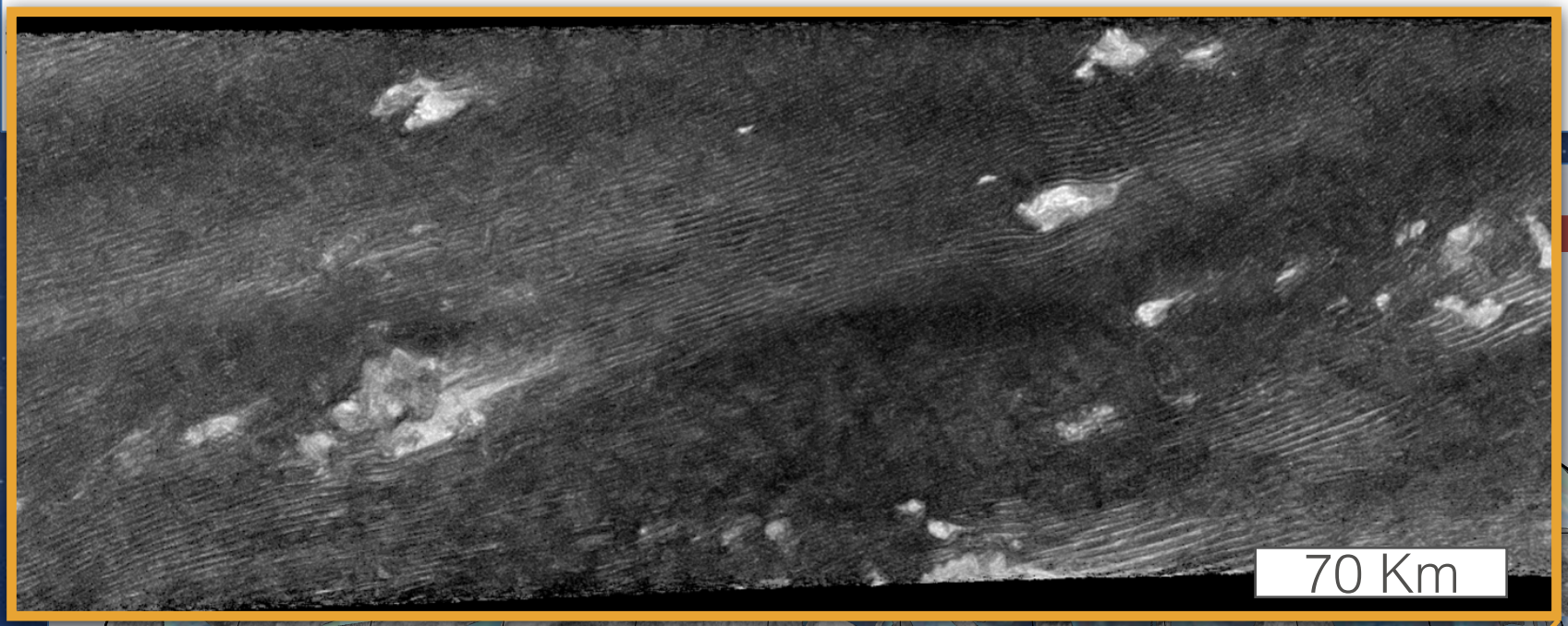
Origin of Dune Orientation on Titan

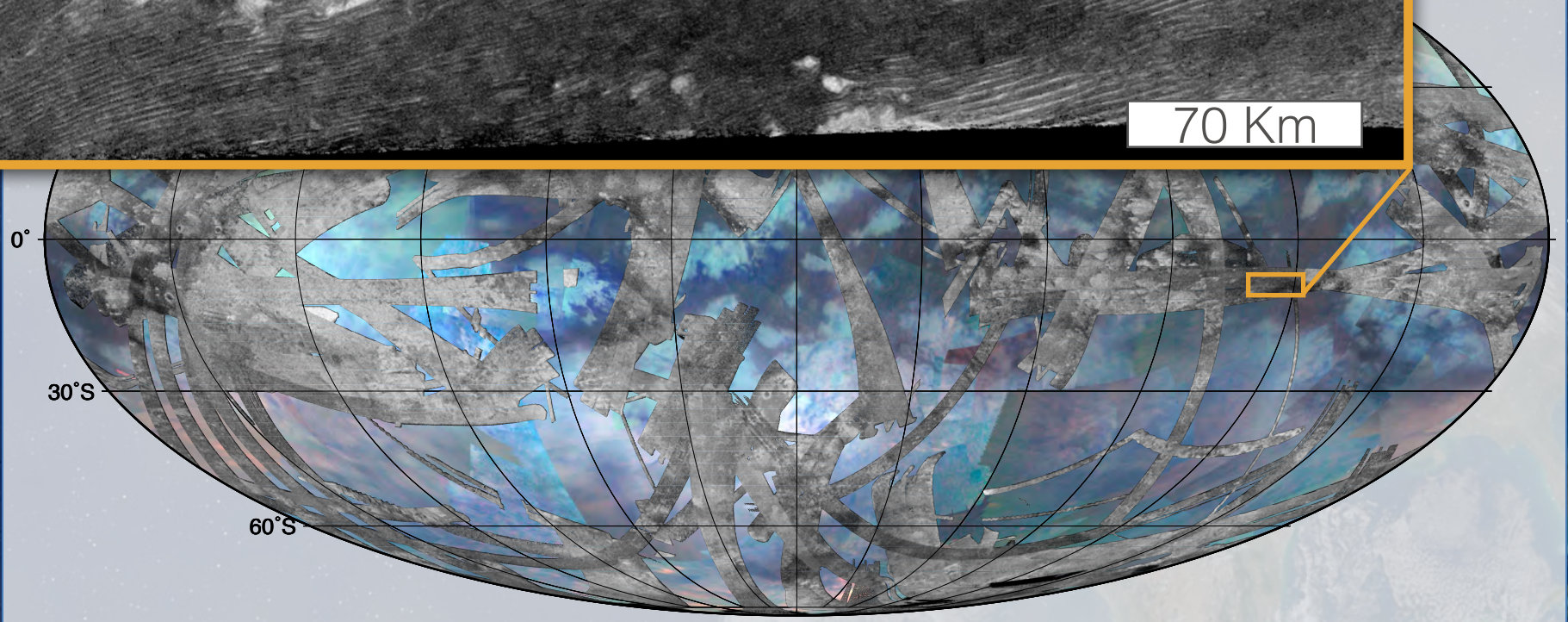
Titan seen by VIMS/Cassini



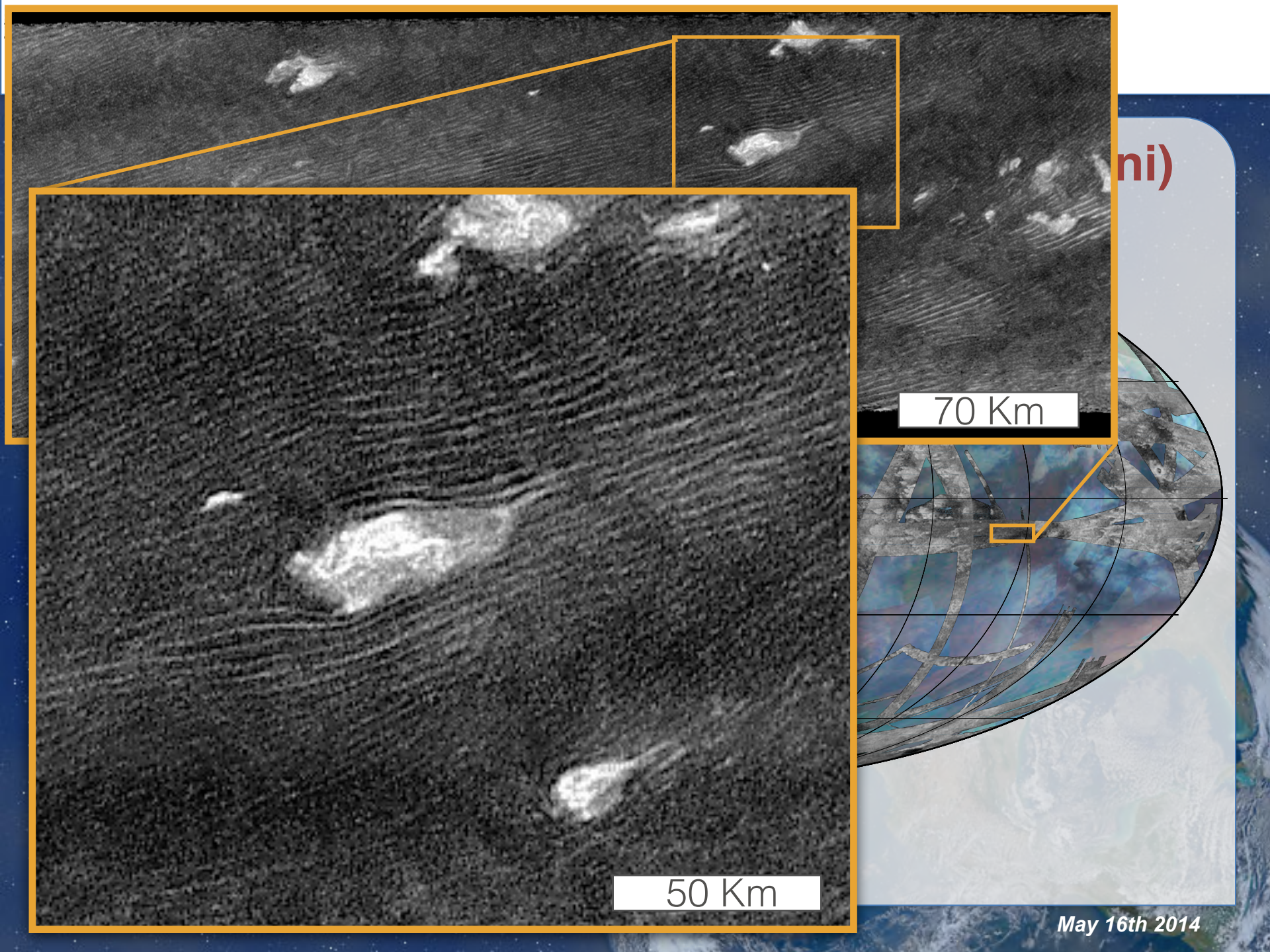
Titan seen by RADAR in SAR Mode (Cassini)





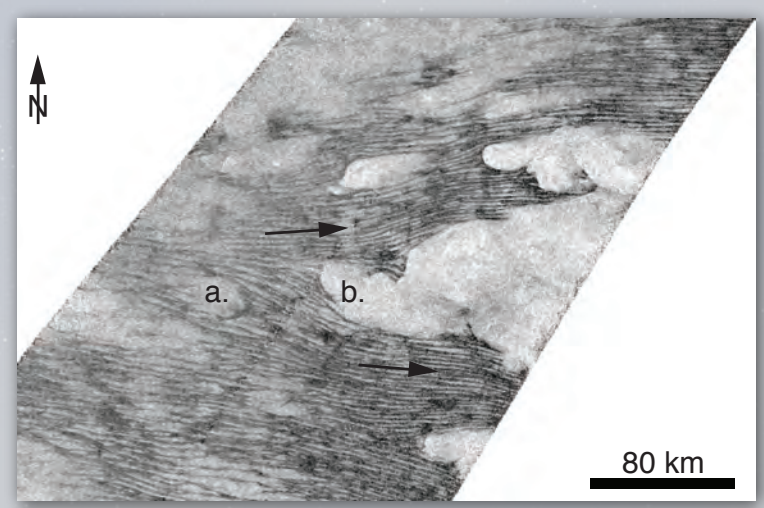


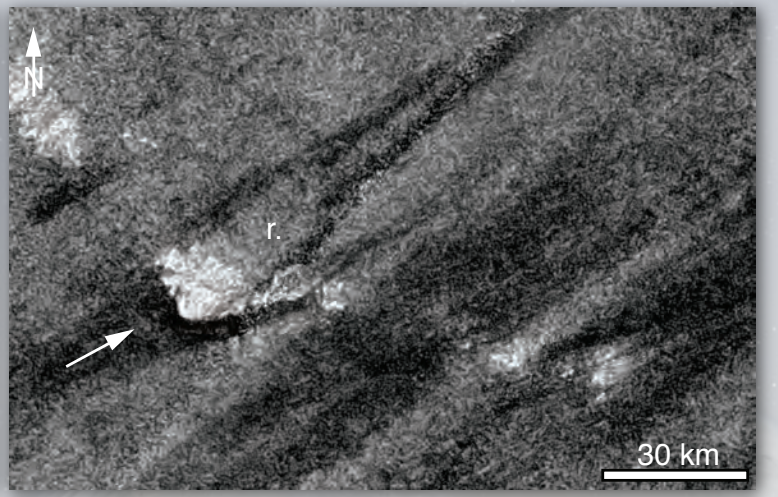
2 500 km (eq.)


70 Km
50 Km
May 16th 2014

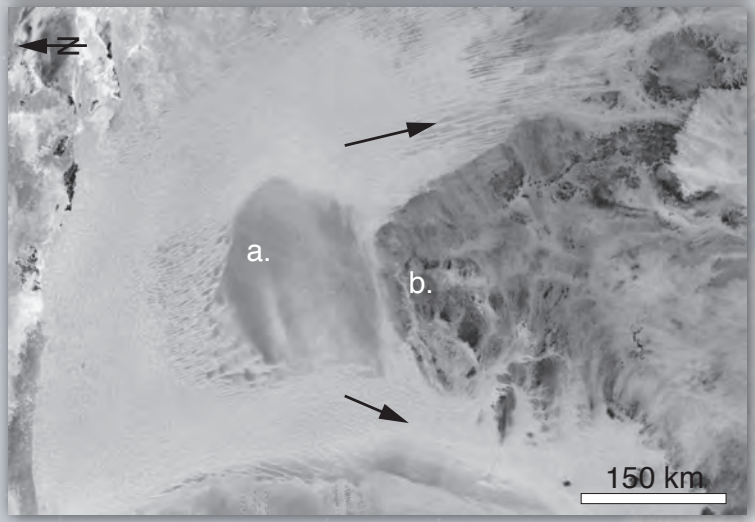
Eastward dune propagation

Titan





Egypt

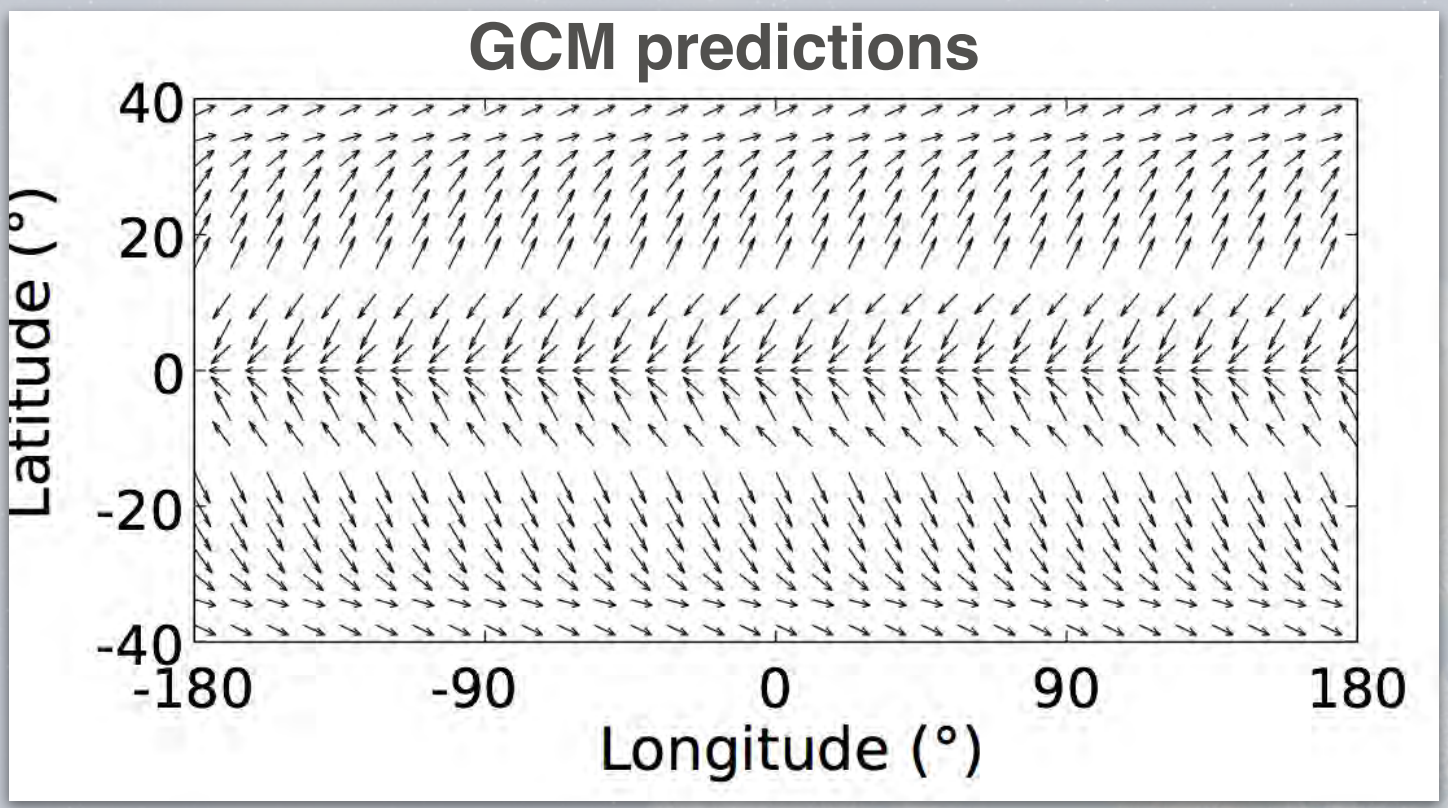


Titan's Dunes properties

Global direction	Type	Length	Wavelength	Height	Location
Eastward	Linear	100-1000' km	~3 km	~ 100' m	equatorial band (+/- 30°)

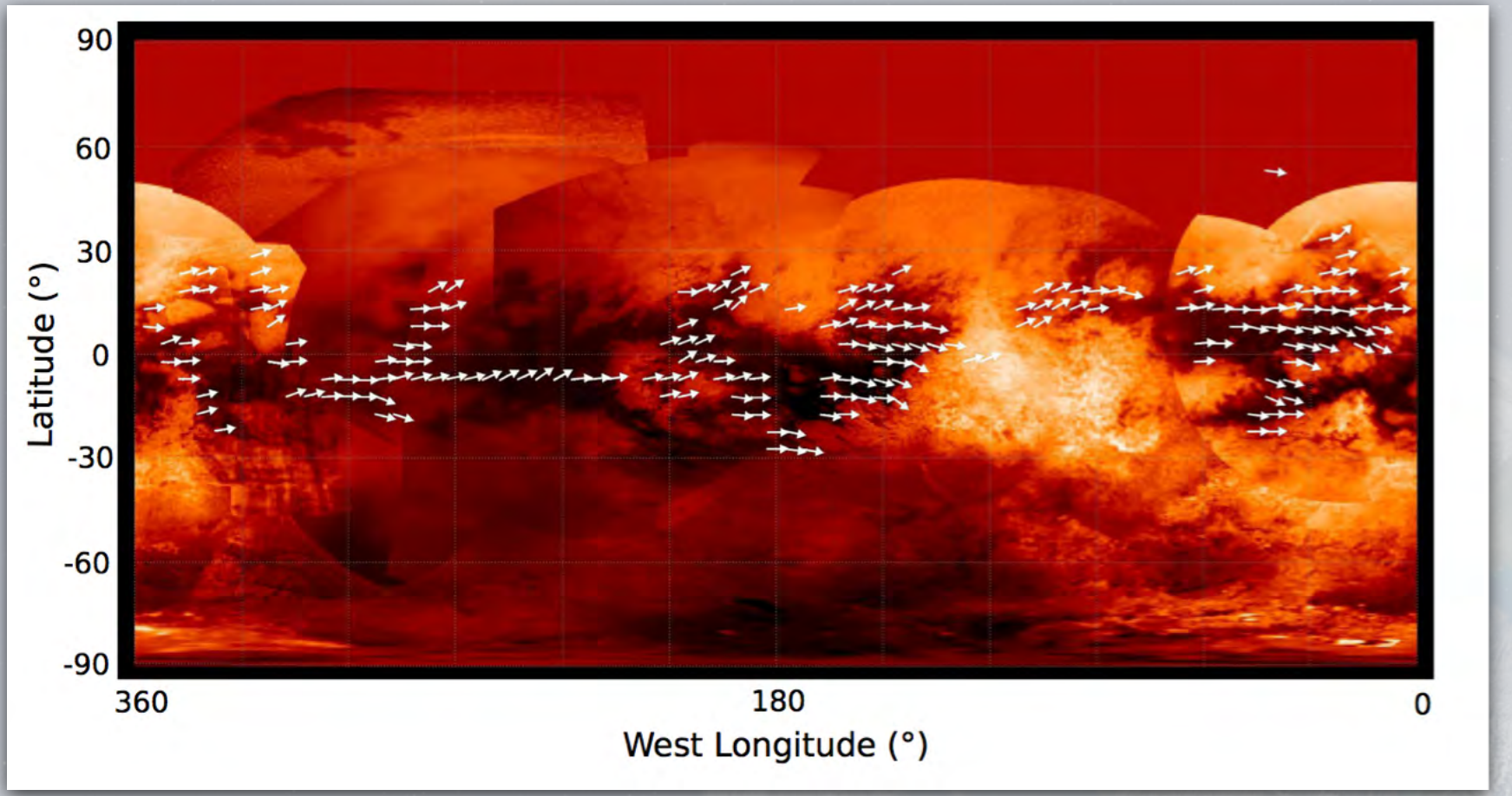
Lorenz et al., 2006; 2008; Radebaugh et al. 2008; 2010; 2013; Rubin & Hesp, 2009; Neish et al. 2010; Le Gall et al., 2011; 2012; Arnold et al. 2013; Rodriguez et al. 2013

Global Circulation Model of Titan



Charnay et al. AGU 2013, &
Charnay et al (incl. Lucas) in review for Nat. Geosc.

Dunes conundrum



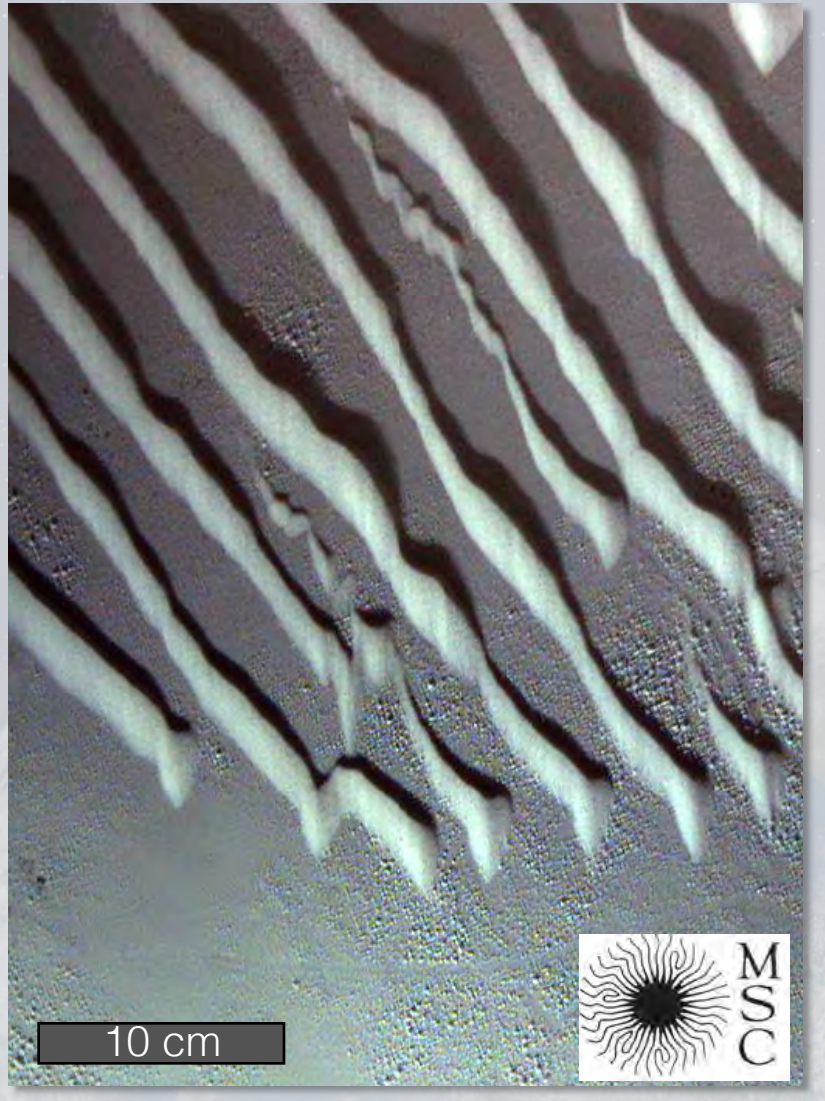
Propagation direction after *Lorenz et al. (2006)* and following works

Fondamental questions

- How to explain their geographic confinement?
- How to explain their linear shape and orientation?
- How to explain their direction of propagation?
- Are they still active?

To answer these questions, we take advantage of new experimental, numerical and analytical results

Origin of Dune Orientation on Titan

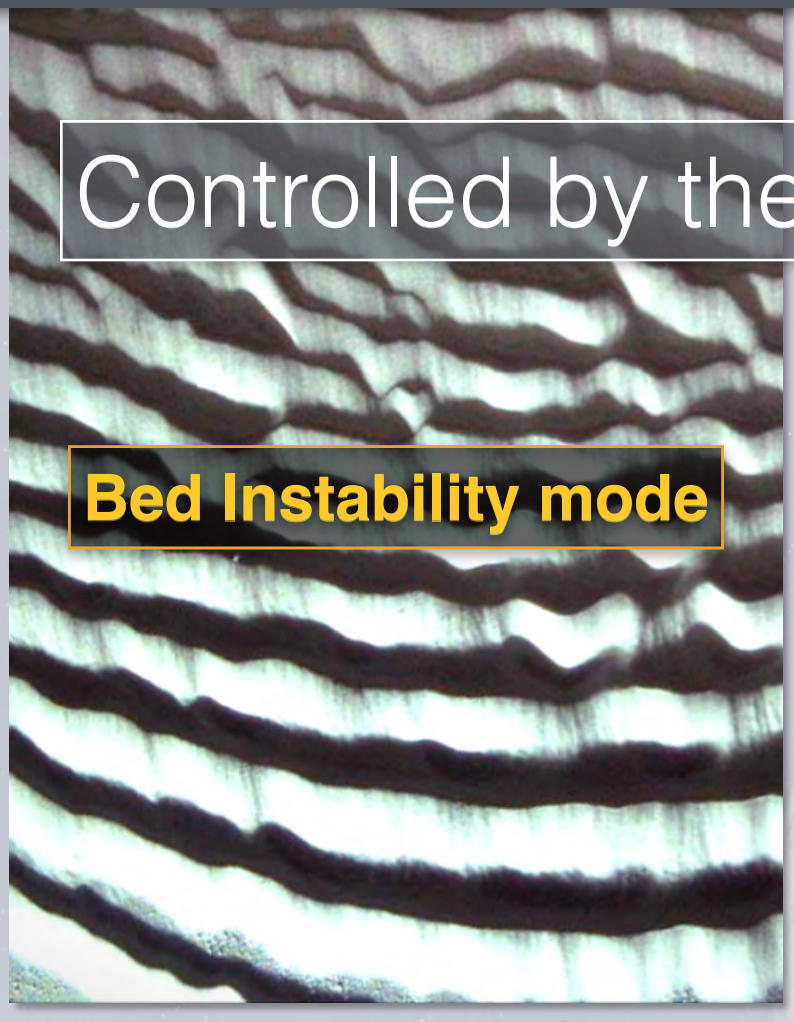


Origin of Dune Orientation on Titan

Two modes of dune orientation in the lab.

Controlled by the Sediment Supply

Two modes of dune orientation in the lab.



Courrech du Pont et al., (2014)

A Method to Derive two Dune Orientations from Wind Data

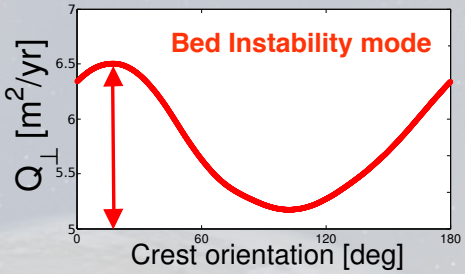
Wind Data

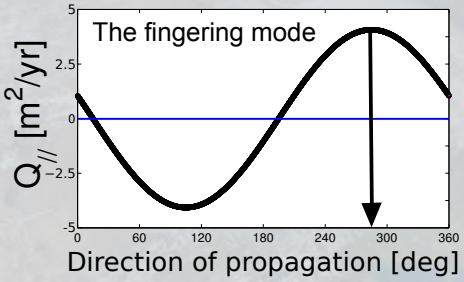
Sediment transport law

$$Q = f(u, u^*_{th}, d, \rho_s, \rho_f, g)$$

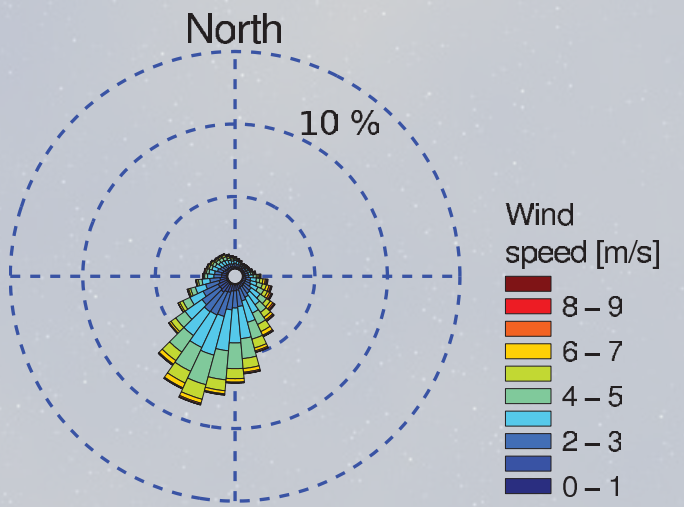
Dune orientation

Courrech du Pont et al., (2014)

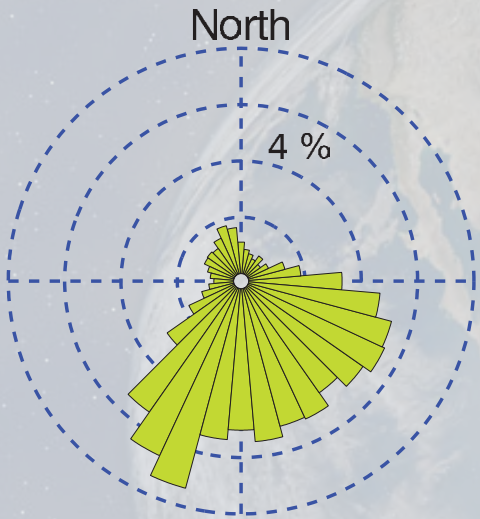


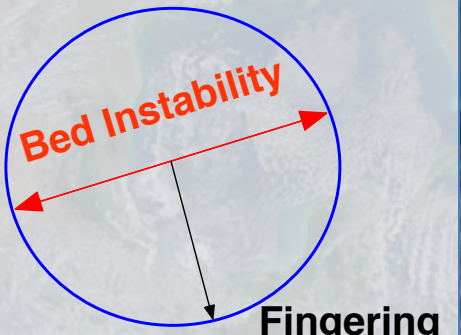


Wind Regime

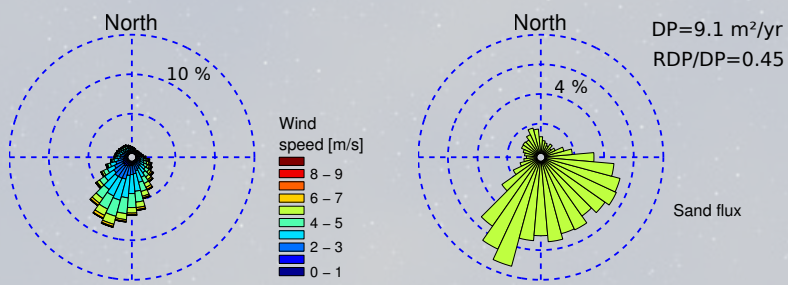


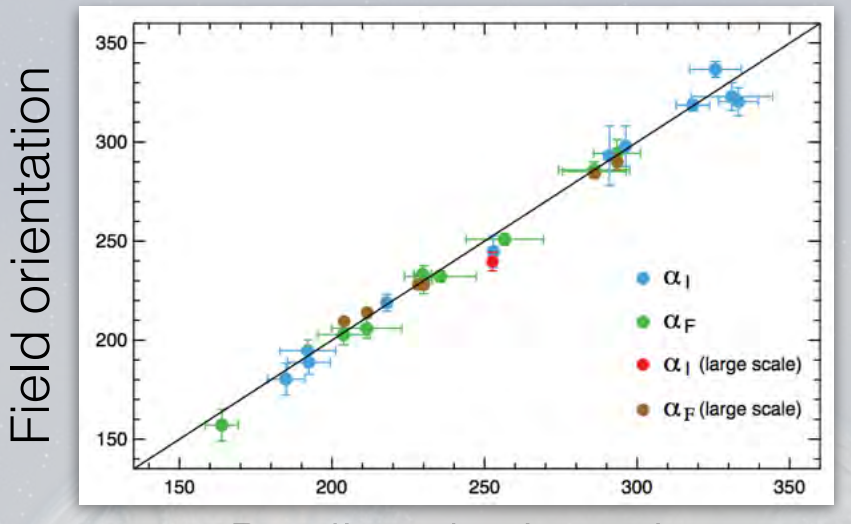
Sediment flux





A Method to Derive two Dune Orientations from Wind Data





We have a method to derive dune alignment from **wind data** accounting for two **dune growth mechanisms** and their corresponding **crest orientations**

Courrech du Pont & Narteau, in review for Geology

Back to Titan

We need an exhaustive and global map orientation

but SAR images suffers from noise (speckle)

Lucas et al. (*in revision for JGR*)
and presented @AGU 2011 and LPSC 2012

Back to Titan

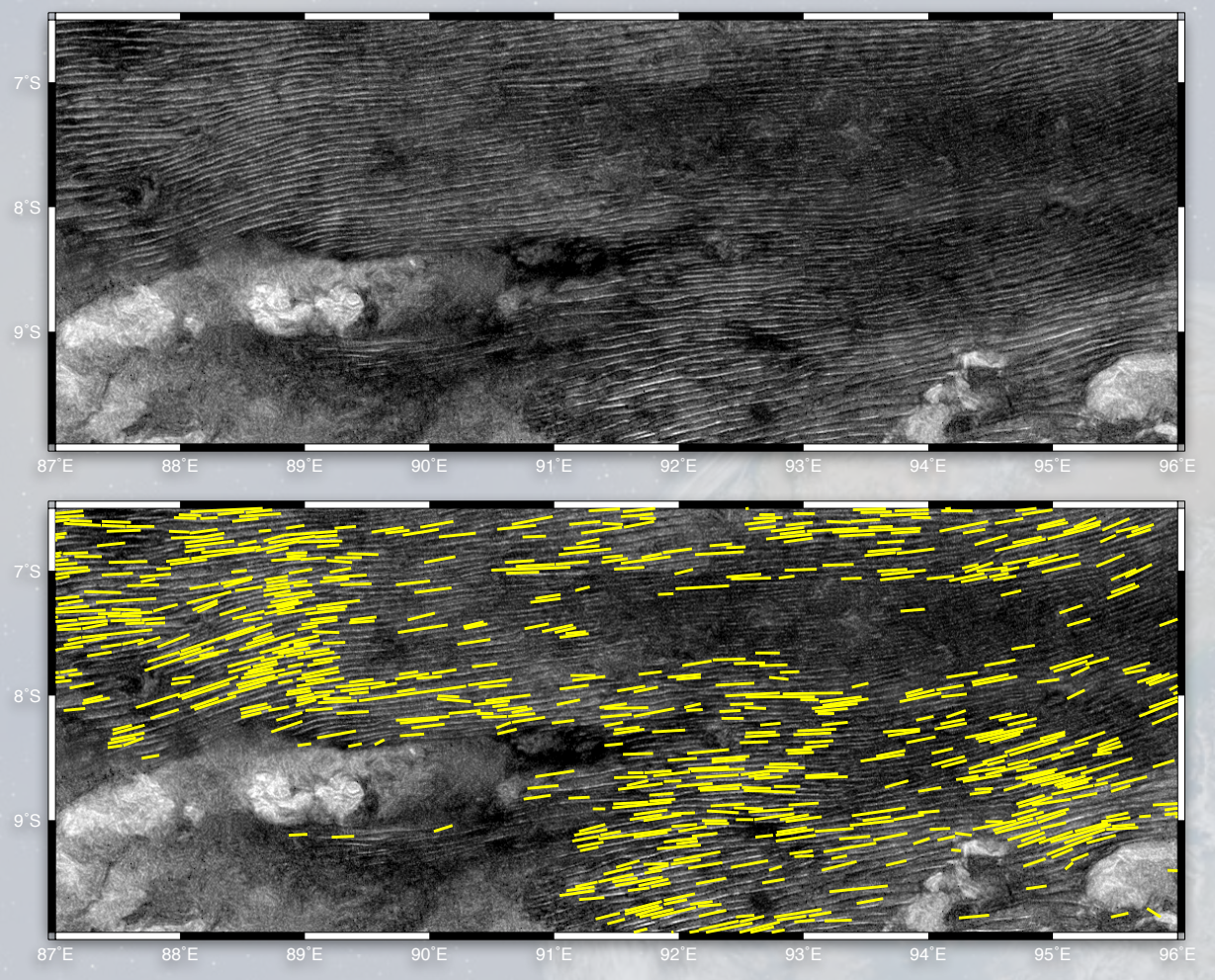
We need an exhaustive and global map orientation

De-noising the SAR data

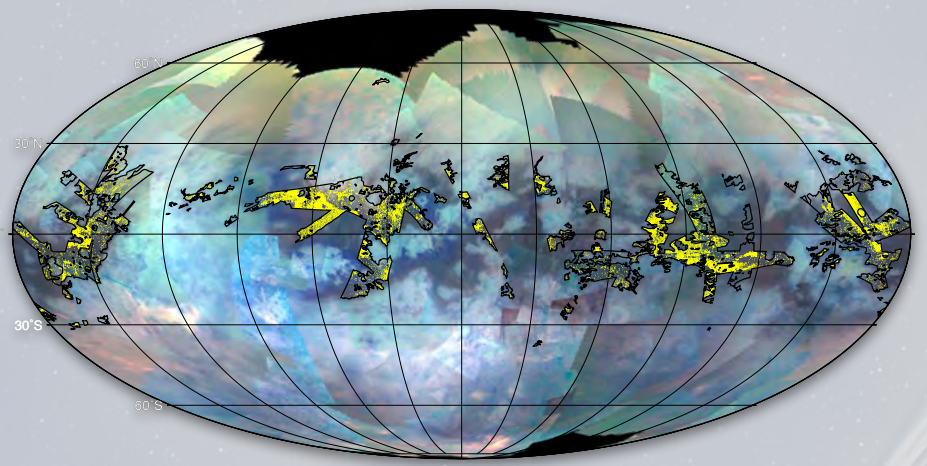
Lucas et al. (*in revision for JGR*)
and presented @AGU 2011 and LPSC 2012

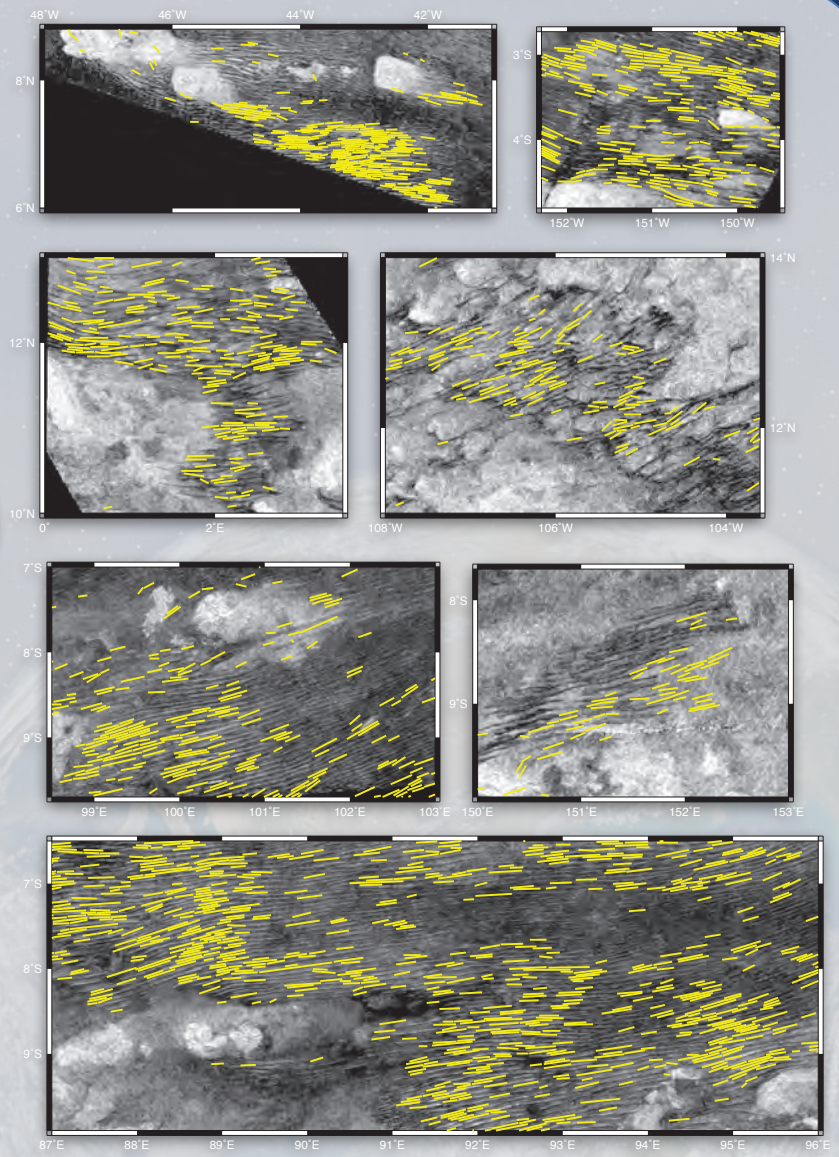
We need an exhaustive and global map orientation

LSD: Linear Segment Detection



Global extraction



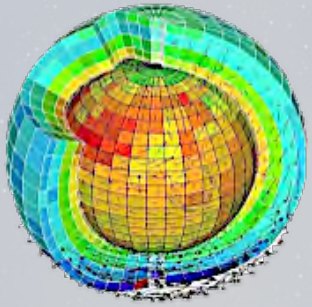


We can do some statistics on that

Prediction of Dune Orientation on Titan

Titan's GCM (IPSL-LMD)

Charnay et al., (2013)



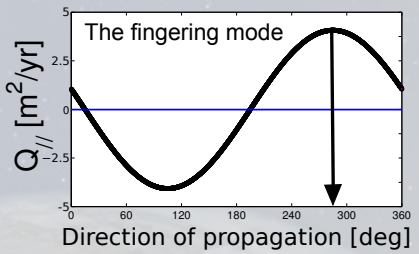
Sediment transport law

Lorenz et al., (1995)

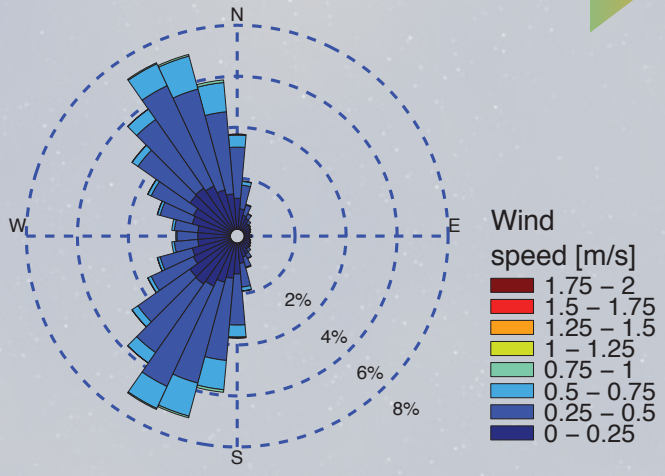
$$Q = f(u, u^*_{th}, d, \rho_s, \rho_f, g)$$

Dune orientation

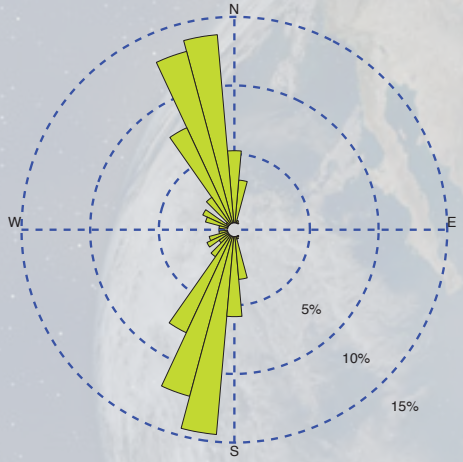
Courrech du Pont et al., (2014)



Wind Regime

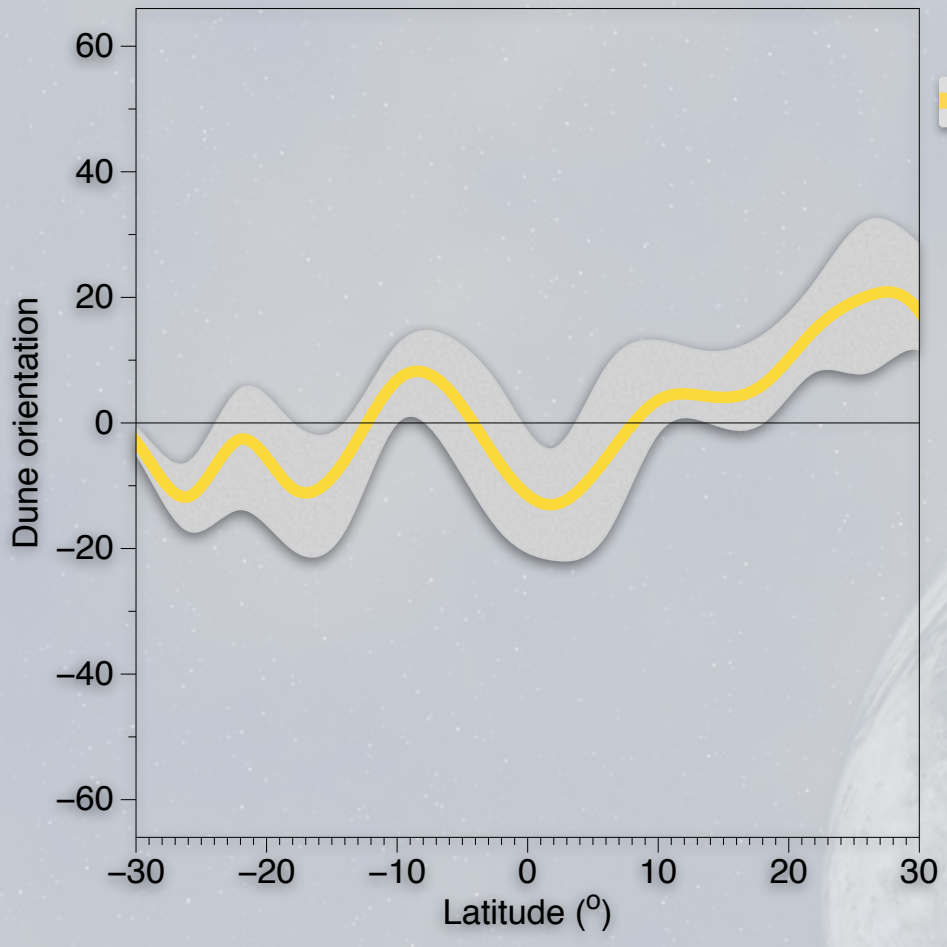


Sediment fluxes

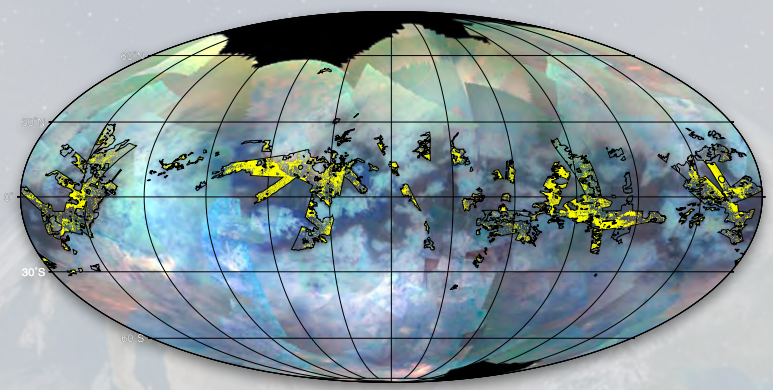


Dune orientation

Observed and Predicted Dune Orientation



Observed Dunes Orientation



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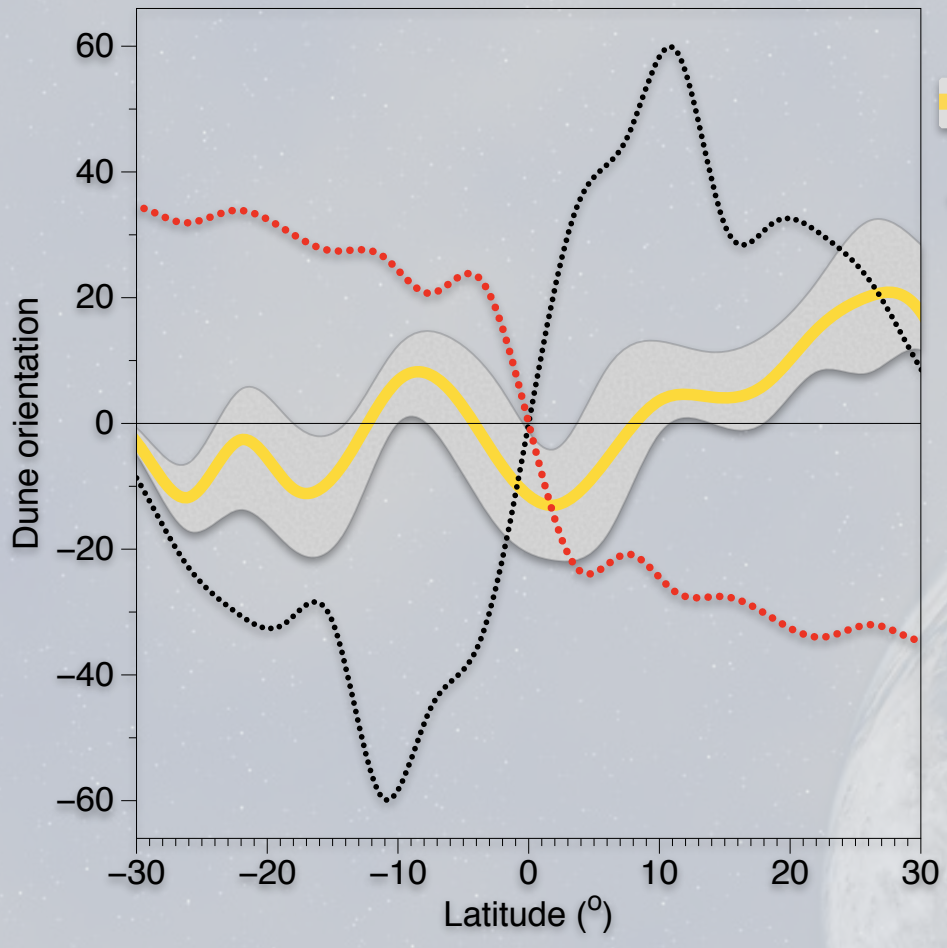


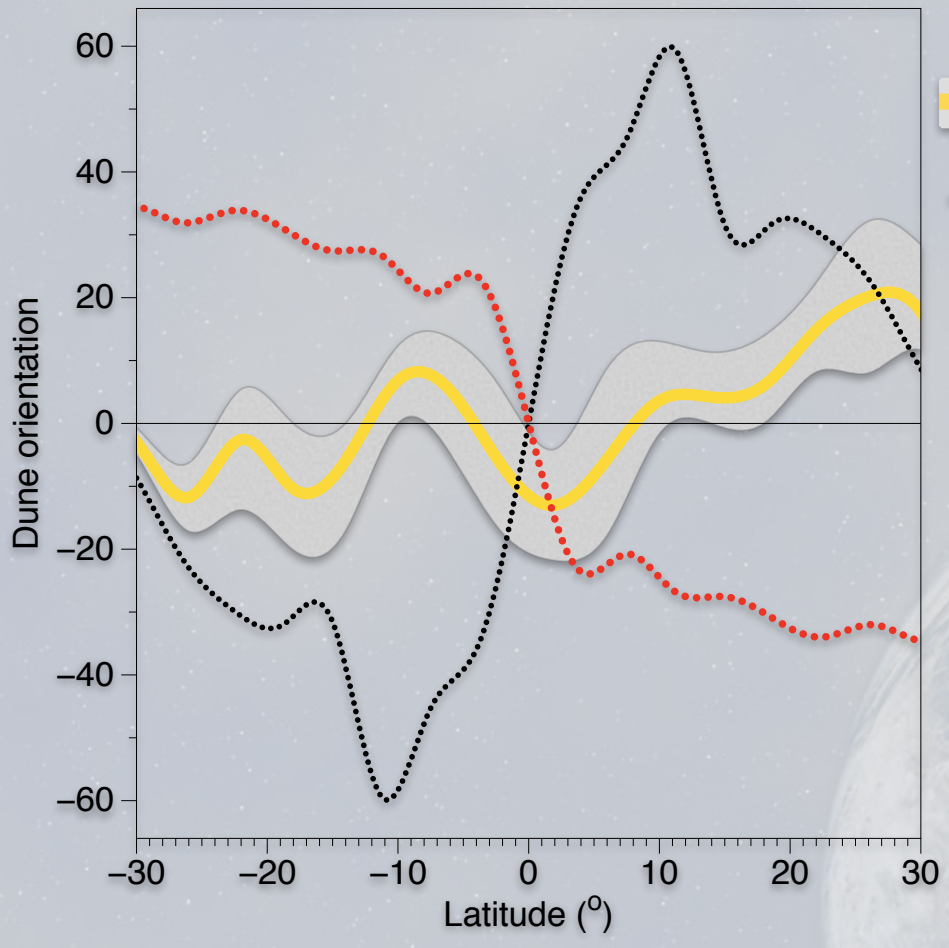
Observed Dunes Orientation

Bed Instability Mode

Fingering Mode

GCM from: Lebonnois & Charnay, 2009

Observed and Predicted Dune Orientation



Observed Dunes Orientation

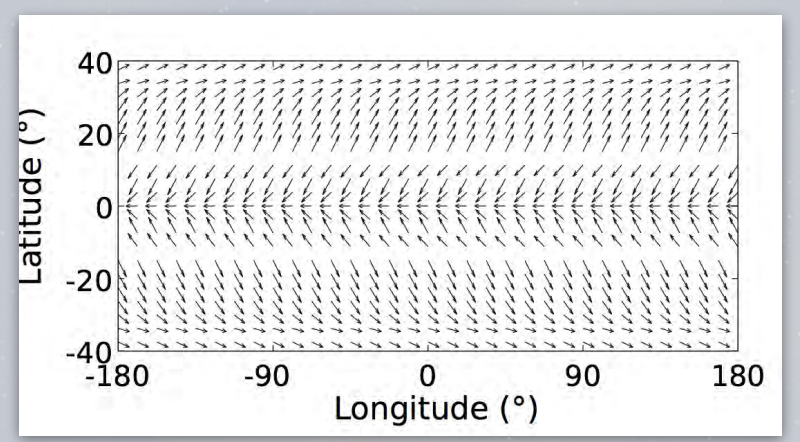
Bed Instability Mode

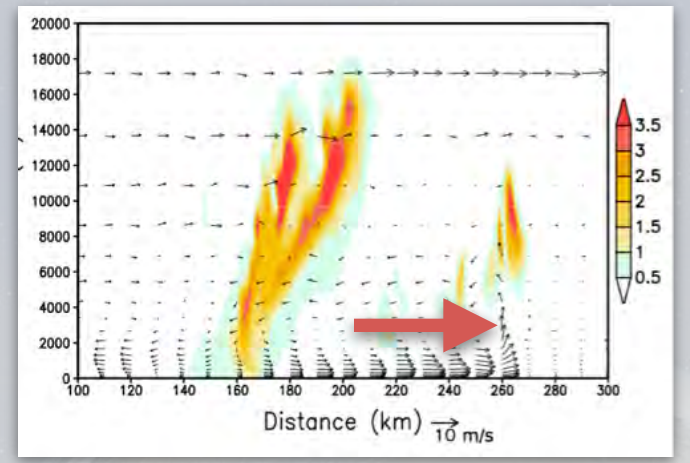
Fingering Mode

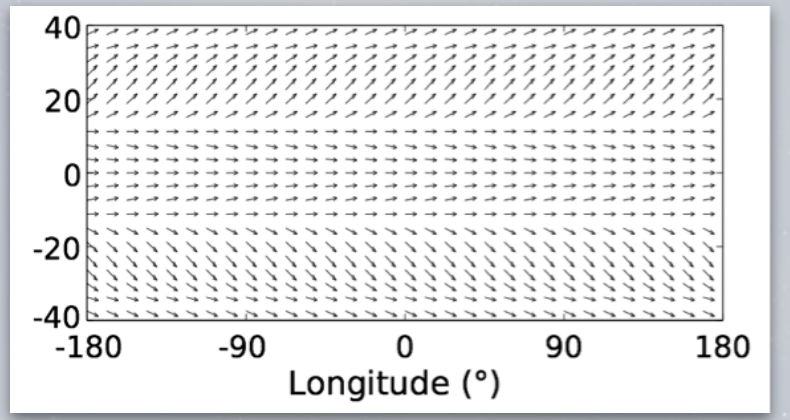
GCM from: Lebonnois & Charnay, 2009

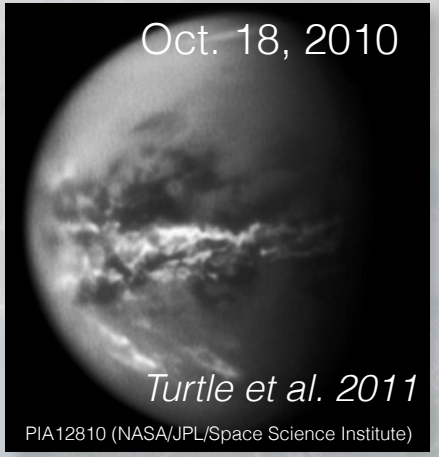
We need an additional force leading to eastwards gusts

Equinoctial storms







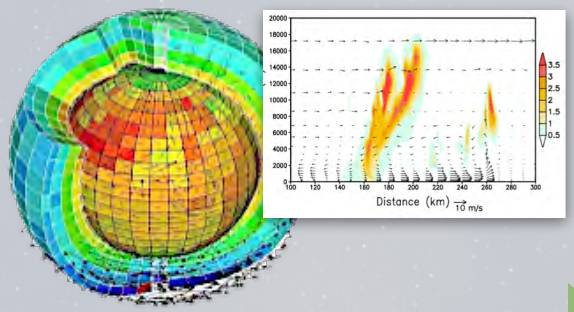


Charnay et al. AGU 2013, &
Charnay et al in review for Nat. Geosc.

Prediction of Dune Orientation on Titan

Titan's GCM + Storms

Charnay et al., (2013)



Sediment transport law

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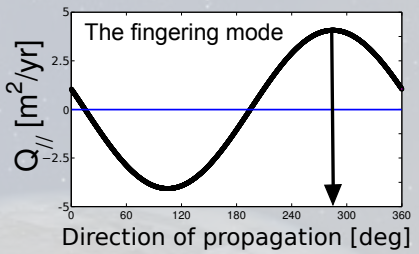
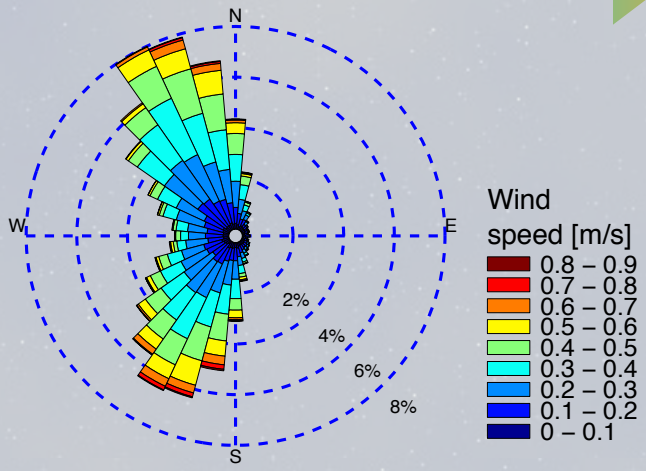
$$Q = f(u, u^*_{th}, d, \rho_s, \rho_f, g)$$

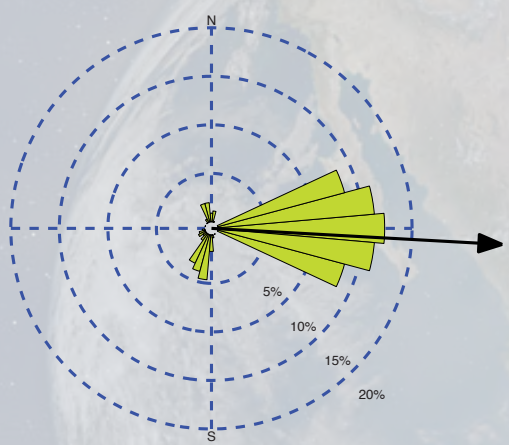
Dune orientation

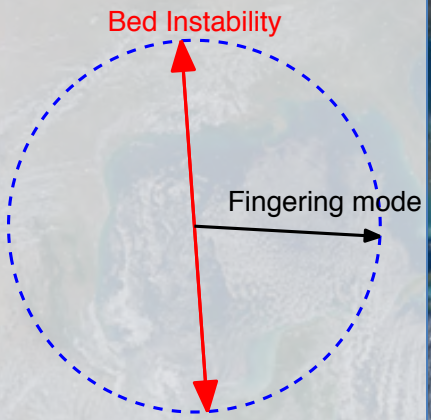
Courrech du Pont et al., (2014)



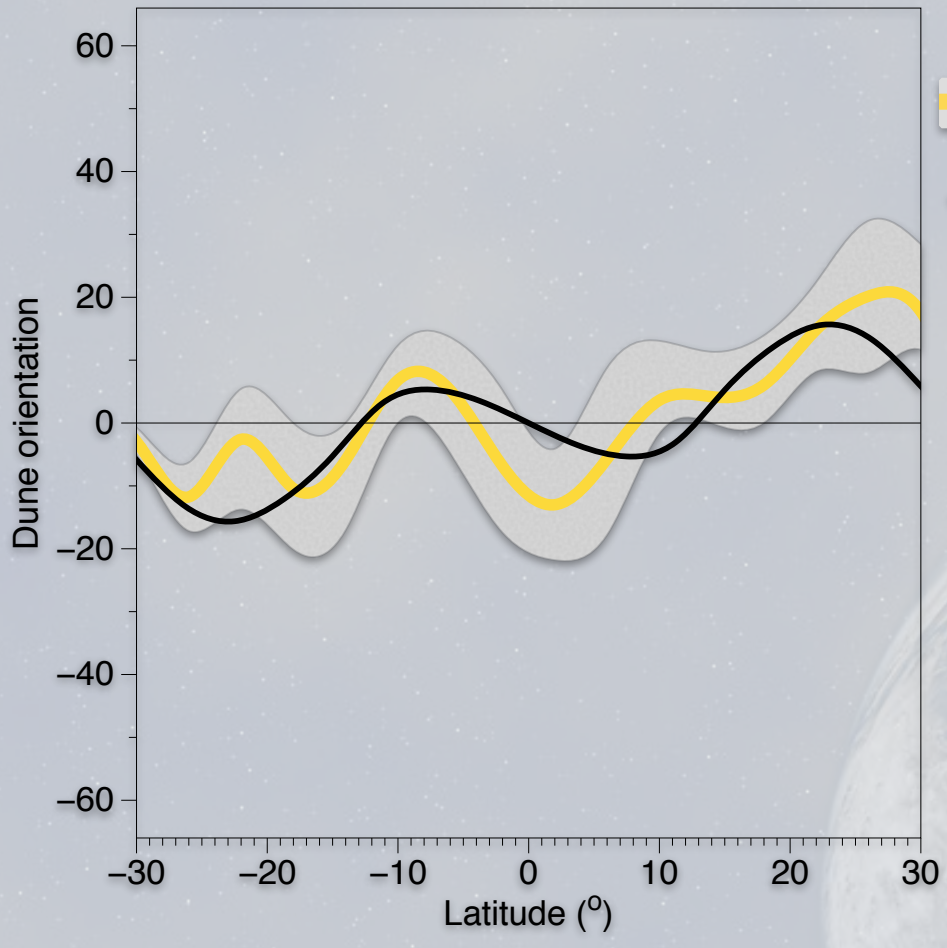
Wind Regime → **Sediment fluxes** → **Dune orientation**







Observed and Predicted Dune Orientation



Observed Dunes Orientation

Bed Instability Mode

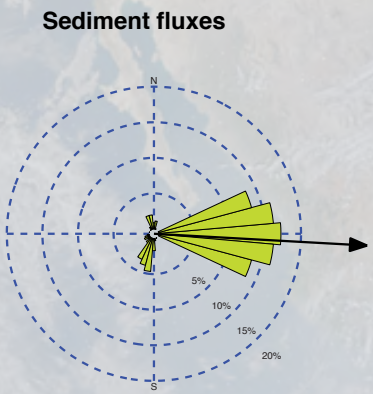
Fingering Mode

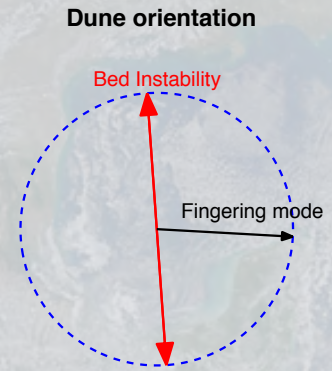
Equinoctial Storms:

GCM from: Lebonnois & Charnay, 2009

Meso-scale in Charnay et al. under review

Fingering Mode with Storms





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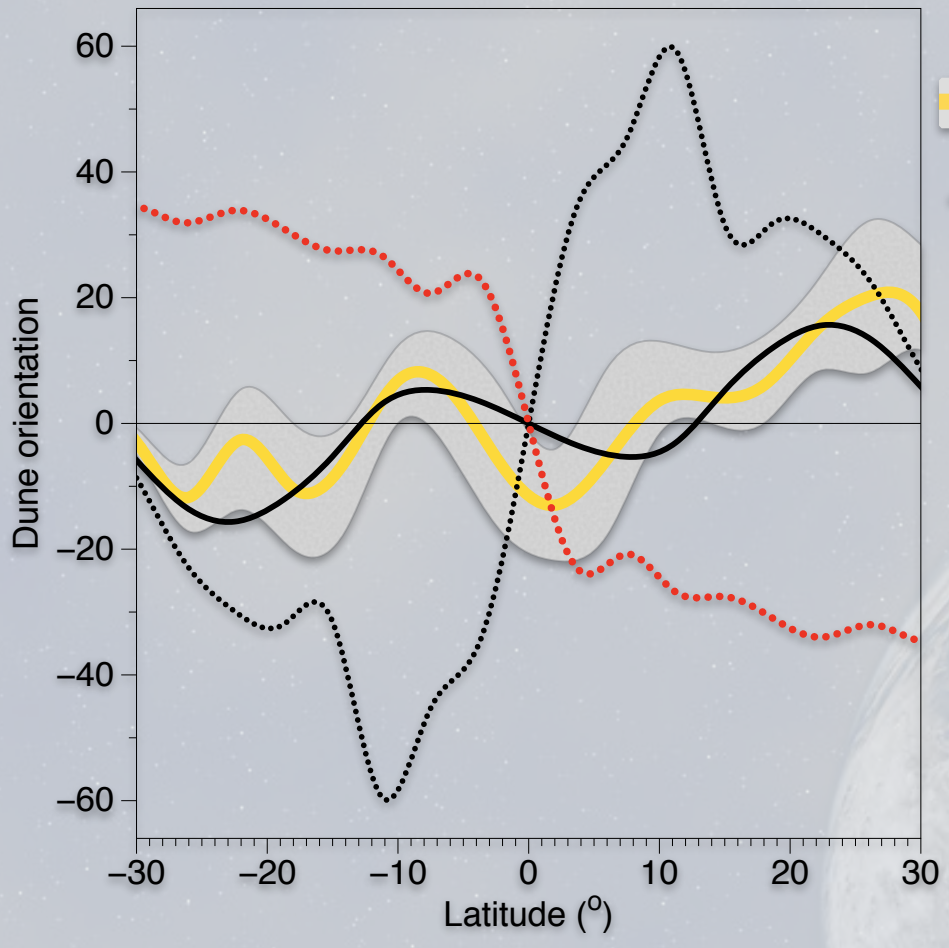

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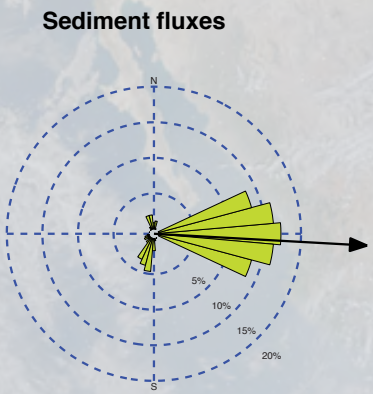
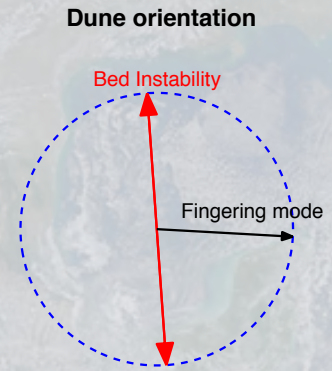
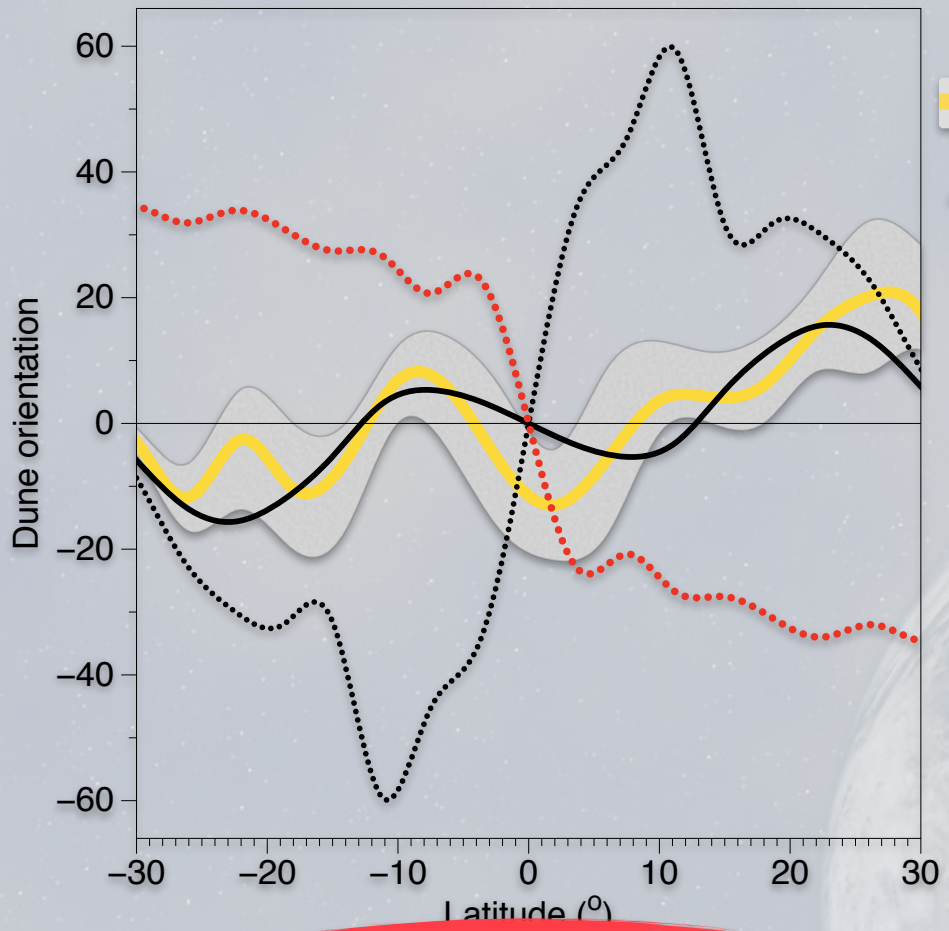
Fingering Mode with Storms





Bed instability Mode with Storms

Observed and Predicted Dune Orientation



Observed Dunes Orientation

Bed Instability Mode

Fingering Mode

Equinoctial Storms:

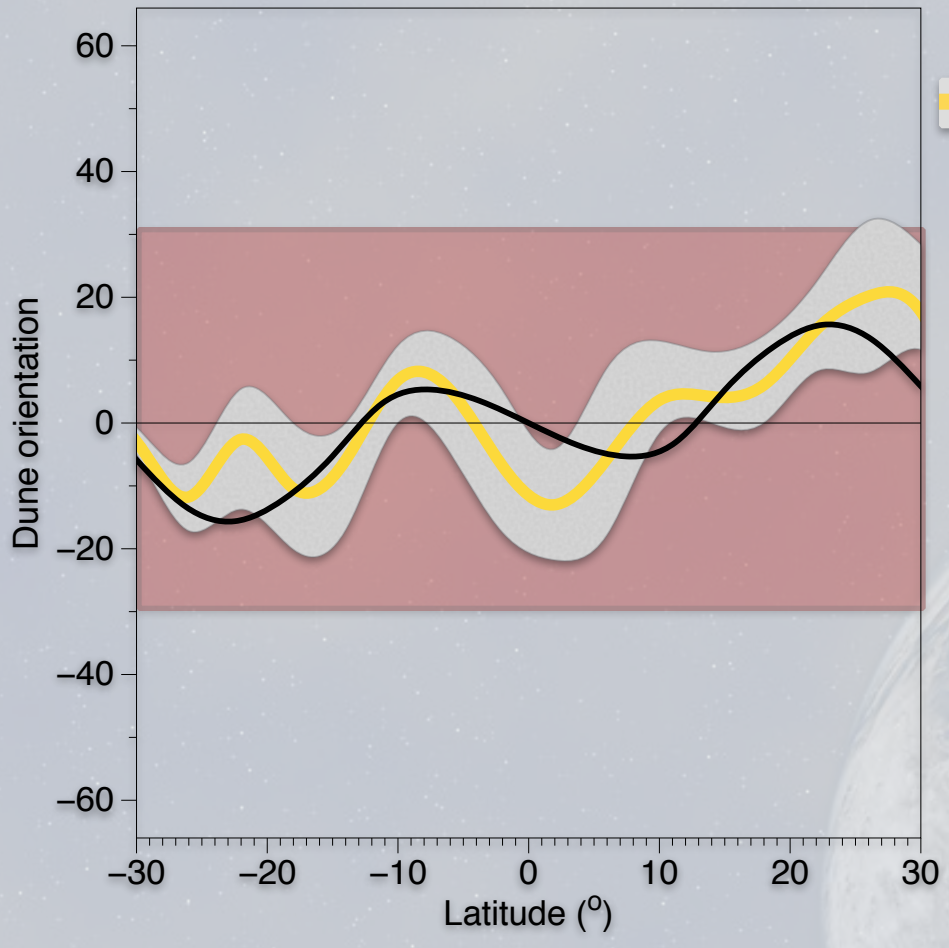
GCM from: Lebonnois & Charnay, 2009
Meso-scale in Charnay et al. under review

Fingering Mode with Storms

Bed Instability Mode

Bed instability Mode with Storms

Observed and Predicted Dune Orientation



Observed Dunes Orientation

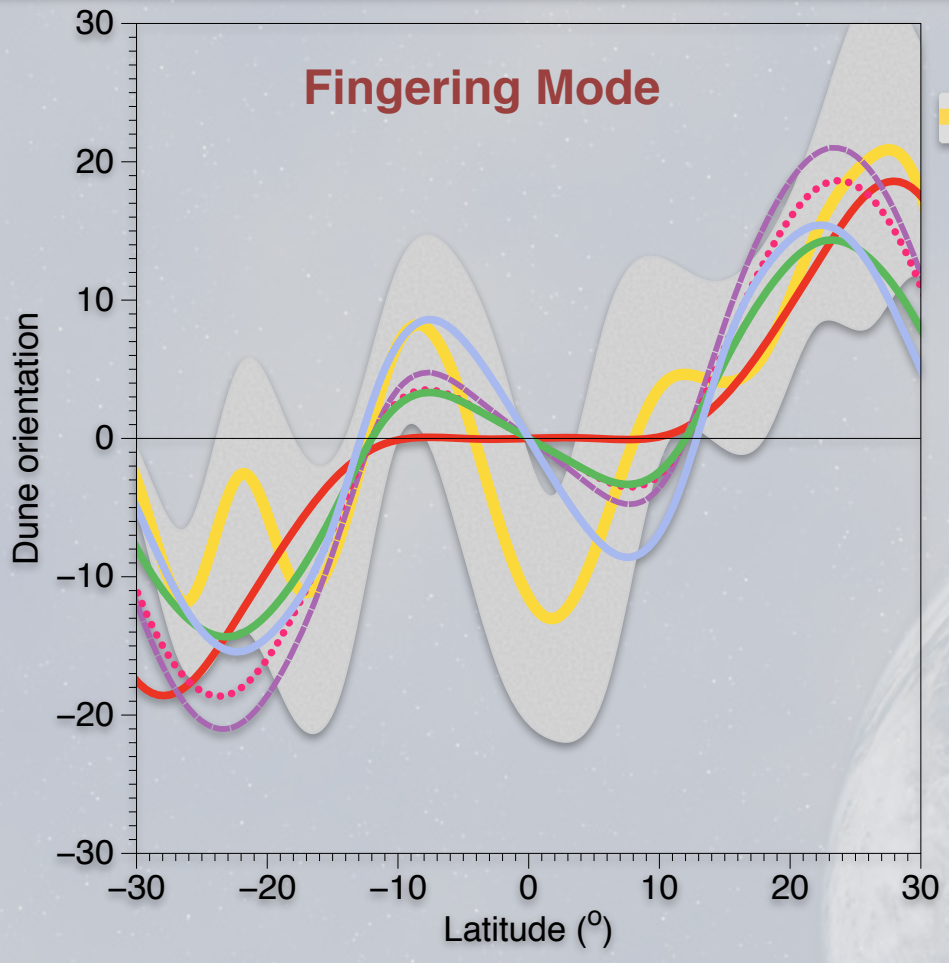
Equinoctial Storms:

GCM from: Lebonnois & Charnay, 2009

Meso-scale in Charnay et al. under review

Fingering Mode with Storms

Storm properties effects on predictions



Observed Dunes Orientation

Equinoctial Storms:

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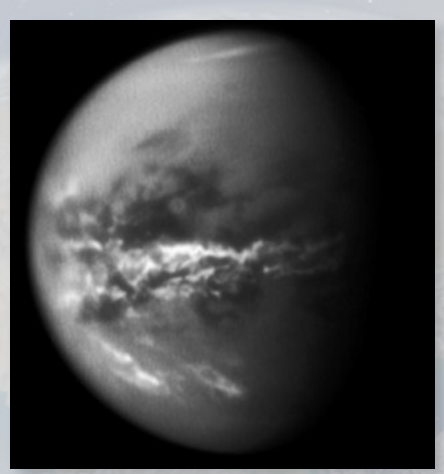
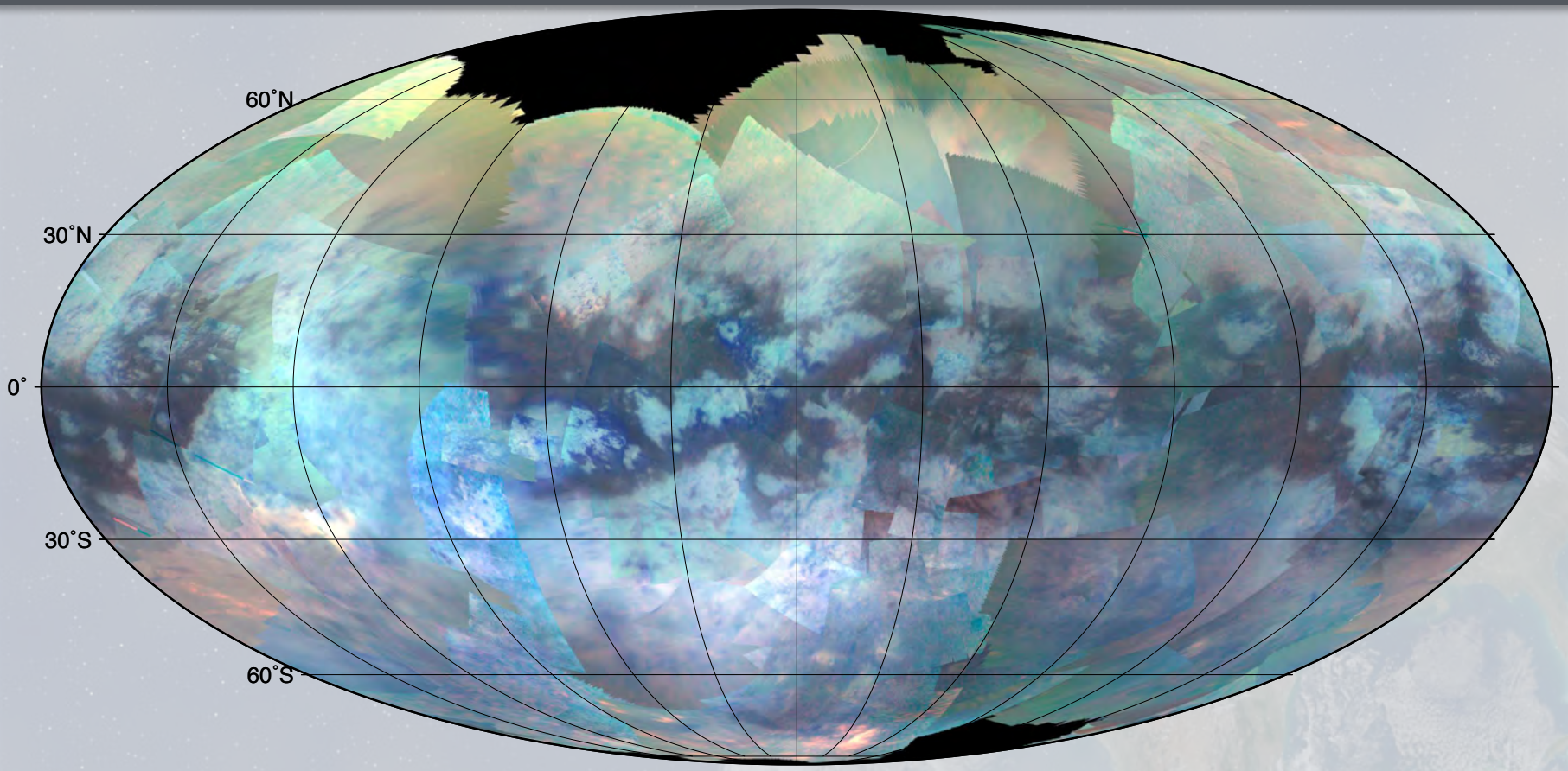
Meso-scale in Charnay et al. under review



- Size of storms
- Frequency of storms
- Friction Velocity threshold

Can we explain the equatorial segregation?

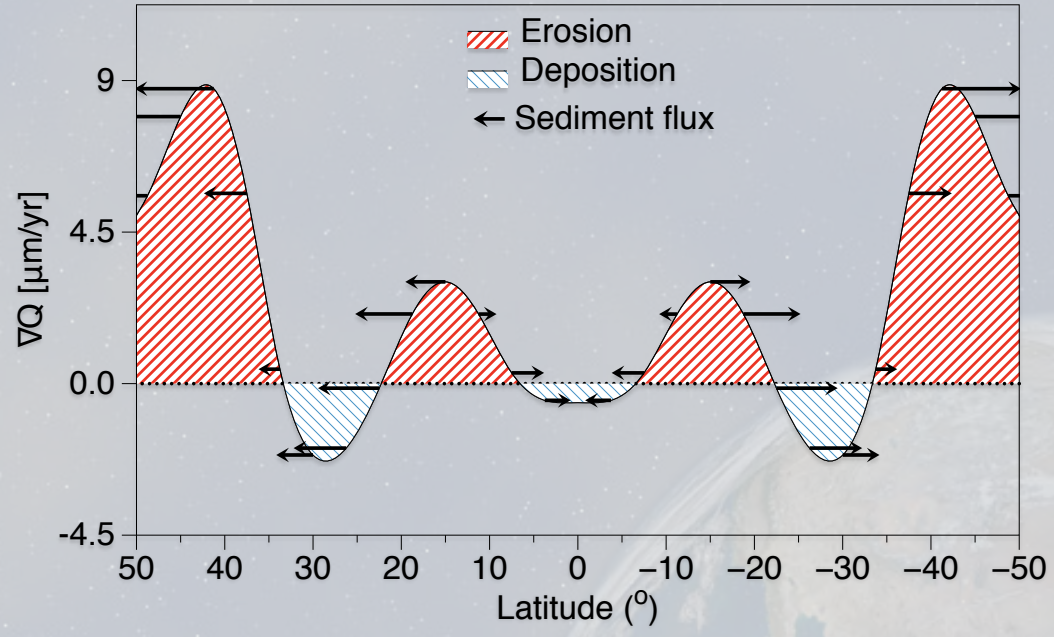


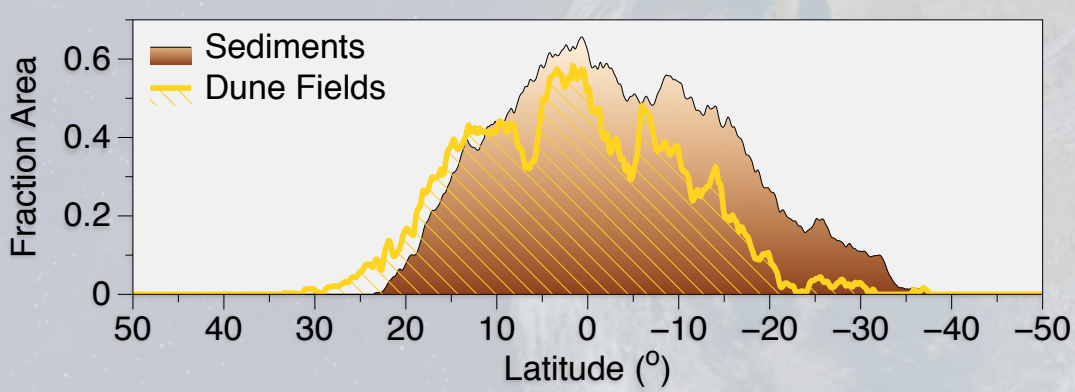
2 500 km (eq.)

Conservation of mass using wind data :

$$\partial_x Q = -\partial_t h$$

Can we explain the equatorial segregation?





New Insights on Titan's dune orientation

How to explain their geographic confinement?

✓Sand fluxes maintain the sediment in the equatorial belt

How to explain their shape and orientation?

✓Dunes form in the fingering mode.

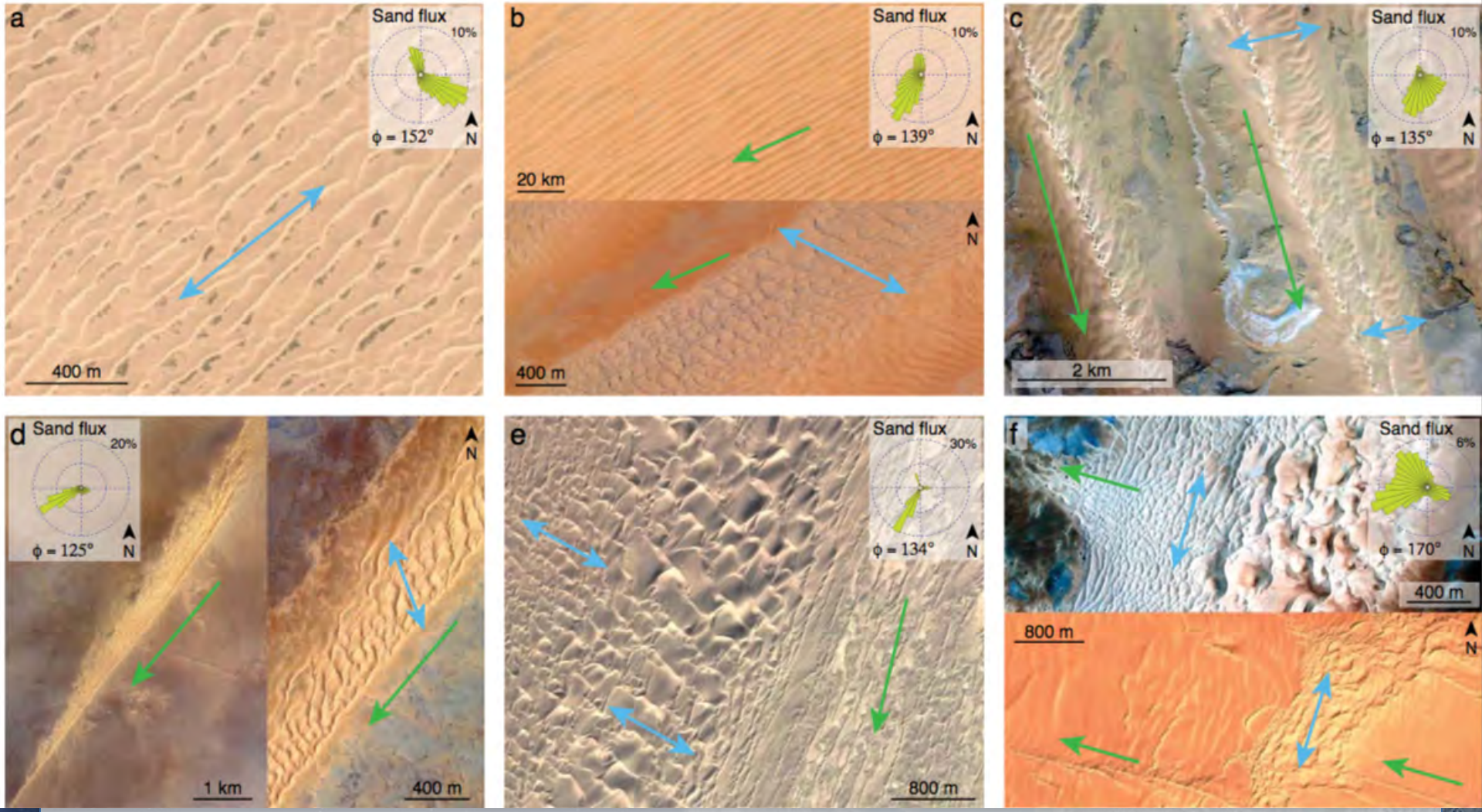
✓Controlled by the **current two-winds regime** (secondary incl.)

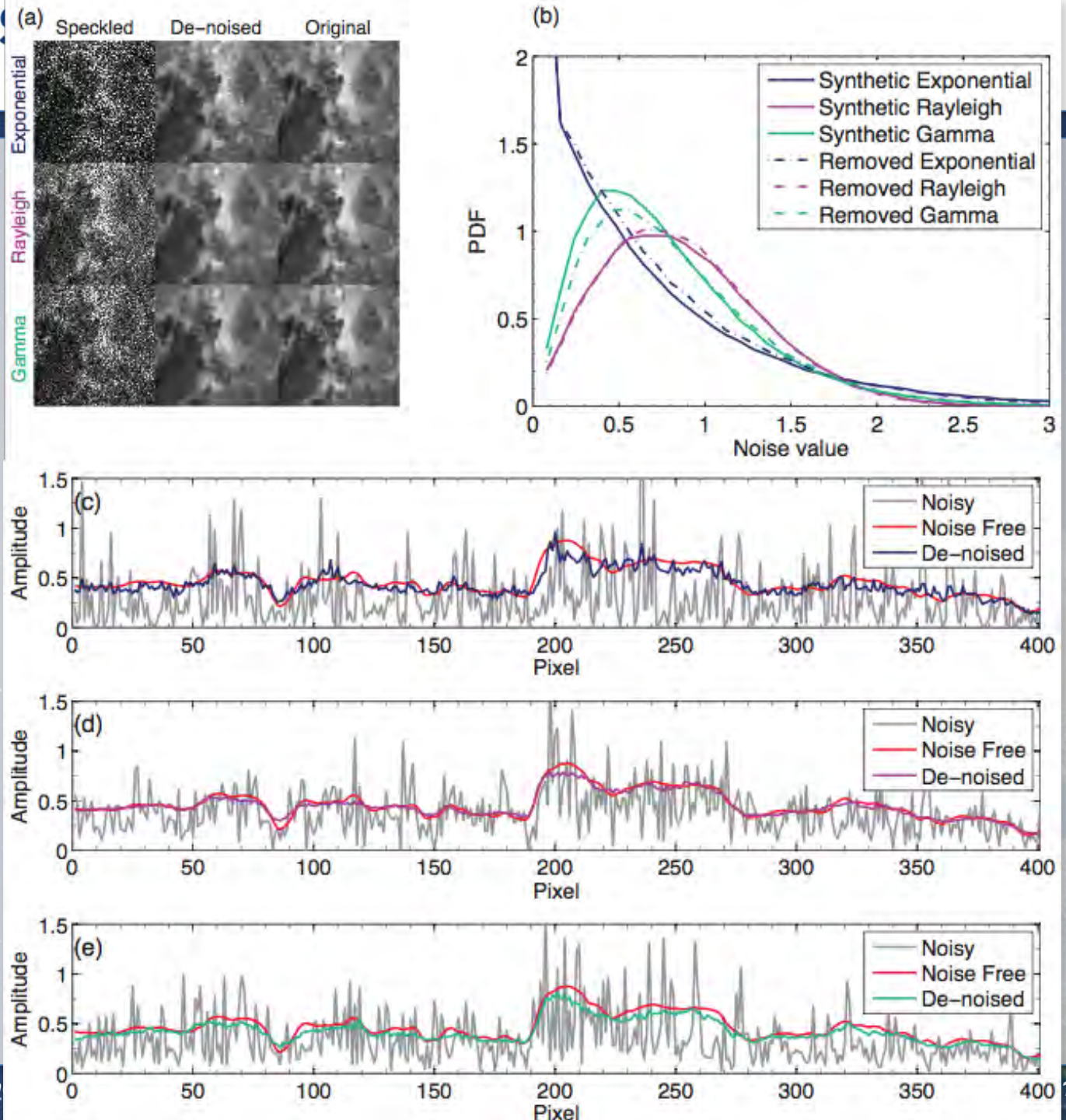
✓Elongating ("fingering") mode of growth

How to explain their direction of propagation?

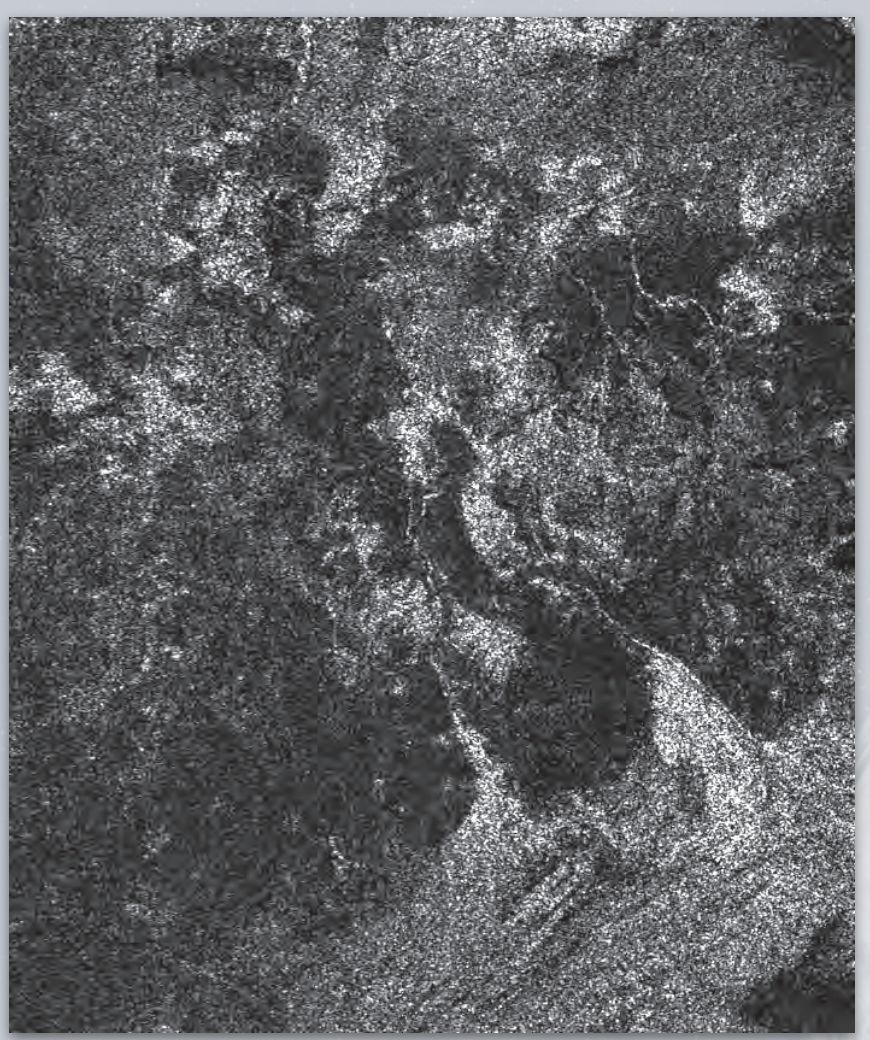
✓Dunes elongate like fingers on a non-erodible bedrock from a localized source (where?)

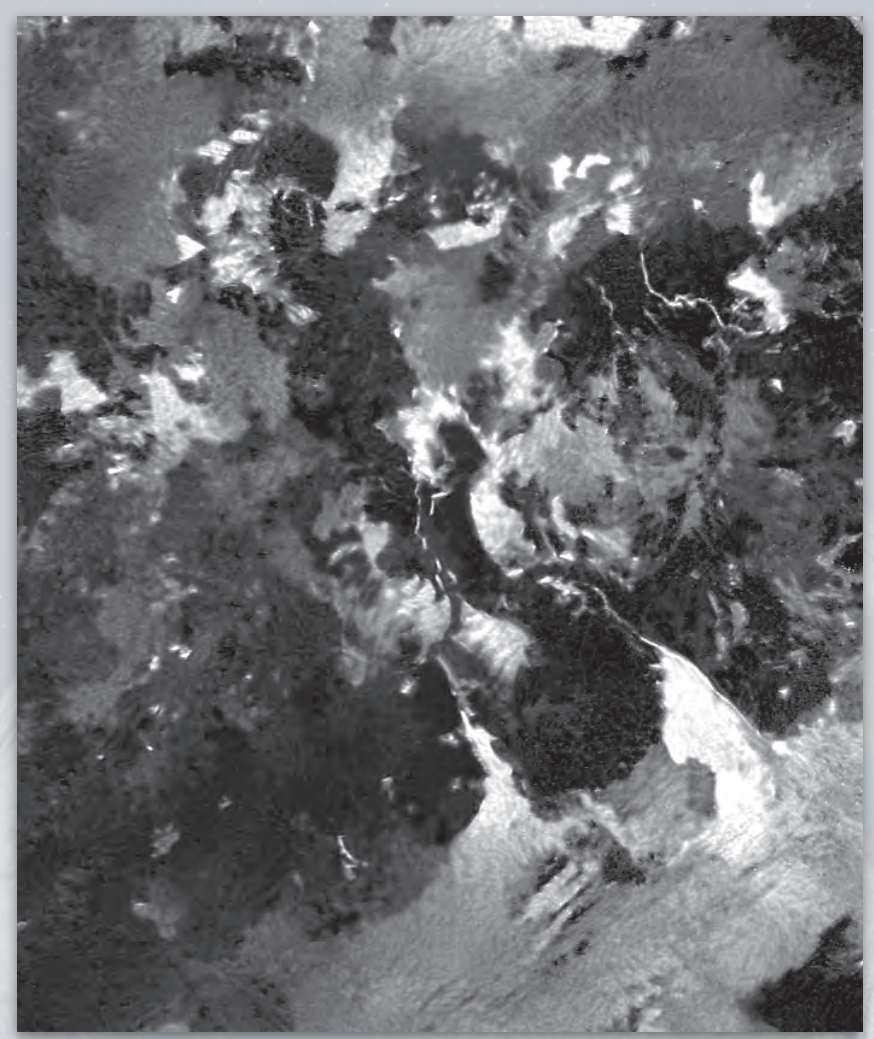
Origin of Dune Orientation on Titan




(a)
Speckled
De-noised
Original
Exponential
Rayleigh
Gamma
(b)
PDF
Noise value
Synthetic Exponential
Synthetic Rayleigh
Synthetic Gamma
Removed Exponential
Removed Rayleigh
Removed Gamma
(c)
(d)
(e)
Amplitude
Pixel
Noisy
Noise Free
De-noised

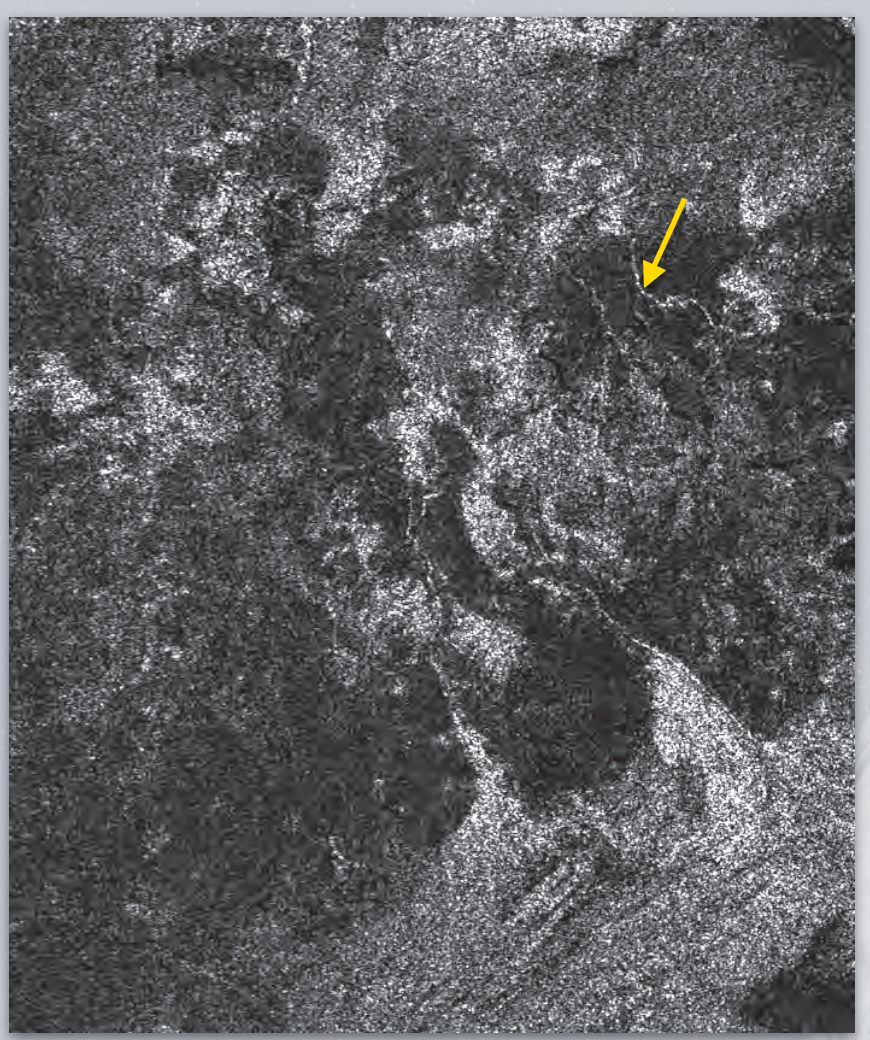
De-noising the SAR data

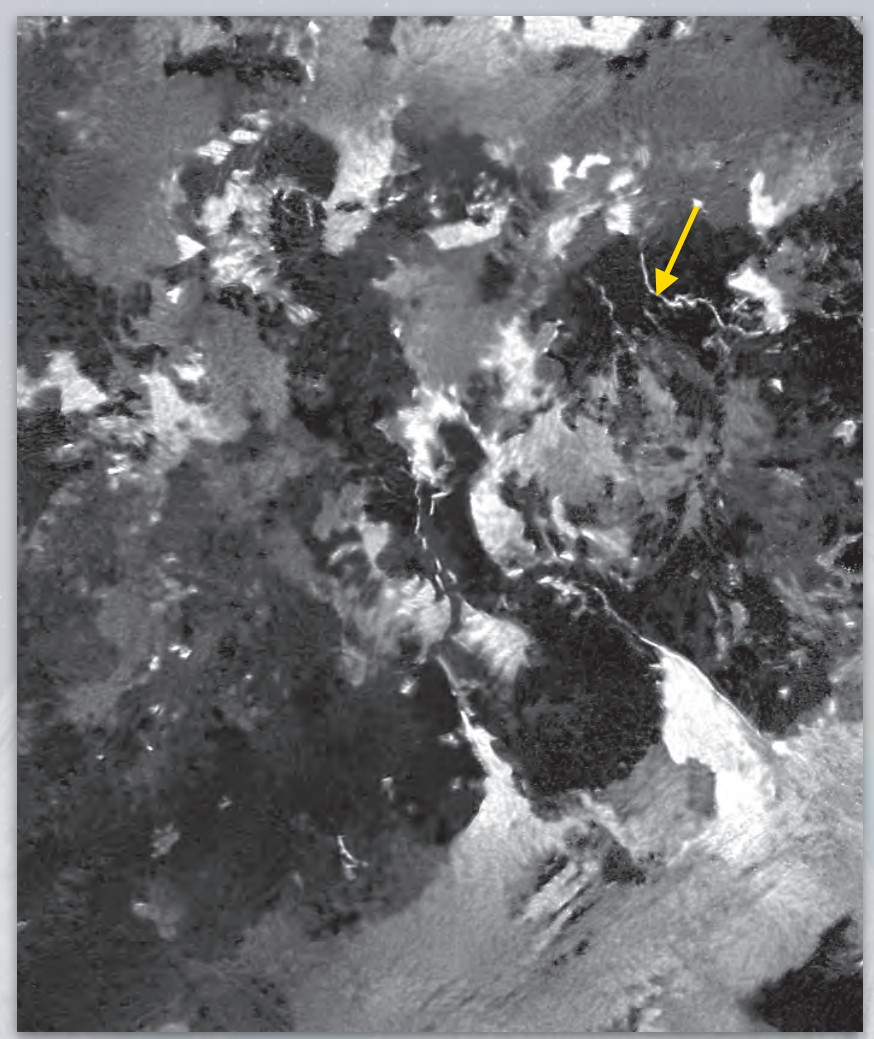




Lucas et al. (*in revision for JGR*)

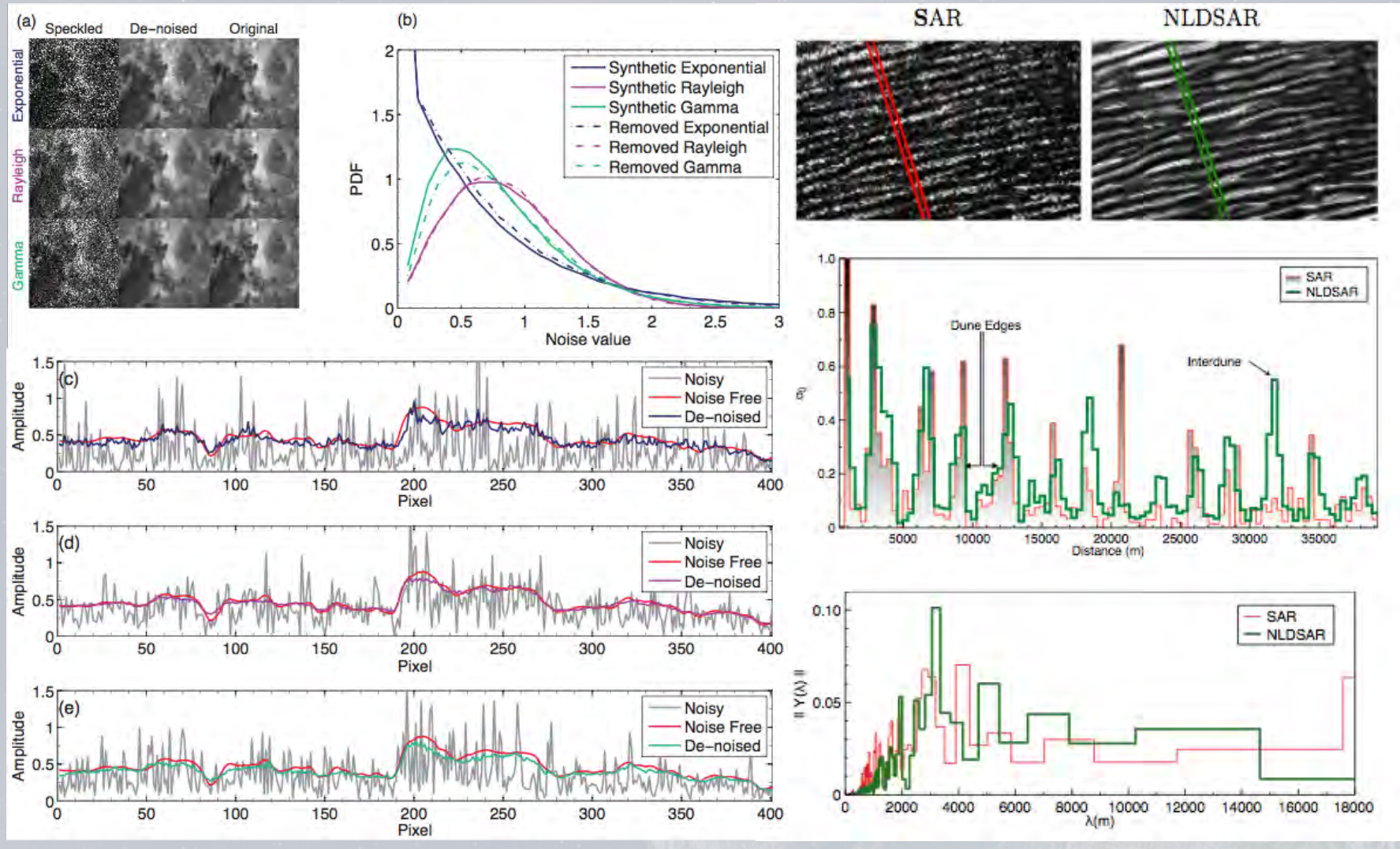
De-noising the SAR data





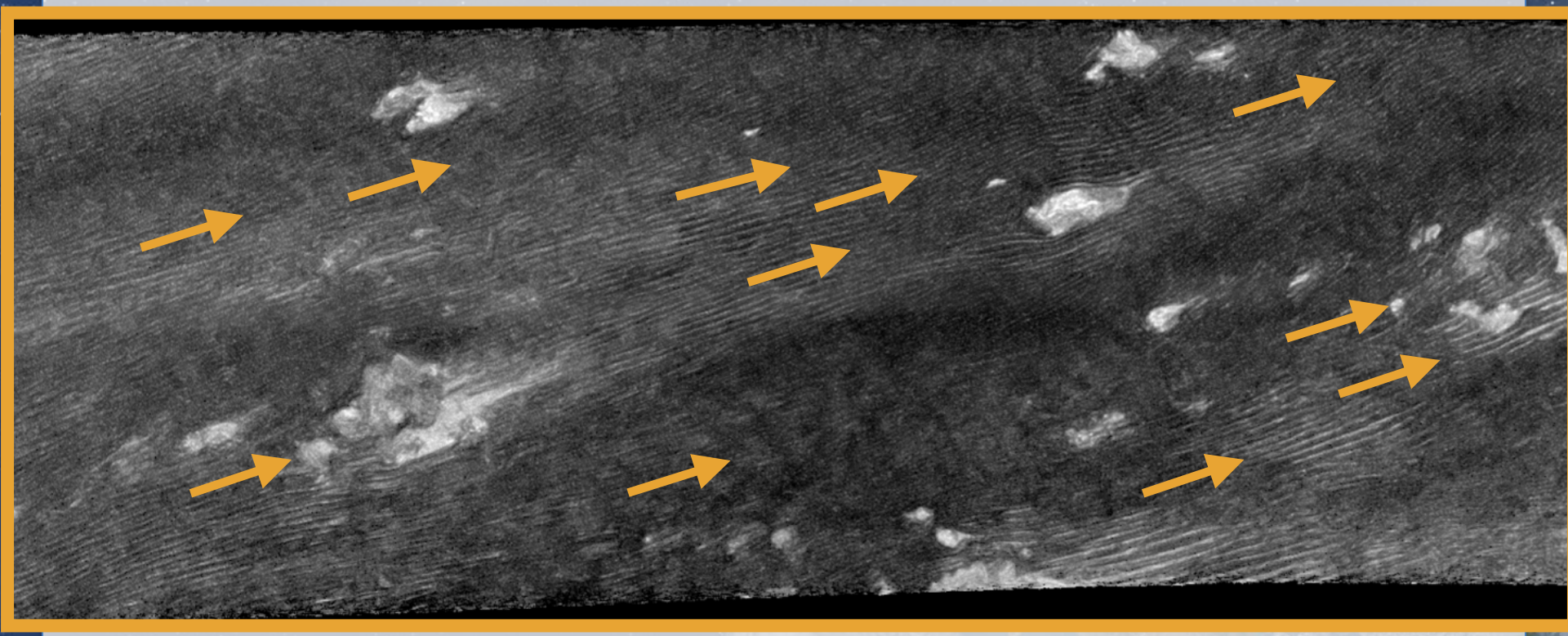
Lucas et al. (*in revision for JGR*)

Origin of Dune Orientation on Titan

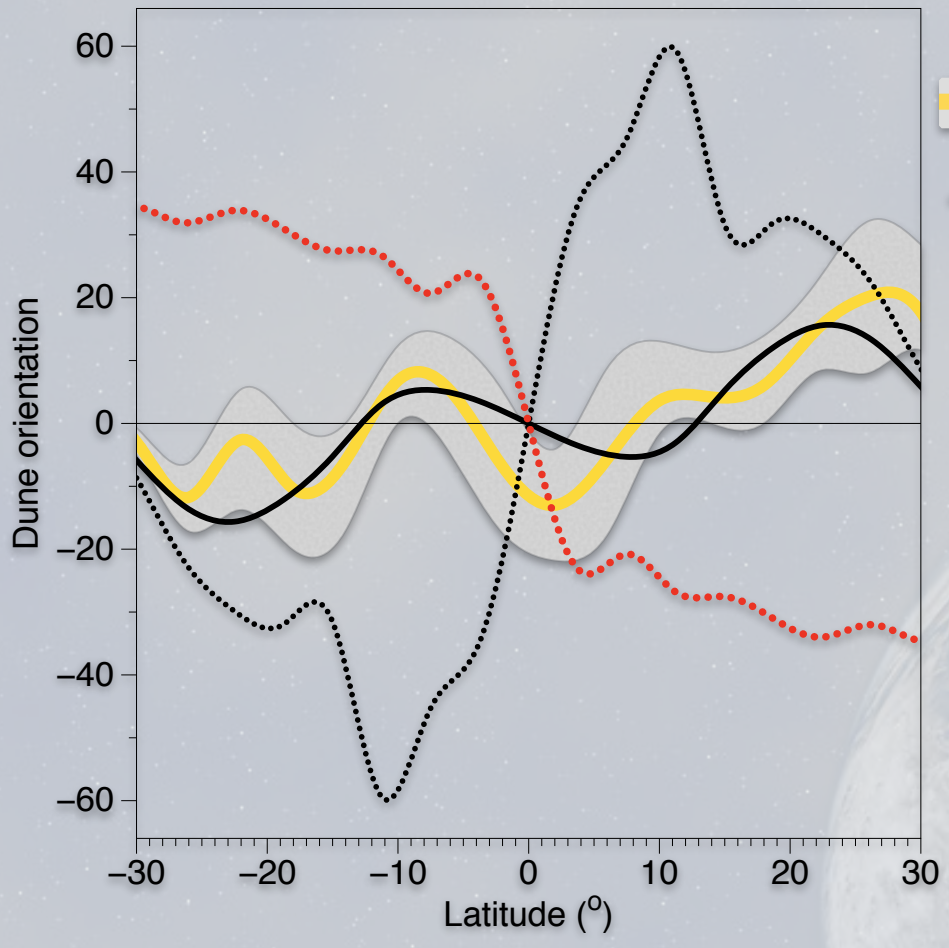


Lucas et al. (*in revision for JGR*)

Dunes conundrum



Observed and Predicted Dune Orientation



Observed Dunes Orientation

Bed Instability Mode

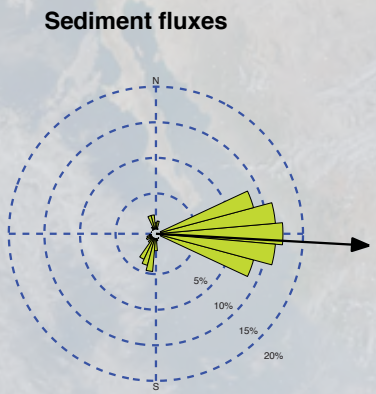
Fingering Mode

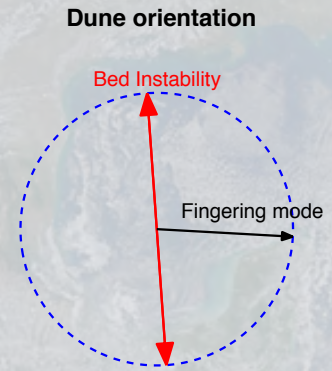
Equinoctial Storms:

GCM from: Lebonnois & Charnay, 2009

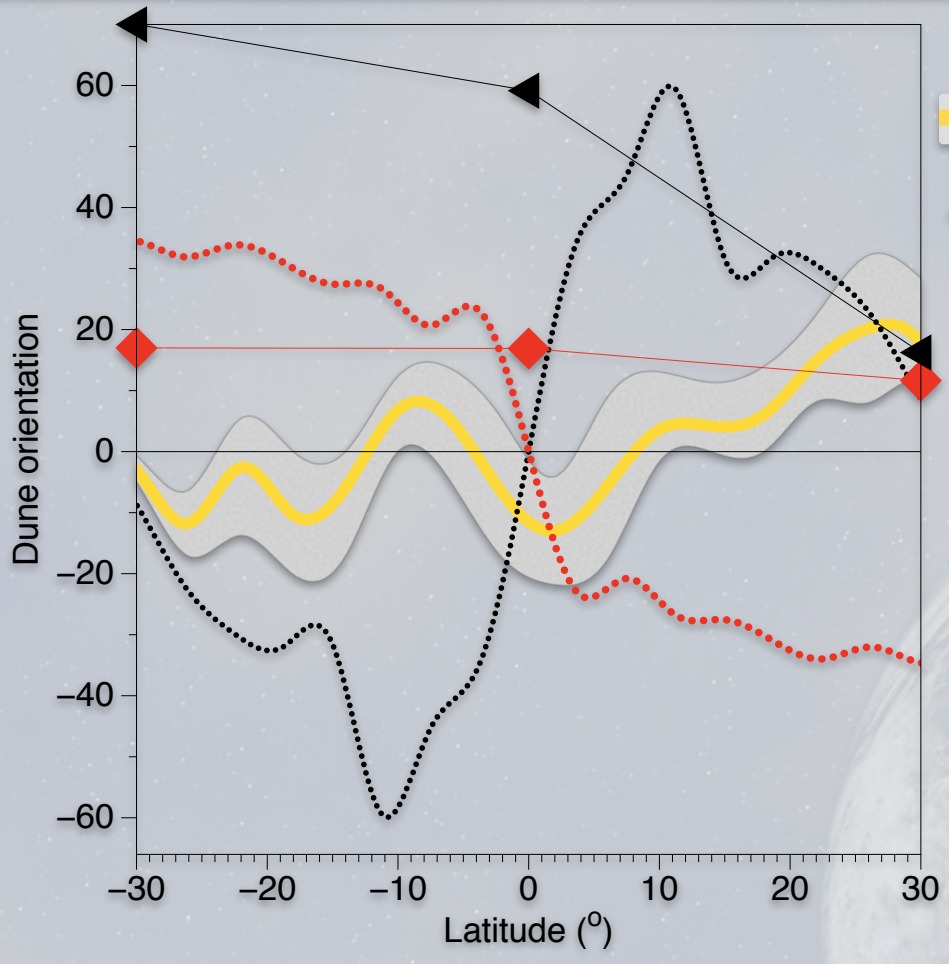
Meso-scale in Charnay et al. under review

Fingering Mode with Storms





Observed and Predicted Dune Orientation



Observed Dunes Orientation

Bed Instability Mode

Fingering Mode

GCM from: Lebonnois & Charnay, 2009

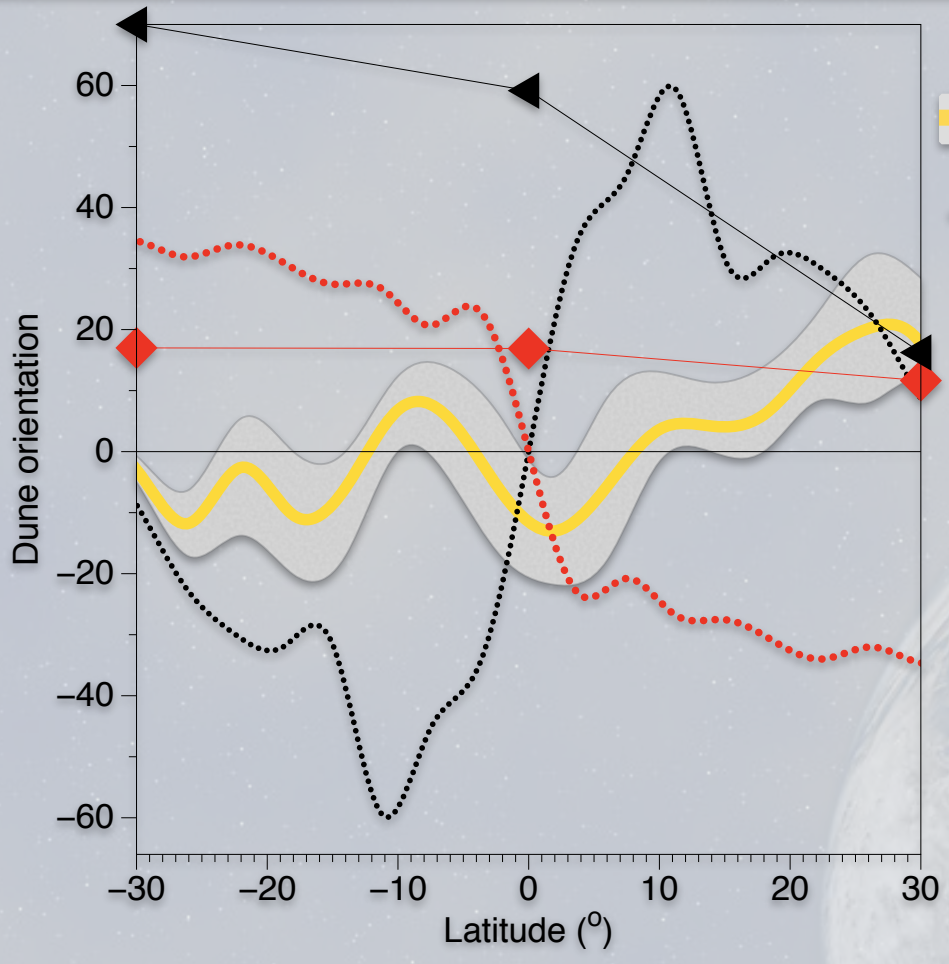
Equinoctial perturbations:

GCM: Tokano, 2010

Bed Instability Mode

Fingering Mode

Observed and Predicted Dune Orientation



Observed Dunes Orientation

Bed Instability Mode

Fingering Mode

GCM from: Lebennois & Charnay, 2009

Equinoctial perturbations:

GCM: Tokano, 2010

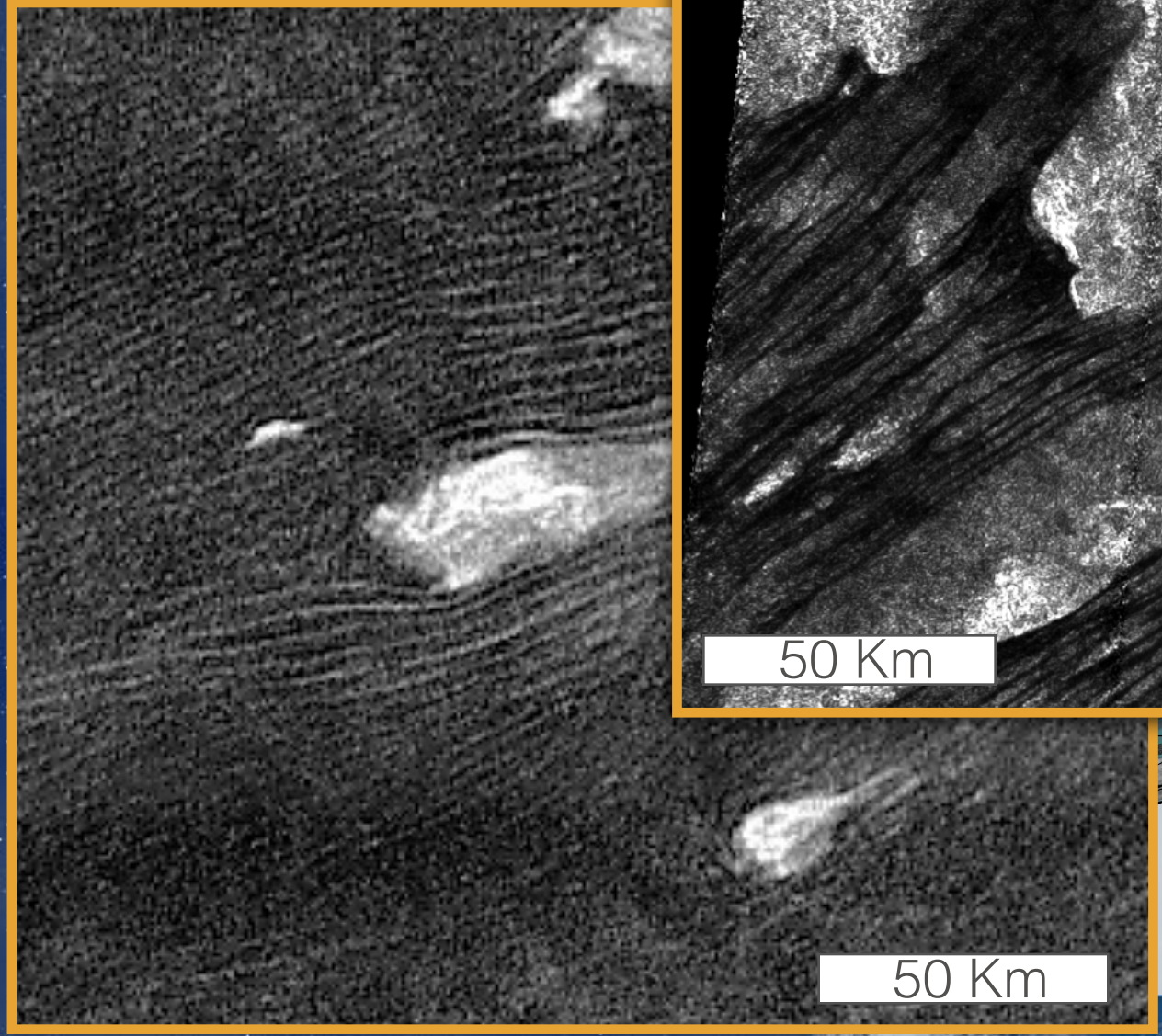
Bed Instability Mode

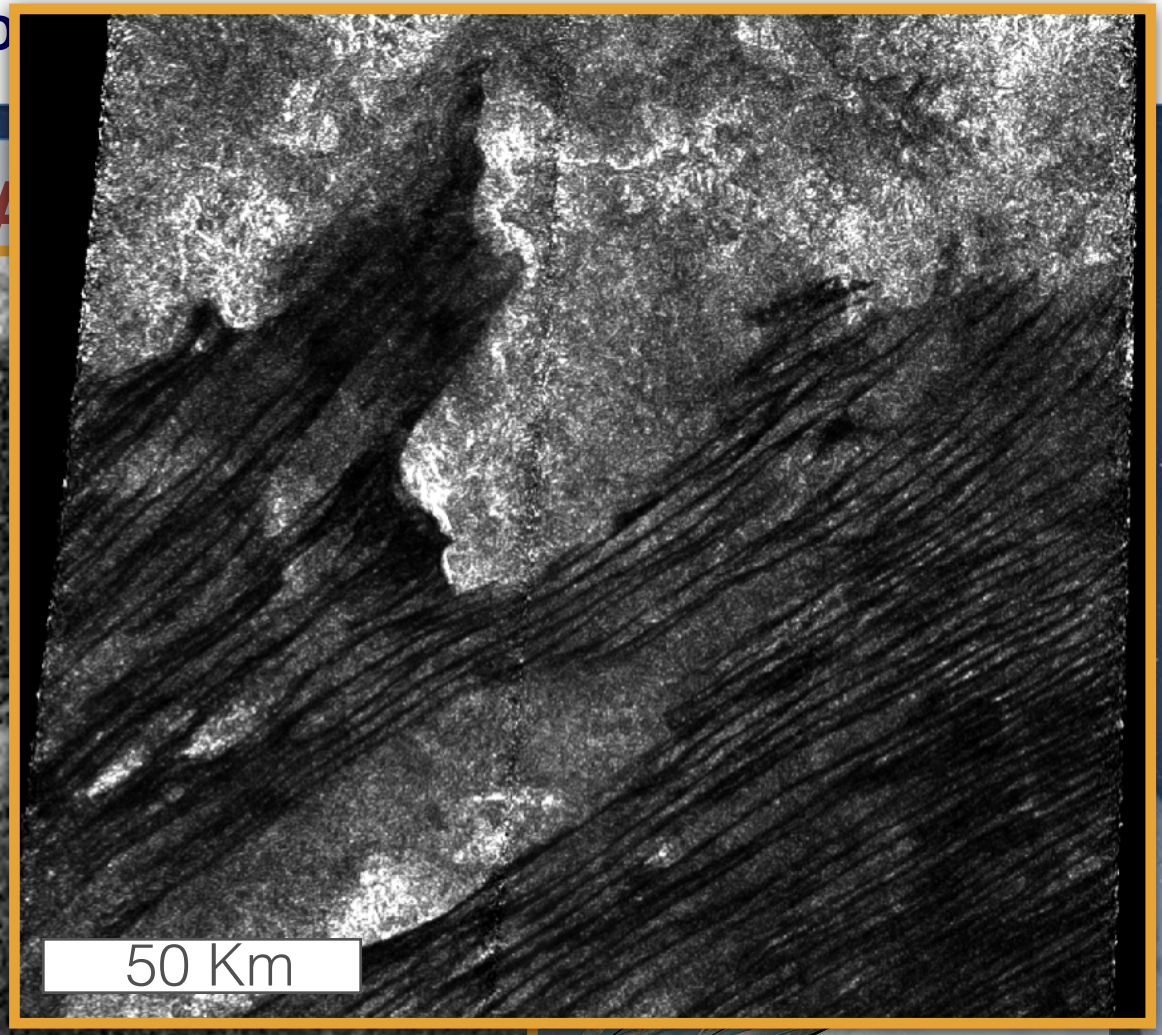
Fingering Mode

We need STILL an additional force leading to eastwards gusts

Labex UnivEarthS

Titan seen by RA



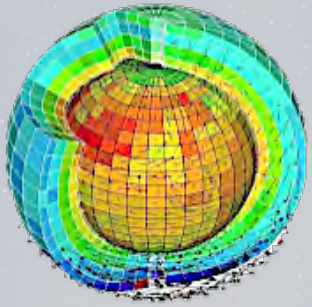


May 16th 2014

Prediction of Dune Orientation on Titan

Titan's GCM (IPSL-LMD)

Charnay et al., (2013)



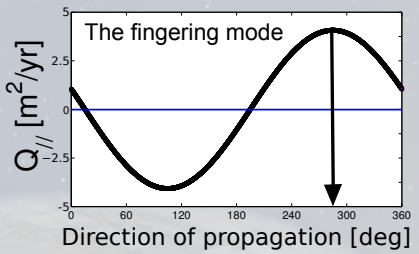
Sediment transport law

Lorenz et al., (1995)

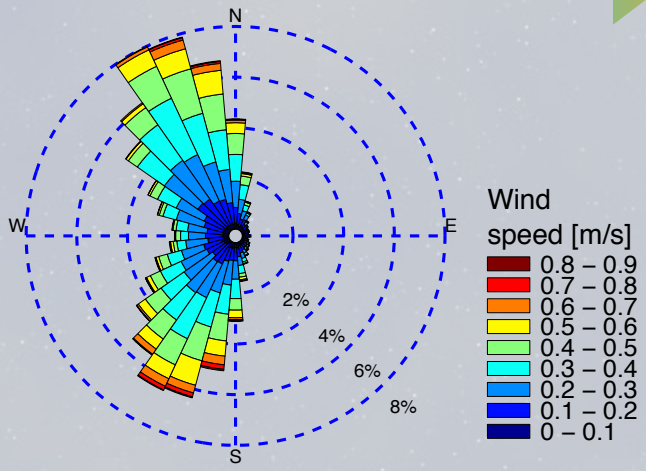
$$Q = f(u, u^*_{th}, d, \rho_s, \rho_f, g)$$

Dune orientation

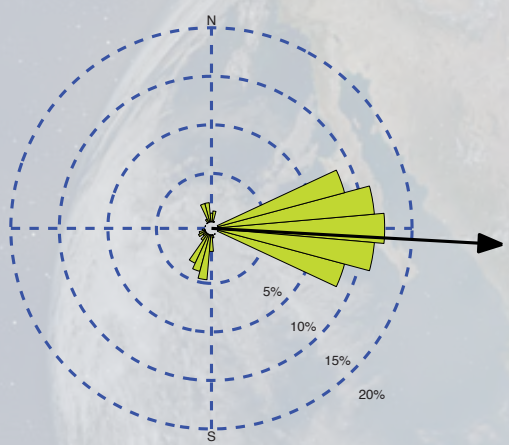
Courrech du Pont et al., (2014)



Wind Regime



Sediment fluxes



Dune orientation